Progress of the EPOS Project: Gamma-Induced Positron Spectroscopy (GiPS)

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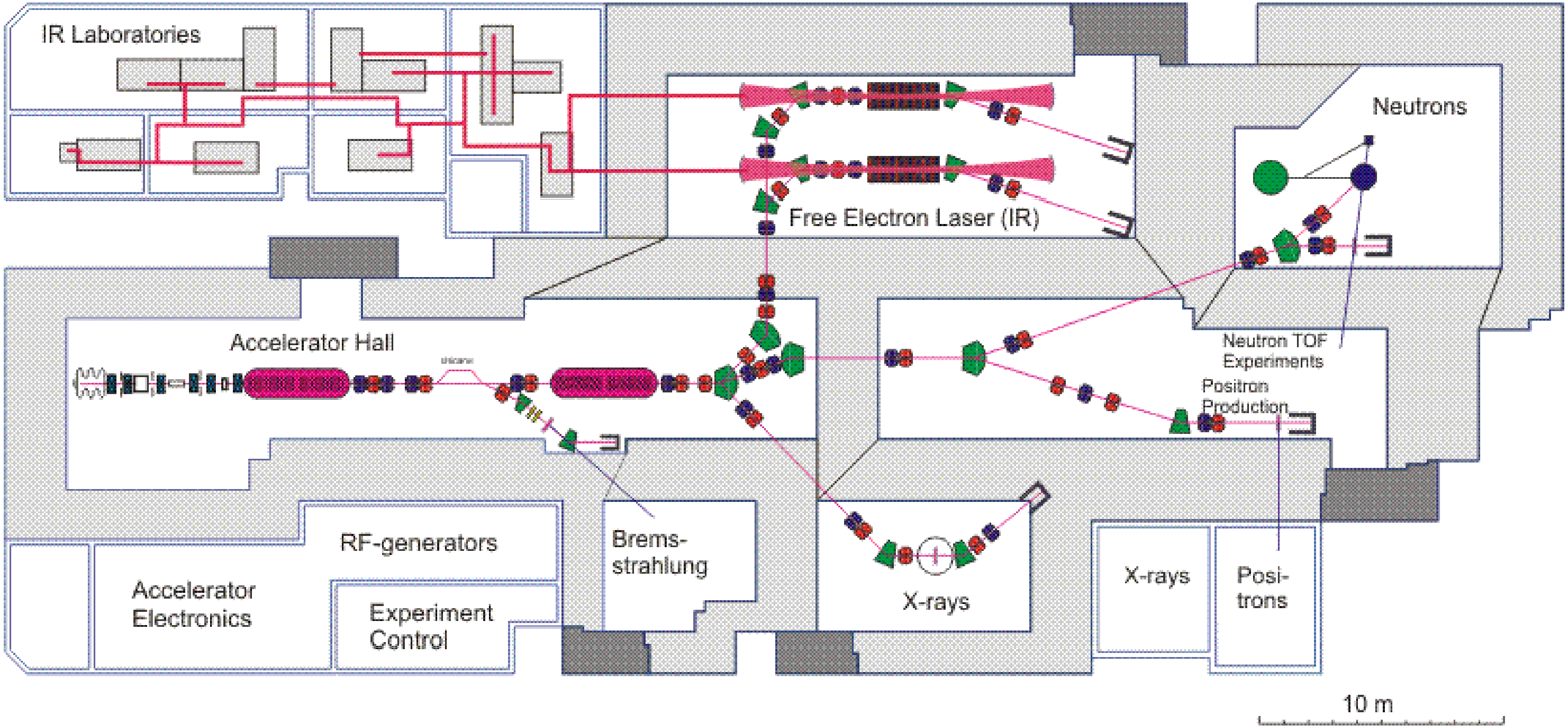
- New Concept of EPOS
- Progress of the Mono-energetic Positron Beam (MePS)
- Gamma-induced Positron Spectroscopy (GiPS)

Ground plan of the ELBE hall



New Concept of EPOS (ELBE Positron Source)

MePS

Mono**e**nergetic **P**ositron **S**pectroscopy

- Cave 111b / Lab 111d
- monoenergetic (slow) positrons
- pulsed system
- LT, CDBS, AMOC
- Still under construction

Information Depth: 0…5 µm

CoPS

Conventional **P**ositron **S**pectroscopy

- LT, CDBS, AMOC
- using ^{22}Na foil sources
- He-cryostat
- automated system
- digital detector system

Information Depth: 10…200 µm

GiPS

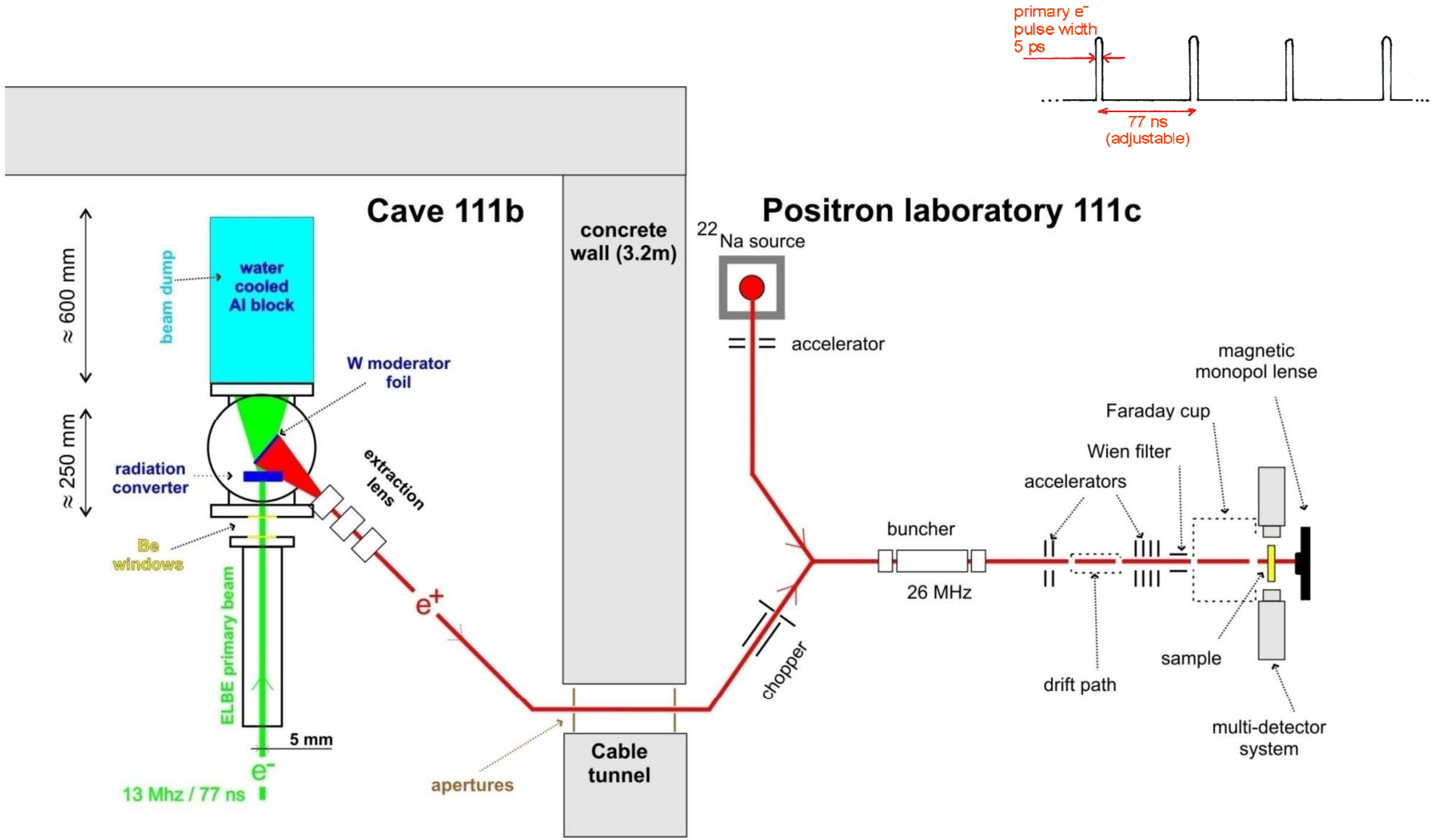
Gamma-**i**nduced **P**ositron **S**pectroscopy

- Cave 109 (nuclear physics)
- Positron generation by Bremsstrahlung
- Information in complete bulky sample (up to 00 cm^3)
- all relevant positron techniques (LT, CDBS, AMOC)

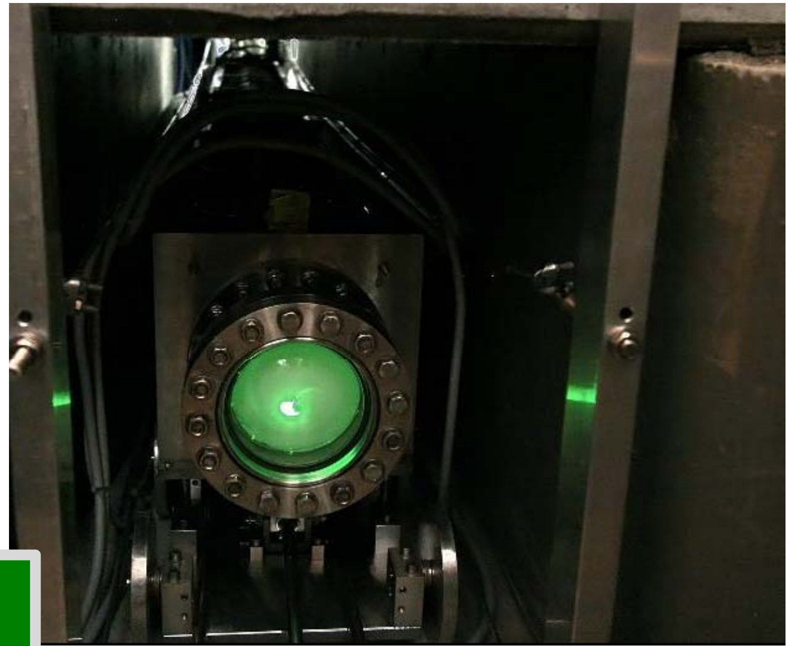
Information Depth: 0.1 mm …5 cm

Progress of Mono-energetic Positron Beam

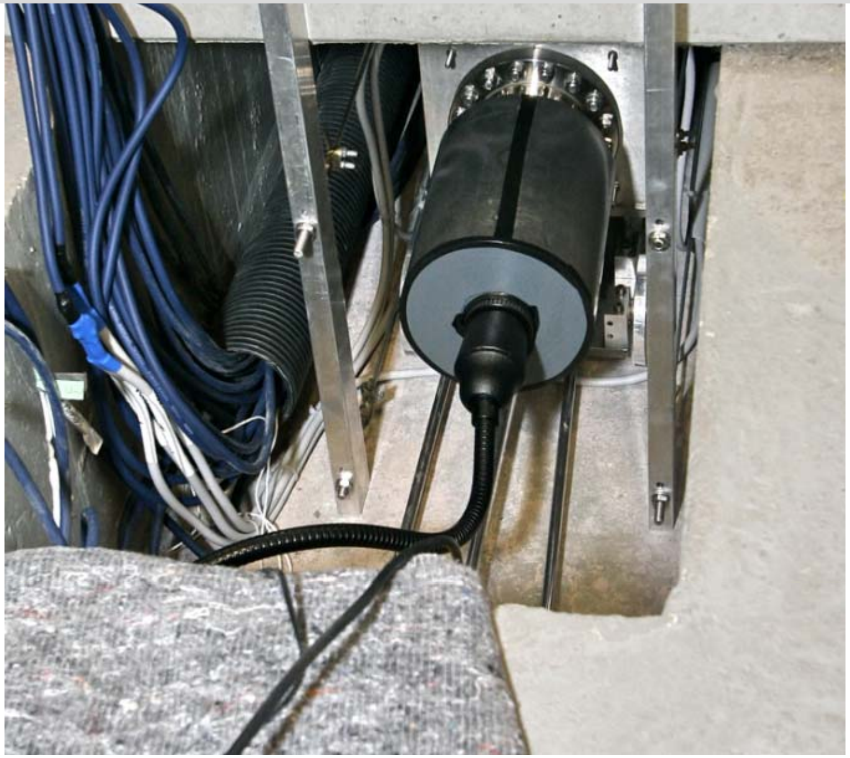
- 40 MeV, 1 mA, 26 MHz repetition time in cw mode; lifetime, CDBS and AMOC with slow e^+
- Retain original time structure for simplicity and best time resolution



Electron-Positron Converter almost finished



Test of Beam Guidance with an Electron Source

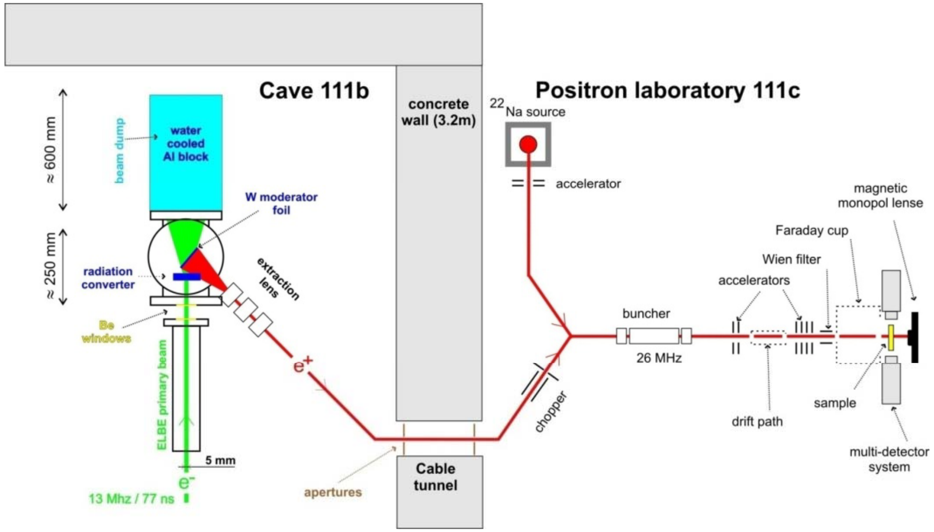


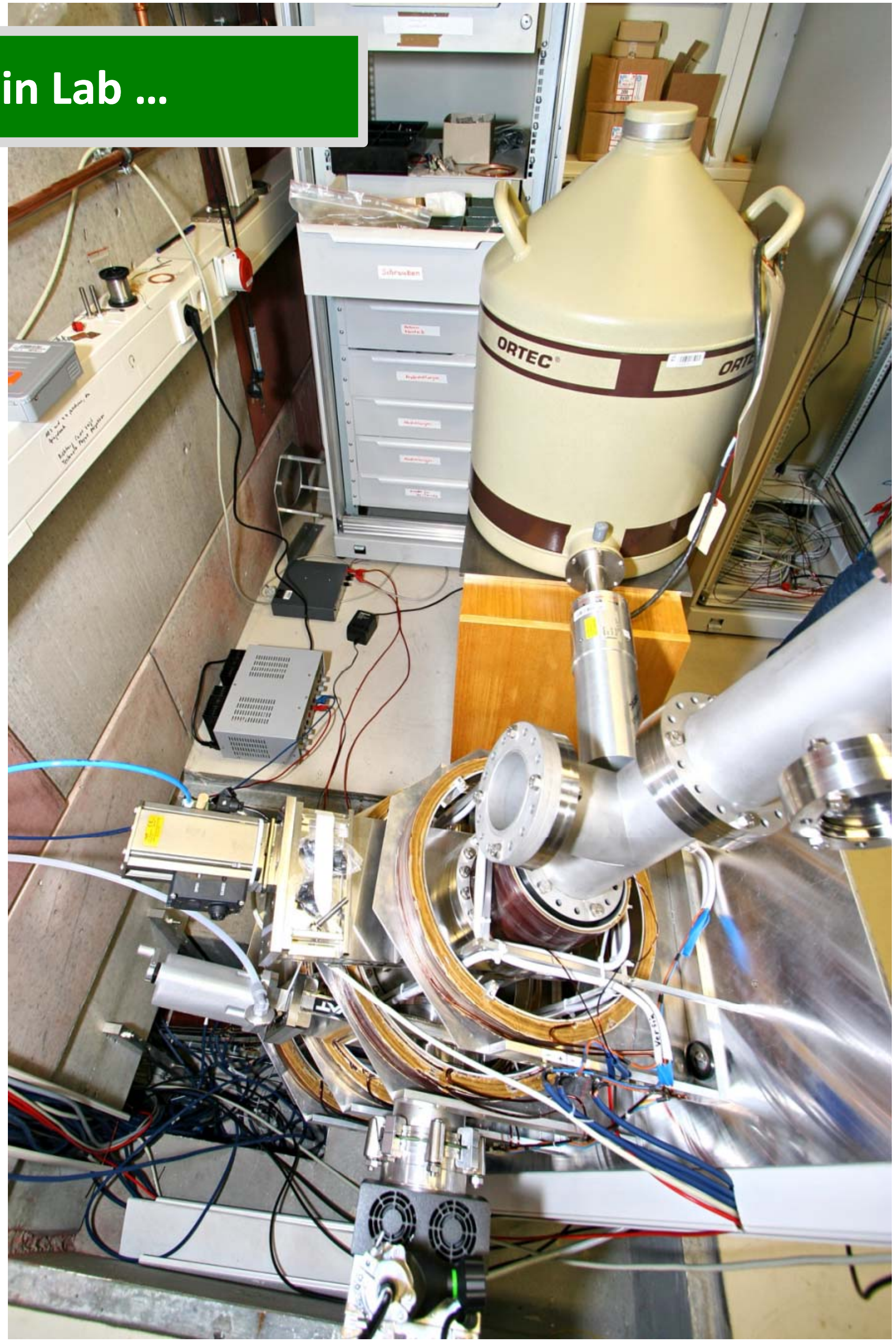
Adjustment of magnetic Guidance System with ^{22}Na source and Moderator

mounting of ^{22}Na source

Still waiting for γ Quanta in Lab …

- Problem: 10 x 2 steering coils must be adjusted
- automatic LabView program is looking for annihilation gamma at end of beam line





Gamma-induced Positron Spectroscopy

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Bremsstrahlung-induced highly penetrating probes for nondestructive assay and defect analysis

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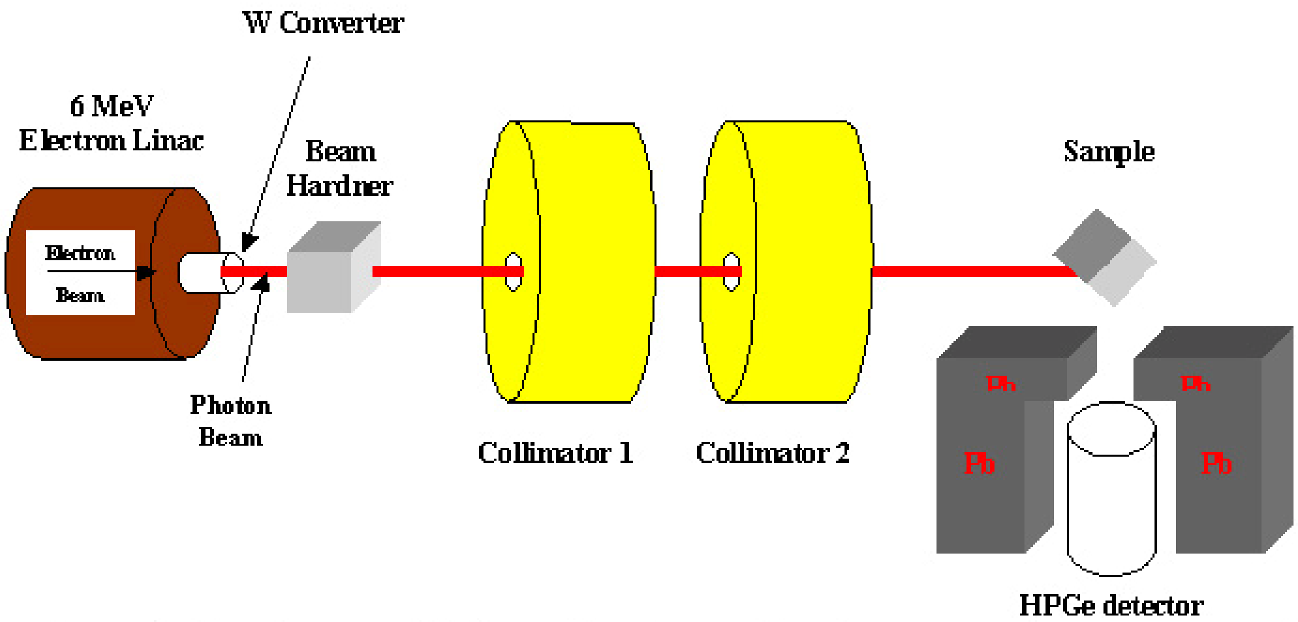


First spectra

Advantages

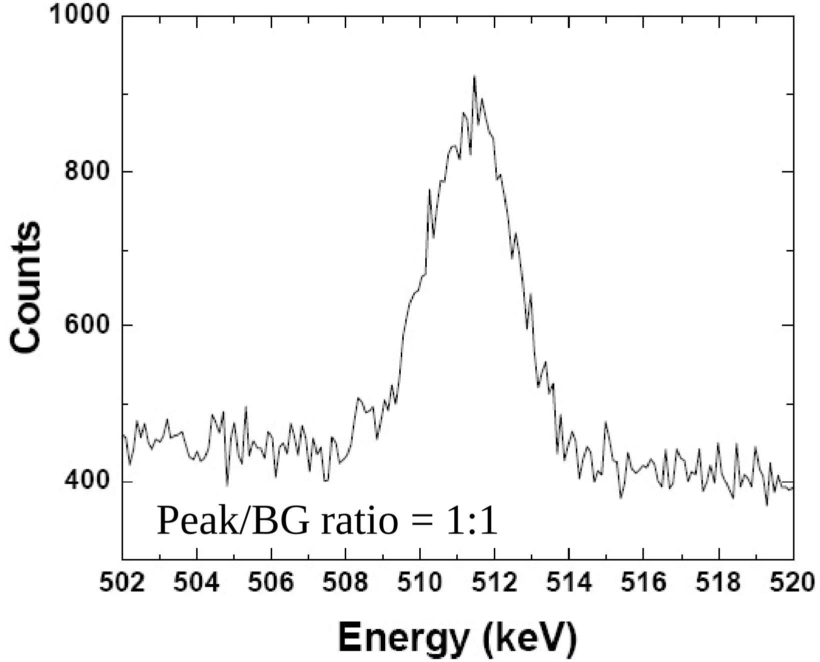
- information depth 0.1 … 5 cm
- ideal for bulky samples (NDT), liquids, gases, biological objects, coarse powder, dispersions …

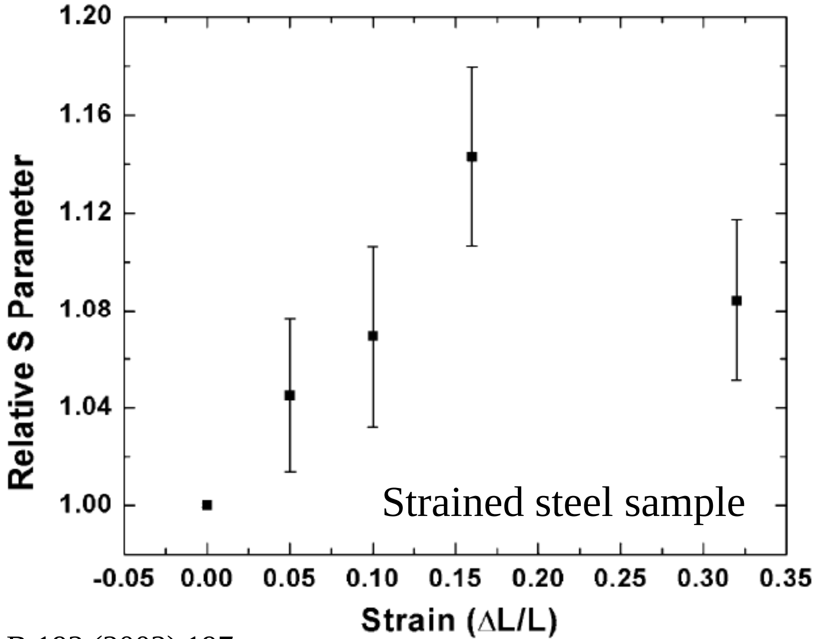
Disadvantage of slow LINACs

- Use of “normal” LINAC with 200 Hz has the problem of high gamma flux in only very few bunches
- Count rate very low, thus no coincidence techniques applicable such as CDBS or AMOC
- Peak / BG ratio bad (1:1)
- no lifetime spectroscopy possible
- Gammas which were scattered into the detector can not be suppressed
- S parameter with huge errors ± 4% (more than many effects to be measured)

All this **disadvantages can be overcome** by use of a superconducting LINAC with > 10 MHz

Annihilation line in steel





F.A. Selim et al., NIM B 192 (2002) 197

Bremsstrahlung Gamma Source of ELBE (FZ Dresden-Rossendorf)

- Gamma source; pulsed 26 MHz; bunch length < 5 ps; up to 20 MeV; 20 kW beam power
- ideal for GiPS

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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The photon-scattering facility at the superconducting electron accelerator ELBE☆

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Abstract

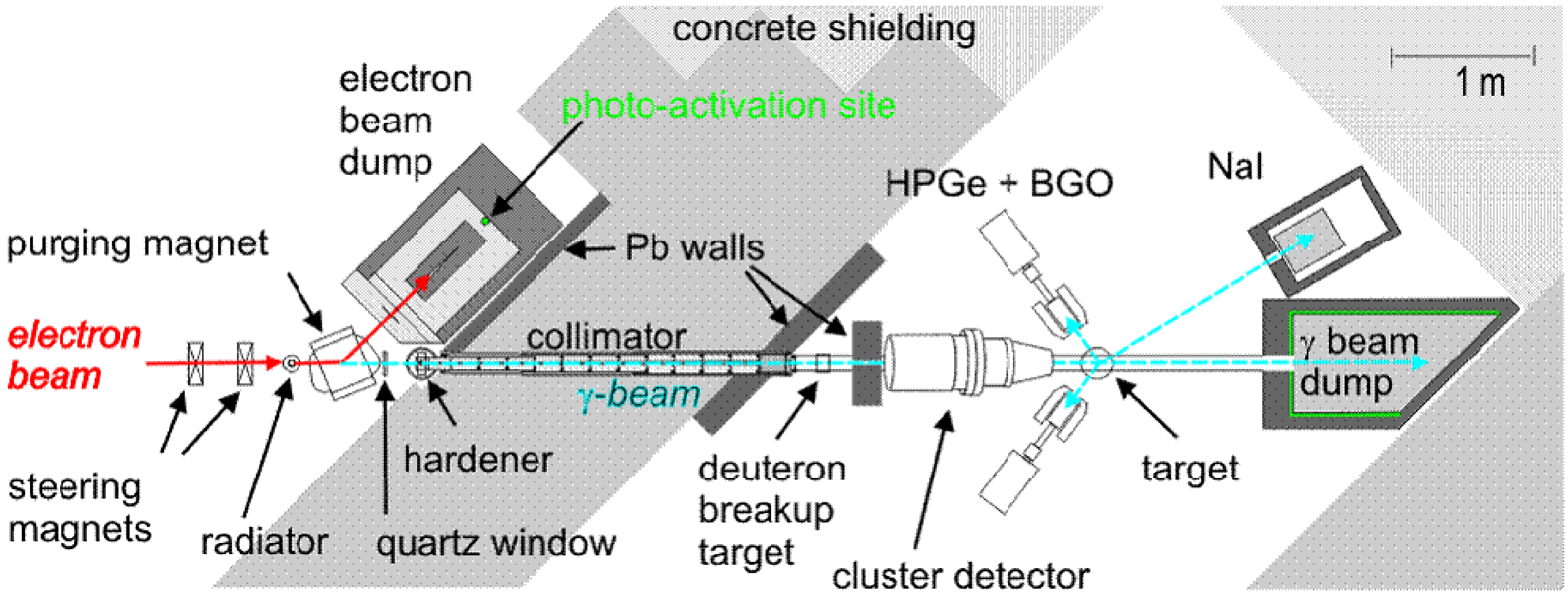
A new facility for the production of polarised bremsstrahlung has been built at the superconducting electron accelerator ELBE of the Forschungszentrum Rossendorf. The bremsstrahlung facility and the setup for photon-scattering experiments are designed such that the background radiation caused by the scattering of photons and the production of neutrons is minimised. The sensitive setup in connection with electron energies up to 20 MeV and average currents up to 1 mA delivered by the ELBE accelerator enables novel experiments using photon-induced reactions. First results of photon-scattering experiments are presented.

PACS: 23.20.−g; 25.20.Dc; 29.30.Kv

Keywords: Superconducting electron accelerator; Polarised bremsstrahlung; Photon scattering

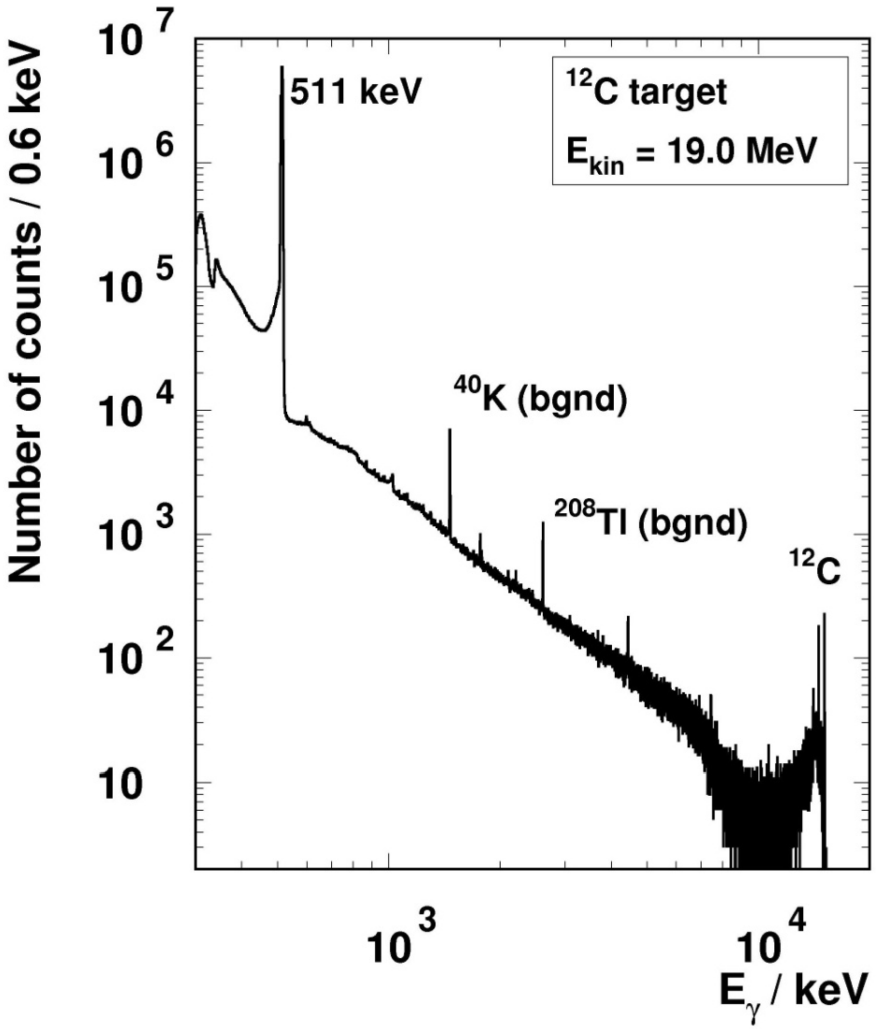
Bremsstrahlung Gamma Source of ELBE (FZ Rossendorf)

- Pulsed gamma source using superconductive Linac ELBE
  - repetition frequency 26 MHz (or smaller by factor 2^n) in CW mode!
  - bunch length < 5 ps
  - up to 20 MeV
  - average electron current 1 mA = 20 kW beam power; electron beam dump outside lab
  - thus gamma background at target position is very low (Ge detectors with 100% efficiency)
- **Ideal for GiPS ! Is now part of EPOS project – user dedicated positron source.**



Gamma Spectrum obtained by scattering at ^{208}Pb

- 511 keV annihilation line is by far strongest line although absorber plates were used in front of Ge detectors to reduce the low-energy photons



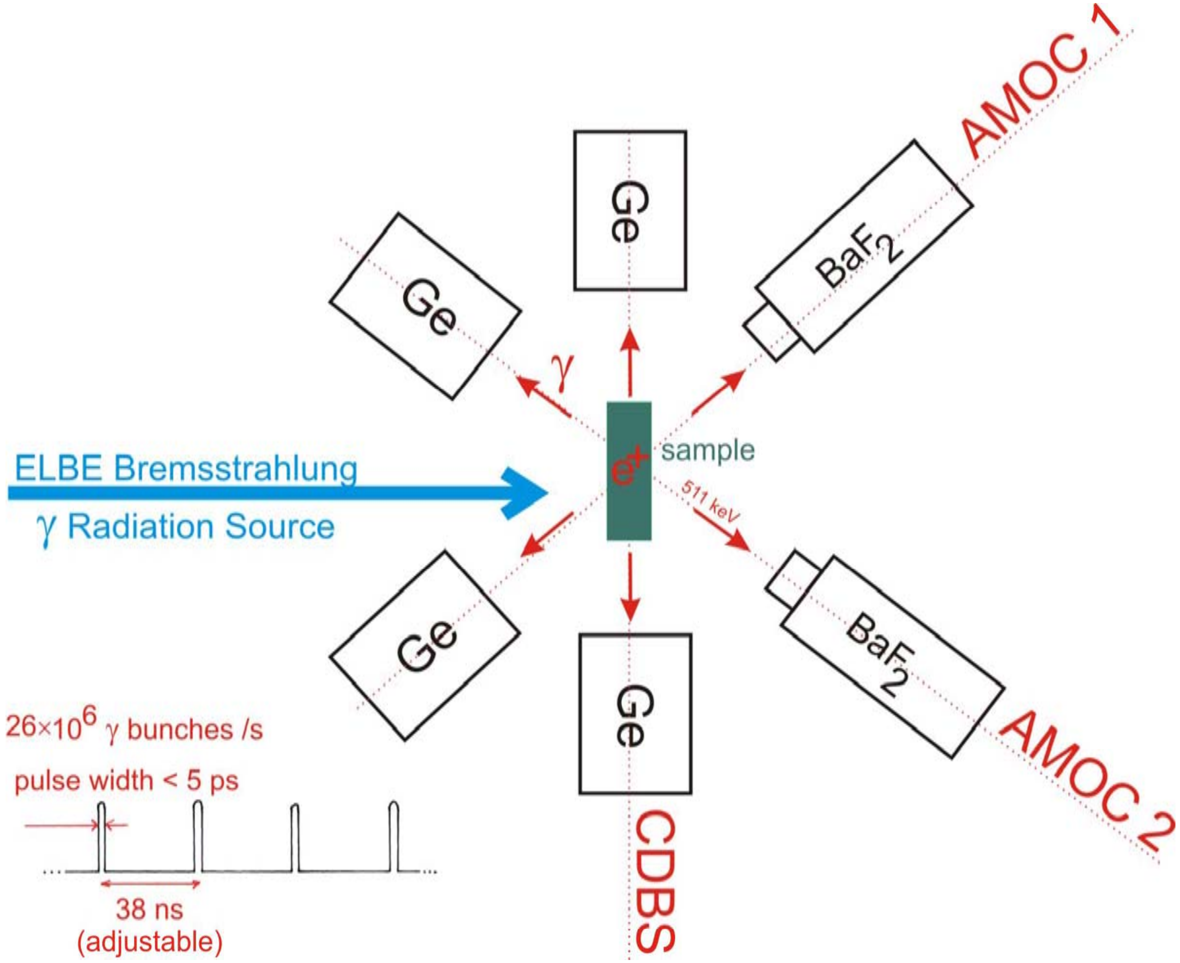
Spectrum of photons scattered from ^{12}C using Bremsstrahlung produced by electrons with an energy of 19 MeV.

Setup extended by BaF_2 detectors for lifetime measurement

- 3 coincident setups were used: 2 AMOC and 1 CDBS spectrometer
- only coincident detection ensures high spectra quality

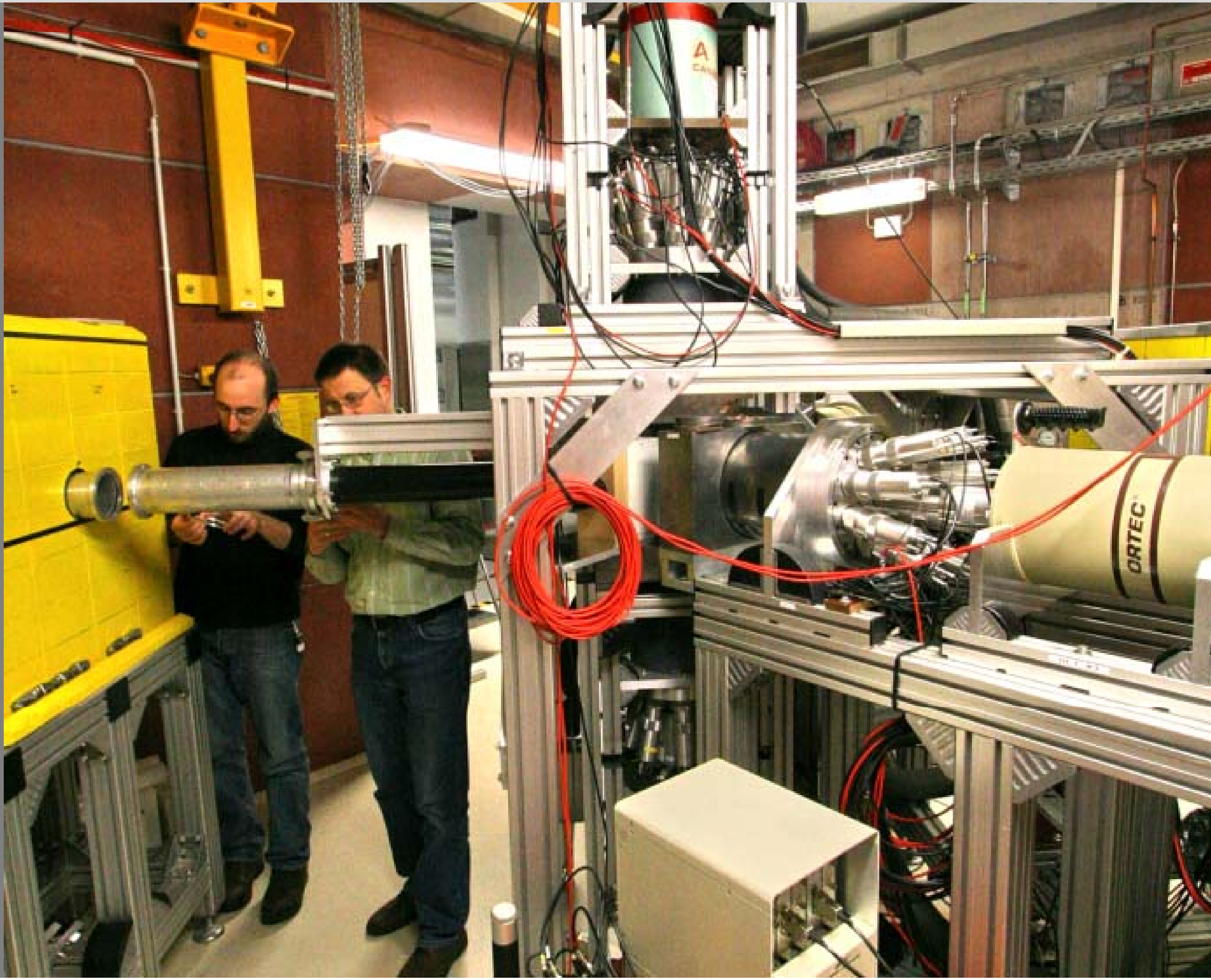
Problem

- all scattered quanta appear within positron lifetime – time coincidence alone does not reduce background at all
- but distance helps: for 2 x 511 keV quanta in coincidence the distance dependence is proportional to r^{-2}
- for arbitrary scattered gamma it is $\propto r^{-4}$



AMOC: Age-Momentum Correlation
CDBS : Concidence Doppler-Broadening Spectroscopy

The GiPS setup includes 6 Detectors (4 Ge and 2 BaF_2)



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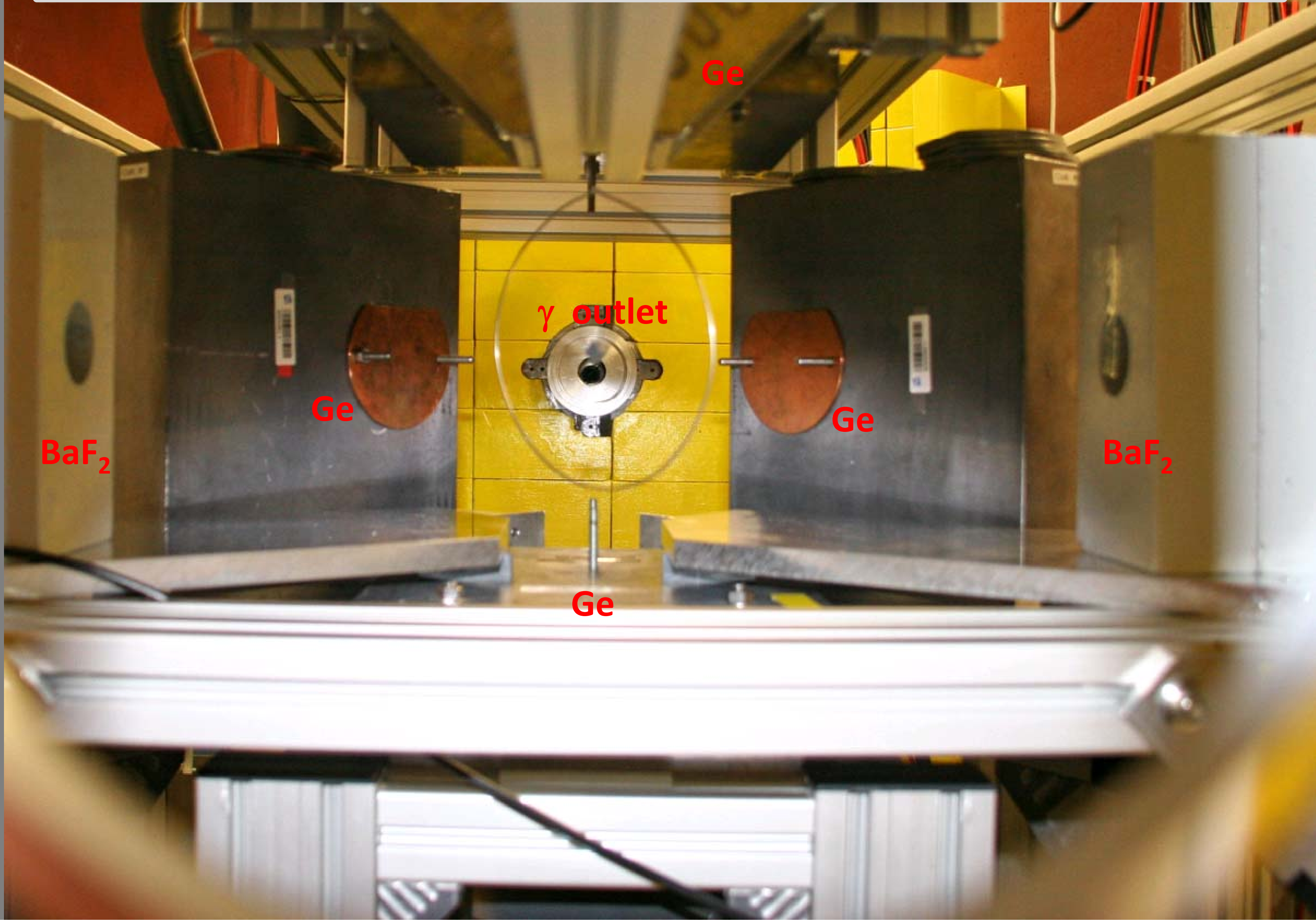
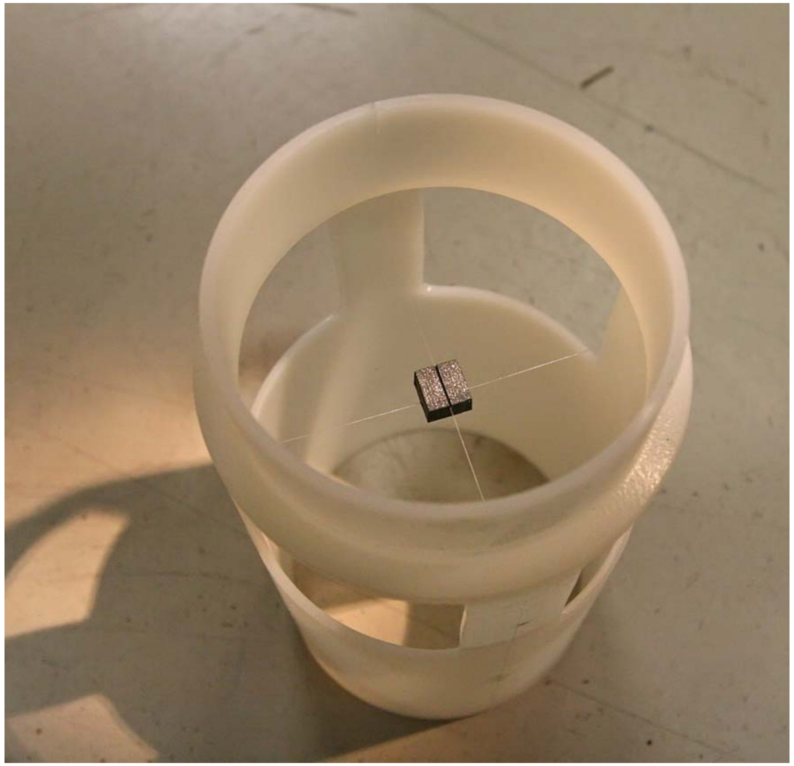
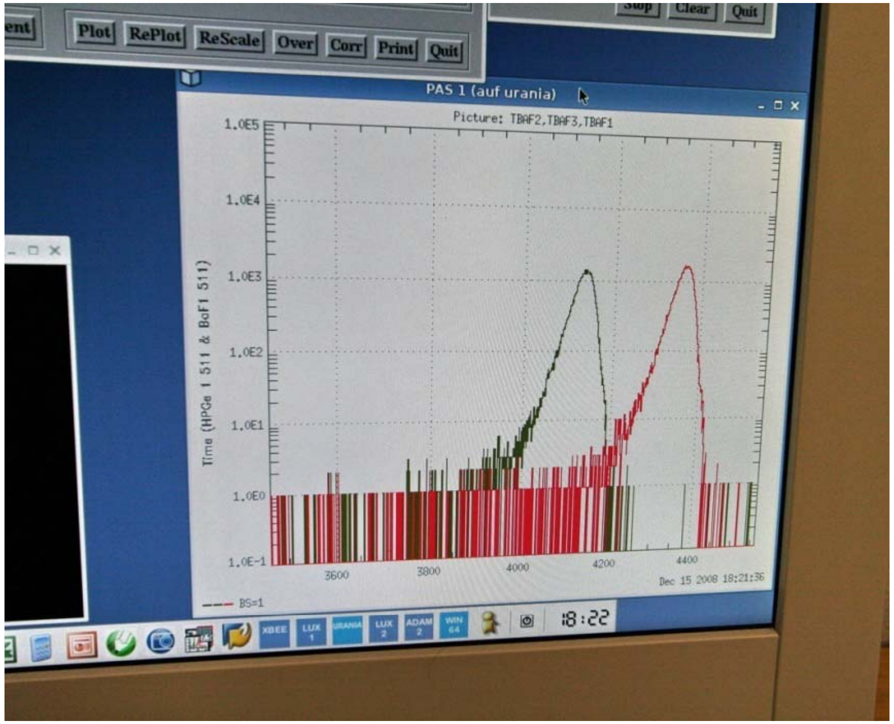


First experiment: annealed and deformed Fe

- Sample 1: well annealed pure sample (< 4N)
- Sample 2: same sample material but 50% thickness reduction by cold rolling



sample holder: Fe sample is hold by thin nylon fibers



first spectra growing: stop pulse for timing from BaF_2 and start pulse is accelerator bunching pulse of ELBE

Adjustment of single Channel Count Rates

- **all single channel rates together** can be adjusted by changing the electron beam current
- for our Fe samples (0.13 cm^3) we used: I ≈ 100µA – thus even 10 times smaller sample volume would be possible
- here: 8x8x0.5 mm^3 should be enough for having the same rates
- **and the individual rates** can be adjusted:
  - for Ge: by adding absorber materials (here 5 mm Cu plate)
  - for BaF2: increase of distance

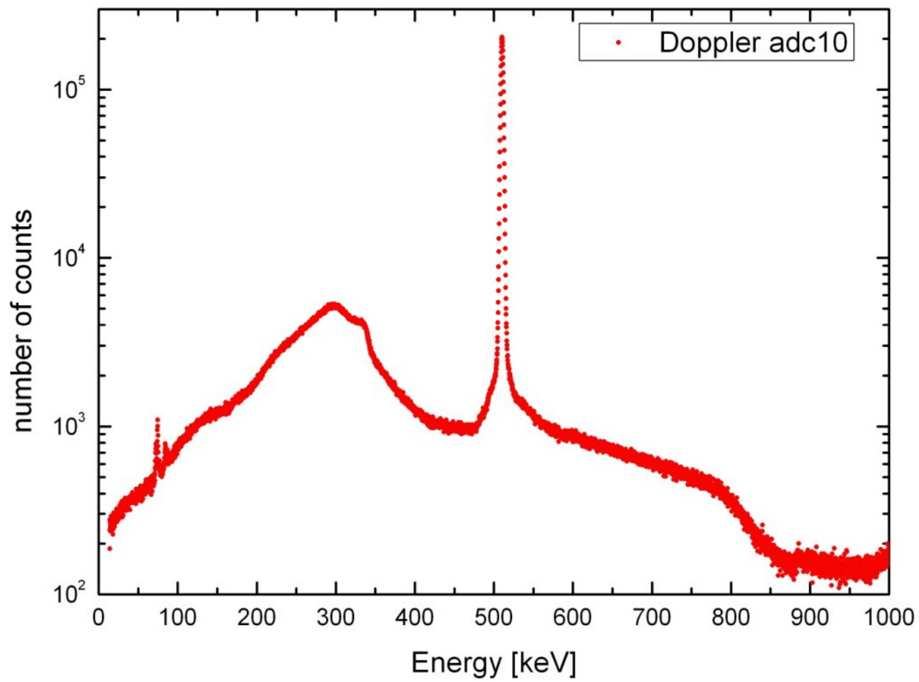
- Read the **counter display** as:
  - first 4 rates from top: 4 Ge detectors (1 and 3 for the AMOC system, 2 and 4 for CDBS)
  - rate 5 and 6: rates of BaF_2 detectors
  - rate 7 and 8: LT coincidence rates of both AMOC systems
- Thus a single channel …

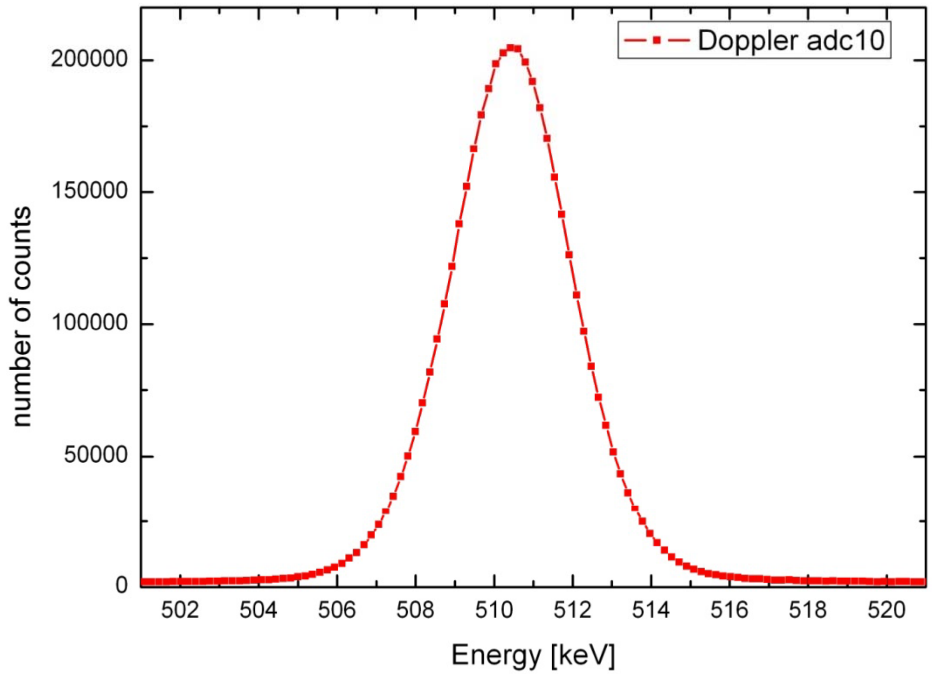
  …lifetime spectrum (4x10^6 counts) needs about 7 min, there were 2 detectors, thus 3.5 min

  …Doppler spectrum (1x10^6 counts) requires 90 s (50% of whole intensity is within 511 peak) – but there are 4 Ge detectors, thus 20 s should be enough

Single-channel Ge Spectrum of annealed Fe

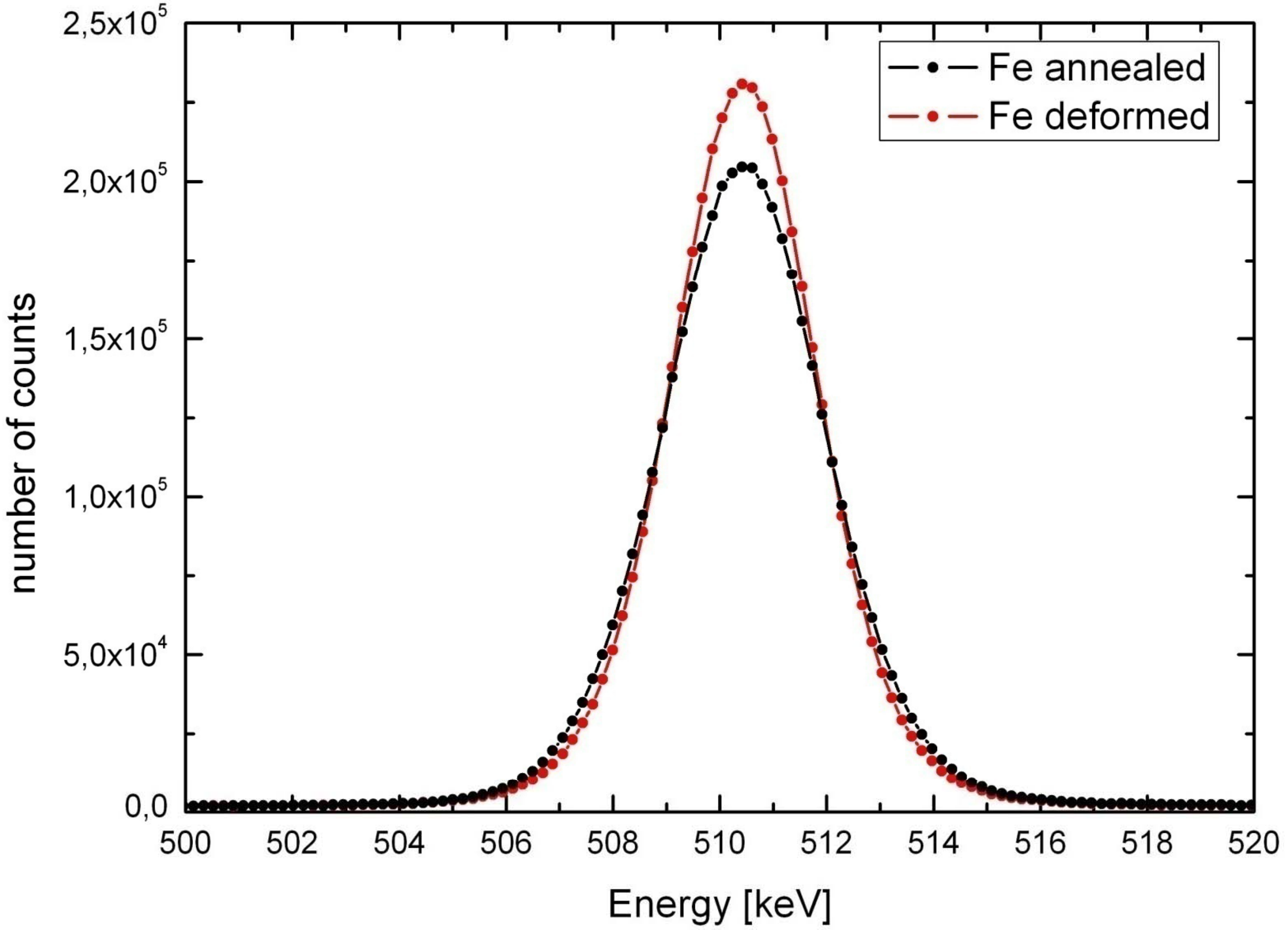
- count rate about 20 kHz; total counts in example: $8x10^6$
- about 50% of intensity in 511 peak
- decrease below 350 keV due to 5 mm Cu absorber plates in front of Ge detectors
- detection with analog electronics





Comparison annealed and deformed Fe

- normal behavior
- curve of deformed Fe is distinctly taller due to open-volume defects and thus increased fraction of annihilation with valence electrons (small energies – small Doppler shift)



Single-channel Lifetime Spectrum of Fe

- single channel lifetime spectrum (Start: BaF_2 - Stop: accelerator machine pulse)
- obvious: without coincidence – many quanta different from annihilation quanta
- scattered photons
- they are not visible in Doppler spectrum
- only coincidence measurement ensures suppression of scattered gamma (next slide)

delay of side peaks

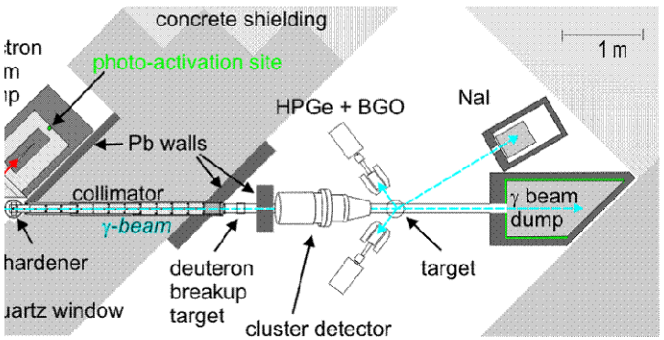
1: -0.84 ns = 25.2 cm

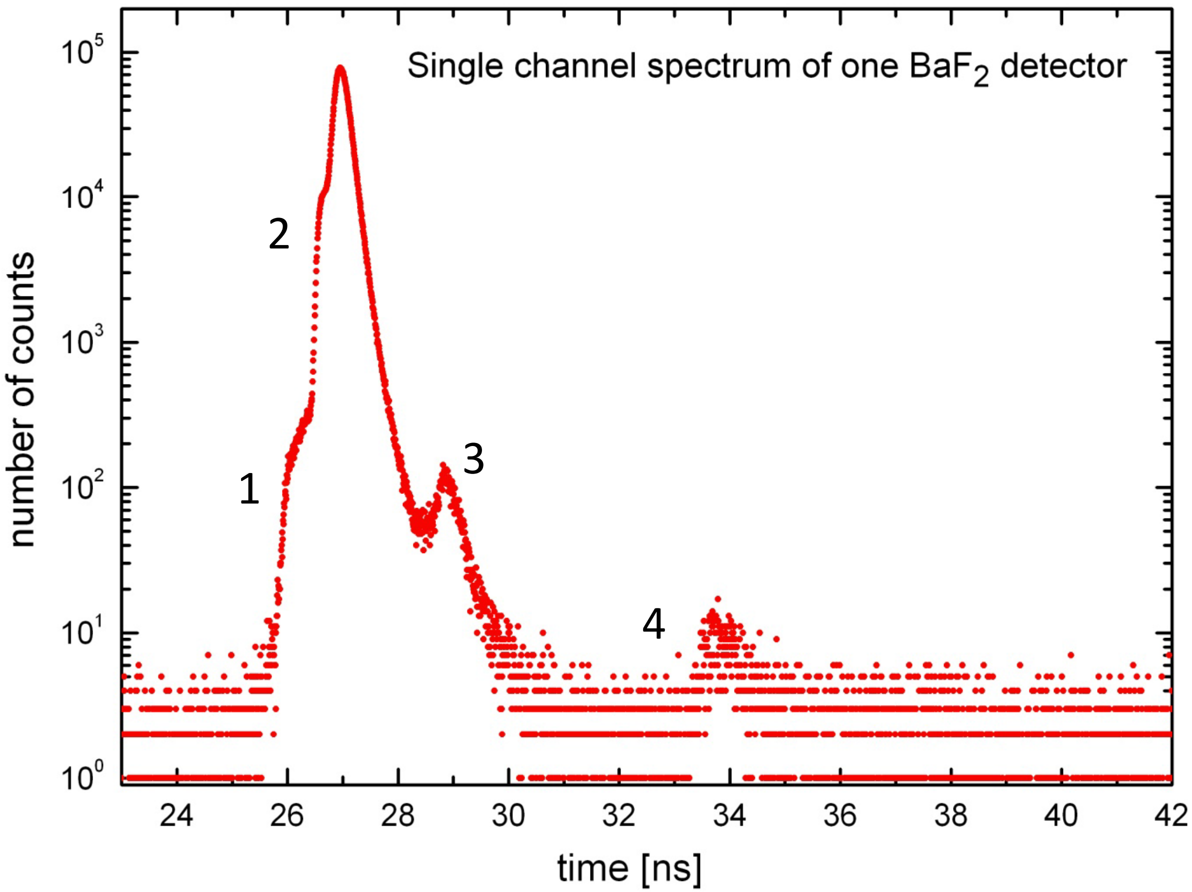
2: -0.42ns = 12.6 cm

3: 1.8 ns = 54 cm

4: 7.0 ns = 2.1 m

scattering occurs from all over the detectors, even from the γ beam dump





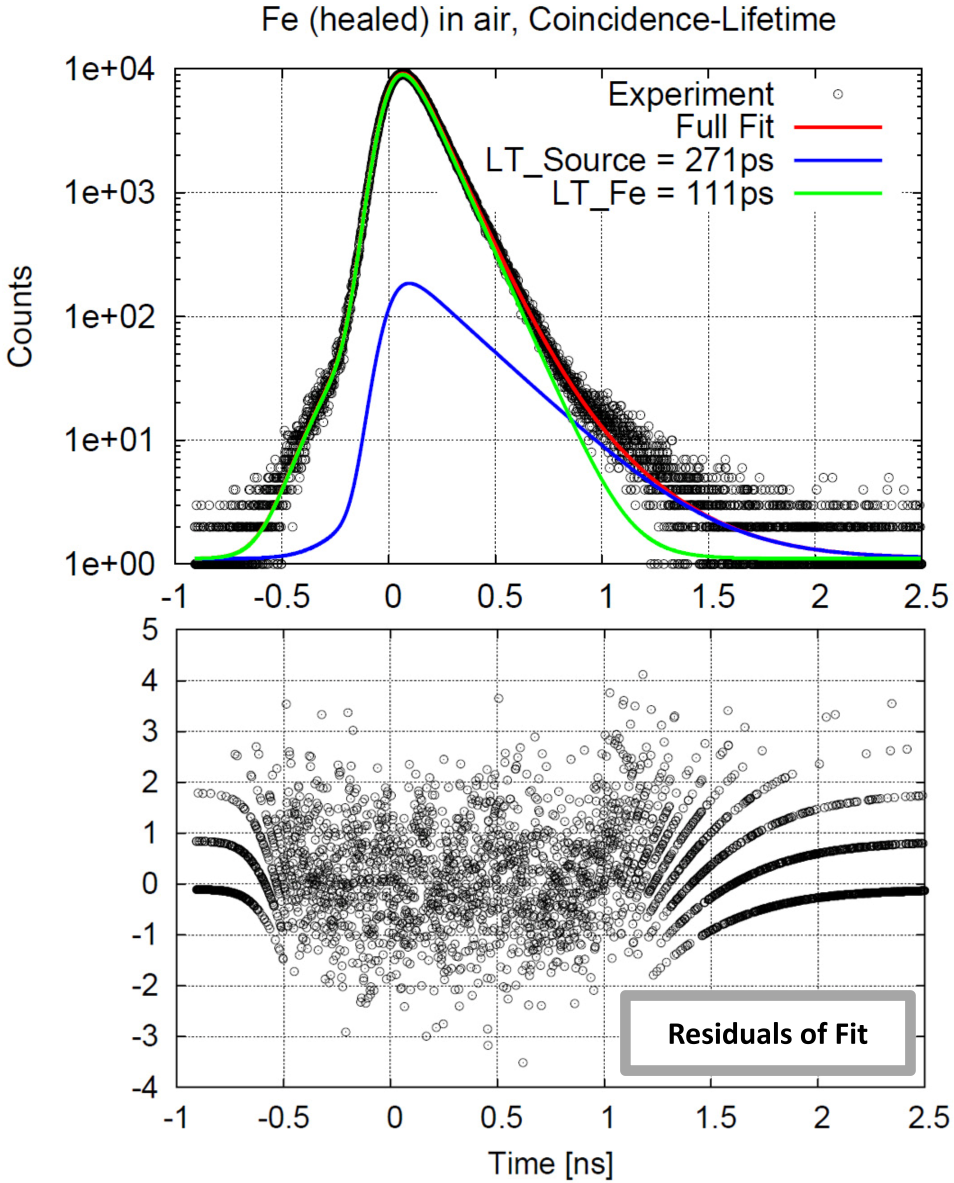
Coincidence Lifetime Spectrum (2 x BaF_2)

Improvement of resolution

- spectra in list mode: 2 obtained lifetimes were averaged to improve resolution
- Fit requires 3 Gaussian for the resolution
- $FWHM_{coinc}$ = 160 ps
- $FWHM_{single}$ =210 ps
- $FWHM_{coinc}/FWHM_{single}$ = 0.76
- almost expected improvement of resolution

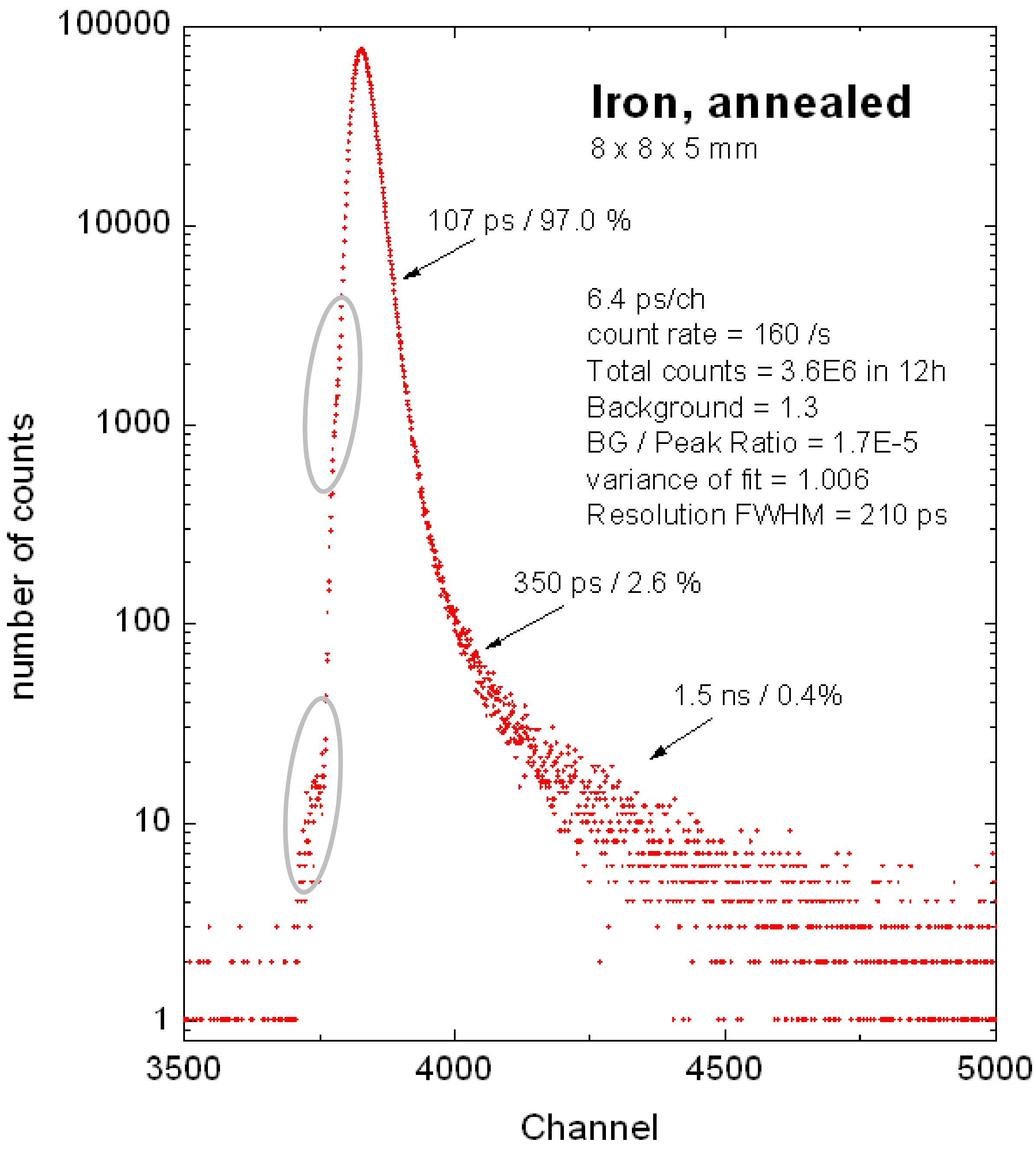
Result of Fit

- 2 Lifetimes:
  - 111 ps / 96.8%
  - 271 ps / 3.2%
- Residuals are okay
- coincidence to second BaF_2 eliminates almost all scattered gammas



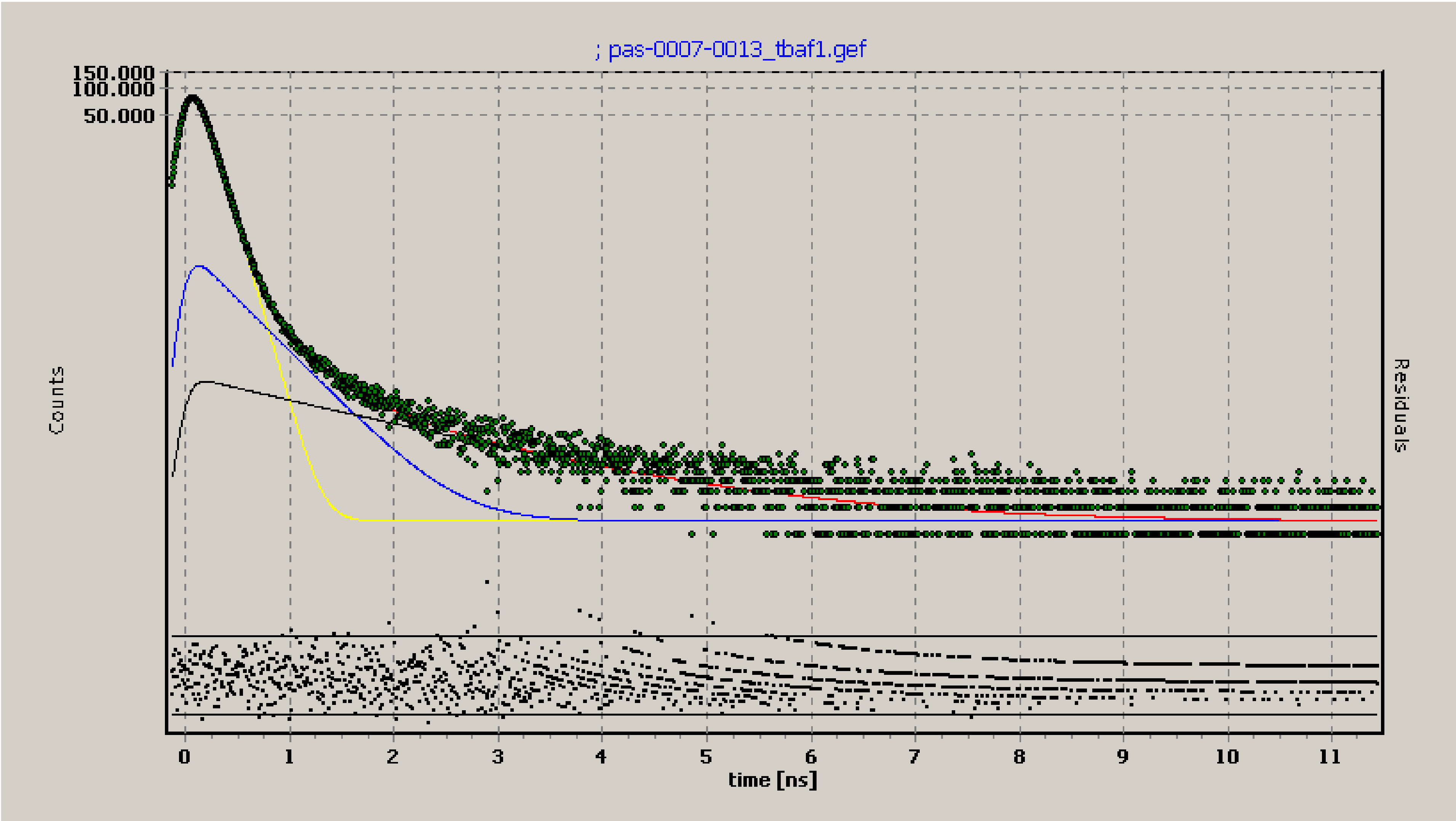
Coincident lifetime spectrum: annealed Fe

- here coincidence with Ge detector
- spectrum is projection to the time scale of AMOC spectrum
- Count rate for single AMOC spectrum = 160 /s
- both spectra: 320 /s – 1 million counts in 1 hour
- Time resolution = 210 ps
- BG/Peak = 1.7 x 10-5
- 350 ps & 1.5 ns: annihilation at vacuum tube (polyethylene)
  - two areas below t_0 exhibit sometimes disturbances
  - probably due to detection of scattered gammas (at sample and vacuum tube)
  - but nothing after t_0



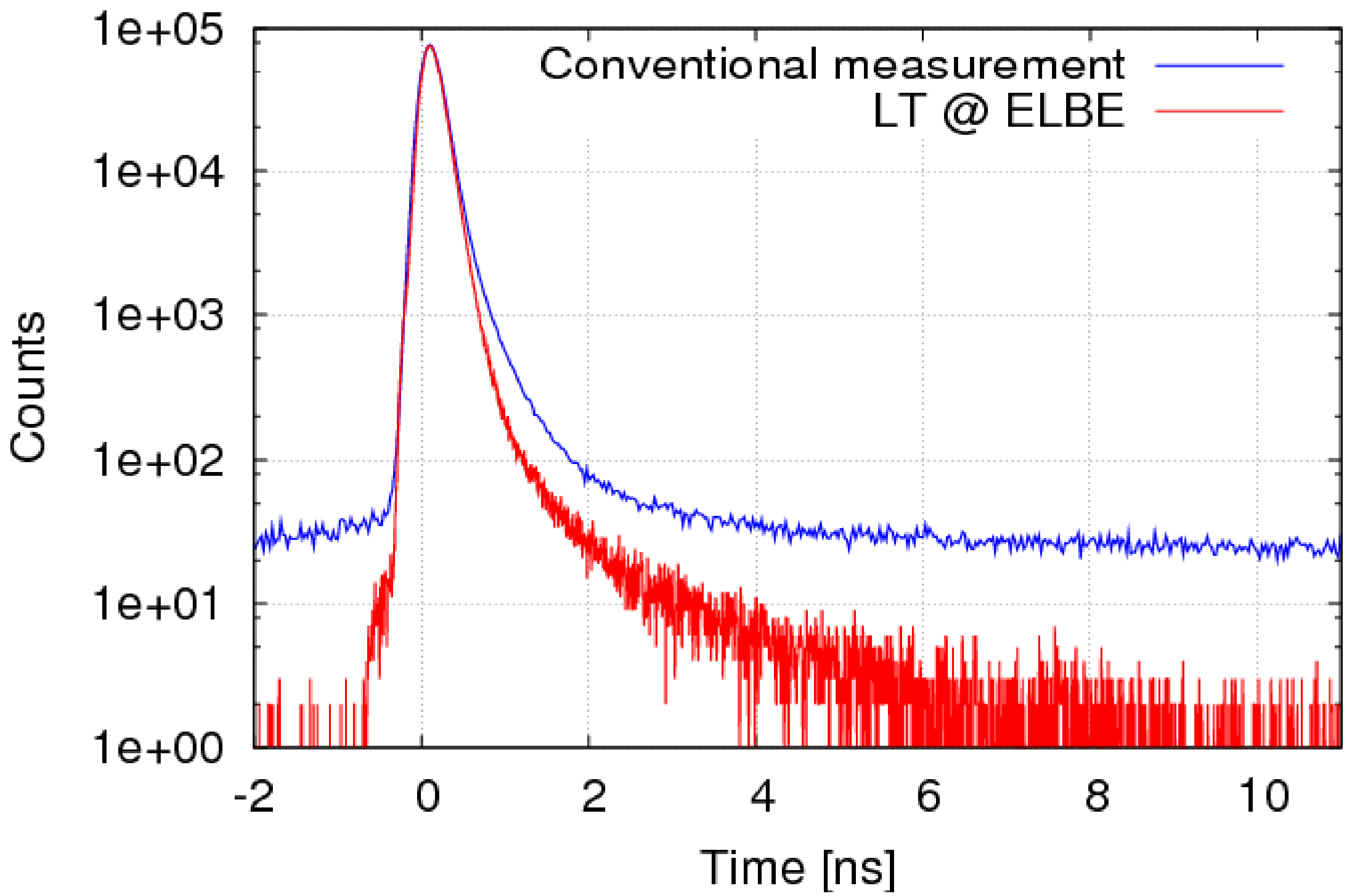
Residuals of fit show perfect fit

- analysis by LT 9.0 (J. Kansy)



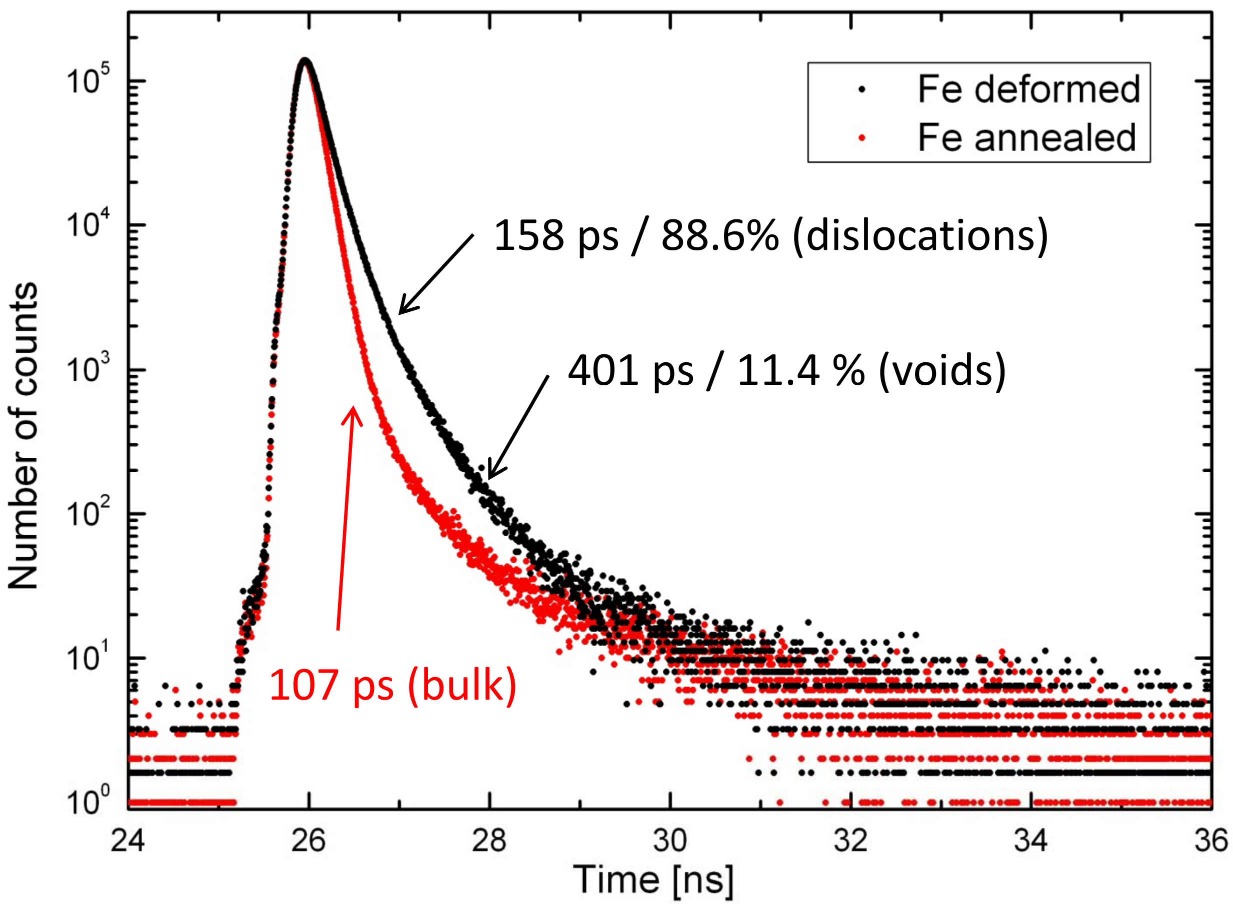
Comparison: GiPS spectrum with conventional measurement

- same sample material – almost same statistics, similar time resolution
- conventional measurement with ^{22}Na source 20 µCi (0.7 MBq) in sandwich geometry
- advantage of periodic positron source is obvious: background distinctly reduced
- result of spectra analysis is the same: 107 ps (bulk value for Fe; corresponds to literature)



Comparison annealed and deformed Fe

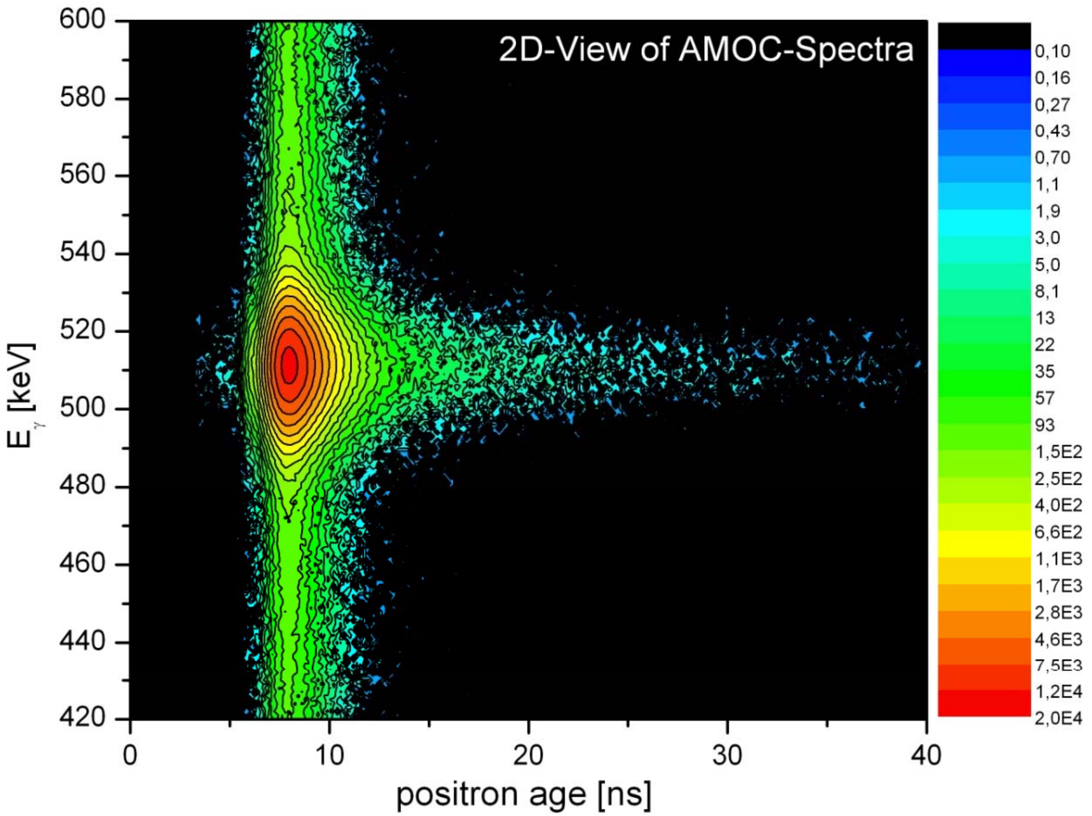
- two mechanically identical samples were prepared
- Fe annealed (1100°C; 2h in vacuum) and Fe (50% thickness reduction by cold rolling)
- spectra were easily decomposed
- expected results: annealed sample – one component 107 ps; deformed sample has 158 and 401 ps (dislocations and small vacancy clusters)



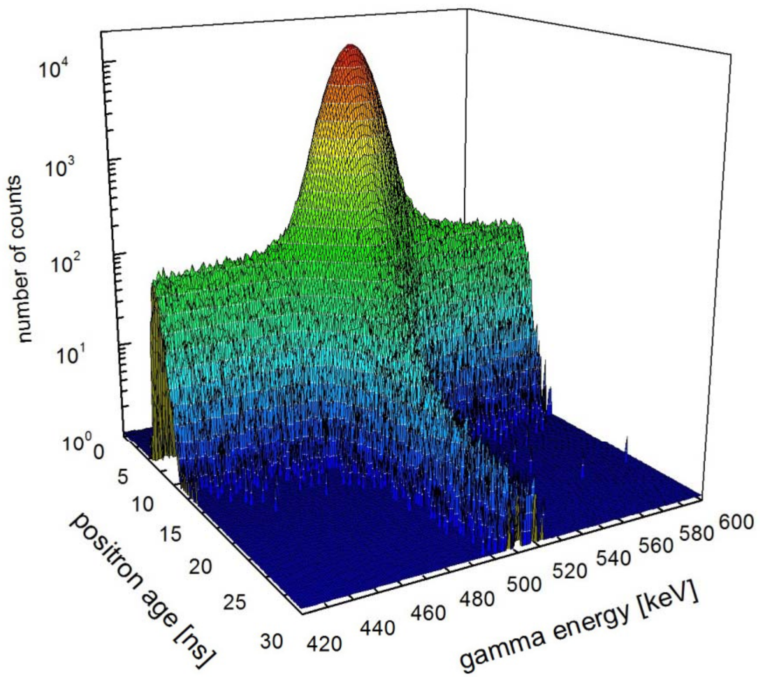
AMOC spectrum of annealed Fe

- AMOC: measurement of momentum of annihilating electron as function of positron age
- AMOC detection is not an extra gimmick, but is required to maintain quality of spectra
- only by coincident measurement of 511 keV annihilation line: suppression of scattered gamma (can be concluded from lifetime spectra)

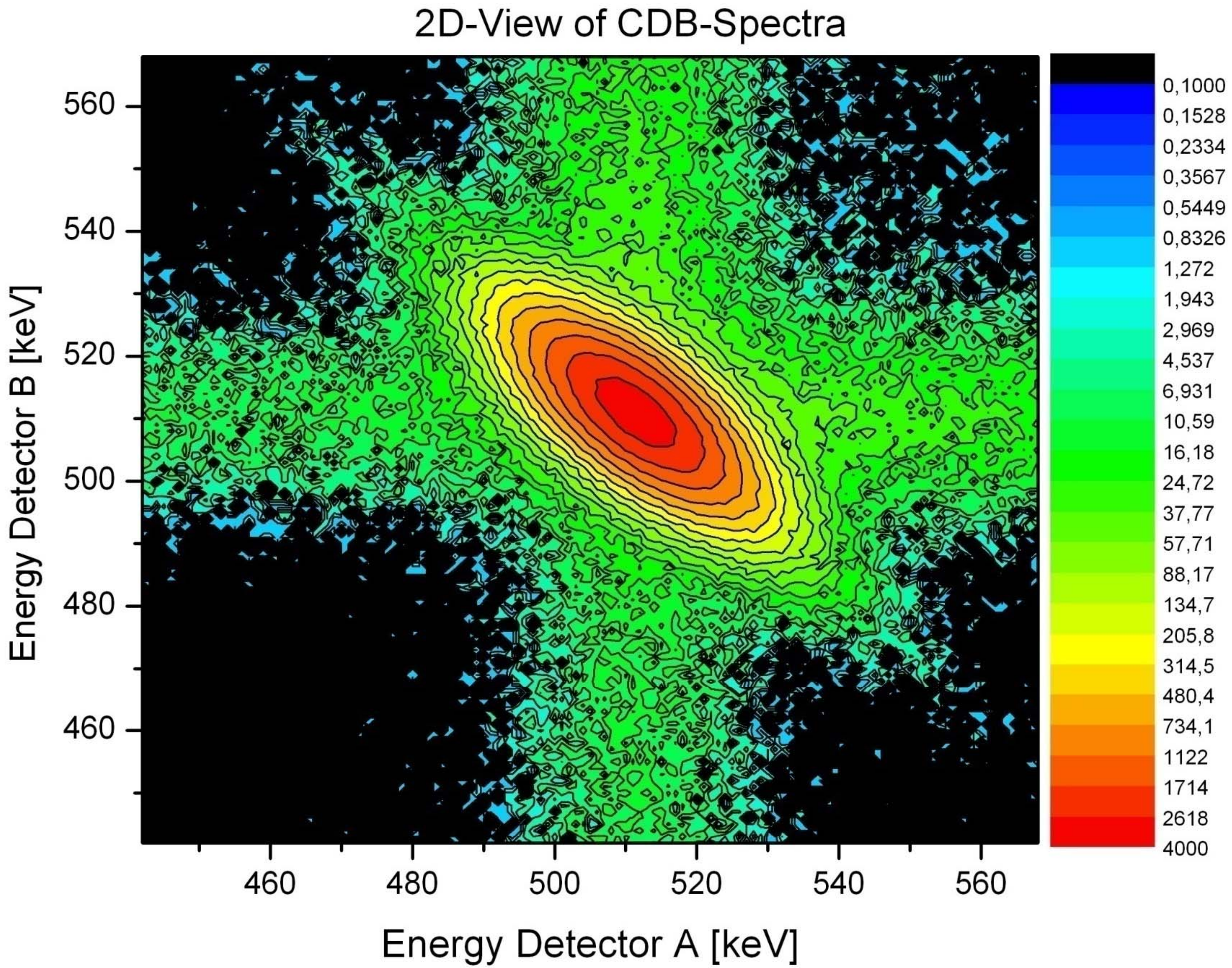
2D-Plot



3D-Plot

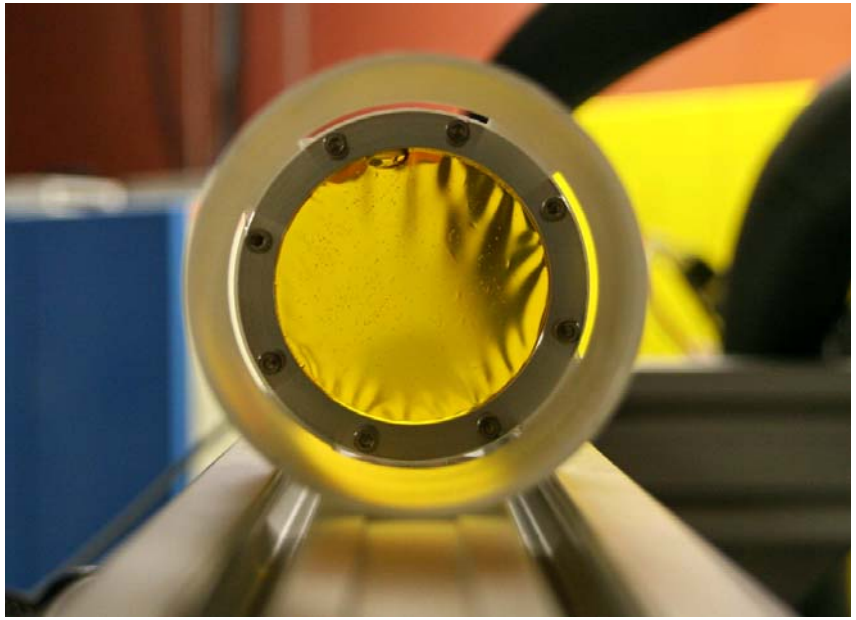


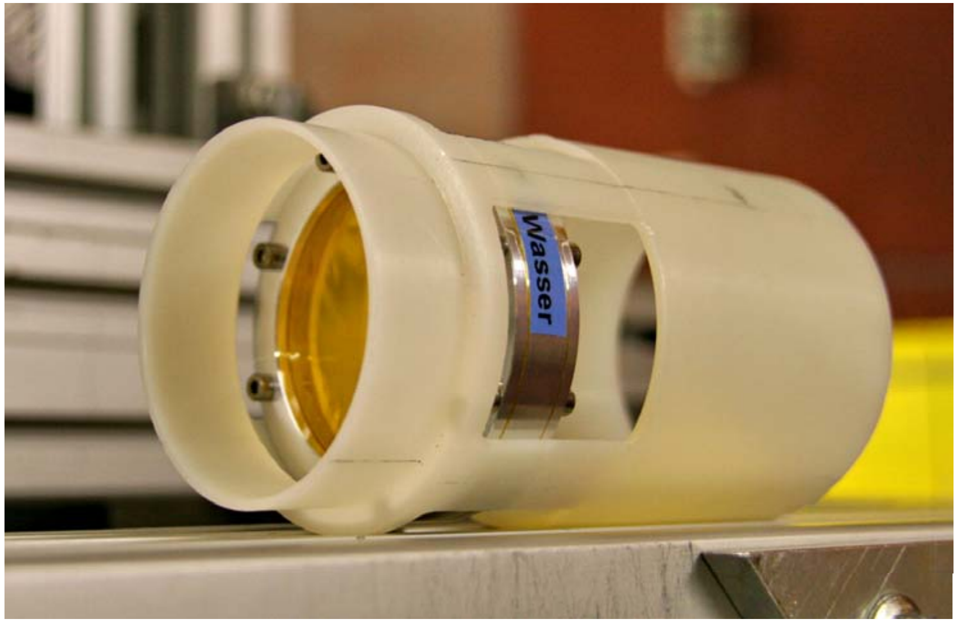
Coincidence Doppler-Broadening Spectroscopy of Fe sample



Sample holder for water

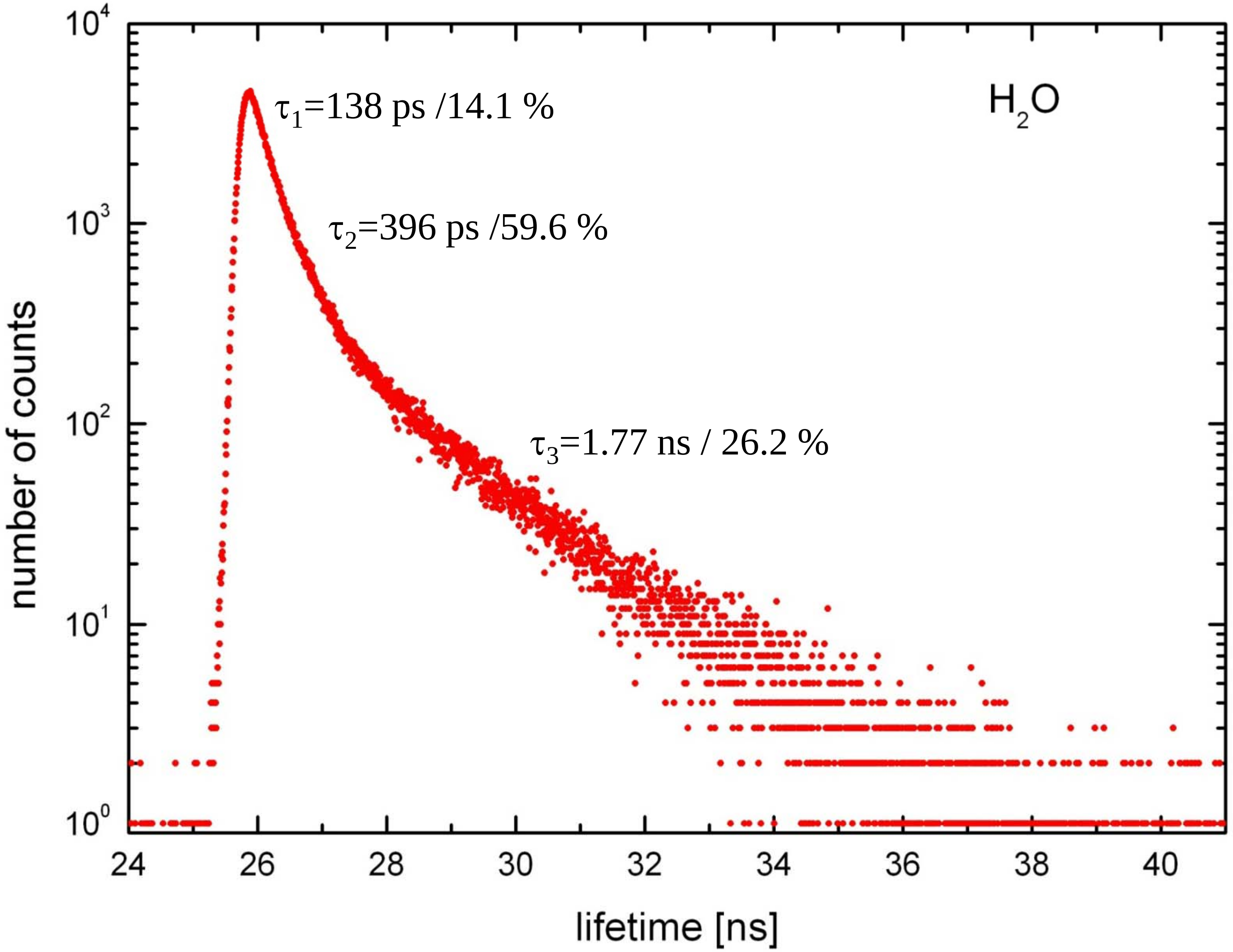
- Water is hold between two thin Kapton foils (few µm)
- inner diameter of Al rings is 50 mm
- Kapton was used because of simple lifetime spectrum (single component of 382 ps)
- but volume fraction of Kapton is very small (0.4%): almost no contribution to spectrum expected
- gamma beam has 20 mm diameter





Water at RT

- total count rate: $5x10^5$
- no such visible deviations on $t < t_0$ (due to much smaller gamma scattering compared to Fe)

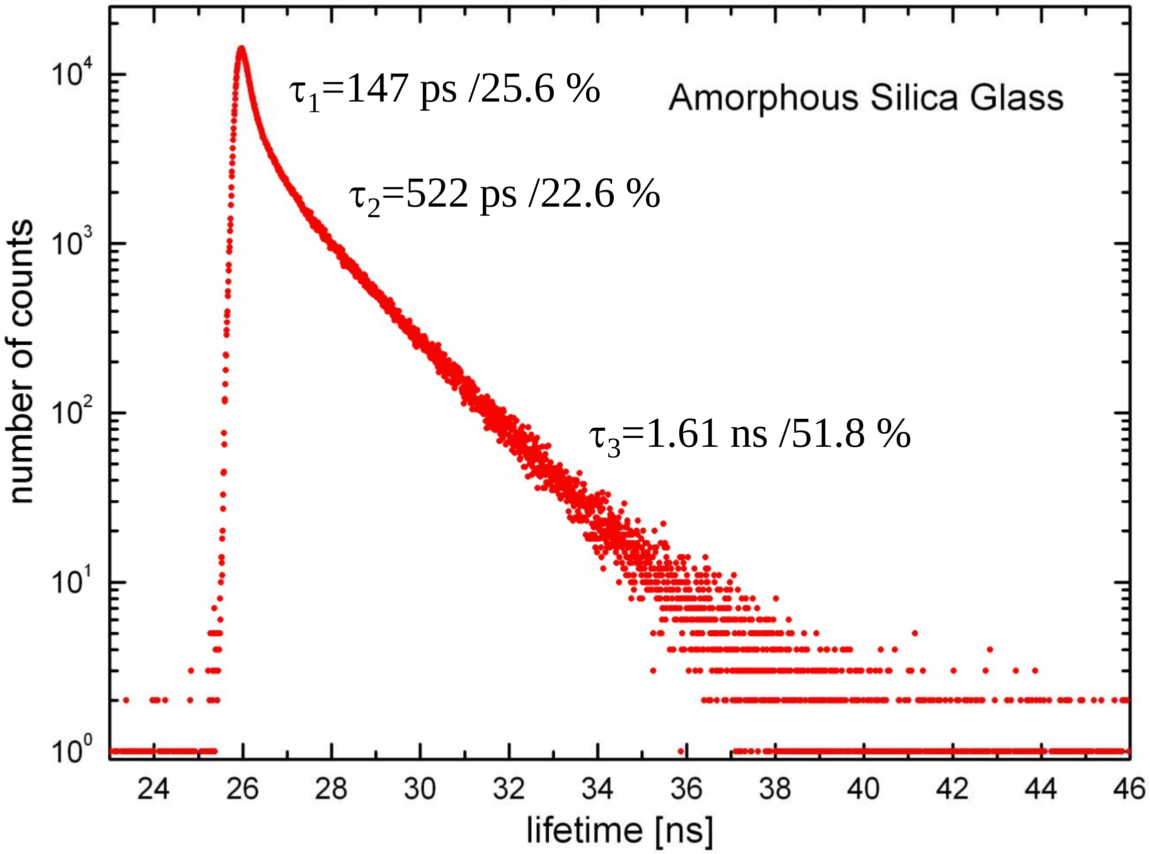


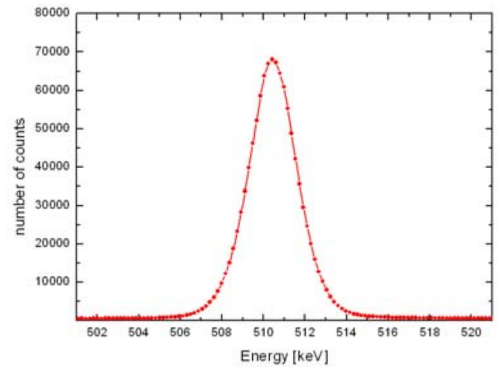
Amorphous Silica Glass

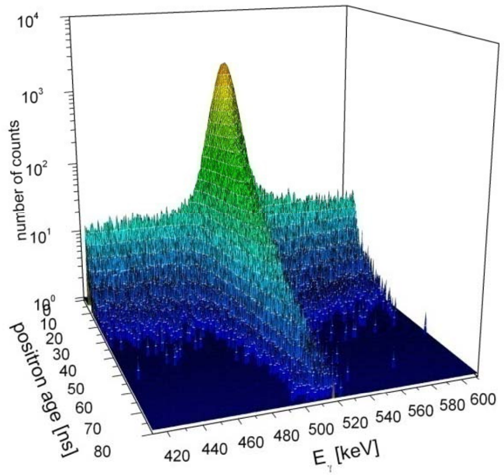
- round piece 1.5 cm thick, about 5 cm^3
- lifetime spectrum: total count rate: $2x10^6$
- same sample was measured conventionally in 1978 also in the same institute (former ZfK Rossendorf):

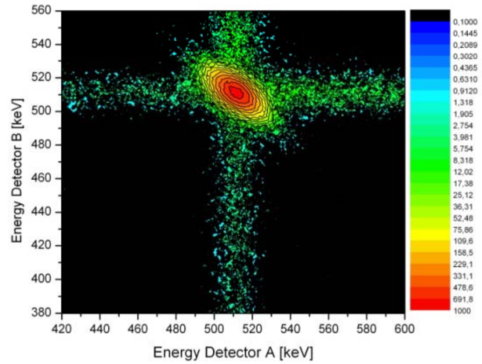
  151 ps - 523 ps - 1.57 ns (FWHM ≈350 ps)

  G. Brauer et al., Appl. Phys. 16 (1978) 231









Conclusions

- new concept of EPOS project is now extended to use mono-energetic Positrons (MePS), Gamma-induced (GiPS) and conventional spectroscopy (CoPS)
- all spectrometers are equipped with LT, CDB, AMOC
- fully digital system (in the future)
- EPOS can cover sample thickness range from 10 nm to 10 cm (7 orders of magnitude)
- MePS still under construction
- GiPS has been tested successfully
  - GiPS only possible because of the unique properties of the ELBE Linac (cw mode of 26 MHz intense and extremely short electron bunches, < 5ps bunch length)
  - background suppression by coincident measurement of Lifetime and Doppler (AMOC)
  - surprisingly good spectra quality
  - coincidence between 2 BaF_2: resolution improves by 24% (FWHM = 160 ps)
  - problem: heating / cooling of sample because in holder positrons are also generated

Talk available at http://positron.physik.uni-halle.de