A simple design for a continuous magnetically guided positron beam – and – News from the EPOS project

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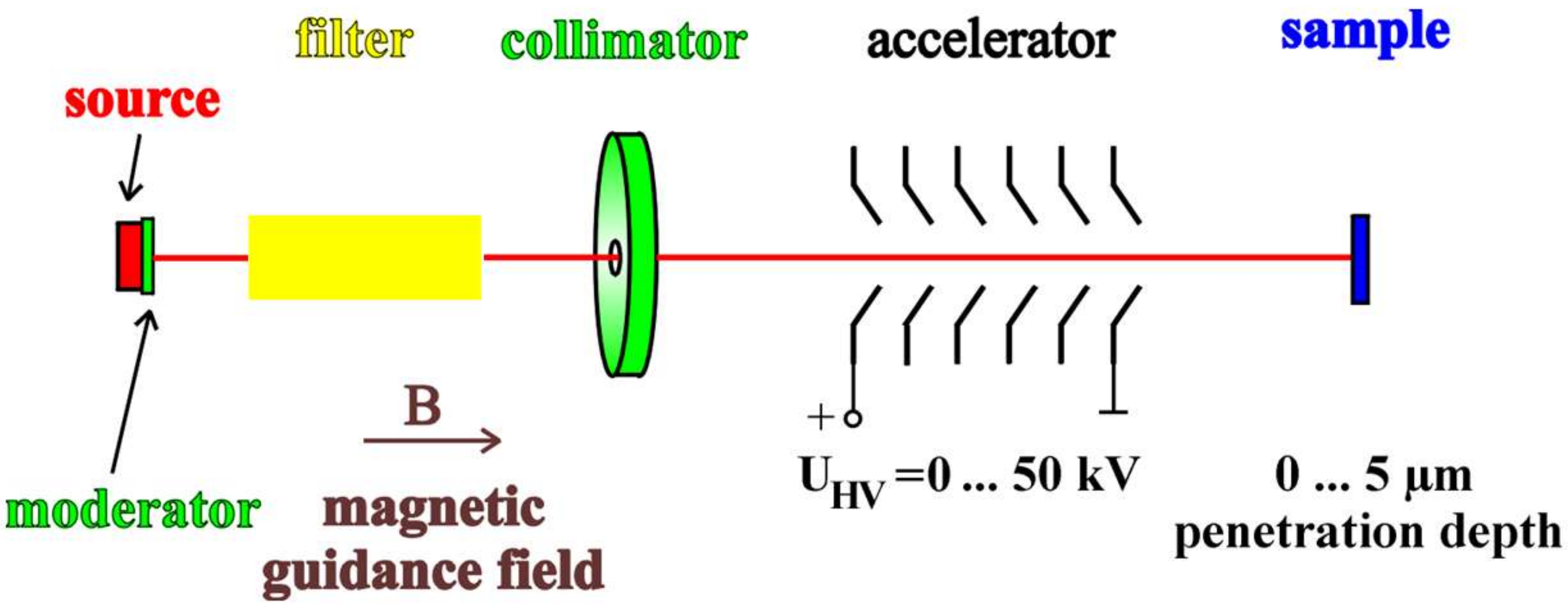
Halle-Wittenberg

- Simple beam setup for a continuous, magnetically guided positron beam
- News from the EPOS project

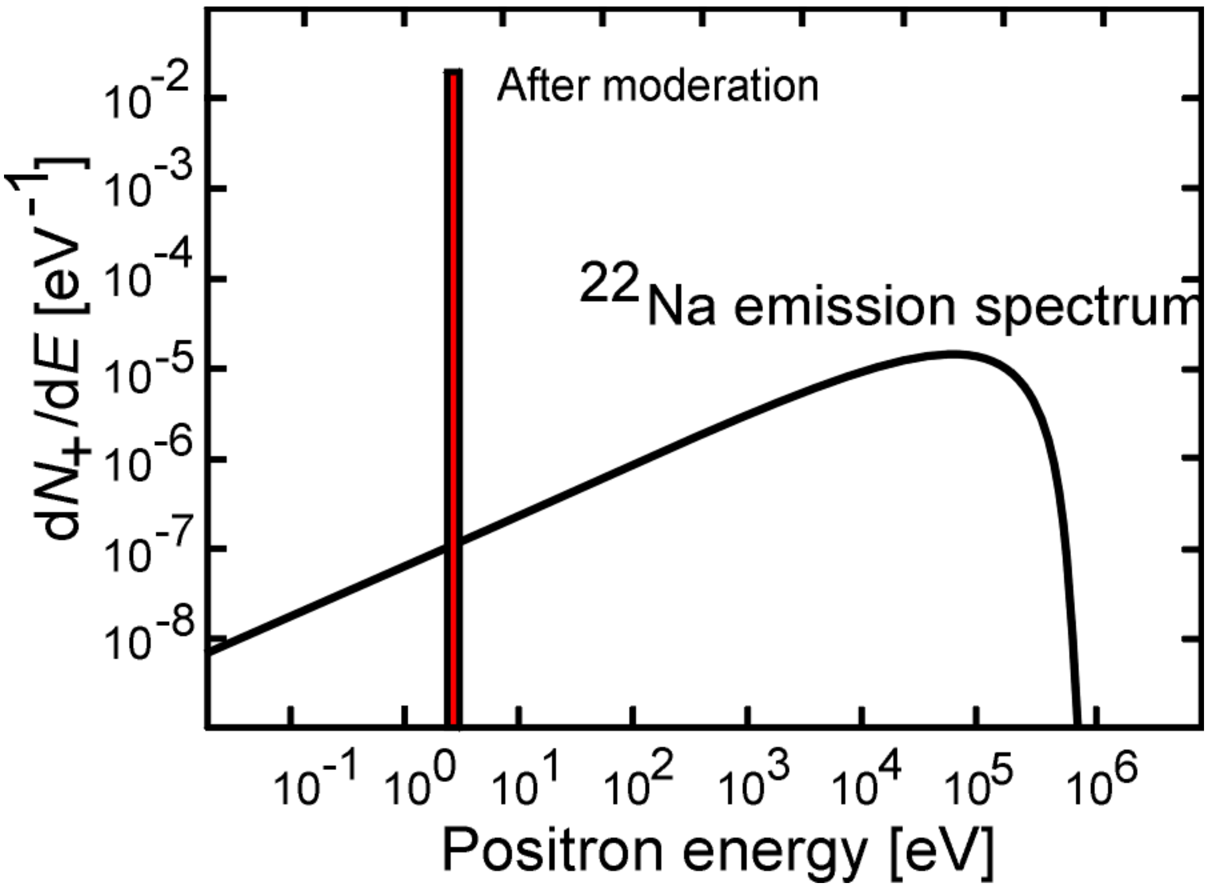
Beam setup for a continuous, magnetically guided positron beam



- β^+ source is used with **moderator** (efficiency $10^{-4}...10^{-3}$)
- filter is required to separate few slow from many fast positrons
- filter can be: **ExB filter** or simply a **bended vacuum tube**
- collimator / aperture defines beam size
- accelerator for final positron implantation depth
- source at high voltage: sample can be grounded – much easier sample chamber
- earth magnetic field must be compensated

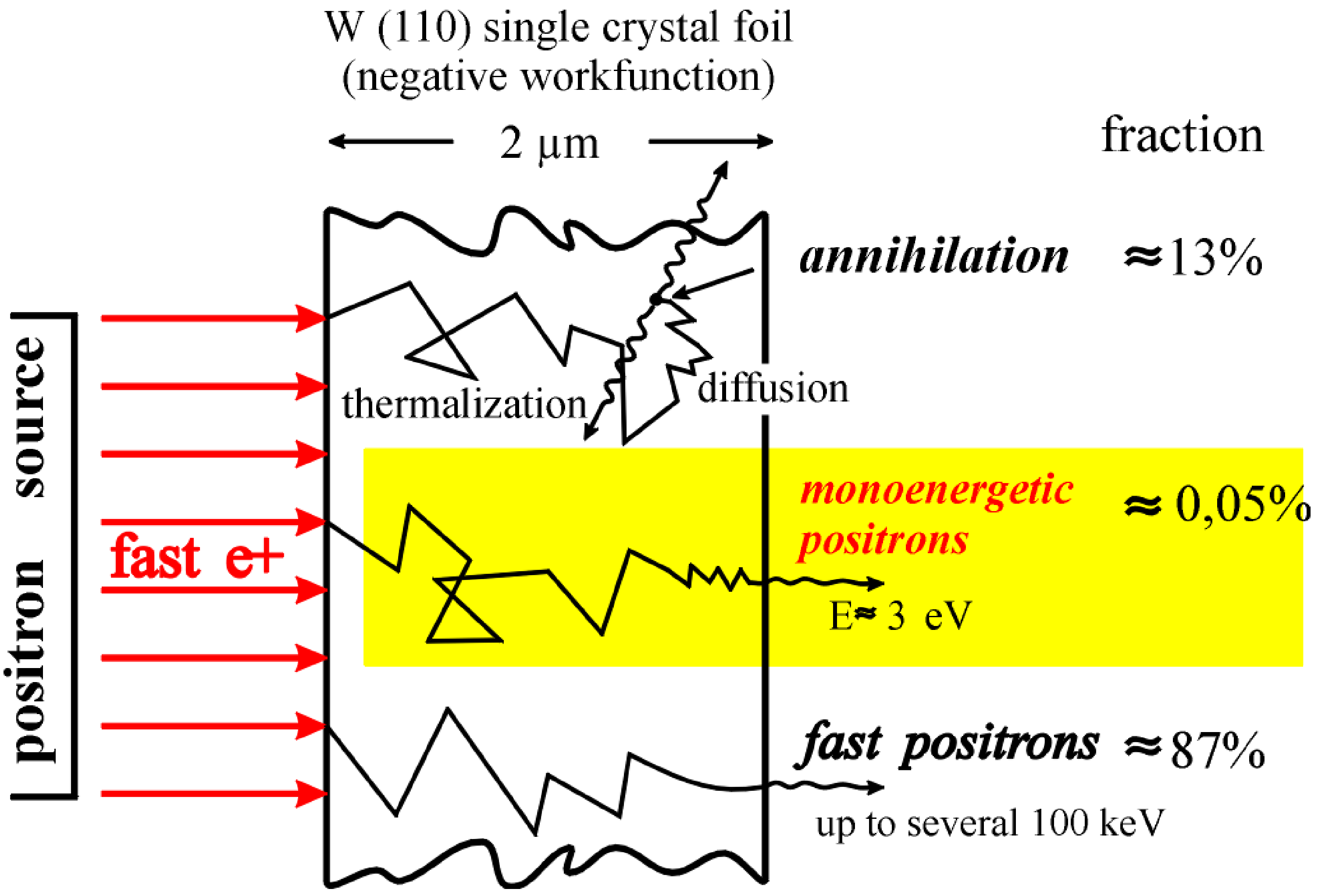
Moderation of Positrons

Mean implantation depth of un-moderated positrons from an isotope ^{22}Na source (1/e): Si: 50μm ⇨ moderation necessary for thin laers



- broad β^+ positron emission spectrum
- deep implantation into solids
- not useful for study of defects in thin layers
- for defect depth profiling: moderation necessary
- monoenergetic positrons can be implanted to different depth

Moderation of Positrons



moderation efficiency: $\approx 10^{-4}$

Moderation of Positrons by Tungsten Meshes

- mono-crystalline foil of W(100) has often be used as moderator
- W meshes can also be used
- meshes should be annealed (> 2000°C)
- and should be electro-polished
- there should be ≈ 10 meshes as a stack
- Moderation efficiency can be up to ≈ 10^{-3}
- 20 µm wires with 85% transmission

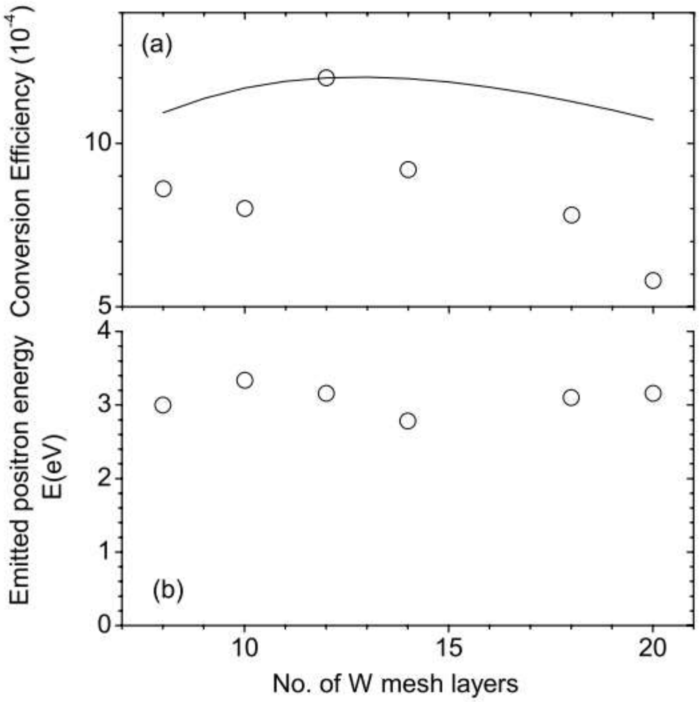


Fig. 2. (a) The conversion efficiency, and (b) the maximum emitted positron energy of the multi-folded W mesh moderators as a function of the number of the layers. The solid line in (a) is derived from a simple model involving the stopping of the fast positrons and the screening of the slow positrons by the mesh wires as described in the text.

H.M. Weng et al. / Nucl. Instr. and Meth. in Phys. Res. B 225 (2004) 397–401

High voltage design

High voltage can be applied

at sample

- \+ Whole vacuum system on ground potential
- \+ all electronics before accelerator also on ground potential
- − Sample must be isolated in small chamber
- − Accelerator and Faraday cup on HV in sample chamber necessary
- − High voltage feed through at sample chamber
- − Problems with temperature control, heating, other treatments (sputtering)

at source

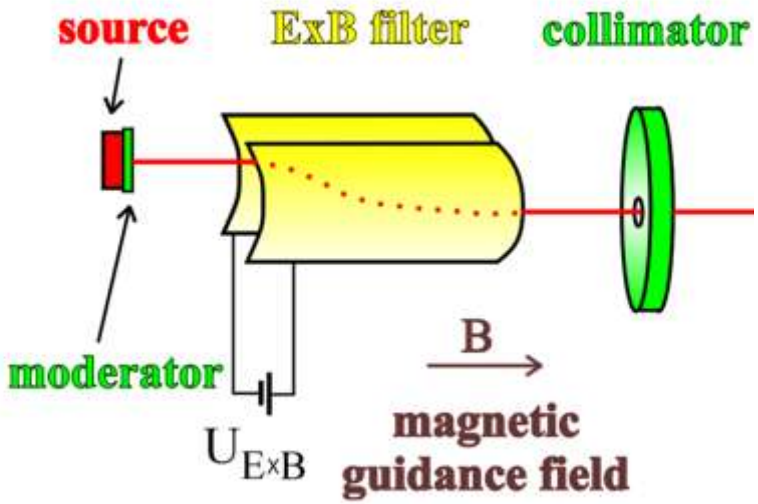
- \+ Sample chamber and sample at ground potential
- \+ High voltage can be connected at vacuum tube at source end outside (no high voltage feed through)
- − power supplies until accelerator must be at high voltage potential
- − Part of vacuum systems must be screened due to HV

My suggestion: source @ HV

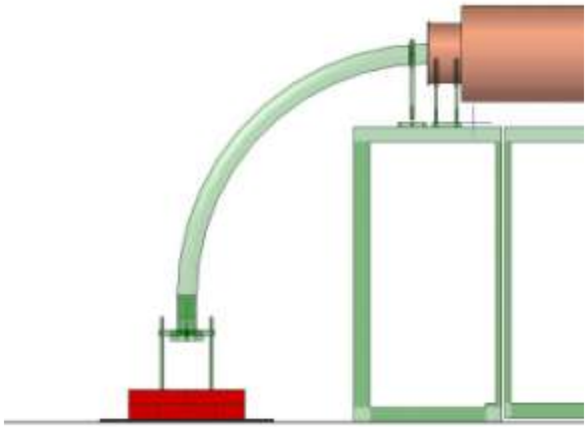
Filtering of slow positrons

only 1 out of 1000…10000 positrons is moderated ⇨ energy filtering needed

ExB filter



bended vacuum tube

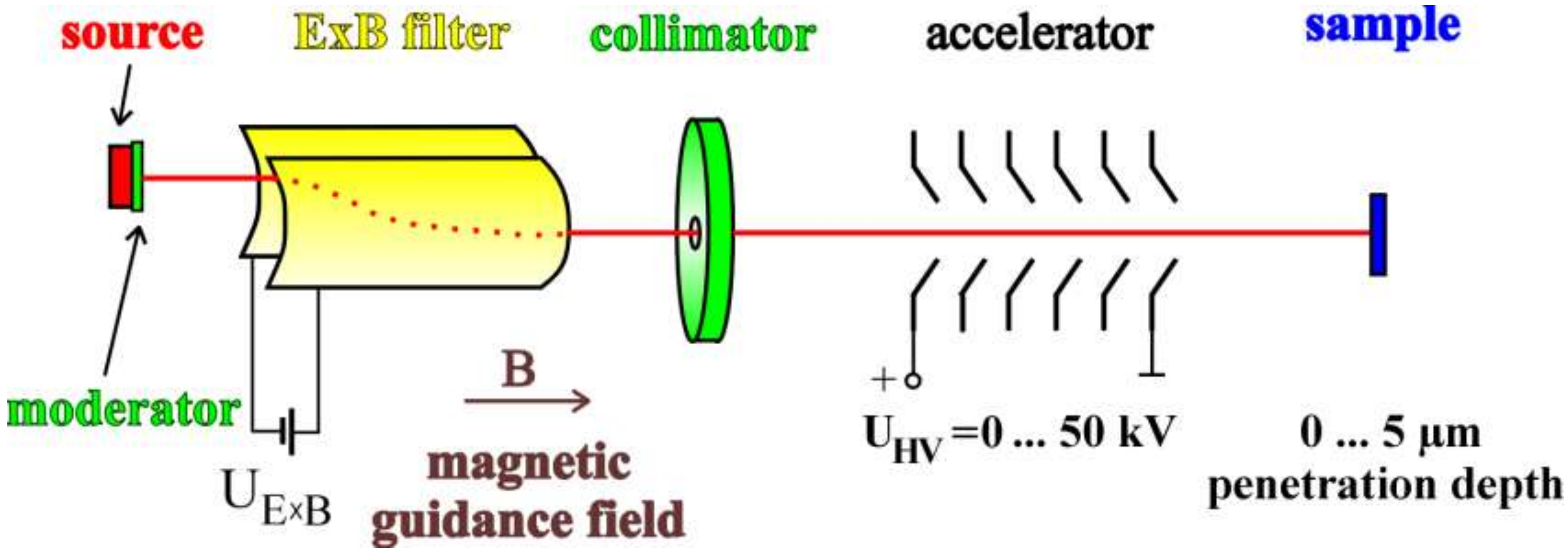


- \+ relatively compact
- − adjustable and stable voltages needed at high voltage potential
- − parts not so easy to machine
- − static voltages without current ⇨ contact problems
- − problems to screen source and detector

- \+ easy parts (bended tube ≈ 300 €)
- \+ directly wired
- \+ radiation protection screening easy
- \+ very robust beam guidance (DC currents)
- − current supply for coils at HV
- − isolation transformer needed

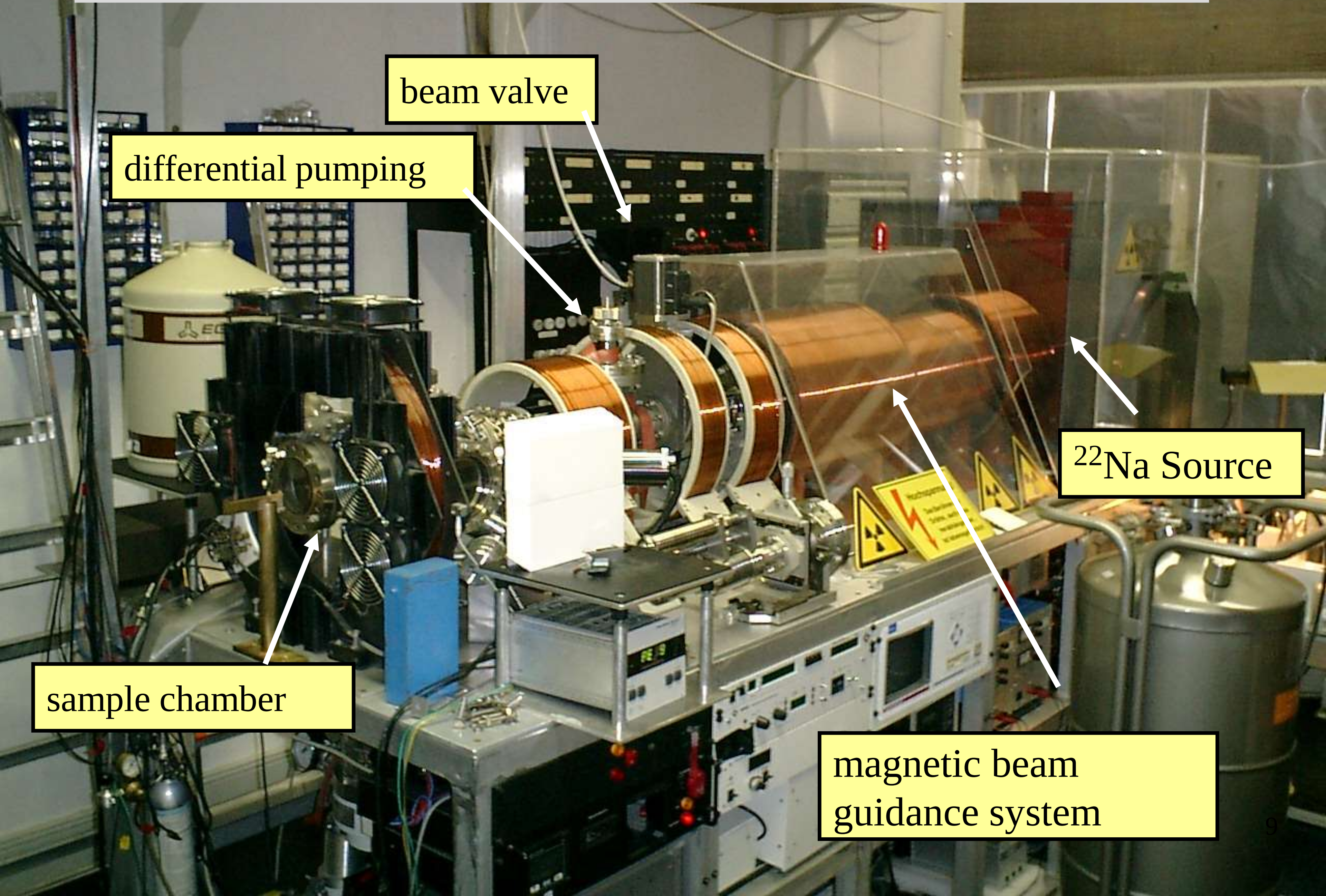
my recommendation: bended tube

The Positron Beam System at Halle University – first setup

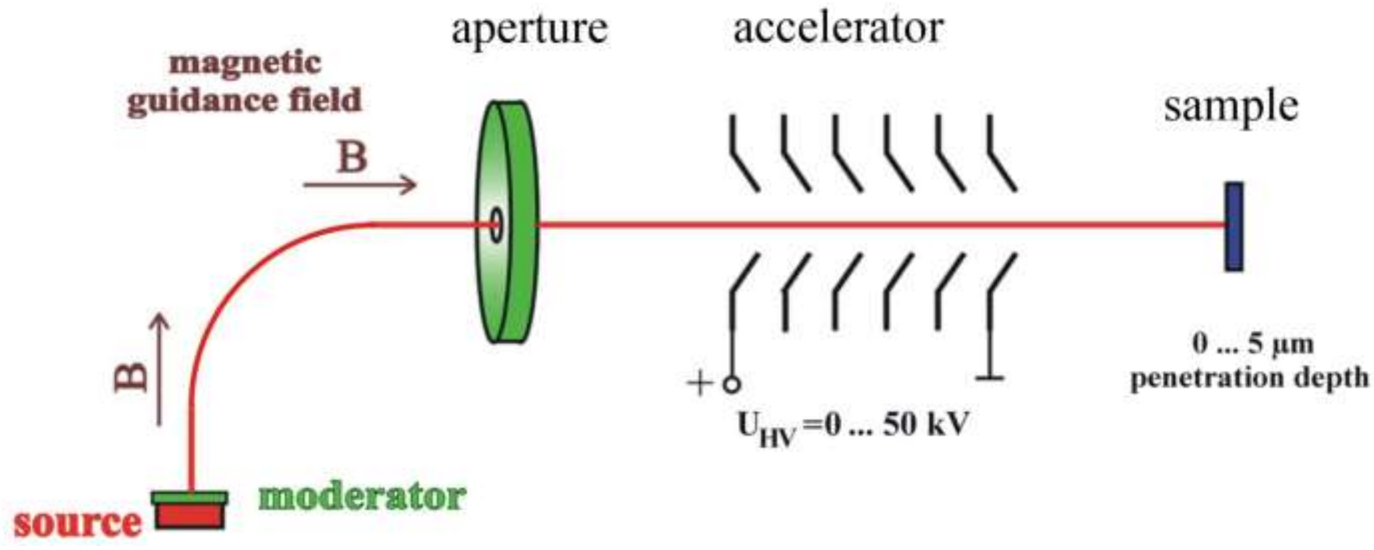


- 5 DC voltages needed at HV potential
- optimizing is time consuming
- after new setting ⇨ steerer also need new adjustment
- minimum energy 150 eV

The positron beam system at Halle Univ – old setup

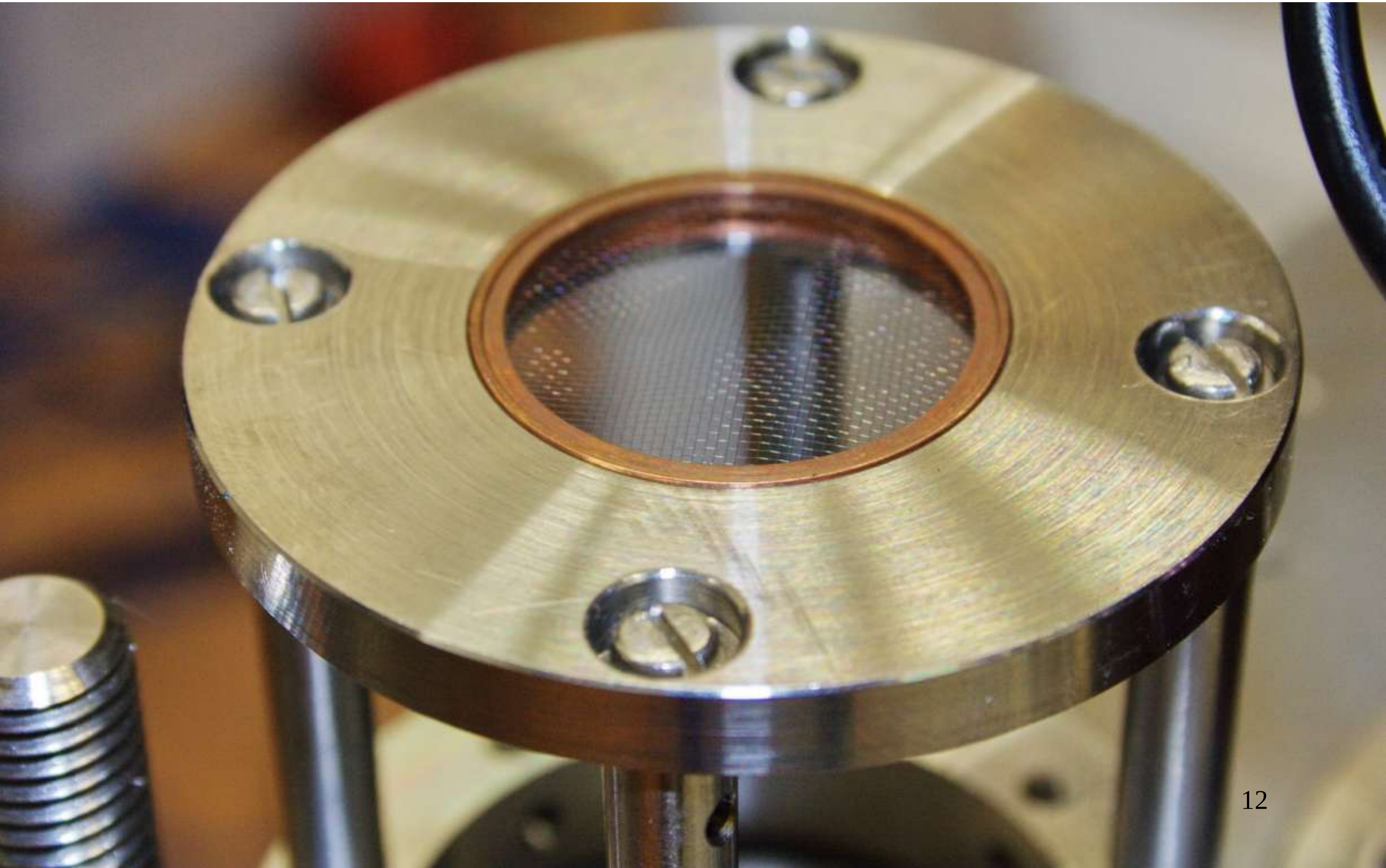


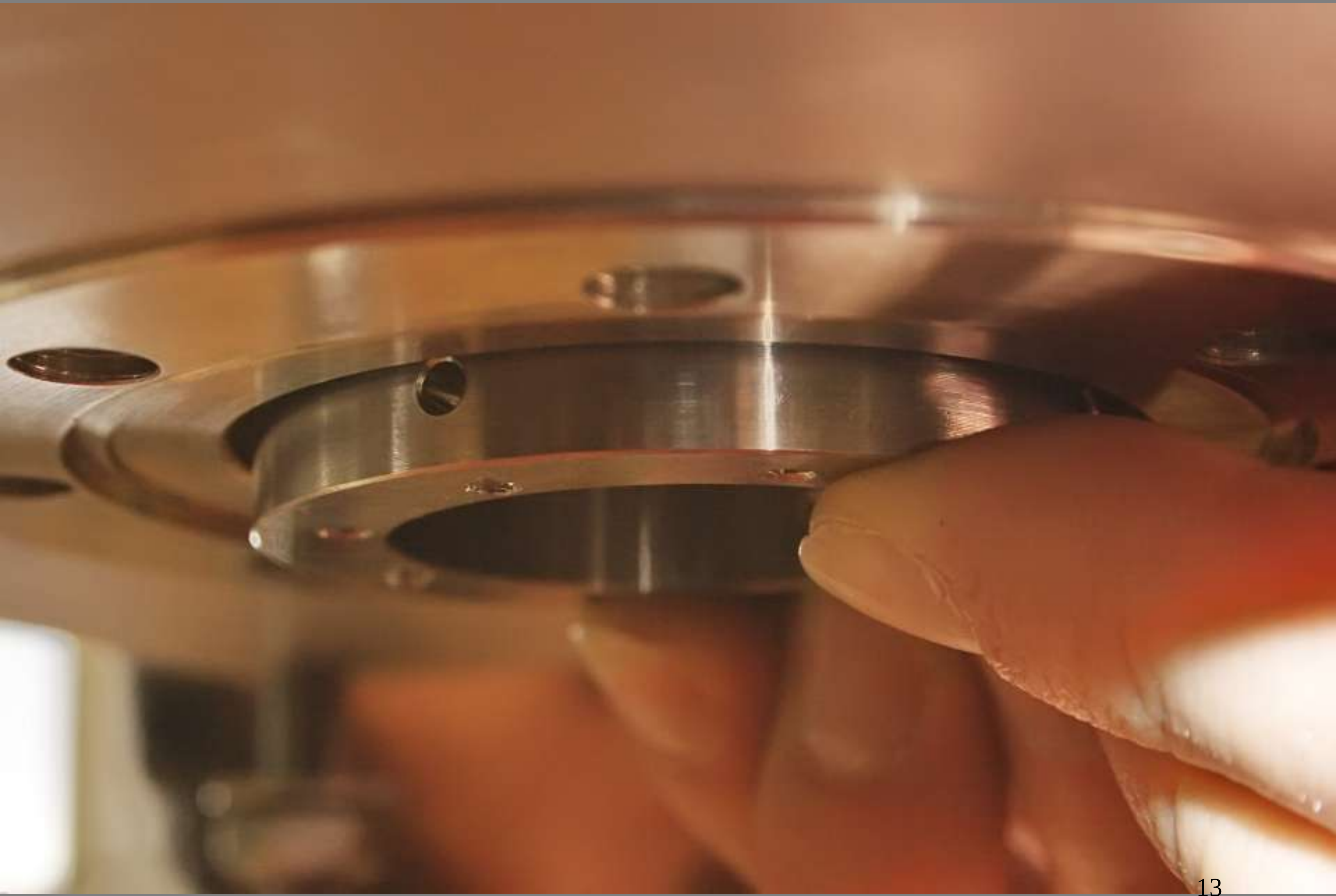
The Positron Beam System at Halle University – new setup



- W-grid moderator in direct contact to source
- beam transportation acceleration of 20…30V needed
- could be 3 x 9V alkaline battery (no current - stands for years)
- low energy better for defect profiling
- very easy: grid in front of moderator (positive e^+ work function – stainless steel)

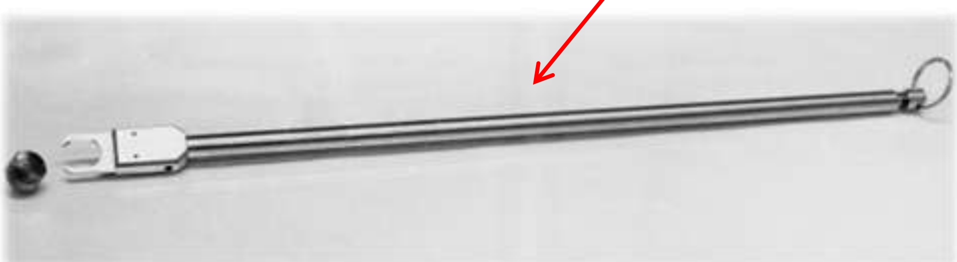
- beam acceleration of 25V done by a stainless steel mesh 10mm on front of source
- material must have positive positron work function






Source and Moderator

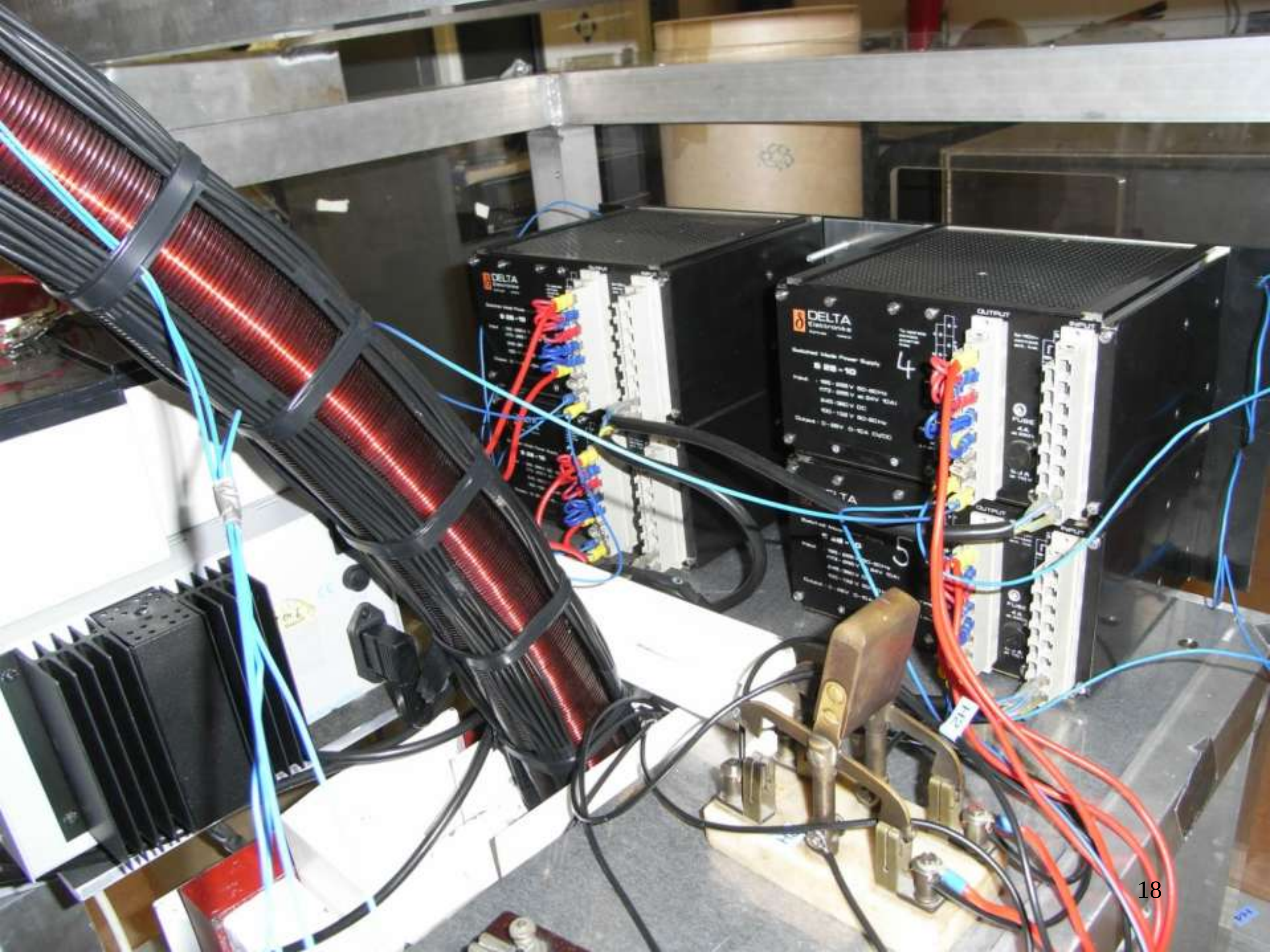
- standard source of iThemba Labs (Faure/South Africa)
- 20…50 mCi (0.75…1.85 GBq) initial activity
- W-grid moderator has 12 meshes
- clamps of moderator holder fit into side slits of source
- holder completely from W
- can be made simpler …
- in front of moderator in 1cm distance: stainless steel mesh for 25V acceleration
- is beam transportation energy
- there are drawings for a manipulator on our website



Source and moderator manipulators

Magnetic beam guidance in bend

- easiest way: Cu wire winded directly on surface of bended tube
- 2 layers and about 10A are sufficient (≈50 G)
- problem: coil is on high-voltage potential
- coil power supply must also be on high voltage
- must have constant current mode
- isolation transformer is required (≈30kV/300W)
  cost ≈ 700€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Elektronika
DELTA
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OUTPUT
INPUT
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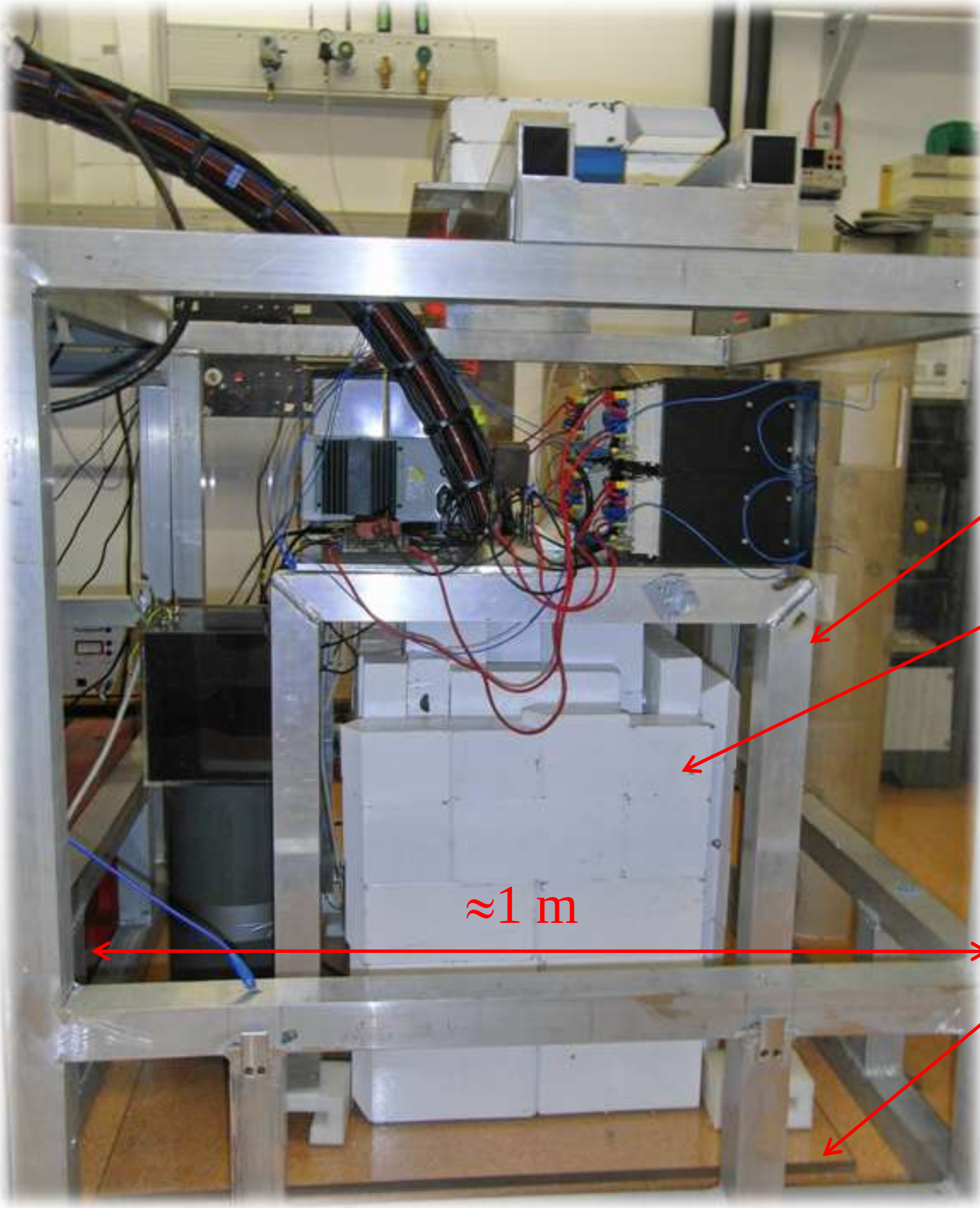
5
FUSE



extra table on HV

Pb screening for source

HV isolation to ground

Earth magnetic field compensation

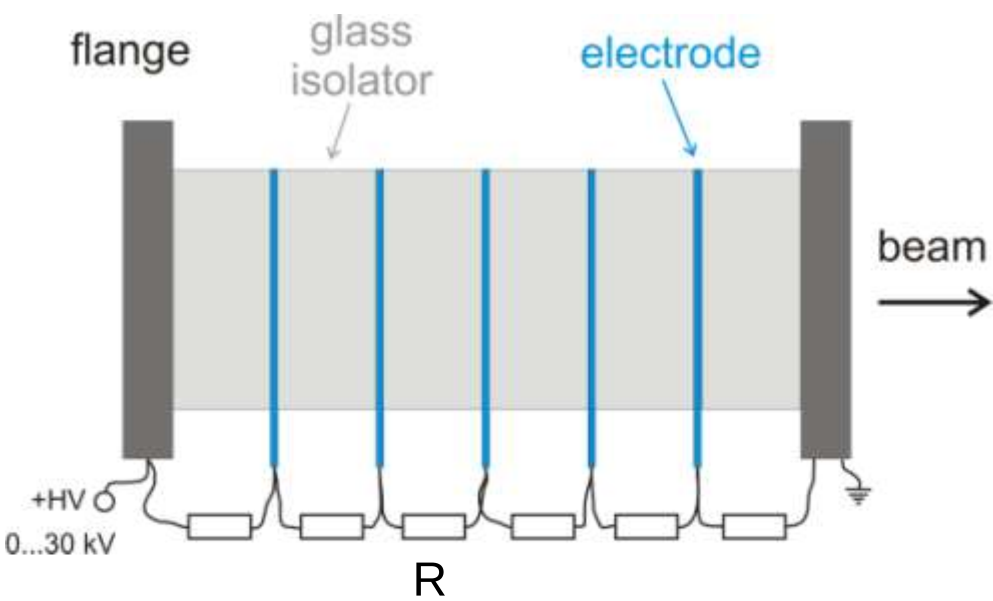
- Earth field of 50 μT (0.5 G) at a length of 3m and 2 keV beam energy: 25 mm deviation! But most beams are slower until accelerator …
- Must be compensated
- Compensation necessary only in the two perpendicular directions to the beam
- We used thin Al profile and 10 turns of wire and a few amps

Magnetic beam guidance in bend: steering coils

- two pairs of steering coils are needed along bends
- They compensate the effect of centrifugal force and the inhomogeneous magnetic field in the bend
- Moreover it can be used to move the beam to the input of the accelerator
- Just use a few turns of isolated wire and fix it by cable clips
- Power supplies must be at high voltage table
- It is a very robust beam tuning (setting of a few amps)

Beam Accelerator

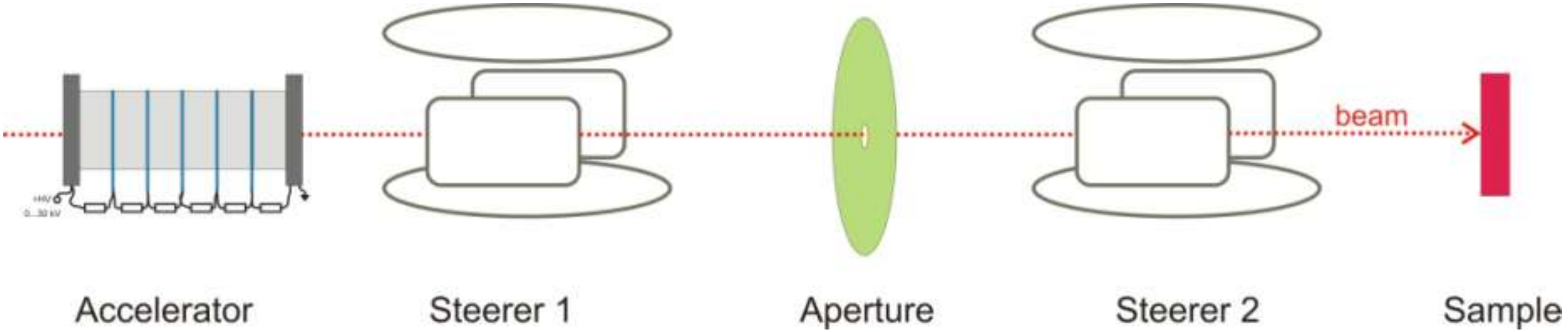
- Beam energy should be ≈20 V … ≥ 30 keV
- Accelerator must be subdivided to have ≈ 5 kV / stage ⇨ 6 stages
- Simple home made accelerator:
- glue a stack of stainless steel circular rings with short isolation tubes (thick glass tube pieces, each ≈ 20mm long, wall thickness > 5mm) to a stack and glue it to two CF65-flanges both sides
- use a bellow at one side
- Inner diameter of hole in rings ≈ 20 mm
- There exists high vacuum compatible epoxy glue
- Let the rings look out from the glass tubes to be able to connect resistors there
- Resistor chain is high-resistive, e.g. $R = 1\ G\Omega$
- then : $6\ G\Omega$ ⇨ $I = 5\ \mu A$ @ 30kV
- $P_R = 25$ mW and $P_{all} = 150$ mW

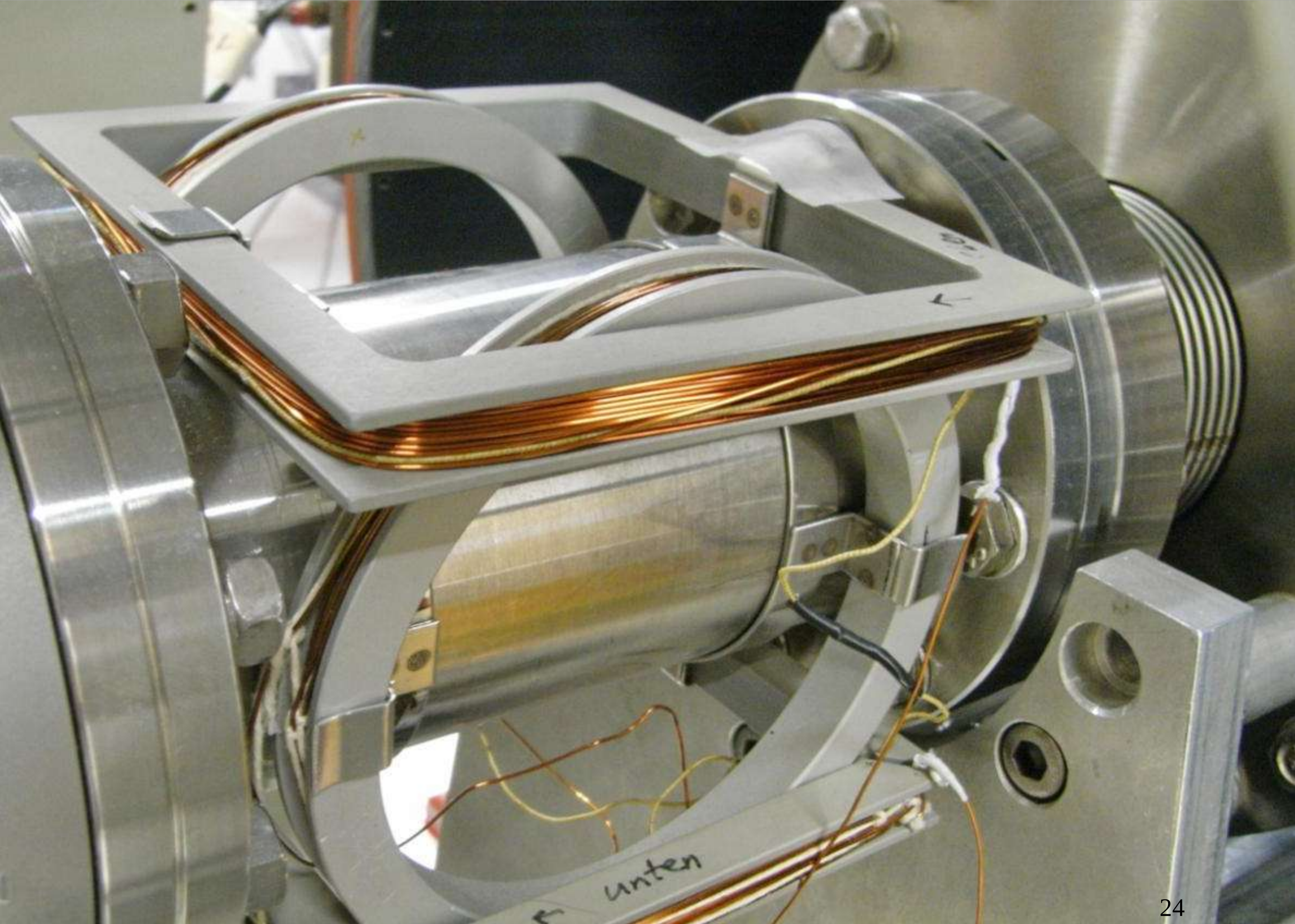


Resistor chain

Beam steering

- Beam needs an aperture of about 4…6 mm (could be adjustable 2…8 mm)
- Steering necessary to hit 1) the aperture and 2) the sample
- After passing the accelerator: beam often has gyrations and thus oscillates over the sample
- One can make this effect visible by channel plates:

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steerer between
aperture and sample

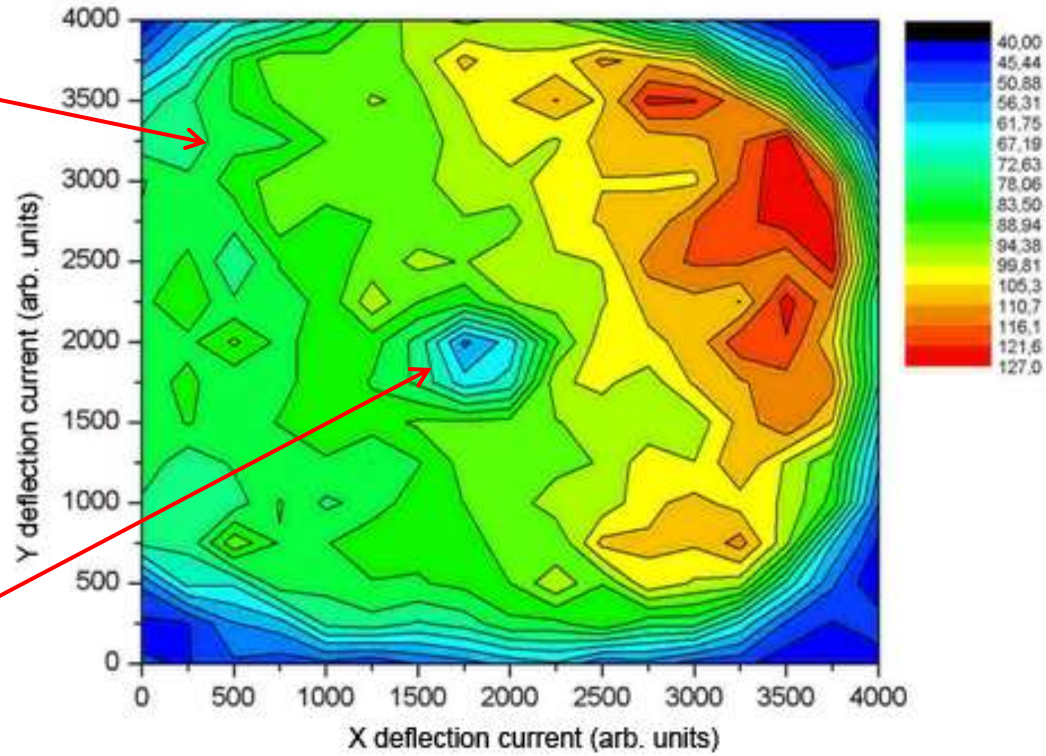
aperture (inside tube) –
with linear drive for
different hole size

Adjustments of Beam steeres

- Correct currents for X-Y deflection of a steerer are found by a count rate contour plot
- Detector close to either aperture or sample during adjustment
- Measurement for a few seconds gives a clear picture
- Current setting must be obtained and stored in a table for all high voltage values

Aperture sheet

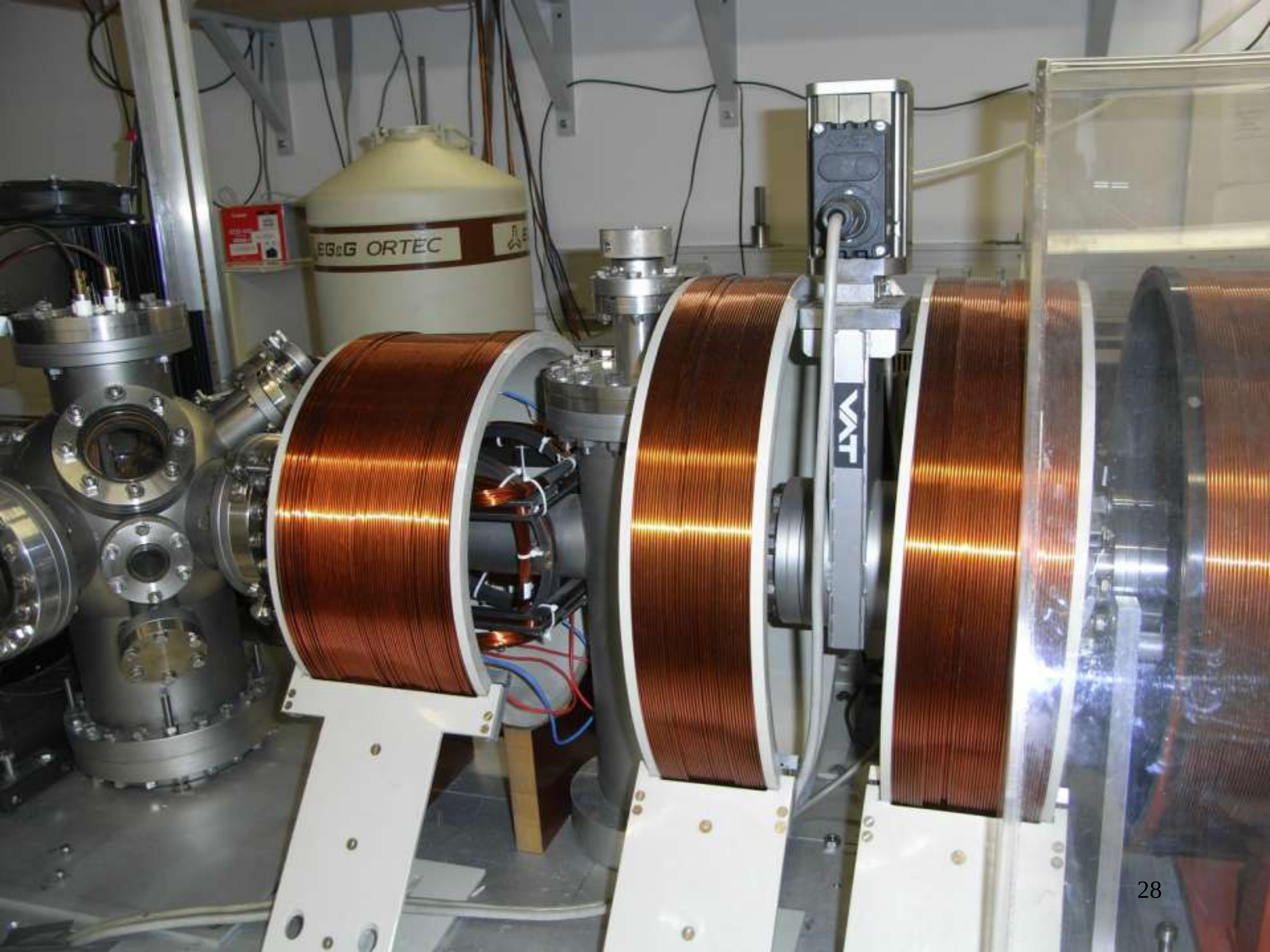
- Second steerer defines sample position
- Finally 4 current values are stored and recalled during measurement



Aperture hole

Vacuum system

- oil-free pre-vacuum (scroll- or membrane pumps) to avoid contamination of moderator
- Turbo pump as main pump (must have drag/Holweck stage – so 1 mbar pre-vacuum pressure is ok)
- for defect depth scans: necessary < **1×10^{-6} mbar**
- then: mean free path including gyrations is long enough
- viton sealing for the whole system is sufficient
- **beam valve necessary** to keep source/moderator always under vacuum
- second pump at source side useful but not necessary
- closed source part holds vacuum at a level < 10^{-4} mbar for 24 h – enough for sample change and some maintenance
- **very useful**: linear drive to move sample holder sheet to have 5…10 samples in vacuum
- have the detector flange from the side, so CDBS is possible
- an extra sample flange with heater (up to 1000K)


EG&G ORTEC
VAT


EG&G ORTEC

Laboratory automation

- my suggestion: LabView under Windows/Linux
  - drivers for most devices available
  - easy to understand for others
  - longstanding support
- have a second I/O and ADC/DAC card on stock in the lab for fast replacement
- useful: internet remote control
- simplest solution install remote control server like VNC
- try to include sample linear drive into automation (will save your weekends)

EPOS = ELBE Positron Source

- ELBE -> electron LINAC (40 MeV and up to 40 kW) in Research Center Dresden-Rossendorf
- EPOS -> collaboration of Univ. Halle with FZD
- EPOS will be the combination of a positron lifetime spectrometer, Doppler coincidence, and AMOC
- User-dedicated facility
- main features:
  - high-intensity bunched positron beam (E_+ = 0.5…30 keV)
  - very good time resolution by using the unique primary time structure of ELBE
  - digital multi-detector array
  - fully remote control via internet by user

Extended 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

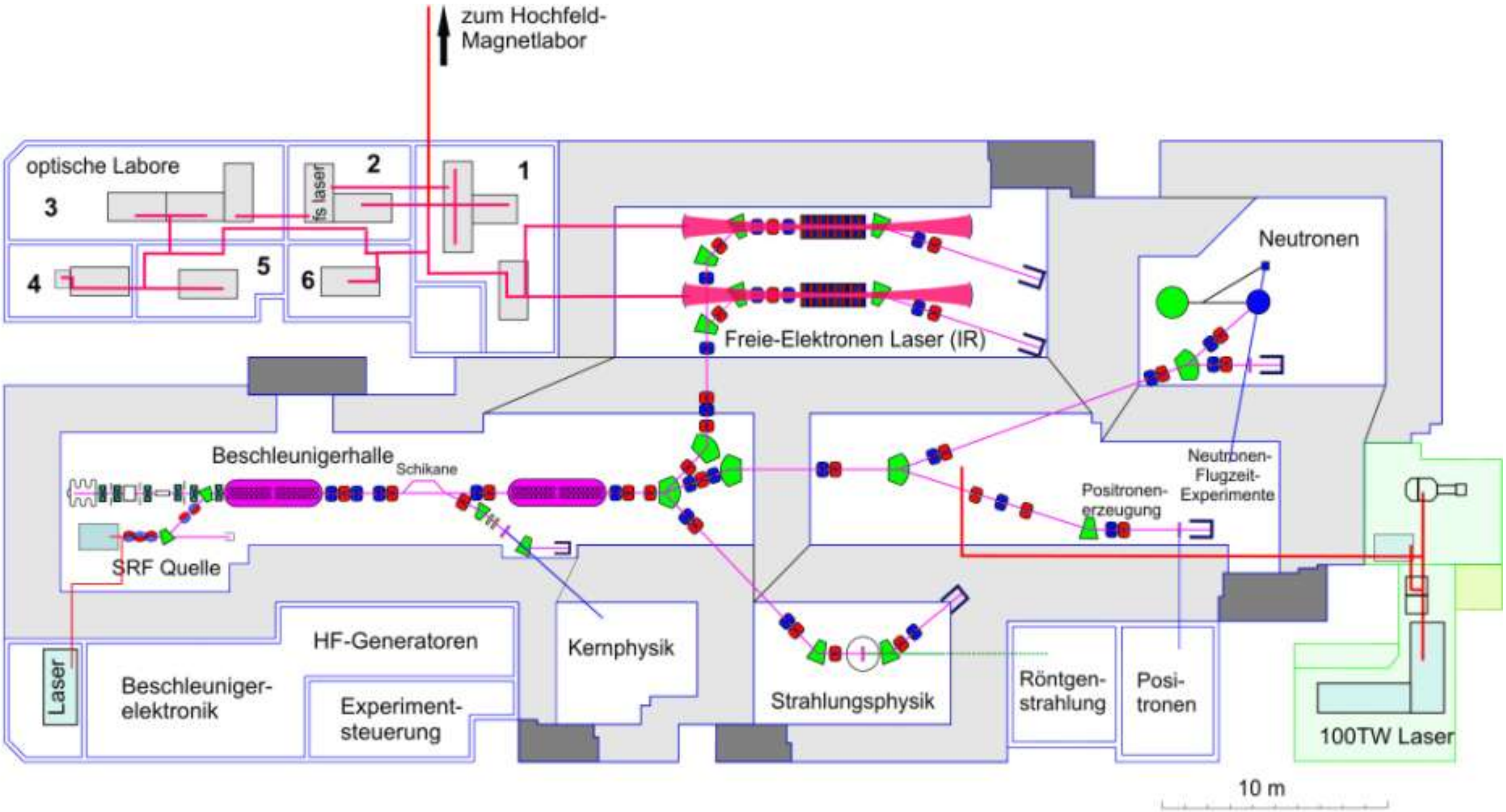
GiPS

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

- Cave 109 (nuclear physics)
- Positron generation by Bremsstrahlung
- Information in complete bulky sample (up to 100 cm^3)
- all relevant positron techniques (LT, CDBS, AMOC)

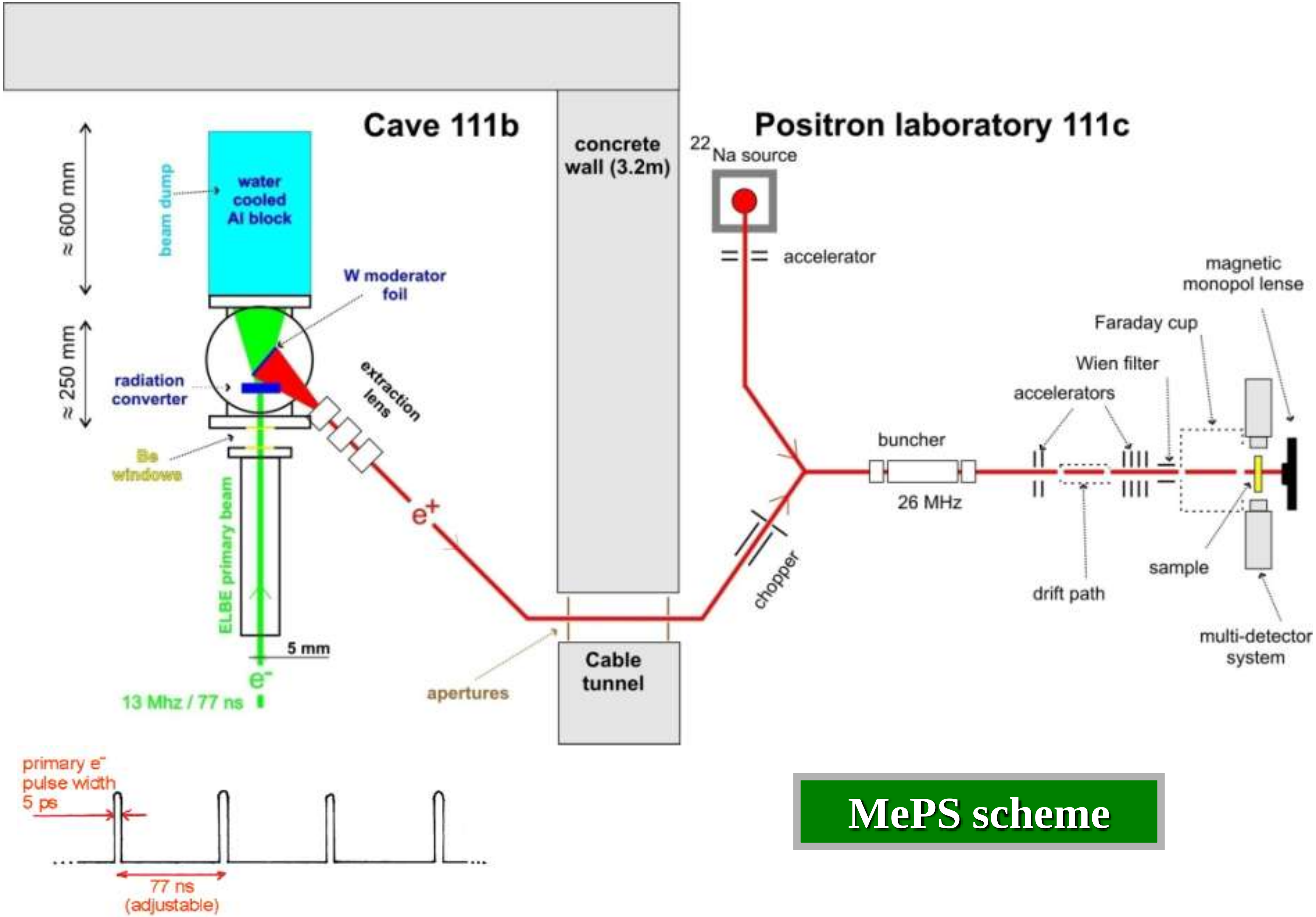
Information Depth: 0.1 mm …5 cm

Ground plan of the ELBE hall



1: Diagnosestation, IR-Imaging und biologische IR Experimente
2: Femtosekundenlaser, THz-Spektroskopie, IR Pump-Probe Experimente
3: Zeitaufgelöste Halbleiter-Spektroskopie, THz-Spektroskopie

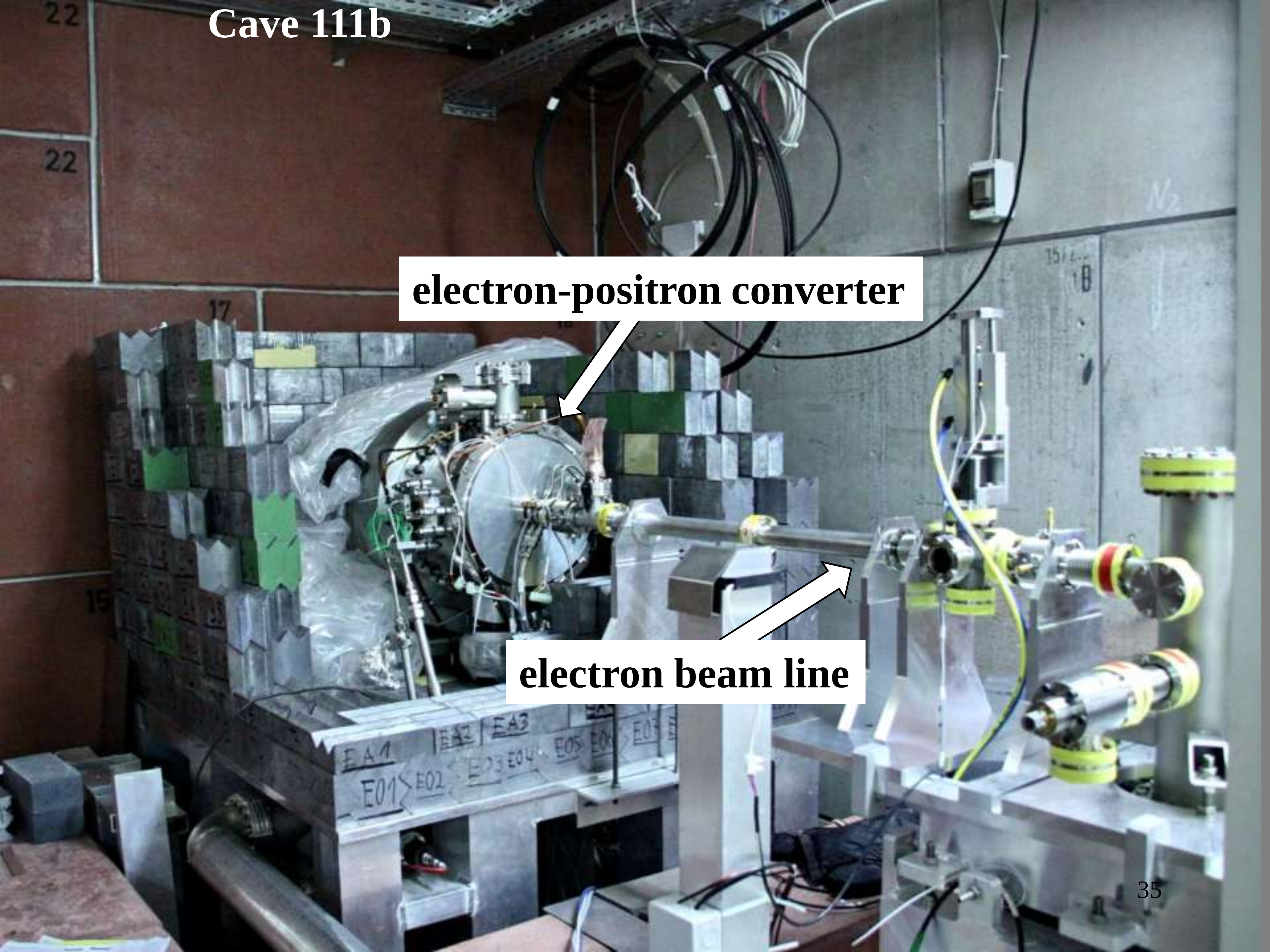
4: FTIR, biologische IR Experimente
5: Nahfeld und Pump-Probe IR Experimente
6: Radiochemie und Summenfrequenz-Erzeugung, photothermische Spektroskopie

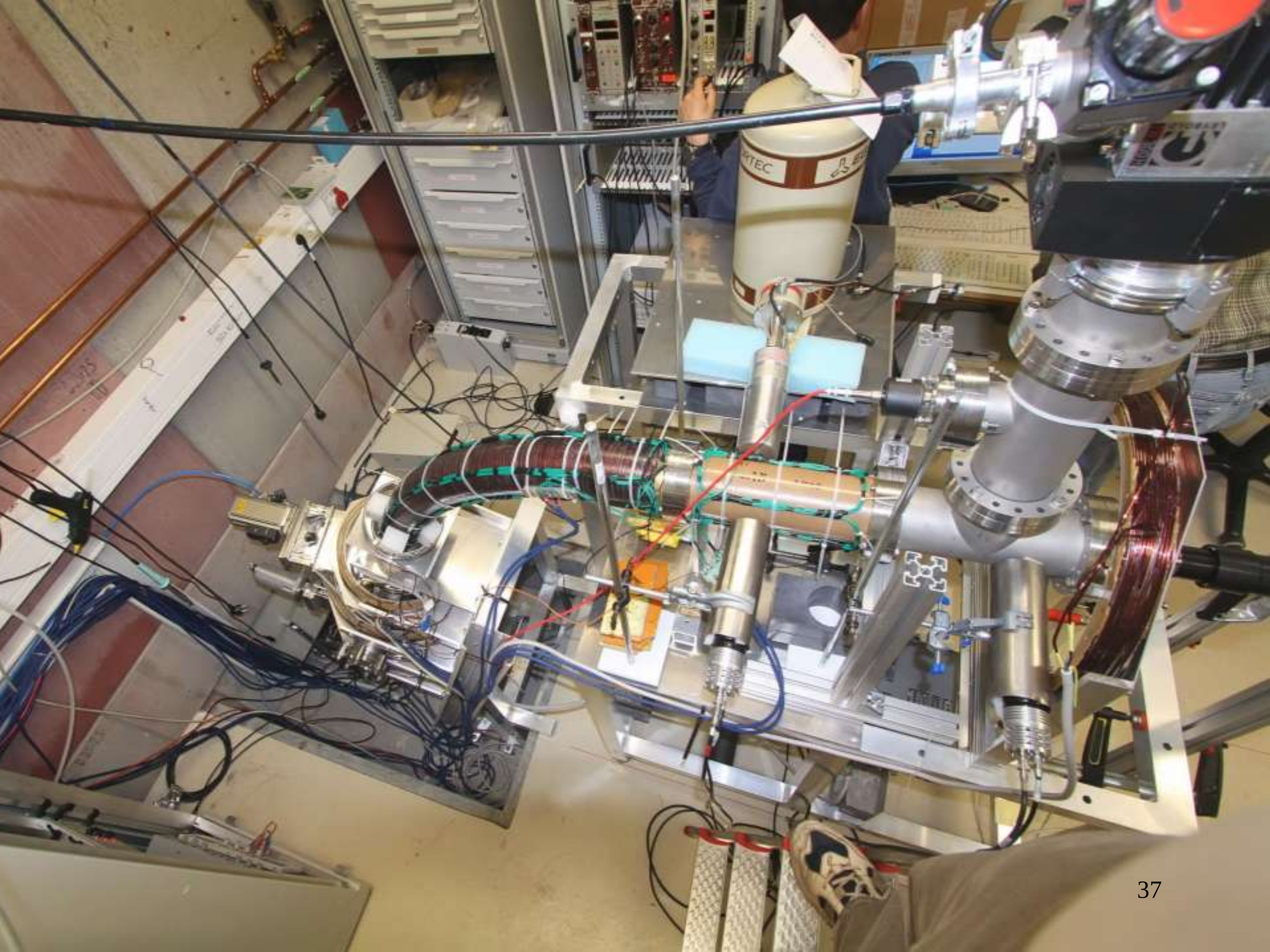


Cave 111b
concrete wall (3.2m)
Positron laboratory 111c
≈ 600 mm
≈ 250 mm
beam dump
water cooled Al block
W moderator foil
radiation converter
extraction lens
Be windows
ELBE primary beam
5 mm
e⁻
13 Mhz / 77 ns
e⁺
apertures
Cable tunnel
22Na source
accelerator
chopper
buncher
26 MHz
accelerators
drift path
Wien filter
Faraday cup
magnetic monopol lense
sample
multi-detector system
primary e⁻ pulse width 5 ps
77 ns (adjustable)

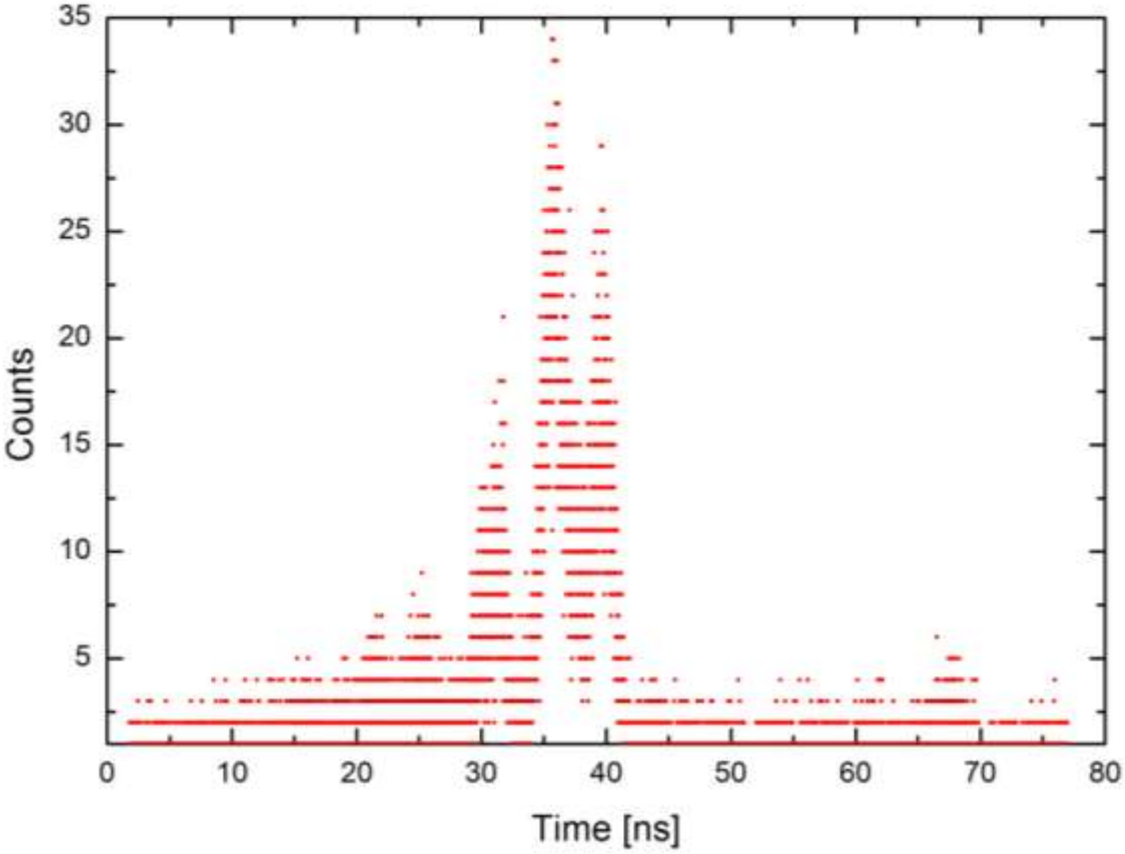
MePS scheme

Cave 111b





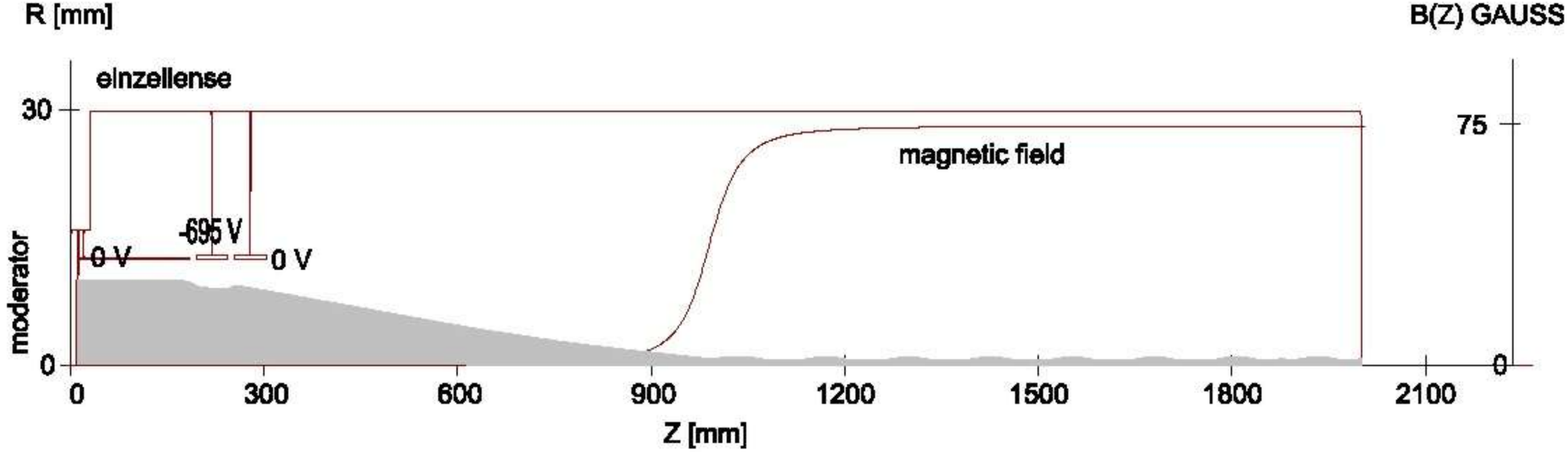
First time spectra – many side peaks



- BaF_2 starts TAC and ELBE machine pulse stop it
- Positron bunch before chopper and buncher System at about 6m

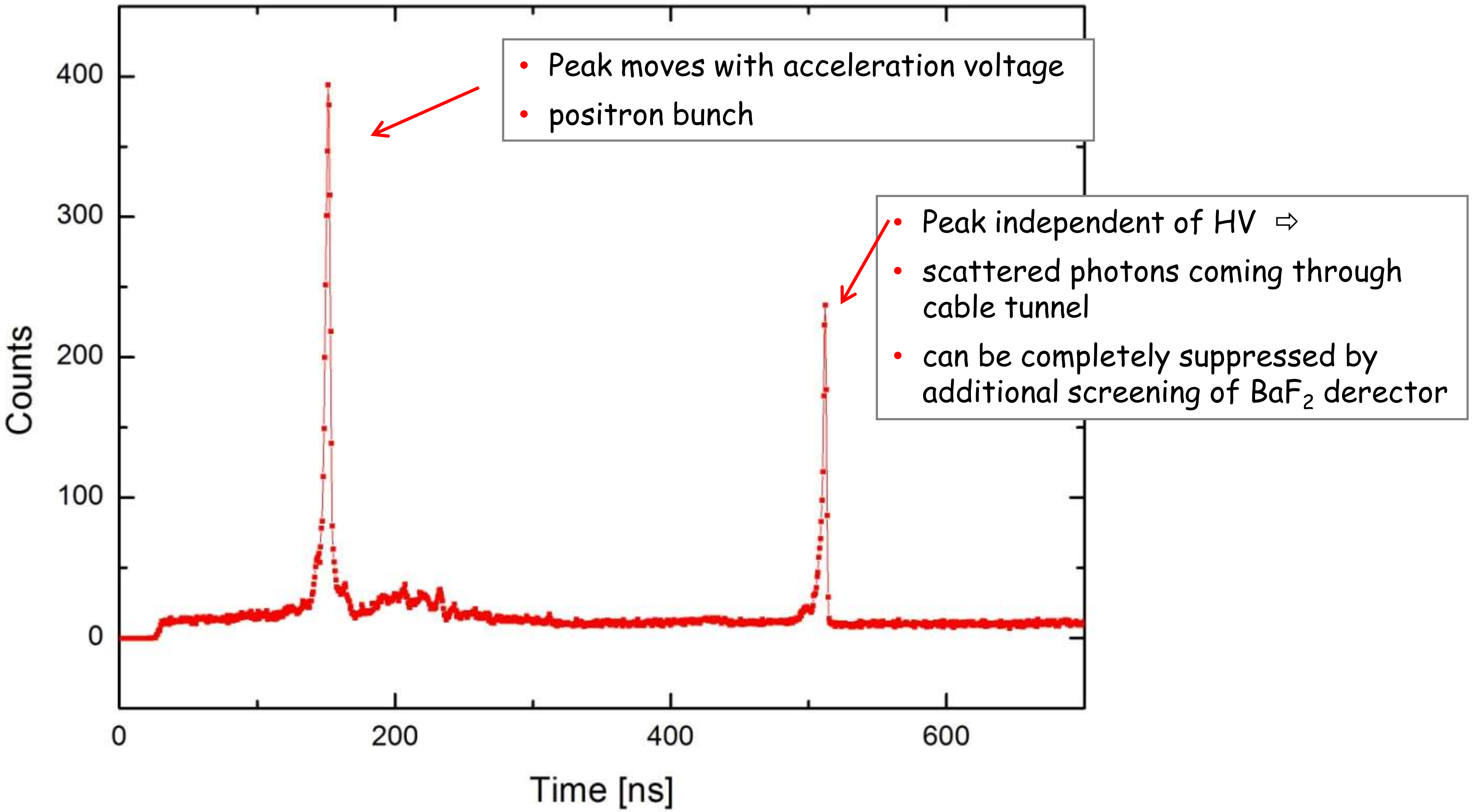
Time structure

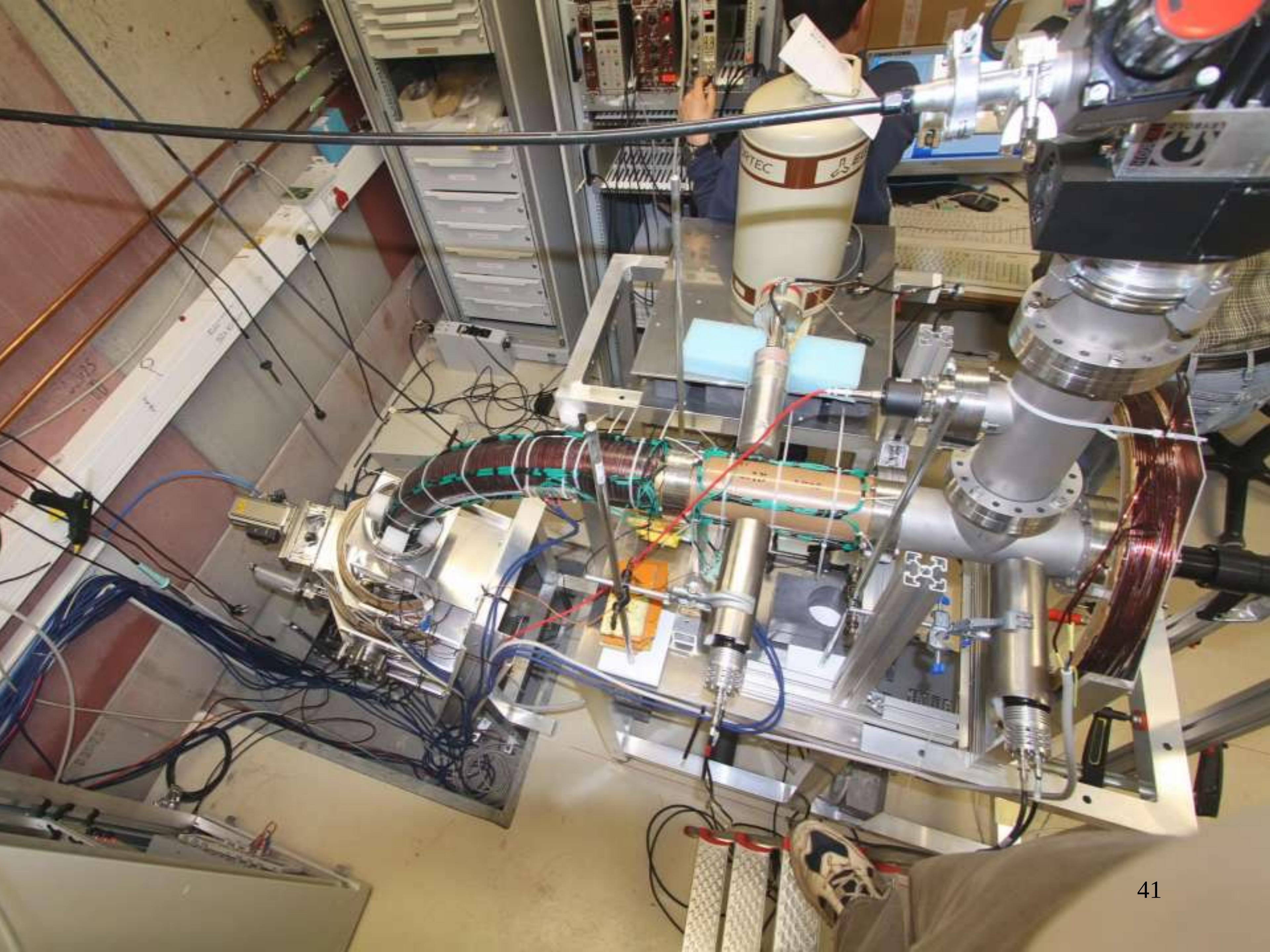
- reason for broad time structure: electro-static lens did no work as expected
- spot at entrance into magnetic field too large ⇨ transversal component very large (>100 eV)
- this energy is missing in longitudinal component ⇨ broad time spectrum

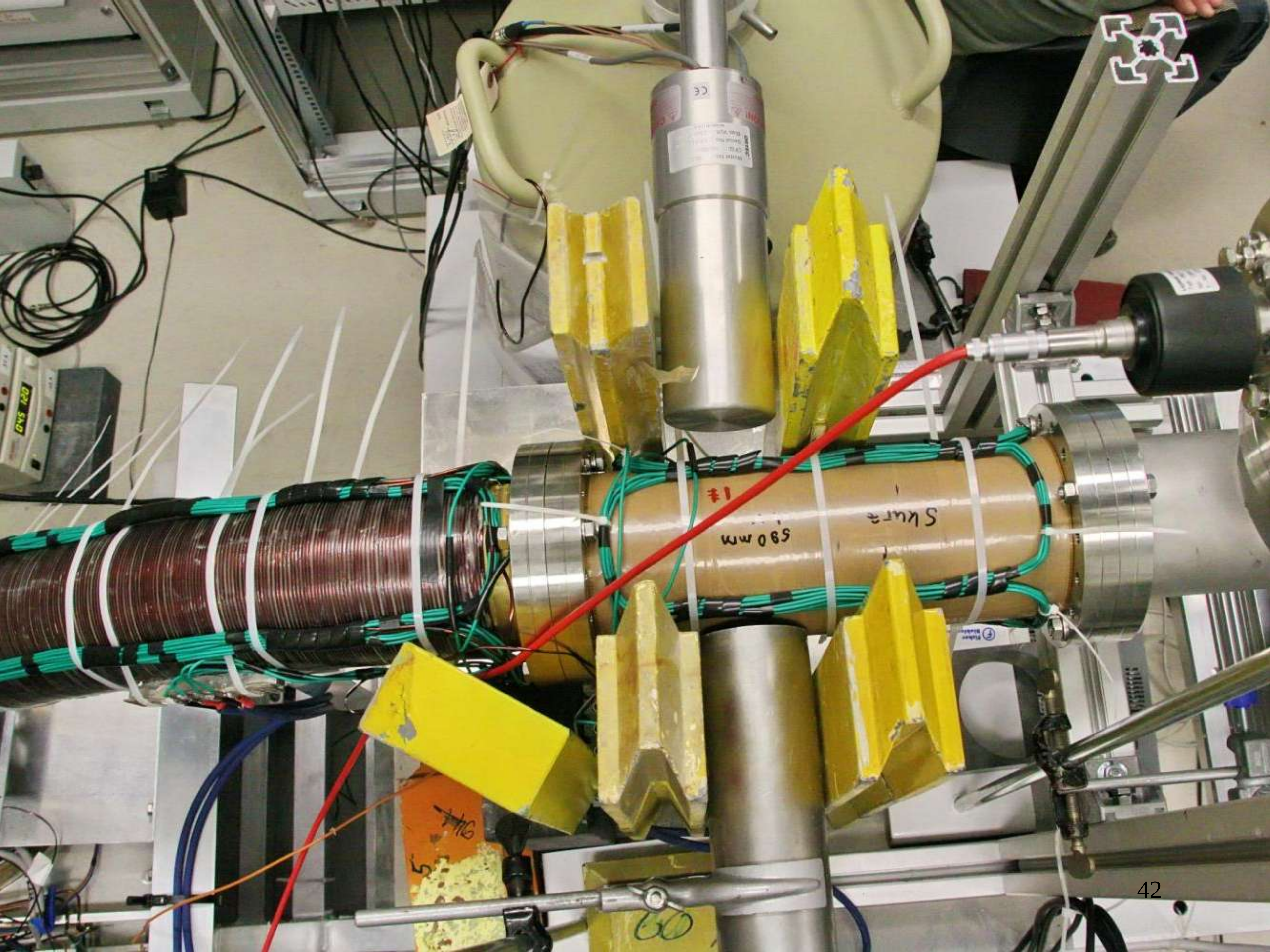


- Solution for the moment: extension of magnetic field behind moderator
- then ⇨ only two peaks appear

Time spectrum now



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Gamma-induced Positron Spectroscopy

ELSEVIER

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

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

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

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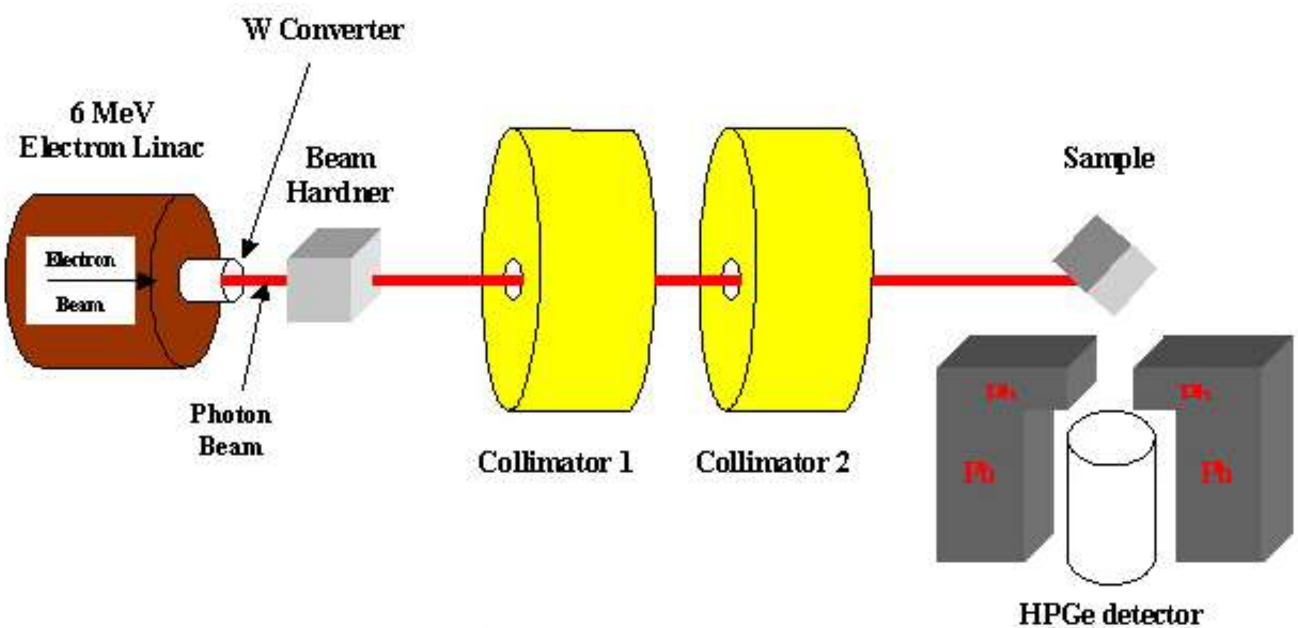
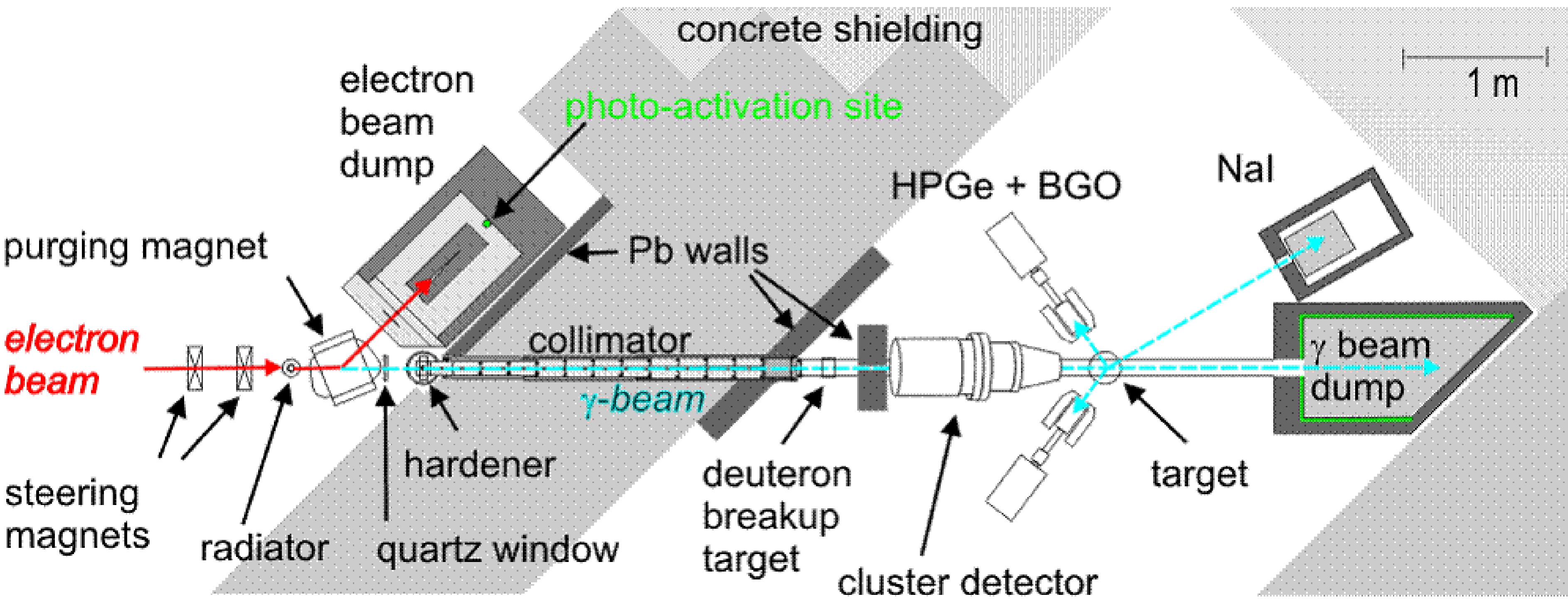
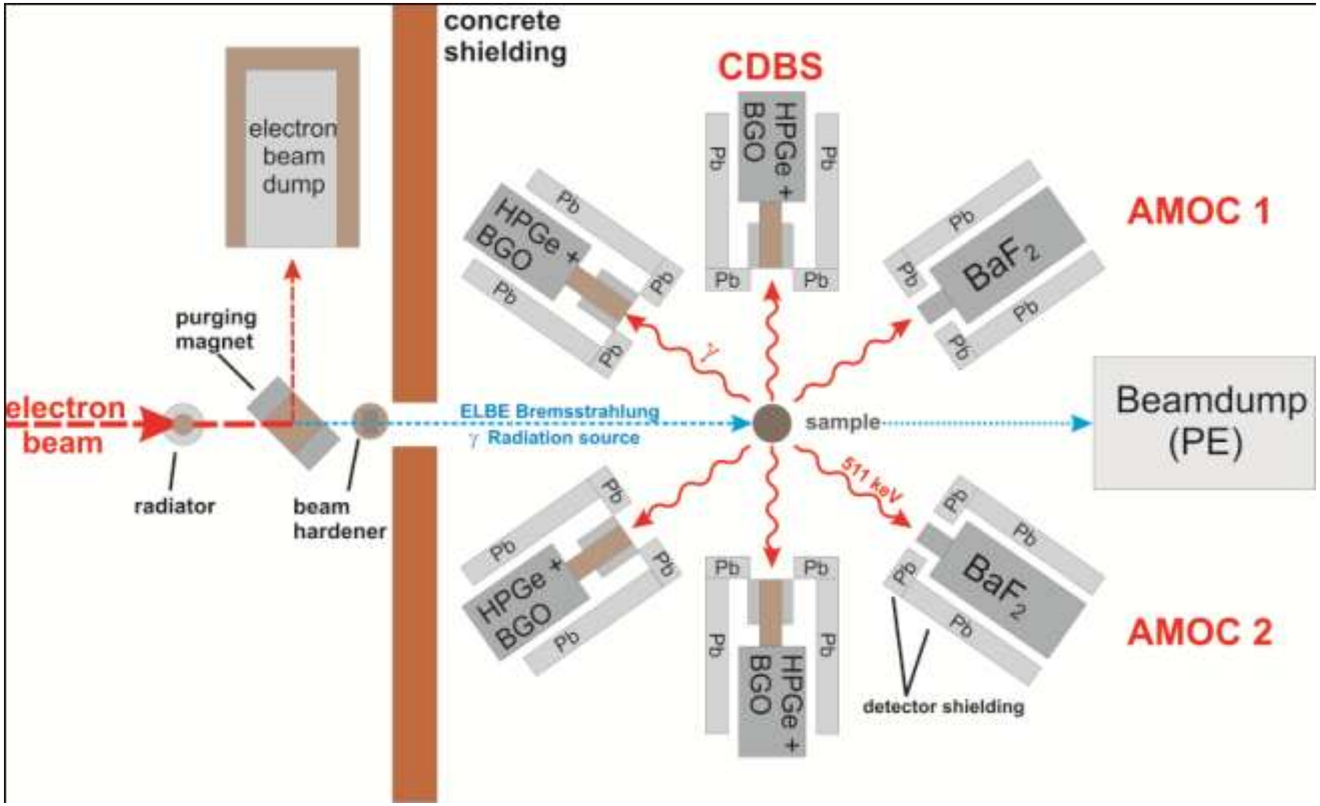


Bremsstrahlung Gamma Source of ELBE (FZ Dresden-Rossendorf)

- 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 (we used 16 MeV), no activation of samples by γ-n processes was found
  - 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 ! It's now part of EPOS project – user dedicated positron source.**



GiPS: Gamma-induced Positron Spectroscopy



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

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

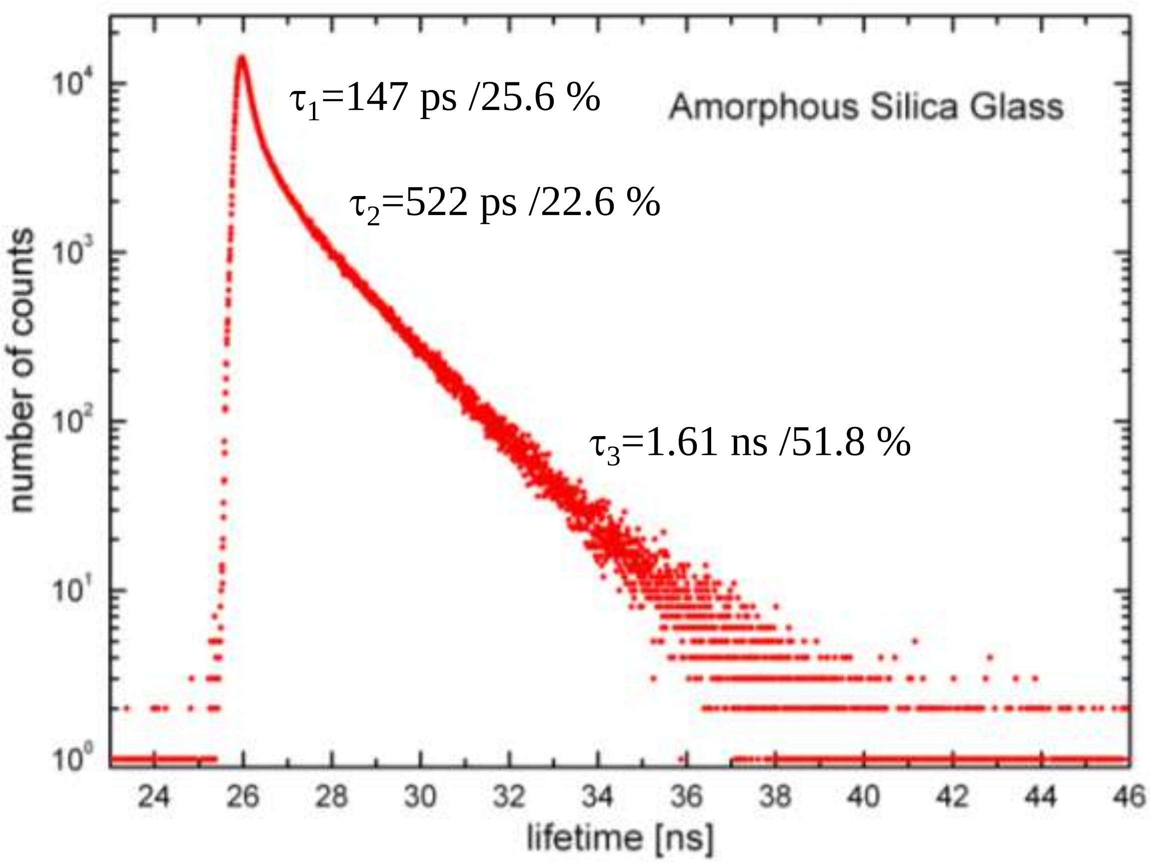
The GiPS setup includes 6 Detectors (4 Ge and 2 BaF_2)

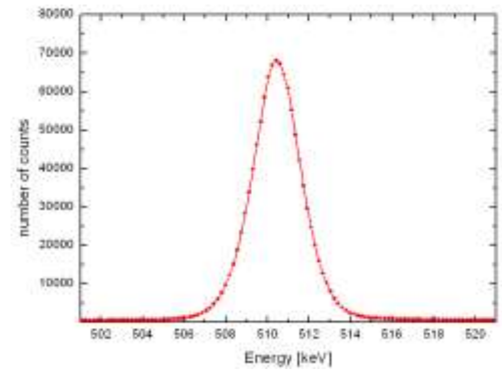
Amorphous Silica Glass

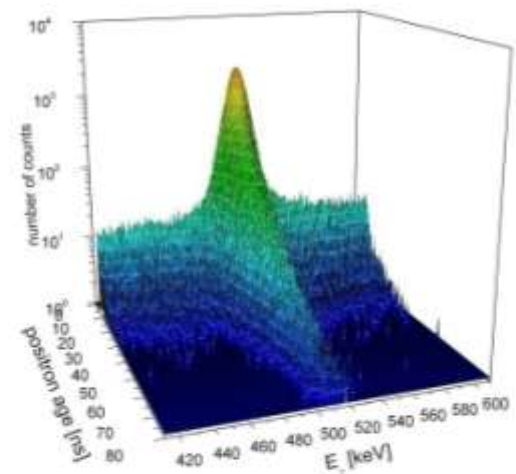
- round piece 1.5 cm thick, about 5 cm^3
- lifetime spectrum: total count rate: $2x10^6$
- same sample was measured conventionally in 1978 also in the same institute (former ZfK Rossendorf):

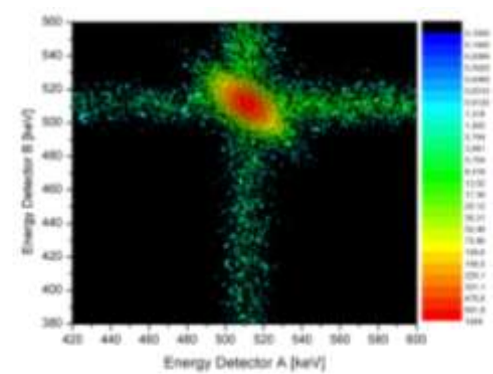
  151 ps - 523 ps - 1.57 ns (FWHM ≈350 ps)

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



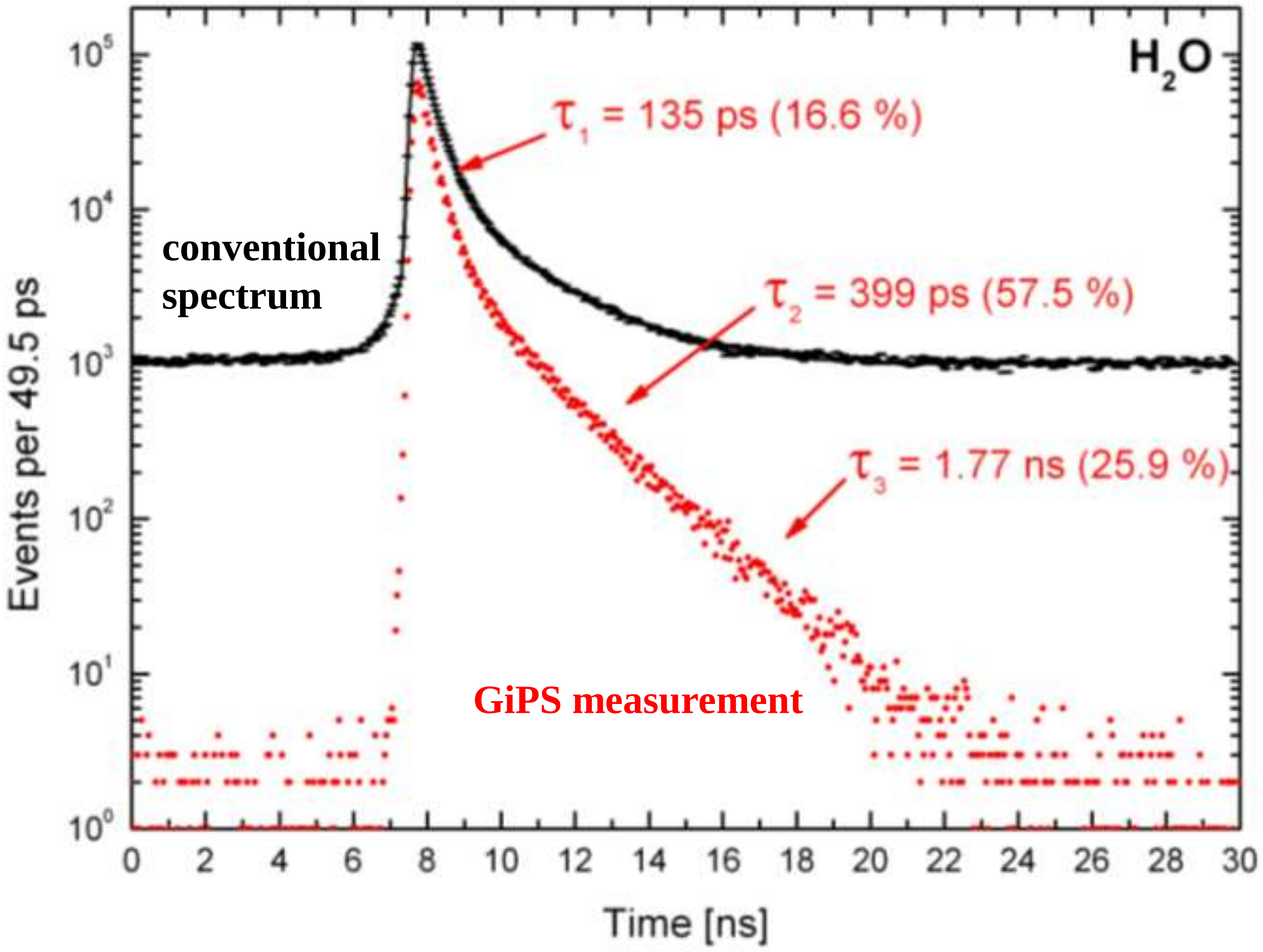






Example: Water at RT

- total count rate in spectrum: 12×10^6



Black spectrum: conventional measurement by Kotera et al., Phys. Lett. A 345, (2005) 184

Applications of GiPS since begin of 2009

- neutron irradiated Fe-Cr alloys (highly activated up to 50 MBq ^{60}Co)
- Reactor pressure vessel steel samples from Greifswald nuclear power station
- Iron samples after mechanical damage (LCMTR-ISCSA-CNRS, Frankreich)
- set of Zircony alloys (Collaboration Mumbai/India)
- porous glass (Chem. Department/Univ. Leipzig)
- biological samples
- liquids