Study of the LHC Luminosity at the ATLAS Experiment using Scintillating Counters

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Summary

- What is luminosity and why it is important to determine it?
- What are the methods used to measure it?
- What are the main difficulties?
- Results of luminosity analysis in the presence of pile-up
- Conclusions and outlooks

Introduction

- LHC is colliding protons inside 4 main experiments
- What is an interaction?

It is the physical process, the collision between two protons

- What is an event?

It is defined by the trigger
(the trigger threshold and time window define an event)

⇒ There might be several interactions in an event (*pile-up*)
My job consisted in checking the influence of pile-up on luminosity

What is luminosity?

- For a given process of kind a, the luminosity $\mathscr{L}$ relates the cross section σ_a to the detected number of events N_a^{seen}:

$$\frac{1}{\epsilon \cdot A}\frac{dN_a^{seen}}{dt} = \sigma_a \mathscr{L}$$

- Acceptances (A) and efficieny (ϵ) have to be taken into account
- All the measurement of cross sections consist in counting number of events. Therefore, they need the normalization trough luminosity
- Luminosity determination is a limiting factor for cross section measurements

$\Rightarrow$ We have to measure luminosity accurately

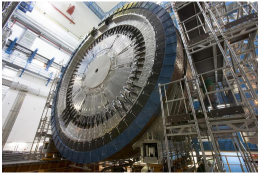
How to measure luminosity?

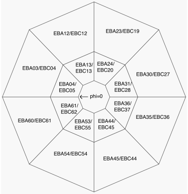
- From the LHC beam parameters: $\mathscr{L} = f_{rev} \frac{1}{2\pi} \frac{n_{bunches} \cdot N_{protons}}{\Sigma_x \cdot \Sigma_y}$
- By using the $\frac{1}{\epsilon \cdot A} \frac{dN}{dt} = \sigma \cdot \mathscr{L}$ formula
  - We have to measure luminosity in the range $10^{27} \rightarrow 10^{31} cm^{-2} \cdot s^{-1}$ and we know that $\frac{1}{\epsilon \cdot A} \frac{dN}{dt} \simeq \mathcal{O}(1)$

  $\Rightarrow$ Therefore the cross section used has to be of the order of the mb $(10^{27} cm^{-2})$
  - In this study, we are counting inelastic proton-proton collisions $(\sigma_{pp} \simeq 70\ mb)$
- How to count those interactions?

Minimum Bias Trigger Scintillators

- 2×16 scintillators on the barrel endcaps ($2.1 < |\eta| < 3.8$)
- MBTS has a good acceptance ($\sim 80\%$) for inelastic pp events





- A MIP produces photons by ionization
- Photons are collected to the photocathodes and converted to photoelectrons with an efficiency $\mathcal{O}(20\%)$
- The signal is amplified by the PMTs $\mathcal{O}(10^5)$
- The charge are collected at the output of the PMTs and further amplified by the electronics $\mathcal{O}(10^2)$
- A MIP in MBTS $\rightarrow$ charge deposit of $\mathcal{O}(0.2)$ pC

Pile-up

- The average number of interactions per bunch crossing μ follows a Poisson distribution:

$$P(N,\mu) = \frac{\mu^N \cdot e^{-\mu}}{N!}$$

We assume that the detection efficiency for an interaction ϵ_1 is independent of the number of interactions in the event

This means that the probability to miss an event with N interactions is:

$$(1-\epsilon_1)^N$$

- Using the Poisson distribution and the expression of the efficiency for N interactions, we obtain the efficiency as a function of μ:

$$\epsilon(\mu) = 1 - e^{-\epsilon_1 \cdot \mu}$$

Methodology (1/2)

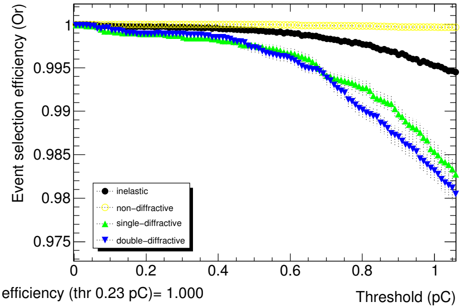
- For Monte-Carlo
  - The events are generated in three steps: simulation of the inelastic interaction between two protons; extrapolation of the primary particles to the MBTS; simulation of the detector response (energy deposit $\rightarrow$ charge)
  - *By definition*, a MC generated event has only one interaction
  - There are different kinds of interactions
  - An event with pile-up is generated by hand in three steps: for a given μ value, take the number of interactions in the event according to a Poisson distribution centered on μ; take the piled-up interactions randomly but according to their cross sections; add the response for each MBTS counters

Methodology (2/2)

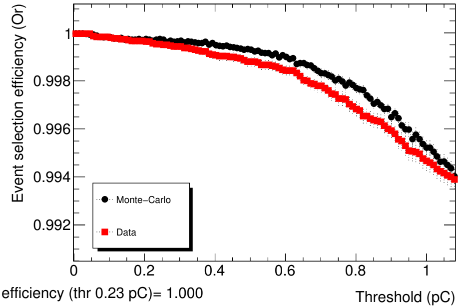
- For data:
  - The events have background
  - To remove it, we take only events that have one vertex (supposedly one interaction)
  - An event with pile-up is generated in the same way as for MC
- We can compare Monte-Carlo and data because the pile-up is done in the same fashion. We can then check the accuracy of our Monte-Carlo events.

Results (1/3)

- Efficiencies as a function of the threshold for events with exaclty one interaction



MC Results for the mixing

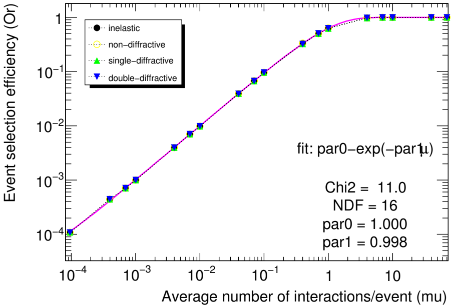


Comparison between data and MC

- Condition: at least one module in MBTS passes the threshold
- Good agreement between data and MC for the actual thresholds

Results (2/3)

- Efficiencies as a function of μ for piled-up events

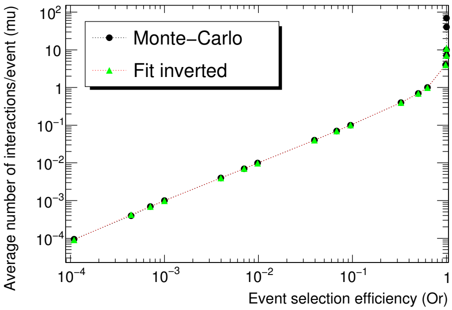


MC Results for the mixing

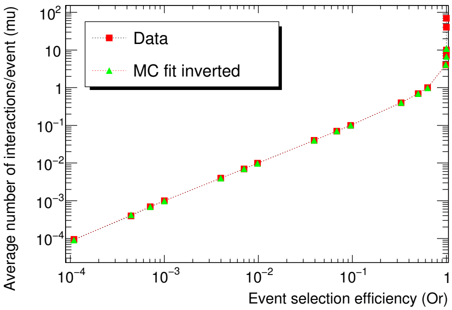
- The fit converges

Results (3/3)

- Inverse function (data-like analysis): μ as a function of the efficiencies for piled-up events



Fit results for MC



Applying the MC fit to Data

- The fit well describes the behavior of Monte-Carlo and Data

Conclusions & Outlooks

- In the near future, the expected μ will be up to 5
- Determining luminosity at μ higher than $\mathcal{O}(5)$ is harder
- A solution might consist in tightening the event selection
- Differences between Monte-Carlo simulation and data have to be studied further on
- The effects of bunches with different μ have to be understood
- Luminosity is an input to every physics analysis $\rightarrow$ its measure is fundamental