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Event Display Development for Mu2e using Eve-7

N Chithirasreemadam[1], S Middleton[2] and S Donati[1]

[1] Università di Pisa, Pisa, Italy
[2] California Institute of Technology, Pasadena, California 91125, USA

E-mail: `n.chithirasreemad@studenti.unipi.it`

Abstract. The Mu2e experiment at Fermilab will search for the Charged Lepton Flavor Violating coherent, neutrinoless $\mu^- N \to e^- N$ conversion in the field of an aluminum nucleus. A custom online event display has been developed for Mu2e using Eve-7, a ROOT based 3-D event visualization framework, which allows remote access for live data taking and lets multiple users to simultaneously view and interact with the display.

1. Introduction

The Mu2e experiment will search for the Charged Lepton Flavour Violating process of coherent, neutrinoless $\mu^- N \to e^- N$ conversion in the field of an aluminum nucleus, by measuring the ratio $R_{\mu e}$:

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z) \to e^- + N(A,Z))}{\Gamma(\mu^- + N(A,Z) \to \nu_\mu + N(A,Z-1))} \quad (1)$$

For an Al Stopping Target (ST), the expected signal is a monochromatic ∼104.97 MeV/c electron [1]. A schematic view of the experiment is given in Fig.1.

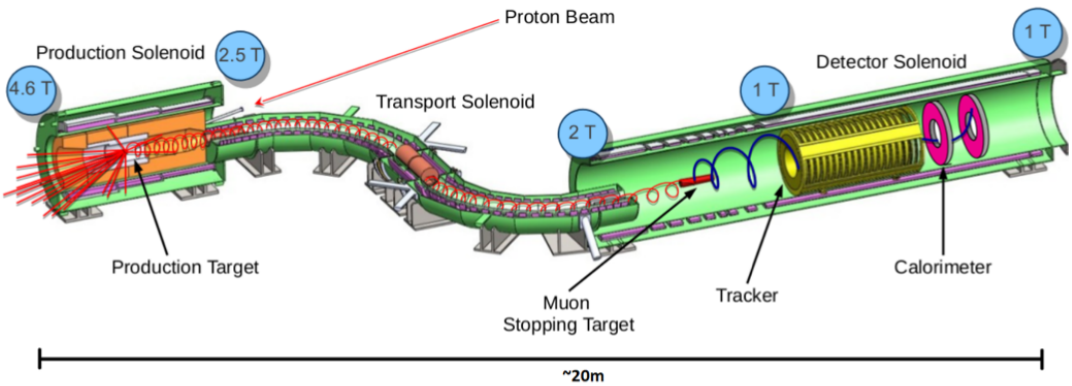


Figure 1: Schematic view of the Mu2e experiment [2].

Mu2e will use an 8 GeV pulsed proton beam which interacts with a tungsten production target in the Production Solenoid (PS), and produces pions which decay to muons. These particles drift towards the S-shaped Transport Solenoid (TS). The curved magnetic field of the TS causes the oppositely charged particles to drift vertically in opposite directions. A rotating collimator in the center of the TS will be used to select the μ^+/μ^- beam. The muons enter the Detector Solenoid (DS) and stop in the Al ST. The DS also contains the main detectors: a straw tracker and an electromagnetic calorimeter. The tracker consists of 18 stations with 1152 straws per station. The straws are filled with 80%:20% Ar:CO_2 mixture. The calorimeter consists of 2 disks covering radii 37 cm - 66 cm. Each disk consists of 674 undoped CsI crystals. The main backgrounds to this search are cosmic muons interacting or decaying within the detector, decays in orbit of muons stopped in the ST, radiative capture of stopped pions and $\bar{p}$ annihilation in the ST. A cosmic ray veto (CRV) system built from scintillator counters surrounds the DS to identify cosmic rays entering the detector.

2. Motivation for developing the Mu2e event display

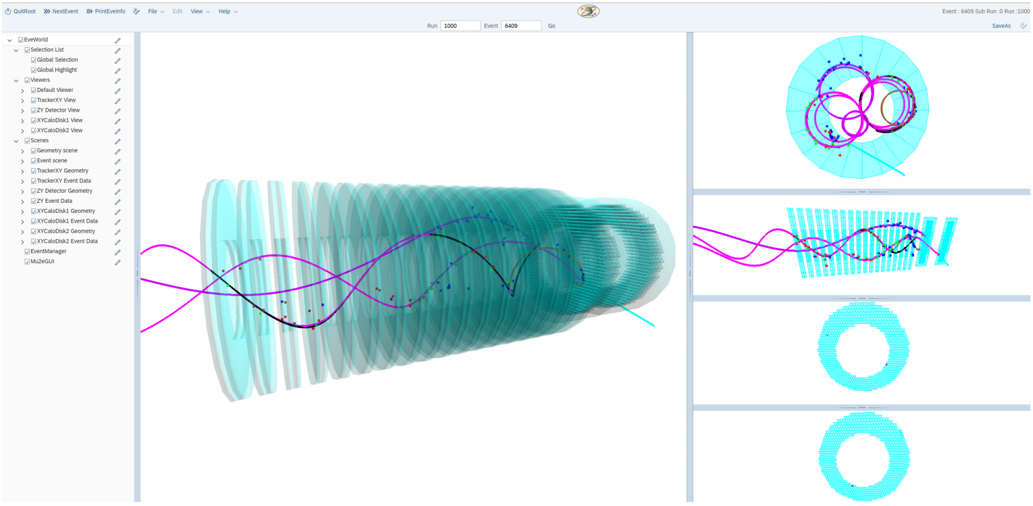
Event display is an invaluable tool during the development of simulation and reconstruction algorithms. It is necessary for detector calibration, physics analysis, online monitoring during data taking and for public outreach. For Mu2e, we first developed a custom Offline Display using TEve [3]. It is a high-level environment developed using ROOT's data-processing, GUI and OpenGL interfaces allowing visualization of the detector geometry, simulated and reconstructed data such as the hits in the tracker, the calorimeter clusters, the CRV scintillation bars, and the MC true and reconstructed particle trajectories. A custom GUI was developed specifically for the Mu2e experiment. The Mu2e geometry is imported directly from a GDML file, which can be modified easily in the case of altered or updated geometries without affecting the display module. TEve is well integrated with the Mu2e Offline framework [4], as they are both based on the ROOT framework. More information about the TEve based Mu2e display can be found at [5].

3. Online event display using Eve-7

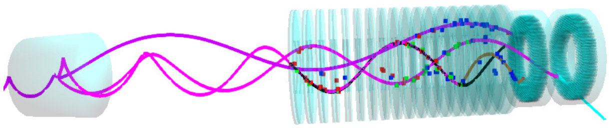
The online display is developed using Eve-7 [6], an update of EVE for the ROOT-7 era, using modern C++ and relying on ROOT's built-in http server for communication with GUI clients. Eve-7 has direct counterparts to most TEve objects making it a convenient translation from the offline to online environment. Eve-7 allows users to remotely access the display from anywhere, an essential feature required during live data taking. It also supports multiple client connections which enables to show different views in different browser tabs and can also be used for connections from different client machines, by different users. Visual feedback for marking selected and highlighted objects are synchronized across all clients. Since Eve-7 is also ROOT based, it can be easily ported into the art framework [7] and the OTSDAQ [9] system which is used for data acquisition in Mu2e. Eve-7 fits perfectly with the Mu2e environment with access to all the Mu2e objects and it can run directly on the art output files. Reconstructed data like the tracks, hits and clusters can be displayed within the detector geometries upon GUI request.

4. Features of the Mu2e Online Display

Some of the key features of the Mu2e online display are described in this section. Fig.2.(a) shows the main window of the online event display. The 3-D view of the detector elements is displayed in the center of the screen and it comes with in-built zoom, rotation and perspective change features. The 2-D projections of the tracker and the calorimeter disks are given on the right panel of the window and the buttons to select specific 2-D views of the detector elements and geometries are provided on the left panel.



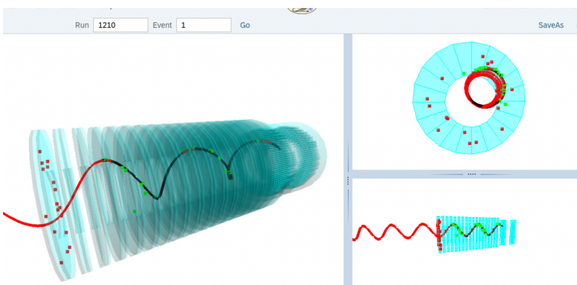
(a) Main window of the online event display



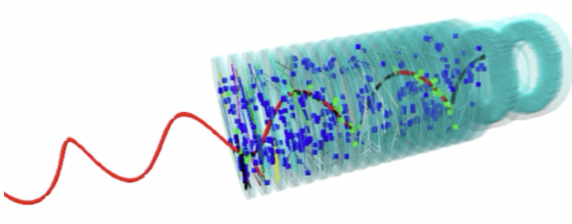
(b) Zoomed-in view of the DS

Figure 2: This example display is a simulated event of $p\overline{p}$ annihilation occurring at the ST, generating pions (shown in magenta). The reconstructed track (shown in black) and the hits made by the particles in the tracker are displayed as well. The right panel shows the XY, YZ views of the tracker and the calorimeter disks.

The top bar contains some of the essential GUI attributes like buttons to navigate between events, to access different projection views in separate browser tabs, to save an event and to print relevant physics information about the event and a text-entry based feature to navigate to any event. These features can be customized and developed according to the needs of the users. For instance, the “PrintEventInfo” button was customized to print physics analysis relevant information like the track and helix parameters, hit coordinates etc.



(a) CE event without pile-up



(b) CE event with pile-up

Figure 3: 3-D, 2-D XY and YZ views of a simulated CE event. The MC true and reconstructed trajectories are shown in red and black respectively. The hits used in the reconstruction of the track are highlighted in green.

This particular event displayed in Fig.2 is a simulated event of $p\overline{p}$ annihilation occurring at the

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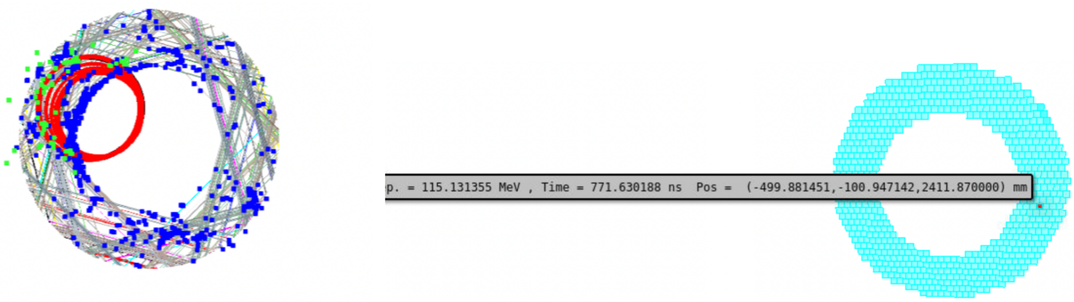
ST which results in downstream moving pions that make hits in the tracker and calorimeter. Fig.2.(b) shows a zoomed in, 3-D view of the same event, enabling a better visualization of the particle trajectories and tracker hits. In Fig.3.(a) and Fig.3.(b), 3-D and 2-D views of a simulated event containing a conversion electron (CE) signal is displayed. The event displayed in Fig.3.(b) is a CE event with pile-up, background hits. From Fig.2 and Fig.3, the following can be observed:

- The particles are color coded according to their particle ID. For instance, an electron is displayed in red and pion in magenta.
- There is a user defined track selection feature which lets the user selectively display the particle tracks of interest.
- The tracker straw hits used by the track reconstruction algorithms are highlighted in green while the unused hits are displayed in blue.
- The MC truth and reconstructed tracks (shown in black color) can be displayed together, allowing visualization of the track resolution.



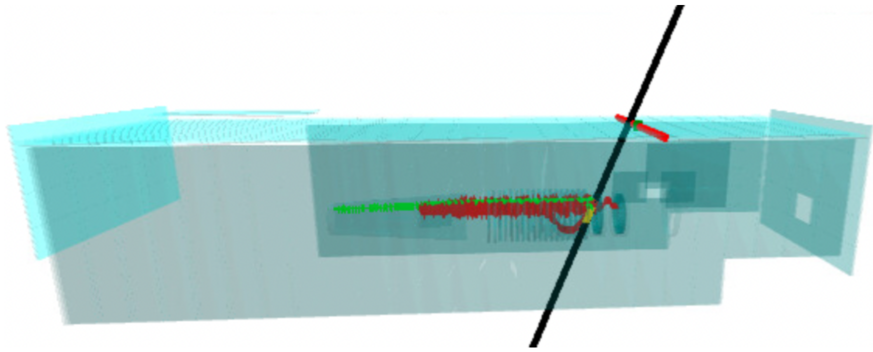
(a) 2-D XY view of the tracker (b) 2-D XY view of the calorimeter

Figure 4: 2-D views of the tracker and calorimeter. The CE trajectory is shown in red. The "hit" tracker straws and calorimeter crystals are highlighted. Further information about the hit can be obtained on tool-tip as shown in Fig.(b).

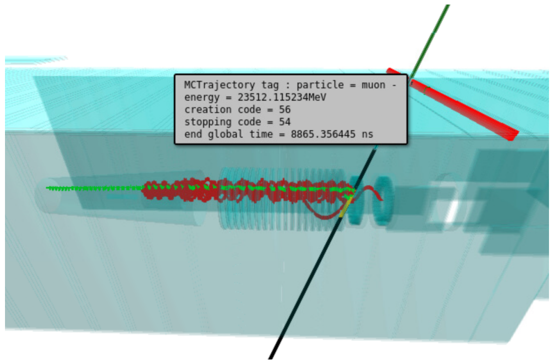
Given in Fig.4.(a) and Fig.4.(b) are the 2-D XY projections of the tracker and the calorimeter. The "hit" tracker straws can be highlighted in both the 3-D and 2-D views. Relevant information about the hit like the straw, panel and station numbers and details like the hit coordinates, time and energy deposited in the calorimeter crystals can be obtained on tool-tip. The PS and TS have also been added to the display enabling a complete illustration of the Mu2e world. GUI options like "ShowCRV", "ShowPS", "ShowTS" were added to let the user selectively view the CRV, PS or TS geometries respectively. Given in Fig.5 is the display of an event where a cosmic muon enters the DS from the top, hits the CRV scintillation bars (shown in red), interacts with the calorimeter crystals and generates electrons (shown in red) and positrons(shown in green). These particles follow a helical trajectory in the DS, due to it's magnetic bottle structure. Fig.5.(a) shows the complete view of the CRV and DS. Fig.5.(b) is a zoomed in view with a dialog box that appears on tool-tip, giving more details of the cosmic muon trajectory.

5. Conclusion

We have developed an event display that is compatible and well-integrated with the Mu2e computing environment. It provides a complete illustration of the Mu2e experiment. We developed a custom GUI for the experiment. It is a useful tool in debugging the reconstruction algorithms and simulation issues. We are also in communication with the Eve-7 developers



(a) 3-D view of the CRV



(b) Zoomed-in view of the event

Figure 5: Display of a cosmic muon event. In this event, a muon (shown in black) hits the CRV (scintillation bars are highlighted in red), enters the DS, interacts with the calorimeter and generates electrons (shown in red) and positrons (shown in green).

and the plan for the future is to incorporate new features as they are rolled out in the ROOT source code. Further customization and developments shall be made on the display based on the requirements of the Mu2e collaboration.

Acknowledgments

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