

RAL Masterclass Higgs Exercise

Sam Harper , Emmanuel Olaiya, A. R. Sahasransu
STFC-RAL-PPD

UK Particle Physics Masterclass Meeting
Liverpool
Sept 11th 2026

Introduction

- RAL PPD last year deployed a new masterclass exercise which we would like to share with you
- we would welcome feedback / suggestions and are happy to make it available to the community to use in whole, in part or for inspiration if they wish
- the website is at <https://ralmasterclass.app.cern.ch/>
 - will be a live demo as part of the talk, best to see the recording of the session if reading these slides after the fact

note: this talk is simply on the computer exercise, Sophie will talk next about the entire program and feedback from schools

Logins

here are some logins for you play with for
<https://ralmasterclass.app.cern.ch/>

- user: student_XX pass: password_XX
 - XX is 01 to 25
 - so student_10, password_10

online logins (you get the answer)

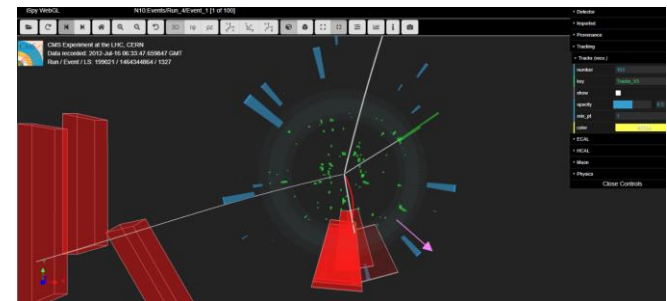
- user: student_online_XX , pass: password_XX
 - XX is 01 to 25

RAL MasterClass Computing Exercise Format

- two rooms with 25 computers each
 - students work in pairs
 - computers are very underpowered (small self contained sticks)
- run an online session and then various in person sessions
 - a morning and afternoon session for each of the 3 days
 - a session lasts for 1hr15mins
- each session is run by three demonstrators
 - lead with two helpers
 - lead gives the intro, then all three wander the room helping the students and giving more context in what they are doing

RAL Masterclass Exercise in 2024

- in 2024 we switched to using the i2u2 / quarknet masterclass
 - <https://web.quarknet.org/mc/cms/imc2021/pages/cmswz.html>
 - <https://quarknet.org/content/cms-masterclass-documentation>
- using the [ispy event display](#) students work through a bunch of CMS Run I data events and for each based on the number of leptons classify it as W, Z or Higgs candidates
 - if its Z or Higgs, they calculate the mass of it by selecting the tracks and pressing m
- they have a separate tool to input the classification and mass of event
- and at the end all the inputs sum up and they get a histogram for the class

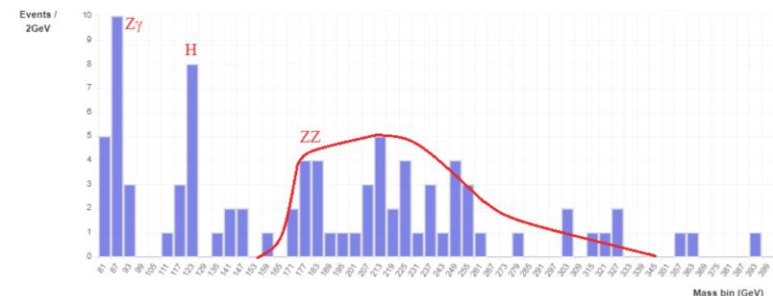


Back Events Table (Group 10.4) Mass Histogram (Table04) Results (Table04) Event Display

Masterclass: Sandbox-31Dec2023
Location: Table04
Group: 10.4

Select Event Event index: 2 Event number: 10.4.2	Final State ☐ e ⁺ e ⁻ ☐ e ⁺ e ⁺ ☐ e ⁻ e ⁻ ☐ e ⁺ e ⁻ ☐ e ⁺ e ⁺ ☐ e ⁻ e ⁻	Primary State Charged Particle: ☐ W ⁺ ☐ W ⁻ ☐ Neutral Particle ☐ Z, H ₀ ☐ Z ₀	Enter Mass 209.96 Next
--	--	--	---

Event index	Event number	Final state	Primary state	Mass
9001	10.4.1	2e 2p	neutral	209.96

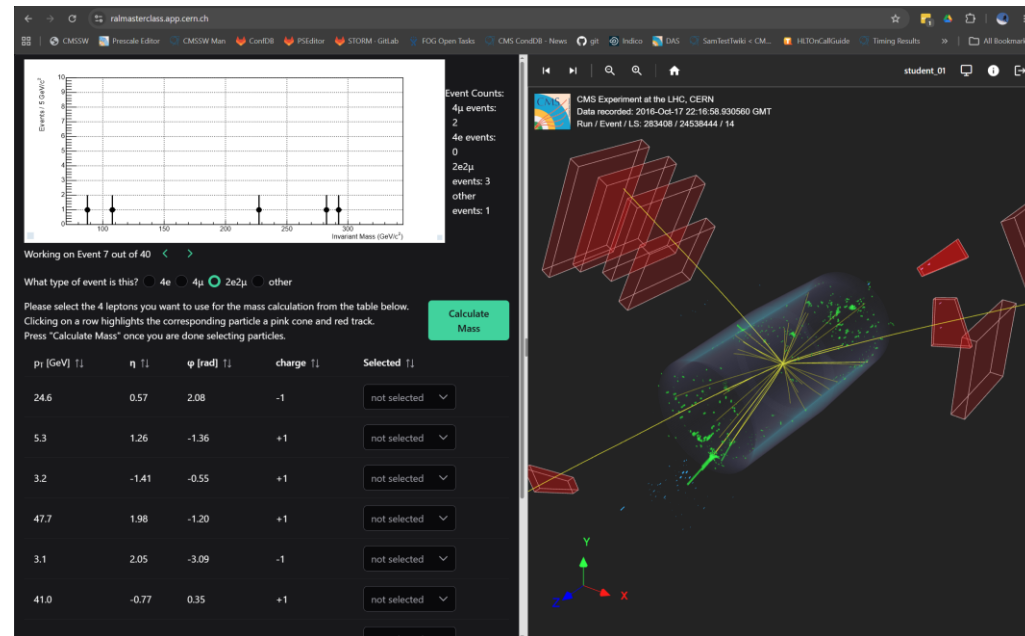


Our Experience of 2024 exercise

- we really liked the concept
 - the whole summing up everybody's work into histograms was a great to show the power of stats and how we discover particles
 - visualizing the events had better results than our previous programming exercise
- however we felt the implementation could use work
 - the gui was clunky and difficult to use
 - the calculated mass was often wrong to the trickiness of selecting 4 leptons
 - no real idea how well they were doing the exercise
 - the exercise was trying to do too much in a 1hr15min
 - Ws , Zs , Higgs and “other”
 - MET was a tricky concept to explain, particularly with how its represented in the display
 - required a bit of fiddly setup , students had to select the correct dataset manually
 - they would sometimes get this wrong
 - no immediate link to what they were doing to the mass plot
 - the final plot was a bit underwhelming and rarely came out well
 - the students contribution to it also wasn't clear to them

Revamped Exercise

- updated to CMS Open Run2 (2016) data
 - background estimate from CMS H→ZZ analysis
- integrated the event display, the histogram and the collection form into the same single webpage
 - now there is an immediate link between assigning an event and it appearing in the histogram
- removed the clicking issue
 - couldn't find a good way solve it due to 3D nature of the view so select via a table
- automatically loads the correct dataset based on student login
 - progress on this dataset is saved per login
- customised the ispy display to only show what is needed for this exercise
 - no confusing options for the student which can lead to the GUI getting into a bad state

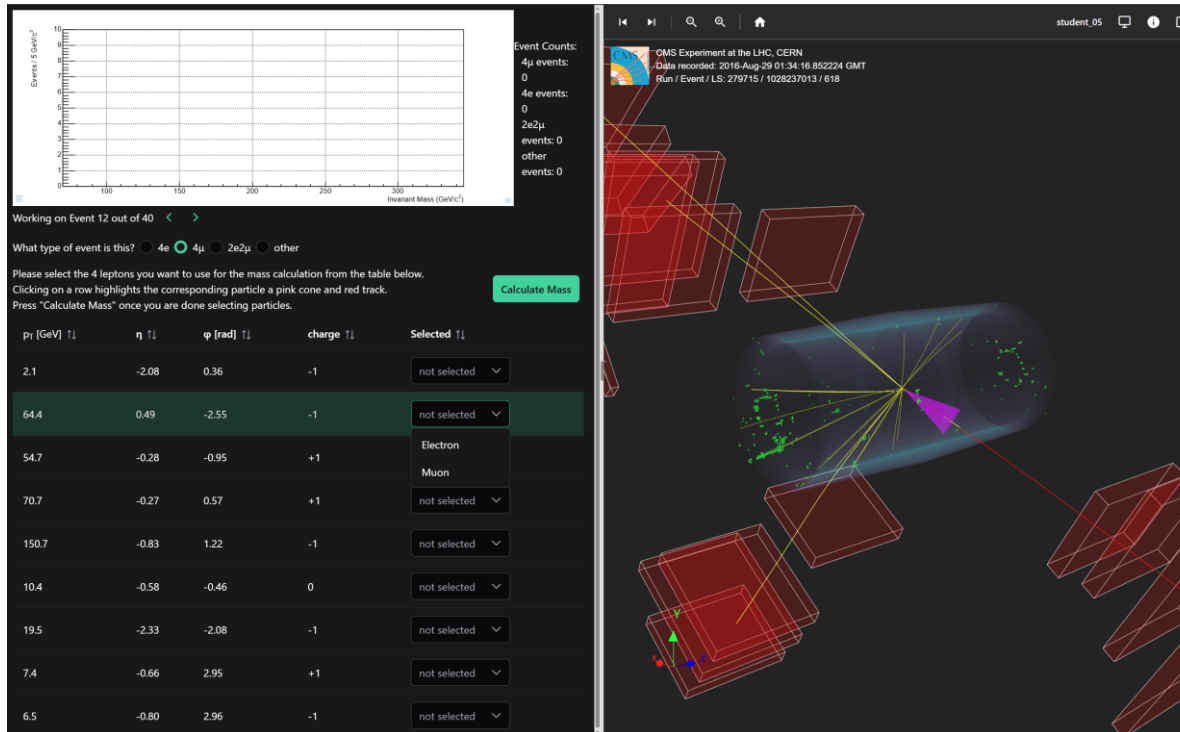


what the student sees now

Input Data & Setup

- input data consists of 4 lepton ($4\mu, 2e2\mu, 4e$) events mixed in with background events (aka “other”)
 - all collected in Autumn 2016 by CMS
- divided into 25 separate datasets, 40 events per dataset
 - limited by the number of 4 lepton events we have, believe its ~ 25 per dataset on average
 - we keep track of what events and particles we think are what so we can check against the students selections
 - note we do tell the students there is no guarantee we got it right!
- each student gets a given a login
 - identifies which session they are in
 - identifies which room/school they are
 - determines which dataset to load
 - persists their progress
- at the end we sum the results on a room/school basis

Event Selection



selecting a particle in the table highlights that particle in the event display

in future would like to upgrade it so clicking on particle in display highlights table

- student looks at the event and decides on the type (4e, 4 μ , 2e2 μ or other)
- for 4 μ , 2e2 μ , 4e, a table of “interesting particles” in the event is displayed
- student then clicks through it and selects which of them they think is an electron or muon
 - we only give the option for electron/muon to streamline the process
 - those particles form the invariant mass
 - sanity check on ensuring that when they say it's a 4e event, they select 4 electrons

Event Submission

- progress is automatically persisted
 - students can skip events and come back to them later
 - students can go back and review/change their selections
- progress per student is monitored in real time by demonstrators
 - we know how many they have submitted and what percent they have “correct”
 - we use this to go find struggling ones and see if we can help them
- tool will give hints if something is obviously wrong in the selection
- online days have an “auto demonstrator” which if the selection was incorrect, alerts the student to this
 - otherwise its very difficult for them to know if they were correct or not

we found this vital for engagement

demonstrators can go up to a student and go back to some events they've previously done and discuss with them their answers

Technical Setup

application:

- frontend: vue3 + typescript + primevue
 - event display ispy is javascript running in its own iframe
- backend: fastapi (python)
 - also serves the frontend & the data events it displays
- database: mongodb
- reverse proxy: nginx
- staff auth: uses CERN auth, also supports MS Entra

hosting:

- CERN PaaS
 - but its just two docker images + nginx, can run anywhere
 - resources are minimal (<1 GB RAM, very little CPU, very little storage)
- currently automatically deployed by CI/CD to the ral-masterclass CERN PaaS project

Code

hosted in CERN gitlab

- group: <https://gitlab.cern.ch/ral-masterclass>
 - <https://gitlab.cern.ch/ral-masterclass/ispy-webgl>
 - our fork of ispy-webgl, we use branch ralmc
 - <https://gitlab.cern.ch/ral-masterclass/ralmasterclass>
 - the masterclass application
 - contains both frontend and backend
- frontend code isn't of fantastic quality, backend where it matters more for security is
- based of the CMS trigger groups standard application layout

Security and Privacy

- there are two auth modes
 - student and staff
- staff is actually secure and is handled by CERN SSO
 - could move to MS Entra if needed
- student “auth” is more a way to preserve their work and to serve them the correct setup
 - any student input to the server is completely untrusted
 - input is extensively validated and highly restricted what it can be
 - effectively it can really just be “these are my particle assignments for event Y”
- student username (that we choose!) is all that is shown
 - we give the student username/passwords to the schools or hand them out randomly at RAL, we have no way of linking this back to an individual
 - we do know what school was given which usernames though

Demonstrator View

- RAL Staff can monitor the progress of the exercise in real time
 - this works on the phone
- we also have access to the summary page where at the end we can combine their results in real time

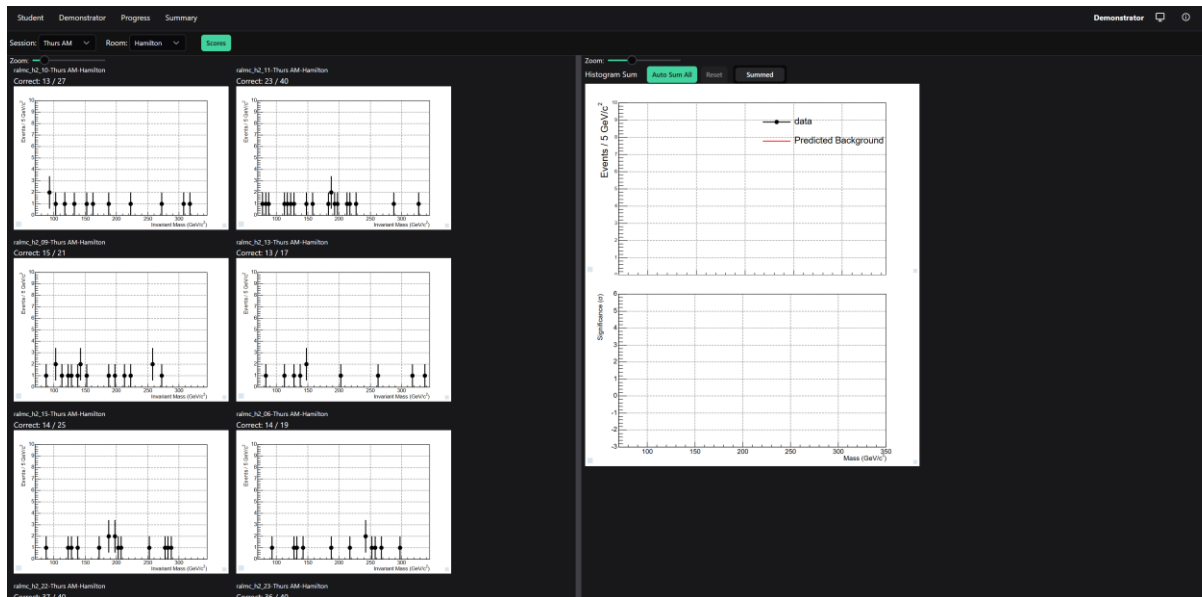
typically we give a prize for coming top

Demonstrator

Session: Fri AM Room: Hamilton

Final Scores:

#	Student	Correct	Total	%
1	ralmc_h4_23	35	40	88%
2	ralmc_h4_06	33	40	83%
3	ralmc_h4_12	31	40	78%
4	ralmc_h4_10	31	40	78%
5	ralmc_h4_25	30	40	75%
6	ralmc_h4_02	30	32	94%
7	ralmc_h4_03	29	33	88%
8	ralmc_h4_21	28	40	70%
9	ralmc_h4_16	27	40	68%
10	ralmc_h4_07	26	36	72%
11	ralmc_h4_08	25	40	63%
12	ralmc_h4_18	25	40	63%
13	ralmc_h4_17	24	40	60%
14	ralmc_h4_14	23	40	58%
15	ralmc_h4_05	23	27	85%
16	ralmc_h4_20	23	34	68%
17	ralmc_h4_24	21	40	53%
18	ralmc_h4_15	17	32	53%
19	ralmc_h4_04	7	12	58%



the demonstrator can then drag the individual histograms into the sum and we can see a Higgs peak forming in real time

student

Online & Mobile

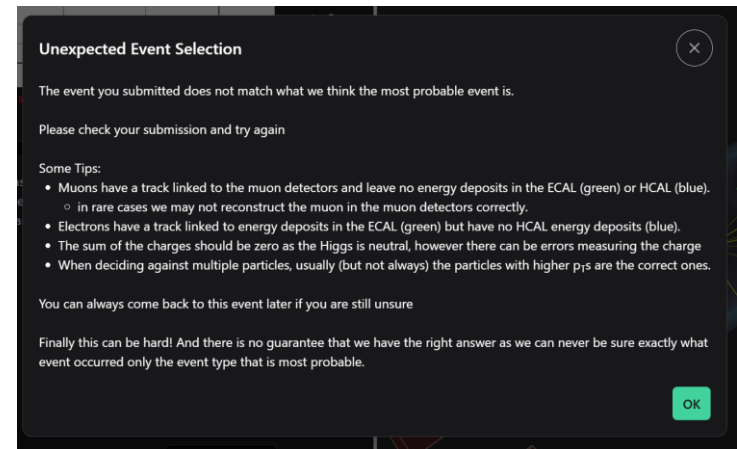
Online:

- our target was in person days and online was an afterthought last year
- would like to improve the online experience for this year
- currently online accounts also tell you if you got it wrong
 - gives at least some feedback
- but perhaps there could be a better thing to do here

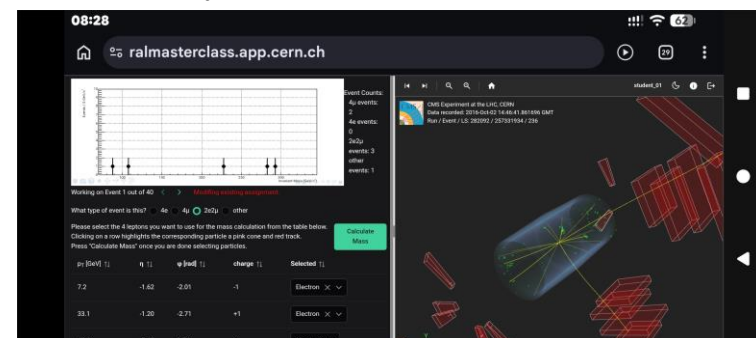
Mobile:

- not designed for mobile usage
- does sorta work, you can use it on your phone
- still not really recommended
- probably works on a tablet well enough though

pop up if you select the wrong particles in “online” mode



taken on my pixel9a



Improvements

- last year focused on getting it up and running
- still some rough edges that we want to improve upon
 - have a bunch of feedback from students/teachers from last year
- biggest issues
 - background events are not the best
 - due to input data format, HCAL info is limited which presents a misleading view -> have a plan to fix it
 - there is a need for one or two “demo” events to get them started
- various clunky bits in the gui need fixing
 - mostly on the demonstrator side which was lower priority
- try and improve the online experience

Summary

- we hope it has been useful sharing our masterclass setup
 - we would appreciate any feedback/suggestions
- we welcome others using this
 - we can offer some support here if interested but limited personpower so its it'll be on a case by case basis
- we also welcome others pinching any ideas here they think are useful
 - base ideas are common and not ours
 - we are just refining them based on our experience
 - happy to discuss the technical details “in person” if anybody is interesting in building their own

Hope this can be useful on our mission to inspire
young folks about STEM!