

# Design of field cage electrical elements

protoDUNE Design and Production Review

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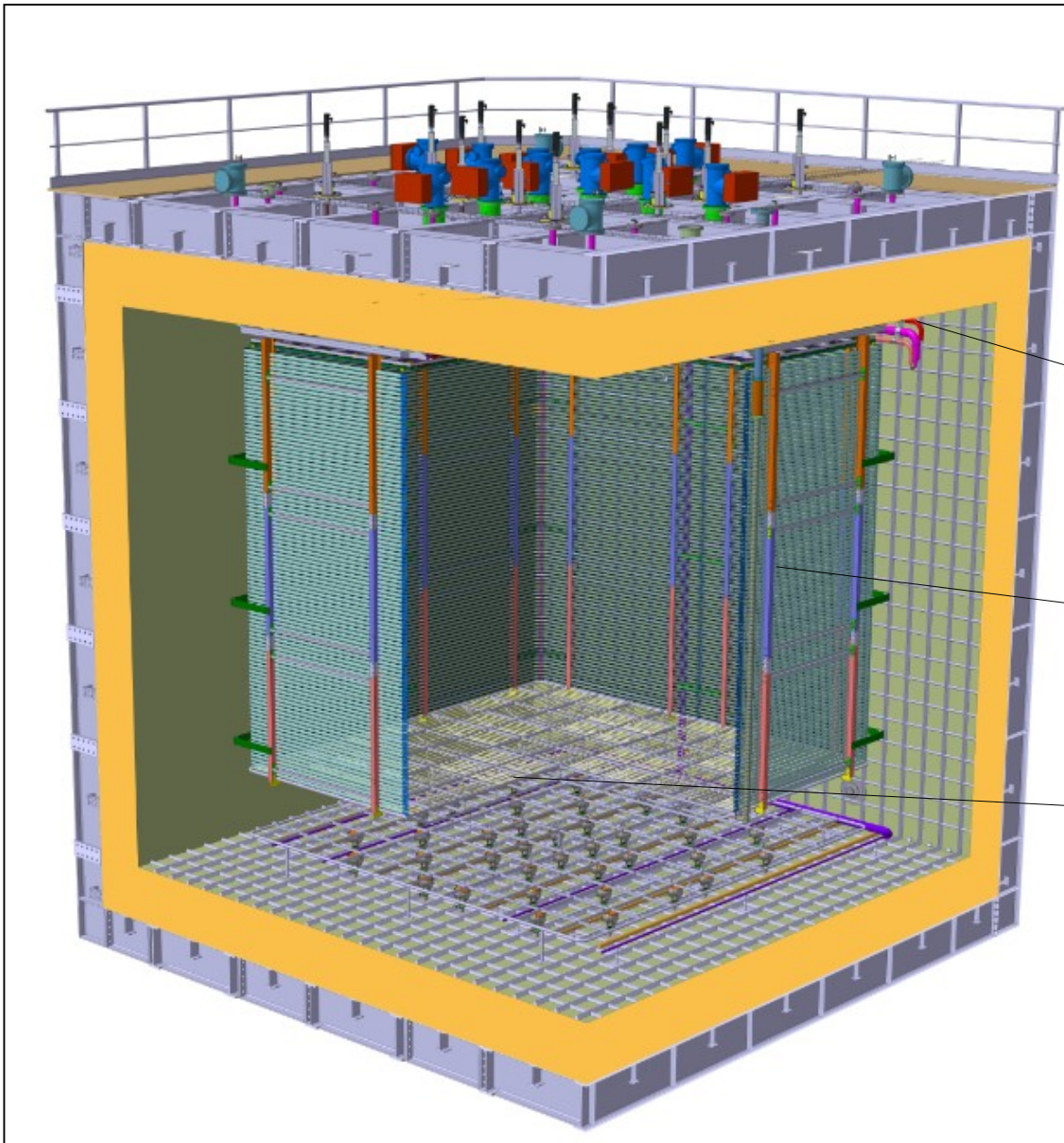
A. Gendotti, S. Murphy, C. Cantini & ETH Team

F. Pietropaolo & CERN Team

# Outline

- DP FC Design overview
- Motivation
- Design of the High Voltage Divider Board
- Electrical components of the Board
- Conclusions

# DP FC in protoDUNE



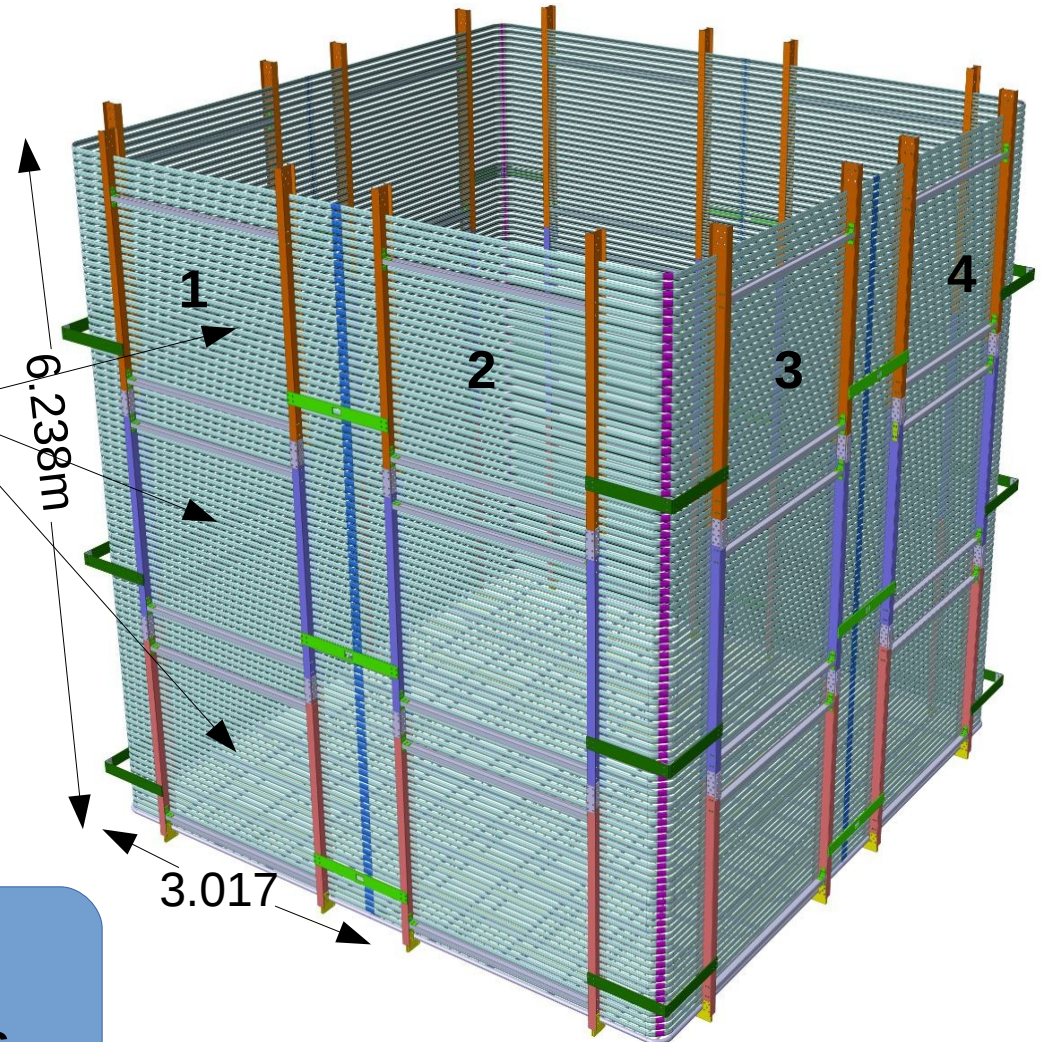
Charge readout planes

Field Cage (Based on modular concept as SP)

Cathode

# Overview of DP-FC

- Total 8 modules.
- 2 modules in each detector side.
- Size of each module is 6.2m x 3.0 m.
- Each module is composed of 3 sub-modules.
- **Each module has 98 profiles.**
- Center to center distance between two profiles is 60mm.



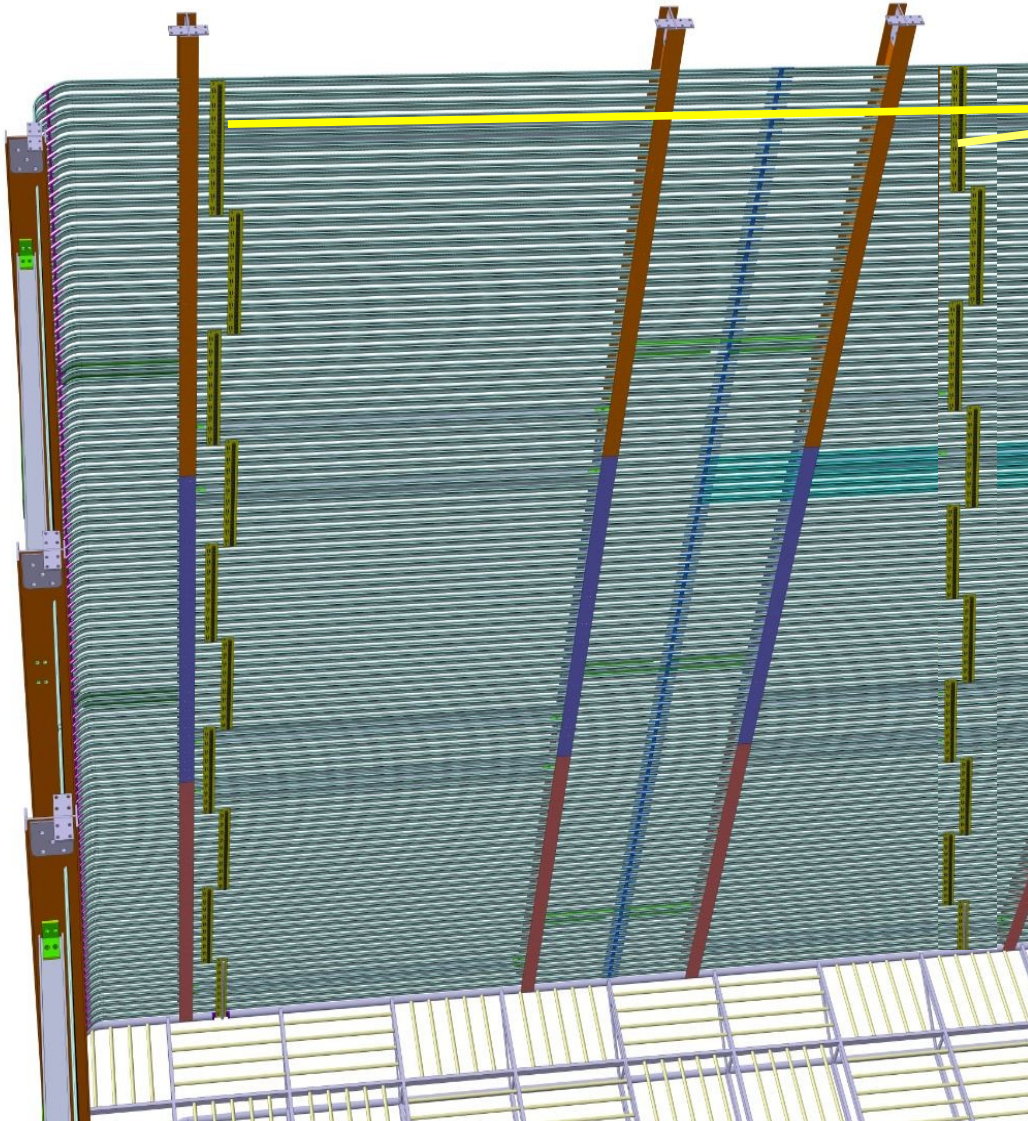
**Profiles are connected with aluminum clips, making entire loop continuous structure .**



# HV Divider Board: Motivation

- To generate uniform electric field of 500 V/cm (1kV/cm) across the entire drift volume.
- Use the printed circuit board
  - Easy handling and installation, robust mechanical and electrical connections
  - perform and survive in LAr for a long time.
  - ample redundancy
- Important issues before the design of the board:
  - High Voltage power supply characteristics
  - Total number of profiles
  - Center to center distance between two profiles (60 mm).
  - Current flow across the circuit.

# HV Divider Board



Two columns of board  
( for redundancy)

The Voltage difference between the first  
field shaper ring and the cathode  
= 294 kV(588 kV, in case of 600kV power  
supply).

0.5 Gohm resistance in each  
stage, total resistance= 49 GOhm

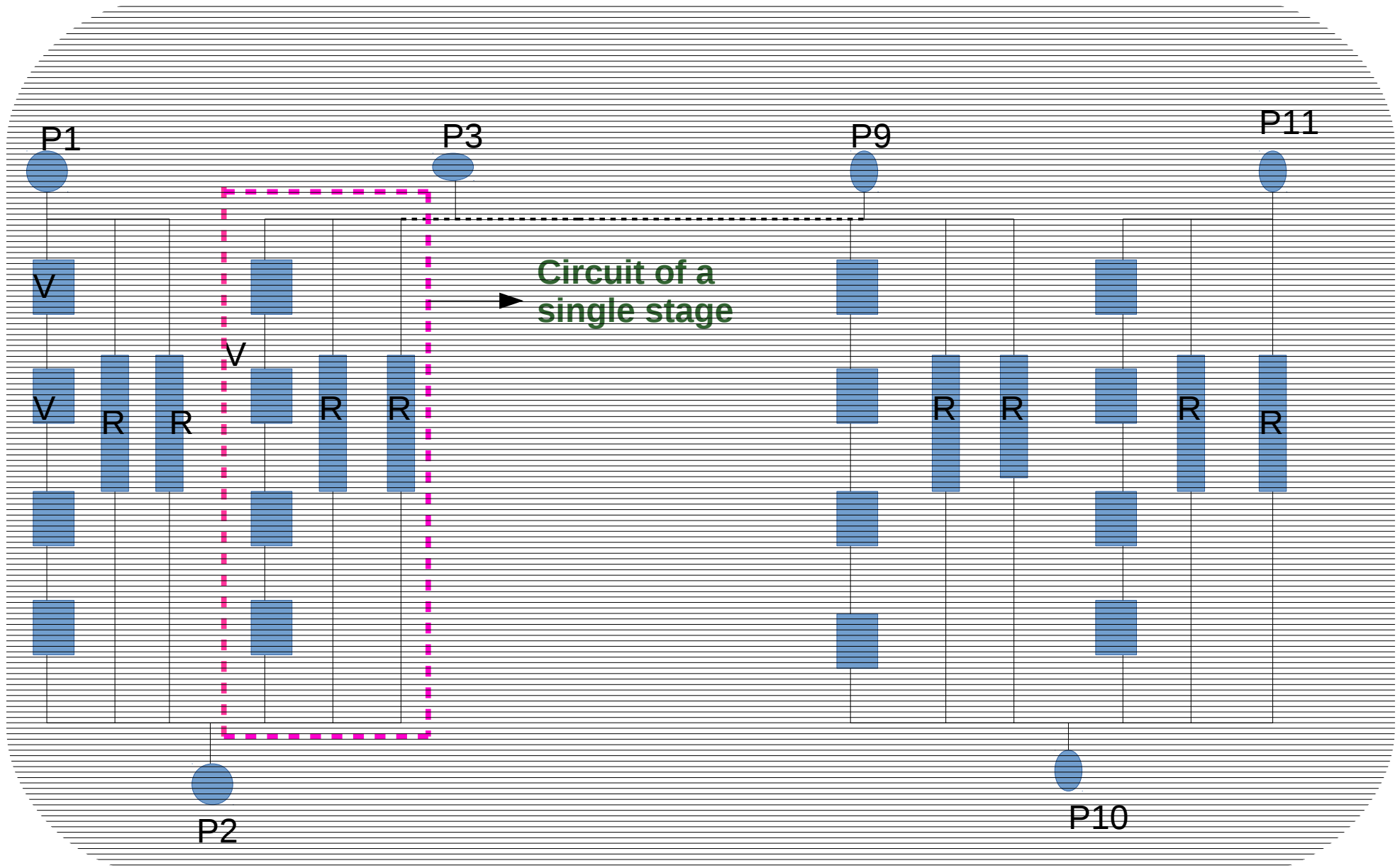
Current flowing through  
the circuit =  $6\mu\text{A}^*$  (12 $\mu\text{A}$ )

\* calculation of the current, which is 100 times from cosmic ray flux

# HV Divider Board at a glance

- Each divider board will connect 11 field shaping profiles.
  - Two profiles will be overlapped with two boards
  - Total board required to cover entire module = 20
- **Electrical components for each board :**
  - Resistors :
    - 2 resistors in parallel in each stage for redundancy.
    - Each of 2 GOhm, total 1 GOhm in each stage.
  - Varistors : Protect the circuit in case of
    - High voltage discharge
    - In case both resistors die.
    - 4 varistors in each stage, 4 in series are in parallel with resistors.

# Schematic diagram of a HV Divider Board





R= 2 Gohm, V= varistors, P1, P2, .. P11 connections with each profile



# Electrical Components

- Design to sustain voltages for 600 kV operation
- Electrical components
  - Resistors with higher voltage and power rating.
    - **THICK FILM RESISTOR, 2GOHM, 2.5W, 1%, part number SM108032007FE.**
    - **Voltage rating of the resistor is 20 kV.**
    - **Temperature rating -55c (same as SP)**
- **Varistors :**
  - **Clamping voltage 1.8 kV each.**
  - **4 Vaistors in series total clamping voltage is much higher than the voltage drop between two profiles.**

# Components of the divider board

Elements	Values (unit)	Part#	Requirement for each board	#Total (with spare)	
Resistors	2 GOhm	SM108032007 FE(2.5kW, 1%)	20	400 (600 )	
Varistors	4 varistors in series	ERZV14D182	40	800 (1000 )	
Connections with profiles	M4 size brass screw		22	220 (300)	
Nuts and washers			22	220 (300)	

# Requirements of the divider board

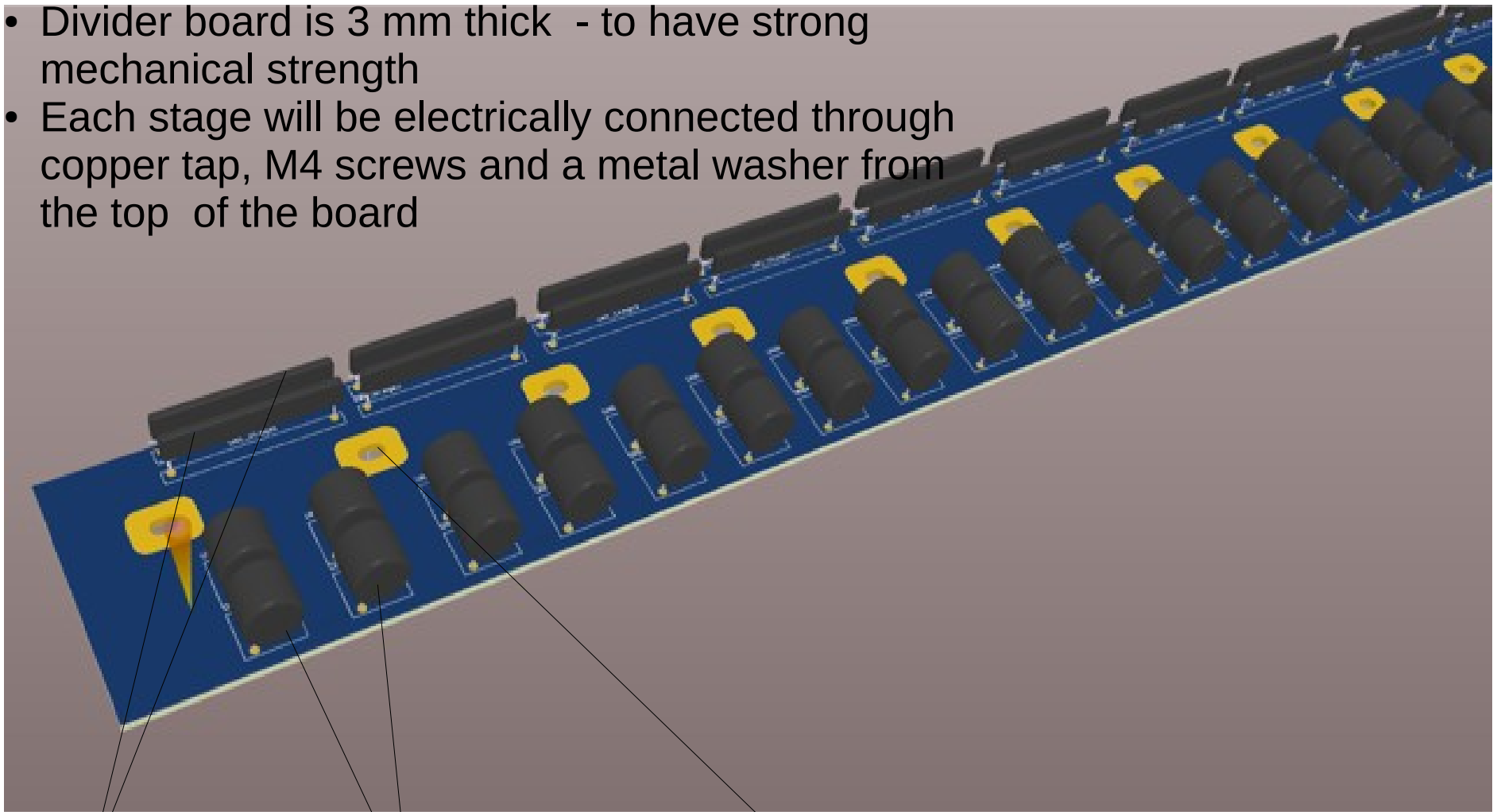
Parameter	Values	units	notes
FC-resistance tolerance per resistor	+ - 1	%	
FC- total resistance tolerance for the board	+ - 1	%	
FC max voltage per stage	150	%	9 kV
Maximum heat generated across a single resistors	9	mW	Much less than the resistor power rating

# HV Divider Board: Summary

Parameter	Values	Note
Total number of profiles	98	
Number of profiles in each sub module	33, 33, 32	
Number of profiles connected with each PCB Board	11	
Number of stages per board	10	
Distance between two profiles	60 mm	
Total number of PCB board for entire volume	20	
Length of each PCB board	650 mm	(10x60)mm +25mm +25mm= 650mm
Width and thickness	75 mm wide, 3mm thick	
Current flowing	6 uA (12uA)	300 kV(600 kV) operation
Total Resistance in each stage	0.5 Gohm	4 resistors in parallel (each of 2 Gohm)
Varistors in each stage	8 varistors in series .	8 varistors in two columns.
Voltage drop between two profiles	3 kV (6kV)	6 kV in case of 600 kV power supply

# 3D image of the Divider Board:Top layer

- Divider board is 3 mm thick - to have strong mechanical strength
- Each stage will be electrically connected through copper tap, M4 screws and a metal washer from the top of the board



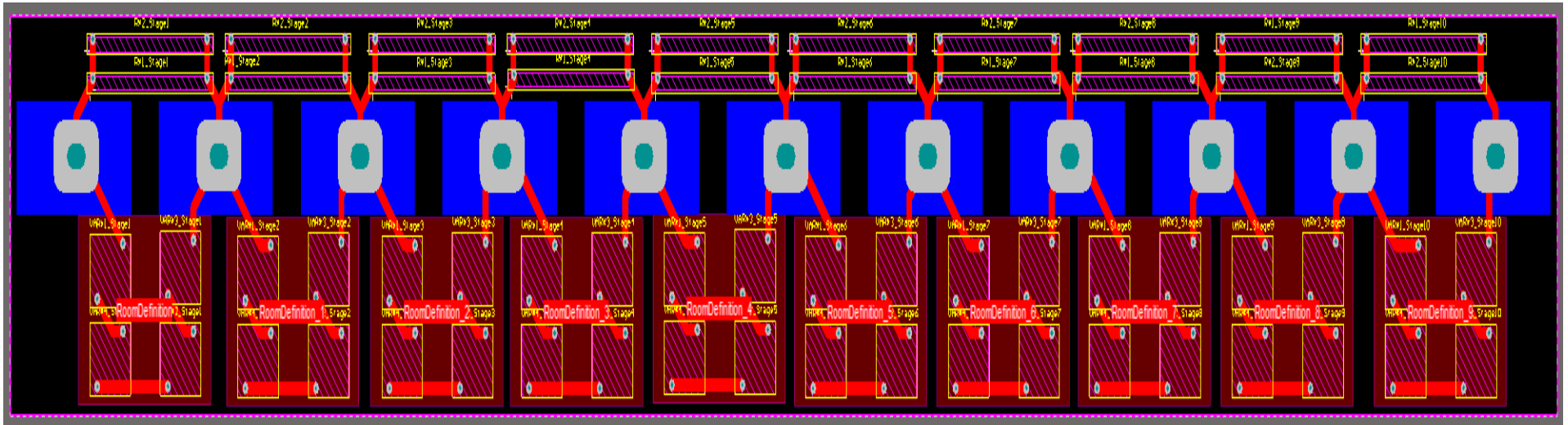
Two 2G  
Resistors

4 Varistors in  
series

Copper tap  
Connections  
with the profiles

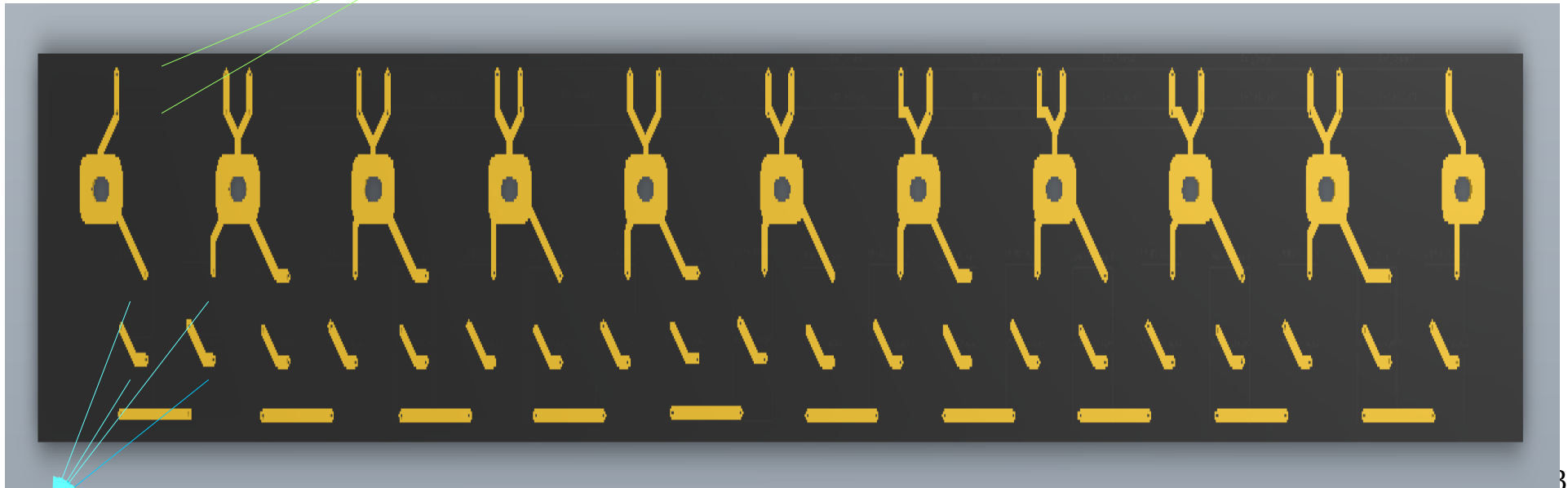


# Top and Bottom view



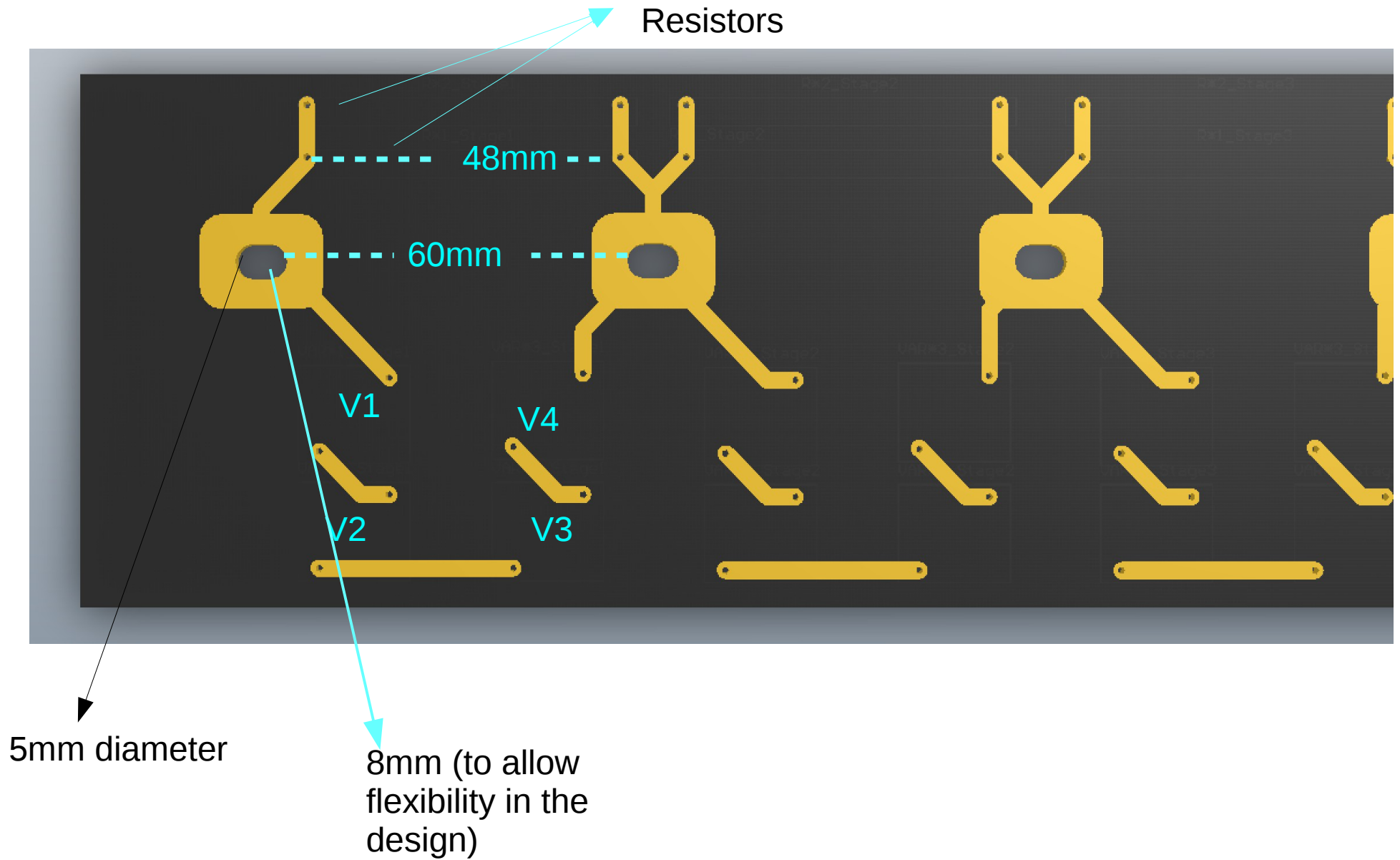
Bottom view

Resistors



4 Varistors in series

# Bottom layer :Zoom



# Conclusions

- Proper design of the voltage divider board is very important to get uniform electric field within the drift volume.
- Board should perform and survive inside LAr for long time.
- Divider board design has been finalized and signed off.
- Each divider board will connect 11 profiles.
- Two columns of boards will be employed for redundancy.
- Each stage will have 8 resistors total (2GOhm each) in parallel.
- 8 Varistors (4 in series are in parallel with resistors in each board) in each stage.
- Mechanical and electrical connections will be through the M4 screws and washer.
- Copper tap at the bottom will provide additional redundancy in electrical connections.
- Ready for production.

# Backup



# High Voltage system

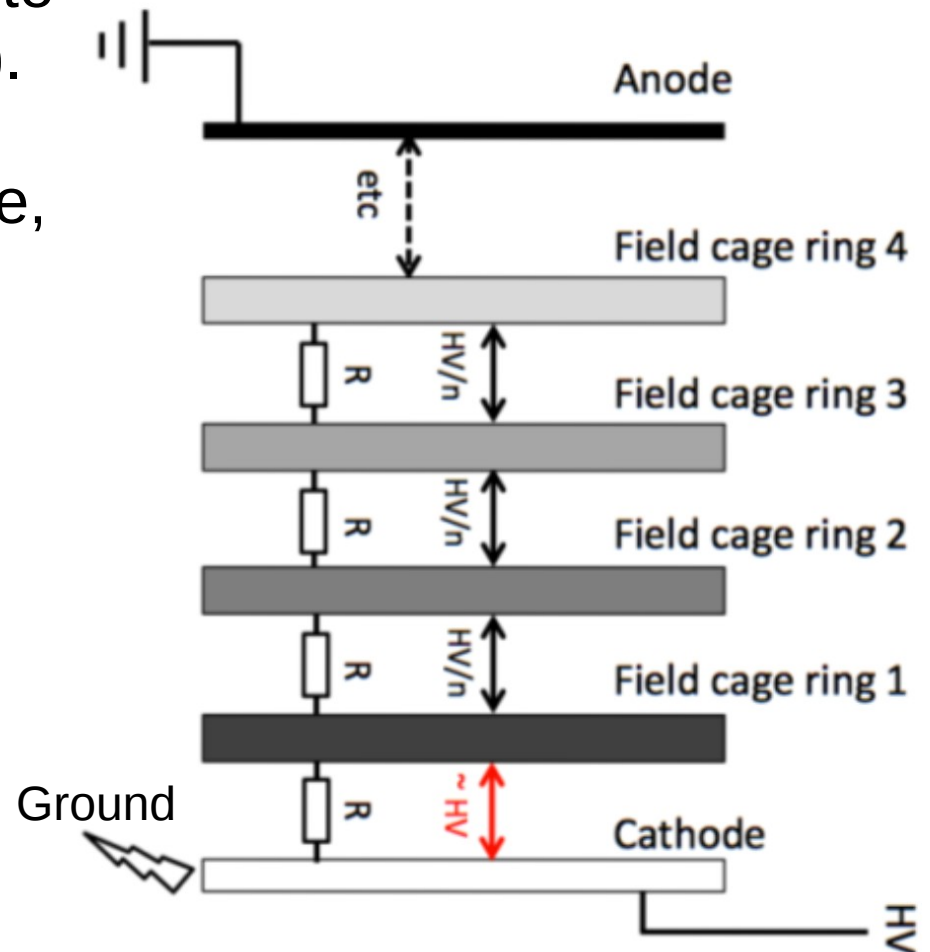
- How the high voltage system will look like to have 500 v/cm E field?

Insulation space	Voltage (kV)	Drift field (kV/cm)
	0	0
Anode	-1(LU)	5
LEM	-4(LL)	30
Extraction Grid	-6.5	2.5
First field shaper	-9.5	0.5
⋮		
	-300.5	0.5
Last Field Shaper	-303.5	0.5
Cathode		
Ground		

Power supply

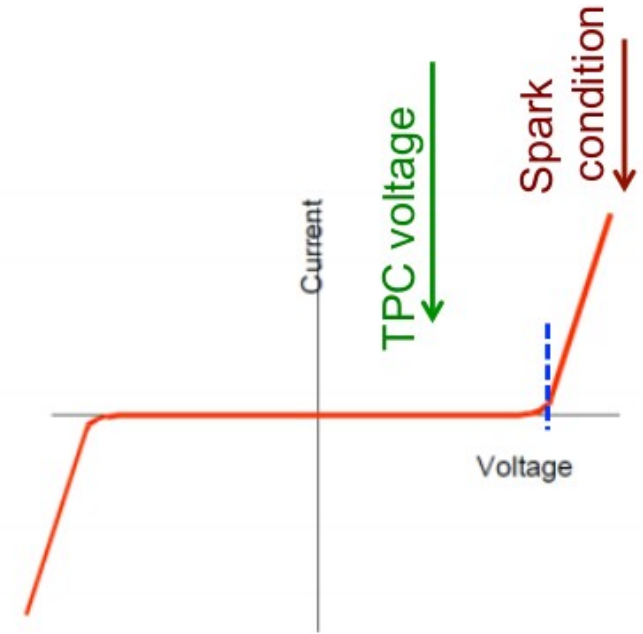
# What will happen to the discharge (breakdown)

- Lets consider cathode discharge to ground (due to some breakdown).
- Field cage profile has capacitance, so remain charged.
- Large resistance prevent charge redistribution in the field cage.
- The relaxation time of a single stage is  $= 1 \text{ Gohm} * 1 \text{ nF} = 1 \text{ s}$ .
- In this time the large voltage difference (much higher than resistors rating) will damage the resistors.
- Same thing will happen if any profile discharges.

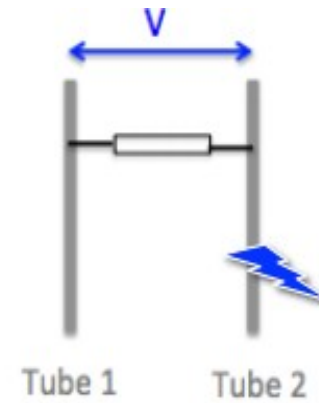
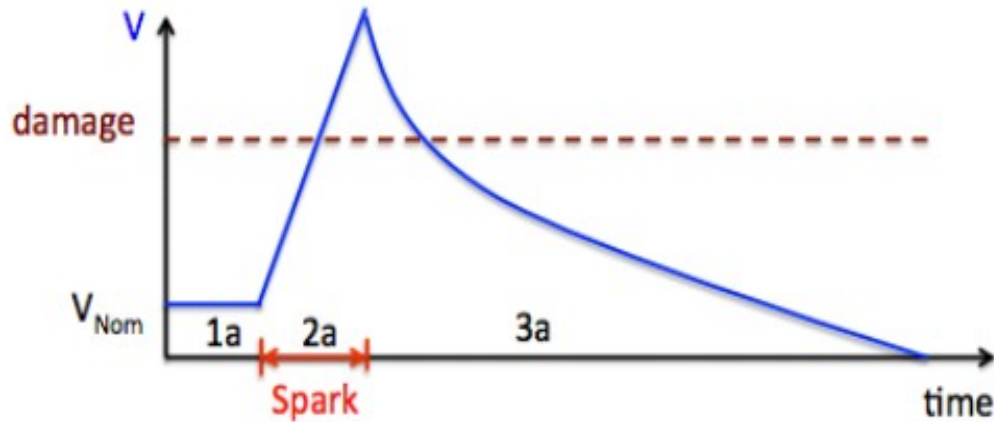


# With Varistors

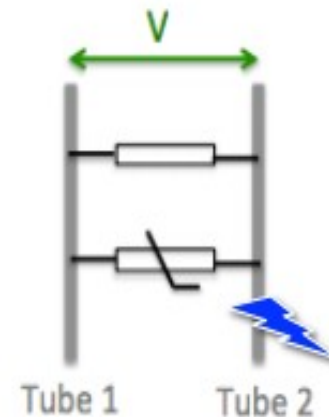
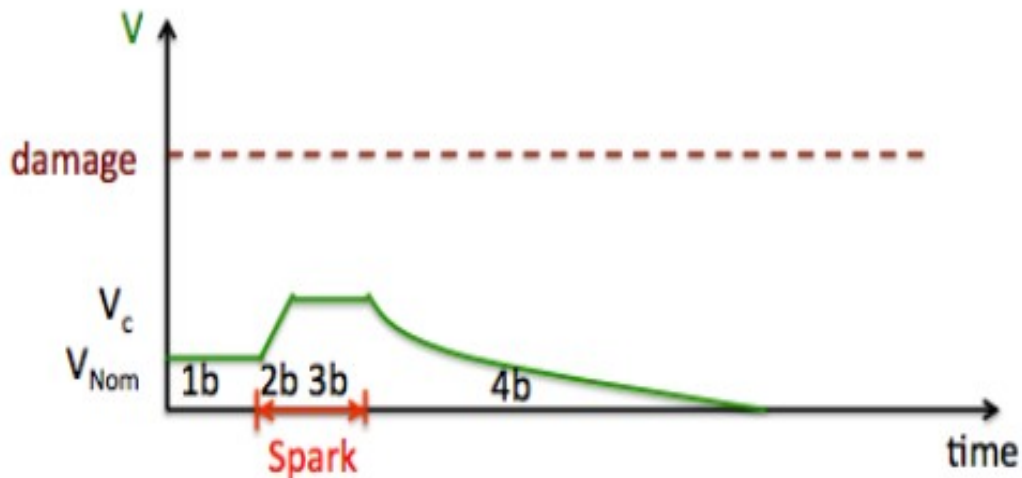
- Varistors have non-linear I-V characteristics.
- During the discharge, the voltage difference will be much higher than the clamping voltage of the varistors
- The resistance will go to be very low and voltage will be fixed at the clamping voltage.
- The relaxation will become very less and will be redistributed quickly.
- The voltage rating of the resistor should be higher than the clamping voltage of the varistors.



# Without varistors



# With Varistors



- With the varistors, the voltage never increases than the clamping voltage.
- It also helps G10 and argon breakdown.



# Maximum current flow

Parameter	Single Phase	Dual Phase
Total volume for a board	2.3m x 3.6mx 6 m	6mx 6mx 6m
Length of Cosmic ray tracks	$3/2 * 100/m^2$ muon flux x 2.3m x 3.6 m x 6 m = 7452 m/s	$3/2 * 100/m^2$ muon flux x 6m x 6m x 6m = 32400 m/s
Total energy loss (mainly ionization, 2.12 MeV/cm)	1579824 MeV/s	6868800 MeV/s
Total Charge deposition (2/3 survived)	1.07107E-08 C/s	3.10454E-08 C/s
Equivalent current	1.0710E-08 A	3.10454 E-08 A
Let the divider current will be 50 times	1.071 E-06 A	<b>6.10454 E-06 A</b>
Power supply voltage	-180 kV	-300 kV
Total resistance	~ 180 GOhm	49 Gohm

- We have 98 profiles, need 0.5 Gohm resistors in each stage, with current 6  $\mu$ A