The LAr Calorimeter Alignment in Time and Search for new physics at high mass di-electron spectrum with the ATLAS experiment

Journees Jeunes Chercheurs 2010

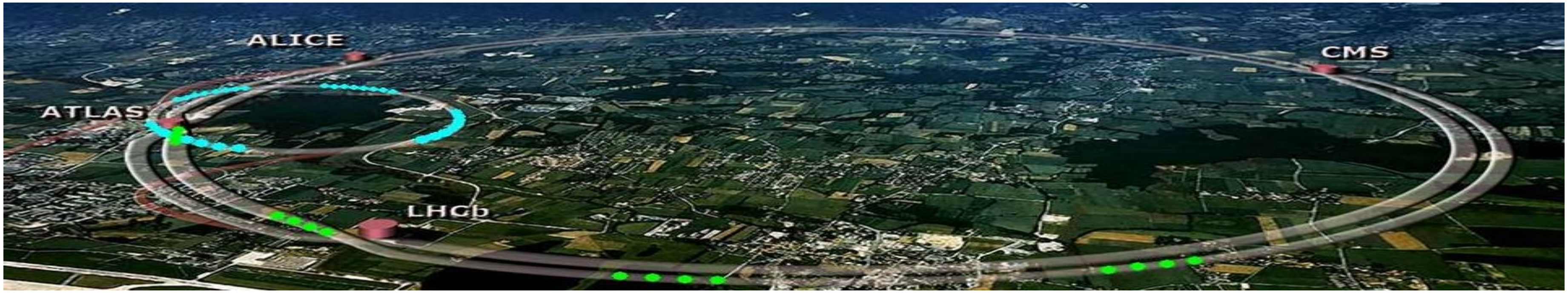
Ludovica Aperio Bella

LAPP (Laboratoire d'Annecy Le Vieux de Physique des Particules)

Talk Layout

1. The ATLAS experiment at LHC
   - The ATLAS Liquid Argon calorimeter
     - LAr timing alignment
2. Searching for new physics at high-mass di-electron resonances

LHC



LHC Data taking plan:

2010 pp run at 7TeV

→ 45 pb^{-1} collected

→ inst lumi up to $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$

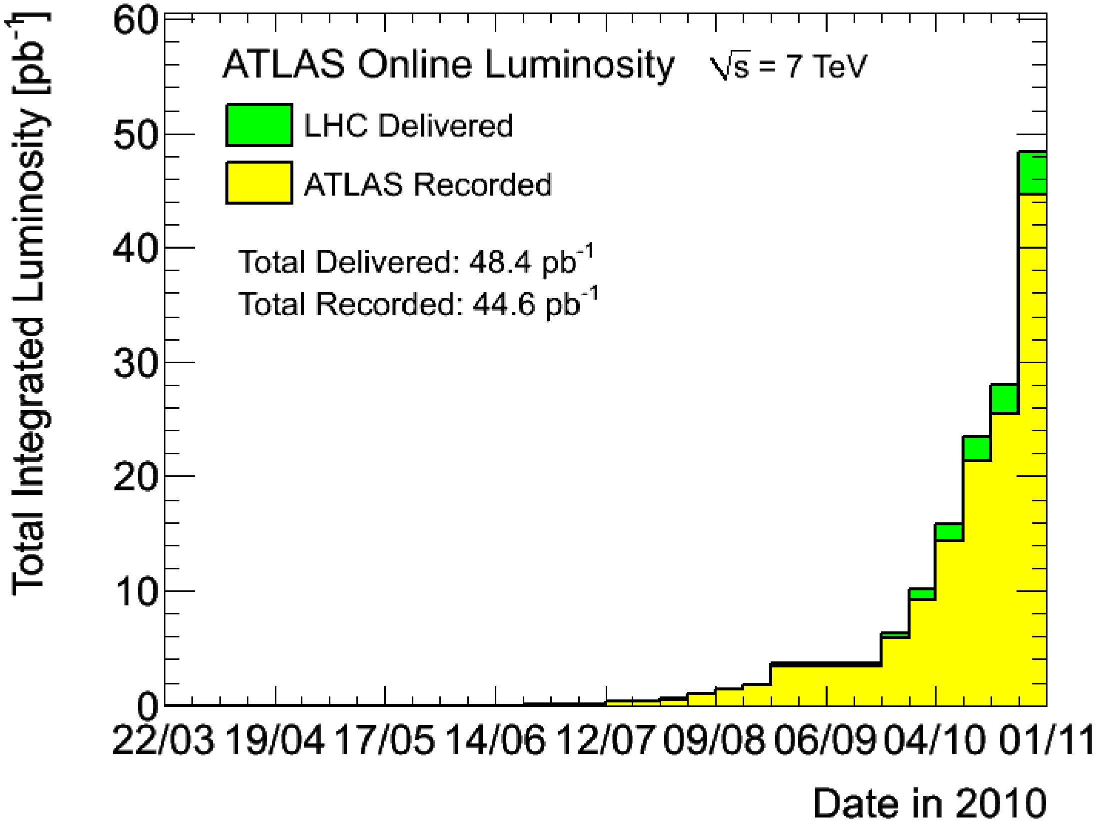
By the end of 2011 with peak luminosity of 10^{33} $cm^{-2}s^{-1}$

→ ~ 1fb^{-1} is expected

Nominal value:

→ 14TeV,

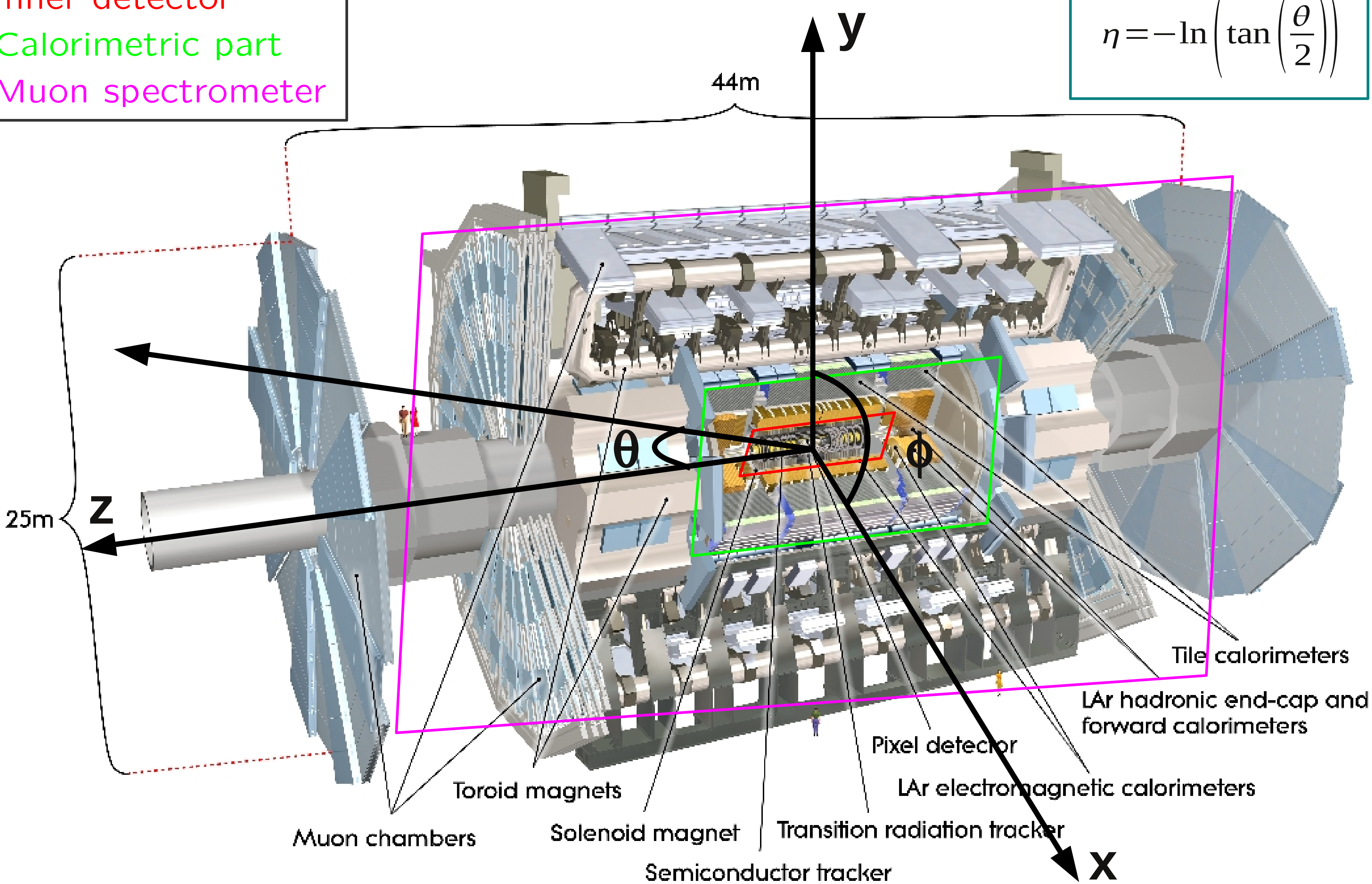
→ lumi 10^{34} $cm^{-2}s^{-1}$,



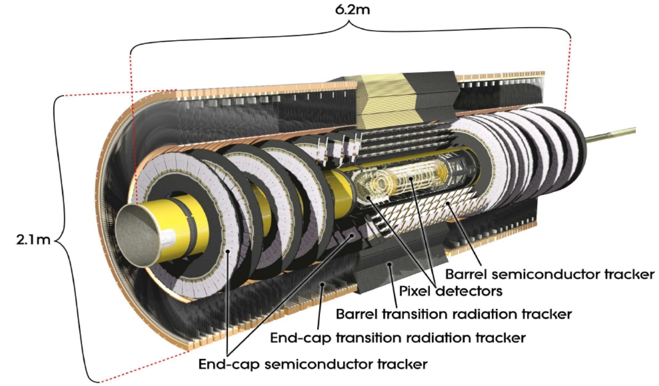
The ATLAS experiment

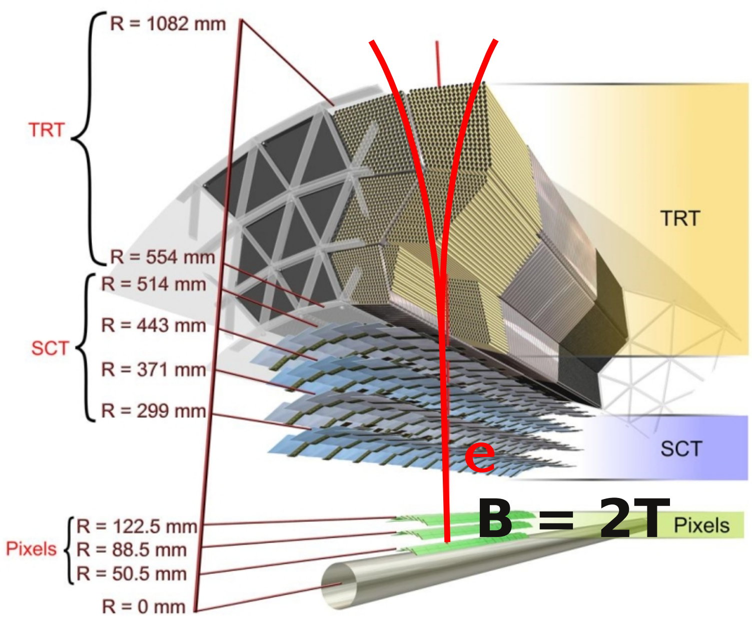
Inner detector
Calorimetric part
Muon spectrometer

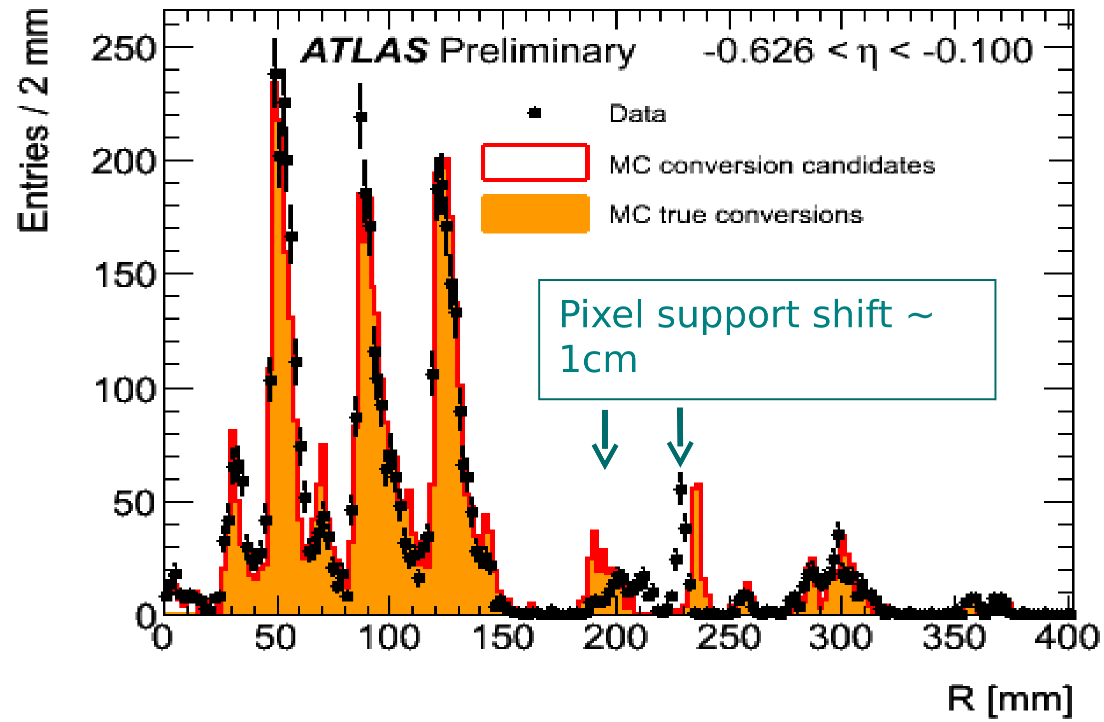
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$



ATLAS: inner detector



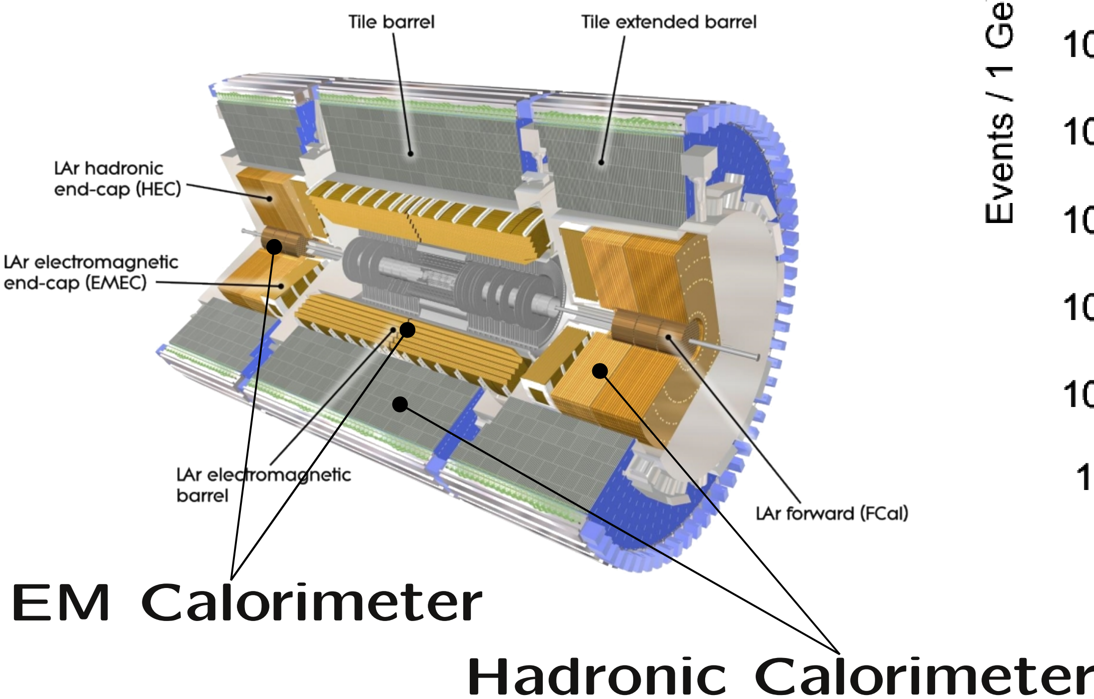


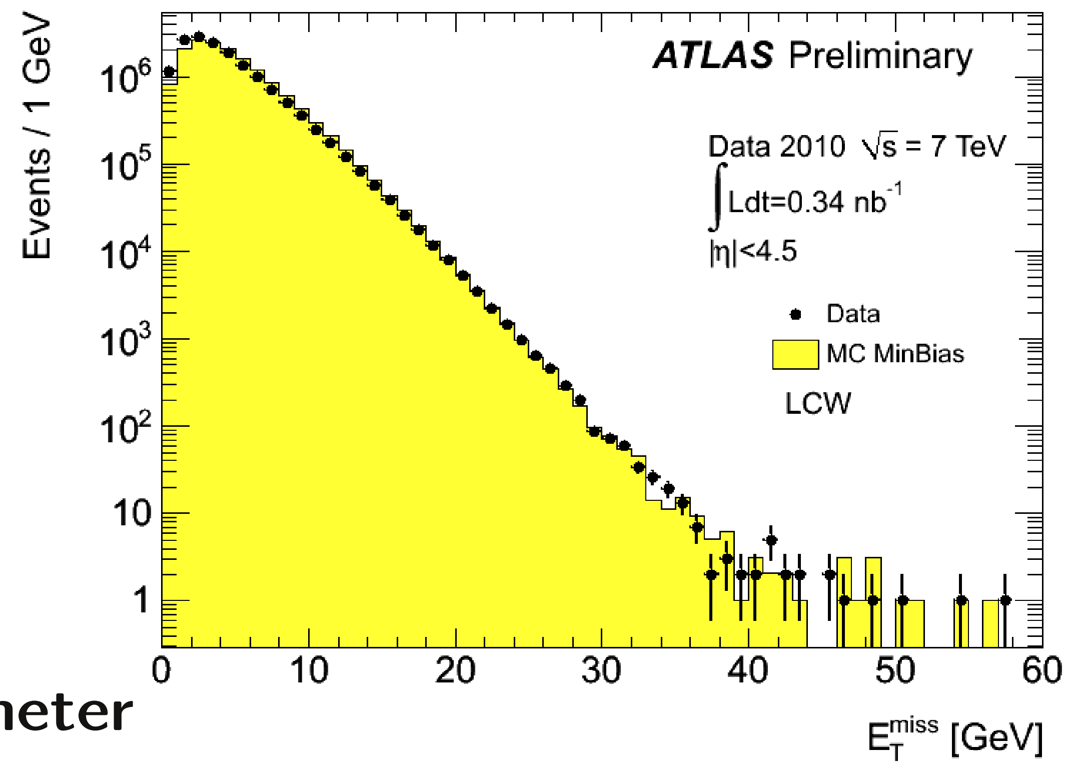


- Material distribution good agrement 10% X_0

- **Tracks reconstruction**
  - Momentum
  - Direction (η, ϕ, …)
- **Vertex reconstruction** (primary, secondary, conversions)
- **Particles identifications** (TRT)

ATLAS: calorimetric subsystem

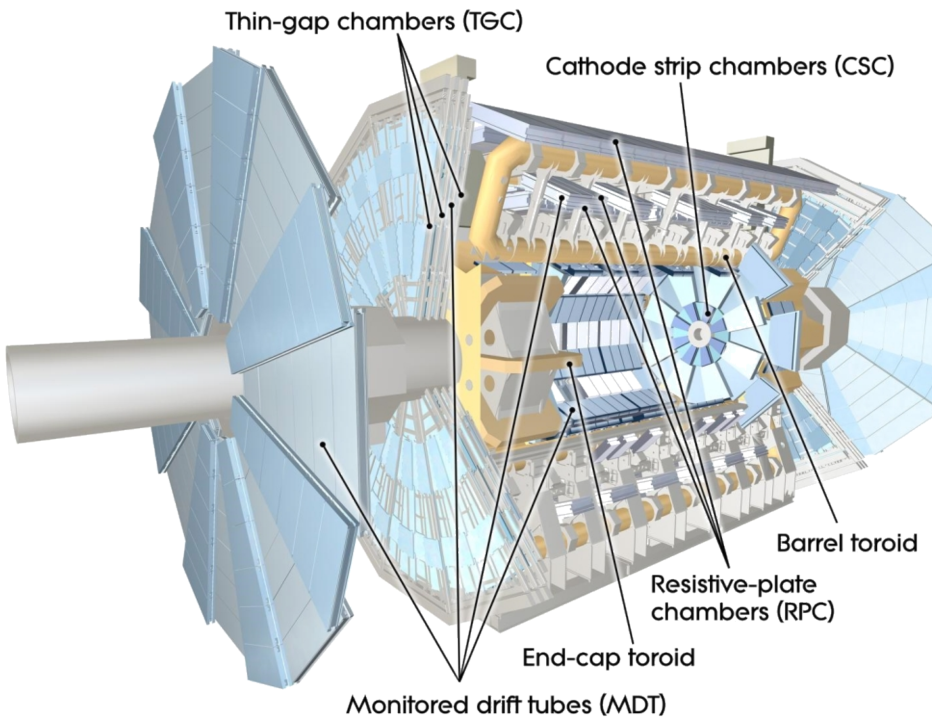


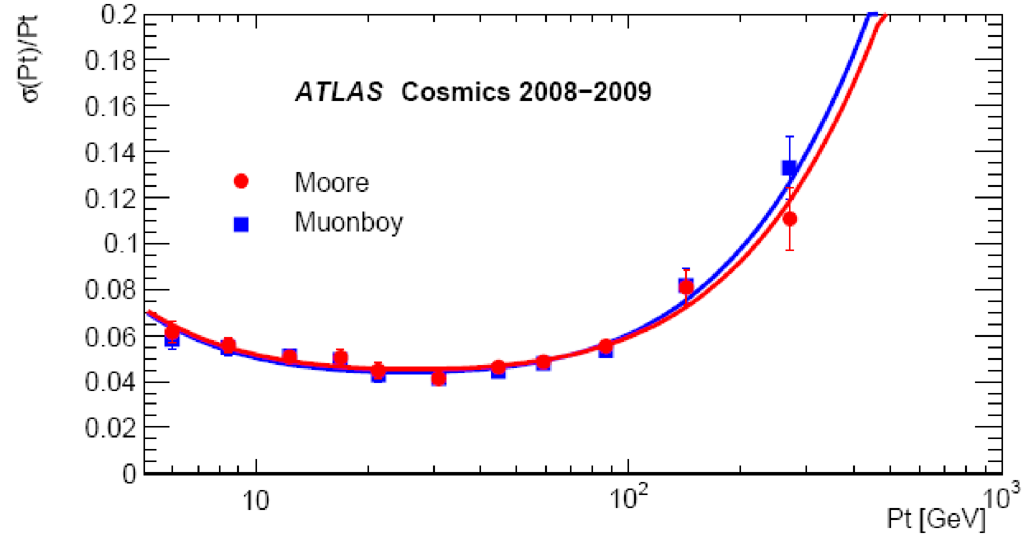


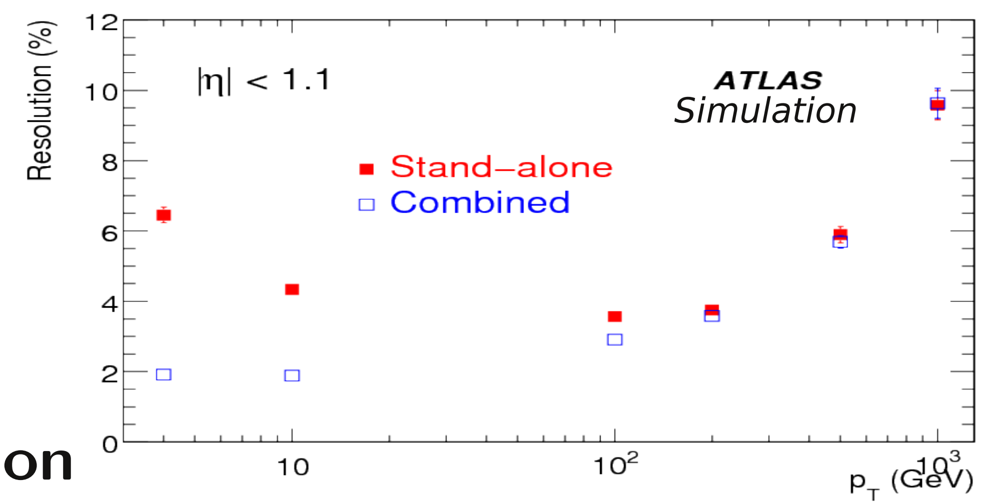
- Good performance on the missing Energy reconstruction

- **Energy deposit reconstruction** (EM and hadronic)
  - → Energy, missing transverse energy, jet properties
  - → Position, direction
- **Particle identification** (electron and photon)

ATLAS: muon spectrometer







- **Tracks reconstruction et identification**

→ Momentum

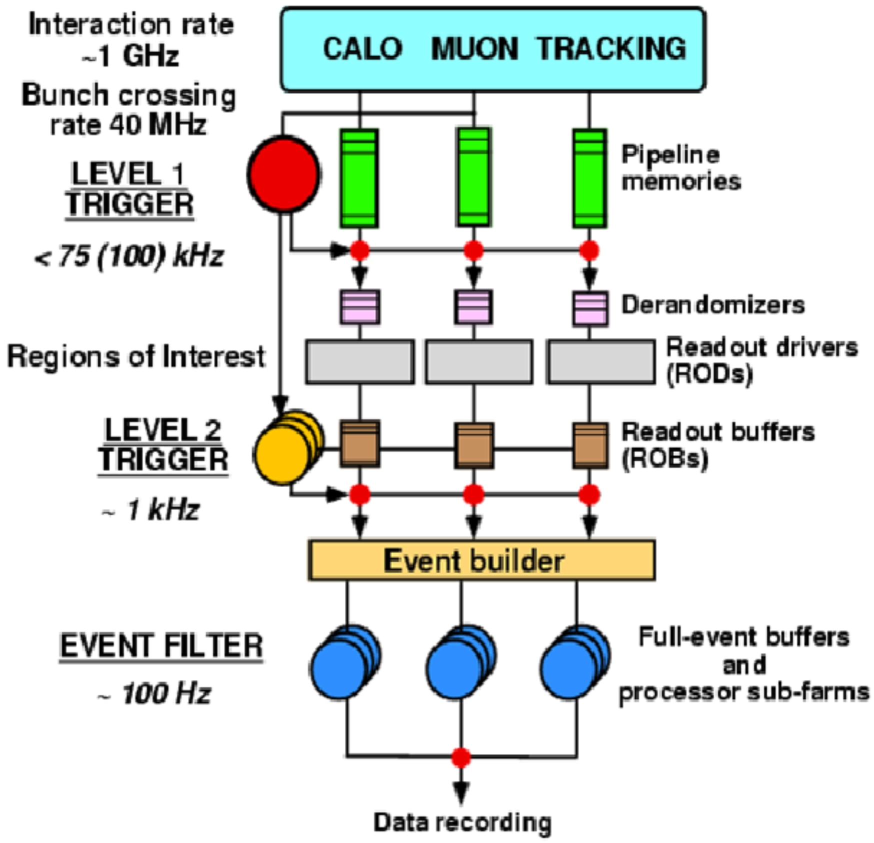
→ Direction (η, ϕ, …)

- **Trigger**

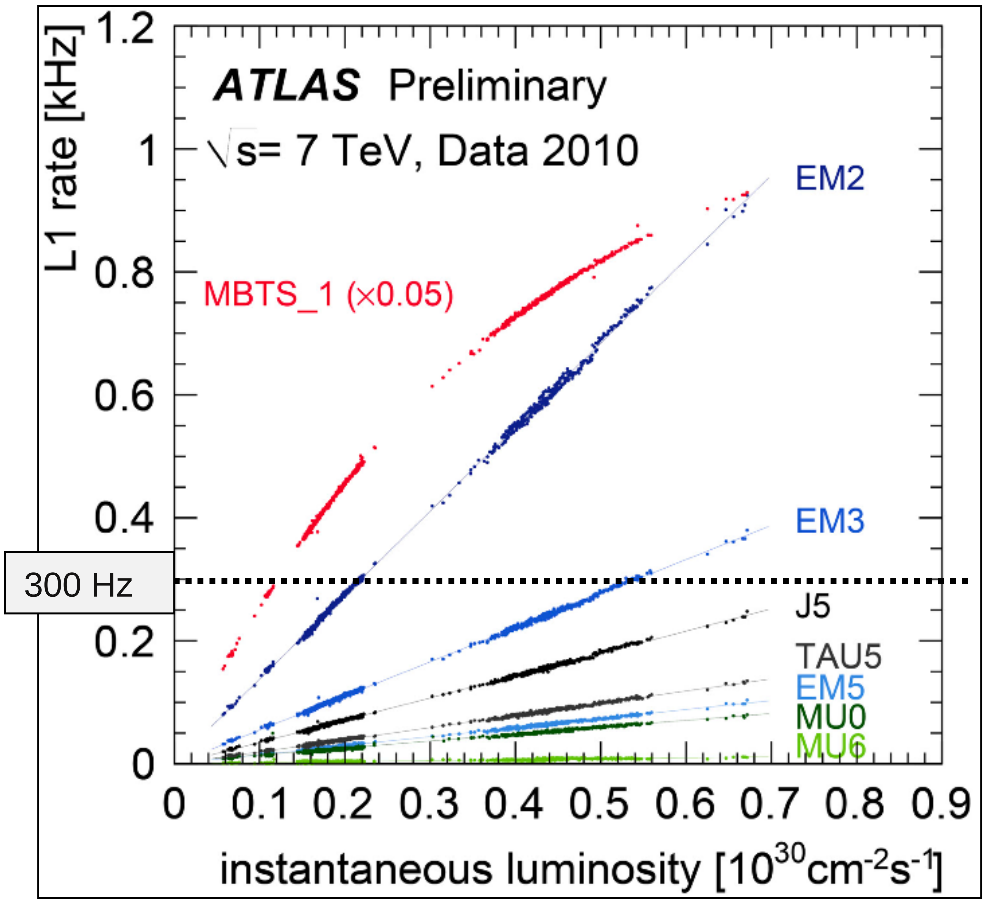
- *Muons transverse momentum resolution*

ATLAS: Trigger system

3 levels: LVL1, LVL2, Event Filter (EF) → High-Level-Trigger (HLT): LVL2 and EF



Un-prescaled rates of some LVL1 items vs L



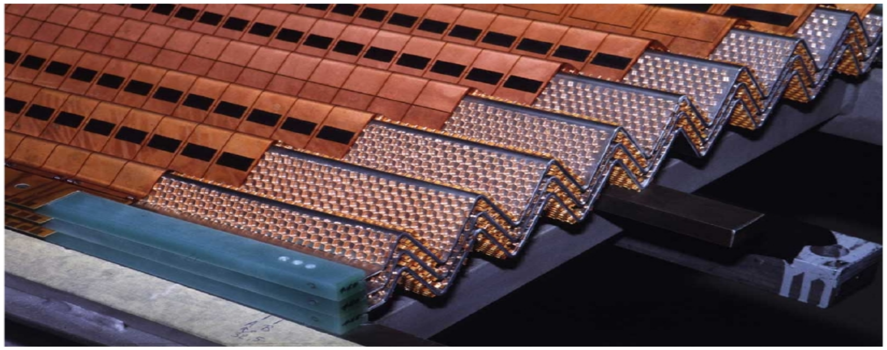
Trigger output: typically 300 Hz
The trigger menu is been update to increasing value of luminosity

HLT on (e/γ) for EM2, EM3 J5 pre-scaled

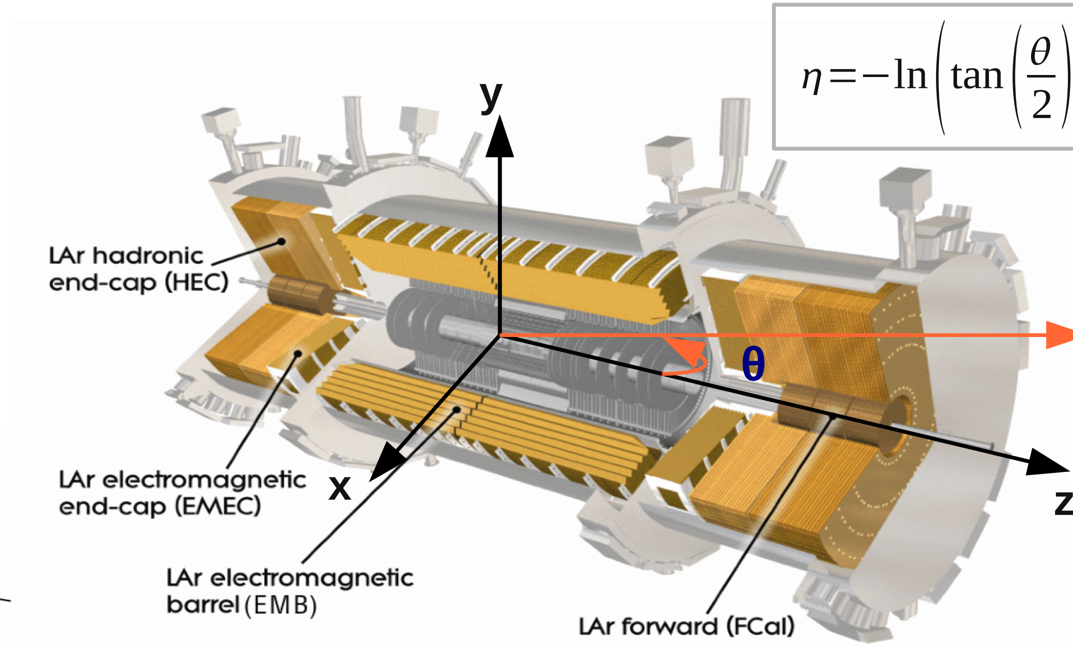
HLT on (τ) for TAU5

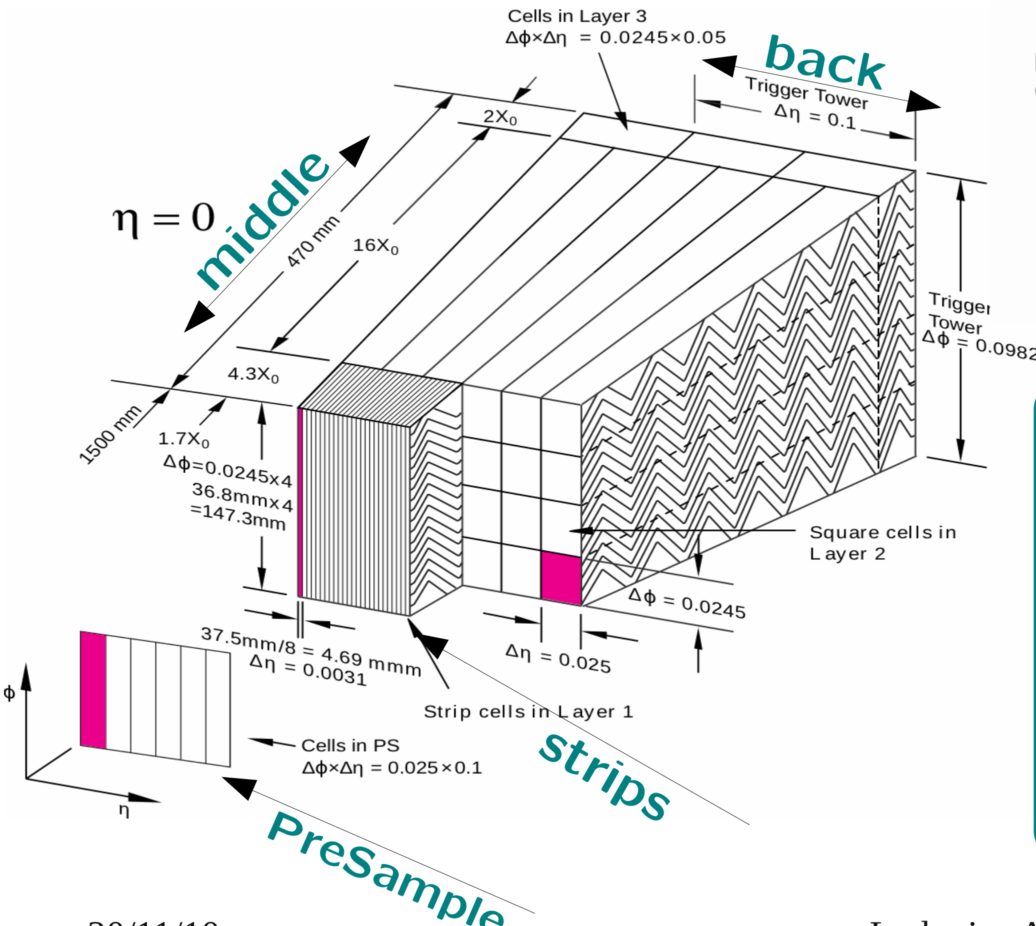
HLT on (μ) for MU0 fwd

The ATLAS LAr Calorimeter (1/2)



$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$



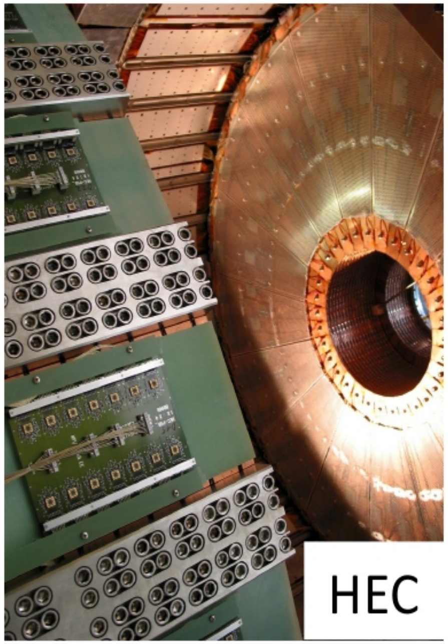


EM calorimeter

- Pb+ LAr, accordion geometry
- Coverage: $|\eta| < 3.2$, 2π ϕ coverage
- Longitudinal segmentations
- **173312** readout channels
- Resolution:

$$\frac{\Delta E}{E} = \frac{10\,\%}{\sqrt{E(\mathrm{GeV})}} \oplus 0.7\,\%$$

The ATLAS LAr Calorimeter (2/2)



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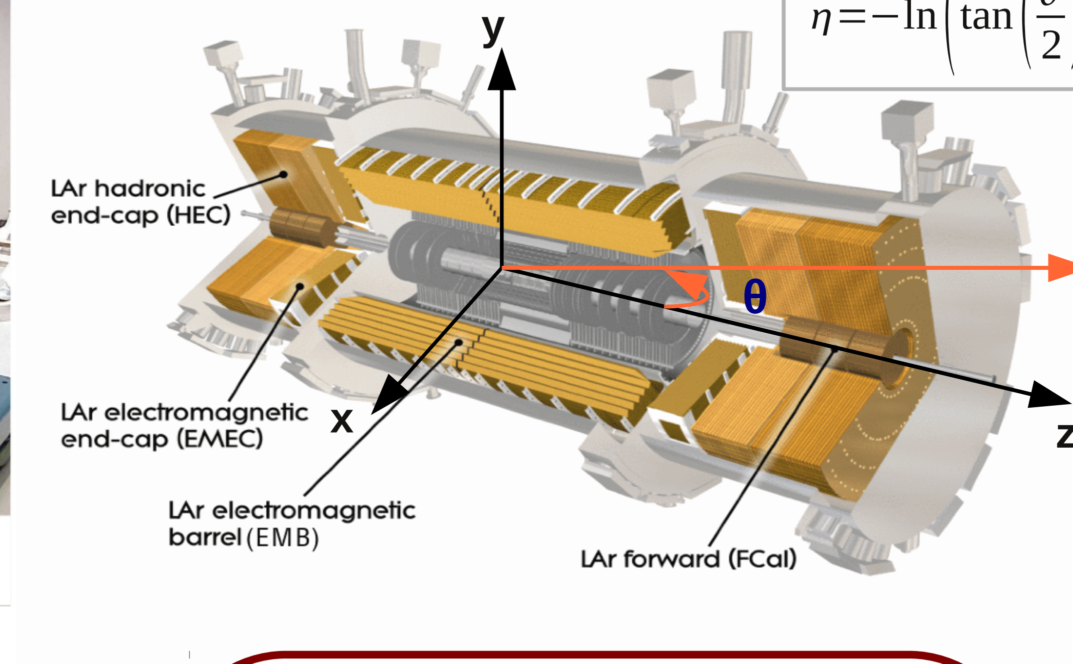


Hadronic EndCap (HEC)

Cu+ LAr flat plates

- Coverage : $1.5 < |\eta| < 3.2$
- **5600** readout channels
- Resolution:

$$\frac{\Delta E}{E} = \frac{50\,\%}{\sqrt{E(\mathrm{GeV})}} \oplus 3\,\%$$

Forward calorimeter (FCal)

- Cu/ W tubes + LAr
- Coverage : $3.1 < |\eta| < 4.9$
- **3500** readout channels
- Resolution:

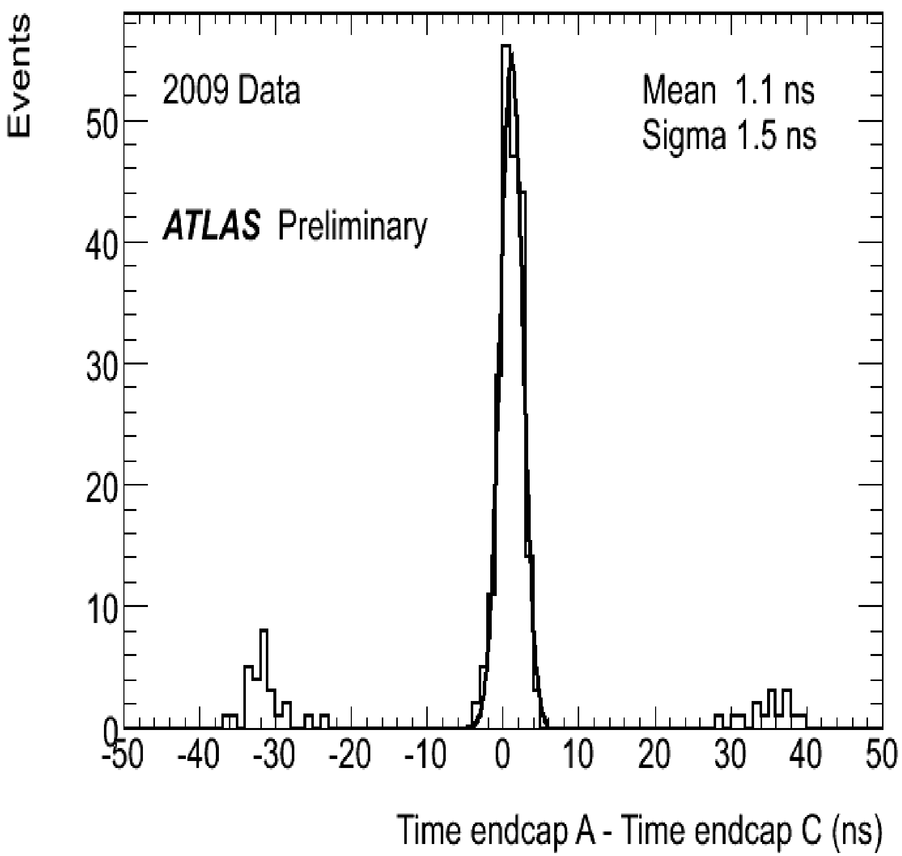
$$\frac{\Delta E}{E} = \frac{100\,\%}{\sqrt{E(\mathrm{GeV})}} \oplus 10\,\%$$

LAr Timing alignment

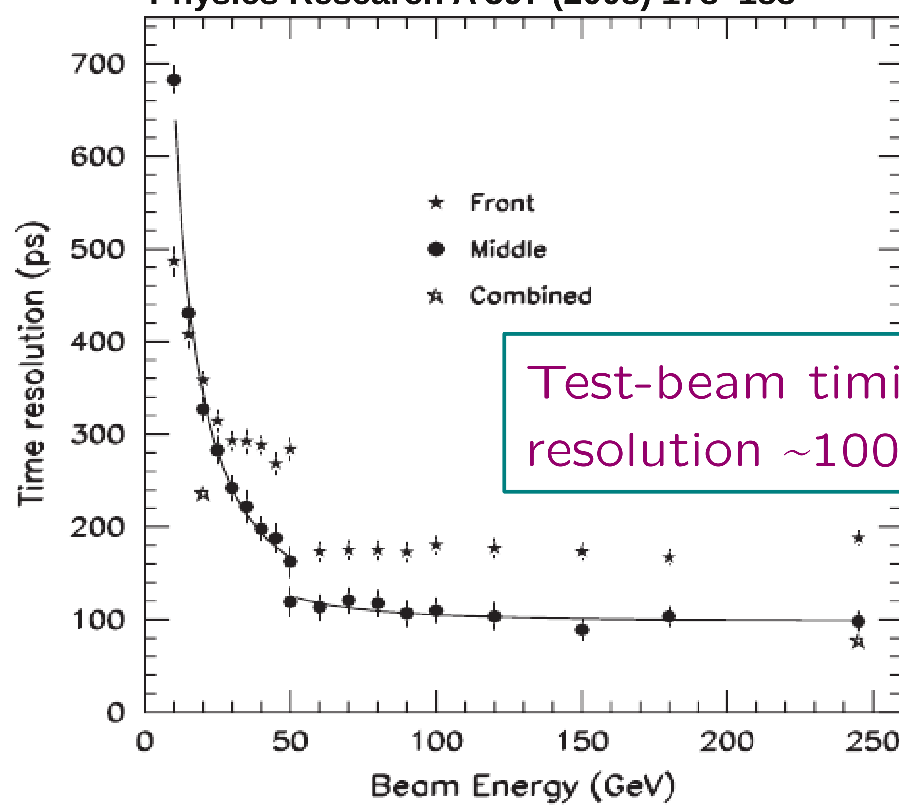
LAr timing alignment: motivation

Why is the timing alignment important?

- to reject cosmic-events and not in time physics background
- to identify exotic particles → measuring velocity (β) or lifetime;

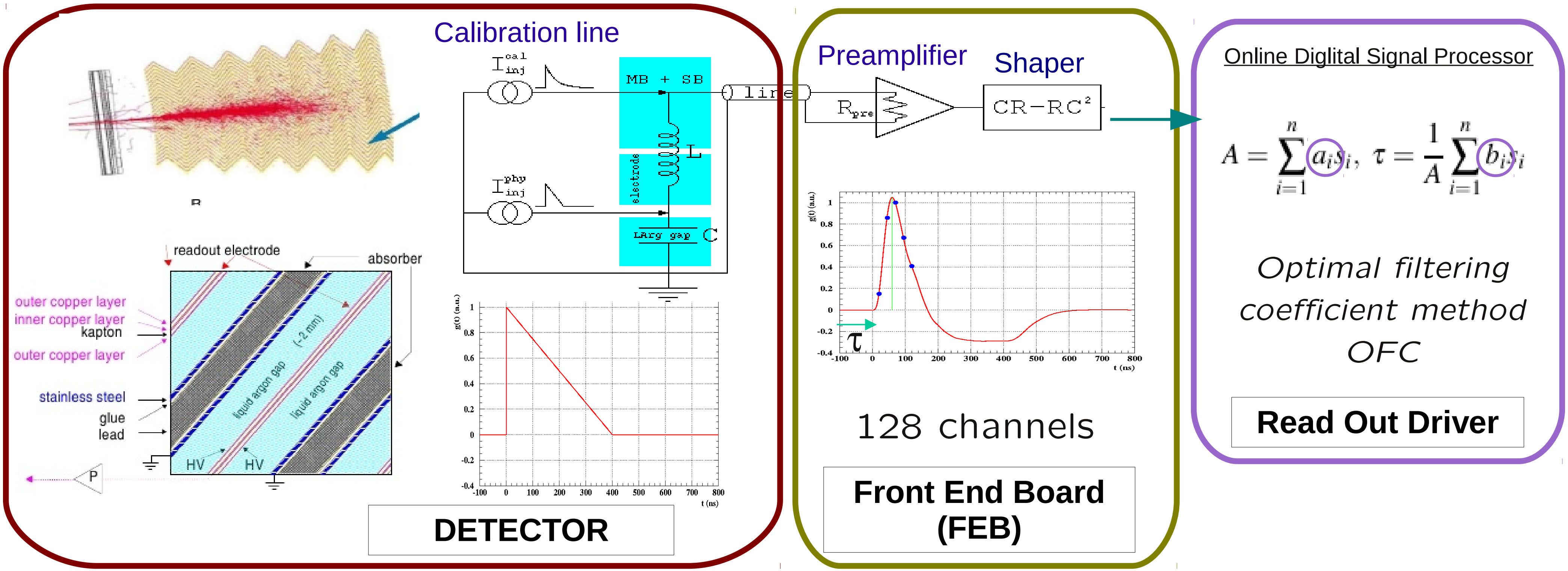


Nuclear Instruments and Methods in Physics Research A 597 (2008) 178–188



Test-beam timing resolution ~100ps

Signal reconstruction



To align in time the ~180k cells of the LAr calorimeter two adjustments are used:

Hardware alignment at the level of the FEB

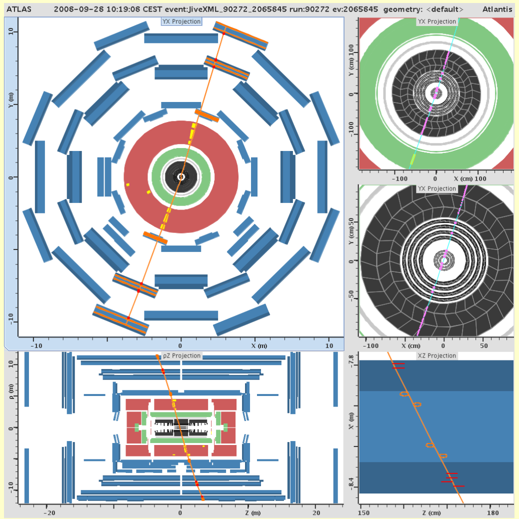
Single cell adjustment on the set of Optimal Filtering Coefficients (OFC).

Timing alignment steps (1/2)

Due to differences in the FEB cabling, timing offsets between boards are of the order of 15 ns.

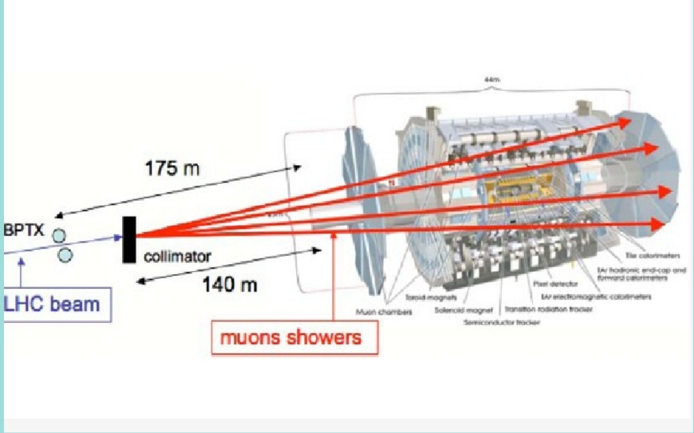
Cosmic Muons (since 2006)

Muons : MIP
in the Liquid Argon Calorimeter



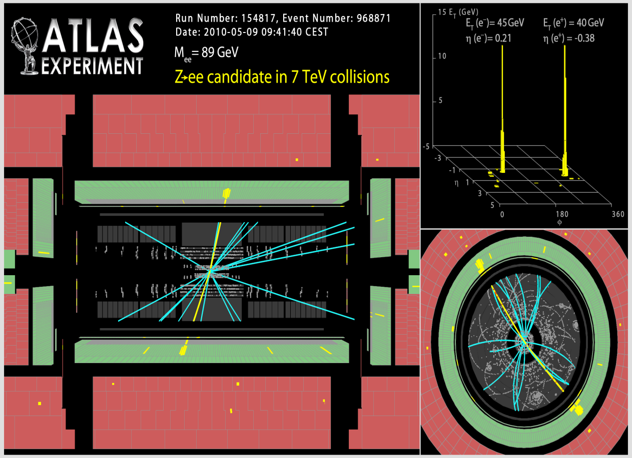
First LHC Beams (Sept. 10-12, 2008)

Very large energy deposited in most of LAr cells !



First Collisions (Nov. 23, 2009)

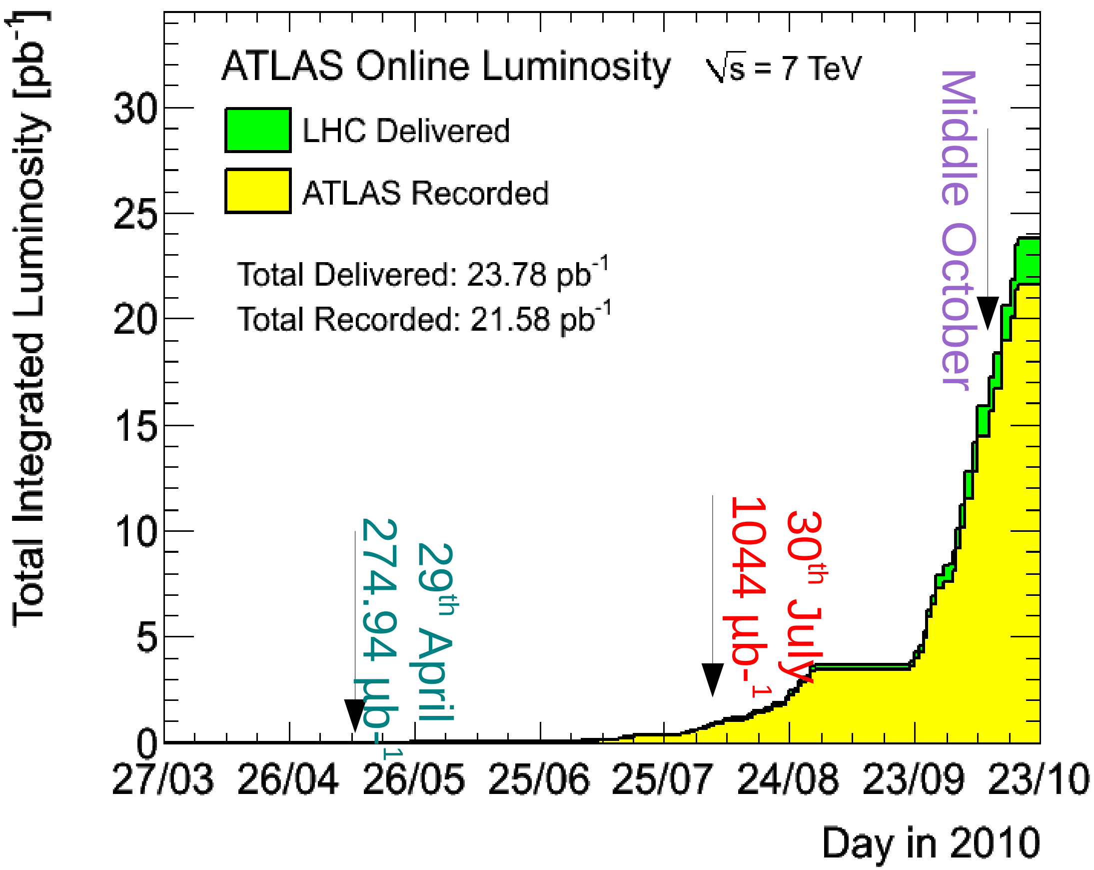
Real events !



All commissioning steps are used to estimate the FEBs offsets. → accuracy of the time alignment ~ 2-3 ns.

→ My work is to improve these values

Timing alignment steps (2/2)



→ FEB time correction (applied 29th April 2010)

→ OFC phase correction (30th July 2010)

More statistics available now (October):

- ~30M events ~ 7800 nb^{-1}
- # Channels with more than 5 events 160799/182468 → 88,1%

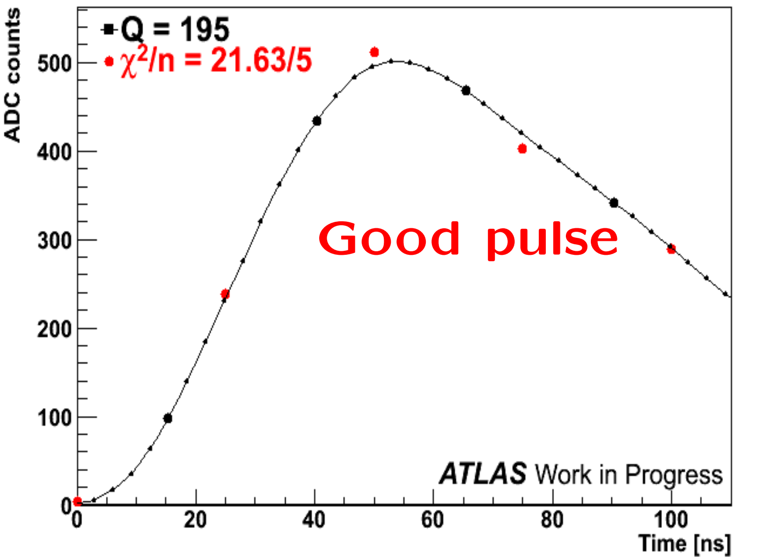
Selections and Results presented here

Quality factor of the cells

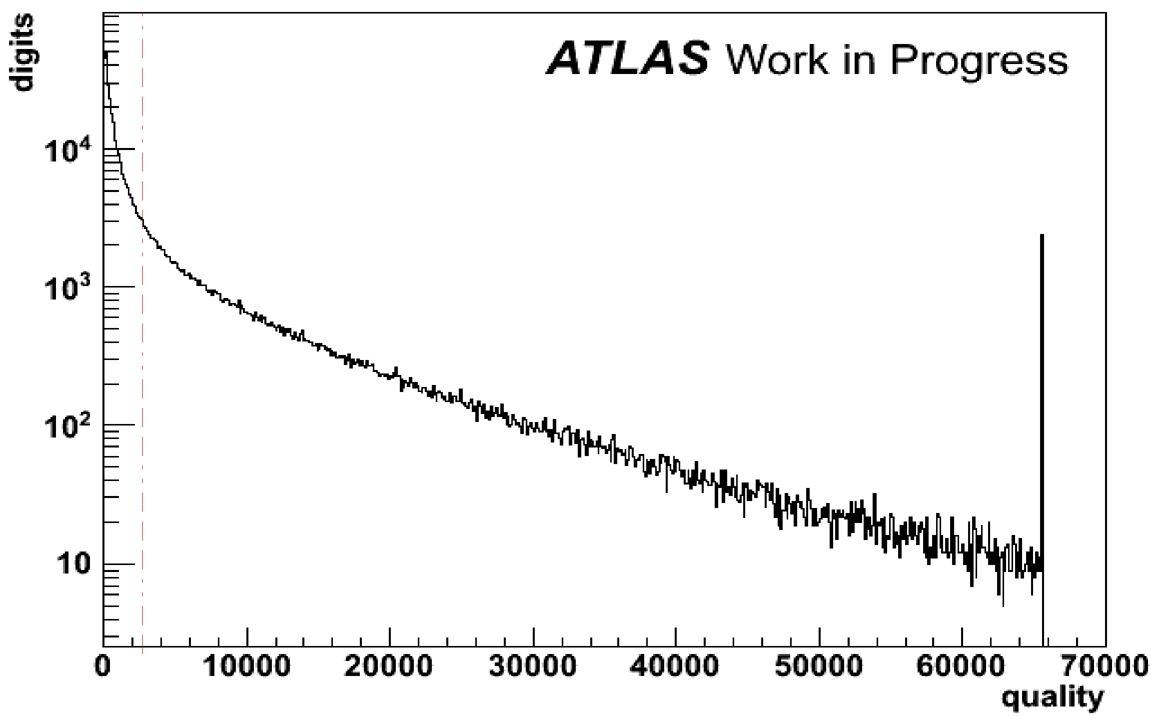
χ^2-like quality factor is use to comparing the measured pulse shape with the reference shape:

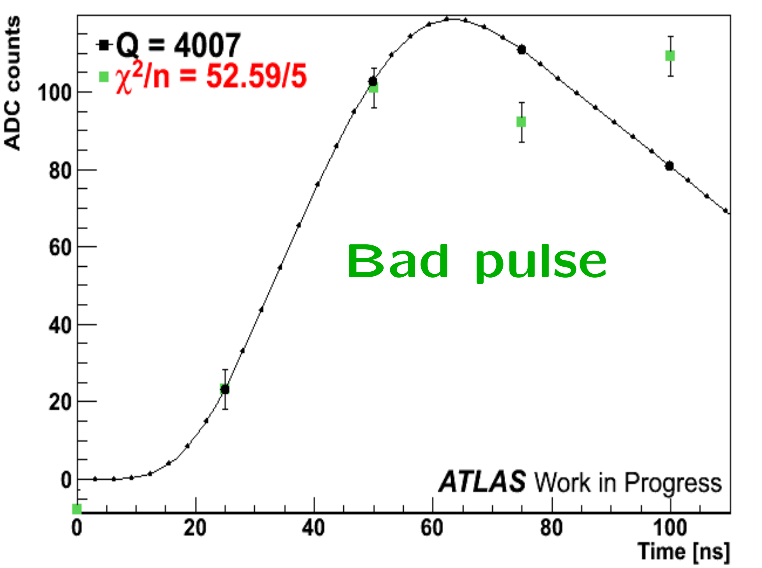
$$Q = \sum_{i=1}^{5} \frac{\left(s_i - Ag(t_i - \tau)\right)^2}{n^2}$$

- s_i: sample values
- t_i: sampling times
- A: pulse amplitude
- τ: pulse time
- g(t): reference shape
- n: noise



Remove cells with hight Q factor





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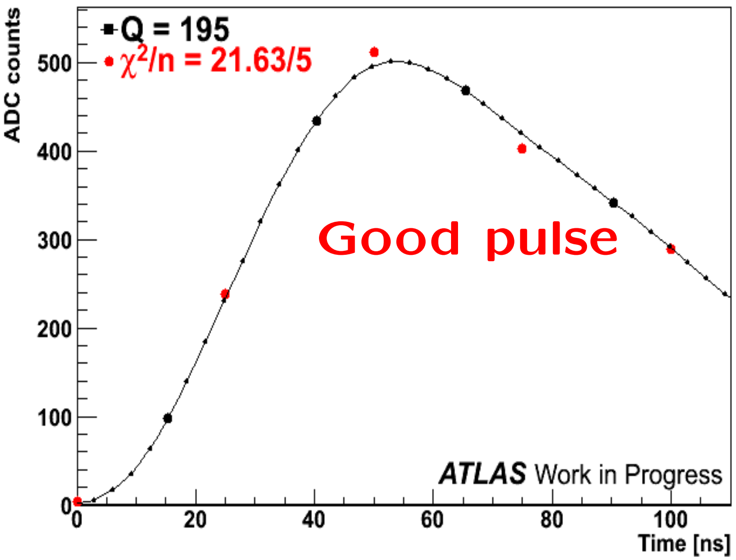
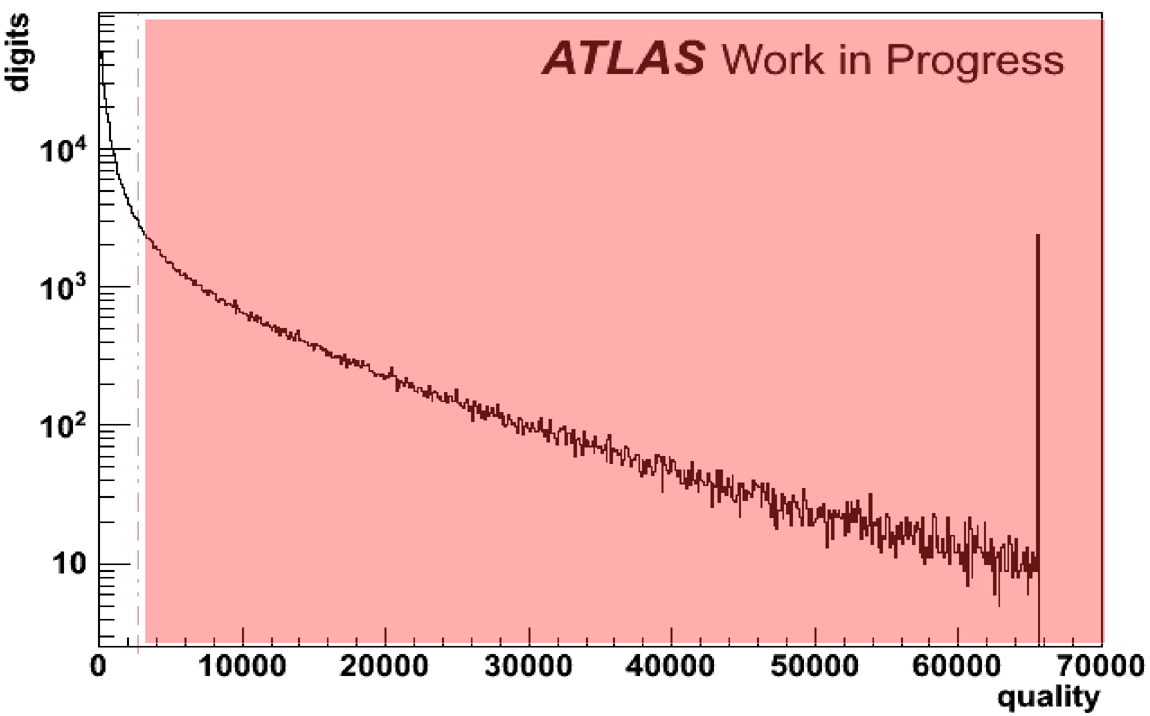
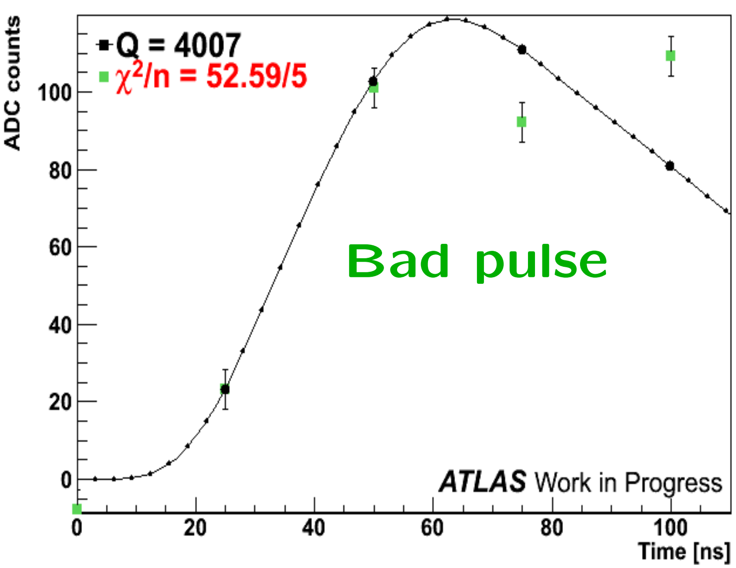
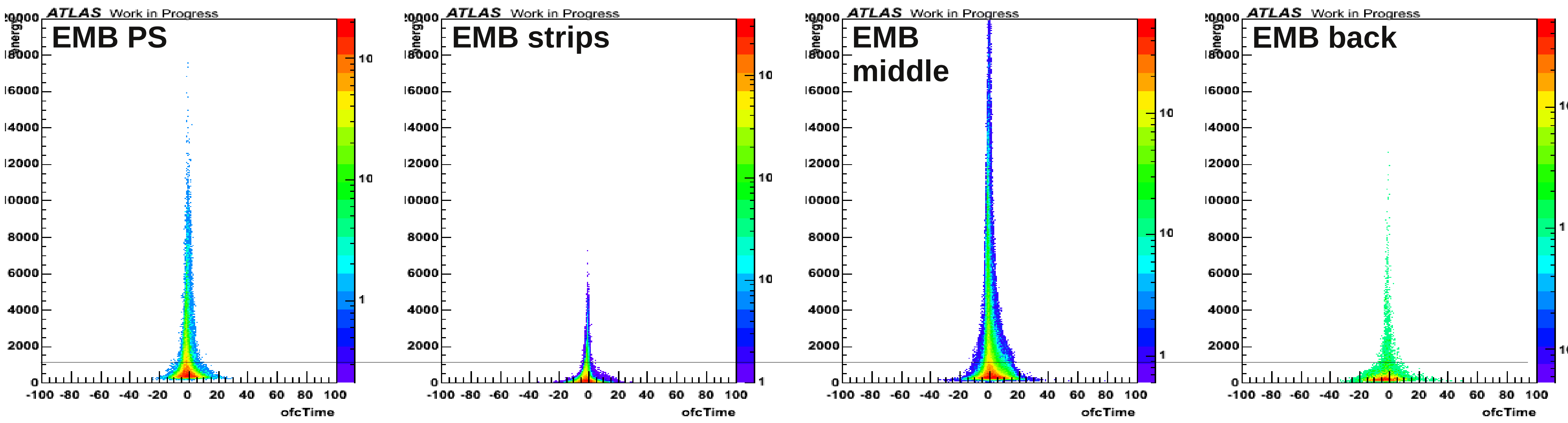


Remove cells with hight Q factor





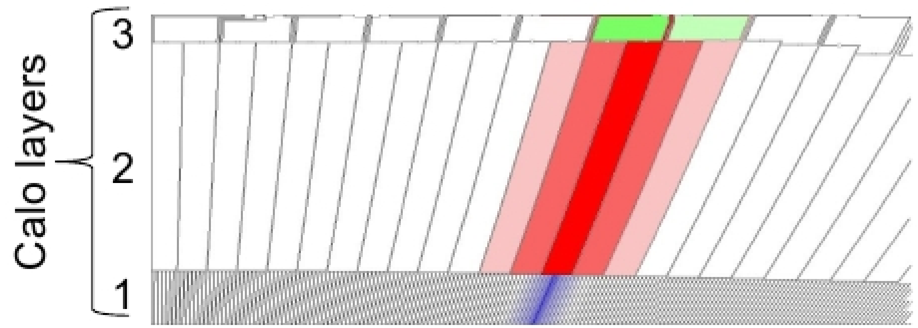
Energy dependences of timing resolution

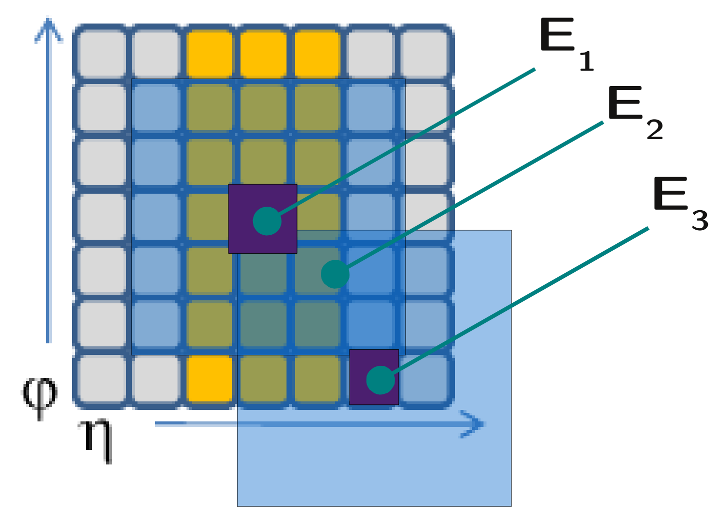


- The accuracy of the FEB time is dependent on the energy, $\rightarrow$ the cell time distribution is affected by the bad intrinsic time resolution at low energy range
- Time resolution improves at high energy: $\sigma_t = \frac{a}{E} \oplus c$
  - For this analysis, perform an E cut on the different LAr subdetectors to reduce the effect of the bad timing resolution at low energy

Method to select the cells

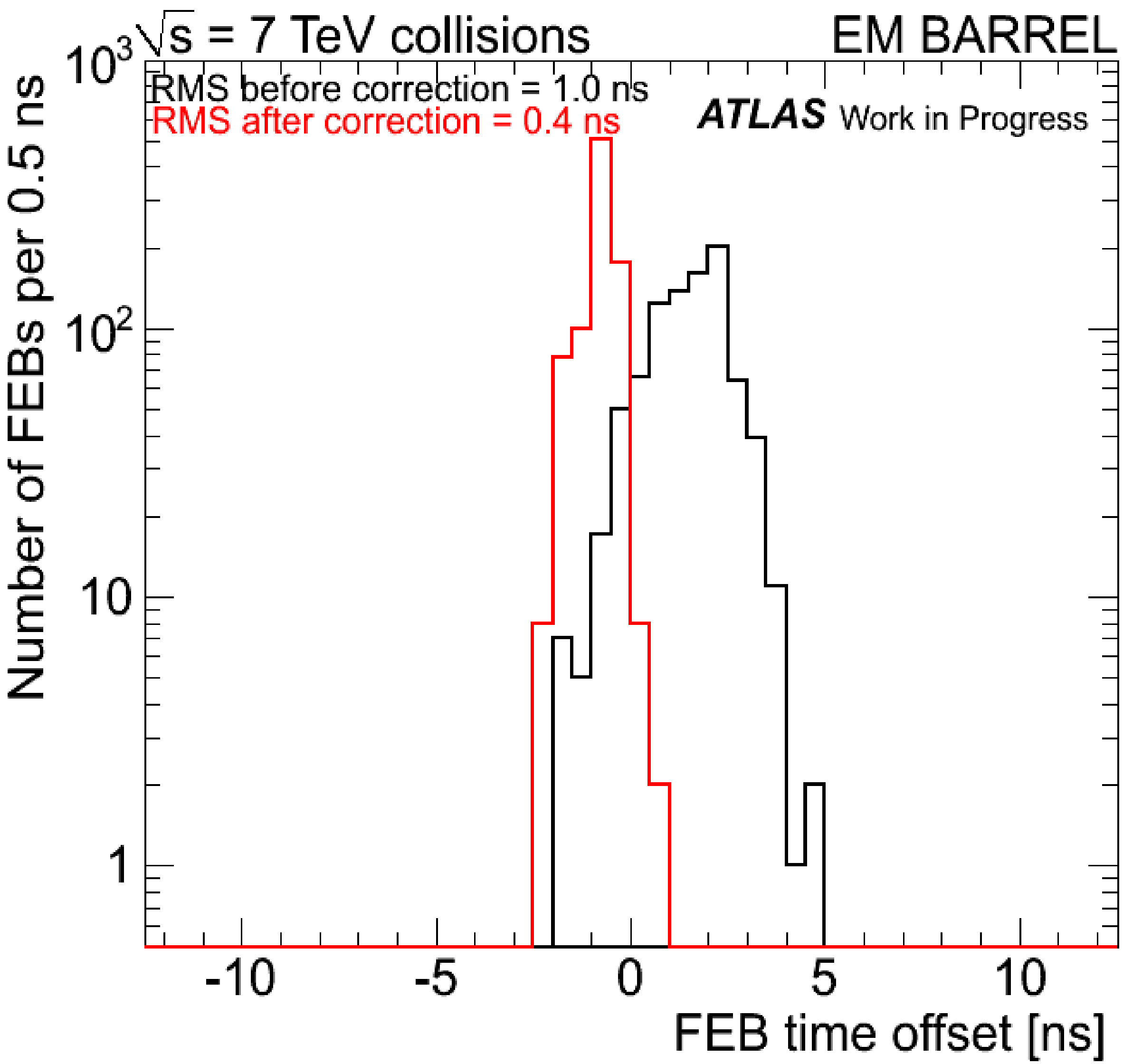
- Electronic cross-talk (mainly in the strips) could bias the time measurement
- ➔ To clean up the sample:
  - Consider only the highest energy cell for each layer (E_1) and don't consider the first two neighboring cells.
  - To increase statistics → also consider the highest energy cell (E_3) after the second neighbors if $\mathbf{E_3 > E_2}$





FEB timing alignment (1/2)

- The FEB time offset is calculated as the average of the mean time of each channel in that FEB with more than two events.
  - For the channel with more than five events the mean time is obtained with a Gaussian fit.



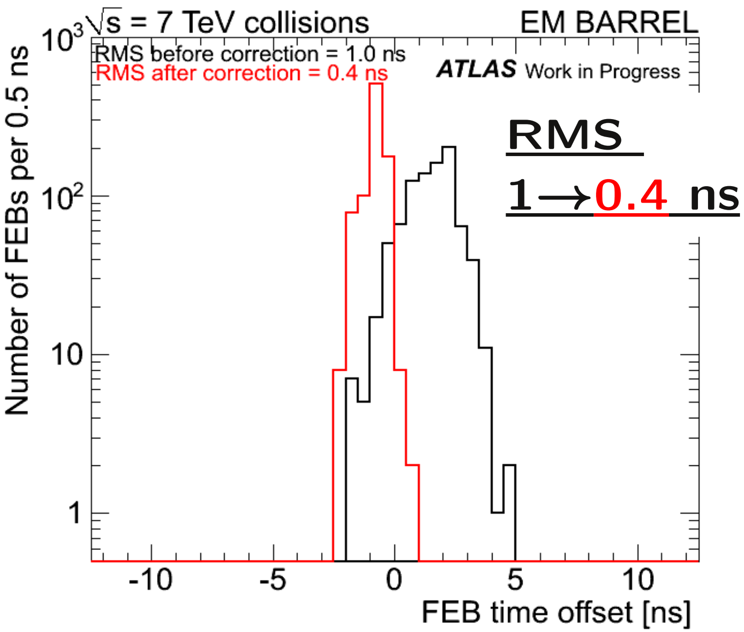
Black $\longrightarrow$ FEB time offsets before correction

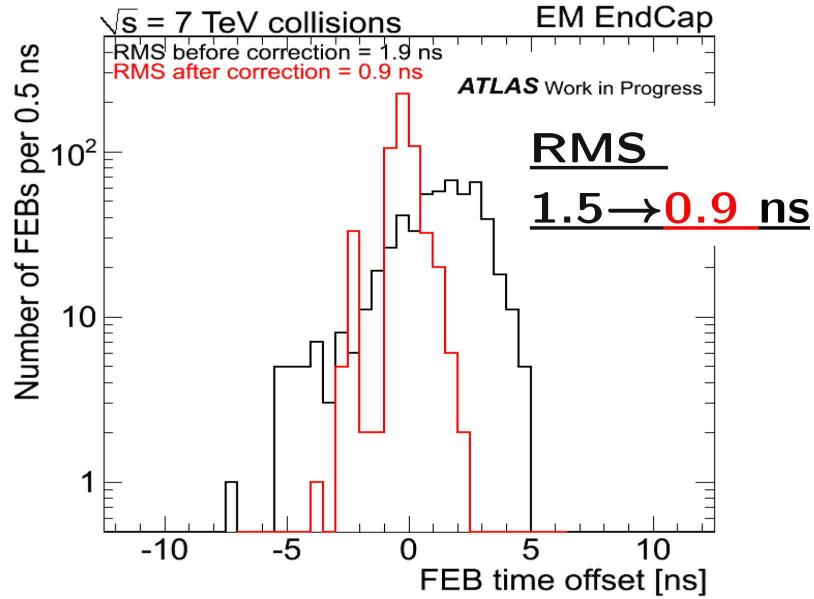
Red $\longrightarrow$ FEB time offsets distribution current status

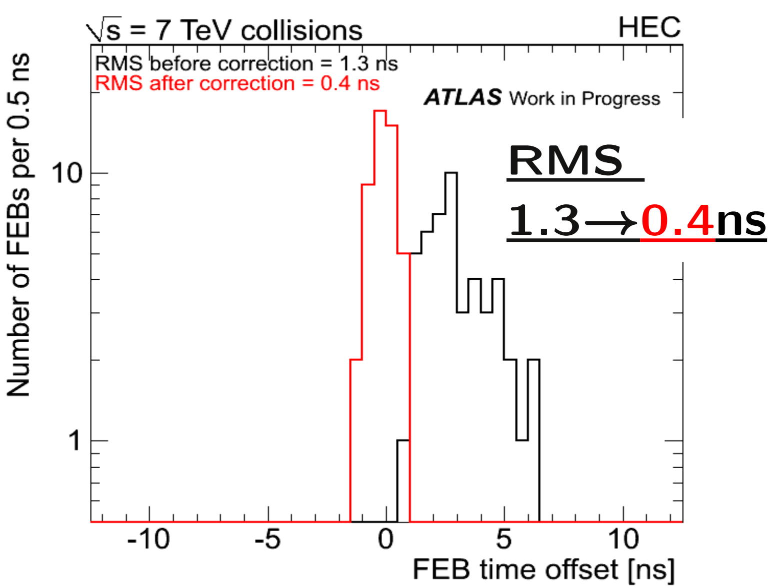
Significant improvement $\longrightarrow$ all FEBs are well aligned, RMS $\sim$ 0.4 ns

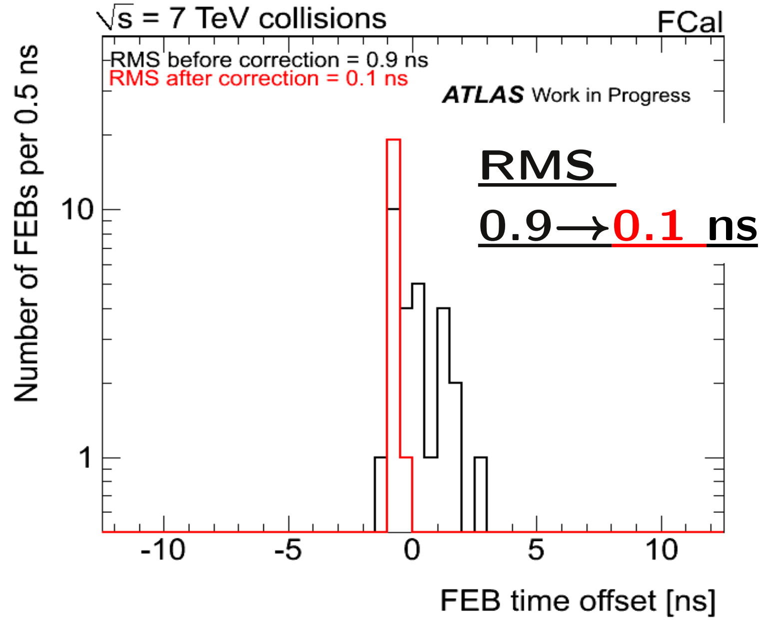
FEB timing alignment (2/2)

Significant improvement on the FEB alignment → For all the sub-detectors









Black → before correction

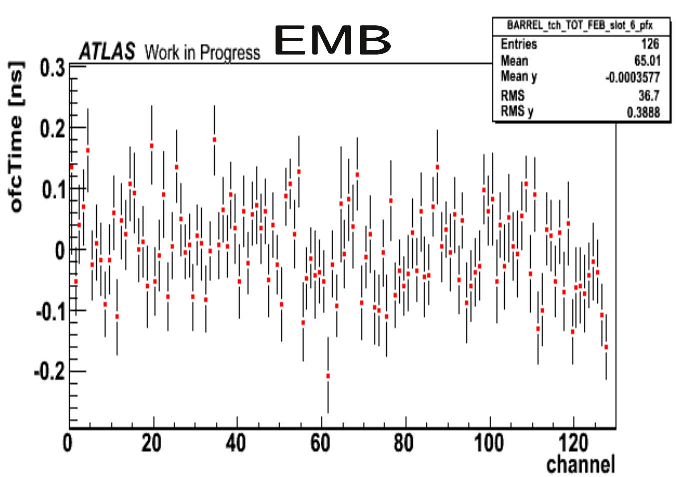
Red → current status

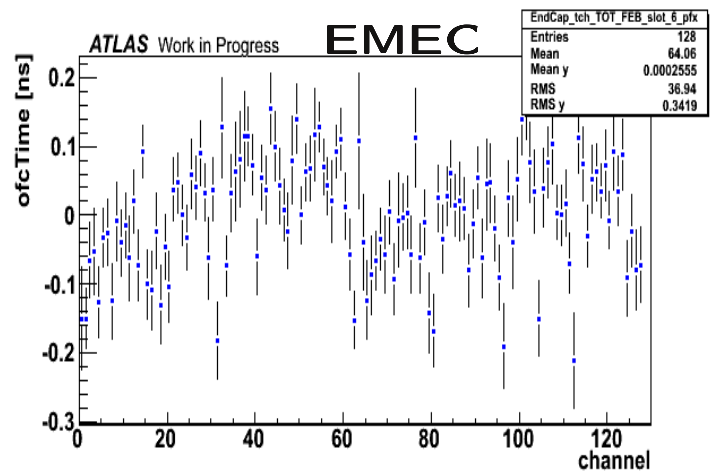
Channel by channel correction

The second step in the timing alignment is to study the channel time spread within a FEB: $<<time>_{ch} - <time>_{FEB}>$

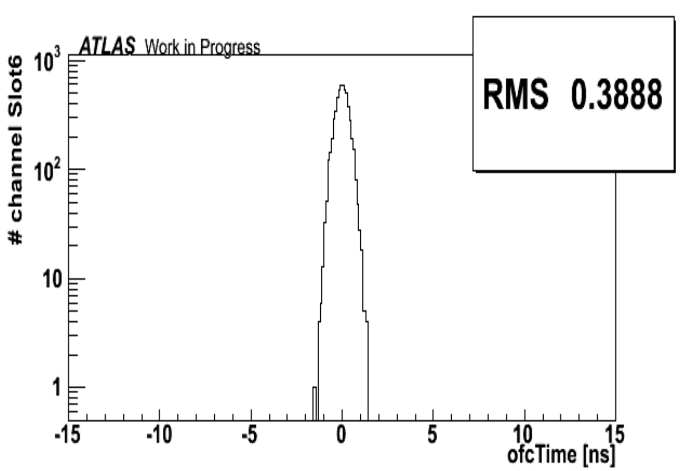
This correction is applied offline.

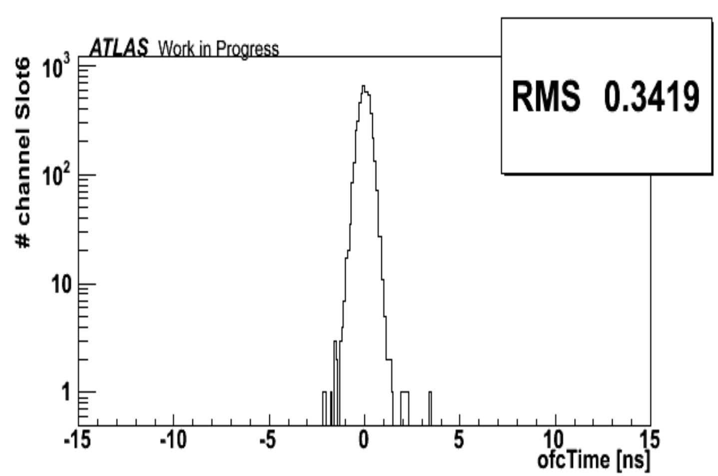
→ Introduces a phase to the set of OFCs, should set all the single channel times within a FEB to ∅





We can improve the alignment of the channel time inside a FEB





In the channel by channel alignment now we reach a spread of ~ 400ps for almost all the cells

Conclusion

- The FEB average time correction was applied on 29^{th} April 2010.
- The Optimal Filtering Coefficients phases correction was applied on 30^{th} July 2010.

➔ After this correction all the FEBs are well aligned in time; centered on zero, with a channel spread of $\sim$ 400 ps.

➔ Update of the two corrections is in preparation

➔ Ultimate time resolution goal $\sim$100 ps.

➔ A note on the Timing Alignment is in progress

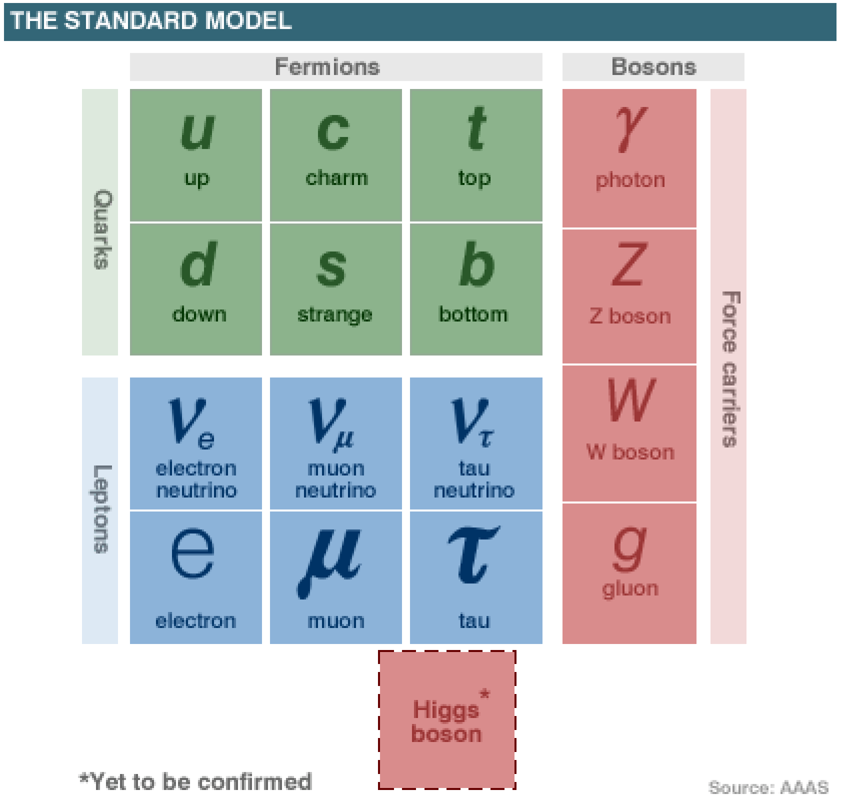
Searching for new physics at high-mass di-electron resonances

The Standard Model

The Standard Model (SM) describes very well particle physics at energies attainable so far but

→ is a low energy effective theory

→ needs experimental discovery of the Higgs sector.



Still major open problems in particle physics today:

→ Quantum gravity

→ The hierarchy problem

→ Neutrino masses

→ Coupling unification

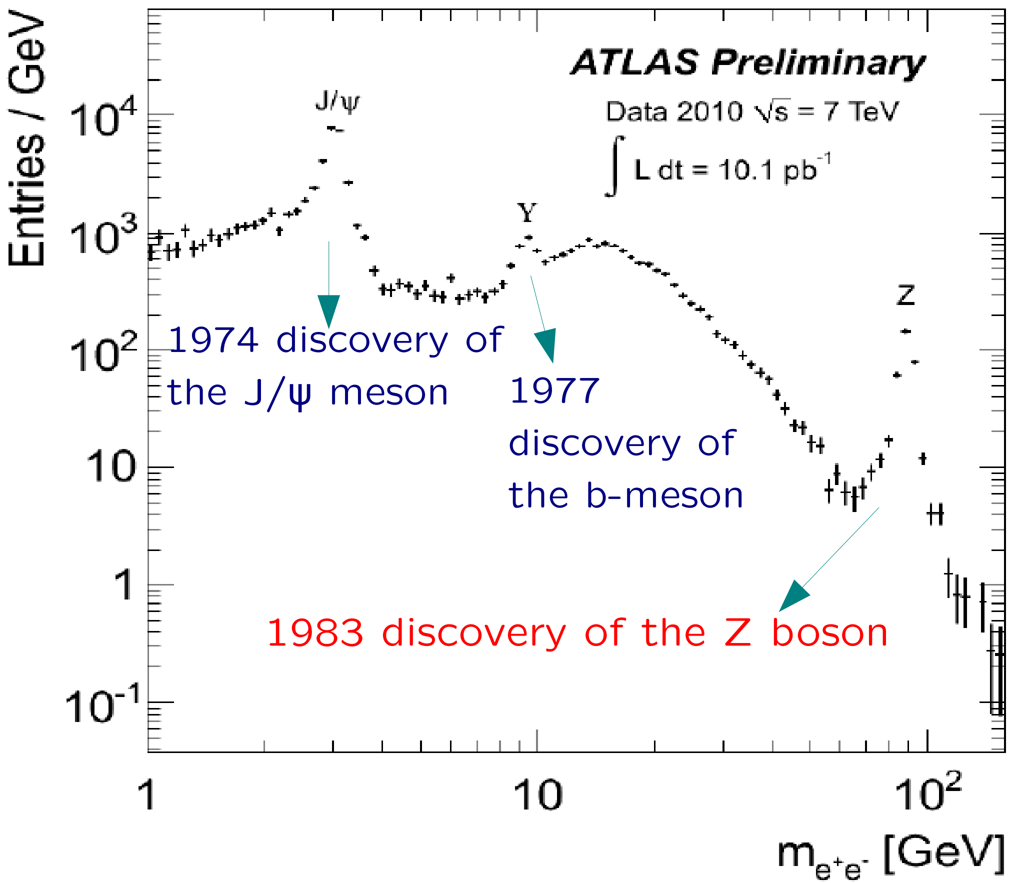
→ strongly suggesting the need for new physics near the weak scale ~ 1TeV.

What is it ?

Perform a model independent search.

Resonances in di-lepton spectrum

The di-lepton invariant mass spectrum is one of the most famous model independent probe of new physics

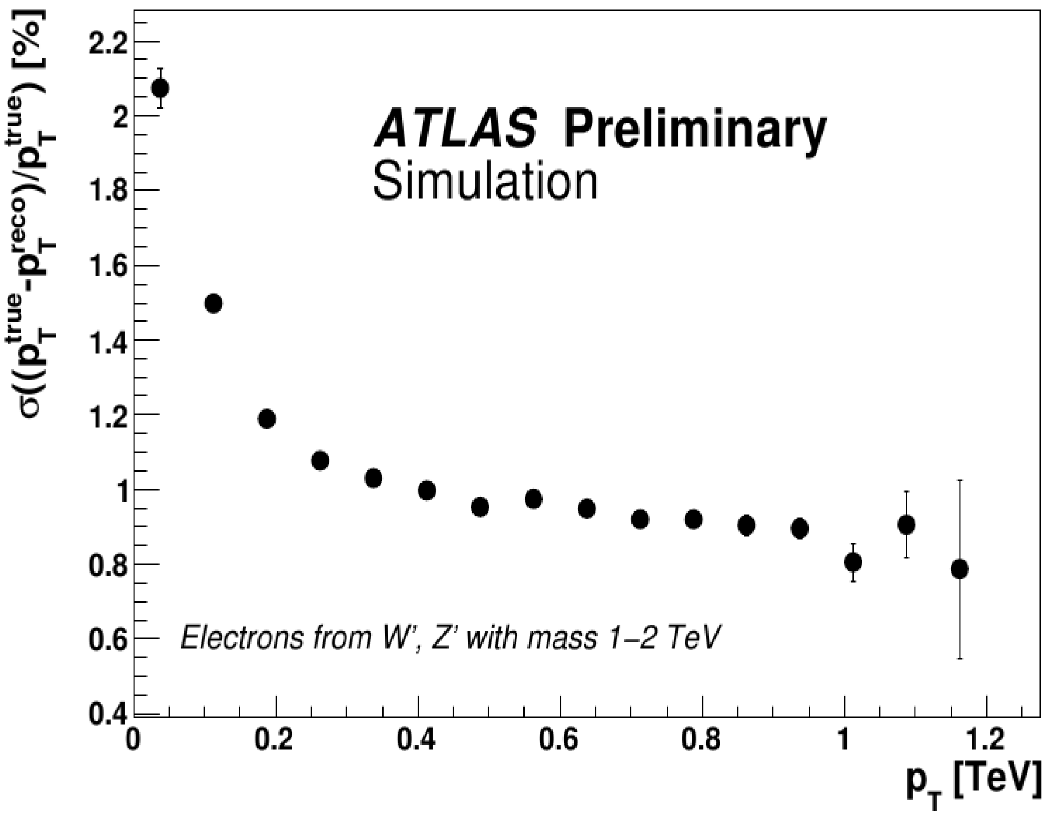


Neutral resonances are predicted in many models:

- New spin-1 gauge boson (Z')
- The "little Higgs" models
- The Kaluza-Klein excitations of gauge bosons
- The graviton from Randall-Sundrum model.

→ Any excess above the SM expectation can be interpreted as evidence of new physics.

Lepton reconstruction at high p_T

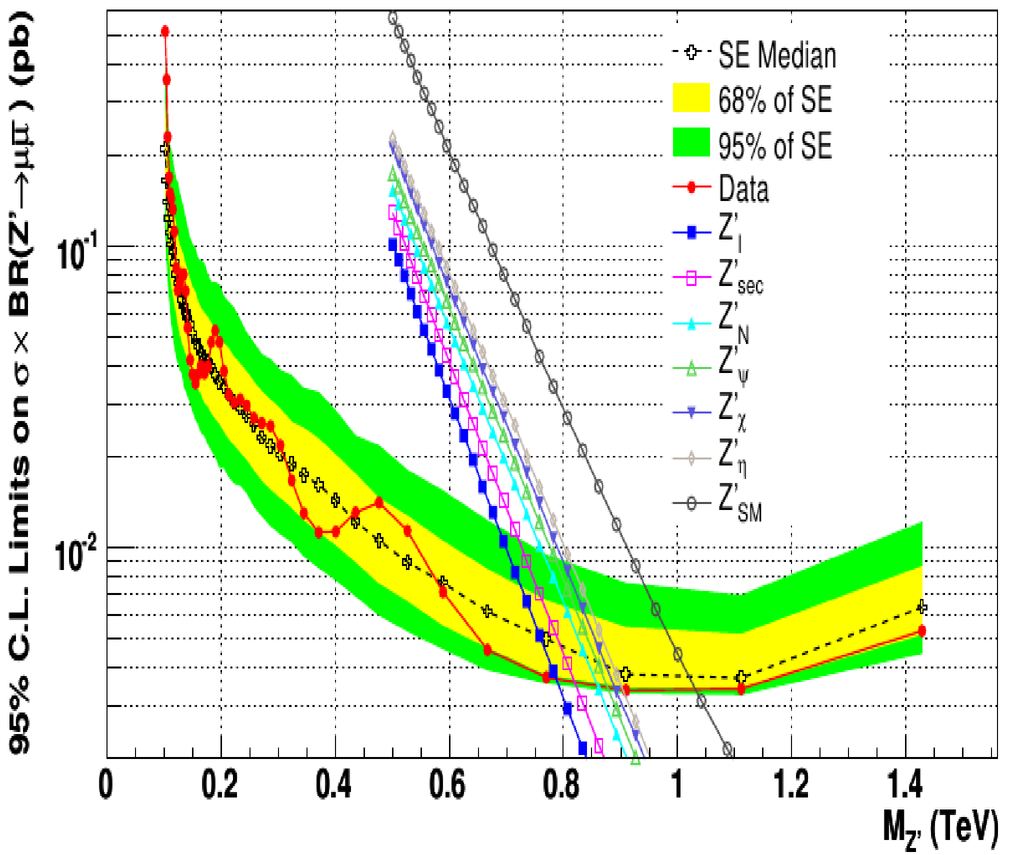


- The decay $Z' \rightarrow l^+ l^-$ simple and clean signature high pT leptons.
- Energy resolution of reconstructed electrons ~ √E
  - Hight p_T electrons (W'&Z') resolution is expected to be close to 1%.

- The invariant mass of the two leptons good probe to discover the resonance over a rapidly falling background at high masses:
  - high-mass tail of the Drell-Yan process. (irreducible background)
  - t tbar
  - QCD dijet production.

Di-electron resonances search

CDF: arXiv.org > hep-ex > arXiv:0910.1770v1



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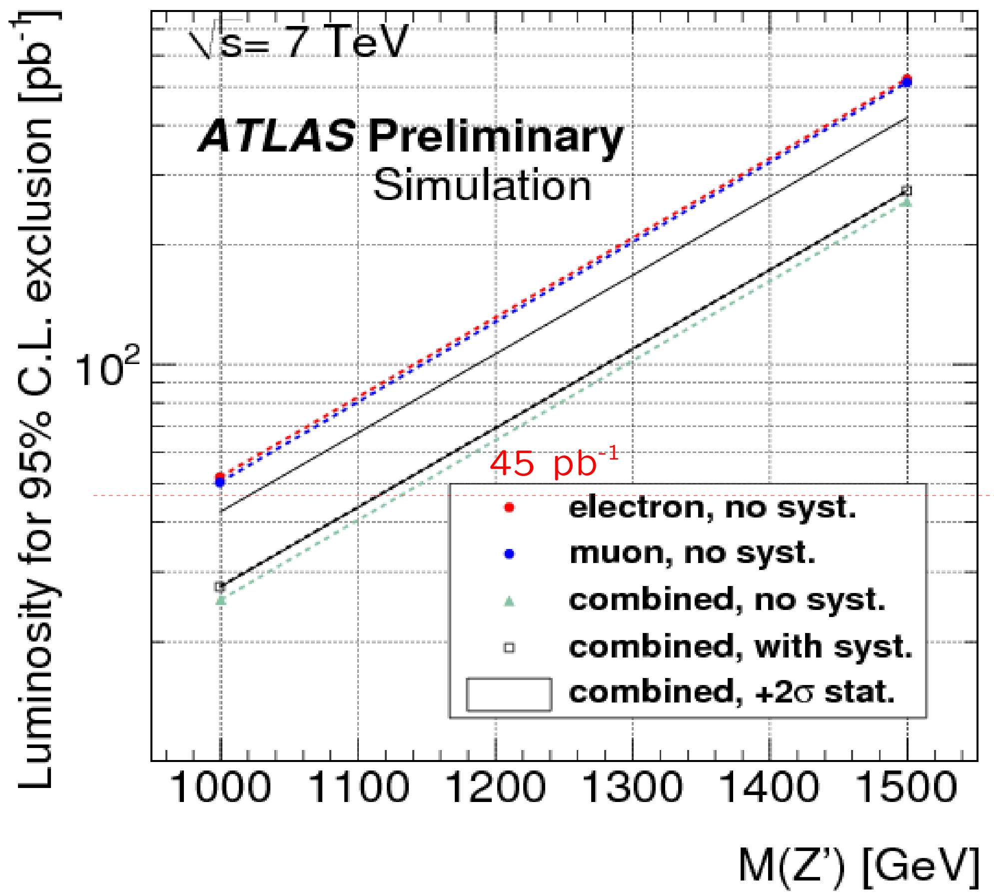
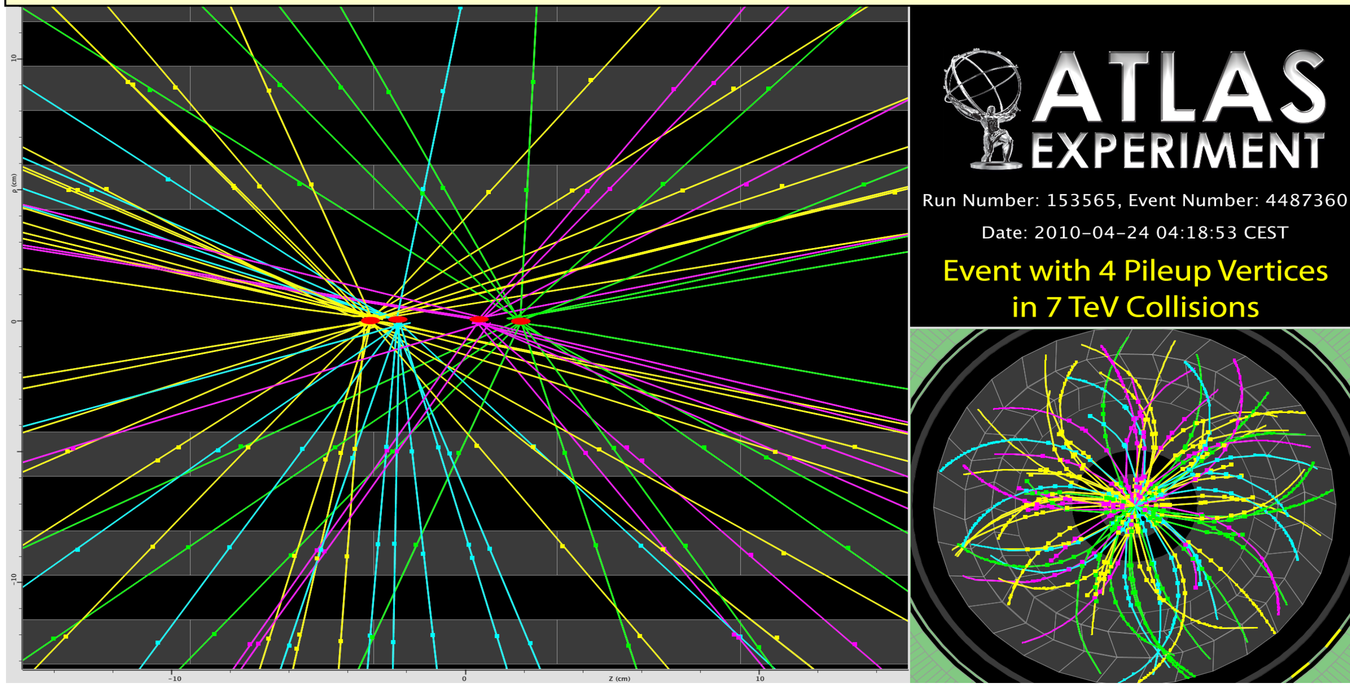


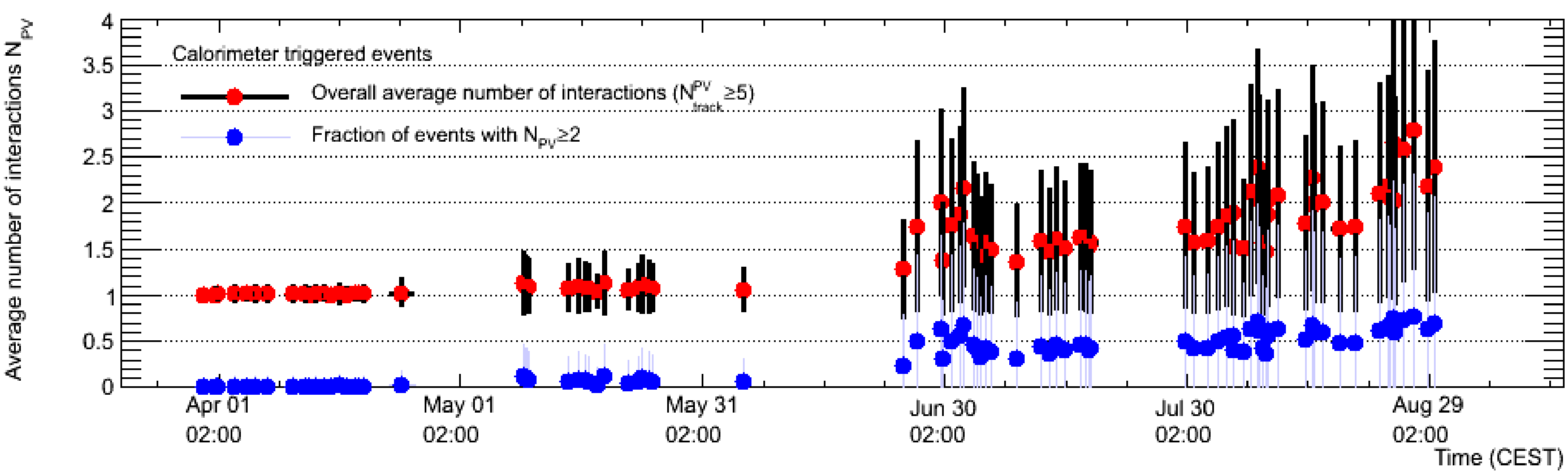
Z' exclusion beyond the TeVatron limit may be possible soon at LHC →50 pb^{-1} per channel (electrons and muons) are needed for a 1 TeV exclusion limit.

My work on Z' search: Pile-up studies

Max peak luminosity: L~2×10^{32} cm^{-2} s^{-1}
→ average number of pp interactions per bunch-crossing: up to 3
→ "pile-up" (~40-60% of the events have > 1pp interaction per crossing)



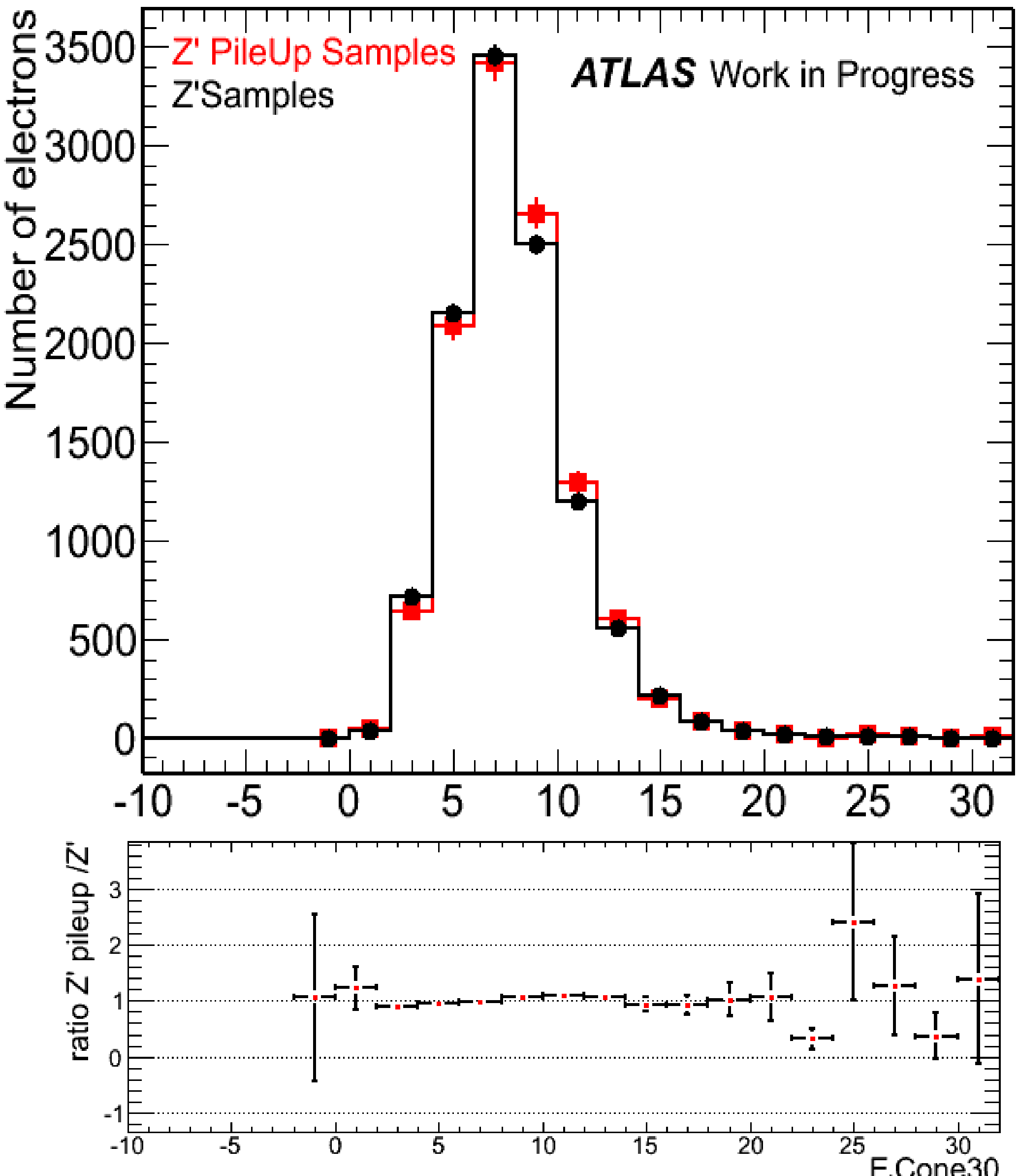
It is not YET possible to have a proper simulation of the in-time pile-up events in MC ⇒ using a weighting technique to remove the differences

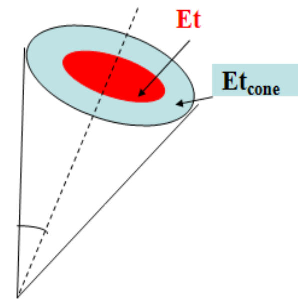


Evaluation of the pile-up effect on high p_T electrons

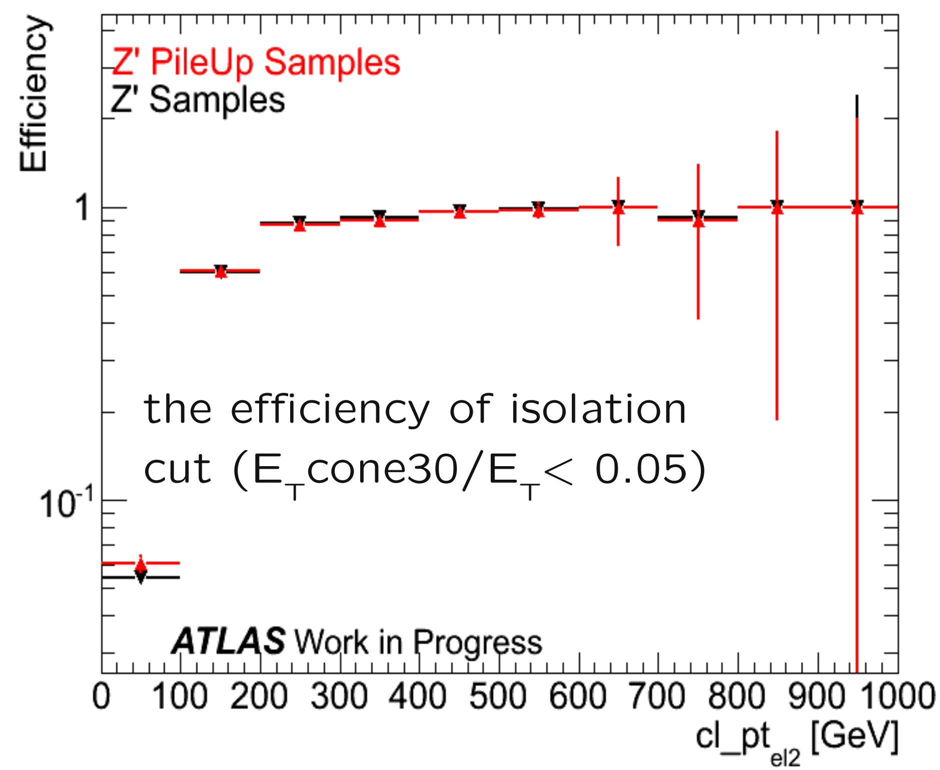
• MC Pile-up events: <N>=2 pile-up events (Poissonian distribution) are weighted according to the number of primary vertices in data

→ pile-up effect on the isolation variable:





Energy in a cone around the shower → More isolated object smaller values, less activity around it



Pile-up effect not significant

Conclusion

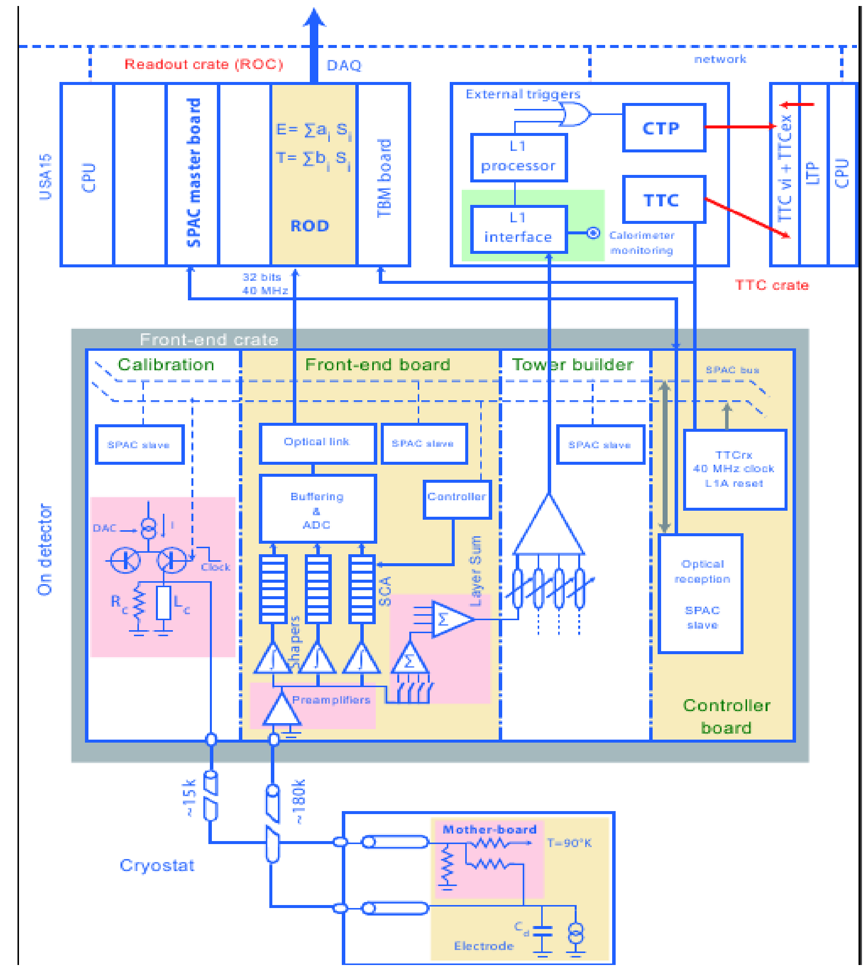
- My thesis “Search for new physics at high mass di-electron spectrum” will use full 2010-2011 dataset
- Currently I participate in search for Z' boson with the data collected by ATLAS.
  - Pile-up study
  - Background study
  - etc...
- I continue to work on the ATLAS LAr calorimeter timing alignment, and currently write a note.

Backup slides

Online Digital Signal Processor

The DSP is part of the LAr Back-End electronics.
It computes the energy, signal timing and a quality factor for each cell.
Compute high level information rather than getting all digital samples out.

The energy is calculated for every LAr cell during data taking. There is an energy threshold for time and quality factor calculation.

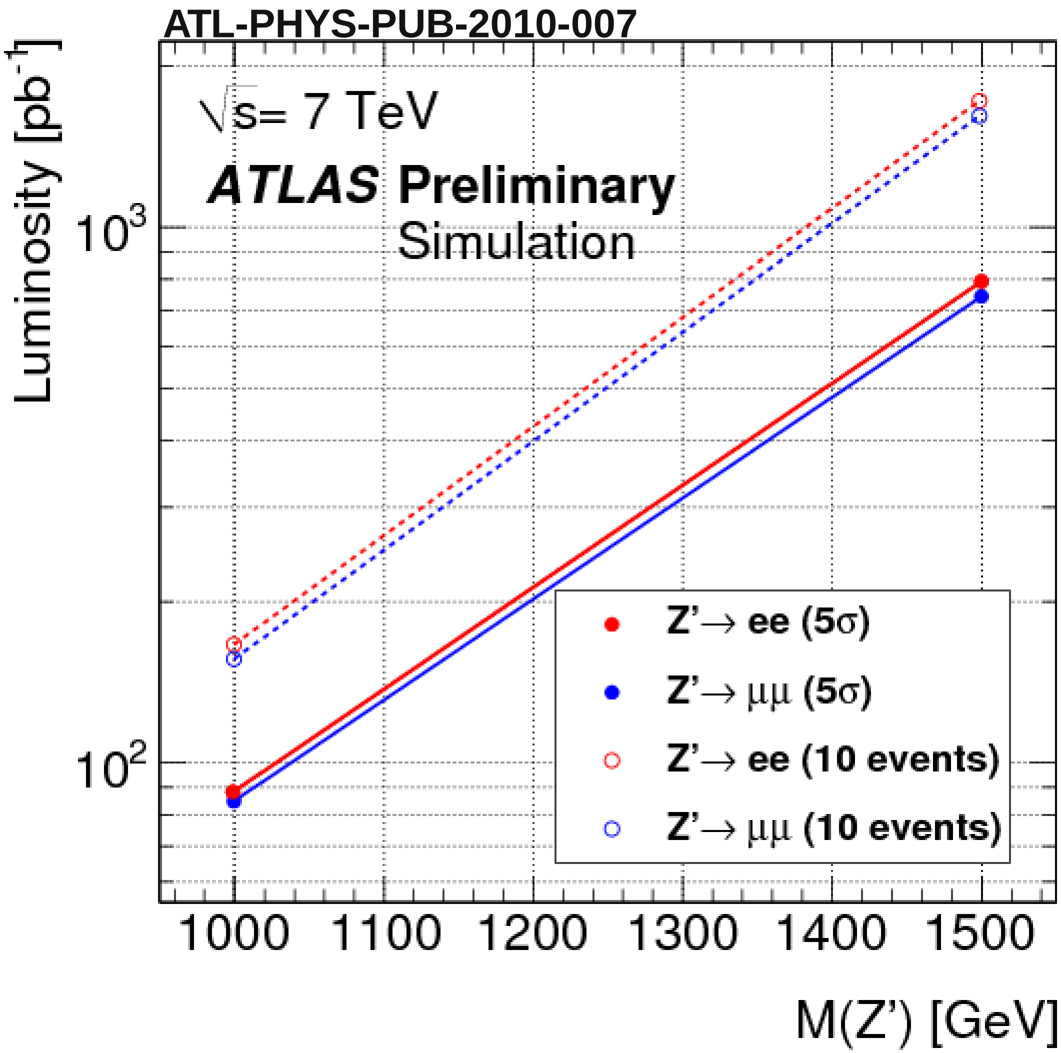


Electron identification and isolation

- To obtain a clean sample of electrons, some identification cuts are used:
  - Discriminating variables:
    - Hadronic calo : leakage
    - EM calo : shower shape in 1st and 2nd samplings
    - Track : track quality (hits)+ TRT (hits, fraction)
    - Cluster/track matching

- ➔ Loose: calorimetric criteria (lateral shower shapes)
- ➔ Medium: lateral and longitudinal shower shapes criteria, track variables
- ➔ Tight: cluster-track matching, track variables

Discovery potential



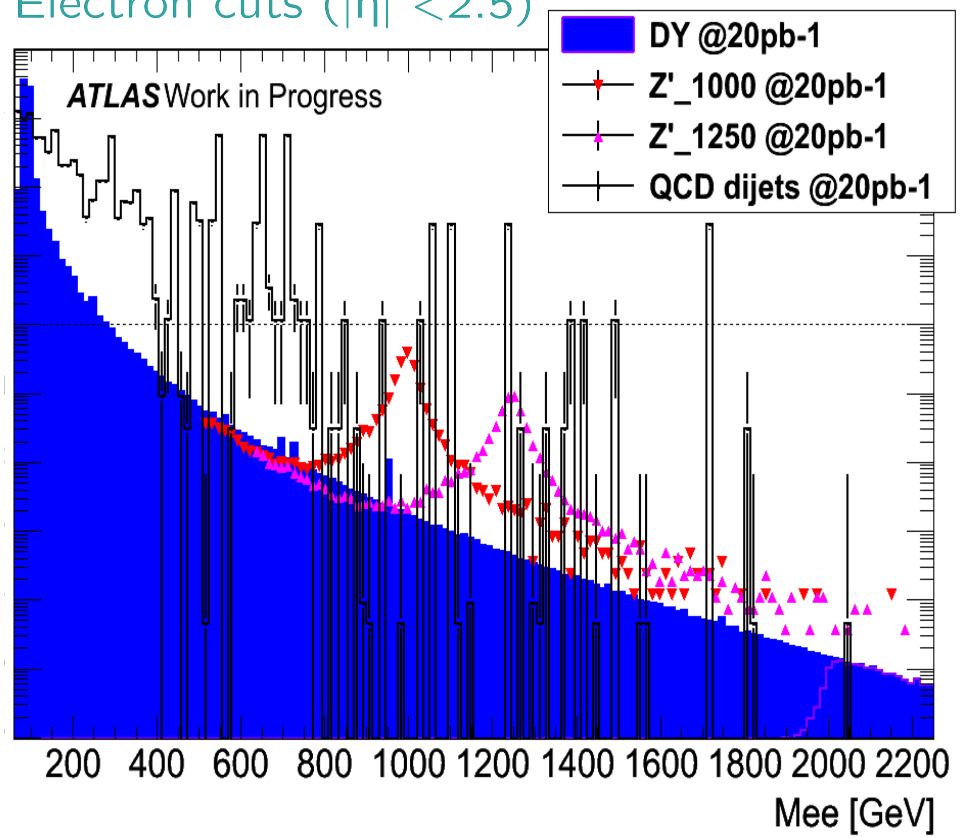
Amount of integrated luminosity that would be required to observe a signal with
a statistical significance of 5σ
(function mass of the Z' boson)

Even for integrated luminosities of O(100 pb^{-1}), a Z' boson with a mass slightly above the current limit (1 TeV) could be found with a statistical significance above 5σ

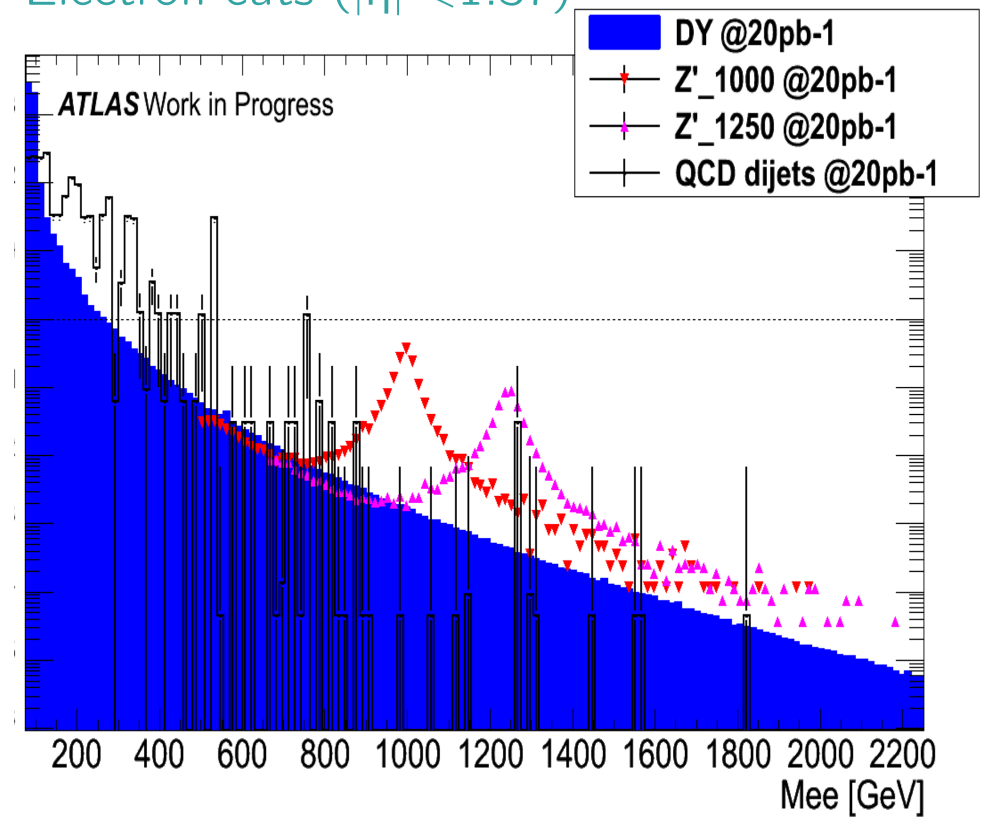
MC study for the background estimation

I looked at the invariant mass of the electron passing loose electron ID for signal and QCD background.

Electron cuts ($|\eta| < 2.5$)



Electron cuts ($|\eta| < 1.37$)



10 times more background in the endcaps → requires different analysis strategy

For our study main source of background is the QCD processes at high pt but not enough MC statistic is available → To estimate the QCD background a data-driven method will be needed