Laboratory experiments with the high-intensity low-energy positron beam POSH

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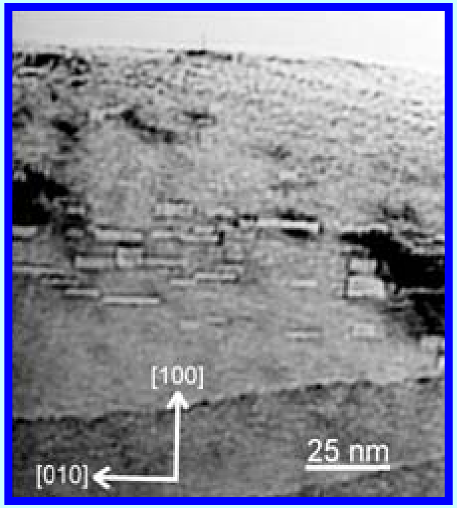

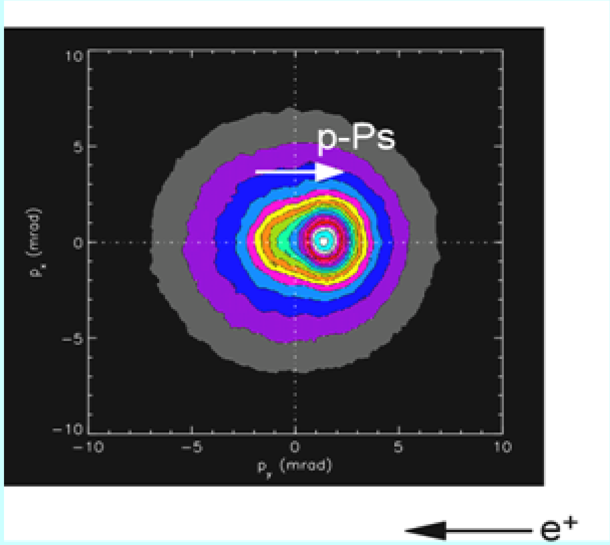

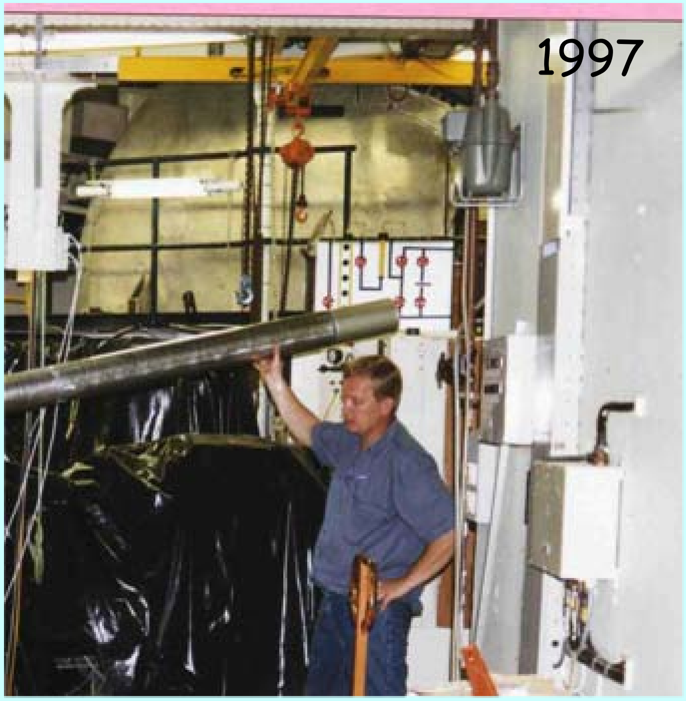

Henk Schut
RRR/NPM2

Positronium emission from oxides

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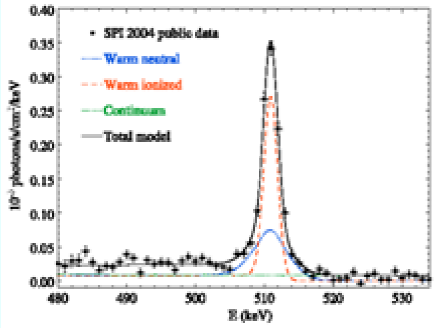
1. Positron facilities and sources at the Reactor Institute Delft (RID)

- Positron Doppler broadening spectroscopy
- Positron 2D-ACAR

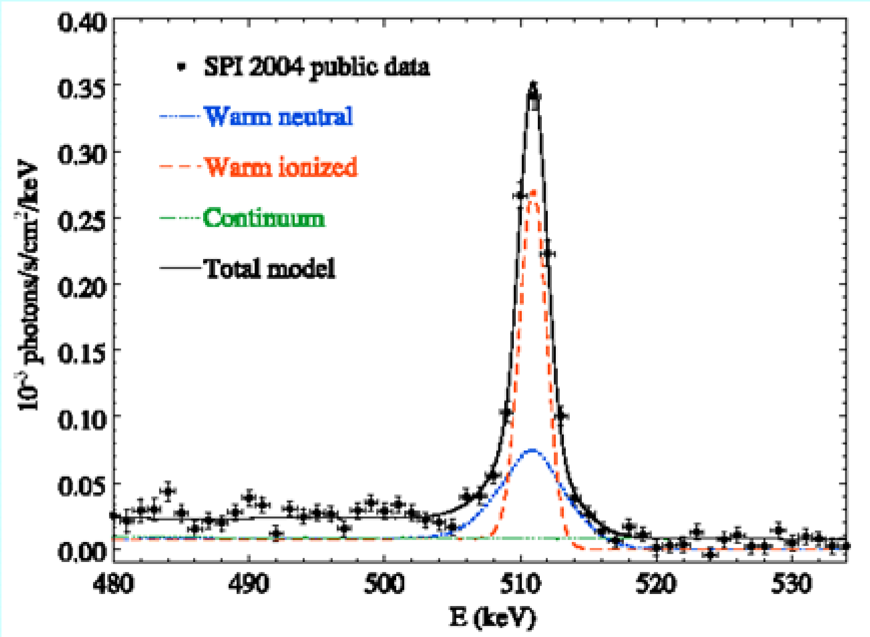
2. Positronium momentum distributions and linewidths

- emitted from MgO surfaces
- emitted from SiO_2 surfaces

3. Implications



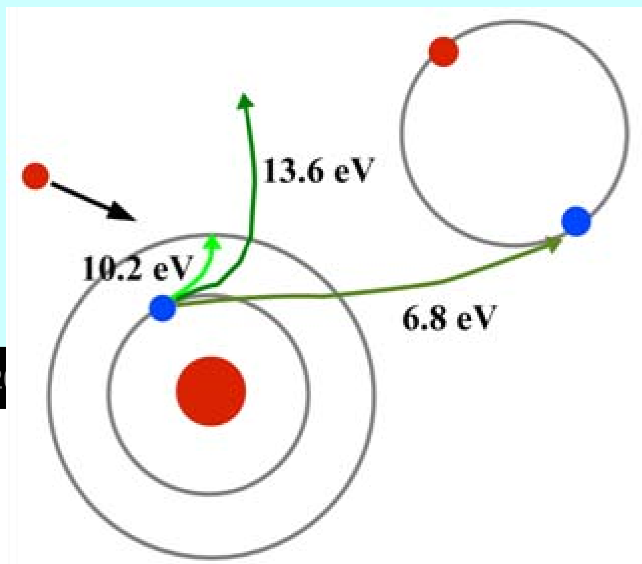
Galactic 511 keV annihilation line: spectral analysis



P. Jean et al. (2006)

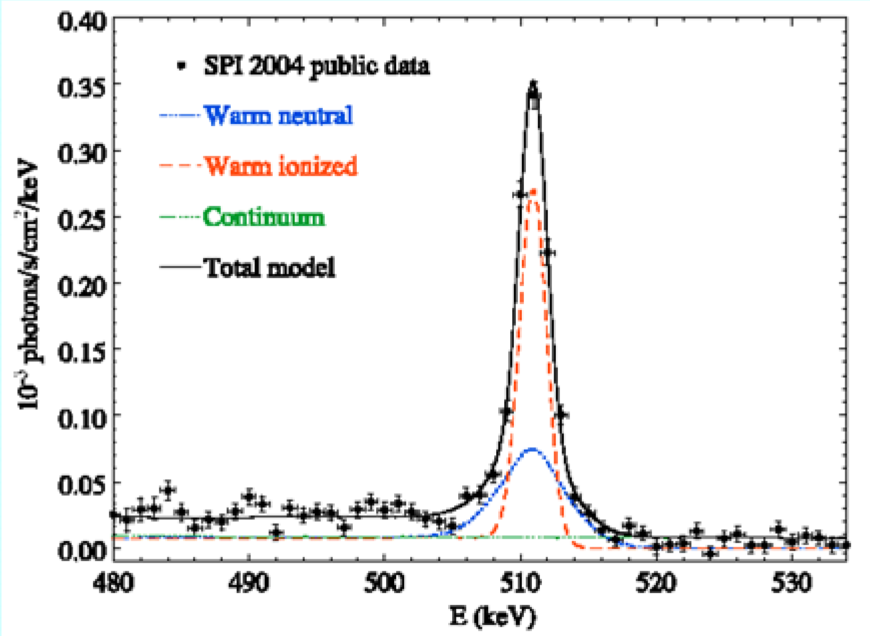
Parameters	Measured values
I_n (10^{-3} s^{-1} cm^{-2})	$0.72 \pm 0.12 \pm 0.02$
Γ_n (keV)	$1.32 \pm 0.35 \pm 0.05$
I_b (10^{-3} s^{-1} cm^{-2})	$0.35 \pm 0.11 \pm 0.02$
Γ_b (keV)	$5.36 \pm 1.22 \pm 0.06$
$I_{3\gamma}$ (10^{-3} s^{-1} cm^{-2})	$4.23 \pm 0.32 \pm 0.03$
A_c (10^{-6} s^{-1} cm^{-2} keV^{-1})	$7.17 \pm 0.80 \pm 0.06$

$$f_{Ps} \sim 93\%$$



possible mechanism of Ps formation:
interaction with neutral hydrogen atoms

Galactic 511 keV annihilation line: spectral analysis



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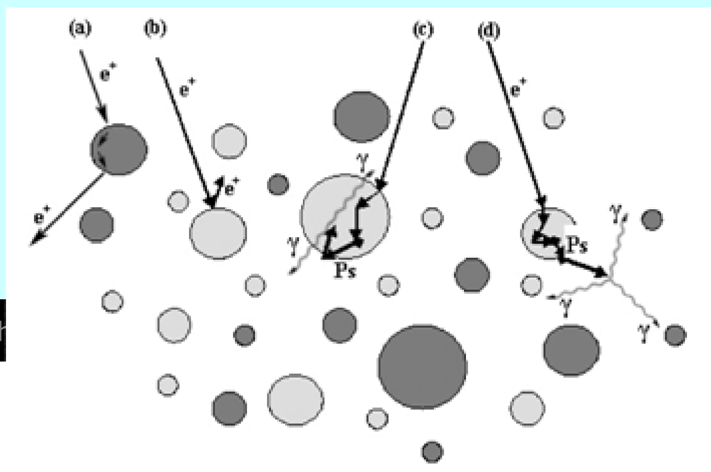


possible mechanism of Ps formation:
interaction with interstellar dust grains

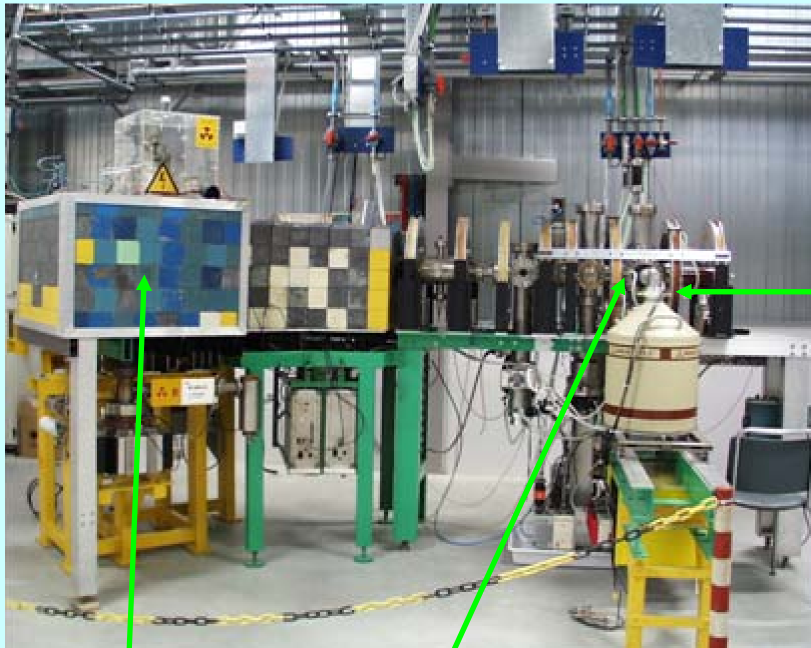
oxide grains
e.g. $(Mg,Fe)_2SiO_4$

Lab-based sources and instruments 1:

β-decay $^{22}Na \rightarrow {}^{22}Ne + e^{+} + \nu_e$

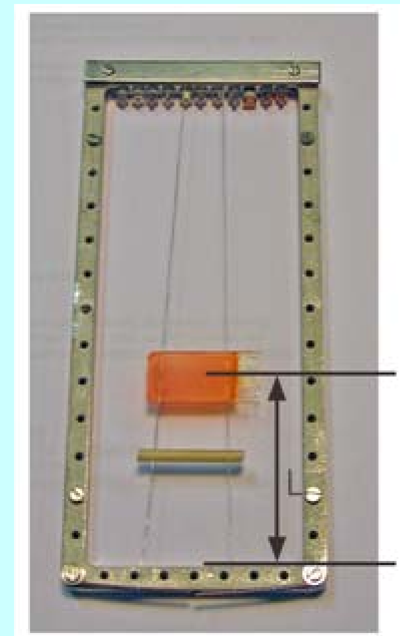
The Variable Energy Positron beam (VEP)

1) Doppler broadening
2) 3γ-detection



Ge detector

sample holder



10x10 mm^2 sample

^{22}Na source

sample chamber

10^5 e^+/s at a low energy ([3 eV] 0.1-30 keV):
thin films and surfaces

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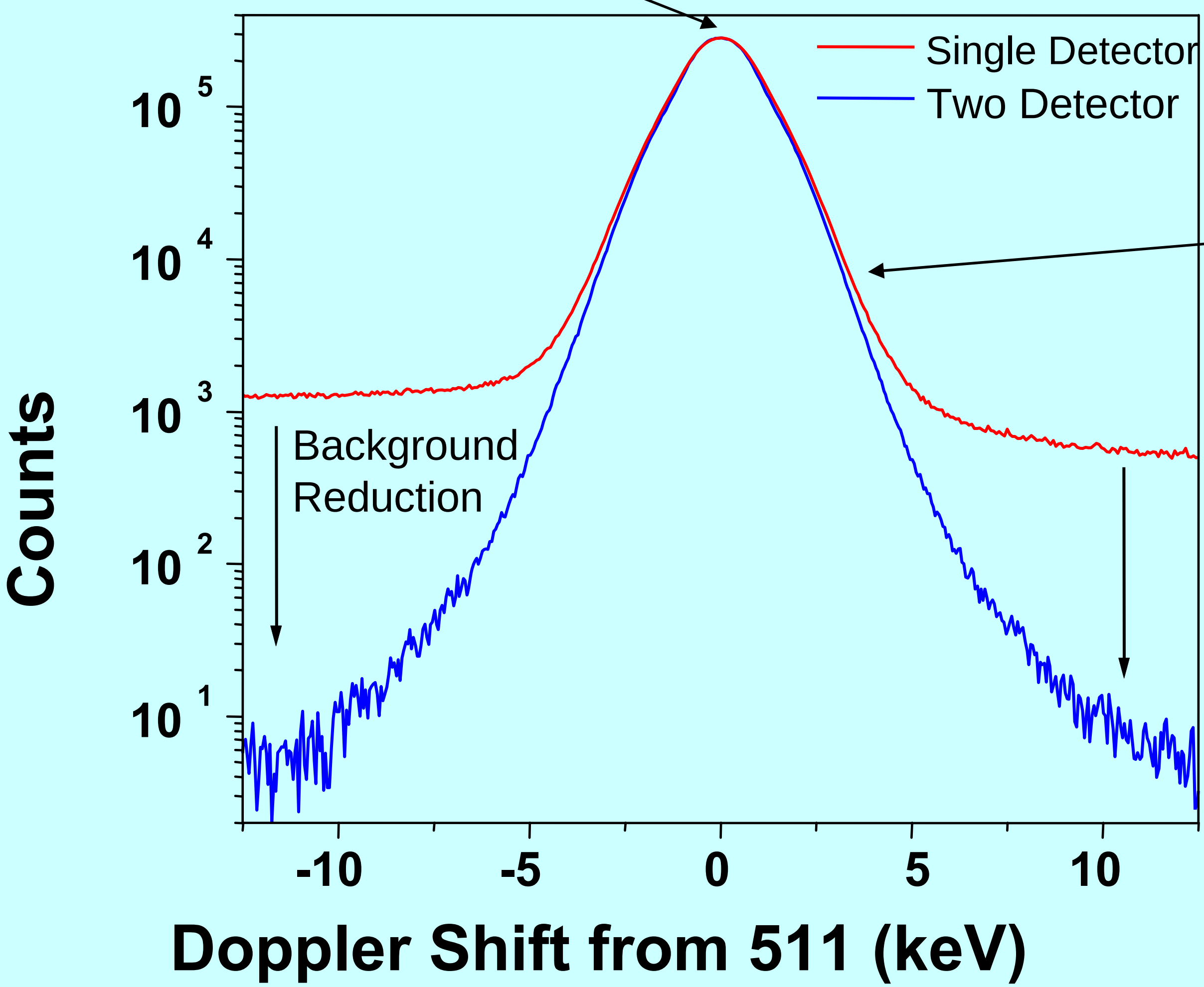
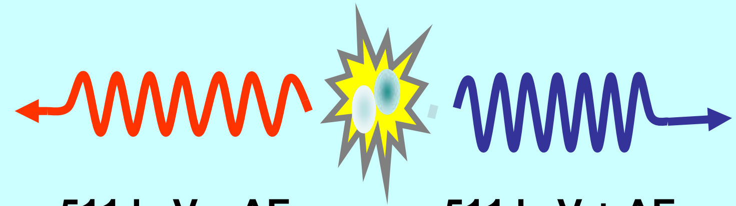
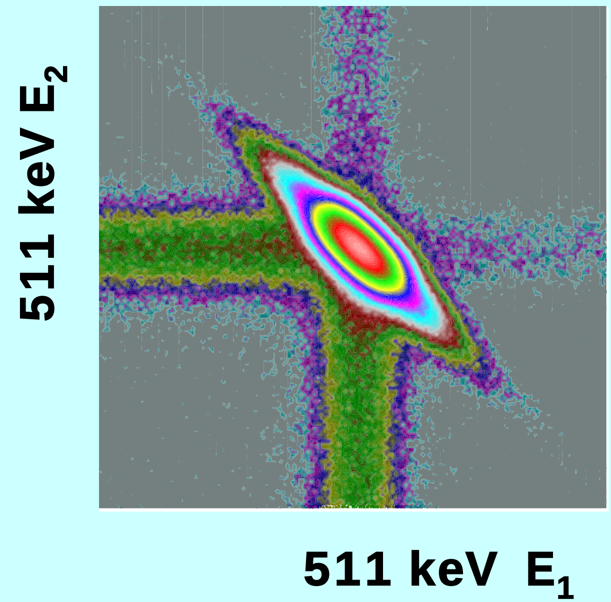
Low momentum electrons

High momentum electrons





Coincidence detection (2 detectors)

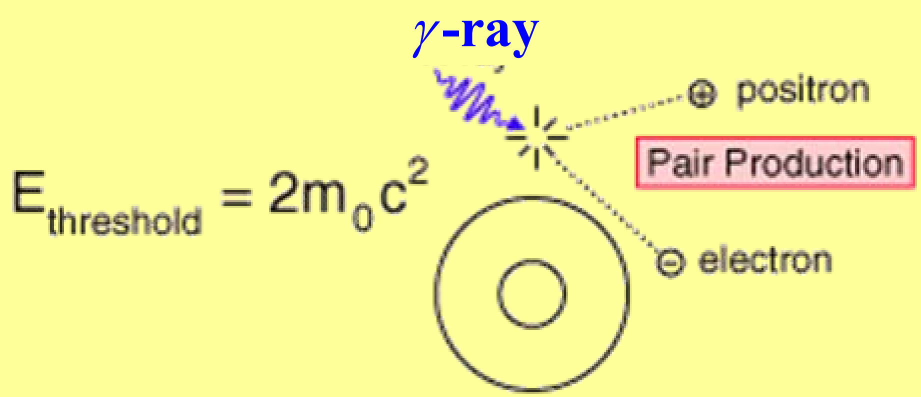


$$\Delta E = 1\,keV \;\hat{=}\; p = 3.91\cdot 10^{-3} m_0 c$$

Lab-based sources and instruments 2:

Electron-Positron Pair Production $\gamma \rightarrow e^{+} + e^{-}$

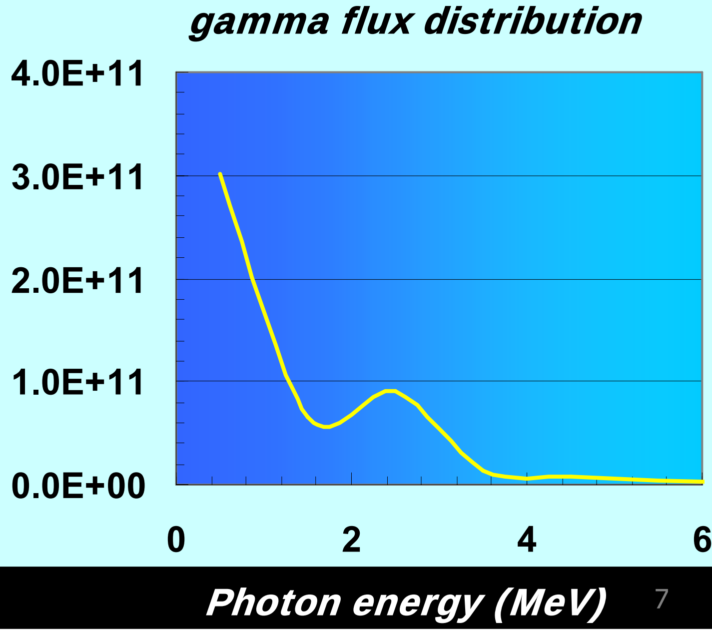
Energetic γ-rays required



Coulomb field of a heavy nucleus

Threshold energy $2m_ec^2$ = 1022 keV

Reactor Institute Delft



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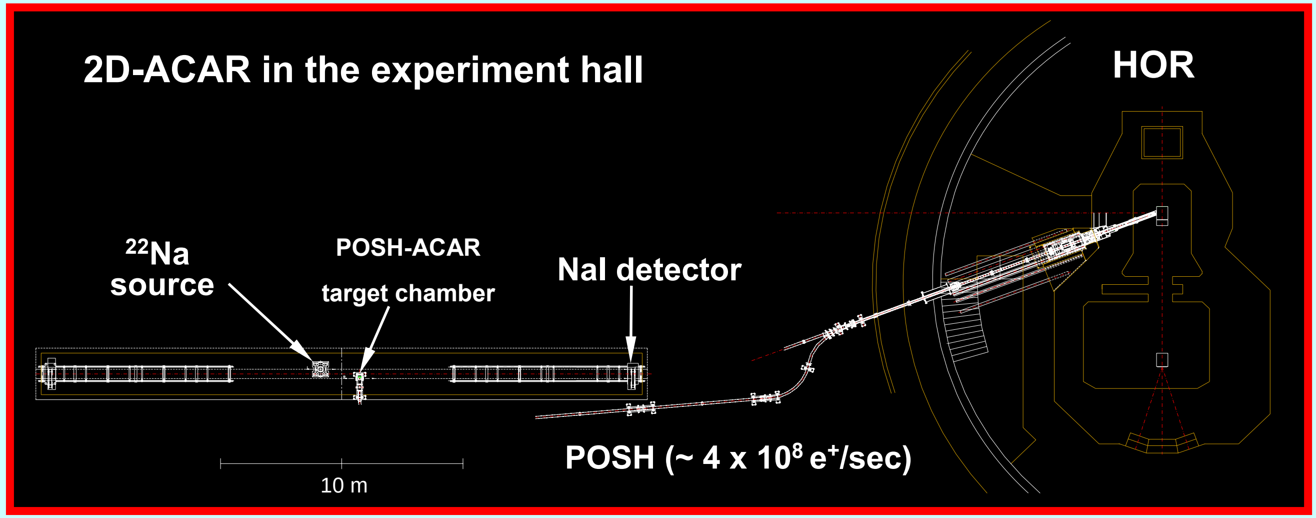
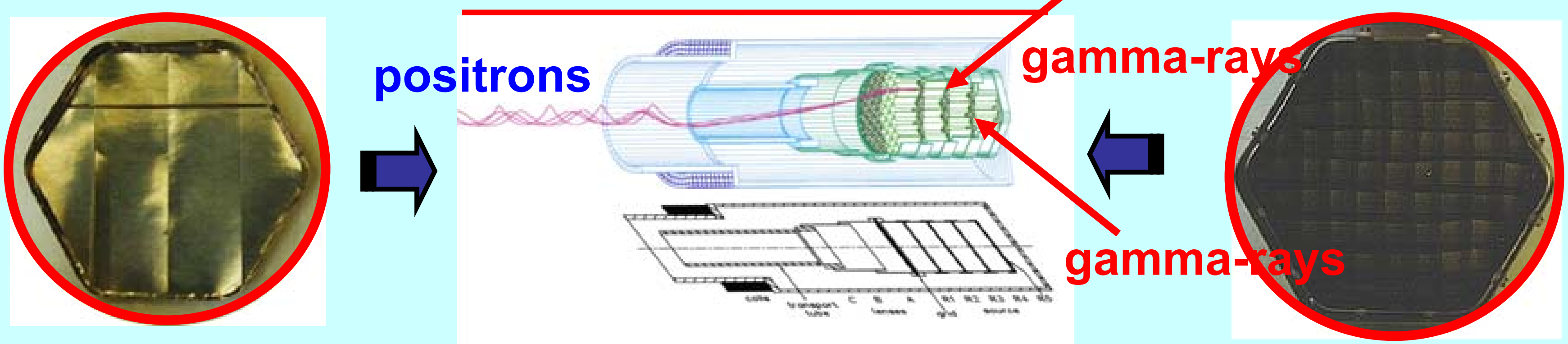
Pair production: creation of a very brilliant positron beam POSH

Reactor Institute Delft



Tungsten foil **The positron source** **Tungsten grid**

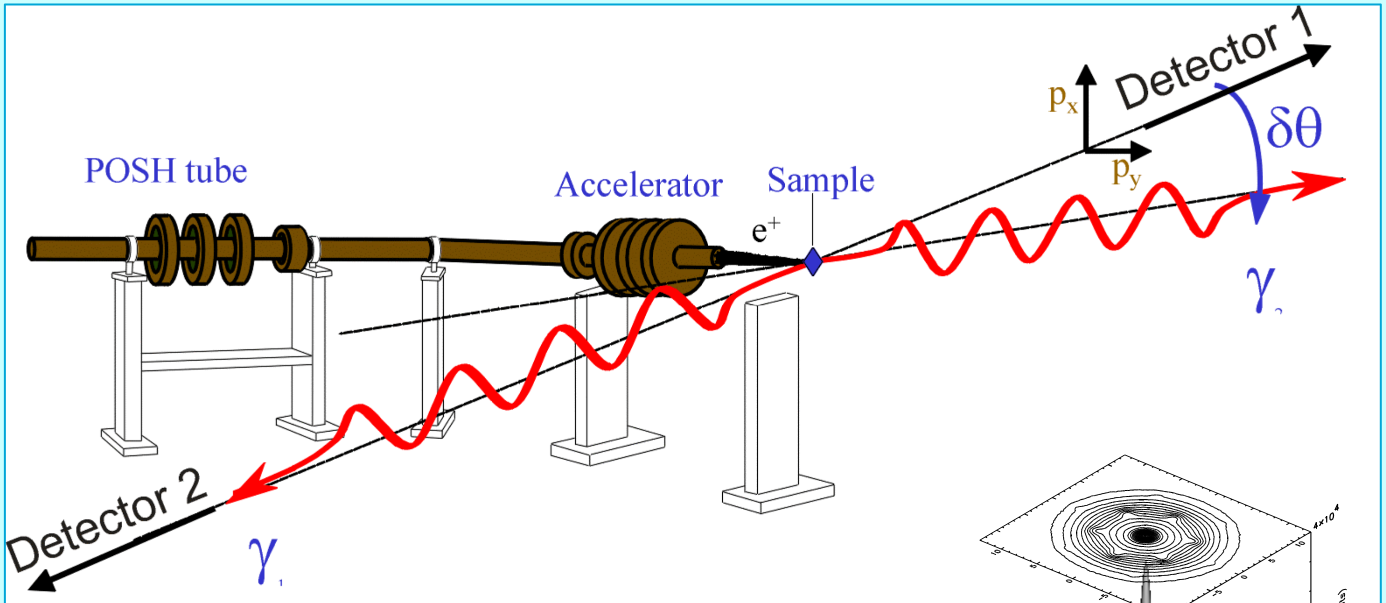


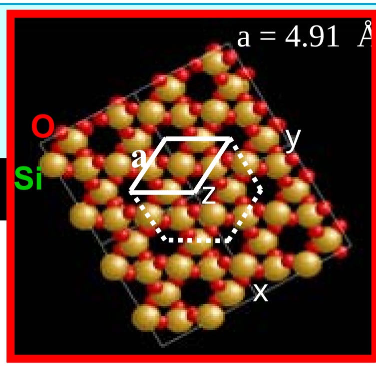
$4x10^8$ e^+/s at a low energy (100 eV - 15 keV):
thin films and surfaces

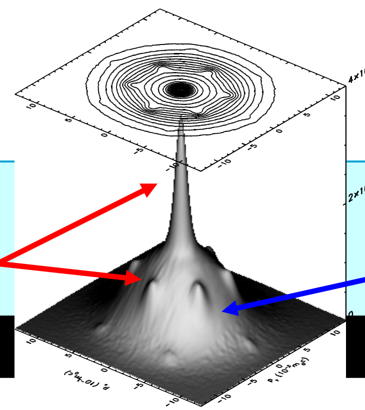
2D-ACAR method: high resolution positron-electron momentum distributions

2D-Angular Correlation of Annihilation Radiation

coupled to the POSH-beam



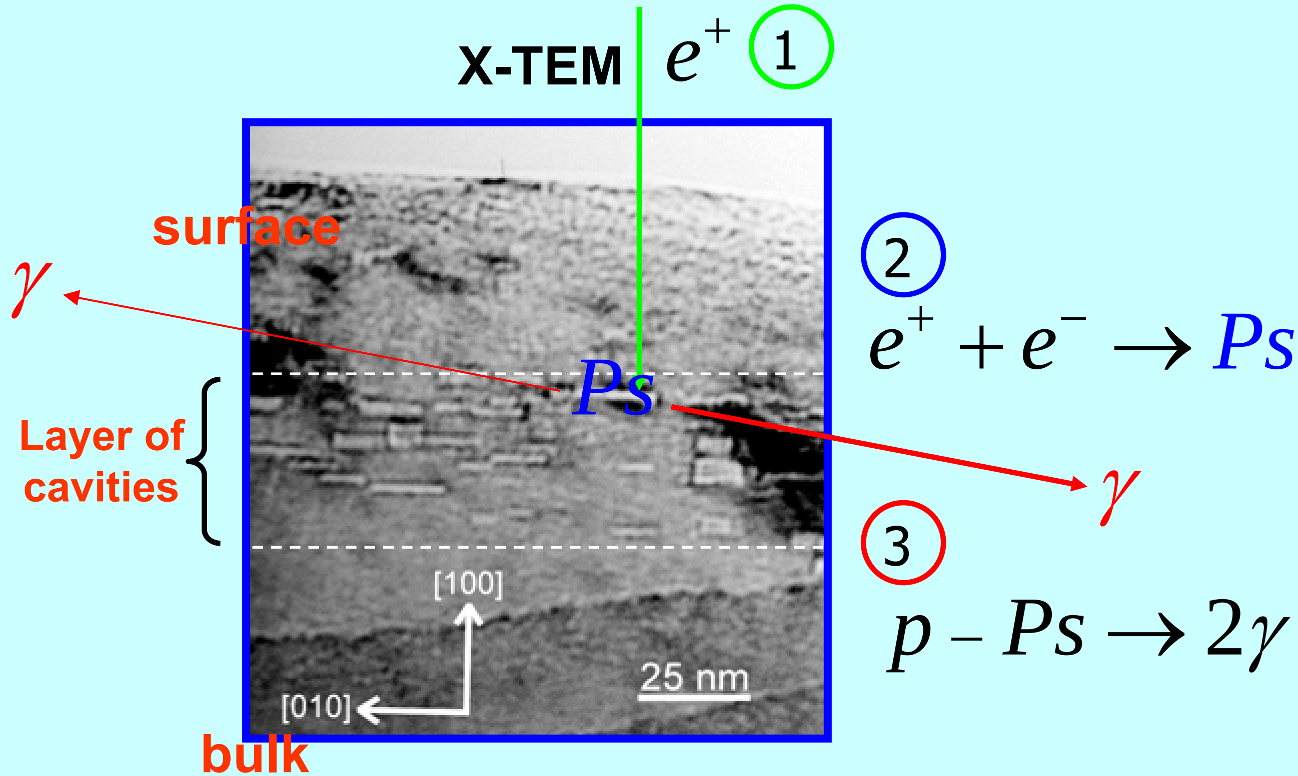




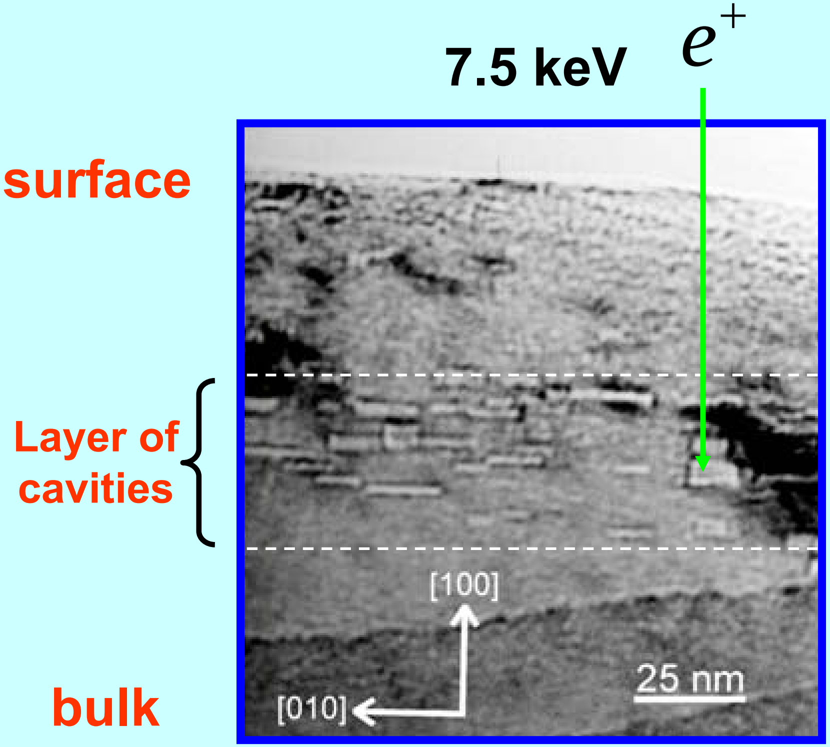
2D-ACAR spectrum for quartz

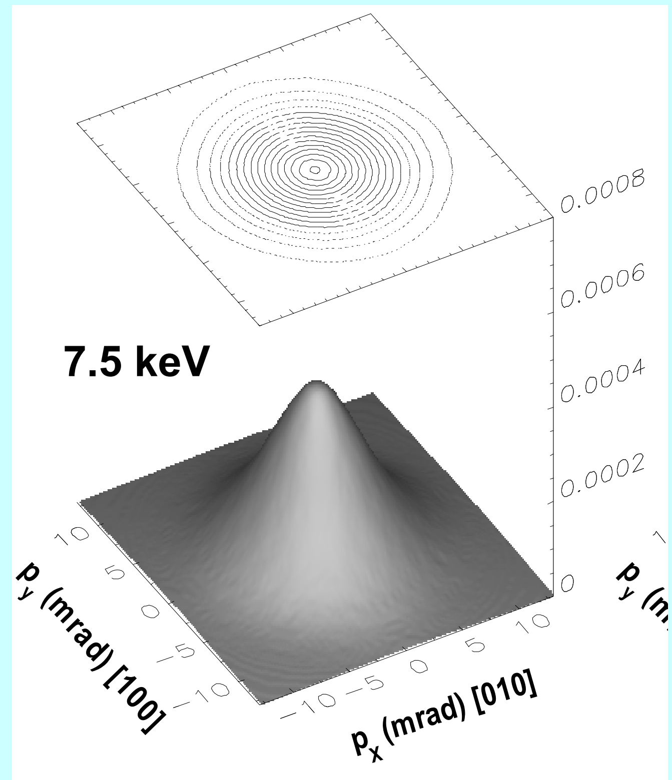
Positron study of Ps emission from internal surfaces of MgO

Band of rectangular voids in crystalline MgO



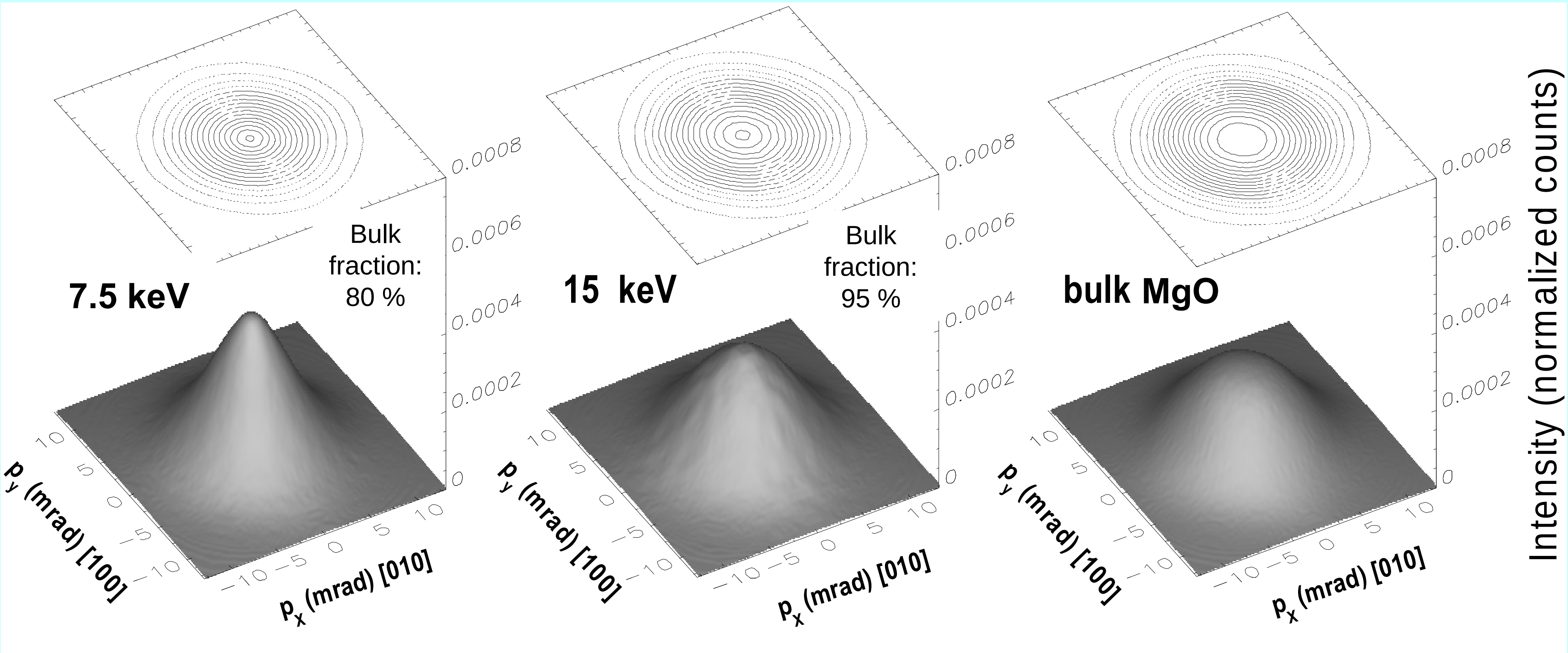
Positron study of Ps emission from internal surfaces of MgO

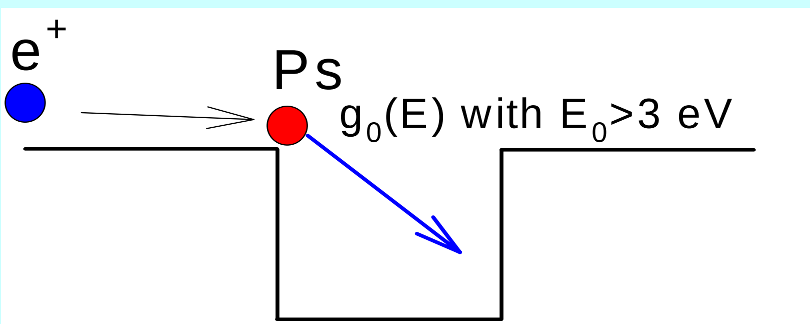


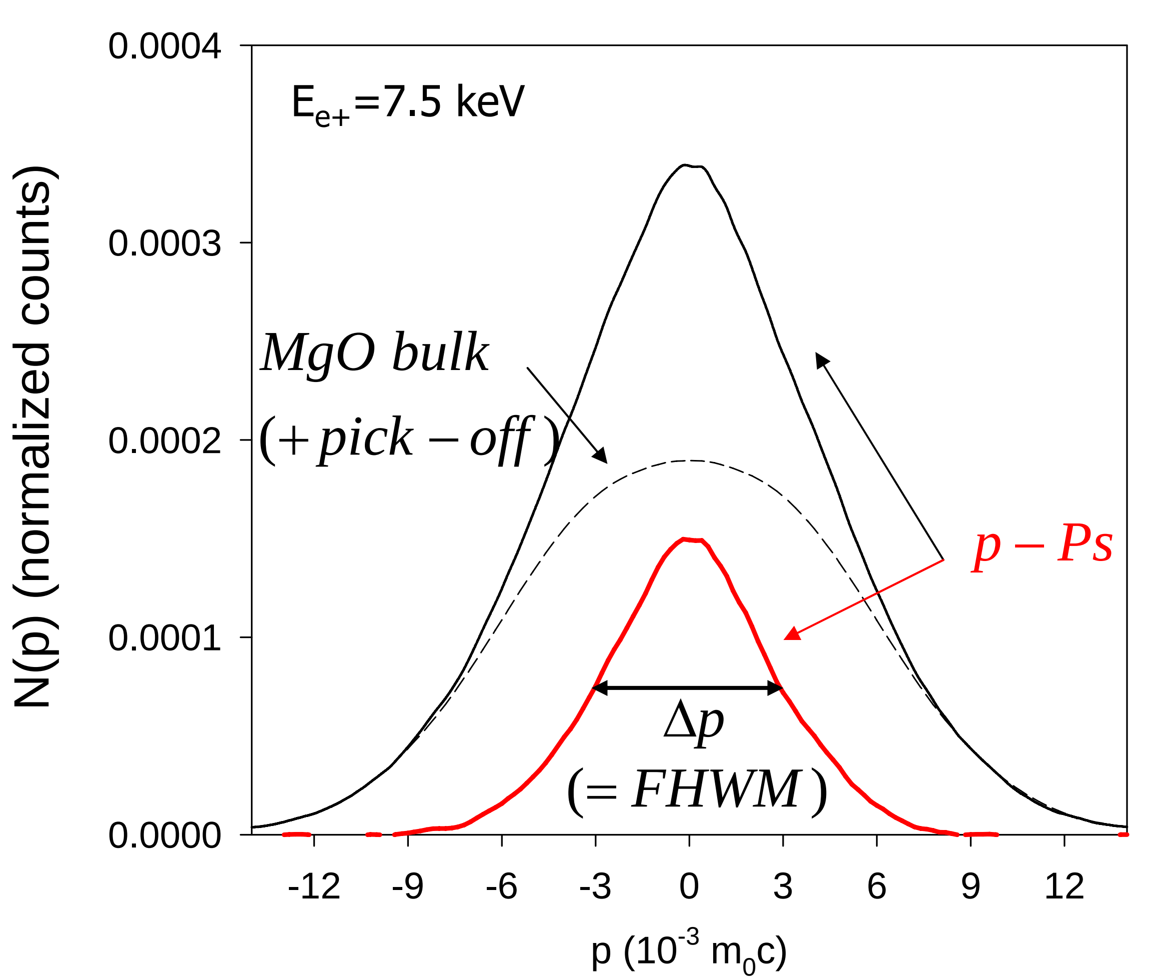


T= 295 K
(room temperature measurement)

2D-ACAR distributions







p-Ps component:

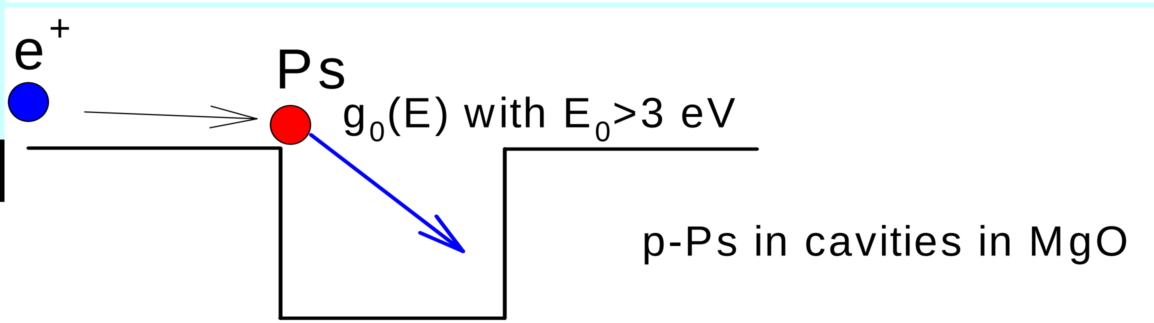
$$\Delta p = 6 \cdot 10^{-3}\ m_0 c$$

$$FWHM = 1.6\ keV$$

broad component:

$$\Delta p = 15.5 \cdot 10^{-3}\ m_0 c$$

$$FWHM = 4.0\ keV$$



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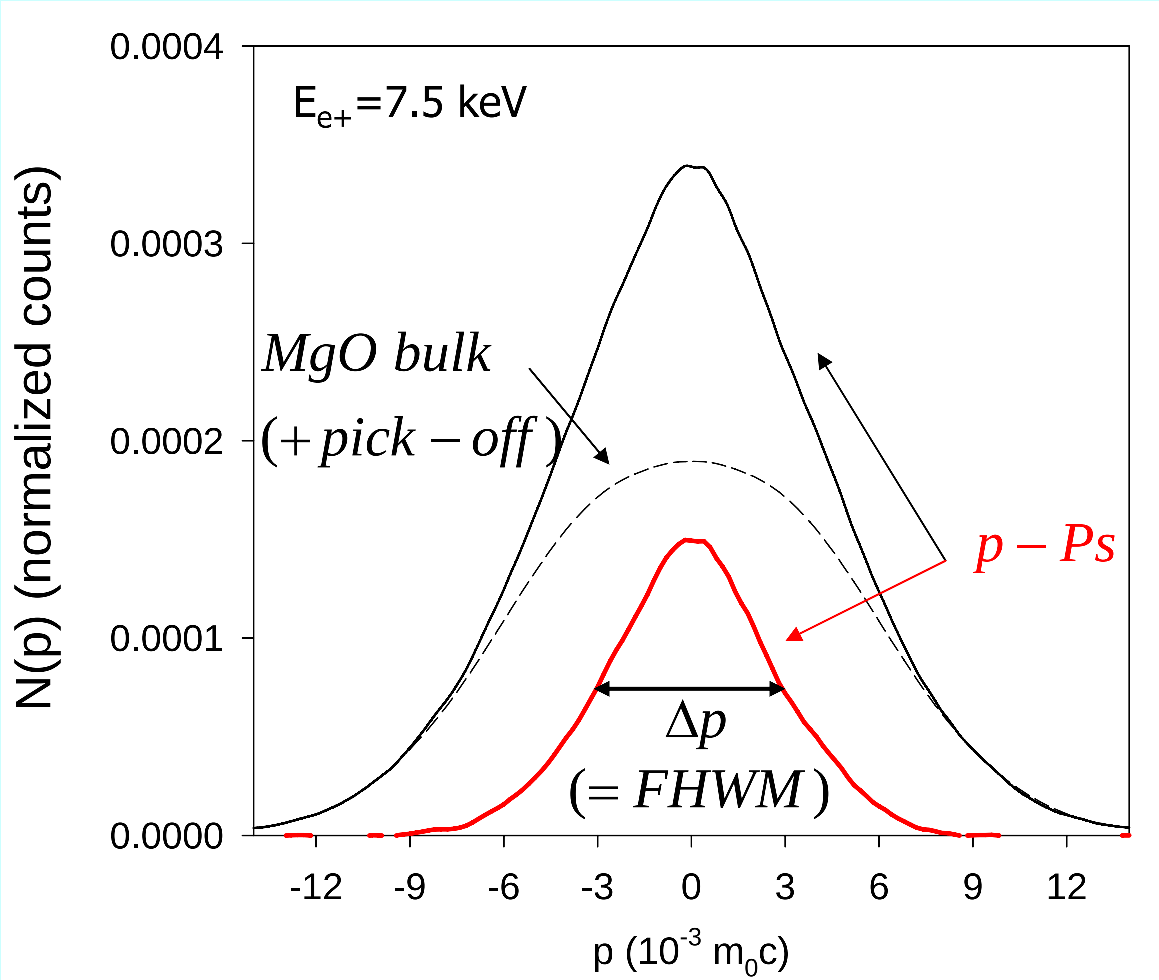

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$$FWHM = 4.0\ keV$$

Compare Galactic 511 keV line:

$$FWHM = 1.3 \pm 0.4\ keV$$

$$FWHM = 5.4 \pm 1.2\ keV$$

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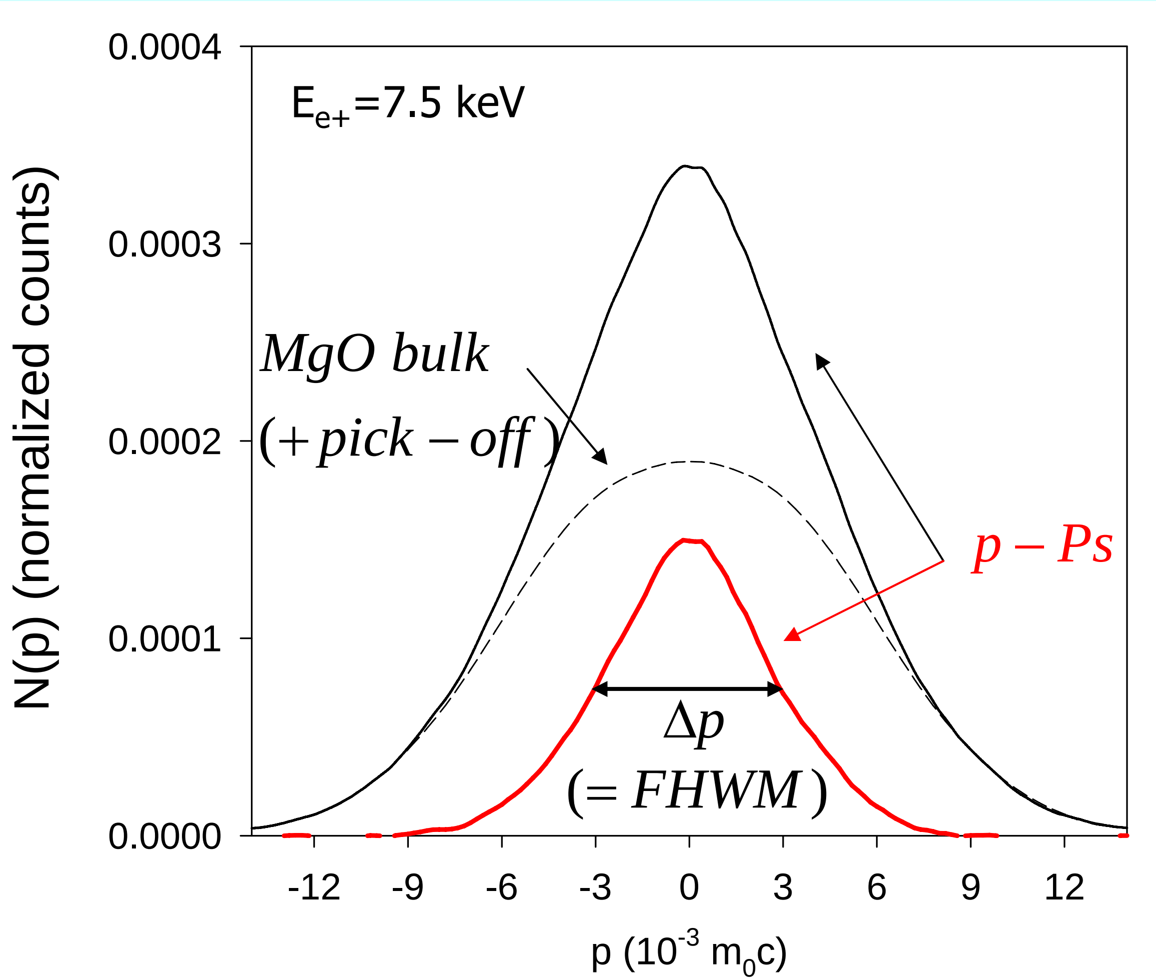

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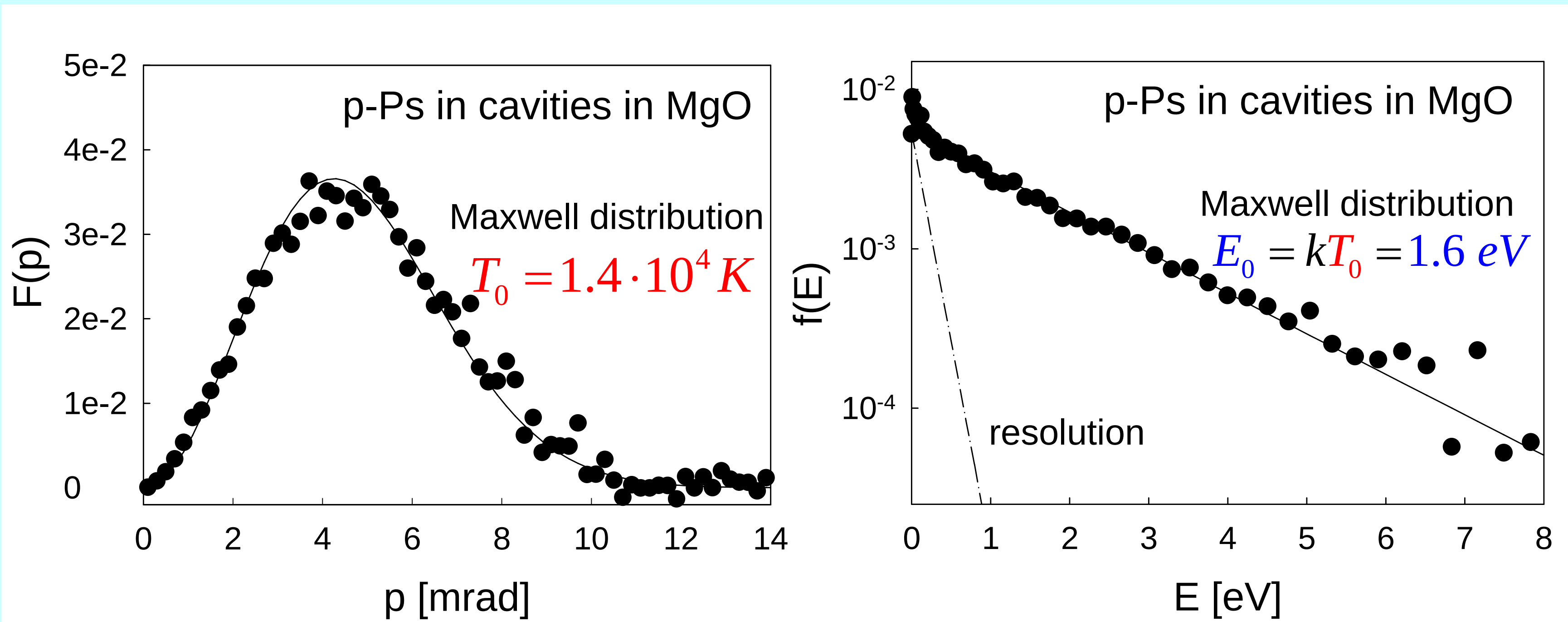
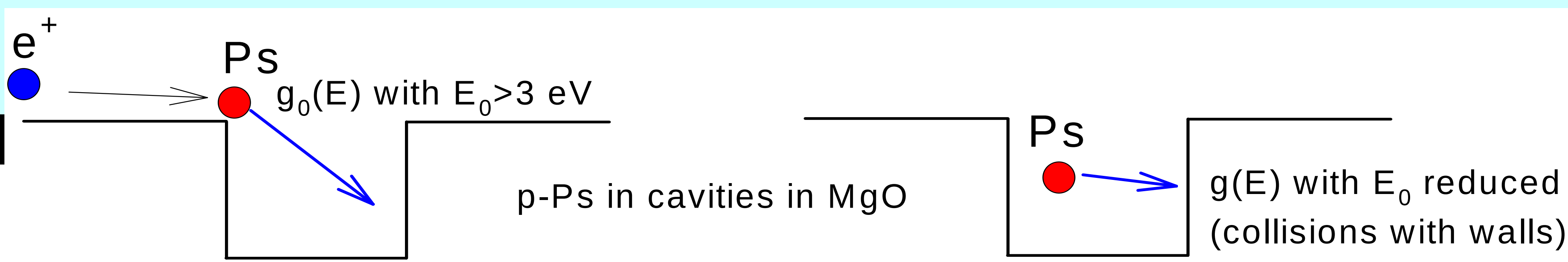
Maxwellian velocity distribution: $N_{p-Ps}(p) = ae^{-p^2/p_0^2} = ae^{-p^2/2mkT_0}$

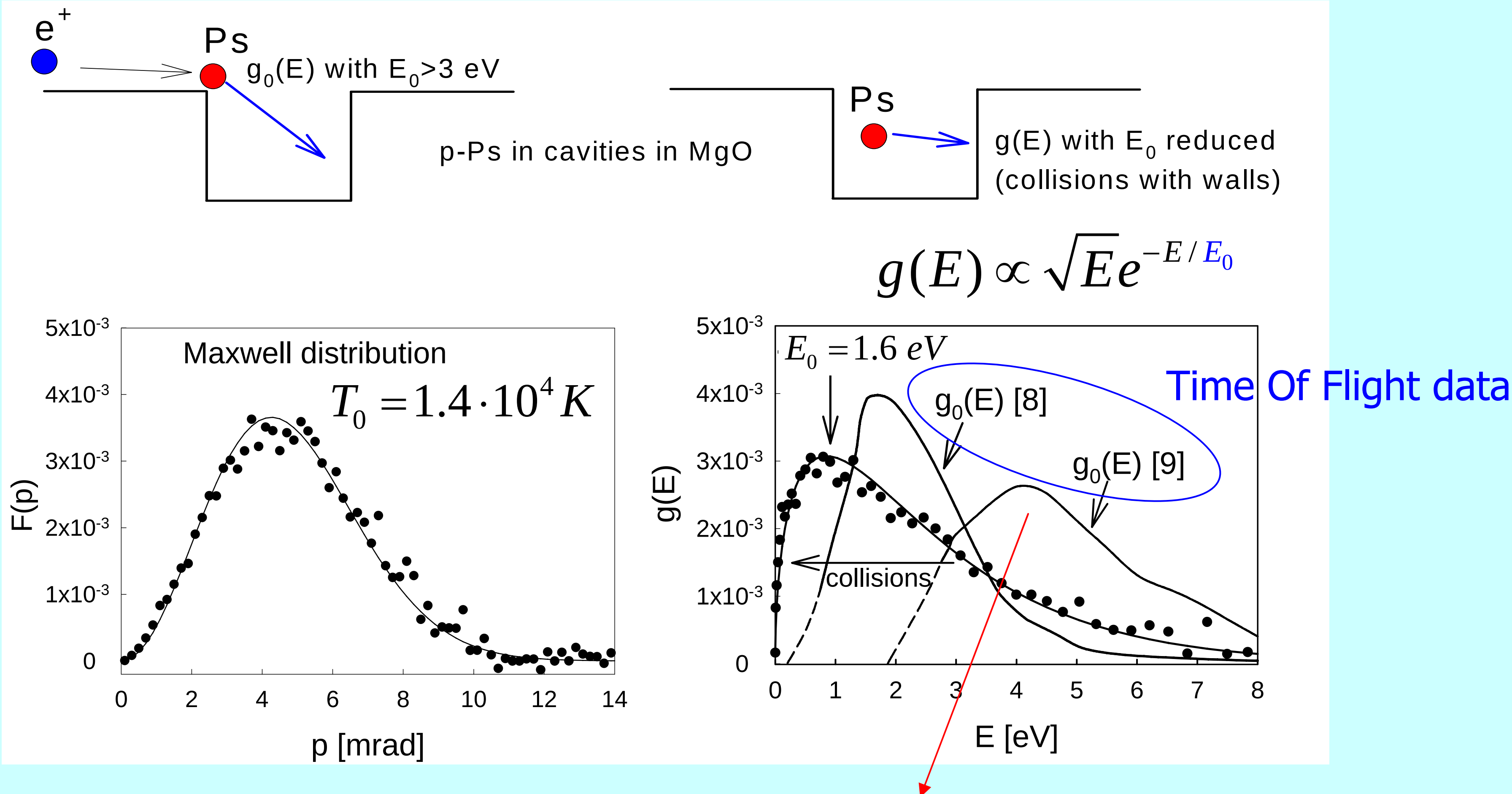
Momentum and Energy distributions for the emitted p-Ps

$\Rightarrow$ resembles Maxwell velocity distribution, **hot-Ps**

$$F(p) \propto p^2 e^{-p^2/2mkT_0} \qquad f(E) \propto e^{-E/E_0}$$







$$<E> = \frac{3}{2} kT_0 = 4.7\ eV \quad and \quad T_0 = 2.7 \cdot 10^4 K$$

$$FWHM = 2.1\ keV$$

Compare Galactic 511 keV line: $FWHM = 1.3 \pm 0.4\ keV$

(narrow component)

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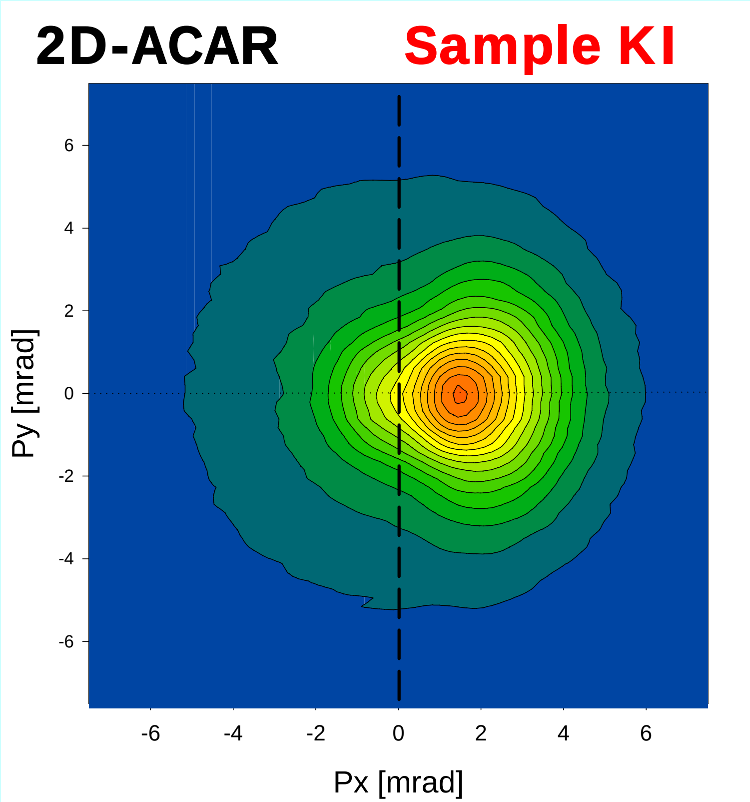
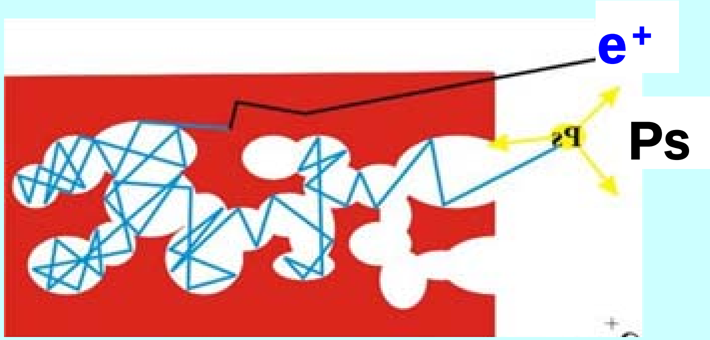
p-Ps emission from SiO_2 mesoporous films

Collaboration with K. Hirata, K. Ito, Y. Kobayashi, AIST, Tsukuba, Japan



1 keV

386 ºC



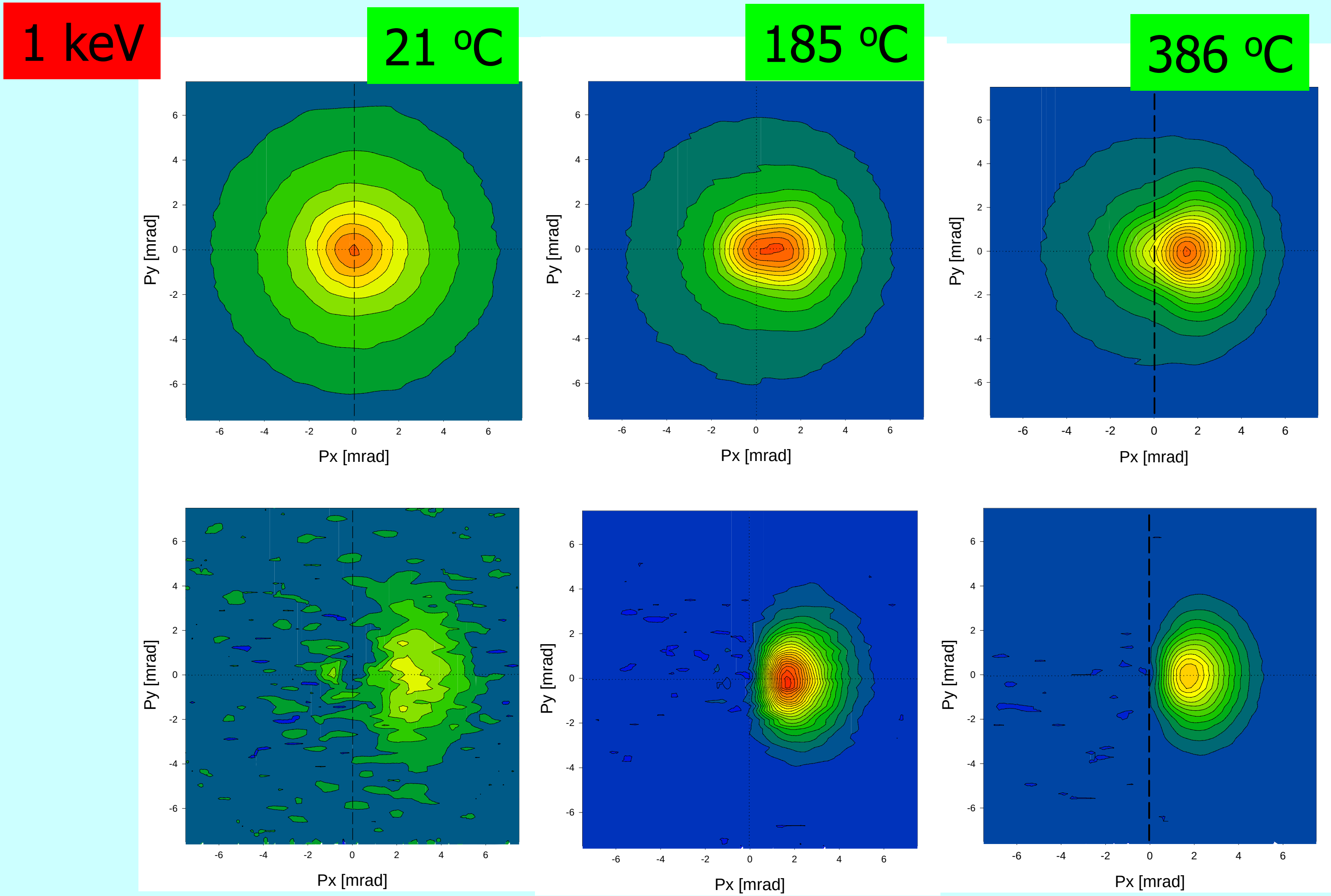
p-Ps emission

Typical values for p-Ps linewidth $FWHM = 0.7\ keV$ $(T_0 \sim 1.1 \cdot 10^4\ K)$

Compare Galactic 511 keV line: $FWHM = 1.3 \pm 0.4\ keV$

(narrow component)

f_{Ps} is strongly temperature dependent



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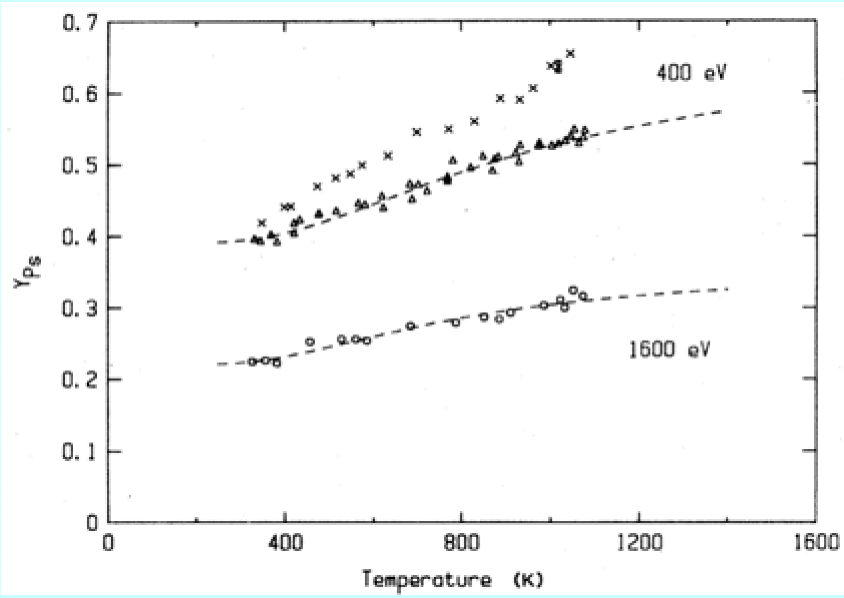
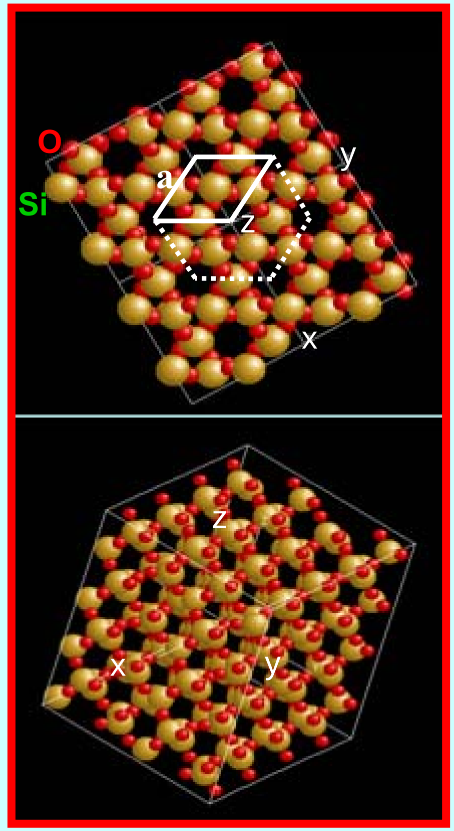
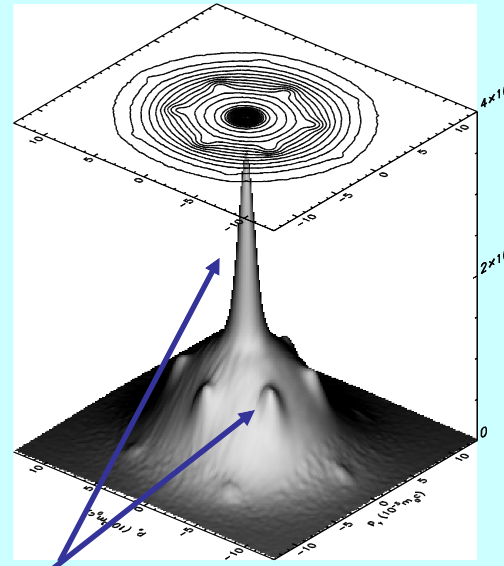
Ps-fractions surface emission quartz (c-SiO_2)

P. Sferlazzo et al. Phys. Rev. B 32 (1985) 6067



Ps fraction emitted from
the **surface of quartz**





para-Ps peaks
Inside quartz
(bulk Ps state)

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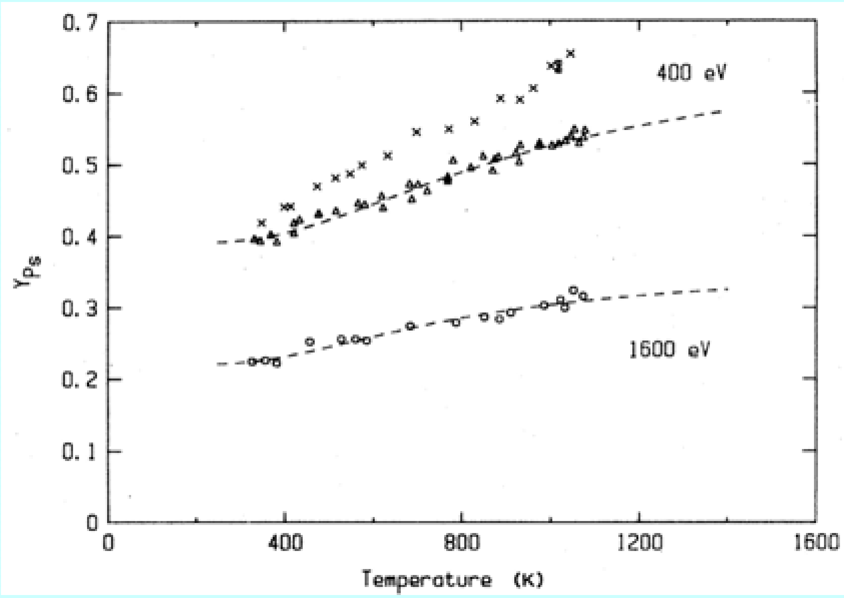
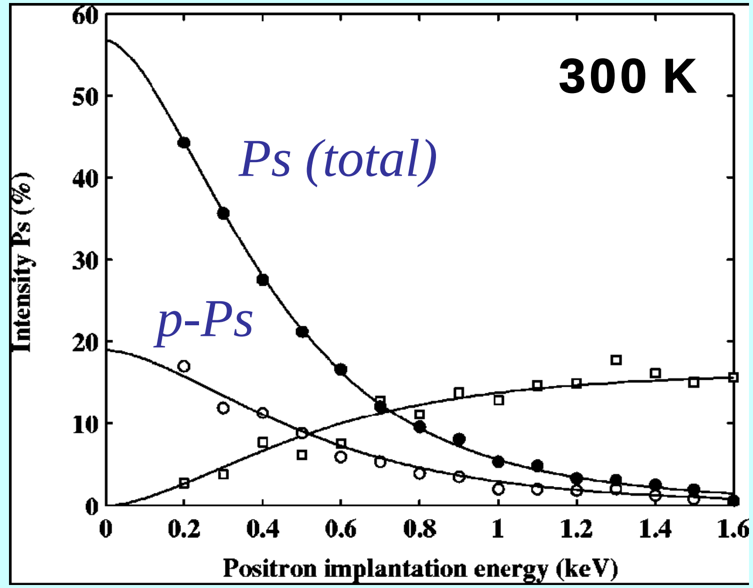
Ps-fractions surface emission quartz ($c\text{-}SiO_2$)

P. Sferlazzo et al. Phys. Rev. B 32 (1985) 6067



Ps fraction emitted from the surface of quartz

S. van Petegem Phys. Rev. B 70 (2004) 115410



Ps fractions as a function of depth below the surface

$f_{Ps} \sim 57\%$ Ps emission from the surface of quartz

Compare Galactic 511 keV line: $f_{Ps} \sim 93\%$

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Conclusions and Implications

- *Oxides may give rise to a p-Ps component compatible to the narrow component of the Galactic 511 keV annihilation line* [similar in width]

- fractions of emitted Ps are high for SiO_2, up to f_{Ps}~60%, but lower than f_{Ps}~93% seen for the Galactic annihilation
  >fractions for oxides increase with temperature
  >oxidized Al-surfaces may lead to very high fractions up to 90%, at high T

- Further studies seem promising, e,g, on oxides such as $(Mg,Fe)_2SiO_4$ silicates - abundantly present as grains in the ISM ('Star Dust')