Design of the HV divider board for Proto-DUNE Dual Phase Field Cage

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Outline

- Motivation

- Design of the divider board

- Redundancy: Two parallel chain of board

- Testing and production plan

- Conclusion

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.
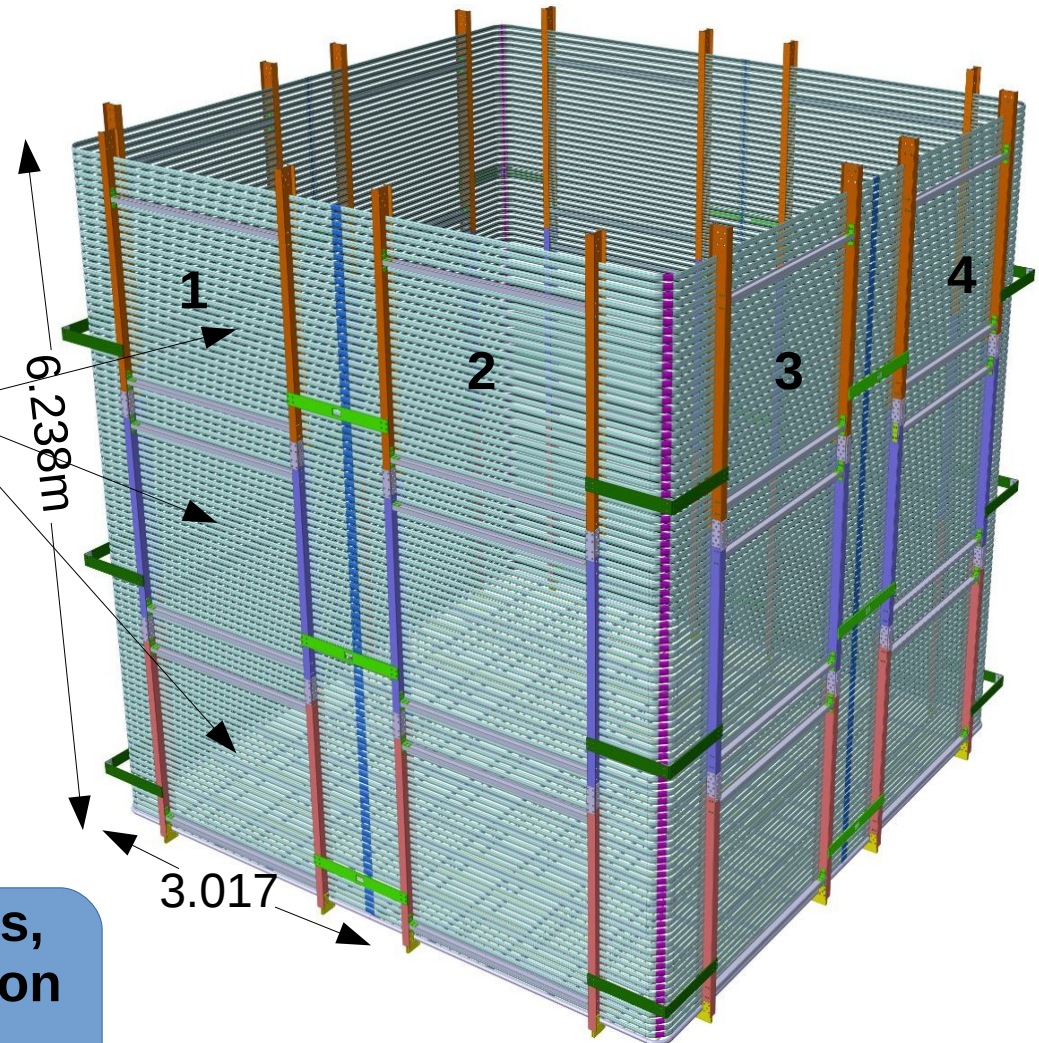
Profiles are connected with clips, Continuity of Electrical connection across 4 sides of the Module.

HV Divider Board: Motivation

- To generate uniform electric field of 500 V/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.
    - Total number of profiles, or total number of gaps (stages) including the connection with cathode.

    - Center to center distance between two profiles (60 mm).
    - Current flow across the circuit.

High Voltage layout

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

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

Power supply

Ground

The Voltage difference between the first field shaper ring and the cathode = (303.5 − 9.5) = 294 kV.

Important Parameters for board design

Total Number of profiles =98, total number of (gaps) stages including the connection with Cathode = 98

Center to center distance between two profiles = 6 cm.
Voltage drop between the two profiles = 3kV.

1 Gohm resistance in each stage, total resistance= 98 GOhm

Current flow = 294 kV / 98 GOhm = 3 uA*. (single row)
(Current flow for 2 rows will be = 294/49= 6uA)

* 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 or in other words 10 stages.
  - One profile will be overlapped with two boards.
  - Total board required to cover entire module = 10 (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

  – 3 varistors in series are parallel with the resistors

3D model
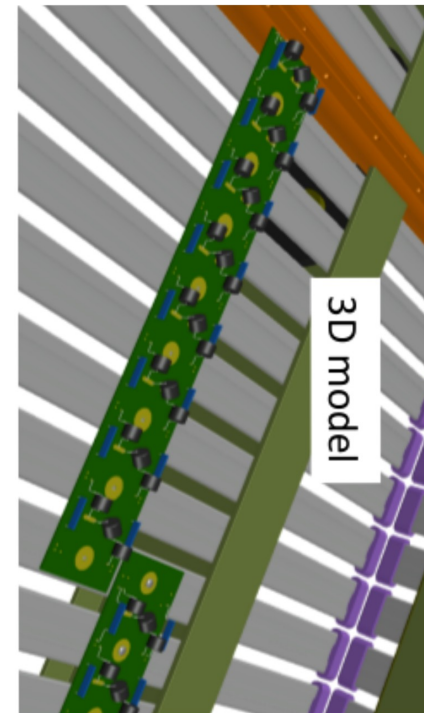
Schematic Diagram of a Divider Board

Circuit of a single stage

V

R R R R R R R R

P1 P3 P9 P11 P2 P10
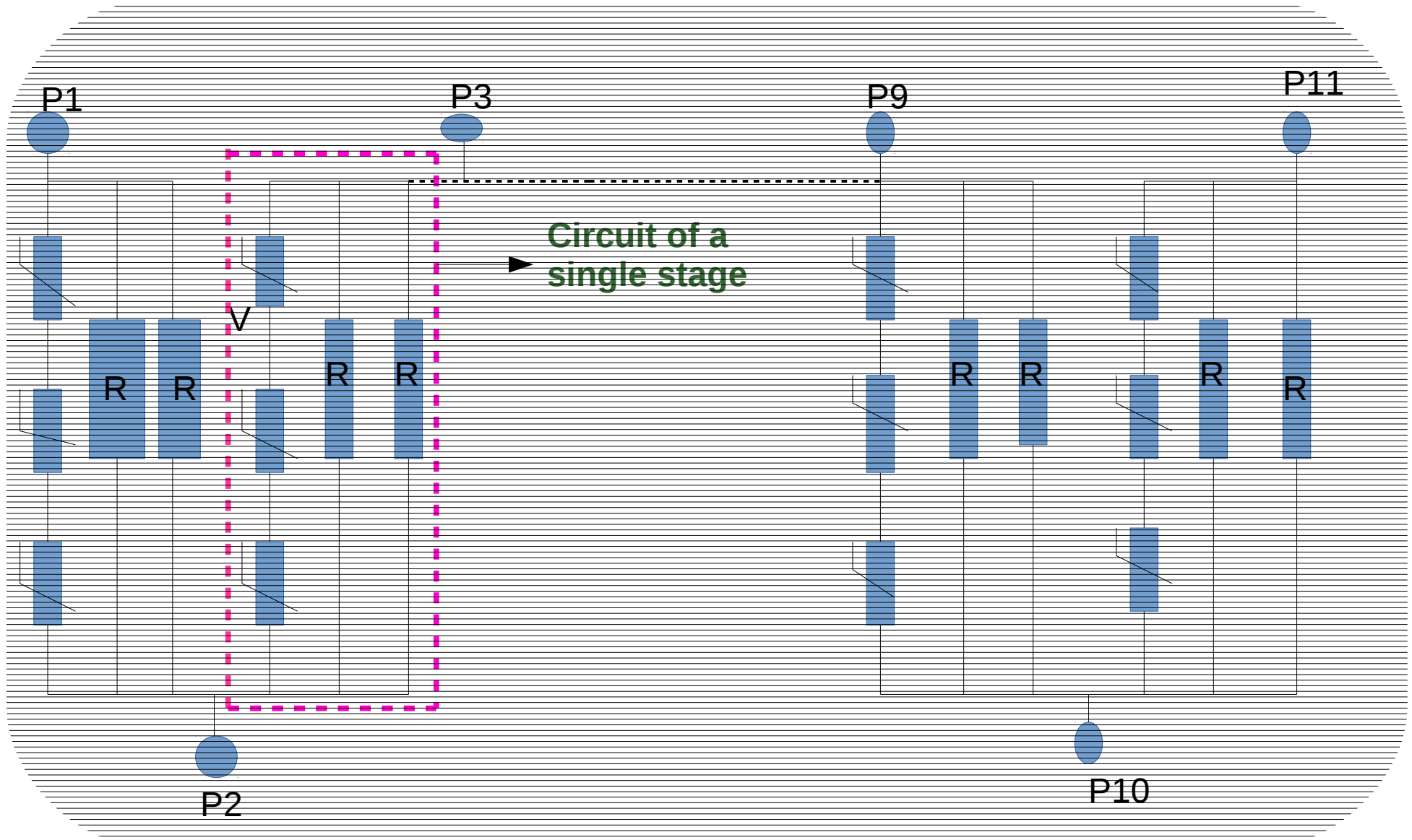
R= 2 Gohm, V= varistors, P1, P2, .. P11 connections with each profile

Components of the Divider Board

Elements	Values (unit)	Part#	Requirement for each board	#Total (with spare)	
Resistors	2 GOhm	SM102032007FE	20	200 (260)	
Varistors	3 varistors in series	ERZV14D182	30	300 (400)	
Connections with profiles	M4 size brass screw		11	110 (150)	
Nuts and washers			11	110 (150)	

Requirements of the Divider Board

Parameter	Values	units	notes
FC-resistance tolerance	+- 1	%	
FC- total resistance tolerance	+- 1	%	
Electric field tolerance in a single stage	150*	%	750 V/cm in

*Number taken from single phase design.

Divider Board Dimension in 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	10	
Distance between two profiles	60 mm	
Total number of PCB board for entire volume	10 (20)	Number of boards will be 20 in case of 2 rows.
Length of each PCB board	(10x60 mm) + 15 mm+ 15 mm = 630 mm	
Width and thickness	61 mm wide, 3mm thick	
Current flowing	3 uA(6uA)	
Resistance in each stage	1 Gohm (0.5 GOhm)	2 resistors in parallel (each of 2 Gohm)
Varistors in each stage	3 varistors in series.	Clamping voltage each varistor is 1.8kV, total =5.4 kV
Voltage drop between two profiles	3 kV	

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 top.
- Through the capacitive contact of the tap with the profiles.
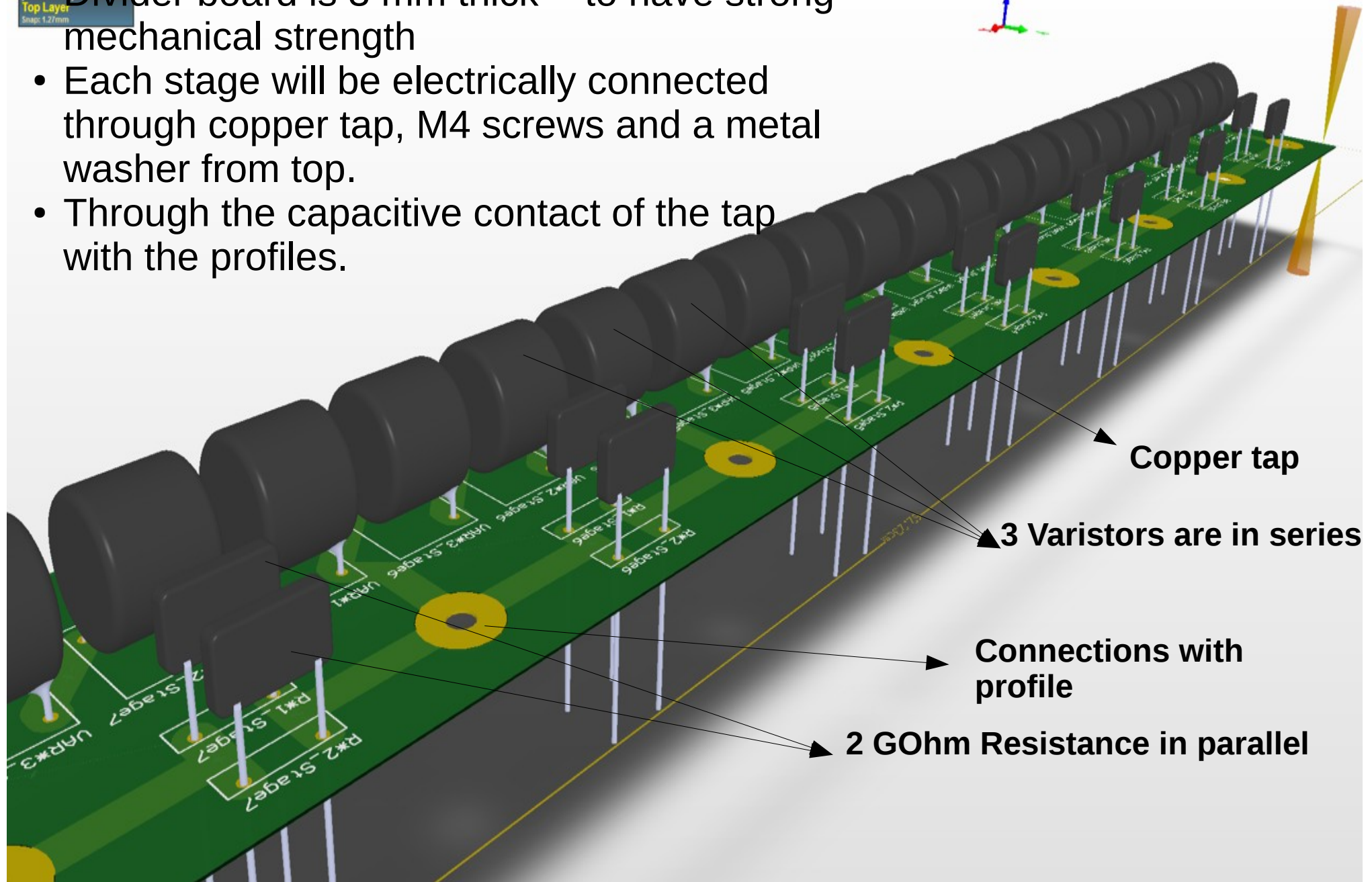
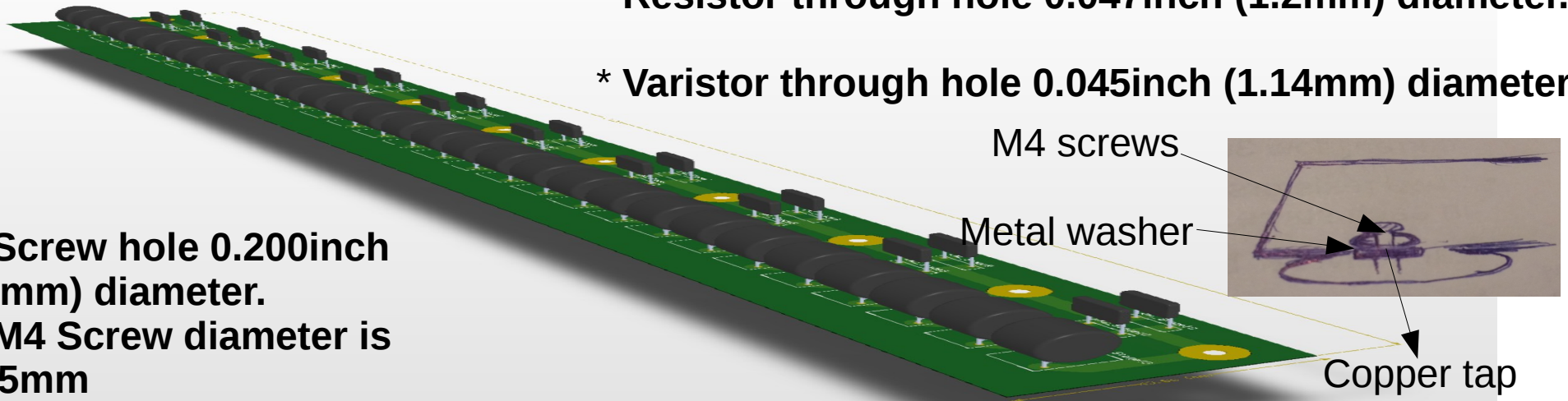**Copper tap**

3 Varistors are in series
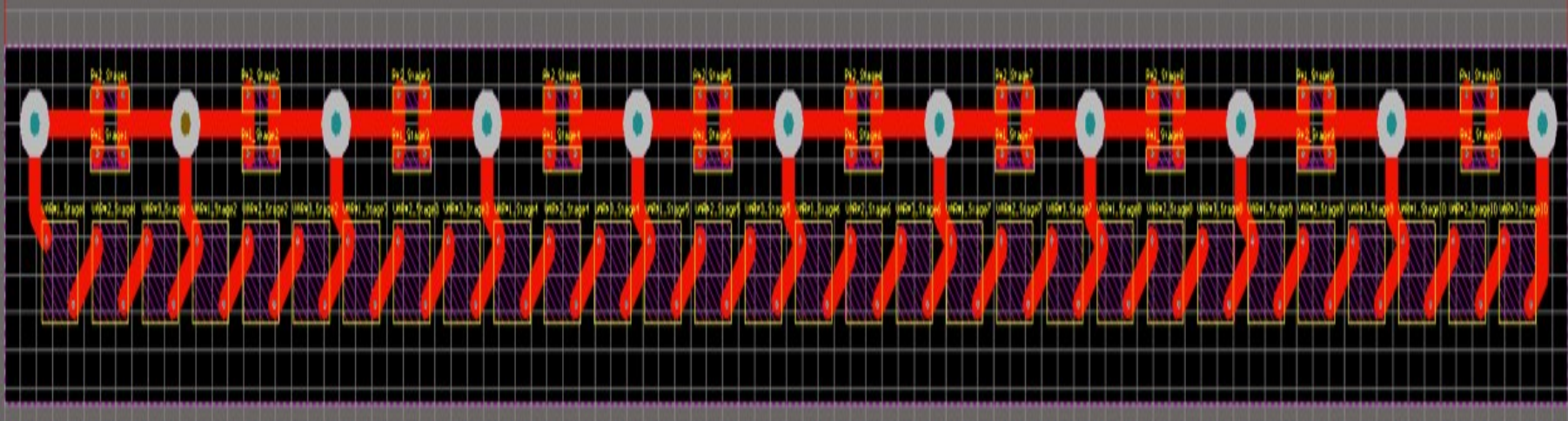
Connections with profile

2 GOhm Resistance in parallel

Top and Bottom view

* Resistor through hole 0.047inch (1.2mm) diameter.

* Varistor through hole 0.045inch (1.14mm) diameter.

M4 screws

Metal washer

Copper tap

* Screw hole 0.200inch (5mm) diameter.
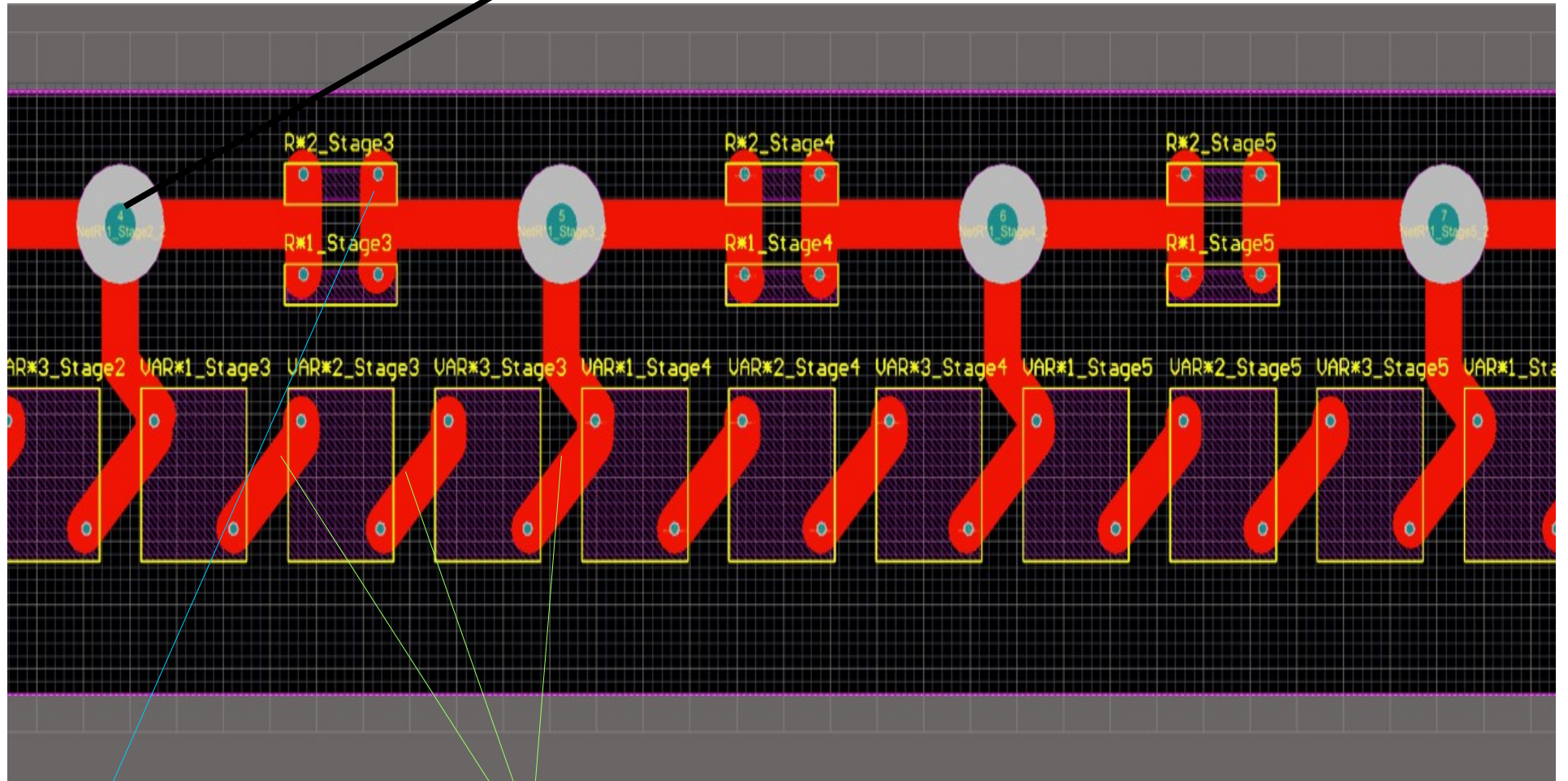* M4 Screw diameter is 4.5mm

* 2oz (0.0028inch) trace thickness top and bottom.

Bottom Layer: Close View

Capacitive contact with profiles

Resistors connections

3 varistors connected in series (in parallel with resistors)

HV Divider Board : Summary

- Voltage difference between the first field shaper and the cathode is 294 kV.

- Two(4) resistors and 3(6) varistors in series are in parallel in each stage.

- Each divider board will connect 11 profiles.

- Mechanical and electrical connections will be through the M4 screws and washer.

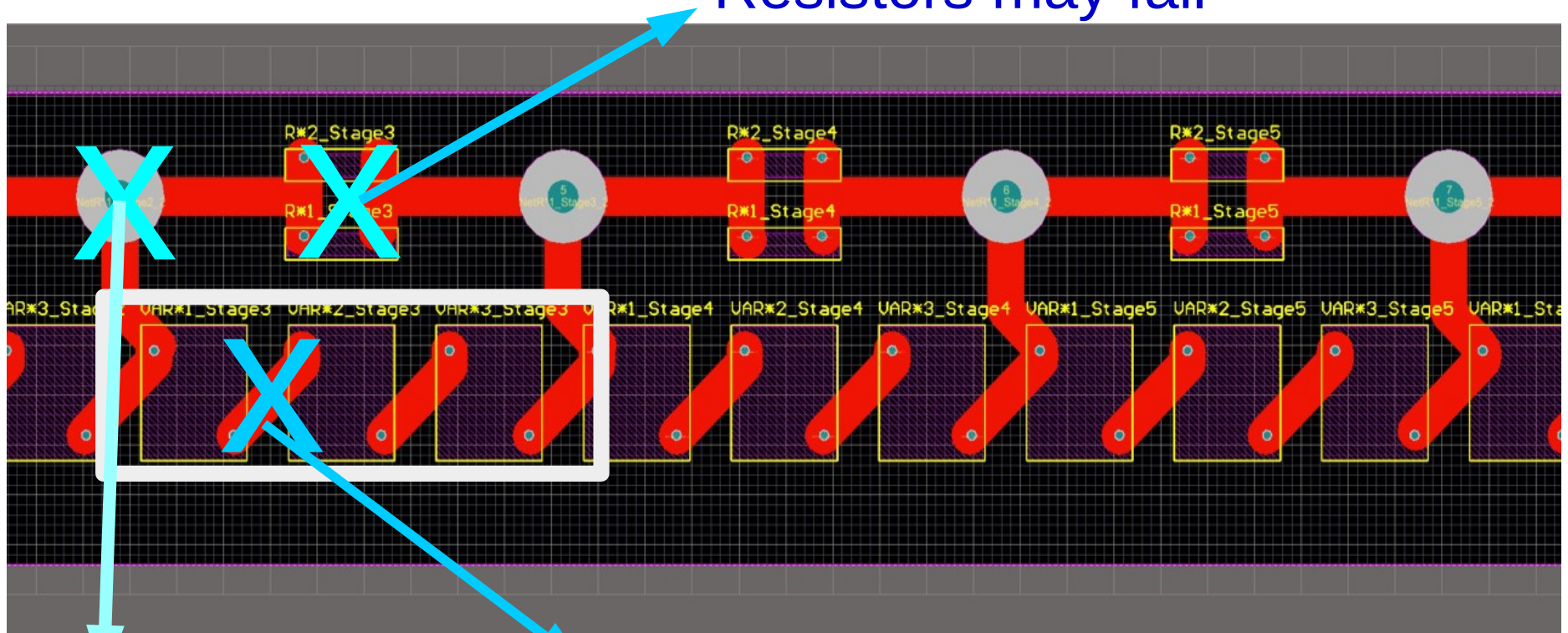- Copper tap at the bottom will provide additional redundancy in electrical connections.

Are we missing obvious points for the design of the board?
Any question, comments at this point?

Use One or Two Rows of board?

# Cases of divider board Failure

Resistors may fail

Electrical connection with the profile may break

One of the Varistors may not work

Condition	Circuit operation	Note
1. If one of the resistors in a stage fails	Current will flow	Current change is 1%.
2. If both the resistors fail in a stage	Current will flow	Current change ~ 1%
3. If both resistors and varistors fail in a stage	No current flow	

Redundancy : Two divider board in parallel

- Redundancy

  - Two divider board in parallel

- 4 resistors in parallel of value 2 GOhm each.

- Total resistance in each stage = 0.5 GOhm.

- Current = 294 kV/49 Gohm = 6 uA.

- Current flow in case of one column of PCB board is 3 uA.

- Number of necessary electrical components will be double.
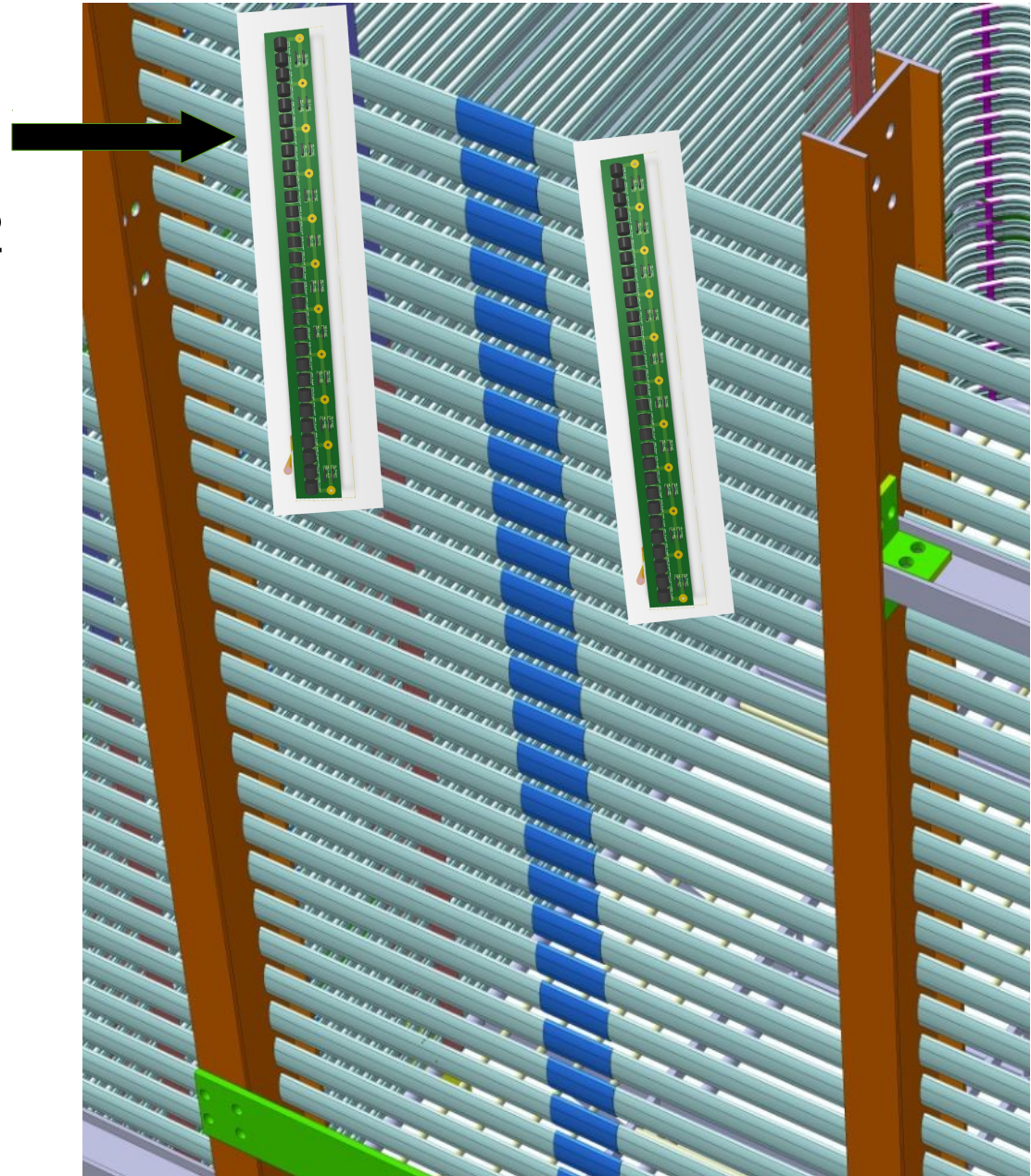
Advantage and disadvantage of having two boards in parallel

- Advantage : More effective in term of sustainability of electrical connection.

- Chances of failure will be greatly reduced.

- Disadvantage : More current flow, but within the limit of the current drawn by the supply.

- Double the number of components.

It will be better to have two rows board in parallel in-order to reduce failure.

Testing and Production Plan

- Will test the divider boards, resistors, and varistors both in warm and cold.

- Resistors :

    - Measure the resistance from I-V curve both in warm and cold for each individual resistors, repeat the process for 3 times.

    - Select the appropriate one within its tolerance.

- Varistors :

    - Do the same as resistors.

    - Measure the clamping voltage and select the proper one according to the tolerance of the clamping voltage.

- Divider board :

    - Electrical continuity

   - Voltage drop in each stage.

Conclusion

- 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.

- Divider board design is in place, needs to signed off the design of the board.

- Make a conclusion how many chain of board do we need?

- Test all the components and the board in warm and cold condition.

- Complete the production of the board within time-schedule(August 15, 2017).

Thank You

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 Gohm * 1 nF = 1 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.
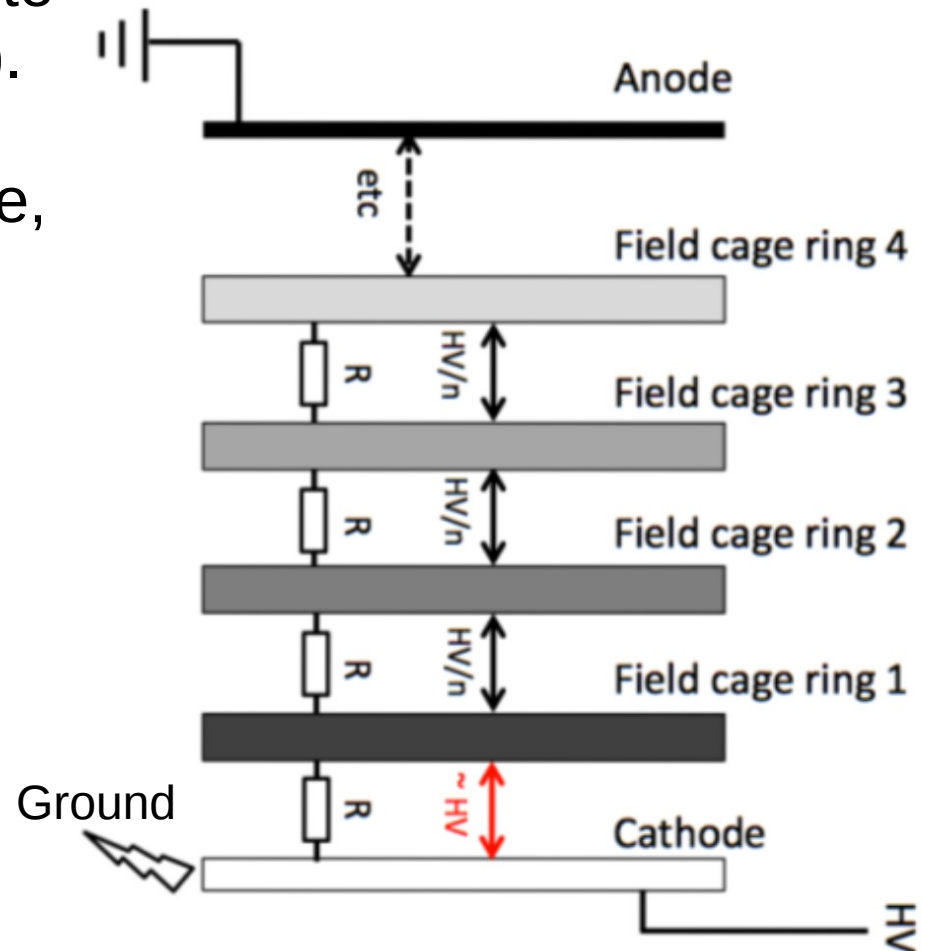
With Varistors

- Varistors have noon I-V characteristics.

- During the discharge, the voltage difference will be much higher than the clamping voltage of the varistors

- The resistance will go 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.
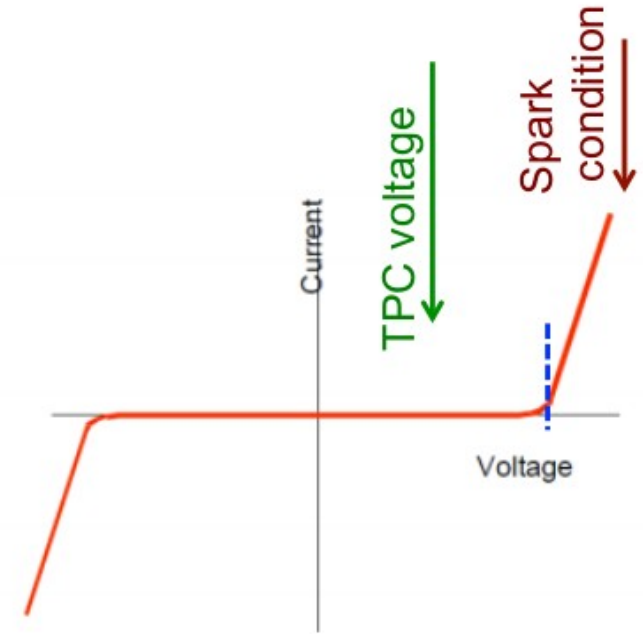
Without varistors
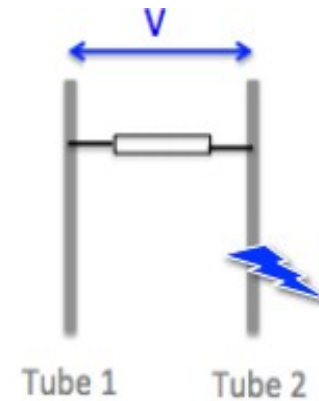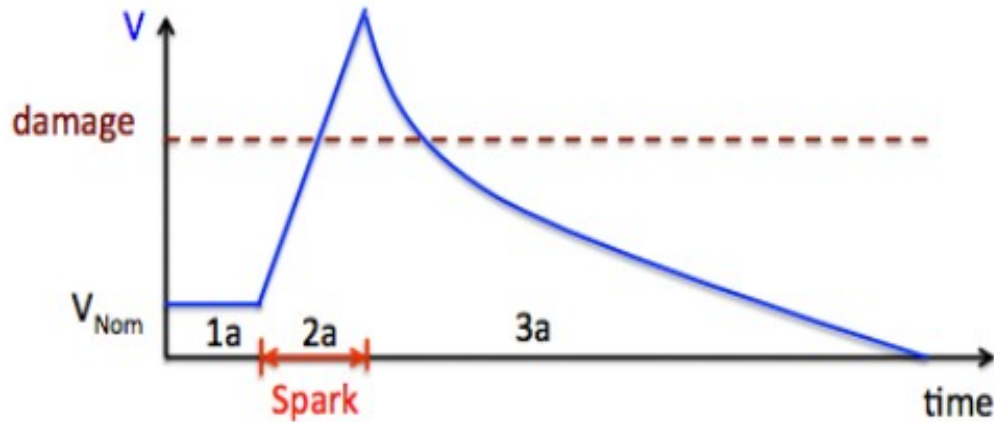
With Varistors
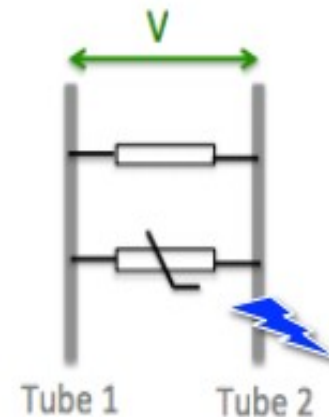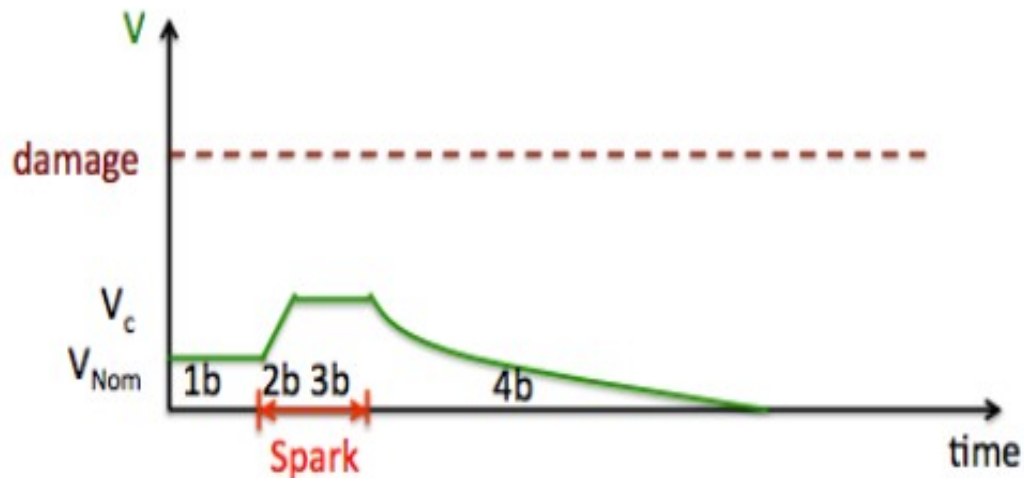
- With the varistors, the voltage never increases than the clamping voltage.
- It also helps G10 and argon breakdown.