Smart cold electronics

XLZD Meeting 2 Jul 2025

Alessandro Razeto for the LNGS/AQ group

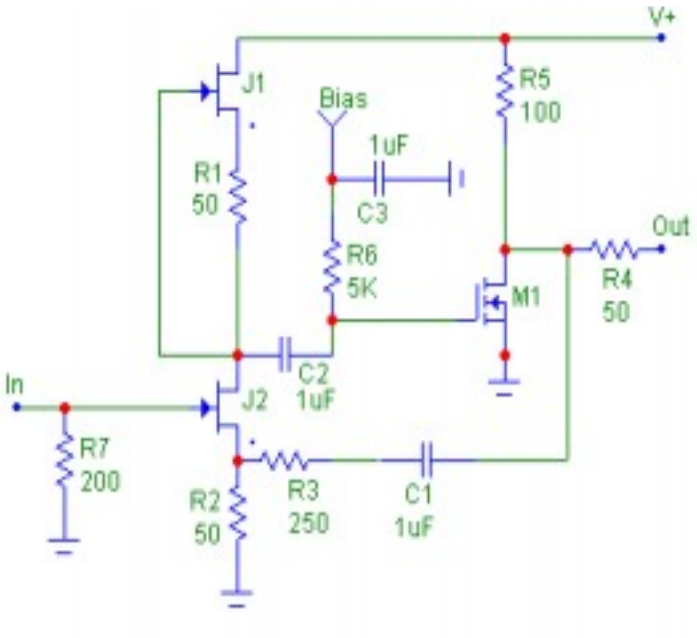
GROUP

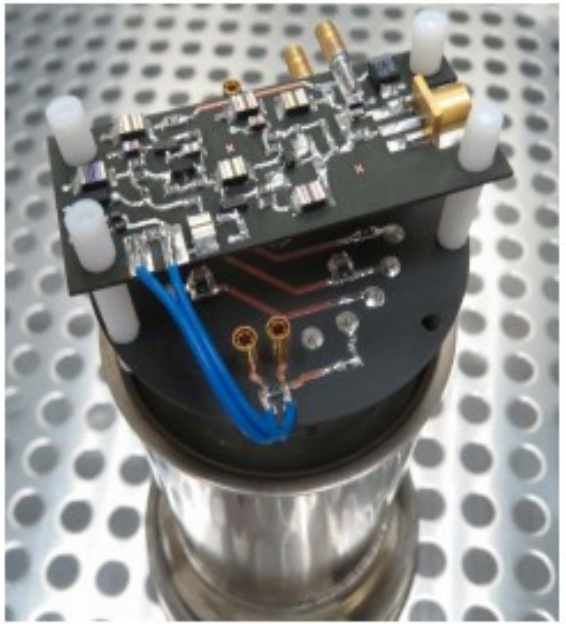
- A strong group with proven experience
  - Radiopurity
  - Packaging
  - Photodectors
  - Cryo-electronics
  - Integrated electronics

- LNGS + University of L’Aquila

PAST RESULTS

DS-50

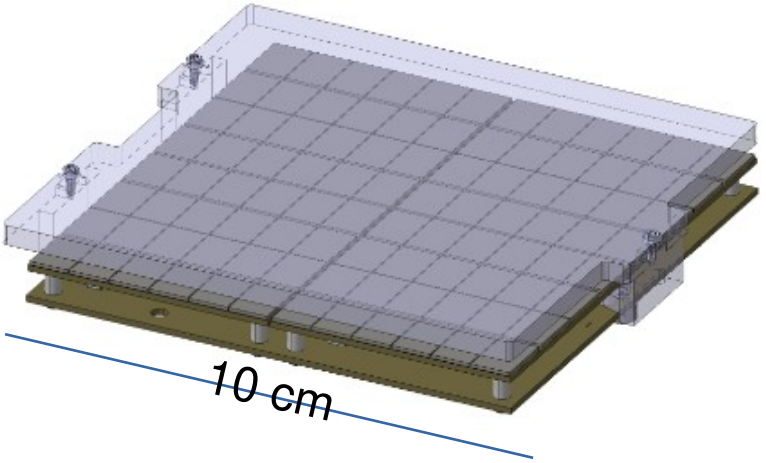


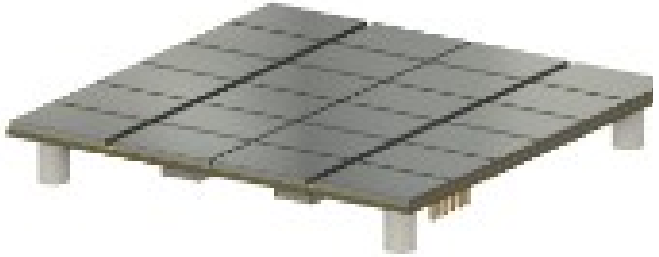


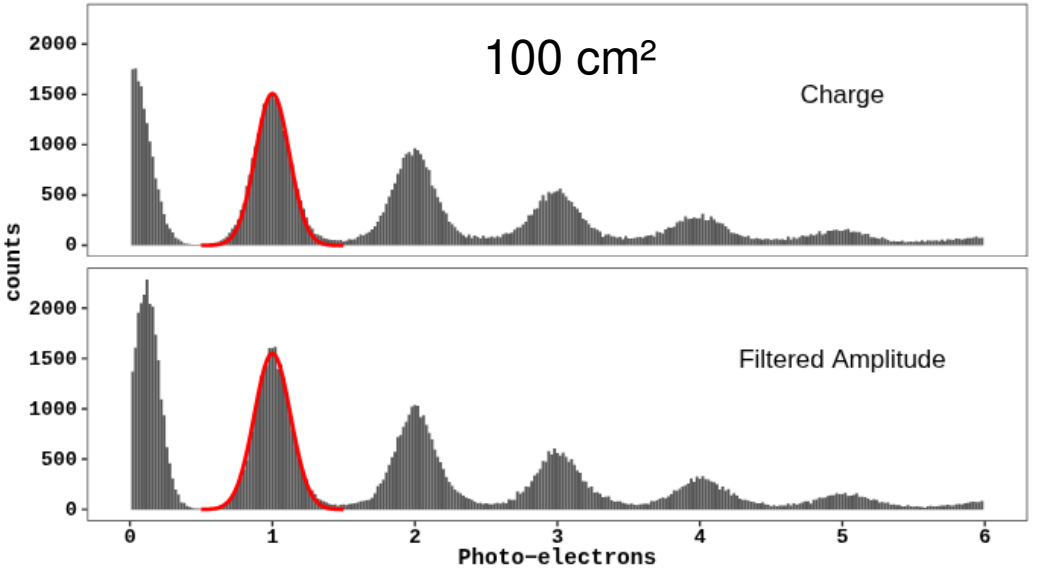
DOI 10.1088/1748-0221/12/12/P12011

PAST RESULTS

DS-20k







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Why cold electronics?

Signal integrity

- A signal to noise over 30 can be easily achieved (see later)
  - A small signal (mV level) on long cable can get noisy and attenuated
    - Pre-amplification produces larger signals that can be easily transmitted for 10 meters with small cables
- The largest noise contribution in XenonNT is from ground loops
  - From single ended (coax) cabling
  - Differential transmision would suppress it
- We could keep PMT HV lower
  - Improve long term stability for PMTs
    - DS50 PMT were running at a gain of 10^5 e^- with SNR > 10

Radiopurity

- Coaxial cables are not radiopure
  - Contaminants remain trapped in the mesh
  - Radon emanation
  - Differential transmission over twisted cables with PTFE/FEP jacket
    - With solid conductor – if needed
- Low voltage components are radiopure
  - In term of U/Th
    - Plastic capacitors, inlined resistors, wire bonded chips
  - Largest contamination from the divider components
    - High voltage ceramic capacitors and 10 MΩ resistors
- Radiopure PCBs
  - LNGS will install in the next few years a facility for fused silica PCBs
    - It may be possible to deposit there LV resistors

Integration

- A much simpler detector integration
  - Reduced number of HV cables
    - On divider HV switch
  - Reduced number of signal cabling
  - Easier signal feedtroughs

- Strongly reduce the budget
  - Feedtroughs, digitizers, … → several M€

Cons

- Of course things can go wrong
  - More components that can fail
- Not everything can be done in cold
  - Full digitization not possible
    - Limited by the power dissipation in LXe
- The dynamic range of each channel will be smaller
  - PMTs can reach 10^5 photons
    - Impossible to match with standard configuration
      (but semi-logaritmic solutions can be implemented)
- Immutable
  - Once the detector is installed it is hard to modify the read-out chain

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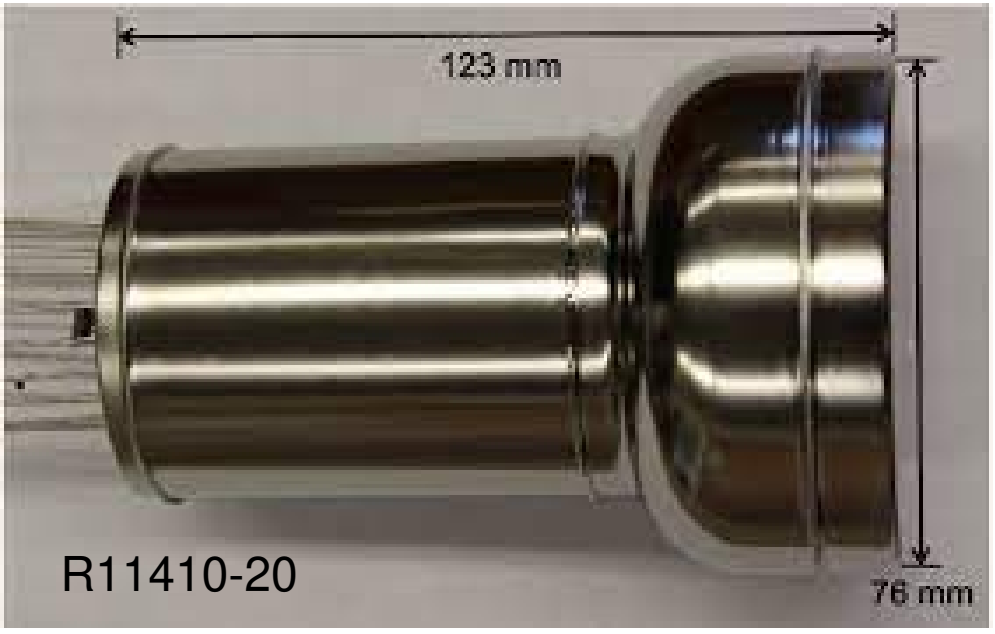
PMTs

PMTs

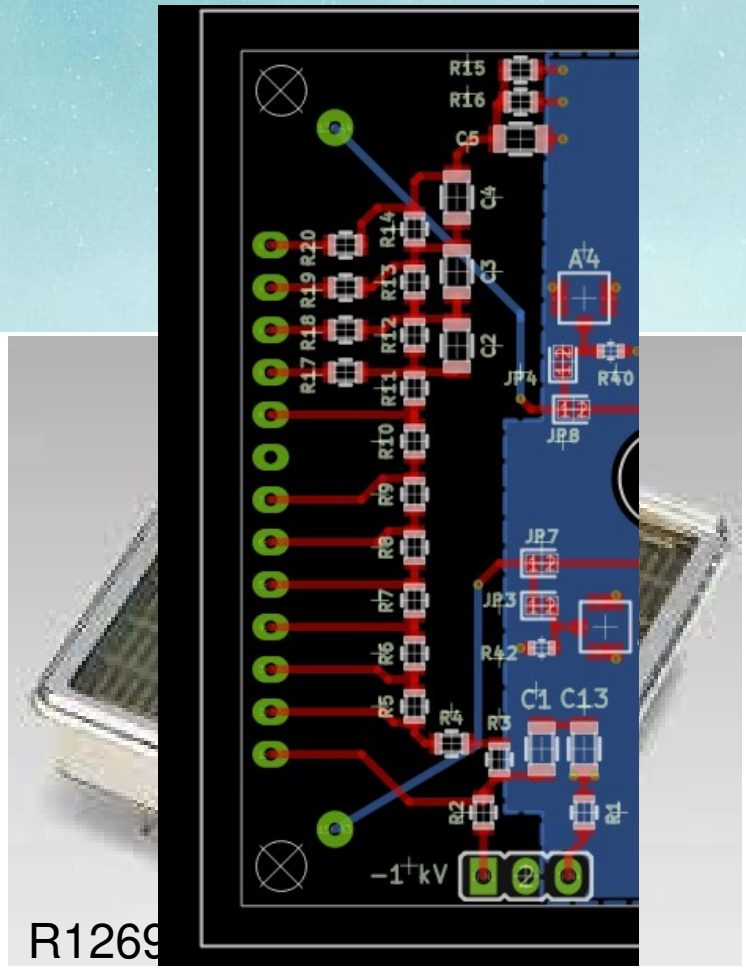


R11410-20

R12699-406-M4

PMTs

R1141



R1269

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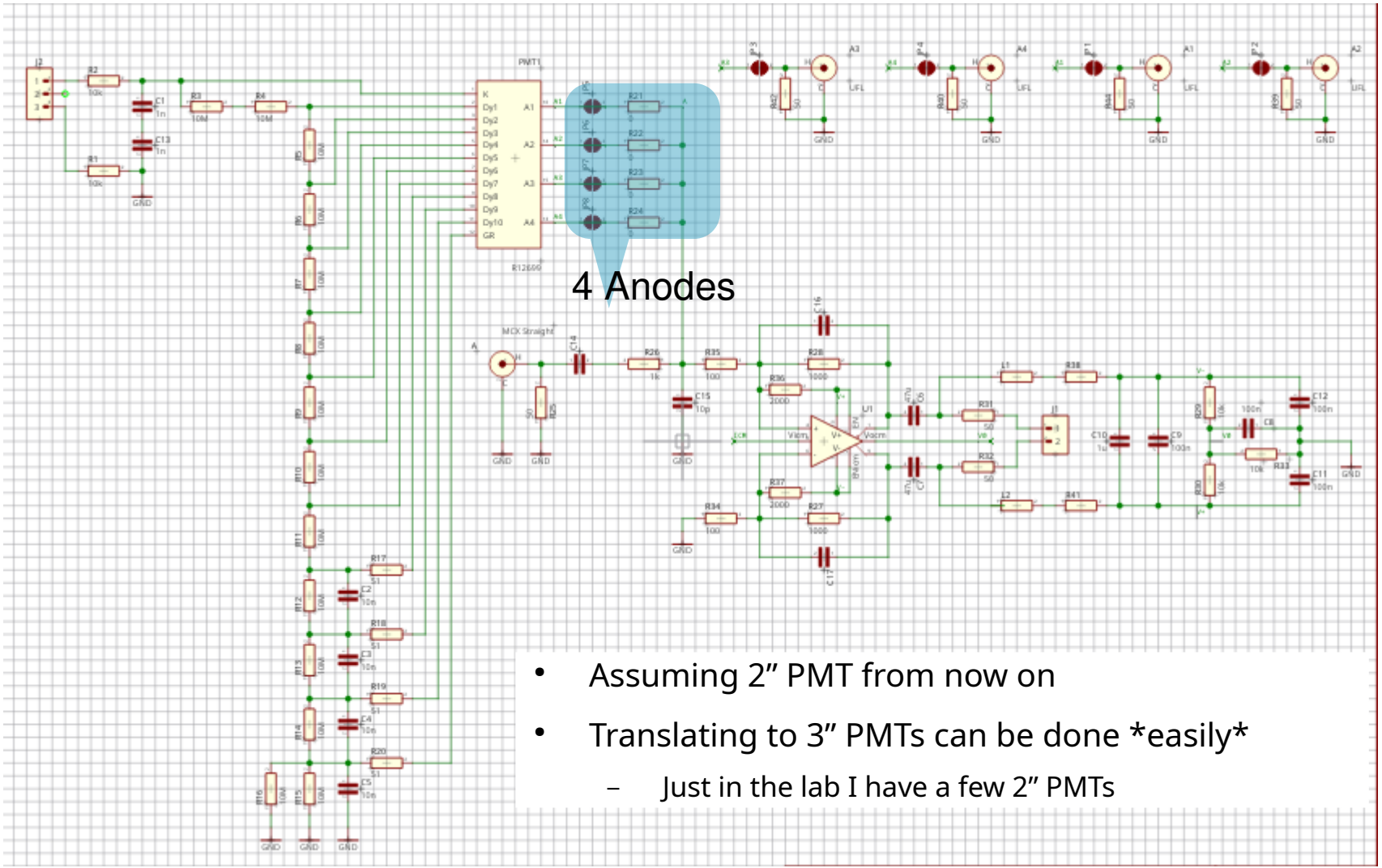
A graded approach

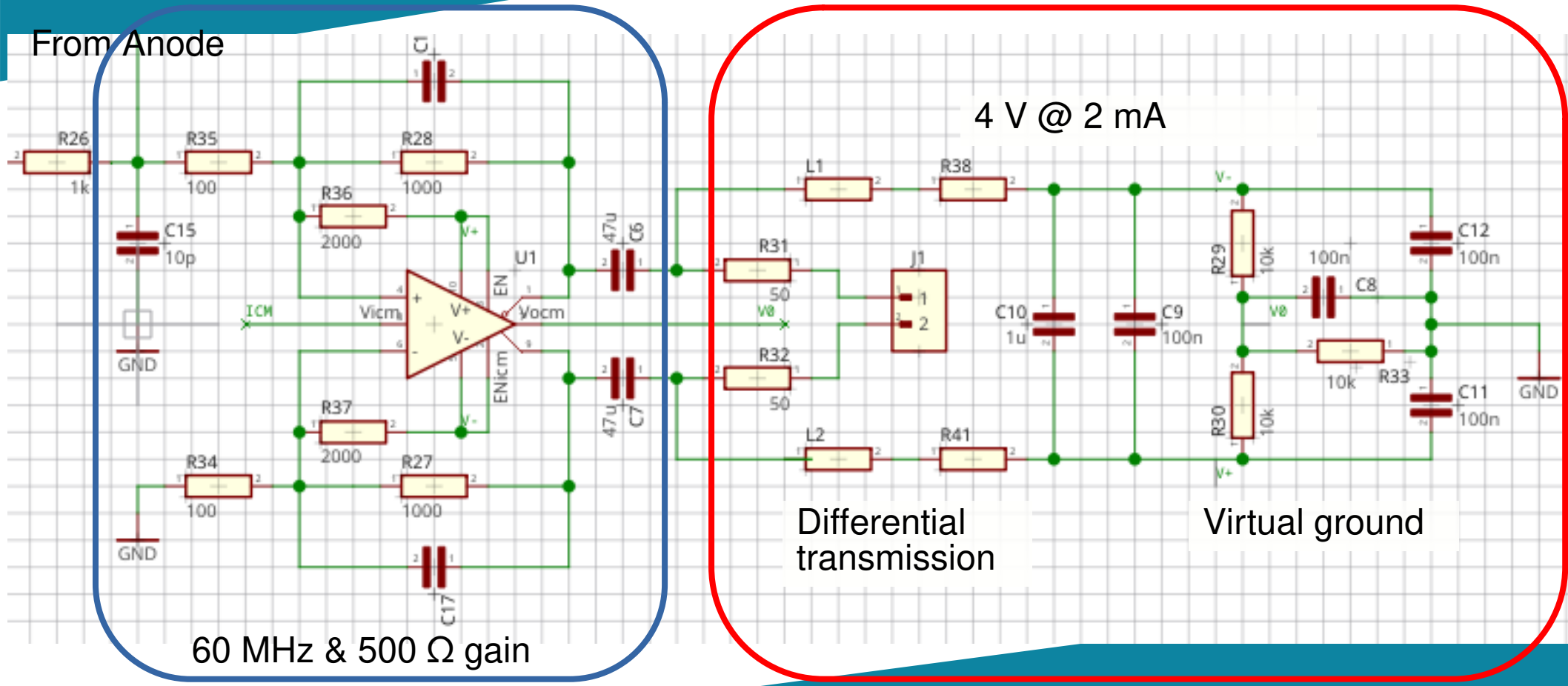
Amplify in cold and digitize ouside

Fully differential TIA

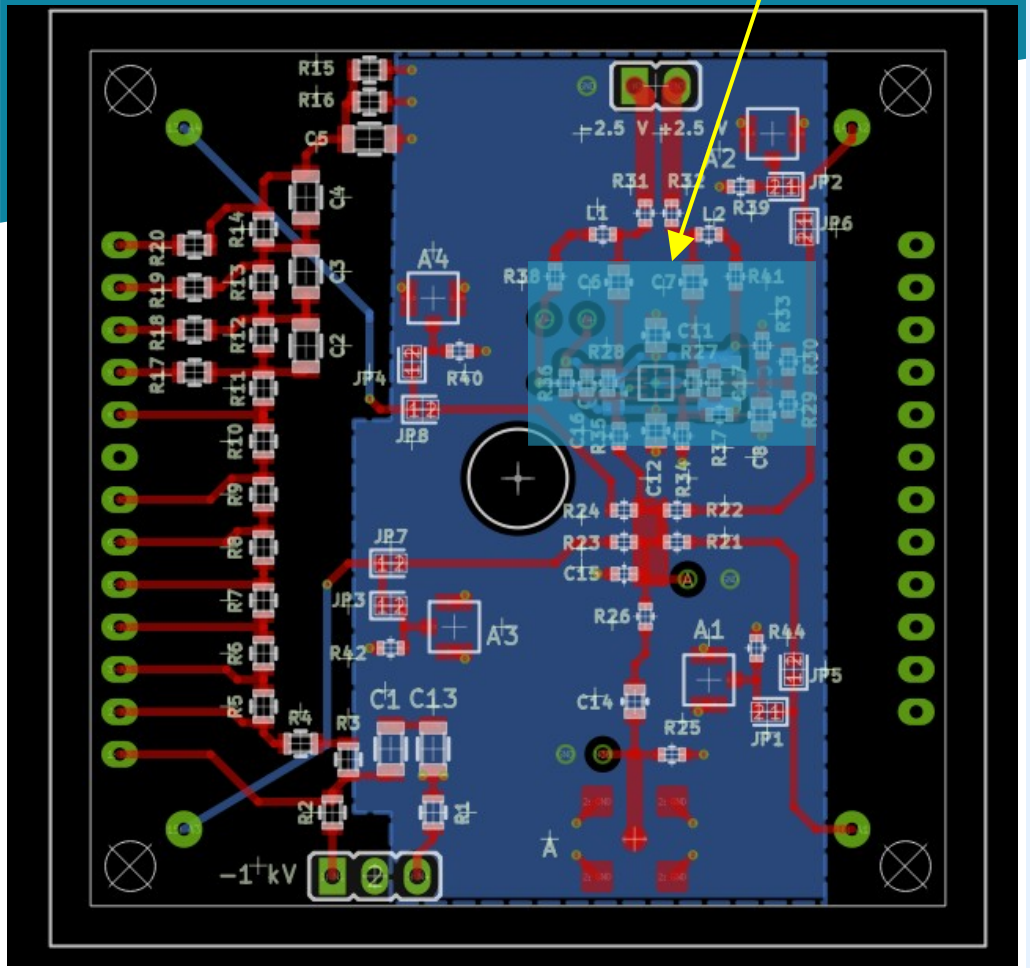


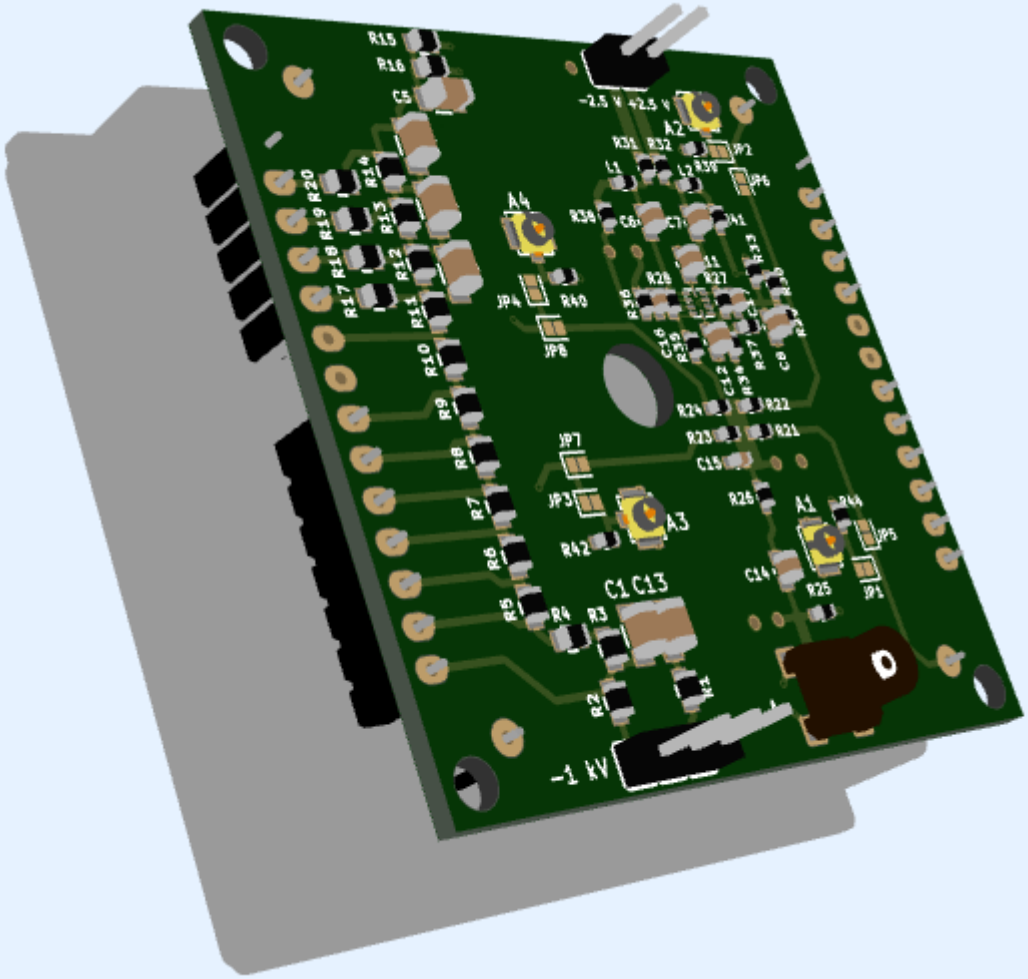
- Assuming 2” PMT from now on
- Translating to 3” PMTs can be done *easily*
  - Just in the lab I have a few 2” PMTs

Parasitic power



10x15 mm²


R15
R16
C5
+2.5 V
+2.5 V
A2
R31
R32
JP2
L1
L2
R39
JP6
A4
R38
C6
C7
R41
C11
R28
R27
R33
R30
R29
R36
C16
R35
R37
C8
C12
R34
JP4
R40
JP8
R24
R22
R23
R21
C15
JP7
JP3
R26
A1
R44
JP5
R42
A3
C1 C13
C14
R25
JP1
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R17
R18
R19
R20
C3
C2
-1 kV
A


R15
R16
C5
-2.5 V +2.5 V
A2
R31
R32
JP2
L1
L2
R39
JP6
A4
R38
C6
C7
R41
C11
R28
R27
R33
R30
R29
R36
C16
R35
R37
C8
C12
R34
JP4
R40
JP8
R24
R22
R23
R21
C15
JP7
JP3
R26
A1
R44
JP5
R42
A3
C1 C13
C14
R25
JP1
R3
R4
R5
R6
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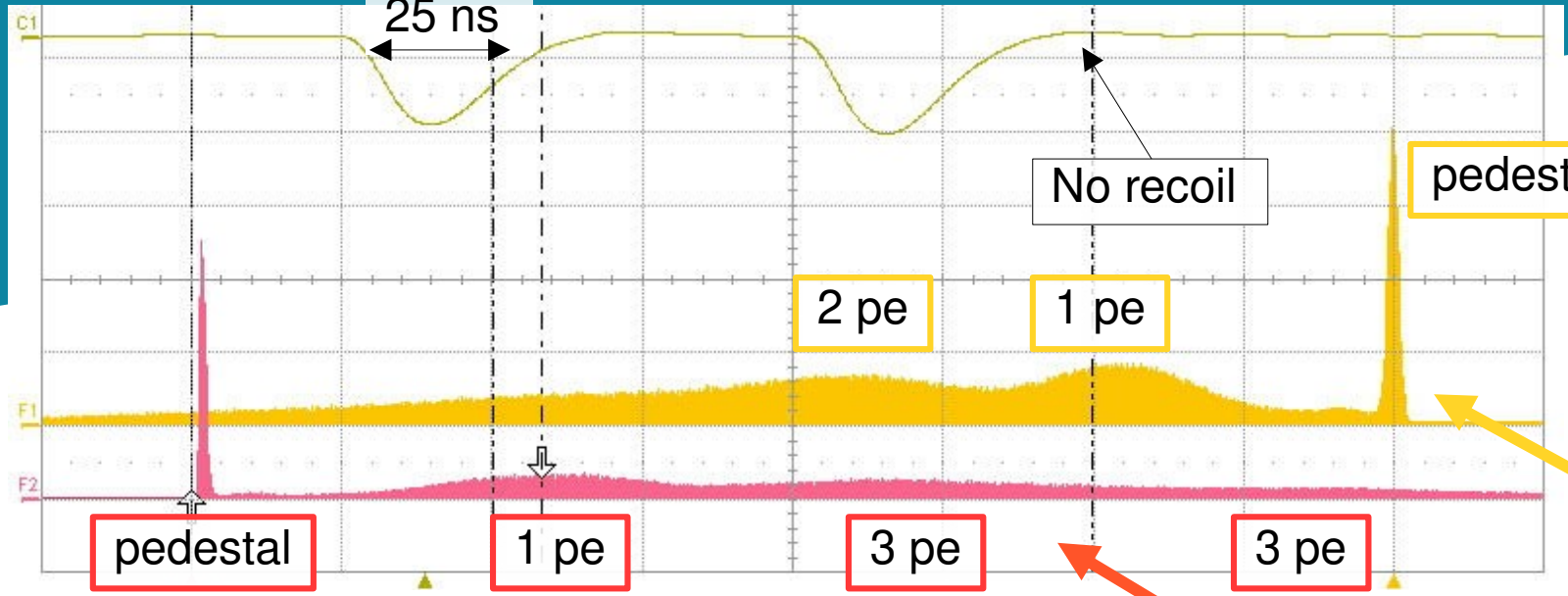
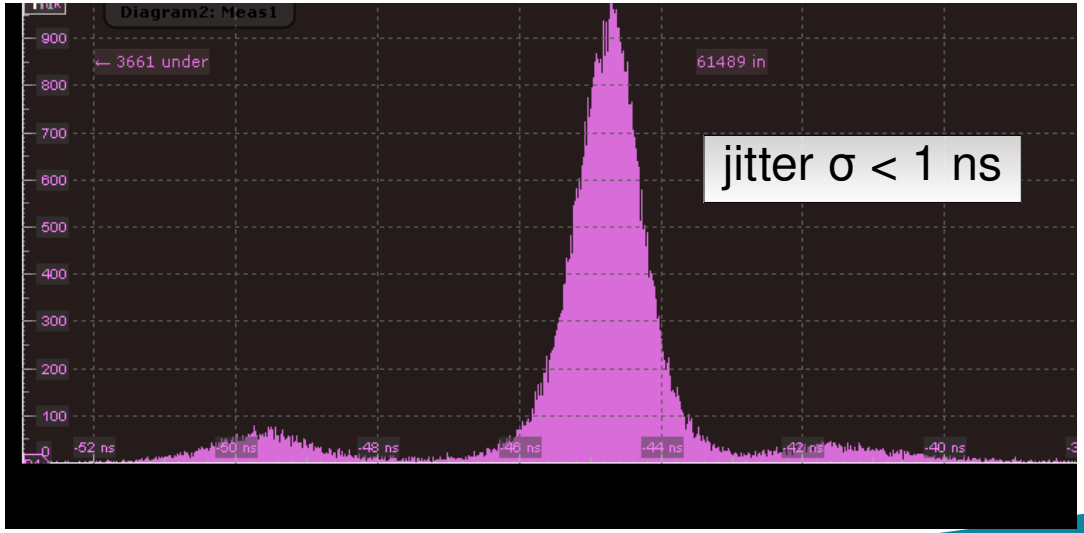
R17
R18
R19
R20
C3
C2
-1 kV



PMT @ 1000 V

Charge
- Gain 2 10^6 e^-
- Noise 3 10^4 e^-
- SNR 75



Amplitude
- Gain 25 mV
- Noise 150 µV
- SNR 150

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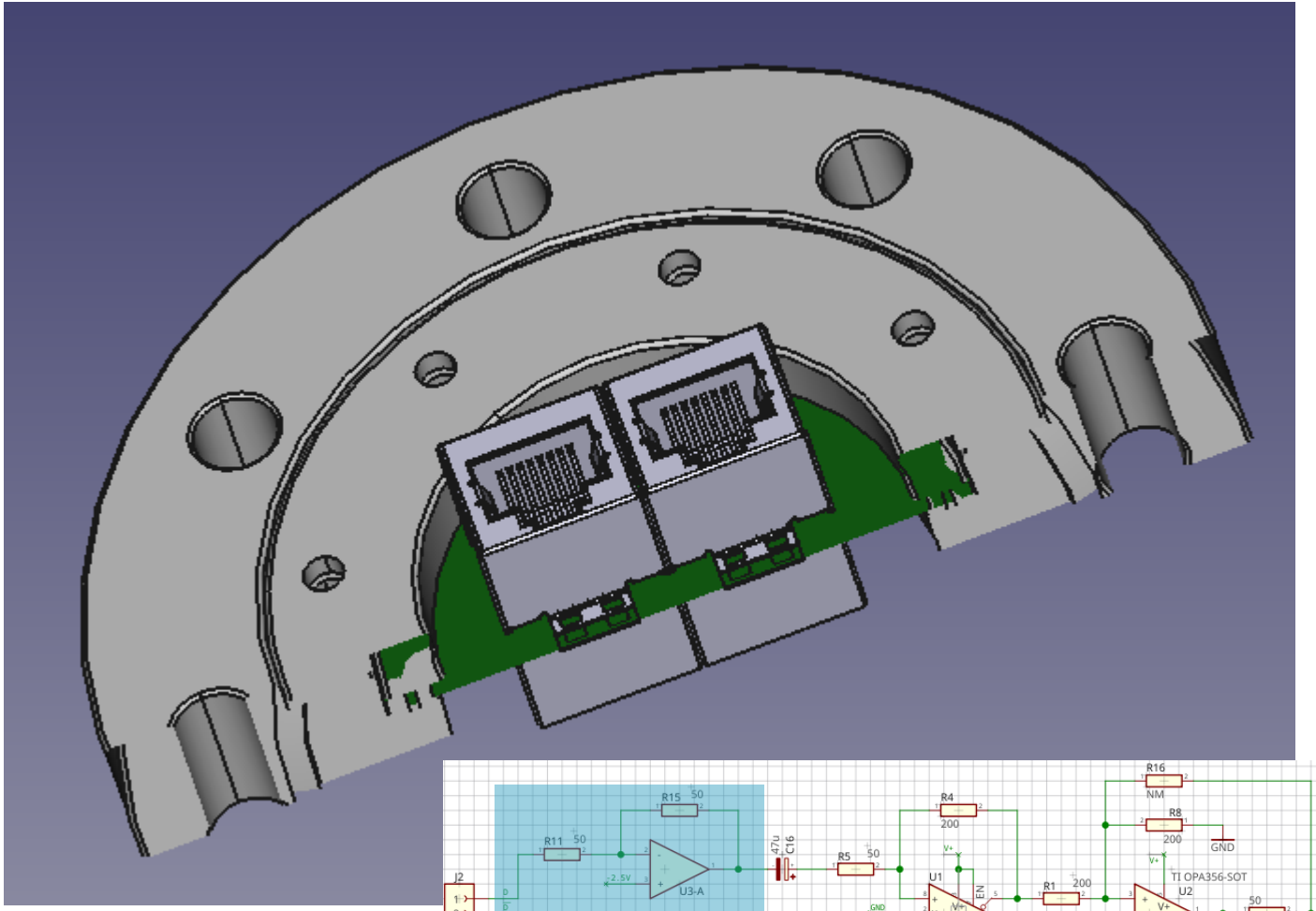
A graded approach

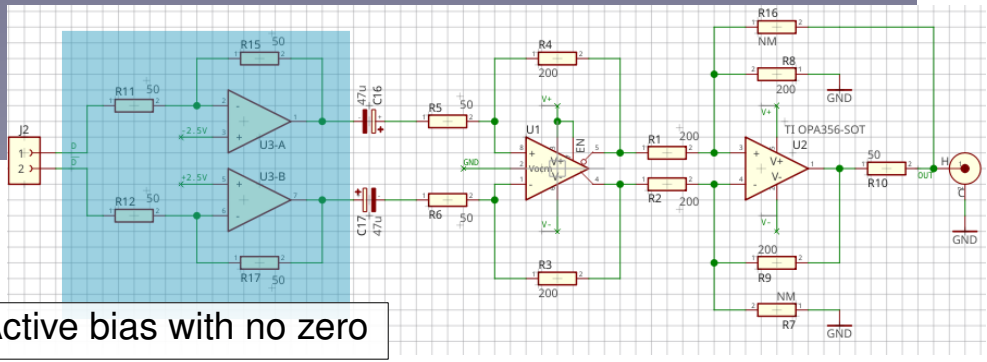
Cabling

Cabling

- Differential transmission goes with twisted pairs
  - The simplest solution is a pair from a CAT.6 RJ45 cable
    - Yes the ethernet cable
    - PTFE isolated
  - SAMI produced radiopure twisted pair cables for LEGEND
- The feedtroughs can be implemented with PCB
  - Leak < 10^{-10} mbar/l/s
- A differential to single ended receiver can be used

Cabling





Active bias with no zero

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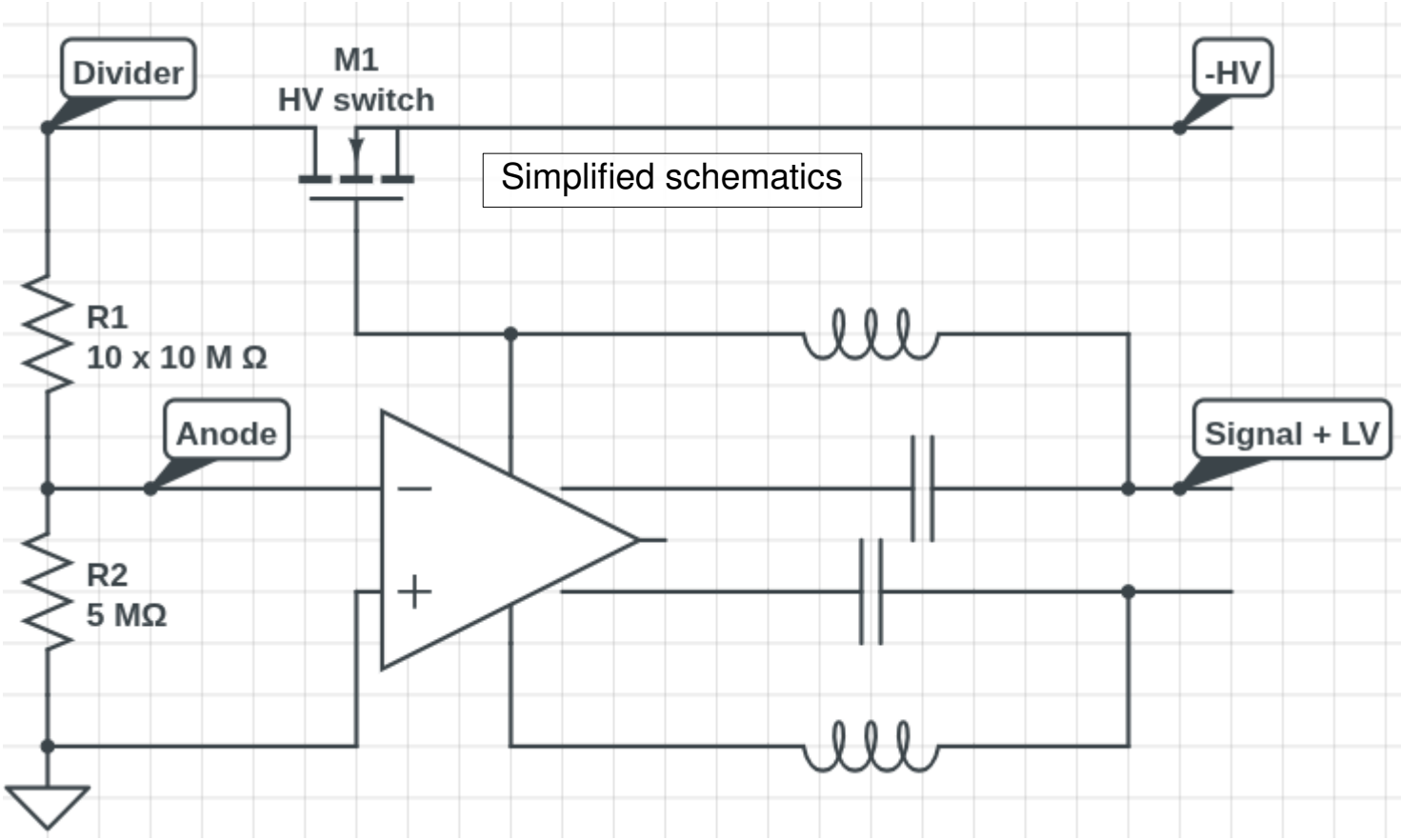
A graded approach
HV distribution

HV distribution

- It is possible to bin the PMTs in groups with similar curve HV-vs-GAIN
  - During the acceptance tests
- We suggest to bring a single HV to group of similar PMTs
  - One each 25?
- Then each PMT can turn off by itself when needed
  - With an on-board switch
  - Without additional cables or controls
    - Remove power to the cold-amplifier and disable the PMT as well

HV distribution



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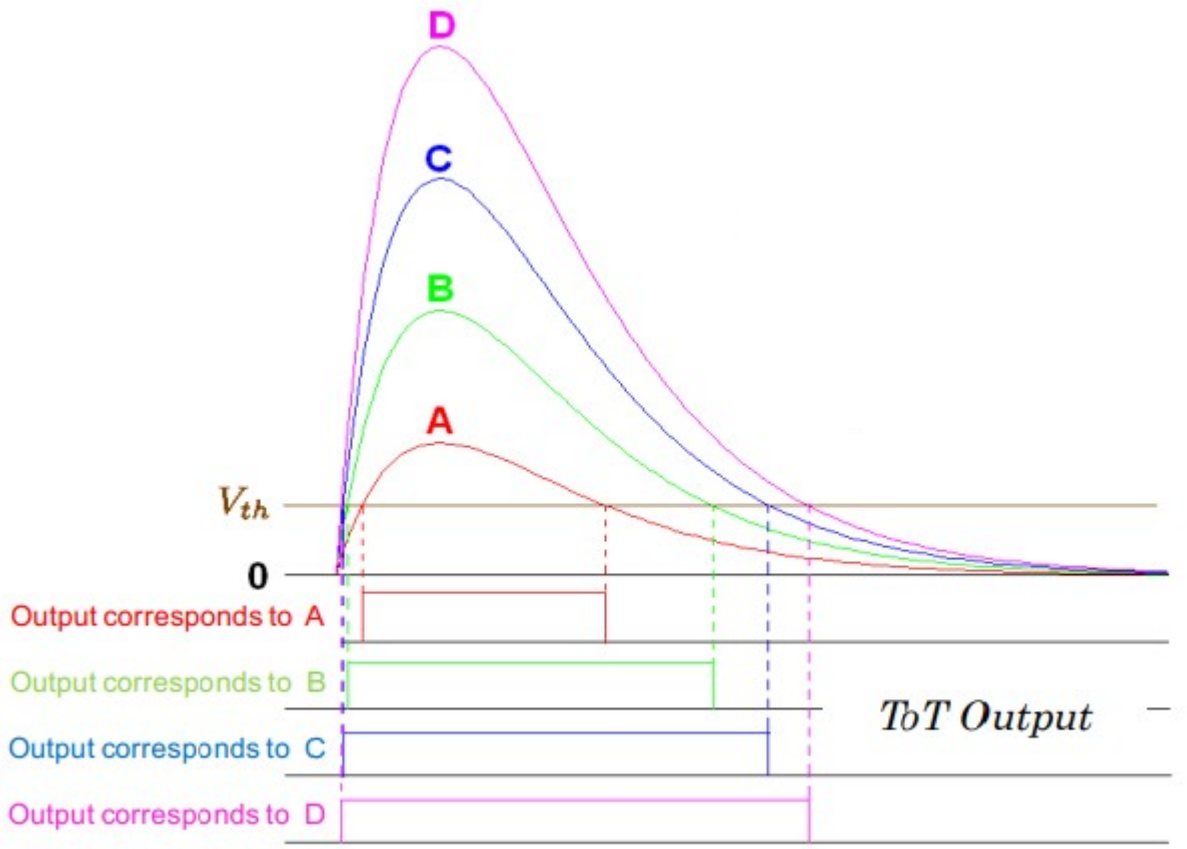
A graded approach

Amplify and digitize cold

Digitize at cold

- We have the technology to develop chips working in LXe
  - PDK certified in cryogenic environment
- A full digitizer however uses way too much power
  - Too much heat would prevent Rn-chain topological tagging
  - Boubbling
- The proposed solution is to develop a programmable TDC with time over threshold
  - Per each anode - 2.5 x 2.5 cm^2
  - And to bring out the sum of a PMT group analog signal

Time over Threshold



Time & amplitude for each photoelectron

~ 10k anode in XLZD, the pileup of S1 at 3 MeV ~ 3 pe per channel

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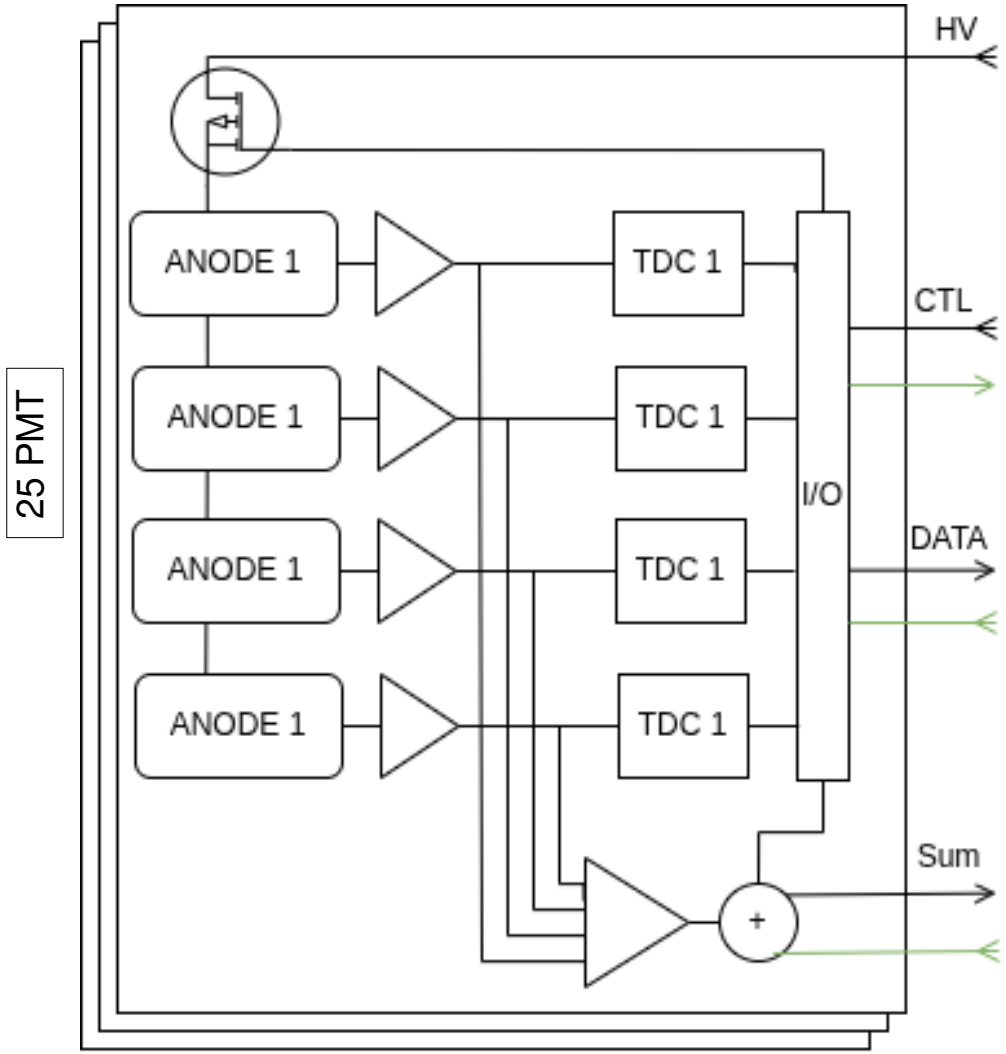
A graded approach

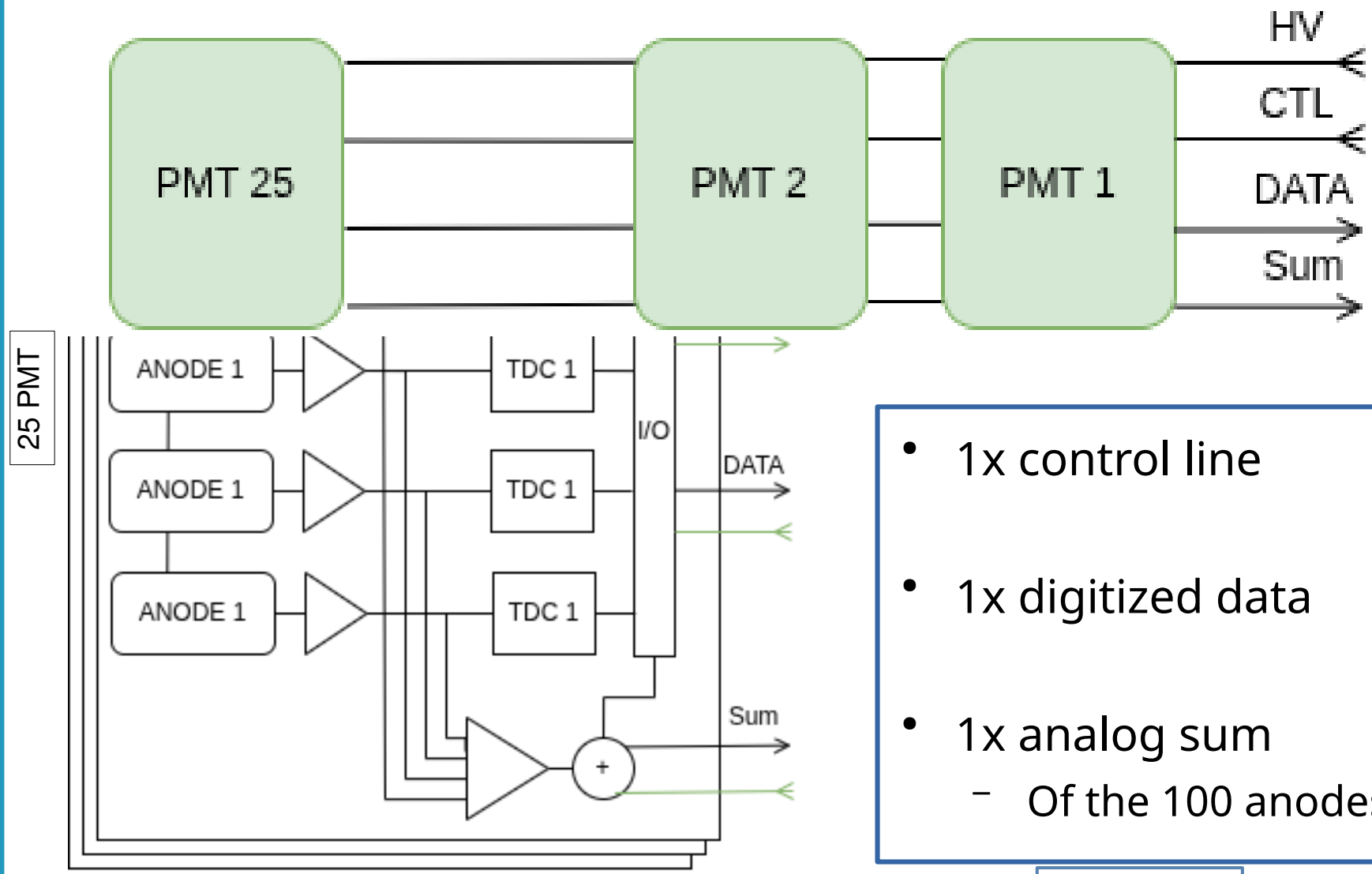
Fully integrated solution

Integrated unit



- 25 x 25 cm² module
  - 25x 2” PMTs
- 1x HV
- 1x control line
- 1x digitized data
- 1x analog sum
  - Of the 100 anodes

Integrated unit



- 1x control line
- 1x digitized data
- 1x analog sum
  - Of the 100 anodes

1 RJ45 cable

Summary

Conclusions

- We already have a cryogenic pre-amplifier
  - Low noise
  - Low power
  - Low radioactive ← will require some time depending on the PCB choice
- A highly integrated unit can be developed in a few years
  - 25x25 cm^2 aggregated photodetector with 2” PMTs
    - with a single HV and a single RJ cable for signal and control
    - With low power (20 mW/PMT) and high radiopure components
  - 3” PMTs can be used as well → 4x4 PMTs
    - Maybe with a PCB piggyback for the cold-electronics
- The LNGS group is actively working on this topic
  - Proven results with simple pre-amplifier
  - Working on the ASIC design
  - Working on the smart power distribution
  - Working on radiopure PCBs

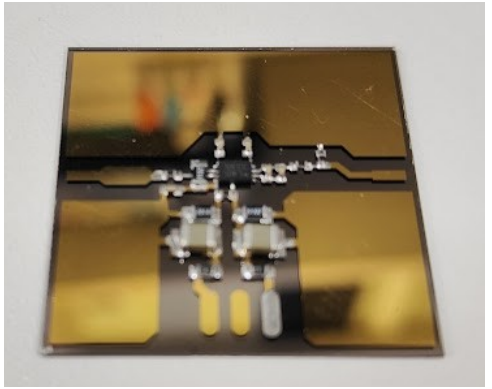
Thank you

Technologies

To overcome the limitations

Radio-purity

- Ceramic capacitors have high U & Th
  - Plastic, silicon, tantalum capacitors have low high-Z contaminations
    - Though they may have 40K and other traces
- PCB can be produced in fused silica
  - With embedded resistors with laser trimming
  - Or in pyralux/cyrlex/…
- Connectors contain glass-fiber
  - can be produced out of pure nylon
- Radio-pure inductors exists



Technologies

- Pure Si BJT not working below 200 K
  - Freeze-out of minority carriers
  - Ethero-junction BJT are working down to 20 K
    - With very low noise figure
- FET transistors are working in LN2
  - Based on majority carriers
- For both technologies both single transistors and op-amp are available

Field effect transistors

- Field effect transistors are based on majority carriers
  - FETs work down to the freeze-out
  - Higher gain and bandwidth
  - Lower noise
  - LOW POWER

- Problems:
  - JFETs have increased noise below 120K
  - Hot carriers reduce life of devices
  - Increased 1/F noise
  - Trapping / Recombination

Rescia @ Mi
Radeka @ BNL