Polarisation of *W* and *Z* bosons and upgrade of the Liquid Argon calorimeter in ATLAS

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First year presentation

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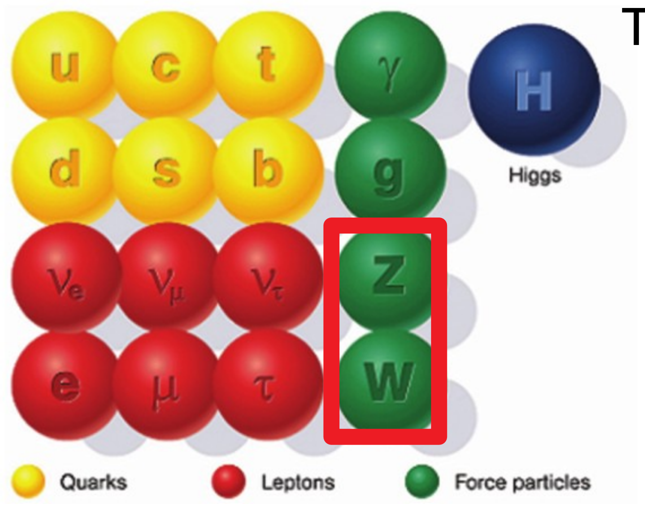
06/11/2020

ATLAS EXPERIMENT

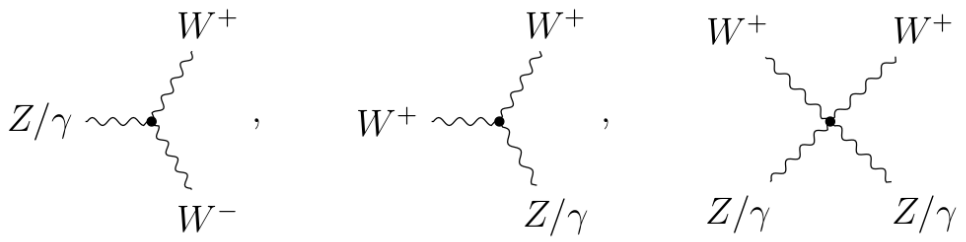
LAPP

UNIVERSITÉ SAVOIE MONT BLANC

W and Z bosons

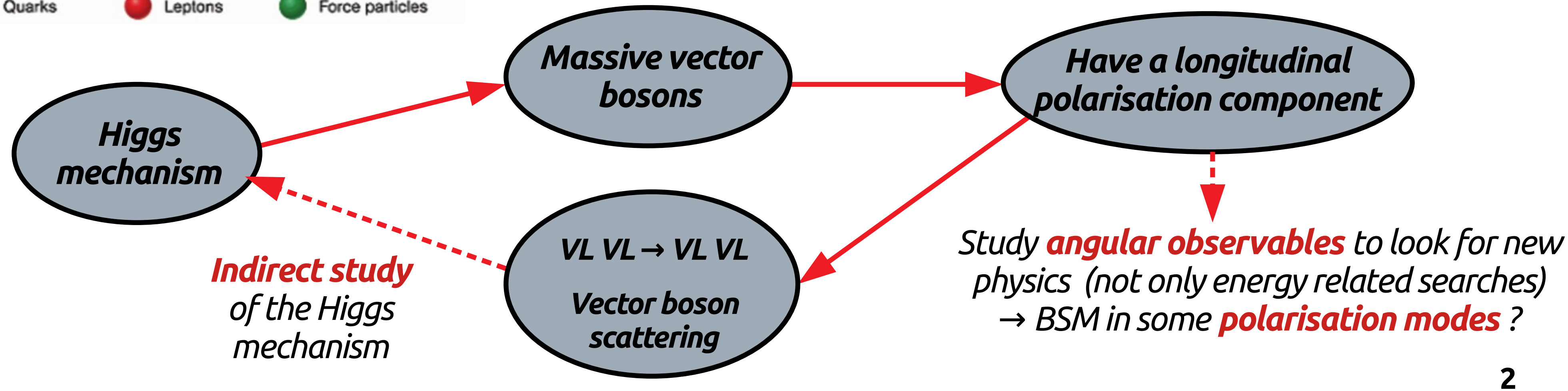


Triple and quadruple gauge couplings ➔ search for **deviations**

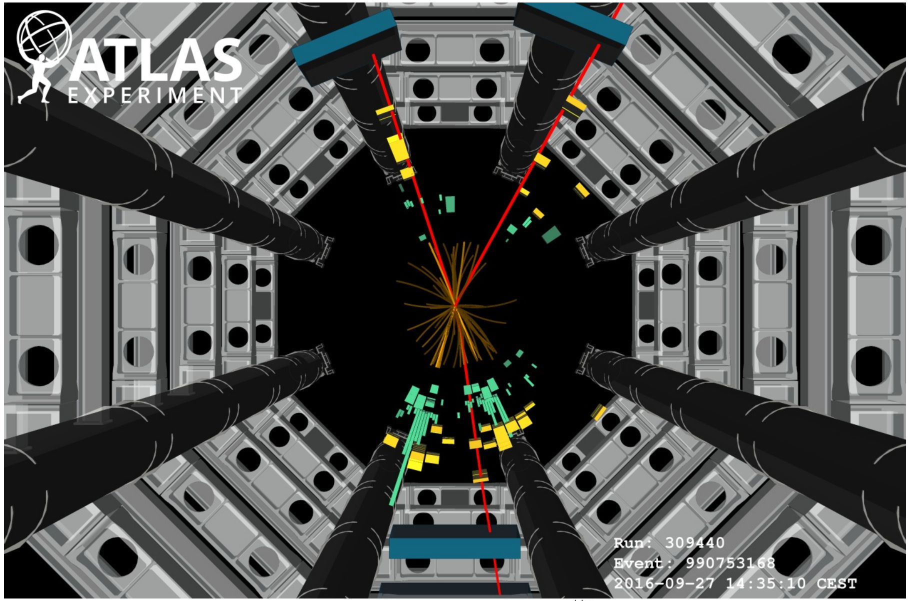


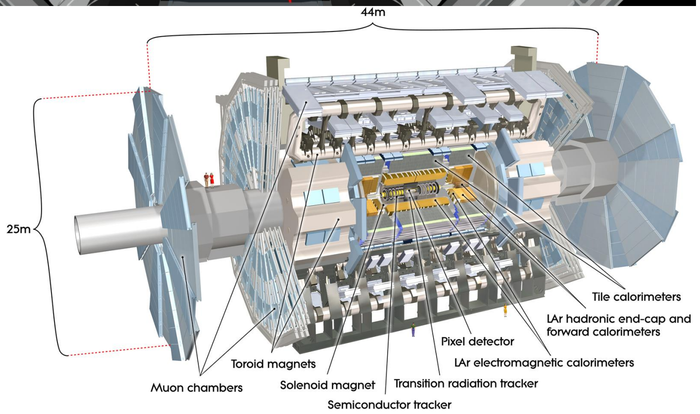
etc.

$W^\pm$ and Z = **massive bosons** of the electroweak interaction (along with massless γ)



The ATLAS detector





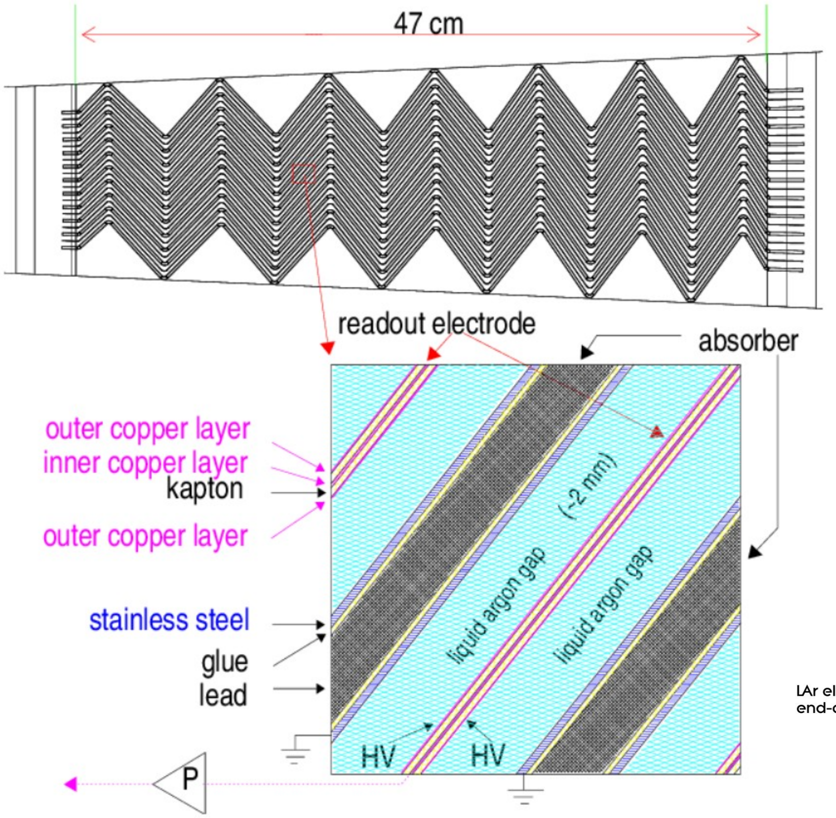
A multi-purpose detector:

From inner layers to outer layers

- **Trackers :**
  - ➔ Tracks of charged particles (electrons, muons, charged hadrons in jets)
- **Calorimeters :**
  - ➔ Measure the energy of particles stopped inside
- **Muon detector :**
  - ➔ Tracks of muons that went through the calorimeters

Particle Identification (depending on which detectors are activated) and **measurement** of its parameters (energy, pT,...)

The Liquid Argon Calorimeter

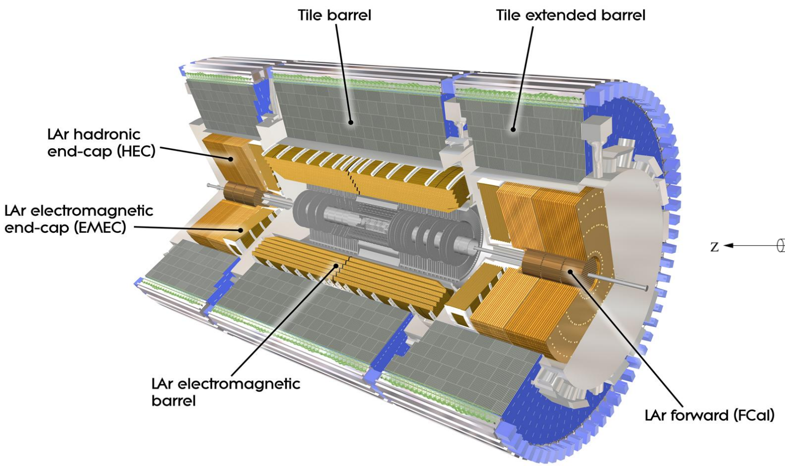


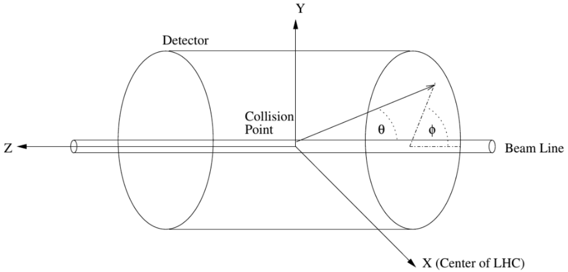
Sandwich of **absorber material** (Pb) and **Liquid Argon** (LAr)

➔Particles ionize LAr : electrical signal linked to the deposited energy

Divided into ~200 000 cells in 4 subsystems

➔ Rapidity $\eta = -\ln(tg\theta)$ and φ angle information





LHC timeline

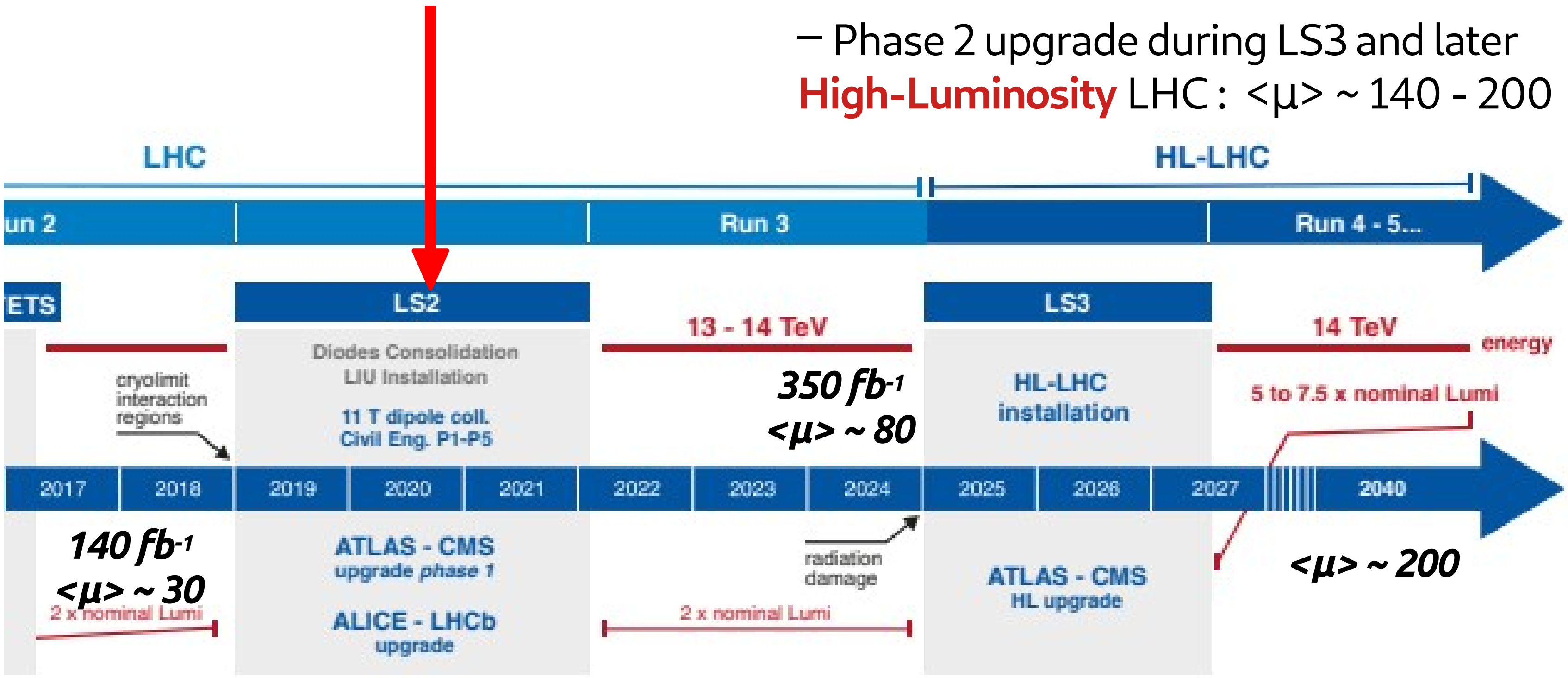
Now :

➔ Long Shut-down 2,
Phase 1 Upgrade

Next :

– Run 3 : mean number of interaction per bunch crossing up to <μ> = 80

– Phase 2 upgrade during LS3 and later
High-Luminosity LHC : <μ> ~ 140 - 200



PHASE 1 UPGRADE OF THE LIQUID ARGON CALORIMETER IN ATLAS

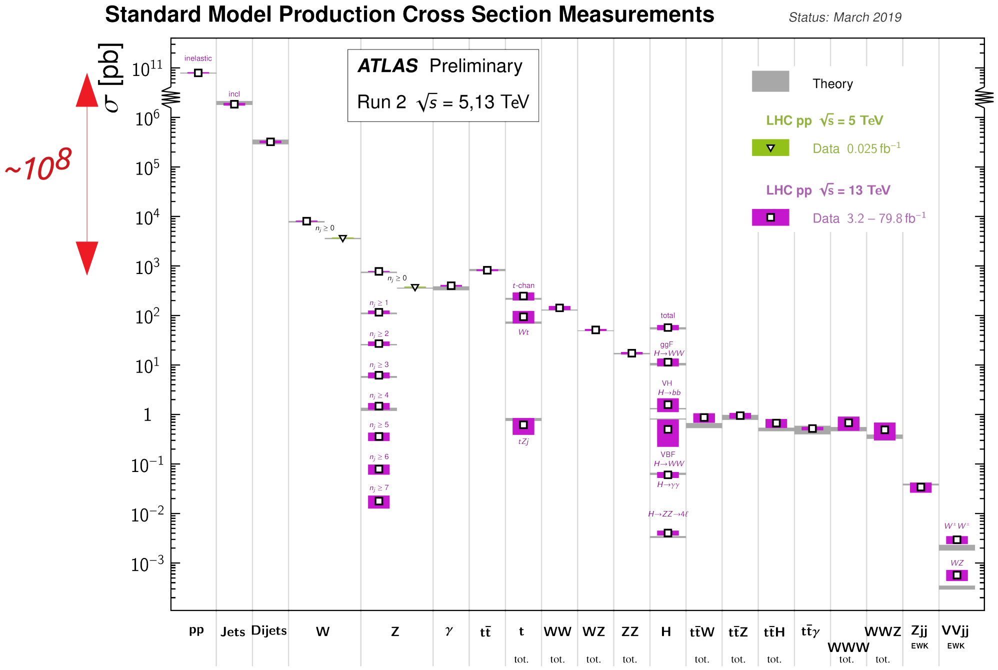
Trigger Tower

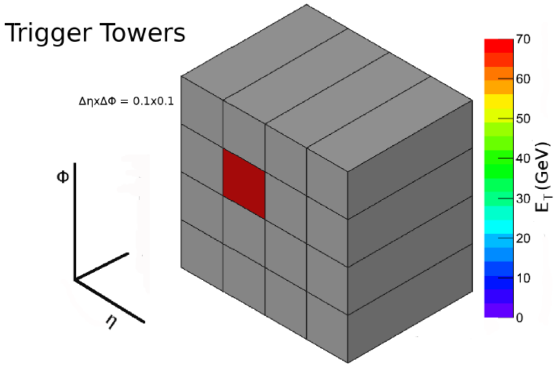
Why a trigger : one bunch crossing (BC) every **25 ns** that is a frequency of **40 MHz**

➔ Record only **physically interesting events**

L1 accept : **hardware trigger** system
40 MHz→100 kHz = decide in **few μs**

➔ Reduced granularity !





Data Stream

1 event = 1.5 Mb
No trigger = 60 Tb/s
With triggers = 1 Gb/s

Trigger Tower :

– Phase space : ΔφxΔη ~ 0.1 x 0.1

– No longitudinal granularity

➔ 1 TT ~ 60 cells

Goal of the Phase 1 Upgrade

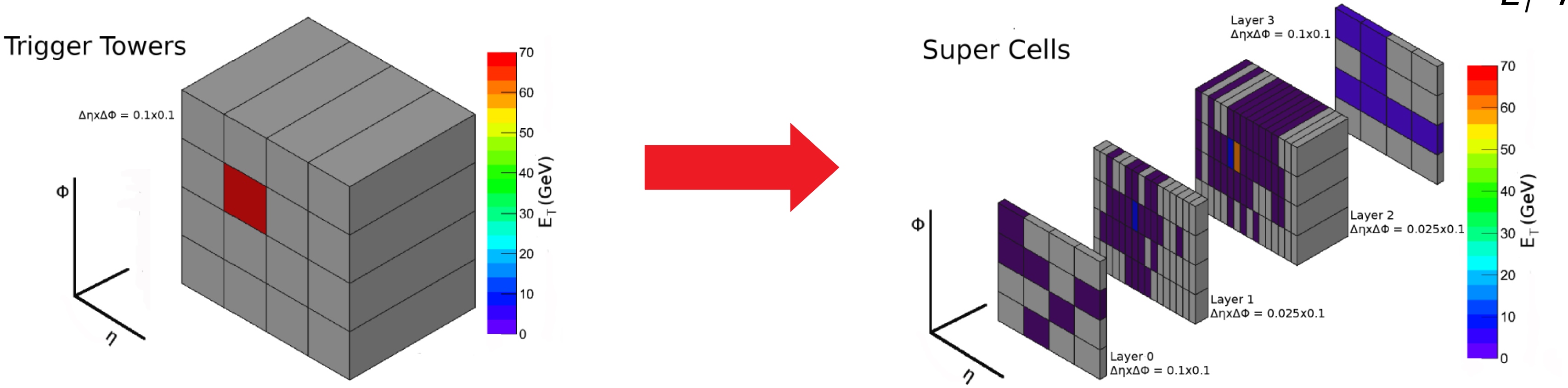
Higher pile-up expected : <μ> = **80** (Run 3) to **200** (HL-LHC)

➔Improve Trigger discriminating power = **Increase granularity**

➔Exploit electron/photon **shower shape** at L1A, not only the energy

From Trigger Tower to SuperCells :

Electron with E_T=70GeV



– Granularity : 1 TT = 10 SC = 1 + 4 + 4 + 1 SC

➔ From **5248 TT** to **34 049 SC**

– Digitization (improved precision) and better pile-up subtraction (baseline correction)

What is changed

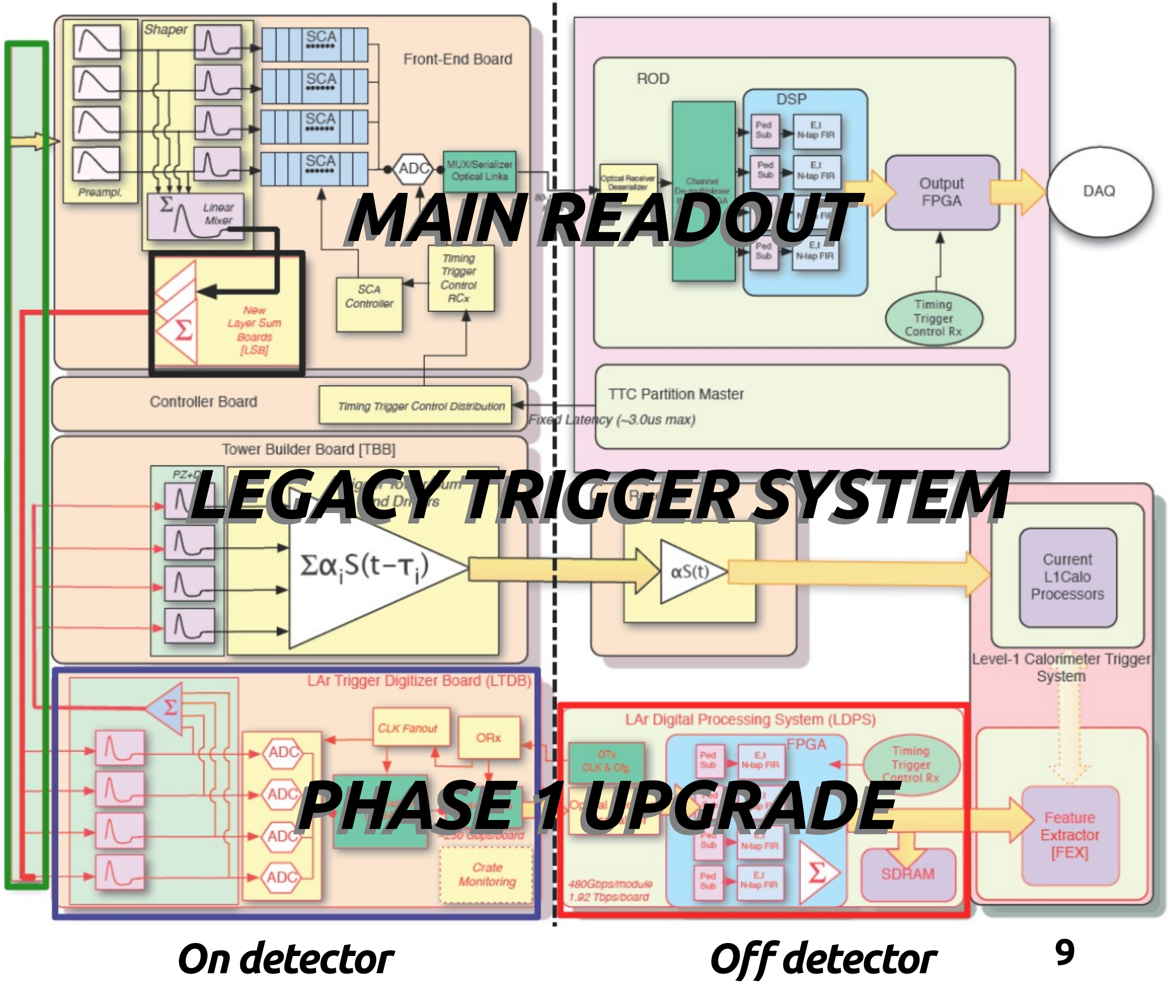
Layer Sum Board (LSB) : sum LAr cells in SuperCells

Baseplane : new cabling for the higher granularity signal

LAr Trigger Digitizer Board (LTDB) : Digitize analogical signals (and re-sum for the legacy trigger system)

Lar Digital Processing system (LDPS) : Compute energy per SuperCells and assign it to a Bunch Crossing

At LAPP !



From detector to back-end electronics

Detector pulse lasts around 400 ns, that is **around 20 bunch crossings** !

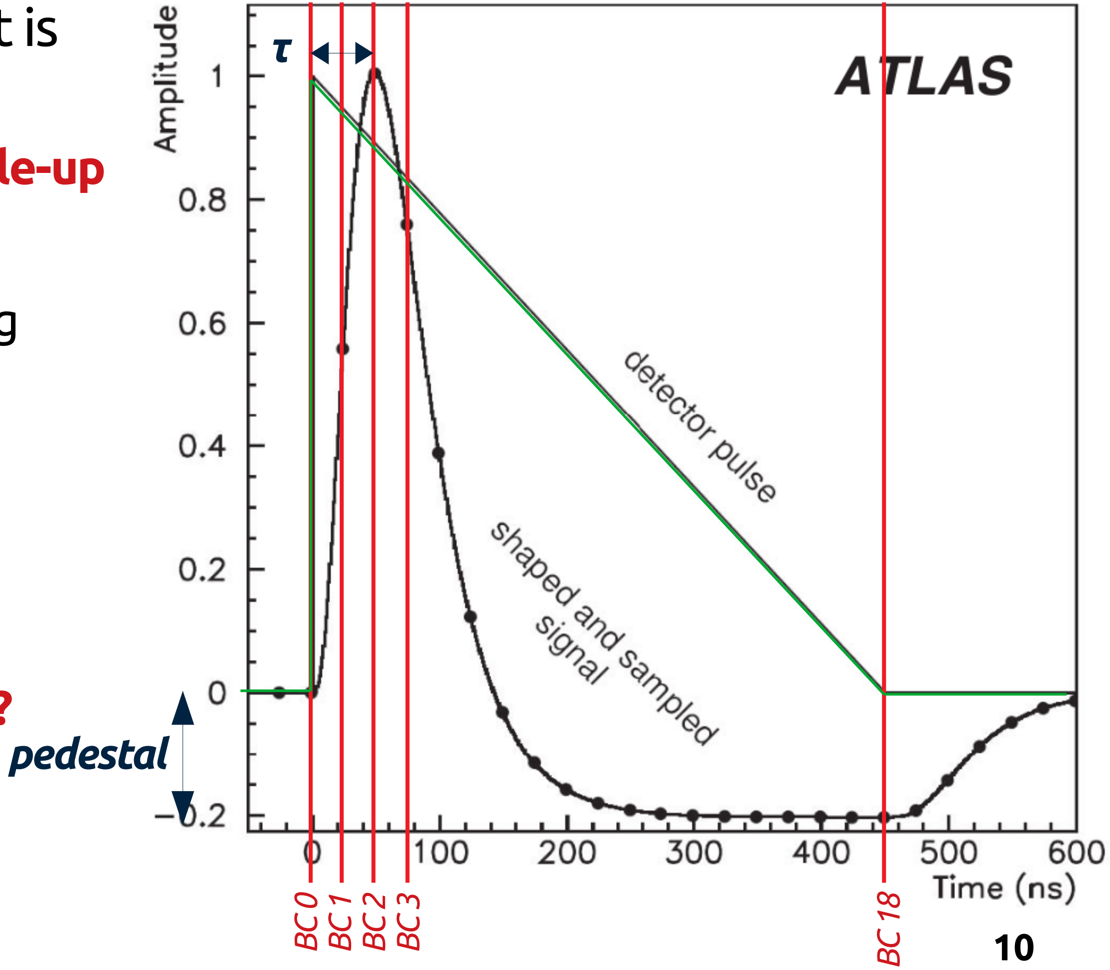
- Shaper : cancel out this **out-of-time pile-up**

➔ Negative part → pedestal

- Digitization : at 40 MHz (bunch crossing frequency), **encoded on 12 bits**

Input data in LDPS : One sample (12 bit integer) per bunch crossing

- **Compute energy ?**
- **Associate to correct bunch crossing ?**
- Saturated pulse ?
- Out-of-time pile-up ?

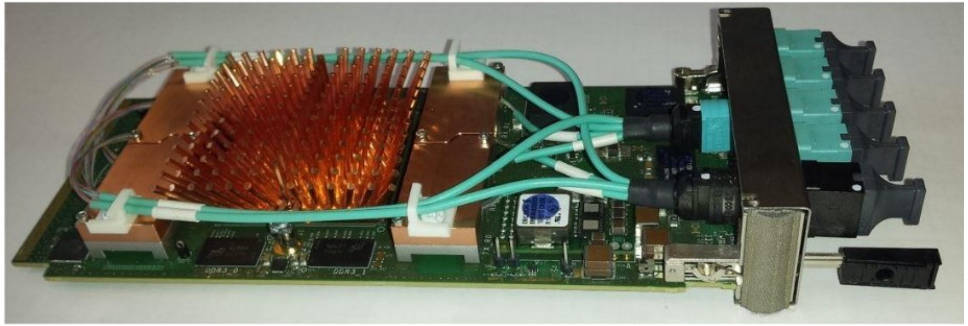


Zooming in : LDPB and LATOME board

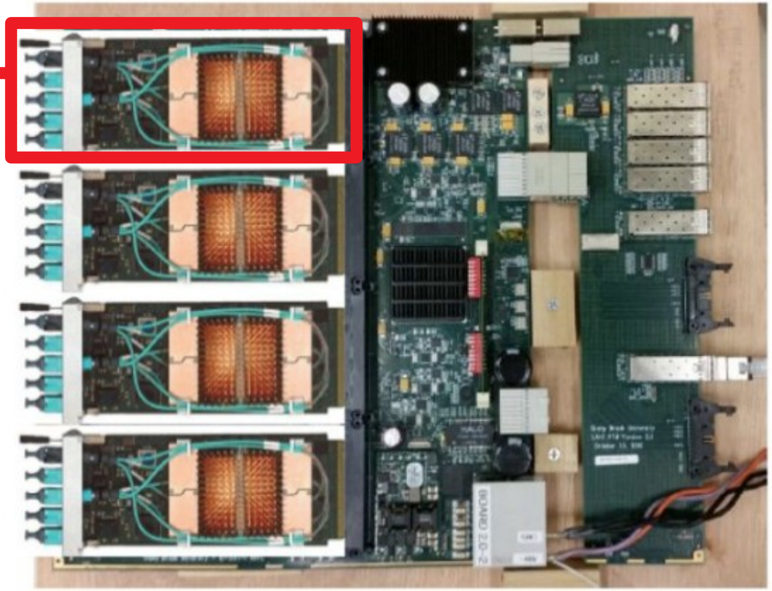
LDPSystem = 3 ATCA crates holding 30 LDPBlades each made of :

- **4 LATOME :** card built around a FPGA providing memory and logic (~200,000 registers) to compute E_T for each SC and assign Bunch Crossing ID
- **1 LAr Carrier :** Hold the LATOME and do the interface with the ATCA crate

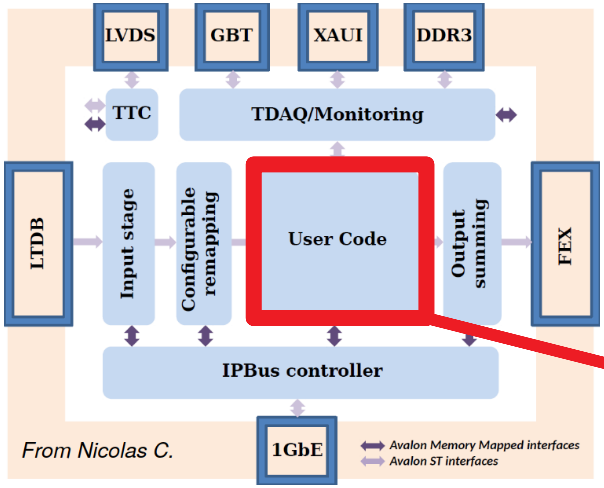
LATOME



Developed built and tested at LAPP



UserCode : Energy computation



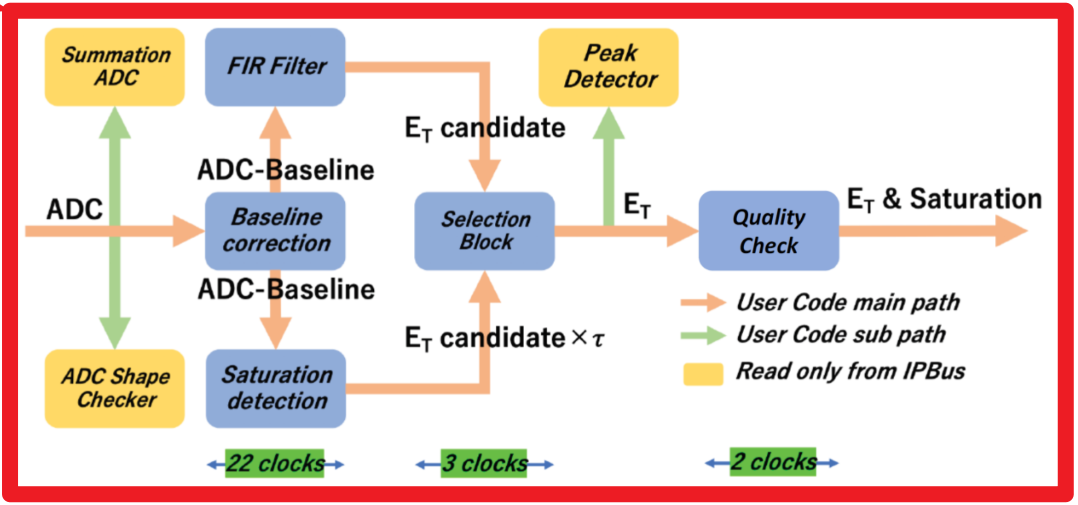
FPGA Firmware of the LATOME made of several blocks

- 48 fibers from LTDB send digitized ADC samples as input
- 48 fibers send computed energy to L1 trigger

➔ **Energy computation** happens in the UserCode

UserCode does:

- **Energy E_T computation** (FIR Filter)
- **Bunch crossing identification**
- Baseline correction (out of time pile-up)
- Saturation detection



SuperCell specific parameters

Pedestal : ADC counts are integer → signed output of sampled signal is ***S_i = ADC – ped = ∝ E_T + noise***

Optimal filtering coefficient :

– Define random variables ***u*** and ***v*** with lists of parameters ***(a)$_i$*** and ***(b)$_i$***

$$u = \sum_i a_i S_i, \qquad v = \sum_i b_i S_i.$$

– Choose ***(a)$_i$*** and ***(b)$_i$*** such that ***<u> = E_T*** and ***<v> = $E_T\tau$*** with minimal variance (constraint)

➔ With **4** consecutive ADC samples and calibrated ***(a)$_i$*** and ***(b)$_i$*** for a given SuperCell:

$$E_{\mathrm{T}}(m) = \sum_{i=0}^{N-1} a_i \cdot (ADC_{m+i} - ped_{m+i})$$

$$\xi(m) = \tau(m) \cdot E_{\mathrm{T}}(m) = \sum_{i=0}^{N-1} b_i \cdot (ADC_{m+i} - ped_{m+i})$$

Saturation selection : 6 thresholds on ***E_T*** and ***ξ*** allow to detect saturated pulses

➔ **16** parameters per SuperCell

➔ **7936** registers to load per LATOME, 116 LATOMES

➔ **544 784** parameters in total

The COOL database

Goal : Load these parameters in the **correct register** of the correct LATOME at **configuration stage**

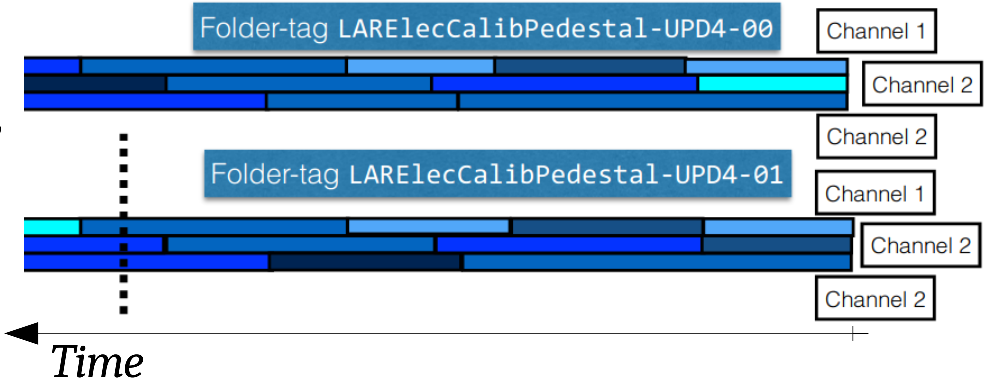
1. Create a dummy database holding these parameters

– **Prototyped** a condition **database** on SQLite back-end for SuperCells for Run 3

➔ Possibility to store a database for each LHC run conditions : **every minute** ! (lumi blocks)

– Developed a package to integrate it into the LarOnline code

The COOL condition database



PrepareUserCodeCoefficient

2. Read mapping files of the LATOME

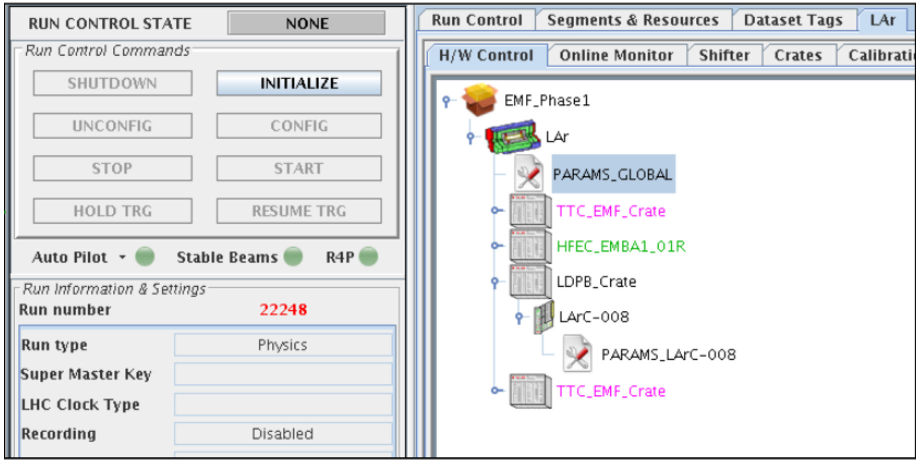
– Map a SuperCell to the registers holding its parameters

➔ Issue with IDs : from SuperCell name to numerical identifier in database

– Write all register with values from the database

3. Integrate the database and new code into the LArOnline code

➔ **Validated** on test (EMF) and production LATOME (installed at Point 1)



TDAQ Graphical User Interface

Validation

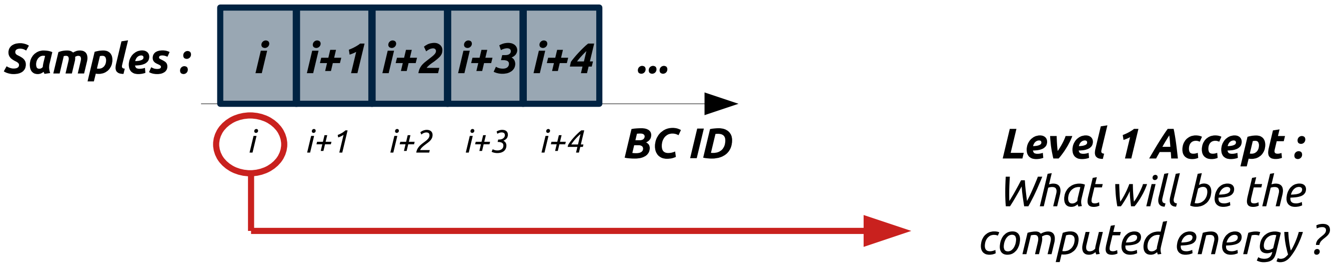
Goal : Use what has been developed to **test the UserCode as a whole** !

➔ **Idea :** Send data to a LATOME → Record its outputs

– Choose **OFC configuration** wisely !

$a_i = b_i =$ **(1 ; 0 ; 0 ; 0)**, (0 ; 1 ; 0 ; 0), (0 ; 0 ; 1 ; 0), (0 ; 0 ; 0 ; 1), (2 ; 0 ; 0 ; 0), etc.

– Choose **sent dataset** : sample sent = bunch crossing ID



$$E_T(m) = \sum_{i=0}^{N-1} a_i \cdot (ADC_{m+i} - ped_{m+i})$$

*Set to **0***

➔ Example : **Output = Input** for $a_i = (1 ; 0 ; 0 ; 0)$

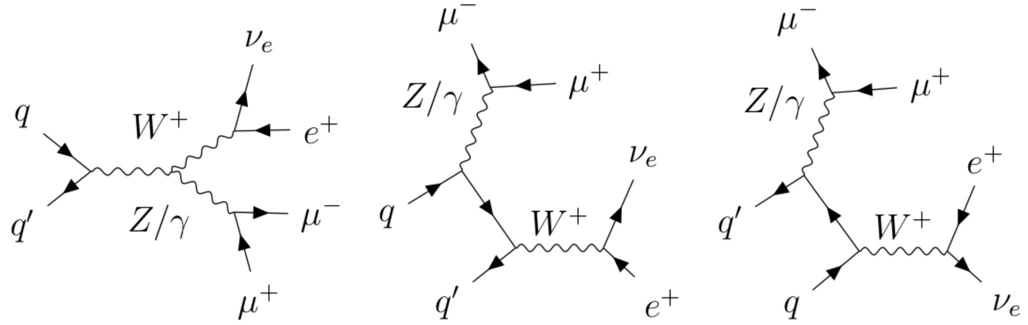
WZ POLARISATION STUDIES

Inclusive WZ channel

Look for events at LHC of the type :

$$\mathrm{p\,p} \rightarrow \ell\,\bar{\ell}\,\ell'\,\nu_{\ell'} + X$$

➔ Main diagrams = resonant W and Z



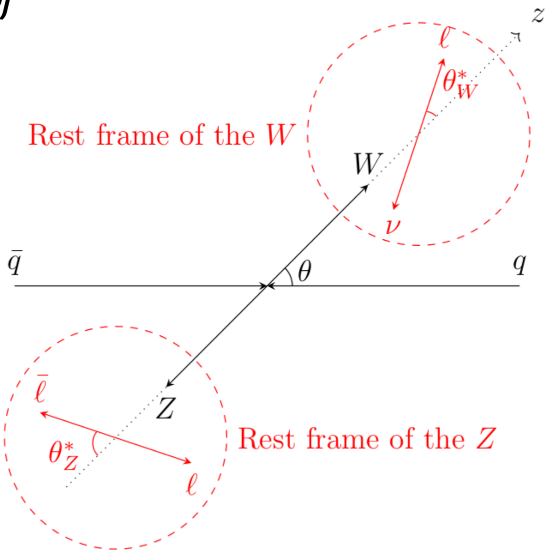
+ any other combination of muons and electrons

Measure kinematic parameters of W and Z boson

– Specifically **cosθ*** : distribution directly linked to **polarisation**

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{8}\left[f_R(1+\cos^2\theta^* + 2C_W\cos\theta^*) + f_L(1+\cos^2\theta^* - 2C_W\cos\theta^*) + 2f_0\left(1-\cos^2\theta^*\right)\right]$$

➔ Polarisation retrieved from generated Truth level data through **fits**



Template Fit

How to measure polarisation fraction **on data** ?

– Done through **template fit** of the data

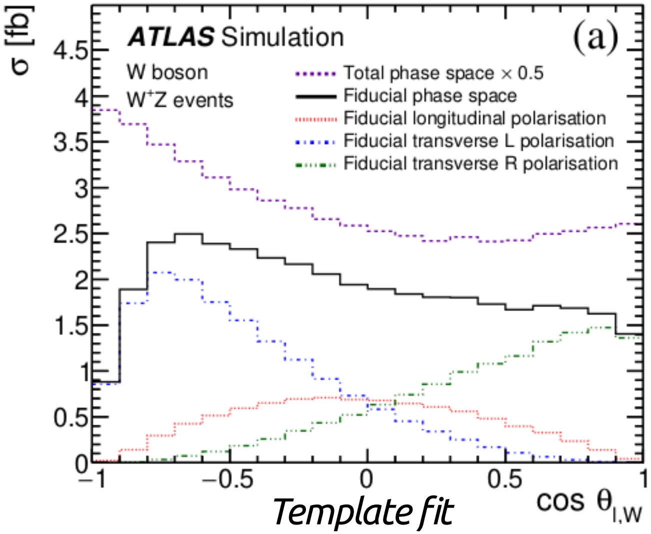
➔ Need templates for each polarisation 0, L ,R of a boson !

Already done for a **single boson** polarisation :

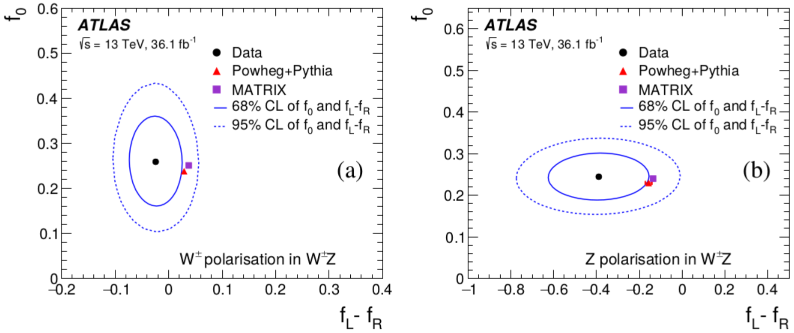
– Generate templates at **truth level** (Monte-Carlo generated)

– Process these templates up to **reconstructed level**

– **Fit** to data !



Template fit



*Polarisation fractions measurement for **one boson at a time***

https://arxiv.org/pdf/1902.05759.pdf

Goal of the WZ analysis

Measure for the first time **both polarisation fractions** of massive vector bosons

– $f_0 \approx 25\ \% \rightarrow f_{00} \approx 5\%$

➔ 36 $fb^{-1} \rightarrow$ 139 fb^{-1} (full Run 2 data) = **measurable** !

How to get these templates ?

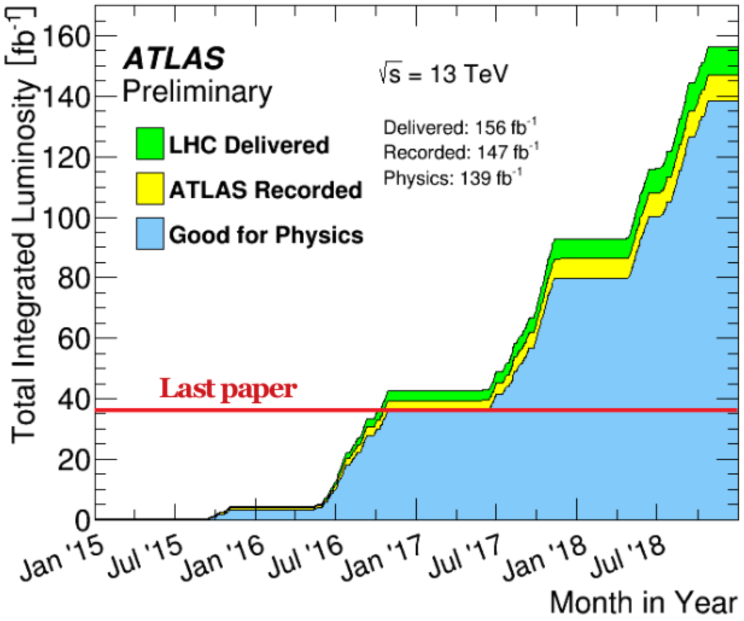
– **Direct generation** of polarised Monte-Carlo

➔ Challenging at NLO

– **Reweighting** of unpolarised Monte-Carlo

➔ Need both polarisation fractions estimation at generated level, polarisation dependences,...

➔ Main **systematic uncertainty** probably from these templates



Luminosity recorded by ATLAS during Run 2

CONCLUSION

Work on ATLAS LAr calorimeter :

- Challenging work in interaction with many LAr experts
- Work regularly presented during LAr Weeks

➔ **ATLAS qualification task completed**

Work on *WZ* polarisation analysis :

- Developed different methods to obtain polarisation fractions of both bosons
- Developed a method to reweight unpolarised Monte Carlo samples of *WZ* events

Teaching at IUT d'Annecy :

➔ 24 h of TP in physics (half less than planed due to Covid)

PREFIT school in Hambourg (01/03/2020 – 13/03/2020) :

➔Effective field theory and precision physics
(deemed last in-person physics event of the year ?)

PROSPECTS

LAr calorimeter :

➔ Continue the commissioning of the UserCode

***WZ* polarisation analysis :**

– Finalize the reweighting

– Look at directly generated templates in interaction with theoreticians

➔ Finalize the inclusive analysis

– Study polarisation in *WZ* Vector Boson Scattering

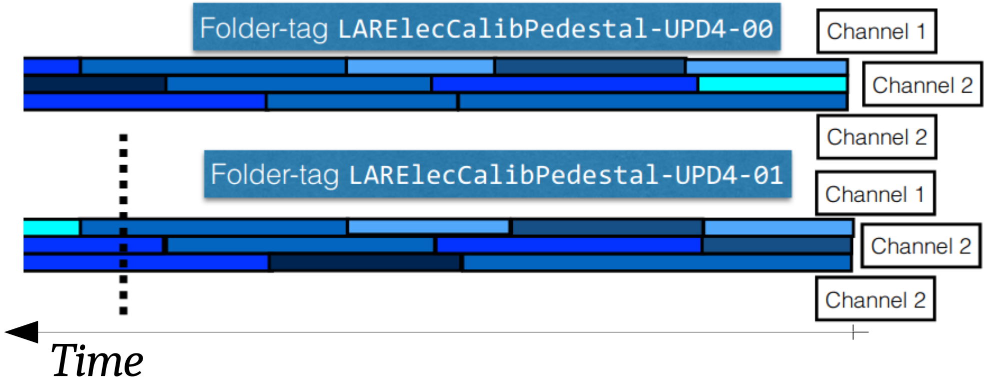
LAr Phase 1 upgrade team at LAPP

QUESTIONS ?

BACKUP SLIDES

1st step : Load values from the database

All values will be stored in a condition database (COOL).



New package to read such databases : OnlineLatomeDB

- Create a condDB object and connect to the database
- Load all required data as blobs in attribute of the condDB object

I developed a dummy database on a SQLite backend for SuperCells

```
  Name                Description
  /LARSC/ElecCalibFlat
  /LARSC/Identifier
  /LARSC/Selection
  Name                Description         Count     Size
>>> cd /LARSC/ElecCalibFlat
>>> ls
  Name                Description
  Name                Description         Count     Size
  /LARSC/ElecCalibFlat/OFC  OFC a and b         -         -
  /LARSC/ElecCalibFlat/Pedestal  Pedestal         -         -
>>> more /LARSC/ElecCalibFlat/OFC
[0,0] - [2147483647,4294967295) (0) [OFCa (Blob16M) : size=544800,chk=-474351604], [OFCb (Blob16M) : size=544800,chk=-1327606476],
[nSamples (UInt32) : 4], [HardpointOFCa (UInt32) : 8], [HardpointOFCb (UInt32) : 6], [version (UInt32) : 0]
```

Main folders of the database

Payload : 2 blobs and 3 values

2nd step : Read mapping file

Mapping file of the LATOME :

- SC arrive to the LATOME in 48 streams (input fiber) of 8 SC per BC (25 ns)
- After configurable remapping step, **62 streams of 6 SuperCells**
- Need for a mapping of a specific SuperCell to a position in a stream

Streams

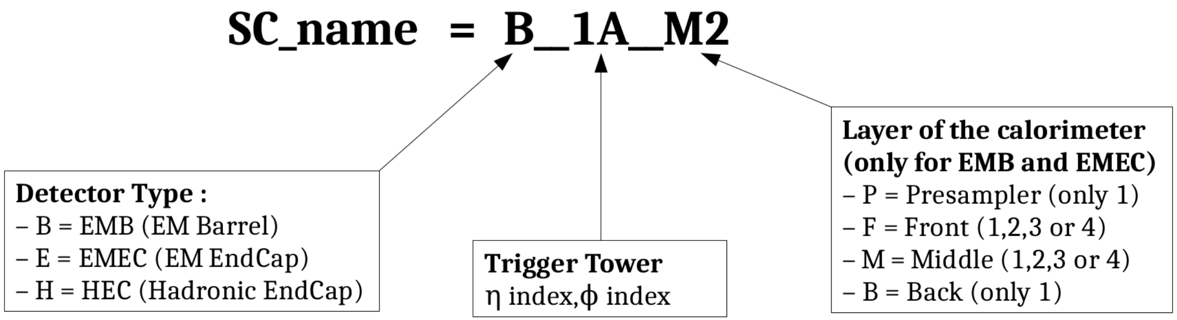
		SC1	SC2	SC3	SC4	SC5	SC6
1	PU1	B_1A_P1 (7:5/7)	B_2A_P1 (7:2/6)	B_1C_P1 (31:7/7)	B_2C_P1 (31:3/6)	B_7A_P1 (7:1/1)	B_8A_P1 (7:0/0)
2	PU2	B_1A_F1 (11:5/7)	B_2A_F1 (11:1/3)	B_1C_F1 (35:6/7)	B_2C_F1 (35:2/3)	B_7A_F1 (10:0/0)	B_8A_F1 (10:4/4)
3	PU3	B_1A_F2 (11:4/6)	B_2A_F2 (11:0/2)	B_1C_F2 (35:7/6)	B_2C_F2 (35:1/2)	B_7A_F2 (10:3/1)	B_8A_F2 (10:5/5)
4	PU4	B_1A_F3 (11:7/5)	B_2A_F3 (11:3/0)	B_1C_F3 (35:4/5)	B_2C_F3 (35:0/0)	B_7A_F3 (10:2/2)	B_8A_F3 (10:6/7)
5	PU5	B_1A_F4 (11:6/4)	B_2A_F4 (11:2/1)	B_1C_F4 (35:5/4)	B_2C_F4 (35:3/1)	B_7A_F4 (10:1/3)	B_8A_F4 (10:7/6)

...

Problem :

– SuperCell identified in the mapping file with a **name**

– SuperCell identified in the COOL database with an **OnlineID hash** (parameters stored in blobs)



Per side (A or C) and quadrant !

From SC_name to onlineID_hash

Conversion needed : **SC_name** → **offlineID** → **onlineID_hash**

Will never change, done with Athena tools

Mapping stored in COOL database (can change)

A small **SQLite database** (800K) allows for the conversion (full) SC_name → OfflineID

A python script reads the txt mapping files, does the conversion and **writes an .ini file** then used by the code.

pu_list_offlID.ini

for Latome EMBA_1

```
[PU1]
SC1=0x2d800001
SC2=0x2d800201
SC3=0x2d800005
SC4=0x2d800205
SC5=0x2d800c01
SC6=0x2d800e01
[PU2]
SC1=0x2da00001
SC2=0x2da00801
SC3=0x2da00005
SC4=0x2da00805
SC5=0x2da03001
SC6=0x2da03801
[PU3]
SC1=0x2da00201
SC2=0x2da00a01
SC3=0x2da00205
SC4=0x2da00a05
SC5=0x2da03201
SC6=0x2da03a01
```

. . .

3rd step : Retrieve and write all parameters

Convert OfflineID to OnlineID_hash with the condition DB

- hash_id is the index in all retrieved blobs of the conditionDB object

Registers are vectors with 8 slots (only 6 used) **to hold parameters in the order of the stream**

- Pedestal, saturation selection thresholds : 1 vector
- OFC : same, but with 1 vector per OFC (with N = 4 of them)

latome.user.stream_<m>.fir.pedestal[<o>]

latome.user.stream_<m>.fir.tap_<n>[<o>]

m = stream number

o = position of the SuperCell in the stream (and block number in the register)

n = For OFCs, from 0 to 3 thus coding the 4 of them

Extracting polarisation fractions

Goal : Create templates of fully polarised dibosons events at reconstructed level

➔First, get templates at truth level from Monte Carlo samples

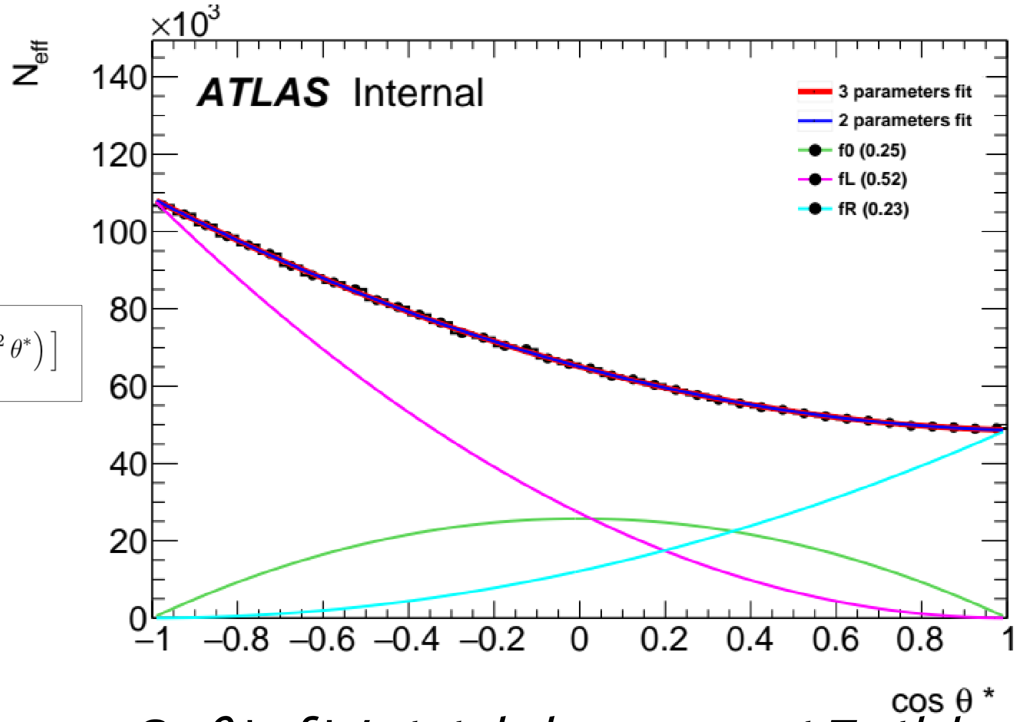
Using the cosθ* distribution of both bosons : **3 methods** to get the polarisation fraction of 1 boson

- Fit with 3 parameters

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{8}\left[f_R(1+\cos^2\theta^* + 2C_W\cos\theta^*) + f_L(1+\cos^2\theta^* - 2C_W\cos\theta^*) + 2f_0\left(1-\cos^2\theta^*\right)\right]$$

- Fit with 2 parameters (using $f_0 + f_L + f_R = 1$)
- Moments' method

Problem : Are the **polarisations** of the two bosons **independent ?**



Cosθ of W+, total phase space at Truth level*

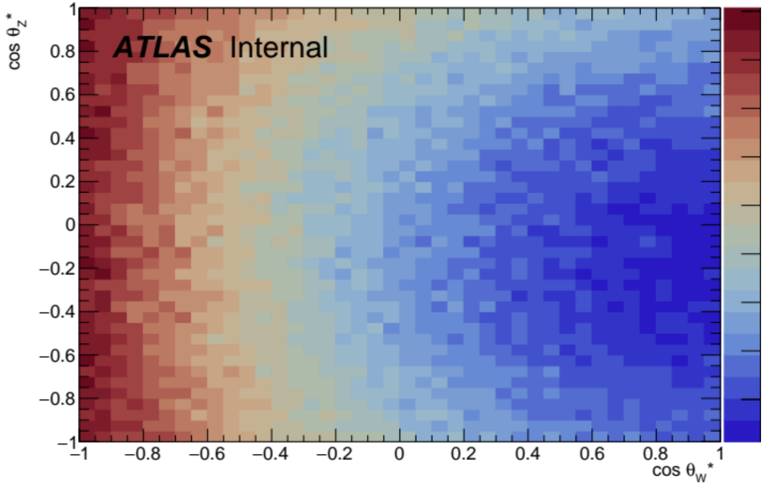
Fractions of diboson polarisation configuration

Get **both** bosons polarisations (taking into account dependencies) : **2D fit** !

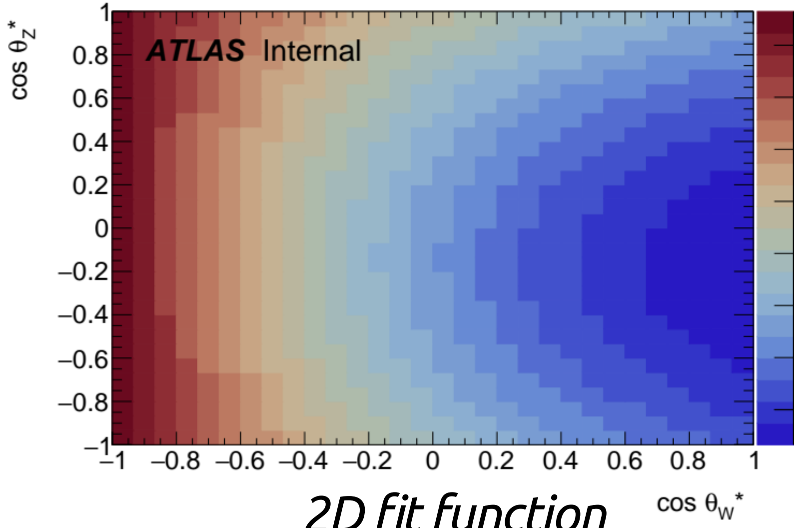
$$\frac{3}{8}\left[f_R(1+\cos^2\theta^* + 2C_W\cos\theta^*) + f_L(1+\cos^2\theta^* - 2C_W\cos\theta^*) + 2f_0\left(1-\cos^2\theta^*\right)\right] \;\; X \;\; \frac{3}{8}\left[f_R(1+\cos^2\theta^* + 2C_W\cos\theta^*) + f_L(1+\cos^2\theta^* - 2C_W\cos\theta^*) + 2f_0\left(1-\cos^2\theta^*\right)\right]$$

W boson *Z boson*

➔ 9 parameters : f_{00}, f_{0L}, f_{0R}, f_{L0}, ...



2D histogram



2D fit function

W+Z , total phase space at Truth level

Reweighting

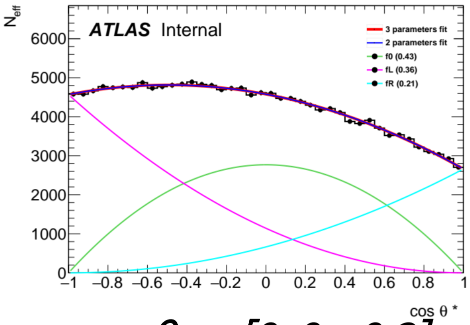
Idea : Apply to each event a **weight = probability** (from its kinematic variables) that the event had a given polarisation configuration.

➔ For one boson, probability it has polarisation h_0 knowing its $\cos\theta^*$: **Bayes formula** !

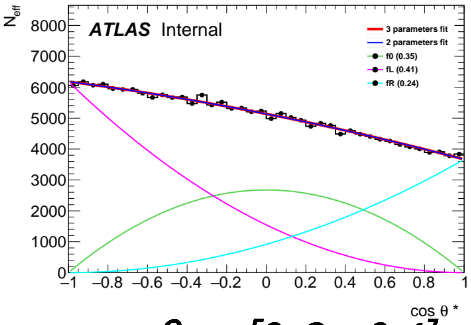
$$\mathbb{P}(h_0|\cos\theta^*,\boxed{|\cos\theta_V|}) = \frac{f_{h_0}(\boxed{|\cos\theta_V|})\mathbb{P}(\cos\theta^*|h_0,\boxed{|\cos\theta_V|})}{\sum_{h=0,L,R} f_h(\boxed{|\cos\theta_V|})\mathbb{P}(\cos\theta^*|h,\boxed{|\cos\theta_V|})}$$

Warning : a variable (here, $\cos\theta_V$) needs to be in the **conditional part** to have its reweighted distribution correctly modified !

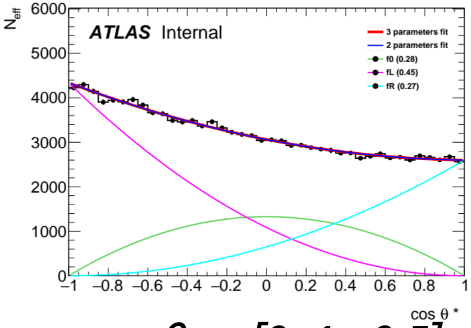
➔ Compute fractions in bins of this variable !



$\cos\theta_V \in [0.0\ ;\ 0.2]$



$\cos\theta_V \in [0.2\ ;\ 0.4]$



$\cos\theta_V \in [0.4\ ;\ 0.5]$

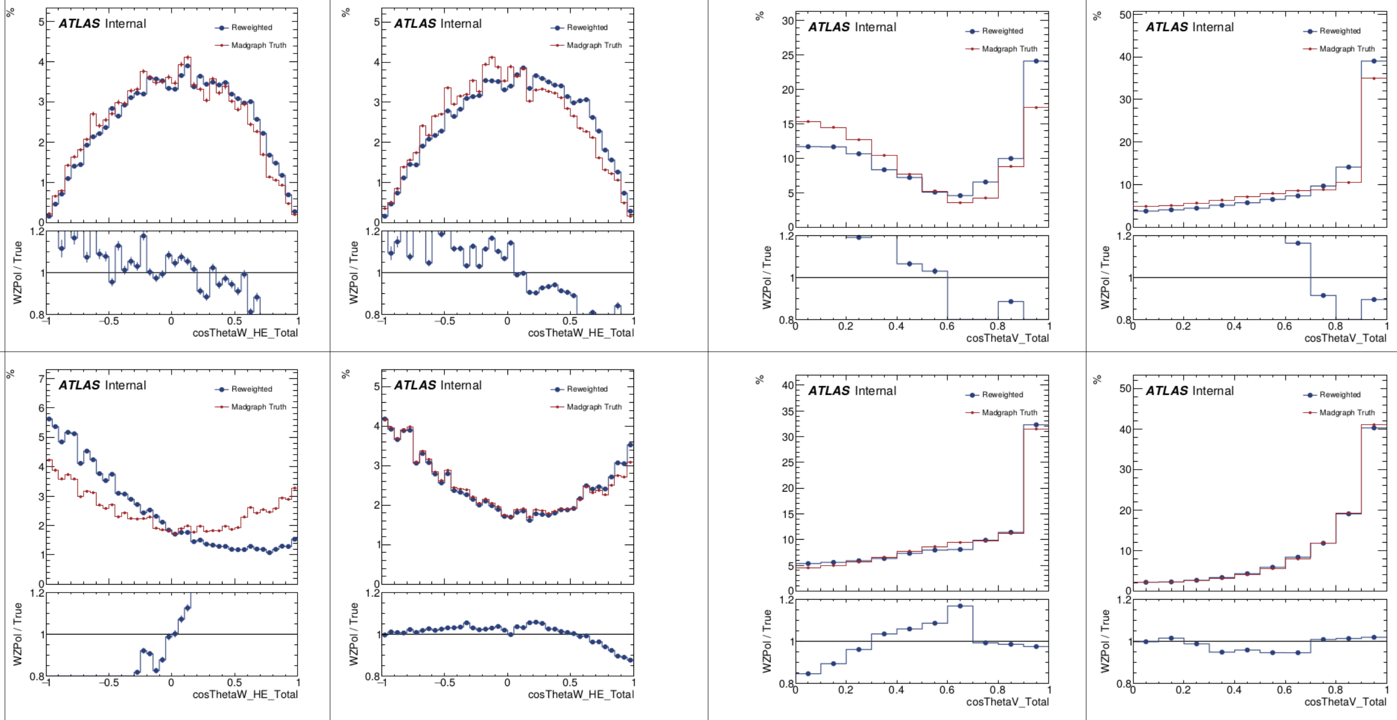
Reweighting results

For the **validation** of the reweighting, used a **MadGraph Monte Carlo** generated already with polarised bosons (at Leading Order only, few statistics)

Z_0 | Z_T | Z_0 | Z_T

W_0

W_T



cosθ of the W* | $|cos\theta_V|$

Work still going on

MG sample issues :

- buggy
- few statistics

Parameters to optimise :

- Conditional variable ?
- Its binning ?
- Fractions accuracy