Status of CMS LGAD sensor testing

Jae Hyeok Yoo (Korea University)

11/03/2022

APCTP Workshop on the Physics of Electron Ion Collider

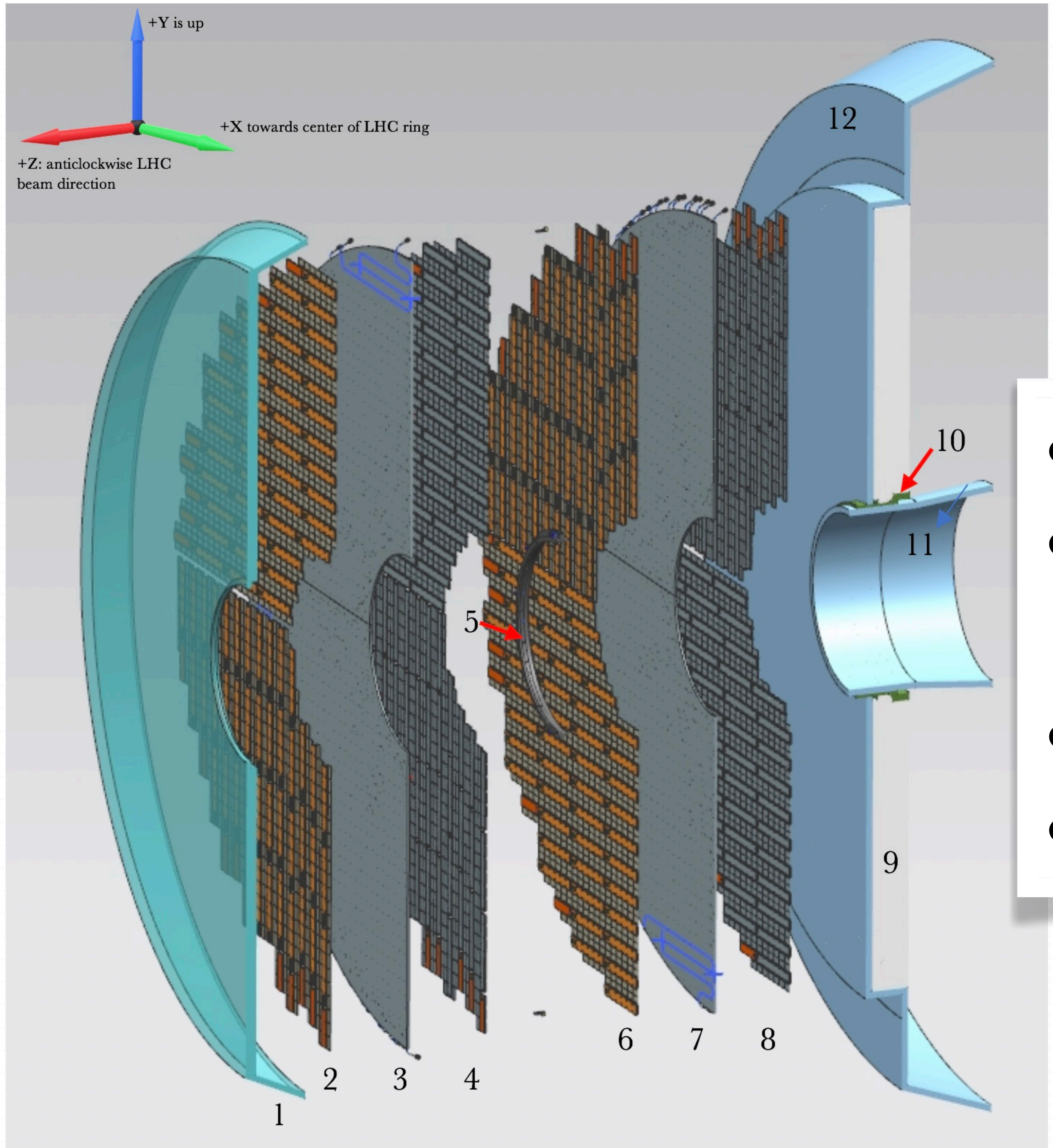
@ Howard Johnson Incheon Airport Hotel

Endcap Timing Layer (ETL)

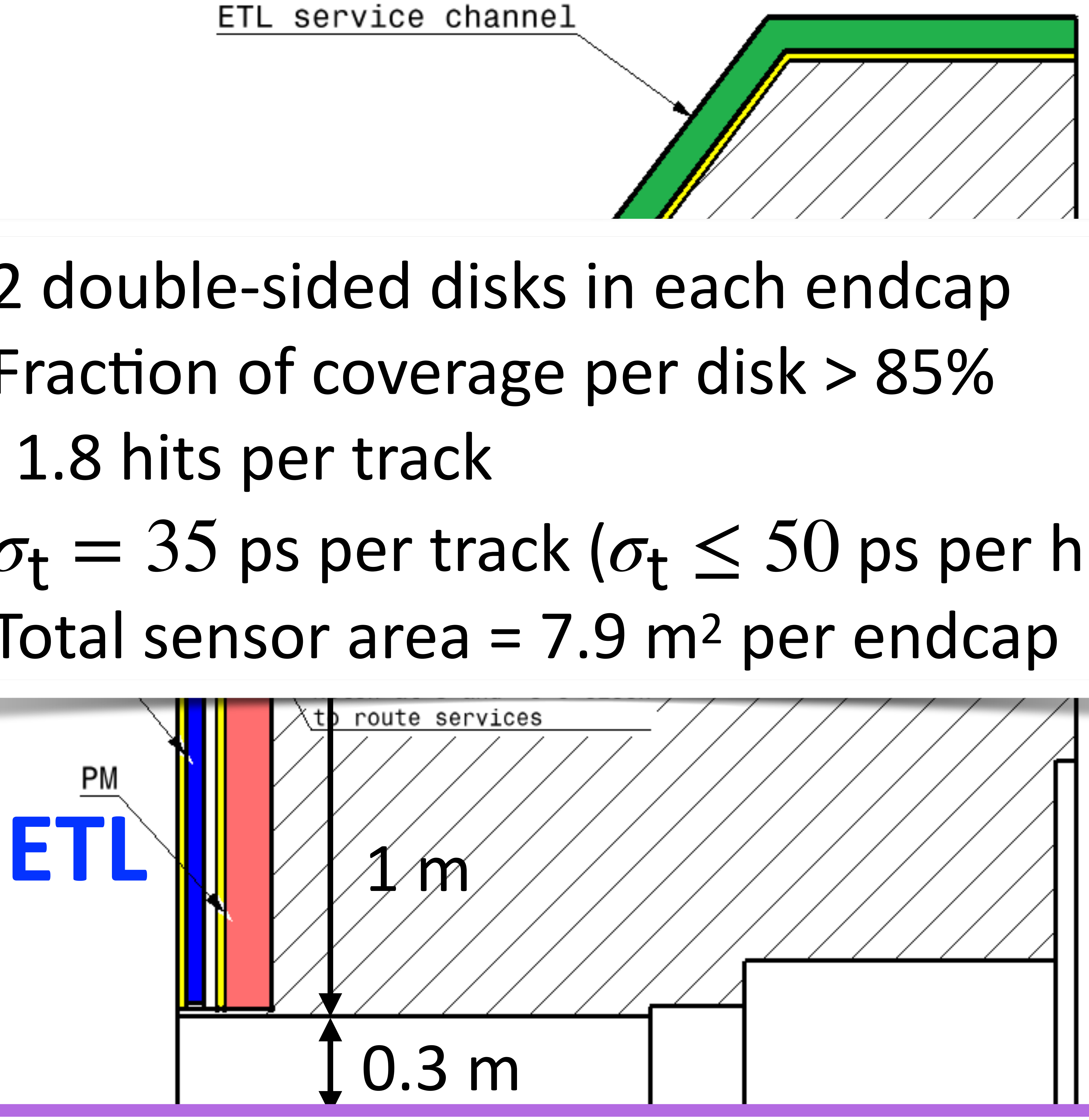
η coverage: 1.6 - 3.0
3 m from IP
Width = 4.5 cm

Endcap Timing Layer (ETL)

1: ETL Thermal Screen
2: Disk 1, Face 1
3: Disk 1 Support Plate
4: Disk 1, Face 2
5: ETL Mounting Bracket
6: Disk 2, Face 1
7: Disk 2 Support Plate
8: Disk 2, Face 2
9: HGCal Neutron Moderator
10: ETL Support Cone
11: Support cone insulation
12: HGCal Thermal Screen



- 2 double-sided disks in each endcap
- Fraction of coverage per disk > 85%
  - 1.8 hits per track
- $\sigma_t = 35$ ps per track ($\sigma_t \leq 50$ ps per hit)
- Total sensor area = 7.9 m^2 per endcap

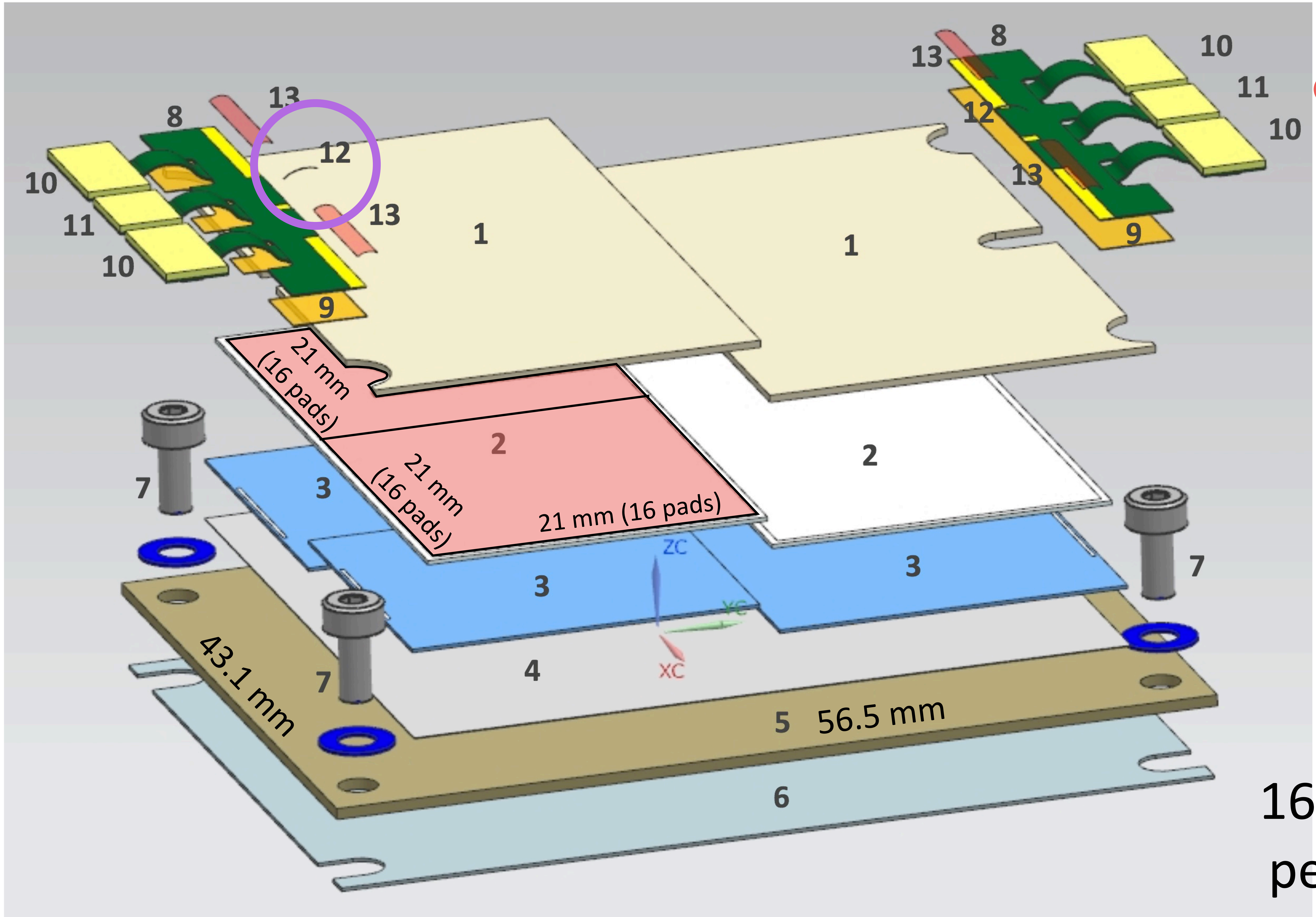


beamline

IP

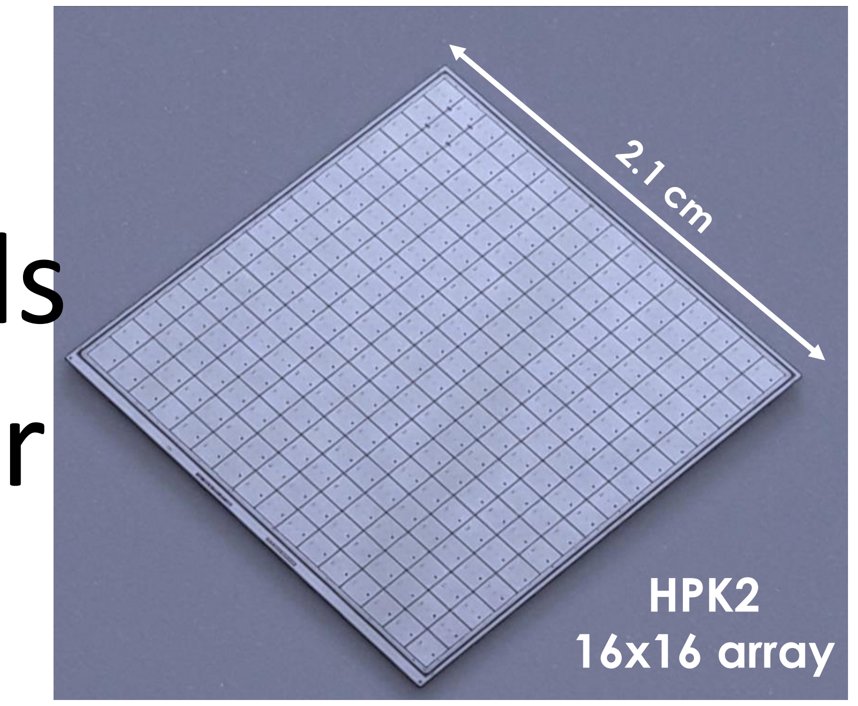
3 m

LGAD sensors in module

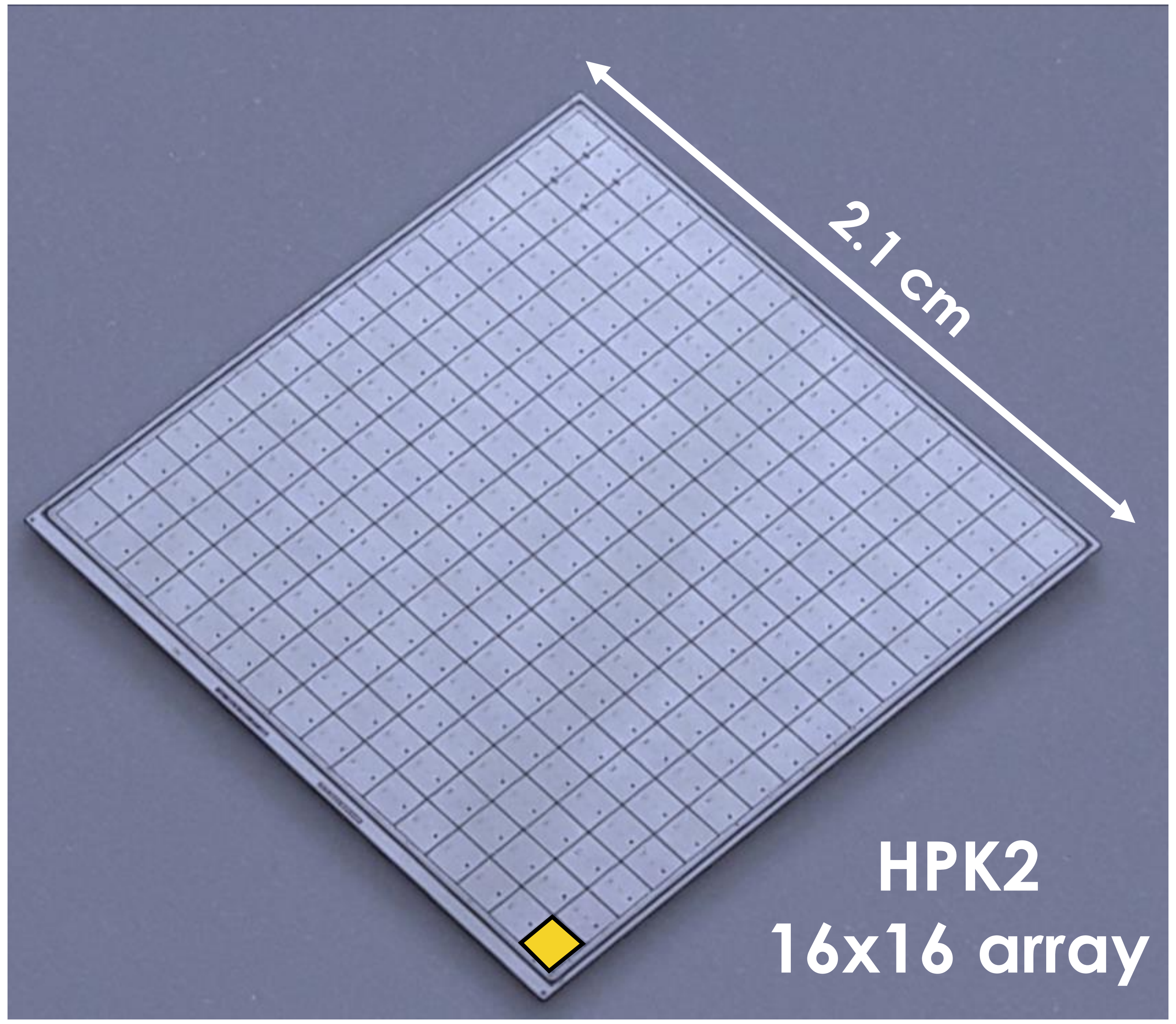


1: AlN module cover
2: LGAD sensor
3: ETL ASIC
4: Mounting film
5: AlN carrier
6: Mounting film
7: Mounting screw
8: Front-end hybrid
9: Adhesive film
10: Readout connector
11: High voltage connector
12: LGAD bias voltage wirebond
13: ETROC wirebonds

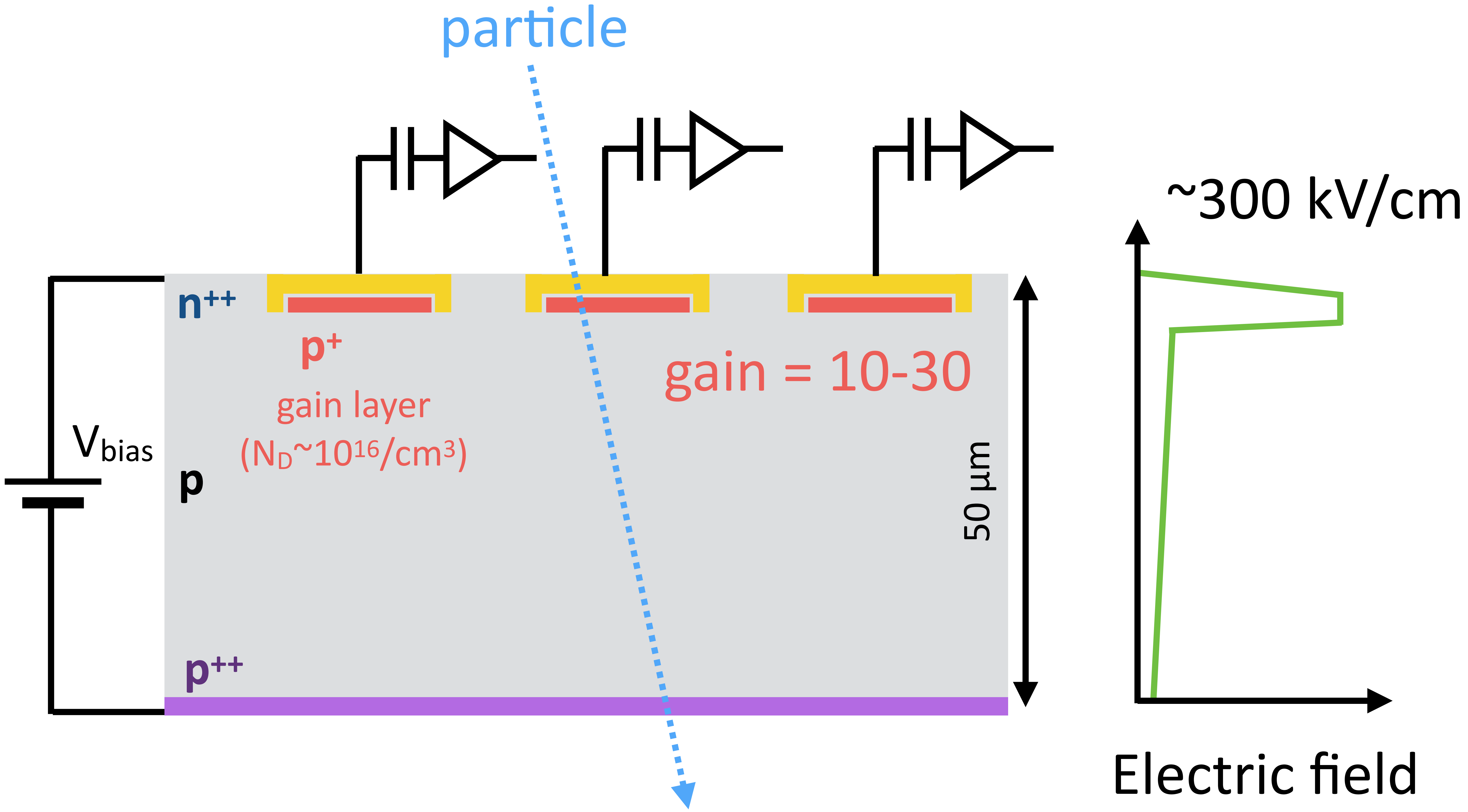
16x16 pads
per sensor



LGAD sensor



One pad (pixel) = 1.3x1.3 mm^2

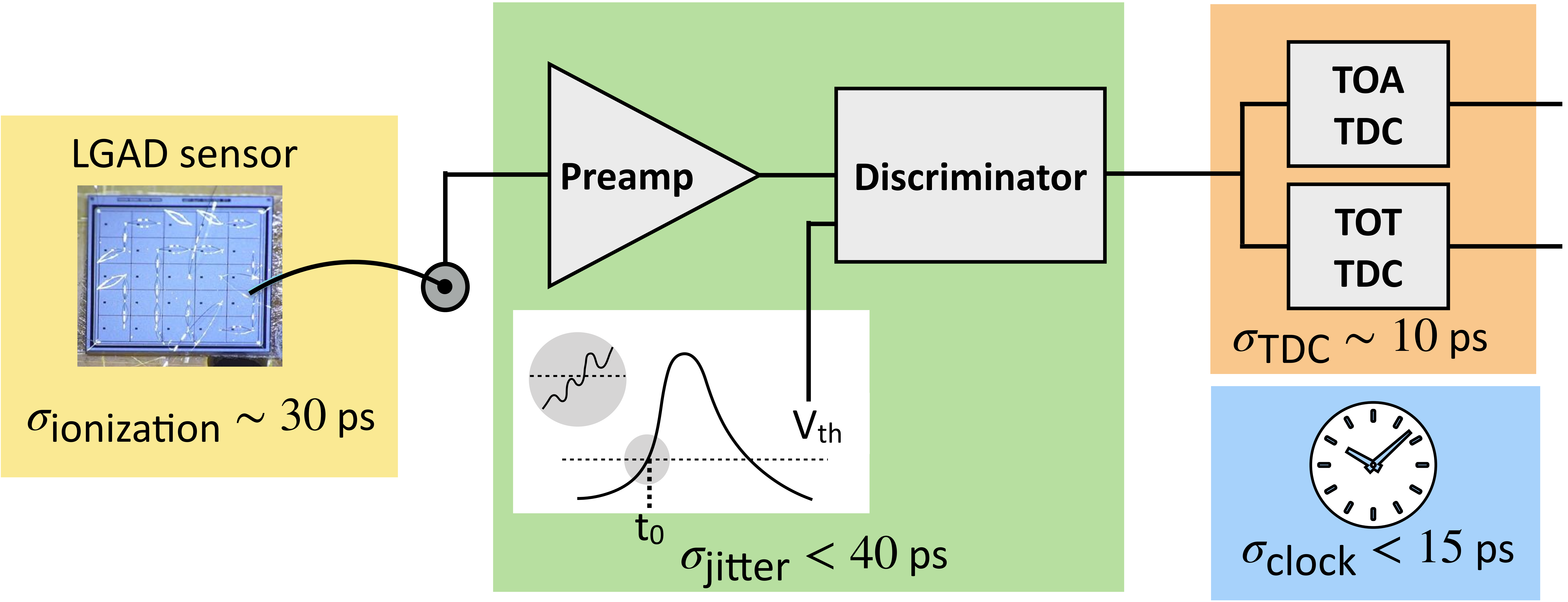


Additional layer added to traditional n-in-p sensor

Parameters that affect time resolution

How to obtain 50 ps resolution per hit

$$\sigma_t^2 = \sigma_{\text{ionization}}^2 + \sigma_{\text{jitter}}^2 + \sigma_{\text{TDC}}^2 + \sigma_{\text{clock}}^2$$



Main contributor to time resolution

How to obtain 50 ps resolution per hit

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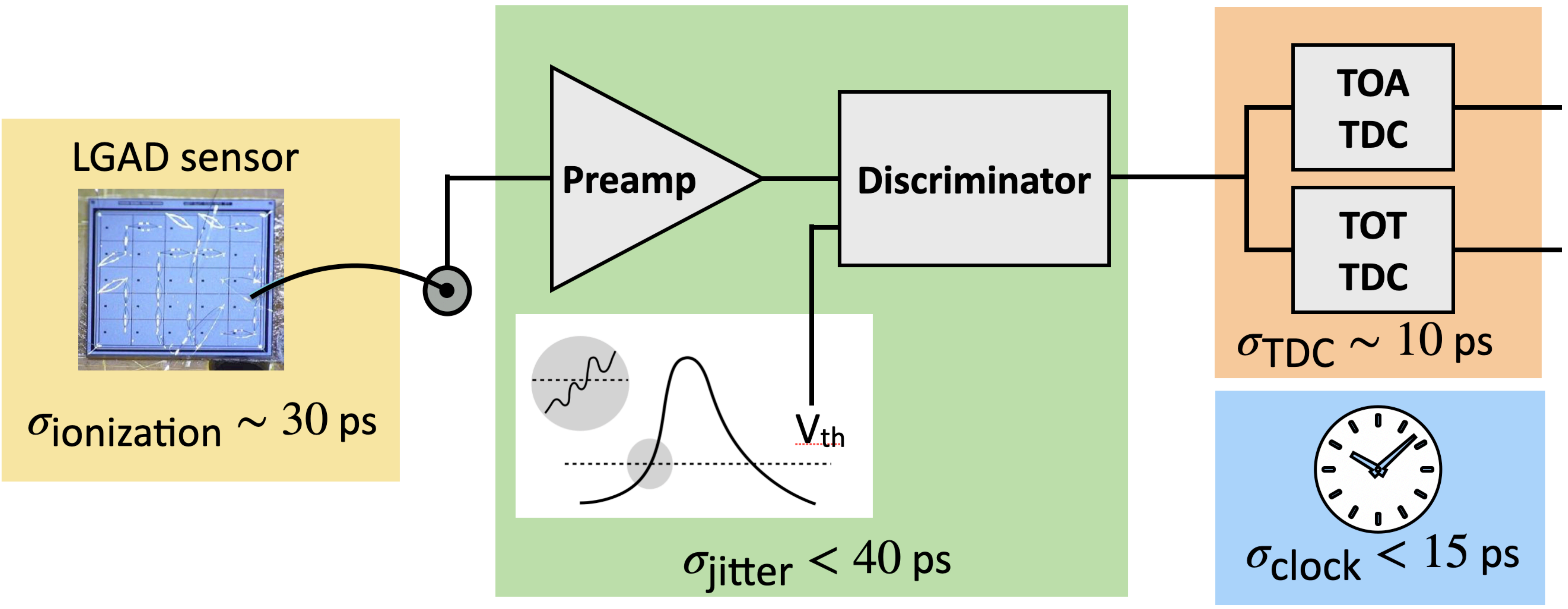

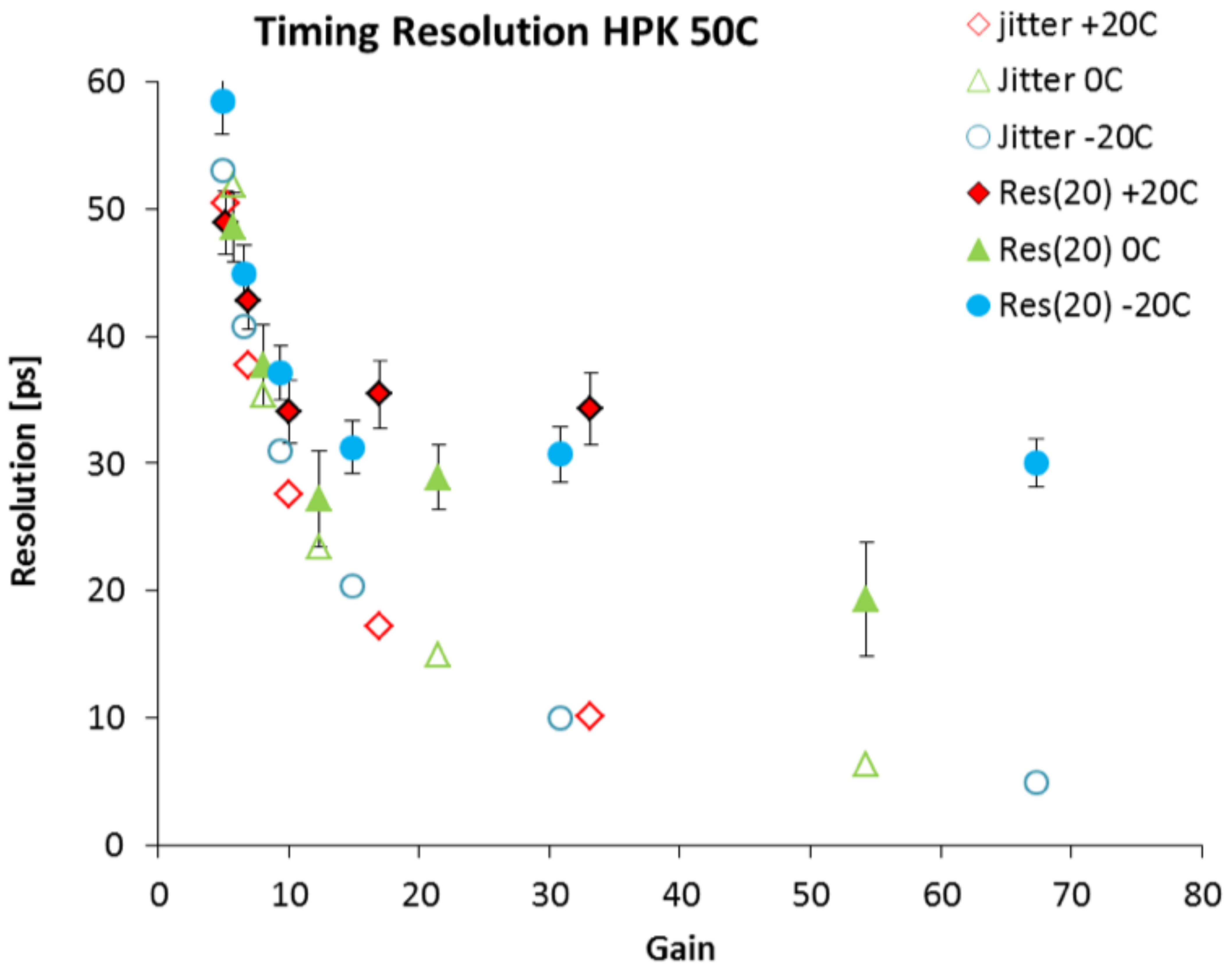

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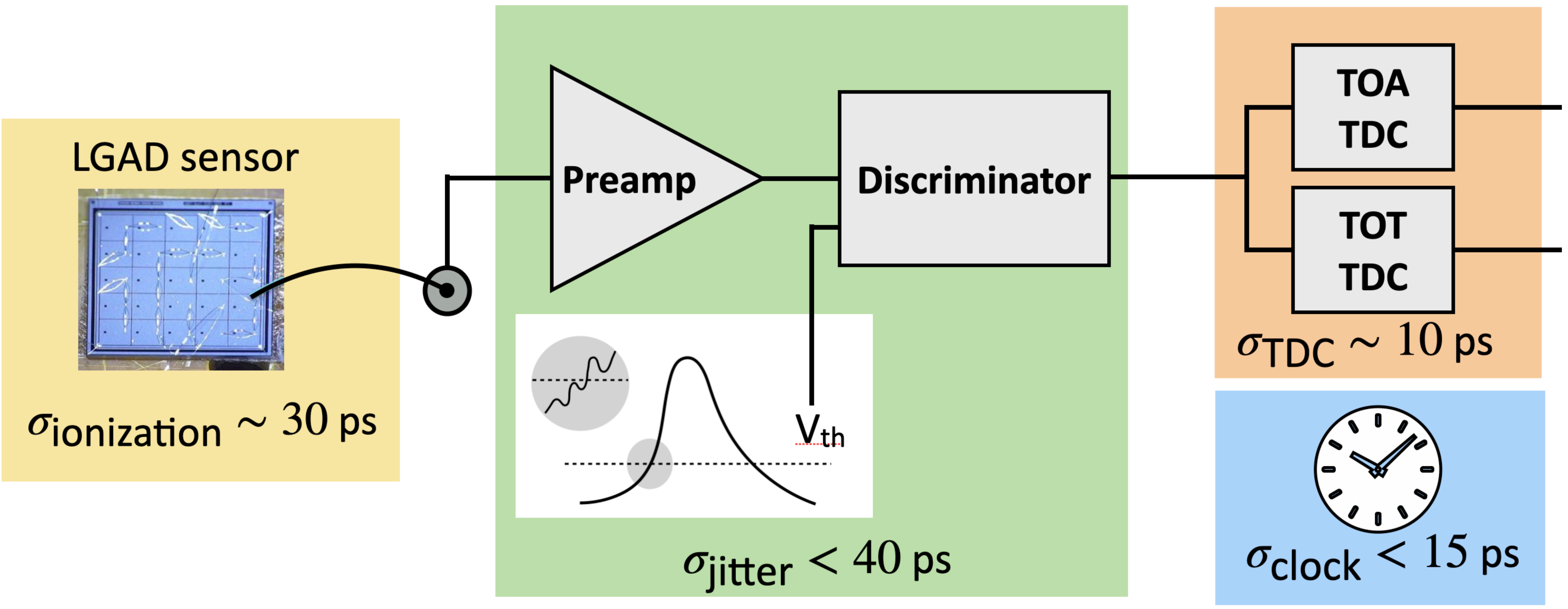

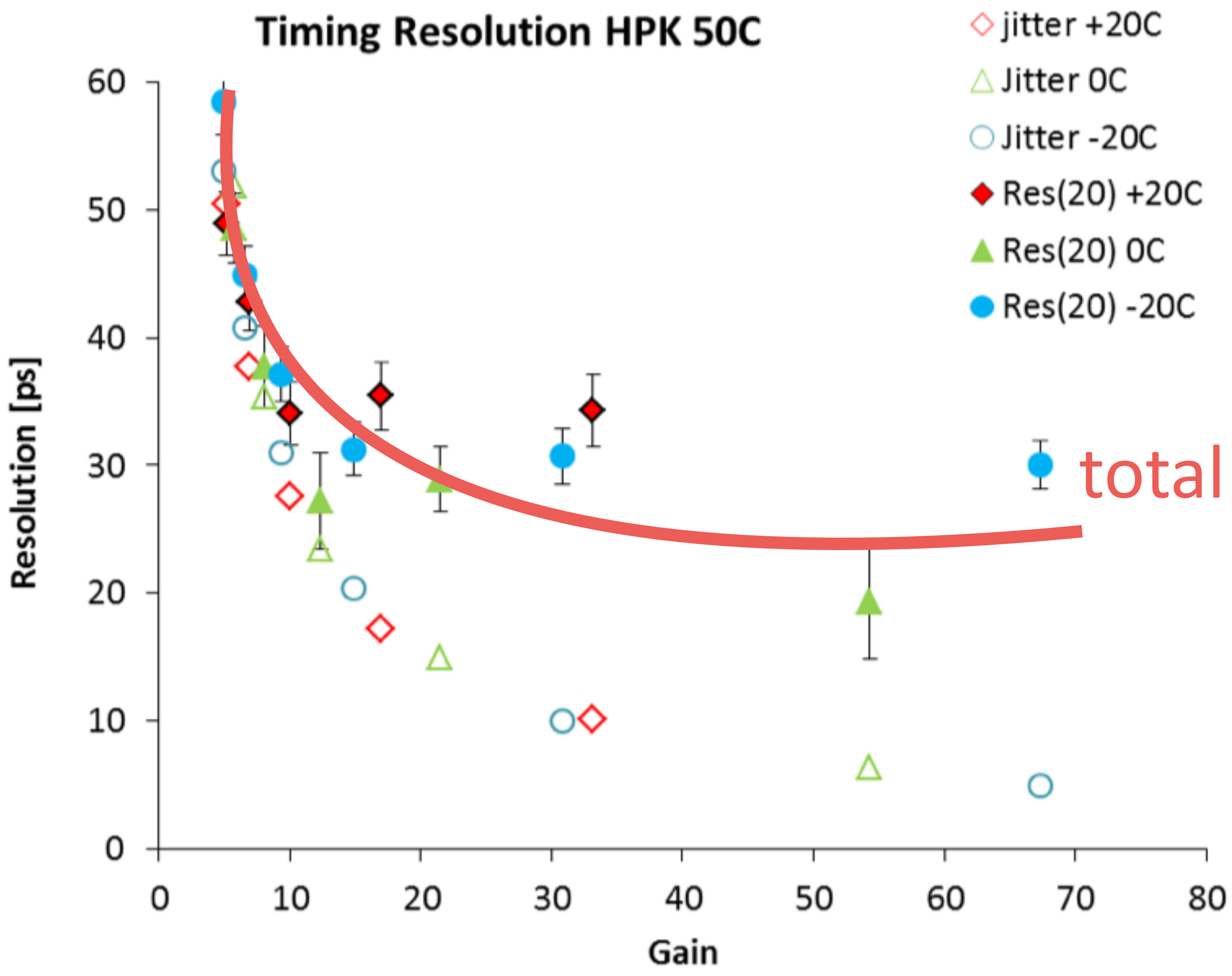

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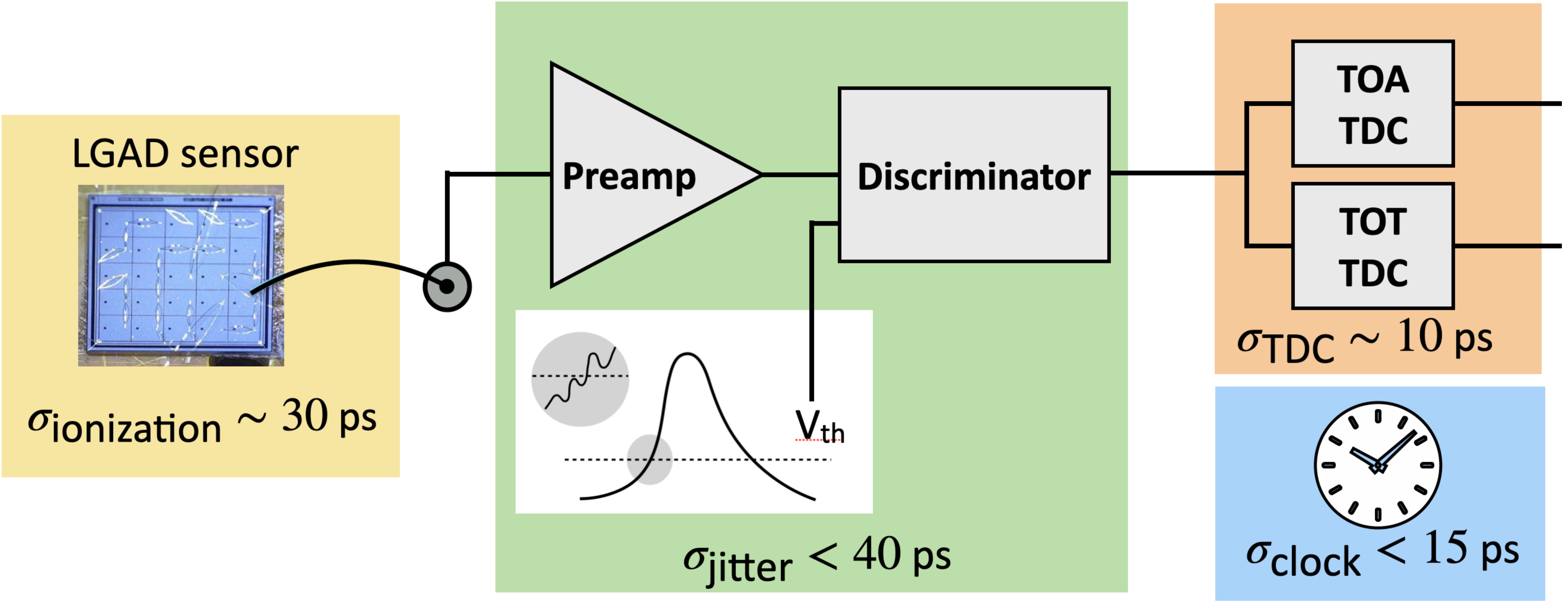
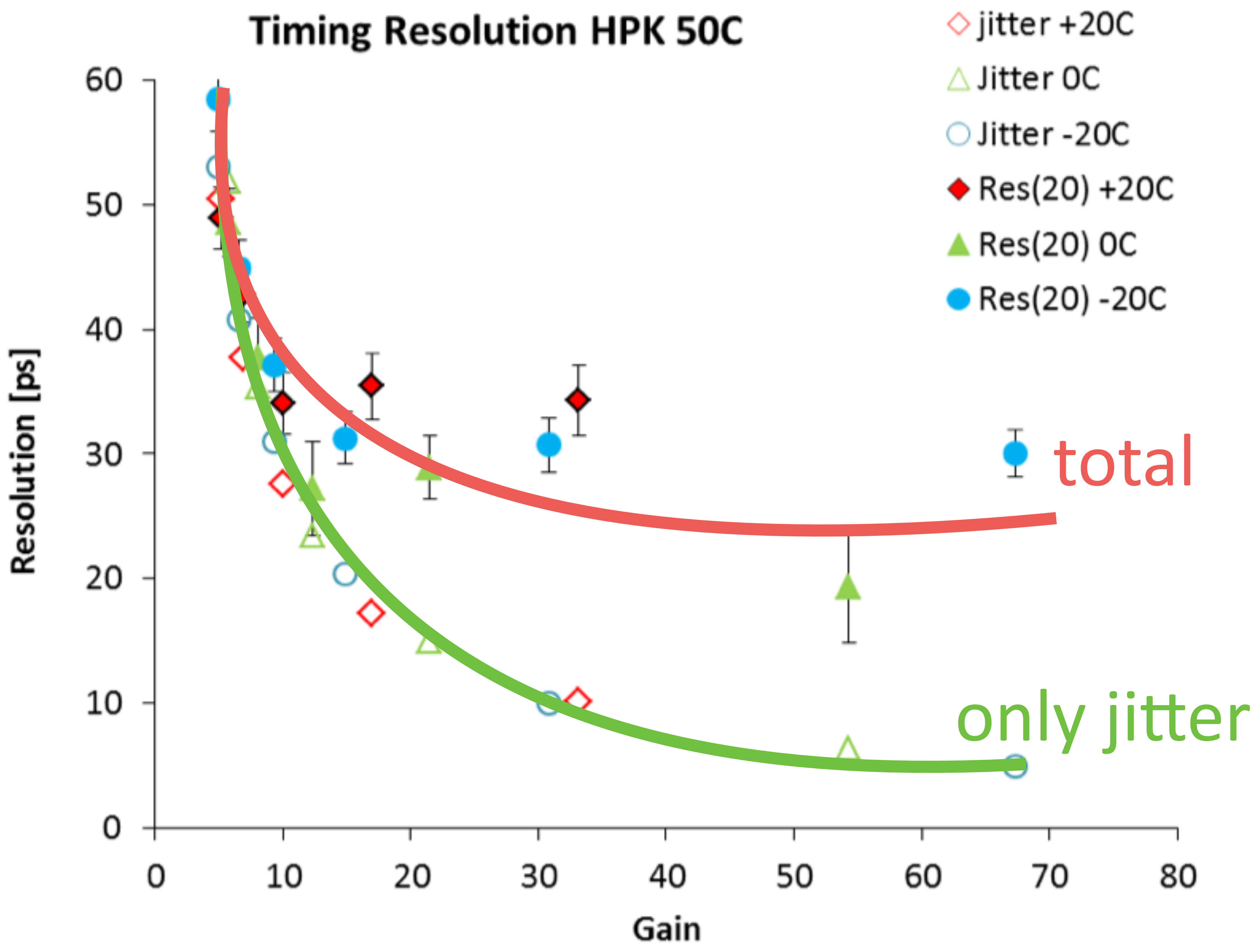
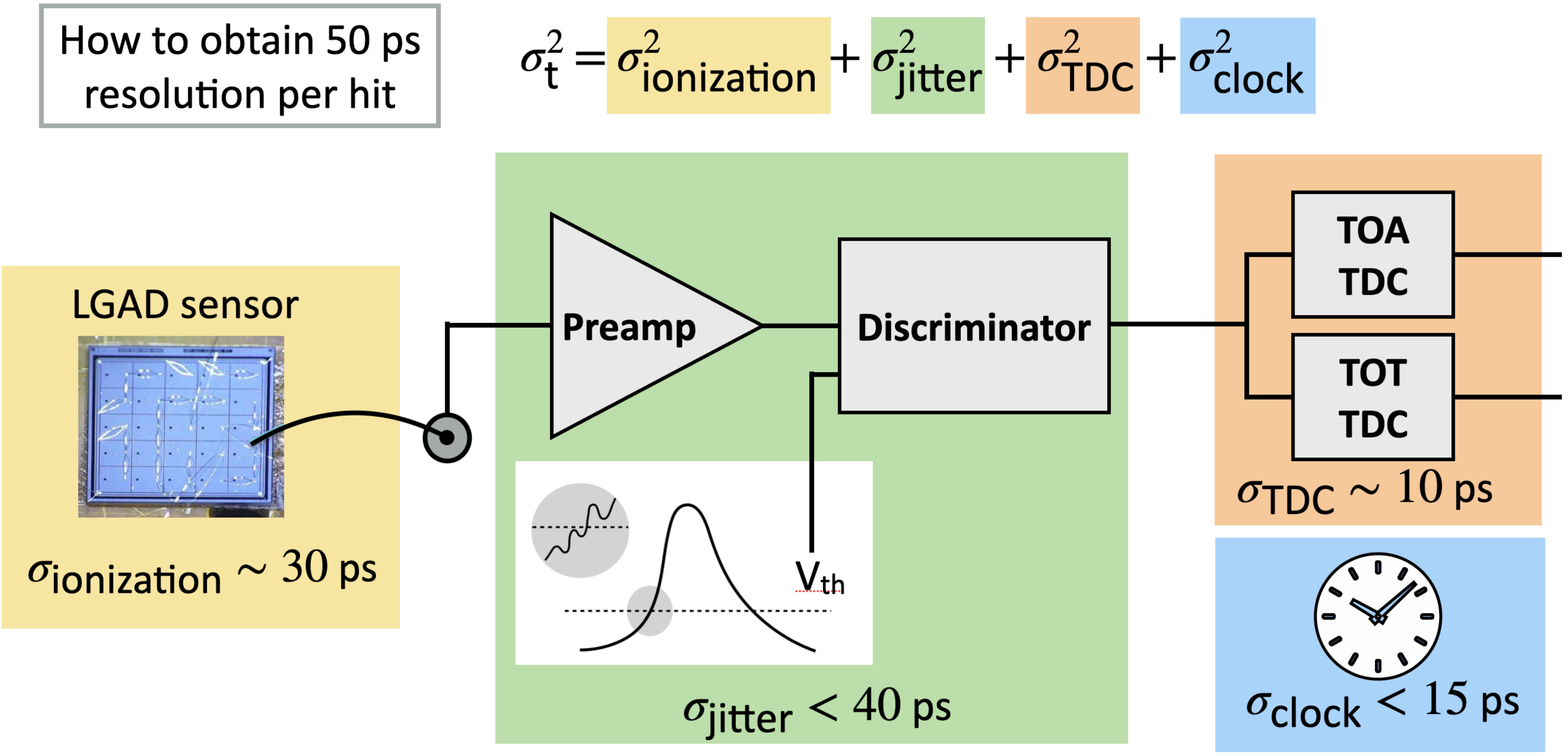
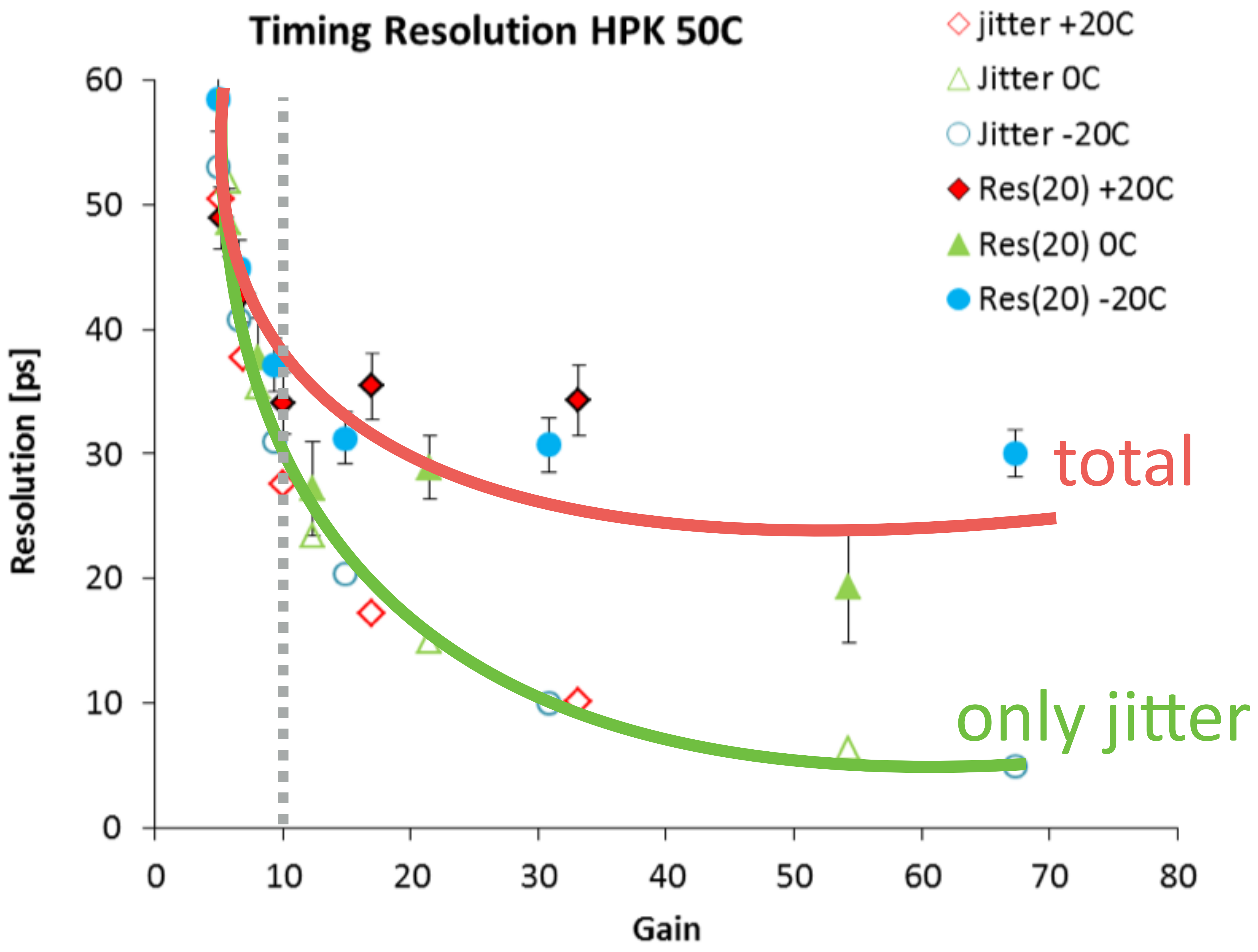




Main contributor to time resolution





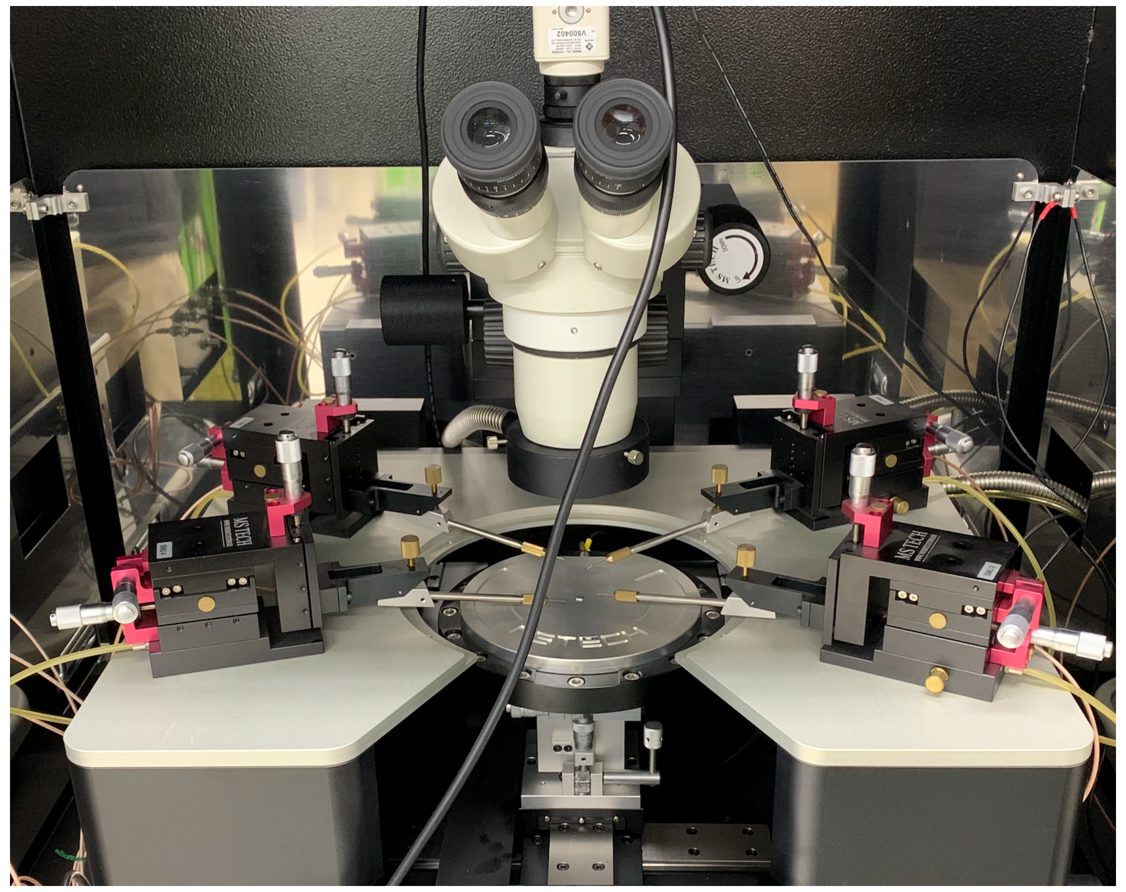
In gain > 10, main contribution is sensor resolution (dominated by Landau fluctuations)

Market Survey (MS)

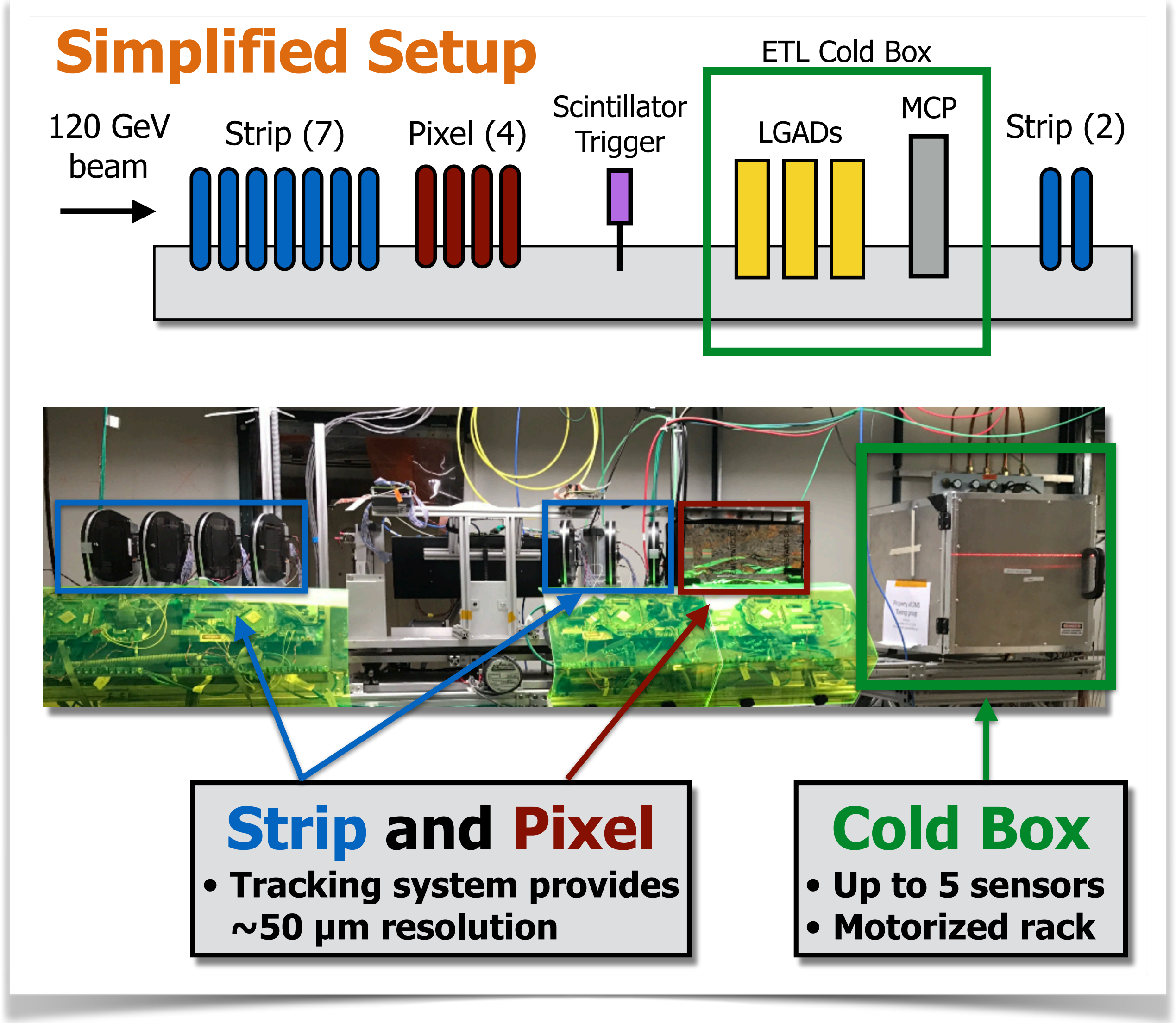
- We are in the process of Market Survey (MS)
- Goal is to identify potential sensor manufacturers
  - FBK (Italy), HPK (Japan), IHEP-IME (China-Singapore), Teledyne (U.S.), MICRON (U.S.), CNM (Spain)
- INFN Torino, Fermilab, IFCA, UCSB, UZH, HIT and Korea University (KU) are participating in the MS sensor testing
- Rest of the talk will focus on the recent activities @KU

How are sensors tested?

Probe station @KU

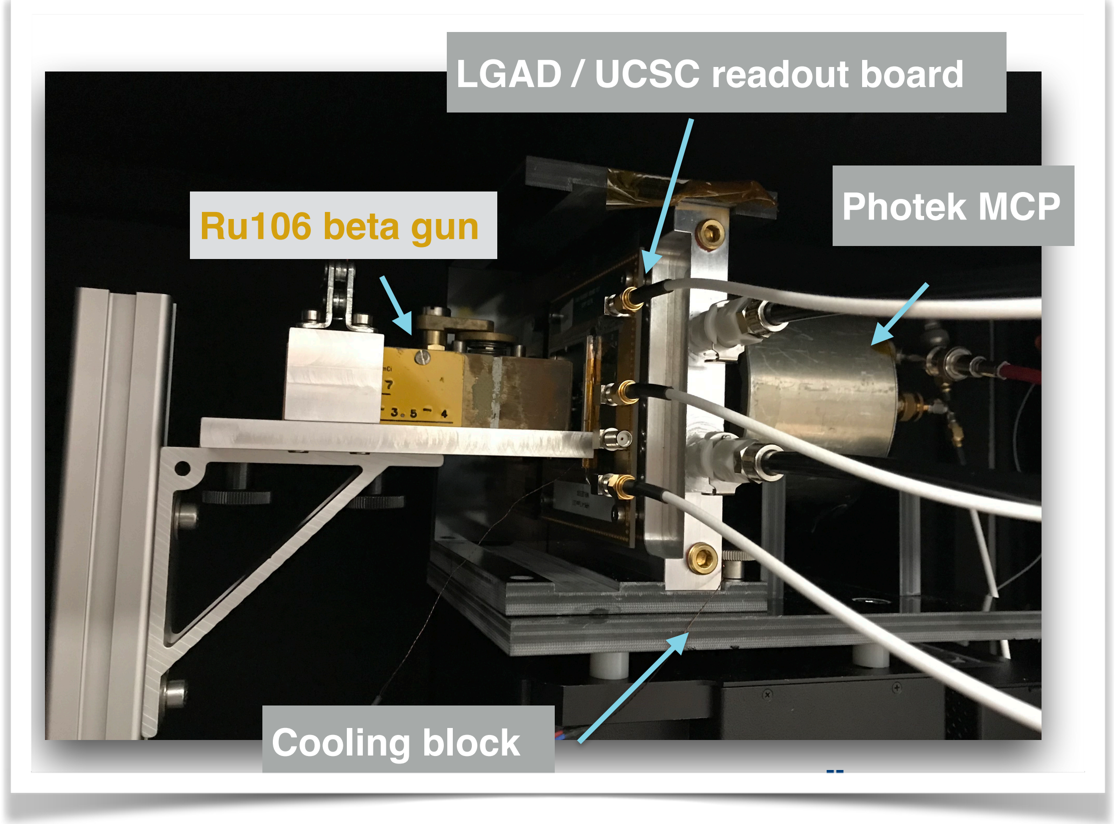


Test beam setup @FNAL

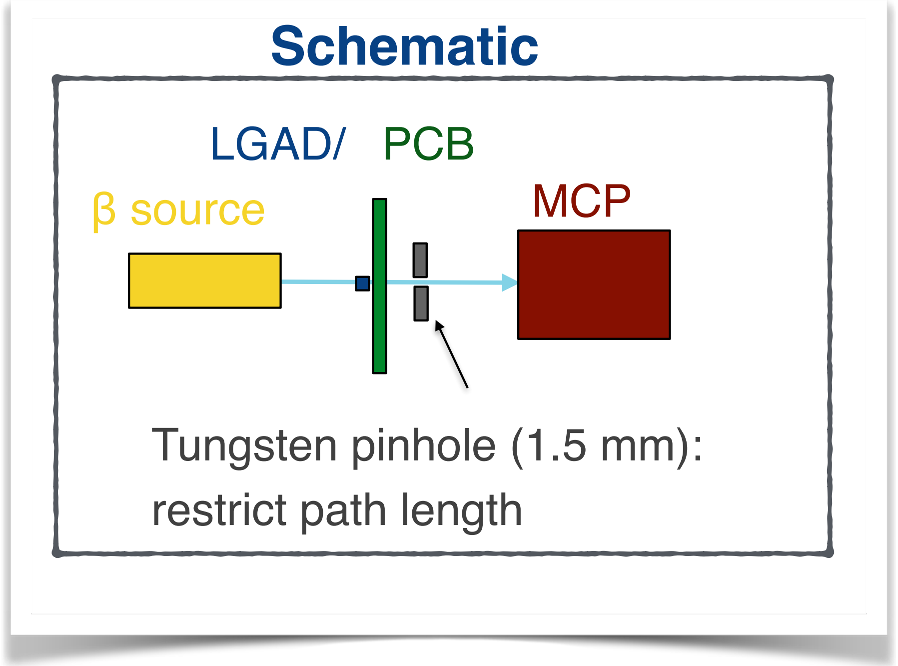


Andres Abreu Nazario

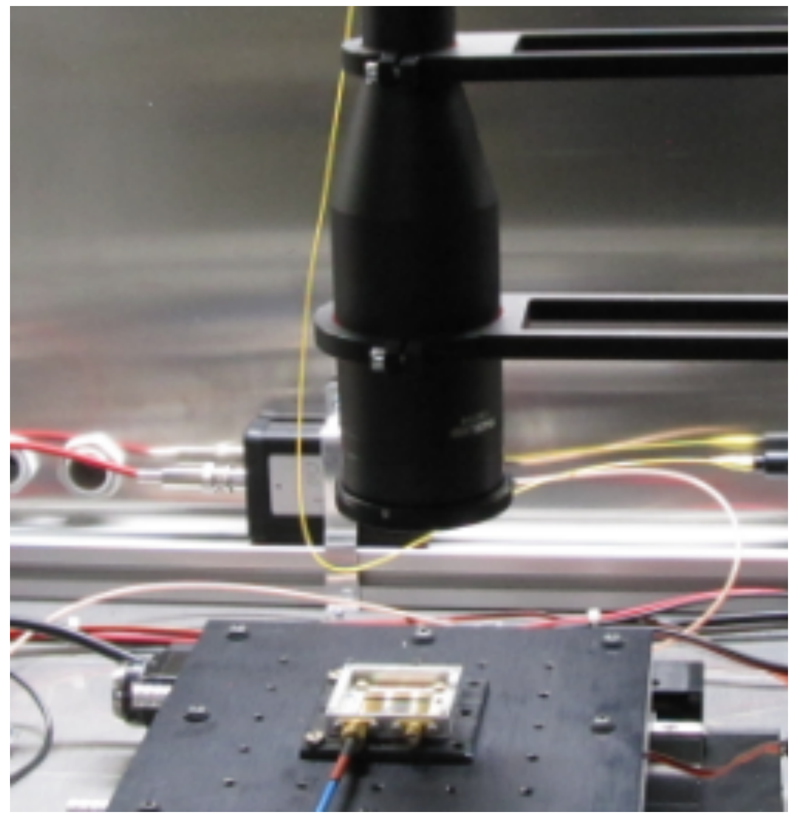
Beta source test setup @FNAL



Ryan Heller



Laser scanning device @KU



- Probe station
  - Measure IV and CV curves
- Test beam
  - Measure gain, hit efficiency, timing
  - At FNAL, 1-2 times per year
- Beta source
  - Measure gain, timing
- Laser scanning device
  - Measure uniformity of gain, inter-pad gap

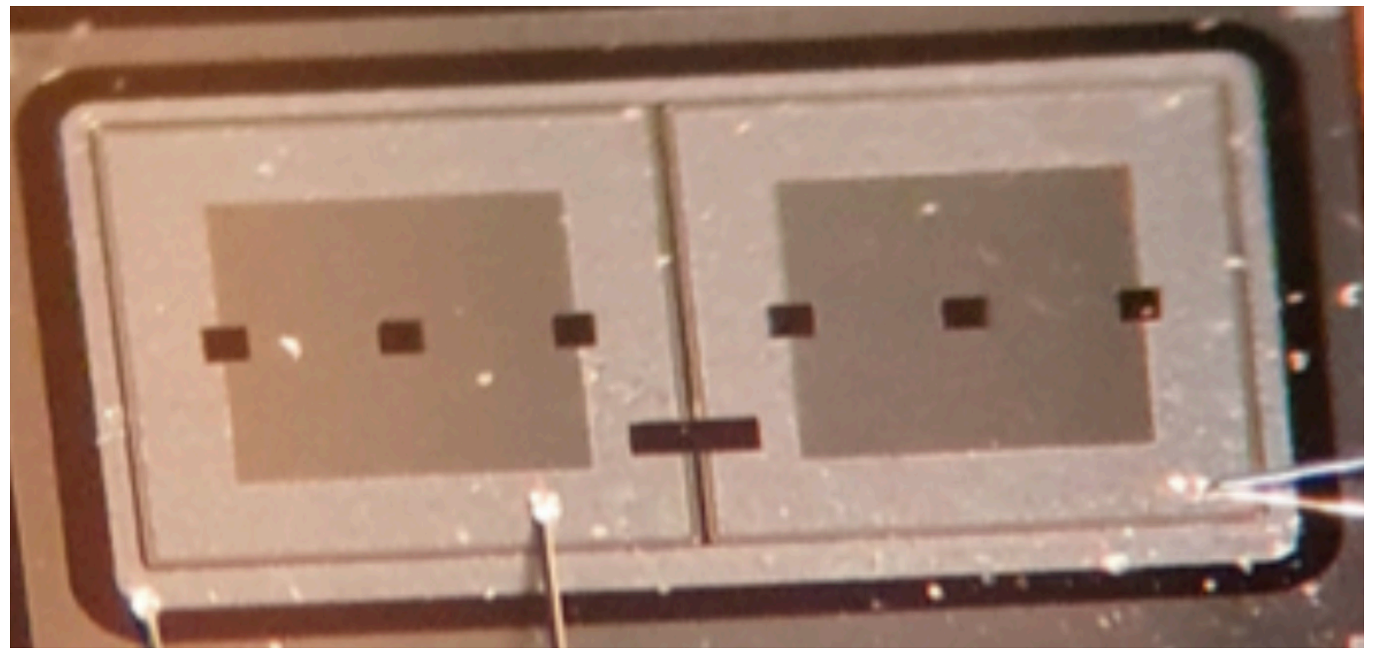
Highlights of sensor testing at KU

- KU participated in the FBK sensor testing campaign
- Some highlights from our testing on the FBK sensors are shown in this talk
- Used probe station and laser scanning device for the tests

Dr. Kyungmin Lee

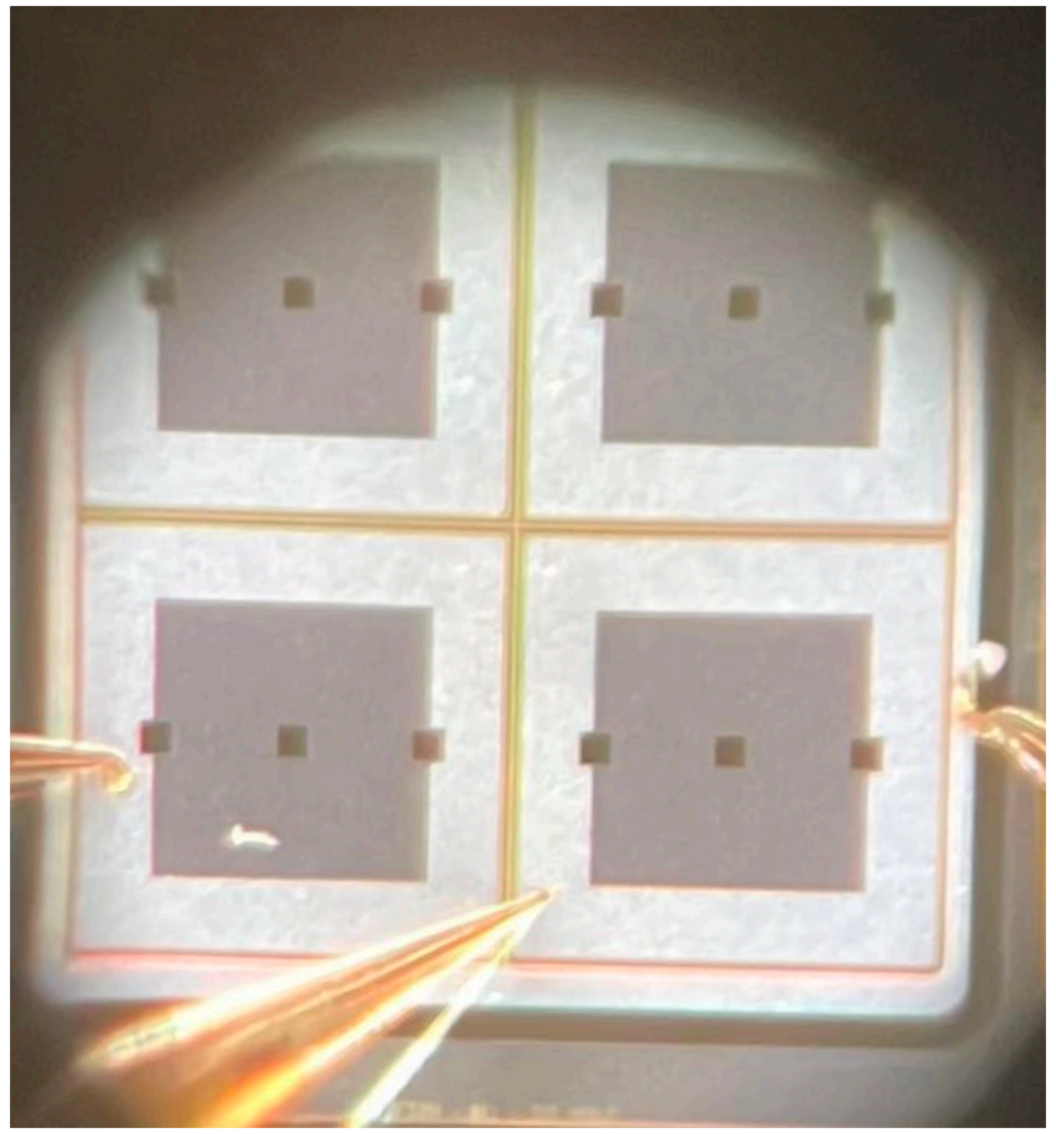
Byeong Jin Hong (G2)

FBK 1x2 sensor



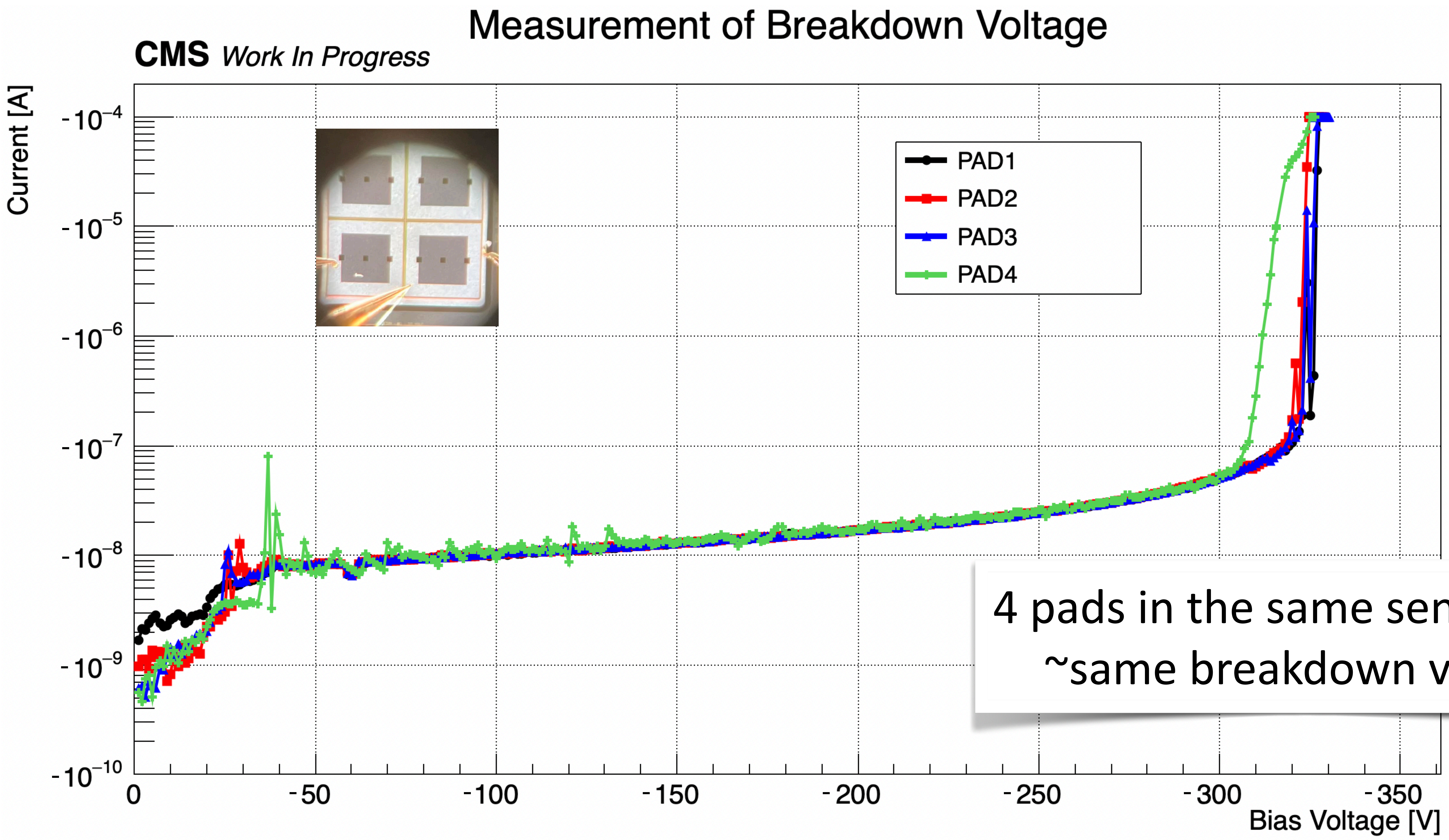
- Breakdown voltage (I-V)
- Bulk depletion voltage (C-V)

FBK 2x2 sensor



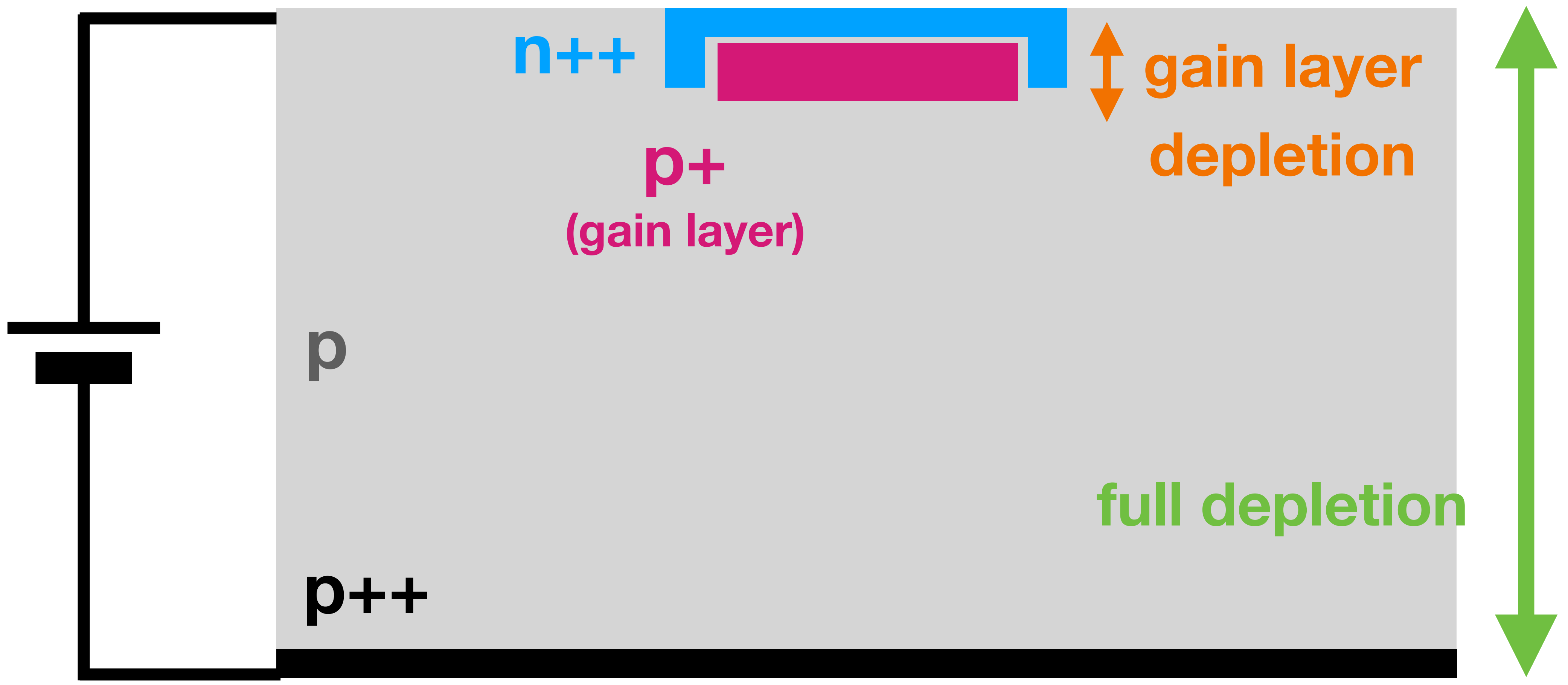
- Pad isolation (inter-pad resistance)
- Inter-pad distance (gap measurement)

Breakdown voltage (I-V measurement)



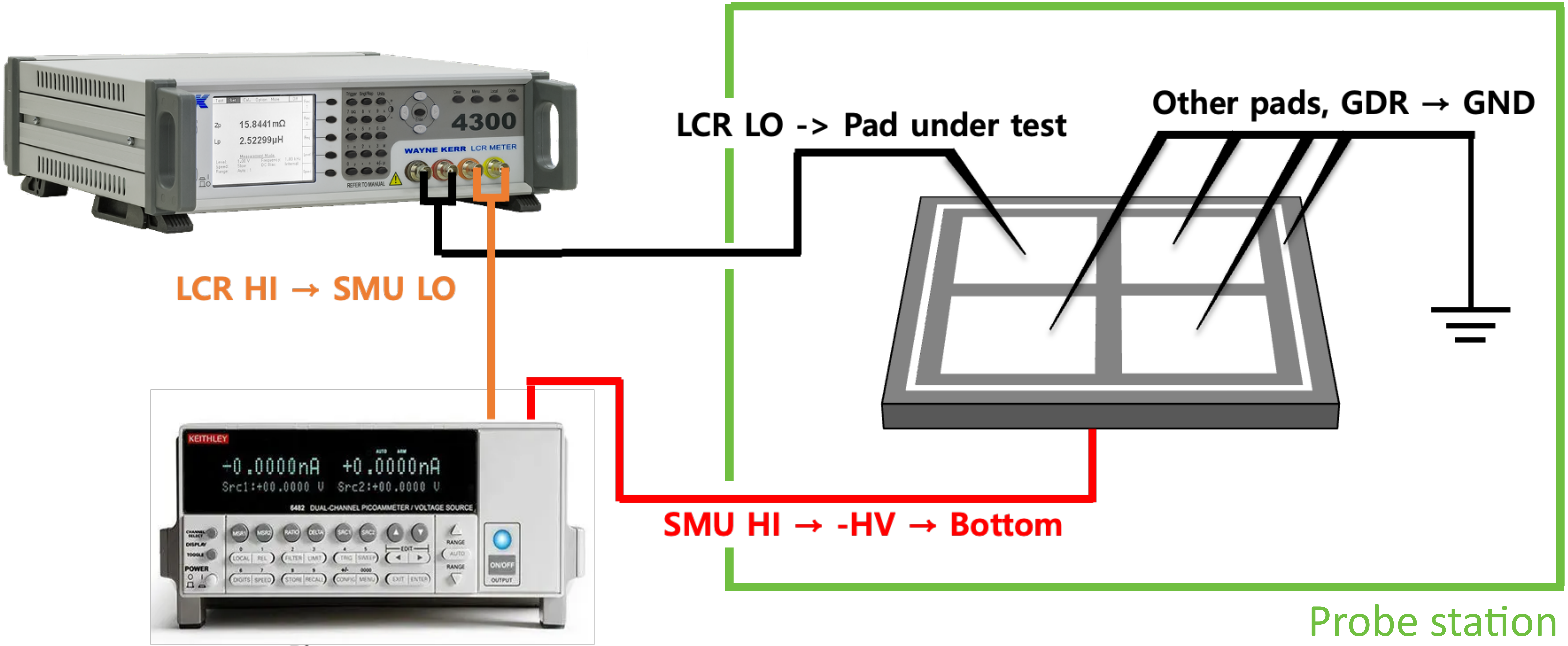
4 pads in the same sensor have ~same breakdown voltage

C-V measurement



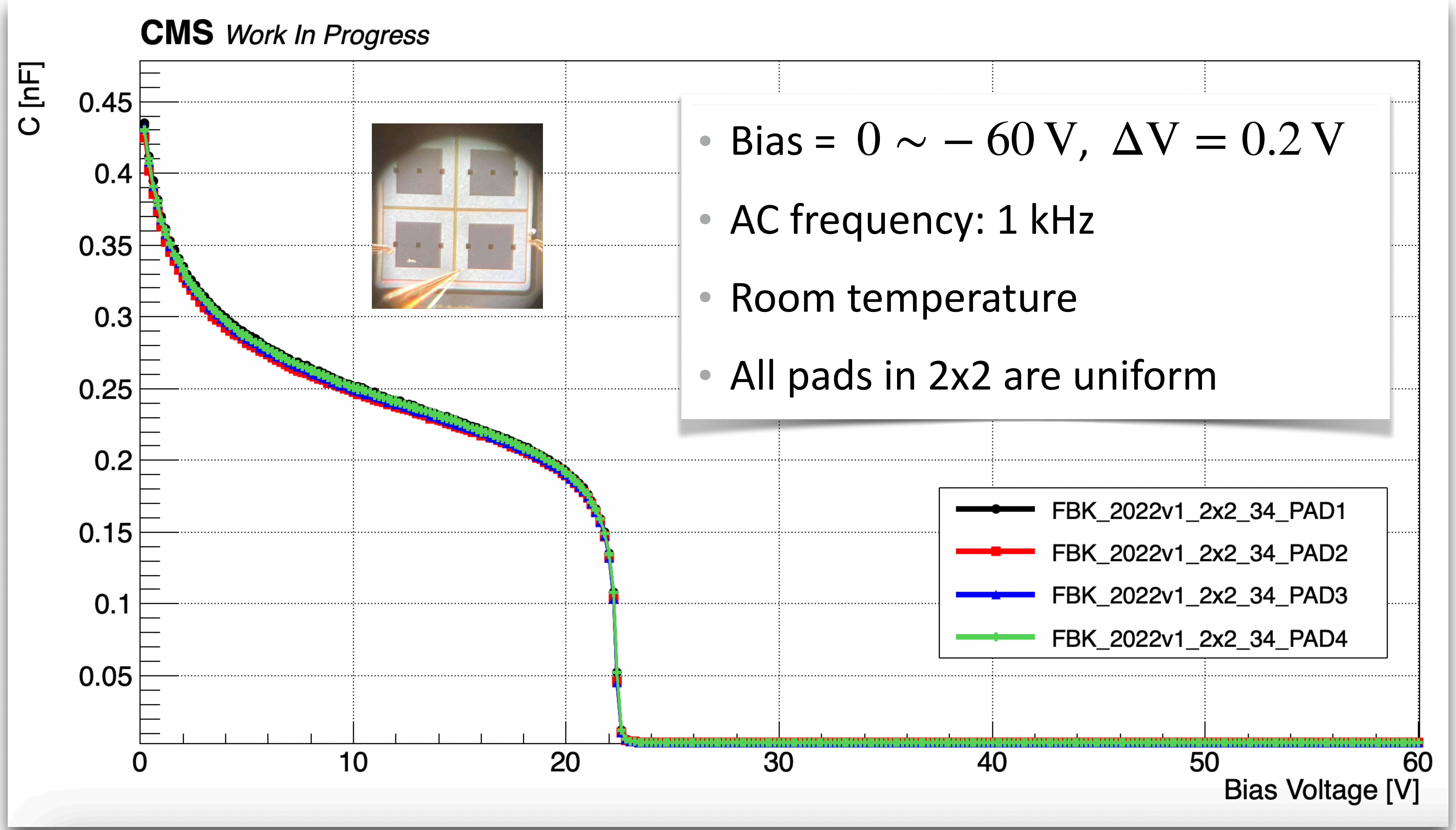
- The full depletion voltage is the value of voltage when the capacitance becomes constant
- $C = A\sqrt{\dfrac{\epsilon q N_{\text{eff}}}{2V}}$: This equation works until the bulk is fully depleted
- $V \propto \dfrac{1}{C^2}$ $\rightarrow$ Get full depletion voltage by plotting $\dfrac{1}{C^2}$ vs V

Setup for C-V measurement

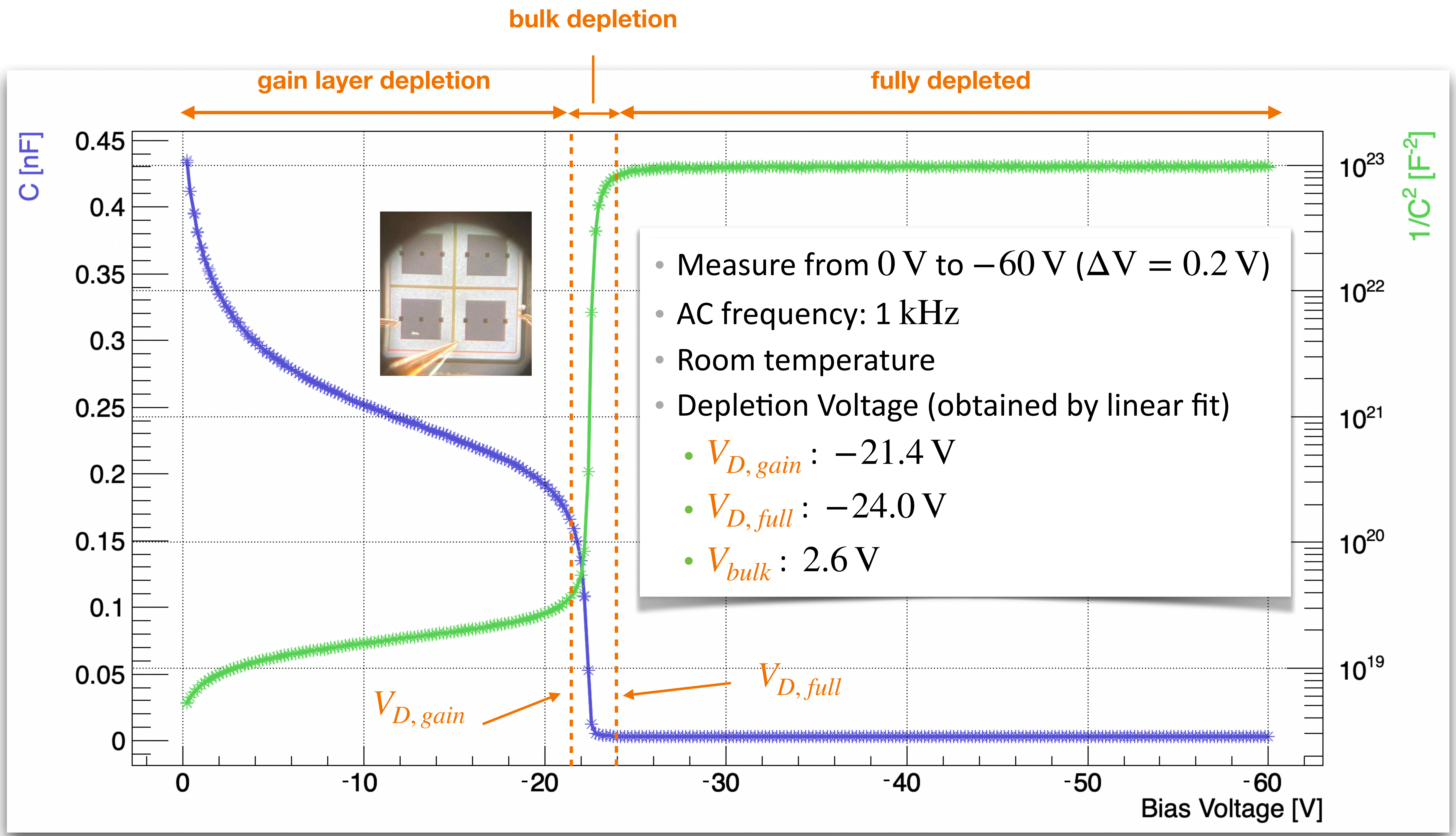


Picoammeter
(Keithley 6487)

Results (C-V measurement)

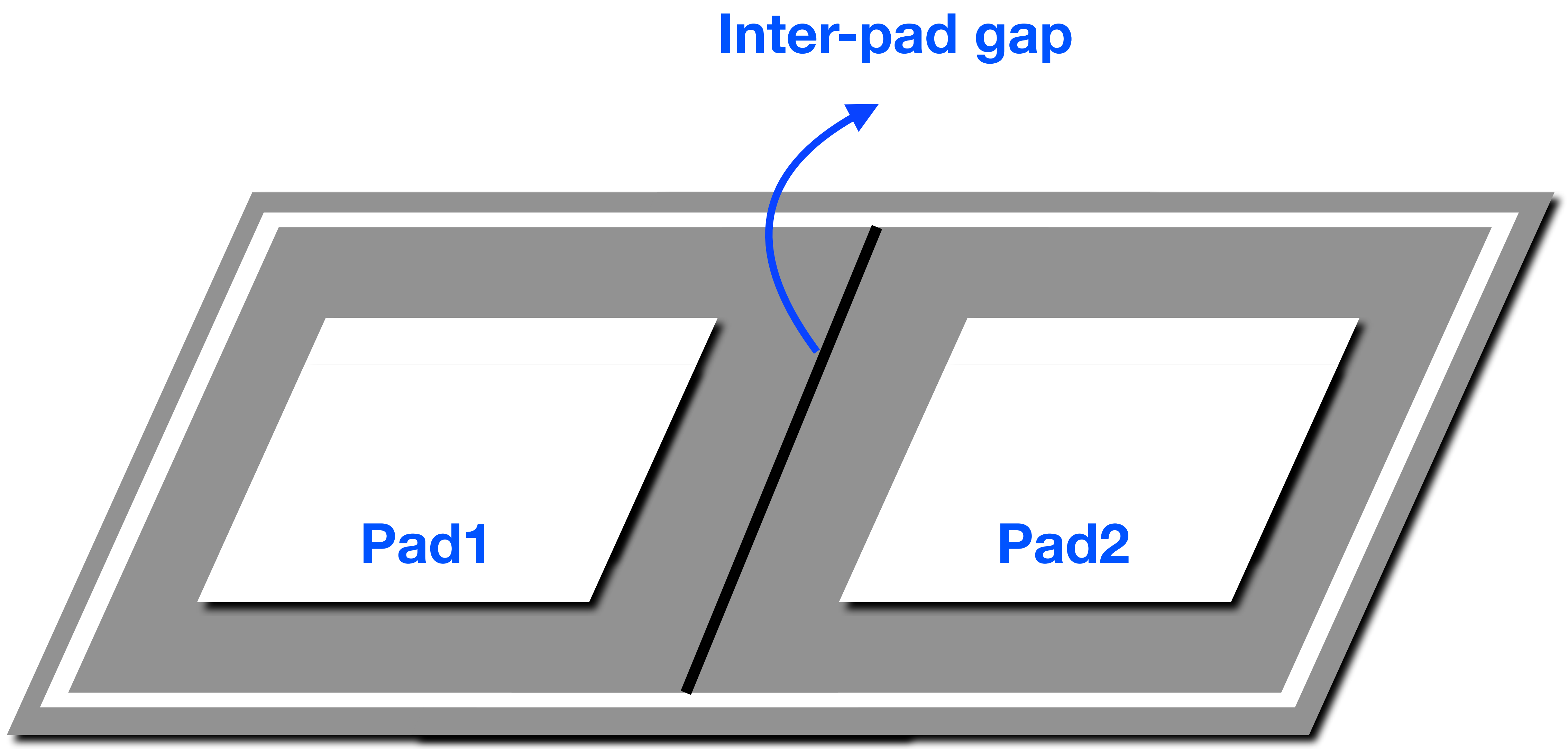


- Bias = $0 \sim -60\,\mathrm{V},\ \Delta V = 0.2\,\mathrm{V}$
- AC frequency: 1 kHz
- Room temperature
- All pads in 2x2 are uniform



- Measure from $0\,\mathrm{V}$ to $-60\,\mathrm{V}$ ($\Delta \mathrm{V} = 0.2\,\mathrm{V}$)
- AC frequency: $1\,\mathrm{kHz}$
- Room temperature
- Depletion Voltage (obtained by linear fit)
  - $V_{D,\,gain}$: $-21.4\,\mathrm{V}$
  - $V_{D,\,full}$: $-24.0\,\mathrm{V}$
  - V_{bulk} : $2.6\,\mathrm{V}$

What should we test for 1x2 sensor ?



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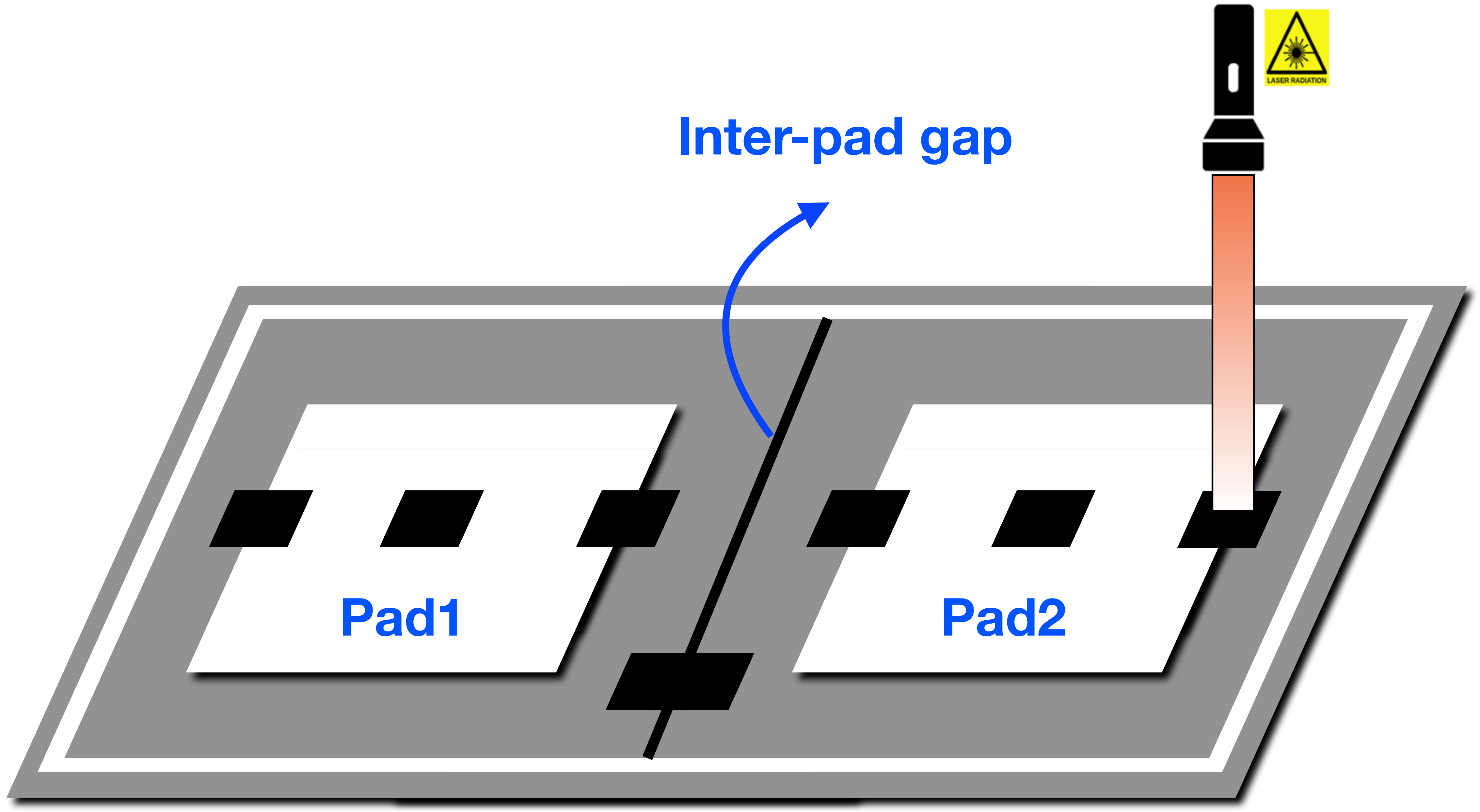
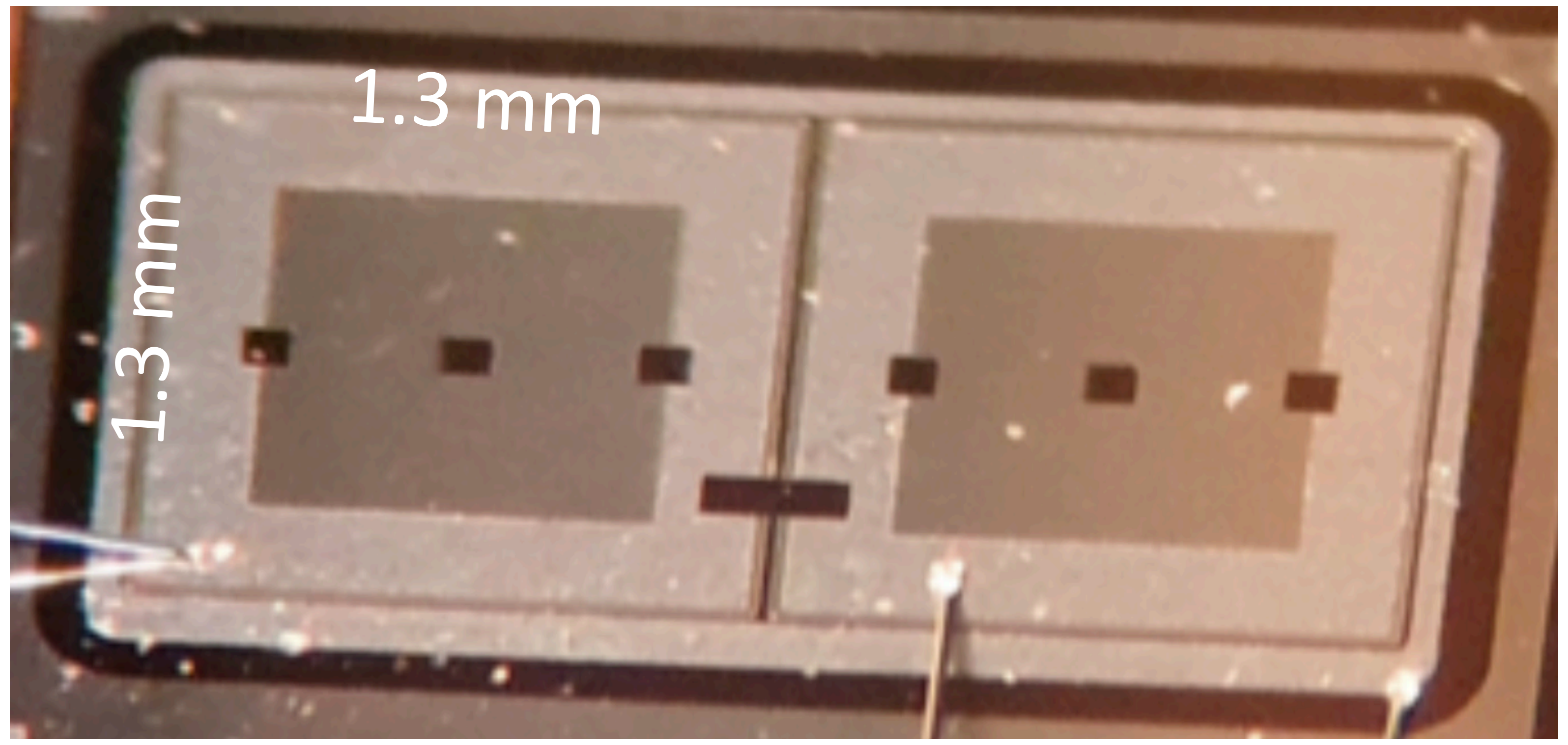
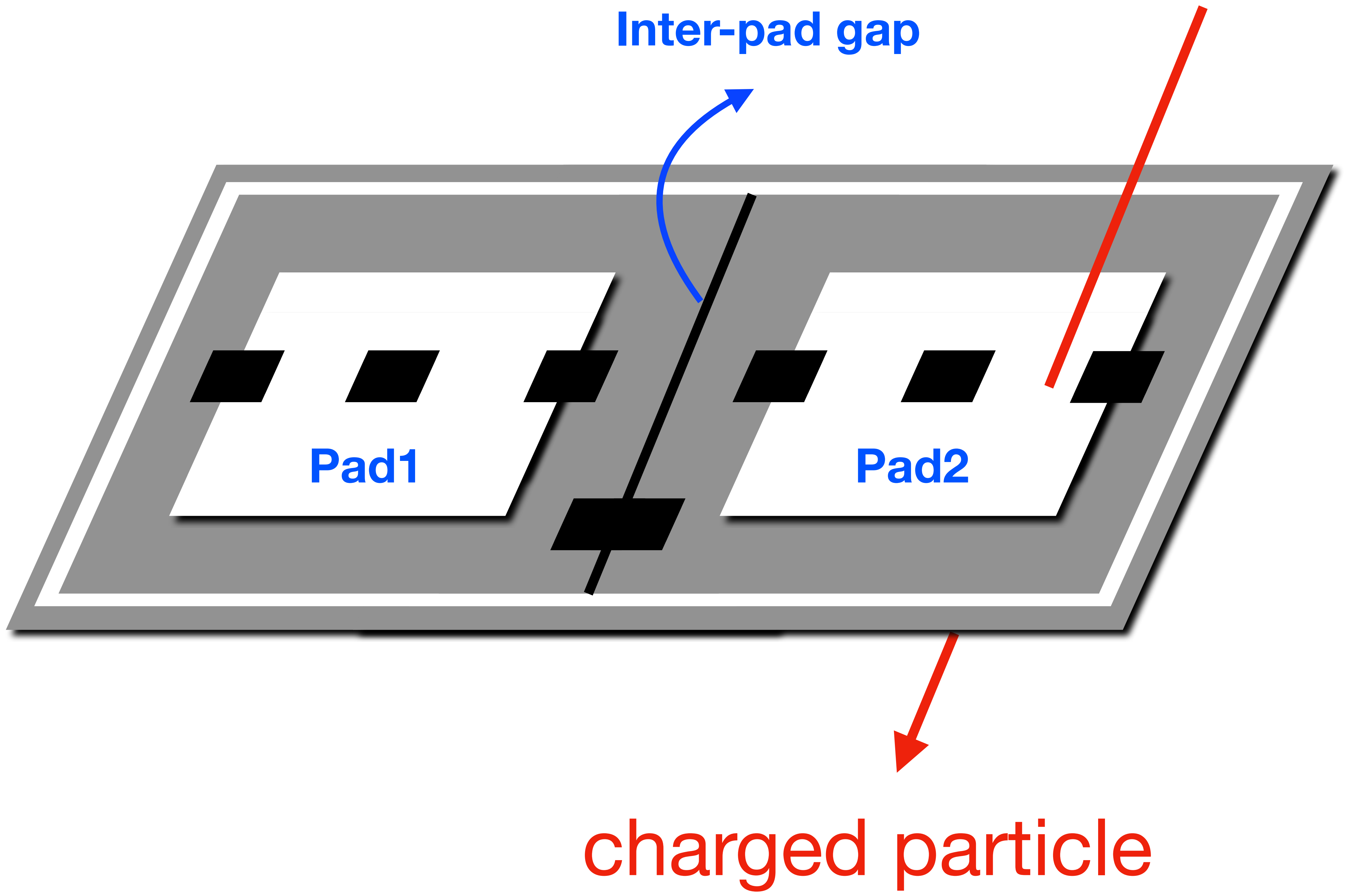




- **FBK 1x2 sensor**

What should we test for 1x2 sensor ?



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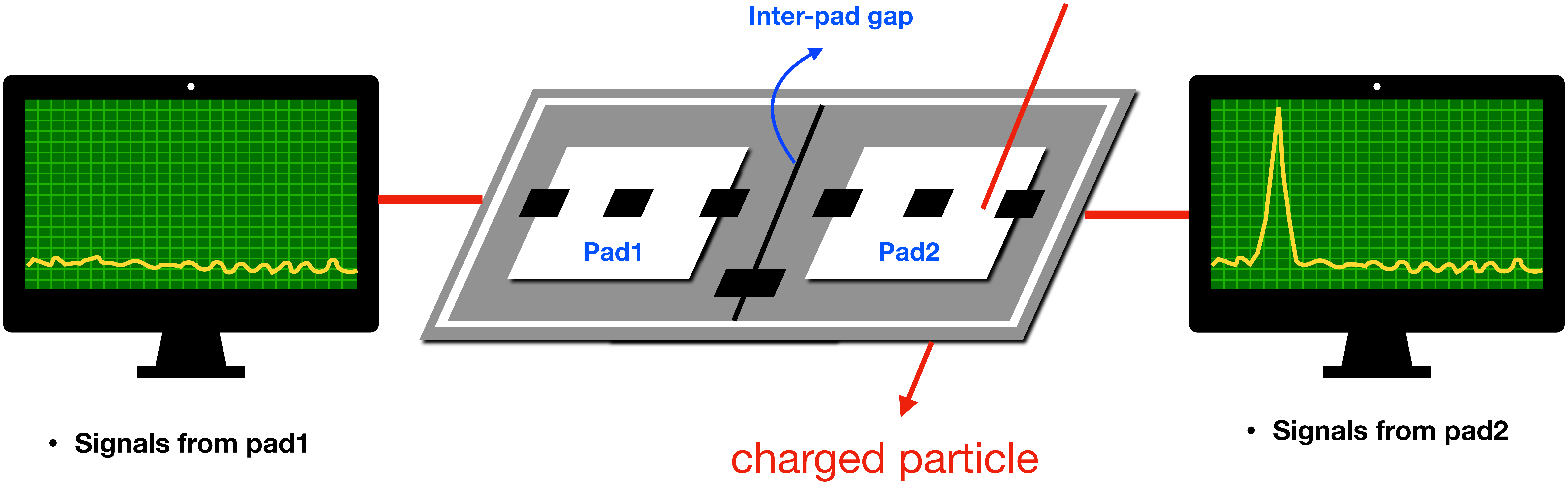
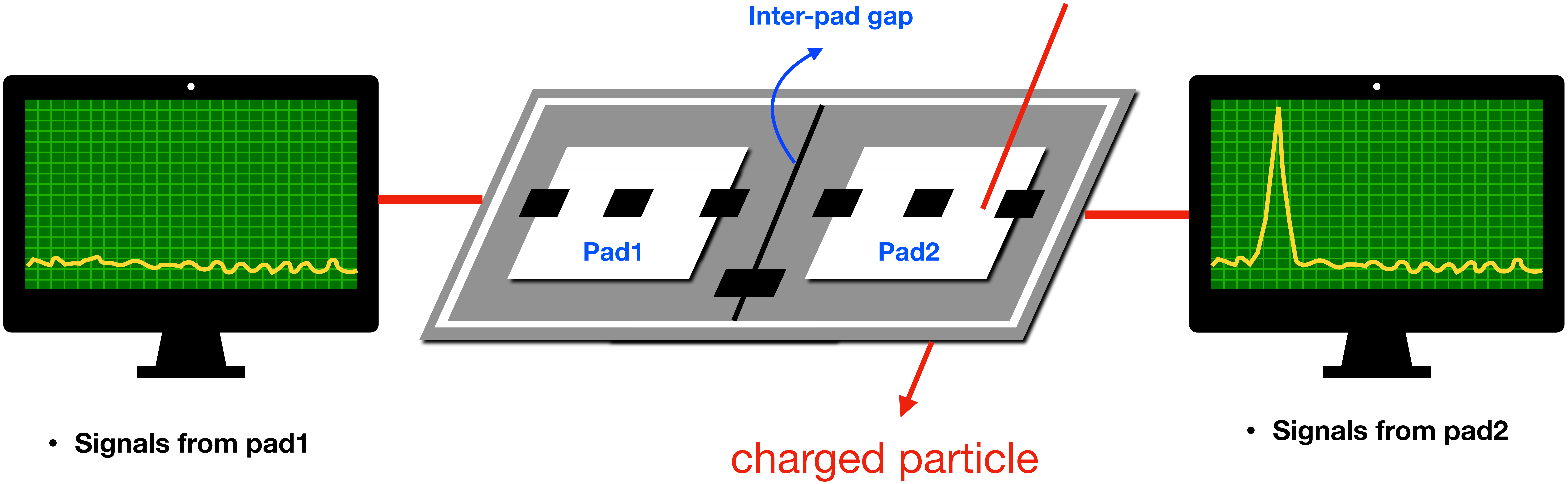


- **Signals from pad1**
- **Signals from pad2**

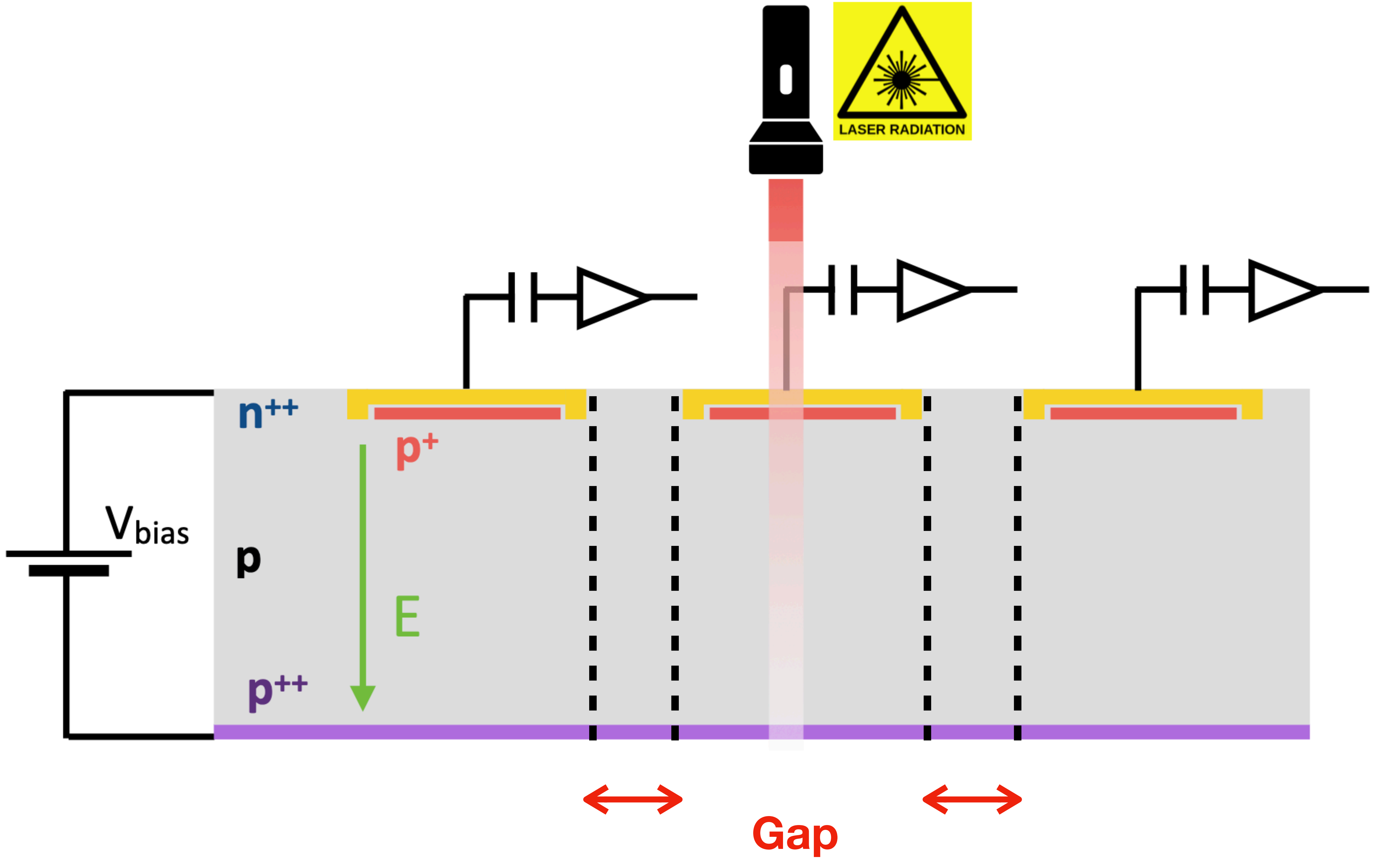
What should we test for 1x2 sensor ?

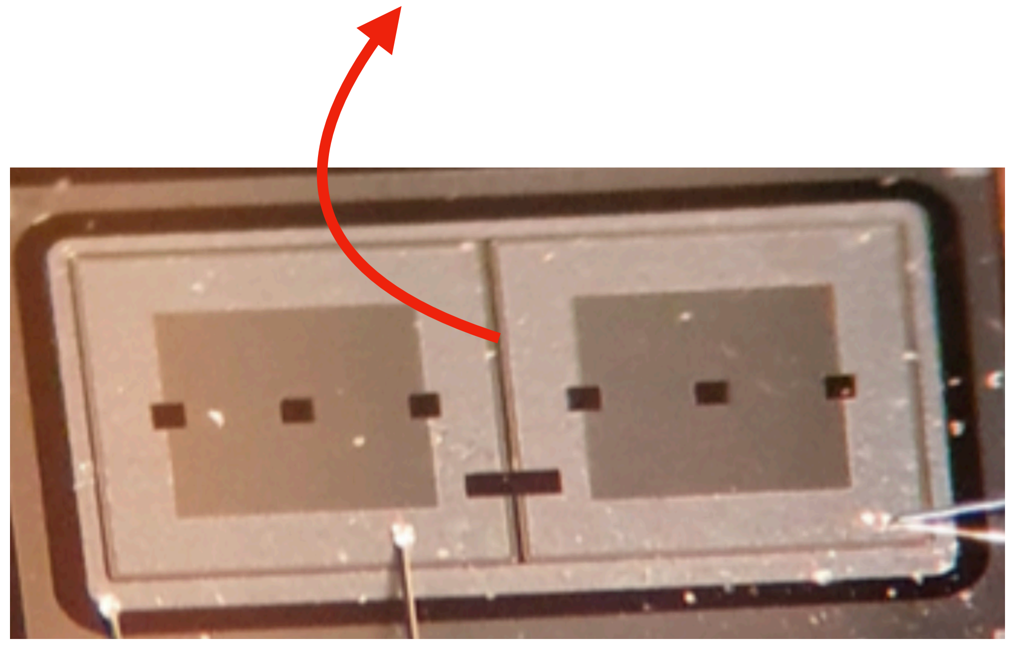


- Signals from pad1
- Signals from pad2

- We can test
  - Inter-pad resistance (pad isolation)
  - Inter-pad distance (gap measurement)

Gap Measurement



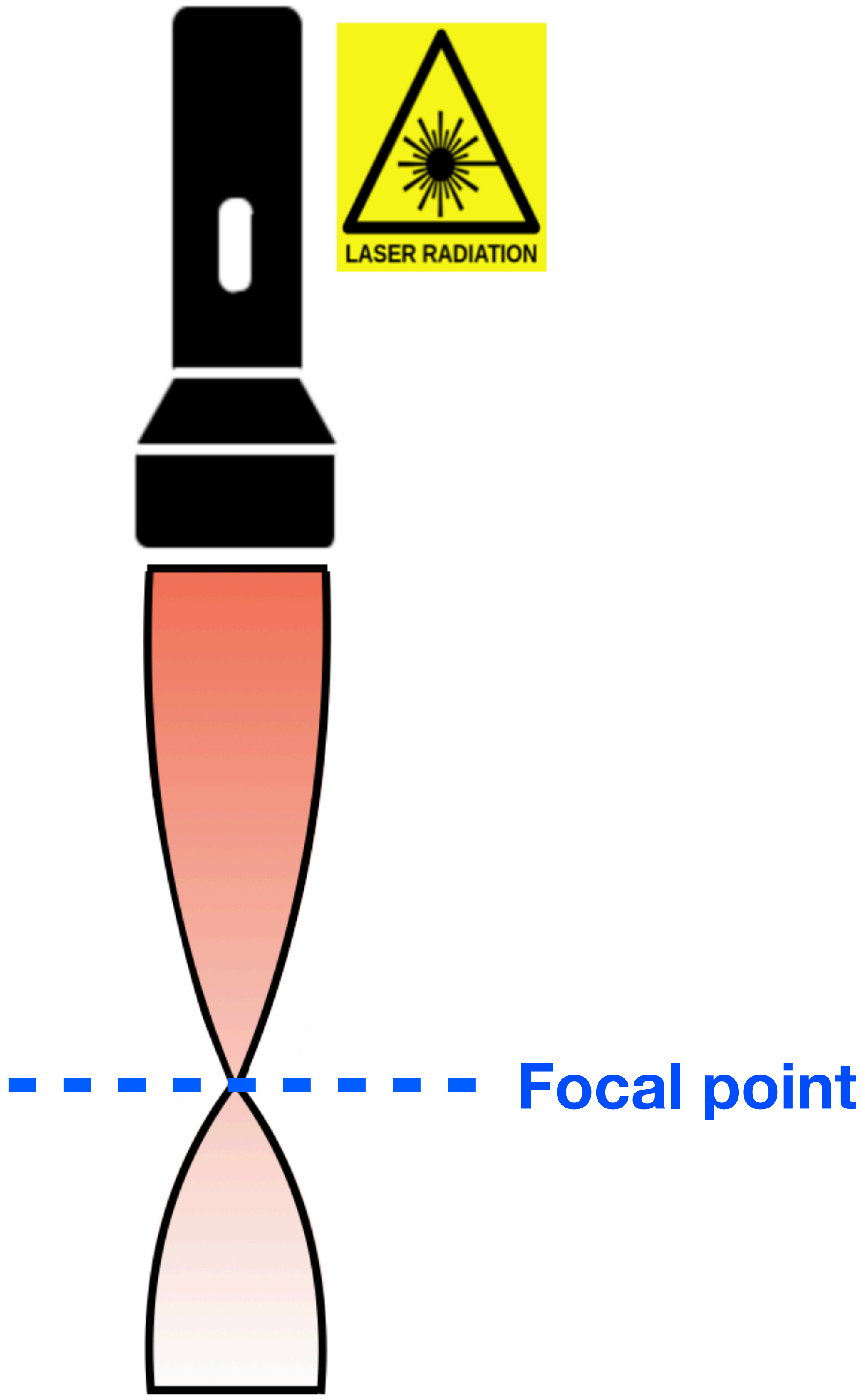


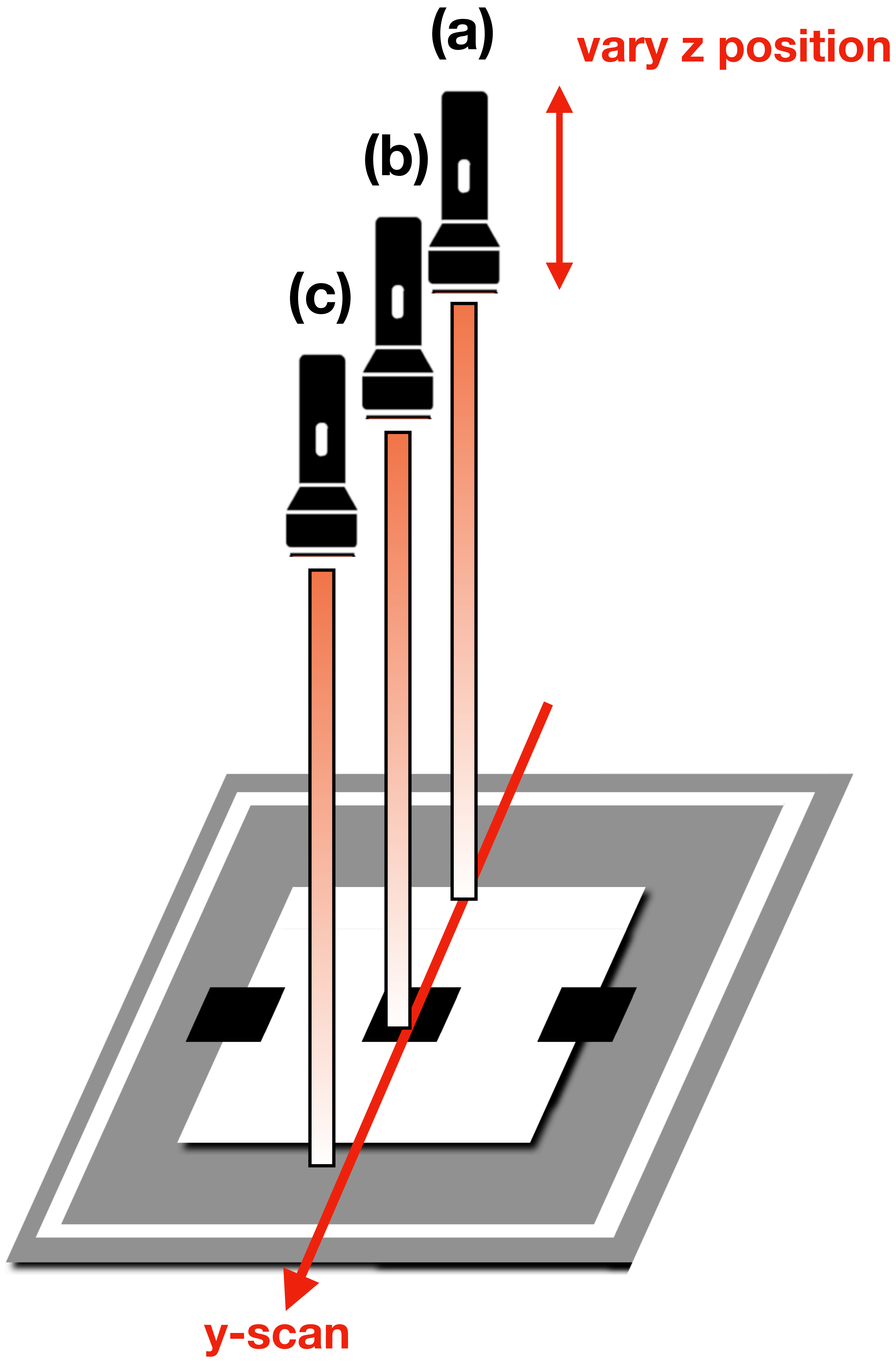
- Shoot laser to LGAD sensor
  - Wavelength: 1064 nm infrared
  - FWHM: ~ 12 μm
  - Pulse power: **1-10 MIPs**
- Use Transient Current Technique (TCT) apparatus by **Particulars**
- Change the position of sensor using built-in position controller
  - Resolution: < 1 μm

Need to optimize our setup before measurements

- Find focal point of laser
- Set the laser intensity to correspond to 1-10 MIPs

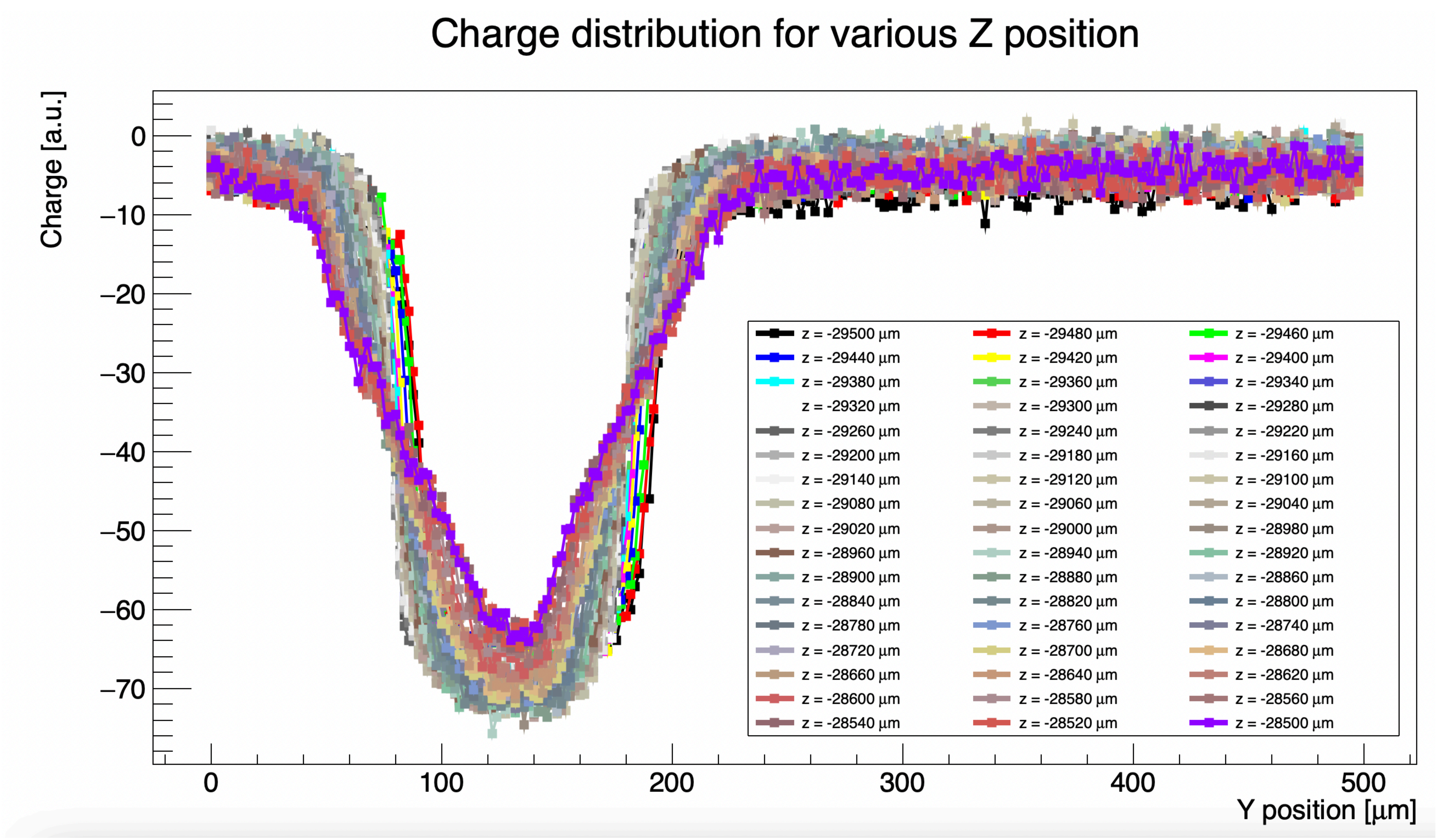
Gap Measurement - Find focal point





- Before calculating the area of PIN diode…
  - Due to optics, the laser doesn't go straight
    - We should find the focal point at which FWHM of laser is minimized
  - Perform y-scan with various z positions
    - y step = 2 μm, z step = 20 μm

Gap Measurement - Find focal point



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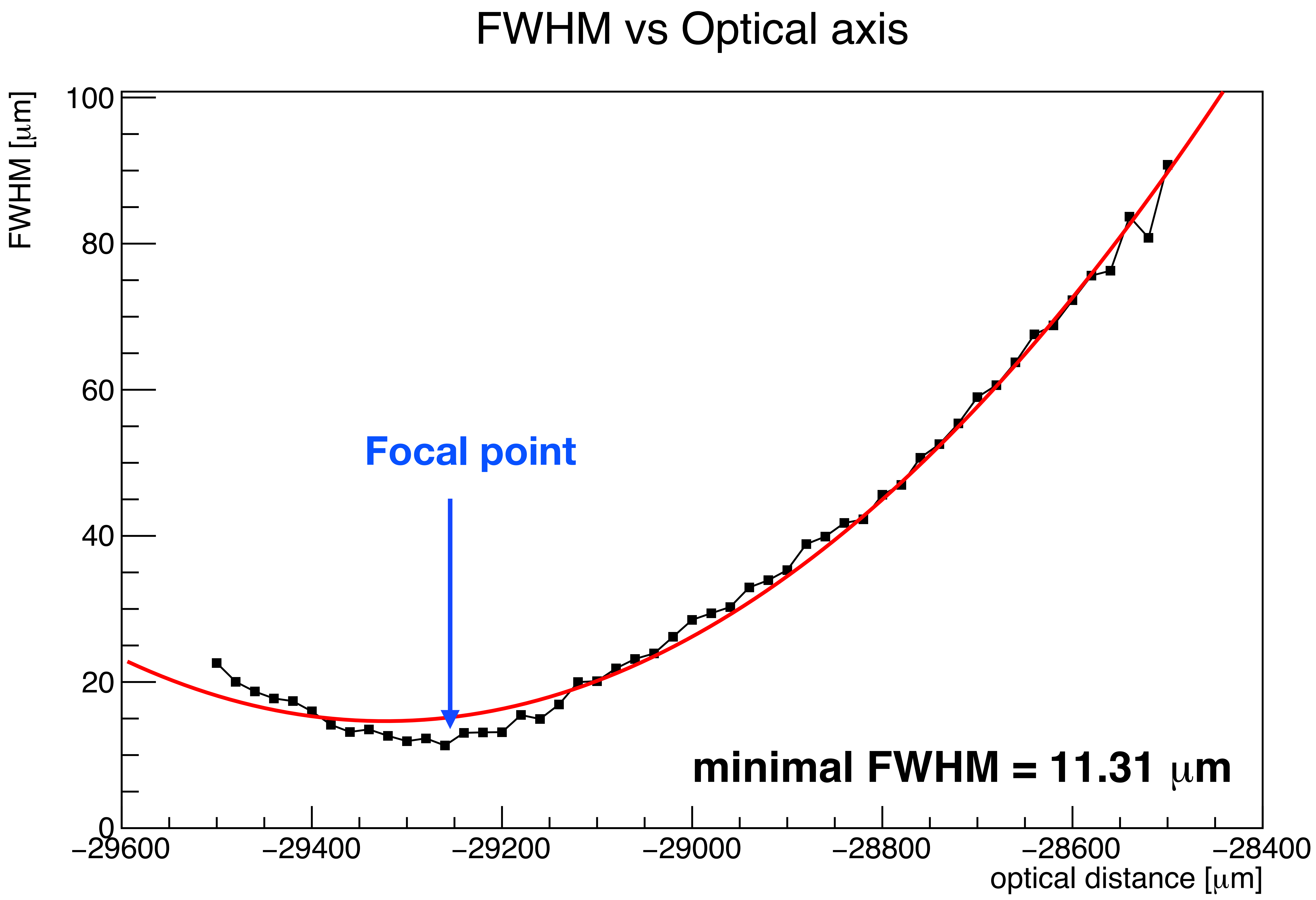

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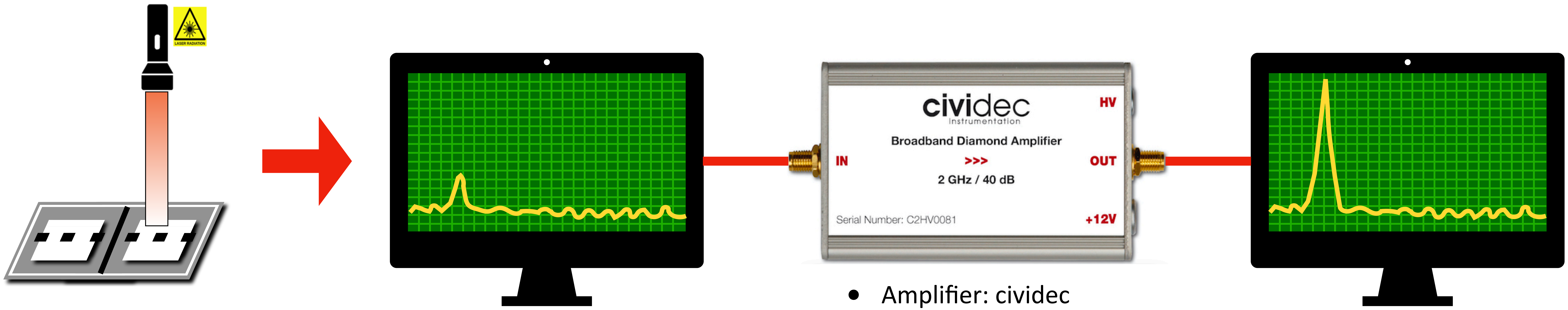
Gap Measurement - How many MIPs laser corresponds to?

- How many MIPs correspond to the charge generated by laser?



- **PIN diode (no gain)**

- Amplifier: cividec
- Gain: 40dB

- Unit of scope window

: [mV][ns] = 10^{-12} [V][s]

= 10^{-12} [C][Ω]

= 1 p[Wb]

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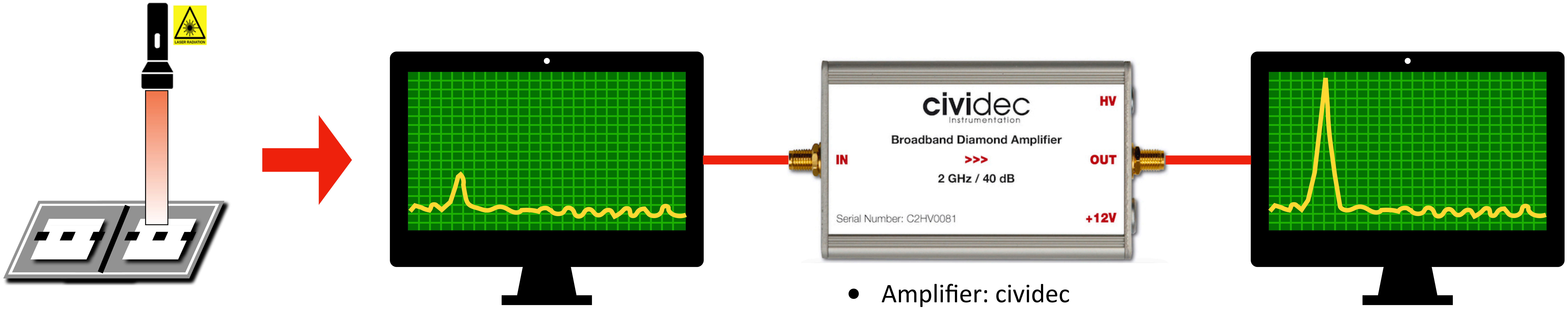

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: [mV][ns] = 10^{-12} [V][s]

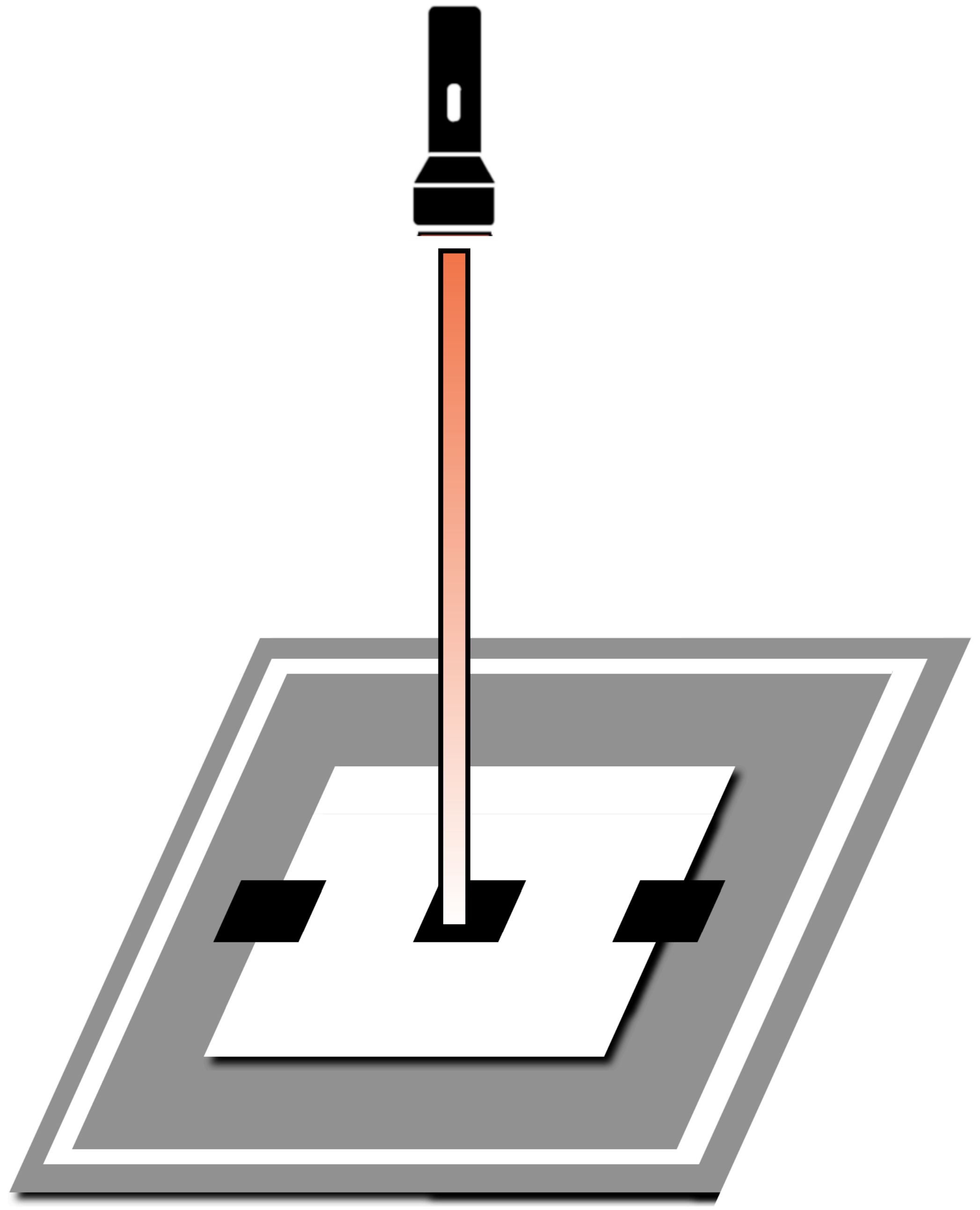
= 10^{-12} [C][Ω]

= 1 p[Wb]

- 1MIP generates 0.5 [fC] on 50 μm thickness (no gain)
  - with impedance of 50 [Ω] : 2.5×10^{-14} [C][Ω] = 2.5×10^{-2} p[Wb]
  - with gain of 40 [dB] : 2.5×10^{-12} [C][Ω] = 2.5 p[Wb]

Gap Measurement - How many MIPs laser corresponds to?

Focal z position



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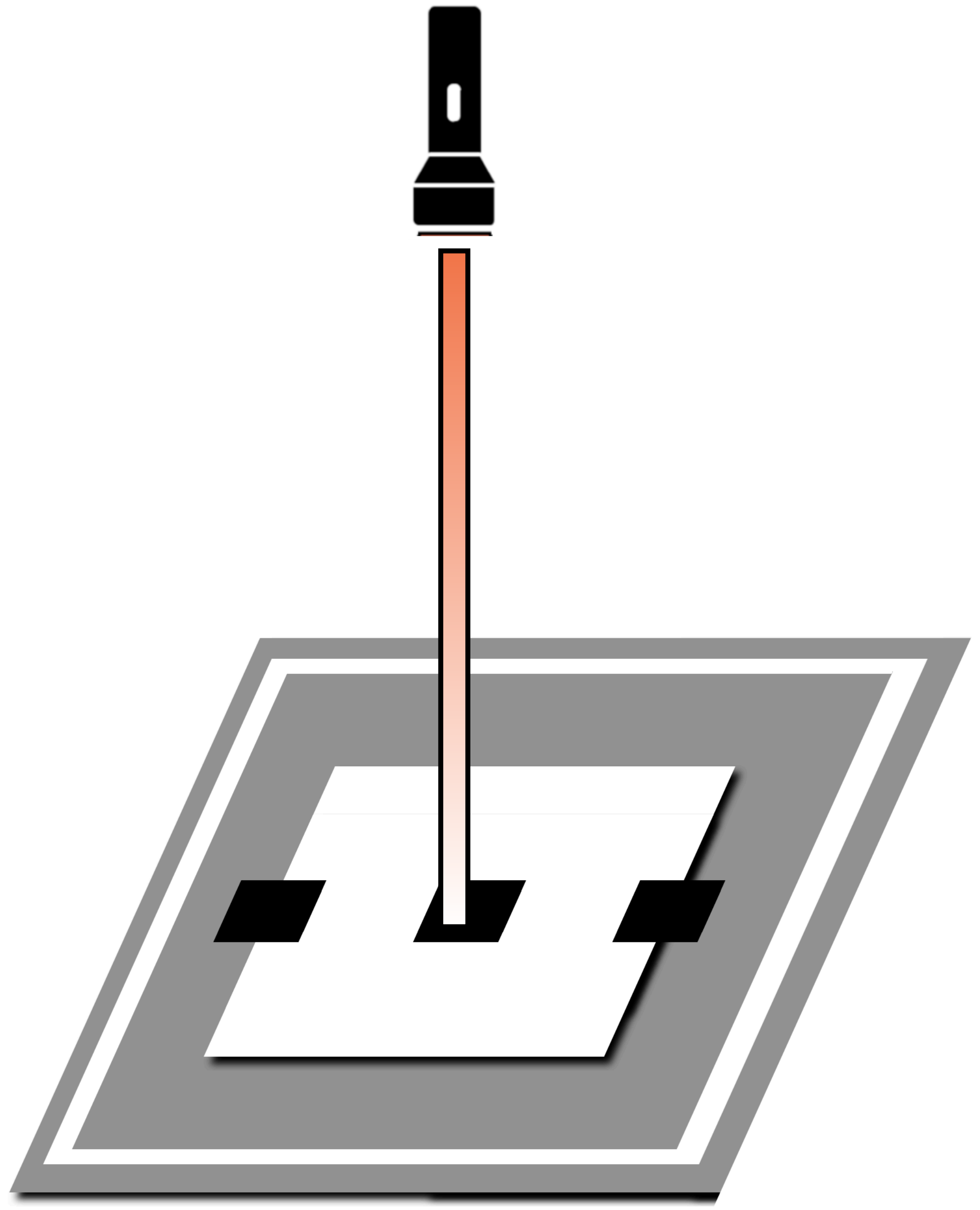
Gap Measurement - How many MIPs laser corresponds to?

Focal z position



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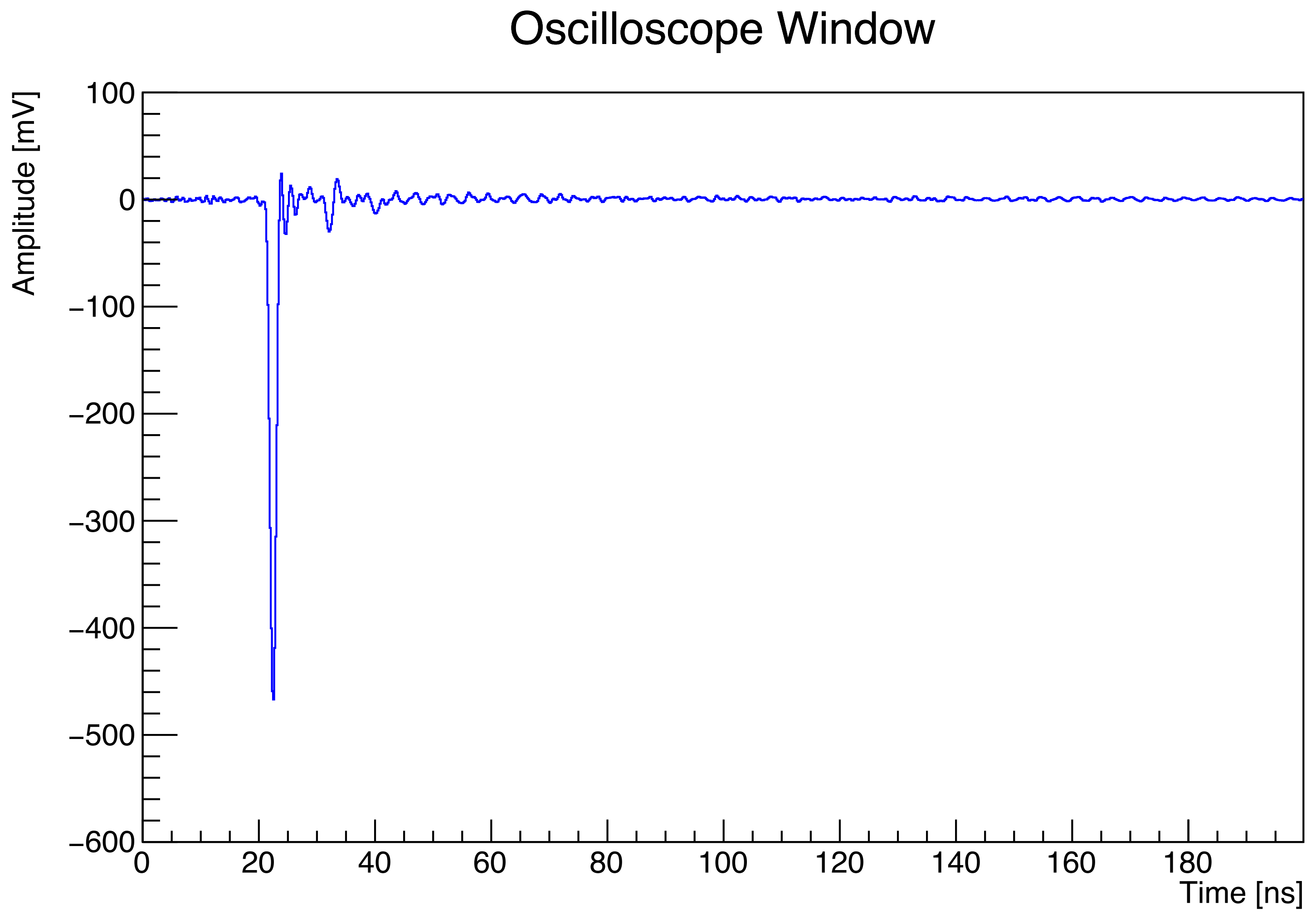
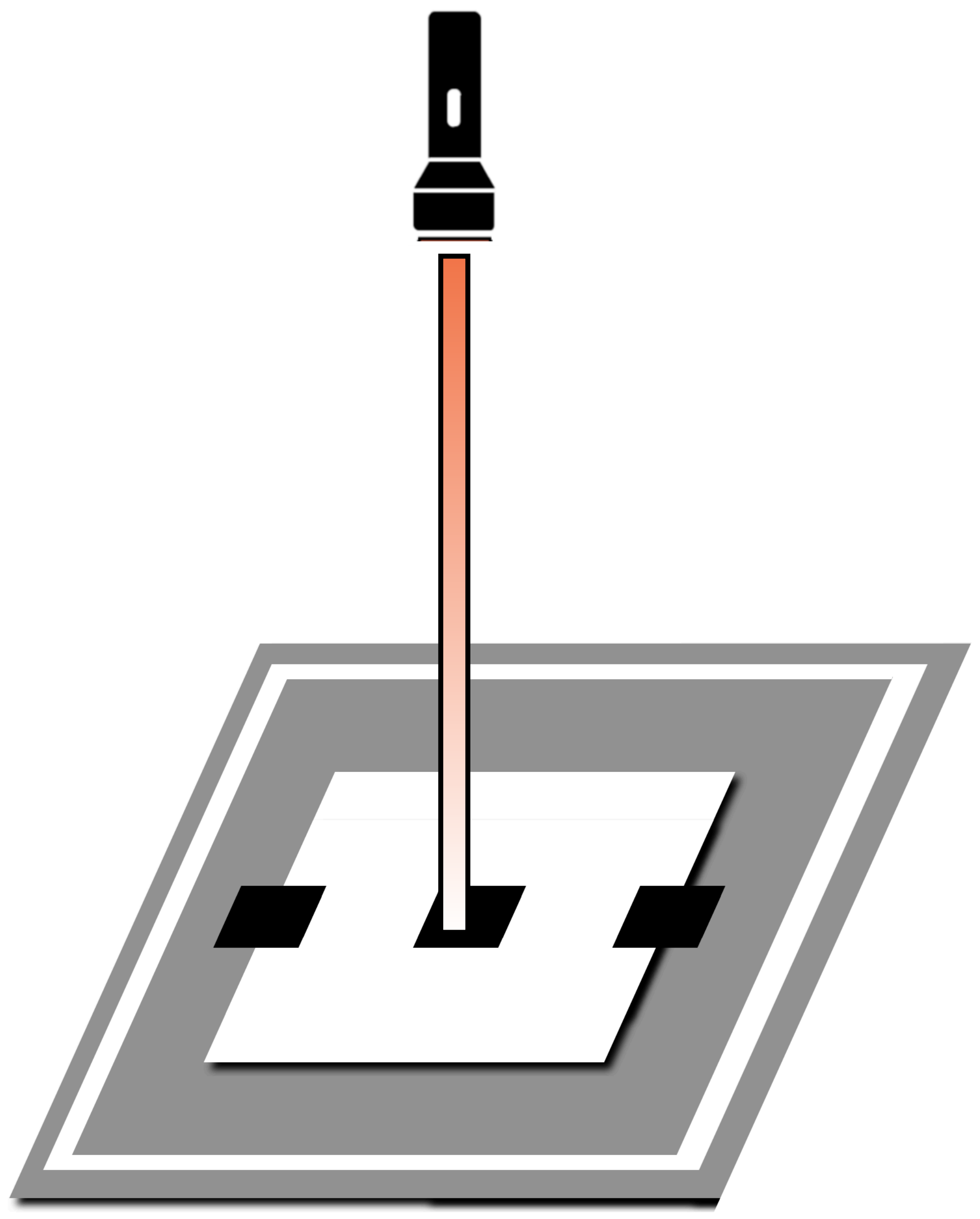


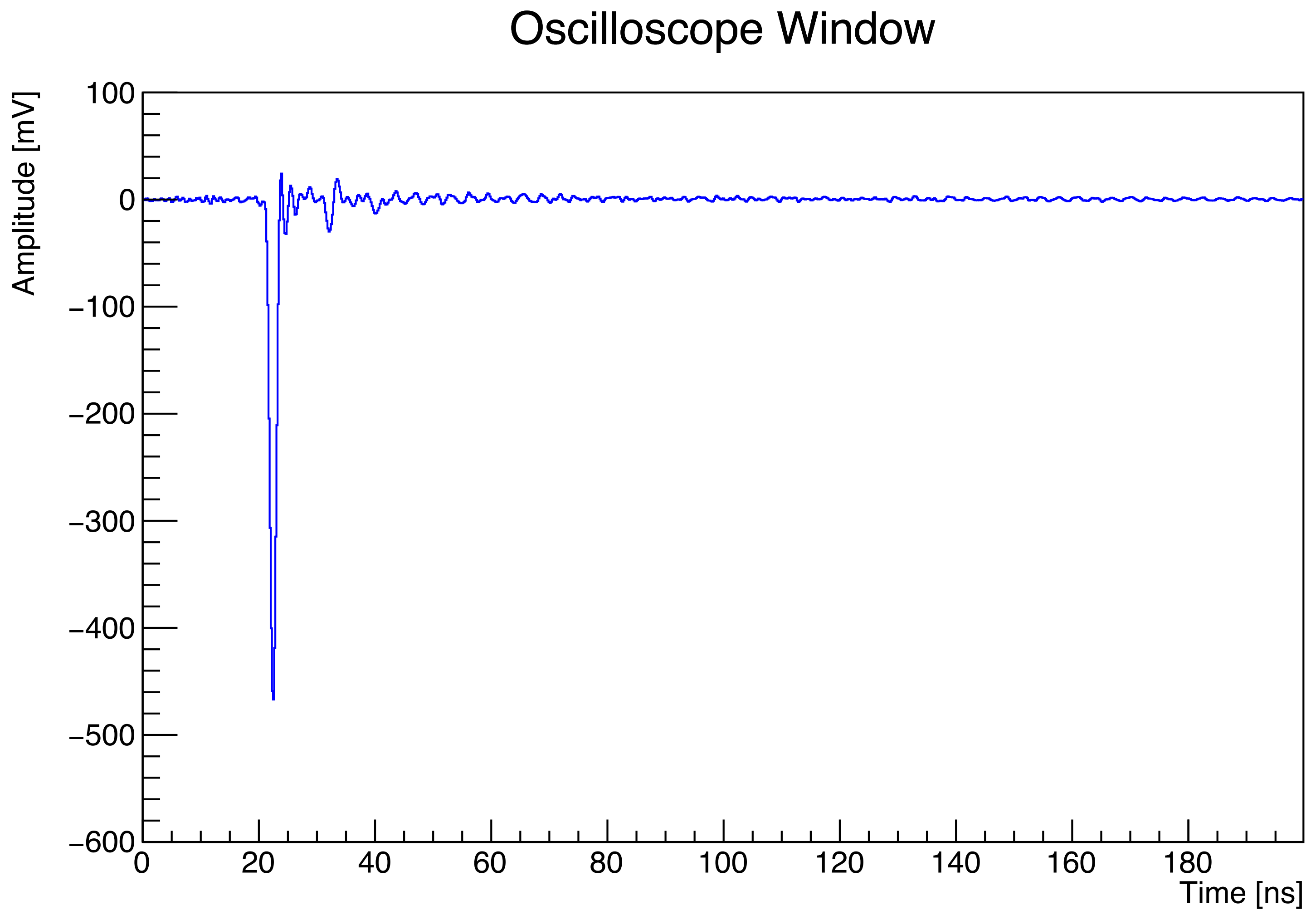
- **Area: ~600 pWb → ~250 MIPs**

Gap Measurement - How many MIPs laser corresponds to?

Focal z position



- PIN diode



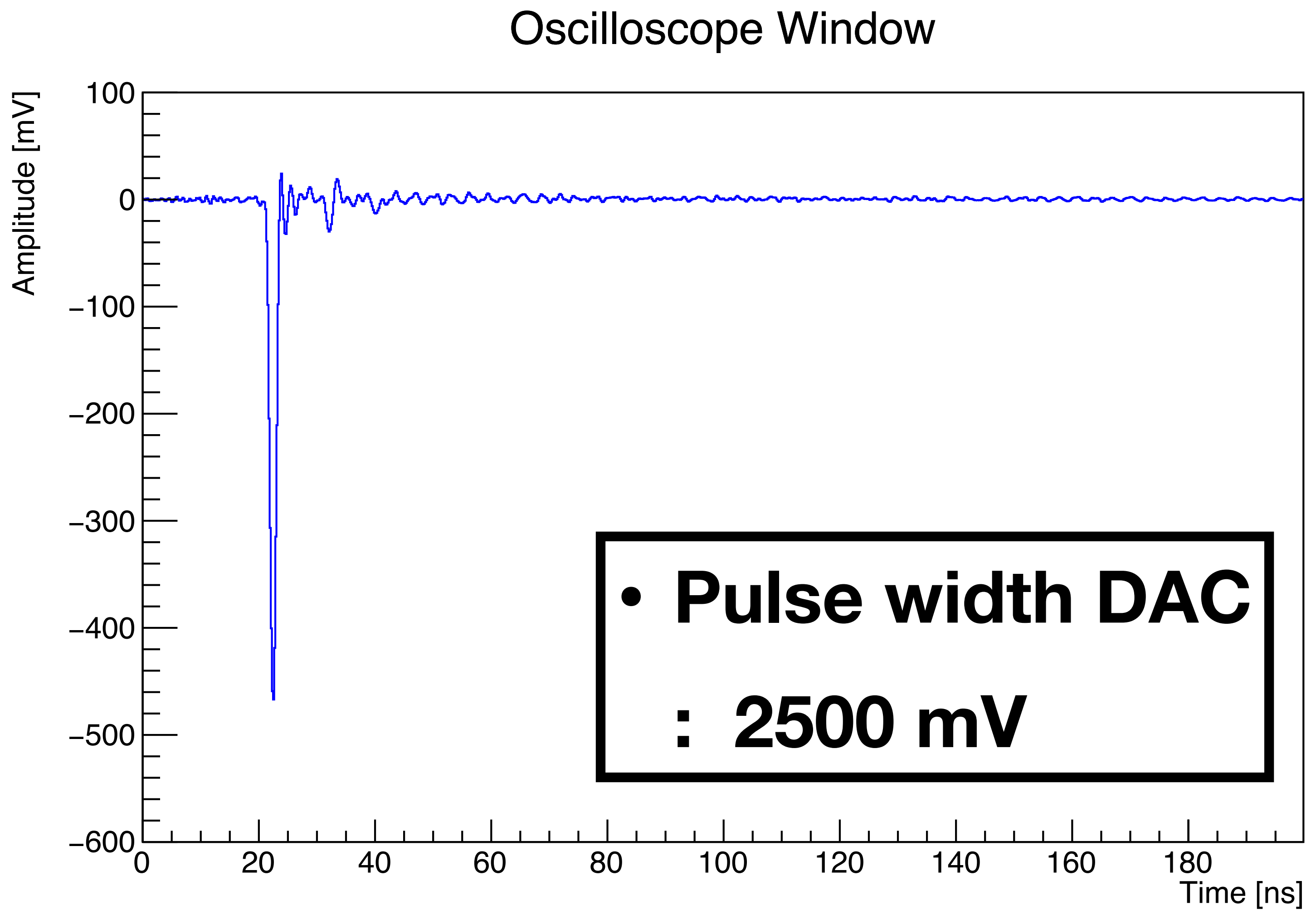
- **Area: ~600 pWb → ~250 MIPs**

- Pulse area (charge) is too large
  - Laser with high intensity generates charges of high density

    ↓

  - Charges electrically could repel each other and affect charge distribution

Gap Measurement - How many MIPs laser corresponds to?



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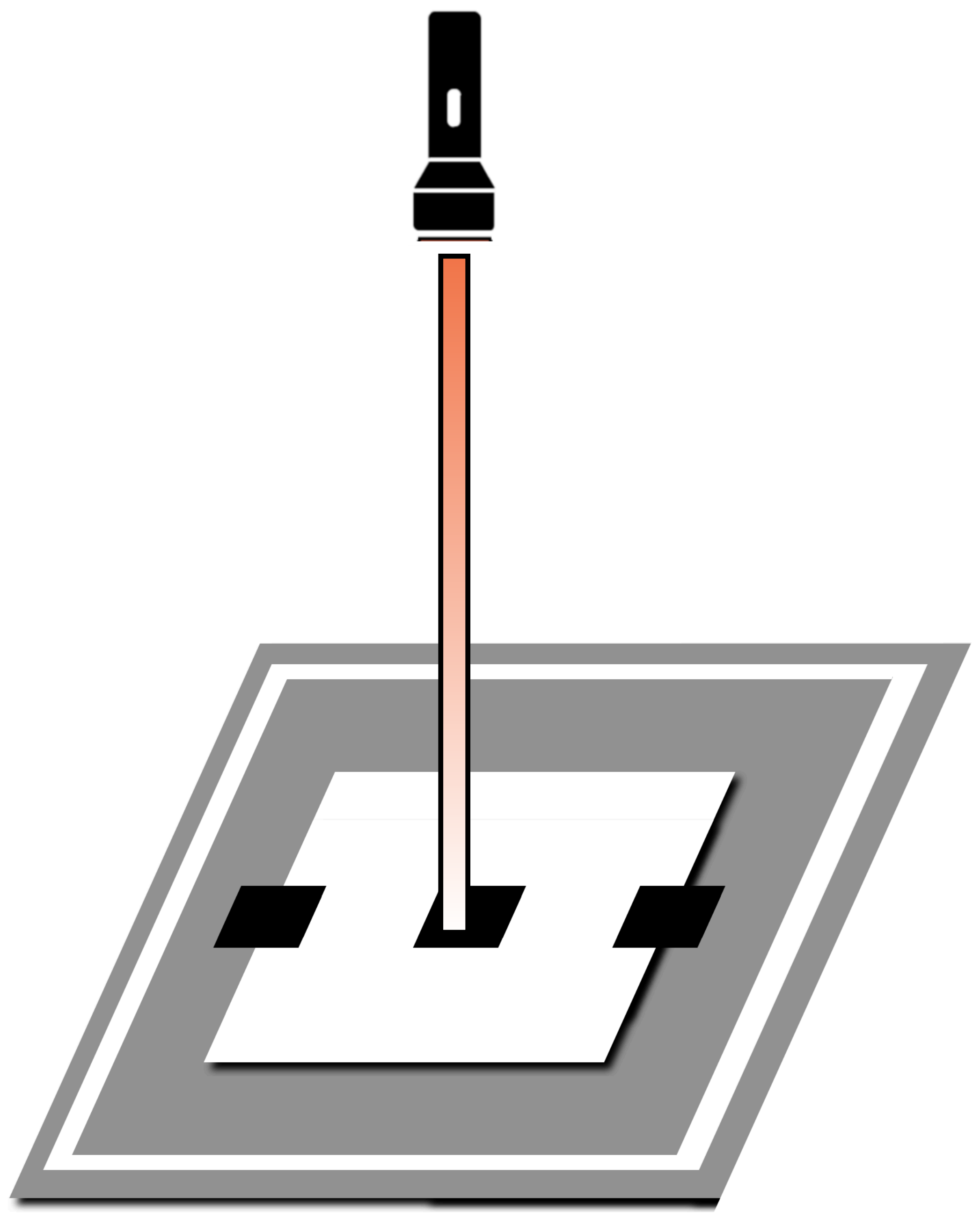
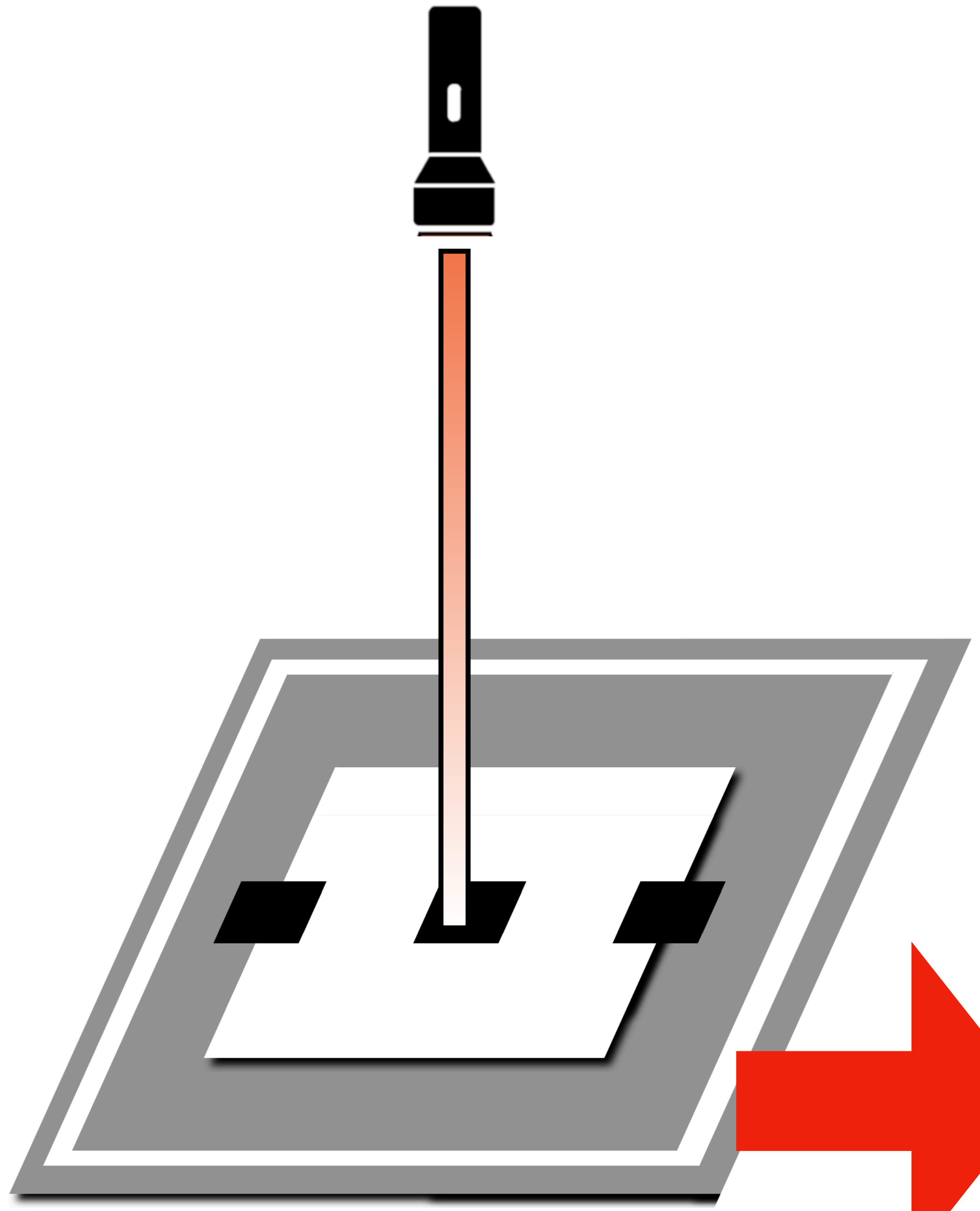


- **PIN diode**

Gap Measurement - How many MIPs laser corresponds to?

Focal z position



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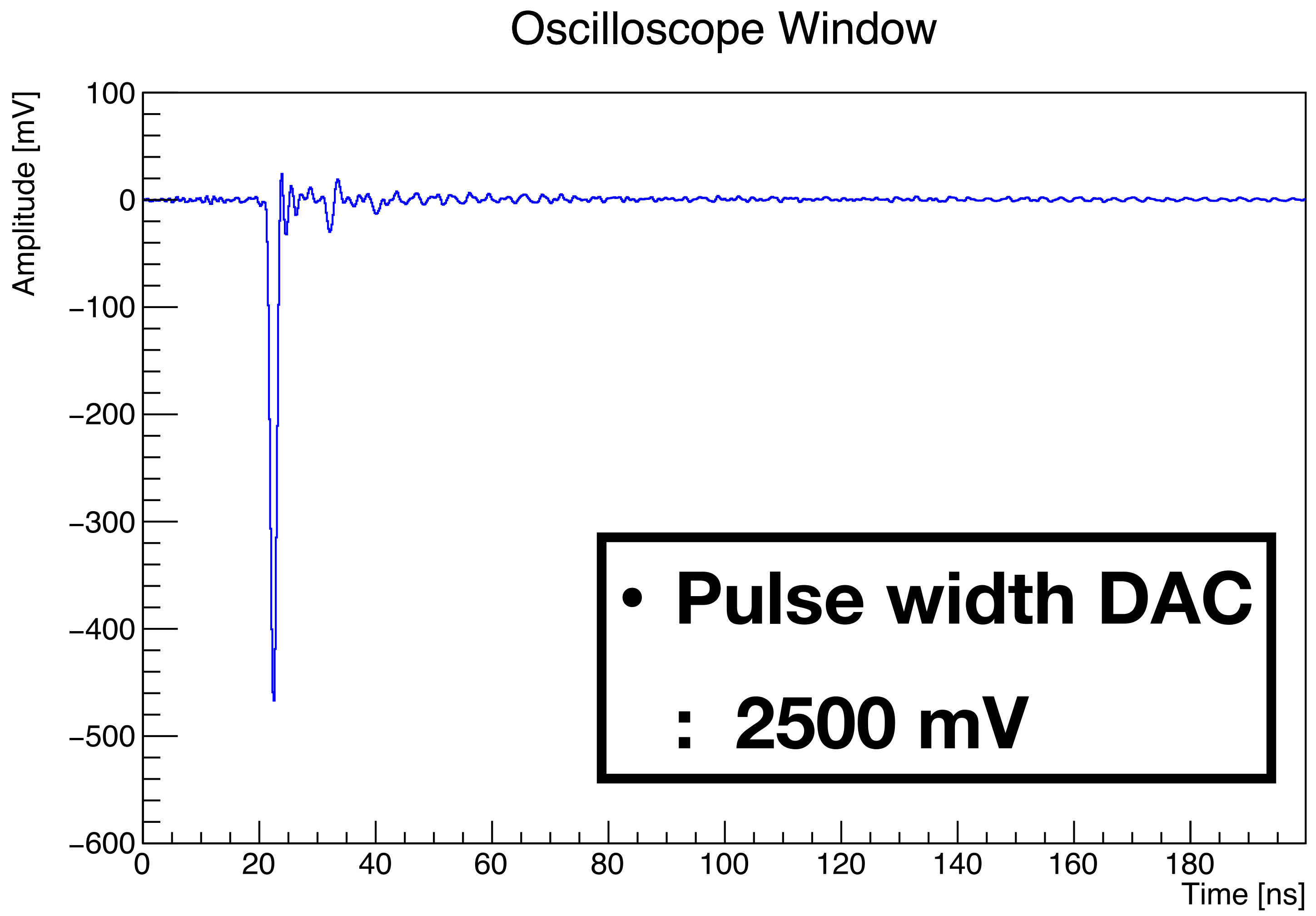

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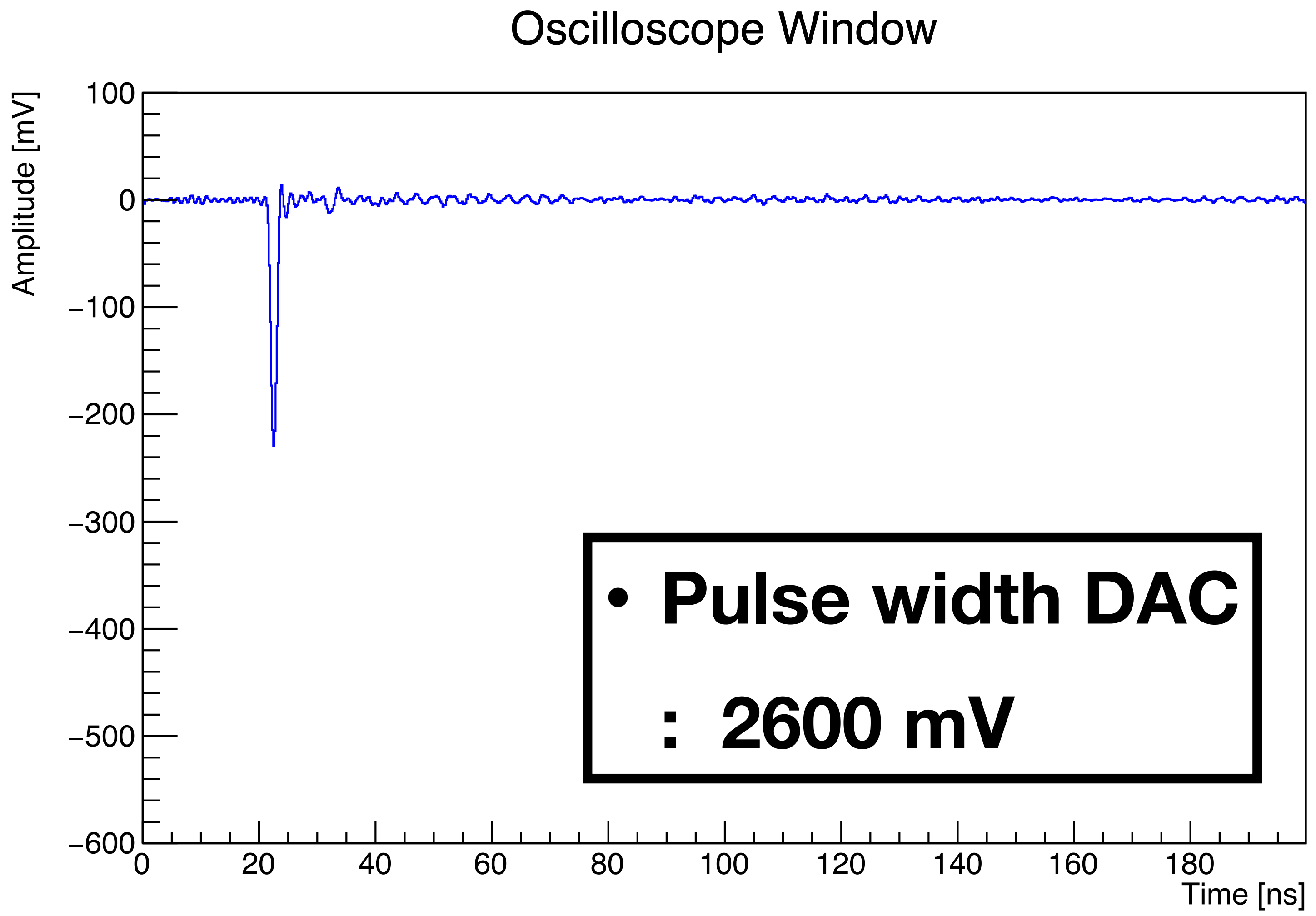
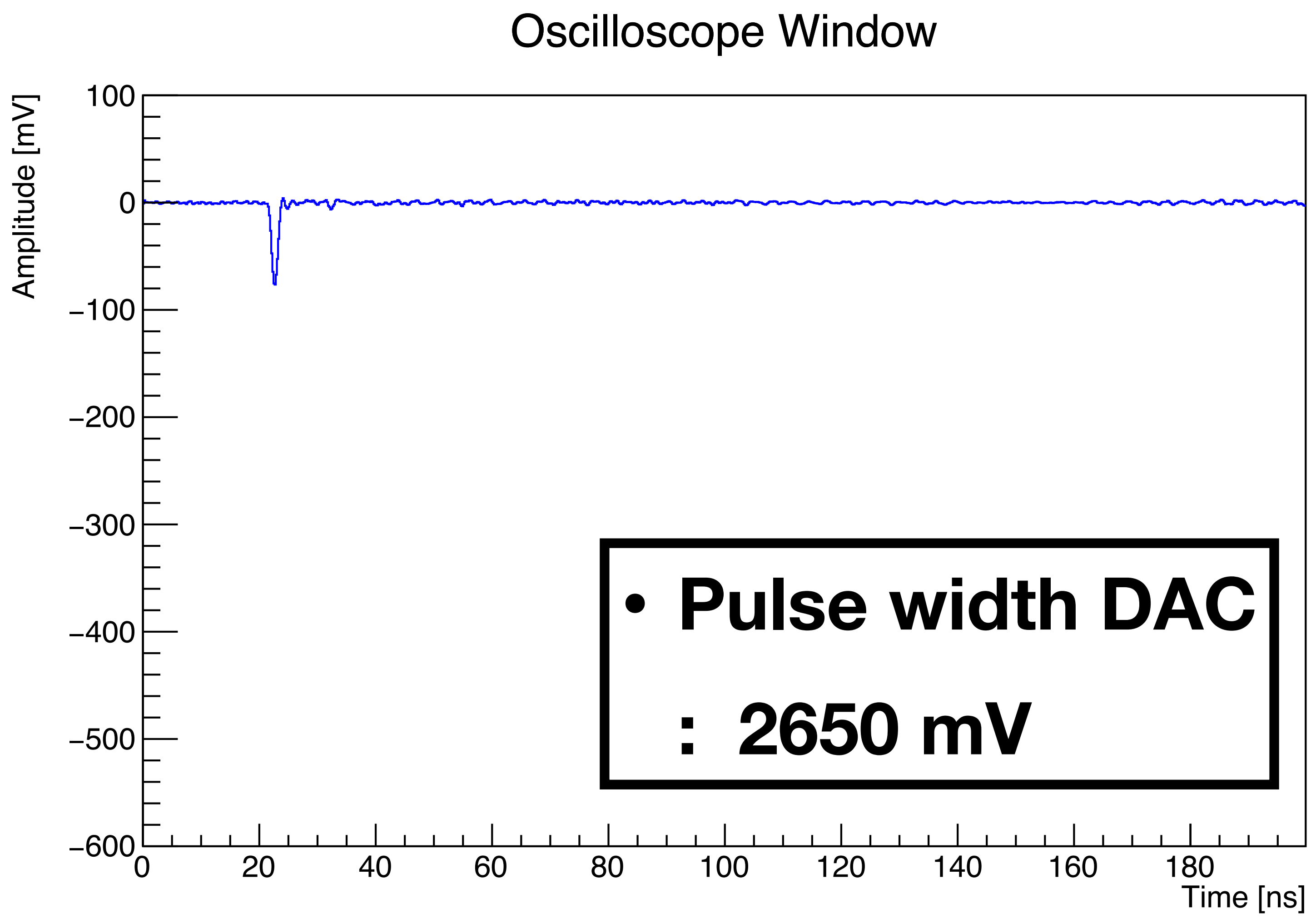
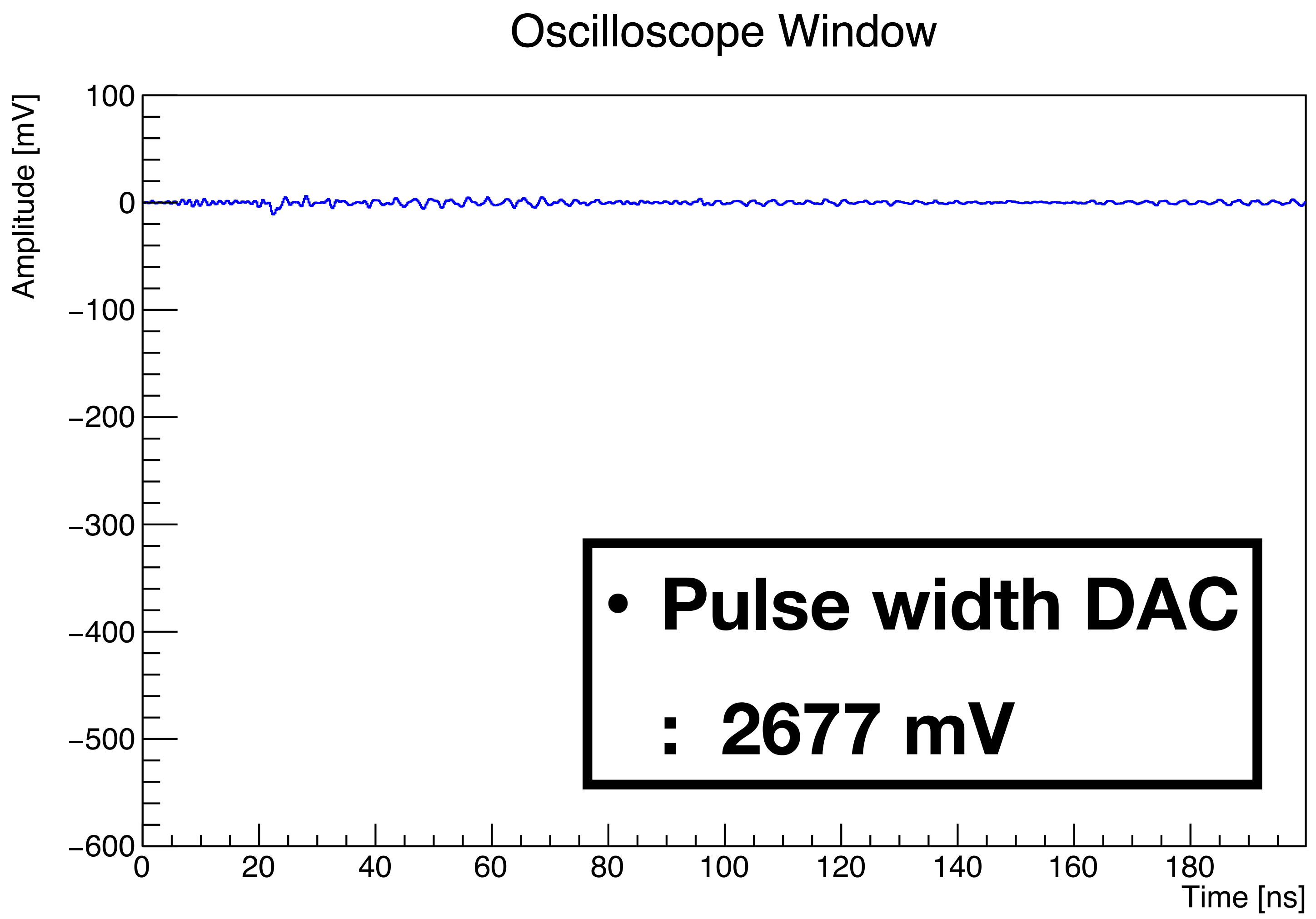


- **Area: ~290 pWb → ~100 MIPs**



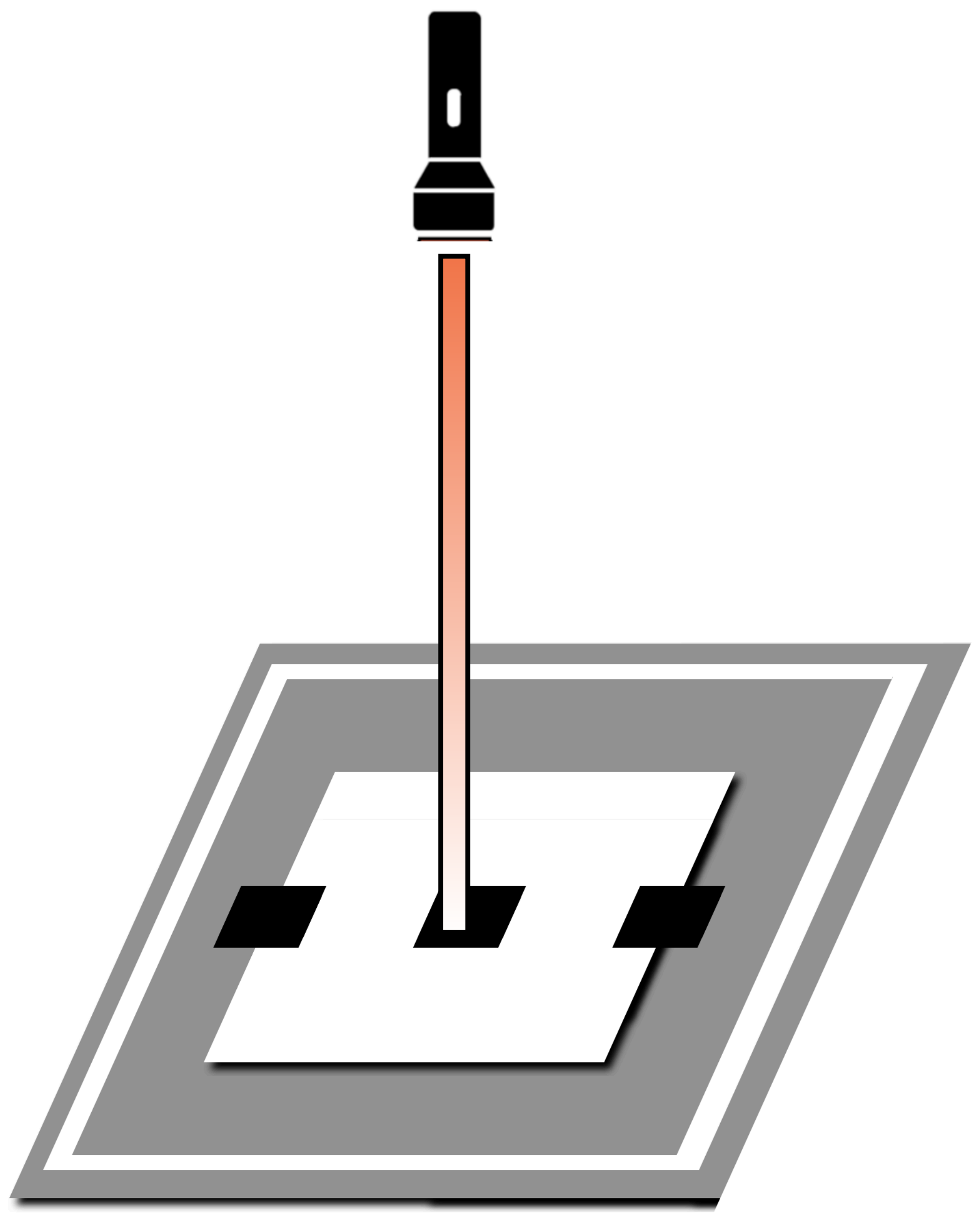
- **Area: ~100 pWb → ~40 MIPs**



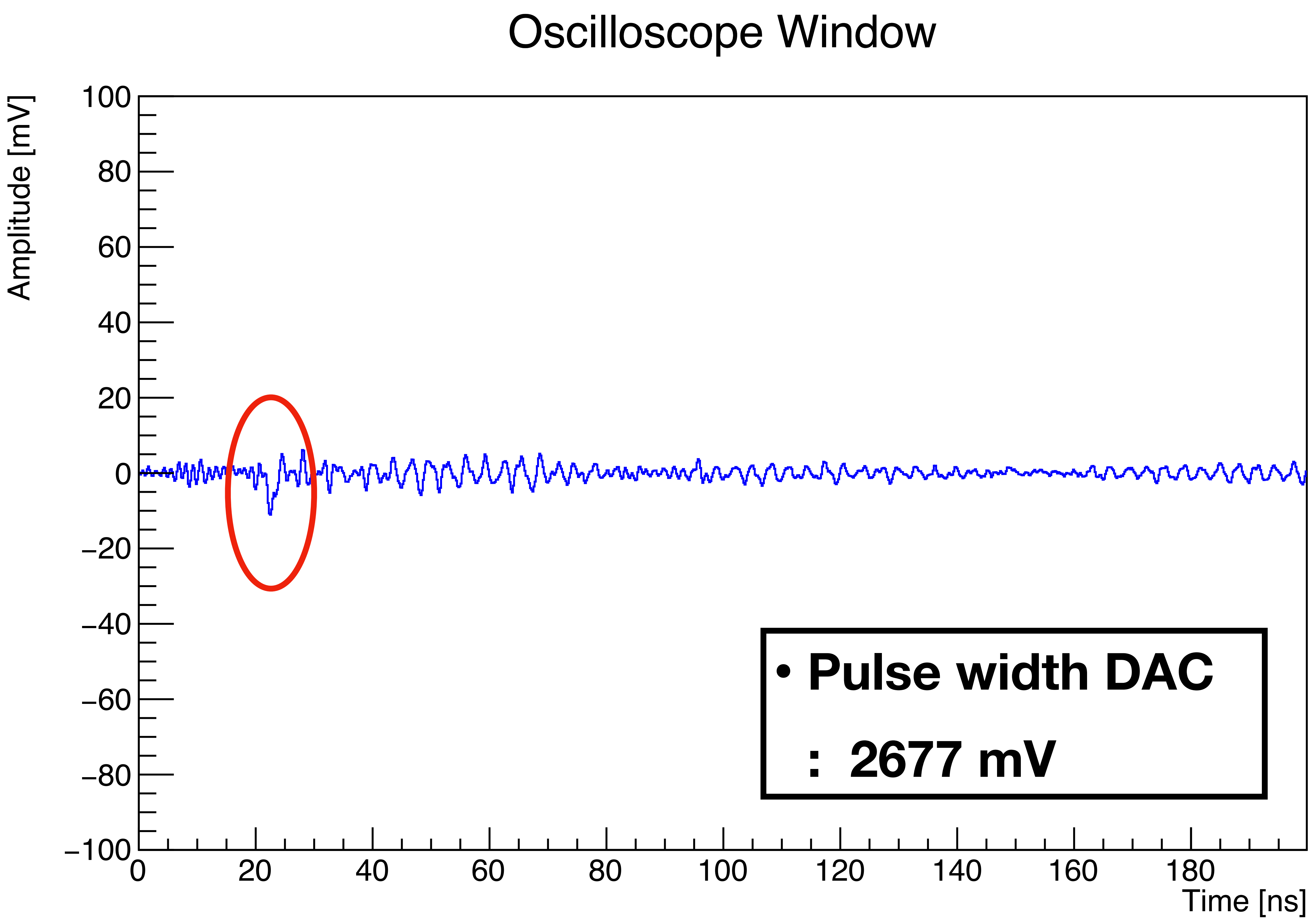
- **Area: 17.7 pWb → ~7 MIPs**

Gap Measurement - How many MIPs laser corresponds to?

Focal z position



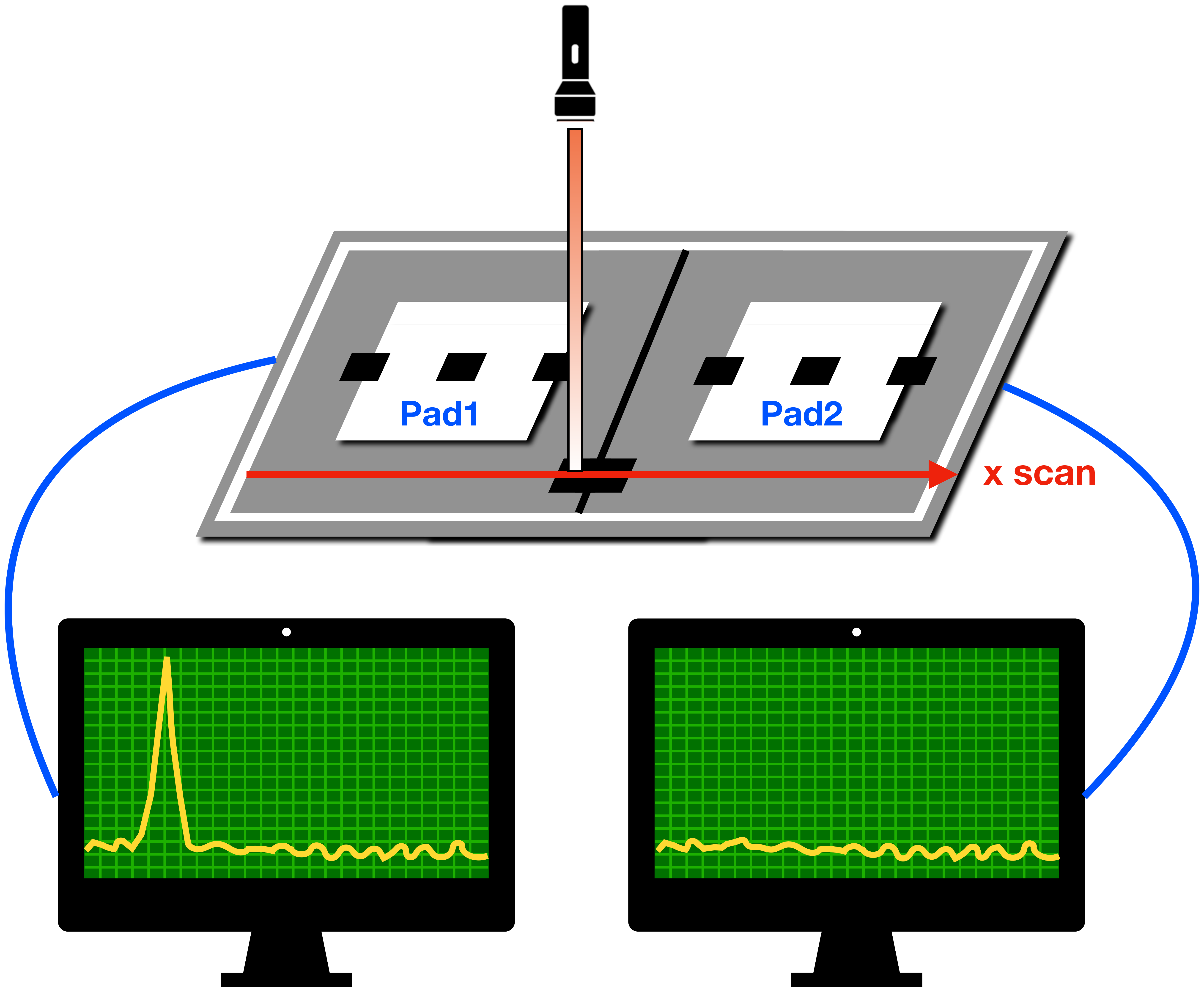
- **PIN diode**



- **Area: 17.7 pWb → ~7 MIPs**

- Our laser intensity corresponds to 1-10 MIPs !

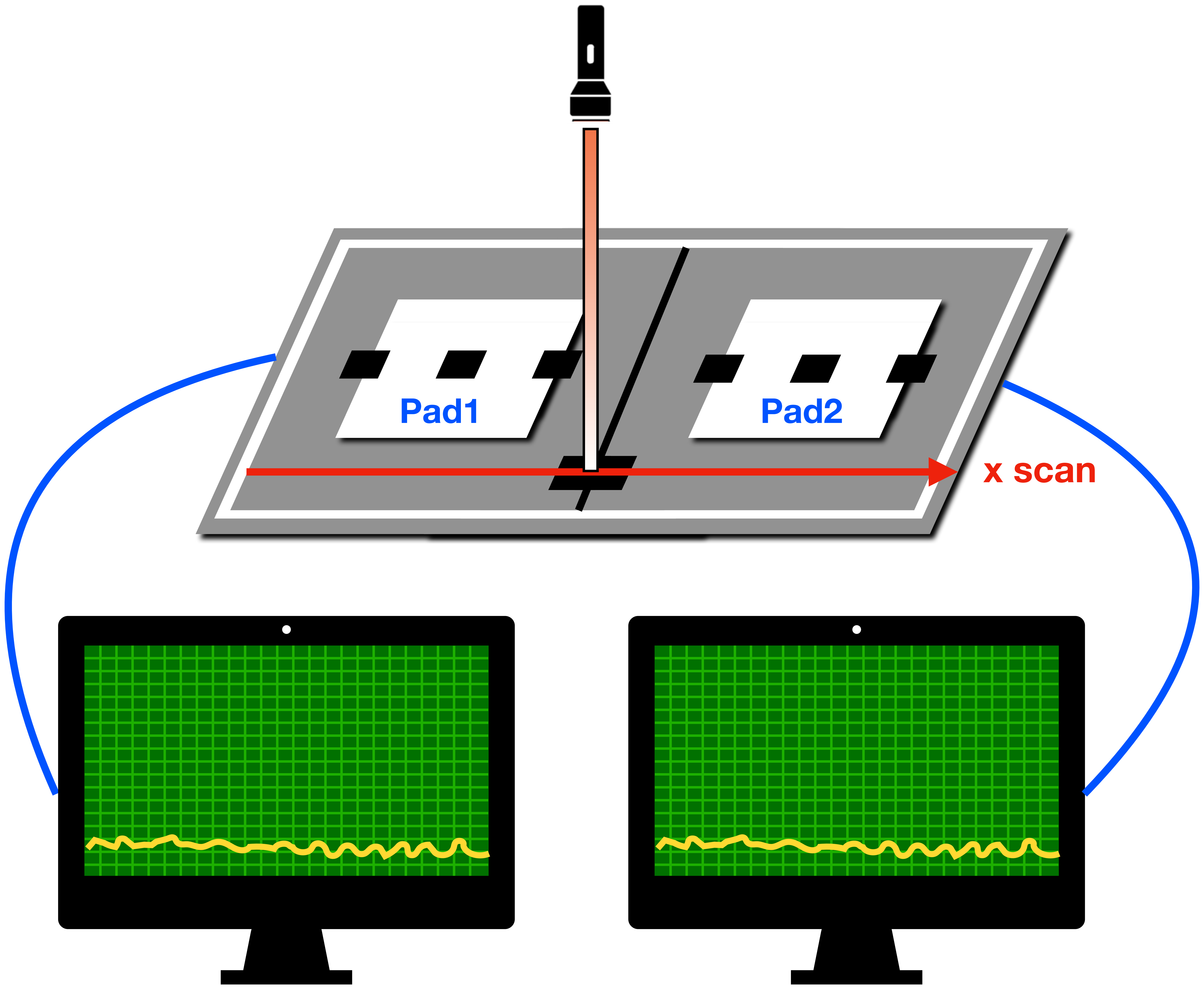
Gap Measurement - LGAD sensor



- Signal from pad1
- Signal from pad2

- There is an open area across the two pads to measure gap distance
- Perform 50 x scans at focal z position with 1-10 MIPs (x step = 2 μm)
- Fit Erf(x) and 1-Erf(x) to each corresponding charge distribution and calculate the gap distance

Gap Measurement - LGAD sensor



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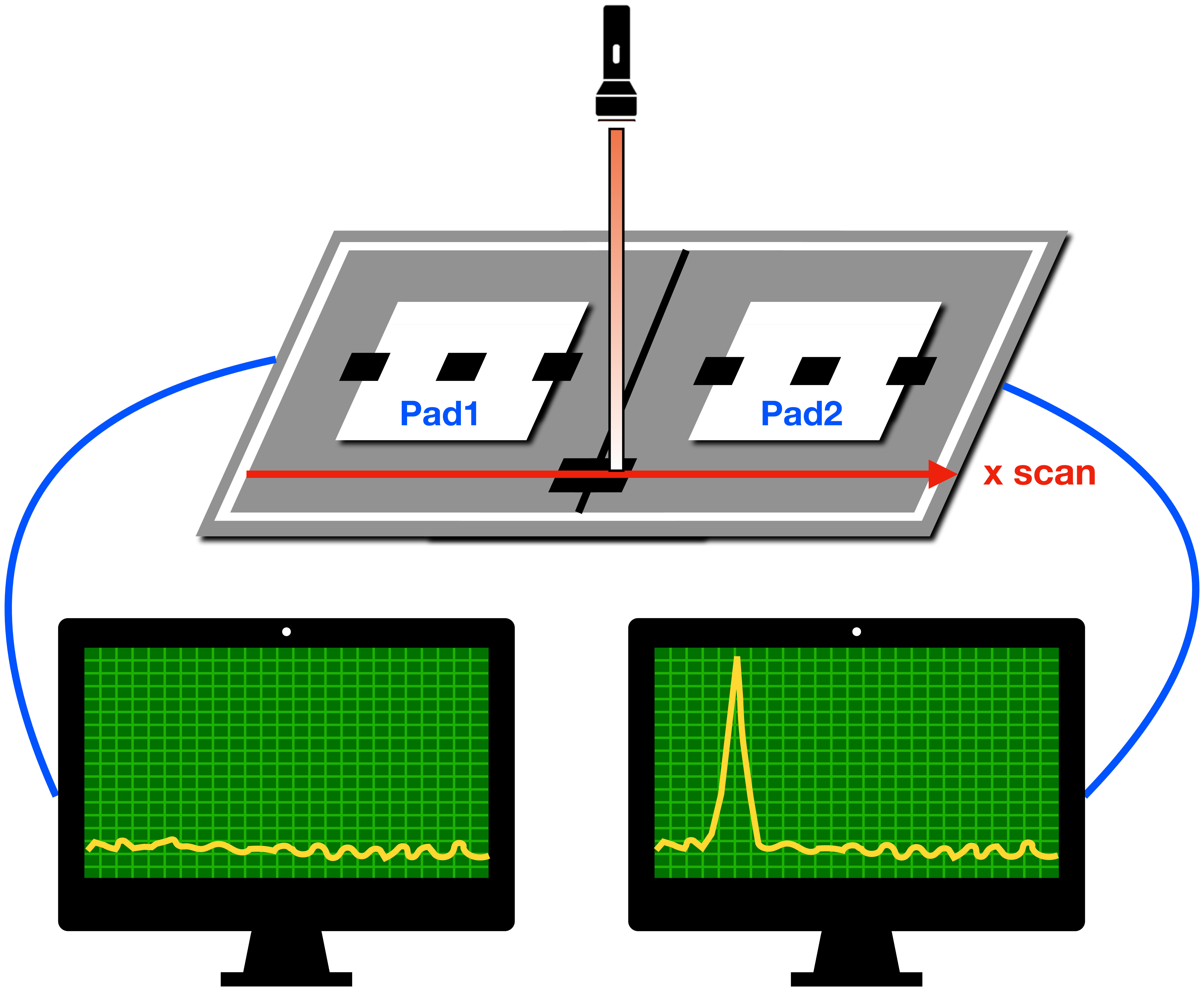
- **Signal from pad1**
- **Signal from pad2**

Gap Measurement - LGAD sensor



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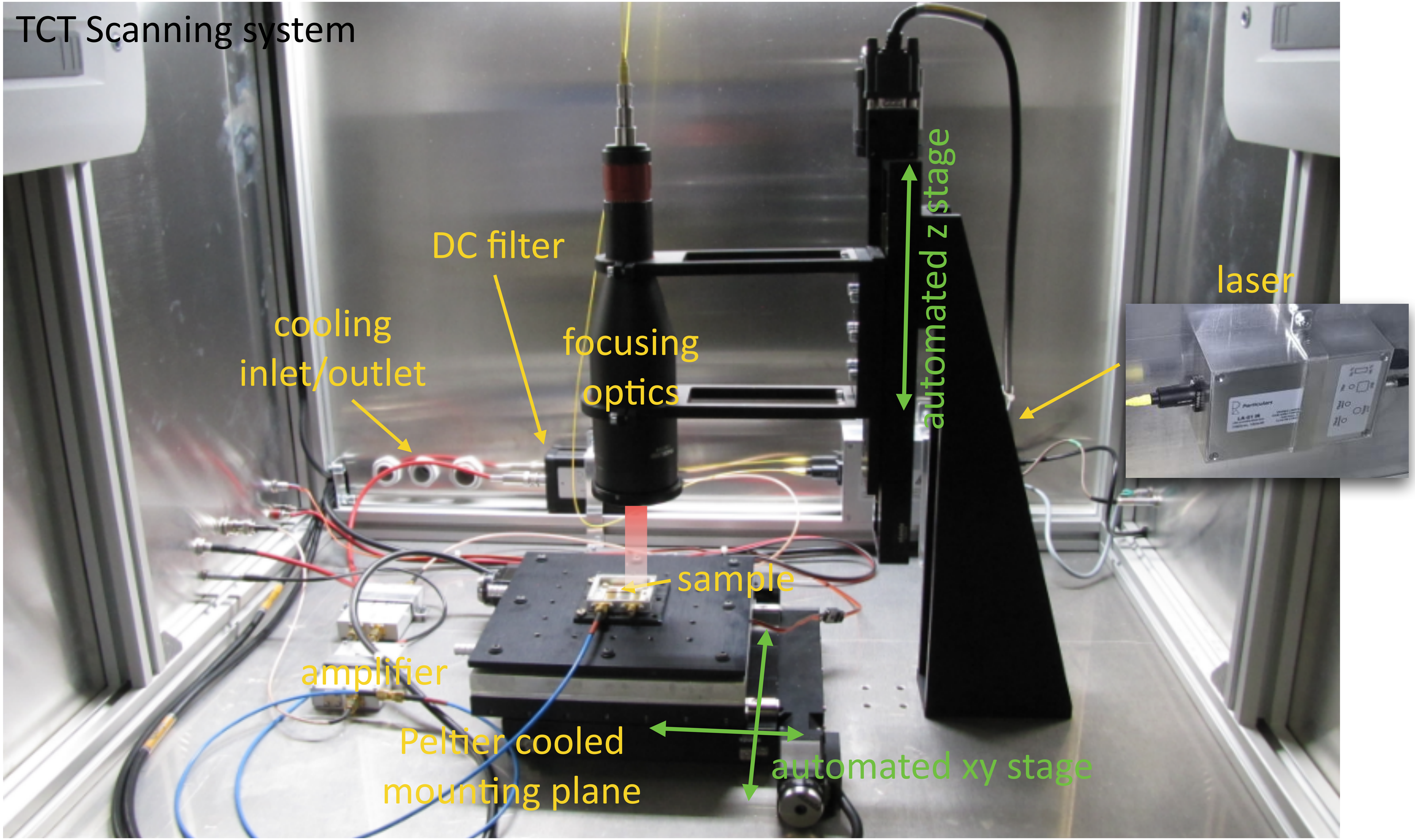
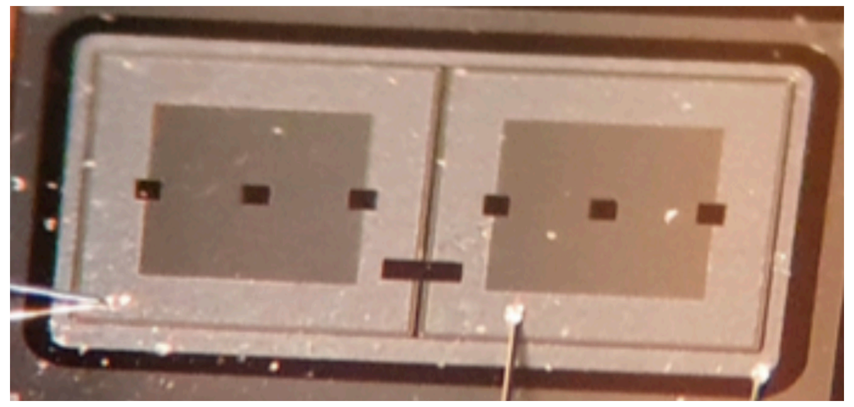
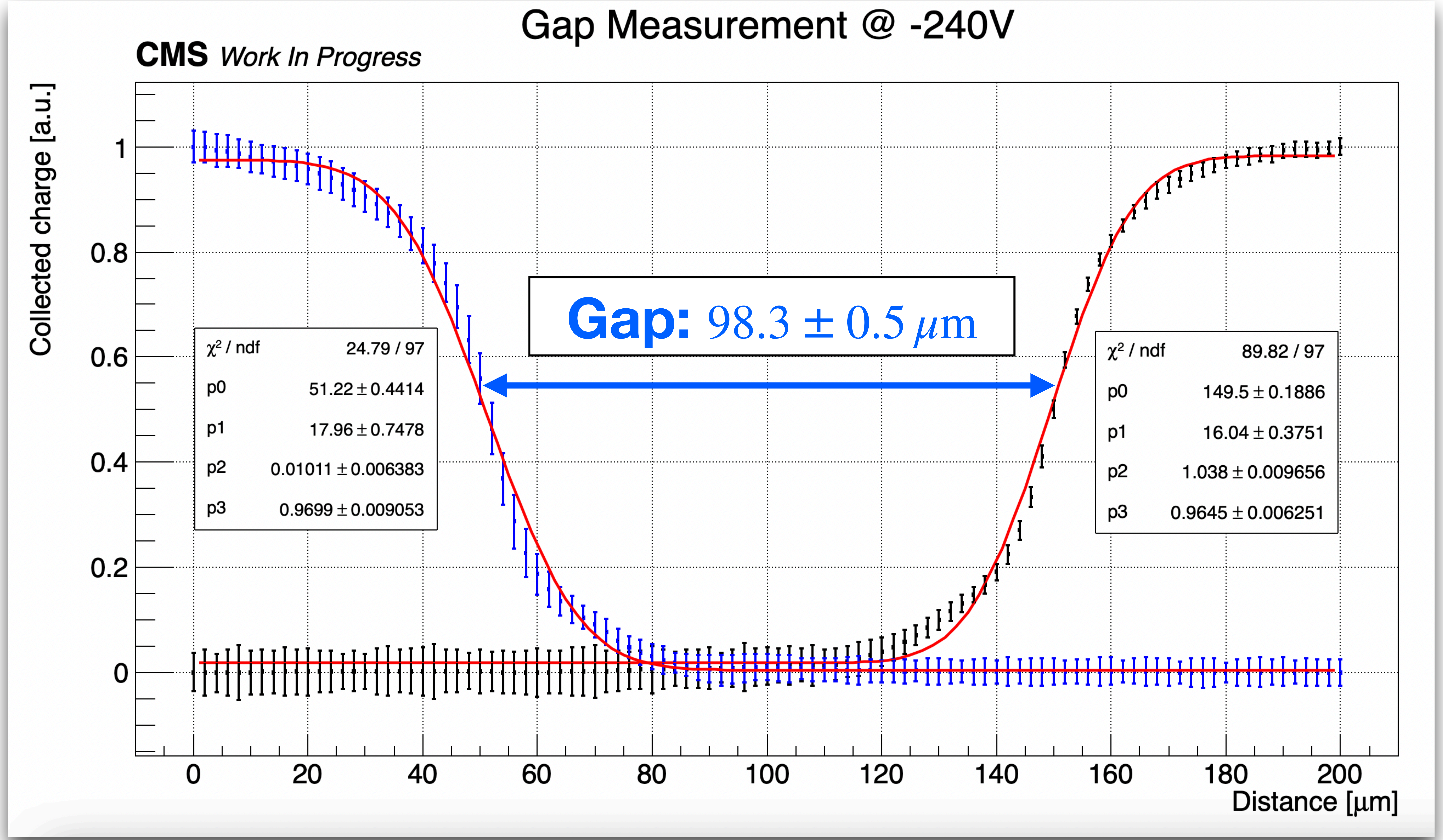

TCT Scanning system
DC filter
cooling
inlet/outlet
focusing
optics
automated z stage
laser
sample
amplifier
Peltier cooled
mounting plane
automated xy stage

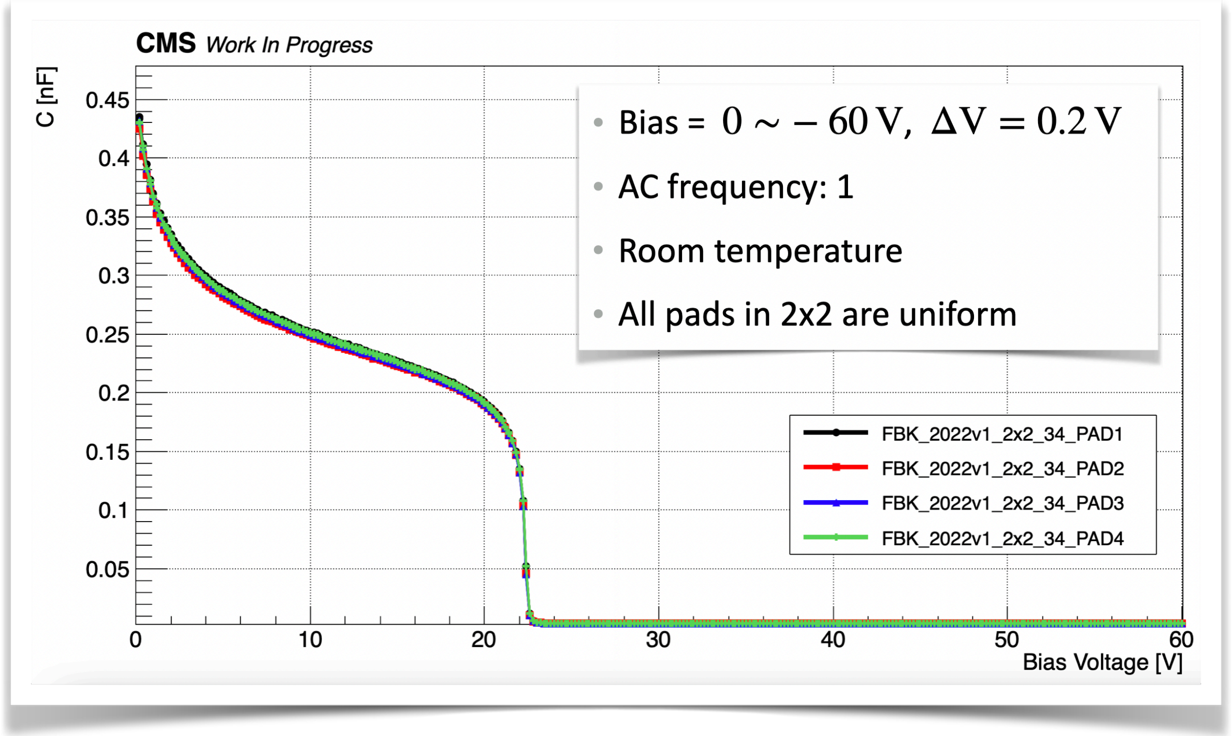
Gap Measurement - LGAD sensor

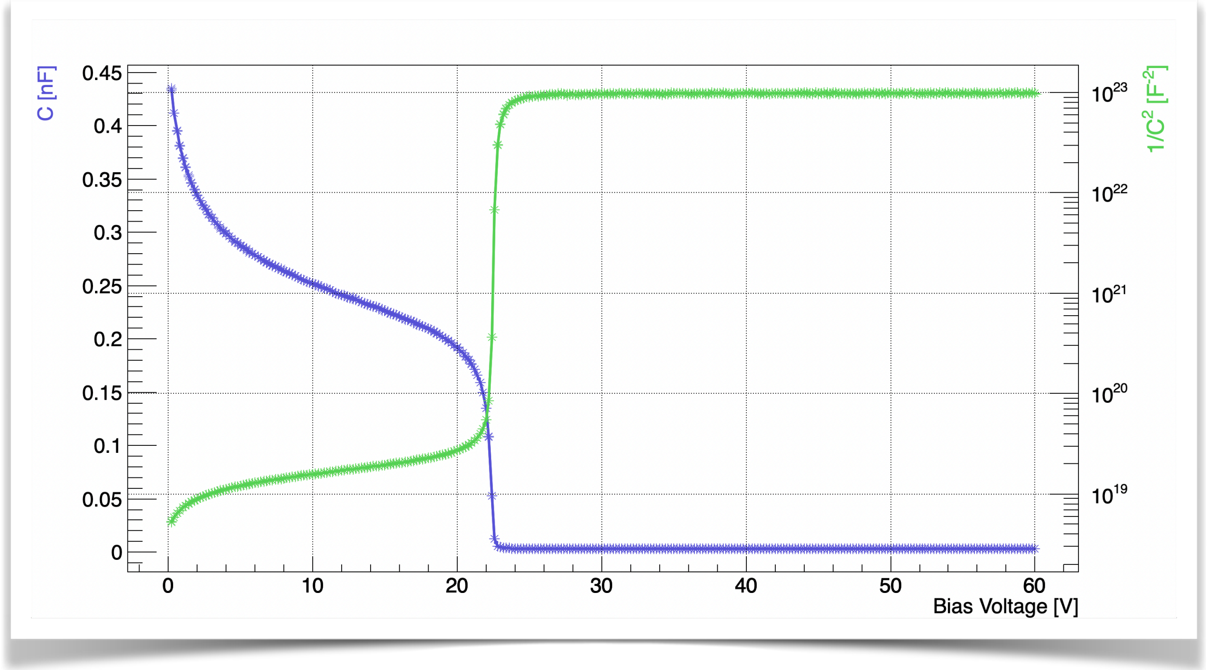


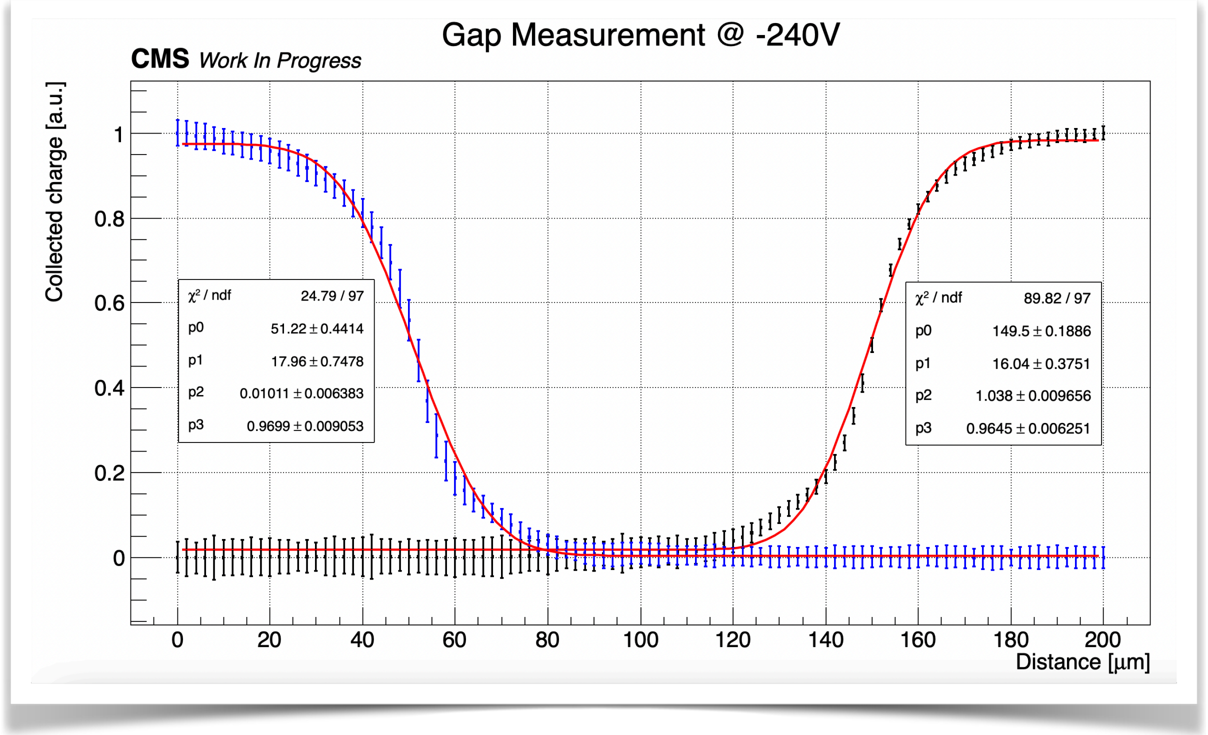


- Laser intensity: 1-10 MIPs
  - Performed 50 scans
  - Bias Voltage: $-240\ \mathrm{V}$ ($50\ \mathrm{V}$ before Breakdown)
  - Room temperature
  - Gap: $98.3 \pm 0.5\,\mu m$
  - Consistent with results of other groups

Summary and Outlook







- CMS LGAD sensors can provide single hit time resolution < 50 ps
- Testing Market Survey sensors (FBK as well as other vendors) is being finalized
- KU have tested 1x2 and 2x2 FBK sensors
  - Test for 2x2 sensors: I-V, C-V, micro discharge
  - Test for 1x2 sensors: inter-pad distance, inter-pad isolation
- Next step is preproduction and establishing QA/QC procedure
  - We KU have validated our testing setup, so we are ready for the future tests!