TWEPP 2023 Topical Workshop on
Electronics for Particle Phyiscs

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Design and performance of the front-end electronics of the charged particle detectors of PADME experiment

Simeon Ivanov,
Sofia University

On behalf of the PADME collaboration

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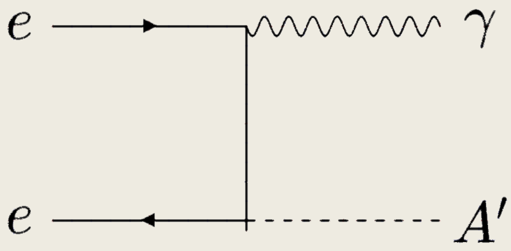
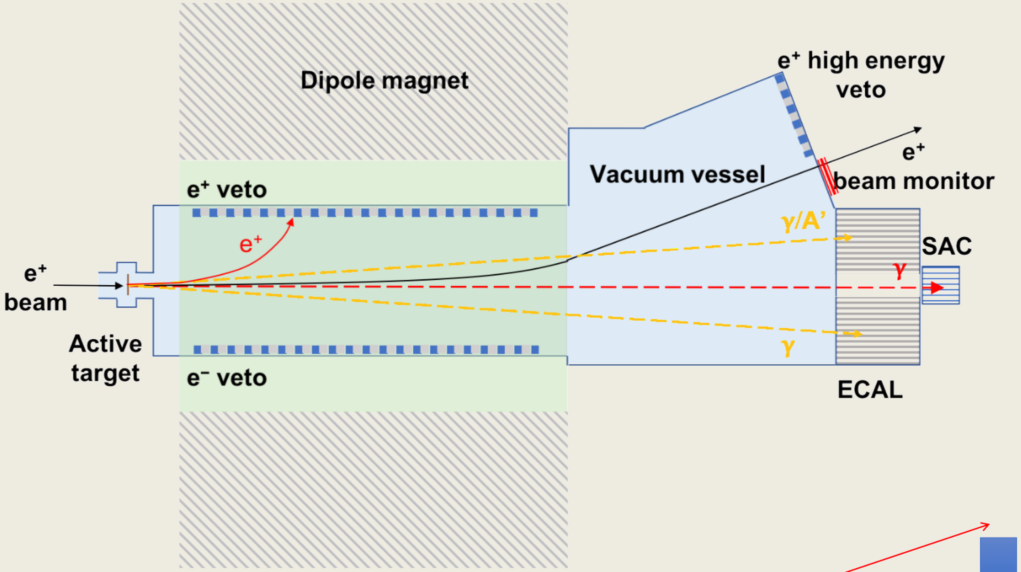
Search for the Dark Photon

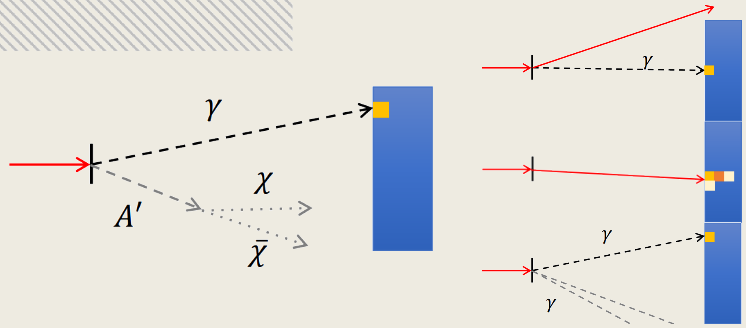
- Hypothesis
  - Dark sector with a vector mediator A' weakly coupled to SM
  - Wide range of mass and couplings
  - Potentially can explain other physics problems (muon g-2 anomaly, ^{8}Be anomaly, etc.)
- Method
  - Missing mass in decays to the dark sector from positron annihilation on a thin target
  - $M^2_{miss} = (p_{e+} + p_{e-} - p_{\gamma})^2$
  - Need only to determine initial and final state **(and remove noise)**



Experiment summary

- Located at LNF, Italy
- LINAC accelerator
  - Beam properties
    - up to 600MeV, tunable
    - <1% energy dispersion
    - 49 bunches/s from 10 to 200 ns
    - up to 2.5e4 e^+/bunch
- e^+e^- annihilation on optimized thin target
- Signal vs. noise: noise consists mostly from charged particles

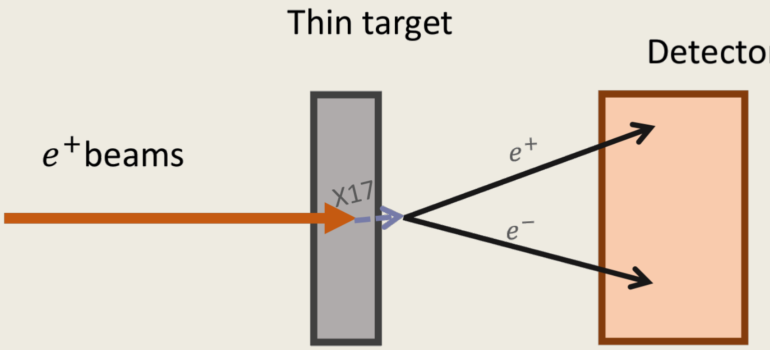




The PADME Experiment

Additional Physics Programme

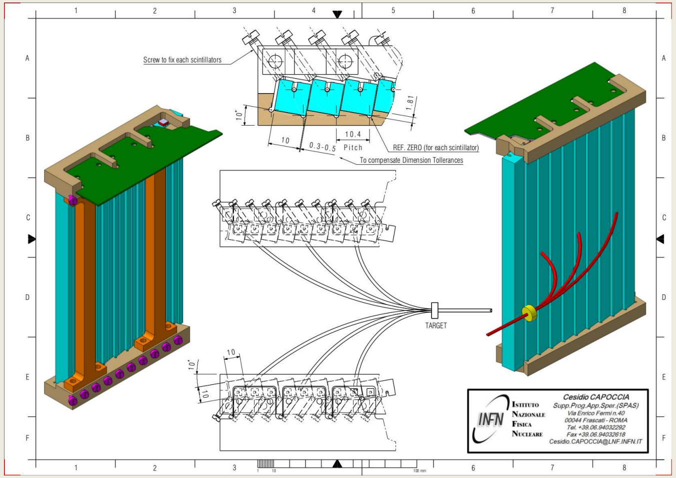
- X-17 particle
  - Hypothetical heavy invisible particle, decays to e^+e^- pair
  - Method: number of secondary pairs compared to initial state number
  - Padme detector was easily reconfigurable for this search
- Cross-section observations:
  - 3-way gamma annihilation
  - bremsstrahlung

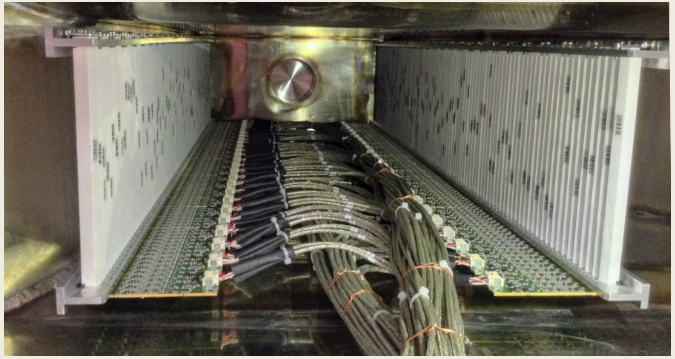


The Charged Particle Veto

The Veto Detectors

- Role:
  - Bremsstrahlung background suppression
  - Registration of visible decays
- Requirements:
  - Momentum resolution: 5MeV or better
  - Time resolution: 1ns or better
- Characteristics
  - Plastic scintillators 10x10x178mm^3, glued-in WLS fiber
  - 96 in e$^-$ veto, 90 in e$^+$ veto, 16 in HEP veto
- Readout Electronics
  - **SiPM front-end electronics inside vacuum chamber**
  - Hamamatsu S13360 3x3mm2 25um cells
  - Power supply/analog readout modules

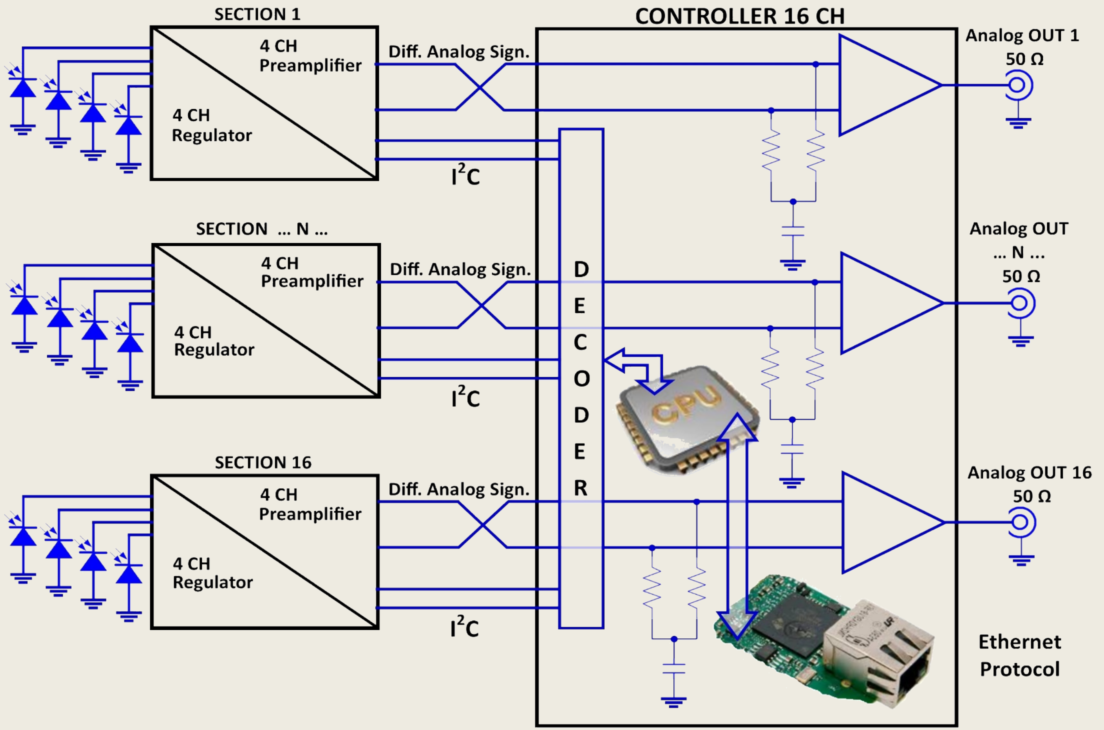




The Veto FEE Architecture

The veto detectors front-end electronics

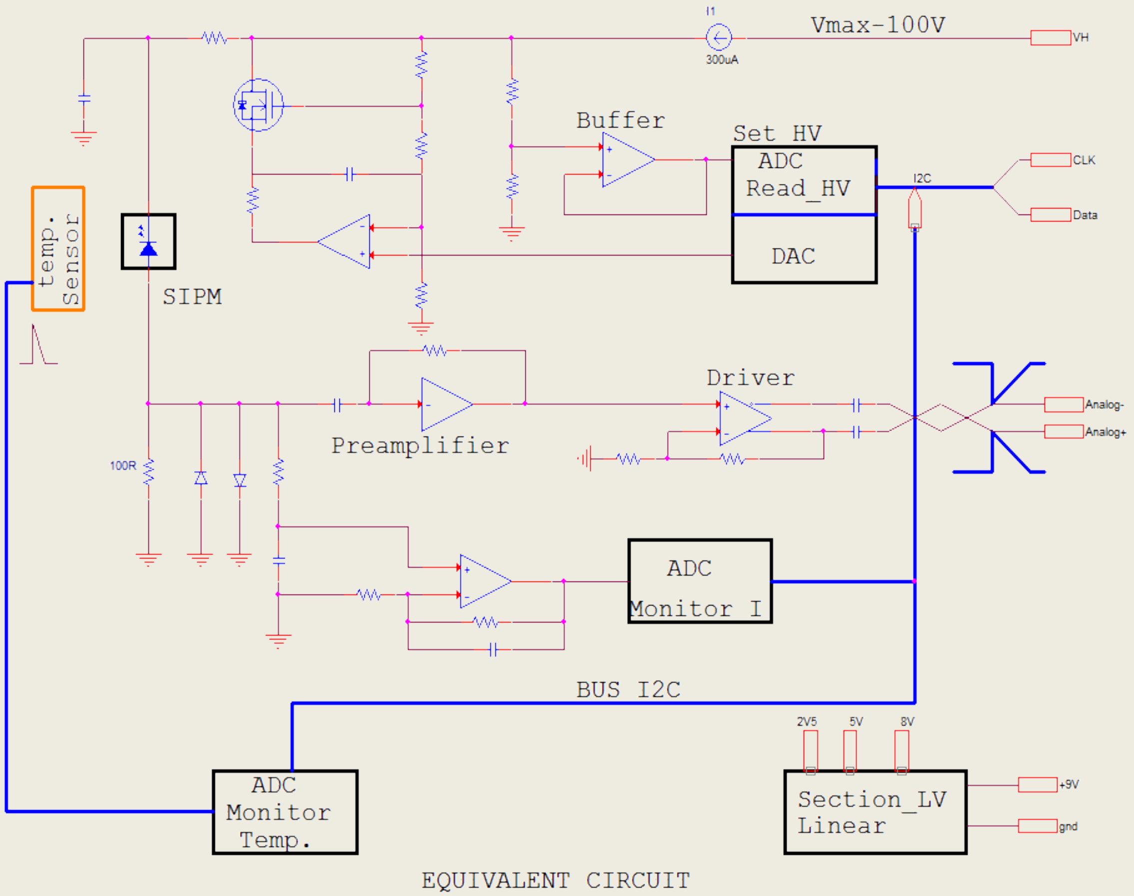
- Requirements
  - Fast, ensuring the time resolution, required by the veto detectors
  - Low thermal dissipation
  - Remotely configurable and controllable
- General Architecture
  - 4 4-channel pre-amplifier cards operate in vacuum chamber
  - Differential analogue signals sent to control unit
  - Control of operation using I^2C
  - Telnet/HTTP command interface



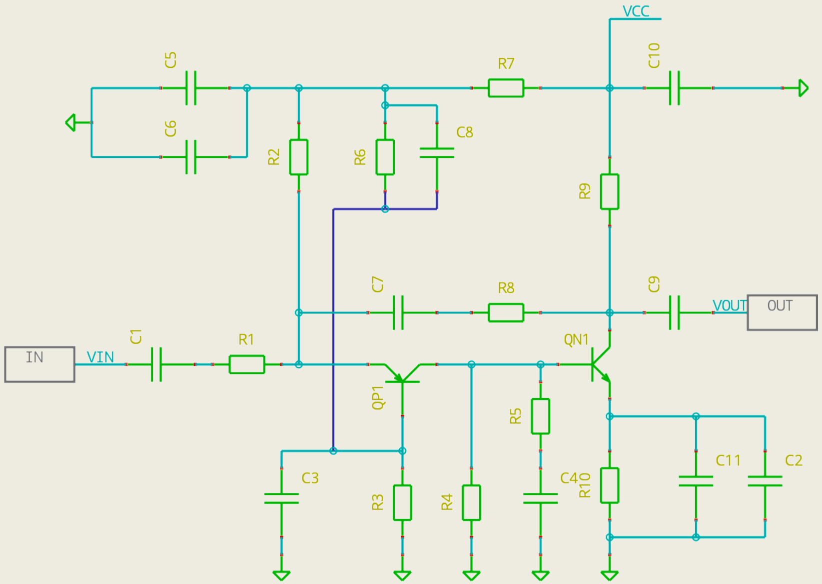
Single Channel Design

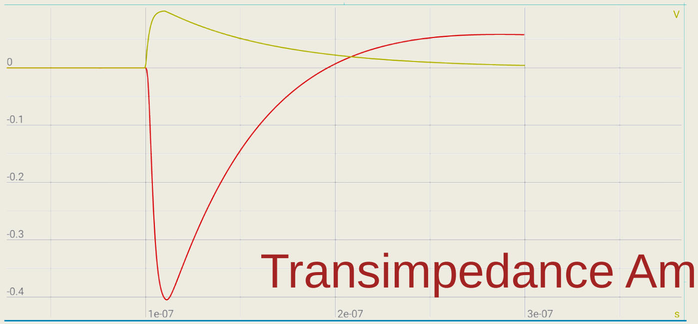
Design Overview

- 4 independent channels per board
- Each channel is composed :
  - Programmable shunt regulator
  - Fixed gain(=4) preamplifier
- Differential 100Ω output analog signal
- Measurement of the current in the detector
- Measurement the temperature of the detectors
- Single supply voltage
- Low power dissipation



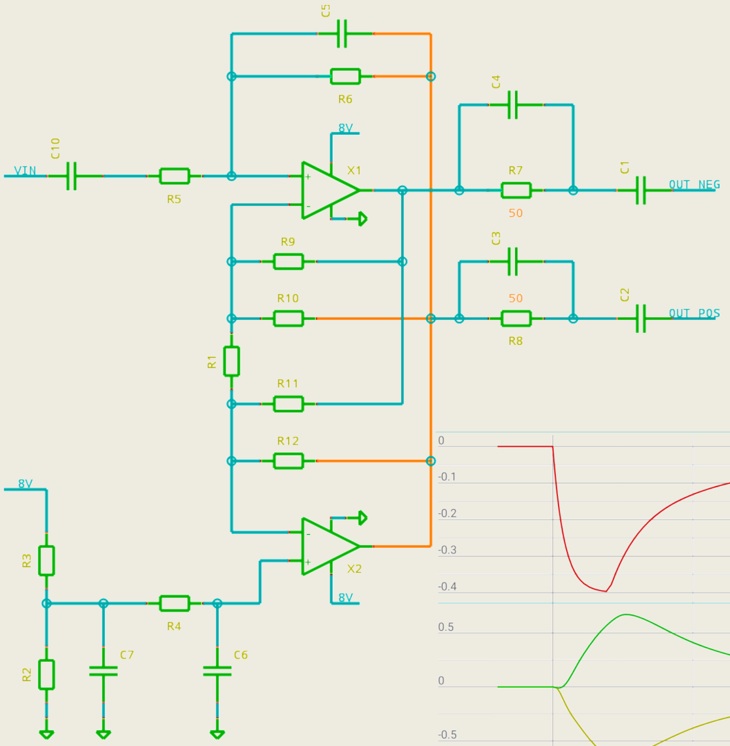
Preamplifier Design

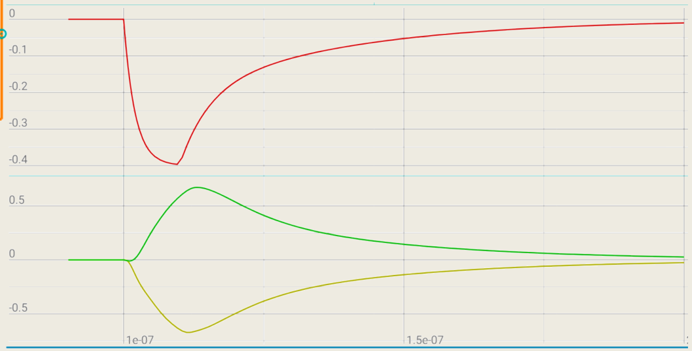




Transimpedance Amplifier

Balanced driver



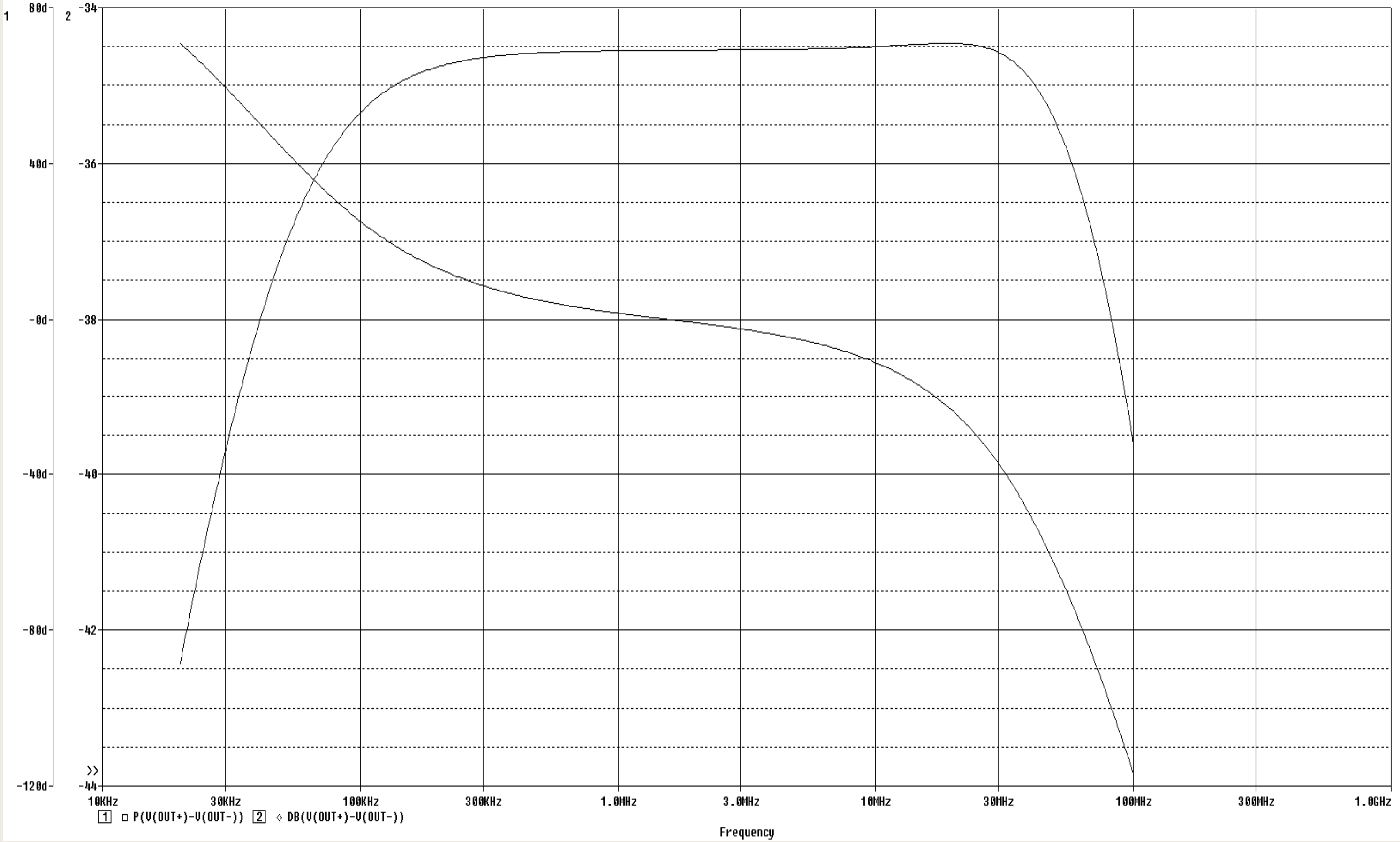


Performance Overview

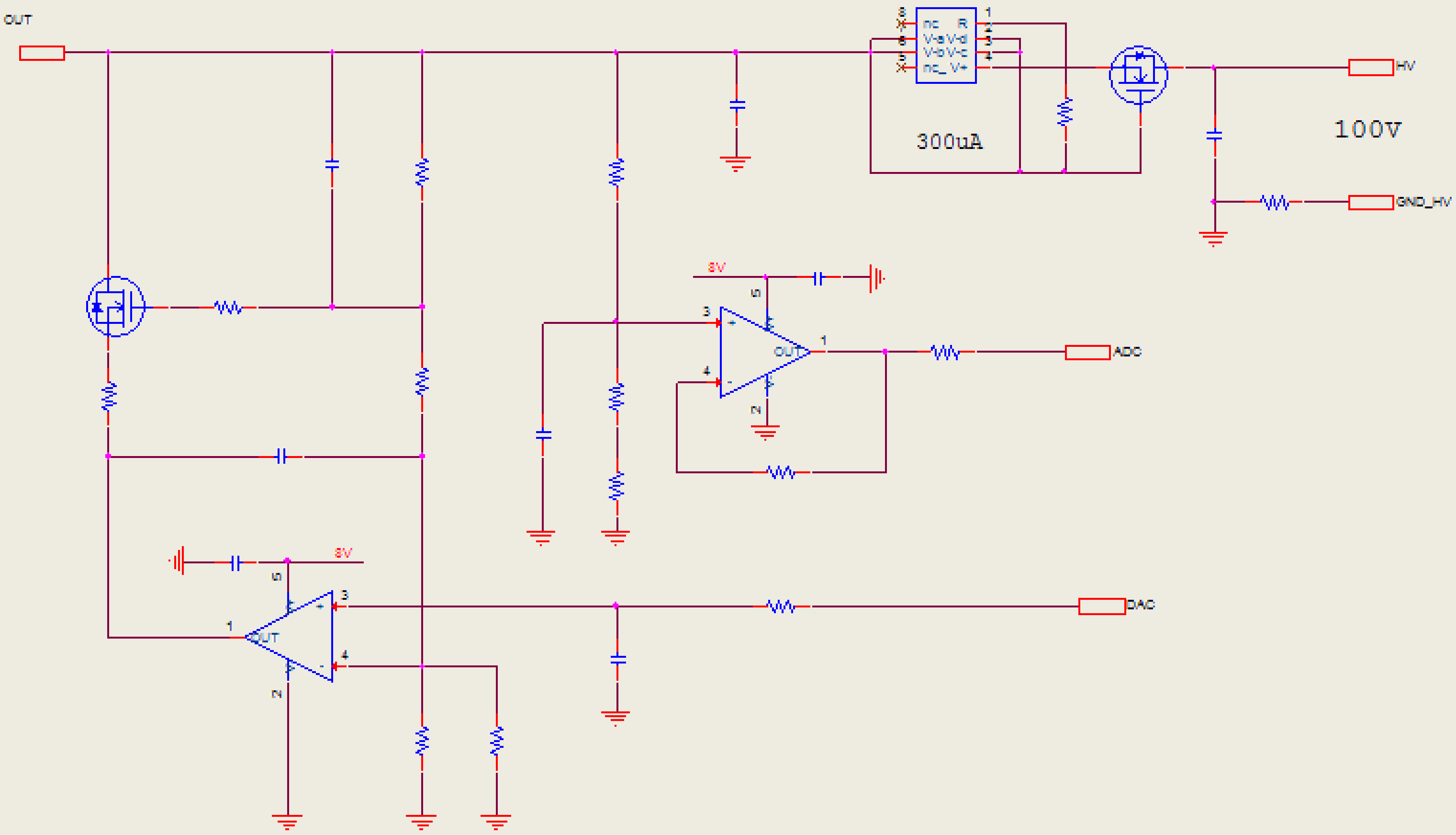
- Fixed Gain = 4
- Differential output at 100Ω
- 70MHz Bandwidth
- Excellent stability with C_{in} < 500pF
- Repetition rate > 1MHz
- Pulse resolution: better than 10 ns

- Output signal range = 1V
- Total noise with Cin 2pF equivalent = 2nV/√Hz
- Input protection = 300mJ
- Single power supply = 8V
- Dissipated power for channel = 35mW

Amplitude and Phase Characteristics



Shunt Linear Regulator



Power Supply

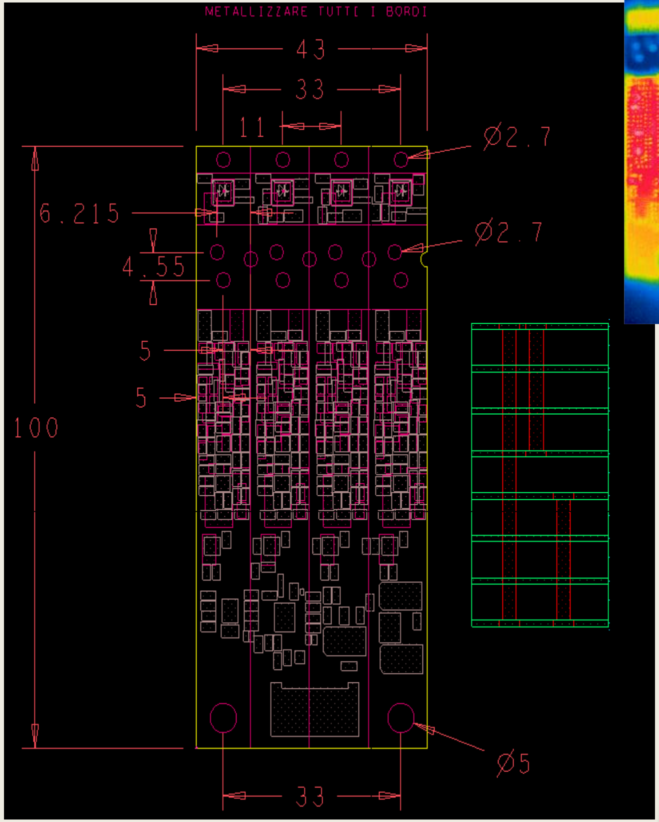
Linear Regulator Details

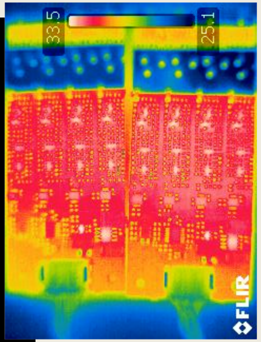
- Adjustment range of out voltage: 0 to 95V
- Accurancy writing and reading voltage: 16 bit
- Local feedback high stability: 1/000
- Current protection (adjustable): default 300uA
- Thermal stability, theoretical: 50ppm
- Dissipated power V_{in} at 100V: 30mW
- Rejection to the input voltage: 60dB
- Response load variation: 100us
- Maximum input voltage: 200V
- Noise to the maximum load: 2mVpp
- Control digital I2C - 2wire

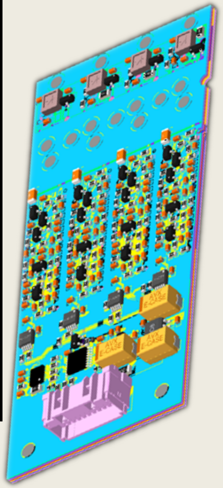
PCB Design and Board View

Multi-layer PCB

- 8 Layer PCB
- Isolated dissipation area to gnd power by means of bridge resistors
- Thermal control through PCB plans (necessary for vacuum operation)
- Theoretical value of the maximum power dissipation, per board with 4 channels online: 400mW



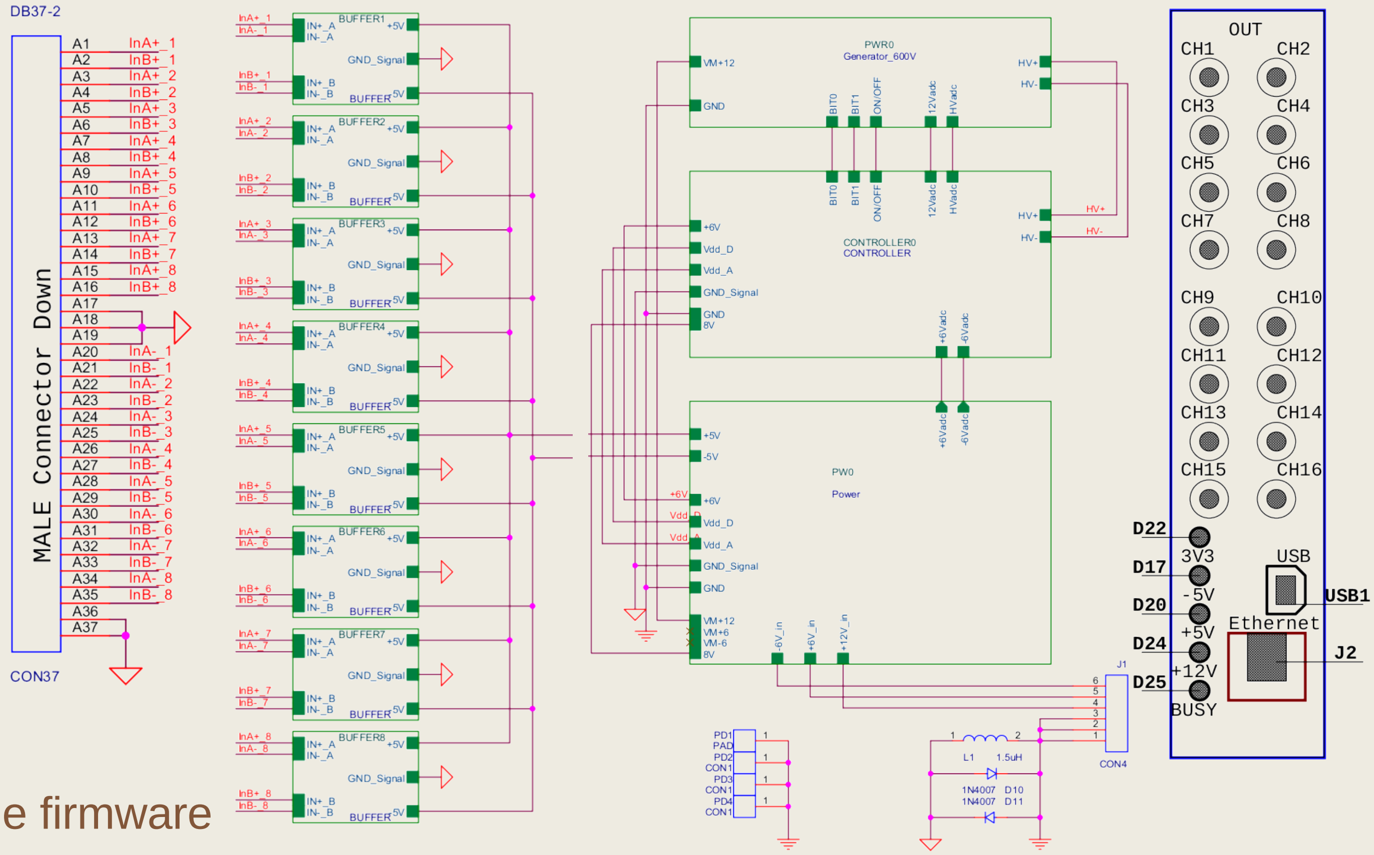




Controller Hardware

Design Overview

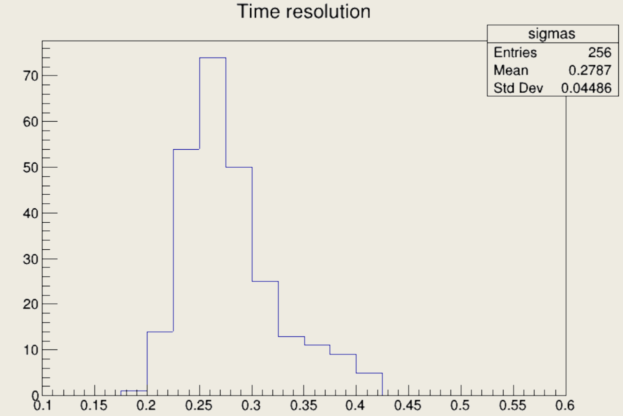
- Standard Nim realization
- Arm Cortex3 CPU for the control software
- Ethernet port for operation
- Diagnostics USB port
- 16 I2C control lines with peripheral buffers
- Power distribution to the front end
- Integrated primary high voltage generator
- Integrated control panel in the firmware

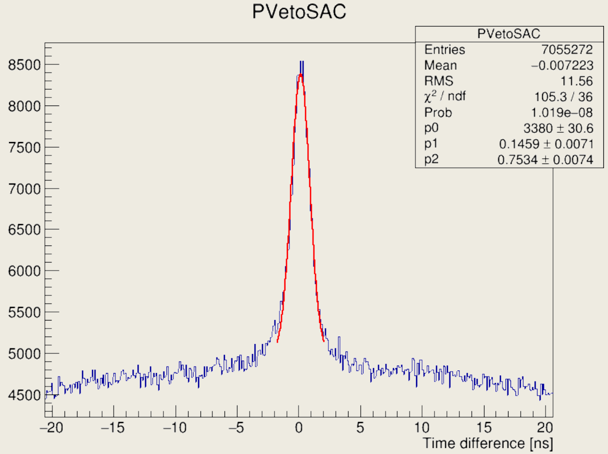


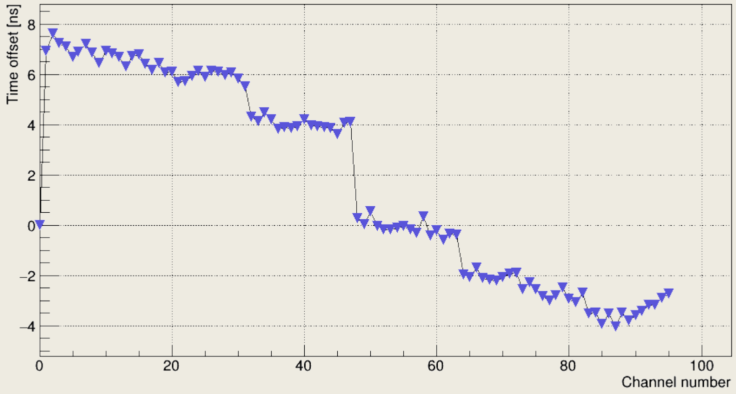
Calibration and Performance

Timing Characteristics

- Time resolution between any two SiPM channels: ~300 ps
- Time resolution between neighboring scintillators: ~700 ps
- Time resolution between veto system and the rest of the detector system (SAC): ~750 ps

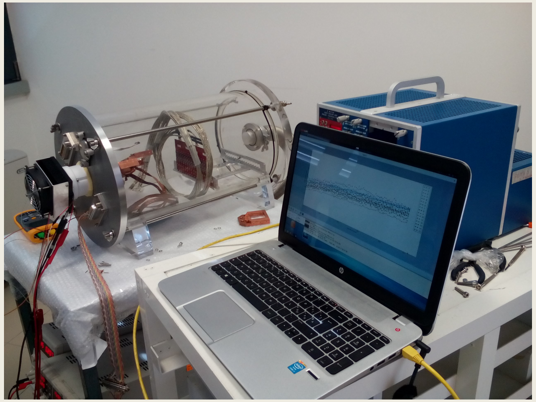


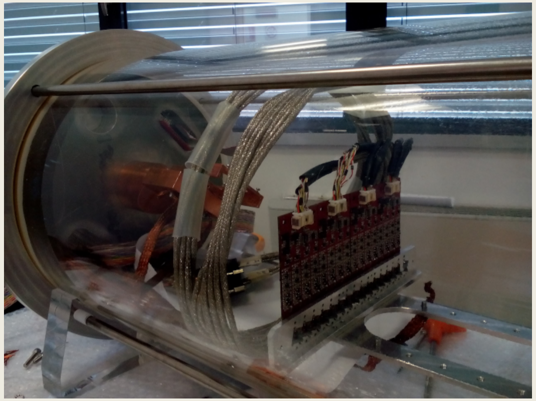


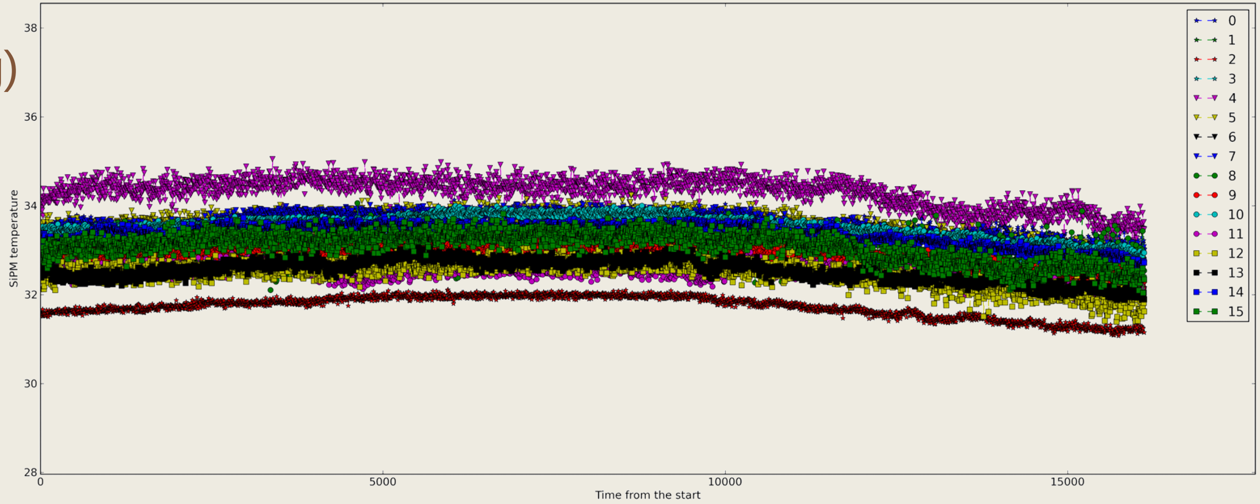


Power Dissipation and Thermal Performance in Vacuum

- Power consumption per channel: ~125mW, for a total of 12W per veto station (96 channels), 2 veto stations in vacuum
- Only passive cooling used (braided copper wire to mounting)
- Temperatures recorded for extended periods of time show an increase of ~8 degrees over ambient temperature in range 20-30C, well within the tolerance of all system components







Conclusion

FEE electronics developed at LNF

- Low-power, low-noise, high-speed
- Performs within the experiment design parameters without fancy chips
- Allows fully automated control and management
- Reliable performance in vacuum
- Minor mechanical issues in the prototype versions