POSITRONIUM COLLISIONS WITH ATOMS AND MOLECULES

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Electron-Like Scattering of Positronium

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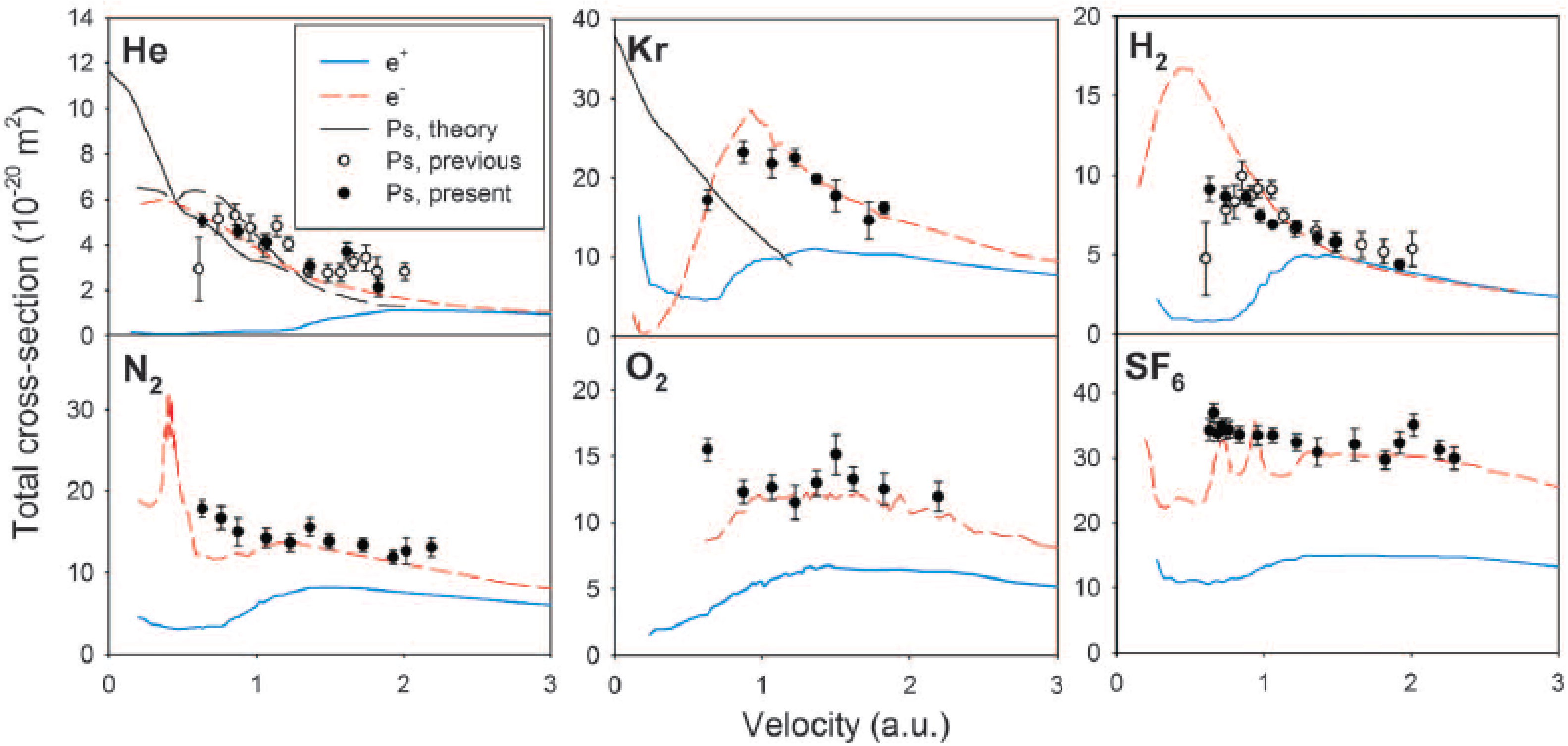

Resonant Scattering of Positronium in Collision with CO_2

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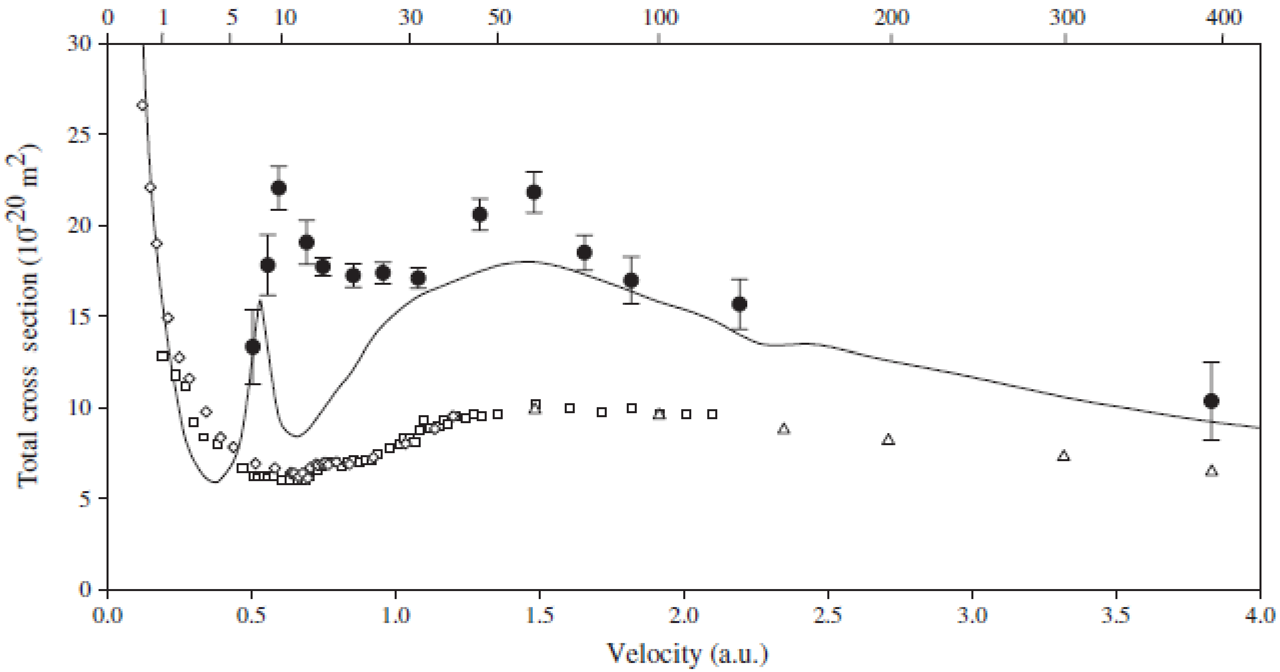


Ps Scattering Processes

- Elastic: $Ps(1s) + B \rightarrow Ps(1s) + B$
- Excitation: $Ps(1s) + B \rightarrow Ps(nl) + B$
- Ionization: $Ps(1s) + B \rightarrow e^{+} + e^{-} + B$
- Assuming B remains in the ground state.

Thermal collisions of Rydberg atoms with ground-state atoms (E. Fermi, M. Matsuzawa)

$$k_d = \int_0^\infty v\,\sigma_e(v)\,f(v)\,dv$$

Does this work for a ground-state Ps?

Impulse approximation

$$f_{ba}(\mathbf{p}_f, \mathbf{p}_i) = 2\int g_b^*(\mathbf{q}) f^-(\mathbf{v}_f^-, \mathbf{v}_i^-) g_a(\mathbf{q} + \Delta\mathbf{p}/2) d^3\mathbf{q}$$
$$+ 2\int g_b^*(\mathbf{q}) f^+(\mathbf{v}_f^+, \mathbf{v}_i^+) g_a(\mathbf{q} - \Delta\mathbf{p}/2) d^3\mathbf{q}$$

$$\mathbf{v}_i^{\pm} = \mathbf{p}_i/2 - \Delta\mathbf{p}/2 \pm \mathbf{q}, \quad \mathbf{v}_f^{\pm} = \mathbf{p}_i/2 + \Delta\mathbf{p}/2 \pm \mathbf{q}.$$

Proof of the principle

- Assume positron scattering small compared to electron scattering
- Ps energy is well above the ionization (break-up) threshold

Then

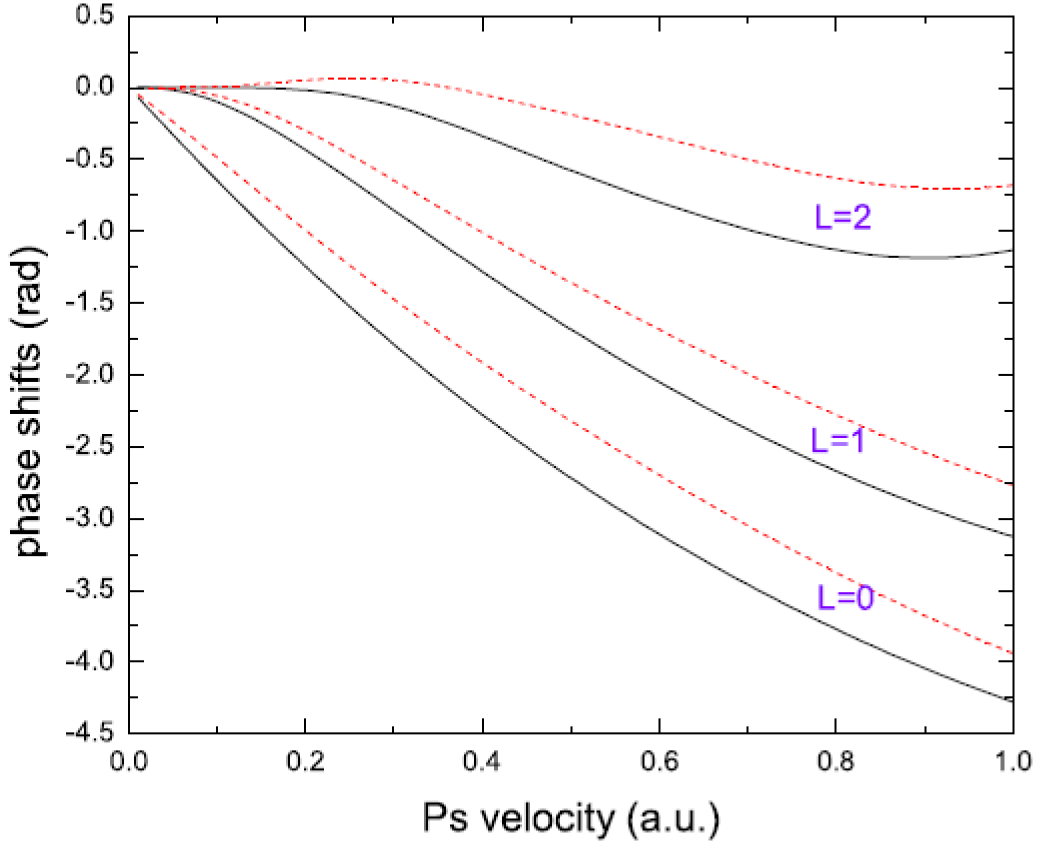
$$\sigma_a(\mathrm{Ps}) = \sigma_a(e^-).$$

Pseudopotential calculations

- Pseudopotential from e^- - A and e^+ - A scattering phase shifts in the static-exchange approximation
- Average pseudopotential over the Ps density distribution
- Add van der Waals interaction in the form

$$V_W(R) = -\frac{C_6}{R^6}\left\{1 - \exp[-(R/R_c)^8]\right\}$$

Ps-Kr



0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
phase shifts (rad)
0.0
0.2
0.4
0.6
0.8
1.0
Ps velocity (a.u.)
L=2
L=1
L=0

TABLE II: Mean atomic radii $\langle r \rangle$, core radii R_0, and Ps-atom scattering lengths A for Ar, Kr and Xe. All values are in a.u.

System	C_6	$\langle r \rangle$	R_0	A^a	A^b	A^c
Ar	104.5	1.66	2.67	1.73	2.14–2.33	1.30–1.98
Kr	152	1.95	3.14	2.35	2.35–2.50	1.22–2.26
Xe	234	2.39	3.85	3.23	2.45	1.50–2.60

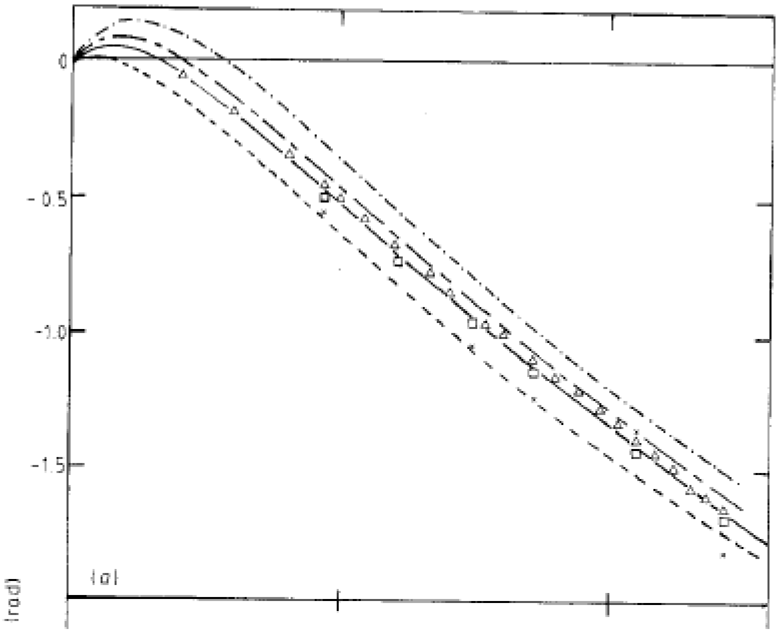
[a] Scattering length from Eq. (20), obtained using Eq. (21) with $\gamma = 1.61$.

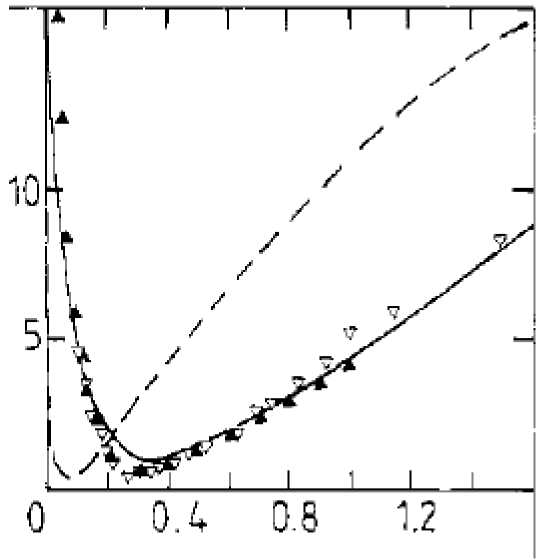
[b] Present scattering calculations.

[c] Values obtained by Mitroy *et al.* [9, 15].

Low-energy electron scattering

$$\tan \delta_0 = -Ak - \pi k^2 \alpha / 3 + O(k^3 \ln k)$$

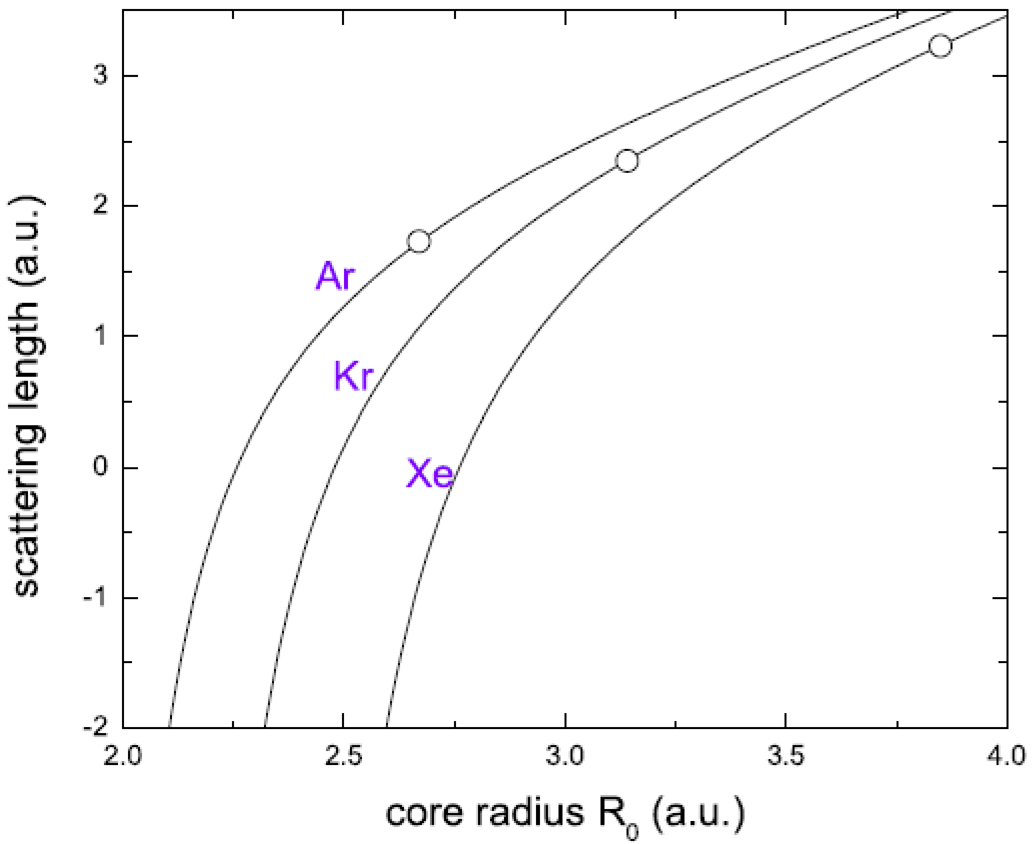




R P McEachran and A D Stauffer

e-Ar A<0

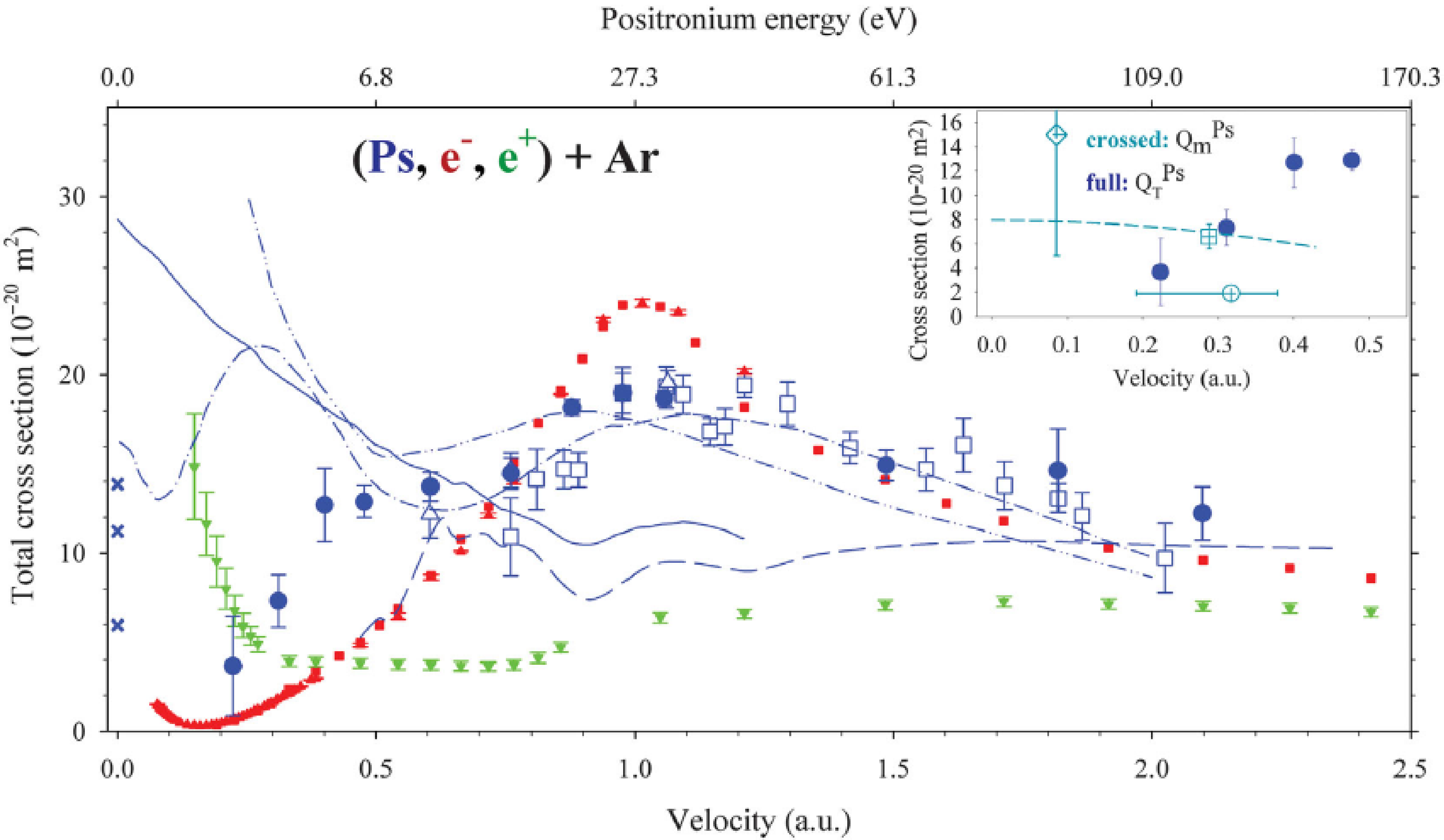
Low-energy scattering – controlled by van der Waals interaction



A>0 – no Ramsauer-Townsend minimum

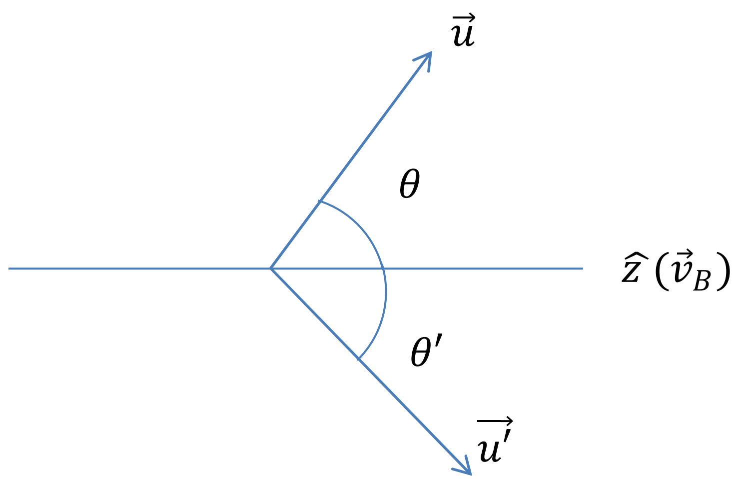
Positronium Production and Scattering below Its Breakup Threshold

S. J. Brawley, S. E. Fayer, M. Shipman, and G. Laricchia*

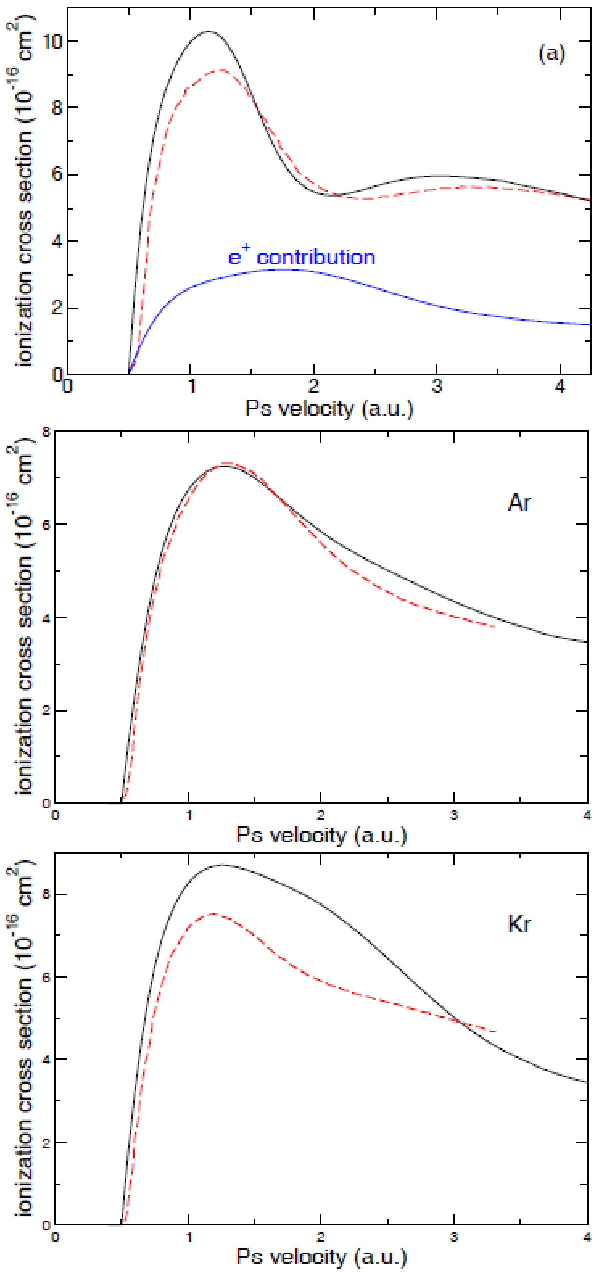


Ionization-Binary Encounter Approximation

- Assume electron and positron scatter independently and neglect interference.

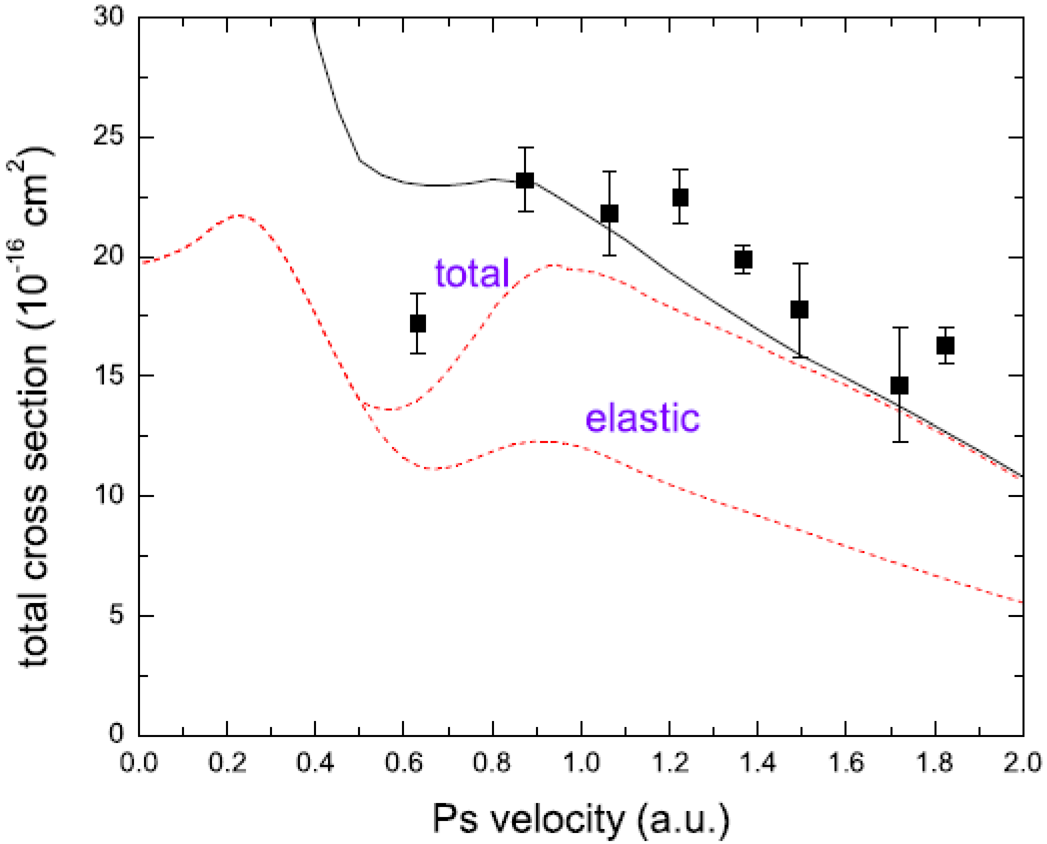


$$|\vec{u}| = |\hat{u}'|$$



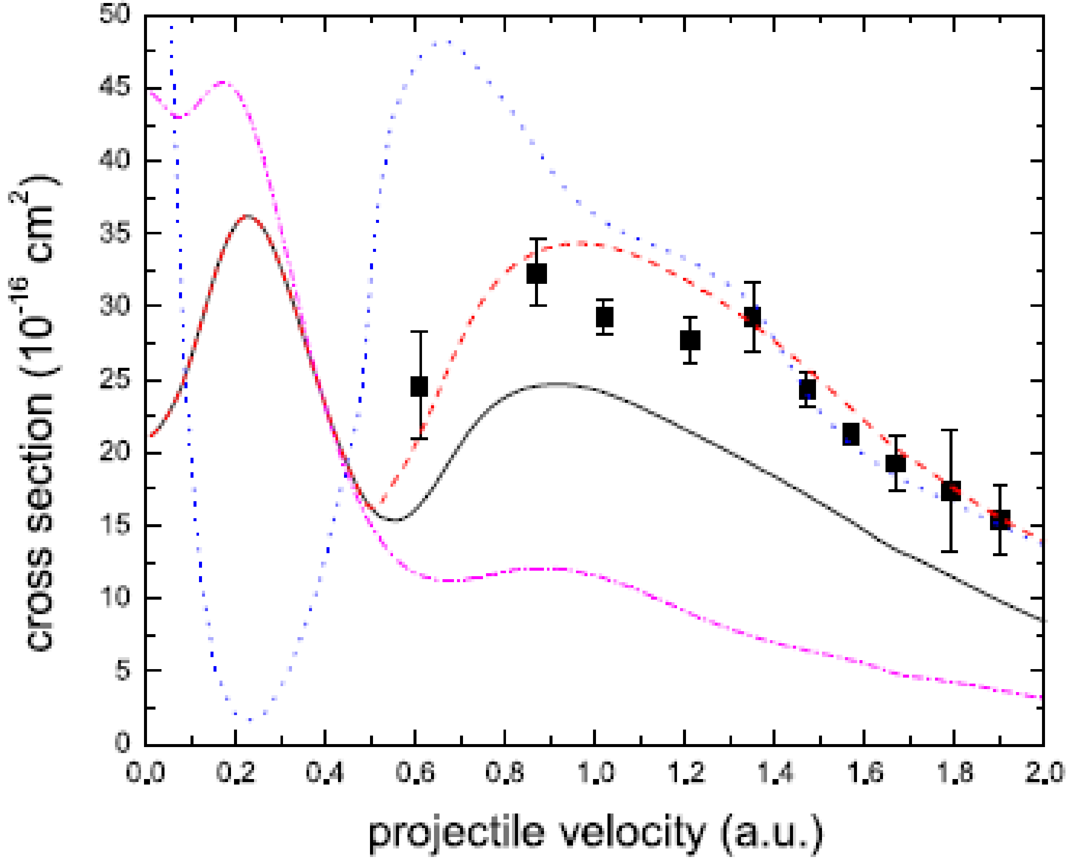
ionization cross section (10^{-16} cm^2)
(a)
e^+ contribution
Ps velocity (a.u.)
Ar
Kr

Ps - Kr

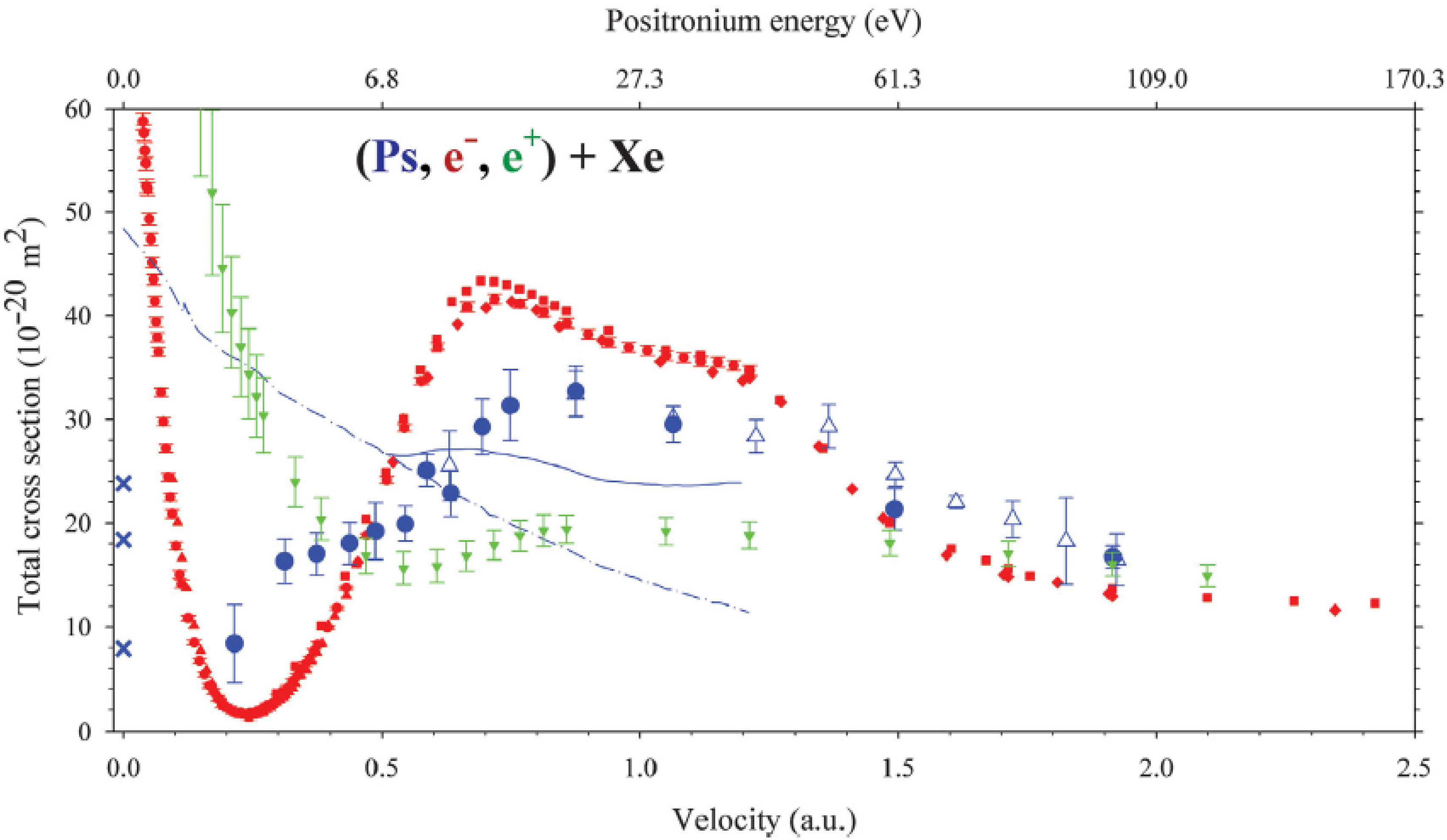


total cross section (10^{-16} cm^2)
Ps velocity (a.u.)
total
elastic
0
5
10
15
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

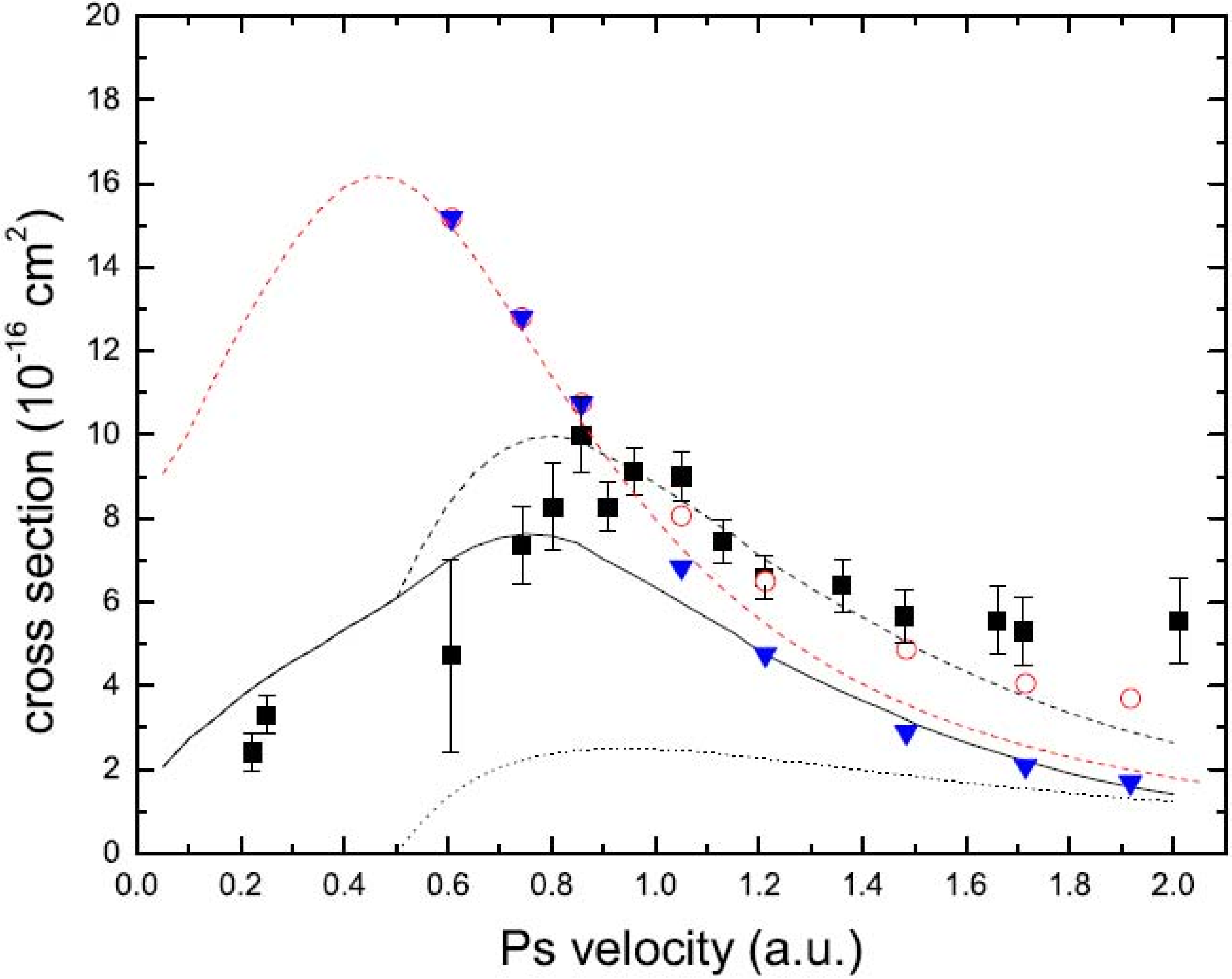
Ps-Xe cross sections



Brawley et al., PRL **115**, 223201 (2015)

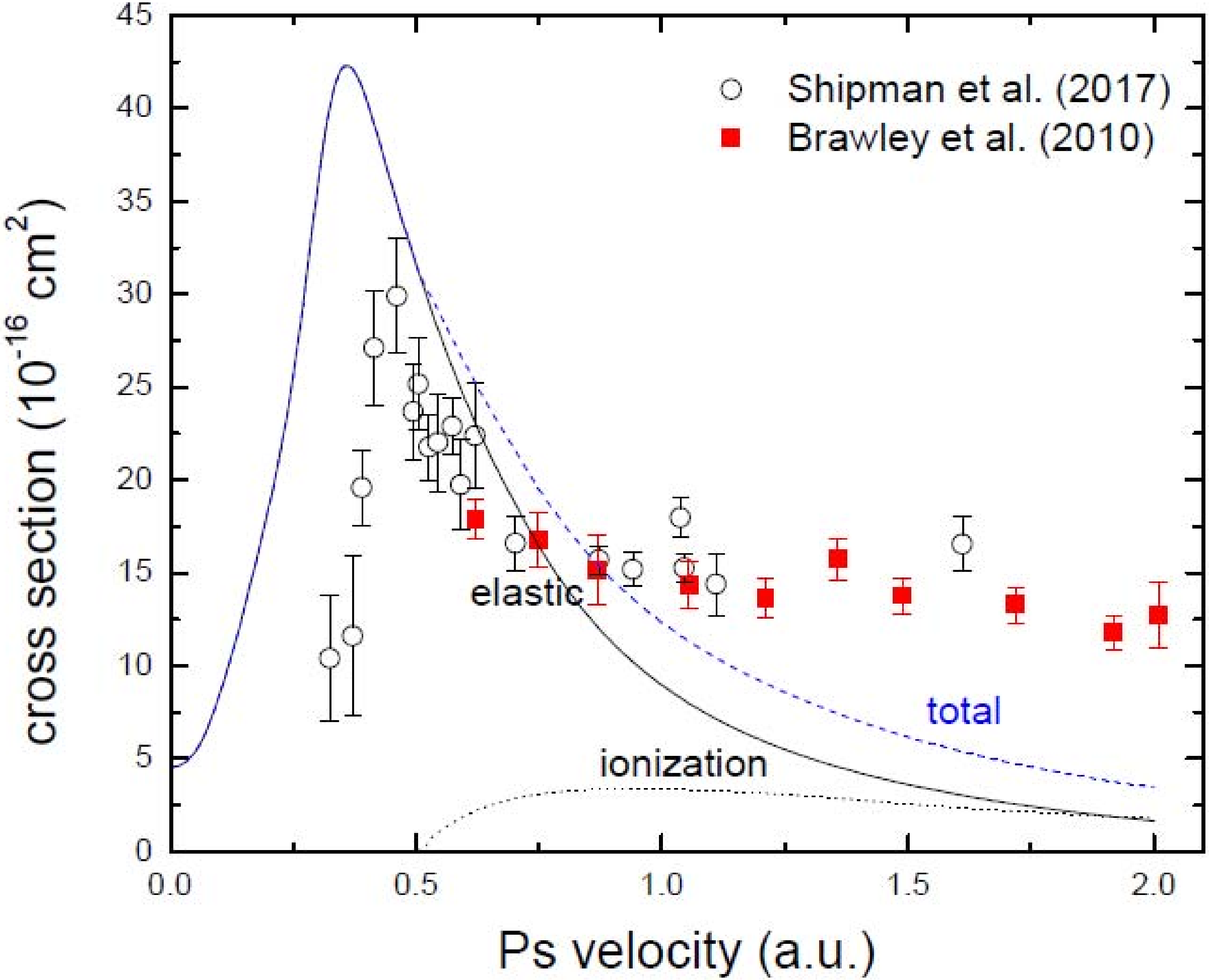


$Ps\text{-}H_2$



cross section (10^{-16} cm^2)
Ps velocity (a.u.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
2
4
6
8
10
12
14
16
18
20

$Ps\text{-}N_2$



Shipman et al. (2017)
Brawley et al. (2010)
cross section (10^{-16} cm^2)
Ps velocity (a.u.)
elastic
total
ionization
0
5
10
15
20
25
30
35
40
45
0.0
0.5
1.0
1.5
2.0

Conclusions

- Energy range above the Ps ionization threshold: impulse approximation (quasifree electron model) works and explains similarities between e^- -A and Ps-A scattering
- Low energies: no similarity, no Ramsauer-Townsend minimum (???)
- Approach works for Ps-H_2 collisions
- New calculations: Resonance Ps-N_2 scattering is confirmed theoretically