UCLA College | Physical Sciences Physics & Astronomy

Simulating Dark Matter Detection with GEANT4 and G4VR

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Cali-X TPC

- Incident particle interacts with xenon nucleus → scintillation light (S1) detected by photomultiplier tubes (PMTs)
- Interaction ionizes atoms, freeing electrons, which travel upward due to electric field
- Electrons reach the top → produce second signal (S2)
- Timing of S1 and S2, PMT data used to reconstruct initial particle trajectories

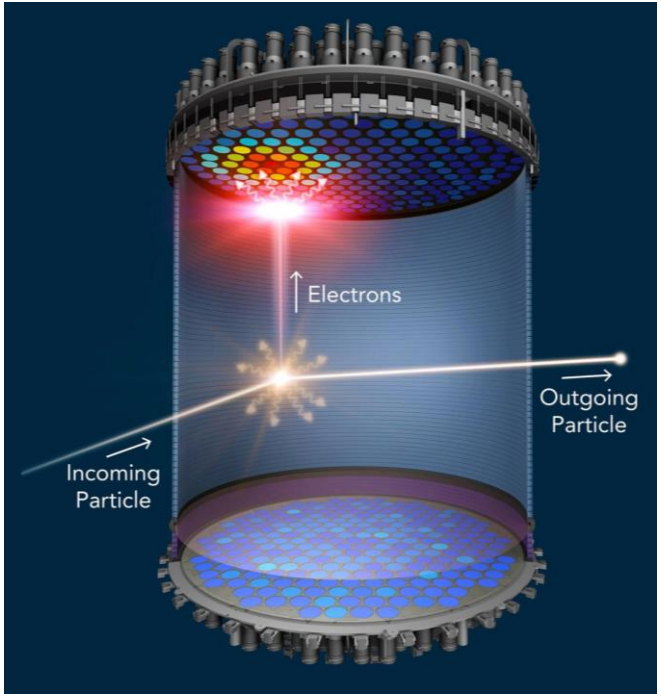


Fig. 1: Example of scintillation process in LZ detector [8]

Cali-X TPC

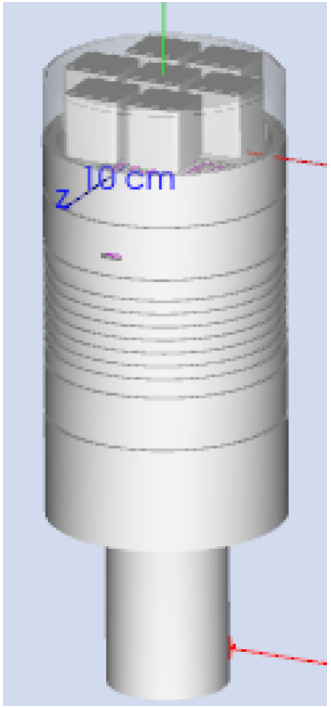


Fig. 2: GEANT4 Simulation of Cali-X TPC

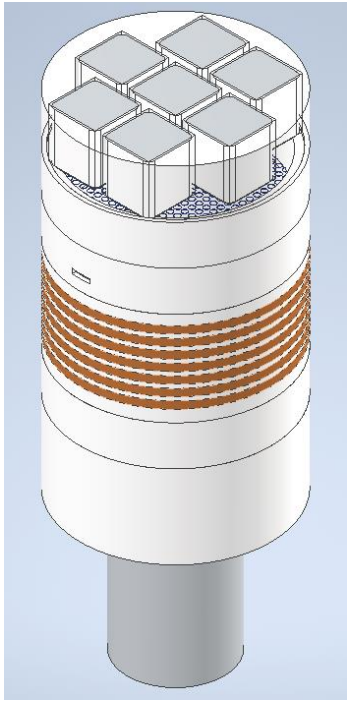


Fig. 3: CAD Drawing of Cali-X TPC [4]

What is GEANT4?

- GEANT4 = GEometry ANd Tracking 4
- “Toolkit for the simulation of the passage of particles through matter”
- C++ based platform that uses Monte Carlo methods to simulate interactions between particles

Designing the Simulation

DETECTOR GEOMETRY

- Can manually build volumes in C++ or import CAD files

3 Types of Volumes

- Solid
  - Shape of component
- Logical
  - Material, visual attributes, detection properties
- Physical
  - Location, orientation

PARTICLES AND SOURCES

- Particle Gun
  - Point source
  - Specified direction, momentum
  - Best for simple monoenergetic sources
- General Particle Source (GPS)
  - Point or volume source
  - Better for more complex sources

Designing the Simulation

PHYSICS AND FIELDS

- Specify desired physics
- Reduce computation cost
- prevent unwanted interactions (e.g. gravitational force)
- Implement electric fields in liquid xenon
- Implement Noble Element Simulation Technique (NEST) package to accurately determine photon and electron yields from scintillation

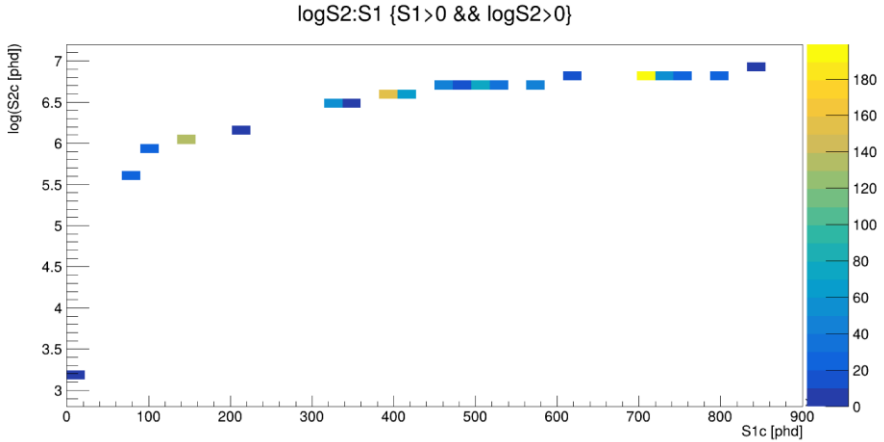
```
RegisterPhysics (new G4OpticalPhysics());
RegisterPhysics (new G4DecayPhysics());
RegisterPhysics (new G4RadioactiveDecayPhysics());
RegisterPhysics (new G4HadronElasticPhysicsHP());
RegisterPhysics (new G4HadronPhysicsQGSP_BIC_HP());
RegisterPhysics (new G4IonElasticPhysics());
RegisterPhysics (new G4IonPhysics());
RegisterPhysics (new G4StoppingPhysics());
RegisterPhysics (new G4EmLowEPPhysics());
RegisterPhysics (new G4StepLimiterPhysics());
```

Fig. 4: GEANT4 physics lists included in experiment

Designing the Simulation

DATA COLLECTION

- Data analysis done through ROOT
- Can export histograms, N-tuples,etc.
- Energy depositions, hits, etc. can be analyzed



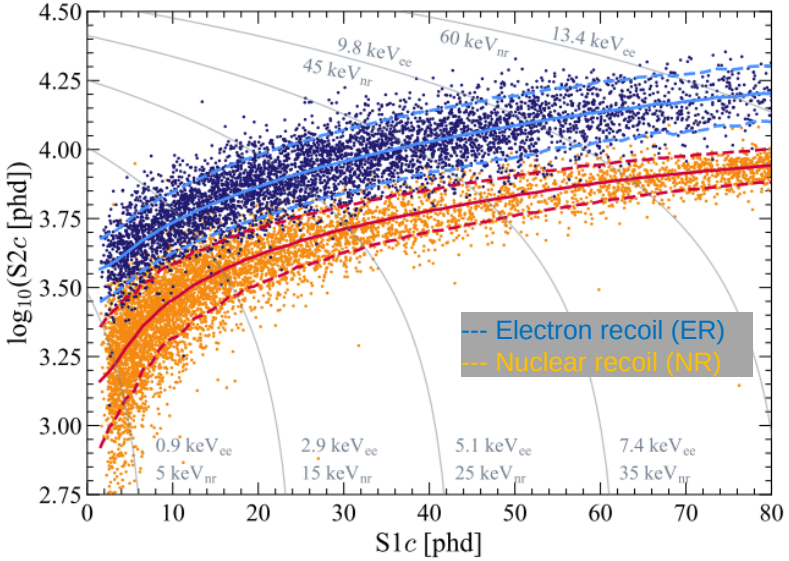


Fig. 5 (Above): Expected ratio of S1 to S2 photons from LZ experiment [13]
Fig. 6 (Left): Ratio of S1 to S2 photons in GEANT4 simulation

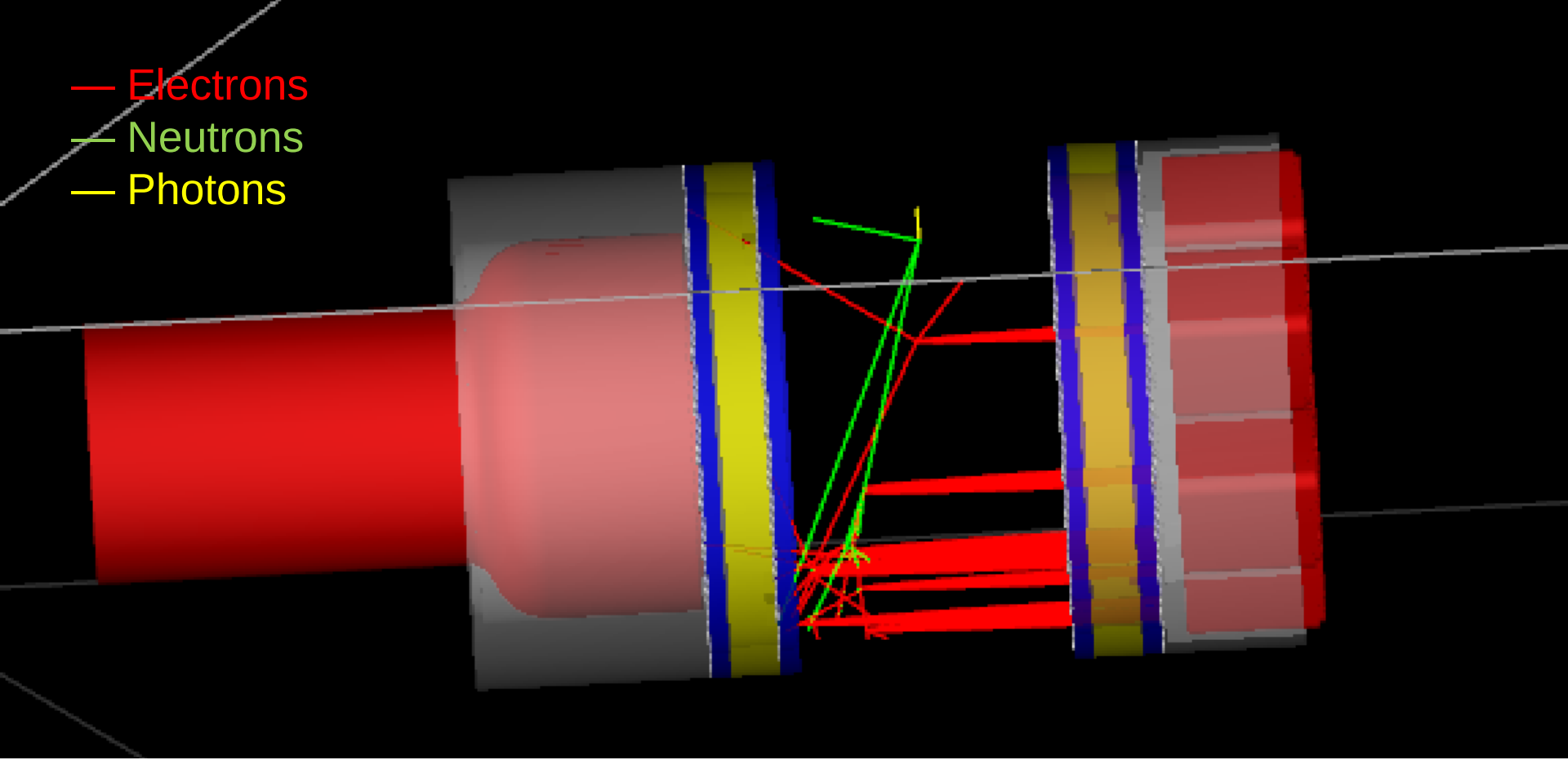


Fig. 7: S2 event as seen in GEANT4 viewer

Visualization in Virtual Reality

- G4VR is a visualization tool developed by Benjamin Jobilal that allows GEANT4 runs to be viewed in virtual reality
- View energy depositions in specific volumes, energy depositions of specific tracks
- Time evolution for GEANT4 example scenes
- G4XR saves scene geometry as a .glb file and each run as an individual .csv file
- This data is stored on a local server and parsed by G4VR to produce the scenes we see in VR

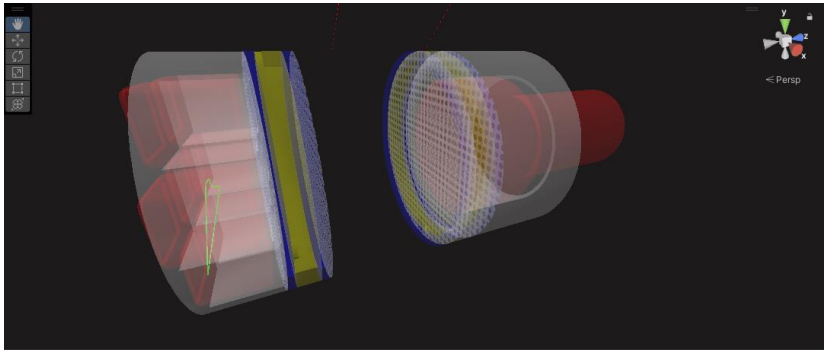


Fig. 8: CALI-X TPC as seen in G4VR

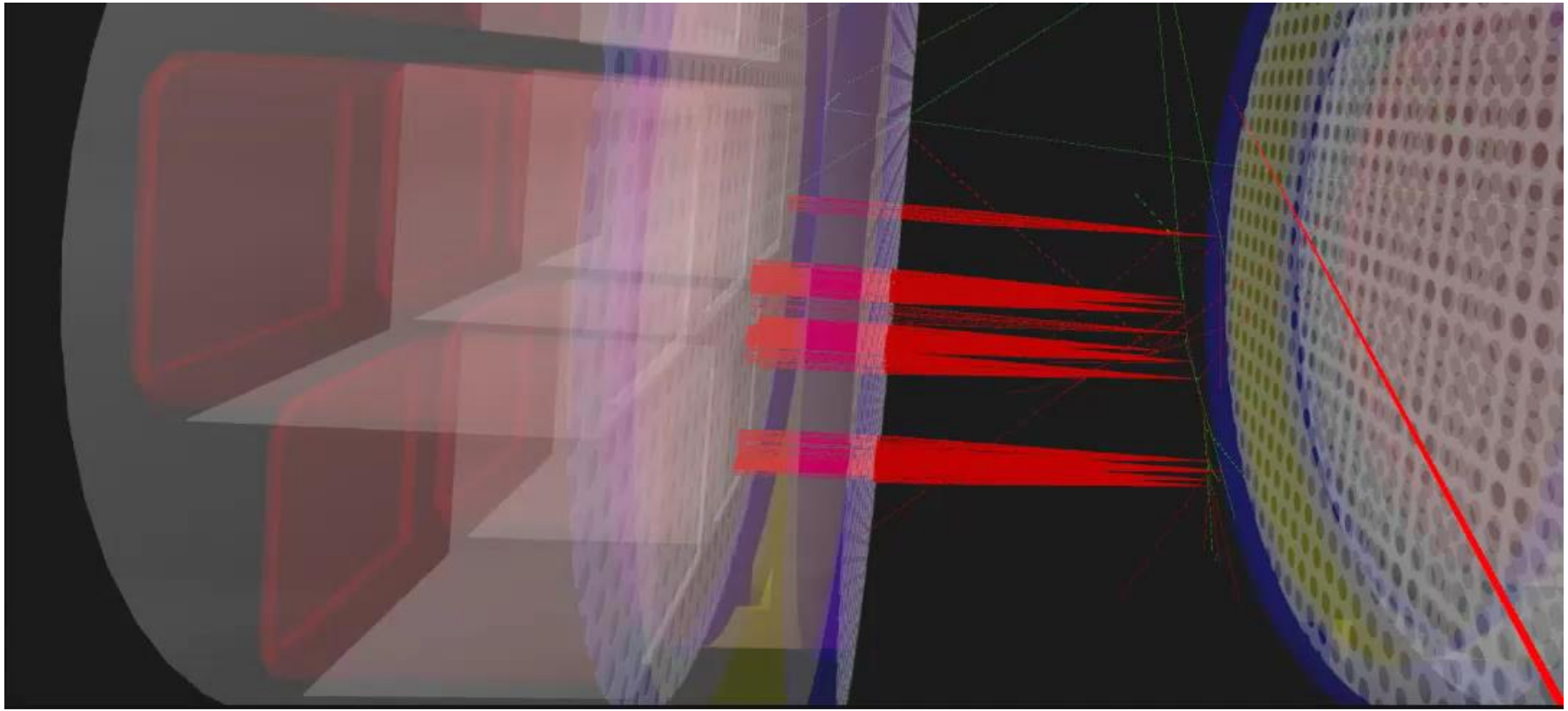


Fig. 8: Example event in GEANT4 simulation viewed in virtual reality via G4VR

Simulating Dark Matter in GEANT4

DMG4

- DMG4 is a GEANT4 add-on developed by Mikhail Kirsanov
- Simulates dark matter production in electron, muon, and positron beams
- Plan to implement this in simulation when testing additional sources

NEST

- NEST has options for simulating yields for WIMP collisions
- Plan to explore this further to see what impacts in can have

Next Steps

- Test more sources to try to replicate results from real detector (AmBe, DD, tritium, etc.)
- Compare electron drift time and drift velocity to real-world results
- Fix scintillation ratios to be more accurate
- Create completely accurate visualization of electric field lines inside the TPC using FEniCS software

Thank You

References

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