Sharing ATLAS data and research with young students

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on behalf of the ATLAS experiment and IPPOG

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Sharing ATLAS data and discoveries

- LHC is a discovery machine
- Our ambition is to share ATLAS data and LHC discoveries with high school students
- IPPOG ATLAS masterclasses created to accommodate this
- uses simple techniques and tools to measure known particles and discover new
- Two main approaches
  1. Invariant mass technique using the Z-boson as starting point
  2. Probe inner structure of the proton using the W-boson

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1. Z-Path Oslo, 2. W-Path Dresden
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In IPPOG masterclasses students

- Analyze real ATLAS data
- Work like a real physicist
  - Analyze collision data according to particle content - particle detectives
  - Statistically combine results with other students
  - Discuss results
  - Compare with ATLAS measurements

\(^1\)Z-Path Oslo, \(^2\)W-Path Dresden
ATLAS data for the public

Two main data-samples, both include Higgs candidates.

1. Invariant mass - 8 TeV data (Z-path)
   - Di-leptons: 20 000 events
     - $Z \rightarrow \ell^+ \ell^-$, $J/\Psi \rightarrow \ell^+ \ell^-$, $\Upsilon \rightarrow \ell^+ \ell^-$
   - Higgs $H \rightarrow \gamma \gamma$ candidates: 12 000 events (2 $fb^{-1}$)
   - Higgs $H \rightarrow 4 \ell$ candidates: 40 events (2 $fb^{-1}$)
     - $H \rightarrow 2 \times e^+ e^-$ $H \rightarrow 2 \times \mu^+ \mu^-$ $H \rightarrow e^+ e^- + \mu^+ \mu^-$
   - $Z' \rightarrow \ell^\pm \ell'^\mp$ di-lepton events: 2000 fully simulated events

2. Inner structure of proton and Higgs search - 7 TeV data (W-path)
   - $W^\pm$ single lepton: $\sim$ 1000 events
     - $W^\pm \rightarrow e^\pm \nu$, $W^\pm \rightarrow \mu^\pm \nu$
   - $W^+ W^-*$ Higgs candidates: $\sim$ 700 events
     - $W^+ W^-* \rightarrow e^+ \nu + e^- \nu$, $W^+ W^-* \rightarrow \mu^+ \nu + \mu^- \nu$, $W^+ W^-* \rightarrow e^\pm \nu + \mu^\mp \nu$
   - Background: 3300 events, jets, Z-boson (di-lepton) production
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All data selected using official (or close to official) ATLAS selection criteria. Data produced in an xml-format to be visually analyzed in event-displays.

- Each student (pair) analyzes 50 events
- Z-path uses **HYPATIA** event-display
- W-path uses **MINERVA** event-display
- Both HYPATIA and MINERVA are based on the official ATLAS event-display ATLANTIS.
Key Concepts

- Heavy particles like the Z- and W-boson live only a fraction of a second before they decay
- Students learn that the decays occur according to conservation rules (collected in the SM)
  - The decay products, or the final-states, are recorded in ATLAS
- Through the decay-products we can play detectives and reconstruct the originally produced particle - i.e. identify the event
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ATLAS particle identification (link: ATLAS wedge)

- Electrons: Track in Inner Detector (ID), deposit in Electromagnetic Calorimeter (ECal),
- Photons: Deposit in ECal
- Muons: Track through ID and Muon Spectrometer (MS)
- Jets: Multiple Tracks in ID, deposit in ECal and Hadronic Calorimeter (HCal),
- Neutrino: Missing energy-momentum

Particle identification - means to event identification
The ATLAS Z- and W-paths IPPOG Masterclasses

Employed at common web-platform:

○ 10500 students participated in 2014 IPPOG MC
  ○ 67 institutes used Z-path
  ○ 51 institutes used W-path

○ Both paths can be used standalone outside the the International Masterclasses arranged each year by IPPOG

LHC@InternationalMasterclasses

Join us on a journey to the smallest pieces of matter! Learn what is happening 100 meters below the ground at the European Organization for Nuclear Research (CERN). In the Large Hadron Collider, with a circumference of 27 kilometres, the experiments ALICE, ATLAS, CMS, and LHCb are running. The following short video gives an impression of the start of a fascinating journey looking for the origin of mass, Dark Matter, and new phenomena such as Supersymmetry or Extra Dimensions.
The ATLAS Z-path

Introducing the Z boson

Identifying particles

Identifying events

Rediscover the Z boson

Get to work

Discover the Unknown

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4th July 2014
Physics measurement Z-path

- The Z-path focuses on the concept of invariant mass as a powerful identification and discovery tool

\[ m_0^{(Z)} = \sqrt{\left(\frac{(E_{e^-} + E_{e^+})}{c^2}\right)^2 - \left(\frac{\not{p}_{e^-} + \not{p}_{e^+}}{c}\right)^2} \]

- Use the invariant mass to measure well known particles
  - \( J/\psi \rightarrow \ell^+ \ell^- \)
  - \( \Upsilon \rightarrow \ell^+ \ell^- \)
  - \( Z \rightarrow \ell^+ \ell^- \)

- Discover new phenomena (particles, interactions, symmetries, dimensions)
  - new gauge bosons: \( Z' \)

- Use the same technique to discover the Higgs boson
  - \( H \rightarrow \gamma \gamma \)
  - \( H \rightarrow ZZ^* \rightarrow 4\ell (\ell^+ \ell^- + \ell^+ \ell^-) \)
Identifying events Z-path

1. $\mu^+ \mu^-$ or $e^+ e^-$ pair?  
   - $J/\Psi$, $\Upsilon$ or $Z$ candidate

2. Di-photon event?  
   - Higgs candidate!

3. Four “good” leptons?  
   - Higgs $ZZ^*$ candidate!

4. Photons or electrons: photon conversions  
   - Construct invariant mass of electron-pair - close to 0? → converted photon!  
   - Cut on inner detector hits and momentum - do tracks disappear? → converted photon.
Overview of results in OPloT

- Students upload results into the OPlot web-interface
  - OPlot php-based - developed in Oslo to ease submission, combination and discussion of results

- Results per institute and per day are automatically combined by OPloT

OPloT – MasterClass – Combination for all institutes on 2014-03-14
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M. Pedersen

Di-lepton result

Discussion points

- Compare electrons and muons.
- Measure mass and width.
- What are the events at 1000 GeV?
Students did a great job in identifying di-photon events
- No prominent peak - but as expected
- A small fraction of events around 125 GeV are Higgs
- With more statistics a discovery could be made
- Comparison of ATLAS official and student results

Student distribution

Expected distribution (simulation) with 25 $fb^{-1}$
Z-path: 4l analysis results and Higgs
Analysis discussion

○ Compare $4\mu$, $4e$, $2e+2\mu$

○ Why is the student result (much) larger than what is expected?

○ Do we see any sign of the Higgs?

○ If not, why?
The ATLAS W-path

Identifying particles

Looking for the Higgs

Identifying events

Exploring the Proton

Key Concepts
IPPOG Masterclass web-pages
Z-path measurement and results
Identifying events with Z-bosons
Identifying events with W-bosons
W-path results
Future prospects
Conclusions
Identifying events $W$-path

⊙ **Single $W$-candidates**
  ⊙ Probe inner structure of proton - valence quarks (uud) - sea quarks
  ⊙ Count number of positively and negatively charged leptons
  ⊙ Ratio $N_{W^+}/N_{W^-} = 2$ if proton only consisted of uud

⊙ $W^\pm W^{\mp\ast}$ events - Higgs candidate
  ⊙ Measure opening angle between leptons

1. **Single isolated lepton?**
   **Missing energy?**
   ⊙ $W^\pm \rightarrow \ell^\pm \nu$ candidate
   ⊙ Determine charge

2. **Opposite sign, same flavour lepton pairs and little missing energy?**
   ⊙ Background ($Z$) - discard

3. **Jets, and no isolated leptons?**
   ⊙ Background - discard

4. **Opposite sign, any flavour lepton pair? Large missing energy?**
   ⊙ Higgs candidate $H \rightarrow W^\pm W^{\mp\ast} \rightarrow \ell^\pm \nu + \ell^{\mp \nu}$
   ⊙ Measure opening angle between leptons
W-path result $N_{W^+}/N_{W^-}$

- Each group of two students deliver their results to an online spreadsheet
- Results are automatically combined

**IMC 2014: $R_\pm$ measurement**

Avg: $1.33 \pm 0.20$

**Student result:** $1.33 \pm 0.20$

**ATLAS Official:** $1.50 \pm 0.03$
W-path result $N_{W^+}/N_{W^-}$

- Each group of two students deliver their results to an online spreadsheet
- Results are automatically combined
- Results are compared to ATLAS' official measurement

**IMC 2014: R± measurement**

Avg: $1.33 \pm 0.20$

Student result: $1.33 \pm 0.20$

ATLAS Official: $1.50 \pm 0.03$
Opening angle between the two oppositely charged di-leptons from Higgs candidate events

- Higgs candidate events expected to accumulate at low values, while SM background and SM $W^+ W^-$ does not
- Connected with the decay products of the Higgs particle flying off in the same direction (boosted)
Future prospects

The Z-path:

○ In addition to MC Z' (1 TeV) add MC Graviton (500 GeV).
  ○ Z' can be seen in ee and μμ channels
  ○ Graviton would be seen also in γγ and ZZ channel
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- Introduce SUSY final states with 2 leptons, make use of invariant mass (end-point) and missing transverse energy

- More advanced version of Z-path to be available for physics student projects possibility to loop through large samples
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The W-path:

○ Improve data-sample
  ○ Increase identification success-rate
  ○ Decrease complexity
Conclusions

○ ATLAS Masterclasses (and web-pages) developed for LHC data, and used for the first time in 2011

○ Z-path
  ○ developed in Oslo
  ○ a general invariant mass path, to measure known particles, and discover new ones
  ○ flexible: can follow up important discoveries at CERN

○ W-path
  ○ developed in Dresden
  ○ Internal structure of proton, Higgs discovery through WW*

ATLAS Masterclasses bring LHC discoveries to the classroom, and are alive and kicking!