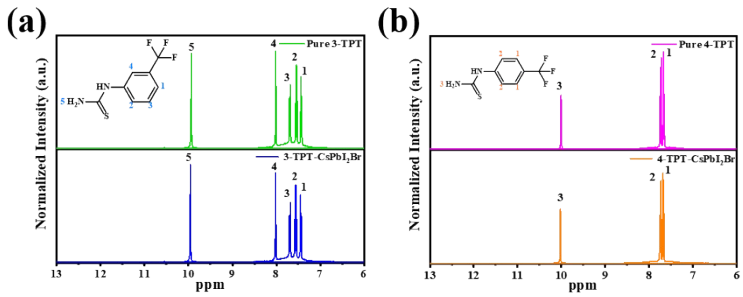

Figure S1: ^{1}H NMR spectra in DMSO-d6 of (a) pure 3-TPT and 3-TPT mixed with $CsPbI_2Br$, and (b) pure 4-TPT and 4-TPT mixed with $CsPbI_2Br$.

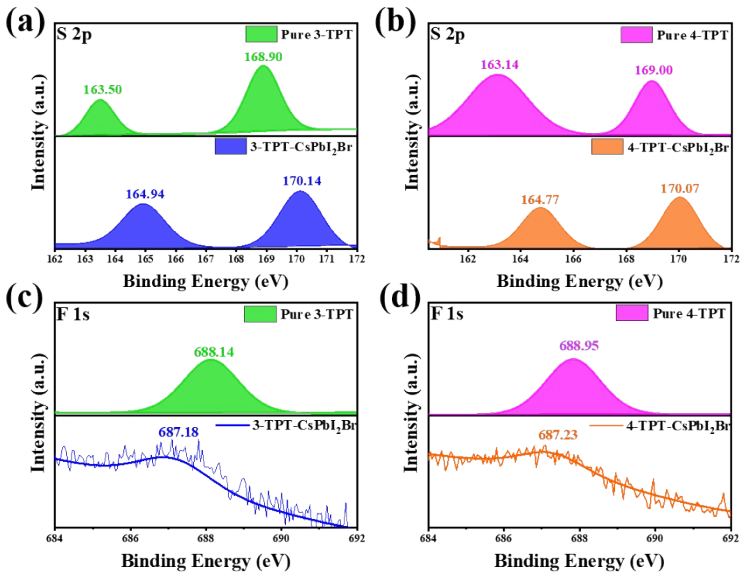

Figure S2: XPS S 2p spectra of (a) pure 3-TPT and 3-TPT-$CsPbI_2Br$, and (b) pure 4-TPT and $CsPbI_2Br$; XPS F 1s spectra of (c) pure 3-TPT and 3-TPT-$CsPbI_2Br$, and (d) pure 4-TPT and 4-TPT-$CsPbI_2Br$.

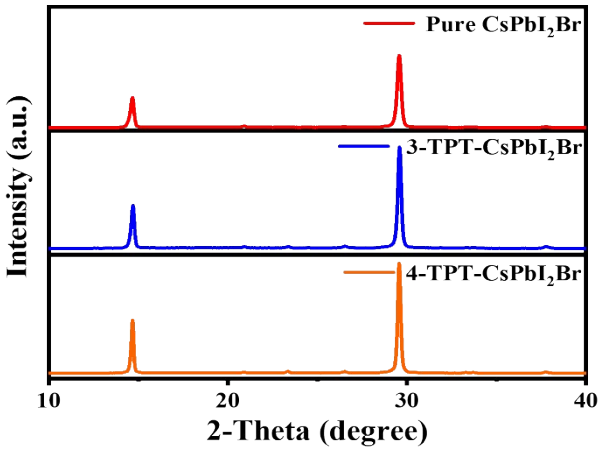

Figure S3: XRD patterns for pure $CsPbI_2Br$, 3-TPT-$CsPbI_2Br$, and 4-TPT-$CsPbI_2Br$.

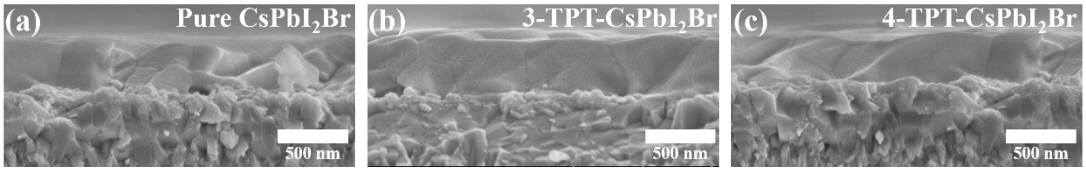

Figure S4: Cross-sectional SEM images of (a) $CsPbI_2Br$, (b) 3-TPT-$CsPbI_2Br$, and (c) 4-TPT-$CsPbI_2Br$.

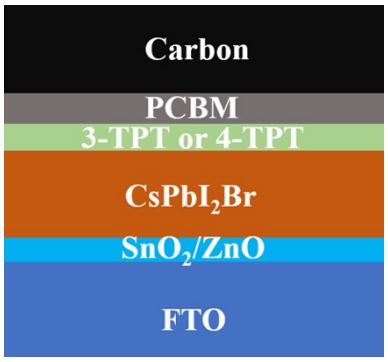

Figure S5: Schematic representation of the structure of carbon-based $CsPbI_2Br$ devices (FTO/SnO_2/ZnO/$CsPbI_2Br$/ 3-TPT or 4-TPT/PCBM/ carbon) for SCLC.

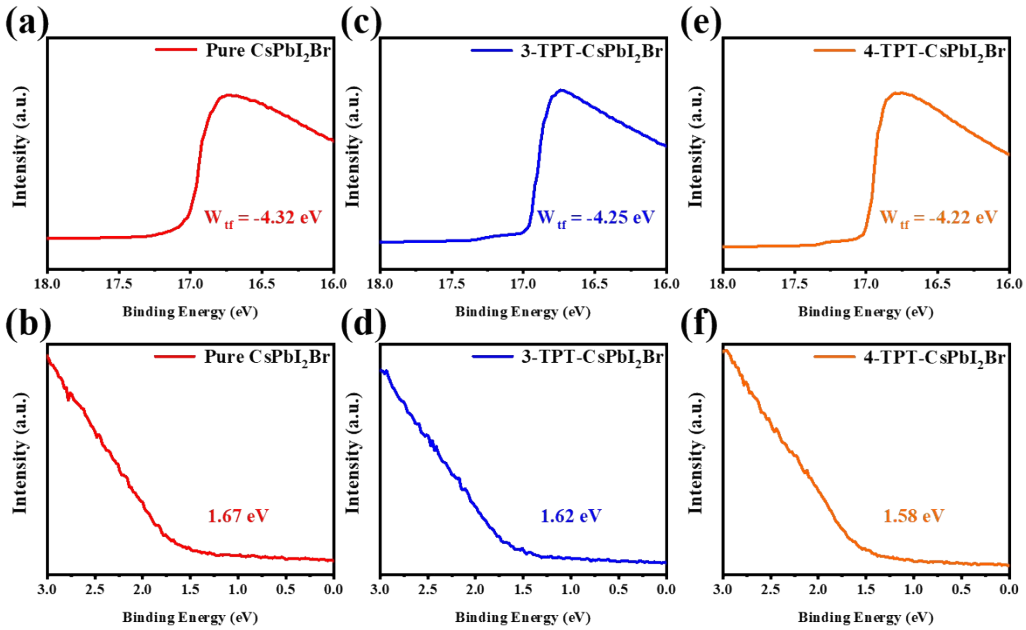

Figure S6: Ultraviolet photoelectron spectroscopic (UPS) analysis of (a) pure $CsPbI_2Br$, (b) 3-TPT-$CsPbI_2Br$, and (c) 4-TPT-$CsPbI_2Br$.

Table S1. The optical properties of $CsPbI_2Br$, 3-TPT-$CsPbI_2Br$ and 4-TPT-$CsPbI_2Br$ by UPS characterization.

Sample	$E_{cut-off}$ (eV)	E_V-E_F (eV)	E_F (eV)	E_V (eV)	E_C (eV)	E_g (eV)
Pure $CsPbI_2Br$	16.90	1.67	4.32	5.99	4.07	1.92
3-TPT- $CsPbI_2Br$	16.97	1.62	4.25	5.87	3.95	1.92
4-TPT- $CsPbI_2Br$	17.02	1.58	4.20	5.78	3.86	1.92

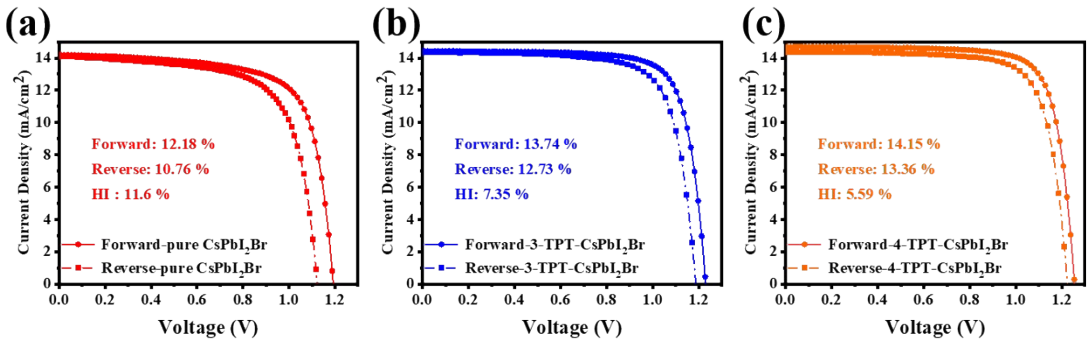

Figure S7: The J-V curves for pure $CsPbI_2Br$, 3-TPT-$CsPbI_2Br$, and 4-TPT-$CsPbI_2Br$ devices in both forward and reverse scans.

Table S2. Performance parameters of pure $CsPbI_2Br$, 3-TPT-$CsPbI_2Br$, and 4-TPT-$CsPbI_2Br$ devices in both forward and reverse scans, derived from J-V curves.

Sample	V_{oc} (V)	J_{sc} (mA/cm^2)	Fill factor	PCE (%)	HI (%)
Forward-Pure $CsPbI_2Br$	1.19	14.19	72.14	12.18	11.66
Reverse-Pure $CsPbI_2Br$	1.12	14.10	68.12	10.76	
Forward-3-TPT-$CsPbI_2Br$	1.23	14.42	77.47	13.74	7.35
Reverse-3-TPT-$CsPbI_2Br$	1.19	14.37	74.48	12.73	
Forward-4-TPT-$CsPbI_2Br$	1.25	14.47	78.22	14.15	5.59
Reverse-4-TPT-$CsPbI_2Br$	1.22	14.39	76.25	13.39	

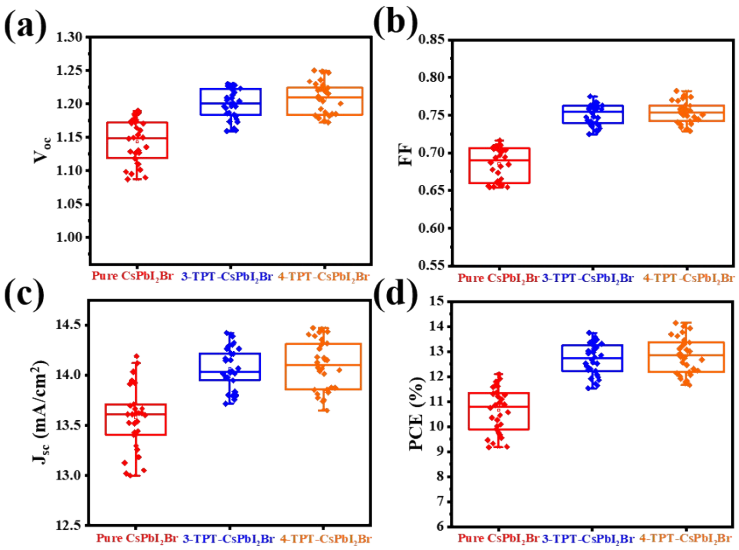

Figure S8: Boxplot distributions for 30 solar cell devices based on pure $CsPbI_2Br$, 3-TPT-$CsPbI_2Br$, and 4-TPT- $CsPbI_2Br$, illustrating (a) V_{oc}, (b) FF, (c) J_{sc}, and (d) PCE.