

Experience of studying Z bosons with ATLAS open data for high school diploma project (gymnasiearbete)

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Supervisors: Christian Ohm & Giulia Ripellino

2019



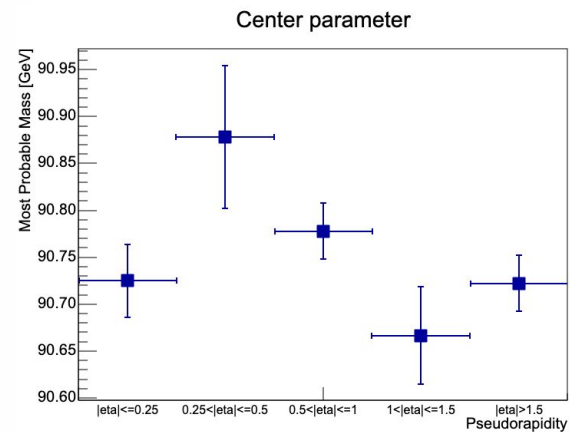
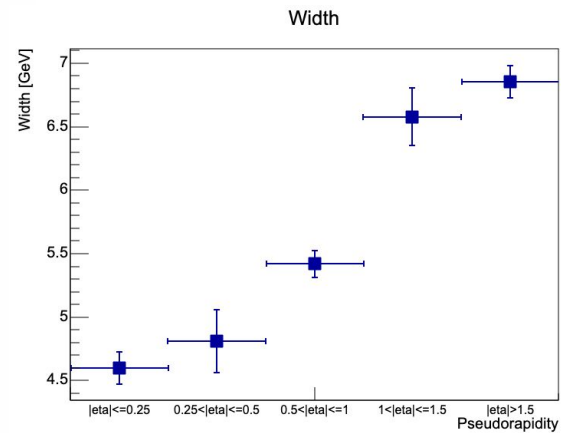
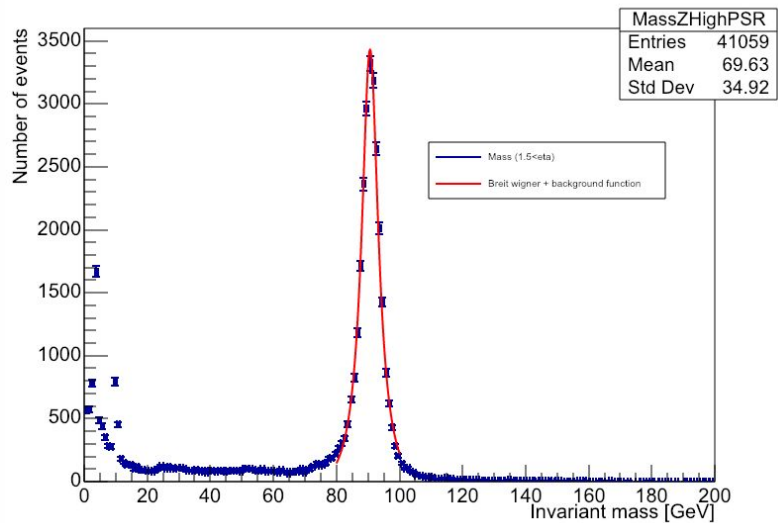
What I did

- Diploma project (Gymnasiearbete) → mandatory project last year of high school
- Studied the performance of the ATLAS detector for measuring the mass of the Z boson using the ATLAS open data collection
- Calculated the invariant mass of the Z boson
 - Muon decay channel
 - Electron decay channel
 - $m = \sqrt{(2p_{T1}p_{T2}((\cosh(\eta_1 - \eta_2) - \cos(\phi_1 - \phi_2)))}$ where η is the pseudorapidity, p_T is the transverse momentum and ϕ is the angle from the x -axis in the xy -plane.

Subsamples of the data & fitting the invariant mass

- Muon and electron decay channels
- Pseudorapidity for the muon decay channel
 - $|\eta| \leq 0.25$, $0.25 < |\eta| \leq 0.5$, $0.5 < |\eta| \leq 1$, $1 < |\eta| \leq 1.5$ and $|\eta| > 1$
- Transverse momentum of the muons
 - $p_T \leq 30$ GeV, 30 GeV $< p_T \leq 40$ GeV, 40 GeV $< p_T \leq 45$ GeV, 45 GeV $< p_T \leq 50$ GeV and $p_T > 50$ GeV
- Transverse momentum of the Z boson
 - $p_T(Z) \leq 20$ GeV and $p_T(Z) > 20$ GeV
- Breit-Wigner function
 - Center parameter
 - Width parameter

Histograms



Results

- More accurate and precise for the muon decay channel
- Precision decreased as pseudorapidity increased
- Precision and accuracy decreased as the transverse momenta of the muon increased
- For increasing Z boson momenta:
 - Accuracy increased for the electron decay channel
 - Accuracy increased but precision decreased for the muon decay channel

Accuracy and Precision of the Z Boson Mass
Measurement with the ATLAS Detector

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Teachers of the Natural Science Specialization Course:
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Kungsholmen's Gymnasium
27/05-2019



My experience

- Fun and interesting
- New concepts
- Challenging
- Most difficult: ROOT and programming
- Most interesting: The theory

Back-up material

The KTH open-data analysis framework

- Purpose:

- Developed as a platform for computer labs (Edvin Sidebo, Christian Ohm)
- Includes mini tutorial on python, ROOT and fitting distributions

- Technical details:

- Based on [Jupyter notebook](#) running [ROOT](#) in python
- Packed up in a [docker](#) image - up and running within minutes!
- Try it yourself:

```
docker run -p 3000:8080 kthatlas/opendatalab:SH1015
```

Point your browser to 127.0.0.1:3000 and put in the token printed in the terminal

The screenshot shows a web browser window displaying a GitHub repository page. The browser's address bar shows 'github.com'. The repository is titled 'cohm / OpenDataZmassLab' and is forked from 'sidebo/sh1015-opendatalab'. The repository has 2 unwatchers, 0 stars, and 3 forks. The main content area shows the repository name 'notebook (python) based lab: measuring the Z boson mass with ATLAS open data' and an 'Edit' button. Below this, there are statistics: 44 commits, 4 branches, 0 releases, and 2 contributors. A 'Branch: master' dropdown and a 'New pull request' button are visible. A green 'Clone or download' button is also present. The commit history shows a list of commits, including 'cohm Update README.md' (latest commit 593fc5c on Dec 20, 2018), 'for-teachers' (Adding first instructions for how to easily edit the contents of the ...), 'the-exercise' (Cleaning up separation of information and exercise for notebook 1 int...), '.gitignore' (going through lab myself, struggling with the fit part atm...), and 'README.md' (Update README.md). A 'README.md' file is also visible at the bottom of the commit list.

Repository containing the exercises and code templates in the Jupyter notebook

The screenshot shows a web browser window displaying the GitHub repository page for 'cohm/docker-opendatalab'. The browser's address bar shows 'github.com'. The repository page includes a search bar, navigation links for 'Pull requests', 'Issues', 'Marketplace', and 'Explore', and repository statistics such as 'Unwatch 1', 'Star 0', and 'Fork 0'. The main content area is titled 'Dockerfile for labs using ATLAS open data' and features a table of recent commits. The most recent commit is 'Update README.md' by 'cohm' on Dec 20, 2018. Below the commit list, the 'README.md' file content is visible, describing the Docker image and providing a command to run it.

cohm / docker-opendatalab

Unwatch 1 Star 0 Fork 0

Code Issues 0 Pull requests 0 Projects 0 Wiki Security Insights Settings

Dockerfile for labs using ATLAS open data Edit

Manage topics

4 commits 4 branches 0 releases 1 contributor

Branch: master New pull request Create new file Upload files Find File Clone or download

Commit	Message	Time
cohm Update README.md	Update README.md	10 months ago
Dockerfile	Update Dockerfile	10 months ago
README.md	Update README.md	10 months ago

README.md

Docker image for lab exercises with open data from the ATLAS experiment, using pyROOT in jupyter notebooks. Different branches check out different repos of actual exercises. Each branch is built into an image with a tag named as the branch, so for the lab for determining the Z boson mass, run with like this:

```
docker run -p 3000:8080 kthatlas/opendatalab:SH1015
```

Repository containing the definition of the docker image containing the full setup

cloud.docker.com

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cohm/OpenDataZmassLab: notebook (...) cohm/docker-opendatalab: Dockerfile f... Docker Hub OpenDataZmassLab/the-exercise/ 2-Fitting-with-ROOT

New in Docker Hub: Personal Access Tokens. [Learn more >](#)

docker hub Explore Repositories Organizations Get Help kthatlas cohm

Repositories kthatlas / opendatalab Using 0 of 0 private repositories. [Get more](#)

General Tags Builds Timeline Permissions Webhooks Settings

kthatlas / opendatalab

Lab exercises with ATLAS open data inside a jupyter notebook. [✎](#)

Last pushed: 20 days ago

Docker commands [Public View](#)

To push a new tag to this repository,

```
docker push kthatlas/opendatalab:tagname
```

Tags

This repository contains 3 tag(s).

SH1015		20 days ago
SH1015-test		9 months ago
SH2103		9 months ago

Recent builds

- [cohm/docker-opendatalab](#)
- [Build in 'SH1015'](#)
- [Build in 'SH1015' \(01946...](#)
- [Build in 'SH1015'](#)

At dockerhub.com the image is automatically built when the code repo is updated

The image shows a Docker Hub repository page for 'kthatlask / opendatalab'. The page includes a navigation bar with 'docker hub', 'Explore', 'Repositories', 'Organizations', and 'Get Help'. The repository name 'kthatlask / opendatalab' is displayed, along with the text 'Using 0 of 0 private repositories. [Get more](#)'. Below the repository name are tabs for 'General', 'Tags', 'Builds', 'Timeline', 'Permissions', 'Webhooks', and 'Settings'. The 'Tags' tab is active, showing a list of tags: 'SH1015' (20 days ago), 'SH1015-test' (9 months ago), and 'SH2103' (9 months ago). To the right, the 'Recent builds' section shows three builds, all for the 'SH1015' tag, with the first one being 'Build in 'SH1015''.

```
OhmBookPro13-6:~/Documents/Work/HGTD/hgtd-digitization > docker run -p 3000:8080 kthatlask/opendatalab:SH1015
[I 22:47:40.539 NotebookApp] Writing notebook server cookie secret to /root/.local/share/jupyter/runtime/notebook_cookie_secret
[I 22:47:41.179 NotebookApp] Serving notebooks from local directory: /work
[I 22:47:41.179 NotebookApp] The Jupyter Notebook is running at:
[I 22:47:41.179 NotebookApp] http://(c5d21e76e1dd or 127.0.0.1):8080/?token=b11bb2bf72f994065f98a8aa2760b03c2add90d60ebd0419
[I 22:47:41.179 NotebookApp] Use Control-C to stop this server and shut down all kernels (twice to skip confirmation).
[W 22:47:41.181 NotebookApp] No web browser found: could not locate runnable browser.
[C 22:47:41.181 NotebookApp]
```

Copy/paste this URL into your browser when you connect for the first time,
to login with a token:
`http://(c5d21e76e1dd or 127.0.0.1):8080/?token=b11bb2bf72f994065f98a8aa2760b03c2add90d60ebd0419`

You start the docker image on any laptop (windows, linux, mac) in a matter of seconds

127.0.0.1

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cohm/OpenDataZmassLab: notebook (...)

cohm/docker-opendatalab: Dockerfile f...

Docker Hub

OpenDataZmassLab/the-exercise/

2-Fitting-with-ROOT

Jupyter

Quit Logout

Files Running Clusters

Select items to perform actions on them.

Upload New ↻

<input type="checkbox"/>	0		Name ↓	Last Modified	File size
		📁	..	seconds ago	
<input type="checkbox"/>		📁	hints	20 days ago	
<input type="checkbox"/>		📁	images	20 days ago	
<input type="checkbox"/>		📄	0-Python-Jupyter-Notebook-intro.ipynb	20 days ago	19.7 kB
<input type="checkbox"/>		📄	1a-Introduction-information.ipynb	20 days ago	10.4 kB
<input type="checkbox"/>		📄	1b-Introduction-exercise.ipynb	20 days ago	12.7 kB
<input type="checkbox"/>		📄	2-Fitting-with-ROOT.ipynb	Running 20 days ago	17.1 kB
<input type="checkbox"/>		📄	3-TheTask-ZbosonMass.ipynb	20 days ago	6.25 kB
<input type="checkbox"/>		📄	4-LabReport.ipynb	20 days ago	3.46 kB

Docker container runs a local web server, you code through the web interface

127.0.0.1

April 14, 2018 2 ▾ April 14, 2018 1 ▾ KTH ▾ ATLAS ▾ ATLAS code ▾ HGTD ▾ Physics ▾ Statistics ▾ Computing ▾ Old ▾ Private ▾ JediMon Search E-groups cern.ch/go >>

cohm/OpenDataZmassLab: notebook (...)

cohm/docker-opendatalab: Dockerfile f...

Docker Hub

OpenDataZmassLab/the-exercise/

2-Fitting-with-ROOT

Jupyter 2-Fitting-with-ROOT Last Checkpoint: 09/12/2019 (unsaved changes)

Logout

File Edit View Insert Cell Kernel Widgets Help

Not Trusted Python 3

Run

2.2 Gör en anpassning

Nu ska vi göra en anpassning av en funktion till data i histogrammet ovan. Syntax är `TH1F::Fit(fcn, "fit_opt", "draw_opt", xlow, xup)` där

- `fcn` är antingen en sträng med namnet på en funktion (ett `ROOT::TF1` -objekt), eller själva funktionsobjektet.
- sedan kommer anpassnings- och plot-alternativ, t.ex. `fit_opt = "V"` för mer detaljerad output och `draw_opt="E"` för att rita histogrammet med osäkerheter. Flera bokstäver bakas ihop i en och samma sträng för att aktivera flera alternativ samtidigt.
- sist är vilket intervall på x-axeln (nedre och övre gräns) i vilken anpassningen ska göras.

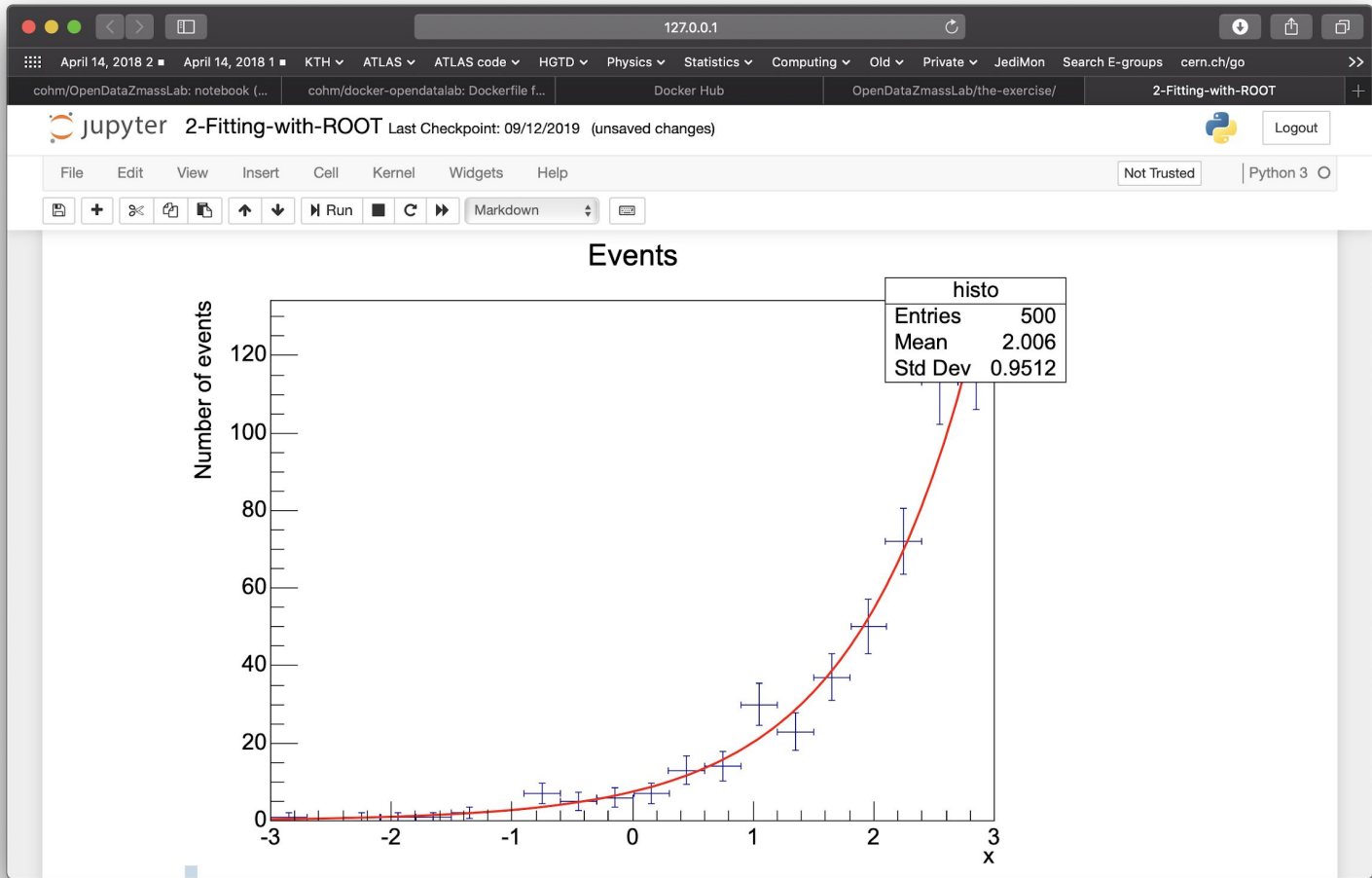
För mer information, see [dokumentationen för TH1::Fit\(\)](#). Framförallt kan man läsa om de olika alternativen för att kontrollera anpassningen (mer om detta snart).

Vi testar först att helt enkelt att anpassa till den fördefinierade funktionen "expo" som användes för att fylla histogrammet (borde per definition ge en bra anpassning). Genom att ropa på `Fit` görs anpassningen och den resulterande kurvan ritas upp. Per default används en viktad minsta-kvadrat-anpassning, även kallad χ^2 -anpassning (se "Statistik för fysikexperiment.pdf" på Canvas)

```
In [6]: fitresult = histo.Fit(fname, "S") # option "S" makes sure the fit result is returned
print("\n***** Fit results: ")
canvas.Draw()
```

```
***** Fit results:
FCN=11.1487 FROM MIGRAD STATUS=CONVERGED 50 CALLS 51 TOTAL
EDM=6.99001e-10 STRATEGY= 1 ERROR MATRIX ACCURATE
EXT PARAMETER STEP FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE
1 Constant 2.01321e+00 1.10331e-01 7.69597e-05 -3.04534e-04
2 Slope 9.93862e-01 4.97127e-02 3.46776e-05 -1.31571e-03
```

The notebook contains exercises to learn how to make fits with PyROOT



Voilà!

