REVE - The dream come true

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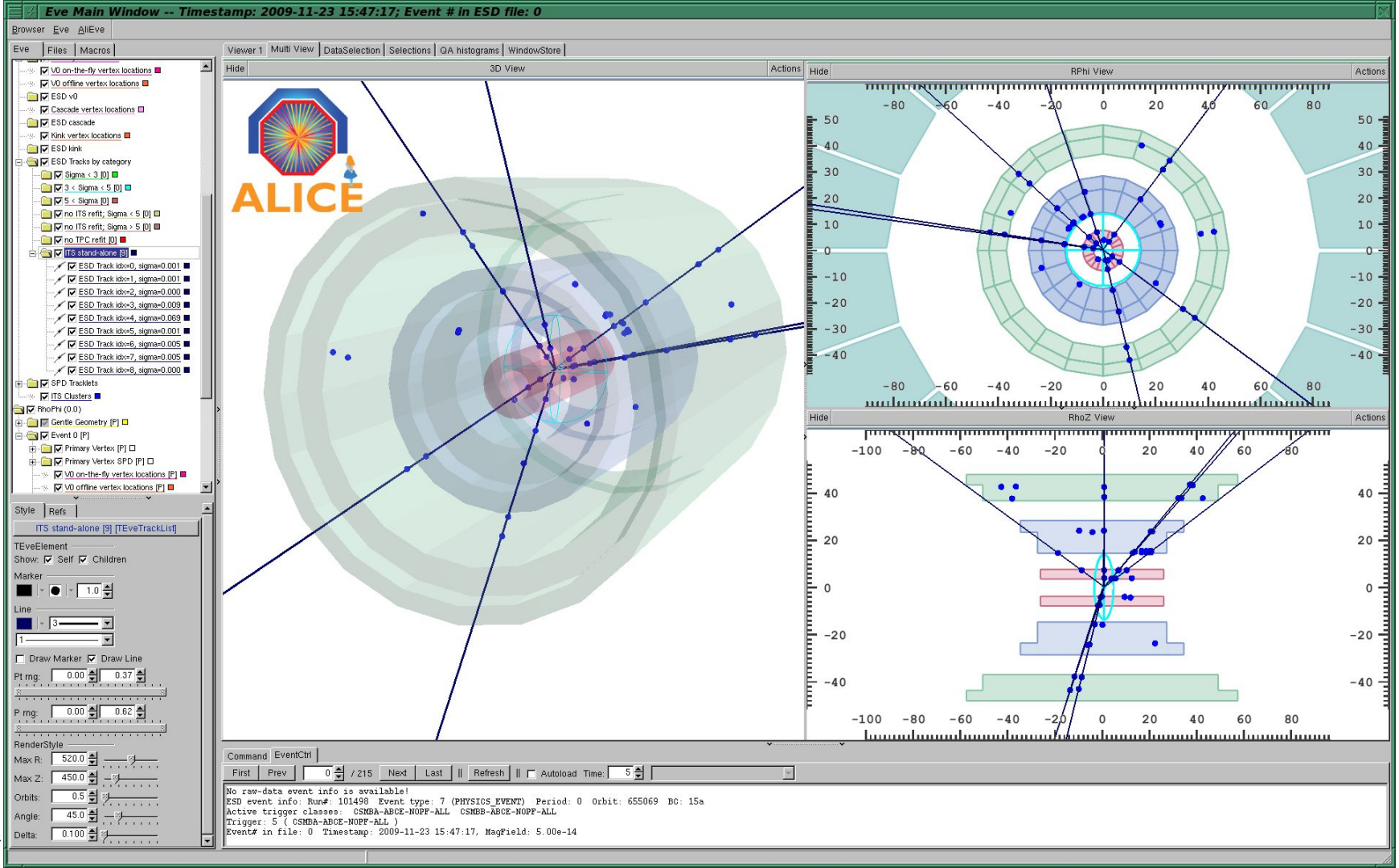
Overview

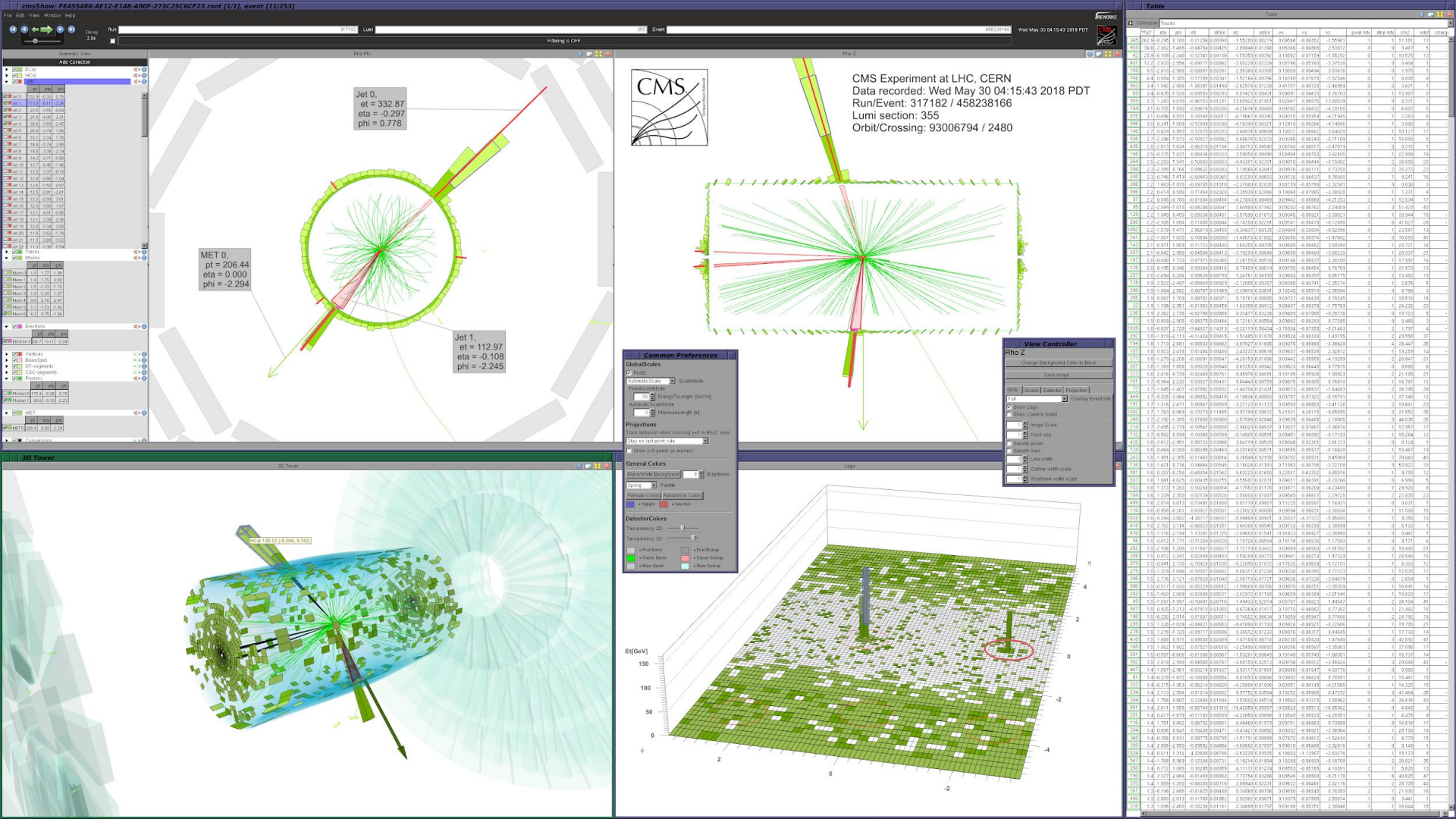
- Introduction:
  - EVE? → TEve → REve (a history lesson)
  - Project outline
- REVE – details & highlights
  - Components, server-client architecture, status
- Additional features existing in CMS FireworksWeb
  - Event filtering
  - Event-display as a Service
- Future work & plans
  - What is in the oven …
  - Development plans for 2022 - 2023

Introduction

EVE?

- What is EVE? → Event Visualization Environment
  - 3D graphics toolkit with HEP components (hits, tracks, detector digits, calorimeters … geom)
  - Event-display framework
  - Manage object hierarchies with multiple object representations (3D, RPhi, RhoZ, Lego)
  - Presentation layer top-levels: views; application & object GUI scaffolding; object selection
  - Low-level drawing code, separate from data / style objects
- Why is it in ROOT? → that's where the data, dictionaries & analysis code live :)
  - Requires (and partially drives!) GUI & 3D graphics development
  - A composite example of data access, presentation & interaction
- Who is it intended for?
  - Users – Provide a quick way to visualize relatively simple setups (eg., debug a reco algorithm)
  - Developers – A solid base for building experiment-specific applications


Eve Main Window -- Timestamp: 2009-11-23 15:47:17; Event # in ESD file: 0
Browser Eve AliEve
Eve Files Macros
Viewer 1 Multi View DataSelection Selections QA histograms WindowStore
Hide 3D View Actions
Hide RPhi View Actions
Hide RhoZ View Actions
ALICE
Style Refs
ITS stand-alone [9] [TEveTrackList]
TEveElement
Show: Self Children
Marker
Line
Draw Marker Draw Line
Pt rng:
P rng:
RenderStyle
Max R:
Max Z:
Orbits:
Angle:
Delta:
Command EventCtrl
First Prev Next Last Refresh Autoload Time:
No raw-data event info is available!
ESD event info: Run#: 101498 Event type: 7 (PHYSICS_EVENT) Period: 0 Orbit: 655069 BC: 15a
Active trigger classes: CSMBA-ABCE-NOPF-ALL CSMBB-ABCE-NOPF-ALL
Trigger: 5 (CSMBA-ABCE-NOPF-ALL)
Event# in file: 0 Timestamp: 2009-11-23 15:47:17, MagField: 5.00e-14


cmsShow: FE455488-AE12-E148-A90F-273C25C6CF23.root [1/1], event [11/253]
Rho Phi
Jet 0,
et = 332.87
eta = -0.297
phi = 0.778
MET 0,
pt = 206.44
eta = 0.000
phi = -2.294
Jet 1,
et = 112.97
eta = -0.108
phi = -2.245
Rho Z
CMS
CMS Experiment at LHC, CERN
Data recorded: Wed May 30 04:15:43 2018 PDT
Run/Event: 317182 / 458238166
Lumi section: 355
Orbit/Crossing: 93006794 / 2480
Common Preferences
View Controller
Rho Z
Table
3D Tower
Lego
Et[GeV]

TEVE → REVE

- TEVE timeline:
  - 2005 development starts (within ALICE / AliRoot)
  - 2007 ROOT package graf3d/eve; *ROOT GL co-developed to support advanced EVE features*
  - 2008 CMS choses EVE for physics-analysis event display – ***Fireworks***
    - Prototype development 2008 / 09 followed by intense 5-developer effort in 2010 / 11
      - Full CMSSW support, geometry visualization, detailed views of all RECO objects
  - ***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
- REve – follow migration of ROOT to web GUI & graphics
  - Same rationale + GL-1.5 becoming deprecated, remote GL rarely supported
  - REve development started in 2018 (some research & explorations done in 2016, 2017)
  - ***CMS has committed to support development of REVE and FireworksWeb.***

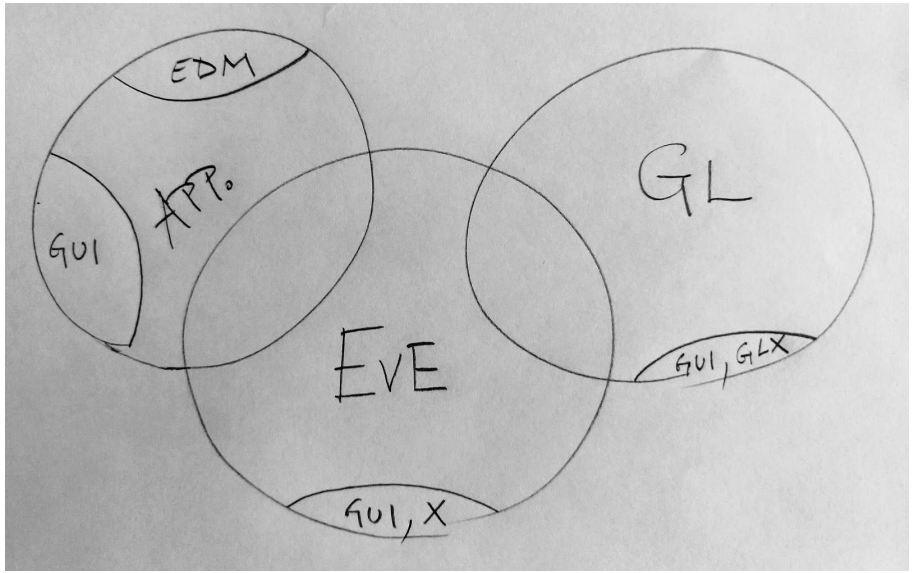
REVE Project outline

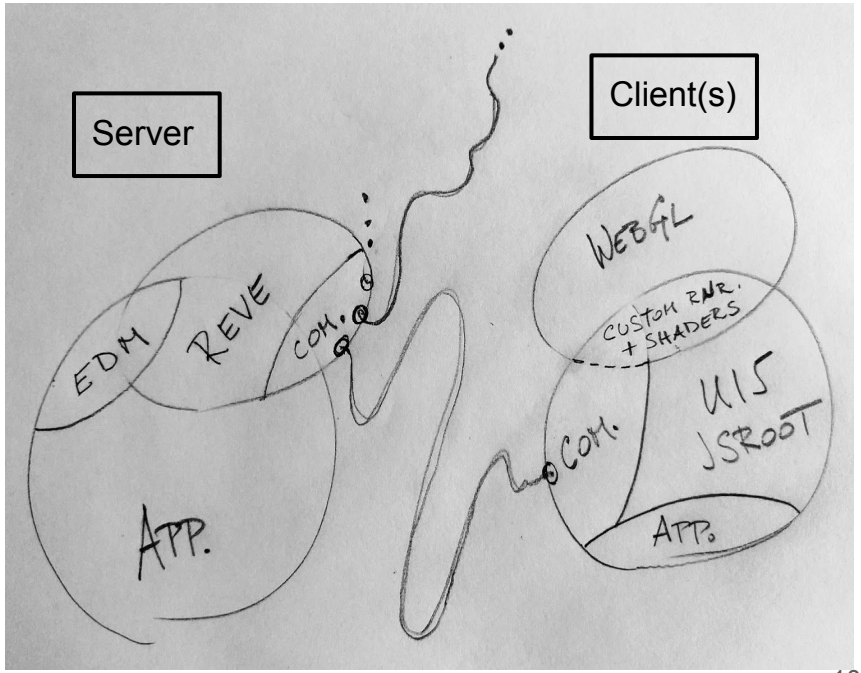
- Mission statement: *Rewrite EVE for ROOT-7 and Fireworks for LHC Run 3 and beyond*
  - Keep most of EVE functionality in place while modernizing the code
  - Move some functionality from Fireworks into REVE:
    - **Physics data: collections, items, item filtering, and table views - possible because of Cling and C++ lambdas**
    - CMS Geometry browser – not started yet but Sergey has done a lot of groundwork
- Development Focus / Driver: FireworksWeb prototype!
  - First release before Run 3: Support physics-analysis / event-scanning use case. (Done in Nov. 2021)
- 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, memory usage and rendering performance

REVE – Migration, Components, Server-client communication, Status

Migration

- ROOT GL: 64 kLOC, TEVE: 40 kLOC, Fireworks: 114 kLOC
  - REve: 52 kLOC, FireworksWeb: 34 kLOC as of now
  - A really hard start, sigh.





Components

- Server / core: ***C++*** *graf3d/eve7/*
  - 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 objects *executed via Cling or TMethodCall*
  - Data served through RWebWindow and ROOT's built-in civetweb web server
- Client side: *JavaScript* *ui5/eve7/*
  - **JSRoot**: integration of OpenUI5, initialization / bootstrap
    - colors, some 3D primitives & attributes, tree browser, file dialogs (local / remote)
  - **OpenUI5**, the standard Web-GUI for ROOT
  - **Three.js**: 3D rendering → now in process of integrating **RenderCore**
    - Light-weight WebGL engine developed at University of Ljubljana
    - The team has contributed to Phoenix & provided graphics for Tracking ML challenge
    - Optimal / concise rendering of all elements; support instancing & instance picking
      - prepare shader-input data on server, pass it directly into GL → minimal transfer, no JS processing
    - Get professional help & support + be able to modify rendering pipeline at any stage

Server-Client communication

- Existence of C++ / ROOT runtime server is crucial for the main goal of REVE & 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

REVE Status as of May. 2022

- **Functional partial implementation :)**
  - Missing some of TEve functionality:
    - Visualization of digits / raw-data with automatic color mapping (TEveDigit/Quad/BoxSet classes)
    - Better window / session manager, camera controls (esp. for multi-user usage)
    - Graphics view overlay support – buttons, annotations, logos
  - Still in *ROOT::Experimental* – would like to have all functionality implemented before the move
- Supported / implemented features
  - *REVE:*
    - Visual objects: pointsets, linesets, tracks, ellipsoid, jets, calorimeters, all TGeoShapes (including CSG)
    - Support for physics collections and physics items – including item filtering and table views
    - Handling of scene changes (user interaction) and destruction (going to another event)
    - Selection and highlight mechanism works across graphical views and different representations
  - *FireworksWeb:* uses all REVE 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, calorimeters, MET, electrons, vertices, muons, and CSC segments
    - Event navigation through CMS EDM data file, including event filtering
    - Uses custom client GUI elements for event info and event control

Demos & Examples in $ROOTSYS/tutorials/eve7

cmake -DCMAKE_CXX_STANDARD="17" -Dhttp="ON" -Droot7="ON" ../root

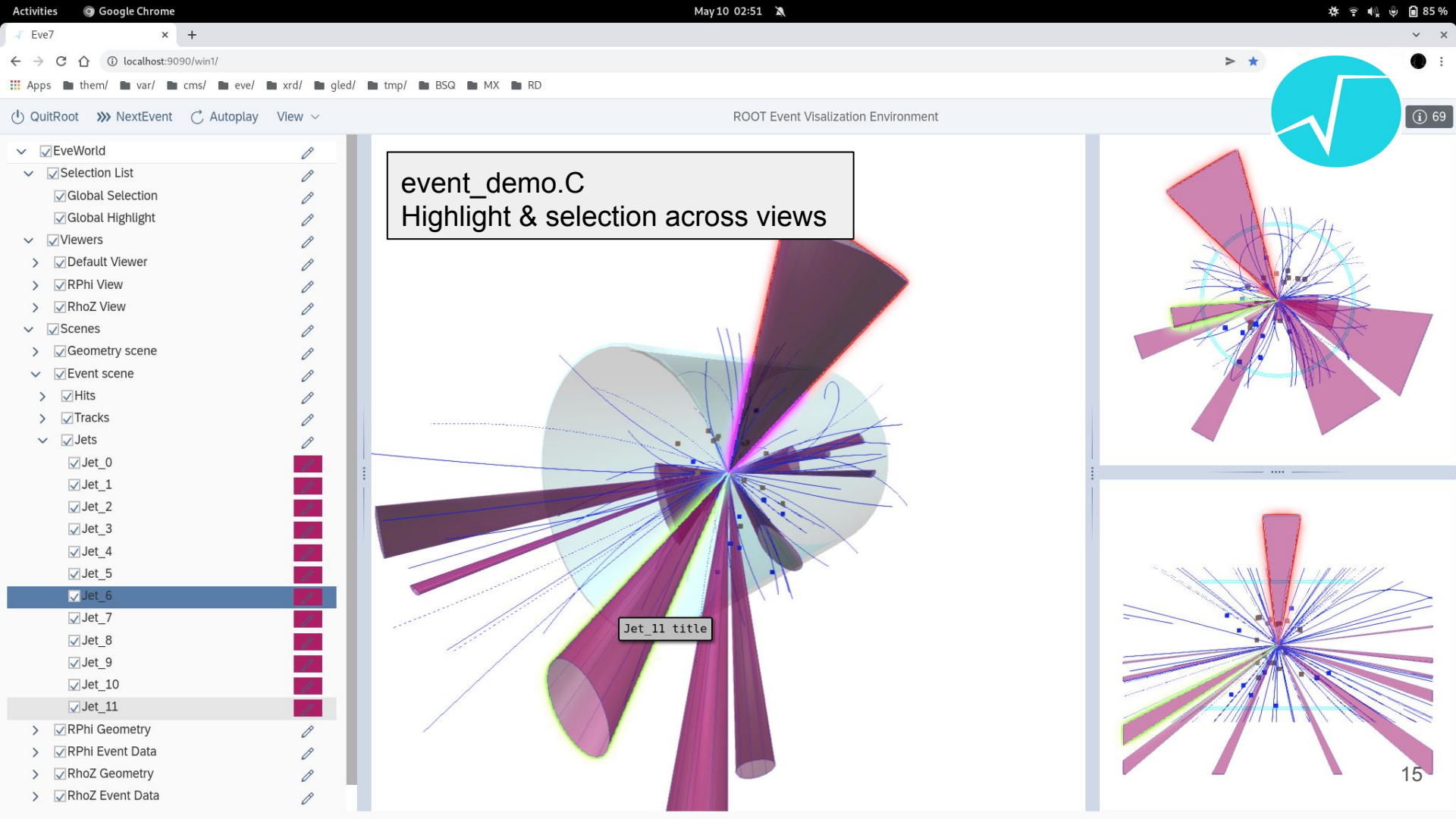
- Note: tutorials also serve for development & testing
  - Some of them use all possible features.
  - Several small demos show individual REve classes.
- Compound demos:
  - event_demo.C
  - collection_proxies.C

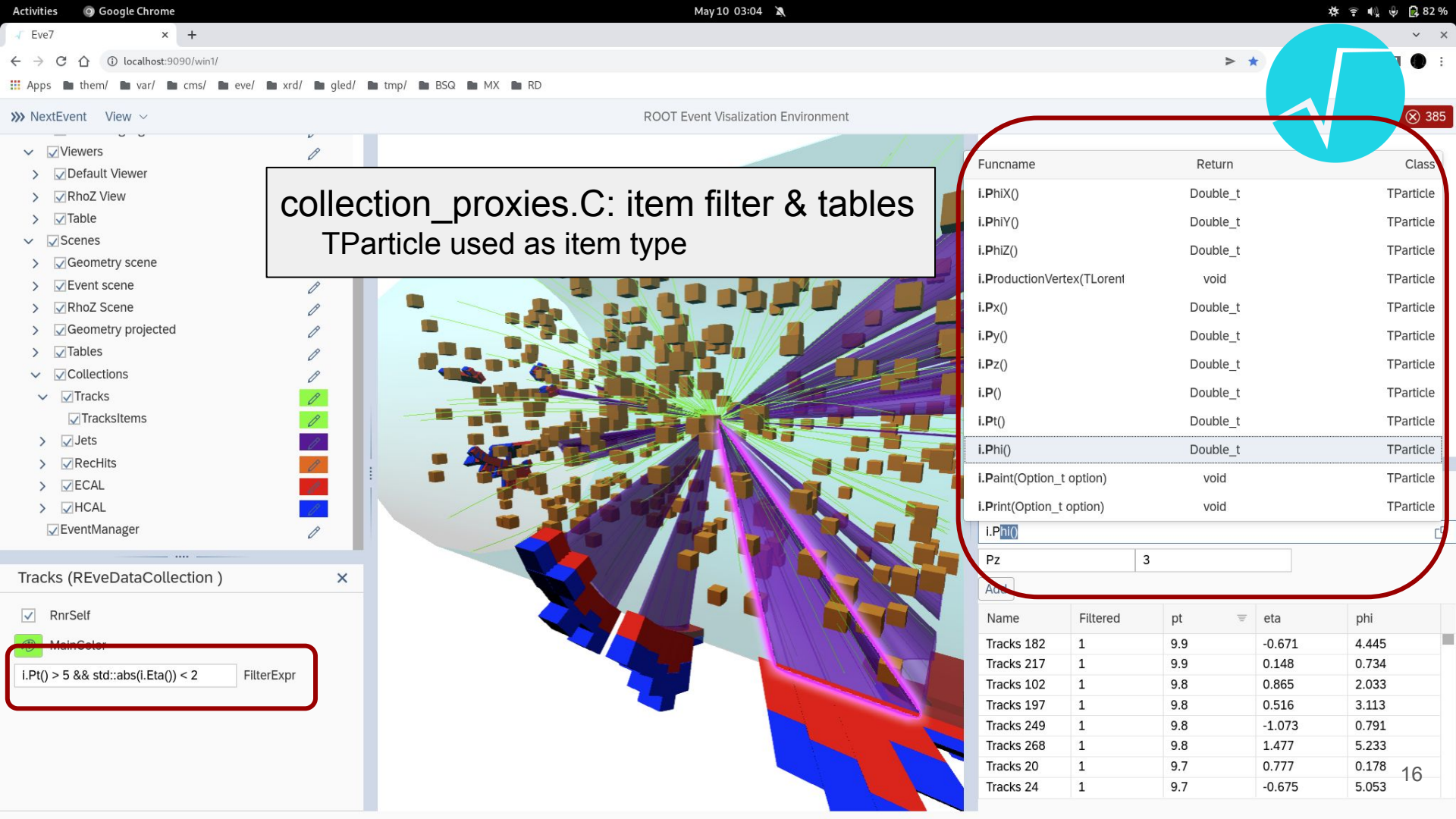
```
matevz@dull eve7> root.exe -l collection_proxies.C
Processing collection_proxies.C...
Info in <TGeoManager::TGeoManager>: Geometry Geometry, default geometry created
Info in <THttpEngine::Create>: Starting HTTP server on port 9090
EVE URL http://localhost:9090/win1/
root [1]
```

matevz@dull eve7> cat **.rootrc**

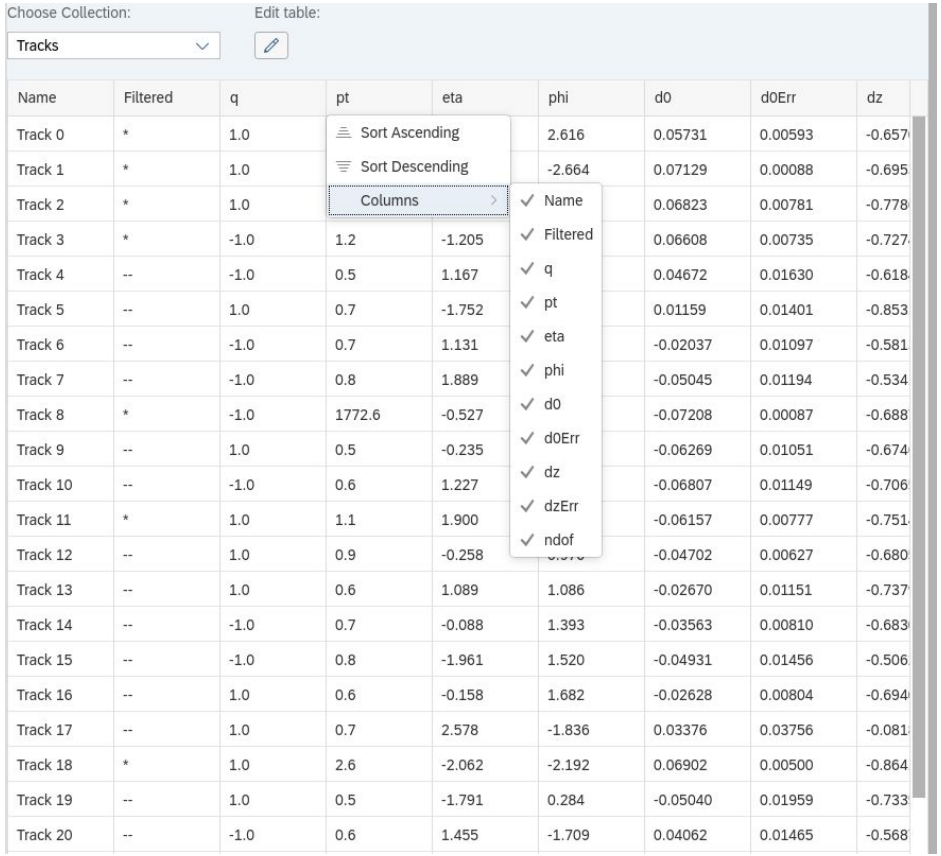
```
# Fix port number
WebGui.HttpPort: 9090
# WebGui.UseHttps: yes
# WebGui.ServerCert: /home/matevz/letsencrypt-server.pem

# Do not pop-up a browser window
WebEve.DisableShow: 1
```


Activities
Google Chrome
May 10 02:51
85 %
Eve7
localhost:9090/win1/
Apps
them/
var/
cms/
eve/
xrd/
gled/
tmp/
BSQ
MX
RD
QuitRoot
NextEvent
Autoplay
View
ROOT Event Visalization Environment
69
EveWorld
Selection List
Global Selection
Global Highlight
Viewers
Default Viewer
RPhi View
RhoZ View
Scenes
Geometry scene
Event scene
Hits
Tracks
Jets
Jet_0
Jet_1
Jet_2
Jet_3
Jet_4
Jet_5
Jet_6
Jet_7
Jet_8
Jet_9
Jet_10
Jet_11
RPhi Geometry
RPhi Event Data
RhoZ Geometry
RhoZ Event Data
event_demo.C
Highlight & selection across views
Jet_11 title
15


Activities
Google Chrome
May 10 03:04
82 %
Eve7
localhost:9090/win1/
Apps
them/
var/
cms/
eve/
xrd/
gled/
tmp/
BSQ
MX
RD
NextEvent
View
ROOT Event Visalization Environment
385
collection_proxies.C: item filter & tables
TParticle used as item type
Viewers
Default Viewer
RhoZ View
Table
Scenes
Geometry scene
Event scene
RhoZ Scene
Geometry projected
Tables
Collections
Tracks
TracksItems
Jets
RecHits
ECAL
HCAL
EventManager
Tracks (REveDataCollection)
RnrSelf
MainColor
i.Pt() > 5 && std::abs(i.Eta()) < 2
FilterExpr
Funcname
Return
Class
i.PhiX()
Double_t
TParticle
i.PhiY()
Double_t
TParticle
i.PhiZ()
Double_t
TParticle
i.ProductionVertex(TLorent
void
TParticle
i.Px()
Double_t
TParticle
i.Py()
Double_t
TParticle
i.Pz()
Double_t
TParticle
i.P()
Double_t
TParticle
i.Pt()
Double_t
TParticle
i.Phi()
Double_t
TParticle
i.Paint(Option_t option)
void
TParticle
i.Print(Option_t option)
void
TParticle
i.Phi()
Pz
3
Add
Name
Filtered
pt
eta
phi
Tracks 182
1
9.9
-0.671
4.445
Tracks 217
1
9.9
0.148
0.734
Tracks 102
1
9.8
0.865
2.033
Tracks 197
1
9.8
0.516
3.113
Tracks 249
1
9.8
-1.073
0.791
Tracks 268
1
9.8
1.477
5.233
Tracks 20
1
9.7
0.777
0.178
Tracks 24
1
9.7
-0.675
5.053
16

Configurable OpenUI5 tables



Name	Filtered	q	pt	eta	phi	d0	d0Err	dz
Track 0	*	1.0			2.616	0.05731	0.00593	-0.657
Track 1	*	1.0			-2.664	0.07129	0.00088	-0.695
Track 2	*	1.0				0.06823	0.00781	-0.778
Track 3	*	-1.0	1.2	-1.205		0.06608	0.00735	-0.727
Track 4	--	-1.0	0.5	1.167		0.04672	0.01630	-0.618
Track 5	--	1.0	0.7	-1.752		0.01159	0.01401	-0.853
Track 6	--	-1.0	0.7	1.131		-0.02037	0.01097	-0.581
Track 7	--	-1.0	0.8	1.889		-0.05045	0.01194	-0.534
Track 8	*	-1.0	1772.6	-0.527		-0.07208	0.00087	-0.688
Track 9	--	1.0	0.5	-0.235		-0.06269	0.01051	-0.674
Track 10	--	-1.0	0.6	1.227		-0.06807	0.01149	-0.706
Track 11	*	1.0	1.1	1.900		-0.06157	0.00777	-0.751
Track 12	--	1.0	0.9	-0.258		-0.04702	0.00627	-0.680
Track 13	--	1.0	0.6	1.089	1.086	-0.02670	0.01151	-0.737
Track 14	--	-1.0	0.7	-0.088	1.393	-0.03563	0.00810	-0.683
Track 15	--	-1.0	0.8	-1.961	1.520	-0.04931	0.01456	-0.506
Track 16	--	1.0	0.6	-0.158	1.682	-0.02628	0.00804	-0.694
Track 17	--	1.0	0.7	2.578	-1.836	0.03376	0.03756	-0.081
Track 18	*	1.0	2.6	-2.062	-2.192	0.06902	0.00500	-0.864
Track 19	--	1.0	0.5	-1.791	0.284	-0.05040	0.01959	-0.733
Track 20	--	-1.0	0.6	1.455	-1.709	0.04062	0.01465	-0.568

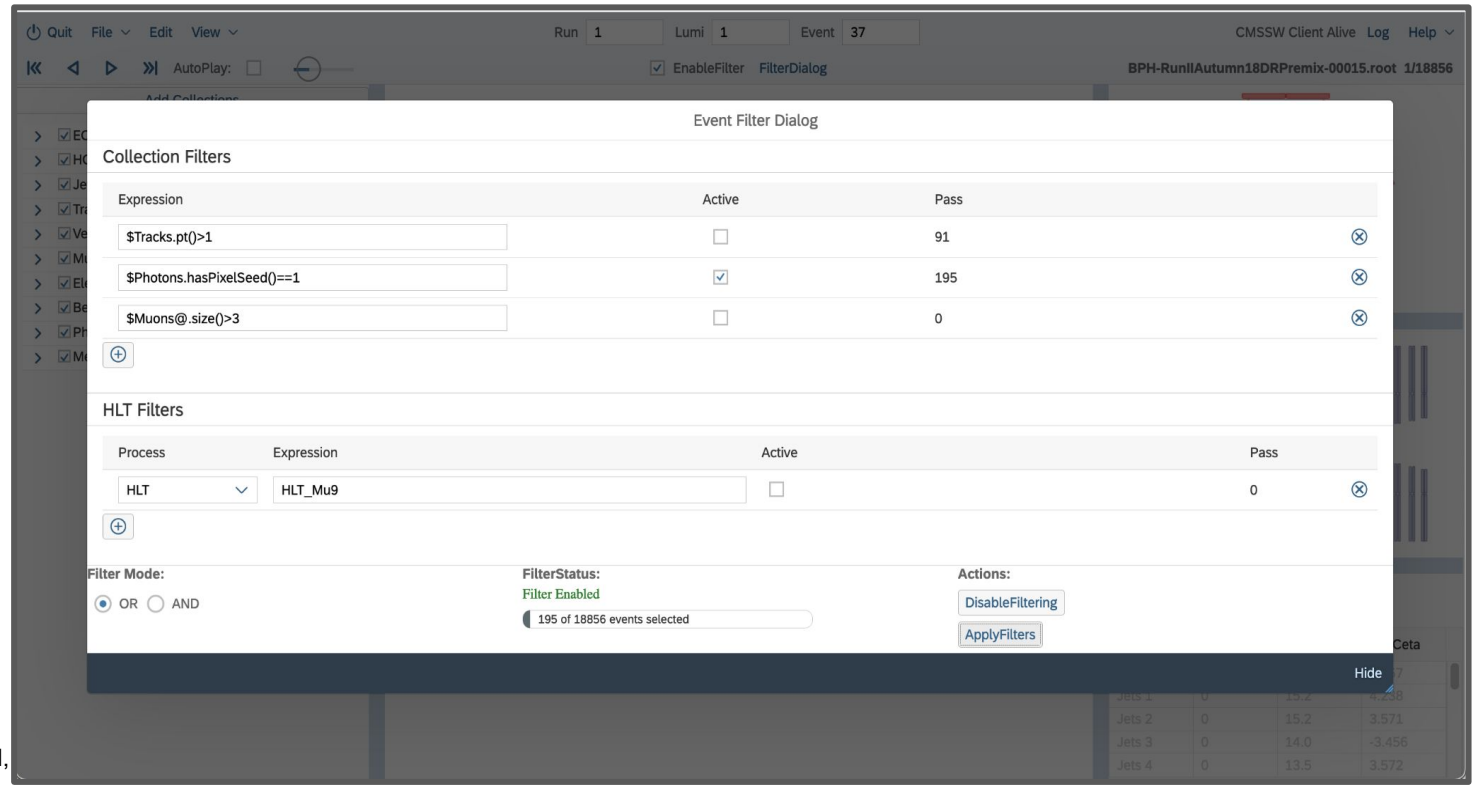
Extra goodies in FireworksWeb

that can serve at least as inspiration
but could also be generalized for other experiments

Event Filtering in large files

Still uses custom TTreeSelector → TEventList – should modernize this :)

Multi-threaded, each expression runs in parallel



FireworksWeb Service

- Application *cmsShowWebService.exe*:
  - TCP server that accepts requests to spawn *cmsShowWeb* instances
    - Is in itself partially initialized *cmsShowWeb*
      - forks itself and the child opens the file (fast as dictionaries are already pre-loaded!)
      - provides management of child processes
  - Uses service X509 proxy -- can access AAA, EOS (CERN) XCache (UCSD)
  - Installed from FireworksWeb tarball or run from CVMFS-based build
- Web frontend:
  - Apache with CERN SSO - all CMS members allowed, Let's Encrypt certs, https only
  - Frontend CGI script (perl, *revetor.pl*) that communicates with the service:
    - issue open file / spawn child requests
    - query status / usage; access logs and configurations
  - Instances run on a range of assigned ports, access to them can be through:
    - opening this port range (UCSD), or [still protected with a session key]
    - proxying access through Apache (CERN).

Further work & Plans

Development plan

- Plan for 2022 - 2023:
  - RenderCore integration
  - Optimizations for Heavy Ion data, HGCal visualization
  - Usability & interactivity – window management, cameras, annotations, multi-user, …

- Beyond 2023:
  - REVE should be feature complete
    - continue with optimization & beautification … and user support!
  - FireworksWeb - advanced functionality:
    - Running from full CMSSW framework & editing of CMS algorithm parameters
    - Port over CMS geometry browser

Conclusion

- REVE and FireworksWeb rewrites have reached the first stable point
- FireworksWeb as the driving force for the migration had positive influence:
  - Focus on most important core elements required for actual physics applications
  - 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 REVE was to share this with other experiments.
  - Extremely useful for CMS physics … please use it :)
- We know there is more work to be done … and we'll do it as it comes.
  - If you need a certain thing sooner, we can make it happen.

Thank you!

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