First ideas and developments for a LAr EM calorimeter at FCC-ee

Workshop FCC-France

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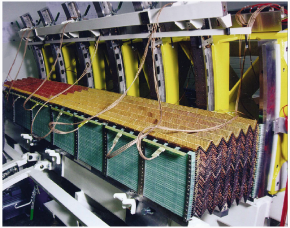
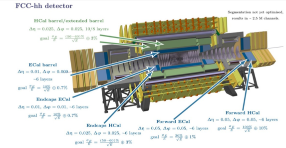
LAr Calorimeters

- LAr Calorimeters very successful at particle physics experiments: HERA, D0, NA31, ATLAS
- Sampling calorimeters, e.g Lead/LAr for ATLAS
- Excellent linearity, stability
- EM energy resolution $\frac{10\%}{\sqrt{E}} \oplus \frac{0.25}{E} \oplus 0.3\%$
- e/γ identification through 3D shower shapes



LAr Calo for FCC-hh

- First LAr study for future colliders, thanks to intrinsic radiation hardness
- $\sim 10\times$ ATLAS granularity, for better use of PFlow techniques and pileup mitigation
- Reach same performance as ATLAS at much higher pileup levels



LAr Calo for *ee* machine ?

- A priori, similar concept can work very well at an e^+e^- collider too
- With *ee* conditions allowing for significant optimisations
  - On noise for low energy measurements
  - On segmentation for PID/PFlow use

Reaching 10× ATLAS granularity

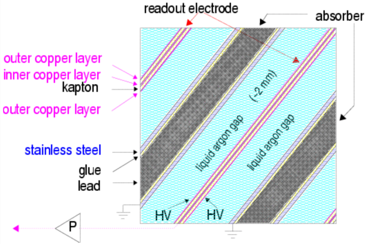
- 200000 cells → few million cells
- Readout in ATLAS uses simple copper/kapton electrodes
- Issue: traces to route signals to front or back of electrode take space !
- For 10× more granular: go to multilayer PCB to route signals in a deep layer

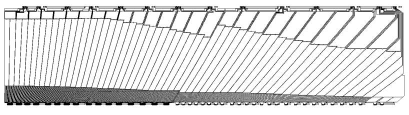
Basic design

- Cannot use accordion shape for PCBs

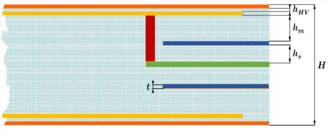
⇒ Straight planes inclined around the barrel

- Simulation in a specific IDEA-LAr setup





Design of ATLAS electrodes



Side view

Physics performance

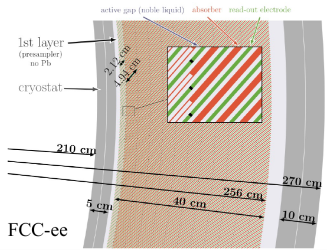
- Simulation and integration into FCC software (CERN, Prague)
- Electroweak physics performance vs detector geometry, choice of absorber (Edinburgh)
- Tau physics studies and π^0/γ identification (Copenhagen)

Necessary R&D

Some items can be blockers to be able to build such a calorimeter

- Thin cryostats: R&D ongoing at CERN
- High density feedthrough: R&D ongoing at CERN
- Cold electronics
- PCB electrodes (CERN and IJCLab)

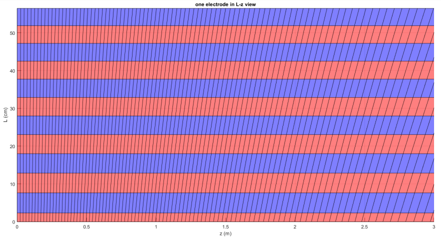
- Enveloppe from IDEA tracker
- Aim for 20–22 X^0
- Initial proposal: 1536 electrodes around ϕ
  - 2 mm Pb absorber, 1.2 mm PCB, 2 $\times$ 1.24 mm LAr. Sampling fraction $\sim$ 20%
  - Angle 50^o
- Segmentation in θ: $\Delta\theta \sim 0.56^o$
- 12 segments in depth, first one without any Pb (presampler)
  - Length adjusted for constant depth along radial direction
- All parameters still subject to optimisation



For FCC-ee: 12 cells (initial proposal)

$\Delta r_m\,(cm)$	$r_m\,(cm)$		$L_m\,(cm)$	$\Delta L_m\,(cm)$
	256		56,5	
+3,5				+4,6
	252,5		51,9	
+3,5				+4,7
	249		47,2	
+3,5				+4,7
	245,5		42,5	
+3,5				+4,8
	242		37,8	
+3,5				+4,8
	238,5		32,9	
+3,5				+4,9
	235		28	
+3,5				+5
	231,5		23,1	
+3,5				+5
	228		18	
+3,5				+5,1
	224,5		12,9	
+3,5				+5,2
	221		7,7	
+3,5				+5,3
	217,5		2,3	
+1,5				+2,3
	216		0	

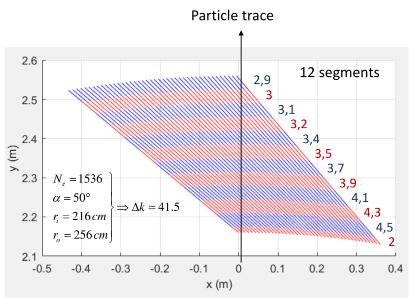
Choice of constant radial depth segments

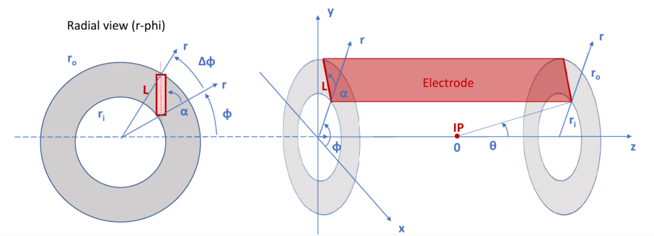


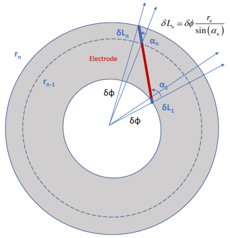
Longitudinal vew (without 'strips' for 2nd segment)

Tilted planes around cylinder: non-trivial geometry !

- Developed Matlab calculations of the geometry
- Allows to study crossings of electrodes by particles at all positions
  - 41.5 electrodes on the path



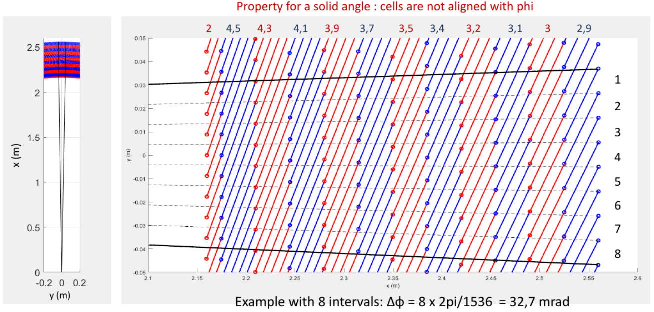




Drawbacks of initial proposal

Segments along the electrode have equal length

- They are not seen under the same angle $\delta\phi$
- Cell boundaries are not aligned
- More material (X^0) in the front cells than in the back ones

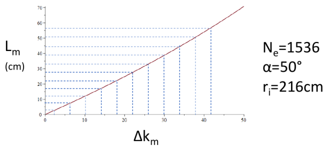


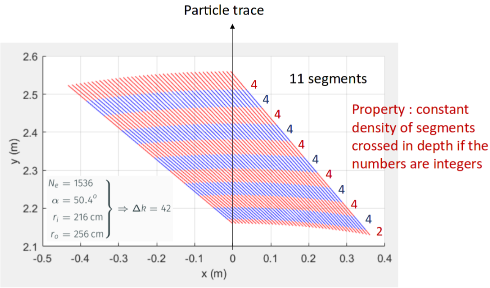
Proposed solution

- Calculated relation between length on electrode and number of electrodes crossed before reaching that point:

$$L_m = \frac{r_i}{\sin(\alpha)\text{cotan}\left(\Delta k_m \frac{2\pi}{N_e}\right) - \cos(\alpha)}$$

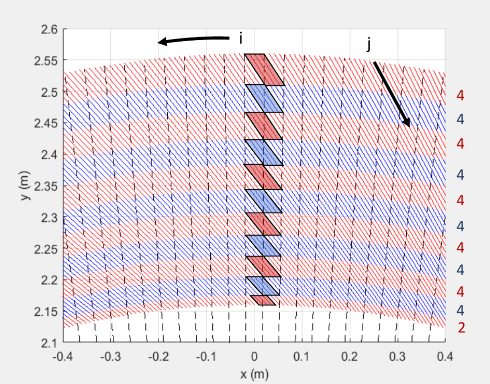
- New proposal: 10+1 segments, exactly 4 electrodes crossings / segment
- Cell boundaries well aligned
- Can have exactly 2 electrodes crossings in presampler if depth increased by 6 mm or angle of electrodes 50.4^o





Δr_m (cm)	r_m (cm)	L_m (cm)	ΔL_m (cm)
	256	56,5	
+4,8			+6,4
	251,2	50,1	
+4,6			+6,1
	246,6	44	
+4,3			+5,9
	242,3	38,1	
+4,1			+5,7
	238,1	32,4	
+3,9			+5,5
	234,2	26,9	
+3,7			+5,3
	230,4	21,6	
+3,6			+5,2
	226,9	16,4	
+3,4			+5
	223,5	11,4	
+3,2			+4,9
	220,2	6,5	
+3,1			+4,7
	217,1	1,8	
+1,1			+1,8
	216	0	

- New proposal allows for nice formation of calorimeter cells by grouping electrodes together in ϕ
- First idea: grouping by 4
  - Largest cell: $L \times H \sim 4.2 \times 4.8\,\text{cm}$
  - Presampler cell: $L \times H \sim 3.5 \times 1.5\,\text{cm}$
  - 4608 cells / slice in θ
- Grouping by 2 can be easily studied in simulation

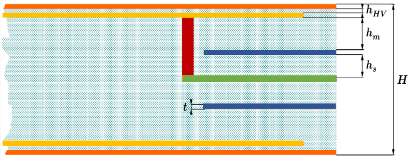


Principle

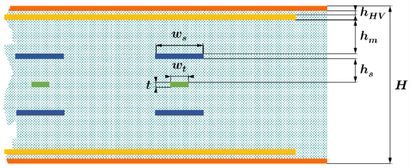
- HV layer capacitively coupled to readout layer
- Signal transferred from both sides to read-out trace through a via
- Shielding traces reduce cross-talk from other segments

Questions to answer

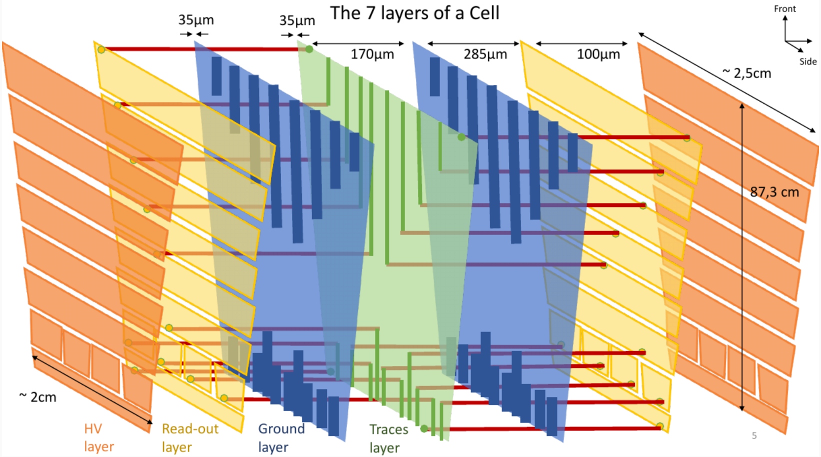
- What is the detector capacitance ?
  - Presumably quite a bit smaller than in ATLAS: $O(10 - 100)$ pF
- What are the properties of the transmission line ?
- What is the level of cross-talk ?
- What is the maximum density of signal traces can we get ?
- Can we readout all cells at the back, or do we have to route the first segments to the front ? (as in ATLAS)



Side view

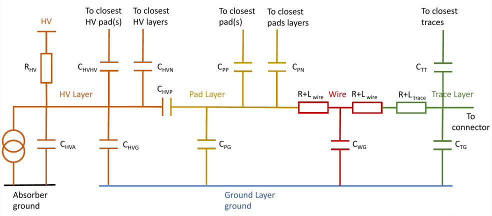


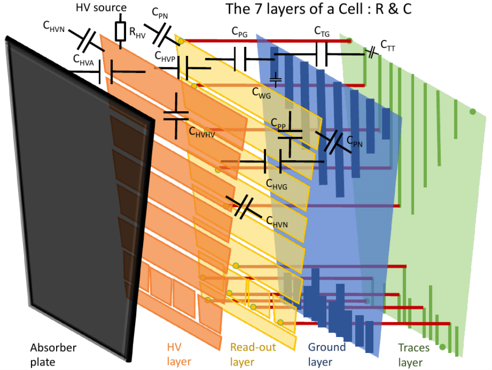
Front view


The 7 layers of a Cell
35µm
35µm
170µm
285µm
100µm
~ 2,5cm
Front
Side
87,3 cm
~ 2cm
HV layer
Read-out layer
Ground layer
Traces layer
5

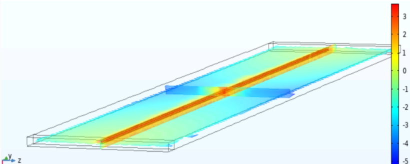
A nightmare of capacitances

- Capa of interest (detector capacitance): H_{VA}
- But all the rest matters
- As well as R+L of all traces





- Analytical models can give a rough idea of some of the parameters for a cell in isolation
- To go to more realistic setups, need finite elements tools
  - COMSOL multiphysics
  - Need to be cross-checked against the analytical models on simple setups first
  - Finding the appropriate meshing for calculation requires time and expertise
- Building simple PCB prototypes will be extremely valuable to validate the simulations



Layer 5 of electrode 1 ($|\eta| \leq 0.01$)

Name	Type	Model	W (mm)	S/H (mm)	L (mm)	ε_r	C (pF)
$C_{HV\text{-}A}$	microstrip	Wheeler	24	2,1	120	1,6+4	80,8
$C_{HV\text{-}N}$	coplanar	Xiang	24	1	120	1,6+4	10,5
$C_{HV\text{-}HV}$	coplanar	Xiang	120	1	24	1,6+4	2,77
$C_{HV\text{-}G}$	?						
$C_{HV\text{-}P}$	parallel	Xiang	23	0,1	120	4	0,0185
$C_{P\text{-}N}$	coplanar	Xiang	23	2	120	4	12,9
$C_{P\text{-}P}$	coplanar	Xiang	120	1	23	4	3,8
$C_{P\text{-}G}$	microstrip	Wheeler	0,25	0,285	120	4	13
$C_{W\text{-}G}$	?						
$C_{T\text{-}G}$	strip line	Wheeler	0,127	0,170	120	4	13,7
$C_{T\text{-}T}$	coplanar	Xiang	0,127	2,27	120	4	2,9

Potential for low noise

From ATLAS to an optimised electronics for ee collider

- ATLAS: noise term $\sim 250\,\text{MeV}$ for e^- cluster
- Use charge collection preamp instead of current-sensitive preamp
- Use much larger integration time: $O(1\,\mu s)$ vs 45 ns
  - More charge collection $\rightarrow$ more signal
- Dominant noise term goes as $C\sqrt{4kT/(g_m\tau_p)}$
- In addition, possibility to use cold electronics
  - Would also simplify design of feedthroughs

Estimation

- With 20% sampling fraction, collected charge for 1 MeV deposited $\sim 3200e^-$
- Use noise figure from cold PA designed by BNL for Dune[1]: RMS $1000e^-$ for $C = 200$ pF

$\Rightarrow$ 300 keV noise for a 200 pF cell

Consequences

- dEdx from muons $O(10)$ MeV/cell

$\Rightarrow$ Observe MIPs with $S/N > 5$

- Noise for an electron cluster < 10 MeV (if coherent $\ll$ incoherent noise)

$\Rightarrow$ Sampling term dominant for energy resolution even at low energies

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[1] G. De Geronimo et al., Front-end asic for a liquid argon TPC, IEEE Transactions on Nuclear Science 58 (2011) 1376–1385

Conclusions

Project of LAr calo for FCC-ee still in early stages

- Many open questions, even basic ones
  - Constant or variable absorber thickness ?
  - What design for the endcaps ?
- Physics performance evaluation for design optimisation and R&D for critical items in the design need to go in parallel
  - IJCLab working so far on electrodes design and calculations

Making a LAr calo design for FCC-ee is a high-tech project !

- Some of the building blocks require exploring new technologies
  - Thin cryostat, cold integrated electronics

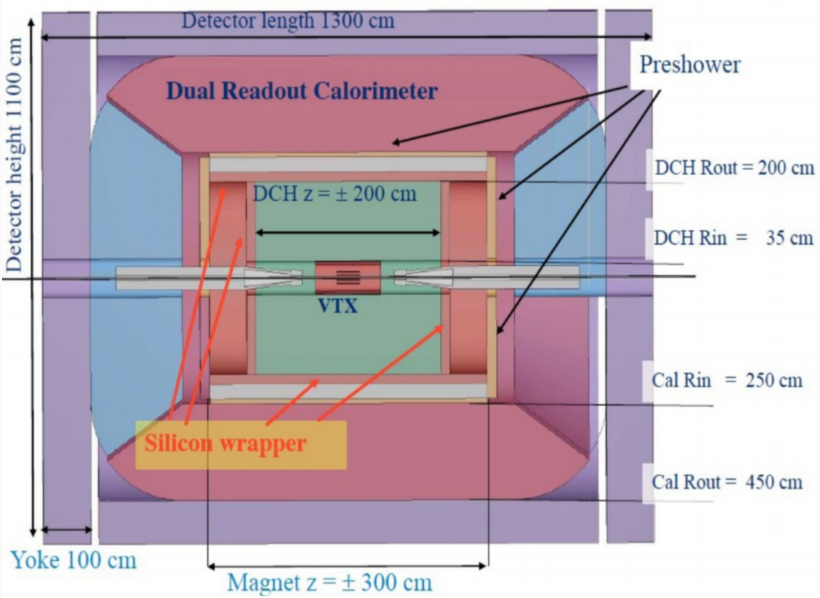
It has the potential to be a versatile calorimeter for FCC-ee

- Excellent EM resolution, including at low energy ($< 10\%/\sqrt{E}$ + low noise)
- Fine granularity for PID and for PFlow
- Invariant in ϕ rotations, without any crack
- Pointing cells in both ϕ and θ

Community around the project

- Small team, which very much welcomes newcomers !
- More involvement of French institutes would be much appreciated !

Bonus slides


Detector length 1300 cm
Detector height 1100 cm
Preshower
Dual Readout Calorimeter
DCH Rout = 200 cm
DCH z = ± 200 cm
DCH Rin = 35 cm
VTX
Cal Rin = 250 cm
Silicon wrapper
Cal Rout = 450 cm
Yoke 100 cm
Magnet z = ± 300 cm