Positron annihilation studies using the superconducting electron LINAC ELBE @ HZDR

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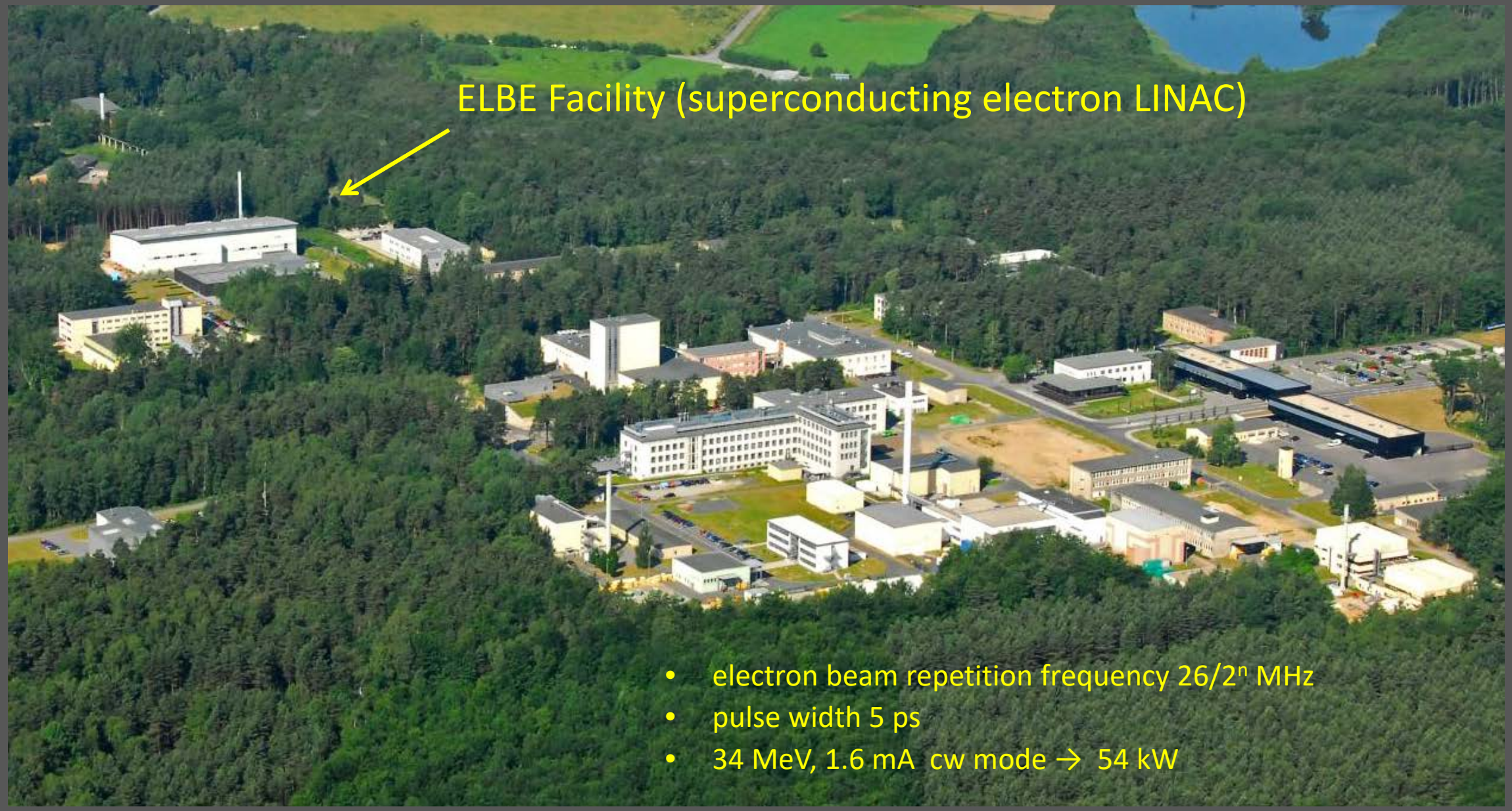
Halle-Wittenberg

- ELBE = Electron LINAC with high Brilliance and low Emittance
- MePS = Mono-energetic Positron source
- GiPS = Gamma-induced Positron Source
- User-dedicated Positron Facilities in Germany (FRM-II & ELBE)

HZDR = Helmholtz Zentrum Dresden-Rossendorf



- electron beam repetition frequency $26/2^n$ MHz
- pulse width 5 ps
- 34 MeV, 1.6 mA cw mode → 54 kW

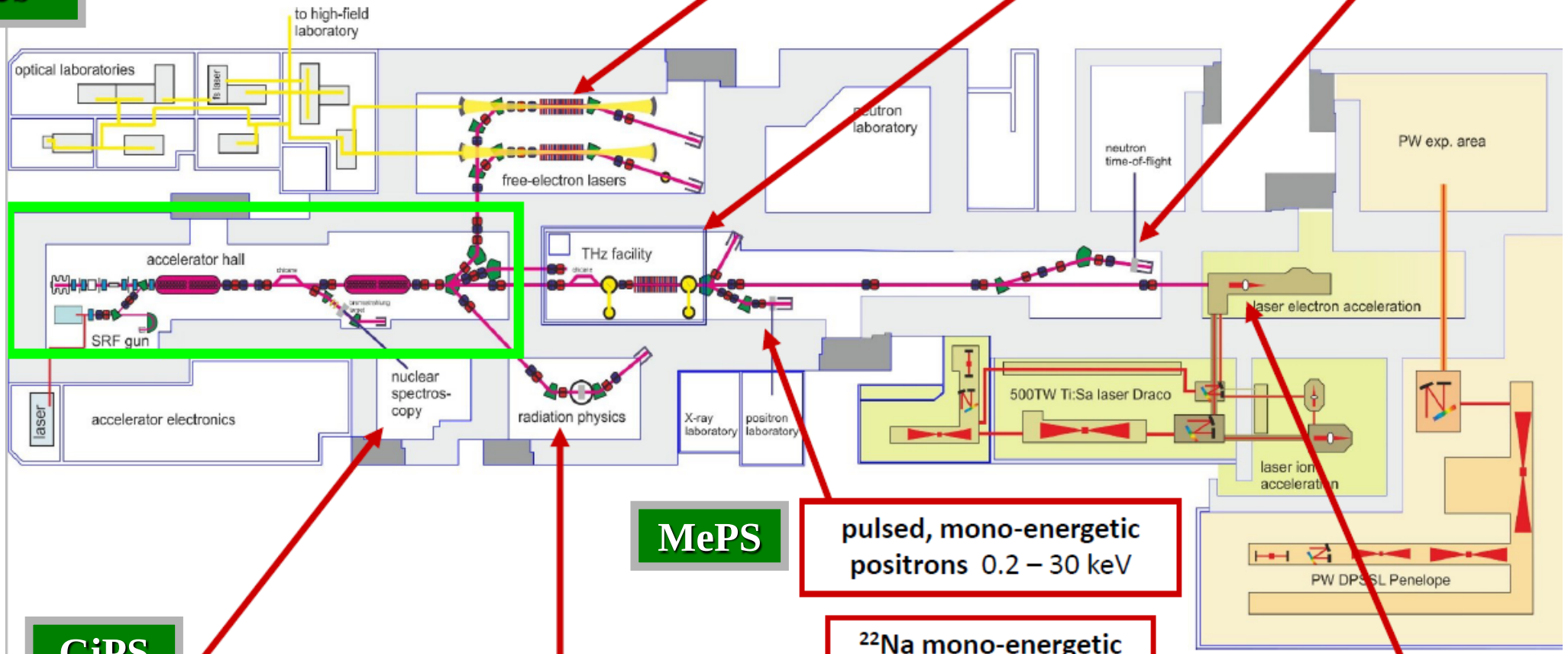
ELBE facilities

1.6mA, 40MeV CW electron accelerator

coherent IR-radiation
3 – 230 µm

coh. THz radiation
100 µm – 3 mm

neutron time of flight
E_n 0 – 10 MeV



MePS

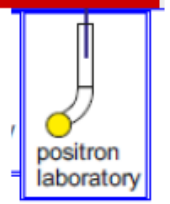
pulsed, mono-energetic positrons 0.2 – 30 keV

GiPS

Bremsstrahlung
0 – 17 MeV
bulk sample positrons

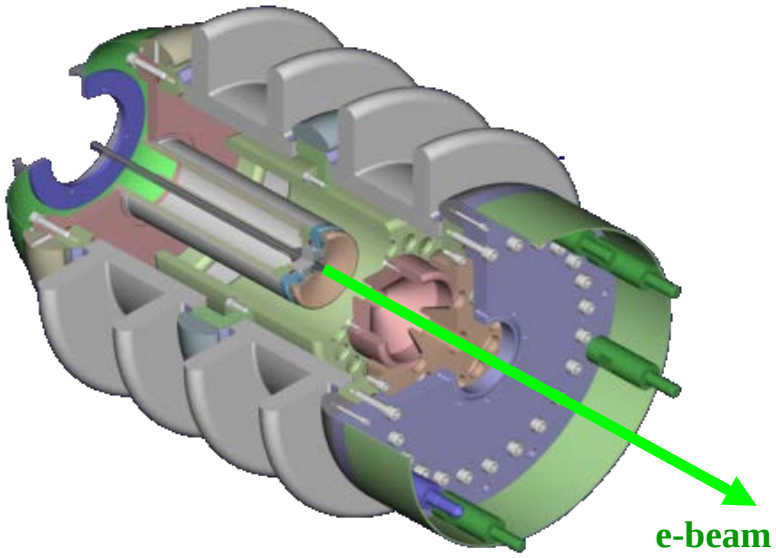
ELBE electrons
10 – 34MeV

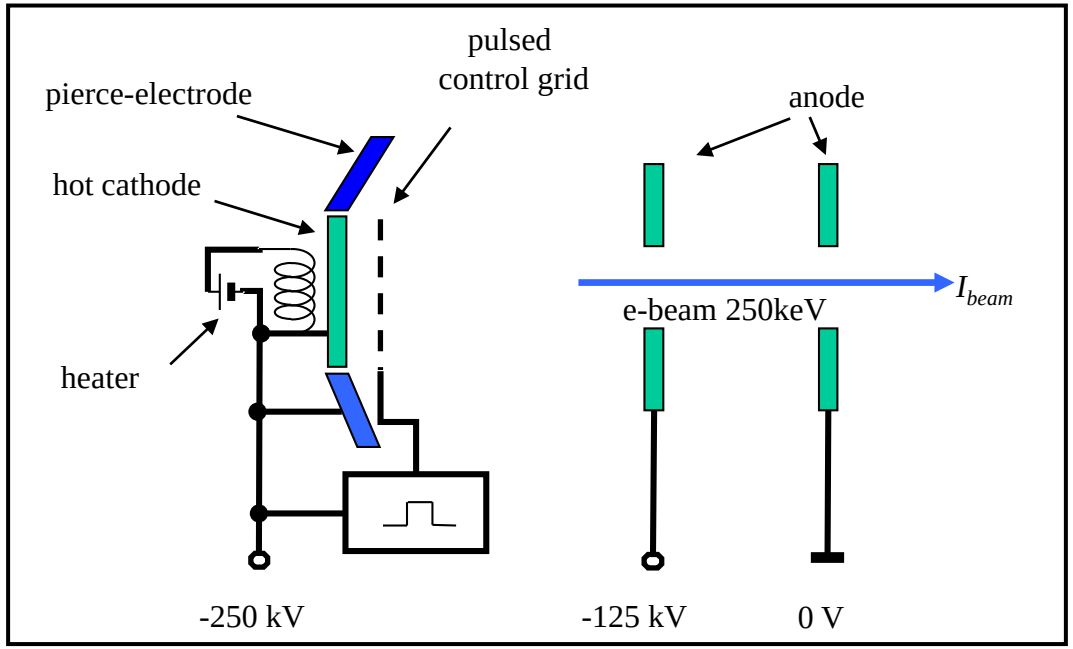
^{22}Na mono-energetic positrons 0.2 – 30 keV



electron laser interaction

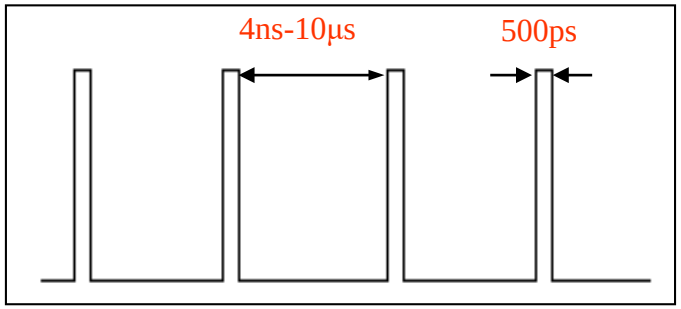
Thermo-ionic electron source at ELBE





- working principle of triode
- 250 kV DC voltage
- pulse length 500ps → 11cm
- energy 250 keV
- bunch charge up to 120 pC @ 13 MHz
- but cannot be larger, also not for reduced repetition time

→ I_{beam} up to 1.6 mA for 13 MHz



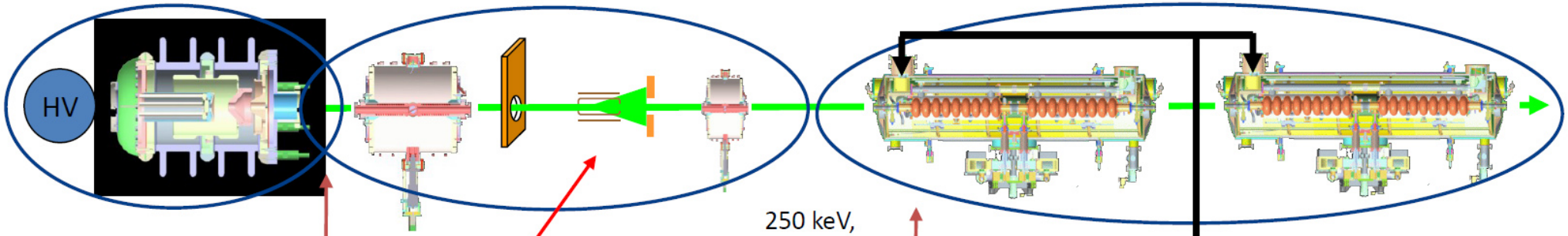
Superconducting LINAC – Beam Generation

thermal-ionic gun
250 kV DC
13 MHz pulsed grid

injection
two RF bunch compressors,
apertures, macro pulse generator

linac 1
DE ~17 MeV
@ 10 MV/m CW

linac 2
DE ~ 19 MeV
@ 10 MV/m CW



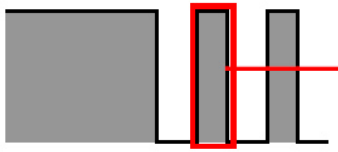
250 keV,
1 mA, β=0.74

Bunch length: 500ps

~5ps

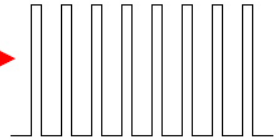
Time structure:

beam
(a) CW
(b) macro-pulsed



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

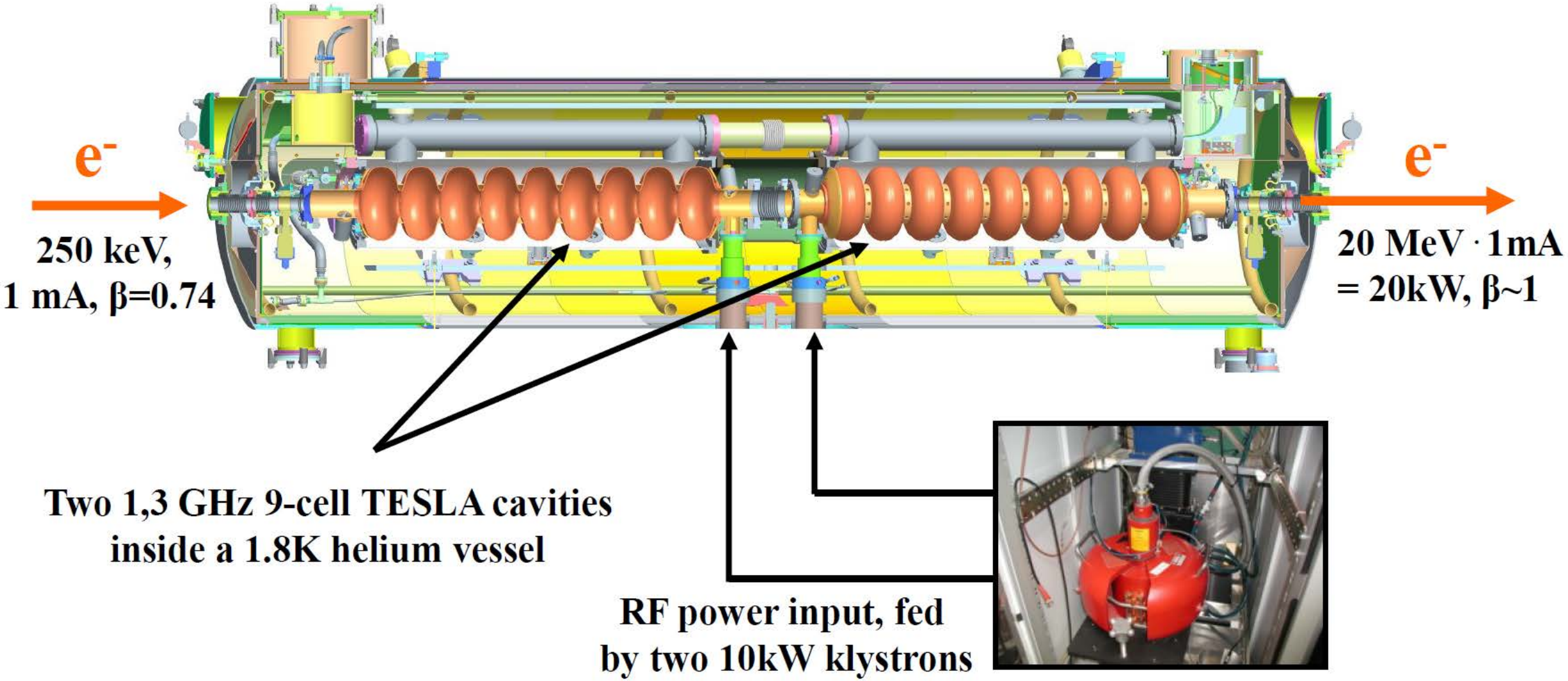
0...77 pC bunch train
(480 Mio electrons)

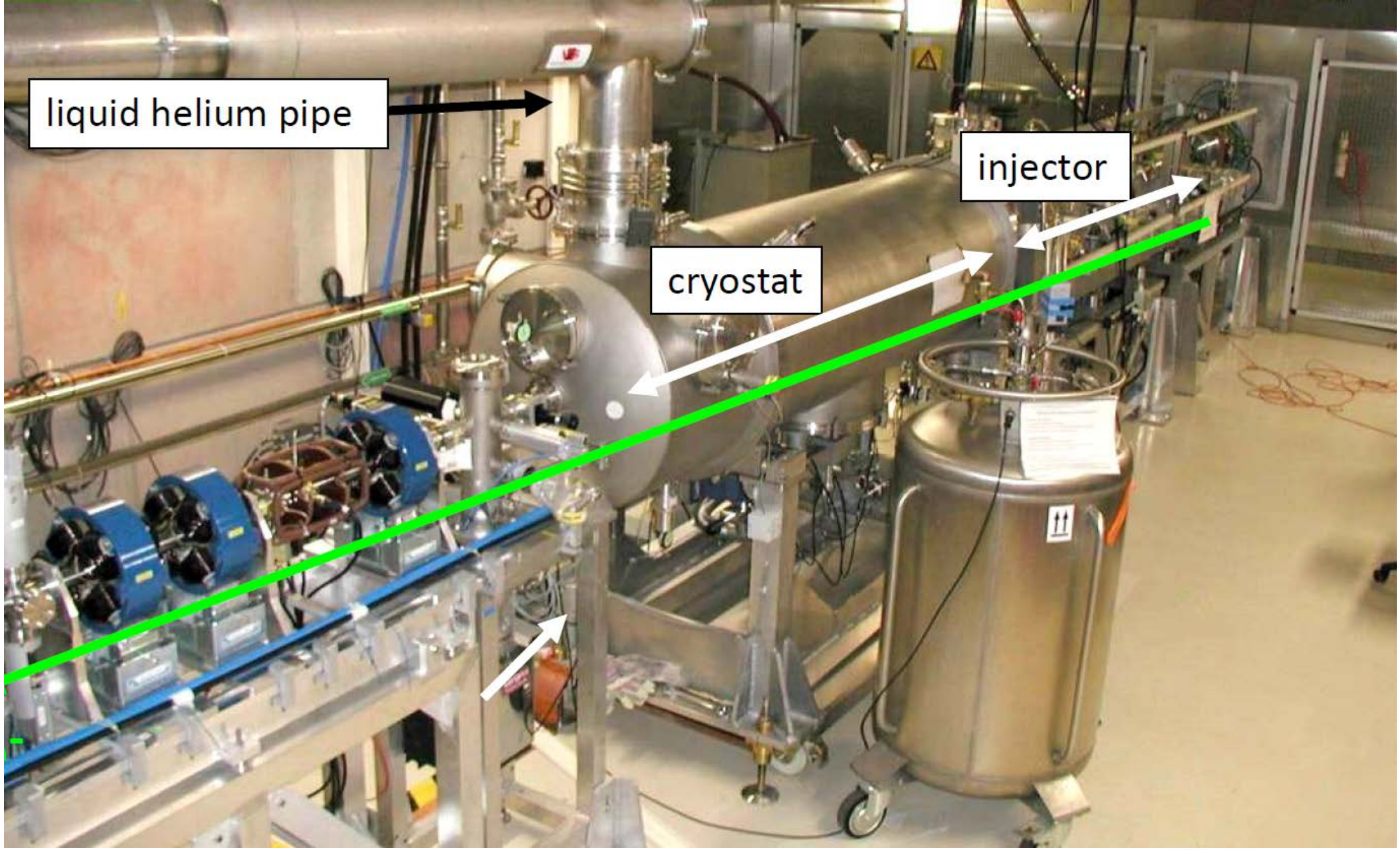


1.5...10 ps bunches
4 ns...10 µs period

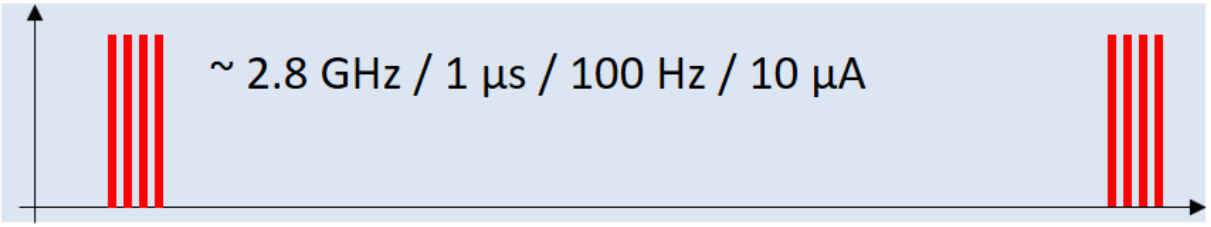
Helium Liquifier LINDE
200 W @ 1,8 K

HZDR in house developed CW superconducting accelerators

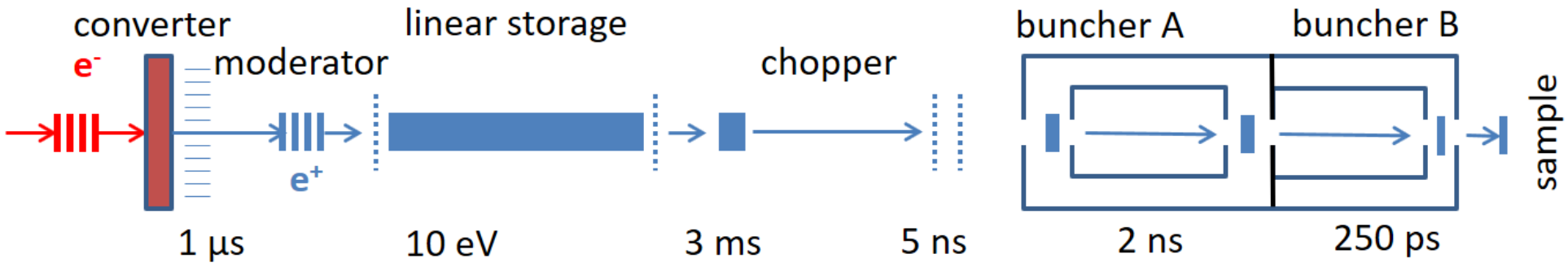


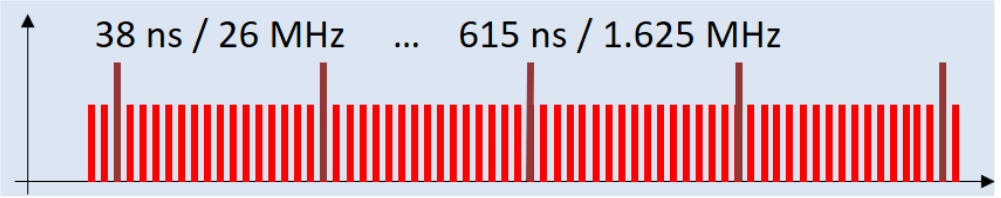

liquid helium pipe
injector
cryostat

Positrons from accelerators



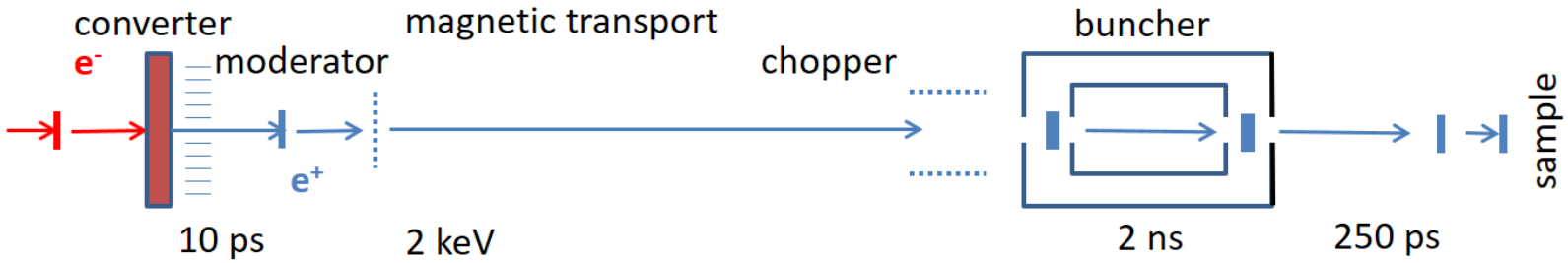
NC-LINAC in macro-bunched mode





SC-LINAC in CW mode

EPOS / MePS facility



- Bunch length can be adjusted according to lifetimes to be measured
- SC accelerators may provide CW mode – are very useful

EPOS (ELBE Positron Source)

MePS
Monoenergetic Positron Spectroscopy

- monoenergetic (slow) positrons
- pulsed system
- LT, CDBS, AMOC

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

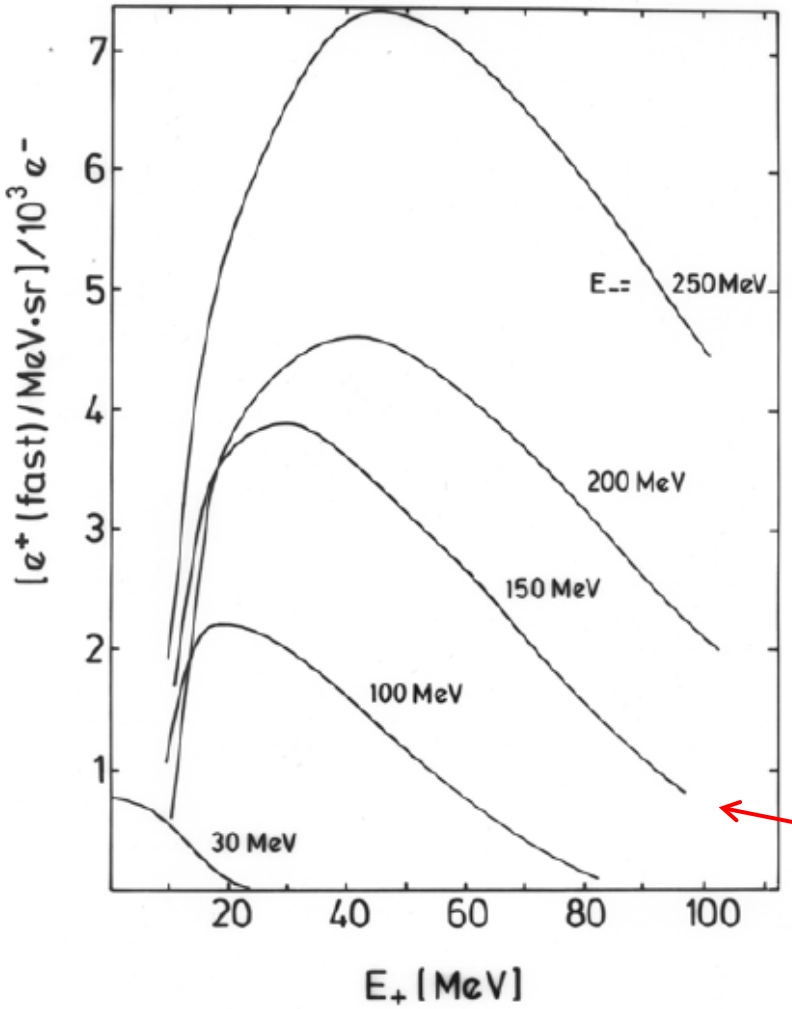
GiPS
Gamma-induced Positron Spectroscopy

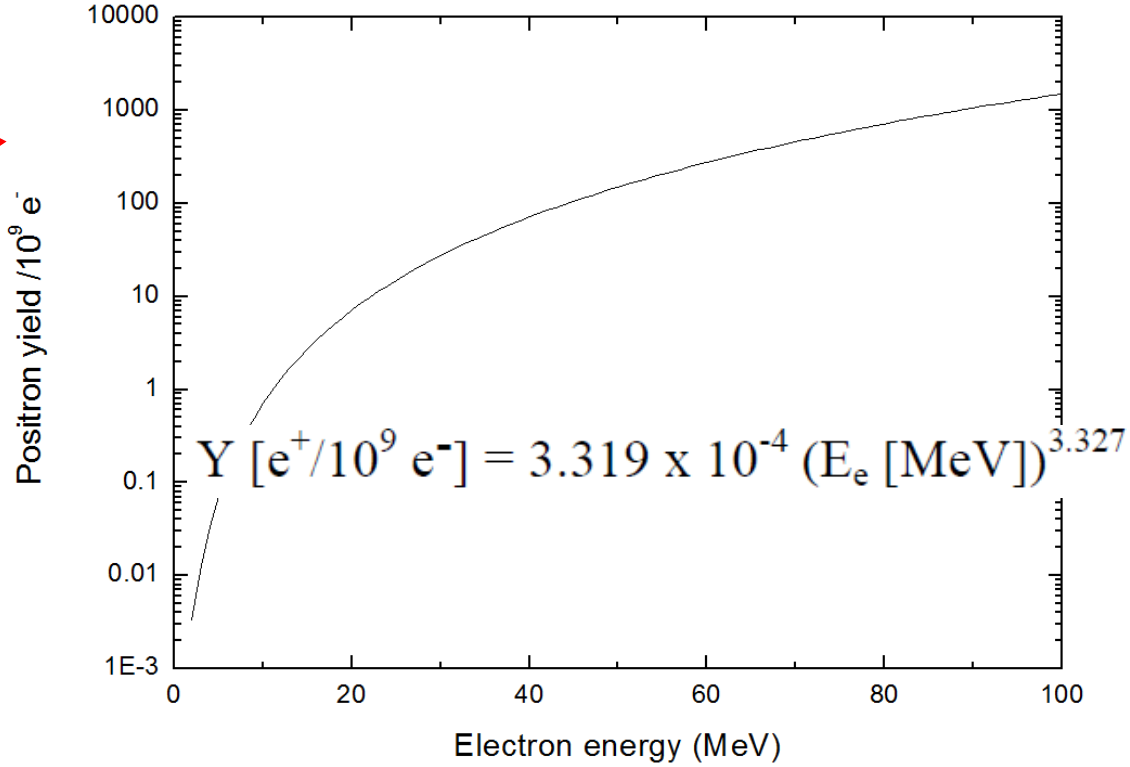
- Positron generation by Bremsstrahlung
- Investigation of bulky samples (up to 10 cm^3)
- all relevant positron techniques (LT, CDBS, AMOC)

Information Depth:
0.1 mm …2 cm

What is the optimum electron energy for positron generation?

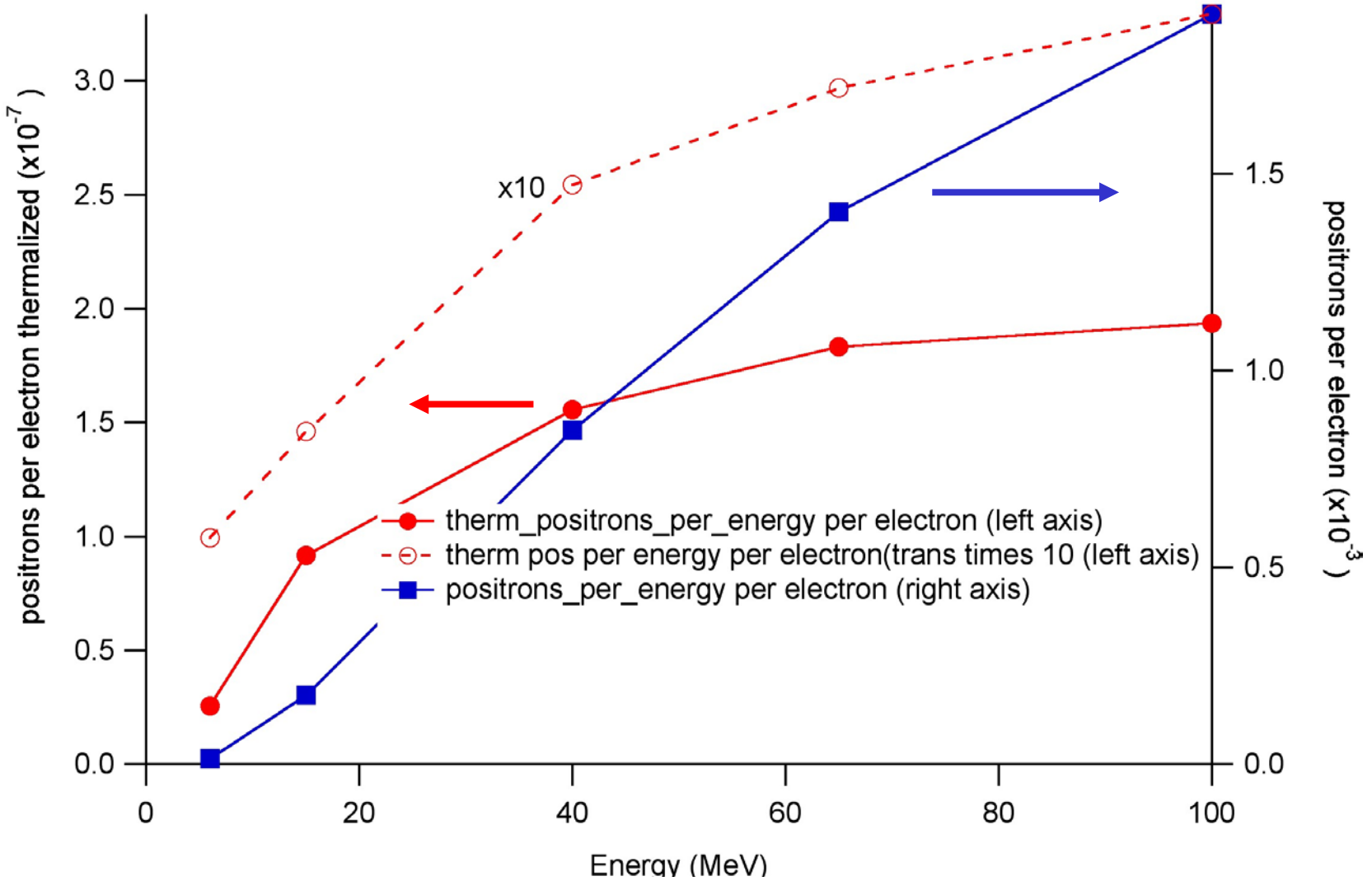
- positron yield is strong function of electron energy
- however: mean positron energy increases strongly





- 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

What is the optimum electron energy for positron generation?



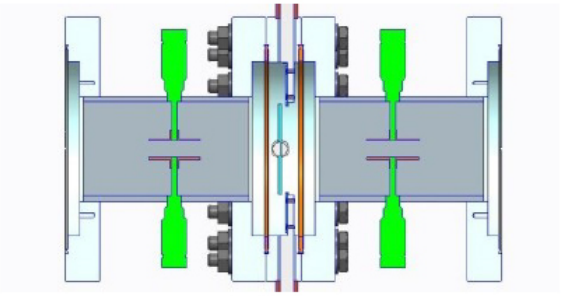
- Relative yield of positrons as a function of the incident electron energy.
- The yield of total positrons increases virtually continuously (closed squares)
- the number of thermalized positrons appears to approach saturation at about 60 MeV both for reflected moderation (filled circles) or transmitted moderation (open circles).

SLOPOS-12 (Magnetic Island, Australia) talk of Sergey Chemerisov, Chemistry Division, Argonne National Laboratory

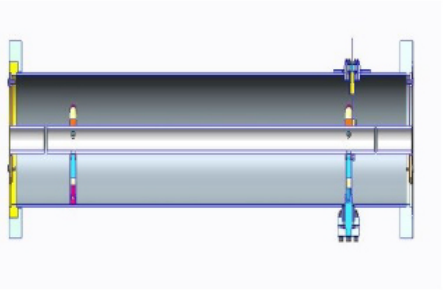
MePS: Monoenergetic Positron Source

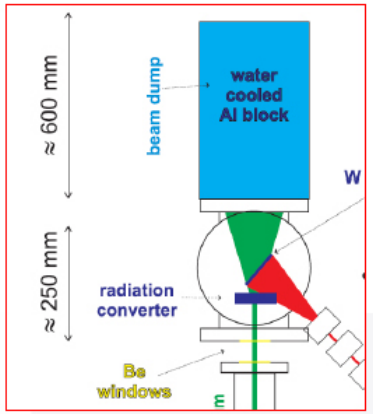
Flux: $1.2 \cdot 10^6$ e^+/s on sample

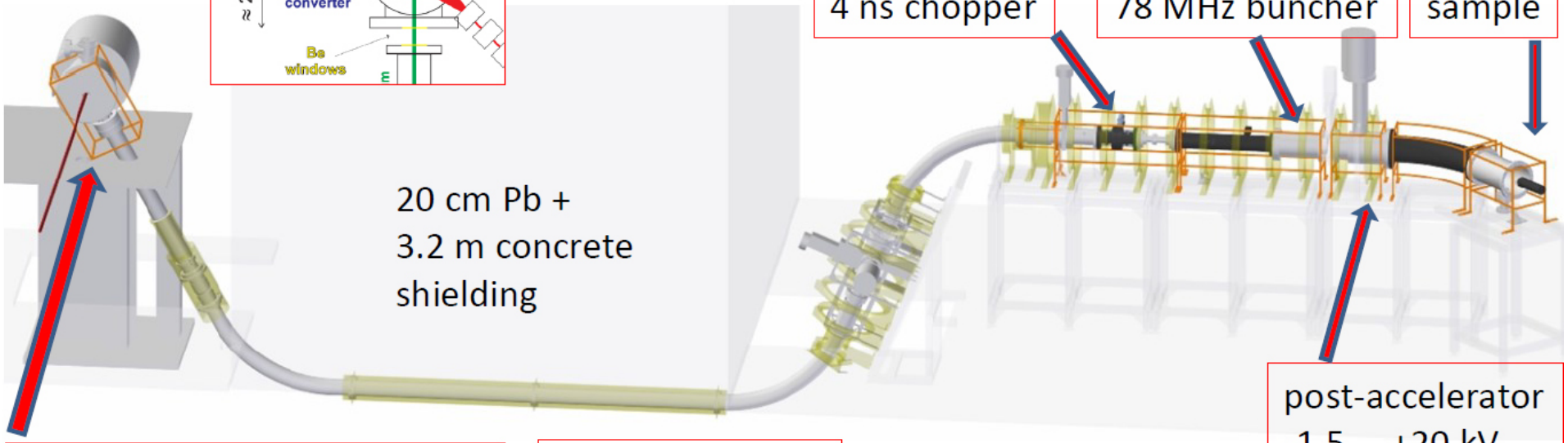
max 500 V/cm



max 2.5 kV/cm







4 ns chopper

78 MHz buncher

sample

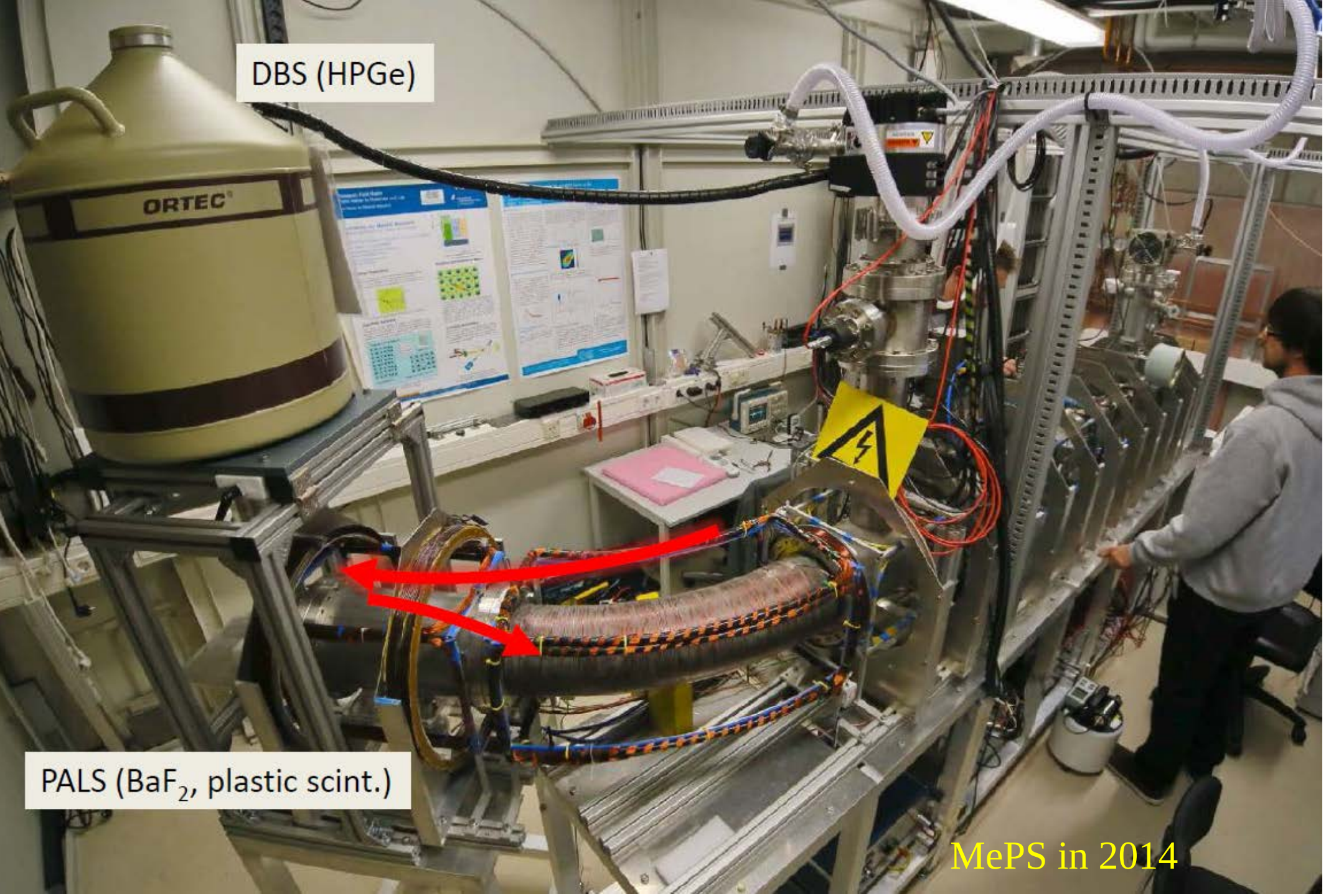
20 cm Pb +
3.2 m concrete
shielding

post-accelerator
-1.5 … +20 kV

SC-LINAC beam
- 30 MeV, 0.1 mA
- 1.625 MHz repetition rate
  615 ns spacing

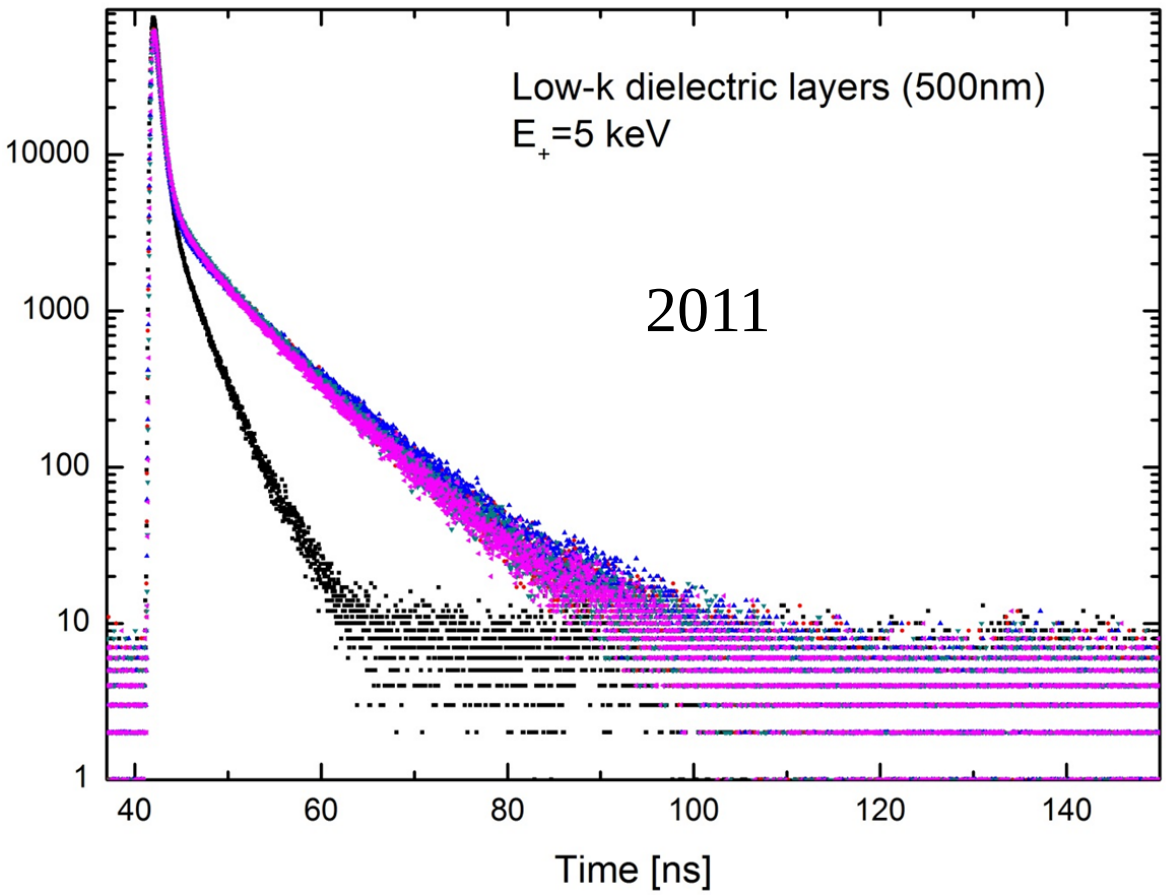
2 keV magnetic
transport system

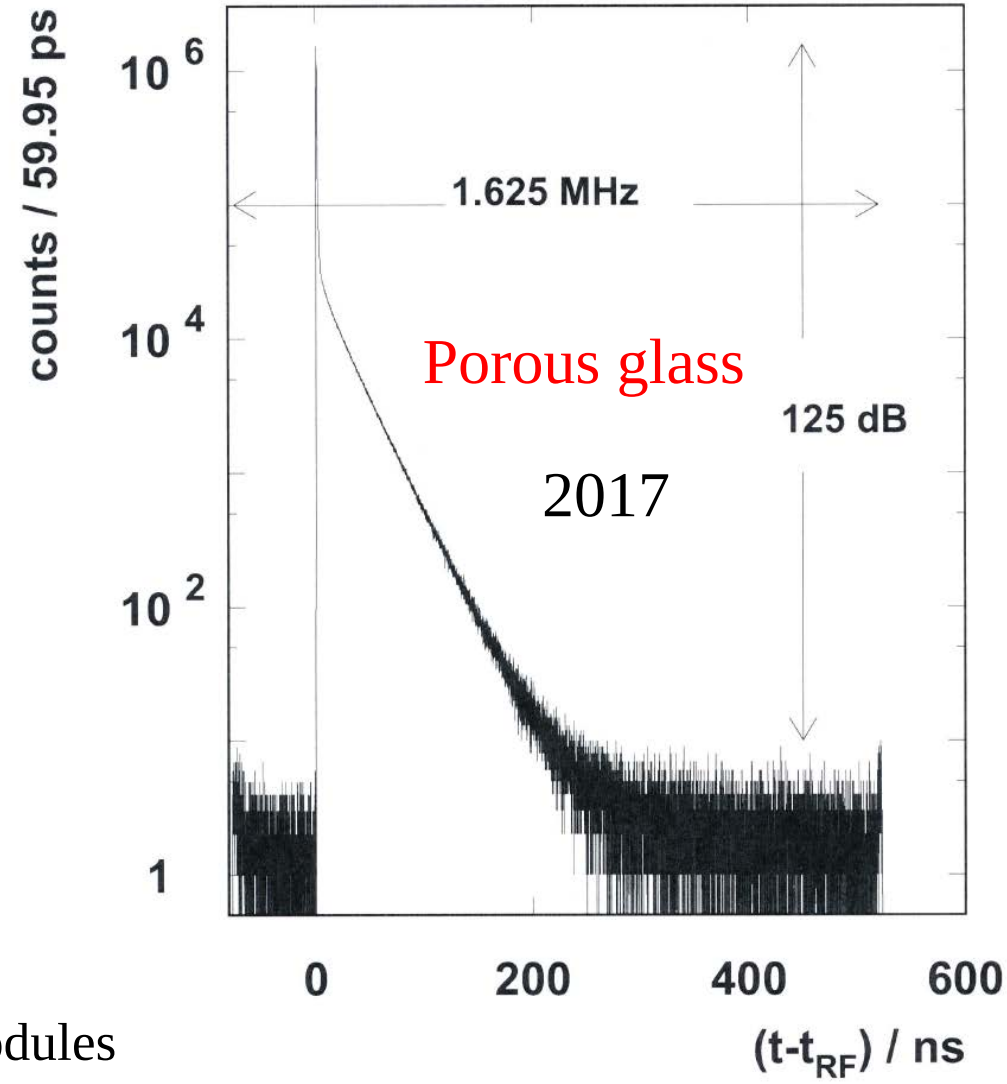
30% HPGe detector for DBS
BaF_2 detector for PALS


DBS (HPGe)
ORTEC
PALS (BaF_2, plastic scint.)
MePS in 2014

MePS in 2018

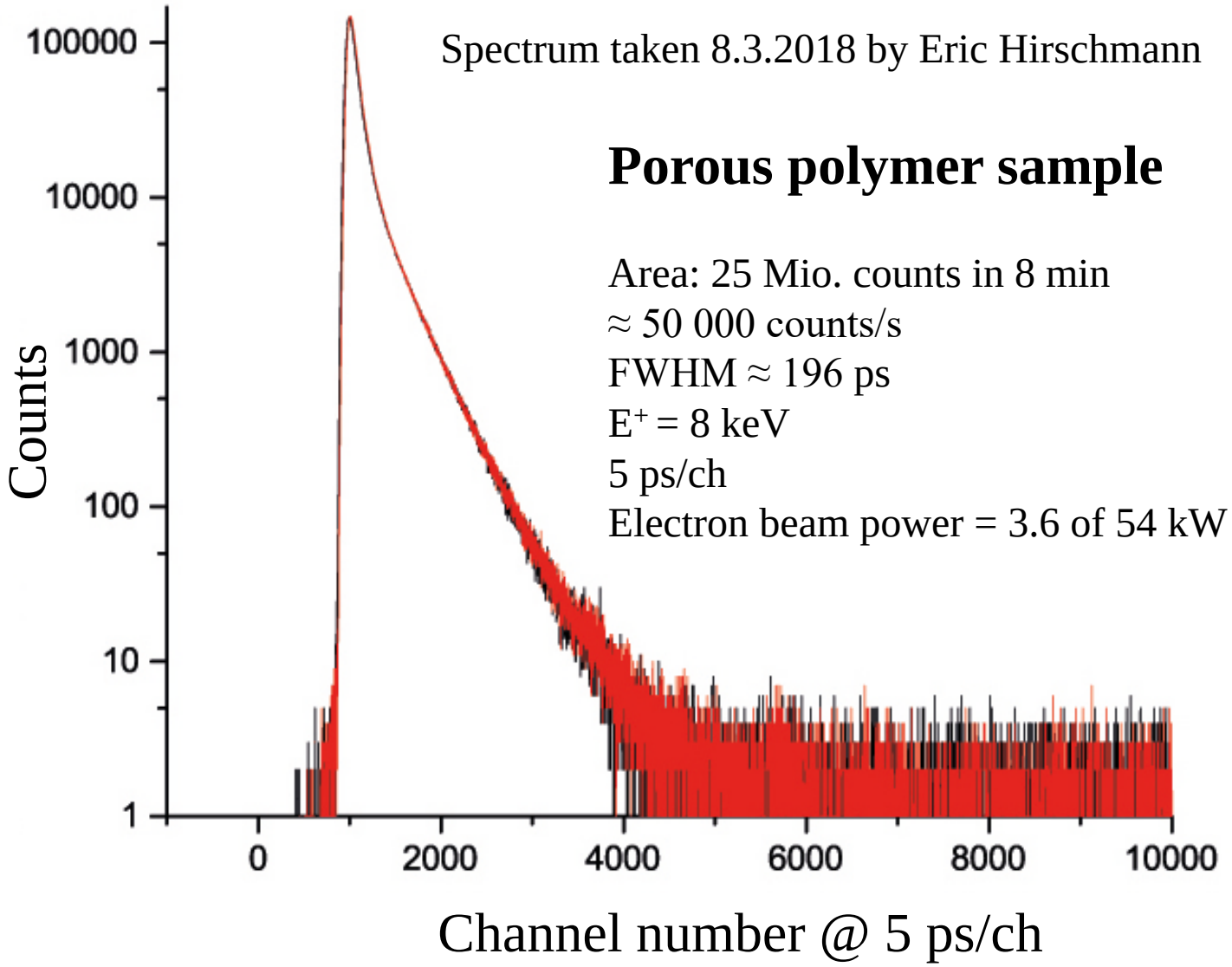
Improvement of spectra quality





Measured by an analogue System using ORTEC modules

MePS: Digital Positron Lifetime System

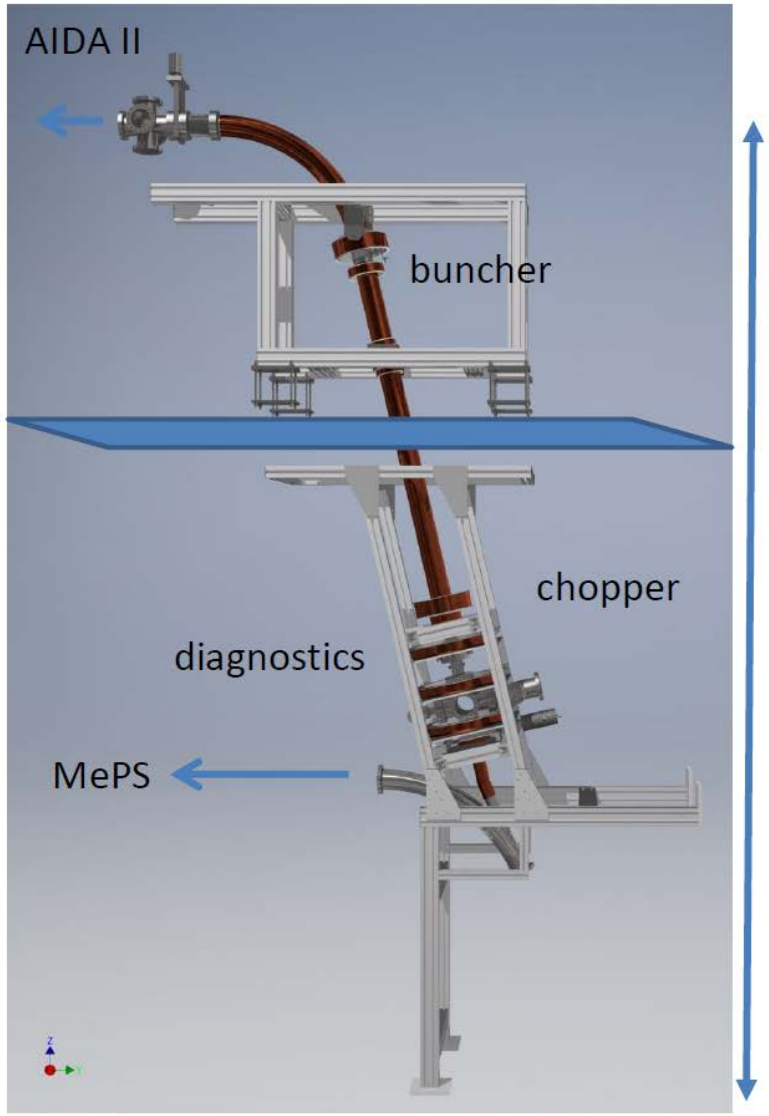


- Digitizer: ADQ14-DC for MTCA Form factor
- Teledyne SPDevices
- 14 bit resolution, 2 GS/s, 1.2 GHz analogue bandwidth
- 1 CPU core = Maximum count rate ≈ 5×10^4 /s
- Possible count rate with hyper-threading is expected to be > 5E5 /s

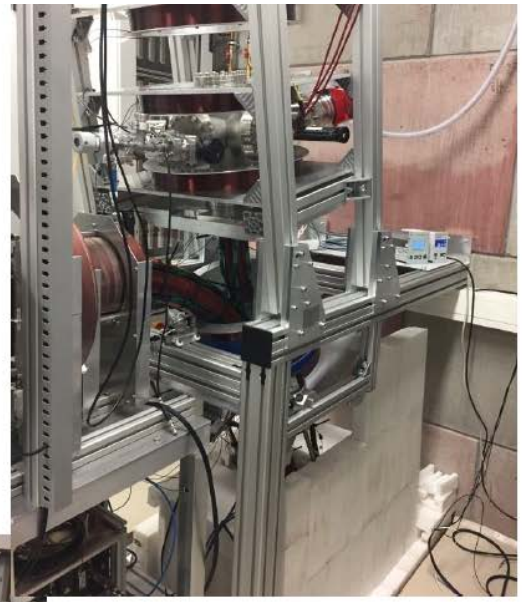
Advantages of dPALS

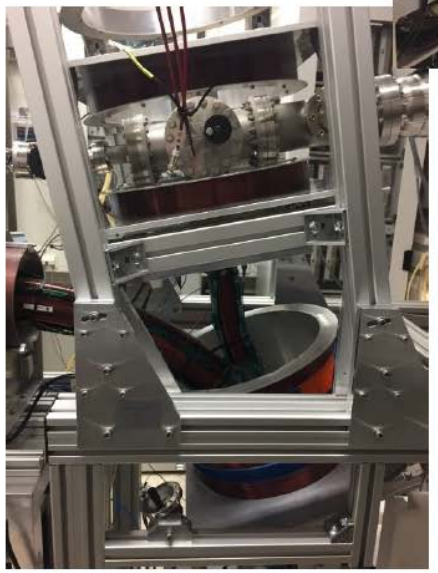
- Timing with 10^{-6} accuracy
- Nothing to be adjusted/calibrated
- Main advantage: 5 ps/ch possible even for 2 µs long spectra (for 14 bit-MCAs @ 2µs only 122 ps/ch)

AIDA-II at MePS Beamline



500 cm

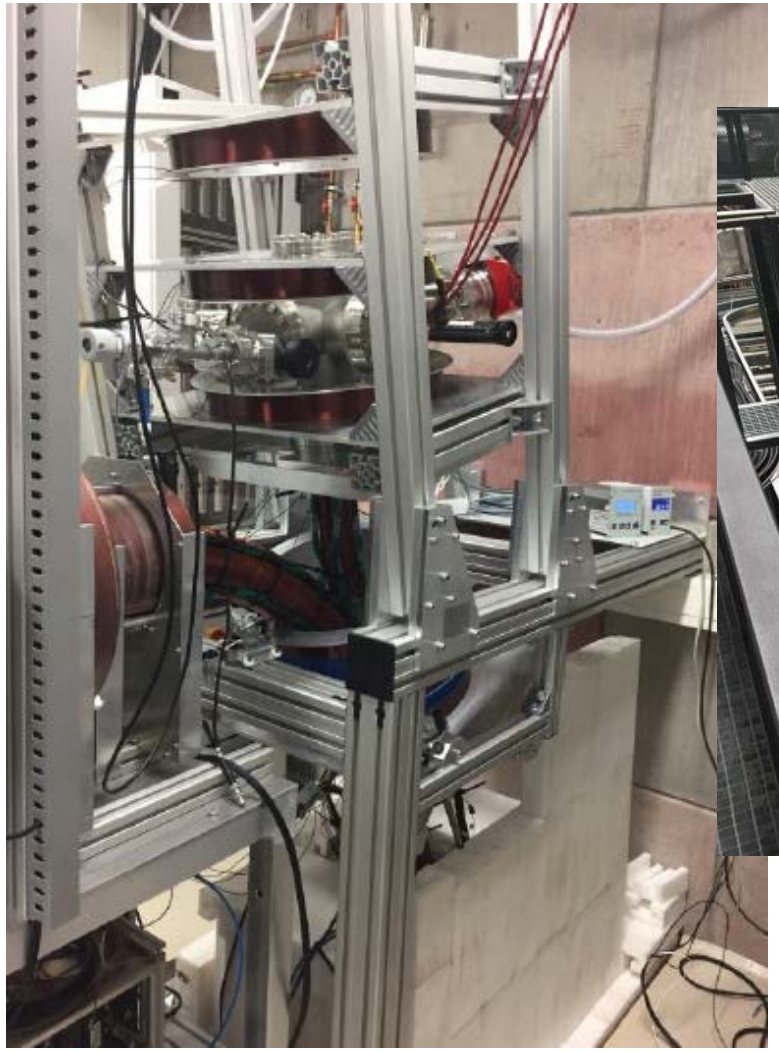




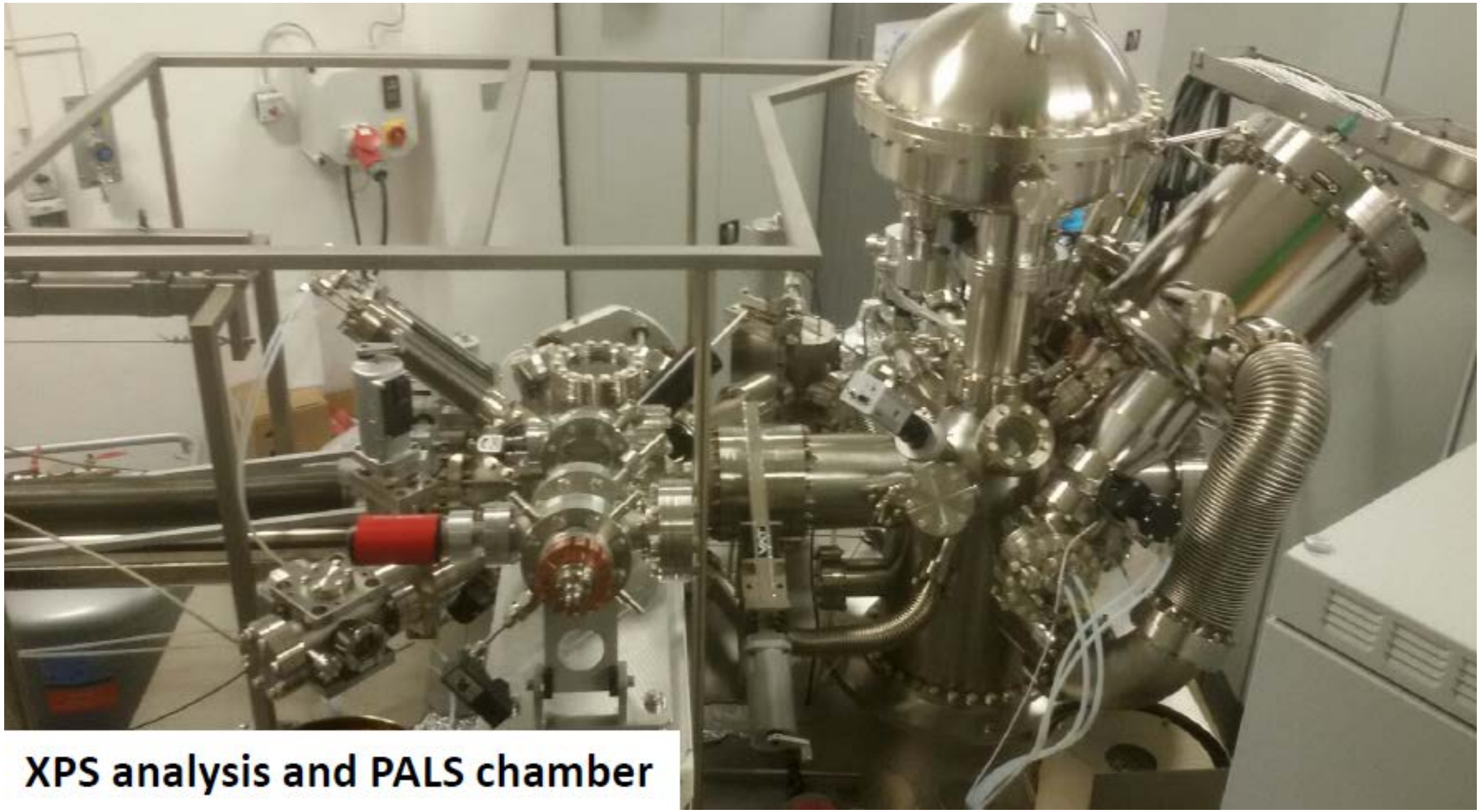
MCP diagnostics
Feb. 2017

- AIDA = Apparatus for in-situ Defect Analysis
- Will be on top of MePS lab
- UHV system for surface analysis and treatment (ions, wide T-range, XPS, positron lifetime)
- Layer deposition
- Time schedule:
  - 2017: beam switch tested
  - April 2018: positron beam tests (resolution, intensity …)
  - End of 2018: setup finished

AIDA-II at MePS Beamline

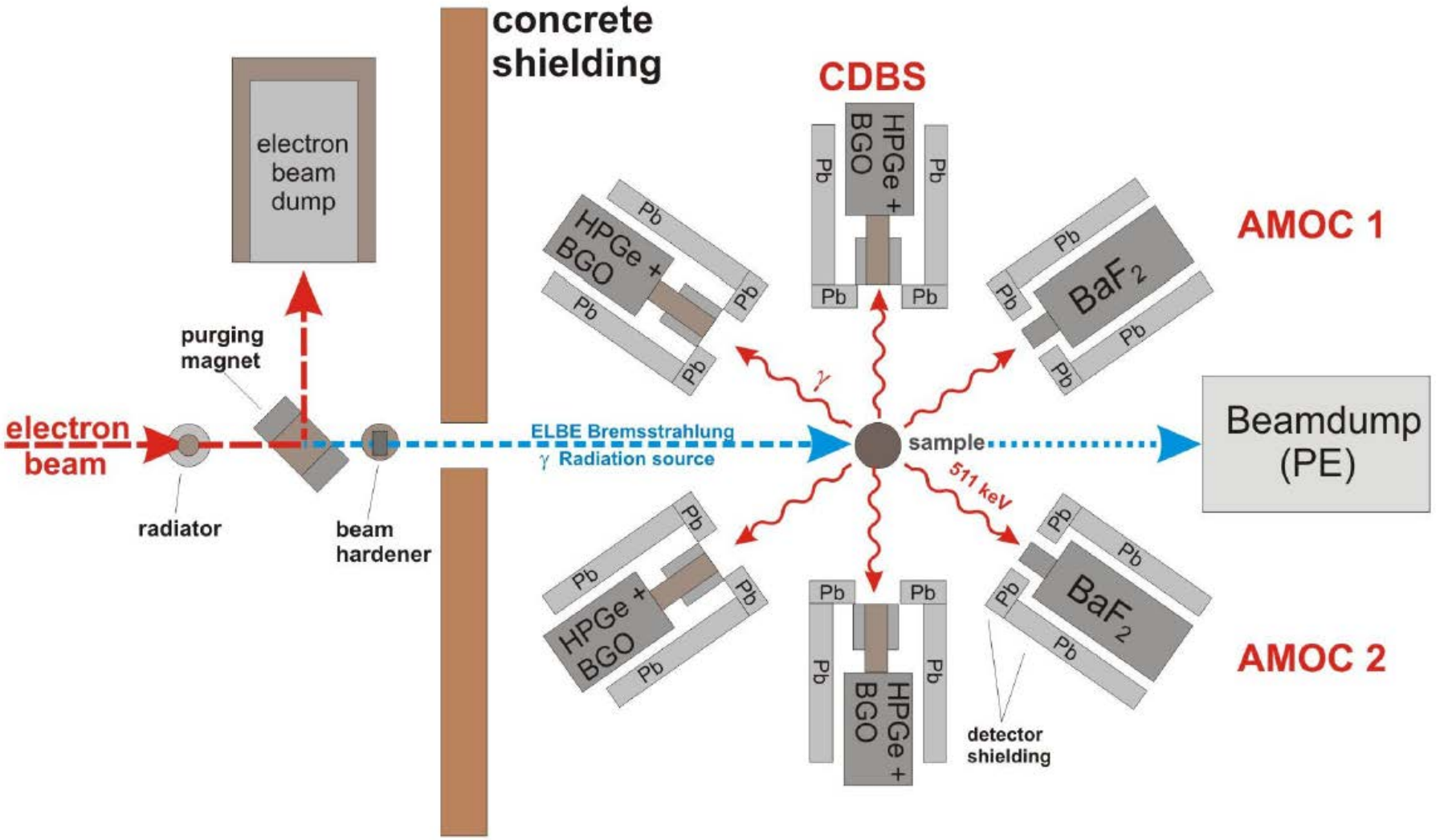


AIDA-II at MePS Beamline



XPS analysis and PALS chamber

GiPS: Gamma-induced Positron Spectroscopy



- Positrons are generated in the whole sample volume
- Up to 2cm diameter
- Idea: F.A. Selim, D.P. Wells, J.F. Harmon, et al. Nucl. Instr. Meth. A 495 (2002) 154
- Volume of large samples are completely measured
- Useful for liquids, coarse powders, radioactive samples…
- In spite of scattered original gammas the Peak-to-BG is up to 10^{-5}
- One has to measure AMOC spectra in 12…24 h

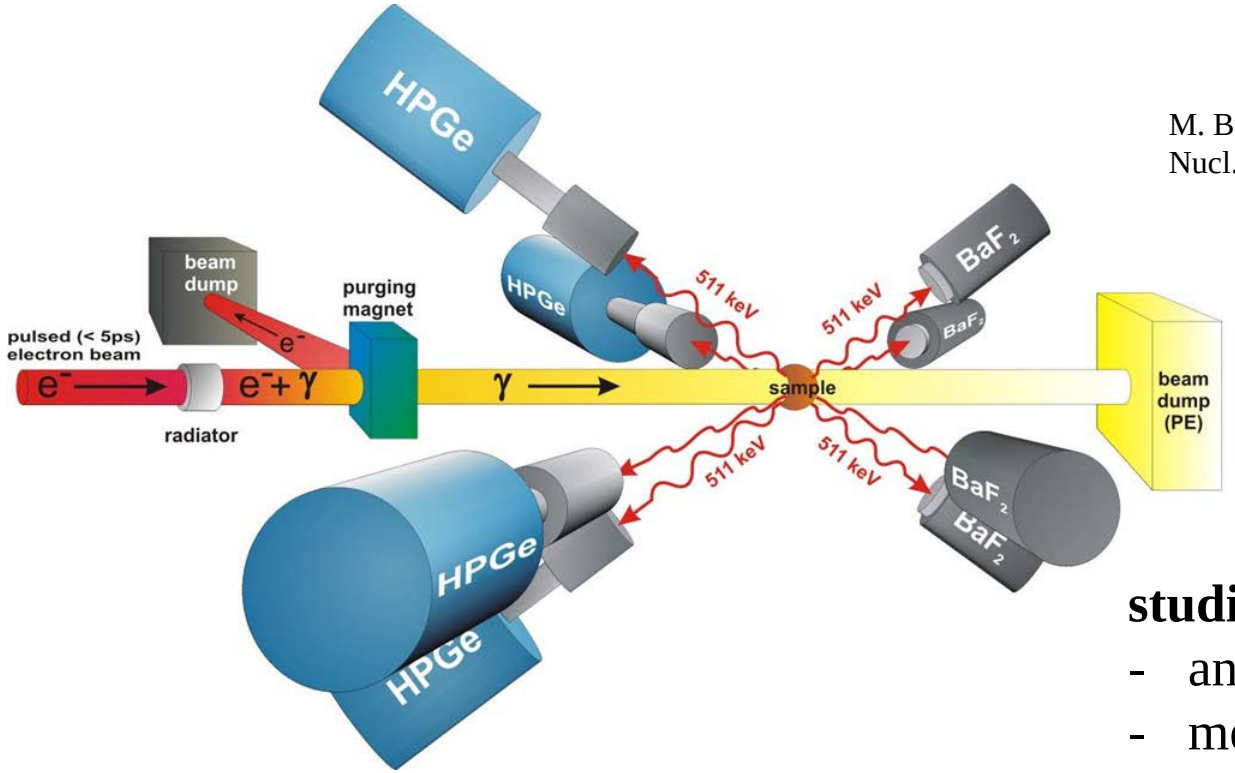
GiPS: Gamma-induced Positron Spectroscopy

$E_e = 16\,\mathrm{MeV}$

$I_e = 900\,\mu\mathrm{A}$

$f = 26\,\mathrm{MHz}$

$\sigma_t < 10\,\mathrm{ps}$



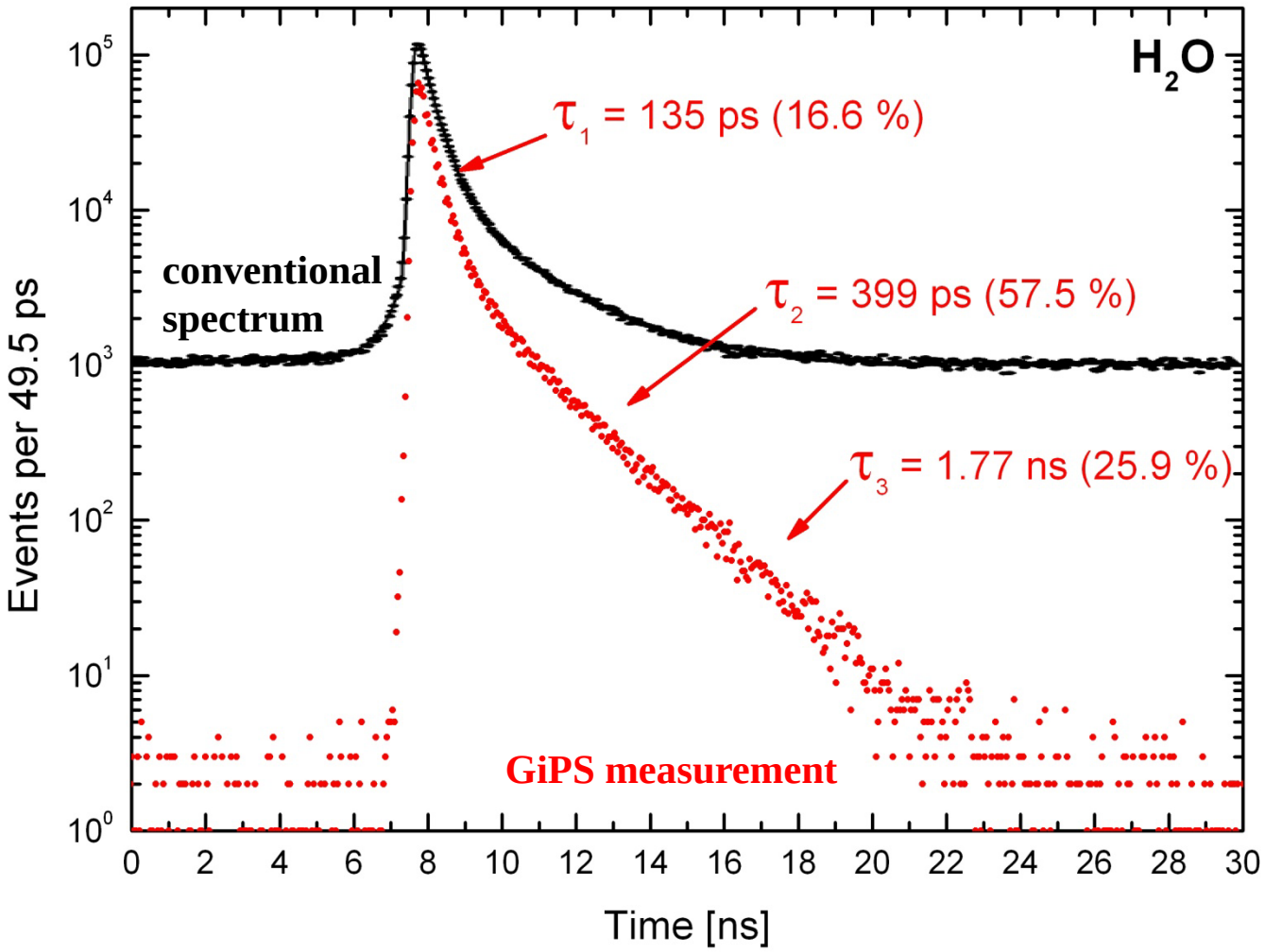
M. Butterling, et al.,
Nucl. Instr. Meth. B 269 (2011) 2623

studies performed so far:

- animal tissue
- metals and alloys
- semiconductors
- (neutron-activated) reactor materials
- water, glycerol from 10°C to 100°C

- Positrons are generated inside the sample
- Coincident measurement → no problem with scattered gammas from sample

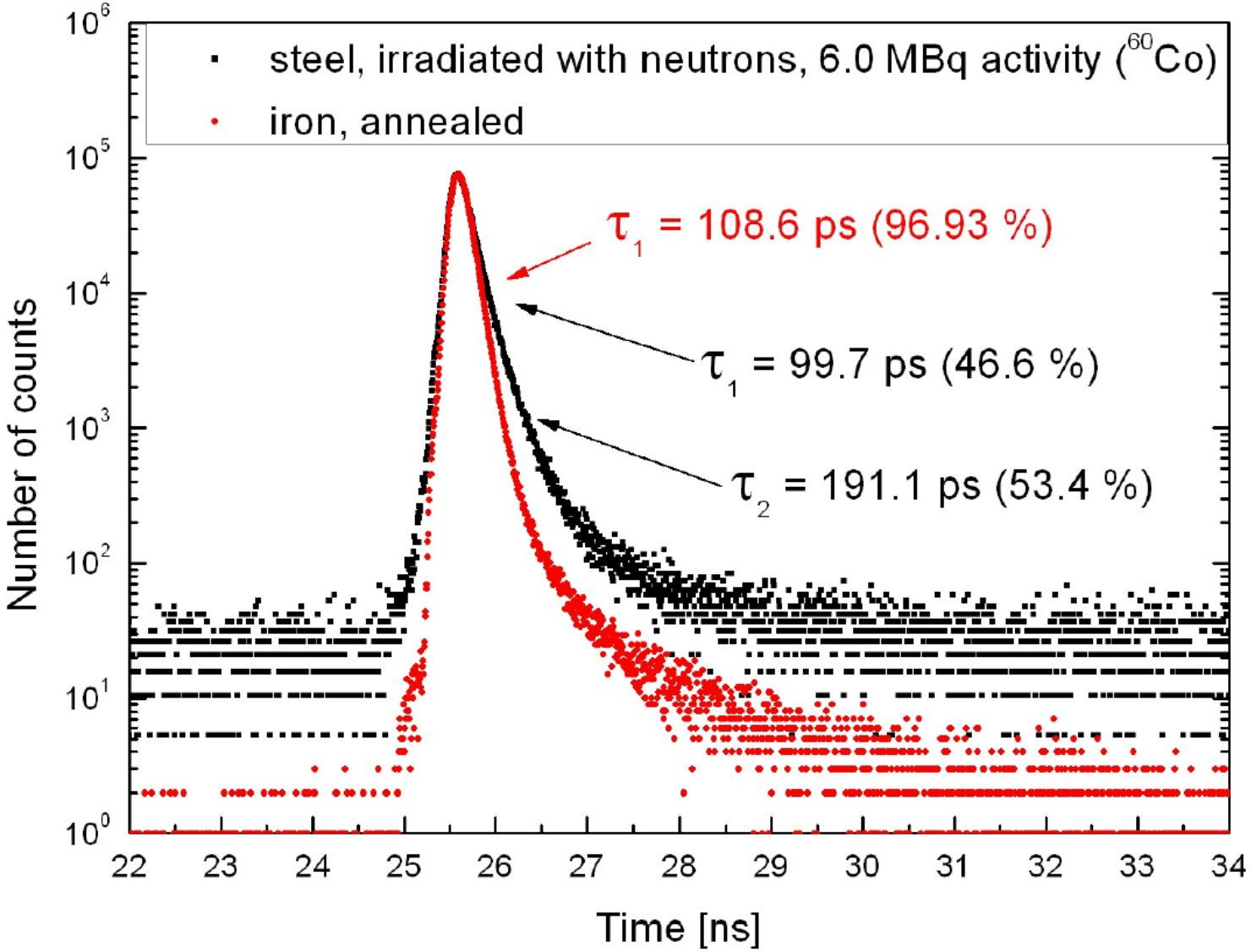
Example: Water at RT



- total count rate in GiPS spectrum: 12×10^6
- Extremely clean spectra
- FWHM ≈ 160 ps
- Peak-to-BG > 10^5

- Black spectrum: conventional measurement by Kotera et al., Phys. Lett. A 345, (2005) 184
- M. Butterling et al., Nucl. Instr. & Methods 2011, Volume 269, pp. 2623

GiPS: radioactive samples



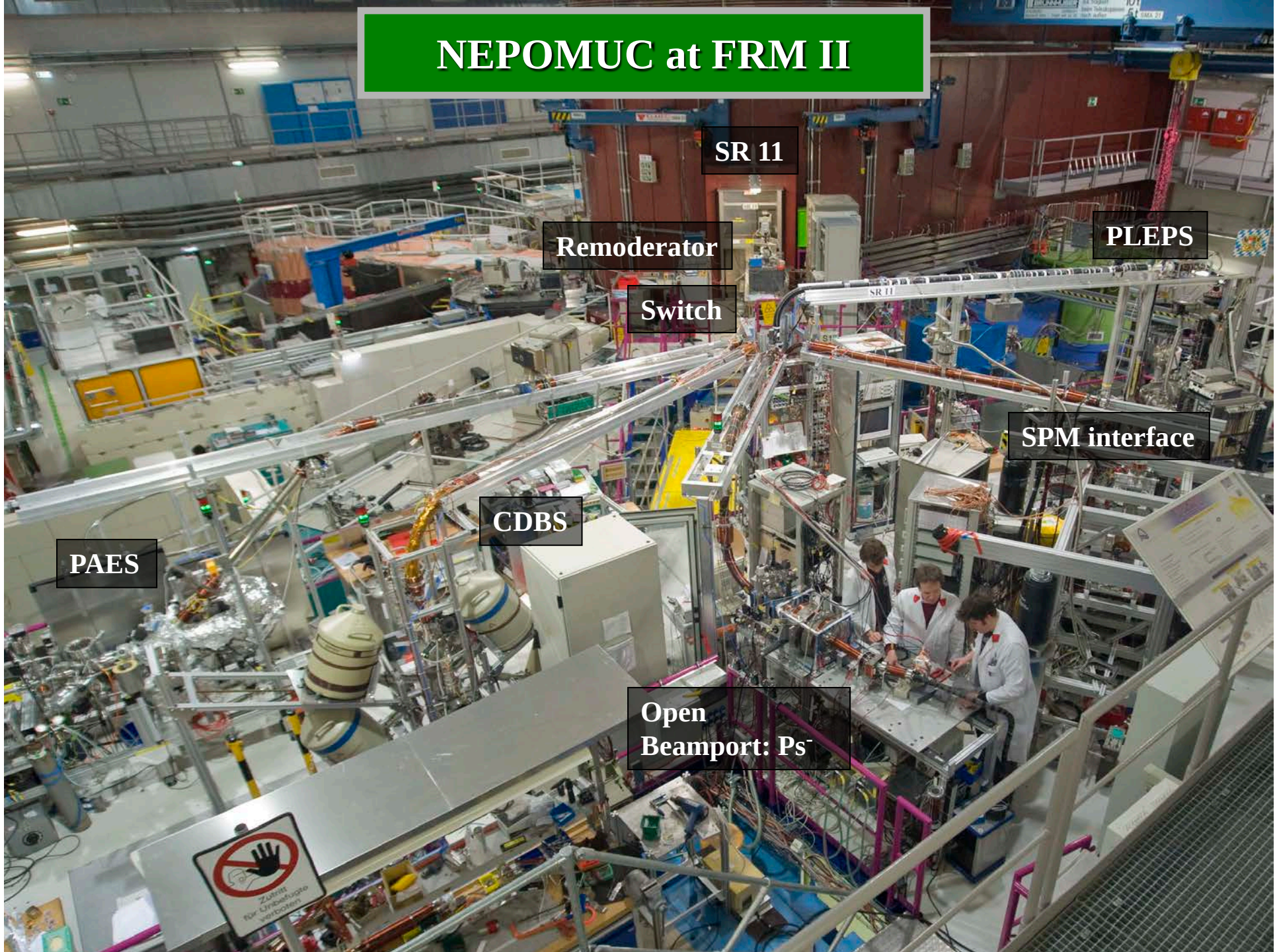
- Neutron irradiated steel from reactor vessel steel shows 60Co activity
- Conventional lifetime takes up to 14 days in triple coincidence
- Due to HPGe coincidence at sharply 511 keV with BaF2 detector: high statistics and low background

User-dedicated intense Positron Sources in Germany

- Two intense positron sources available (positrons by pair production)
- **NEPOMUC** (NEutron induced POsitron Source MUniCh) at FRM-II
  - PLEPS (monoenergetic positron lifetime system)
  - PAES (Positron-induced Auger Electron Spectroscopy)
  - CDBS (Coincidence Doppler Broadening Spectroscopy)
  - SCM (Scanning Positron Microscope)
  - user beam line
- **EPOS** (ELBE Positron Source) at Helmholtz Center Dresden-Rossendorf
  - MePS (Mono-energetic Positron Spectroscopy)
  - GiPS (Gamma-induced Positron Spectroscopy)
  - CoPS (conventional setup using 22Na sources)

- at both sites: web-based application system for beam time
- Next date at ELBE is 9. April 2018 (contact me for help)

NEPOMUC at FRM II



Conclusions

- A superconductive LINAC is an ideal positron source due to unique time structure
- Optimum electron energy is 40…60 MeV
- Electron beam repetition time can be adjusted according to positron lifetime (38 ns …. 1.3 μs)
- **MePS**:
  - 1 μs bunch length is possible without intensity losses: 5…10×10^4 cps possible now
  - Digital positron lifetime for high count rates available
- **GiPS**:
  - high-quality spectra possible for bulky, radioactive or liquid samples
  - All data measured as AMOC spectra

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

Thanks to

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W. Anwand

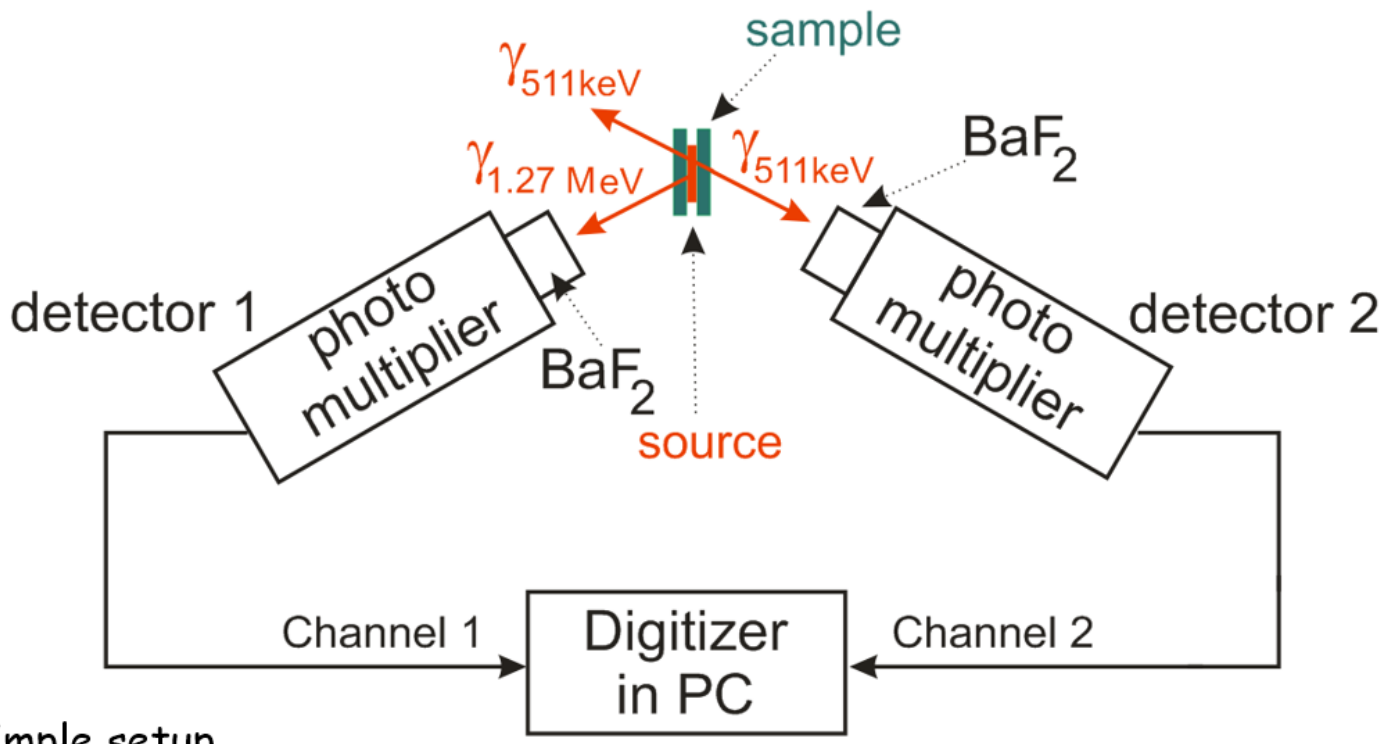
University Halle

A.G. Attalla, M. Elsayed,
A. Ibrahim, M. John,
M. Jungmann, A. Müller

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

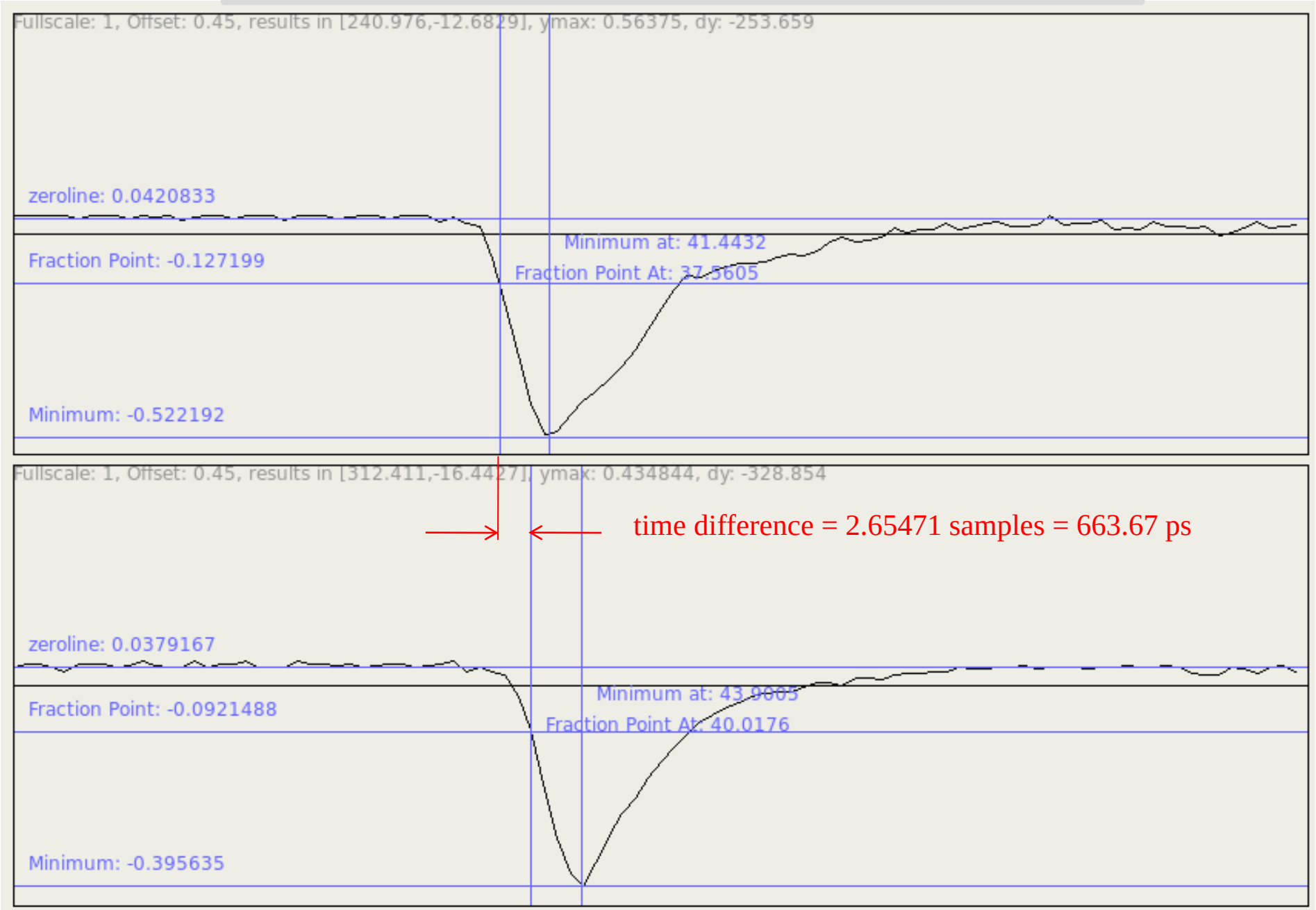
The GiPS setup includes 8 Detectors (4 Ge and 4 BaF_2)

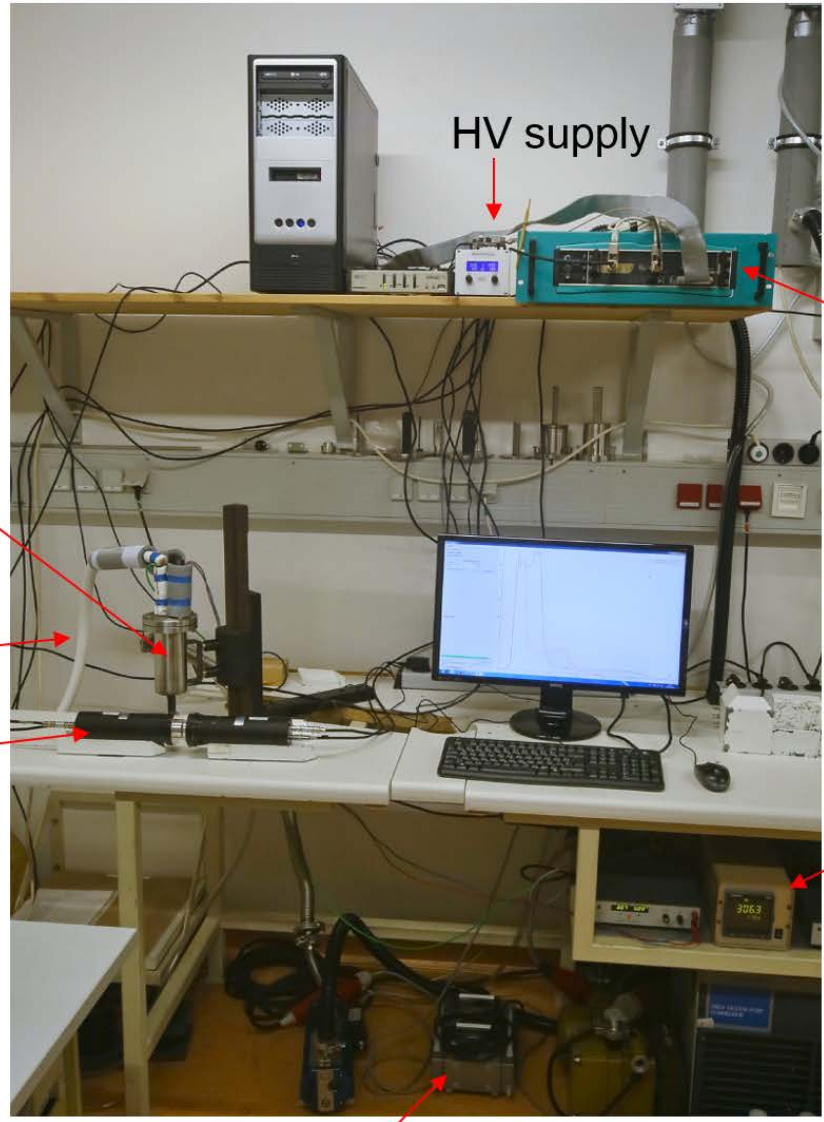
Digital positron lifetime measurement



- simple setup
- timing very accurate
- each detector for start & stop (double statistics)

Screenshot of two digitized anode pulses




HV supply
Digitizer
Cryostat
LN2 supply
for sample cooling
PMTs
PID controller for
sample heating
Vacuum pumps