High Voltage Distribution: Design and Performance

Saba Parsa, L3 HV Subsystem Lead

ND-LAr Preliminary Design Review

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Schweizerische Eidgenossenschaft
Confédération suisse
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U.S. DEPARTMENT OF ENERGY | Office of Science

Who am I (or We with subsystem lead and engineer)

- Saba Parsa
  - Postdoc at University of Bern since April 2021

Outline

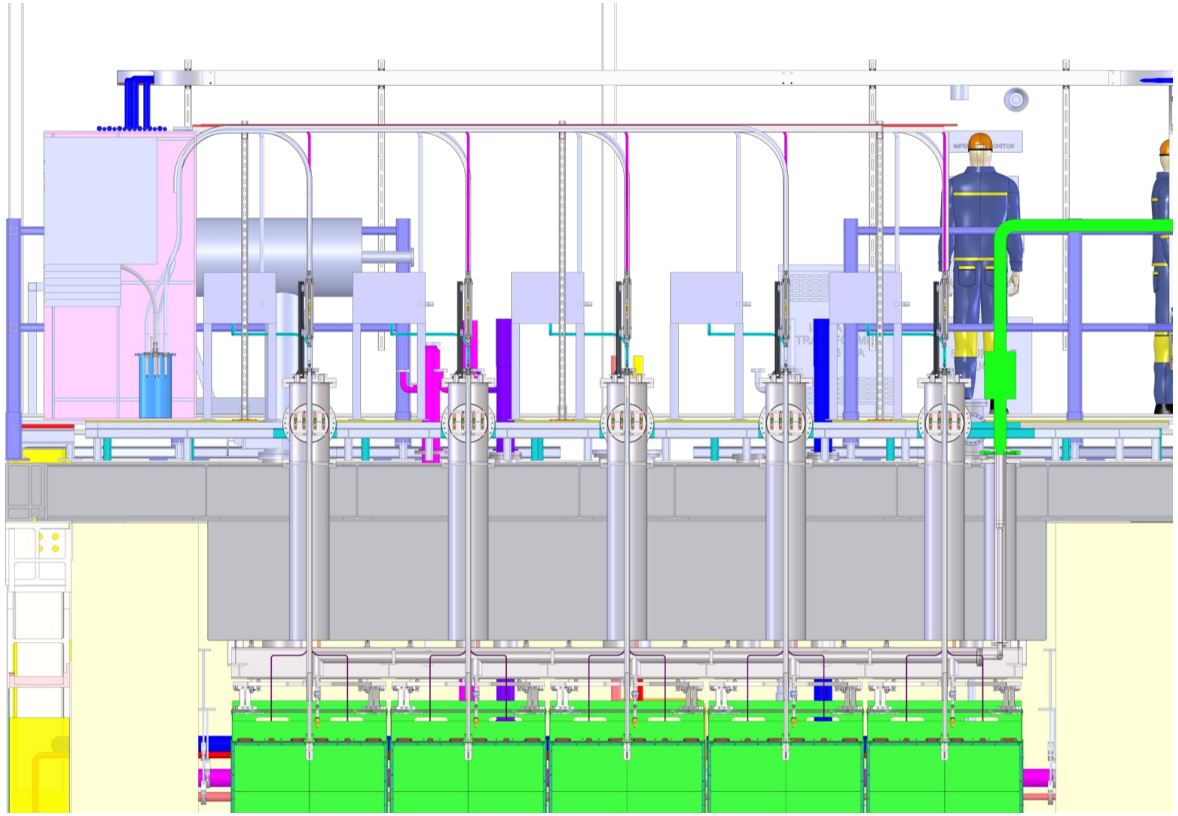
- Key Documents (table)
- Design elements & status / CAD model
- Key Analyses / Performance Assessment
- EH&S / Codes & Standards
- Summary

Key Documents

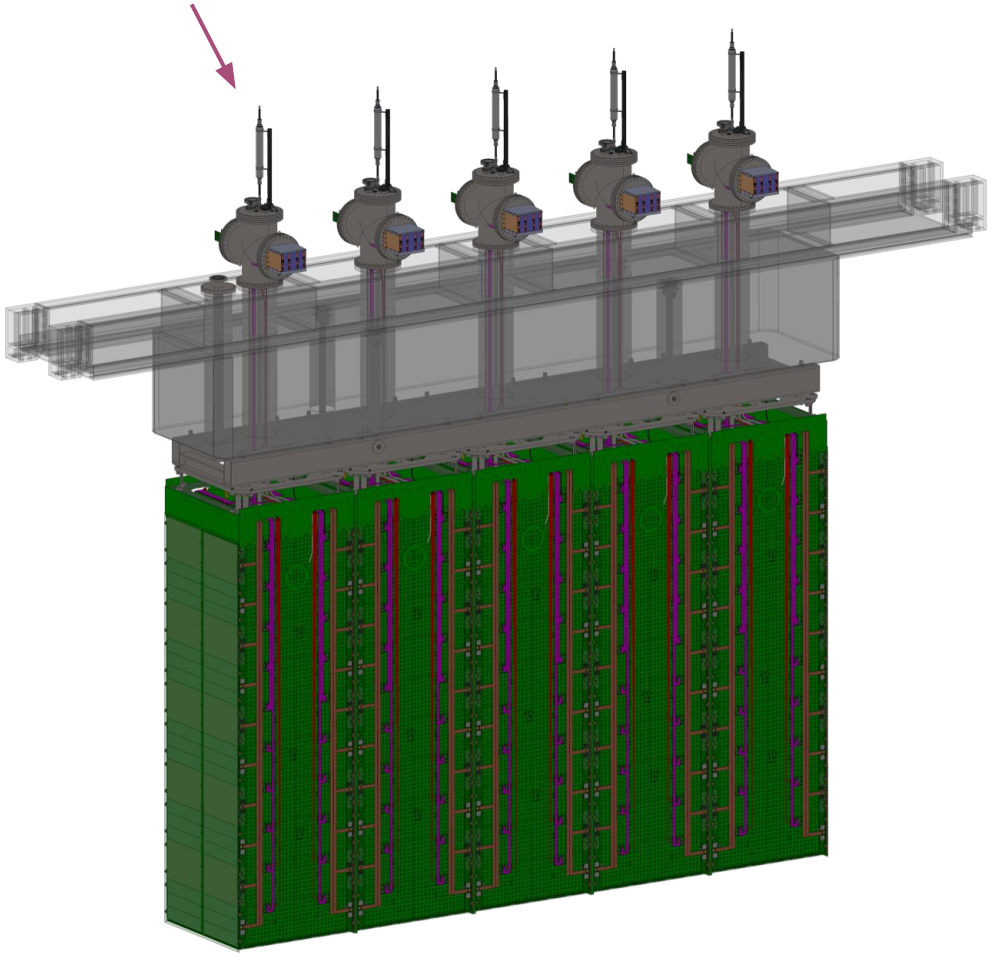
HV Documentation	Description	EDMS links
High Voltage folder	Top level folder for High Voltage documentation	https://edms.cern.ch/project/CERN-0000217526
Requirements	Spreadsheet with all ND-LAr requirements, see sheet “High Voltage”	https://edms.cern.ch/document/2589287
Interface	Interface control documents (ICDs) internal to the ND-LAr Consortium	https://edms.cern.ch/project/CERN-0000223195
Analyses	HV distribution system technical description	https://edms.cern.ch/document/2588658
Procurement Plan	Subsystem Procurement plan	https://edms.cern.ch/document/2611199
Manufacturing Plan	Subsystem Manufacturing plan	https://edms.cern.ch/document/2611198
QAQC Plan	Subsystem QAQC plan with focus on high-level QAQC test plans	https://edms.cern.ch/document/2611197
Previous Review Tracking	Spreadsheet with previous review recommendations, see ”High Voltage"	https://edms.cern.ch/document/2741842
Cost	High-level cost estimate for ND-LAr and subsystems	https://edms.cern.ch/document/2742778
Schedule	High-level "one-pager" schedule for ND-LAr Consortium activities	https://edms.cern.ch/document/2603073
Mechanical Component Drawings	Subsystem mechanical component drawings	https://edms.cern.ch/project/CERN-0000220720
Mechanical Assembly Drawings	Subsystem assembly drawing	https://edms.cern.ch/document/2747038
Electrical Schematics and Board Layouts	Subsystem electrical schematics and board layouts	https://edms.cern.ch/project/CERN-0000223249

Design Elements & CAD Model

HV Distribution Subsystem CAD model



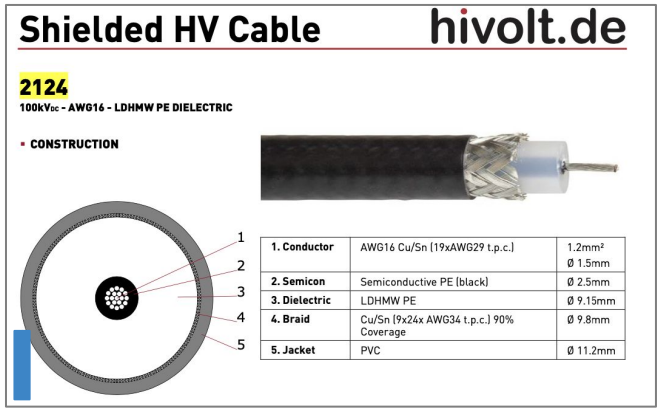
HV cables Arriving on top of the modules
See Field Structure Subsystem



Design Elements - Overview

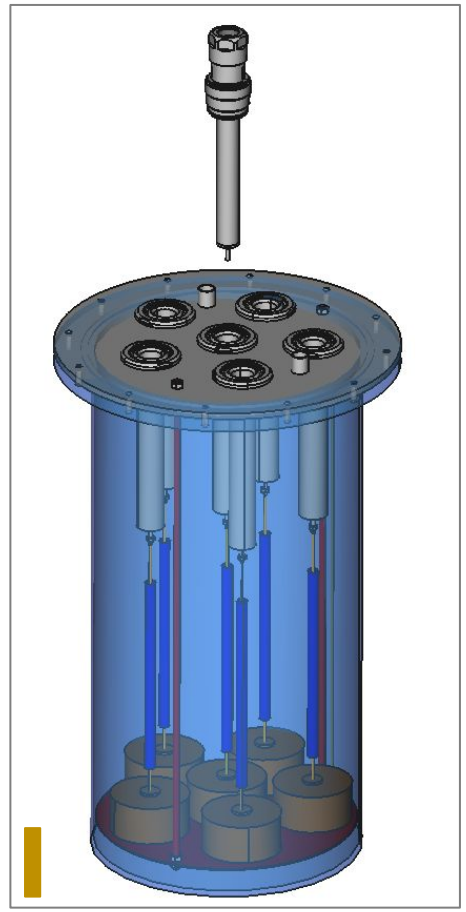
Item	Rated Voltage	Rated Current	Impedance	Expected Nominal Voltage/Current
HV PS (Spellman eSL50x300)	50 kV	6 mA	-	25 kV , 2.5 mA
HV Cables (hivolt.de)	100 kV	-	61 Ω	
HV Connectors (HC7-50A)	75 kV	30 A	-	
HV Filter (PFD-5)	50 kV (input)	6 mA	-	

HV Power Supply



HV Cables

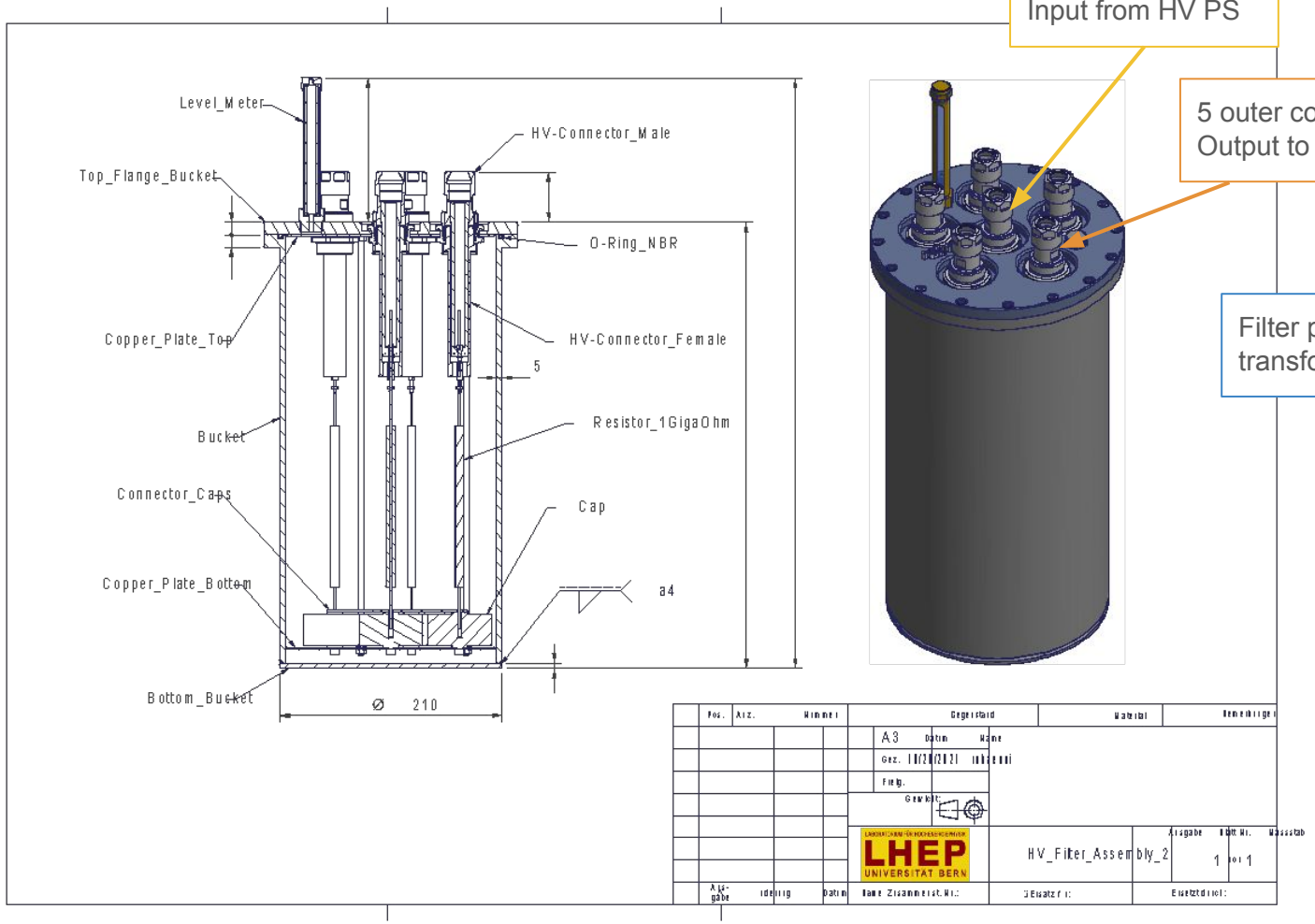
HV Connectors



HV Filter

Design Elements & CAD Model

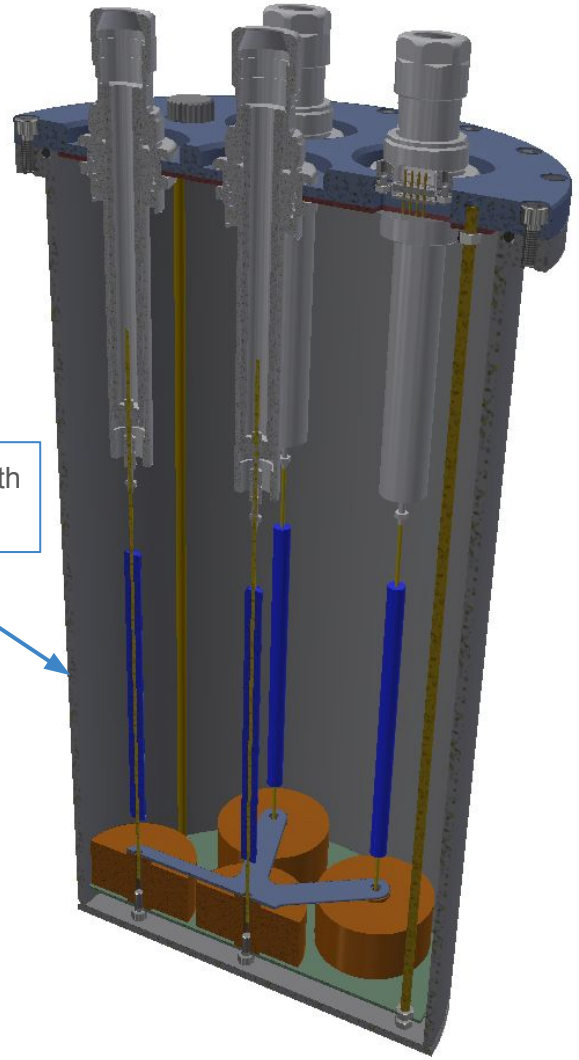
HV filter, PFD-5



Central connector:
Input from HV PS

5 outer connectors:
Output to Modules

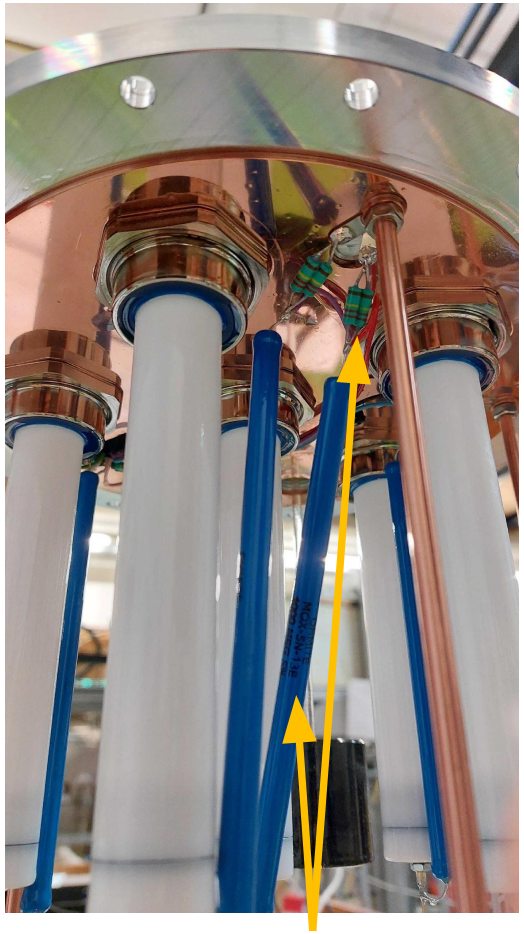
Filter pot is filled with
transformer oil



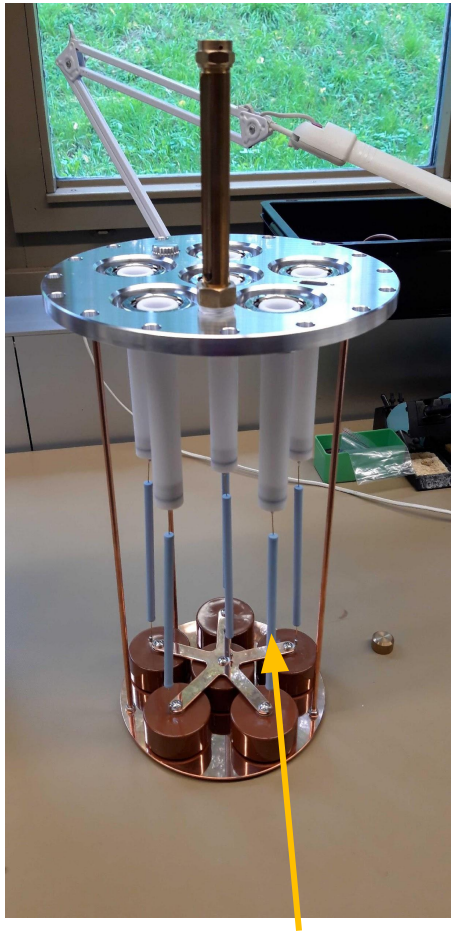
HV Filter, PFD-5 inner view

LBNF/DUNE

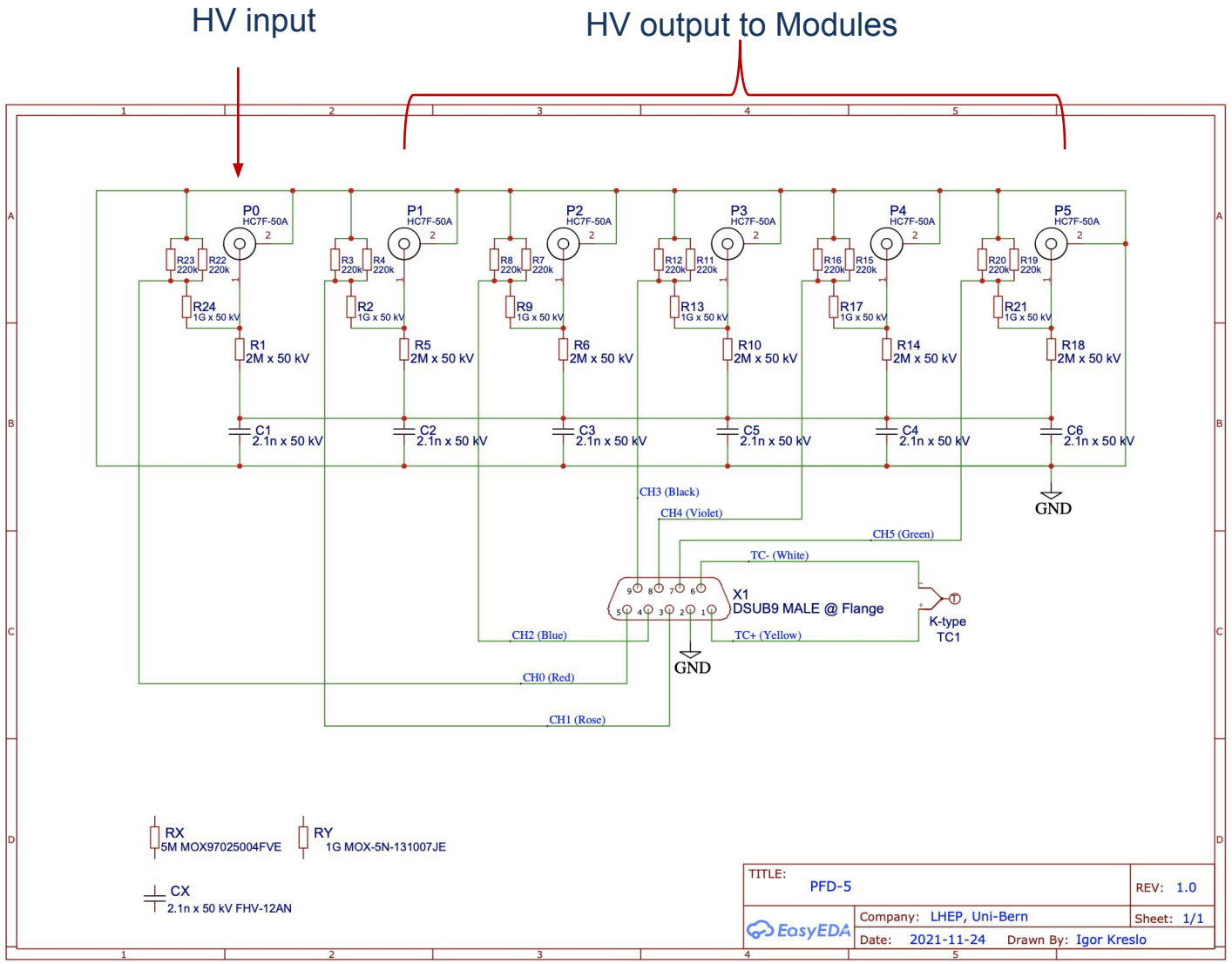
Electrical schematic of PFD-5



Voltage divider resistors for HV monitoring



Decoupling resistors 2 MΩ



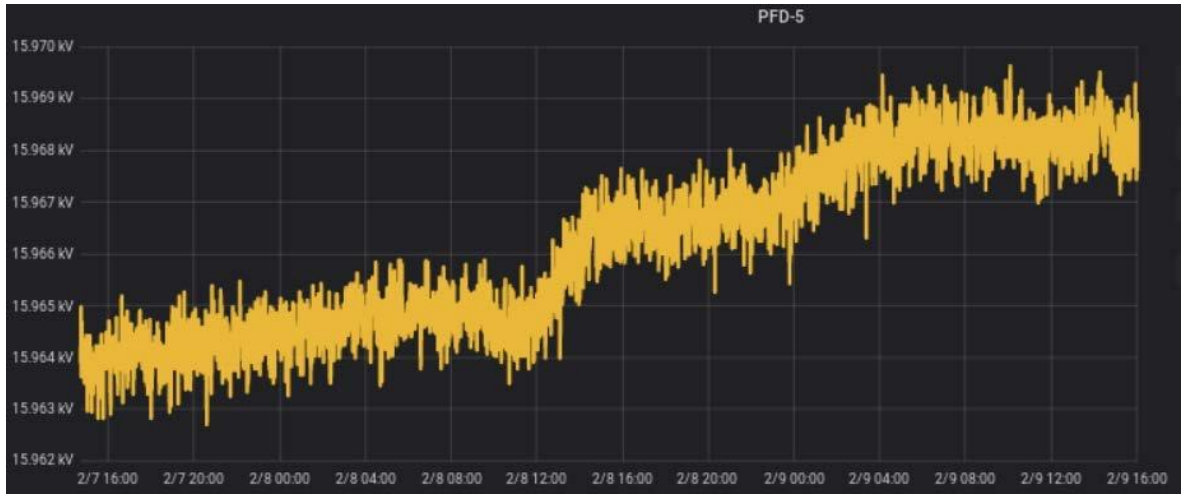
LBNF/DUNE

Electrical Analysis, Performance Assessment

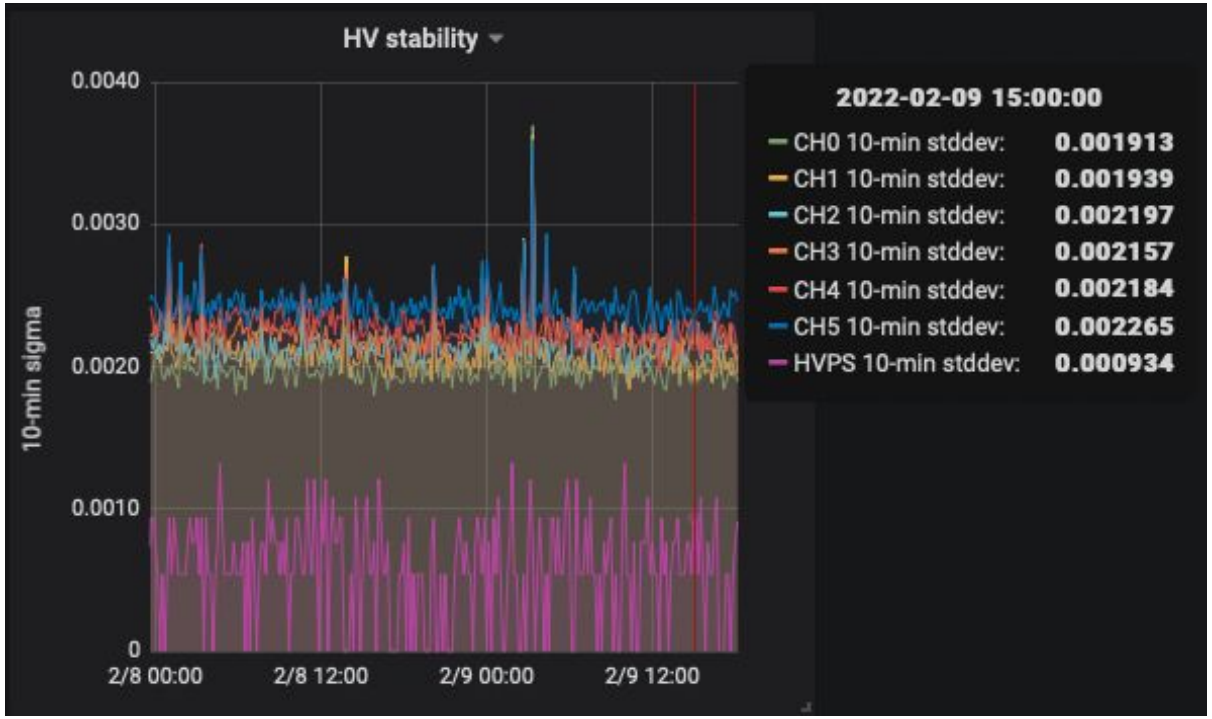
HV-002 requirement

Variation of HV shall be 0.1% at f<1Hz

https://edms.cern.ch/document/2588658



@ 15 kV: Example peak to peak variation <5V or 0.03%, well below 0.1% of required.



@ 15 kV: Fluctuations on output channels (10 min σ): ~ 2 V
Data from Module-1 run, February 2022

Electrical Analysis, Performance Assessment

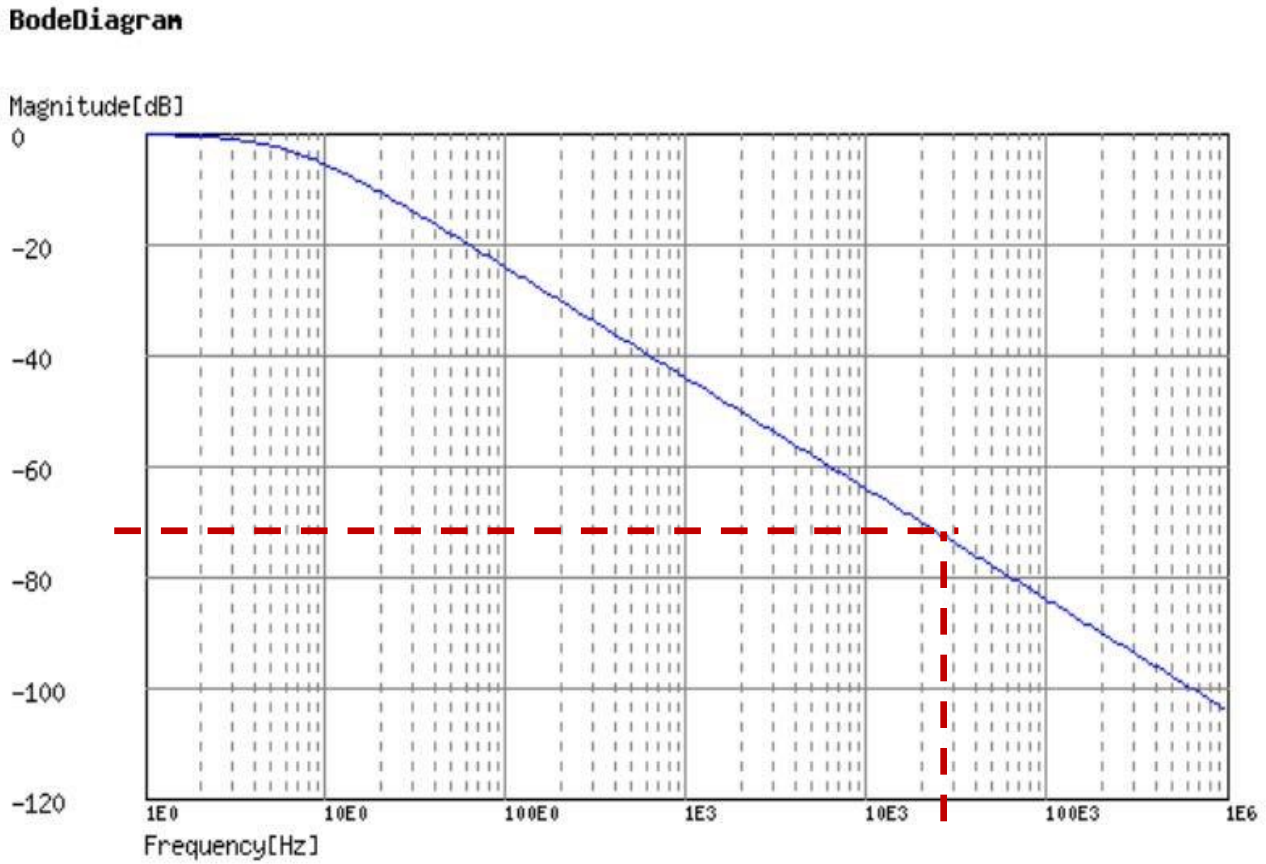
HV-003 & HV-004 requirement

Variation of HV shall be < 4mV (1Hz< f <100 Hz)

https://edms.cern.ch/document/2588658

- Spellman ripple voltage < 14V p-p at nominal 32 kV (25 kV at the PFD-5 output)
- At 25 kHz of conversion frequency the filter rejection ratio is approximately -72dB
- -> Resulting residual ripple pf <3.5 mV p-p

- During 2x2 Module-1 run, no regular noise was observed on the charge data as a function of HV.



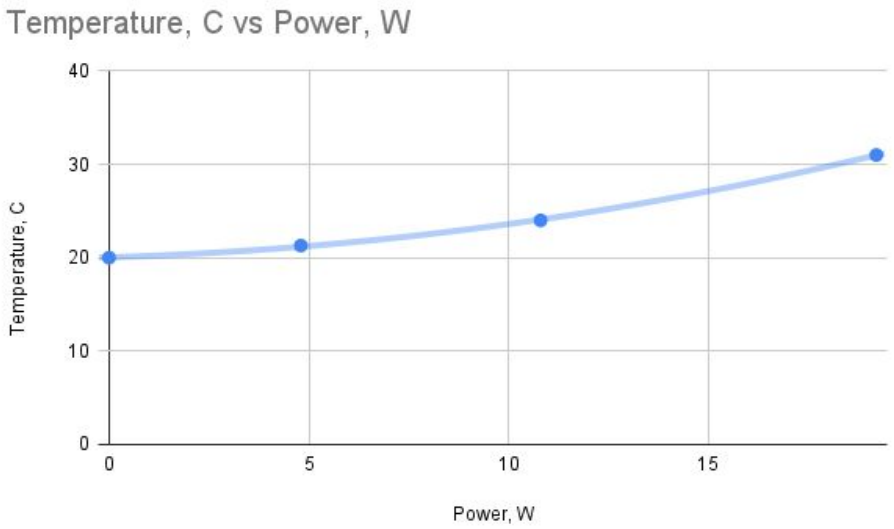
Thermal Analysis

https://edms.cern.ch/document/2588658

Oil data sheet: https://edms.cern.ch/document/2588690

- Resistors in the circuit of the PFD-5 dissipate heat
- The heat is transferred by the Nytro 10 XN transformer oil within a cylindrical aluminum pot 26 cm in diameter, 41 cm high, to the outer wall and is dissipated to the atmosphere.

- 2x2 Module-0 run measurement of equilibrium temperature as a function of dissipated power in PFD-4 prototype (below)



V_Cathode [kV]	25.000	35.000
R_Module [MΩ]	51.250	39.406
V_HVPS [kV]	30.854	45.658
I_HVPS [mA]	2.439	4.441
P per module [W]	12.195	31.0886
P dissipated in filter [W]	14.277	47.332

- Expected oil temperature of PFD-5 with 5 modules operational is ~45 ˚C, well below 140˚C of the oil flash point

ESH Codes and Standards

- Adheres to all ESH codes/standards established by LBNF/DUNE Project plus home institutional ESH requirements
- All Near Site deliverables must satisfy FNAL FESHM requirements
  - **2x2 Program providing experience through ORC process**
- Specifically, ND-LAr has completed an initial review of applicable areas of FESHM, found at EDMS 2602421

  Applicable topics for HV distribution subsystem:

  FESHM 9100 - Fermilab Electrical Safety Program FINAL

  FESHM 9150 - Requirements for Experimental and Accelerator High Voltage Utilization Equipment

  FESHM 9190 - Grounding Requirements for Electrical Distribution and Utilization Equipment FINAL

  FESHM 6020.5 Flammable and Combustible Liquids FINAL

- ND-LAr has also completed a Hazard Registry in coordination with the ND sub-project, found at EDMS 2663898

Summary

- The CAD model and associated design documentation is developed
- The analysis described in the slides supports the design of the HV distribution system in the context of fulfilling subsystem requirements for the ND-LAr detector and safe operation.
- HV distribution system is ready to move towards final design and production of Full-Scale Demonstrator prototype

Backups

Accidental rapid ramp down of HV during 2x2 Single module run

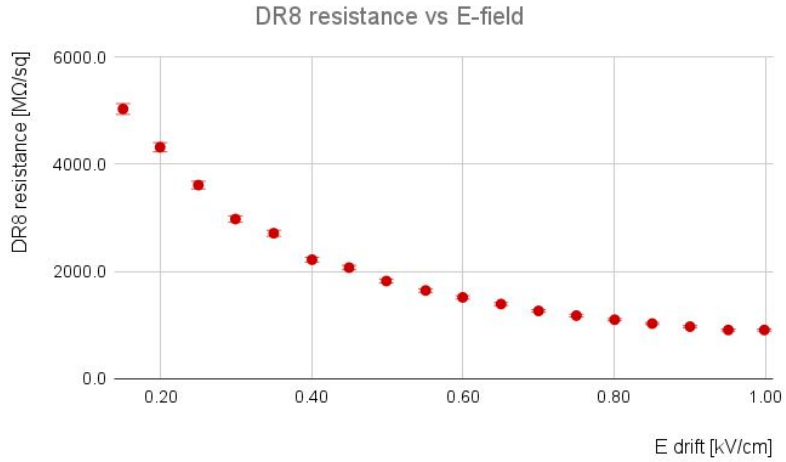
No damage to the charge/light readout electronics

-> Implementation of slow ramp up/down, limited to 1 kV/s

Data from Module-0 run, March 2021

Expected HV values

Based on 2x2 Single module operation



2x2 Module: squares per module	ND-Lar Module: squares per module
0.041	0.031

DR8 surface resistance GΩ/sq		
at 0.5kV/cm	at 0.7kV/cm	at 1kV/cm
1.64	1.261	0.904

HV Measurement/Calculation for 2x2		
E drift, kV/cm	0.5	1.0
Vcath, kV	15.100	30.200
R module, MΩ	66.570	36.695
I module, mA	0.227	0.823
V_HVPS, kV	27.196	72.860
I_HVPS, mA	0.907	3.292
P per module, W	3.425	24.855
P dissipated in filter, W	10.975	140.439

HV Calculations for ND-LAr one row			
E drift, kV/cm	0.5	0.7	1.0
Vcath, kV	25.000	35.000	50.000
R module, MΩ	51.250	39.406	28.250
I module, mA	0.488	0.888	1.770
V_HVPS, kV	30.854	45.658	71.239
I_HVPS, mA	2.439	4.441	8.850
P per module, W	12.195	31.086	88.496
P dissipated in filter, W	14.277	47.332	187.955