MASS TESTING
FINAL DESIGN REVIEW

Testing methods

N. Anfimov. L3 manager

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Final design review

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WHO AM I

Dr. Nikolay Anfimov

- Ph.D. in Physics and Mathematics “Development and application of methods for studying photodetectors”
- Background in EM-calorimetry for COMPASS-II (CERN), APD and scintillator studying for NOvA (FNAL), 20-inches PMT scanning and testing for JUNO (China), SiPM testing for TAO (China), SiPM R&D.
- Head of the Sector of Experimental Methods, Experimental Department of Particle Physics, Dzhelepov Laboratory of Nuclear Problems, Joint Institute for Nuclear Research
- Start working at JINR in 2005

TAO SIPM

➢TAO physics goals

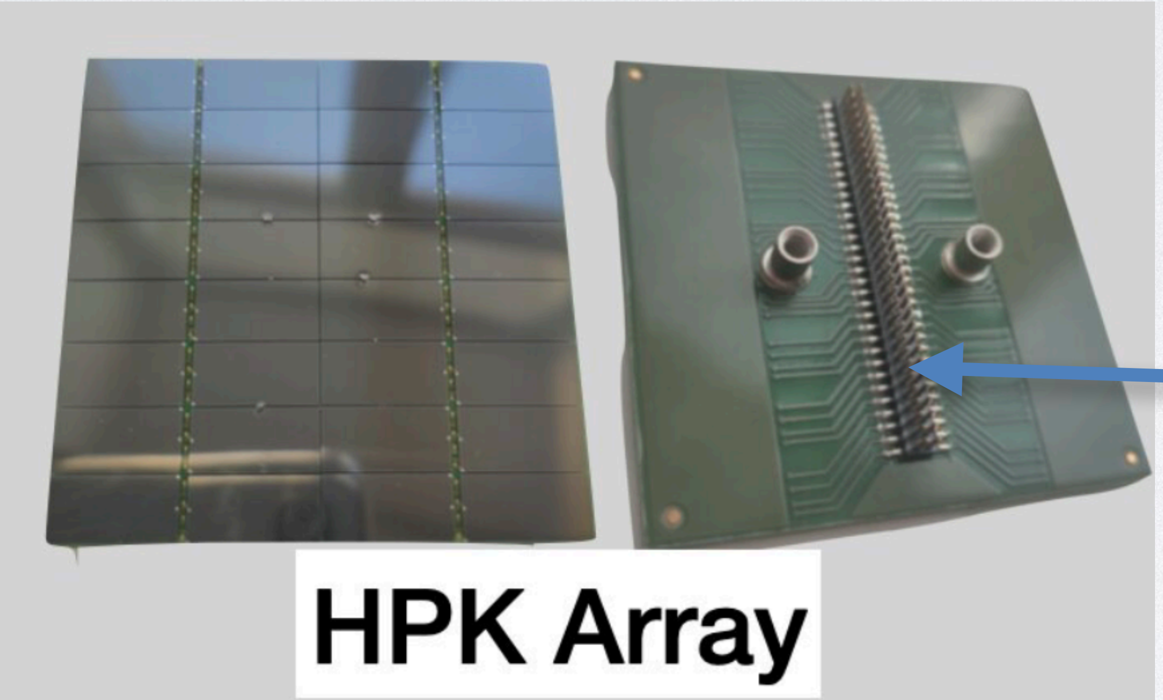
1. Model-independent reactor neutrino spectrum for JUNO (with energy resolution < 3% /√E) .
2. A new benchmark to test the nuclear database

➢Detector scheme

2.8t Gd-LS + **4π SiPM** (~10m²) + **3.5t LAB/Silicon Oil (SO)**
Running at -50 ℃, ~30m to core

➢SiPM Tiles

PDE ~ 50 %
Coverage ~95%
Size = 5x5 cm²

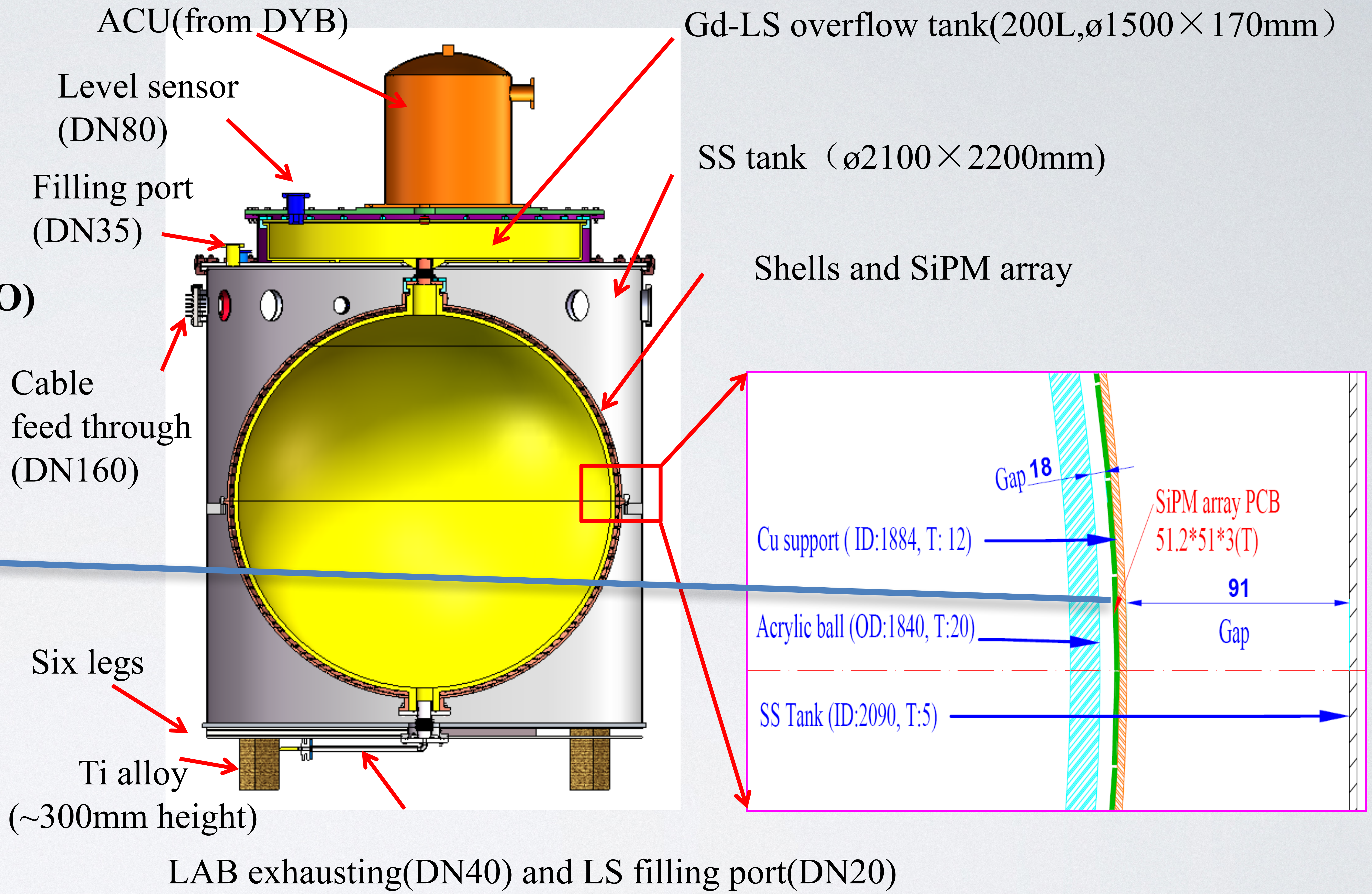


4100 tiles

➢Sub detectors

1. Central detector (CD)
Acrylic vessel + Gd-LS
SiPM array + copper shell
SS tank + LAB/Silicon Oil
ACU（from DYB）
Cryogenic system+ cooling pipes + Heat insulation (PU)

2. Veto and shielding
Top: HPDE + plastic scintillator
Surround: Water tank+ PMT（3"）
Bottom: 10-cm lead



This review addresses SiPM mass-testing and SiPM power system

THIS REVIEW

- Requirements and testing methods on SiPM testing. N. Anfimov
- SiPM burn-in testing. P. Hu
- Technical overview on SiPM mass-testing. A. Rybnikov
- SiPM power System. N.Anfimov

SIPM MASS-TESTING REQUIREMENTS AND METHODS

- Overview of requirements on SiPMs specifications
- Uniformity of breakdown voltage
- Range of operating voltage
- Deviation of dark current
- DCR
- Gain
- PDE deviation from effective PDE
- Crosstalks
- Afterpulses
- ΔPDE

- **Summary**

OVERVIEW OF REQUIREMENTS

ON SIPMS SPECIFICATIONS

1. Dimensions of Tiles
2. Window material
3. Defects in the window material (bubbles, pits, etc)
4. Cracks and pattern defects on silicon
5. Radio purity of Tiles
6. Compatibility with LAB
7. Type and mounting of connectors

All will be carry out by IHEP group

II (d) Burning test

(from contract)

OVERVIEW OF REQUIREMENTS

ON SIPMS SPECIFICATIONS

(for Mass testing)

8. Uniformity of **breakdown voltage** (V_{bd}) within 0.19V range
9. Range of **operating voltage** (V_{op}) > 6.5V
10. Deviation of **dark current** @V_{op} ± 95%
11. **DCR** in each channel < 41.7 Hz/mm^2
12. **Gain** in each channel >1×10^6
13. For each channel, $\boldsymbol{\Delta_\epsilon}$ ≥ -25% (PDE_{eff}, PDE, P_{cn})

(from contract)

Item 8: Uniformity of **breakdown voltage** (V_{bd}) 0.19V [peak-to-peak]

Item 9: Range of **operating voltage** (V_{op}) > 6.5V

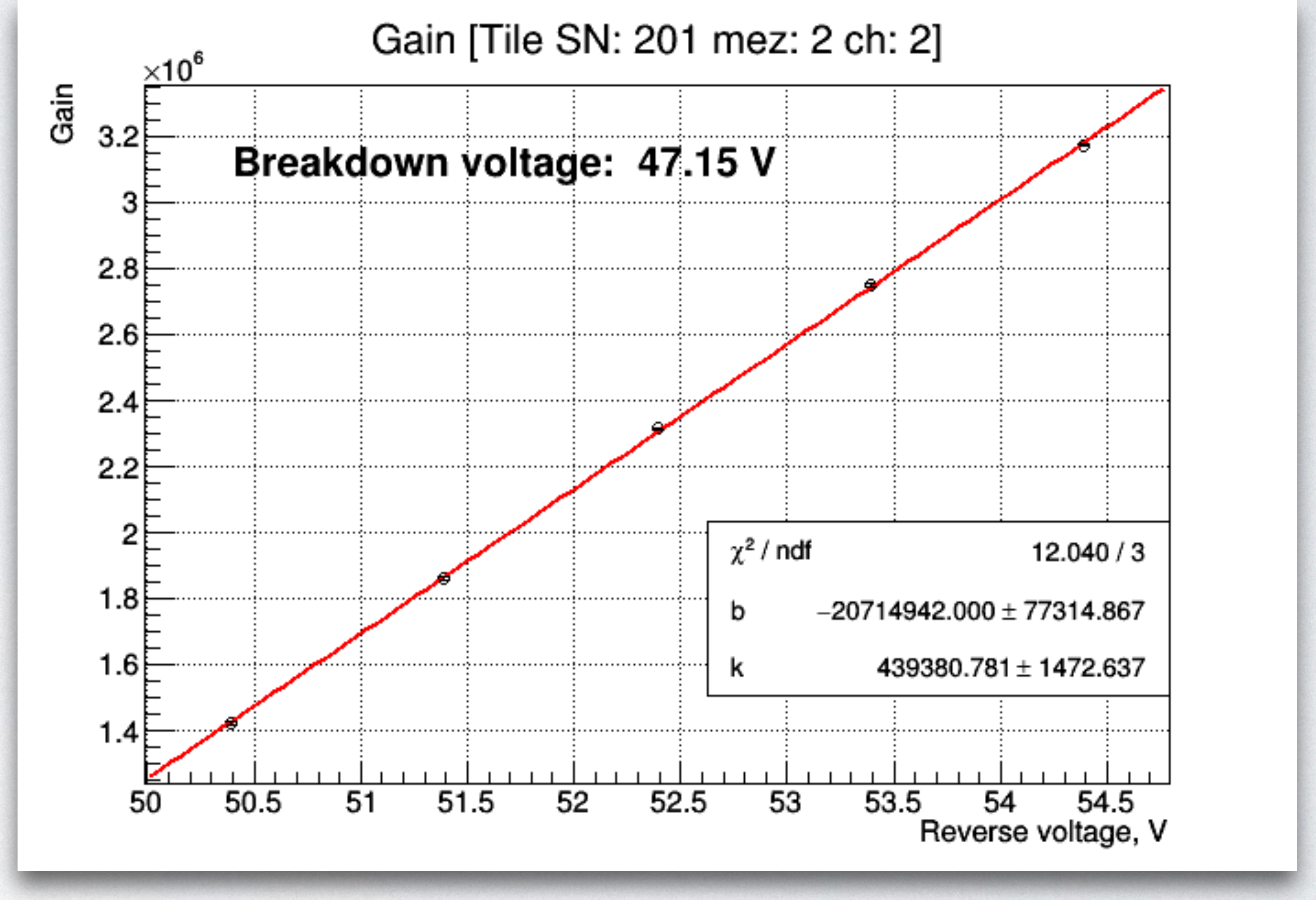
Good uniformity over all SiPMs on the tile → Good uniformity on the wafer → Small spread btw tiles

Add Average Vbd

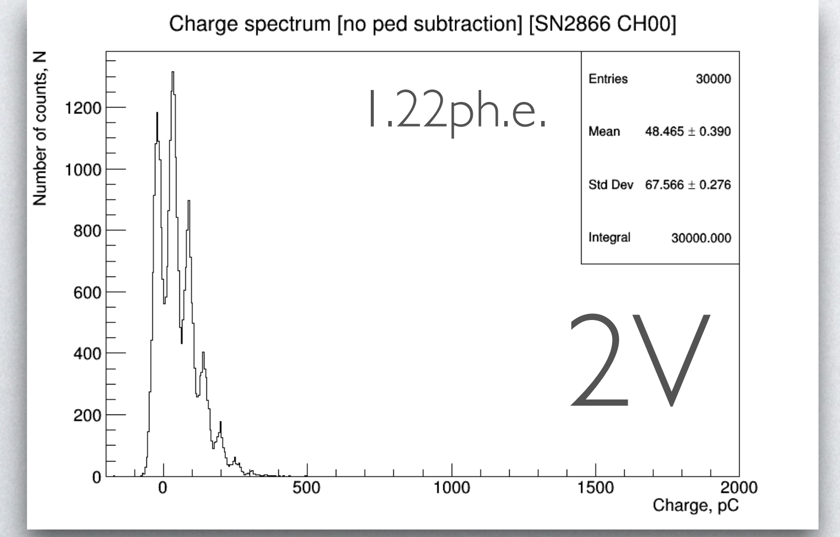
Our assumption is in the worst case:
approximate V_{bd} spread btw SiPMs < ± 5x0.19V

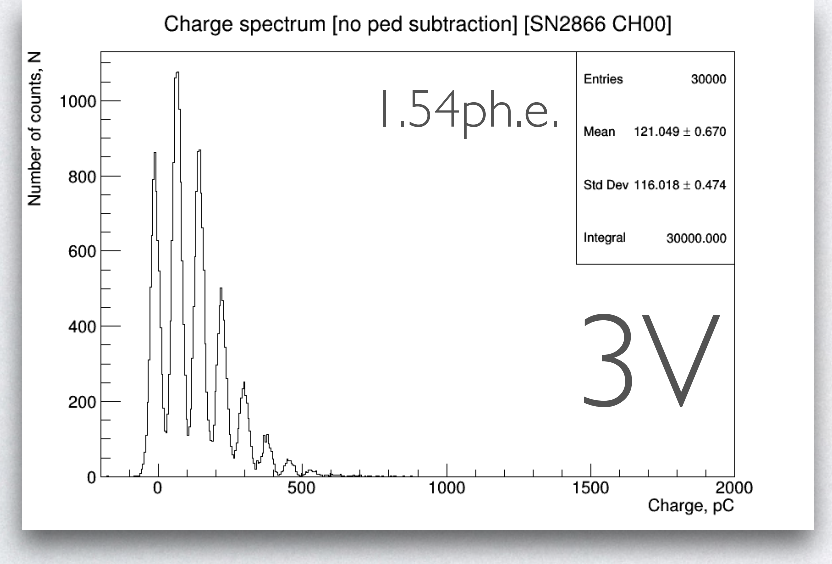
Tile#	V_{bd}	V_{op} range	Optimal V_{op} range
1	47.5	3.0 ÷ 7.0	
2	48.0	→ 2.5 ÷ 6.5	→ 2.0 ÷ 7.0V
3	48.5	2.0 ÷ 6.0	

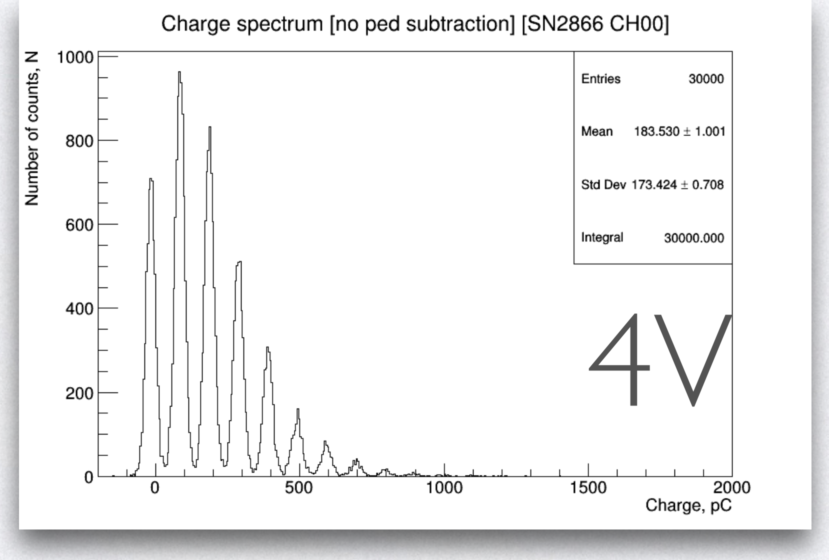
Gain-Voltage dependence

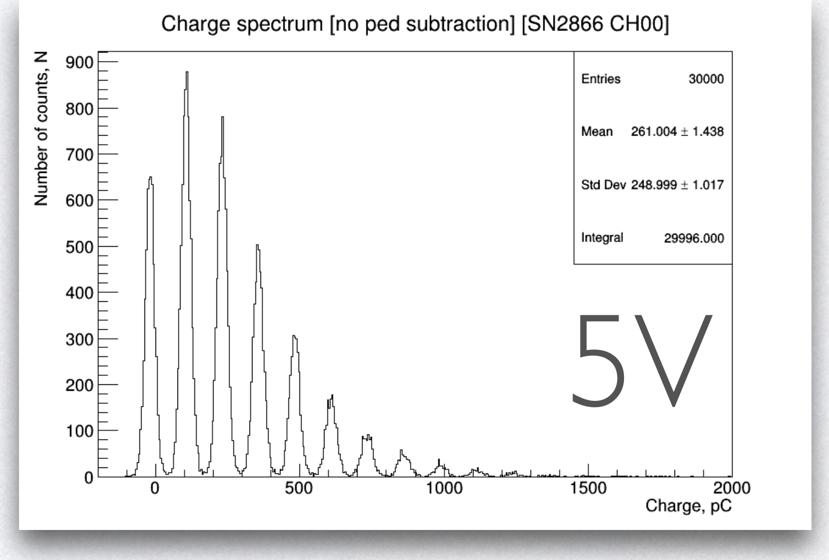


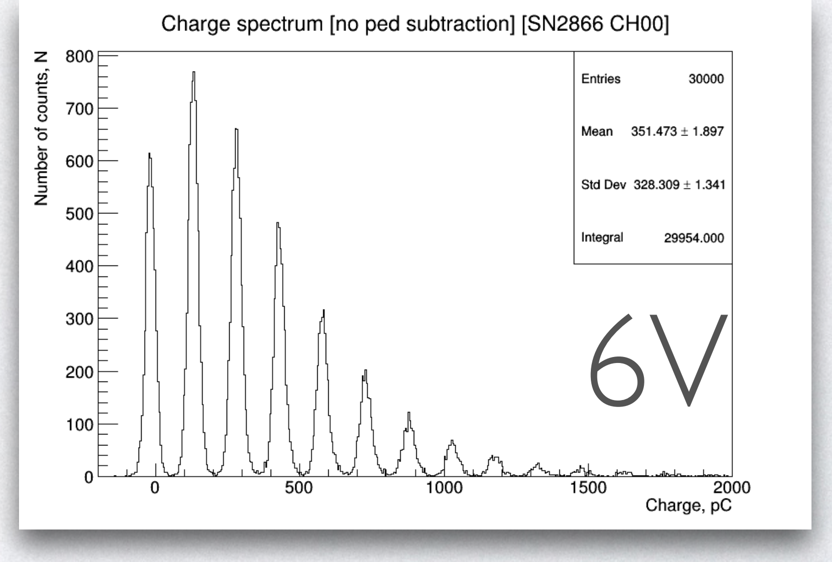
V_{bd} Accuracy: ±0.013%

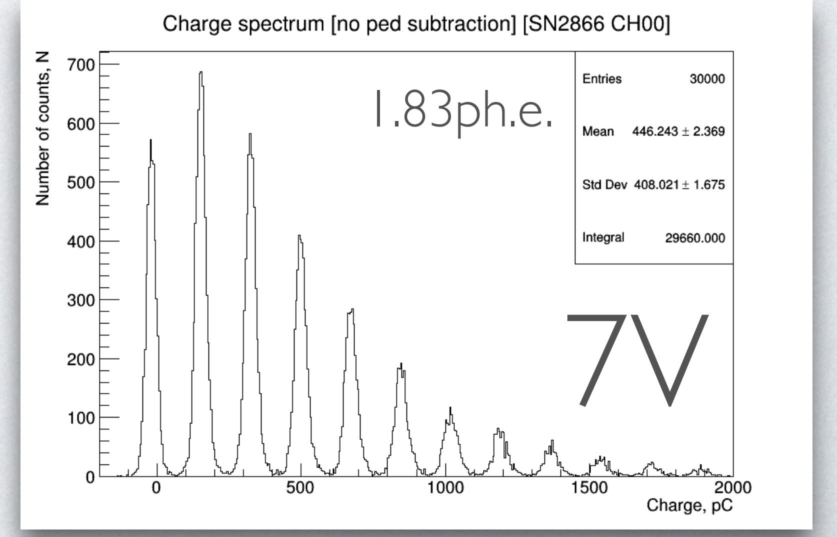






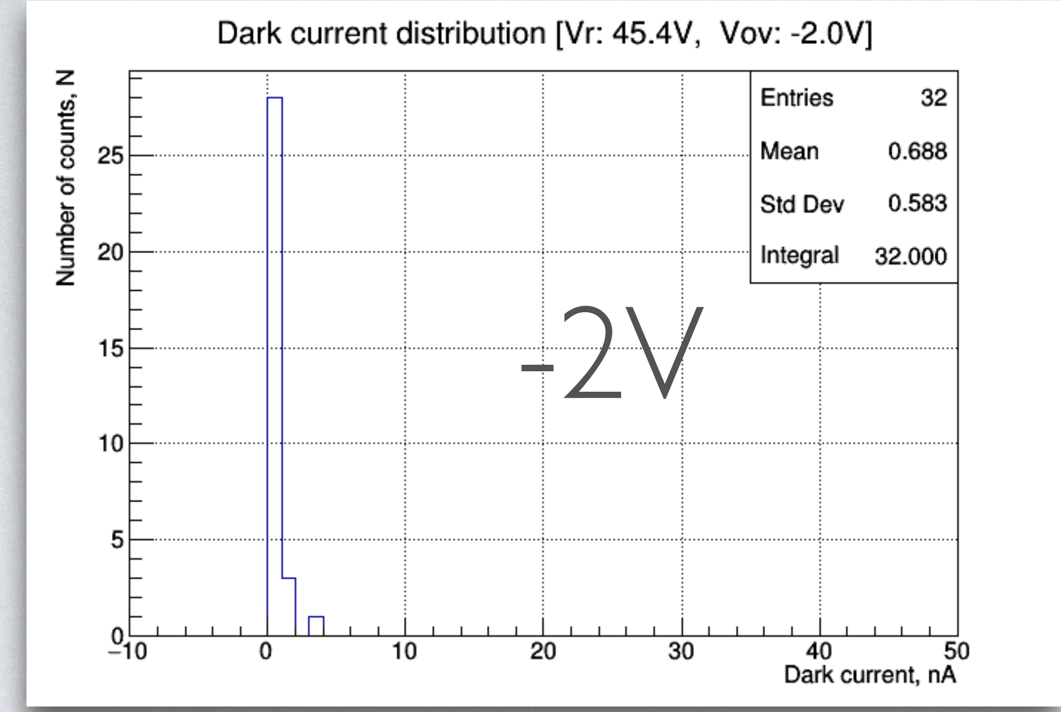


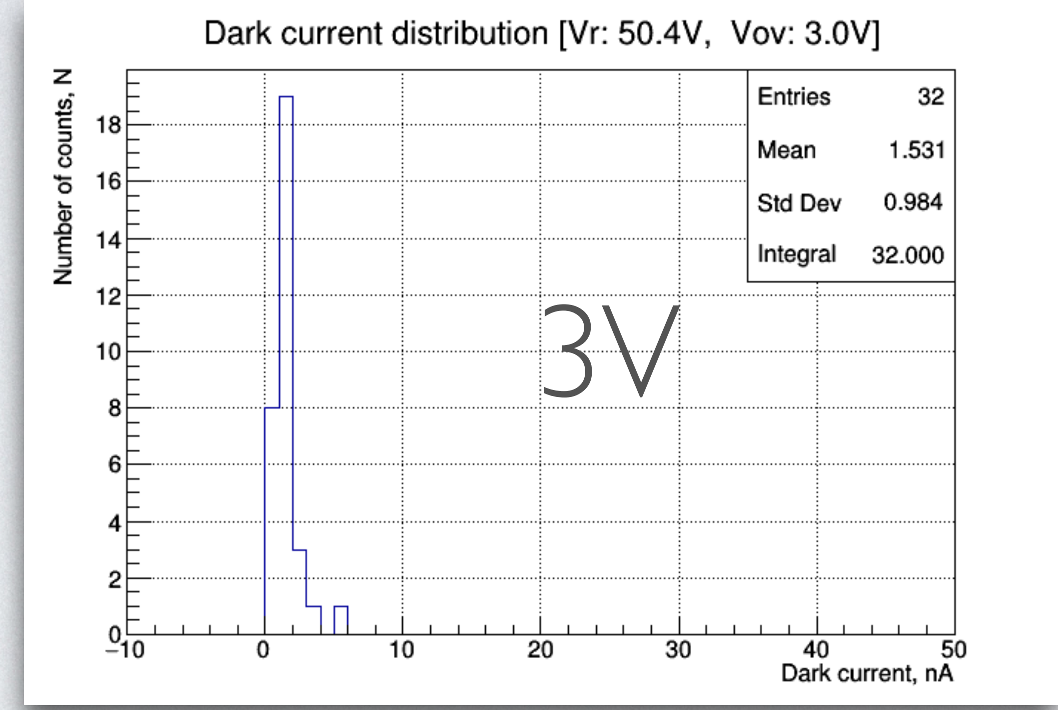


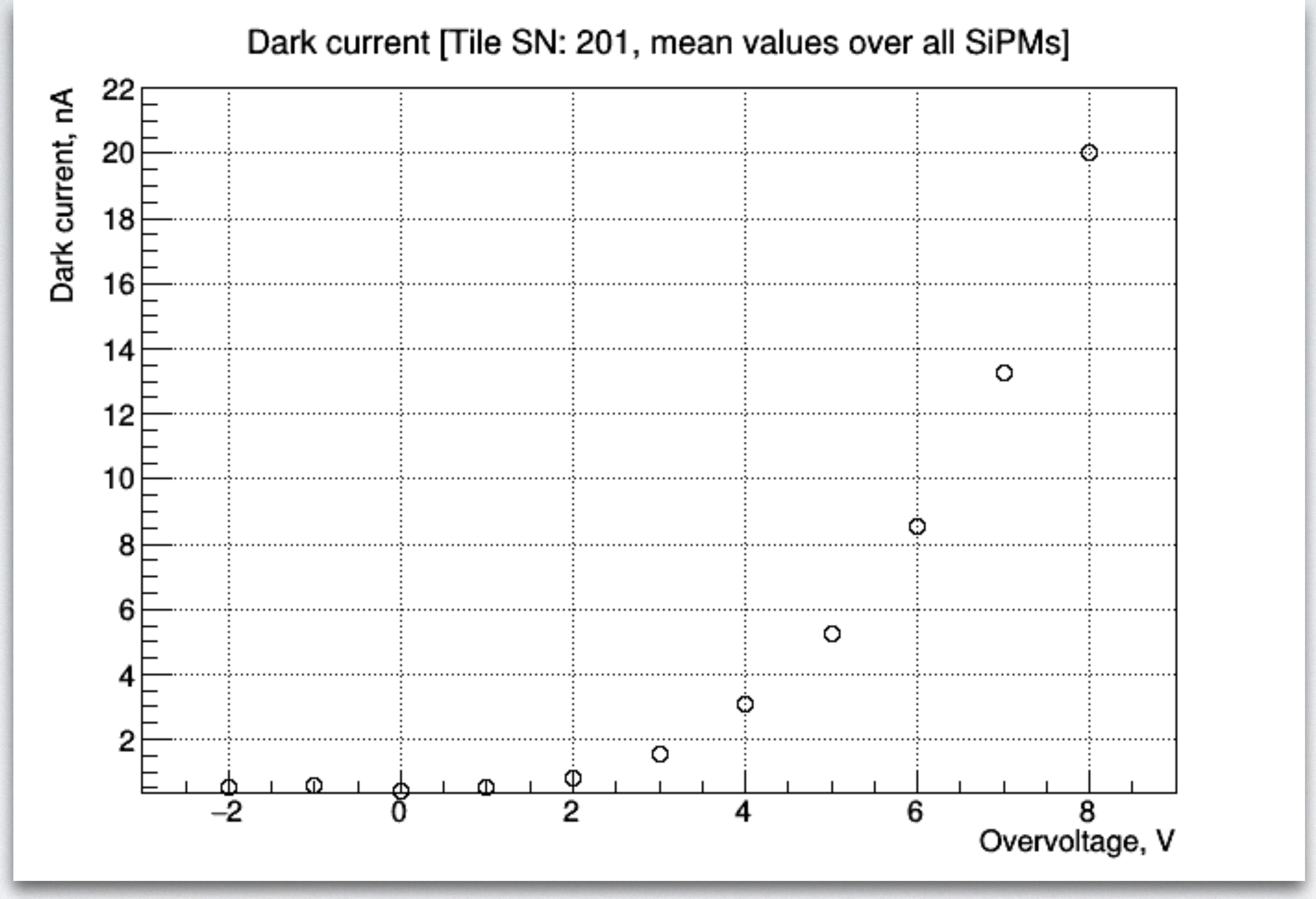


DEVIATION OF DARK CURRENT

[MAX: 95% / TYPICAL: 40%(4St.Dev.) from average value]

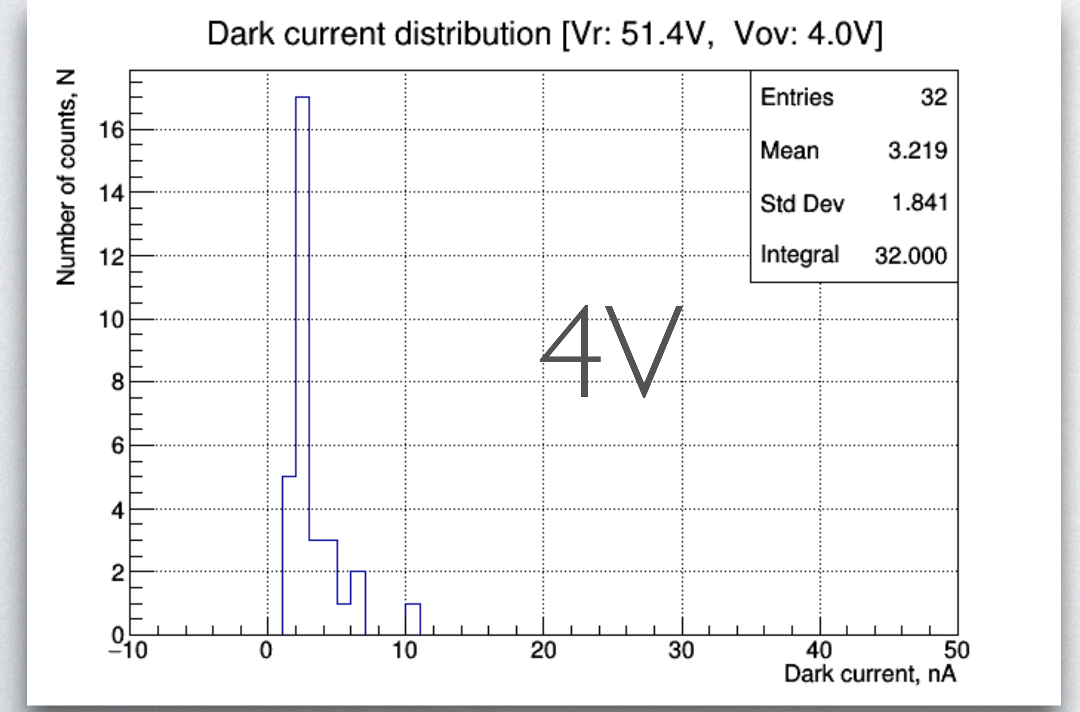


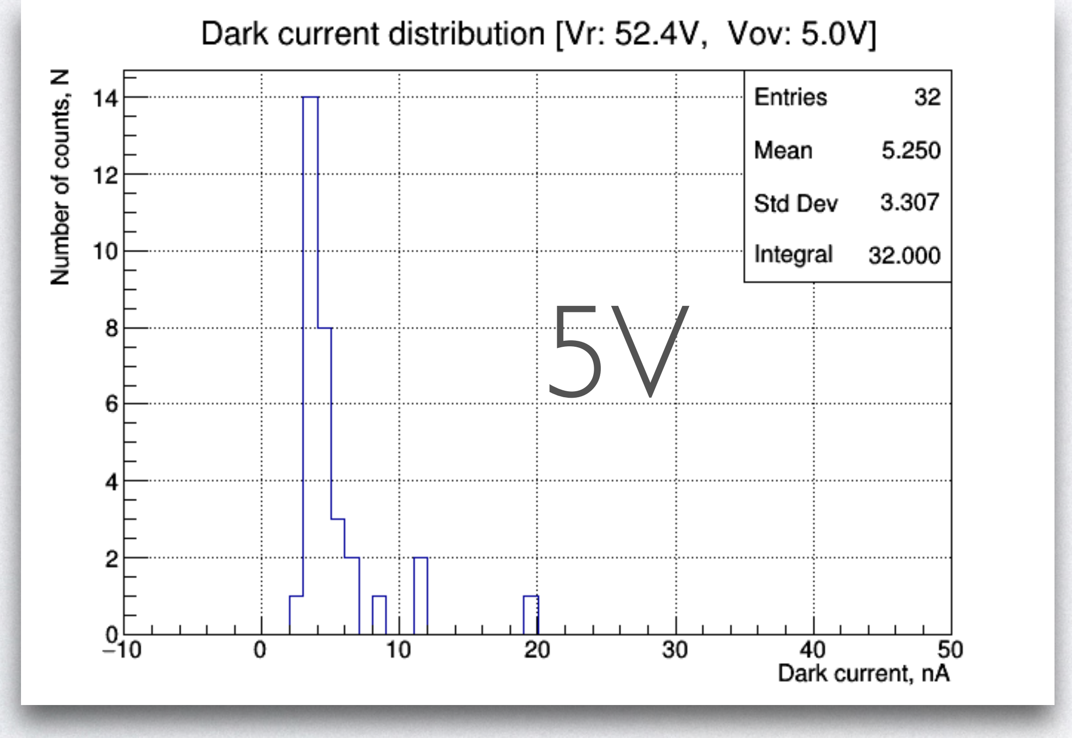


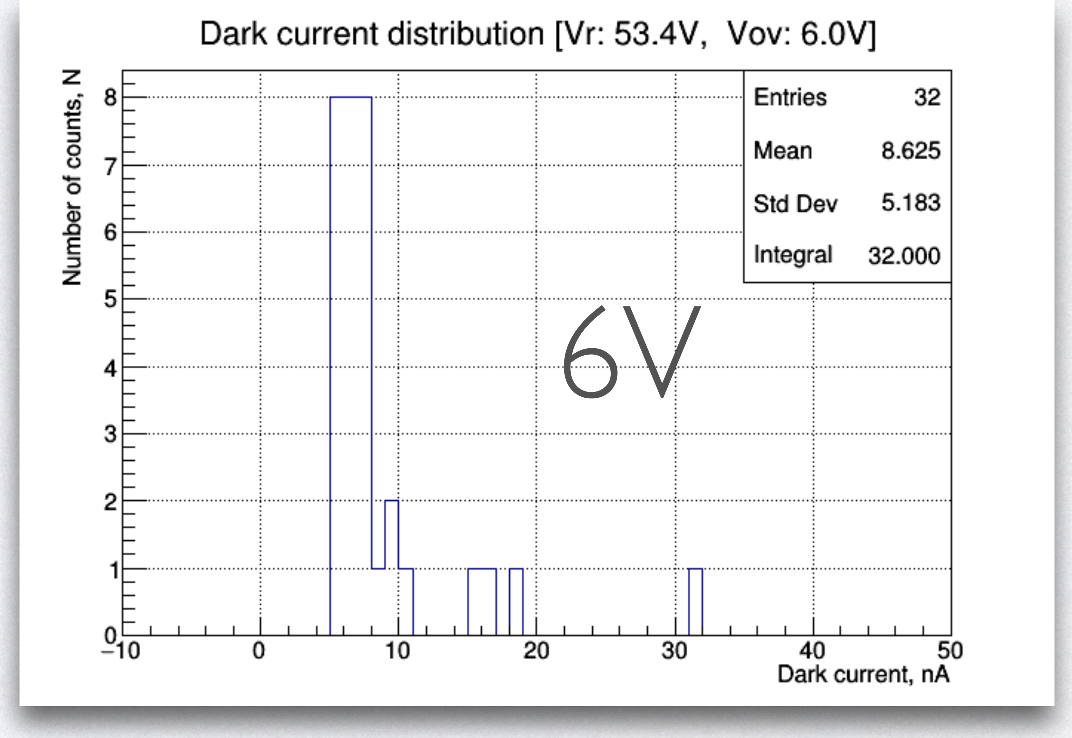


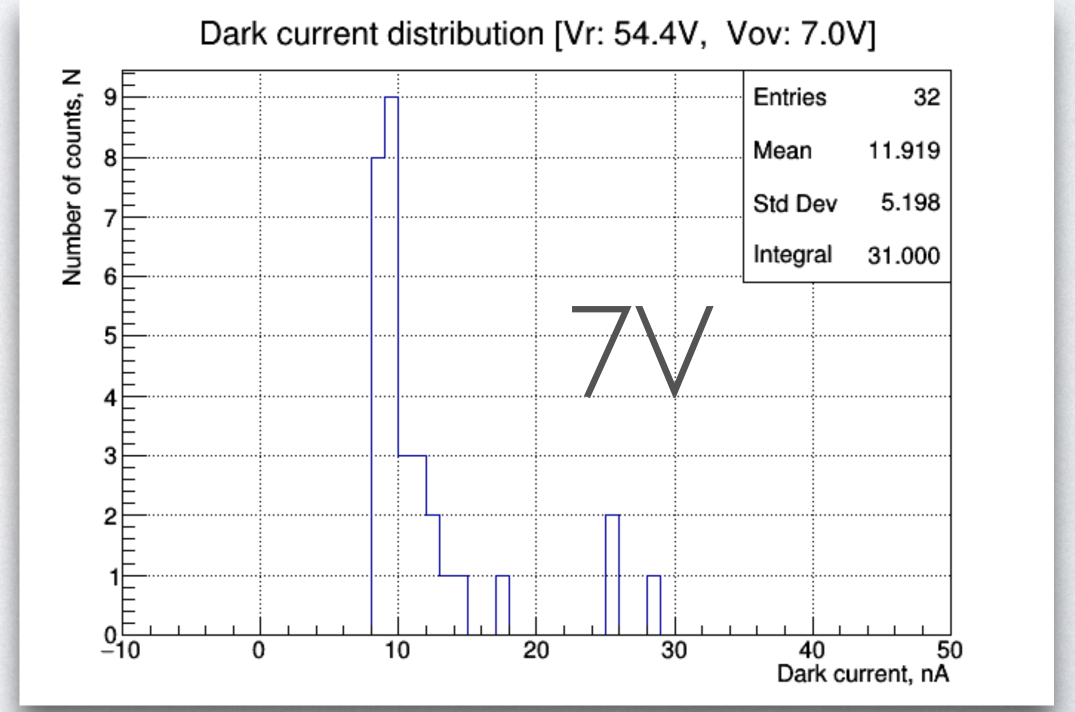
Direct measurement of dark current by means of Keithley 6487 picoammeter

Accuracy: ±(13.2 ÷ 3.3)% (3 ÷ 7V)





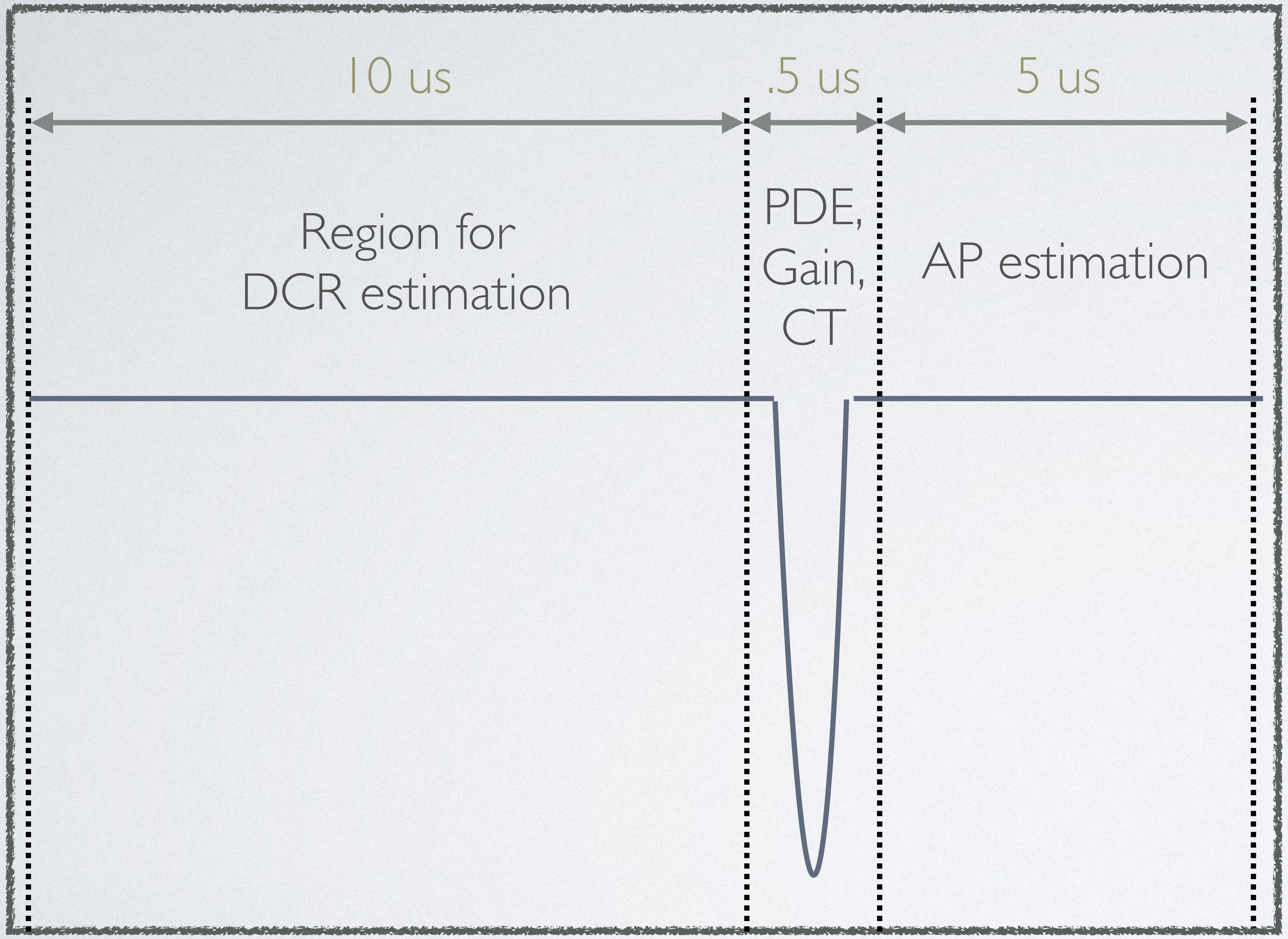




DARK COUNT RATE

[MAX: 41.7 Hz/mm2 / TYPICAL: 13.9 Hz/mm2]

Single oscillogram



JINR ADC (16ch/125MHz/14bit/2V/16us/10GBLink)

Run parameters:

Parameters	Values	Units
Time window	10	us/oscillogram
Number of oscillograms	30k	-
Total acquisition time	0.3	second
SiPM area	144	mm^2

Expected DCR

DCR	Rate@-50°C/mm^2	Rate@-50°C/ SiPM	Accuracy [1std.dev.]
Minimal	10 cps	430 cps	~4.8%
Typical	13.9 cps	600 cps	~4.1%
Maximal	41.7 cps	1800 cps	~2.4% (+0.002%)

Max probability of pile-ups:

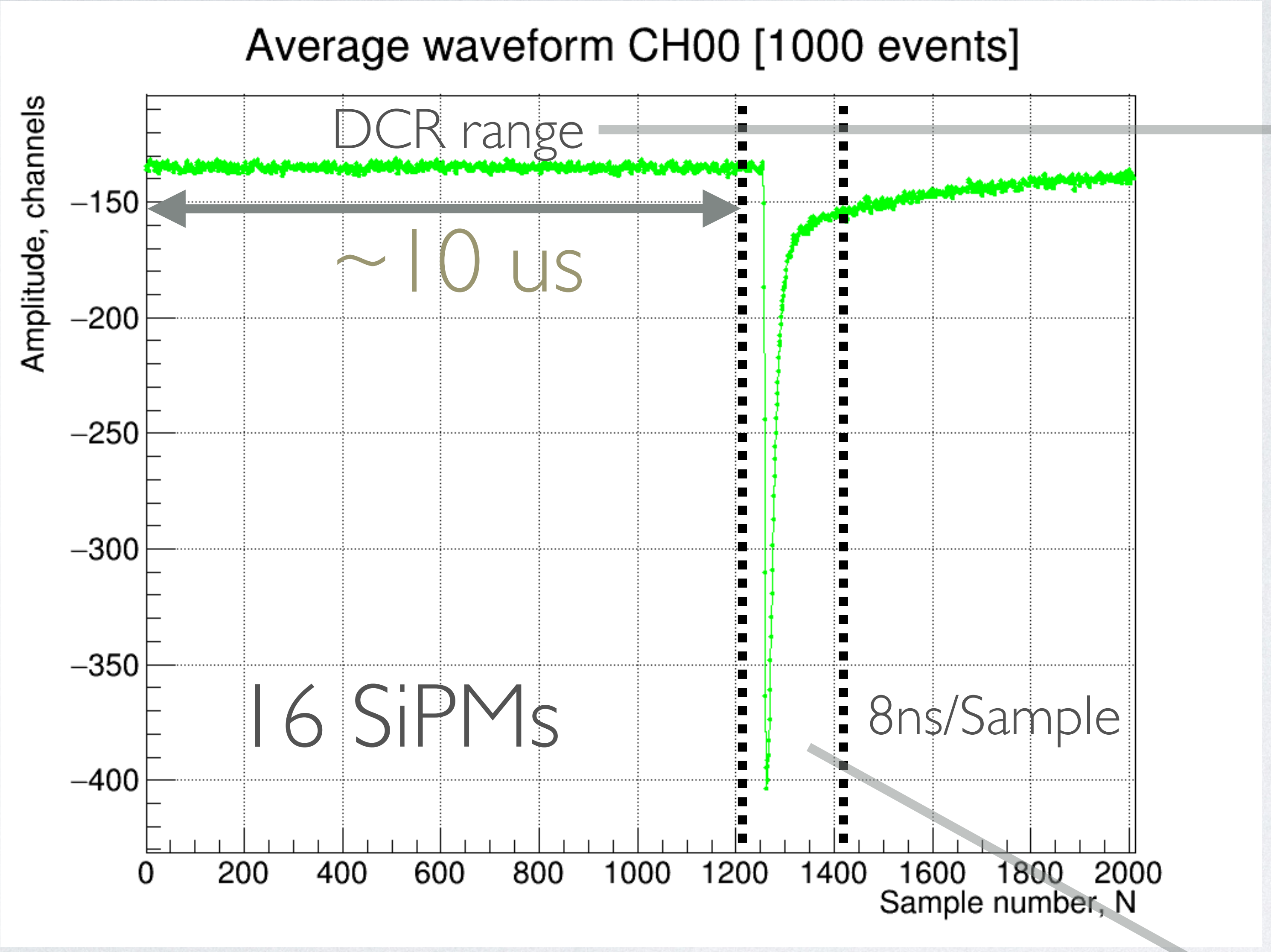
Typical pulse duration: 500 ns

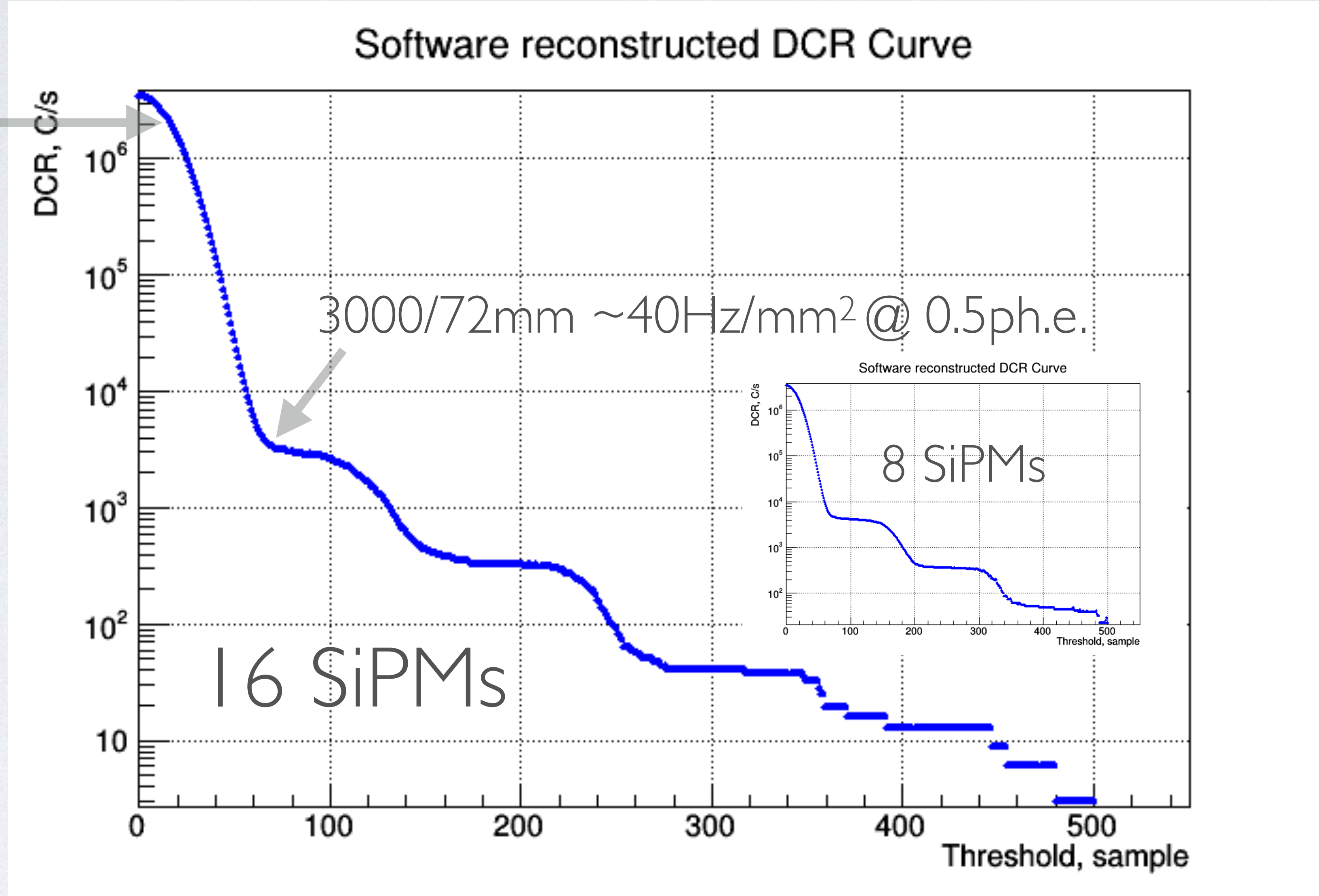
Average rate in window (1us): 0.006 [2pulses*500ns*144mm2*41.7cps]

Probability of pile-up (2 or more pulses): 0.002%

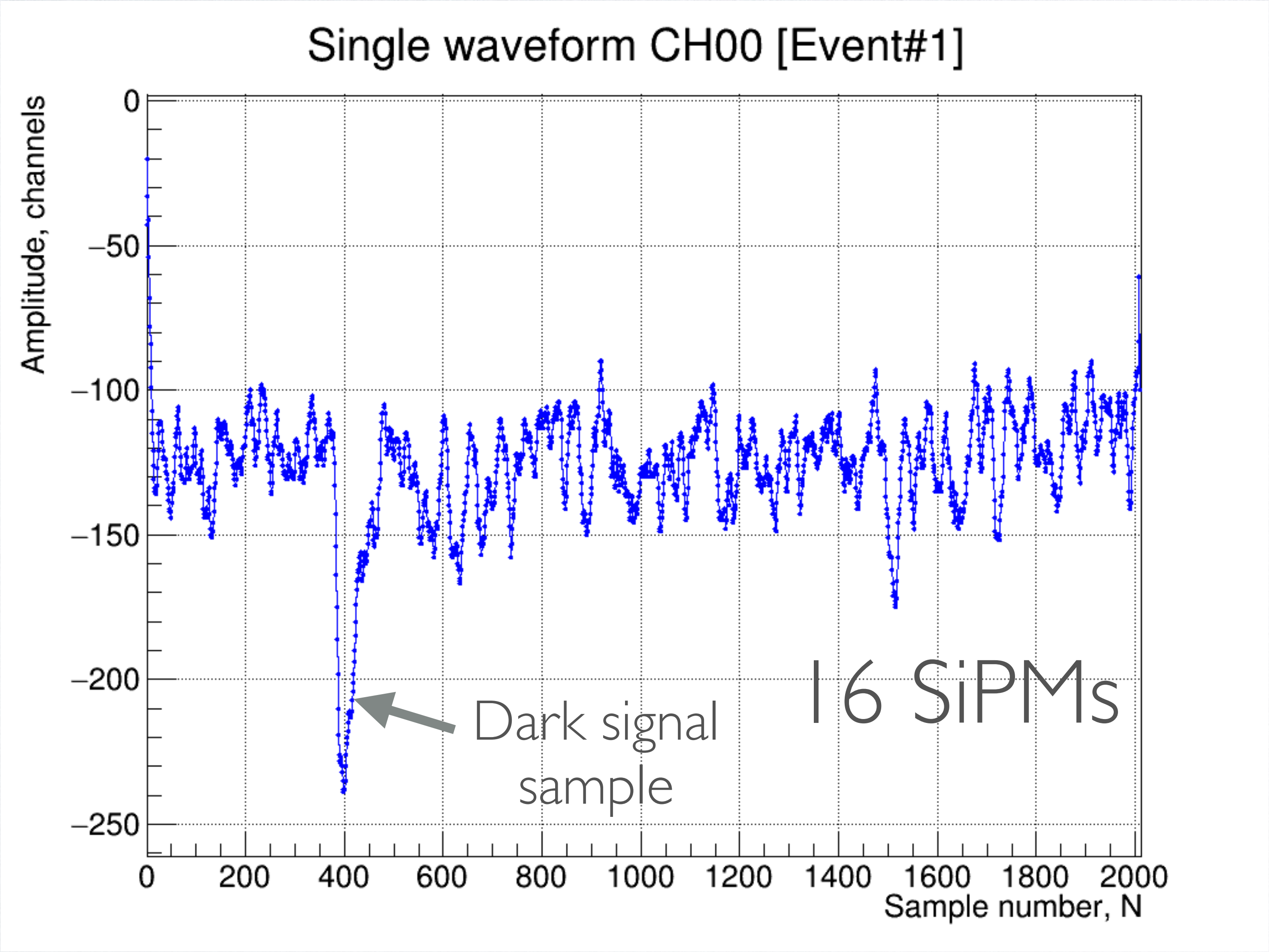
DARK COUNT RATE

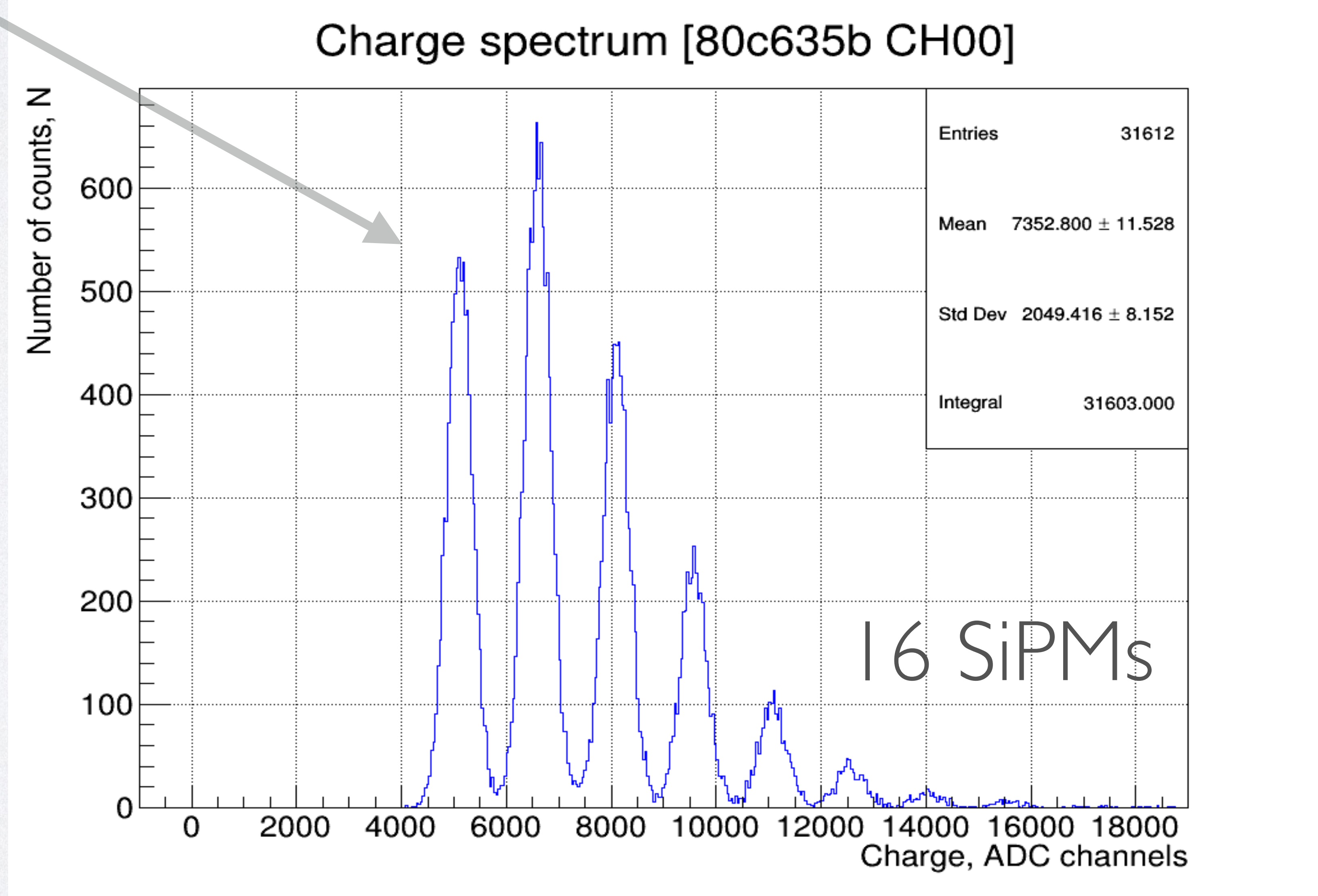
[MAX: 41.7 Hz/mm^2 / TYPICAL: 13.9 Hz/mm^2]

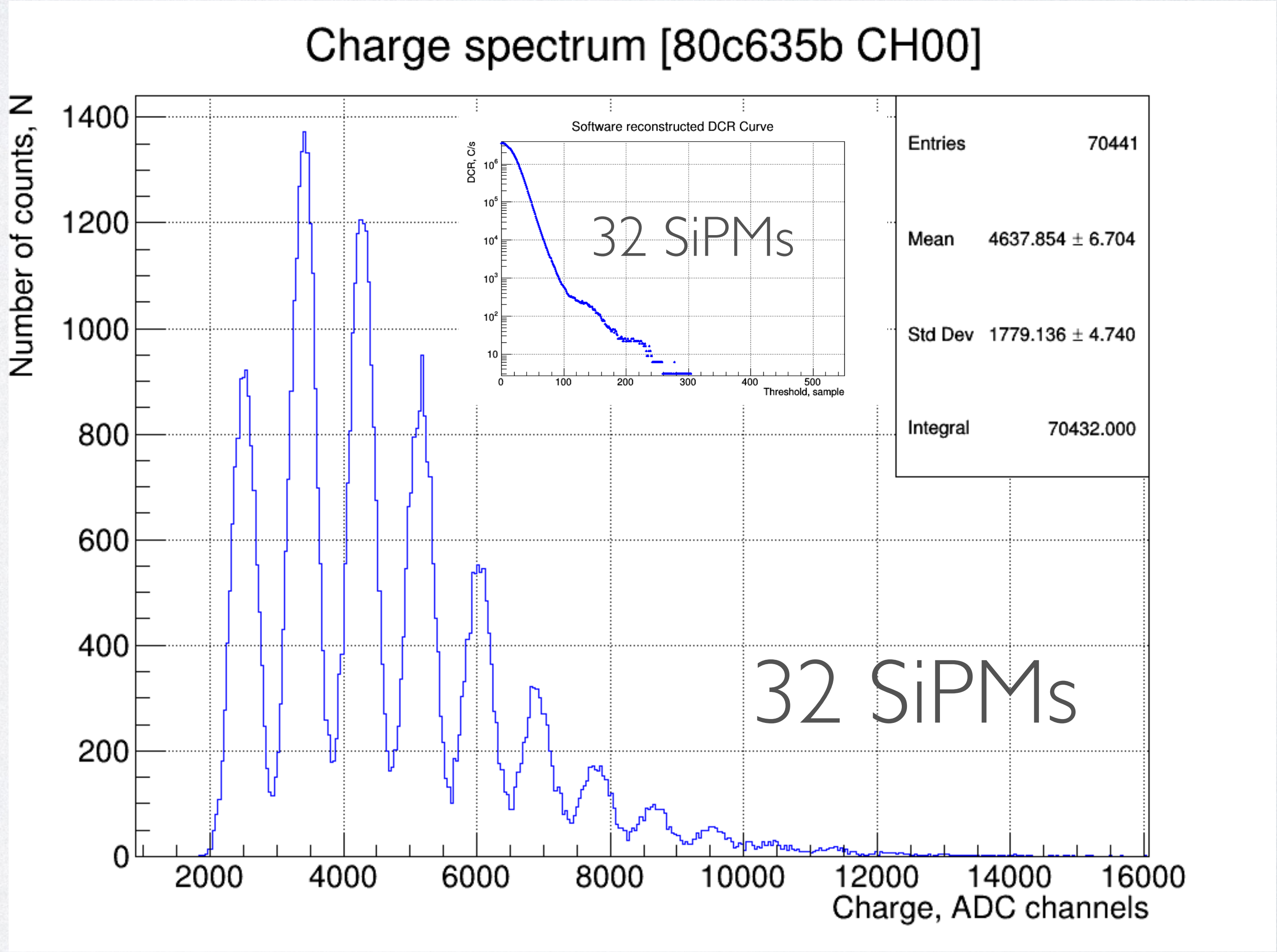




Performance of DCR curve reconstruction by means of Software analysis of JINR ADC data file

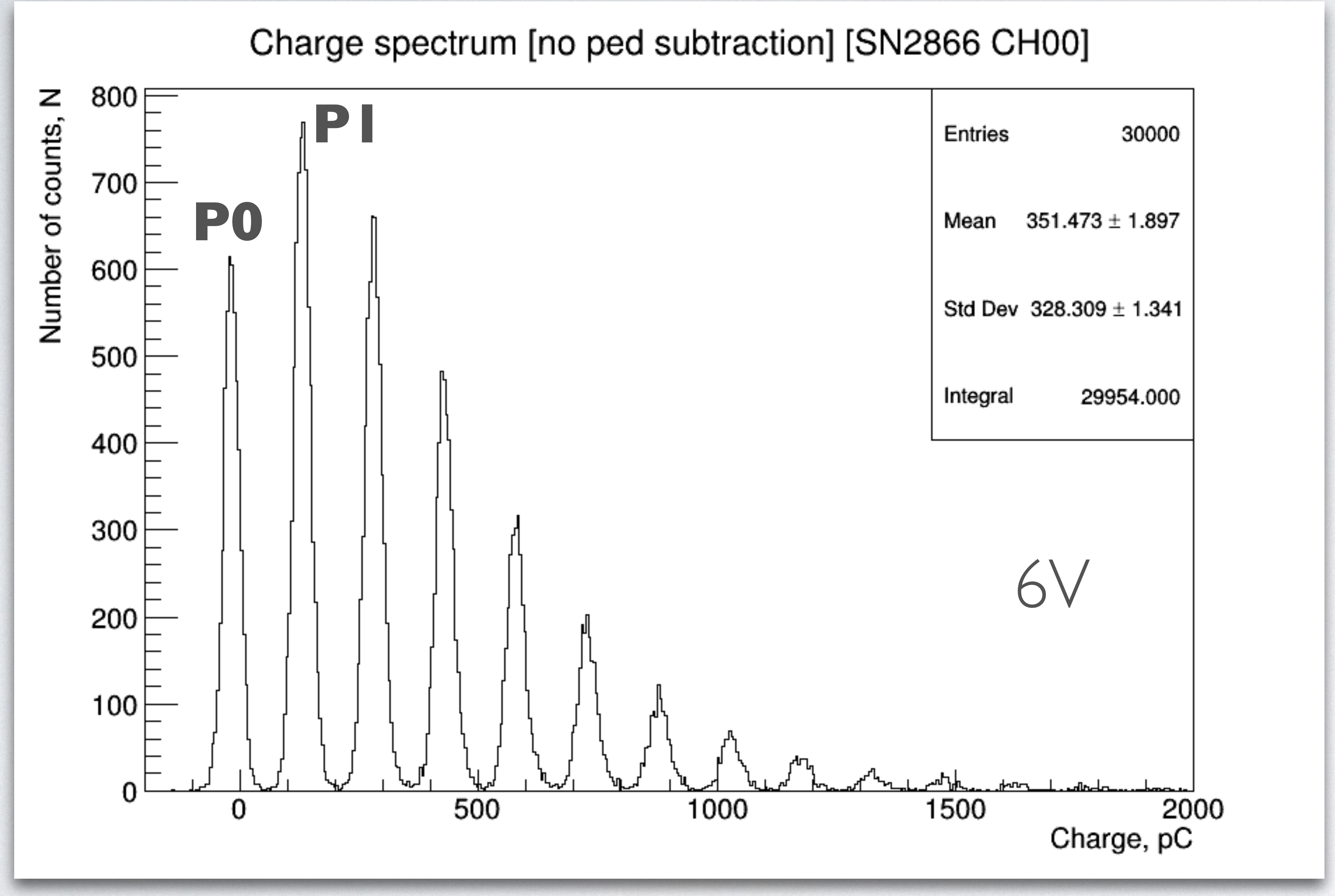






GAIN

[MIN: 1E6 / TYPICAL: 4E6]



$$GAIN_{pixel} = \frac{P0 - P1}{K_{amp} \cdot q}$$

@ the full length of signals

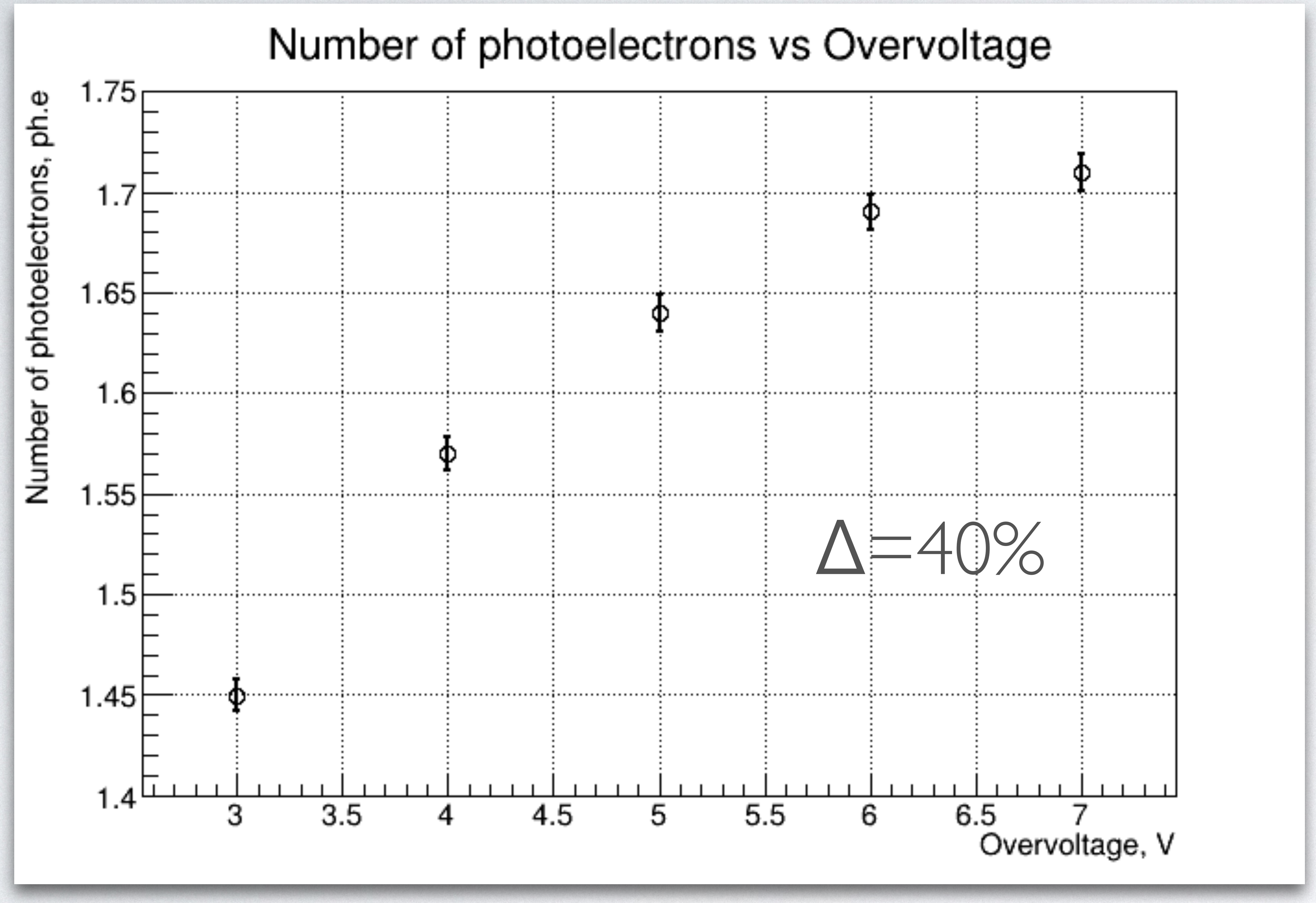
P0 - pedestal position
P1 - position of the 1st peak
K_{amp} - coeff. of the amplifier
q - elementary charge

Accuracy: ±(0.42 ÷ 0.13)% (3 ÷ 7V)

PHOTON DETECTION EFFICIENCY

[MIN: 44% / TYPICAL: 47%]

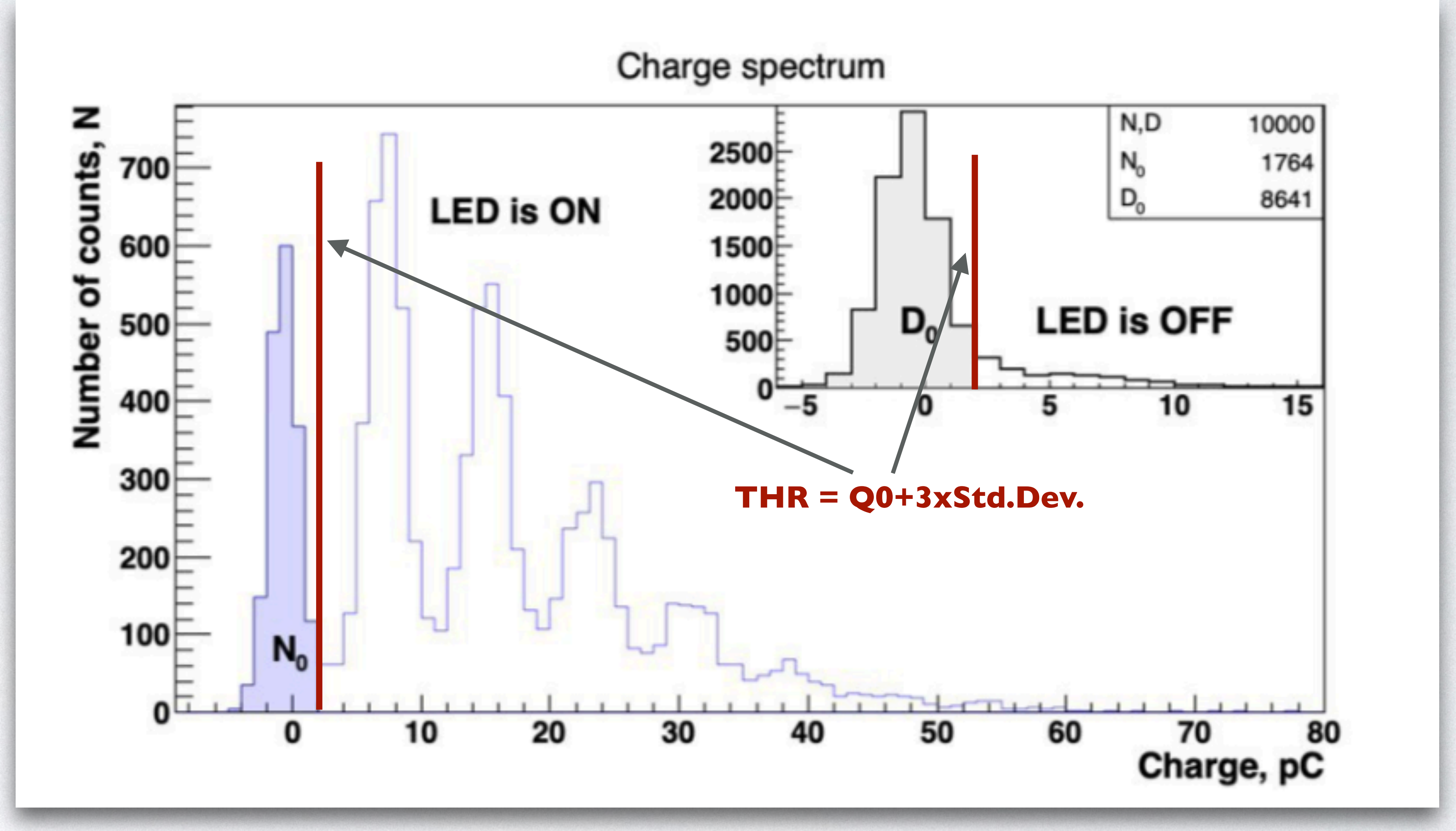
Mean values over all SiPMs on Tile



Absolute PDE value:

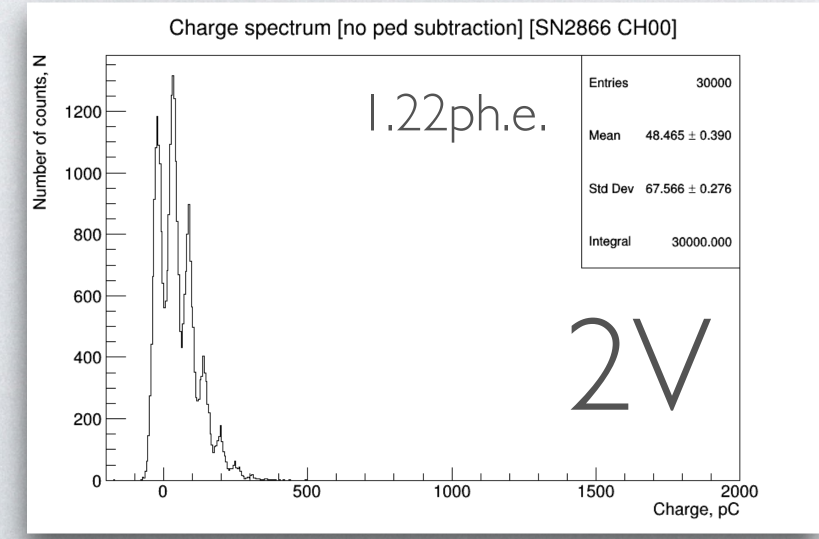
$$PDE_{tao\ sipm} = \frac{\mu_{tao\ sipm}}{\mu_{ref\ sipm}} \times PDE_{ref\ sipm}$$

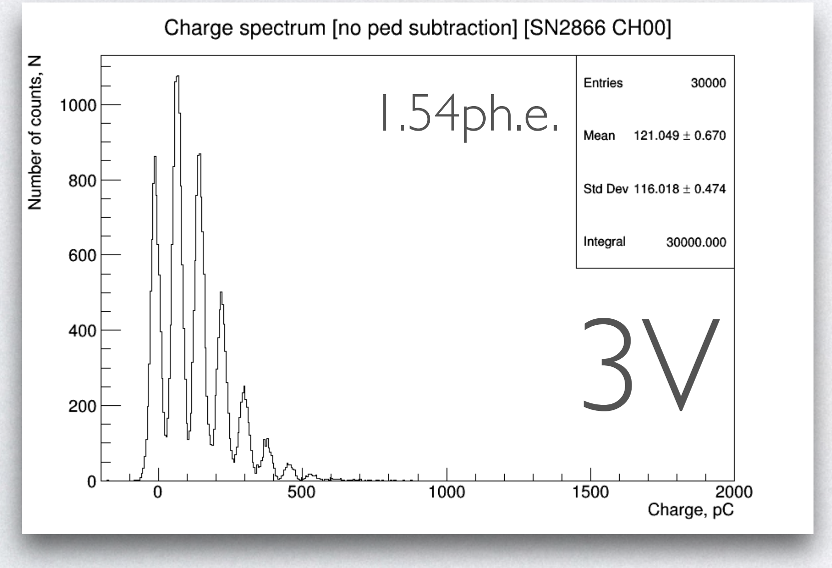
Estimation of the number of photoelectrons

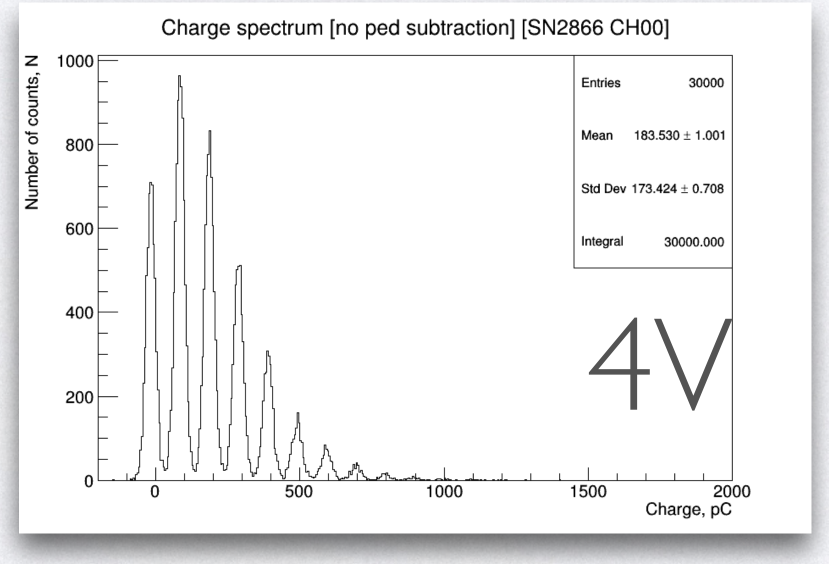


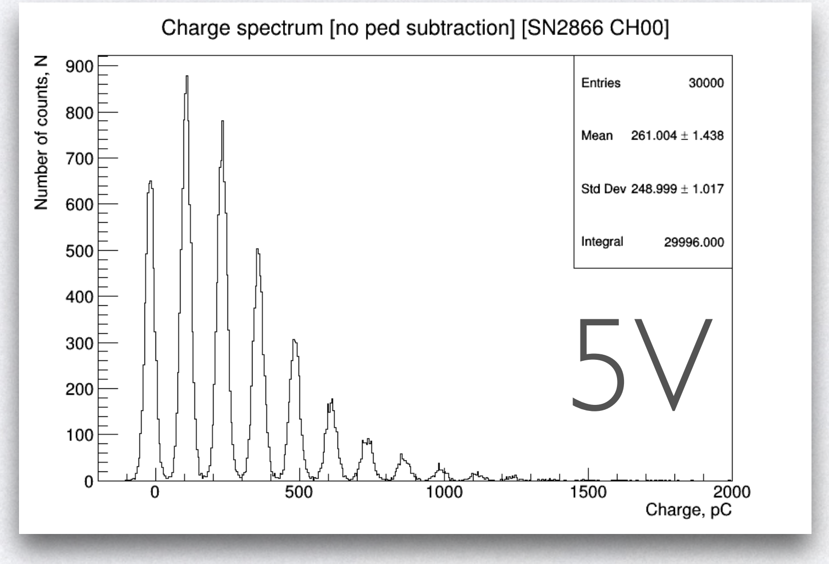
$$e^{-\mu} = \leftarrow \underline{Poisson(\mu, n=0)} \rightarrow = (\frac{N0}{N})/(\frac{D0}{D}), \quad \rightarrow \quad \mu = -ln((\frac{N0}{N})/(\frac{D0}{D}))$$

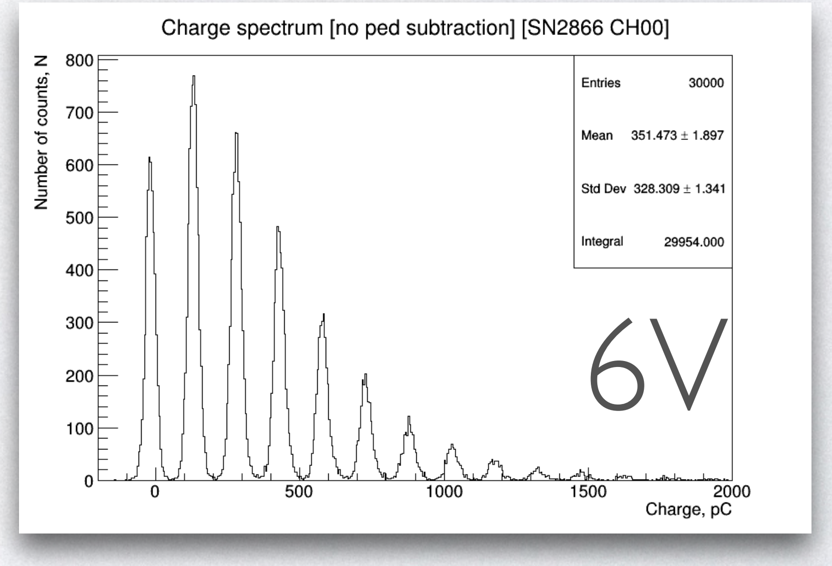
Accuracy: ±0.55% (3 ÷ 7V)

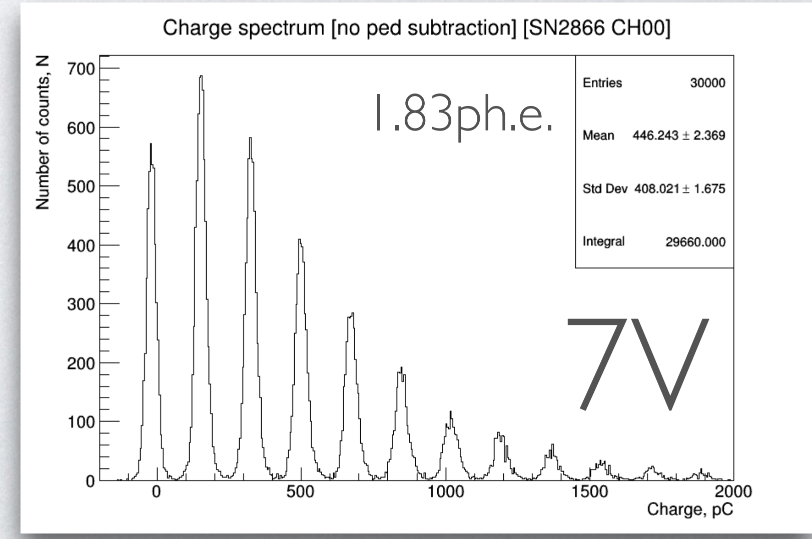








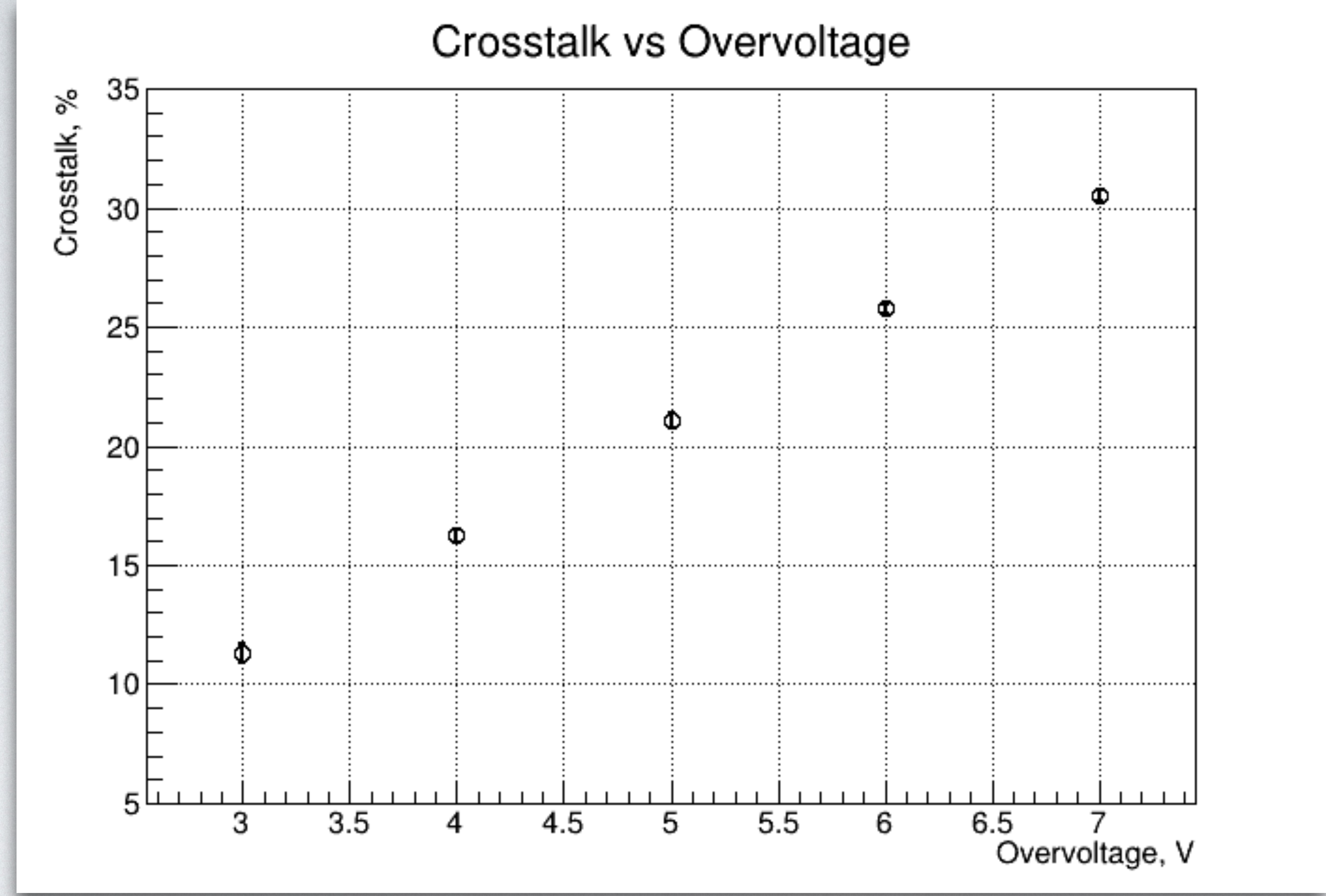




CROSSTALKS

[MAX: 15% / TYPICAL: 12%]

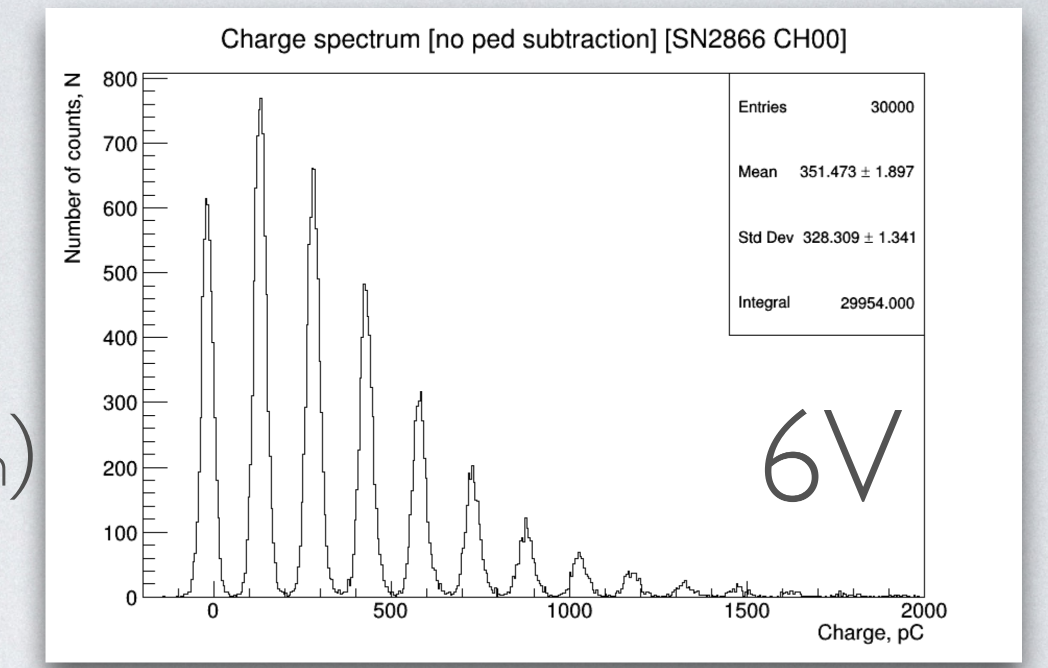
Mean values over all SiPMs on Tile



Building charge spectra

Extract and calculate values:

- Mean of spectrum
- Number of photoelectrons ($\mu_{tao\ sipm}$)
- Gain of pixel



Estimate crosstalk probability

Gate window: 500ns

$$n = \frac{S}{\mu_{tao\ sipm} \cdot GAIN_{pixel}}$$

where S:

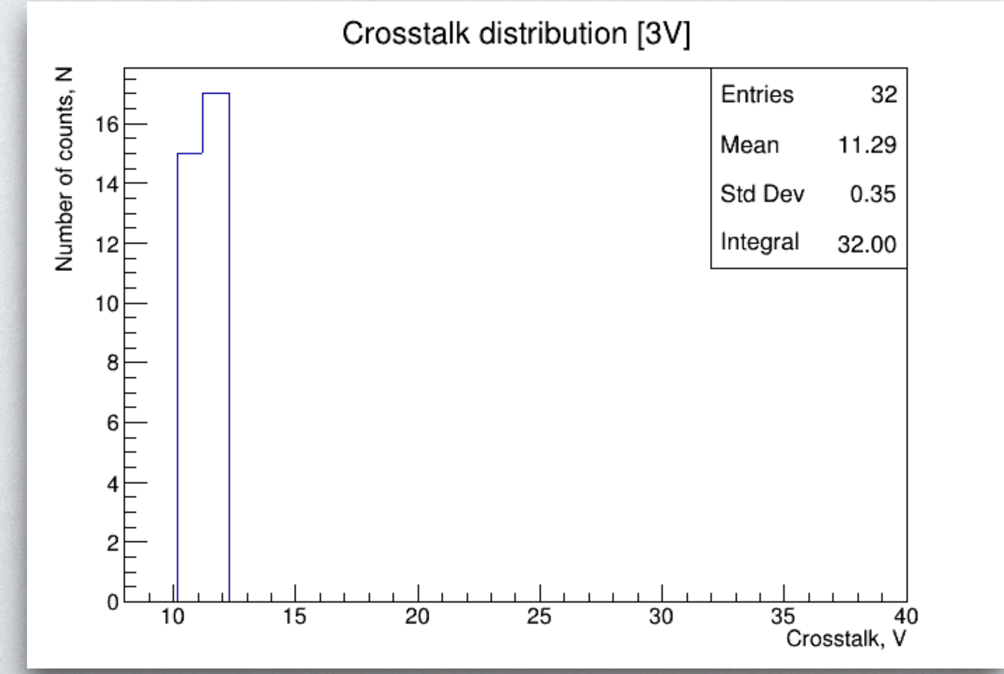
$$S = Mean_{spectrum} - Pos_{pedestal}$$

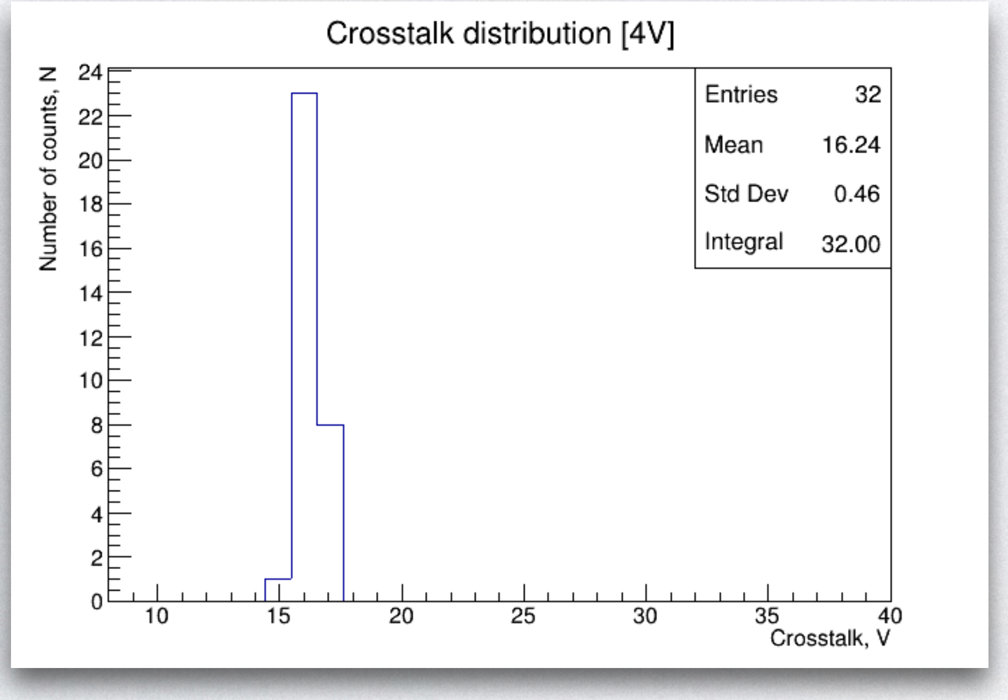
S.Vinogradov, (2011). Analytical models of probability distribution and excess noise factor of Solid State Photomultiplier signals with crosstalk. NIM A 695. 10.1016/j.nima.2011.11.086.

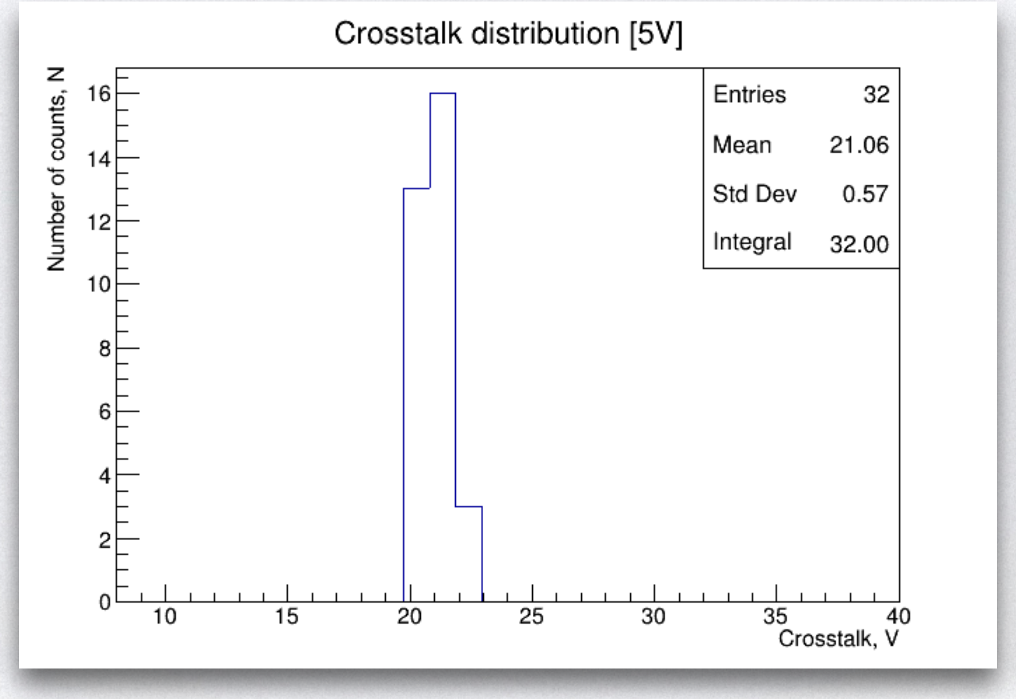
$$\lambda = 1 - \frac{1}{n}$$

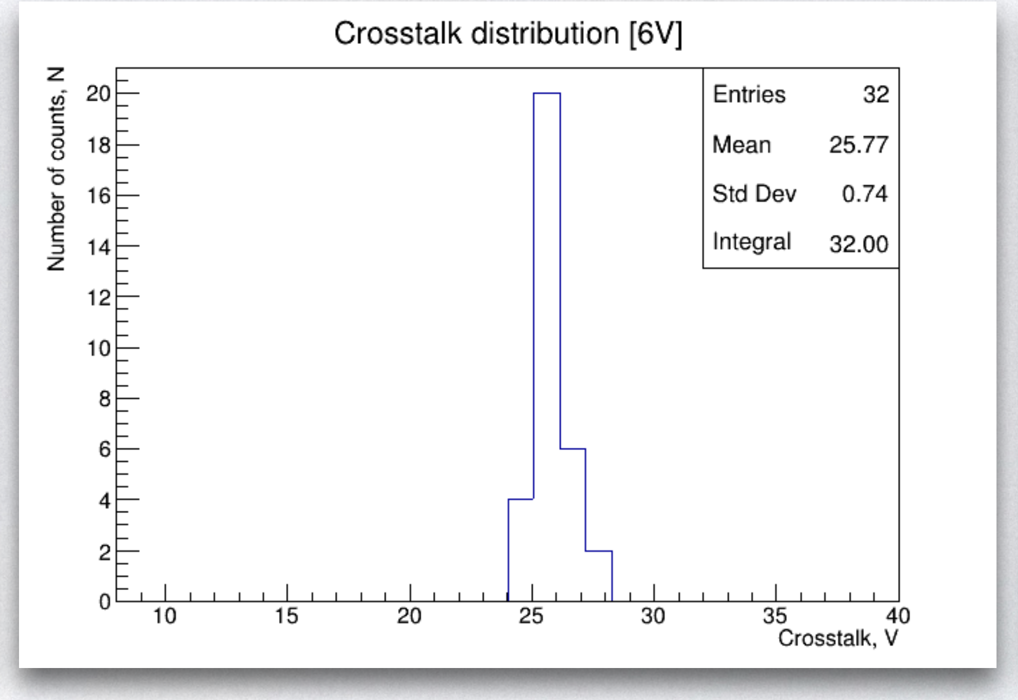
$$P_{crosstalk} = 1 - exp(-\lambda) = P_{crosstalk} = \frac{N_{1.5phe}}{N_{0.5phe}}$$

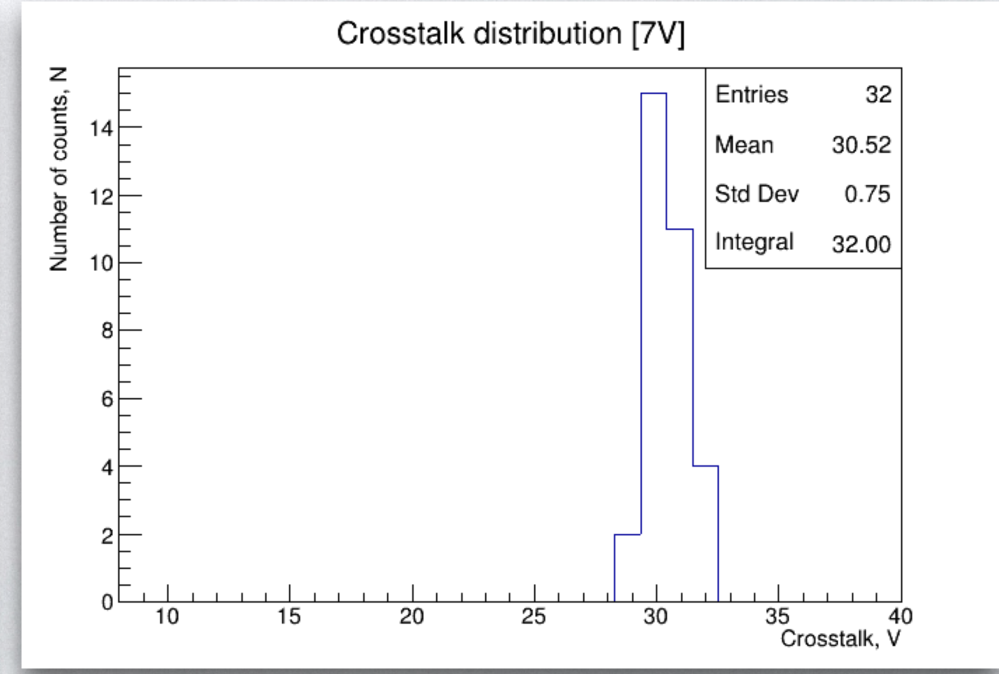
Accuracy: ±(3.6 ÷ 0.7)% (3 ÷ 7V)











Δ PDE

[For each channel: $\Delta_\epsilon \geq -25\%$]

Mean coverage of the SiPM cells in a Tile
C=0.896 (by contract)

Final accuracy

$$\Delta_\varepsilon = PDE \times \frac{C}{0.9} - PDE_{Eff}$$

Absolute PDE value:

$$PDE_{tao\ sipm} = \frac{\mu_{tao\ sipm}}{\mu_{ref\ sipm}} \times PDE_{ref\ sipm}$$

Number of photoelectrons:
($\mu_{tao\ sipm}$, $\mu_{ref\ sipm}$)
Accuracy: ±0.55% (3 ÷ 7V)

Accuracy depends on calibration of Ref.SiPMs (IHEP team)
Accuracy: ±3%

Effective PDE value:

$$PDE_{Eff} = 0.51 + 0.35 \times P_{cn} + 0.84 \times P_{cn}^2 + (4.2 \times 10^{-4} + 2 \times 10^{-4} \times P_{cn}) \times DCR$$

Correlated noise probability [max 23%]:

Crosstalk probability :
Accuracy: ±(3.6 ÷ 0.7)% (3 ÷ 7V)

Afterpulse probability:
Offline analisys

DCR:
Accuracy: ±4%

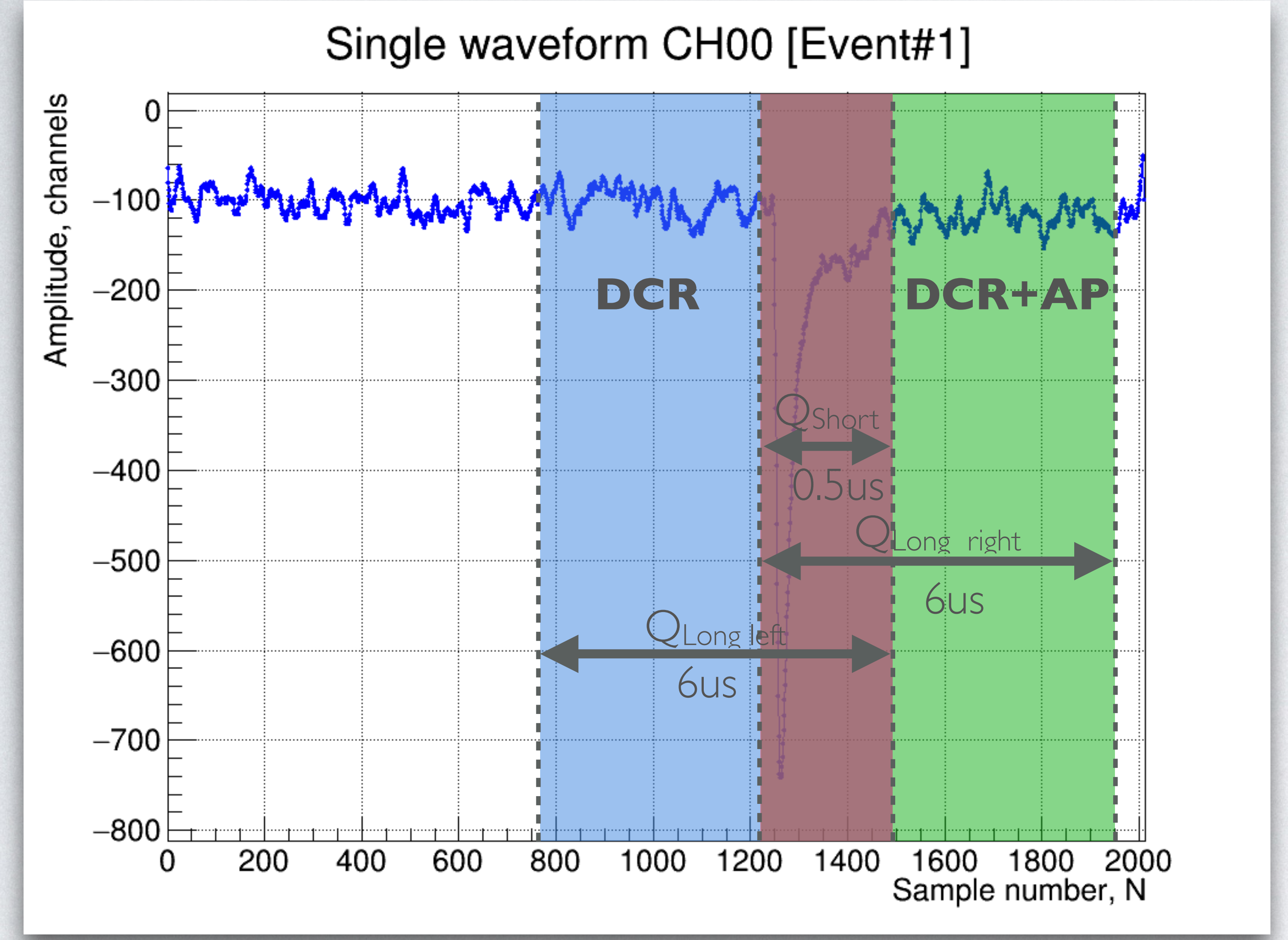
SUMMARY

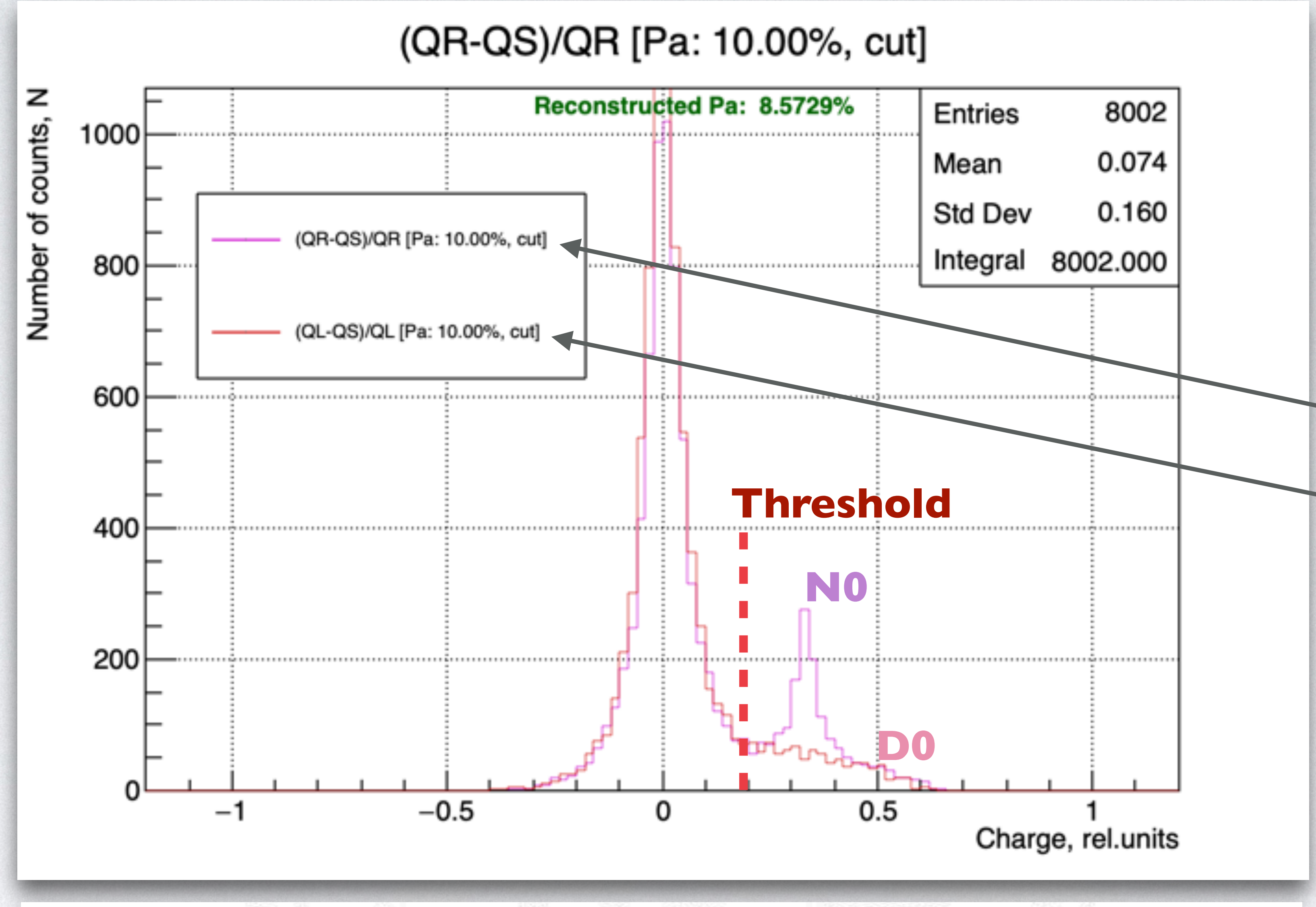
- Method maturity ~100%
- Equipment maturity ~50%
  - Existing components: PS boards, ADCs, Light system, Current system, Trigger unit
  - Missing components: mechanics, interface and mother PCBs
- Software maturity ~70%
  - ADC SW no CLI, PS SW no CANOpen support, Analysis SW no WF analysis
- Export restrictions from Russia
  - Partial production in China
- Total cost: ~60k$ (Onsite)
- Semi-Clean room, gloves, ESD protection, wearing

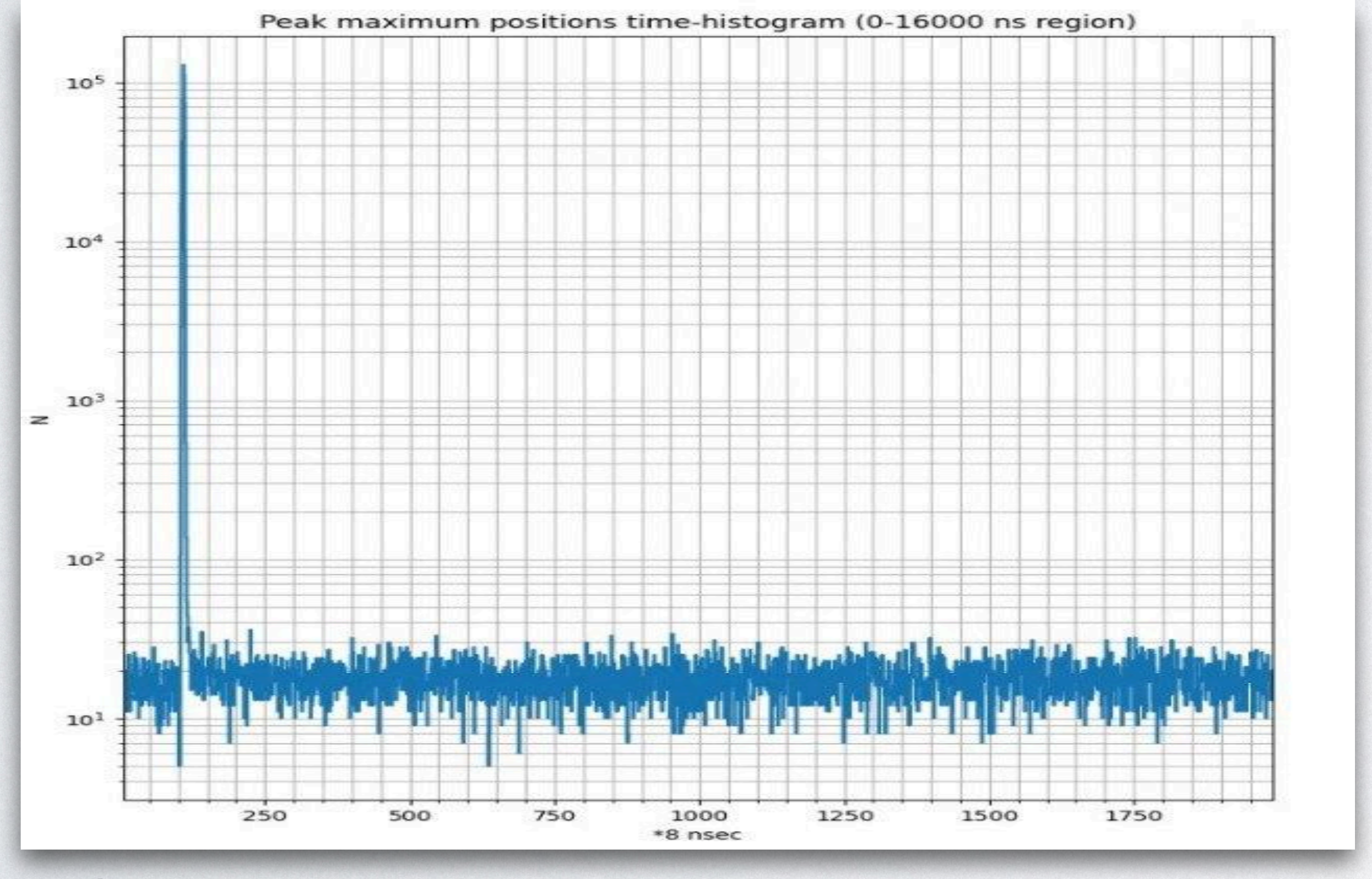
BACKUP SLIDES

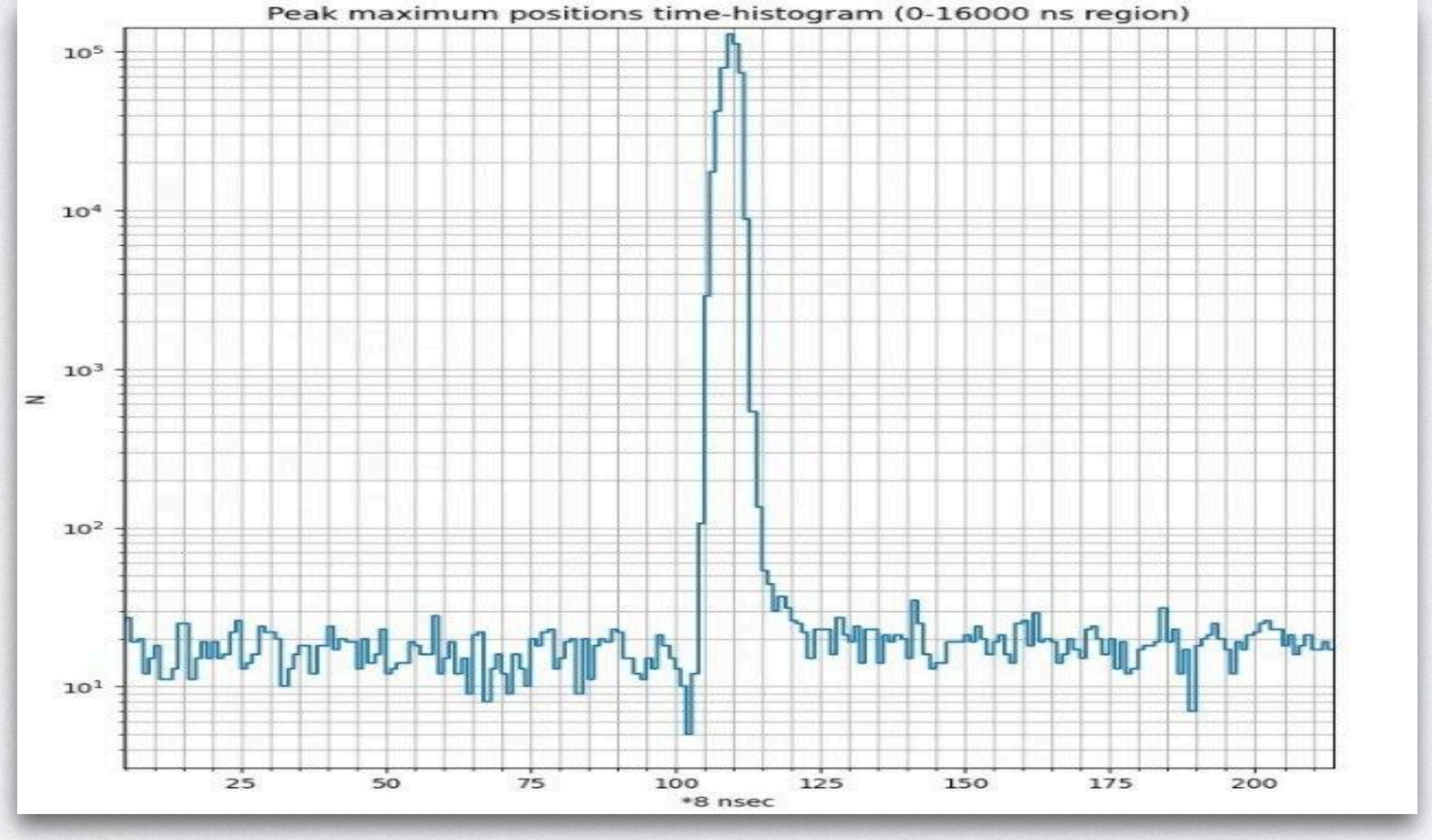
AFTERPULSES

[MAX: 8% / TYPICAL: 4%]









Afterpulse estimation techniques:

1. **Fast/Total**
   - Integration of waveforms in the long/short time gates:

     $(Q_{Long\ right} - Q_{Short})/Q_{Long\ right}$

     $(Q_{Long\ left} - Q_{Short})/Q_{Long\ left}$
   - Estimation of afterpulse probability:

     $P_{afterpulse} = P_{N0} - P_{D0}$

     where: $P_{N0} = N_0/Entries$, $P_{D0} = D_0/Entries$

2. **Fitting of waveforms**
   - requires computing power
   - offline analisys
   - is not resolved within 100-200 ns

Outstanding issues:

- what is the gate for afterpulse estimation
- what is the minimal time to resolve afterpulse signals from the prime pulse

AFTERPULSES