Positron and positronium for the GBAR experiment

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and the GBAR collaboration

Outline

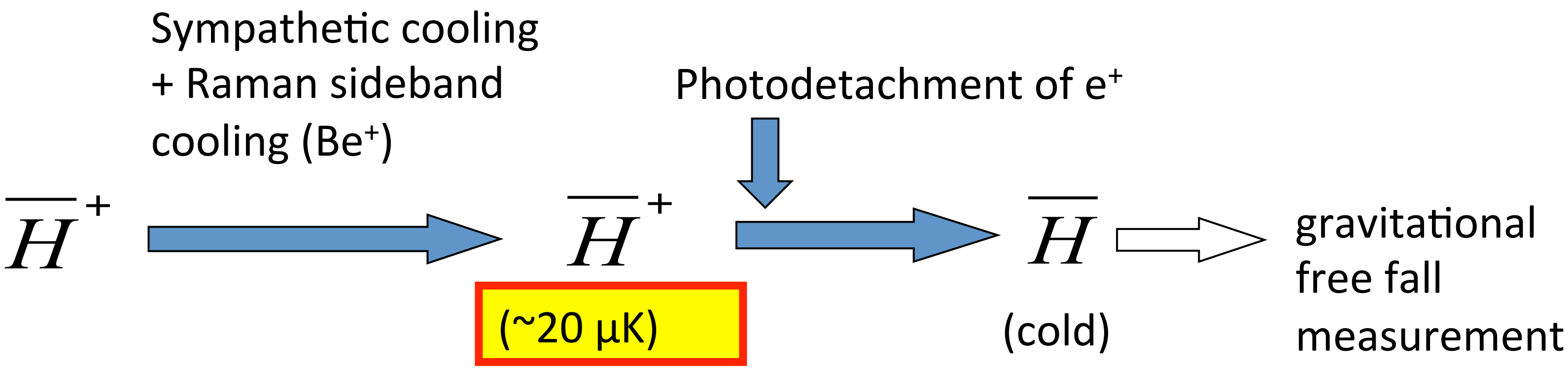
- The GBAR (Gravitational Behaviour of Antimatter in Rest) experiment
- Linac-based positron source for GBAR
- Mesoporous silica film as efficient positron/positronium converter

The GBAR experiment

- Direct test of the weak equivalence principle by the observation of the free fall of antihydrogen at extremely low energy (~20 μK)

- ~1 % precision in $\bar{g}$, determined mostly by temperature (+stat.)

- Cooling path through positively charged antihydrogen ions



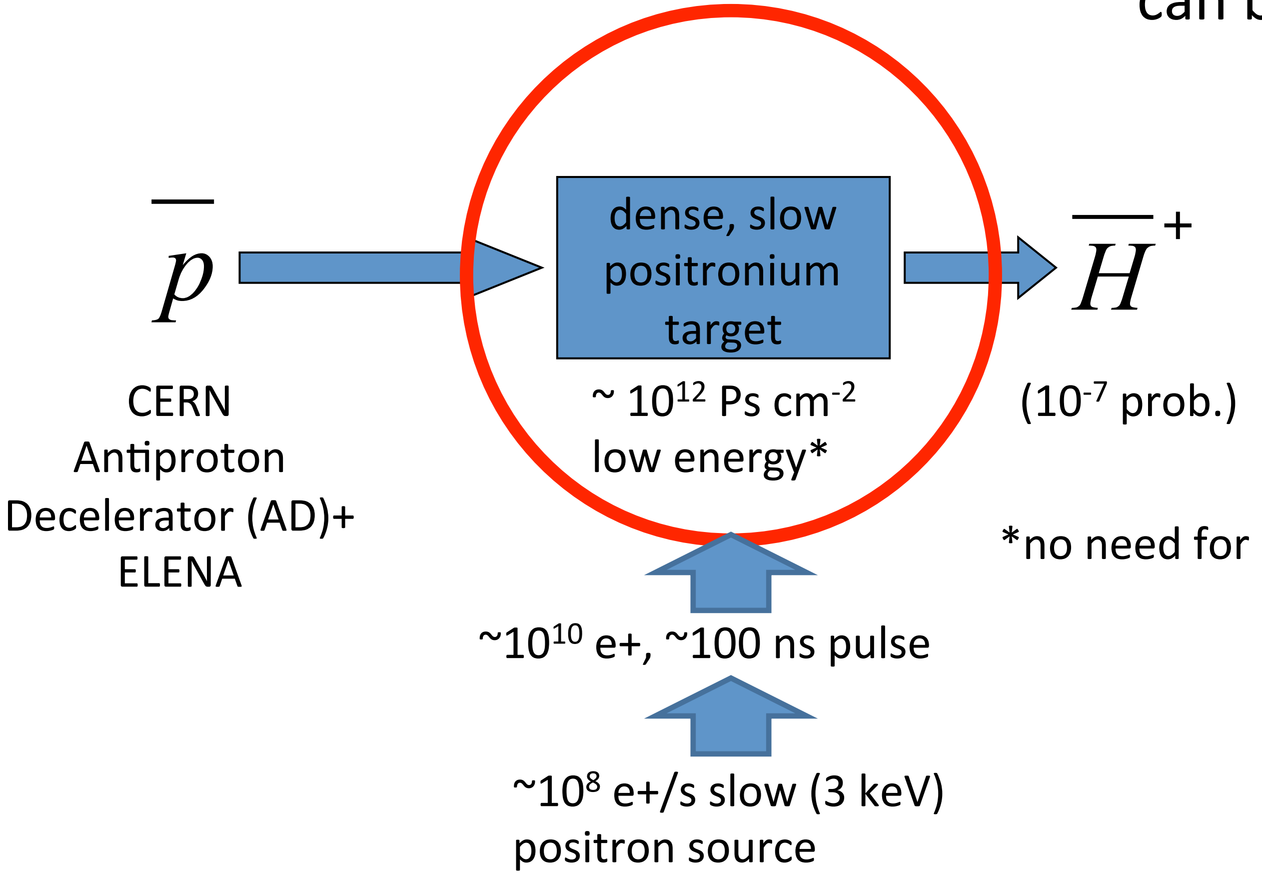
J. Walz and T. Hänsch, General Relativity and Gravitation 36, 561 (2004).
P.Pérez and A. Rosowsky, Nucl. Inst. Meth. A 532 (2004) 523-532.

Production of the antihydrogen ion

$$\bar{p} + Ps \rightarrow \bar{H} + e^-$$

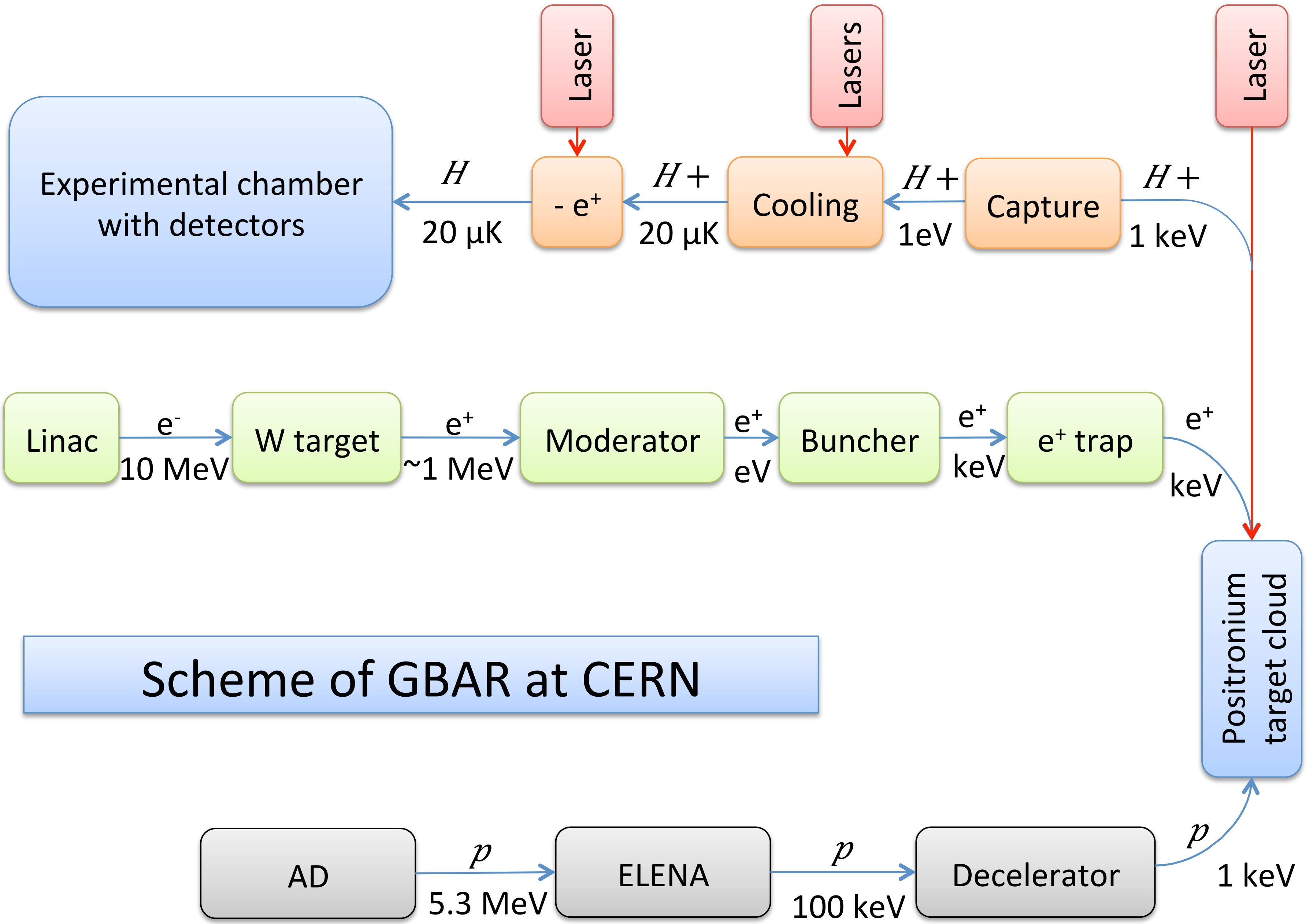
$$\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$$

(only o-Ps can be used)

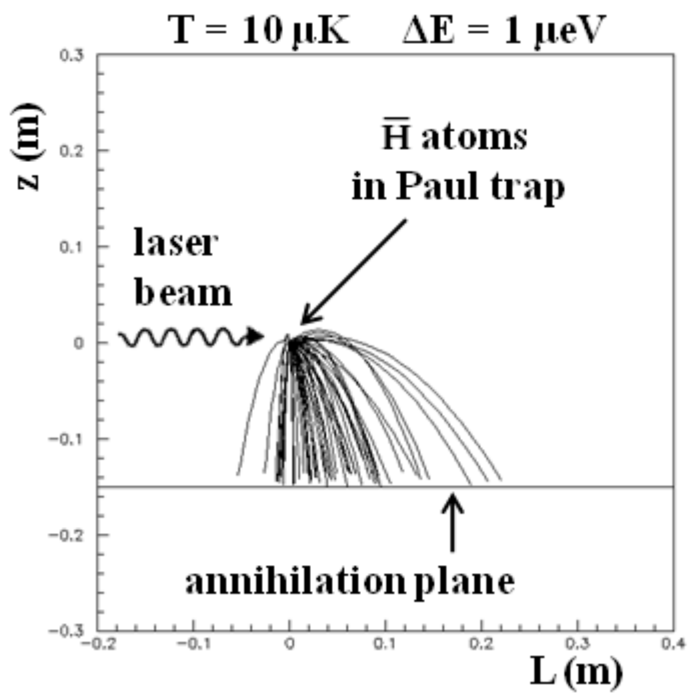


*no need for ultracold o-Ps

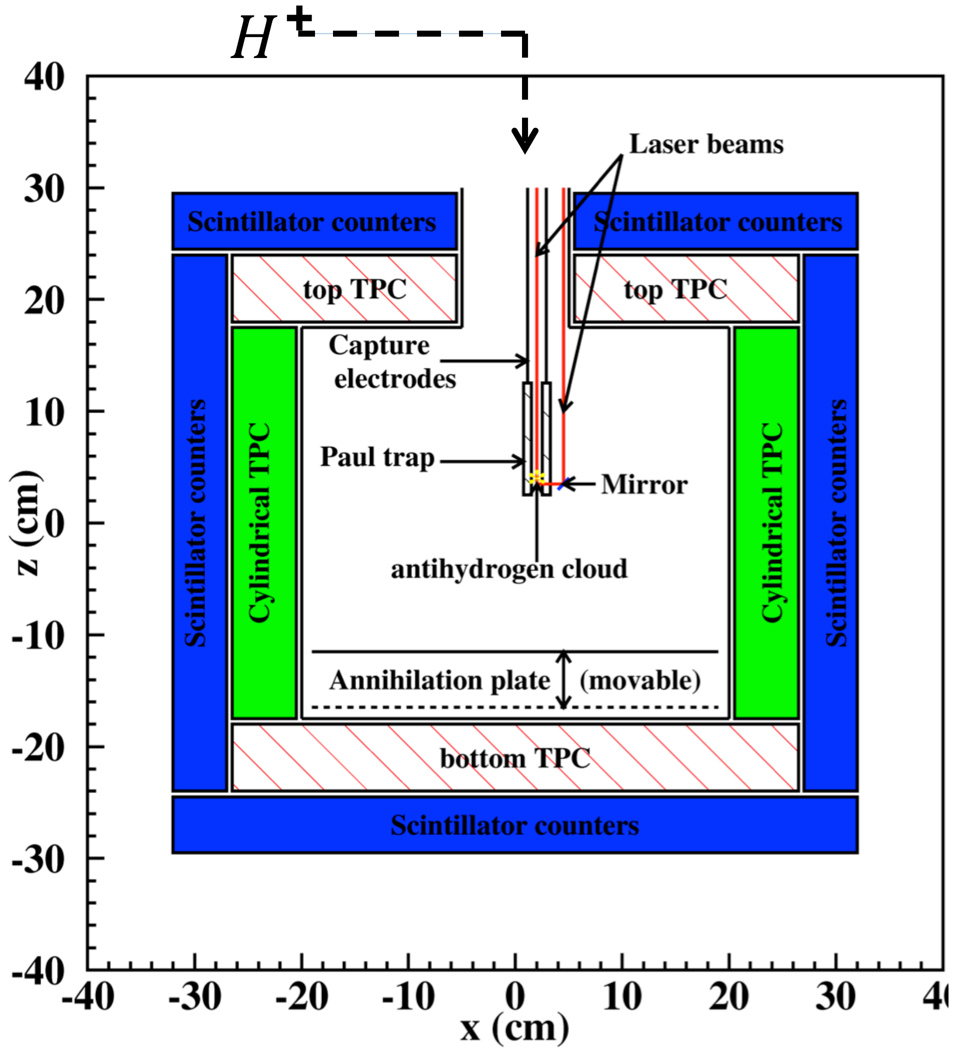
Scheme of GBAR at CERN



Detection of the free fall



Detection	Requirement
TOF precision	150 μs
Annihil. vertex precision	2 mm
Background rejection	event topology

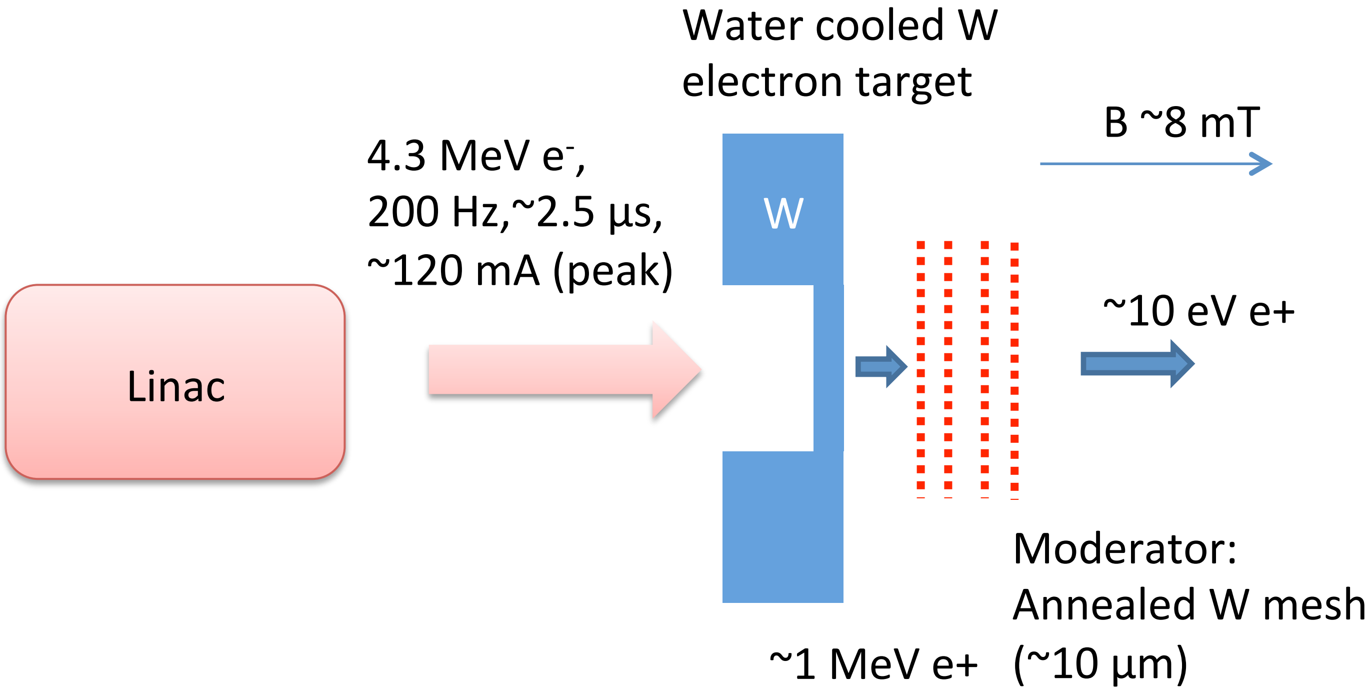


Status of the GBAR experiment

- Recommended by the SPS and PS experiments Committee (SPSC) of CERN

- Decision of the CERN Research Board (RB) is pending (expected in May)

The slow positron source



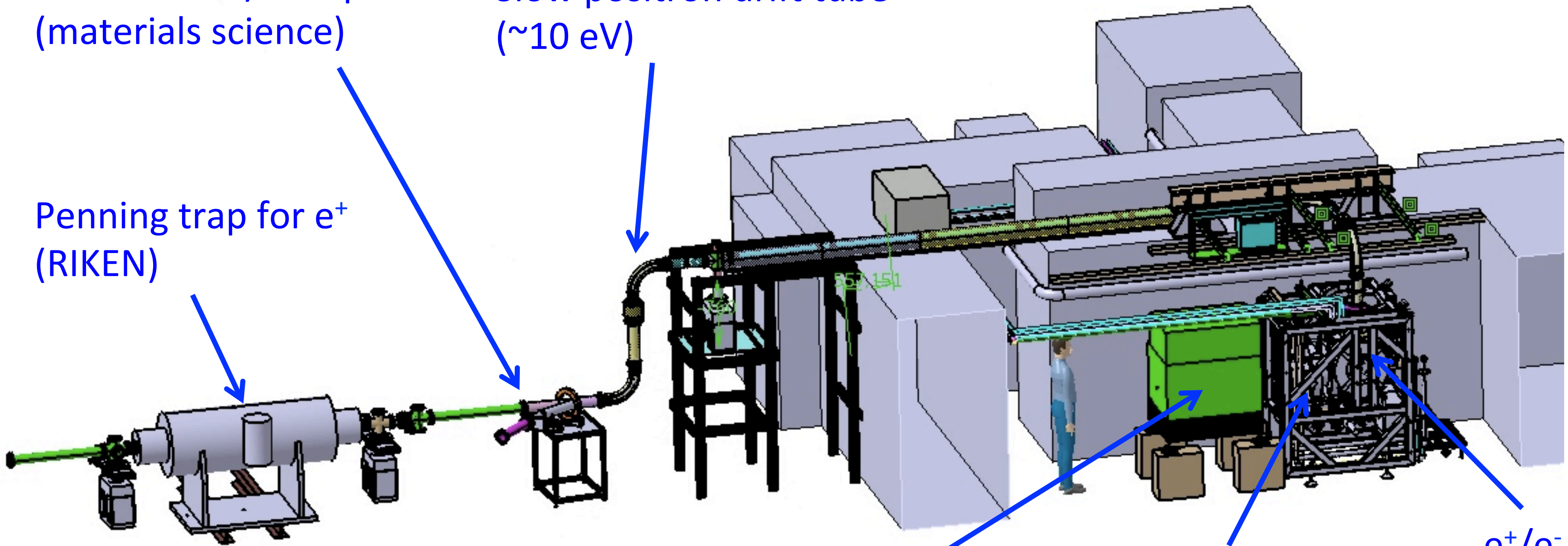
- Total efficiency is approximately 5 x 10^{-9} slow e^+ / e^-
- Efficiency has to be improved (higher electron energy, improvement in moderation)
- Optional solution: solid Ne moderator (using existing electron/positron separator)

The slow positron source at Saclay (CEA/IRFU)

- Positron production by a low energy (<10 MeV) linear electron accelerator (linac)

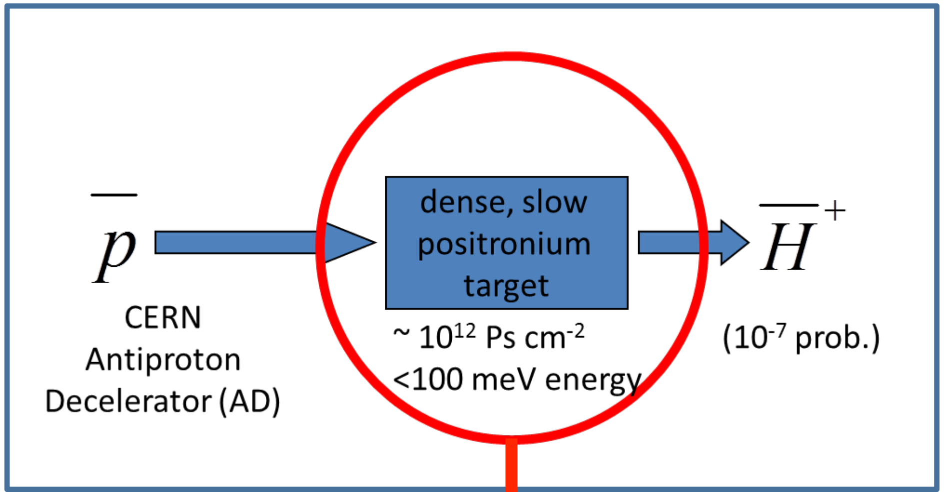
Saclay source	^{22}Na-based sources	Positron sources based on nuclear reactors or high energy accelerators
On/off operation, < 10 MeV electron source (no activation)	Radioactive source can't be switched off, capsule with thin exit window (~open source)	Limited access to the source, permanent activation of the source environment, radioactive waste
Dedicated positron source	Dedicated source	Time-sharing (reactor cycle, shared facility)
Possibly compact (+ biological shield)	Compact (thinner biological shield)	Large installation
High intensity (up to about 10^8 e^+/s	Intensity limited to about $6x10^6$ e^+/s	Very high intensity possible (up to ~10^9 e^+/s)

The slow positron source at Saclay (CEA/IRFU)



Present slow e^+ rate	$3.2\ 10^6\ s^{-1}$
Extrap. to 10 MeV linac (CERN)	$4.3\ 10^7\ s^{-1}$
target value	$2.8\ 10^8\ s^{-1}$

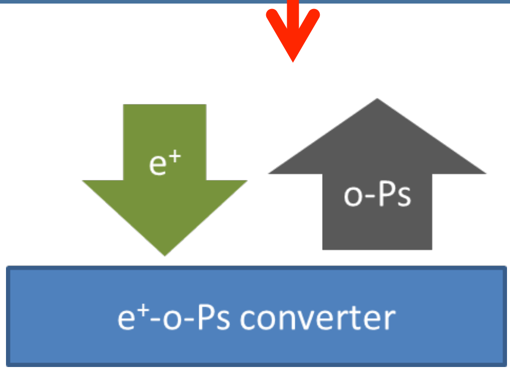
Positron-positronium converter for the Ps cloud

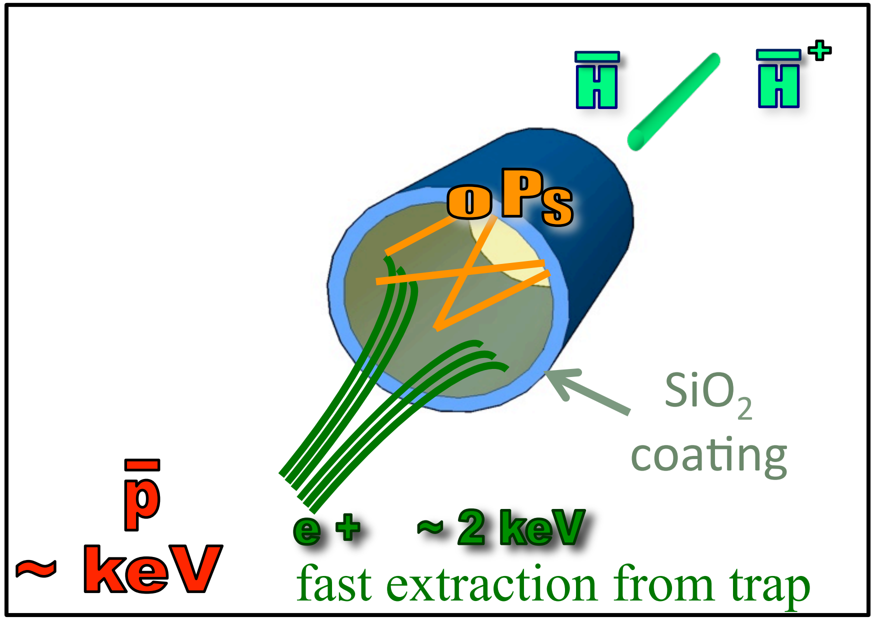


High efficiency

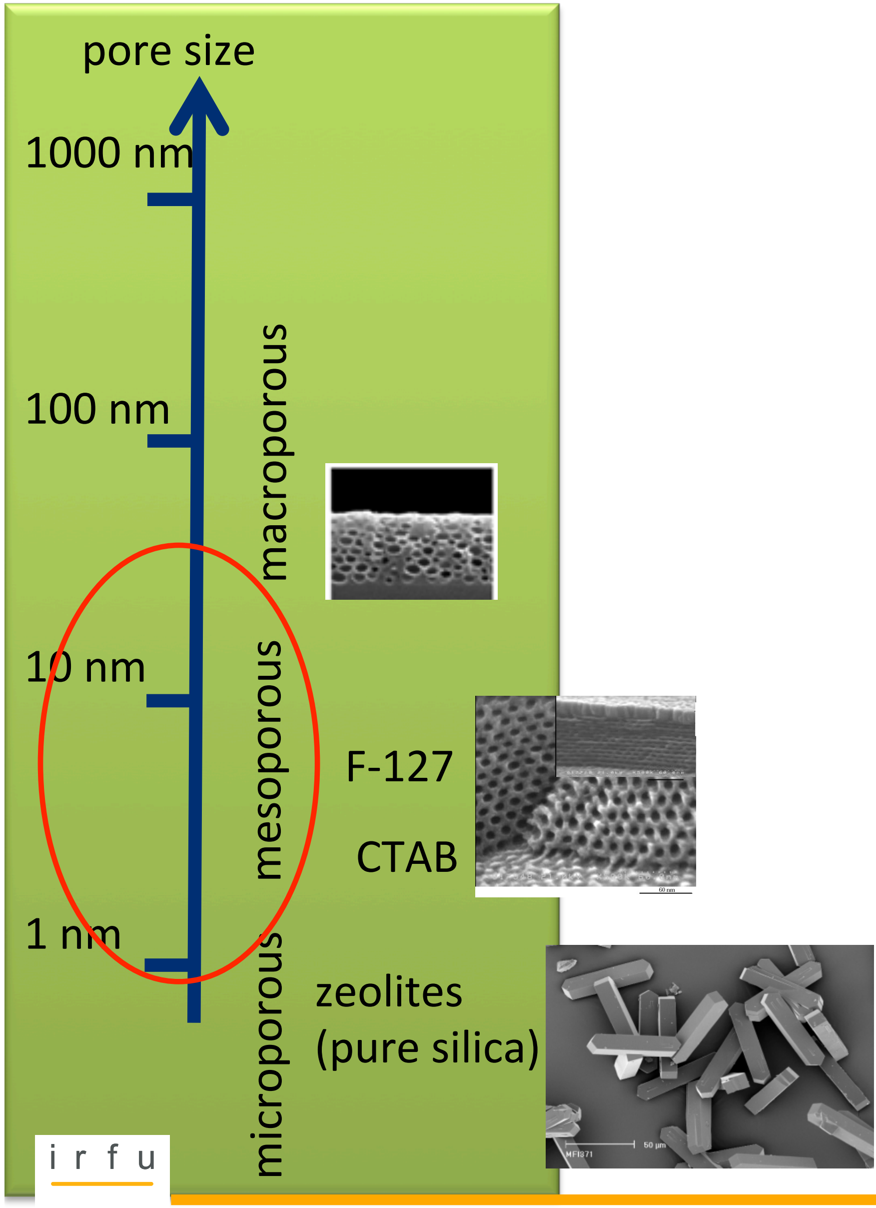
Low o-Ps energy
but
no need for ultracold o-Ps

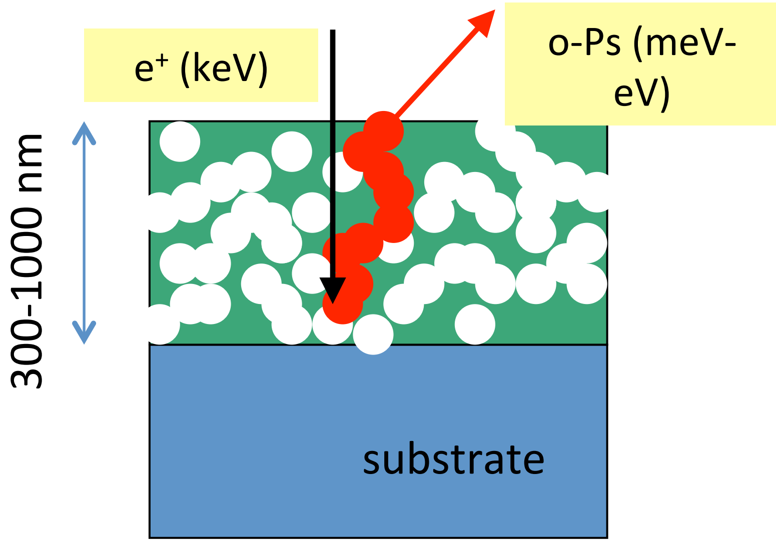
Must withstand radiation
with intense e+ pulse





Material of choice: porous silica films



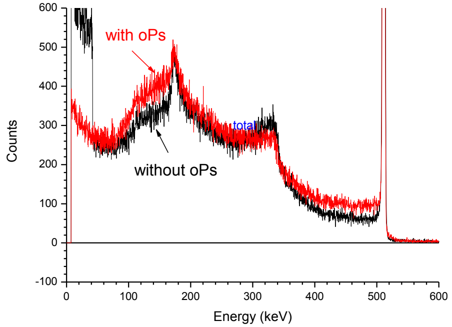


- pure SiO_2 structure
- known efficiency in positron-positronium conversion
- very large variety of structures, tunable properties
- intensively studied because of the current or potential applications

Characterization: experimental methods

Energy distribution of the annihilation radiation

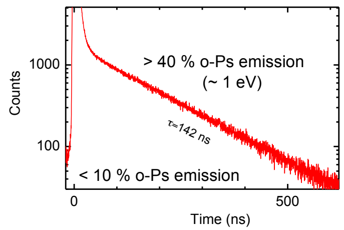
3 gamma annihilation fraction + Doppler broadening shape parameters (S, W)



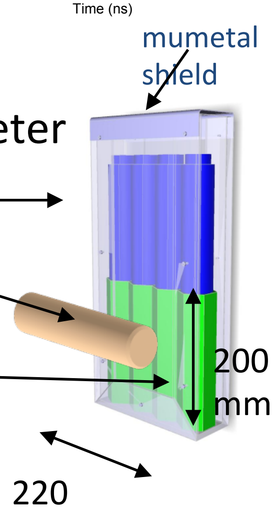
High resolution gamma spectrometer

Ortho-positronium lifetime (PALS)

Lifetime spectrum (more detail on trapping + escape)

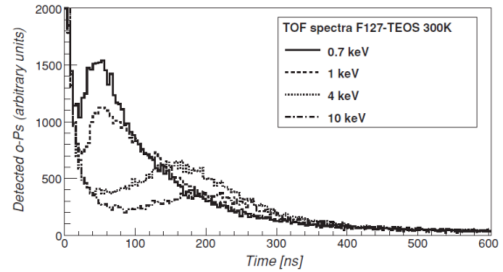


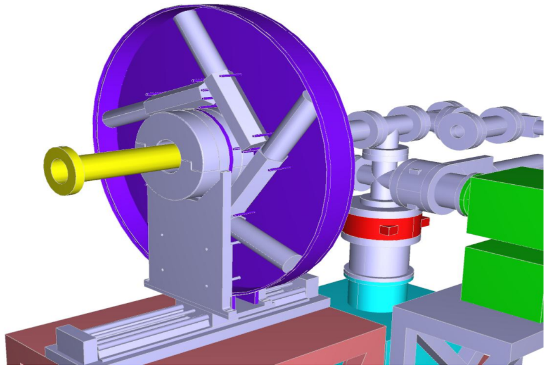
ETHZ-IRFU
PALS spectrometer



Ortho-positronium tine-of-flight (TOF)

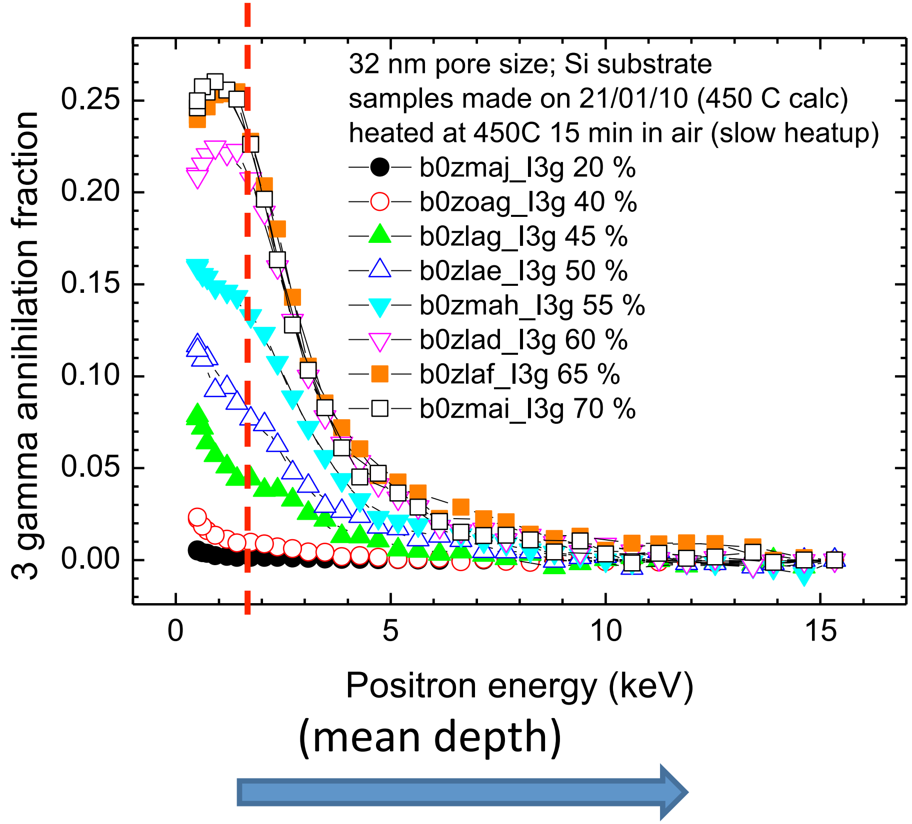
Kinetic energy (temperature) spectrum





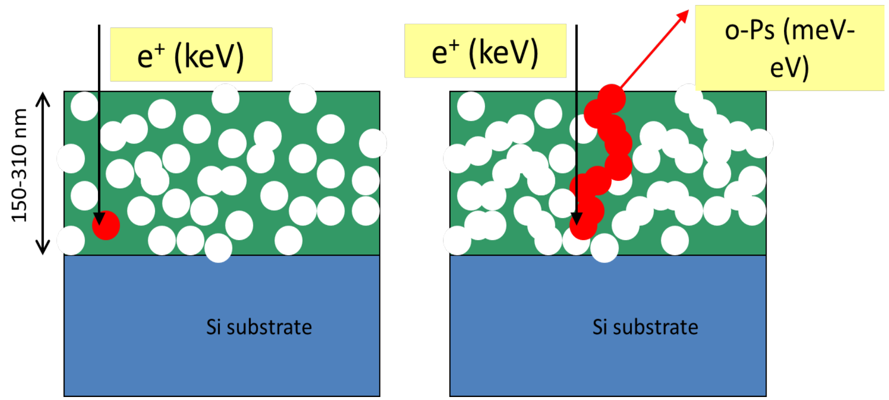
ETHZ-IRFU
TOF spectrometer

3 gamma annihilation fraction: energy distribution of the annihilation photons

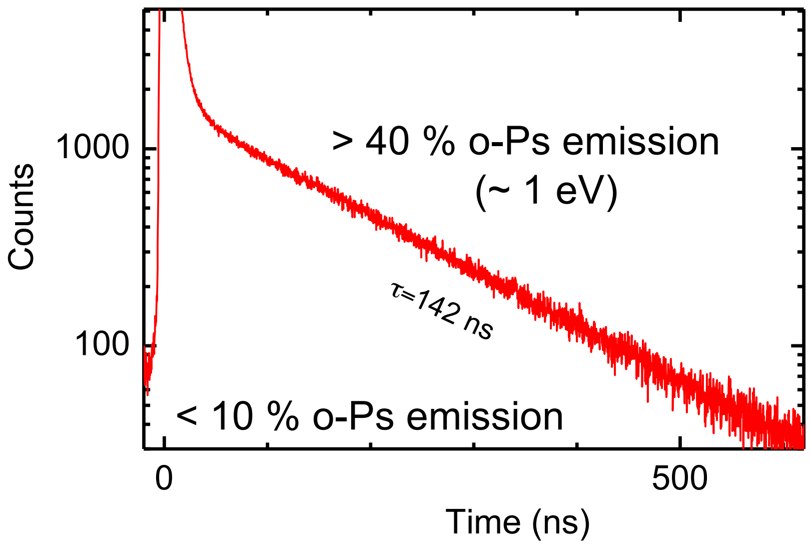


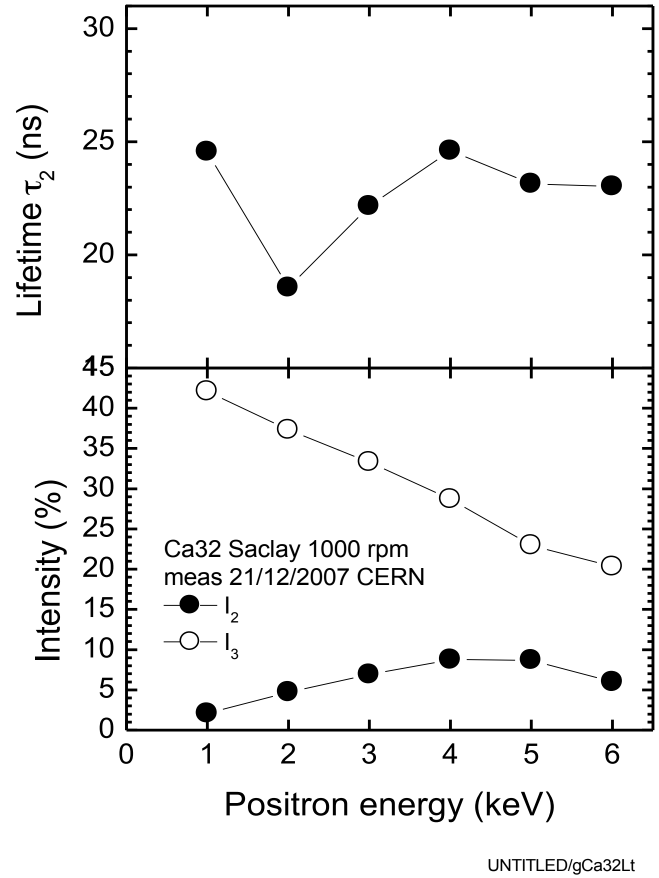
(Film thickness ~250 nm)

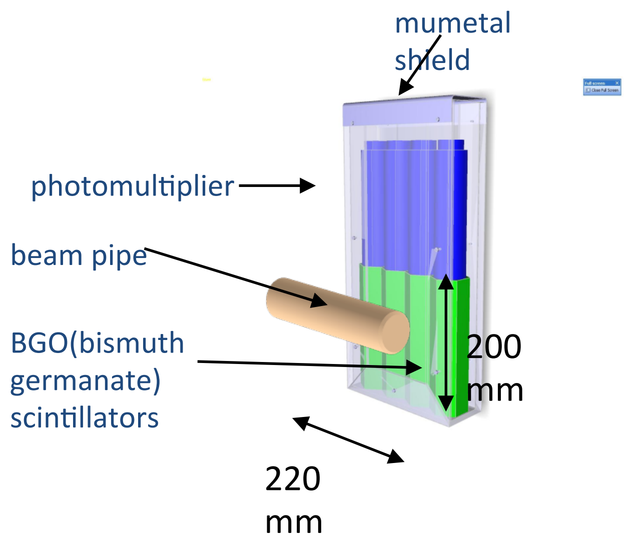
- Quick and available method
- No direct evidence for o-Ps emission into vacuum
- Upper limit for vacuum o-Ps



o-Ps emission: lifetime (PALS) measurements

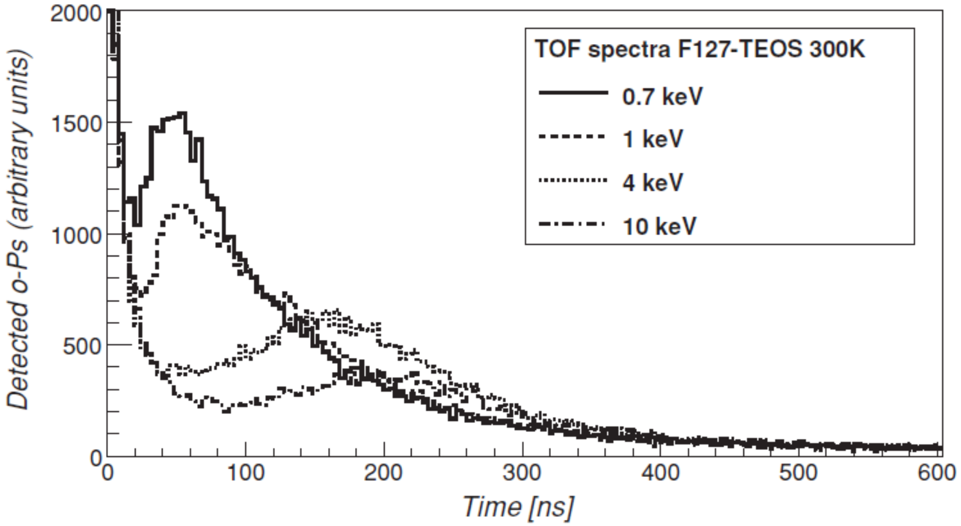




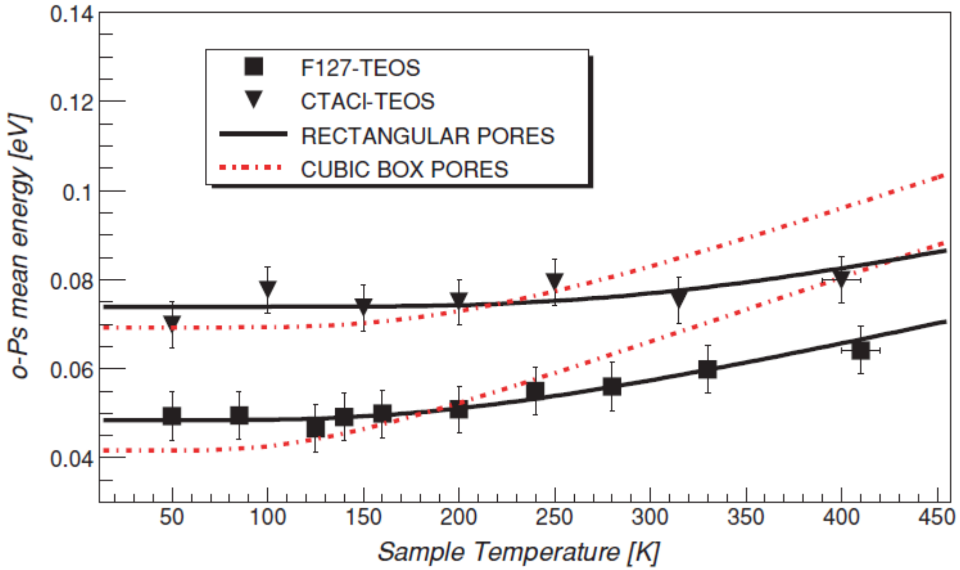


Proof of o-Ps emission into vacuum + reemission (escape) yield

o-Ps energy: TOF measurements



- ~50 meV o-Ps energy
- Minimum is reached at ~3-4 keV e+ energy
- Minimum energy is determined by quantum confinement



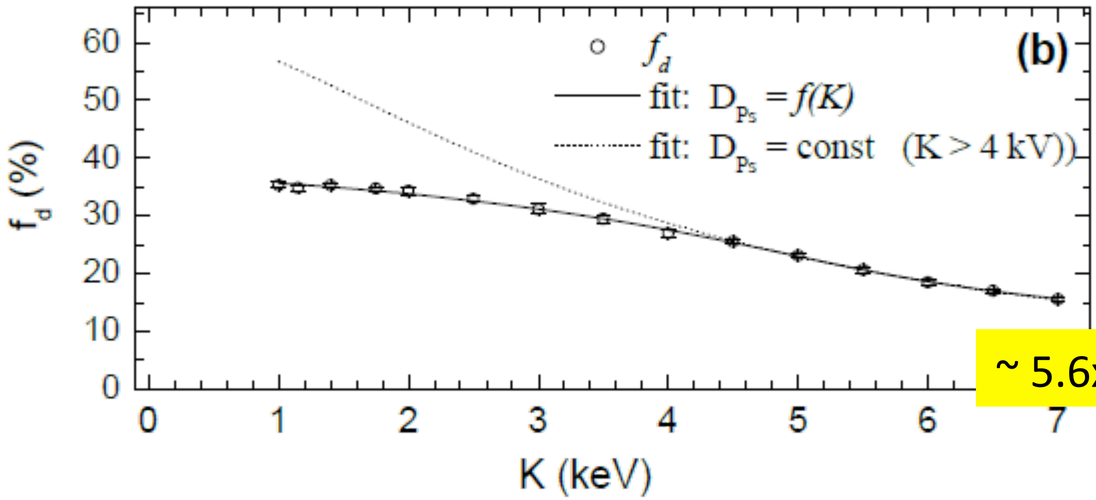
P. Crivelli et al, Phys. Rev. A 81, 052703 (2010)

o-Ps reemission at intense puses: comparison CERN / UCR

Measurement

at UCR

D. Cassidy et al, Phys. Rev; A 81, 012715 (2010)

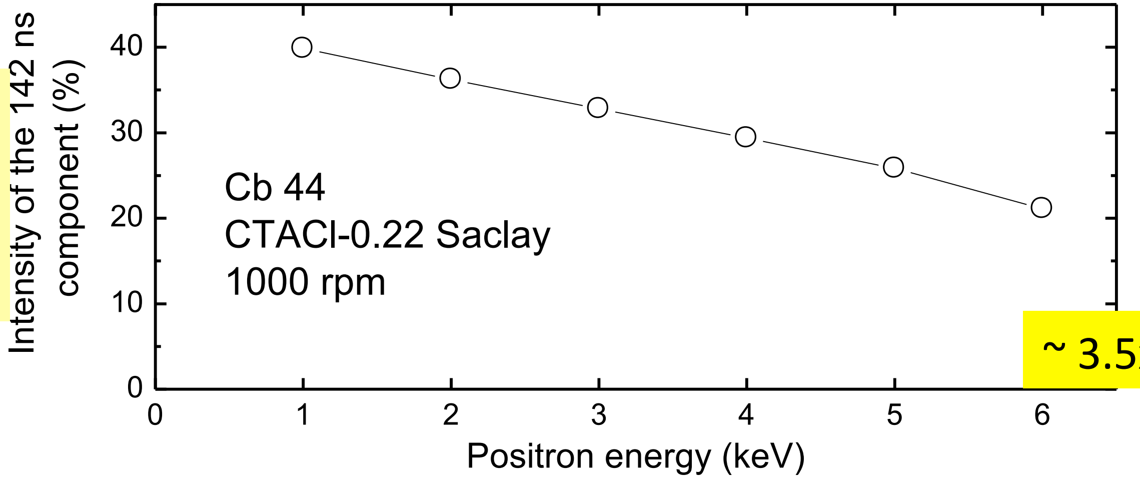


$$f_d = \int_{50ns}^{300ns} V(t)dt \Big/ \int_{-50ns}^{300ns} V(t)dt \, .$$

~ 5.6×10^{16} $e^{+}cm^{-2}s^{-1}$

> 10^{11}x

Measurement at the ETHZ/ IRFU spectrometer



~ 3.5×10^{5} $e^{+}cm^{-2}s^{-1}$

No loss in conversion efficiency due to the high e^{+} intensity is observed

Conclusions

- GBAR collaboration has been formed
- A feasible experimental scheme was developed
- Advances in the development of
  - Positron/positronium converter
  - Linac-based positron source
  - Positron trap
- Model calculations on Ps excitation, antihydrogen production cross sections, cooling… are underway
- First beamtime is expected in 2016 (see ELENA)
- First measurements in 2017

Multiring trap (RIKEN): cooling by trapped electrons