Mu2e Event Visualisation Development

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Overview

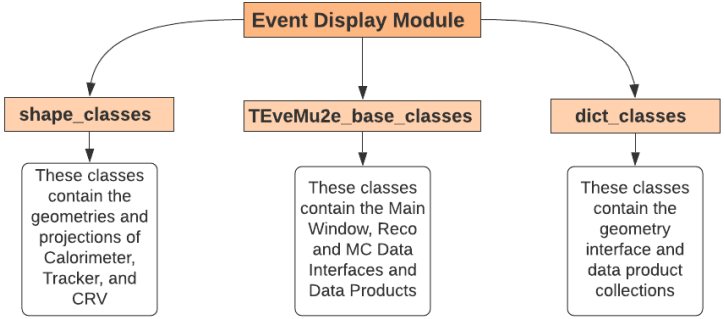
- Mu2e Offline
- TEve based Offline event display
- Features of the Mu2e event display
  - Upstream visualisation
  - User defined track selection and colour coded tracks
  - “Hit” Tracker Straws and CaloCluster display
  - CRV and cosmic muon tracks display
- Online event display development using Eve-7
- Conclusion

Mu2e Offline

- Offline is the core of Mu2e's software environment.
- It contains code used for GEANT4 based simulation of the entire Mu2e geometry as well as algorithms for reconstruction and analysis.
- Mu2e Offline uses C++ and is based on **ART(**https://art.fnal.gov/**)**, an Event Processing Framework. Under the covers, art uses the ROOT package to read and write the files.
- All Mu2e data and Monte Carlo output are stored in ".art" files.
- All reconstructed objects (e.g. straw hits, calorimeter clusters, particle tracks) are stored in the event as art data products.
- These objects are accessed and created in C++ modules. For instance, the **TEveMu2e Event Display** runs from a single analyser module.

Event Display using TEve

- Event displays are the top layer of any robust framework. It helps to visualise the physics in each event.
- Crucial for monitoring and debugging during live data taking.
- Great tool for public outreach.
- Useful for offline analysis.
- A custom display for Mu2e has been developed using **TEve**, a ROOT based 3-D event visualisation framework.
- A **custom GUI** was developed specifically for the Mu2e experiment.
- A GDML file containing the Mu2e geometry can be created in Mu2e Offline and directly imported to TEve for 3D visualisation.
- The user can add/remove specific geometries using the node names.
- Maintains access to the raw art file making it convenient to go between the raw and reconstructed data within the TEve browser.
- Being ROOT based, TEve fits in seamlessly with the Mu2e environment with access to all the Mu2e objects.
- It can run directly on the Mu2e output .art files.
- Easy to use event display with in-built zoom, rotation, perspective change, event navigation and 2-D projection functionalities.



TEveMu2e Namespace

The base classes provide the interface between TEve and the Mu2e Objects

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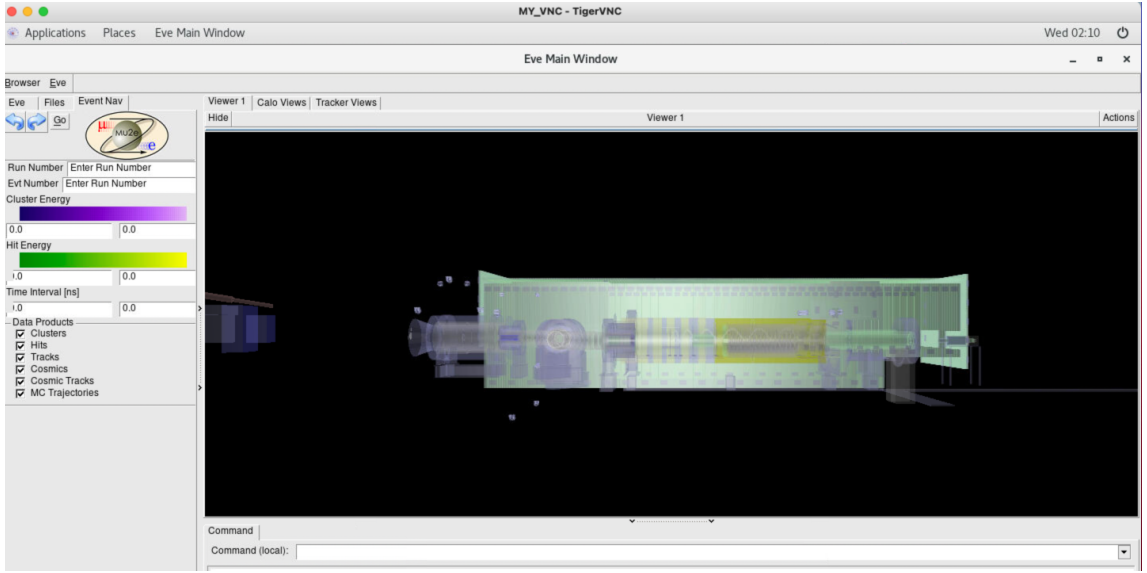
Offline Event Display Main Window

Event Navigation

Event selection by entry

Energy/Time based selection window

Data product visibility selection



Offline Display Main Window

In the left column, there are buttons for event navigation, time interval selection and the option to select the data products that one wishes to display.

The user can also open the ROOT browser to peruse the finer details of the events.

The Calorimeter and Tracker view tabs on the top bar contain the 2-D projections

CRV 2-D projection view tabs appear when the user selects the “ShowCRV” option

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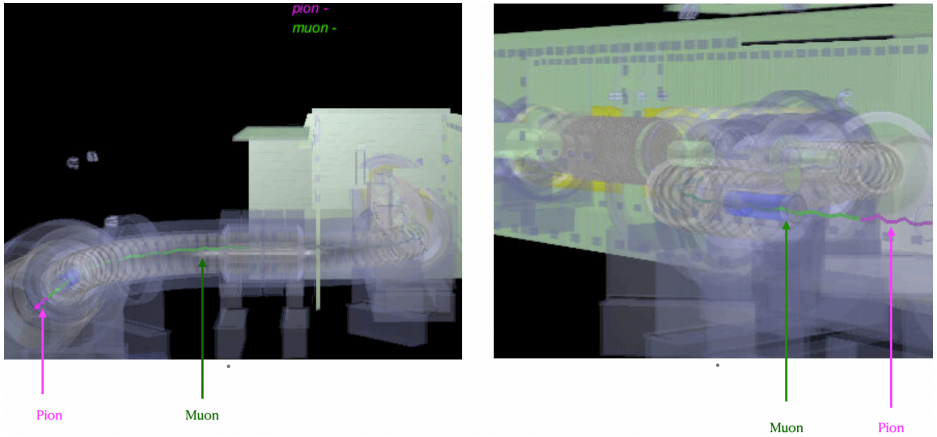
Upstream visualisation

- Production and Transport solenoids have been added to the display enabling a complete illustration of the Mu2e world.
- It helps the user to follow the MC true trajectory of muons from the production region to the muon stopping target, where the conversion may take place or view the pion to muon decay in the TS region.
- A track selection feature was added into the GUI of the event display for the user.
- The tracks are colour coded and labeled according to their ID and sign allowing to distinguish the multiple tracks possibly present in an event.

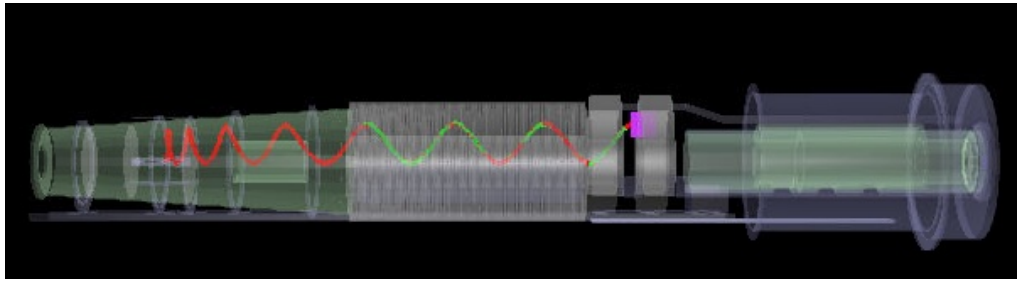


Pion to muon decay

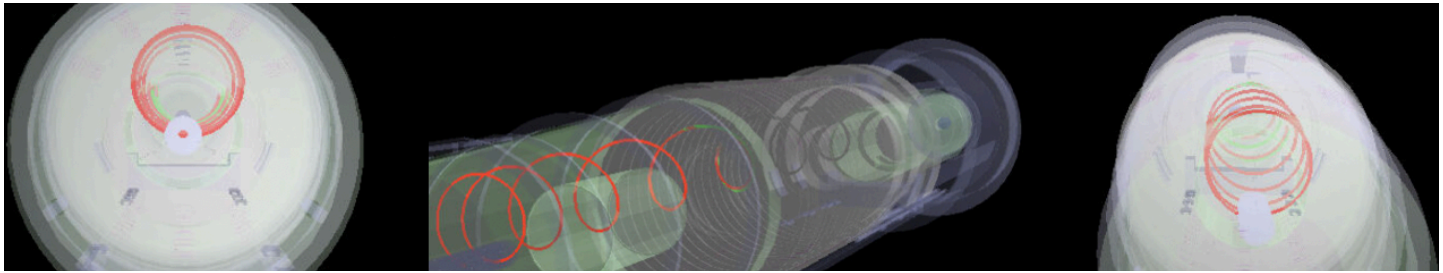
Event X

Detector Solenoid display

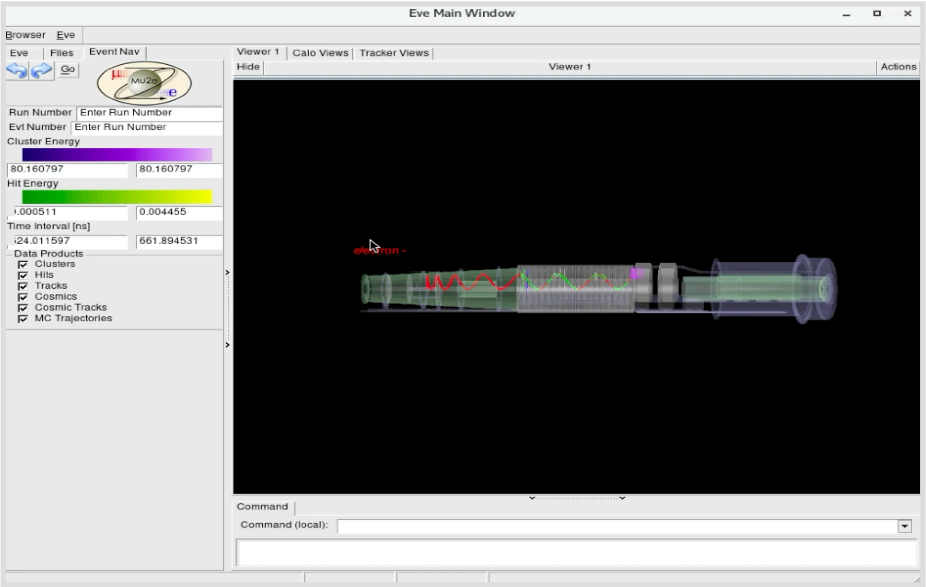
- The truth and reconstructed tracks are displayed together in the Detector Solenoid, providing visualisation of the track resolution.
- The reconstructed helix is formed using the segment by segment information provided by the “KalSegment” module which provides the Kalman filtered co-ordinate information.



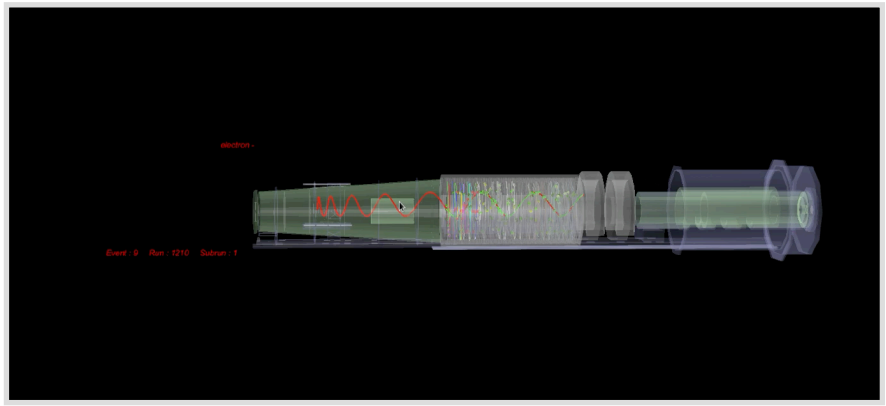
Conversion electron 3-D Event Display,
Red : MC truth track, Green : Reconstructed track



MC truth and reconstructed track display in the Detector Solenoid



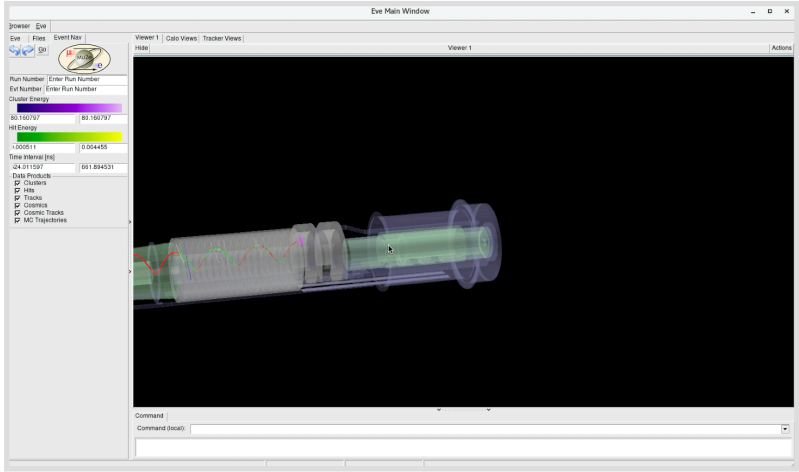
An event with a single conversion electron track

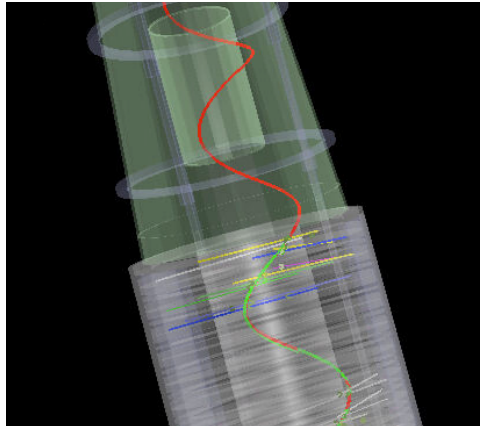


Event with signal and background particles

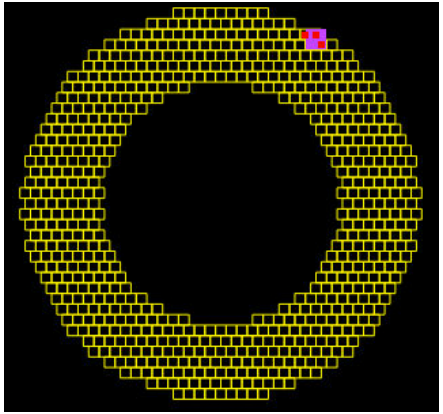
Straw and CaloCrystal “hit” highlights

- The “hit” straws and calorimeter crystals are highlighted along with a label which can be visualised when the pointer is placed on the straw.
- The label contains the straw, panel and plane information.
- The user can opt to view the particular hits used by the reconstruction algorithm to form the conversion electron track. The hits used in the reconstruction are displayed in green and the background hits in red.





3-D view of the helix and “hit” straws



Calorimeter disk with the crystal hits

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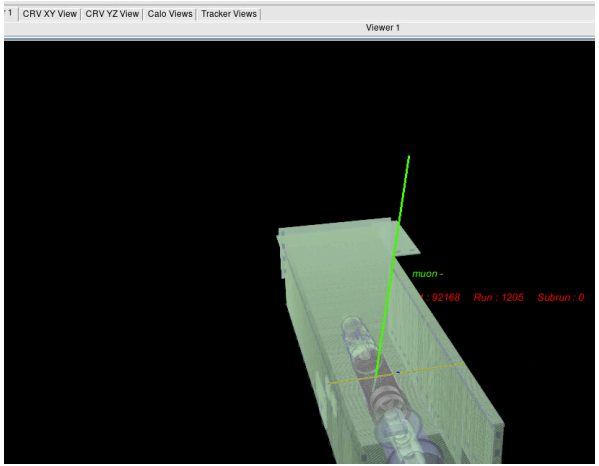
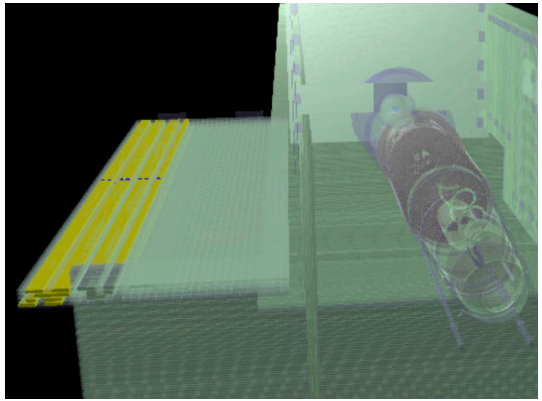
Cosmics display

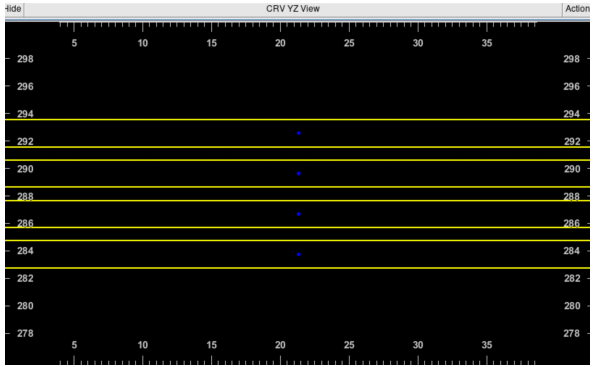
- The GUI “ShowCRV” option lets the user view the CRV geometry and the cosmic muon tracks.
- The 2-D projections are activated as well to view the “hit” CRV scintillation bars closely.



Cosmic muon track



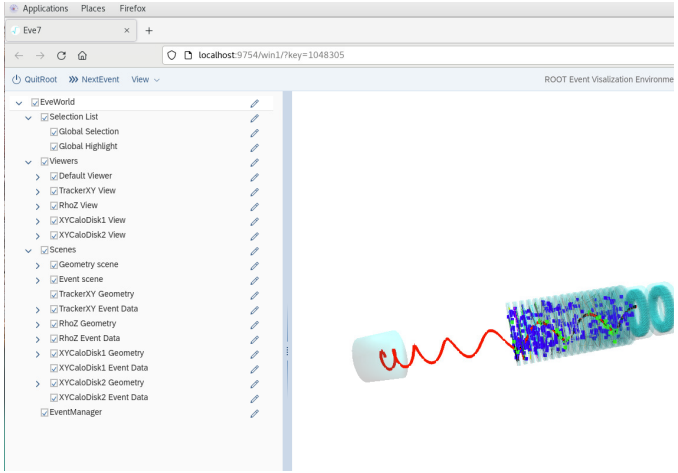
3-D view of the hit scintillation bars



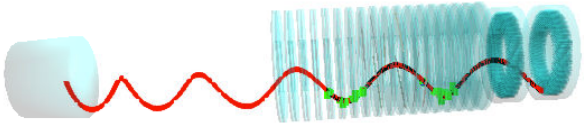
2-D YZ view

Online Event Display

- The offline display is a prototype and an online event display, is currently under-development using Eve-7 which allows remote access for live data taking.
- Eve-7 is part of the ROOT7 upgrade. It has direct counterparts of most TEve objects making the translation from the present display to Eve-7 easy.
- It also alleviates the problem of the ageing ROOT GUI infrastructure as Web-based technologies are platform independent.
- Eve-7 allows users to remotely access the display from anywhere (provided FNAL VPN).
- Multiple users can simultaneously view and interact with display.
- Many of the Offline features have already been adapted to the online display.



Online display of an event containing the conversion electron and other background hits



Conversion electron event

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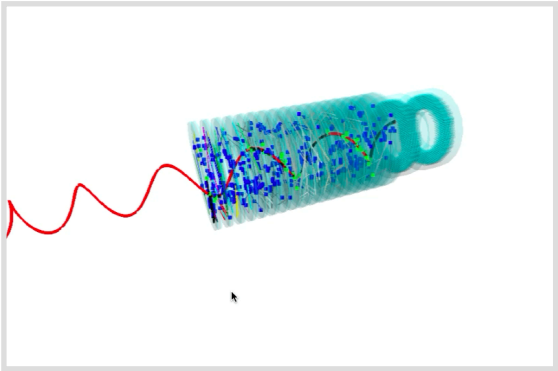
Online Event Display

- All the solenoids can be displayed. The user can selectively view the CRV, PS, TS or the DS.
- The hits, the “hit” straws and the calorimeter clusters can be displayed in both the 3-D and 2-D views. The user can opt to view them if and when they need.

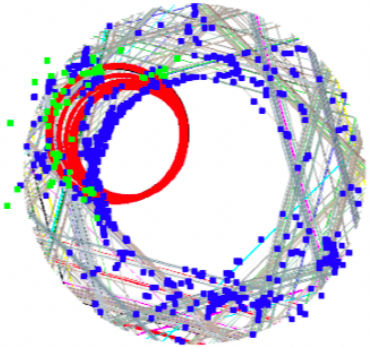


A signal+background event

The possible conversion electron hits are displayed in green

All the solenoids can be displayed

Conversion electron track shown in red emerging from the Stopping target



2-D XY projection of the hits and the conversion electron track

The possible conversion electron hits are displayed in green

Conclusion

- The offline and online event displays can be used to visualise the complete Mu2e world. All the three solenoids can be displayed and the MC truth trajectory is visible in all of them.
- The particle tracks can be selectively visualised and studied.
- Further details of the trajectories like the hits used in the reconstruction, the “hit” straws, the calorimeter clusters can be viewed through the display as well.
- The event display module is well integrated and compatible with the Mu2e software and computing systems. So, it can be run as any other art job and on any output art files directly.
- The displays have easy to use GUI features which makes it appealing and useful to a general user as well as for an expert.
- The online event display is still being developed and new features are added according to the needs of the different working groups of Mu2e.

References

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- EVE-7_and_FireworksWeb_The_next_generation_event_visualization_tools_for_ROOT_and_CMS
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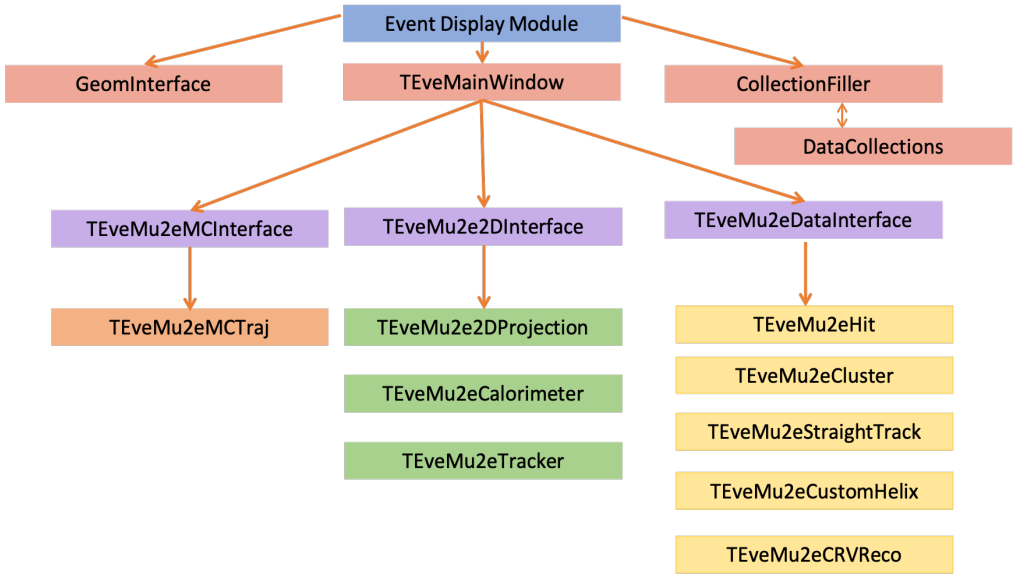
- https://mu2e-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=38597
- https://mu2e-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=42334

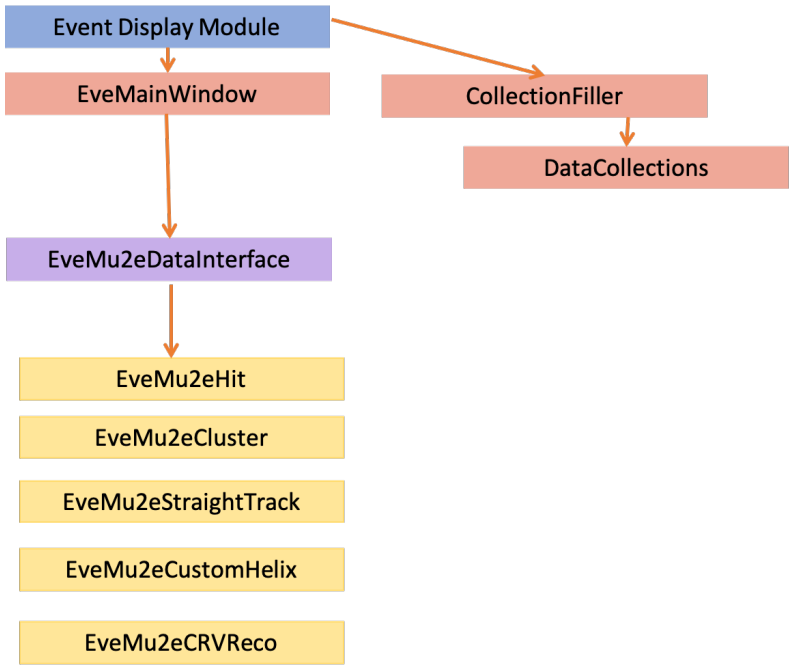
Back up Slides

Eve-7

- The EVE-7 architecture is using the server-client paradigm.
- Server is implemented in C++, as ROOT module EVE-7.
- Class REveManager is the entry point holding a list of top-level EVE directories or scenes, each holding a hierarchy of EVE objects.
- EVE objects support serialization into JSON format with additional binary data buffers for transport of low-level rendering data.
- Object data is served through RWebWindow class and ROOT's built-in CivetWeb web server.
- The client side is implemented in JavaScript. JSRoot is used for interfacing to basic ROOT system. OpenUI5 the standard Web-GUI for ROOT, is used for GUI components.
- Client commands sent to the server as C++ method.
- The final form of the method call is constructed on the server and gets executed via Cling.
- Graphical views, table view configuration, selection, etc. are all implemented as EVE objects.
- This allows the same server-client protocol to be used for administrative operations as for the graphics and UI operations.
- As an example from the CMS implementation the payload sent to a client for an event with 1,000 tracks (3D + 2 projected views) is O(1 MB) spread over 6 messages.

TEve v/s Eve-7





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