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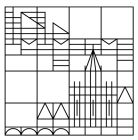

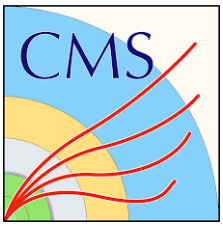

J/Ψ analysis with datasets from ZEUS to CMS conversion - DESY Summerschool Project B12

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Abstract

The main goal of my project is to convert ZEUS data into one standard format such that ZEUS, CMS, ATLAS data can be analysed with the same code. The chosen standard format is the CMS one. A conversion of the ZEUS data into CMS format is successfully done and results show a clear J/Ψ peak. Addition to the conversion of the ZEUS data, I also took a part of NanoAOD format generation for the CMS open data. Namely this was done by implementing trigger information in a code which converts CMS AOD format into NanoAODplus format.

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Contents

1 Introduction

One of the most important factors when it comes to data analysis, no matter if it is sociology or physics, is to have a valid base of statistics. As one could see at the Higgs-discovery the statistics for data analysis from different detectors, runs and data samples play a very important role in experimental particle physics. So one natural motivation is to bring the data from different detectors together and analyze them with one code. Which is the main goal of the general project for previous and future summerstudents in this project.
The work of this project can be seperated in two different areas. The first part is the analysis of the (Muon) ZEUS data with an analysis code which is compatible with CMS data sets. The second part is to extend a part of a code which converts CMS data from AOD format into NanoAOD(plus) format. The AOD and NanoAOD(plus) format here are for CMS data.

1.1 ZEUS to CMS data conversion and analysis

This part mainly focuses on the conversion from the ZEUS data into the CMS format so that this data can be analyzed with the same code as for example the ATLAS data which has been converted into CMS format (see also the report from Leonardo Olivi, summerstudent for the remote part of the project) or just the CMS data itself. Besides the setup/logic for the conversion and the technical implementation the comparison of the analysis of different data samples from different detectors is an important part of the project.

1.2 AOD to NanoAODplus conversion and analysis

The other part of the project to extend the code converting CMS AOD format into NanoAOD(plus) format is connected to this goal. It makes Run 1 AOD format to be compatible with Run 2 NanoAOD format so that Run 1 and Run 2 data can be analysed together in NanoAOD format and this is expected to increase the statistics. Besides that NanoAODplus format stores more information.. This has advantages like that the information in which data sample each event enables to run analysis codes over many data samples and making sure that no events are double counted. So in principle there is no need to preselect the trigger beforehand.

2 Data format conversion and implementation

2.1 ZEUS to CMS

The starting status was that the ZEUS data is already in form of n-tuples. In the following representative examples of the mapping from ZEUS data into CMS data are explained. The mapping of the other Muon-information can be found at the end of this section.

- In general many variables just have to be renamed, e.g.

$$\text{ZEUS data} \ni \texttt{Nmu} \mapsto \texttt{nMuon} \in \text{CMS data}$$

  since the amount of μ is identical in both formats.

- Some variables do not exist in both n-tuples, e.g. we map

$$\texttt{0} \mapsto \texttt{luminosityBlock} \in \text{CMS data}$$

  since it does not exist in ZEUS data, but in CMS it does.

- Other variables need to be calculated from several variables, e.g. the error of transverse momentum we get through

$$\underbrace{\texttt{Muperr}}_{\in\text{ZEUS data}} \cdot \sin\Big(\underbrace{\texttt{Muth}}_{\in\text{ZEUS data}}\Big) \mapsto \texttt{Muon\_ptErr} \in \text{CMS data}$$

  since in the ZEUS data there is only the total error of the momentum but in order to get the transervse component of it which is a variable in CMS data one simply has to multiply with $\sin(\theta)$ to calculate the transverse momentum $p_\perp$.

- Since the μ-quality variables are quite different in ZEUS and CMS the mapping is not completely straight forward.

$$\begin{aligned}
\overbrace{\texttt{Muon_looseId} \equiv \texttt{true}}^{\text{CMS}} &\iff \overbrace{\texttt{Muqual} > 0}^{\text{ZEUS}} \\
\texttt{Muon_softId} \equiv \texttt{true} &\iff \texttt{Muqual} > 3 \\
\texttt{Muon_mediumId} \equiv \texttt{true} &\iff \texttt{Muqual} > 4 \\
\texttt{Muon_tightId} \equiv \texttt{true} &\iff \texttt{Muqual} = 6
\end{aligned}$$

  Remark: The numbers 0,3,4,6 are just guesses which seem to be sensible to convert the μ-quality and worked pretty good. But it is not a fixed setting an could be changed if appropriate reasons appear.

  In the following table the complete mapping of the ZEUS variables is documented.

ZEUS data	**CMS data**
Runnr	run
Eventnr	event
0	luminosityBlock
Xvtx	PV_x
Yvtx	PV_y
Zvtx	PV_z
Chivtx	PV_chi2
1	nPVtx
Xvtx	PVtx_x(1)
Yvtx	PVtx_y(1)
Zvtx	PVtx_z(1)
Chivtx>=0	PVtx_isValid(1)
some cuts	PVTx_isGood(1)
1	PVtx_isMain(1)
Chivtx<0	PVtx_isFake(1)
Ntrkvtx	PVtx_ntrkfit(1)
Chivtx	PVtx_chi2(1)
1	PVtx_Id(1)
$\sqrt{(\text{Xvtx-Bspt\_x})^2 + (\text{Yvtx-Bspt\_y})^2}$	PVtx_Rho(1)
Nmu	nMuon
Mucharge	Muon_charge
Mupt	Muon_pt
-log(tan(Muth/2)	Muon_eta
Muph	Muon_phi
0.105658	Muon_mass
Muqual>0	Muon_looseId
Muqual>3	Muon_softId
Muqual>4	Muon_mediumId
Muqual=6	Muon_tightId
Mutrid	Muon_trkIdx
Muperr*sin(Muth)	Muon_ptErr
Muzufid>0	Muon_isPFcand
1	Muon_isTracker
Muqual>0	Muon_isGlobal
Muqual=6	Muon_isStandAlone
-13*Mucharge	Muon_pdgId
Muchid	Muon_chi2
Muz	Muon_z
Mudxy	Muon_dxy
Mudz	Muon_dz
Muisol/Mupt	Muon_pfreliso03_all
Muvtxid	Muon_vtxIdx
Muvtxfl	Muon_vtxFlag
Mujetid_a	Muon_jetIdx
Bspt_x	Bsp_x
Bspt_y	Bsp_y
Bspt_z	Bsp_z
Bspt_xer	Bsp_widthx
Bspt_yer	Bsp_widthy
Bspt_zer	Bsp_sigmaz
Bspt_dxdz	Bsp_dxdz
Bspt_dydz	Bsp_dydz

In general the data for each event is stored in arrays with length `nMuon` $\in \mathbb{N}$. But the length of the arrays must be declared *before* they are used. This issue is handled by declaring `const int Nmax = 20`, and set the length of the array to `Nmax`. This is maximum length for arrays since there are no events with more than 20 Muons on the n-tuple. Additionally the code will throw a warning if this should not be correct and `nMuon` > 20 appears. This will not happen on the used n-tuples but if the code is used for any other dataset or as a template for another conversion this technicality might not be observed so the warning makes this clear to the user.
The output of the code is a `.root` file which contains the corresponding data from the ZEUS n-tuple but in the CMS format.
The applied cuts are more or less normal cuts which are documented in the next section. Special are the cuts for cosmic muons which are appear in the ZEUS datsets and have not been filtered out good enough for this application. The cosmic muon cut works the following. First we define the angle difference

$$\Delta\varphi := \varphi_{\mu_1} - \varphi_{\mu_2}.$$

Convert periodicity

$$\Delta\varphi \mapsto \begin{cases} \Delta\varphi, & \text{if } \Delta\varphi \in [-\pi, \pi] \\ \Delta\varphi - 2\pi, & \text{if } \Delta\varphi > \pi \\ \Delta\varphi + 2\pi, & \text{if } \Delta\varphi < -\pi \end{cases}.$$

Cut event if

$$||\Delta\varphi| - \pi| < \frac{5\pi}{100} \quad \wedge \quad |\eta_{\mu_1} + \eta_{\mu_2}| < \frac{5\pi}{100}.$$

2.2 AOD to NanoAODplus

The NanoAnalyzer.cc program converts AOD format into NanoAOD(plus) format. The trigger information is stored in the different formats in the following way. In the AOD format the trigger path that lead the event it is memorized as a string, e.g.: `triggerName(i)=="HLT_DimuonXX_v1"`.
For the NanoAOD format this information is stored in a different way since there is a boolean variable which is true for an event exactly when this event has the corresponding trigger path, e.g.: `HLT_DimuonXX_v1==1`.
The NanoAODplus format is now the same like the NanoAOD format but has additional variables, namely

- `Dataset` - is a boolean variable corresponding to a data sample type which is only `true` if the event is of this type.
- `Alsoon` - is a variable which says for a specific datatype if the event is also in this data sample.
- `Trig`- stores information about a trigger if an event has passed this trigger.

This implementation has been done for some data samples but still many are missing. To make this code complete all trigger paths must be explicitly implemented which has been done for example for Run 2011A SingleMu and DoubleMu previosly and by this year (2021) DESY summerstudent Murillo Rebuzzi Vellasco for more triggers like for example Run 2011A/B MuEG or Run 2012B/C DoubleElectron etc. The contribution to this is the implementation of the Run 2011A/B MuOnia triggers which are now a further extention to the code.
The implementation has been done the following way: The missing trigger paths have to be added to the `NanoTrigger.cc.forinclude` code. First on the CERN open data website the corresponding high-level trigger information has to be checked. For example for the Run 2011B MuOnia `https://opendata.cern.ch/record/280`. But from these runs only the valid runs which appear in the JSON file have to be considered. From these files one can extract the corresponding triggers, in this case for the MuOnia triggers. Also the different versions have to be considered and then finally be added to the code. In some cases this is more or less straight foreward if similar triggers already have been implemented. If nothing similar has been implemented this is more difficult such like putting additional flags.

3 Results

After a successful conversion from ZEUS to CMS data one can run the CMS analysis code with these files. The following plot shows the J/Ψ-peak from the converted ZEUS data, created with the CMS analysis code and the corresponding ZEUS cuts.These ZEUS cuts are mainly changes to the ATLAS $p_\top$ cuts and additional cosmic cuts since previous results showed that cosmic muons have not been selected out strict enough before in the ZEUS data. This also decreased background for the J/Ψ analysis. Table 1 shows the to the ZEUS data applied cuts.

Table 1: Table for J/Ψ analysis with converted ZEUS data.

J/Ψ
$\mathrm{pT}(\mu_1) \geq 1$ GeV $\wedge$ $\mathrm{pT}(\mu_2) \geq 1$ GeV
$Q_{\mu_1} + Q_{\mu_2} = 0$
$M_{\mu\mu} \leq 3.4$ GeV $\wedge$ $M_{\mu\mu} \geq 2.8$ GeV
`Muon_isGlobal == true`
`Muon_softId == true`
Cosmic cuts

The cosmic cuts have an effect that the rapidity distribution looks now reasonable. Before there was a single peak at 0 rapidity (see Figure 1). The asymetric distribution comes mainly from the ZEUS detector. The plots in Figure 2, 4-13 show

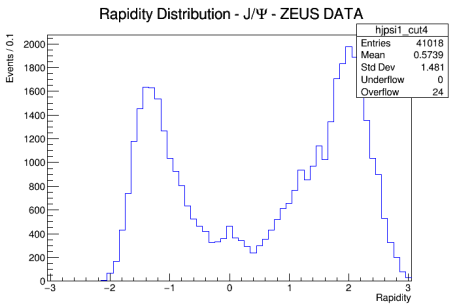

Figure 1: ZEUS data `06p`

the analysis of the different ZEUS datasets. In Figure 3 there is a plot produced with the same analysis code with the converted ATLAS 2012 data. A clear J/Ψ peak shows that ZEUS conversion is working. Additionally there is a hint for the Ψ' is recognizable. In Figure 3 there is a plot produced by Leonardo Olivi who analyzed the converted ATLAS 2012 data with the same code. This plot is a good comparison between datasamples from a different experiment. The quality cuts for this plot although were different. There are no cosmic cuts since the ATLAS data has already high quality muons and the transverse momentum cuts are higher than for the ZEUS cuts. Details for that are available in Leonardos Report. In the `04` datset the distribution has a linear decreasing background.

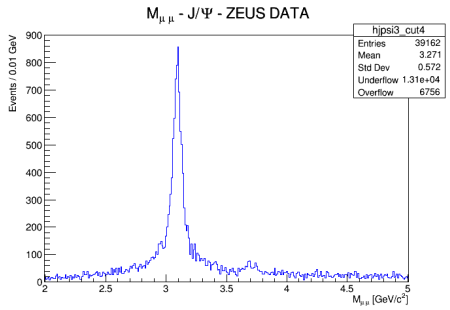

Figure 2: ZEUS Data 00p

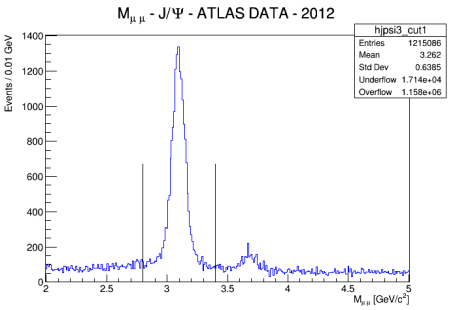

Figure 3: ATLAS 2021 Data

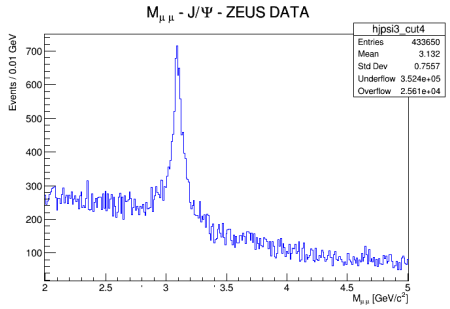

Figure 4: ZEUS Data 04

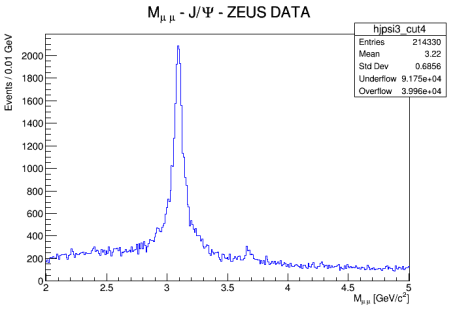

Figure 5: ZEUS Data 05

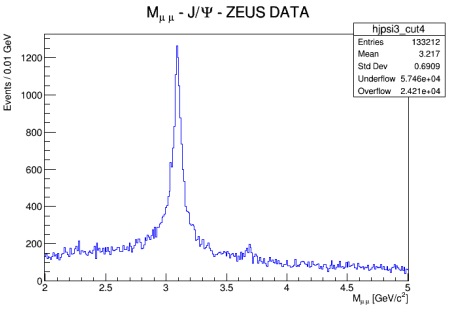

Figure 6: ZEUS Data 06e

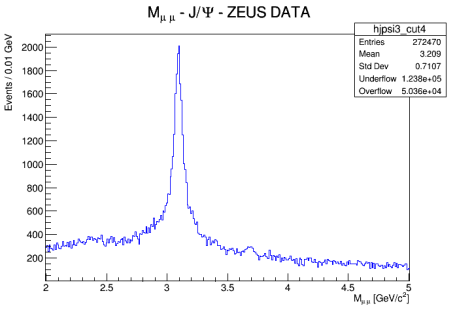

Figure 7: ZEUS Data 06p

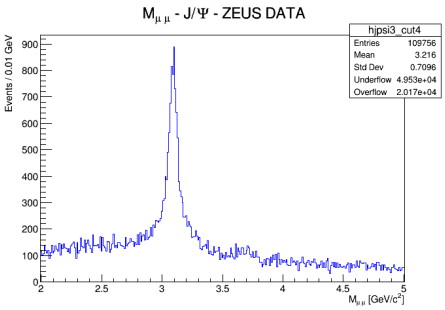

Figure 8: ZEUS Data 07p

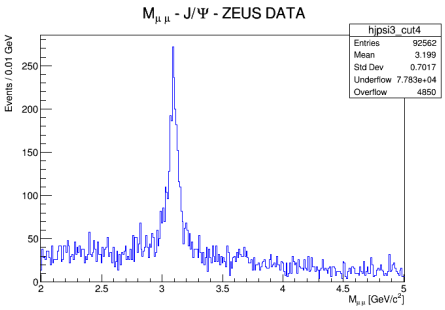

Figure 9: ZEUS Data 96

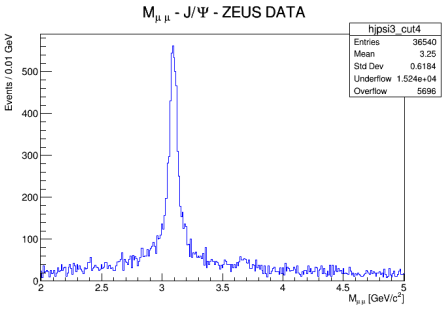

Figure 10: ZEUS Data 97

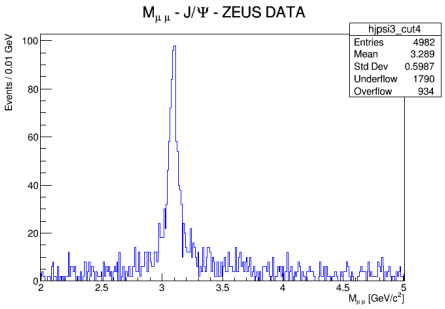

Figure 11: ZEUS Data 98

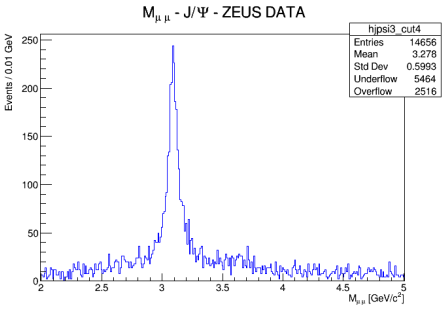

Figure 12: ZEUS Data 99e

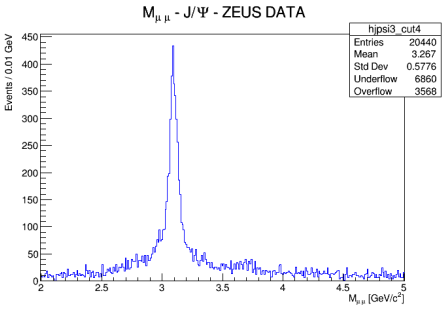

Figure 13: ZEUS Data 99p

4 Conclusion

All in all the project can be considered as a success. The fundamental code which converts the ZEUS data is working and the plots produced with the converted datasets in the CMS format show meaningful results. One common analysis code gives clear J/Ψ peaks for the datasets. Since the project is in a line of previous and future summerstudent projects it is part of a bigger project to make step by step different datasets compatible and increase statistics by doing that. For technical aspects, the trigger implementation will contribute to improvement of results in future applications.
In the future the ZEUS to CMS conversion code can be extended for example by adding the mapping for the electron data. And of course the trigger implementation could be extended.

5 Acknowledge

I want to take this oppurtunity here to express thanks here to my supervisor Achim Geiser for the great support during the project. The same goes for my co-supervisor Yewon Yang who was very important for this project especially considering technical support. I am very thankful that i had the oppurtunity to have this great experience from which i benefited in many ways.
Very important for this project are also the other summerstudents from the projects B11 and B12, namely Aritra Bal, Leonardo Olivi and Murillo Rebuzzi Vellasco. The discussions with them about physics, technical aspects but also all kind of different topics were a big support. Especially the conversation with Murillo with whom i shared the office really developed a friendship between us. I also want to point out the awesome international atmosphere in the team. This is really something i really enjoyed during my stay here at DESY.

References

|1| Code to produce plots: `/afs/desy.de/user/s/schwenzr/public/RAPHAEL/CMSanalysisCODE`

|2| Code to convert ZEUS to CMS: `/afs/desy.de/user/s/schwenzr/public/RAPHAEL/condor_zeustocms`

|3| nanoAODplus trigger conversion: `/afs/desy.de/user/s/schwenzr/public/RAPHAEL/NanoTrigger.cc.forinclude`

|4| nanoAODplus: `https://www.desy.de/~geiser/nano/nanoAODplusv0.8.html`