Dual Phase Field Cage

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Version 2

In the LArTPC, each pair of facing cathode and anode planes forms an electron-drift region. A field cage must completely surround the four open sides of this region to provide the necessary boundary conditions to ensure a uniform electric field within, unaffected by the presence of the cryostat walls.

Single Phase Reference design :

For the single phase reference design the field cages are constructed using multiple copper-clad FR-4 sheets reinforced with fiber glass I-beams to form modules of 2.3 m x 3.6 m in size. Parallel copper strips are etched on the FR-4 sheets using standard printed circuit board fabrication techniques. Strips are biased at appropriate voltages provided by a resistive-divider network (also called voltage divider). These strips create a linear electric potential gradient in the LAr, ensuring a uniform drift field in the LArTPC active volume.

Requirements :

The maximum electron-drift distance between a cathode and an adjacent anode is 3.6 m. This requires a −180 kV bias voltage on the cathode plane to reach the 500 V/cm nominal drift field.

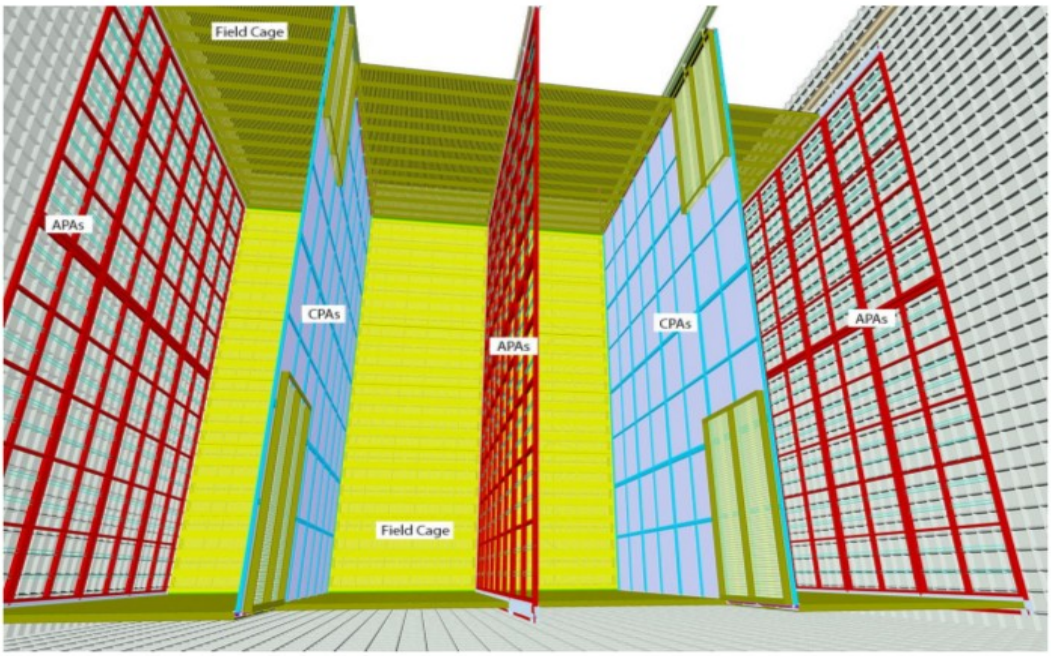

Fig 1: A view of the Field cage installed inside the membrane cryostat. 2

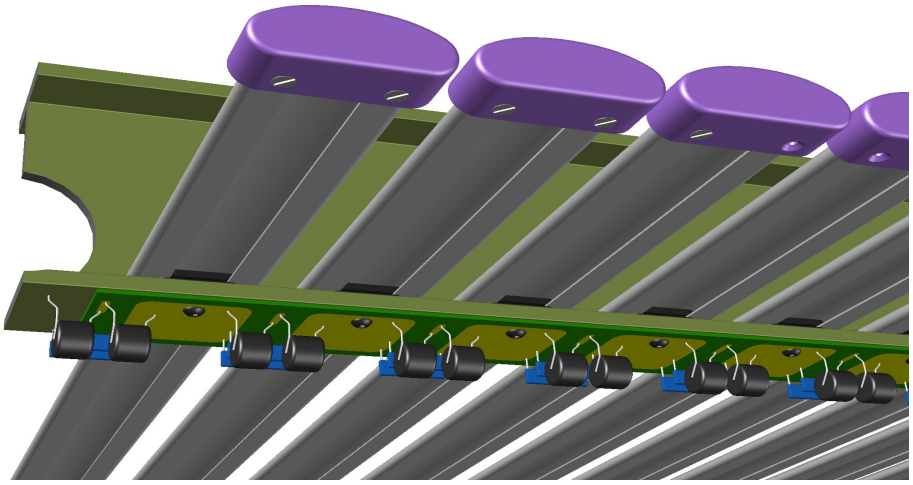

Fig 2 : Field cage profile with voltage divider circuit

Voltage divider network: The voltage-divider network will be soldered directly onto the field-cage panels. Multiple resistors will be connected in parallel between any two taps of the divider, in order to provide fault tolerance. One end of the divider chain is connected directly to the cathode, while the other end is connected to ground at the APA through resistors of the appropriate value.
In addition to the voltage-divider network, surge suppressors such as varistors or gas discharge tubes will be installed between the field-cage strips to avoid the occurrence of an over-voltage condition between field-cage electrodes and the cathode in the event of a high voltage discharge. Single phase uses 2 resistors parallel to provide redundancy.

Voltage divider circuit for SP:

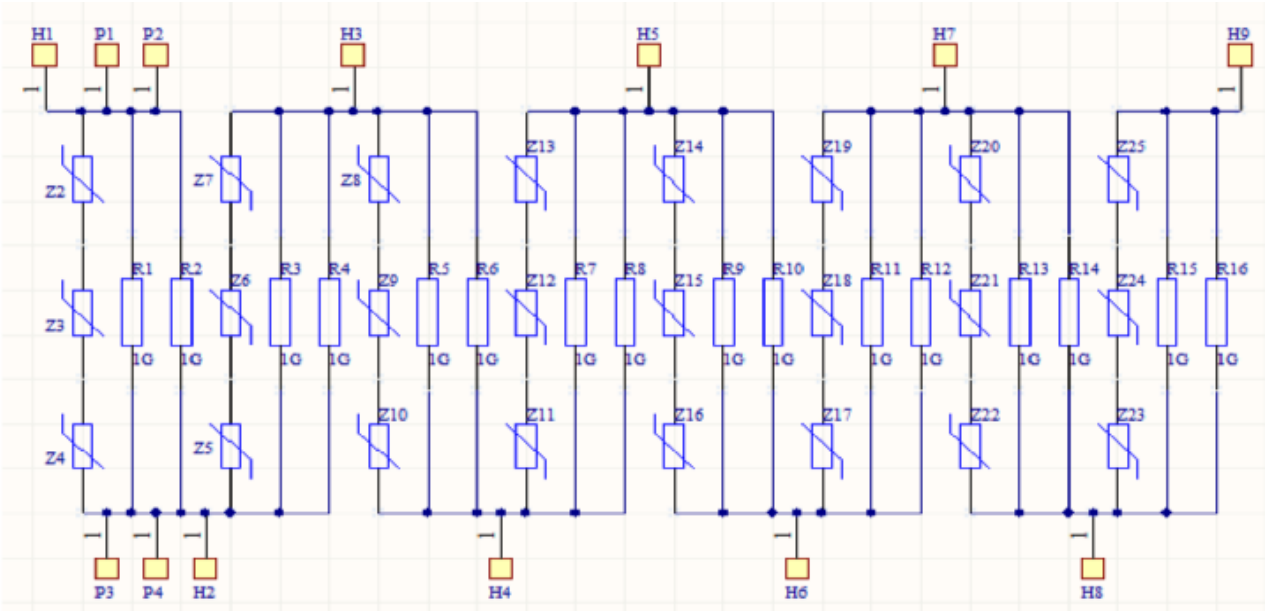

Fig 3 : Schematic diagram of voltage divider circuit 3

The Resistor Divider Board consists of eight resistive stages in series. Each stage consists of two 1GΩ resistors in parallel yielding a parallel resistance of 500MΩ per stage. Each stage is protected against high voltage discharge transients by transient/surge absorbers (varistors).

To achieve the desired clamping voltage three varistors are wired in series and placed in parallel with the associated resistors. A schematic of the Resistor Divider Board is shown in Fig 3.

Upper limit of resistance value:
Total resistance over the 3.6 m drift region is 80Gohm. Number of divider loops or taps is 64. Hence the resistance per divider loop is 1.3Gohm. The equivalent current is 7 nA.

Beam Plug :
The beam plug is constructed from a fiberglass. It can filled with nitrogen glass (pressure balanced with LAr). A picture of the beam plug is shown in fig[3]. It will have a field shaping electrodes both on the beam exit window surface and the cylindrical surface of the FC to the cryostat wall.

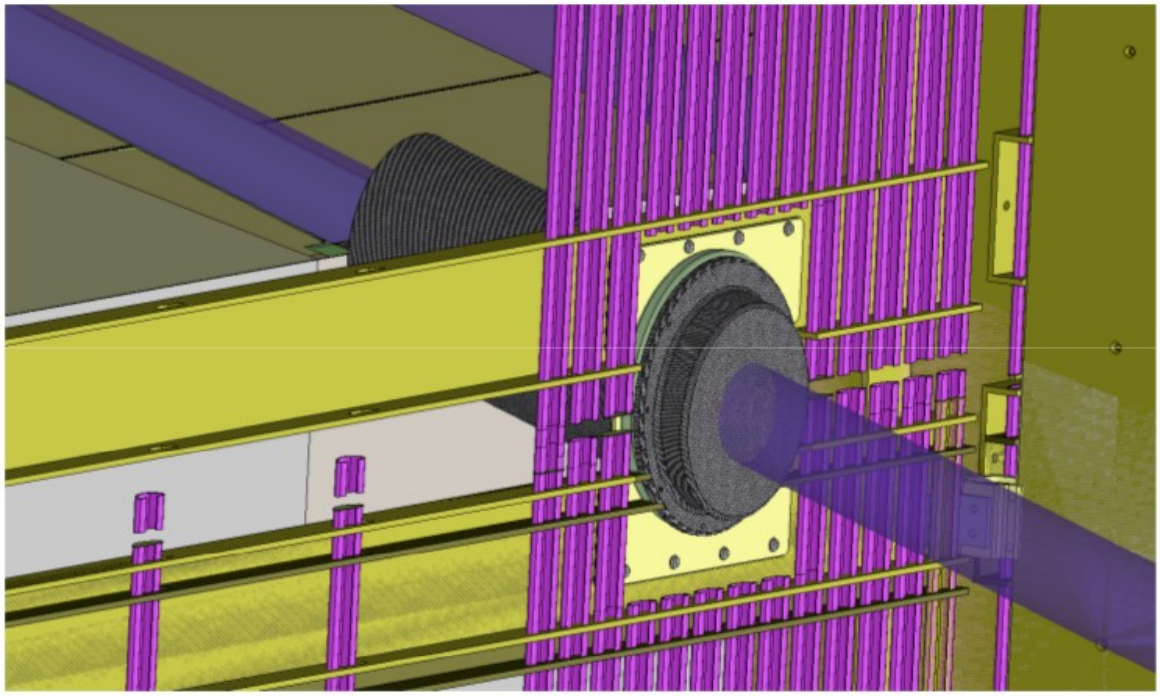

Fig [4]: Conceptual design of the beam plug

Laser Beam :

Calibration laser beams have angular coverages of ±45° in both vertical and horizontal directions. Need two crossing beams to uniquely identify a 3D point inside the TPC.

Why we need 500V/cm as the uniform value of field?

As the readout time associated with a trigger is proportional to the drift time, it is important to know the drift velocity precisely. Likewise, the reconstruction of track position from the drift time of ionization electrons depends on knowledge of the drift velocity.
Kalinin et al., and also Walkowiak, fit the measurements to a function that parameterizes the electron drift velocity v with respect to the electric field E and temperature T

v(E,T) = [P1(T – T0) +1] [P3*E*ln(1+ P4/E) + P5E^p6] + [P2(T -T0)] …..... (1)

The parameters P1,...,P6 obtained by Walkowiak from a global $\chi 2$ fit.

At the nominal operating temperature of T =87K, Eq(1) predicts that electron drift velocity will be 1.63 mm/μs for a drift field of 500V/cm. Hence depending on the trigger rate the drift distance will be finalize.

Table 1: Comparison between Dual-Phase FC and Single-Phase FC

Parameter	**Single-Phase FC**	**Dual-Phase FC**
Total Size of the drift volume	6.9m x 3.6m x 6m	6 m x 6m x 6m
Drift distance	3.6m	6m
Voltage at Cathode	-180 kV	-300 kV
Nominal drift field	500V/cm	500 V/cm
Total number of Modules	28	8
Total number of profiles	Each module with 58 profiles	Each module with 98 profiles
Total length of cosmic ray tracks inside the active volume	22356 m/s	32400 m/s
Total energy loss	4739472MeV/s	6868800 MeV/s

Total charge deposition	3.21E-08 C/s	4.65681E-08 C/s
survived charge	2.142E-08 C/s	3.10454E-08 C/s
equivalent current	2.142E-08 A	3.10454E-08 A
let the divider current be 100 times	2.142E-06 A	3.10454E-06 A
Total resistance over total drift length	80Gohm	96.77 Gohm
Number of divider tap	57	97
Resistance per divider tap	1.4 Gohm	1 Gohm

Why 30kV/cm will be the maximum voltage within LAr Volume :

The optimum electric field depends on dielectric strength of the material. (LAr).The need for larger LArTPC detectors with higher applied voltages has led to new studies of the dielectric strength of liquid argon. In contrast to the commonly used reference value of 1.4 MV/cm, which was measured using only moderately pure argon, recent investigations have shown that the dielectric strength of argon at LArTPC purity with sub-ppb concentrations of oxygen and water may be much lower than anticipated.

Requirements for Surge protection device

1. The device must have a significantly higher resistance than the field cage resistances.
2.The device must clamp the over-voltage that evolves during a fault condition to less than the voltage which can damage the field cage resistors in liquid argon.
3.The device must be able to survive repeated discharges of the system.

4.The device must function in cryogenic temperatures and in the dielectric environment of LArTPC purity liquid argon.

5.The device must not damage the argon purity in the detector.

Table 2: Mechanical Parameter list for both SP and DP :

	Parameter	SP	DP	note
1	Total size of Field Cage	7.2m x 6.9 m x 6m	6m x 6m x 6m	
2	Total Number of FC modules	6 Top, 6 Bottom, 8 in each endwall side (total 28)	8 Modules	
3	Number of Sub Module in each module		3	There is no as such submodule for SP
4	Size of each Module	Top and Bottom : 3.6m x 2.3 m Endwall module : 3.6 m x 1.5 m	6.238m x 3.017 m	Do not know thickness of single phase
5	Number of profiles in each module	58	98	
6	Distance between two modules	3mm	3mm	Cap- Cap distance
7	Distance between each profile in a module	60mm	60 mm	Same as SP
8	Number of main I beam in each module	2	2	Same as SP
9	Length of main I beam	3.6 m	6.238m	
10	Height of I beam	6 inch	6 inch	Height is not decided yet, but 6inch proposed for DP
11	Material used for I beam	FRP	FRP	Material for

				DP is not decided (FRP proposed)
11	Number of cross I beam in each module	4	4	Proposed same as SP
12	Material used for Cross I beam	FRP	FRP	Material for DP is not decided (FRP as proposed)
13	Length of each profile	Top and Bottom 2.3 m End wall 1.5 m	3.1 m	
14	Width of each profile	46mm	46mm	We proposed the same width as SP
15	Thickness of each profile	8mm	8mm	
16	Material used for profile	Stainless steel (default)	Aluminum or stainless stell	Aluminum or stainless steel

Table 3: Electrical Parameters for SP and DP FC :

	Parameter	SP	DP	Note
1	Number of resistive stages	8 in series		Inputs from LSU will be important
2	Number of resistors(parallel) in each stages	2	2	Proposed same as SP
3	Value of parallel resistance	1 GOhm	1.3GOhm	Inputs from LSU will be crucial
4	Number of varistor in each stage	3	3(Final number will depend on the model of varistor)	3 varistors are in series with each other and placed parallel with resistors.
5	Company of varistor	Panasonic	Panasonic (if varistor is used)	Inputs from LSU will help to make choice.
6	Size of Voltage divider Printed circuit board	520mm x 80 mm		Can be finalize once resistors are fixed
7	Material used for PCB	0.062 inch thick FR-4 laminate with 1 ounce		LSU might have different option

		weight copper cladding on top and bottom		
8	Number of mounting holes with the profile	9		Depends on the number of profile connection
9	Space between Mounting holes	60 mm	60 mm	Same as SP

Table 4 :Requirements for FC

	Parameter	Value for SP	units	Value for DP	notes
1	FC-maxcurrent : Limit of total bias current at 500V/cm	1	nA	1 nA	Same as SP
2	FC-maxvoltage : Maximum percentage of bias voltage corresponding to 500V/cm drift field	150	%	150%	Same as SP
3	FC resistance tolerance :	1	%	1	Same as SP
4	FC bar- separation: constant separation with respect to neighbors	1	mm	1	Same as SP
5	Frame flatness tolerance over full length.	3	mm	5	Same as SP
6	FC- straightness Maximum	5	mm	8	Same as

	sagitta for each profile				SP
7	FC- smoothness : FC profile shall have no surface defect with a depth exceeding the tolerance	100	microns	100	Same as SP
8	FC lifetime : The FC shall maintain its integrity for the specified lifetime.	1	years	1	Same as SP
9	FC- Qfactor : maximum allowable resistance over a bar length that can develop over the specified lifetime.	1	Ohm	1	Same as SP

Time-line for FC design :

1. Comments, suggestions within September 29.
3. Send the final version of the draft within this weekend.
4. Present the proposal next Wednesday meeting.
5. Come to a conclusion about the design parameter and upload the draft on Doc-db. (before October 7)