

To the ascent of advanced material characterization with

POSITRON



To the ascent of advanced material characterization with

POSITRONS

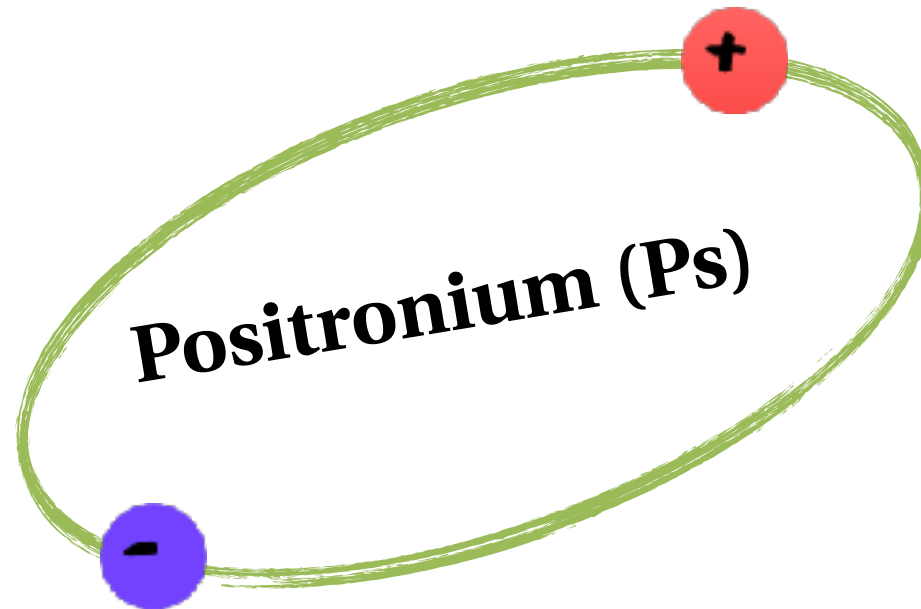
- ▶ How and Why
- ▶ Challenges
- ▶ Our lab's contribution



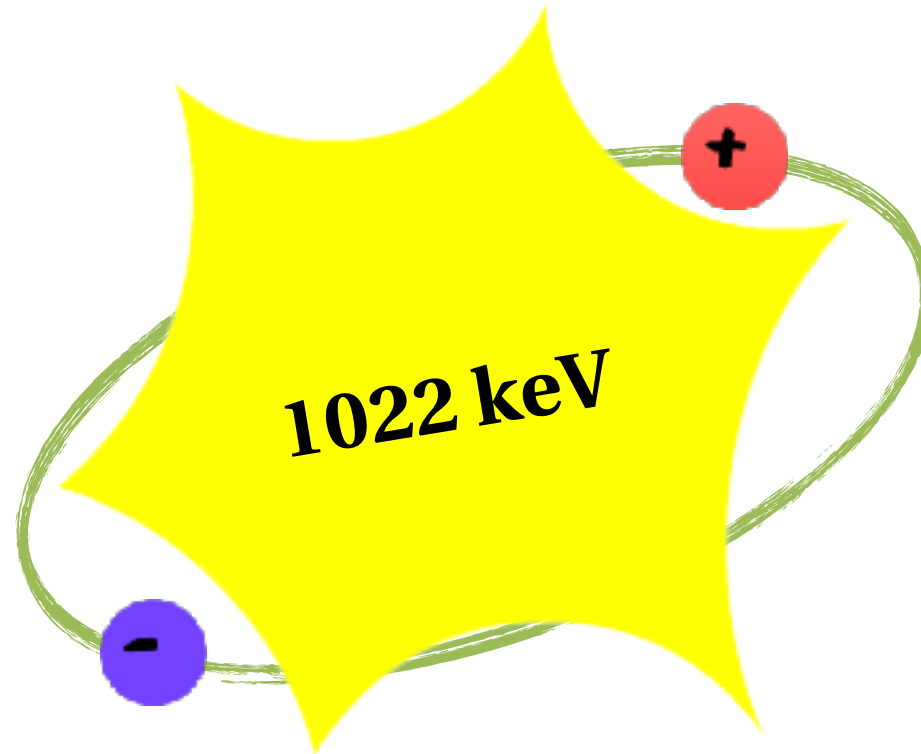
Positron and Positronium



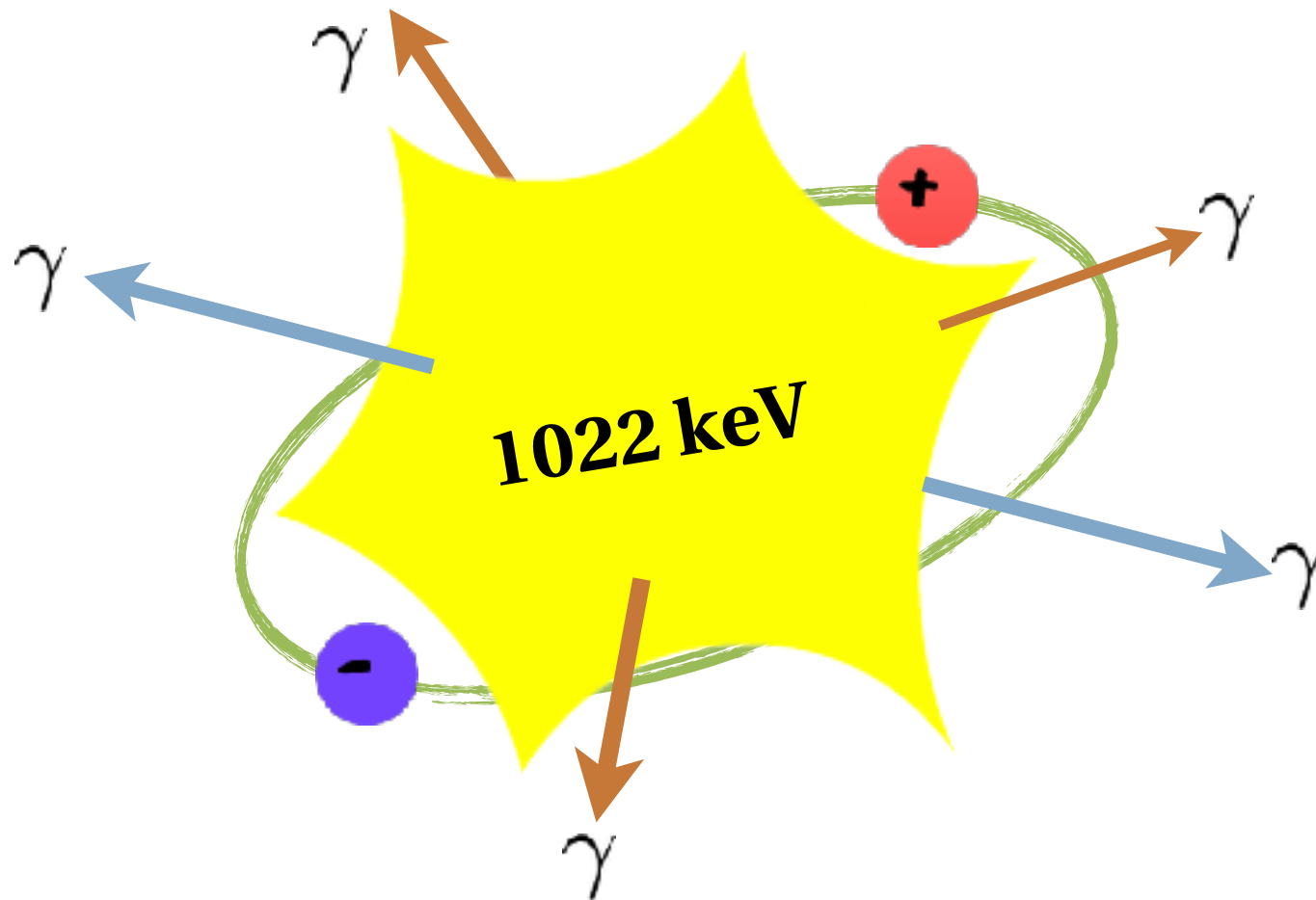
Positron and Positronium



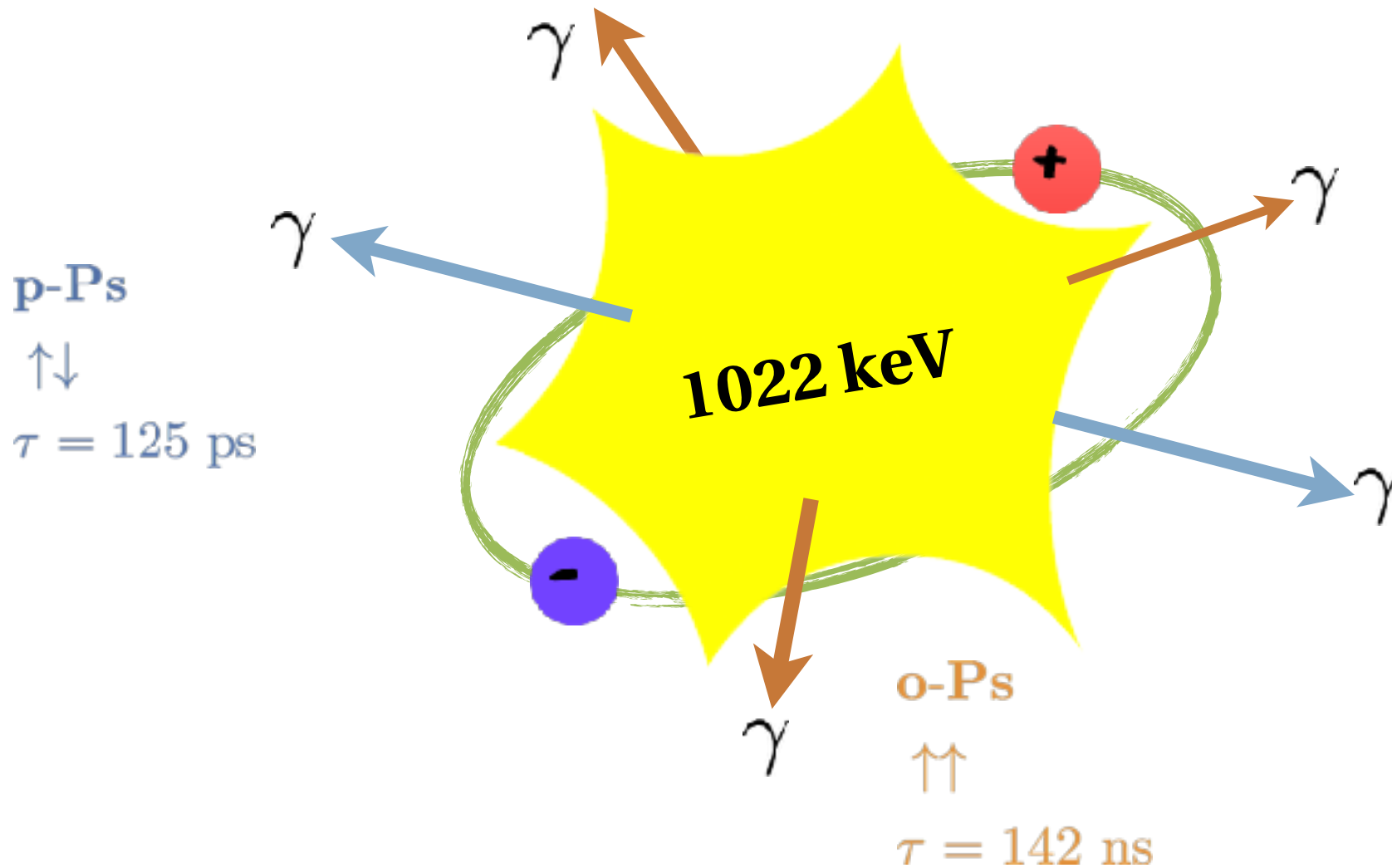
Positron and Positronium



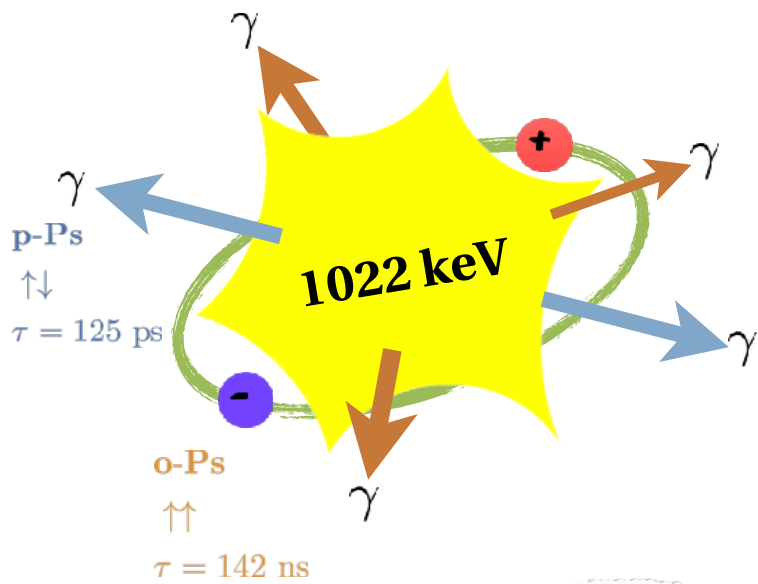
Positron and Positronium



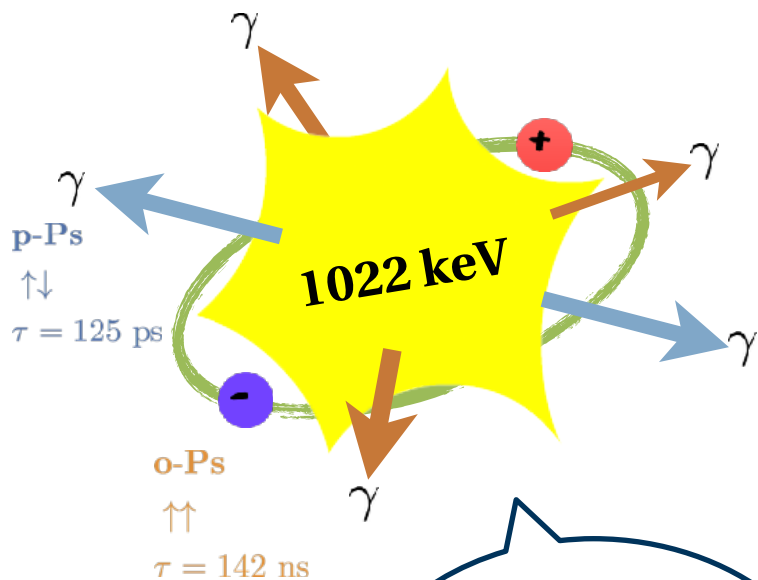
Positron and Positronium



Applications



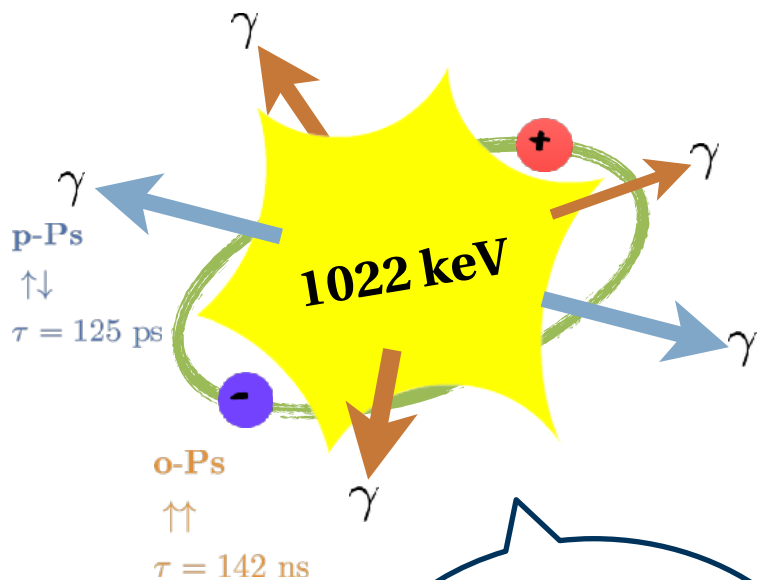
Applications



**Fundamental
Studies**



Applications

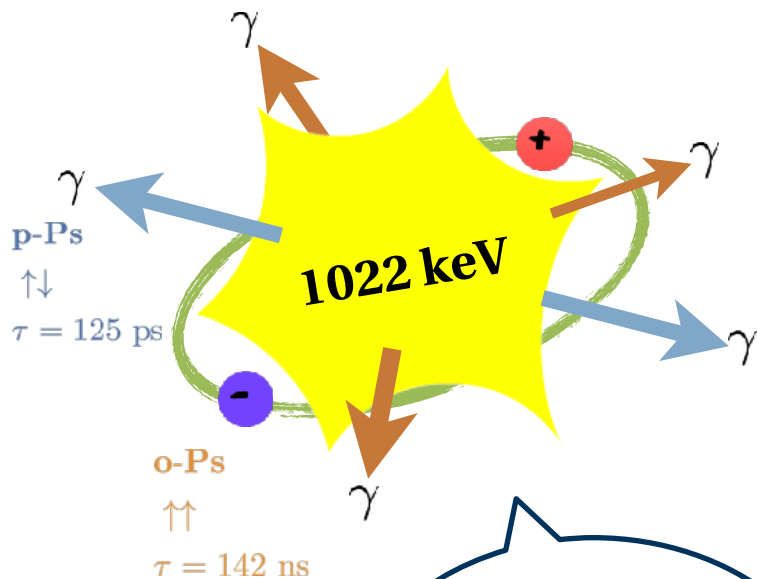


**Medicine
(PET)**

**Fundamental
Studies**



Applications



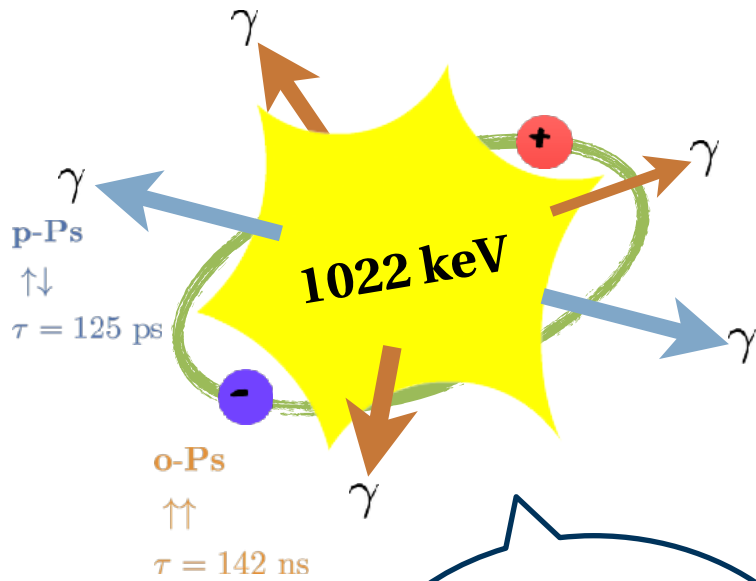
**Material
Studies**

**Medicine
(PET)**

**Fundamental
Studies**



Applications



**Material
Studies**

**Antimatter
Propulsion**

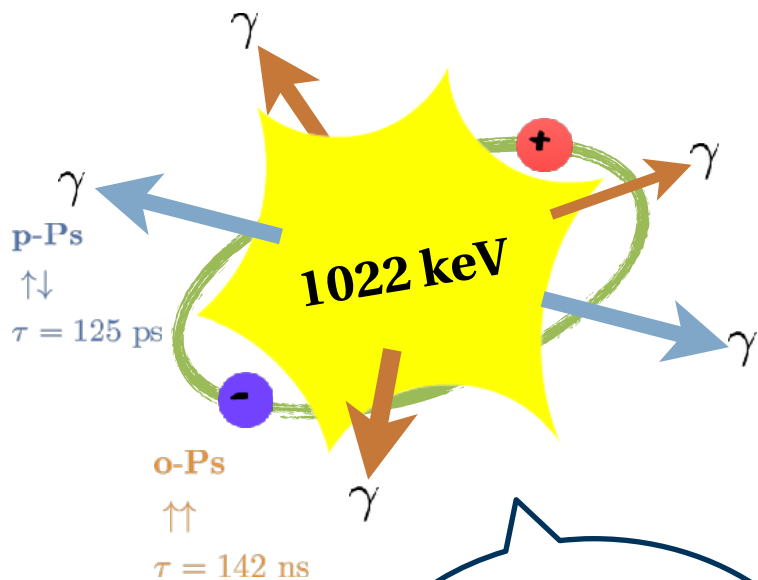
**Medicine
(PET)**



**Fundamental
Studies**



Applications



**Material
Studies**

**Antimatter
Propulsion**

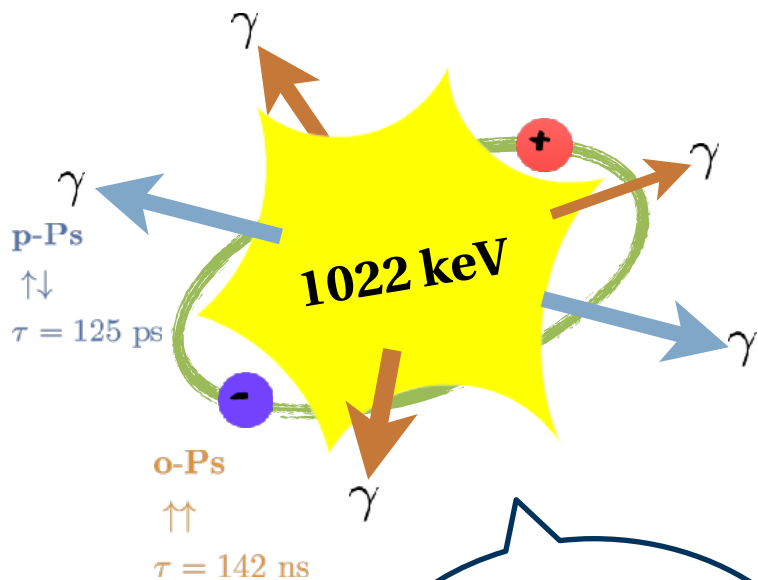
**Medicine
(PET)**

**Gamma Ray
Laser**

**Fundamental
Studies**



Applications



**Material
Studies**

**Antimatter
Propulsion**

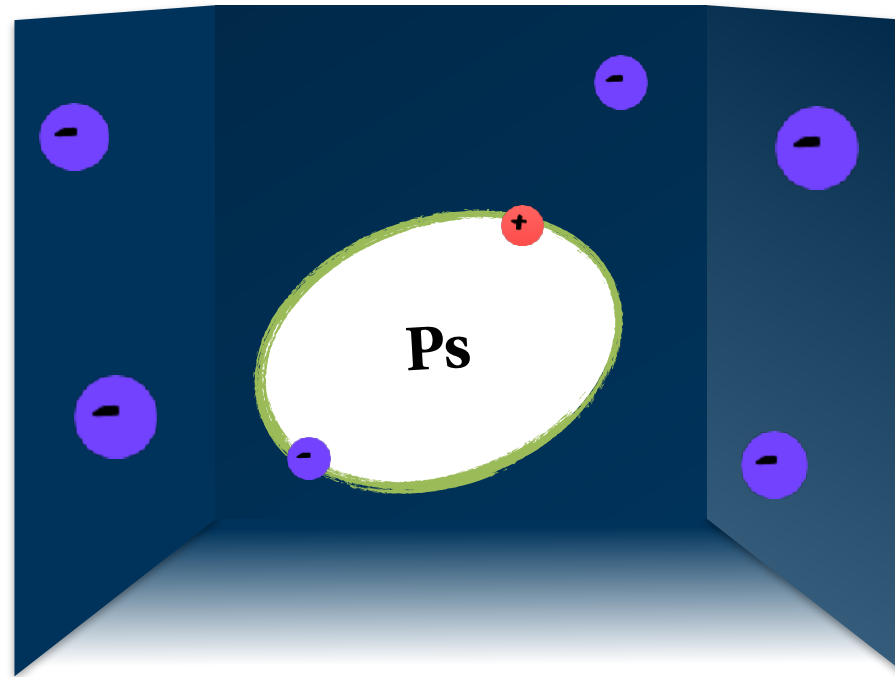
**Medicine
(PET)**

**Gamma Ray
Laser**

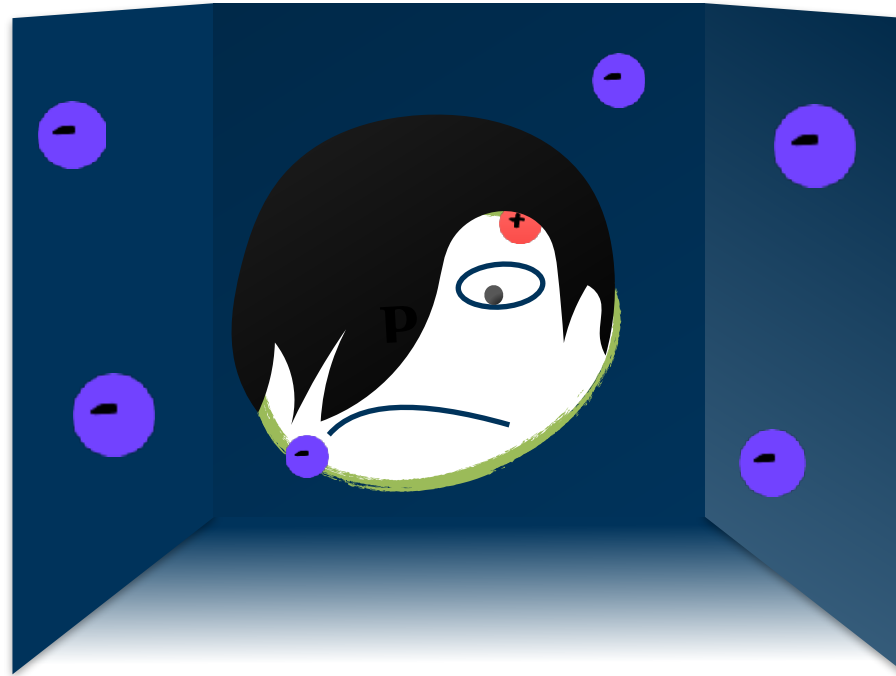
**Fundamental
Studies**



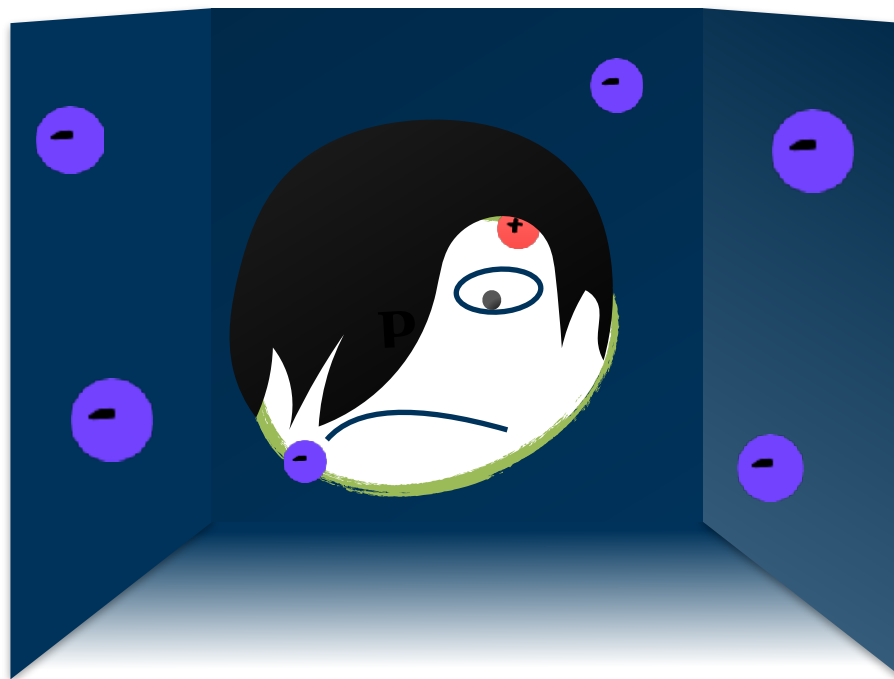
Unique Sensitivity



Unique Sensitivity

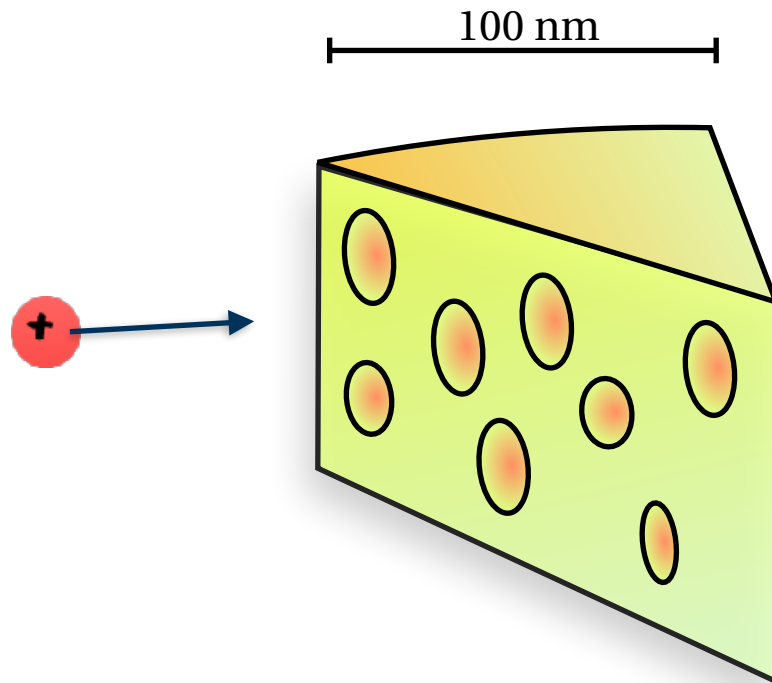


Unique Sensitivity

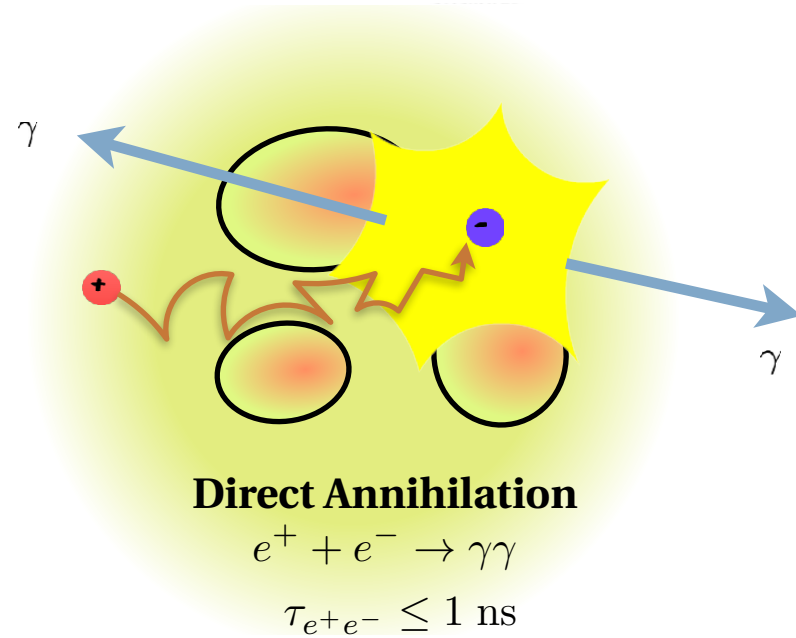
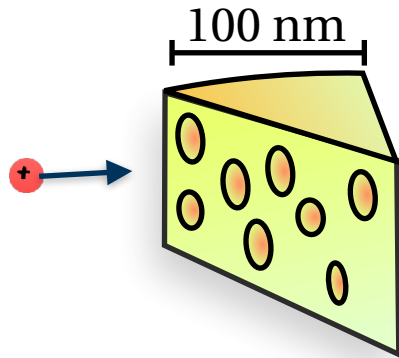


- ▶ oPs lifetime τ_{oPs}
- ▶ QM energy states E_{oPs}
- ▶ annihilation energy of “511”
- ▶ “back to back” angle $\theta_{\gamma-\gamma}$

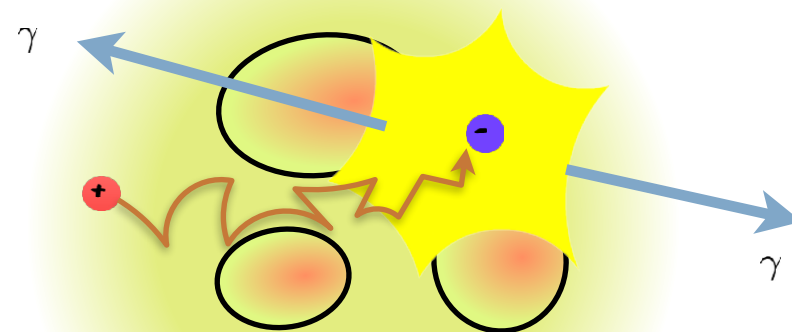
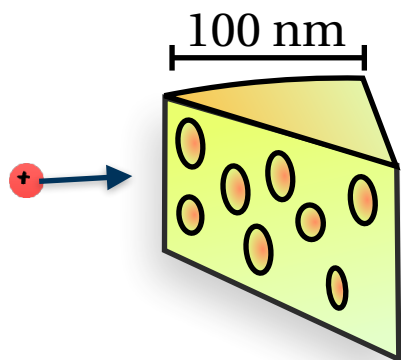
Ps in matter



Ps in matter



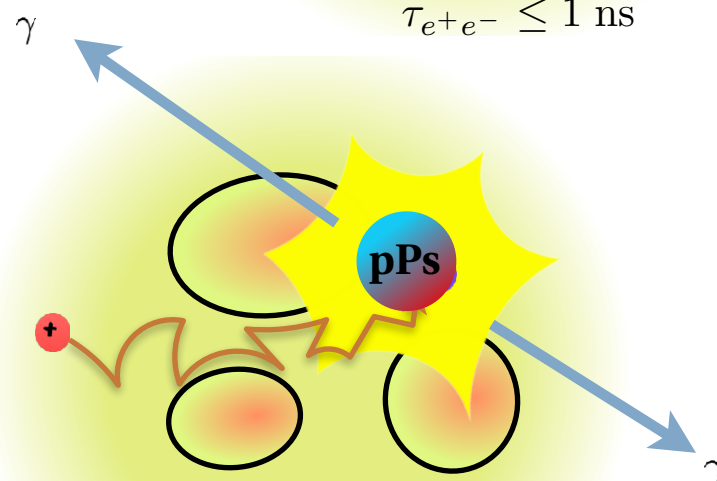
Ps in matter



Direct Annihilation

$$e^+ + e^- \rightarrow \gamma\gamma$$

$$\tau_{e^+e^-} \leq 1 \text{ ns}$$

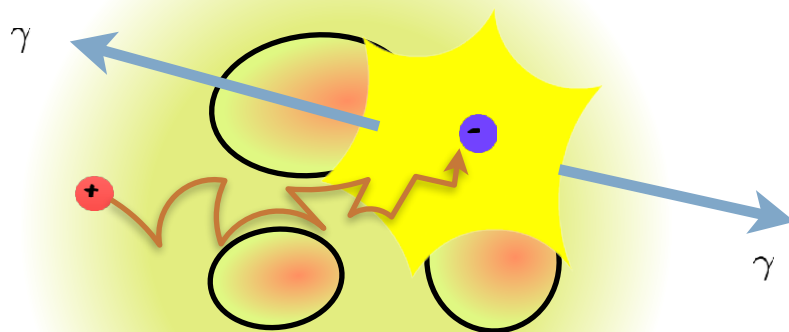
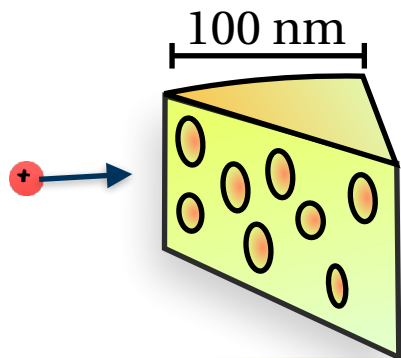


para Positronium pPs

$$e^+ + e^- \rightarrow \text{pPs} \rightarrow \gamma + \gamma$$

$$\tau_{\text{pPs}} \leq 125 \text{ ps}$$

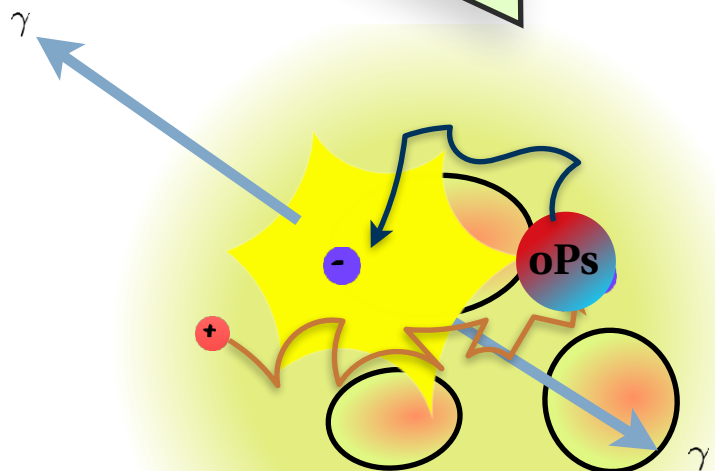
Ps in matter



Direct Annihilation

$$e^+ + e^- \rightarrow \gamma\gamma$$

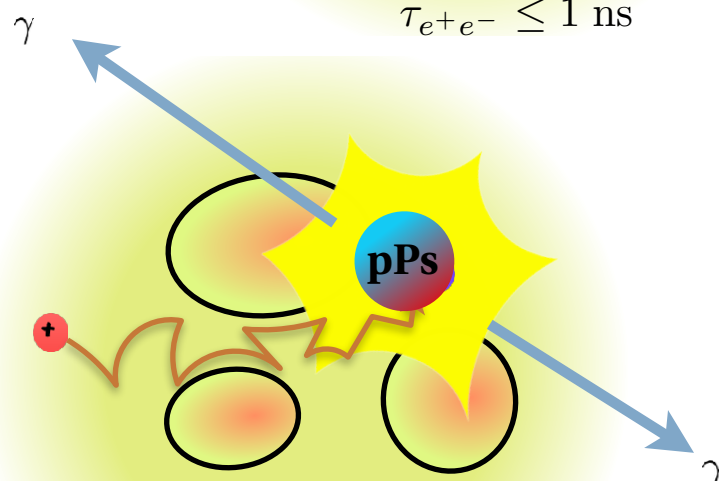
$$\tau_{e^+e^-} \leq 1 \text{ ns}$$



ortho Positronium oPs

$$e^+ + e^- \rightarrow \text{oPs} \rightarrow \text{oPs} + e^- \rightarrow \gamma + \gamma$$

$$1 \text{ ns} \leq \tau_{\text{oPs}} \leq 142 \text{ ns}$$

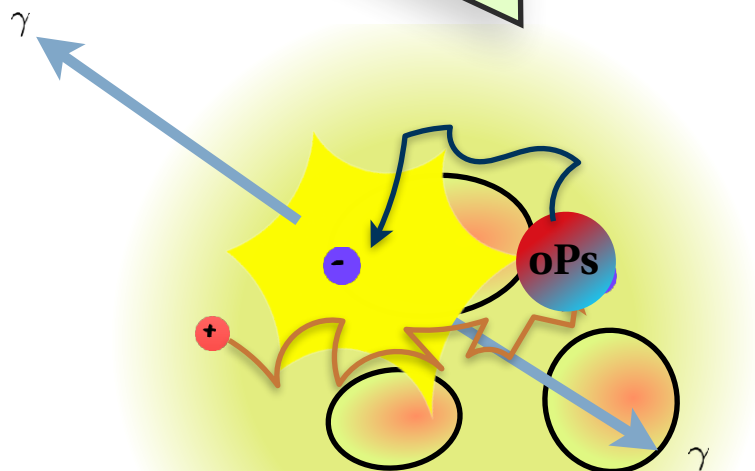
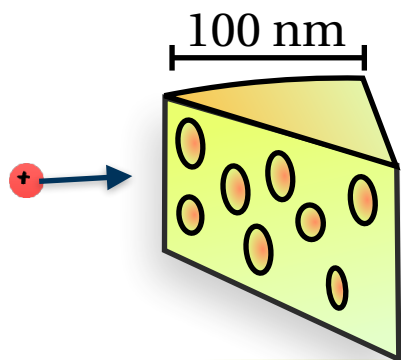


para Positronium pPs

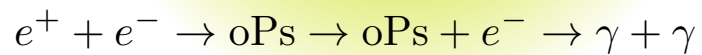
$$e^+ + e^- \rightarrow \text{pPs} \rightarrow \gamma + \gamma$$

$$\tau_{\text{pPs}} \leq 125 \text{ ps}$$

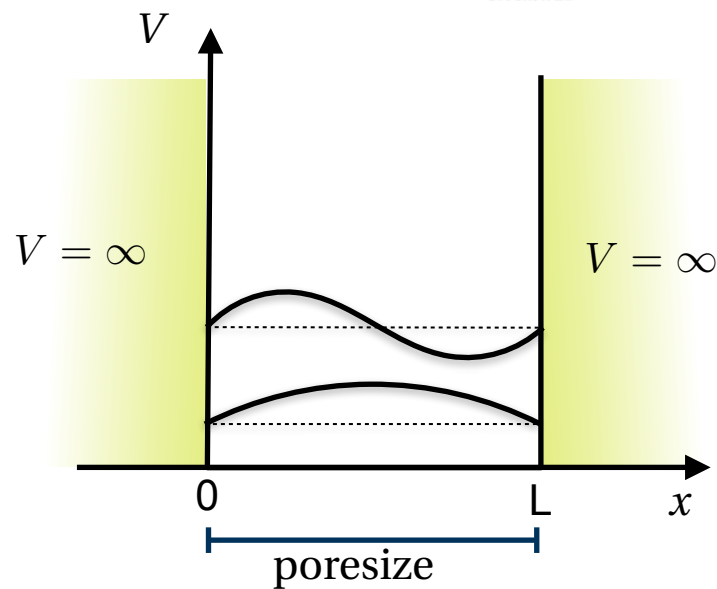
Ps in matter



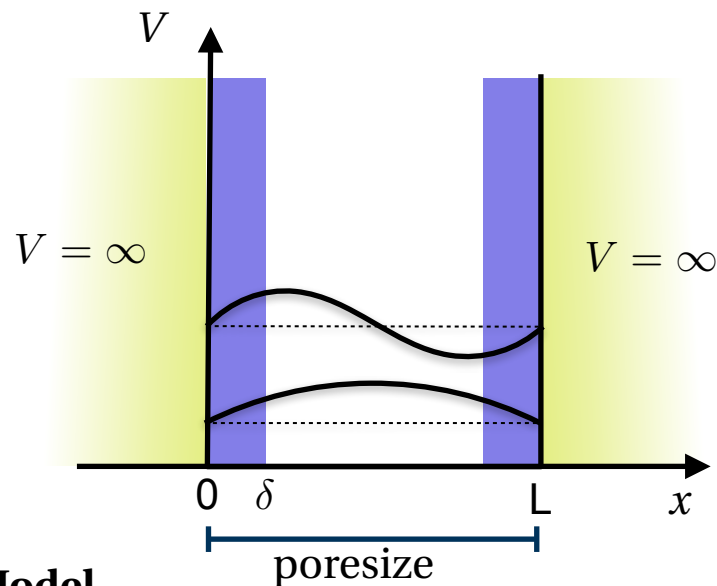
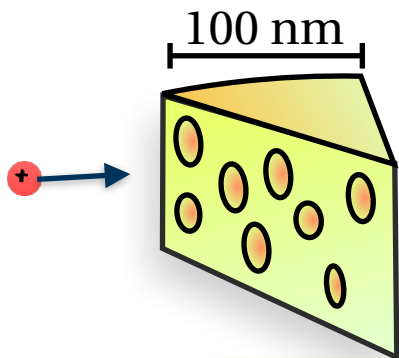
ortho Positronium oPs



$$1 \text{ ns} \leq \tau_{\text{oPs}} \leq 142 \text{ ns}$$

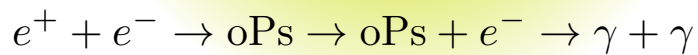
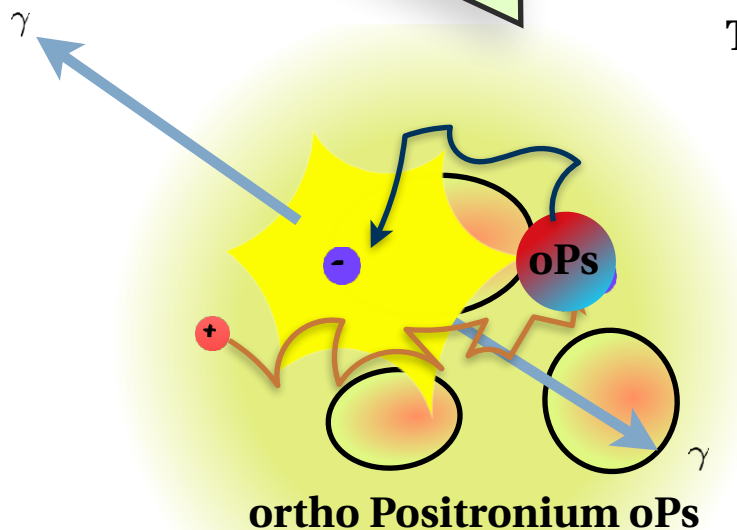


Ps in matter

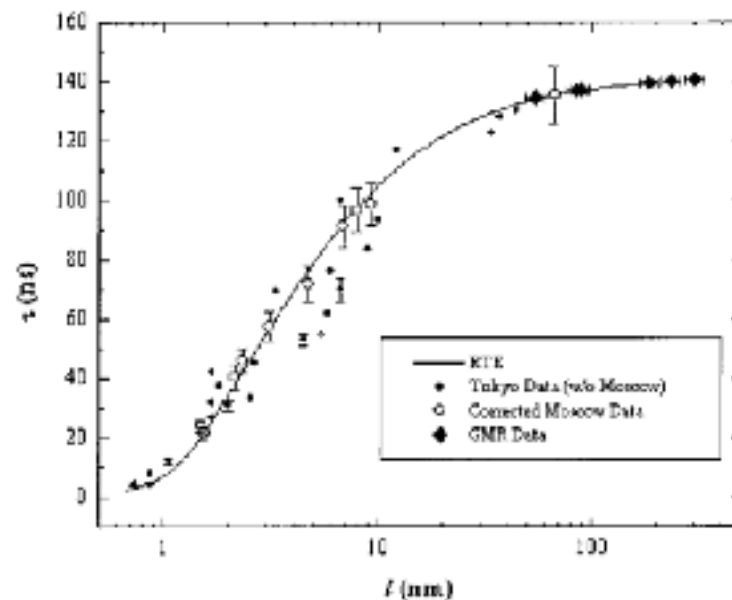


Tao-Eldrup Model

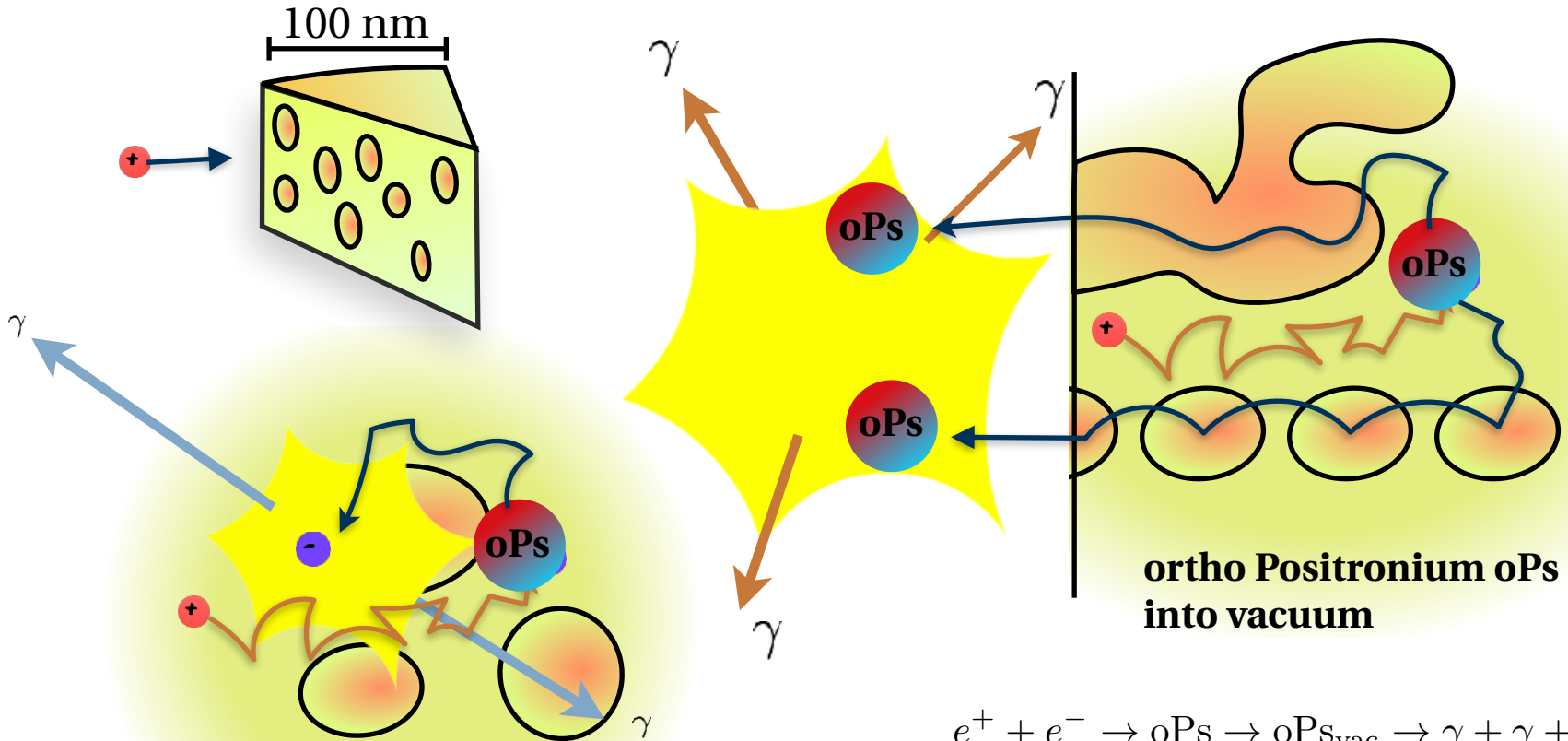
J. Phys. Chem. B, Vol. 105, No. 20, 2001 4661



$$1 \text{ ns} \leq \tau_{\text{oPs}} \leq 142 \text{ ns}$$



Ps in matter



ortho Positronium oPs

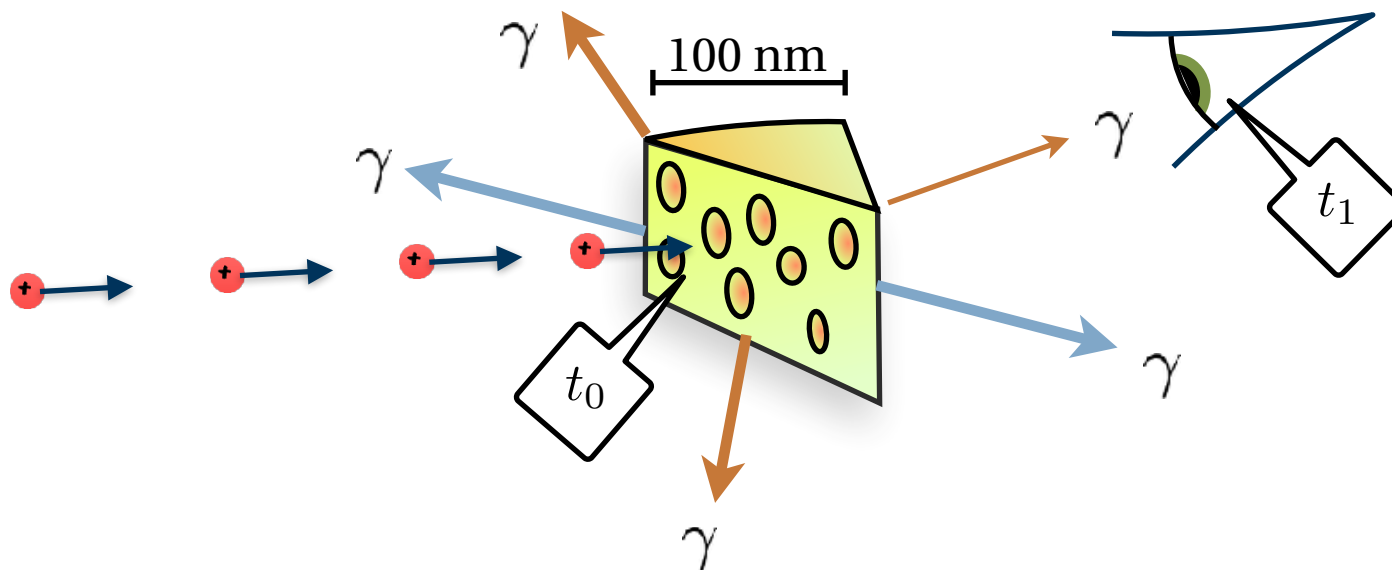
$$e^+ + e^- \rightarrow oPs \rightarrow oPs + e^- \rightarrow \gamma + \gamma$$

$$1 \text{ ns} \leq \tau_{oPs} \leq 142 \text{ ns}$$

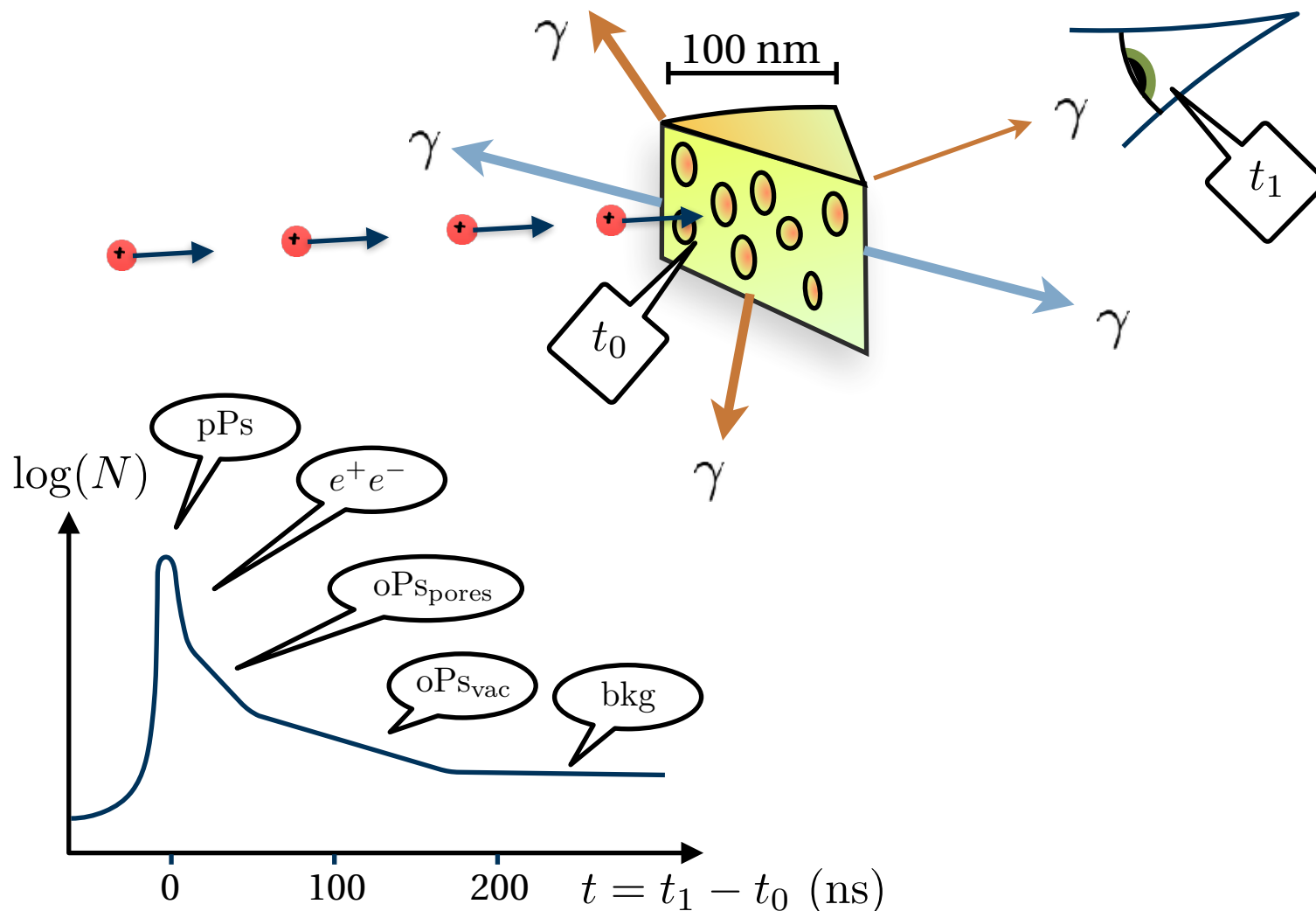
$$e^+ + e^- \rightarrow oPs \rightarrow oPs_{vac} \rightarrow \gamma + \gamma + \gamma$$

$$\tau_{oPs} = 142 \text{ ns}$$

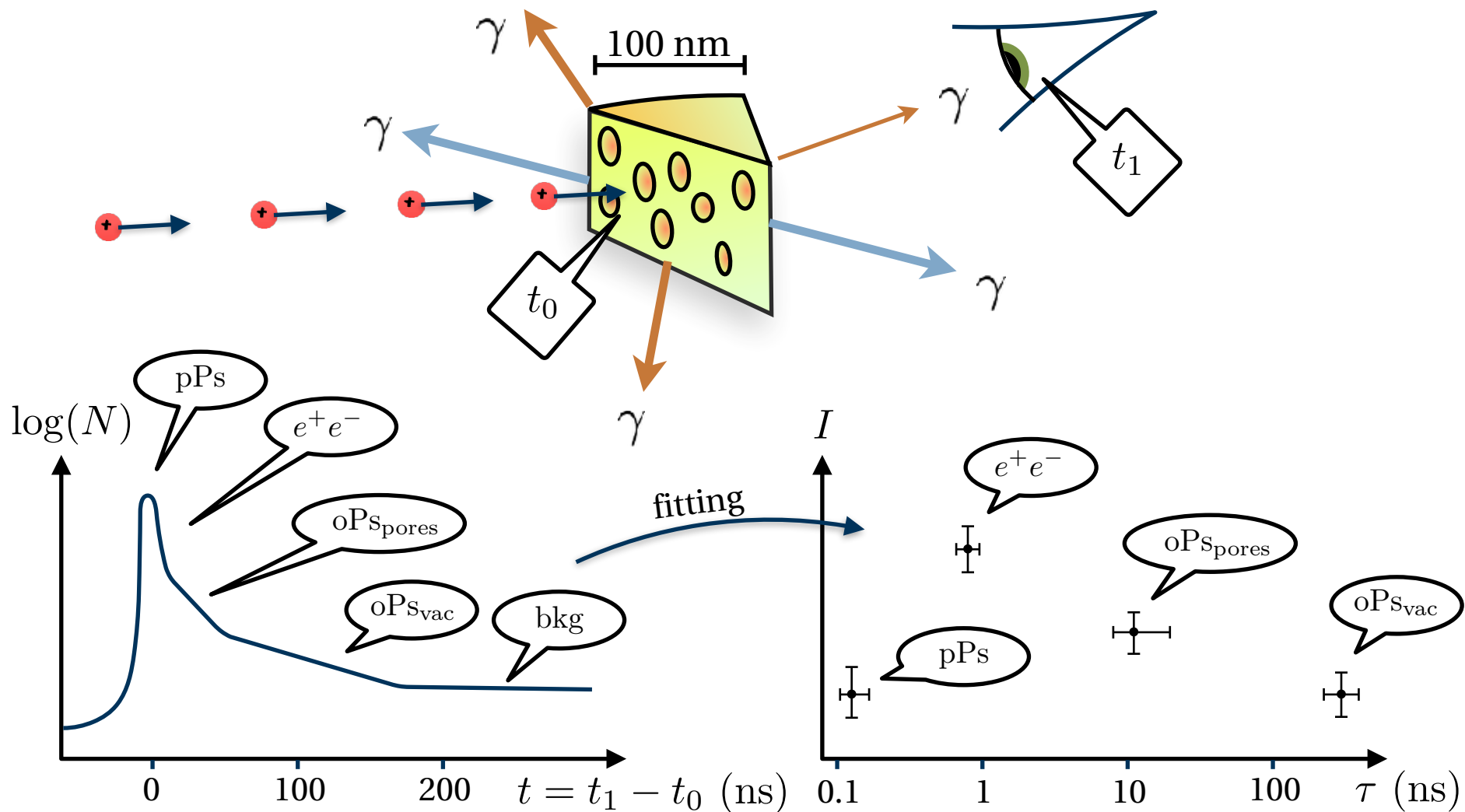
Positronium Annihilation Lifetime Spectroscopy (PALS)



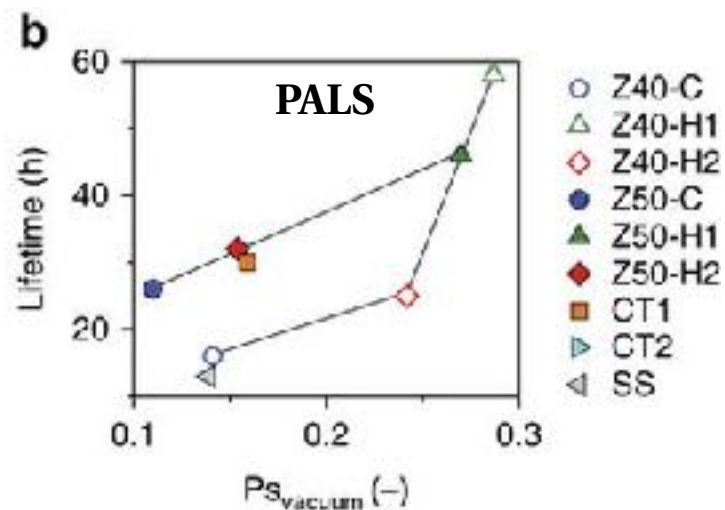
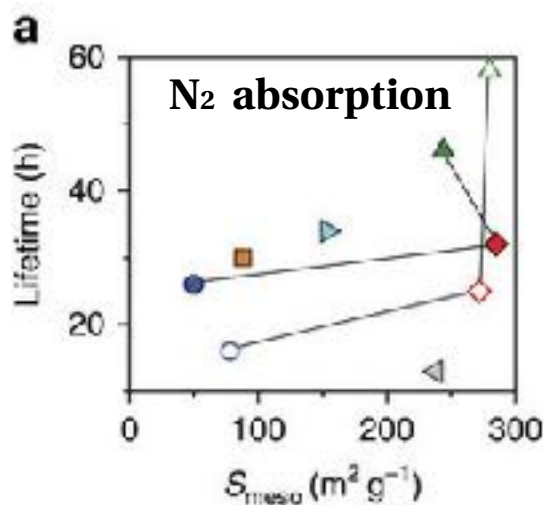
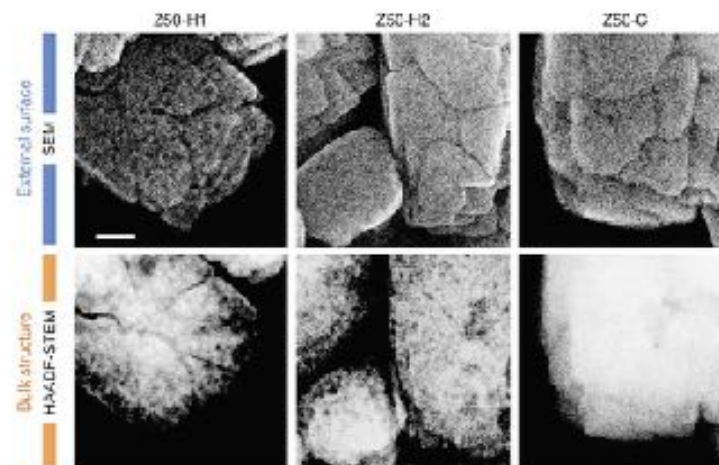
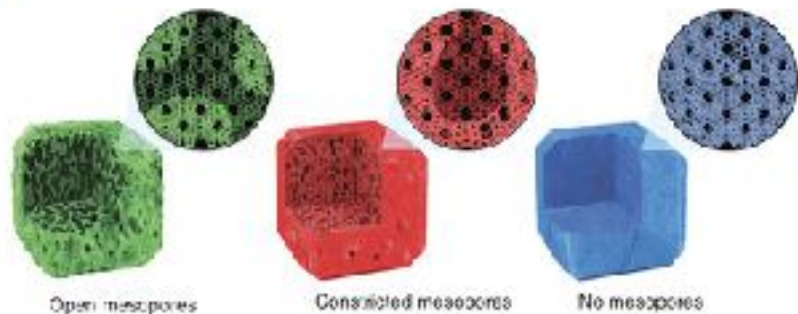
Positronium Annihilation Lifetime Spectroscopy (PALS)



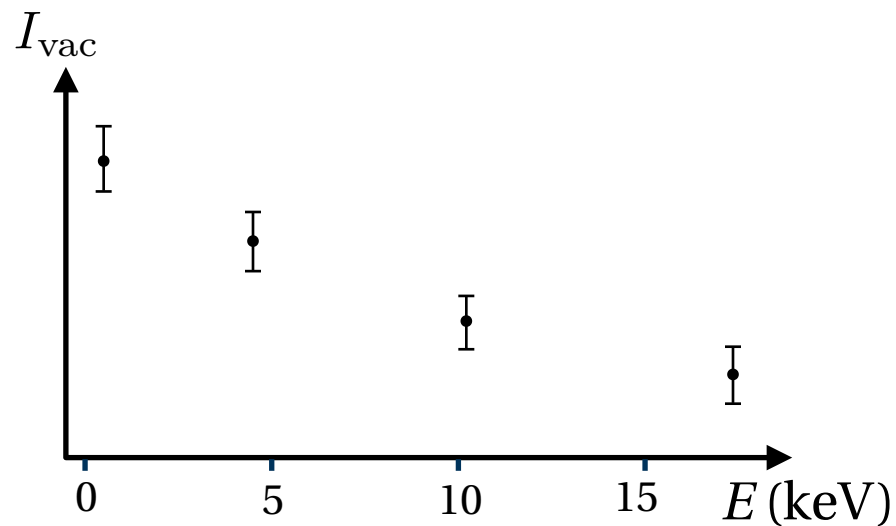
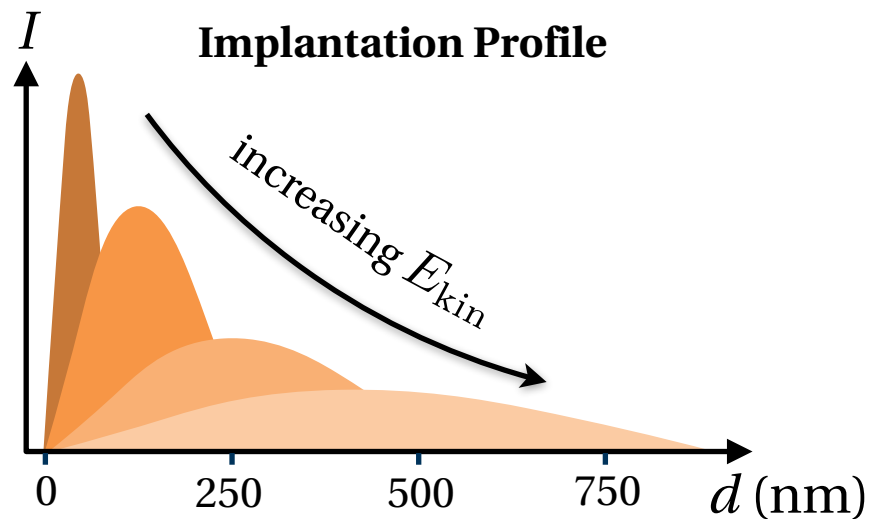
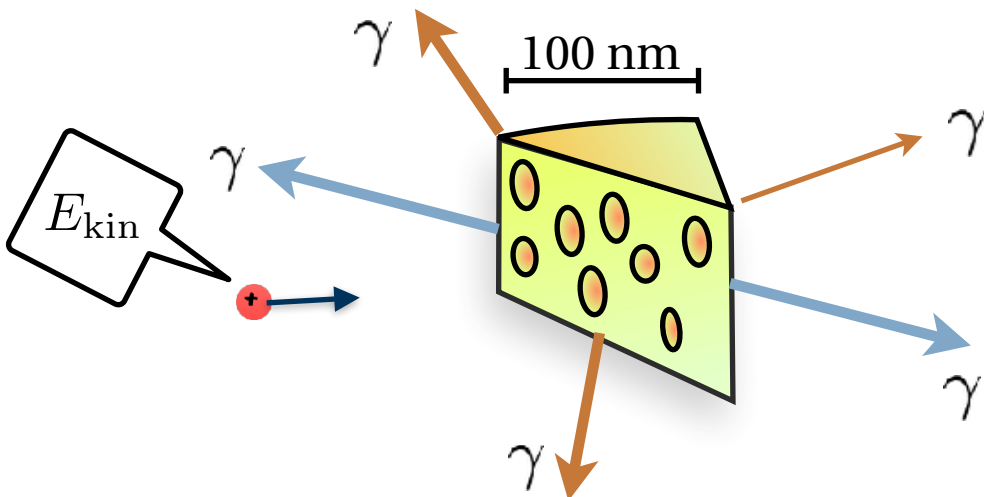
Positronium Annihilation Lifetime Spectroscopy (PALS)



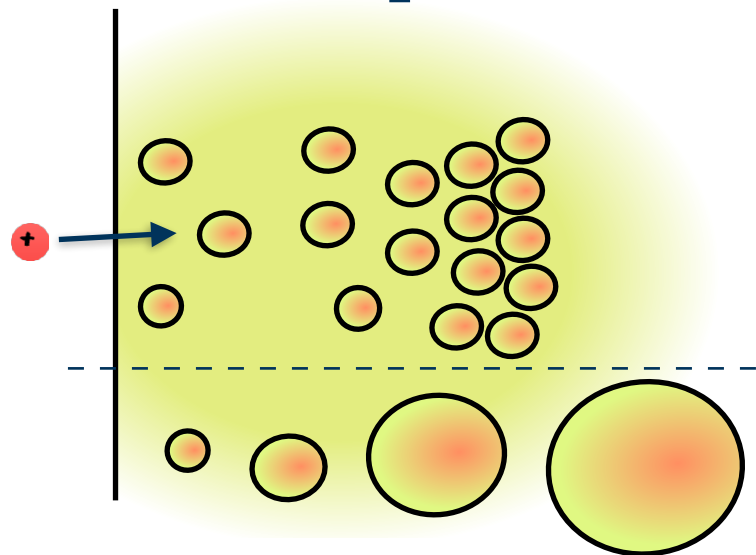
PALS on hierarchical zeolites



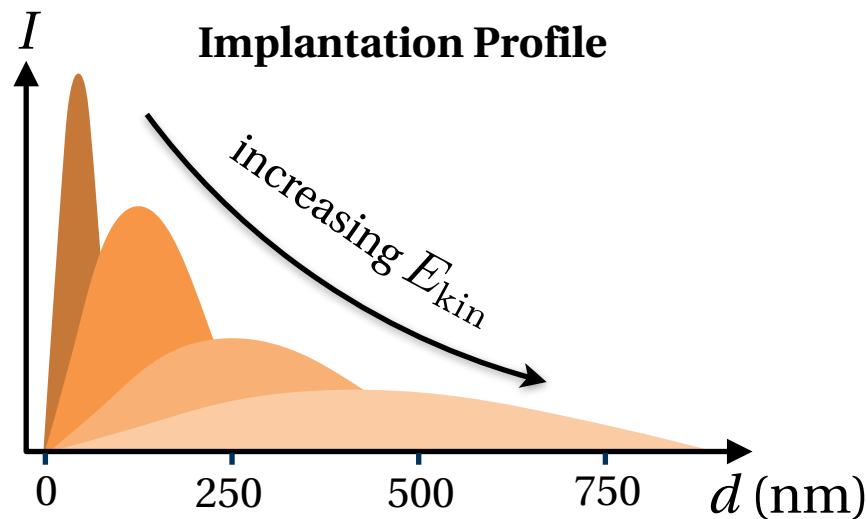
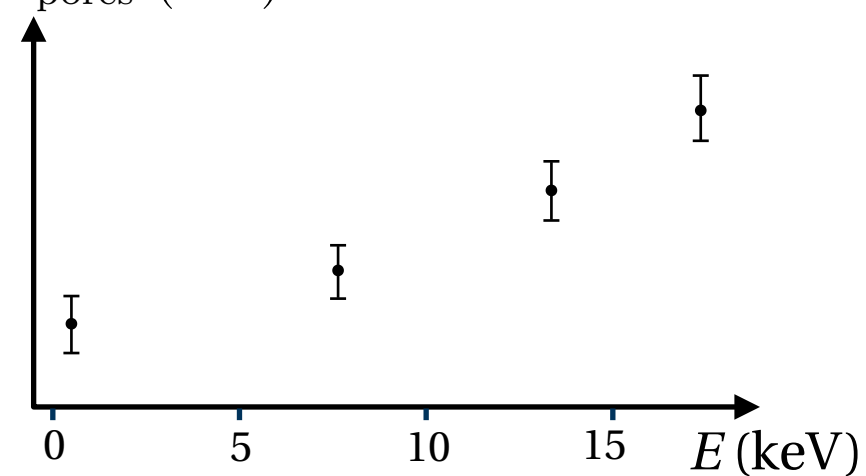
PALS vs implantation energy



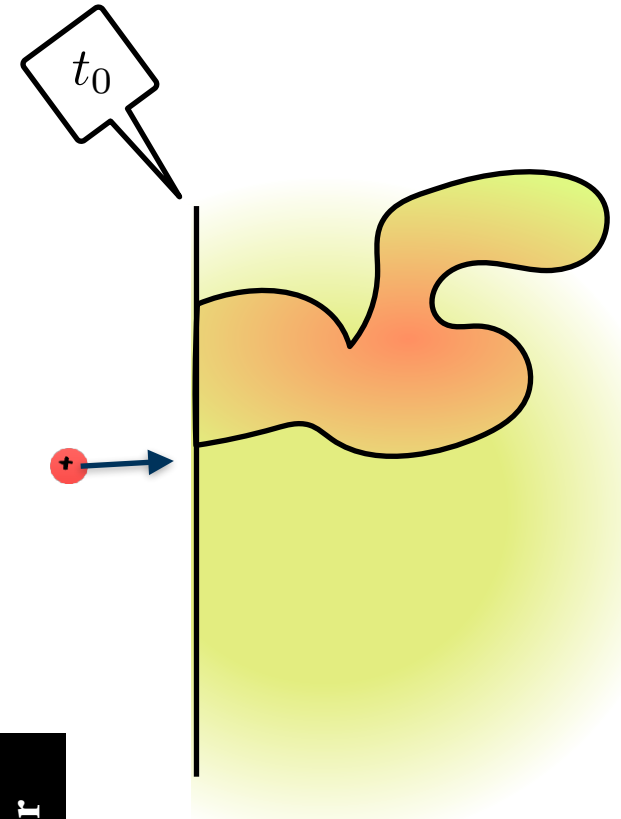
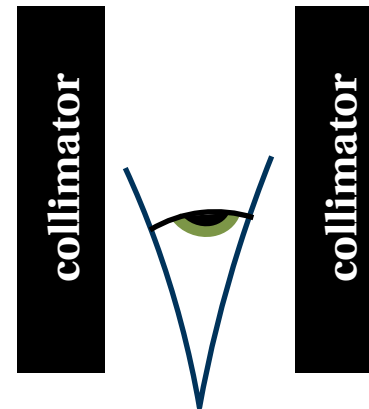
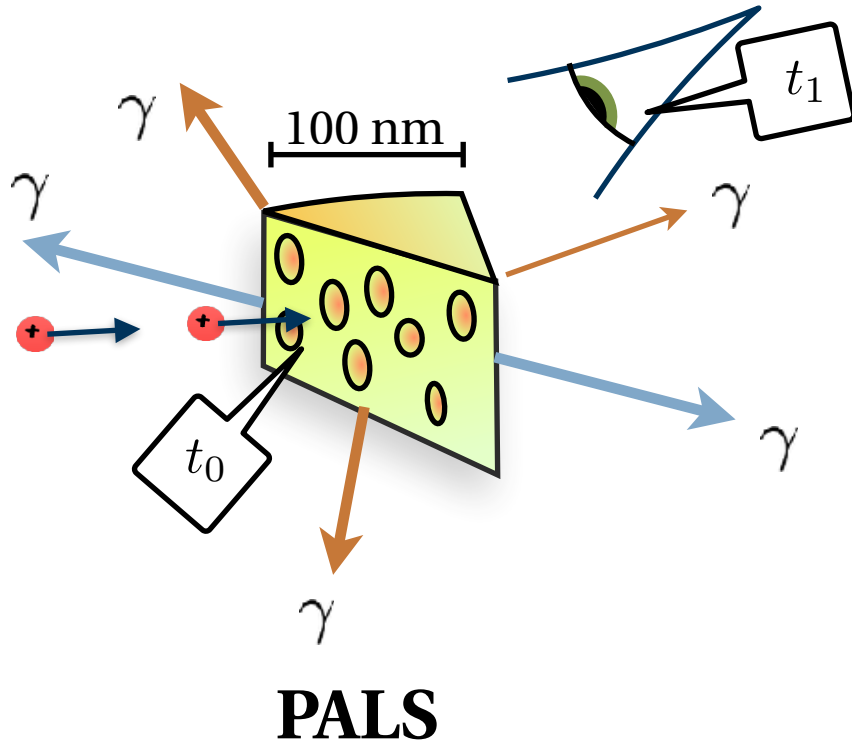
PALS vs implantation energy



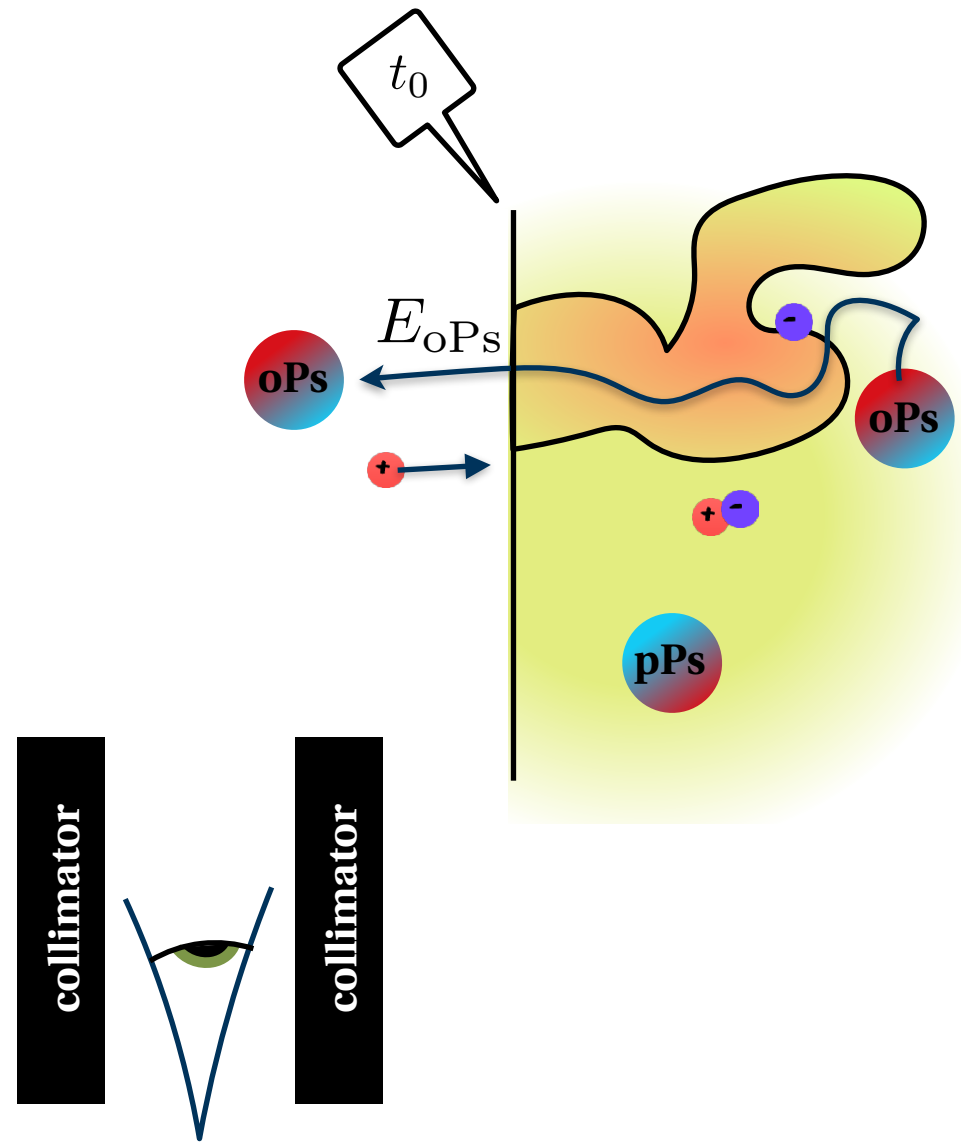
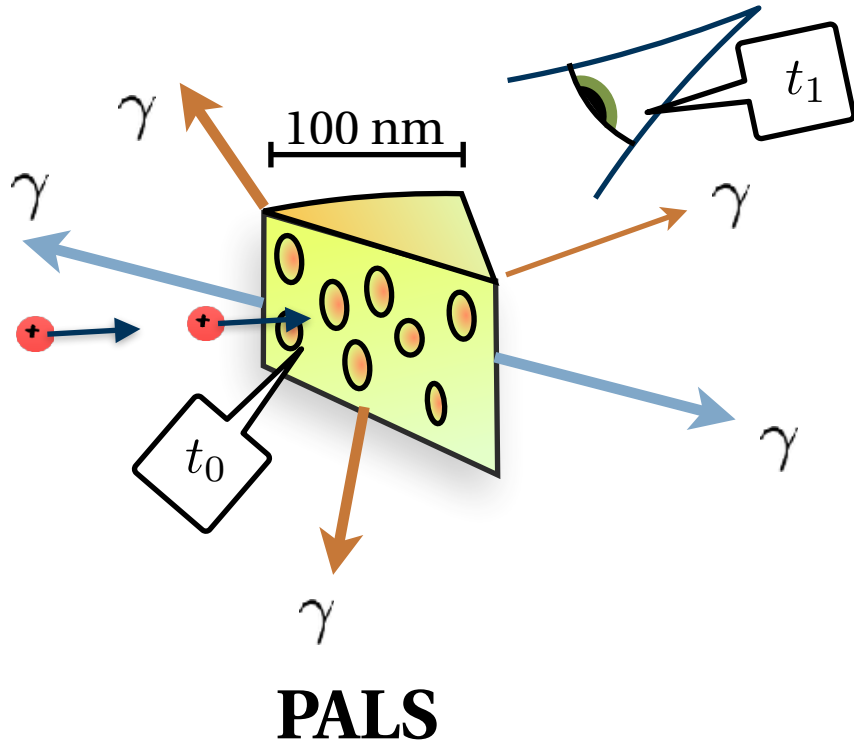
$I_{\text{pores}} / \tau_{\text{pores}}$ (a.u.)



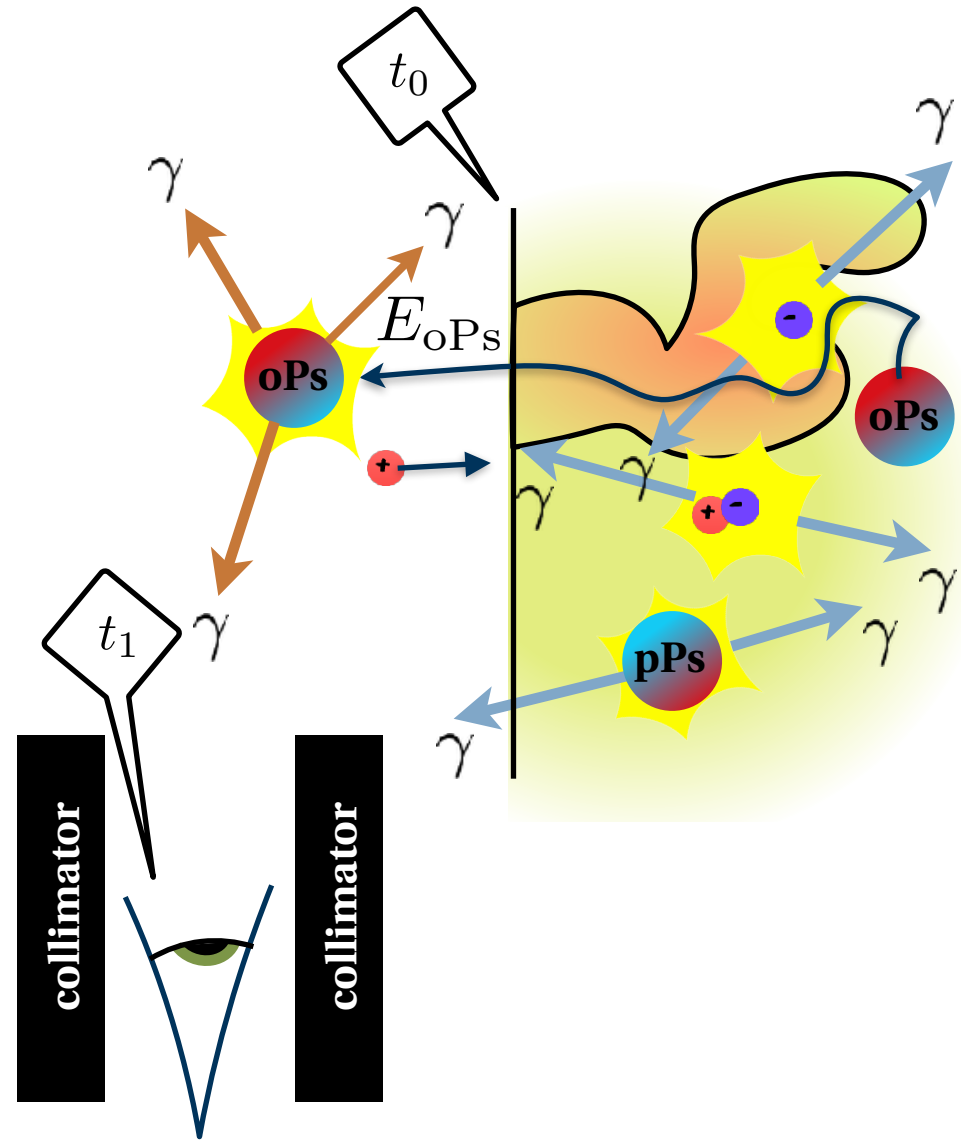
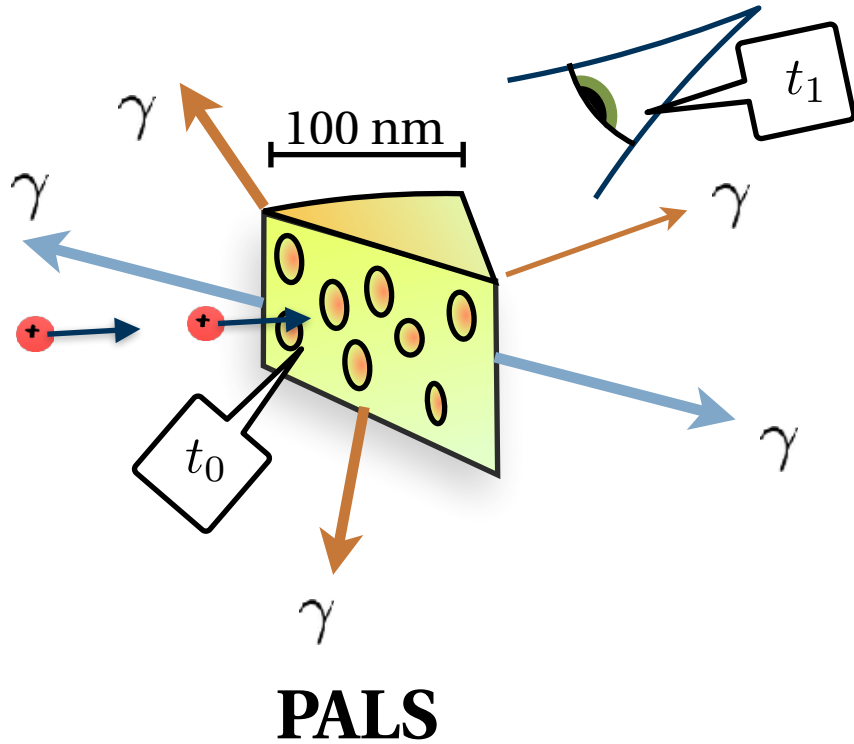
Time of flight (TOF)



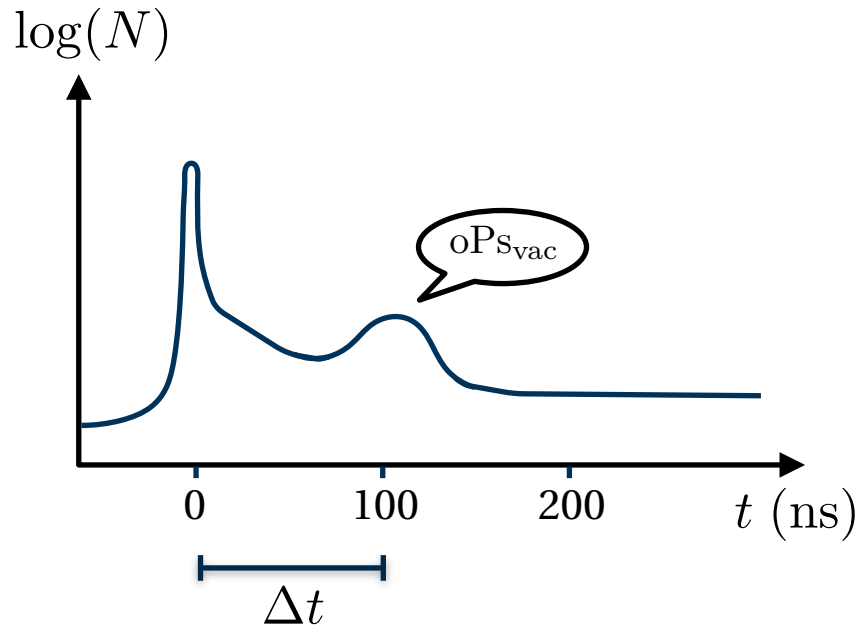
Time of flight (TOF)



Time of flight (TOF)

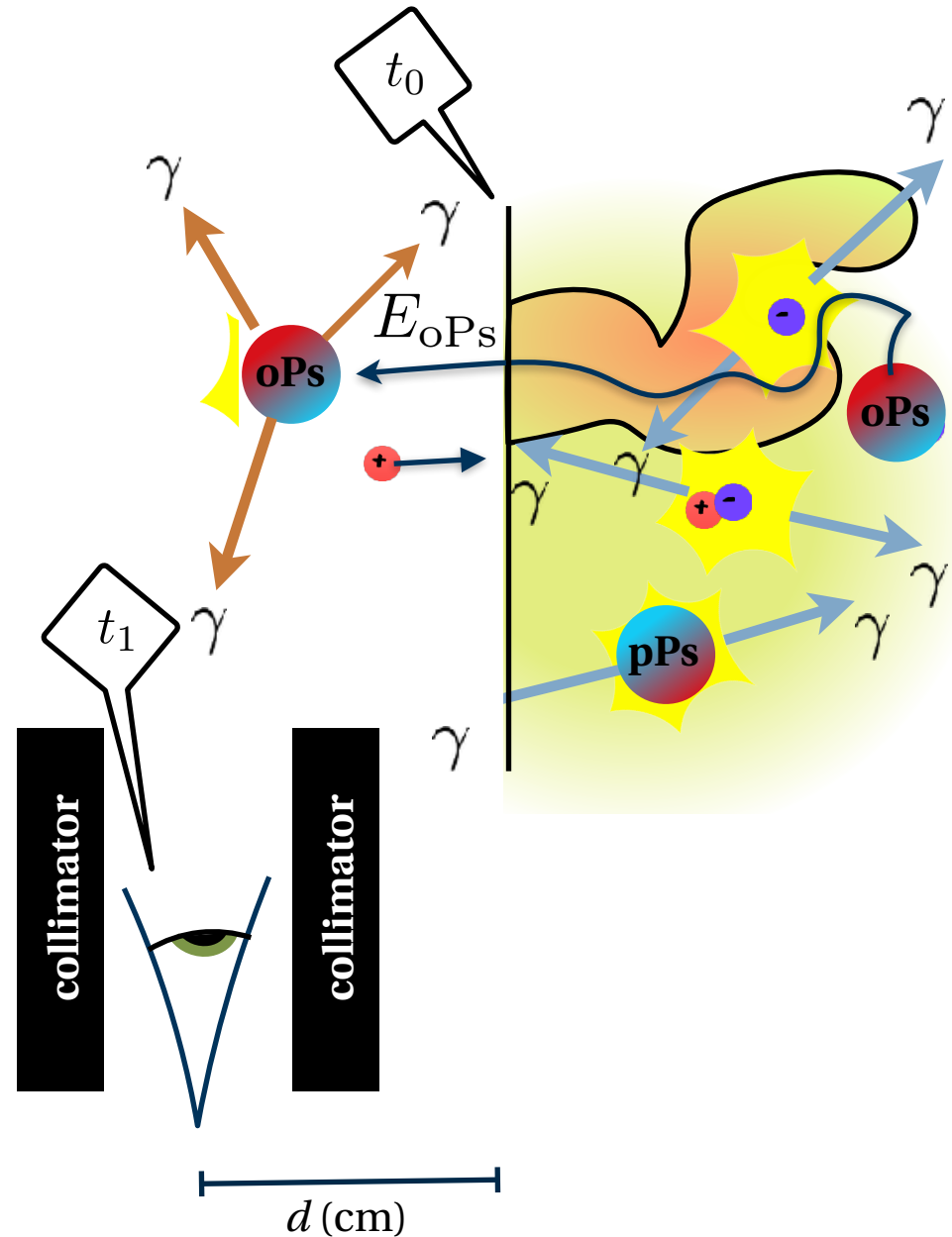


Time of flight (TOF)

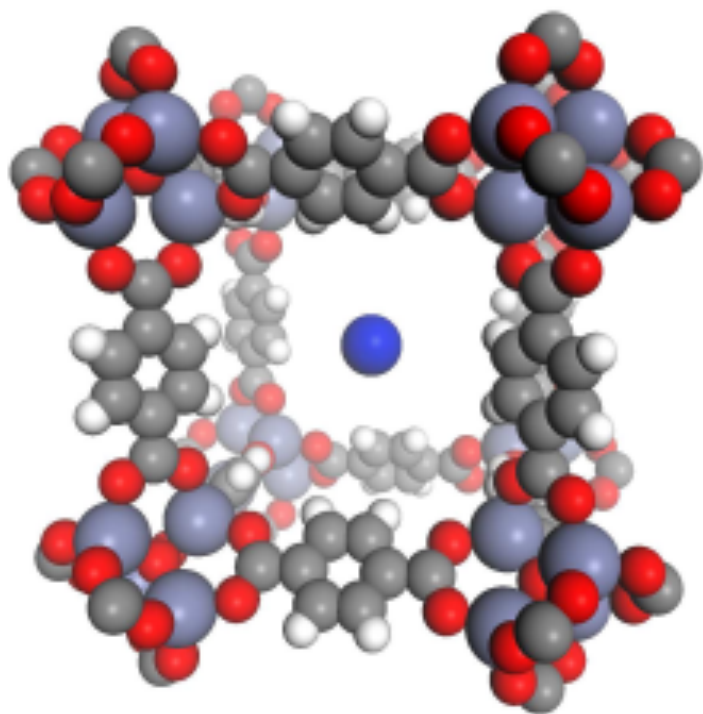


Estimation

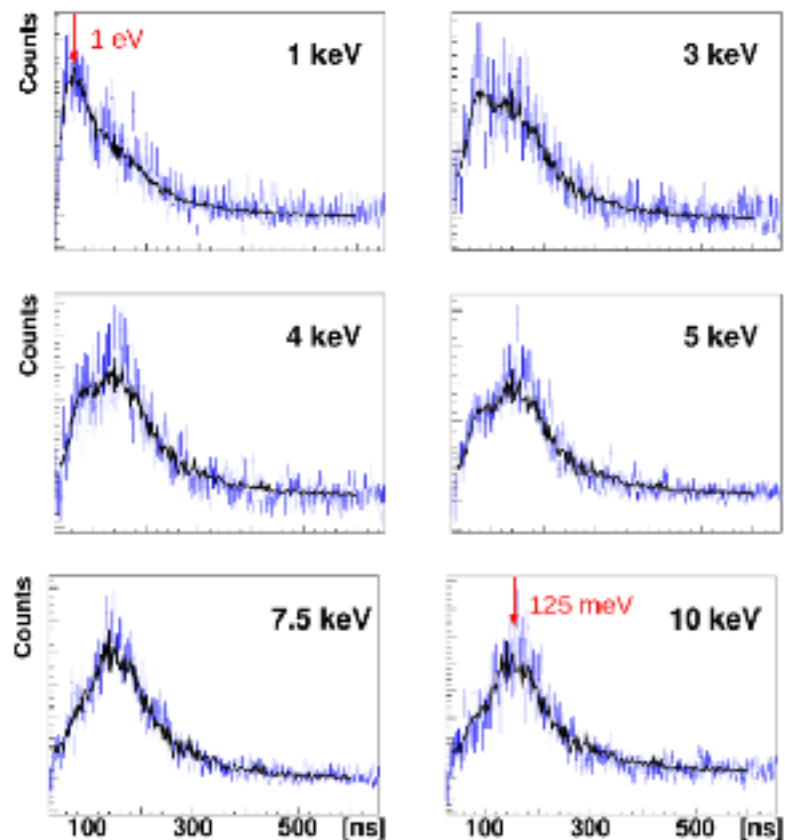
$$v = \frac{d}{\Delta t}$$



TOF in Metal Organic Frameworks (MOF)

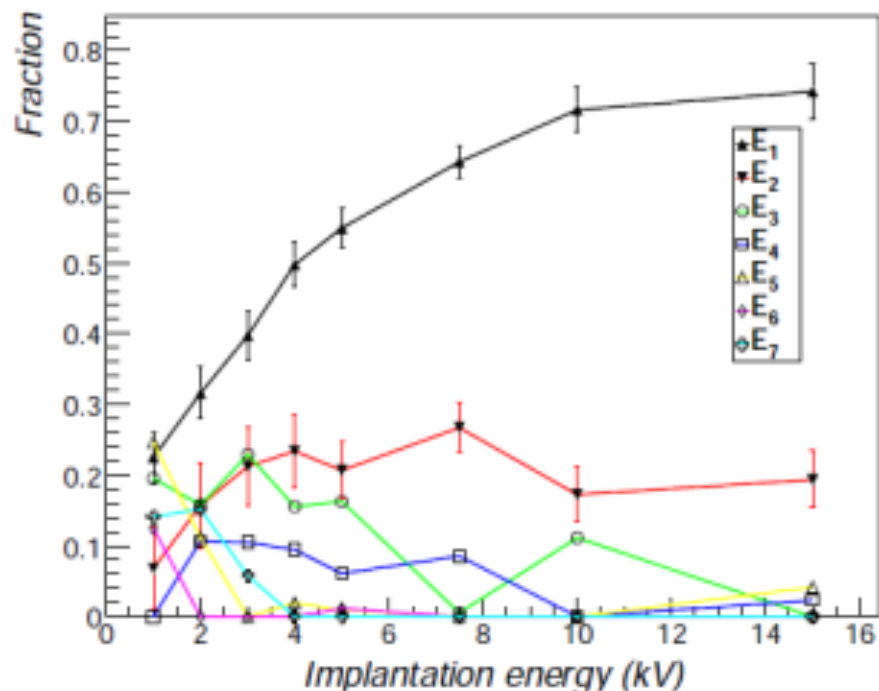


MOF unit cell

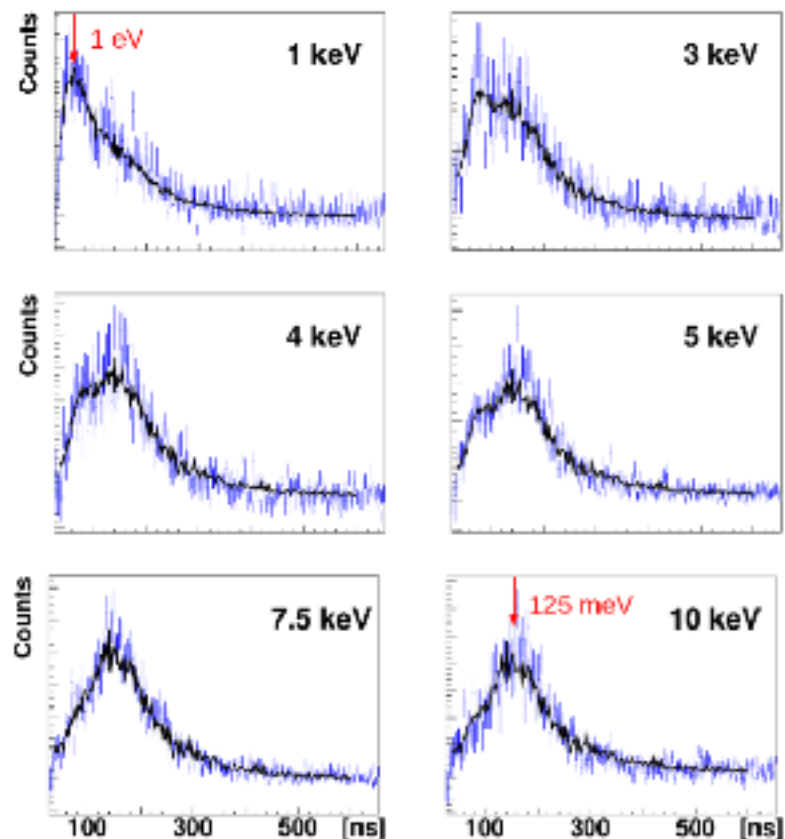


MOF5 TOF spectra

TOF in Metal Organic Frameworks (MOF)

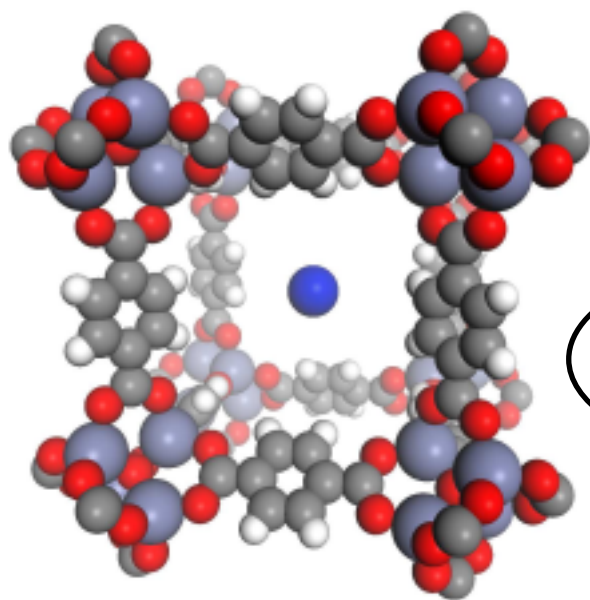


TOF components

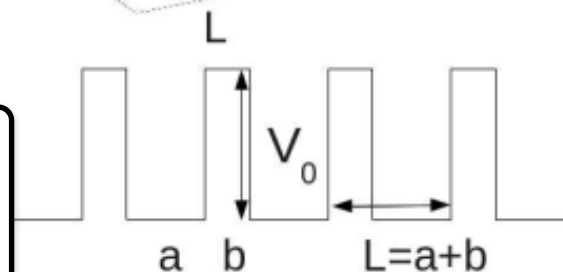
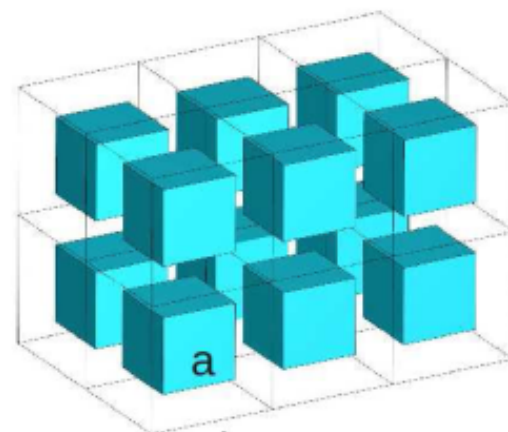


MOF5 TOF spectra

TOF in Metal Organic Frameworks (MOF)



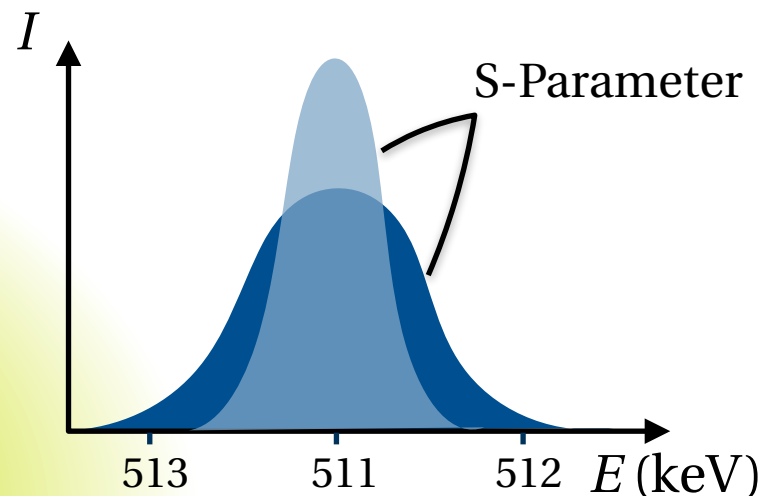
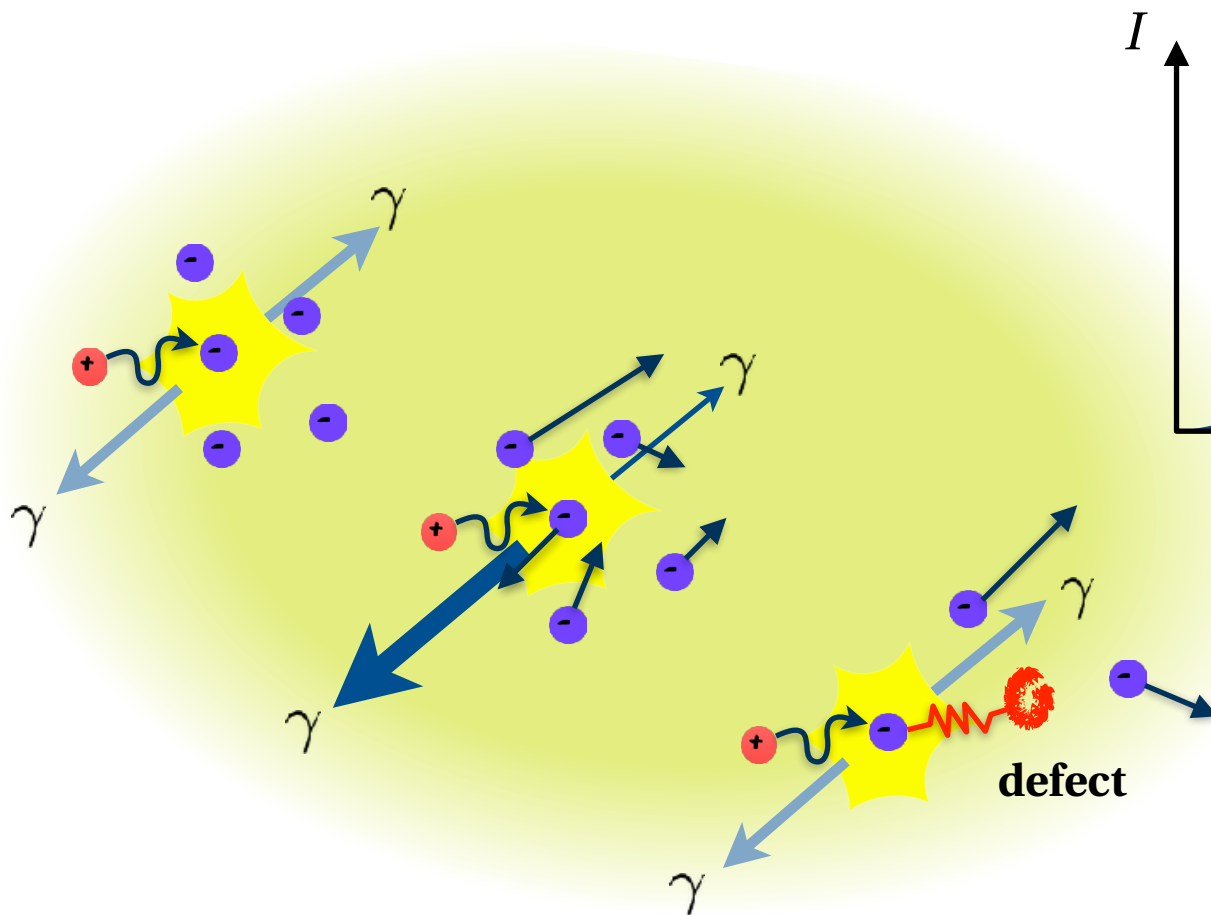
smaller than E
 QM-well ground state



**Confirmation of
 delocalized Ps
 Bloch states**

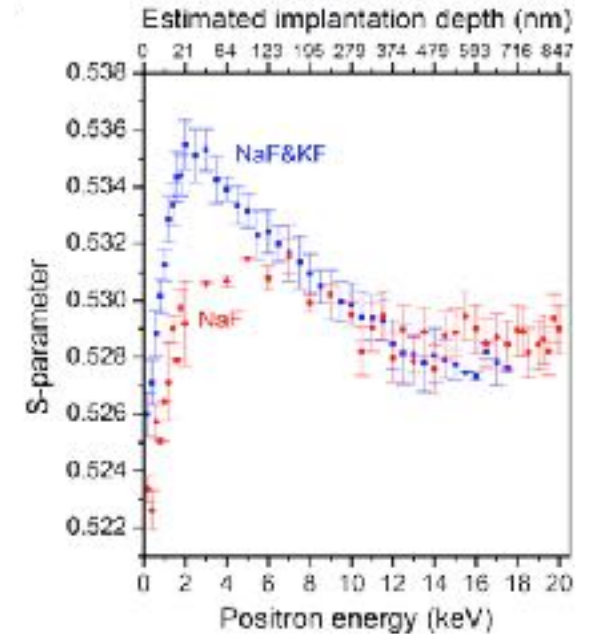
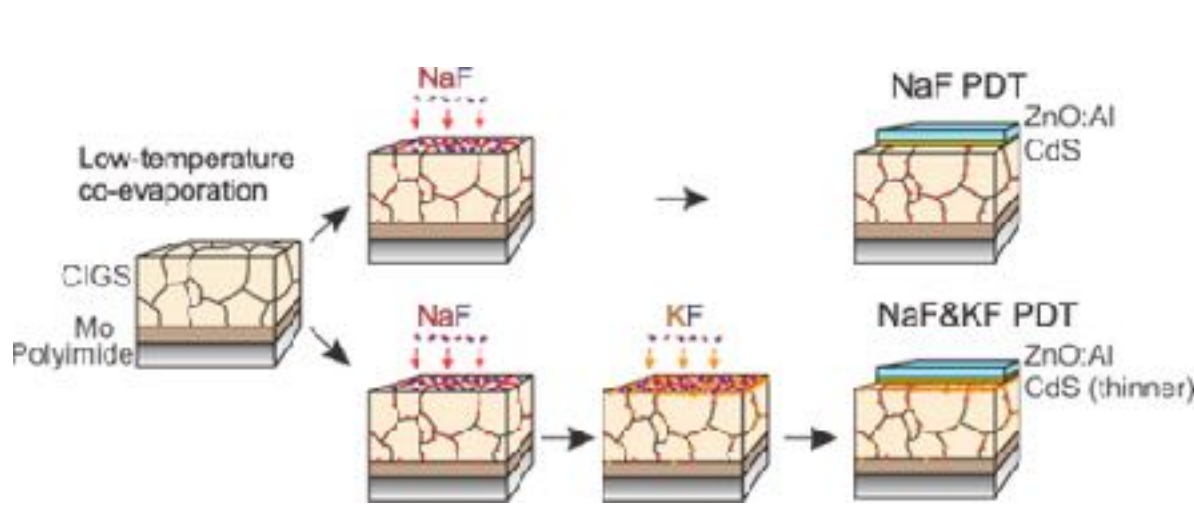
Sample	E_1
IRMOF-20	120 ± 10
IRMOF-8	138 ± 15
MOF-5	125 ± 5
FMA	162 ± 5

Doppler Broadening Spectroscopy (DBS)



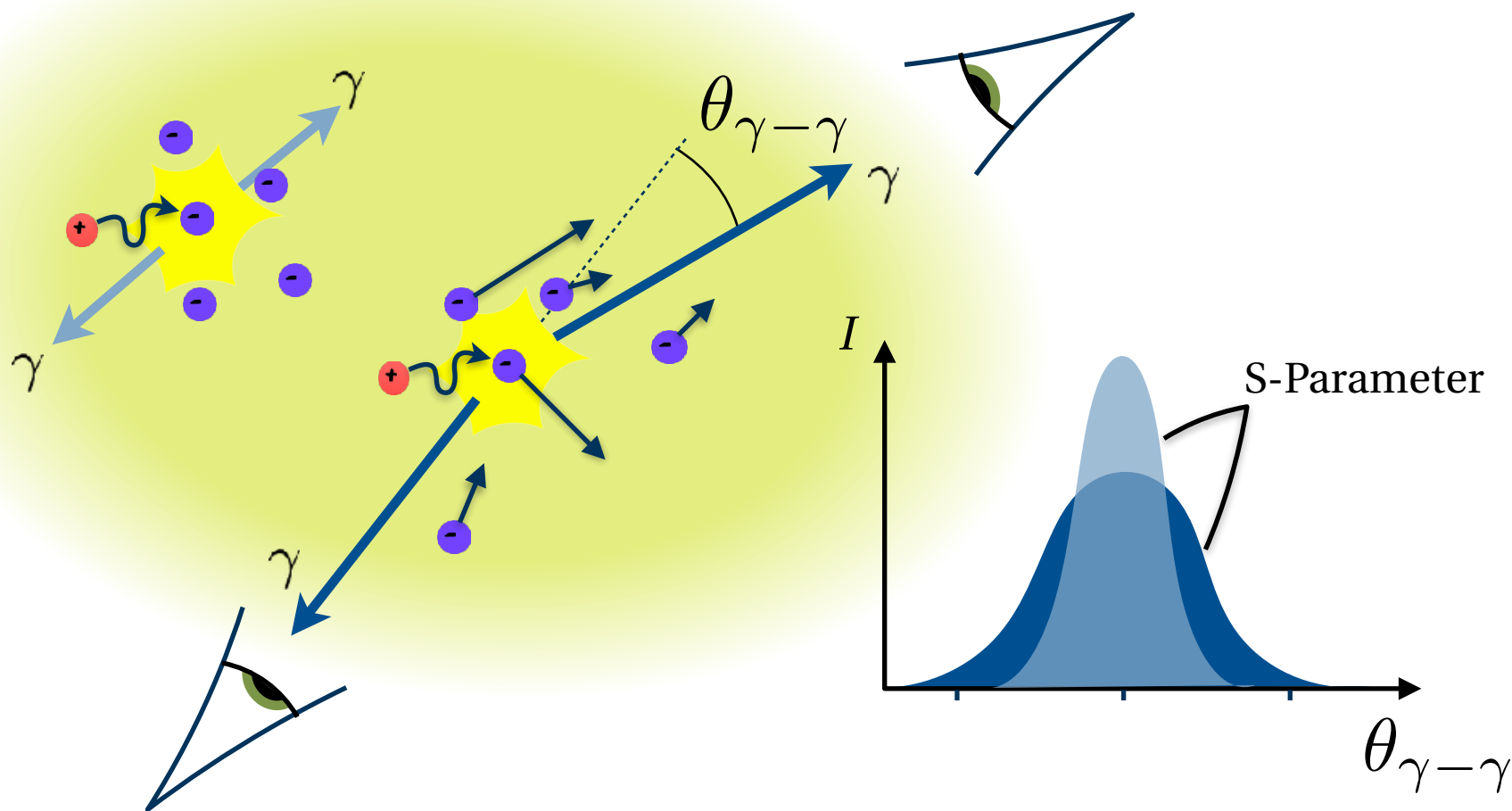
**High Purity
Germanium
Detector (HPGe)
necessary**

DBS on Thin Film Solar Cells

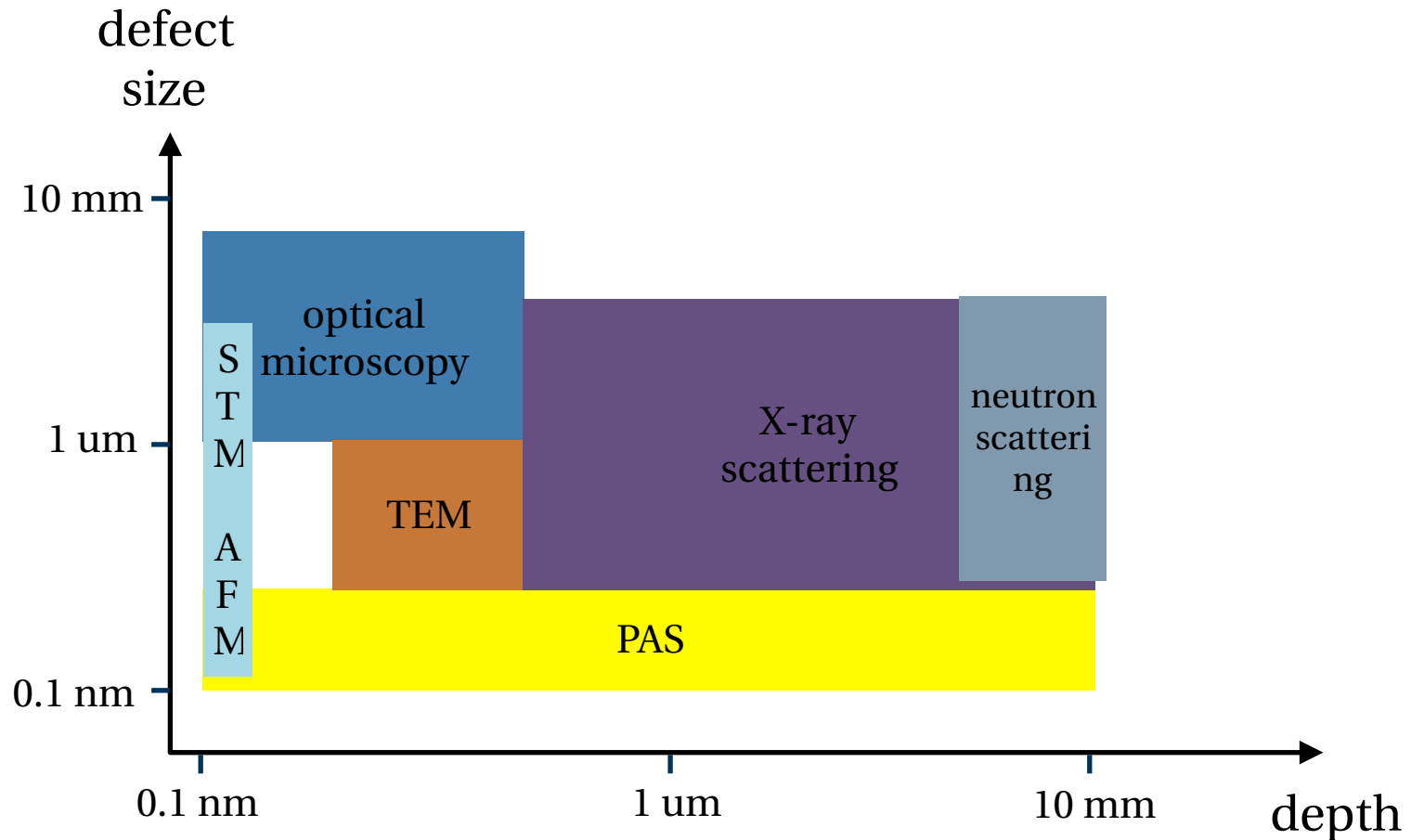


“new world record for CIGS solar cell technology”

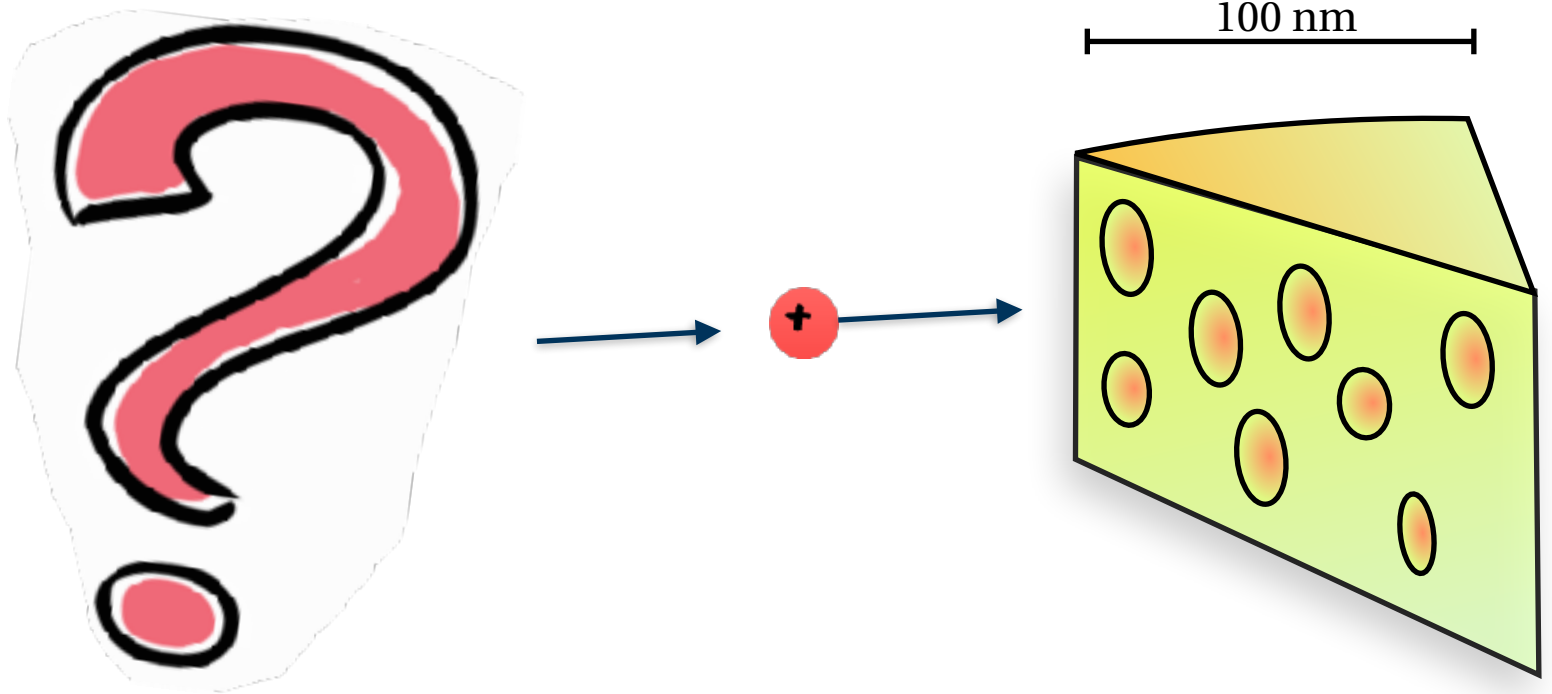
Two-dimensional angular correlation of annihilation radiation (2D-ACAR)



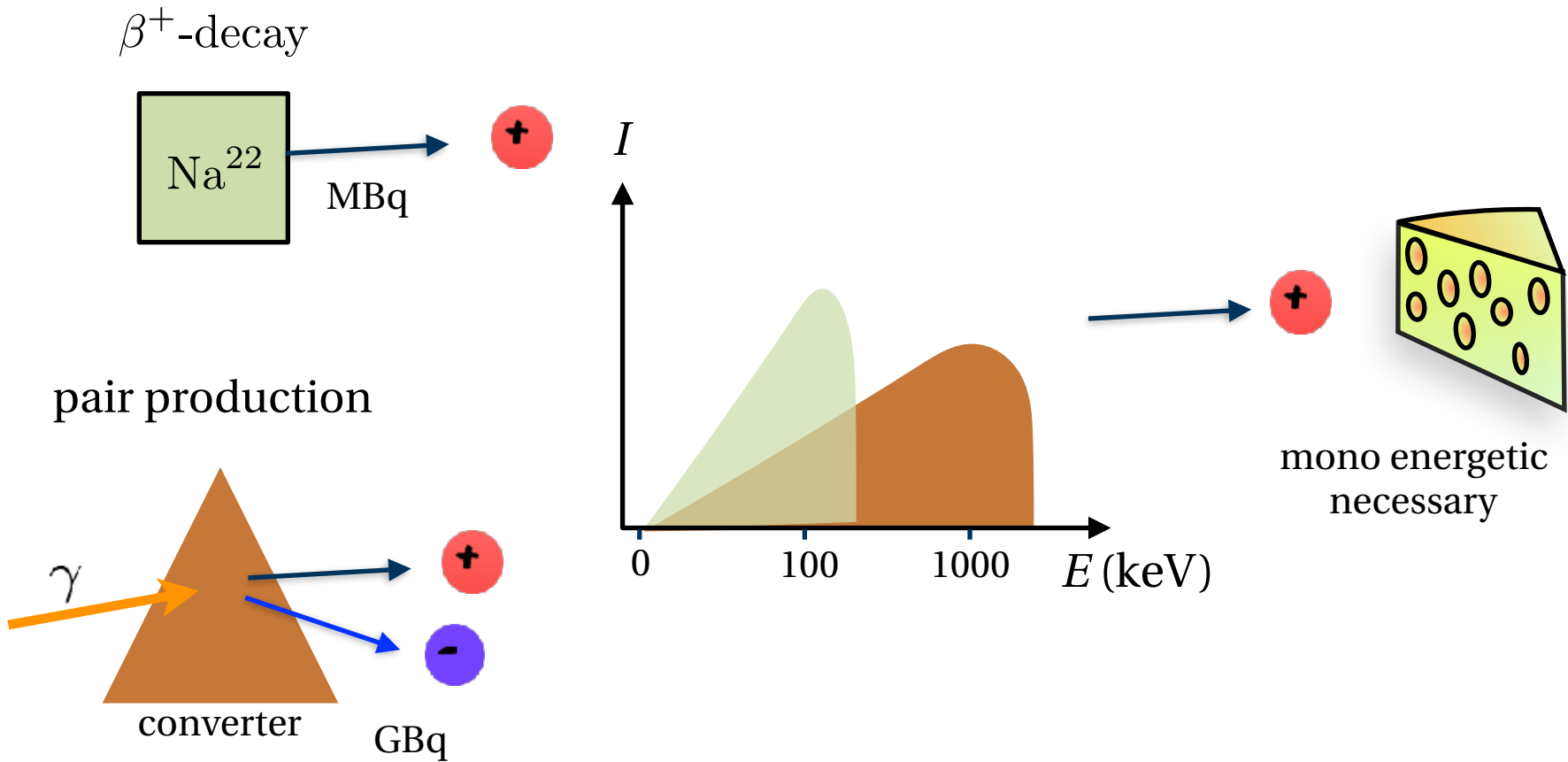
PAS comparison



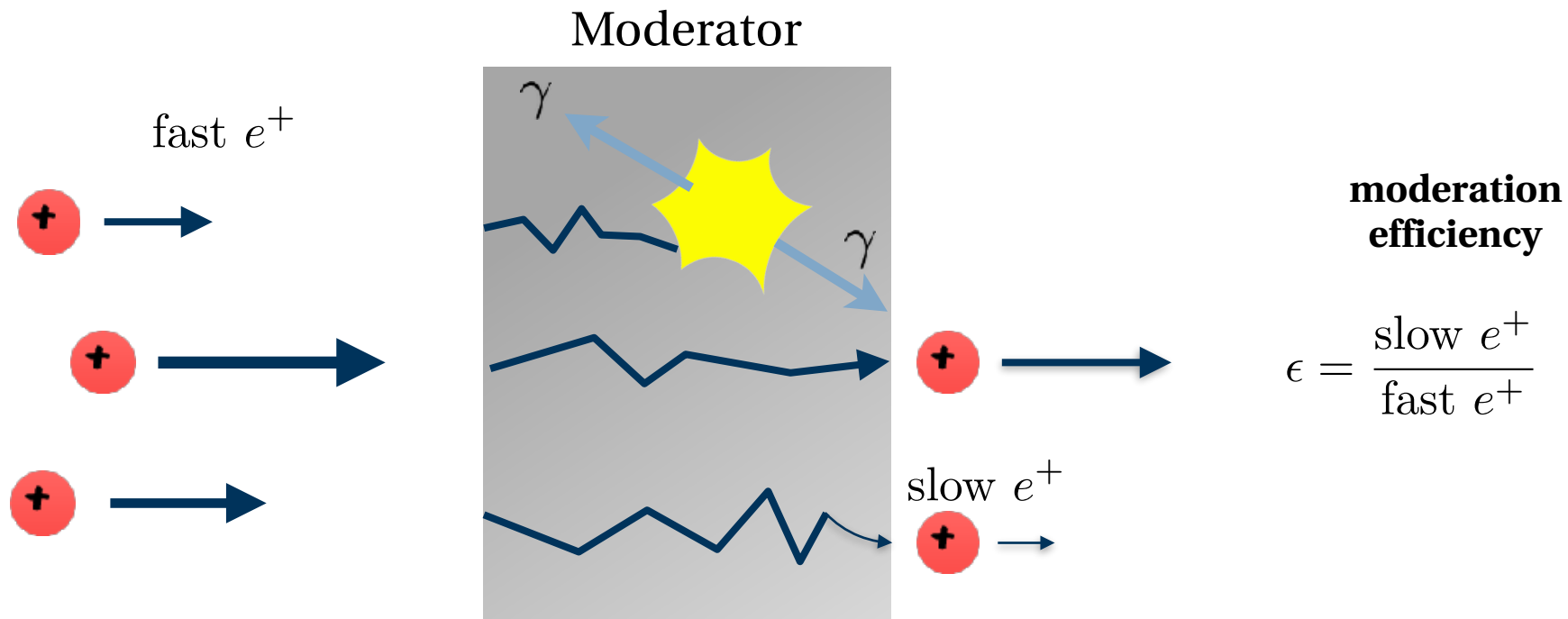
Source



Source



Moderation

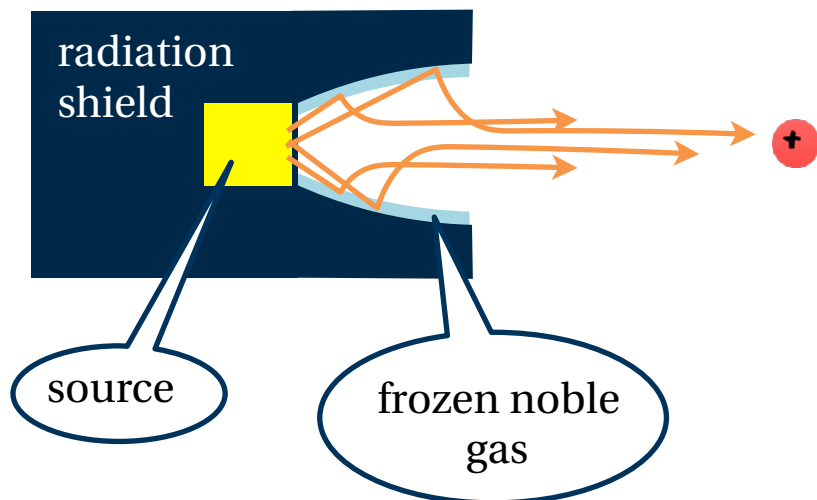


Moderation

noble gas moderators

Ne, Ar, ...

long diffusion length

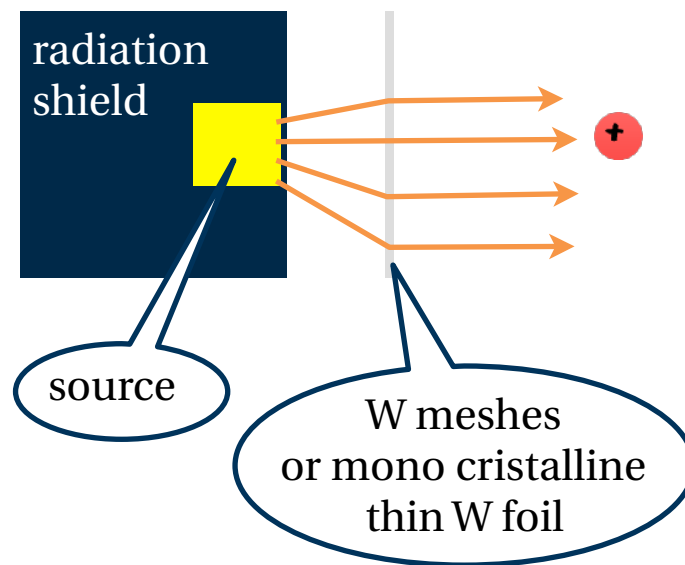


$$\epsilon \approx 10^{-3}$$

metal moderators

W, Ni, ...

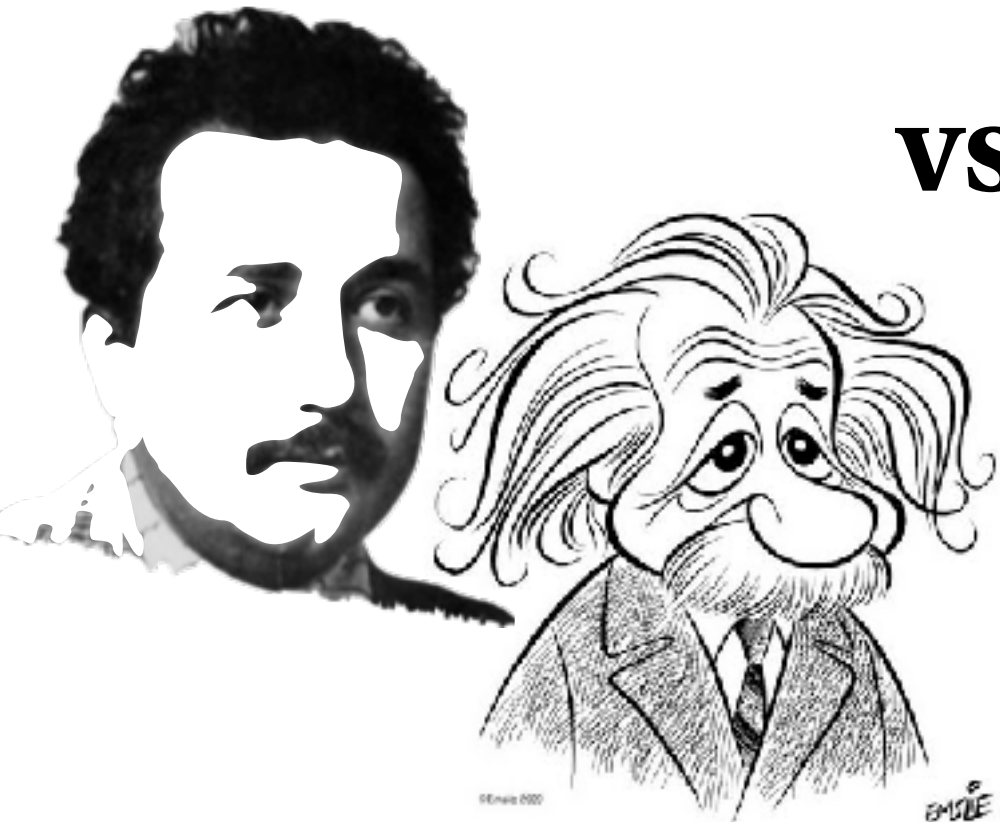
negative workfunction $\Phi_{e^+} < 0$



$$\epsilon \approx 5 \cdot 10^{-5}$$

Limitation

weak source



strong source



Development

- Work towards more accessible positron-devices
 - ▶ Improve moderation efficiency
 - ▶ New sources
 - ▶ Adapted detectors & DAQ
 - ▶ Incorporated analysis
 - ▶ Modeling Ps behavior
 - ▶ Downscaling
 - ▶ Explore new applications

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Questions

