Dissociative background estimation for exclusive $\gamma\gamma \to \mu\mu$ events in ultraperipheral lead-lead collisions in the ATLAS experiment

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Introduction

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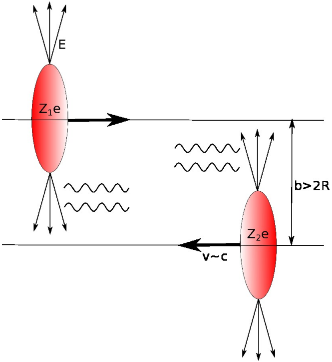
- LHC, apart from the collision of protons, also collides heavy ions such as lead
- In ultraperipheral collisions there is no physical collision, only the electromagnetic fields of the nuclei interact
- In particular, exclusive muon pairs can be produced in such collisions;
  the considered process is:
  $\gamma\gamma \rightarrow \mu^+\mu^-$



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- In the signal process, we expect two muons in back-to-back configuration, opposite in azimuthal angle. We use the following requirements that reflect the signal topology:
  - GRL selection (for data - periods with fully operational detector)
  - HLT_mu4_hi_upc_FgapAC3_L1MU4_VTE50 trigger selection
  - Exactly two muons with $|\eta| < 2.4$ and $\mathrm{p_T} > 4$ GeV each
  - Muons have opposite charges
  - Muons have to pass "LowPt" identification
  - Only two reconstructed tracks per event are allowed (veto other activity)
  - Pair selection: $\mathrm{M}_{\mu\mu} > 10$ GeV and $\mathrm{p_T^{\mu\mu}} < 2$ GeV
  - Transverse-parameter significance $|\mathrm{d_0}/\sigma(\mathrm{d_0})| < 3$.

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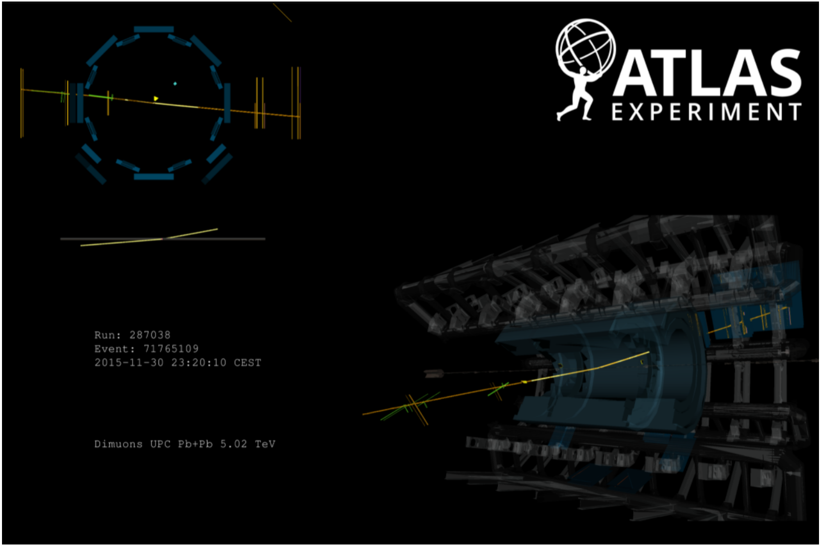
  - Transverse-parameter significance $|\mathrm{d_0}/\sigma(\mathrm{d_0})| < 3$.
- Definitions: $\eta = -\ln(\tan\frac{\theta}{2})$, $\quad Aco = 1 - \frac{|\Delta\Phi|}{\pi}$, $\quad p_T = p\sin\Phi$,

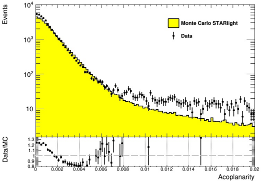
$$m = \sqrt{(\sum_{i=1}^{n} E_i)^2 - (\sum_{i=1}^{n} \mathbf{p}_i)^2}, \quad y_{\mu^+\mu^-} = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

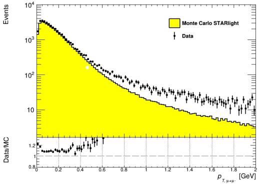
Event display

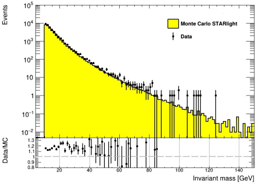


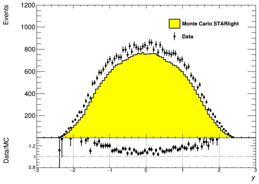
Without dissociation

Results of data and STARlight+Pythia8 Monte Carlo comparison:









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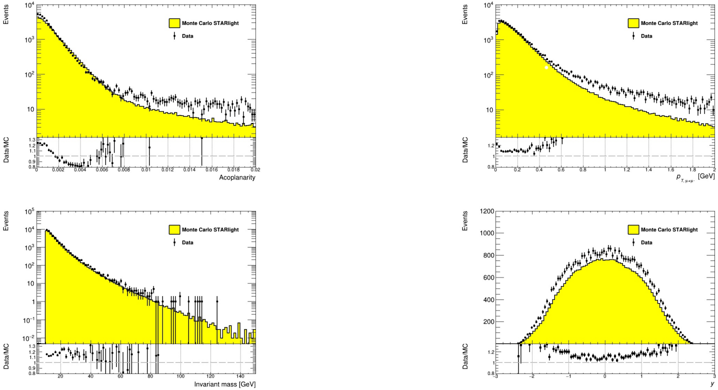
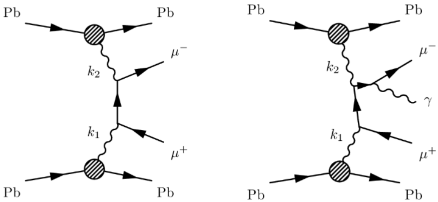


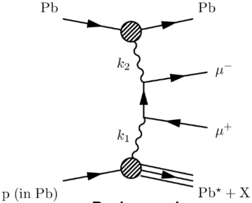
Conclusion: Not very good agreement in the tail region in acoplanarity and p_T.

Background

In background processes there is a break-up (dissociation) of one or both ions, what results in emission of one or more neutrons.



Signal



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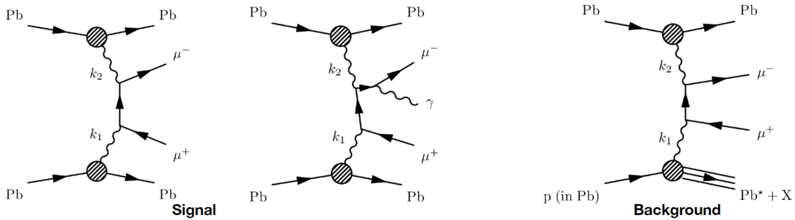
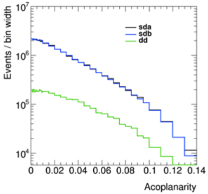
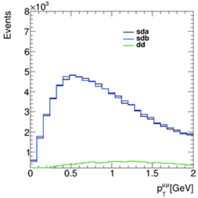


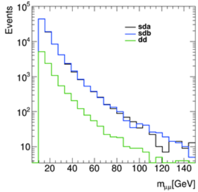
Neutrons are emitted in the forward direction (along the beam).

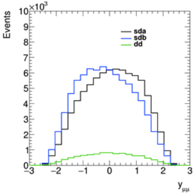
Background

We have 3 sets of dissociative samples (SuperChic4+Pythia8): two with single dissociation (one per each side of the detector) and one with double dissociation.









Background

Signal and background differs in the forward activity and in dimuon acoplanarity.

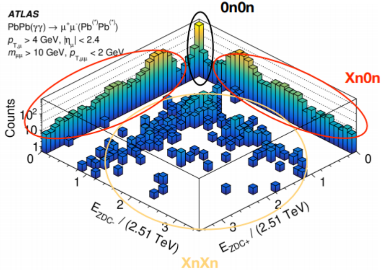
We don't have simulation for Pb-Pb collisions available. Instead we use sample for proton collisions and we estimate the fraction of dissociative events by fitting the background template shape to data. For this purpose we use the TFractionFitter tool available in Root.

The background shape template is obtained by adding three dissociative samples normalized to their cross sections.

ZDC topology classes

Events are divided into 3 classes based on the signal in the Zero-Degree Calorimeter (ZDC), which describes forward neutron activity (0n0n, 0nXn, XnXn).

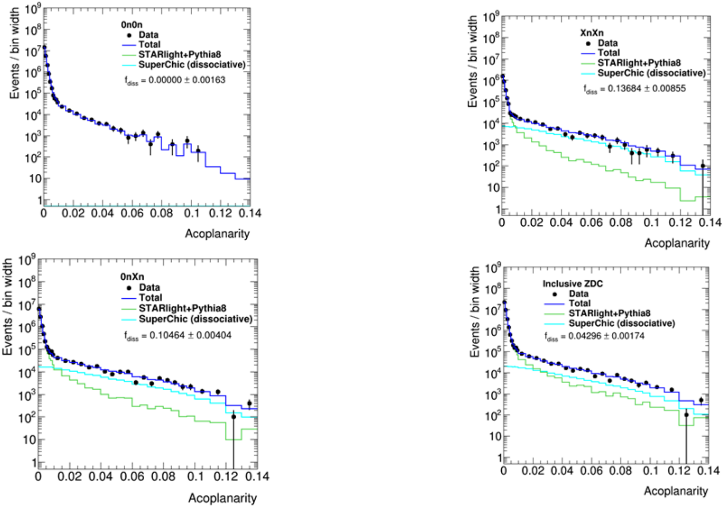
Figure: arXiv:2011.12211



The goal is to calculate dissociative fraction in each of these classes in order to adjust in the tail region of acoplanarity.

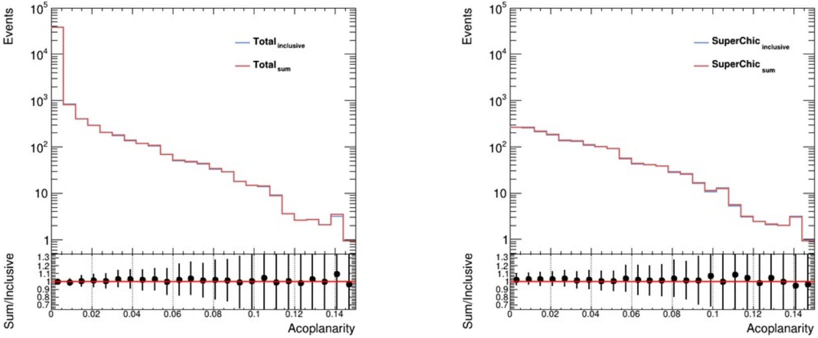
Background estimation - nominal fit

Inclusive result is a weighted sum of results for three ZDC classes.



Background estimation

As a cross-check also fit to inclusive sample was performed.
It is compared to the sum of results for three ZDC classes.



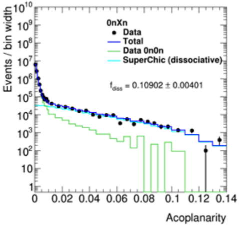
Systematic uncertainties

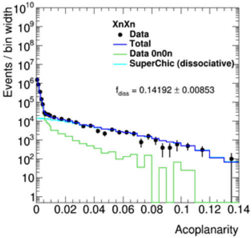
Two sources of systematic uncertainties are considered:

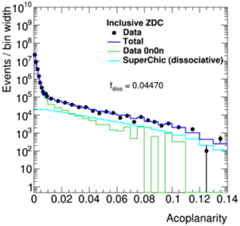
- Instead of STARlight Monte Carlo we used 0n0n data from nominal samples
- Only single dissociation samples were used

Background estimation

First systematic - 0n0n data used instead of STARlight Monte Carlo

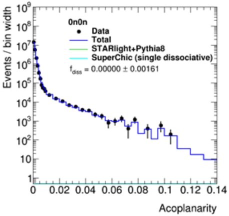


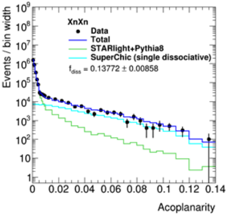


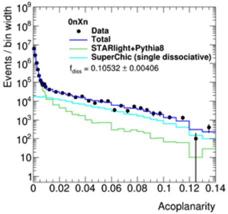


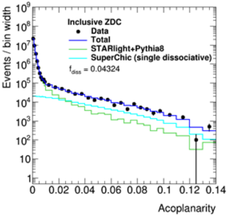
Background estimation

Second systematic - without double dissociation









Dissociative fractions - summary

Inclusive result is a weighted sum of results for three ZDC classes.
The uncertainty is calculated using the propagation of uncertainties.

	Inclusive	**0n0n**	**0nXn**	**XnXn**
Nominal	0.0430 $\pm$0.0017	0 $\pm$0.0016	0.1046 $\pm$0.0040	0.1368 $\pm$0.0086
Data 0n0n	0.0447	-	0.1090 $\pm$0.0040	0.1419 $\pm$0.0085
Without dd	0.0432	0 $\pm$0.0016	0.1053 $\pm$0.0041	0.1377 $\pm$0.0086

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Both systematics give higher fractions of dissociative background.
Systematic differences are mostly smaller than the fit uncertainties.

Summary

- The sample of exclusive dimuon sample was selected in 2018 Pb-Pb ATLAS data
- The samples was divided into three ZDC classes: 0n0n, 0nXn, XnXn
- Dissociative fractions from nominal fit and two systematic uncertainties were determined
- Other sources of systematic uncertainties may also be considered e.g. adding trigger corrections to MC in event selection (to account for differences in trigger efficiency in data and MC)