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Preliminary estimate of the noise achievable in a FCC-ee/LAr calorimeter

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1) Estimation of the sampling fraction in “baseline” and some variant

Dedx plomb=12,7 MeV/cm X0 Pb= 0.56 cm
Fer = 11,4 MeV/cm X0 Fe= 1.76 cm
Dedx Lar = 2,13 MeV/cm X0 LAr= 14 cm
Dedx G10 = 3,1 MeV/cm* X0G10= 17 cm

*my own estimate from 60% glass, 40% “polycarbonate” as a proxy to epoxy
3.17 from private/Martin

1.1)<u>Baseline design/ Martin:</u>

absorber = 1.4mmPb + 2x0.2mm Fe + 2x0.1mm G10= 2mm
Electrode = 1.2mm G10

A radial track crosses 42 absorbers with an average angle of 45 degrees (goes from 50 to 40)

Lead 1.4mm*42*1.41= 83 mm Pb -> 14.8 X0 and 105 MeV dEdx
G10 1.4mm*42*1.41=83 mmG10 -> 0.5 X0 and 26 MeV
Fe 0.4mm*42*1.41=24 mm Fe -> 1.4 X0 and 27 MeV
Argon (comp. to 400mm) =210 mm Ar-> 1.5 X0 and 44 MeV →
Total 18.2 X0 and 202 MeV

Sampling Fraction Lar= 44/202= 21.8% (average: SF increases from front to back)
Average track length in a double gap= 210/42= 5mm (gap is narrower by √2)

1.2) <u>With 2 steps of + 0.6 mm lead ie absorbers of 2mm, then 2.6, then 3.2mm thickness</u>

Lead is increased by 14*0.6*1.4 + 14*1.2*1.4= 35 mm
LAr is decreased by the same amount:

For the same radial track:

Lead 2mm*42*1.41= 118 mm Pb -> 21 X0 and 149 MeV dEdx
G10 1.4mm*42*1.41=83 mmG10 -> 0.5 X0 and 26 MeV
Fe 0.4mm*42*1.41=24 mm Fe -> 1.4 X0 and 27 MeV
Argon 175 mmAr-> 1.2 X0 and 37 MeV
Total 24.1 X0 and 239 MeV

Sampling Fraction Lar= 37/239 = 15.5 %

Average track length in a double gap = 175/42= 4.2mm (dble gap is narrower by sqrt(2))
➔probably not a good solution; too thick in terms of X0.
Could allow a "shorter" calorimeter if dictated by other constraints

1.3) Thinner absorbers at the beginning, then 2 steps of + 0.6 mm lead ie
absorbers of 0.6mm for PS, then 1.6mm, then 2.2 mm, then 2.8mm thickness
Lead thickness is 0mm for PS, then 1mm, then 1.6mm, then 2.2mm

For the same radial track:

Lead	1.6 mm*42*1.41= 95 mm Pb ->	17 X0 and	121MeV dEdx
G10	1.4mm*42*1.41 =83 mmG10 ->	0.5 X0 and	26 MeV
Fe	0.4mm*42*1.41=24 mm Fe ->	1.4 X0 and	27 MeV
Argon	198 mmAr ->	1.4 X0 and	42 MeV
Total		20.3 X0	and 216 MeV

Sampling Fraction LAr= 42/216 = 19.4 %
Average track length in a double gap = 198/42= 4.7mm (/√2→dble gap=3.4 mm)

For consistency with the depth segmentation, the split into 3 parts (+presampler) could take place:
After pad 1 and 2 absorbers for the presampler part gap= 1.72 to 1.76mm
pad 5 and 18 absorbers for the first part, Pb =1mm t=220mm gap= 1.46 to 1.87mm
pad 8 and 30 absorbers for the 2nd part, Pb =1.6mm t=385mm gap= 1.57 to 1.91
pad11 and 42 absorbers for the last part, Pb =2.6mm t=568mm gap= 1.61 to 1.98
The number of X0 for each segment is thus 6.8 X0 for the first one (PS included), 5.8 for the second and 7.6 for the third one (at θ=90 degres).
All gaps being between 1.5 and 2 mm, a constant high voltage could perhaps accommodate them.
The sampling fraction in the 3 segments is correspondingly about:25%,19% and 15%. The signals from the first 4 pads (the last 3) would have to be scaled down by a factor 0.76 (up by a factor 1.27) in a first approximation.

2) From deposited energy to Collected charge.

Take 19% as sampling fraction and 90% charge survival (recombination…)
Take 26 eV as the average energy loss per electron-ion pair created (debatable , perhaps a smaller value around 24 eV is better…)
Collected charge for 1 MeV deposited =10^6 eV/(2*26) eV *0.17 = 3200 electrons
(factor 2 because positive ions are not collected during the integration time)

3) Noise Estimate

In the charge collection mode, the dominant series noise Q(rms) is proportional to the capacitance at input, inversely proportional to g_m of the input transistor and to the peaking time τ_P.

$$Q=C \times \sqrt{4kT/(g_m*\tau_P)}$$

2.1 Noise at Dune

Cold PA from BNL :

-spec noise rms = 1000 electrons for 200 pF capacitance, and 1 µs integration time.

PA directly connected to sensor (wire) no cables,…

MOSfet PA 180nm; performance improves at cold (factor ~2)

1/f noise under control for shaping time not longer than ~ a few µs

Power dissipation: 5mW PA alone, 50 mW for full chain

-measurements : somewhat better than spec

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

Cold PA from Lyon, for Dune as well ->similar performance (no published reference found)

2.2 Noise per cell at FCC_ee

Capacitance ; not yet fully settled depends on geometry

Brieuc Francois reports 200<C<1000pF

Takes these 2extremes :

Assuming noise as in the specs of Dune:

- 200 pF -> 1000 electrons <-> 0.3 MeV
- 500 pF -> 2500 electrons <-> 0.8 MeV
-1000pF-> 5000 electrons <-> 1.5 MeV

=➔ take 1 MeV as " average" until capacitances are known better

2.3 Noise per " cluster" at FCC_ee

Assumes "coherent" noise remains<incoherent even for hundreds of cells together (a general problem for highly granular calorimeters).

-for muons: 2cells in rphi, 1 or 2 in theta, 12 in depth ➔ <=48 cells ie 7 MeV for a ~200MeV signal ; in average ~5 MeV signal per cell ; S/N ~5 per cell

-for high energy EM shower : 3x3x12-> ~ 100 cells -> 10 MeV

-for low energy EM shower : 3x2x8 -> 50 cells → 7 MeV

At 1 GeV , 5%/sqrt(E) -> 50 MeV sampling fluctuation-> electronics noise remains comparatively small

➔ **Cold preamps " a la Dune" would give superb noise performance**

Possible problem: dynamic range. For Dune it is limited to about 2000.
at FCC-ee a very rough estimate of the maximum deposited energy per cell is ~10 GeV, meaning a dynamical range of 10 000 , or 14 bits. Coping with this is likely to require more power dissipation….