
# *SiPM Front-end for CTA*

# *SMART3: a SiPM Multichannel ASIC for high Resolution Cherenkov Telescopes*

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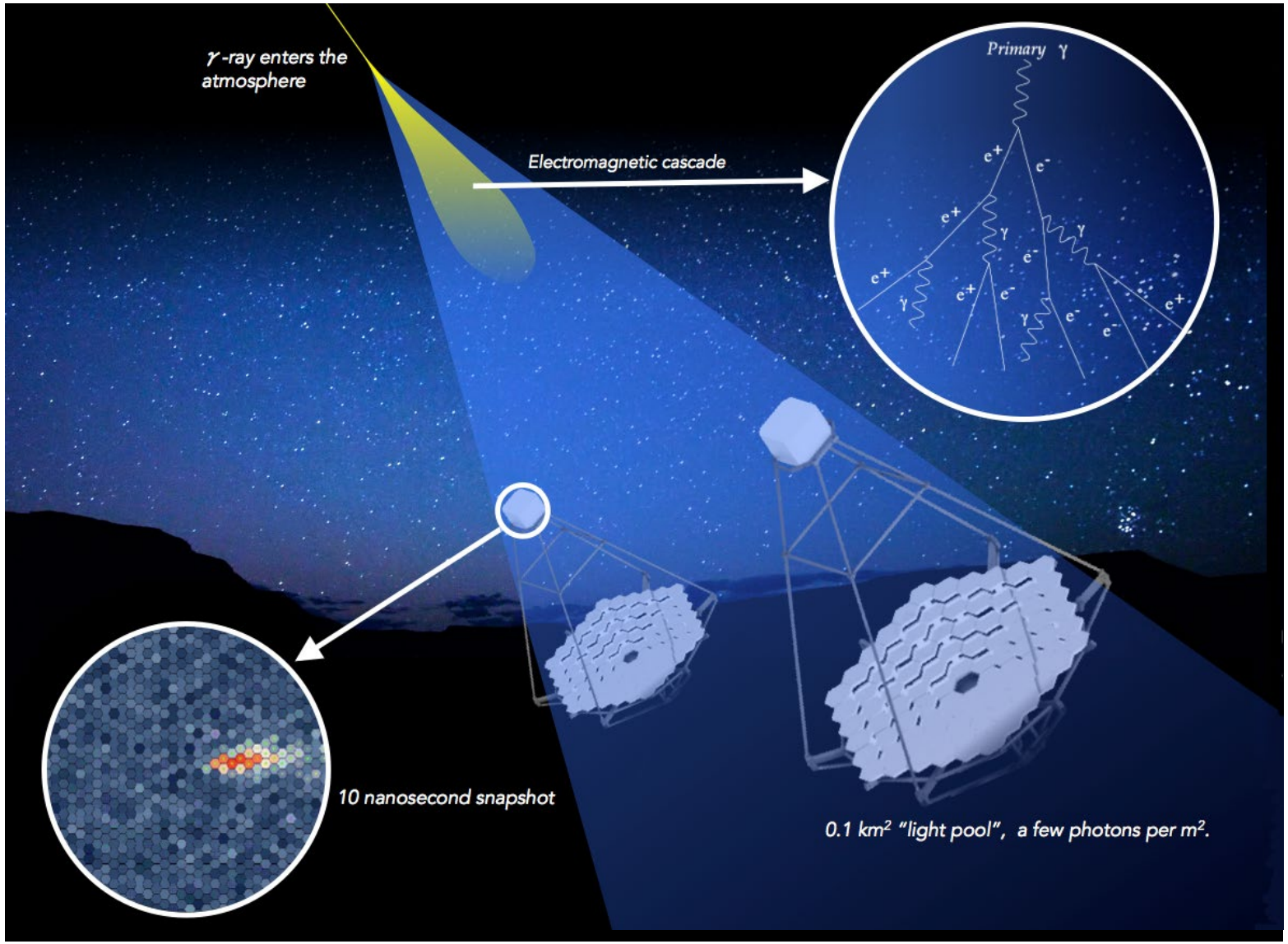
**ASPIDES – Kick-off Meeting – Bologna - 30/31 January 2025**

# The Cherenkov Telescope Array

- New generation of ground-based gamma-ray instrument to improve sensitivity in the range of 30 GeV - 300 TeV;
- Two sites: La Palma for the northern emiphere, Atacama Desert (Chile) for the southern observatory;
- 3 sizes of telescopes: large (PMT), medium (PMT single mirror, SiPM double mirror ) and small (SiPM);
- For the medium size a candidate is the Schwarzchild-Couder Telescope (SCT): higher FoV, aberration corrections and high camera resolution - > SMART front-end development.

# How CTA works




Basic physics:

- Gamma – ray interacts with atmosphere generating an electromagnetic cascade
- Cascade secondary products (charged particle) emit Cherenkov flashes
- Cherenkov flashes arrive on the camera with different times enlightening a small area of elliptical shape, event duration about 10 ns
- Other particles (hadrons, muons) can be observed and recognized analysing the detected images

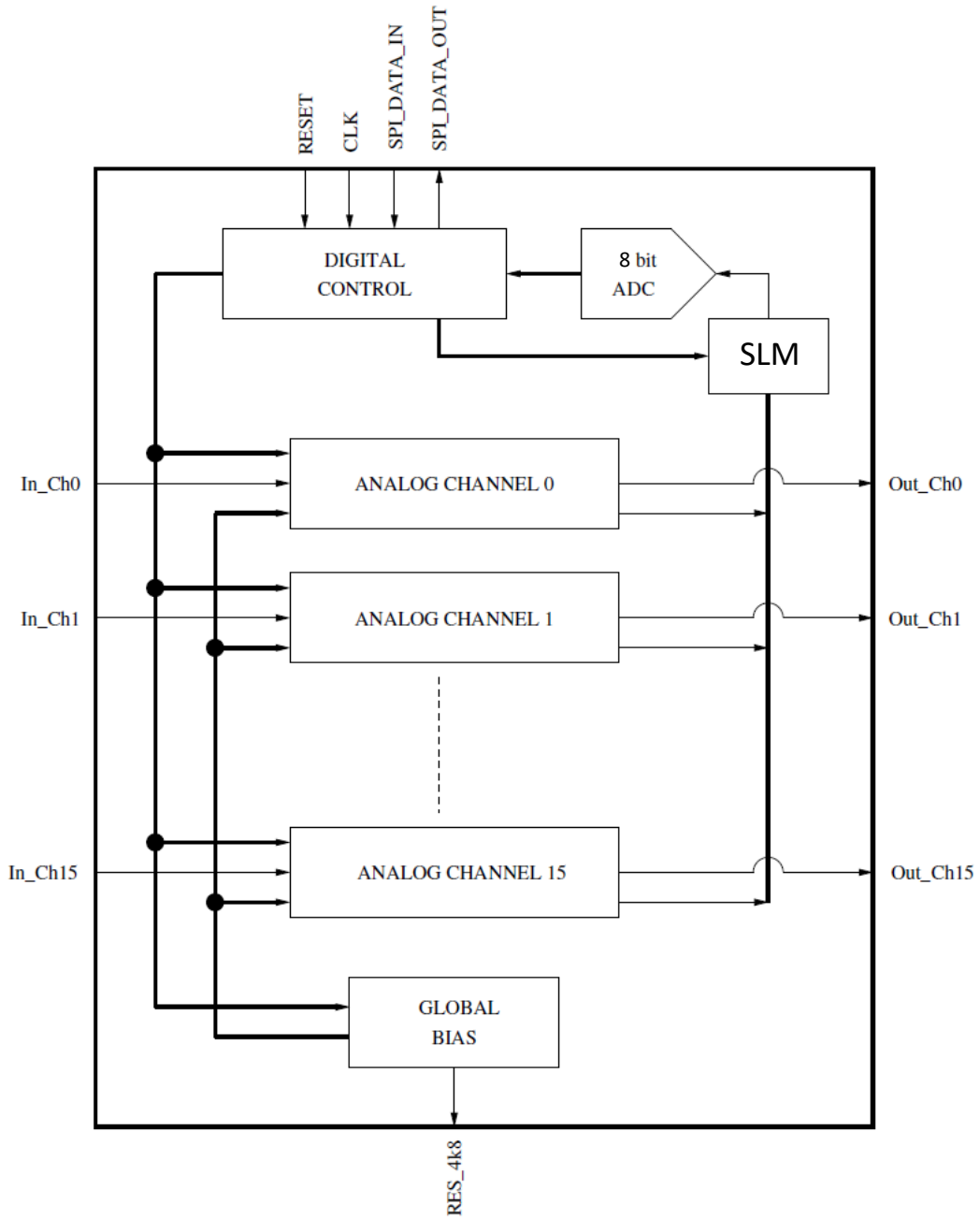
Electronics requirements for the physics:

- Photon counting: 1 – hundreds photon/pixel
- Signal time evolution recording: about 10 ns -> sampling at 1 Gsps
- Event separation: possibility to avoid pile-up with noise due to other sources (stars, moon light) -> Night Sky Background (NSB) in the order of tens of MHz

# Front-end requirements

- Single photon resolution
- Detector capacitance: 2 nF (SiPM FBK NUV-HD3-5 6x6 $mm^2$)
- Single photo-electron charge: 150 fC
- Linearity range: up to hundreds of photons
- DCR + NSB in the order of tens of MHz -> a circuit to suppress the recovery tail is need to avoid pile-up
- Signal sampled at 1 Gsps (sampling done by a dedicated ASIC) -> output signal FWHM about 10 ns
- Possibility to fine adjust the SiPM bias voltage to compensate the gain mismatches among SiPMs
- Slow monitoring for SiPM mean current measurements (high luminosity enlightening, SiPM aging, telescope pointing )

# SMART3: ASIC architecture overview



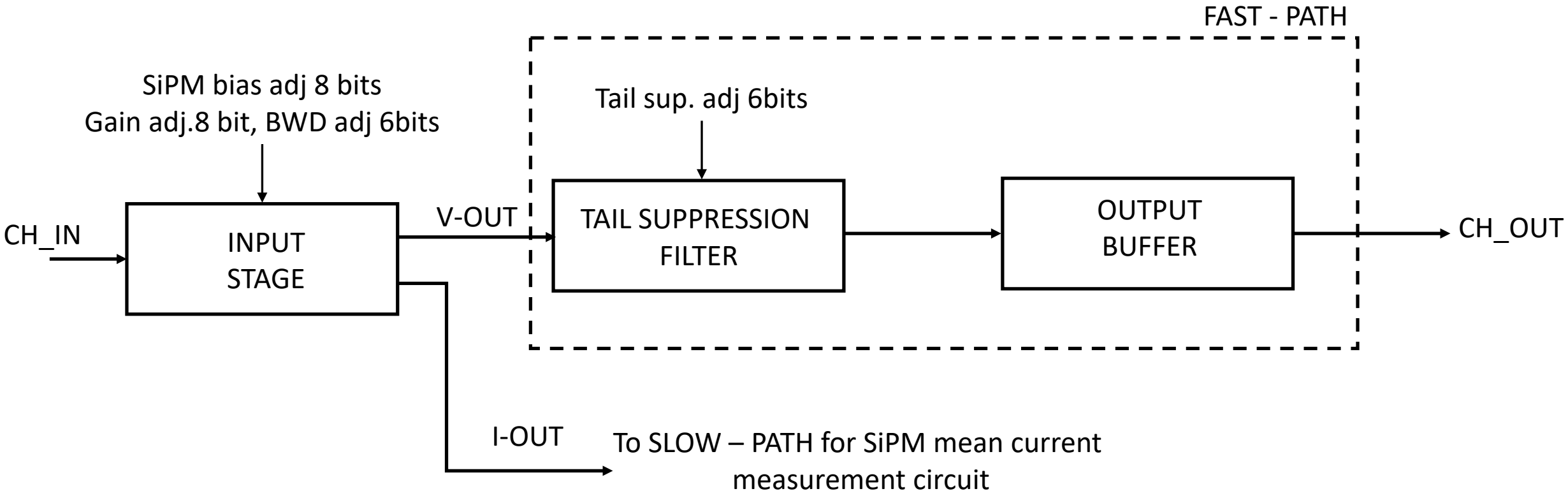

***Analog Section:***

- 16 Front-end channels:
  - Direct output: designed for photon-counting
  - Internal output: SiPM mean current measurement
- Global Bias: temperature and power supply independent
- 8 bit 1 MHz SAR ADC for channel internal output conversion

***Digital Section:***

- Control Unit:
  - 1 MHz SPI SLVDS link
  - Channel & Global bias adj. bits
  - ADC control

# SMART3: Channel architecture overview




**Input-Stage:**

- V-OUT:
  - trans-impedance output, input current conversion into an output voltage
  - Low pass filtering to reduce noise
- I-OUT:
  - Current output for SiPM mean current measurement
- Fine adjustment of the SiPM bias

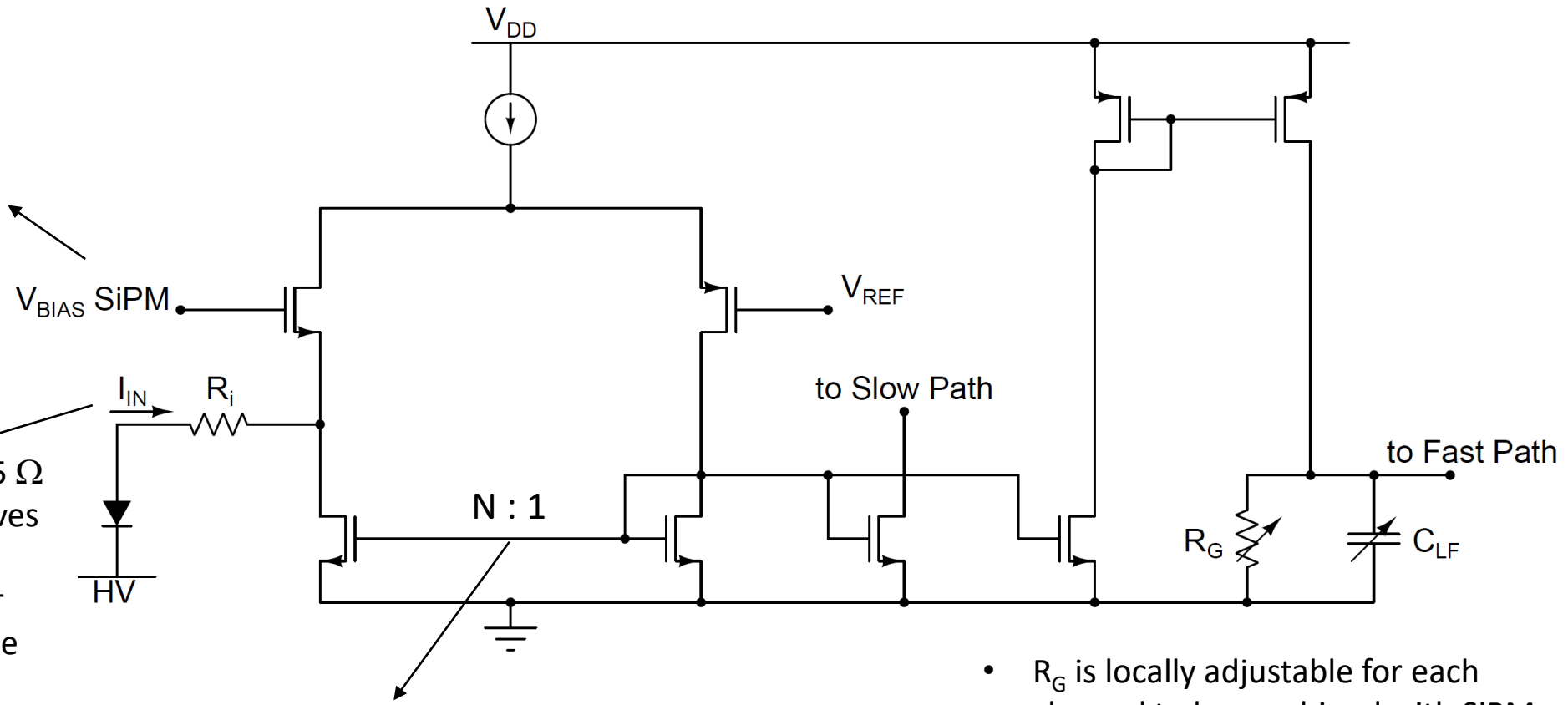
**Tail suppression filter:**

- Filters the output pulse tail due to the SiPM recovery

**Output buffer:**

- Drives the output path providing the current to a low impedance load

# SMART3 front-end architecture

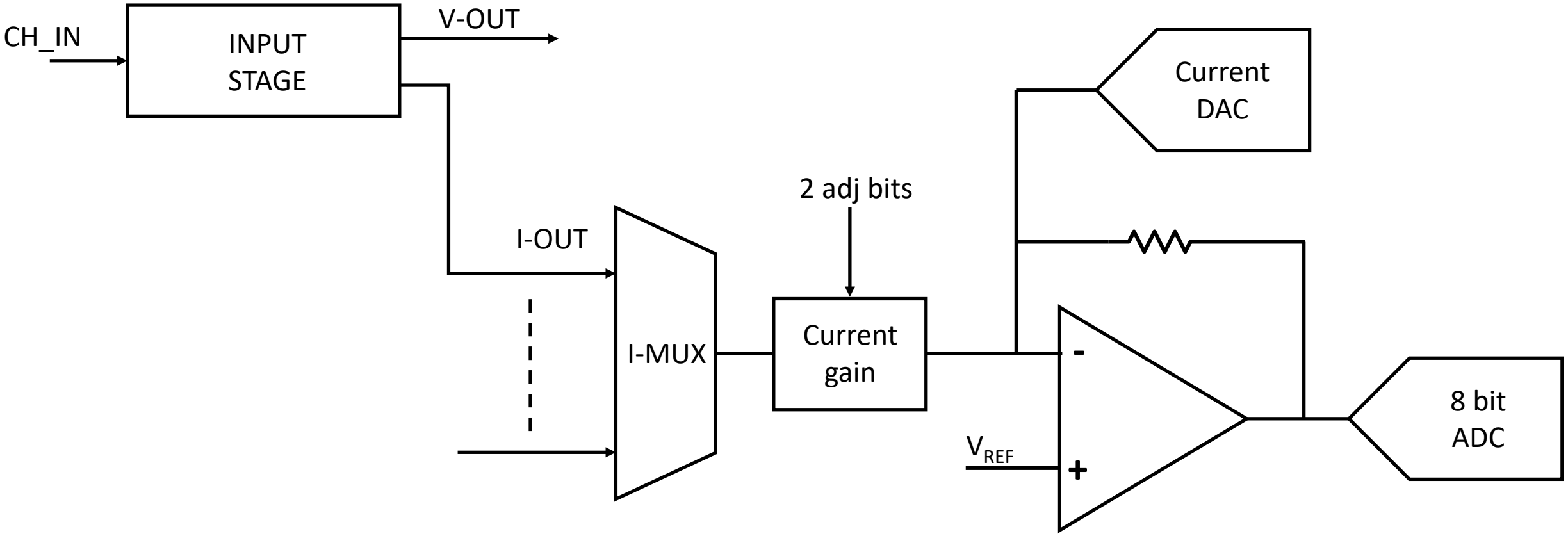



- Equivalent input resistance ~ 35 Ω
- $R_i$ introduces a zero that improves loop stability
- $R_i$ reduces both input transistor noise and input signal amplitude

N and the bias current control the input dynamic range

- $R_G$ is locally adjustable for each channel to be combined with SiPM bias fine adjustment to improve gain equalization

# Slow monitoring circuit

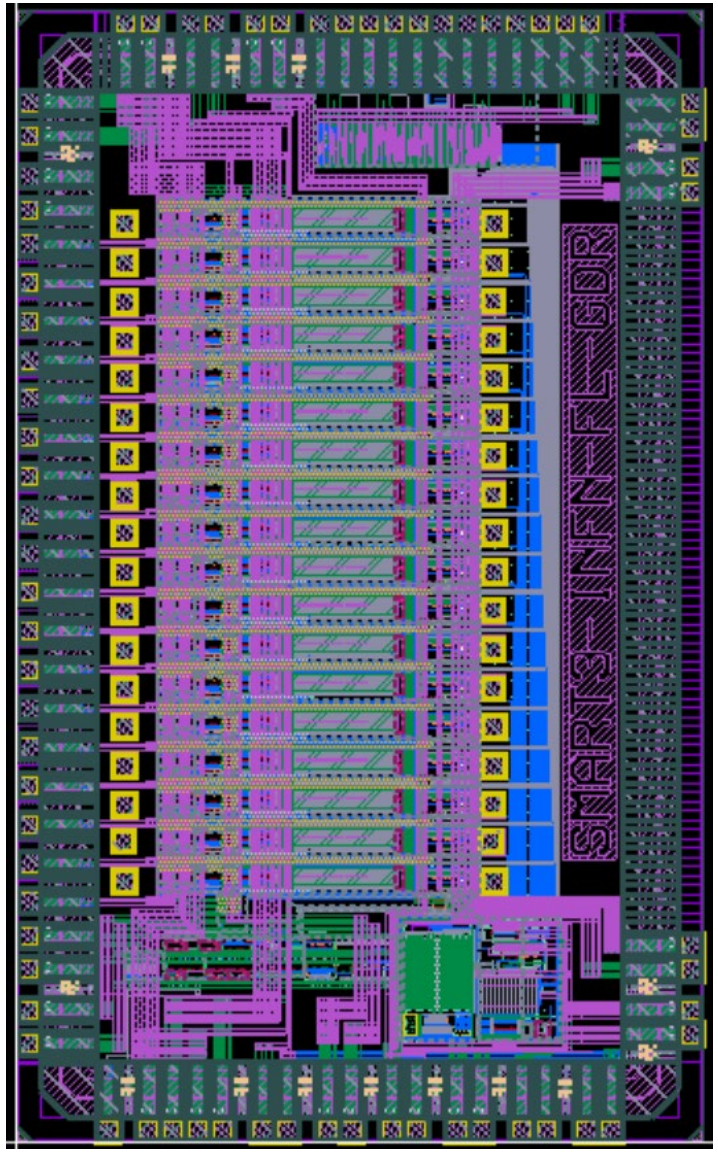



- I-MUX: SiPM current selection for the mean current measurement
- Current DAC: compensate the DC bias current of the I-OUT path (used to set the OPAMP output at 0 V)
- Rail to rail trans-resistance amplifier: very low-pass bandwidth in order to have the output proprotional to the mean value of the input current
- 8 bit ADC for digital conversion

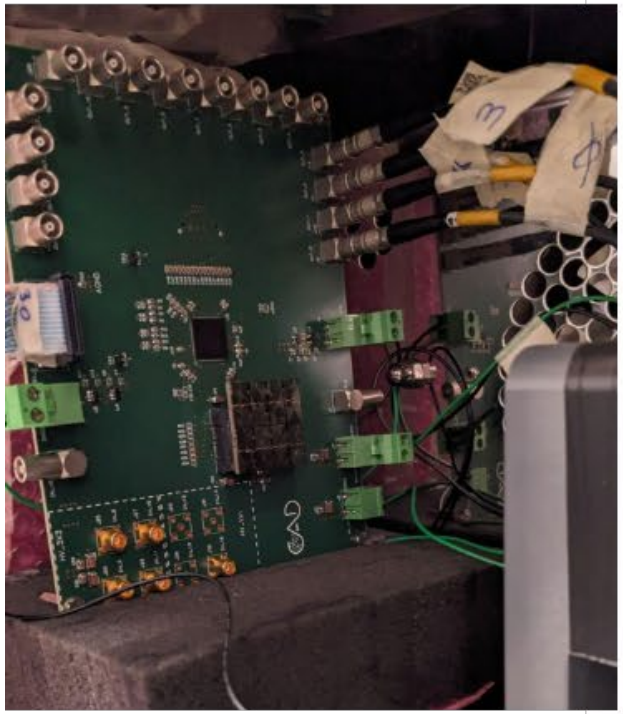
# SMART3 features

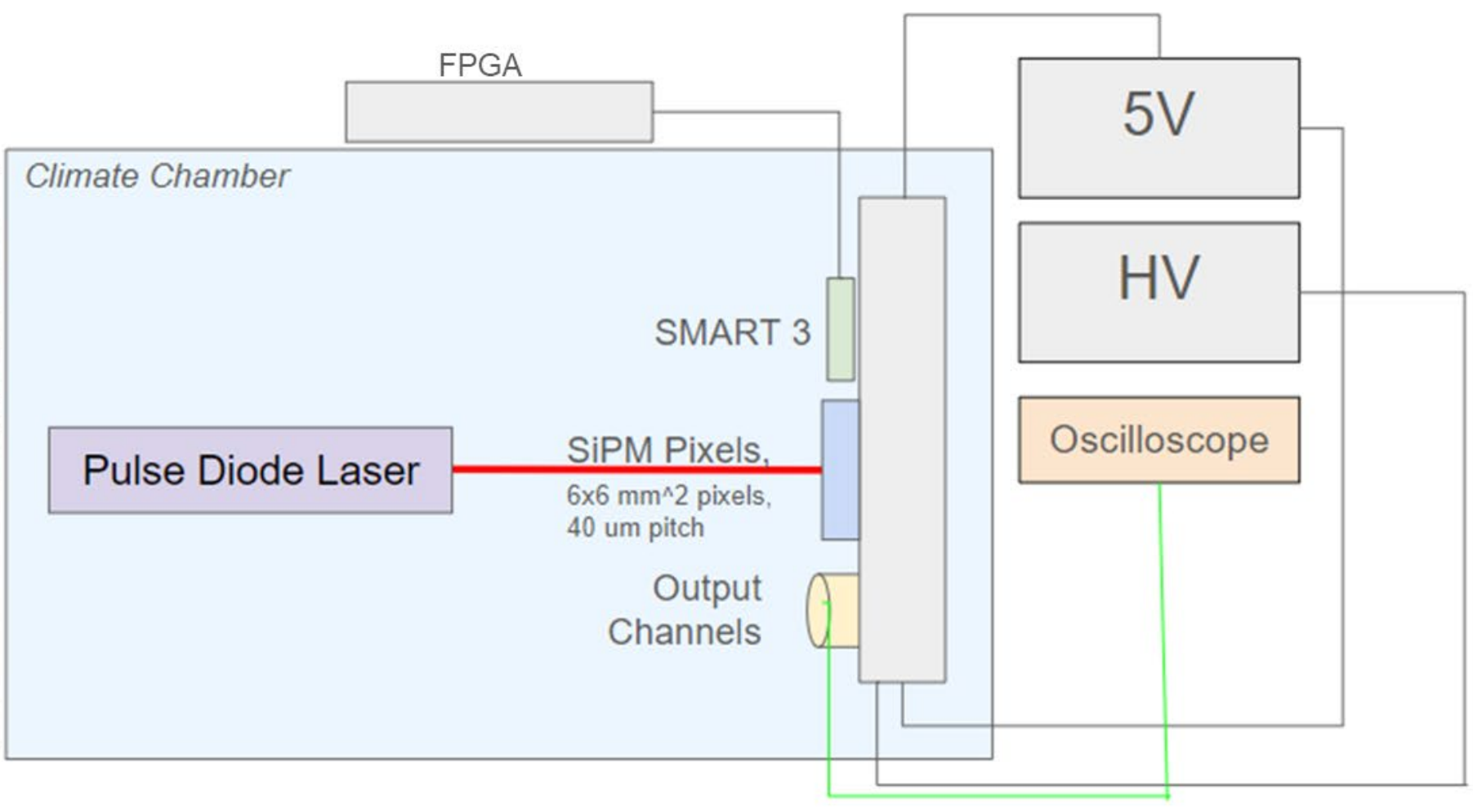
**SMART3:**

- 16 channel front-end ASIC
- LF110nm technology node
- 3.3 V & 1.2 V power supply
- SiPM fine bias adjust range: 1.7 V
- SMART3 current consumption 75 mA
- Fast-path output dynamic range: up to 1.7 V on 50 Ohm load (AC coupled)
- Slow-path input dynamic range: up to 2 mA of mean SiPM current (1 pC/pe at 2 GHz)
- Programmable gain, bandwidth and tail suppression
- 8 bit ADC
- 1 MHz SLVDS SPI link



# SMART3 test: experimental setup

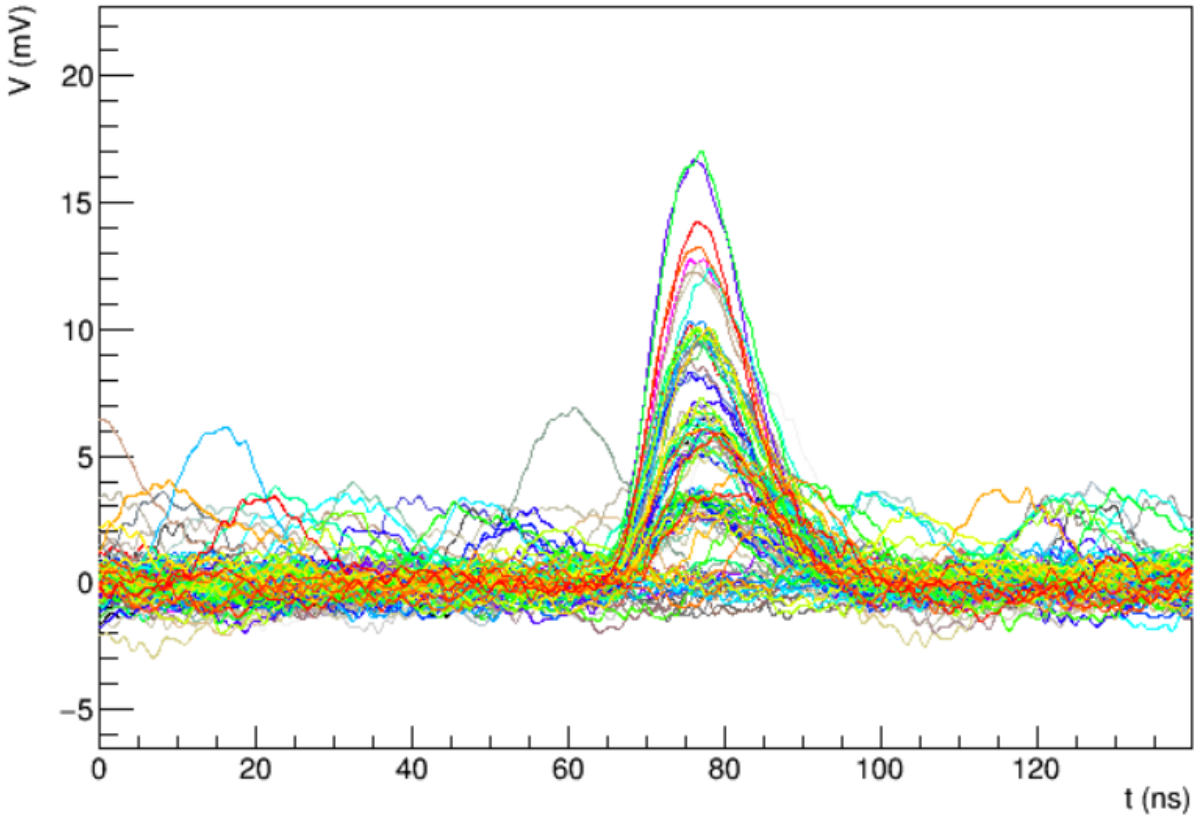




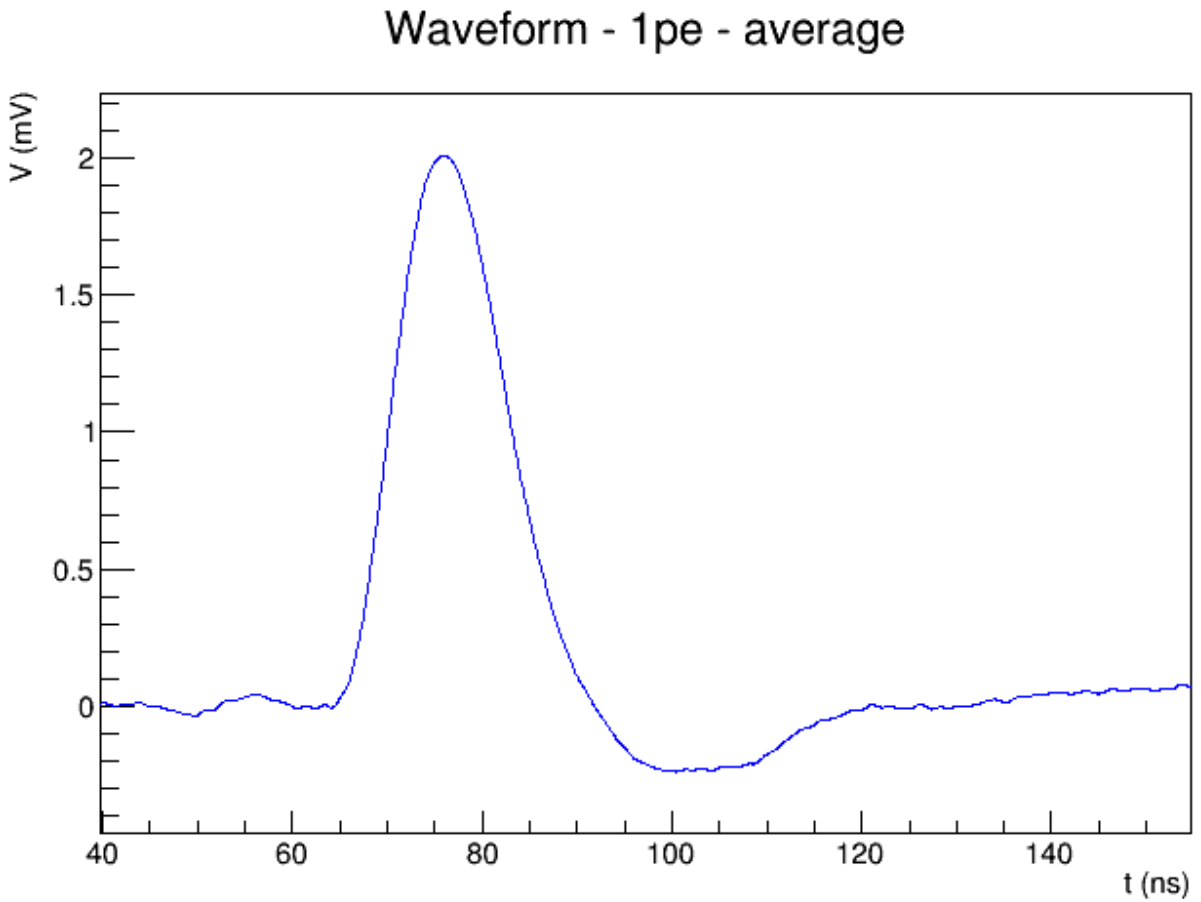
# SMART3: fast-path output waveforms

**Measurement conditions:**

- SiPM NUV HD3-5 - produced by FBK
- HV = 41 V -> OV = 13.5 V
- Laser pulse mode




Fast-path output waveforms
(oscilloscope acquisition)

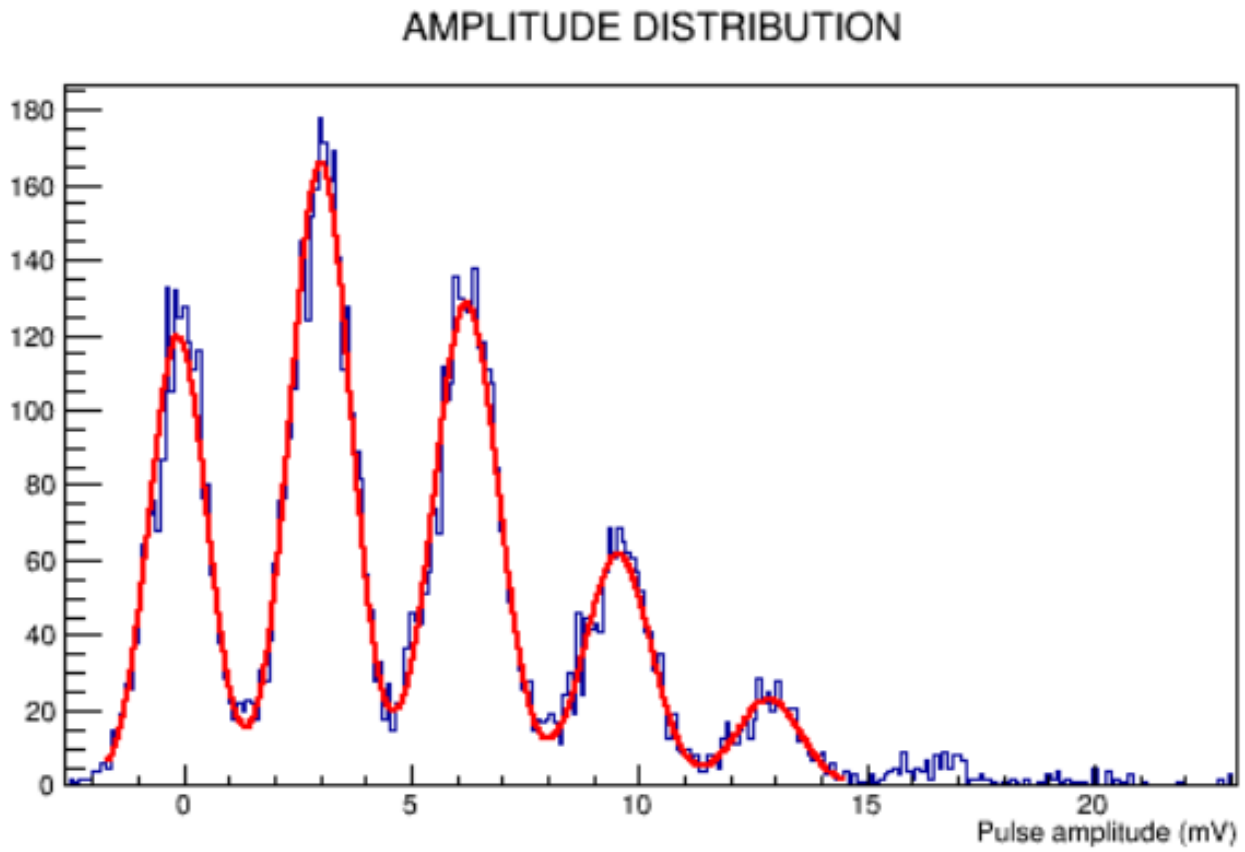



- Full SiPM recovey tail compensation with internal network
- FWHM about 13 ns

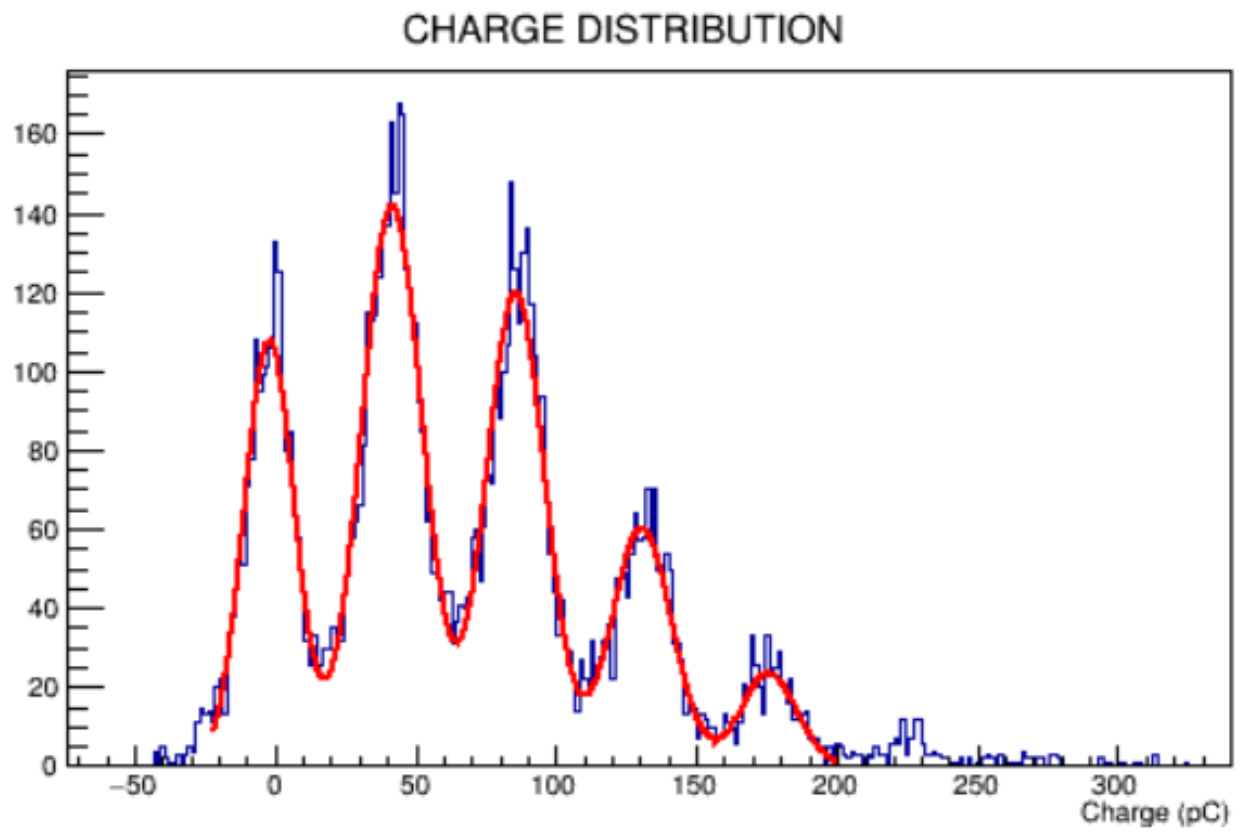
# SMART3: fast-path photon-counting

**Measurement conditions:**

- SiPM NUV HD3-5 - produced by FBK - same as those installed on pSCT camera
- HV = 41 V -> OV = 13.5 V
- Laser pulse mode

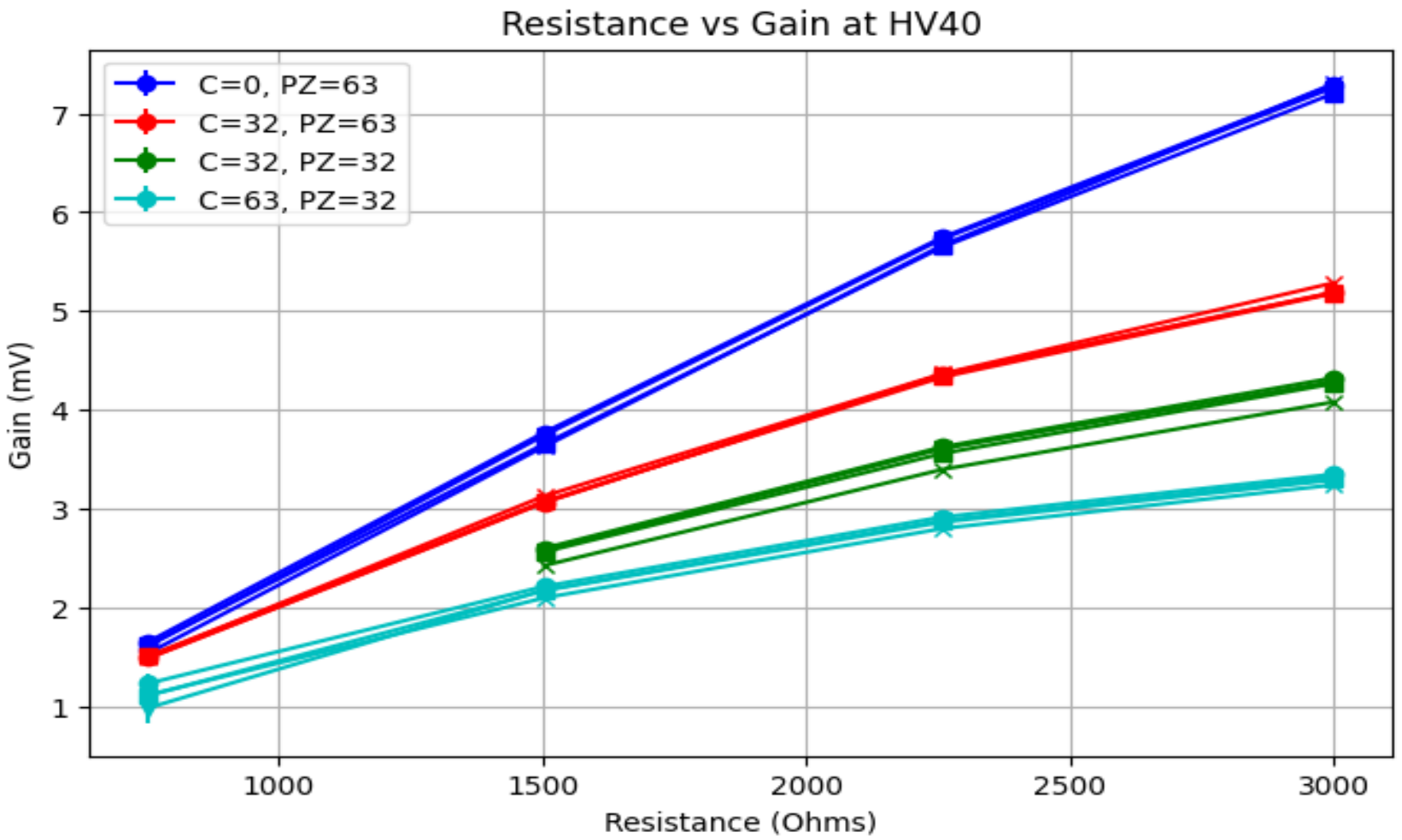


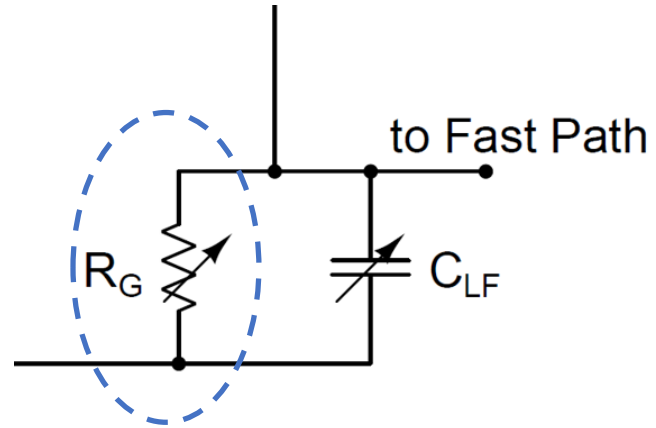

SNR = 4.85



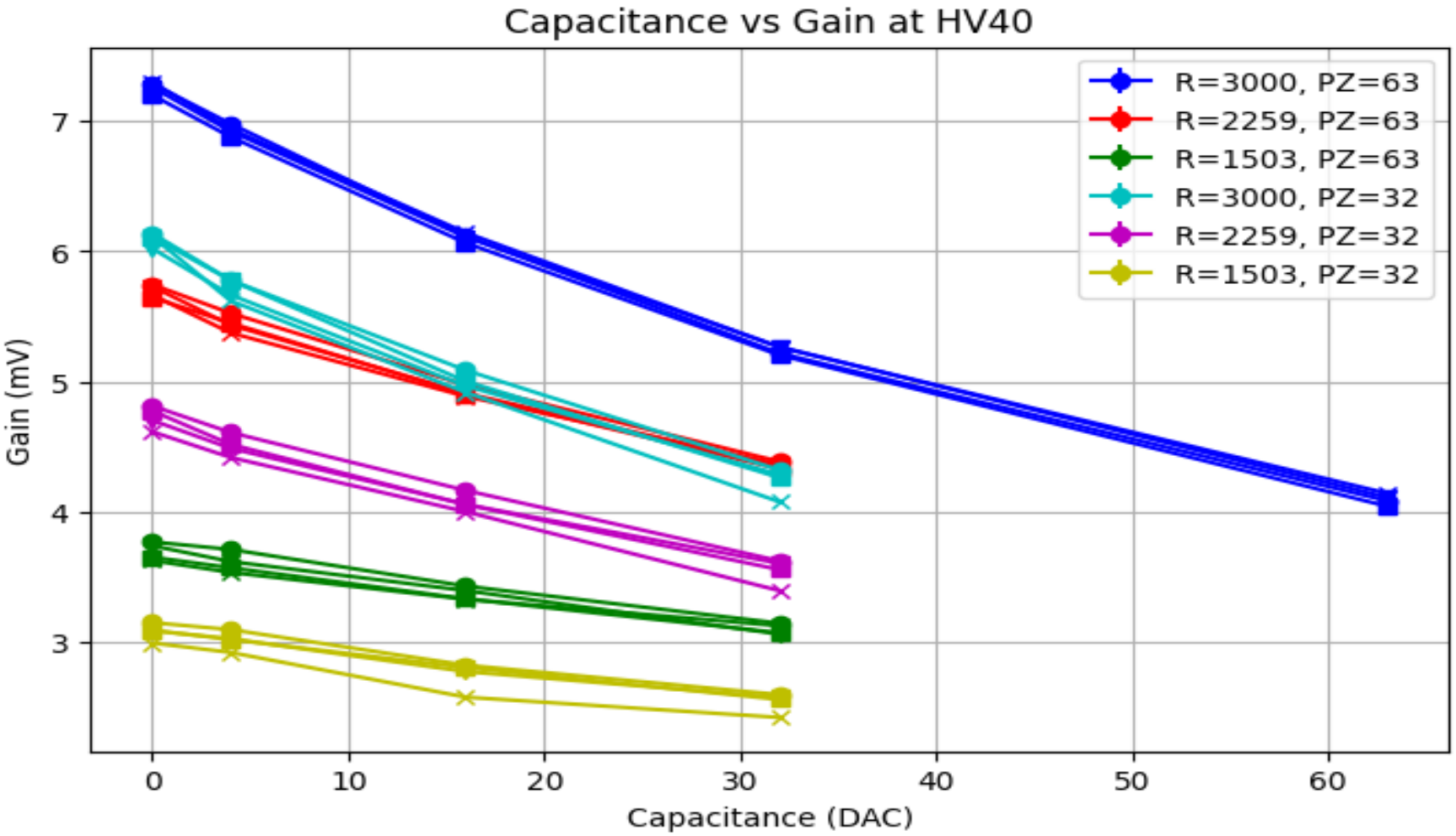

SNR = 4.39

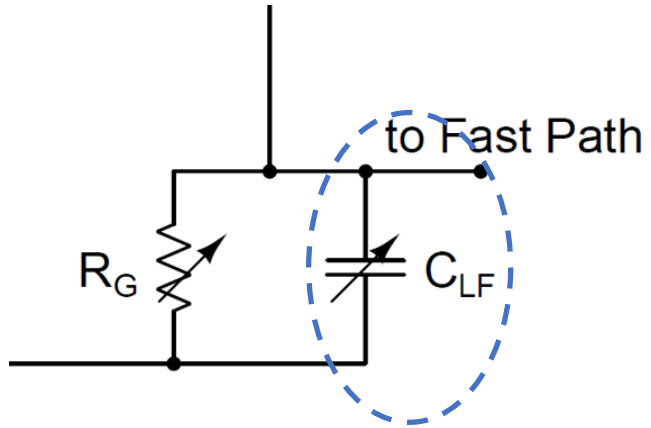
# SMART3 channel: fast path gain vs gain control bits



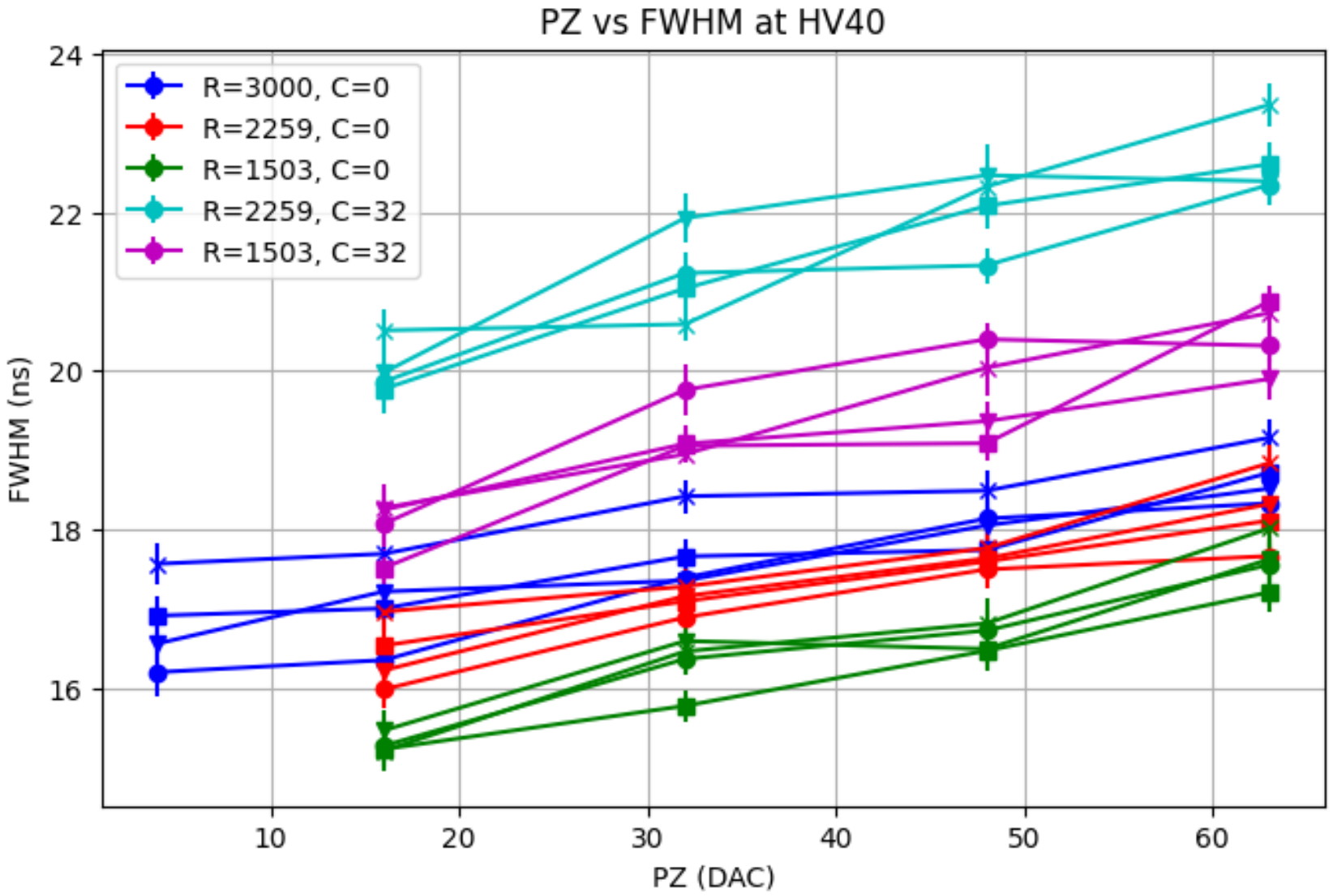



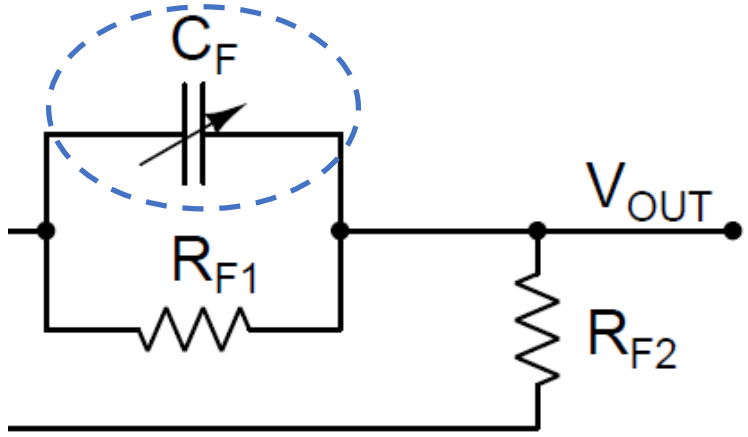
# SMART3 channel: fast path gain vs BWD control bits



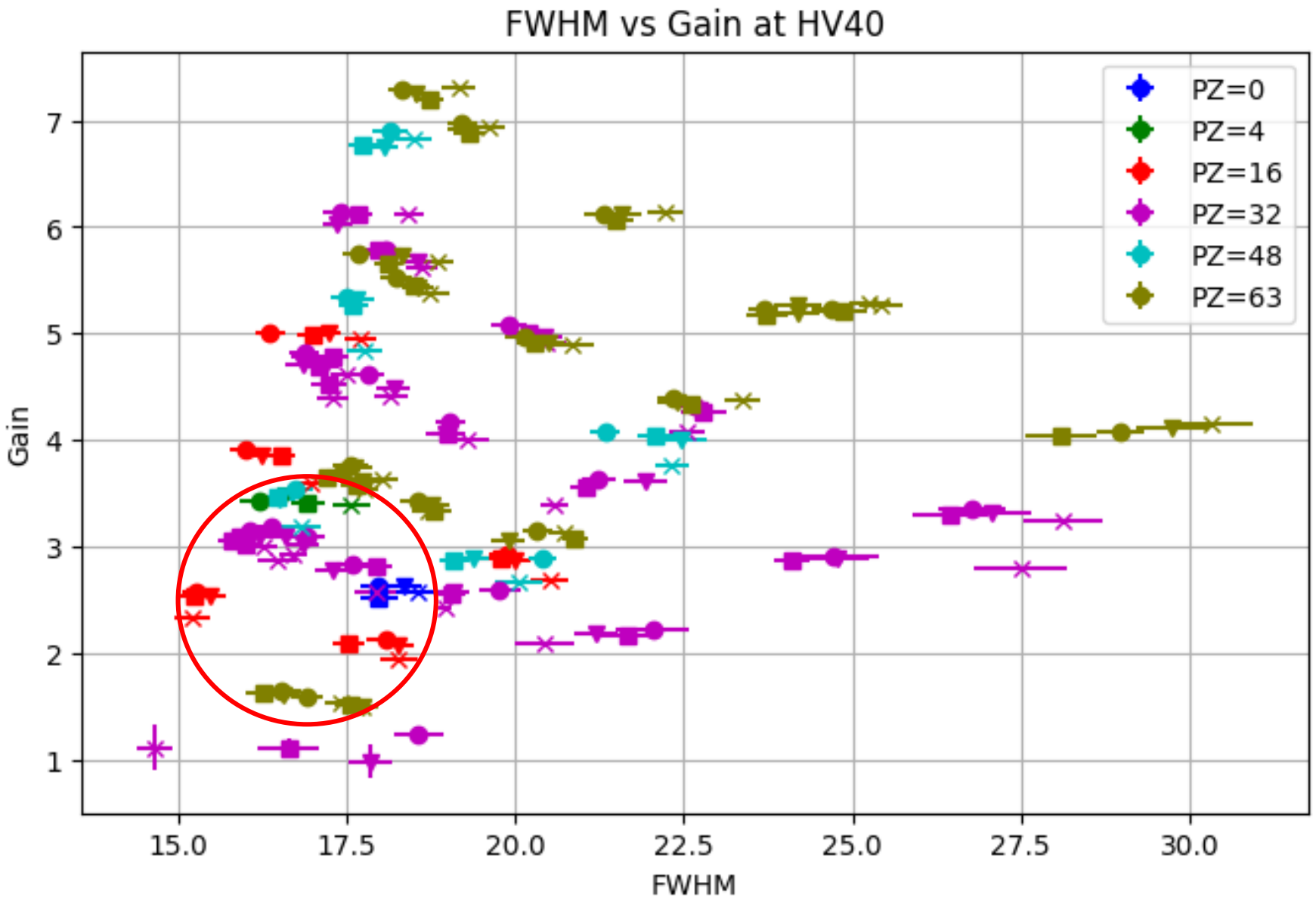
# SMART3 channel: fast path FWHM vs PZ control bits



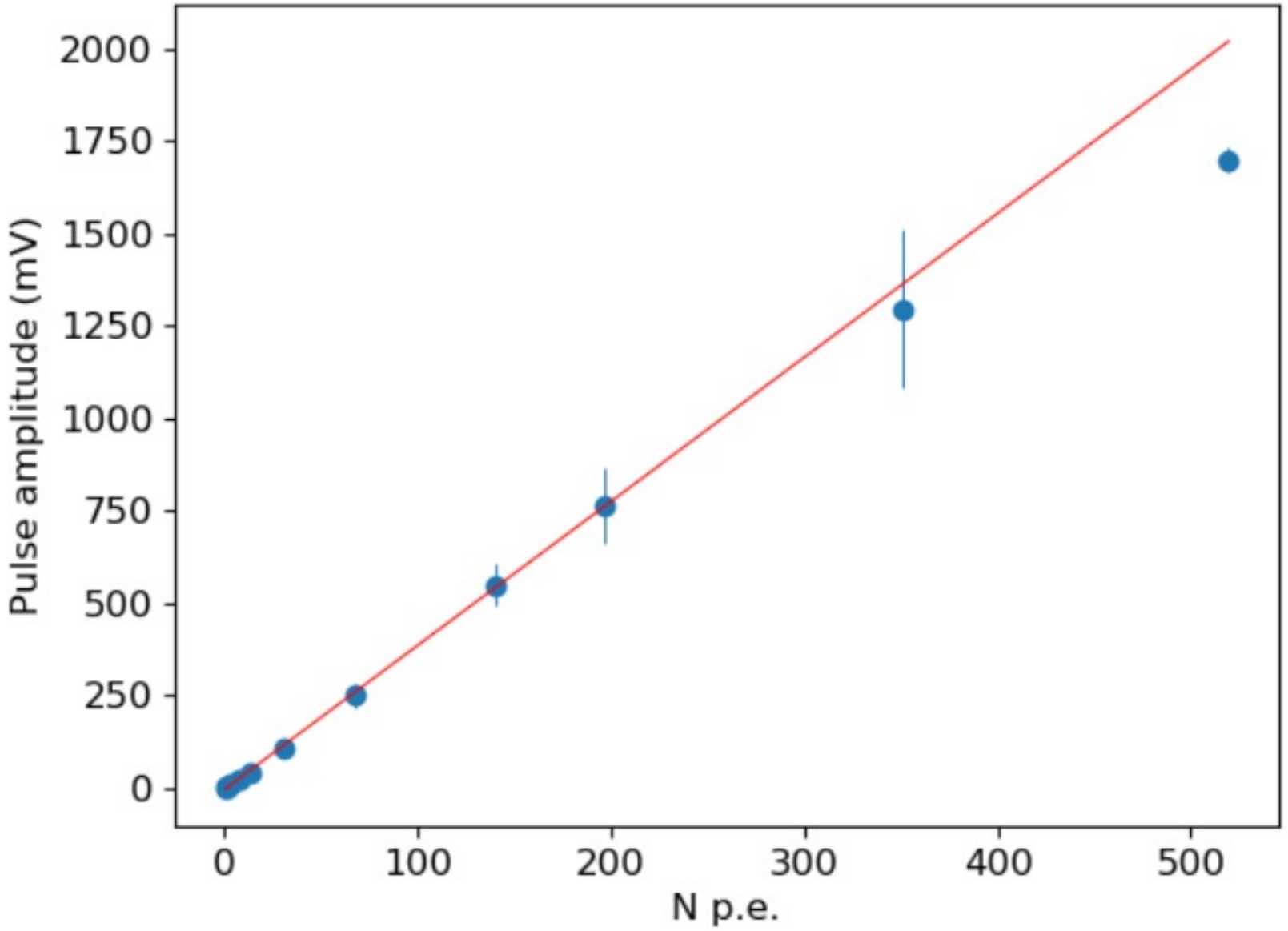




Tail suppression filter

# SMART3 working region for CTA



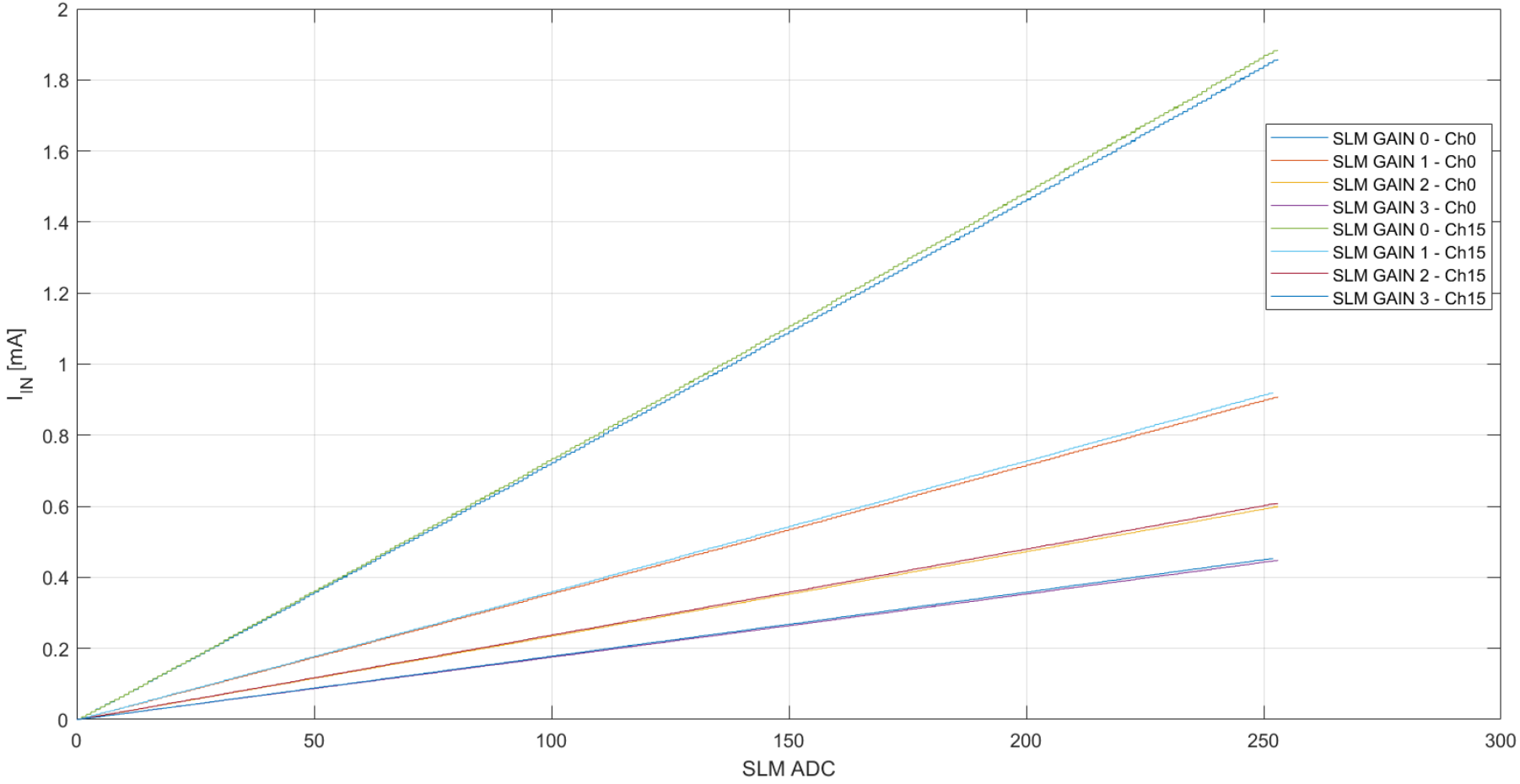
# SMART3 channel: fast-path output dynamic




- Fast-path output dynamic up to 1.7 V on 50 Ohm load

# SMART3 slow monitoring: DC measurement

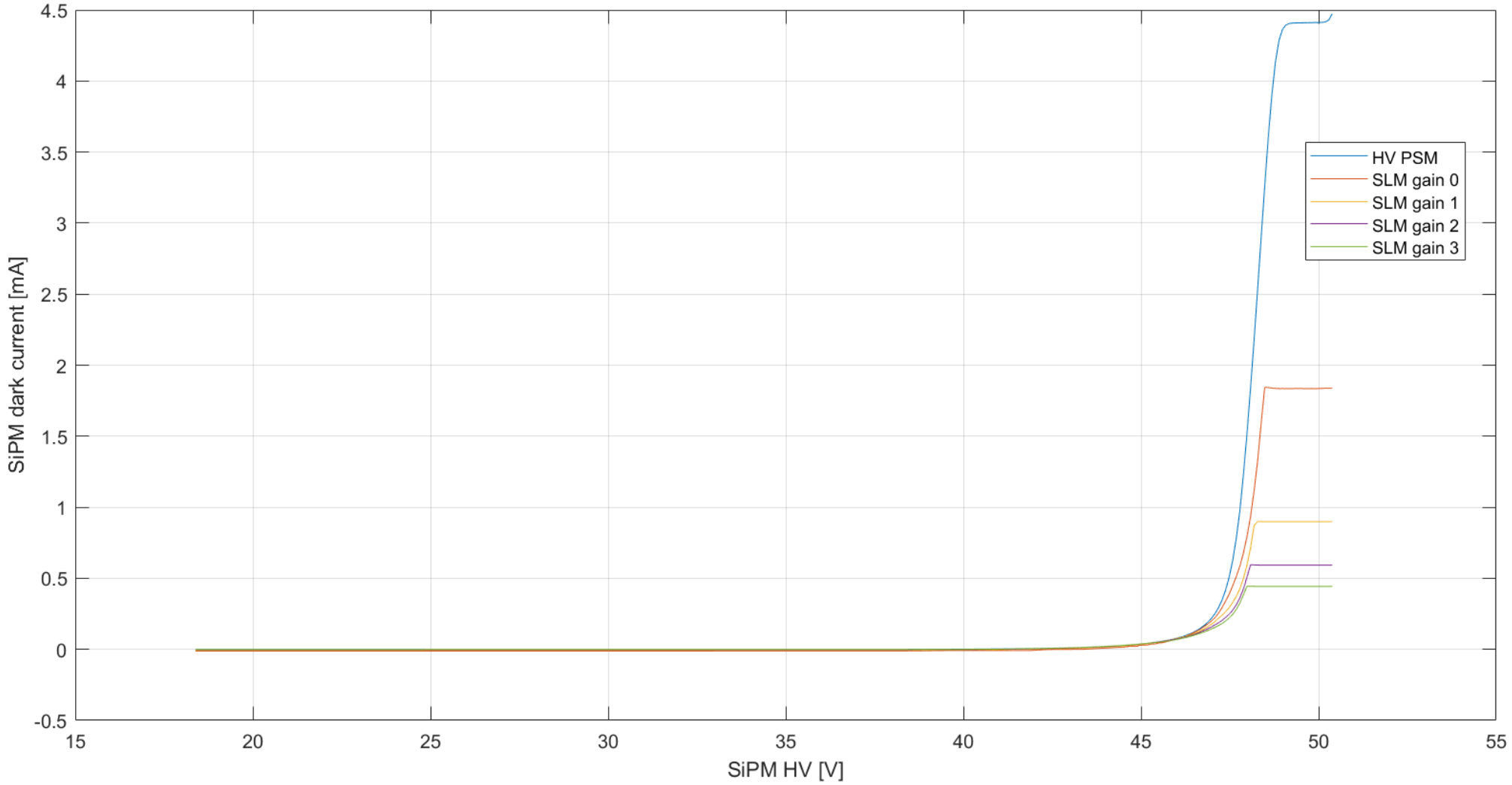
- DC current measurement: a DC current is injected by means of an external resistor at the channel input
- Input current measured using both an external ammeter and the internal slow monitoring circuit for the 4 gain configurations




SMART3 slow monitoring characteristic for 2 channels and the 4 gain configurations

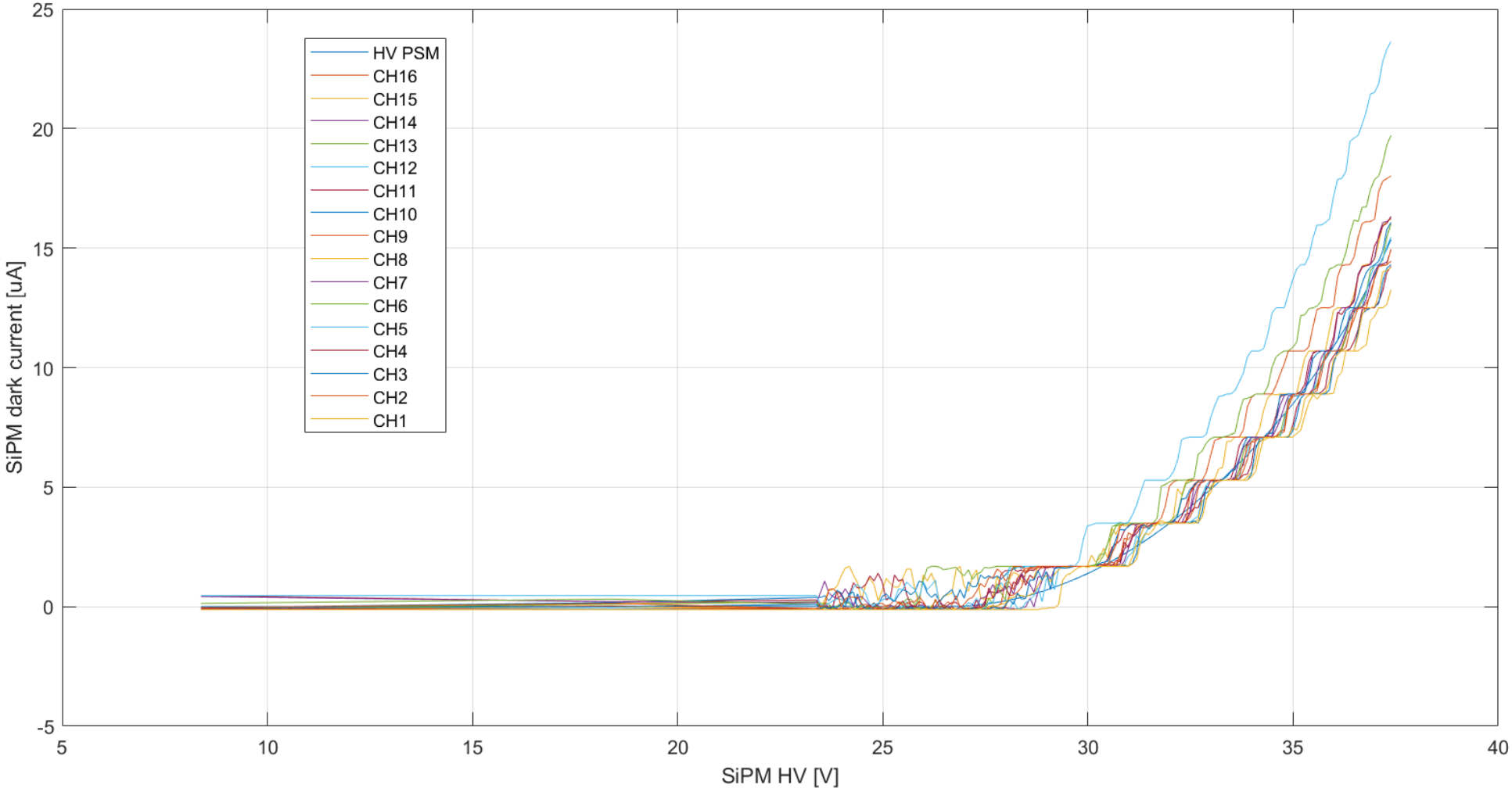
# SMART3 slow monitoring: SiPM I-V characteristic

- 6x6 mm2 FBK SiPM connected to the SMART3 channel input
- SiPM I-V characteristic measured both by means of the HV power supply ammeter and the SMART3 slow monitoring



# SMART3 slow monitoring: SiPM matrix I-V characteristic

- 6x6 mm2 FBK SiPM matrix connected to the SMART3 channel input
- SiPM I-V characteristic measured both by means of the HV power supply ammeter and the SMART3 slow monitoring



# Thanks