Study of the effect of neutron irradiation on SiPM based 10-channel prototype of scintillation detector

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Motivation

Light readout by SiPM is widely used or planned to be used in HEP in different experiments

ECAL at COMPASS-II,

PSD at NA61,

HCAL at CMS,

PSD at CBM,

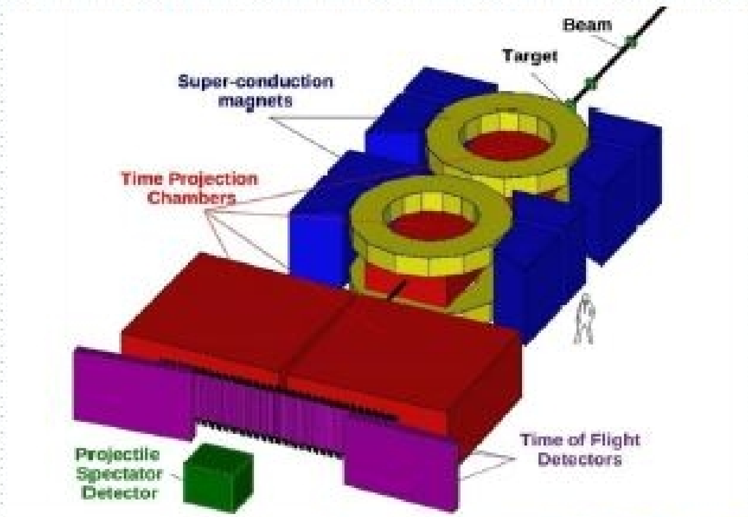
ECALand FHCAL at MPD

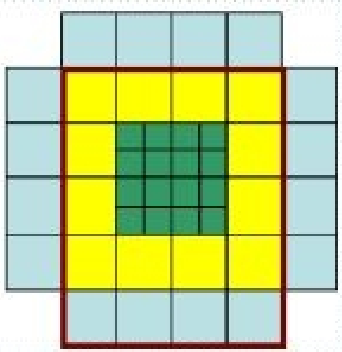
But! Apart from high quatum efficiency, linearity etc. one needs to know the radiation hardeness of the SiPM from different producers.

Other application – neutron detector for material studies.

PSD and ZDC

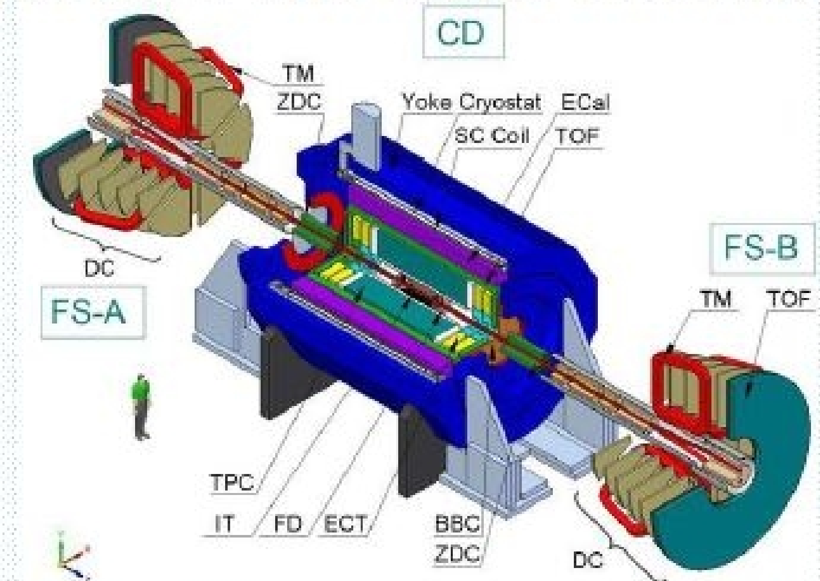
NA61 Projectile Spectator Detector

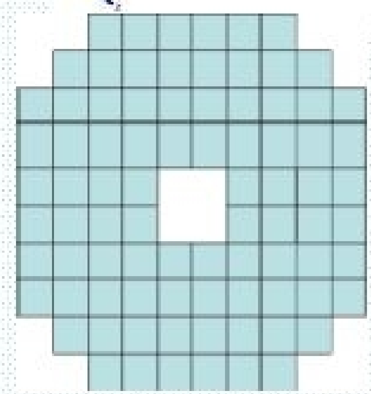


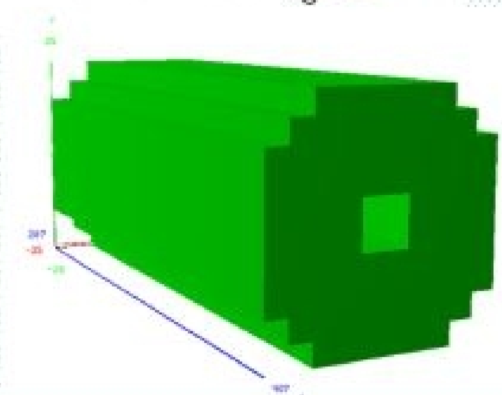


60 sandwiches in one module
16 inner modules of 10 x 10 x 120 cm^3
28 outer modules of 20 x 20 x 120 cm^3
Total weight ~ 17 tons, 17-25 m from target
No beam hole for intensity up to $2x10^5$ ions/sec
NA61 beam energy up to 150 AGeV

NICA MPD Zero Degree Calorimeter

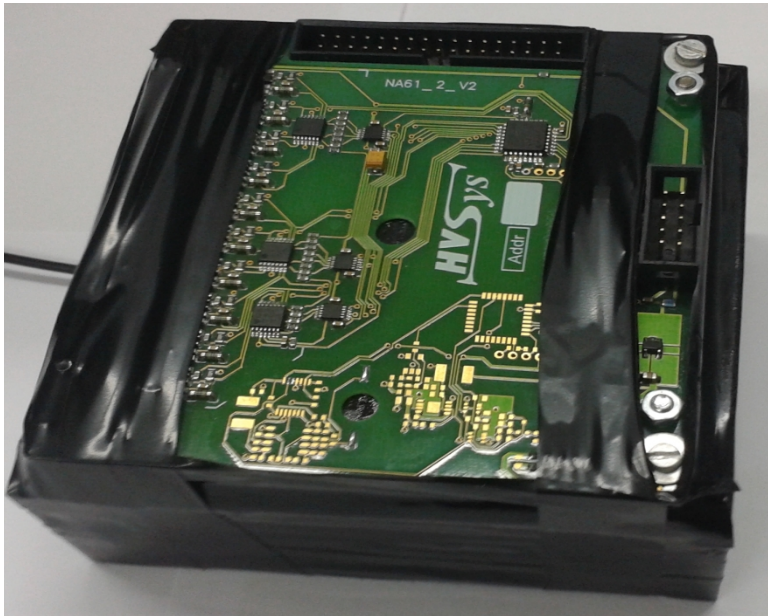


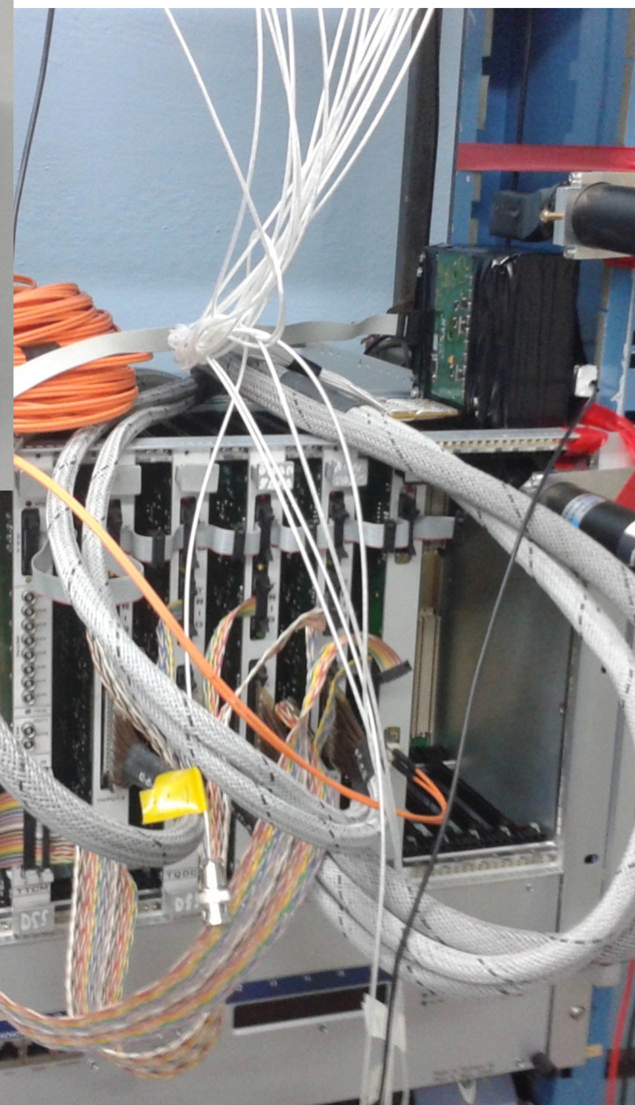


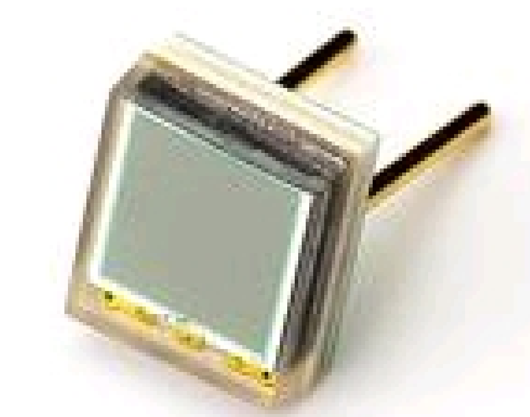


60 sandwiches in one module
16 modules of 5 x 5? x 120 cm^3
Total weight ~ 10 tons, 28 m from collision estimate
Beam hole (10x10 cm) for intensity up to $1x10^9$??? ions/sec
NICA beam energy up to $\sqrt{s_{NN}}$ =11GeV?(~ E_{beam}=63 AGeV)

SiPM based 10-channel prototype module

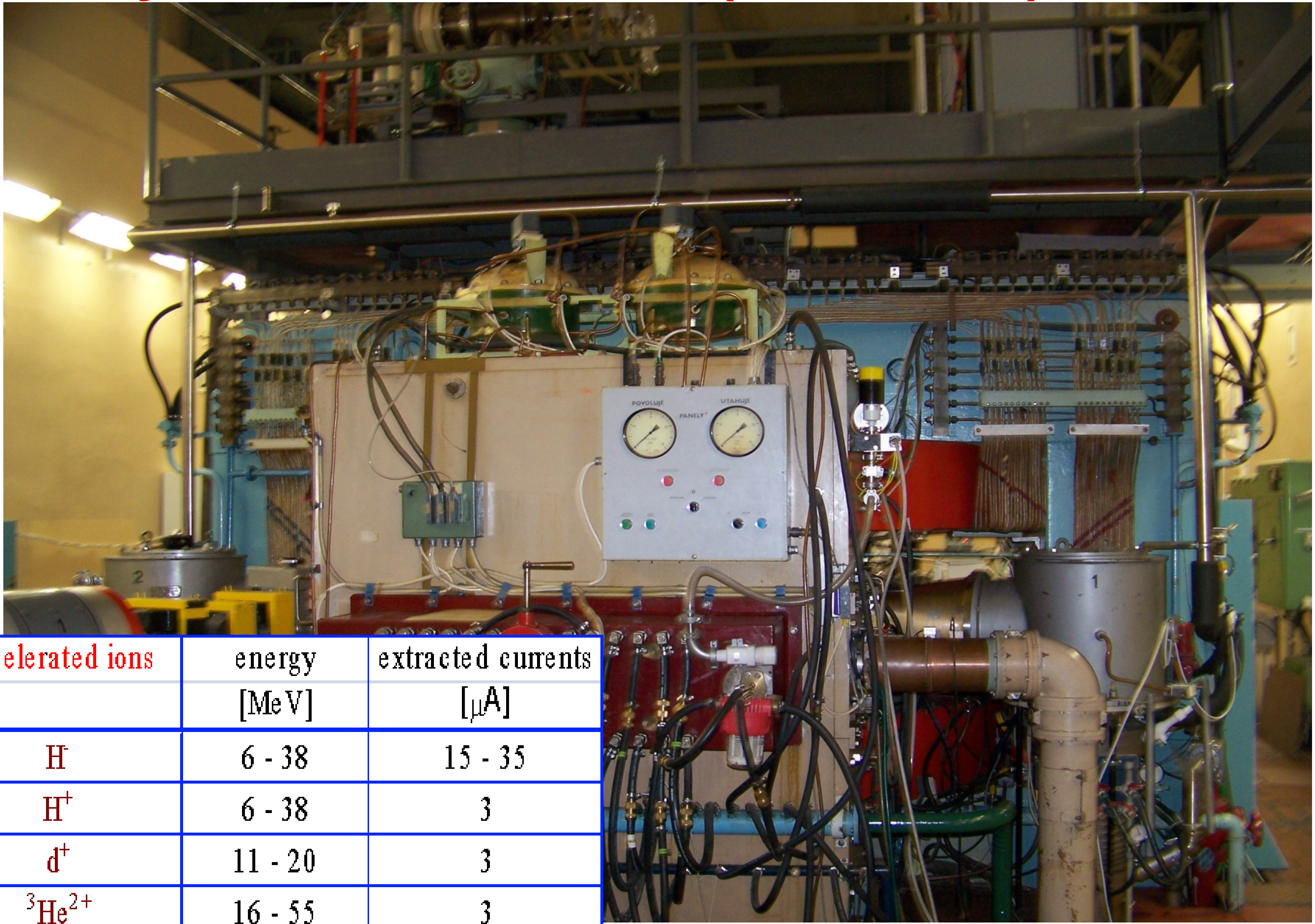






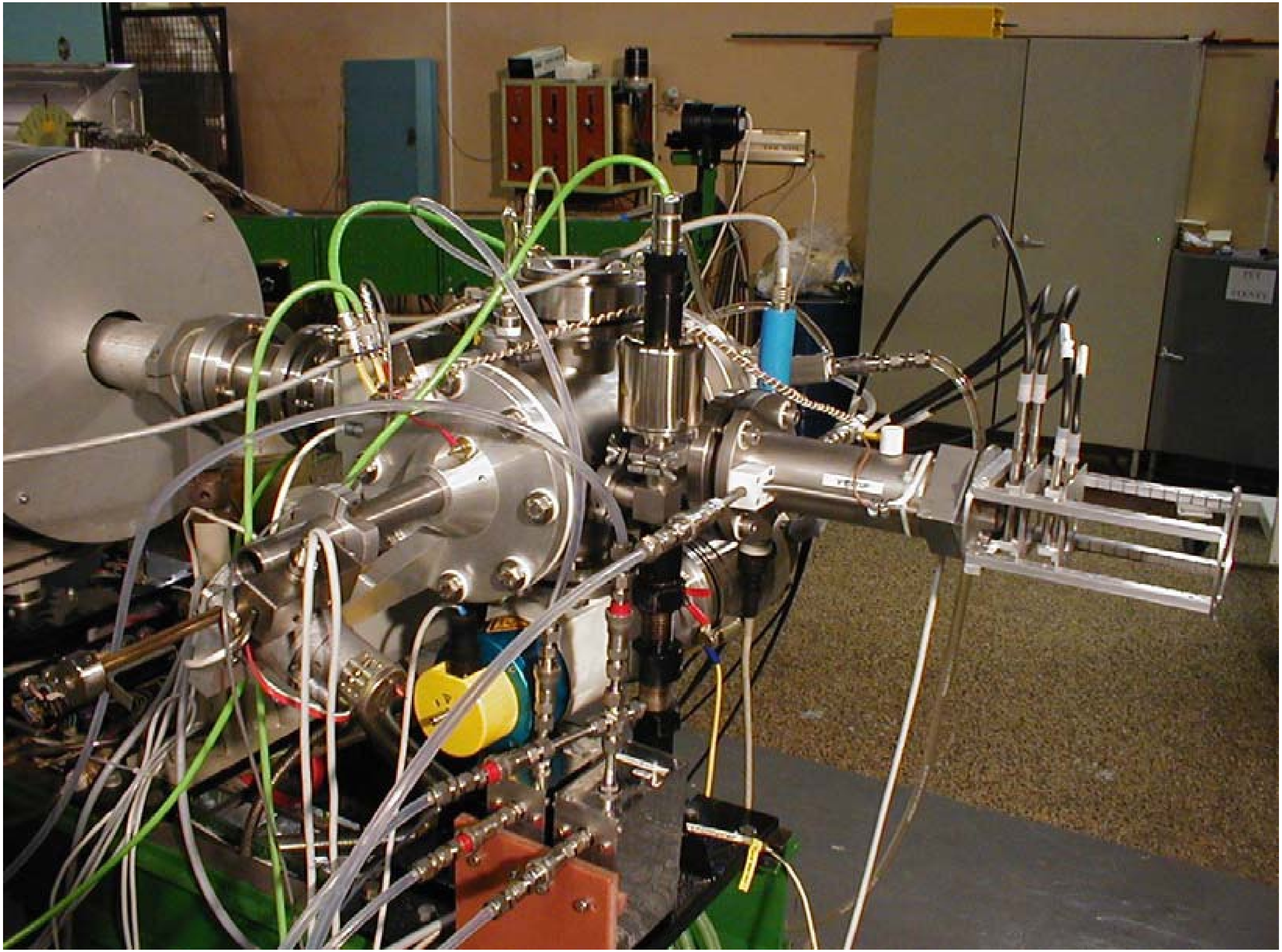
KETEK PM3350

Cyclotron U120M (NPI Rez)

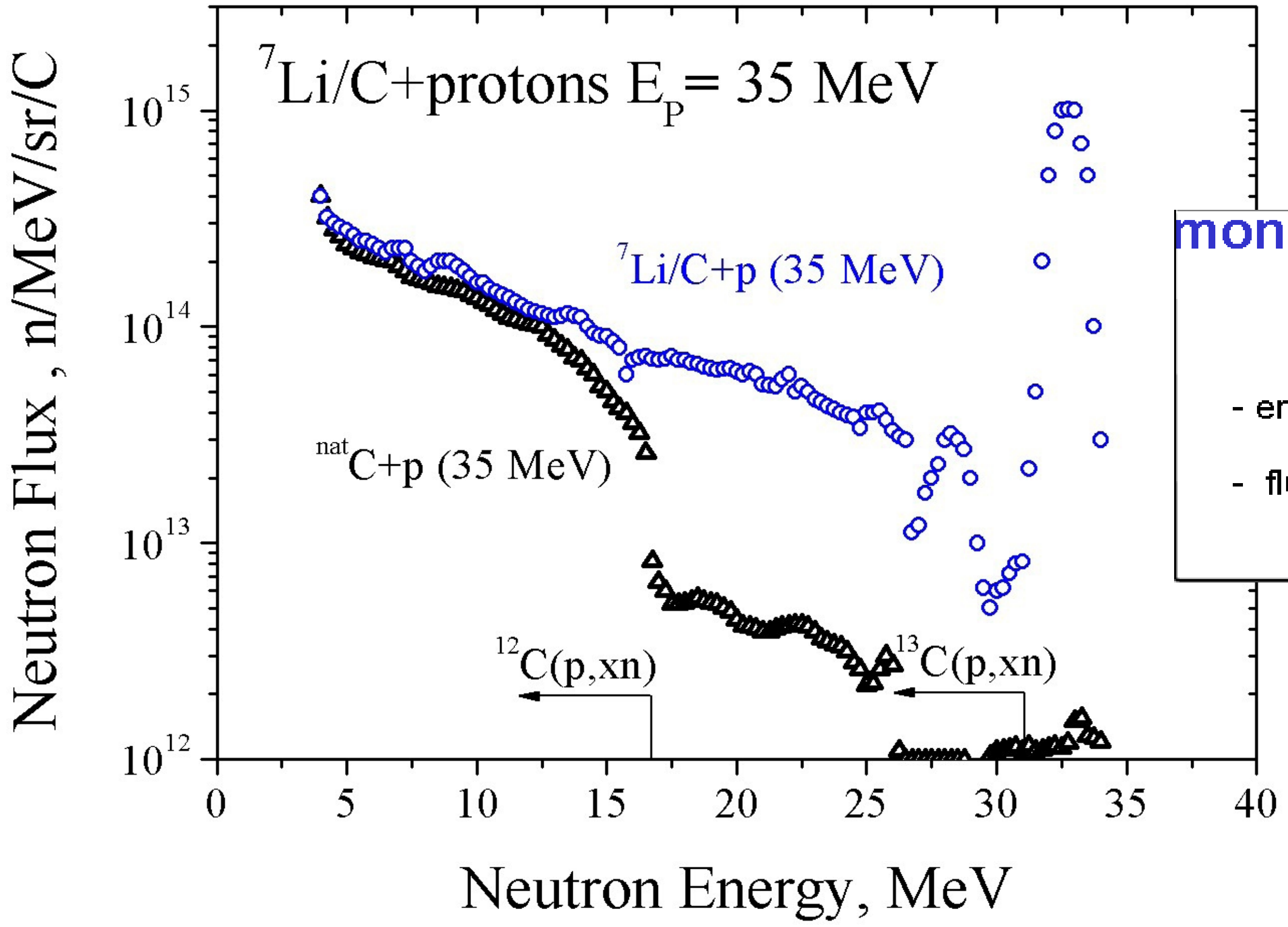


accelerated ions	energy [MeV]	extracted currents [μA]
H^-	6 - 38	15 - 35
H^+	6 - 38	3
d^+	11 - 20	3
$^3He^{2+}$	16 - 55	3
$^4He^{2+}$	22 - 40	3

Cyclotron U120M (fast neutrons)



Cyclotron U120M (p + D_2O)



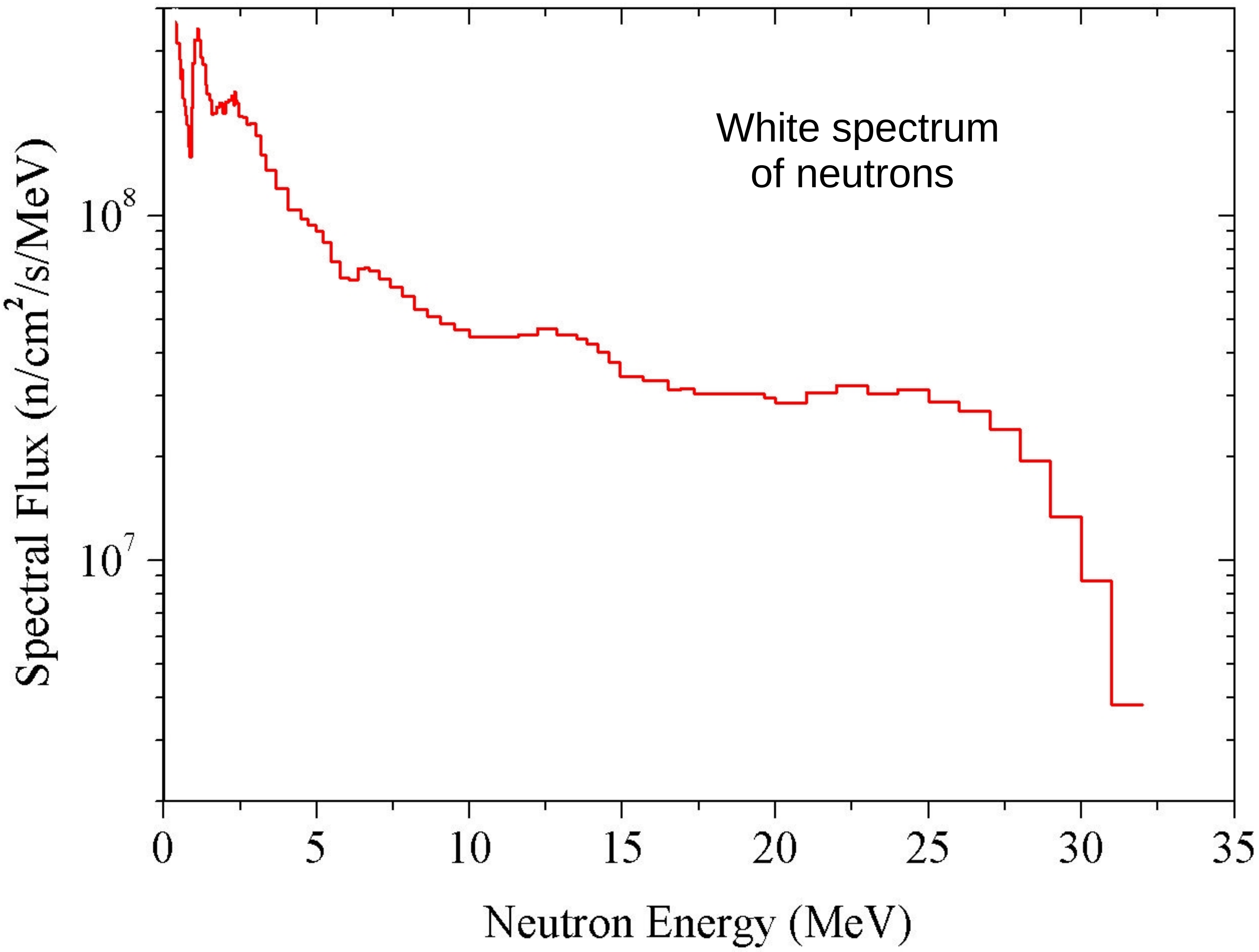
mono-energetic 20-37 MeV

Source reaction p+7Li

- energy range **20 - 37 MeV**
- flux density

3 10^9 n/cm²/s

Cyclotron U120M(p + Be)



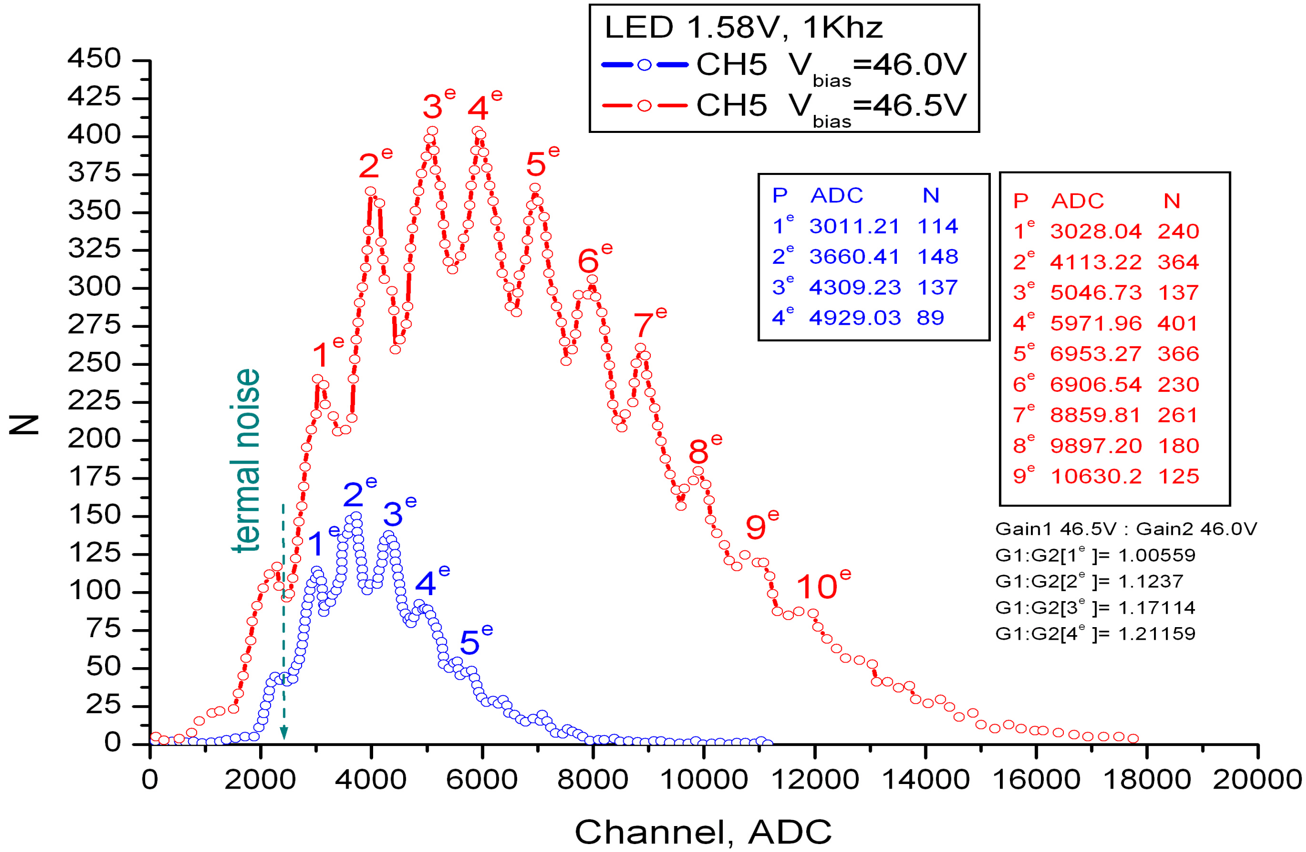
For source NG1
Maximum of Flux

~10^8 - 10^9 -
[n/cm^2/s]

For source NG2
Maximum of Flux

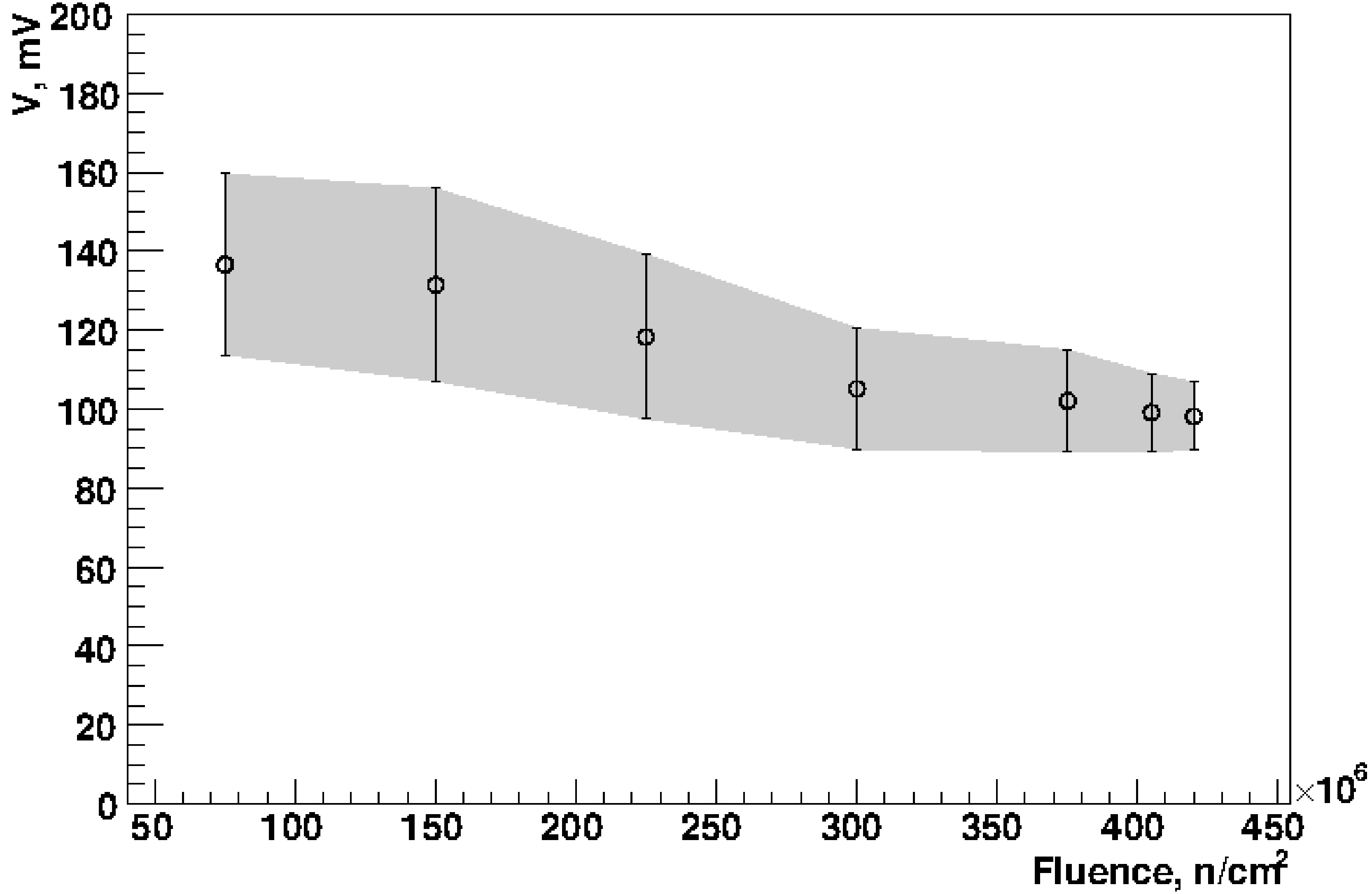
~10^{11} [n/cm^2/s]

Tests with LED before irradiation

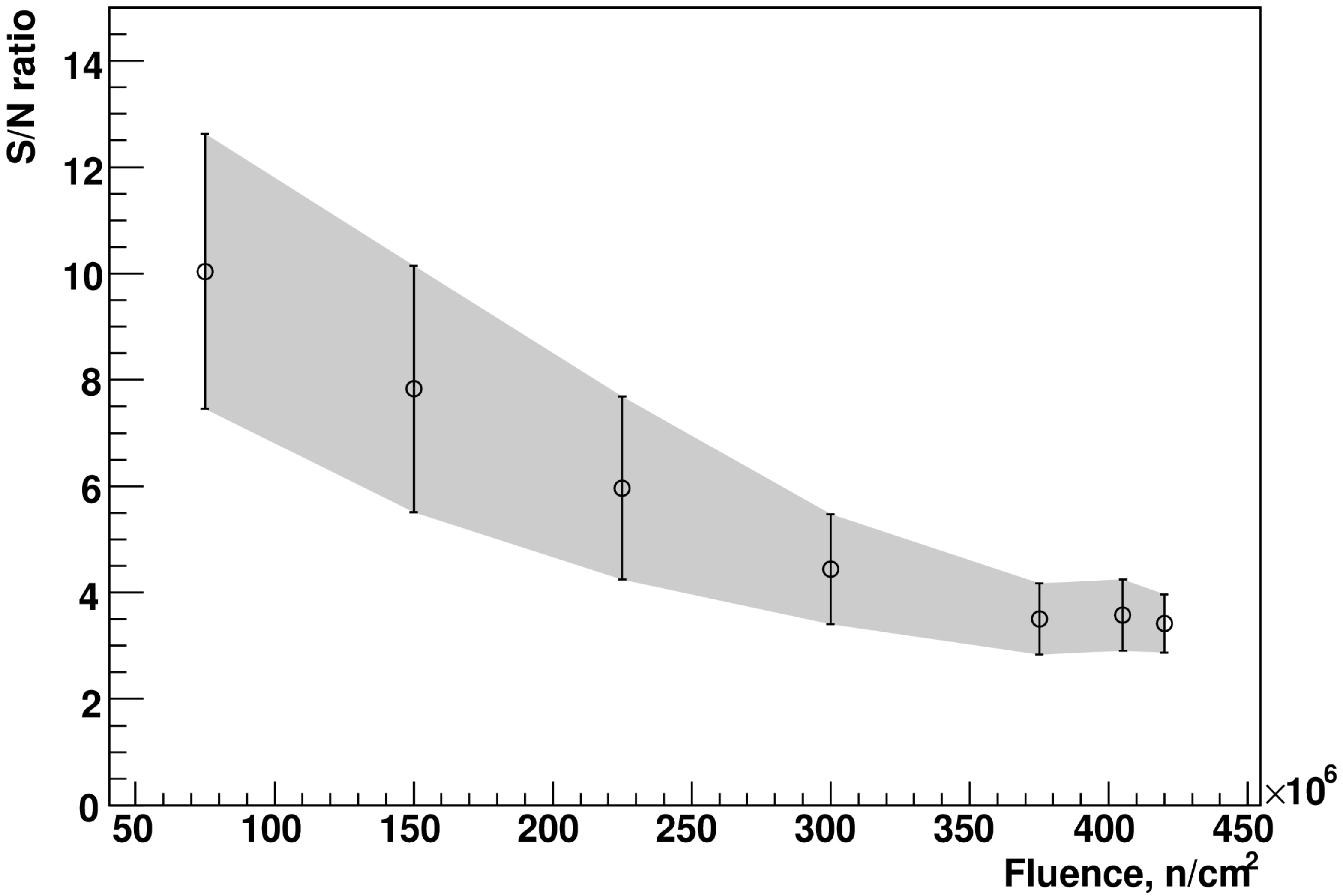


S.G.Reznikov et al., Performance studies of the PSD readout board prototype, CBM Progress Report 2015, GSI, Darmstadt, ISBN: 978-3-9815227-3-0, p.102.

SiPM signal as a function of fluence

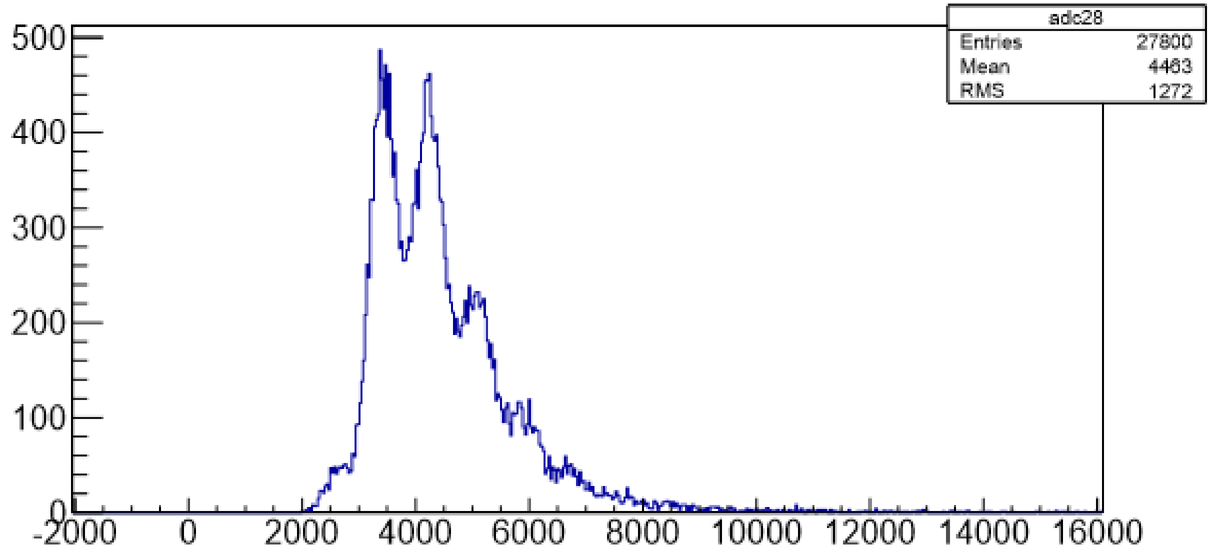


SiPM signal/noise ratio

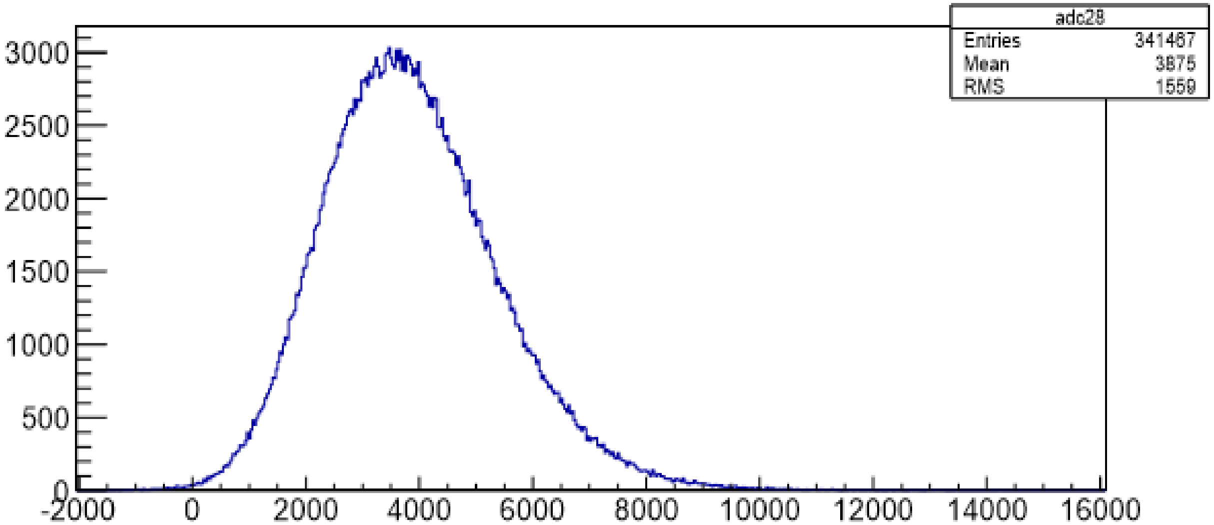


Beta source spectra

Before irradiation

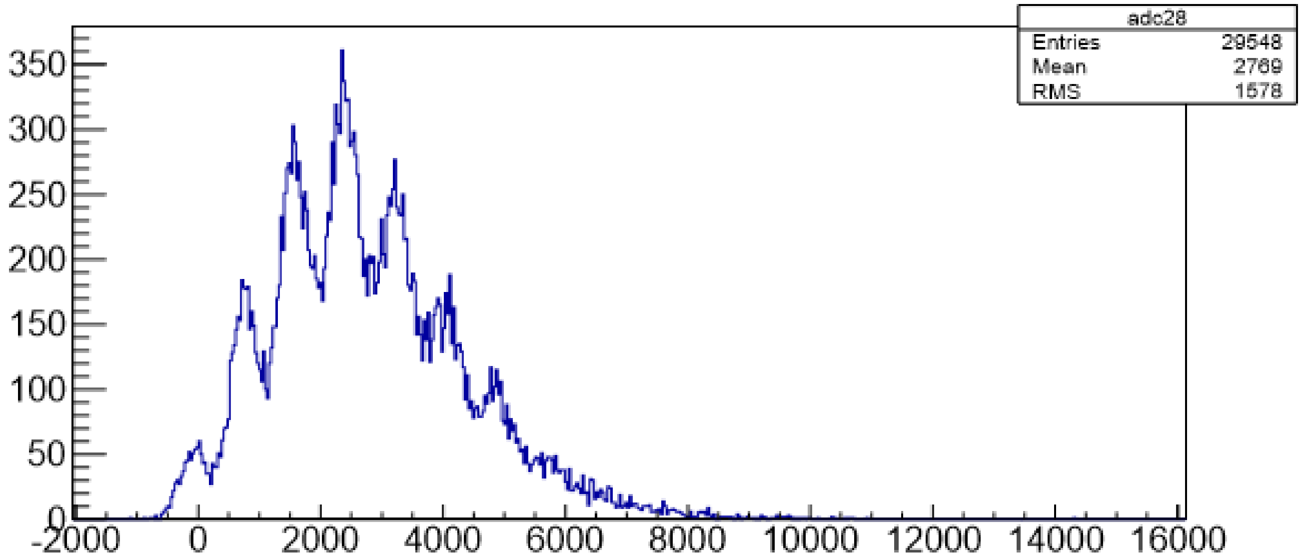


After ~4.2x10^8 n/cm2

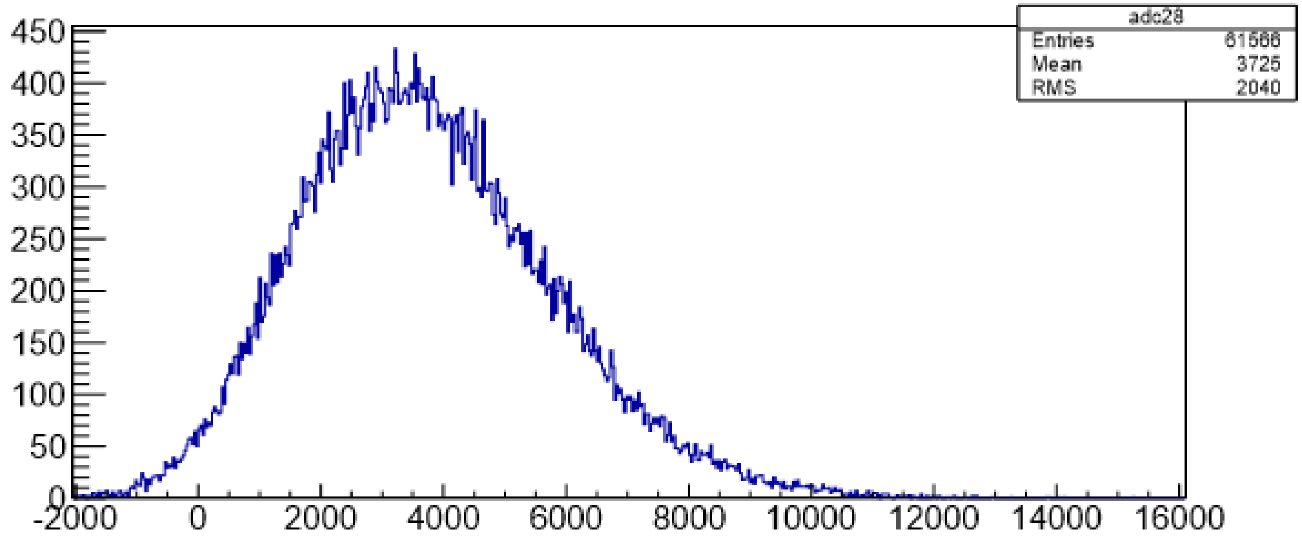


LED spectra

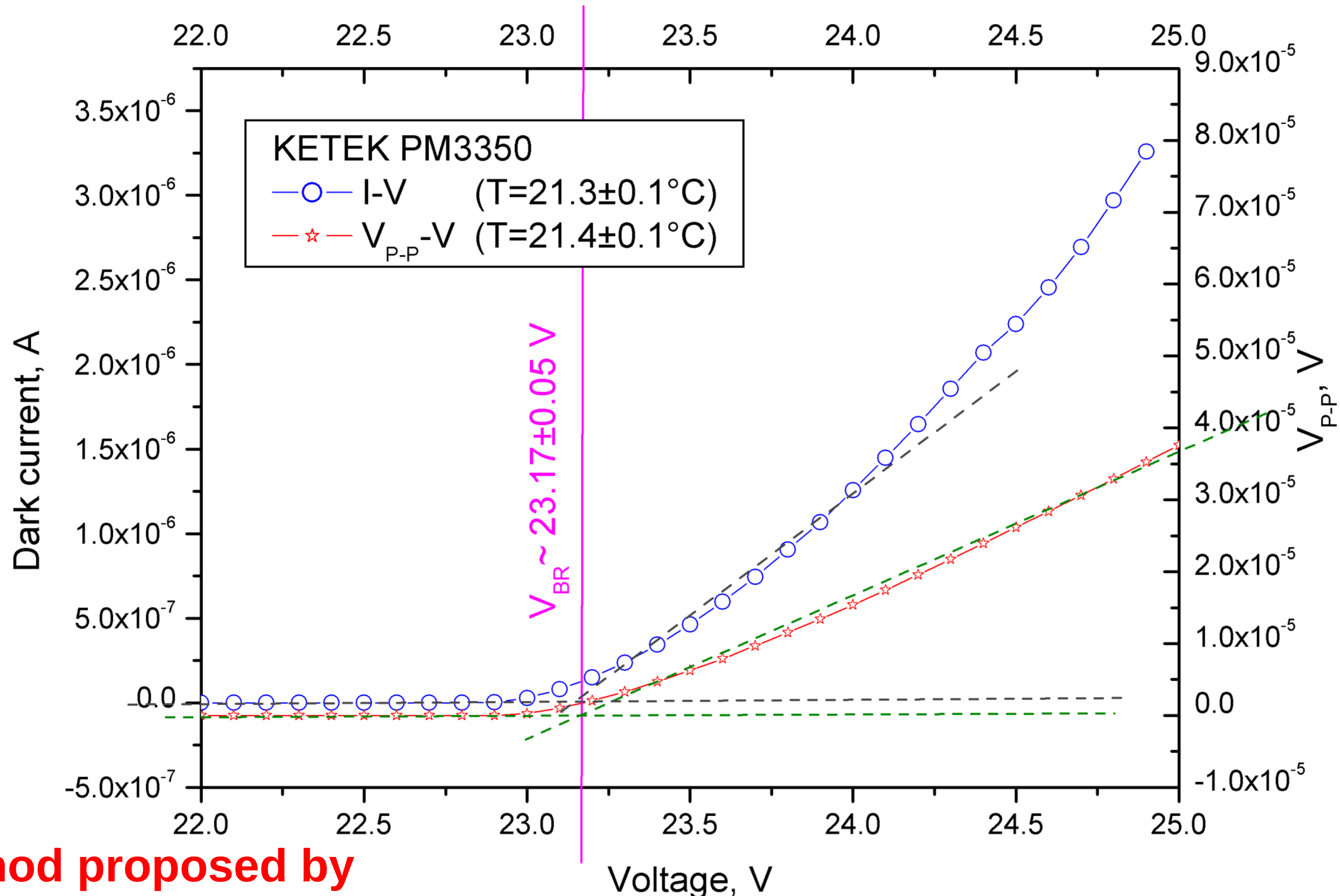
Before irradiation



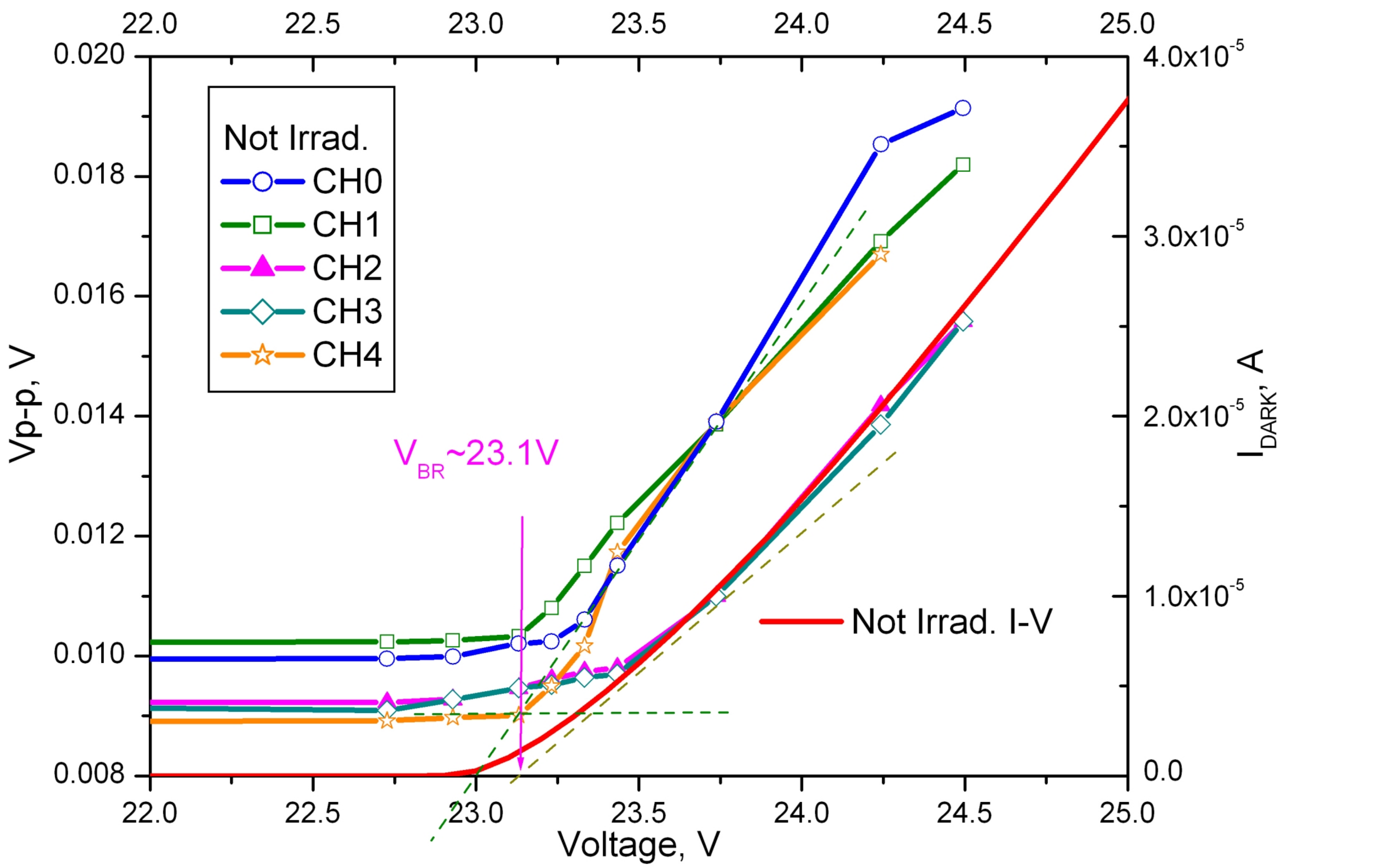
After ~4.2x10^{8} n/cm2



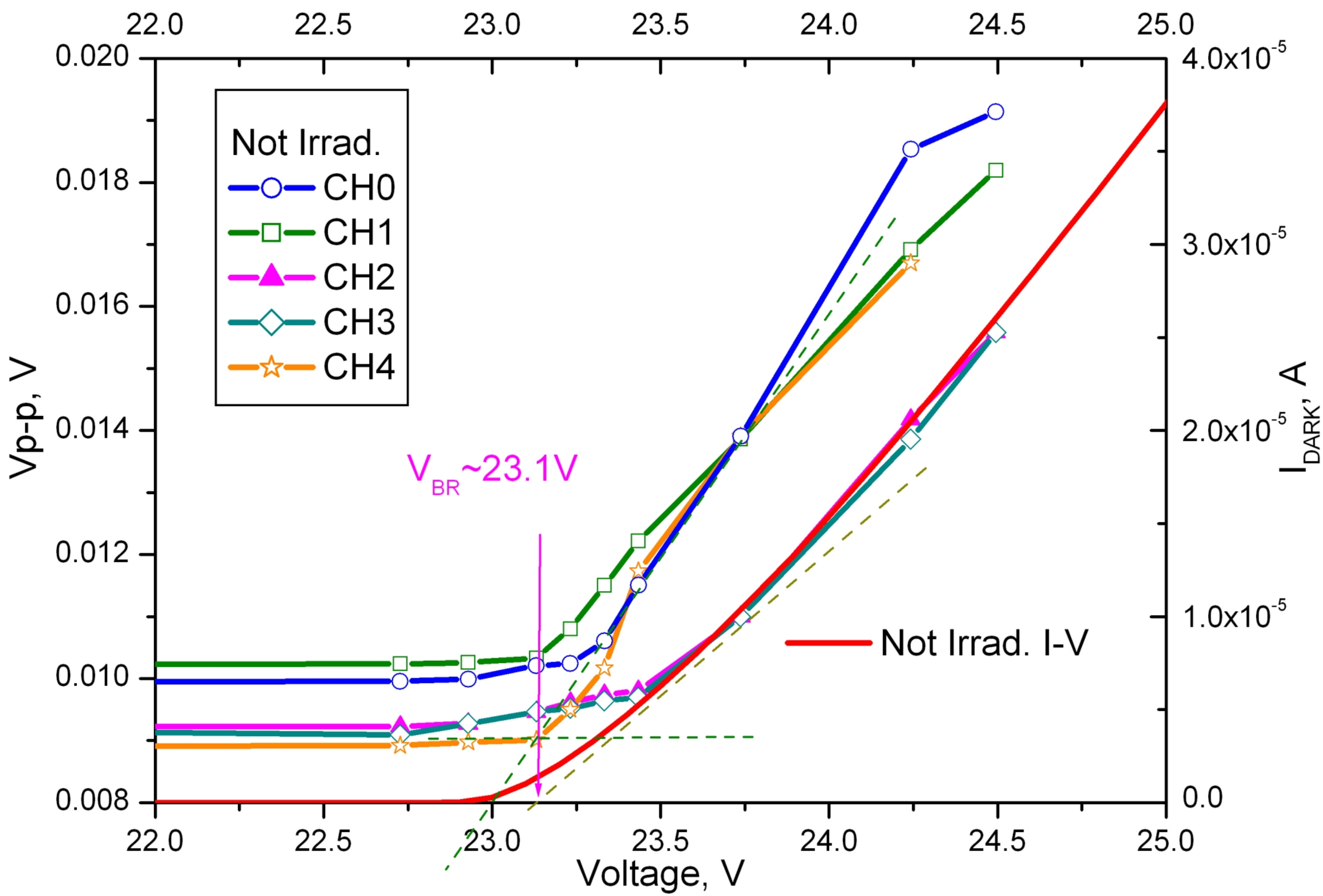
Vpp-V & I-V curves



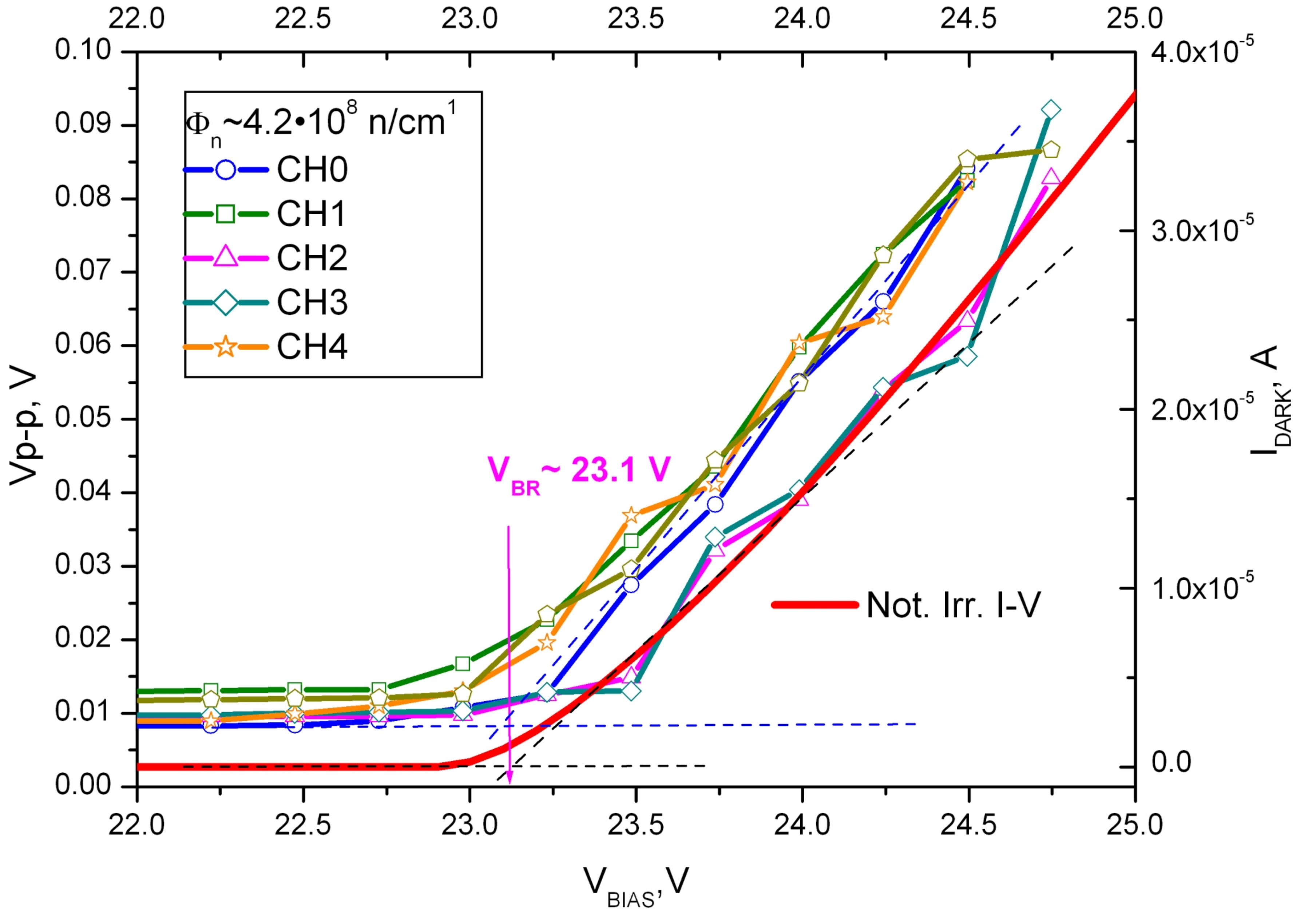
Method proposed by V.Kushpil



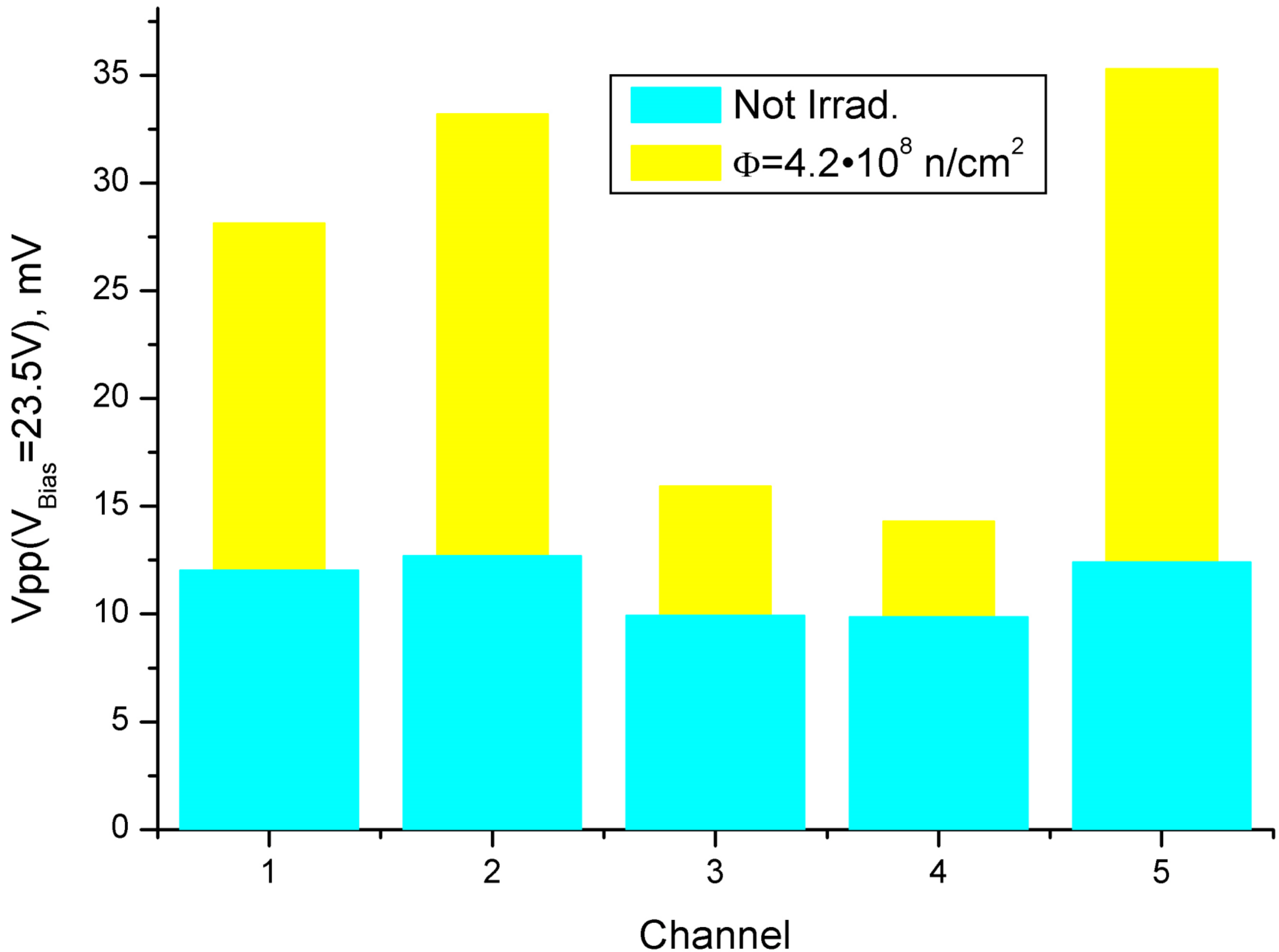
Not Irrad.
CH0
CH1
CH2
CH3
CH4
Not Irrad. I-V
V_BR~23.1V
Vp-p, V
I_DARK, A
Voltage, V
0.020
0.018
0.016
0.014
0.012
0.010
0.008
4.0x10^-5
3.0x10^-5
2.0x10^-5
1.0x10^-5
0.0
22.0
22.5
23.0
23.5
24.0
24.5
25.0



Not Irrad.
CH0
CH1
CH2
CH3
CH4
Not Irrad. I-V
V_BR~23.1V
Vp-p, V
I_DARK, A
Voltage, V
22.0
22.5
23.0
23.5
24.0
24.5
25.0
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.0
1.0x10^-5
2.0x10^-5
3.0x10^-5
4.0x10^-5



22.0
22.5
23.0
23.5
24.0
24.5
25.0
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
4.0x10^-5
3.0x10^-5
2.0x10^-5
1.0x10^-5
0.0
Φn~4.2•10^8 n/cm^1
CH0
CH1
CH2
CH3
CH4
VBR~ 23.1 V
Not. Irr. I-V
Vp-p, V
IDARK, A
VBIAS,V



Not Irrad.
Φ=4.2•10^8 n/cm^2
Vpp(V_Bias=23.5V), mV
0
5
10
15
20
25
30
35
1
2
3
4
5
Channel

Conclusions

1. KETEK PM3350 and corresponding electronics behave good enough till fluence of about $4.2x10^8$ n/cm2.
2. The decreasing of signal amplitude by a factor of 1.4 could be explained by uncontrolled temperature drift at least partially.
3. The main effect of neutron irradiation is noise increased by a factor of 2-3 depending on bias voltage. Again it could be explained by temperature rise, but only to some extent. The increased noise also spoiled resolution.
4. The proposed procedure of estimation of breakdown voltage by measuring dependence of noise Vpp (or Vrms as alternative) vs bias voltage seems to be adequate for practical use. No changes of breakdown voltages were observed after irradiation to the fluence mentioned above.

Status and plans

1. KETEK PM3350 and corresponding electronics have been irradiated up to 10^{10} n/cm2. The data analysis is in progress

2. The electronic board with 16 KETEK PM3350 has been developed and produced at VBLHEP JINR. It will be tested at ITS at Nuclotron.

3. New electronic board with 16 Hamamatsu S12572-010P is under consideration. Hopefully, it will be more tolerant to the neutron fluence.

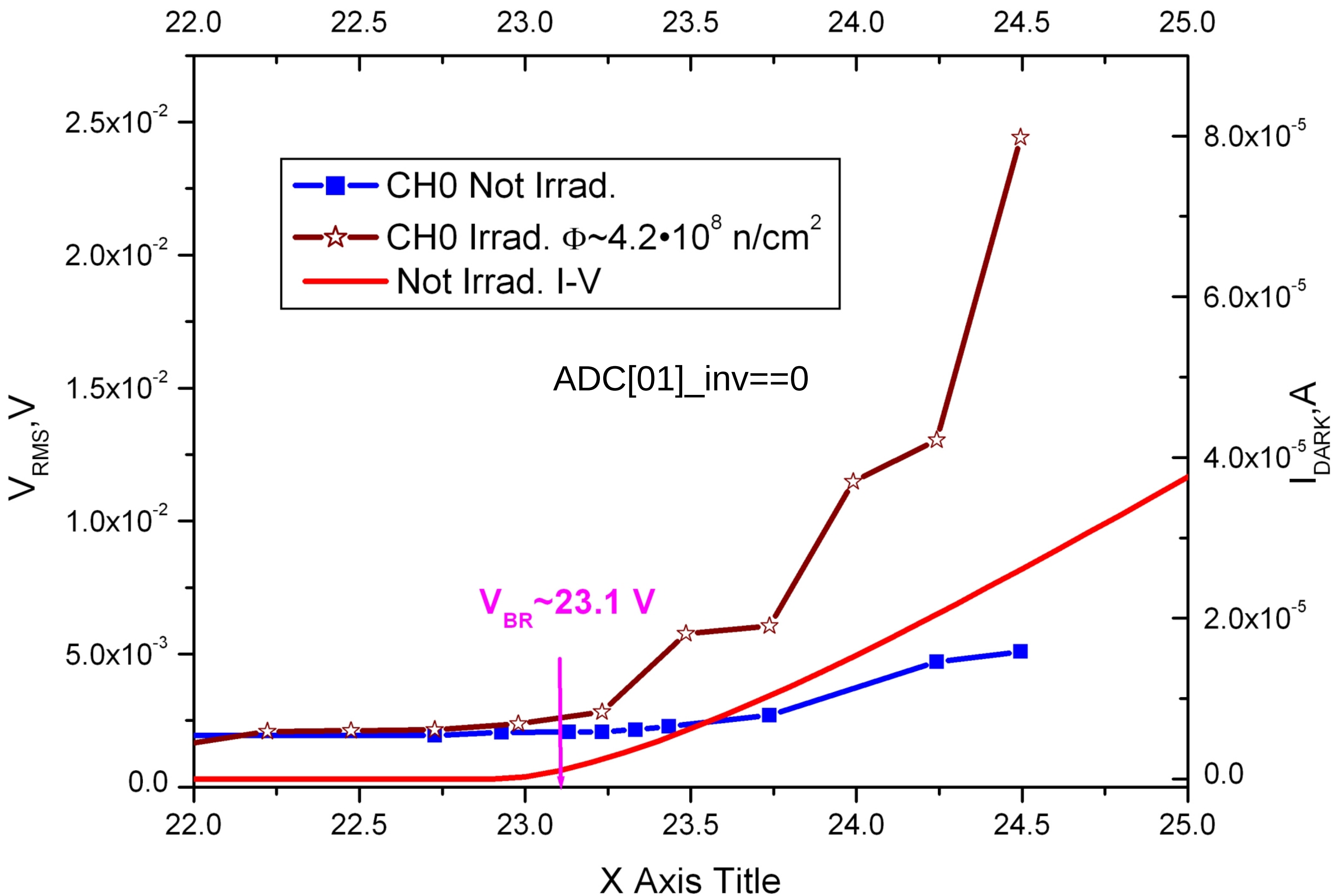
Possible application:

-neutron hodoscope for material studies

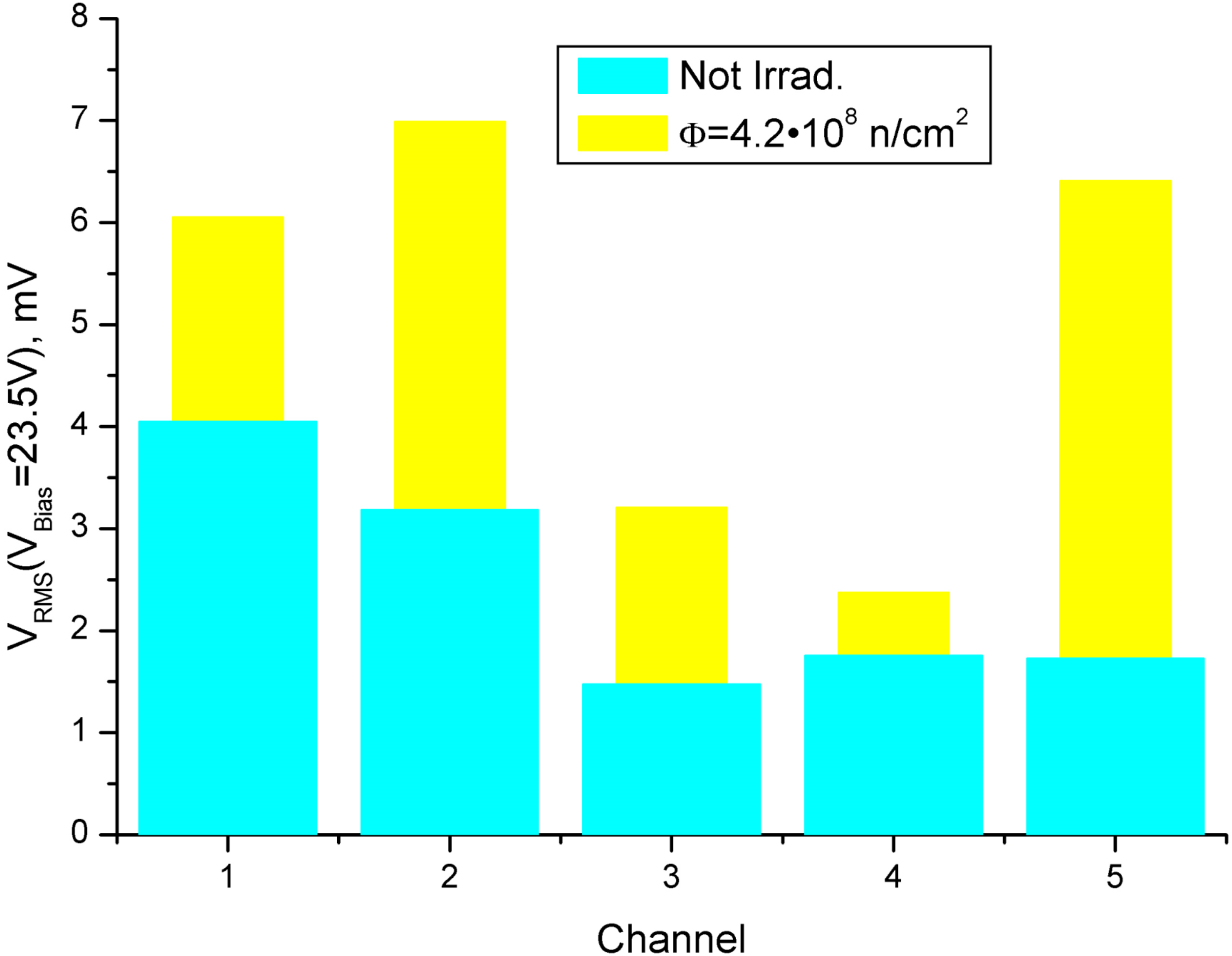
-detectors for the beam polarimetry

-forward detector for reaction plane determination

Thank you
for your attention!

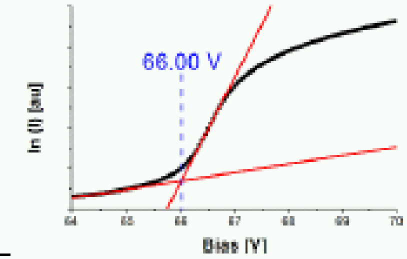
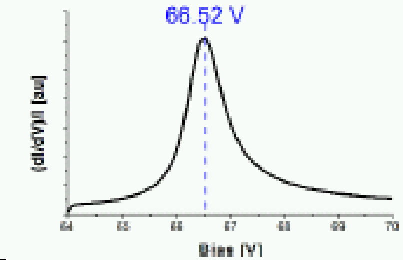
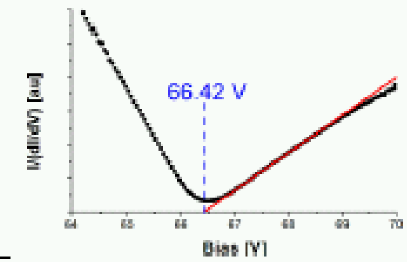
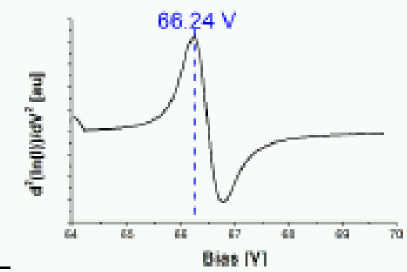
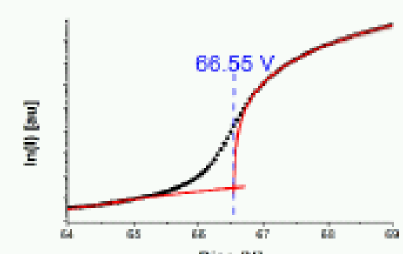


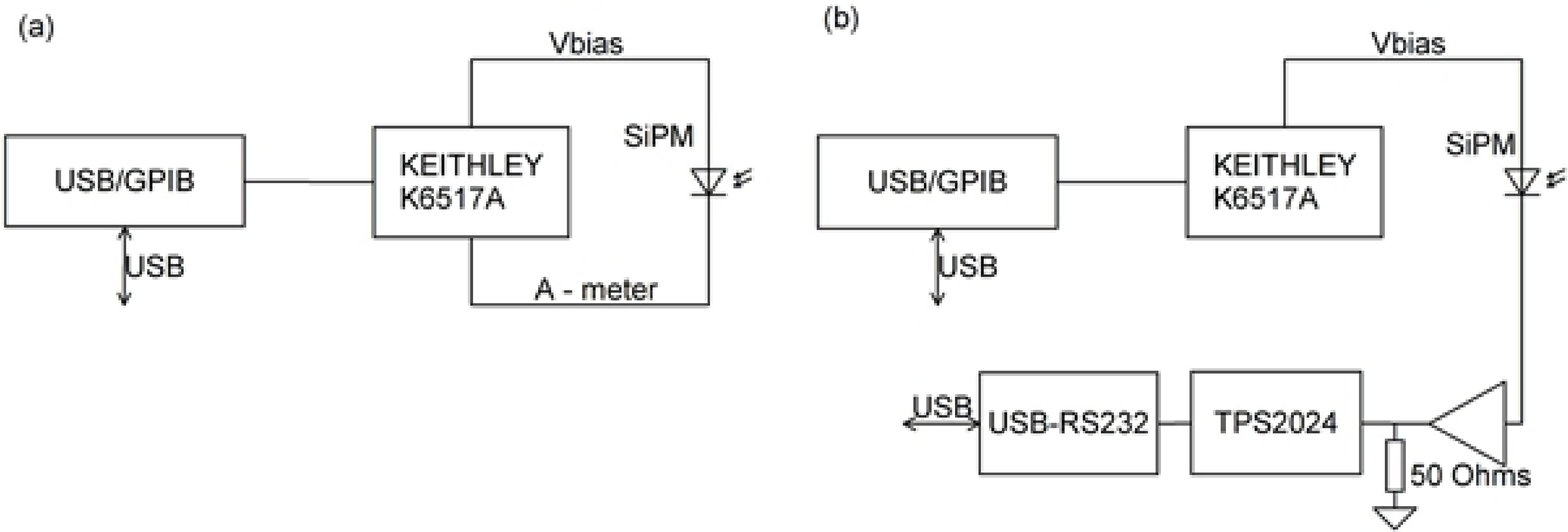
22.0
22.5
23.0
23.5
24.0
24.5
25.0
2.5x10^-2
2.0x10^-2
1.5x10^-2
1.0x10^-2
5.0x10^-3
0.0
8.0x10^-5
6.0x10^-5
4.0x10^-5
2.0x10^-5
0.0
CH0 Not Irrad.
CH0 Irrad. Φ~4.2•10^8 n/cm^2
Not Irrad. I-V
ADC[01]_inv==0
V_BR~23.1 V
V_RMS, V
I_DARK, A
X Axis Title



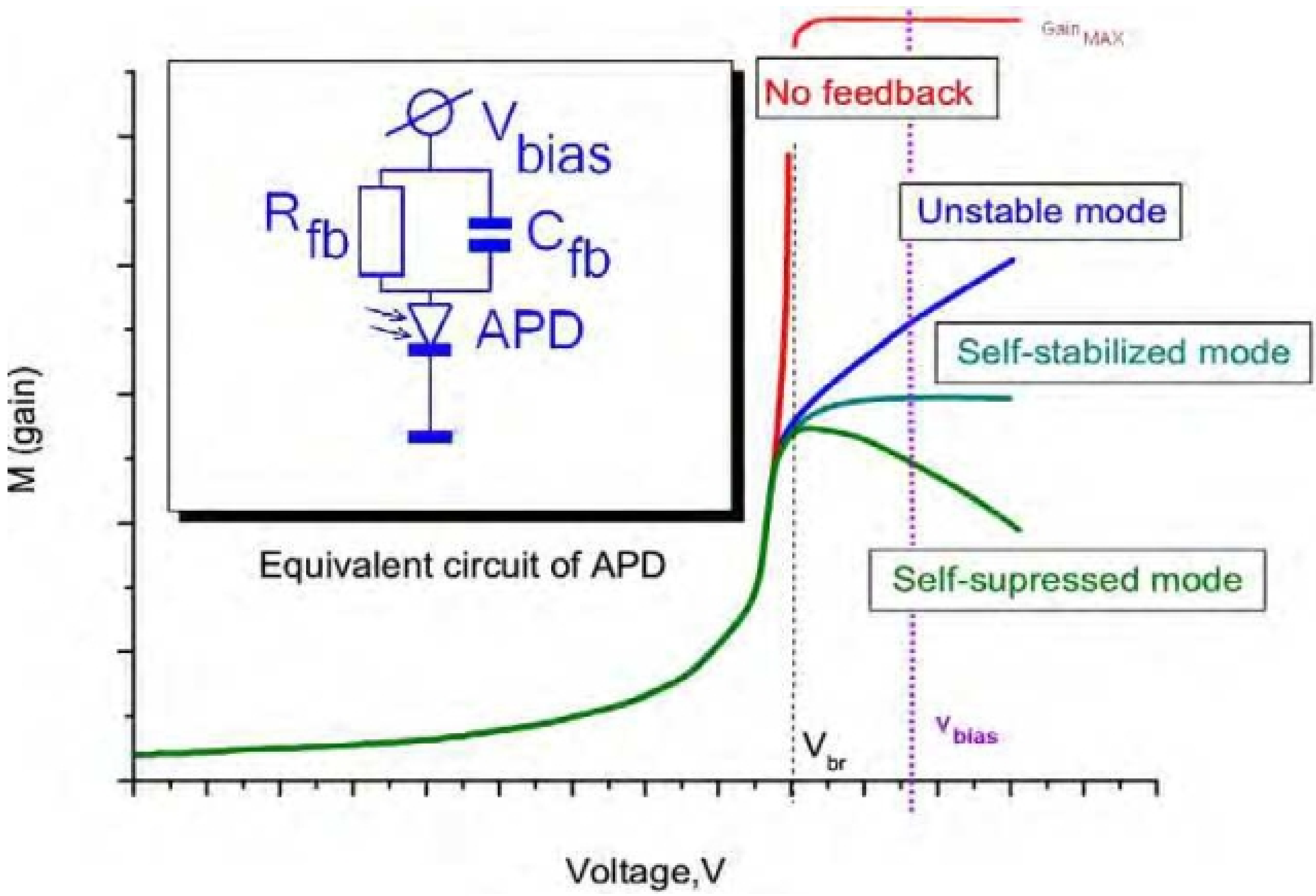
Not Irrad.
Φ=4.2•10^8 n/cm^2
$V_{RMS}(V_{Bias}$=23.5V), mV
Channel
0
1
2
3
4
5
6
7
8
1
2
3
4
5

Table 1: Known DC methods to determine the SiPM breakdown voltage from a real I-V curve

Tangent	Linear fitted "baseline" and tangent drawn to $ln(I)$	Intercept of tangent and the "baseline"	
Relative derivative	$\frac{d}{dV} ln(I)$ $= I'/I$	Position of the maximum	
"Inverse" relative derivative	$1/\frac{d}{dV} ln(I)$ $= I/I'$	Intercept of the x-axis and the fitted line	
Second derivative	$\frac{d^2}{dV^2} ln(I)$	Position of the maximum	
Parabolic fitting	Linear fitted "baseline" and parabola fitted to I	Intercept of the fitted parabola and the "baseline" on semi-log scale	



(a)
Vbias
SiPM
USB/GPIB
KEITHLEY
K6517A
USB
A - meter
(b)
Vbias
SiPM
USB/GPIB
KEITHLEY
K6517A
USB
USB
USB-RS232
TPS2024
50 Ohms



Gain MAX
No feedback
V bias
R fb
C fb
APD
Unstable mode
Self-stabilized mode
M (gain)
Equivalent circuit of APD
Self-supressed mode
V br
V bias
Voltage,V