Detection and energy measurement of neutrons

at radioactive ion beams:

Charge exchange, Coulomb break-up, β-delayed neutrons etc.

Eckart Grosse et al.

Dresden

Forschungszentrum Rossendorf and Techn. Univ.

Neutron interactions in detector materials

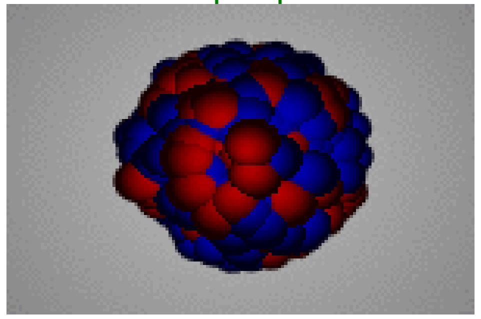
Neutron energy measurements

MeV neutron time of flight measurements

Detector efficiency determination

GeV neutron time of flight measurements

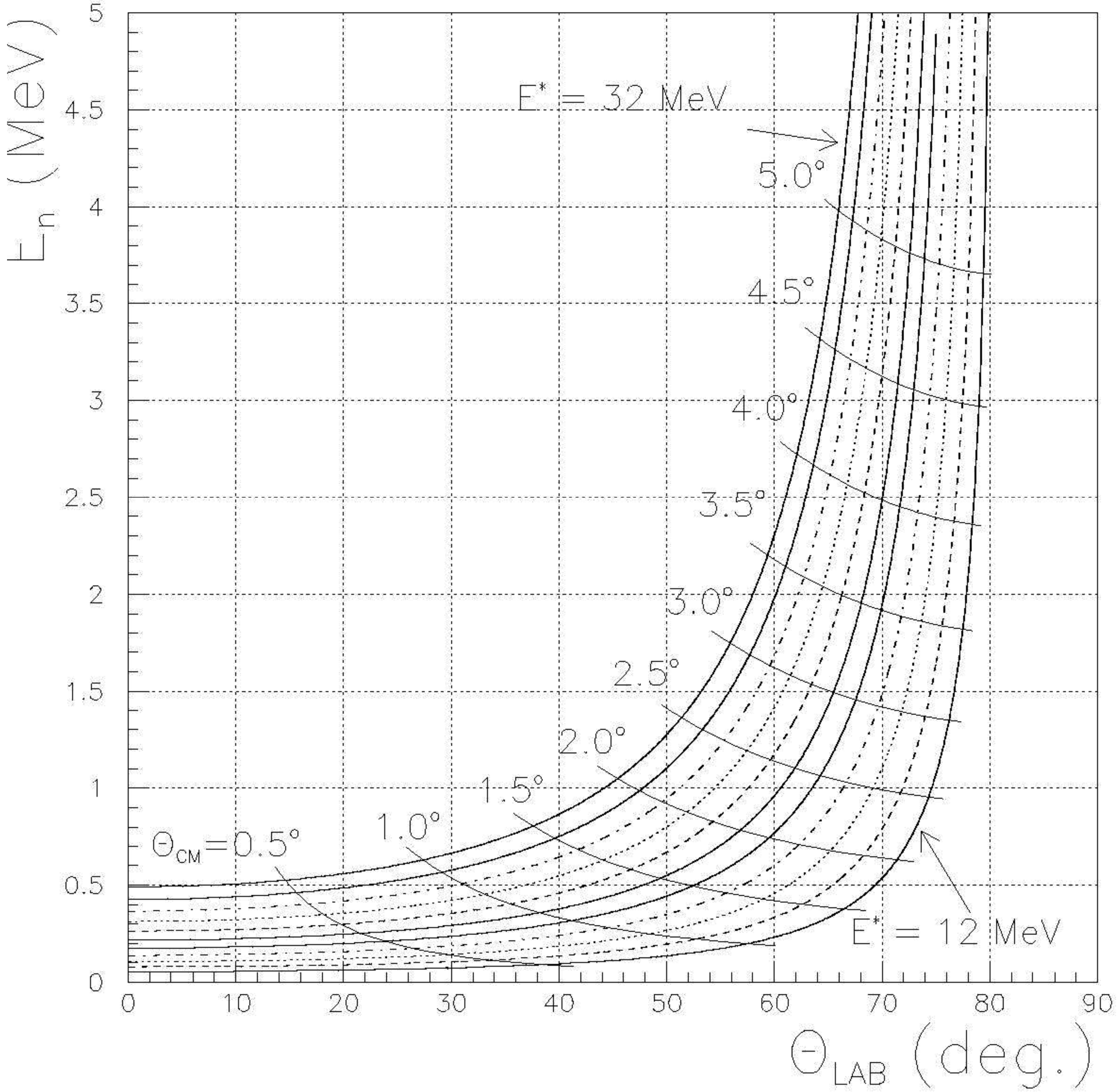
Spin-isospin GR's in unstable nuclei



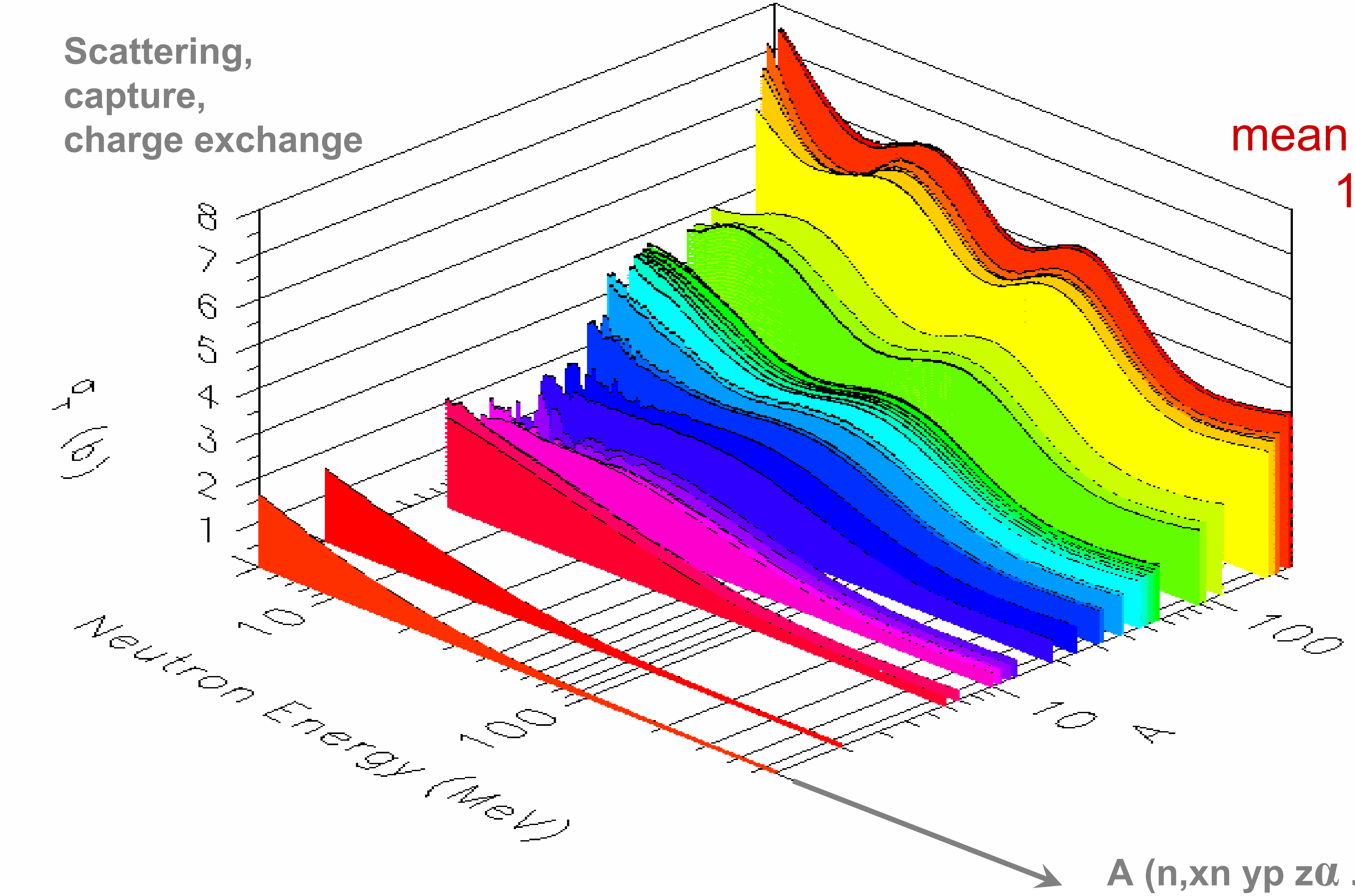
Attila Krasnahorkay et al., Debrecen

- **The physics case**
  - Macroscopic & microscopic info
  - Neutron skin
    - SDR sum-rule (Krasznahorkay et al., Phys. Rev. Lett. 82 (1999) 3216)
    - E_x(GTR)-E_x(IAS)
  - astrophysics e.g. ν-process
- **Experimental considerations** ((p,n) in inverse kinematics)
  - High cross sections (~10mb/sr)
  - Complete kinematics (use FRS)
  - low-E_n, no energy loss in target
- **Neutron detection**
  - aim: 1 MeV resolution in E_x
  - required: $\Delta\Theta<1^0$ $\Delta E_n/E_n$ = 10 % flight path: 1 m, Timing resolution: 1 ns

(p,n) reaction in inverse kinematics
p(^{132}Sn,n) E=400 AMeV



Important ingredient for any neutron detection:
Total cross section as function of neutron energy and atomic mass A



mean free path per b:
1.7 mol/cm²

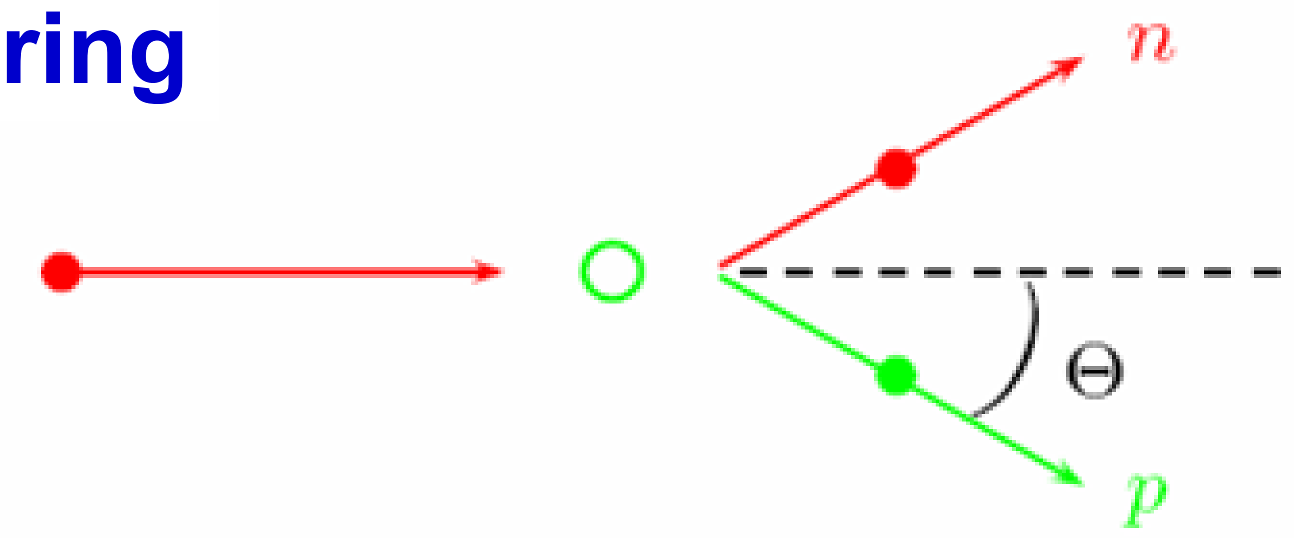
A (n,xn yp zα ..),
production of π, . .

cf.: W. P. Abfalterer, (werner@lanl.gov) or F. S. Dietrich, (dietrich2@llnl.gov), Web site -- http://mesa53.lanl.gov
Phys. Rev. Letters **81**, 57 (1998), LA-UR-99-666, Phys. Rev. **C47**, 237 (1993), Phys. Rev. **C47**, 1033 (1993)

Nuclear reactions for neutron detection

- $n + {}^{3}He \rightarrow {}^{3}H + {}^{1}H + 0.764$ MeV
- $n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79$ MeV
- $n + {}^{10}B \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48$ MeV γ +2.3 MeV (93%)
  $\rightarrow {}^{7}Li + {}^{4}He$ +2.8 MeV (7%)
- $n + {}^{155}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{157}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{235}U \rightarrow$ fission fragments + ~160 MeV
- $n + {}^{239}Pu \rightarrow$ fission fragments + ~160 MeV
- $n + p \rightarrow n + p$ elastic scattering, detect recoil proton

Elastic n-scattering



$$E_n = E_n' + E_p$$

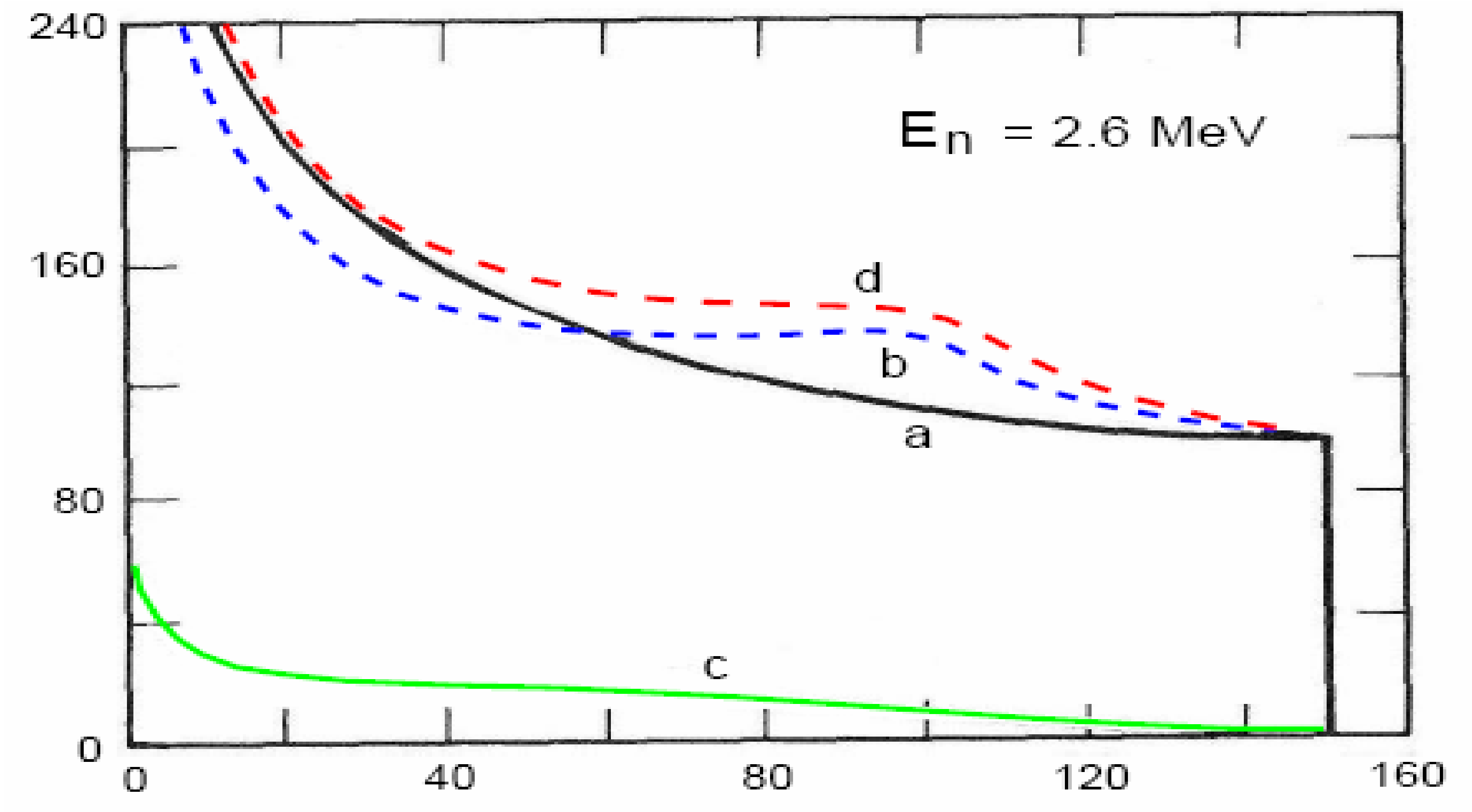
$$\frac{\vec{p}_n^{\,2}}{2\,m} = \frac{\vec{p}_n^{\,\prime 2}}{2\,m} + \frac{\vec{p}_A^{\,2}}{2\,mA} \quad \rightsquigarrow \quad \vec{p}_n^{\,\prime 2} = \vec{p}_n^{\,2} - \vec{p}_A^{\,2}\,\frac{1}{A}$$

recoil energy:

$$\boxed{E_A = \frac{4A}{(A+1)^2}\,E_n\,\cos^2\theta}$$

$$np \rightarrow np$$

$$\boxed{E_p = E_n\,\cos^2\theta}$$

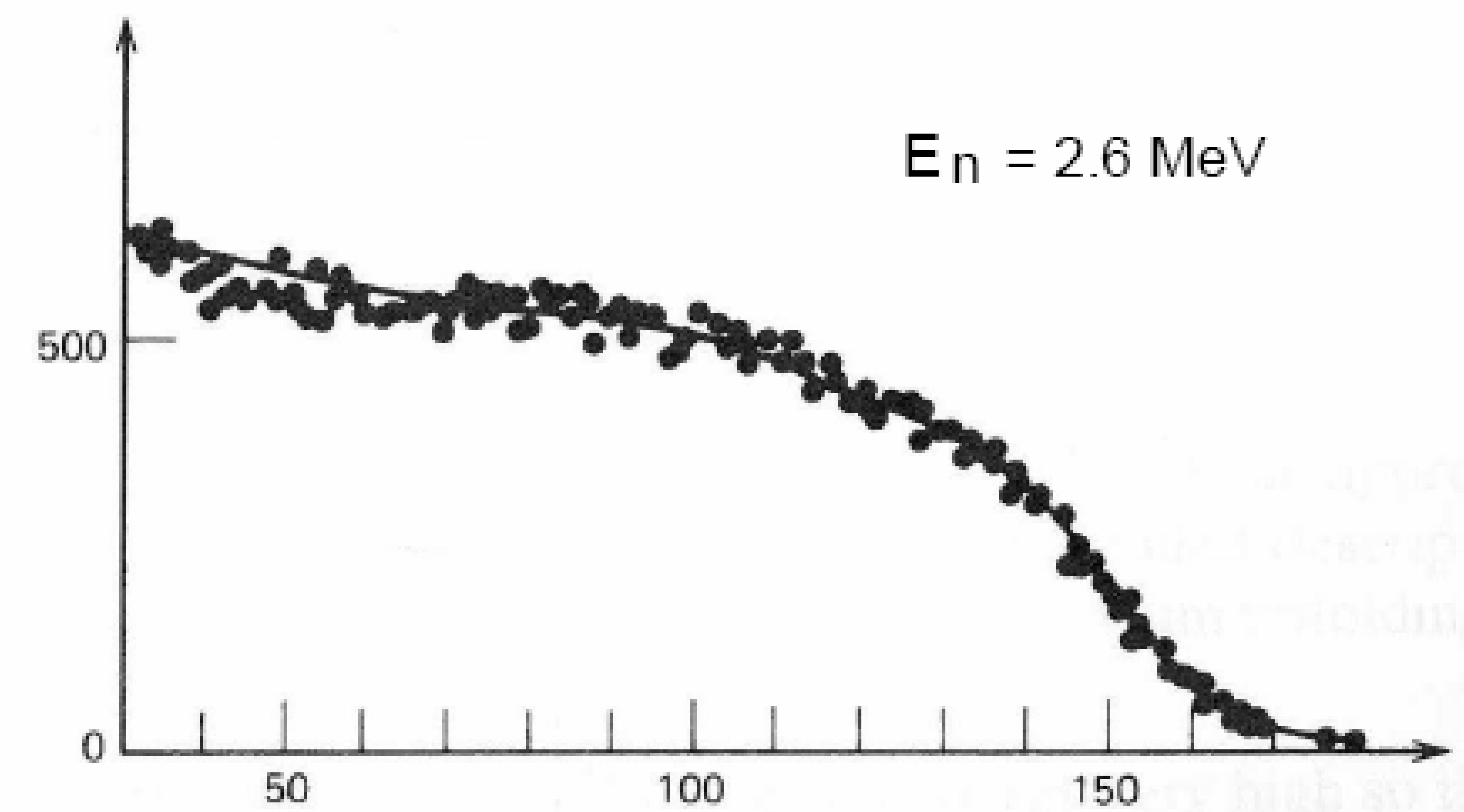


schematic

and

measured

spectrum



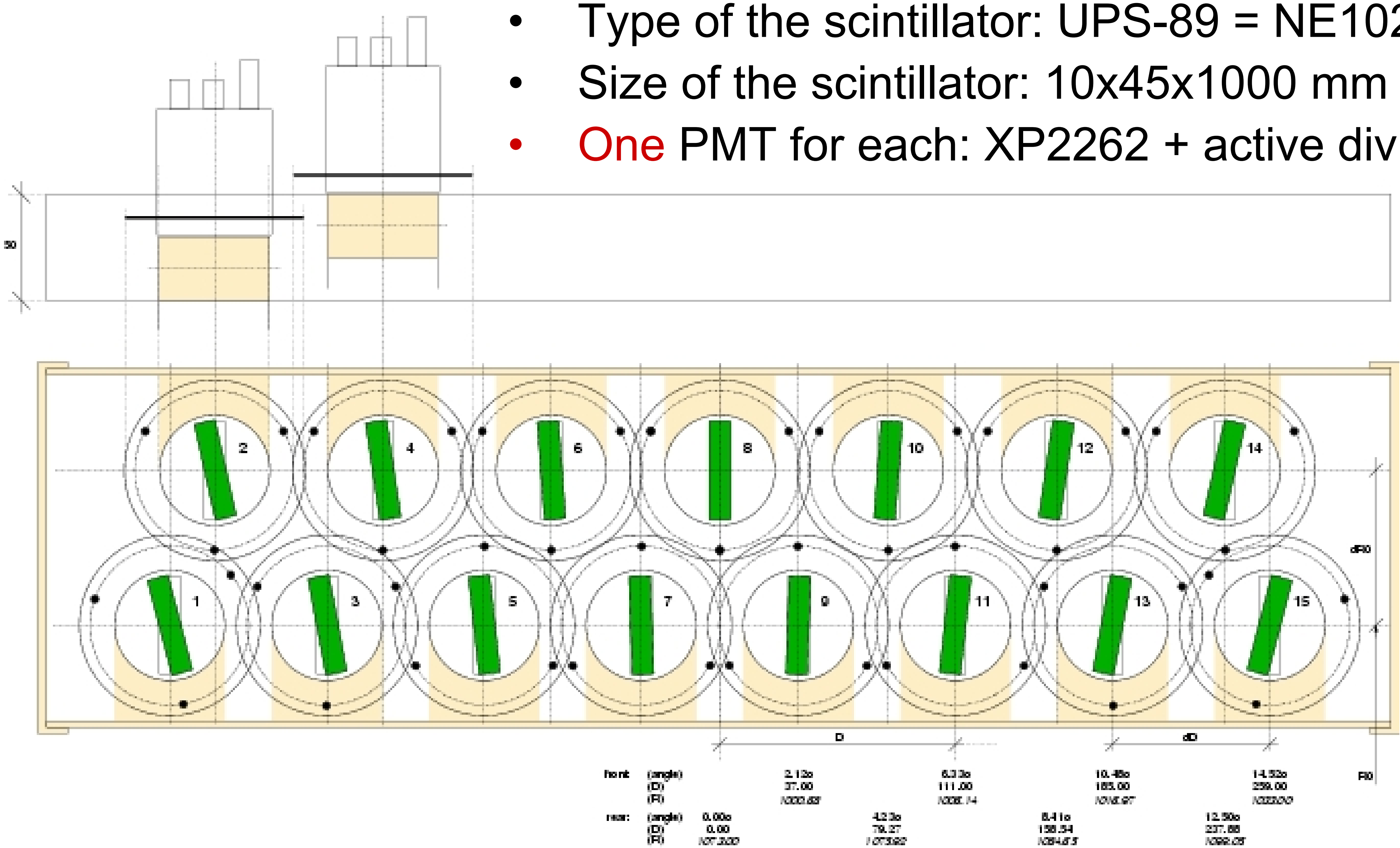
The ELENA setup for neutron detection

aim: 1 MeV resolution in E_x

required: $\Delta\Theta<1^0$ $\Delta E_n / E_n = 10$ %

flight path: 1 m, timing resolution: 1 ns

- Type of the scintillator: UPS-89 = NE102A
- Size of the scintillator: 10x45x1000 mm
- One PMT for each: XP2262 + active dividers



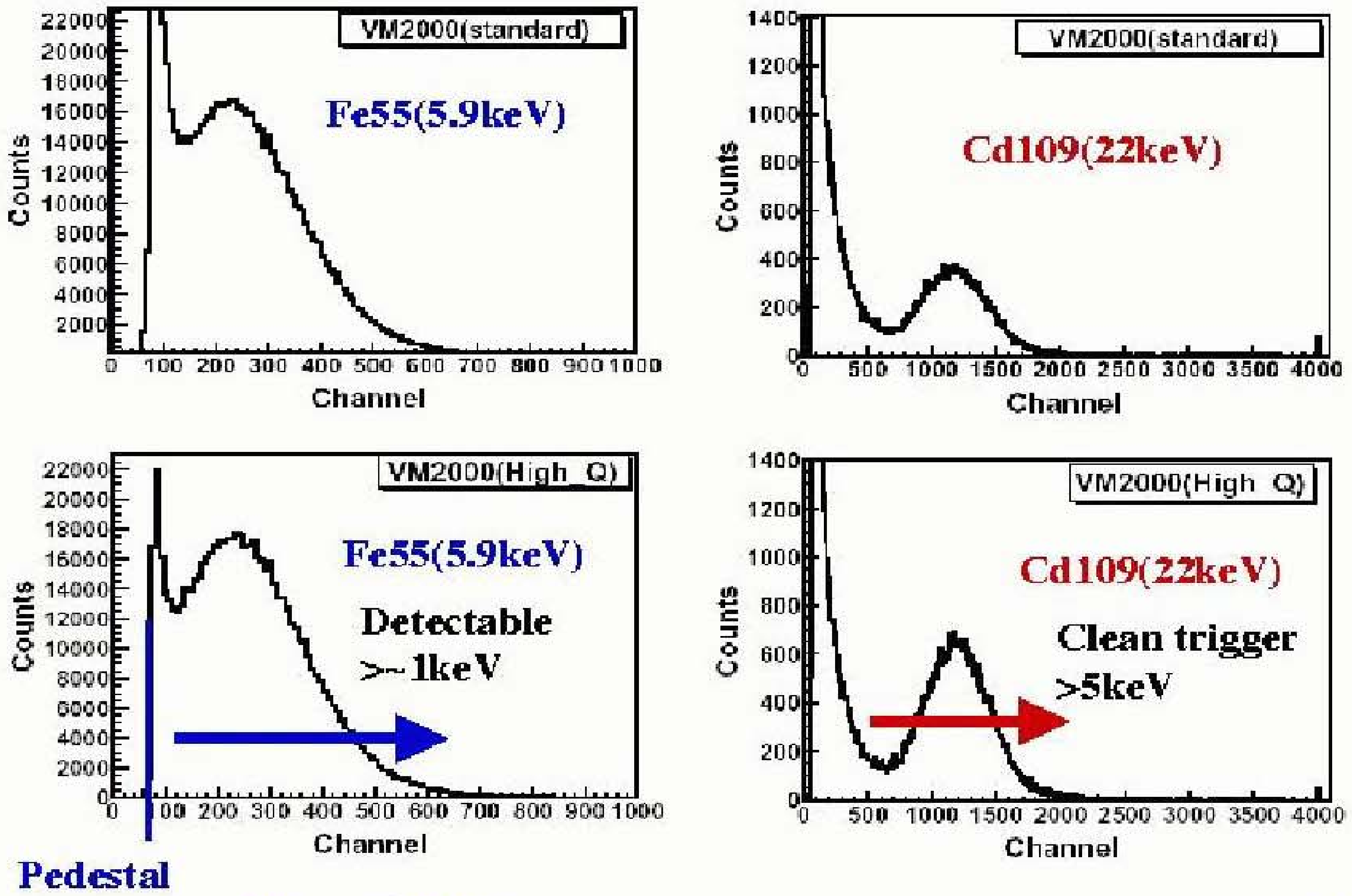
VM2000 multilayer reflector for wrapping the scintillators

On-Going R/D: No.1

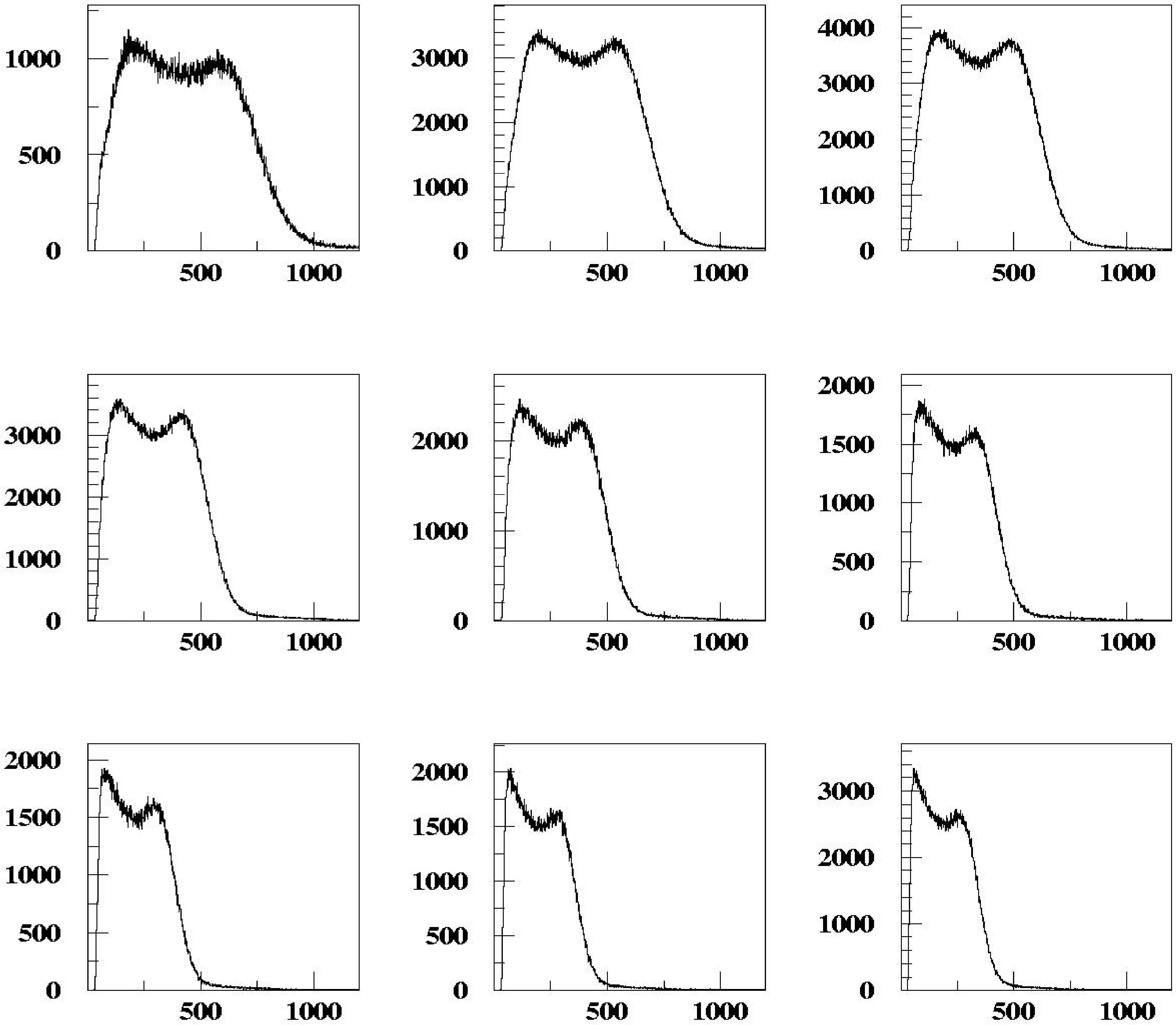
Summary	VM2000(standard)		VM2000 (highquality)	
	Peak	FWHM	Peak	FWHM
Cd109(22keV)	1169ch	11.6keV	1185ch	11.4keV
Fe55(5.9keV)	221ch	8.6keV	230ch	8.1keV

Light yield of plastic scintillator

Minimum triggerable Energy >5keV

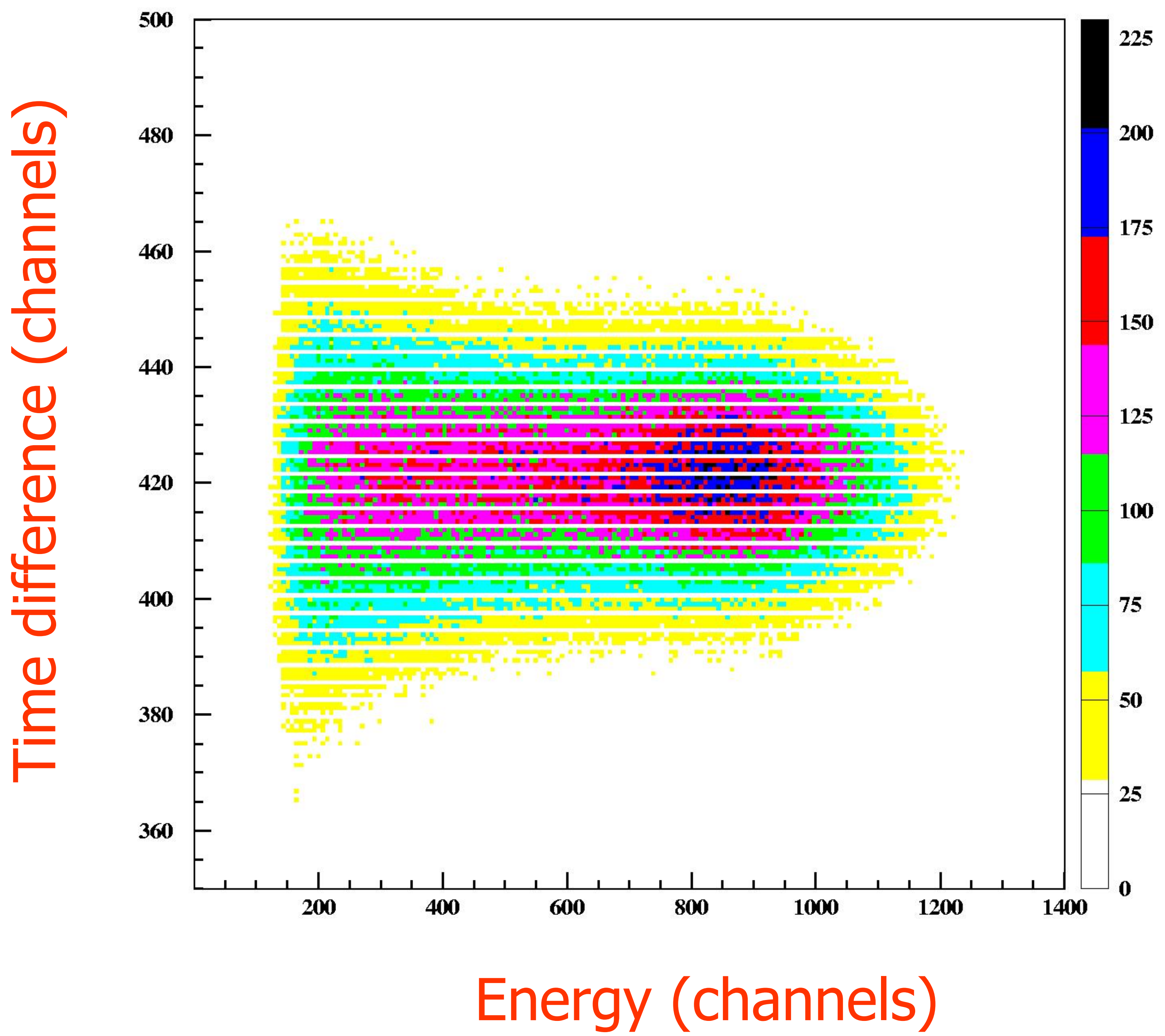


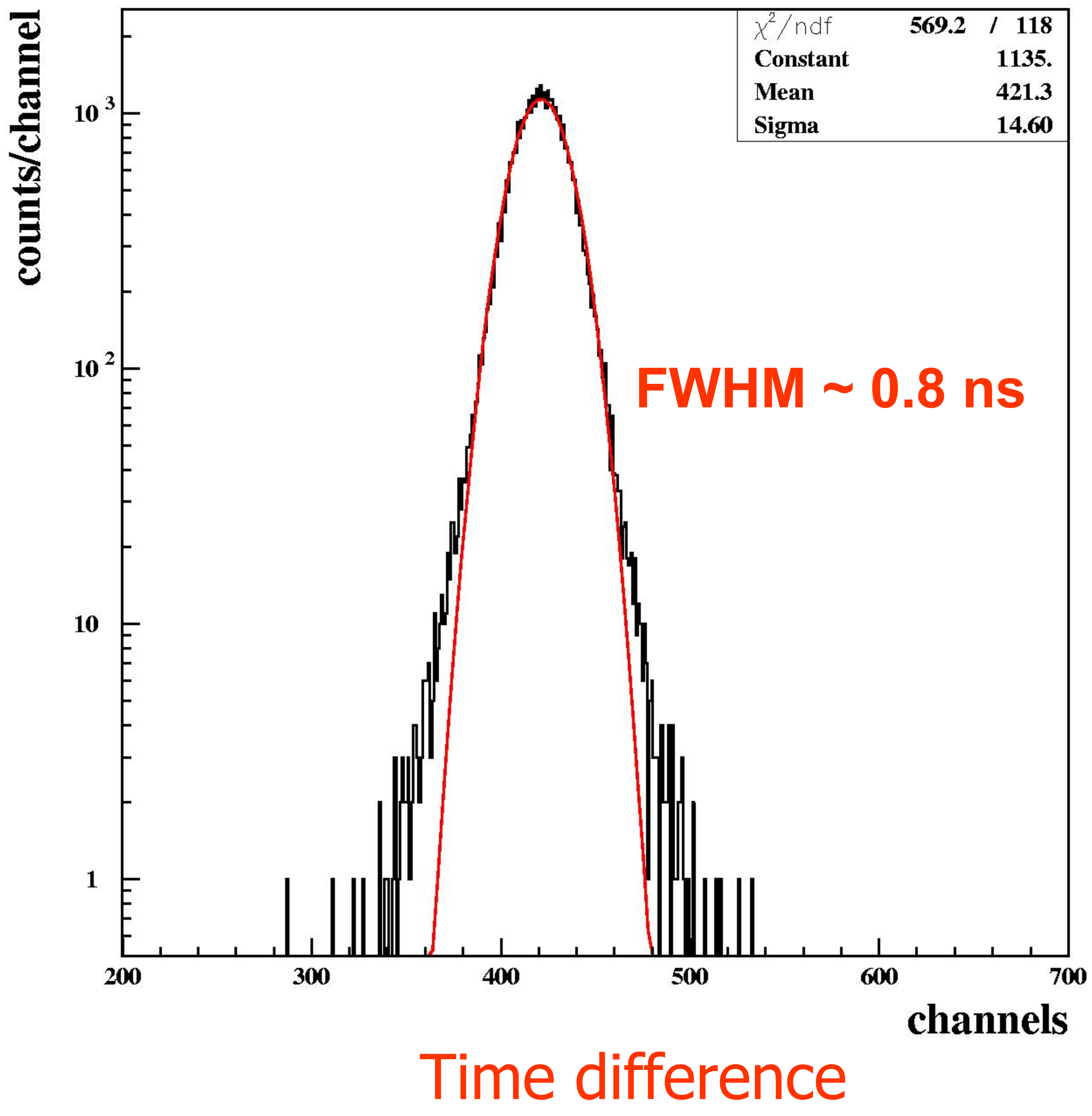
Light attenuation studies with ^{60}Co



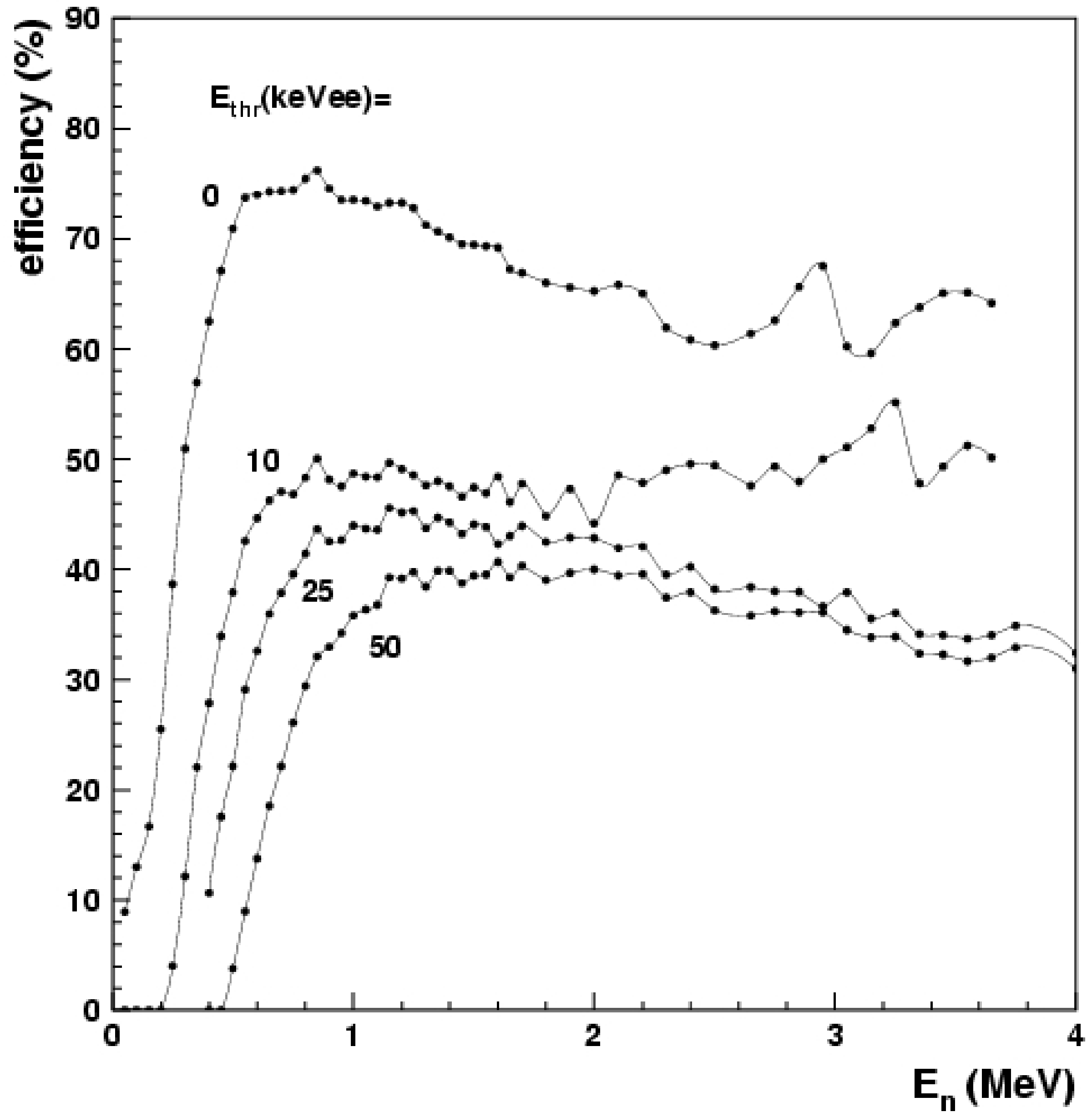
50 % decrease after 100 cm

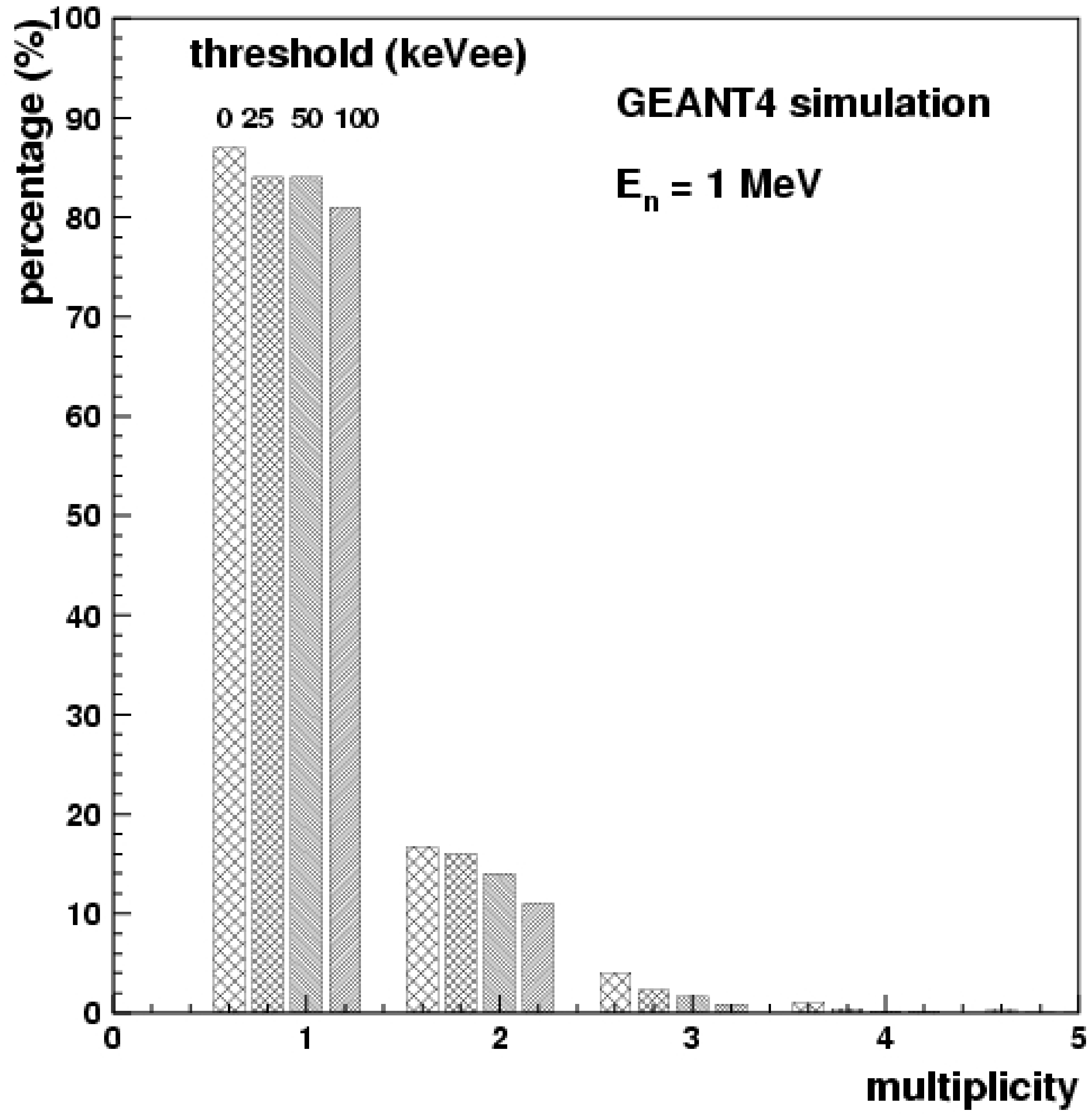
Time resolution
(50 ps/channel)





Monte-Carlo simulations



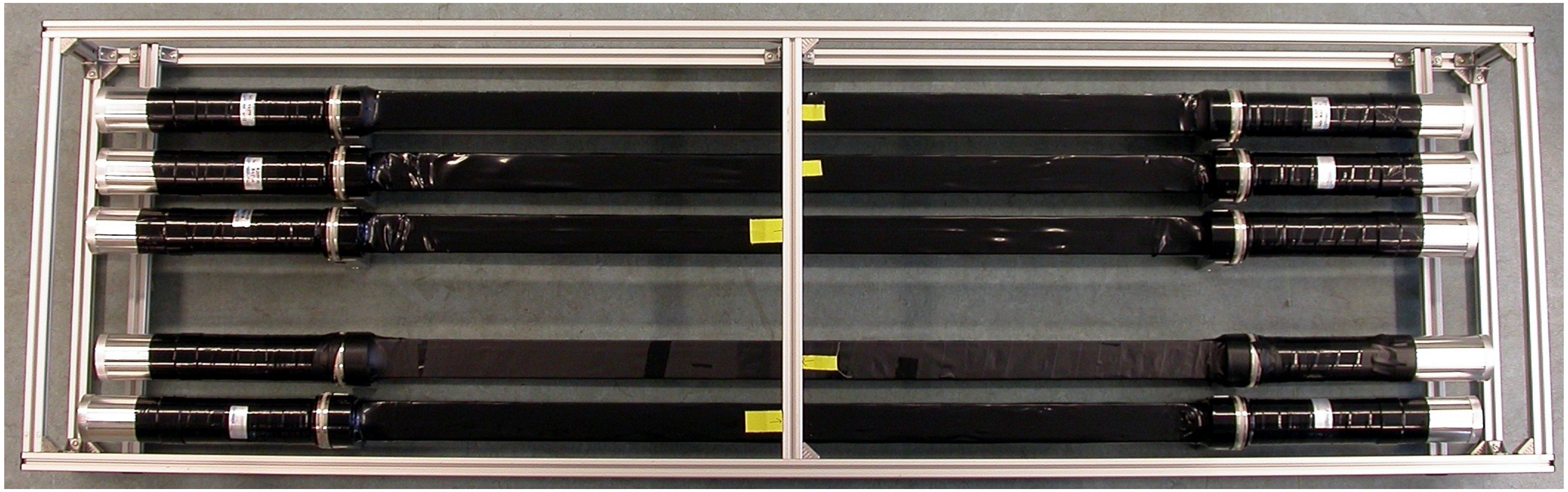


Cross-talk by n-scattering may be possible

FZR-detectors for tof-measurements of MeV n's

Roland Beyer, Rossendorf (Diplom-Arbeit)

- plastic scintillator EJ-200 (ELJEN Technologies)
  (equivalent to BC-408)
- signal rise and fall time in the order of 1 ns
- dimensions: 1000 x 42 x 11 mm^3 or 1000 x 42 x 22 mm^3
- two PMTs per detector: Hamamatsu R2059-01: 2'', 12 stages,
  high gain ($2x10^7$), quartz window
- active HV-bases: iseg-PHQ2059

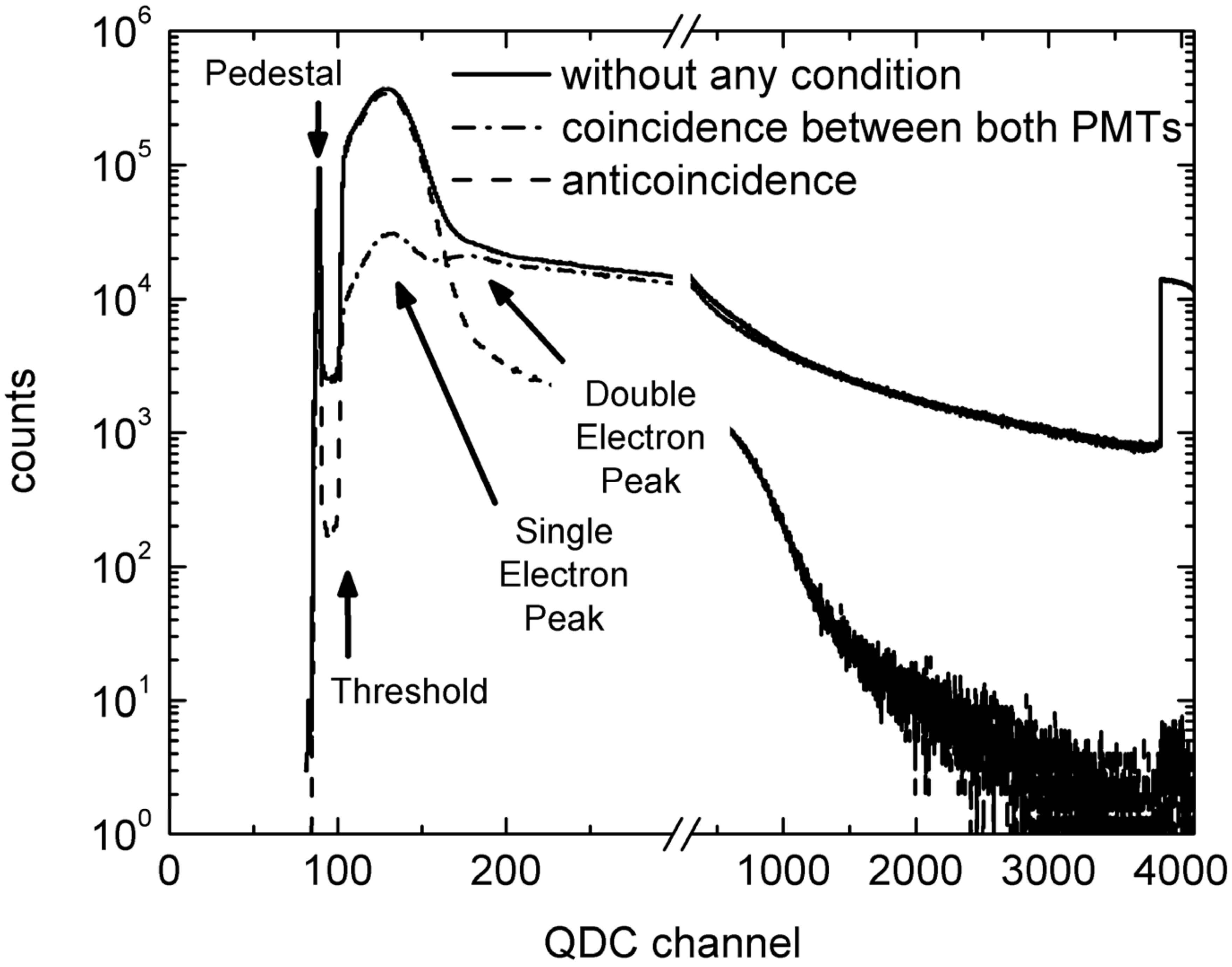


Very low trigger level !

- PMTs are used in highest gain mode (approx. 2×10^7)
- CFD threshold: about 50 mV

➔ Threshold just below the single electron peak

➔ Coincidence of PMTs at both ends required!



Position and time resolution

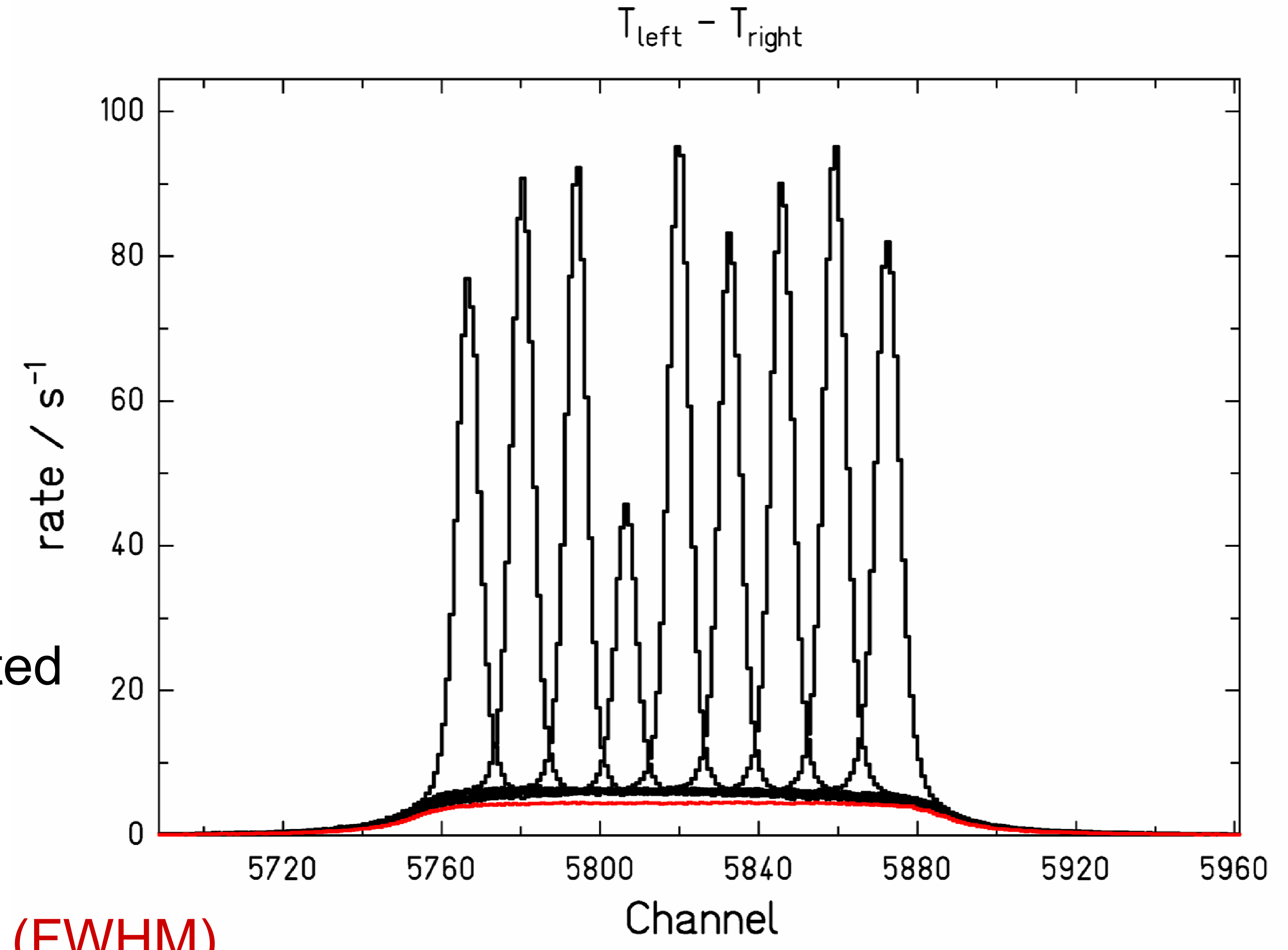
R. Beyer, E. Grosse, K. Heidel, A.R. Junghans, J. Klug, A. Wagner (FZ Rossendorf)

Time of Flight:

$$T_{flight} = \tfrac{1}{2}\left(T_l + T_r - T_{offset1}\right)$$

Position:

$$x = \frac{c_{eff}}{2}\left(T_l - T_r - T_{offset2}\right)$$



Measurements with collimated ^{90}Sr electron source :

c_{eff}: 15.5 cm/ns

Position Resolution: 5.2 cm (FWHM)

Time Resolution: 670 ps (FWHM)

s=2m: ΔE/E (1.2 MeV) = 0.5 %

ΔE/E (24 keV) = 0.07 %

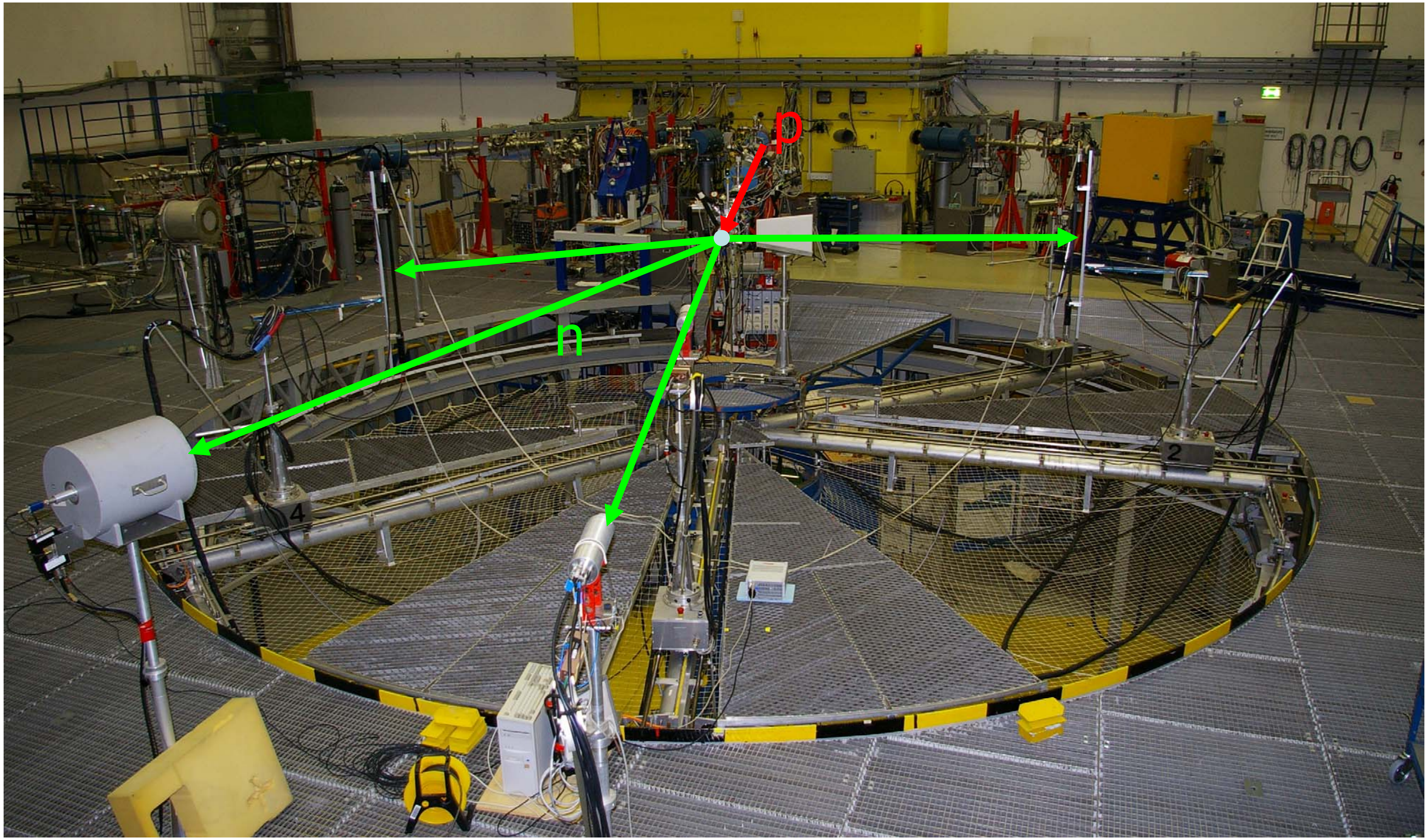
Efficiency calibration

R. Beyer, E. Grosse*, K. Heidel, A.R. Junghans, J. Klug,D. Légrády, A. Wagner (FZ Rossendorf)
&
R. Nolte, S. Röttger (Physikalisch-Technische Bundesanstalt/PTB Braunschweig)

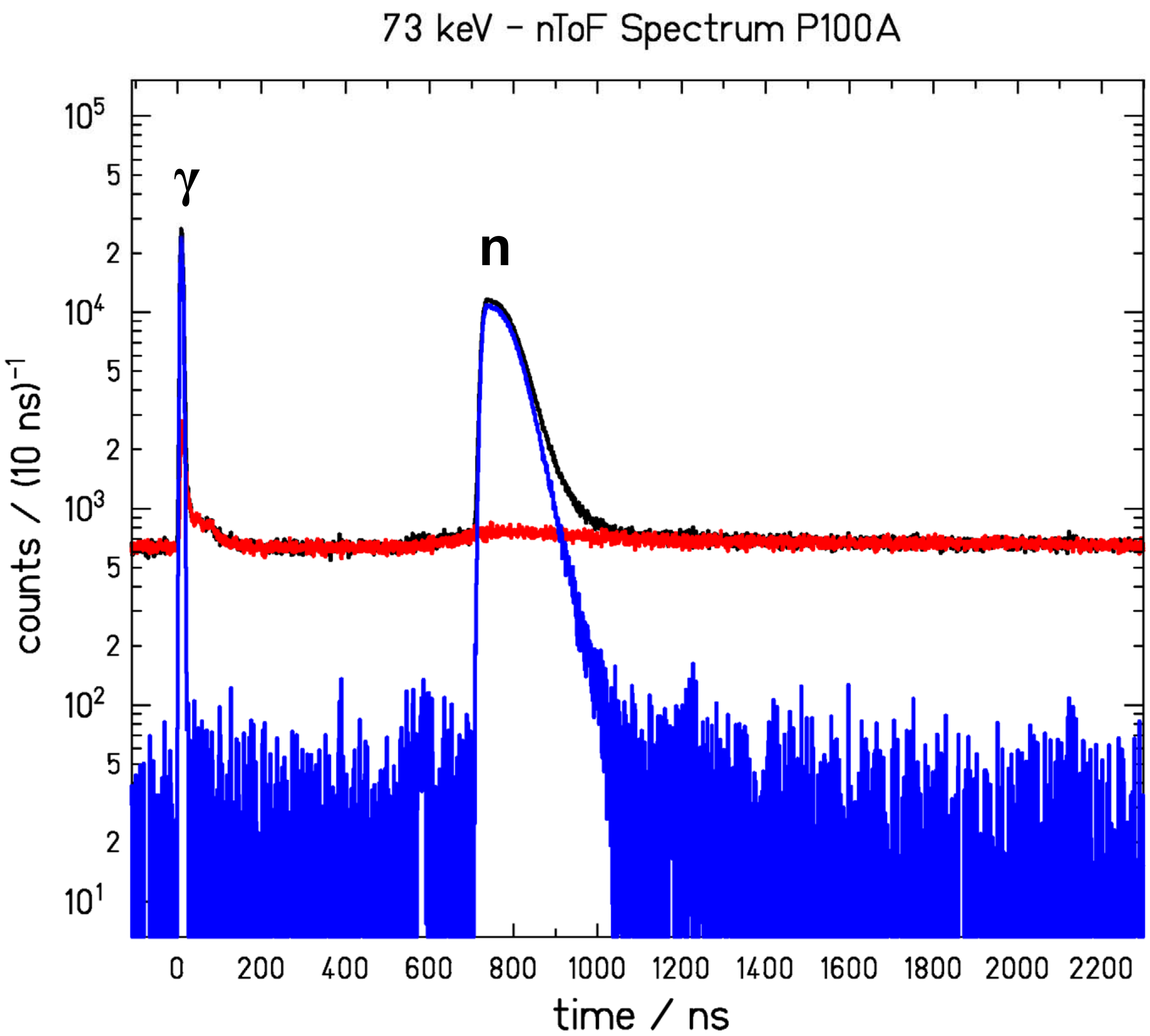
- pulsed proton beam at PTB Braunschweig hits target and produces quasi-mono-energetic neutron fields by (p,n) reactions
- time reference is given by accelerator pulse
- 5 different energies:
  - 1200 keV at 0° from $^{3}H(p,n)^{3}He$, E_p = 2050 keV
  - 560 keV at 0° from $^{7}Li(p,n)^{7}Be$, E_p = 2303 keV
  - 150 keV at 0° from $^{7}Li(p,n)^{7}Be$, E_p = 1952 keV
  - 73 keV at 50.5° -"-
  - 24 keV at 76.5° -"-
- measurements with and without shadow bar (PE) to determine the background of scattered neutrons

Efficiency calibration

at PTB Braunschweig



Measured tof-spectrum



without shadow bar

with shadow bar (normalized)

difference spectrum

400 ns → 294 keV

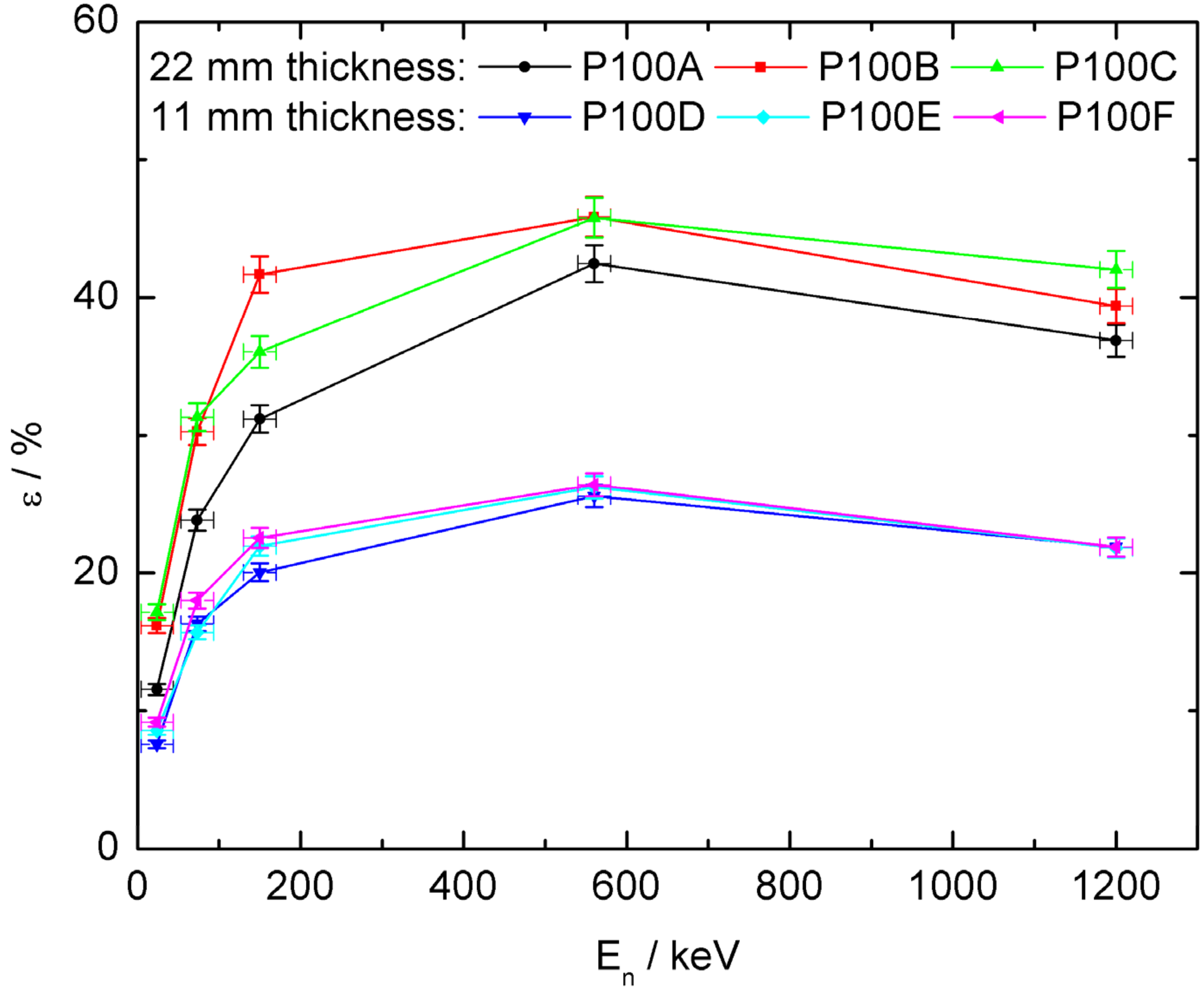
800 ns → 74 keV

1200 ns → 33 keV

1600 ns → 18 keV

Preliminary results of efficiency calibration

E_n / keV	**ε** /% @22mm
1200 ± 8	36.9 ± 1.2
560 ± 8	42.5 ± 1.3
150 ± 8	31.2 ± 1.0
73 ± 8	23.8 ± 0.8
24 ± 8	11.6 ± 0.4



Δε/ε ~ 3.2 %

→ mainly caused by uncertainties of the neutron fluence

→ high efficiency down to some tens of keV and good time resolution of 670 ps (FWHM)

Preliminary results for **MeV neutrons**

as detected in tof-scintillators of 1 m length and 22 mm thickness

- time resolution: 670 ps (FWHM)
- s = 1 m ➔ ΔE/E = 1 % @ 1.2 MeV

  3 % @ 10 MeV

  9 % @ 90 MeV
- ε ~ 35 % @ > 0.2 MeV . . . Δε/ε ~ 3 %
- MCNP - simulations to understand and minimize background due to n-scattering

Detectors for tof-measurements of GeV n's

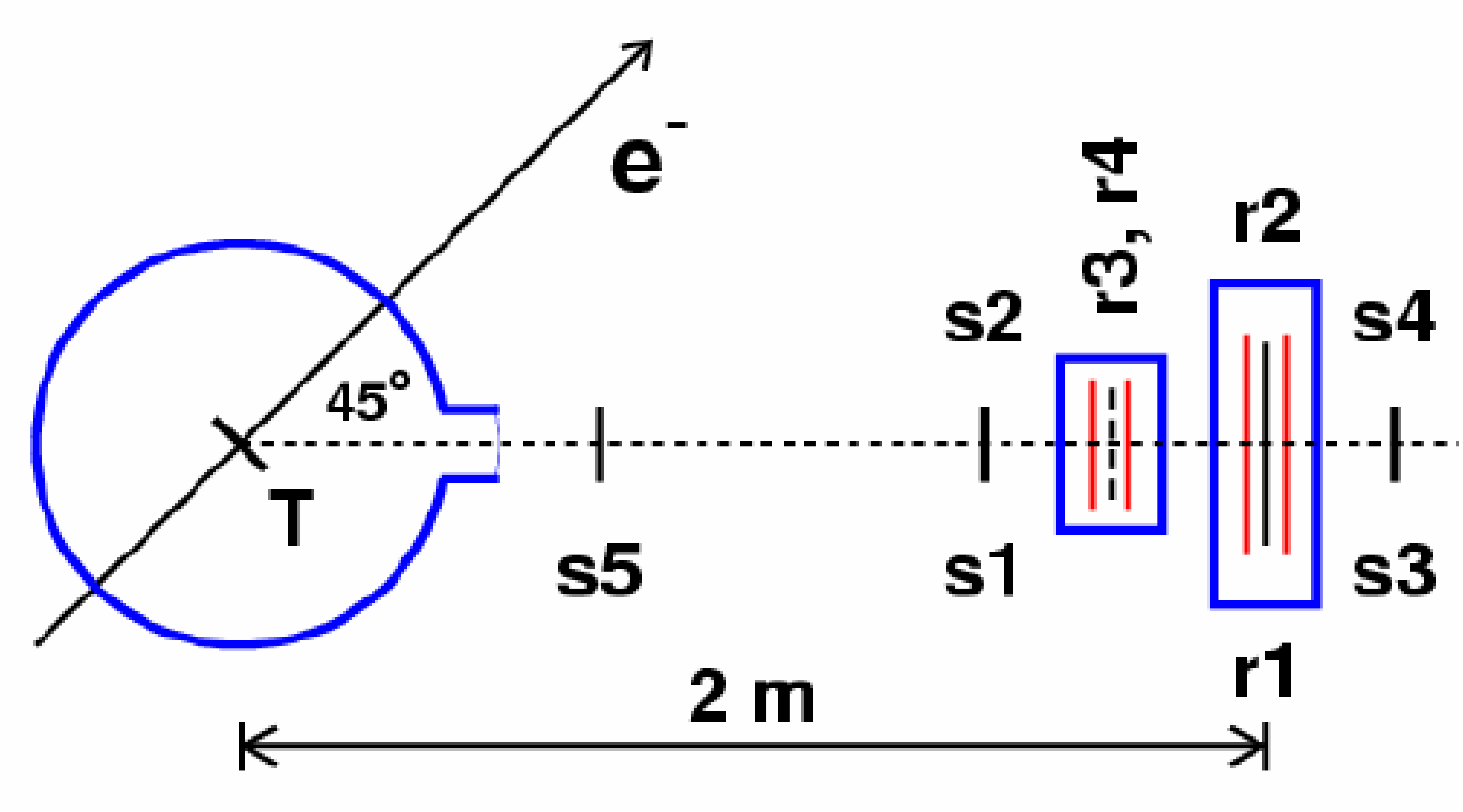
- As charged particle production cross sections are well below 1b one has to introduce converter planes between many charged particle detectors (cf. LAND).
- As the neutrons may produce many charged particles at different positions these positions have to be determined accurately in all planes to allow averaging and tracking.
- Because of the high neutron energy a flight path of >10 m is envisaged and consequently a large detector surface.
- High granularity has to be realized.
- The best possible time resolution is aimed for.

➔ **Scintillators may not be the ultimate choice**

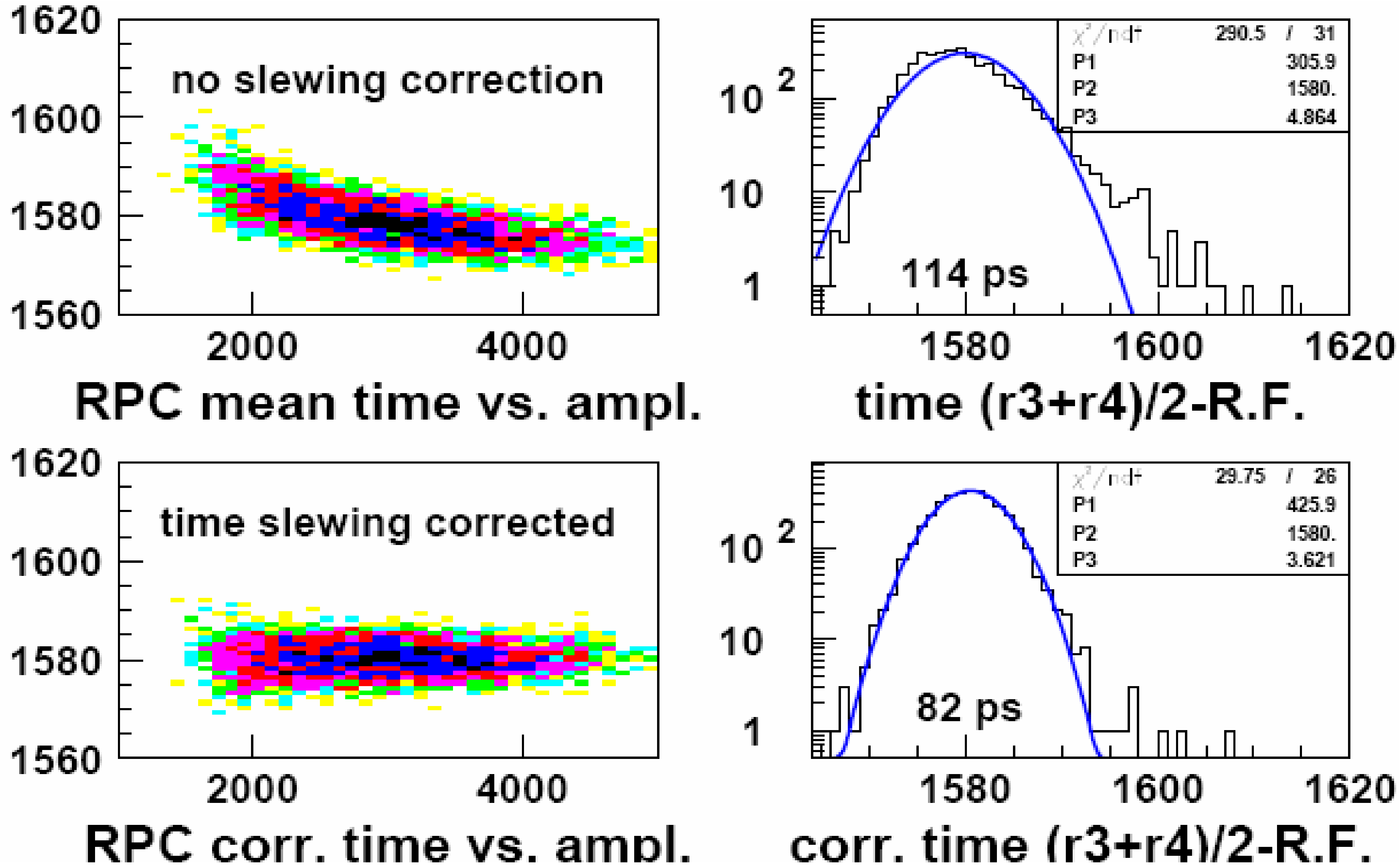
Rossendorf timing RPC detectors

- tests at the electron linac ELBE -

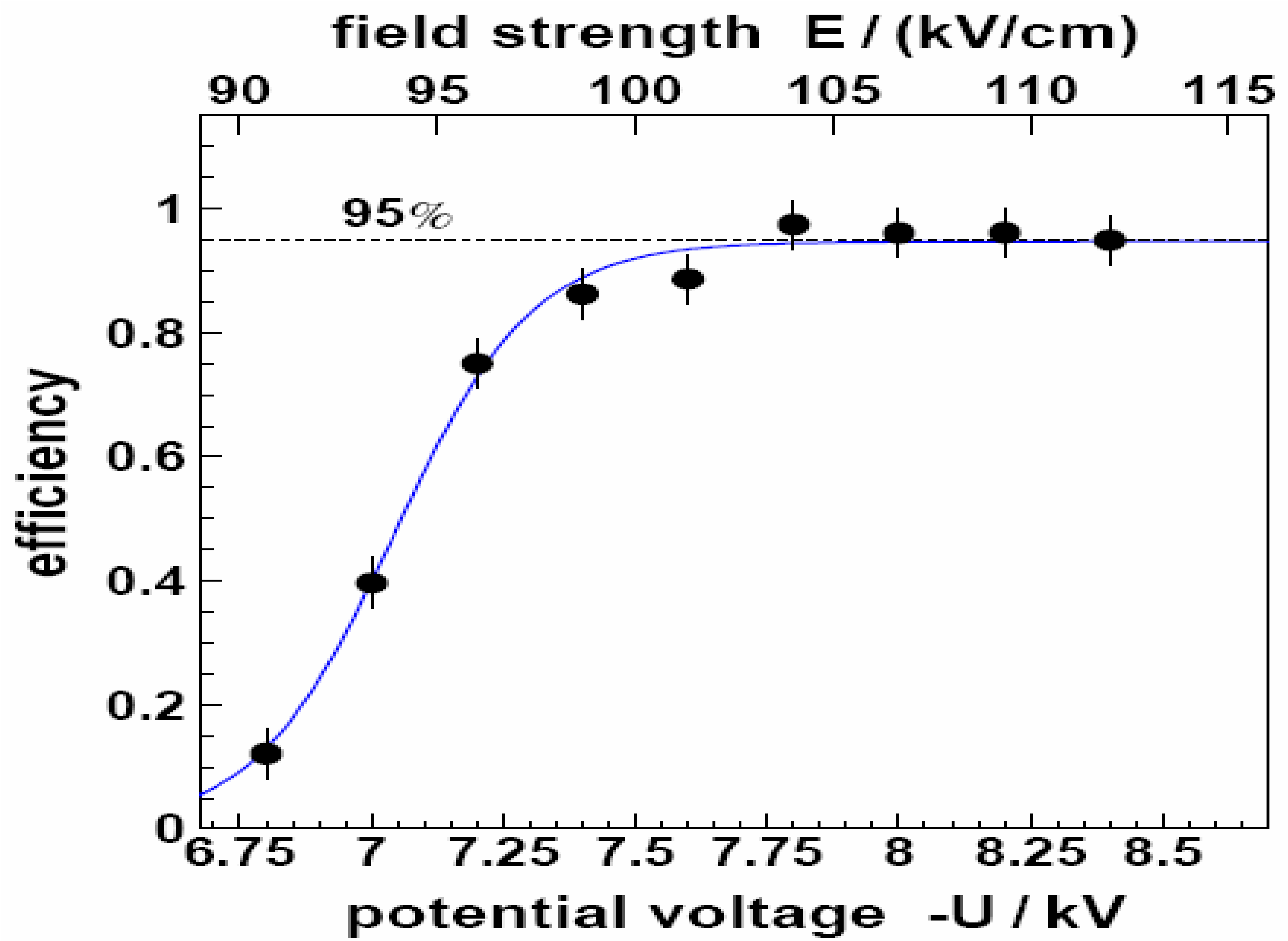
R. Kotte et al., NIMA 2006



Correction for walk and position

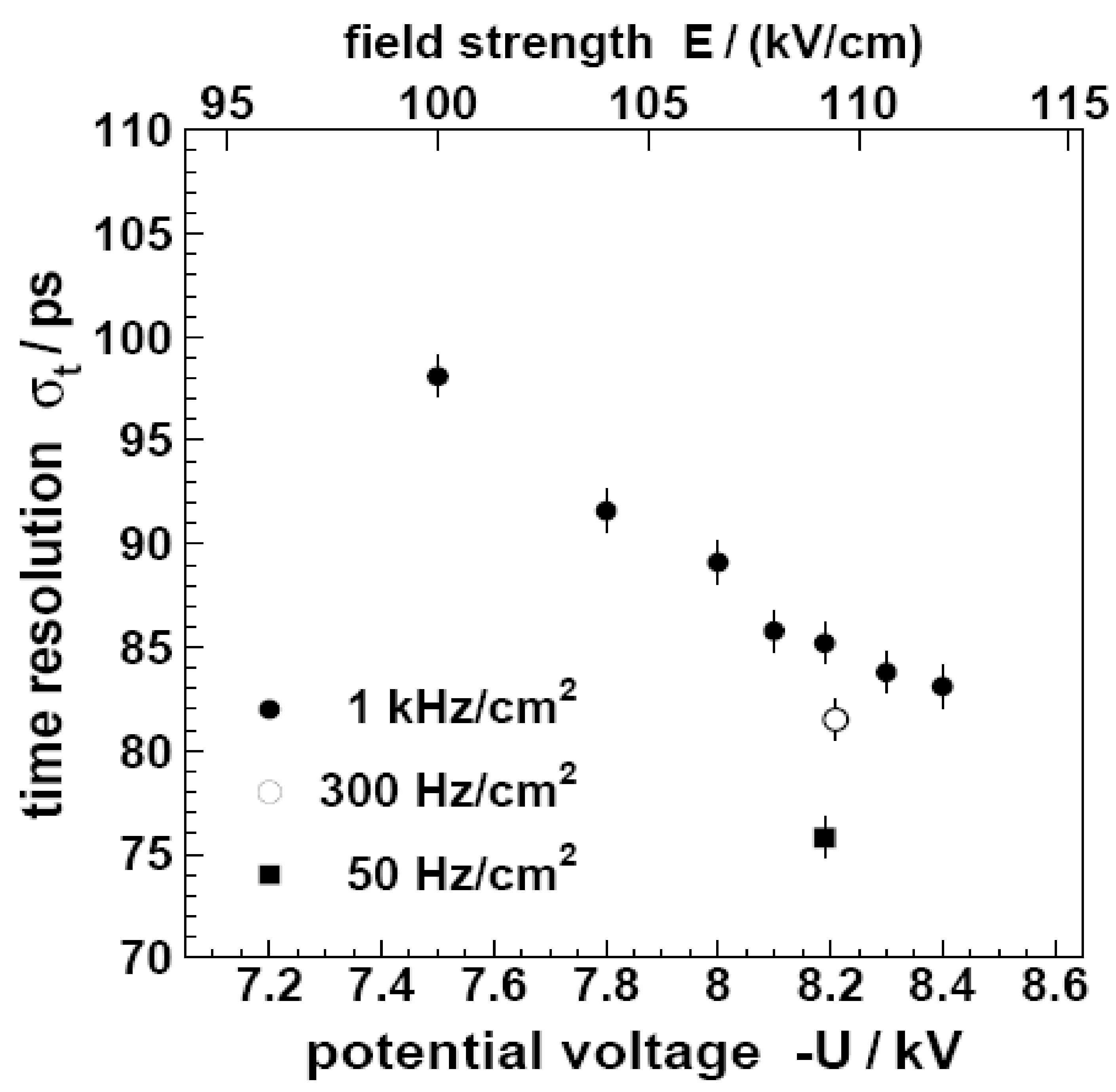


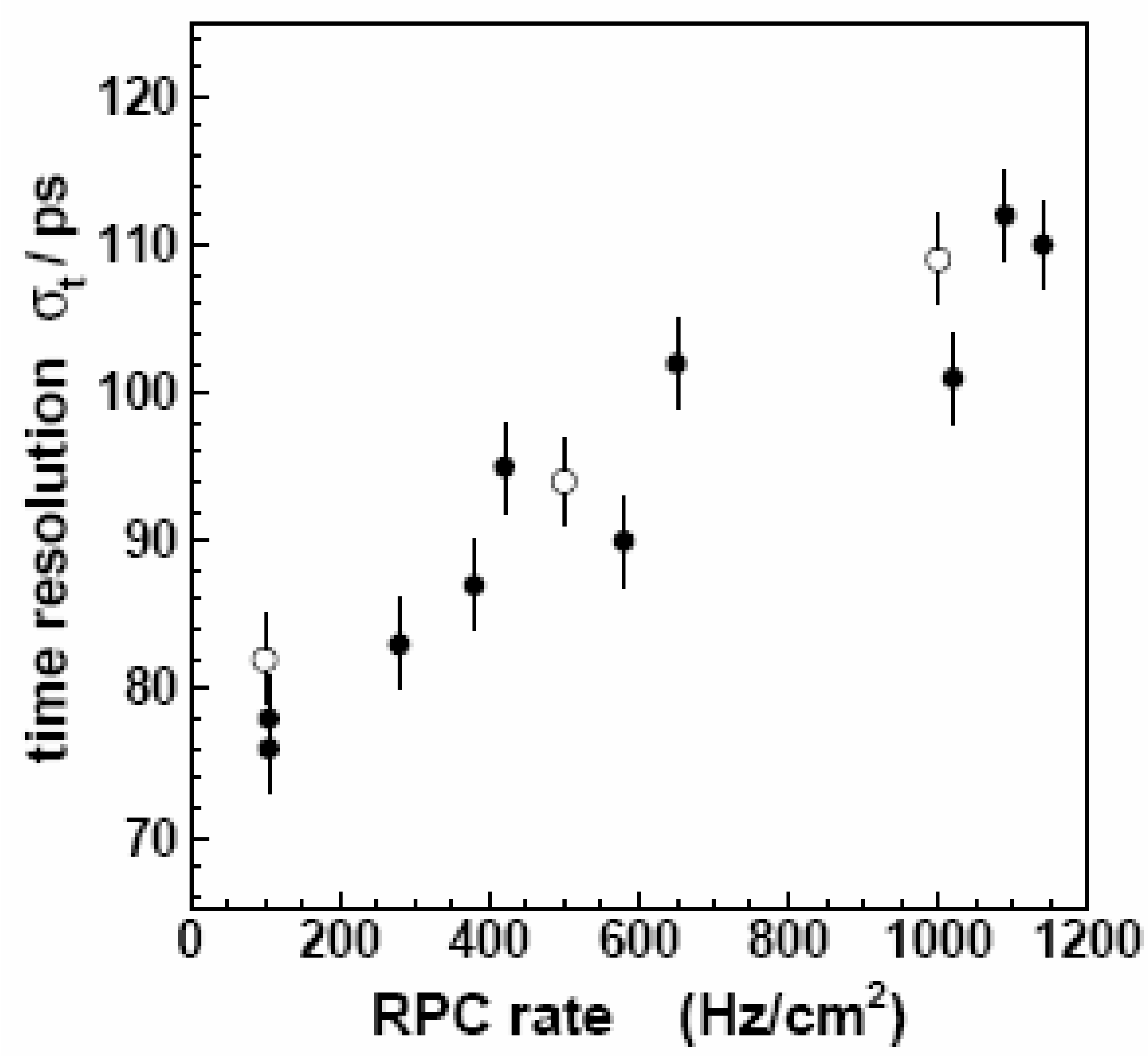
Plateau curve



Time resolution in dependence of

electric field and count rate





Preliminary results **for RPC-detectors** of possible use for GeV neutrons

- time resolution: < 200 ps (FWHM) @ 400 cts/cm²s
  < 300 ps (FWHM) @ 1200 cts/cm²s
- s = 10 m ➔ $\Delta E/E$ = 0.3 % @ 100 MeV
  0.5 % @ 300 MeV
  0.7 % @ 1000 MeV
- position resolution Δx < 10mm
- coincidence curves are Gaussian for > 2 decades
- MCNP calculations started to predict overall efficiency **ε**
  for various converter materials and geometries