Masters thesis: Impact of ATLAS phase II performance on a mono-jet analysis

Half-time presentation

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Brief introduction

This presentation serves to present what goals were set up and what progress has been made.

Goals

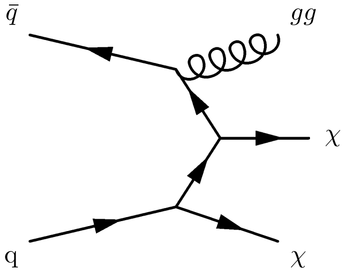
- Implement a C++ programme that loops over the collisions inside the signal and background datasets. **Complete**
- For each collision retrieve the relevant observables (variables used to extract the signal over the background) and apply "smearing functions" to emulate the effect of the high luminosity on the observables. **Complete**
- For both signal and background datasets, compare observables before and after smearing. What observables are the least/most affected? **Complete**
- Implement selection criteria that selects the signal collisions efficiently while reduces significantly the background. In a first step the selection criteria should be taken from existing studies. **Complete**
- Selection criteria can be evaluated and compared with each other using a figure of merit Z, that measures the sensitivity of the experiment to the dark matter signal. Calculate Z for the given selection criteria before and after smearing. **Complete**
- What is the effect of the high luminosity (smearing) on the value of Z? **Work in progress**
- Investigate other selection criteria and observables, to mitigate the effect of high luminosity. Use Z to rank different criteria after smearing. **Work in progress**
- Conclude on the effect of the high luminosity on the sensitivity for dark matter and possible ways to mitigate its effects using alternative observables and selection criteria. **Work in progress**

Dark matter

Dark matter is the name given to the solution to the discrepancies of galactic rotations. It is not known what it is only that it should not interact electromagnetically, (dark) and that it should interact through gravity (matter).
It is experimentally shown that the dark matter in the universe is mostly cold dark matter (high mass [GeV]).
There are no candidates anywhere in the standard model that fulfils all three requirements. (Neutrinos could fulfil two.)

Beyond the standard model: Supersymmetry

SUSY has several different possible candidates for dark matter. This will be expanded during the course of time.



Effective field theory

- The WIMP (usually denoted χ) is assumed as the only particle in addition to the standard model fields.
- χ will be assumed odd under some Z_2 symmetry. This means that an even number of χ must be in every coupling.
- It is assumed that the whatever mediator exists is heavier that the WIMPS, meaning that their interactions are in higher order terms of the effective field theory and thus not included in the operators.
- For simplicity, the WIMPS are assumed to be SM singlets, thus invariant under SM gauge transformations, and the coupling to the Higgs boson is neglected.

Effective field theory

The focus for the operators will be quark bilinear operators on the form $\bar{q}\Gamma q$ where Γ is a 4×4 matrix of the complete set,

$$\Gamma = \left\{1, \gamma^5, \gamma^\mu, \gamma^\mu\gamma^5, \sigma^{\mu\nu}\right\}$$

This, together with the couplings to GG define an effective field theory of the interaction of singlet WIMPS with hadronic matter. It is a non-renormalizable field theory which will break down when the mediator mass close to the mass of the WIMP.

$$m_\chi \leqslant 2\pi M_*$$

Where m_χ is the mass of the WIMP and M_* is the mass of the mediator.

Effective field theory

In this work, WIMPS are assumed to be Dirac fermions (half integer spin and is not its own antiparticle).

Name	Initial state	Type	Operator
D5	qq	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q$

Table : From CERN-PH-EP-2012-210

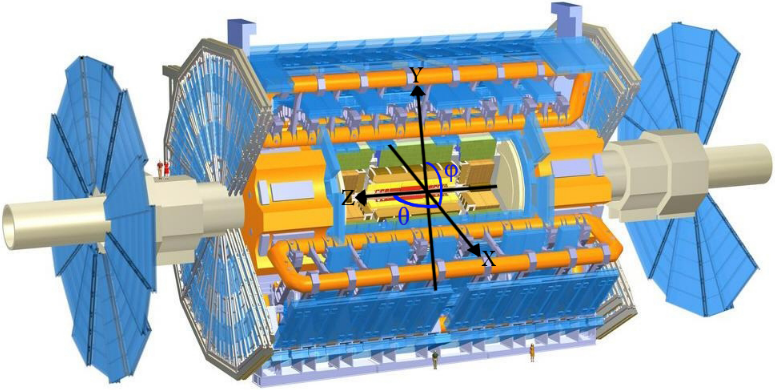
Search for WIMPS

One of the candidates for dark matter, the one of interest here, is a WIMP (Weakly Interactive Massive Particle).
Through SUSY there are particle candidates.
The idea of my research is to find limitations of the mass in the different models. As in the operators above.

Monte Carlo simulation

The simulated data is produced using a Monte Carlo simulation.
The simulation only takes the interaction into account, no detectors.
This is why in the thesis several "smearing" functions are used.
These functions alter the data to simulate what will be detected when the pile-up has been taken into account.

Coordinate system



Jet and missing energy

In particle collisions, often jets are produced. These are showers of quarks or gluons that travel with high energy in a conform direction and interact during their time in the detector.
How does one find dark matter?
If the detectors can not find it, look in the transversal missing energy (Mono-jet events). Can be comprised of neutrinos and exotic matter.

Jet and missing energy

Missing energy refers to the modulus of the missing momenta. It is well known that in the transversal direction momenta before should be 0.

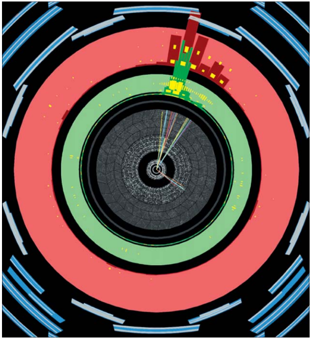
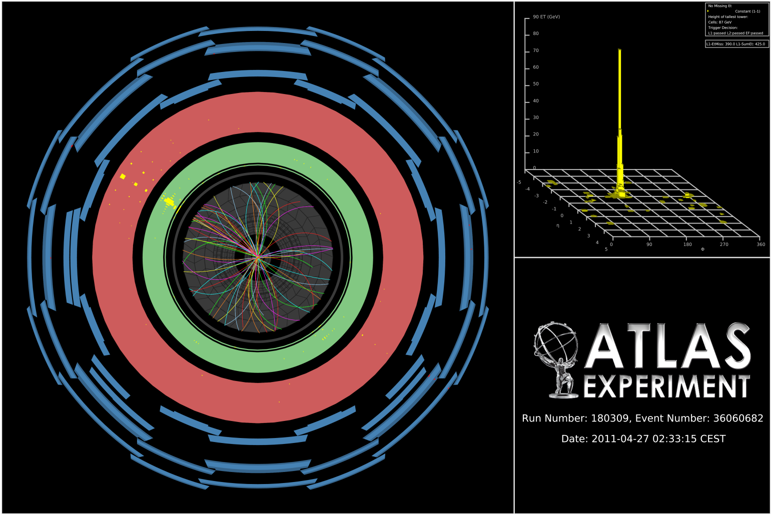


image from http://cerncourier.com/cws/article/cern/52017



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-096/fig_08.png

Terminology I

- For two collinear intersecting particle beams the instantaneous luminosity is defined as:

$$I = \frac{fkN_1N_2}{4\pi\sigma_x\sigma_y} \tag{1}$$

where N_i are the number of particles in each of the bunches, f is the frequency at which the bunches collide , k the number of colliding bunches in each beam, and σ_x (σ_y) is the horizontal (vertical) beam size at the interaction point.

Terminology II

- The expected number of events can be calculated by using the instantaneous luminosity through the following:

$$N = \sigma \int I dt := \sigma L \tag{2}$$

where L is the luminosity and σ is the cross section which is often measured in barn. 1 barn(b)$= 10^{-24}$ cm^2. The luminosity is a measurement of total number of interactions that have occurred over time.

Terminology III

- The cross section is defined through the integral of the differential cross section over the whole solid angle:

$$\sigma = \oint d\Omega \frac{d\sigma}{d\Omega} \tag{3}$$

The cross section is therefore a measure of the effective surface area seen by the impinging particles, and as such is expressed in units of area. The cross section is proportional to the probability that an interaction will occur. It also provides a measure of the strength of the interaction between the scattered particle and the scattering center.

Phase II high luminosity upgrade

I am looking at the upgrade which will be done at CERN and will be completed around 2022-2023 and is denoted High Luminosity LHC Phase 2 upgrade. When this is running the following is expected:

Entity	Expected	Last run (2012)
Luminosity	1000-3000 fb^{-1}	20.8 fb^{-1}
Pile-up	$\langle \mu \rangle = 200$	$\langle \mu \rangle = 20.7$
Center of mass energy	$\sqrt{s} = 14$ TeV	$\sqrt{s} = 8$ TeV

What have I done?

So far I have quickly gone over some theory, the question still remains, what have I done so far and what is left to do?
Most of what has been done so far is to set the foundation for the analysis work (which has just started). Hopefully the following will serve as a nice appetizer

Smearing

As discussed before, the MC simulation does not take the detectors or pile-up into account. This is done by "smearing" functions. One of the first steps in the project was to ensure that the given functions conformed to the letter of intent for the phase II HL upgrade.

Validation

- This is a part of a talk I gave at SU.
- Emulate the ATLAS detector performance and the beam conditions of the Phase 2 LHC by smearing the Lorentz vectors of the truth data.
- The expected response has been calculated and taken from: ATL-PHYS-PUB-2013-004
- Below are figures that compare energies before and after the smearing.

Processes simulated

Example

The smearing functions affect the following, and data is taken from the following processes.

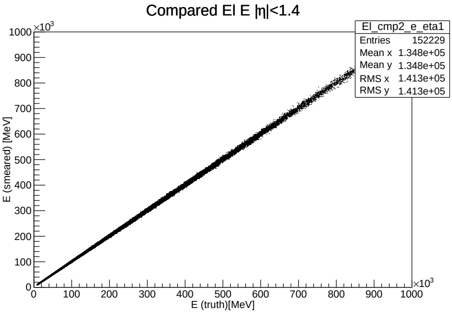
- Electron, W$\rightarrow e\nu$
- Muon, W$\rightarrow \mu\nu$
- γ, γ + Jet sample.
- Tau, W$\rightarrow \tau\nu$
- Jets, Jet sample.
- E_T^{Miss}, Z$\rightarrow \nu\nu$ + Jet sample

Processes simulated

The pile-up rate was fixed at 60 for all these validations, also to shorten the presentation only the electron was presented in full.

Electron

Here are all electrons paired with their smeared counterparts.



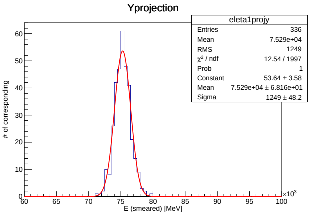
As expected, the smearing produces a widening line. Where: $\eta = -\ln(\tan\frac{\theta}{2})$

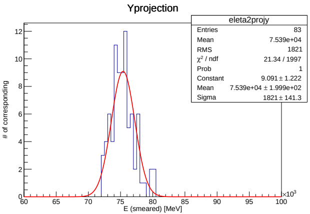
Electron

- To emulate the fact that not all particles/jets are identified (efficiency), a random number generator is used to randomly throw away electrons that exist at the truth level.
- Also, the code makes sure that only the data which is smeared is plotted against its unsmeared counterpart.

Electron

Taking a slice of truth around E=75 GeV. Taking here for $|\eta| < 1.4$ and $1.4 < |\eta| < 2.47$





$\sigma = 0.3 \oplus 0.1\sqrt{E(GeV)} \oplus 0.01E(GeV),\ |\eta| < 1.4$
$\sigma = 0.3 \oplus 0.15\sqrt{E(GeV)} \oplus 0.015E(GeV),\ 1.4 < |\eta| < 2.47$

Comparing sigma

Entity	Expected σ MeV	σ MeV	significance
Electron, low eta 75GeV	1184	1249	1.35σ
Electron high eta 75GeV	1744	1821	0.5σ
Muon low eta 75GeV	1497	1190	2.8σ
Muon high eta 75GeV	1593	1707	2.5σ
γ low eta 75GeV	1184	1189	0.14σ
γ high eta 75GeV	1744	1802	1.5σ
τ 150GeV	10339	10899	1.0σ
Jet low eta 100GeV	11598	11397	0.6σ
Jet low mid eta 100GeV	11935	11509	0.8σ
Jet high mid eta 100GeV	10944	11291	1.1σ
Jet high eta 100GeV	13500	16611	2σ
E_X^{miss} 750GeV	48448	45201	2.0σ
E_Y^{miss} 750GeV	48448	42690	2.3σ

Concerns

- Looking at the data and comparing to expected results one sees some discrepancies.
- The two main sources of errors are: small amount of statistics (smaller σ) and the error calculations in ROOT (programming language used).

Signal to background ratio

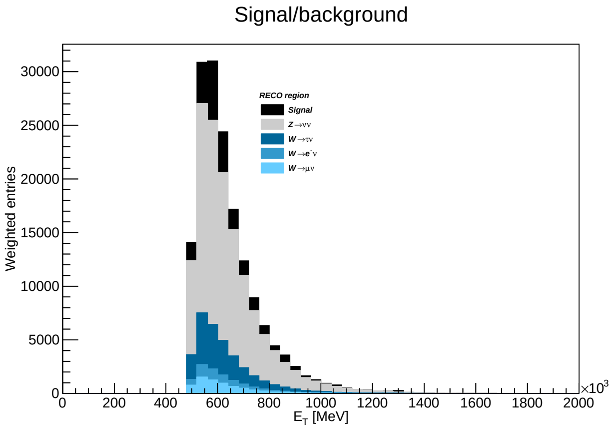
This is still a work in progress. All pieces are in place, what is needed is time to analyse all the signals from the models and to see which ones are viable.

Figure of merit

The figure of merit used is the p-value instead of previously declared z-value. The difference is that the p-value gives the percentage of probability that the signal is masked by statistical variations in the background where as the z-value gives this value in terms of σ (Standard deviations). This will be discussed more in the report when more work on this has been done.

A sample figure of signal/background

Signal to background diagram of a model where: we assume WIMP pairs , with a light vector mediator.



Remaining work

- Evaluate different simulated signals for different WIMP candidates using the p-value and see how they are affected by pile-up.
- See how the effect varies depending on signal region and observables.
- Conclude which models are most viable and in which regions.
- Finalize the report.

Thank you

Thank you for your attention.

Backup