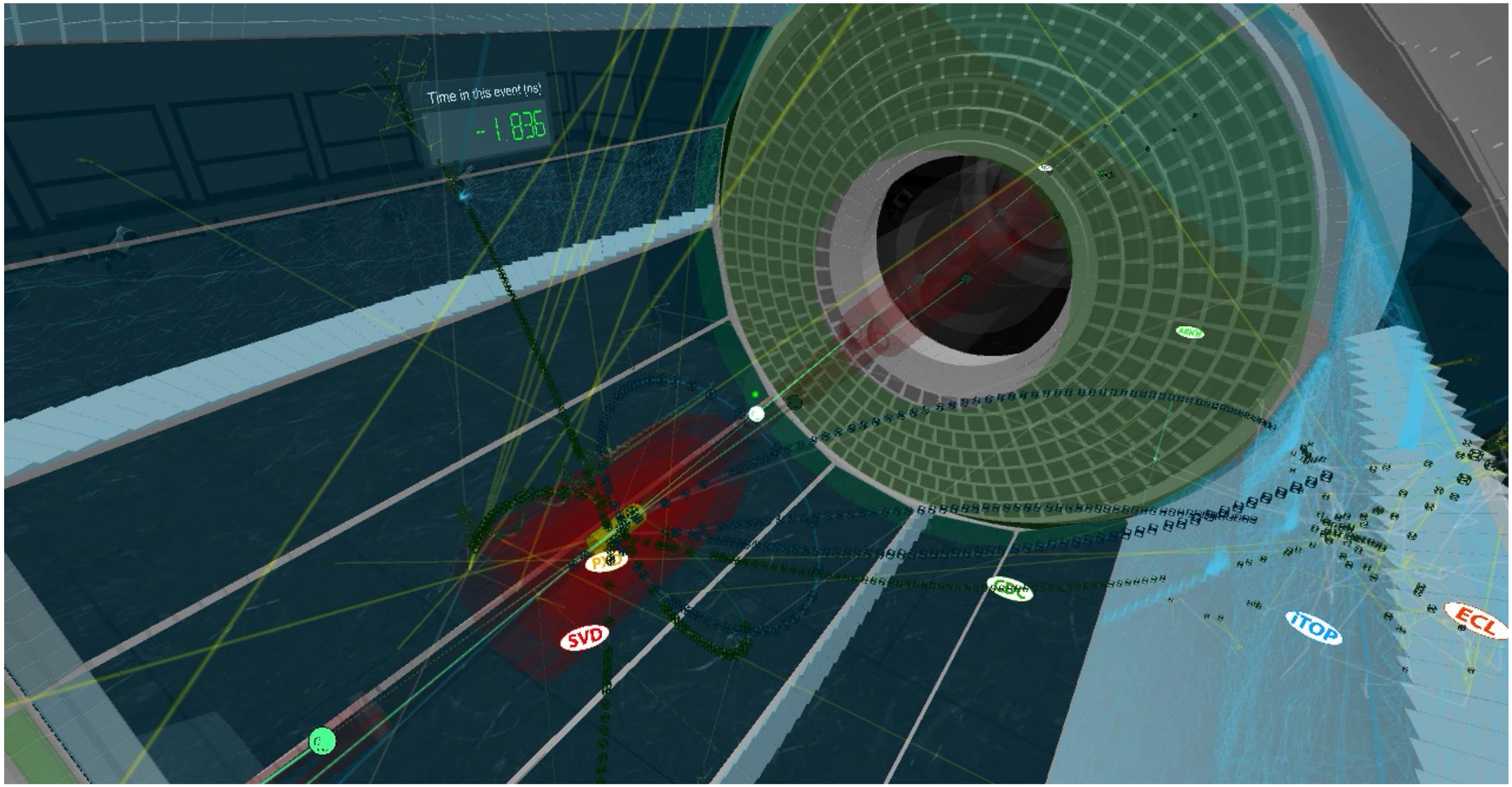
# Belle2VR: An interactive virtual reality visualization of GEANT4 event histories

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]*

(*) Nucl. Instrum. Meth. A **835** (2016) 186

(#) Comput. Softw. Big Sci. **3:1** (2019)

# 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*

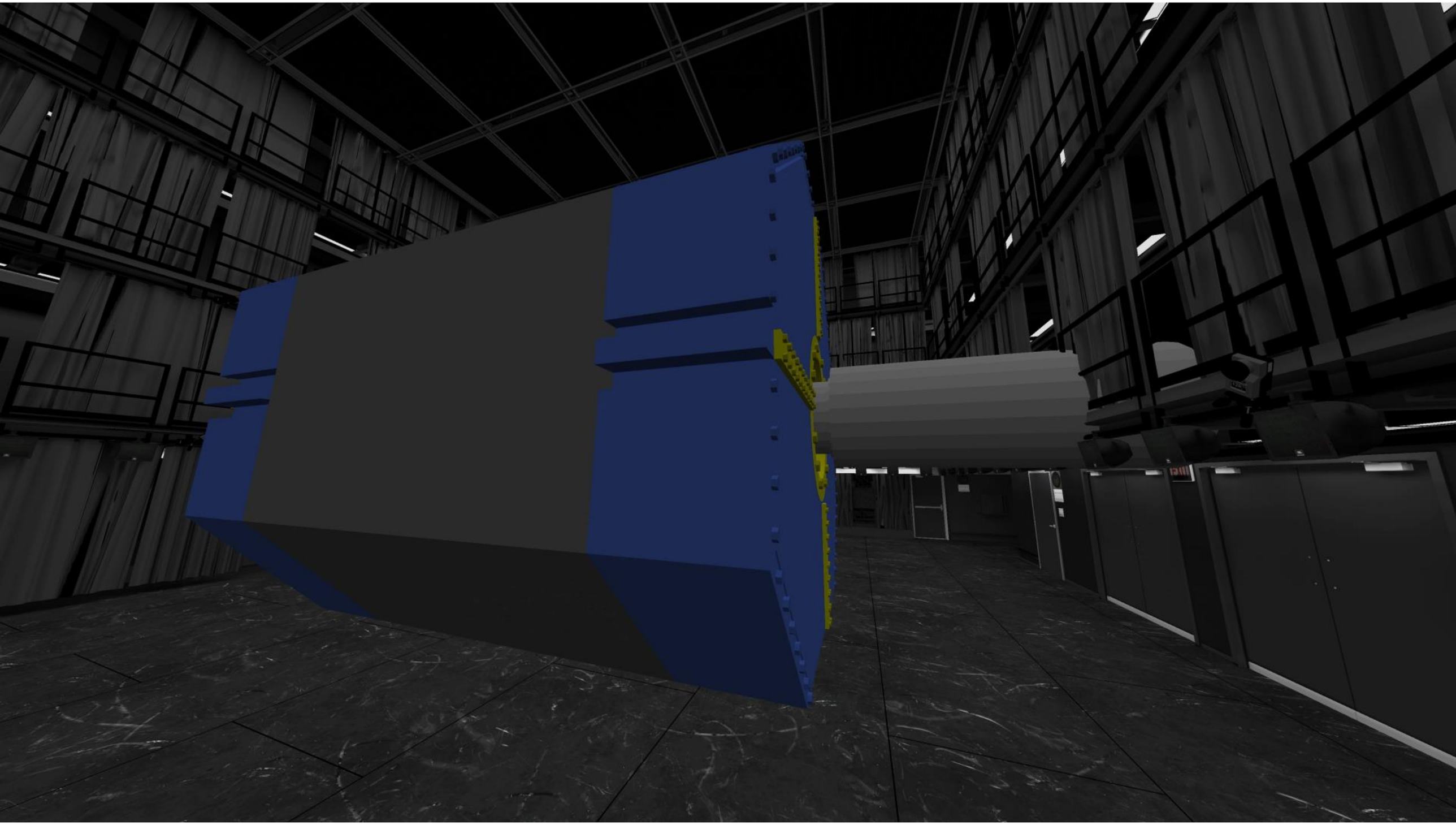
  - *you may download from github.com/HSF/Visualization*

## 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

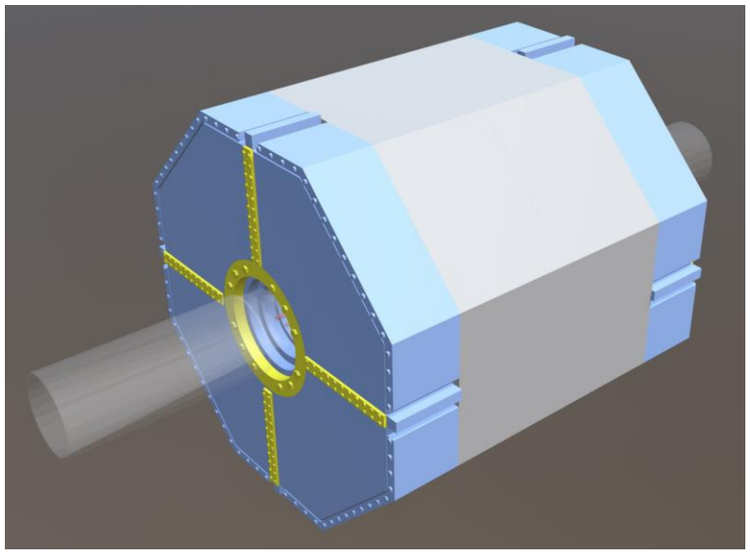
# GEANT4 detector geometry (2)

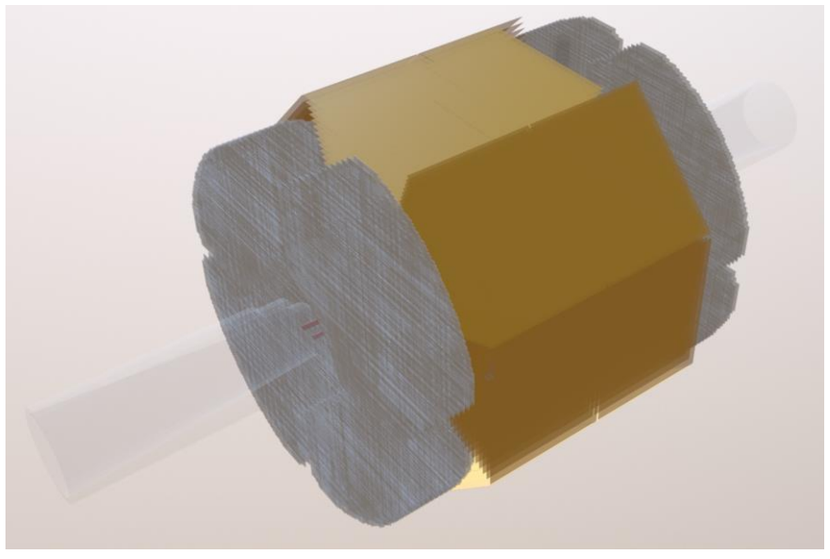


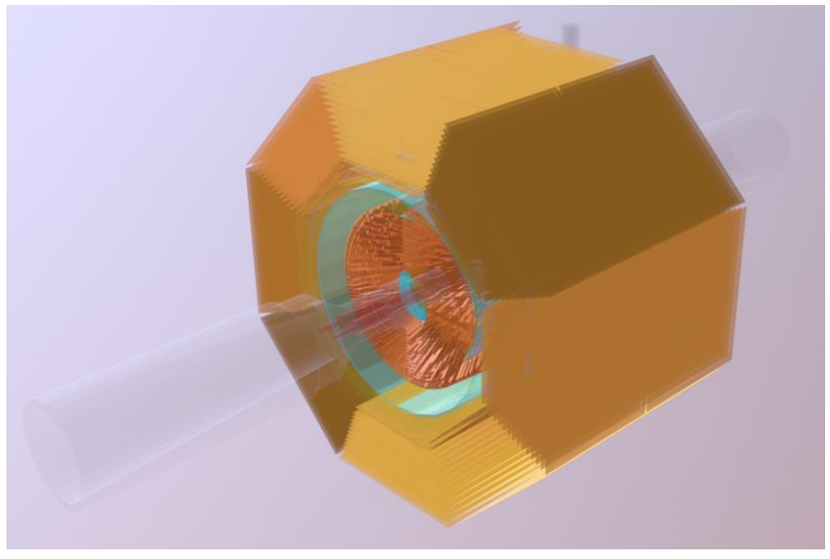
Belle II detector at full scale (positioned in the CUBE at Virginia Tech)

# 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

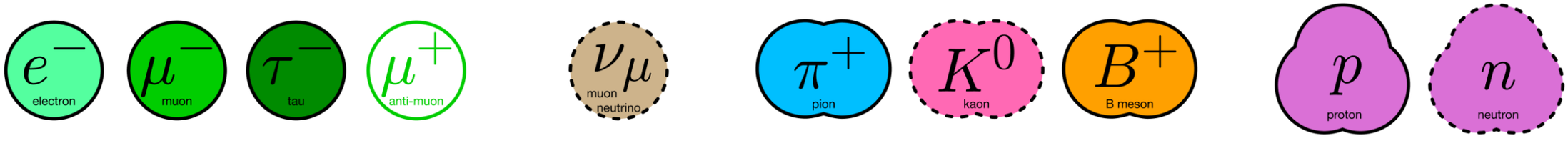
# GEANT4 event histories (2)

## 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

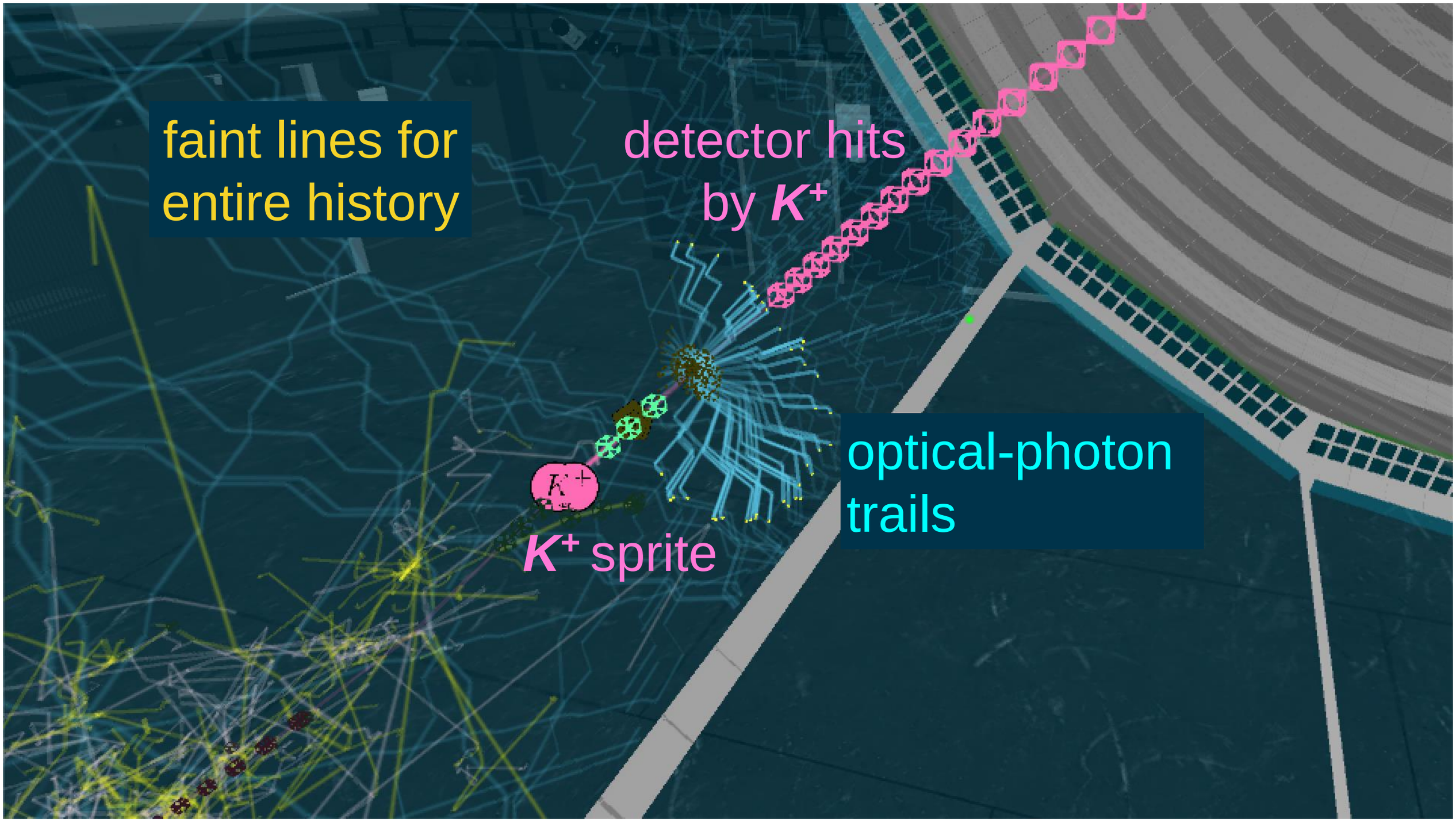



- colour-coded and shape-coded
- de-emphasis *[fade]* if particle's history is finished

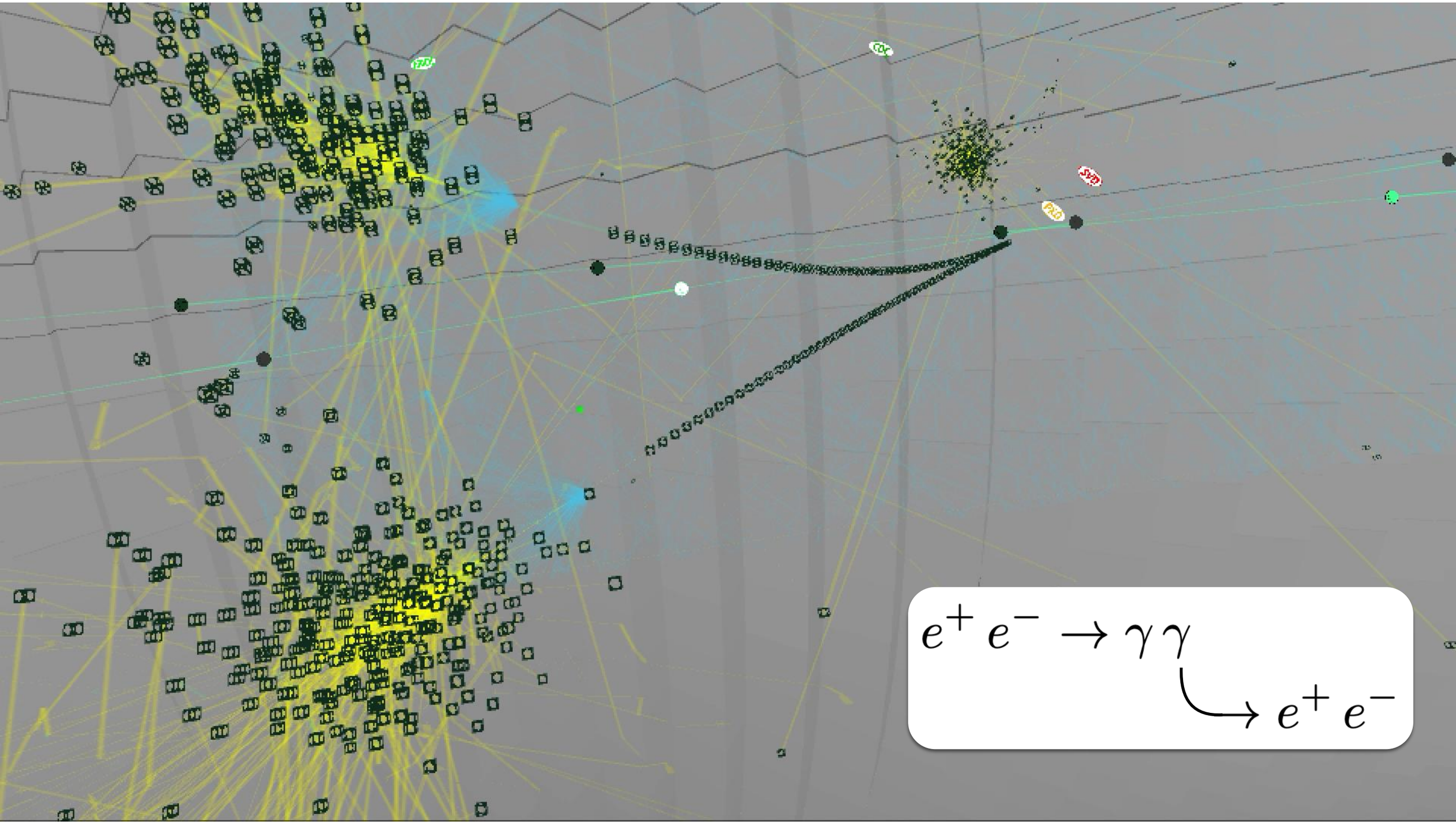
✓ dynamic trails highlight particle motion during animation
✓ sensitive-detector hits, with detector-specific sound
✓ last few seconds of animation: show only the detector hits

✓ *for VR headset, must run at **90 fps** at all times*

# GEANT4 event histories (3)



# GEANT4 event histories (4)



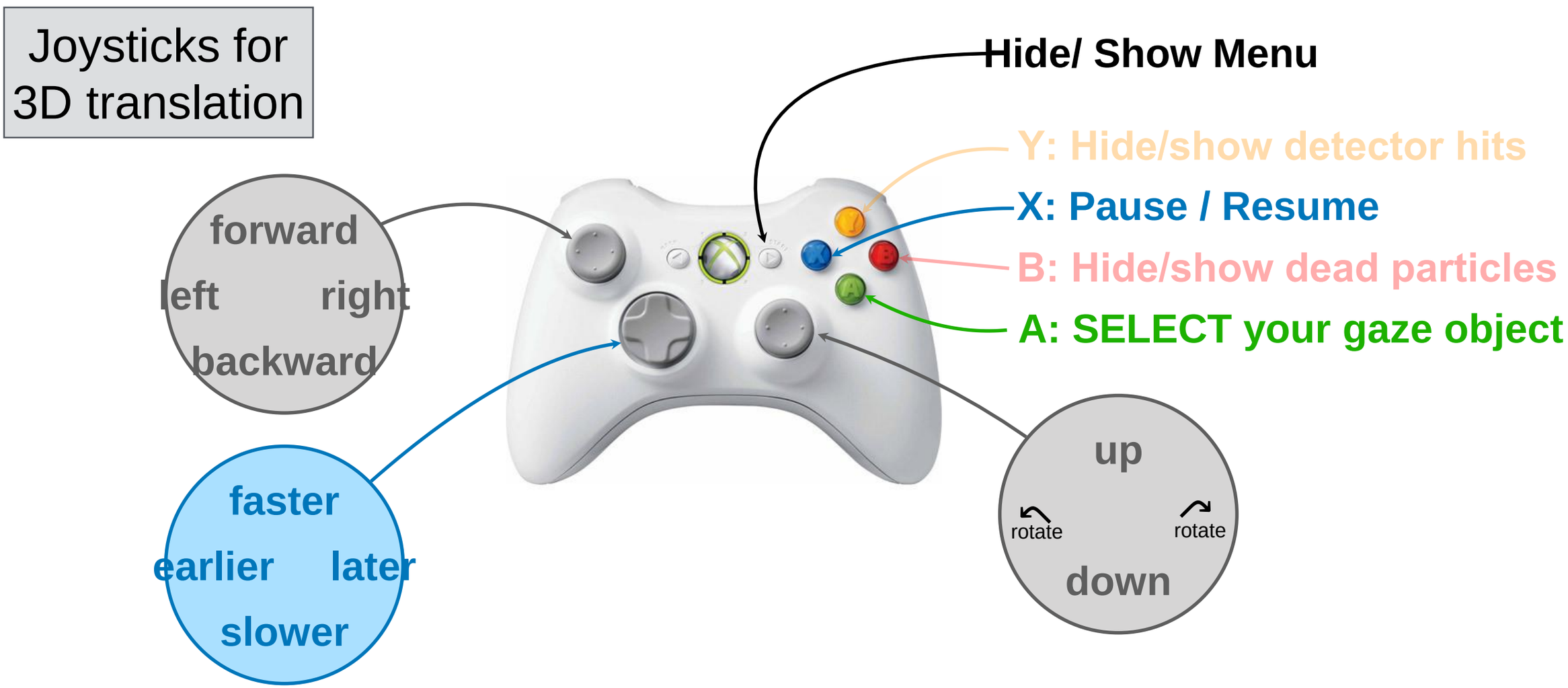
# Belle2VR operation: in the CUBE at Virginia Tech

# 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
  - gamepad (tethered or Bluetooth)
  - Oculus Touch hand controllers
  - HTC Vive hand controllers
  - keyboard/mouse

# VR-world user controls

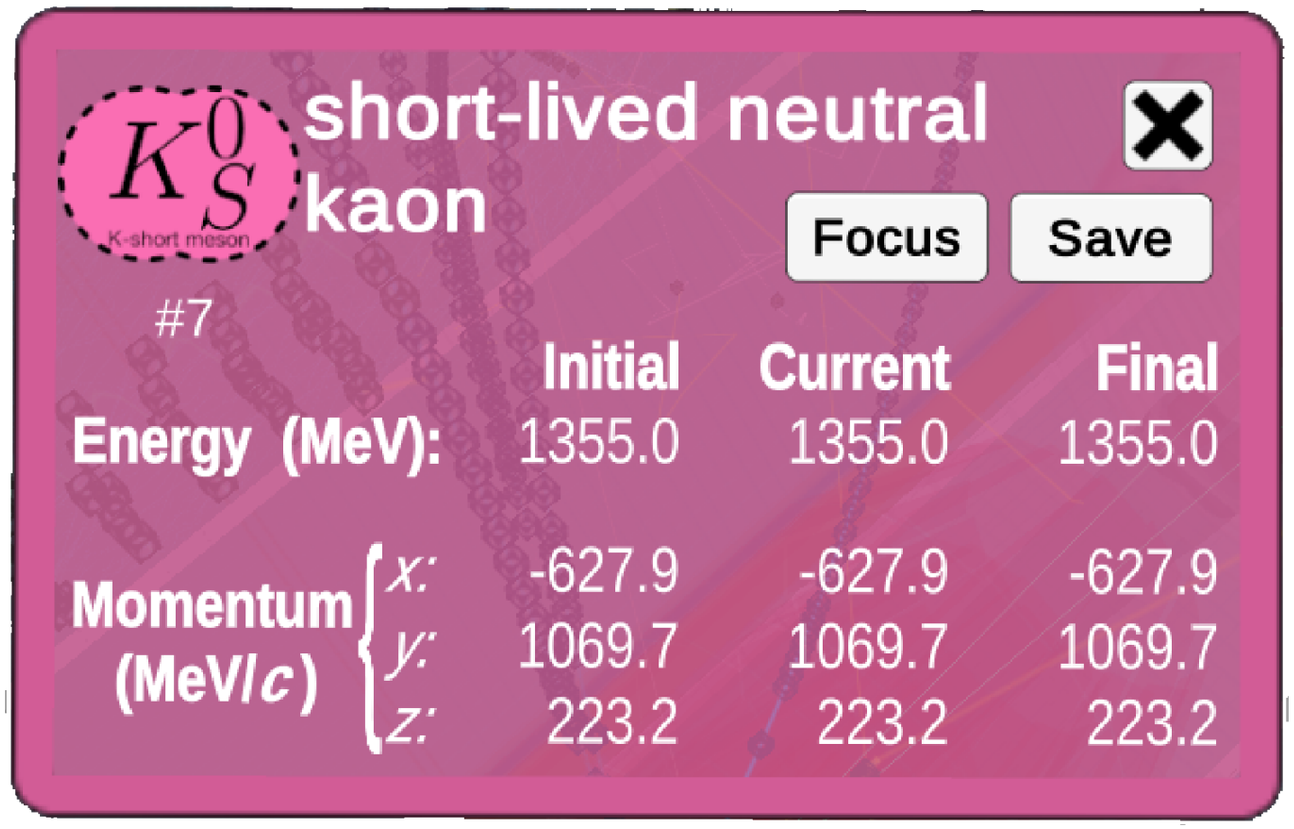
- ✓ Your gaze is always indicated by a green dot in front of you.
- ✓ Turn your head to move this gaze dot in the VR world.
- ✓ Interact with the in-world features using a gamepad:




*(some controls are omitted here)*

# VR world features (1)

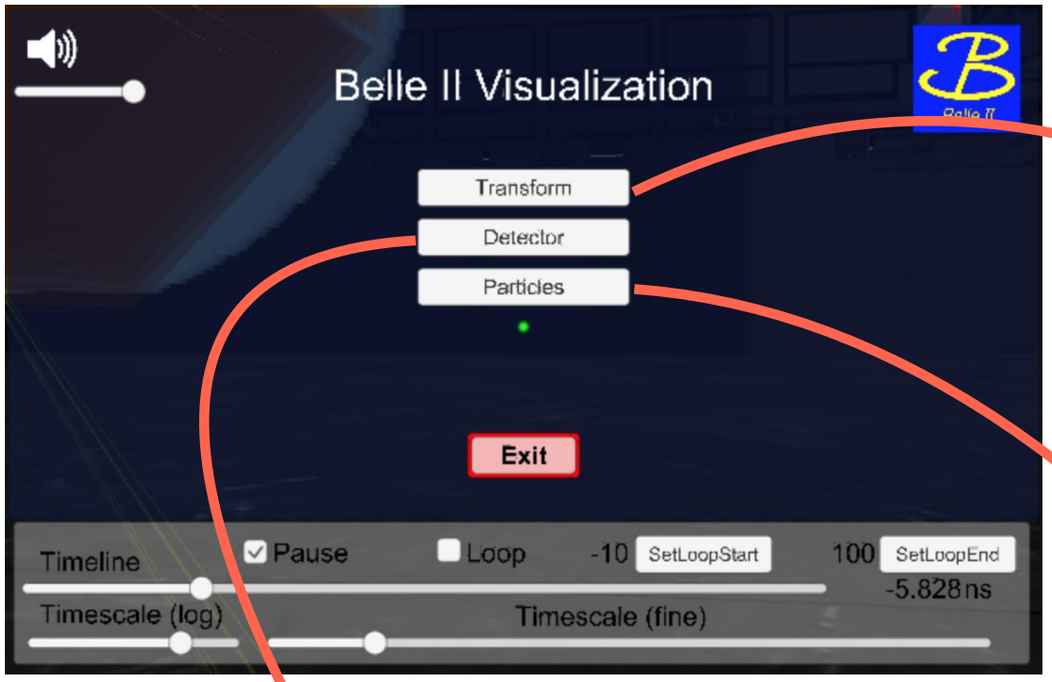
- ✓ If you gaze at a particle and **SELECT**, an information panel appears.



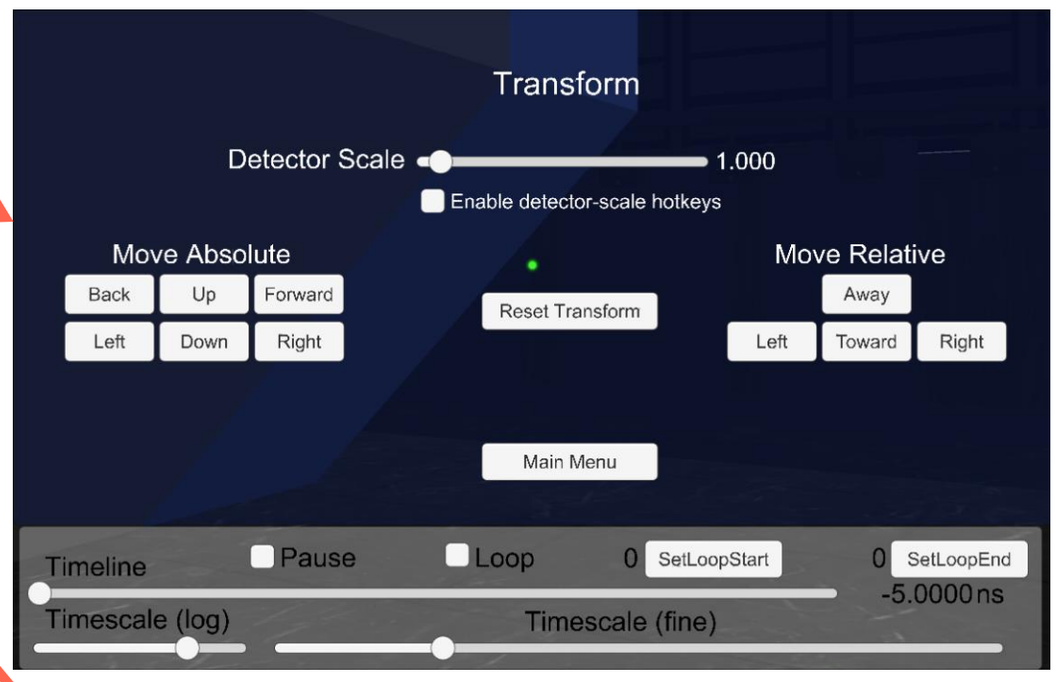

- ✓ The panel's border is black if the particle is dead.
- ✓ If you gaze at **Focus** and **SELECT**, only this particle and its relatives are shown. *(Then, you can "Unfocus" to show all particles.)*
- ✓ If you gaze at **Save** and **SELECT**, this particle's information is saved to a row of the panel 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)

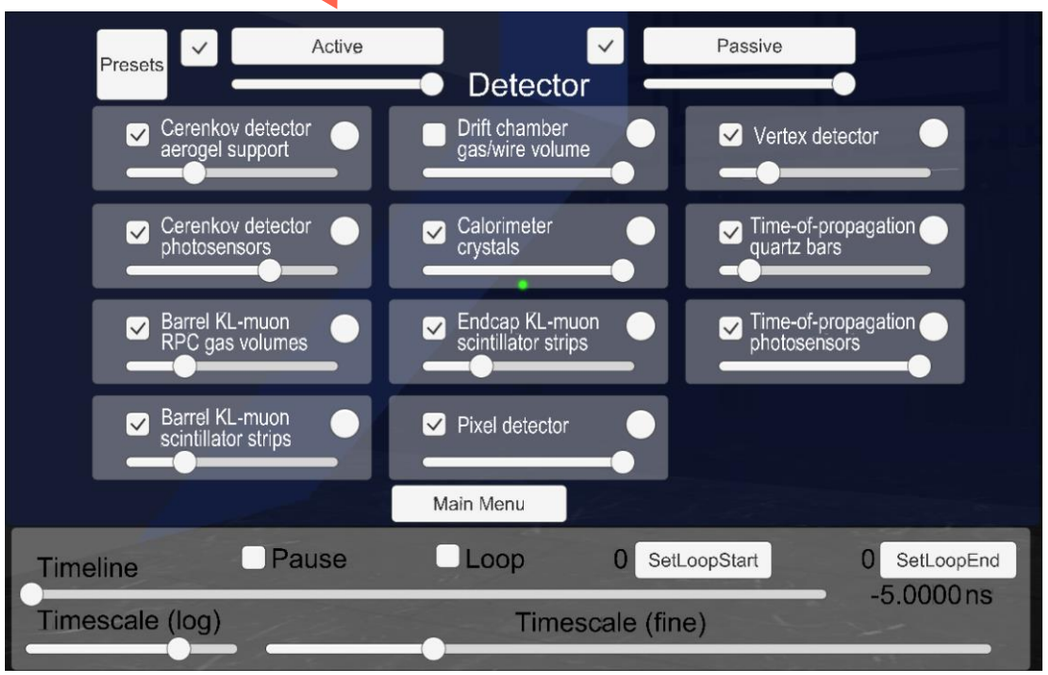
- ✓ Show the **in-game menu** by pressing the gamepad's **Start button**.
- ✓ Gaze at a menu item then press **SELECT** on the gamepad.




Main menu




Transformation menu

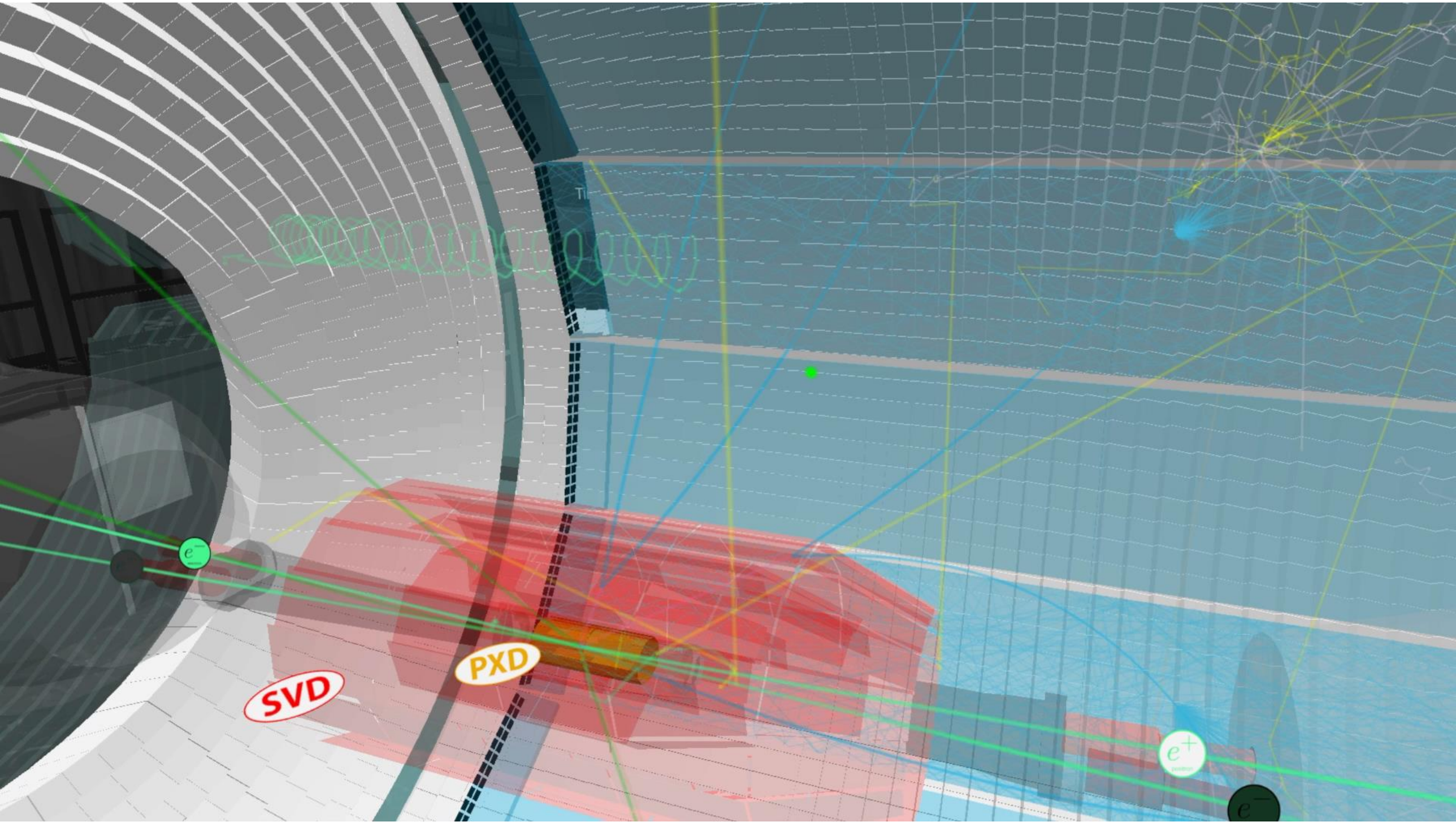



Detector visibility menu


Particles and events menu

# User-interaction examples

# GEANT4 event-history animation examples



# Publicity

✓ Development process:
- vimeo.com/220004044 *(narrated)* & 214899668 *(captioned)*

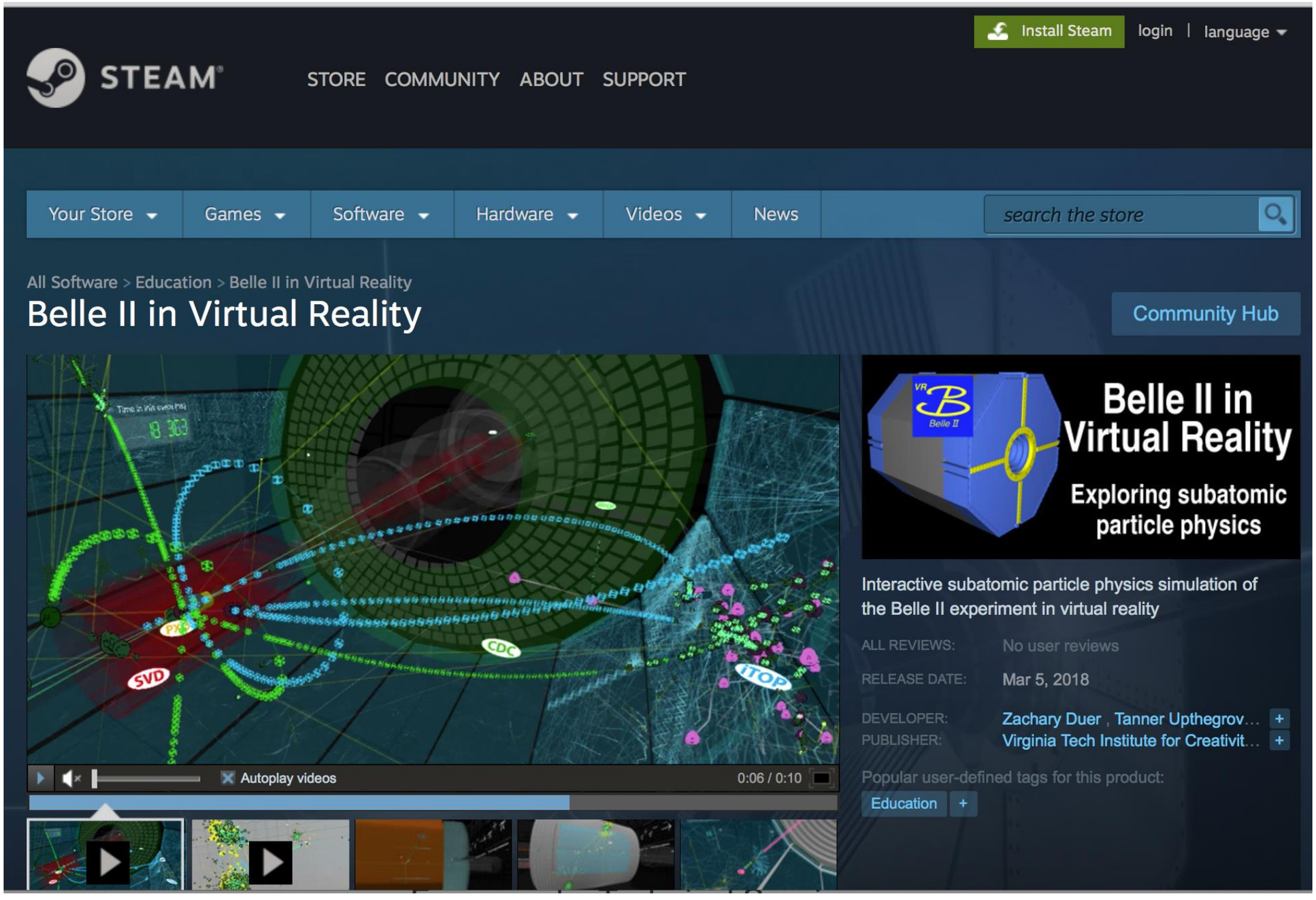
✓ Presentations:
- IEEE Visualization in Practice
  www.visinpractice.rwth-aachen.de (2017)
- Virginia Association of Science Teachers
  www.vast.org (2017)
- HEP Software Foundation (2018)
  indico.cern.ch/event/658060/
- ICHEP 2018 and CHEP 2018
- ACAT 2019

IEEE Comp. Graphics and Appl. **38(3)** (2018) 33

✓ 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/




# 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

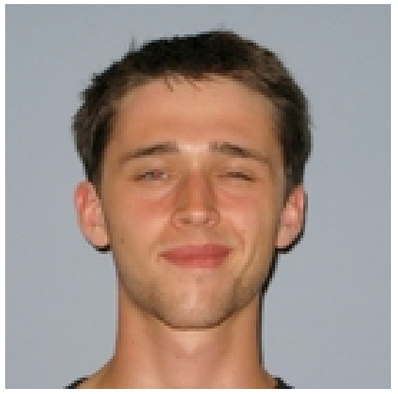
# Project Participants

Zach Duer
formerly ICAT Staff
→ now SOVA faculty

Tanner Upthegrove
ICAT Staff
Media Engineer

Jesse Barber
Physics Major
(graduated)

Samantha Spytek
Physics Major
(graduated)



Christopher Dobson
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(graduated)

Leo Piilonen
Dept of Physics

George Glasson
School of Education

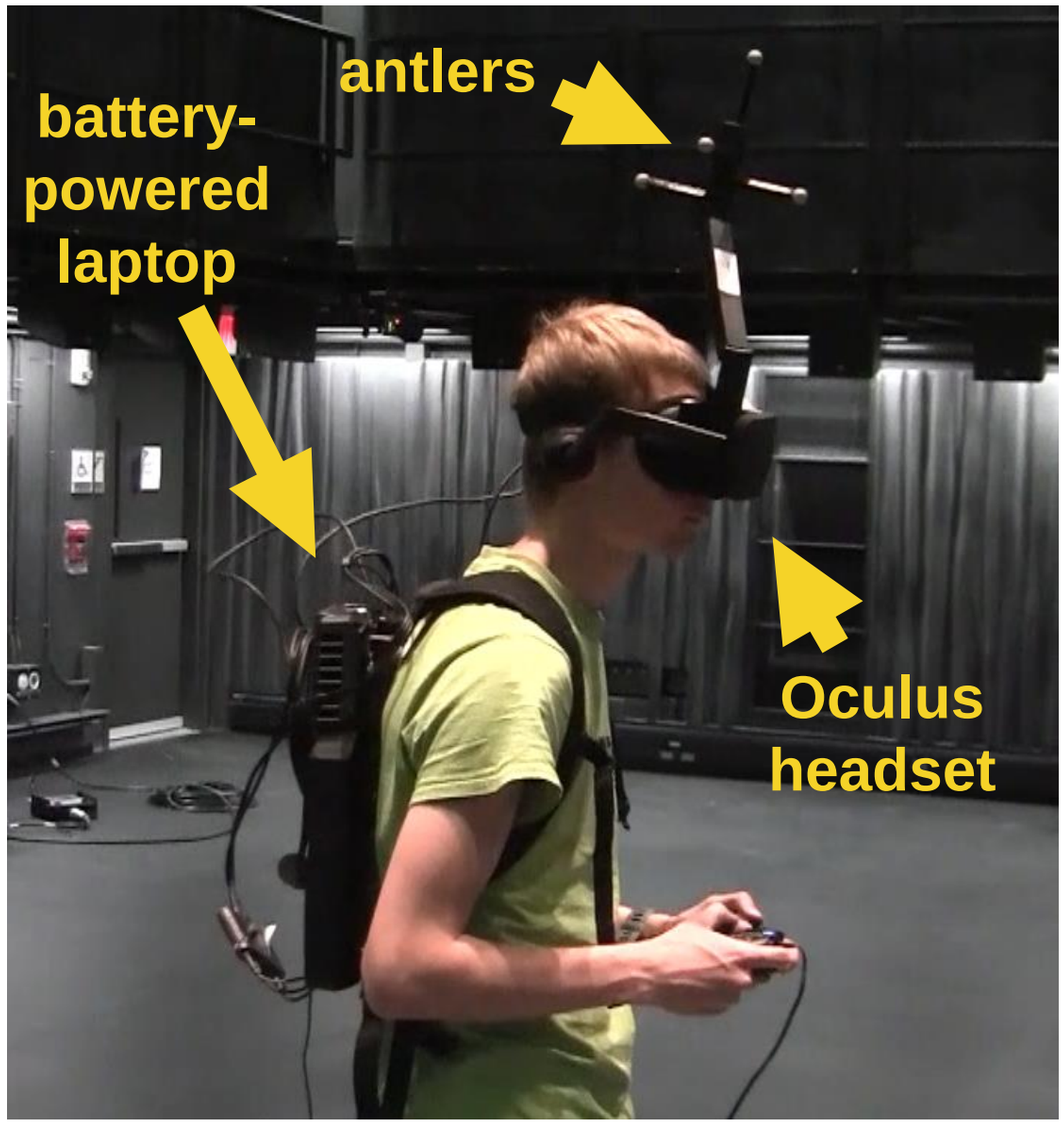
Nicholas Polys
Computer Science

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/LxlW6Zv9uTM
  - 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.

**Click to SELECT (in menu, etc)**
**Double-click to show/hide menu**
***Hold to modify trackpad action***

**Previous scene** **OCULUS Dash menu**

| | **not holding the trigger** | **while holding the trigger** |
|---|---|---|
| **pointing horizontally** | forward / left / right / backward | Y / X / B |
| **pointing vertically** | up / rotate / rotate / down | faster / earlier / later / slower |

**Y: Hide/show detector hit**

**X: Pause / Resume**

**B: Hide/show dead partic**