The ATLAS experiment:
overview, perspectives
focusing on Pisa’s contribution

Nicolò V. Biesuz
on behalf of the ATLAS Pisa group

The Team















- 8 University:
  - 5 staff
  - 2 postDoc
  - 1 Phd candidate

- 7 INFN
  - 7 staff
  - 1 postDoc

Who am I?

2014, MSc, Fast TracKing and τ triggers in ATLAS

2018, PhD, search for diboson resonances in the lvqq final state with the ATLAS detector

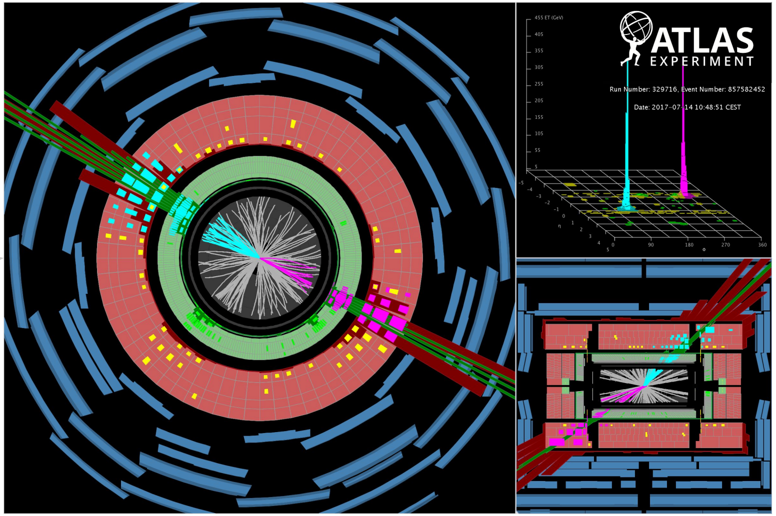
2018-2019, postDoc, DAQ and image analysis for sub-teraHertz imaging systems (SENSORSEK)

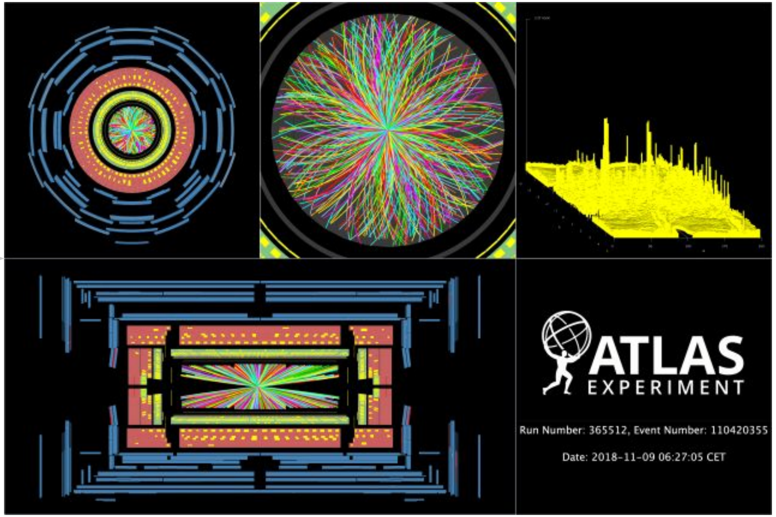
2019-2020, postDoc, Fast TracKing and Hardware Tracking for Trigger for the ATLAS experiment

What’s the ATLAS experiment?

ATLAS experiment:

- CERN, Geneva
- LHC experiment
- multi-purpose detector
- **mainly p-p physics**
- **also Pb-Pb physics**





JINST 3 (2008) S08001

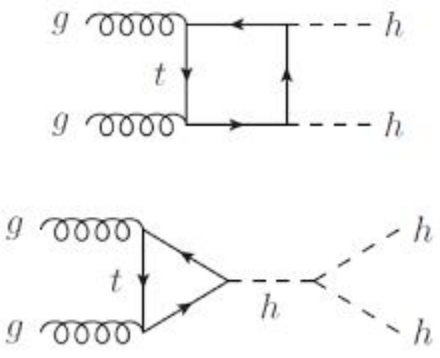
Overview

- The ATLAS detector
  - What's ATLAS
  - latest news from the LHC machine
- Short timescale activities
  - Tile calorimeter
- Ongoing analysis
      - V+H→bb
      - non-collision backgrounds
      - long-lived particles searches
      - τ g-2 (being explored)
- Upgrades to the ATLAS detector
  - HL-LHC upgrades
  - Activities for upgrade
    - Tile calorimeter
    - Hardware Tracking for the Trigger
    - HDL On Git

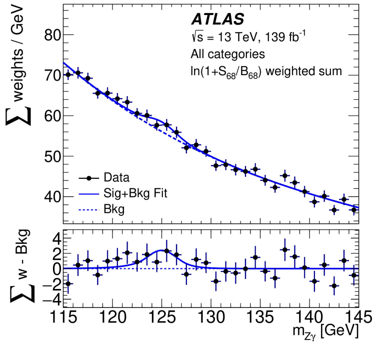
The ATLAS experiment : physics goals

Highlights and perspectives from the ATLAS experiment recently presented at LHCp [video]

- Higgs Boson
  - CP state
  - **search for rare Higgs decays**
  - **self coupling**
- Standard Model
  - vector boson scattering
  - W mass
  - top properties
  - study of QCD/multi-jet production
- BSM searches
  - additional vector bosons
  - dark matter
  - Susy electroweak, SUSY stop

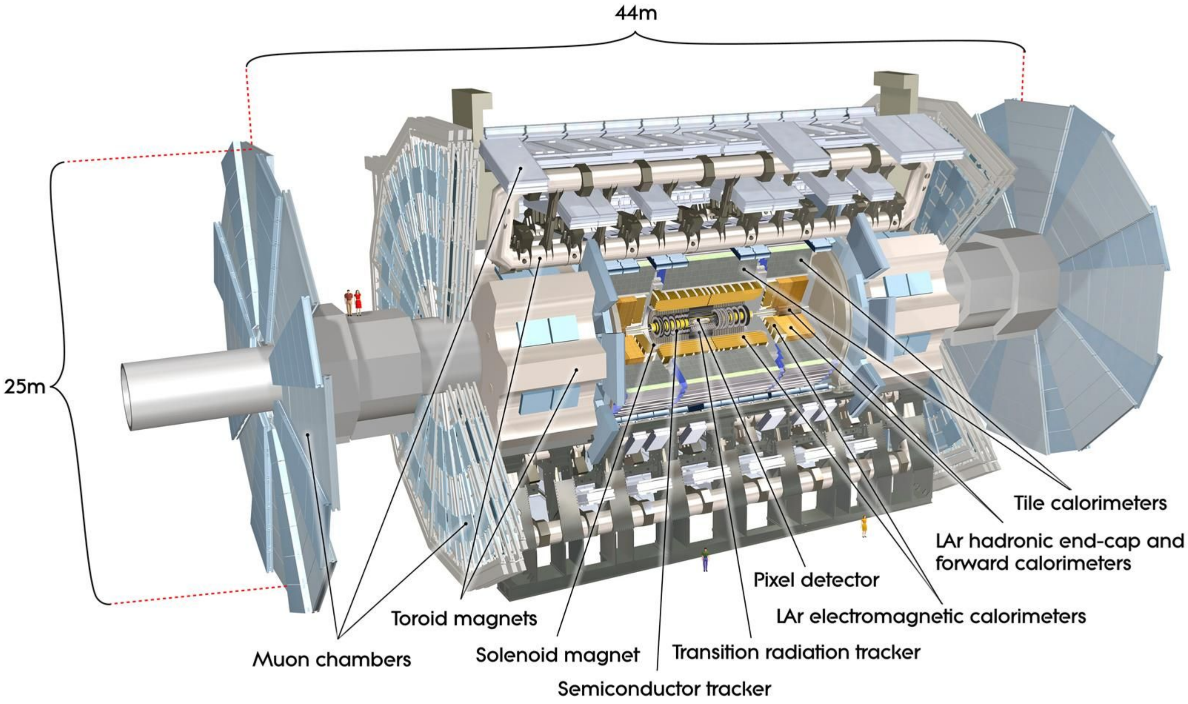


HH production



H→Zγ

The ATLAS detector



LHC delivered data:

- event rate 40 MHz
- data rate 60 TB/s

Requires online selection

Performed by two level trigger

Level 1 trigger

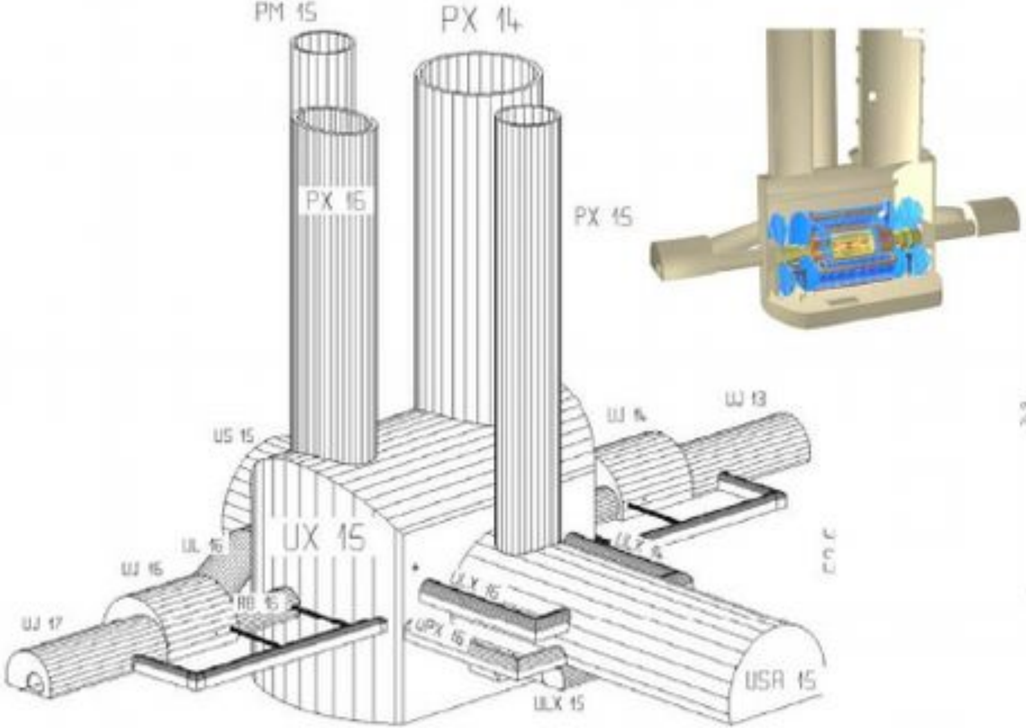
- fixed latency
- hardware based
- Calorimeters + Muon
- event rate 100 kHz
- data rate 160 GB/s

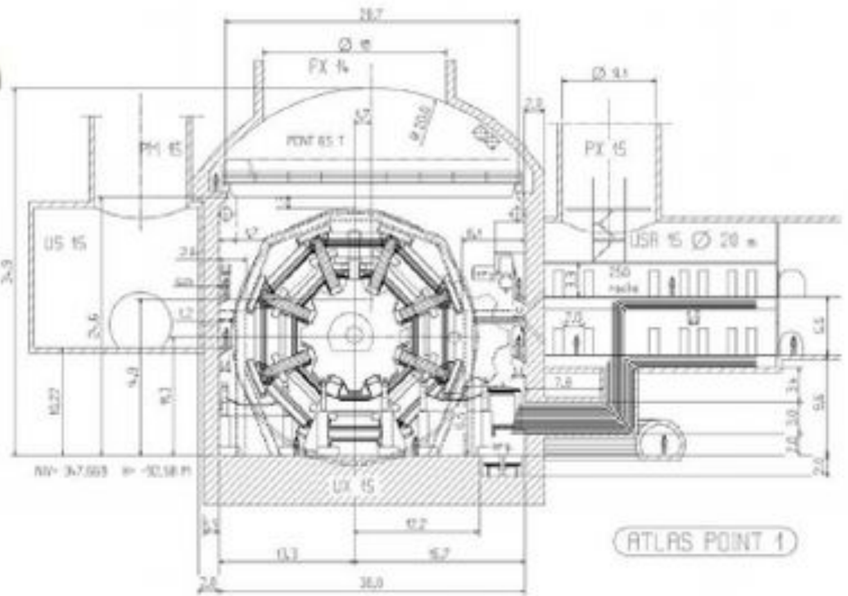
High Level Trigger

- software based
- event rate 1.5 kHz
- data rate 1.5 GB/s

JINST 3 (2008) S08003

Where's all this stuff?





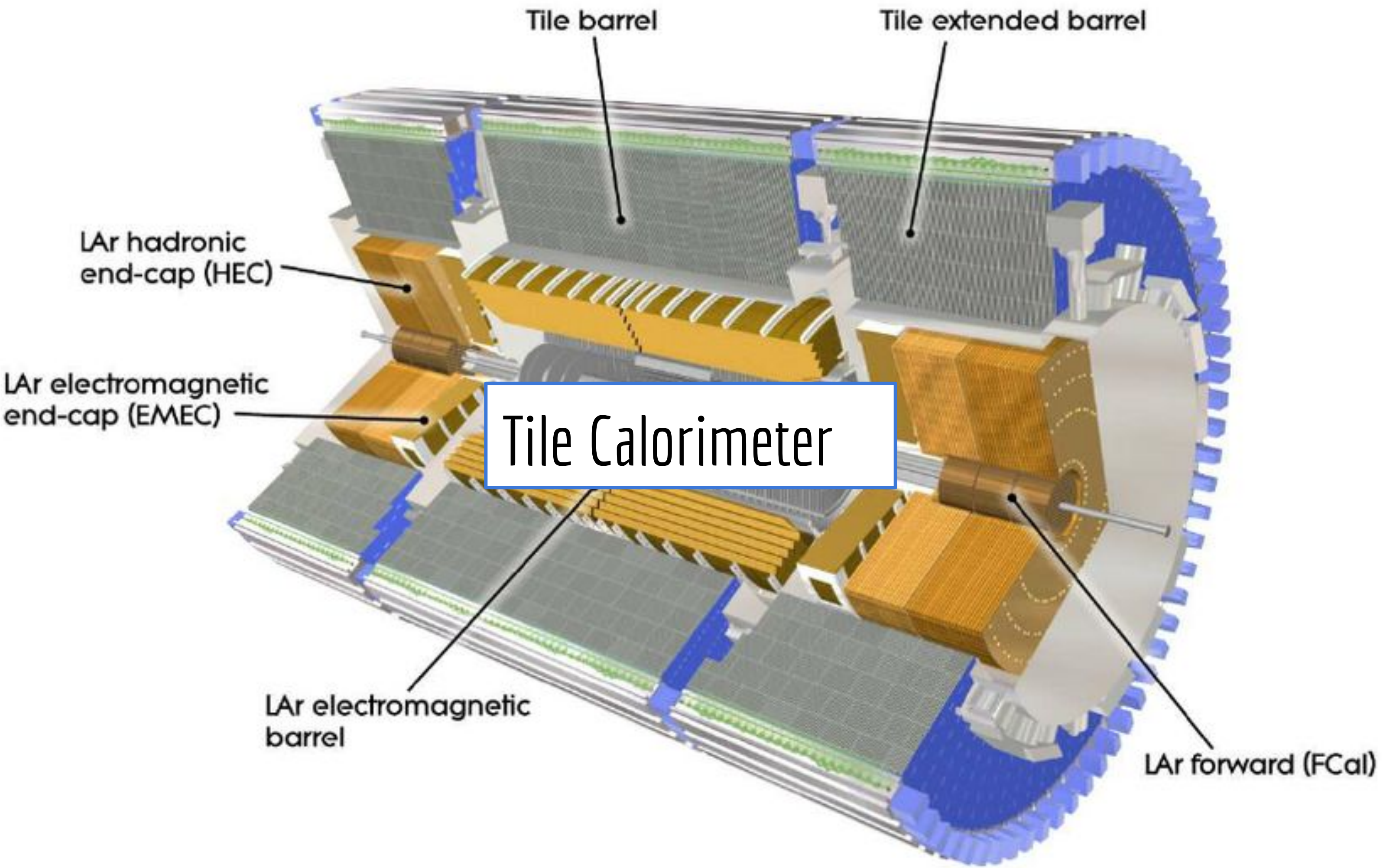
LHC Schedule after covid (to be confirmed)

LHC at present in shutdown

- ATLAS implementing upgrades for Run 3 and in view of the HL-LHC

Preliminary new schedule after Covid-19

- begin of run-3 in february 2022
  - decision to be reviewed at the end of the year
- run-3: 4-years of data taking
- 2.5 years of shutdown
  - upgrades for the LHC High Luminosity phase
- run 4 will mark the beginning of the HL-LHC



Tile Calorimeter

Hadronic calorimeter

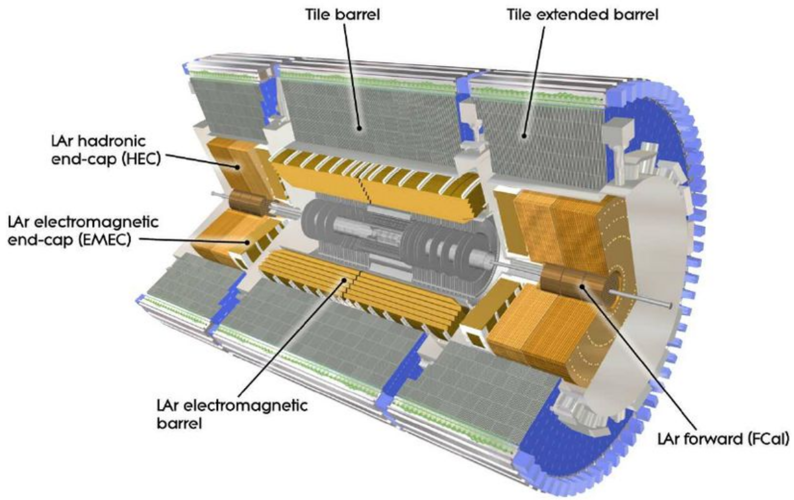
TileCal is the central section of the hadronic calorimeter in the ATLAS detector

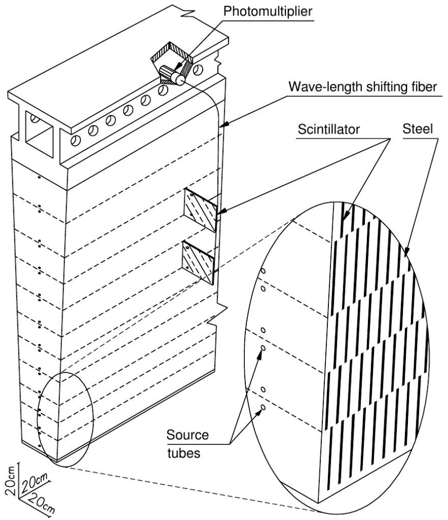
- it is a sampling calorimeter (alternating steel and scintillating tiles)
- light produced by the particles is transmitted to PMTs by WLS fibers

The TILE calorimeter has:

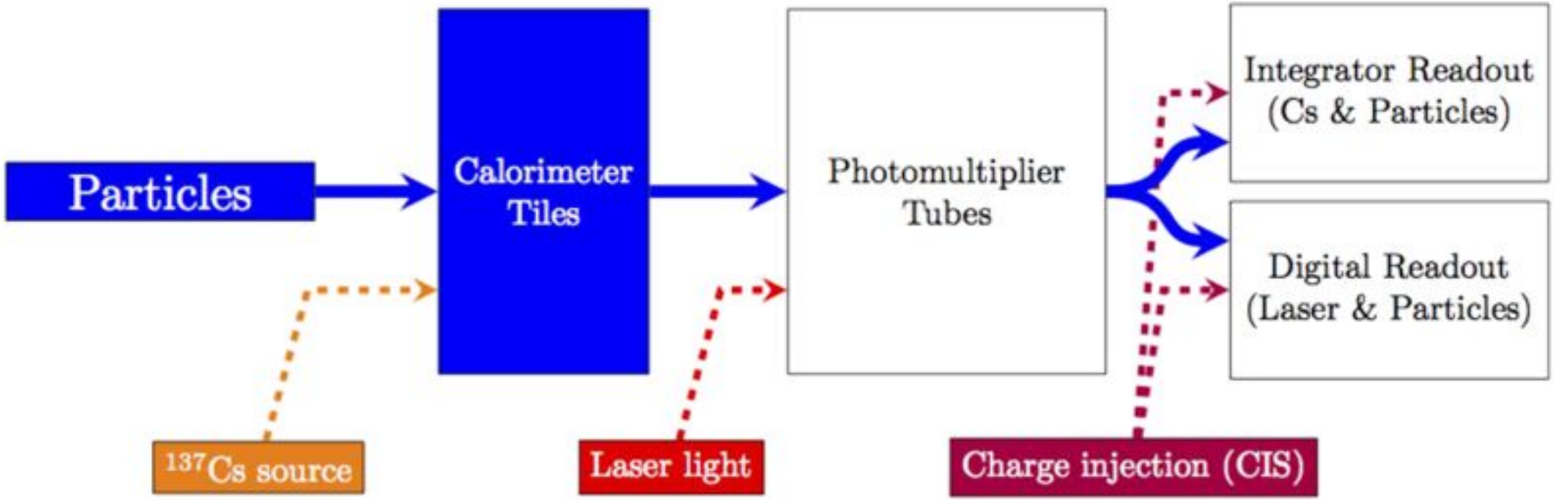
- high segmentation
- good jet energy resolution

$$\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%$$





TILE calorimeter: calibration and monitoring



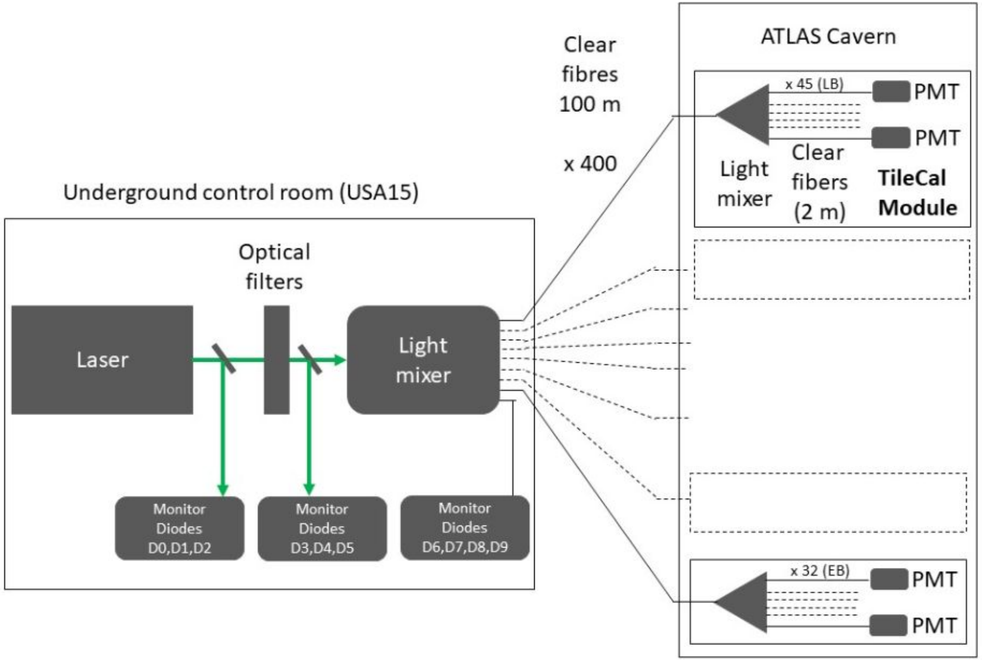
The calorimeter is calibrated using 3 systems

- ^{137}Cs (full chain calibration)
- **laser** **(readout calibration)**
- charge injection (electronics calibration)

TILE calorimeter: the laser calibration system (LASER II)

The laser system monitors the PMTs and the front-end electronics.

An optic box contains a laser, the optic elements and the light monitors. Laser light pulses are transmitted simultaneously to all TileCal PMTs through a bundle of about 100 m long clear fibers.



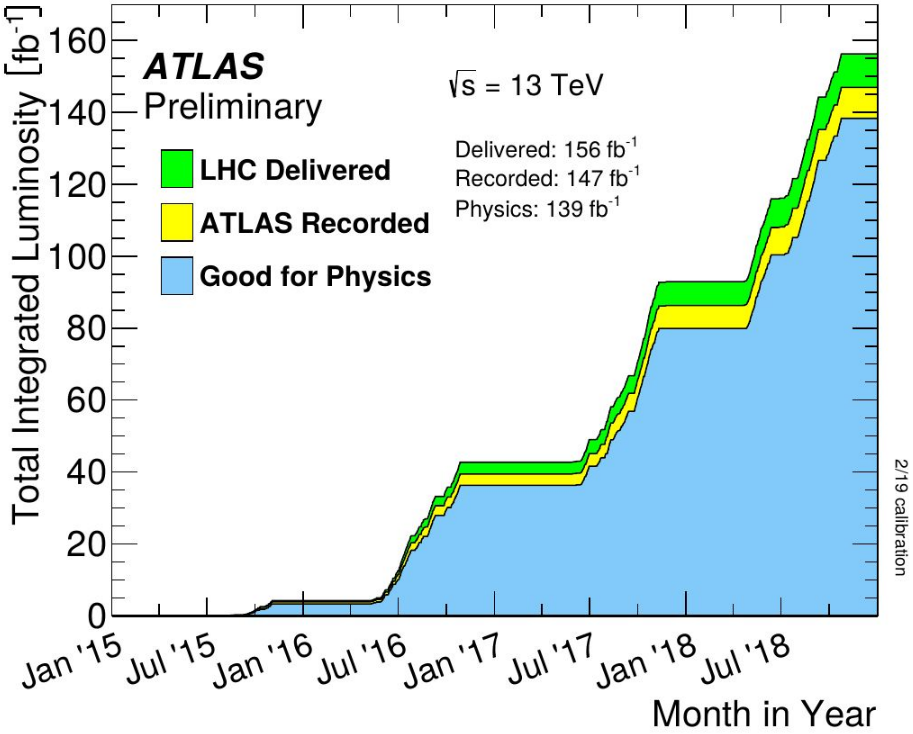
New laser optic box designed and produced in Pisa

It has an improved stability wrt previous system

Currently reached:

- < 1% response fluctuation on 3 months
- 1% response fluctuation on 6 months

Analysis



Run 2 (2015-2018) data:

- Bunch spacing: 25 ns
- Center-of-mass energy: 13 TeV
- Integrated luminosity ~139 fb^{-1} end of 2018
- Average number of interactions per crossing ~34

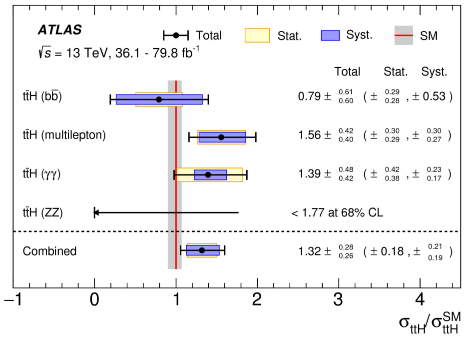
expected luminosity for run 3 (~ 2022-2026)

- Integrated luminosity ~150 fb^{-1}

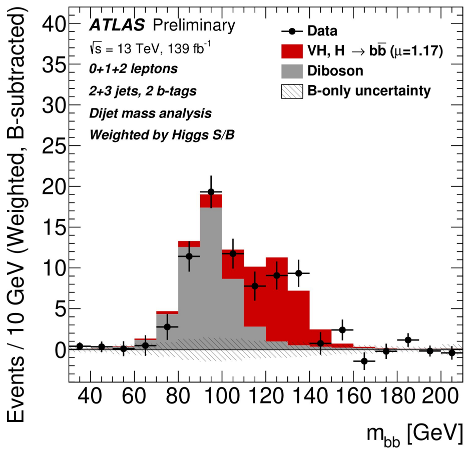
run 2 results will stay with us for a long time

run 3 alone will have similar reach w.r.t run 2

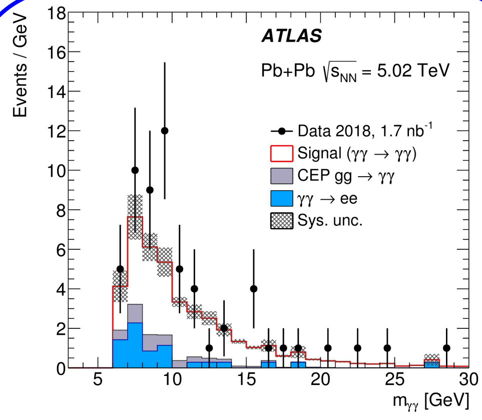
Run 2 Highlights



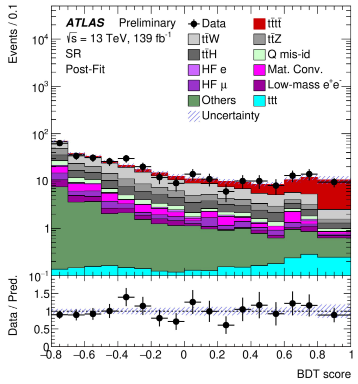
observed ttH process



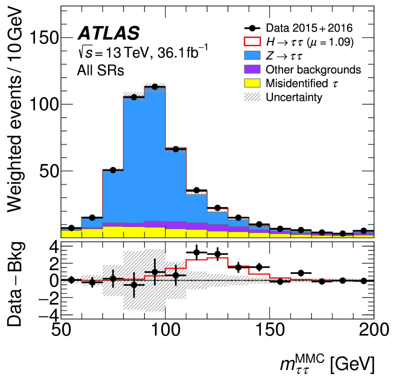
observed VH, Hbb



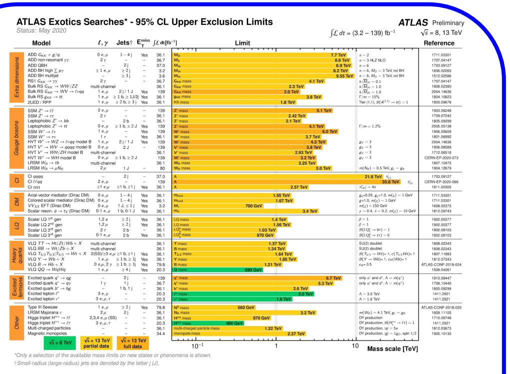
observed light-by-light scattering



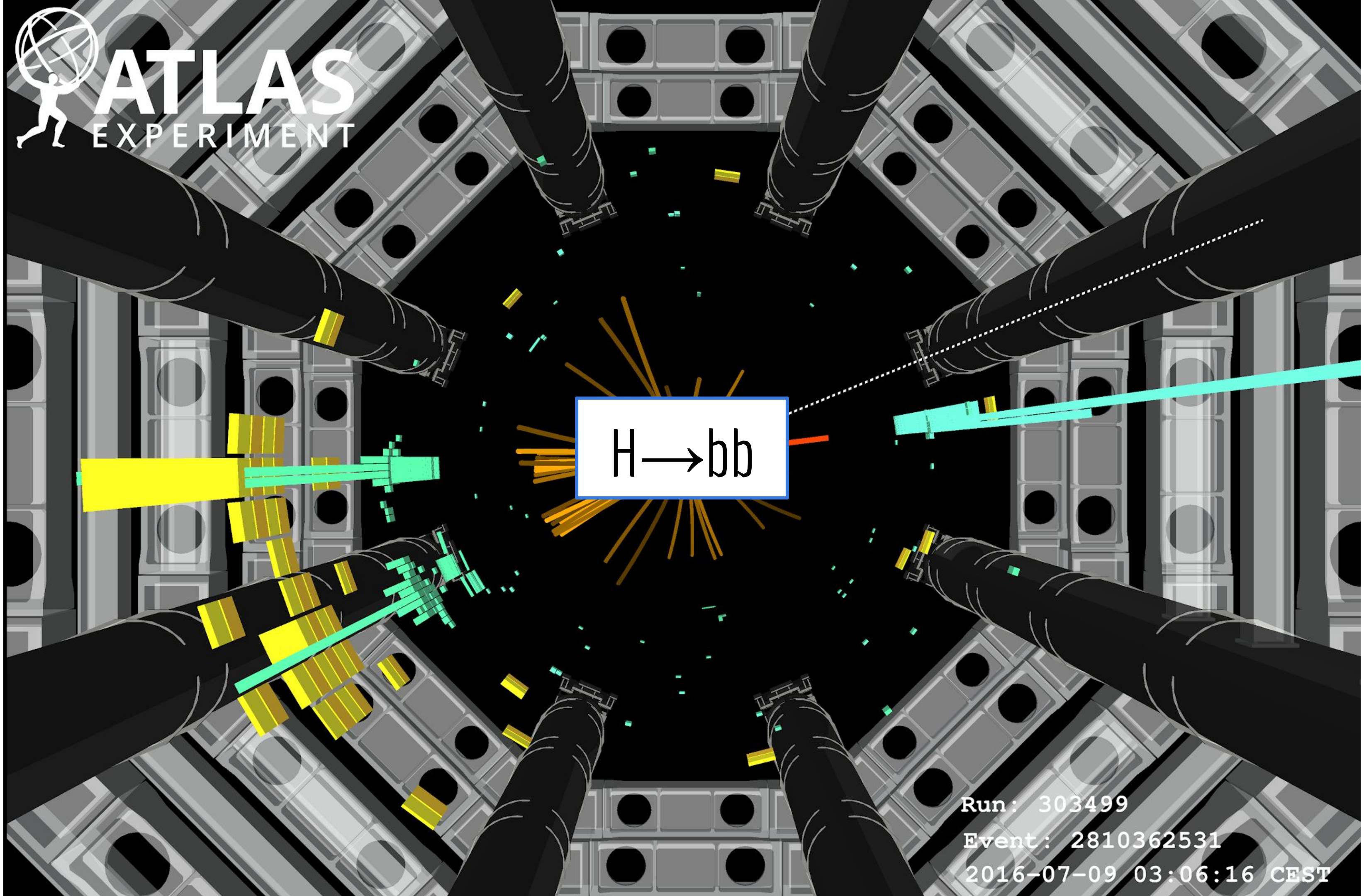
observed 4t production



observed H→ττ

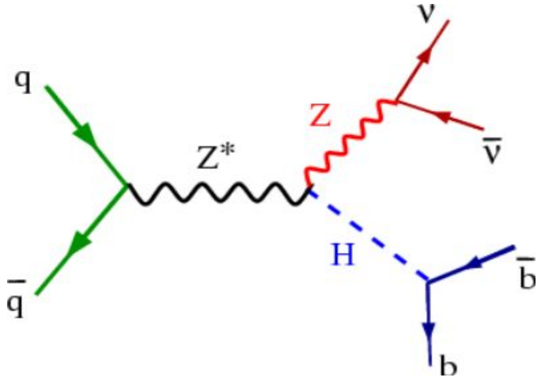


… and many others …

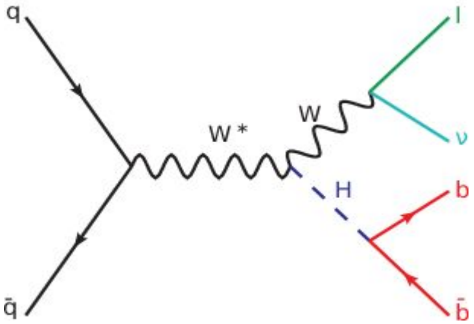

ATLAS
EXPERIMENT
H⟶bb
Run: 303499
Event: 2810362531
2016-07-09 03:06:16 CEST

Introduction - VH, H⟶bb

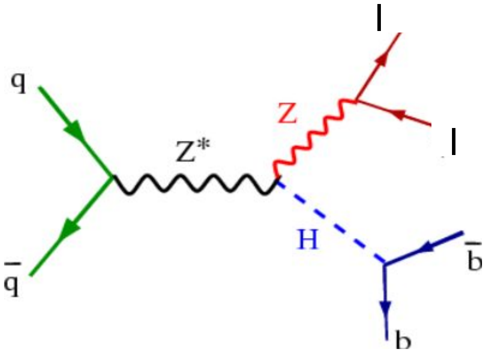
- **BR(H → bb)** ~ 58 % (expected) *YR4, CERN-2017-002-M*
- direct measurement of the **Higgs coupling** to fermions



- Trigger: E_T^{miss}



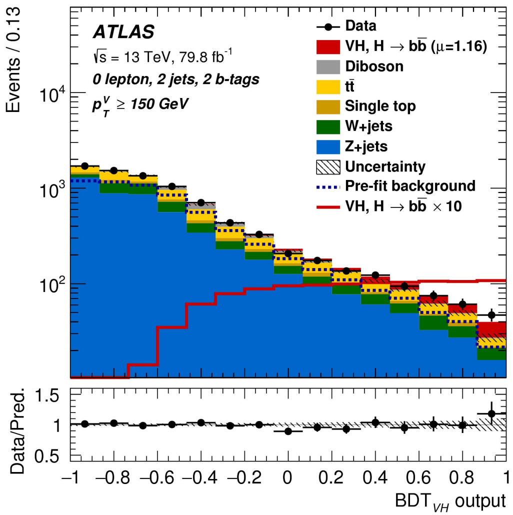
- Trigger: electron or E_T^{miss}

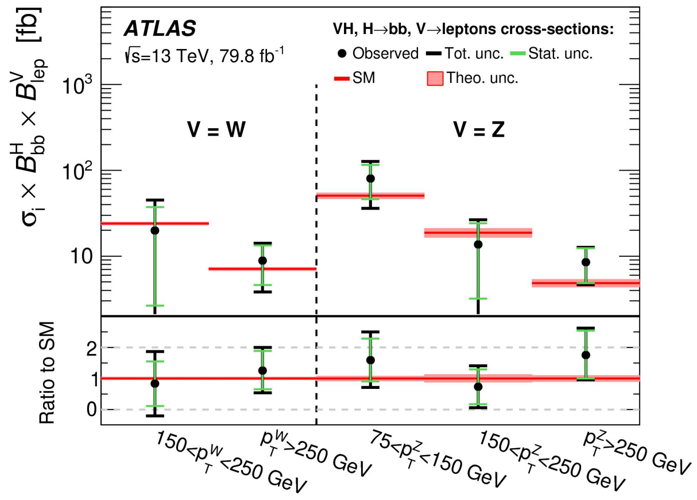


- Trigger: single lepton

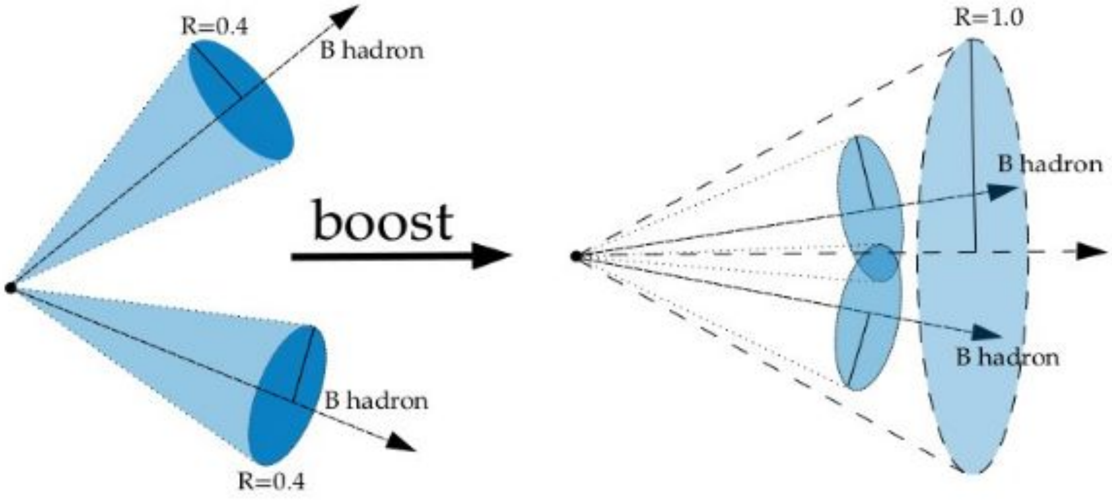
Results

2012 Higgs boson observation → Spring 2017: Hbb and VH evidence → Summer 2018: **H→bb and VH observation** *Phys. Lett. B 786 (2018) 59* → Winter 2018: **VH→bb as a function of p_T^V** *JHEP 05 (2019) 141* → Can we go at higher transverse momentum?





Selection of the candidate Higgs boson



$$\Delta R \sim \frac{2m_H}{p_T^H}$$

$$p_T^H = 250\ \text{GeV} \rightarrow \Delta R \sim 1$$
$$p_T^H = 500\ \text{GeV} \rightarrow \Delta R \sim 0.5$$

"Resolved" selection

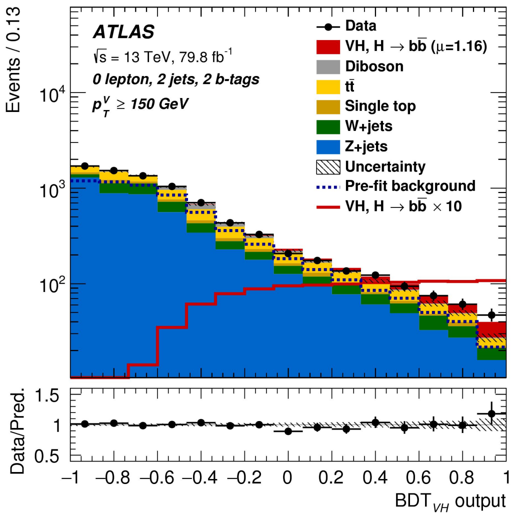
- 2 b-tagged small-R jets

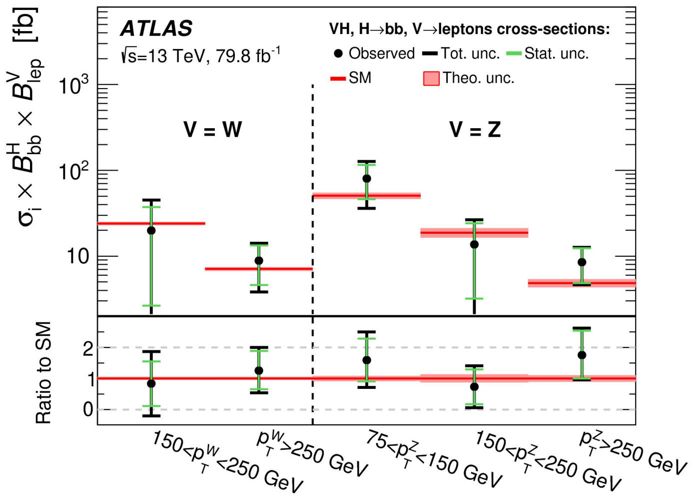
"**Merged**" selection

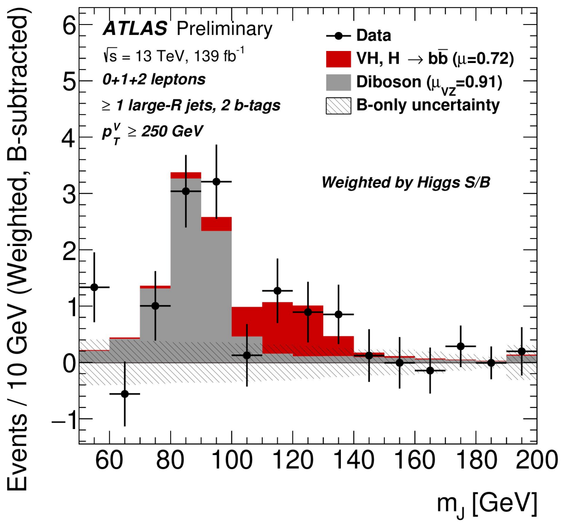
- 1 large-R jet
- 2 variable-R b-tagged track jets

Results

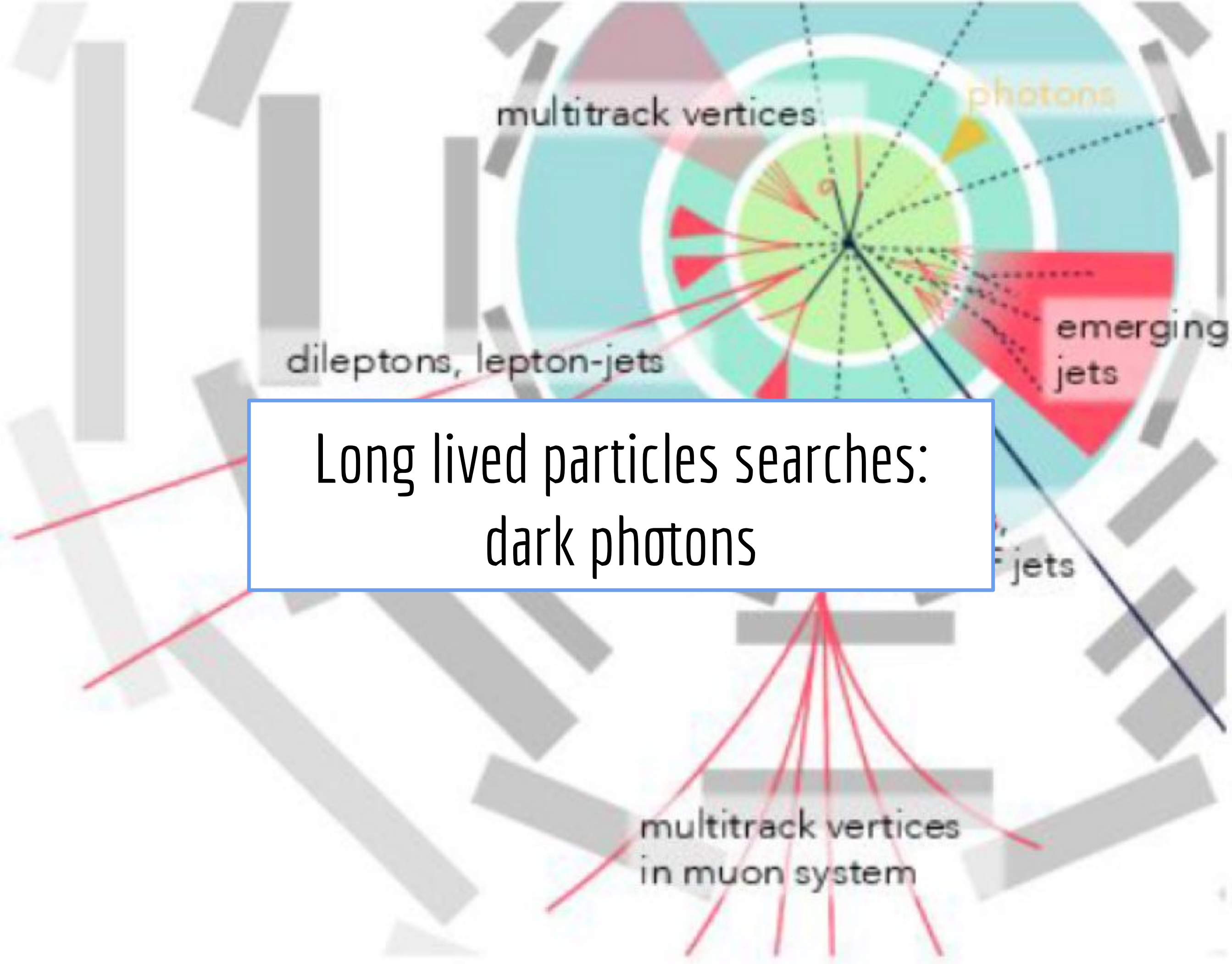
- 2012 Higgs boson observa tion
- Spring 2017: Hbb and VH evidence
- Summer 2018: **H→bb and VH observation** [Phys. Lett. B 786 (2018) 59]
- Winter 2018: **VH→bb as a function of p_T^V** [JHEP 05 (2019) 141]
- Spring 2020 **merged VH→bb results** [ATLAS-CONF-2020-007]
- Study of machine learning techniques in the boosted channel



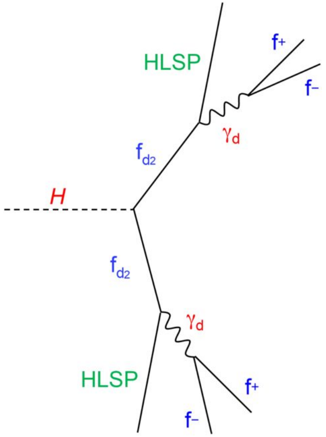




Long lived particles searches: dark photons



Long lived particles searches: dark photons



BSM models predict existence of **dark photons**:

- light neutral particles decaying into collimated leptons or light hadrons.

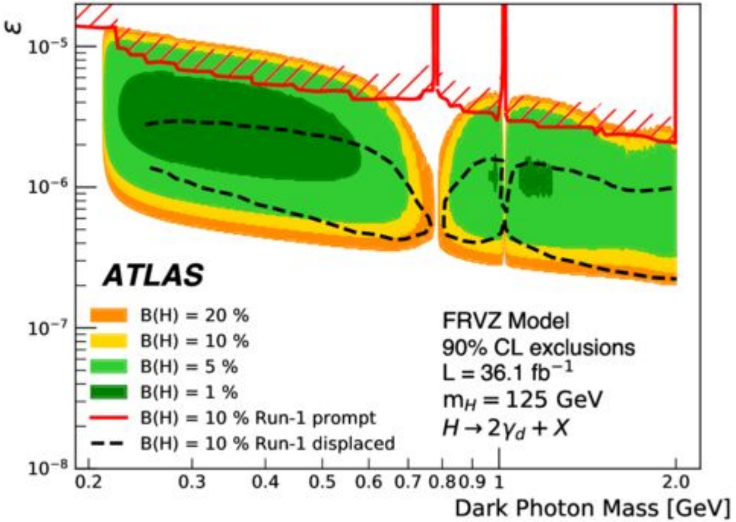
This search looks for a long-lived dark photons from the decay of

- Higgs boson
- heavy scalar boson

Multivariate techniques used multi-jet background suppression

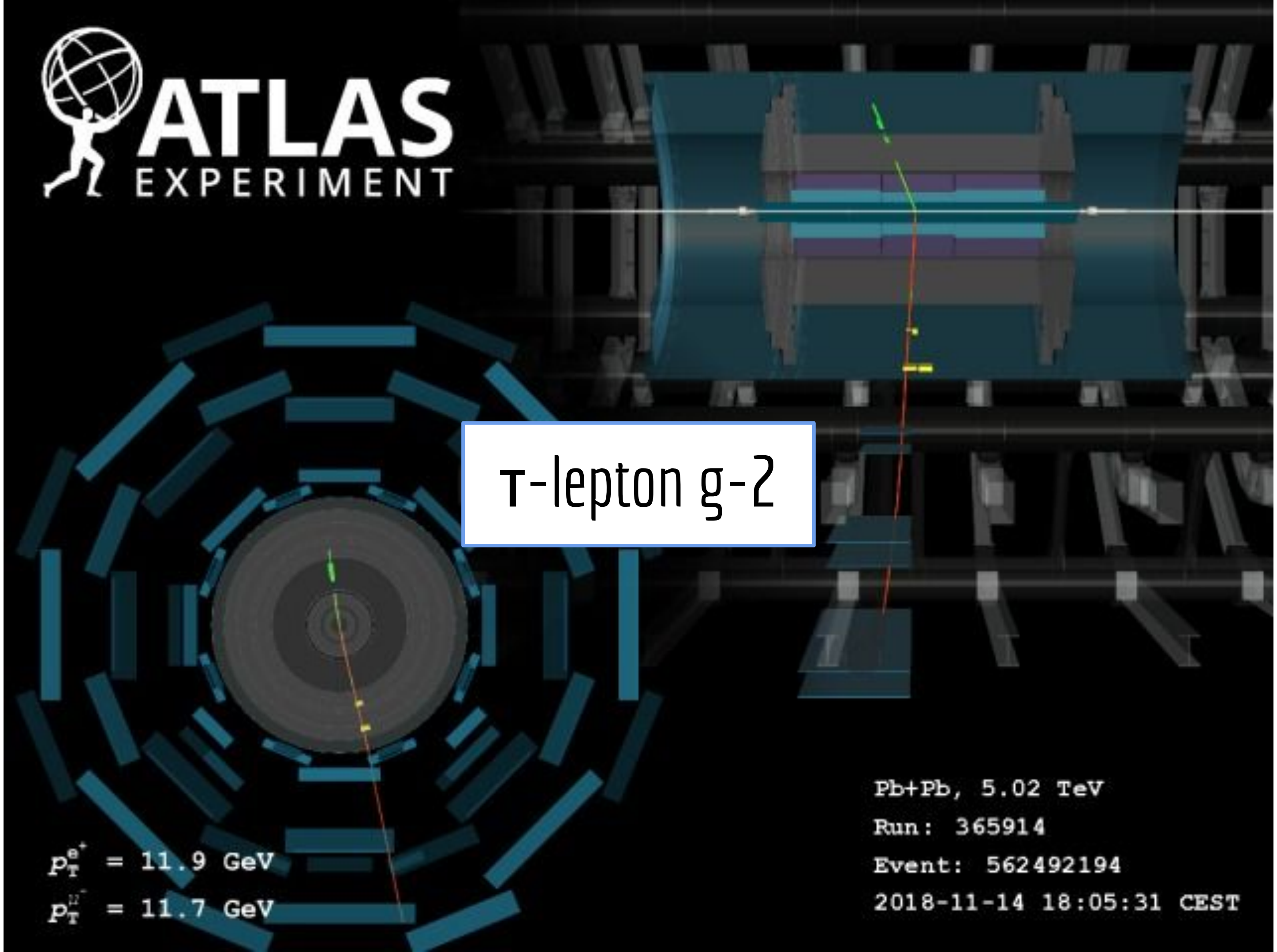
Optimised for different Dark Photon Jets (DPJ) channels

- muonic-DPJ – DPJs decays into displaced muons
- hadronic-DPJ – DPJs decays into displaced electron or pion pairs in TILEcal



ε parameter connecting SM and dark photons $\frac{\epsilon}{2} F^{\mu\nu} b_{\mu\nu}$

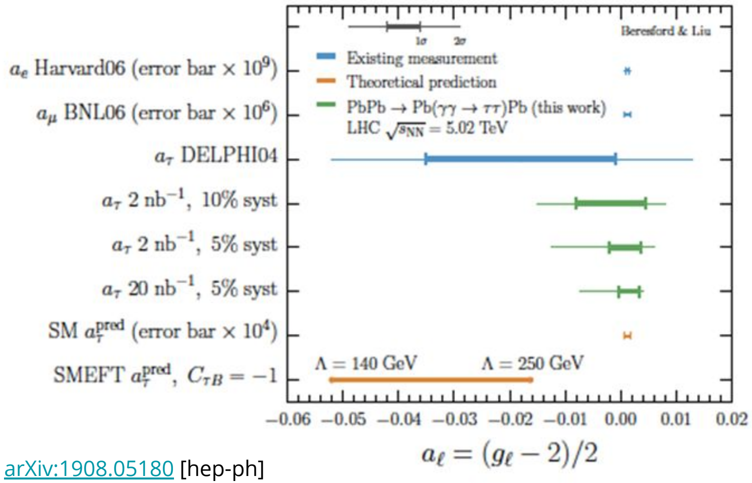
τ-lepton g-2


ATLAS
EXPERIMENT
$p_T^{e^+}$ = 11.9 GeV
$p_T^{\mu^-}$ = 11.7 GeV
Pb+Pb, 5.02 TeV
Run: 365914
Event: 562492194
2018-11-14 18:05:31 CEST

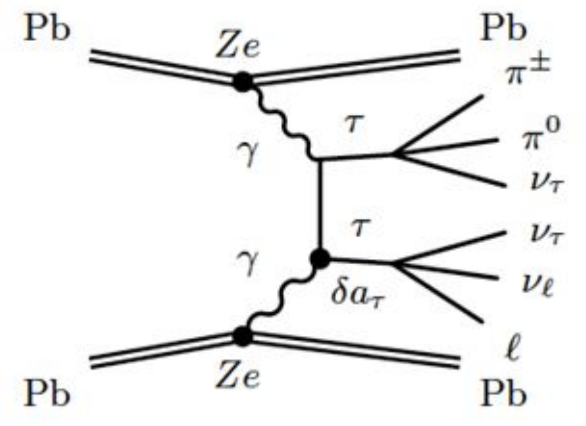
τ-lepton g-2 in heavy ion collisions

Why?

- 3 σ deviation in a_μ
- a_τ experimentally poorly constrained
- sensitive to Beyond the Standard Model scenarios
  - sensitivity is increased by a factor $(m_\tau/m_\mu) \cong 280$
  - *Natascia Vignaroli* (1) modeling a_τ effects on σ_γ



arXiv:1908.05180 [hep-ph]



We want an electromagnetic process

- use Pb-Pb collisions(2): to gain a factor $Z^4 \cong 4.5\ 10^7$

Delivered luminosity is lower: 2018 1.76 nb^{-1}

Search 1l+1(3) π in data:

- use dedicated UPC trigger [$\Sigma E_T < 50$ GeV]

(1) PostDoc @ Pisa theoretical physics, INFN associate (2) In LHC we use $^{208}_{82}$Pb

Upgrade activities

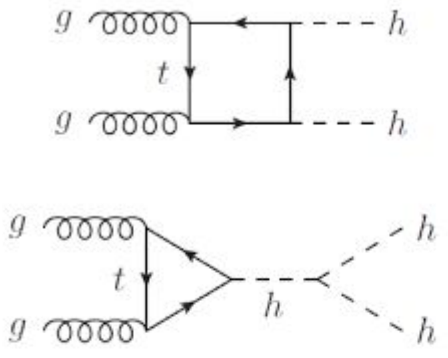
The ATLAS detector: LHC future upgrades

The High-Luminosity LHC (HL-LHC)

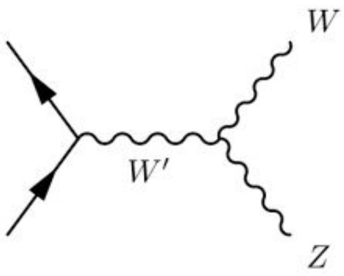
- proton-proton collisions at a center-of-mass energy of 14 TeV
- baseline $\mathscr{L}$ = 5 10^{34} $cm^{-2}s^{-1}$ <μ>≅140-200
- integrated luminosity 3000 fb^{-1} 250 fb^{-1} $year^{-1}$

Physics goals:

- summarised in the [HL/HE-LHC Yellow Report Volume II]
- Standard Model
  - **Higgs Boson self coupling**
  - Other SM processes (vector boson scattering, top physics)
- BSM searches
  - **additional vector bosons**
  - ....

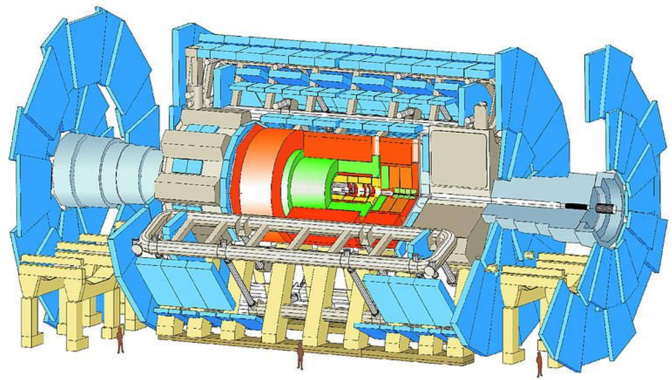


HH production



HVT W′ production

The ATLAS detector: Phase II upgrades

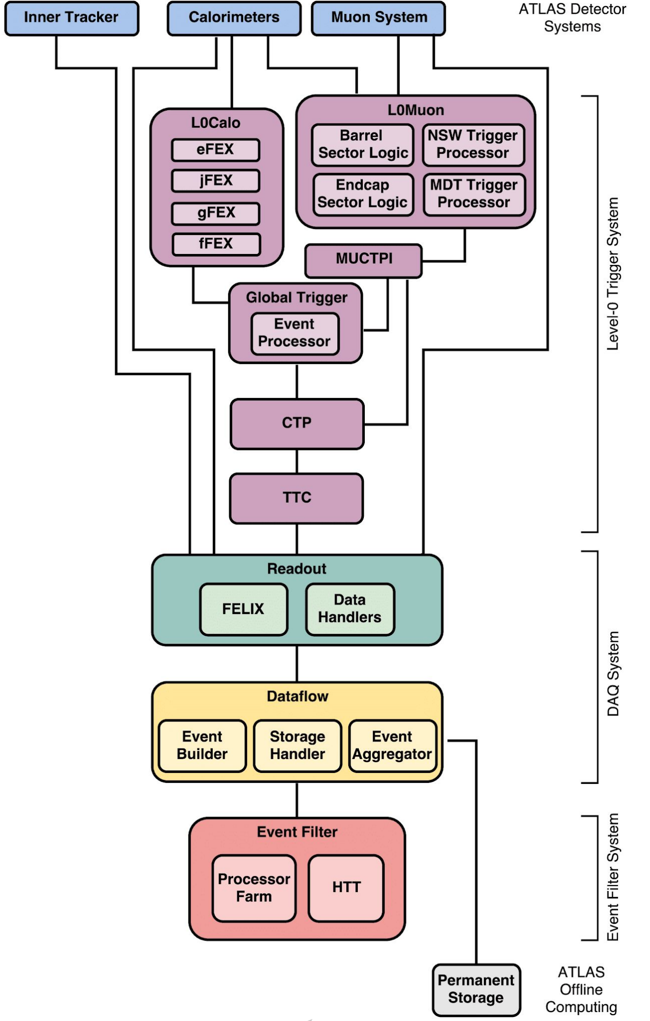


All detectors will need new readout electronics to cope with the enhanced luminosity

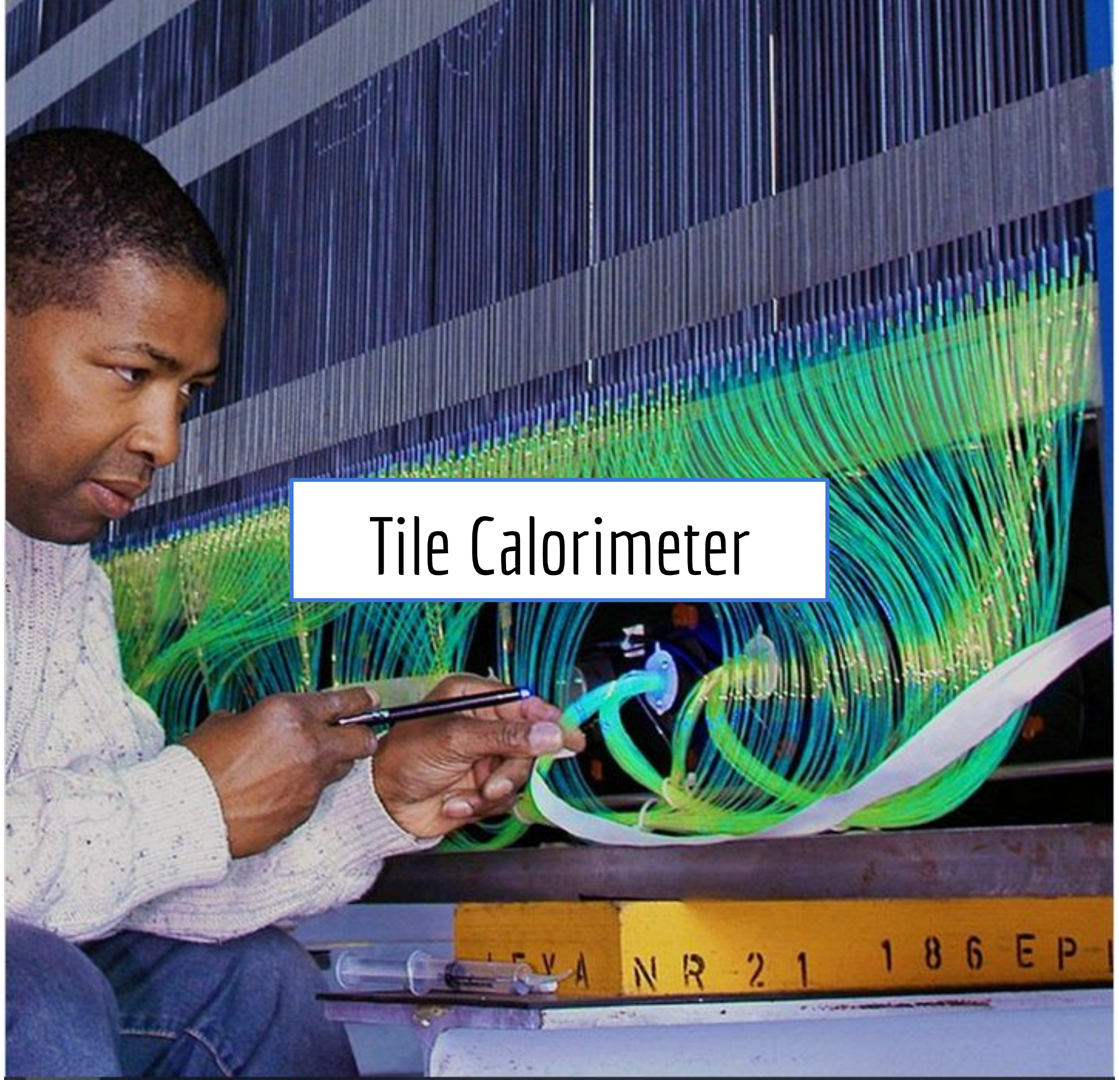
- **Tracker:** replaced by a new detector (ITk)
- **Hadronic calorimeter:** replacement of 1000 (10%) PMTs and upgrade of the calibration system

The trigger and data acquisition system will be improved
It will remain a wo level trigger system

- **Level 0** custom electronics
- **Event Filter** CPU + **HTT coprocessor**



Tile Calorimeter



TILE calorimeter: PMT robustness

Robustness against ageing of PMTs extensively tested in Pisa

Two PMT models tested

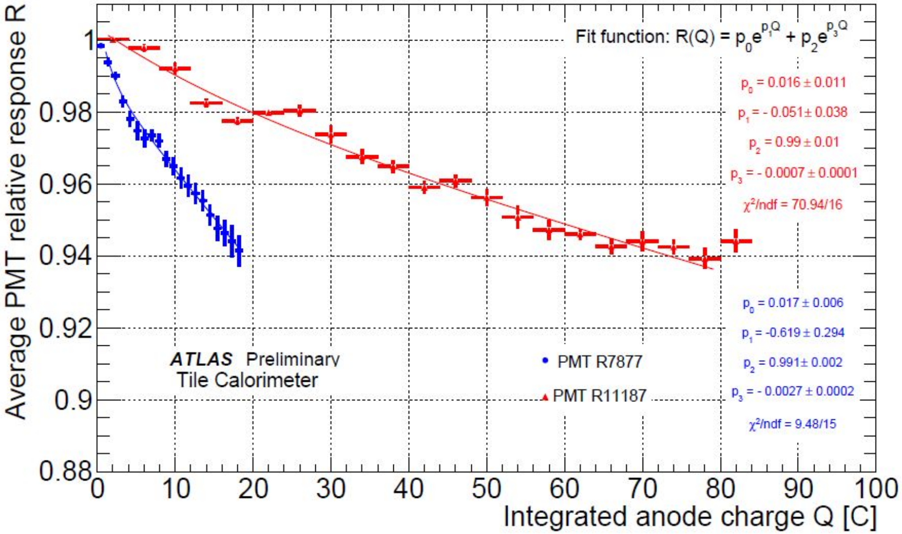
- ● Hamamatsu R7877 **(old)**
- ▲ Hamamatsu R11187 **(new)**

New PMT model shows smaller down-drift as a function of the integrated anodic charge

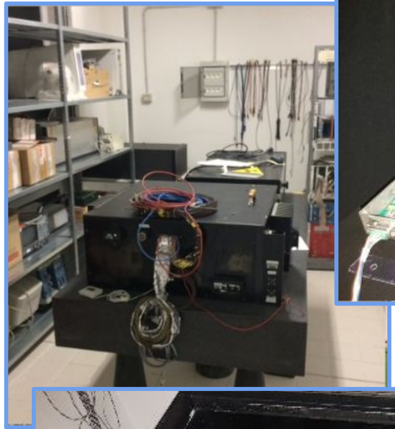
Foreseen substitution of 10% (1000) of PMT

- most exposed TileCal cells

New PMTs have same geometry and better performance



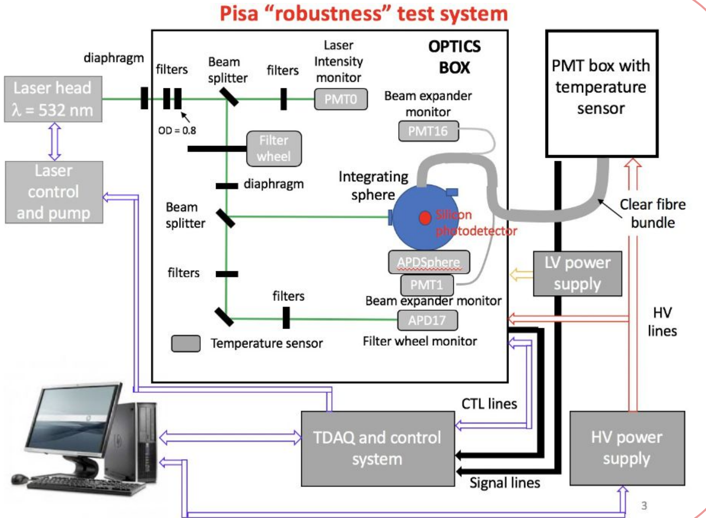
TILE calorimeter: PMT performance



Pisa responsible for testing ~600 new PMTs

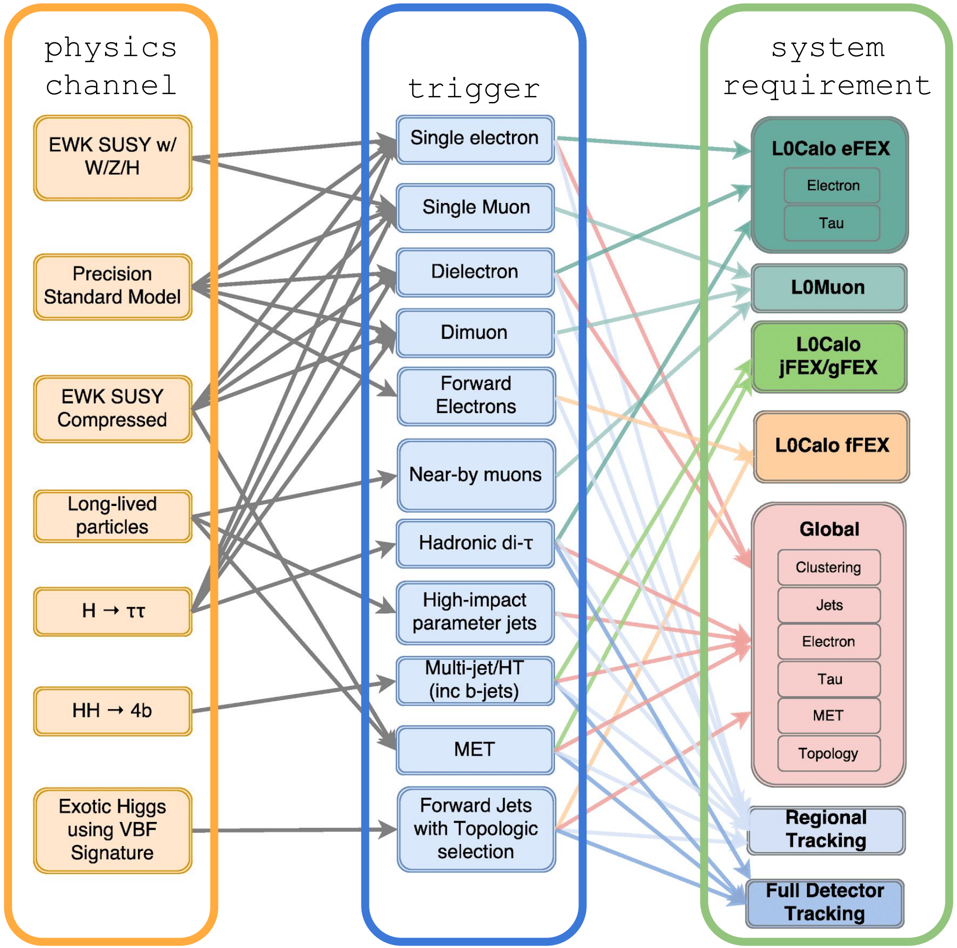
Two test benches active in the ATLAS laboratory:

- one for qualifying the new PMTs
- one for extensive studies of:
  - latest model PMTs
  - high voltage active divider pre-production




HTT

Hardware Tracking for Trigger (HTT)



Most of the physics goals for ATLAS phase-II require regional or global tracking at trigger level

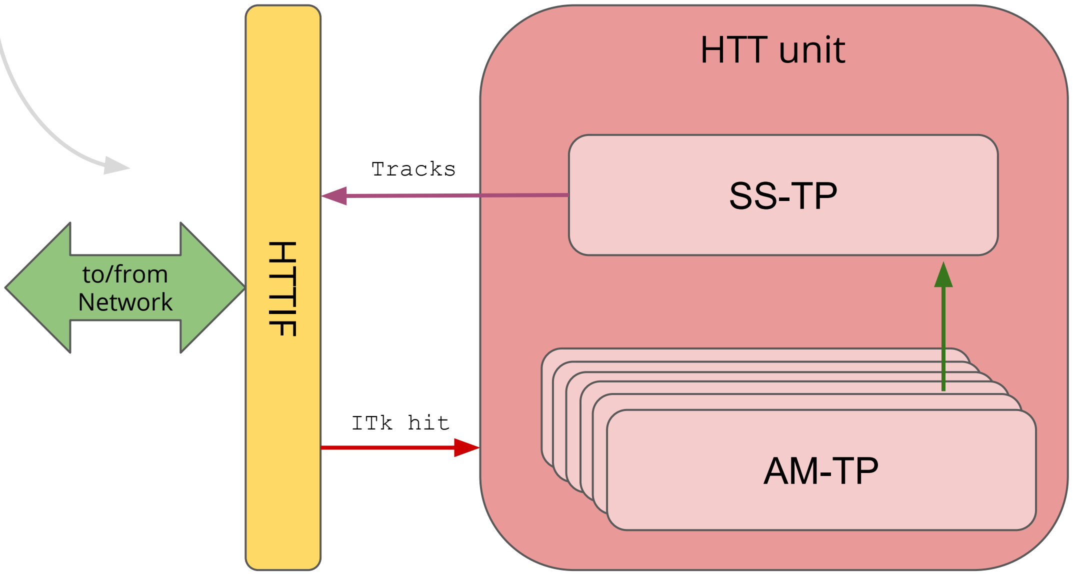
Electron identification is a good example of how tracking improves the trigger performance:

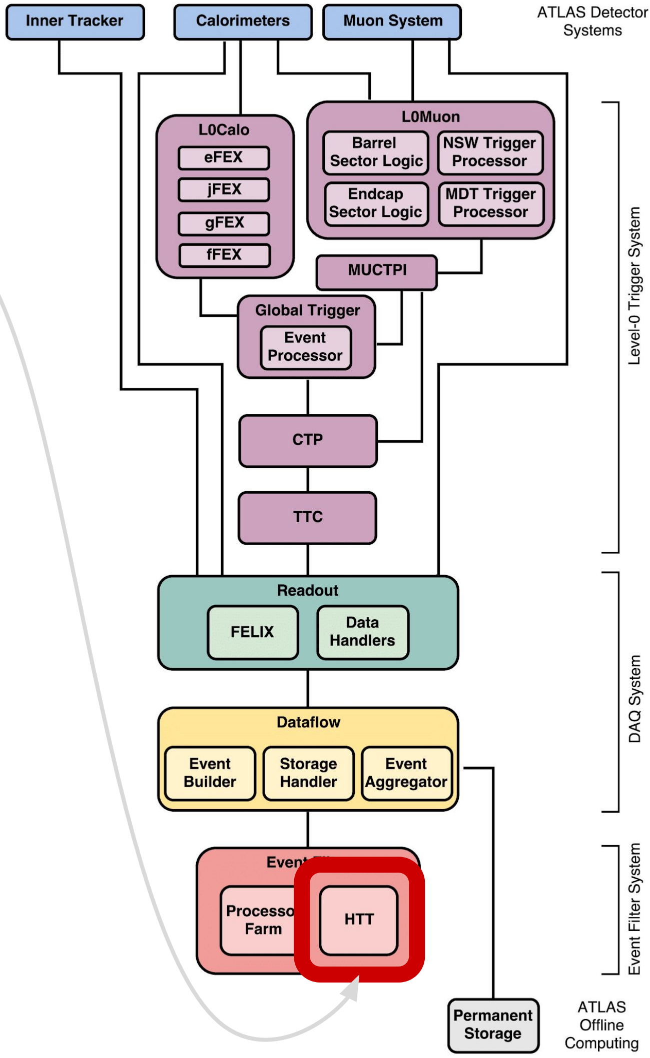
run 2 threshold [GeV]	HL-LHC threshold [GeV]	L0 rate [kHz]	rate after regional tracking [kHz]
27	22	200	40

Hardware Tracking for Trigger (HTT)

The HTT is part of the upgrade of the ATLAS Trigger and data acquisition

It uses ATCA custom electronic boards and an ASIC to perform global and local tracking at trigger level





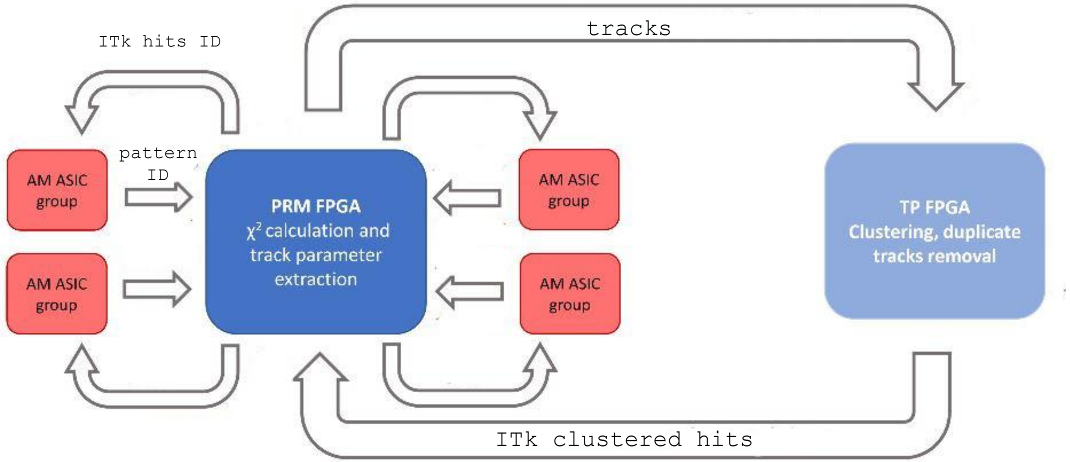
The Pattern Recognition Mezzanine (PRM)

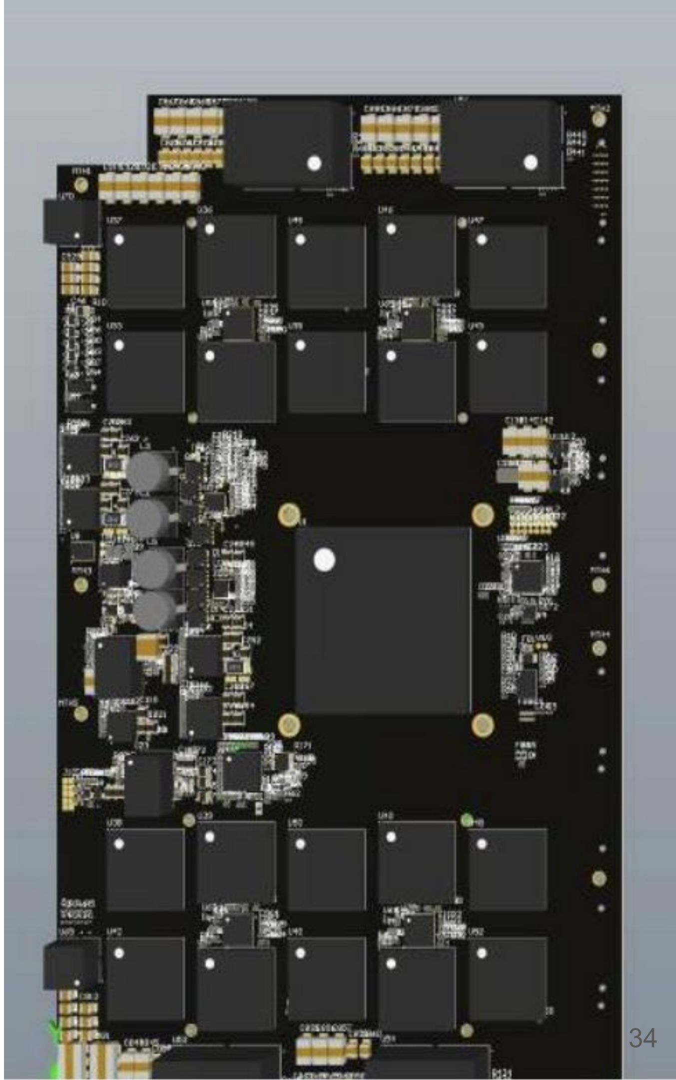
Pisa is tasked with design and test of the PRM.

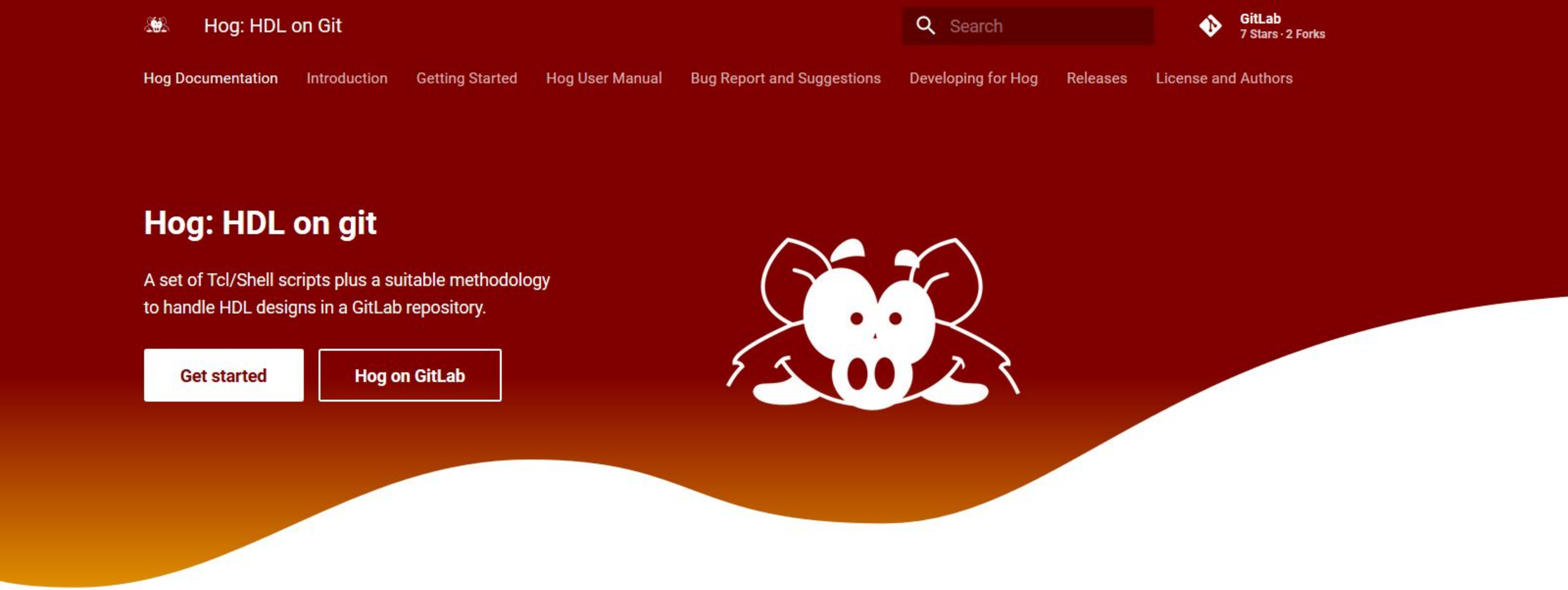
It is an electronic board (ATCA mezzanine):

- data parsing and transformation
- perform pattern matching using ASIC
- first stage track fitting

Uses Associative Memory ASIC and 1 Intel Stratix 10







Firmware development has proven to be one of the critical tasks in the detector upgrades

We want Continuous Integration (CI) and Continuous Deployment (CD) that:

- grants full Place and Route reproducibility
- ensures traceability of binary files

We created few TCL scripts implementing git CI e CD (***for everyone***)

Conclusion

I presented the main activities of the local ATLAS group

We are involved on many topics:

- detector TileCal
- electronics HTT
- data analysis H$\rightarrow$bb, τ-lepton g-2

These activities include

- “short term” activities (run 3 timescale) analysis, TileCal
- “long term” activities (HL-LHC) analysis, TileCal , HTT

Effectiveness of the group confirmed by the many responsibilities given to group members

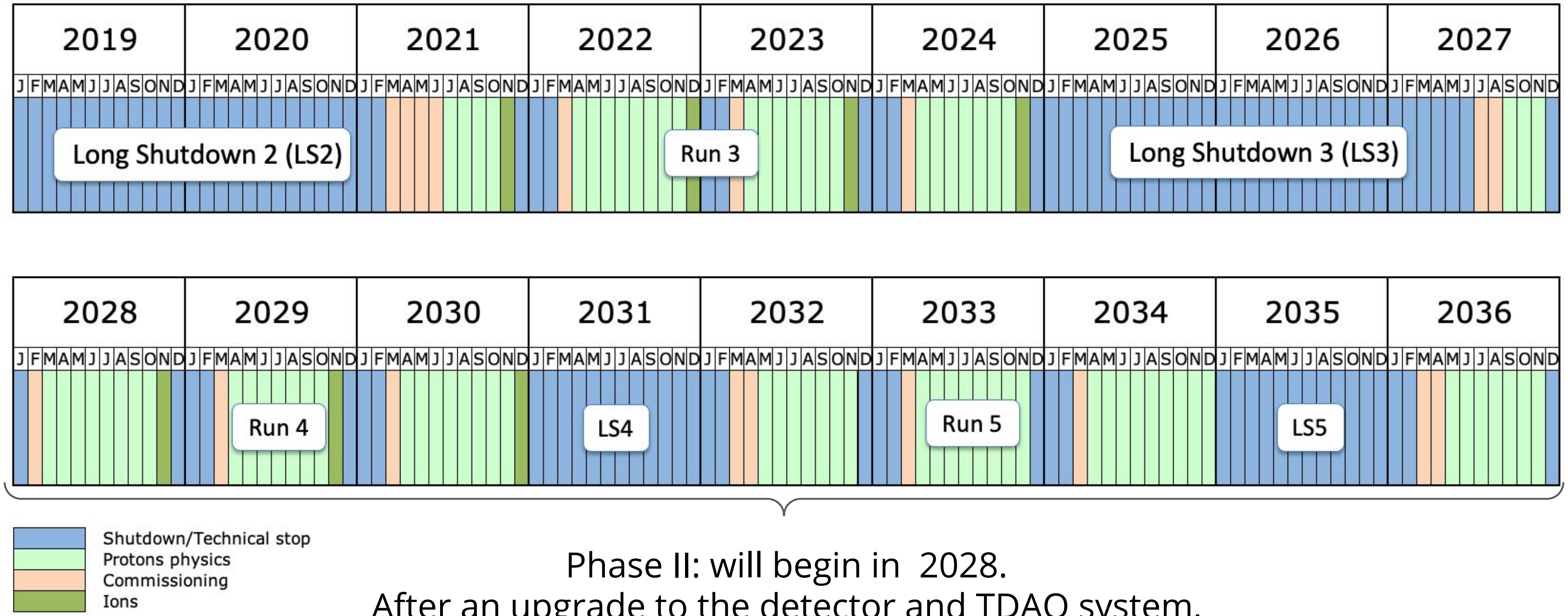
BACK-UP

Responsibilities

PI	L1	F.Scuri	Deputy Upgrade PL TileCal	https://glance.cern.ch/atlas/membership/members/profile?id=8841&view=appointments
PI	L3	F.Scuri	TileCal LASER-P2UG responsible	
PI	L2	C.Roda	Tile IB Chair	http://atlas.web.cern.ch/Atlas/SUB_DETECTORS/TILE/tile_structure/tile_structure_2017.pdf
PI	L2	C.Roda	Chair Upgrade Speaker Committee	https://glance.cern.ch/atlas/membership/members/profile?id=1865&view=appointments
PI	L3	P.Francavilla	coordinamento PRM - HTT	https://twiki.cern.ch/twiki/bin/view/Atlas/HttPrm
PI	L2	M.Verducci	Convener DP - Non Collision Background	https://glance.cern.ch/atlas/membership/members/profile?id=324&view=appointments
PI	L2	S.Leone	Membro ATLAS Speaker Committee	https://glance.cern.ch/atlas/membership/members/profile?id=8586&view=appointments
PI	L3	S.Leone	membro Tile Speaker/Pubb comm	https://twiki.cern.ch/twiki/bin/viewauth/Atlas/TileSC
PI	L3	N.Biesuz	co-responsabile FW integration	
PI	L3	P.Mastrandrea	responsabile integrazione HTT	
PI	L3	G.Di Gregorio	Contatto Hbb per MET	https://twiki.cern.ch/twiki/bin/viewauth/AtlasProtected/Higgsbb

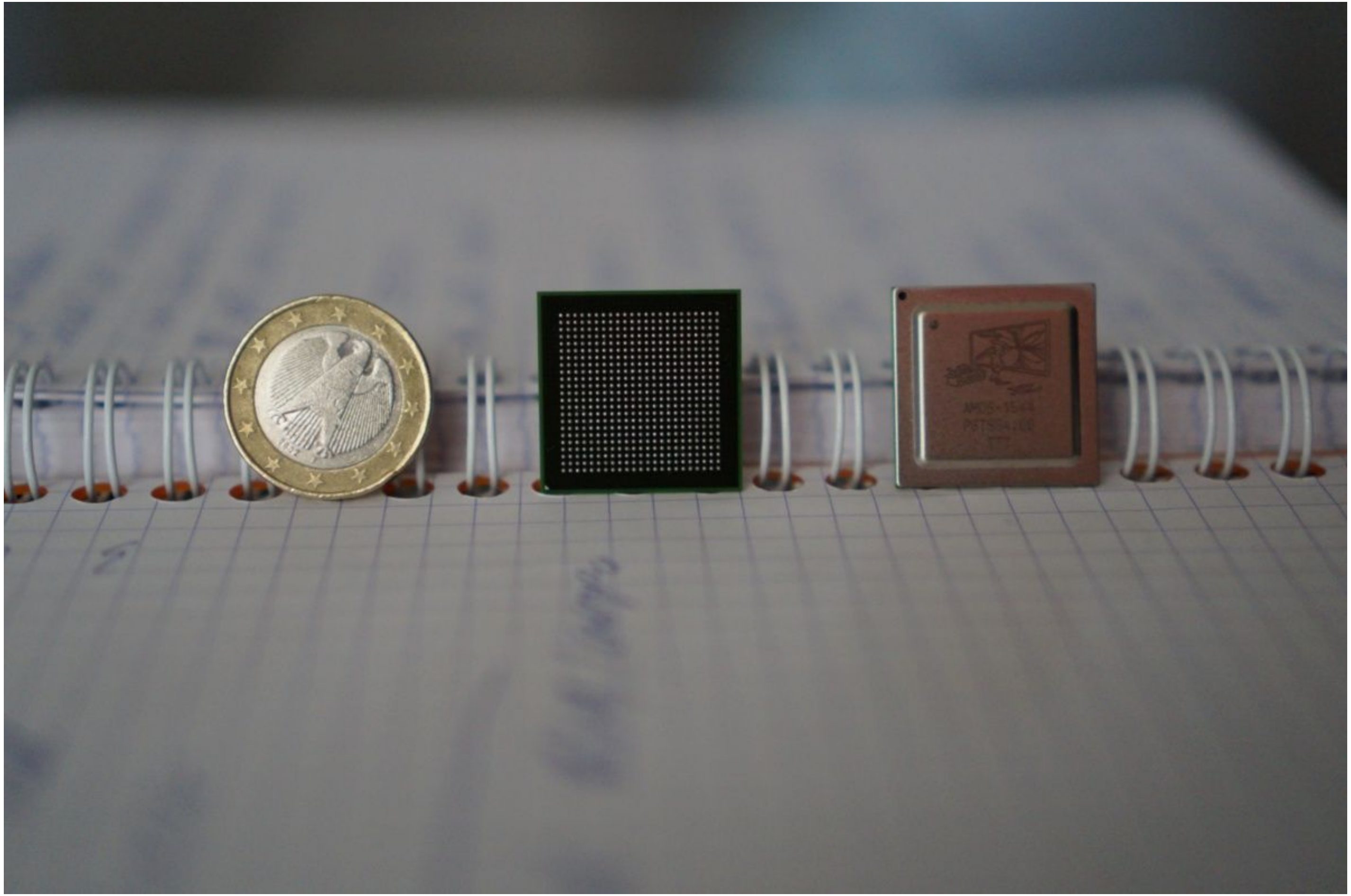
LHC long term schedule (not up to date)

Phase I: will end in 2025 (at the end of run-3)



Phase II: will begin in 2028.
After an upgrade to the detector and TDAQ system, ATLAS will be ready for the high luminosity LHC

FastTracker



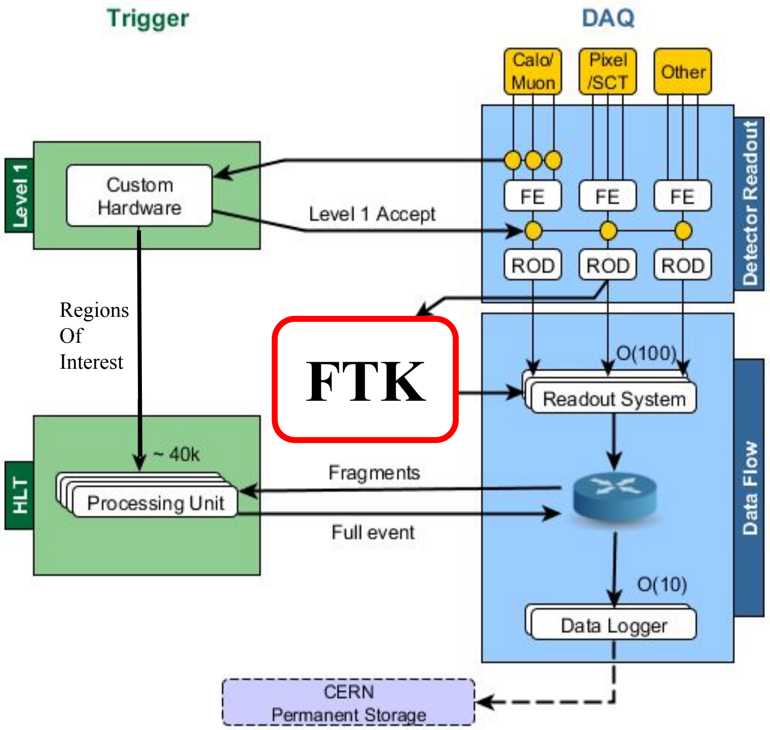
Fast TracKer

Fast TracKer (FTK) is a track reconstruction processor:
It was an upgrade to the ATLAS trigger system

- Gathers data from IBL, Pixel and SCT
- Performs full event tracking
- At L1 trigger acceptance rate of 100 kHz
- Peak latency of ≈ 200μs [FTK-TDR]

Fixed latency obtained with the usage of :

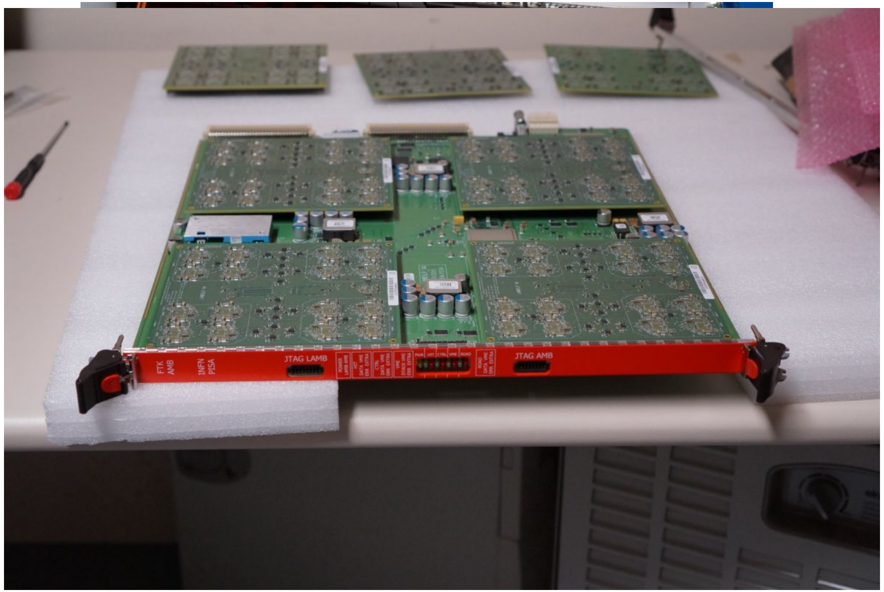
- FPGAs
- Associative memory ASIC



Project cancelled at the end of 2019 due to the lack of person-power

Currently writing a legacy paper

Fast TracKer



Pisa designed the Associative Memory board

- 50% of the boards produced and installed
- system was taking data
  - small portion of the detector
  - data were promising
- project terminated while production was ongoing