Sam Houston State University

Simulations & Background Analysis for MINER

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MINER

Mitchell Institute Neutrino Experiment at Reactor

Nuclear Science Center
College Station, TX

TEXAS A&M UNIVERSITY 1876

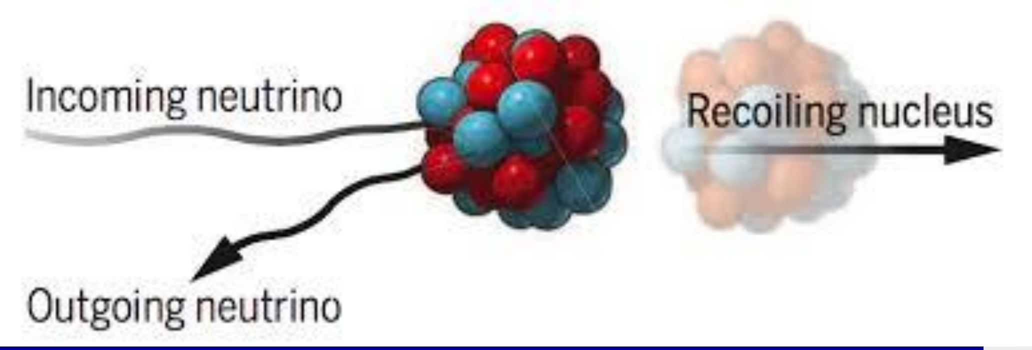
Primary Goal

Observe Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

- Yet to be observed at any reactor experiment
- Long standing prediction of standard model
- New channel to probe neutrino physics and astrophysics

CEvNS used to probe new physics scenarios

- Search for sterile Neutrino
- Neutrino Magnetic Moment
- Process beyond the Standard Model



A&M website

Why haven't we observed CEvNS?

- Mainly detector technology
- Past detectors couldn't provide the low threshold sensitivity needed to register the kinetic energy deposition of the heavy recoiling nucleus

Solution

Cryogenically cooled semiconductor detectors with transition edge sensors

Picture courtesy of Andy Kubik, MINER collaboration, 2019

2 Types of Detectors

iZIP detectors

- Able to recognize electron and nuclear recoils as low as ~ 1keV

Two High Voltage detectors:

-Silicon

-Germanium

Neganov-Luke Phonon Amplification Method

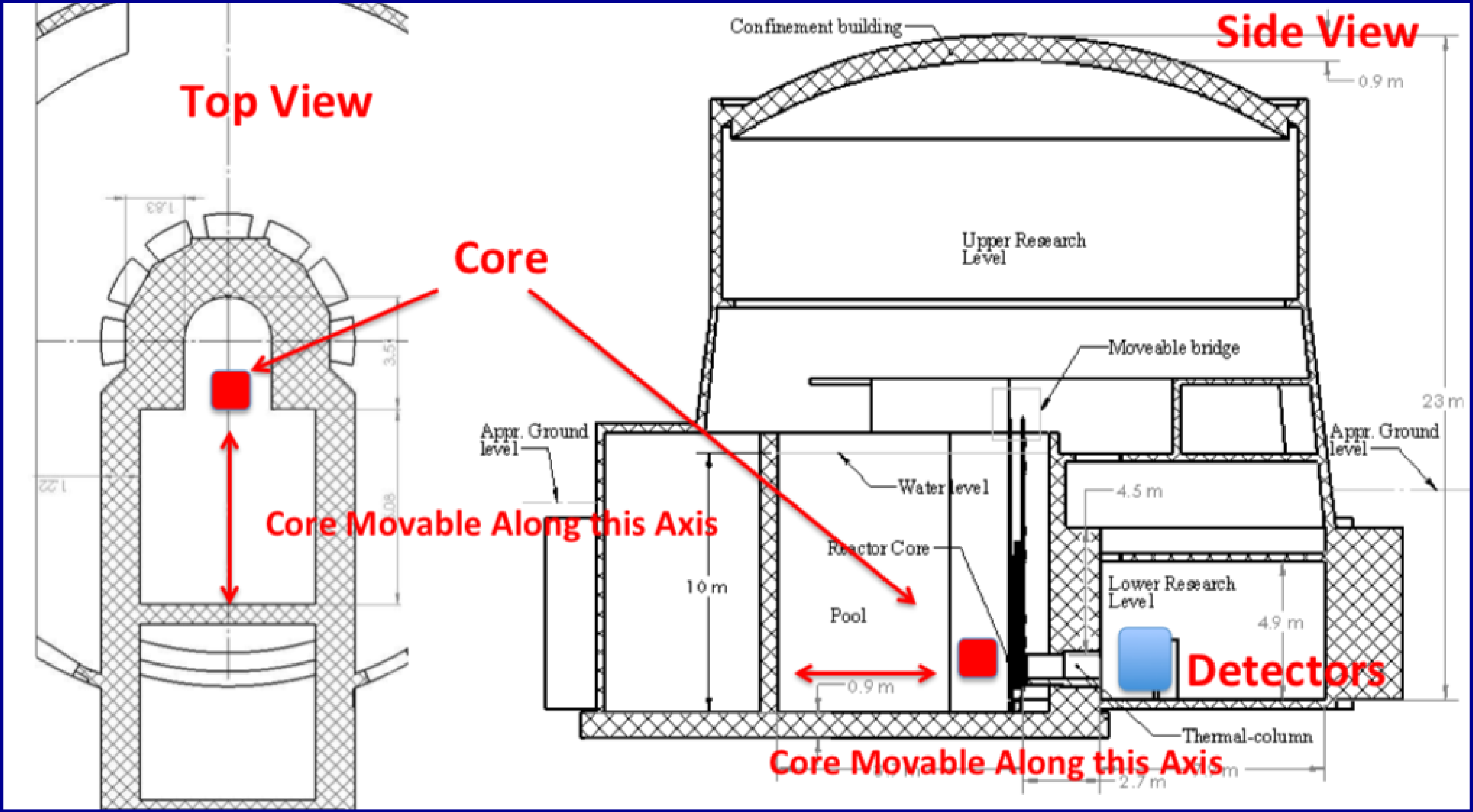
- Amplifies charge without increasing noise!

Reactor

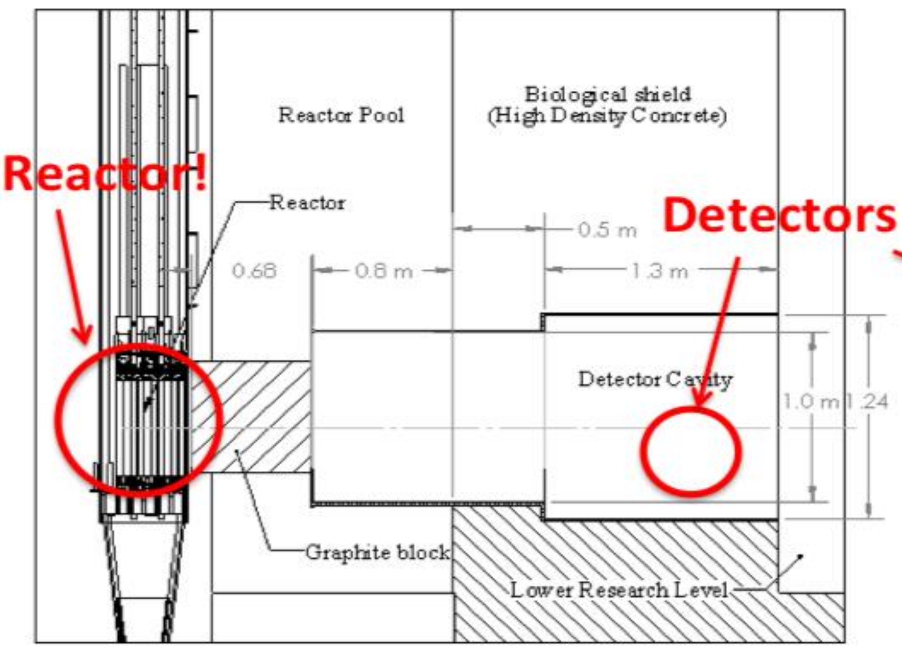
- Mega-Watt class TRIGA(Training, Research, Isotopes, General Atomics) pool reactor stocked with low enriched ^{235}U
- Reactor Advantages
  - Movable Core
  - Access to deploy detectors as close as 1m from reactor
  - Expected to detect 5 to 20 events/kg/day in recoil energy range of 10 and 1000 eV_{nr}

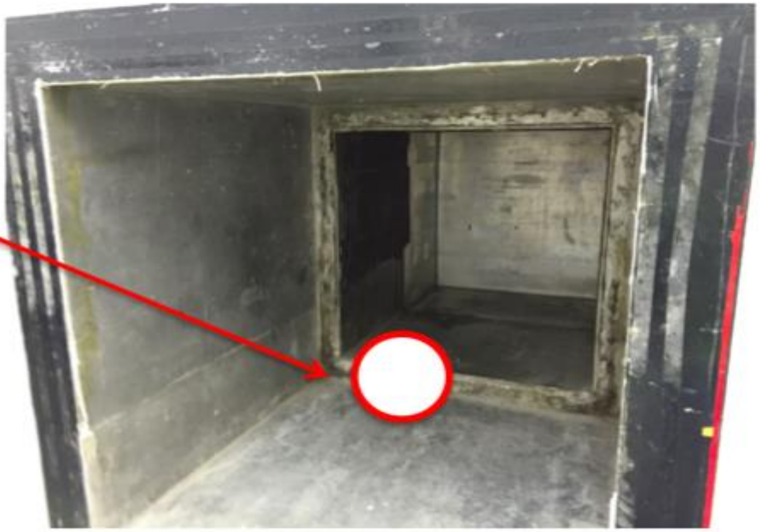
Picture courtesy of Andy Kubik, MINER collaboration, 2019

Nuclear Science Center



Andy Kubik, MINER





“Thermal Column” Experimental Area

Andy Kubik, MINER

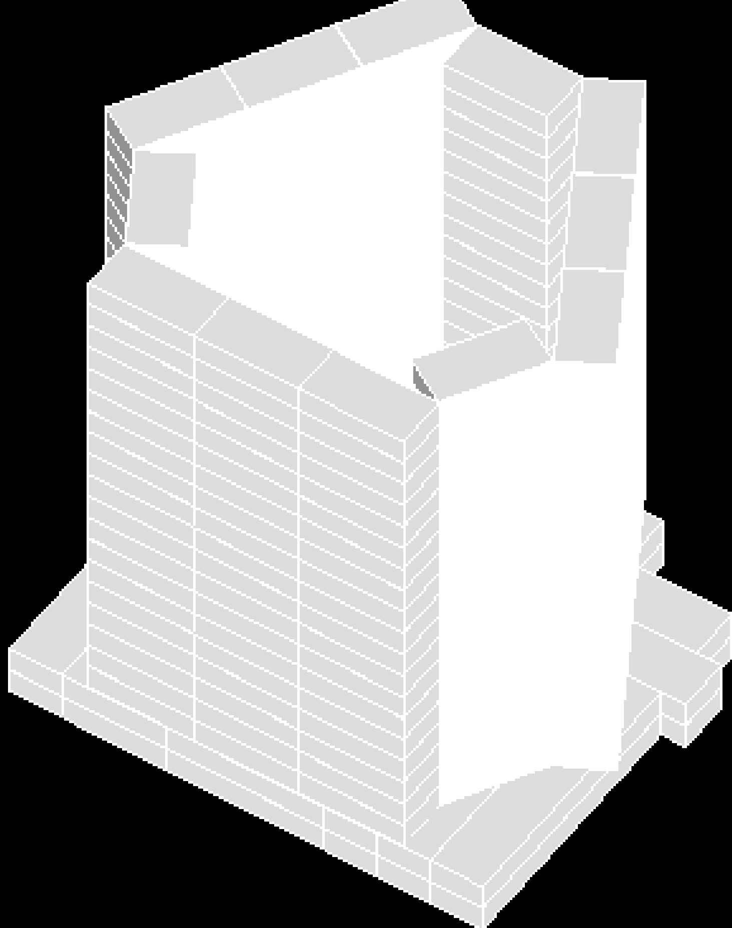
Geant4

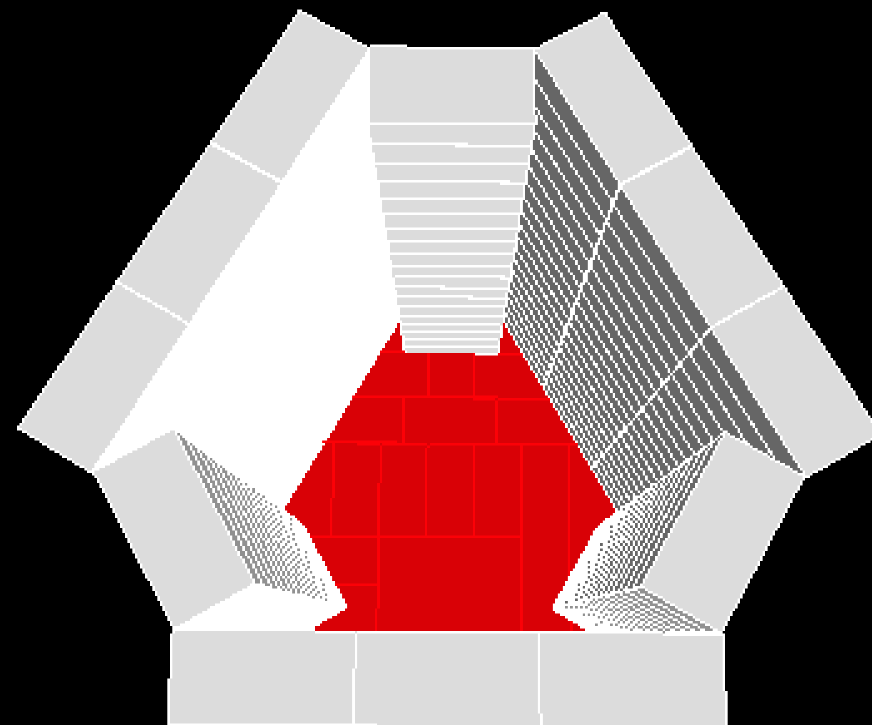
- Toolkit for simulating the passage of particles through matter using Monte Carlo Methods
- Developed by CERN
- World wide collaboration of scientist and software engineers
- Applications
  - High Energy Physics
  - Nuclear Experiments
  - Accelerator and Space Physics
  - Medical

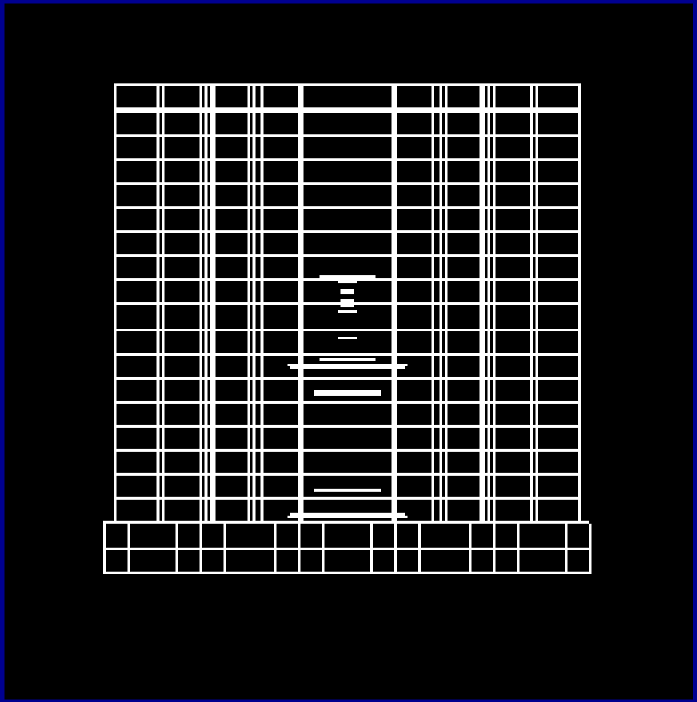
GDML

- Geometry Definition Markup Language
- Specialized XML-based language
  - Designed to be an application-independent format that describes the geometries of detectors associated with physics measurements.
- Can be easily shared
- Easy to learn and implement
- Its universal and most software supports it

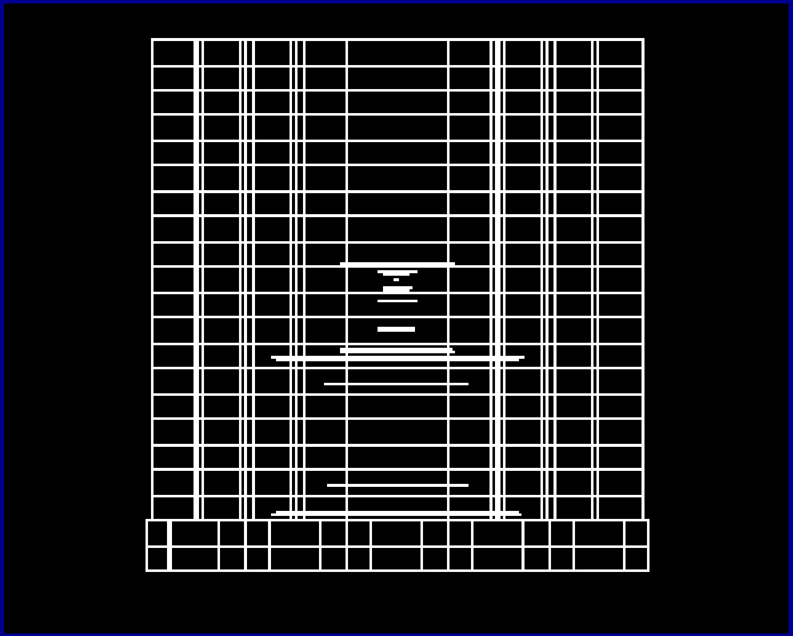
Andy Kubik, MINER





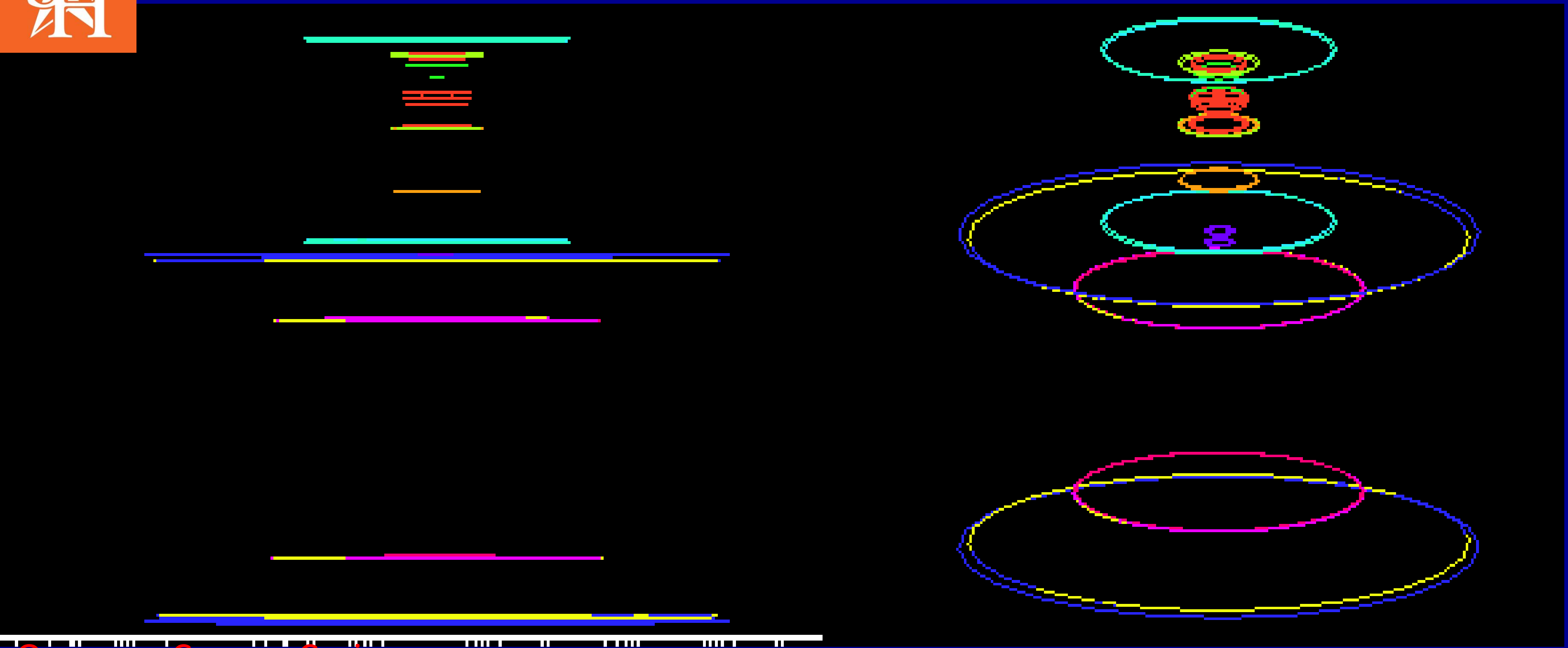


C++



GDML

HPGE Detector



Orange – Copper Casing
Green – Germanium detector
Teal blue – liquid Nitrogen Tube
Yellow – Canberra Casing
Light Purple – Tin Casing
Blue – Stainless steel casing
Orange – Tube A
Lime Green - Tube B
Purple – Tube C
Aqua – Tube D

XML Declaration

GDML Namespace

XML Schema Instance Namespace

GDML Schema Location

Declaration of constants, positions, rotations, scalings, variables and matrices

Definition of elements, materials, isotopes etc. *Only materials can be referenced to volumes*

Simple material defined using fractions of elements defined higher up.

All solids to be used inside the geometry defined here

All volumes declared in the structure section.

World volume is declared

Physical Volumes placed inside a Logical Volume with a specified position, rotation and scale

The top volume of the geometry is specified

```xml
<?xml version="1.0" encoding="UTF-8" ?>

<gdml xmlns:gdml="http://cern.ch/2001/Schemas/GDML"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:noNamespaceSchemaLocation="schema/gdml.xsd" >

<define>
 <constant name="const1" value="100" />
 <position name="pos1" unit="mm" x="0" y="0" z="0" />
 <rotation name="rot1" unit="deg" x="const1" y="0" z="0" />
 <scale name="scl1" x="-1" y="+1" z="+1"/>
</define>

<materials>
   <element Z="7" formula="N" name="Nitrogen" >
     <atom value="14.01" />
   </element>
   <element Z="8" formula="O" name="Oxygen" >
     <atom value="16" />
   </element>

   <material formula=" " name="Air" >
     <D value="0.00128" />
     <fraction n="0.7" ref="Nitrogen" />
     <fraction n="0.3" ref="Oxygen" />
   </material>
</materials>

<solids>
   <box aunit="radian" lunit="mm" name="world" x="10000" y="10000" z="10000" />
   <box aunit="radian" lunit="mm" name="det" x="2000" y="2000" z="2000" />
</solids>

<structure>
   <volume name="Detector" >
     <materialref ref="Air" />
     <solidref ref="det" />
   </volume>
   <volume name="World" >
     <materialref ref="Air" />
     <solidref ref="world" />
     <physvol>
       <volumeref ref="Detector" />
       <positionref ref="pos1" />
       <rotationref ref="rot1" />
```

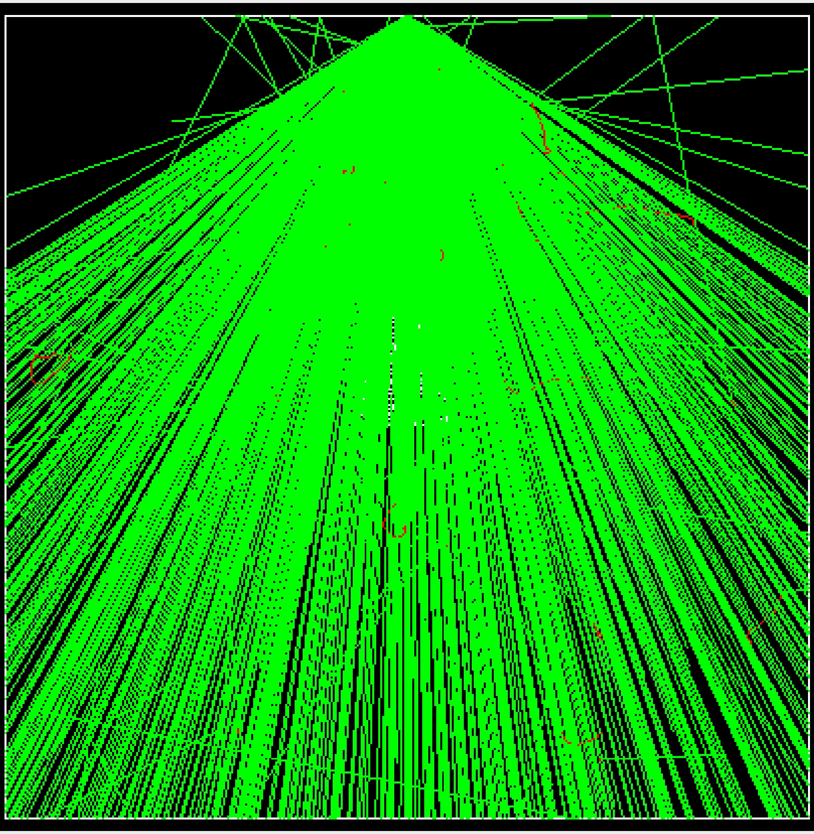
Cern, GDML guide

C++

```xml
<tube name="Target1" rmin="0" rmax="detRad" z="detHalfZ" deltaphi="TWOPI"
    aunit="radian"/>
<tube name="Target2" rmin="0" rmax="4.75" z="15" deltaphi="TWOPI"
    aunit="radian" lunit="mm"/>
<subtraction name="target">
    <first ref="Target1"/>
    <second ref="Target2"/>
    <positionref ref="targetOffset"/>
</subtraction>

<tube name="cuCasing1" rmin="0" rmax="detRad+cuCasingThick"
    z="35.5/2+detHalfZ+cuCasingThick/2" deltaphi="TWOPI" lunit="mm"/>
<tube name="cuCasing2" rmin="0" rmax="detRad+.001" z="35.5/2. + detHalfZ +
    cuCasingThick/2" deltaphi="TWOPI" lunit="mm" />
<subtraction name="cuCasing">
    <first ref="cuCasing1"/>
    <second ref="cuCasing2"/>
    <positionref ref="casingOffset"/>
</subtraction>

<tube name="cuRing" rmin="detRad+cuCasingThick"
    rmax="detRad+cuCasingThick+cuRingThick" z="cuRingHeight/2"
    deltaphi="TWOPI"/>
<tube name="cuRingT" rmin="detRad+cuCasingThick"
    rmax="detRad+cuCasingThick+cuRingThick" z="cuRingHeight/6"
    deltaphi="TWOPI"/>
<union name ="cuDetHousing1">
    <first ref ="cuCasing"/>
    <second ref ="cuRingT"/>
    <positionref ref="ringOffsetT"/>
</union>
<union name ="cuDetHousing2">
    <first ref ="cuDetHousing1"/>
    <second ref ="cuRing"/>
    <positionref ref="ringOffset1"/>
</union>
<union name ="cuDetHousing">
    <first ref ="cuDetHousing2"/>
    <second ref ="cuRing"/>
    <positionref ref="ringOffset2"/>
</union>
```

720

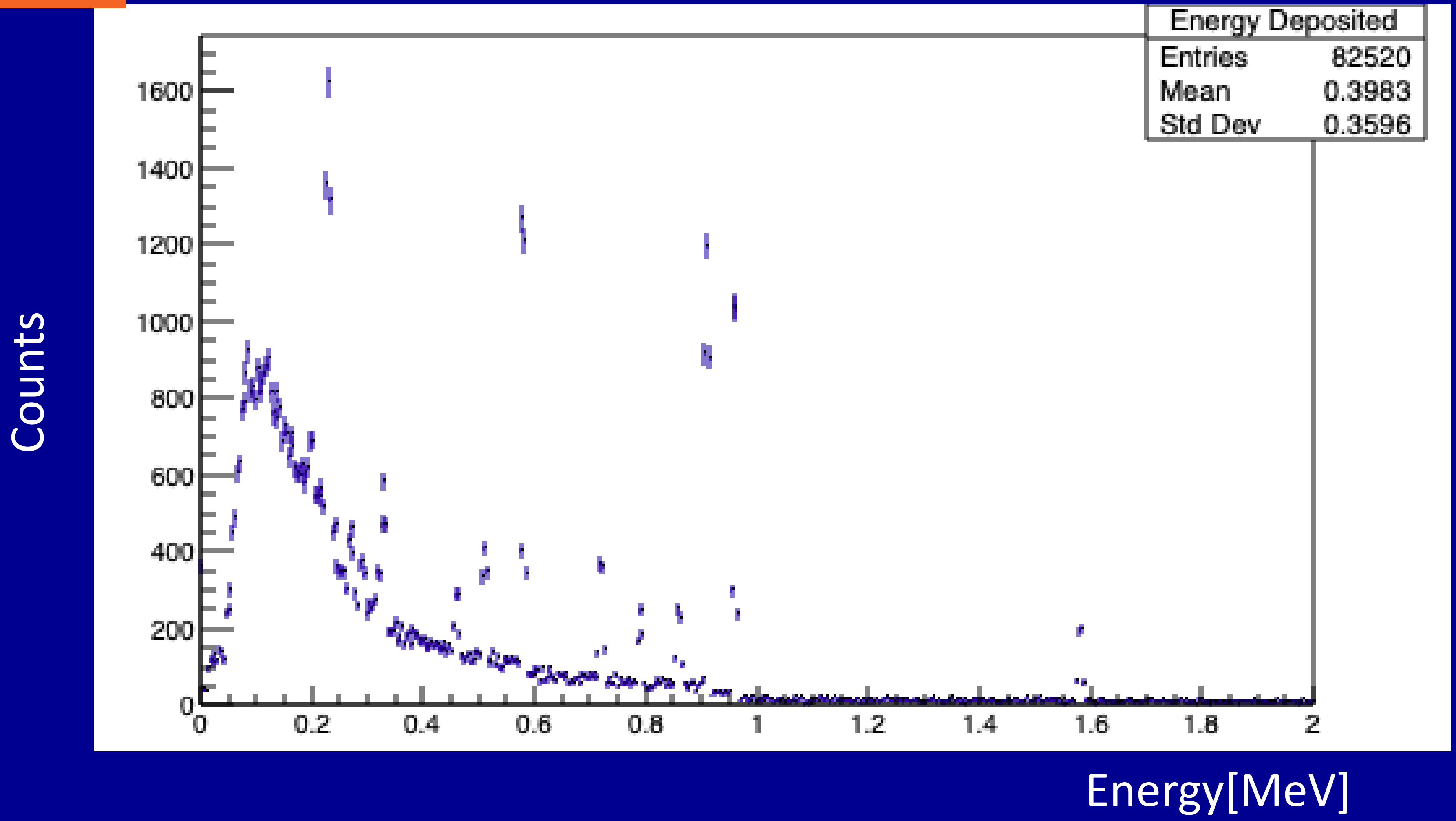
```cpp
G4SubtractionSolid *target = new
    G4SubtractionSolid("Target"+name,target1,target2,0,targetOffset);
G4LogicalVolume *fLogicDet = new G4LogicalVolume(target, fGe,"Craig_log"+name);


G4double cuCasingThick = 0.76*mm;
//G4double cuCasingThick = 2.25*mm;
G4double cuRingThick = 2.7*mm - 0.76*mm;
//G4double cuRingThick = 3.5*mm;
G4double cuRingHeight = 8.6*mm;


G4VSolid* cuCasing1 = new G4Tubs("cuCasing1"+name,0.,detRad+cuCasingThick,35.5*mm/2. + detHalfZ
    + cuCasingThick/2.,0,360*deg);
G4VSolid* cuCasing2 = new G4Tubs("cuCasing2"+name,0.,detRad+.001*mm,35.5*mm/2. + detHalfZ +
    cuCasingThick/2.,0,360*deg);
G4ThreeVector casingOffset(0,0,3.0*mm);
G4SubtractionSolid *cuCasing = new
    G4SubtractionSolid("cuCasting"+name,cuCasing1,cuCasing2,0,casingOffset);


G4VSolid* cuRing = new
    G4Tubs("cuRing"+name,detRad+cuCasingThick,detRad+cuCasingThick+cuRingThick,cuRingHeight/2
    .,0,360*deg);
G4VSolid* cuRingT = new
    G4Tubs("cuRingT"+name,detRad+cuCasingThick,detRad+cuCasingThick+cuRingThick,cuRingHeight/6
    .,0,360*deg);
G4ThreeVector ringOffsetT(0,0,35.5*mm/2. + detHalfZ + cuCasingThick/2.-cuRingHeight/6.);
```

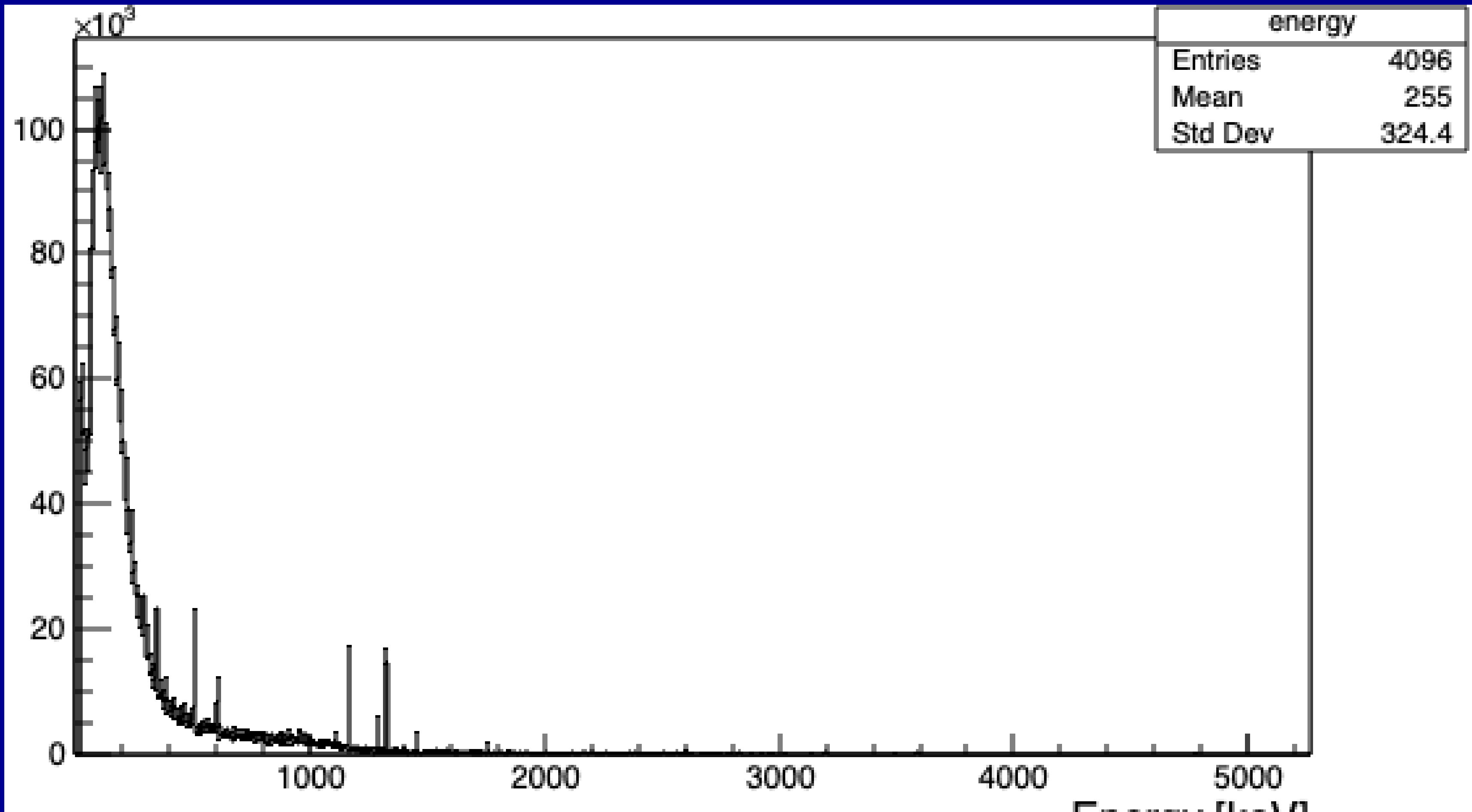


Output

```
PDG ID: 11 time: 12.1854 Particle Energy: 58.4143 keV Edep: 58.4143 keV Position: -12.9521 35.0191 -0.420979 cm
PDG ID: 11 time: 12.1853 Particle Energy:  8.5369 keV Edep:  8.5369 keV Position: -12.952 35.0176 -0.419002 cm
PDG ID: 11 time: 12.1826 Particle Energy:  1.5139 keV Edep:  1.5139 keV Position: -12.917 35.0884 -0.397135 cm
PDG ID: 11 time: 12.1733 Particle Energy: 6.07972 keV Edep: 6.07972 keV Position: -12.812 35.2796 -0.222434 cm
PDG ID: 22 time: 12.1879 Particle Energy: 170.982 keV Edep:        0 eV  Position: -15.8058 35.0642 -8.86112 cm
PDG ID: 22 time: 12.1894 Particle Energy: 170.661 keV Edep:        0 eV  Position: -15.8031 35.0198 -8.86241 cm
PDG ID: 22 time: 12.1948 Particle Energy: 170.661 keV Edep:        0 eV  Position: -15.793 34.859 -8.86706 cm
PDG ID: 22 time: 12.1958 Particle Energy: 170.661 keV Edep:   378.32 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:   53.29 eV  Edep:    53.29 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:   35.58 eV  Edep:    35.58 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:    32.8 eV  Edep:     32.8 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:   10.87 eV  Edep:    10.87 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:   34.14 eV  Edep:    34.14 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:   34.14 eV  Edep:    34.14 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:    98.2 eV  Edep:     98.2 eV  Position: -15.7904 34.8304 -8.86756 cm
PDG ID: 11 time: 12.1958 Particle Energy:  116.87 eV  Edep:   116.87 eV  Position: -15.7904 34.8304 -8.86756 cm
```

4 million Gamma particles





Counts/Kg/day

Energy[keV]

Conclusion

- Geant4 is powerful tool!
- MINER phase I begins this summer
- When Geant4 simulation is fully built, it should mimic the exact results MINER puts out
- In the future Geant4 could be used to run before the experiment begins, allowing the reactor to confirm the simulation