Use of Superconducting LINACS for Positron Generation

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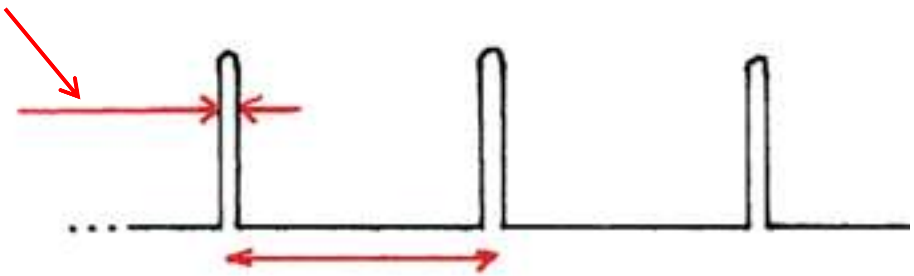
- Superconducting Linacs
- EPOS-System at Research Center Dresden-Rossendorf
  - MePS
  - GiPS

Magnetic Island, Australia, 2010
SLOPOS-12

A positron annihilators dream source

- pair production instead of isotope source (self-absorption of β^+)
- best: electron beam bunched with final time structure in cw-mode

pulse width: < 10 ps



repetition time: ca. 1 µs

- **Repetition time** = 8 × longest lifetime to be measured ≈ 1 µs
- **Energy** >> 1022 keV for pair production

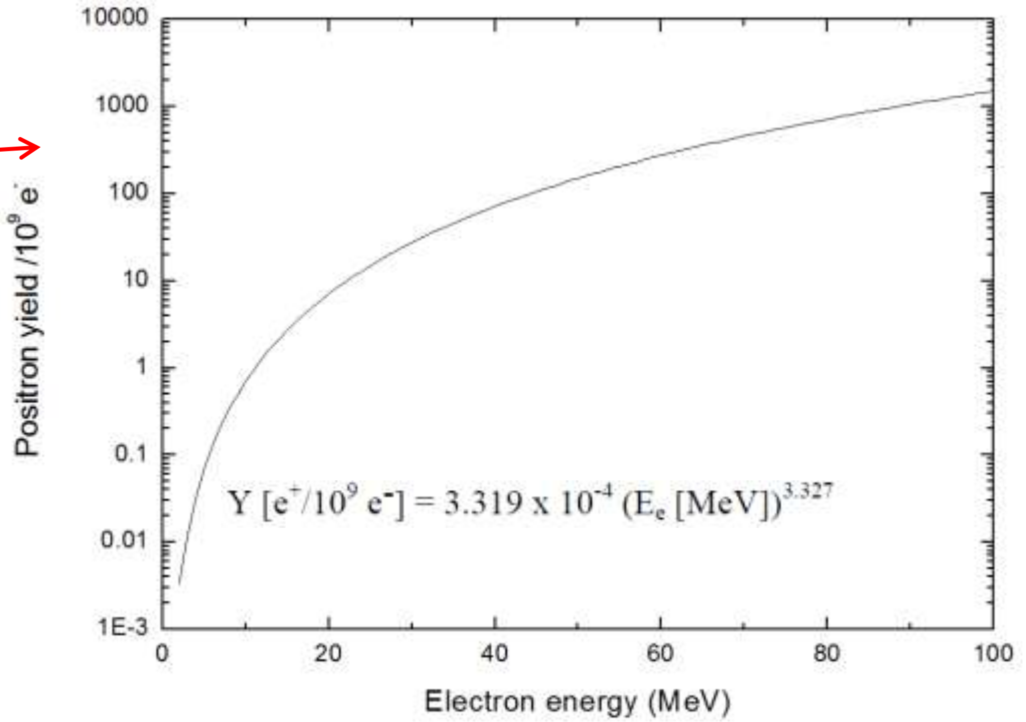
maximum output:

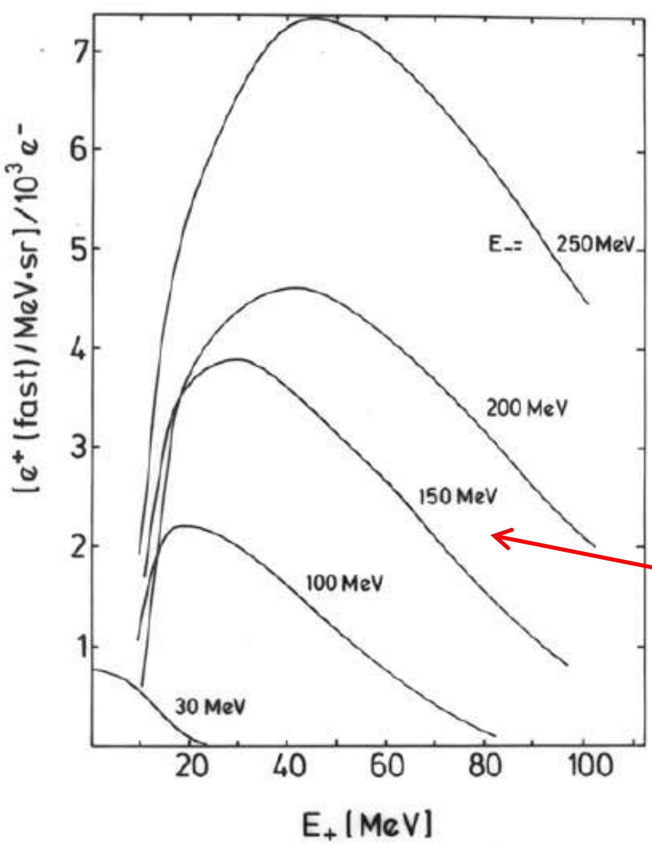
E_{e-} = 30…60 MeV

< 10 MeV: no isotope activation by (γ,n) processes -> no radiation when electron beam is switch off

What electron energy for pair production?

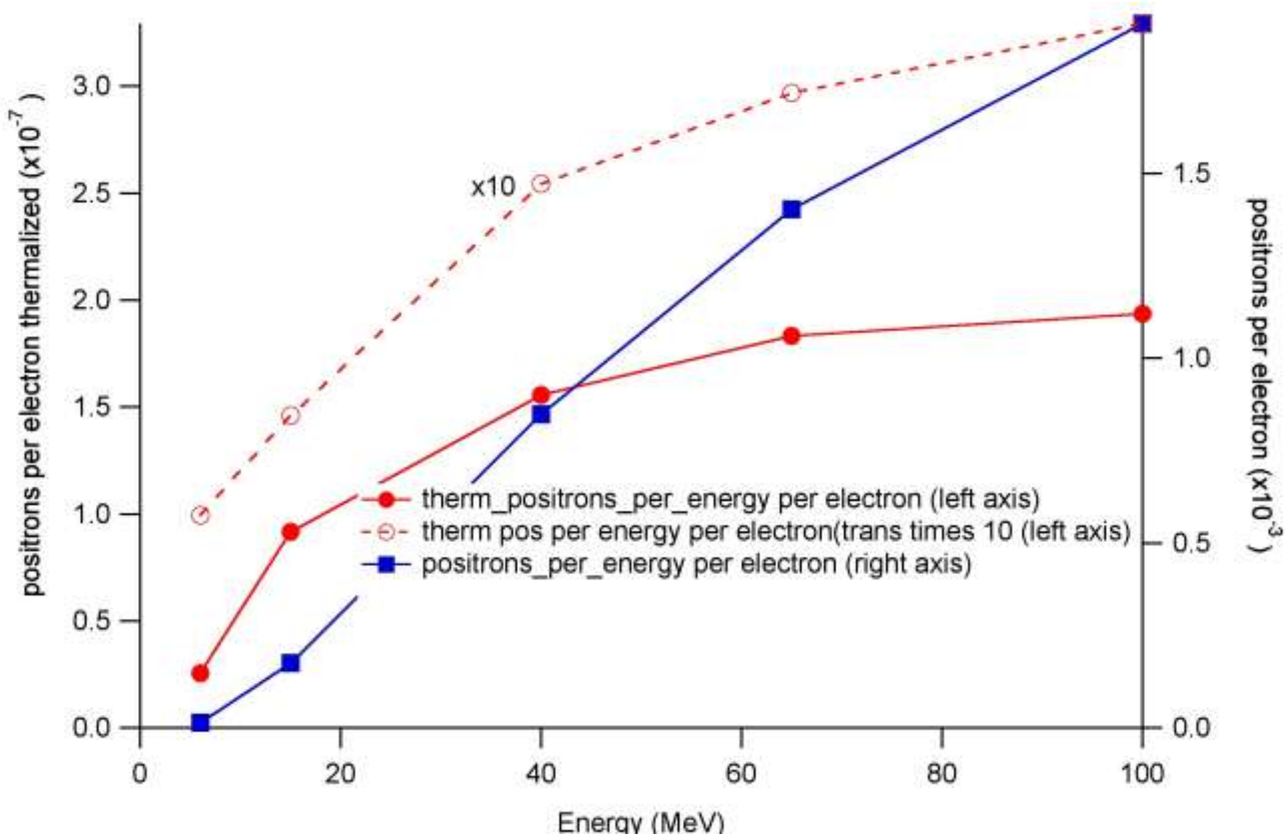
- positron yield is strong function of electron energy
- for 10 MeV < E < 100 MeV (opt. target thickness for each energy)
- however: mean positron energy increases strongly





- mean positron energy is about 1/5 of electron energy for E_{e-} > 100 MeV
- moderation efficiency drops strongly at high e^+ energy
- there must be an optimum energy
- MC simulations required including moderation

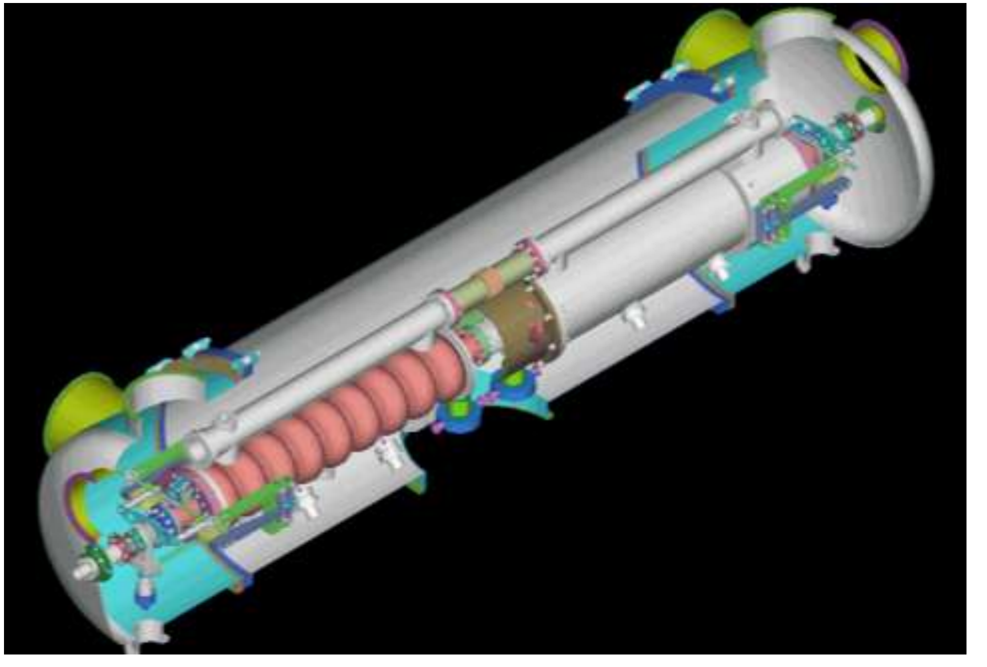
Where is the "sweet" spot for slow positron production?

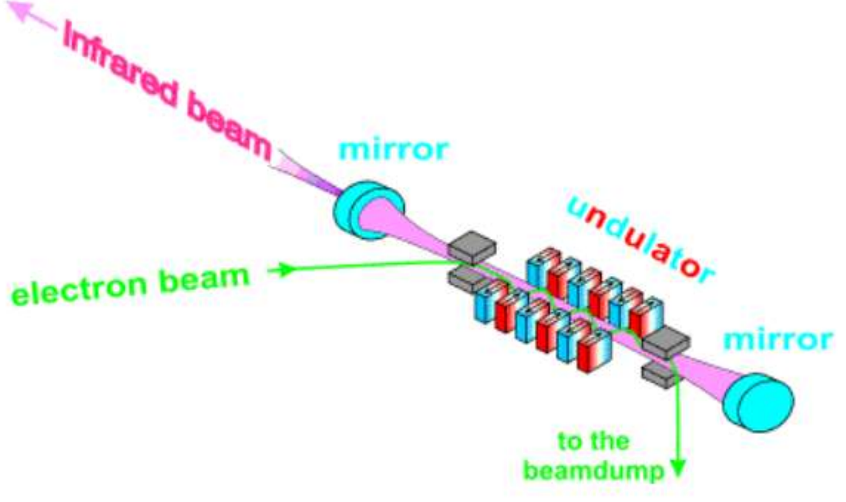


Relative yield of positrons as a function of the incident electron energy. The yield of total positrons increases virtually continuously (closed squares) while the number of thermalized positrons appears to approach saturation at about 60 MeV both for reflected moderation (filled circles) or transmitted moderation (open circles). If one is going to design an electron-linac-based positron source the optimal electron energy for positron generation will be in of 40-60 MeV range.

Solution: Superconducting LINAC

- RF cavities with standing micro waves (f = 1.3 GHz)
- Nb cavities operates at 1,8 K - Accelerating gradient 15 MV/m
- Large bunch charges possible, high repetition frequencies possible (up to 26 MHz)
- commercially available
- very useful for high energy accelerators and free-electron Laser (FEL)
- FEL at ELBE: 4…250 µm IR radiation





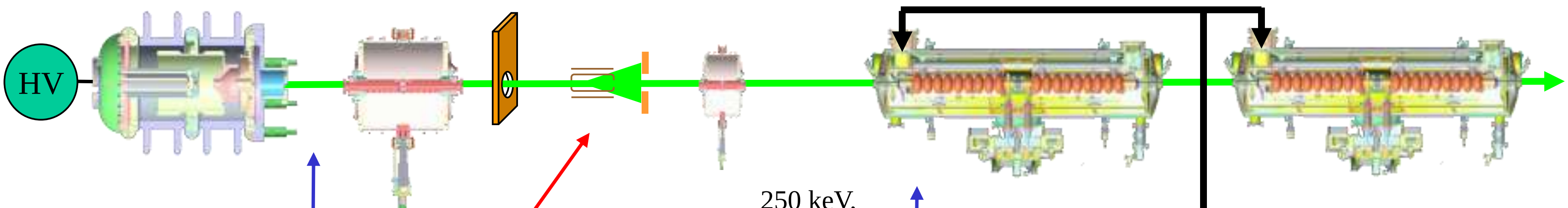
Beam generation, conditioning and acceleration

thermal-ionic gun
250 kV DC
13 MHz pulsed grid

injection
two RF bunch compressors,
apertures, macro pulse generator

linac 1
ΔE ~17 MeV
@ 10 MV/m cw

linac 2
ΔE ~ 19 MeV
@ 10 MV/m cw

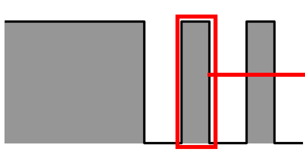


250 keV,
1 mA, β=0.74

Bunch length: 500ps ... ~5ps

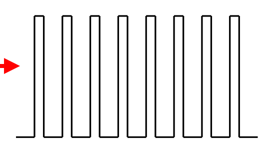
Time structure:

beam
(a) cw
(b) macro-pulsed



0.1…36 ms pulse length
40 ms…1 s period
➔ 1E-4…0.9 duty cycle

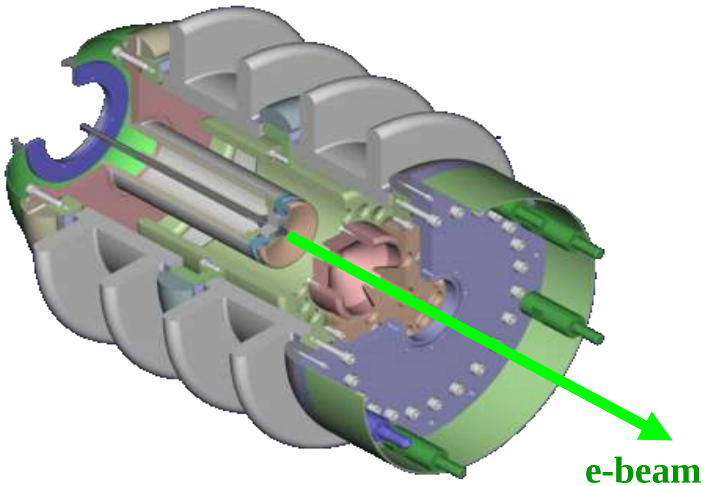
0…77 pC bunch train
(480 Mio electrons)

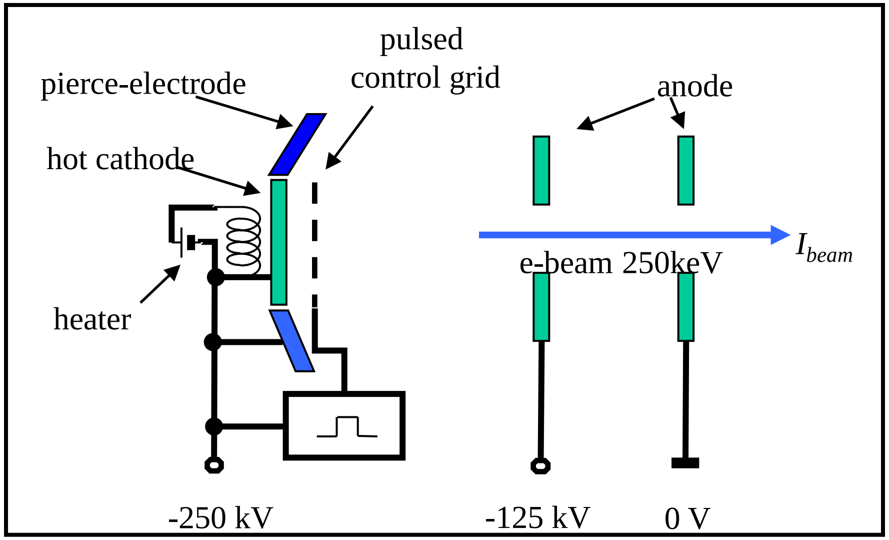


1.5…10 ps bunches
4 ns…10 µs period

Helium Liquifier LINDE
200 W @ 1,8 K

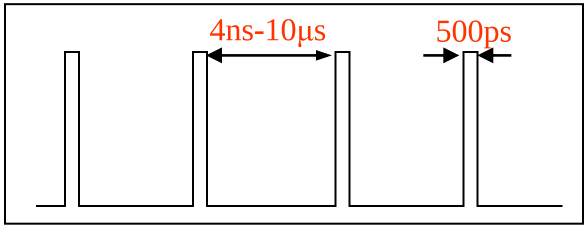
Thermionic electron source at ELBE





- working principle of triode
- 250 kV DC voltage
- pulse length 500ps → 11cm
- energy 250 keV
- bunch charge up to 77 pC @ 13 MHz
- but cannot be larger, also not for reduced repetition time

→ I_{beam} up to 1mA for 13 MHz



Existing Thermionic Electron Source @ ELBE

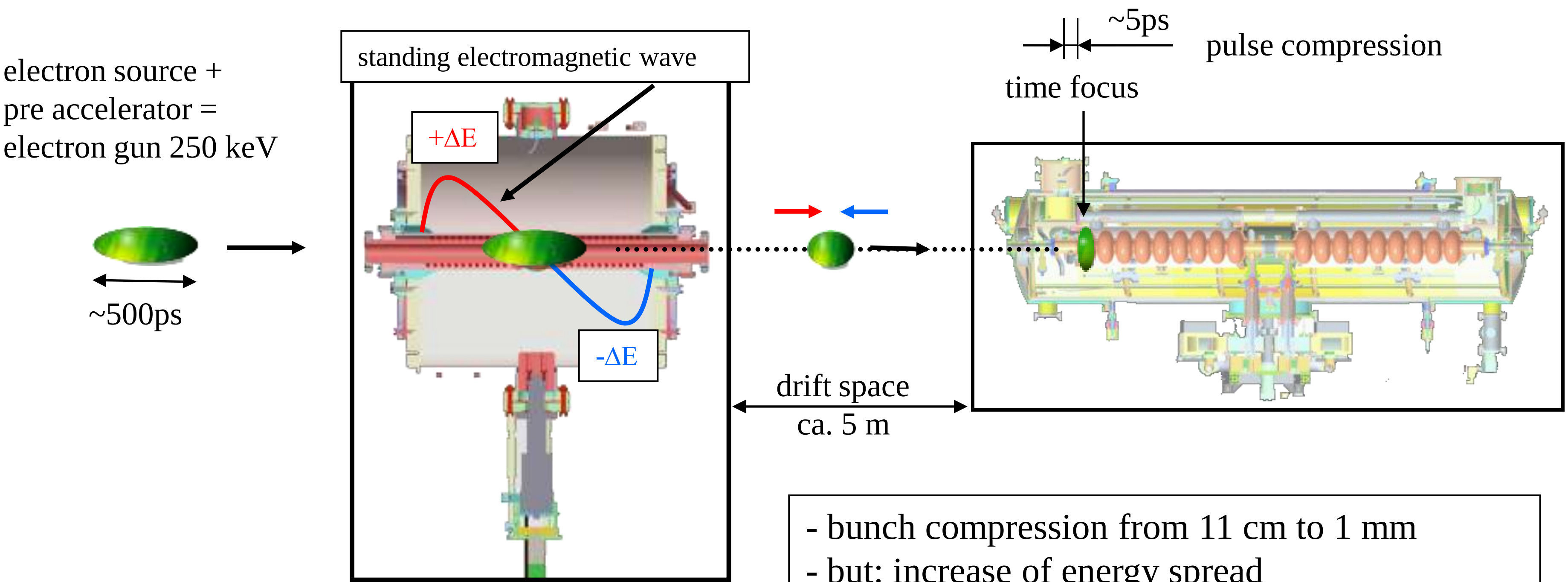
DC high voltage (250 kV) & gridded thermionic cathode

- CW operation with ≈ 1 mA
- rather simple setup
- robust and reliable

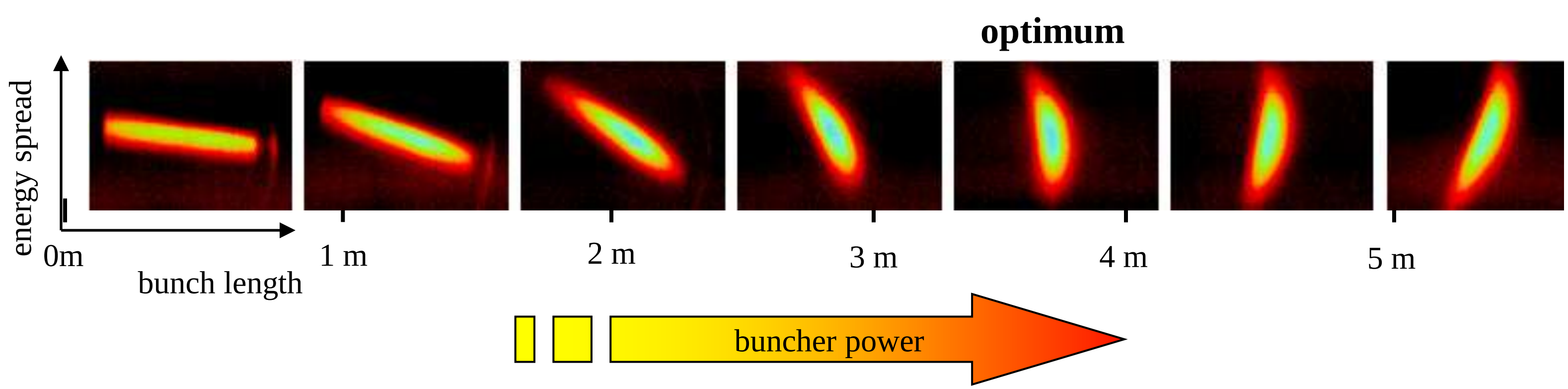
But

- low bunch charge ≤ 77 pC
- high transverse emittance, ≈ 10 mm mrad
- long pulses, 500 ps
- requires bunching

Bunching of electron beam required



- bunch compression from 11 cm to 1 mm
- but: increase of energy spread

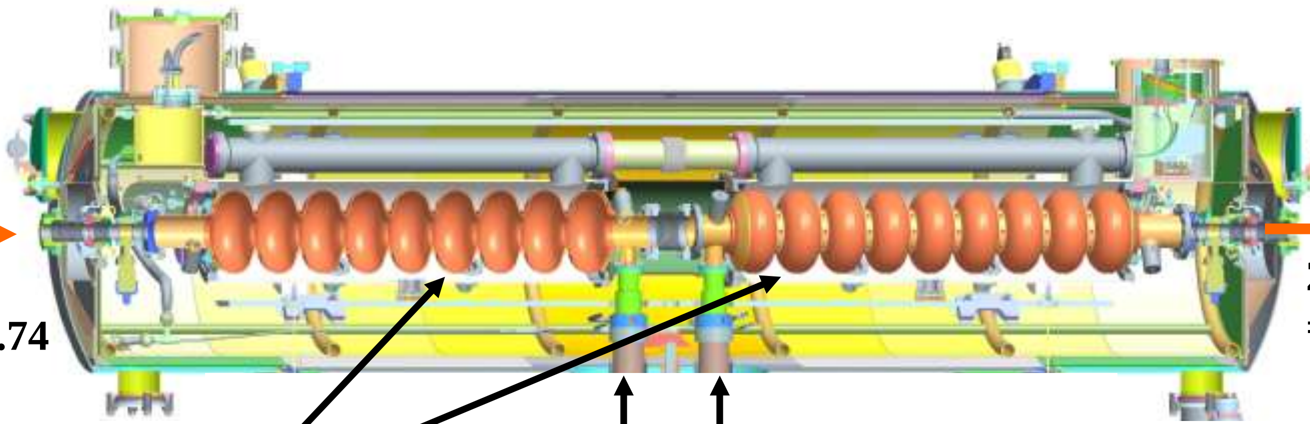


The accelerator

FZD in house developed CW superconducting acceleration module

e^-

250 keV,
1 mA, β=0.74

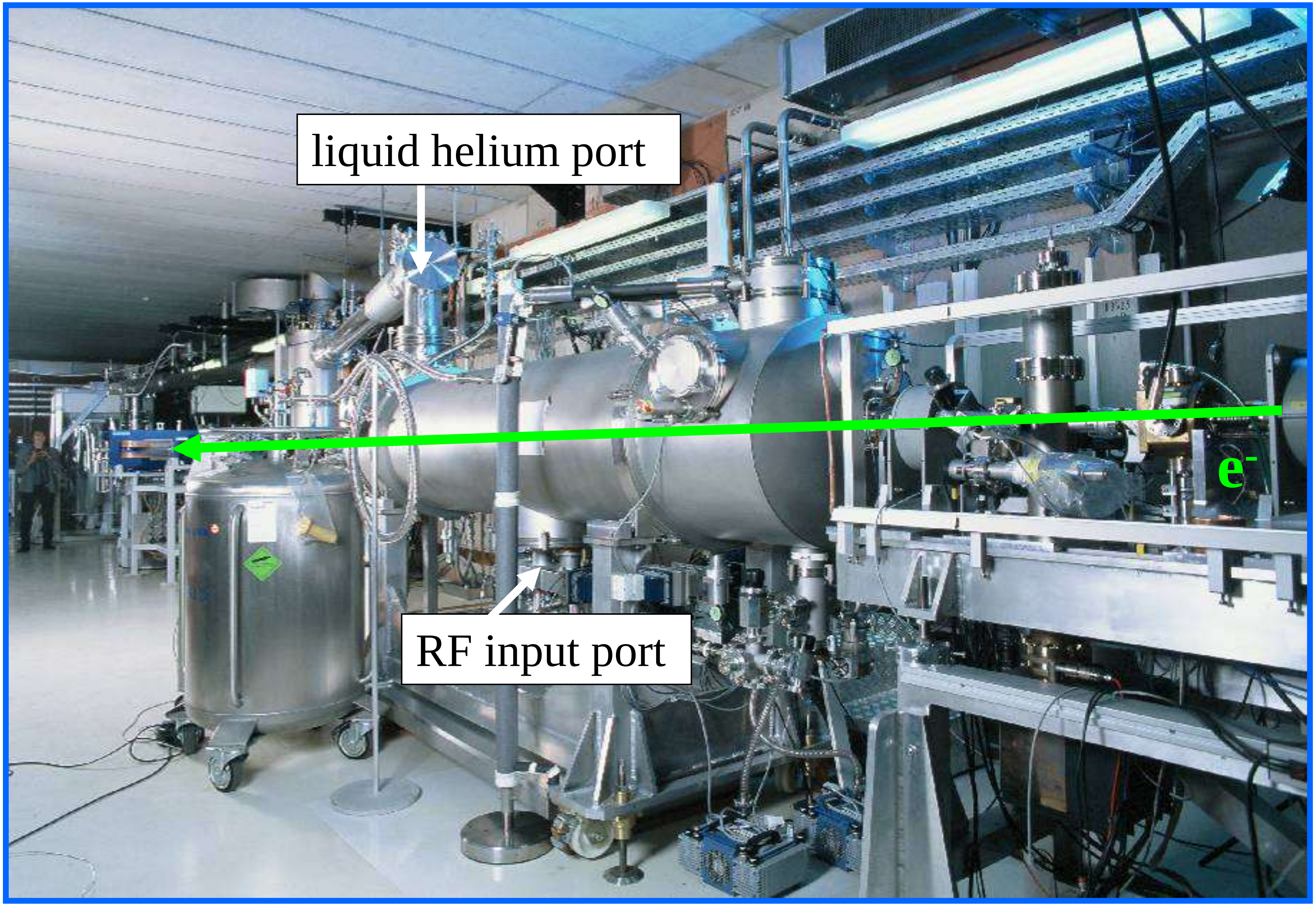


e^-

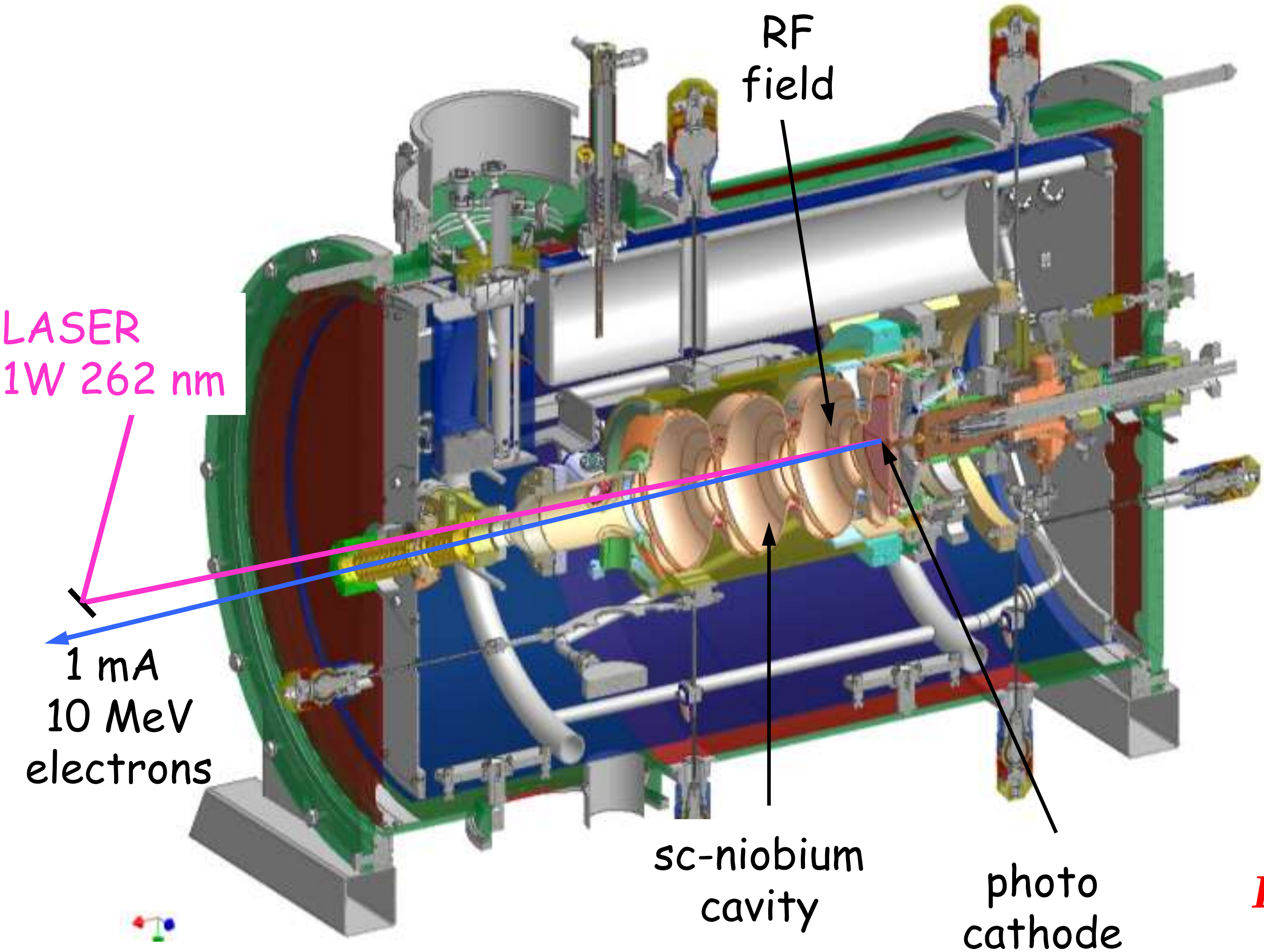
20 MeV · 1mA
= 20kW, β~1

Two 1.3 GHz 9-cell TESLA cavities
inside a 1.8K helium vessel

RF power input, fed
by two 10kW klystrons


liquid helium port
RF input port
e-

The alternative: superconducting photo-gun

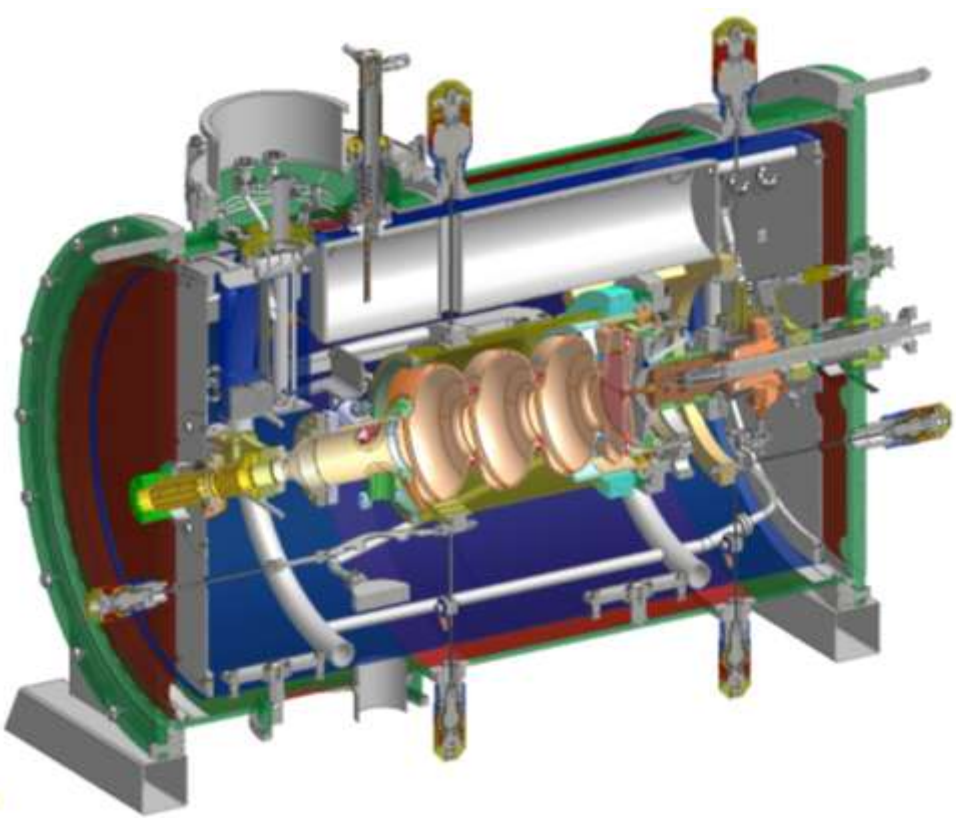


- very short bunches by using pulse Lasers (≈10 ps) from generation
- high bunch charge up to 1 nC
- 77 ns up to 100 kHz repetition time
- for positron generation: 1μs ideal
- no e^- bunchers required
- small setup

⇩

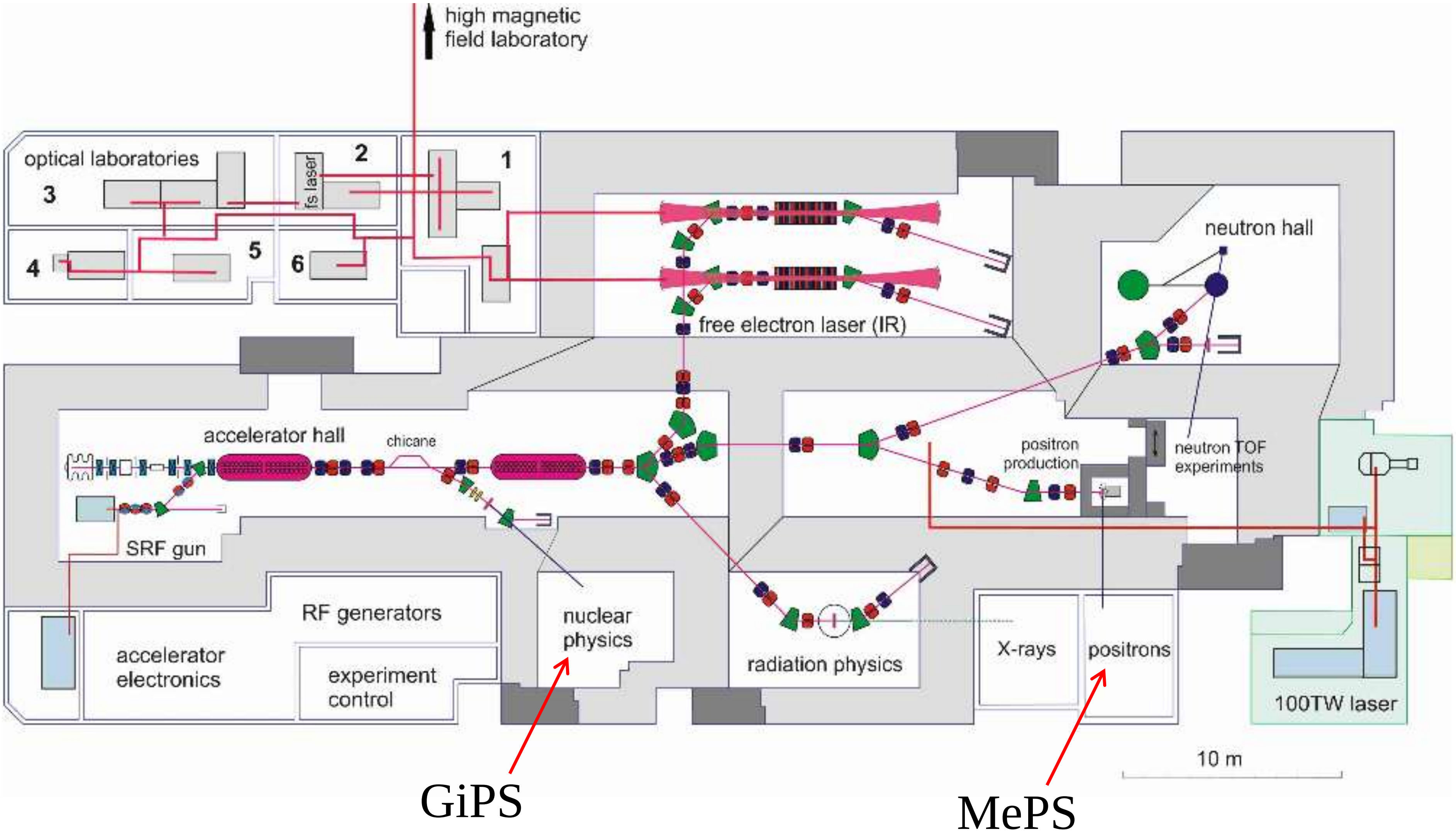
ELBE SRF PHOTO INJECTOR

Superconducting electron Photo-Gun



Mode	ELBE	High Charge
final electron energy	≤ 9.5 MeV	
RF frequency	1.3 GHz	
operation mode	CW	
bunch charge	77 pC	1 nC
repetition rate	13 MHz	500 kHz
laser pulse (FWHM)	4 ps	15 ps
transverse rms emittance	1 mm mrad	2.5 mm mrad
average current	1 mA	0.5 mA

Ground plan of the ELBE hall



EPOS (ELBE Positron Source)

MePS
Monoenergetic Positron Spectroscopy

- monoenergetic (slow) positrons
- pulsed system
- LT, CDBS, AMOC
- Still under construction (in 2010)

Information Depth: 0…5 µm

CoPS
Conventional Positron Spectroscopy

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

Information Depth: 10…200 µm

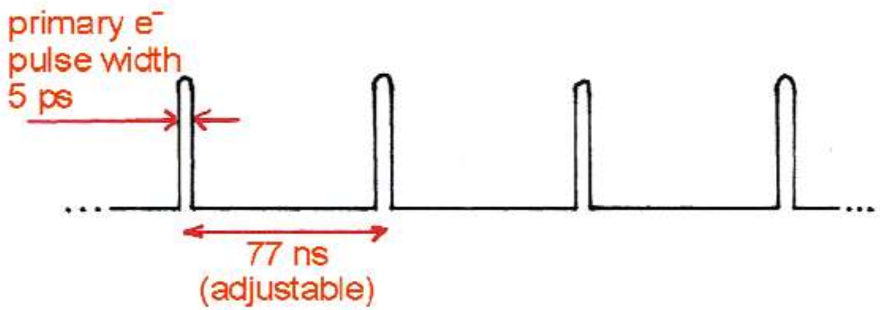
GiPS
Gamma-induced Positron Spectroscopy

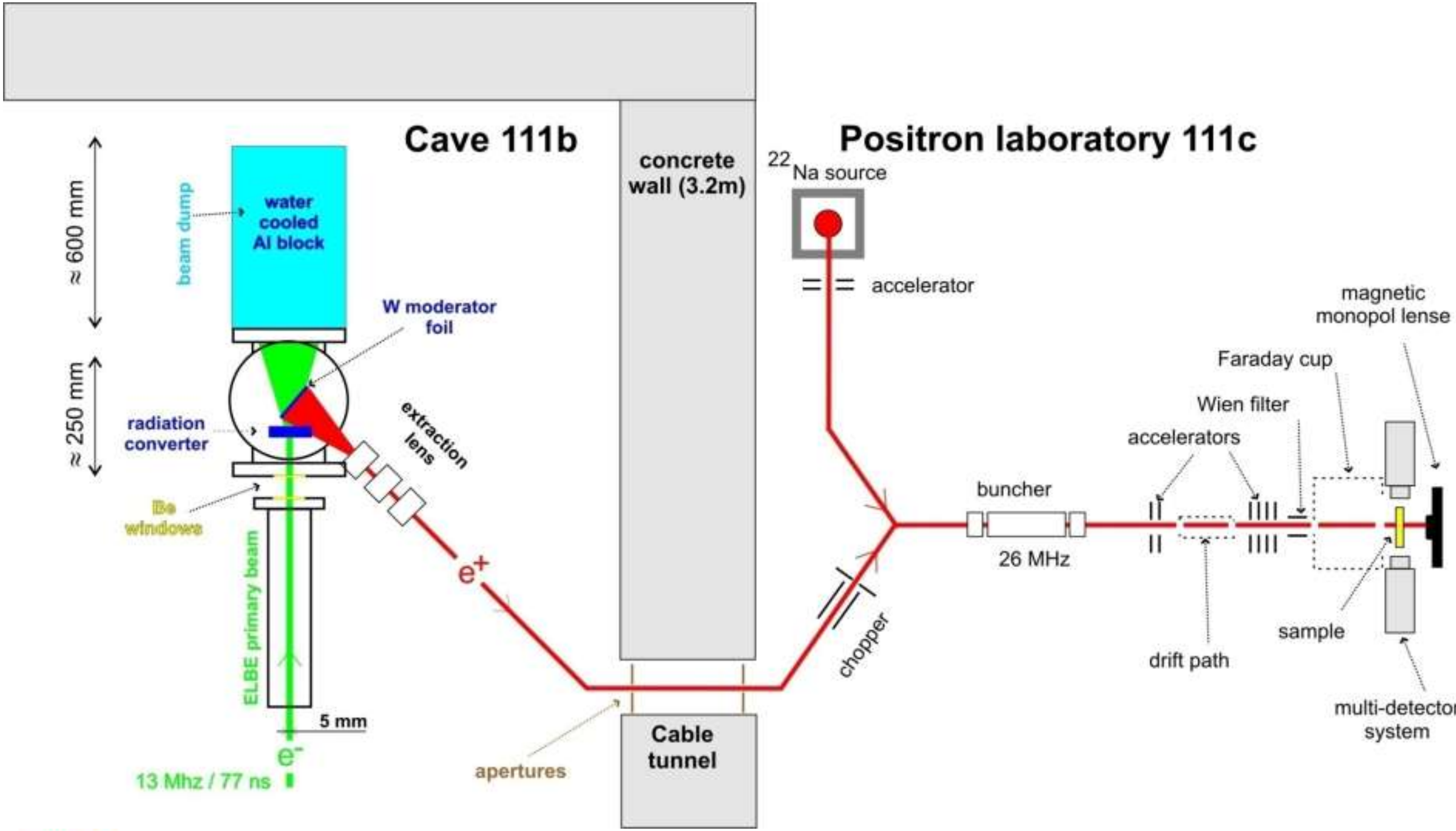
- Positron generation by Bremsstrahlung
- Investigation of bulky samples (up to 10 cm^3)
- all relevant positron techniques (LT, CDBS, AMOC)

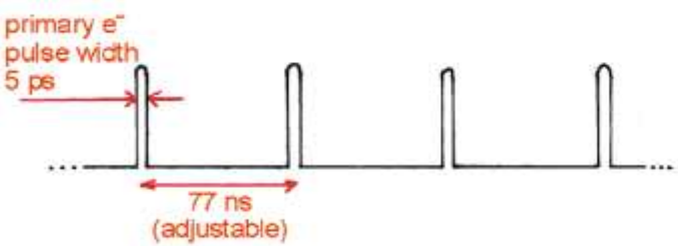
Information Depth: 0.1 mm …2 cm

MePS – Mono-energetic Positron Spectroscopy

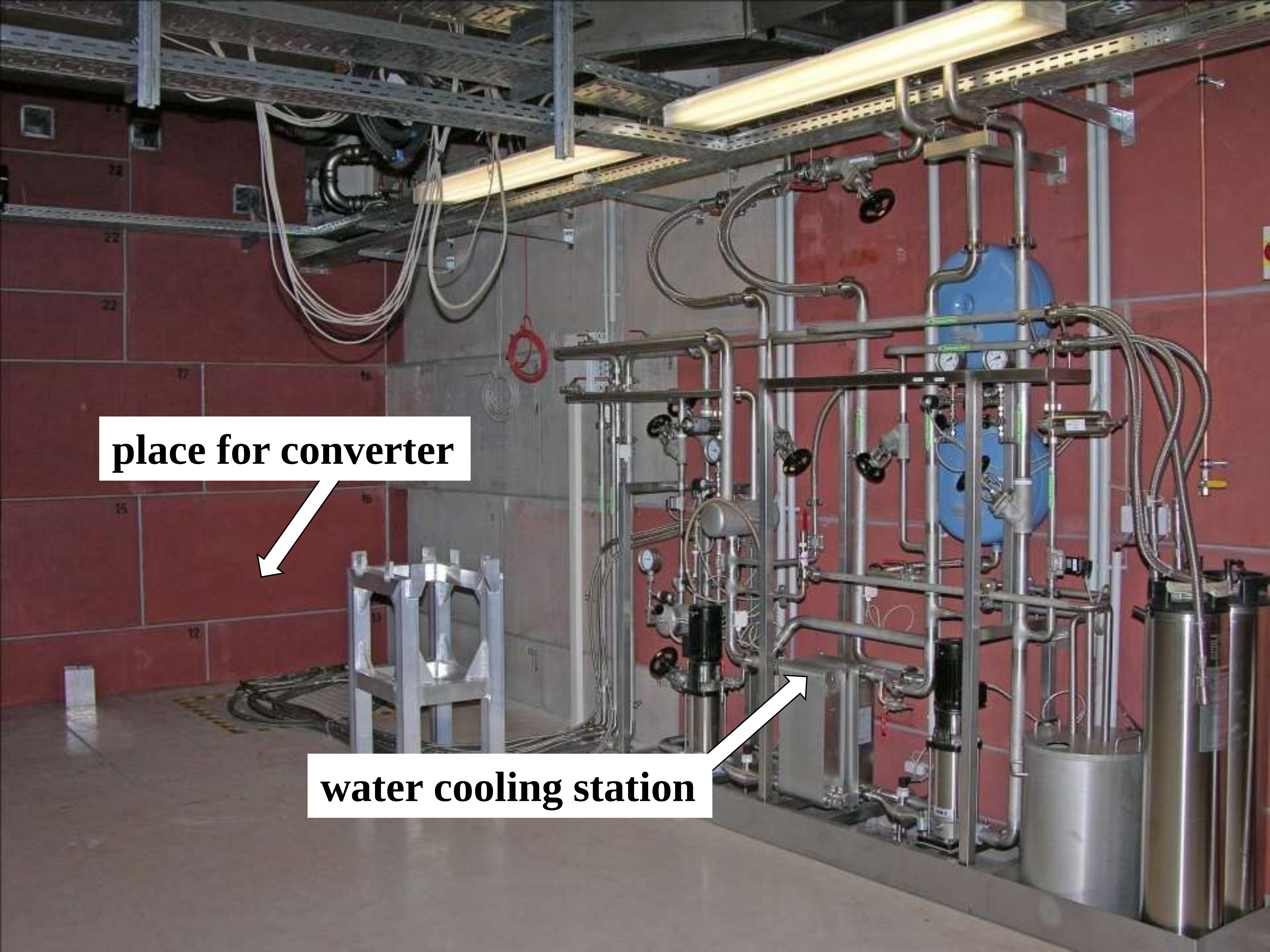
- ELBE -> electron LINAC (40 MeV and up to 40 kW) in Research Center Dresden-Rossendorf
- EPOS -> collaboration of Univ. Halle with FZD
- User-dedicated facility
- main features of MePS:
  - high-intensity bunched positron beam (E_+ = 0.5…30 keV)
  - Coincidence Lifetime & Coincidence Doppler Spectroscopy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




Cave 111b
Positron laboratory 111c
concrete wall (3.2m)
≈ 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
Wien filter
Faraday cup
magnetic monopol lense
drift path
sample
multi-detector system

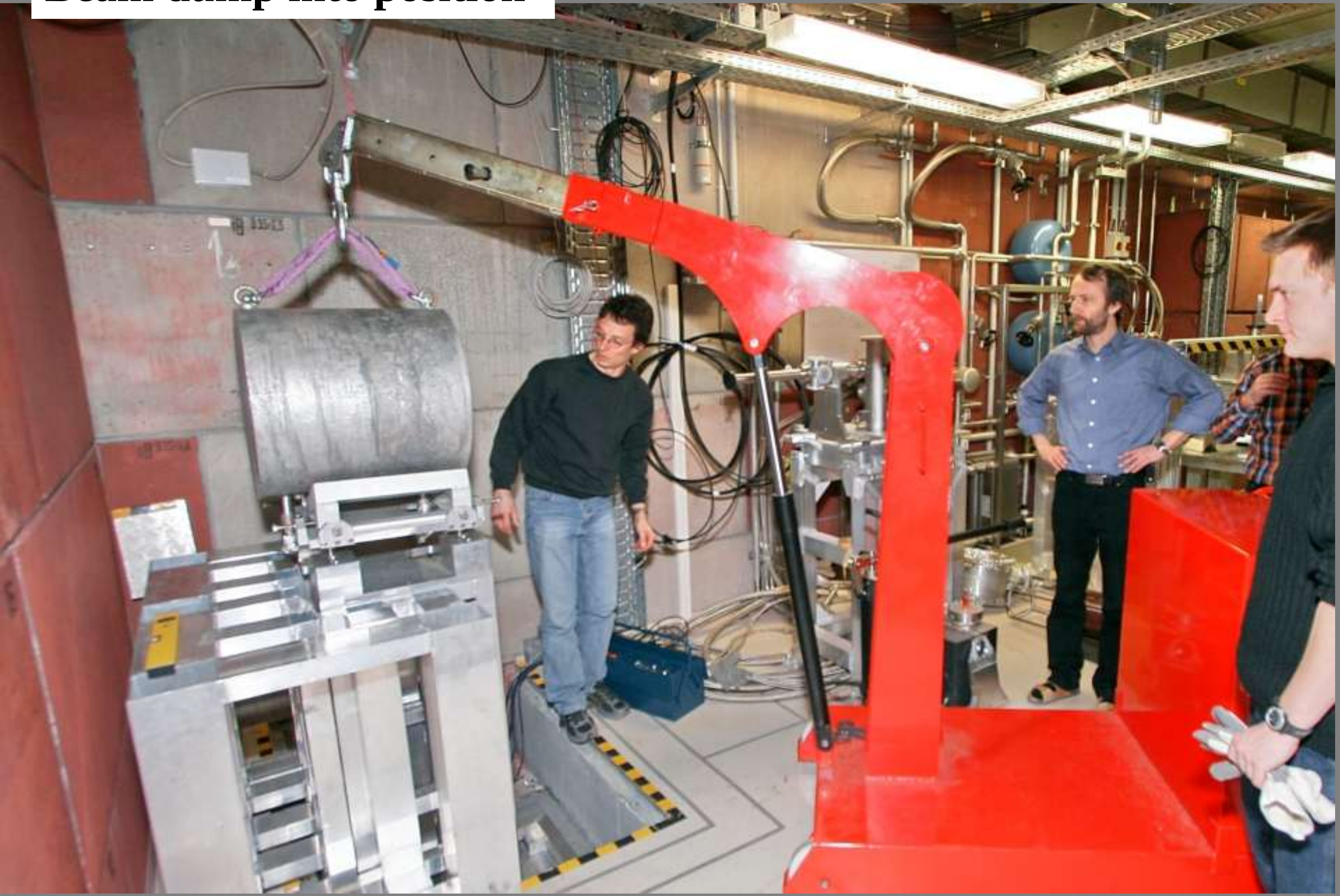

primary e-
pulse width
5 ps
77 ns
(adjustable)

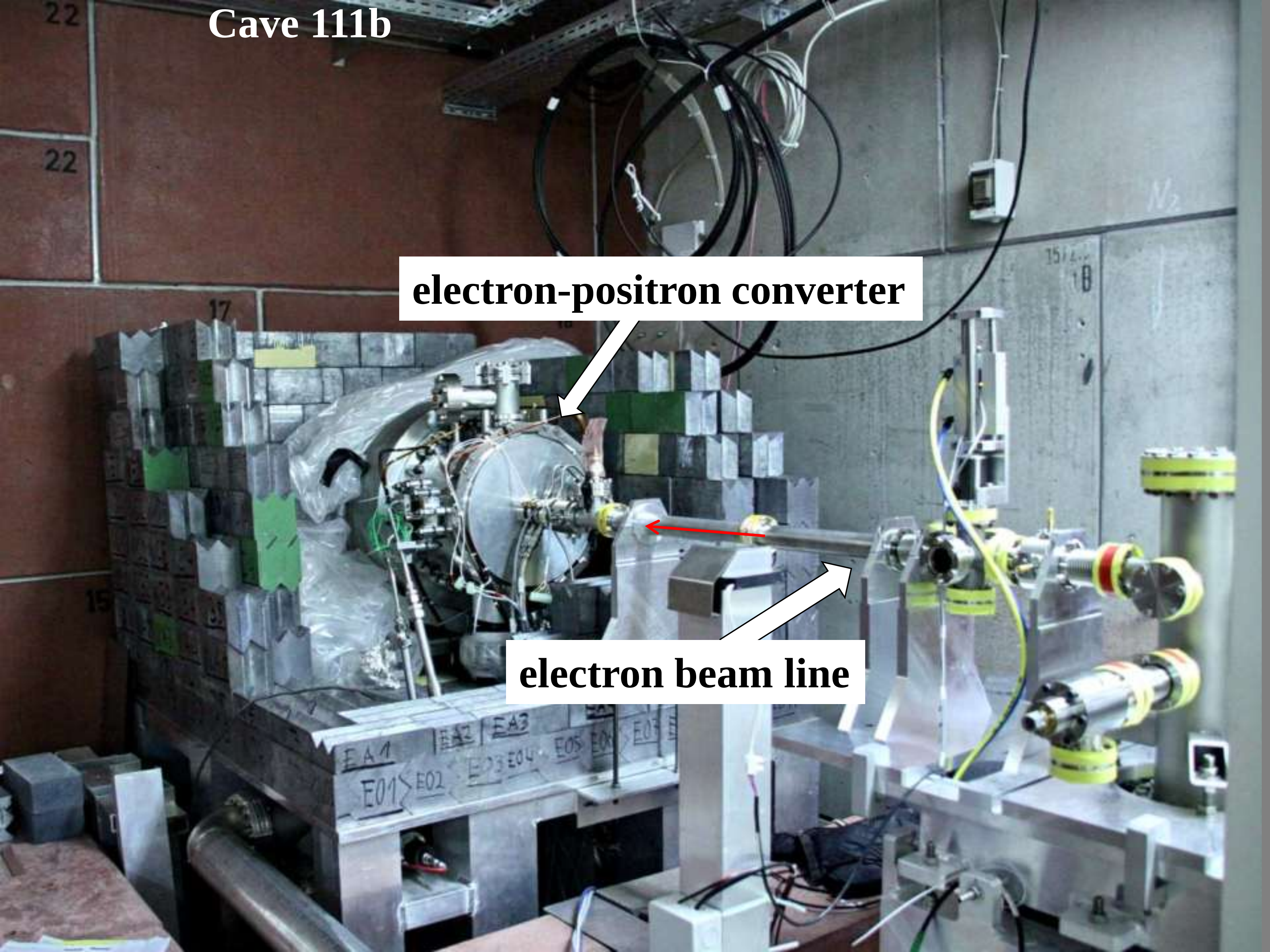
EPOS scheme

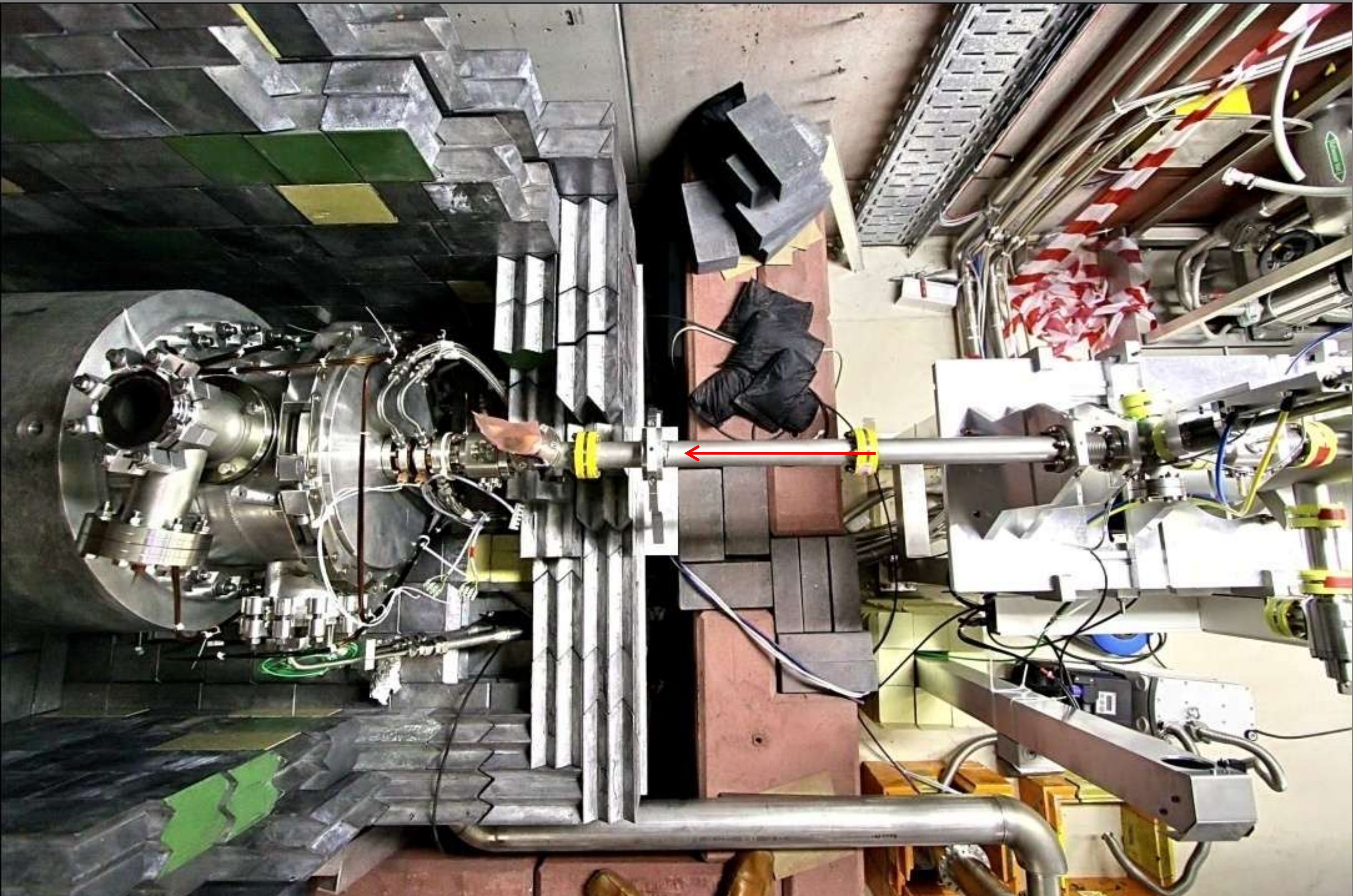

place for converter
water cooling station

Start of Mounting

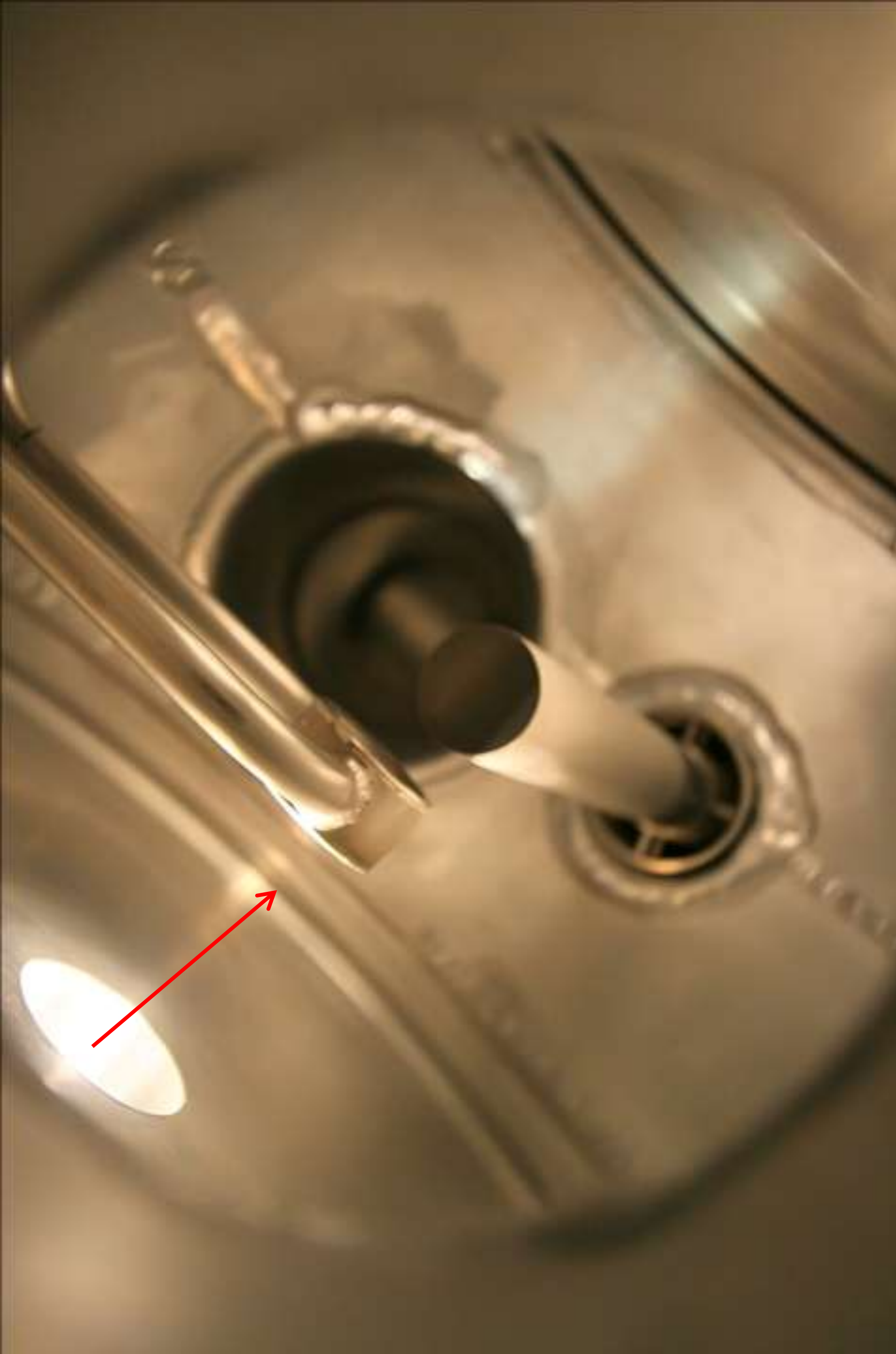
Beam dump into position

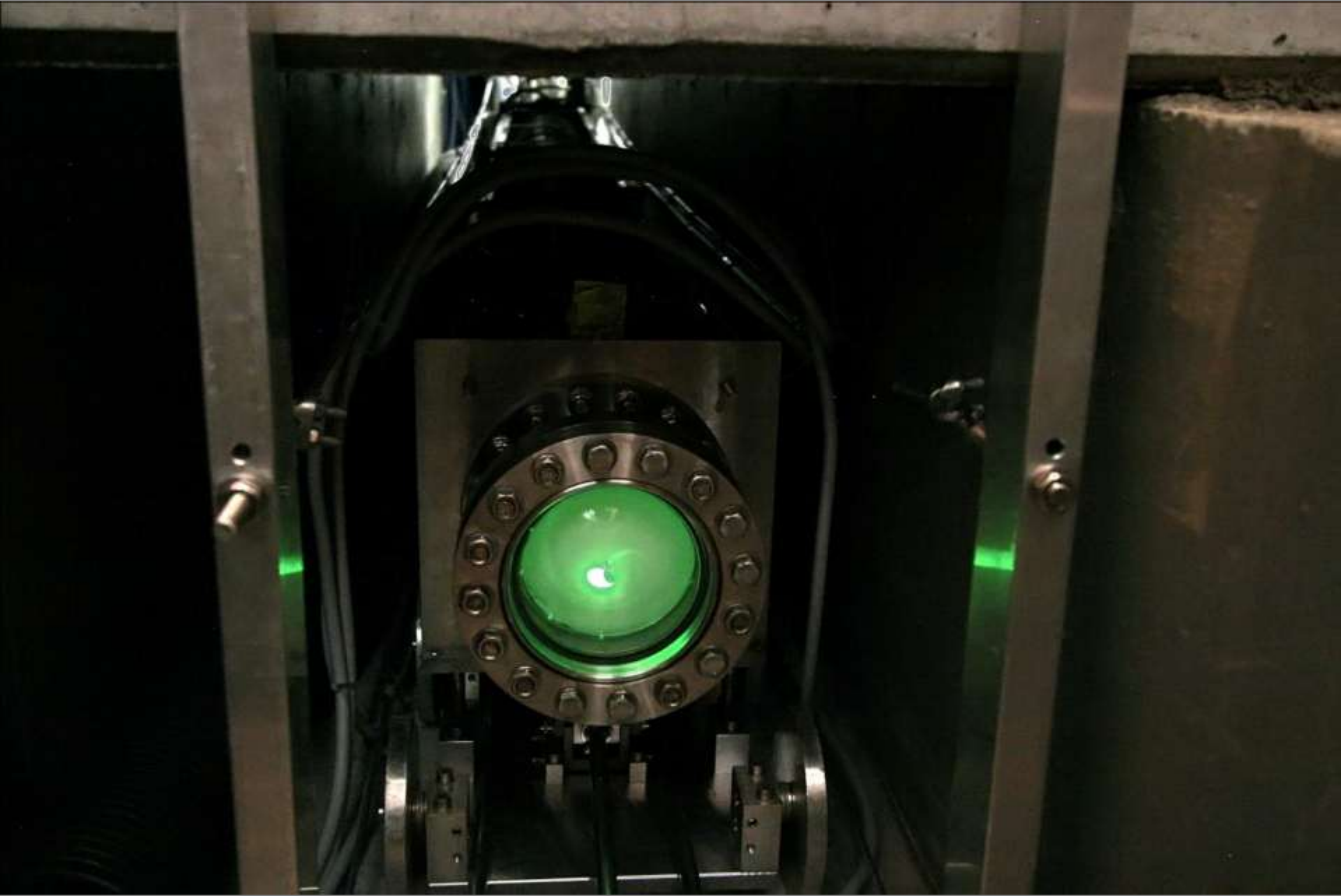


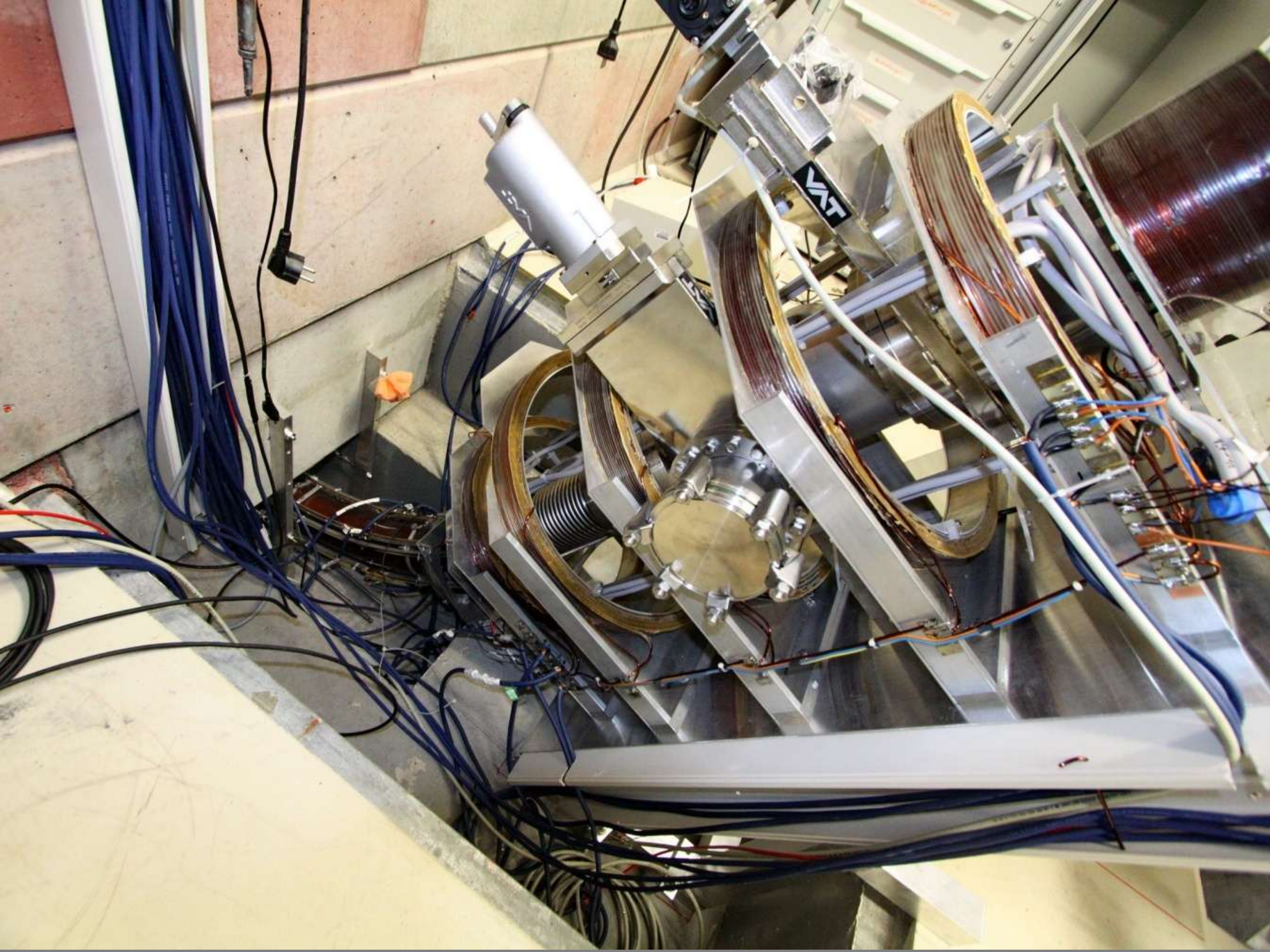

Cave 111b
electron-positron converter
electron beam line

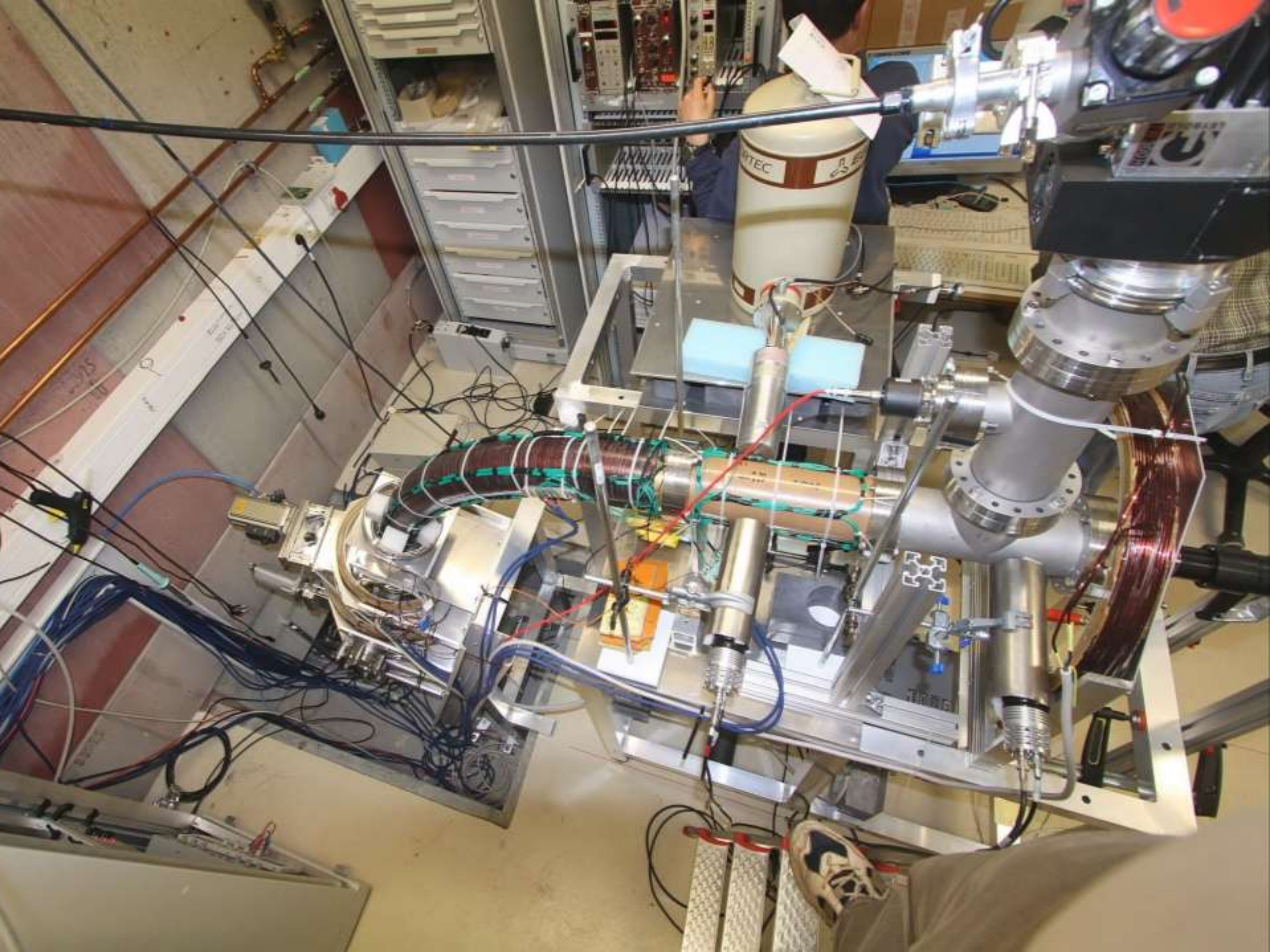


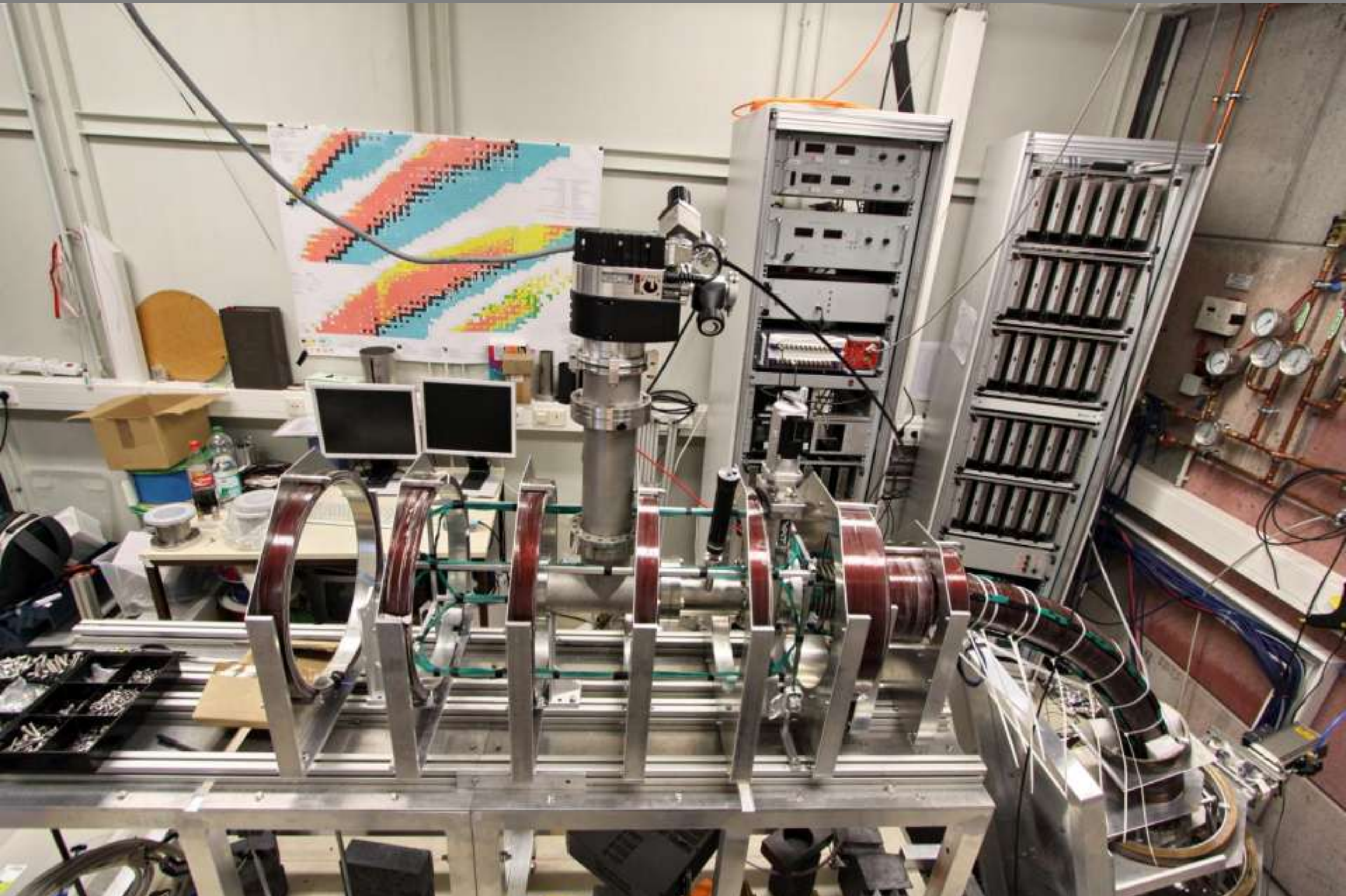

22
NH4
NH9
NE7
ND6




VAT

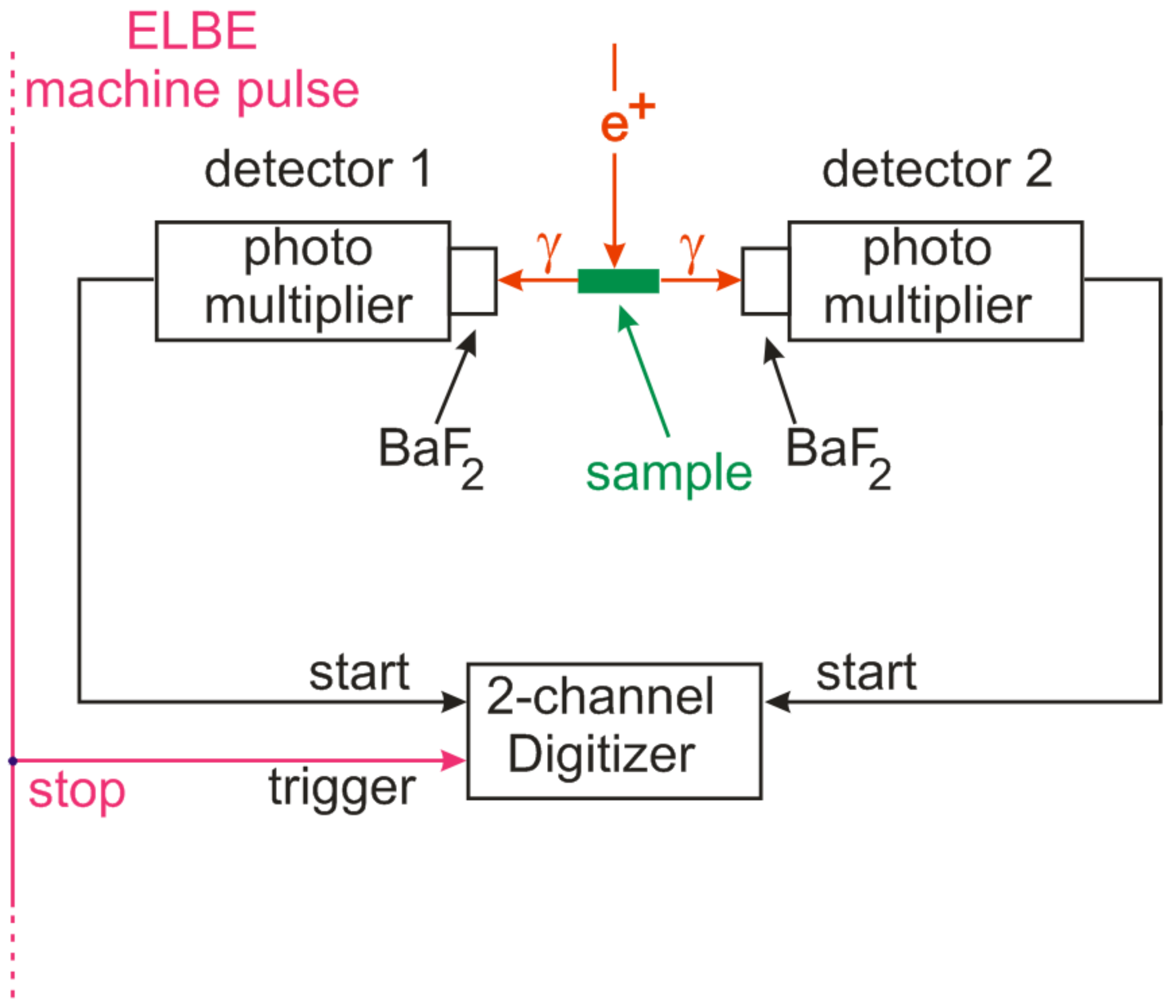




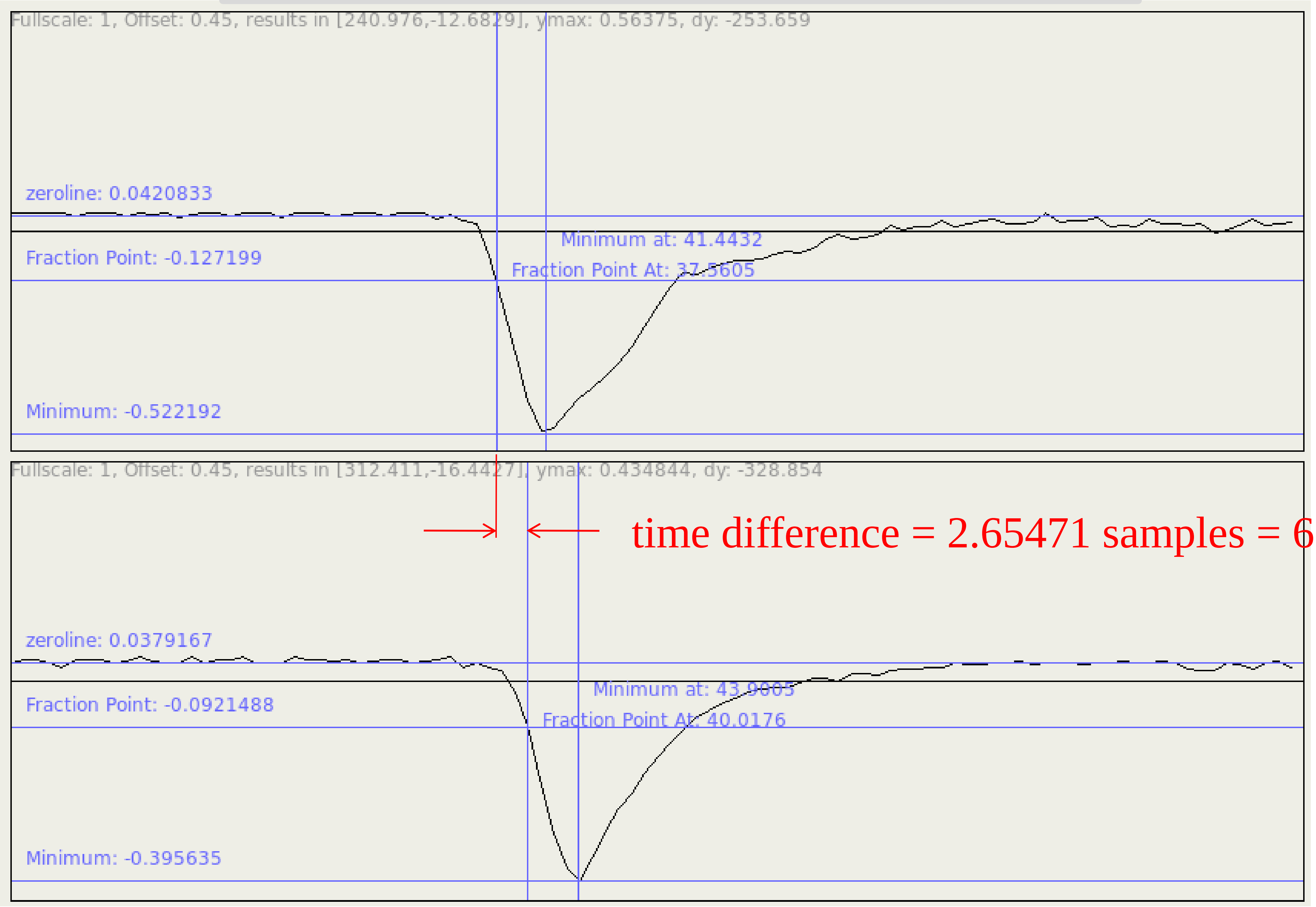

Ich bin

Digital lifetime measurement

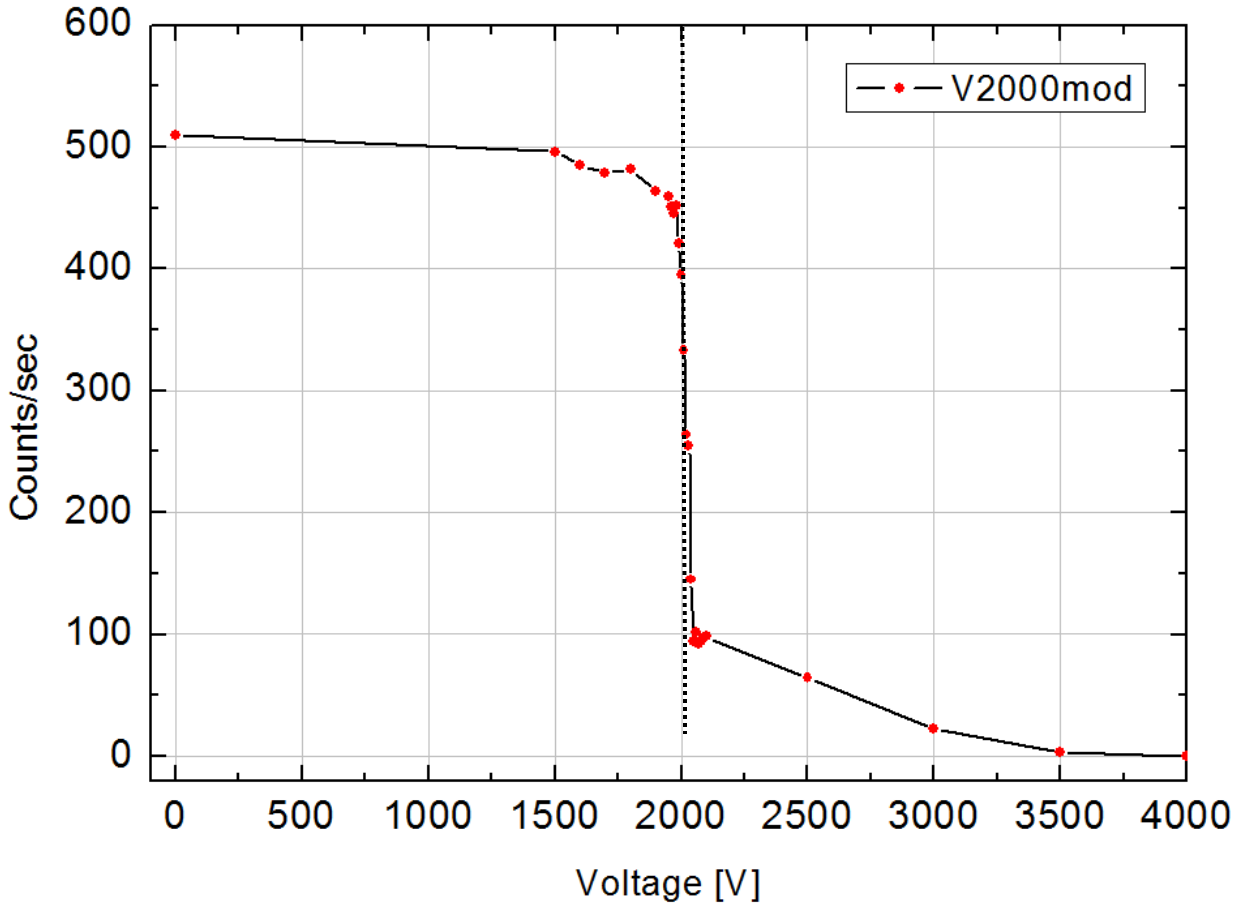
- much simpler setup
- nothing to adjust
- timing very accurate
- pulse-shape discrimination (suppress "bad pulses")
- same time scale for all detectors in a multi-detector setup



screenshot of two digitized anode pulses

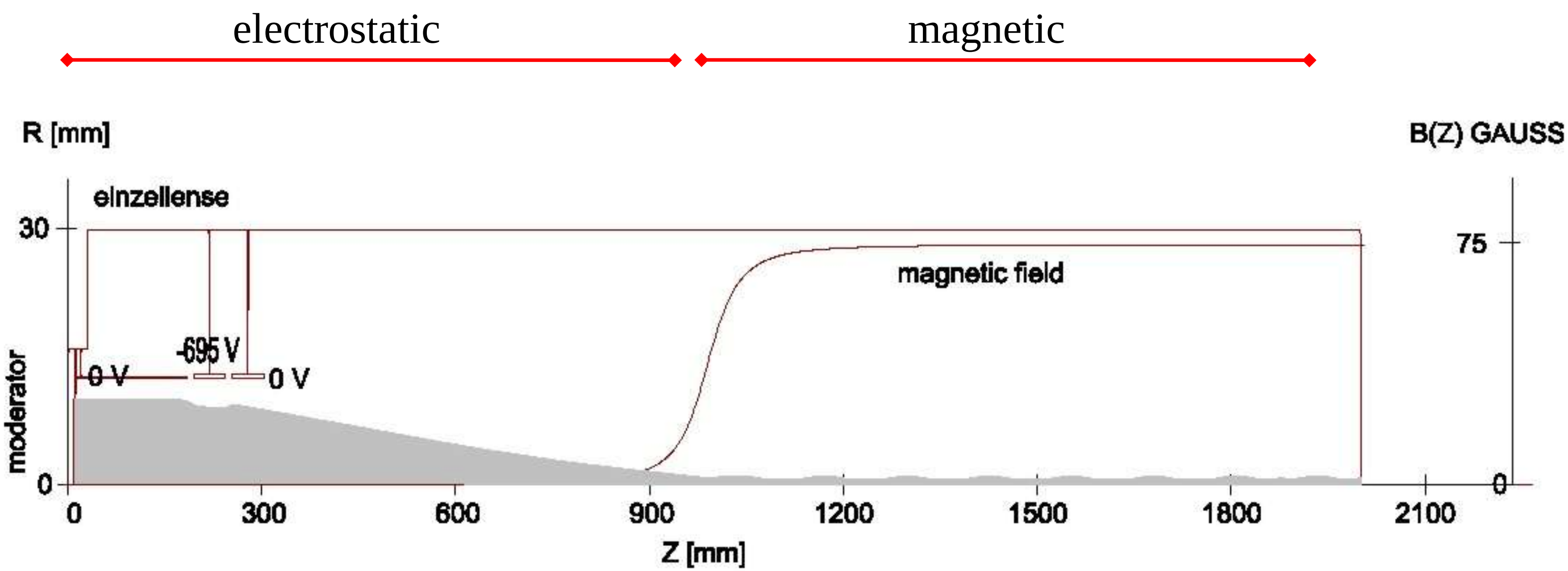


Energy spectrum: retarding field measurement



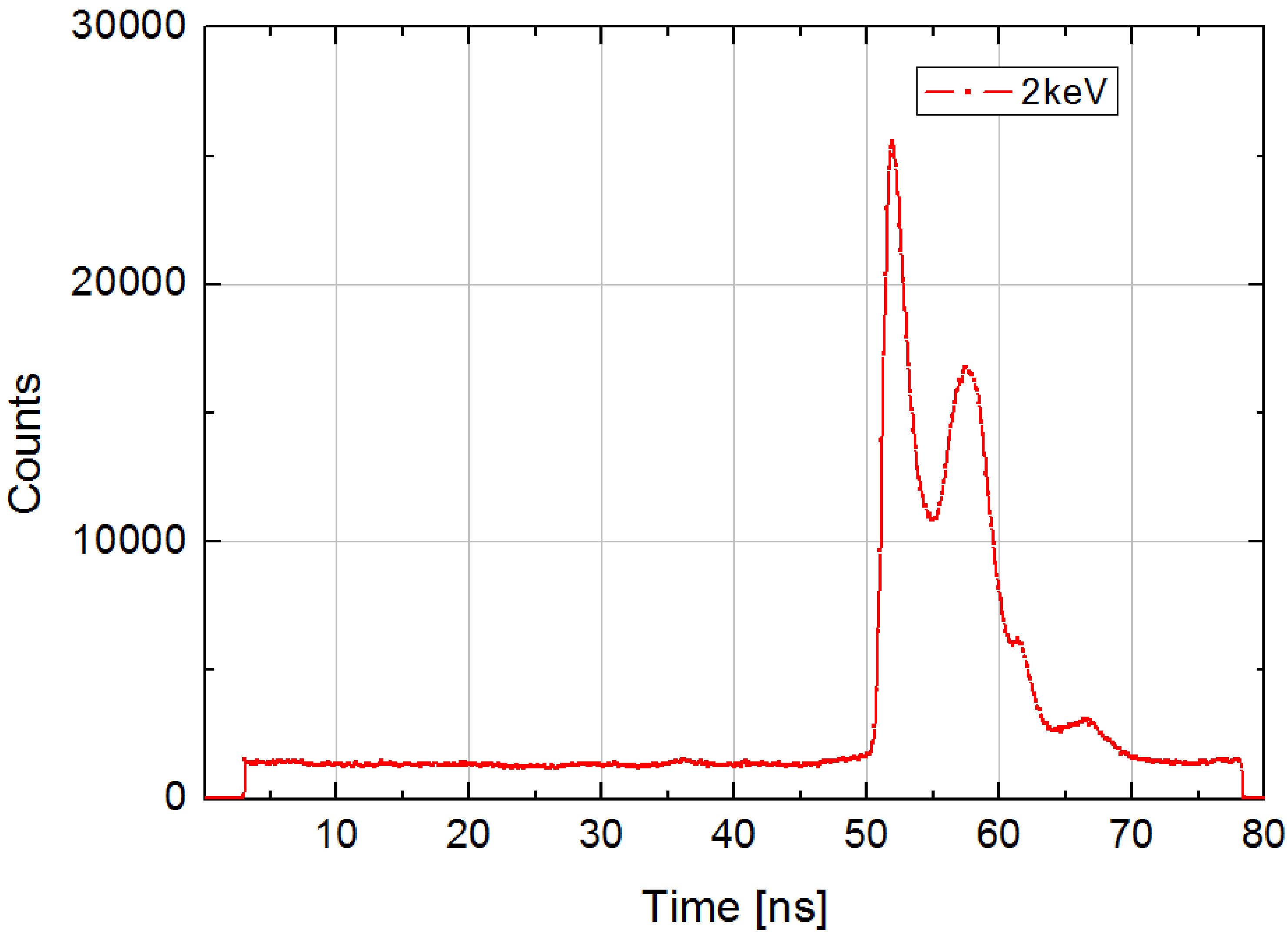
- sharp decrease at beam energy but still intensity with lower and higher energies

GiPS: Gamma-induced Positron Spectroscopy

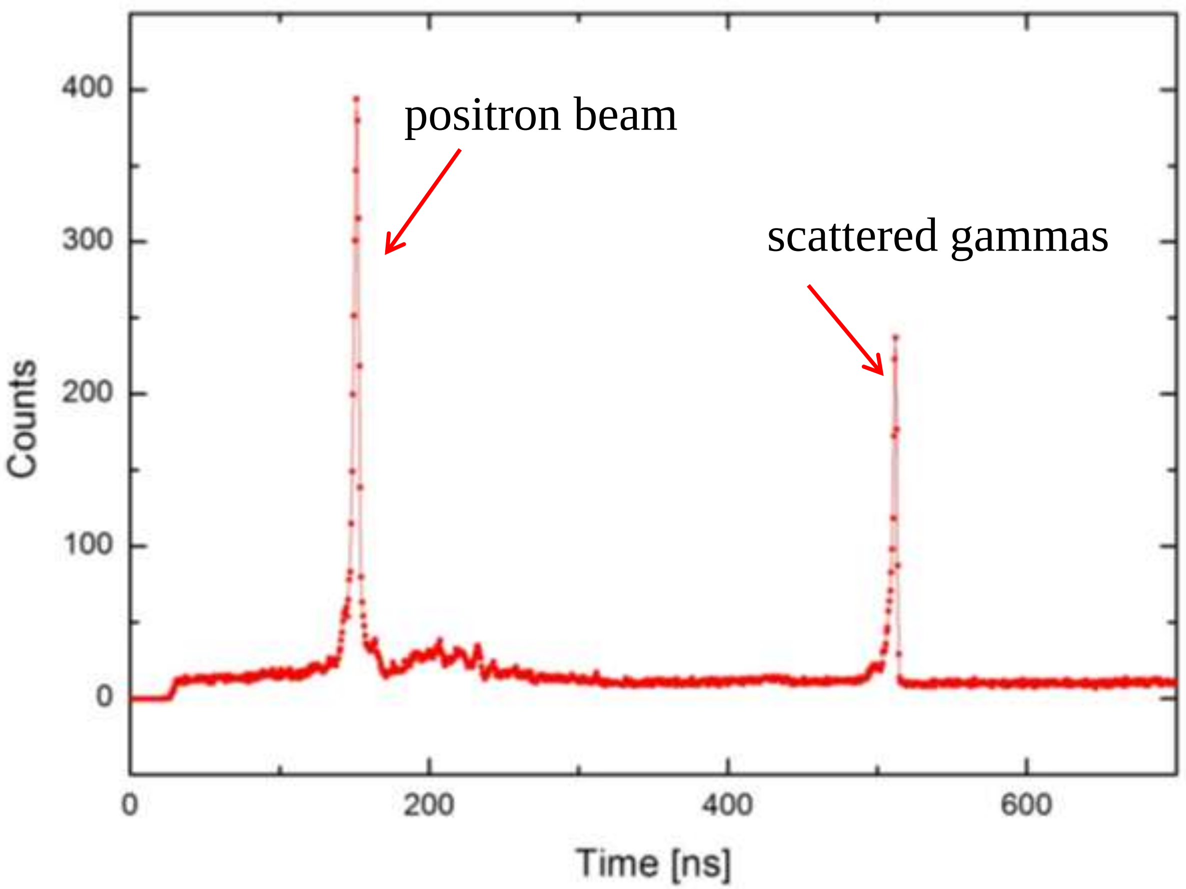


- positrons which are not well focused get transversal energy
- this is missing in transversal component: broad time structure
- this part must be filtered out
- realized by the three vacuum tube bends and a double aperture

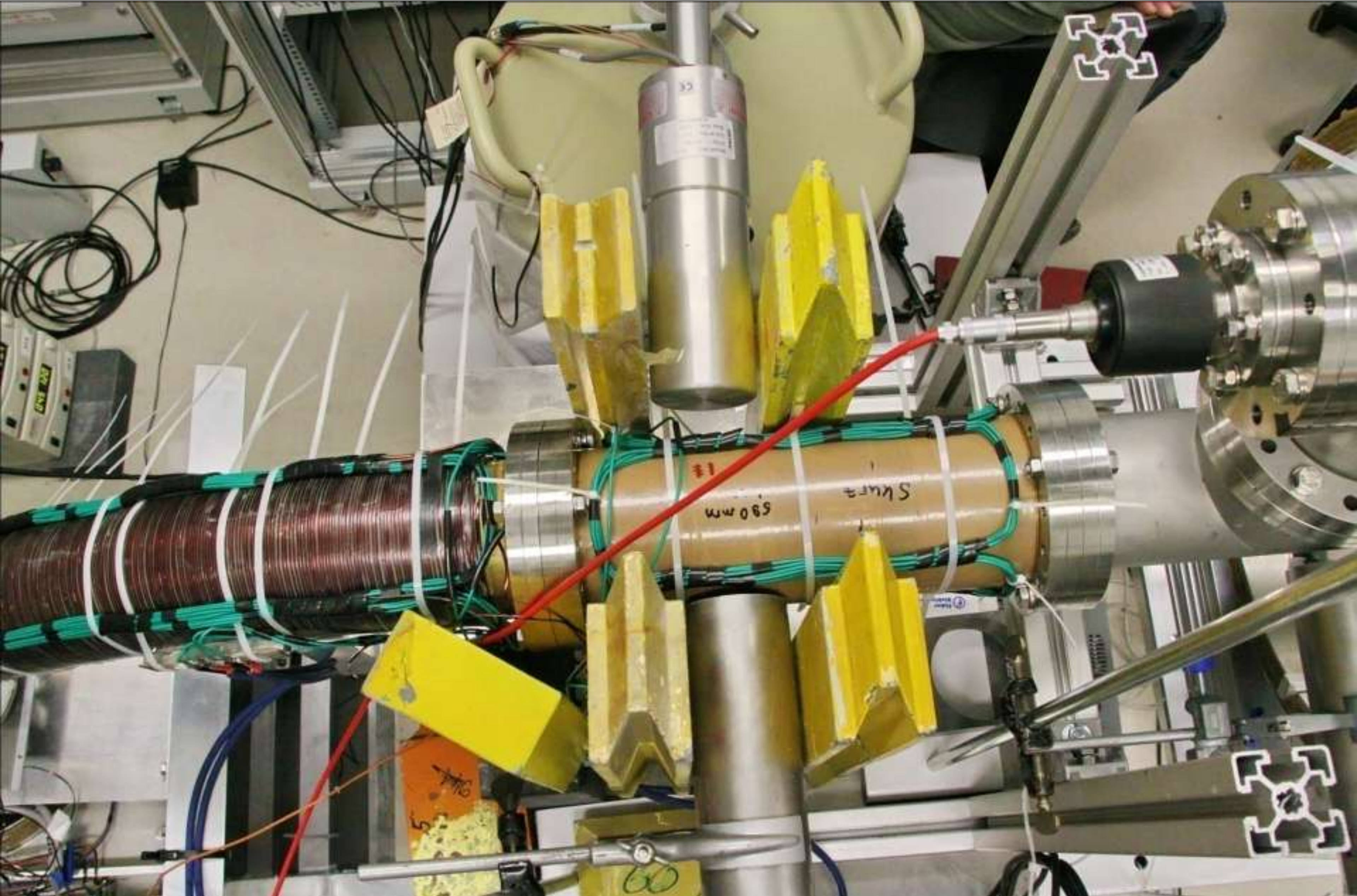
Time structure without lens and energy filtering



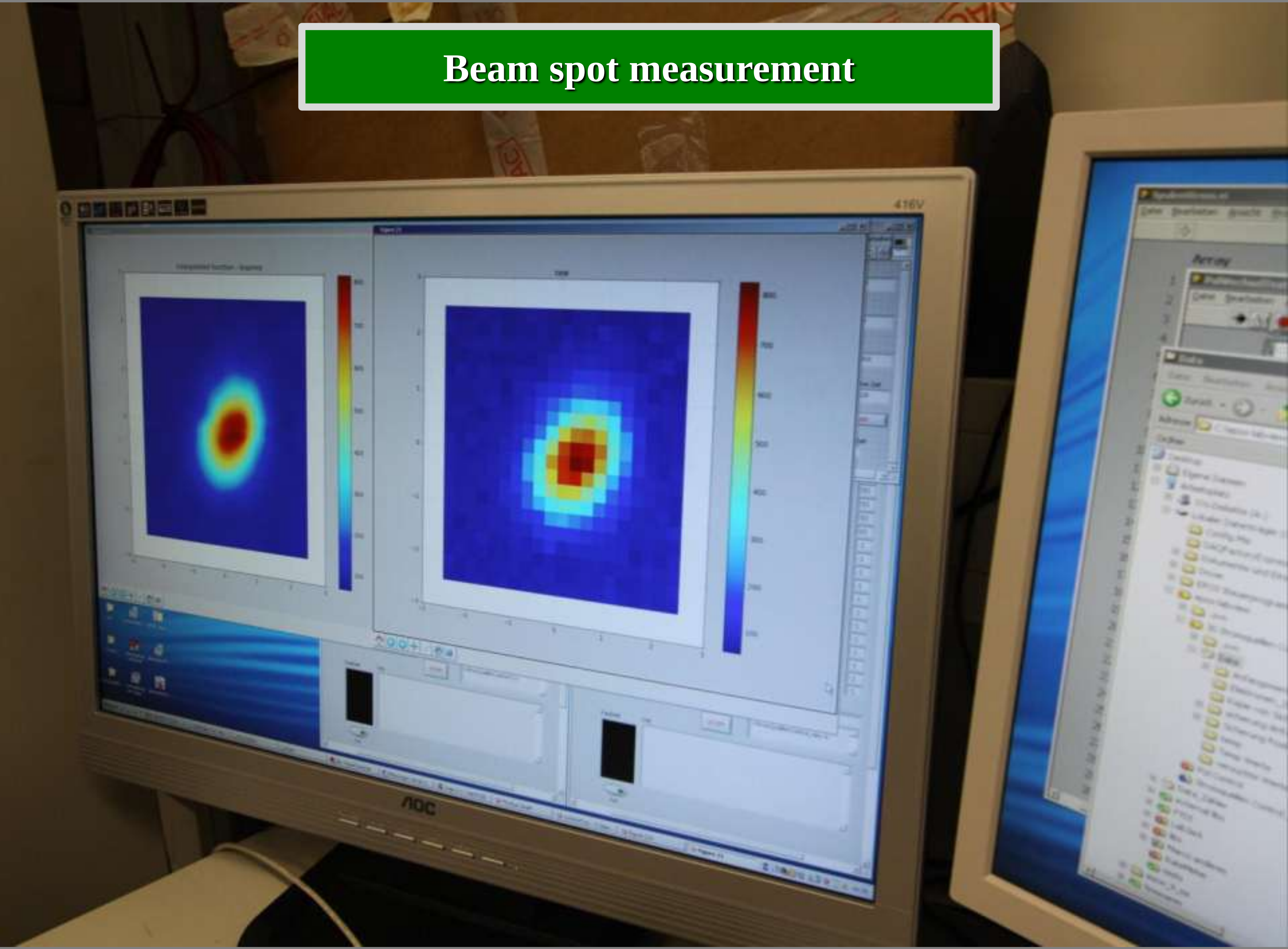
Another unwanted peak: scattered gammas through cable tunnel

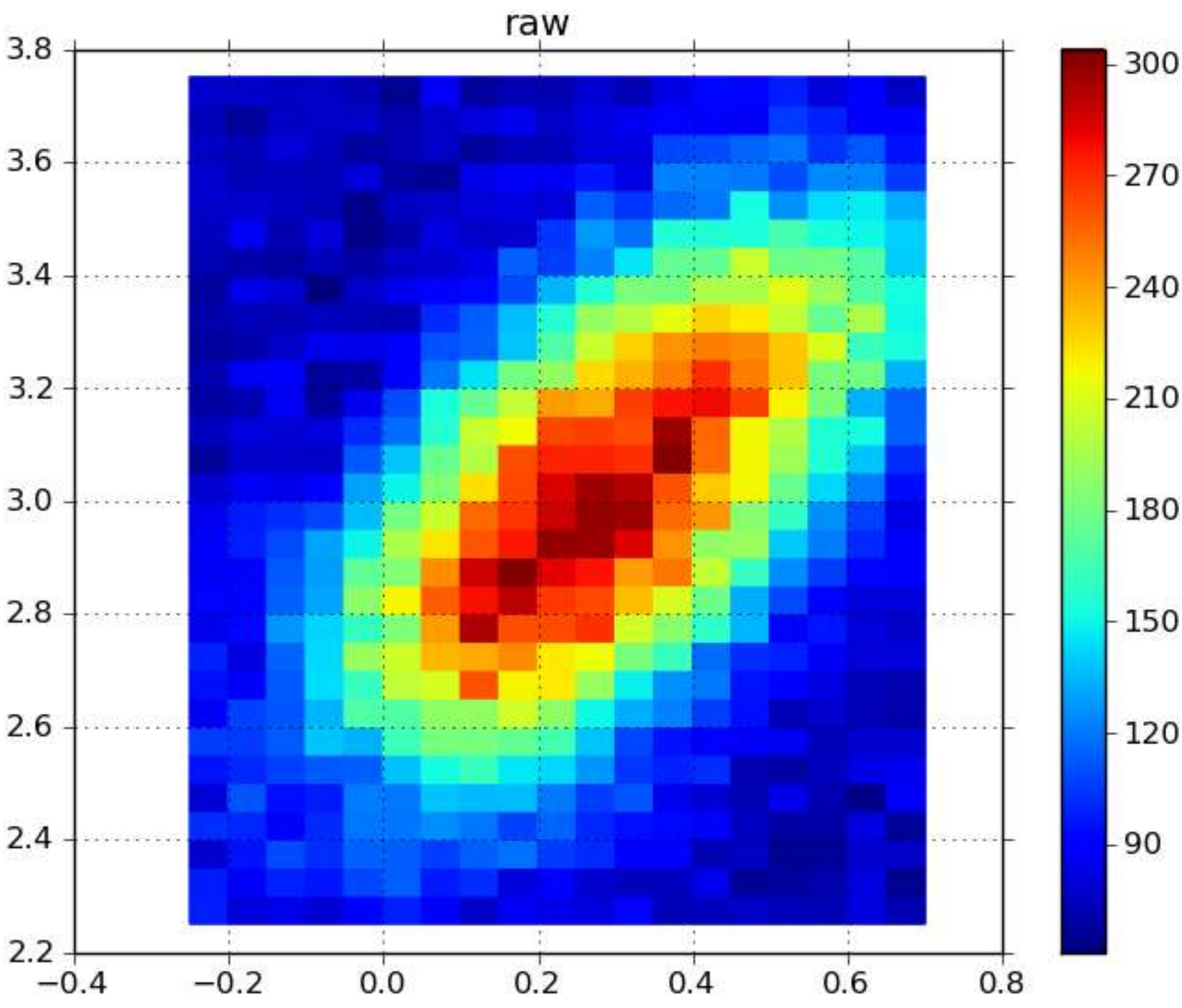


- additional peak is due to scattered gammas which came through cable tunnel
- additional screening solved the problem



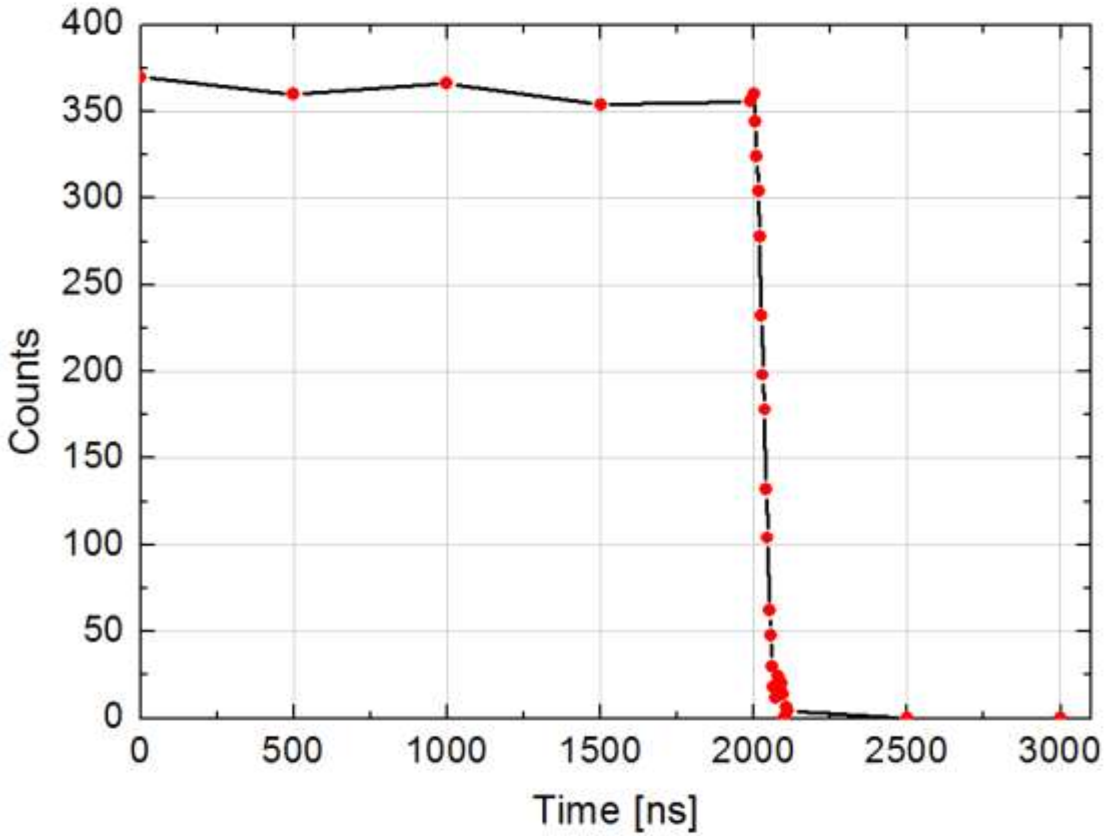
Beam spot measurement





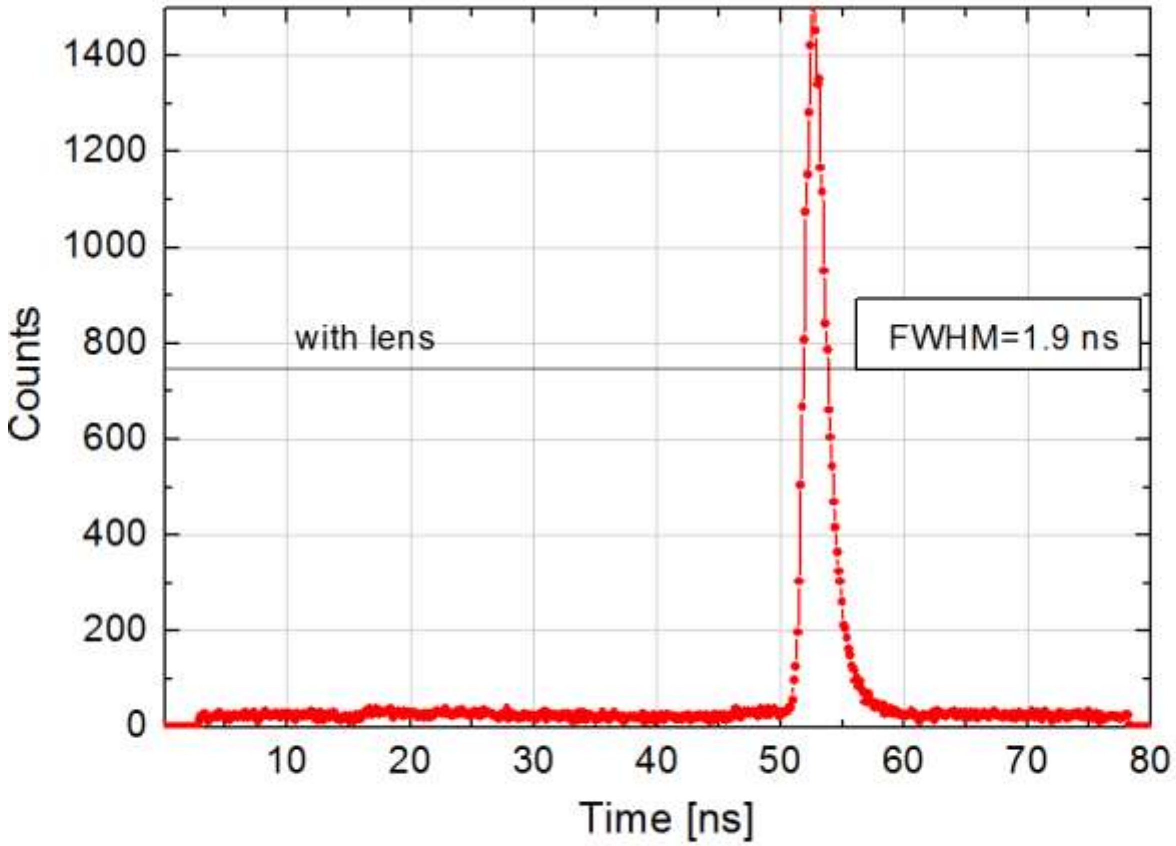
raw
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
300
270
240
210
180
150
120
90

Energy filtering by a double aperture



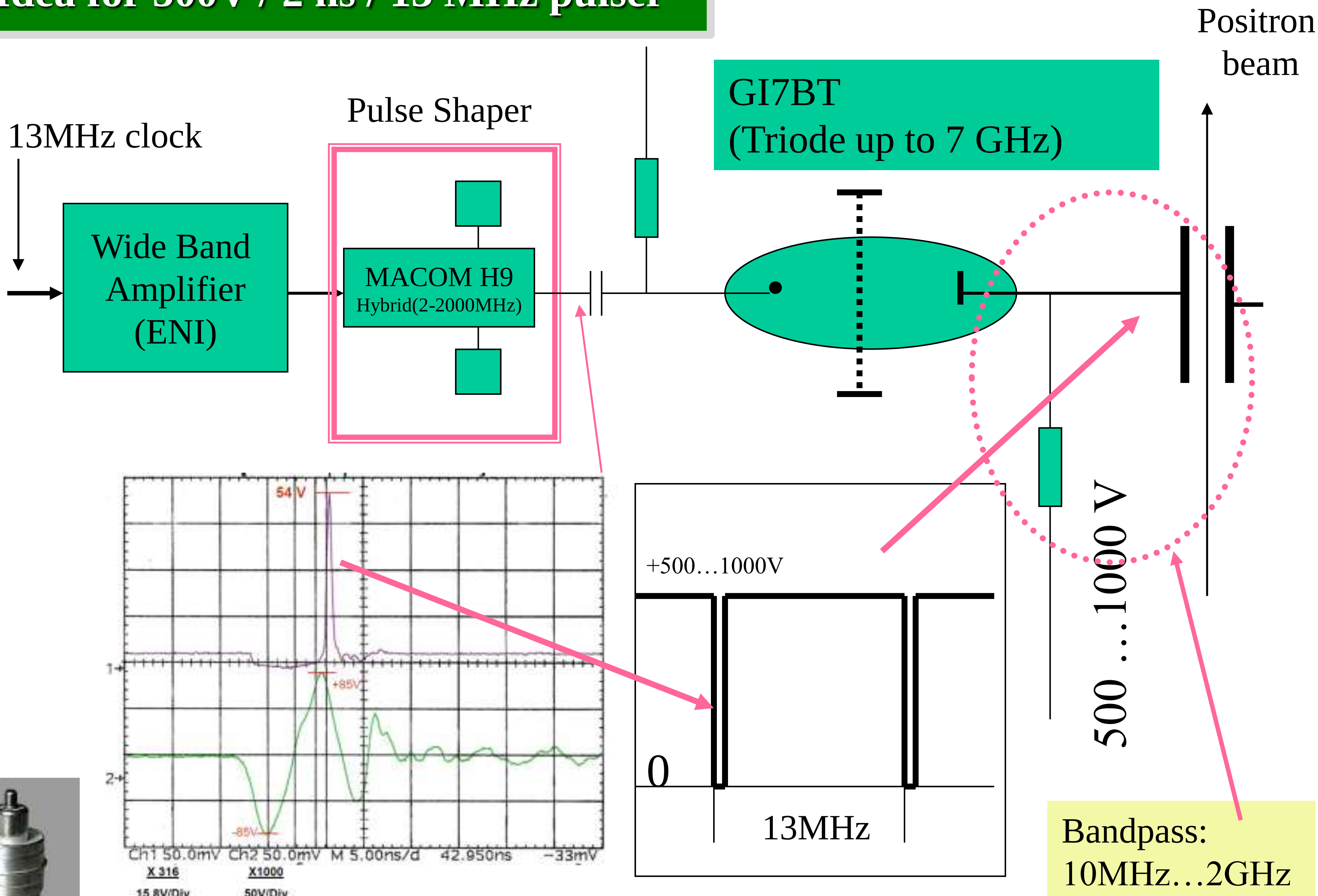
- electrostatic lens in action
- 2 apertures of 5mm were mounted in a distance of half a gyration length (63 mm)

GiPS: Gamma-induced Positron Spectroscopy



- using the double aperture: time structure very useful and according to former simulation
- problem: Chopper signal must be 2 ns / >500V / 13 MHz repetition frequency
- very difficult to do with semiconductor amplifiers

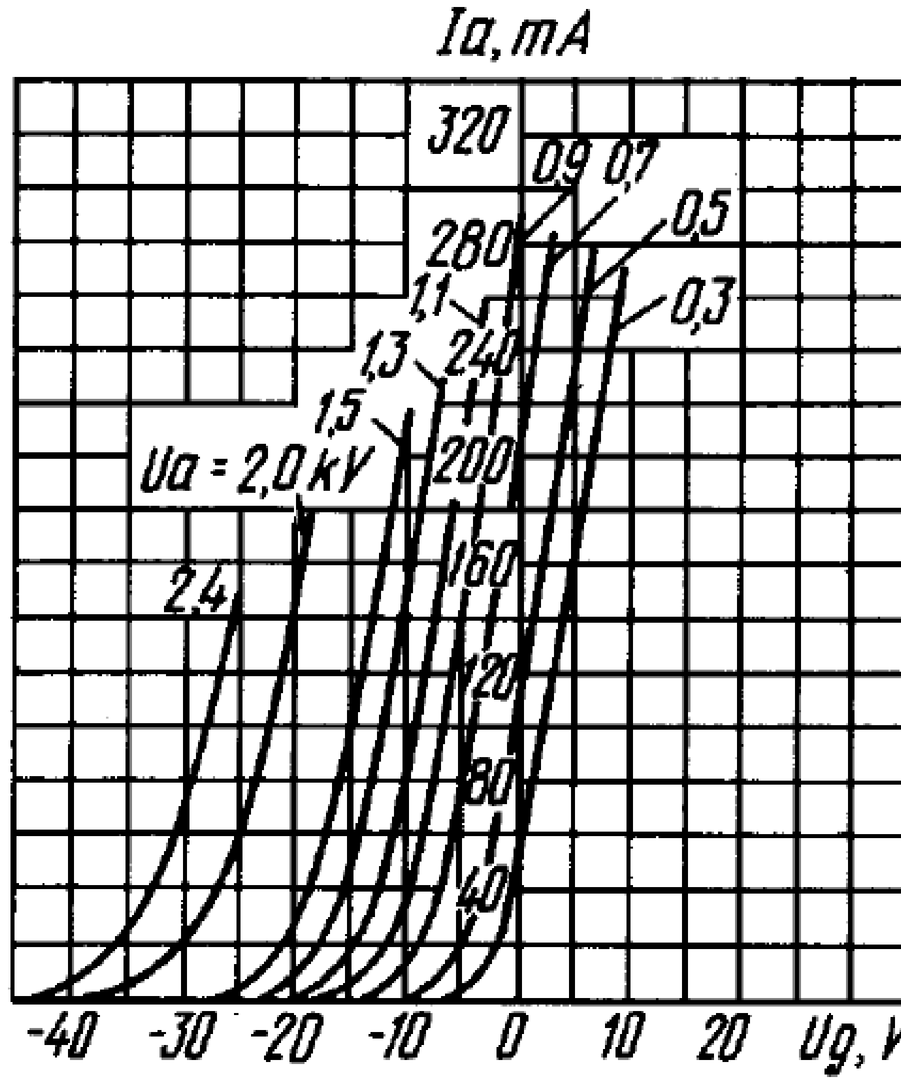
Idea for 500V / 2 ns / 13 MHz pulser



scheme by Hartmut Büttig, FZD

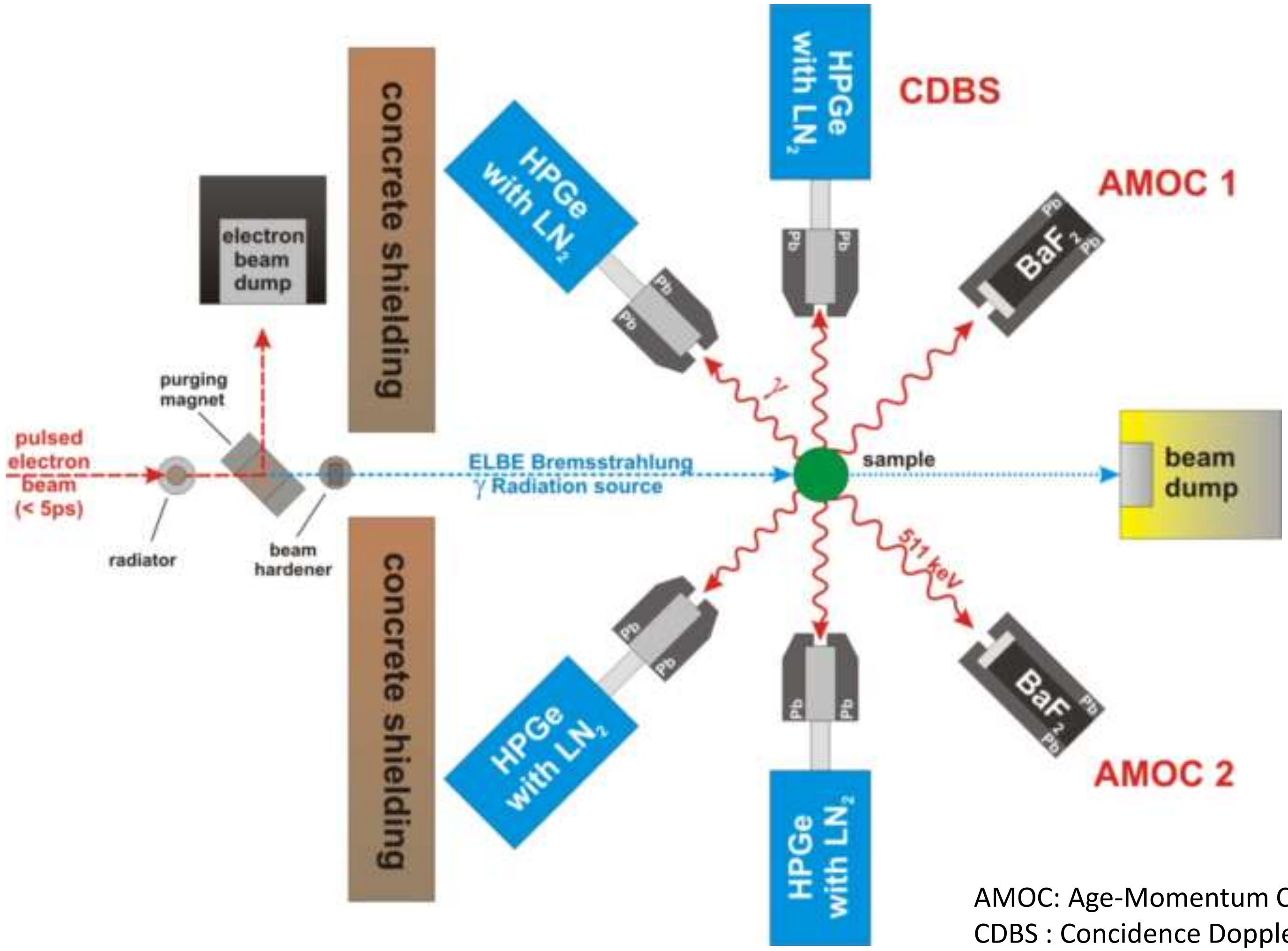
Idea for 500V / 2 ns / 13 MHz pulse generator

- GI7BT is a Russian military radar pulse tube
- up to 7 GHz / 350 W
- Anode capacity ≈ 5 pF
- I = 7.5 A (in pulse mode)



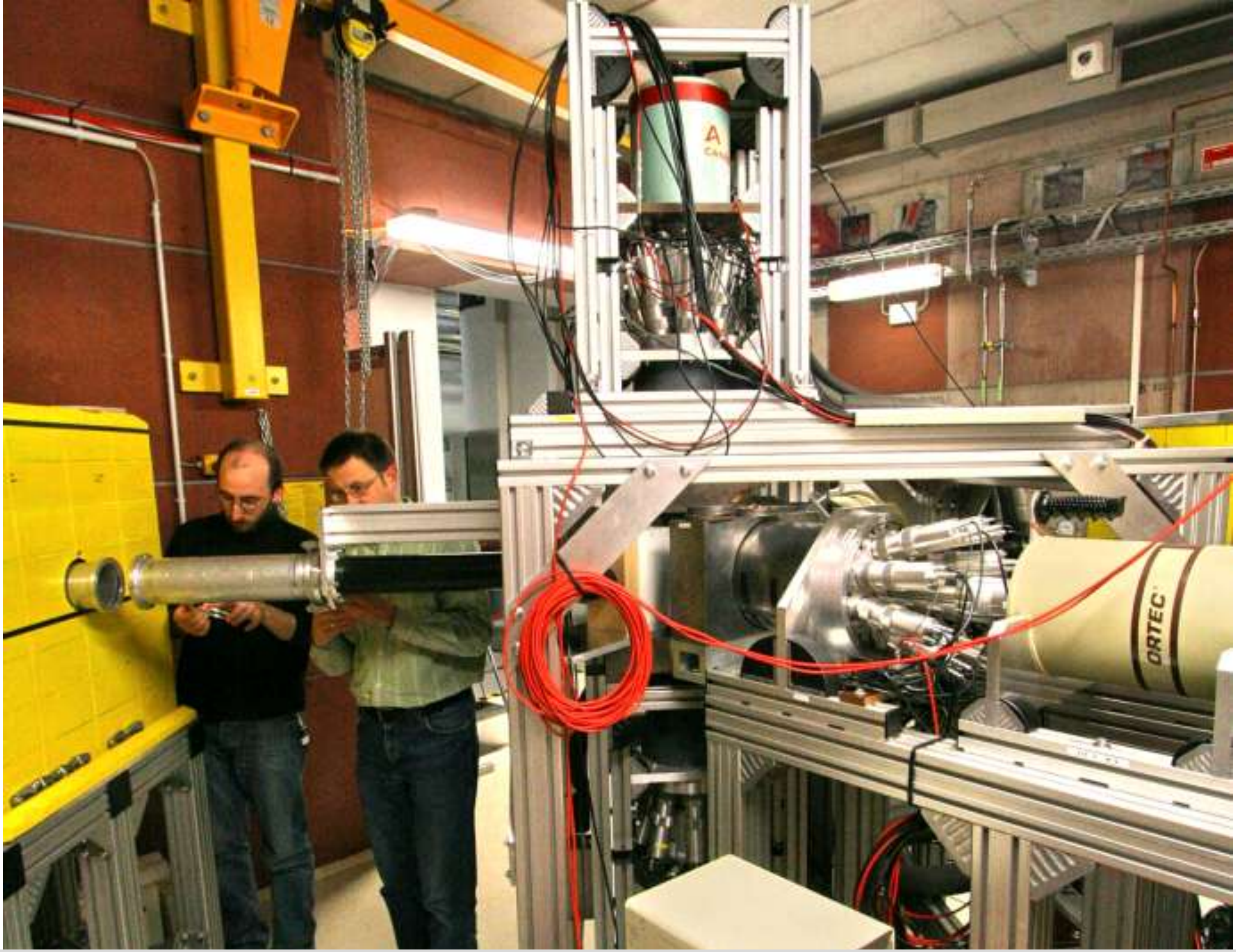
Averaged Anode-Grid Characteristic Curves:
U_f = 12.6 V

GiPS: Gamma-induced Positron Spectroscopy



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

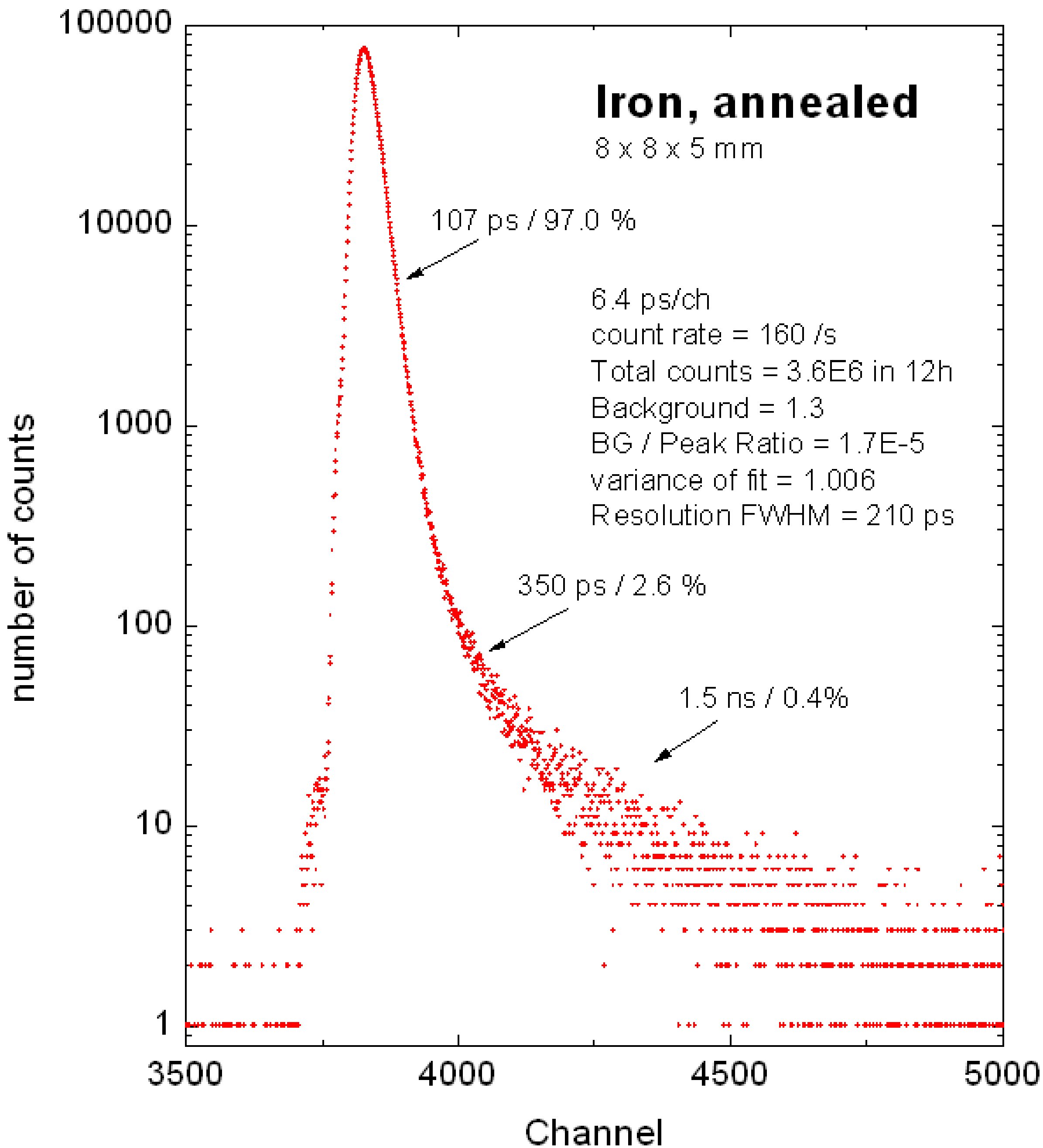
- 3 coincident setups are used: 2 AMOC and 1 CDBS spectrometer
- only coincident detection ensures high spectra quality



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

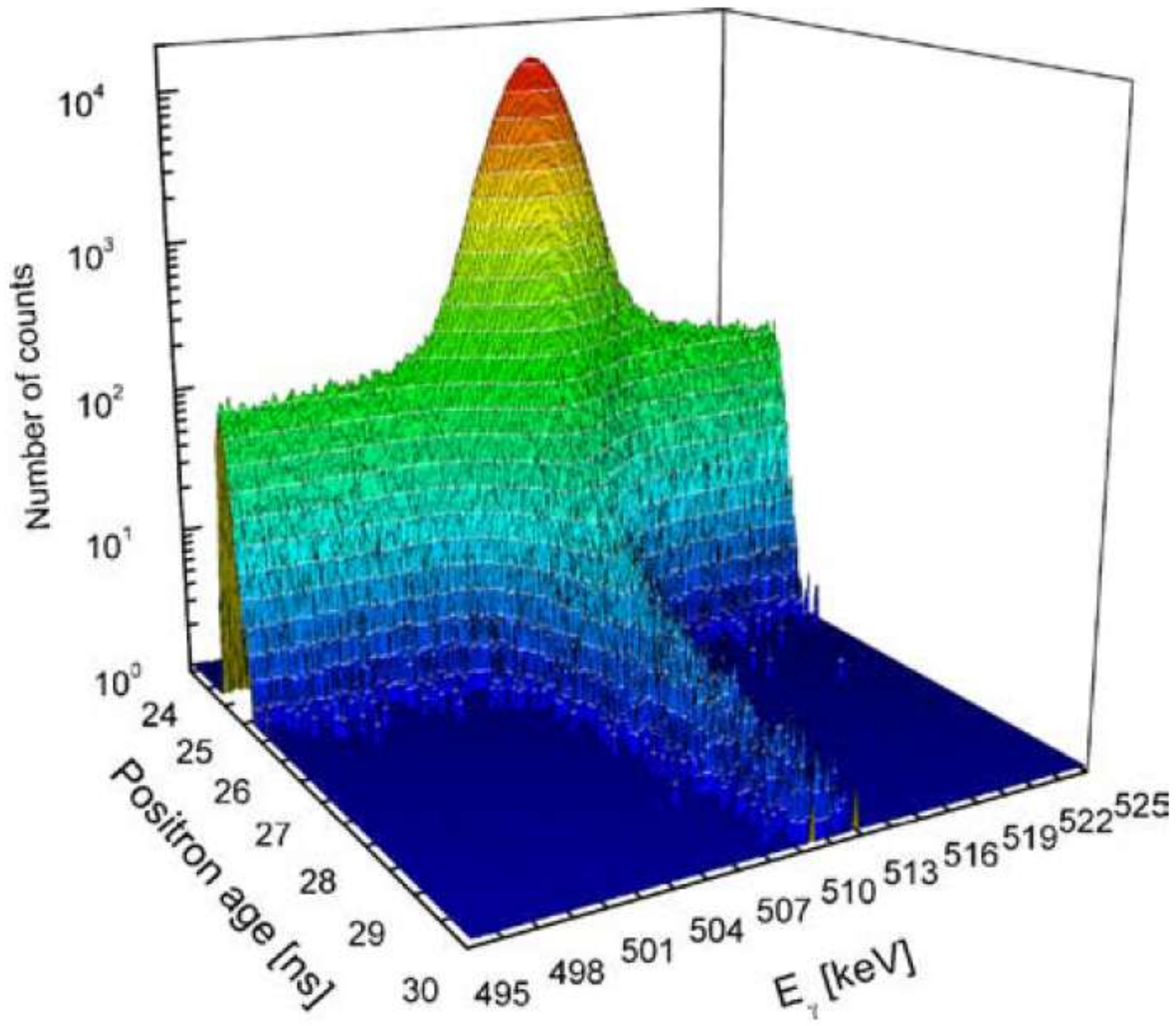
Coincident lifetime spectrum: annealed Fe

- here coincidence with Ge detector
- spectrum is projection to the time scale of AMOC spectrum
- Count rate for AMOC spectrum = 320 /s
- One spectrum in 2h
- Time resolution = 210 ps
- BG/Peak = 1.7 x 10-5
- 350 ps & 1.5 ns: annihilation at vacuum tube (polyethylene)



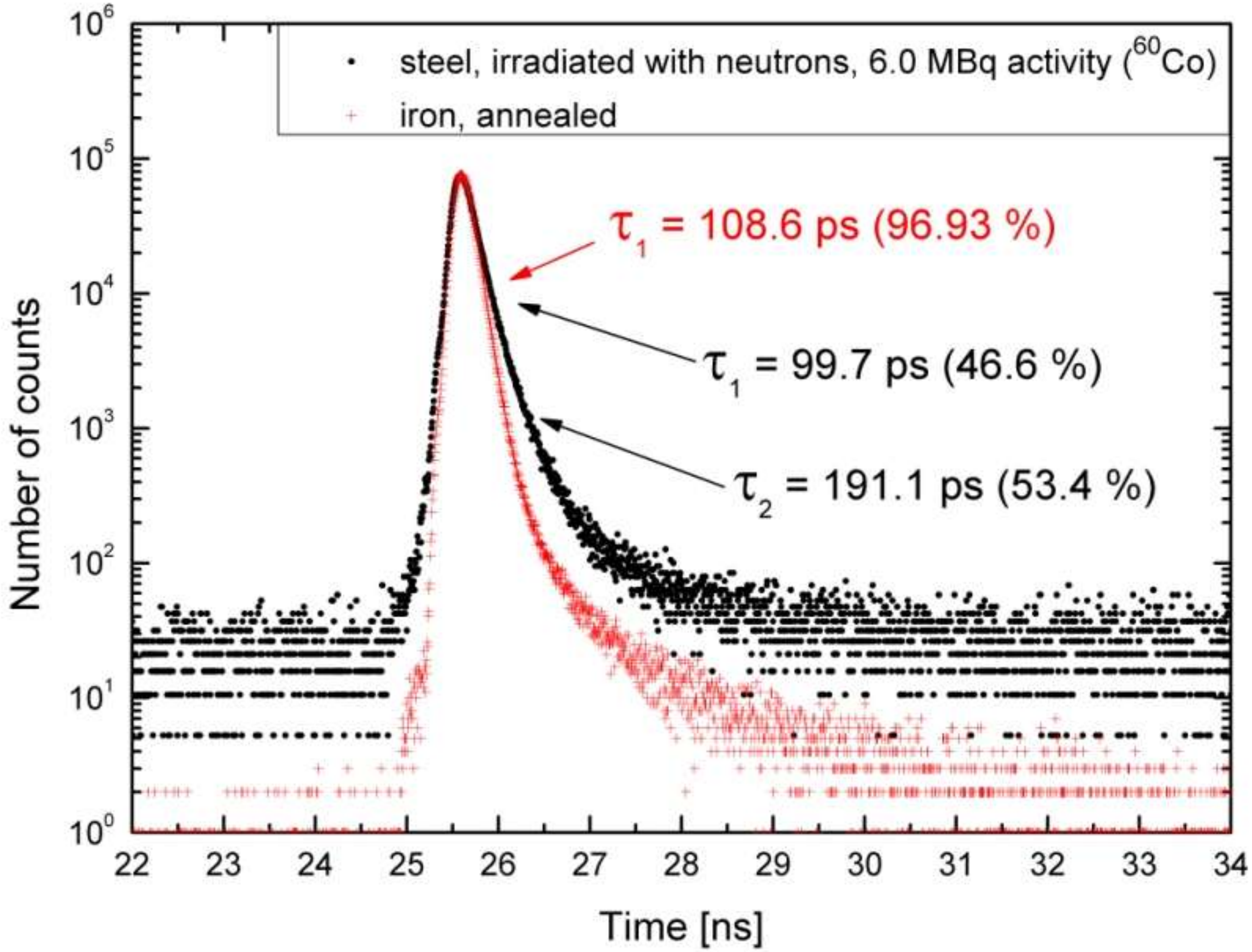
Corresponding AMOC Spectrum of Fe

- all lifetime spectra are measured as AMOC spectra
- are projections along the momentum axis



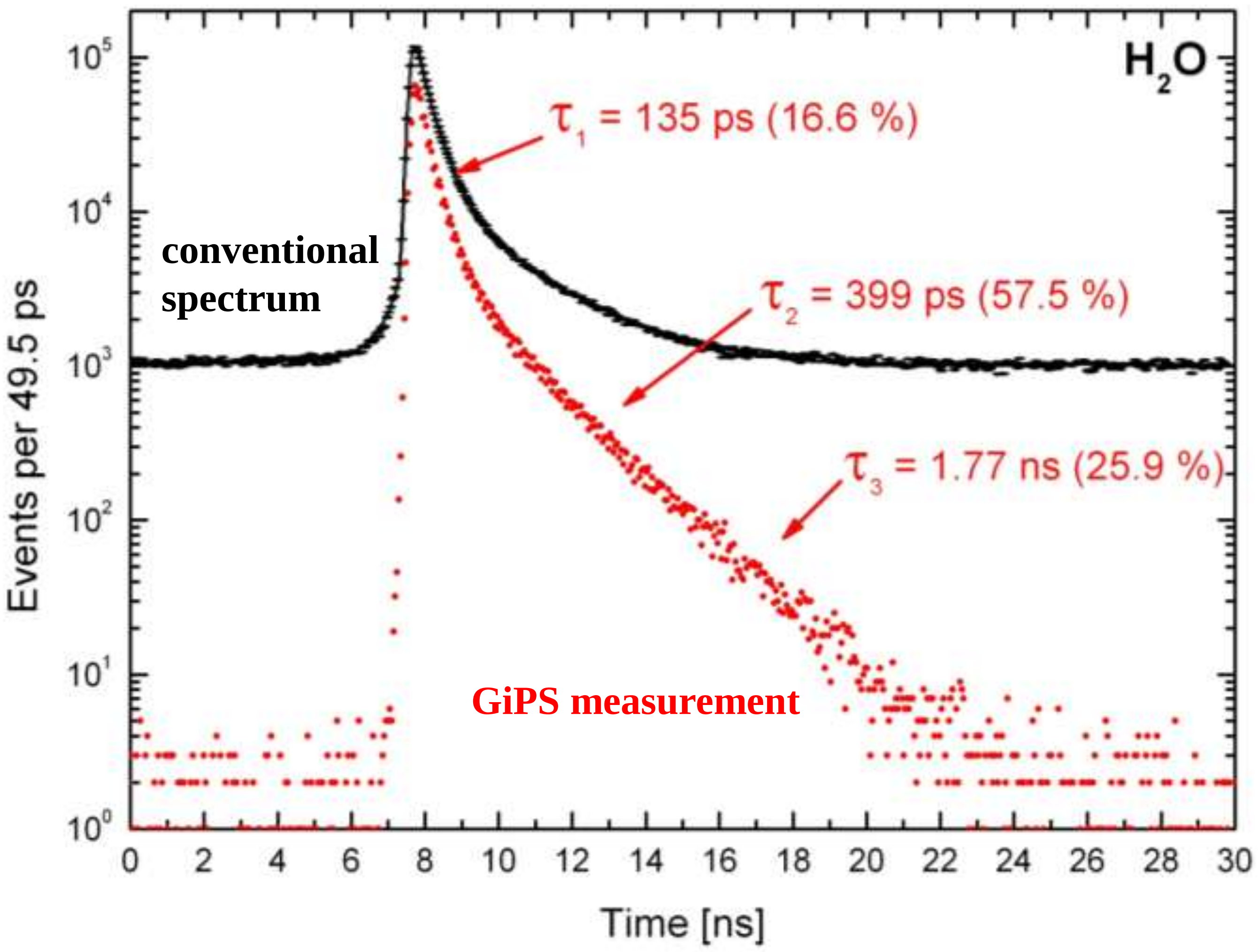
Activated Steel

- Reactor Pressure Vessel Steel
- neutron activated by ^{60}Co up to 30 MBq ≈ 1 mCi (acc. to 1.5 dpa)



Example: Water at RT

- total count rate in spectrum: $12x10^6$



- 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 30 MBq acc. to 1.5 dpa)
- 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

You can also apply for your own beam time in the web-based user application interface

Conclusions

- superconducting LINACs with high repetitions rates are ideal hosts for intense and bunched positron sources
  - very easy setup: superconducting Photo-Gun
- Gamma-induced Positron Spectroscopy only possible this way
- pulsed VEPAS very easy: preserve time structure of original beam

Thank you for your attention!

This presentation can be found as pdf-file on our Website:
http://positron.physik.uni-halle.de