

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS partículas e tecnologia

# Master and PhD Possibilities at ATLAS

Patricia Conde Muíño (IST, LIP)

# The ATLAS Experiment



# The ATLAS experiment

- Specialised detectors
- Cutting edge technology
- 10<sup>8</sup> electronic channels
- Home made fastest electronics



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- Specialised detectors
- Cutting edge technology
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More than 30 years of continuous work





### - 30 Anniversary of the Collaboration



# **ATLAS Collaboration**

- Truly global:
- 181 Institutes,
- 38 countries

Composed of:

- >5000 members
- >3000 scientists
- ~1000 PhD students



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Chile

Italy

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Morocco Argentina Armenia Netherlands Australia Norway Austria Poland Azerbaijan Portugal Belarus Romania Brazil Russia Canada Serbia Slovakia China Slovenia Colombia South Africa **Czech Republic** Spain Denmark Sweden **ATLAS** France Switzerland Georgia Taiwan **Collaboration** Turkey Germany Greece UK Israel USA 181 institutions (231 institutes) from 38 countries CERN IINR Japan



Status: November 2018



Portuguese ATLAS Team: national team LIP (Lisbon, Coimbra, Minho), FCUL, FCTUC, U. Minho, CFNUL CEFITEC/UNL, INESC, CFMC, AdI engineers training program



# **Physics** topics

- Higgs couplings to quarks and W's
  - Spin/CP properties
- Search for new physics
  - Anomaly detection
- Study of the Quark Gluon Plasma
  - B-jets
  - Time evolution

### History of the Universe





#### Top quark properties

#### Comprehensive programme of top

# From discovering the Higgs to measuringits properties201820182018





2015

First observation of



m<sub>T</sub> [GeV]

First observation
 of H→bb



2018

 First observation of ttH production





# And now what?



 $\mathcal{L}_{SM} = D_{\mu}H^{\dagger}D_{\mu}H + \mu^{2}H^{\dagger}H - \frac{\lambda}{2}\left(H^{\dagger}H\right)^{2} - \left(y_{ij}H\bar{\psi}_{i}\psi_{j} + \text{h.c.}\right)$ 



 $m_H = \sqrt{2}\mu = \sqrt{\lambda}v \ (v = \text{vacuum expectation value})$ 

Measure couplings even more precisely

- Spin/CP properties of the vertices
- Probe SM predictions
- Search for new physics
  - Are they new particles in the loops?
  - Other Higgses?

# **Higgs coupling to W bosons**

Spin/CP properties of the HWW vertex

- Angular observables Run 2 measurements ongoing
- Machine Learning Inference methods future?



R. Barrué, PhD thesis M. Kholodenko, PhD thesis M. Silva, Master thesis B. Rosalino, Master thesis



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### Measuring the Higgs coupling to the b-quarks

•  $H o b \bar{b} \gamma$  decay sensitive to anomalous couplings in the  $H o \gamma \gamma$  and  $H o b \bar{b}$  interaction vertices

How sensitive is the ATLAS experiment to measure this decay using jets in the final state?





Carolina Costa, master thesis

# Searching for the unknown...

 Despite our efforts, no new particles have been observed at the LHC

	Model	S	ignatur	e∫	`£ dt [fb⁻	Mass limit		Reference
	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_{1}^{0}$	0 e, µ mono-jet	2-6 jets 1-3 jets	$E_T^{miss}$ $E_T^{miss}$	140 140	[1x, 8x Degen.] 1.0 1.85 [8x Degen.] 0.9	m( $\tilde{\chi}_{1}^{0}$ )<400 GeV m( $\tilde{a}$ )=5 GeV	2010.14293 2102.10874
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$	0 e, µ	2-6 jets	$E_T^{miss}$	140	2.3 Earbidian 115,195	m(x <sup>0</sup> )=0 GeV	2010.14293
	$\bar{\rho}\bar{\rho}, \bar{\rho} \rightarrow a\bar{a}W\bar{\chi}_{1}^{0}$	1 c.µ	2-6 jets		140	2.2	m( $\tilde{k}_{1}^{0}$ )<600 GeV	2101.01629
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell)\tilde{\chi}_{1}^{0}$	ee, µµ	2 jets	$E_T^{miss}$	140	2.2	m( $\tilde{k}_{1}^{0}$ )<700 GeV	2204.13072
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_{1}^{0}$	0 c.μ SS c.μ	7-11 jets 6 jets	$E_T^{miss}$	140 140	1.15	m( $\tilde{\chi}_{1}^{0}$ ) <600 GeV m( $\tilde{e}$ )-m( $\tilde{\chi}_{1}^{0}$ )=200 GeV	2008.06032 2307.01094
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t \tilde{D} \tilde{\ell}_1^0$	0-1 e, μ SS e, μ	3 b 6 jets	$E_T^{\rm miss}$	140 140	1.25	m( $\tilde{\ell}^0_{\lambda}$ )<500 GeV m( $\tilde{g}$ )-m( $\tilde{\ell}^0_1$ )=300 GeV	2211.08028 1909.08457
Ī	$\tilde{b}_1 \tilde{b}_1$	0 e, µ	2 b	$E_T^{\rm miss}$	140	0.68	m[k <sup>0</sup> <sub>1</sub> ]<400 GeV 10 GeV - Am(k <sub>1</sub> , k <sup>0</sup> )<20 GeV	2101.12527 2101.12527
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 {\rightarrow} b \tilde{\chi}_2^0 {\rightarrow} b h \tilde{\chi}_1^0$	0 e,μ 2 τ	6 b 2 b	$E_T^{miss}$ $E_T^{miss}$	140 140	Forbidden         0.23-1.35         Δm( <sup>2</sup> / <sub>2</sub> )           0.13-0.85         Δm( <sup>2</sup> / <sub>2</sub> )         Δm( <sup>2</sup> / <sub>2</sub> )	$\tilde{k}_{1}^{0}$ )=130 GeV, m( $\tilde{k}_{1}^{0}$ )=100 GeV $\tilde{k}_{2}^{0}, \tilde{k}_{1}^{0}$ )=130 GeV, m( $\tilde{k}_{1}^{0}$ )=0 GeV	1908.03122 2103.08189
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$	0-1 e, µ	$\ge 1$ jet	$E_T^{miss}$	140	1.25	m( ${ar t}_1^0)$ =1 GeV	2004.14060, 2012.03799
	$\tilde{i}_1 \tilde{i}_1, \tilde{i}_1 \rightarrow W h \tilde{\chi}_1^0$	1 e, µ	3 jets/1 b	$E_T^{miss}$	140	Forbidden 1.05	m(t <sup>0</sup> <sub>1</sub> )=500 GeV 20	12.03799, ATLAS-CONF-2023-0
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 b\nu, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$	1-2 T	2 jets/1 b	$E_T^{miss}$	140	Forbidden 1.4	m(7)=800 GeV	2108.07665
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \mathcal{X}_1' / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \mathcal{X}_1'$	$0 e, \mu$ $0 e, \mu$	2 c mono-jet	$E_T^{miss}$	36.1 140	0.85	$m(\tilde{x}_{1})=0 \text{ GeV}$ $m(\tilde{x}_{1},\tilde{c})-m(\tilde{x}_{1}^{2})=5 \text{ GeV}$	1805.01649 2102.10874
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow t \tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h \tilde{\chi}_1^0$	1-2 e, µ	1-4 b	$E_T^{miss}$	140	0.067-1.18	$m(\tilde{t}_{2}^{0})$ =500 GeV	2006.05880
_	$\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e,µ	1 b	$E_T^{mas}$	140	Forbidden 0.86 m(X <sup>0</sup> )=	360 GeV, m(t̃ <sub>1</sub> )·m(t̃ <sub>1</sub> )= 40 GeV	2006.05880
	$\tilde{x}_1^* \tilde{x}_2^*$ via WZ	Multiple <i>t</i> /jets ee, µµ	s ≥1 jet	$E_T^{miss}$ $E_T^{miss}$	140 140	χ <sup>2</sup> χ <sup>2</sup> <sub>2</sub> 0.205	$m(\tilde{k}_1^c)=0$ , wino-bino $m(\tilde{k}_1^c)-m(\tilde{k}_1^c)=5$ GeV, wino-bino	2106.01676, 2108.07586 1911.12606
	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{\mp}$ via WW	2 e, µ		$E_T^{miss}$	140	0.42	m(t <sup>0</sup> <sub>1</sub> )=0, wino-bino	1908.08215
	$\tilde{\chi}_1^* \tilde{\chi}_2^0$ via Wh	Multiple <i>l</i> /jets	5	$E_T^{miss}$	140	x <sup>2</sup> <sub>2</sub> Forbidden 1.06	m(X1)=70 GeV, wino-bino	2004.10894, 2108.07586
	$\chi_1 \chi_1$ via $\ell_L / \tilde{\nu}$	2 e, µ		ET IIIII	140	[în în 1] 0.24 0.48	$m(\ell, \bar{\nu})=0.5(m(\chi_1^-)+m(\chi_1^-))$	1908.08215 ATLAS. CONF. 2022.020
	$\tilde{h} = \tilde{h} = \tilde{h} = \tilde{\ell} \rightarrow \ell \tilde{k}_{1}^{0}$	2 e.u	0 iets	Emiss	140	0.7	$m(\tilde{c}_1)=0$ $m(\tilde{c}_1)=0$	1908.08215
	CERCERTS CONT	ee, µµ	≥ ĺjet	$E_T^{\text{fniss}}$	140	0.26	$m(\tilde{\ell})-m(\tilde{\chi}_1^0)=10 \text{ GeV}$	1911.12606
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, µ	$\geq 3 b$	ETiss	140	0.94	$BR(\tilde{\xi}_{j}^{0} \rightarrow h\tilde{G})=1$	To appear
		4 e, μ 0 e, μ	≥ 2 large jet	IS Emiss	140	0.55	$BR(\mathcal{X}_1^- \rightarrow ZG)=1$ $BR(\mathcal{X}_1^0 \rightarrow ZG)=1$	2103.11684 2108.07586
		2 e, µ	$\geq 2$ jets	$E_T^{miss}$	140	0.77 BF	$R(\hat{k}_1^0 \rightarrow Z\hat{G})=BR(\hat{k}_1^0 \rightarrow h\hat{G})=0.5$	2204.13072
	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	$E_T^{\rm miss}$	140	0.21	Pure Wino Pure biogsino	2201.02472
	Stable 2 B-bartron	nixel dE/dx		rmiss	140	2.05	r die niggenie	2205.06013
	Metastable ē B-badron ē→aak	pixel dE/dx		Emiss	140	[r(g) =10 ns] 2.2	m( $\tilde{k}_{+}^{0}$ )=100 GeV	2205.06013
	$l\bar{l}, \bar{l} \rightarrow t\bar{G}$	Displ. lep		$E_T^{miss}$	140	0.7	$\tau(\bar{t}) = 0.1 \text{ ns}$	2011.07812
		pixel dE/dx		$E_T^{miss}$	140	0.34 0.36	$\tau(\tilde{\ell}) = 0.1 \text{ ns}$ $\tau(\tilde{\ell}) = 10 \text{ ns}$	2011.07812 2205.06013
	$\tilde{\chi}_{1}^{\pm}\tilde{\chi}_{1}^{\mp}/\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{\pm}\rightarrow Z\ell \rightarrow \ell\ell\ell$	3 c, µ		main	140	$k_1^0$ [BR(Zr)=1, BR(Ze)=1] 0.625 1.05	Pure Wino	2011.10543
	$\hat{\chi}_1^* \hat{\chi}_1^r / \hat{\chi}_2^o \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 c,μ	0 jets	$E_T^{mas}$	140	$(X_2^{(2)}   \lambda_{133} \neq 0, \lambda_{122} \neq 0)$ 0.95 1.55	m(V)=200 GeV	2103.11684
	$gg, g \rightarrow qq\chi_1, \chi_1 \rightarrow qqq$ $\overline{a}, \overline{c}, \overline{c}^0, \overline{c}^0, \overline{c}^0$ , the		≥o jets Multiple		140	[mtr_[=50 GeV, 1250 GeV] 1.6 2.25 [2" =2e-4, 1e-2] 0.55 1.05	m(k <sup>0</sup> )-200 GoV bios like	ATLAS.CONE.2018.003
	$\overline{\mu}, \overline{\mu} \rightarrow h\overline{\chi}^{\dagger}, \overline{\chi}^{\dagger} \rightarrow hbs$		$\geq 4b$		140	Forbidden 0.95	m(x))=200 GeV, bino-ike	2010.01015
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$		2 jets + 2 b		36.7	[qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 e, µ	2 b		36.1	0.4-1.45	$BR(\tilde{t}_1 \rightarrow be/b\mu) > 20\%$	1710.05544
	** *0 *0 · 0 · ** · ·	1μ	DV		136	[10:10< x <sub>20k</sub> <10:0, 30:10< x <sub>20k</sub> <30:0] 1.0 1.6	BH(/1→qu)=100%, cos/l,=1	2003.11956
	$\chi_1^-/\chi_2^-/\chi_1^-, \chi_{1,2}^0 \rightarrow tbs, \chi_1^+ \rightarrow bbs$	1-2 e, µ	≥6 jets		140	0.2-0.32	Pure higgsino	2106.09609

# Searching for the unknown...

- Despite our efforts, no new particles have been observed at the LHC
- ML Anomaly Detection
  - Train deep learning models to learn SM background
  - Reconstruction error is a measurement of anomaly
  - Increases search generality



Artificial Intelligence FOTOLIA - SERGEY TARASOV



## Example:

- Method: auto-encoder
- Background: Standard Model
  - Top quark production
  - Di-boson production
  - Top quark + vector boson production
  - ► W+jets
  - ► Z+jets

#### Testing several signal models of dark matter production





I. Pinto, Master thesis I. Moreira, Master thesis A. Berti, PhD thesis (Minho U.)

# The Quark Gluon Plasma

- New state of matter created in PbPb collisions
- Jets are suppressed as they cross the QGP
- Study jets to understand the way particles interact with the QGP
- b-quark jets particularly interesting



The Quark-Gluon Plasma **Heavy Ion** Collisions First observation

in 2010 Probe of Quark-Gluon Plasma





Distinguish the nature of the energy loss







# **B-tagging algorithms**

Master thesis proposal for 2024

- Development of b-tagging algorithms for Heavy Ion Collisions in ATLAS
- GN2 flavour-tagging algorithm (2nd generation Graphical Neural Learning)
  - New approach using Graph Neural Nets
  - The focus is to evaluate the ability of the GN2 tagger to differentiate and consequently identify the flavour of the jets produced in Pb+Pb collisions.



#### **Detector Control System**



High Granularity Timing Detector



### LHC / HL-LHC Plan





# Z→µµ event with 20 pile-up interactions



# Upgrade challenges

 Huge detector occupancy
 Evento com um decaimento Z→µµ e mais outras 65 colisões pp



## High Precision Timing Detector

 Improve primary vertex identification
 30 ps resolution timing





# **High Precision Timing Detector**

- 30 ps resolution timing using Silicon Low Gain Avalanche Diodes (LGAD)
  - Improves pileup vertex separation and luminosity measurements
- LIP contributes to several areas
  - Electronics: readout ASIC tests, High Voltage filtering
  - Detector control system and safety Interlocks
  - Monitoring
- Other possibilities being followed
  - Cable production in Portuguese industry
  - Mechanical design and production at LIP





### Electronics and High-Voltage

- HV patch panels
- Routing the High Voltage to HGTD detector
- HV brought to low pass filters in the patch panels to filter AC noise
- LIP responsability Master student António Caramelo (U. Coimbra) developed this project





- -

## **Detector Control System (DCS)**

- DCS architecture design
- Readout of DCS environment data through ELMB2 communication board

monitoring of the CO<sub>2</sub> cooling

system via Pt10k sensors



- Temperature range: from -45°C
   to +20°C
- Maximal tolerable offset

(accuracy) of sensor: ±0.2°C

■ Precision of sensor: ±0.5°C



- same ELMB board as ITk
- Signal Conditioning board, backplane of both boards and power supply to be designed

### The Interlock of the High Granularity Timing Detector

- LIP responsibility
- Master students Rui Vieira and Alexandre Parreira (FCUL) configure the FPGAs



The ILK-FPGA is the central decision unit



The MON-FPGA is responsible for the monitoring of all parameters which are required to debug an interlock event.



### The Interlock of the High Granularity Timing Detector

- LIP responsibility
- The Transfer Module in the Main interlock Crate propagates the signals from ATLAS Detector Safety System to the FPGA Interlock Matrix



Prototype under tests

Master student Maria Miguel Cruz (U. Coimbra) developed this project

### **TileCal Hadronic Calorimeter Upgrade**

0.0

#### Calibration

- Optimize performance
- Study radiation hardness with pp collisions
- Development of scintillators for future colliders



# TileCal-like calorimeter for FCC

Simulation studies of a

 TileCal-like
 calorimeter

 Development of new
 scintillators materials
 to meet the
 challenges of the
 future collider

#### Future Circular Collider

- 100 km ring!
- Two possible colliders:
  - First: e+e- collisions for precision electroweak physics
  - Next: pp collisions @ 100 TeV to explore the energy



## Development of new scintillators

- Collaboration with IPC (Minho)
- Using PEN and PET
- Study
  - Light output
  - Emission spectra
  - Transmittance spectra
  - Pure PEN/PET and mixtures
  - ► Future:
    - Optimize light output, transparency
    - Increase size of the scintillators
    - Industrialize process
    - Study radiation hardness





## LHC Upgrade Challenges



- Interesting processes have small cross-sections
- Need to process & select interesting events in real time
- 40 MHz event rate
- Very large number of interactions/event

	Run 2	Run 3	Run 4
Energy (√s)	13TeV	14 TeV	14 TeV
Max. Luminosity (cm <sup>-2</sup> s <sup>-1</sup> )	1-2×10 <sup>34</sup>	2-3×10 <sup>34</sup>	5-7×10 <sup>34</sup>
nteractions/event	40	55-80	140-200
Bunch crossing rate	40 MHz	40 MHz	40 MHz
Offline storage rate	1000 Hz	1500 Hz	10 kHz
Bunch spacing	25 ns	25 ns	25 ns

## **GPUs for Accelerating Jet Trigger Algorithms**



- Exploit parallelism
- New paradigm: single instruction-multiple data
- Calorimeter clustering on GPUs
  - Ist prototype demonstrated great potential
  - New framework update and optimisation ongoing



 Study also FPGAs as alternative

## **Topo-Automaton Clustering (TAC)**

 TopoClustering: Groups neighbours according to signal/noise



Seed (S/N>4) Growing (S/N>2) Terminal (S/N>0) Not enough S/N Not evaluated

- TAC: Maximimize parallelism:
  - Data organised in cell pairs
  - Use cellular automaton
    - Propagate flag on a grid of elements (cell pair)
  - Cells get the largest flag on each iteration



# More information:

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# **Thanks**!

Acknowledgments



### TileCal current HV regulation system

- Located inside the detector
- Will become old and difficult to maintair
- Not expected to survive to Phase II radiation



# The ATLAS Experiment

