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Status of the TPA-TCT system in JSI Ljubljana

41st RD50 Workshop, Sevilla, 30 November 2022

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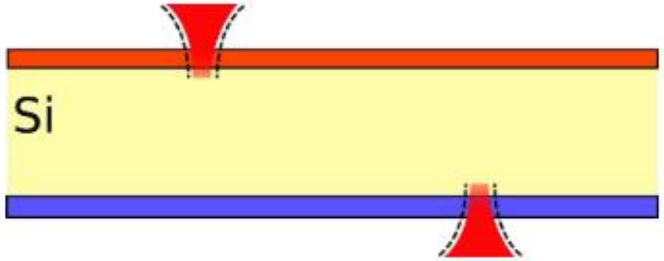
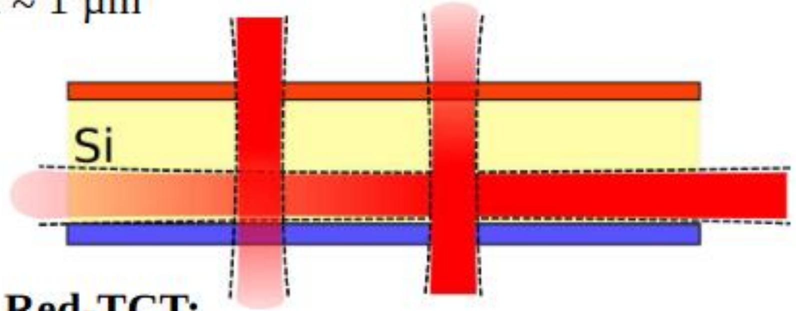
Slide taken from talk by S. Pape

Single Photon Absorption-TCT

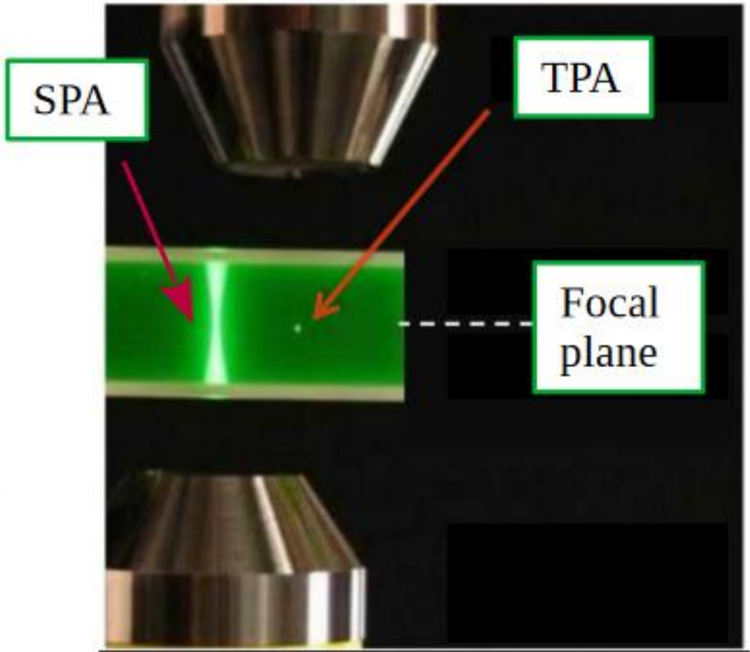
λ ≈ 700 nm



λ ≈ 1 µm



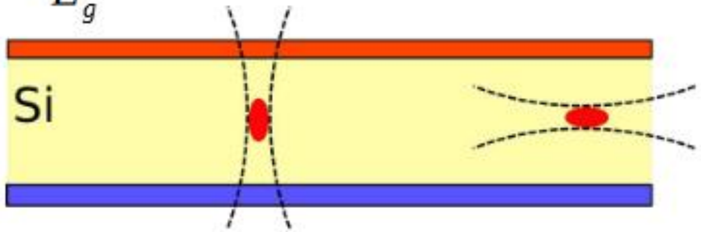
- **Red-TCT:**
  - Full light absorption in ~3-10 µm depth
  - optimal for e/h separation
  - Laser can be micro focused to < 5 µm: **2D resolution**
- **IR-TCT:**
  - To mimic MIPs (continuous laser absorption)
  - Normally 6-10 µm **2D resolution**
  - Edge injection in thick devices allows a depth study



Photography: **Ciceron Yanez**, University of Central Florida

Two Photon Absorption-TCT

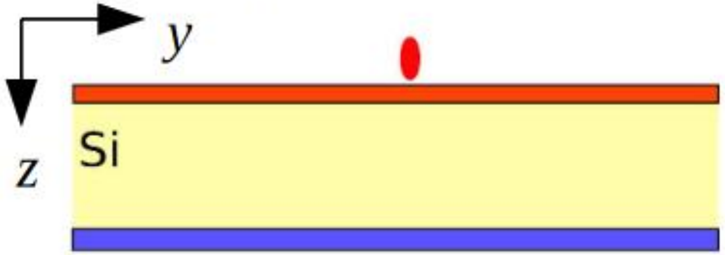
$$\lambda > \frac{hc}{E_g}$$



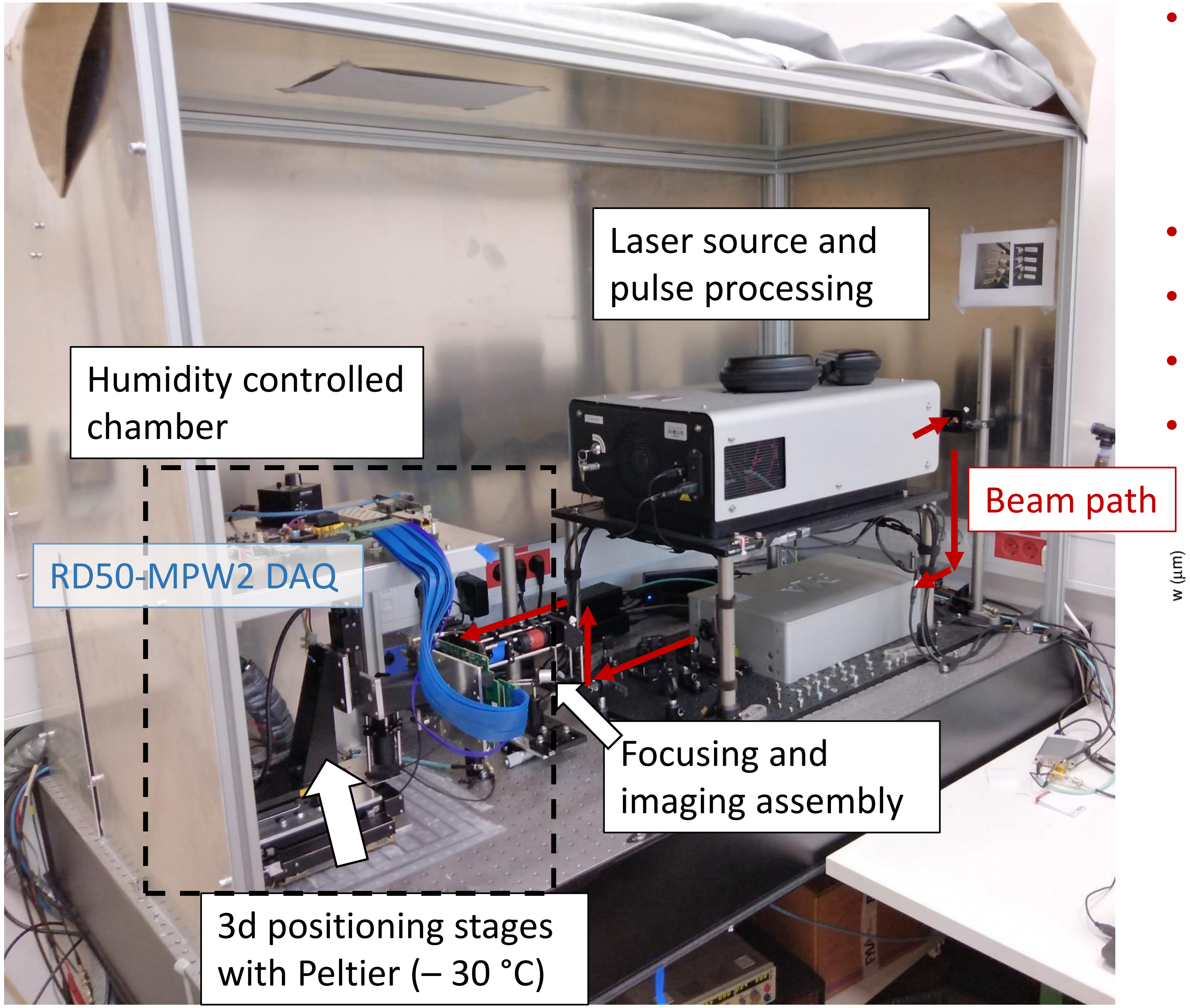
- **TPA** excites charge carriers into the CB
- Non-linear effect, depends quadratic on the intensity

→ main excitation around focal point

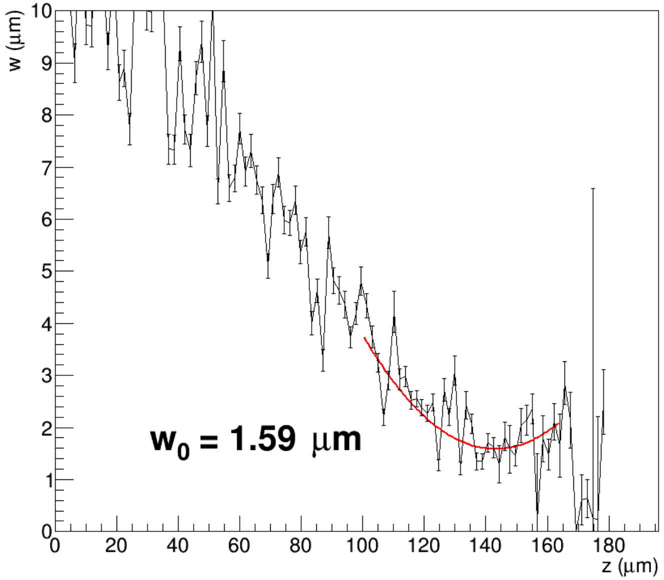
- **3D resolution** tool for the detector characterisation:



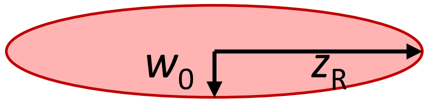
Ljubljana TPA-TCT setup



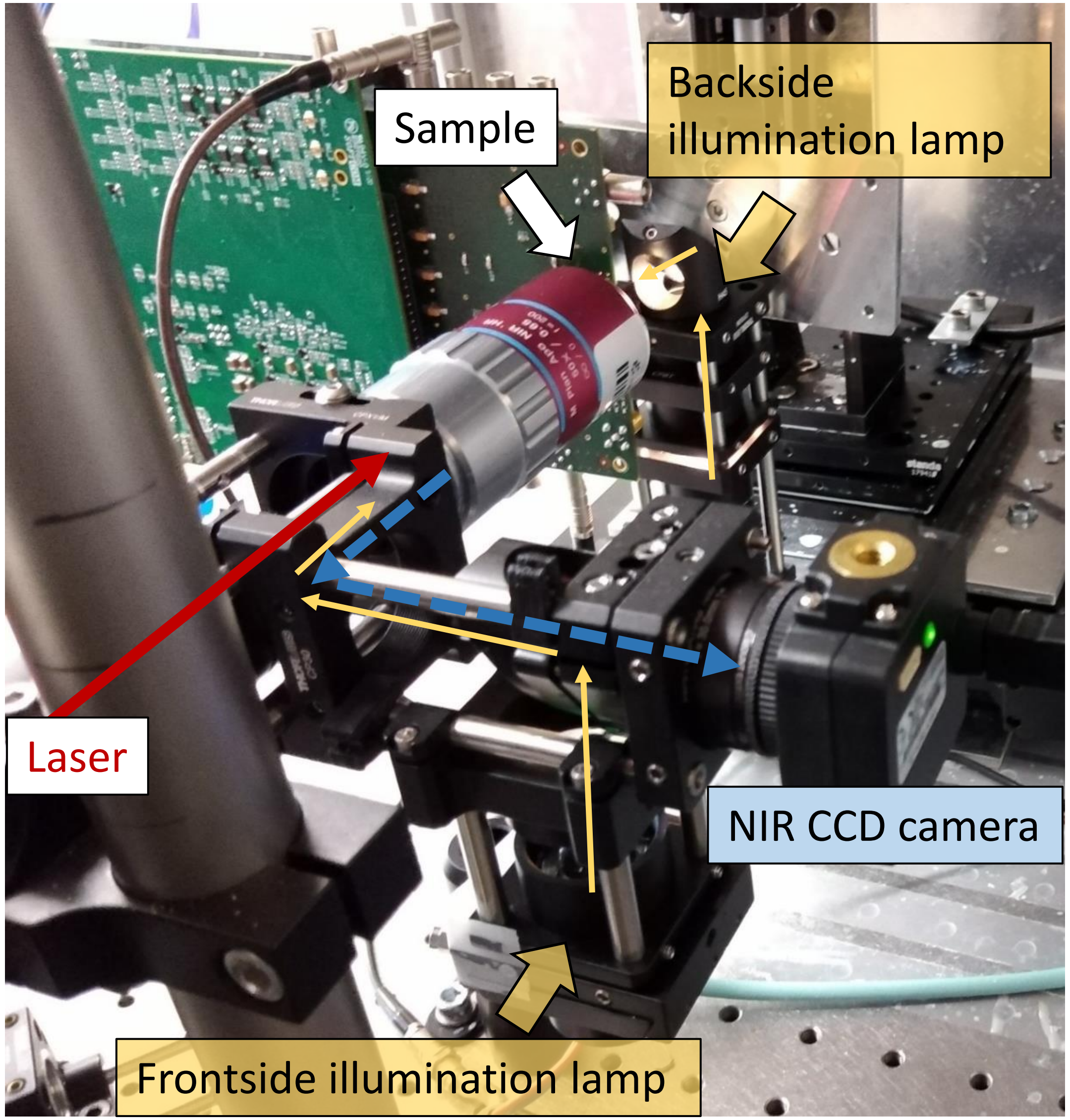
- **FYLA LFC 1500X** femtosecond laser system (λ = 1550 nm)
  - Adjustable pulse energy and repetition rate
  - No pulse compressor
- CCD for beam position imaging
- Peltier based temperature control down to – 30 °C
- DAQ using **Particulars** TCT software
- Focusing objective NA = 0.65, measured beam waist size $w_0 = 1.6\ \mu m$, Rayleigh range $z_R = 18\ \mu m$



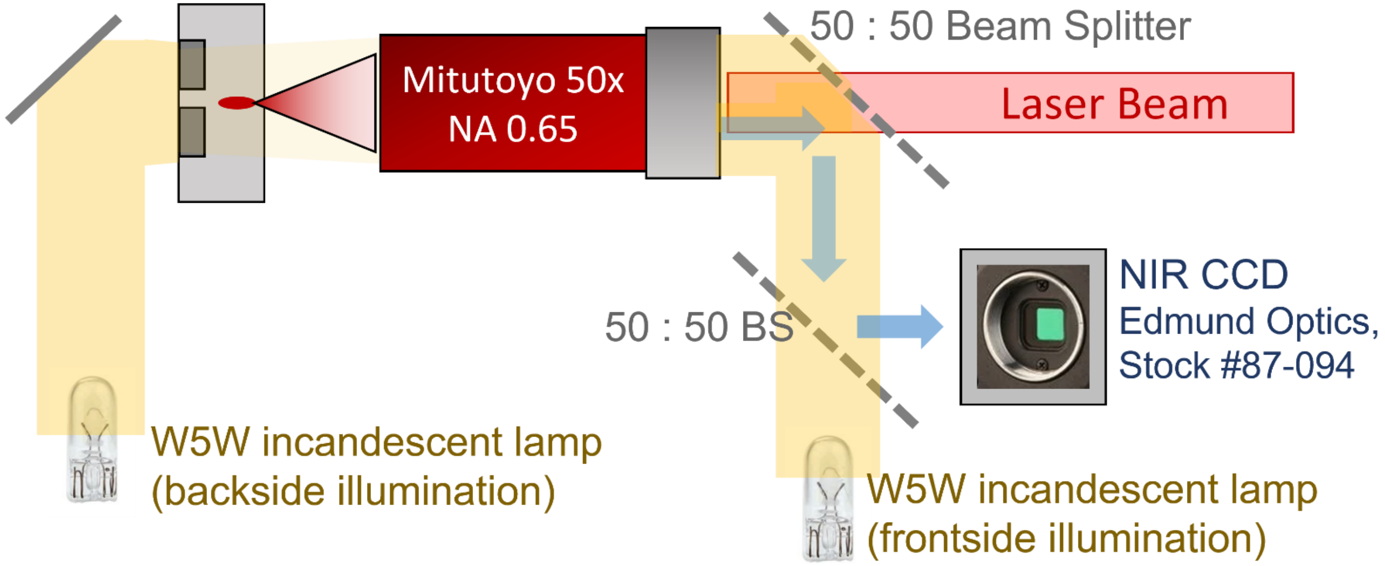
$$z_R = \frac{\pi w_0^2 n_{Si}}{\lambda}$$



Focusing and imaging assembly



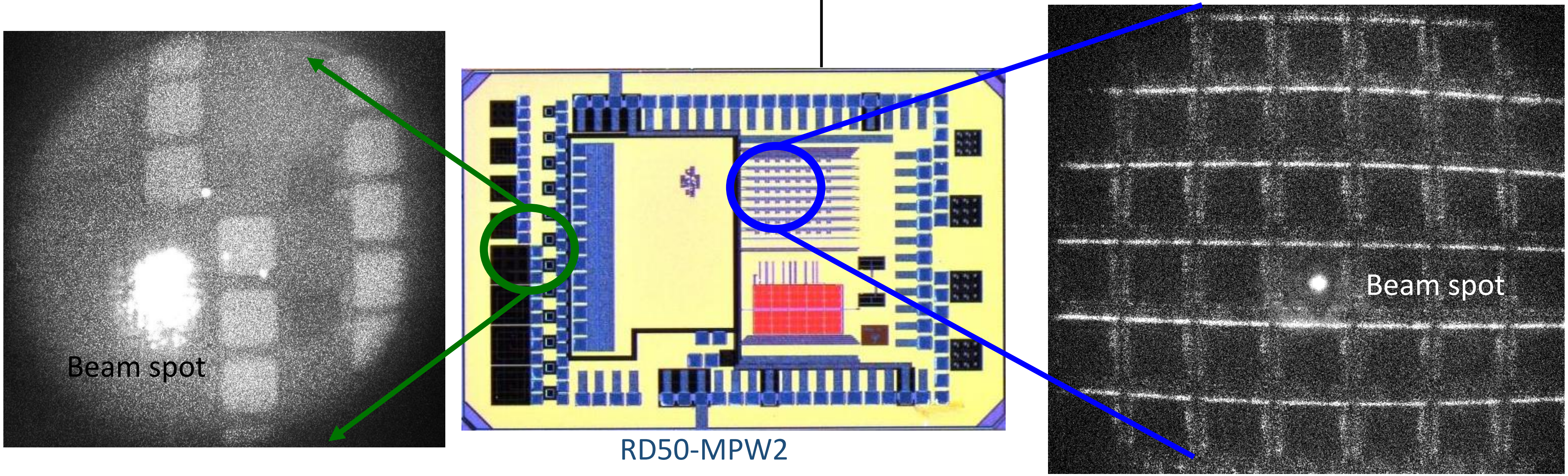
- Beam position imaging vital for locating small structures in three dimensions
- Imaging through the focusing objective using beam splitters
- Frontside or backside sample illumination with incandescent lamp



Imaging and illumination

- Front side illumination (brightfield)
  - ✓ Simple to establish orientation on sample/carrier
  - ✓ Imaging independent of sample surface processing
  - × Glare from beam splitters limits sensitivity
    - Imaging and injection only through front side
  - × Front side injection requires opening in surface metal
    - Not possible with every sample

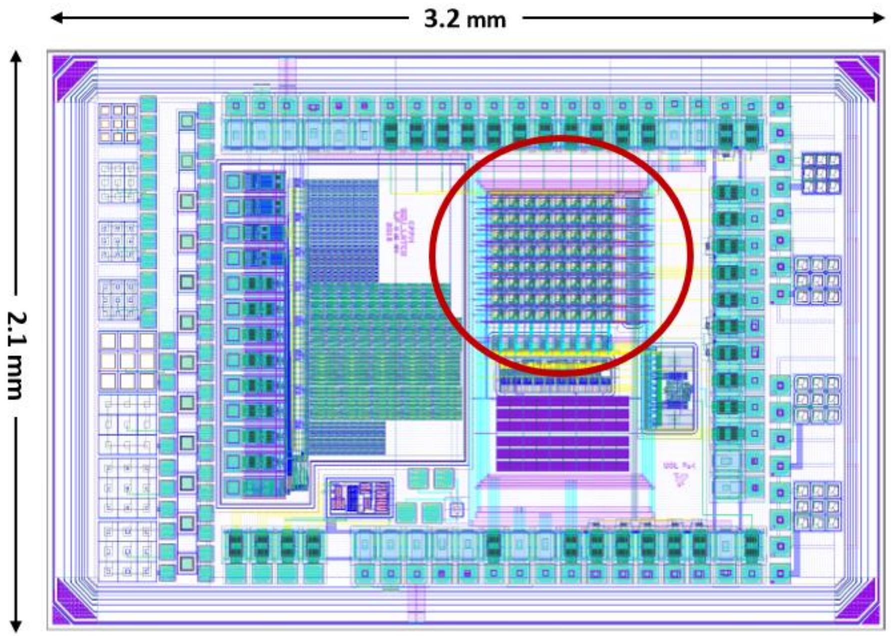
- Back side illumination (darkfield)
  - ✓ Larger sensitivity
  - ✓ Front or backside laser injection
  - × Cooling (thermal contact) more difficult
  - × Not trivial with backside metallization
    - Chemical methods to remove metal: S. Wonsak, 1st TCT Workshop, 2015

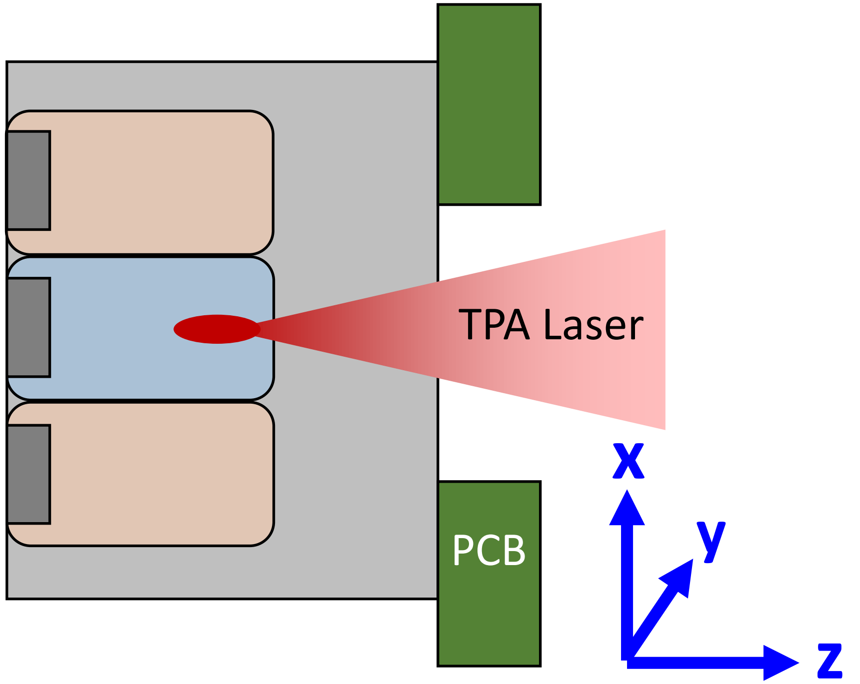


RD50-MPW2

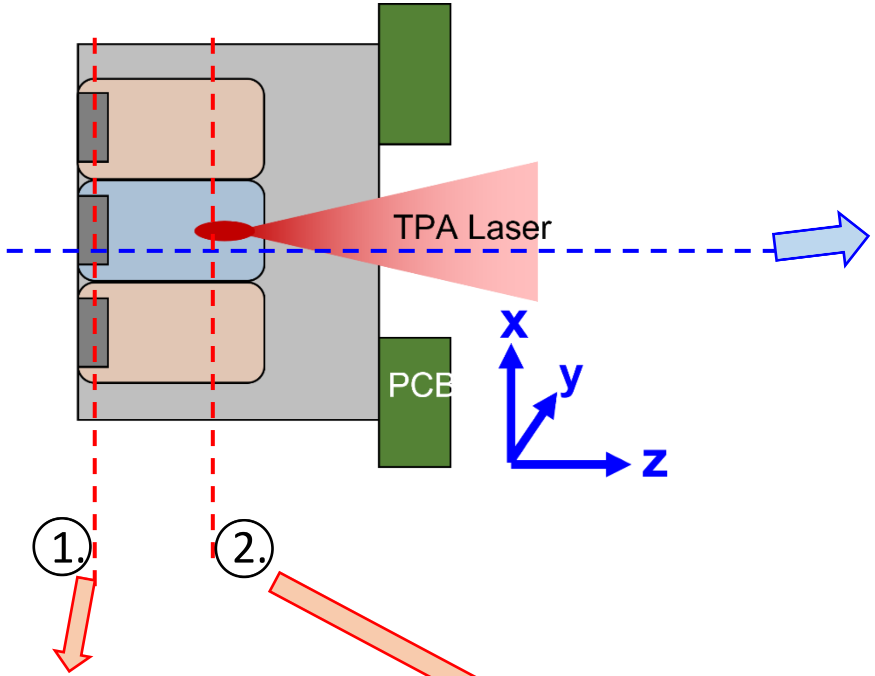
RD50-MPW2 pixel probing

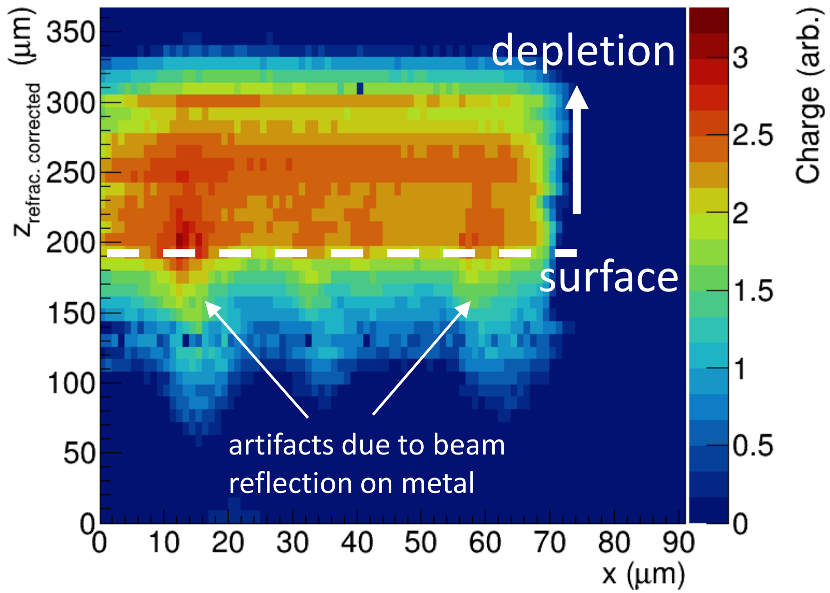
- Test sample: unirradiated RD50-MPW2 CMOS chip
  - 8 x 8 active pixel matrix
  - 60 µm × 60 µm pixel size
  - 1.9 kΩ·cm substrate resistivity
    - 180 µm depletion depth at 100 V bias (partially depleted)
  - No backside metallization
- Probing single pixel comparator output
  - Pulse Time-over-threshold proportional to charge
  - Waveform sampling with DRS4
  - Averaged over 10 waveforms, not corrected for pulse energy

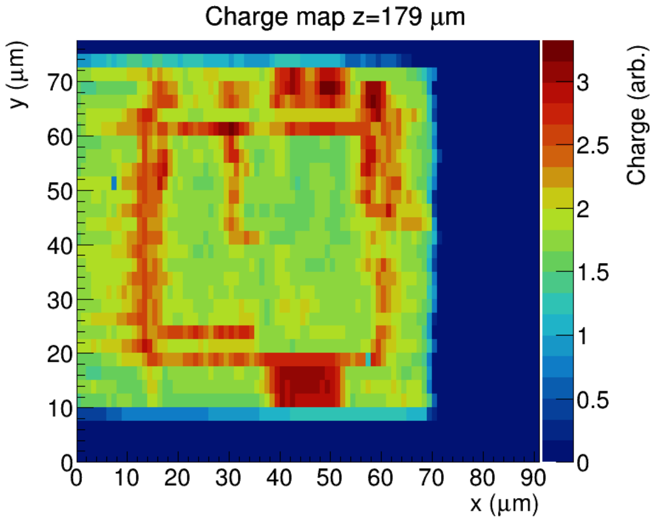


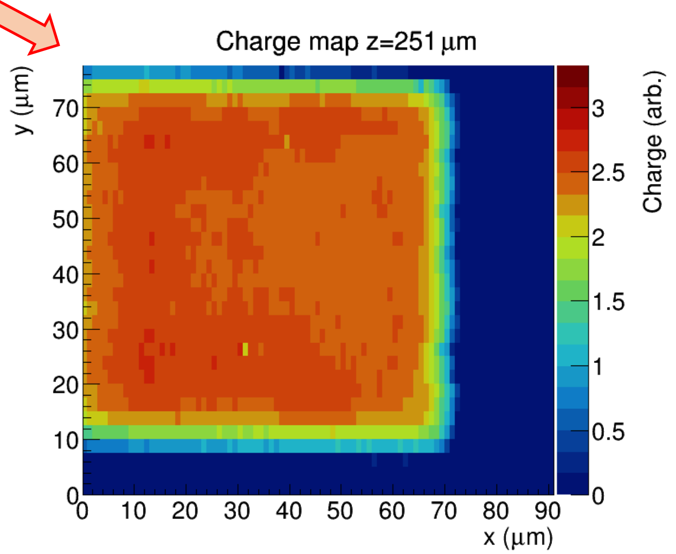


2d charge collection profiles









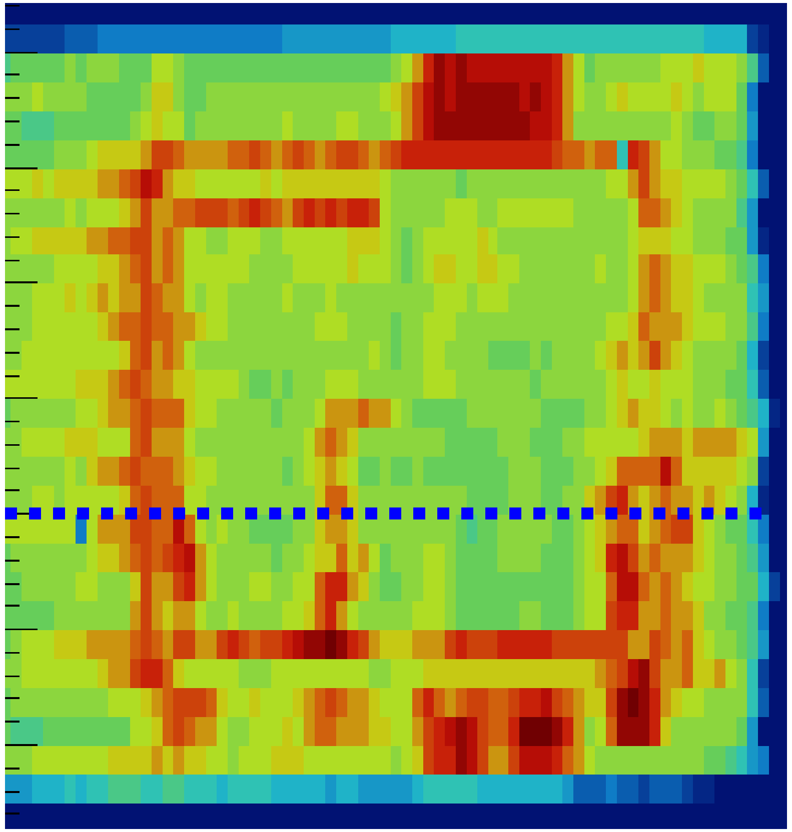
z-scale corrected for refraction on Air-Silicon interface

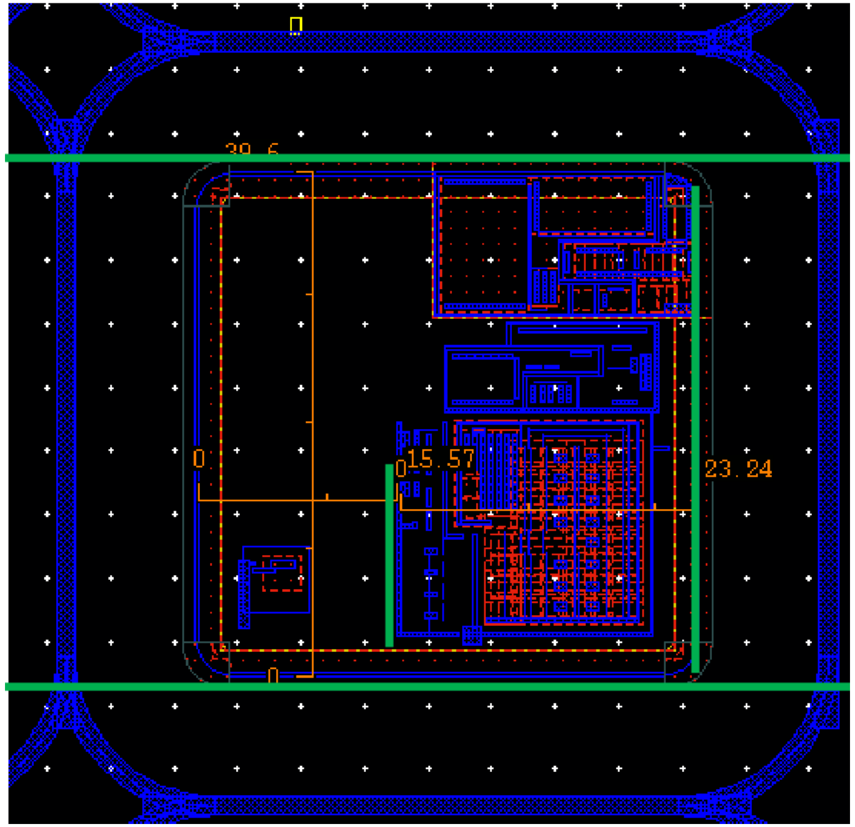
Beam waist region in silicon is longer than in air due to refraction on sample surface.

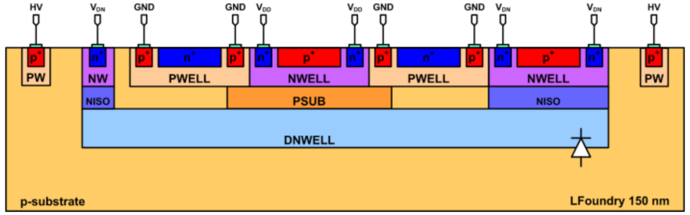
$$z_{\text{Si}} = z_{\text{stage}} \cdot \sqrt{\frac{z_{\text{R}} \pi n_{\text{Si}}^3}{z_{\text{R}} \pi n - \lambda n^2 + \lambda}}$$

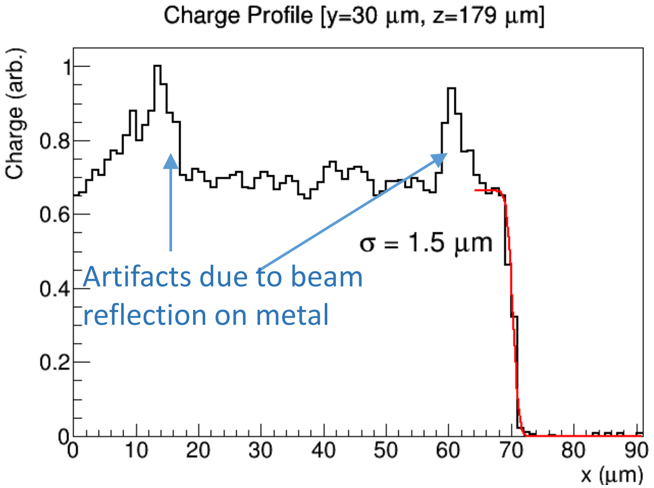
$$z_{\text{R}} = \frac{\pi w_0^2 n_{\text{Si}}}{\lambda} \qquad w_0 = 1.6\ \mu m$$

In-pixel structures







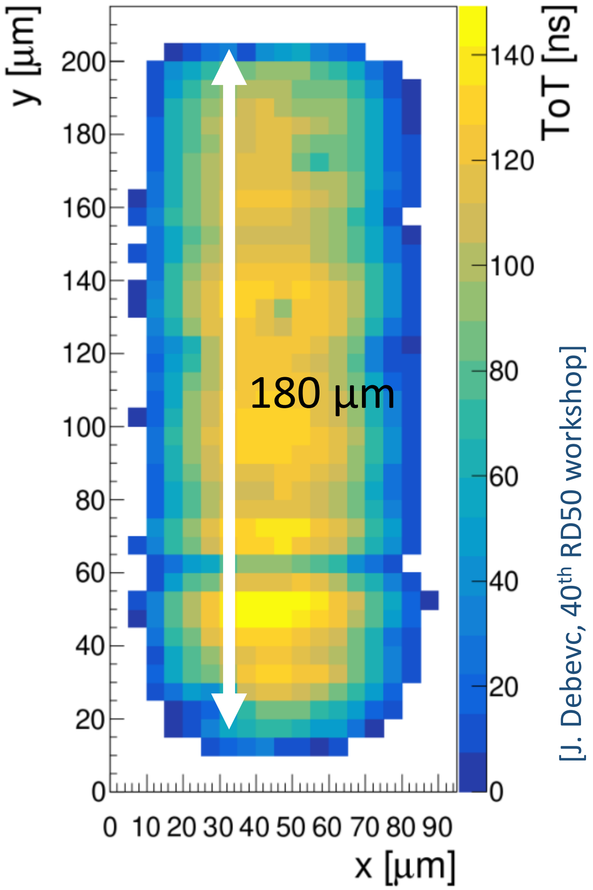


Artifacts due to beam reflection on metal

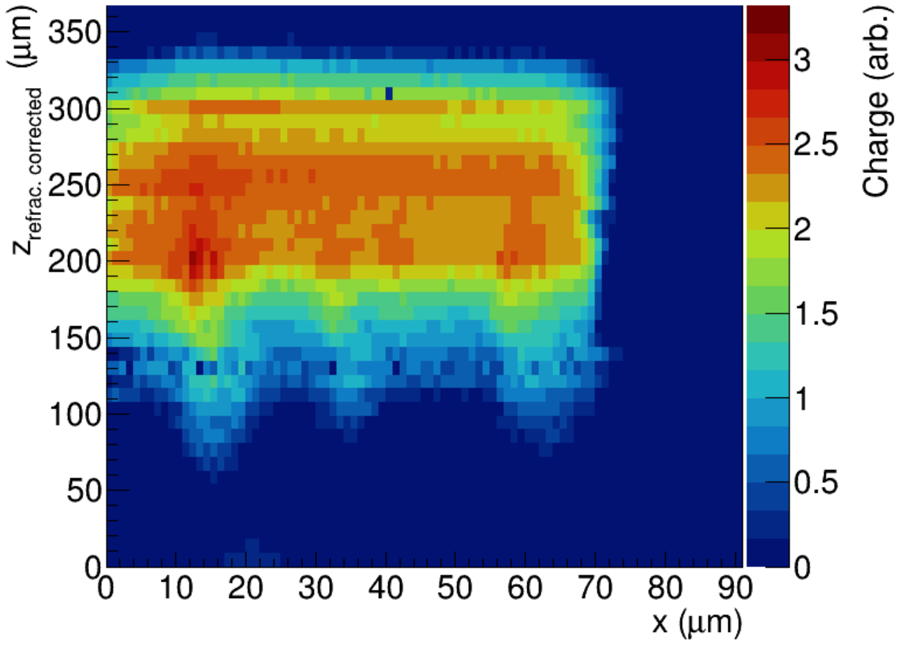
- Metal layer on chip surface visible
  - Contacts for the DNWELL (DNWELL + NISO + NWELL + NPLUS + CONT + MET1)
  - Produce higher signals due to light reflection → more TPA
- Transition on pixel border within 1.5 µm

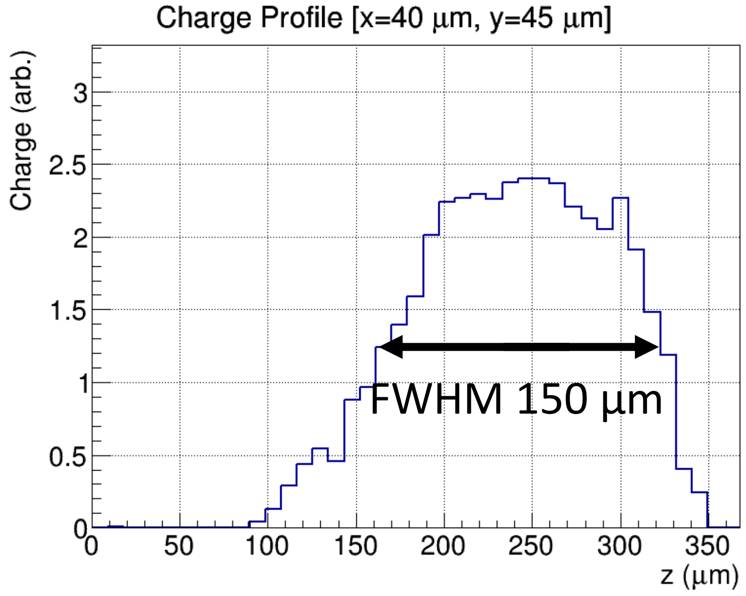
Depletion depth Edge-TCT (SPA) vs. TPA-TCT

V_{bias} = 100 V



[J. Debevc, 40th RD50 workshop]





SPA Edge-TCT
z_{depl} = 180 µm

TPA-TCT
$z_{depl} \approx$ 150 µm

Measured depletion depth roughly matches between both methods
Edge-TCT has much better resolution

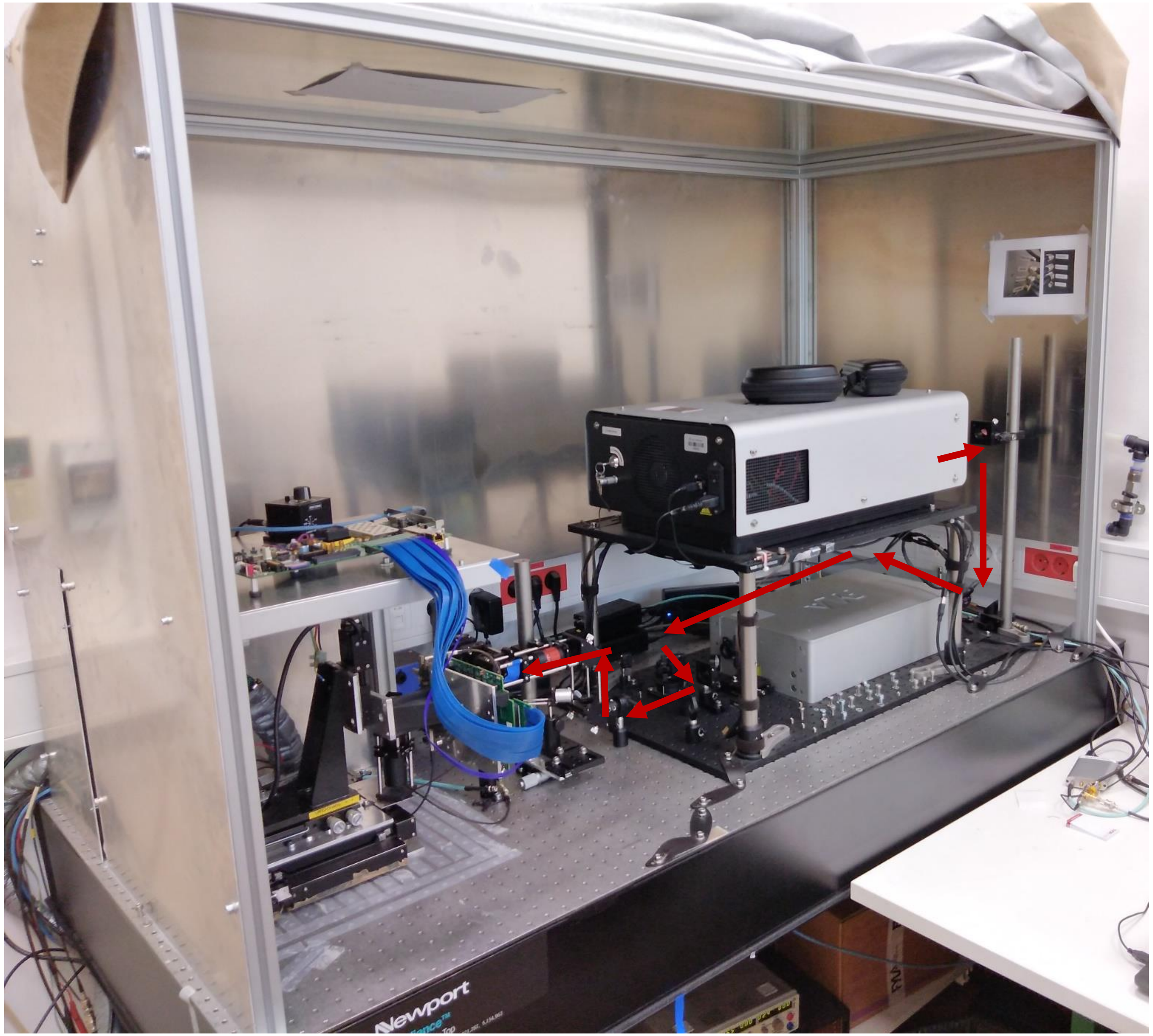
LGAD mortality study with TPA-TCT setup

Background: LGAD Single Event Burnout

- Destructive electrical breakdown observed in irradiated LGAD
  - Observed in testbeam and Laser studies at ELI Beamlines (R. Heller, 38th RD50 Workshop; G. Lastovicka-Medin, 38th RD50 Workshop)
  - Occur at large electric fields > 12 V/µm
  - Mechanism:
    - Rare events with extremely high energy deposition ≥ 20 MeV
    - Localized conductive path → destructive electrical breakdown (Single Event Burnout – SEB)

- Try to replicate SEB with TPA-TCT setup

SEB setup with TPA

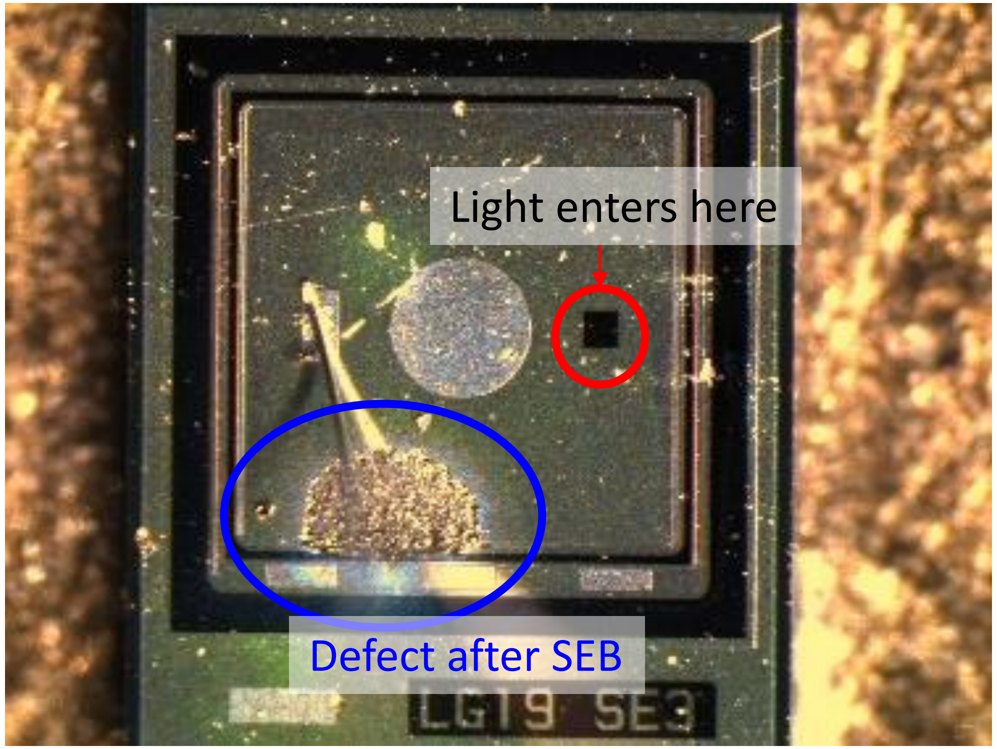


- Maximizing pulse energy is a priority
  - Pulse management module has high losses (75 %) → bypassed
  - 8 MHz repetition rate
  - Pulse energy 5 nJ after objective (40 mW)

- Samples
  - Single channel HPK Type 3.2 LGADs
  - Thickness 50 µm
  - 3e15 n_{eq}/cm^2 neutron irradiated
  - Cooled to –30 °C

SEB study results

- SEB induced on two samples at 670 V bias
  - Within seconds after turning on max power
  - Visible defect appears on one sample
  - Sample does not recover
- No SEB induced on two other samples (same fluence)
  - Probably higher pulse energy is required
- An issue of the method is thermal runaway
  - Large ionization current due to pulse repetition rate of 8 MHz
  - Leakage current up to 5 mA at –30 °C in a 1.3 mm x 1.3 mm pad
  - This causes thermal runaway around 670 V, measurement cannot be sustained for longer than a few seconds



Summary

- TPA-TCT setup is running at JSI
- Demonstrated charge injection through the backside of a sensor
- Depletion depth compatible with SPA Edge-TCT measurements
- High precision *xy* probing of in-pixel structures on RD50-MPW2 CMOS chip
- Trialed Single Event Burnout tests on irradiated LGAD
  - SEB induced on two out of four tested LGADs (3e15 n_{eq}/cm^2)
  - Method is limited by maximal achievable pulse energy
  - Problems with high leakage current (pulse repetition rate) causing thermal runaway