正电子概况14

正电子技术及其发展

Pulsed positron beam and its application

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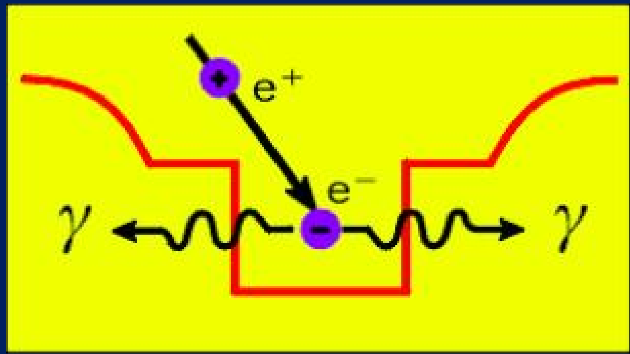
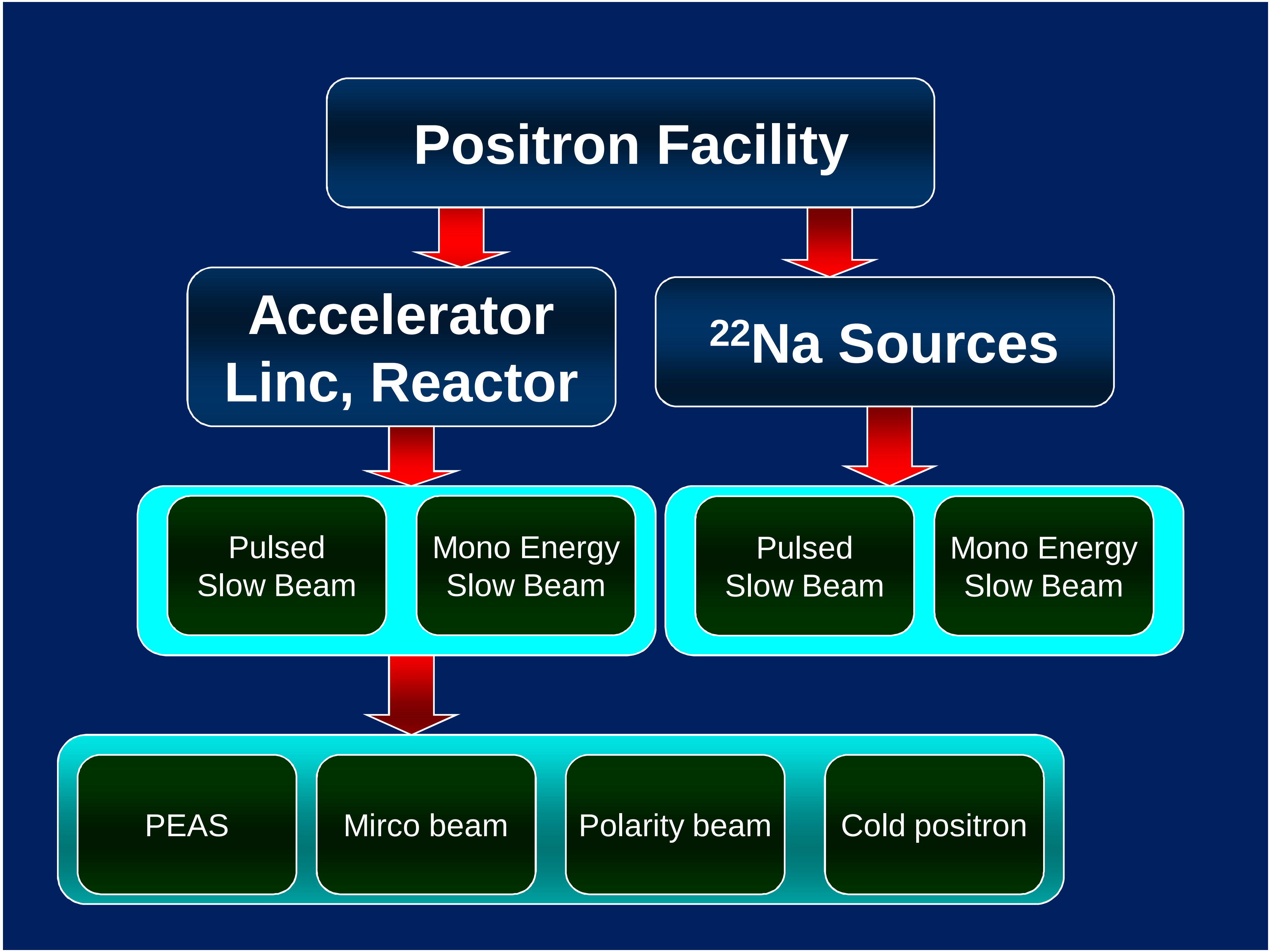
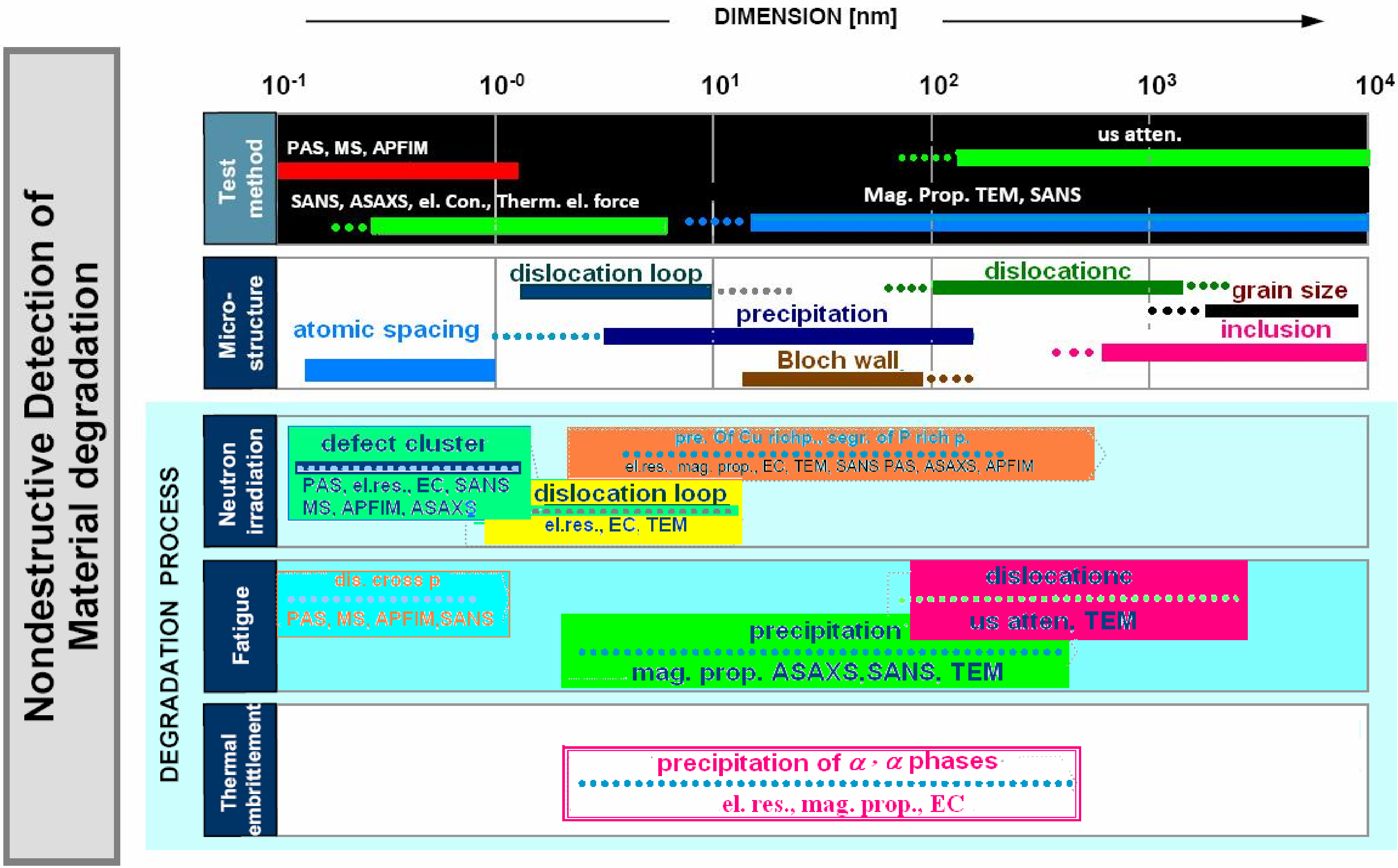
2007-9-7



- 基于脉冲正电子束的探测技术
- 脉冲束寿命谱仪的关键问题
- 世界各国脉冲正电子束装置
- 脉冲正电子束的应用

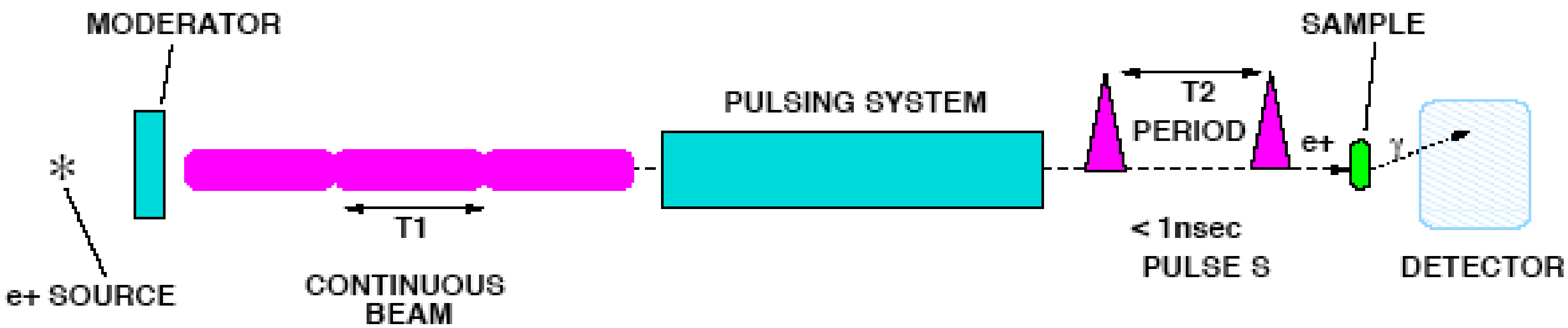

Positron Facility
Accelerator
Linc, Reactor
22Na Sources
Pulsed
Slow Beam
Mono Energy
Slow Beam
Pulsed
Slow Beam
Mono Energy
Slow Beam
PEAS
Mirco beam
Polarity beam
Cold positron

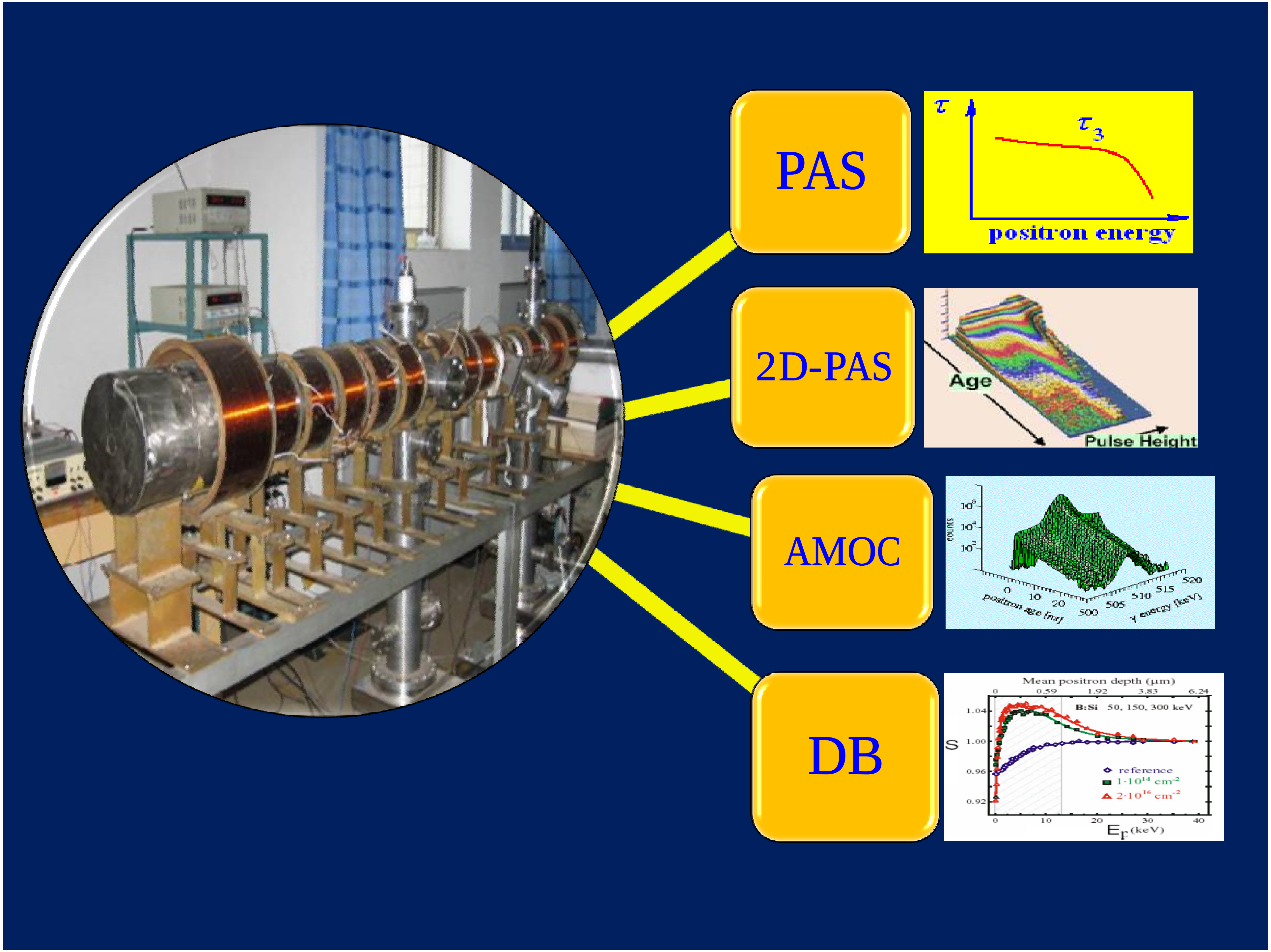
Methods - overview



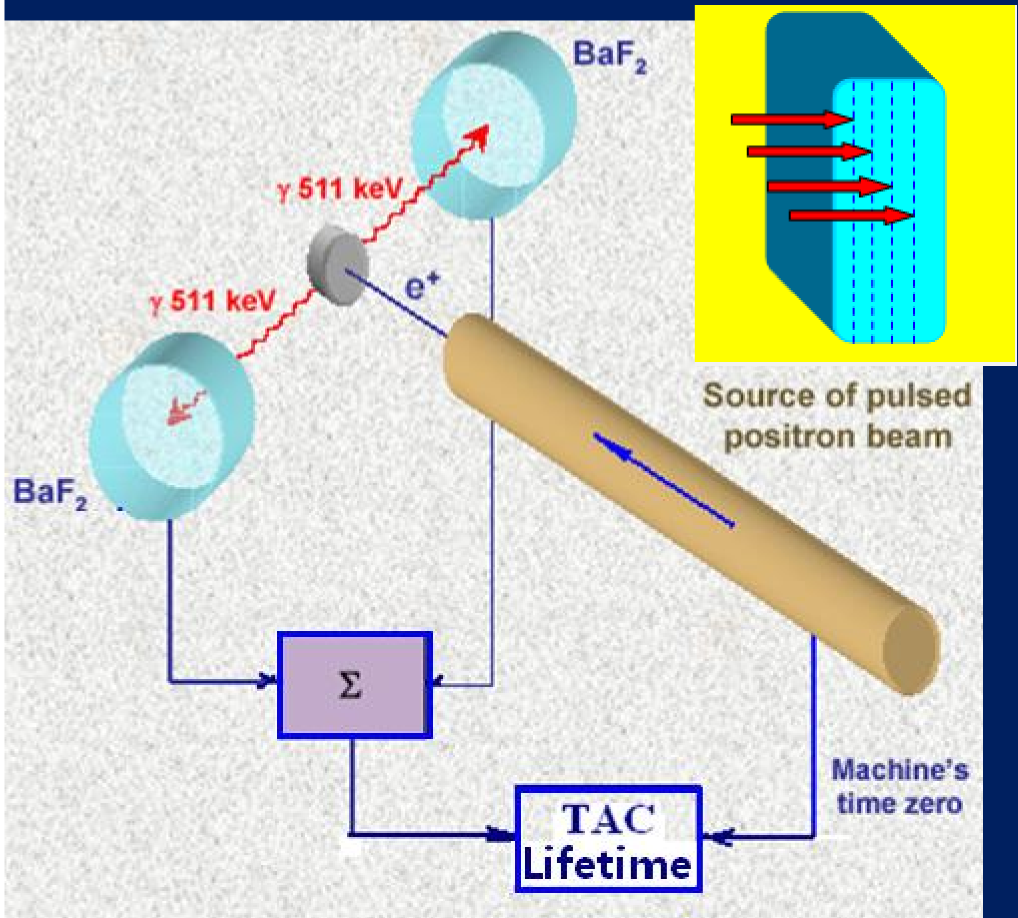
ASAXS – anomalous small angle X-ray scattering
APFIM – atom probe field ion microscopy
EC – Eddy current
MS – Mössbauer spectroscopy
PAS - positron annihilation spectroscopy
SANS – small angle neutron scattering
TEM – transmission electron microscopy
US – ultrasonic waves

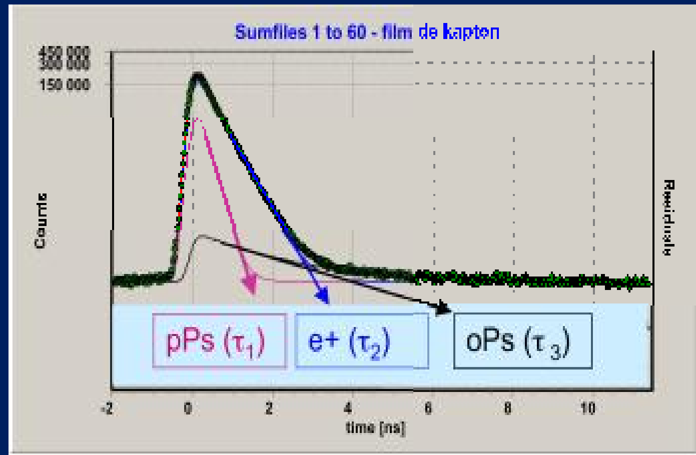
基于脉冲正电子束的探测技术

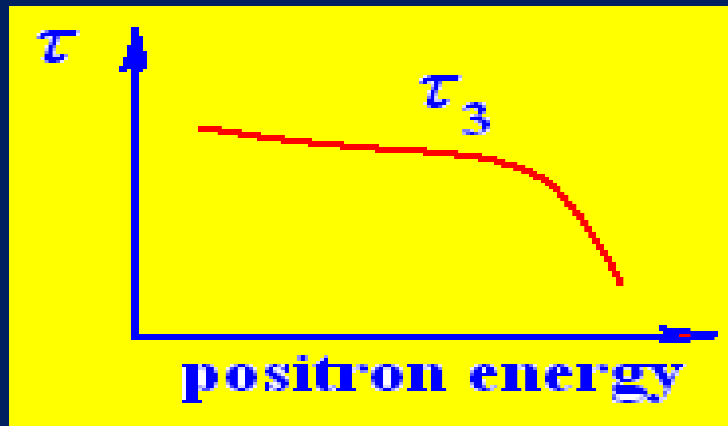


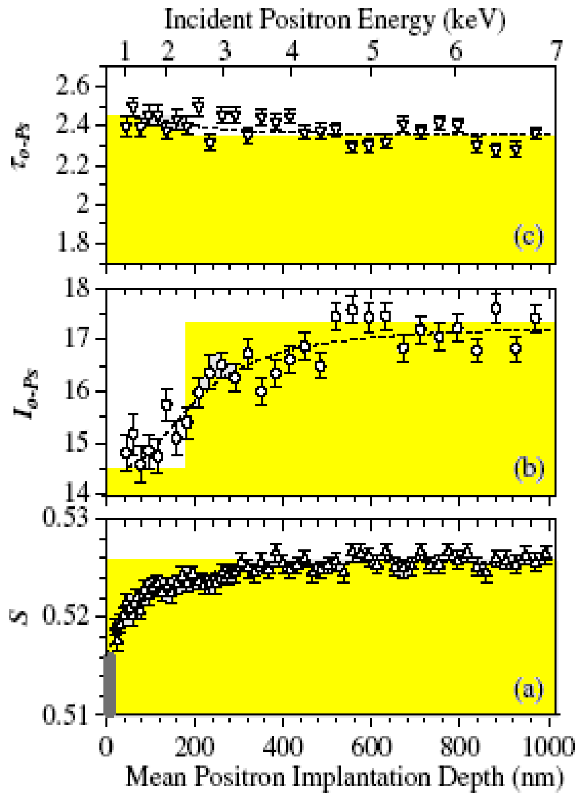

PAS
τ
τ3
positron energy
2D-PAS
Age
Pulse Height
AMOC
counts
positron age [ns]
γ energy [keV]
DB
Mean positron depth (μm)
B:Si 50, 150, 300 keV
S
reference
1·10^14 cm^-2
2·10^16 cm^-2
E_P (keV)

基于脉冲束的数字化寿命谱仪

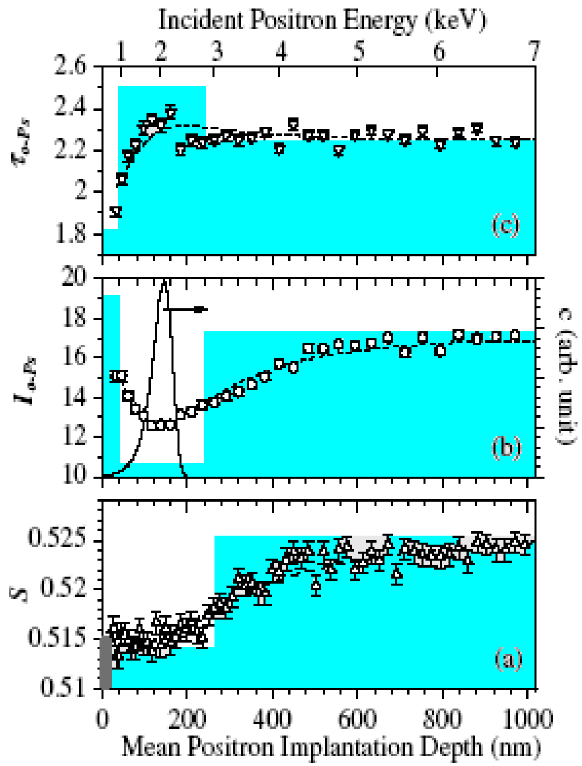




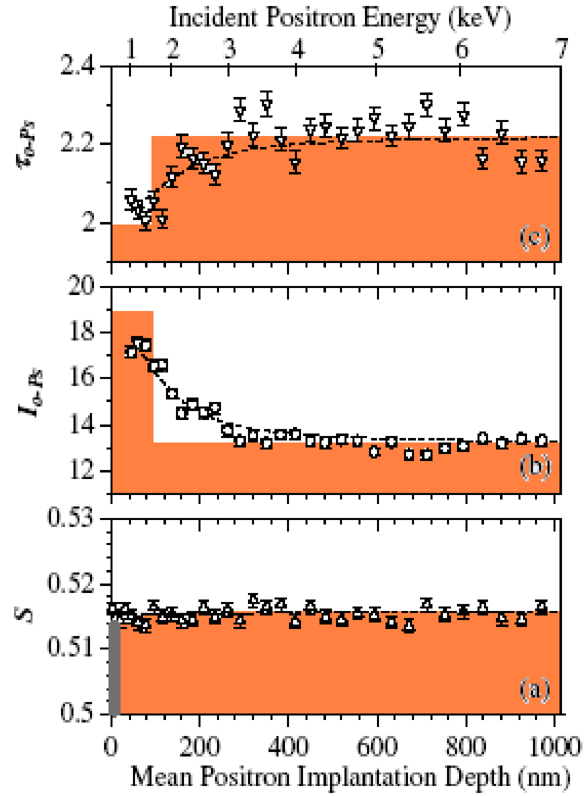




Polyethylene(PE)

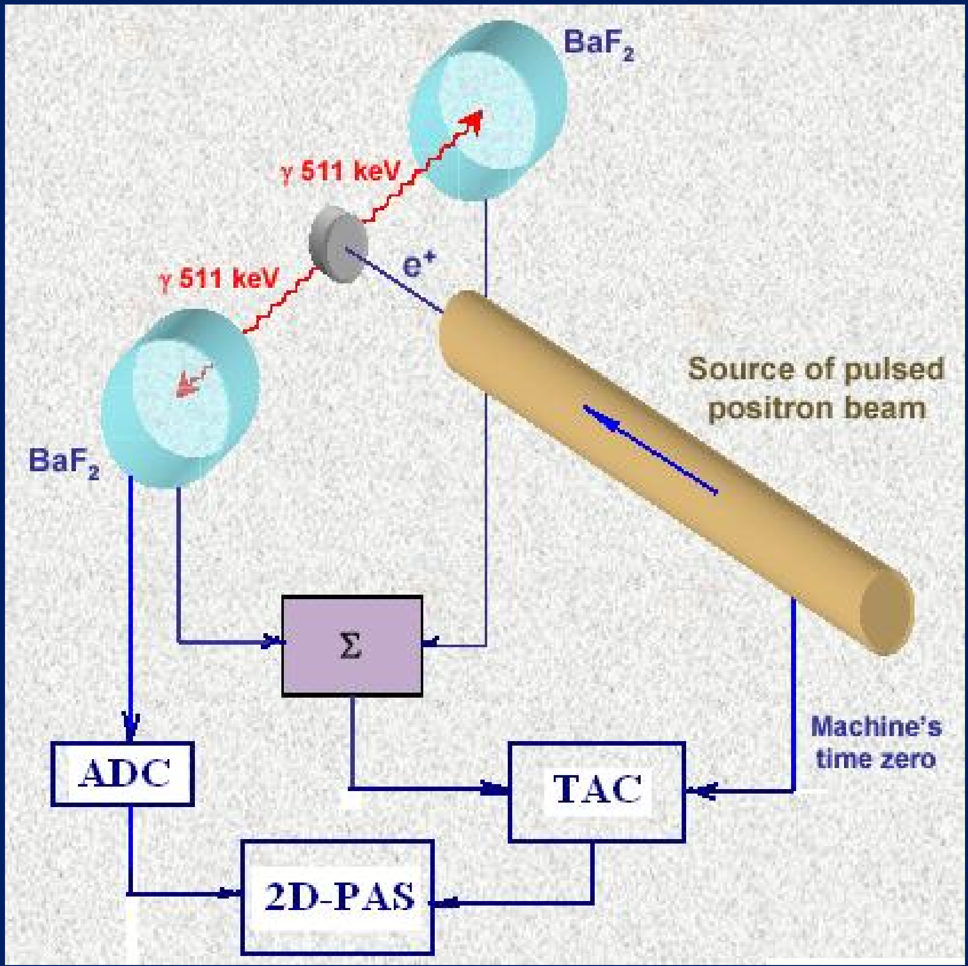


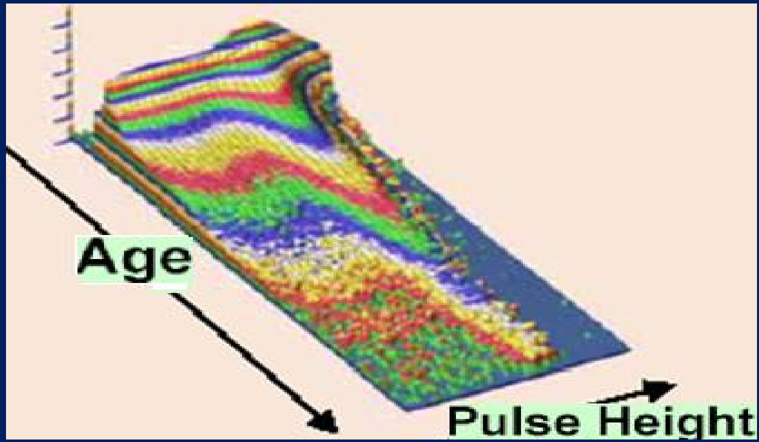
Carbon-implanted ($5*10^{14}$ ions/cm^2) PE

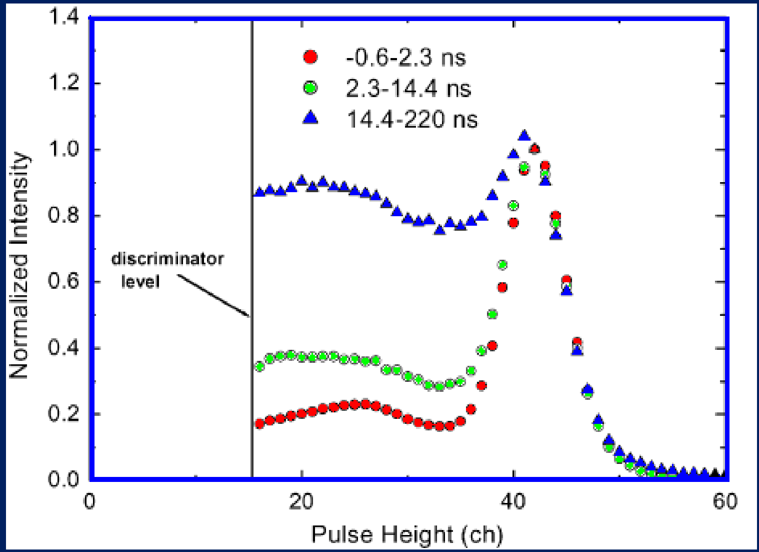


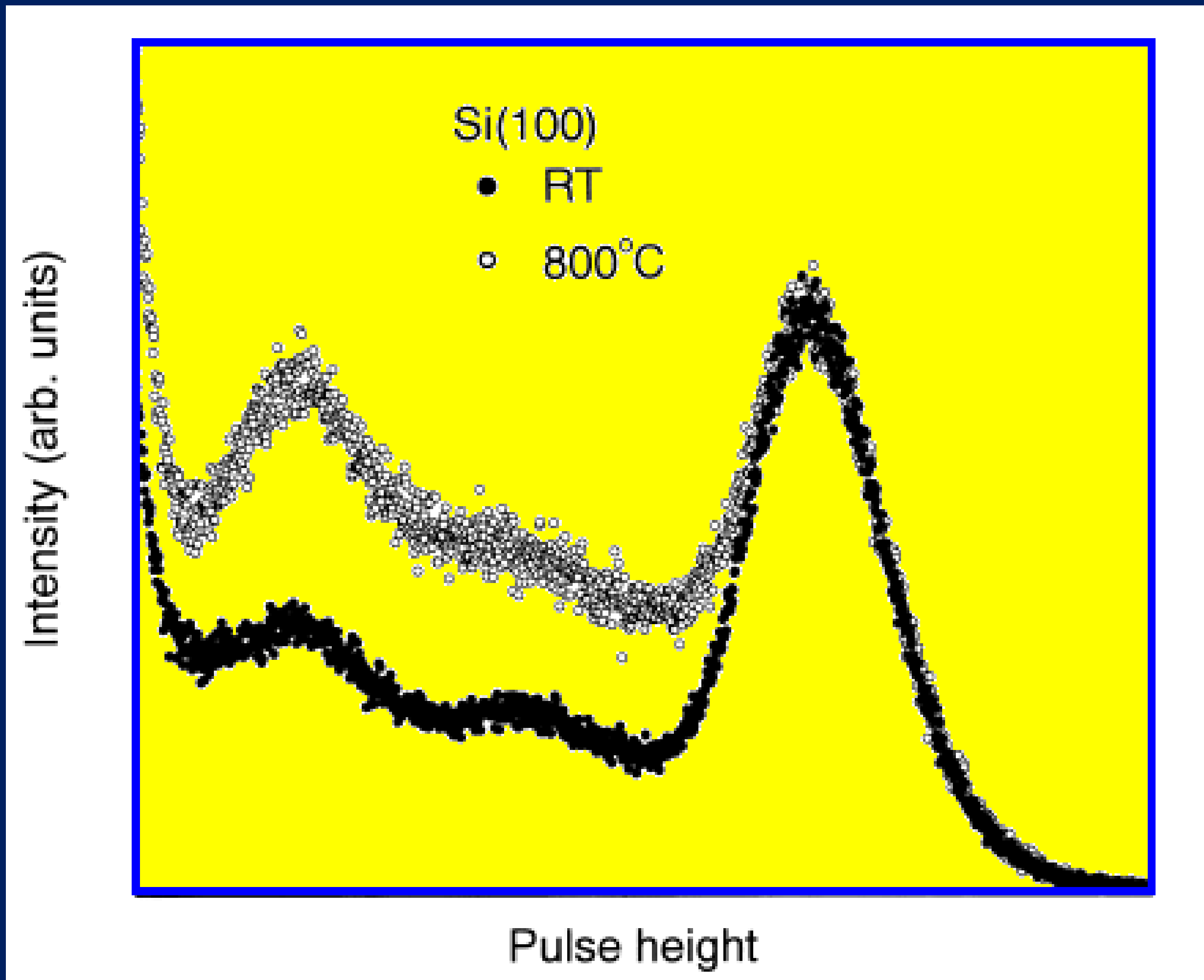
Gamma-irradiated(30kGy) PE

基于脉冲束的数字化幅度-寿命谱仪

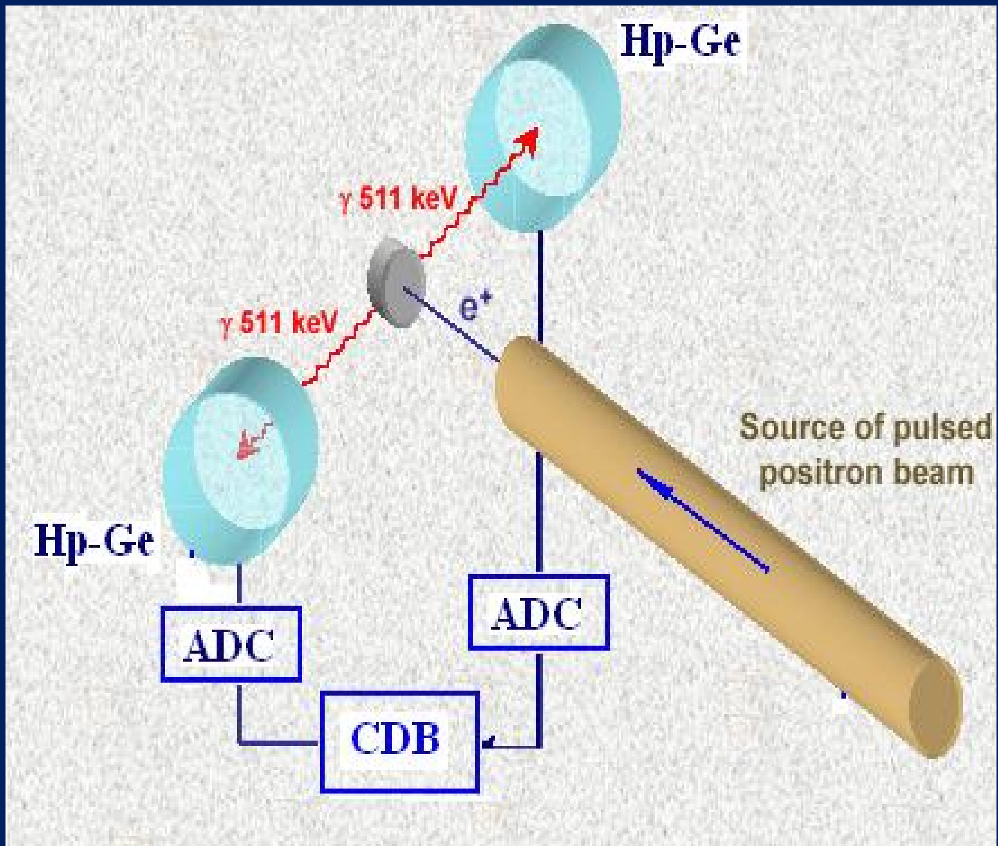


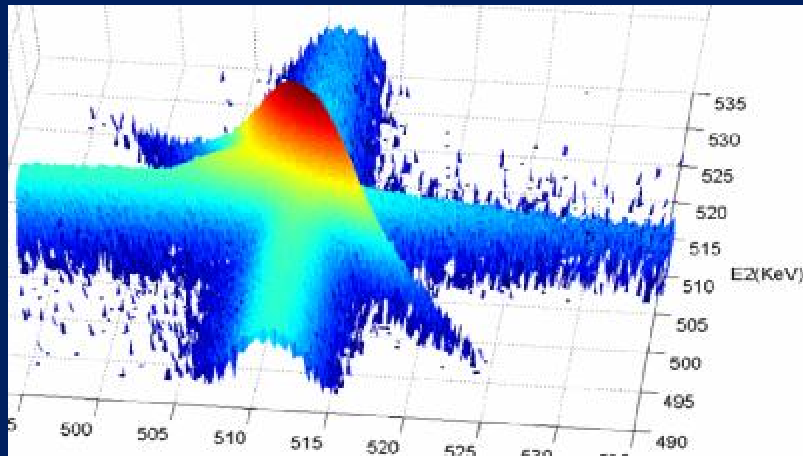


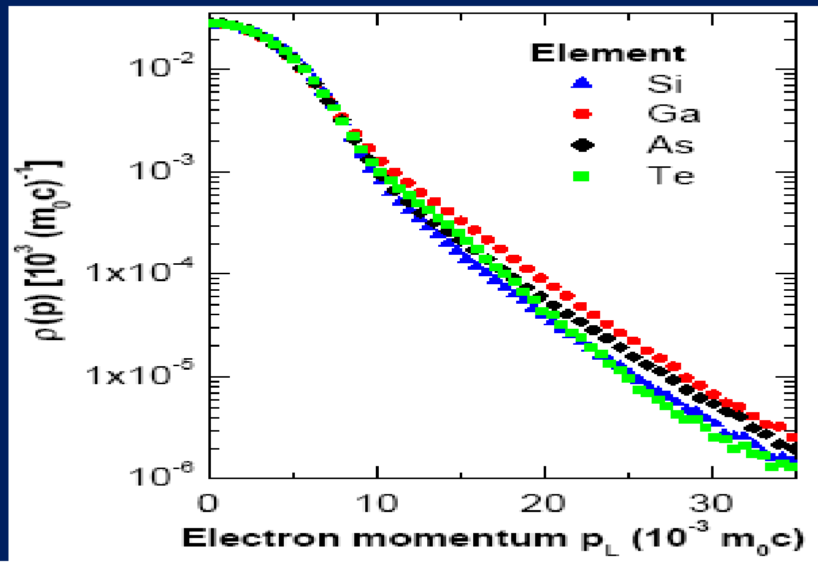



Si(100)
RT
800°C
Intensity (arb. units)
Pulse height

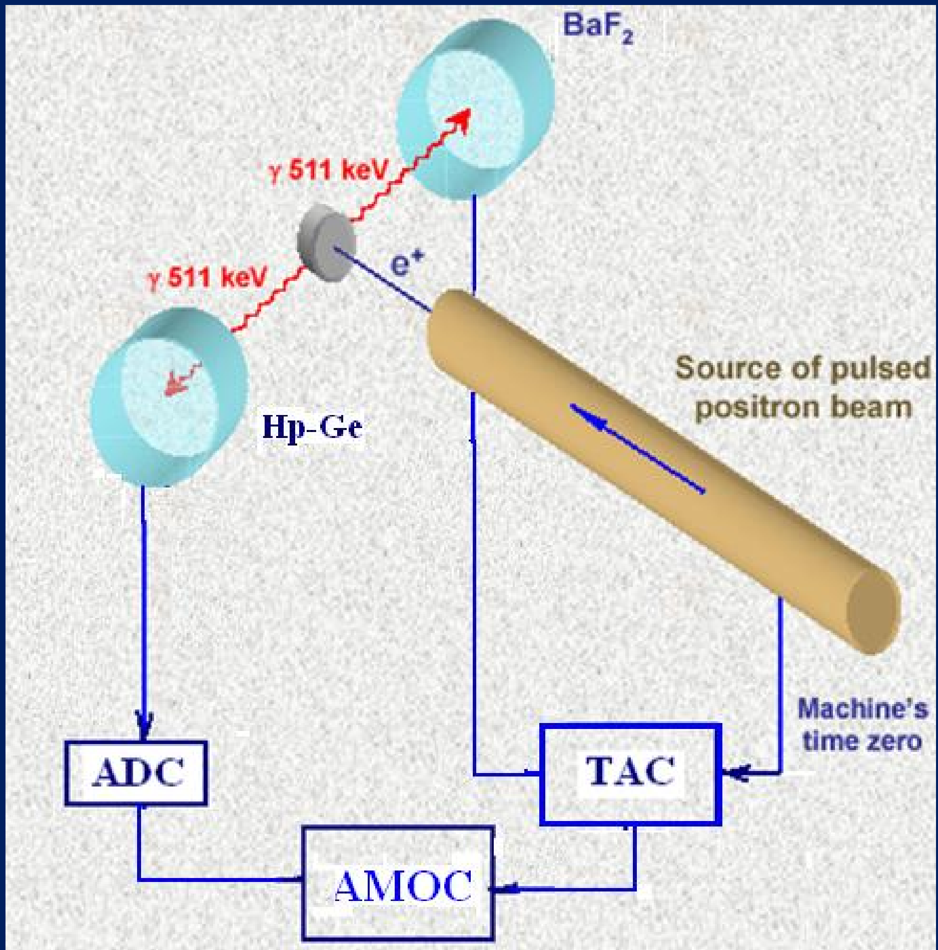
基于脉冲束的数字化双多普勒展宽符合寿命谱仪

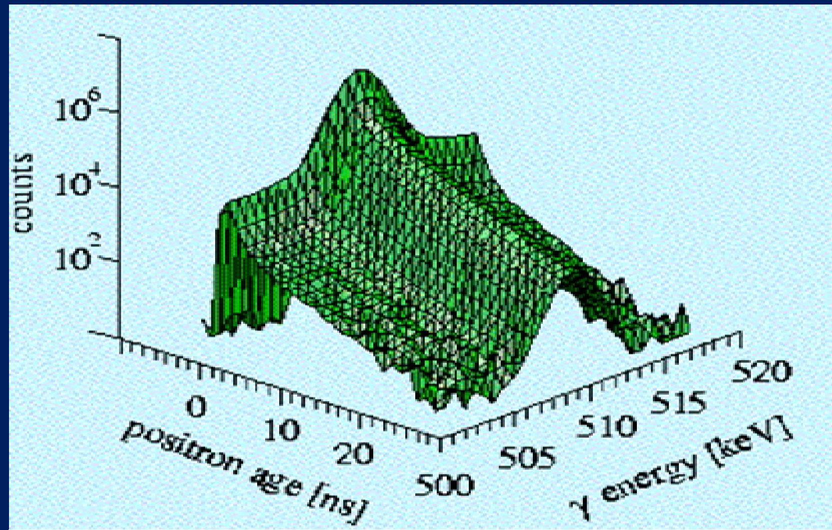


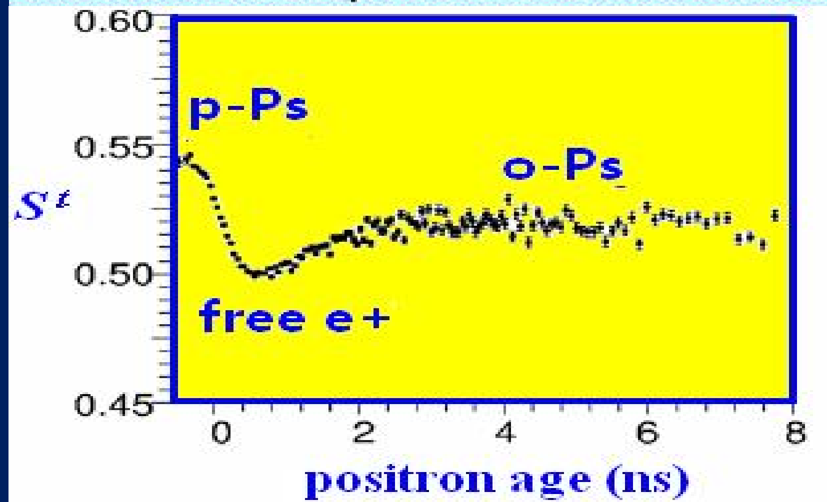




基于脉冲束的数字化寿命-动量关联谱仪







脉冲束寿命谱仪的关键技术

- Time resolution
  - CF-timing technique in digital measurement
  - Triple coincidence improves time resolution
  - Repetition time for long lifetimes
- Cut art in off-line

CF-timing technique in digital measurement

Digital Systems

First important fact

No need to have dedicated start- and stop-tubes.
Simple coincidence for pulses to reduce background-noise is enough.

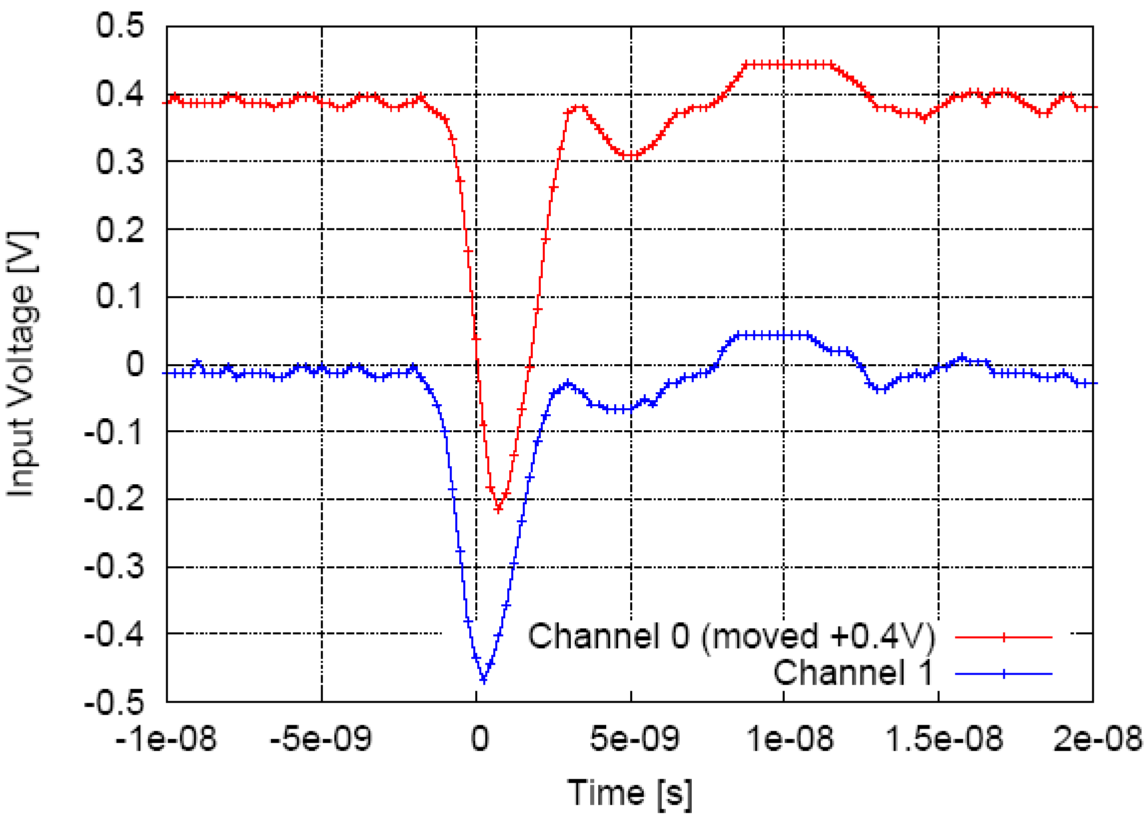
Second important fact

Moore's Law also applies to ideas.

- Current testing includes two tubes either in 90°- or 180°-Setup.
- Tubes are directly connected to digitizers, no external amplification is applied.
- For better S/N-Ratio an external coincidence (logical AND) is used to trigger data acquisition only on good pulse-pairs.

I Time resolution

Extracting the time-information is the crucial part of the system.



Lets look at different ways to extract the timing-information:

Constant Fraction: **Polynom-Fit**

1. Finding the minimum and interpolating it.
2. Interpolate constant fraction of minimum - baseline

Resolution

Several groups have resolution of 200ps to 250ps.
Own measurements (see Demo) are around 170ps with ^{60}Co.

Constant Fraction: **Gauss-Fit**

1 Apply fit of Gauss-Function: $y = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{s\sigma^2}}$

Resolution

[Aavikko, 2004 NIM A]: 200ps - 220ps

Constant Fraction: **Spline**

1. Smoothing the wave-form
2. Cubic spline interpolation

Resolution

[Saito, 2001] with a 4GS/s digitizer on ^{60}Co: 118ps
[Aavikko, 2004 ACTA] with a 2GS/s digitizer on SiC: 146.7ps

Constant Fraction: **integrals (iCF)**

1. Search for minimum
2. Integrate around minimum
3. Constant fraction with simple polynom-interpolation on integrated pulse

Resolution

A resolution of ~100ps is reached with ^{60}Co and 4GS/s digitizers.

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The asset of ultra-fast digitizers for positron-lifetime spectroscopy

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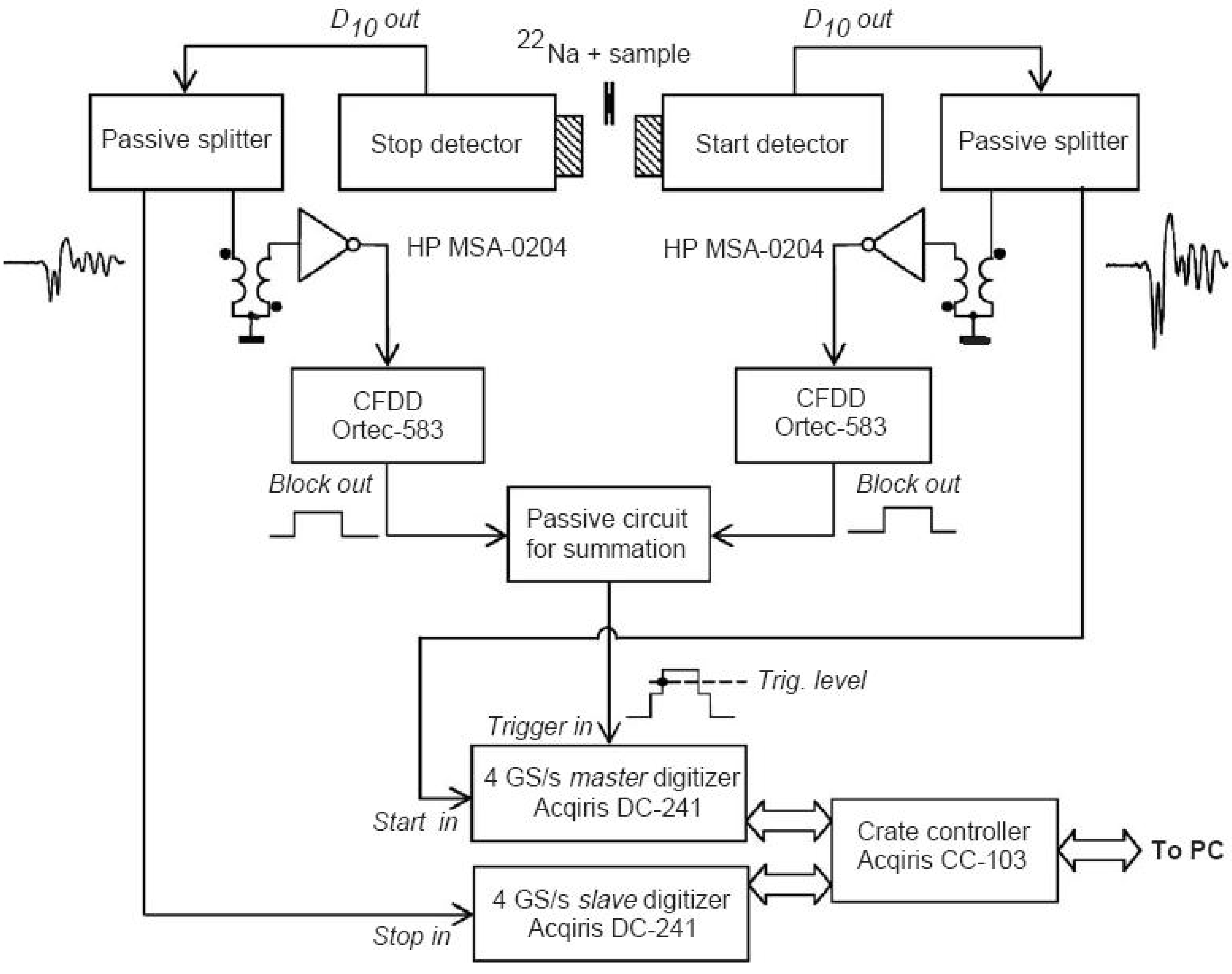
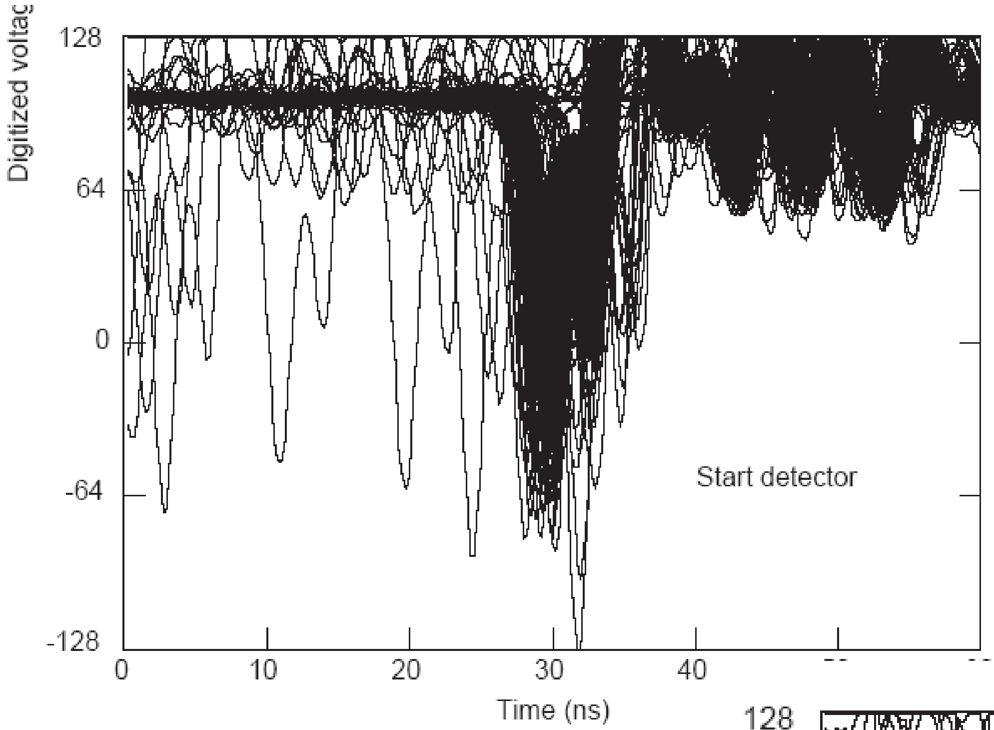


Fig. 1. Block scheme of the setup based on the exploitation of the Acqiris DC-241 digitizers.



As obtained detector waveforms

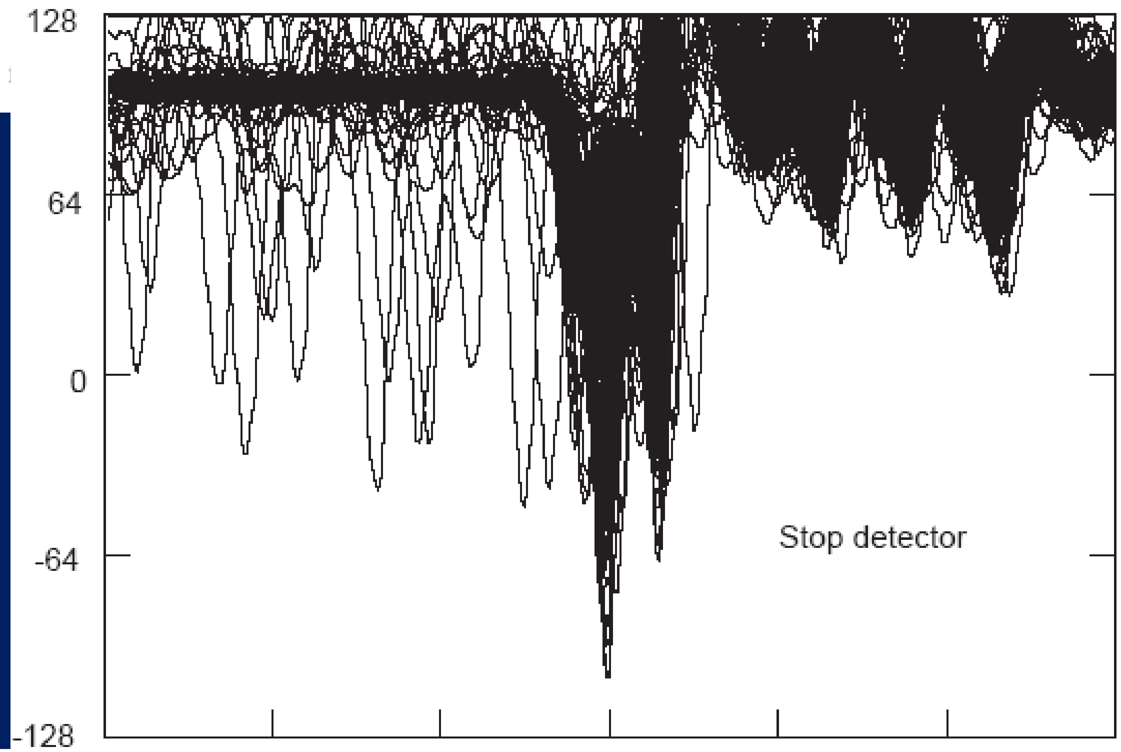


Fig. 2. Two sets of 200 waveforms obtained by sampling the signals

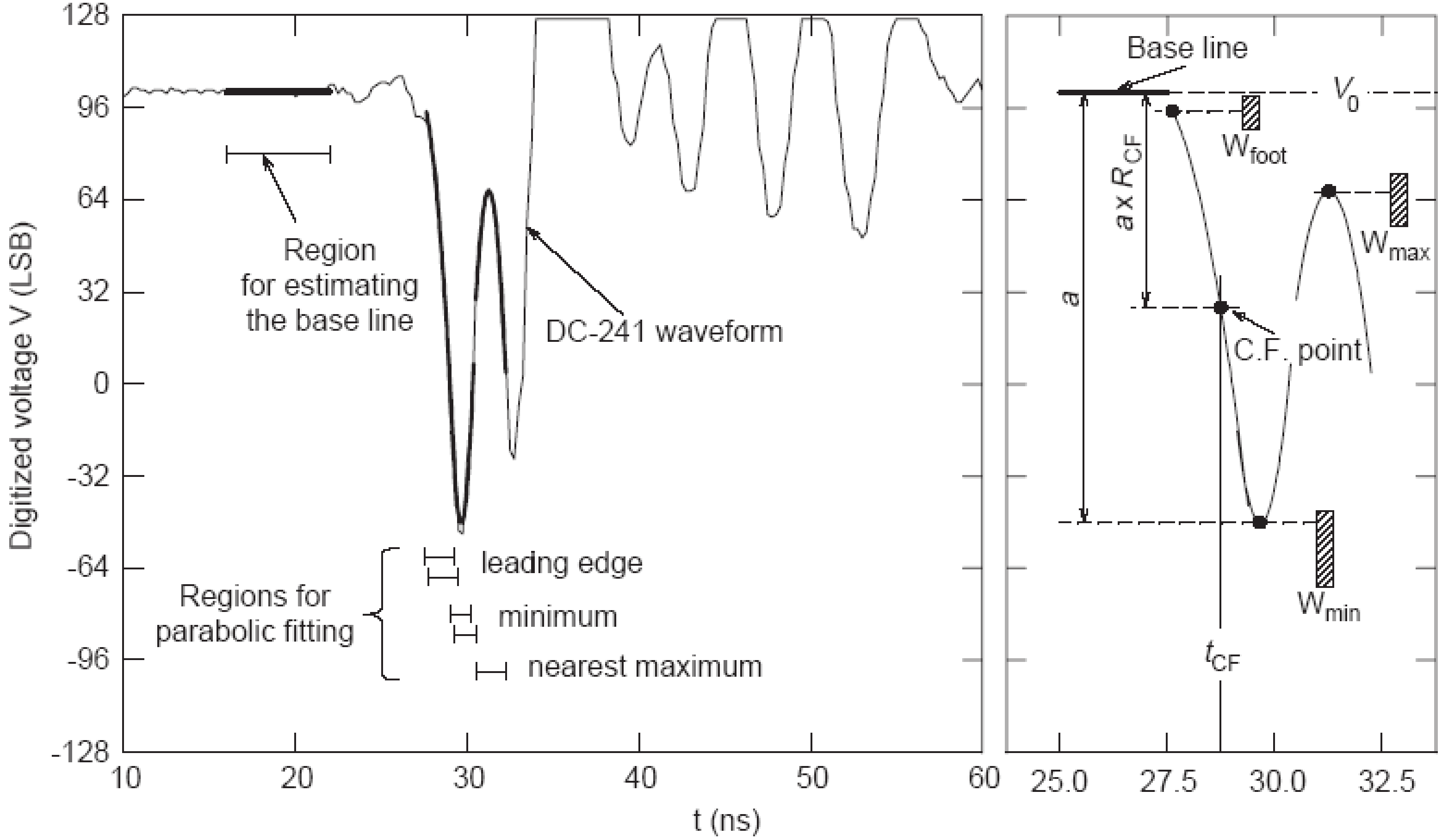


Fig. 3. An example of parabolic approximations of critical sections of a waveform. The right-hand side of this figure elucidates the method for extracting the detection time t_{CF} by the method of constant fraction.

(8) If the above-outlined conditions are fulfilled, the constant-fraction (CF) method is applied for the determination of the detection time, as illustrated in Fig. 3. Expressing the offset-corrected leading-edge parabola as

$$U(t) \equiv V(t) - V_0 = q_0 + q_1 t + q_2 t^2 \qquad (1)$$

the detection time t_{CF} is determined as a root of the quadratic equation:

$$U(t) = -aR_{CF},$$

where R_{CF} is a prefixed [redacted] explanation see the right-hand [redacted]

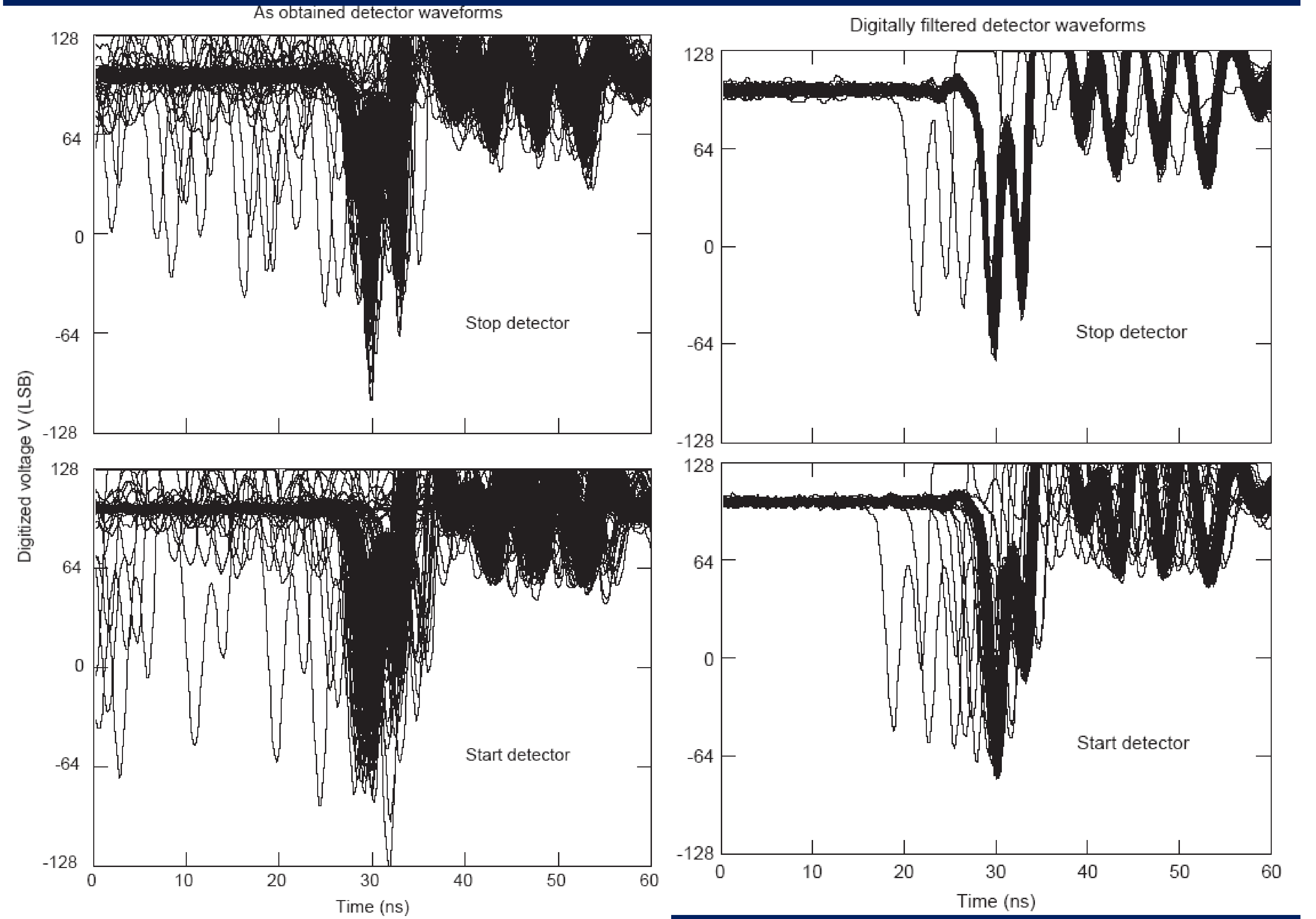
(9) Knowing the co-ordinates of the CF point, a logarithmic derivative of the offset-corrected leading edge at this point is determined

$$\left[\frac{\mathrm{d}}{\mathrm{d}t}\ln U(t)\right]_{t=t_{CF}} = -\frac{q_1 + 2q_2 t_{CF}}{aR_{CF}}. \qquad (3)$$

If its value is higher than a pre-fixed minimum allowed value, in our case

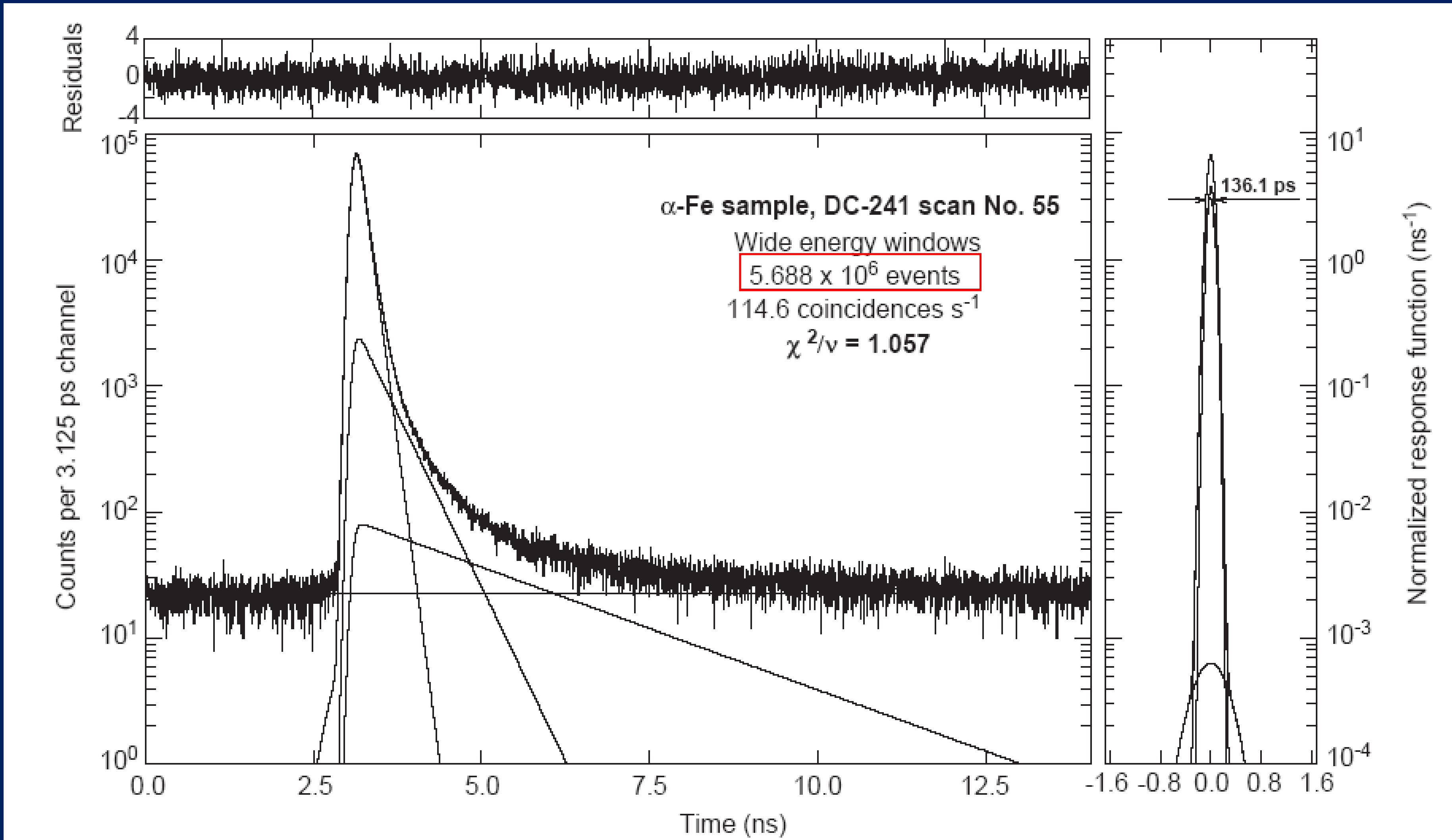
$$\left[\frac{\mathrm{d}}{\mathrm{d}t}\ln U(t)\right]_{t=t_{CF}} > 1.175\ \mathrm{ns}^{-1}, \qquad (4)$$

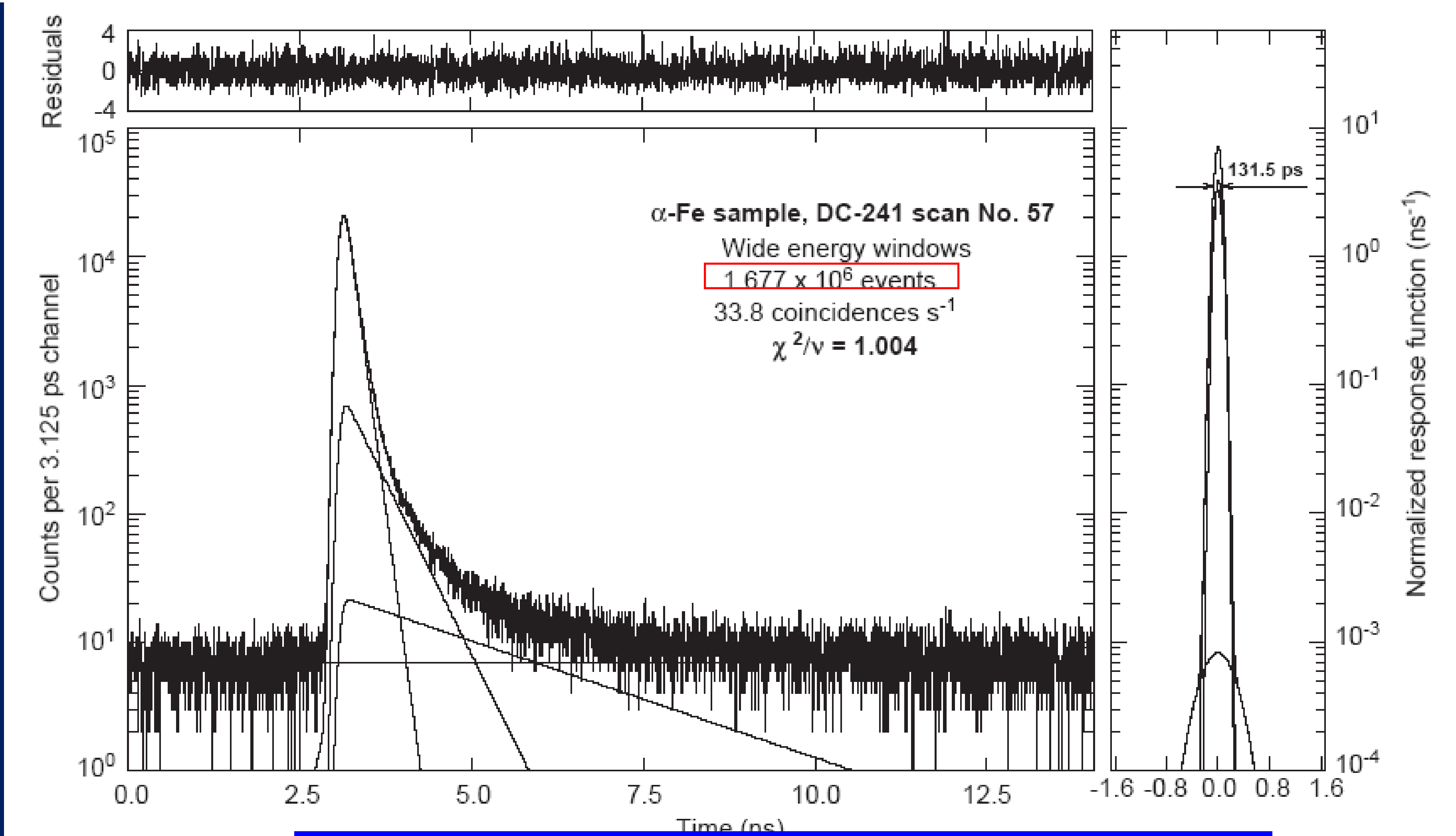
the deduced detection time t_{CF} is accepted for further analysis.



As obtained detector waveforms
Digitally filtered detector waveforms
Digitized voltage V (LSB)
128
64
0
-64
-128
Stop detector
Start detector
0
10
20
30
40
50
60
Time (ns)

13.75h, $4.2*10^7$events





	Setup with DC-241 digitizers		Fast–fast setup
measurement (h)	13.75	13.75	29.0
Number of coin	5.688×10^6	1.667×10^6	13.05×10^6
$\tau_1{}^a$ (ps)	107.8±0.3	108.7±0.5	107.9±0.2
τ_2 (ps)	394.1±4.9	402.9±4.8	368.0^b
τ_3 (ps)	2235±66	2398±136	1616±19
$FWHM_{tot}$ (ps)	136.1	131.5	173.0

- A three-detector setup
- the DC-241 digitizers
- $FWHM_{tot}$ =105 ps has to be reached.

The magic resolution barrier of 100 ps will be broken very soon!

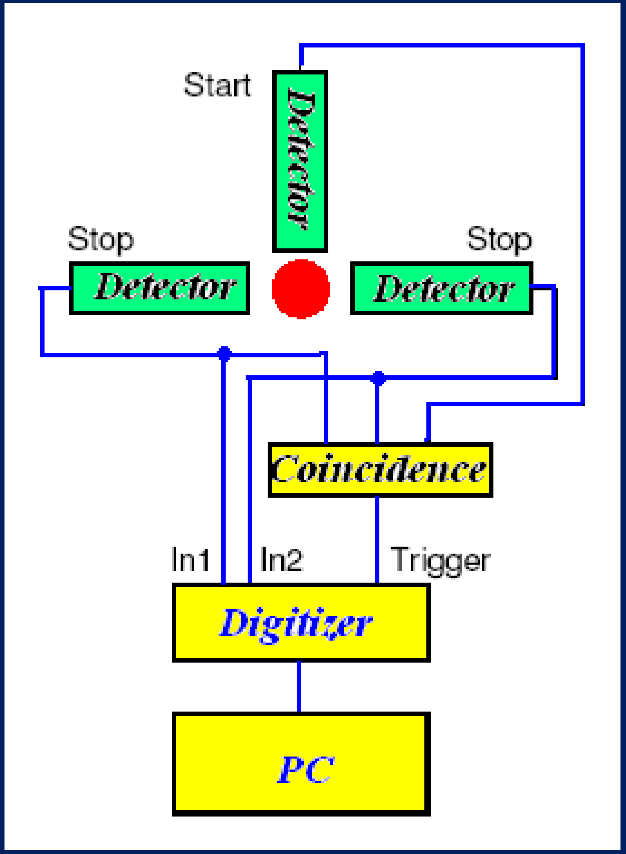
Comparing the results

Method	Resolution
Analog measurements	$>$200ps
Polynom-Fit	200-250ps own: 170ps
Gauss-Fit	200ps - 220ps
Smoothing Spline	118ps - 150ps
integral CF	$\sim$100ps

Table 1
Summary of the results from the benchmark testing measurements with two setups for positron-lifetime measurements

Quantity	Setup with DC-241 digitizers		Fast–fast setup
	Scan No. 55	Scan No. 57	
Duration of measurement (h)	13.75	13.75	29.0
Number of coincidences	5.688×10^6	1.667×10^6	13.05×10^6
Energy ranges:			
$\Delta E_\gamma^{(stop)}$ (keV)	233	132	
$\Delta E_\gamma^{(start)}$ (keV)	510	318	
Lifetimes and intensities:			
τ_1 [a] (ps)	107.8±0.3	108.7±0.5	107.9±0.2
τ_2 (ps)	394.1±4.9	402.9±4.8	368.0[b]
τ_3 (ps)	2235±66	2398±136	1616±19
I_1 [a] (%)	91.57±0.12	91.69±0.21	90.99±0.04
I_2 (%)	7.33±0.11	7.25±0.19	7.62±0.05
I_3 (%)	1.10±0.02	1.06±0.04	1.39±0.01
Parameters of response function:			
$FWHM_1$ [c] (ps)	125.3	121.4	155.3
$FWHM_2$ [c] (ps)	151.6	143.3	184.2
$\delta_{1,2}$ (ps)	13.1	13.4	36.2
$FWHM_3$ (ps)	666.6	651.3	522.7
G_3 (%)	0.045±0.011	0.057±0.020	0.632±0.033
$FWHM_{tot}$ (ps)	136.1	131.5	173.0
Quality of fit:			
χ^2	4739.9	4502.7	3063.0
ν	4483	4483	2984

Triple coincidence improves time resolution

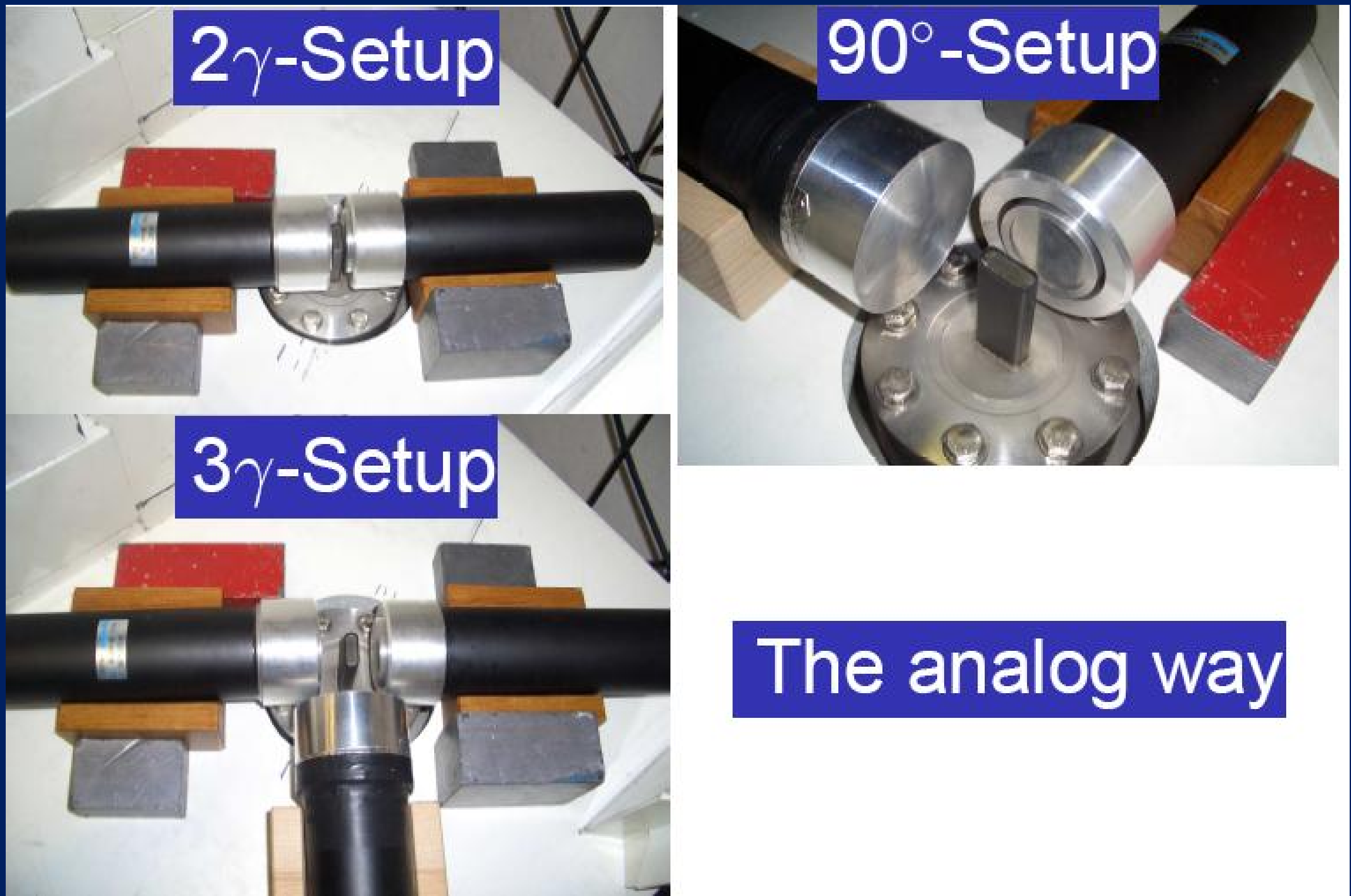


Advanced positron lifetime spectroscopy for pulsed positron beams

R. Krause-Rehberg*, S. Eichler, F. Börner, F. Redmann

MARTIN-LUTHER-UNIVERSITÄT
HALLE–WITTENBERG

The analog way



Triple coincidence improves time resolution

- When measuring also the lifetime by using the second 511 keV γ quantum (times t_1 and t_2, Fig. 2), the time resolution can be improved by averaging the two values (improvement factor: $1/\sqrt{2}$)
- By substracting t_2-t_1, the resolution function itself could be measured. The background should be strongly suppressed.
- Monte-Carlo simulations show the improvement for the resolution function and for the lifetime spectrum (Fig. 3).
- Both improvements are only possible for the fraction of the resolution function which originates from the stop channel.
- Hence, best application is expected for pulsed beams with small time spread of incoming positron beam.

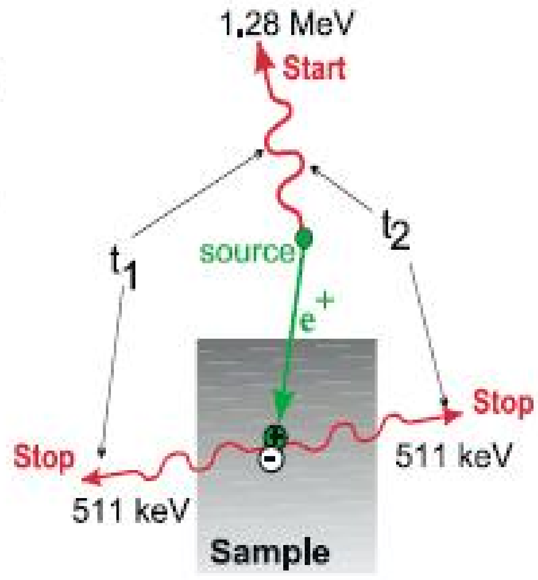


Fig. 2

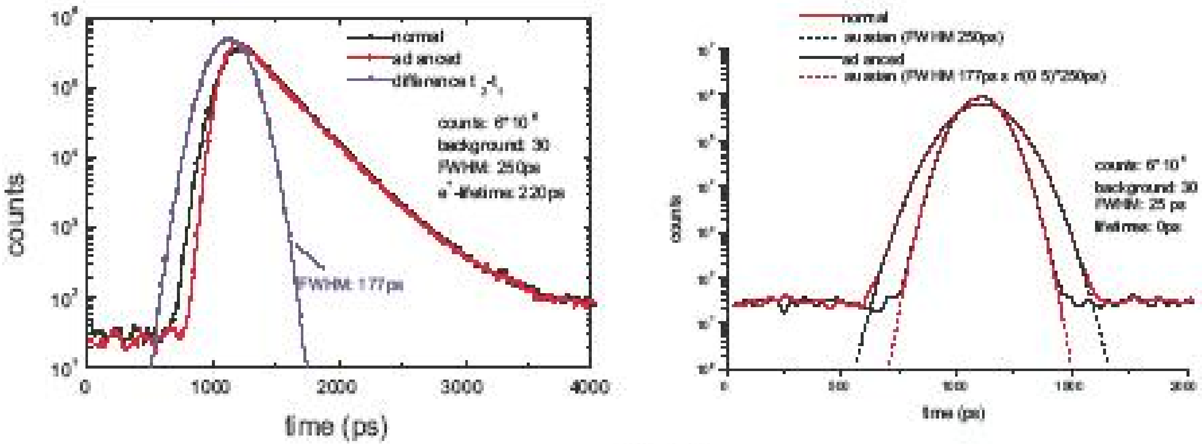


Fig. 3

Realization using a ^{22}Na source

- For testing the principle, the advanced positron lifetime was realized by using an ^{22}Na source and detectors for all three γ quanta (Fig. 4)..
- Data collection was done using a FAST-ComTec two-dimensional coincidence system in list mode (t_1 and t_2 are stored together as a pair).
- The calculation of $(t_1+t_2)/2$ and t_2-t_1 was performed after completing the measurement.

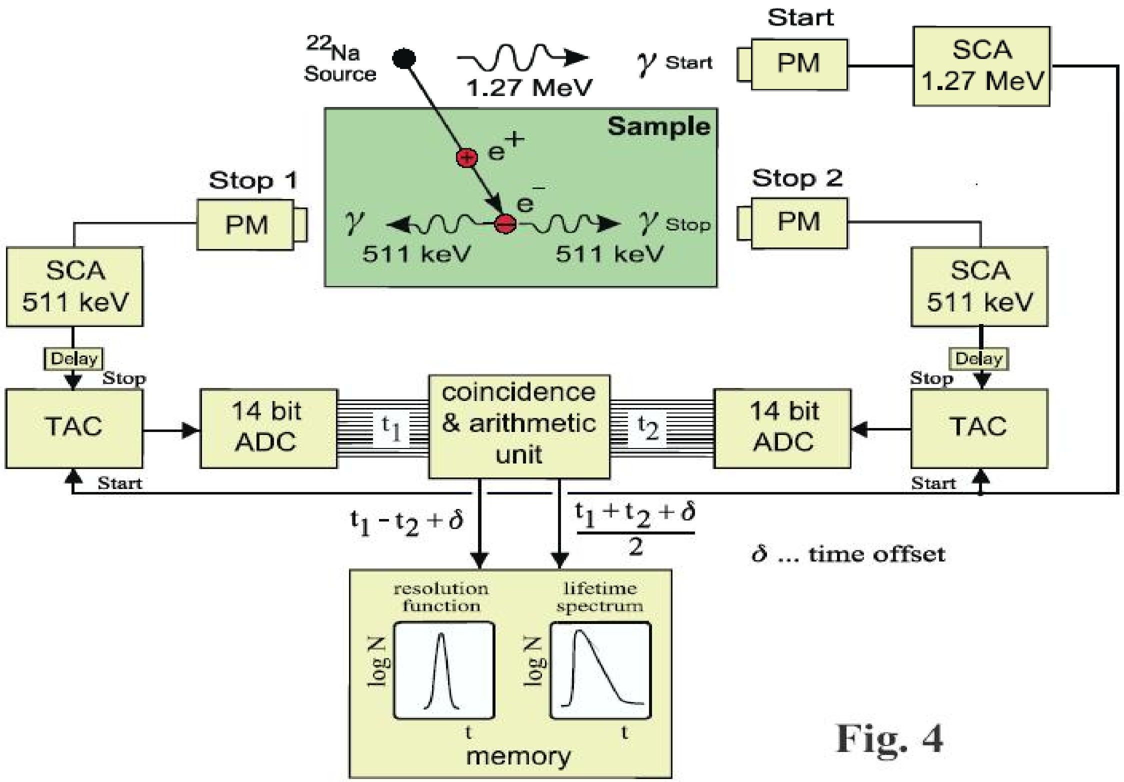


Fig. 4

Results of experiments

- Fig.5 shows the result of the above described test measurements as a 3D-plot. As expected, the coincident spectrum showed only a slight improvement of the time resolution from 240 to 220 ps (FWHM) due to the non-neglectable contribution of the start detector to the resolution function.
- The background was low in the complete t_1-t_2-plane, but surprisingly high in the diagonal. This is due to backscattered 1.27 MeV γ quanta which start the time measurement and still causes a stop pulse. This can be avoided in a beam system where no such high-energy quanta are present at the sample position. Then, a strong background suppression is possible even for a high-brigthness positron source.

For example, pulsed beam

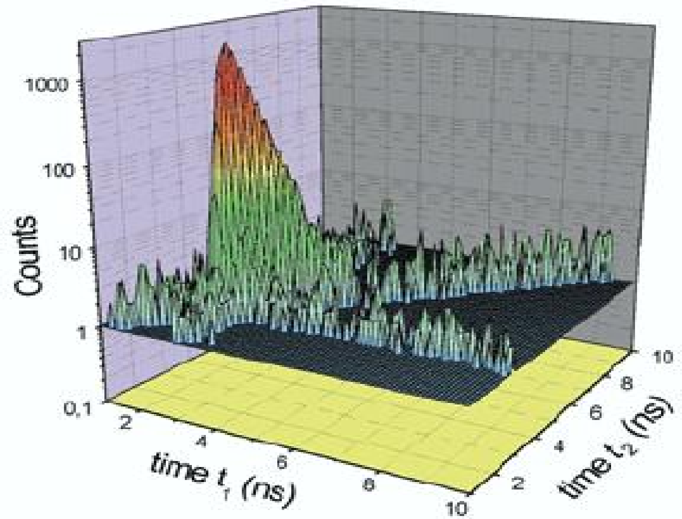


Fig. 5

Application at a high-brightness pulsed beam

- The ideal application is a pulsed positron beam at a strong source. Here, one can make use of all advantages of the triple-coincidence technique. Fig. 6 shows a possible setup.
- A multidetector system is necessary for a high counting rate.

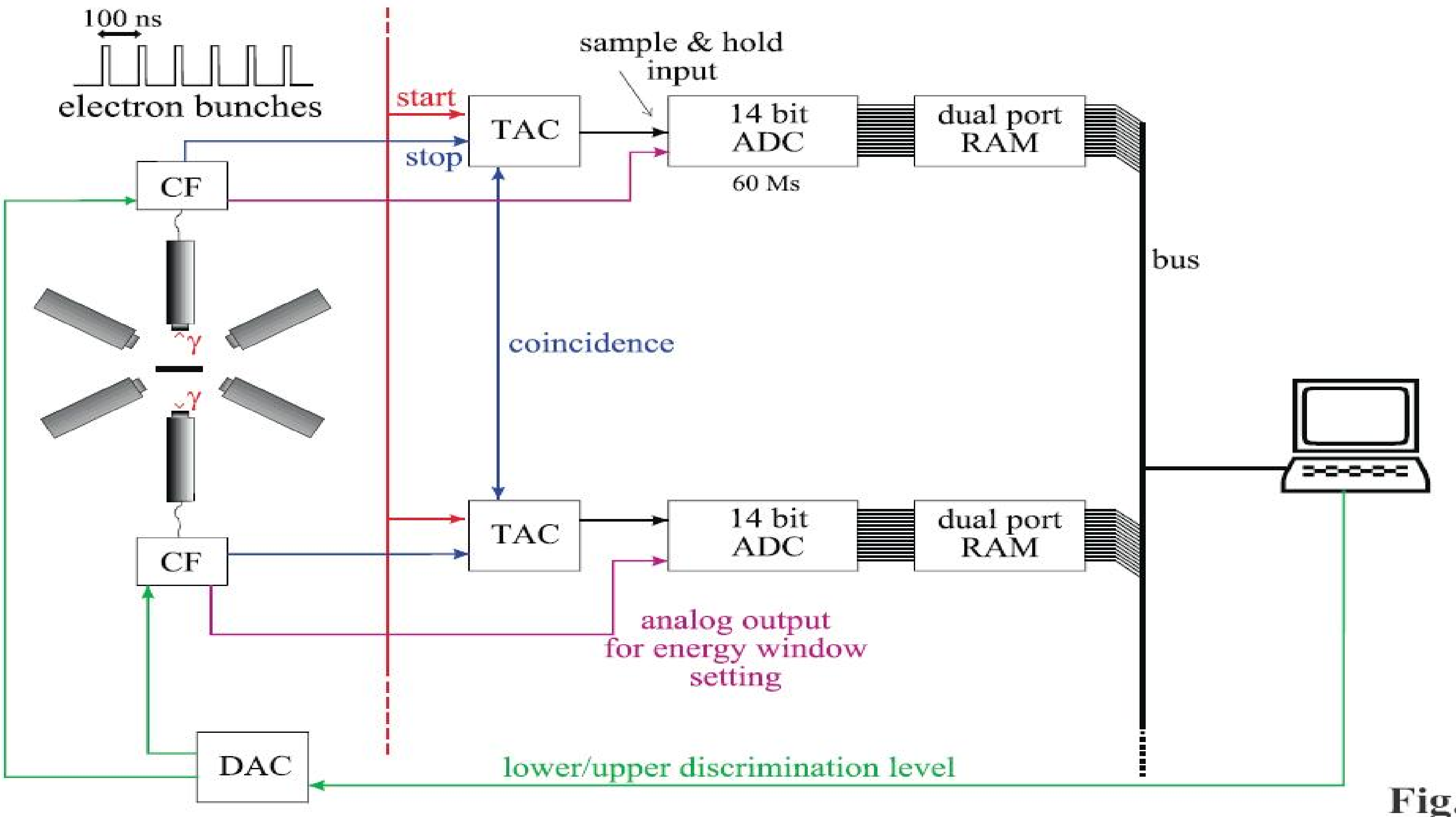
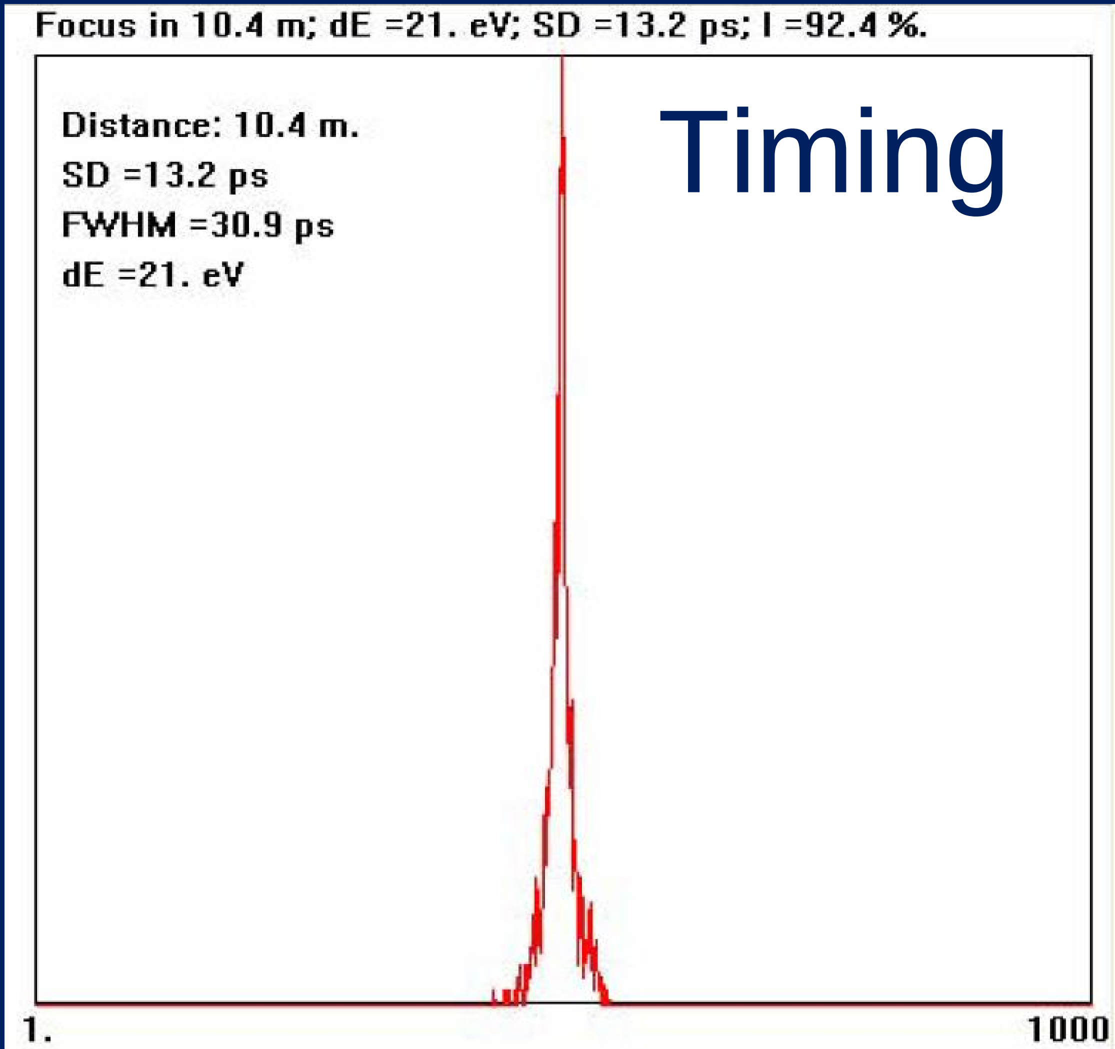


Fig. 6

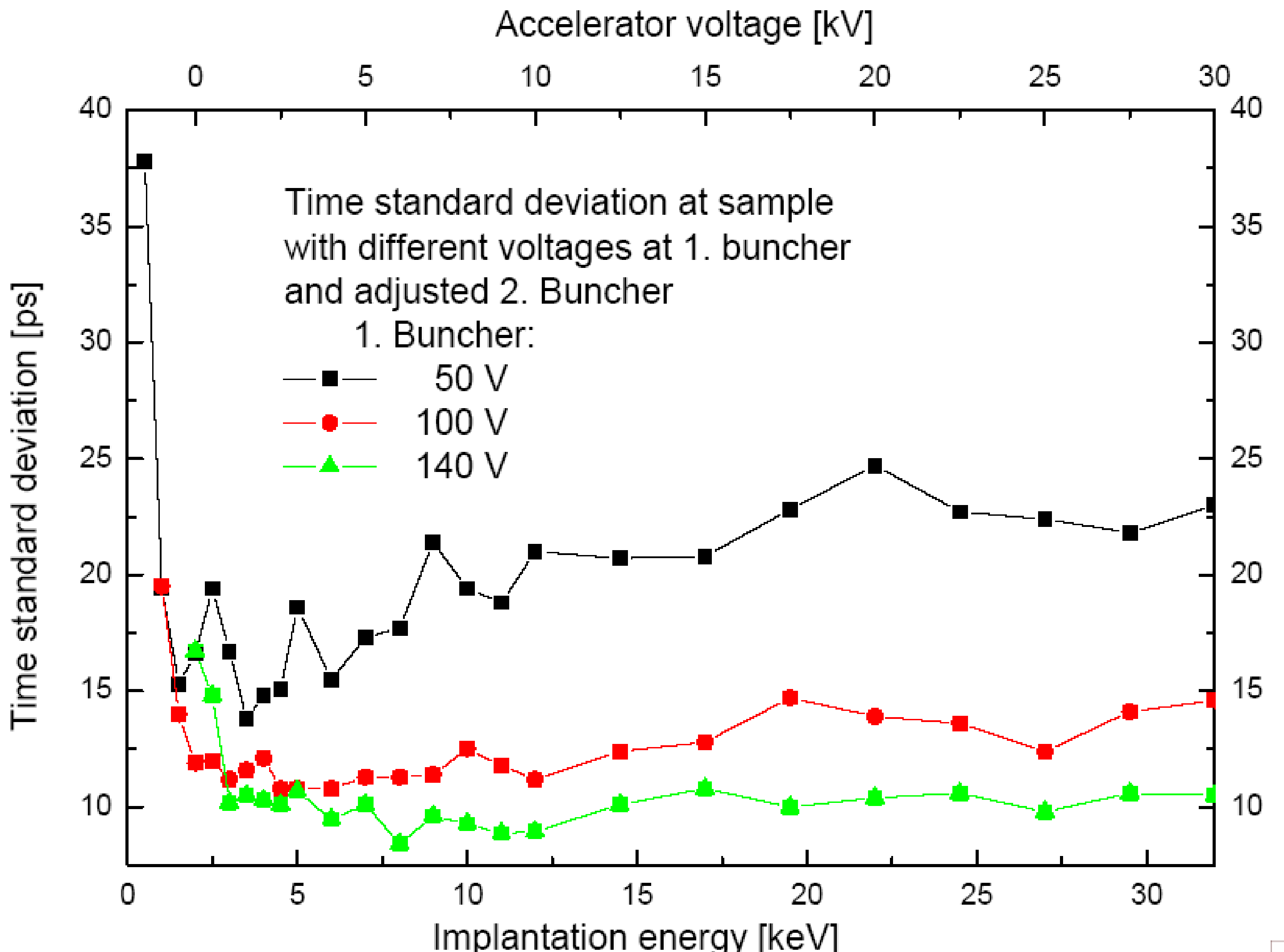
Conclusions

- The detection of both annihilation γ quanta allows the improvement of the time resolution of a positron lifetime measurement. This is especially useful when a pulsed positron beam with a small time spread of the positron bunches is used.
- The fraction of the resolution function originating from the stop pulse can be measured directly.
- The background can be suppressed strongly by the additional coincidence circuit when the 1.27 MeV quanta are not present at the sample position (at a positron beam).
- The advanced positron lifetime technique is not suiatable for a laboratory system using a ^{22}Na source (low counting rate and only partially realization of improvements).
- The application of this technique is strongly recommended for the positron lifetime spectroscopy at a high-brightness positron source. Then, also the source contribution to the spectrum is avoided.

脉冲束重复频率对测量长寿命的限制



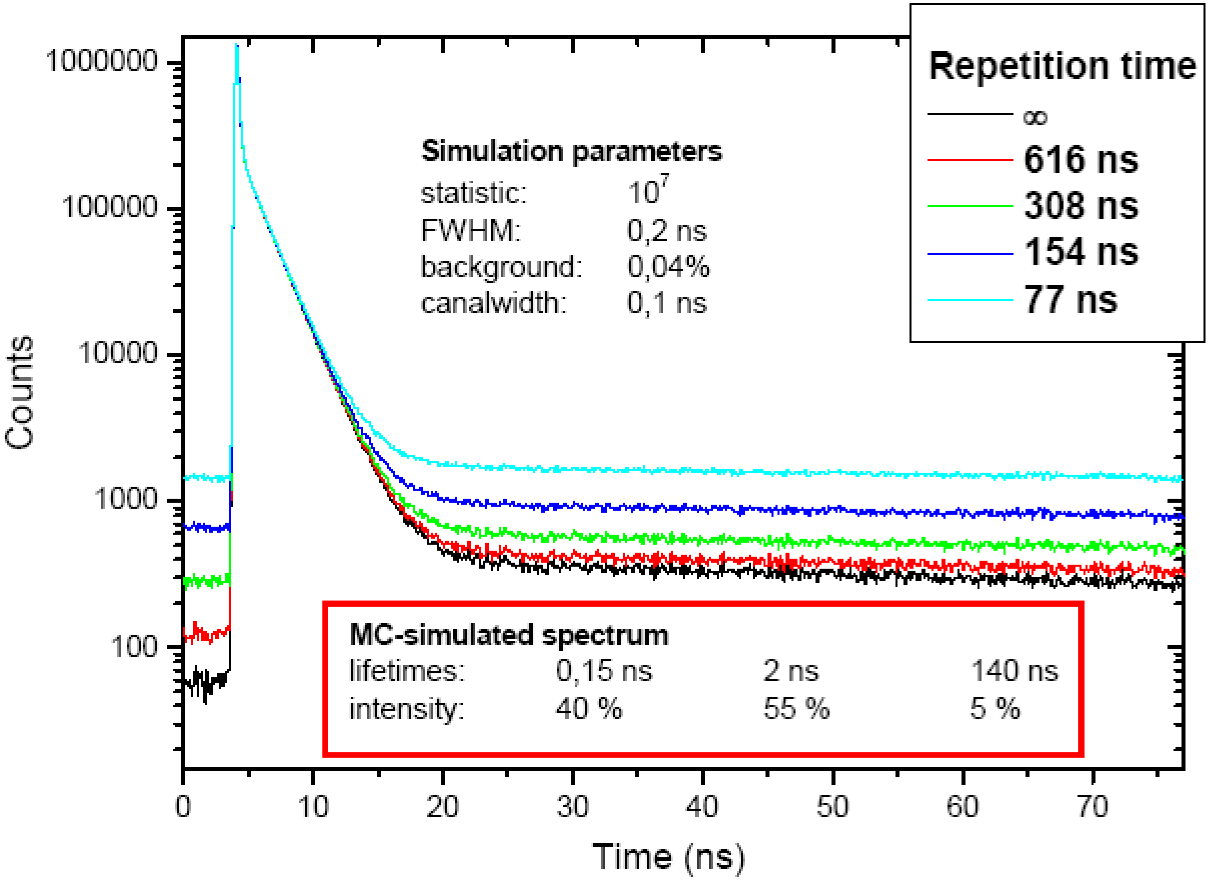
Both buncher RF-voltage amplitudes and the drift path energy must be adjusted for each beam energy for optimum time resolution



Second timing mode needed for long lifetimes

- question: How long repetition time to measure a lifetime of 142 ns?
- we MC-simulated a 3-component spectrum with τ_1=150 ps, τ_2 = 2 ns, τ_3 = 140 ns

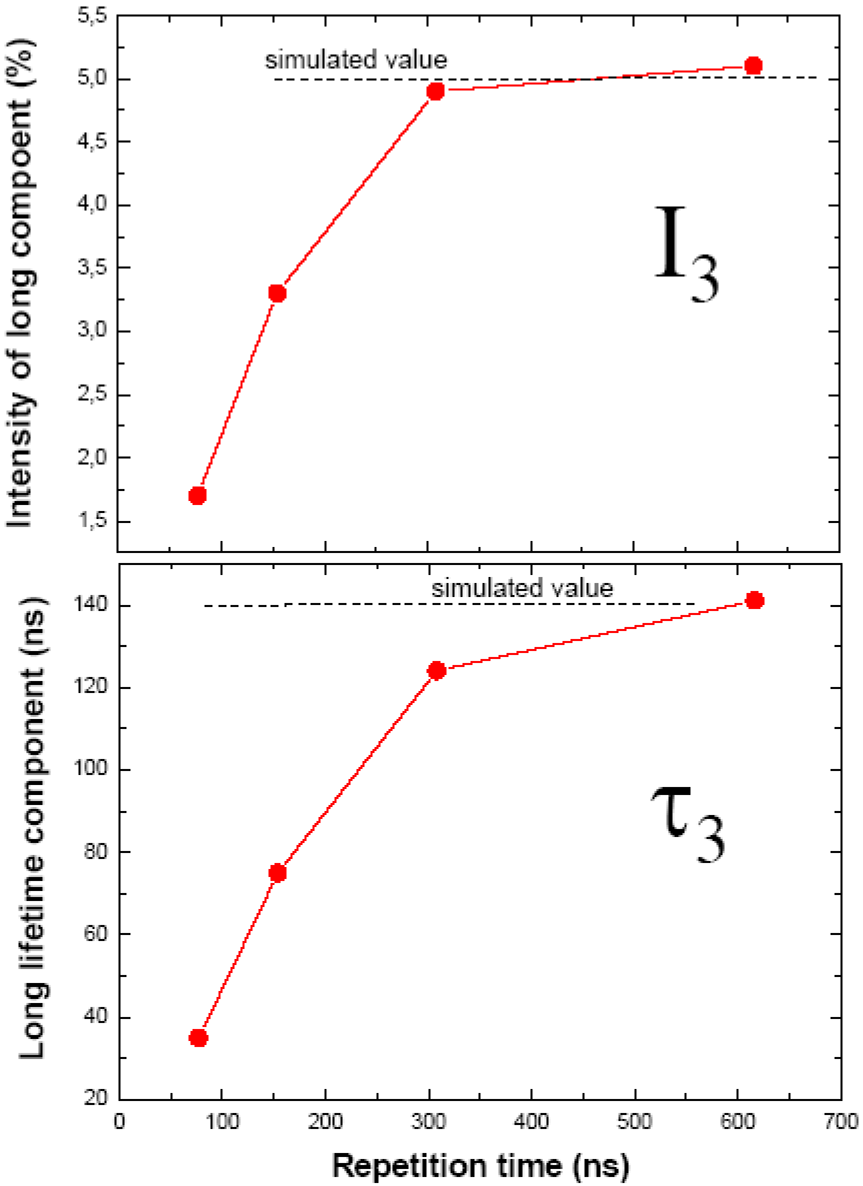
- we simulated different repetition times from 77 … 616 ns
- spectra were analyzed and compared to the original one



Second timing mode needed for long lifetimes

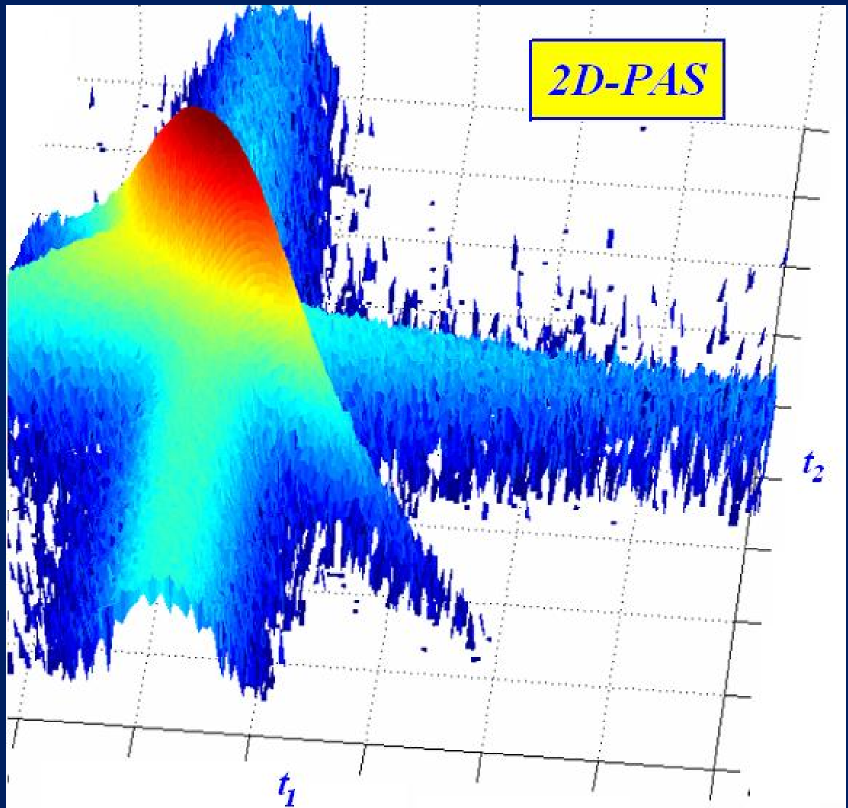
Result:

- repetition time must be at least 8-times longer than longest lifetime to be measured
- 77ns-system: up to 10 ns only
- Thus: EPOS needs a 616ns-timing mode (616 = 8 x 77)
- ELBE electron beam allows such a mode already: 7 of 8 electron bunches are suppressed

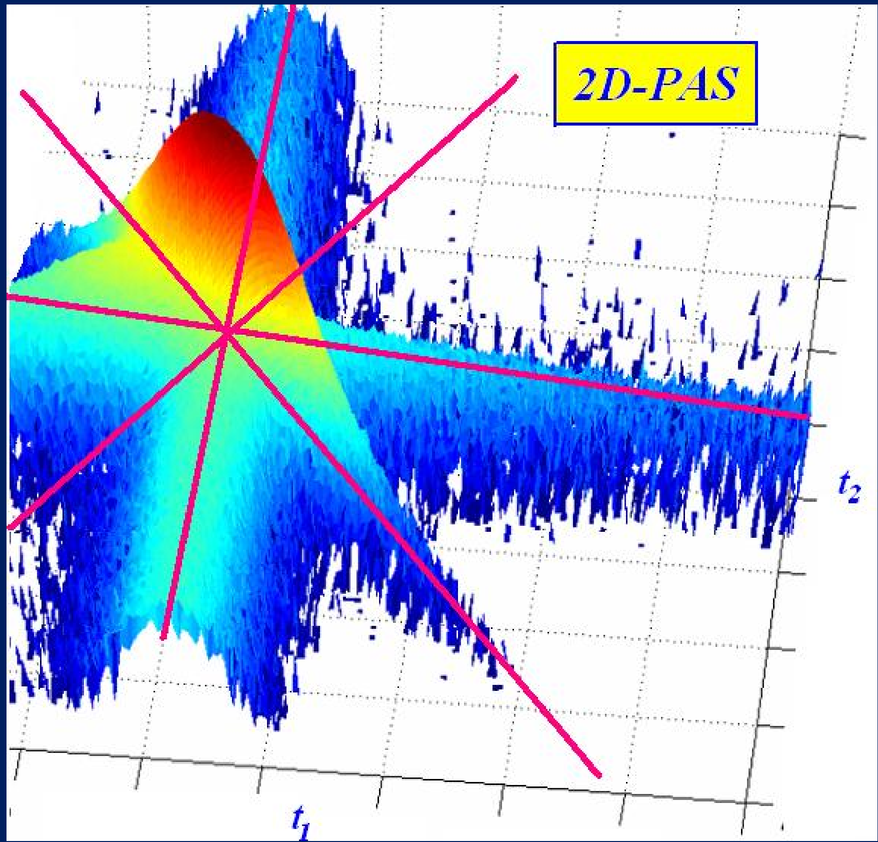


Cut Art in off-line

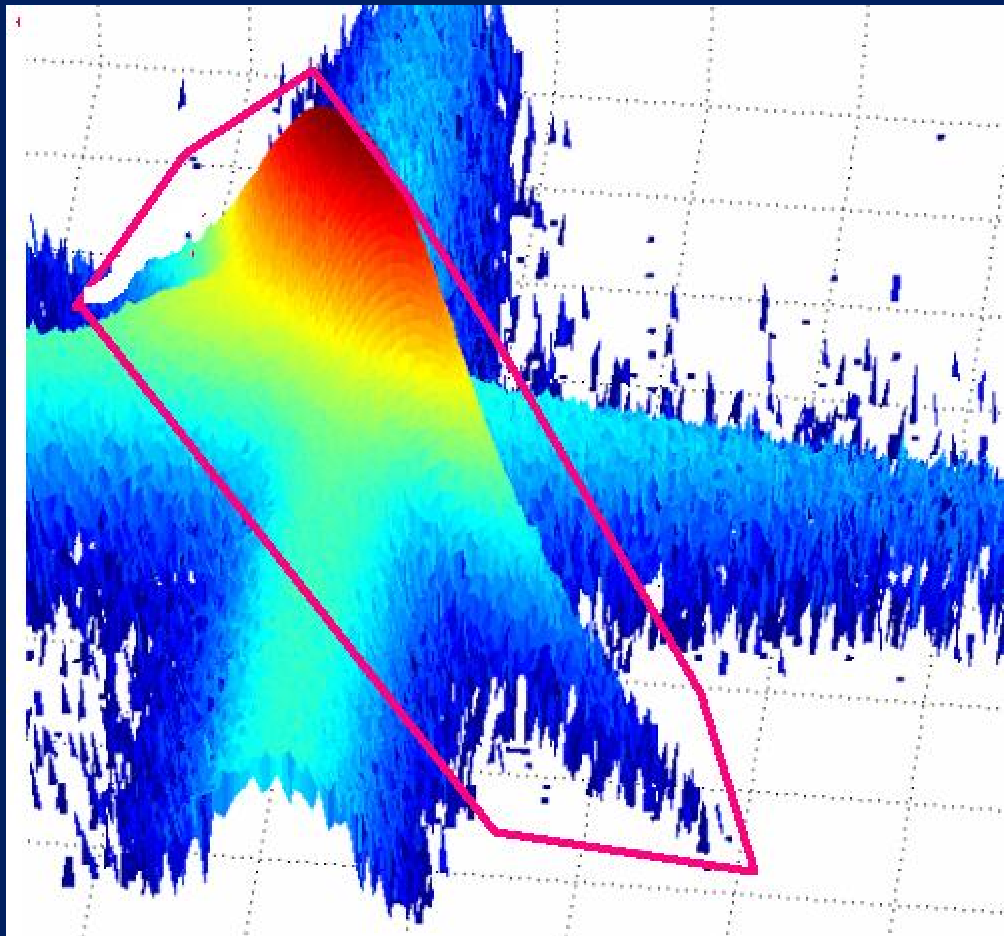
数字化测量的优势



- 数字化谱仪的优势不仅仅是装置简单,价格便宜,使用方便……
- 最重要的是可以采用不同形式的Cut,不同目的Cut,以及重新的数据组合…



- Time resolution can be improved by $1/\sqrt{2}$ by sum the t_1 and t_2.
- Background can be reduced.



组合CUT

- 时间信息: 短寿命,长寿命;
- 能量信息: 511keV峰, 连续谱, 高能散射;
- S-参数信息: 不同区域的S参数选择
- 关联信息: $E_1+E_2=1.02MeV$

  T1+T2=...

  S vs. W

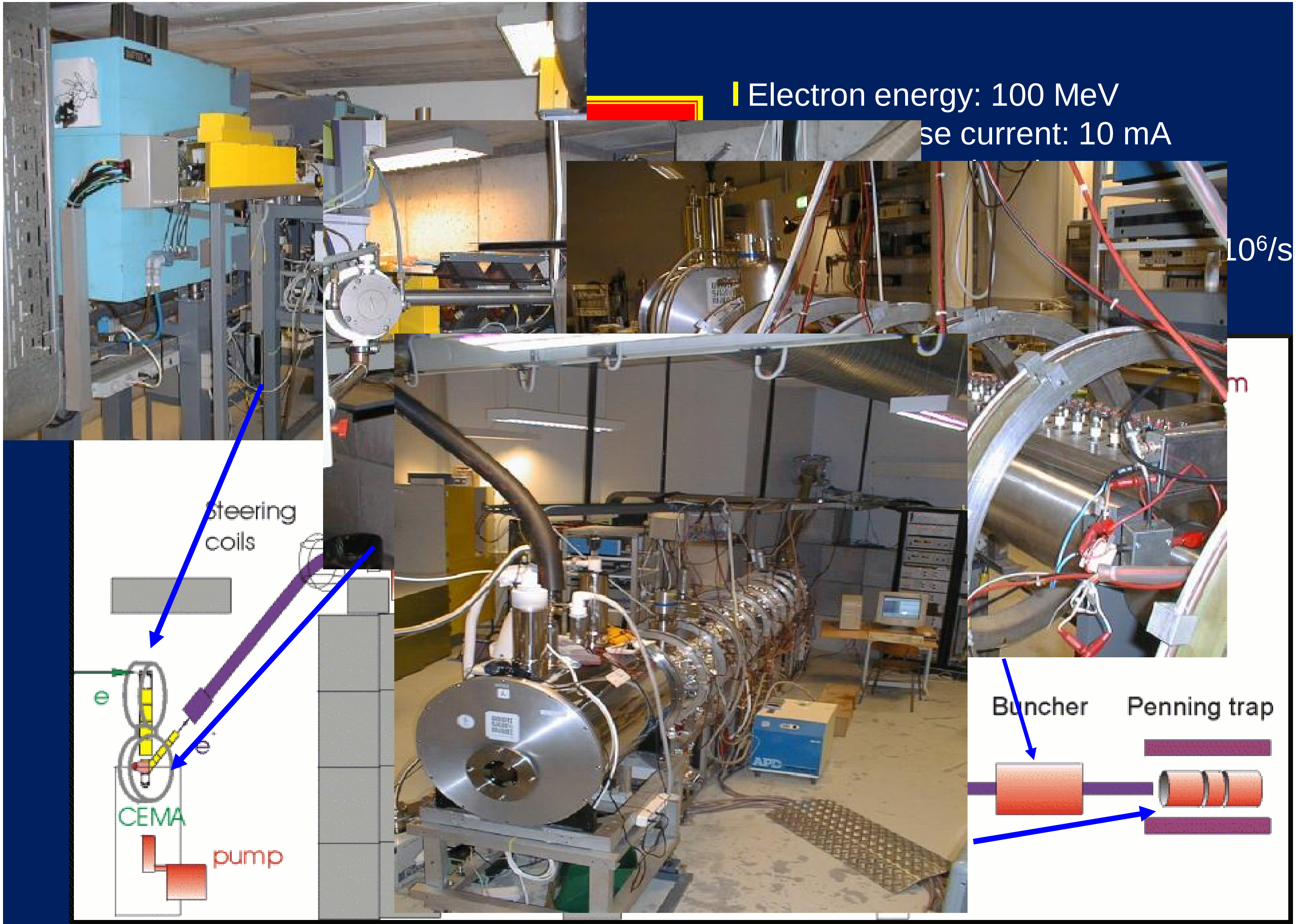
也可以某些参数的简单组合.

世界主要脉冲束装置

- 德国
- 欧洲其它地区
  (法国\英国\丹麦\瑞典\意大利)
- 美国
- 日本

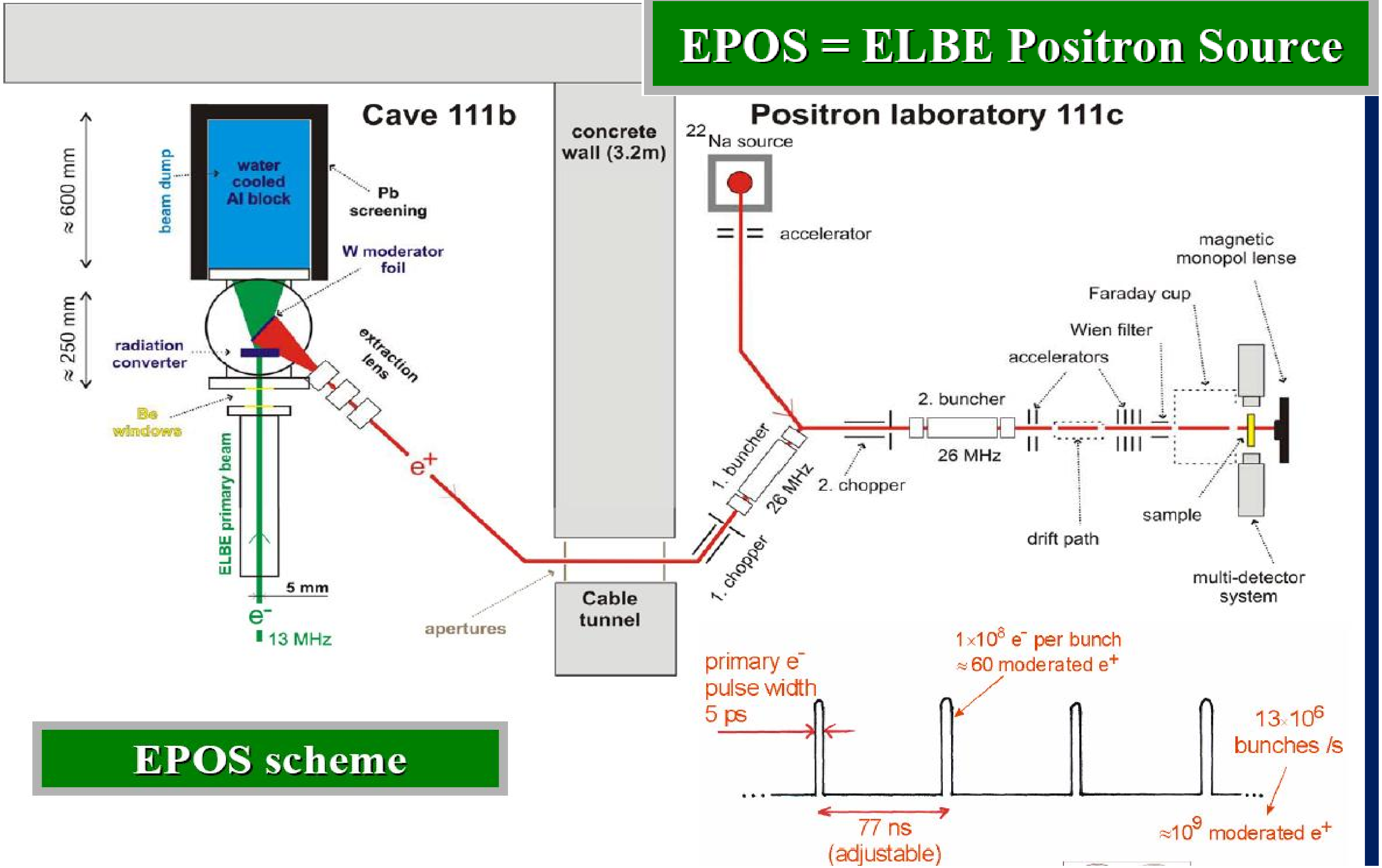
- Electron energy: 100 MeV
- se current: 10 mA

10^6/s



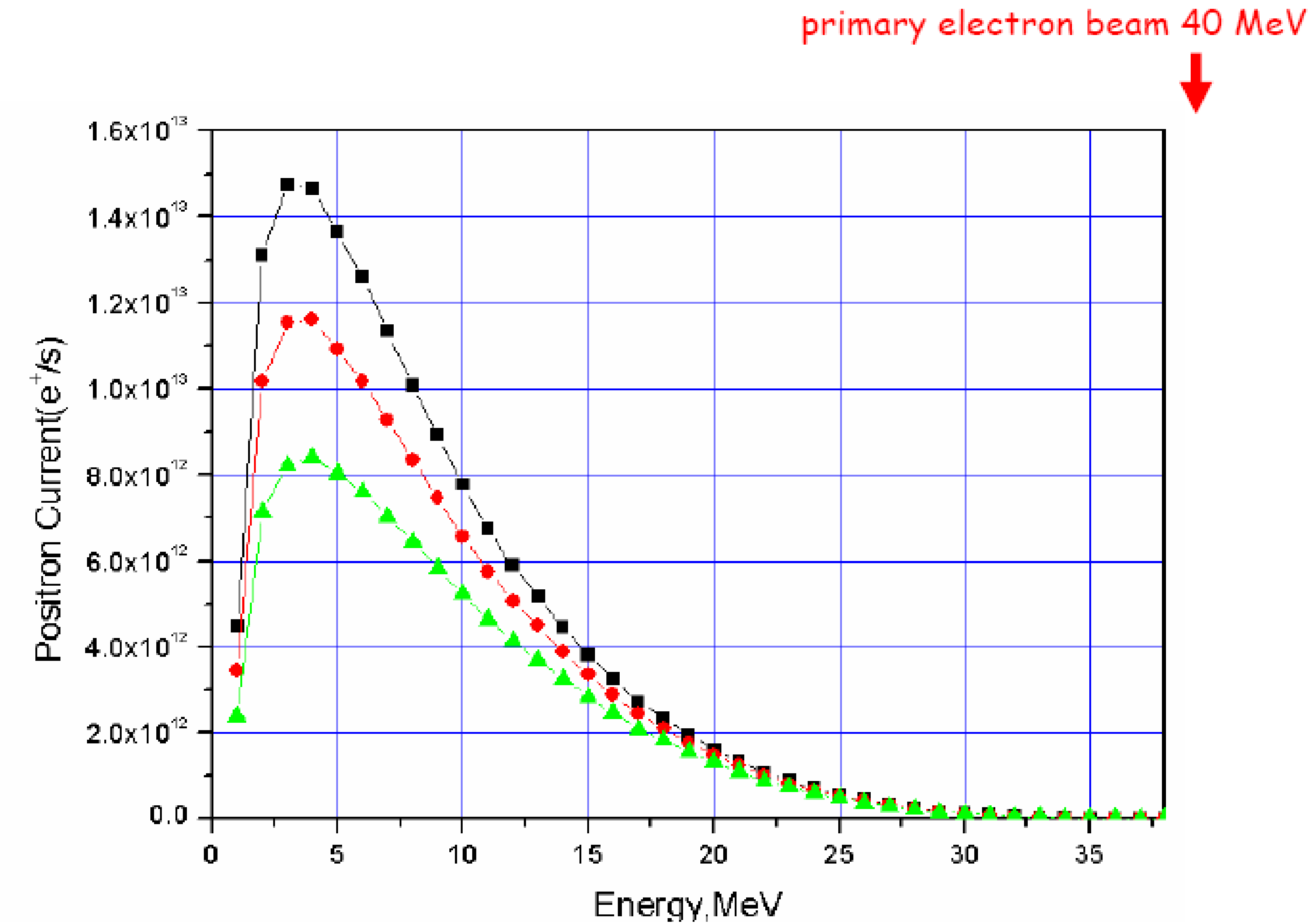
EPOS@epos.ac.ge

EPOS = ELBE Positron Source

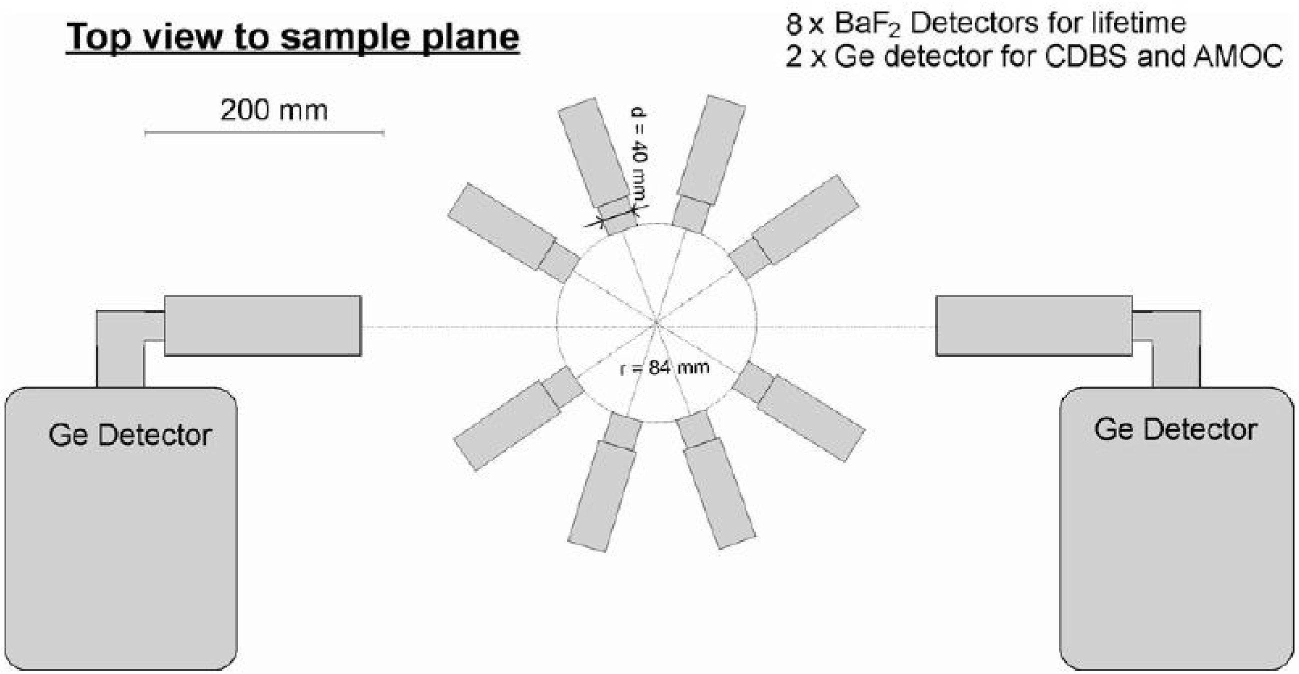


EPOS scheme

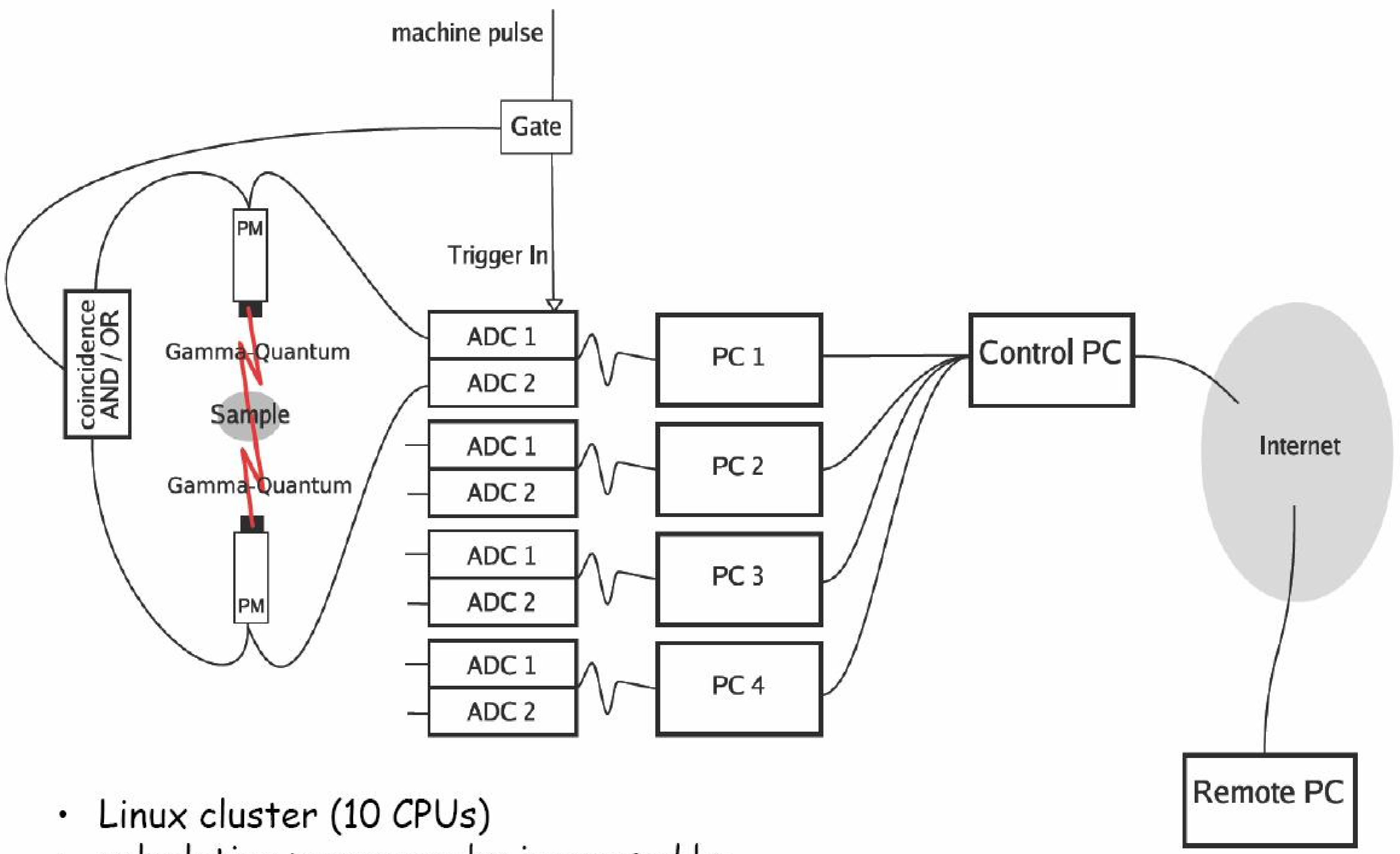
Simulation of Positron Energy Distribution



- **digital detection system**:
  - lifetime: almost nothing to adjust; time scale exactly the same for all detectors; easy realization of coincidence
  - Doppler: better energy resolution and pile-up rejection expected
  - pulse-shape discrimination improves spectra quality



Lifetime detector system



- Linux cluster (10 CPUs)
- calculating power can be increased by adding more PCs to the Control PC

Construction of the Helsinki University of Technology (HUT) pulsed positron beam

K. Fallström *, T. Laine

Laboratory of Physics, Helsinki University of Technology, P.O. Box 1100, FIN-02015 Espoo HUT, Finland

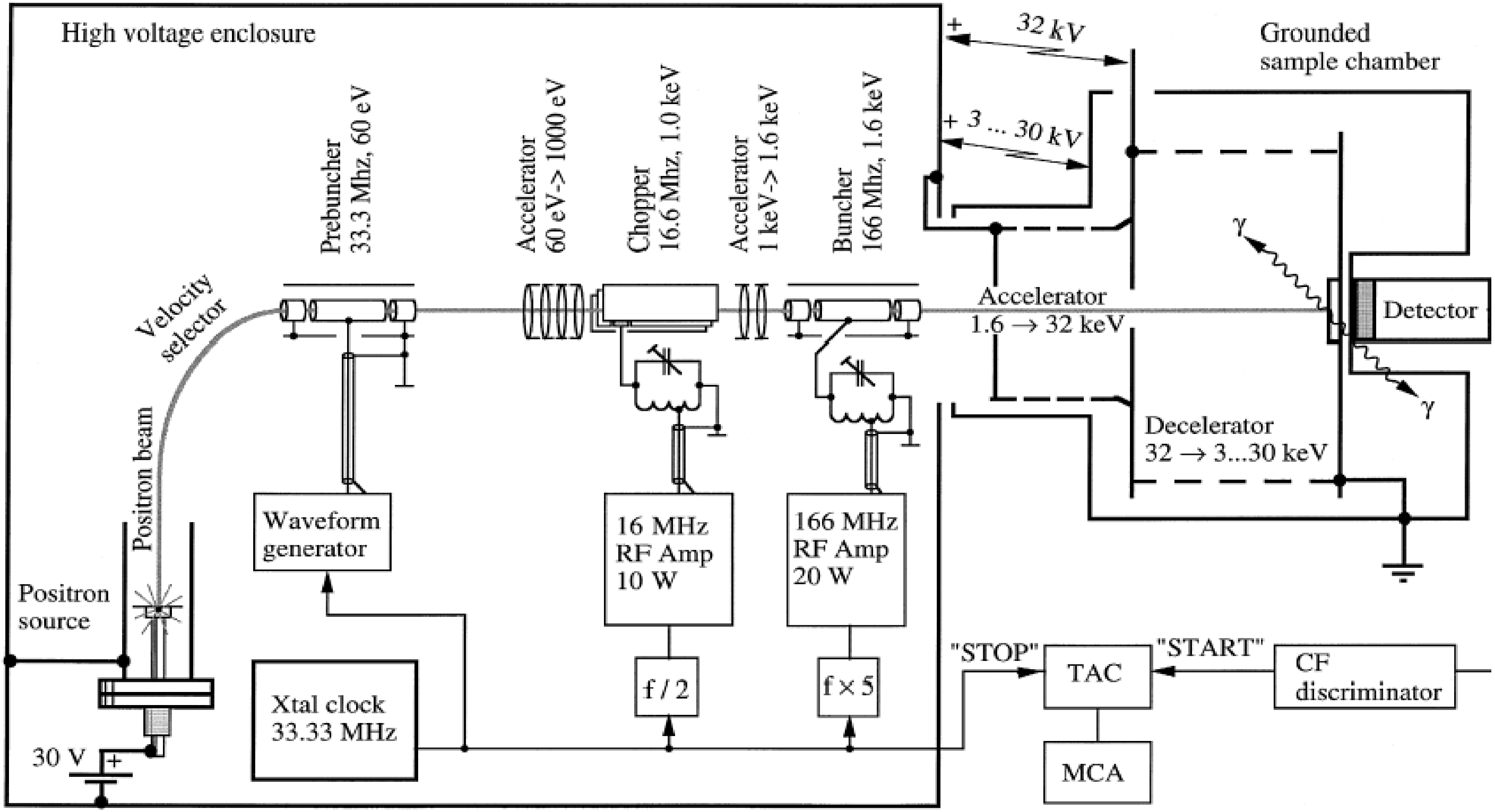
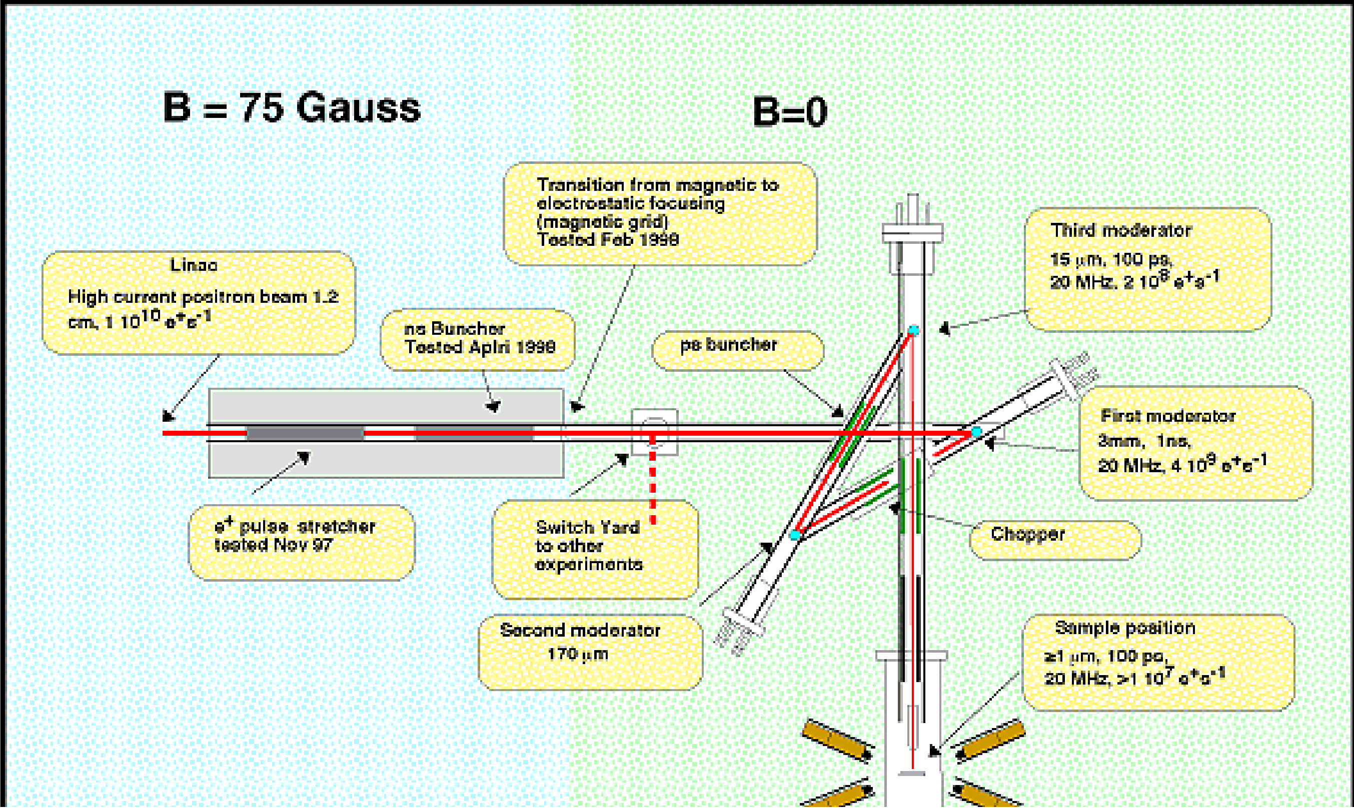


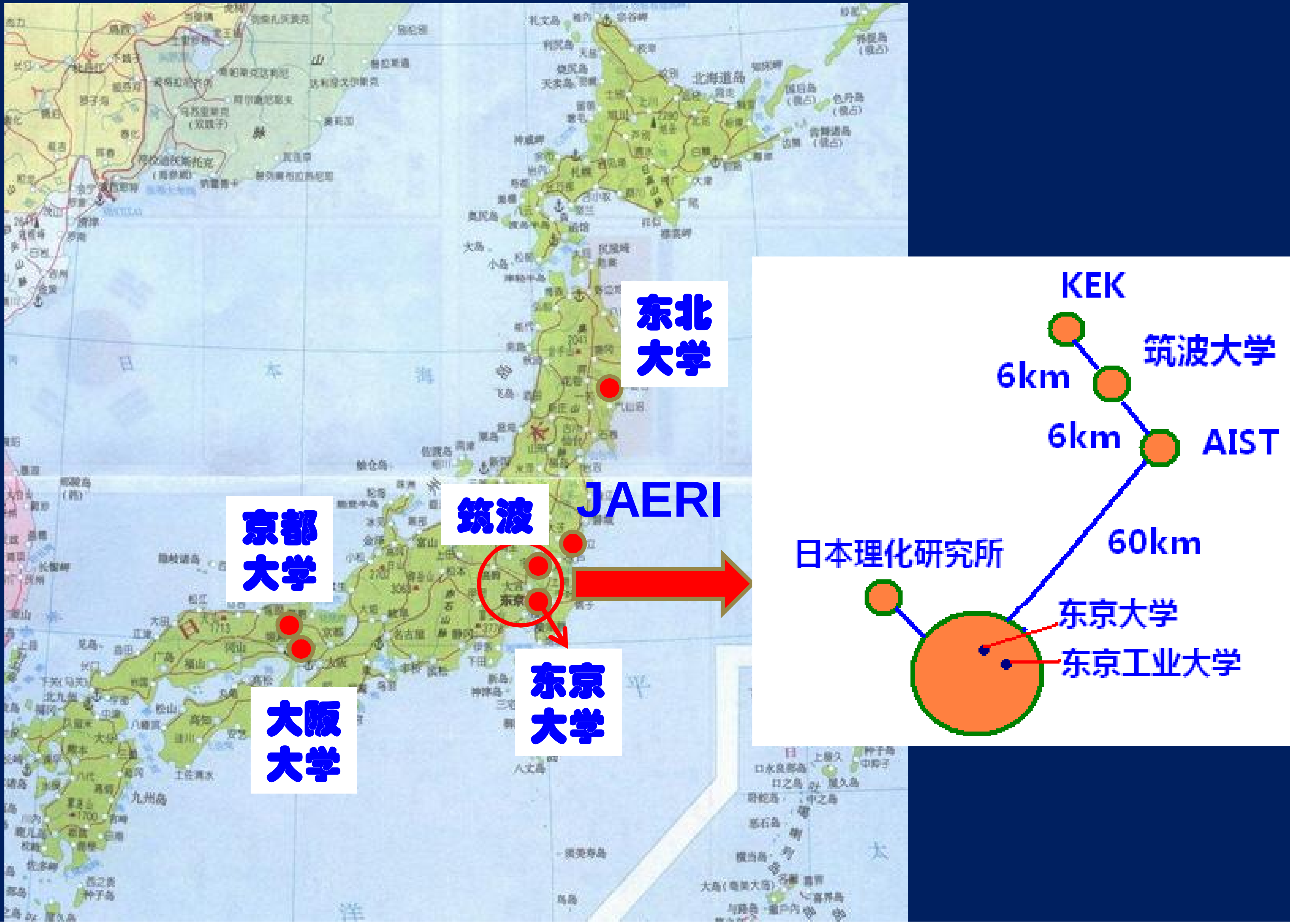
Fig. 1. A schematic view of the pulsed positron beam.

LLNL @llnl.gov

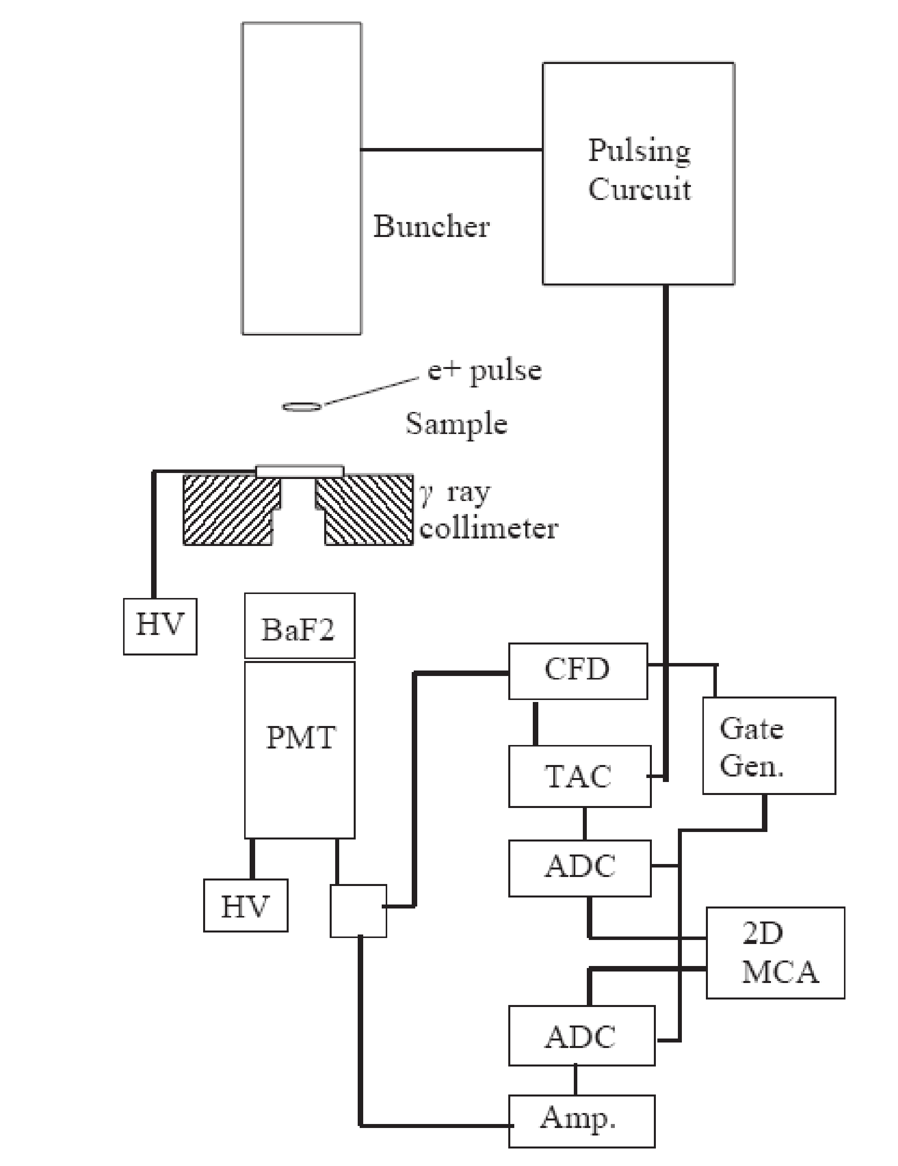


Device	Linac	Stretcher	Buncher	Thermalizer	Focus
E (eV)	10	10	200	2	1k – 50k
Beam Diameter (cm)	1	1	0.1	2×10^{-3}	10^{-4}
Pulse Width (ps)	3×10^{6}	3×10^{9}	100	100	100
Current (e^{+}/s)	10^{10}	10^{10}	5×10^{8}	10^{8}	10^{7}
Energy Width (eV)	4	2×10^{-2}	30	0.2	0.2
	High Current	Narrow Energy Width	Short Pulse	Small Spot Size, Variable Energy	

Japan


东北
大学
JAERI
京都
大学
筑波
东京
大学
大阪
大学
KEK
筑波大学
6km
6km
AIST
60km
日本理化研究所
东京大学
东京工业大学

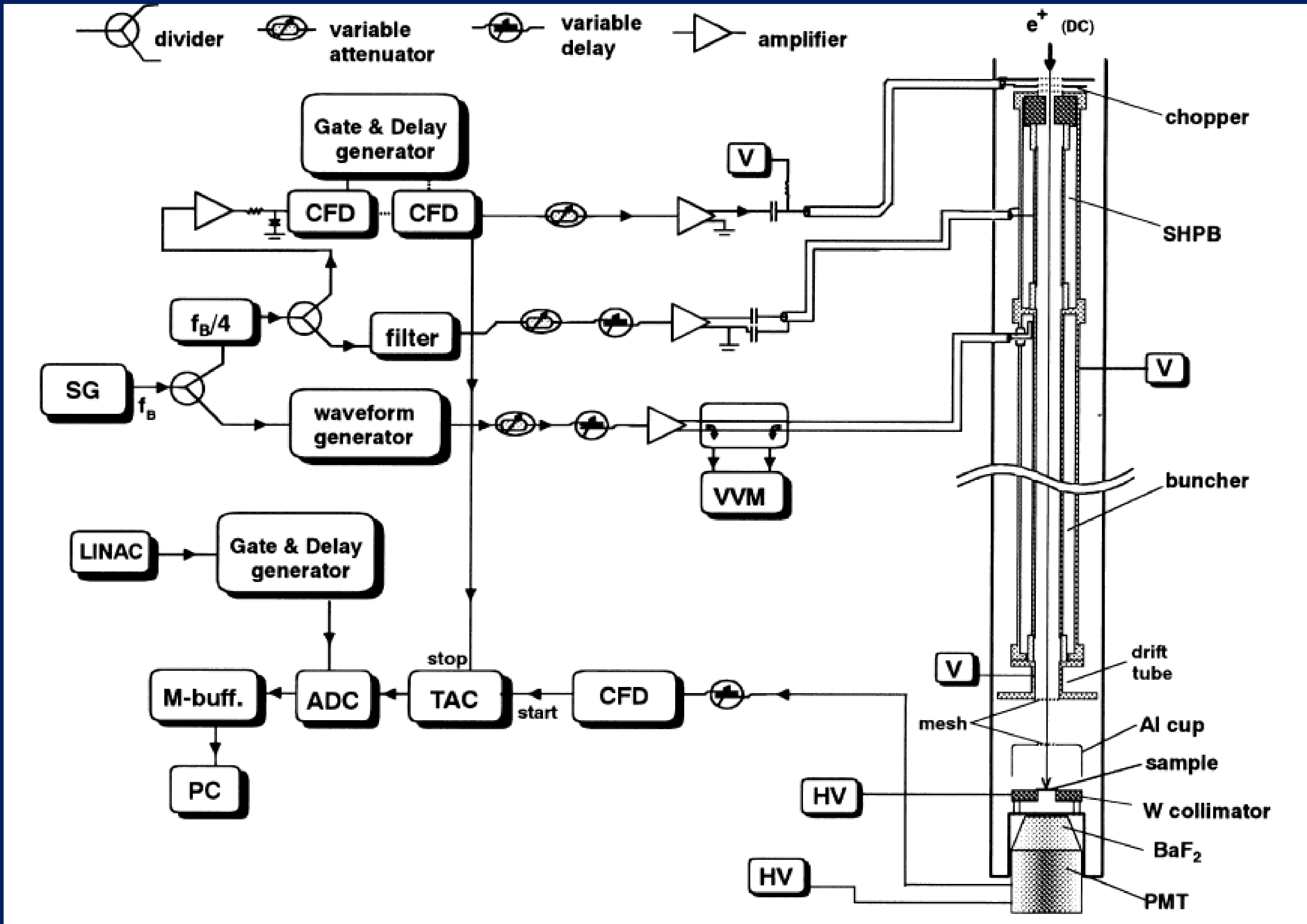
NIST@nist.go.jp



2D-PALs

普及型放射源脉冲正电子束装置

- 装置尺寸 3m x 0.6m x 1.5m(H)
- 正電子源　^{22}Na(1.11GBq)
- 正电子注入能量0.5 keV- 20 keV
- 時間分辨　< 250 ps
- 計数率　> 300 cps
- 測定時間　1 个样品(10^6) ～1小时
- 信躁比　～10^{-3}



divider
variable attenuator
variable delay
amplifier
e+ (DC)
chopper
SHPB
buncher
drift tube
mesh
Al cup
sample
W collimator
BaF2
PMT
Gate & Delay generator
CFD
CFD
V
V
fB/4
filter
SG
fB
waveform generator
VVM
LINAC
Gate & Delay generator
M-buff.
ADC
TAC
stop
start
CFD
PC
V
HV
HV

KEK@kek.ac.jp

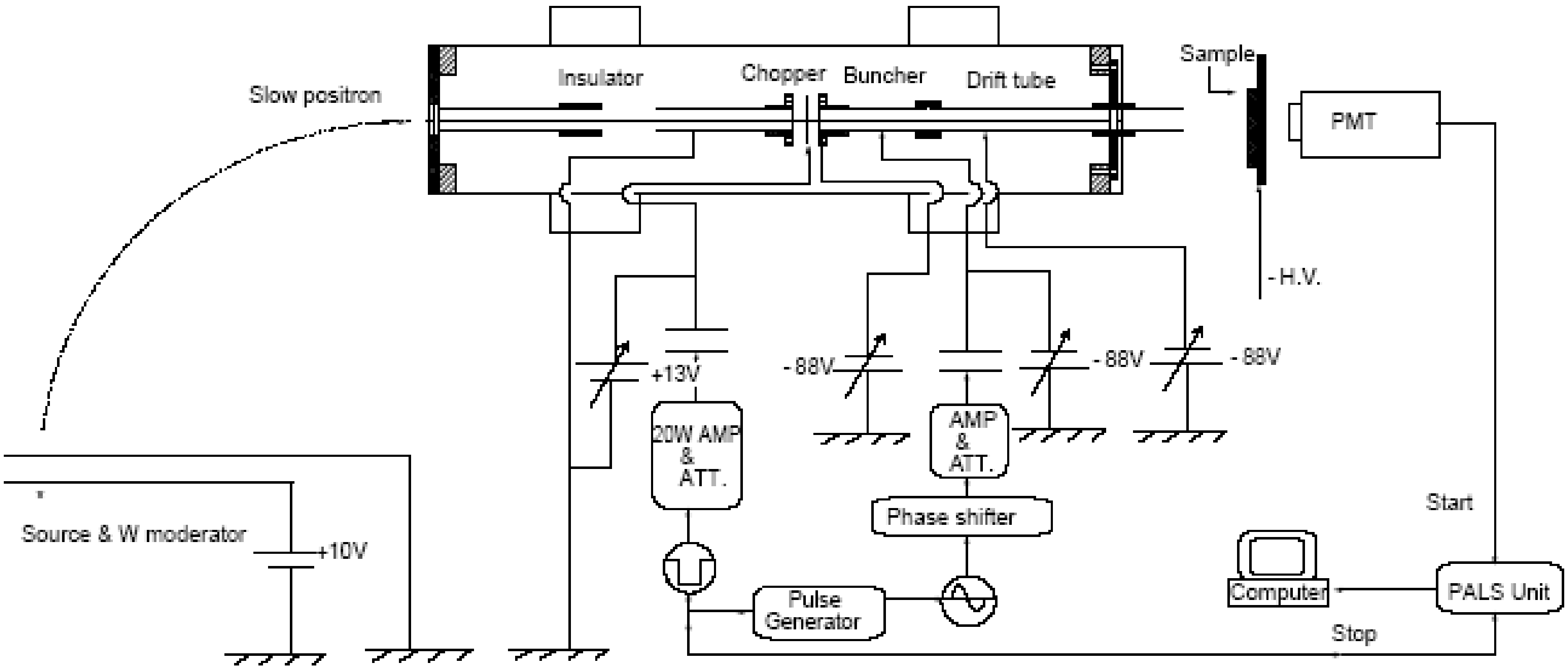
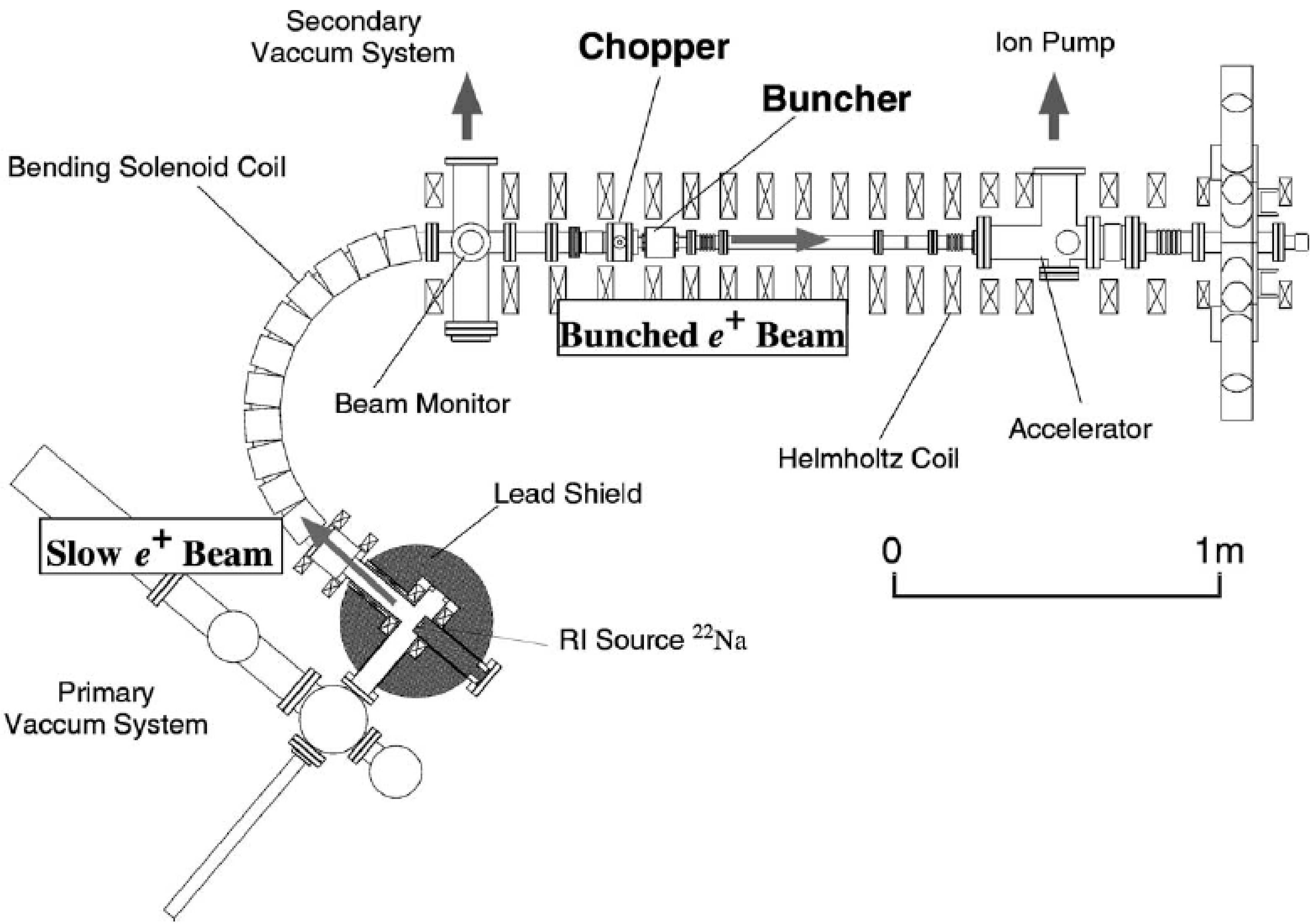


Fig. 1. Schematic diagram of the pulsed slow-positron beam system.

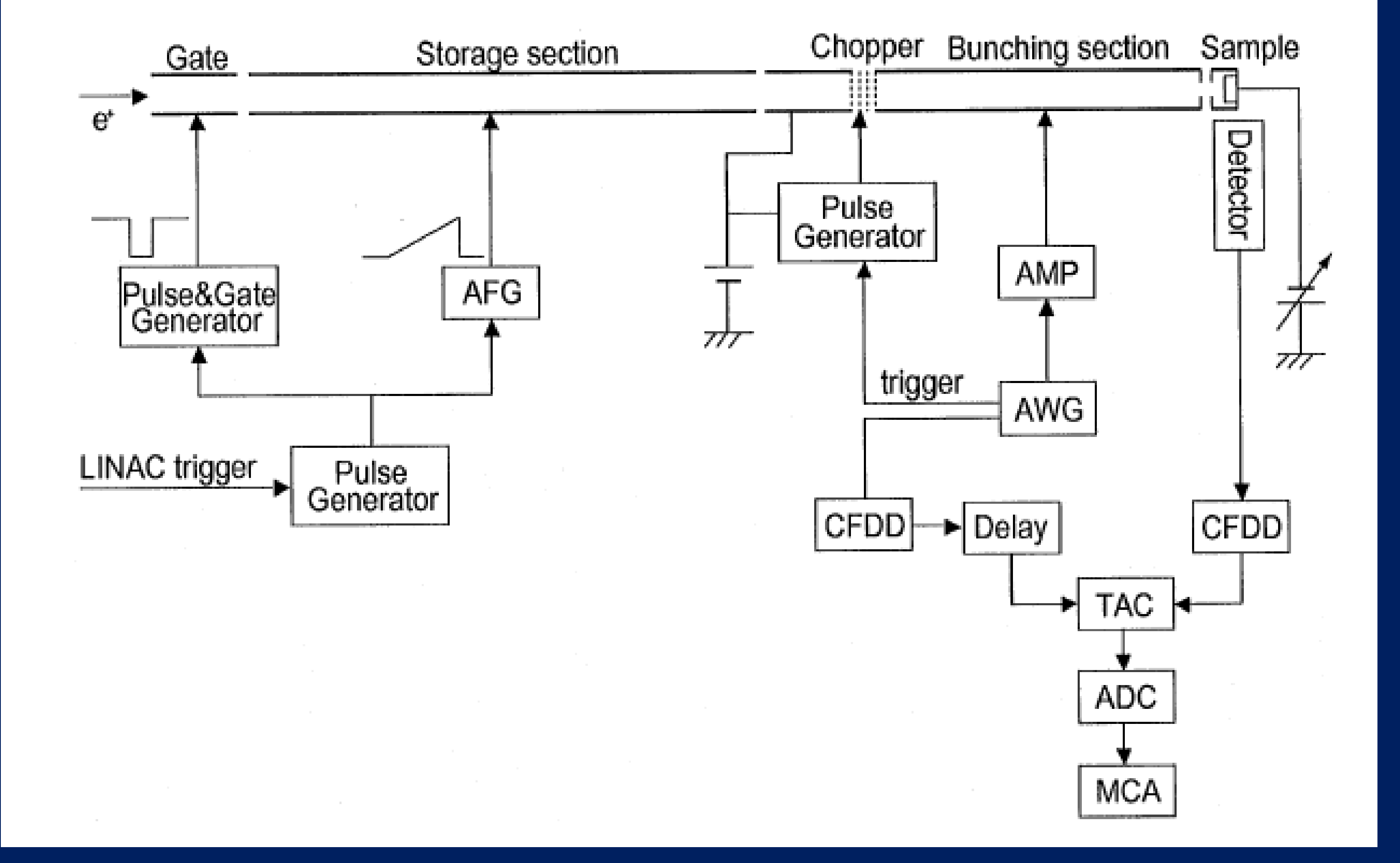
Table 1
Performance of the positron lifetime apparatus at ETL

Maximum time resolution	$<$ 200 ps (at 600 cps)
Maximum count-rate	6×10^4 cps
Maximum peak/background ratio	$> 10^4$
Pulse interval	variable: 23 ns to infinity
Positron energy	variable: 0.2 – 30 keV

Tokyo Metropolitan University



OSAKA University



Development of pulsed MeV positron beam line

JAERI, Takasaki Establishment

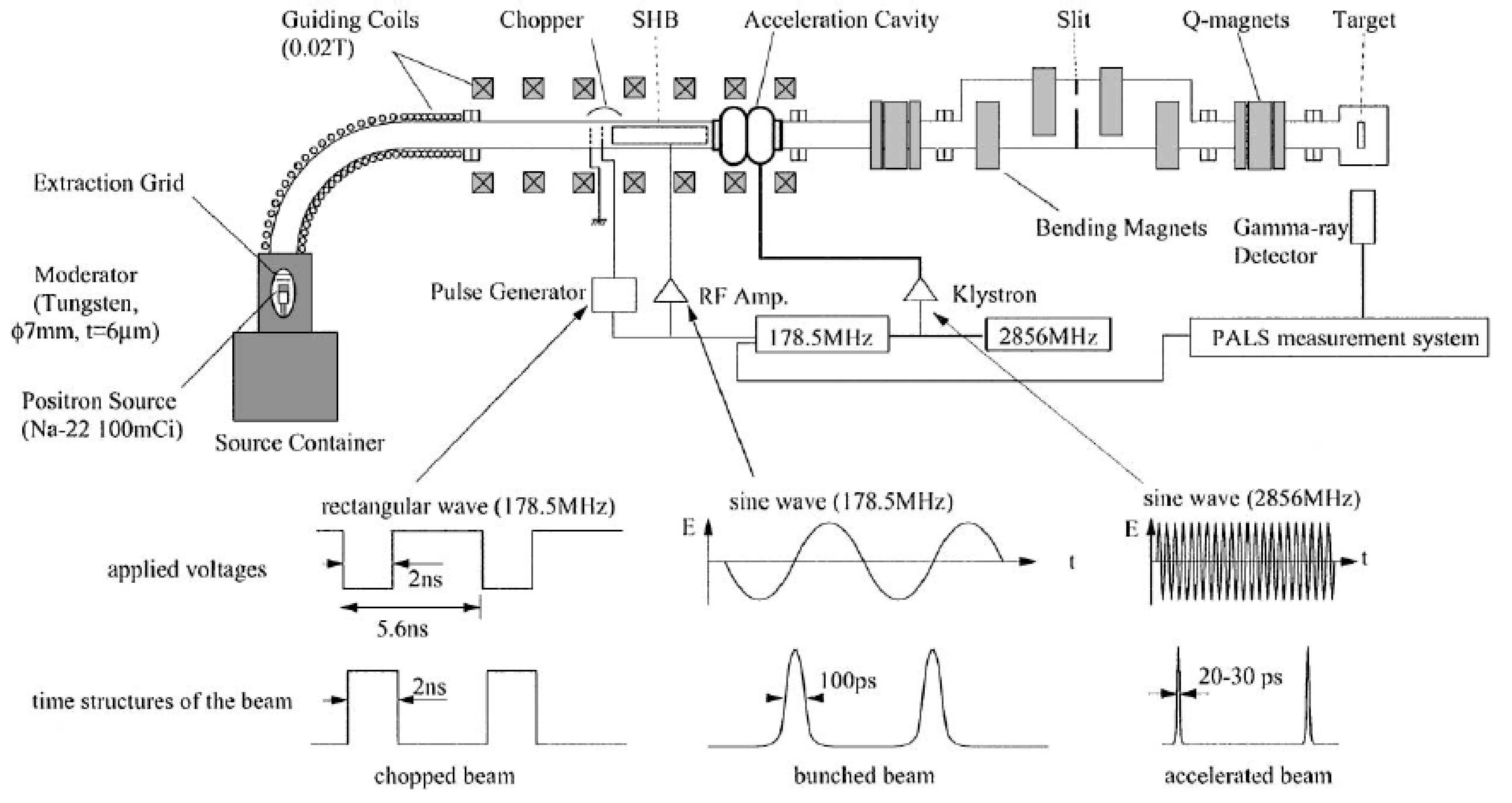
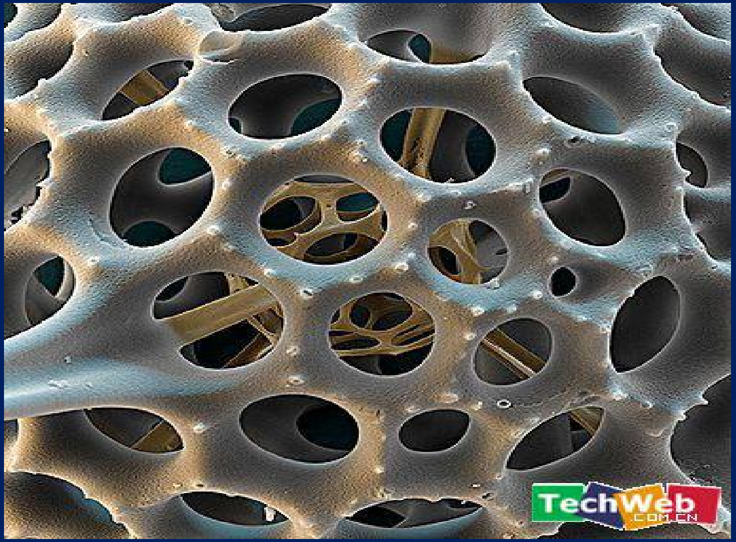


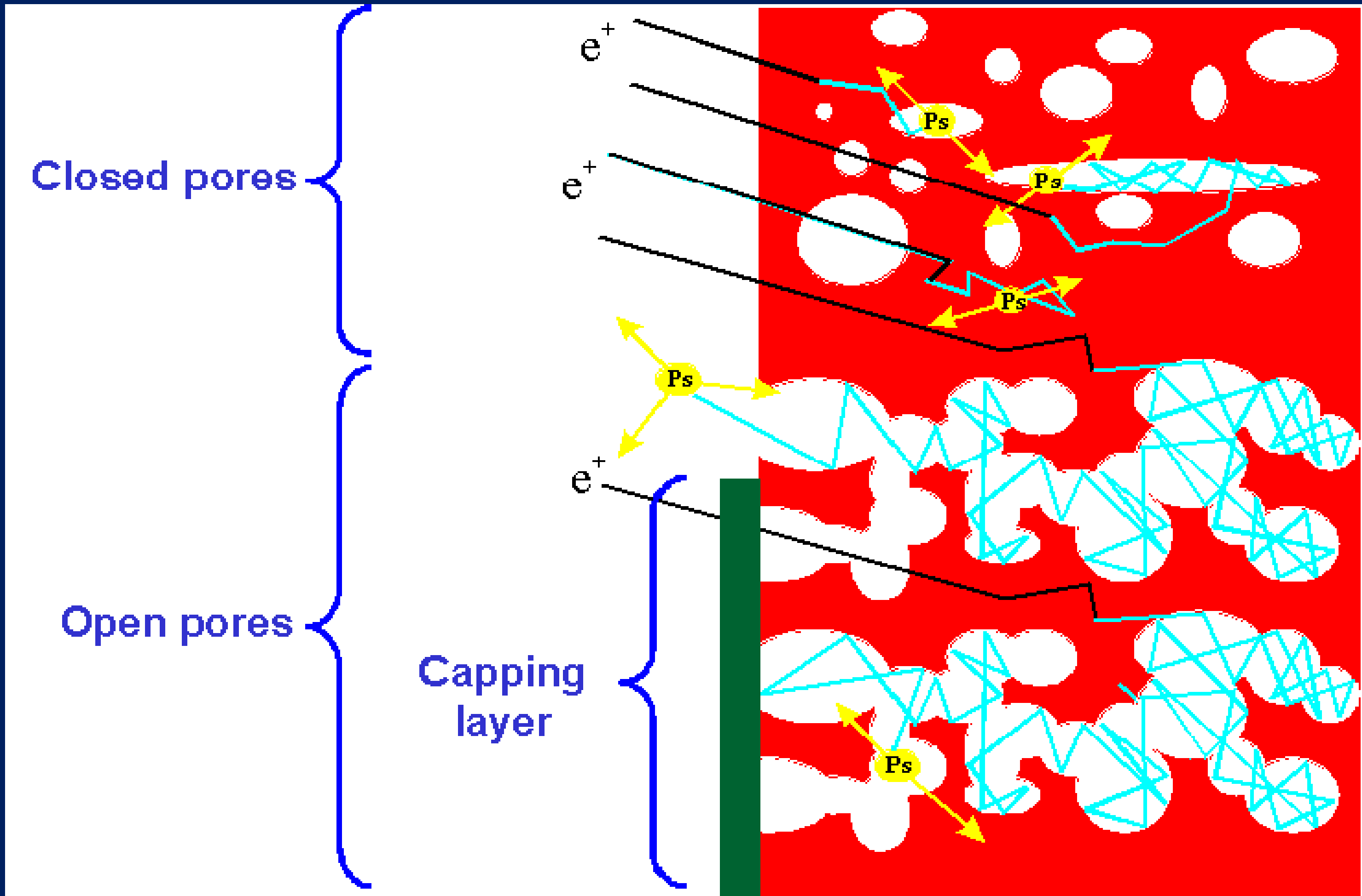
Fig. 1. Schematic diagram of pulsed MeV positron source (PUMPS).

脉冲正电子束的应用

- Nano porous films
- Nano-in-surface
- Polymer films



I Nano Porous Films



Ps in nanoporous films:

- Positrons (50 eV-15keV):
  - scatters of atoms and electrons
  - slows down to atomic scale energy(several eV) in pico-seconds
- **Typically 10%-50%:**

- Capture bound molecular electron **(Ore-model)**
- Recombines with „spur“ e^- from e^+ ionizing collisions **(Spur-model)**
- **Forming Ps**

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Chemical Physics
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Study of mesoporous silica films by positron annihilation based on a slow positron beam: Effects of preparation conditions on pore size and open porosity

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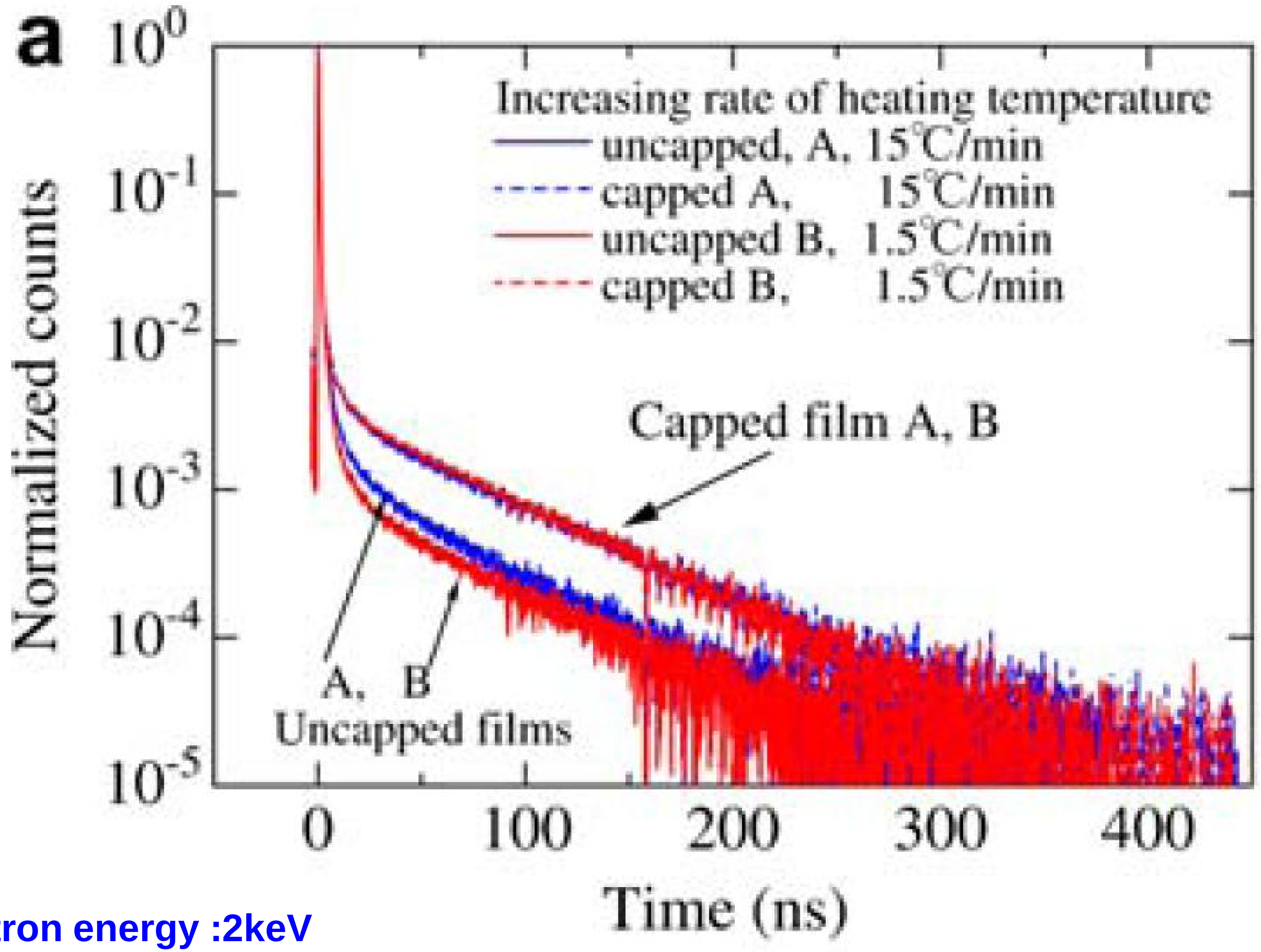
Available online 10 November 2006

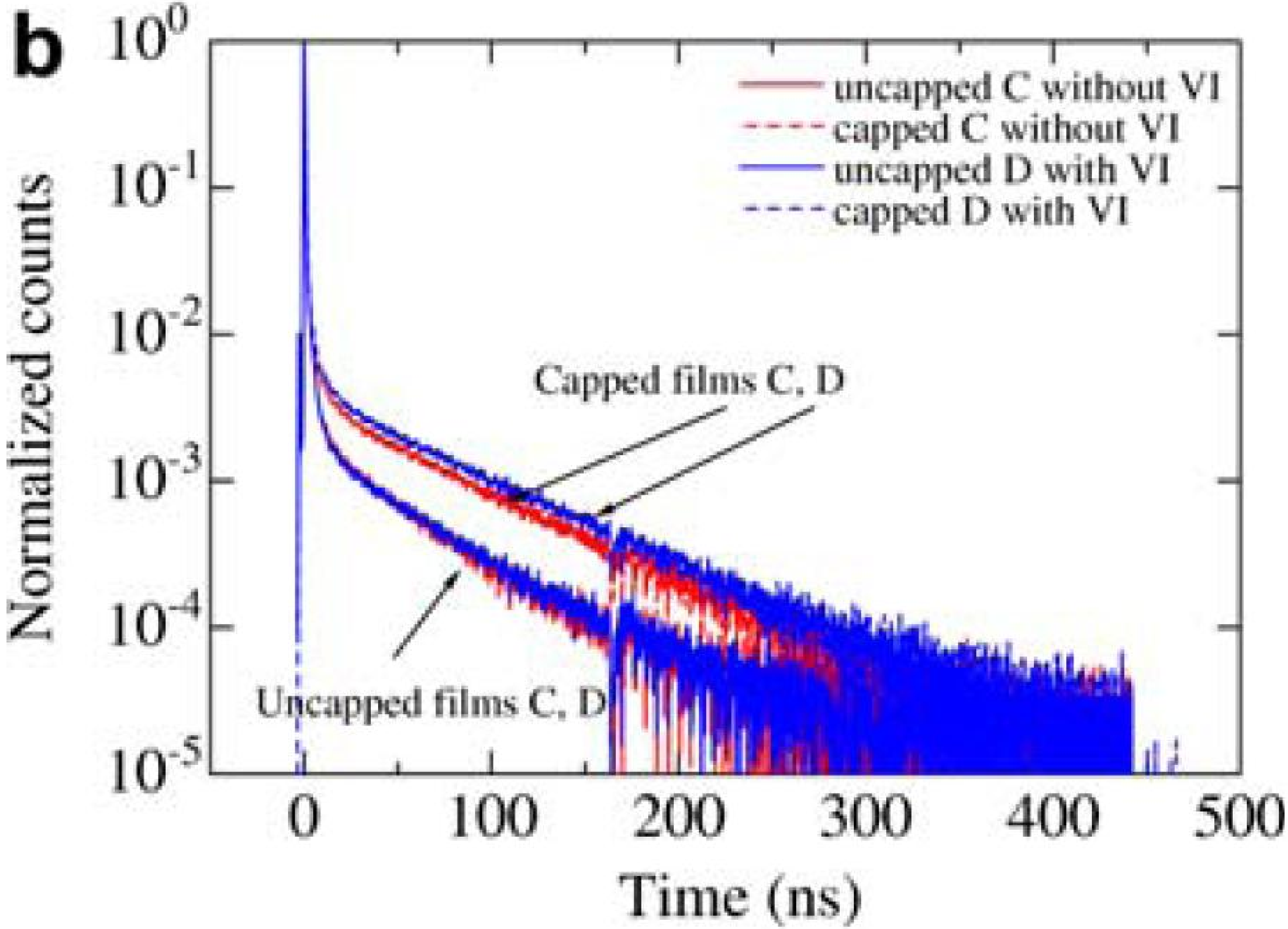
- The mesoporous silica films were deposited by dip-coating on a polished silicon (1 0 0) wafer.
- $TEOS:EO_{106}PO_{70}EO_{106}:EtOH:H_2O:HCl$

  1:0.006:30:8:0.003
- Film preparation conditions

Film	Aging time (day)	Treatment	Heating rate (°C/min)
A	25		15
B	25	~90 °C 3 h	1.5
C	45	~90 °C 3 h	1.5
D	45	With VI, ~90 °C 3 h	1.5



Positron energy :2keV


b
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
Normalized counts
uncapped C without VI
capped C without VI
uncapped D with VI
capped D with VI
Capped films C, D
Uncapped films C, D
0
100
200
300
400
500
Time (ns)

t_1=125ps(p-Ps, fixing), t_2 about 0.4ns(depending),

Positronium lifetimes and their intensities,

diameters/side lengths of microvoids and micro/mesopores for different films

Film	τ_3 (ns) I_3 (%)	τ_4 (ns) I_4 (%)	τ_5 (ns) I_5 (%)	Microvoid $2R$[a] (nm)	Micropore $2R$[a] (nm)	Mesopore[b] D_t/D_c (nm)
A	2.12 ± 0.03	8.68 ± 0.07	68.2 ± 0.1	0.59	1.24	3.89/5.26
	7.21 ± 0.03	5.25 ± 0.04	22.05 ± 0.04			
B	1.86 ± 0.02	7.02 ± 0.04	63.7 ± 0.1	0.57	1.12	3.56/4.76
	7.15 ± 0.07	4.94 ± 0.03	23.35 ± 0.04			
C	2.09 ± 0.02	8.57 ± 0.07	69.8 ± 0.1	0.59	1.23	4.02/5.44
	8.28 ± 0.05	4.06 ± 0.03	23.32 ± 0.05			
D	2.10 ± 0.02	8.95 ± 0.06	73.6 ± 0.1	0.59	1.26	4.34/5.93
	7.13 ± 0.03	4.29 ± 0.03	26.54 ± 0.04			

$R \leqslant 1$ nm

$$\tau_{o\text{-Ps}} = \tau_0 \left(1 - \frac{R}{R + \delta R} + \frac{1}{2\pi} \sin \frac{2\pi R}{R + \delta R}\right)^{-1}$$

Tao and Eldrup model

$R > 1$ nm

RTE model

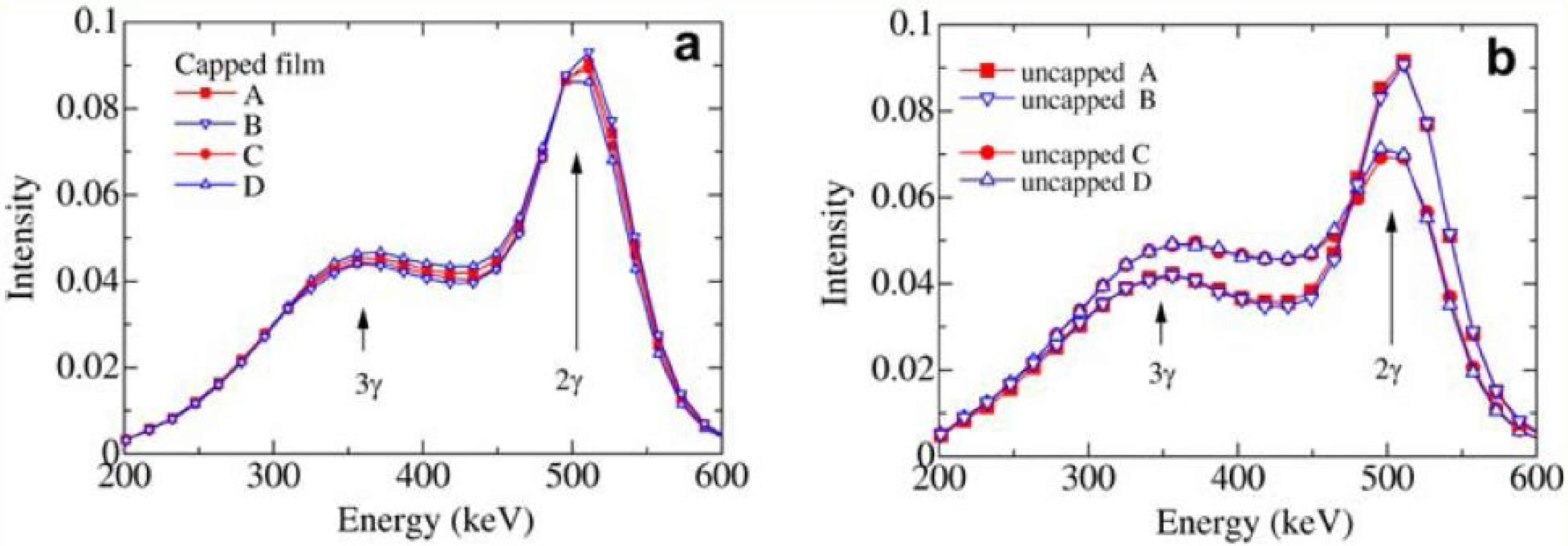


Fig. 4. Normalized positron annihilation γ-ray spectra for (a) capped and (b) uncapped films in the annihilation time region from 28.8 to 340 ns obtained by lifetime–energy correlation measurements. The incident positron energy is 2.0 keV.

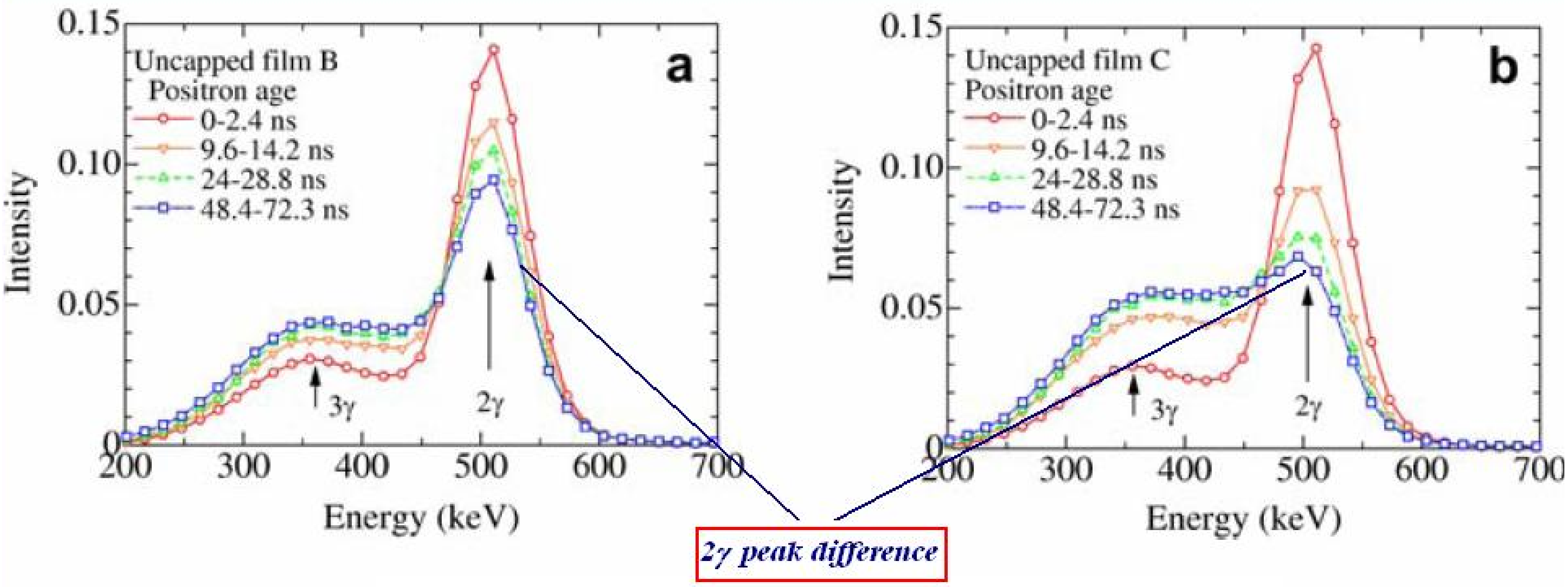


Fig. 5. Normalized positron annihilation γ-ray spectra in different annihilation time regions for uncapped porous silica films (a) B and (b) C obtained by lifetime–energy correlation measurement. The incident positron energy is 2 keV.

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Positron annihilation in SiO_2–Si studied by a pulsed slow positron beam

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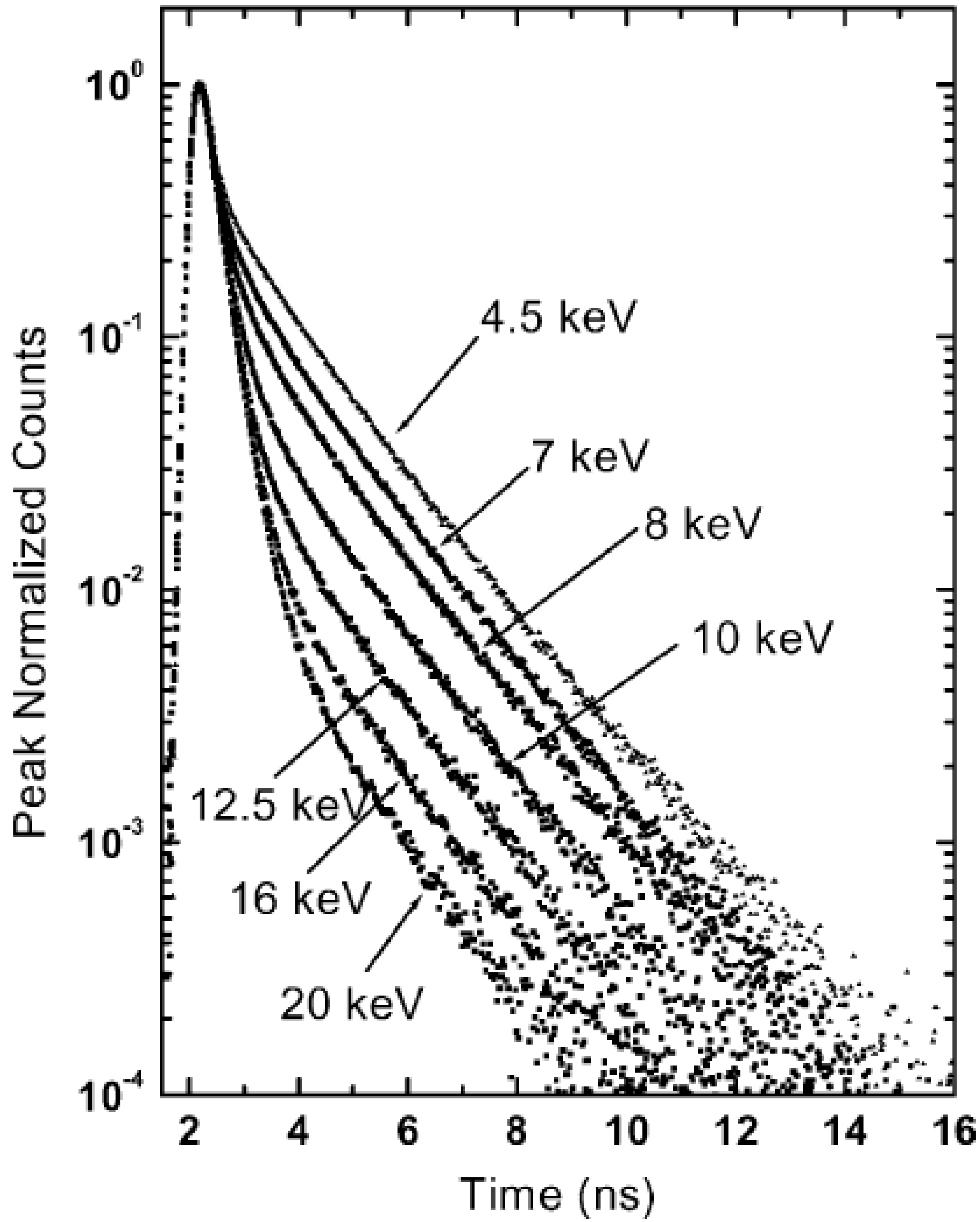


Fig. 1. Positron lifetime spectra of 500 nm thick SiO_2 on Si(1 0 0).

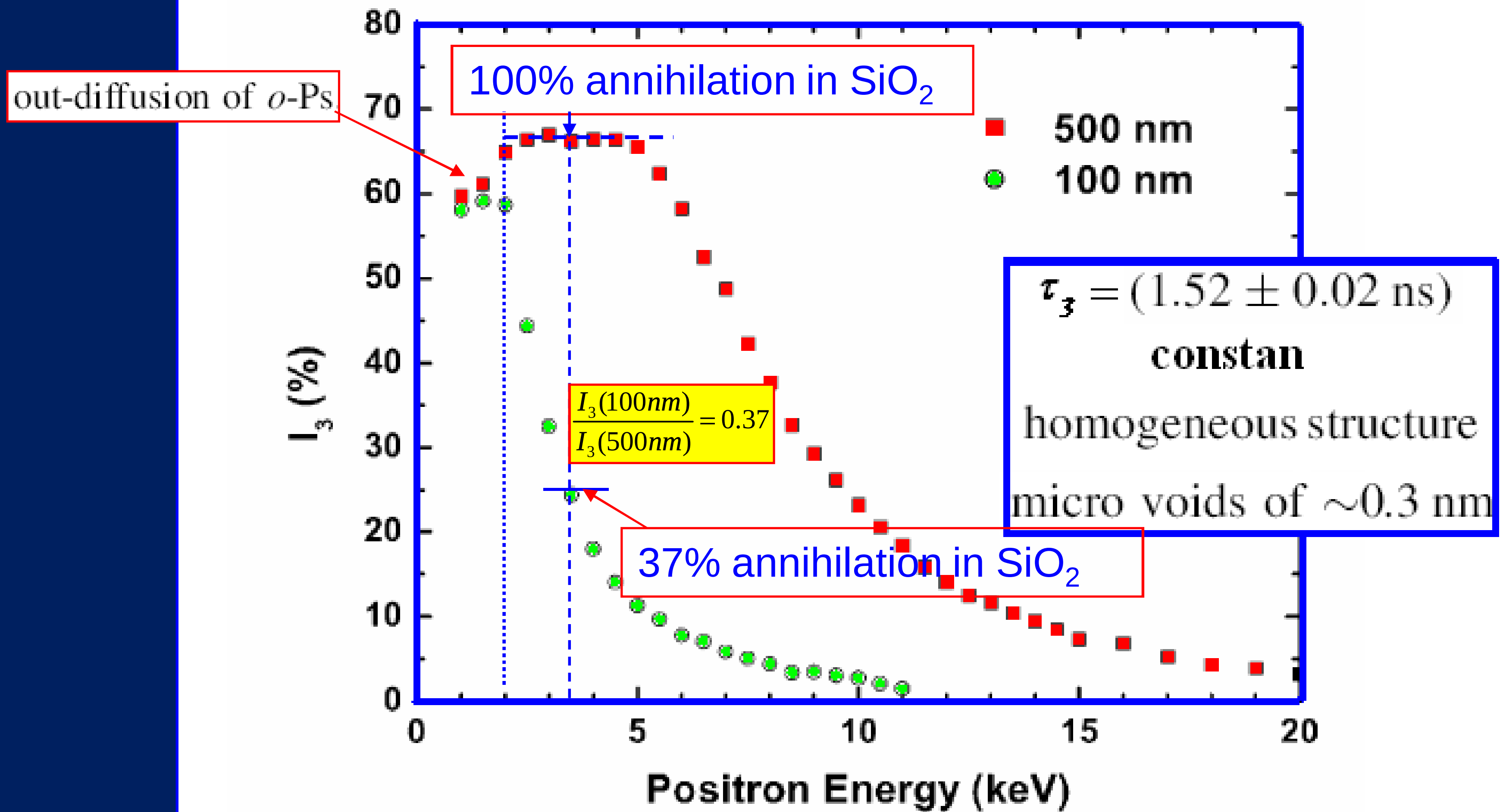
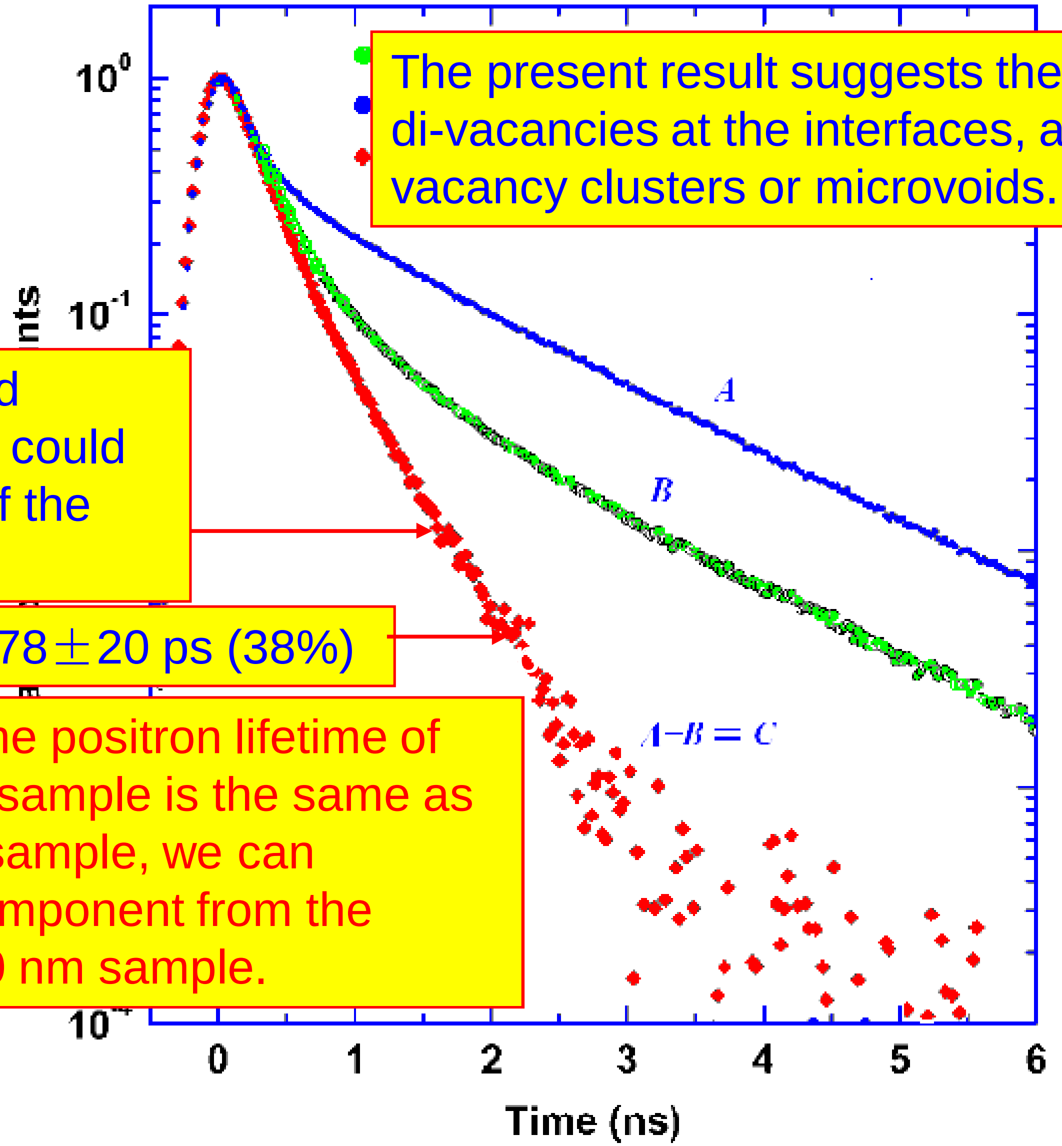


Fig. 2. The longest-lived component intensity I_3 as a function of the incident positron energy for 100 nm thick SiO_2 (●) and 500 nm thick SiO_2 (■) on Si(1 0 0).

The present result suggests the di-vacancies at the interfaces, and larger vacancy clusters or microvoids.



Thus, the subtracted lifetime spectrum of could reflect the lifetime of the interfacial layer.

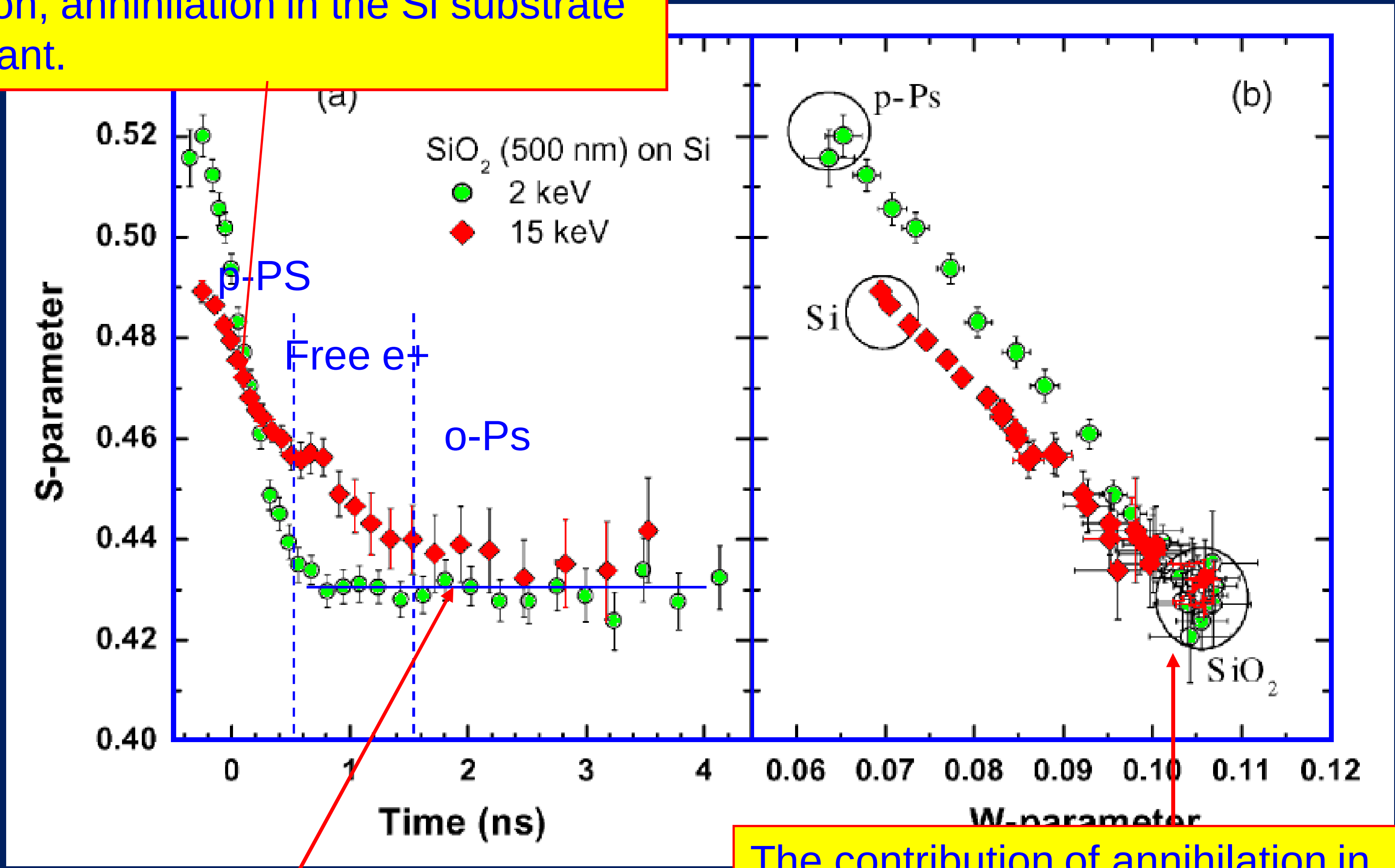
215±10 ps(62%) 478±20 ps (38%)

If we assume that the positron lifetime of SiO_2 in the 100 nm sample is the same as that of the 500 nm sample, we can remove the SiO_2 component from the spectrum of the 100 nm sample.

Fig. 3. Positron lifetime spectra at 3.5 keV for 100 nm thick SiO_2 (●), 500 nm thick SiO_2 (●), and the spectrum of the 100 nm sample (◆) after the SiO_2 component subtraction.

AMOC

At 15 keV, about 90% of positrons are implanted in the Si substrate. In the young age region, annihilation in the Si substrate is dominant.



O-Ps and free e+ annihilation with same e- because of the momentum distribution.

The contribution of annihilation in SiO_2 can be clearly seen in 15 keV even if the fraction of positrons annihilating in SiO2 is only 10%.

Thank you!