Accelerated Simulations with LUX-ZEPLIN

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IoP Joint APP, HEP and NP conference
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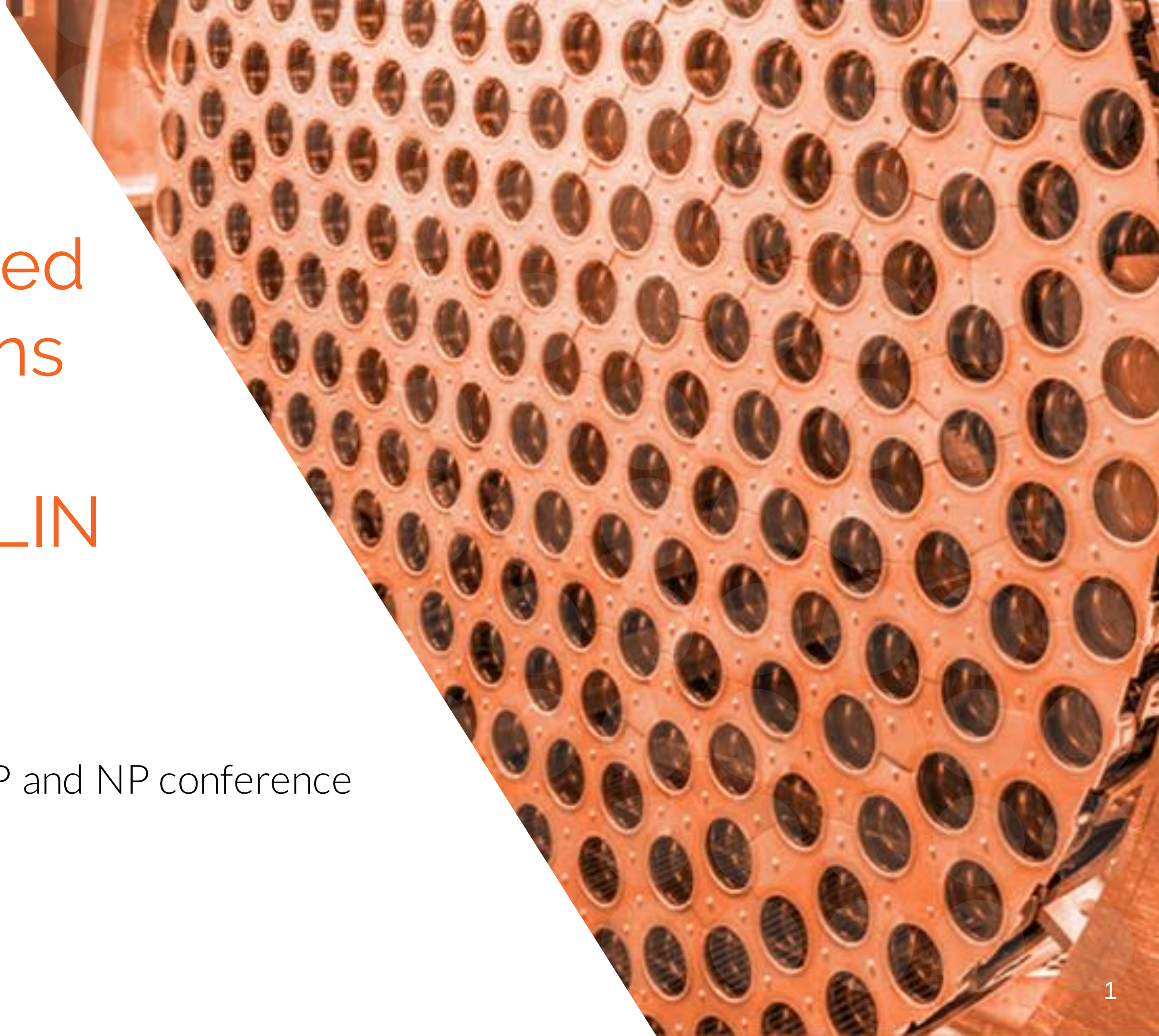
University of BRISTOL



What is LZ

- Very-low background direct dark matter detection experiment
- Based at Sanford Underground Research Facility in SD, USA
- 1 mile underground (4850 feet)

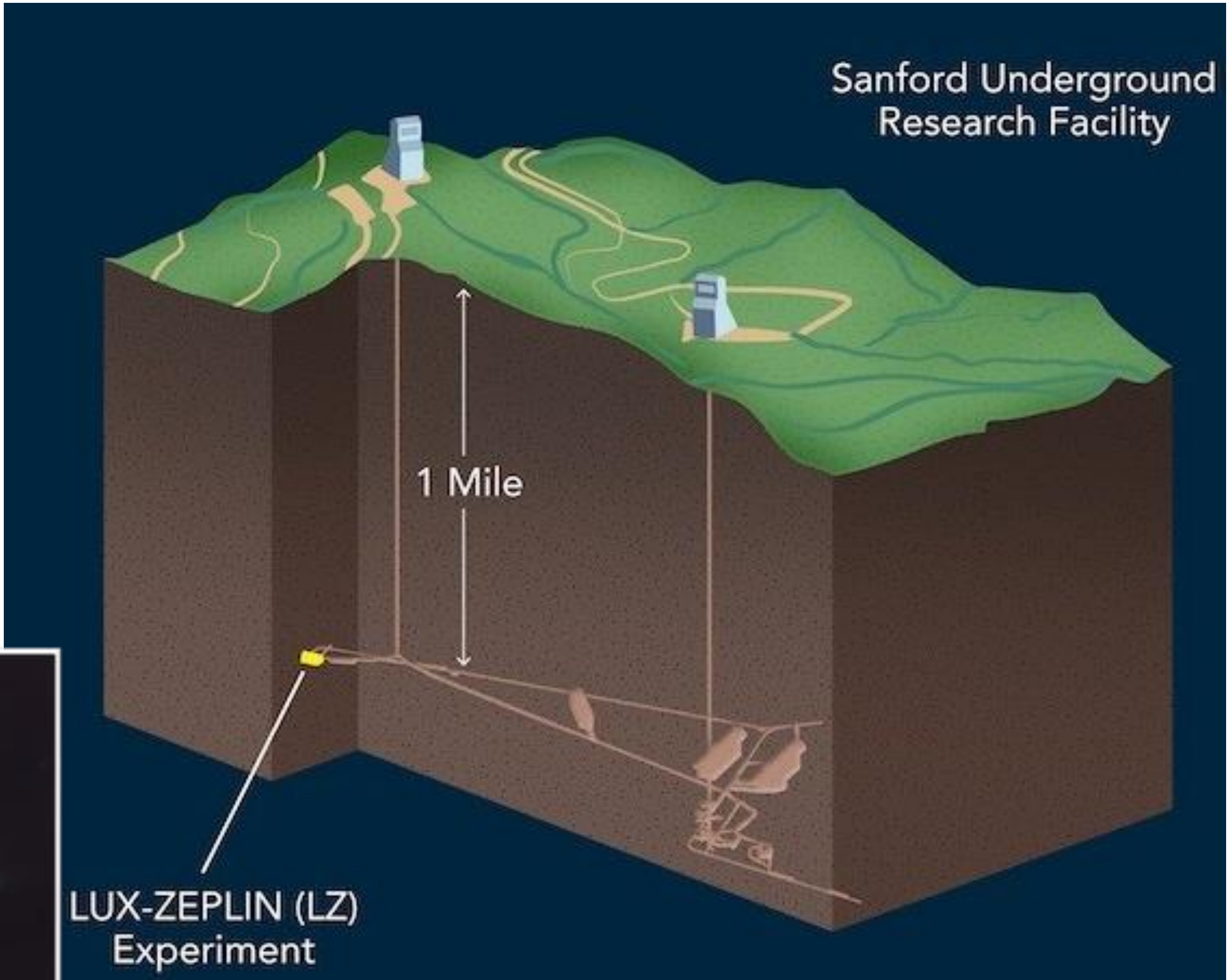


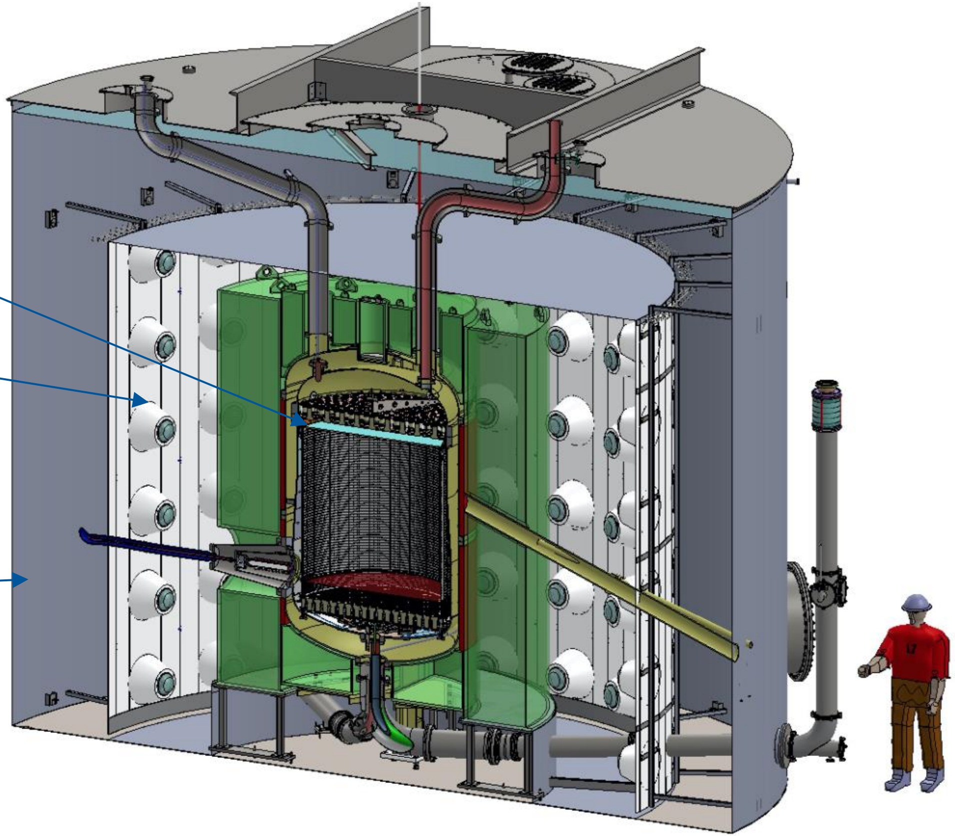
Image from: SLAC National Accelerator Laboratory

Quick Overview of LZ

Two-phase Xenon TPC
- 7 tonnes of liquid Xenon
- 494 3" PMTs

Outer Detector
- 17 tonnes Gd-loaded liquid scintillator
- 120 8" PMTs
- Anti-coincidence detector for neutrons and gammas

Water Tank
- Background shielding



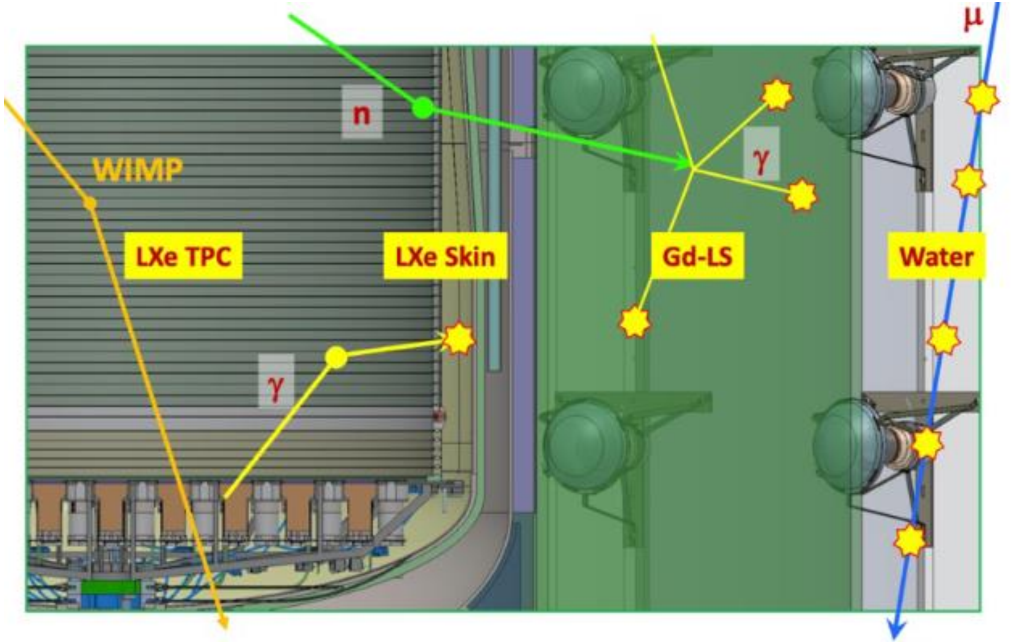
Example LZ Interactions

WIMP
- Interacts once in TPC and nowhere else

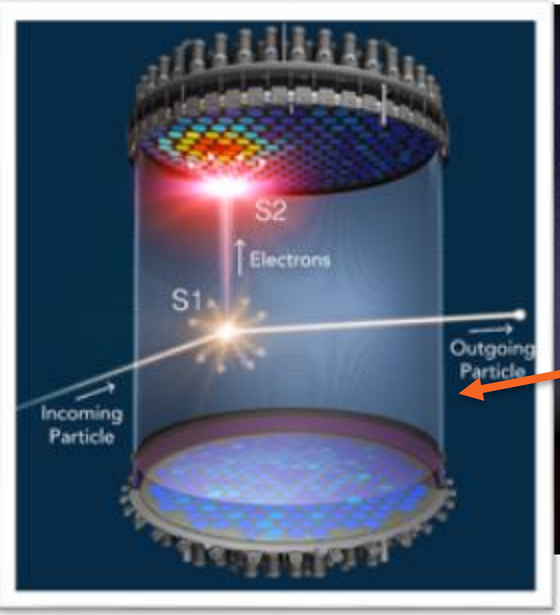
Neutrons and Gammas
- Interact more than once within the detector

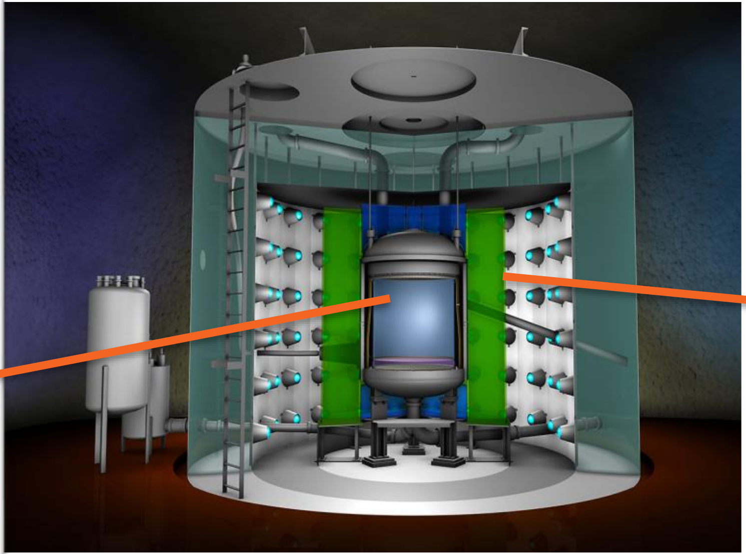
All these interactions result in optical photons which are detected by Photomultiplier tubes

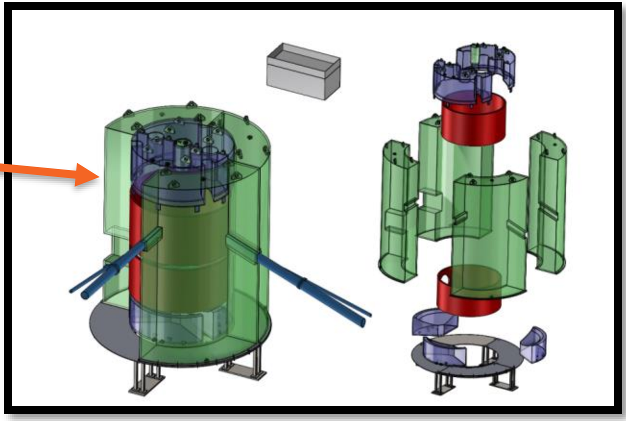
LZ is a low background experiment so need to understand (and simulate) as many sources as possible



The LZ simulation challenge



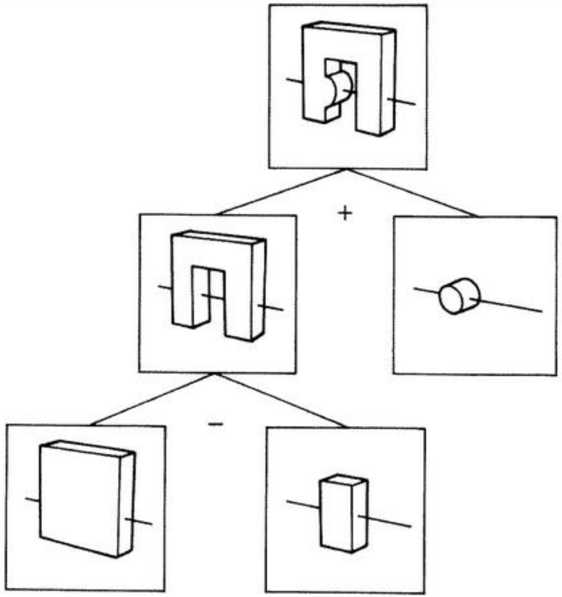




TPC
- Incoming particle interacts with Liquid Xe
- Produces Scintillation light (S1)
- Electrons produce electrolumiecence (S2)
- 900+ optical photons per electron

Outer Detector
- Every MeV of energy results in 9000 optical photons
- Typical neutron capture is 8MeV

The LZ Simulation Challenge



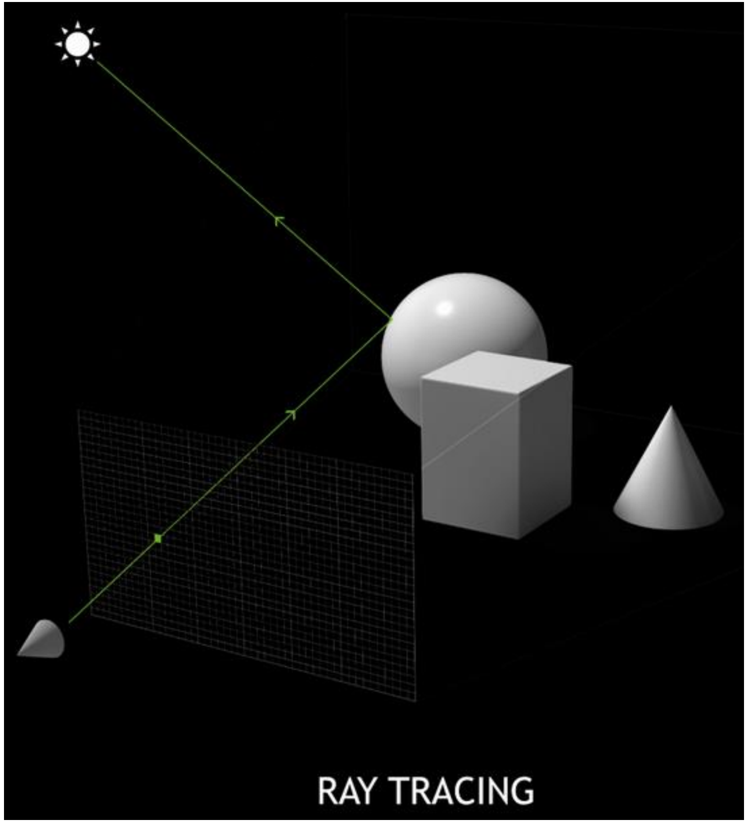
- A simulated particle needs to navigate a geometry tree to find out if it interacted with the material and when it reaches the material boundary

- LZ geometry is very complex
  - So background radiation is better understood
  - all PMT components, cabling etc... is included
- Simulating optical photons takes up 99+% of simulation time. But...
  - They don't interact within the volume, only at the boundary
  - Self-contained so could be simulated in parallel

GPUs

- What are GPUs originally for

https://developer.nvidia.com/orca/nvidia-emerald-square

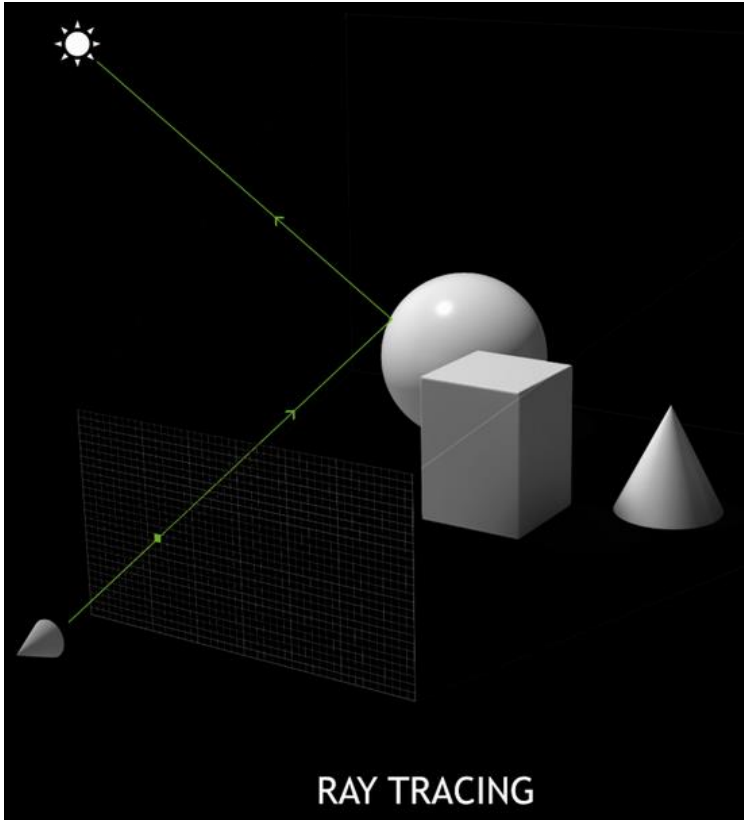


GPUs and NVidia OptiX

- For graphics rendering need: pixel information at image plane
- Limited by ray-geometry intersection
- It's a boundary to boundary problem

- For optical simulations need; photon information at PMT
- Boundary to boundary problem

- Can make use of GPU algorithm advancements and parallelisation

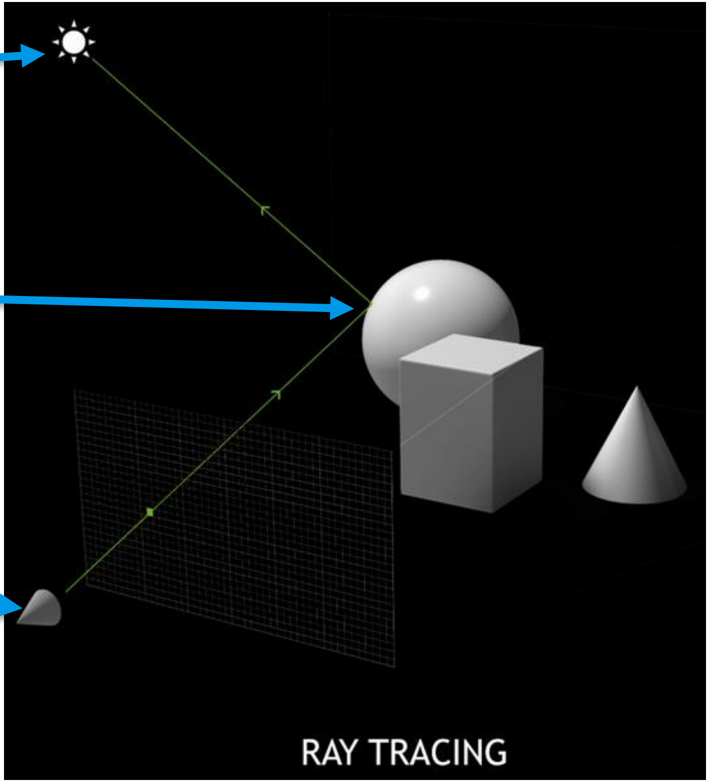


Ray-tracing for Optical Simulations

Optical Photon Source (eg scintillation site)

LZ Geometry

PMT



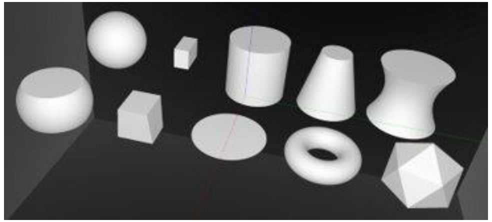
Challenges:

1. Break down geometry from Geant4 form and rebuild in GPU useable way

2. Optical Photon generation

3. Photon propagation

4. Returning the simulation result



Opticks solution

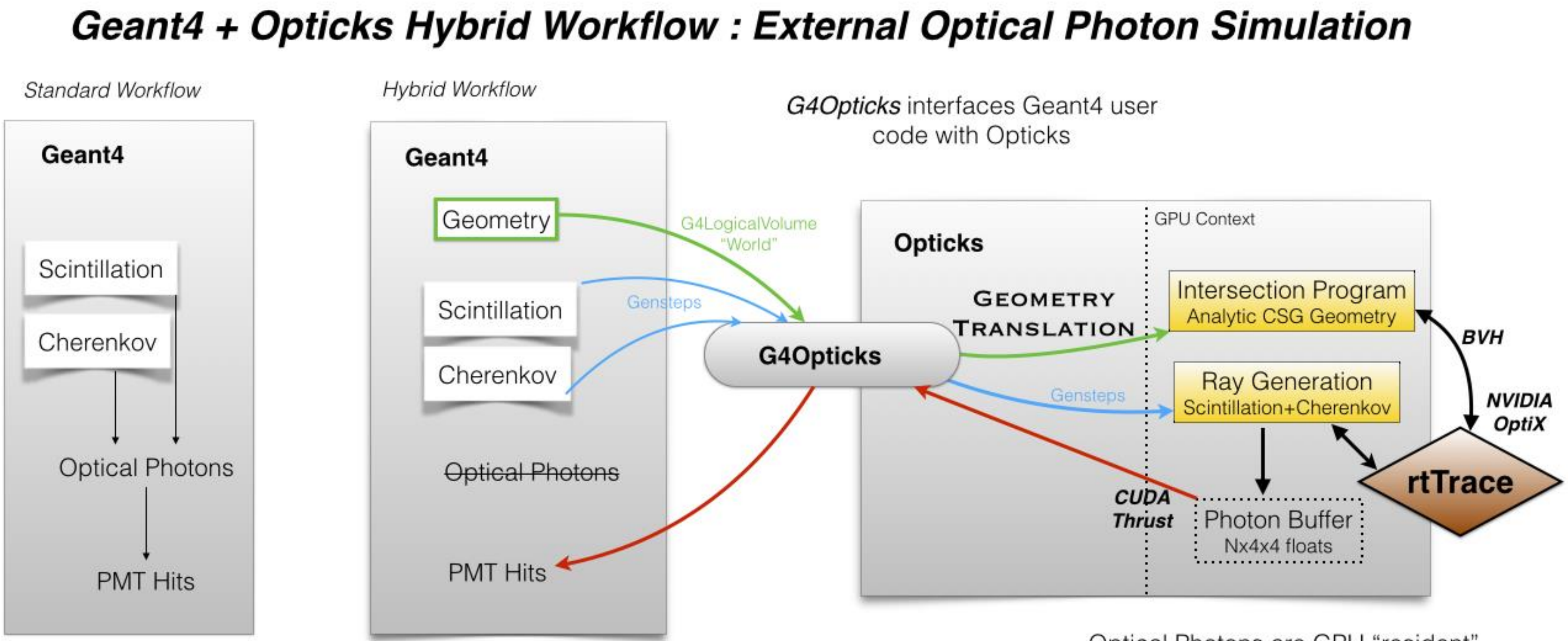
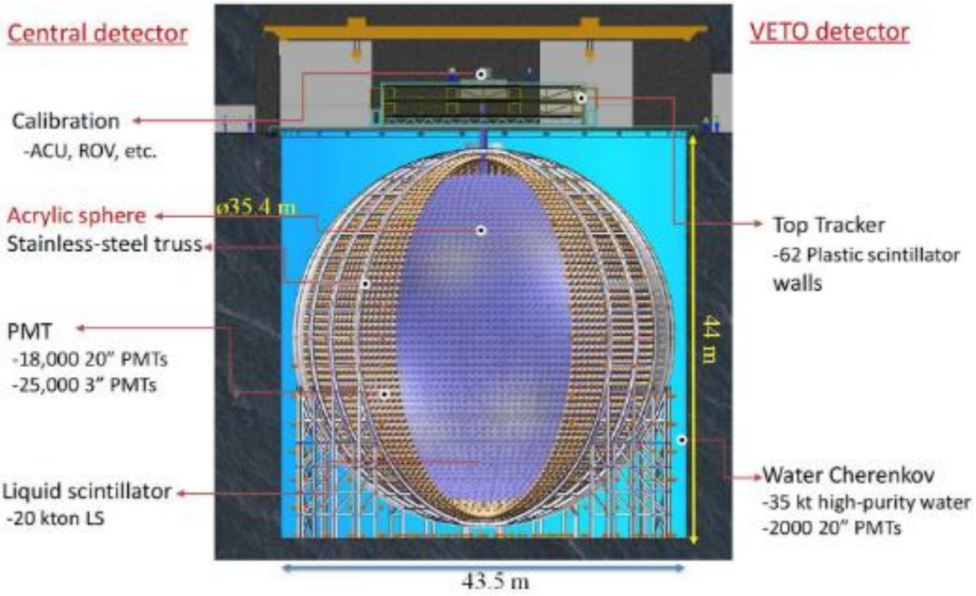
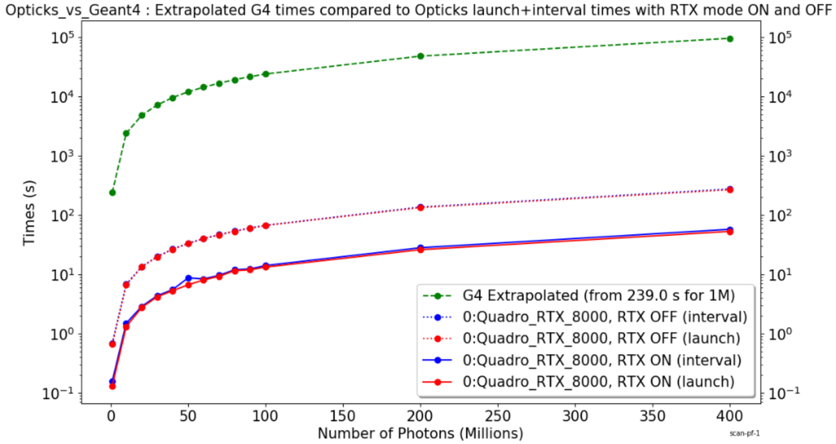


Image from S. Blyth; https://simoncblyth.bitbucket.io/

Expected Performance



https://arxiv.org/pdf/1804.03575.pdf



https://www.epj-conferences.org/articles/epjconf/pdf/2020/21/epjconf_chep2020_11003.pdf

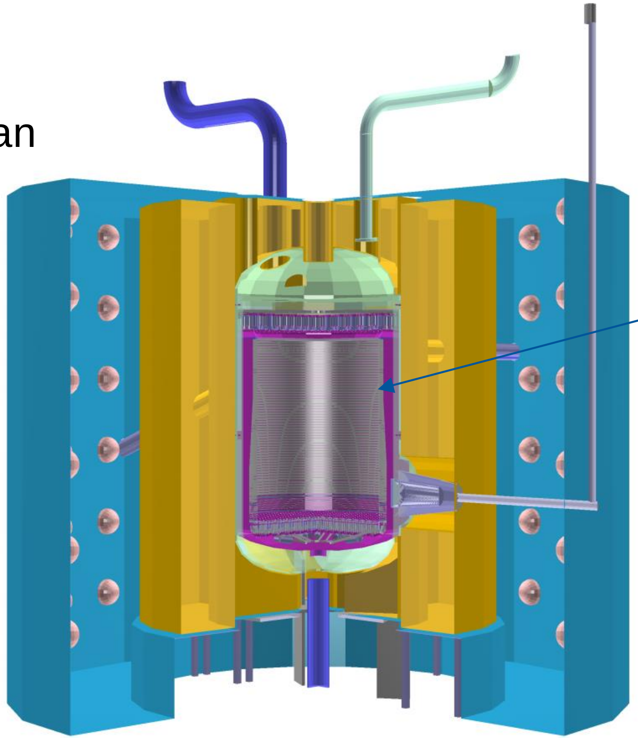
JUNO benchmarking

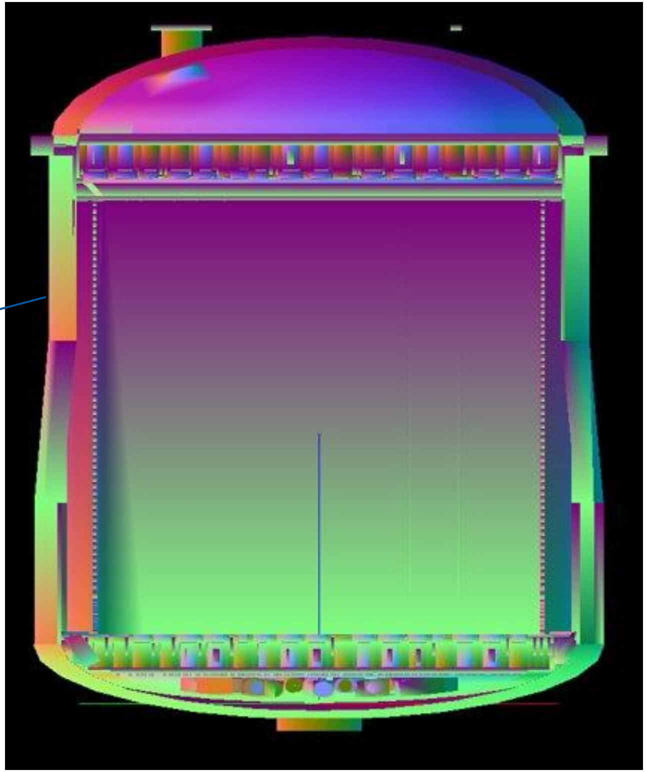
- 1660x speed up with single GPU
- (26 hours vs 1 minute)
- 99.78% identical photons photon paths to CPU

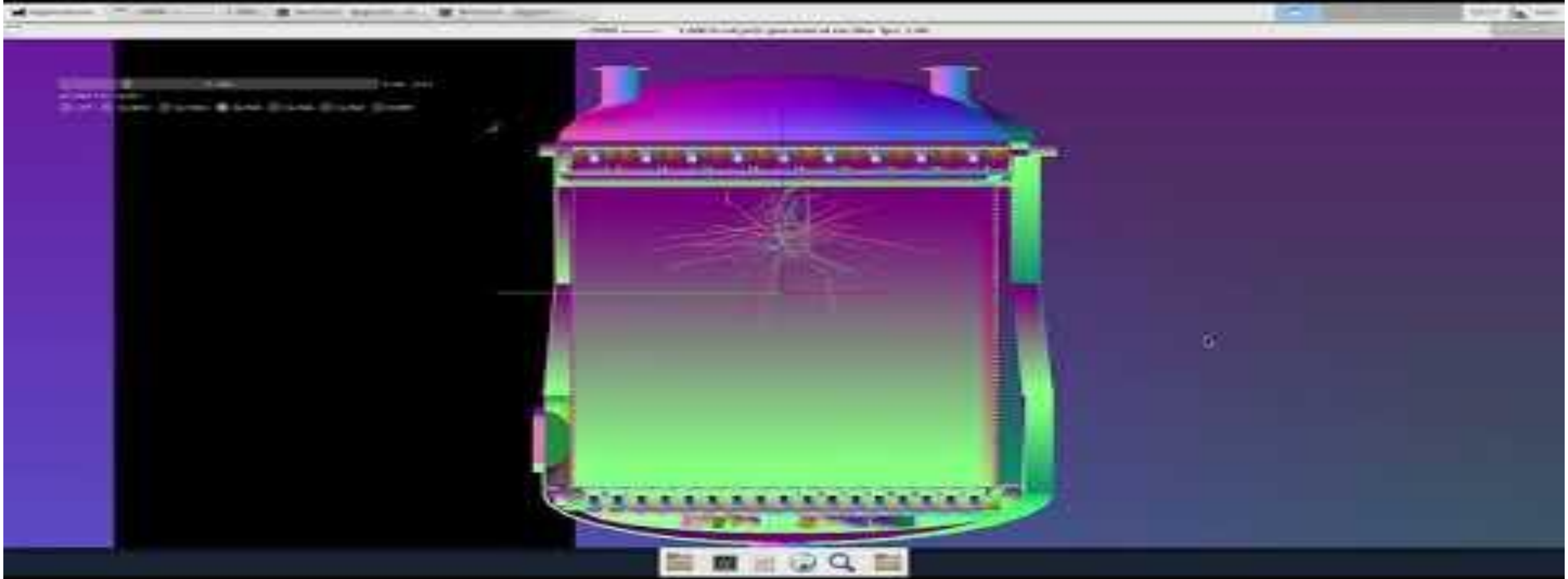
Ray-tracing with LZ

- LZ TPC geometry contains 30x+ more unique solids than other geometries tested

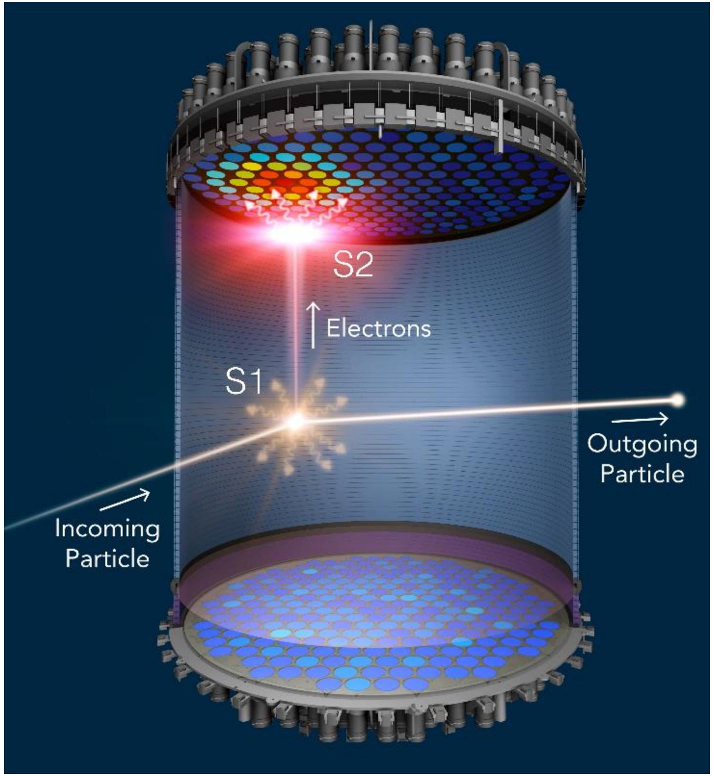
- TPC geometry successfully translated
  - 8000+ different solids
  - All TPC PMTs
  - Near-perfect translation

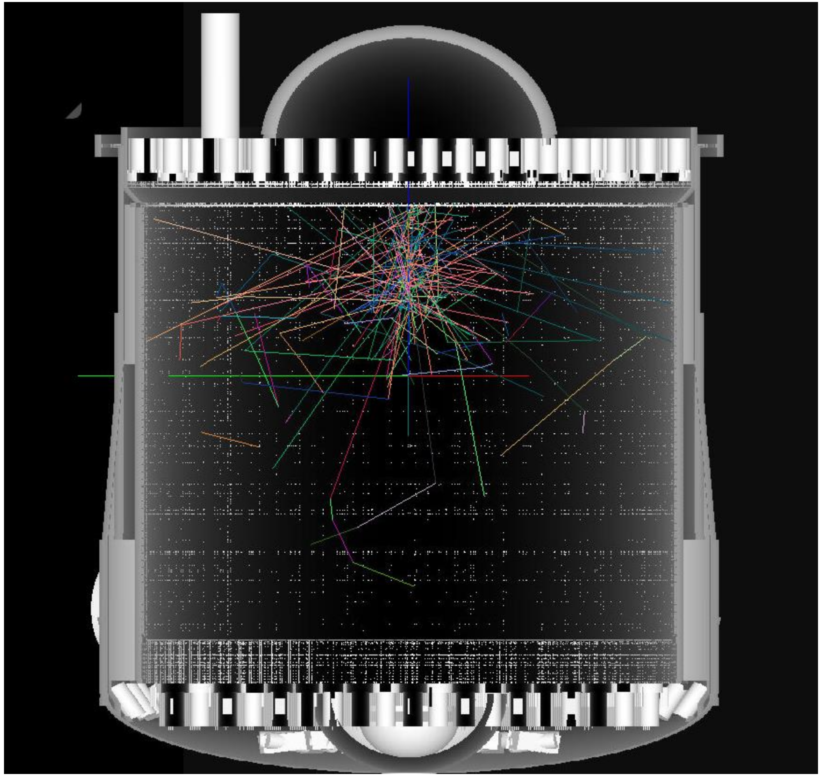






Example S1 light propagation in LZ





Outlook

- Optical simulation of photons is the most computing intensive part of dark matter and background interactions at LZ
- Ray-tracing on GPUs promises a significant improvement in simulation speed
- Able to propagate photons through the TPC
- Now working on validation of GPU simulations and integration into the LZ simulation framework

Thank you