Antimatter Beams in Dark Mater Searches

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INFN- Genova, August 2019

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(Ph.D "Positron-positronium scattering from atoms and molecules")

University of Rome La Sapienza

(Ms "Weak response of neutron matter at low momentum transfer")

Positron (e^+) studies:

- To understand matter-antimatter interactions

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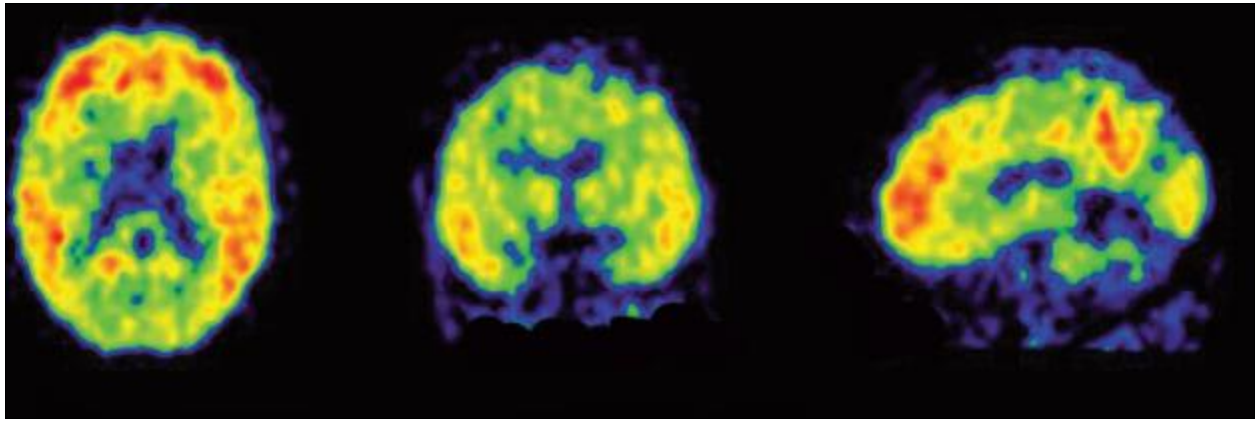
R. E. Robson et al., Scientific Reports, 5, (2015), 12674



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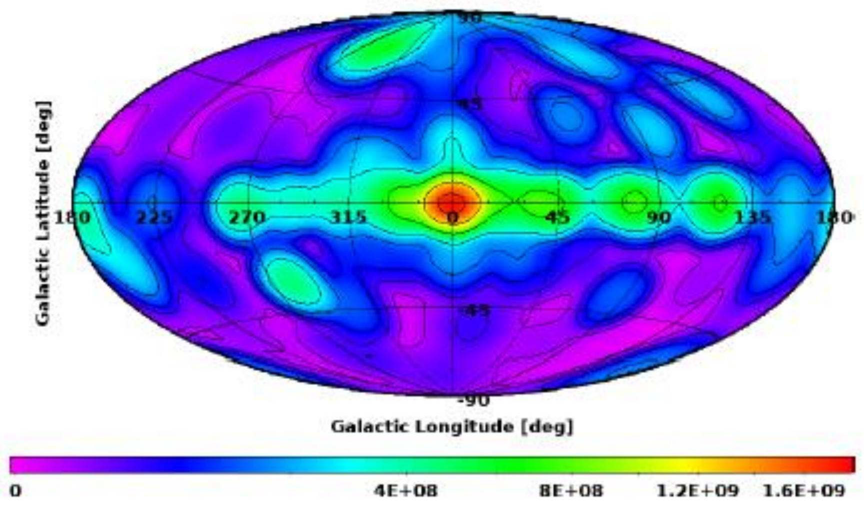

T. Siegert et al., A&A 586, A 84 (2016)

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Positron (e^+) studies:

- To understand matter-antimatter interactions
- Positron Emission Tomography (PET)
- Astronomical observations
- Positron annihilation lifetime spectroscopy
- Fundamental problems in physics and astrophysics:
  - Antihydrogen studies at CERN e.g., ASACUSA, ALPHA
  - Dark photons searches e.g., PADME at INFN

e^+ and Ps scattering from atoms and molecules

Elastic scattering	
A+Ps → A+Ps	elastic scattering
Target-inelastic scattering	
A+Ps → A*+Ps	target excitation
A+Ps → A^+ +Ps + e^-	target ionization
A+Ps → A^+ +Ps^-	Ps^- formation
Ps-inelastic scattering	
A+Ps → A+Ps*	Ps excitation
A+Ps → A + e^- +e^+	Ps fragmentation

$e^+ + A \to e^+ + A$	elastic scattering
$e^+ + A \to A^* + e^+$	target excitation
$e^+ + A \to A^+ + e^+ + e^-$	target ionization
$e^+ + A \to A^+ + Ps$	Ps formation
$e^+ + A \to (F_1,...,F_n) + e^+$	target dissociation

Total cross section

$$\sigma_{Tot}^{e^+} = \sigma_{el} + \sigma_{Ps} + \sigma_{ex} + \sigma_{ion} + \cdots$$

e^+ and Ps scattering theories.

Complicated as they can get

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Close-coupling method

$$\Psi^{sSM} \approx \frac{1}{\sqrt{2}}(1 - P_{12})\Big[\sum_{\alpha}^{N_{\rm He}} F_{\alpha}^{(s)}(\boldsymbol{r}_0)\psi_{\alpha}(\boldsymbol{r}_1, \boldsymbol{r}_2)\chi_{_{sSM}}(0,(1,2))$$
$$+ \sum_{s'}\sum_{\beta}^{N_{\rm Ps}} G_{\beta}^{(s')}(\boldsymbol{R}_1)\psi_{\beta}(\boldsymbol{\rho}_1)\phi_{1s}(\boldsymbol{r}_2)\chi_{s'SM}((0,1),2)\Big],$$

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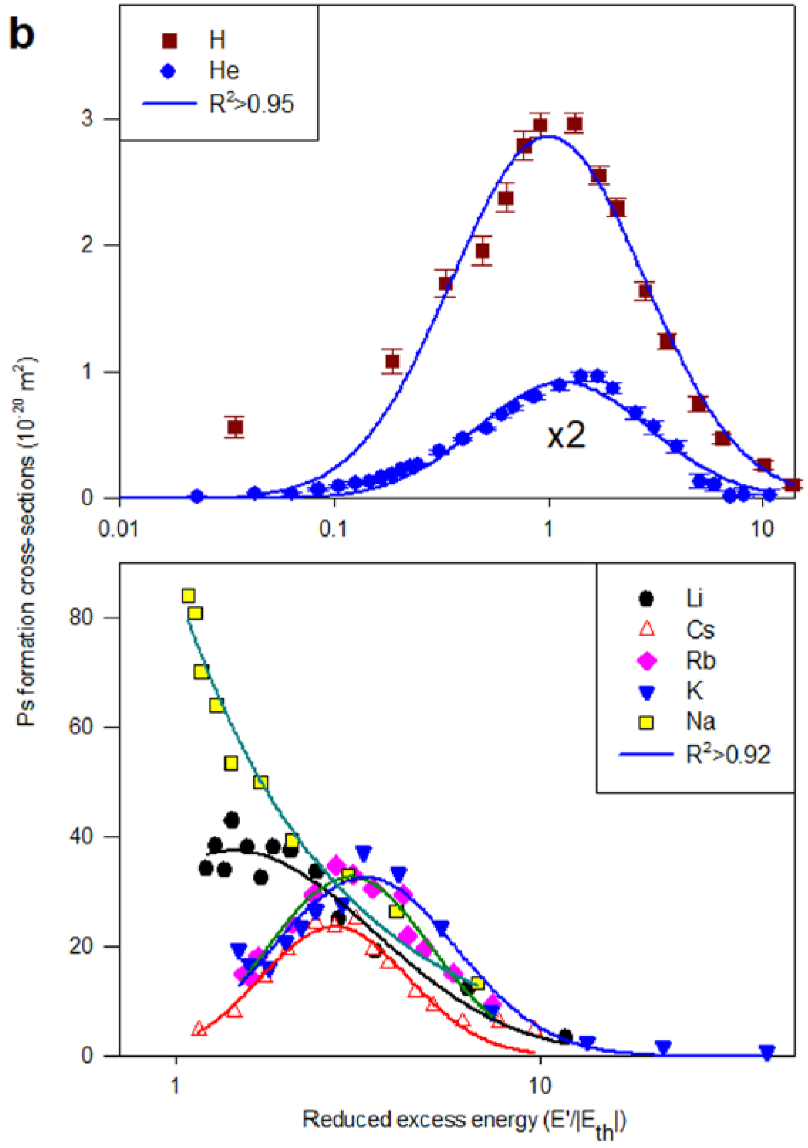
Complex potentials

$$V_{pos}(r > r^*) = +\frac{2}{r} - \frac{\alpha}{2r^4} + iV_{abs}$$

V_{abs}	e^+	e^-
Ionization	•	•
Excitation	•	•
Ps	•	-
2γ	•	-

A statistical description of scattering at the quantum level

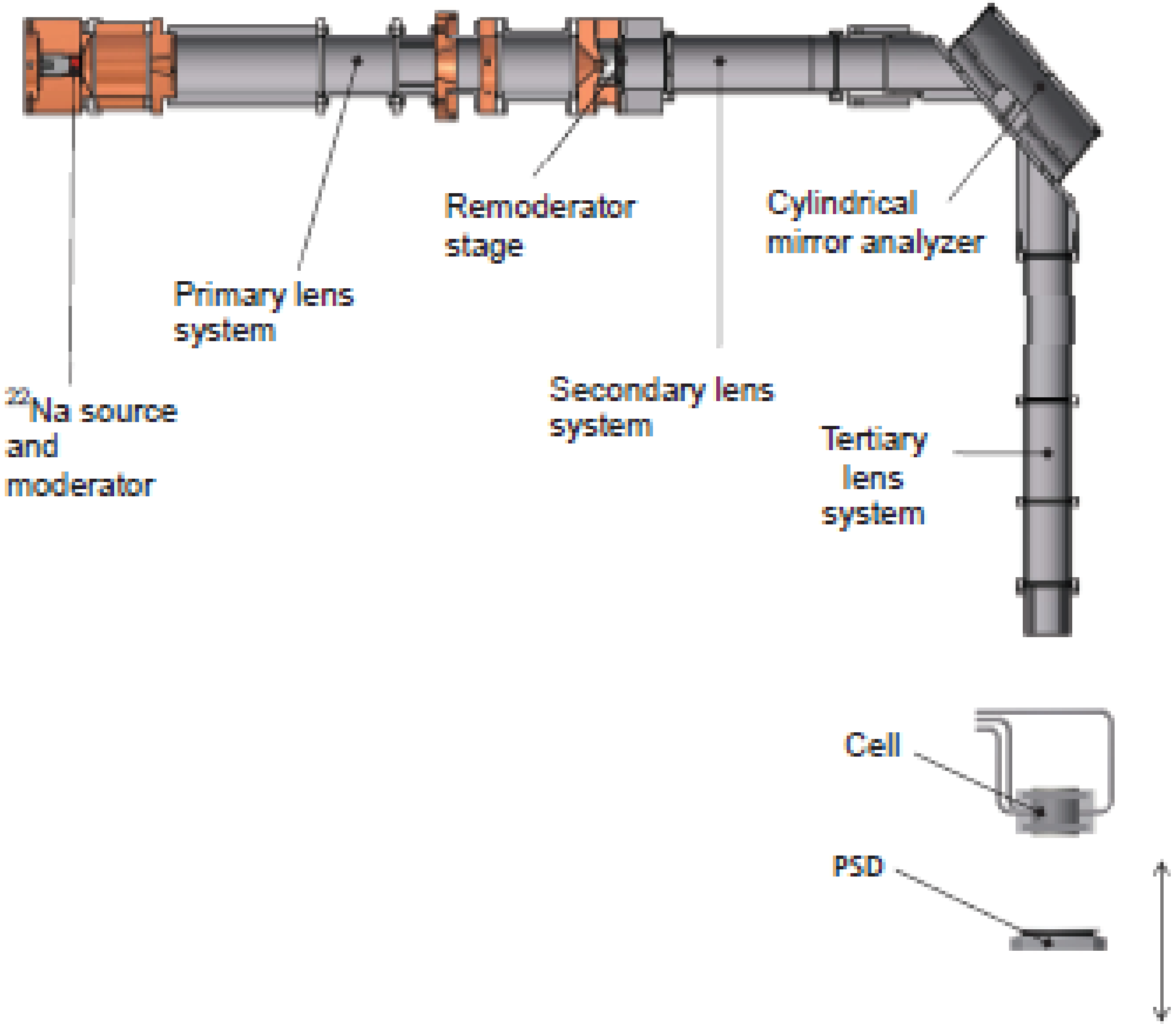


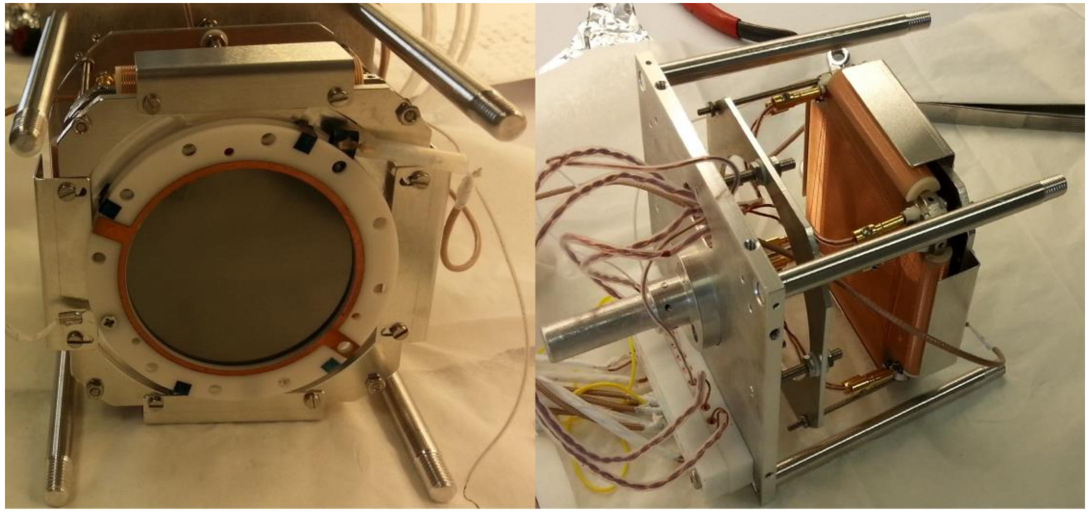
Lognormal distribution; $x=(E- E_{th})/E_{th}$

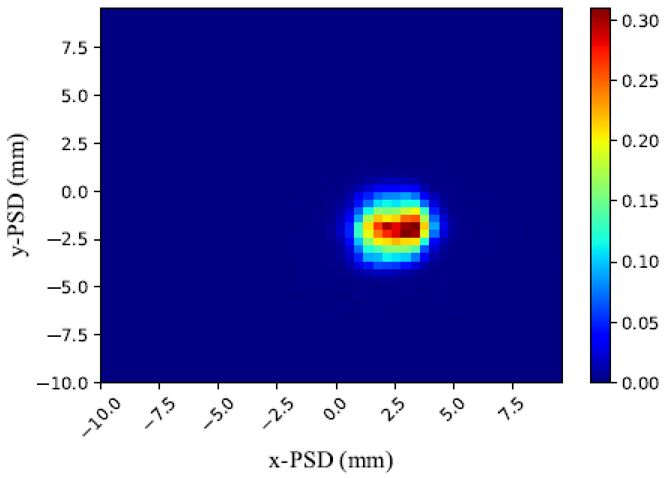
$$f(x) = \frac{a}{x}\exp\left[-\frac{1}{2}\left(\frac{\ln\left(\frac{x}{x_0}\right)}{b}\right)^2\right].$$

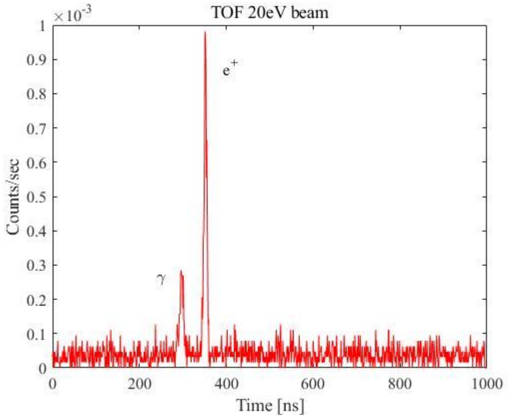
G. Laricchia, P. Van Reeth, S. E. Fayer, S. J. Brawley, R. Kadokura, A. Loreti, M. J. Shipman
Scientific Reports **8**, Article number: 15056 (2018)

Electrostatic positron beam

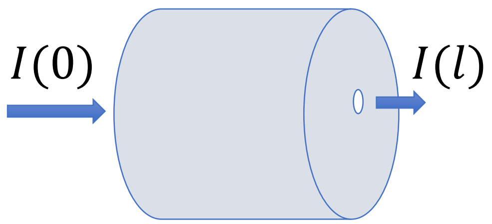








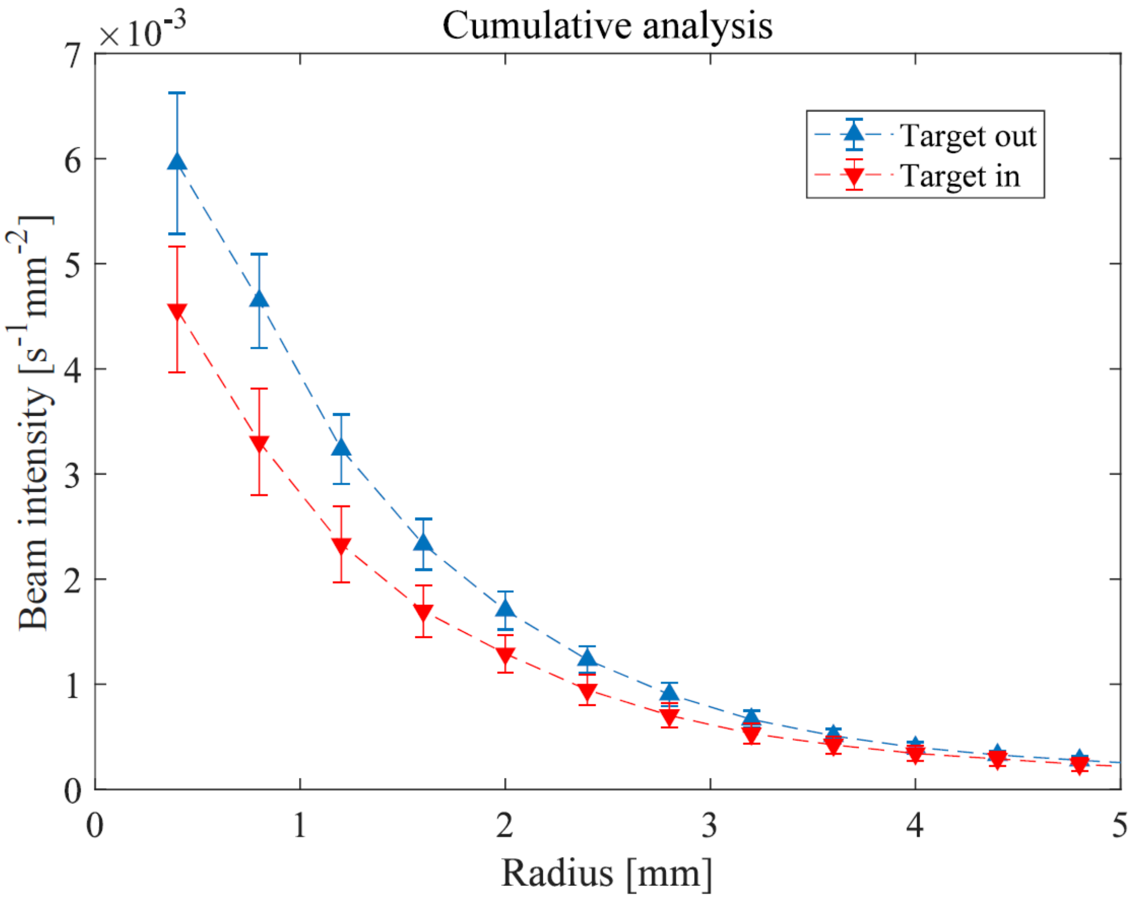
Total cross section measurements



Beer-Lambert law

$$\sigma_{Tot} = \frac{1}{n\,l} \ln\left(\frac{I(0)}{I(l)}\right)$$

$$n = \frac{P}{k_B\,T}$$



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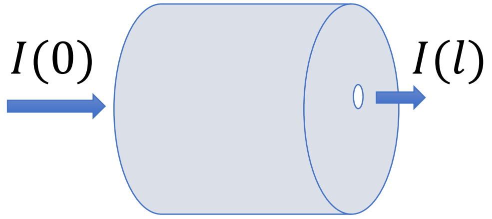

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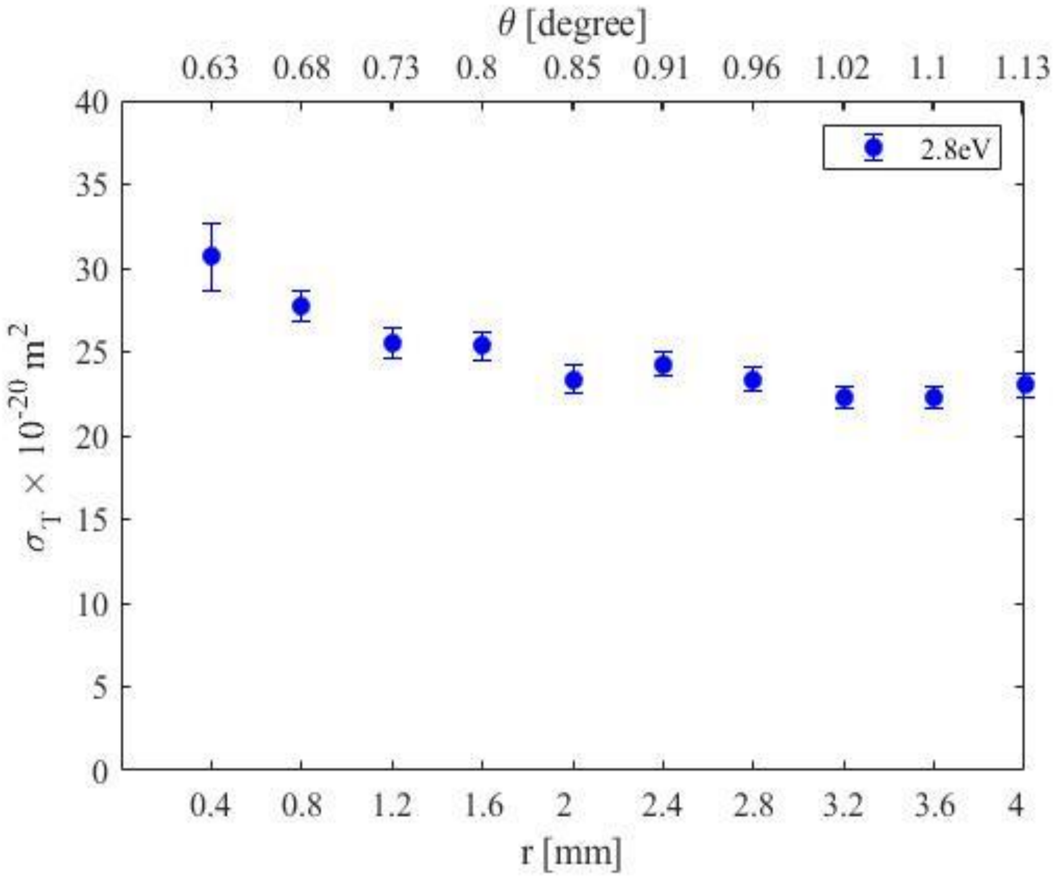


Measurements of e^+ and e^- total cross sections

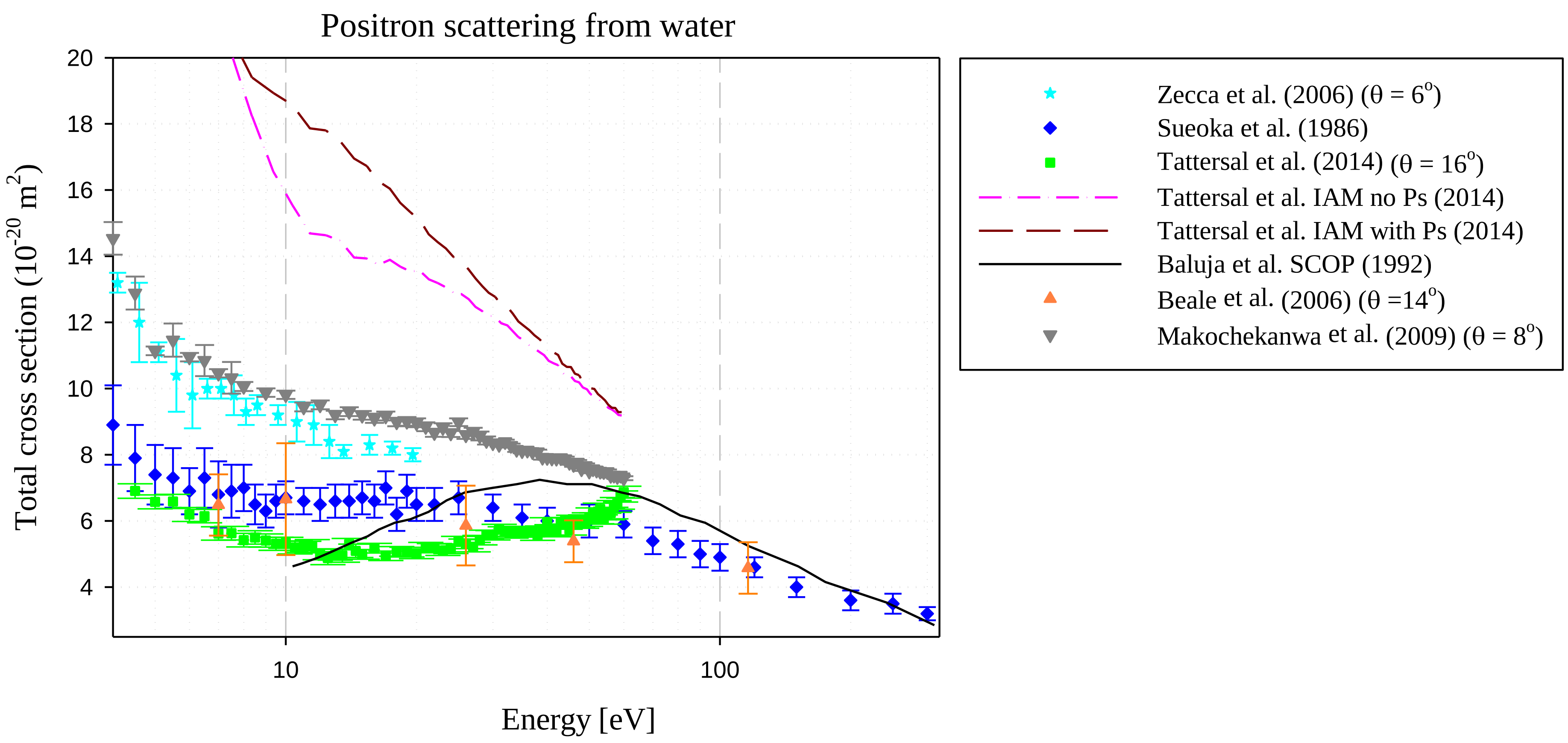
Present results

- Magnetic field-free measurements of the total cross section for positrons scattering from helium and krypton.
  J. Phys. B: At. Mol. Opt. Phys, 49:075202, 2016.

- High resolution (e^+ + H_2O) total cross sections.
  Phys. Rev. Lett., 117:253401, 2016.

- Angle-resolved electron scattering from H_2O near 0 degree.
  Phys. Rev, Lett., 2019.

Positron total cross sections for polar molecules: H_2O



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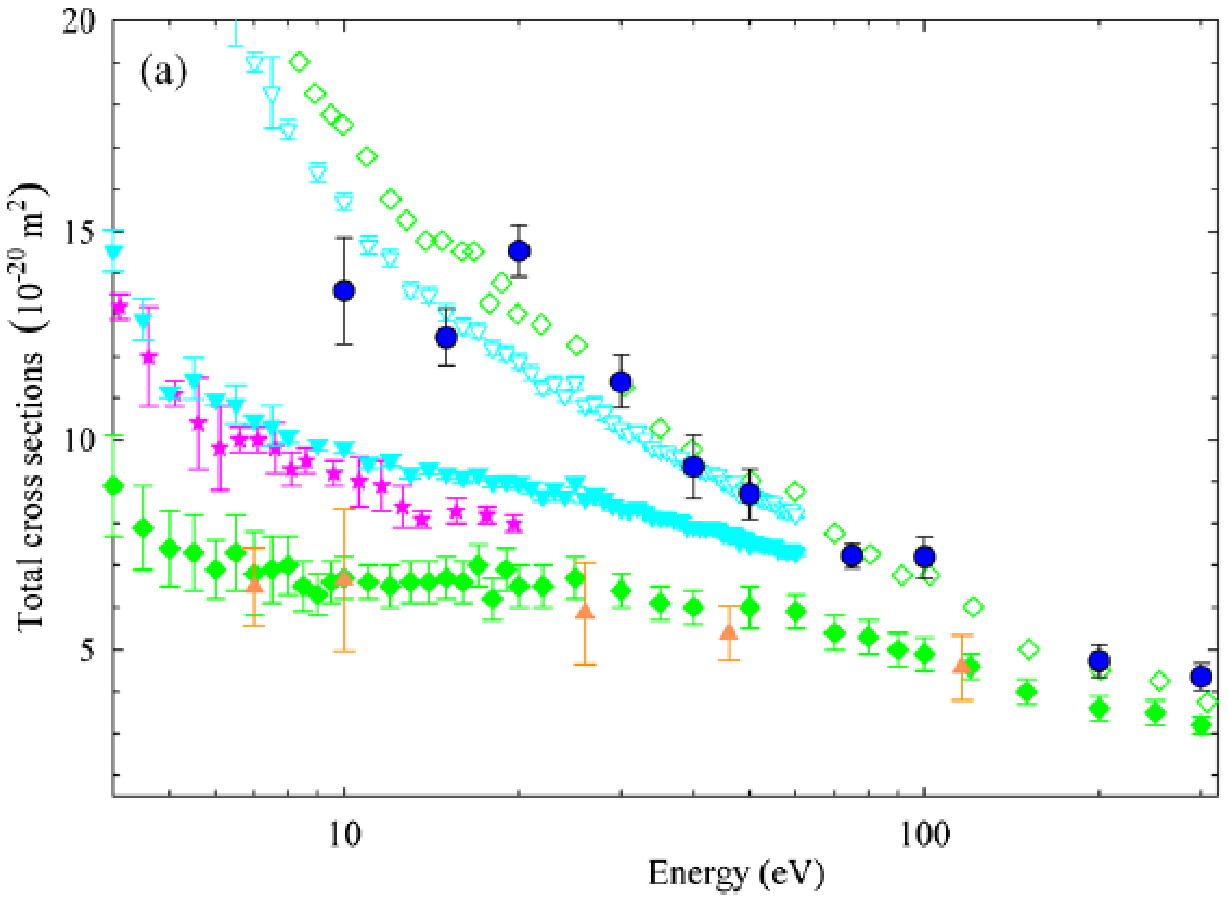


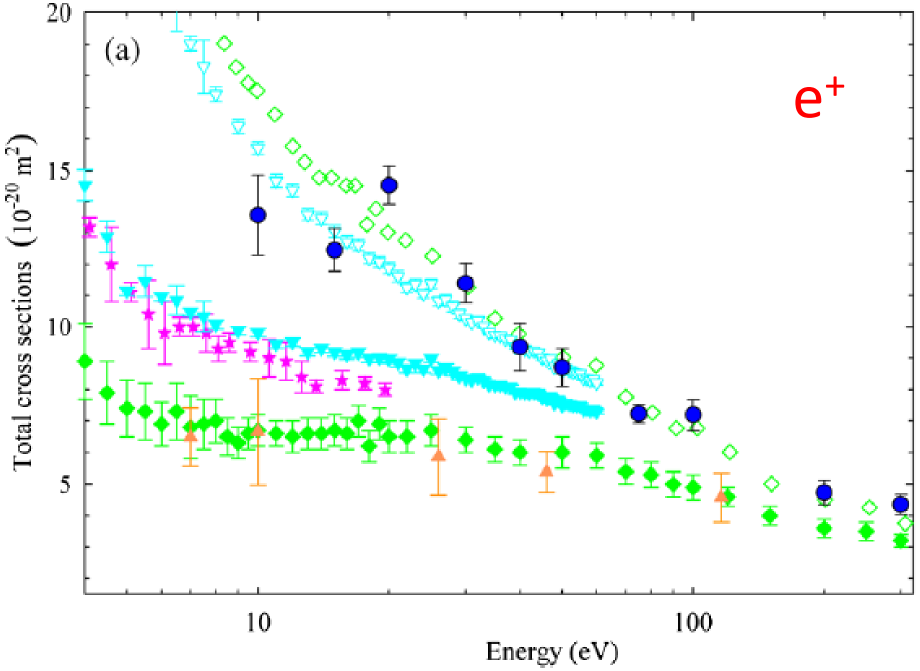
Full symbols: experimental results

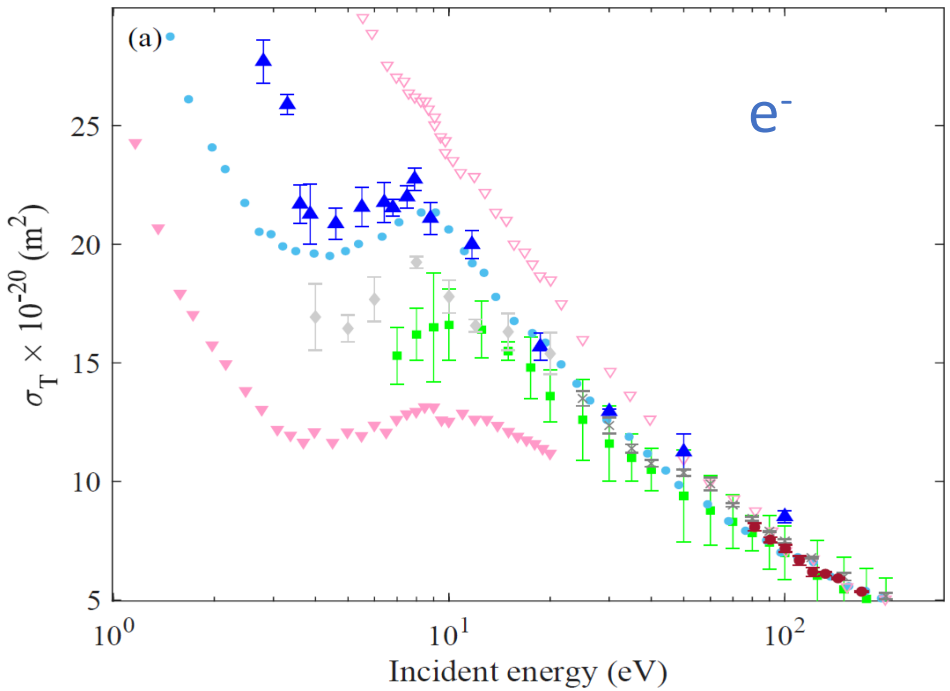
Empty symbols: theoretical corrections to experiments

Blue bullets: present high-precision measurements, Loreti et al. PRL 117, 253401 (2016).

Total cross sections for polar molecules: H_2O

e^+ Vs e^-





A. Loreti, R. Kadokura, S. E. Fayer, Á. Kövér and G. Laricchia Phys. Rev. Lett., **117**, 253401 (2016).

R. Kadokura, A. Loreti, Á. Kövér, J. Tennyson, Faure and G. Laricchia, Phys. Rev. Lett., **123**,033401, (2019).

Thank You
for
Your Attention