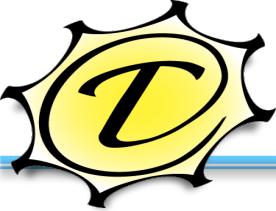




Progress Update on Thin-Film Metrology Systems

CdTe Workshop

Greg Horner, Kyle Lu



Platforms

PixEL = EL, PL: Steady-state imaging

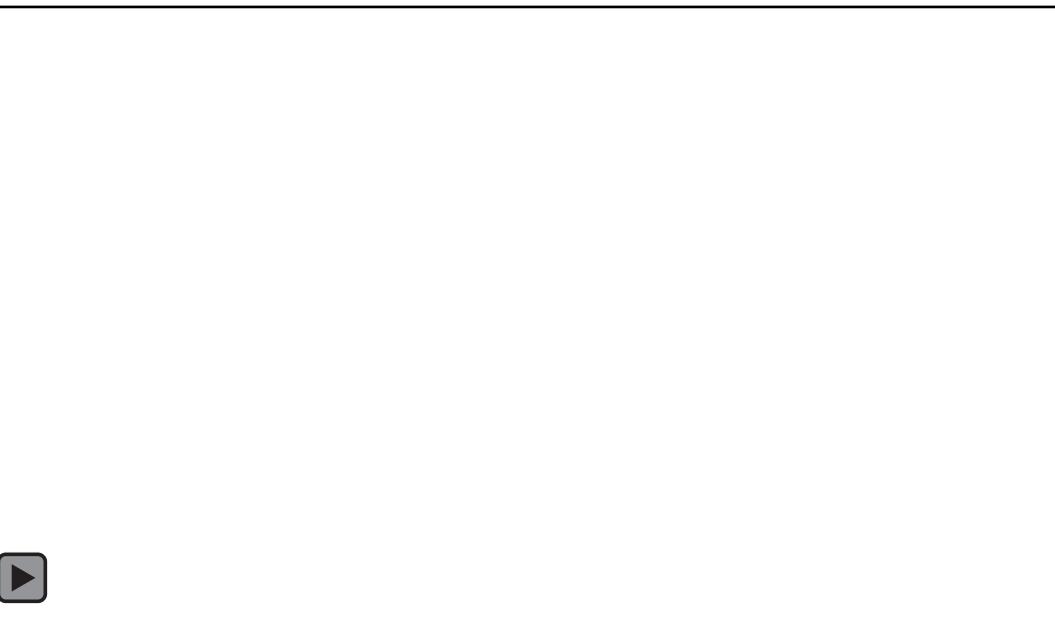
- TRPL Imaging, $\tau >= 5\mu s$

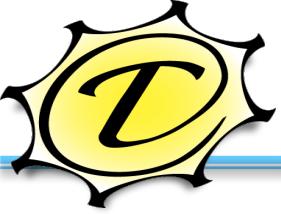
PulseQE = High speed Quantum Efficiency scanner

IRIS = Hotspot imaging, LWIR Camera

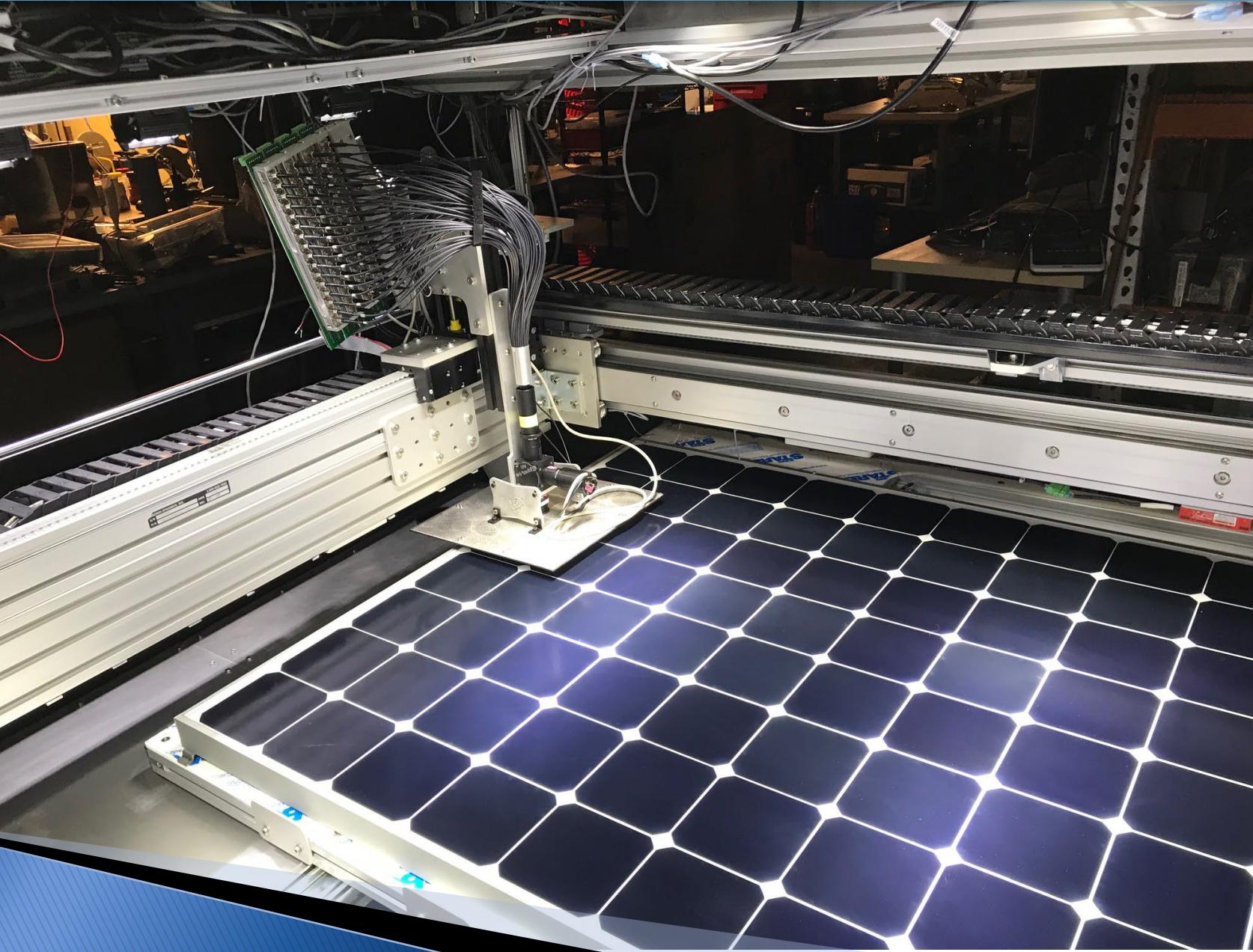


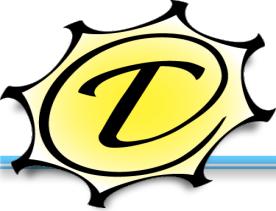
→ Semi-custom systems





QE Scanner- Modules

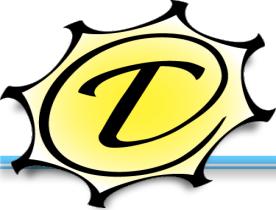




CdTe & Perovskite Metrology in 2022



Work supported by DOE SBIR DE-SC0020718



TRPL Project



Kyle Lu, Tyler Brau, Abasi Abudulimu, Jared Friedl,
Mike Heben, Randy Ellingson, Adam Phillips, Greg
Horner

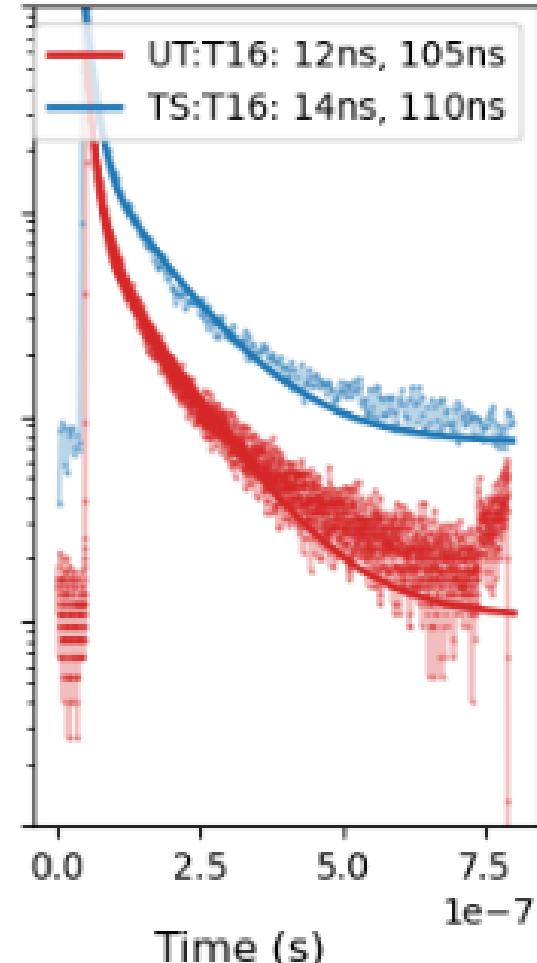
Goal: Low cost TRPL system using TCSPC

Highlight: Ease of use, automation, MES hooks

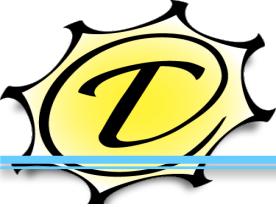
Target: CdTe and Perovskites with $\tau > 1\text{ns}$

First Step

Correlate to established TRPL system at UT



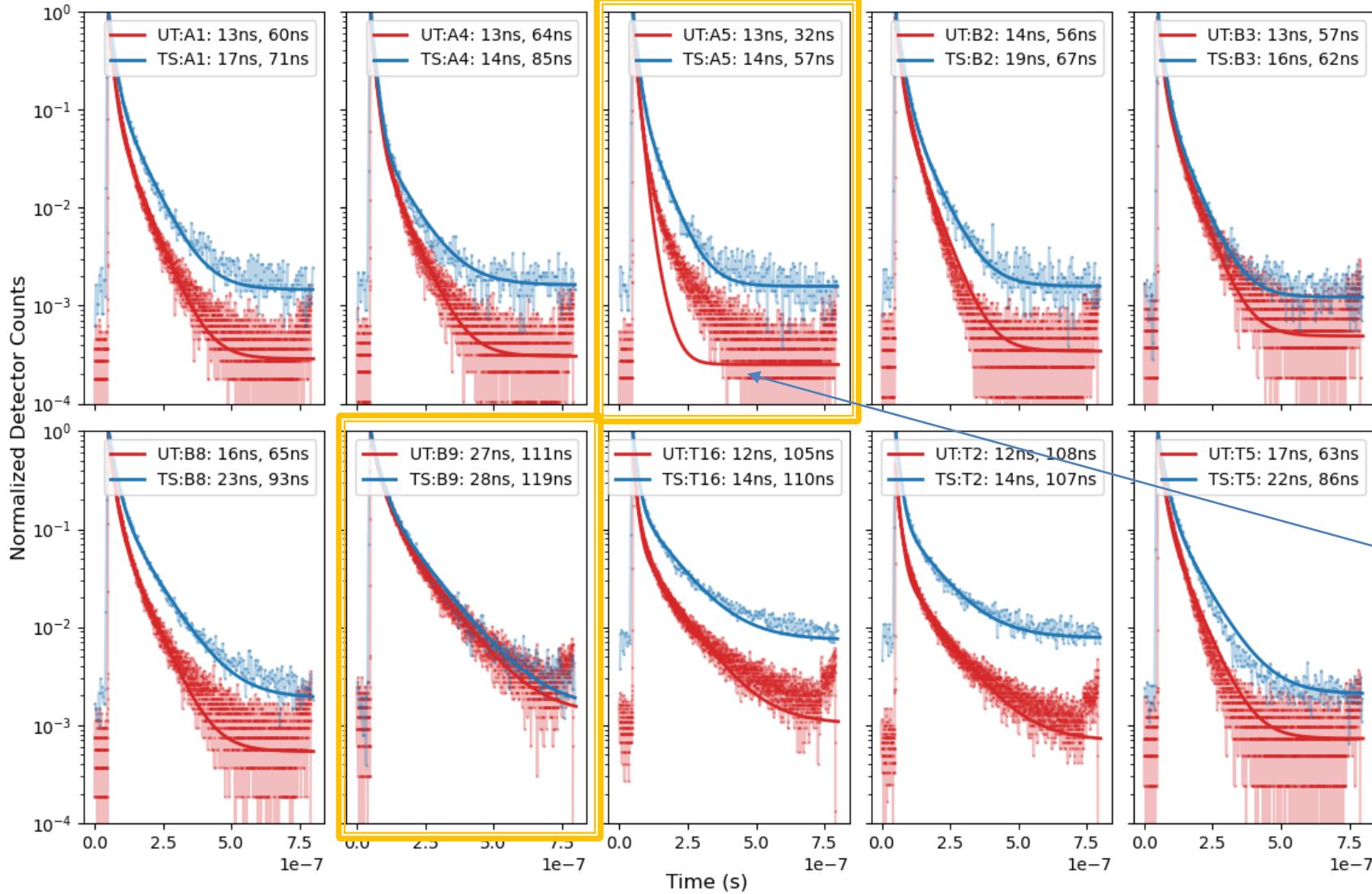
Work supported by DOE SBIR DE-SC0020718



TRPL: Perovskite Correlation Data

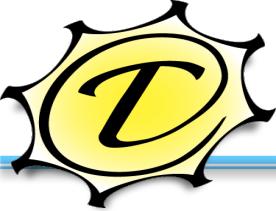


Time-Resolved Photoluminescence

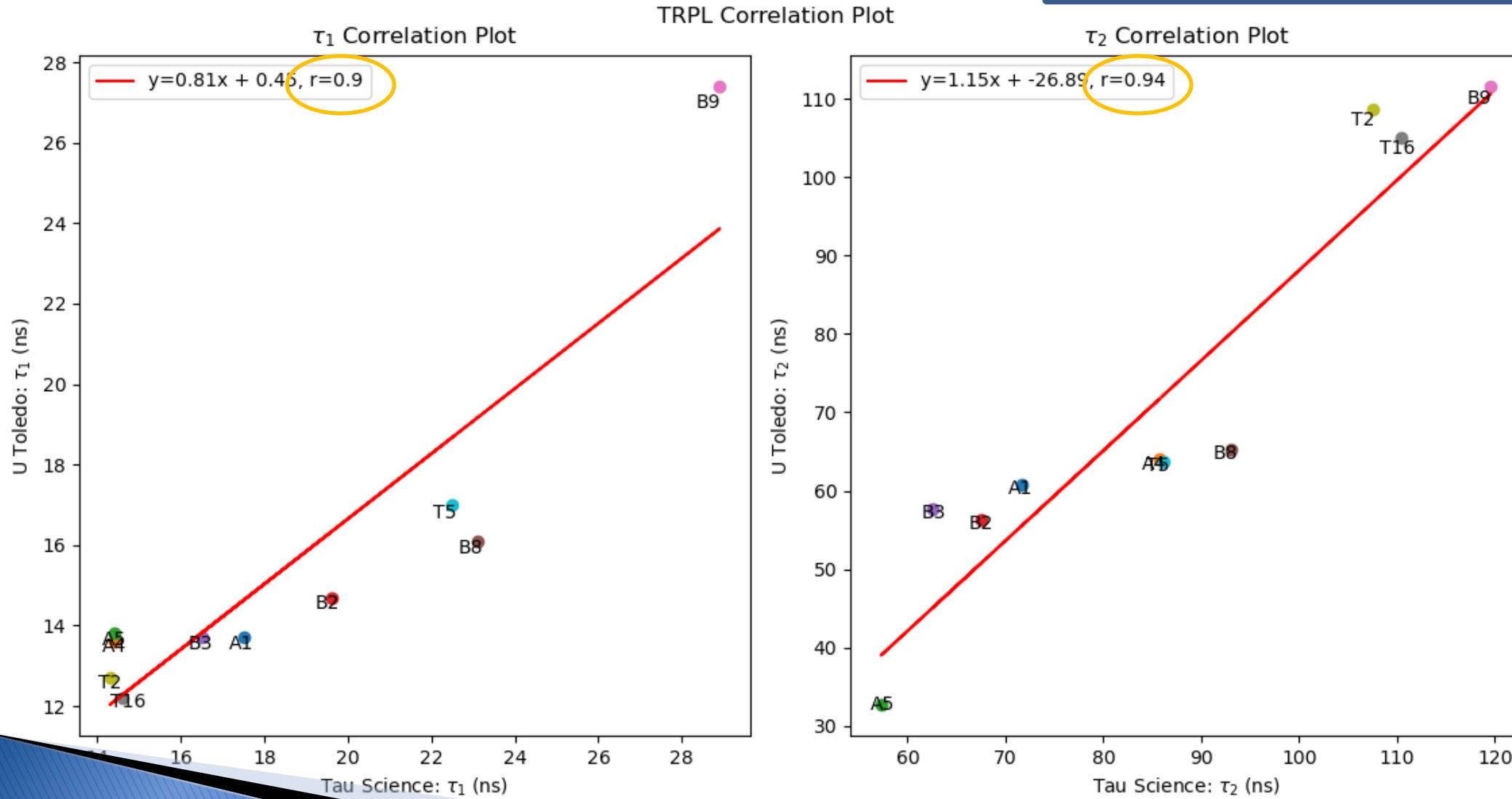


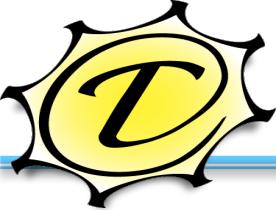
Rev 1 TRPL
TCSPC
 $\lambda=630\text{nm}$
3ns pulse
 $\sim 150\mu\text{m}$ spot
3ns bin width
Si APD

...need to work on
automated curve
fitting



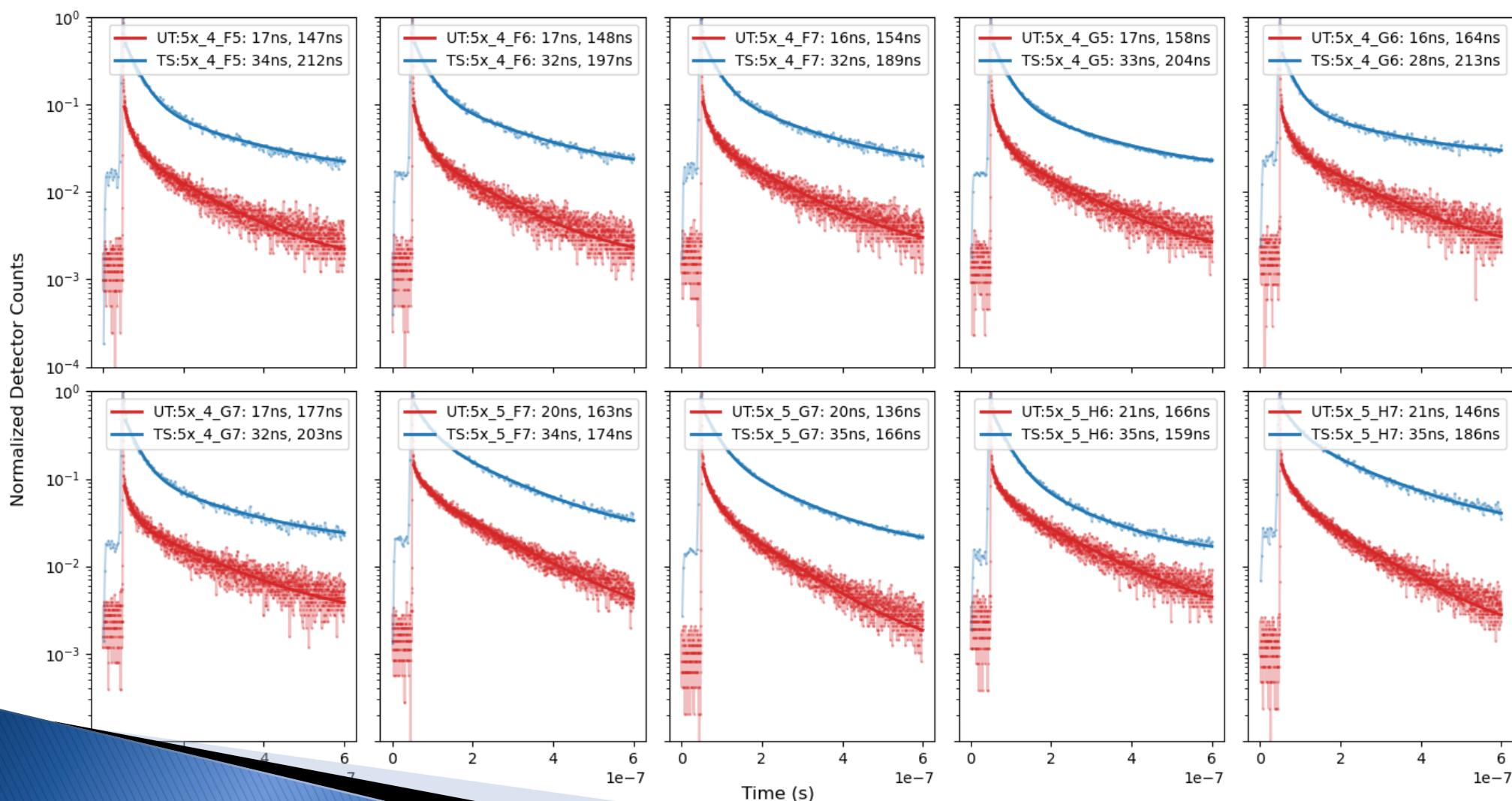
TRPL: Perovskite Correlation Data



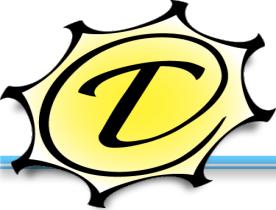


TRPL: CdTe Correlation Data

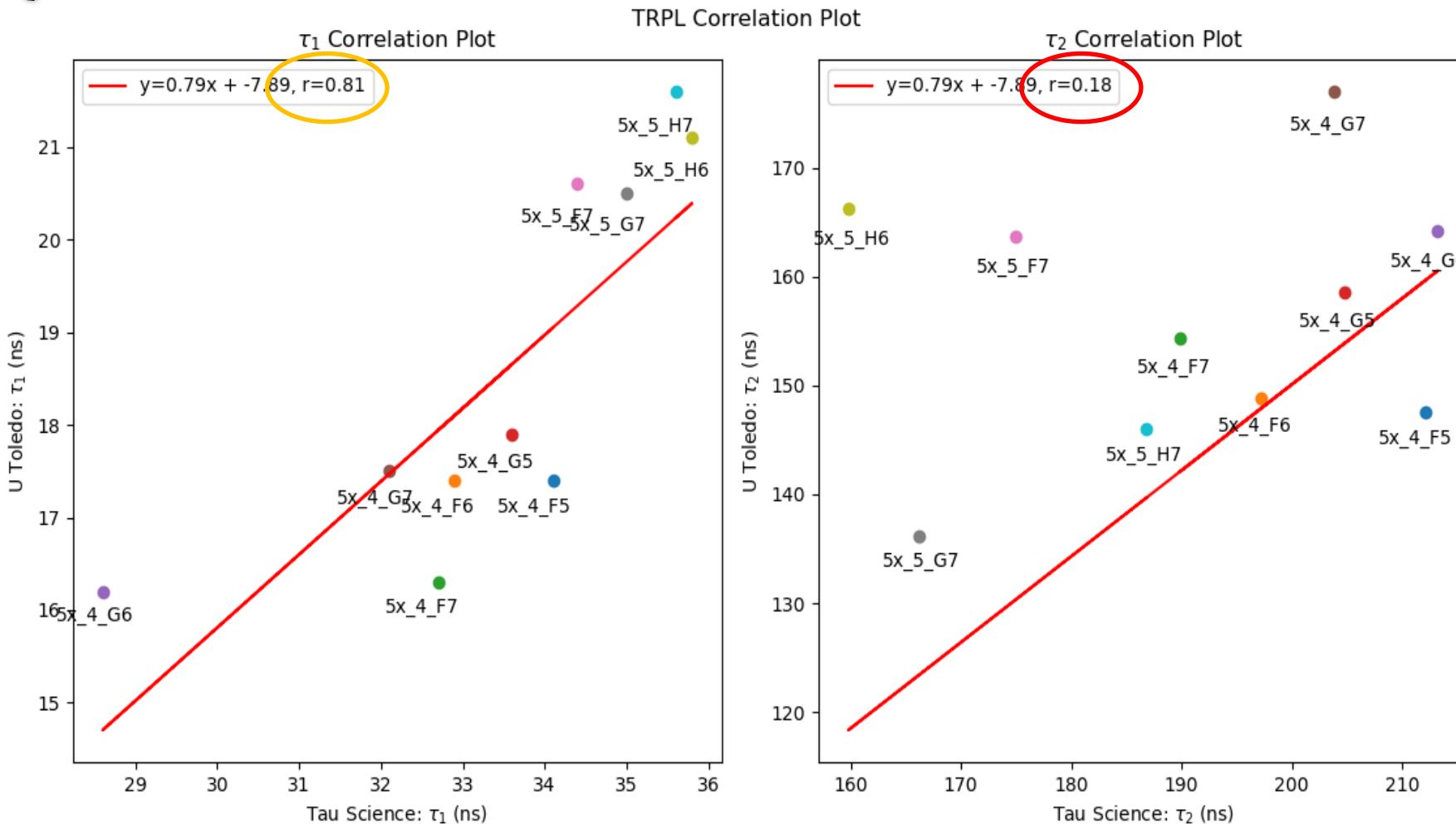
Time-Resolved Photoluminescence



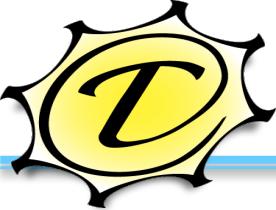
TCSPC
 $\lambda=630\text{nm}$
3ns pulse
 $\sim 150\mu\text{m}$ spot
3ns bin width
Si APD



TRPL: CdTe Correlation Data



What is making the correlation difficult?
Spatial non-uniformity?
150 μ m beamsize sampling different regions?



TRPL, Next Steps

Understand & Improve CdTe TRPL correlation w/ U Toledo

Add automation:

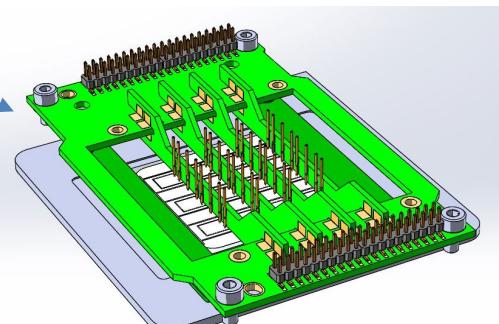
- Spotsize & injection ratio autocal (Z-stage)
- XY stage for mapping spatial non-uniformities
- Improved curve fitting algo's

Improved time resolution 3ns → 500ps

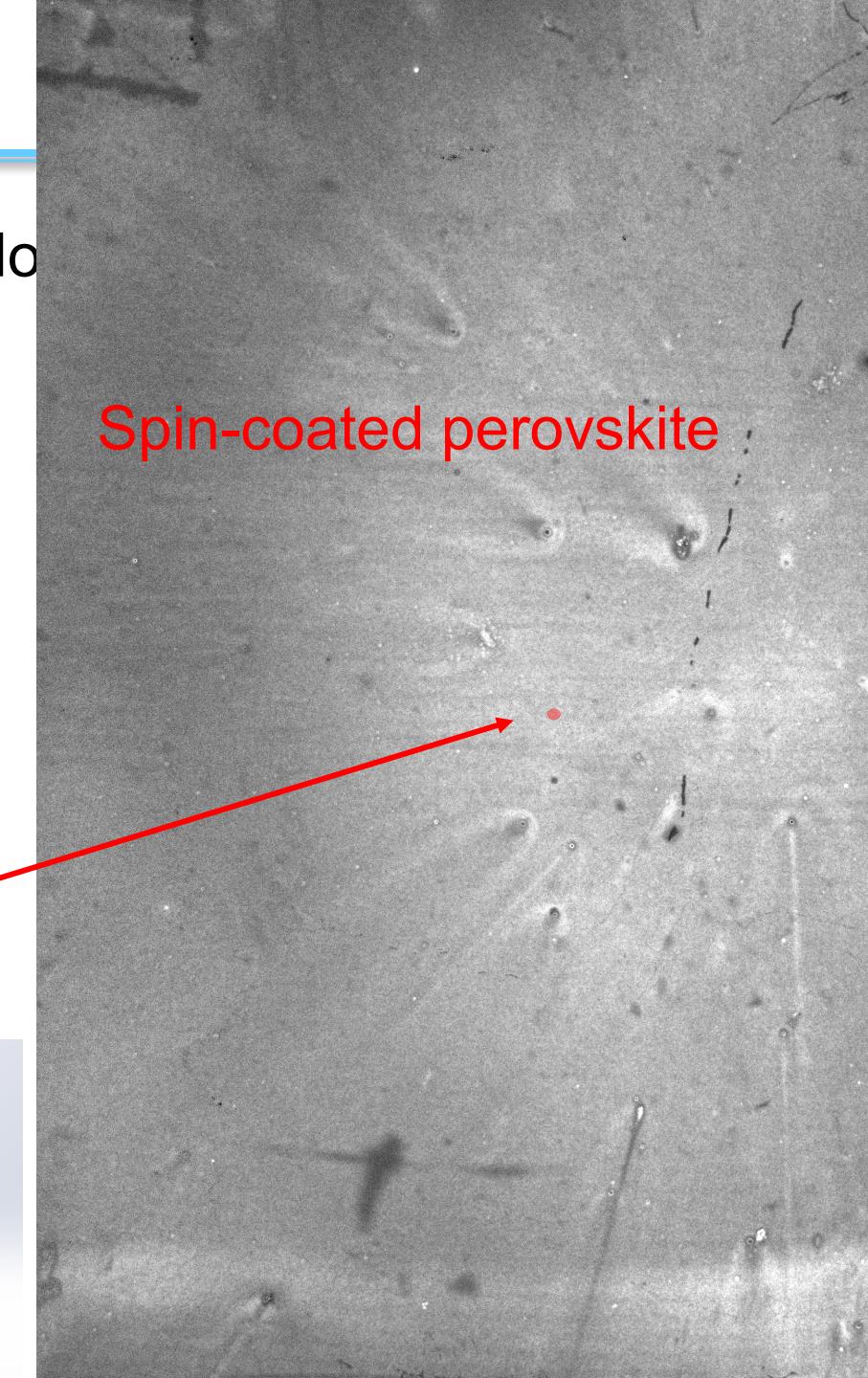
Add EL/PL Imaging:

- Navigate TRPL beam wrt live PL image
- Coupon contactor for EL

→ Beta Machine Q2 2023



Spin-coated perovskite





From 2022 Chicago CdTe Workshop

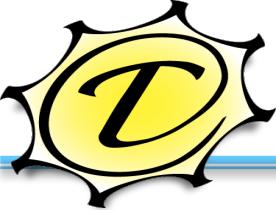
Parsing Voltage Losses in CdSeTe Solar Cells: Drafting a Pathway to Reach $V_{oc} = 1\text{ V}$

Arthur Onno,^{1*} Carey Reich,² Adam Danielson,² Alexandra Bothwell,³ Siming Li,³ Mason Mahaffey,¹ William Weigand,¹ Walajabad Sampath,² Darius Kuciauskas,³ and Zachary C. Holman¹

¹*Arizona State University*

³*Colorado State University*

³*National Renewable Energy Laboratory*



External Radiative Efficiency

Absorptance measurement
(EQE, PDS, PL, or optical model)

'detailed balance'

$$iV_{oc} = V_{oc,ideal} - \frac{k_B T}{q} |\ln (ERE)|$$

$V_{oc,ideal}$

Depends on bandgap and shape
of band edge (band tails...)

ERE measurement
(quantitative PL)

iV_{oc}

Depends on $V_{oc,ideal}$ and
non-radiative recombination in
the bulk and at interfaces

J-V curve tracing
(electrical measurement)

$$S_{oc} = V_{oc}/iV_{oc}$$

V_{oc}

Depends on iV_{oc} and
selectivity of both contacts

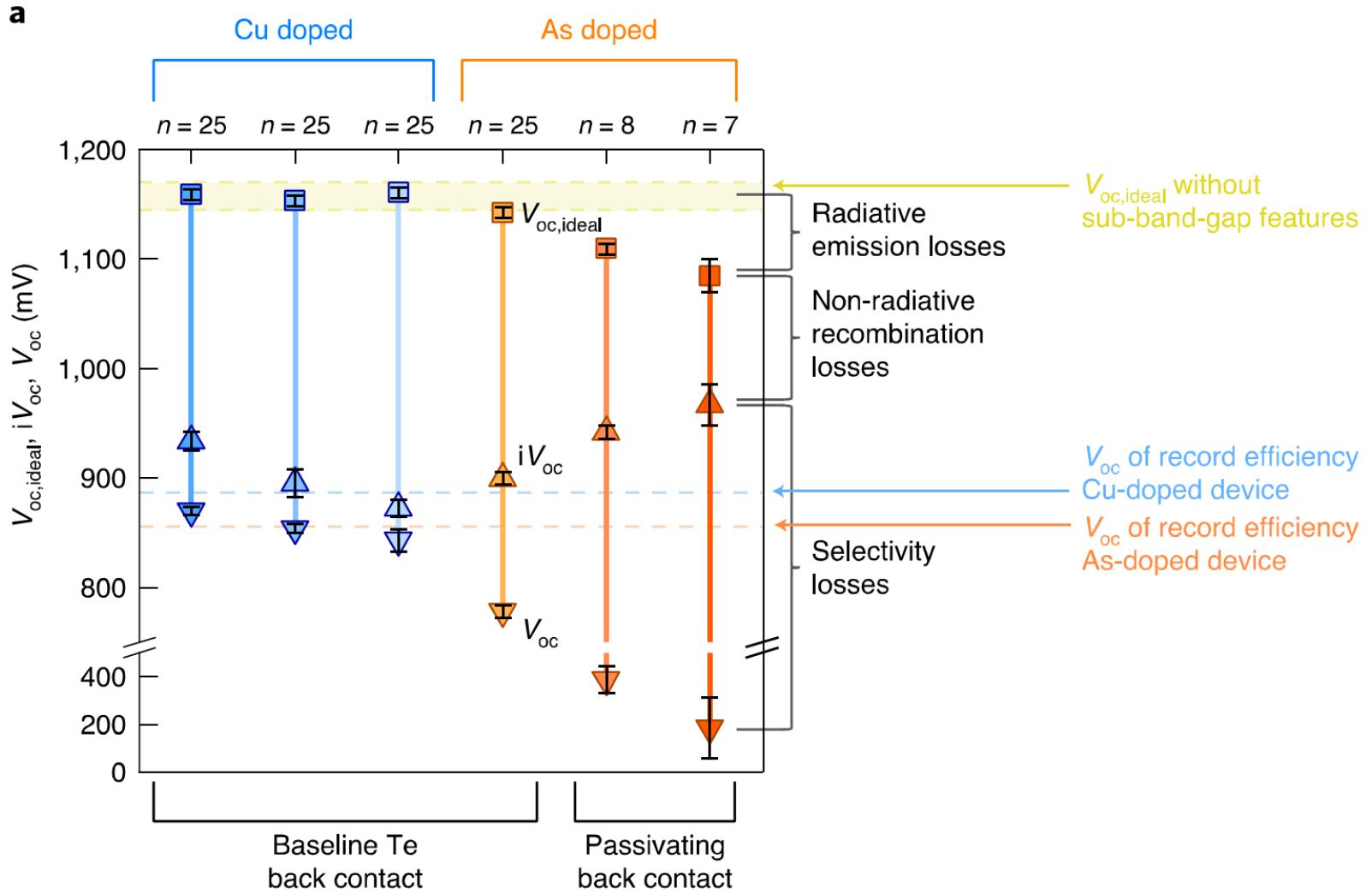
Non-radiative recombination

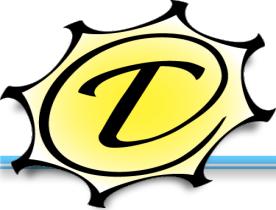
Contact selectivity

Understanding what polycrystalline CdSe^a

Arthur Onno¹✉, Carey Reich², Siming L
Alexandra Bothwell³, Sachit Grover⁴, Jeff
Walajabad Sampath² and Zachary C. Hol

Arizona State University
Colorado State University
NREL
First Solar

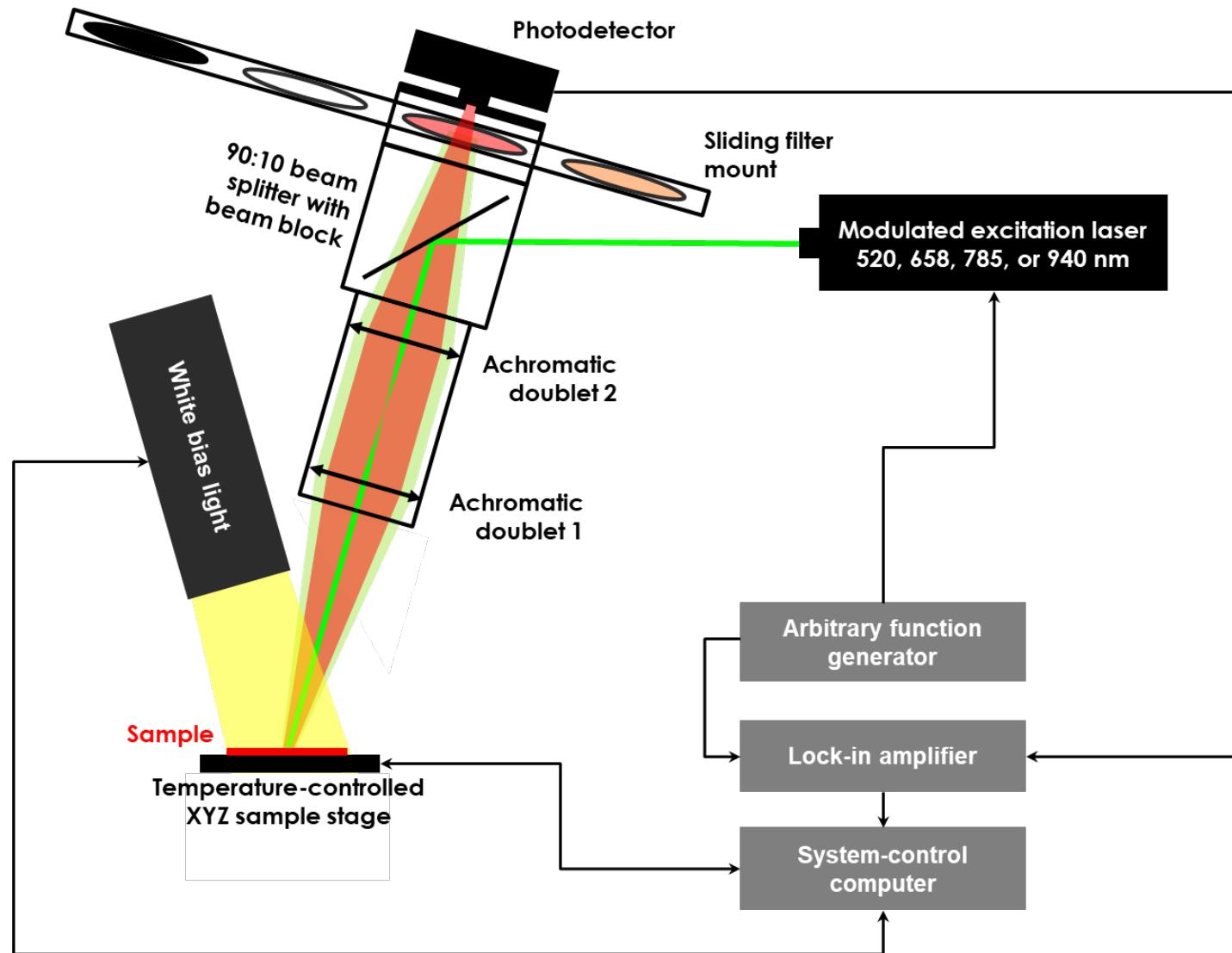




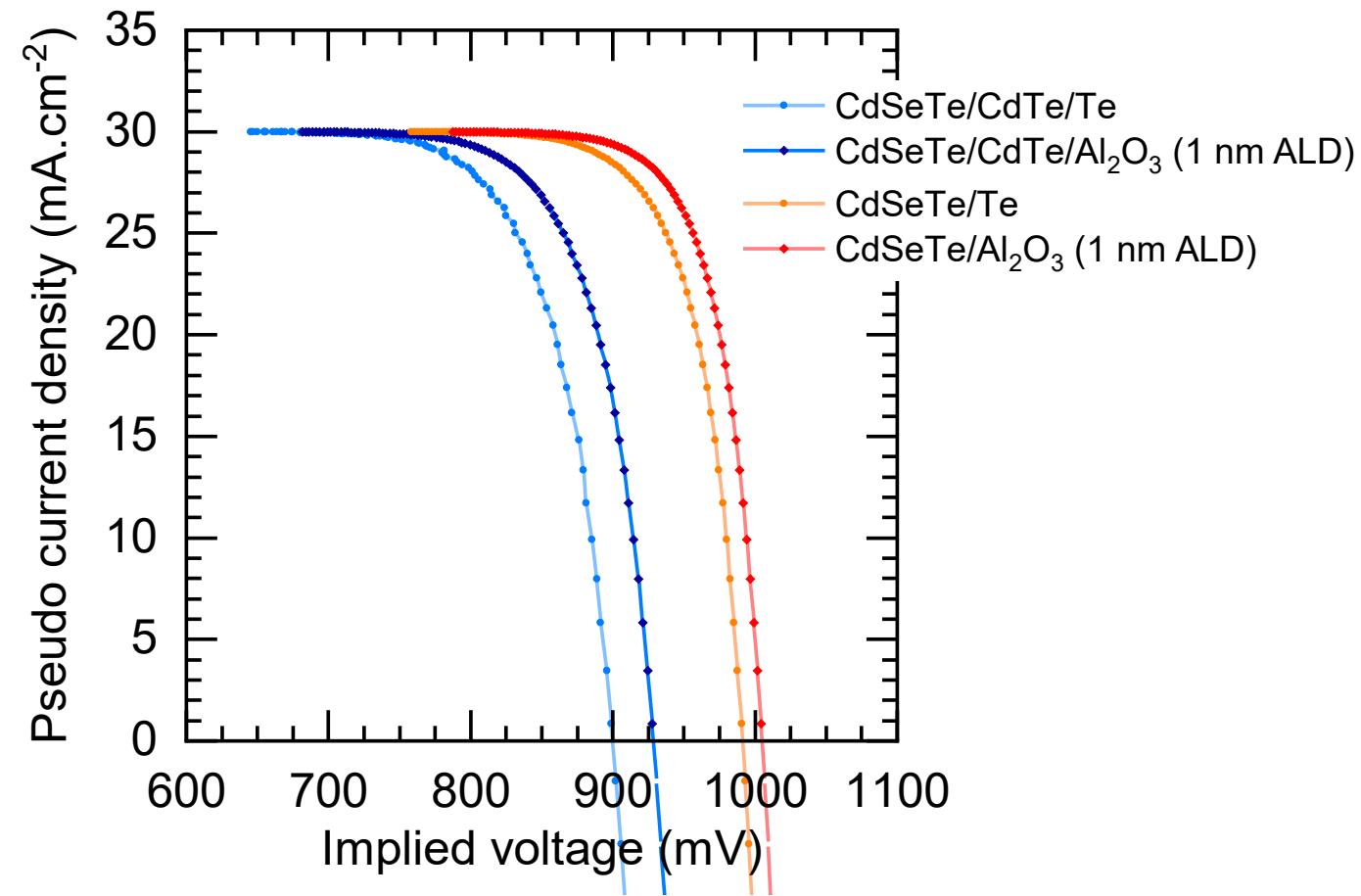
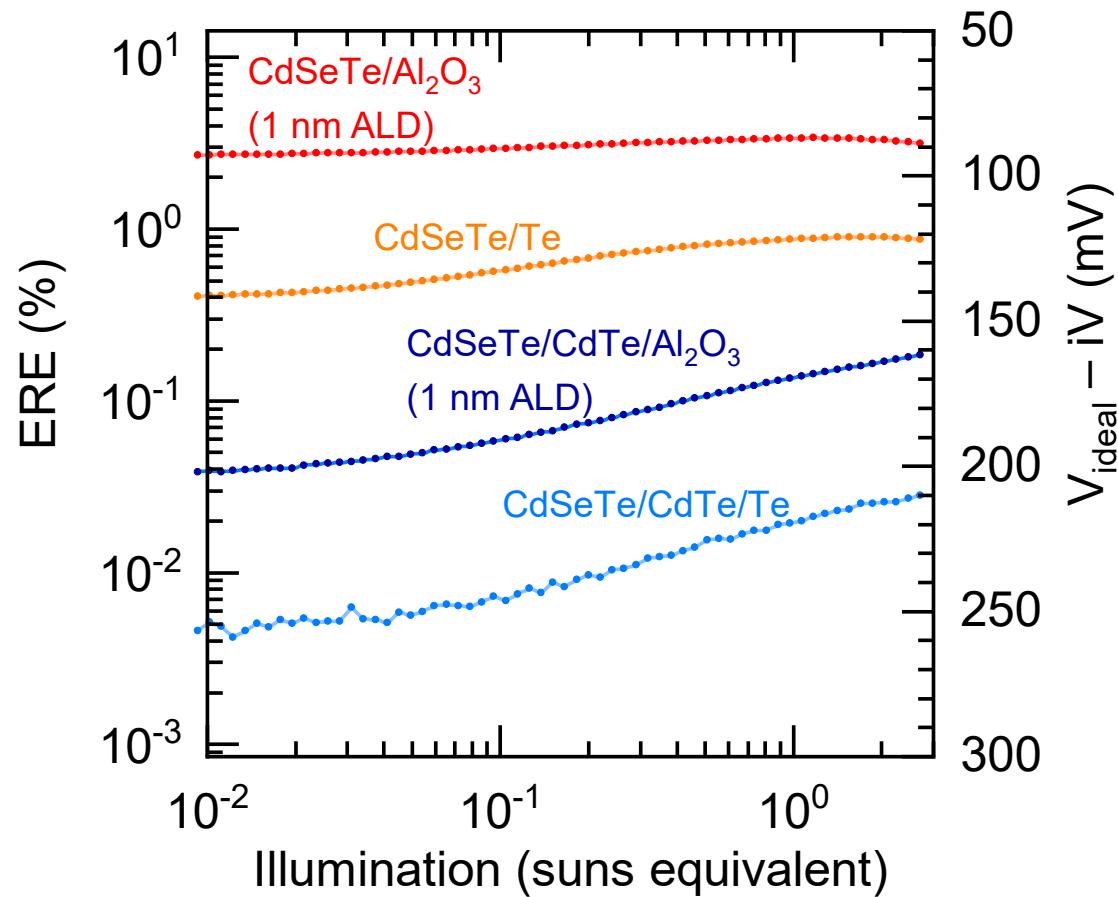
External Radiative Efficiency (ERE)

Currently negotiating
commercial agreement w/ ASU

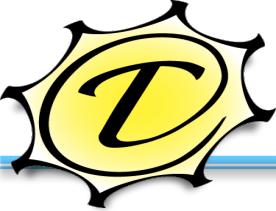
Arthur Onno, Zach Holman,
Mason Mahaffey et al



Measure ERE vs. Illumination: reconstruct the “internal” J-V curve of the absorber



→ Implied efficiency, FF



Next Steps for ERE

ASU- Stay tuned for 2023 publications:

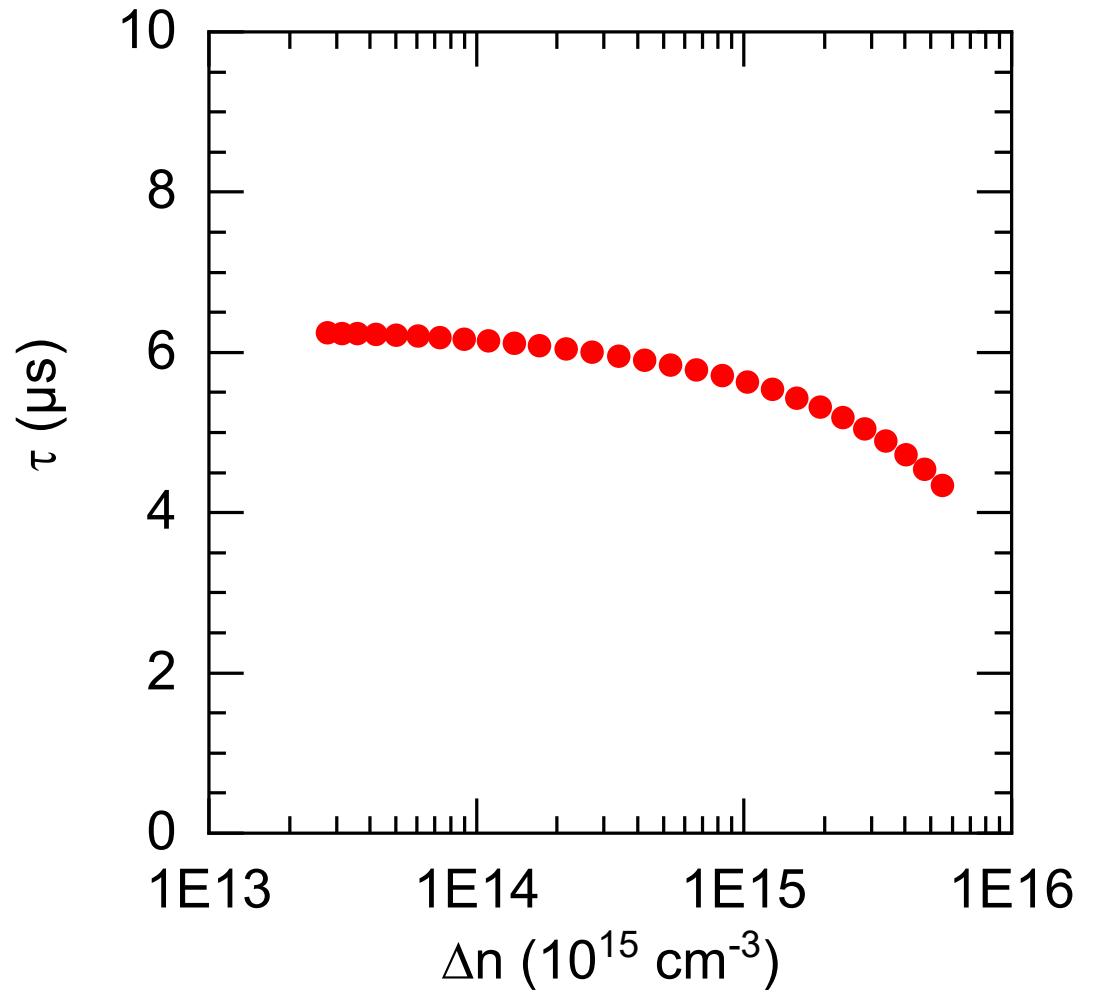
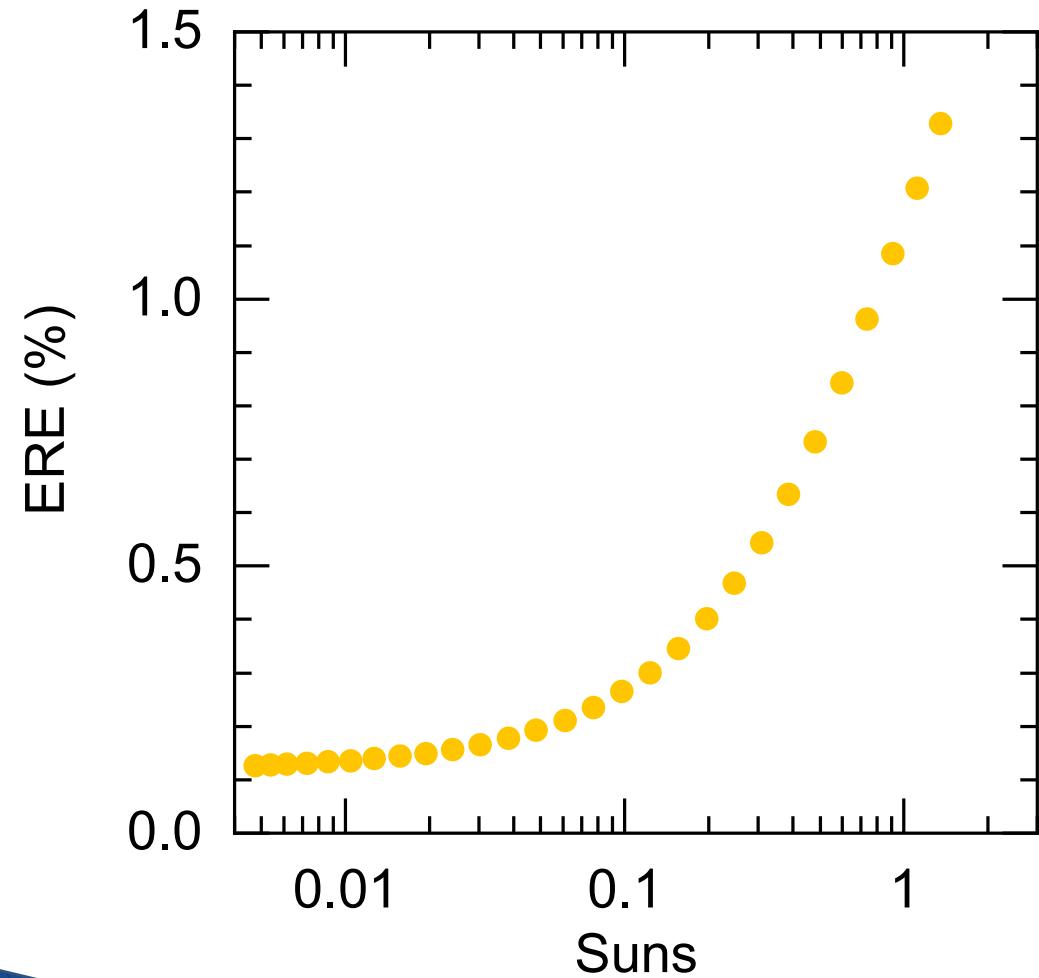
Doping
Lifetime

Tau Science- Develop into commercial system

Beta system in Q2'23
ERE + Doping + Lifetime
Implied I-V analysis
Conventional I-V sweep
Automation!!

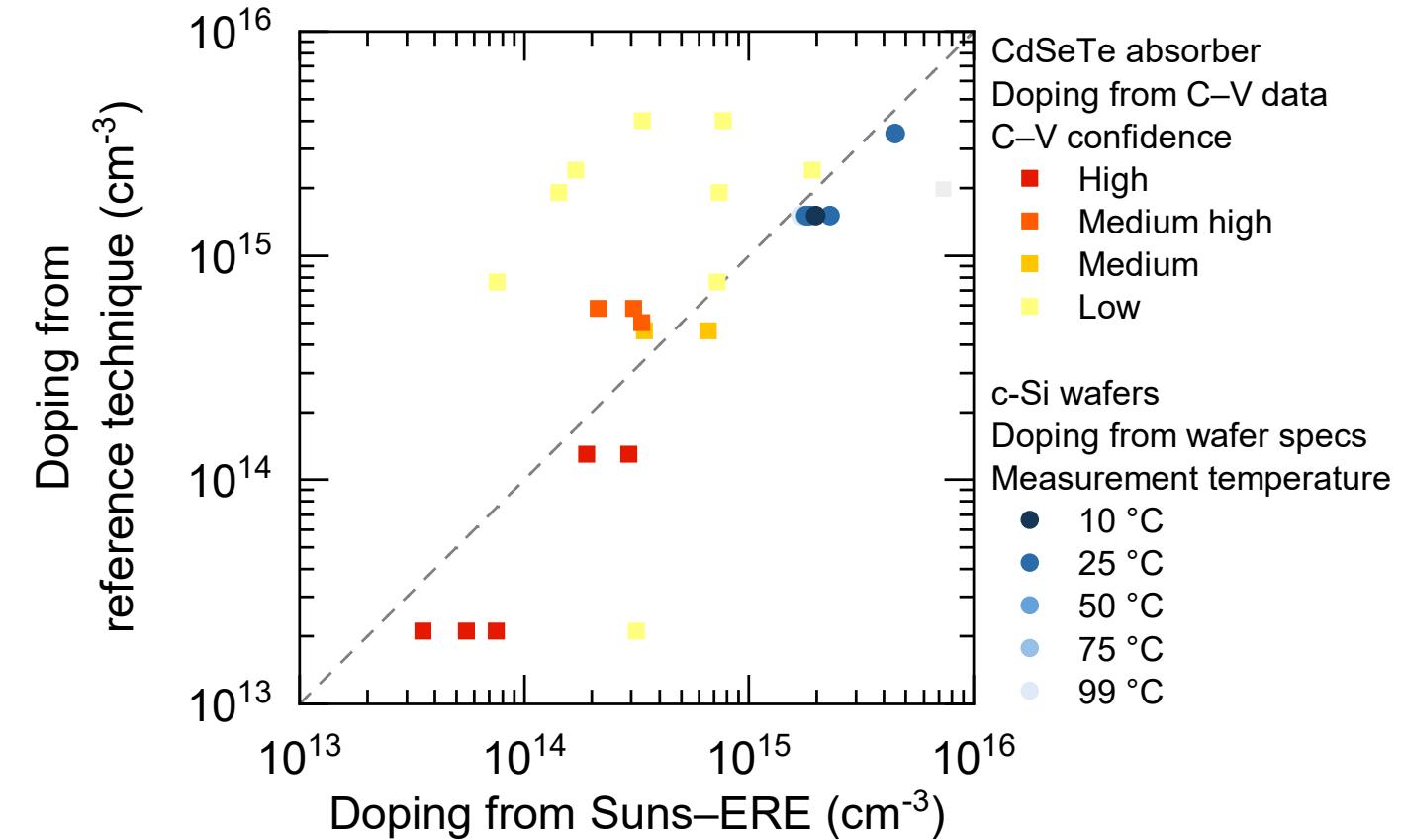
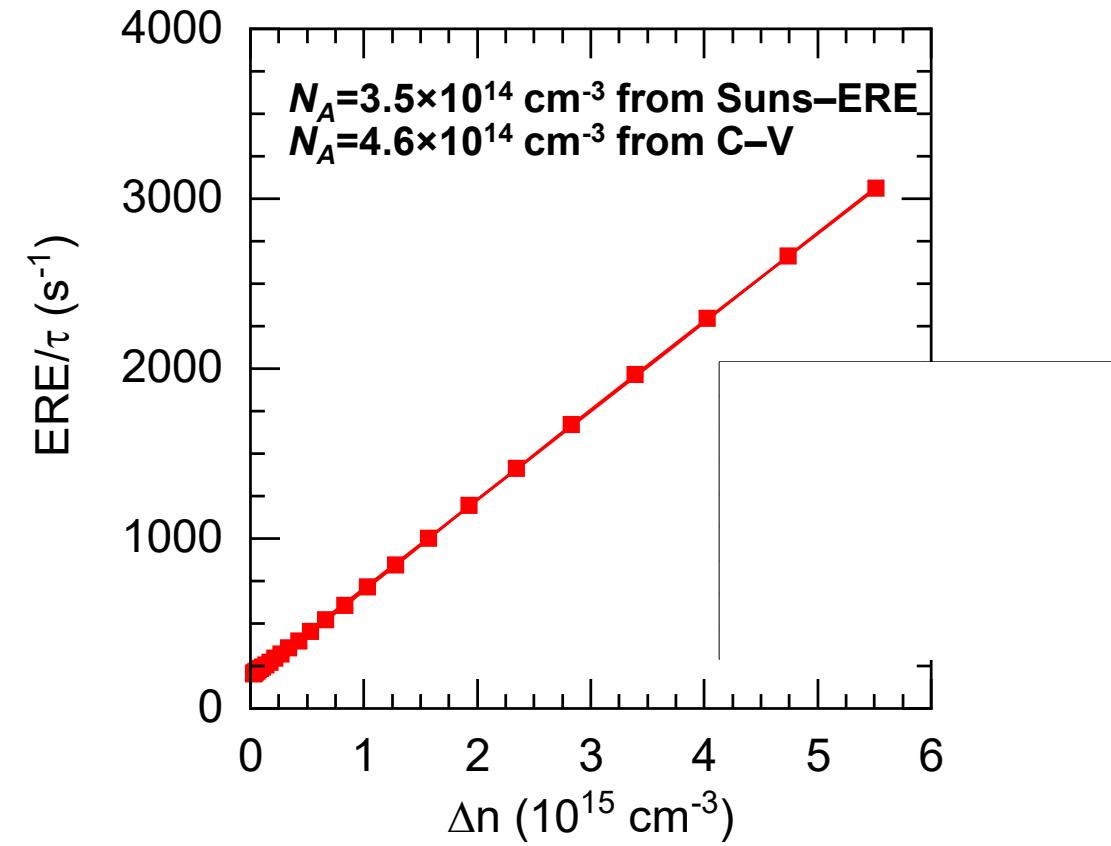
XY stage, autocal, sample holders, MUX...

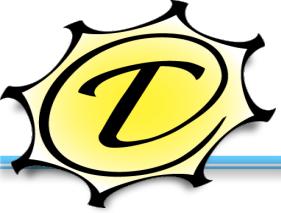
Demonstration of combined measurement of ERE and lifetime on CdSeTe absorbers



Measurements performed simultaneously

Demonstration of doping measurement on CdSeTe absorbers

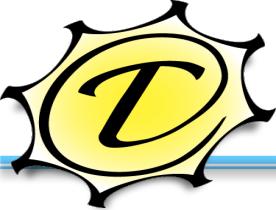




Comments, Questions, Collaborations are welcome!

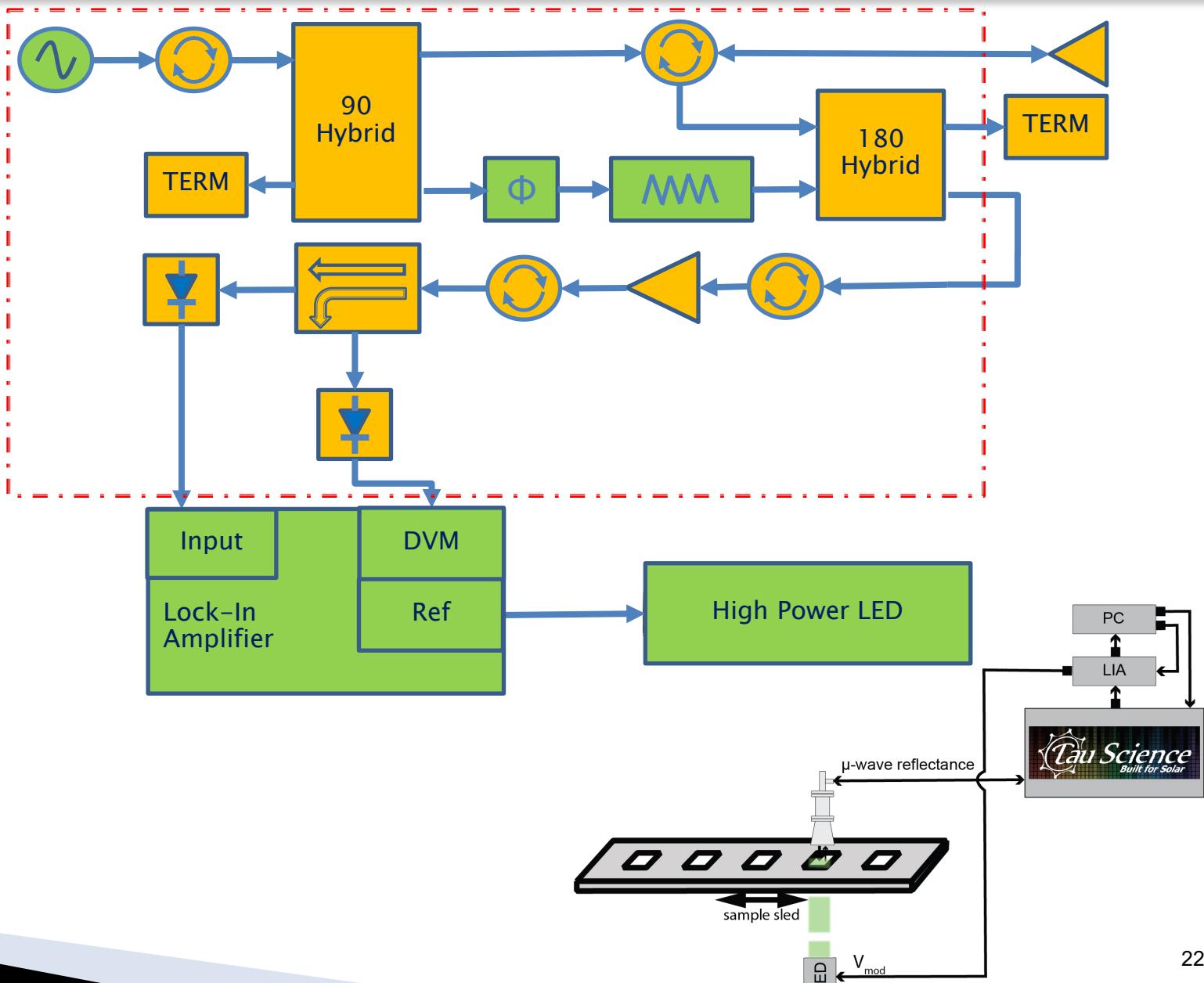
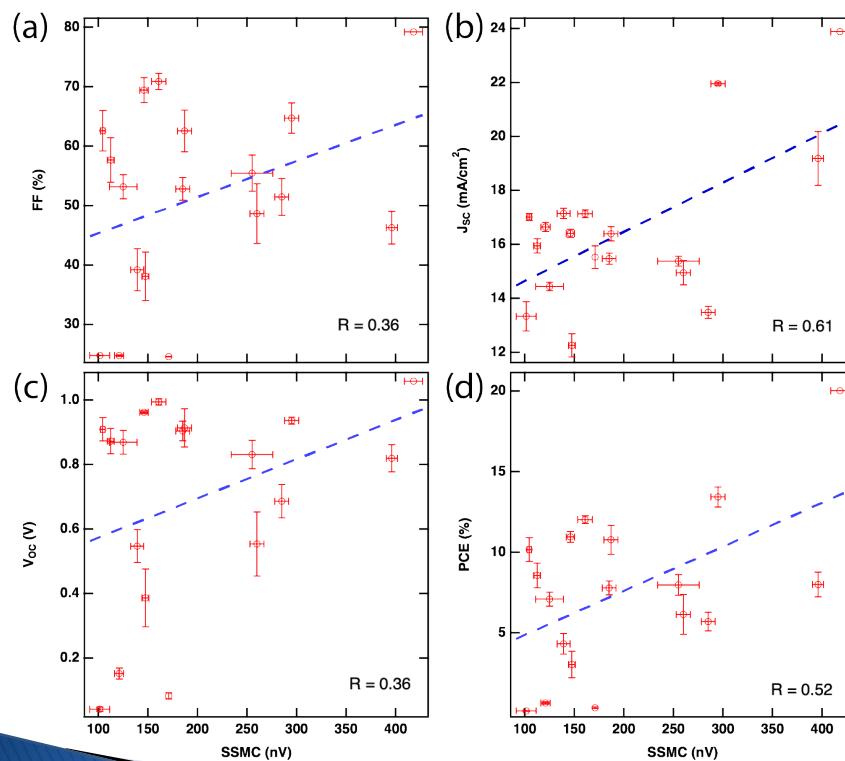
Greg Horner

Ghorner@tauscienc.com



Steady-State Microwave Photoconductance $\sim QE^*\mu^*\tau$

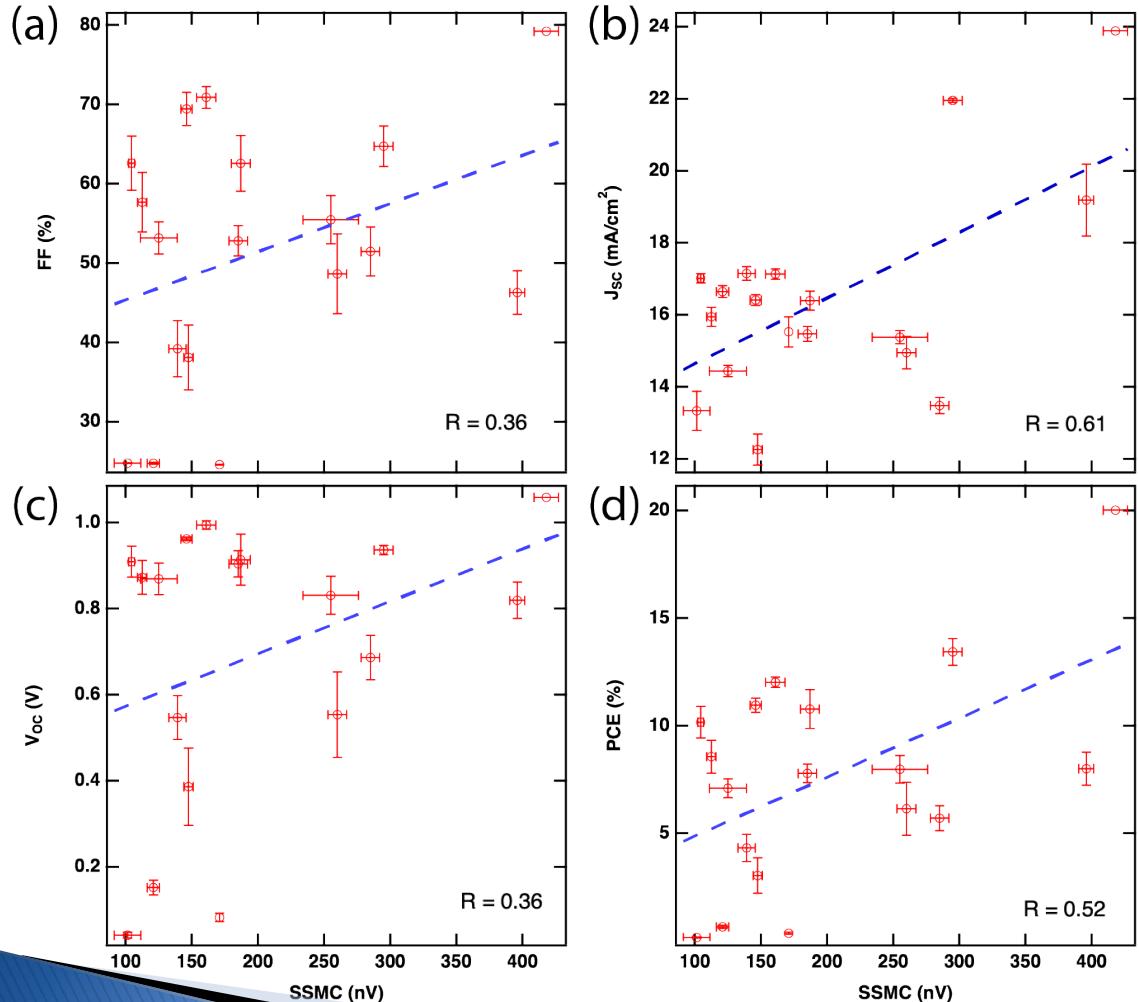
Perovksites
Inline Sensor for QC
Bryon Larson (NREL)
Obadiah Reed (CU, NREL)





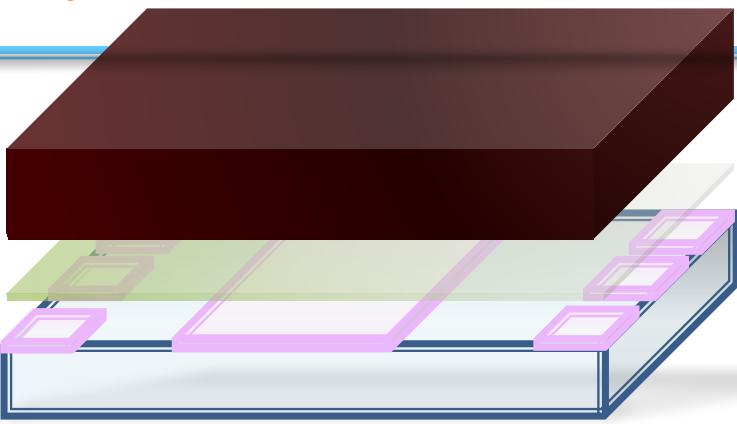
P-i-N architecture, *different fabrication humidity*

½ stack



Reed (NREL)

Perovskite
Absorber



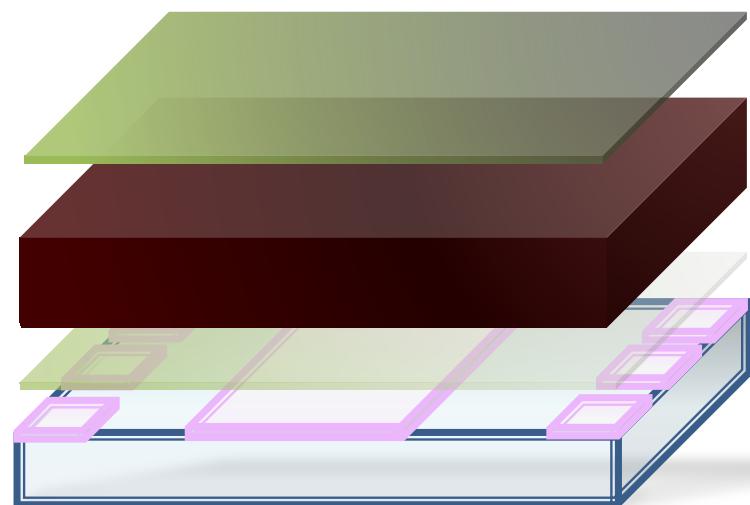
Vs.

¾ stack

C_60/BCP

Perovskite
Absorber

MeO-2PACz



Bottom Contact (ITO on glass)