The ATLAS Brazil : Status and Perspectives for the HL-LHC Era

https://atlas.cern/

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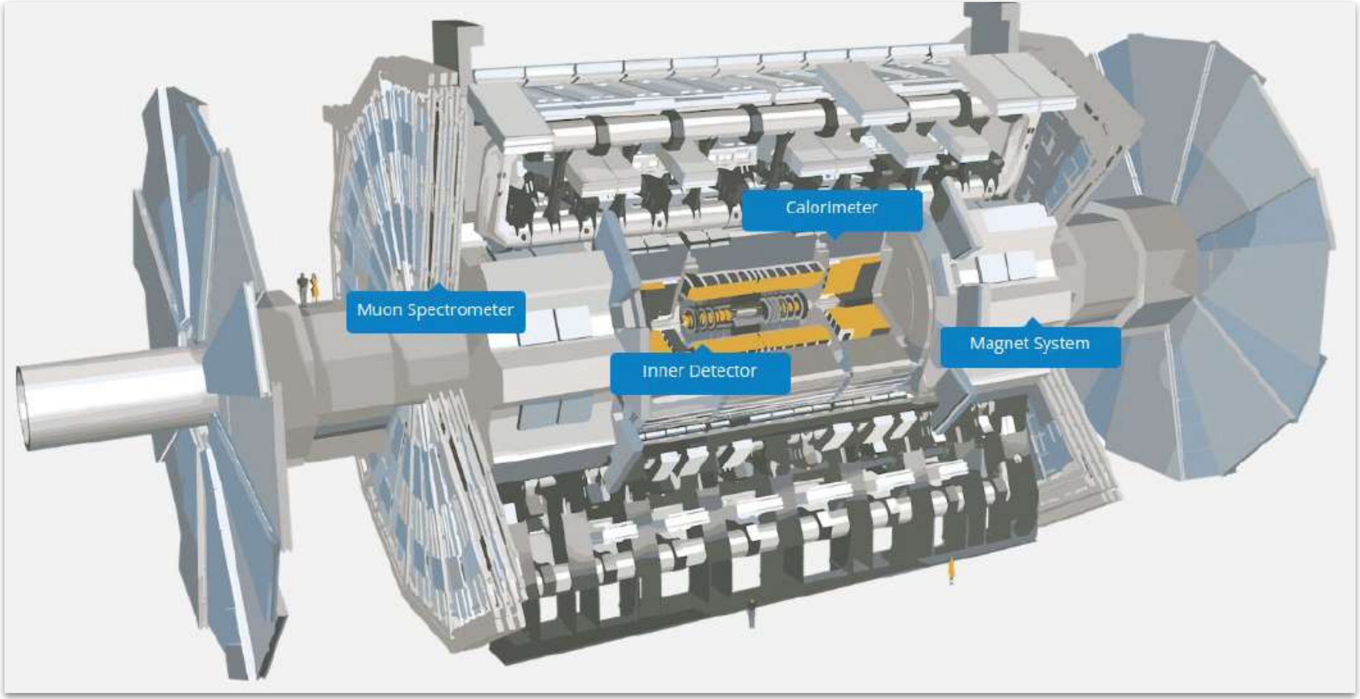
ATLAS EXPERIMENT

Introduction

- **Why** : The Physics Case
- **Who** : The ATLAS Brazil cluster
- **How** : The analysis, the instrumentation and the outreach



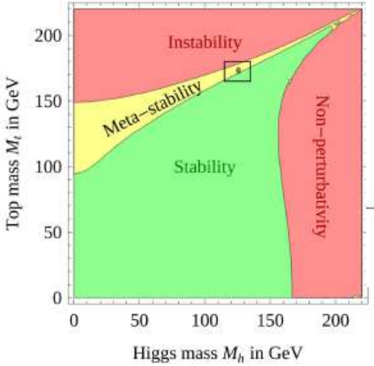
Why ?

cerncourier

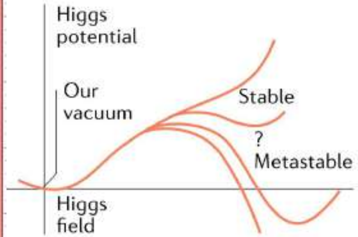
The Physics Case

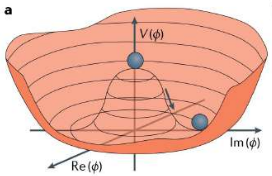
- No new signs of Physics beyond the SM from LHC so far …
- But an overwhelming (and puzzling) reassurance of the SM through precision measurements
- We will turn our batteries the uncharted territory of the Higgs Potential :
- This has a very deep connection with questions that goes beyond the particle physics itself, connecting to cosmology :
  - What is the origin of Universe inflation ?
  - What is the real nature of the EW symmetry breaking mechanism ?
  - How can we understand the vacuum metastability ?
- The LHC will be herald of new era in physics, when the increased luminosity will allow us to access very rare process in extreme regions of the phase space
- A main priority in HL-LHC era will be probing the Higgs potential, constraining the Higgs couplings through di-Higgs production measurements.
- There is a significant discovery potential even if we do not find evidences in single Higgs couplings measurements (D., M. S.)
- Interpretation is accomplished in the *k and Higgs-Effective Field Theory (EFT) frameworks*
  - Needs strong interplay between theory/experimental communities !

10.1007/JHEP08%282012%29098



10.1038/s42254-021-00341-2





$$V(h) = \frac{1}{2} m_H^2 h^2 + \lambda_3 v h^3 + \frac{1}{4}\lambda_4 h^4$$

$$\text{with} \quad \lambda_3^{SM} = \lambda_4^{SM} = \frac{m_H^2}{2v^2}.$$

k-framework

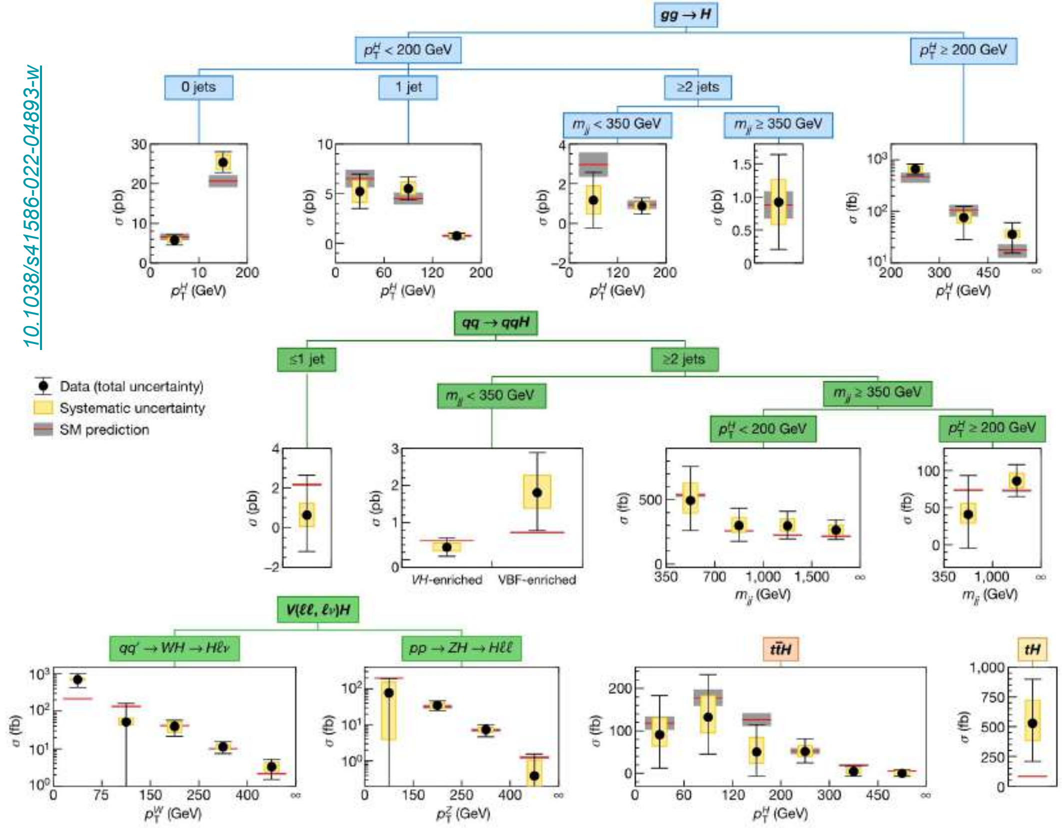
$$(\sigma \cdot BR)(i \to H \to f) = \frac{\sigma_i^{SM}\kappa_i^2 \cdot \Gamma_f^{SM}\kappa_f^2}{\Gamma_H^{SM}\kappa_H^2} \quad \to \quad \mu_i^f \equiv \frac{\sigma \cdot BR}{\sigma_{SM} \cdot BR_{SM}} = \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}$$

- in SM , $k_i = 1$
- *k-framework* is good to spot large deviations from SM
- for a systematic understanding, we need *HEFT framework*

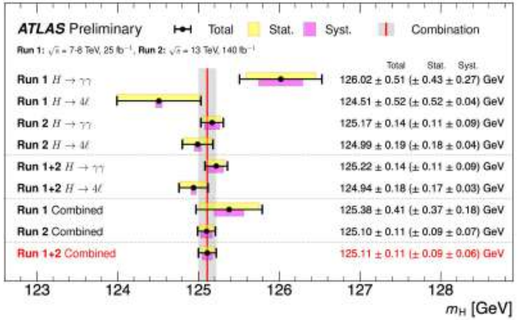
Panorama of Higgs Measurements

We have measured the Higgs boson production cross-sections in different kinematic regions …

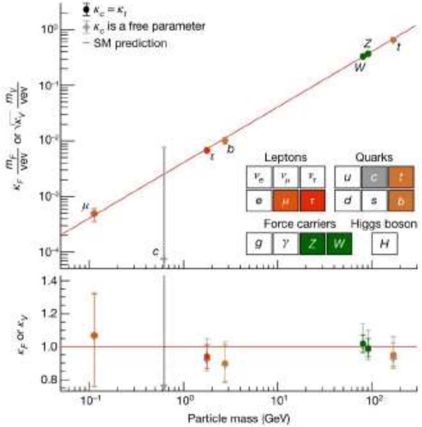
10.1038/s41586-022-04893-w



and measured the Higgs mass (~0.1%) …



and its coupling strength to many particles …



10.1103/PhysRevLett.131.251802

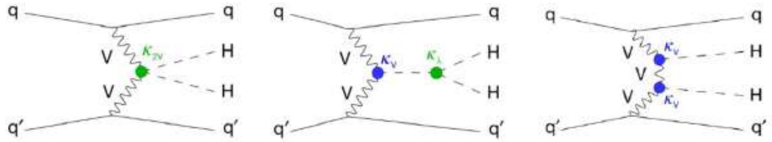
But how does the Higgs couples to itself ?

(so we can explore the Higgs potential)

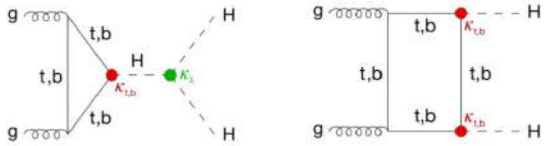
ATLAS EXPERIMENT

Hunting Down the di-Higgs at (HL-)LHC

- The SM *HH* production x-section is **~1000x smaller** than single Higgs
- Looking at *resonant* and *nonresonant* production
- Main processes are *gg* Fusion and Vector Boson Fusion (VBF)
  - VBF mode requires a **good forward coverage** and clean mid-rapidity
- di-Higgs "golden channels" : $HH\to b\bar{b}b\bar{b}$, $HH\to b\bar{b}\tau\tau$ and $HH\to b\bar{b}\gamma\gamma$
  - ***b***-tagging requires very good tracking and jet reco including HLT level (speed & efficiency)
  - τ reconstruction needs robust strategy for fakes (and reconstruction)
  - γ identification and trigger requires excellent EM calorimeter performance
- All this will be plagued by an **unprecedented pileup** scenario at HL-LHC placing a heavy pressure in all detectors, trigger, DAQ, analysis and modeling
- Now limited by statistical uncertainties; with more data, the systematics will kick in
- **Largest backgrounds : MJ, $t\bar{t}$, *Z+jets*** (new ideas for analyses, interpretations …)

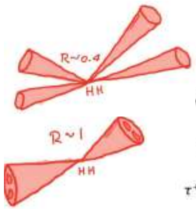


HH production via *Vector Boson Fusion (VBF)*

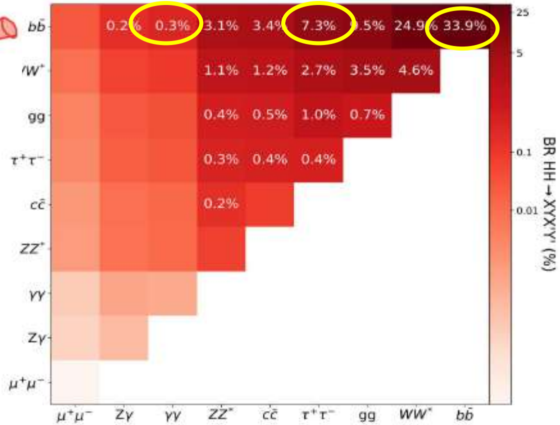


HH production via *gg* fusion

	Advantages	Disadvantages	Resonant best range
$HH\to b\bar{b}b\bar{b}$	highest x-section branch	very challenging background	251 GeV ~1.5 TeV (resolved) 900 GeV ~ 5 TeV (boosted)
$HH\to b\bar{b}\tau\tau$	moderate x-section branch topology helps event id	understanding fake τ uncertainty in mass due to ν_τ	251 GeV ~ 1.6 TeV
$HH\to b\bar{b}\gamma\gamma$	very clean selection (γ)	ultra-low x-section branch	251 GeV ~ 1.3 TeV

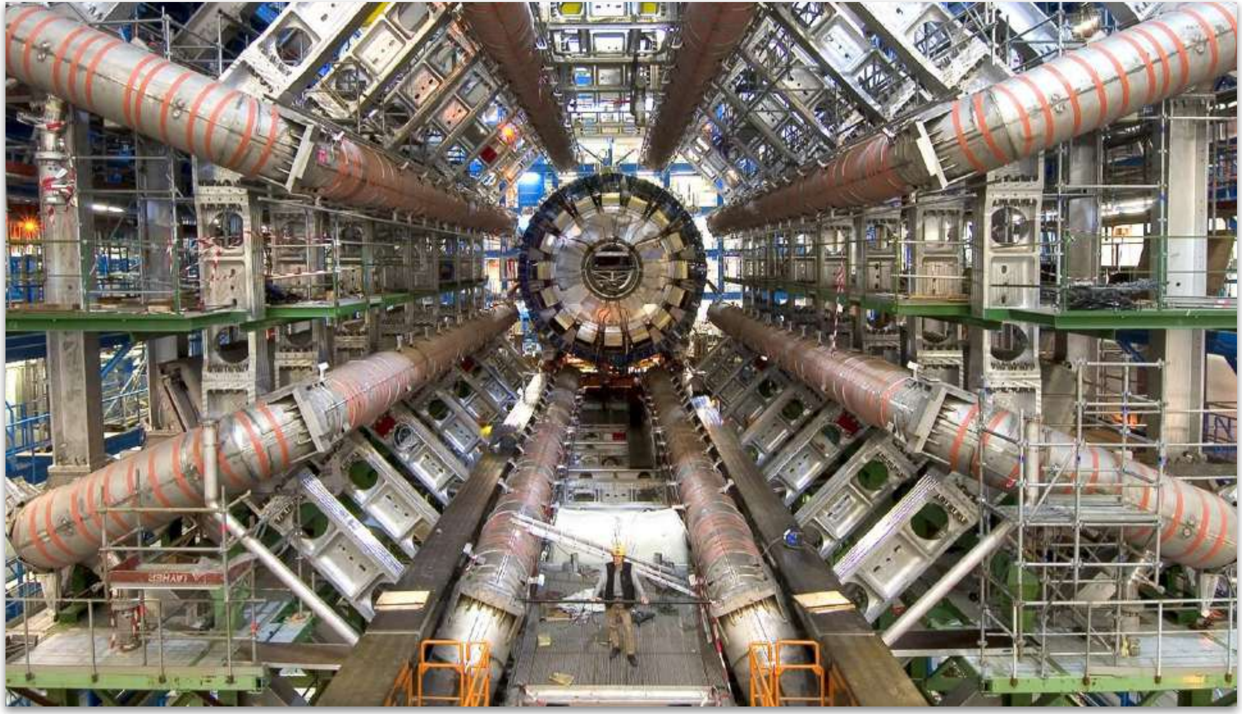


Final analysis is a combination of channels



[10.1016/j.revip.2020.100045](https://doi.org/10.1016/j.revip.2020.100045)

Who ?



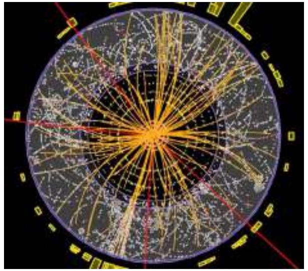
Brazil in ATLAS

- 5 Institutions : USP, UFRJ, UERJ, UFJF and UFBA
- 85 members
  - 15 researchers(M&O A)
  - 23 PhD students
- 29 PhD Thesis in ATLAS topics
- FA : CNPq, FAPESP, FAPERJ, FAPEMIG, FAPESB, FINEP and MCTI

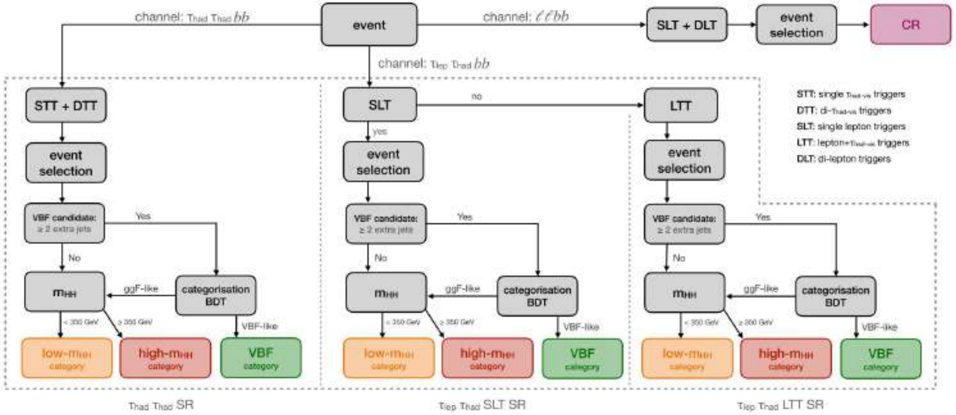
Brazil in ATLAS

- Proton-proton **physics analysis**
- Software development for **performance, trigger and reconstruction**
- Tier-2 **Data processing**(ATLAS + ALICE SAMPA Tier-2)
- **Instrumentation development** (semiconductor sensors and electronics for calorimetry)
- Participation in **Phase-I e Phase-II** upgrade projects
- Detector **operations**
- Strong and **pioneering outreach** initiatives in HEP in Brazil
- Long history of **participation in management and coordination bodies** of ATLAS

- 25 physics analysis (HDBS, SM, Exotics)
- Support for other activities through Technical Coordination (NSW, ITk)
- Collaboration with LA teams (Chile and Argentina)

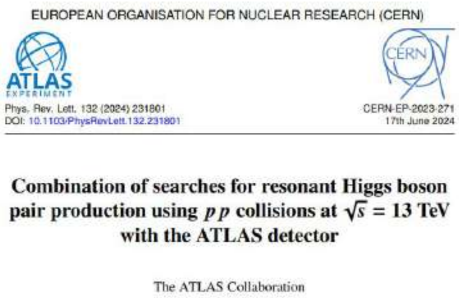


How ?

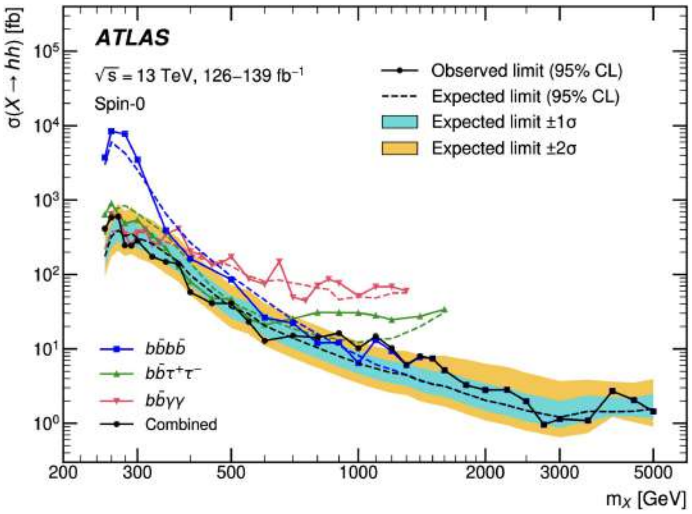

channel: $\tau_{had}\tau_{had}bb$
event
channel: $\ell\ell bb$
SLT + DLT
event selection
CR
channel: $\tau_{lep}\tau_{had}bb$
STT + DTT
event selection
VBF candidate: ≥ 2 extra jets
Yes
No
m_{HH}
ggF-like
categorisation BDT
VBF-like
low-m_{HH} category
high-m_{HH} category
VBF category
SLT
no
yes
LTT
STT: single $\tau_{had\text{-}vis}$ triggers
DTT: di-$\tau_{had\text{-}vis}$ triggers
SLT: single lepton triggers
LTT: lepton+$\tau_{had\text{-}vis}$ triggers
DLT: di-lepton triggers
$\tau_{had}\tau_{had}$ SR
$\tau_{lep}\tau_{had}$ SLT SR
$\tau_{lep}\tau_{had}$ LTT SR

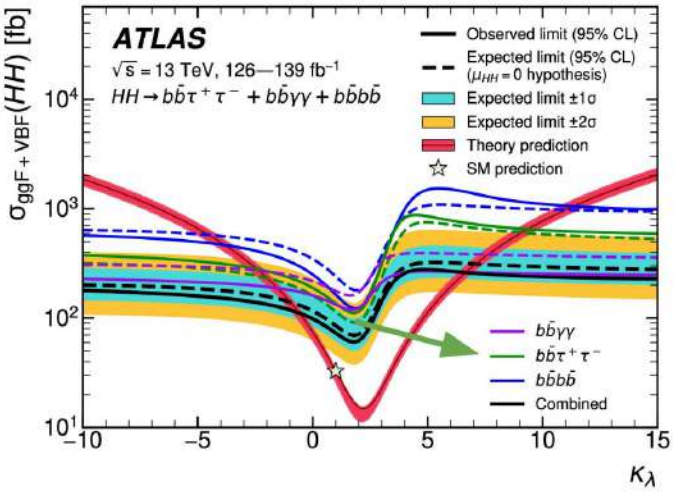
Run-2 HH Analysis

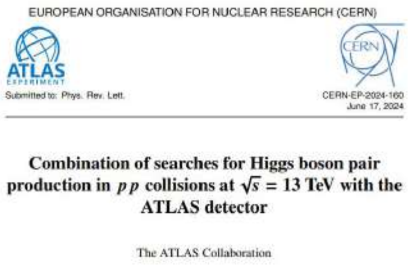
- Combination of ***HH□$b\bar{b}b\bar{b}$***, ***HH□$b\bar{b}\tau\tau$*** and ***HH□$b\bar{b}\gamma\gamma$*** channels
- ***HH□$b\bar{b}\tau\tau$* has shown the best sensitivity** to SM signal strength
- Covering 251 GeV - 5 TeV (*resolved / boosted regimes*)
- Significant sensitivity increase from previous ATLAS work
  - MVA classifiers
  - object reconstruction and identification (τ, b-jets)
- Local fluctuation ~ 1 TeV (3.3 **σ** local) →needs a drill-down



10.1103/PhysRevLett.132.231801



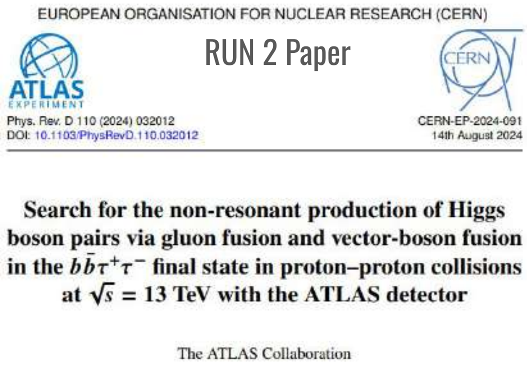




10.48550/arXiv.2406.09971

New Run-3 HH Analysis

- We (ATLAS BR) are focused on $\boldsymbol{HH \square b\bar{b}\tau\tau}$
- RUN 3 @ 13.6 TeV
- Non-resonant ***gg*** and **VBF @ 13.TeV** (resonant will come later …)
- Better b-tagger performance, new triggers and more data (~400 fb^{-1})
- Updates for MC signal and background modeling
    - MadGraph 3.3.1 + Pythia 8.308 [VBF]
    - PowhegBox V2 [*gg*F]
    - Sherpa 2.2.14 [V+jets]
- New analysis framework, and re-analysis of Run-2 data together with Run-3
- κ and EFT frameworks for interpretations


EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

RUN 2 Paper

ATLAS EXPERIMENT

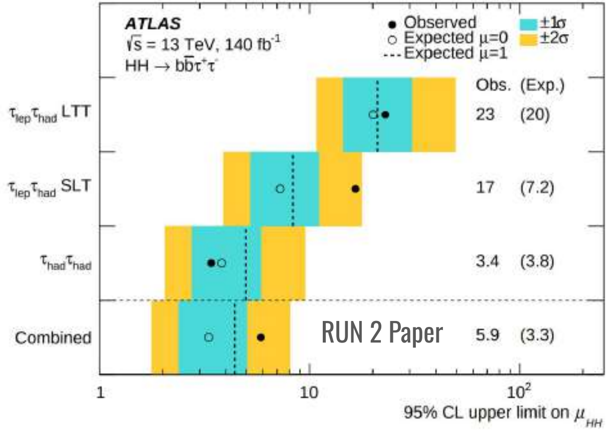
Phys. Rev. D 110 (2024) 032012
DOI: 10.1103/PhysRevD.110.032012

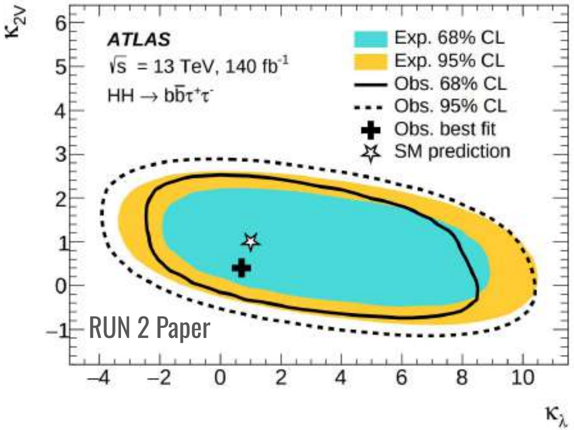
CERN-EP-2024-091
14th August 2024

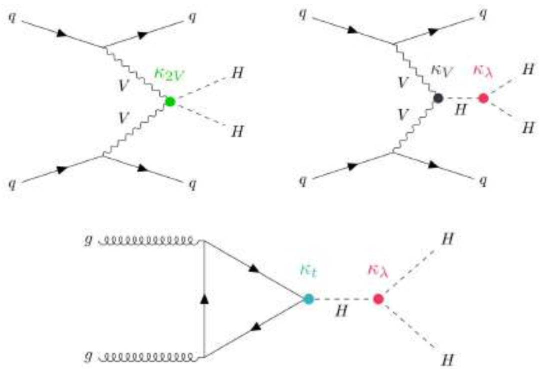
Search for the non-resonant production of Higgs boson pairs via gluon fusion and vector-boson fusion in the $b\bar{b}\tau^+\tau^-$ final state in proton–proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

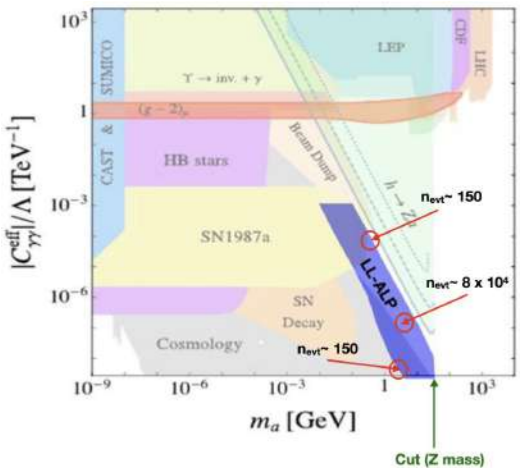
10.1103/PhysRevD.110.032012





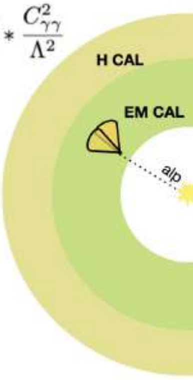


Search for Axion-Like Particle (ALP)



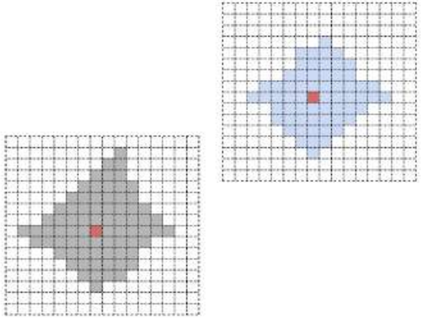
$$h \to Za \qquad a \to \gamma\gamma$$

$$\Gamma_{a\to\gamma\gamma} = 4\pi\alpha^2 m_a^3 * \frac{C_{\gamma\gamma}^2}{\Lambda^2}$$

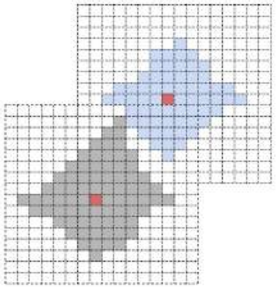


- Exotic decays can produce low mass ALPs
  - Highly collimated pairs of γ in final states seen in calorimeter
- Possible to trigger in Z and leptons
- Background from Z+jets, π0, prompt γ and MJ

- The topology of these decays can lead to a loss of one γ in the current reconstruction
- Techniques using ML for shower identification can help the reconstruction of ALPs



Two γ lost (seen as background)



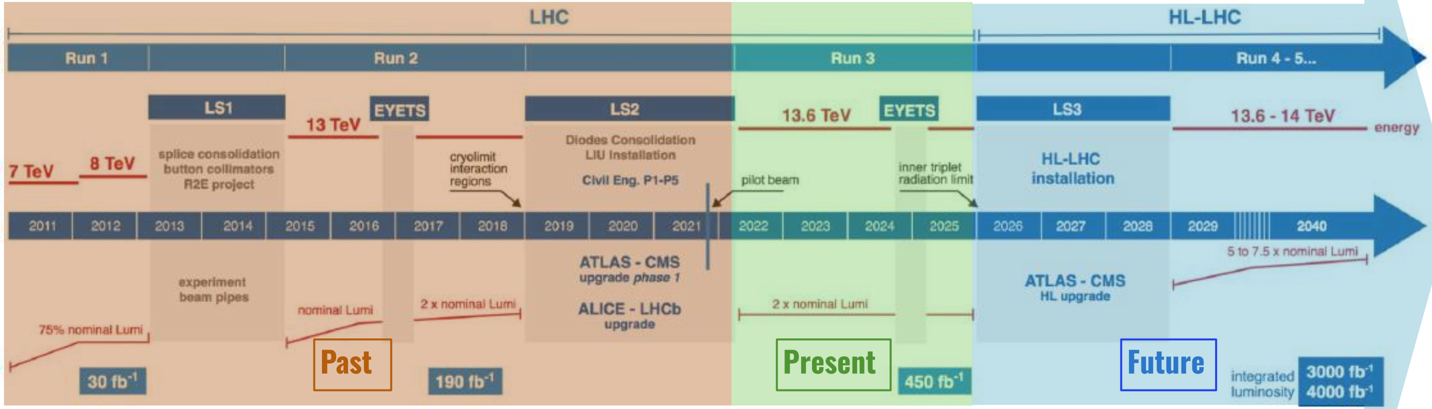
Two γ reconstructed as one

The Challenge That Lies Ahead

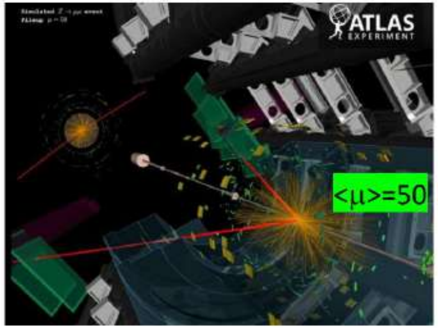
- ~14 TeV is our limit so far
- So many questions still …
- We took only ~5% of (HL)LHC data promised

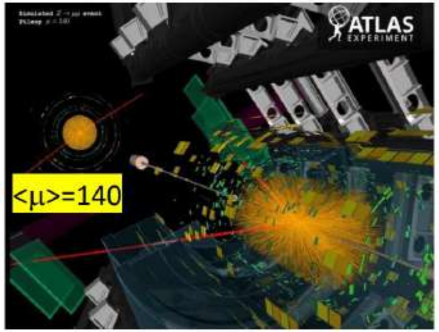
- Increase the number of collisions per bunch crossing (3x of the today)

- Complex topology (pileup)
- Pressure on trigger and DAQ
- (Very) High radiation



- New detectors
- New electronics
- New methods for reconstruction
- New strategies for event generation (MC)
- Precise luminosity determination (bunch-by-bunch, leveling)

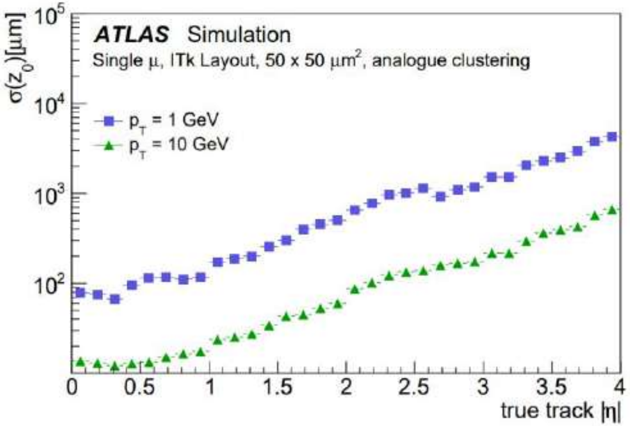




ATLAS High Granularity Timing Detector (HGTD)

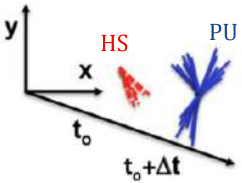
The problem

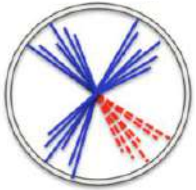
- 200 collisions @ 40MHz
- Irreducible background
- **Challenging for track/vertex reconstruction**
- **New full silicon tracker (ITk) to extend coverage to $|\eta|< 4$**
- **Insufficient spatial resolution in forward region**

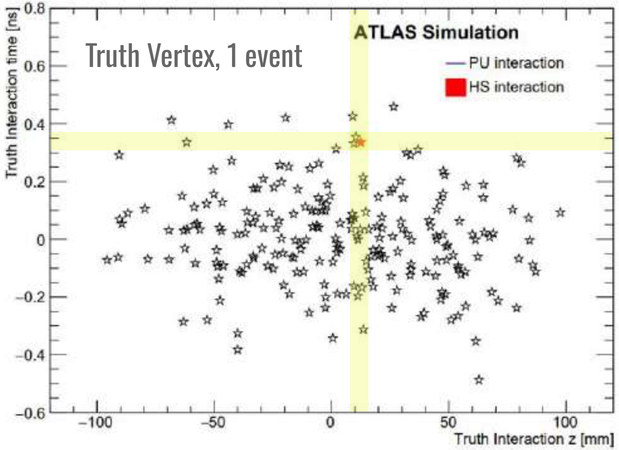


The solution

- Introduce the 4th **dimension** (time)
- **30 ps timing resolution**
- **High segmentation**

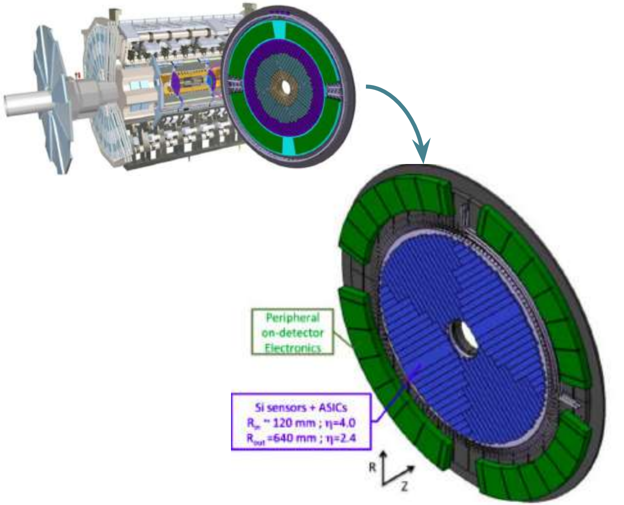






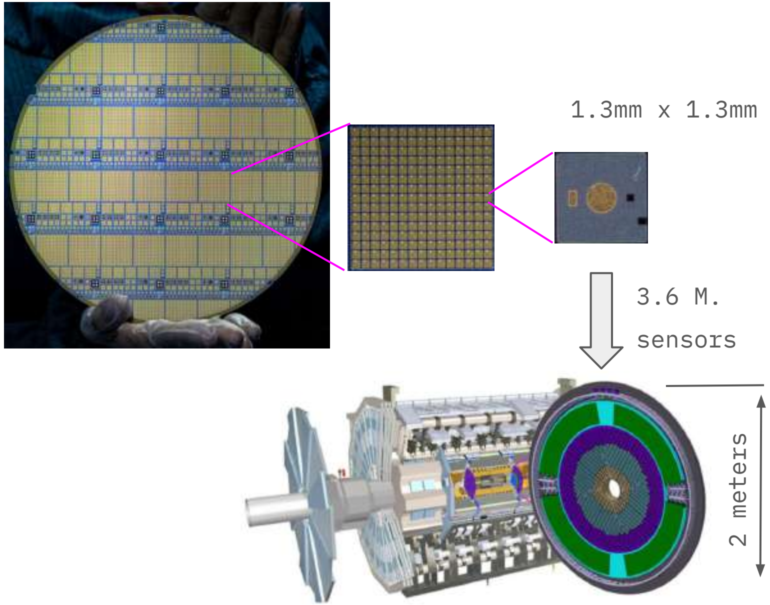
ATLAS HGTD

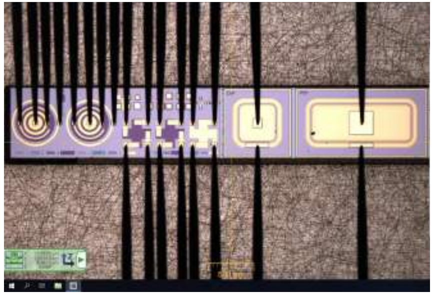
- **New detector**
- 8 layers of state-of-the-art *Ultra Fast Semiconductor Detectors* (LGADs)
- **Two 2m x 12cm disks (2.4 $|\eta|$ 4.0)**
- 3.6 M sensors ($1.3mm^2$ each)
- Very radiation hard



ATLAS High Granularity Timing Detector (HGTD)

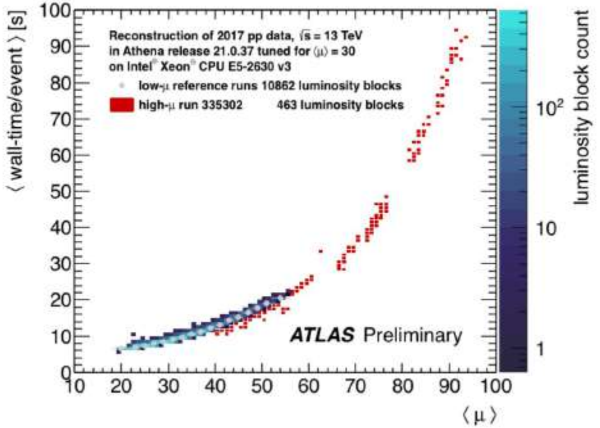
- The HGTD will deploy 3.6 ultra-fast, radiation-hard, state-of-the art silicon sensors arranged in 15x15 arrays
- ATLAS Brasil is collaborating with the HGTD since the R&D phase of the sensors and with CERN is part of production QA/QC
- A semiconductor lab was assembled @USP for this task, and is fully operational
- The Brazilian group will also provide significant contribution to the construction and commissioning of the detector at CERN
- This activity also has an important spin-off as we recently tested the ATLAS sensors for synchrotron radiation applications

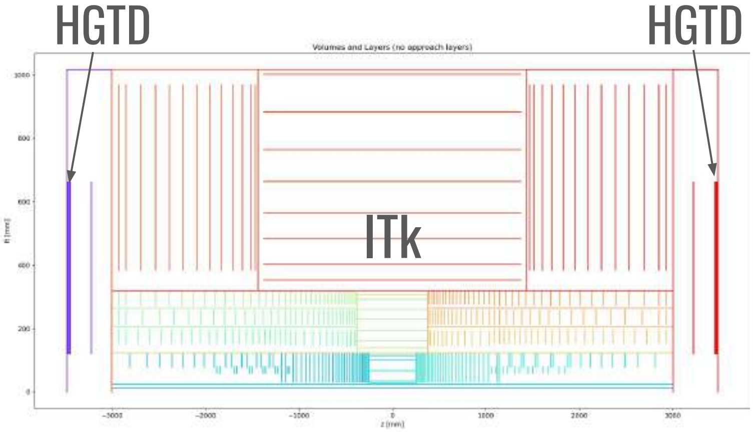


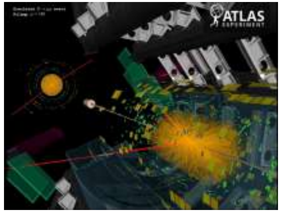


Development of 4D tracking for HL-LHC

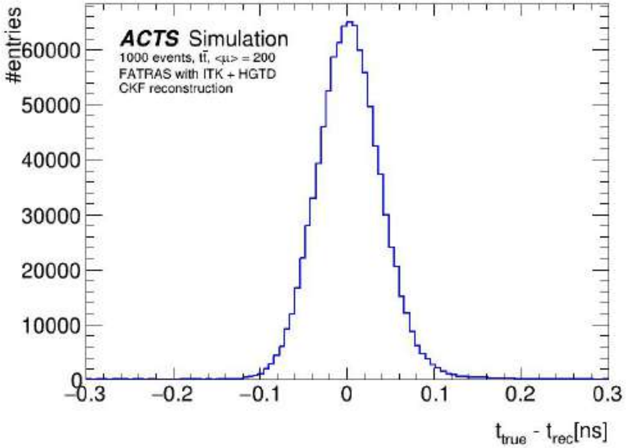
- HL-LHC pileup will exceed track-vertex association capability
- The current Kalman Filter approach does not scale well with number of tracks
- HLT trigger is even more demanding
  - We cannot trade performance for speed (*b*-tagging)
  - New methods for 4D tracking (x,y,z,t) to separate *hard scatter* from *pileup* interactions
- Developed in **ACTS** (A Common Tracking Software) framework
- Simulate ITk + HGTD with Monte Carlo events (*$t\bar{t}$, Z+jets)* and evaluate the reconstruction performance
- Implementation in heterogeneous architectures (GPU+CPU)





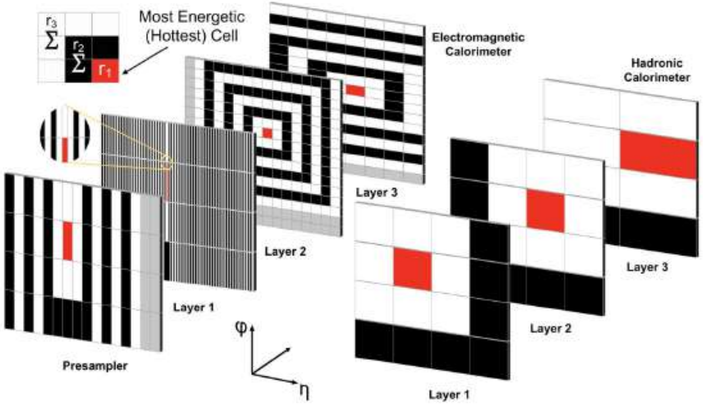


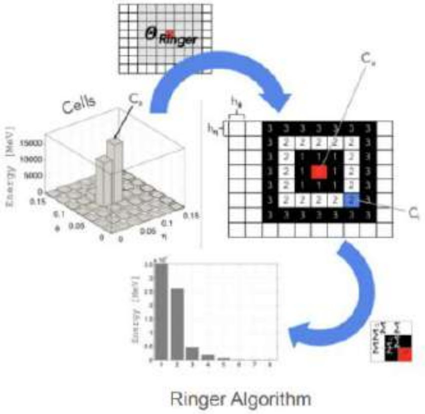
ITk and HGTD detector geometry in ACTS

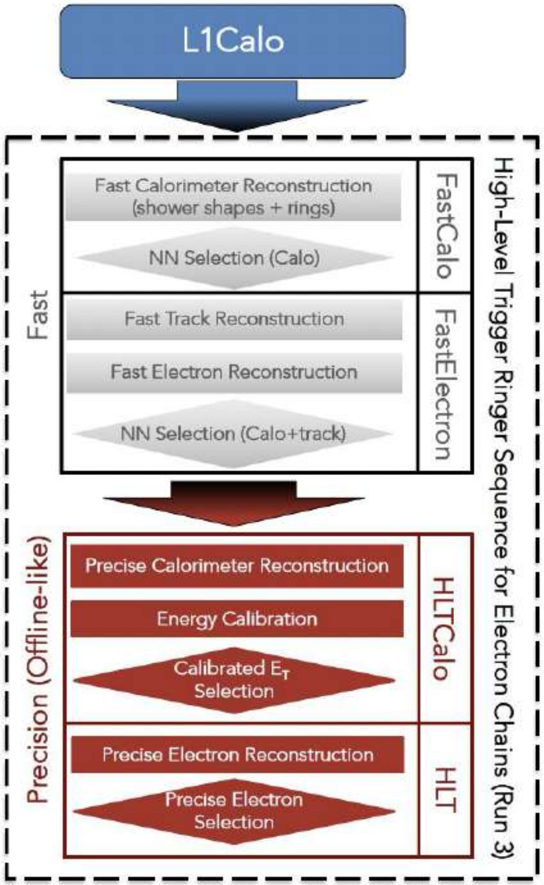


Neural Ringer for Calorimeter Trigger

- Neural networks for shower shape identification (lateral and longitudinal) profiting from the outstanding ATLAS LAr EM Calorimeter performance.
- Currently being extended to photons
- High background rejection at early HLT stages
- Outperforms traditional methods in high pileup environments
- Good performance for low pT thresholds
- Recently included in the Run-3 trigger menu

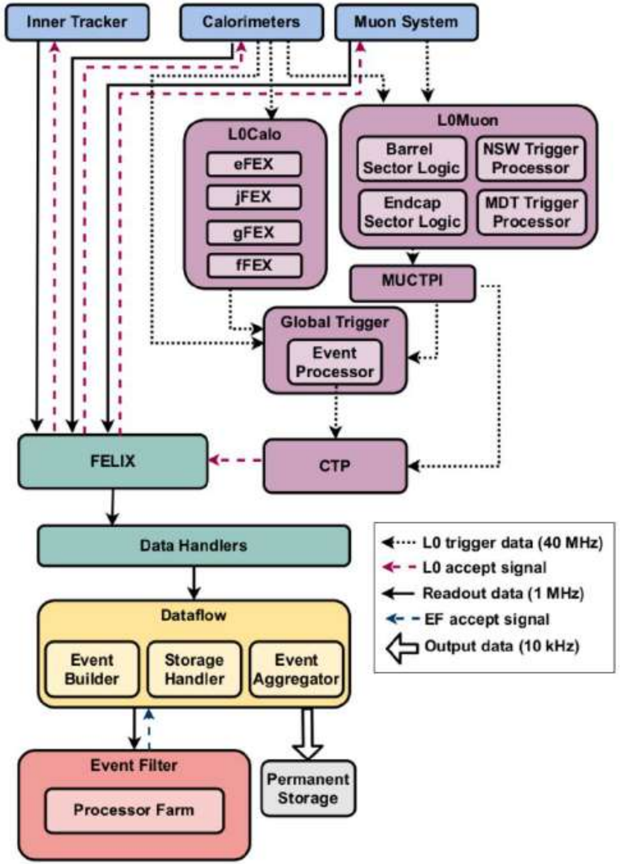






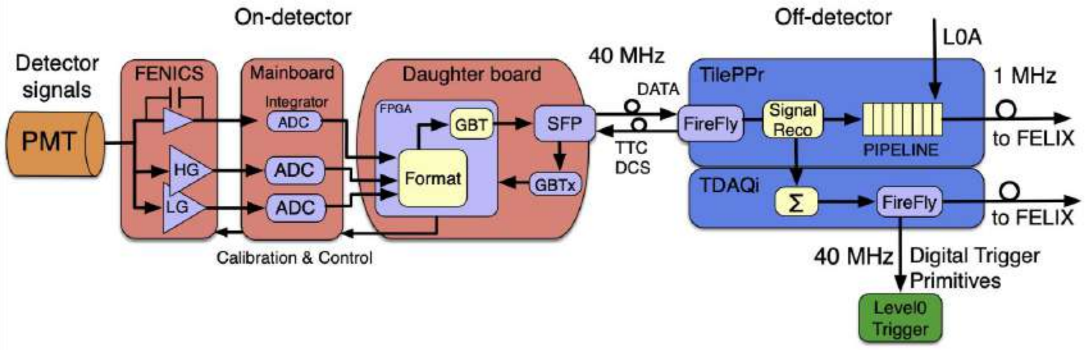
ATLAS HL-LHC TDAQ Upgrade

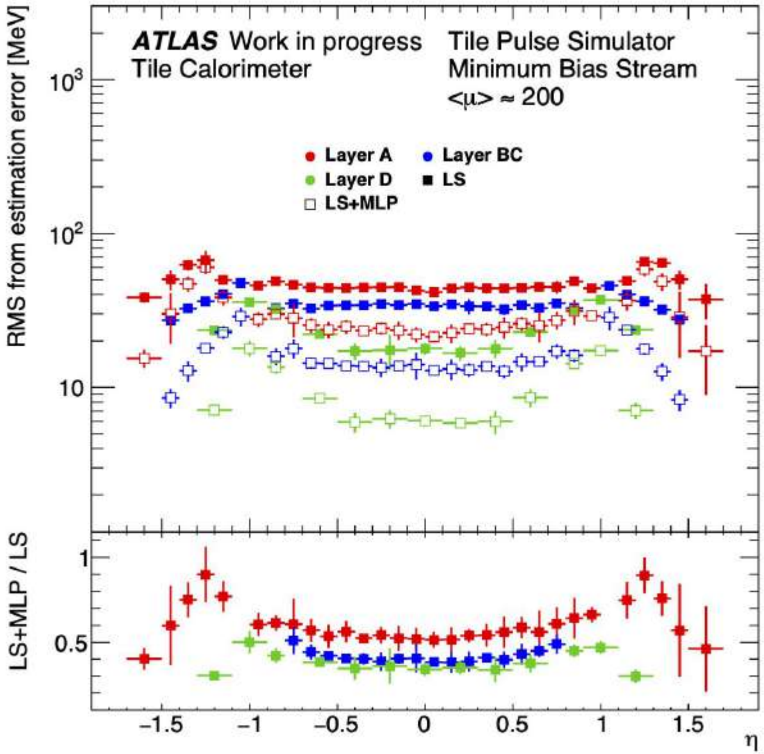
- Implementation of e-gamma algorithm for Global Trigger
- Important for efficient selection of signatures with γ in final states
- Needs hardware implementation @ L0
  - Low latency
  - Parallelized
- Firmware under development in a generic FPGA platform
- Neural ringer added as an additional trigger strategy



Signal Processing in Calorimetry for HL-LHC

- Implementation of linear filter (least squares) is proposed to recover the Hadronic Calorimeter (Tilecal) energy estimation performance under high pileup
  - Good performance when compared to current methods
- Ongoing studies for hardware implementation provides energy estimation at every bunch crossing (L0 trigger)





Outreach

- Strong, pioneering and widespread activities since 2011
- Bringing together ATLAS scientists and thousand students (and teachers) from all Brazilian regions
- Involves Physics grad and undergrad students in organization and support
- The HL-LHC will require a committed and experienced team to bring to the public the challenges and accomplishments

ATLAS MasterClasses (Z & W)

- In person, at Universities or Schools
- Many states (RJ, RN, AM, SP, MG, CE …)
- Deeply rooted as IPPOG activities
- Reaching hundreds of students every year

Virtual visits to ATLAS

- fully online
- Many states (RJ, RN, AL, CE …)
- every 15 days, with ~ 400 students per year
- Introduction + online visit + Q.A. session

~300 students at ATLAS MasterClass in Lavras-2024 !

Z boson activities at USP

Conference with CERN at COPPE-RJ

ATLAS Brazil - Consolidated Information

Strong and significative participation since the early days and a full participation in HL-LHC era

I- Physics

- Higgs pair production in the $HH \rightarrow bb\tau\tau$ channel
- Precision measurements in MP
- MC generator studies
- Search for "*axion-like particles*"

II - Calorimetry

- Energy estimation techniques and implementation in reconfigurable hardware (FPGA)
- Signal reconstruction and pileup mitigation for EM calorimeter
- Data quality and operation
- $e\gamma$ performance

III - Trigger

- Electrons and γ trigger
- Leading new topologies (rings)
- Machine learning and neural networks for event selection
- Trigger data quality

IV - Phase-II Upgrade (HL-LHC)

- Important participation on HGTD (sensors, construction, performance)
- 4D tracking for ATLAS HL-LHC and beyond
- Support on new DAQ hardware platforms (FELIX)
- ITk engineering support

VI - Management

- Several positions in ATLAS boards
- Participation in several editorial boards
- Coordination of MC requests

V - Computing

- ATLAS Tier-2 facility
- GLANCE system

VI - Outreach

- Virtual visits
- ATLAS Masterclass countrywide

Final Remarks

The HL-LHC will be our
next experimental playground.
. . .
we should leave no stone unturned !

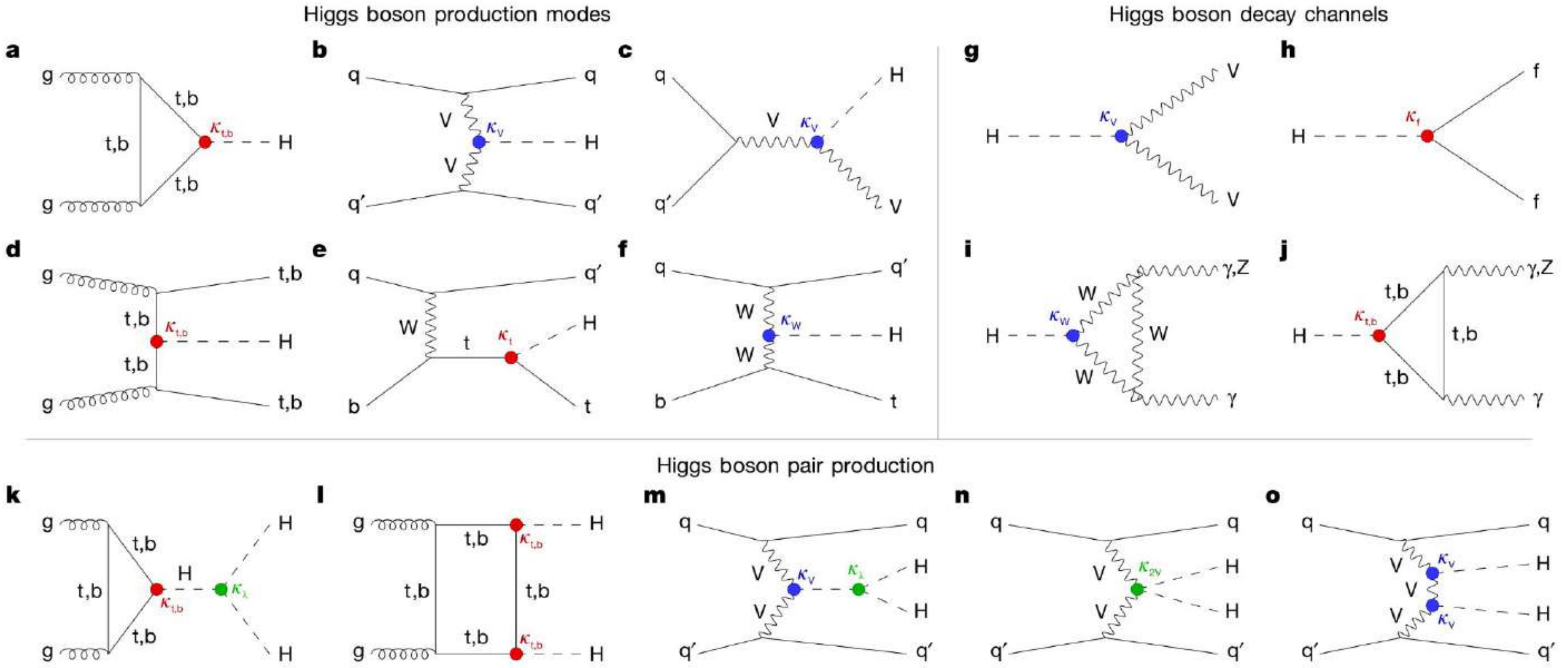
Thank you !

Image from here and after A. Juste 2023

Backup

10.1038/s41586-022-04893-w

Higgs (and di-Higgs) production modes and decays



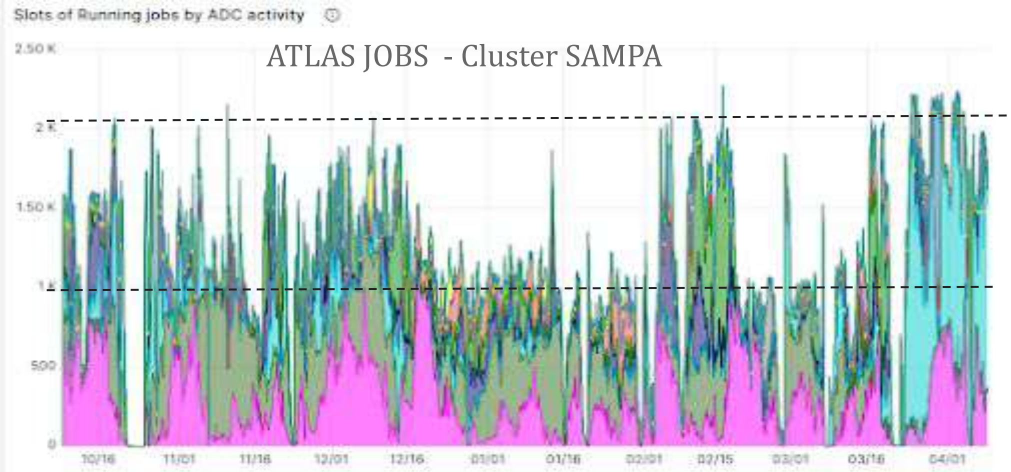
Contribuição em computação

ATLAS GLANCE

- Infraestrutura sofisticada (banco de dados e interface) para o gerenciamento de milhares de colaboradores e análises
- Interface WEB
- Atualmente utilizada também pelo ALICE e LHCb

ATLAS Tier-2

- ATLAS Tier-2 na USP (HEPIC)
- Compartilhamento entre ATLAS e ALICE no mesmo cluster !
  - Uso otimizado dos recursos
- Alta eficiência (>90%)
- Em operação no ATLAS desde 2022



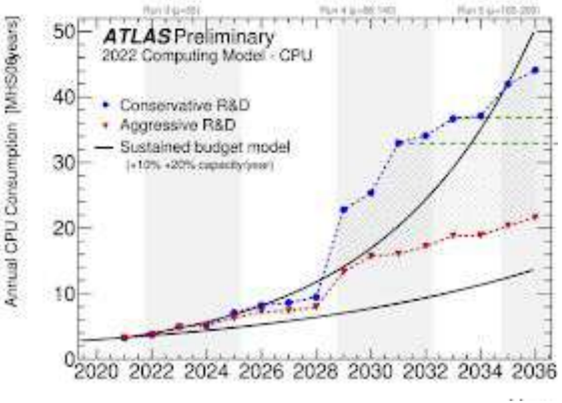
ATLAS Computação

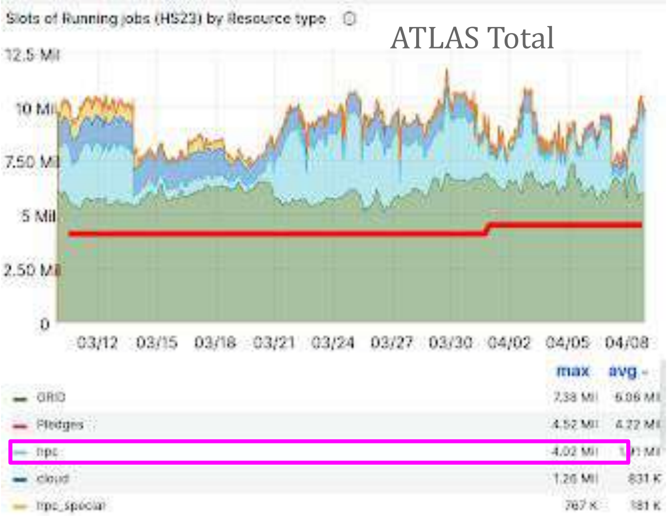
- ATLAS Tier-2 na USP (HEPIC)
- Recursos continuam sendo compartilhados entre ATLAS e ALICE
- Esse sistema compartilhado também implantou o primeiro Stratum-I do CVMFS , servindo todos os experimentos do LHC além de Astronomia e Astrofísica (único Stratum-I no hemisfério sul !)
- A fase do HL-LHC aumentará as demandas de computação (Monte Carlo, reconstrução, armazenamento) de forma significativa
  - Explorar ao máximo as possibilidades da comunicação =(Ella-link)
- O ATLAS já é capaz de utilizar de forma muito eficiente recursos de HPC
  - Explorar os novos centros de HPC no país !
- Necessárias **atualizações constantes** nos próximos 10 anos !

Monitor Squid CVMFS

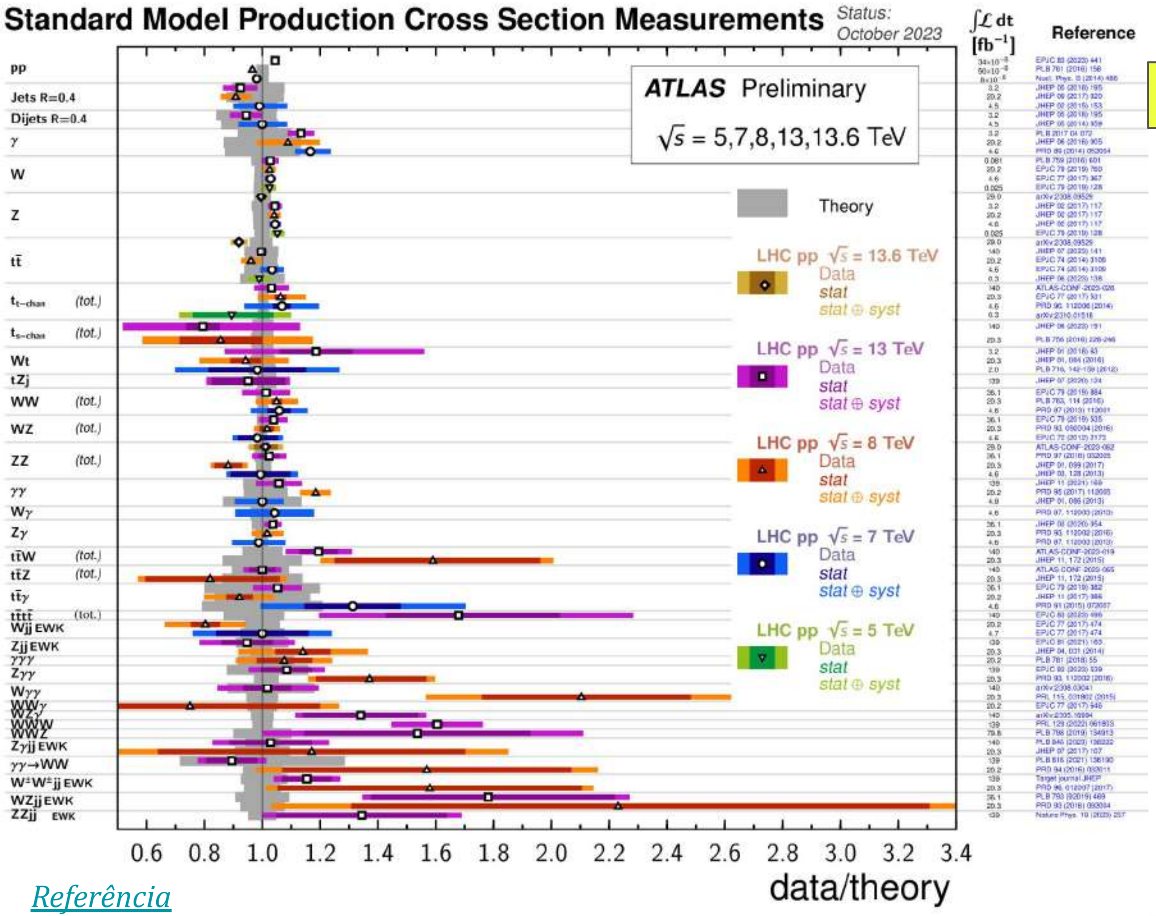
Visitors domains/countries (Top 10) - Full list

Domains/Countries		Pages	Hits	Bandwidth
Brazil	br	6,174,632	6,174,632	963.90 GB
Germany	de	4,331,770	4,331,770	30.25 GB
Unknown	ip	2,700,156	2,700,170	202.35 GB
Switzerland	ch	1,907,986	1,907,986	18.53 GB
USA Educational	edu	1,090,792	1,090,792	410.66 GB
Chile	cl	1,024,990	1,024,990	178.22 GB
United Kingdom	uk	829,040	829,040	1.06 GB
USA Government	gov	325,716	325,716	24.97 GB
Italy	it	294,548	294,548	10.96 GB
Non Profit Organizations	org	245,433	245,436	6.96 GB
Others		971019	971019	22.26 GB





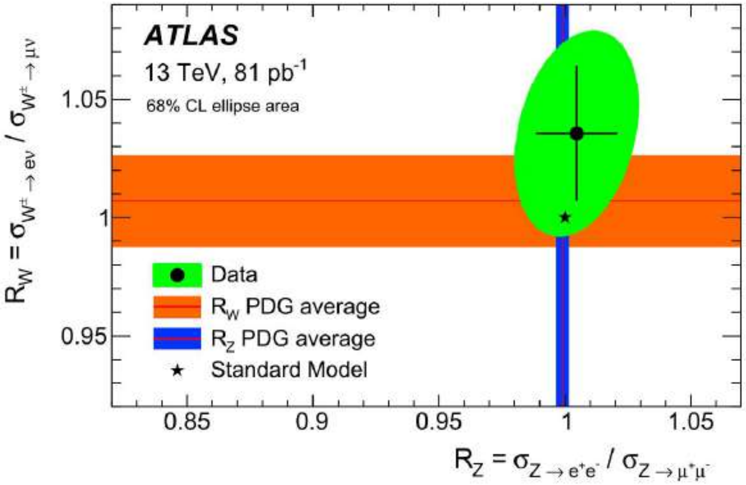
A Física que produzimos I - medidas de precisão



[Referência]

- Incerteza experimental < teoria
- O Modelo Padrão funciona muito bem 😊
- Mas não responde todas as perguntas 😖
- Maior precisão ! 😎

[Referência]



Teste da Universalidade Leptonica já na primeira medida de seção choque W e Z a 13 TeV no LHC

3 - Contribuições em Instrumentação e Trigger

- We (ATLAS/BR) will focus on $HH\to b\bar{b}\tau\tau$

- We (ATLAS/BR) will focus on $HH\to b\bar{b}\tau\tau$

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

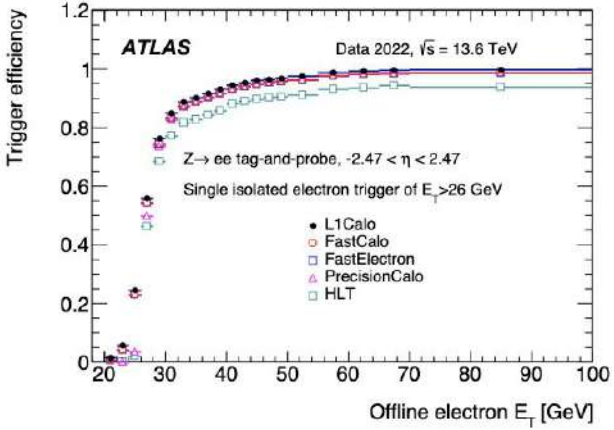
Submitted to: JINST

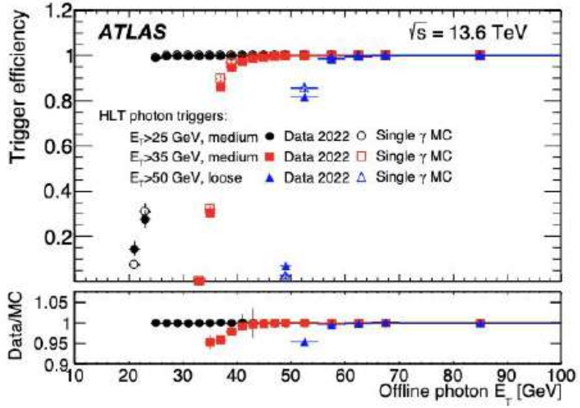
CERN-EP-2023-299
15th January 2024

The ATLAS Trigger System for LHC Run 3 and Trigger performance in 2022

The ATLAS Collaboration

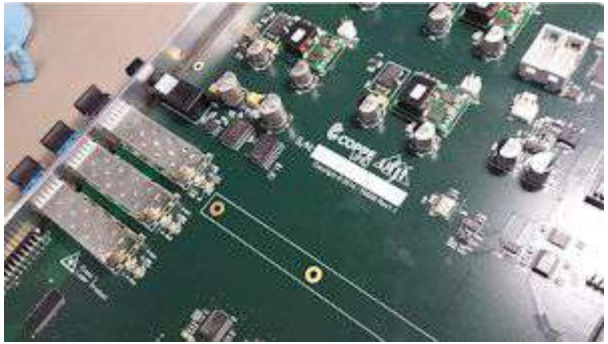
The ATLAS trigger system is a crucial component of the ATLAS experiment at the LHC. It is responsible for selecting events in line with the ATLAS physics programme. This paper presents an overview of the changes to the trigger and data acquisition system during the second long shutdown of the LHC, and shows the performance of the trigger system and its components in the proton–proton collisions during the 2022 commissioning period as well as its expected performance in proton–proton and heavy–ion collisions for the remainder of the third LHC data-taking period (2022–2025).

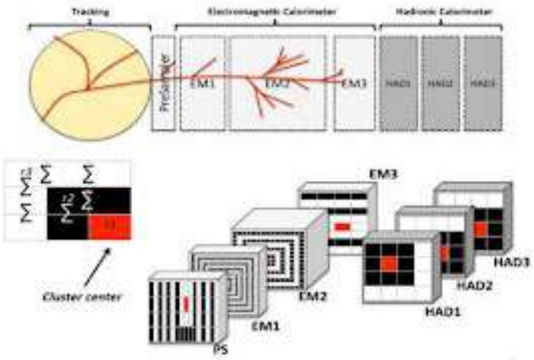


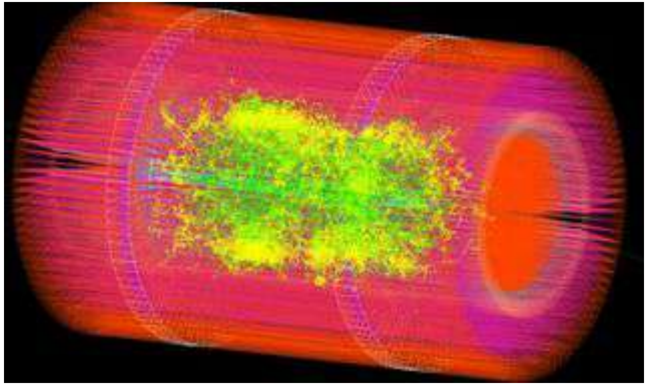


Contribuição na instrumentação - Calorimetria

- Circuitos somadores para o calorímetro hadrônico do ATLAS (Tilecal)
- Métodos de processamento de sinais para a reconstrução da energia das torres do calorímetro
- Trigger de múons de primeiro nível assistido pela calorimetria
- Novas topologias (anéis concêntricos) para o sistema de seleção de eventos do ATLAS
- Simulação e Processamento de Sinais para Futuros Desenvolvimentos em Calorimetria de Altas Energias

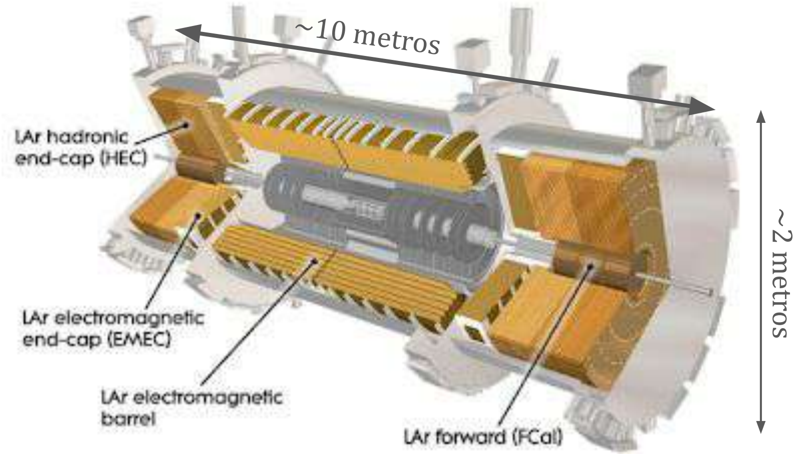


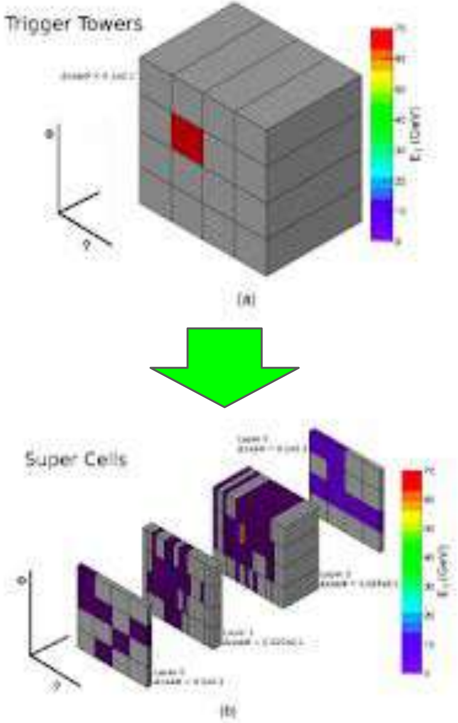


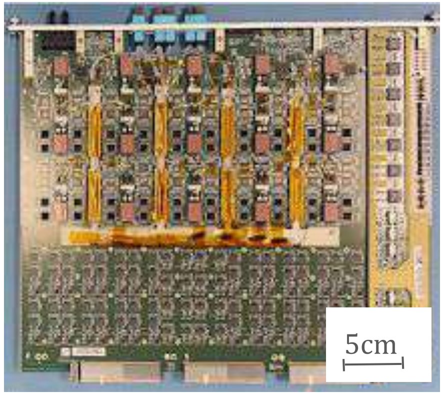


Contribuição na instrumentação - Calorimetria

- Calorímetro eletromagnético de argônio líquido
- Contribuição no desenvolvimento do sistema de trigger digital
  - Testes de radiação dos principais componentes na fase de protótipo
  - Métodos de reconstrução de sinais
  - Comissionamento operações







124 placas , processando cada uma 320 canais =

~40 mil canais e 25 mil Gb/s

O que (quem) é o ATLAS ?

- Um dos 4 grandes experimentos do LHC no CERN (Suíça)
- 5500 membros
  - 3000 autores
  - 1200 estudantes de Doutorado
- 182 Institutos de Pesquisa
- 42 países