

G4VR: A Virtual Reality Extension for Geant4

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Simulations are *necessary* in physics!

Let's say you're designing some experiment searching for some *exotic particle*

- ♦ Theorists will tell you the physics you need to know about the particle.
- ♦ Engineers will build the equipment you need to find this particle.
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Simulations!

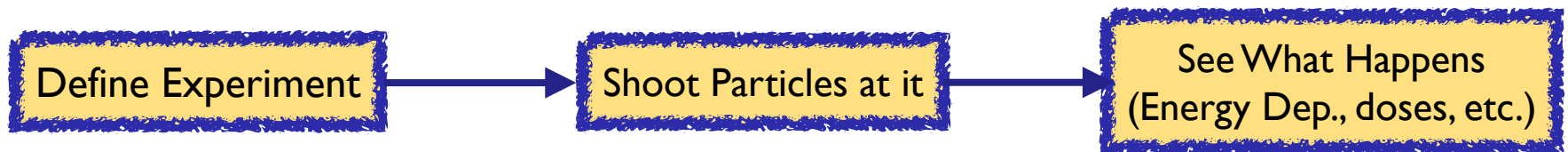
- ♦ can tell you how much signal or background you get
- ♦ can tell if your design is efficient
- ♦ can help you understand your observations better, (*and so on...*)

Enter Geant4

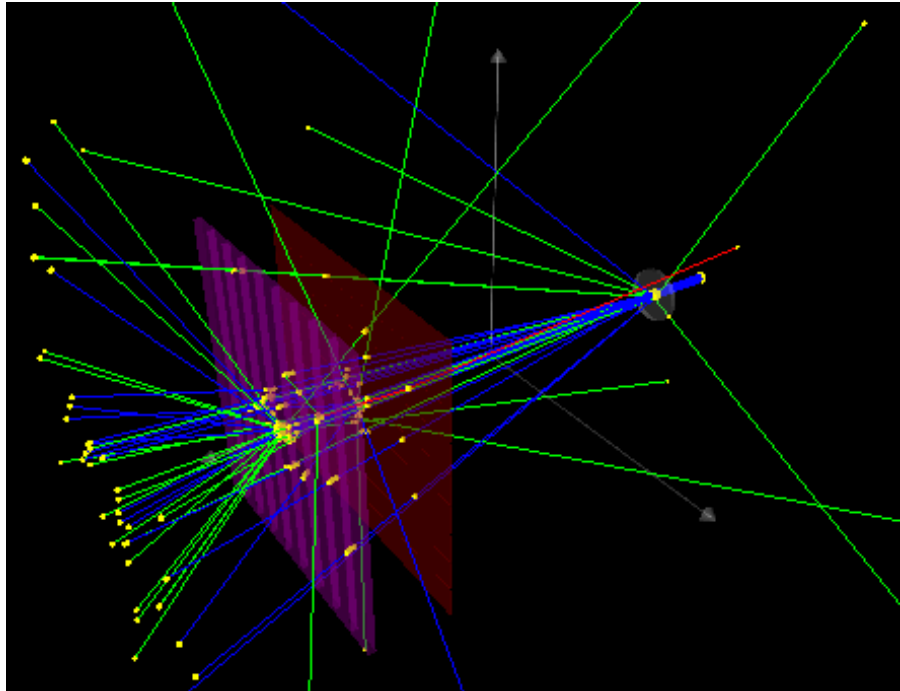
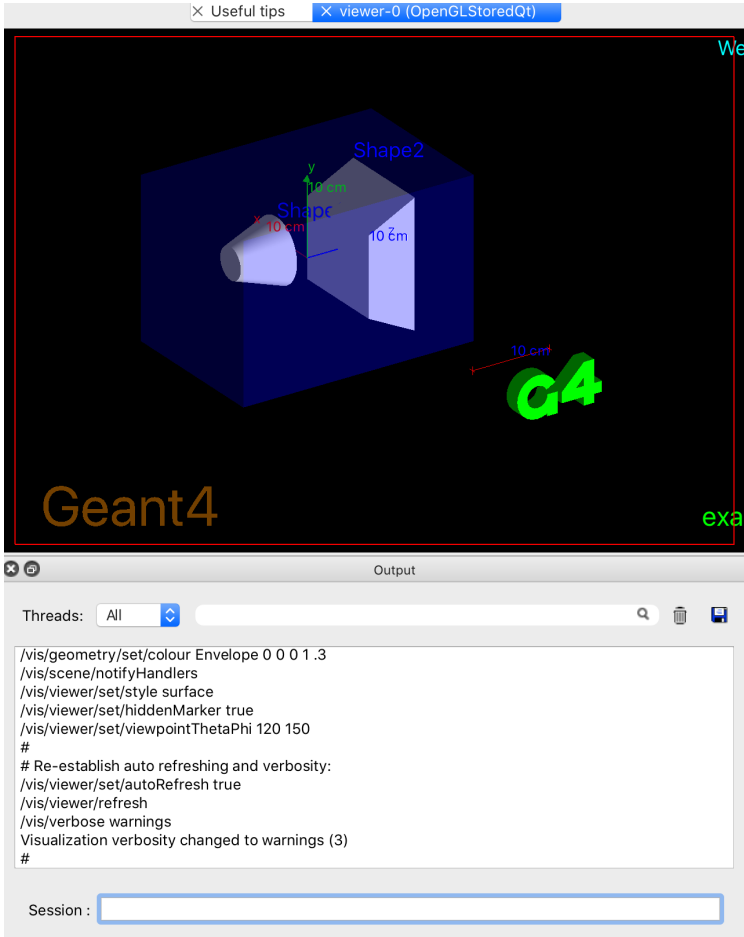
Geant4 is one such simulation toolkit for *simulating particle interactions in matter*

- ♦ Ubiquitous in experimental physics, medical physics, etc.
→ definitely worth learning about!
- ♦ Extensively used at CERN experiments.

Bare workflow looks like:



Enter Geant4



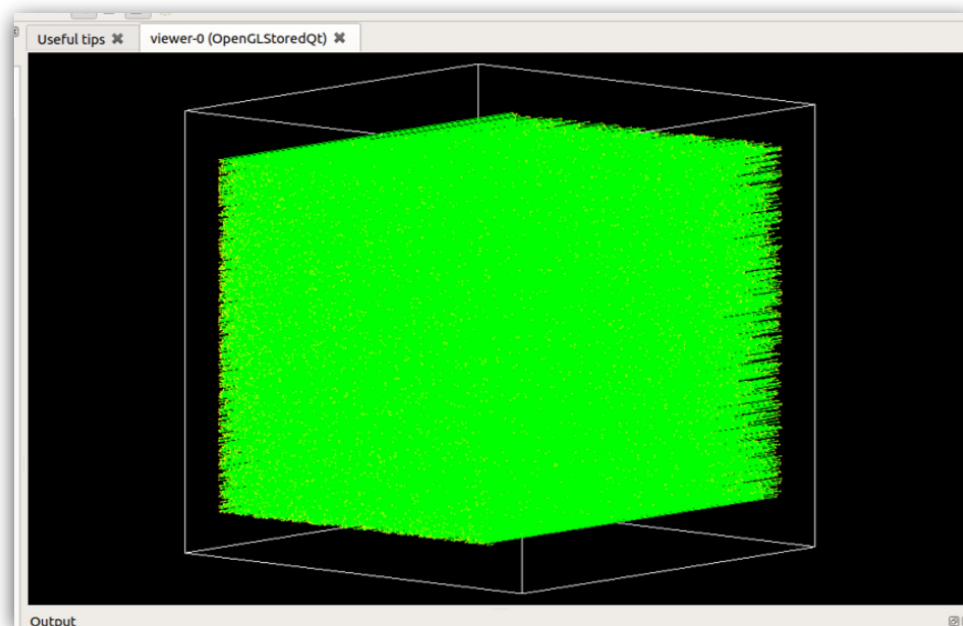
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“Nice! My seemingly innocent simulation has completed!”



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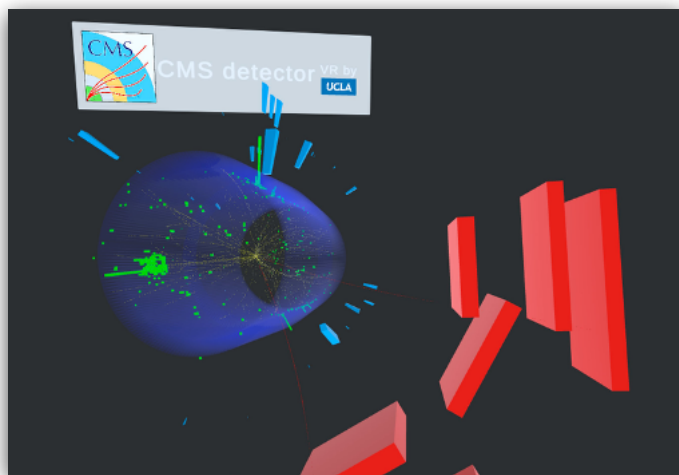


Erm...

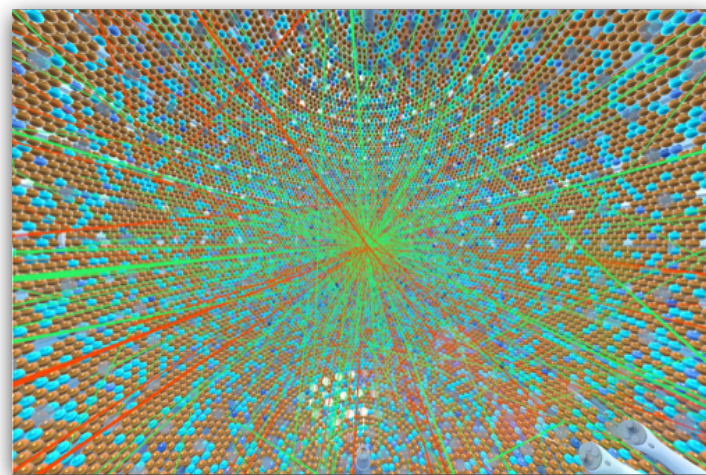
Enter *Virtual Reality*

You can now “insert” yourself into the event and see what unfolded!

- ◆ Allows deep immersion and understanding that is *tricky otherwise*
- ◆ VR event displays exist for JUNO and Belle II experiment simulations
- ◆ CED-VR for the CMS Experiment is developed by the UCLA VR Lab



CED-VR



JUNO

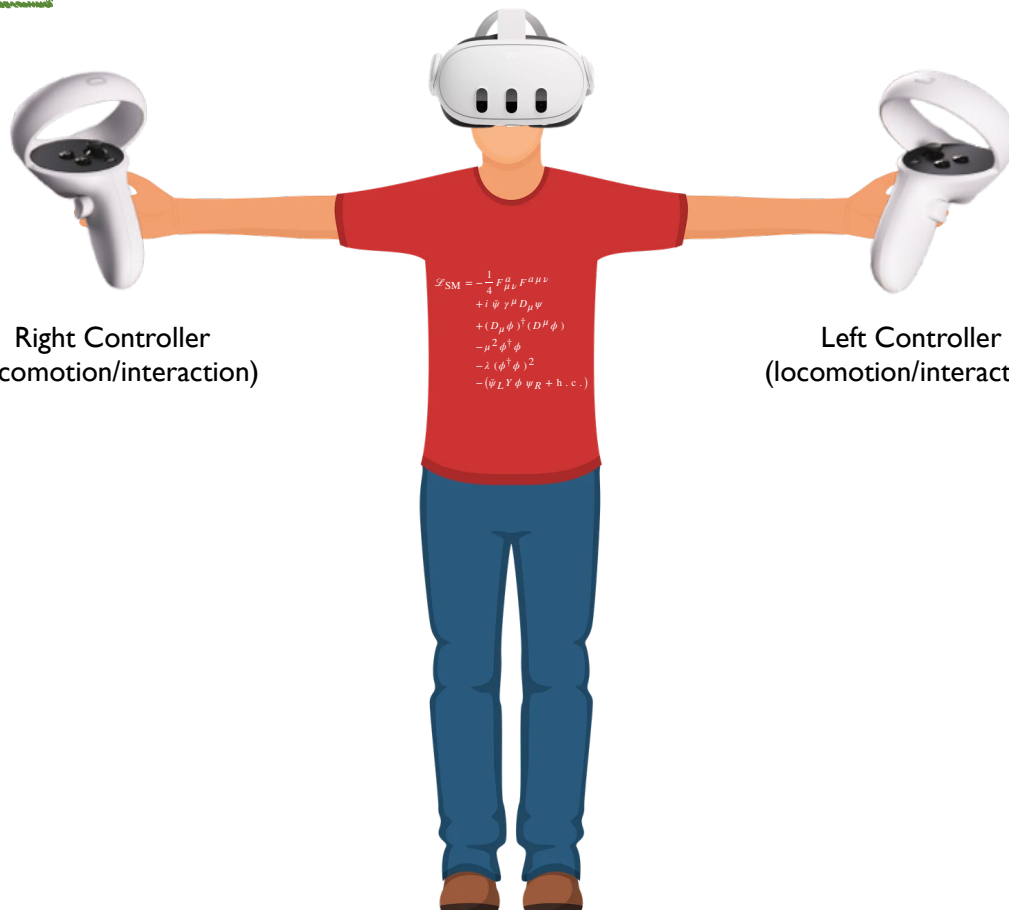
Enter *Virtual Reality*

For Geant4, we have developed **G4VR** - a VR app to visualize Geant4 simulations



Geant4 Simulation

VR Headset (Meta Quest 2+)
Running G4VR



Right Controller
(locomotion/interaction)

Left Controller
(locomotion/interaction)

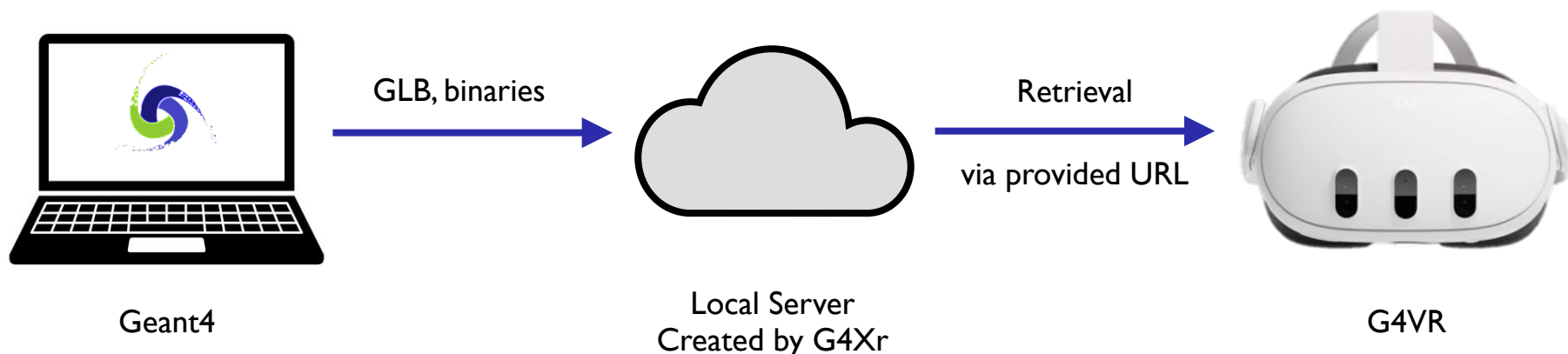
$$\begin{aligned}\mathcal{L}_{SM} = & -\frac{1}{4} F_{\mu\nu}^a F^{a\mu\nu} \\ & + i \bar{\psi} \gamma^\mu D_\mu \psi \\ & + (D_\mu \phi)^\dagger (D^\mu \phi) \\ & - \mu^2 \phi^\dagger \phi \\ & - \lambda (\phi^\dagger \phi)^2 \\ & - (\psi_L^\dagger \gamma^\mu \psi_R + \text{h.c.})\end{aligned}$$

G4XR: The Xr Driver

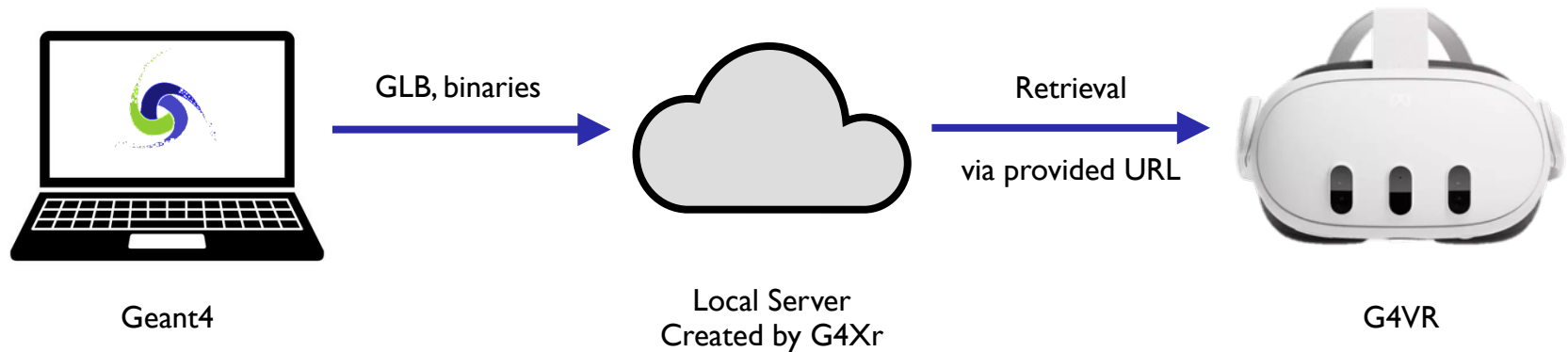
How to communicate between Geant4 and G4VR...?

Introducing the G4Xr driver!

- ♦ New visualization driver developed for Geant4.
- ♦ Produces **experiment geometries (GLB format)** and **track assets (binaries)**
 - ♦ One track asset per run → aggregated events
- ♦ Automatically sets up and pushes to a server that G4VR can find
 - ♦ Runs on the local network from the user's device
 - ♦ *User simply enters a URL in G4VR!*



G4XR: The Xr Driver



Example Usage (Geant4 console)

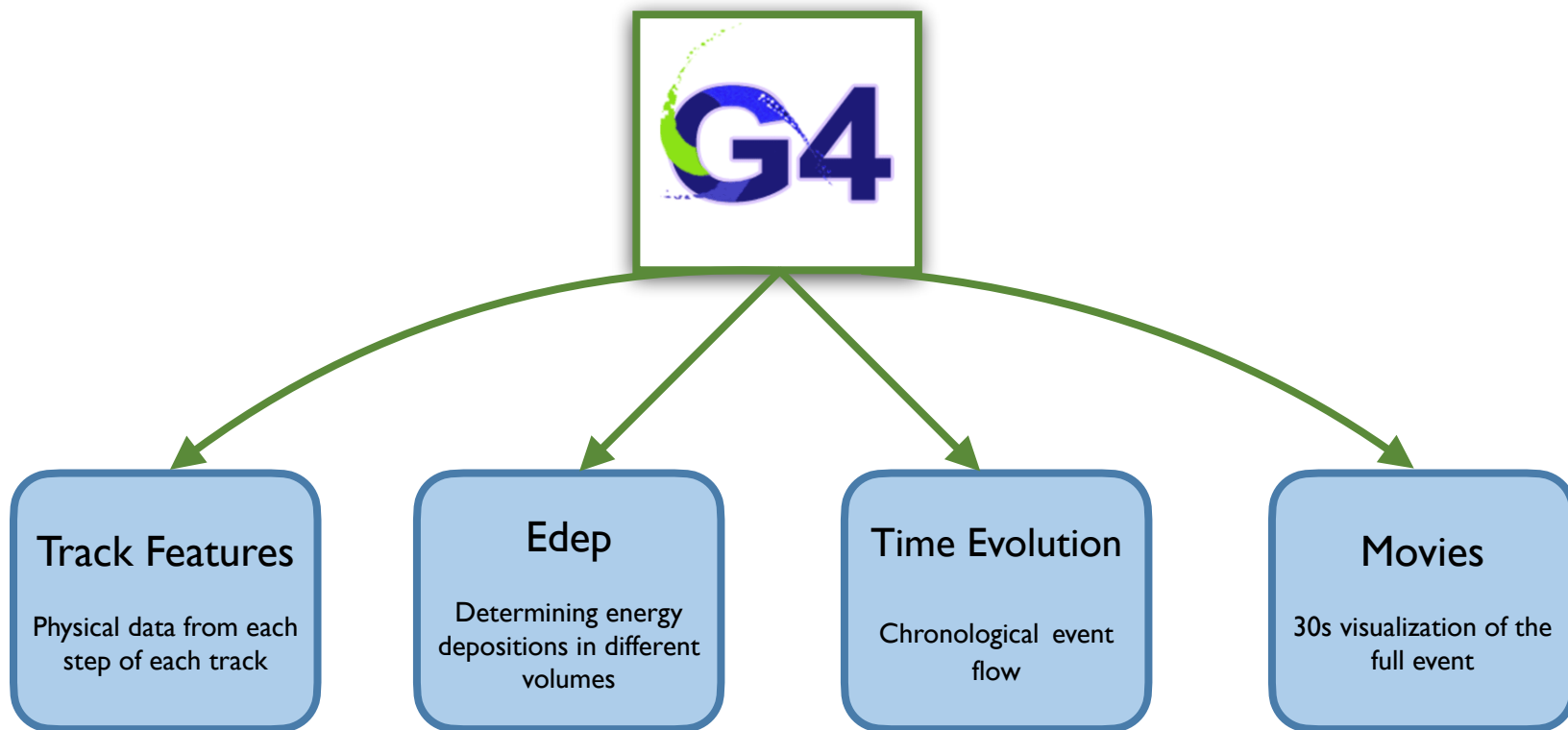
```
/vis/open Xr          # launch G4Xr instance
/run/beamOn 100       # run some events
```

Data Persistence (save to launch and view later w/o simulation)

```
/Xr/session "mysim"   # persist and call the session "mysim"
/vis/open Xr          # launch G4Xr instance
/run/beamOn 100       # run some events
```

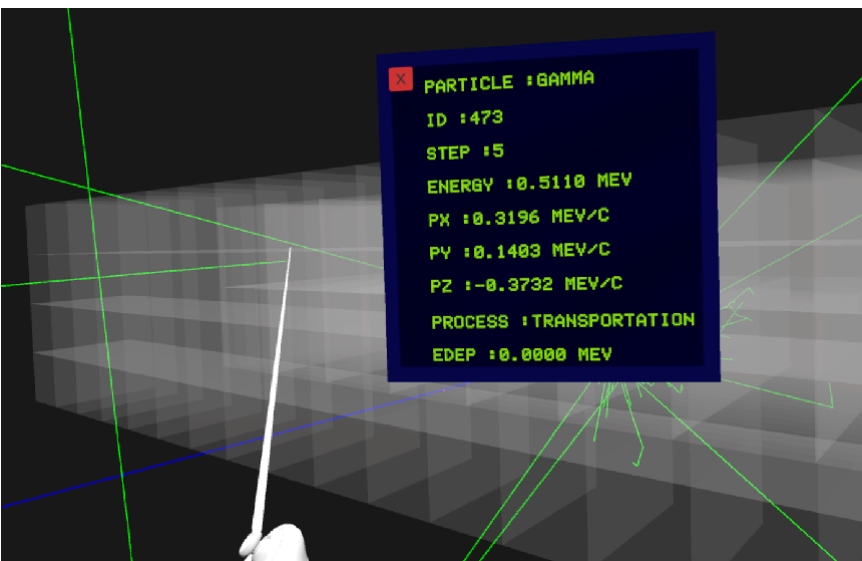
Saves the assets locally to `mysim.zip` and provides a script to launch the server at a later time in G4VR

G4VR: Feature Overview

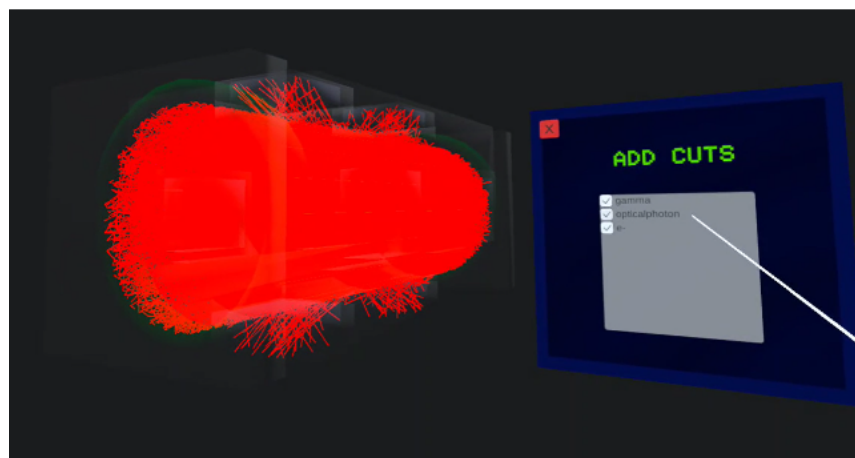


G4VR: Track Features

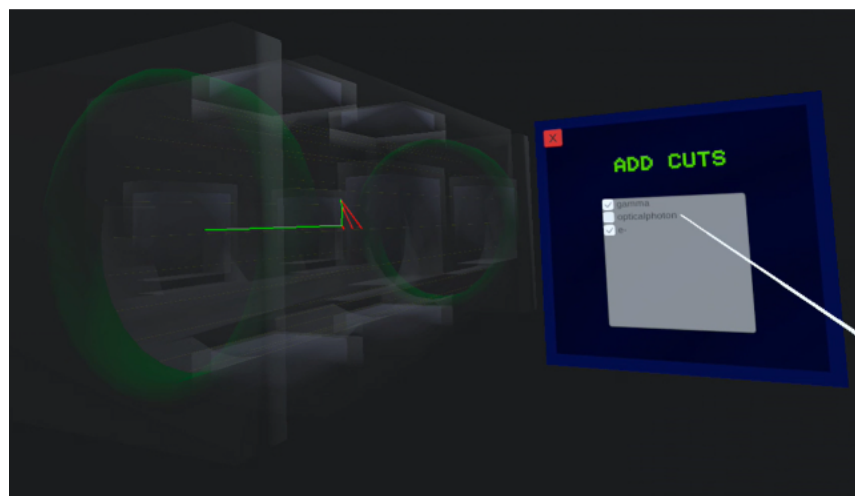
- ◆ Use controllers to interact with tracks in the scene and access step-level information
- ◆ Filter tracks by type (e^+ , e^- , p , n , π^+ , K^- , etc.)



VR Controller to point and select

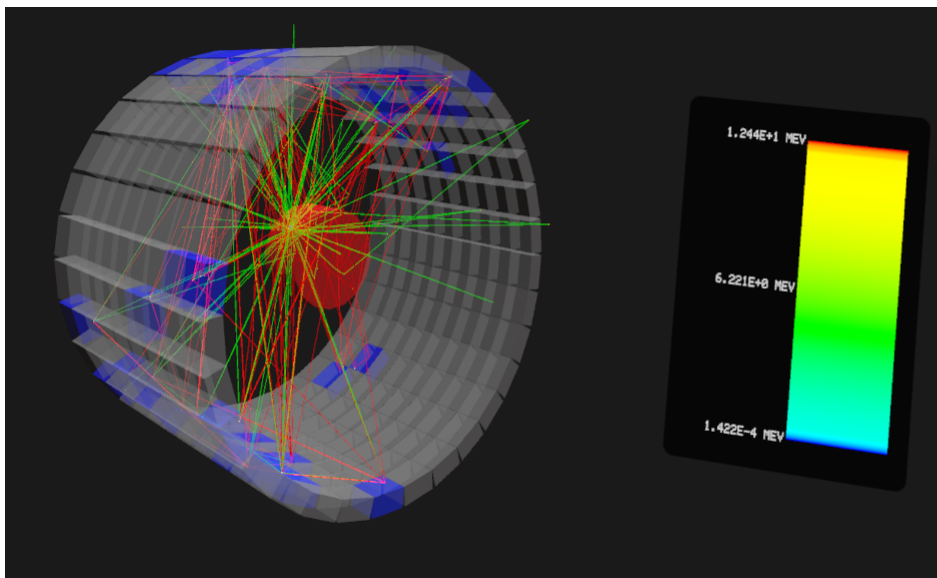


Remove optical photons



G4VR: *Edep*

- ♦ Visualization of the energy deposited in each detector volume defined by the user.



Global energy scale for all edeps in all volumes

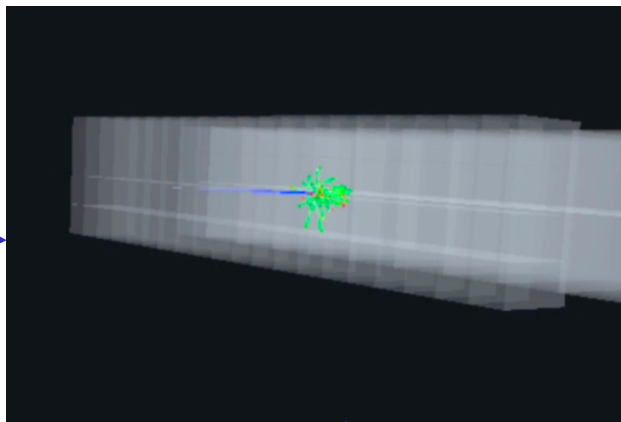
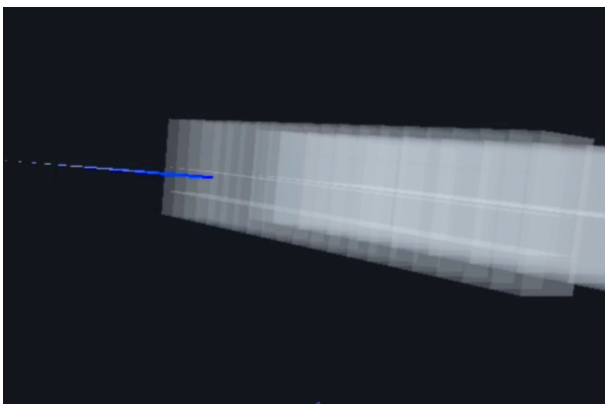


Interacting with volumes using the controller (white line) returns the edep value in it

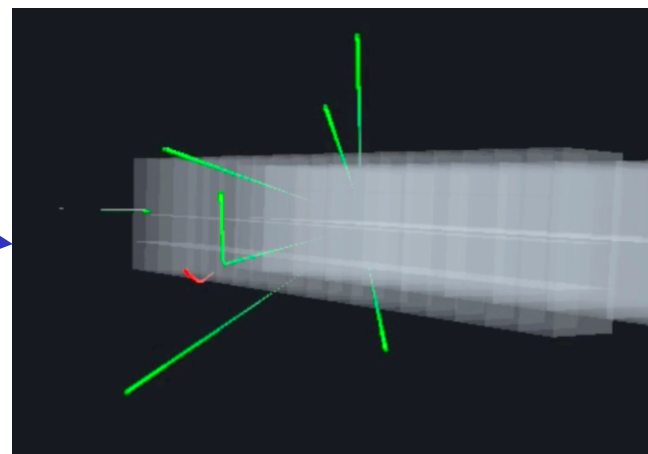
G4VR: *Movie*

- ◆ Event scaled down to a 30s interval to show a quick overview of the run.

Example B5 in G4VR

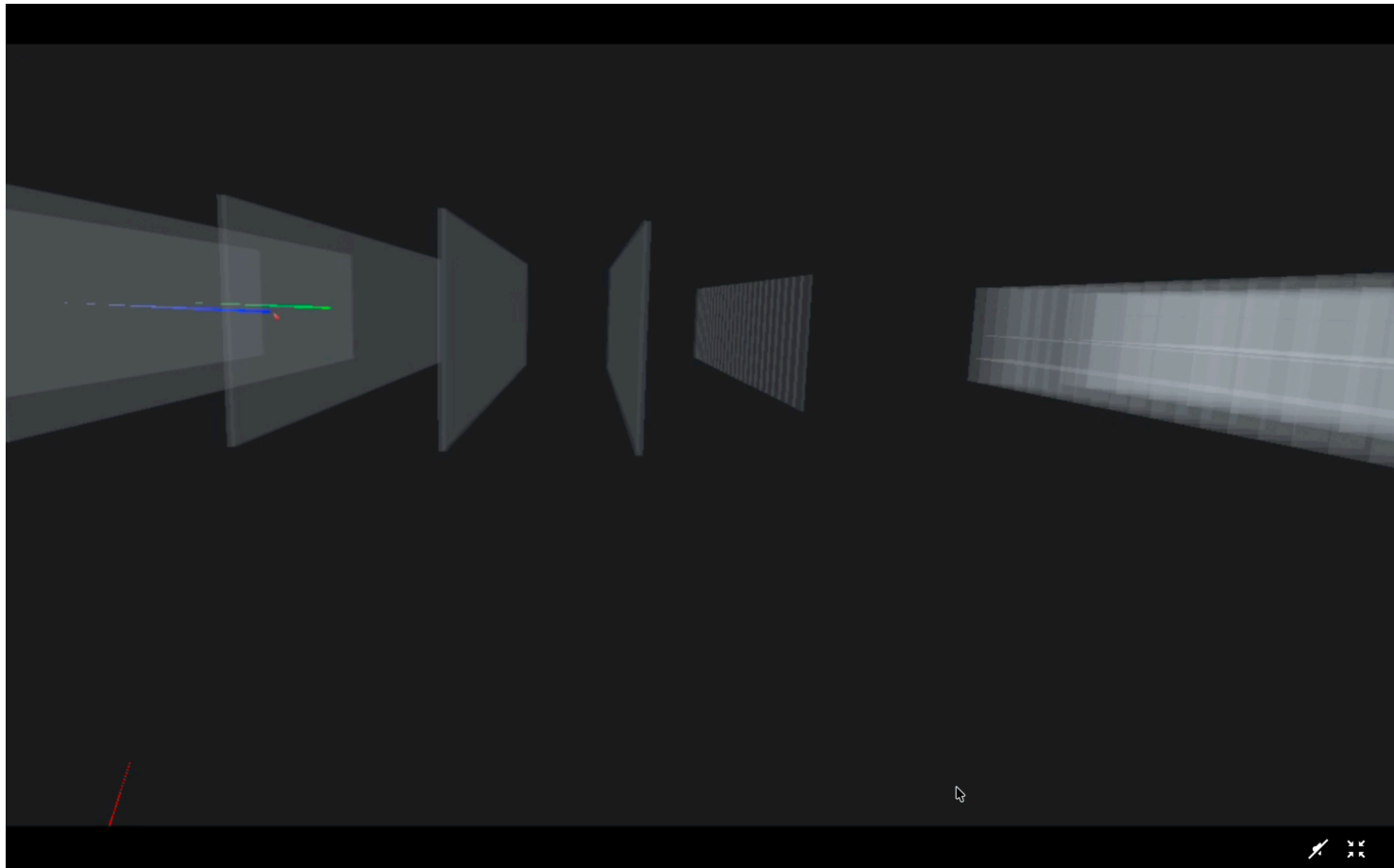


Feature Inspired by Geant4 **EXAMPLE?** Movies
[An Example from Physino](#)



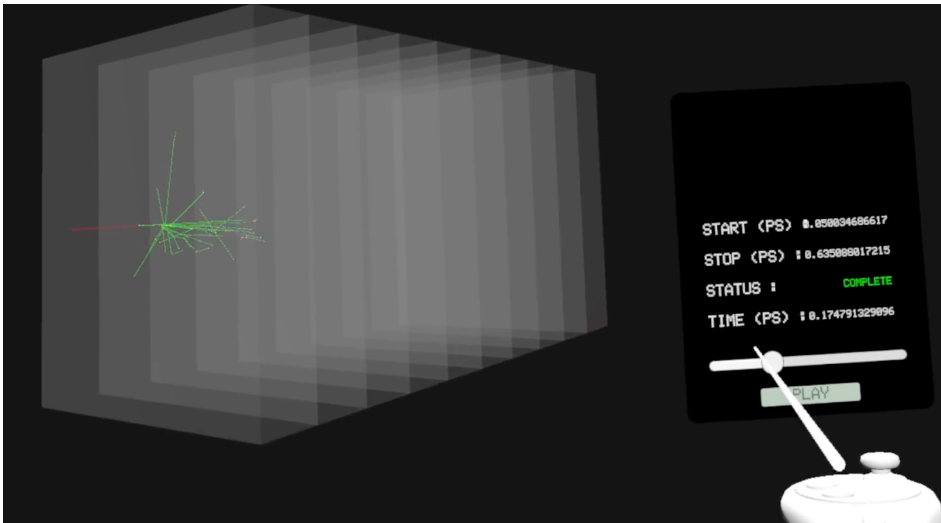
G4VR: *Movie*

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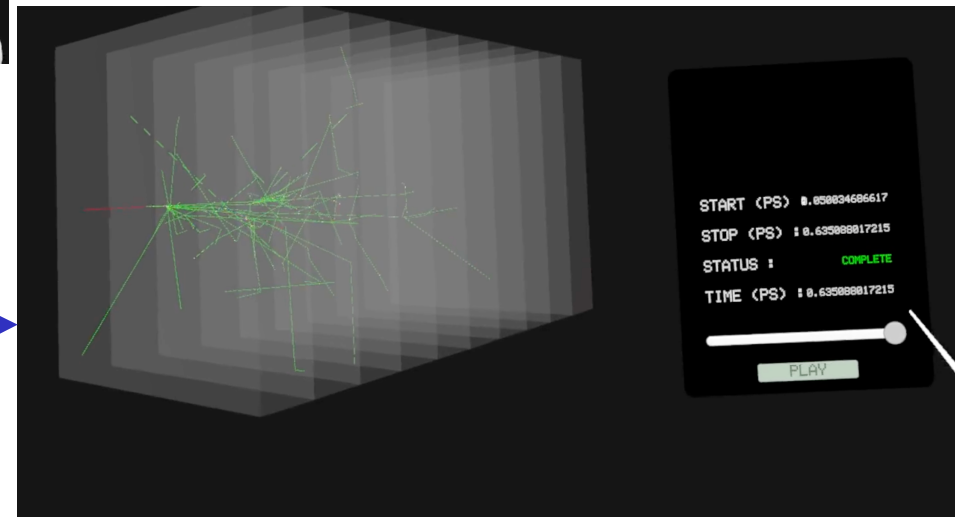


G4VR: *Time Evolution*

- ♦ Similar to [Movies](#), but only tracks appearing up to a certain time are displayed → discretized compared to a movie.

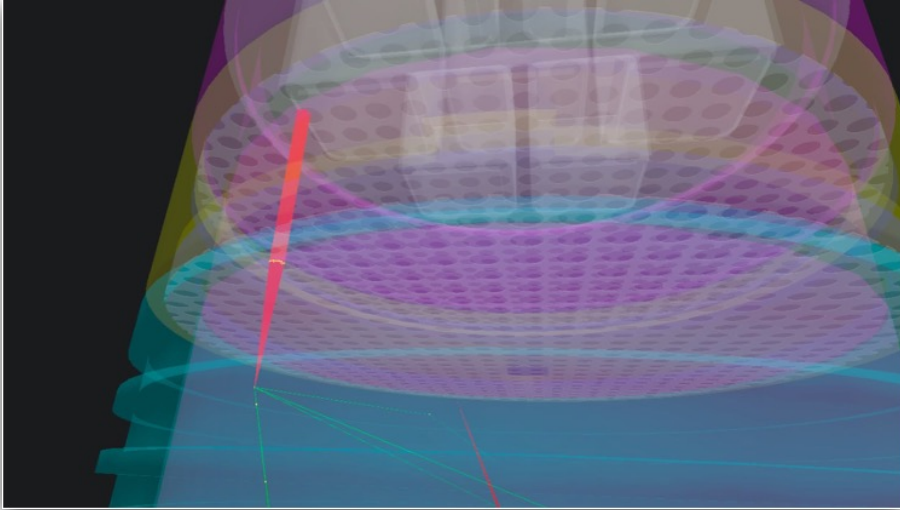


Example B4a in G4VR



Applications

We have positive feedback!

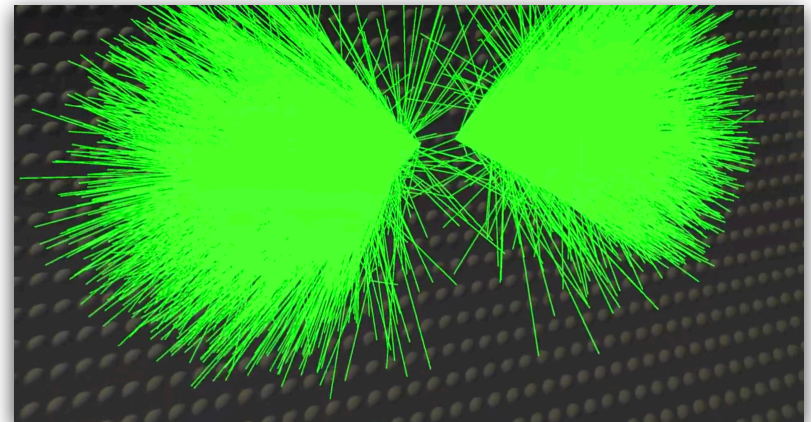


CaliX LXe Time Projection Chamber (UCLA)

- ✦ Picture on the left shows a scintillation signal and electrons drifting up.
- ✦ G4VR useful in debugging the simulation from track-level data.

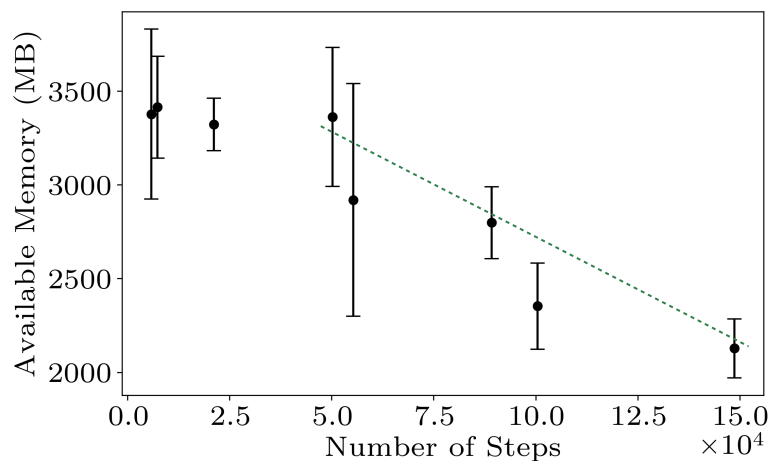
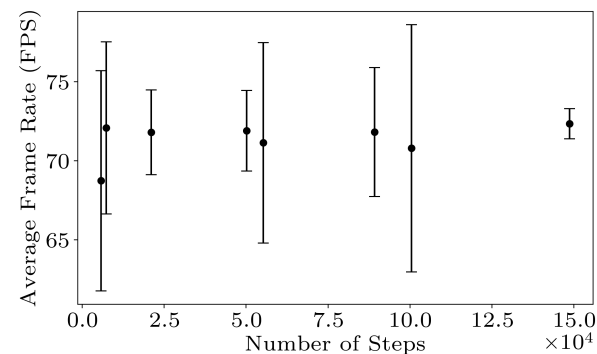
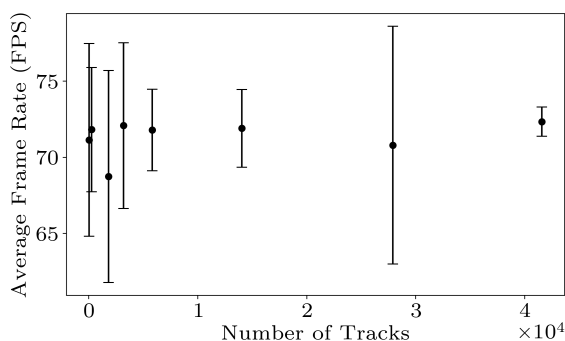
Proton Decay Simulation (UCLA)

- ✦ Simulation of proton decay in a Super-Kamiokande-like detector.
- ✦ Picture on the right shows Cherenkov radiation as a result.



Meta Quest Performance Benchmarking

- ♦ Performance *consistently above 60 FPS* (Meta Standard)
- ♦ Switching to and from edep, movie mode can be heavy.
- ♦ Load up time for very large events can vary from *a few seconds to a minute*.



- ♦ No memory concerns up to 50k steps
- ♦ Available headset memory quickly reduces with more steps

Looking Forward

- ♦ G4VR can be found on the UCLA Physics VR Lab page: <https://vr.physics.ucla.edu/>
 - ✦ Three built-in Geant4 examples: B4a, B3a, B5. Easy to load and view in VR.
- ♦ Driver available for install on GitHub: <https://github.com/bjobilal/g4xr>
 - ✦ Currently binds to Geant4 v11.3.2
 - ✦ Have asked vis team to make this an official Geant4 plugin!
- ♦ [arXiv:2609.08926](https://arxiv.org/abs/2609.08926) provides further details and usage instructions.

Thank You!

