ON THE UNCERTAINTY OF LINEAR ENERGY TRANSFER SPECTRA MEASURED WITH TRACK-ETCHED DETECTORS IN THE SPACE

K. Pachnerová Brabcová[1], I. Ambrožová[1], Z. Mrázová[1, 2], A. Malušek[1, 3]

[1] Nuclear Physics Institute, Academy of Sciences of Czech Republic
[2] Czech Technical University in Prague
[3] Faculty of Health Sciences, Linköping University

THE GOAL

- determination of measurement uncertainty for particular LET spectra
- track-etched detectors as spectrometers of LET in space
- material PADC TD1

LET SPECTRA

- **two-stage process of LET spectra determination:**

1. **Calibration:** determination of the calibration curve L = f(V), where V = f(track parameters) with particles of known LET

2. **Measurements:** determination of LET spectrum

LET SPECTRA: UNCERTAINTIES

- **three categories of independent uncertainties:**

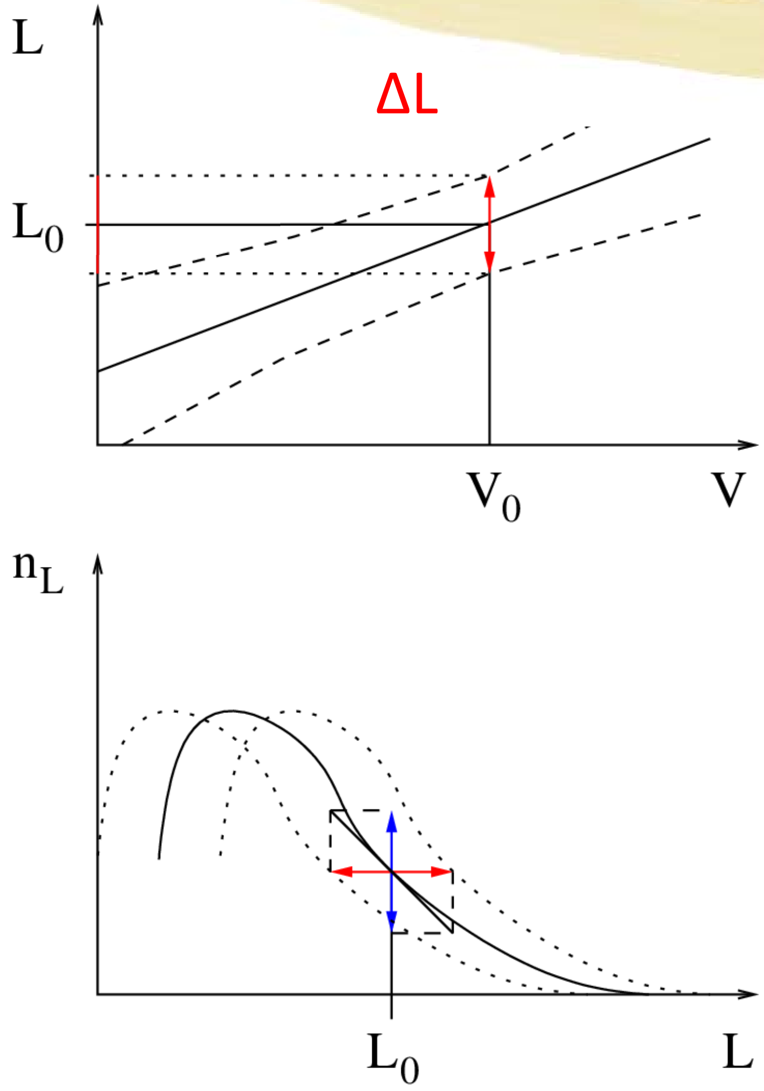
    1. uncertainty associated with randomness of particle detection u_1
    2. uncertainty of the calibration curve u_2
    3. uncertainty of the detector response u_3

- **resulting uncertainty** $u = \sqrt{u_1^2 + u_2^2 + u_3^2}$

u_1 UNCERTAINTIES OF PARTICLE DETECTION

- number of tracks in channel - different due to random nature of particle detection
- Poisson distribution with channel uncertainty $u_{1i} = \sqrt{N_i}$
- usually the only considered uncertainty

u_2 UNCERTAINTIES OF THE CALIBRATION CURVE



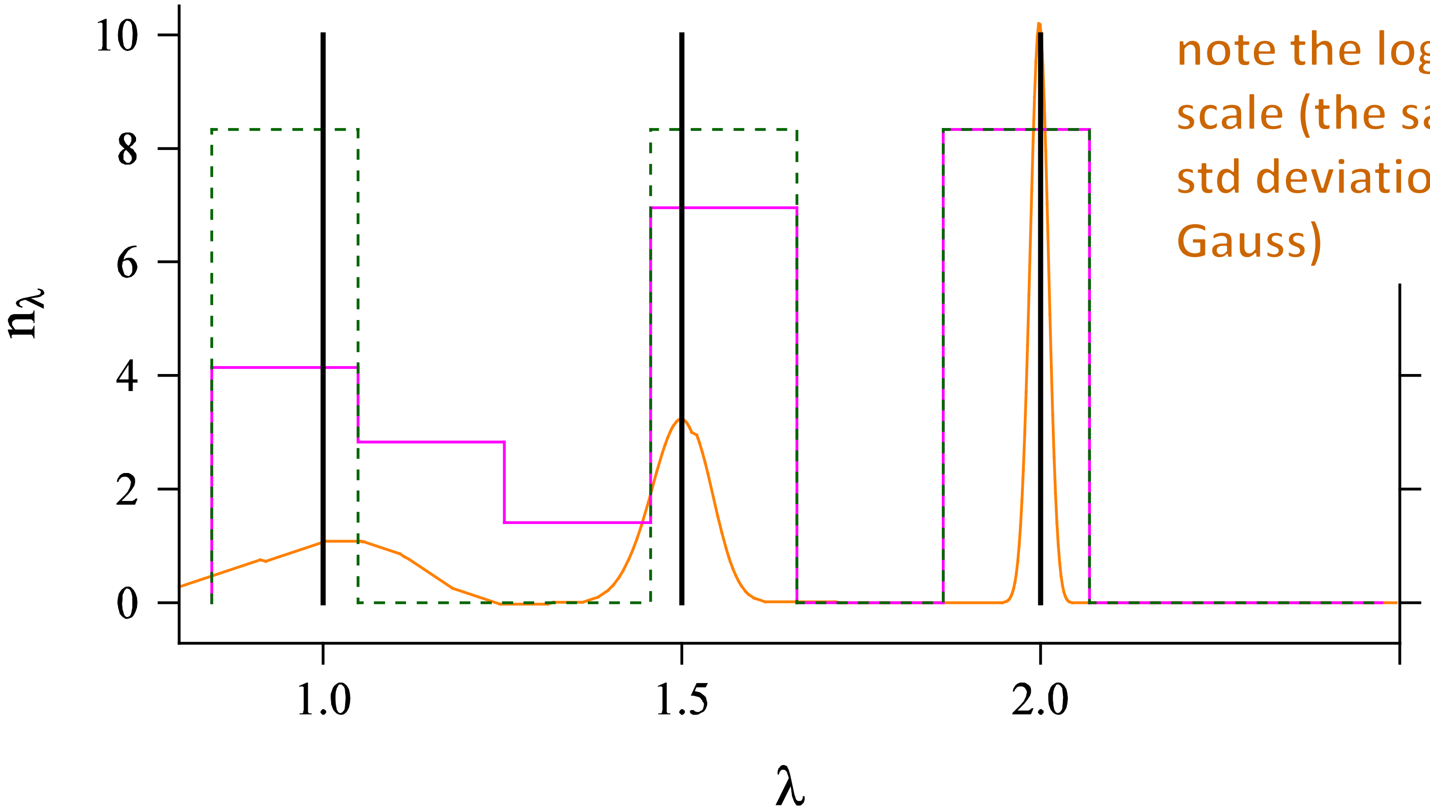
- confidence interval of calibration curve

→ shifts of peaks in spectrum (uncertainty associated with spectrum channel)

$$u_{2i} = \Delta L \left| \frac{dn_L}{dL} \right| u(L)$$

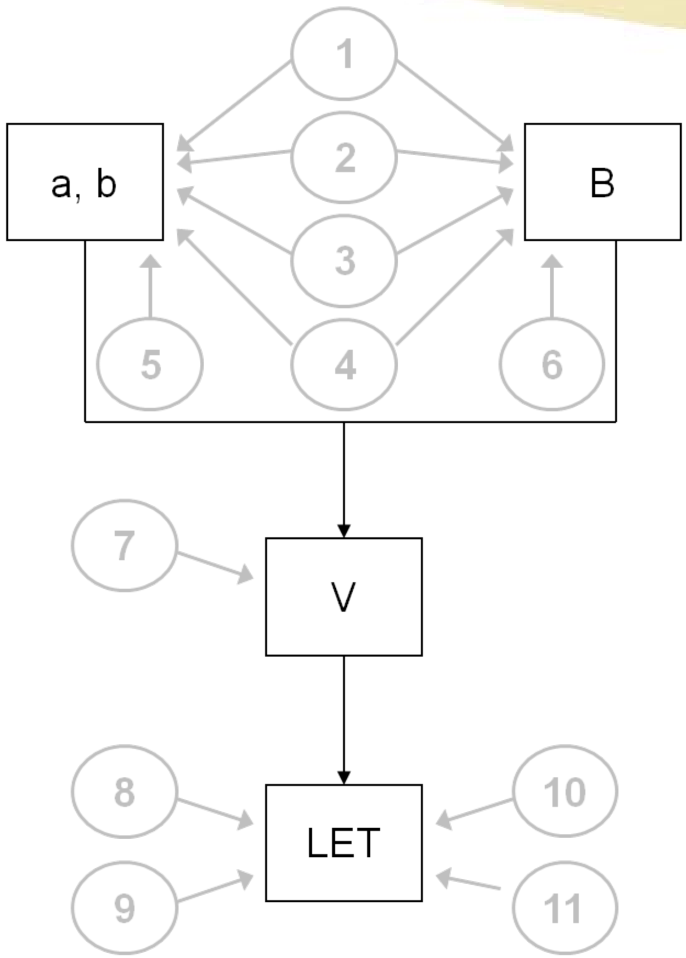
u_3 UNCERTAINTIES OF THE DETECTOR RESPONSE

- the LET specific species are associated with random channel number
- Gaussian distribution



note the log x scale (the same std deviation of all Gauss)

METHODS: factors affecting uncertainties



Measured quantities uncertainty

1 measuring with microscope
2 non-uniform etching conditions
3 detector thickness differences
4 differences in operator´s view
5 separation of peak of primary particles (calibration)
6 separation of “the biggest” fission fragments

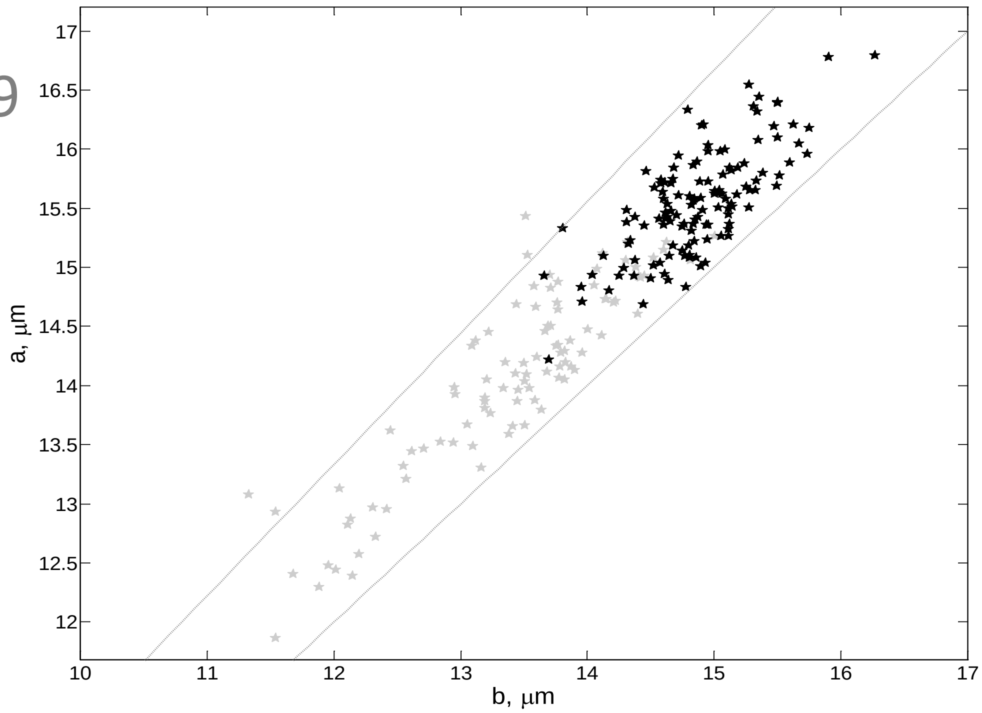
Calculated quantities uncertainty

7 equation uncertainty
8 reference calibration LET values
9 angle dependence
10 calibration curve model
11 ...

UNCERTAINTY OF B

23 samples were irradiated with ^{252}Cf, selection of tracks for analysis:

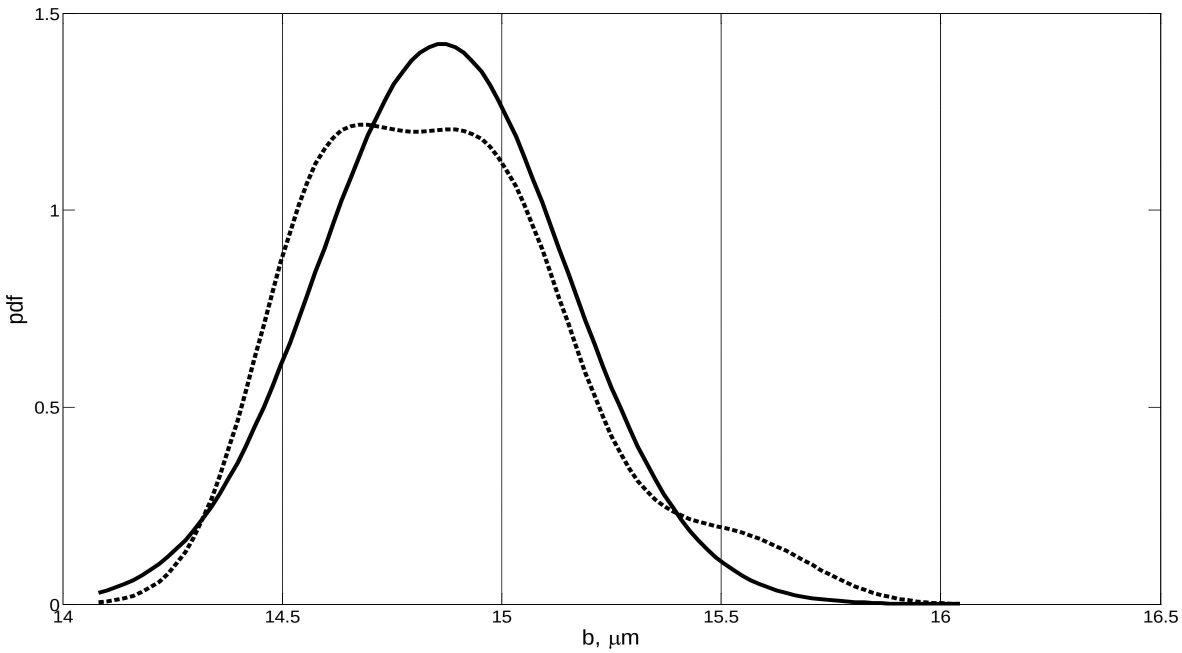
- perpendicularly impinging fission fragments: b/a > 0.9
- heavy fragments (A ~ 143) against light (A ~ 99): operator-specific routine



UNCERTAINTY OF B

Kernel density function of the parameter B corresponding to heavy fragments (dashed line) and normal distribution (full line) with parameters

- B = 14.86 µm
- u(B) = 0.28 µm
- relative standard uncertainty: 1.9 %



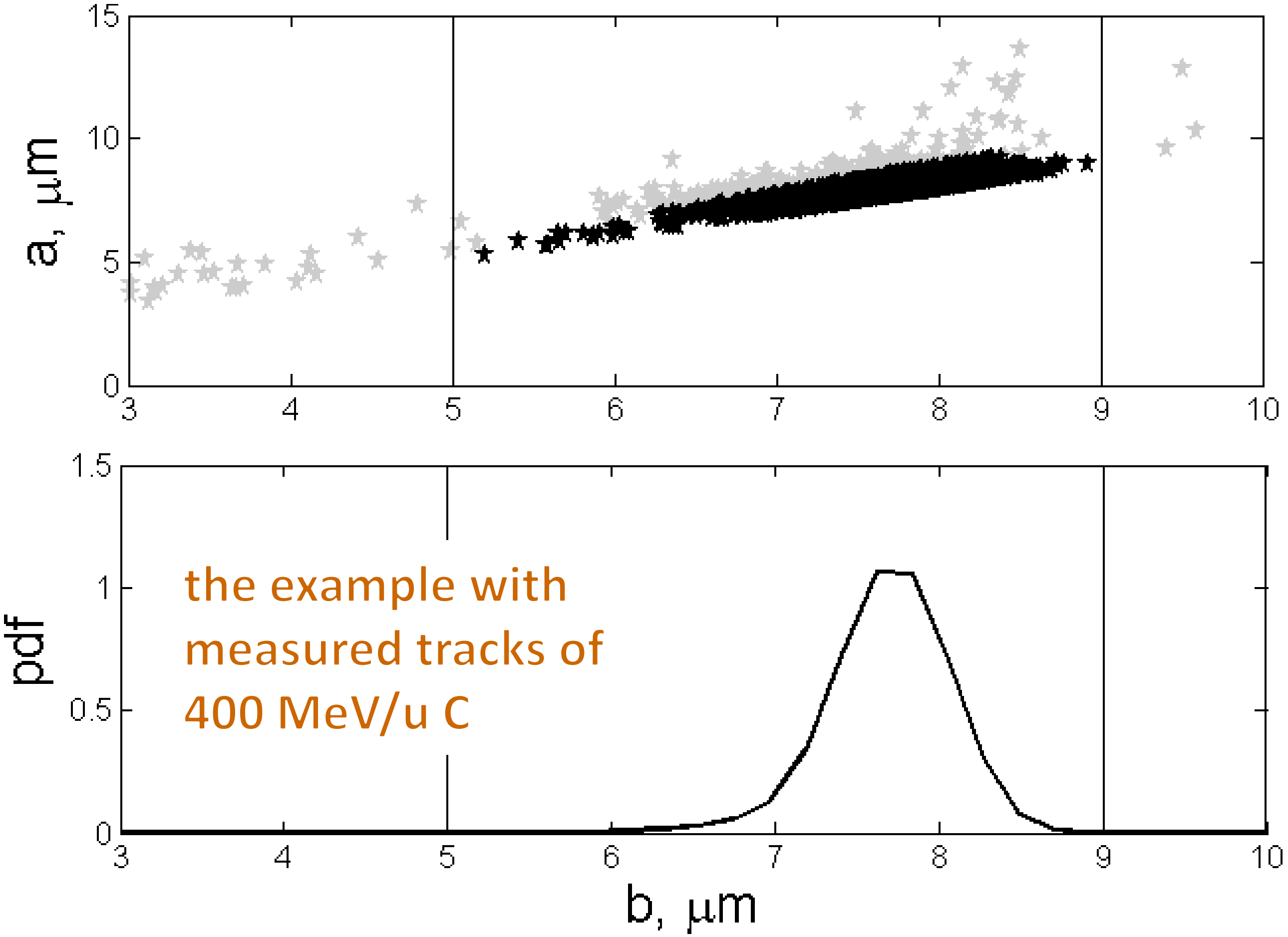
CALIBRATION

- V - LET
- HIMAC-BIO
- He, C, Ne, Si, Ar, Fe, Kr
- 31 calibration points
- uncertainty of a,b: normal distribution with parameters a, u(a), b, u(b), u(a,b)

CALIBRATION

Selection of tracks for analysis:

- $b_{min} < b < b_{max}$
- $0.9 < b/a < 1$



CALIBRATION

- etch ratio calculation

$$V = \left\{ \sin \arctan \left[\frac{B}{2a} \left(1 - \frac{b^2}{B^2} \right) \right] \right\}^{-1}$$

- sensitivity coefficients

$$c_1 \equiv \frac{\partial V}{\partial a} \quad c_2 \equiv \frac{\partial V}{\partial b} \quad c_3 \equiv \frac{\partial V}{\partial B}$$

- combined variance

$$u_c^2(V) = {c_1}^2 u^2(a) + {c_2}^2 u^2(b) + {c_3}^2 u^2(B) + 2 c_1 c_2 u(a, b)$$

CALIBRATION

LET keV.µm^{-1}	V	$u_c(V)$	$u_{rel}(V)$ %
13.06	1.195	0.0307	2.57
13.06	1.1892	0.0188	1.58
13.06	1.1338	0.0199	1.76
14.16	1.2256	0.0225	1.84
15.89	1.2169	0.0229	1.88
23.53	1.4226	0.032	2.25
28.64	1.5045	0.0426	2.83
36.05	1.5978	0.0457	2.86
10.85	1.1575	0.0149	1.29
11.94	1.1793	0.0264	2.24
18.76	1.3019	0.037	2.84
31.23	1.3853	0.0373	2.69
31.23	1.3274	0.0422	3.18
31.23	1.4717	0.0311	2.11
31.45	1.475	0.0313	2.12
32.86	1.4551	0.0453	3.11

LET keV.µm^{-1}	V	$u_c(V)$	$u_{rel}(V)$ %
56.75	1.5308	0.0588	3.84
56.75	1.5864	0.0439	2.77
56.75	1.5269	0.0342	2.24
56.75	1.7276	0.0376	2.18
61.30	1.886	0.1201	6.37
88.59	2.3063	0.2816	12.21
95.46	1.8968	0.0865	4.56
95.46	1.6768	0.048	2.86
95.46	1.7683	0.0563	3.18
197.58	2.6601	0.1592	5.98
197.58	2.5293	0.112	4.43
197.58	3.4448	0.2724	7.91
232.00	4.5008	0.5377	11.95
320.00	6.1918	0.7271	11.74
443.34	5.0559	0.4793	9.48

CALIBRATION

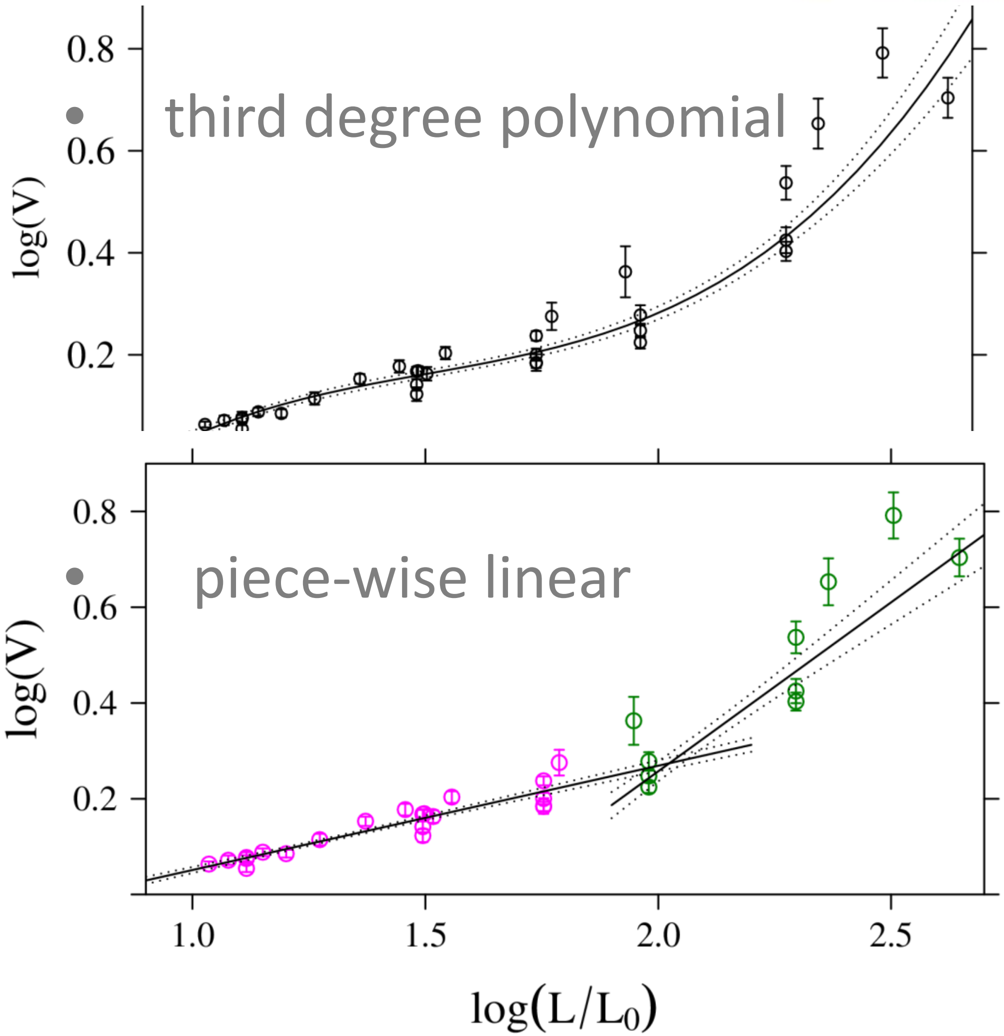
- V = f(L)
- L = f(V) constructed as inverse function

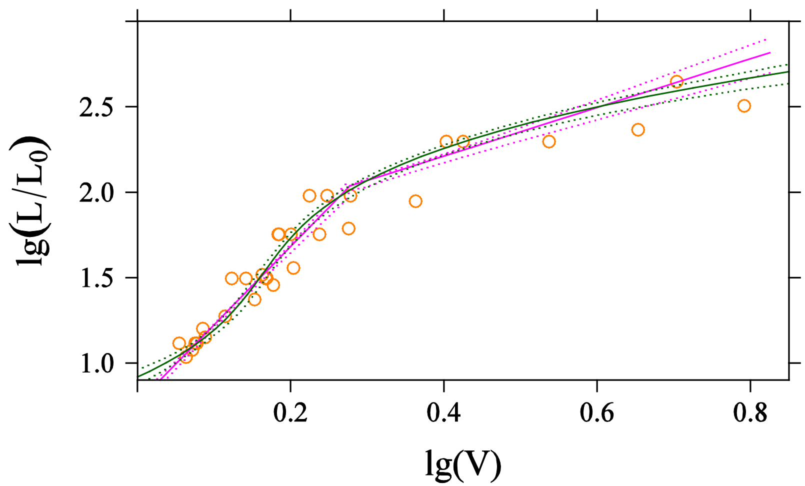
$$u(L) = u(V)\left|\left(\frac{dV}{dL}\right)\right|^{-1}$$

- should respect physical characteristics of TED: detection threshold, saturation
- different models lead to different confidence intervals

CALIBRATION: DIFFERENT MODELS

- third degree polynomial
- piece-wise linear





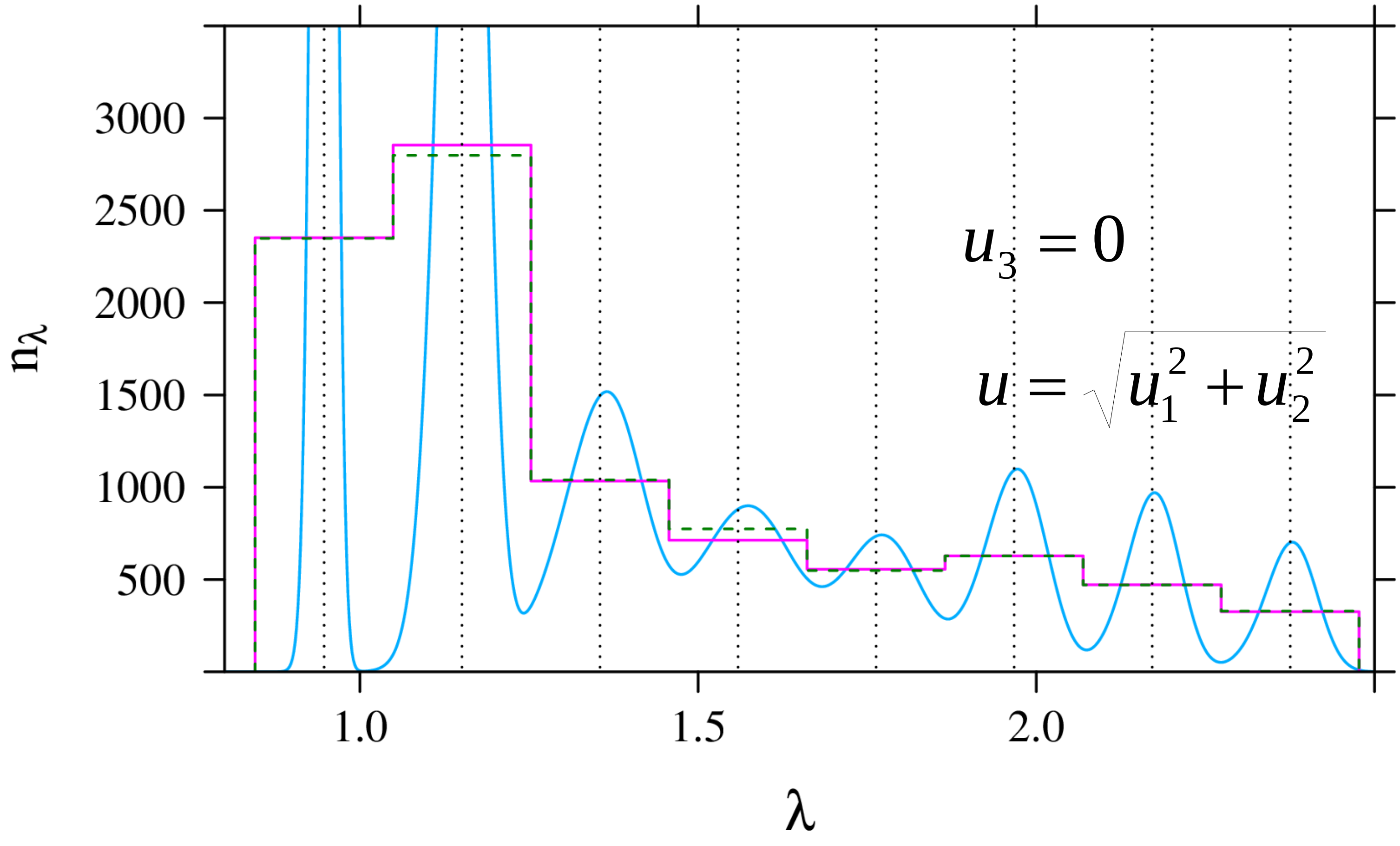
DETECTOR RESPONSE

- smearing of „true signals“
- assumption: minor uncertainties

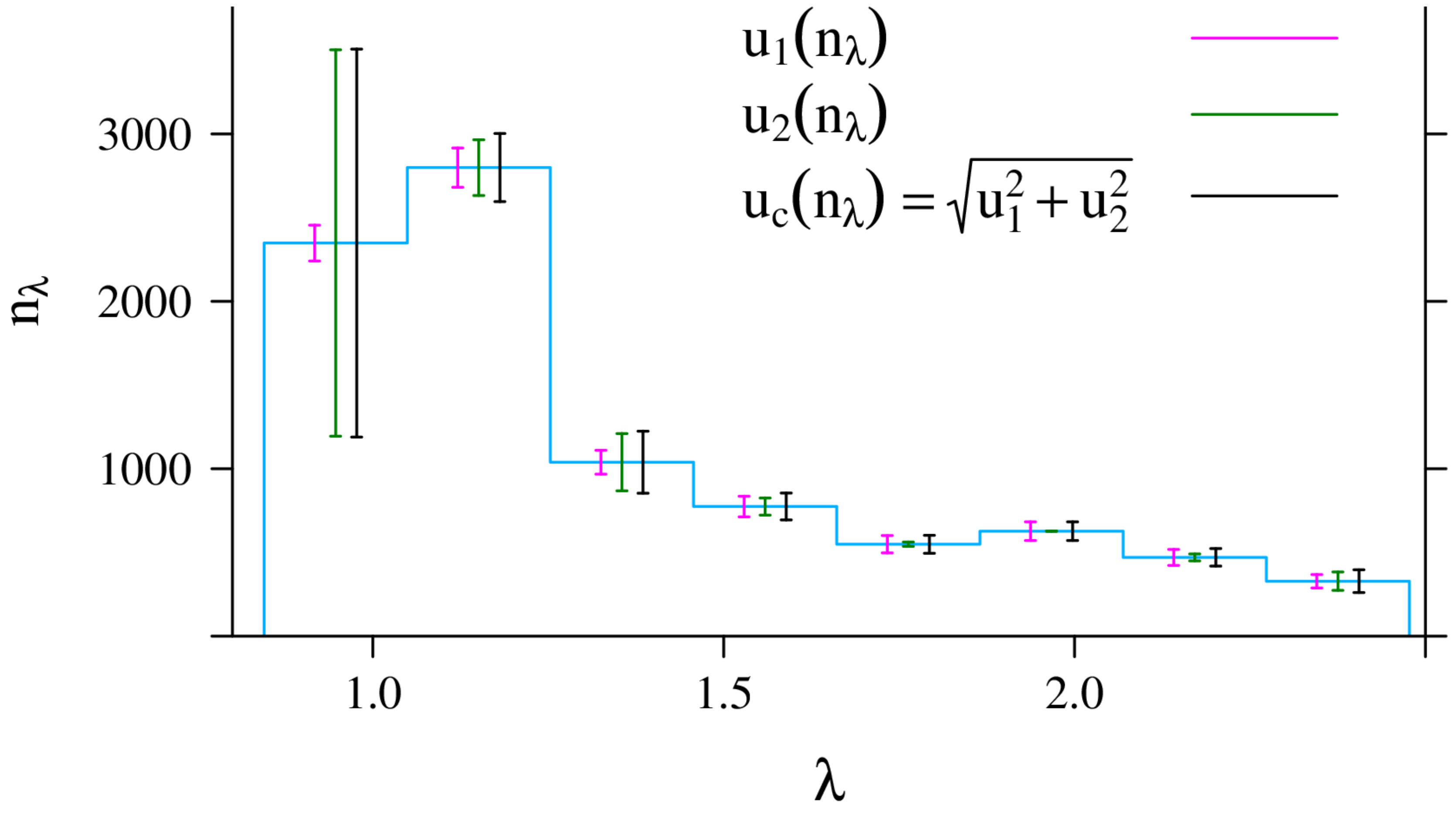
TEST

- convolution with Gaussian distribution – parameters dependent on LET (fit of the calibration data)
- real LET spectrum from ISS: equidistant eight bins

DETECTOR RESPONSE



RESULTS



$u_1(n_\lambda)$
$u_2(n_\lambda)$
$u_c(n_\lambda) = \sqrt{u_1^2 + u_2^2}$
3000
2000
1000
n_λ
1.0
1.5
2.0
λ

RESULTS

λ	nλ	LET keV.µm^{-1}	$relu_1$ %	$relu_2$ %	$relu_c$ %
0.95	2348	8.9	4.6	49.2	49.4
1.15	2799	14.1	4.2	6.0	7.3
1.36	1039	22.9	6.9	16.5	27.9
1.56	774	36.3	8.0	6.6	10.3
1.76	549	57.5	9.4	2.3	9.7
1.97	627	93.3	8.8	0.0	8.8
2.17	470	147.9	10.2	4.4	11.1
2.38	328	239.9	12.2	16.6	20.6

CONCLUSIONS

- calibration model has to be considered very carefully, with respect to physical properties of detectors (which are?)
- uncertainty associated with detector response is difficult to estimate
- uncertainty associated with angle dependence