The EPOS system at Helmholtz Centre Dresden-Rossendorf
An intense pulsed positron source

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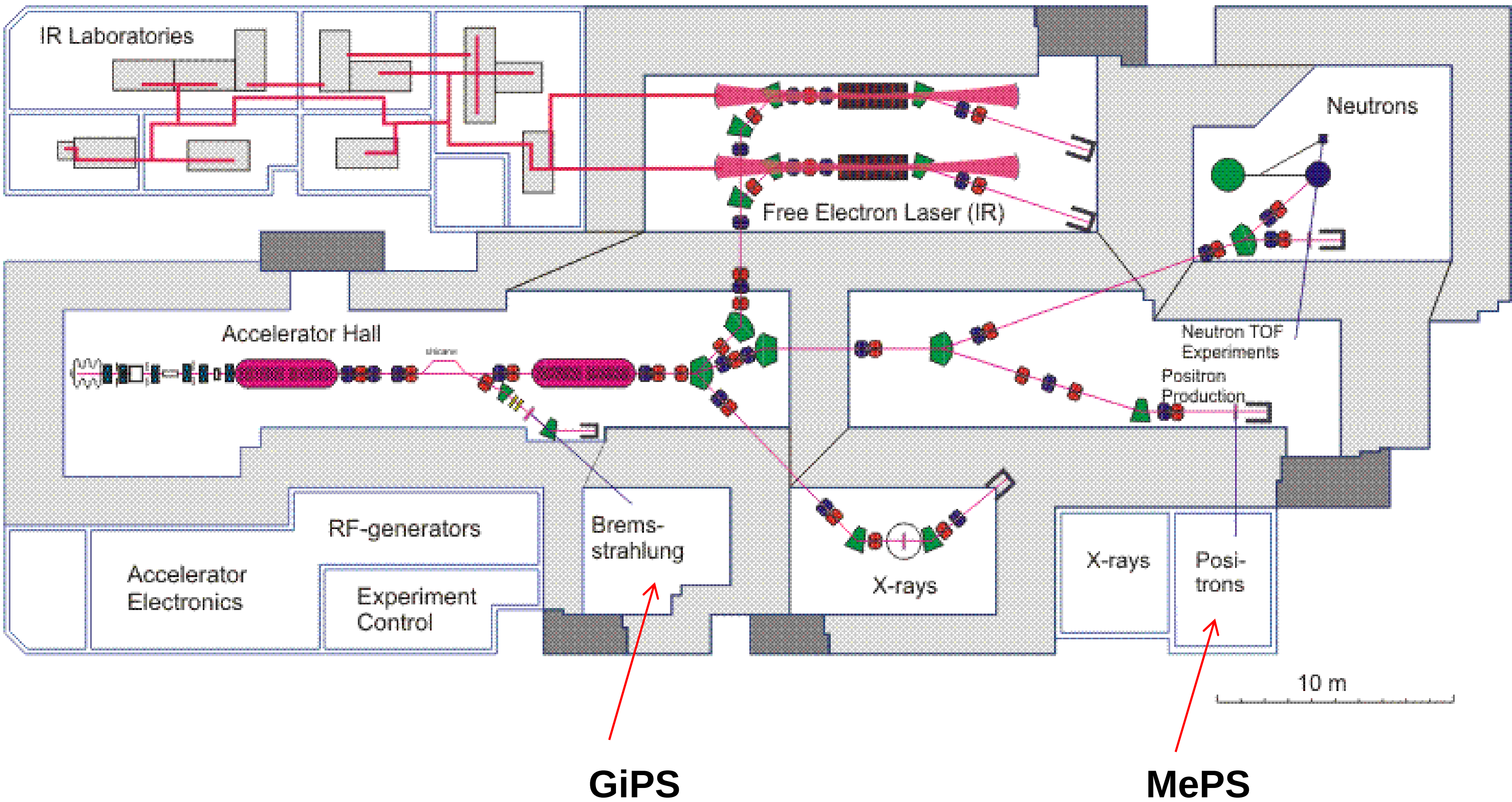
Concept of EPOS

- Progress of the Mono-energetic Positron Beam (MePS)
- Gamma-induced Positron Spectroscopy (GiPS)
- conventional Positron Spectroscopy (CoPS)
  - PALS
  - Sponsor

Ground map of the ELBE hall



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

- 4-tubes PALS digital spectrometer
  - CDBS, AMOC
  - using ^{22}Na foil sources
  - He-cryostat
  - automated system
- SPONSOR: continuous slow-positron beam

Information Depth:
0…200 µm

GiPS

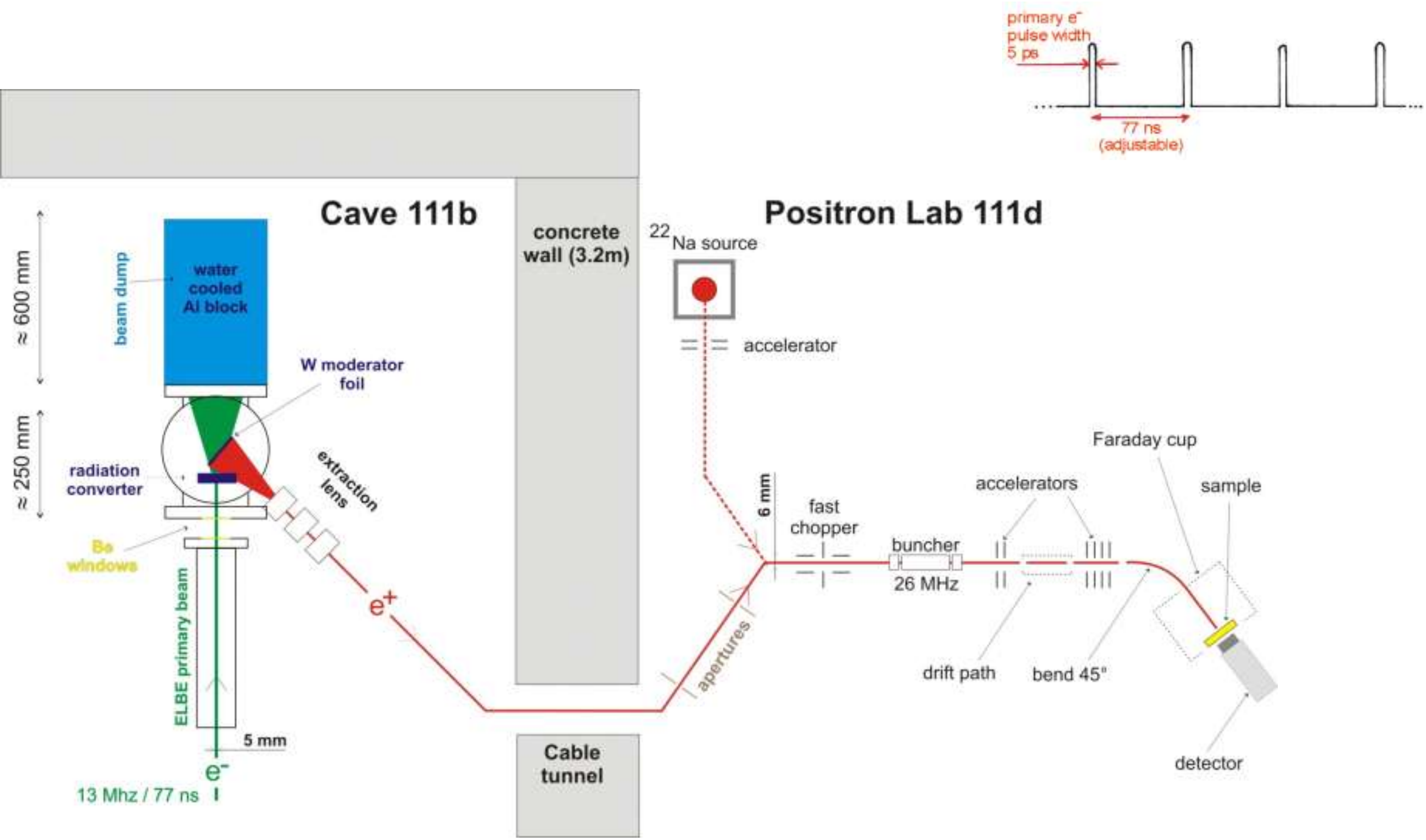
Gamma-**i**nduced **P**ositron **S**pectroscopy

- 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

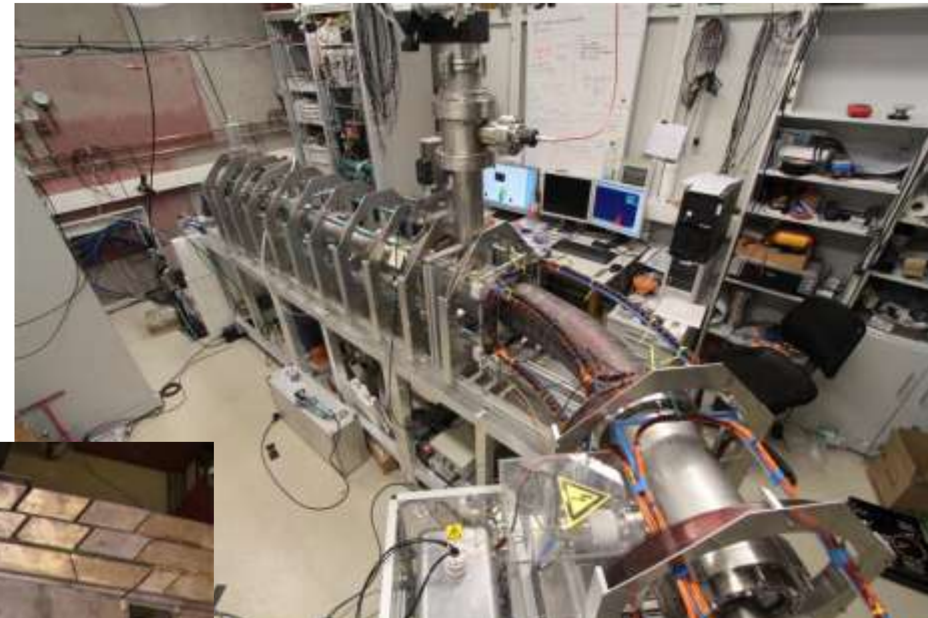
Mono-energetic Positron System - MePS

- 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

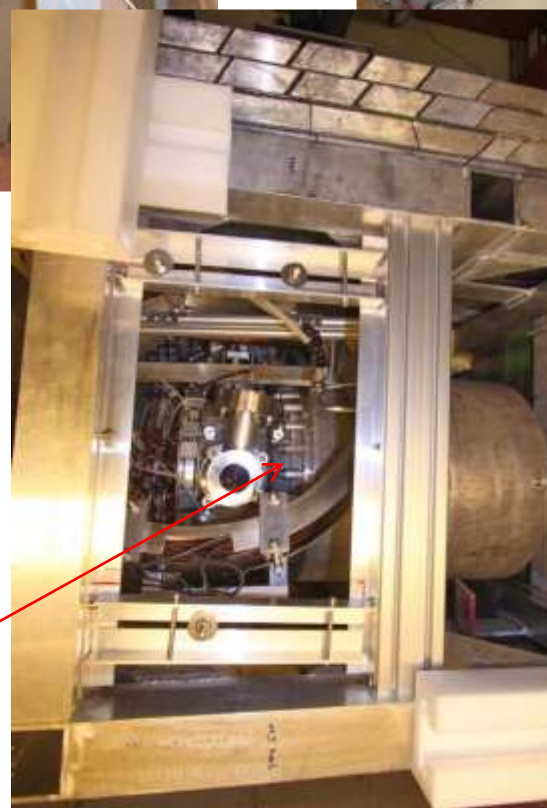


Cave and Laboratory

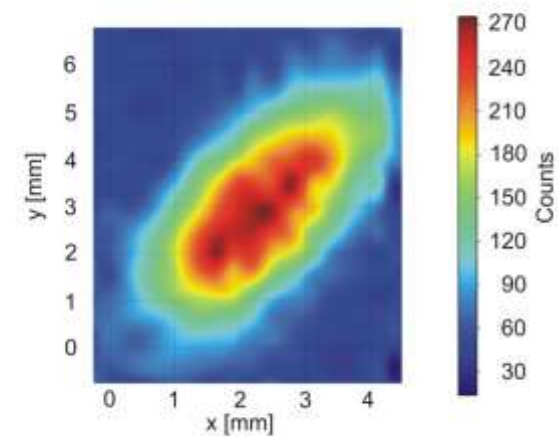
electron-positron converter



Laboratory



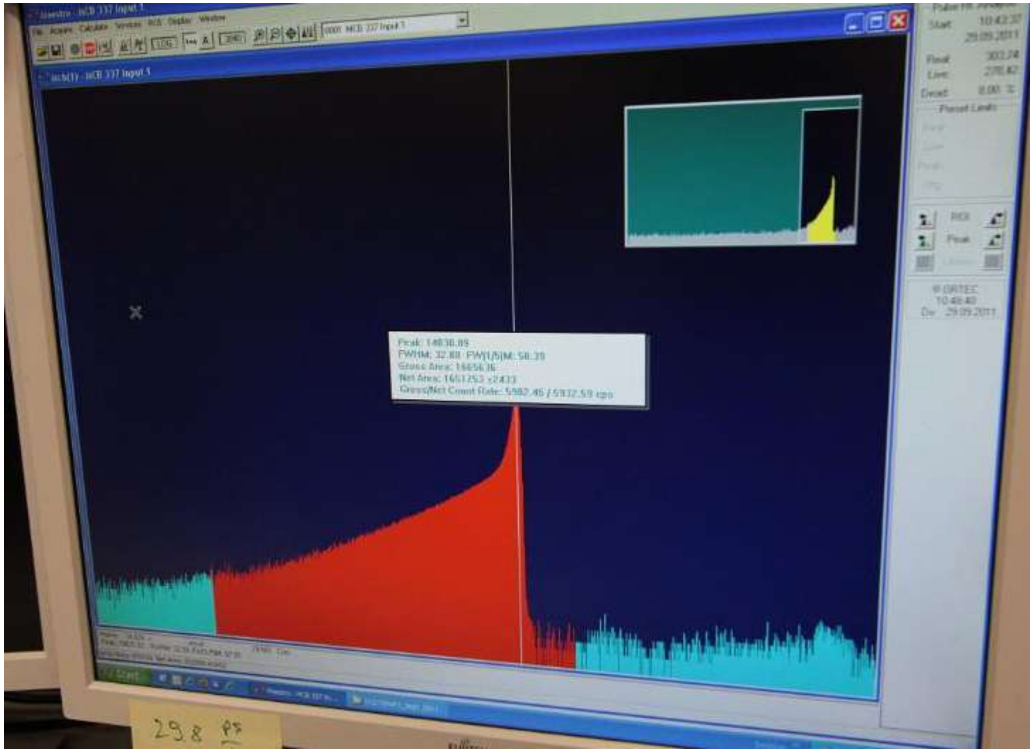
converter and beam dump



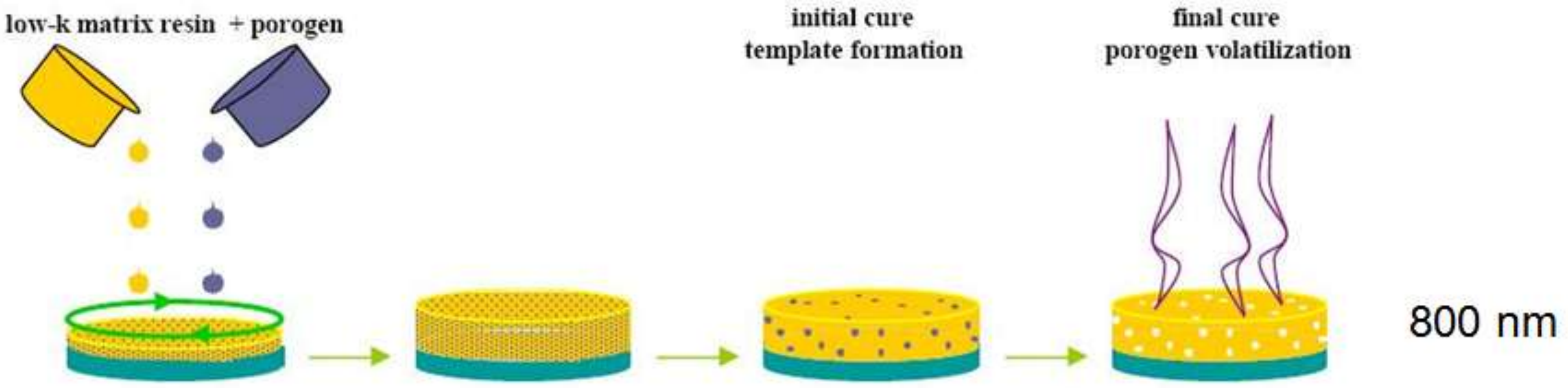
beam spot

MePS characteristics

- Count rate @ 30 µA electron current: 8000 cps (maximum current 1 mA)
- time resolution still too bad: 500 ps FWHM
- we use no chopper yet: will improve the time resolution
- signal-to-BG ratio: about 10^4
- no spurious signals
- user-dedicated facility

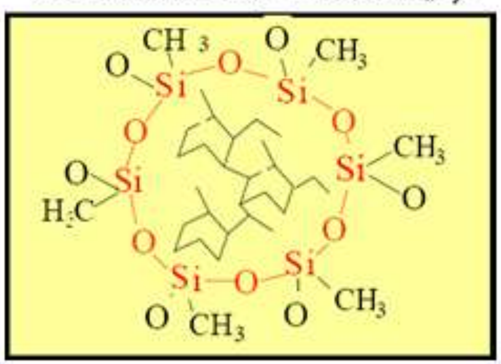


MePS: first experiment
Study of low-k dielectric films

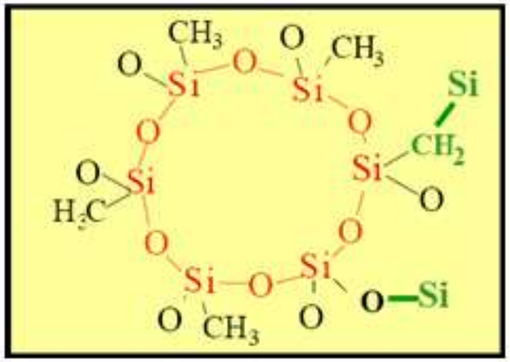


(1) "Low-k Dielectrics." http://fcs.itc.it/

CDO Matrix (SiOCH) + Porogen (C_xH_y)

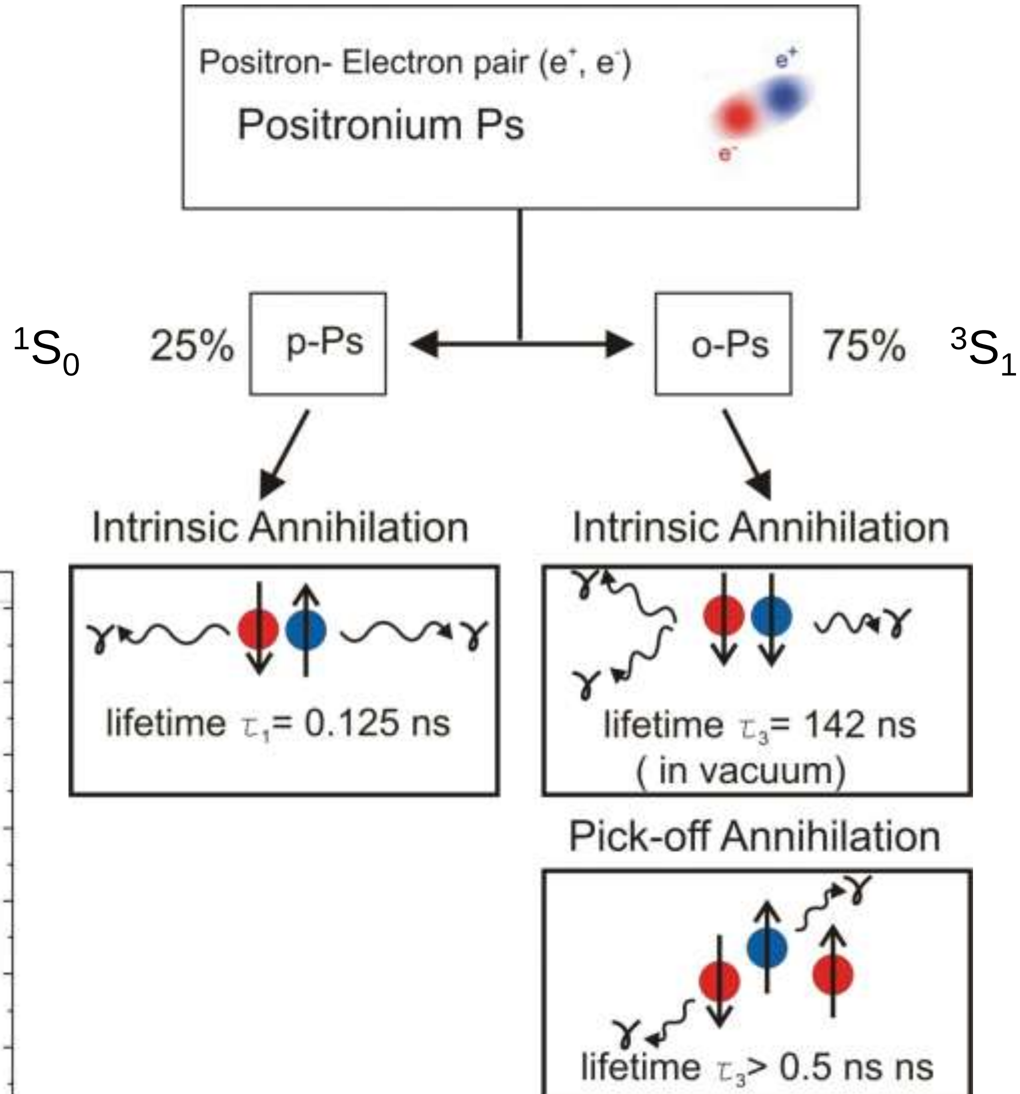


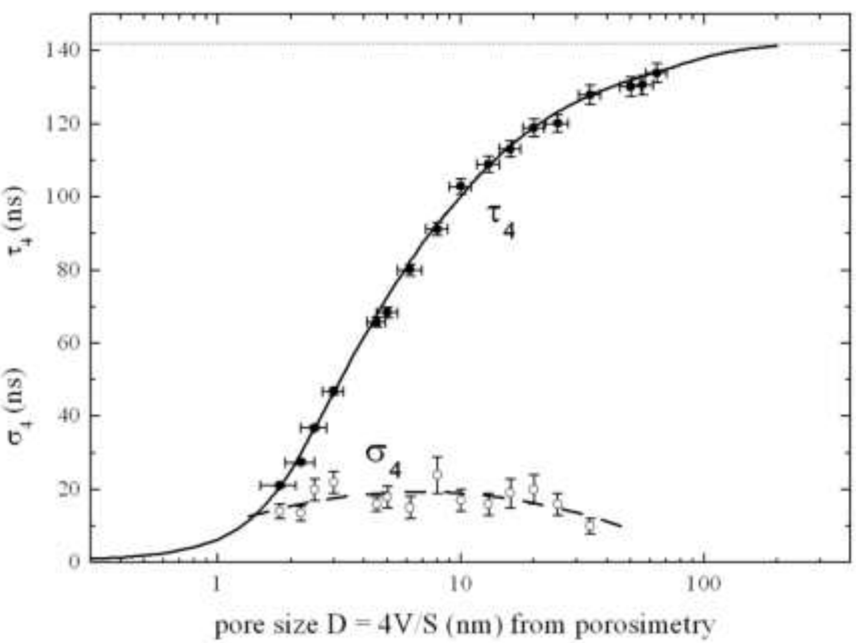
UVTP – Ultraviolet Thermal Processing



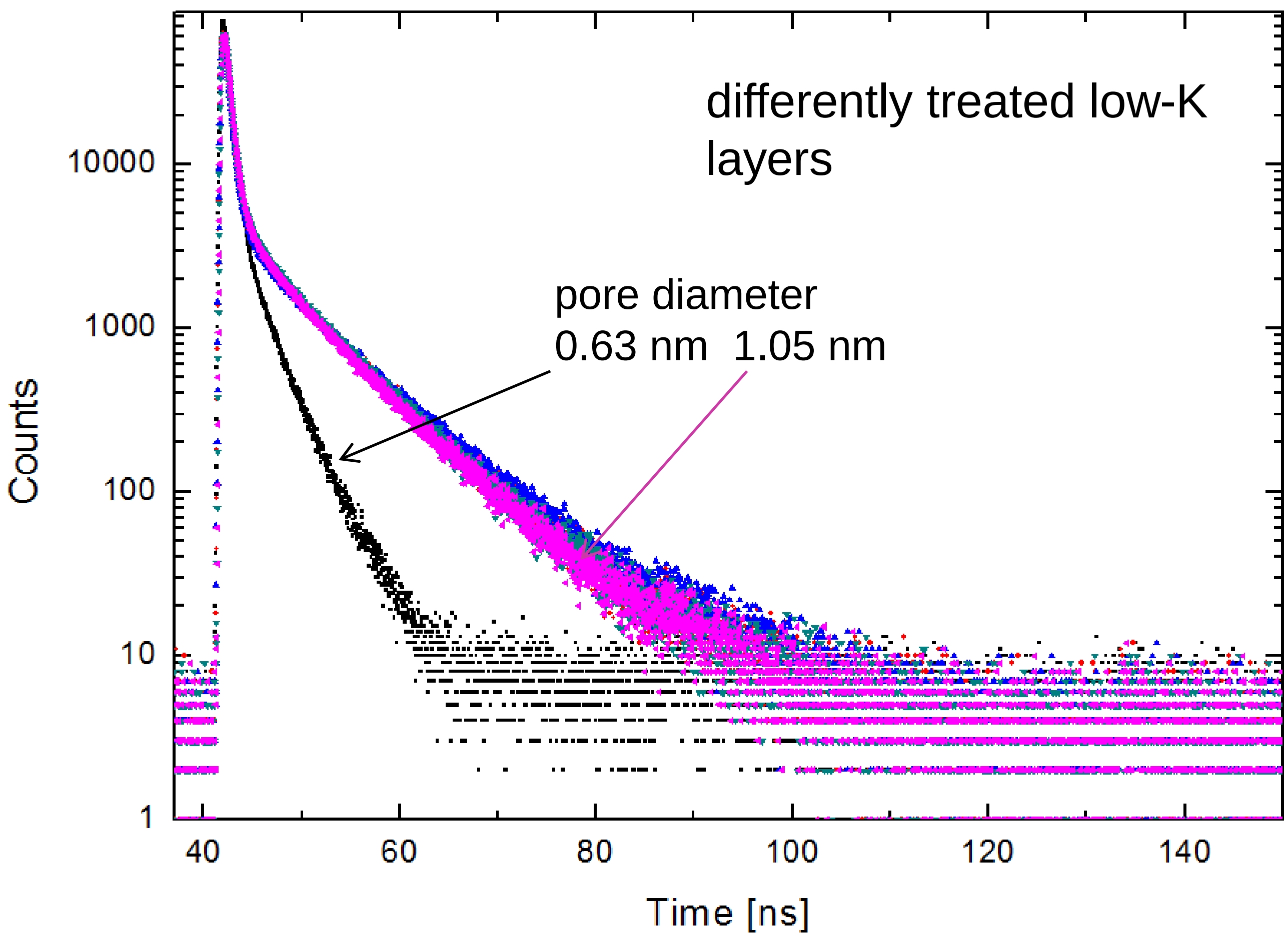
Positronium lifetime can be used for porosimetry

- Ps formation in materials without free electrons
- dielectrics, polymers, glass, liquids, gases, …
- pick-off annihilation is a measure of pore size





Low-K dielectric layers



- Positrons are ideal tool for closed porosity in low-k layers
- Lifetime spectra of differently treated low-K layers
- Treatment:
  - untreated porous layer
  - plasma treatment for compactation
  - TiN cap layer

Gamma-induced Positron Spectroscopy

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Nuclear Instruments and Methods in Physics Research A 495 (2002) 154–160

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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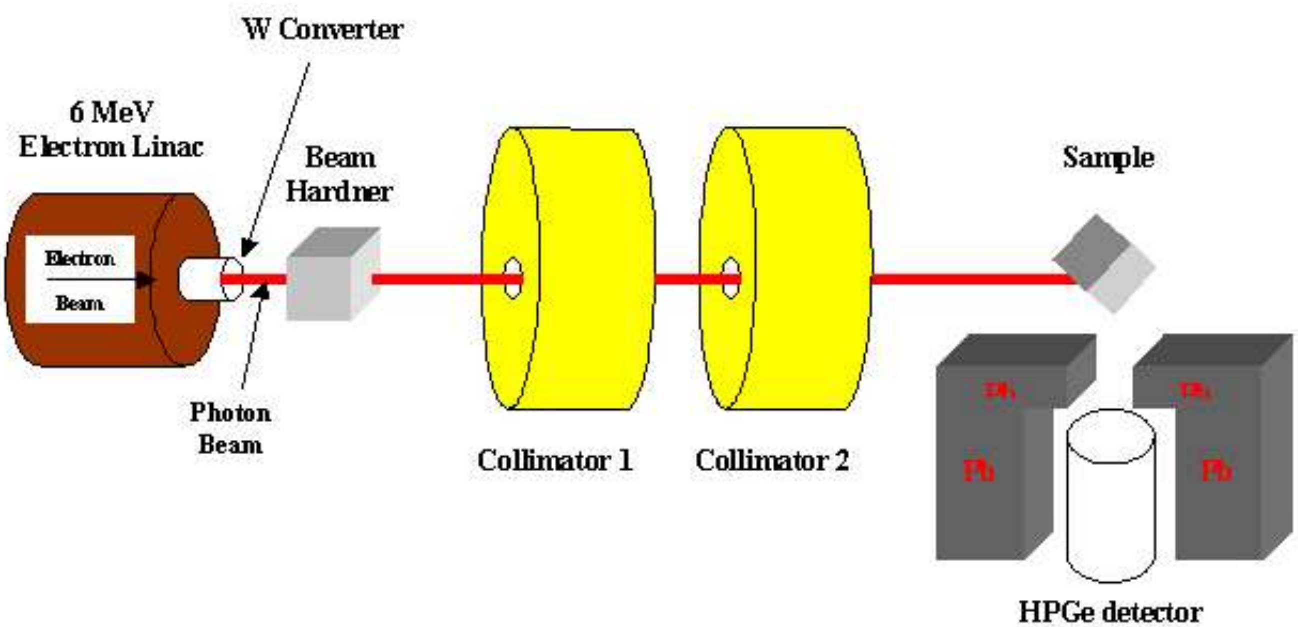
Received 16 April 2002; received in revised form 13 August 2002; accepted 20 August 2002



First spectra

Advantages

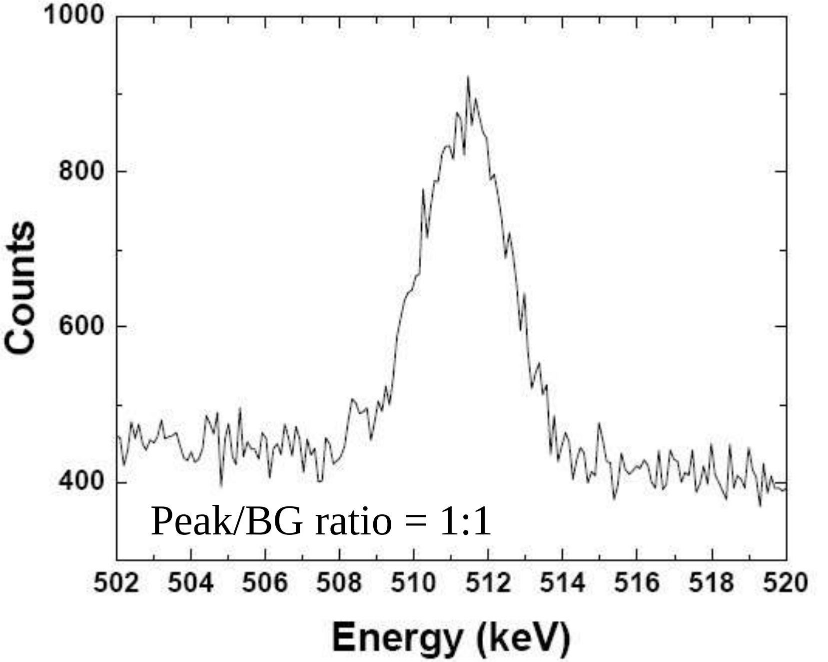
- information depth 0.1 … 5 cm; whole sample
- ideal for bulky samples (NDT), liquids, gases, biological objects, coarse powder, dispersions …

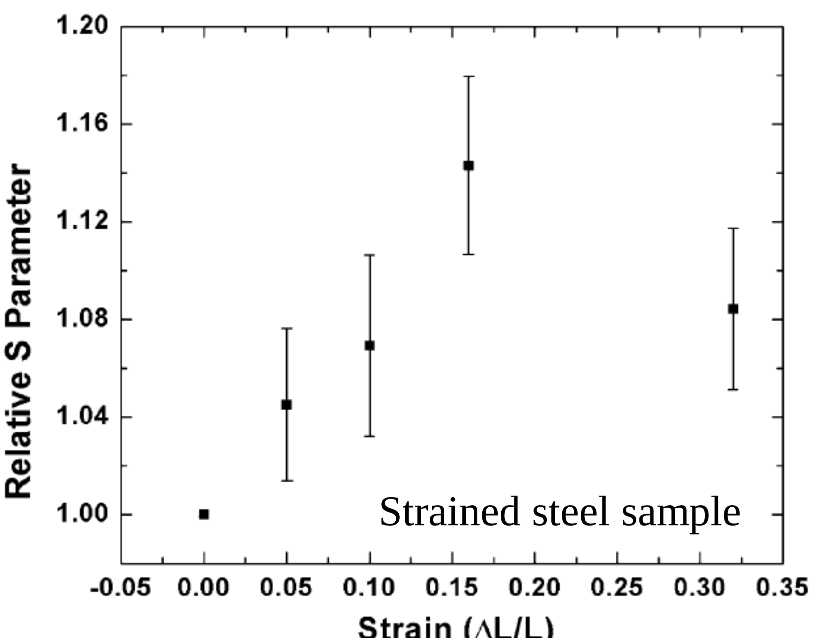
Disadvantage of slow LINACs

- 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 and Methods in Physics Research A 555 (2005) 211–219

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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Received 20 July 2005; received in revised form 6 September 2005; accepted 10 September 2005

Available online 10 October 2005

Abstract

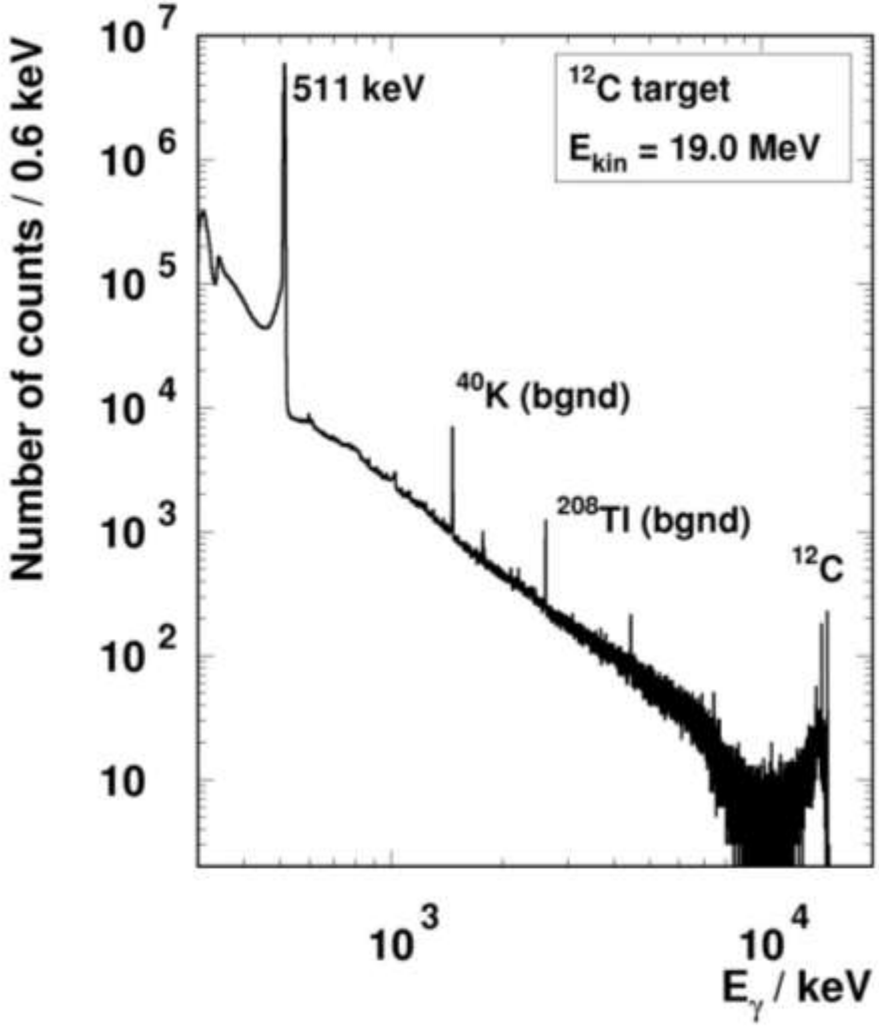
A new facility for the production of polarised bremsstrahlung has been built at the superconducting electron accelerator ELBE of the Forschungszentrum Rossendorf. The bremsstrahlung facility and the setup for photon-scattering experiments are designed such that the background radiation caused by the 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

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



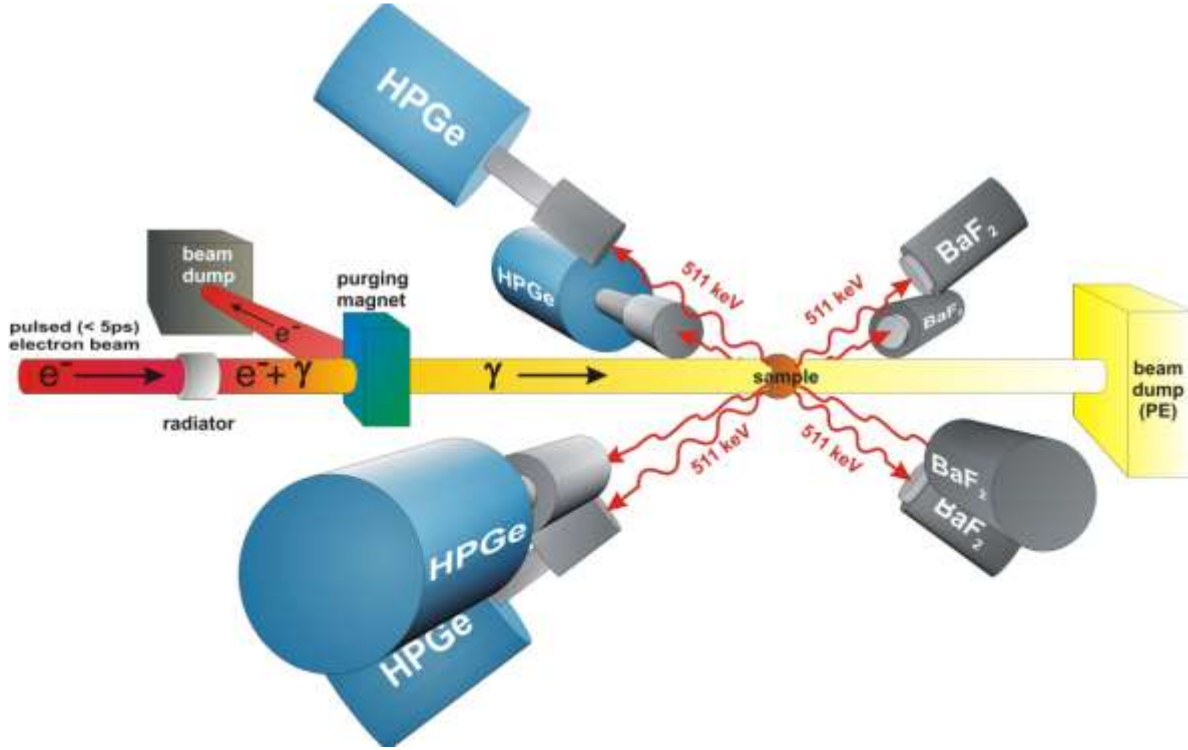
Spectrum of photons scattered from ^{12}C using Bremsstrahlung produced by electrons with an energy of 19 MeV.

Setup extended by BaF_2 detectors for lifetime measurement

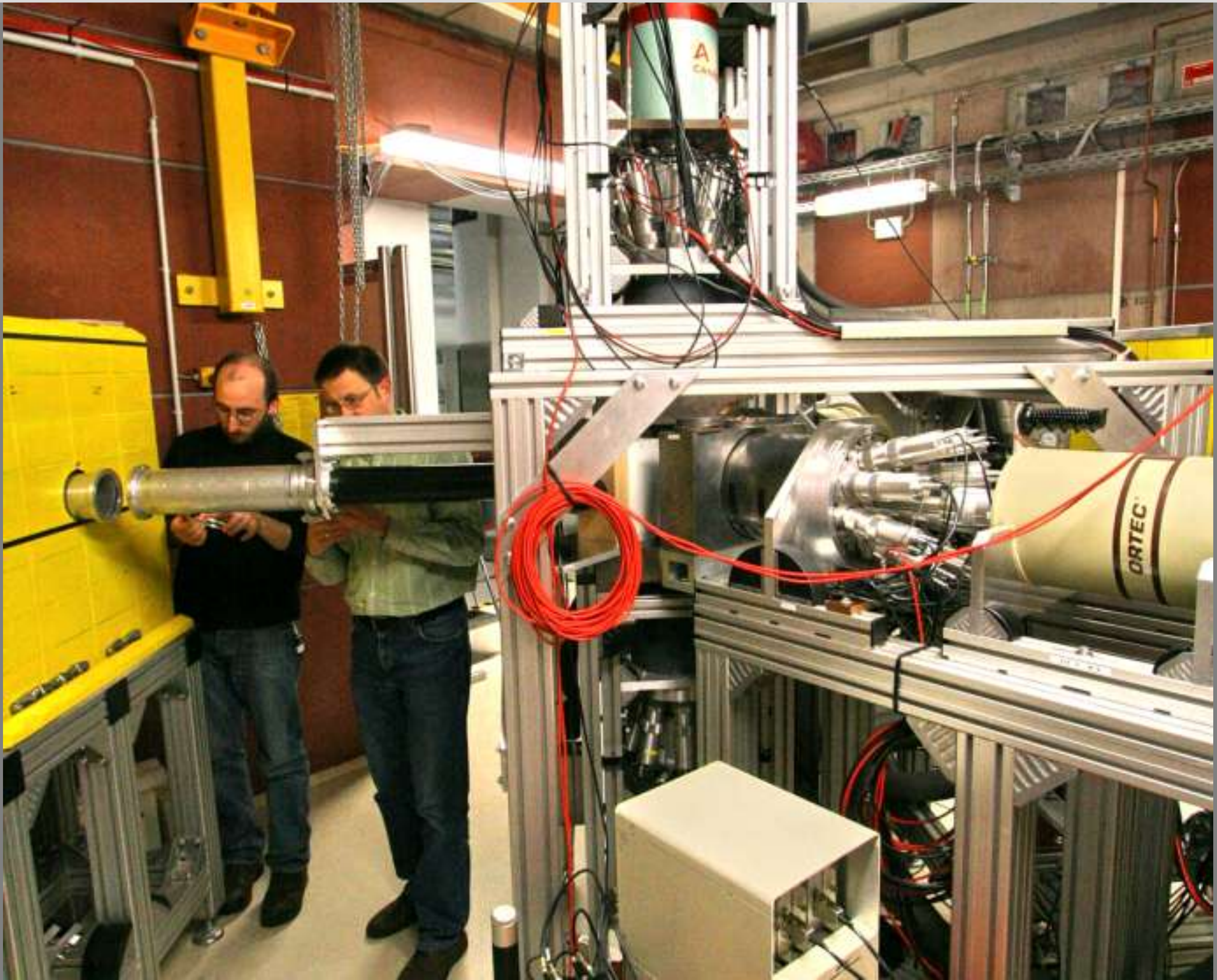
- 4 coincident AMOC setups were used (**A**ge-**MO**mentum **C**orrelation)
- only coincident detection ensures high spectra quality

Problem

- all scattered quanta appear within positron lifetime – time coincidence alone does not reduce background
- but energy selection in Ge detector to 511 keV window reduces background
- and distance helps: for two 511 keV quanta in coincidence the distance dependence is proportional to r^{-2}
- arbitrary scattered gamma: r^{-4}



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



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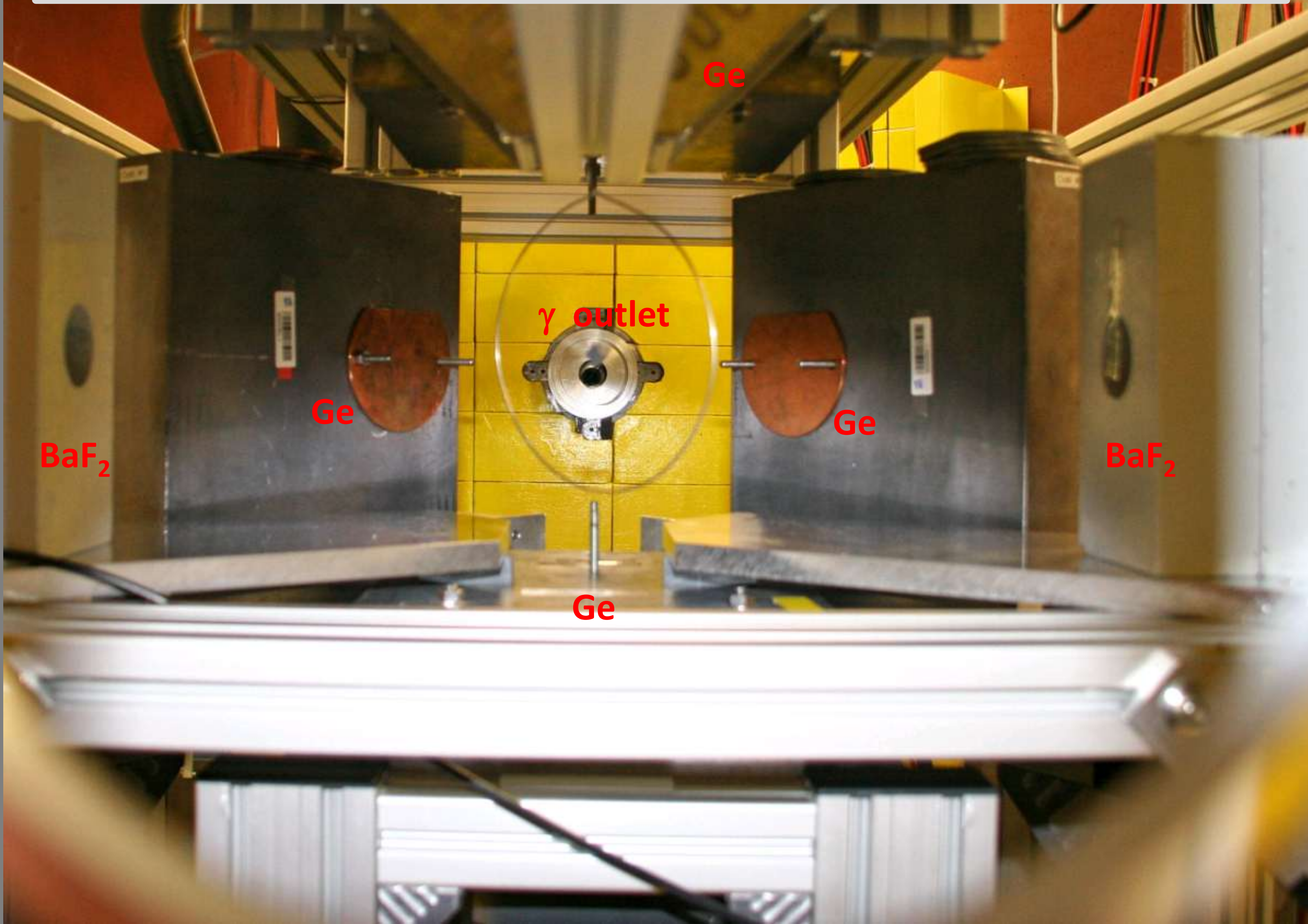
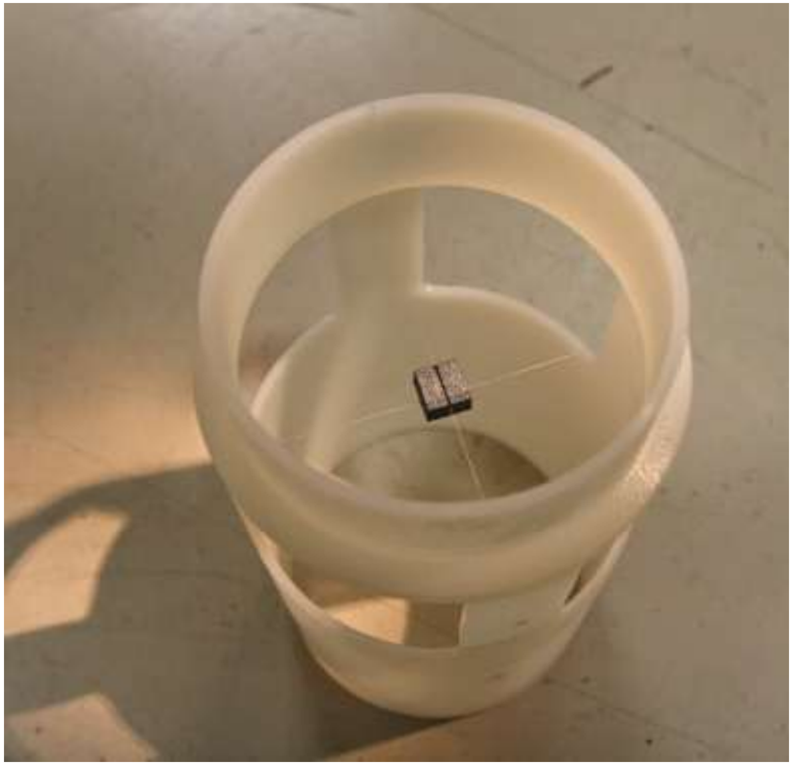
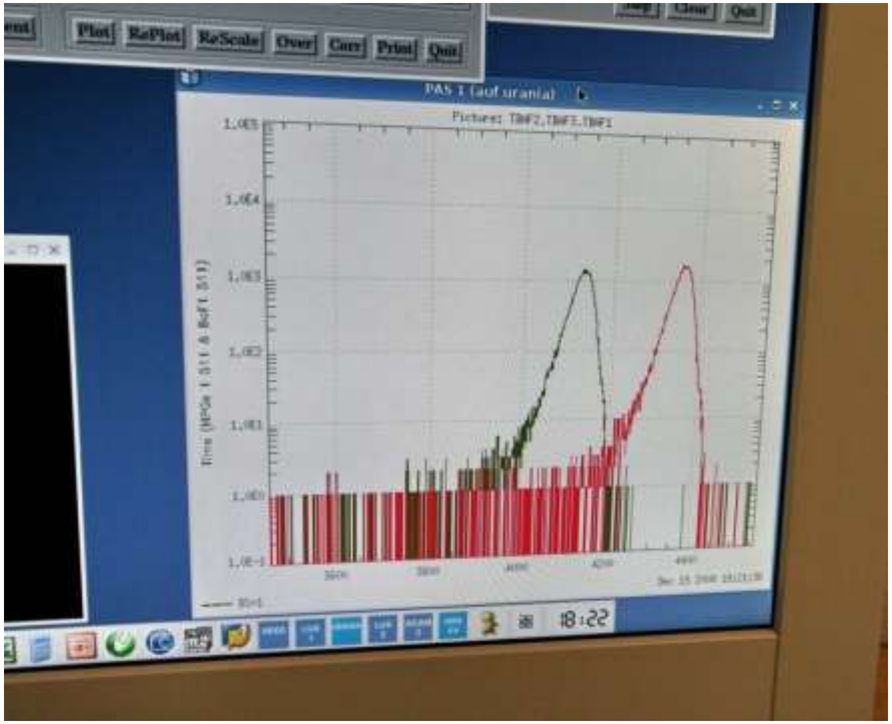


First experiment: annealed and deformed Fe

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



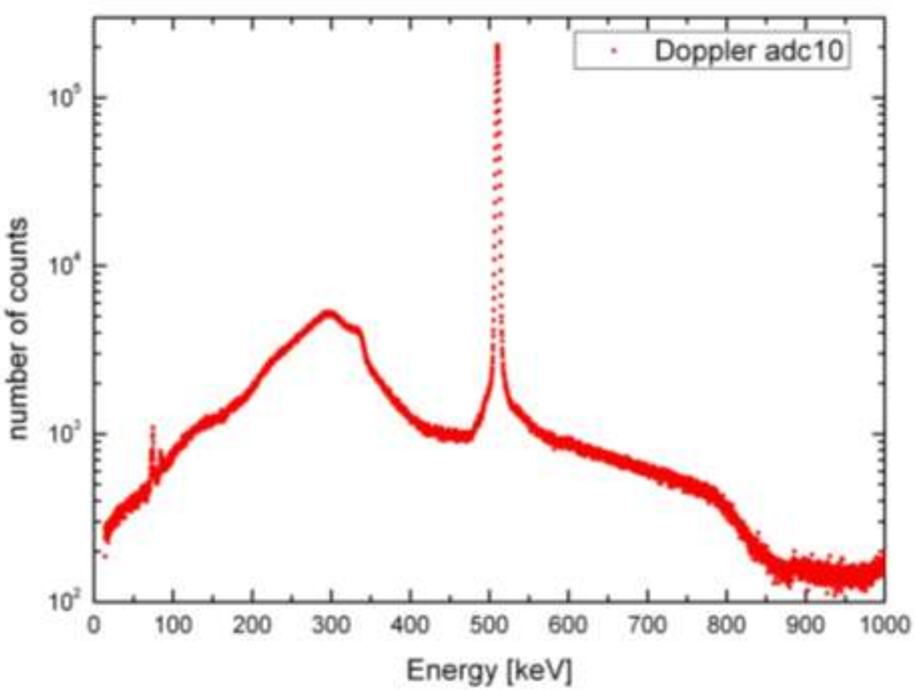
sample holder: Fe sample is hold by thin nylon fibers

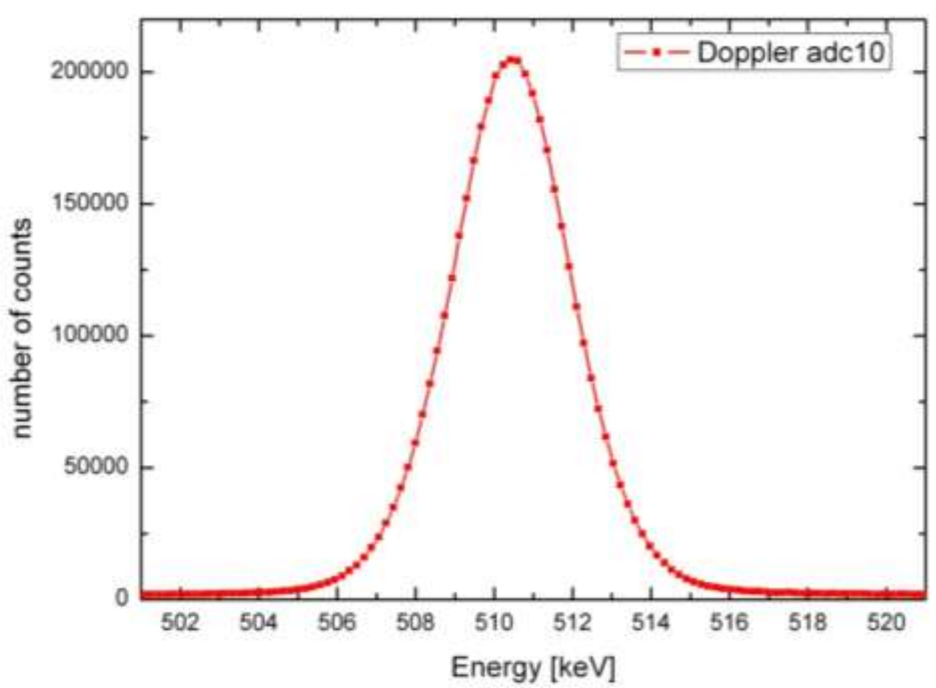


first spectra growing: stop pulse for timing from BaF_2 and start pulse is accelerator bunching pulse of ELBE

Single-channel Ge Spectrum of annealed Fe

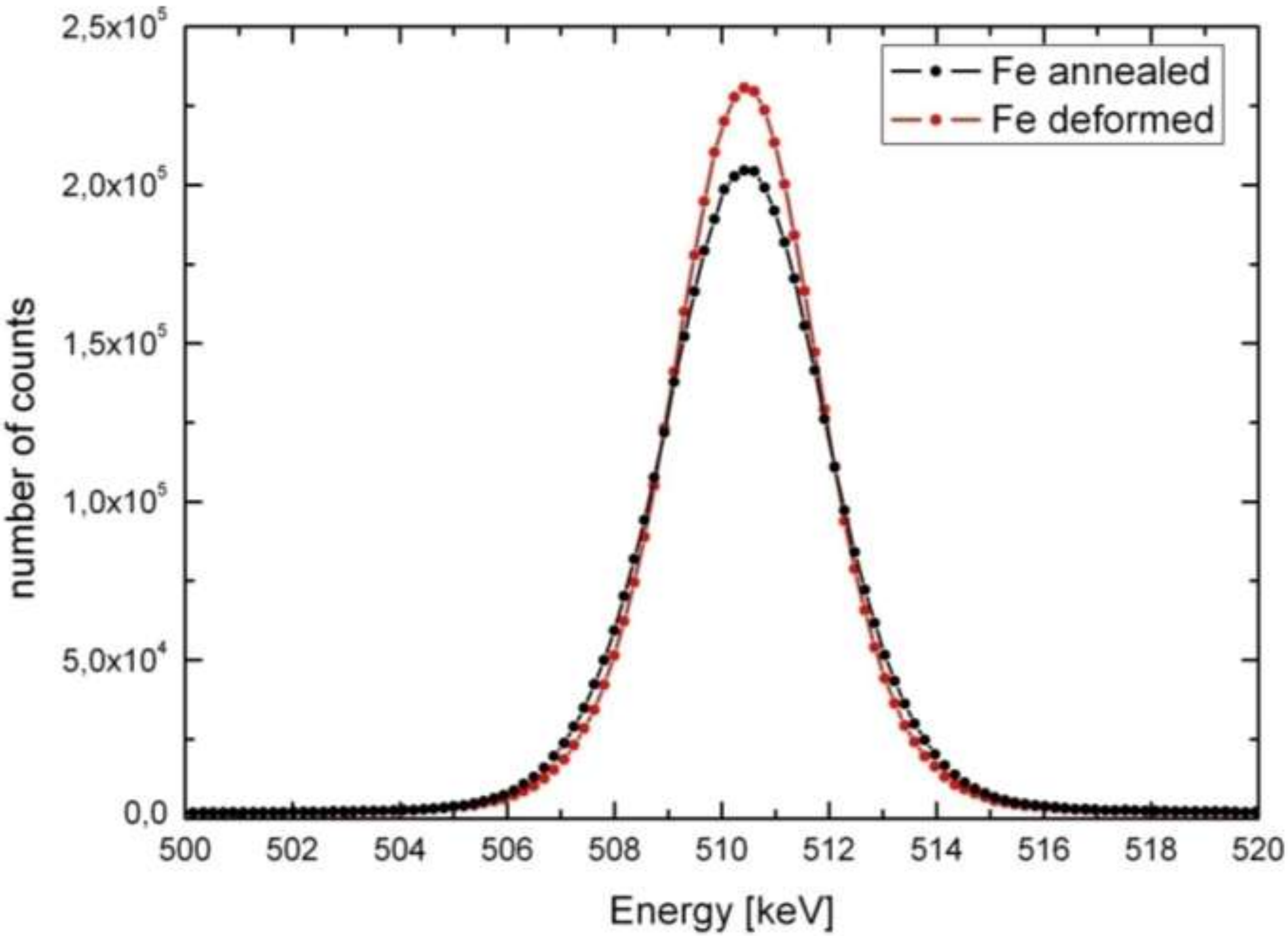
- count rate about 20 kHz (200 kHz would be theoretically possible)
- about 50% of intensity in 511 peak
- decrease below 350 keV due to 5 mm Cu absorber plates in front of Ge detectors (beam hardener)
- detection with analog electronics in list mode





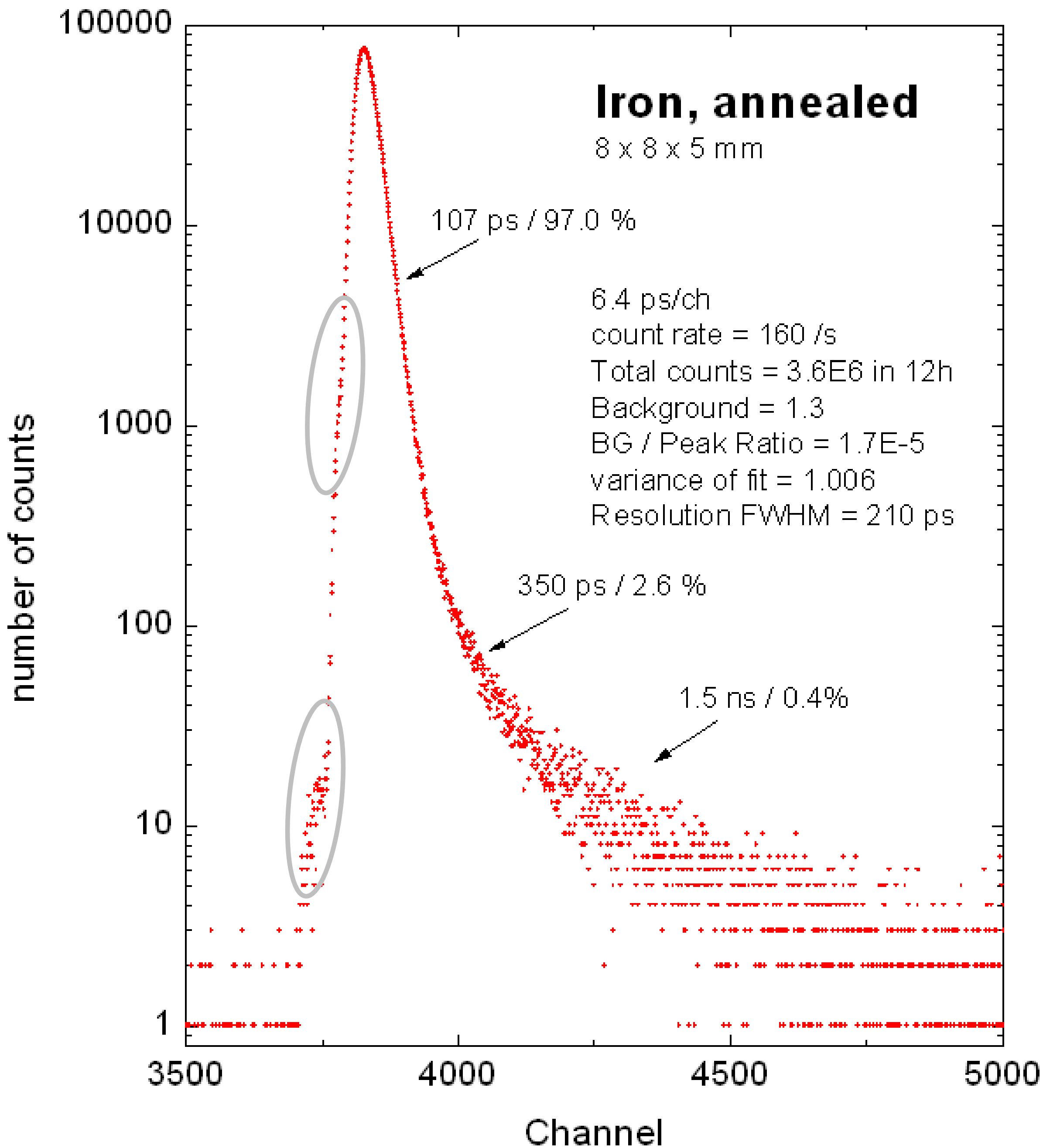
Comparison annealed and deformed Fe

- expected 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)



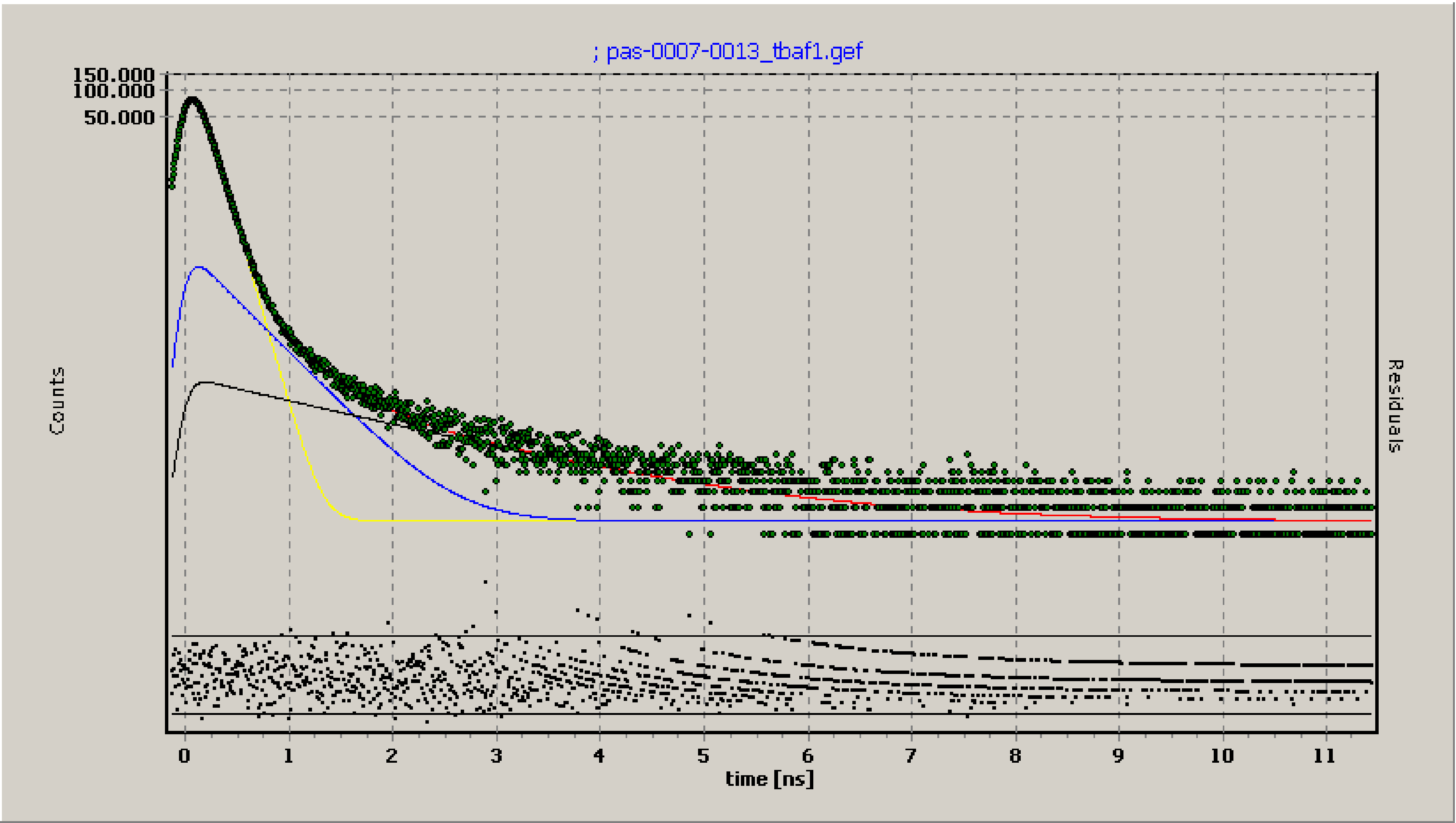
Coincident lifetime spectrum: annealed Fe

- 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



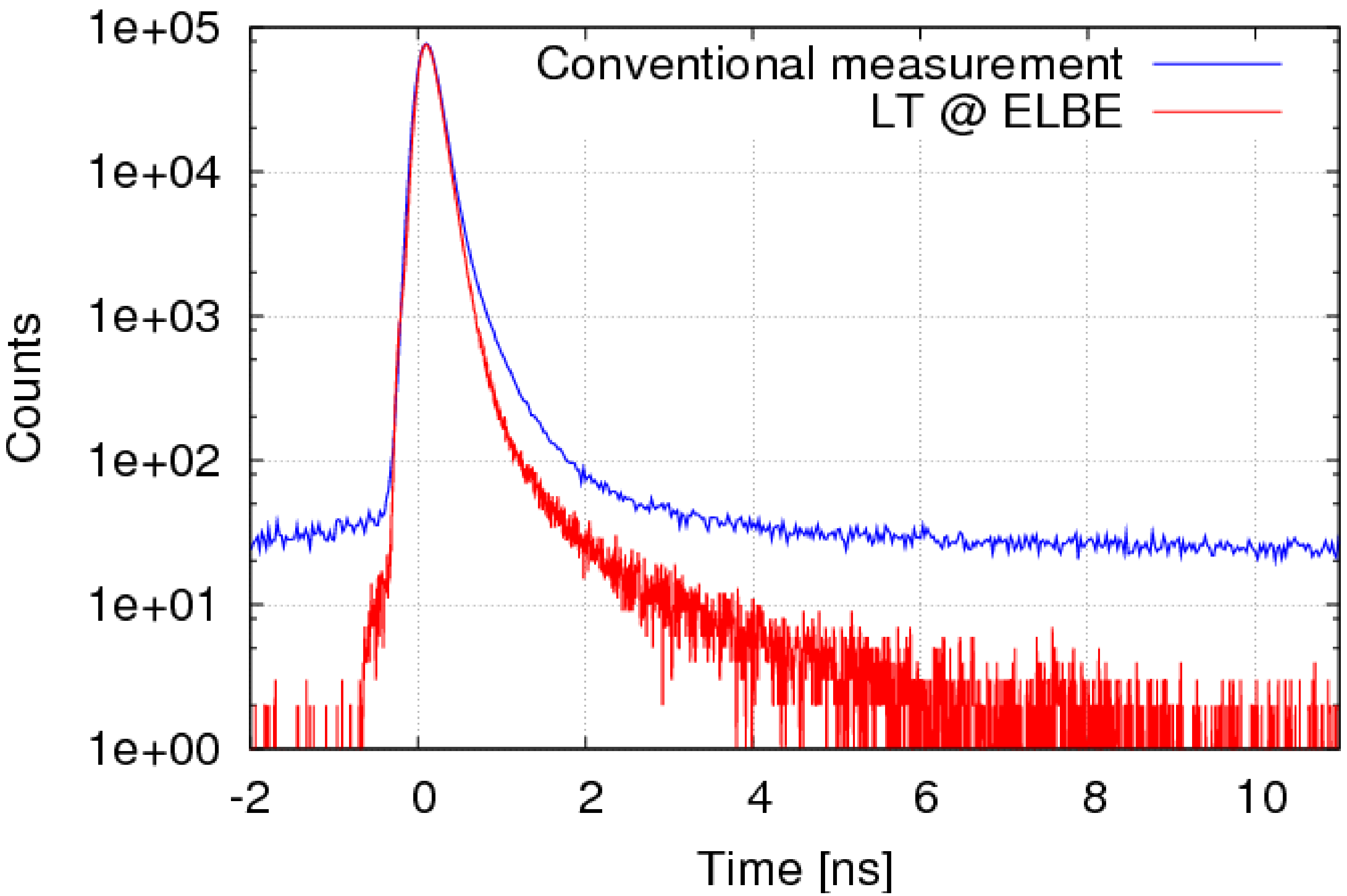
Residuals of fit show perfect fit

- analysis by LT 9.0 (J. Kansy)



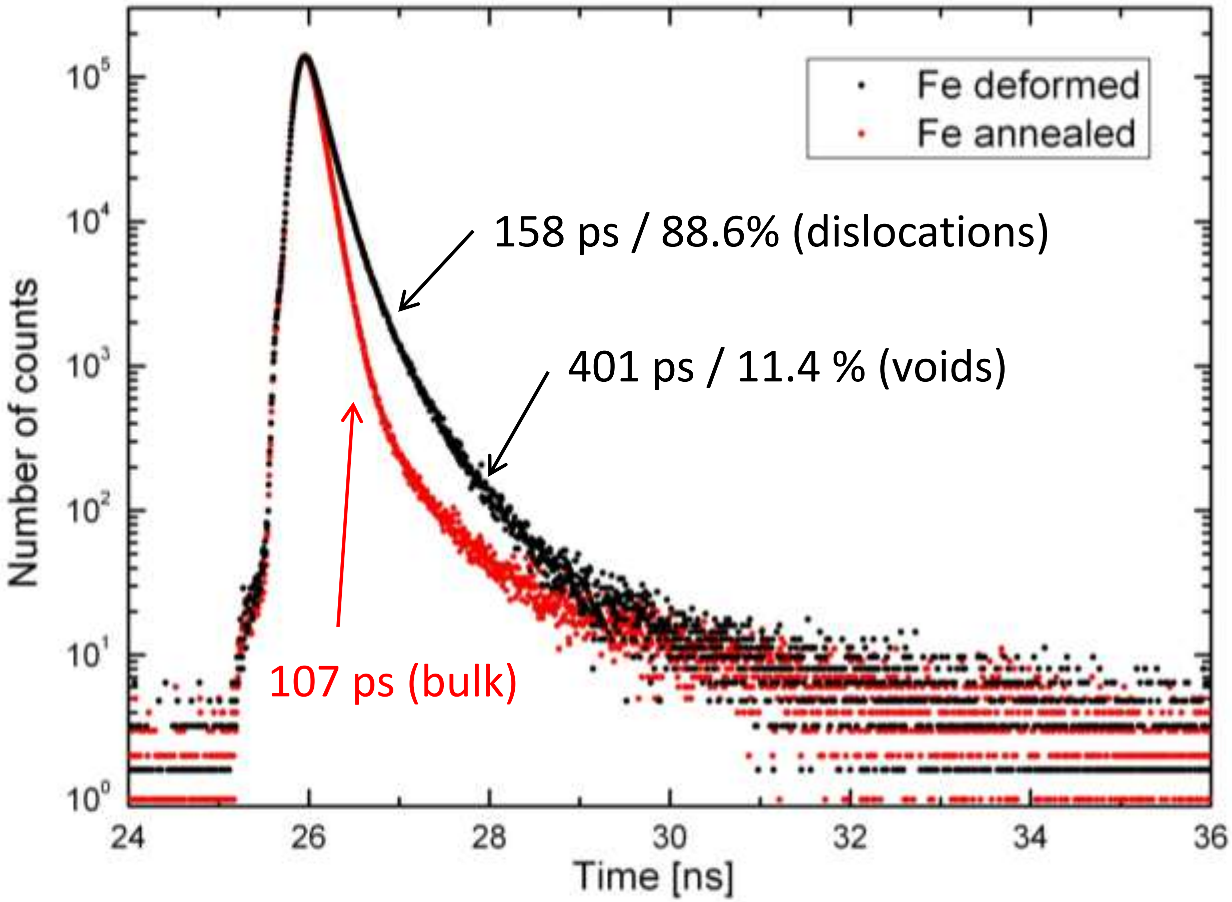
Comparison: GiPS spectrum with conventional measurement

- 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

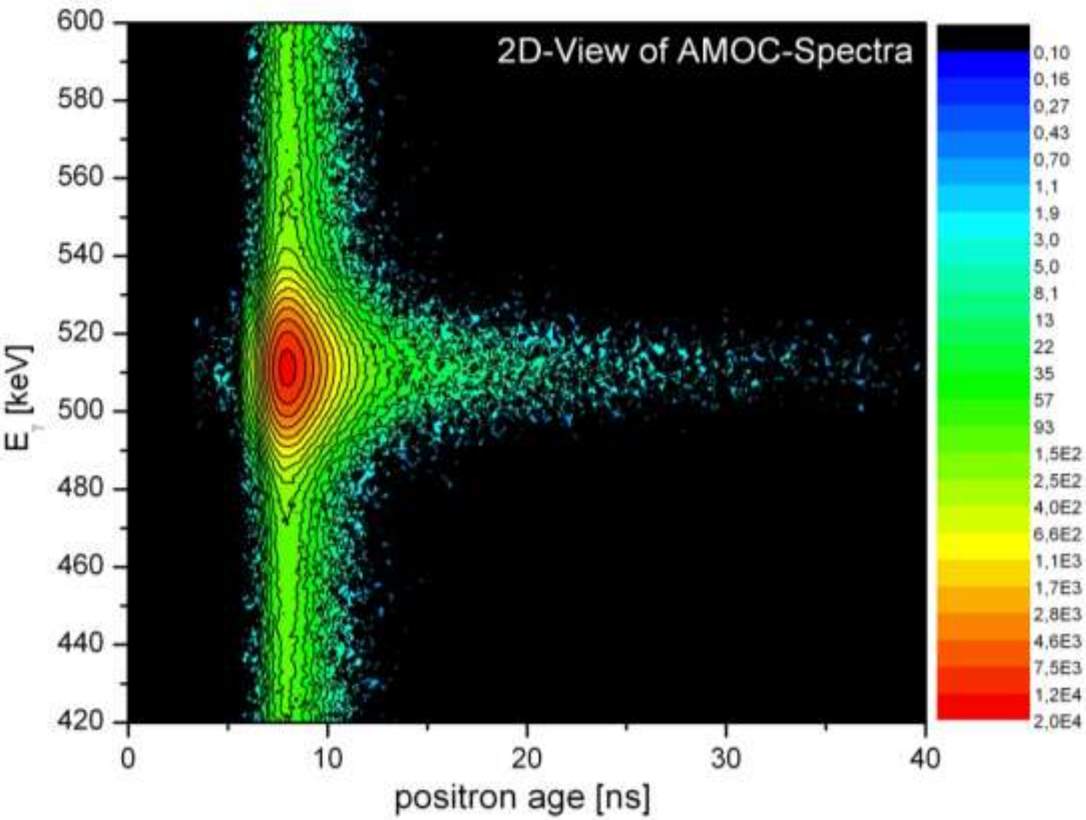
- two mechanically identical samples were prepared
- Fe annealed (1100°C; 2h in vacuum) and Fe (50% thickness reduction by cold rolling)
- spectra were easily decomposed
- expected results: annealed sample – one component 107 ps; deformed sample has 158 and 401 ps (dislocations and small vacancy clusters)



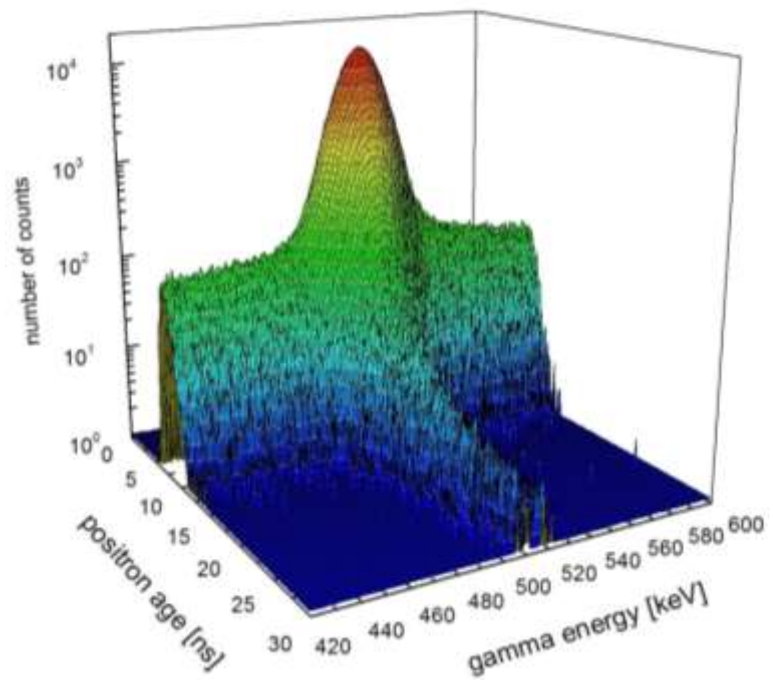
AMOC spectrum of annealed Fe

- 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)

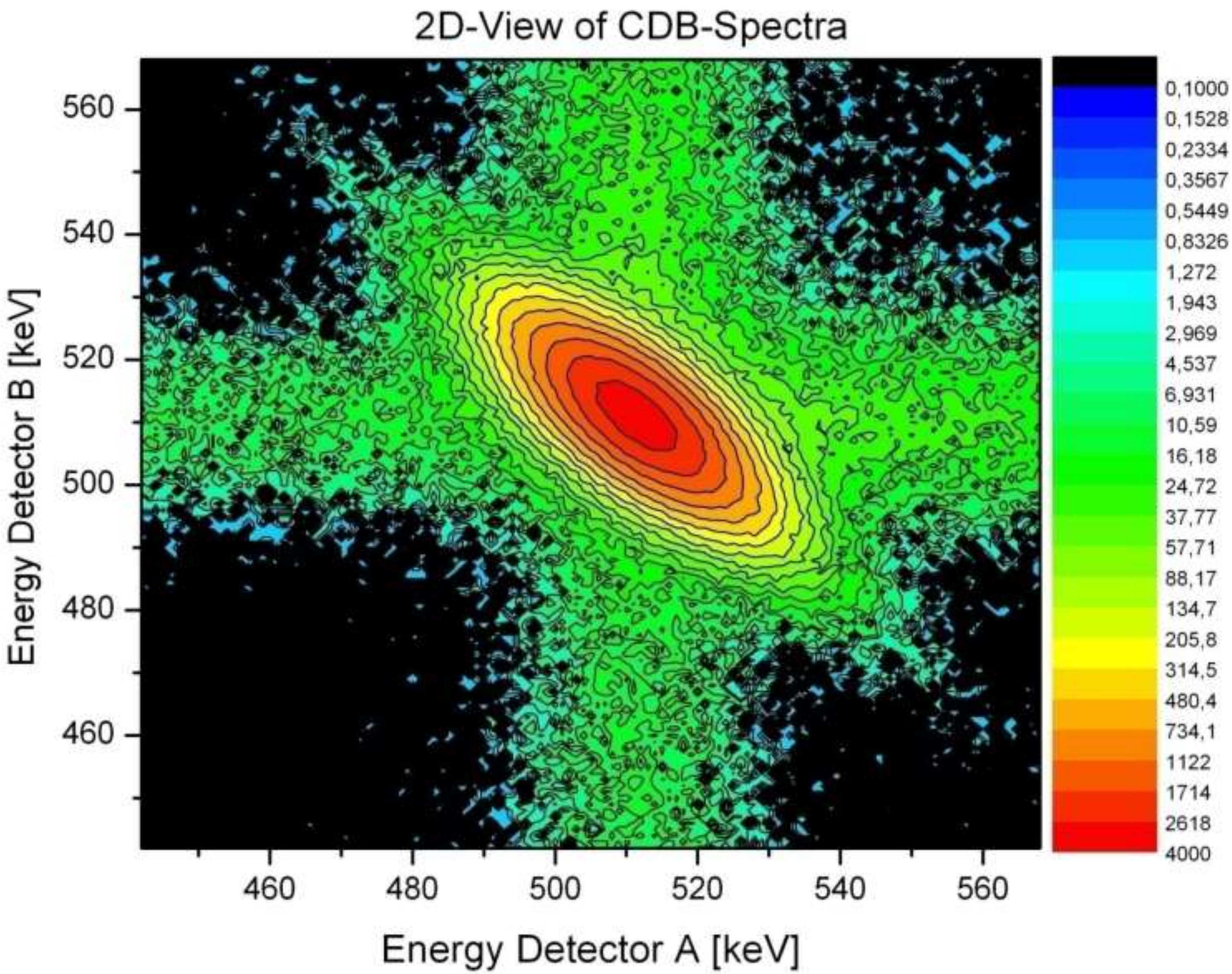
2D-Plot



3D-Plot

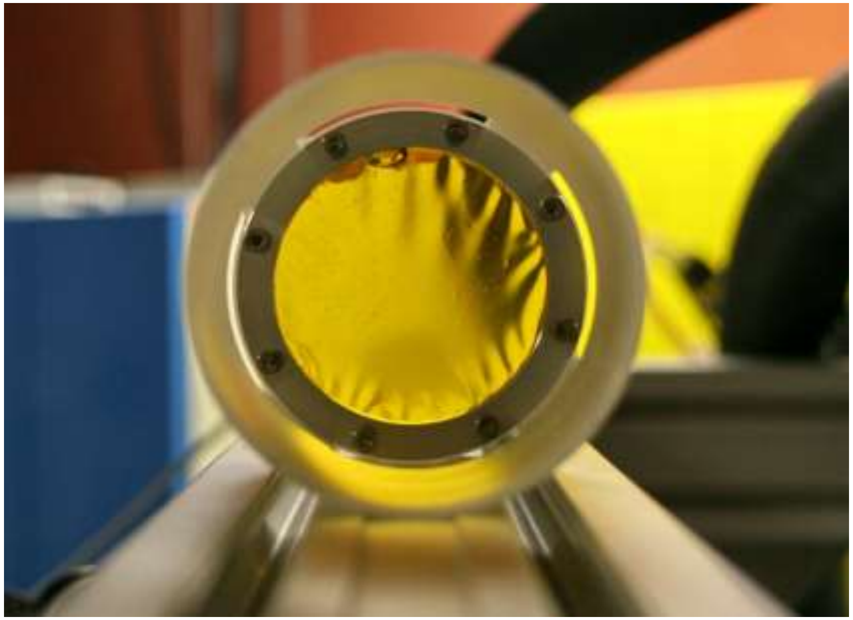


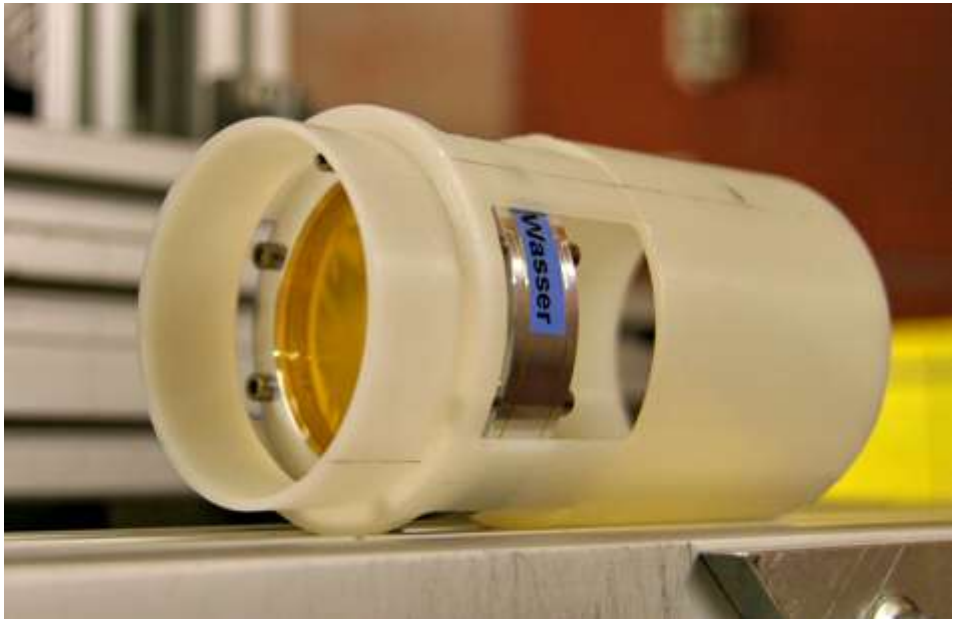
Coincidence Doppler-Broadening Spectroscopy of Fe sample



Sample holder for liquids

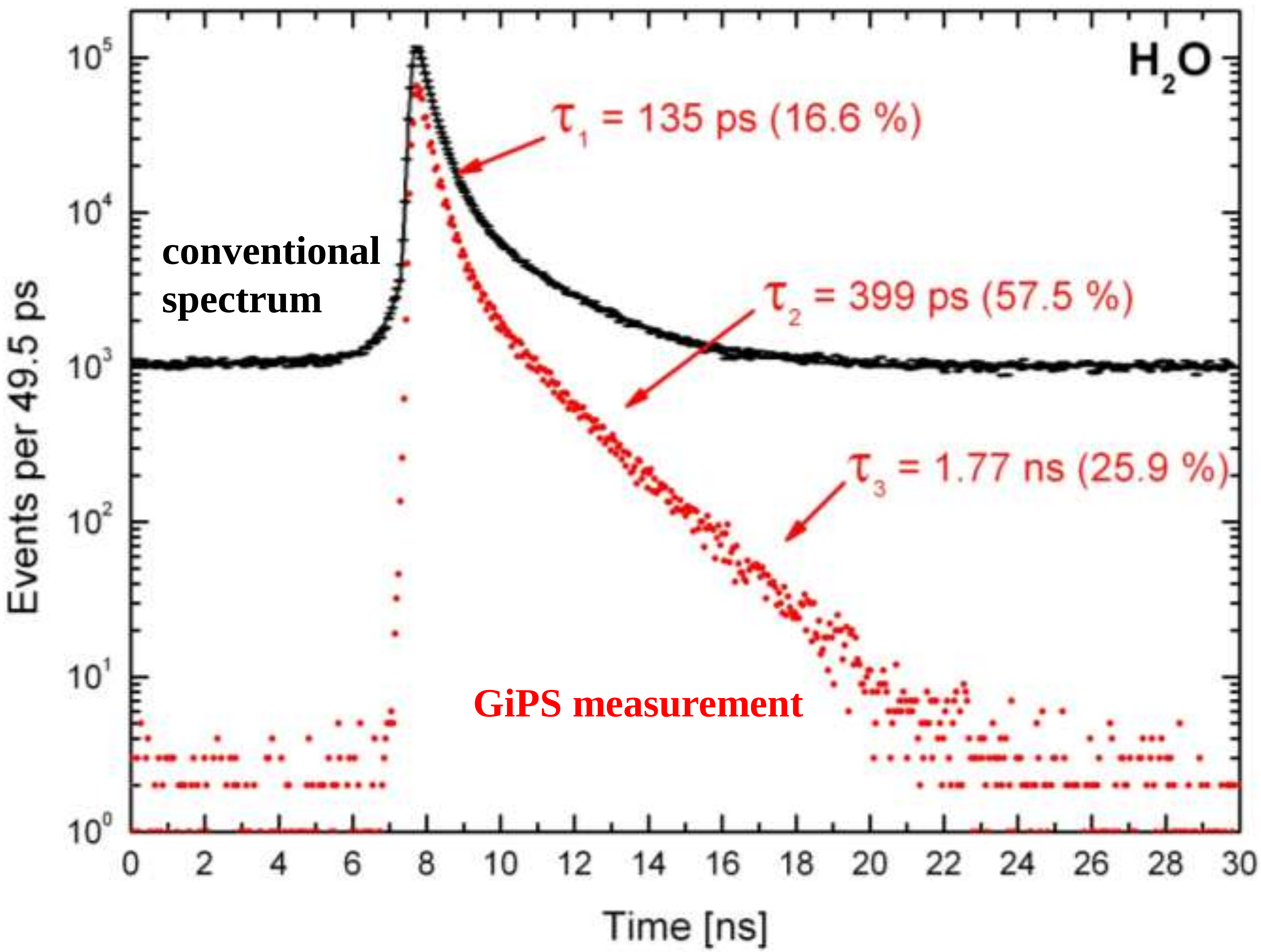
- Water is hold between two thin Kapton foils (few µm)
- inner diameter of Al rings is 50 mm
- Kapton was used because of simple lifetime spectrum (single component of 382 ps)
- but volume fraction of Kapton is very small (0.4%): almost no contribution to spectrum expected
- gamma beam has 20 mm diameter





Water at RT

- total count rate: 12×10^6 s^{-1}



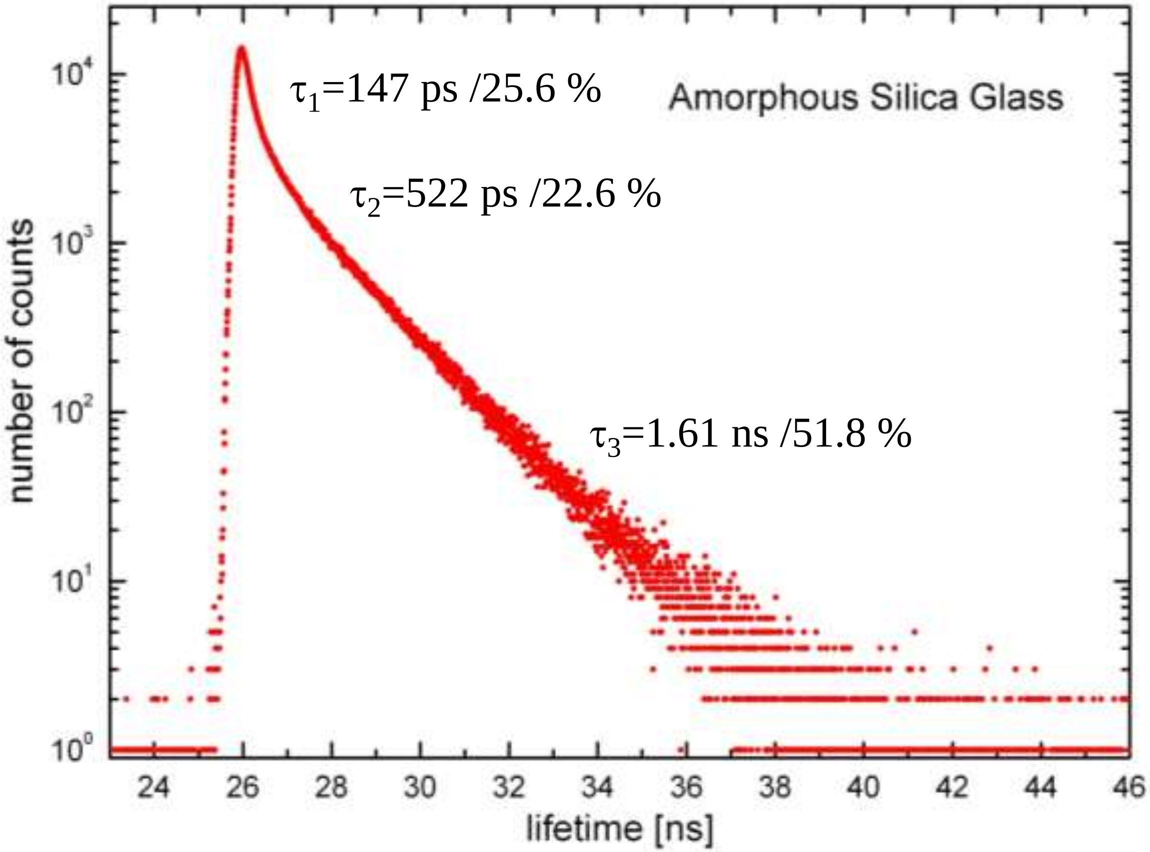
Black spectrum: conventional measurement by K. Kotera, T. Saito, T. Yamanaka, Phys. Lett. A 345, (2005) 184

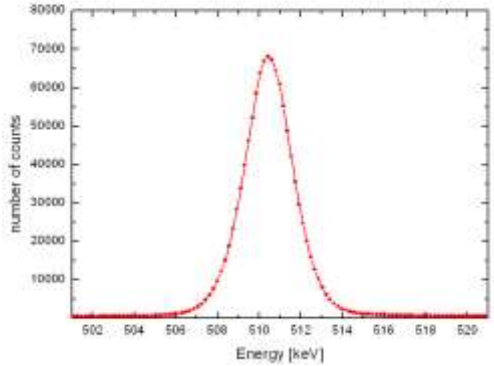
Amorphous Silica Glass

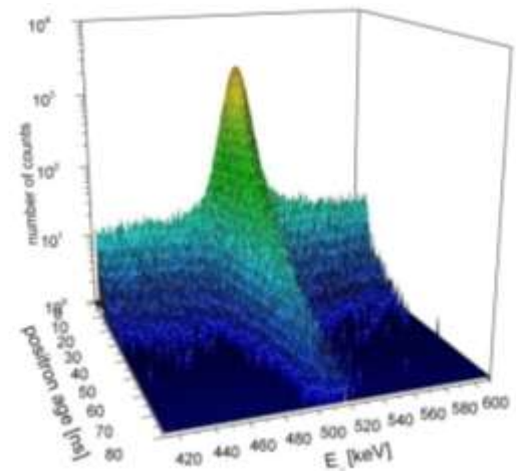
- round piece 1.5 cm thick, about 5 cm^3
- lifetime spectrum: total count rate: 2×10^6
- same sample was measured conventionally in 1978 also in the same institute (former ZfK Rossendorf):

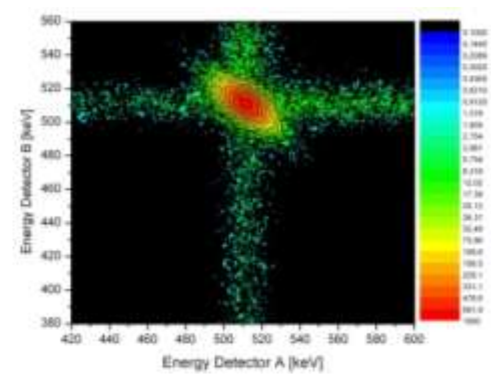
  151 ps - 523 ps - 1.57 ns (FWHM ≈350 ps)

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



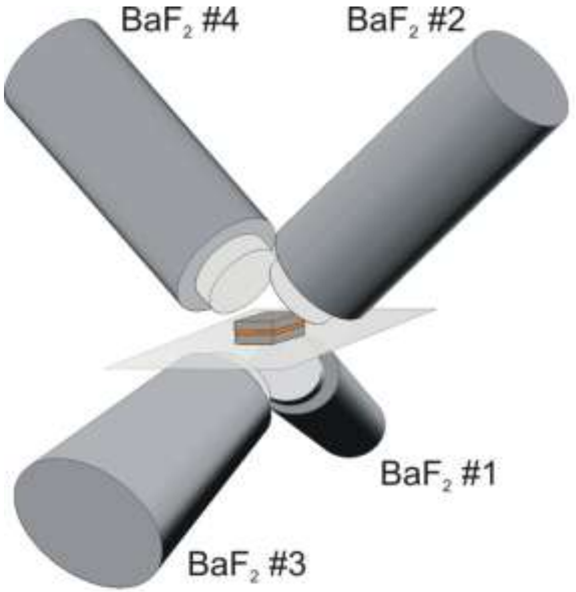






Conventional positron spectroscopy (CoPS): PALS

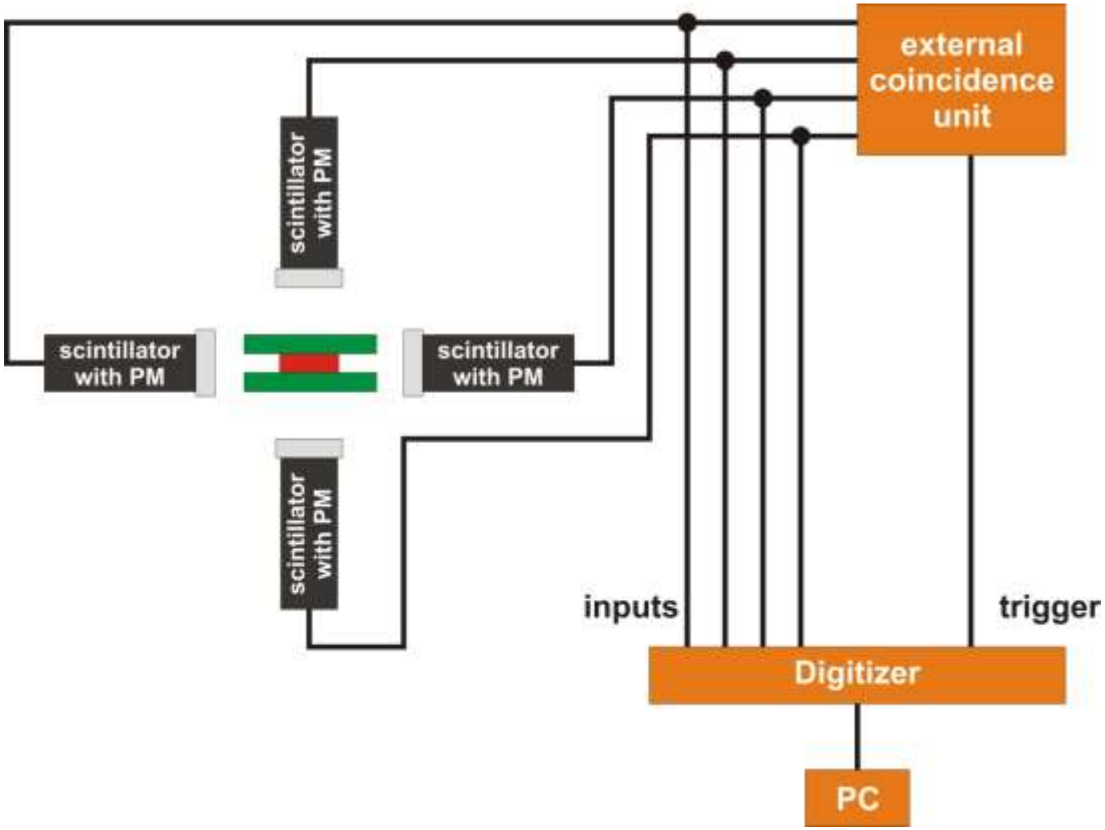
- 4-tube positron lifetime spectrometer
- ^{22}Na sample-source sandwich



Hamamatsu H3378

- each detector acts as start and stop → 12 independent spectra
- data storage in listmode, energy conditions adjustable afterwards
- in future: fully digital system

Conventional positron spectroscopy (CoPS): PALS



Advantages of digital setup

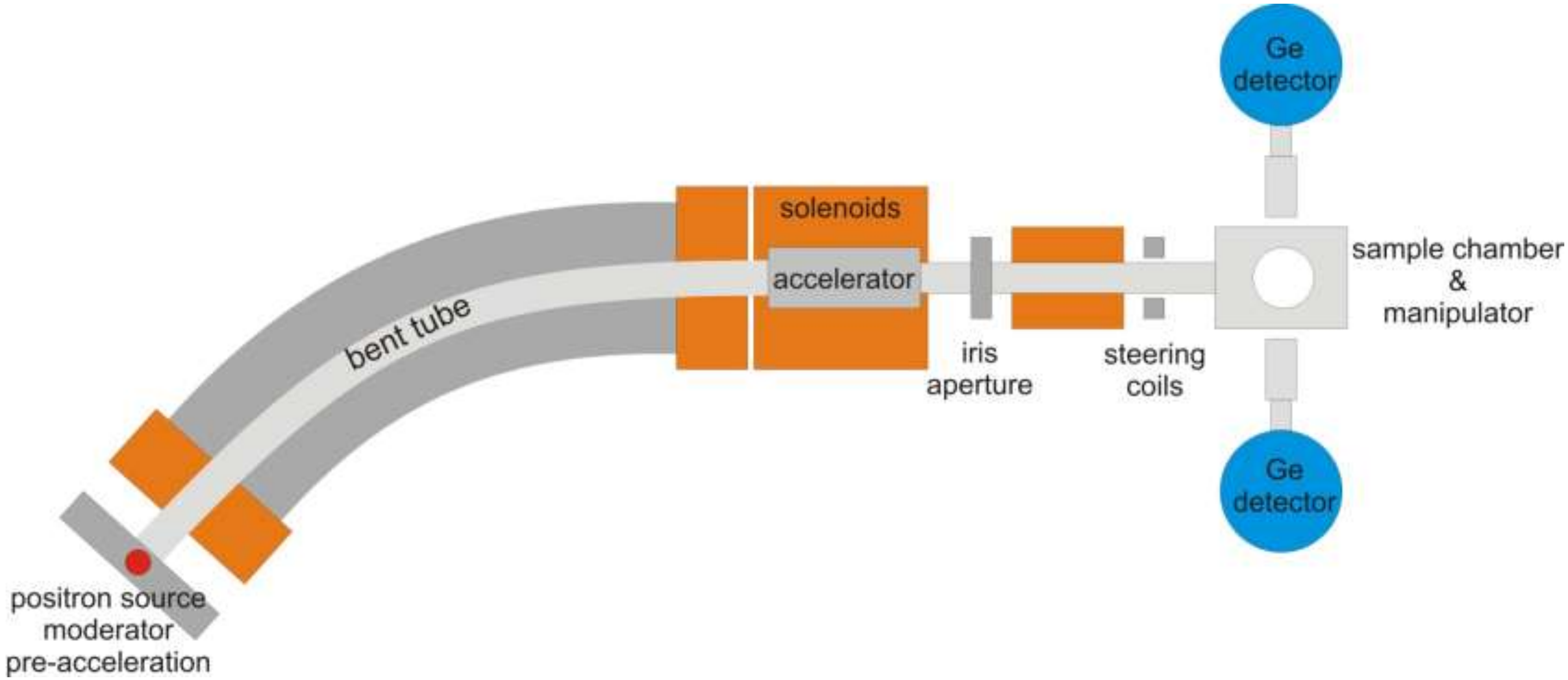
- simple setup
- cheaper
- pulse shape discrimination (supress “bad pulses“)
- each detector for start and stop
- setup easier to extend
- adjustable channel width

4 detectors

- 12 combinations
- 12 lifetime spectra

Conventional positron spectroscopy (CoPS): SPONSOR

- Slow-positron continous positron beam
- operated by strong 22-Na source



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Conclusions

- 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, CDBS, AMOC
- fully digital systems (in the future)
- EPOS can cover sample thickness range from 10 nm to 3cm (>6 orders of magnitude)
- MePS still under construction (chopper)
- GiPS is fully functioning
- CoPS is also very productive – no beam time necessary
- all facilities are user-dedicated – apply for beam time!

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

Collaborators

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H. Büttig

T. E. Cowan

P. Michel

G. Staats

A. Wagner

many more ….

http://positron.physik.uni-halle.de