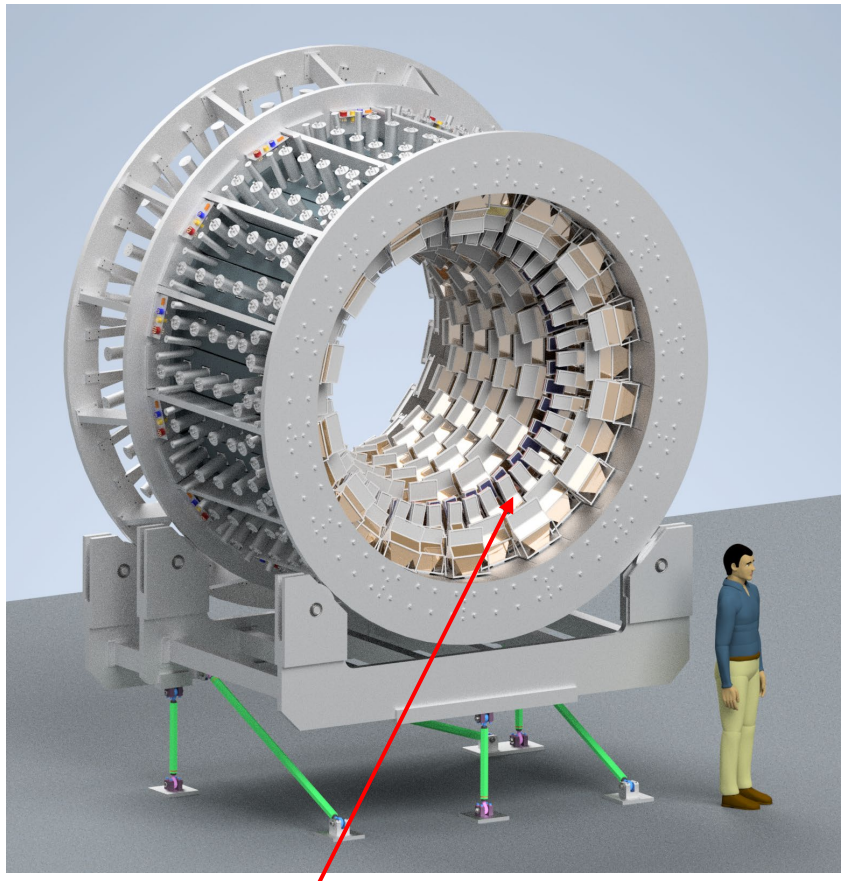
Main detector power needs and cables

Description:

The MOLLER main detector array includes 224 detector modules with components that require both high voltage and low voltage power supply.

The array is arranged into 6 rings numbered beam down-stream to up-stream.

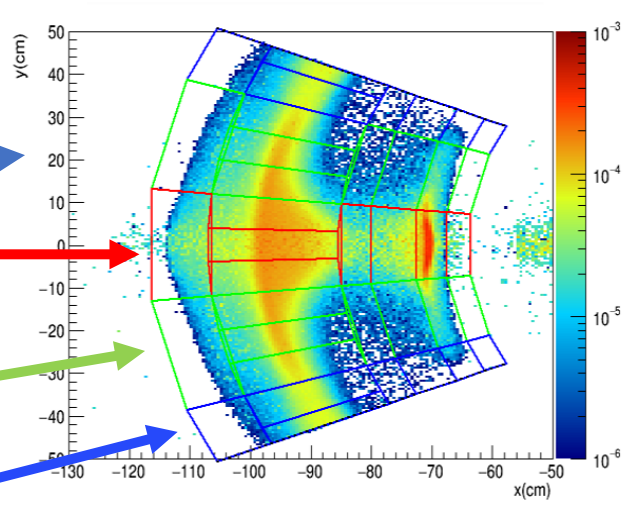
- Each module reads generated light signals via photo-multipliers (PMT), connected to front-end (FE) electronics that are incorporated into the module itself (see next slide)
- The incorporated FE electronics includes a PMT voltage divider with connected HV and two FE amplifiers, one for each of the two running modes of the experiment. The amplifiers require low voltage power to operate.
- Each module requires a high voltage connection to bias the PMT voltage divider
- The 84 ring 5 modules are also equipped with an array of 28 silicon pixel sensor chips for a total of 2352 sensor chips. Each of these requires a low voltage supply to operate and a higher voltage bias.

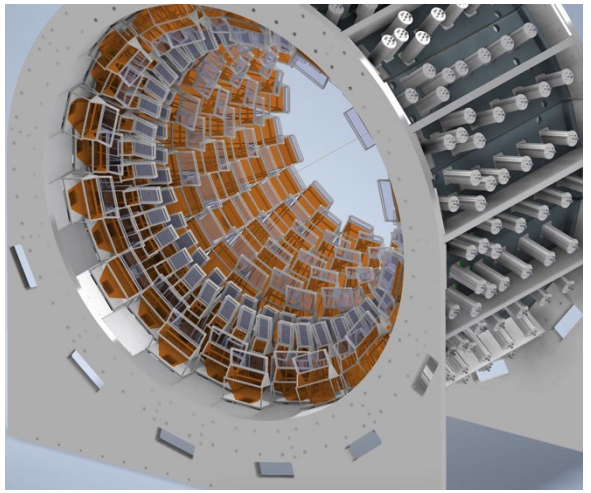


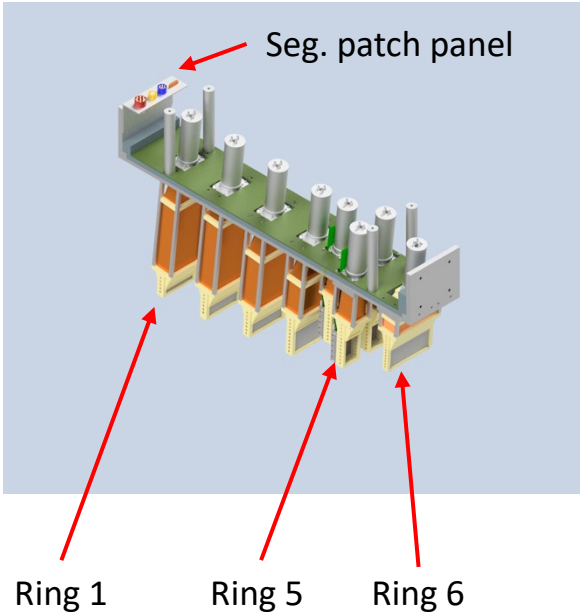
Main detector power needs and cables

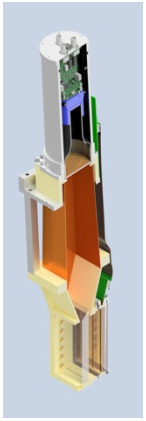
Nomenclature:

- Septant
- Sector (open, transition, closed)
- Segment (one of 28) with 8 detector modules
- Module





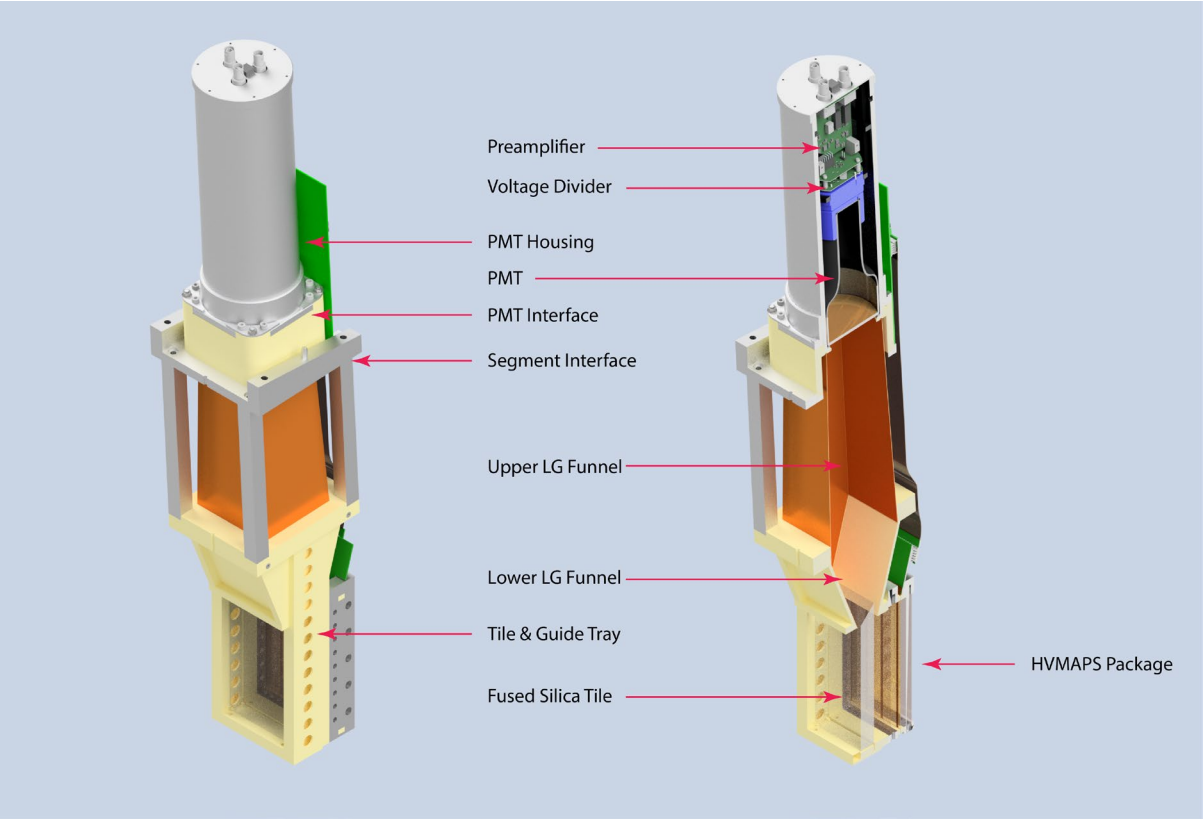




Main detector power needs and cables

1. Main Detector Quartz Modules

- 224 modules with one LV and one HV connection for each.
- Shown below is a ring 5 module, but all the other modules have the same structure and identical electronics.



Integration mode amplifier PCB

Event mode amplifier PCB

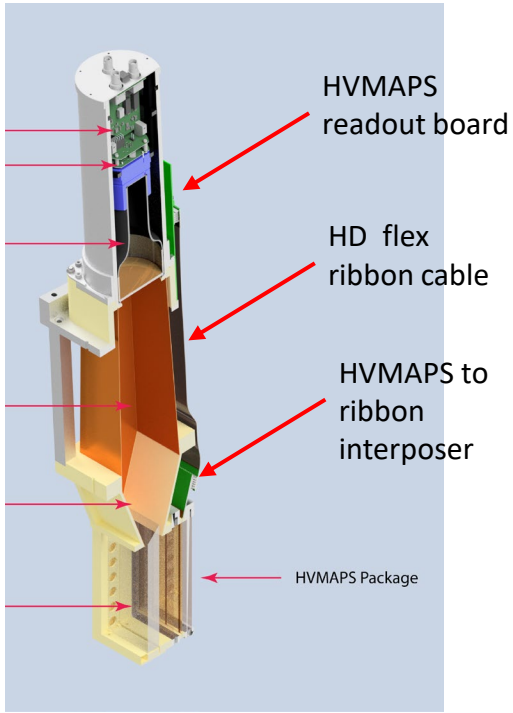
PMT voltage divider

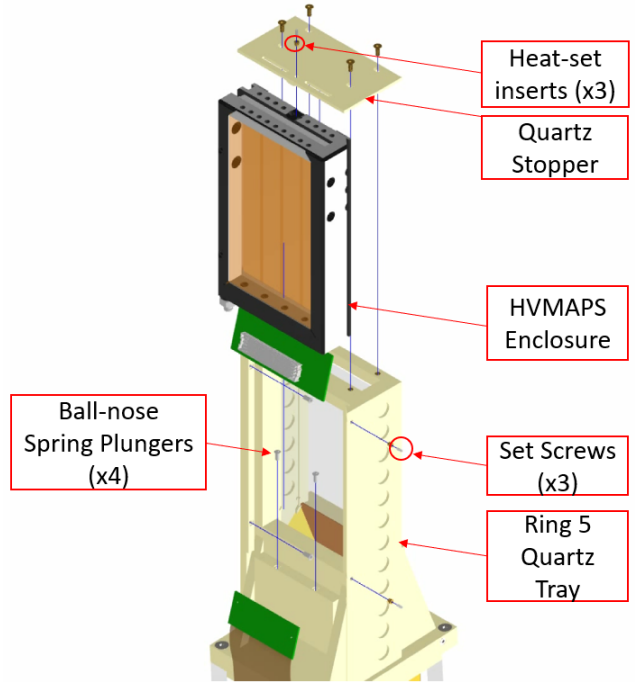
Main detector power needs and cables

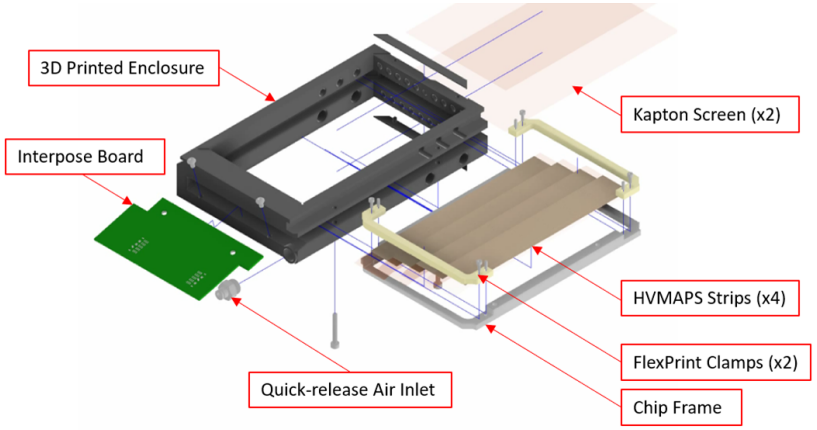
2. HVMAPS

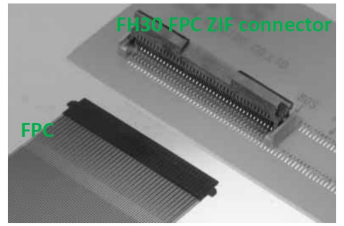
- Located behind each ring 5 quartz tile is an array of 28 pixel sensor chips called High Voltage Monolithic Active Pixel Sensors. The “high voltage” designation is significant only in comparison to other comparable pixel sensor technologies. The bias voltage is negative 60 – 100 V

- The HVMAPS chips are controlled (including low voltage supply) and read out via a readout board that will be located behind the PMT housing.

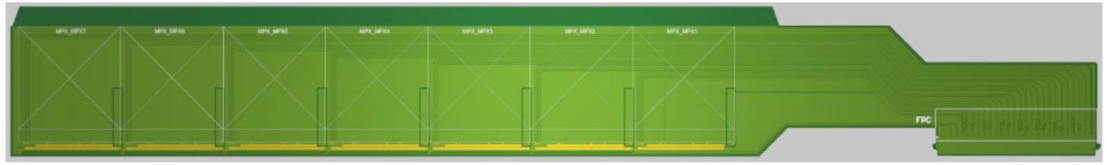








For each Ring 5 Quartz tile: TAB-bond 7 chips to a flex-print, have 4 such strips per detector



Main detector power needs and cables

2. HVMAPS

- Located behind each ring 5 quartz tile is an array of 28 pixel sensor chips called High Voltage Monolithic Active Pixel Sensors. The “high voltage” designation is significant only in comparison to other comparable pixel sensor technologies. The bias voltage is negative 60 – 100 V

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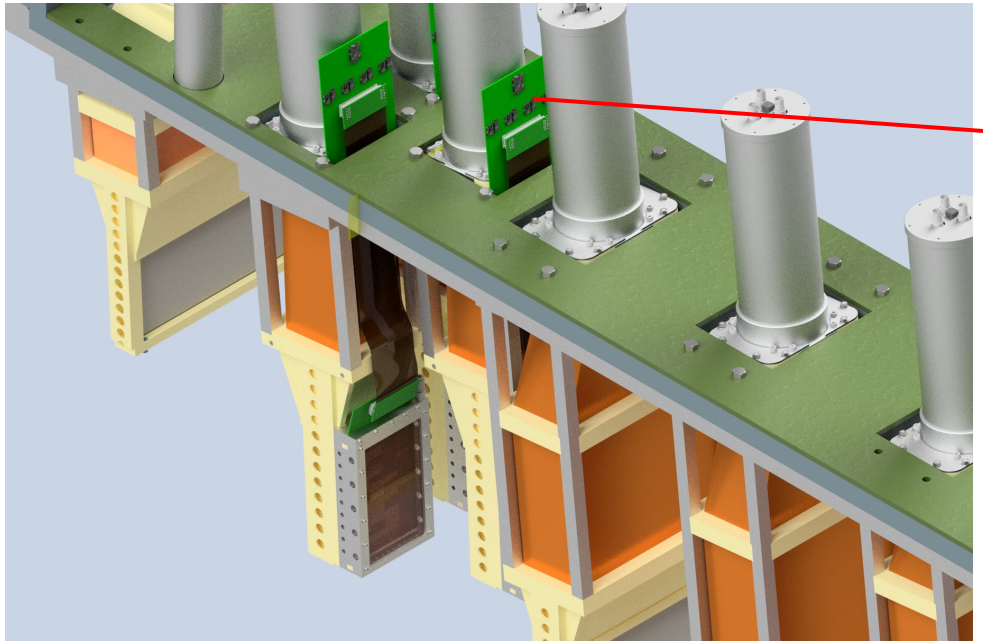
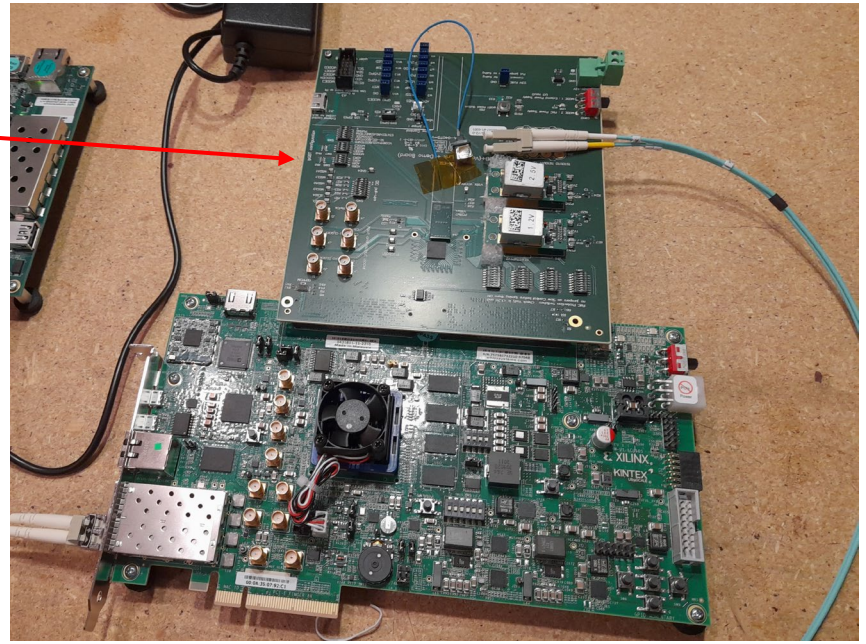




HVMAPS prototype readout board

Main detector power needs and cables

There are two possible locations for the power supplies :

1. **Cable run to GEM huts**
   - Longest one-way distance about ~25 meters along red line

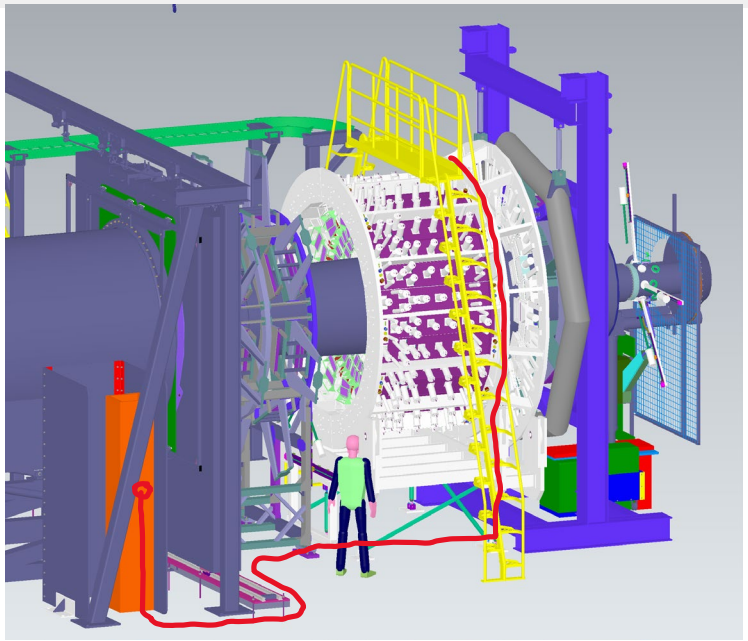
2. **Cable run to SBS bunker**
   - One way distance about ~70 m

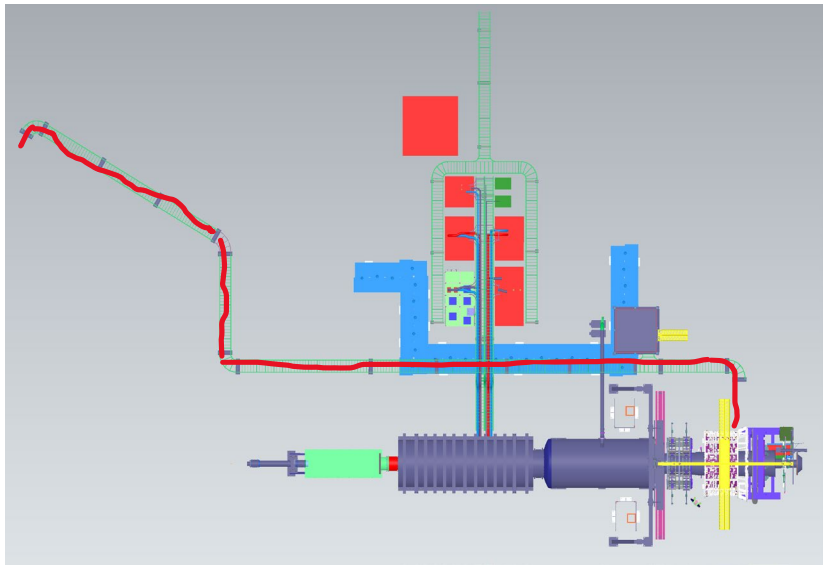
The two detector systems require different cable specs as far as current and voltage are concerned. In general the cable lengths should be the same for all elements within a given detector system.

For the thin quartz detectors (PMT signal) the HV is low current: $\leq 1\ mA\ @\ 1.2\ kV$ (max) For the quartz electronics low voltage $\leq 0.5\ mA\ @\ {\sim}10\ V$. These PS units can be located in the SBS bunker.

For the HVMAPS, each pixel sensor takes about ${\sim}1W\ @\ {\sim}2\ V$ operating and ${\sim}20\ \mu A\ @\ {\sim}100\ V$ bias, plus lower power needs for the readout board (more details provided on subsequent slides). But there are many of these.

The HVMAPS are noise and power stability sensitive. We are therefore planning to locate the HVMASP PS units unit in the GEM huts, close to the detector array.



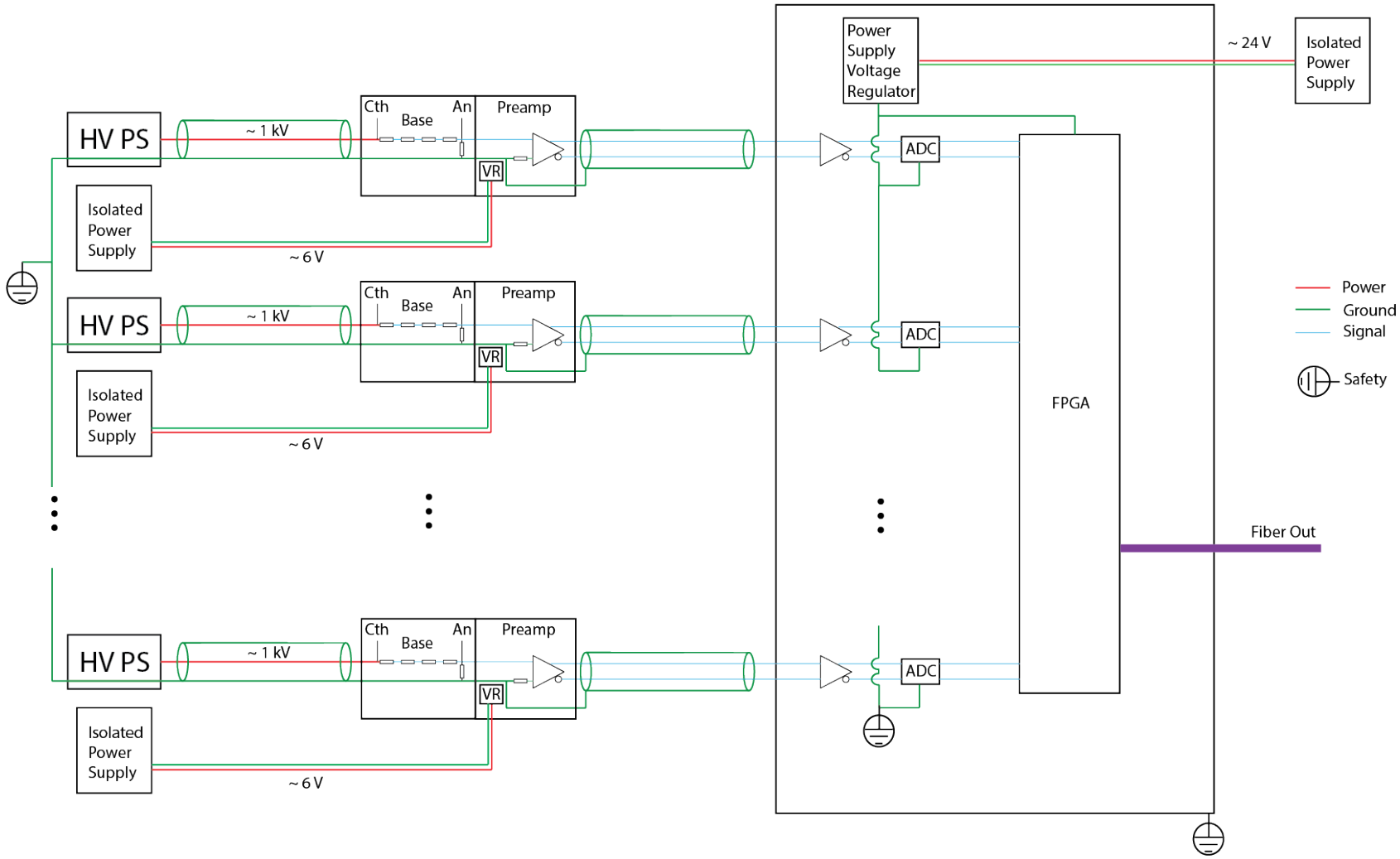


Main detector power needs and cables

Thin quartz detector grounding plans:

It is crucial for the experiment to avoid ground loops as much as possible. The figure on the right shows the planned grounding layout:

- Detector ground to safety at the HV end
- Preamps are powered from commercial LV isolated PS
- ADC boards are powered via POE with isolation on the board via regulators.
- Preamps and ADCs have voltage regulators
- In the figure, ground lines (green) are only connected to components (black boxes) if the line is ending in/on the box
- The ADC modules and electronics have separate connection to safety; hopefully well isolated from the HV safety



Main detector power needs and cables - Details

1. Thin Quartz LV (original DC/DC converter option)

- 224 modules with one LV connection each.
- The LV connection on each module supplies power to the integration mode and pulse mode amplifiers and the switching relays via three DC/DC converters. The modules are designed to switch between the two modes via switching the LV polarity.

Per Module:

- Integration mode: $V_I = +5.6V$
- Pulse mode: $V_P = -5.6V$
- Integration mode current: $I_I \simeq 400\ mA$
- Pulse mode current: $I_P \simeq 200\ mA$
- Max power: $P_I \simeq 5.6 \times 0.5 = 2.8\ W$ (includes ~20% safety factor) this is continuous in production mode

Cables:

- We need to stay $|V_{I,P}| \geq 5.3\ V$. So we need to know the voltage drop along the cables
- 200 m AWG 18 (RG141 if need be) $\Delta V \sim 2V$ (SBS bunker distance x 2) – this might be too large, depending on PS unit
- 200 m AWG 18 (RG141 if need be) $\Delta P \sim 1W$
- Used central conductor size for coaxial cable and return shield (not clear to me how accurate this is – return is braided sheet)
- Assume 50 mm bend radius for RG141 (5 mm diameter x 8)

Main detector power needs and cables - Details

1. Thin Quartz LV (new DC/DC converter option)

- 224 modules with one LV connection each.
- The LV connection on each module supplies power to the integration mode and pulse mode amplifiers and the switching relays via three DC/DC converters

Per Module:

- Integration mode: $V_I = +10V$
- Pulse mode: $V_P = -10V$
- Integration mode current: $I_I \simeq 200\ mA$
- Pulse mode current: $I_P \simeq 200\ mA$
- Max power: $P_I \simeq 10 \times 0.24 = 2.4\ W$ (includes ~20% safety factor) this is continuous in production mode

Cables:

- We need to stay $|V_{I,P}| \geq 9.6\ V$. So we need to know the voltage drop along the cables
- 200 m AWG 18 (RG141 if need be) $\Delta V \sim 1V$ (SBS bunker distance x 2) – this might be too large, depending on PS unit
- 200 m AWG 18 (RG141 if need be) $\Delta P \sim 0.2W$
- Used central conductor size for coaxial cable and return shield (not clear to me how accurate this is – return is braided sheet)
- Assume 50 mm bend radius for RG141 (5 mm diameter x 8)

Main detector low voltage power supply candidates

1. Thin Quartz

Wiener MPV8016I

- Low Voltage floating modules with 8 or 4 channels of 50W or 100W max. with 0-8V, 0-16V, 0-30V, 0-60V and 0-120V ranges
- 6U height, 220mm deep fully shielded mechanics
- All DC outputs with individual return lines, individually sensed, floating channel to channel and channel to chassis ground (125V, 500V optional)
- Extremely low noise and ripple: <3mVpp (0-20MHz)
- Voltage and current settings / monitoring for each channel, 15 bit resolution, accuracy +/-0.1% of full scale value (Standard Series) and 21 bit resolution for High Precision Series
- Current monitoring and limiting for each channel, 15 bit resolution (Standard Series) and 21 bit resolution for High Precision Series
- high stability, 0.2%/10k
- Programmable channel parameters:
  - Terminal and load voltage, under voltage / over voltage trip points
  - current limit (current or voltage controlled mode)
  - power, regulation type, internal / external sense
  - ramping speed up and down (1V/s … 500V/s)
  - group features / error handling

Power supply

and MPV32SW

- 32 Channels individually programmable
- Programmable Channel Functions:
  – Switch on / off,
  – Reverse Polarity
- Switching element: Semiconductor
- Short reaction time <5ms (on/off; reverse polarity)
- Maximum switching rate per Channel up to 50/sec.
- All channels floating channel to channel and channel to chassis ground (125V, 500V tested)
- Maximum continuous current per Channel: 5A
- Maximum Voltage rating: 60V
- Max voltage loss/channel: 200mV (5A / 2x 20mR Rdson)
- Max power loss/channel: 1W (200mV / 5A)
- Max power loss: 32W + 2W (driver+µC etc.)

Polarity switching module

Main detector low voltage power supply candidates

1. Thin Quartz (alternative)

CAEN A255x

- 8 Individual floating channels
- Individual channel sense wire possible (currently not implemented on the PMT side)
- Sense wire compensation range ~ $2 - 3\ V$
- Programmable
- No programmable polarity switch, but programmable negative floating possible. Possibly design separate switching board (cost).
- Modules per channel limited by power
- $60\ W$ per channel supports ~ 15 modules for A2551
- 2 modules to power all of the thin quartz
- Would need to design breakout PCB
- Crate same type as HV crate.
- Not sure if we can mix HV and LV
- Individual channel control -> ~30 modules + two crates
- Polarity switching module would have to be designed first, leading to significant time constr.

Series		A2551	A2552	A2553
Packaging		1 unit (5 TE) wide; 6U – High mechanics		
No. of Channels		8		
Polarity		Individual Floating (±500V isolation)		
Output Voltage		0 ÷ 8V	0 ÷ 16V	0 ÷ 32V
Max Output Current		12A	6A	3A
Max Output Power (connector Output)		60W	60W	60W
Vset Resolution		0.2mV	0.5mV	1mV
Iset Resolution		0.5mA	0.2mA	0.1mA
Vmon Resolution		0.2mV	0.5mV	1mV
Imon Resolution		0.5mA	0.2mA	0.1mA
Ramp Up/Down		1-500V/s (1 V/s step)		
Voltage Ripple (10Hz ÷ 20MHz)	Typ	<3mVpp	<4mVpp	
	Max	<5mVpp	<8mVpp	
Accuracy[1]	Vout/Vmon	± 0.1% ± 20mV	± 0.1% ± 20mV	± 0.1% ± 50mV
	Vset/Vout	± 0.1% ± 20mV	± 0.1% ± 20mV	± 0.1% ± 50mV
	Iout/Imon	± 1% ± 50mA	± 1% ± 20mA	± 1% ± 10mA
	Iset/Iout	± 1% ± 100mA	± 1% ± 50mA	± 1% ± 50mA
Hardware OVV Protection		10.5V typ	18V typ	35V typ
Trip		0 to 999.9s; 1000s = Infinite; step 0.1s		
Temperature range		0 ÷ 45°C		

Main detector power needs and cables - Details

2. HVMAPS

Each HVAMPS chip draws $0.5\ A$ at 100% duty cycle (we will be operating the chip below that).

The supply voltage for the chip operation (not the bias) is $2\ V$. Due to noise concerns associated with voltage regulators, we aim to remote supply all of the HVMAPS associated LV using compensating PS units and assuming a manageable voltage drop/compensation of $\Delta V \sim 1\ V$.

Within each segment we have 84 chips, which means we will be drawing $42\ A$ through the patch panel connectors at each segment (segment patch panel - see slide 4).

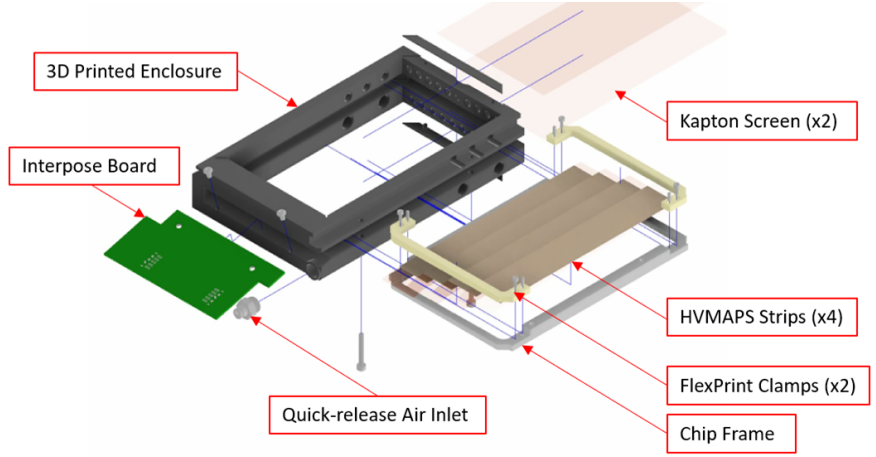
Each module combines 4 flexprint strips (upper right figure) to each of which 7 chips are bonded (lower right figure).

There is a single $2V$ supply trace for the 7 chips on each strip, which will therefore carry $3.5A$

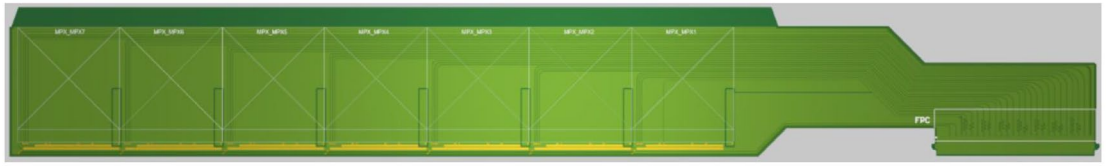
There are then 24 cables @ $3.5A$ each, needed to supply all 3 modules within a segment.
This includes the return.

The flexprint uses an individual layer for GND and VDD equivalent to about ~ 21 AWG over a distance of about $0.18\ \mathrm{m}$. The corresponding voltage drop with return should be about $\sim 100\ mV$@ $3.5A$ for the furthest chip.

The wire temperature at full current was set to $60°\ \mathrm{C}$ for all calculations.



For each Ring 5 Quartz tile: TAB-bond 7 chips to a flex-print, have 4 such strips per detector



Main detector power needs and cables - Details

2. HVMAPS

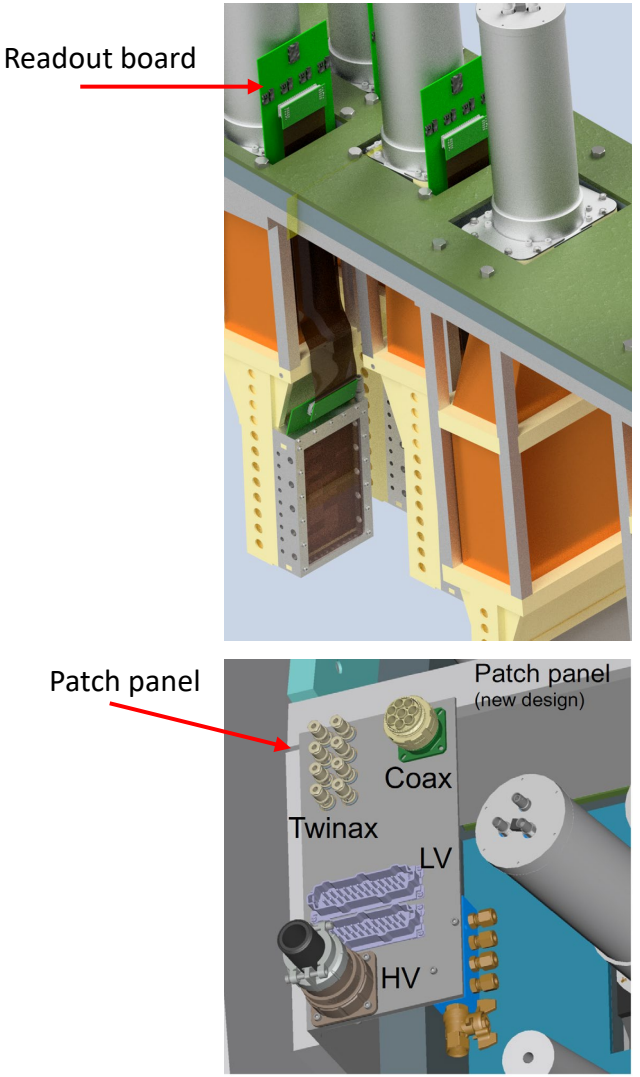
A high density flex cable (see slide 4) connects the HVMAPS module (upper tight) to the readout board at the PMT end of the R5 detector module. The length of the ribbon cable is about 0.35 m. We will have to run separate cables from the HVMAPS to the readout board, because we cannot support the wire required wire thickness in the ribbon cable

For AWG ~ 15 the corresponding voltage drop with return should be about $42\ mV @\ 3.5A$.

Slide 5 shows the development readout board. The actual board for the full module is under development. The primary purpose of the readout board is the data readout. Depending on the design details, we will either run the VDD/GND lines from each of the strips through the readout board or have a separate connector for these, if there is space.

The longest distance from the readout board to a segment patch panel is about 1.6 m. We propose to run AWG ~ 16 cables (one for each flexprint strip – all the same length) from the readout board to the segment patch panel. With that we would have a voltage drop of about $170\ mV @\ 3.5A$.

We propose to either implement the needed connectors at the module end into the readout board or make a separate connector. We are planning to implement an over-current protection circuit at this point.

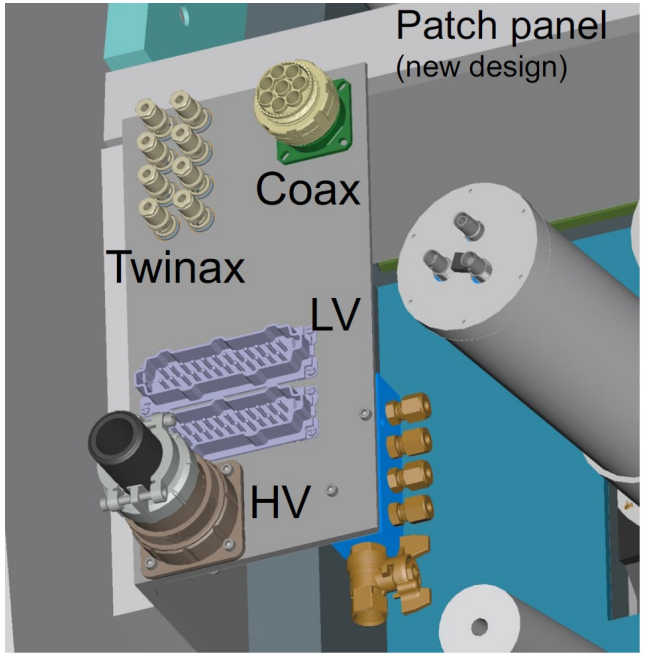


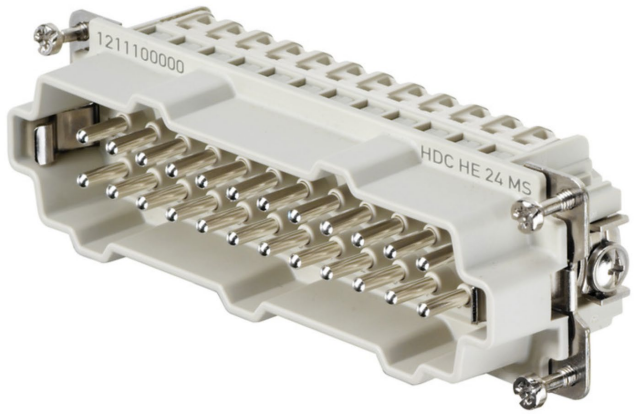
Main detector power needs and cables - Details

2. HVMAPS

At the patch panel a candidate connector would be the Weidmüller HDC-KIT-HE 24.130 M, part of which is shown below, with the following partial specs:

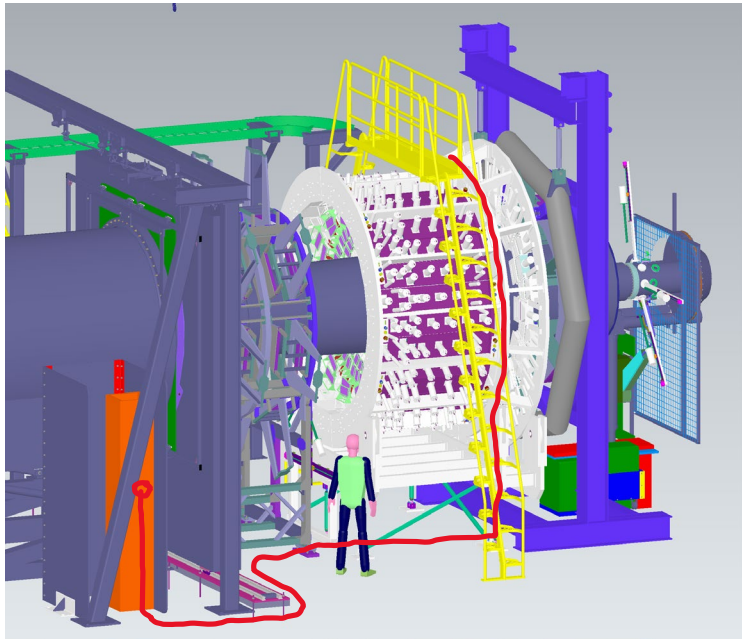
General data	
BG	8
Conductor cross-section	2.5 mm²
Free from halogens	true
Insulating material	PC glass-fibre reinforced (UL-listed and railway-certified)
Insulating material group	IIIa
Insulation strength	10^{10} Ω
Low smoke acc. DIN EN 45545-2	Yes
Material	Copper alloy
Max. torque for main contact	0.55 Nm
Min. torque for main contact	0.5 Nm
Number of poles	24
Plugging cycles, silver	≥ 500
Pollution severity	3
Rated current (DIN EN 61984)	16 A
Rated impulse voltage (DIN EN 61984)	6 kV
Rated voltage (DIN EN 61984)	500 V
Rated voltage according to UL/CSA	600 V AC/DC
Series	HE
Size	8
Surface finish	Silver passivated
Type	Male
UL 94 flammability rating	V-0
Volume resistance	≤2 mΩ





Each pin can handle up to 16 A and we are well below that if we connect each of the 12 strips and 12 returns to a separate pin, which would occupy one of the two connectors shown. The other would be available for the remaining LV power and the HVMAPS bias.

Main detector power needs and cables - Details



2. HVMAPS

The connector would add a voltage drop of about $7\ mV@\ 3.5A$ per pin.

All together, this would give a voltage drop of about $320\ mV@\ 3.5A$

We then have to go from the segment patch panel to the rack where the PSU sit. There are two logistically distinct sections to this:

1. From the patch panel to the floor or to the overhead cable tray – depending on the setup that is ultimately chosen (shown in the picture is an approximate path to the floor).

2. From the detector array to the PSU rack

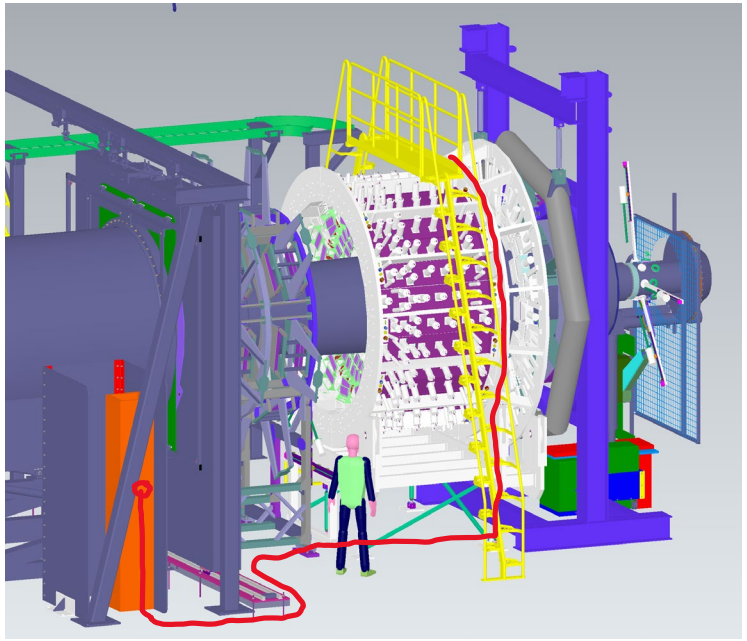
The combined one-way cable distance is about $25\ m$.

One could run individual AWG 9 cables ($\varnothing = 6\text{mm}$!) and keep within a voltage drop of about $\sim 530\ mV@\ 3.5A$ (including the return) which would all together be just below the desired $\Delta V \sim 1\ V$.

A bundle with 24 AWG 9 cables (one per segment) would have a diameter of about $\sim 40\ mm$.

The connector on the previous page only supports up to AWG 12 ($\varnothing = 4\text{mm}$) which would give $\Delta V > 1\ V$ unless we increase the number of cables.

Main detector power needs and cables - Details



2. HVMAPS

We then have to go from the segment patch panel to the rack where the PSU sit. There are two logistically distinct sections to this:

Instead we propose to splice the in-segment AWG 15 cables into pairs of AWG 12 cables at the patch panel and run AWG 12 cables to the PSU.

We can afford a $\Delta V \sim 0.6\ V$ for the 50 distance (including the return) so we need a wire cross-section of

$$a = \rho \frac{LI}{V} = 2 \times 10^{-8} \frac{50 \times 3.5}{0.6} 10^{6} \simeq 6\ mm^2$$

Which is either AWG 9 or two AWG 12 to keep within a voltage drop of about $\sim 530\ mV @\ 3.5A$ (including the return) which would all together be just below the desired $\Delta V \sim 1\ V$.

Main detector power needs and cables - Details

2. HVMAPS

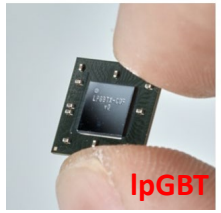
The readout board (see slide 5) requires two operating voltages $2.5\ V @\ 0.08\ A$ and $1.2\ V @\ 1.125\ A$ to supply the 4 serializer-deserializer chips lpGBT and the transceiver chip VTRX+. There are 3 readout boards per segment, which means that we will have one cable with $1.2\ V @\ 3.375\ A$ and one cable with $2.5\ V @\ 0.24\ A$.

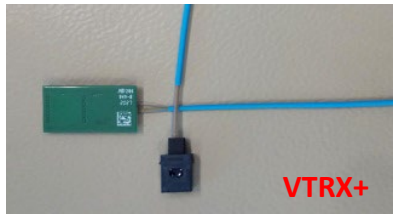
The readout board will be developed to support both, remote power, supplying the operating voltage directly from the PSU, as well as via on-PCB voltage regulators.

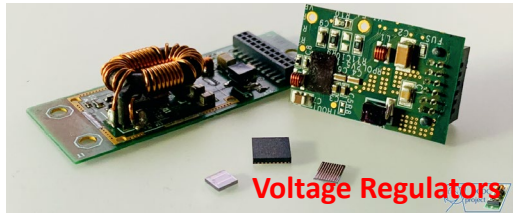
The voltage regulators would allow a $12\ V$ supply to be regulated down to the required $1.2\ V$ and $2.5\ V$.

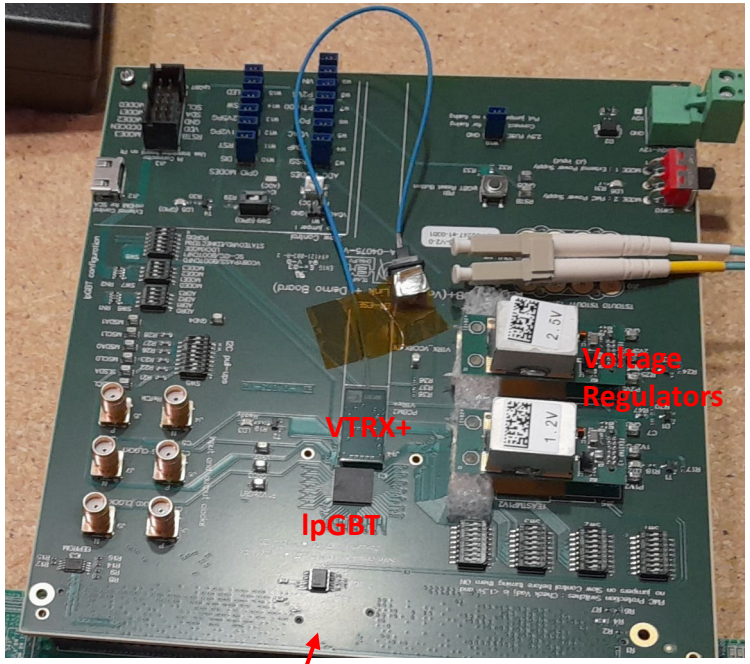
As in the case of the HVMAPS, the use of voltage regulators can lead to noise issues and radiation damage issues.

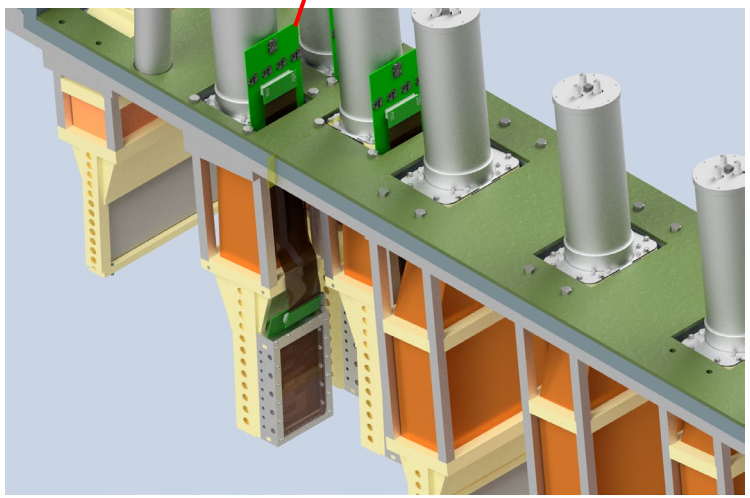
The lpGBT, VTRX+, and voltage regulator chips are sold by CERN:





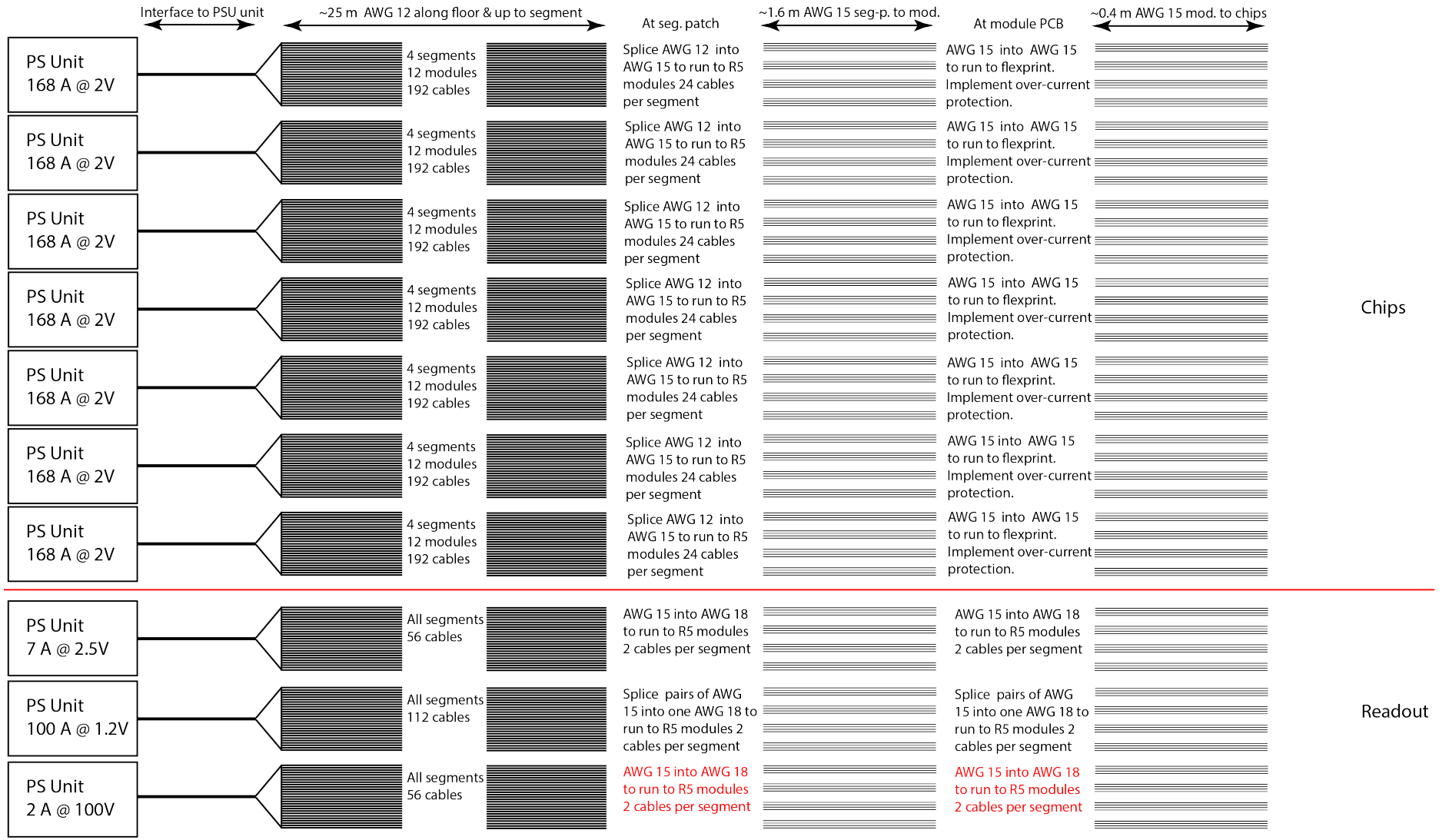






Main detector power needs and cables - Details

2. HVMAPS



Main detector power needs and cables - Details

2. HVMAPS

Candidate PSU Series: GW-Instek PSU 6-200

- Single channel high current

SPECIFICATIONS	
MODEL	PSU 6-200
OUTPUT RATINGS	
Rated Output Voltage (*1)	6V
Rated Output Current (*2)	200A
Rated Output Power	1200W
RIPPLE AND NOISE(*5)	
CVp-p(10 ~ 20MHz) p-p (*6)	60mV
CVrms(5Hz ~ 1MHz) r.m.s. (*7)	8mV
CCrms(5Hz ~ 1MHz) r.m.s.(*12)	400mA
LOAD REGULATION	
Voltage(*4)	2.6mV
Current(*11)	45mA
LINE REGULATION	
Voltage(*3)	2.6mV
Current(*3)	22mA

Main detector power needs and cables - Details

2. HVMAPS

Cable to PSU interface:

At the PSU we need a designed interface to go from the AWG 9 to a much smaller gauge to connect to the Busbar.

We envision a separate PCB that will receive the AWG 12 cables and route them on the PCB into the connector that allows direct connection to the PSU Busbar.

The specific design has not yet started (waiting for input from JLab).

Main detector power needs and cables - Details

2. HVMAPS (Summary)

- 84 modules with 28 chips per module. Need three different LV connections for each module ($2V, 1.2V, 2.5V$) and one "HV" connection ($\lesssim 100\ V$) for bias
- LV powers the chip itself and the readout electronics

Per Module:

- Chip supply voltage: $V_{chip} = 2V\ @\ 0.5A\ \times\ 28$ (parallel)
- Readout lpGBT: $V_{lpBGT} = 1.2V\ @\ 0.27A \times 4$
- Readout VTRX+: $V_{VTRX} =\ 1.2V\ @\ 0.045A + 2.5V\ @\ 0.080A$
- Bias: $V_{bias} =\ 100V\ @\ 0.02A$
- Largest power: $P_{chips} \simeq 34\ W$ (includes ~20% safety factor)
- Total power: $P_{tot} \simeq 38\ W$ (includes ~20% safety factor)

Cables:

- Voltage drops:

• Flexprint to ribbon:	$\Delta V \sim 0.10V$ @ $3.5\ A$	VDD and GND layer width and thickness comparable to ~AWG 21
• Ribbon readout:	$\Delta V \sim 0.04V$ @ $3.5\ A$	AWG 20 (VDD + GND = 24 cables/segment)
• R5 readout to segment patch panel:	$\Delta V \sim 0.17V$ @ $3.5\ A$	AWG 16 (VDD + GND = 24 cables/segment)
• Segment patch panel to GEM hut:	$\Delta V \sim 0.53V$ @ $3.5\ A$	AWG 9 (or Split VDD and GND into two AWG 12 = 48 cables)
• GEM hut floor to PS unit:	$\Delta V \sim 0.12V$ @ $?\ A$	AWG ? (Depends on PS unit we choose)
• **Total:**	$\boldsymbol{\Delta V \leq 1V}$	**(Depending on PS unit we chose)**