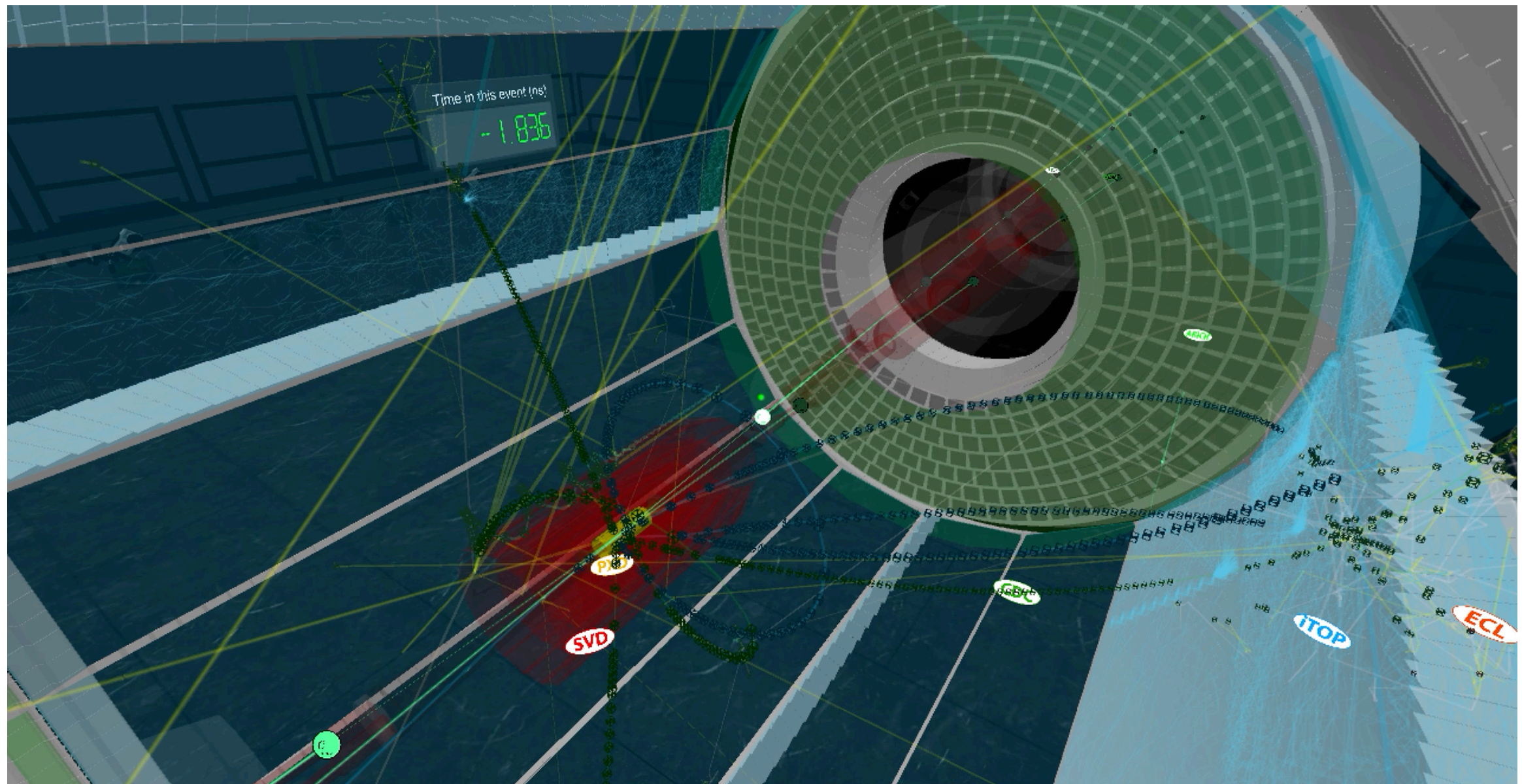


Belle2VR: An interactive virtual reality visualization of GEANT4 event histories



Leo Piilonen, Virginia Tech
on behalf of the Belle II Collaboration's Outreach Group



Background

In 2016–2017, we received a \$25K grant from Virginia Tech's Institute for Creativity, Arts and Technology (icat.vt.edu) to develop a dynamic virtual reality model of Belle II.

Choose Unity (unity3d.com) as the software-development platform (*free for non-commercial use*)

- ✓ the associated scripts in C# look familiar to any C++ user
- ✓ Unity itself is written in C++ ➡ provides C# ↔ C++ interface

Display targets:

- ✓ VR headsets: Oculus Rift, Oculus Go, HTC Vive
- ✓ computer screen: Windows, Mac OSX, Linux
- ✓ web browser
- ✓ smartphones: iPhone, Android

[not distributed in stores; no user interaction is possible]

GEANT4* detector geometry (1)

Export detector geometry from Belle II's basf2# framework

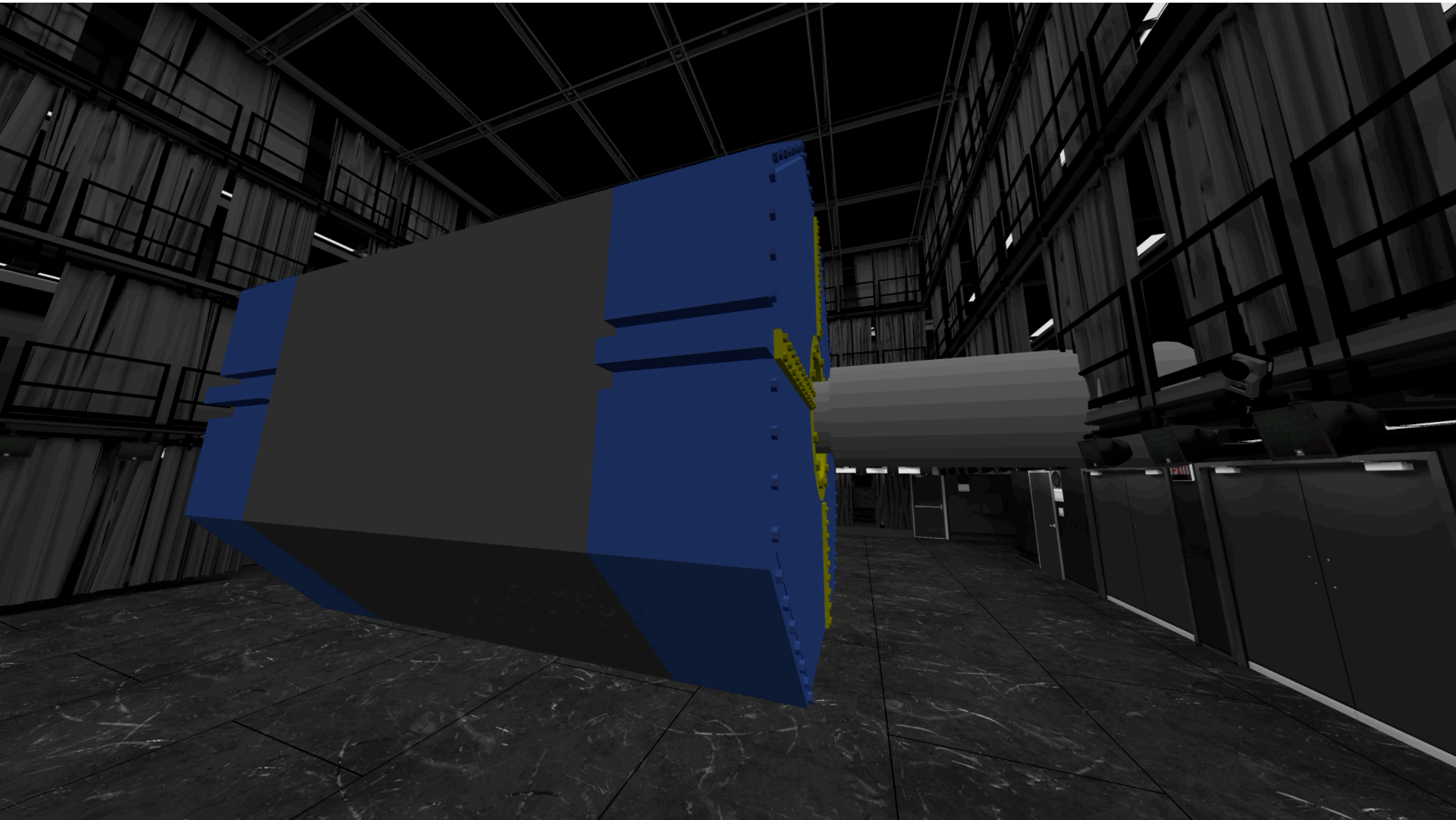
- ✓ In GEANT4, each volume element can be rendered as polygons of its surface, using `GetPolygon()`, before exporting
- ✓ write two new basf2 modules to export to FBX or VRML2
 - geometry/modules/fbxWriter
 - geometry/modules/vrmlWriter } *→ structured text files*
- *you may download from github.com/HSF/Visualization*

Examine the FBX geometry file(s)

- FBX Review: www.autodesk.com/products/fbx/fbx-review
- Cheetah3D: cheetah3d.com (for Mac)
- LynX 3D: ozone3d.net (for Windows)

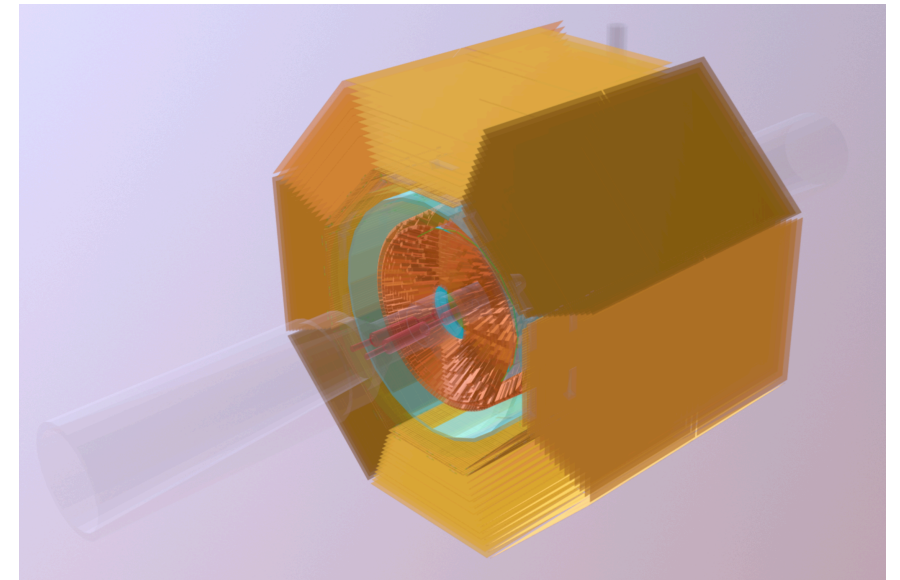
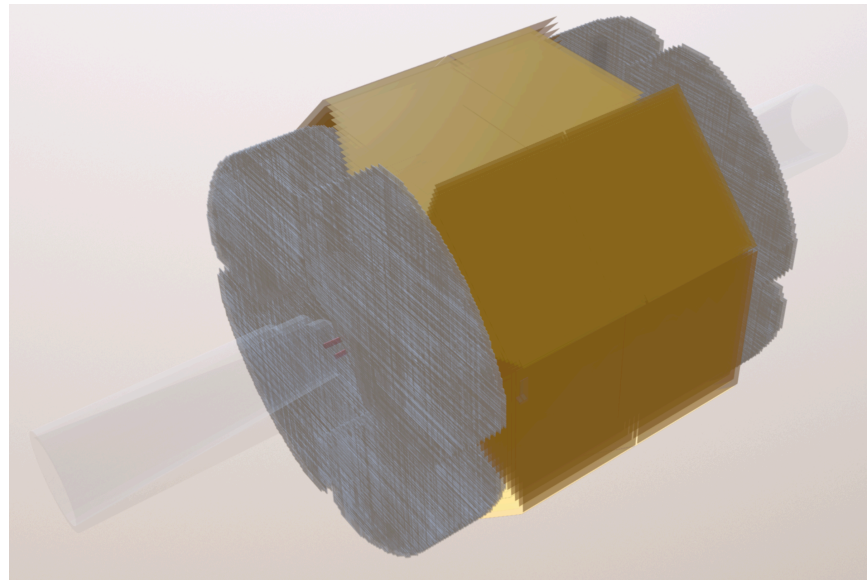
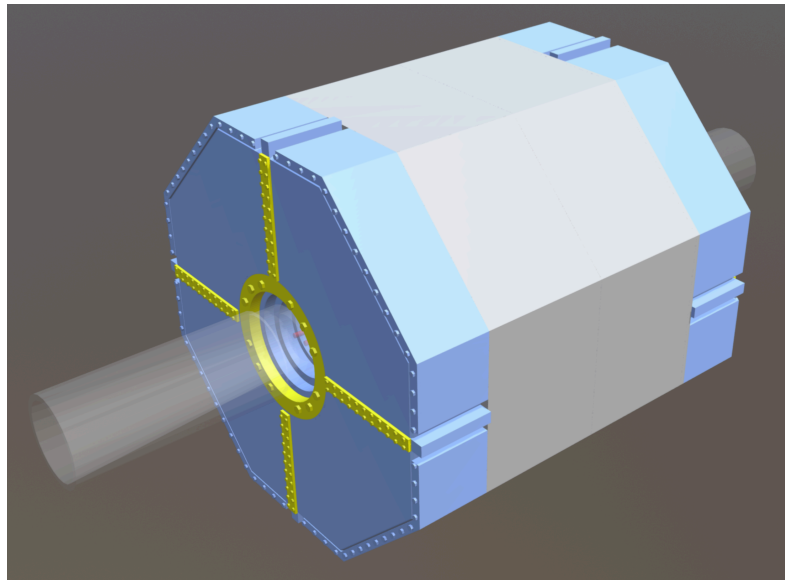
Import the FBX geometry into Unity

GEANT4 detector geometry (2)



GEANT4 Detector Geometry ... *an aside*

Unity can then export the geometry to the glTF™ format (www.khronos.org/glTF/)



sketchfab.com → search for **belleii**
(can be viewed on smartphones)

GEANT4 event histories (1)

Export the GEANT4 simulation event histories from basf2

- ✓ in human-readable format → Excel csv file (one per event)
- ✓ add print statement to the inherited G4UserSteppingAction hook that is called by Geant4 for each step in the history
 - write a record to the csv file for *almost* each step
PreStepPoint (position, time, momentum, energy),
PostStepPoint (position, time, momentum, energy),
volumeName, trackID, parentID, PDGcode, etc
 - ... *but no heavy nuclei ($A > 4$: they don't move, typically)*
 - ... *and cut off after 100 ns (neutron walk, late decays)*

Post-process the csv file

- ✓ perl script adds beam-line particles then sorts the records by ParticleName, then TrackID, then StepNumber
- ✓ *[optional]* compress using gzip

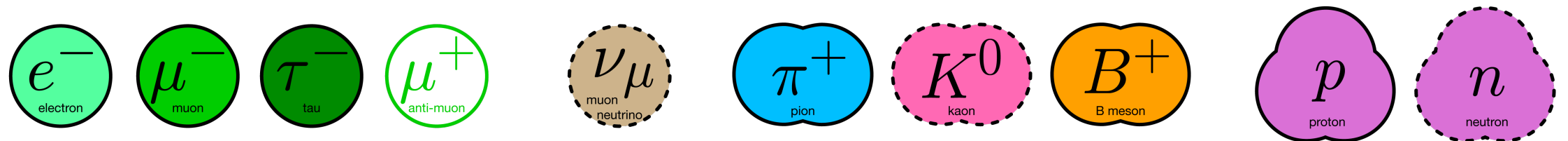
GEANT4 event histories (2)

Import the events into Unity

- ✓ C# scripts in Unity read `csv` file, parse the records, then store the information in internal structures

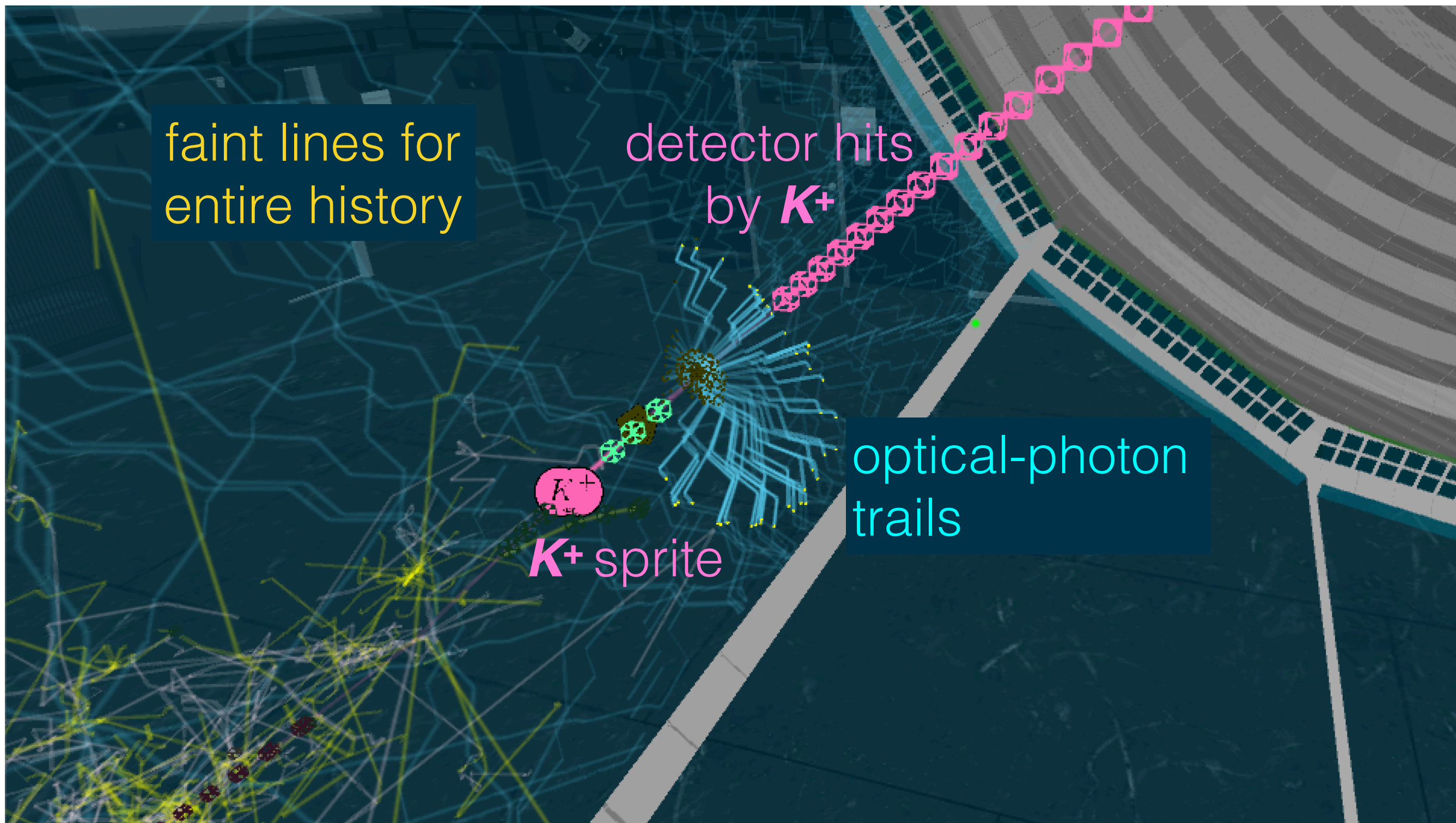
Animate the event history

- ✓ persistent faint lines show the entire simulation history
- ✓ sprite shows each particle during the animation
 - colour-coded and shape-coded

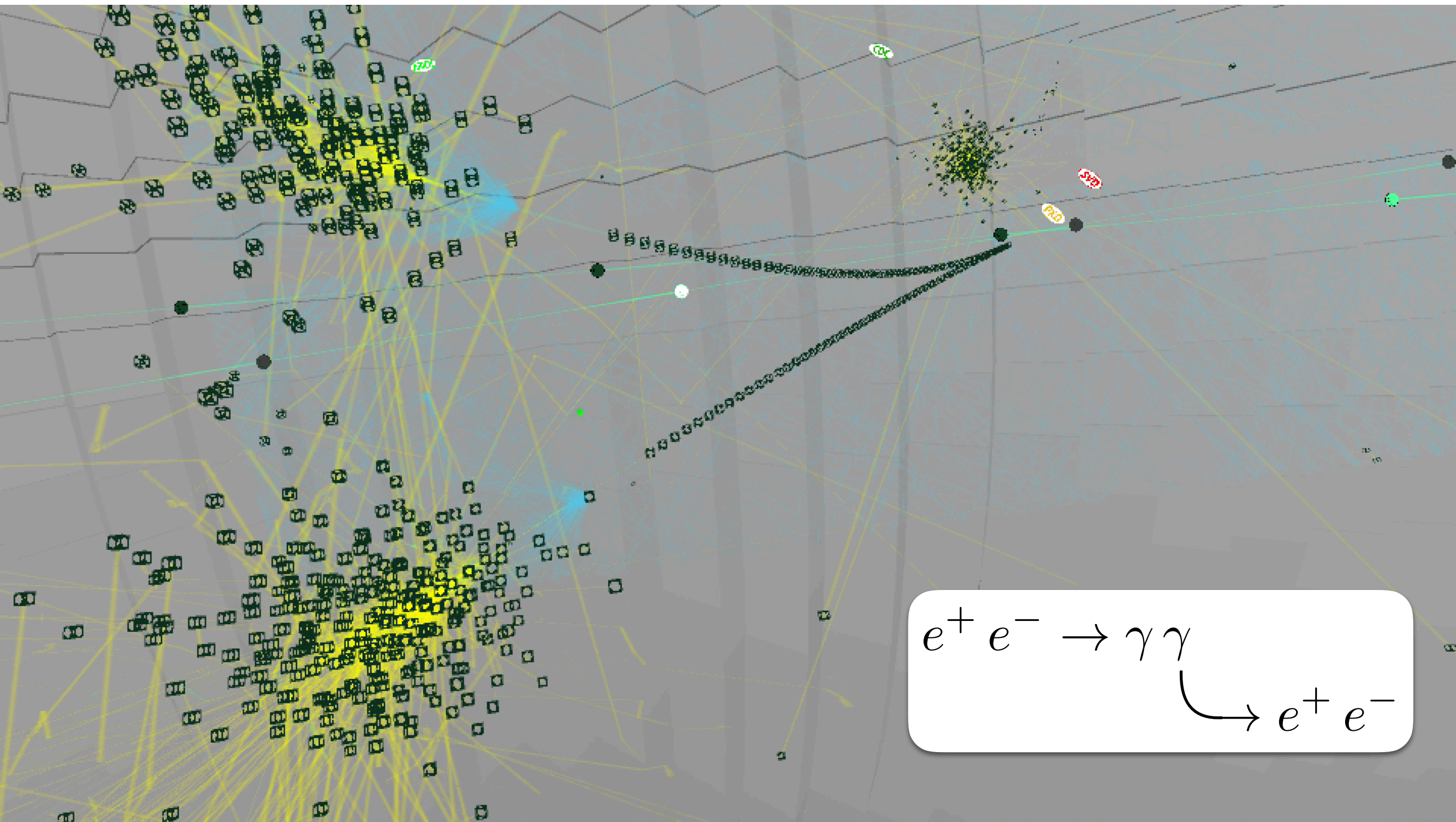


- de-emphasis [*fade*] if particle's history is finished
- ✓ dynamic trails highlight particle motion during animation
- ✓ sensitive-detector hits, with detector-specific sound
- ✓ last few seconds of animation: show only the detector hits
- ✓ *for VR headset, must run at 90 fps at all times*

GEANT4 event histories (3)



GEANT4 event histories (4)



$$e^+ e^- \rightarrow \gamma \gamma \rightarrow e^+ e^-$$

Belle2VR operation: in the CUBE at Virginia Tech



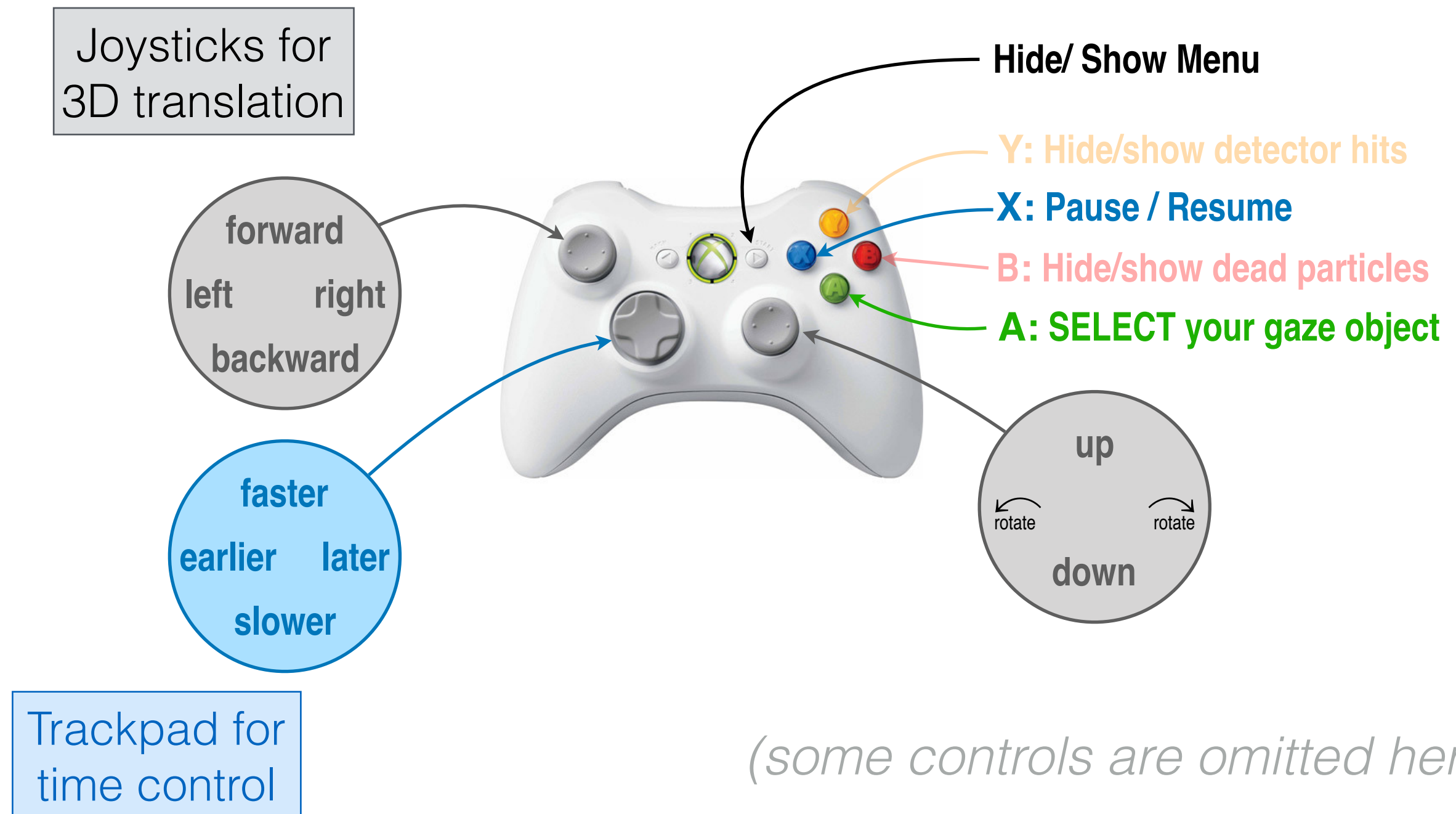
Belle2VR operation: standalone with single VR headset

- ✓ In VR world, the detector and beam line appear within the CUBE at Virginia Tech *since we don't yet have a 3D model of the Tsukuba experimental hall at KEK* 😐
- ✓ Use **Oculus Rift/GO** or **HTC Vive** for immersive 3D experience
- ✓ Use your computer screen for 2D projection of the VR world (*no need for 3D hardware*)
- ✓ Run WebGL app in web browser
- ✓ Control the animation via
 - tethered or Bluetooth gamepad
 - Oculus Touch hand controllers
 - HTC Vive hand controllers
 - keyboard/mouse



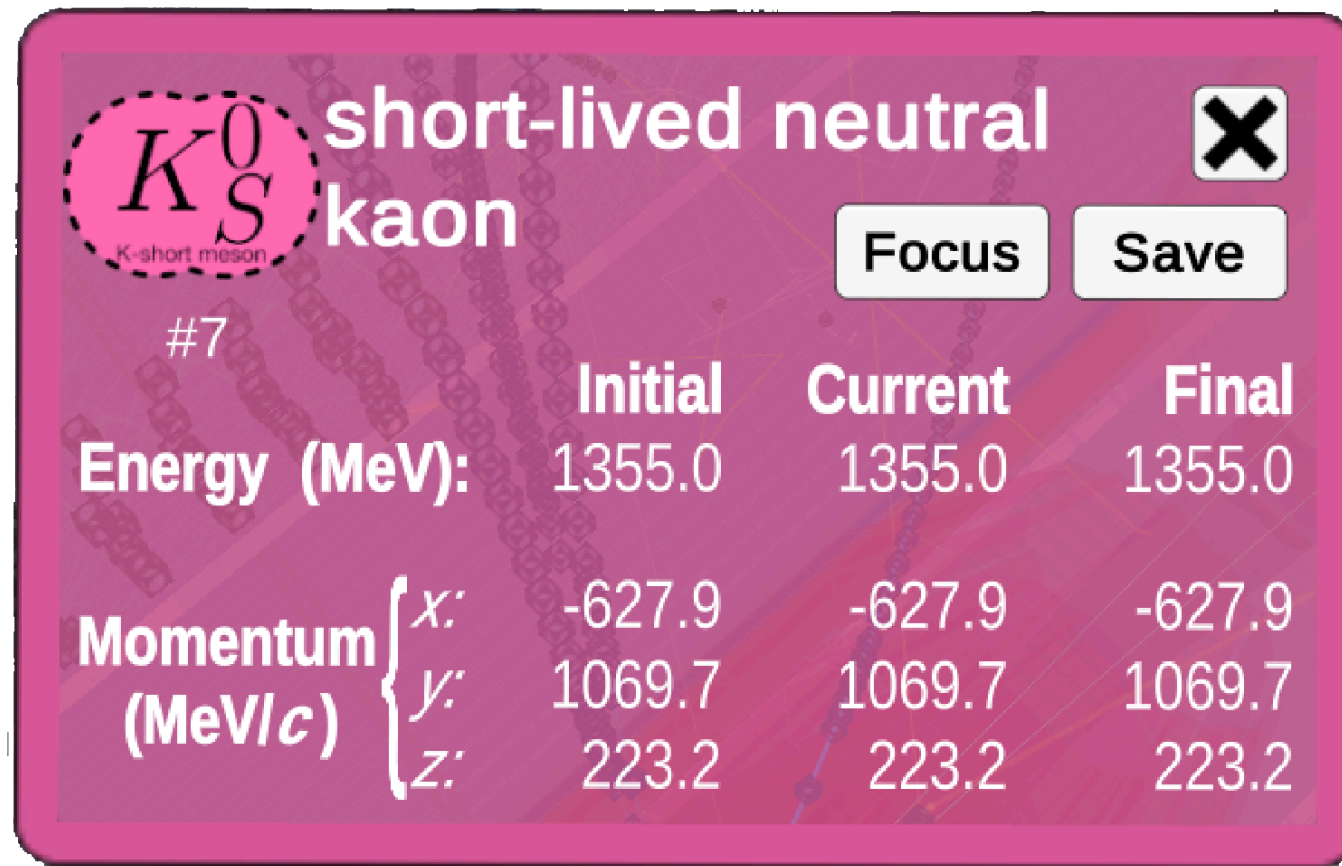
VR-world user controls

- ✓ Your gaze is always indicated by a green dot in front of you.
- ✓ Turn your head to move this gaze dot in the VR world.
- ✓ Interact with the in-world features using a gamepad:



VR world features (1)

- ✓ If you gaze at a particle and **SELECT**, an information panel appears.



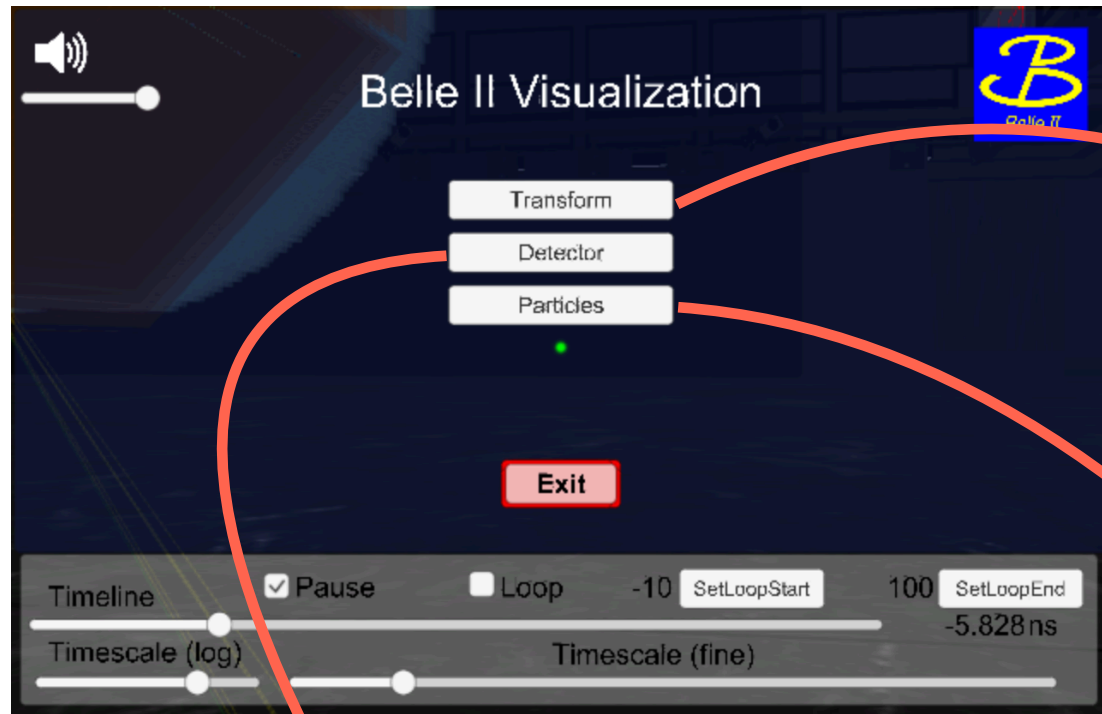
The image shows a semi-transparent pink information panel with a black border. At the top left is a circular icon with the text K_S^0 and "K-short meson" below it. To the right of the icon, the text "short-lived neutral kaon" is displayed. In the top right corner is a close button with a black 'X'. Below the icon is the label "#7". In the center are two buttons: "Focus" and "Save". At the bottom is a table with three columns: "Initial", "Current", and "Final". The first row is "Energy (MeV):" with values 1355.0, 1355.0, and 1355.0. The second row is "Momentum (MeV/c)" with sub-rows for x, y, and z components, all having identical values across the three columns.

	Initial	Current	Final
Energy (MeV):	1355.0	1355.0	1355.0
Momentum (MeV/c)			
x:	-627.9	-627.9	-627.9
y:	1069.7	1069.7	1069.7
z:	223.2	223.2	223.2

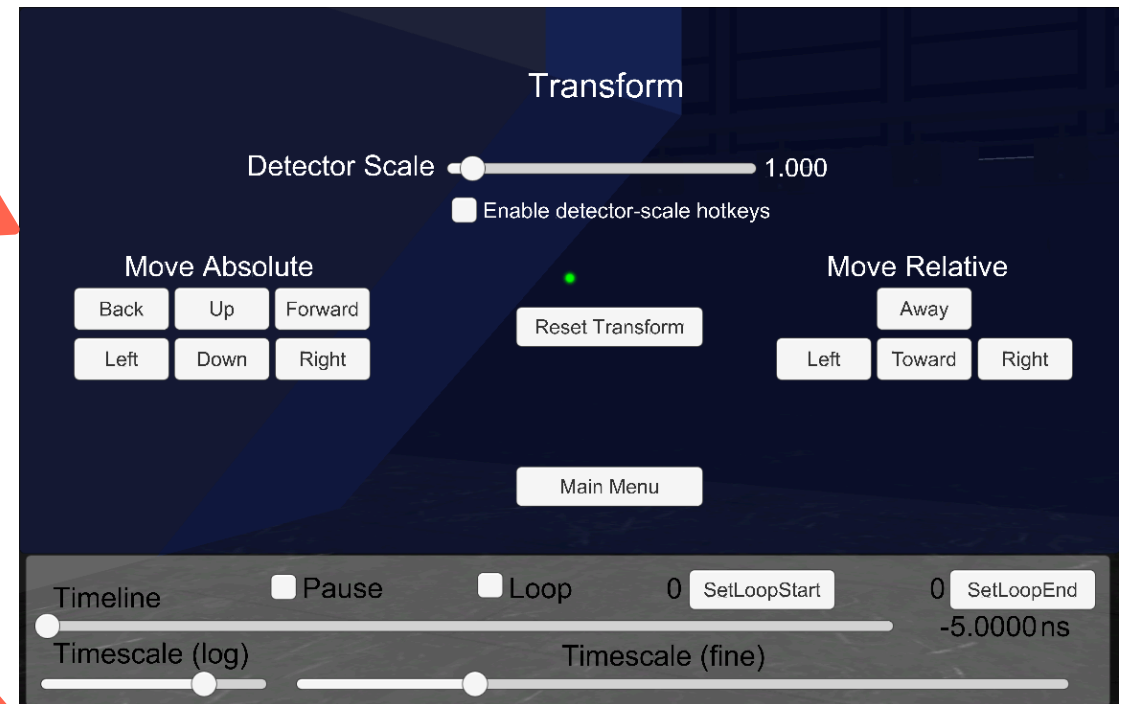
- ✓ The panel's border is black if the particle is dead.
- ✓ If you gaze at **Focus** and **SELECT**, only this particle and its relatives are shown. (Then, you can "Unfocus" to show all particles.)
- ✓ If you gaze at **Save** and **SELECT**, this particle's information is saved to a row of the panel on one wall of the room.
- ✓ You can sum selected entries on the wall display panel to test conservation of energy and momentum.

VR world features (2)

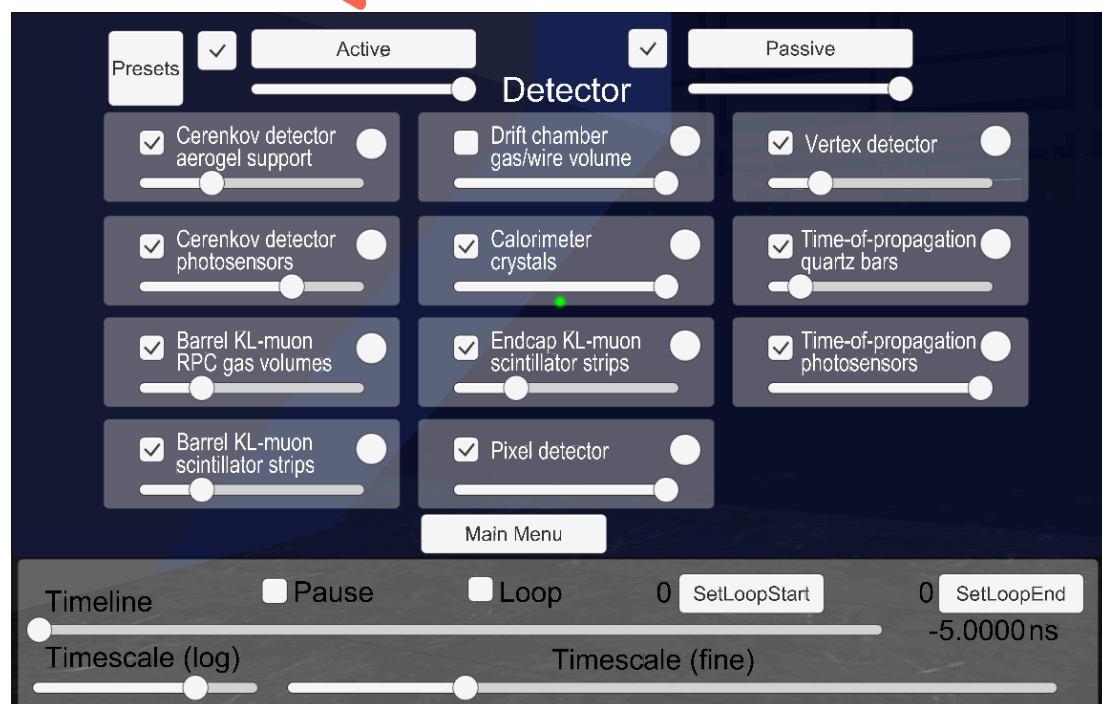
- ✓ Show the **in-game menu** by pressing the gamepad's **Start button**.
- ✓ Gaze at a menu item then press **SELECT** on the gamepad.



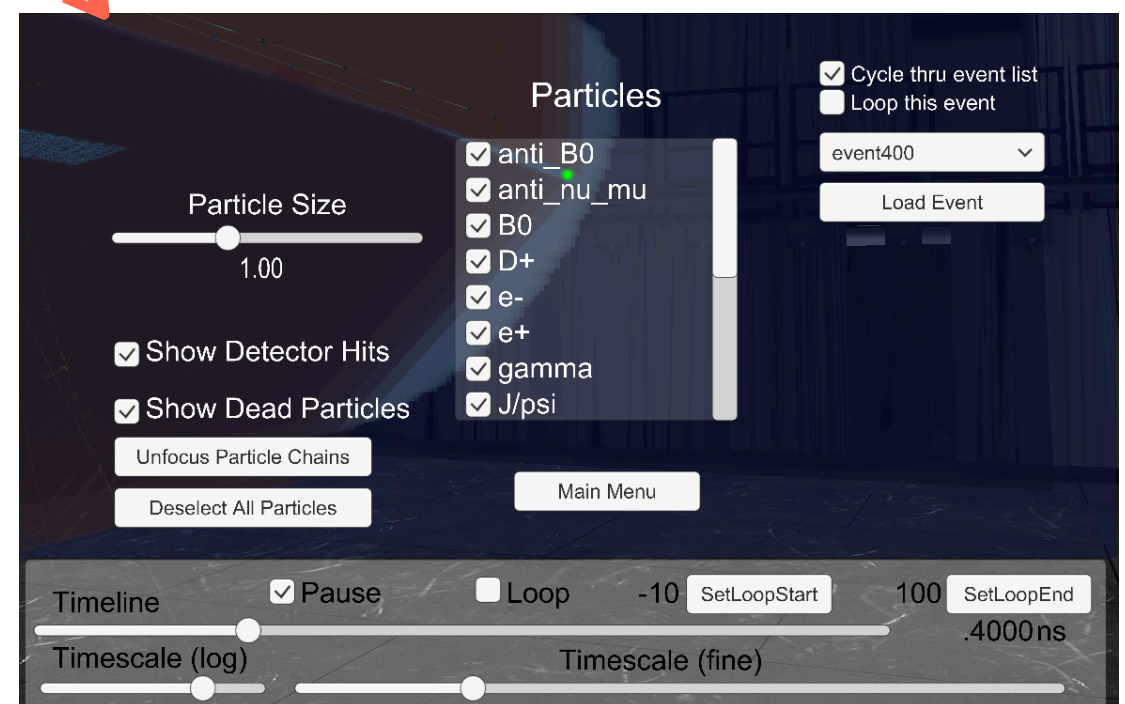
Main menu



Transformation menu



Detector visibility menu

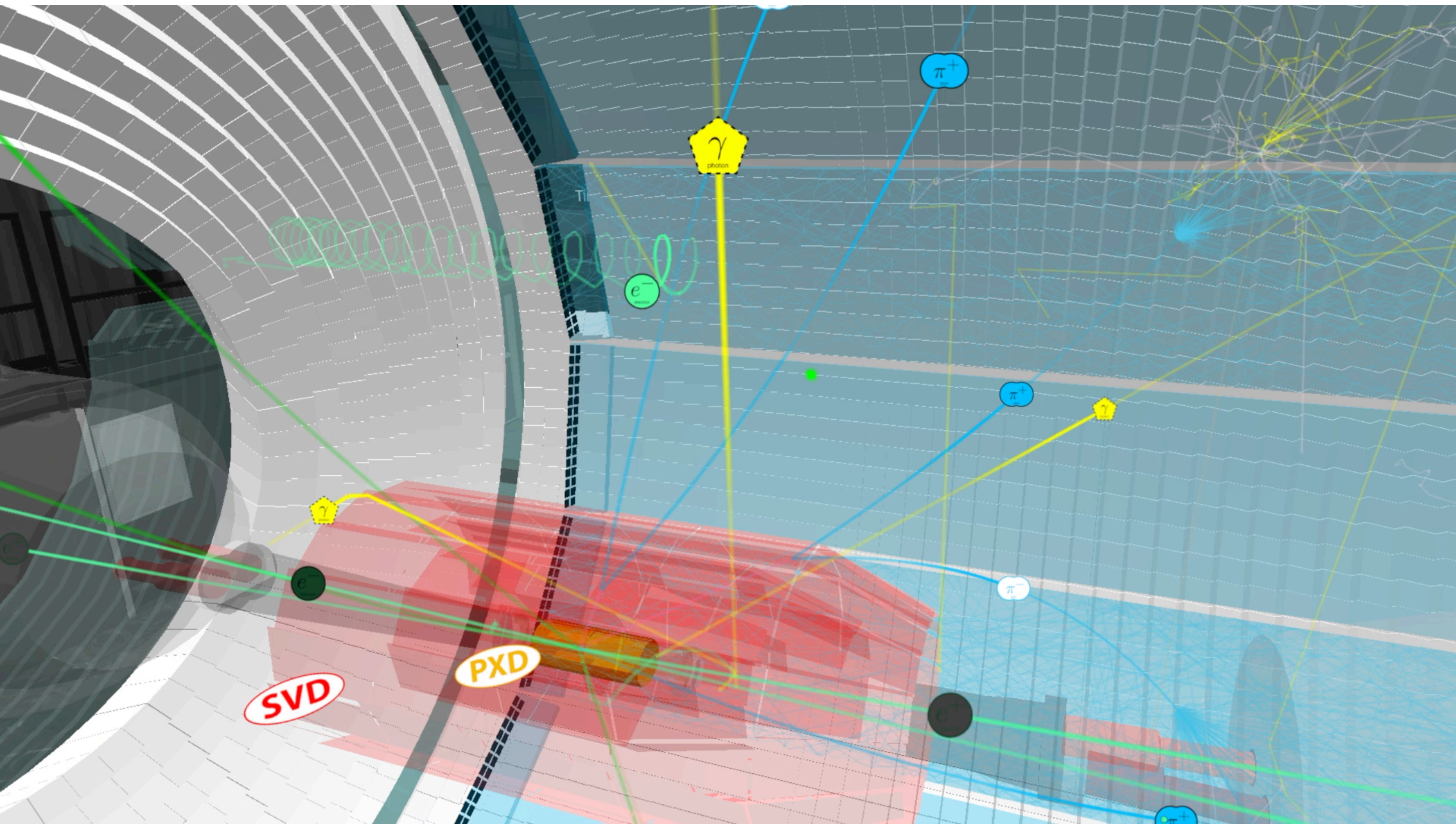


Particles and events menu

User-interaction examples



GEANT4 event-history animation examples



Publicity

✓ Development process:

- vimeo.com/220004044 (*narrated*) & [214899668](https://vimeo.com/214899668) (*captioned*)

✓ Presentations:

- IEEE Visualization in Practice IEEE Comp. Graphics and Appl. **38(3)** (2018) 33
- www.visinpractice.rwth-aachen.de (2017)
- Virginia Association of Science Teachers
www.vast.org (2017)
- HEP Software Foundation (2018)
indico.cern.ch/event/658060/
- ICHEP 2018 and CHEP 2018
- ACAT 2019

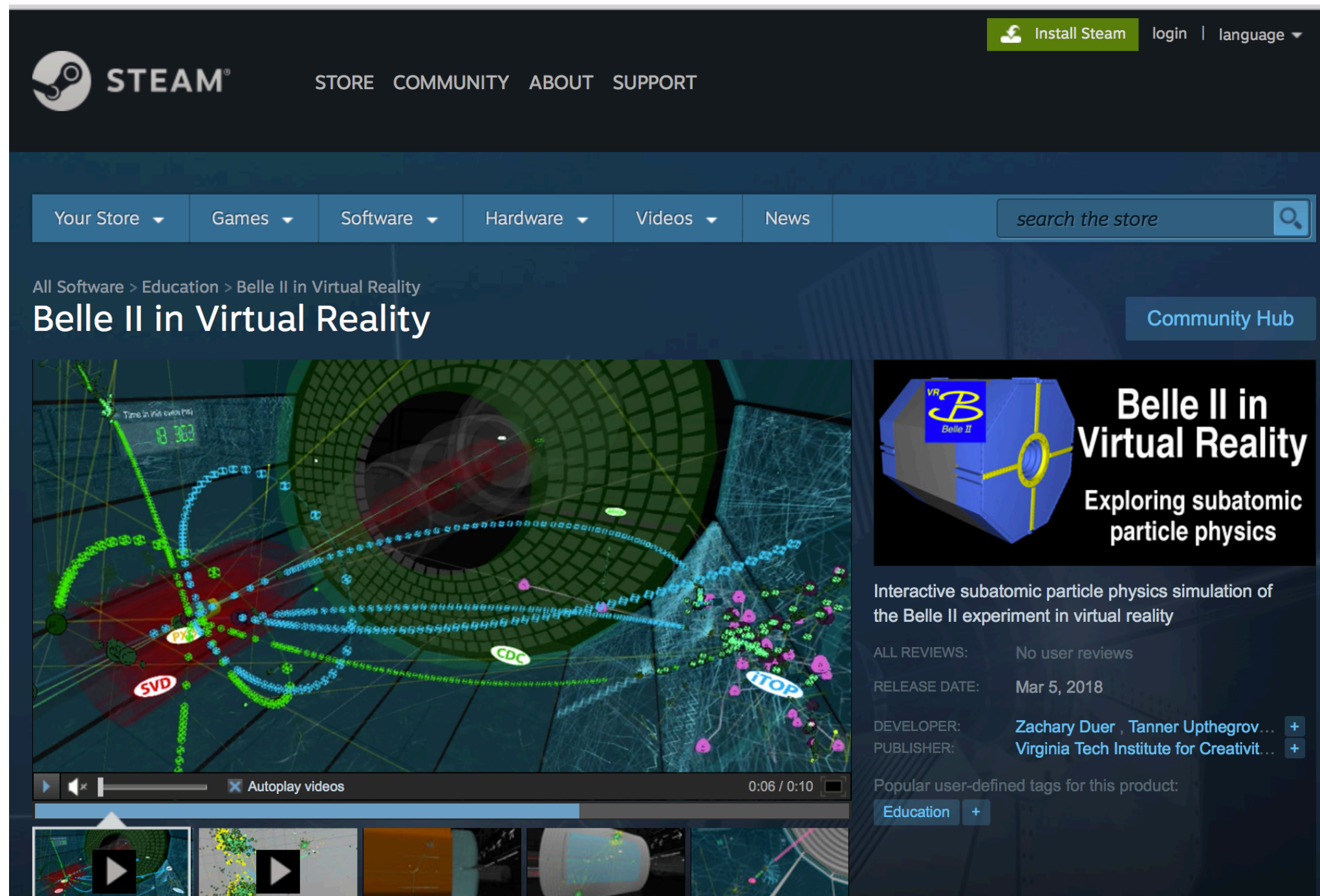
✓ Public displays and outreach:

- many! used by ~40 institutions
- Belle II MasterClasses in 2019
with versions in French, German, Italian, Slovenian, . . .



App (free) is available on Steam

store.steampowered.com/app/810020/



The screenshot shows the Steam store page for the application "Belle II in Virtual Reality". The page layout includes a top navigation bar with the Steam logo, "STORE", "COMMUNITY", "ABOUT", and "SUPPORT". A secondary navigation bar contains "Your Store", "Games", "Software", "Hardware", "Videos", and "News", along with a search bar labeled "search the store". The breadcrumb trail reads "All Software > Education > Belle II in Virtual Reality". The main title "Belle II in Virtual Reality" is displayed, with a "Community Hub" button to its right. Below the title is a large video player showing a 3D visualization of particle tracks within a detector structure. To the right of the video player is a product card for "Belle II in Virtual Reality" with the subtitle "Exploring subatomic particle physics". Below the product card, the following information is listed: "ALL REVIEWS: No user reviews", "RELEASE DATE: Mar 5, 2018", "DEVELOPER: Zachary Duer, Tanner Upthegrov...", and "PUBLISHER: Virginia Tech Institute for Creativit...". At the bottom of the product card, it says "Popular user-defined tags for this product: Education". The video player at the bottom has a progress bar at 0:06 / 0:10 and a thumbnail strip below it.

and on the Oculus store (for the Oculus Go)

secure.oculus.com/my/gear-vr-go → "Redeem code" (*ask me for a code*)

Going forward

- ✓ Seeking new funding to continue this development, particularly as a pedagogical tool in undergraduate physics (university) and high school science education



For more information and downloads
www.phys.vt.edu/~piilonen/VR/

Thank you for your attention!

Backup



Project Participants



Zach Duer
formerly ICAT Staff
→ now SOVA faculty



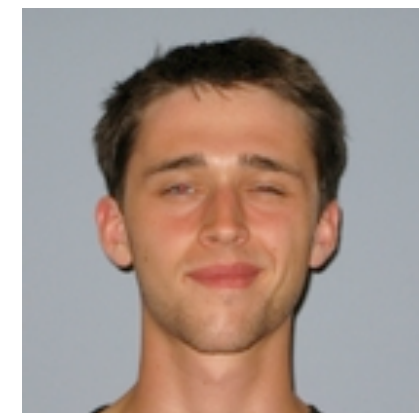
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(graduated)



Samantha Spytek
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(graduated)



Christopher Dobson
Physics Major
(graduated)



Leo Piilonen
Dept of Physics



George Glasson
School of Education



Nicholas Polys
Computer Science



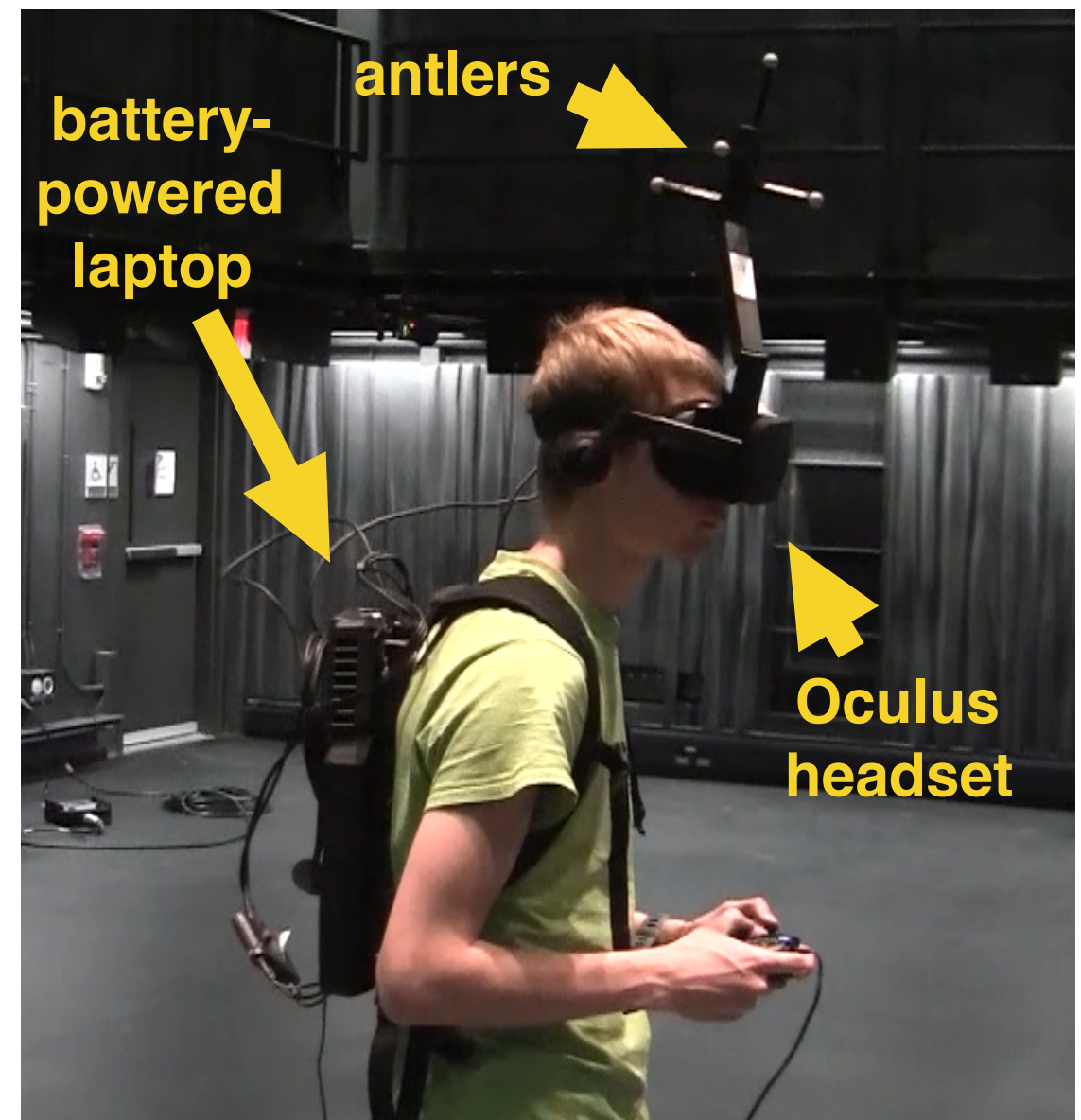
Dane Webster
School of
Visual Arts



Todd Ogle
TLOS

Belle2VR operation: in the CUBE at Virginia Tech

- ✓ In VR world, detector and beam line appear within the CUBE at Virginia Tech to accommodate **N** students' physical location (*also avoids vertigo experienced with a context-free detector*)
- ✓ Students see each others' avatars in the VR world
- ✓ Untethered movement in CUBE with backpack laptop + headset
- ✓ User-specific antlers provide 3D position and orientation via CUBE's motion-capture system
- ✓ Can be projected onto a huge cylindrical screen ("Cyclorama") in the CUBE for large audiences



- youtu.be/LxIW6Zv9uTM
- www.elumenati.com/projects/virginia-tech-cyclorama/

Belle2VR operation: with the standalone Oculus Go



1.5 hours of battery life with Belle2VR
(rechargeable battery in headset)

www.youtube.com/watch?v=Bf1PICzUSHY

VR world user controls with the Oculus Go remote

✓ Your gaze is always indicated by a green dot in front of you.

