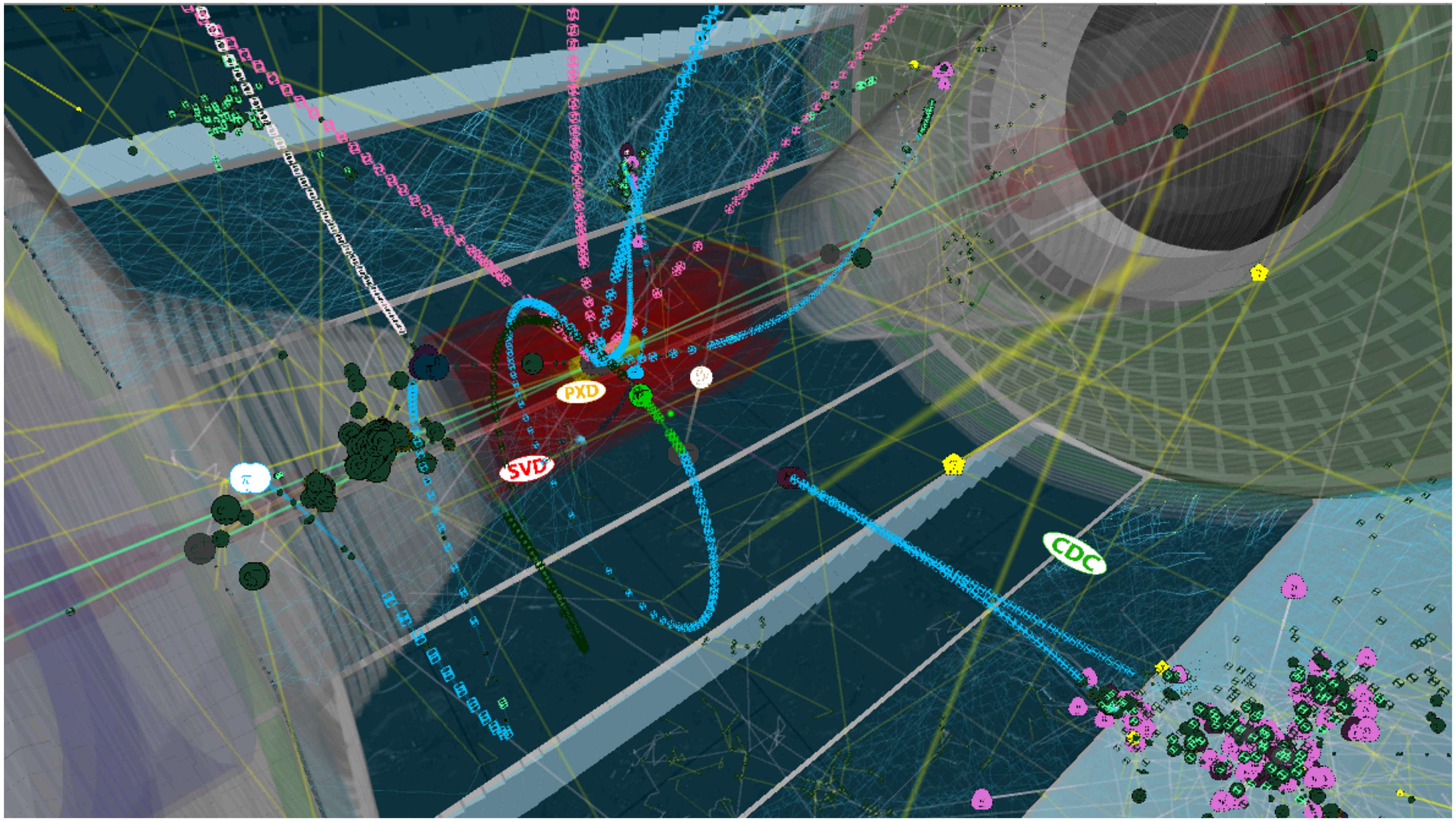
Belle II in Virtual Reality

Leo Piilonen, Virginia Tech

on behalf of the Belle II Collaboration's Outreach Group



XXXIX International Conference on High Energy Physics *July 2018*

History

In early 2016, we submitted an internal grant proposal at Virginia Tech to develop a virtual reality model of Belle II.

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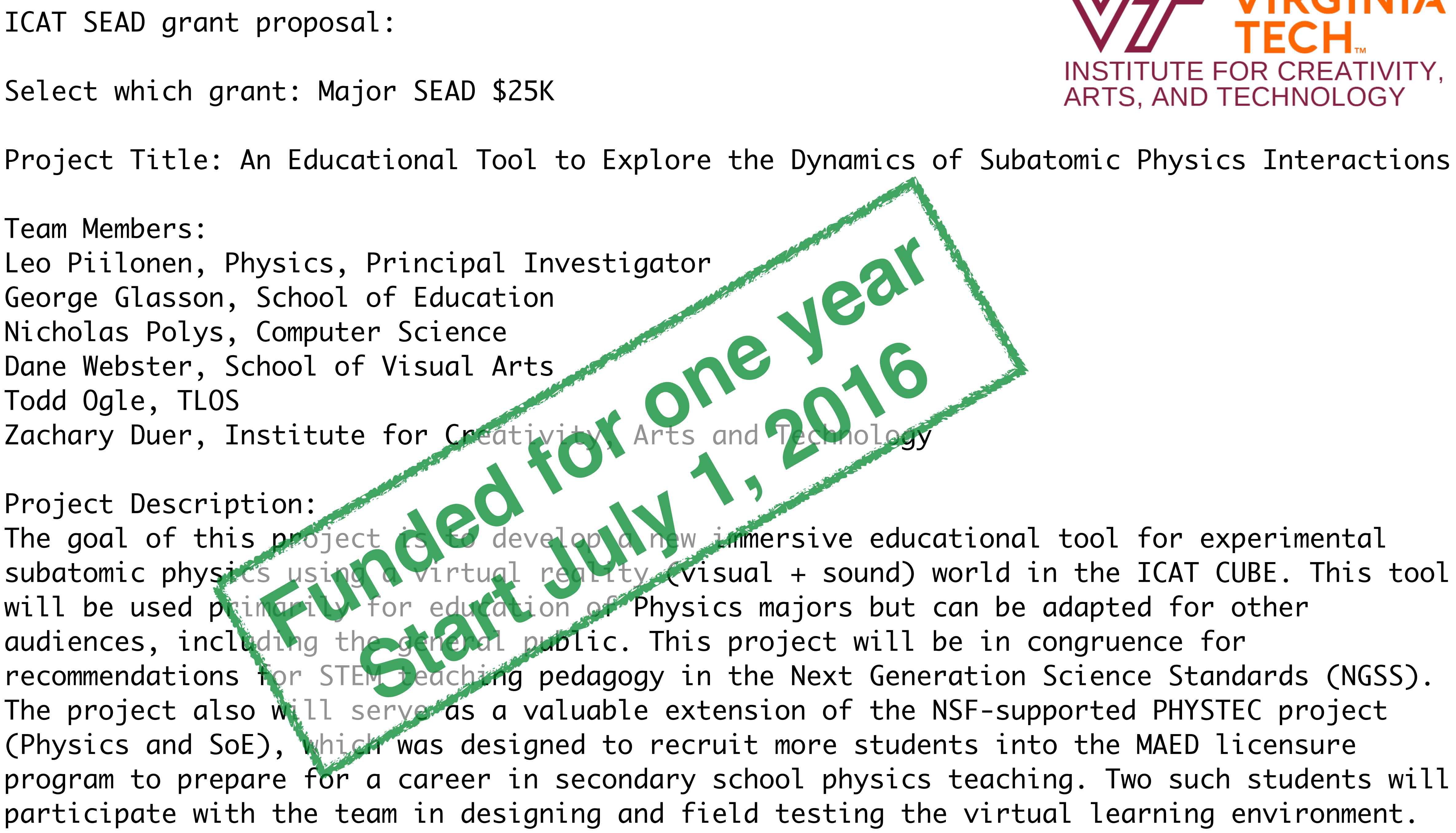


ICAT SEAD grant proposal:

Select which grant: Major SEAD $25K

Project Title: An Educational Tool to Explore the Dynamics of Subatomic Physics Interactions

Team Members:
Leo Piilonen, Physics, Principal Investigator
George Glasson, School of Education
Nicholas Polys, Computer Science
Dane Webster, School of Visual Arts
Todd Ogle, TLOS
Zachary Duer, Institute for Creativity, Arts and Technology

Project Description:
The goal of this project is to develop a new immersive educational tool for experimental subatomic physics using a virtual reality (visual + sound) world in the ICAT CUBE. This tool will be used primarily for education of Physics majors but can be adapted for other audiences, including the general public. This project will be in congruence for recommendations for STEM teaching pedagogy in the Next Generation Science Standards (NGSS). The project also will serve as a valuable extension of the NSF-supported PHYSTEC project (Physics and SoE), which was designed to recruit more students into the MAED licensure program to prepare for a career in secondary school physics teaching. Two such students will participate with the team in designing and field testing the virtual learning environment.

Funded for one year
Start July 1, 2016

Project Participants at VT (who did all the work)

Zach Duer
formerly ICAT Staff
now SOVA faculty
(lead programmer)

Tanner Upthegrove
ICAT Staff
Media Engineer

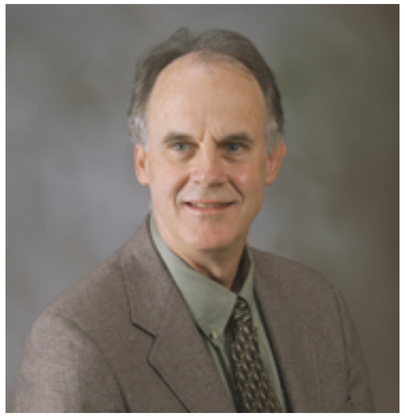
Jesse Barber
Physics Major

Samantha Spytek
Physics Major
(graduated)

Christopher Dobson
Physics Major
(graduated)

Project Participants (kibitzers)

Leo Piilonen
Dept of Physics



George Glasson
School of Education

Ben Knapp
ICAT Director

Platform

Choose Unity (unity3d.com) as the software-development platform

✓ targets many 3D displays (Oculus, HTC Vive, Cyclorama, …)

✓ free for non-commercial use

✓ Zach Duer, our programmer, is experienced in using Unity

✓ the associated scripts in C# look familiar to any C++ user

✓ Unity itself is written in C++ ➠ provides C# ↔ C++ interface

Choose the Oculus Rift (oculus.com) as the first display target

✓ robust high-performance 3D/viz support built into Unity

✓ VT-ICAT had two already

✓ can be integrated with other Rifts (“classroom” deployment)

Geometry (1)

Incorporate the Belle II detector geometry in Unity

- must be identical to our `GEANT4` model (no simplifications)
- requires a method to export the geometry in a cross-platform format that can be imported directly into Unity
  - ✘ NOT `TEve` nor any other `GEANT4/ROOT`-native format – not supported by Unity
  - ✘ Not 3DS, OBJ, STL, PLY, etc – not supported by Unity
  - ✓ FBX (Filmbox) – modern, de facto standard for 3D-model exchange, supported directly by Unity. *A proprietary format (defined by Autodesk Corp), undocumented.*
  - ✓ VRML (Virtual Reality Modeling Language) – archaic, requires an intermediary program to convert to FBX. `GEANT4` *contains method to export geometry to VRML.*

Geometry (2)

Export the Belle II detector geometry from basf2 framework

❖ In GEANT4, each volume element is rendered as polygons of its surface, using GetPolygon(), before exporting

✘ GEANT4 accepts a UI command to write its polygonized geometry to various formats – VRML[2], HepRep, DAWN). *Only VRML2 would be viable here, but this barfs on parts of our geometry, and the output file is unstructured.*

✓ write two new basf2 modules to export to VRML2 or FBX

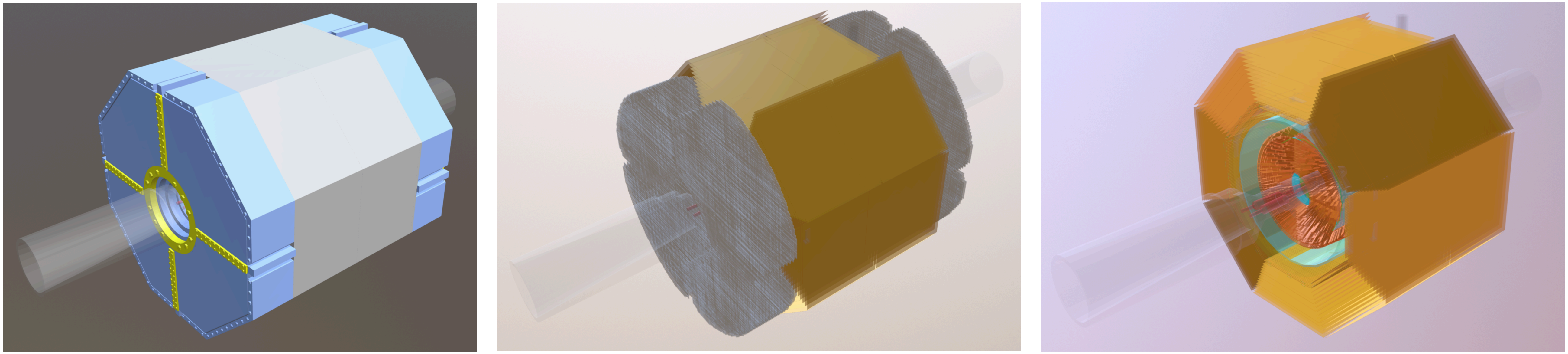
- ◉ geometry/modules/vrmlWriter
- ◉ geometry/modules/fbxWriter

} ⇢ *structured text files*

- ◉ examine the geometry using FBX Review, for example (www.autodesk.com/products/fbx/fbx-review)
- ◉ Unity can import FBX files directly *(VRML2 via translator)*
- ◉ *you may download from github.com/HSF/Visualization*

Geometry (3) *… an aside*

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



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

glTF™ (GL Transmission Format) is a royalty-free specification for the efficient transmission and loading of 3D scenes and models by applications. glTF minimizes both the size of 3D assets, and the runtime processing needed to unpack and use those assets. glTF defines an extensible, common publishing format for 3D content tools and services that streamlines authoring workflows and enables interoperable use of content across the industry.

Events (1)

Export the simulation events from `basf2`

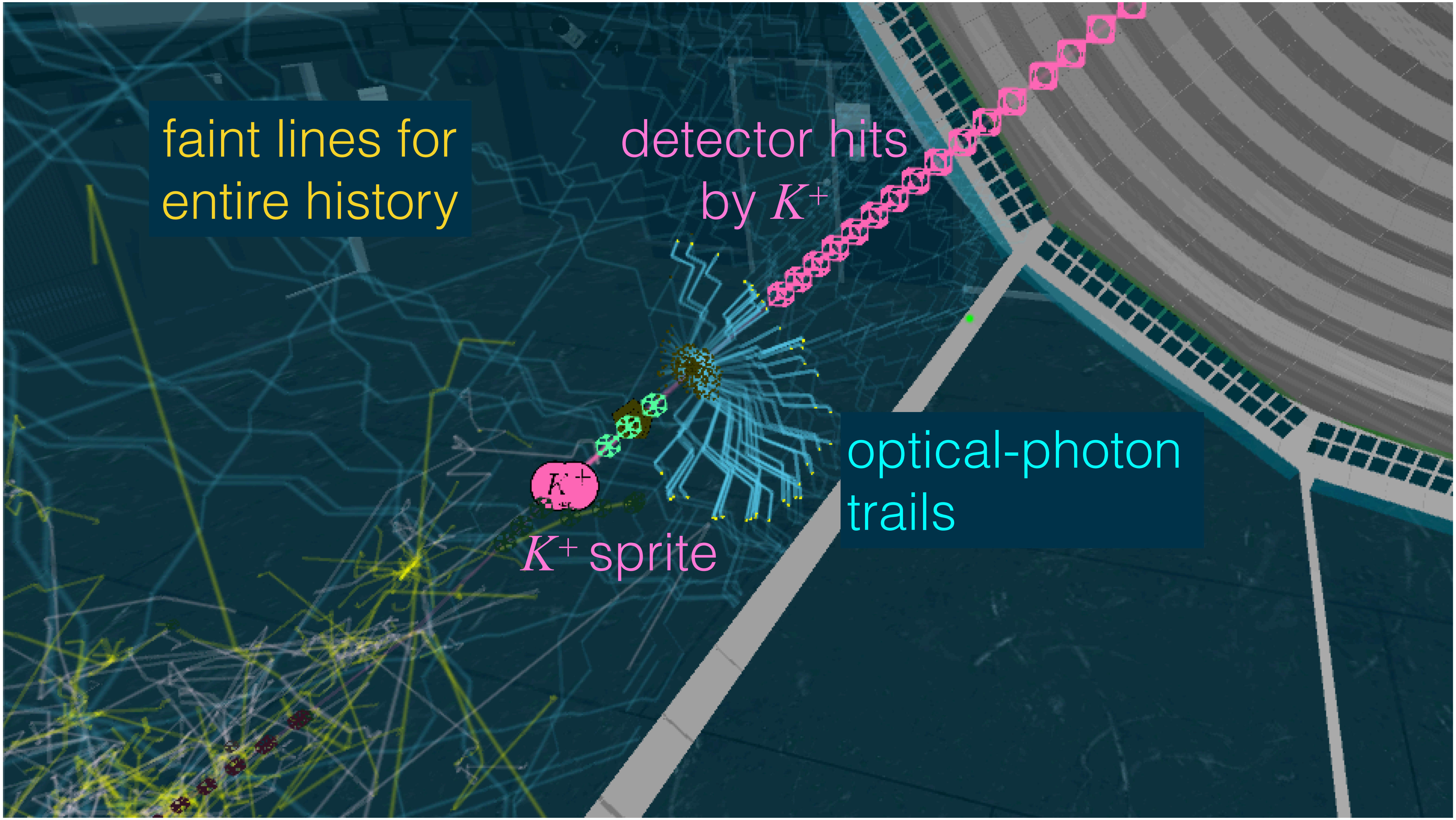
- ✓ must show *almost* entire event history from `GEANT4`
- ✓ must be in human-readable format → Excel `csv` file
- ✓ one `csv` file per event
- ✓ add print line to the inherited `G4UserSteppingAction` hook
  - ◉ write a line for each step (PreStepPoint, PostStepPoint, volumeName, trackID, parentID, PDGcode, etc)
  - ◉ *… but no heavy nuclei (they don't move)*
  - ◉ *… and cut off after 100 ns (neutron walk, late decays)*
- ✓ perl script adds beam-line particles then sorts the `csv` file (by ParticleName, then TrackID, then StepNumber)

Events (2)

Import the events into Unity and animate the history

- ✓ C# scripts in Unity read `csv` file, parse the data into internal Unity structures for efficient / responsive animation
- ✓ persistent faint lines show the entire simulation history
- ✓ sprites show each particle during the animation
  - ◉ colour-coded, shape-coded
  - ◉ de-emphasis *[faded]* when particle history ends
- ✓ dynamic trails highlight particle motion during animation
- ✓ sensitive-detector hits, with detector-specific sound
- ✓ last few seconds of animation: show only the detector hits

Events (3)



faint lines for entire history

detector hits by K^+

optical-photon trails

K^+ sprite

Belle2VR operation: in CUBE Facility at Virginia Tech

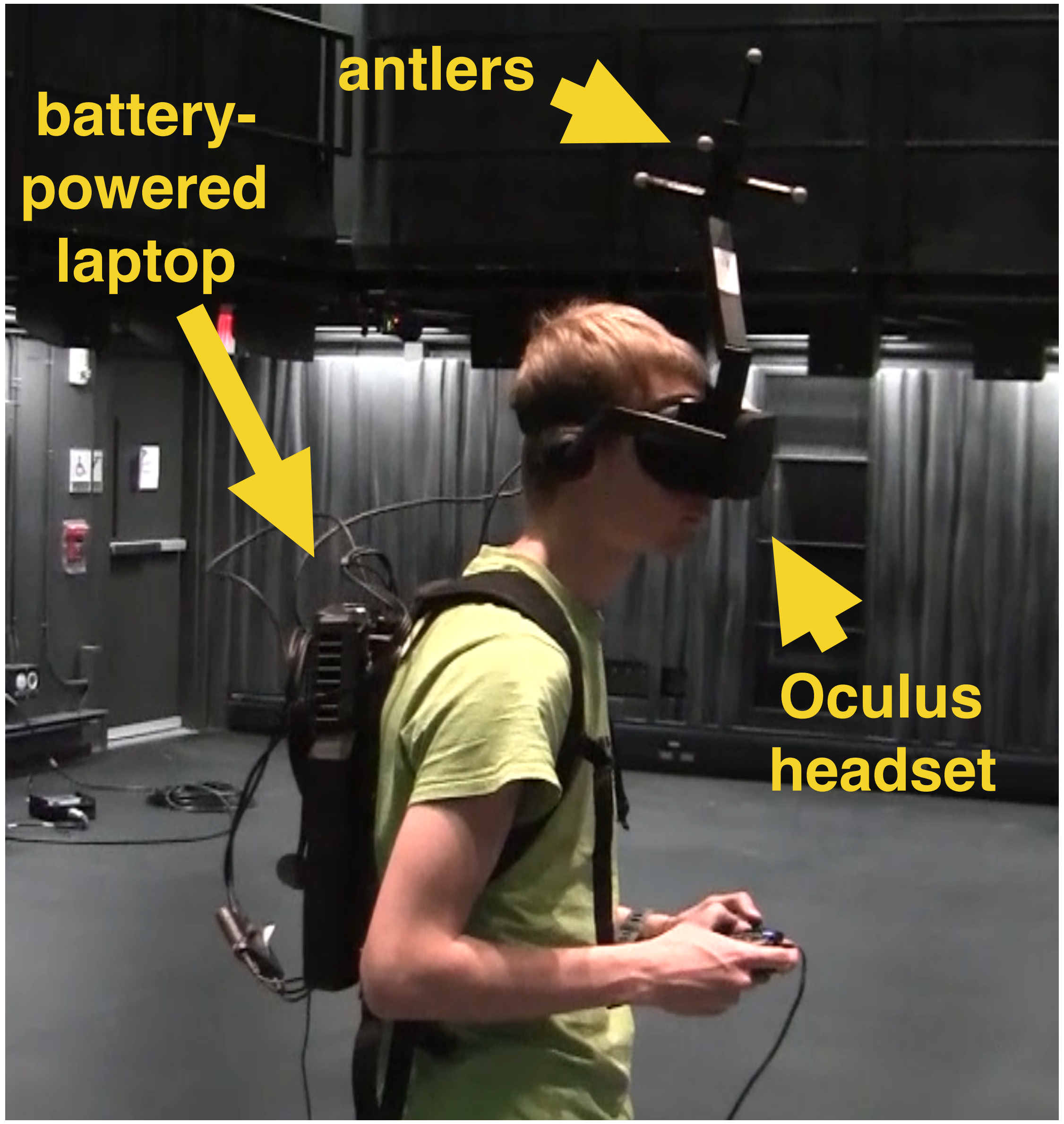
✓ In-game placement of the detector and beam line within the CUBE at Virginia Tech to accommodate N students *(also avoids vertigo experienced with a context-free detector)*

✓ Untethered locomotion with backpack laptop + headset

✓ User-specific antlers provide 3D position and orientation via CUBE's motion-capture system

✓ Students see each others' avatars in-game

✓ Can be projected onto a huge cylindrical screen ("Cyclorama") in the CUBE for large audiences



https://youtu.be/LxIW6Zv9uTM

https://www.elumenati.com/projects/virginia-tech-cyclorama/

Belle2VR operation: standalone

✓ In-game placement of the detector and beam line is still 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)*

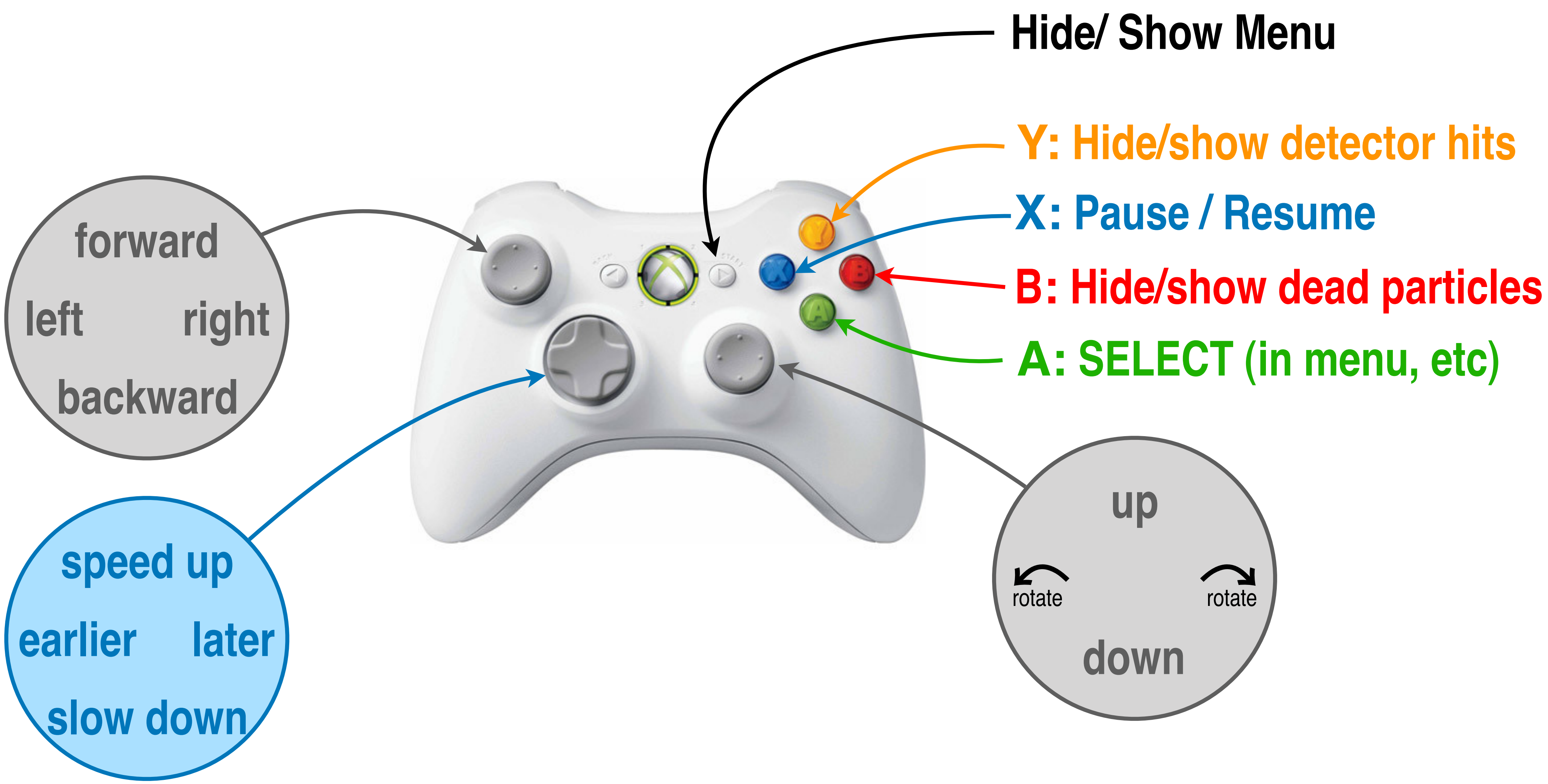
✓ Run WebGL app in web browser

✓ Control the animation via
- tethered or Bluetooth gamepad
- Oculus Touch hand controllers
- HTC Vive hand controllers
- keyboard/mouse

VR world features (1)

- ✓ Your gaze is always indicated by a green dot in front of you.
- ✓ You interact with the in-world features with this gaze dot and your preferred hand controls.

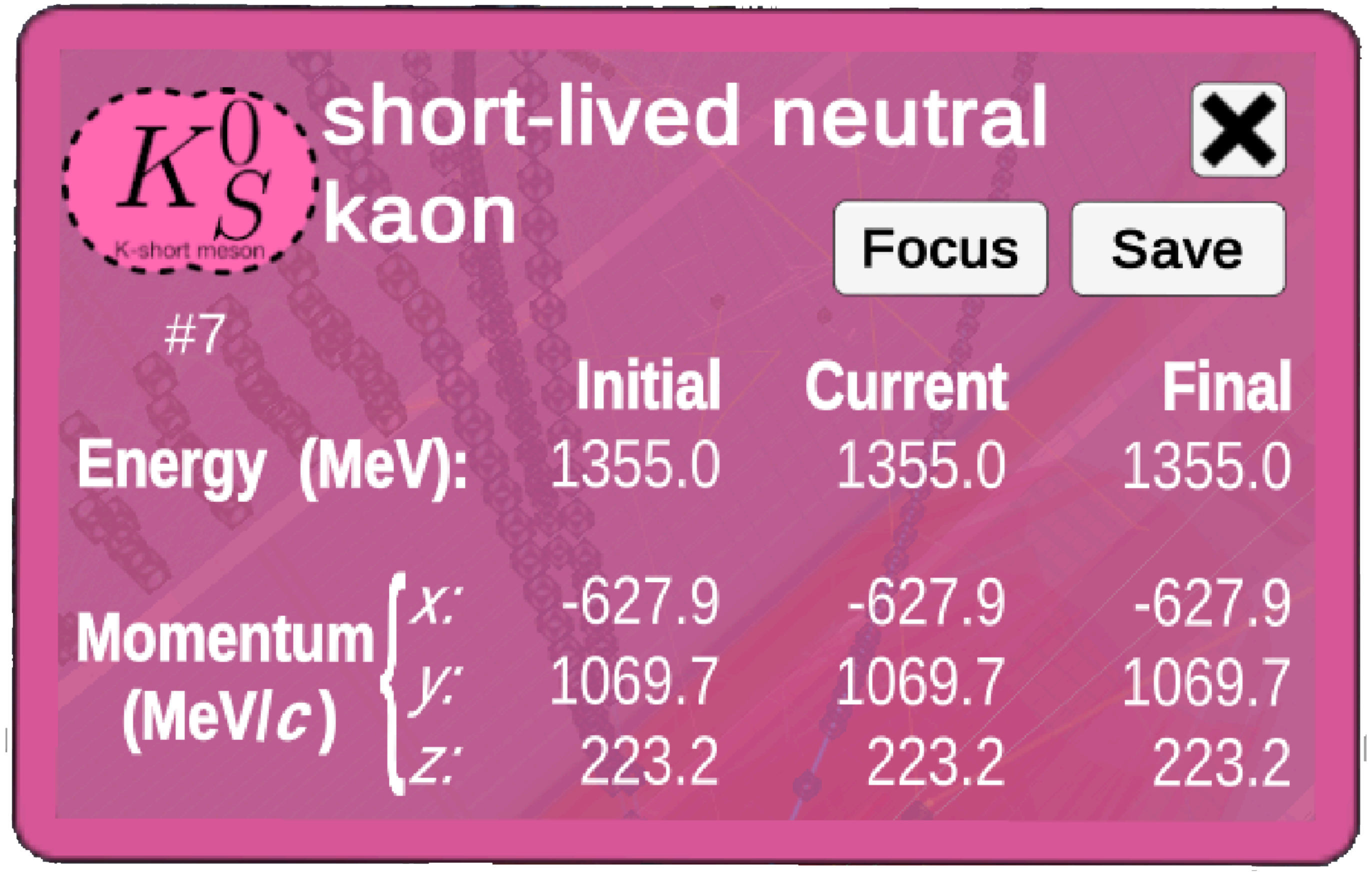
For a gamepad:



(some controls are omitted here)

VR world features (2)

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



short-lived neutral kaon

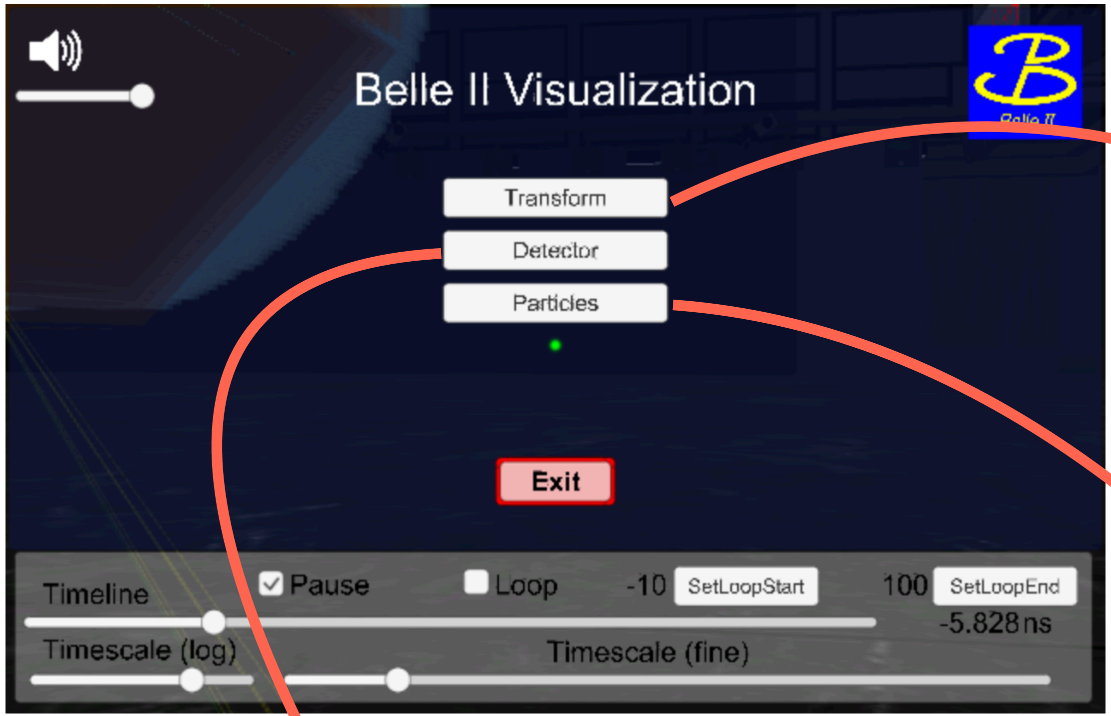
#7

		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. *(If you then open another such panel, you can "Unfocus" this chain.)*
- ✓ If you gaze at **Save** and **SELECT**, this particle's information is saved to 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 (3)

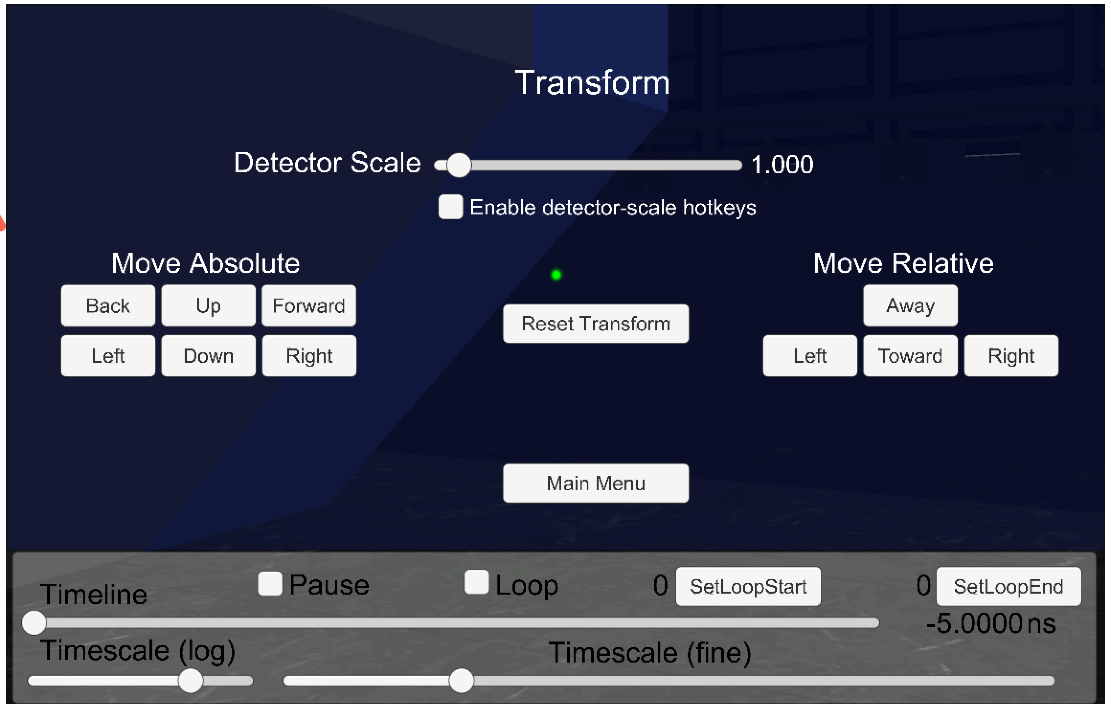
- ✓ Show the **in-game menu** by pressing the **Start button**.
- ✓ Move your gaze to place the green dot on a menu item then press **SELECT**.



Timeline ☑ Pause □ Loop -10 100 -5.828ns

Timescale (log) Timescale (fine)

Main menu



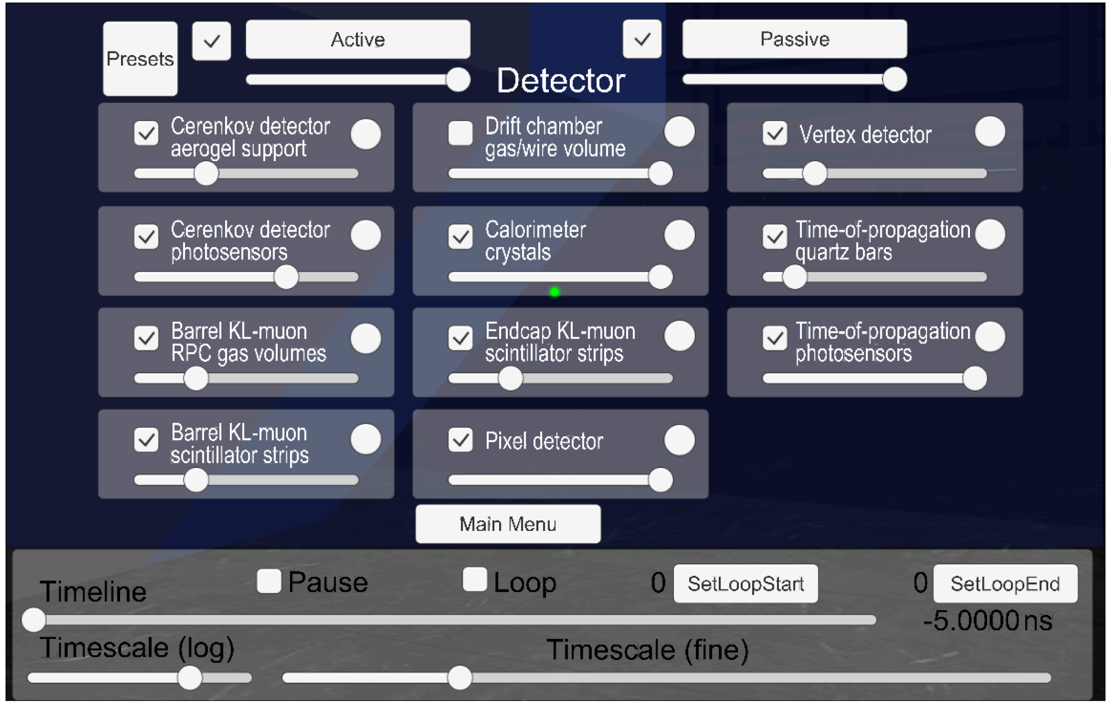
Detector Scale 1.000

□ Enable detector-scale hotkeys

Timeline □ Pause □ Loop 0 0 -5.0000ns

Timescale (log) Timescale (fine)

Transformation menu



☑ Active ☑ Passive

☑ Cerenkov detector aerogel support

□ Drift chamber gas/wire volume

☑ Vertex detector

☑ Cerenkov detector photosensors

☑ Calorimeter crystals

☑ Time-of-propagation quartz bars

☑ Barrel KL-muon RPC gas volumes

☑ Endcap KL-muon scintillator strips

☑ Time-of-propagation photosensors

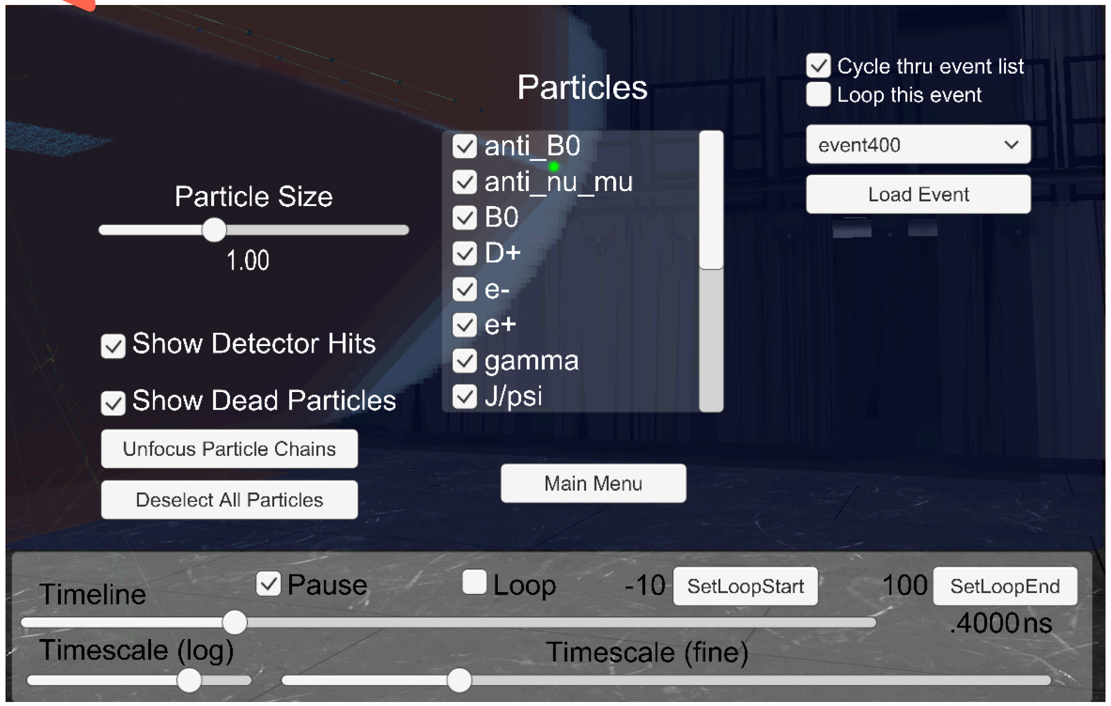
☑ Barrel KL-muon scintillator strips

☑ Pixel detector

Timeline □ Pause □ Loop 0 0 -5.0000ns

Timescale (log) Timescale (fine)

Detector hide/show menu



Particle Size 1.00

☑ Show Detector Hits

☑ Show Dead Particles

☑ anti_B0

☑ anti_nu_mu

☑ B0

☑ D+

☑ e-

☑ e+

☑ gamma

☑ J/psi

☑ Cycle thru event list

□ Loop this event

event400

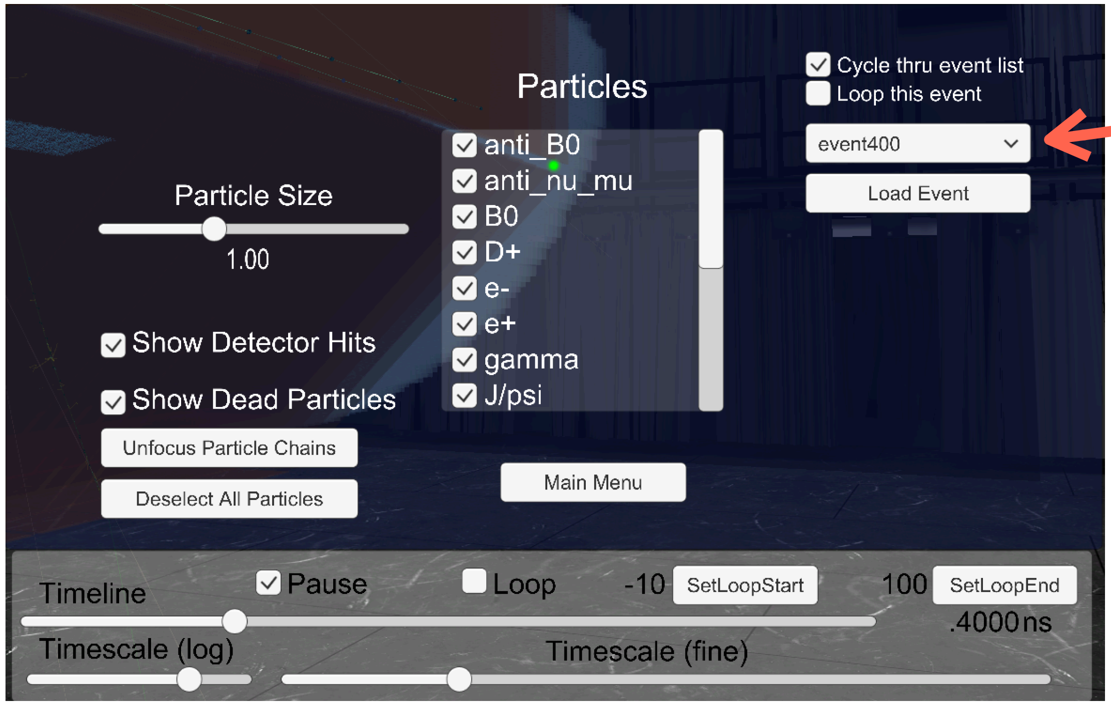
Timeline ☑ Pause □ Loop -10 100 .4000ns

Timescale (log) Timescale (fine)

Particles and events menu

VR world features (4)

- ✓ In the **Particles** menu, select one of the events to animate.
- ✓ With your gaze, scroll to highlight the desired event then **SELECT**.



Particles

☑ anti_B0
☑ anti_nu_mu
☑ B0
☑ D+
☑ e-
☑ e+
☑ gamma
☑ J/psi

☑ Cycle thru event list
☐ Loop this event

event400

Load Event

Particle Size 1.00

☑ Show Detector Hits

☑ Show Dead Particles

Unfocus Particle Chains

Deselect All Particles

Main Menu

Timeline ☑ Pause ☐ Loop -10 SetLoopStart 100 SetLoopEnd

.4000ns

Timescale (log)

Timescale (fine)

- ✓ **Or wait:** the animation automatically skips to the next event

Event legend:

100-109: $e^+ e^- \to \mu^+ \mu^-$

110-119: $e^+ e^- \to \pi^+ \pi^-$

120-129: $e^+ e^- \to e^+ e^-$

130-139: $e^+ e^- \to \gamma\ \gamma$

140-149: $e^+ e^- \to K^+ K^-$

150-159: $e^+ e^- \to K_S K_L$

160-169: $e^+ e^- \to \Lambda\ \bar{\Lambda}$

170-179: $e^+ e^- \to p\ \bar{p}$

180-189: $e^+ e^- \to s\ \bar{s}$

190-199: $e^+ e^- \to c\ \bar{c}$

200-209: $e^+ e^- \to B^0 \bar{B}^0 \to (J/\psi\ K_S)(D^+ \mu^- \nu)$

210-219: $e^+ e^- \to B^+ B^- \to (\tau\ \nu)(D^0 \pi^-)$

second B is hidden $\left\{ \begin{array}{l} \text{220-229: } e^+ e^- \to B^0 \bar{B}^0 \to (J/\psi\ K_S)(D^+ \mu^- \nu) \\ \text{230-239: } e^+ e^- \to B^+ B^- \to (\tau\ \nu)(D^0 \pi^-) \end{array} \right.$

~35 institutions (plan to) use Belle II VR for public outreach

- KEK
- Jefferson Laboratory
- Niigata University
- Nagoya University
- National Taiwan University
- Fu Jen Catholic University
- Josef Stefan Institute
- University of Ljubljana
- Karlsruhe Institute of Technology
- Ludwig Maximilians University
- University of Strasbourg / IPHC
- Universidad Autonoma de Sinaloa
- University of Pisa / INFN
- University of Padua / INFN
- University of Roma 3 / INFN
- University of Frascati / INFN
- University of Trieste / INFN
- University of Perugia / INFN
- University of Hawaii
- University of Cincinnati
- Luther College
- …

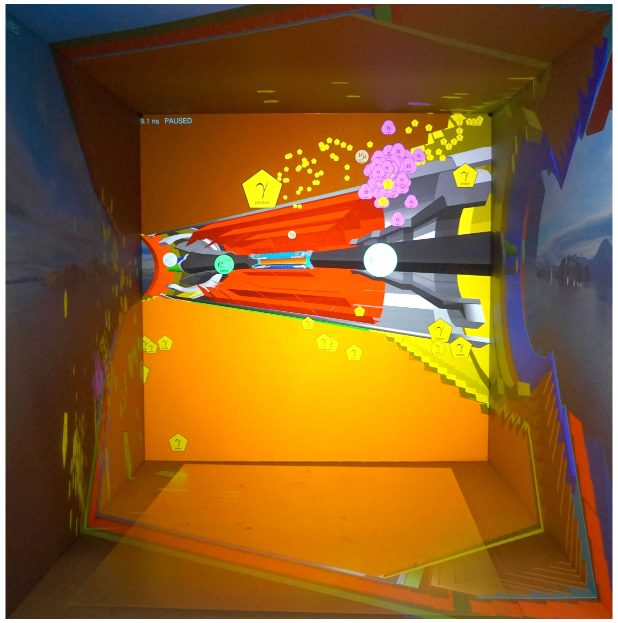
at KEK (June 2017)

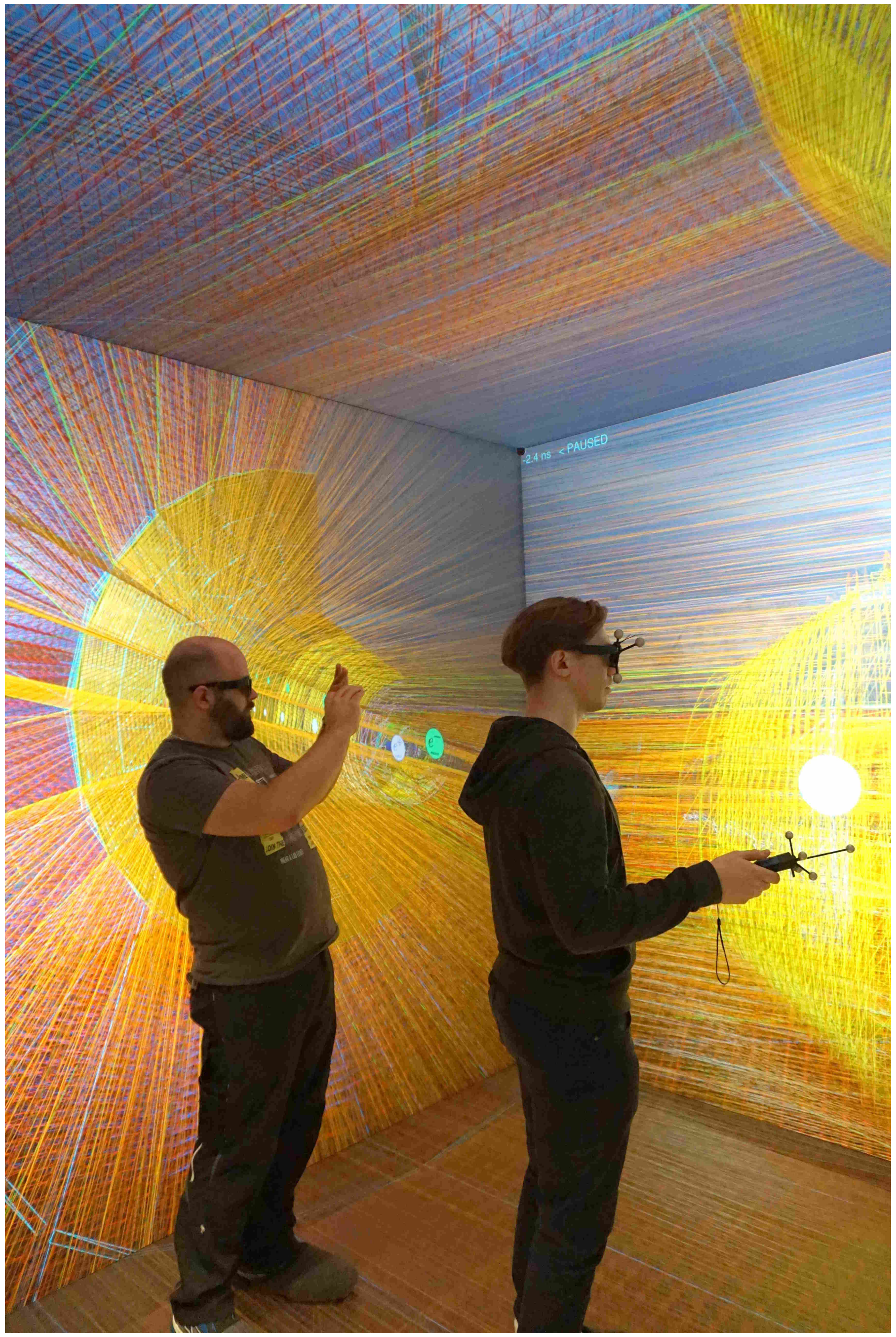
Belle II VR has been adapted for a CAVE environment

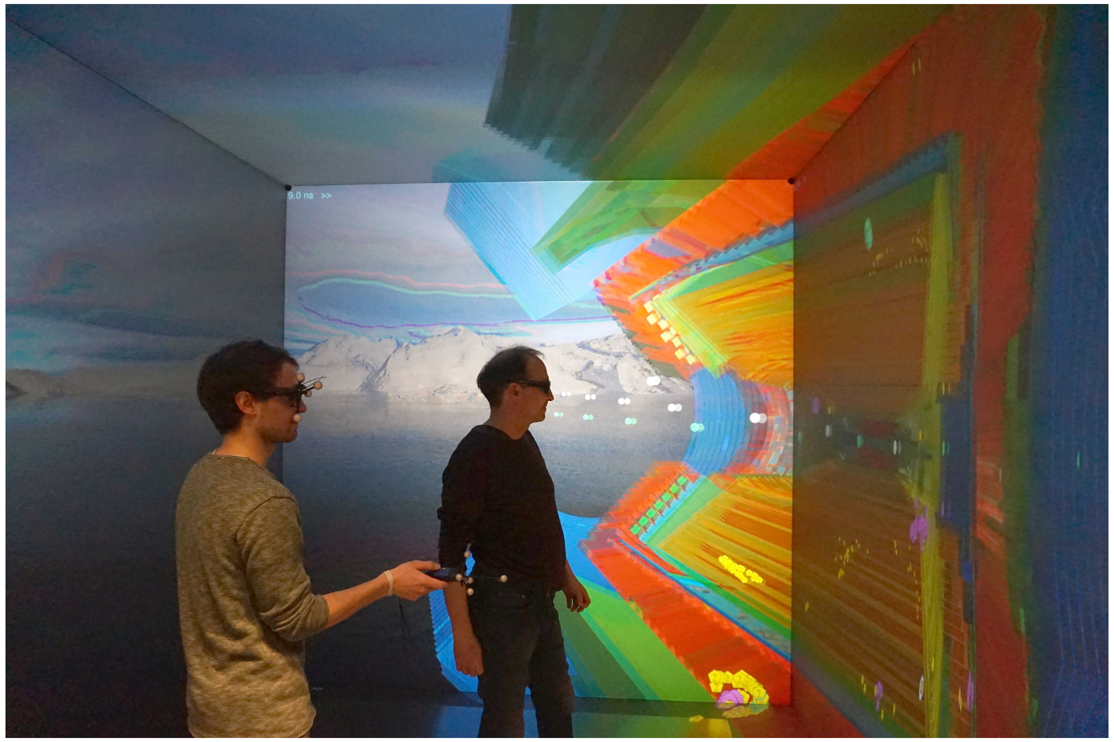
by a team at Ludwig Maximilians University

Belle II GRETCHEN (II)

GRETCHEN

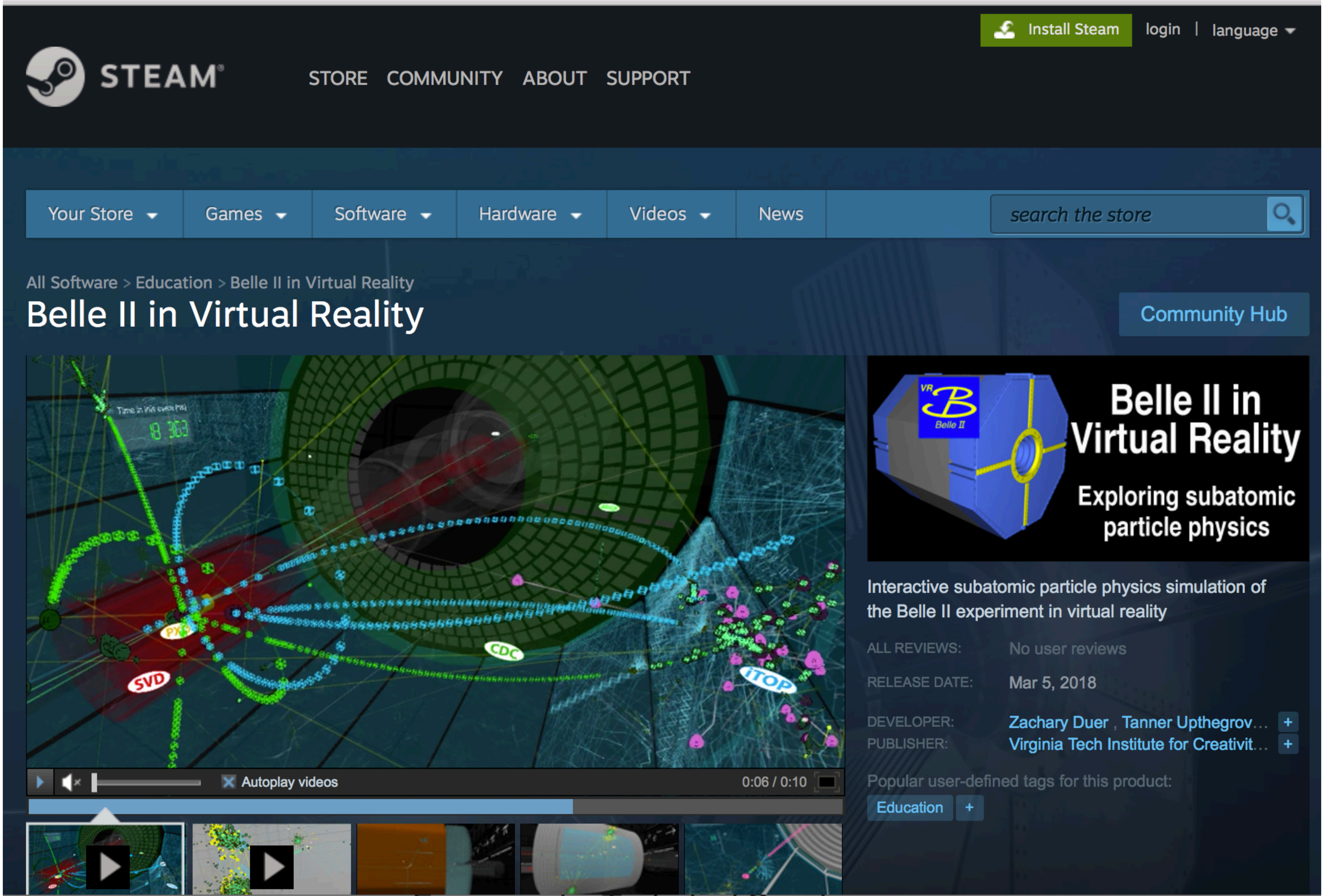






App is available for free on Steam

store.steampowered.com/app/810020/



All Software > Education > Belle II in Virtual Reality

Belle II in Virtual Reality

Belle II in Virtual Reality

Exploring subatomic particle physics

Interactive subatomic particle physics simulation of the Belle II experiment in virtual reality

ALL REVIEWS: No user reviews

RELEASE DATE: Mar 5, 2018

DEVELOPER: Zachary Duer , Tanner Upthegrov...

PUBLISHER: Virginia Tech Institute for Creativit...

Popular user-defined tags for this product:

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!

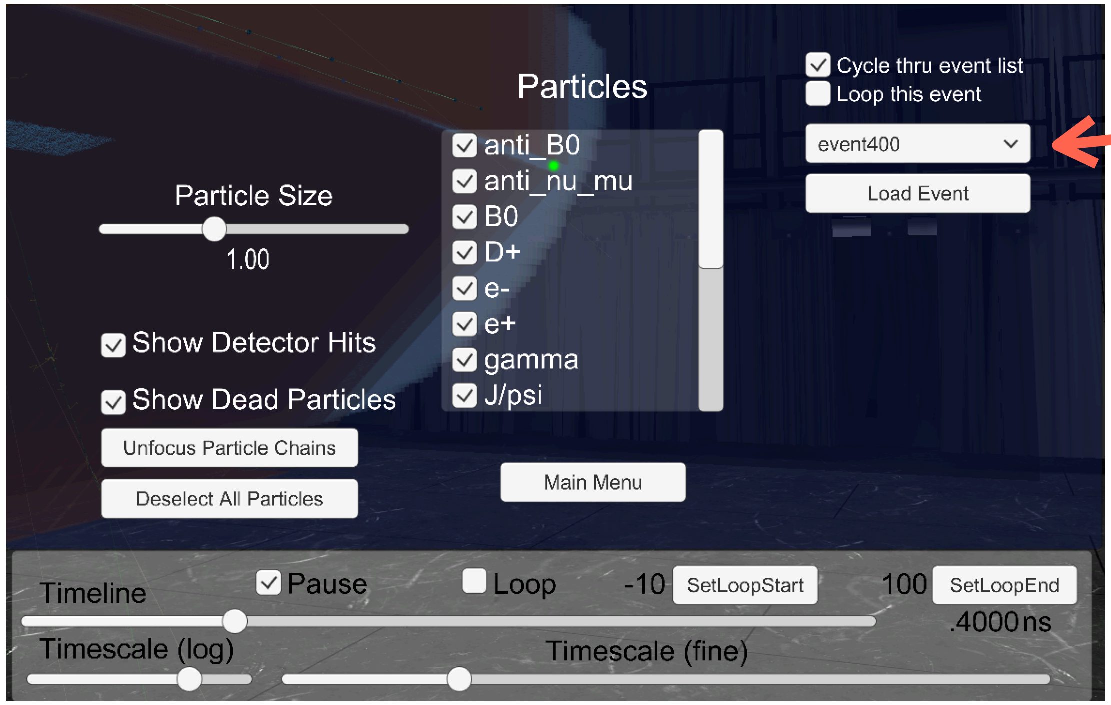
Backup

Development Process

- ✓ Development has been documented in two movies:
  - ◉ vimeo.com/220004044 *(narrated)*
  - ◉ vimeo.com/214899668 *(captioned, no sound)*
- ✓ Public displays of work-in-progress:
  - ◉ Virginia Science Festival (10/2016)
  - ◉ ICAT Day at Virginia Tech (5/2017)
  - ◉ Belle II General Meeting (6/2017)
- ✓ Presentations:
  - ◉ IEEE Visualization in Practice (10/2017) *including paper* www.visinpractice.rwth-aachen.de
  - ◉ Virginia Association of Science Teachers (11/2017) www.vast.org
  - ◉ HEP Software Foundation (3/2018) indico.cern.ch/event/658060/

VR world features (5)

✓ You can customize which events appear in the **Particles** menu.



Particles

☑ anti_B0
☑ anti_nu_mu
☑ B0
☑ D+
☑ e-
☑ e+
☑ gamma
☑ J/psi

☑ Cycle thru event list
☐ Loop this event

event400

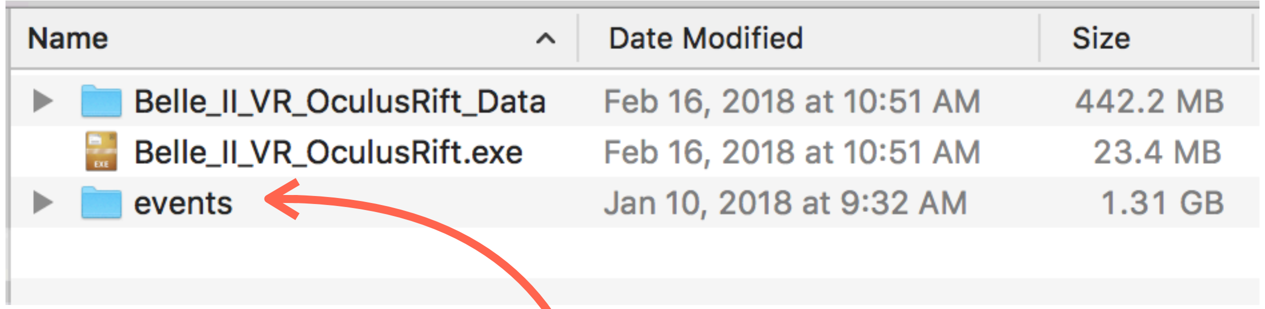
Particle Size: 1.00

☑ Show Detector Hits

☑ Show Dead Particles

☑ Pause ☐ Loop -10 SetLoopStart 100 SetLoopEnd

.4000ns



Name	Date Modified	Size
▶ Belle_II_VR_OculusRift_Data	Feb 16, 2018 at 10:51 AM	442.2 MB
Belle_II_VR_OculusRift.exe	Feb 16, 2018 at 10:51 AM	23.4 MB
▶ events	Jan 10, 2018 at 9:32 AM	1.31 GB

The simulated electron-positron collision events are stored in a folder named **events** at the same level as the app itself. You may modify the contents of this folder to suit your needs, according to the following rules.

The **events.lis** text file in the **events** folder specifies the sequence of event files that are fetched by the app. In your favorite text editor, you may comment out and/or reorder lines here to suit your preferences. Each event file is a plain text file that is exported from the basf2 GEANT4-based physics simulation of the Belle II detector.

If the **events** folder contains the text file **events.url** and this file specifies a valid web address (URL) then **events.lis** and the event csv files will be fetched from this web address instead of the **events** folder.

If the above event-fetching mechanisms fail (due to syntax or file-corruption errors), the app will revert to displaying one of five baked-in events, e.g., $e^+ e^- \to B^0 \bar{B}^0 \to (J/\psi\, K_S)(D^+ \mu^- \nu)$.