Status of APD development

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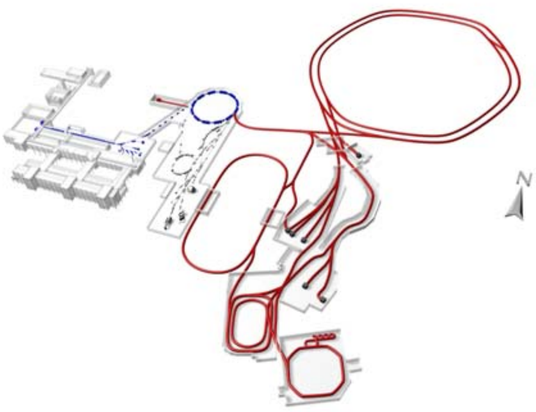


What has been done so far?

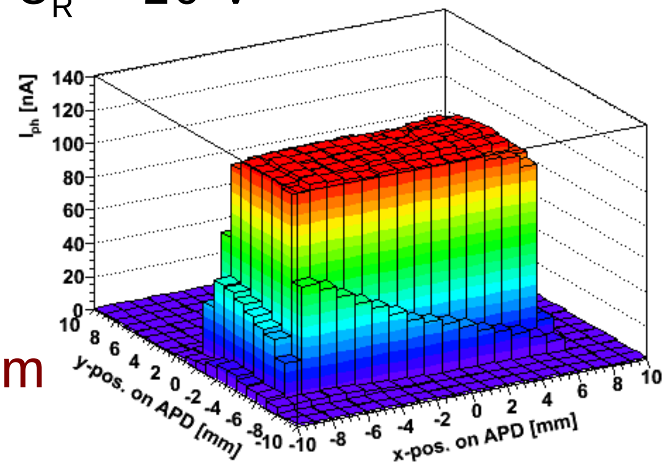
- Measurement of Gain-Surface uniformity
- Measurement of conversion layer thickness
- Measurement of gain and dark current

Temperature dependent:

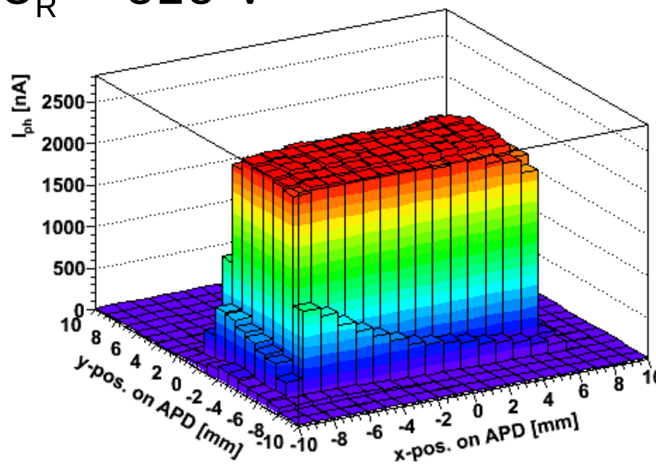
- Measurement of gain / dark current
  - Evaluation of fit functions
- Measurement of temperature coefficient

Measured at room temperature: I(x,y)-scan of APD surface

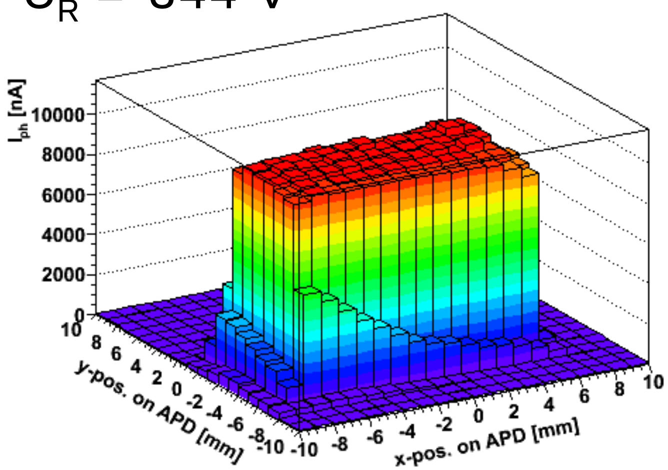
U_R = 20 V



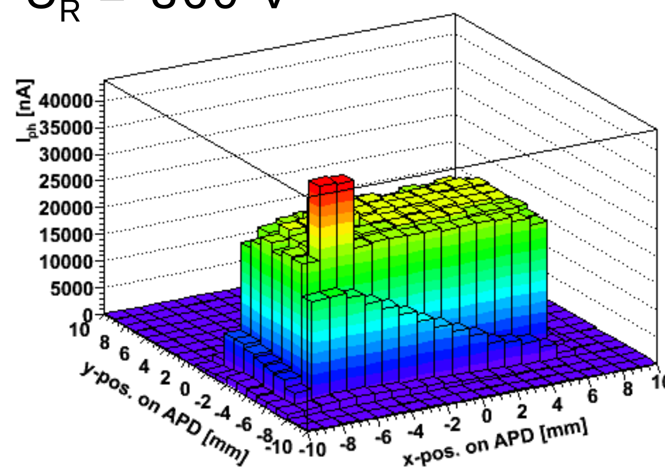
U_R = 325 V



U_R = 344 V



U_R = 360 V



Used for determination of conversion layer thickness d_{conv}

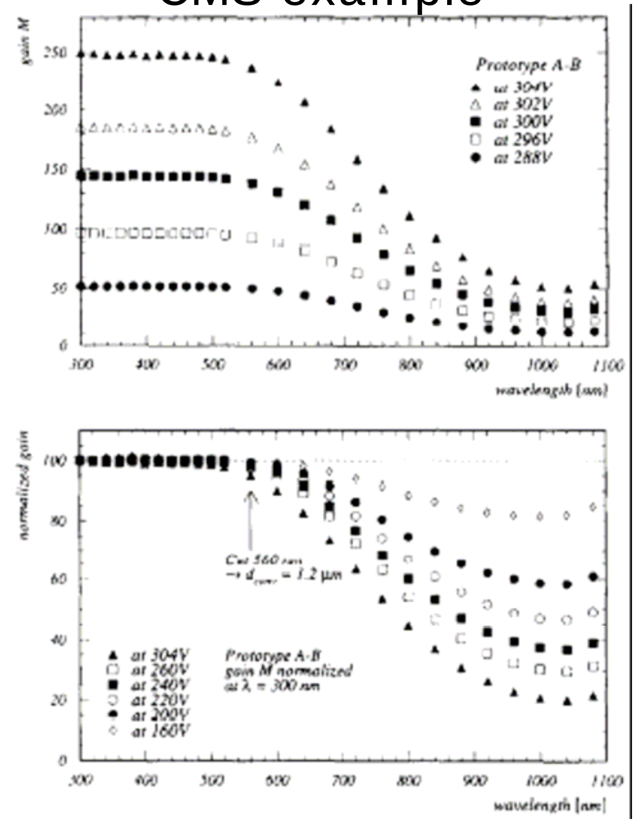
- For light absorbed before conversion layer:
  Gain is constant!
- Gain decreases for light absorbed inside avalanche region

Method:

- Definition of cut-off wavelength:
  λ-value where gain is no longer stable
- Knowledge of absorption coefficient $\alpha(\lambda)$
- Calculation of average penetration depth:

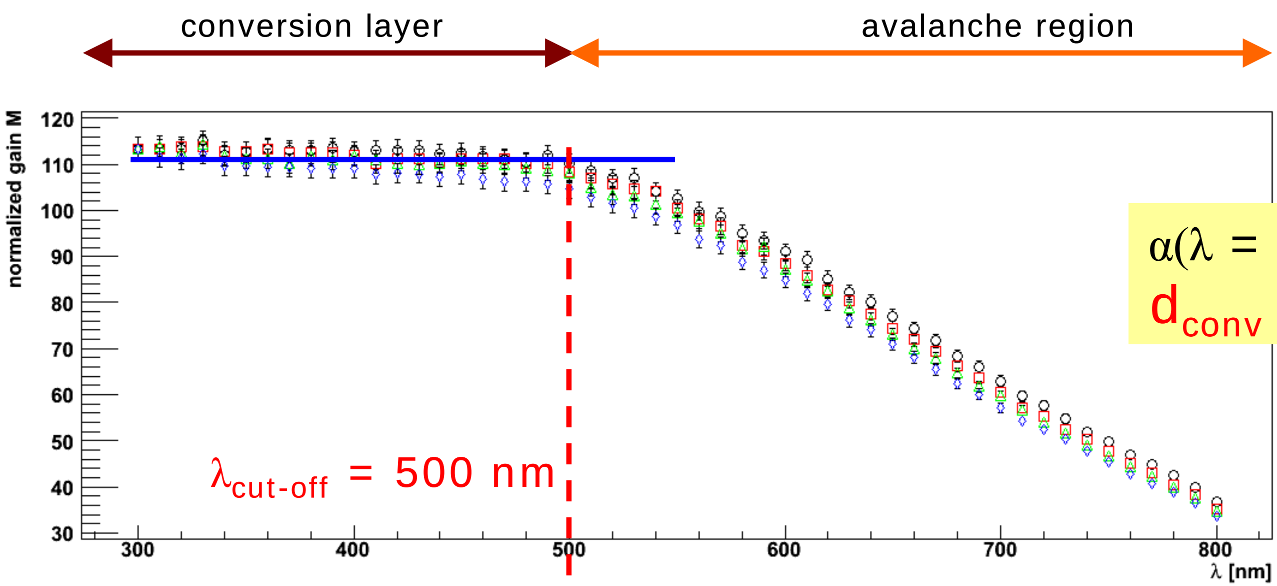
$$1/\alpha(\lambda) \equiv d_{conv}$$

CMS example



Ref: Th. Kirn et al.,'*Wavelength dependence of avalanche photodiode (APD) parameters*', NIM A 387 (1997) 202-204

Measurement example for PANDA-APDs



$\alpha(\lambda = 500\ nm)$: $1.11 \cdot 10^4\ cm^{-1}$

$d_{conv} = 0.09\ \mu m$

Actual APD type:

$\alpha(\lambda = 540\ nm)$: $7.05 \cdot 10^3\ cm^{-1}$

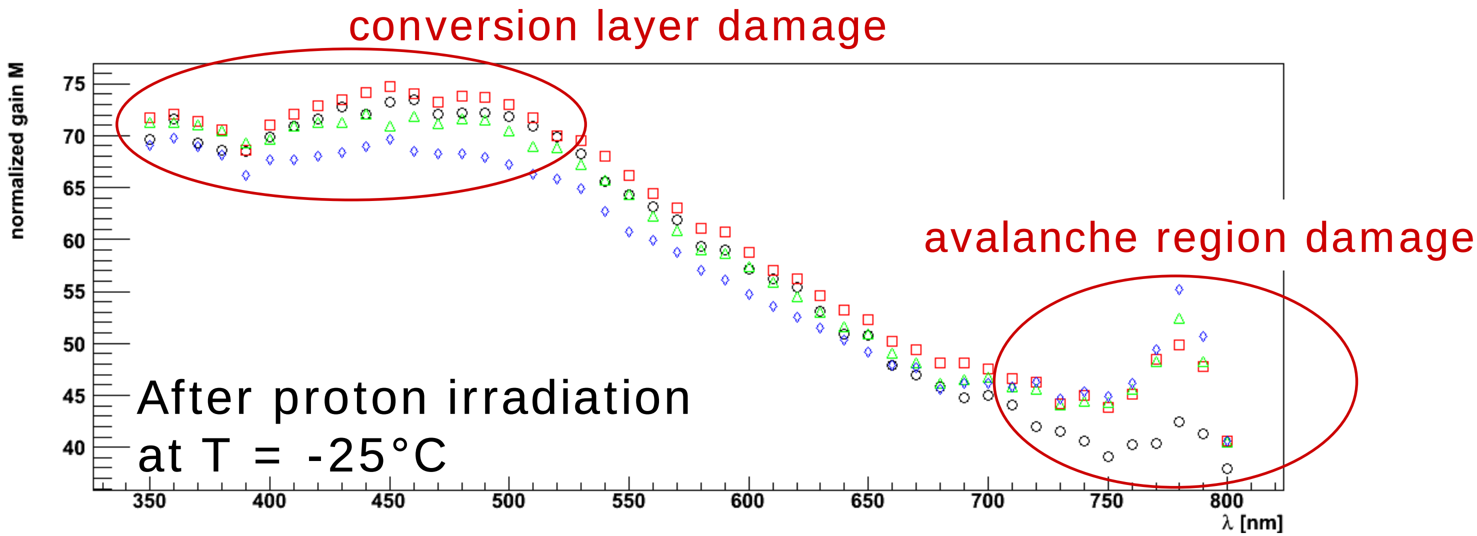
$d_{conv} = 1.2\ \mu m$

Upcoming questions:

- Does any kind of irradiation influence the M(λ) behavior?
- Maybe measurement of normalized gain M(λ) contains a reference to regions in which radiation damage occurs?

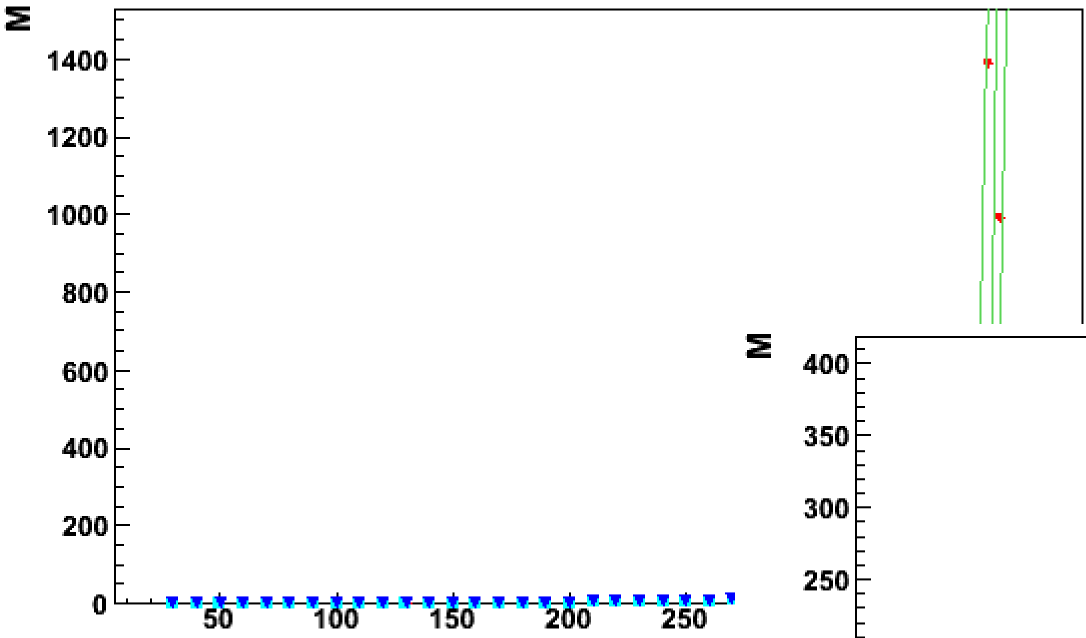
Answer:

- Comparison of normalized M(λ) before and after irradiation!

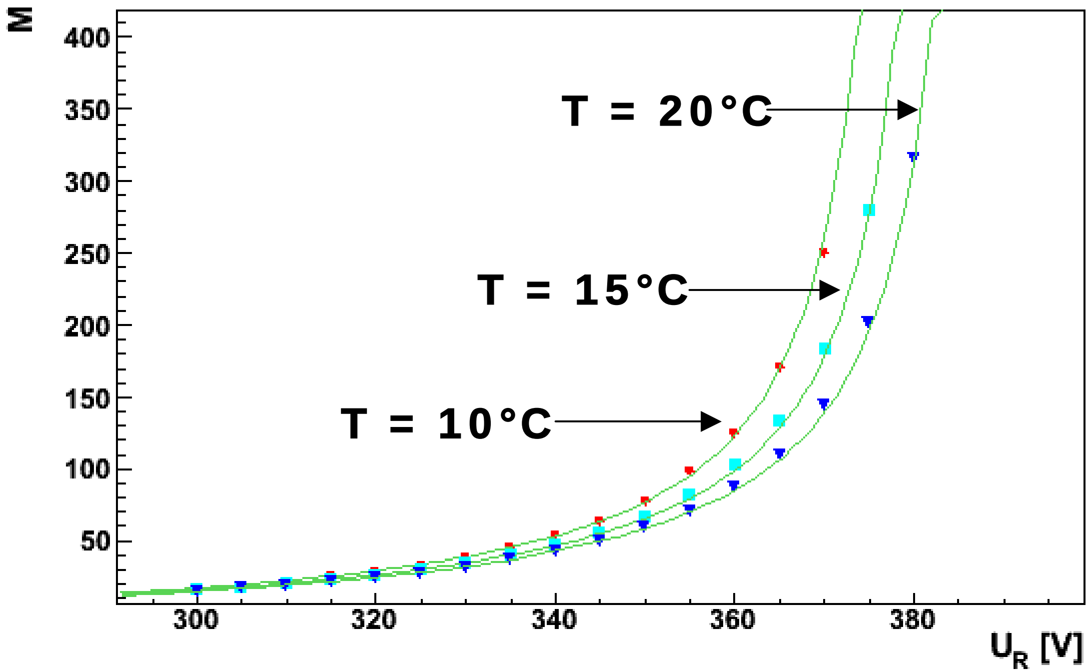


Temp. dependent APD properties M(T)

Internal gain M: M(U,T)



Relevant gain region:
M = 50-200

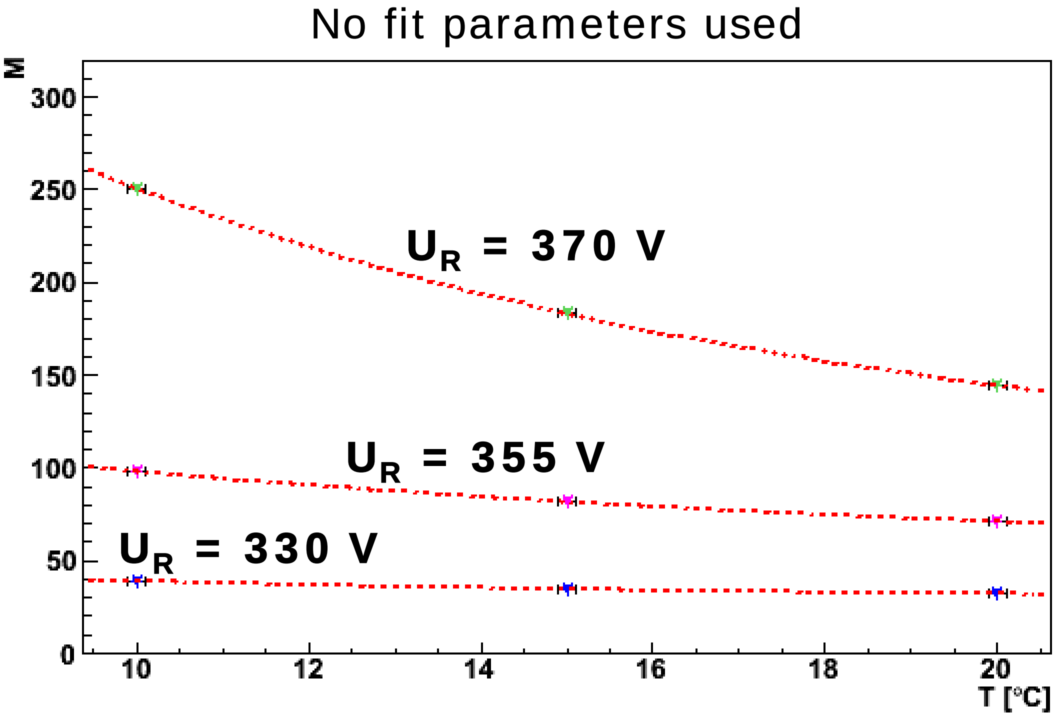


Modified Miller-Formula:

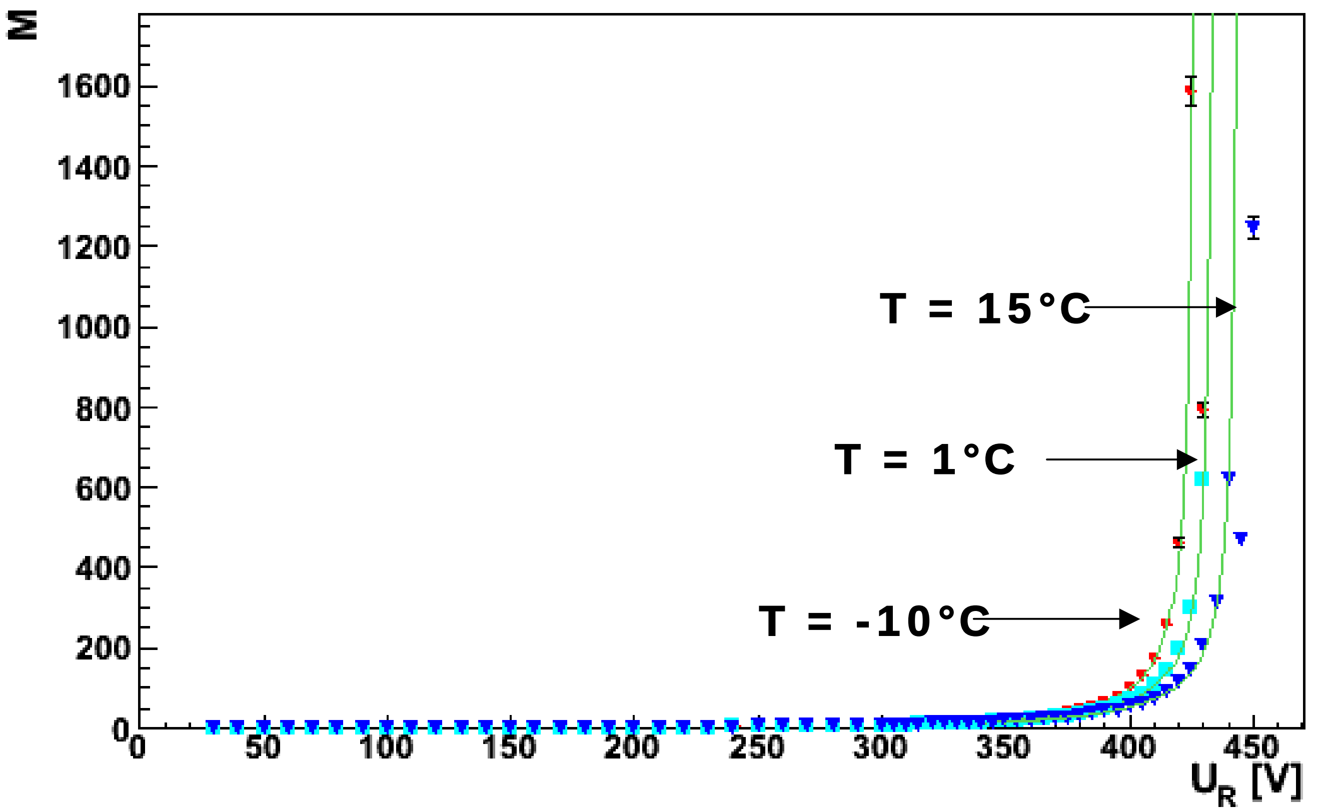
$$M(U) = \frac{1}{1 - \left(\frac{U_R}{U_{Br}}\right)^n}$$

<u>Ref:</u> S.L.Miller, Phys. Rev. 99 (4), 1955

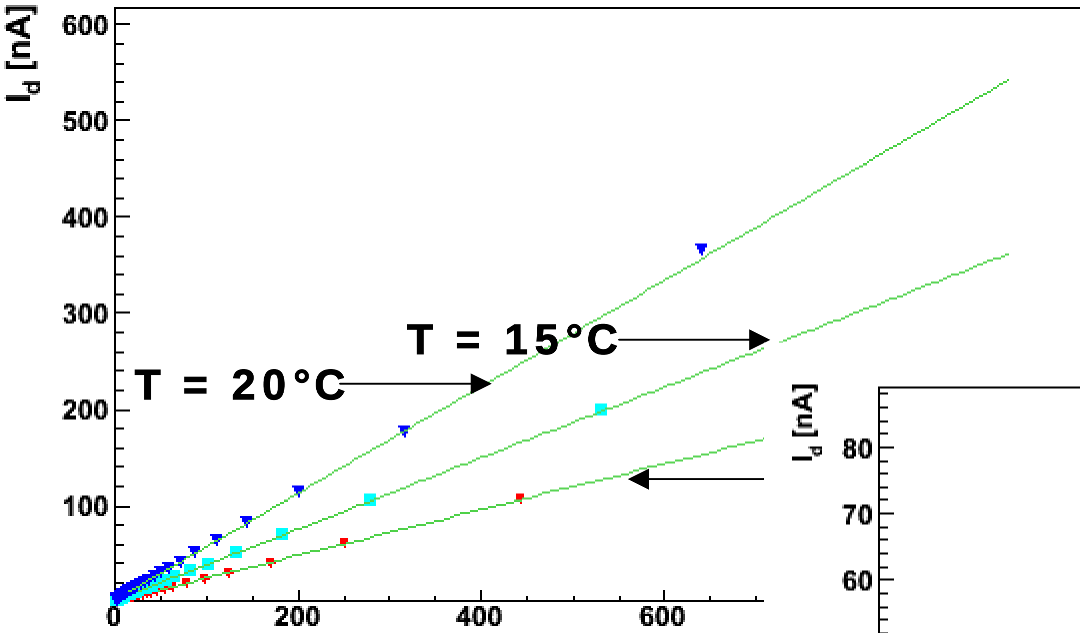
Internal gain M: M(T) at designated bias voltages



Internal gain M: M(U,T) for quadratic APDs @ different T-values

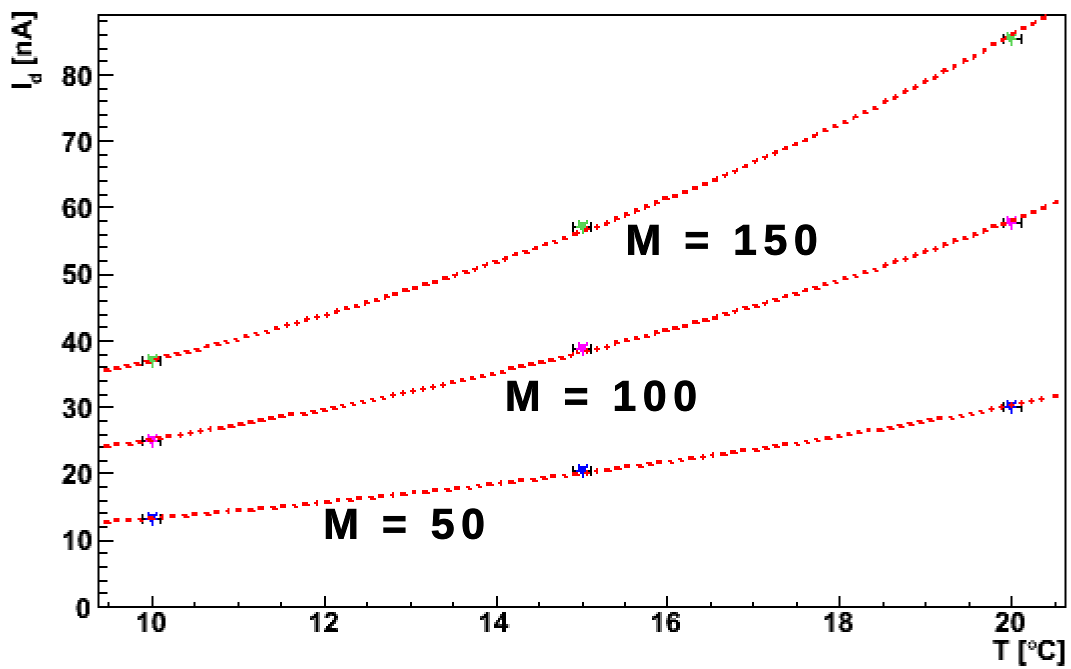


Dark current I_d: $I_d(T)$



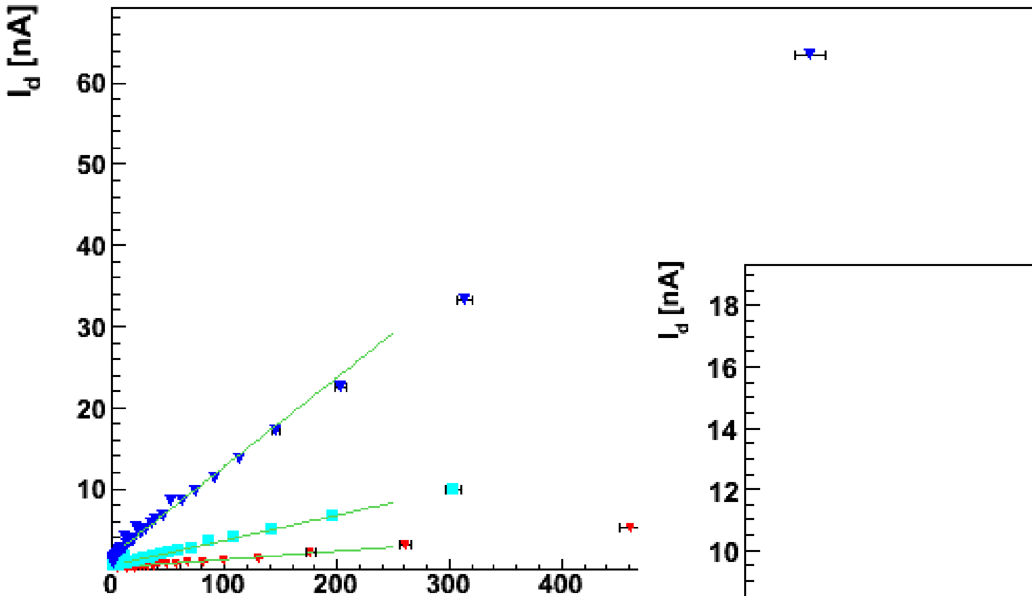
$I_d = I_{ds} + M \cdot I_{db}$

Usage of fit parameters: $I_d(T)$

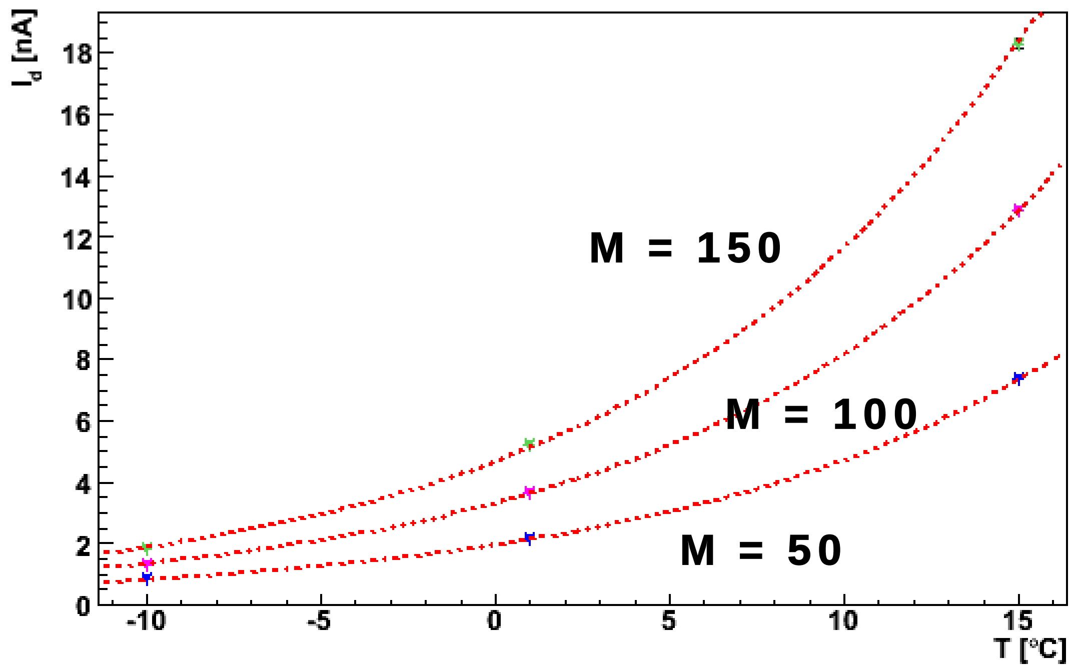


Temp. dependent APD properties $I_d(T)$

Dark current: $I_d(M,T)$ for quadratic APDs @ different T-values



Usage of fit parameter $I_d(T)$



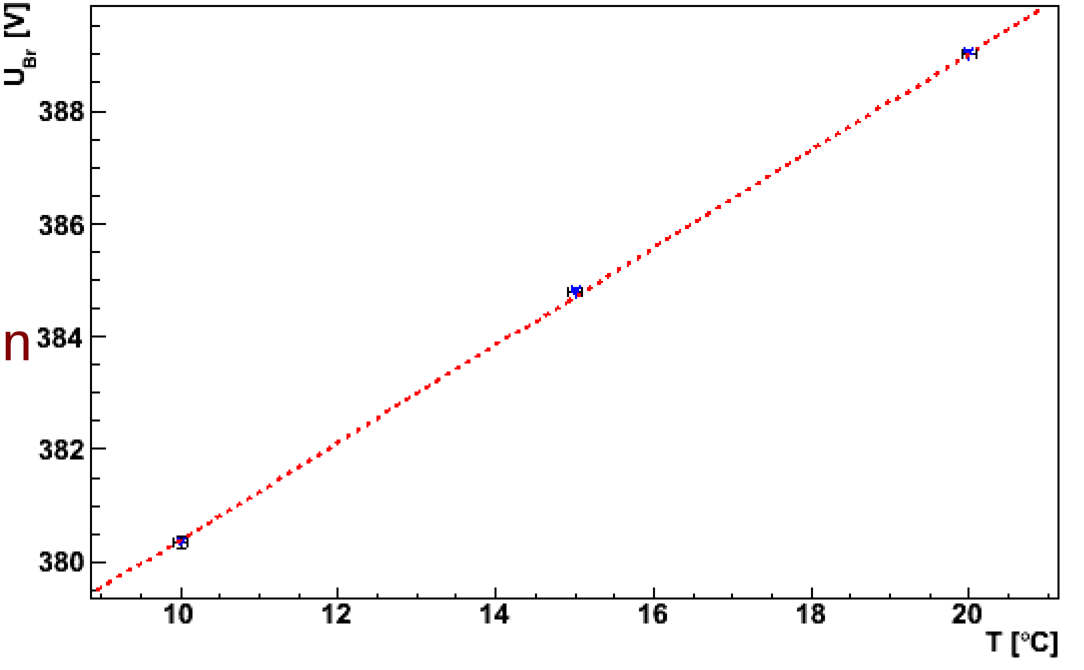
Determination of APD temperature coefficient η_{th}

$U_{Br}(T) = U_{Br}(0) + \eta_{th} \cdot T$

with: $U_{Br}(0)$:
U_{Br} at dark condition

and

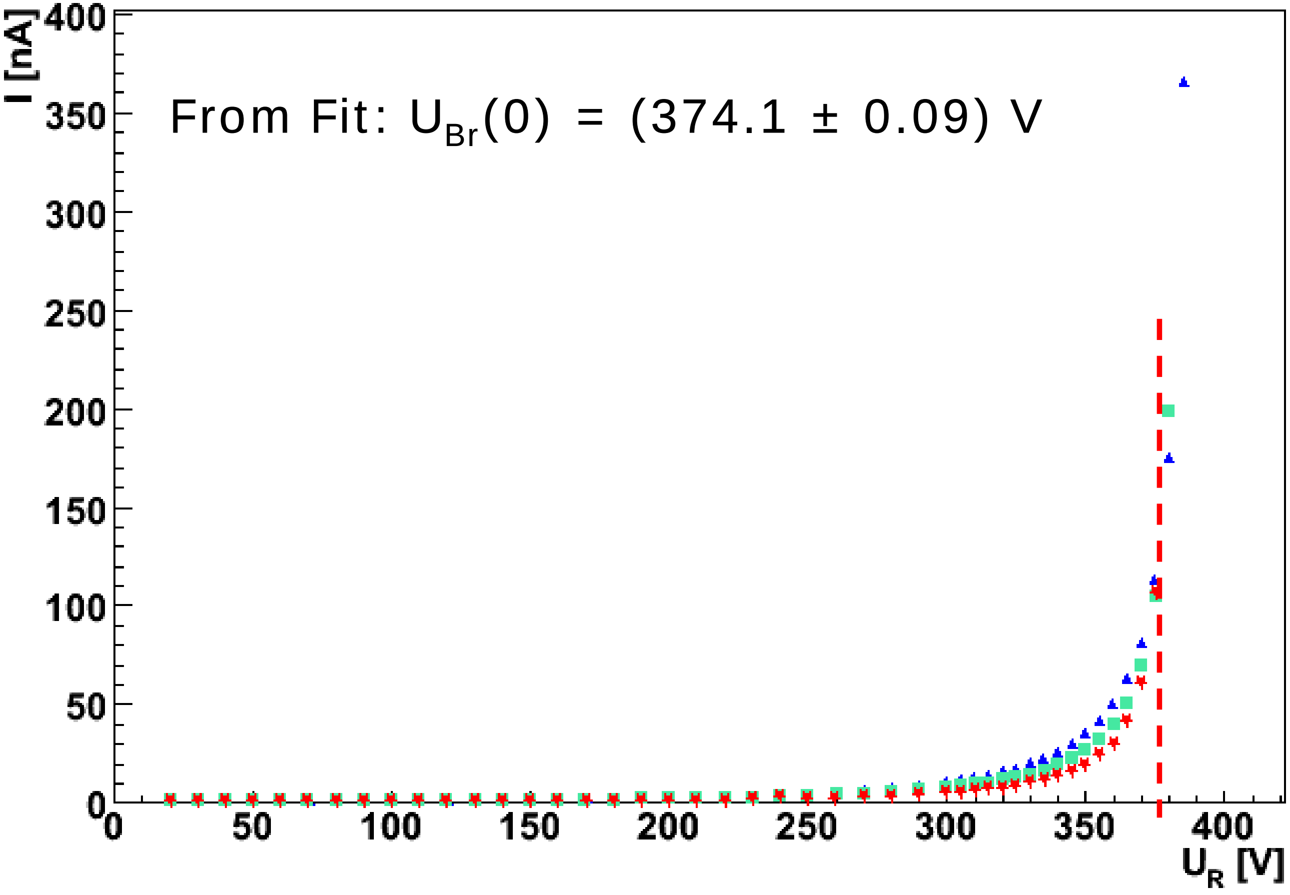
$$\eta_{th} = \frac{\partial U_{Br}}{\partial T}$$



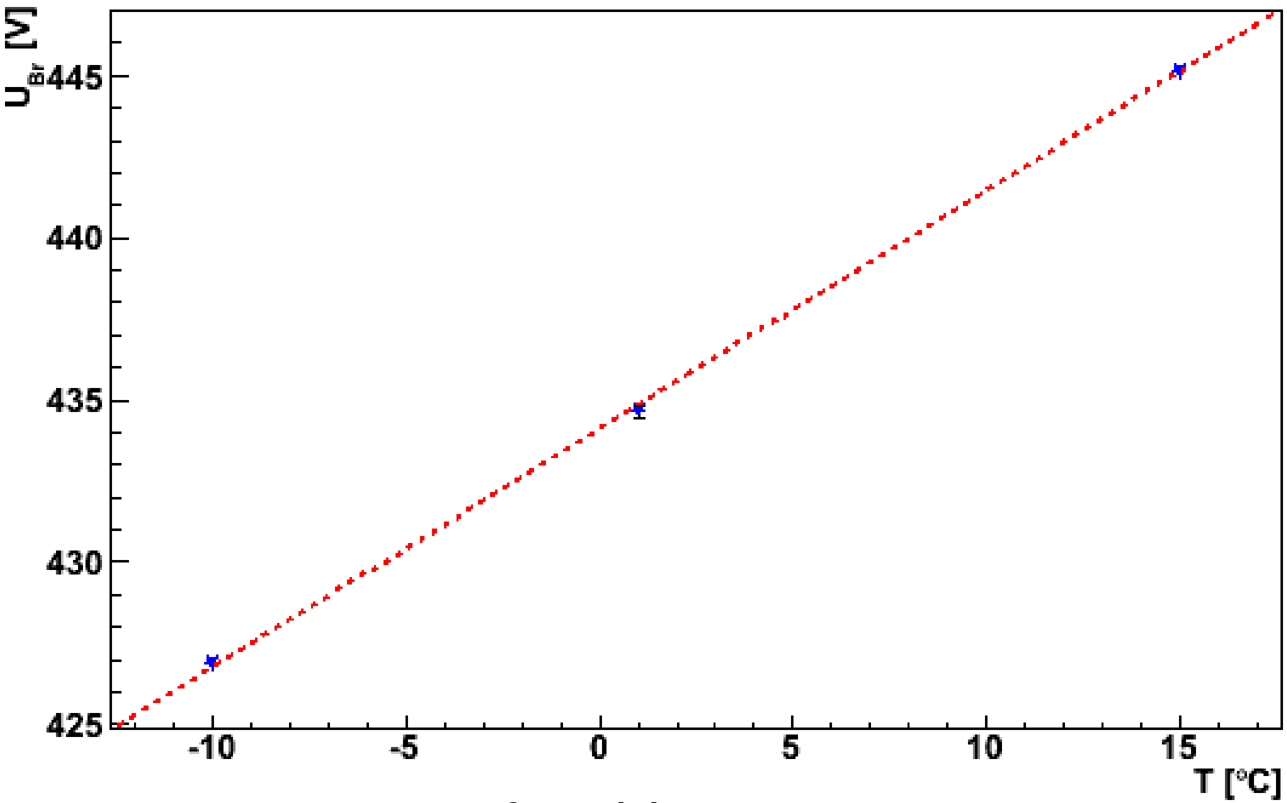
for this APD:
$\eta_{th} = (0.863 \pm 0.016)$ V/°C

Ref: A.Ghose, Disputation, Uni Kassel, 2005

$U_{Br}(0)$ temperature independent!



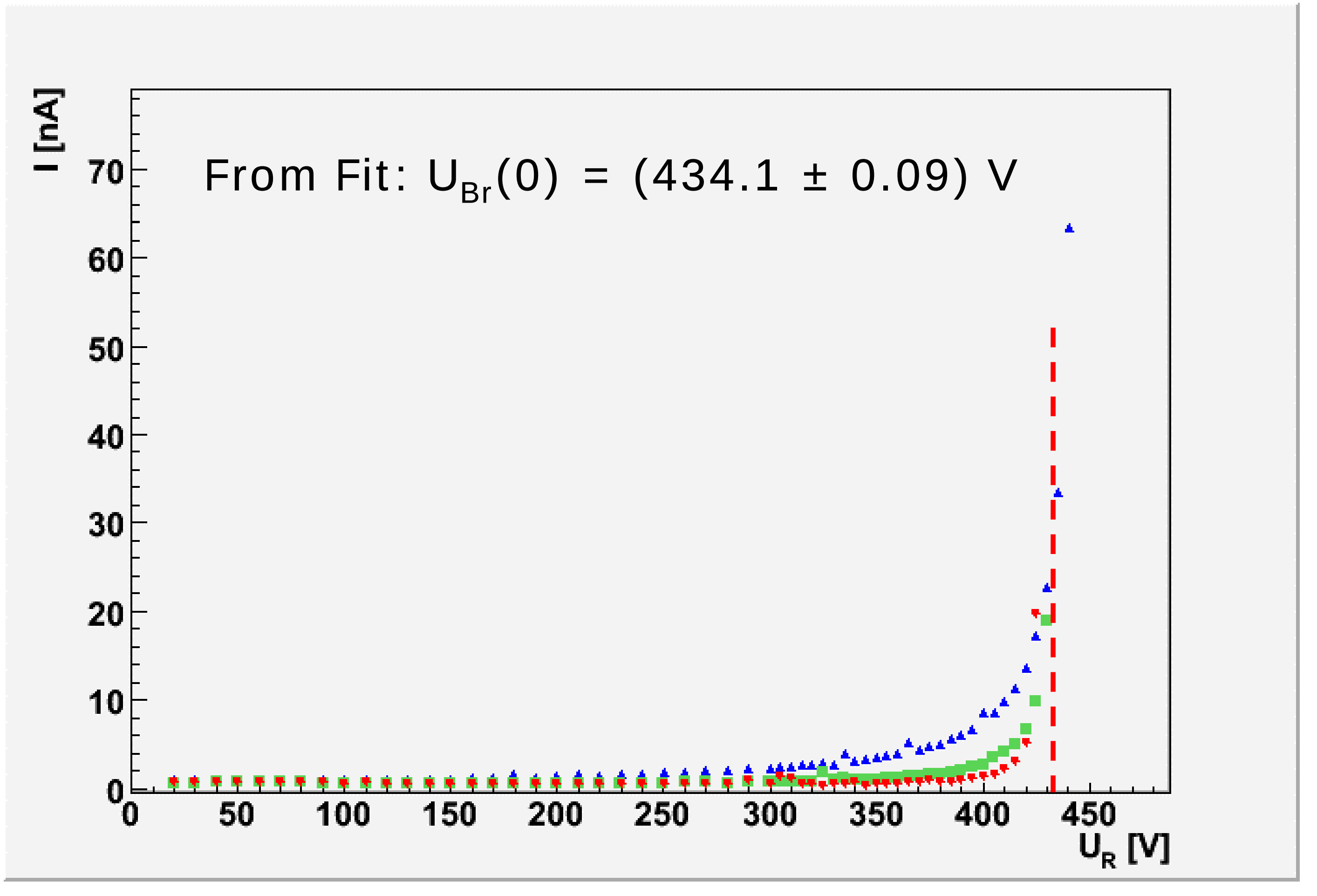
for quadratic APDs
@ different T-values



for this APD:

η_{th} = (0.734 ± 0.06) V/°C

$U_{Br}(0)$ for quadratic APDs!



Procedure for <u>ALL</u> APDs at 5 different temperatures

- Gain-Bias dependence, including
  - I_d-Bias dependence
- Gain variations 1/M*dM/dU (M & T: fix)
- Gain variations 1/M*dM/dT (M & U_{bias}: fix)

- Irradiation with Co-source at operation temperature (T = -25°C)
  - Annealing in oven at T = 80°C (I_d(U) measurement)
  - re-measurement of main parameters

Randomly measured APD properties (most temperature dependent)

- QE(λ)
- Excess Noise Factor (ENF)
- Capacitance & Resistance C(U) & R(U)
- M(λ)