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# Production and transport of long lifetime excited states in pre-equilibrium ion solid collisions

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► **To cite this version:**

Emily Lamour, Benoit Gervais, Jean Pierre Rozet, Dominique Vernhet. Production and transport of long lifetime excited states in pre-equilibrium ion solid collisions. *Physical Review A: Atomic, molecular, and optical physics* [1990-2015], 2006, 73, pp.042715. 10.1103/PhysRevA.73.042715. hal-00021933

**HAL Id: hal-00021933**

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Submitted on 1 Apr 2006

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## TABLES

**TABLE I. Respective contribution of direct and cascade population to the total population for different  $n\ell$  states and two target thickness. The direct contribution corresponds to the population at the exit of the foil. The cascade contribution corresponds to the population coming from upper levels by radiative decay behind the foil.**

$n\ell$ state	$3.5 \mu\text{g}/\text{cm}^2$ target		$98 \mu\text{g}/\text{cm}^2$ target	
	% direct	% cascade	% direct	% cascade
$2p$	60	40	51	49
$2s$	74	26	84	16
$3p$	89	11	86	14
$4p$	$\approx 100$		99	1

**TABLE II.** Energy of each observed line with the associated efficiency and global transmission for one of the Si(Li) detector. The efficiency of the other Si(Li) detector corresponds to 70% of the values given here.  $E_{\text{Proj}}$  and  $E_{\text{Lab}}$  correspond respectively to energies in the projectile and laboratory frames. Energies of the Lyman line are taken from Ref[23]. "\*" marks energy of the centre of the theoretical distribution of the 2E1 decay mode Ref [22].

Observed Lines	Energy (eV)		Si(Li) detector	
	$E_{\text{Proj}}$	$E_{\text{Lab}}$ ( $\theta_L=90^\circ$ )	Efficiency	$T_{\text{glob}}^{n\ell}$
Ly $\alpha$	3321	3273	0.83 ( $\pm 7\%$ )	$8.62 \cdot 10^{-6}$ ( $\pm 9.5\%$ )
Ly $\beta$	3936	3879	0.88 ( $\pm 7\%$ )	$9.20 \cdot 10^{-6}$ ( $\pm 9.5\%$ )
Ly $\gamma$	4150	4091	0.90 ( $\pm 7\%$ )	$9.36 \cdot 10^{-6}$ ( $\pm 9.5\%$ )
$\sum_5^\infty(\text{np} \rightarrow 1\text{s})$	4362	4299	0.91 ( $\pm 7\%$ )	$9.50 \cdot 10^{-6}$ ( $\pm 9.5\%$ )
2E1	1660*	1636*	0.39 ( $\pm 8\%$ )	$4.01 \cdot 10^{-6}$ ( $\pm 10.5\%$ )

## FIGURES CAPTIONS

**FIG. 1.** Schematic representation of the experimental set-up. Effects leading to X-ray auto-absorption are displayed in a zoom (see text).

**FIG. 2.** Energy distribution of the 2E1 decay mode for an  $\text{Ar}^{17+}$  ion: the theoretical distribution (dotted line), the distribution corrected by the Si(Li) detector efficiency alone (dashed line) and the "experimental" distribution (solid line) i.e. the distribution corrected by the efficiency convoluted with the detector resolution. Si(Li) detector efficiency is also plotted (dash-dotted line) for sake of clarity.

**FIG. 3.** Spectra recorded by a Si(Li) detector after backgrounds subtraction at various ion time of flight (delay time) behind the  $3.5 \mu\text{g}/\text{cm}^2$  carbon target: (a)  $t = 0$ ; (b)  $t = 108 \text{ ps}$ ; (c)  $t = 600 \text{ ps}$ .

**FIG. 4.** Normalized evolution of the Lyman lines emission (see text) as a function of the distance behind the target: experimental data (symbols:  $\bullet$  target of  $3.5 \mu\text{g}/\text{cm}^2$ ,  $\blacksquare$   $8.6 \mu\text{g}/\text{cm}^2$ ,  $\square$   $98 \mu\text{g}/\text{cm}^2$  and  $\circ$   $201 \mu\text{g}/\text{cm}^2$ ), binary ion-atom conditions i.e. including cascade contribution without any transport effects accounted for (dotted curves), classical transport "wake off" (solid curves: target of  $3.5 \mu\text{g}/\text{cm}^2$ , dashed dotted curves:  $201 \mu\text{g}/\text{cm}^2$ ). The real distance  $d$  behind the target has been arbitrary shifted by  $0.55 \text{ mm}$  to clarify the graph.

**FIG. 5. Slope evolution of the delayed Lyman line intensities versus foil thickness; circles with error bars: experiment (symbols with error bars); classical transport (triangles); fit with a decay function given in the text (solid lines). The  $a_{3p}$  has been divided by 2 to clarify the graph.**

**FIG. 6. Evolution with the time of flight of the  $\text{Ar}^{17+}$  Lyman line intensities (i.e. number of emitted photon per ion) for the  $3.5 \mu\text{g}/\text{cm}^2$  carbon target: experimental results (symbols), classical transport model "wake off" (solid black lines) and "wake on" (solid grey lines), rate equation model (dashed lines). In the simulations, the CDW calculations have been used to account for the primary capture processes. The distance behind the target has been arbitrary shifted by 0.55 mm for sake of clarity.**

**FIG. 7. Same as Fig. 6 for the  $8.6 \mu\text{g}/\text{cm}^2$  target thickness.**

**FIG. 8. Same as Fig. 6 for the  $12.6 \mu\text{g}/\text{cm}^2$  target thickness.**

**FIG. 9. Same as Fig. 6 for the  $42 \mu\text{g}/\text{cm}^2$  target thickness.**

**FIG. 10. Same as Fig. 6 for the  $98 \mu\text{g}/\text{cm}^2$  target thickness.**

**FIG. 11. Absolute  $2s_{1/2}$  populations of  $\text{Ar}^{17+}$  at  $v_p = 23$  a.u. impact velocity as a function of carbon target thickness: experimental data (symbols); binary ion-atom**

conditions i.e. including cascade contribution without any transport effects accounted for (dotted black curve); classical transport model "wake off" (solid black line) and "wake on" (solid grey line); rate equations model (dashed black line); Master equations model with complete CDW calculations to describe the initial capture process (dashed grey line) and Master equations model with CDW calculations and with the phases of coherences of the initial states taken equal to zero (dash-dot-dotted grey line).

FIG. 12. Geometrical efficiency function of Si(Li) detectors for  $z \geq 0.87$ ;  $z$  is the position of the target support and  $Z$  the position where  $n\ell \rightarrow 1s$  transitions are recorded.

FIG. 13. Geometrical efficiency function of Si(Li) detectors for  $0.55 \leq z \leq 0.87$ ;  $z$  is the position of the target support and  $Z$  the position where  $n\ell \rightarrow 1s$  transitions are recorded. The hatched area is hidden by the support.

FIG. 14. Geometrical efficiency function of Si(Li) detectors for  $0.25 + e \leq z \leq 0.55$ ;  $z$  is the position of the target support and  $Z$  the position where  $n\ell \rightarrow 1s$  transitions are recorded. The parameters  $e$  and  $\delta(z)$  are defined in the text. The hatched area is hidden by the support.

FIG. 15. Geometrical efficiency function of Si(Li) detectors for  $-0.07 + e' \leq z \leq 0.25 + e$ ;  $z$  is the position of the target support and  $Z$  the position where  $n\ell \rightarrow 1s$  transitions

are recorded. The parameters  $e$ ,  $e'$  and  $\delta(z)$  are defined in the text. The hatched area is hidden by the support.

**FIG. 16. Geometrical efficiency function of Si(Li) detectors for  $0.25 \leq z \leq 0.87$ ;  $z$  is the position of the target support and  $Z$  the position where  $n\ell \rightarrow 1s$  transitions are recorded. The hatched area is hidden by the support.**

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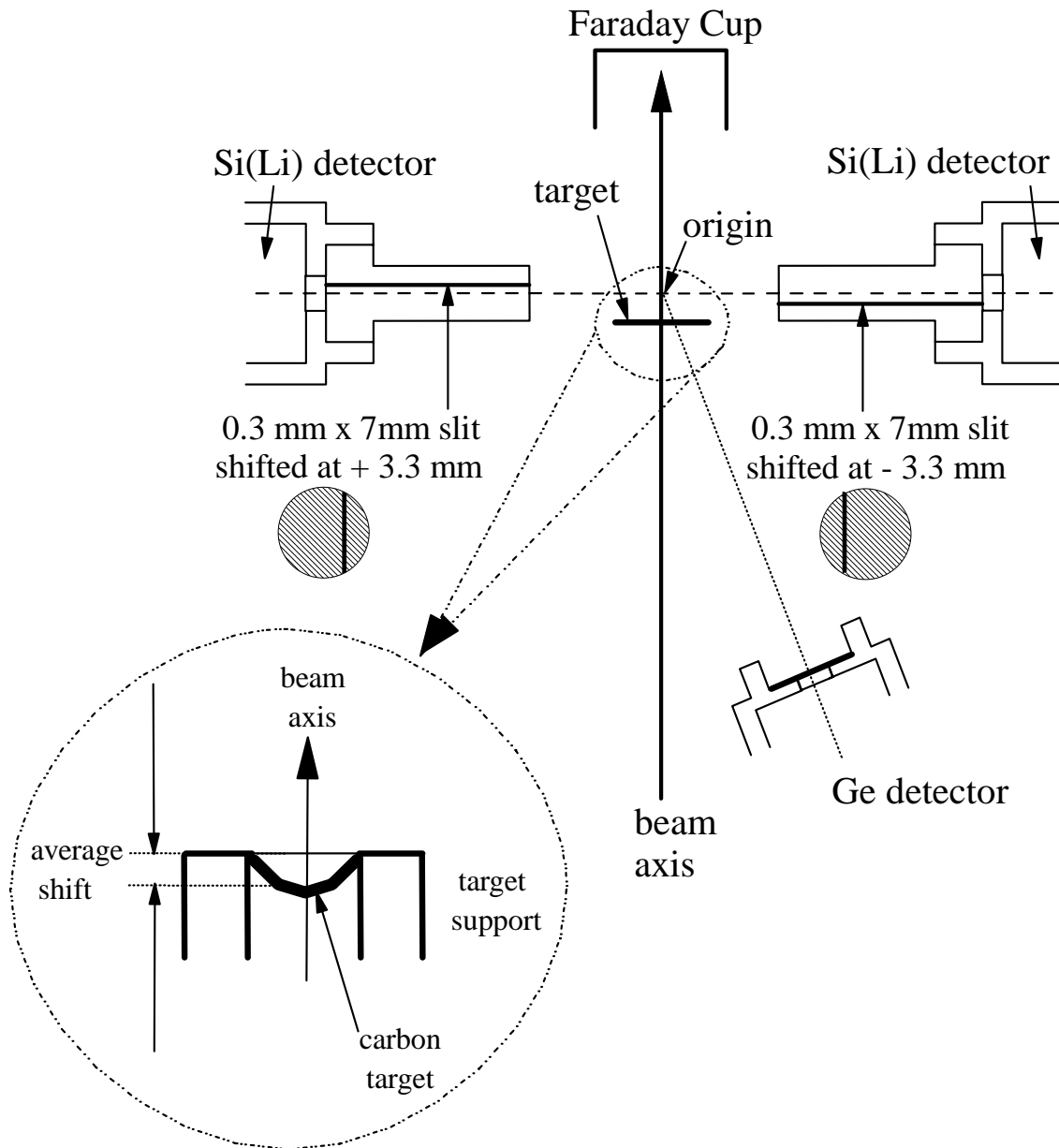




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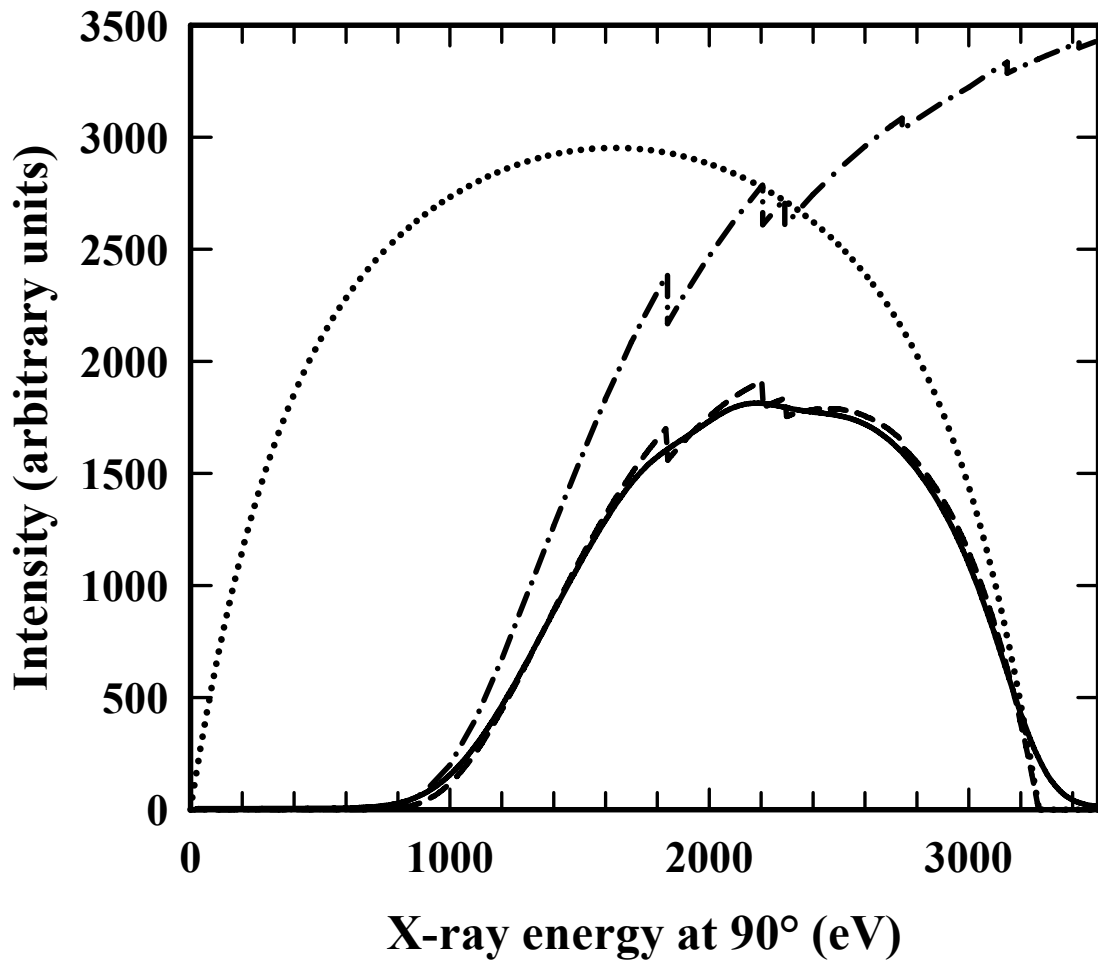


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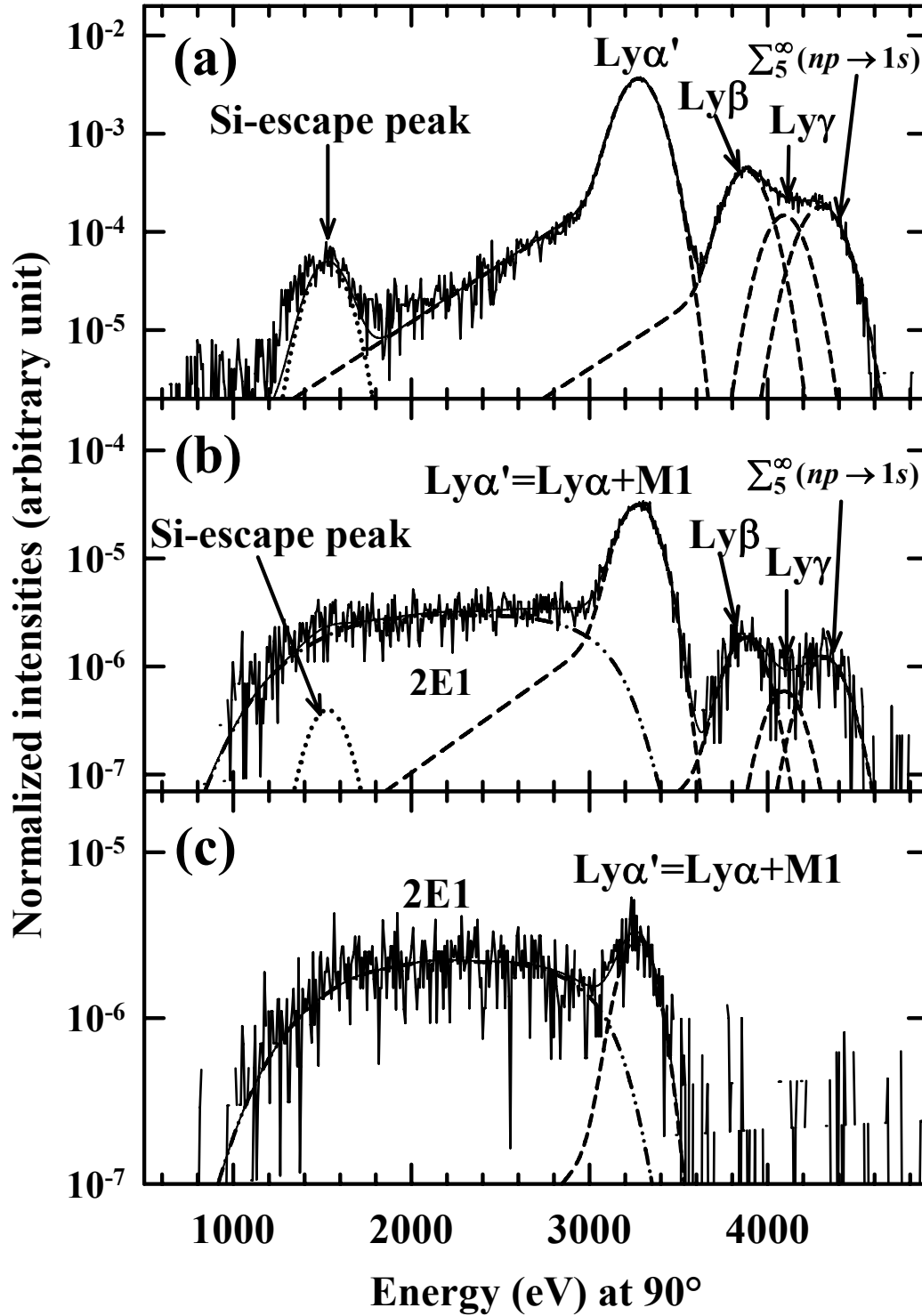


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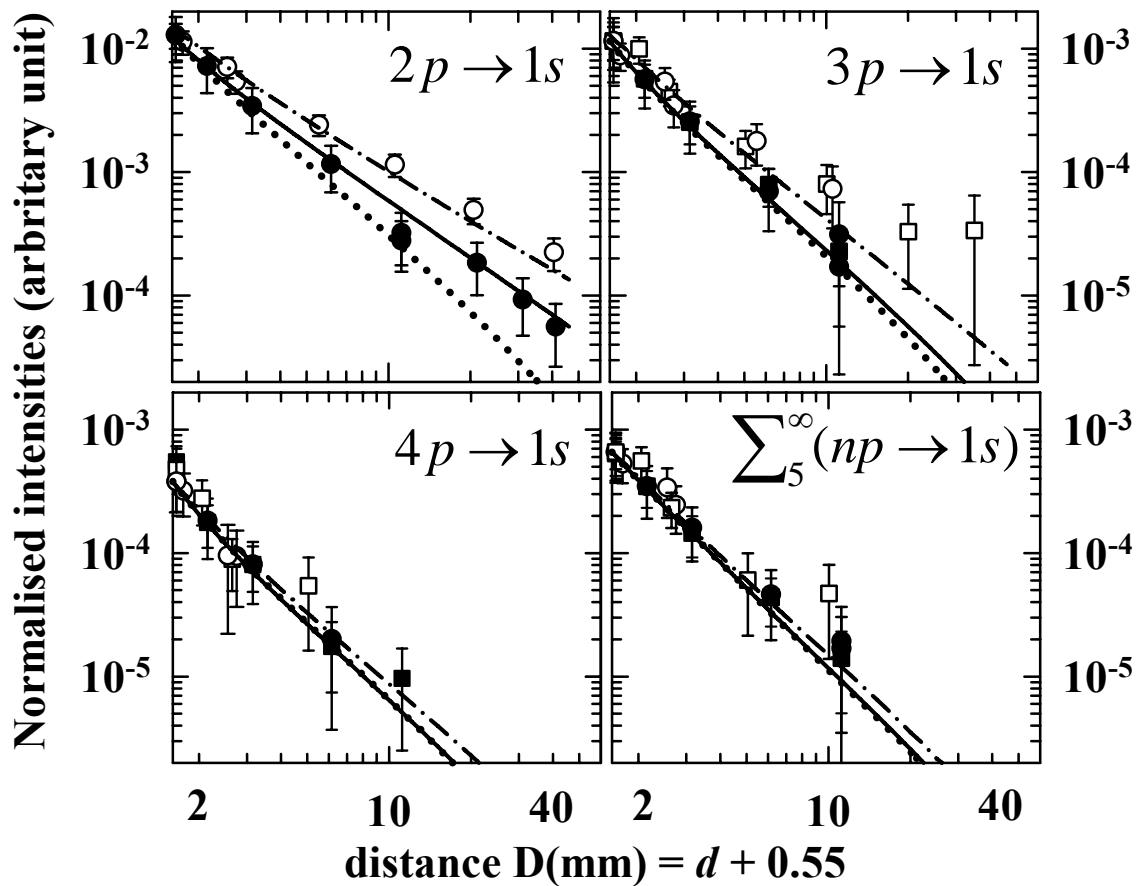


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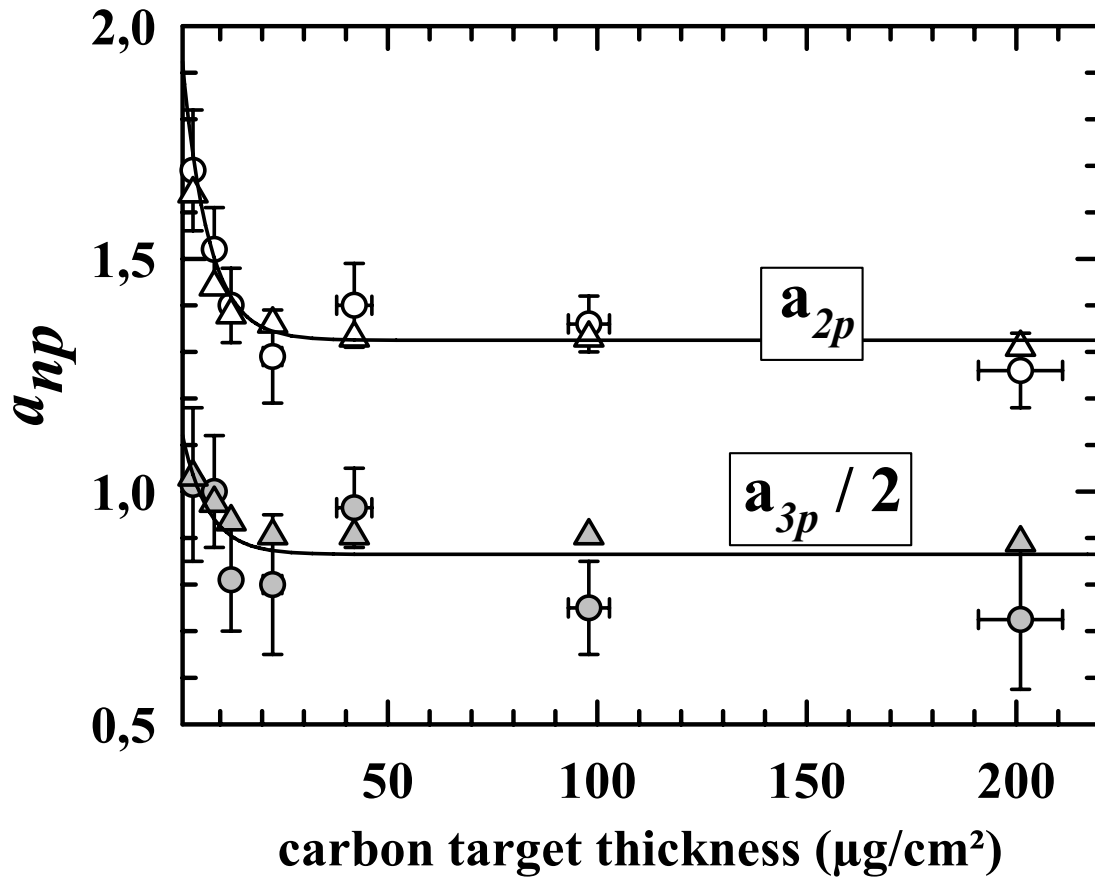


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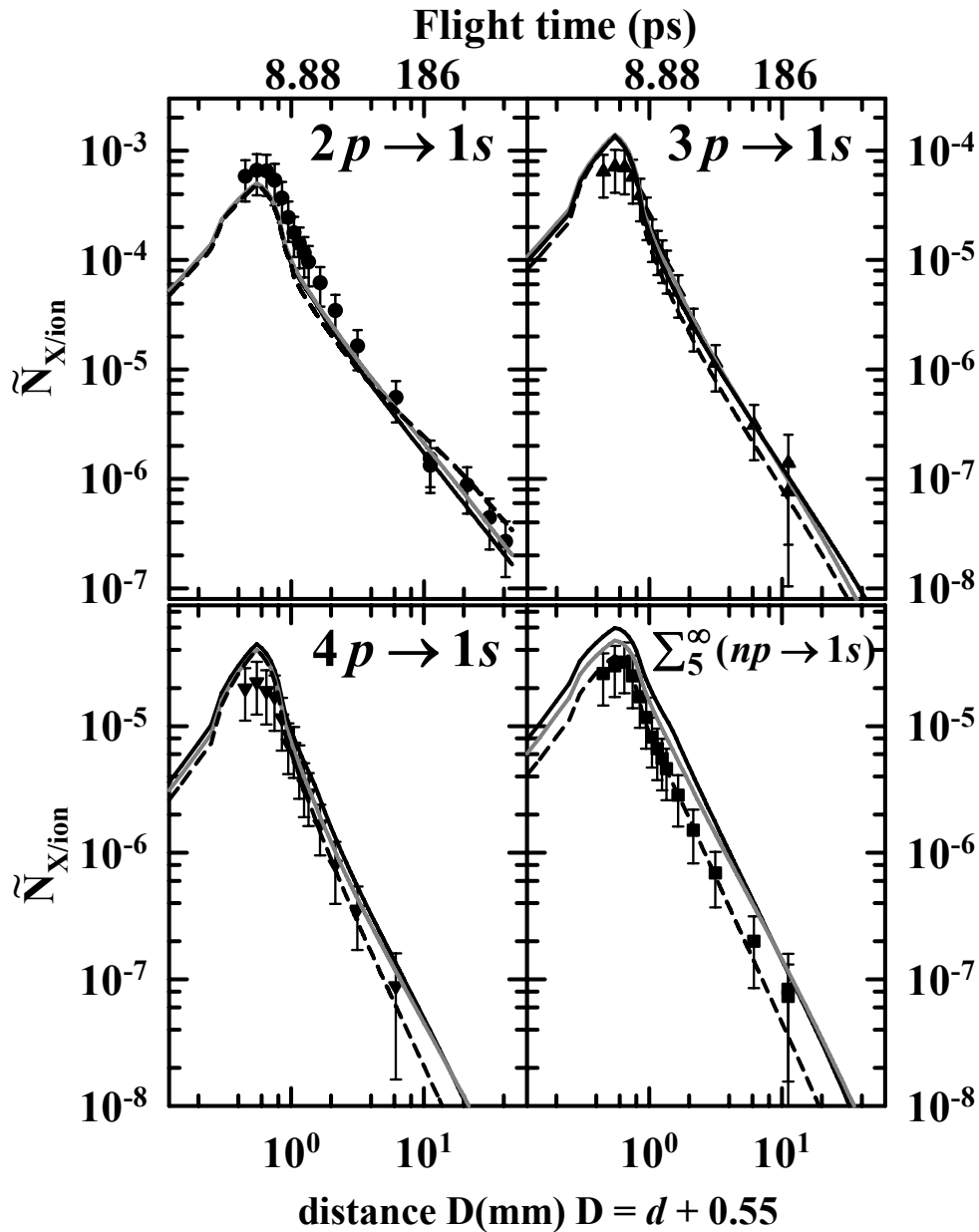


FIG. 7. Same as Fig. 6 for the  $8.6 \mu\text{g}/\text{cm}^2$  target thickness.

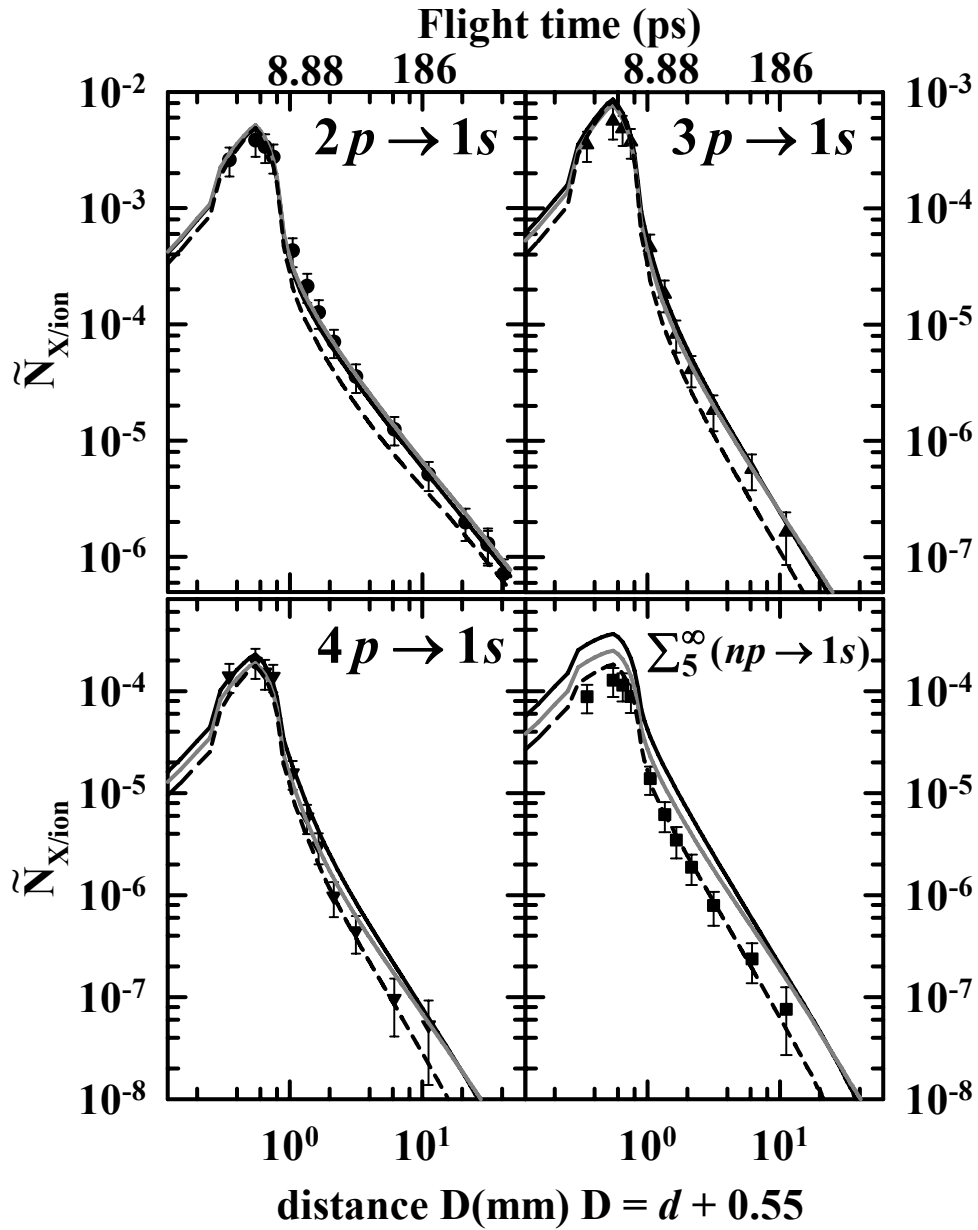


FIG. 8. Same as Fig. 6 for the  $12.6 \mu\text{g}/\text{cm}^2$  target thickness.

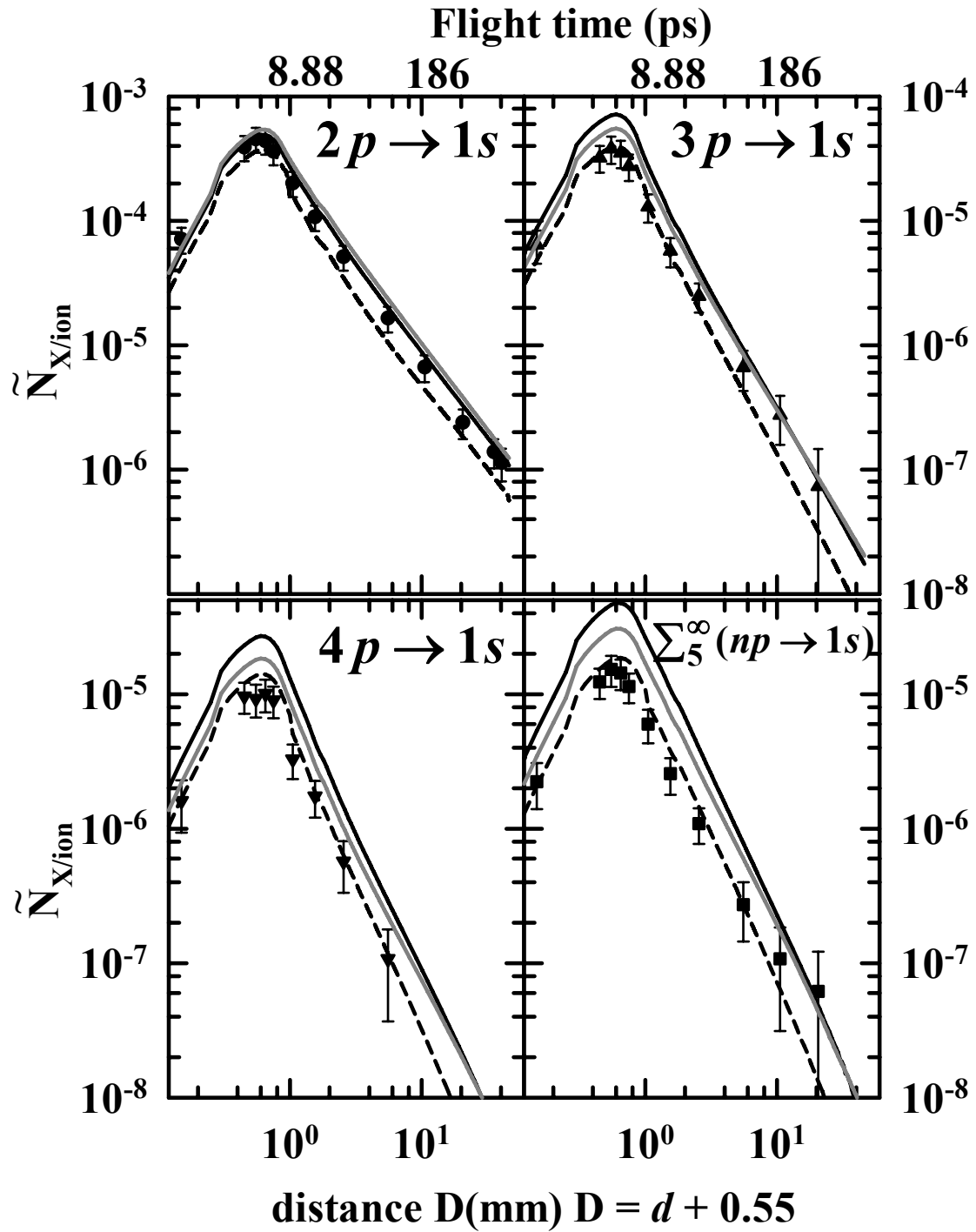


FIG. 9. Same as Fig. 6 for the 42  $\mu\text{g}/\text{cm}^2$  target thickness.

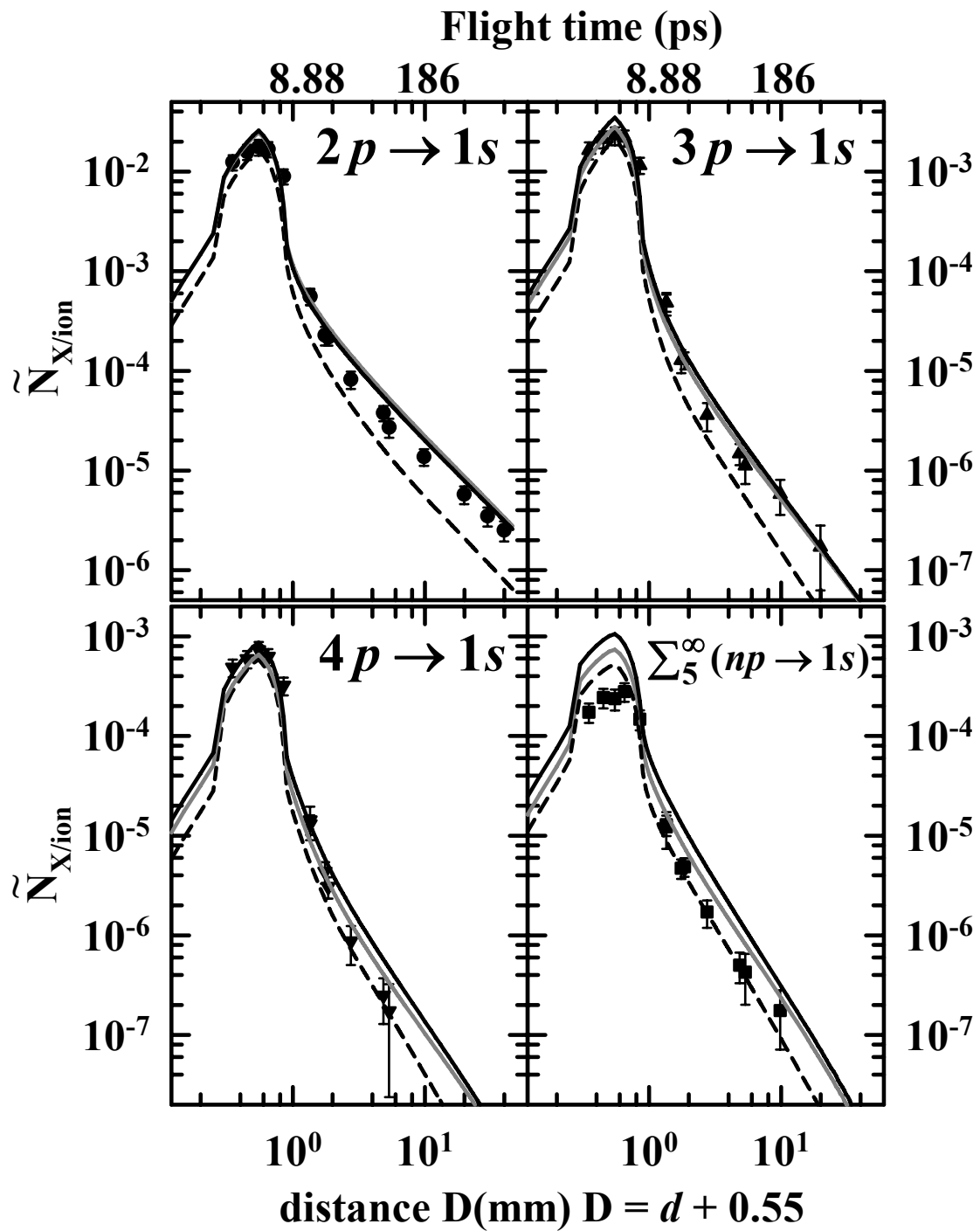




FIG. 10. Same as Fig. 6 for the 98  $\mu\text{g}/\text{cm}^2$  target thickness.

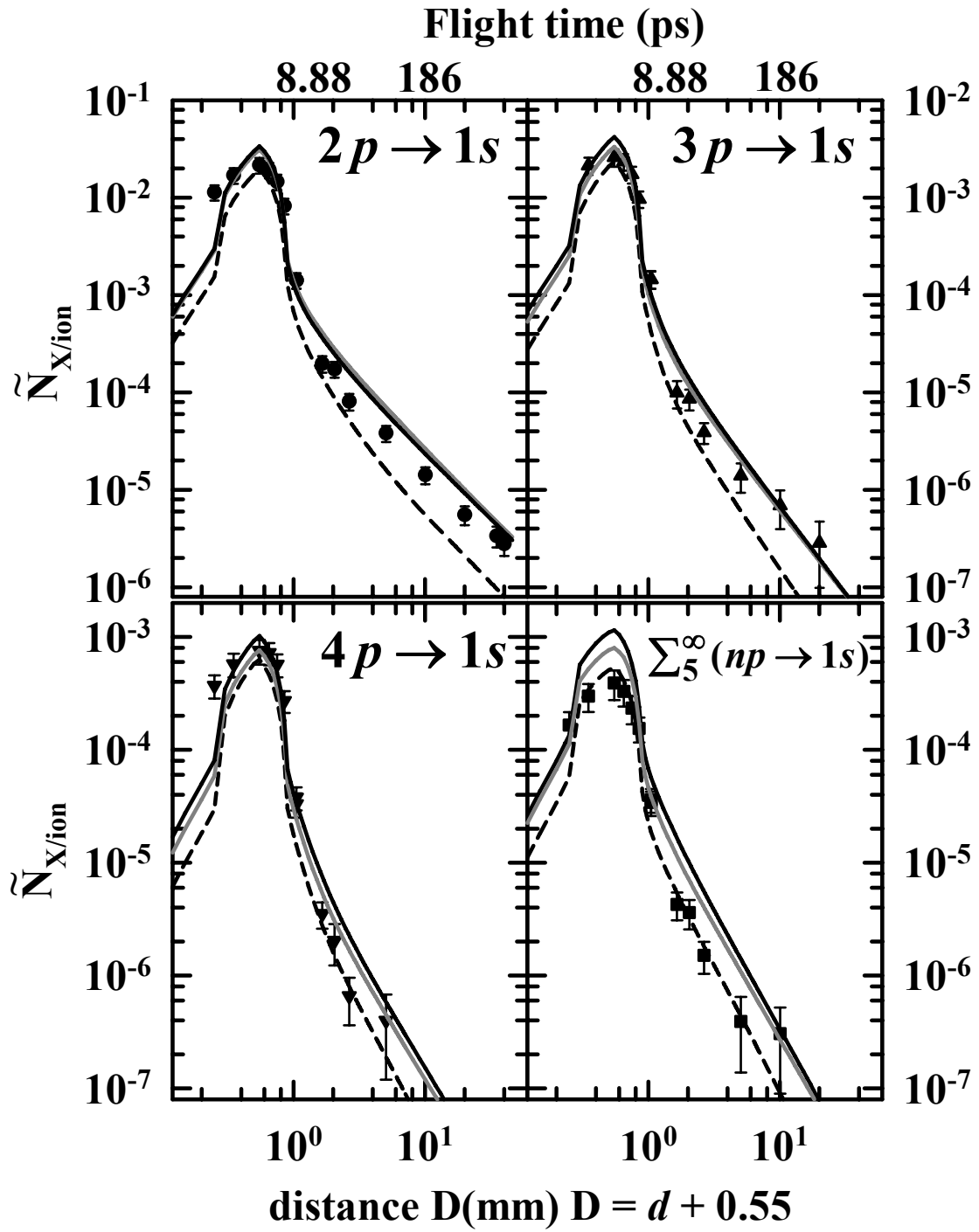
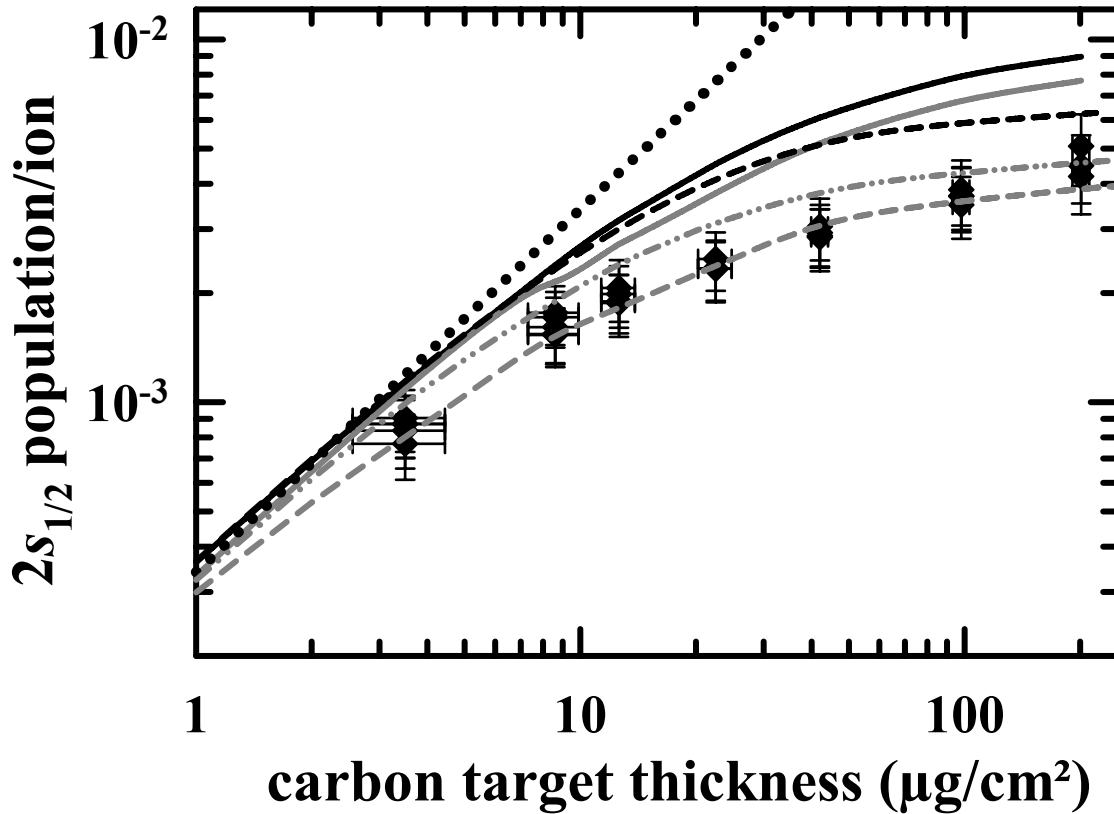
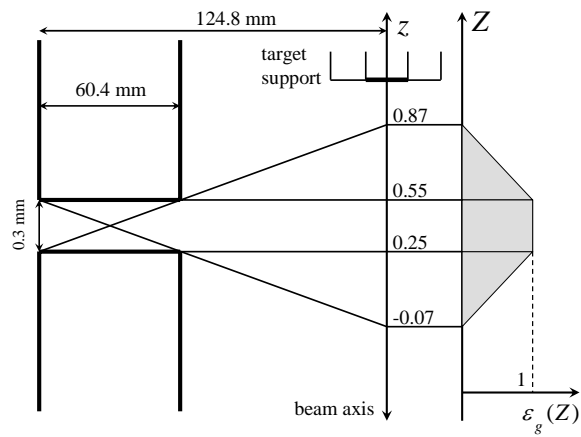


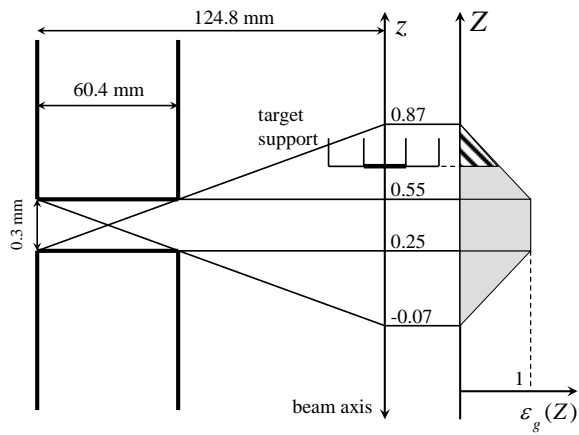
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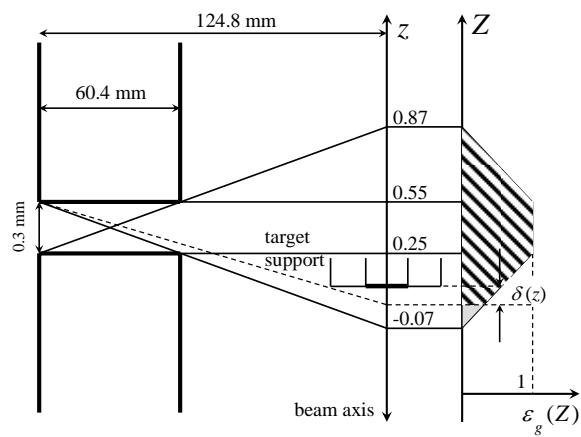


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