# Slow Control of the Liquid Xenon Calorimeter

Prepared for: Cabling at pE5
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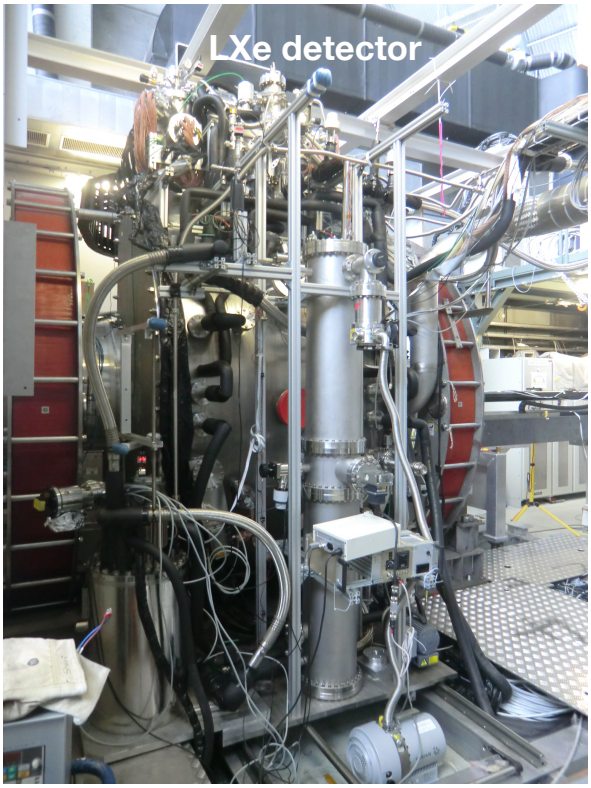
# INTRODUCTION

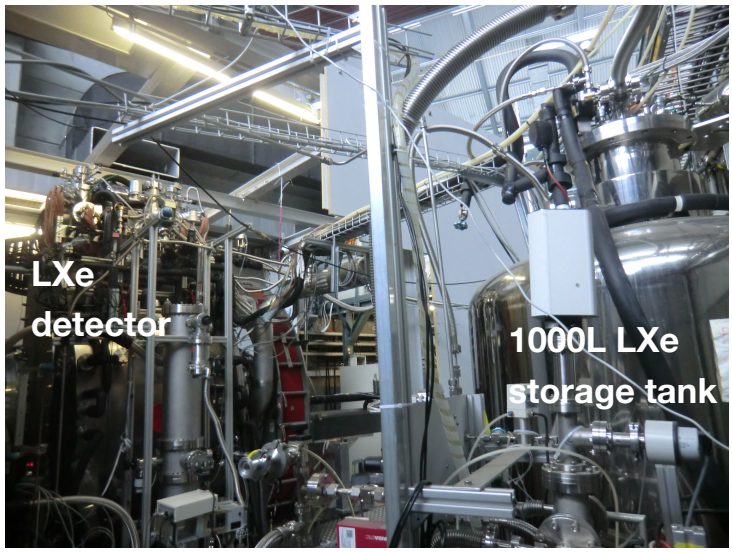
## Objective

We here describe the whole system about the liquid xenon (LXe) gamma-ray calorimeter for the MEG II experiment, mainly about the slow control system at pE5 area. We upgrade the MEG detector, and the MEG II LXe detector has been operational since 2017.

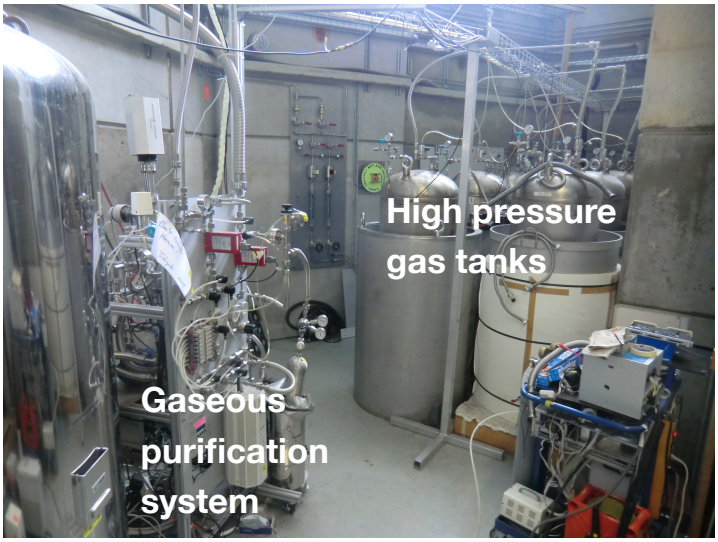
## LXe gamma-ray calorimeter

In order to detect gamma-rays, we use 900L LXe and 4092 MPPCs and 668 photomultipliers. The LXe temperature must be kept to be  around 165K (-108 degree Celsius) at xenon gas pressure of 1 atmospheric pressure, and thus we need cryogenics and many sensors inside the detector. The left picture in this page shows the LXe calorimeter.  During the winter shutdown period, the LXe in the calorimeter is transferred to 1000L LXe storage tank which has a refrigerator and a better thermal insulation, and can keep the LXe safer. Both of the LXe calorimeter and the 1000L LXe storage tank are shown in the right picture as well as thermal insulated pipes.



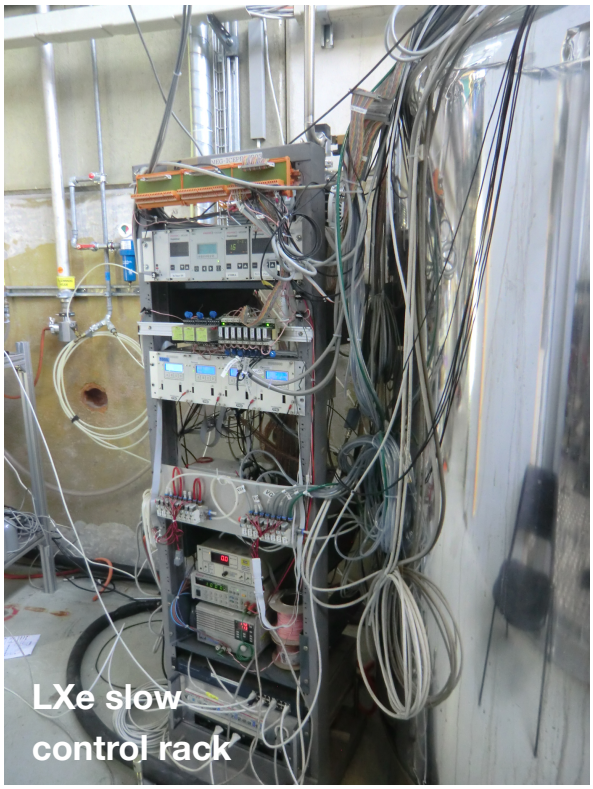



The left picture is a view of the 1000L storage tank. All amount of xenon can be kept during a long break in 8 high pressure gas tanks as shown in the right picture which do not require any control. There is a gaseous purification system located between the 1000L tank and eight high pressure gas tanks also in the picture.

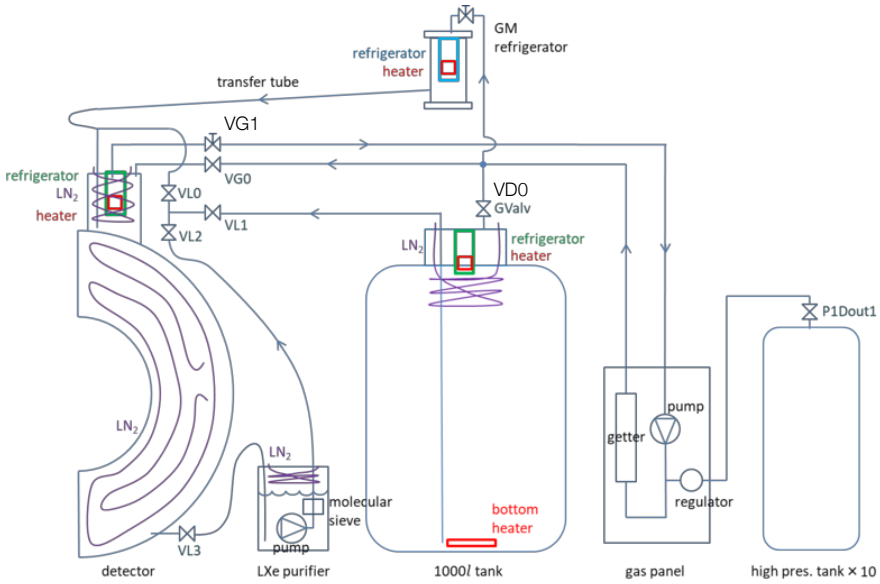




## Slow control system

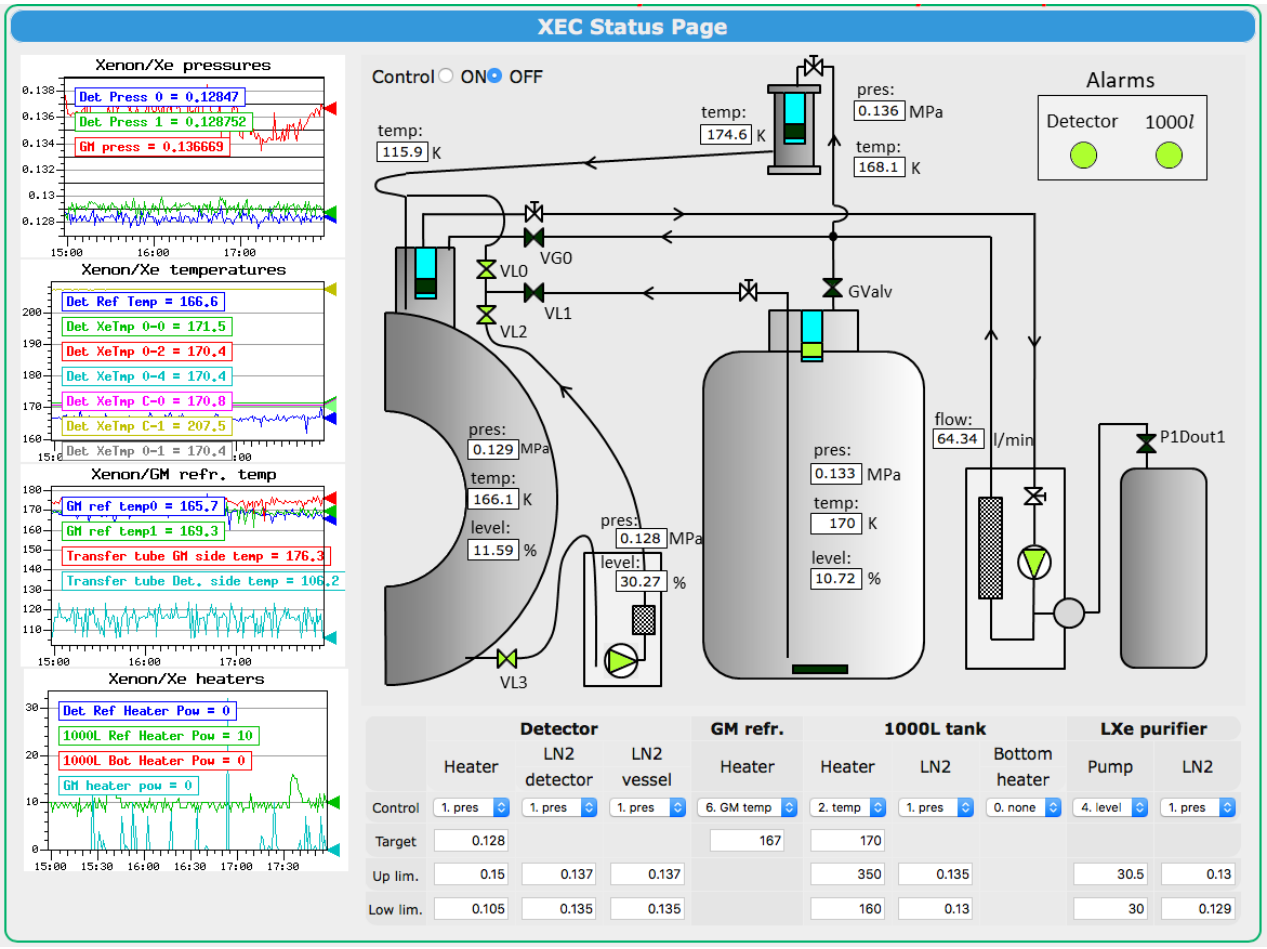
We use Midas Slow Control System (MSCB) to keep the LXe detector stable and safe. A crate is dedicated to the calorimeter slow control system as shown in the right picture. From the bottom, there are a power circuit breaker and a network switch. A 24V DC power supply is for SCS2001(we do not need it anymore), a current source for pt-100 thermometers, and a level meter readout module. There are air actuated valves to control the gas transfer or liquid transfer, and two air control relays are mounted. Four SCS2001 modules are used to control the system. Liquid nitrogen is used to keep the LXe cold, and solenoid valves are used to control LN2. Many relays are prepared to allow us to control LN2 on/off remotely depending on the LXe pressure etc. Three vacuum level gauges and a turbo pump controller are prepared to monitor and control the vacuum. The top of the crate is terminals of cables from detectors into SCS2001. There are two SCS2001 modules dedicated to the gas purification control and potentiometer readout installed in the LXe vacuum vessel which are embedded in the gas purification system.



Three refrigerators are used to control the LXe temperature and the helium lines, cooling water lines are connected between the refrigerators and the water cooling system and compressors on a platform upstairs.
The schematic view of the LXe calorimeter system is shown in the right figure.




We monitored the detector status by a midas custom page as shown in the figure.



## Cabling of each component

In total, we have four SCS2001 modules (XECDetector, XECDetectorSub, XEC1000L, and XECStorage) in the LXe slow control rack , and two SCS2001 modules (XECPurifier, and XECPotentiometer) in the gaseous purification system.

Each module has cards inside, and all cables are connected to the backplane of the module. Here I will put the information about cards and the cable connections.

### SCS2000 XECDetector

This module has eight cards inside as shown in the bottom table, and two terminals are used to connect cables to a SCS2000 backplane. The right table shows cable assignment on the two terminals, the first arrow is the number of the terminal, the second is the channel of SCS2000 backplane, and the third is the explanation of the cable. Vessel temperature 0,1,3,6,8,9,12,14 are directly connected to the SCS2000 module
5-0,5-1,5-2,5-3,5-4,5-5,5-6,5-7, respectively.

| | Equipped cards | driver |
|---|---|---|
| 0 | Uin + 2.5V | 0x60 |
| 1 | Uin +-10V | 0x61 |
| 2 | Uin +-10V | 0x61 |
| 3 | Uout +-10V | 0x81 |
| 4 | Dout 24V | 0x40 |
| 5 | Uin + 2.5V | 0x60 |
| 6 | Dout 24V | 0x40 |
| 7 | Dout 24V | 0x40 |

| | | |
|---|---|---|
| 1 | 0-0 | refrigerator temperature |
| 2 | 0-1 | refrigerator temperature |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | 1-0 | pressure 0 (51 Ohm resistor) |
| 8 | 1-1 | pressure 1 (51 Ohm resistor) |
| 9 | AGND | |
| 10 | 1-2 | level meter 0 |
| 11 | 1-3 | level meter 1 |
| 12 | AGND | |
| 13 | 1-4 | purifier pump pressure (51 Ohm resistor) |
| 14 | 1-5 | level meter 3 (no use) |
| 15 | AGND | |
| 16 | 1-6 | strain meter 0 (no use) |
| 17 | 1-7 | strain meter 1 (no use) |
| 18 | AGND | |
| 19 | 2-0 | GM pressure |
| 20 | 2-1 | GM pressure ( 51 Ohm resistor ) |
| 21 | AGND | |
| 22 | 2-2 | outer vessel vacuum (no use) |
| 23 | 2-3 | liquid phase pump pressure (51 Ohm resistor) |
| 24 | AGND | |
| 25 | 2-4 | liquid phase pump level |
| 26 | 2-7 | liquid phase pump speed (READ) |
| 27 | DGND | |
| 28 | 4-0 | LN2 valve 0 (to relay) |
| 29 | 4-1 | LN2 valve 1 (to relay) |
| 30 | 4-2 | LN2 valve 2 (to relay) |
| 31 | 4-3 | LN2 valve 3 (to relay) |
| 32 | 4-4 | LN2 valve 4 (to relay) |
| 33 | 4-5 | LN2 valve 5 (to relay) |
| 34 | 4-6 | LN2 valve 6 (to relay) |
| 35 | 4-7 | LN2 valve 7 (to relay) |
| 36 | 6-0 | vessel heater (no use) |
| 37 | 6-1 | refrigerator heater (to relay) |
| 38 | DGND | |
| 39 | 6-2 | compressor (to platform) |
| 40 | 6-3 | V0 open (to air terminal) |
| 41 | 6-4 | V0 close (to air terminal) |
| 42 | 7-0 | VG0 (to air terminal) |
| 43 | 7-1 | VG1 (to air terminal) |
| 43 | DGND | |
| 45 | 7-2 | VL0 (to air terminal) |
| 46 | 7-3 | VL1 (to air terminal) |
| 47 | 7-4 | VL2 (to air terminal) |
| 48 | 7-5 | VL3 (to air terminal) |
| 49 | 3-0 | liquid pump speed control (WRITE) |
| 50 | AGND | |

| | | |
|---|---|---|
| 1 | 0-2 | GM refrigerator CH temperature |
| 2 | 0-3 | GM refrigerator CH temperature |
| 3 | 0-4 | GM refrigerator CH temperature, transfer tube temperature |
| 4 | 0-5 | transfer tube temperature |
| 5 | 0-6 | transfer tube temperature |
| 6 | | |
| 7 | | |
| 8 | | |
| 9 | | |
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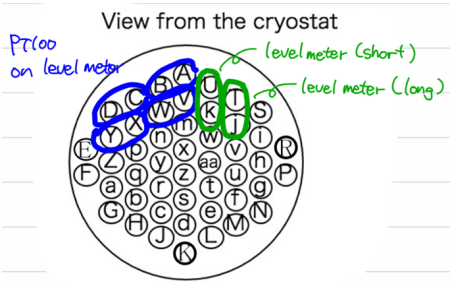
| 43 | | |
| 43 | | |
| 45 | | |
| 46 | | |
| 47 | DGND | |
| 48 | 6-5 | GM refrigerator heater (to relay) |
| 49 | 6-6 | GM refrigerator compressor (to platform) |
| 50 | 7-7 | GXe circulation pump |

### SCS2001 XECDetectorSub

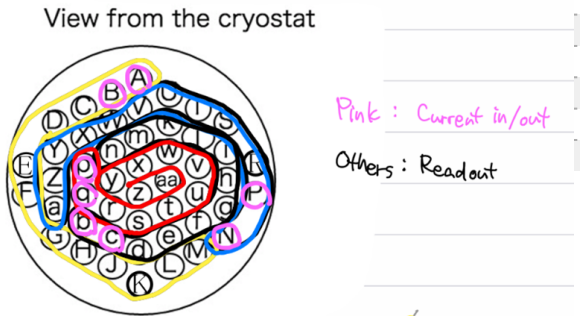
This module has eight cards inside as show in the left table. Cables for this module is directly connected from the detector to the SCS2001 backplane as shown in the right table. The first arrow shows an internal channel number, the second is the name of the parameter, the third is the description, and the fourth is the backplane channels.

| Port | Card | driver |
|---|---|---|
| 0 | Uin + 2.5V | 0x60 |
| 1 | Uin + 2.5V | 0x60 |
| 2 | Uin + 2.5V | 0x60 |
| 3 | Uin + 2.5V | 0x60 |
| 4 | Uin + 2.5V | 0x60 |
| 5 | Uin + 2.5V | 0x60 |
| 6 | IOUT 0–2.5mA | 0x82 |
| 7 | IOUT 0–2.5mA | 0x82 |

Inner vessel temperature 0-1 cables are connected to a feedthrough connector on the top of the XEC detector shown below.




Inner vessel temperature 2-21 cables are connected to a feedthrough connector on the top of the XEC detector shown below.




| channel | name | description | local I/O |
|---|---|---|---|
| 0 | Alarm | Alarm | |
| 1 | Mode | Preset mode | |
| 2 | SaveMd | mode number to save | |
| 3 | Flash | flash EEPROM | |
| 4 | TmpCr0 | IOUT current 0 | IOUT 7–0 |
| 5 | TmpCr1 | IOUT current 1 | IOUT 7–1 |
| 6 | TmpCr2 | IOUT current 2 | IOUT 7–2 |
| 7 | TmpCr3 | IOUT current 3 | IOUT 7–3 |
| 8 | TmpCr4 | IOUT current 4 | IOUT 7–4 |
| 9 | TmpCr5 | IOUT current 5 | IOUT 7–5 |
| 10 | TmpCr6 | IOUT current 6 | IOUT 7–6 |
| 11 | TmpCr7 | IOUT current 7 | IOUT 7–7 |
| 12 | TmpCr8 | IOUT current 8 | IOUT 6–0 |
| 13 | XeTm00 | Inner vessel temperature 0 | ADC 0–0,1 |
| 14 | XeTm01 | Inner vessel temperature 1 | ADC 0–2,3 |
| 15 | XeTm02 | Inner vessel temperature 2 | ADC 1–0,1 |
| 16 | XeTm03 | Inner vessel temperature 3 | ADC 1–2 |
| 17 | XeTm04 | Inner vessel temperature 4 | ADC 1–3,4 |
| 18 | XeTm05 | Inner vessel temperature 5 | ADC 1–5 |
| 19 | XeTm06 | Inner vessel temperature 6 | ADC 1–6,7 |
| 20 | XeTm07 | Inner vessel temperature 7 | ADC 2–0,1 |
| 21 | XeTm08 | Inner vessel temperature 8 | ADC 2–2 |
| 22 | XeTm09 | Inner vessel temperature 9 | ADC 2–3,4 |
| 23 | XeTm10 | Inner vessel temperature 10 | ADC 2–5 |
| 24 | XeTm11 | Inner vessel temperature 11 | ADC 2–6,7 |
| 25 | XeTm12 | Inner vessel temperature 12 | ADC 3–0,1 |
| 26 | XeTm13 | Inner vessel temperature 13 | ADC 3–2 |
| 27 | XeTm14 | Inner vessel temperature 14 | ADC 3–3,4 |
| 28 | XeTm15 | Inner vessel temperature 15 | ADC 3–5 |
| 29 | XeTm16 | Inner vessel temperature 16 | ADC 3–6,7 |
| 30 | XeTm17 | Inner vessel temperature 17 | ADC 4–0,1 |
| 31 | XeTm18 | Inner vessel temperature 18 | ADC 4–2 |
| 32 | XeTm19 | Inner vessel temperature 19 | ADC 4–3,4 |
| 33 | XeTm20 | Inner vessel temperature 20 | ADC 4–5 |
| 34 | XeTm21 | Inner vessel temperature 21 | ADC 4–6,7 |
| 35 | PrTmp0 | LXe purifier temperature 0 | ADC 5–0,1 |
| 36 | PrTmp1 | LXe purifier temperature 1 | ADC 5–1,2 |
| 37 | PrTmp2 | LXe purifier temperature 2 | ADC 5–2,3 |
| 38 | PrTmp3 | LXe purifier temperature 3 | ADC 5–3 |

## SCS2001 XEC1000L

This module has four cards inside as shown in the left table.
Cables for this module is directly connected from the detector to the SCS2001 backplane as shown in the right table. The first arrow shows an internal address of the module, the second is an internal channel number, the third is the name of the parameter, the forth is the description, and the fifth is the backplane channels. The IOUT card ch0 (3-0) is connected to the temperature sensors in series.

| | Equipped cards | driver |
|---|---|---|
| 0 | Dout 5V/24V | 0x40 |
| 1 | Uin +-10V | 0x61 |
| 2 | PT100 | 0x72 |
| 3 | IOUT | 0x83 |

| address | channel | name | description | local I/O |
|---|---|---|---|---|
| 2 | 0 | Alarm | Alarm bit field | |
| 2 | 1 | Mode | Preset mode | |
| 2 | 2 | LN2Vlv | LN2 valve on/off | Dout0(0-0) |
| 2 | 3 | Comprs | Compressor on/off (to platform) | Dout1(0-1) |
| 2 | 4 | VD0 | Gas xenon valve 0 (to air terminal) | Dout2(0-2) |
| 2 | 5 | VD1 | Gas xenon valve 1 (to air terminal) | Dout3(0-3) |
| 2 | 6 | CHOut | Cold head heater out (to realy) | Dout4(0-4) |
| 2 | 7 | BHOut | Bottom heater out (to relay) | Dout5(0-5) |
| 2 | 8 | CHPow | Cold head heater power [%] | |
| 2 | 9 | BHPow | Bottom heater power[%] | |
| 2 | 10 | CHTmp0 | Cold head temperature | Temp0(2-0) |
| 2 | 11 | CHTmp1 | Cold head temperature | Temp1(2-1) |
| 2 | 12 | XeTmp0 | Lxe temperature 0 | Temp 2(2-2) |
| 2 | 13 | XeTmp1 | Lxe temperature 1 | Temp 3(2-3) |
| 2 | 14 | XeTmp2 | Lxe temperature 2 | Temp 4(2-4) |
| 2 | 15 | XeTmp3 | Lxe temperature 3 | Temp 5(2-5) |
| 2 | 16 | XeTmp4 | Lxe temperature 4 | Temp 6(2-6) |
| 2 | 17 | RFOTmp | Refrigerator outside temperature | Temp 7(2-7) |
| 2 | 18 | Press | Inner pressure of 1000L ( 100 Ohm resistor ) | ADC 0(1-0) |
| 2 | 19 | Pupper | Pressure upper (for level meter) (no use) | ADC 1 (1-1)<br>ADC 2 (1-2) |
| 2 | 20 | PLower | Pressure Lower (for level meter) (no use) | ADC 3 (1-3)<br>ADC 4 (1-4) |
| 2 | 21 | Level | Capacitance level meter ( 100 Ohm resistor ) | ADC 5 (1-5) |
| 2 | 22 | RCTLMD | Refrigerator control mode. 0: none, 1:Pressure, 2:Temperature | |
| 2 | 23 | BCTLMD | Bottom heater control mode. 0: none, 1: Pressure | |
| 2 | 24 | CTPTG | Pressure control target | |
| 2 | 25 | CTPUL | Pressure control upper limit | |
| 2 | 26 | CTPLL | Pressure control lower limit | |
| 2 | 27 | RCTTID | temperature sensor ID for controling heater. 0 or 1 | |
| 2 | 28 | RCTPP | Refrigerator control pressure P value | |
| 2 | 29 | RCTPI | Refrigerator control pressure I value | |
| 2 | 30 | RCTTTG | Refrigerator control temperature target | |
| 2 | 31 | RCTTP | Refrigerator control temperature P value | |
| 2 | 32 | RCTTI | Refrigerator control temperature I value | |
| 2 | 33 | RCTTUL | Refrigerator control temperature upper limit. Controller does not heat over this value | |
| 2 | 34 | RCTTLL | Refrigerator control temperature lower limit. Controller does not heat over this value | |
| 2 | 35 | BCTPP | Bottom heater control pressure P value | |
| 2 | 36 | BCTPI | Bottom heater control pressure I value | |
| 2 | 37 | N2CTMD | LN2 control mode. 0: none, 1: Pressure | |
| 2 | 38 | N2CTUL | LN2 control upper level | |
| 2 | 39 | N2CTLL | LN2 control lower level | |
| 2 | 40 | AlPrUL | Upper threshold of pressure for alarm | |
| 2 | 41 | AlPrLL | Lower threshold of pressure for alarm | |
| 2 | 42 | AlTmUL | Upper threshold of cold head temperature for alarm | |
| 2 | 43 | AlTmLL | Lower threshold of cold head temperature for alarm | |
| 2 | 44 | SaveMd | Mode number to save current state | |
| 2 | 45 | Flash | Flash EEPROM | |
| 2 | 46 | PupperH | Measured voltage for pressure sensor upper 1 | |
| 2 | 47 | PupperL | Measured voltage for pressure sensor upper 2 | |
| 2 | 48 | PlowerH | Measured voltage for pressure sensor lower 1 | |
| 2 | 49 | PlowerL | Measured voltage for pressure sensor lower 2 | |
| 2 | 50 | CoCur | Constant current for pt100. [mA] | |
| 2 | 51 | CBRVac | Cobra vacuum | |
| 2 | 52 | CmCtMd | Compressor control mode. 0:none, 1:pressure | |
| 2 | 53 | CmCtDf | Compressor default. 0:off, 1:on | |
| 2 | 54 | PrsSlp | Pressure slope [MPa/min] | |
| 2 | 55 | AlPrSU | Upper limit of pressure slope for alarm [MPa/min] | |
| 2 | 56 | AlPrSL | Lower limit of pressure slope for alarm [MPa/min] | |
| 2 | 57 | ItLcOf | Disable all interlocks when this is 8384. | |

**SCS2001 XECStorage**

This module has three cards inside as shown in the table below.
Four cables are connected from LN2 liquid level sensors to a capacitor card in the module (0-0, 0-1,0-2,0-3).
Card 4 cables are connected to a relay on the LXe slow control rack.

| | Equipped cards | driver |
|---|---|---|
| 0 | Cin 0-10nF | 0x70 |
| 4 | Dout | 0x40 |
| 5 | Dout | 0x40 |

**SCS2001 XECPotentiometer**

This module is located behind the gaseous purification system. If there is space in the new rack, we may move this to the new rack.

This module has two Uin cards. Cables for this module are directly connected from the potentiometers which are installed in the vacuum vessel. Connections are written in the following table.

| address | channel | name | description | local I/O |
|---|---|---|---|---|
| 5 | 0 | P0Uin0 | US top r | ADC 0-0 |
| 5 | 1 | P0Uin1 | US top theta | ADC 0-1 |
| 5 | 2 | P0Uin2 | US top phi | ADC 0-2 |
| 5 | 3 | P0Uin3 | US bot r | ADC 0-3 |
| 5 | 4 | P0Uin4 | US bot theta | ADC 0-4 |
| 5 | 5 | P0Uin5 | US bot phi | ADC 0-5 |
| 5 | 6 | P0Uin6 | unused | |
| 5 | 7 | P0Uin7 | unused | |
| 5 | 8 | P1Uin0 | DS top r | ADC 1-0 |
| 5 | 9 | P1Uin1 | DS top theta | ADC 1-1 |
| 5 | 10 | P1Uin2 | DS top phi | ADC 1-2 |
| 5 | 11 | P1Uin3 | DS bot r | ADC 1-3 |
| 5 | 12 | P1Uin4 | DS bot theta | ADC 1-4 |
| 5 | 13 | P1Uin5 | DS bot phi | ADC 1-5 |
| 5 | 14 | P1Uin6 | unused | |
| 5 | 15 | P1Uin7 | unused | |

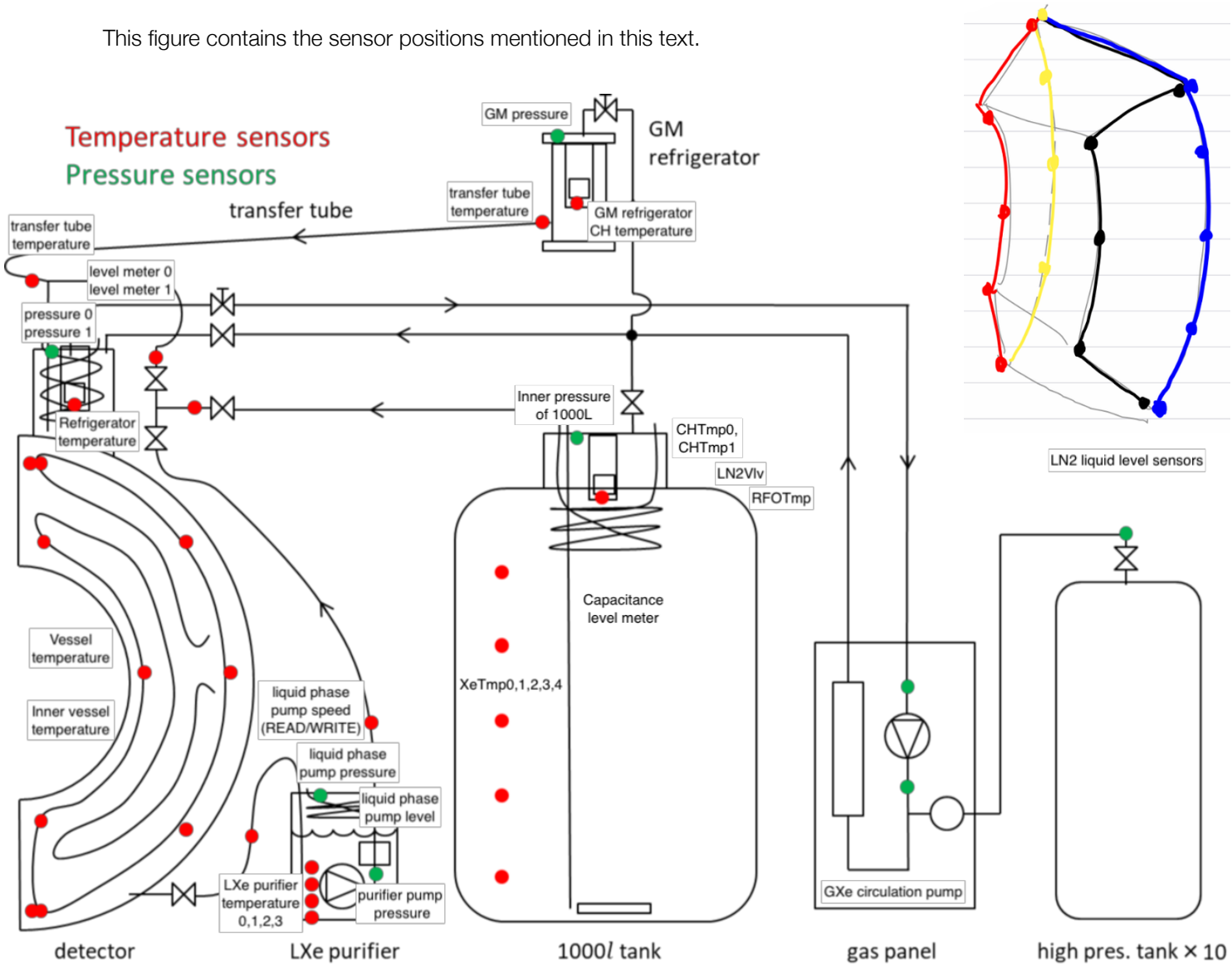
**XECPurifier**

We use one SCS2001 module to control purifier. This module is also located behind the gaseous purification system. We may not need any modification for this time. The definition of address, channel, name, and description are shown below. Local I/O means the XECPurifier module local connections, and the last arrow “connection” means the logical connection in the software to other modules.

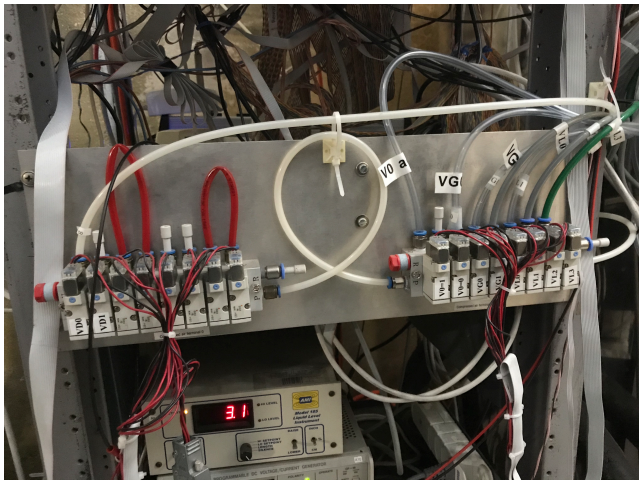
| address | channel | name | description | local I/O | connection |
|---|---|---|---|---|---|
| 0 | 0 | P0Uout0 | | | |
| 0 | 1 | P0Uout1 | | | |
| 0 | 2 | P0Uout2 | | | |
| 0 | 3 | P0Uout3 | | | |
| 0 | 4 | P0Uout4 | | | |
| 0 | 5 | P0Uout5 | | | |
| 0 | 6 | P0Uout6 | | | |
| 0 | 7 | P0Uout7 | | | |
| 0 | 8 | P1Dout0 | high pressure valve 0 | 1-0 | |
| 0 | 9 | P1Dout1 | high pressure valve 1 | 1-1 | |
| 0 | 10 | P1Dout2 | tank pressure power supply | 1-2 | |
| 0 | 11 | P1Dout3 | | | |
| 0 | 12 | P1Dout4 | | | |
| 0 | 13 | P1Dout5 | | | |
| 0 | 14 | P1Dout6 | | | |
| 0 | 15 | P1Dout7 | | | |
| 0 | 16 | P2Dout0 | high pressure valve 2 | | |
| 0 | 17 | P2Dout1 | high pressure valve 3 | | |
| 0 | 18 | P2Dout2 | high pressure valve 4 | | |
| 0 | 19 | P2Dout3 | high pressure valve 5 | | |
| 0 | 20 | P2Dout4 | high pressure valve 6 | | |
| 0 | 21 | P2Dout5 | high pressure valve 7 | | |
| 0 | 22 | P2Dout6 | high pressure valve 8 | | |
| 0 | 23 | P2Dout7 | high pressure valve 9 | | |
| 0 | 24 | P3T0 | | | |
| 0 | 25 | P3T1 | | | |
| 0 | 26 | P3T2 | | | |
| 0 | 27 | P3T3 | | | |
| 0 | 28 | P3T4 | | | |
| 0 | 29 | P3T5 | | | |
| 0 | 30 | P3T6 | | | |
| 0 | 31 | P3T7 | | | |
| 0 | 33 | P4Uin0 | purifier flow meter 0 | 4-0 | |
| 0 | 34 | P4Uin1 | purifier flow meter 1 | 4-1 | |
| 0 | 35 | P4Uin2 | tank pressure 0 | 4-2 | |
| 0 | 36 | P4Uin3 | tank pressure 1 | 4-3 | |
| 0 | 37 | P4Uin4 | tank pressure 2 | 4-4 | |
| 0 | 38 | P4Uin5 | tank pressure 3 | 4-5 | |
| 0 | 39 | P4Uin6 | tank pressure 4 | 4-6 | |
| 0 | 40 | P4Uin7 | tank pressure 5 | 4-7 | |
| 0 | 41 | P6Uin0 | | | |
| 0 | 42 | P6Uin1 | | | |
| 0 | 43 | P6Uin2 | | | |

| | | |
|---|---|---|
| 0 | 44 | P6Uin3 |
| 0 | 45 | P6Uin4 |
| 0 | 46 | P6Uin5 |
| 0 | 47 | P6Uin6 |
| 0 | 48 | P6Uin7 |

This figure contains the sensor positions mentioned in this text.

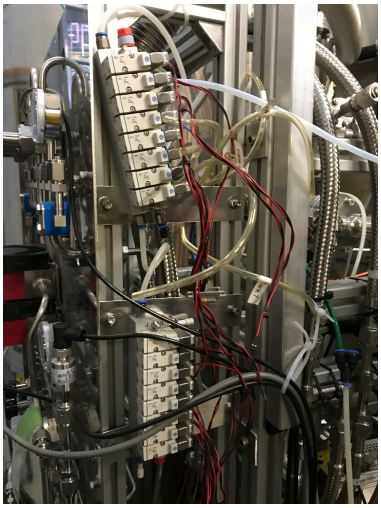


**Air actuated valves**




One air actuated valve control unit is located in the LXe slow control rack as shown in the left picture.

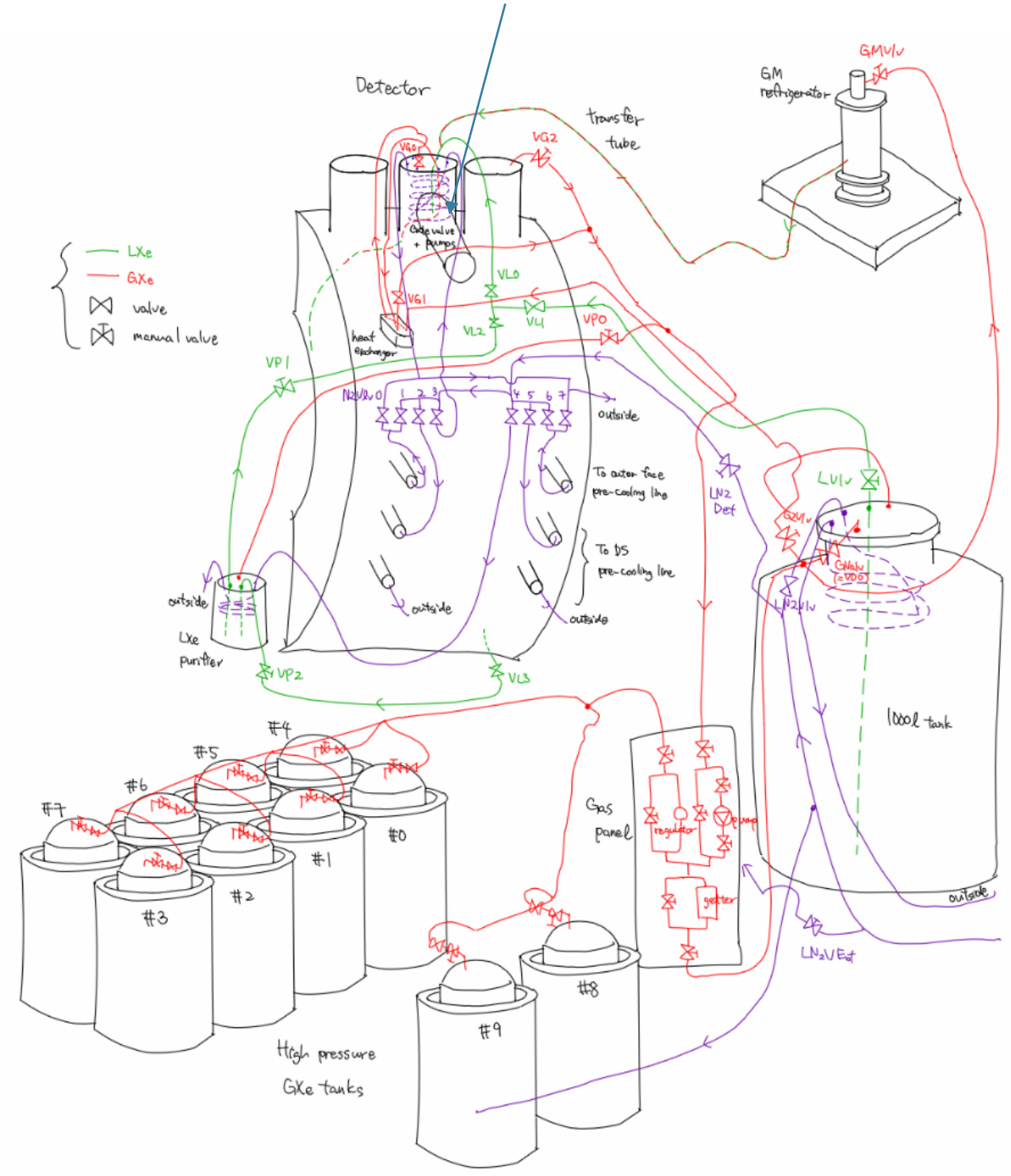
In total, 10 ports (V0=1, V0=1, VG0, VG1, VL0, VL1, VL2, VL3, VD0, VD1) are currently used in the MEG experiment. The remaining ports can be used for spare. The locations of VG0, VG1, VL0, VL1, VL2, VL3, and VD0 are shown in the figure of page 4. VD1 is not used now. V0 is a gate valve, and both V0=1 and V0=0 are connected to the gate valve, written in the figure of page 12. Cables of V0=1, V0=0, VG0, VG1, VL0, VL1, VL2, VL3 are connected to SCS2000 XECDetector(page 5), and the cable of VD0 is connected to SCS2001 XEC1000L (page 7).



The other valve control unit is located in the Gaseous purification system as shown in the left picture.

In total, 10 ports will be used for the valve control of high pressure gas tanks. Previously only two valves are defined in the slow control system (page 9), and I added the information about the other 8 valves. The remaining 6 ports can be used for spare. The locations of the high pressure tanks are shown in the figure of page 12.

V0=1 and V0=0


Detector
transfer tube
GM refrigerator
GMV/v
VG0
VG2
Gate valve + Pumps
VL0
VG1
VL1
VL2
VP0
heat exchanger
VP1
N2VL0
1 2 3
4 5 6 7
outside
To outer-face pre-cooling line
To PS pre-cooling line
outside
outside
outside
LXe purifier
VP2
VL3
LN2 Def
LV/v
GV/v
GVd/v (=VD0)
LN2V/v
1000l tank
outside
LN2VEst
Gas panel
regulator
pump
getter
#0
#1
#2
#3
#4
#5
#6
#7
#8
#9
High pressure GXe tanks
LXe
GXe
valve
manual valve