EVE-7 and FireworksWeb: The next generation event visualization tools for ROOT and CMS

Dmytro Kovalskyi (MIT), Sergey Linev (GSI), Alja Mrak-Tadel, Matevž Tadel & Avi Yagil (UCSD)
Overview

● Introduction:
  ○ TEve, Fireworks
  ○ Motivation for change

● EVE-7 & FireworksWeb
  ○ Project outline
  ○ Components
  ○ Status

● Future work & plans
  ○ Upcoming milestones
  ○ Development plans for 2020

See also: [1] New web-based ROOT GUI, Wed, 11 AM, Track 5
Introduction
Brief history of EVE and Fireworks

- EVE development started in 2005 for ALICE
    - Available as ROOT package graf3d/eve
  - ROOT OpenGL interface was co-developed to support advanced EVE features
- CMS chose EVE for physics-analysis event display in 2007
  - Prototype development 2008 / 09
  - Intense 5-developer effort in 2010 / 11
    - Full CMSSW support, geometry visualization, detailed views of all RECO objects
  - *Faithful representation of EDM objects - what you see is what analysis algorithms see, too!*
- Both EVE and Fireworks essentially in maintenance mode since 2011

Usage of EVE beyond ALICE and CMS:
- Belle2, HyperK, ILC, JUNO, NA-62, T2K
- Several smaller experiments in neutrino, nuclear, and medical physics
Motivation for EVE-7 & FireworksWeb

● **EVE is 15 years old, ROOT-GL even older**
  ■ Despite (or is it *Because of?*) all the progress, supporting native OpenGL still isn't easy.
  ■ OSX support is getting harder with every release.
  ■ SLC 6 / CentOS 7 ... our OSes are lagging years behind desktop versions.
  ■ People still run event display over ssh and this requires some deep tweaks lately.
    ○ This causes trouble for both EVE in general and for Fireworks.

● **OpenGL is getting replaced with Vulkan** over the next couple of years.
  ○ Implementing a low-level rendering engine was a good choice 20 years ago.
  ○ Modern rendering engines completely insulate application from the low-level graphics.

● **ROOT-7 is replacing native GUI & graphics with web browser front-end.**
  ○ EVE has to either grow along or die ...

*CMS has committed to support development of EVE-7 and FireworksWeb.*
EVE-7 and FireworksWeb
Project outline

- **Mission statement:** *Rewrite EVE and Fireworks for LHC Run 3 and beyond.*
  - Keep most of EVE functionality in place while modernizing the code
  - Move some functionality from Fireworks into new EVE-7:
    - Physics data: collections, items, item filtering, and table views - possible because of Cling and C++ lambdas
    - Geometry browser

- **Development Focus / Driver:** *FireworksWeb prototype!*
  - First production release before Run 3.
    - Support at least the physics-analysis / event-scanning use case.

- **Keep all advanced features, including:**
  - Simultaneous (multiple) selection across physics items in table and graphical views
  - Non-linear projections (RPhi and RhoZ views with fish-eye blowup of vertex region)
  - Window management -- group views into independent top-level windows
  - Visualization of digits
  - Calorimeter visualization including Fireworks lego view

- **Performance considerations**
  - Optimize network traffic, data representations and workload on server and client
Components

- **Server / core: C++**
  - REveManager is the entry point holding hierarchy of Scenes / Directories of EVE objects
  - EVE objects support *streaming into JSON + binary data* for rendering
    - Graphical view & table configuration, selection, etc. are all implemented as EVE objects
    - *Client commands are C++ calls* on EVE elements executed via Cling
  - Data served through RWebWindow and ROOT's built-in civetweb web server

- **Client side: JavaScript**
  - JSRoot: initialization, colors, some 3D primitives & attributes, integration of OpenUI5
    - In the future also tree browser, file dialogs and geometry viewer
  - OpenUI5, the standard Web-GUI for ROOT
  - Three.js: 3D rendering
Server-Client communication

● Existence of **C++ server** is crucial for the main goal of EVE-7 & Fireworks: To visualize **exactly the same data** as is seen by analysis / reconstruction algorithms.
  ○ Allow users to use C++ expressions that call functions on actual physics data objects to:
    ■ set up filter expressions on physics objects, and
    ■ display correct values in table views, even for non-trivial expressions specified at runtime.

● Communication is **bidirectional and stateful** → **WebSocket** protocol is used.

● Multiple client connections are supported:
  ○ This is required to be able to show different views in different browser tabs / windows.
    ■ Each client subscribes only to views that are being shown in its window.
    ■ Selection and highlight are synchronized across all clients.
  ○ Likewise, **multiple users** can connect to the same server and view the same event.

● Full object data is sent only when a new event is loaded.
  ○ Within an event, only objects that get changed as a result of user actions are streamed.
  ○ Payload for event with 1,000 tracks (3D + 2 projected views) is O(1MB) spread over 6 messages
Status as of Nov. 2019

● **Prototype & technology demo**
  ○ Testing of various aspects, including performance, server / client communication over WAN
  ○ Will require (quite) some cleanup / restructuring before production release

● **Supported / implemented features & screenshots**
  ○ **EVE-7:**
    ■ **Visual objects:** pointsets, linesets, tracks, ellipsoid, jets, all TGeoShapes (including CSG)
    ■ Support for physics collections and physics items
    ■ Handling of scene changes (user interaction) and destruction (going to another event)
    ■ Selection and highlight mechanism works across graphical views and different representations
    ■ **Screenshots:** Cross view highlight & selection (pg. 12), Collections (pg. 13), Tables (pg. 14)
  ○ **FireworksWeb:** uses all EVE-7 features and has most Fireworks concepts imported.
    ■ Plugin system for adding physics collections
    ■ Collection editors (color, visibility, and physics item filter)
    ■ Proxy builders for tracks, PF candidates, jets, MET, electrons, vertices, muons, and CSC segments
    ■ Event navigation through CMS EDM data file (but no event filtering yet)
    ■ Uses custom client GUI elements for event info and event control
    ■ **Screenshots:** Overview (pg. 15), Table with CMS reco::Track class (pg. 16)
Highlight and Selection across views
Physics collections: item filter & tables

iPt() > 4.1 & abs(Eta()) < 1
# Configurable OpenUI5 tables

![Example of a configurable OpenUI5 table](image-url)

- **Choose Collection:** Tracks
- **Edit table:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Filtered</th>
<th>q</th>
<th>pt</th>
<th>eta</th>
<th>phi</th>
<th>do</th>
<th>doErr</th>
<th>dz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track 0</td>
<td>*</td>
<td>1.0</td>
<td>2.616</td>
<td>0.05731</td>
<td>0.00593</td>
<td>-0.657</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track 1</td>
<td>*</td>
<td>1.0</td>
<td>-2.664</td>
<td>0.07129</td>
<td>0.00088</td>
<td>-0.695</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track 2</td>
<td>*</td>
<td>1.0</td>
<td>-1.205</td>
<td>0.06823</td>
<td>0.00781</td>
<td>-0.778</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track 3</td>
<td>*</td>
<td>-1.0</td>
<td>1.2</td>
<td>-1.205</td>
<td>0.06608</td>
<td>0.00735</td>
<td>-0.727</td>
<td></td>
</tr>
<tr>
<td>Track 4</td>
<td>--</td>
<td>-1.0</td>
<td>0.5</td>
<td>0.04872</td>
<td>0.01630</td>
<td>-0.618</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track 5</td>
<td>--</td>
<td>1.0</td>
<td>0.7</td>
<td>0.01195</td>
<td>0.01401</td>
<td>-0.853</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track 6</td>
<td>--</td>
<td>-1.0</td>
<td>0.7</td>
<td>-1.131</td>
<td>-0.02037</td>
<td>0.01097</td>
<td>-0.581</td>
<td></td>
</tr>
<tr>
<td>Track 7</td>
<td>--</td>
<td>-1.0</td>
<td>0.8</td>
<td>1.889</td>
<td>-0.05045</td>
<td>0.01194</td>
<td>-0.534</td>
<td></td>
</tr>
<tr>
<td>Track 8</td>
<td>*</td>
<td>-1.0</td>
<td>1772.6</td>
<td>-0.527</td>
<td>-0.07208</td>
<td>0.00087</td>
<td>-0.688</td>
<td></td>
</tr>
<tr>
<td>Track 9</td>
<td>--</td>
<td>1.0</td>
<td>0.5</td>
<td>-0.235</td>
<td>-0.06269</td>
<td>0.01001</td>
<td>-0.674</td>
<td></td>
</tr>
<tr>
<td>Track 10</td>
<td>--</td>
<td>-1.0</td>
<td>0.8</td>
<td>1.227</td>
<td>-0.06807</td>
<td>0.01149</td>
<td>-0.706</td>
<td></td>
</tr>
<tr>
<td>Track 11</td>
<td>*</td>
<td>1.0</td>
<td>1.1</td>
<td>1.900</td>
<td>-0.06157</td>
<td>0.00777</td>
<td>-0.751</td>
<td></td>
</tr>
<tr>
<td>Track 12</td>
<td>--</td>
<td>1.0</td>
<td>0.9</td>
<td>-0.258</td>
<td>-0.04702</td>
<td>0.00927</td>
<td>-0.680</td>
<td></td>
</tr>
<tr>
<td>Track 13</td>
<td>--</td>
<td>1.0</td>
<td>0.6</td>
<td>1.089</td>
<td>-0.02670</td>
<td>0.01151</td>
<td>-0.737</td>
<td></td>
</tr>
<tr>
<td>Track 14</td>
<td>--</td>
<td>-1.0</td>
<td>0.7</td>
<td>-0.088</td>
<td>-0.03563</td>
<td>0.00910</td>
<td>-0.603</td>
<td></td>
</tr>
<tr>
<td>Track 15</td>
<td>--</td>
<td>-1.0</td>
<td>0.8</td>
<td>-1.901</td>
<td>1.520</td>
<td>-0.04931</td>
<td>0.01456</td>
<td>-0.506</td>
</tr>
<tr>
<td>Track 16</td>
<td>--</td>
<td>1.0</td>
<td>0.6</td>
<td>-0.158</td>
<td>1.682</td>
<td>-0.02628</td>
<td>0.00804</td>
<td>-0.694</td>
</tr>
<tr>
<td>Track 17</td>
<td>--</td>
<td>1.0</td>
<td>0.7</td>
<td>2.576</td>
<td>-1.836</td>
<td>0.03376</td>
<td>0.03750</td>
<td>-0.051</td>
</tr>
<tr>
<td>Track 18</td>
<td>*</td>
<td>1.0</td>
<td>2.6</td>
<td>-2.062</td>
<td>-2.192</td>
<td>0.06902</td>
<td>0.00500</td>
<td>-0.864</td>
</tr>
<tr>
<td>Track 19</td>
<td>--</td>
<td>1.0</td>
<td>0.5</td>
<td>-1.791</td>
<td>0.284</td>
<td>-0.0504</td>
<td>0.01959</td>
<td>-0.733</td>
</tr>
<tr>
<td>Track 20</td>
<td>--</td>
<td>-1.0</td>
<td>0.6</td>
<td>1.455</td>
<td>-1.709</td>
<td>0.04662</td>
<td>0.01465</td>
<td>-0.558</td>
</tr>
</tbody>
</table>
FireworksWeb: Displaying 8 collections from RECO data.
Interactive table content in Fireworks, screenshot looking at a class dictionary
Further work & Plans
Development plan

- **Short term - clean up existing code:**
  - ROOT 6.20 release in December (EVE-7 is in ROOT since v6.16, Jan. 2019)
  - FireworksWeb technology preview release by the end of 2019 (FWLite based tarball)

- **Plan for 2020:**
  - EVE-7 ready as replacement for EVE
    - Most functionality supported, including physics collection / item handling.
  - FireworksWeb functional for Run3
    - Support CMS physics data-analysis & event scanning / trigger studies

- **Beyond 2020:**
  - EVE-7: optimization & beautification, and user support!
  - FireworksWeb - advanced functionality:
    - Running from full CMSSW framework & editing of CMS algorithm parameters
    - CMS geometry browser
    - Optimization for Heavy Ion runs
Conclusion

- EVE-7 and FireworksWeb rewrites are well underway.
- FireworksWeb as the driving force for the migration had positive influence:
  - Focus on most important core elements required for technology investigation
  - Port high-level functionality from CMS codebase into ROOT
  - Provide a framework for building of comprehensive physics-analysis event displays
- The main motivation for moving physics data representation into EVE-7 was to share this with other experiments.
  - It proved to be extremely useful for CMS physics ...
  - … and it will only make sense if other experiments actually use it.
- Early users / contributors are welcome at this point.
  - But beware there is another year of flux ahead.

See also: [1] New web-based ROOT GUI, Wed, 11 AM, Track 5