G4VR Simulation of Pion Channel Proton Decay in a Water Cherenkov Detector

Trevor Waltersdorf

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Background on Proton Decay

Standard Model

- Explains 3 of the 4 fundamental forces
- **Baryonic symmetry**

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- Mediated through a massive X boson

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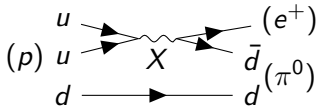
Kaon Channel: $p \rightarrow \bar{\nu} + K^+$

- Favored in supersymmetric GUTs
- Harder detection than π^0 due to the massive K^+
  - Can be detected from the decay of K

Background on Proton Decay

Detection of π^0 Channel Decay

- The π^0 almost immediately decays to $\gamma + \gamma$.
- $v \geq \frac{c}{1.33}$ for all daughter particles
- Undergo Cherenkov radiation to emit optical photons
- Photomultiplier tubes (PMTs) can capture the detect these Cherenkov cones



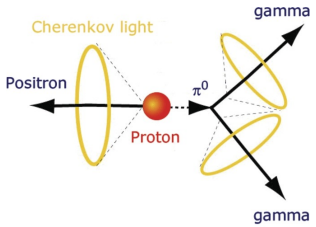


Image credit: Tommy Ohlsson

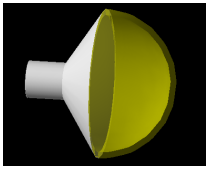
Overview of My Simulation

PrimaryGeneratorAction.cc
PMTConstruction.cc
DetectorConstruction.cc
PhysicsLists.cc
EventAction.cc

- Initial momenta in CM frame: 459.25 MeV
- Sampling of isotropic direction
- 80% bound in O atom $\rightarrow$ must account for Fermi motion
  - Isotropic direction
  - Random momentum up to 225 MeV
- Apply Lorentz boost to bring to lab frame

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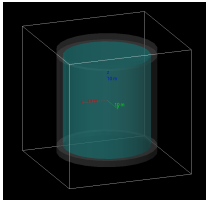
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- Dome
  - Radius of 25cm
  - 2cm thick pyrex glass
  - Encloses a vacuum
- Photocathode
  - Surface between dome & vacuum
  - Quantum Eff. $= 22\%$
- Cone
  - Aluminum
  - Shrinks to 1/4 radius

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- Tank
  - 16.9m inner radius
  - 36.2m inner height
  - 2.5m thick stainless steel
  - Filled with pure H_2O
- PMT Placement
  - Parametric
  - 11,642 total PMTs
    - 2221 per cap
    - 7200 in barrel

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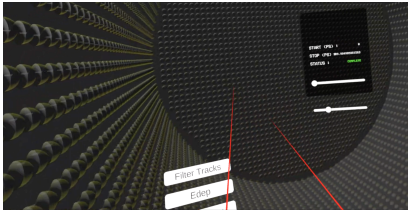
- Modular, built from the Geant4 standard physics list
- Main addition: **Optical Physics**
  - Includes Cherenkov radiation

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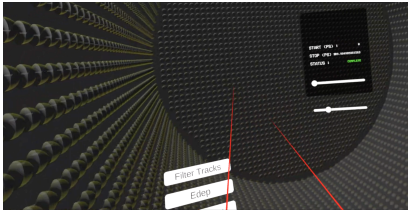
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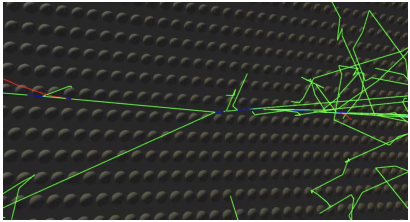
- Collect optical photon hits into container
- Output hit data to .csv
  - Copy number
  - Energy deposited
  - X, Y, and Z positions
- Python program constructs graph of PMT hits

Snapshots from VR

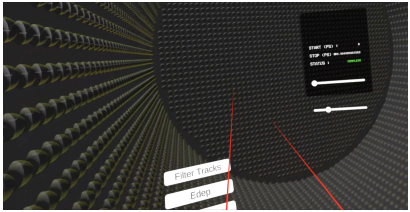


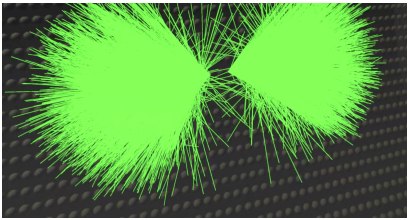
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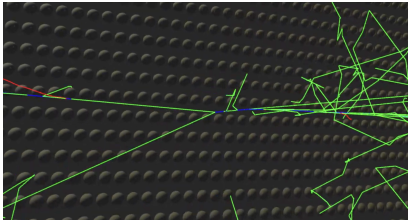




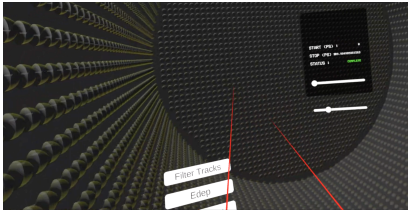
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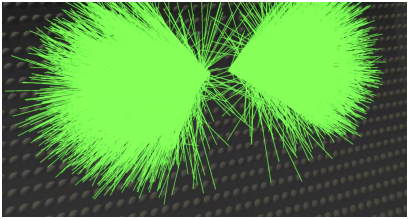


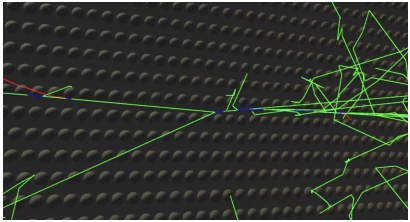


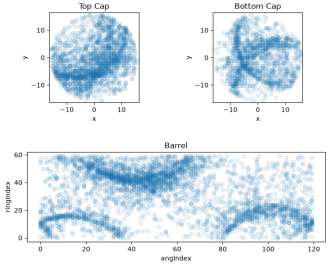


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Future Work & Acknowledgments

Future Work

- Sample proton binding energy
  - Will change Fermi effects
- Simulate neutrino background
  - Will include PMTs on outer wall
- Simulation of neutrino experiments
  - Detection of (simulated) solar neutrinos
  - Oscillations
  - Addition of gadolinium to distinguish $\nu/\bar{\nu}$

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Acknowledgments

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- Benjamin Jobilal
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