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Performance Studies of the sFCal a Proposed Replacement for the ATLAS Forward Calorimeter

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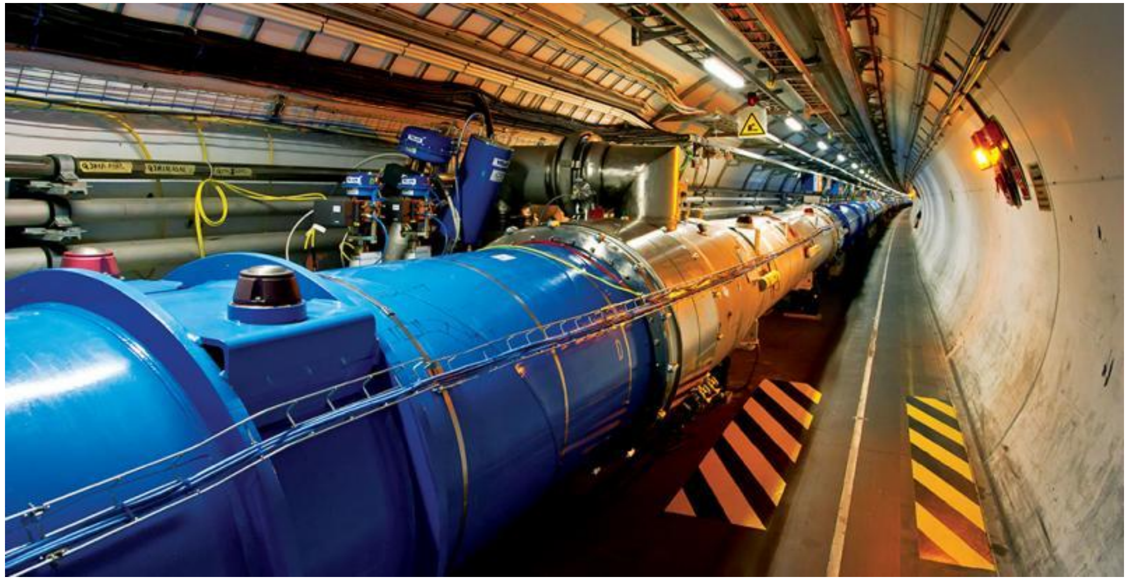
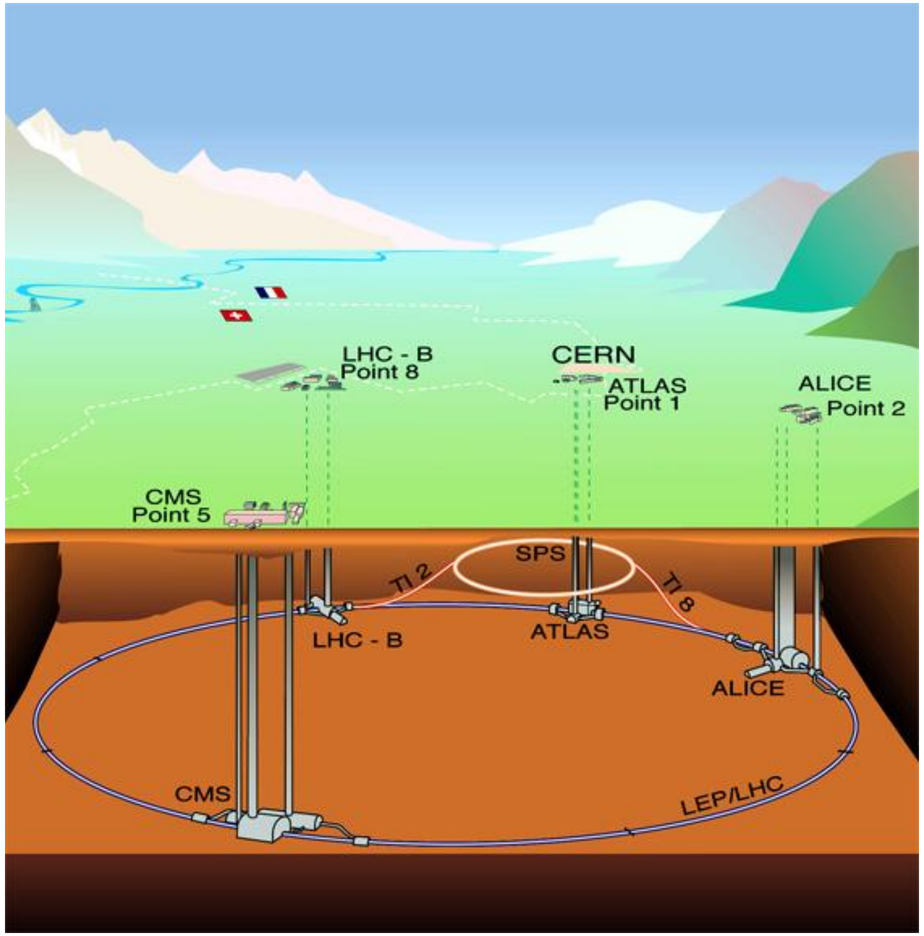
Introduction

- The aim of this study is to give a performance comparison between the actual ATLAS Forward Calorimeter and the ATLAS super Forward Calorimeter (sFCal) as a proposed replacement for the forward calorimeter at High Luminosity LHC.
- A standalone Geant4 simulation of FCal and sFCal was performed to study the impact of readout granularity on position and energy resolution.

The Large Hadrons Collider and ATLAS Experiment

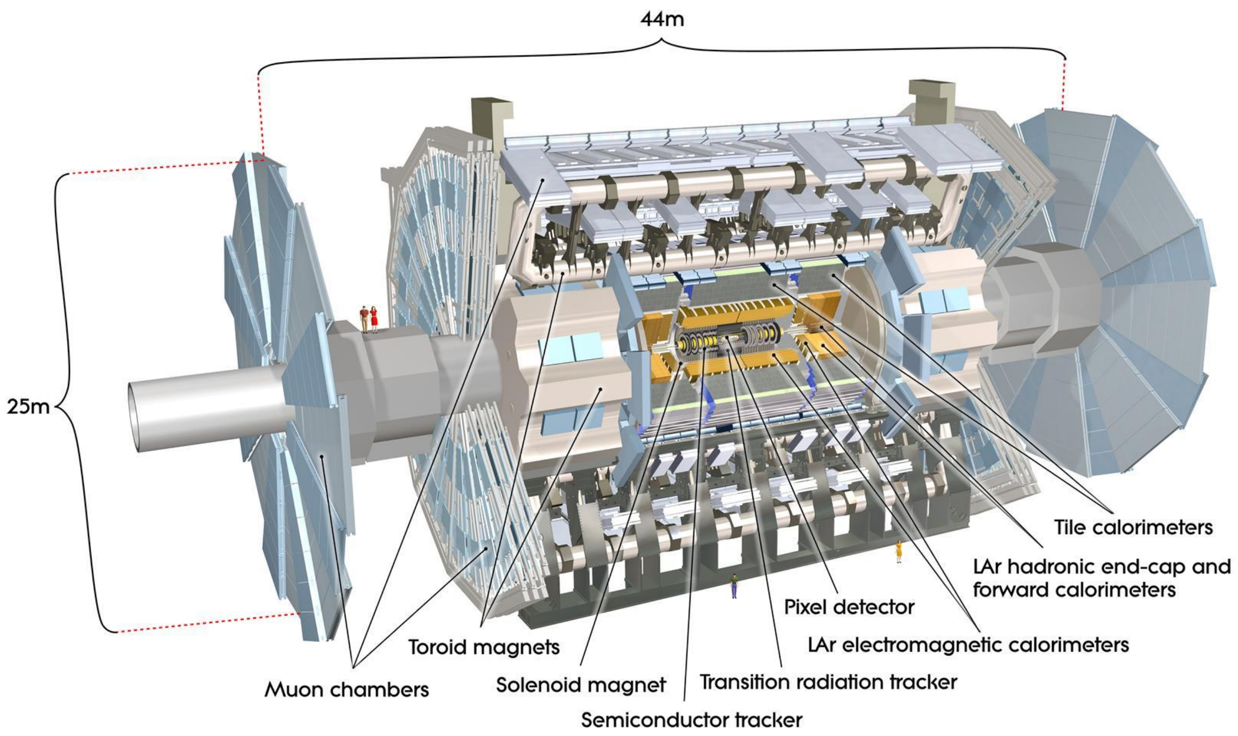
- The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. It consists of a 27 Km ring of superconducting magnets .
- Desingned to collid beams of 7 TeV protons with instantaneous luminosities from $6.10^{33} cm^{-2} s^{-1}$ to $10^{34} cm^{-2} s^{-1}$.
- Physics goals :
  - Discovery of the Standard Model Higgs Boson (Summer 2012).
  - Search for physics beyond the Standard Model



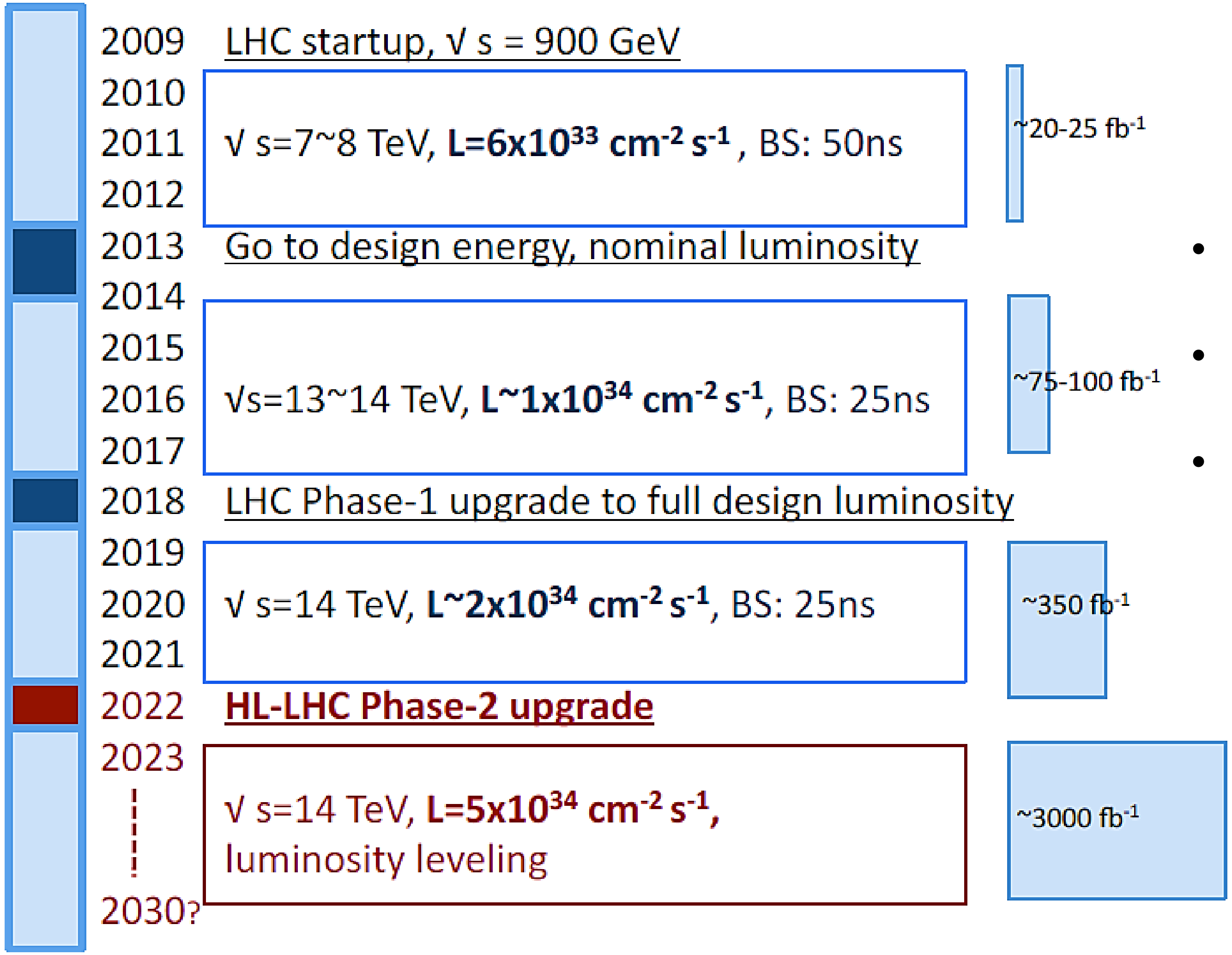


ATLAS Experiment

- ATLAS Experiment is one of the detectors built around one of the four collision points of the LHC. It consists of four major components :
  - **Inner detectors** : Measures the momentum of each charged particle.
  - **Liquid agron and tile calorimeters** : Measures energies carried by neutral and charged particles.
  - **Muon spectrometers** : Identifies and measures the momenta of muons.
  - **Magnet System :** Bends the trajectories of each charged particle to allow the measurement of its momentum



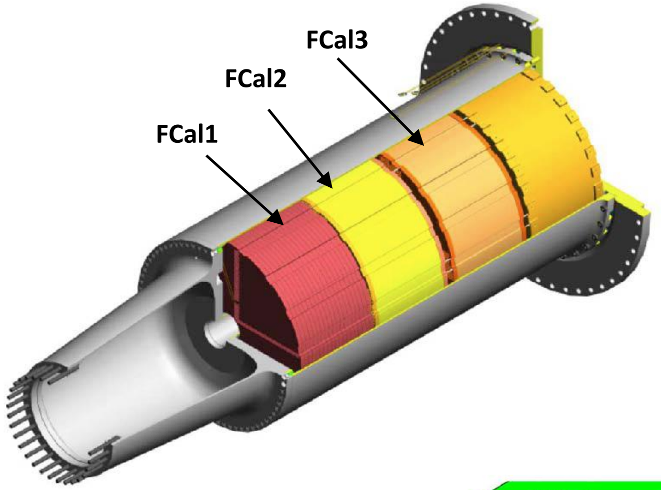
Upgrade Plan for The Large Hadrons Collider (HL-LHC)

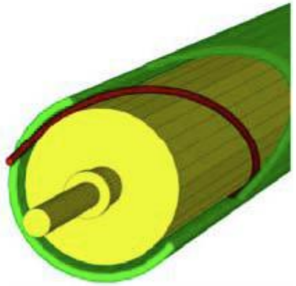


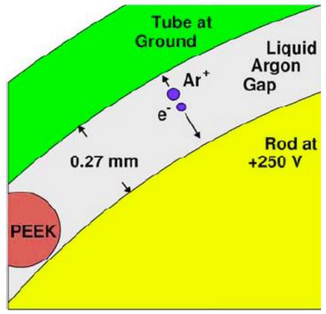
- LHC plans a luminosity upgrade for sometime after 2020.
- Plan is for instantaneous luminosity of $5.10^{34} cm^{-2} s^{-1}$.
- **ATLAS was not designed to run at this luminosity and some components may not survive the integrated dose!!!.**

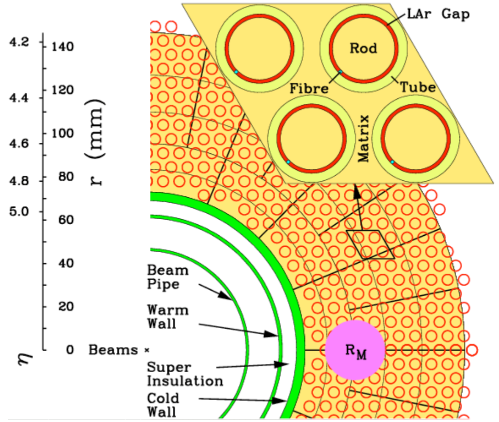
ATLAS Forward Calorimeter .

- The liquid argon Forward Calorimeter (FCal) covers the pseudo-rapidity of about 3.1 to 4.9, its consist of three LAr calorimeter modules named FCal1, FCal2 and FCal3. The particles produced at the interaction point travel 4.7 m before hitting the front of the FCal.
- The first module FCal1 is made of a copper absorber matrix in which a hexagonal range of copper tubes (anodes) and copper rods (cathodes) with 270 μm of liquid-argon gaps between is maintained by PEEK fiber.
- FCal2 and FCal3 modules are a hadronic Lar calorimeters of tungsten tubes because **tungsten is a very high density material where the particles have a short free path**. The gap between the anode and the cathode forms the gap in which is liquid argon of size 380 μm and 500 μm respectively in both modules.
- High voltage supplied to electrode via 1MΩ to 2MΩ resistors on summing boards.



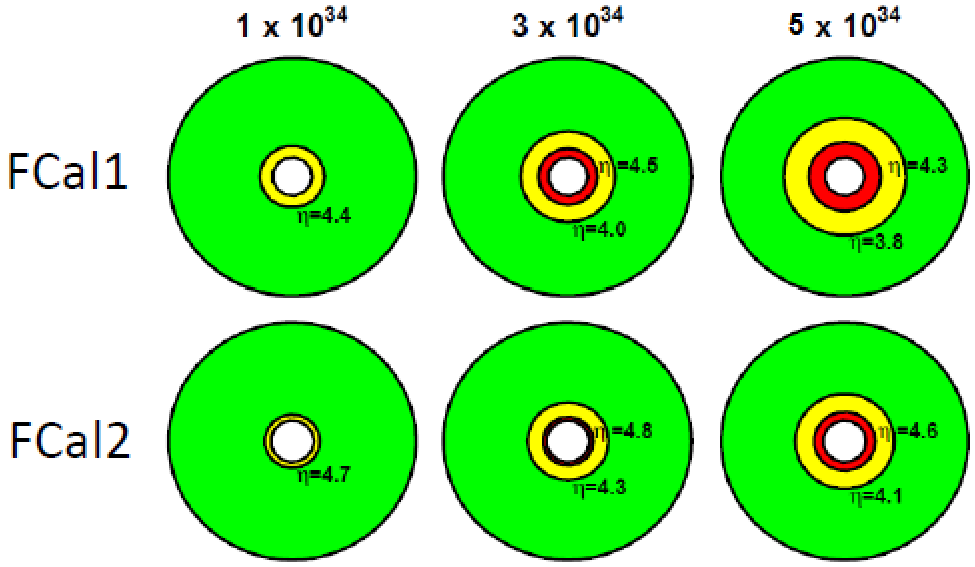






ATLAS FCal at HL-LHC .

Qualitative illustration of the expected degradation of FCal1 and FCal2 in High η region with luminosity increasing from LHC to HL-LHC

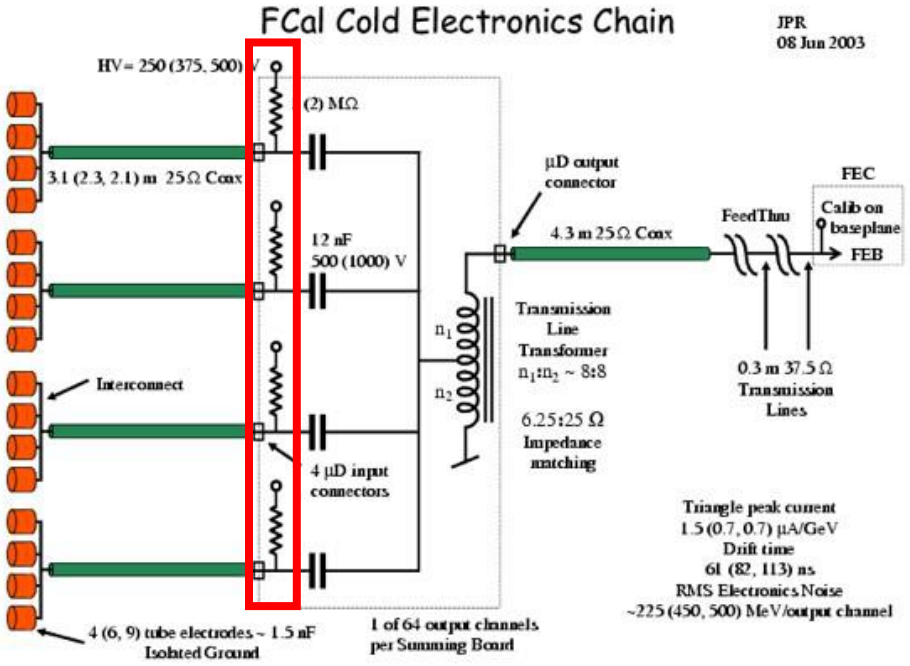


- The ATLAS forward calorimeter is located in the environment near the LHC beam-line where the particle density and the radiation dose are highest.
- The positive argon ions build up in the liquid argon and deform the electric field, the electrons begin to accumulate near the anode while the electric field falls almost to zero.
- In this region the positive argon ions and electrons recombine, as a result of that the signal will break down.
- These resistors are too large to limit current at HL-LHC and then a significant voltage drop across resistors inside cryostat. The heat generated in the calorimeter absorbers due to energy losses will grow and could boil the liquid argon.

Upgrade Plan for the FCal ATLAS at HL-LHC .

- Two solutions for reduction of the degradation are under study :
  - the first option is a complete replacement of the actual FCal system, the new FCal called supper-FCal (sFCal) would have similar design as the existing FCal, with a smaller liquid argon ionization gaps 0.1mm for FCal1, and lower High voltage protection resistors values .
  - The second proposed solution is the installation of a small calorimeter named Mini-FCal .

"This task focus in to simulation studies of the FCal (sFCal) in order to evaluate the impact of a finer readout granularity on the pile-up separation and the jet resolution in the high eta region"

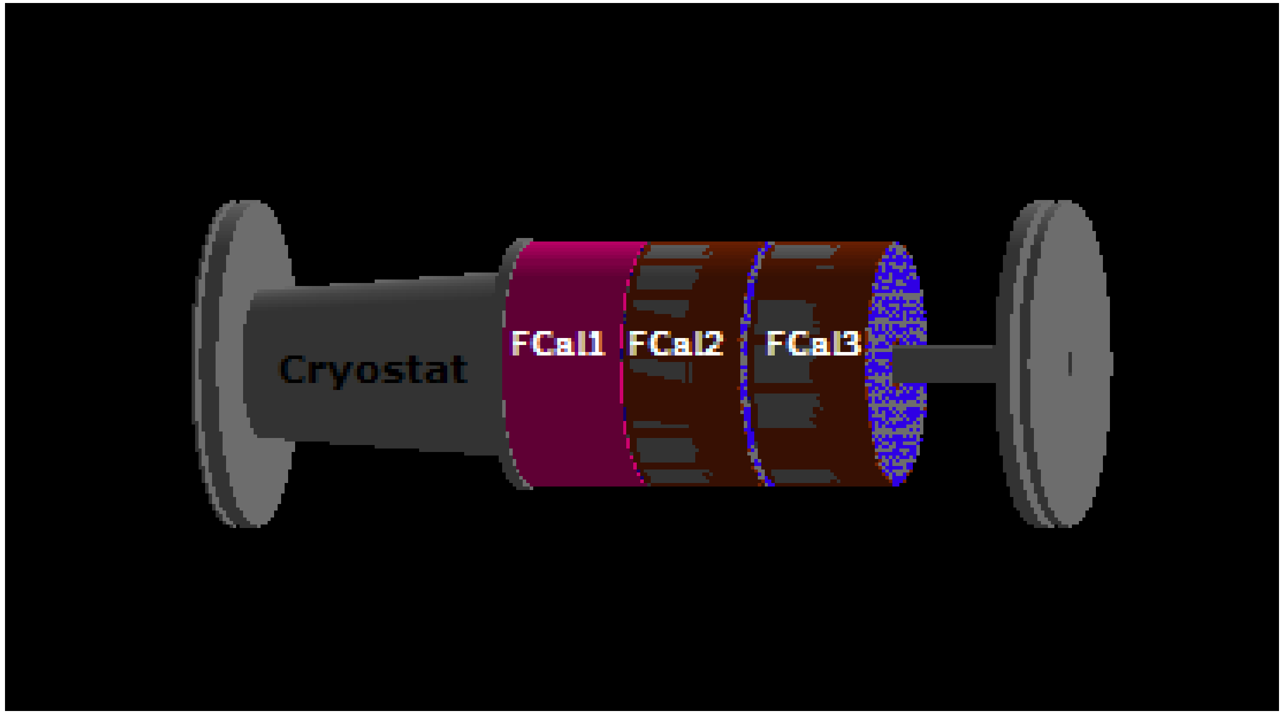


HV delivered via 1MΩ or 2MΩ resistors need to be reduced by Factor of 10 for HL-LHC operation

sFCal/FCal Standalone simulation

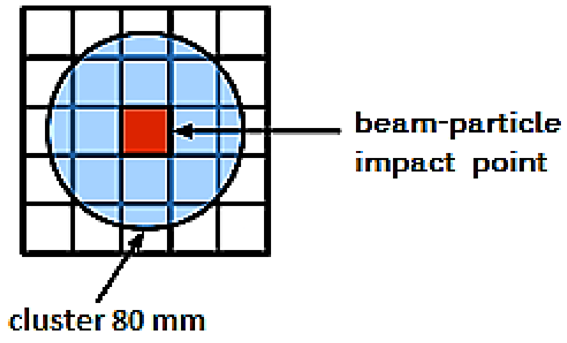
- This study uses a MC samples that have been taken from Monte Carlo Fcal/sFCal standalone simulation **fcalsim/sfcalsim** under Geant4.
- The analysis is performed using a collection of Ntuples provided by the FCal/sFCal standalone simulation saved as fcal.root/sfcal.root which illustrate the final state of the most important kinematics variables.

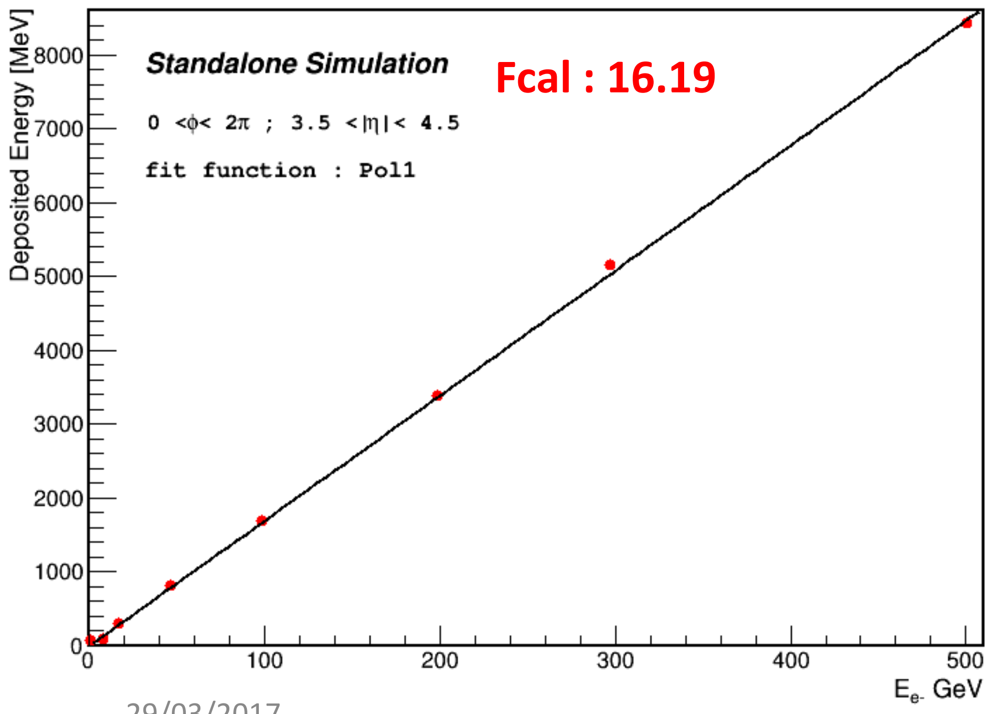
Particle	MC Sampels	Number of events
e^-	fcal_e_5GeV.root	20000
	fcal_e_10GeV.root	20000
	fcal_e_20GeV.root	20000
	fcal_e_50GeV.root	20000
	fcal_e_100GeV.root	10000
	fcal_e_200GeV.root	10000
	fcal_e_300GeV.root	10000
	fcal_e_500GeV.root	10000
	sfcal_e_5GeV.root	20000
	sfcal_e_10GeV.root	20000
	sfcal_e_20GeV.root	20000
	sfcal_e_50GeV.root	20000
	sfcal_e_100GeV.root	10000
	sfcal_e_200GeV.root	10000
	sfcal_e_300GeV.root	10000
	sfcal_e_500GeV.root	10000

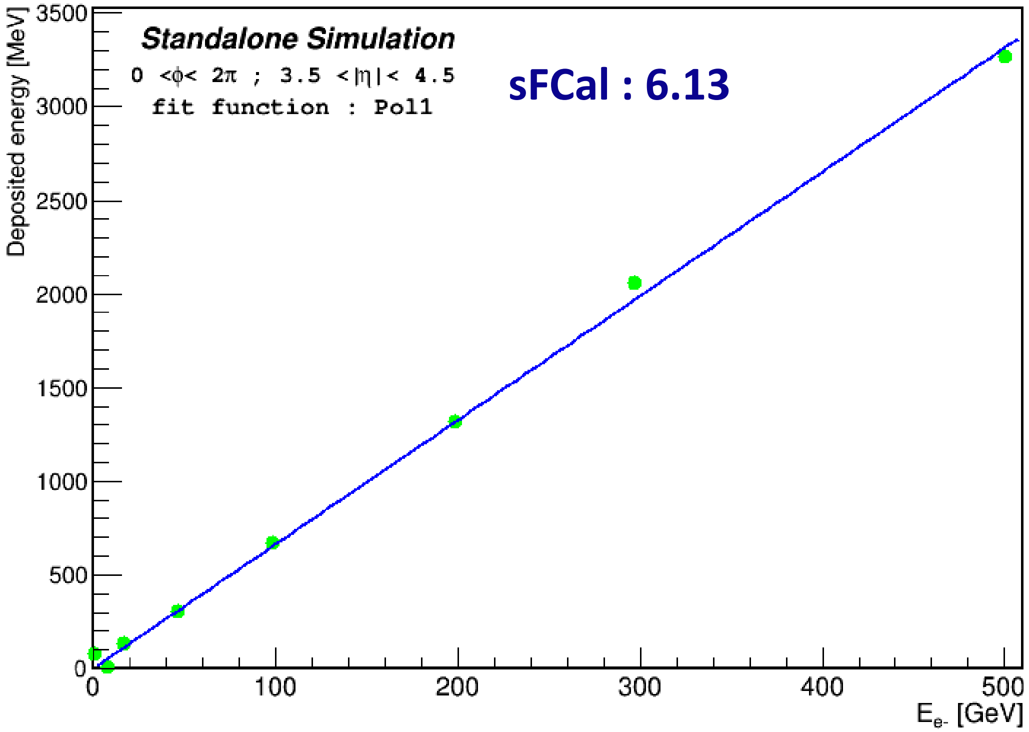


FCal/sFCal response to electrons : Energy reconstruction.

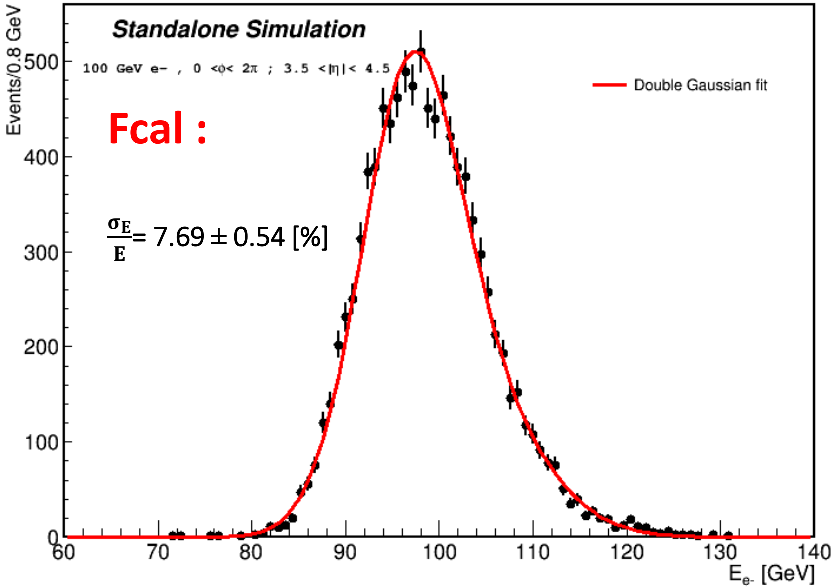
- Reconstructed energy was obtained by summing the energies of all channels within 80 mm for electrons distance of the beam-particle impact point.
- Response = Average signal per unit of deposited energy.
- A linear calorimeter has a constant response.
- Electromagnetic calorimeters are in general linear. If not linear.

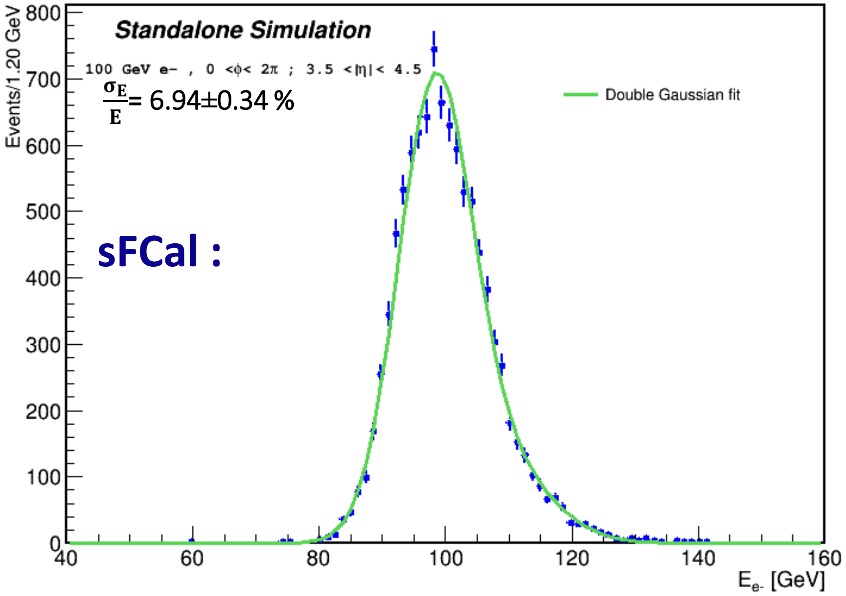




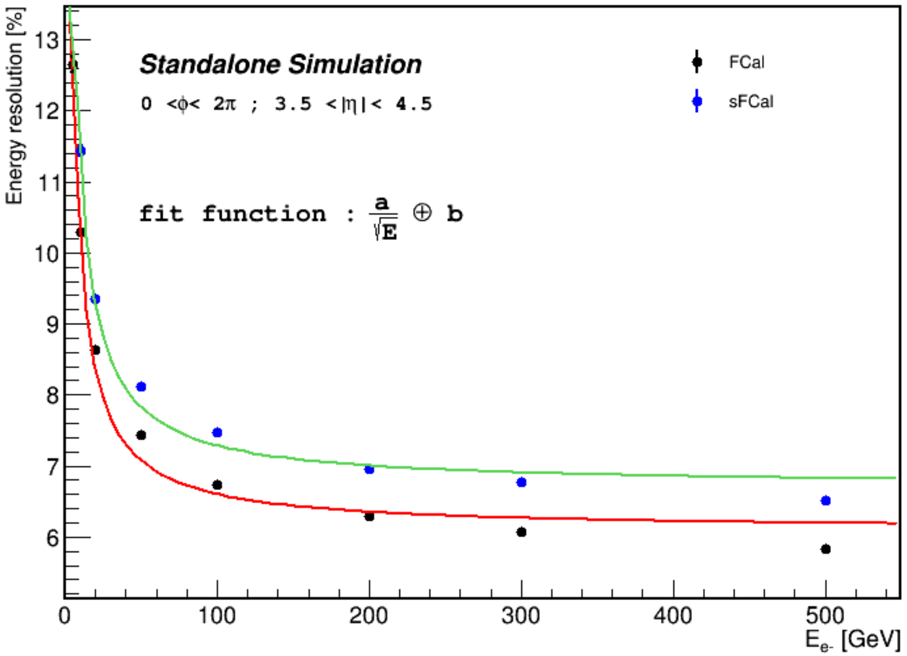


FCal/sFCal response to electrons : Energy resolution





- The energy resolution for a given calorimeter system should vary with particle energy and can be written in a more general way as: $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$



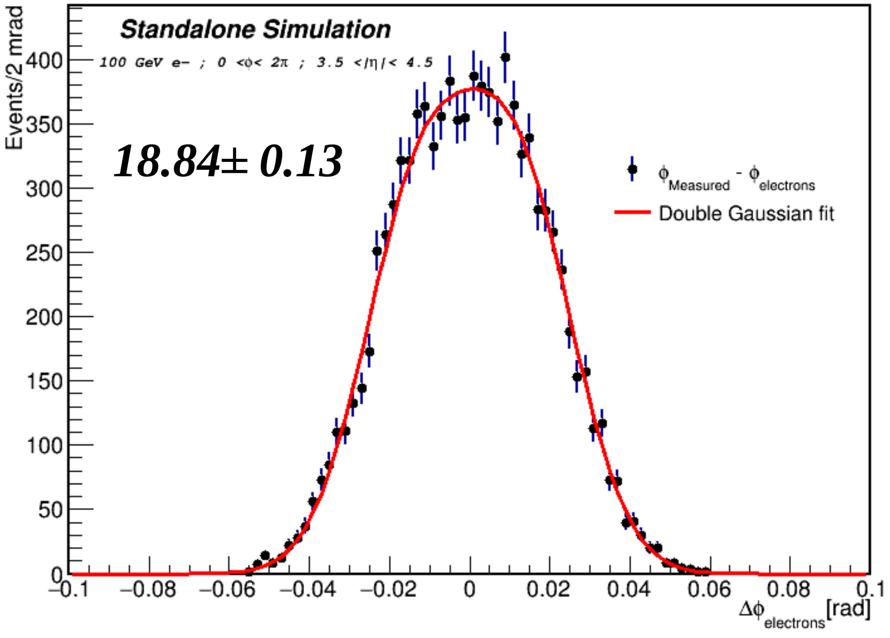
Detector	Stochastic term (% $\sqrt{GeV}$)	Canstant term (%)
FCal	25.5±0.68	6.09±0.14
sFCal	28.6±0.53	6.71±0.11

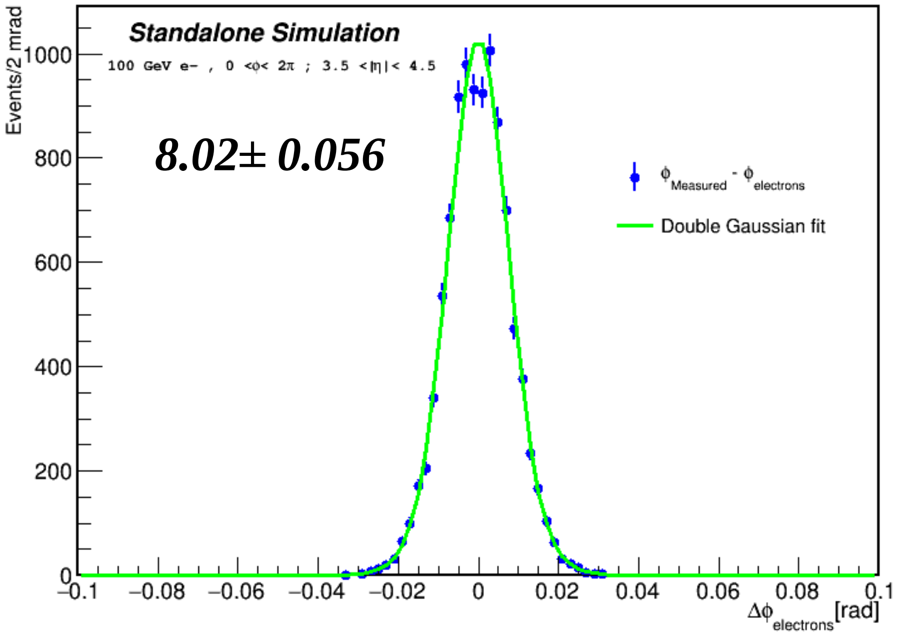
- The Energy Resolution for electrons is slightly worst in sFCal than FCal, since the LAr gap size is small in sFCal than Fcal

FCal Pointing φ resolution

- A study of the position resolution along the coordinate of the first module of FCal/sFCal was performed. The measured coordinate is defined using the center of gravity technique in the calorimeter's Cell. This technique needs the knowledge of the energy and the angle of incidence of the electron in a cell, and the measured is given as follows :

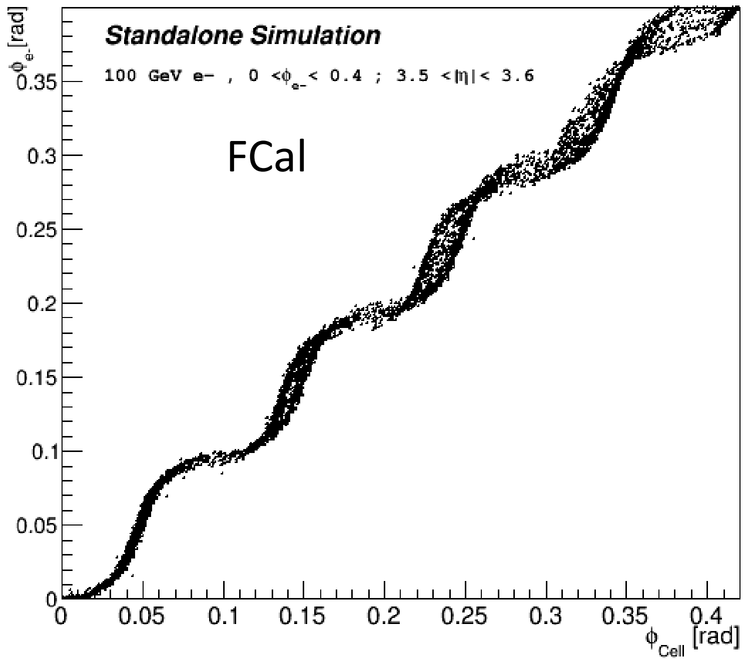
$$\phi_{Measured} = \frac{\sum_{i=1}^{N} E_i.\phi_i}{\sum_{i=1}^{N} E_i},$$

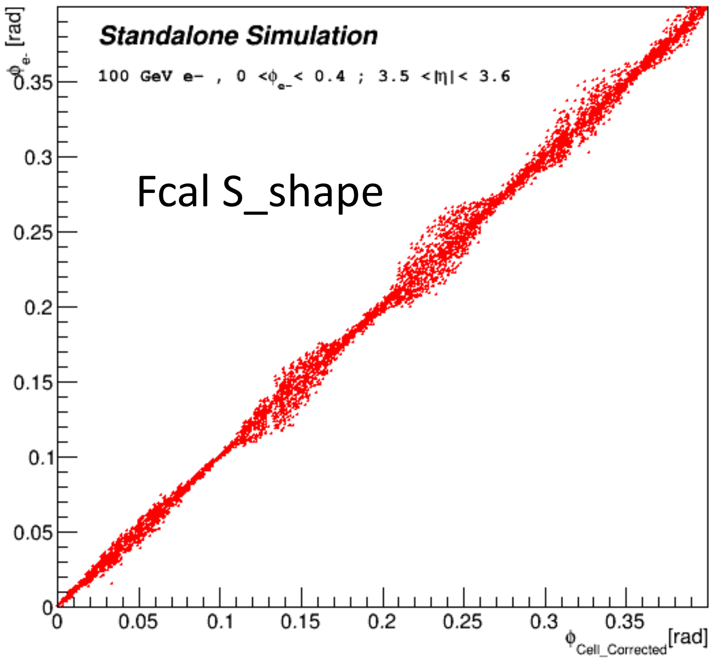


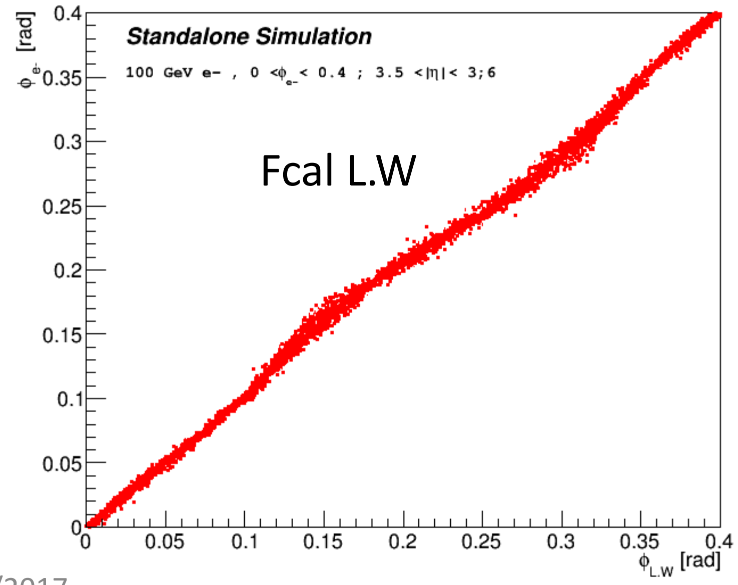


FCal Pointing φ resolution

φ turth vs φ measured





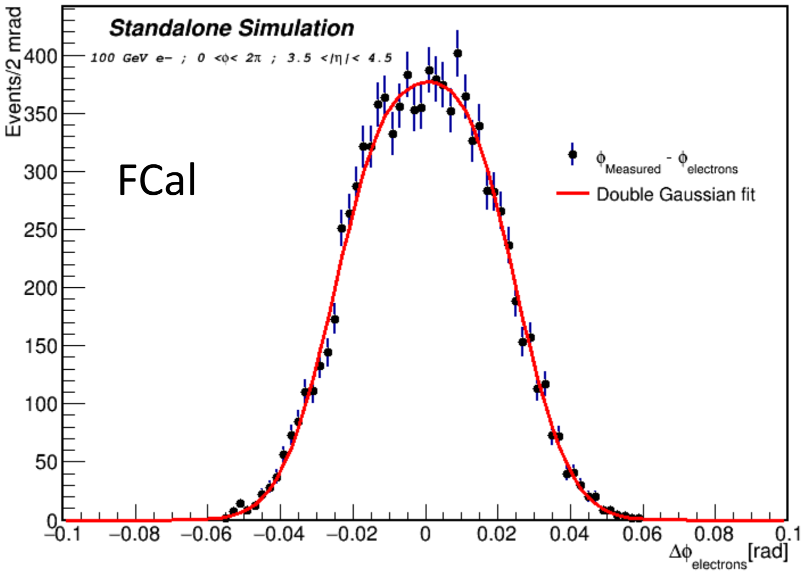


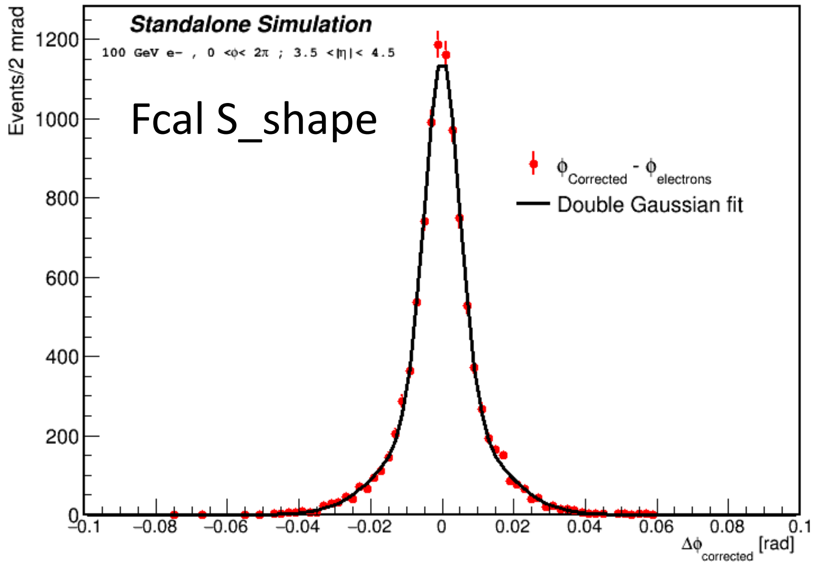
- Due to the finite size of the cells in the FCal the energy weighted barycenter of a cluster is shifted to the center of a cell in direction, conducting to well known ”S” shape in the measurement of the electrons position.
- Linear interpolation .
- L.W is a way to correct S_shape position in the calorimeter wher:

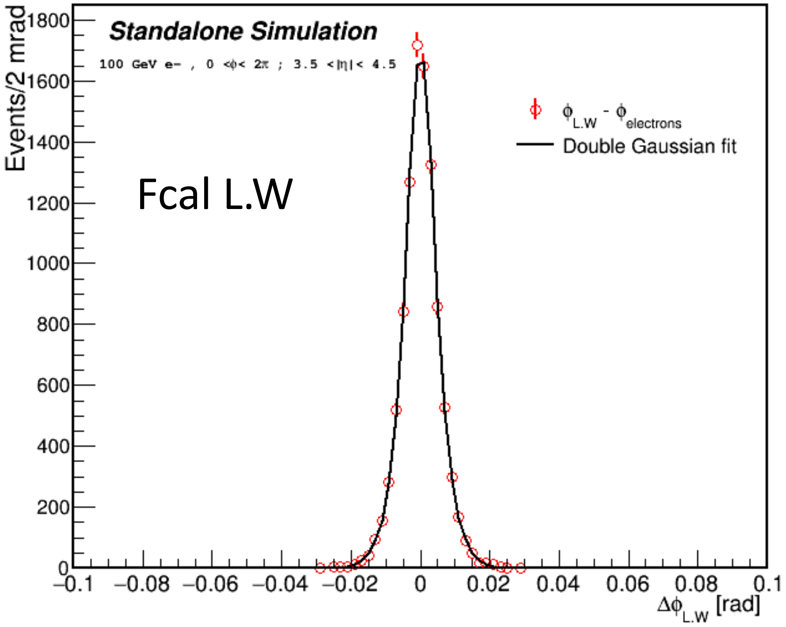
$$\varphi_C = \frac{\sum \varphi_{Cell} w_{Cell}}{\sum w_{Cell}}$$

Pointing φ resolution

- *100 GeV e-*



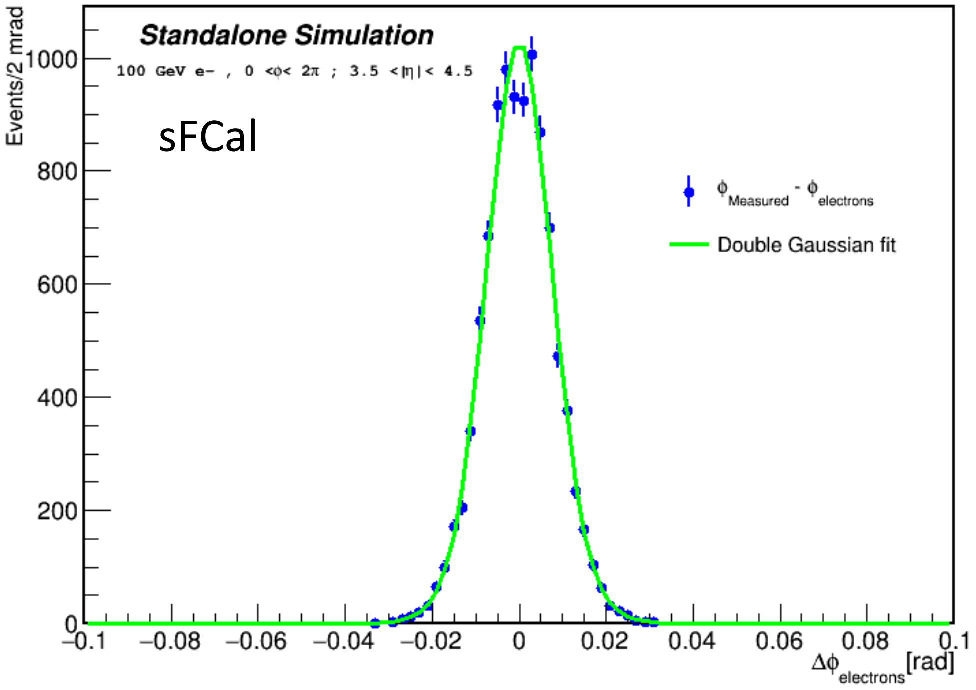


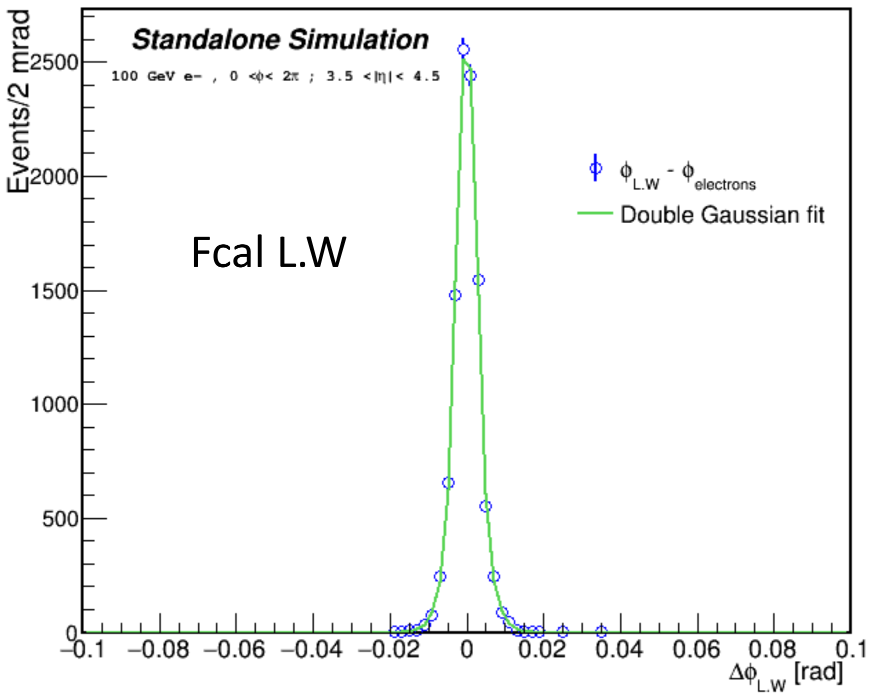


	FCal	Fcal S_shape	Fcal L.W
σ_φ *[mrad]*	*18.84± 0.13*	*10.01± 0.075*	*5.38± 0.038*

sFCal Pointing φ resolution

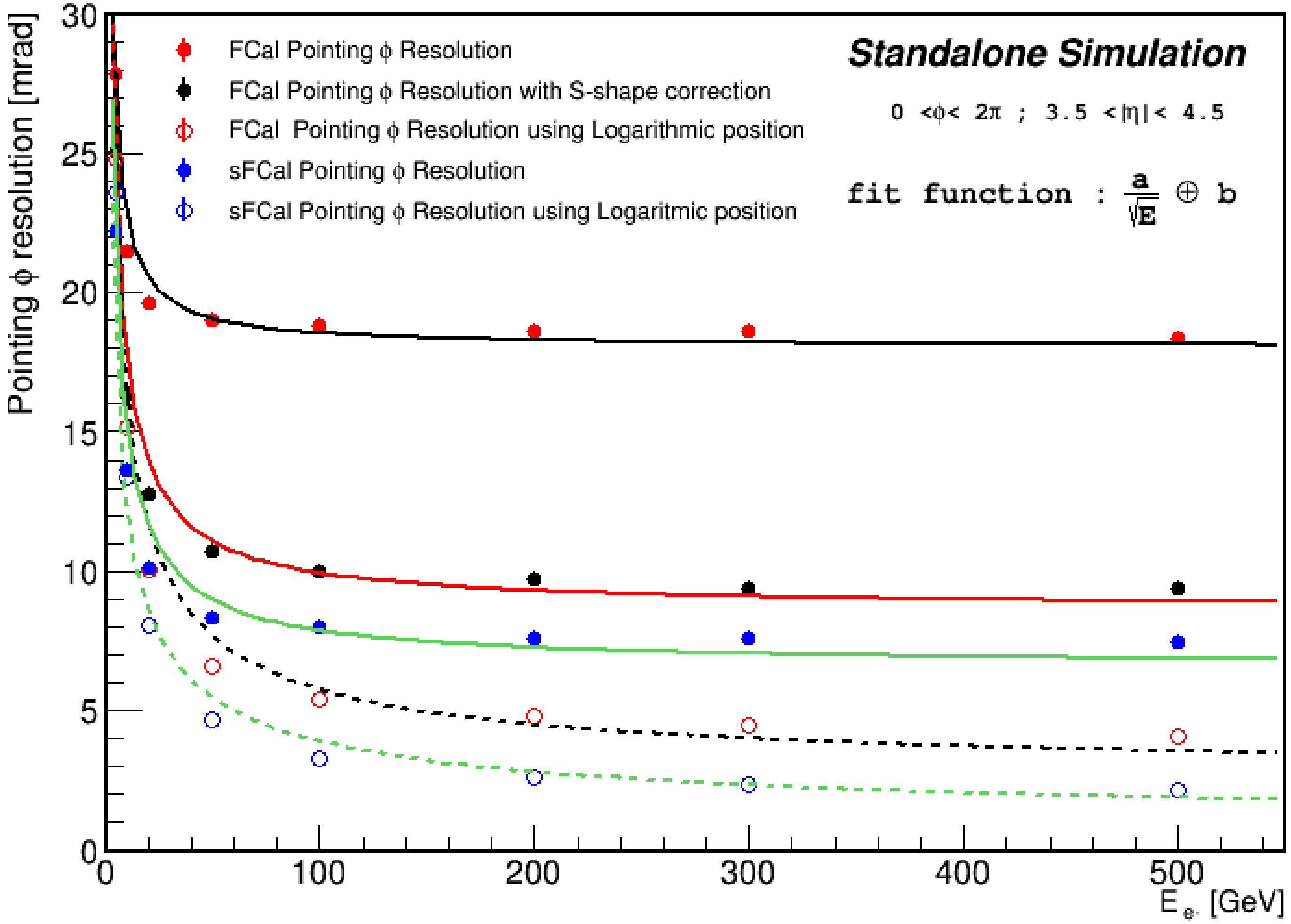
- *100 GeV e-*





	FCal	Fcal L.W
σ_{φ} [mrad]	8.02± 0.056	3.30± 0.023

Fcal/sFCal Pointing φ resolution Vs Energy



- φ *between 0 to* 2π
- η *between 3.5 to 4.5*

	sFCal	sFCal L.W
***a* [mrad.$\sqrt{GeV}$]**	***43.21±2.5***	***38±0.10***
***b* [mrad]**	***6.60±0.6***	***0.75±0.032***

	FCal	FCal S_shape	FCal L.W
***a* [mrad.$\sqrt{GeV}$]**	***44.4±2.45***	***49.1±2.1***	***50.9±2.23***
***b* [mrad]**	***18±0.38***	***8.65±0.51***	***2.73±0.96***

- The pointing resolution in $\boldsymbol{\varphi}$ for electrons is clearly better in SFCal than FCal.

Conclusion :

- Upgrade goal : maintain the existing FCal performance at HL-LHC.
- Replace FCal with improved detector sFCal – smaller gaps ,new summing boards (lower resistances).
- The pointing resolution in ϕ for electrons is clearly better in SFCal than FCal.
- The Energy Resolution for electrons is slightly worse in sFCal than FCal, since the LAr gap size is small in sFCal than FCal.