Detection of neutrons with kinetic energy from 24 keV to 1.2 MeV with long plastic scintillators

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Neutron Detector Development

Time of flight experiments at ELBE:

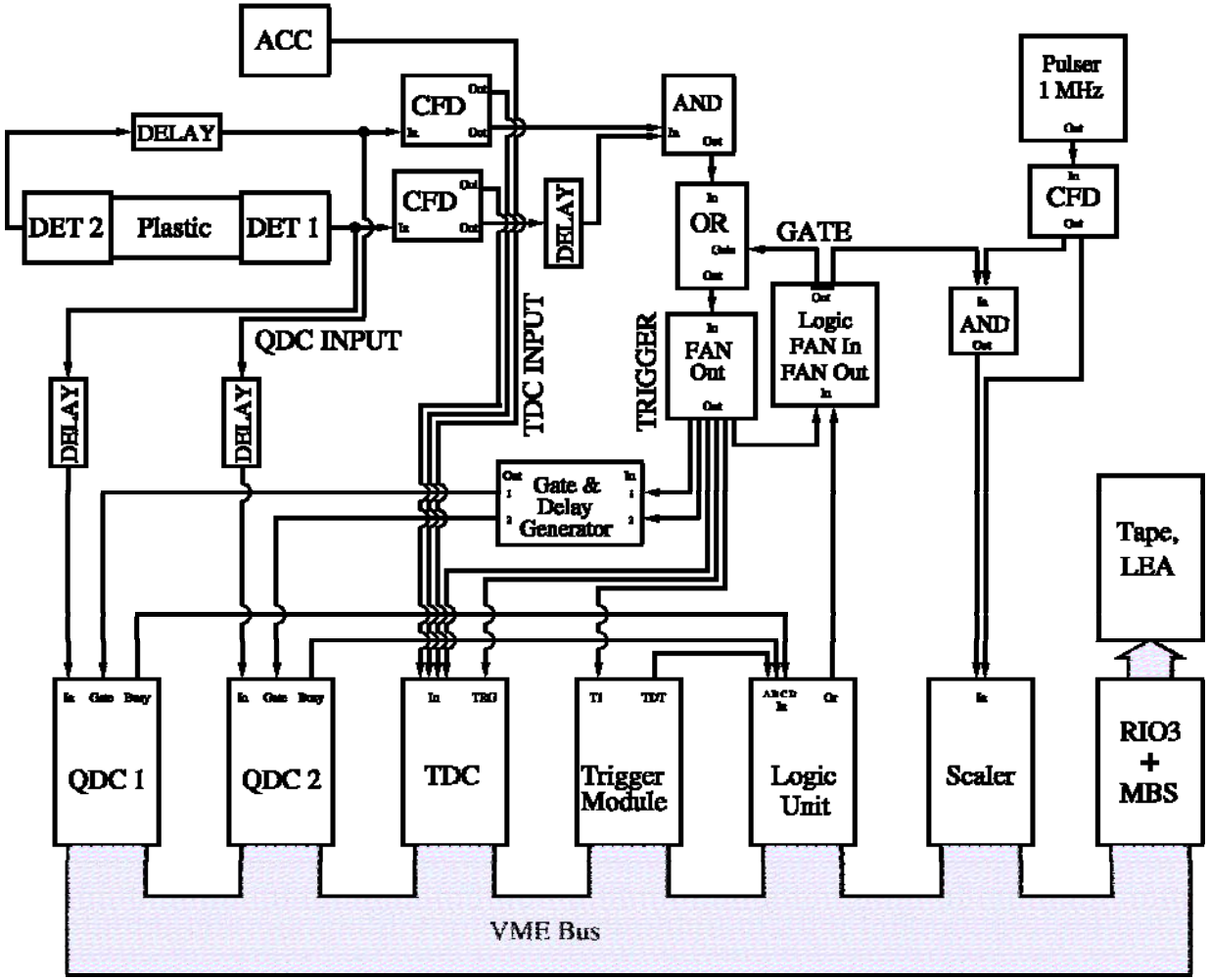
- Neutron time of flight experiment:
  electron beam repetition rate/bunch length 500 kHz / 5 ps
  neutron kinetic energy range ca. 100 keV – 5 MeV
  total neutron flux 2×10^6 /s
  flight path = 4.0 m
  ➔ $\Delta t < 1$ ns required for $\Delta E/E = 1\%$

- Deuteron breakup d(γ,n)p close to the threshold
  with bremsstrahlung
  ➔ high efficiency for neutron detection

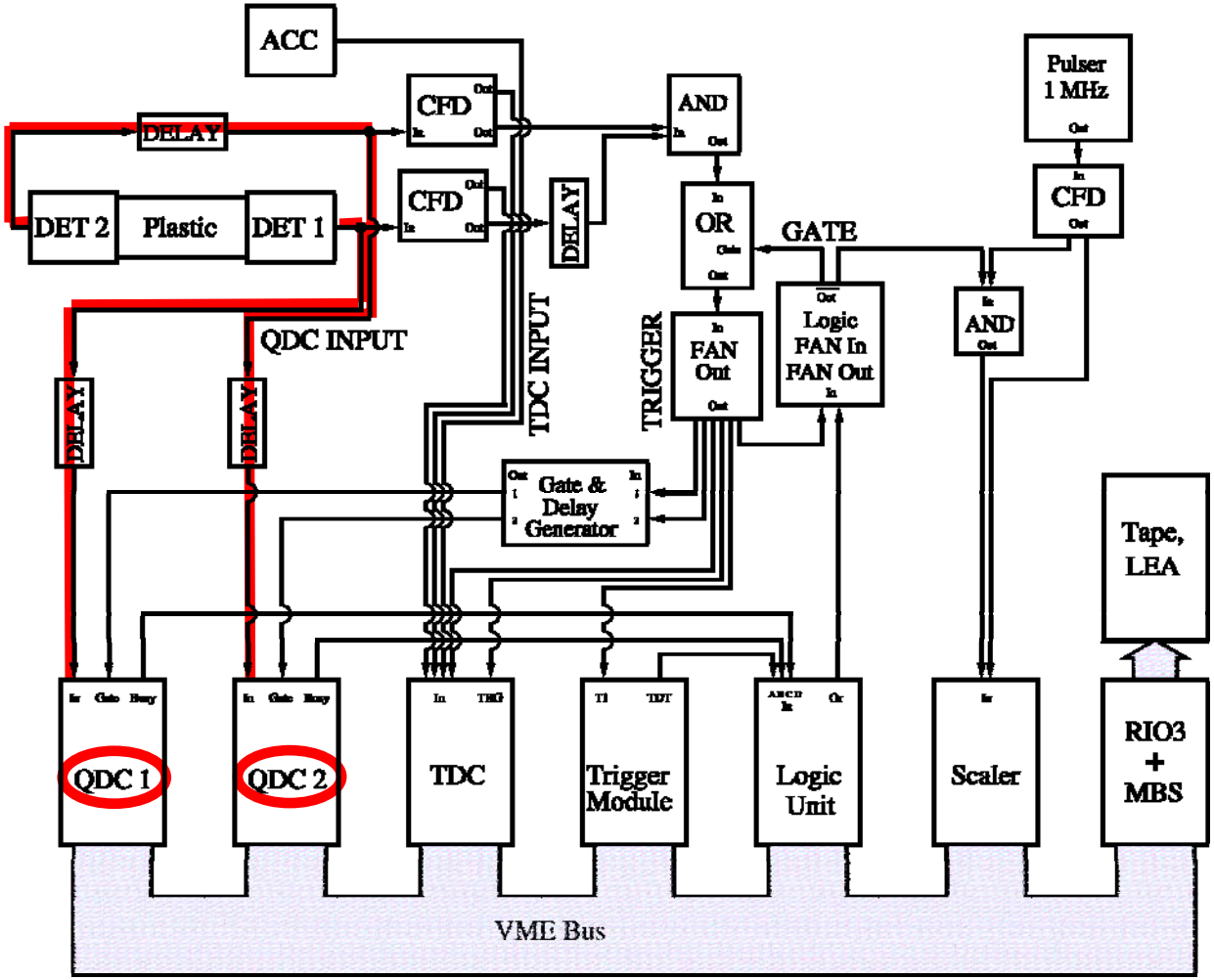
The Detectors

- plastic scintillator material EJ-200 (ELJEN Technologies) (equivalent to BC-400)
  ➔ 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
- 2 PMTs per detector: Hamamatsu R2059-01: 2’’, 12 stages, high gain ($2x10^7$), quartz window
- active HV-bases: iseg-Spezialelektronik PHQ2059

Electronics Setup

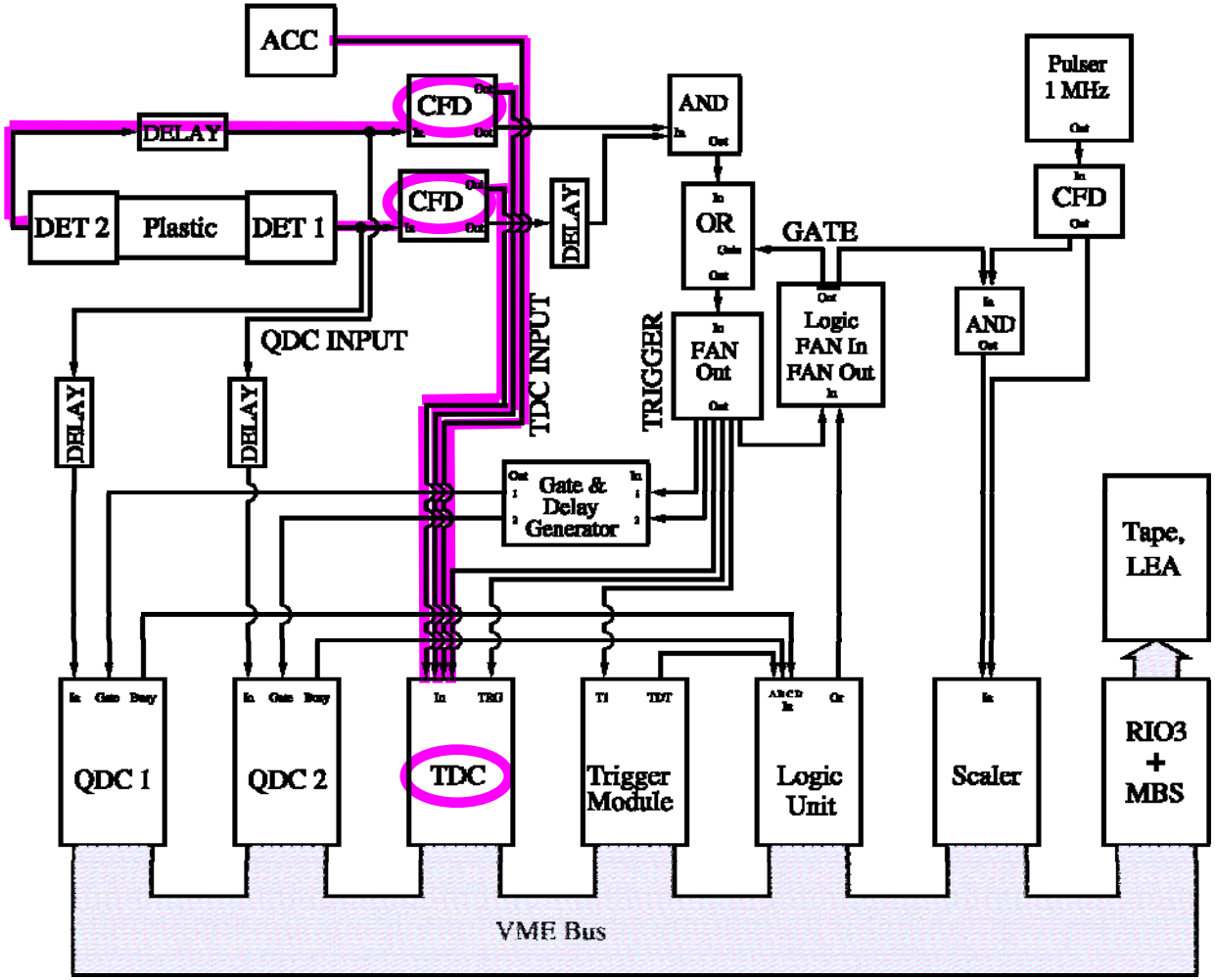


Electronics Setup – Energy Branch



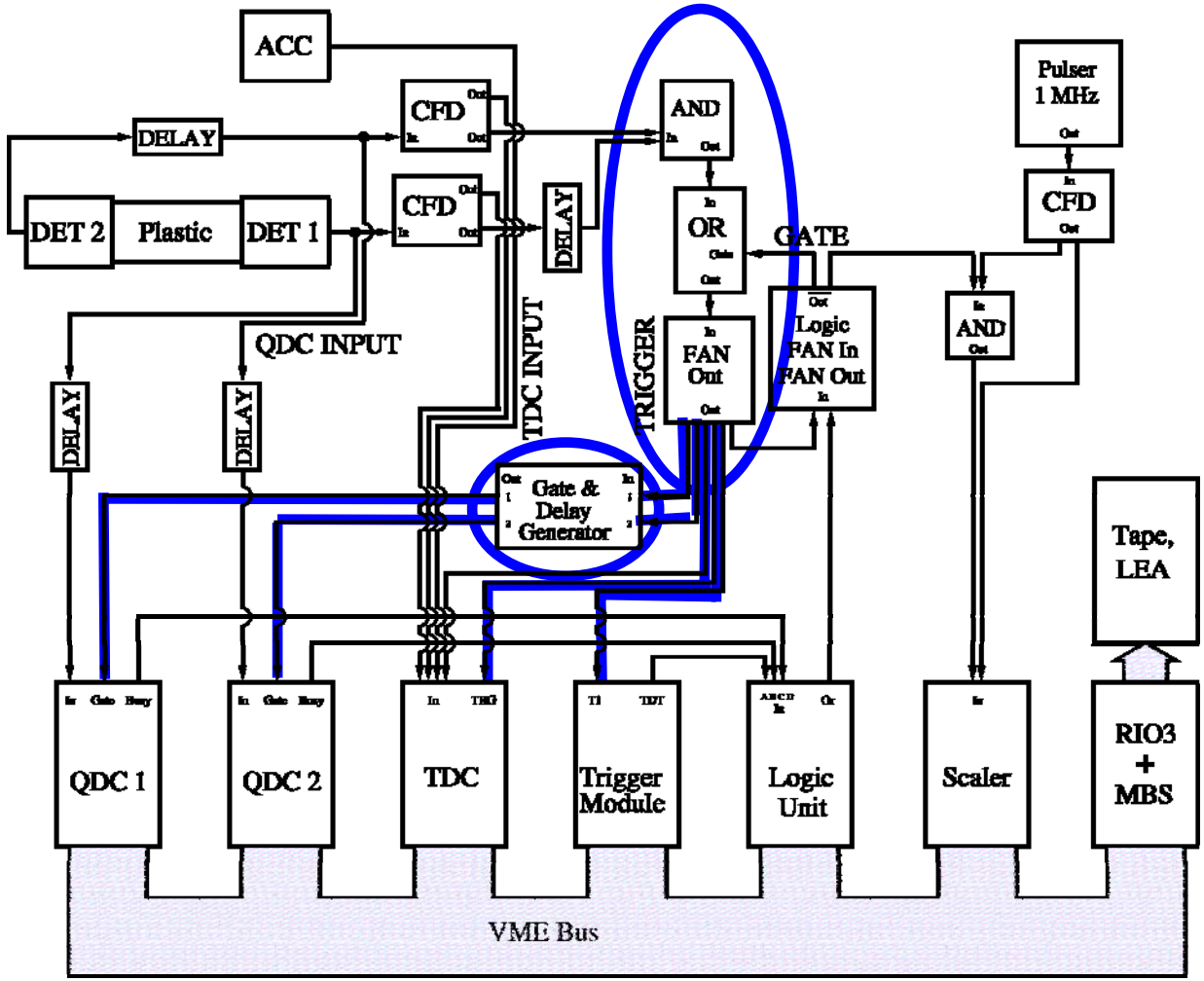
- CAEN V792 32ch QDC

Electronics Setup – Time Branch



- CAEN V792 32ch QDC
- CAEN V1190A 128ch 100ps Multihit TDC
- CFDs: FZR-Development (CFT5386): for fast signals with rt/ft of 1 ns → walk of only 400 ps for amplitudes from 10 mV to 1 V

Electronics Setup – Trigger Branch



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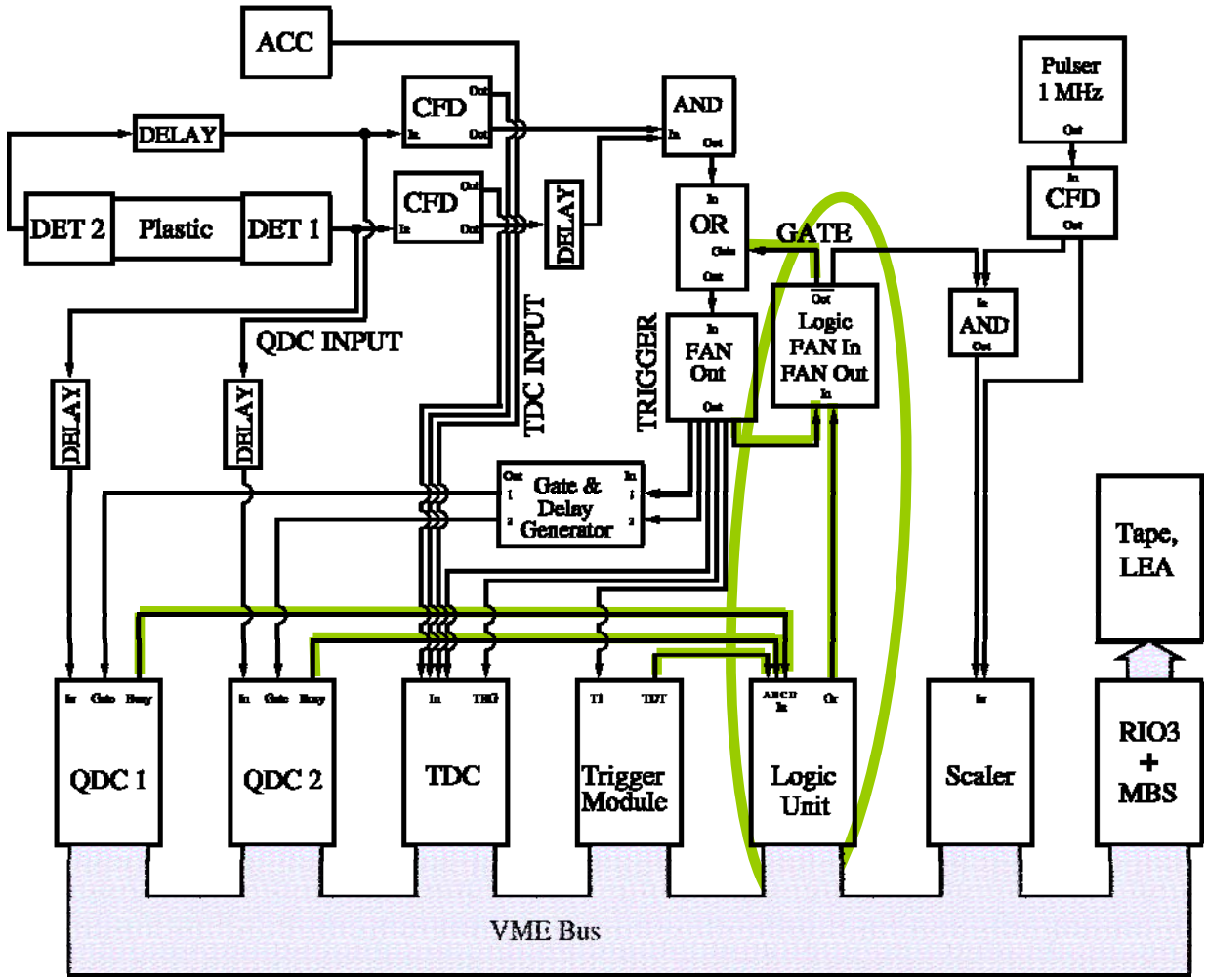
Electronics Setup – Trigger Gate Branch



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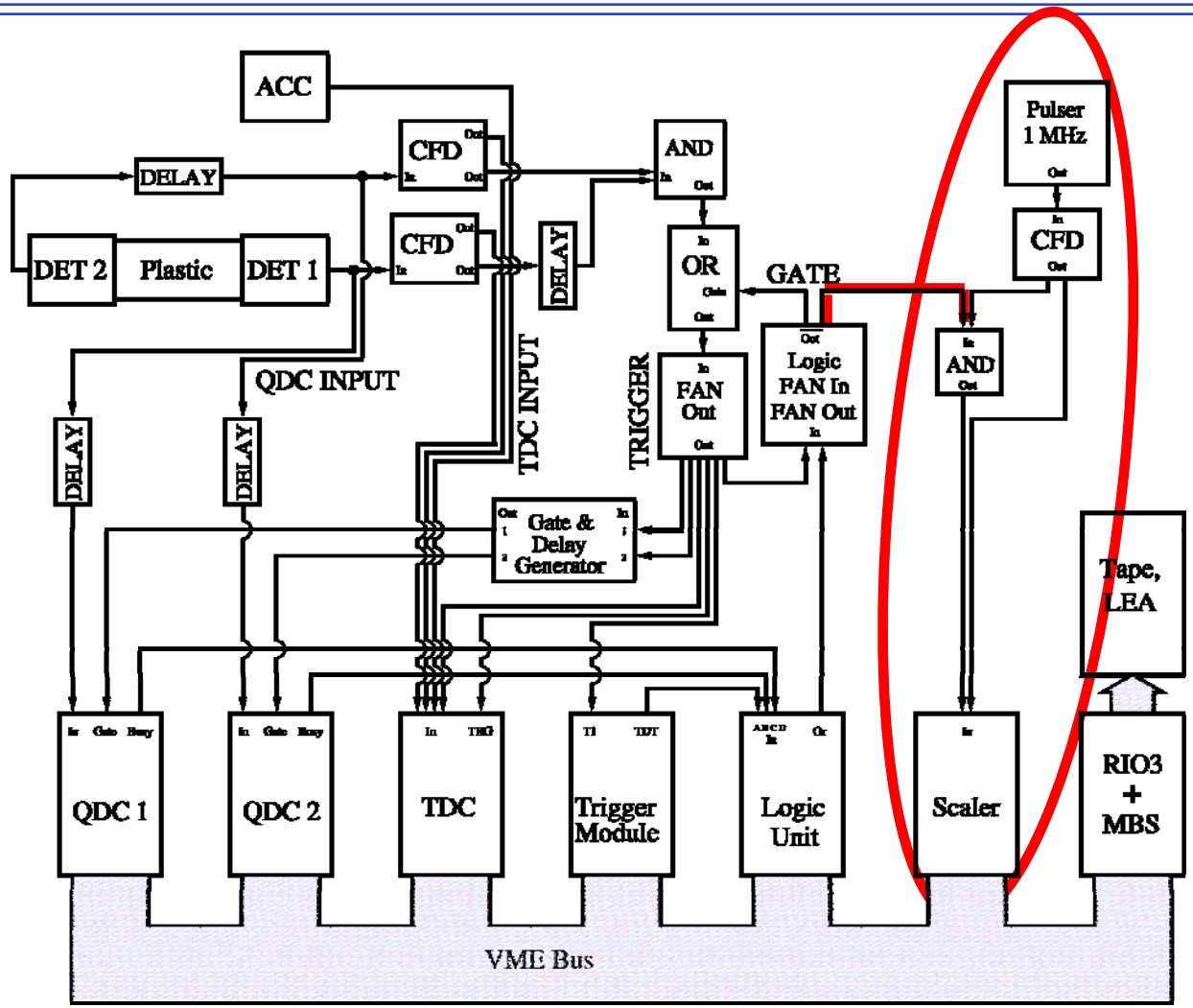
Electronics Setup – Dead Time Branch



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- CAEN V1190A 128ch 100ps Multihit TDC
- CFDs: FZR-Development (CFT5386): for fast signals with rt/ft of 1 ns → walk of only 400 ps for amplitudes from 10 mV to 1 V
- readout is done by CES RIO3 Power PC running MBS*
- typ. dead time 80 μs per event

* from GSI, www.gsi.de, courtesy of N. Kurz & H. Essel

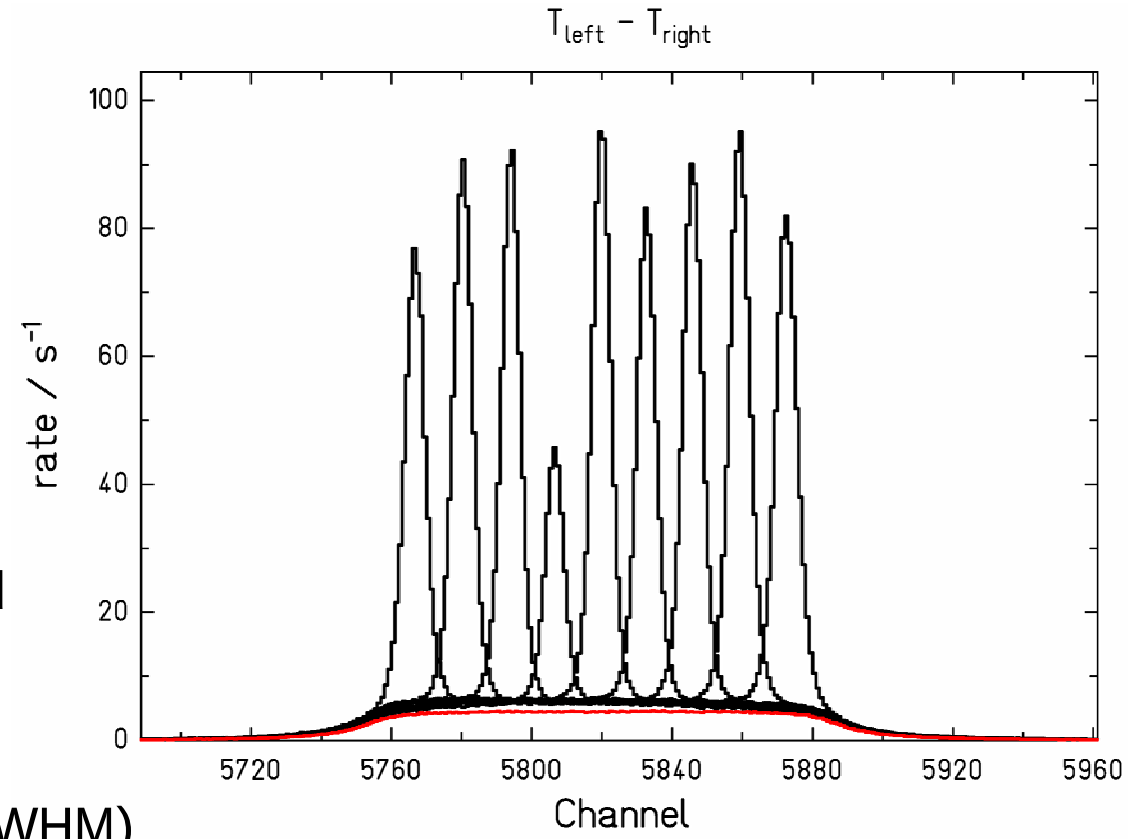
Position and Time Resolution

Time of Flight:

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

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)

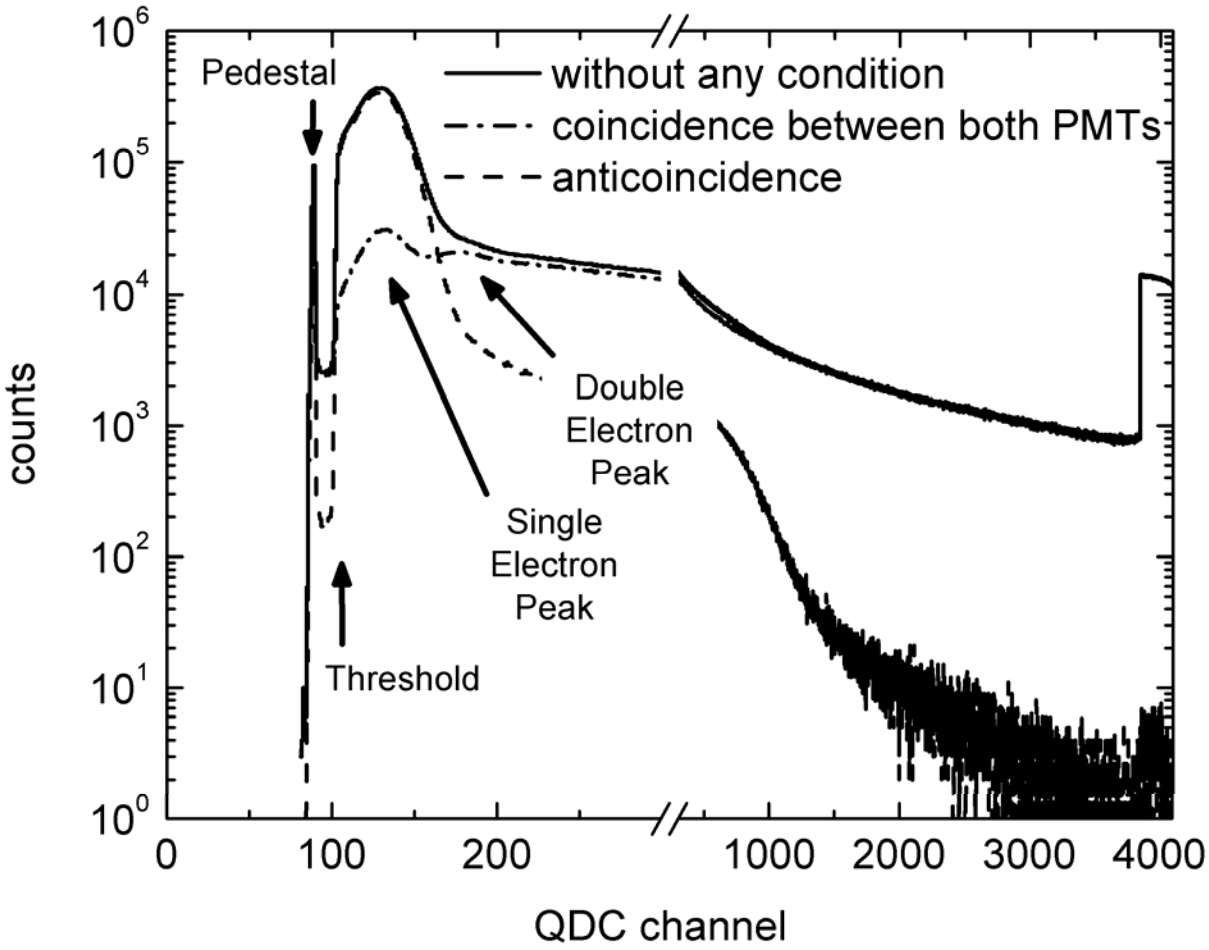
➔ ΔE/E (1.2 MeV) = 0.5 % (s=4m)

ΔE/E (24 keV) = 0.07 %

The Trigger Level

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

➔ Threshold just below the single electron peak

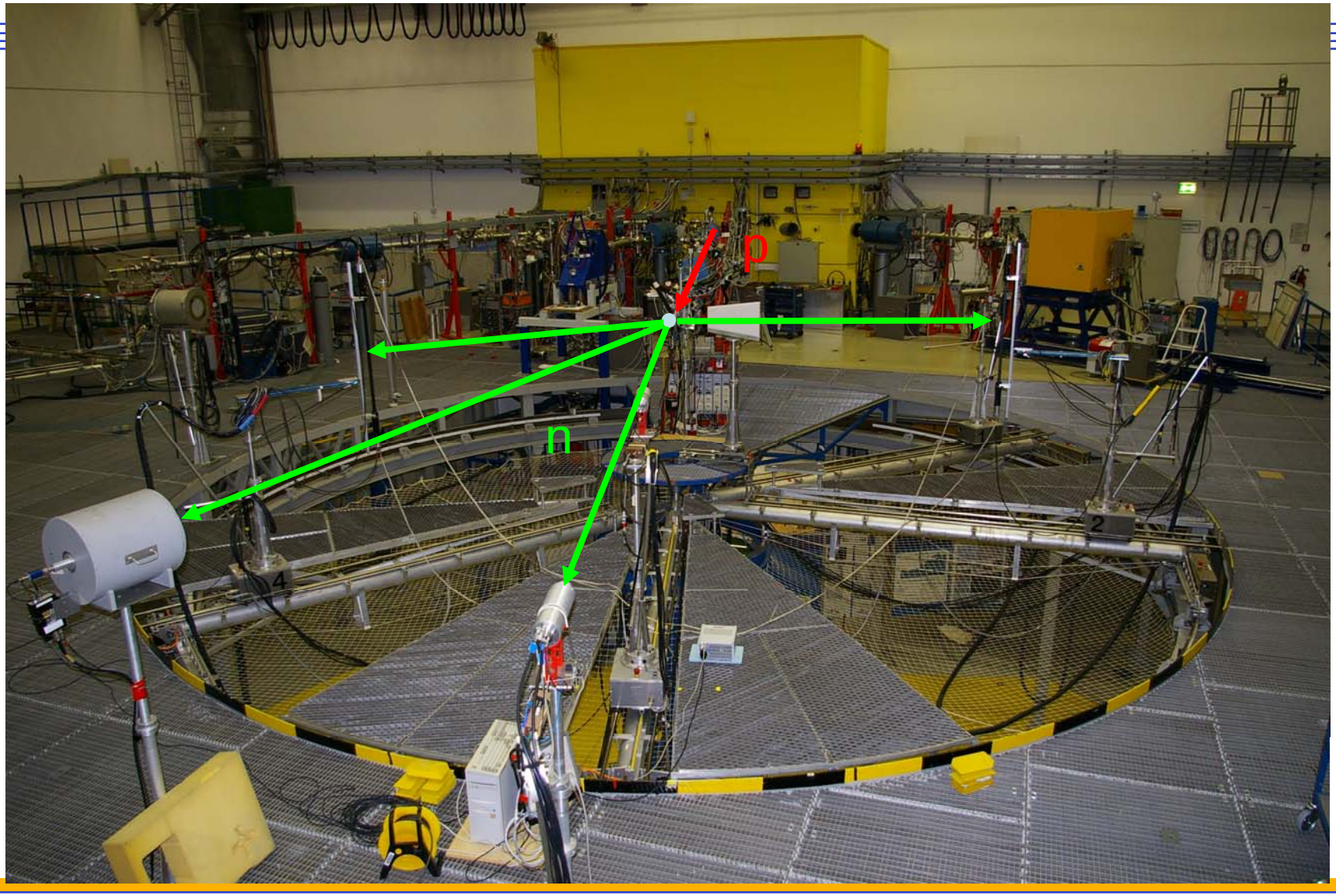


Efficiency Calibration

- done at PTB[1] Braunschweig (Germany)
- pulsed proton beam 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

[1] Physikalisch-Technische Bundesanstalt

Setup for Efficiency Calibration



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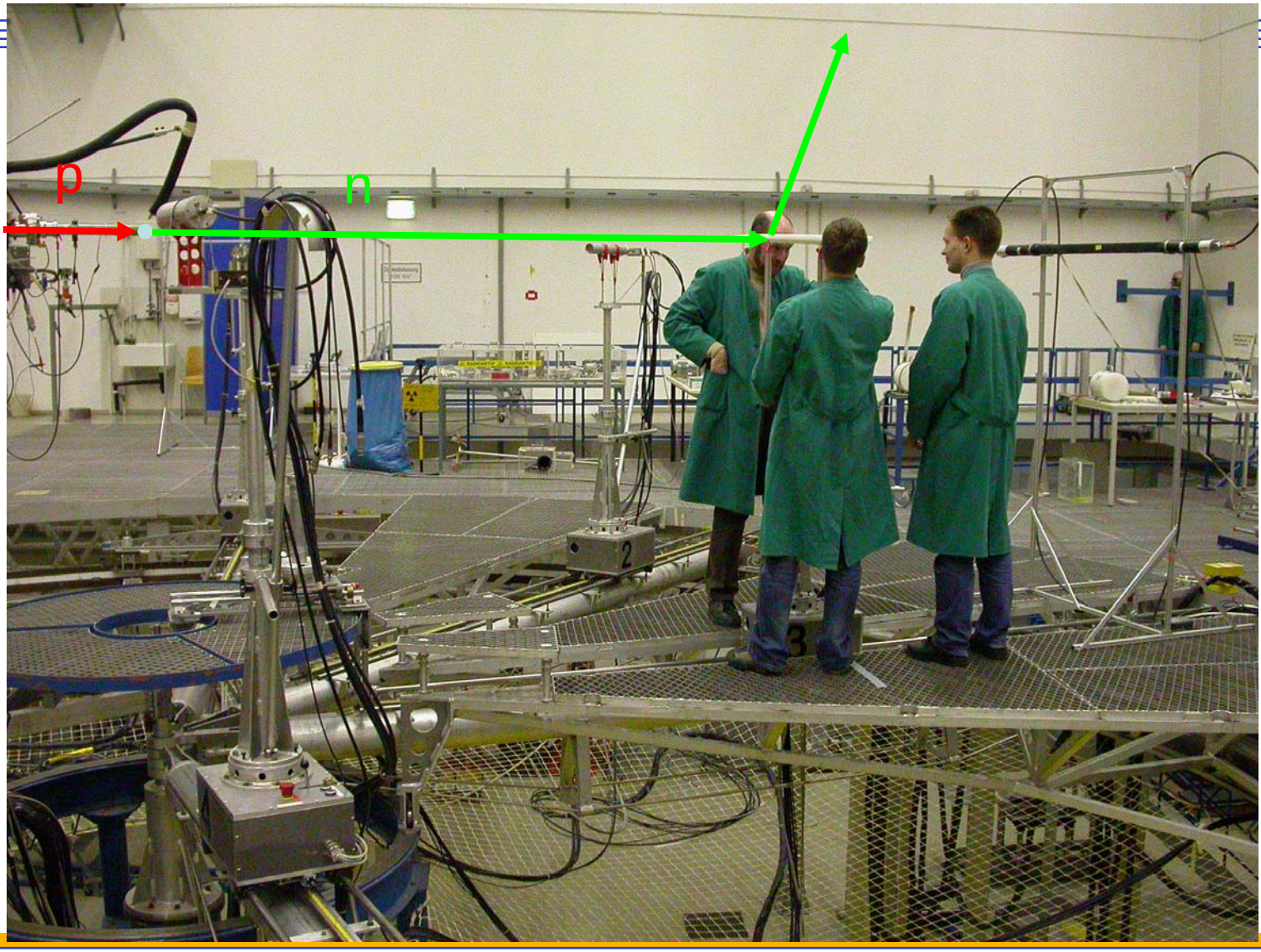

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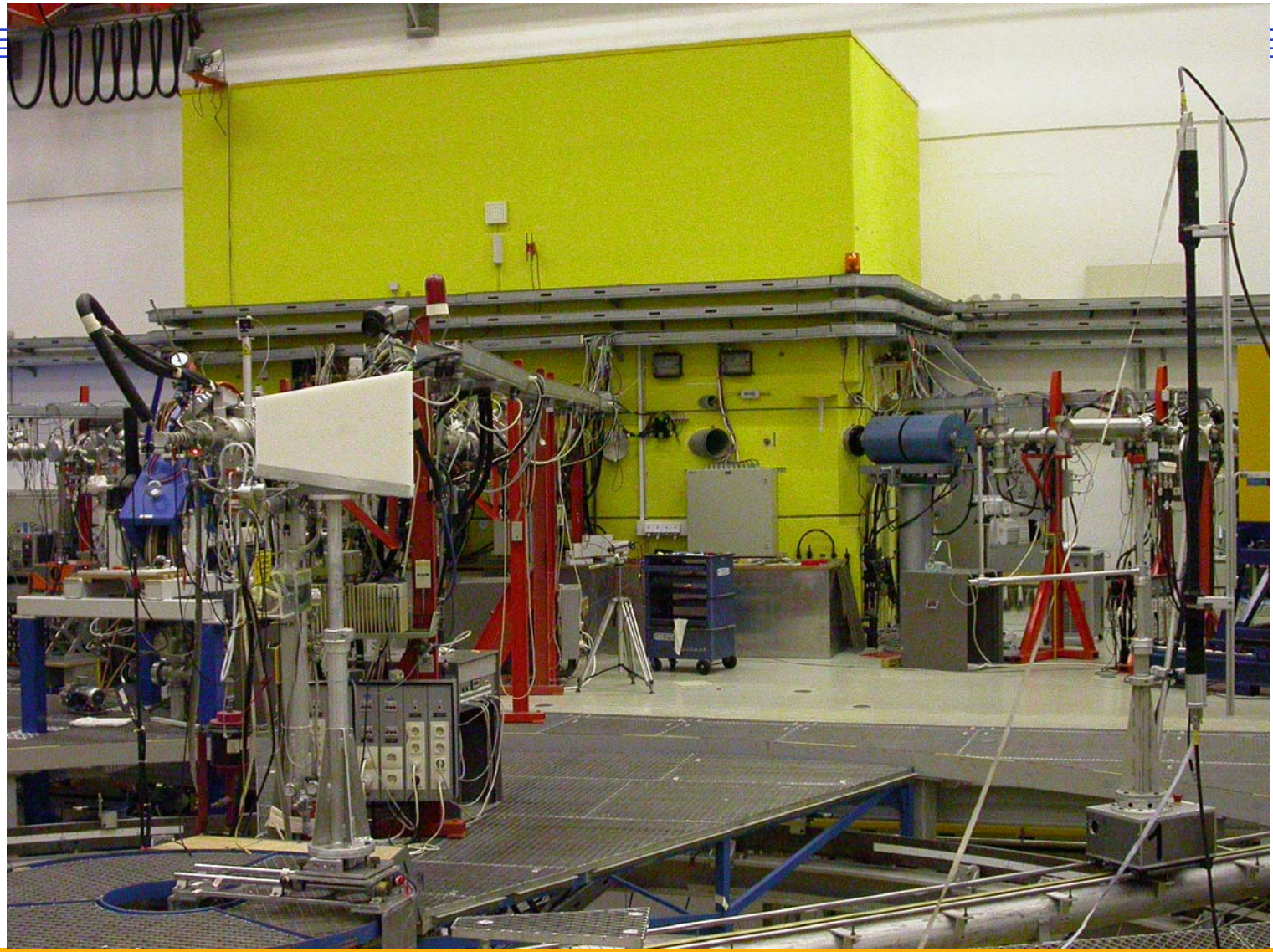
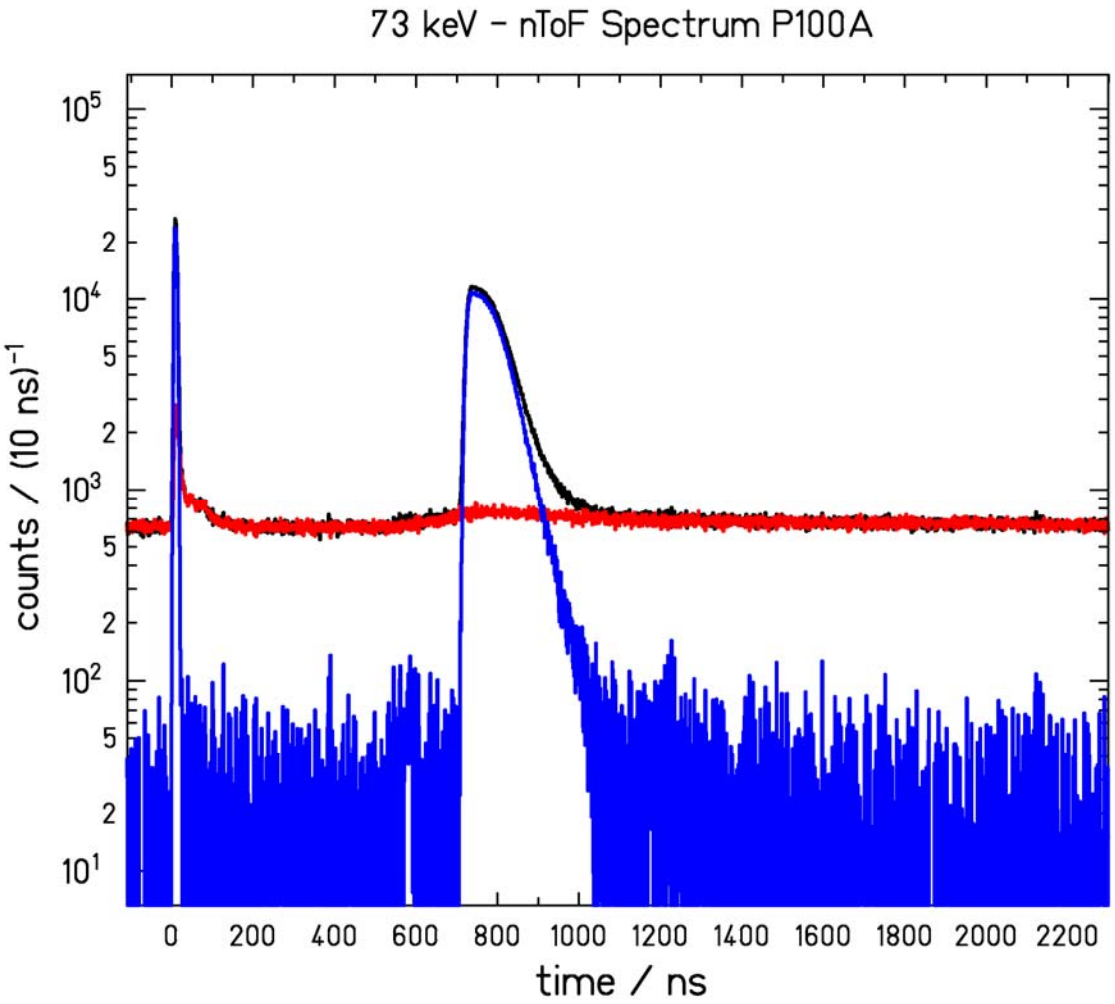


Measured ToF-Spectrum



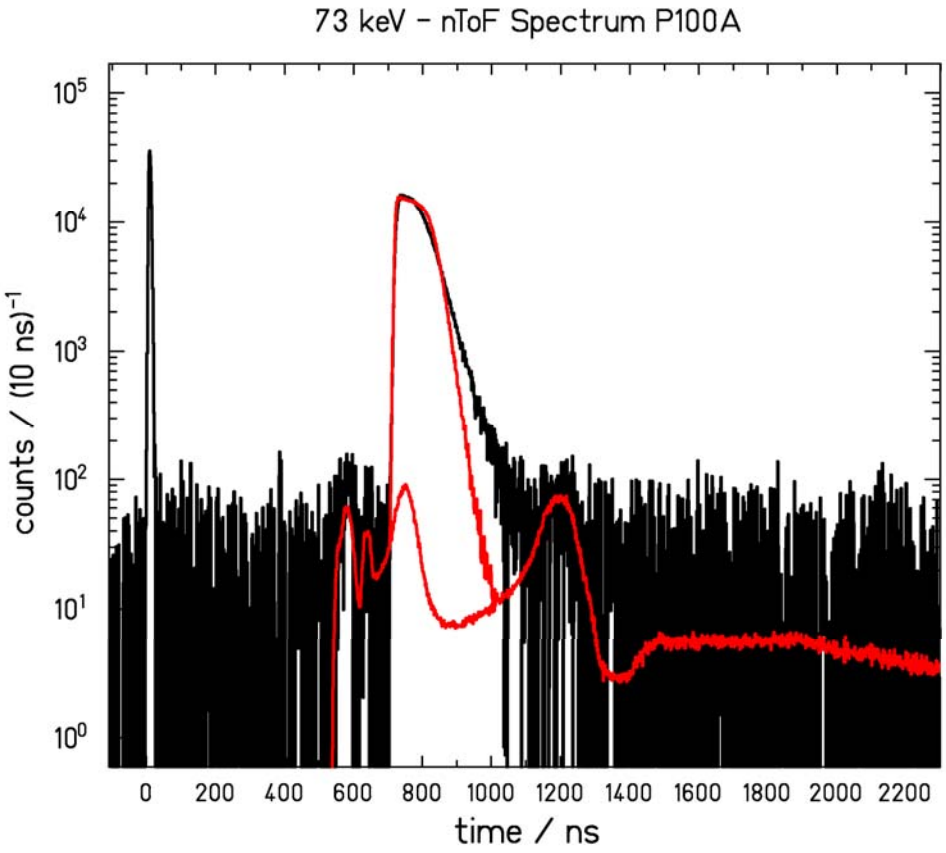
— without shadow bar

— with shadow bar (normalized)

— difference spectrum

400 ns ➔ 294 keV
800 ns ➔ 74 keV
1200 ns ➔ 33 keV
1600 ns ➔ 18 keV

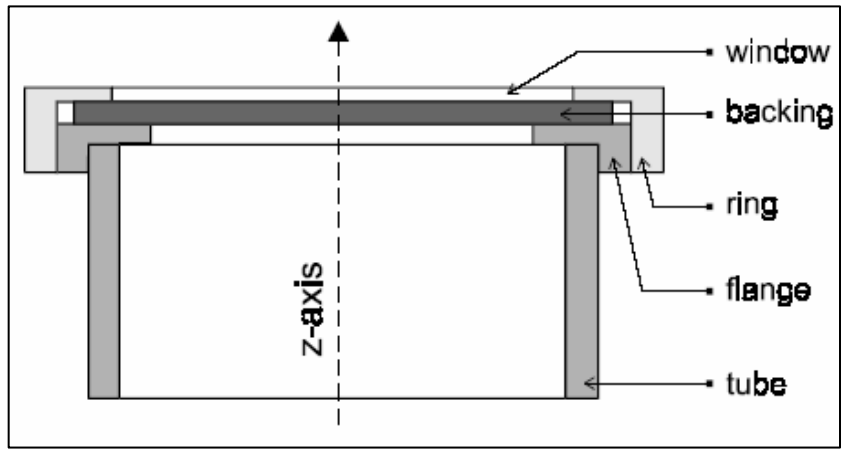
Simulation of the Source Spectra



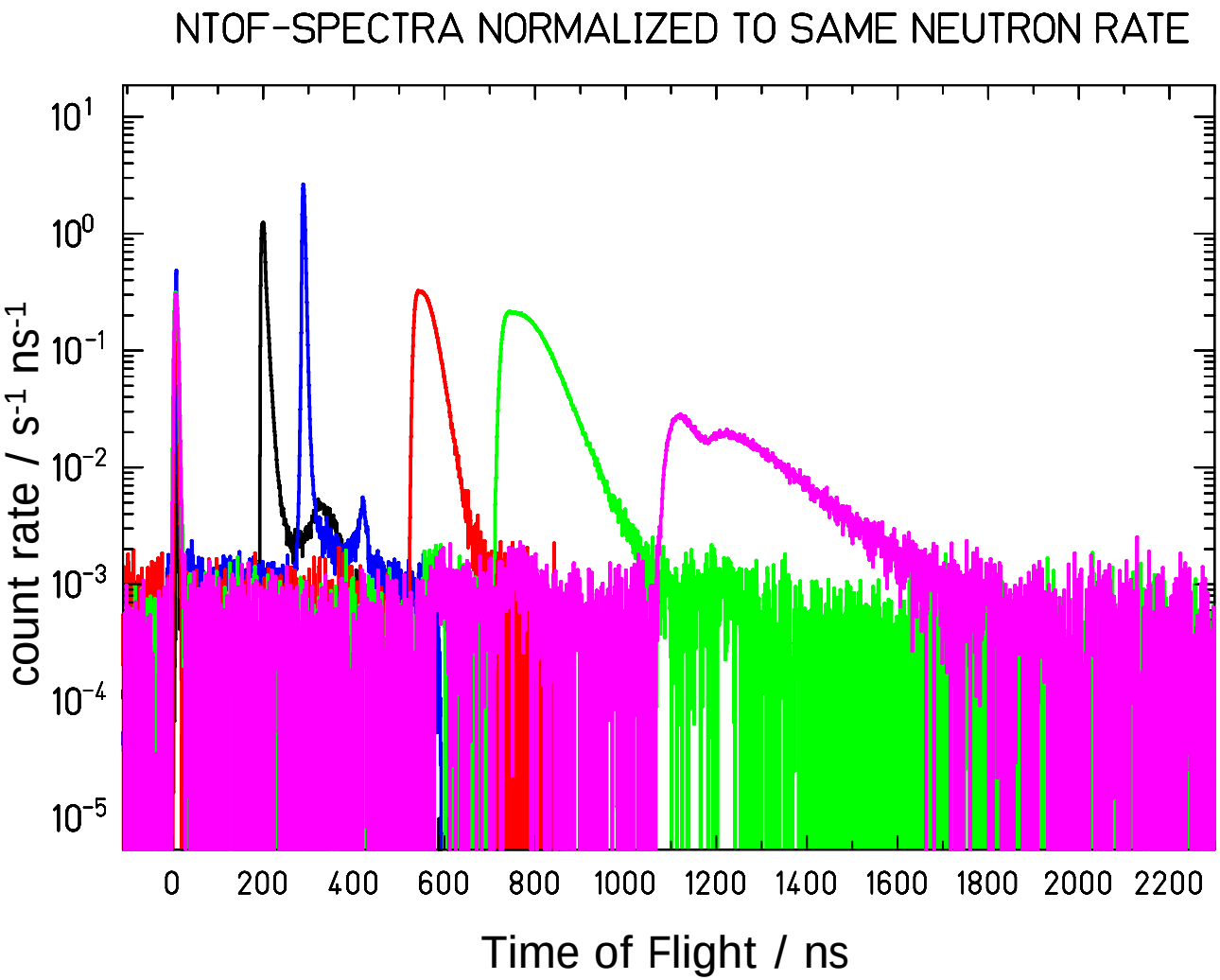
measurement

source spectrum

- Simulations done with TARGET by Dietrich Schlegel (PTB)
- neutron creation and transport inside the target ➔ distribution of direct and scattered neutrons
- includes geometry of the target, proton beam, detector position, neutron cross sections



Measured ToF-Spectra



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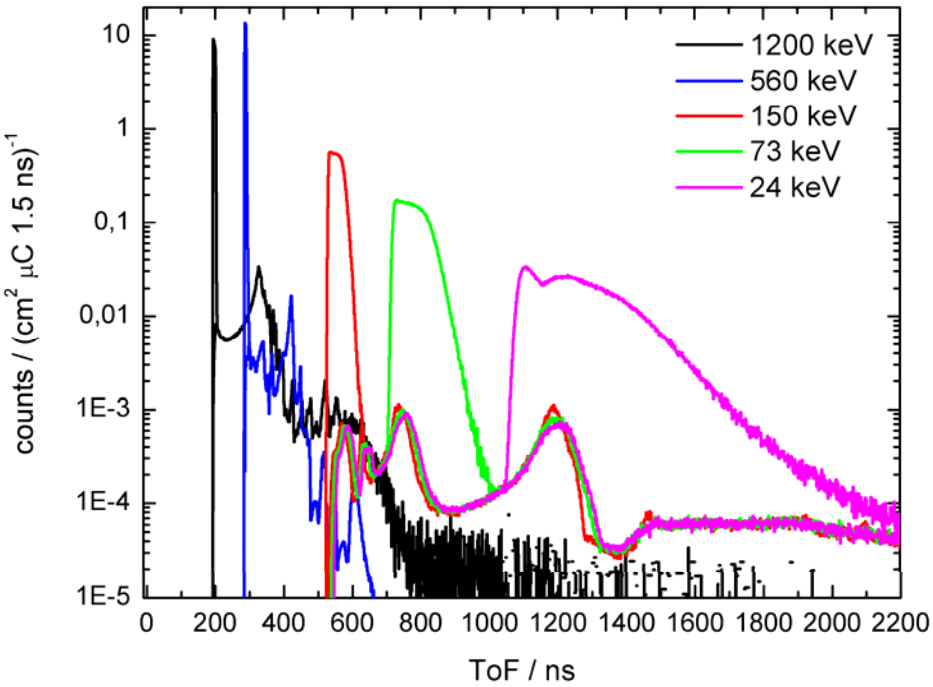
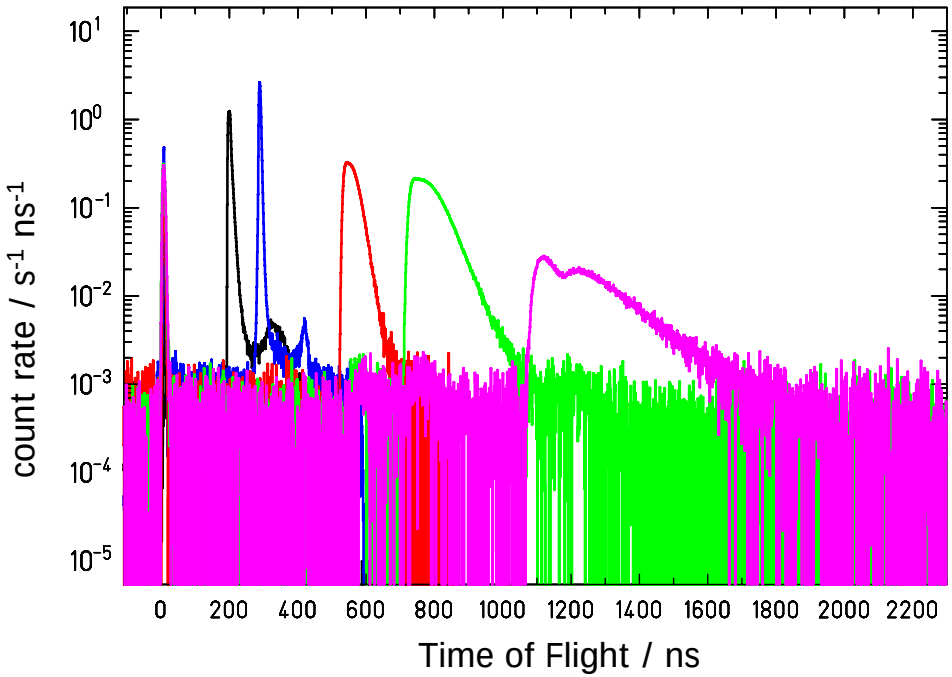


- Energy width of neutron peaks: 20 keV (FWHM)
- Detector response has to be included

- Good agreement between measurement and simulation

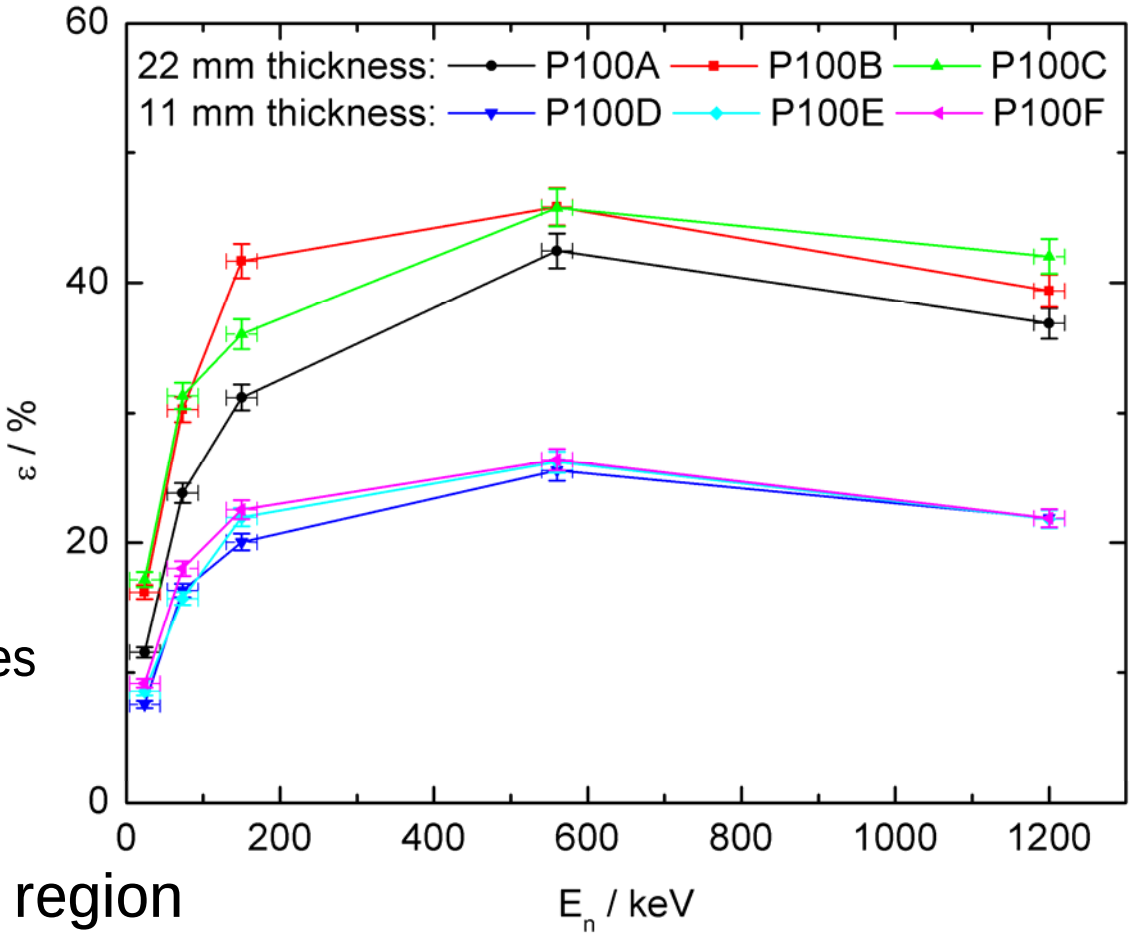


Preliminary Results

E_n / keV	ε / %
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

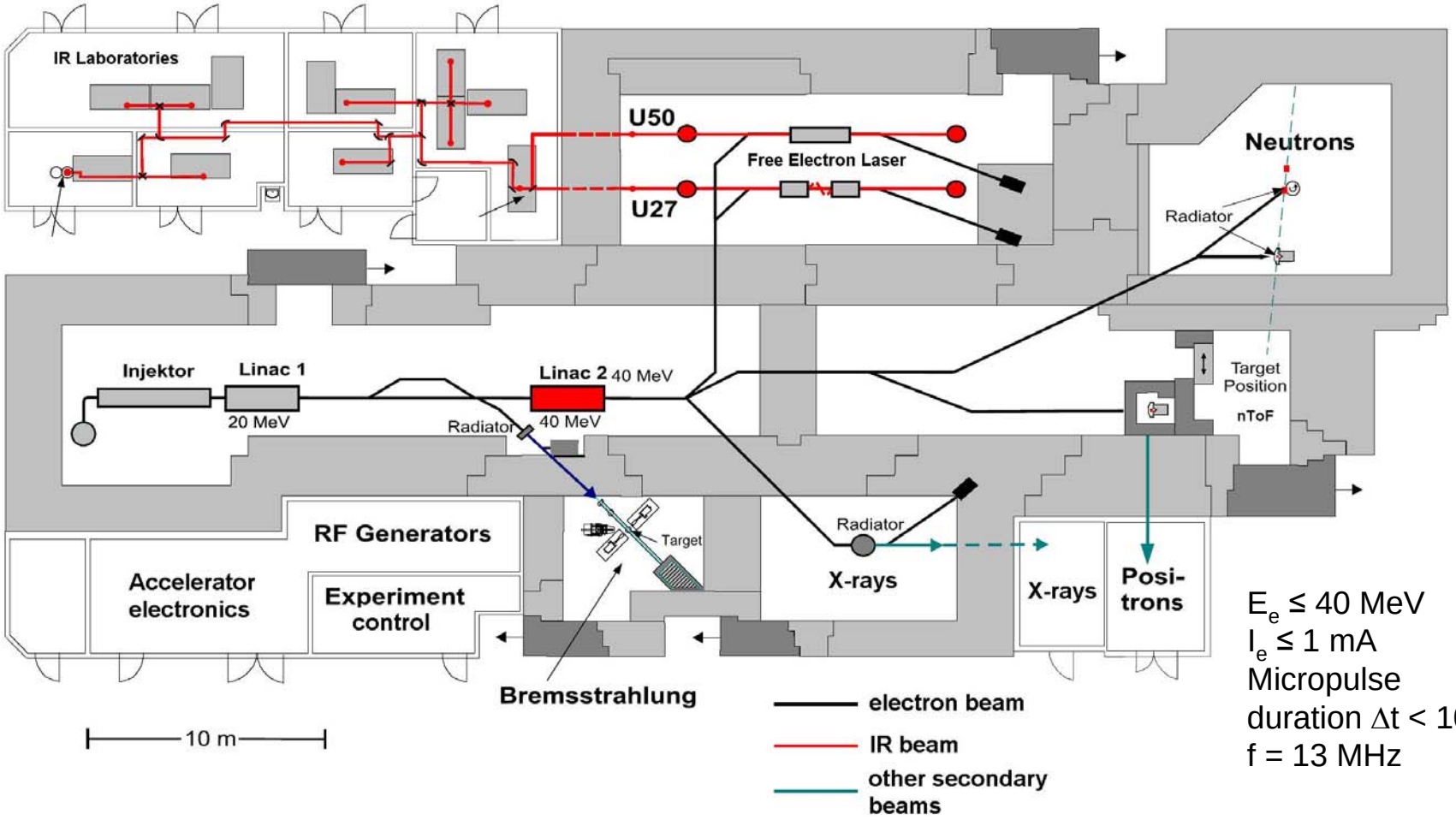
$\Delta\varepsilon/\varepsilon$ ~ 3.2 %

➔ mainly caused by uncertainties of the neutron fluence



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

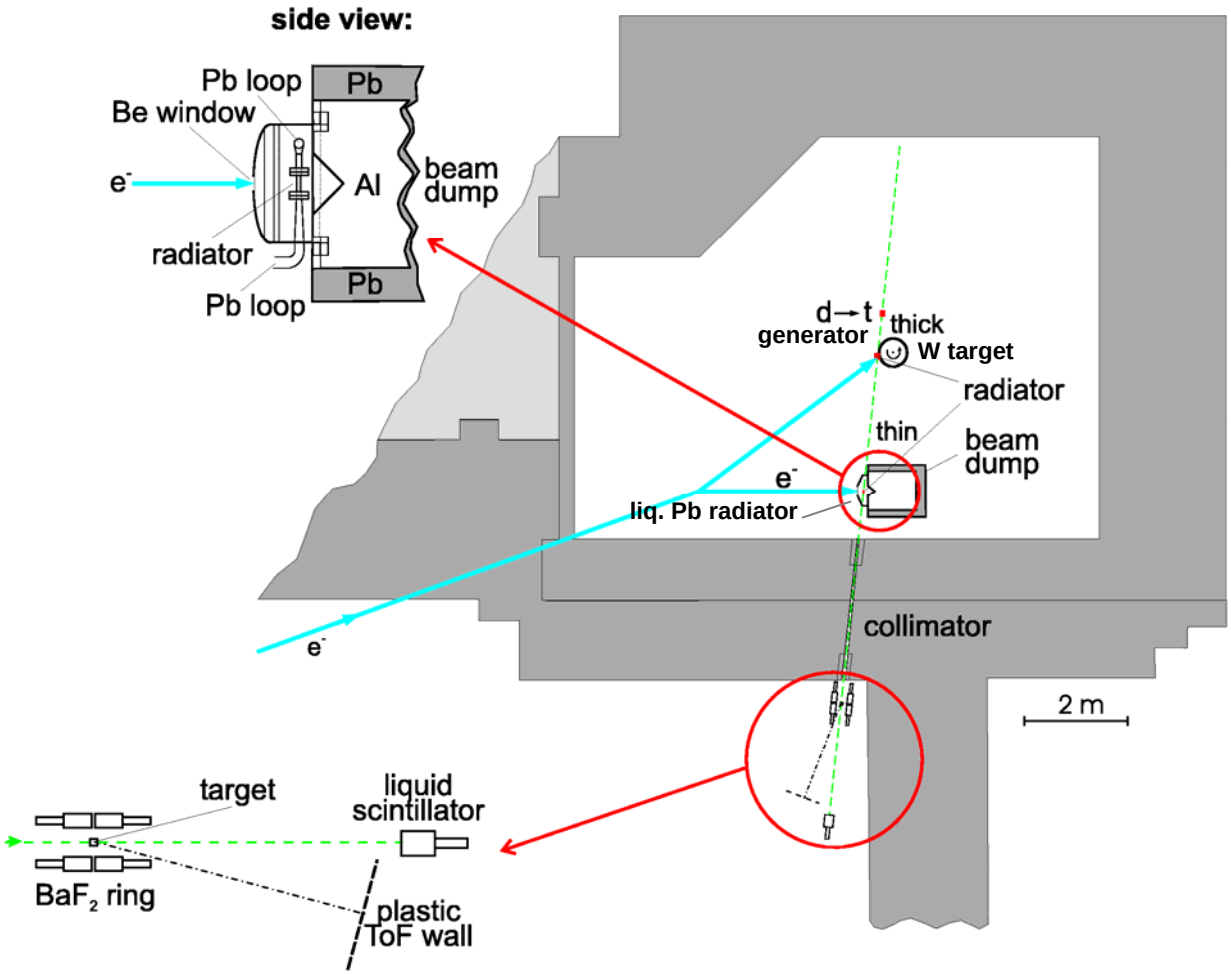
The superconducting electron accelerator ELBE



$E_e \leq 40$ MeV
$I_e \leq 1$ mA
Micropulse duration $\Delta t < 10$ ps
f = 13 MHz

ELBE: **E**lectron **L**inear accelerator with high **B**rilliance and low **E**mittance

Neutron production & detection



Neutron beam intensity table

Facility	CERN n-ToF	CERN n-ToF Phase-2	LANL NSC	ORNL SNS	FZK VdG	ORNL ORELA	IRMM GELINA	ELBE	ELBE with photo-gun
Pulse charge / nC	ca. 10^3	ca. 10^3	$4 \cdot 10^3$	$3 \cdot 10^4$	0.01	ca. 100	ca. 100	0.08	1.8
Power / kW	10	10	60	1000	0.4	8	7	5	40
Pulse rate / s^{-1}	0.4	0.4	20	60	$2.5 \cdot 10^5$	500	800	$1.6 \cdot 10^6$	$5 \cdot 10^5$
Flight Path / m	183	Ca. 20	60	84	0.8	40	20	4	4
n-pulse length / ns	>7	>7	125	100-700	ca. 1	>4	>1	< 0.4	< 0.4
E_{min} / eV	0.1	0.1	1	0.1	10^3	10	10	$2 \cdot 10^5$	$2 \cdot 10^4$
E_{max} / eV	$3 \cdot 10^8$	$3 \cdot 10^8$	ca. 10^8	ca. 10^8	$2 \cdot 10^5$	$5 \cdot 10^6$	$4 \cdot 10^6$	$7 \cdot 10^6$	$7 \cdot 10^6$
resolution at 1 MeV / %	0.5%	5%	> 10 %	> 20 %	ca. 5 %	< 1 %	< 2 %	ca. 1 %	ca. 1 %
n flux density / $s^{-1}cm^{-2}$ (E decade)$^{-1}$	10^5	ca.10^7	ca. 10^6	10^6 -10^7	ca. 10^4	10^4	$4 \cdot 10^4$	$4 \cdot 10^5$	$3 \cdot 10^6$