Significant Results from TES Latest Measurements

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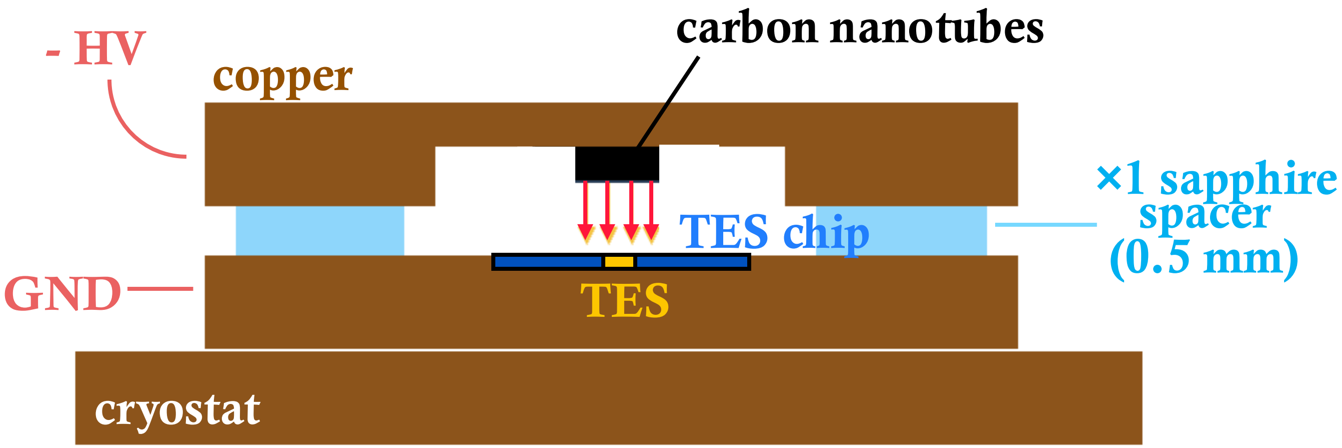
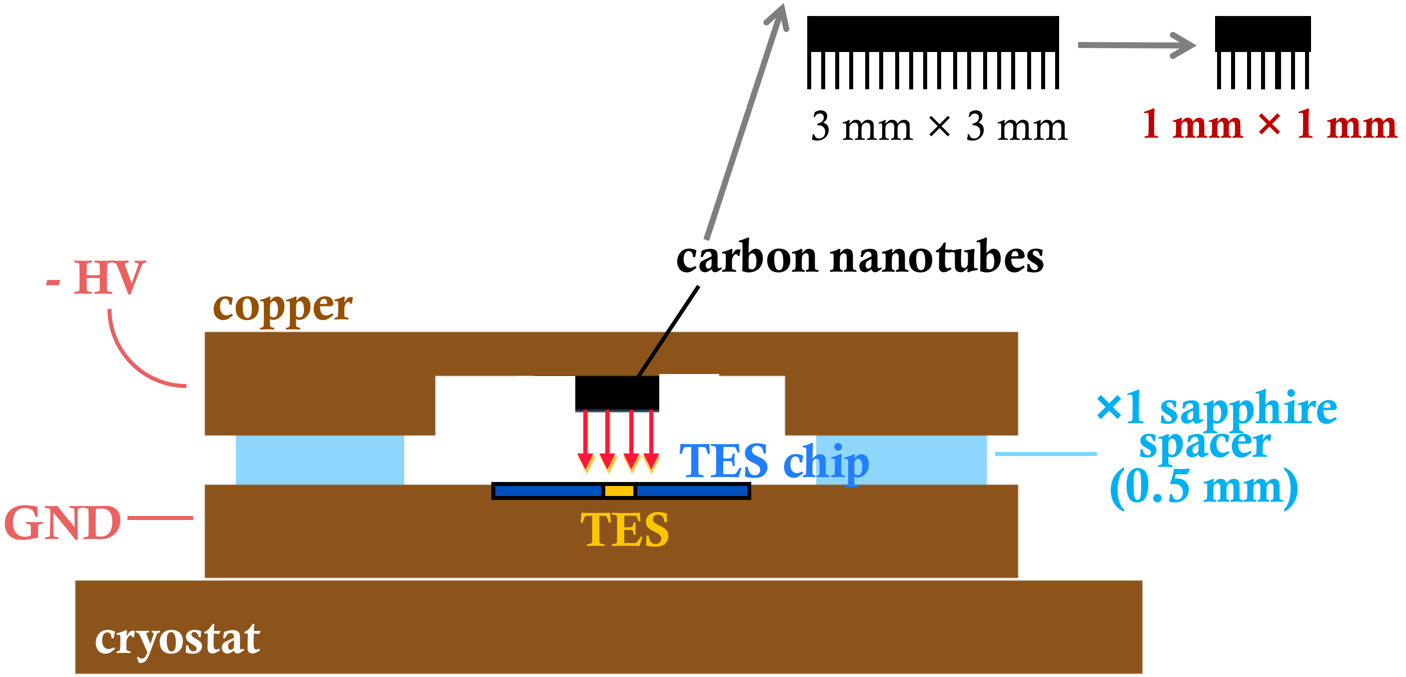
Roma Tre Università degli Studi
INRiM Istituto Nazionale di Ricerca Metrologica

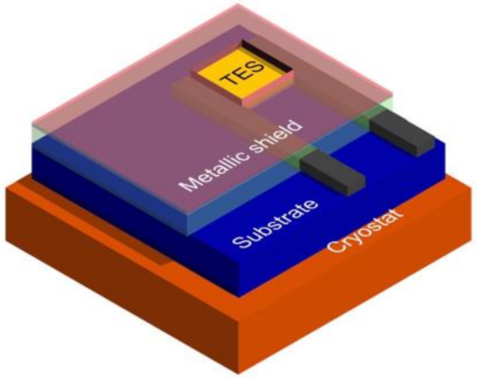
Differences from the Previous Setup



Differences from the Previous Setup

CNTs reduced to send less electrons on the shield



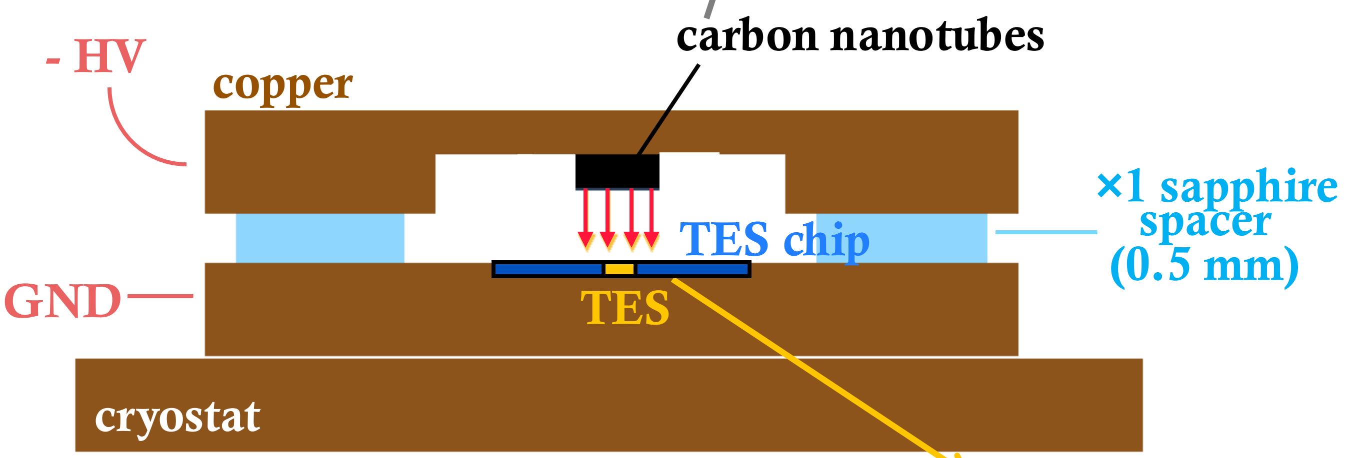


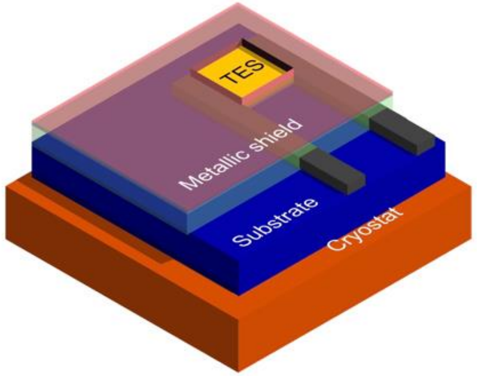
(gold shield to protect wiring and substrate from electron hits)

Differences from the Previous Setup

CNTs reduced to send less electrons on the shield

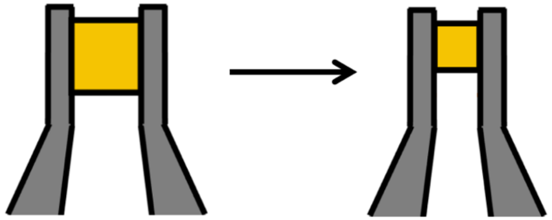
3 mm × 3 mm → **1 mm × 1 mm**





(gold shield to protect wiring and substrate from electron hits)

smaller TES to improve energy resolution



$100\ \mu m \times 100\ \mu m$ → $\mathbf{60\ \mu m \times 60\ \mu m}$

$\sigma_e \propto \sqrt{Area_{TES}} \Rightarrow$ expected **40%** improvement!

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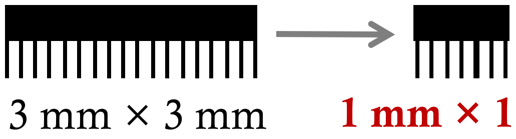

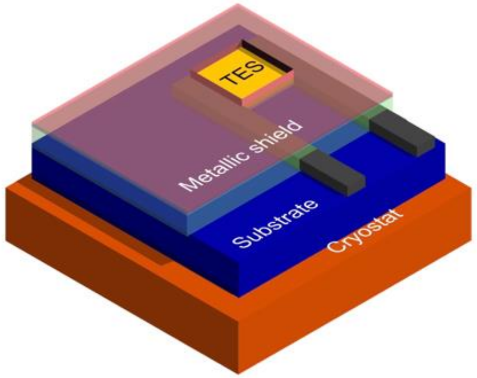

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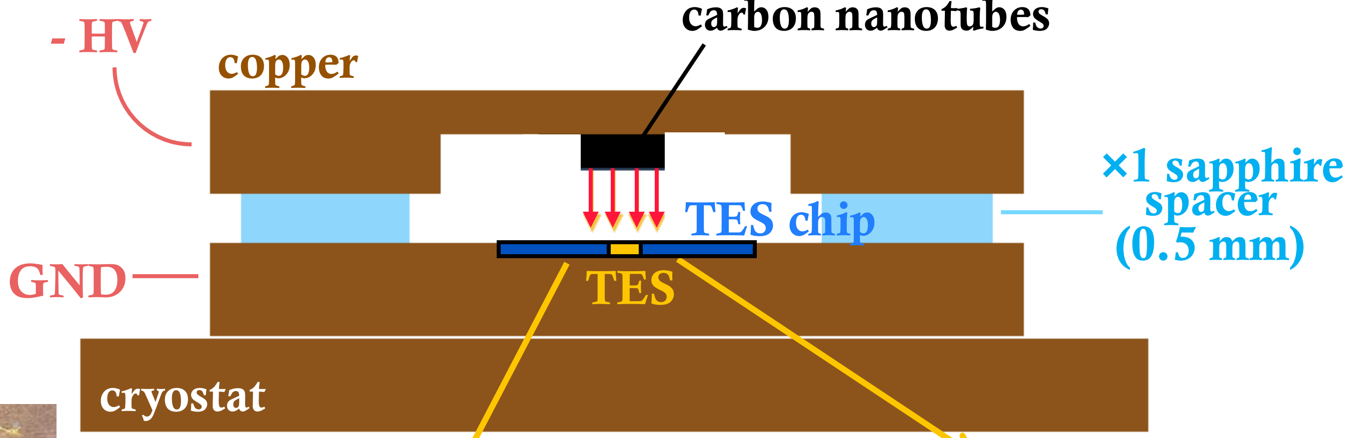

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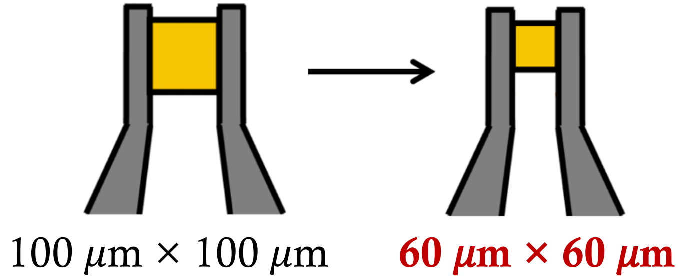
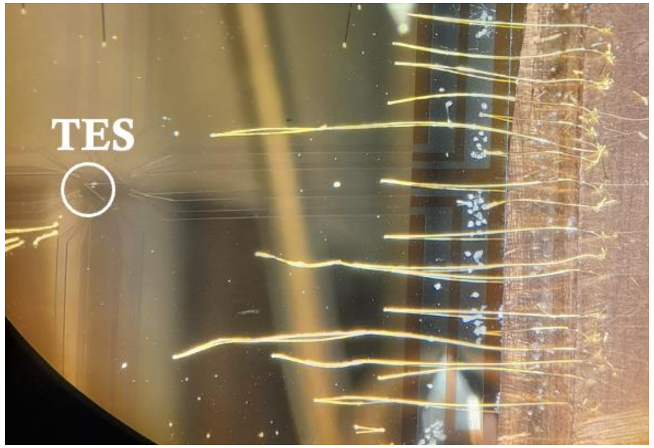


$\sigma_e \propto \sqrt{Area_{TES}}$ ⇒ expected **40%** improvement!

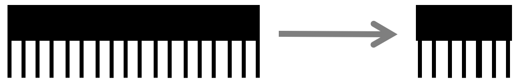


gold wire bondings
between shield and MiC
to facilitate thermalization

Differences from the Previous Setup

added **optical fiber** (not really aligned) to calibrate the TES at lower energies (E_{photon}= 3.05 eV)

CNTs reduced to send less electrons on the shield



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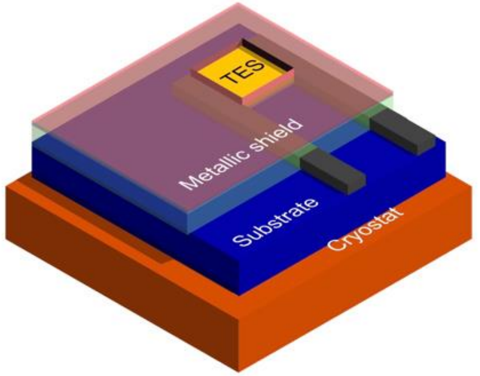

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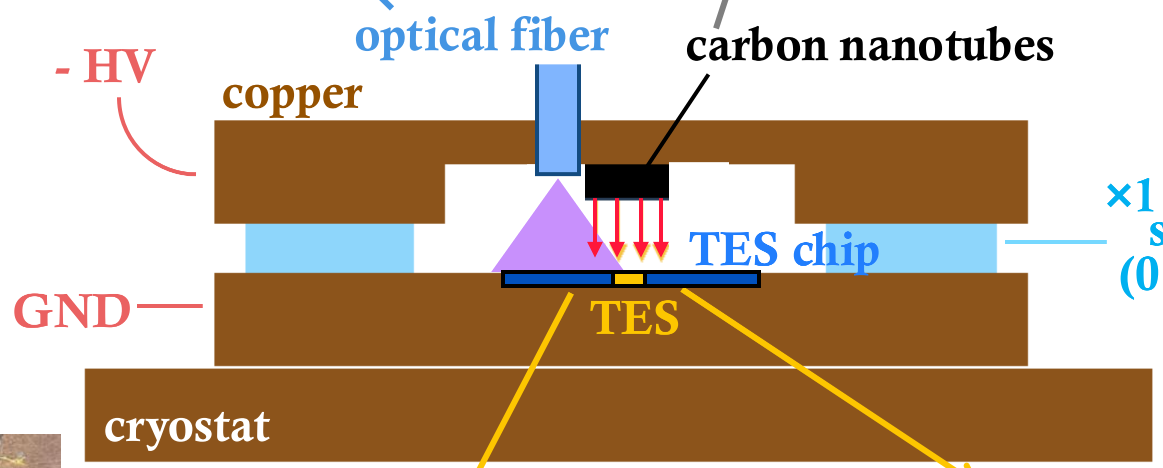

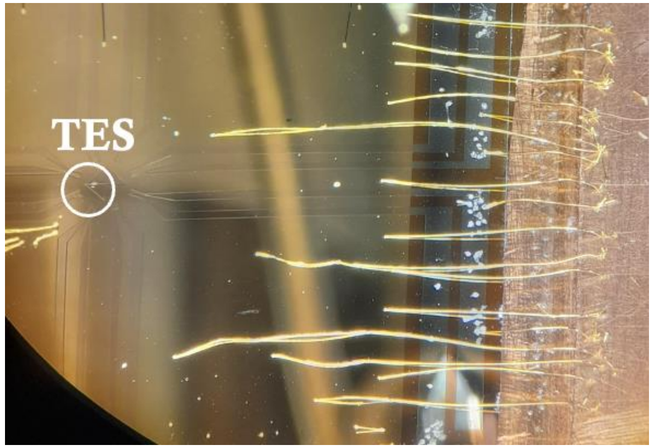

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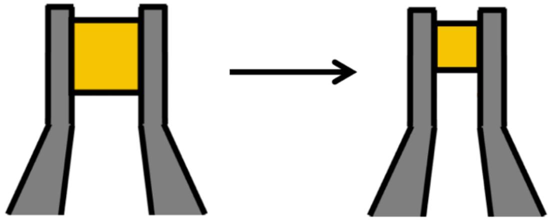


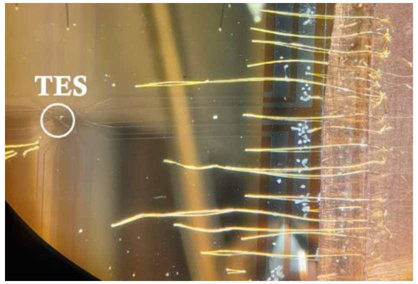
100 μm × 100 μm → **60 μm × 60 μm**

$\sigma_e \propto \sqrt{Area_{TES}} \Rightarrow$ expected **40%** improvement!

Stable TES Working Point

Reducing the CNTs and facilitating the thermalization, the TES working point does not change for different V_{cnt}

(area reduced of a **factor 10**)



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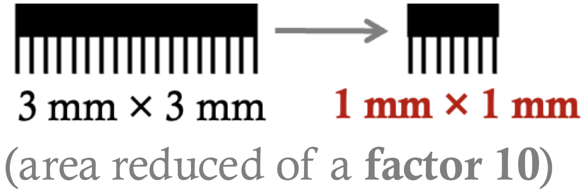
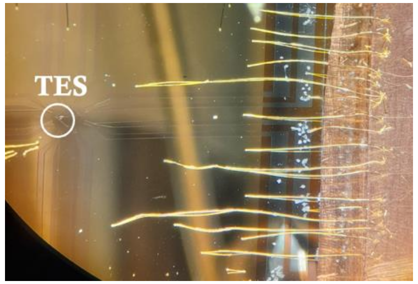
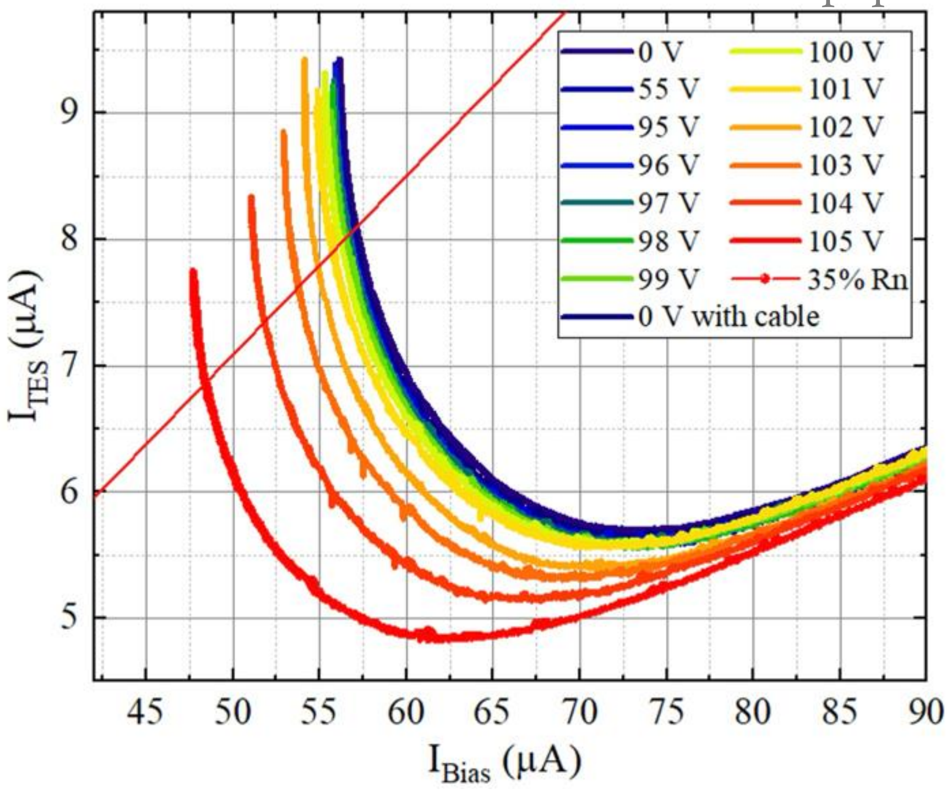
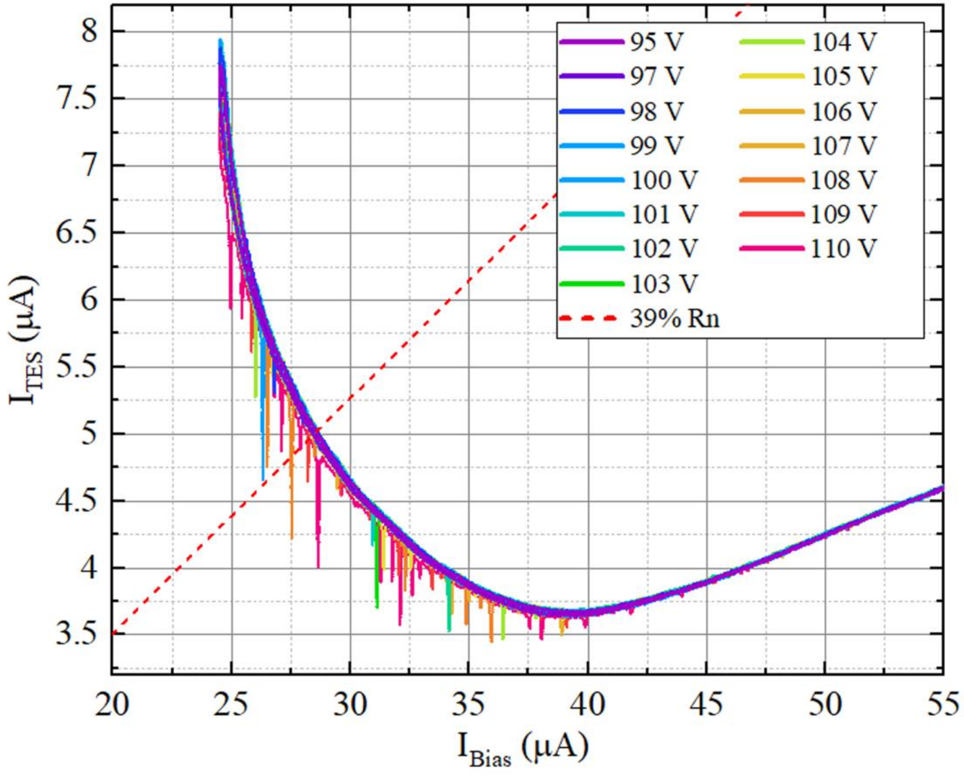




paper



december 2024



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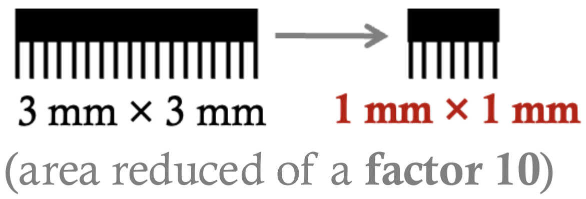
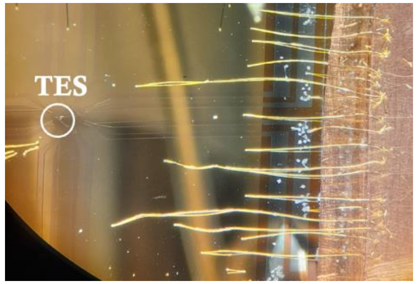
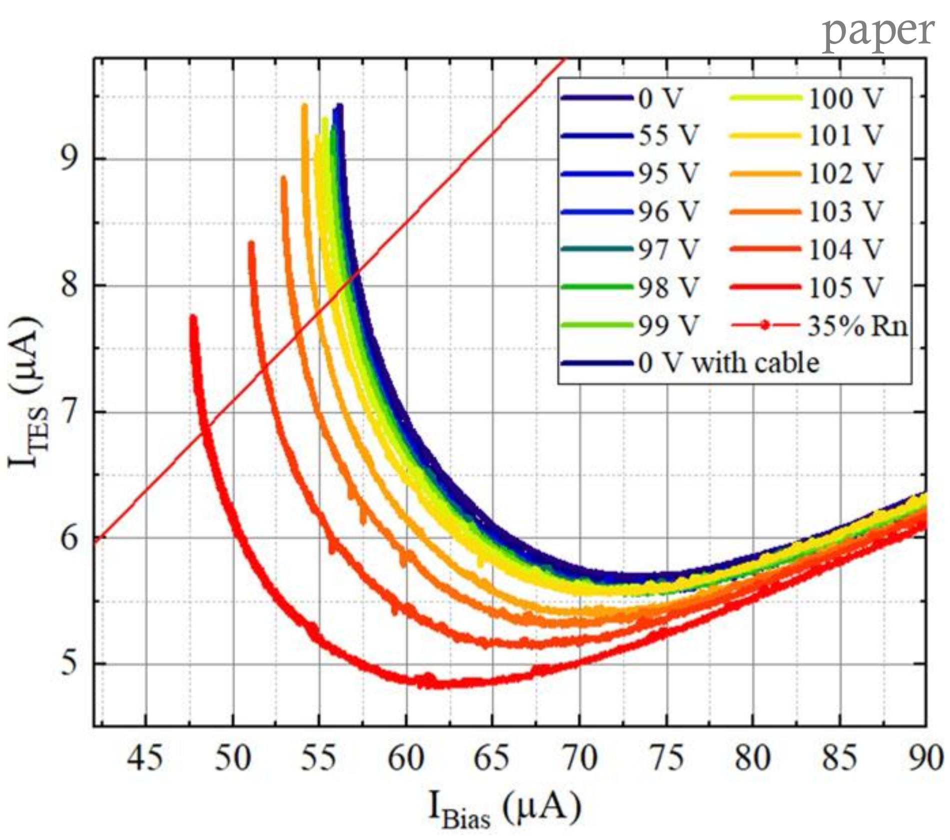
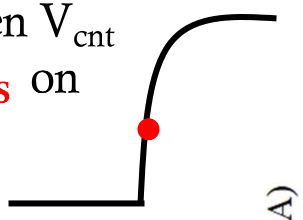


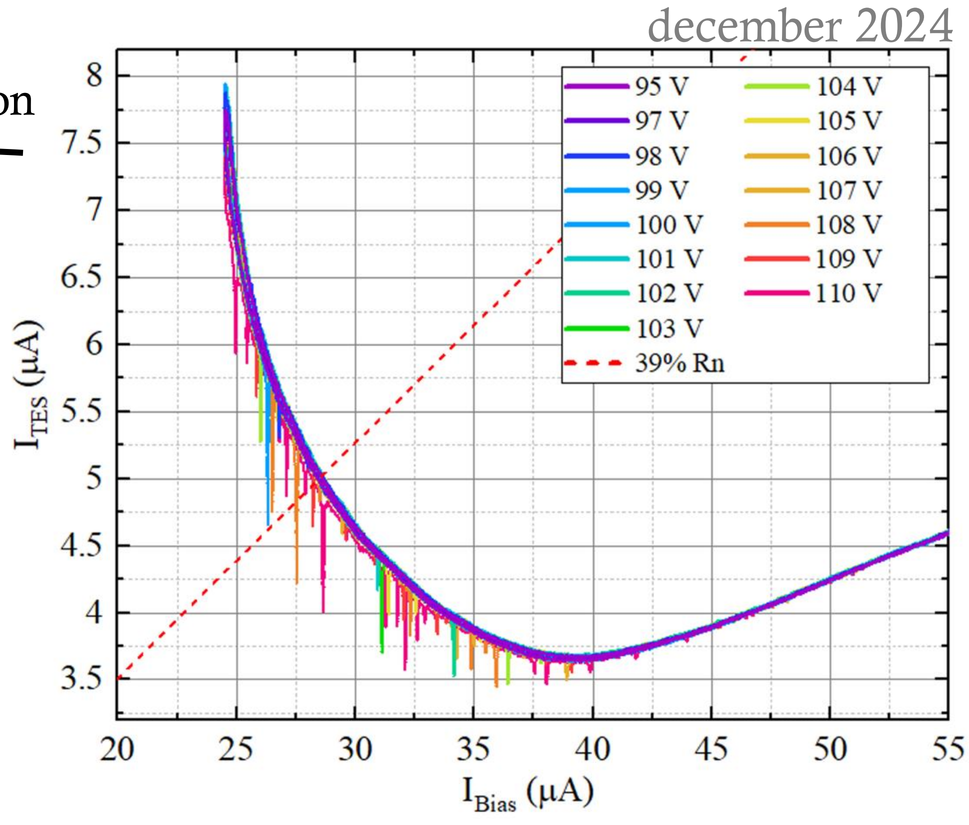




curve: TES operating condition for a given V_{cnt}

line: fixed R_{TES} on transition





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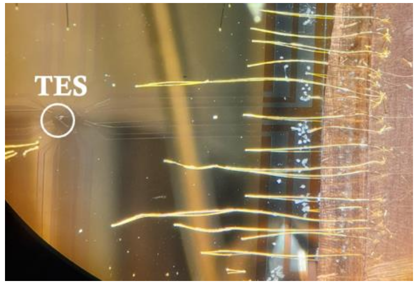
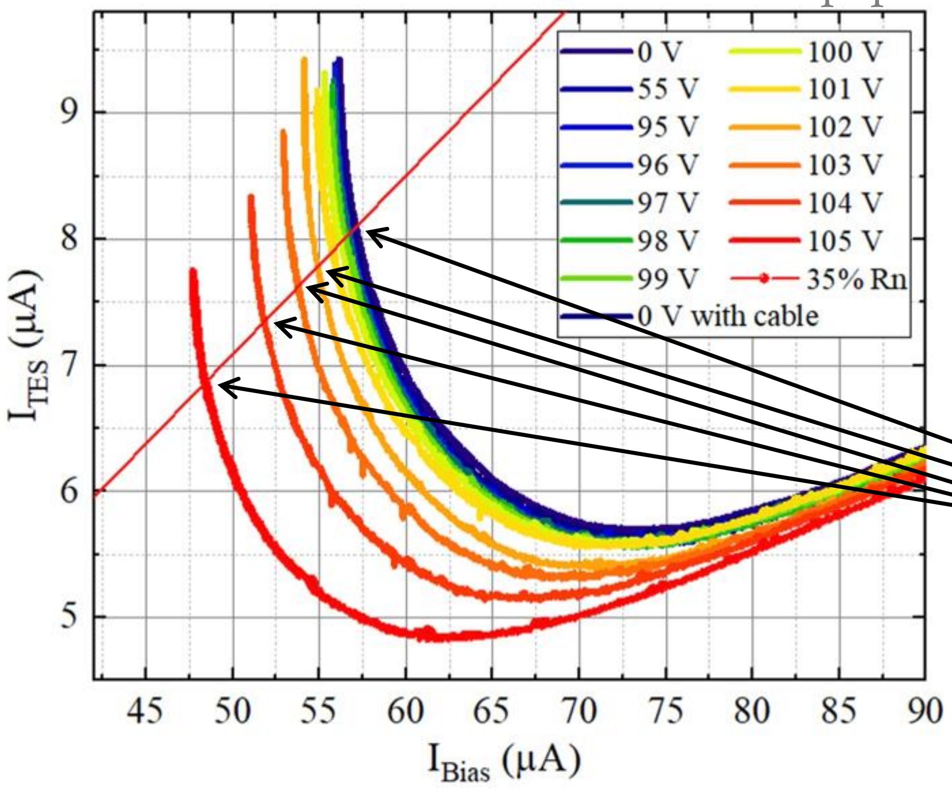


paper



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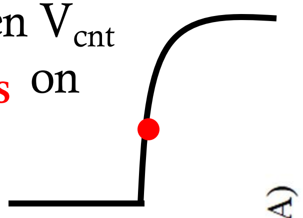

intersection curve-line: TES working point during measurement for a given V_{cnt}

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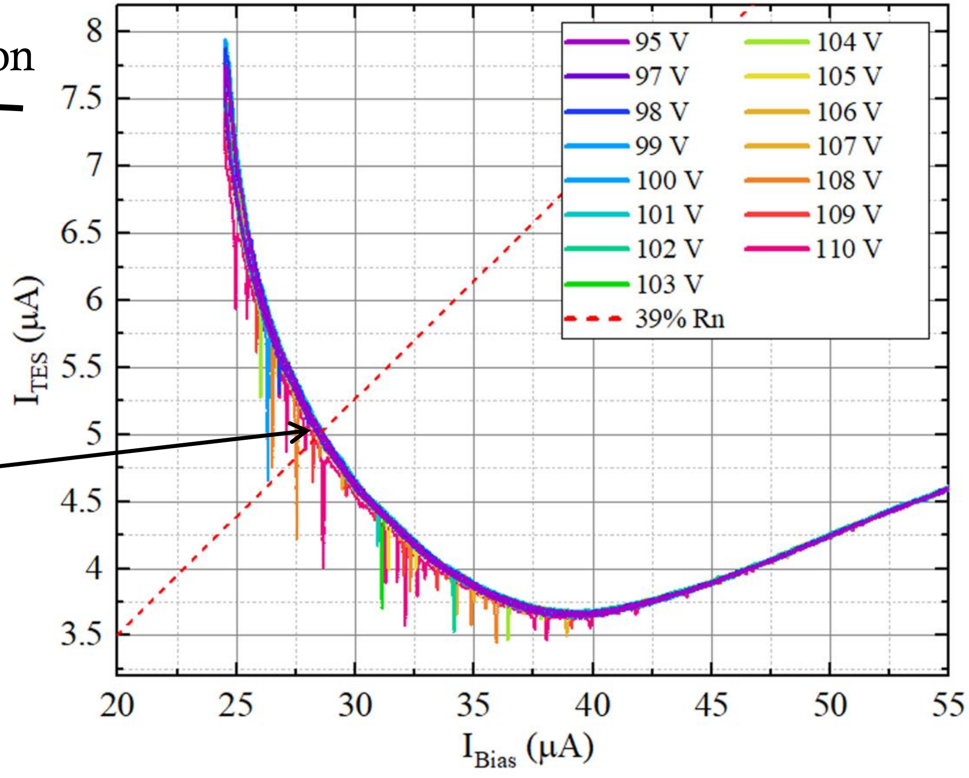

Stable TES Working Point

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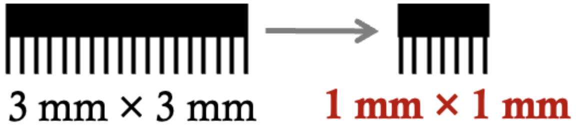

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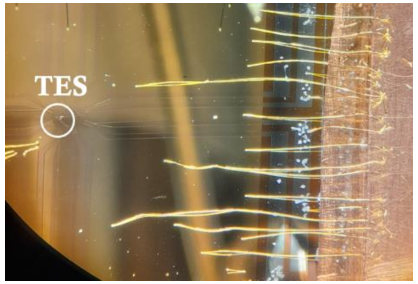

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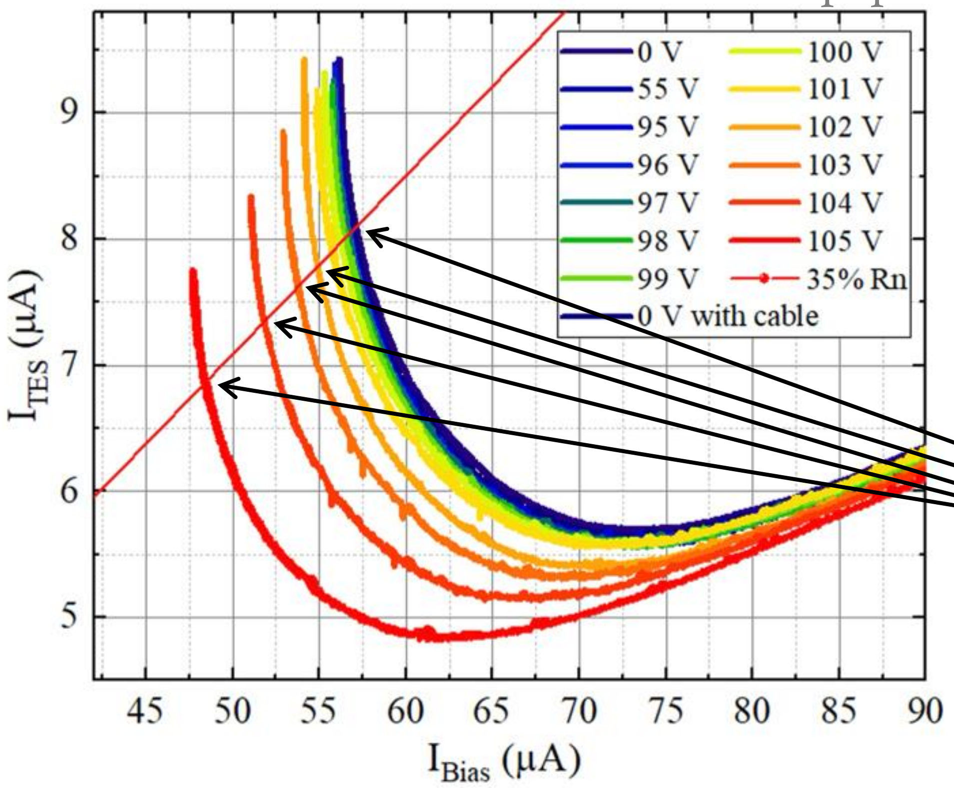

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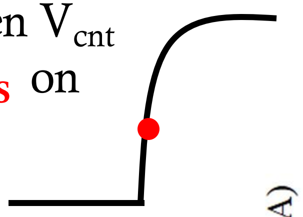

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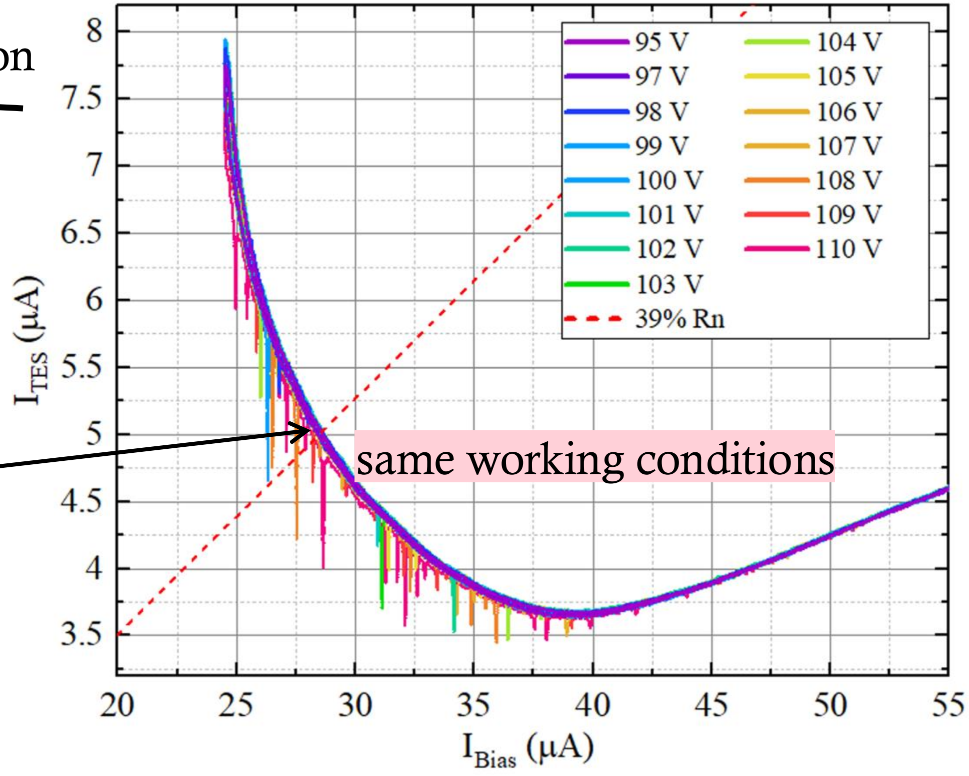
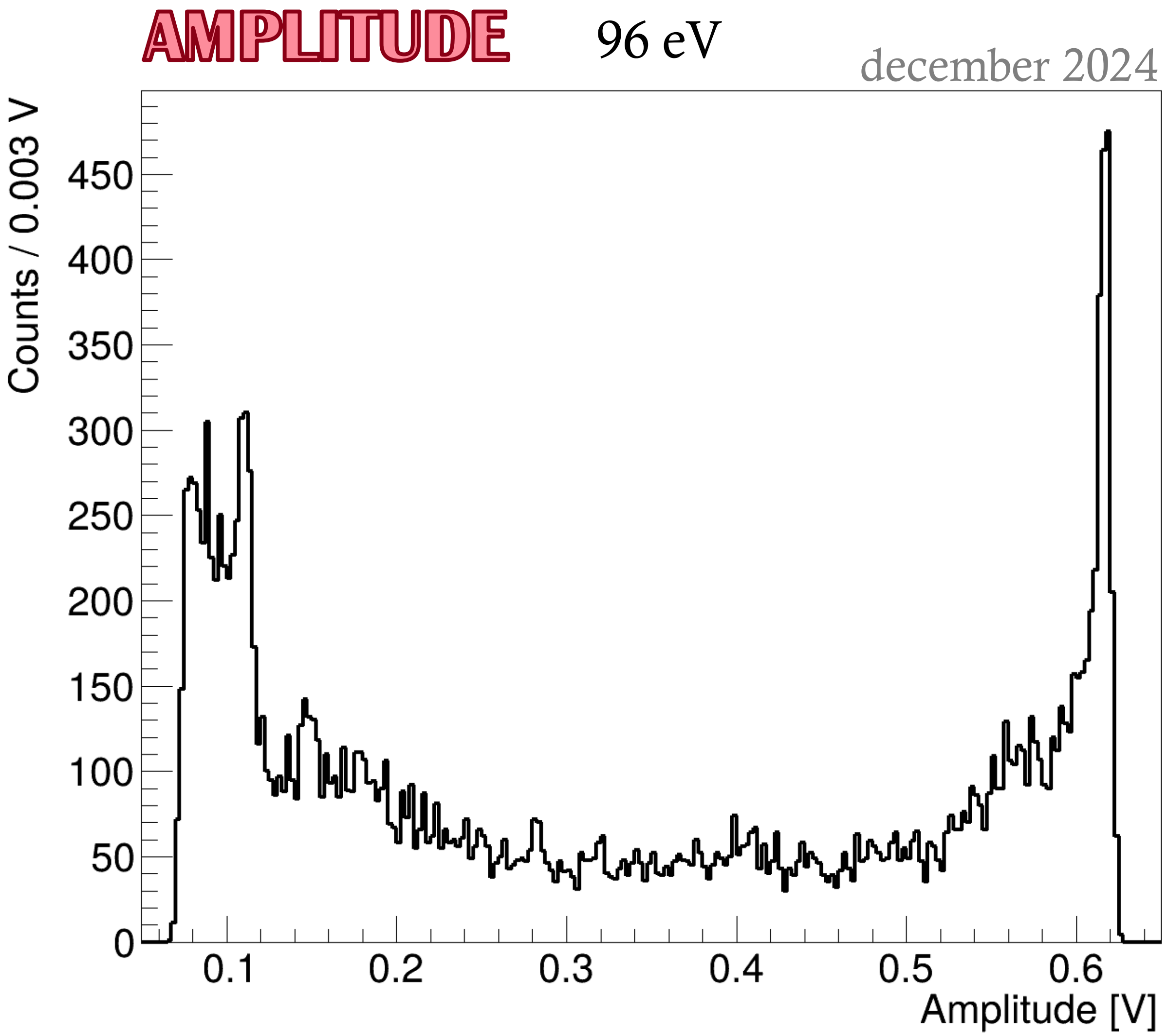
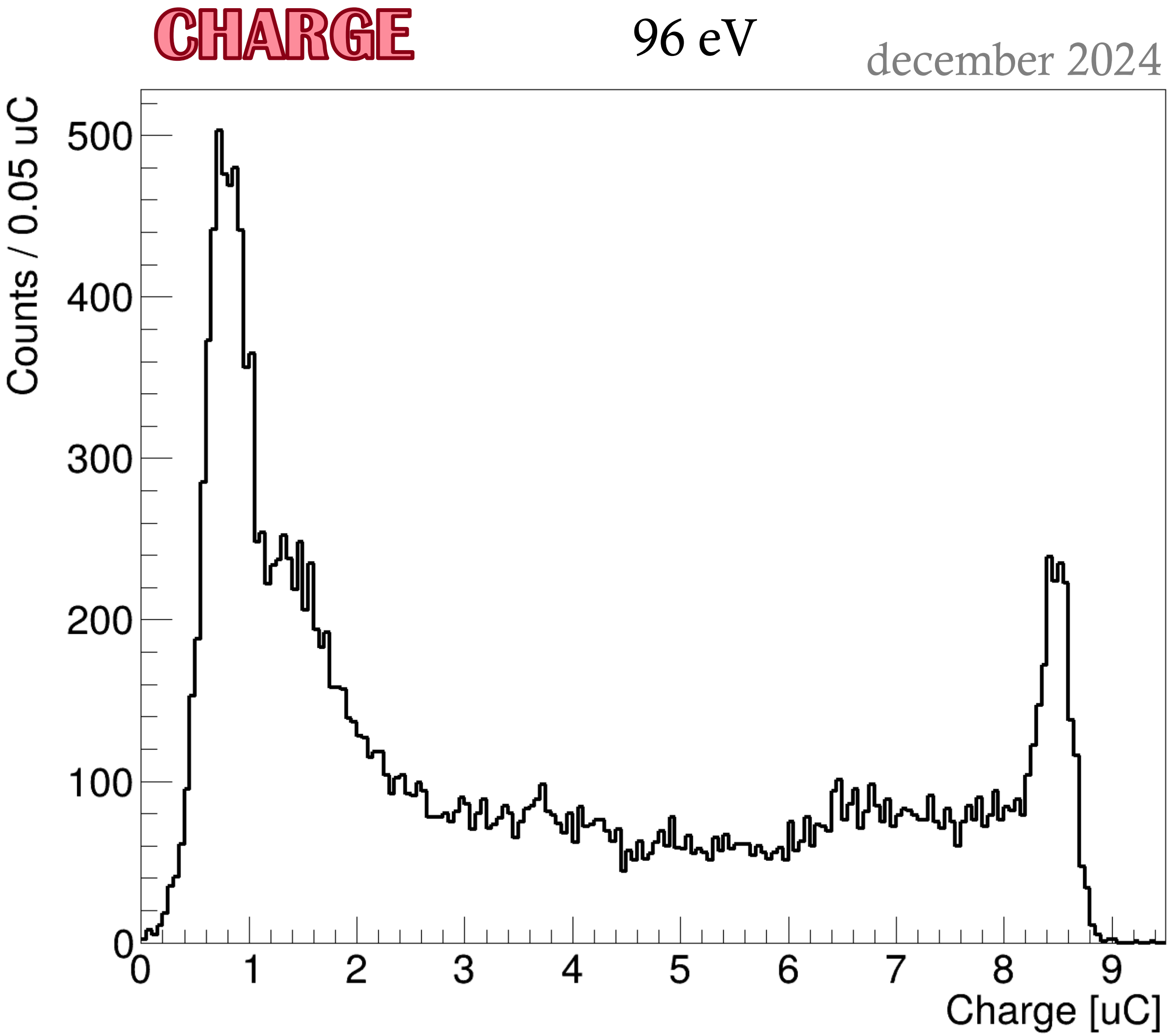


same working conditions

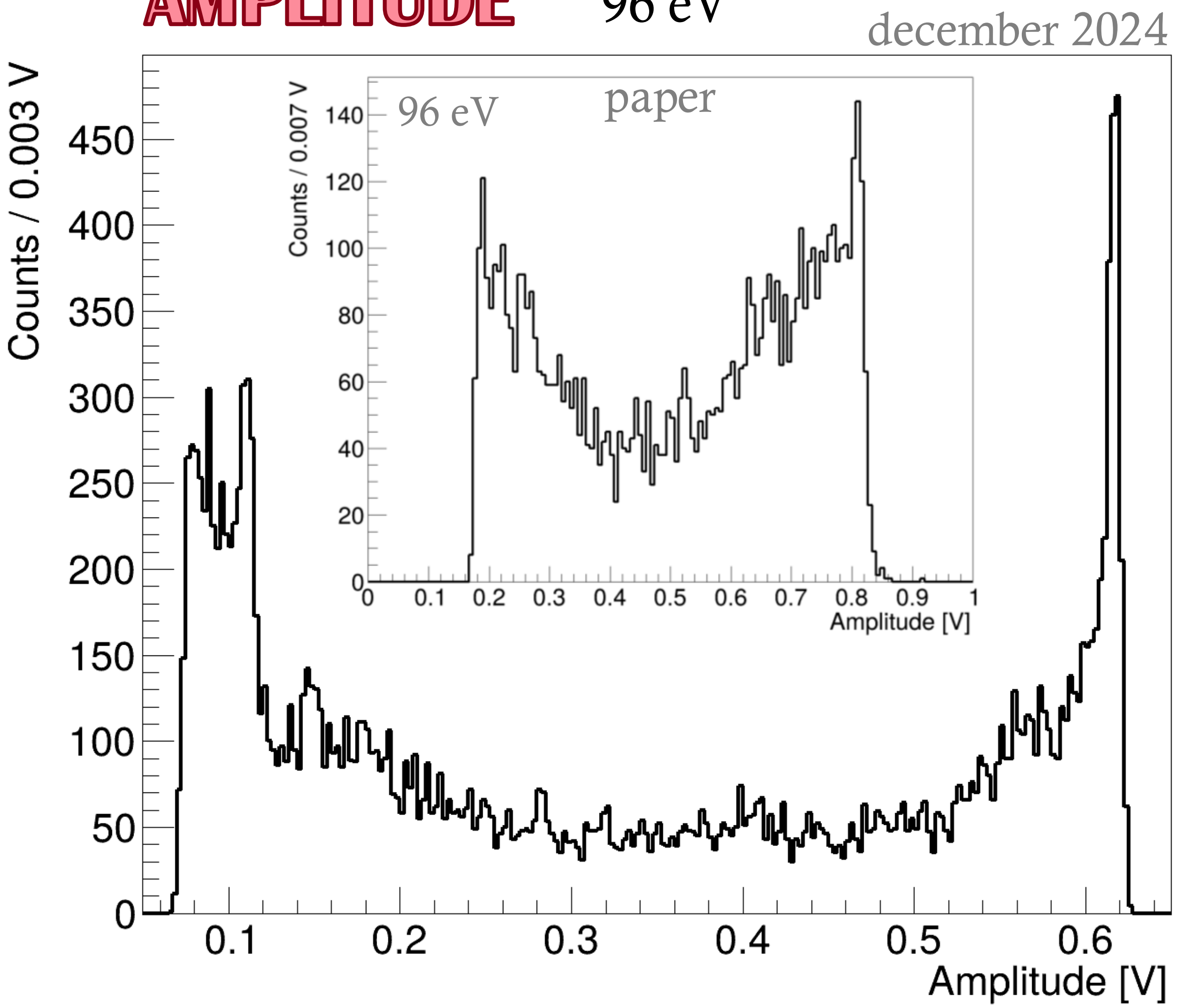
Histogram Shape more Defined!



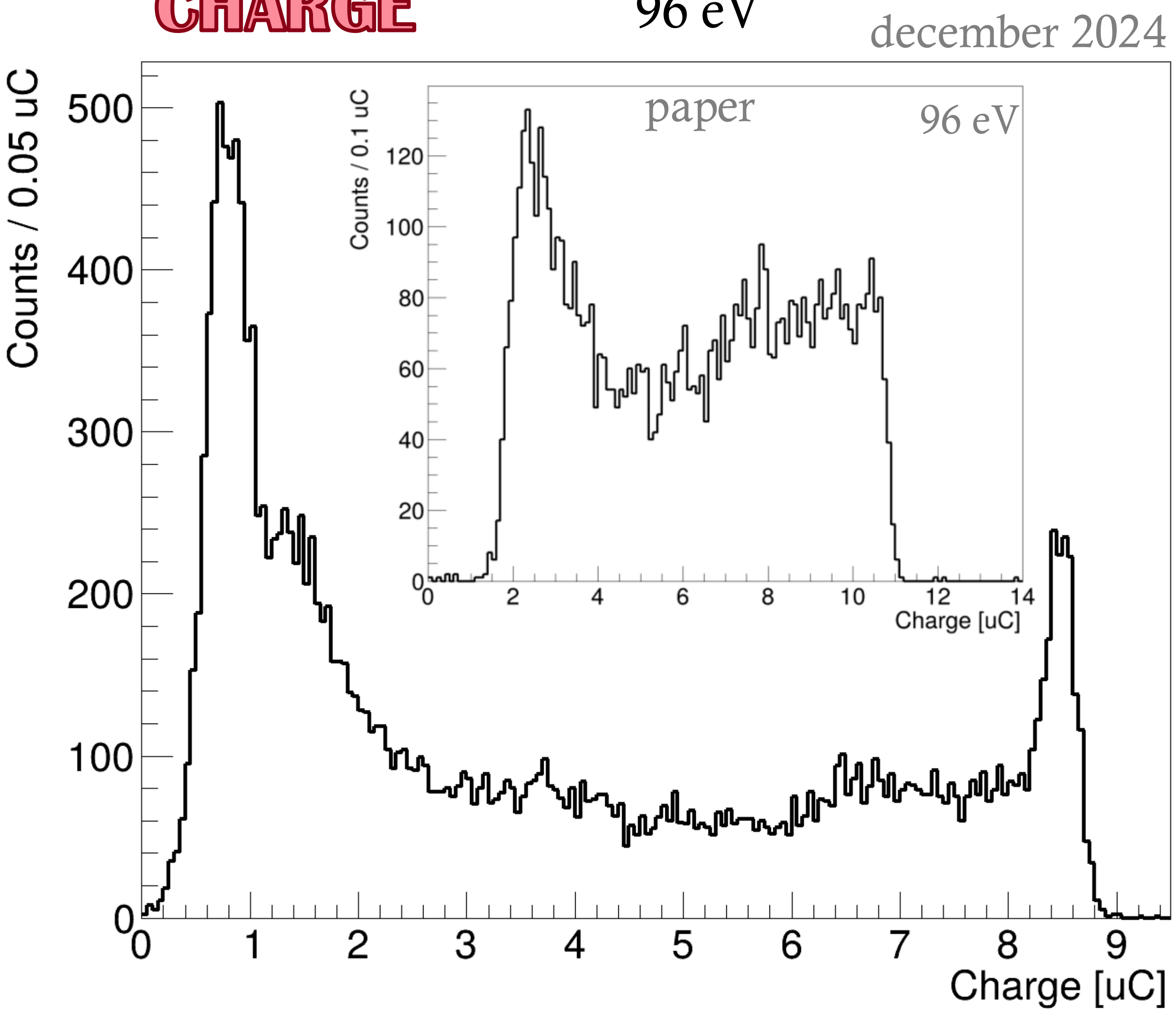


Histogram Shape more Defined!

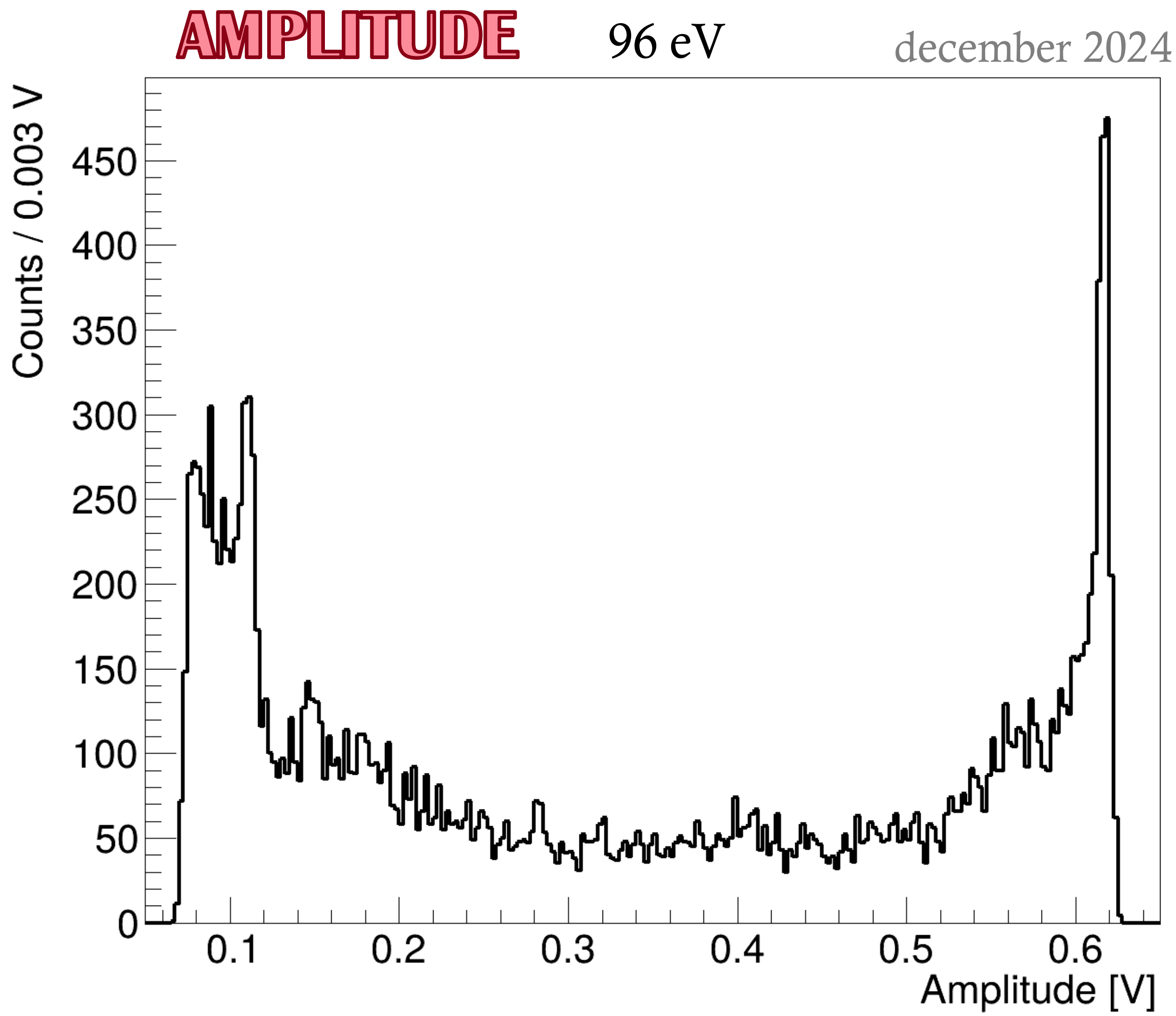
AMPLITUDE 96 eV

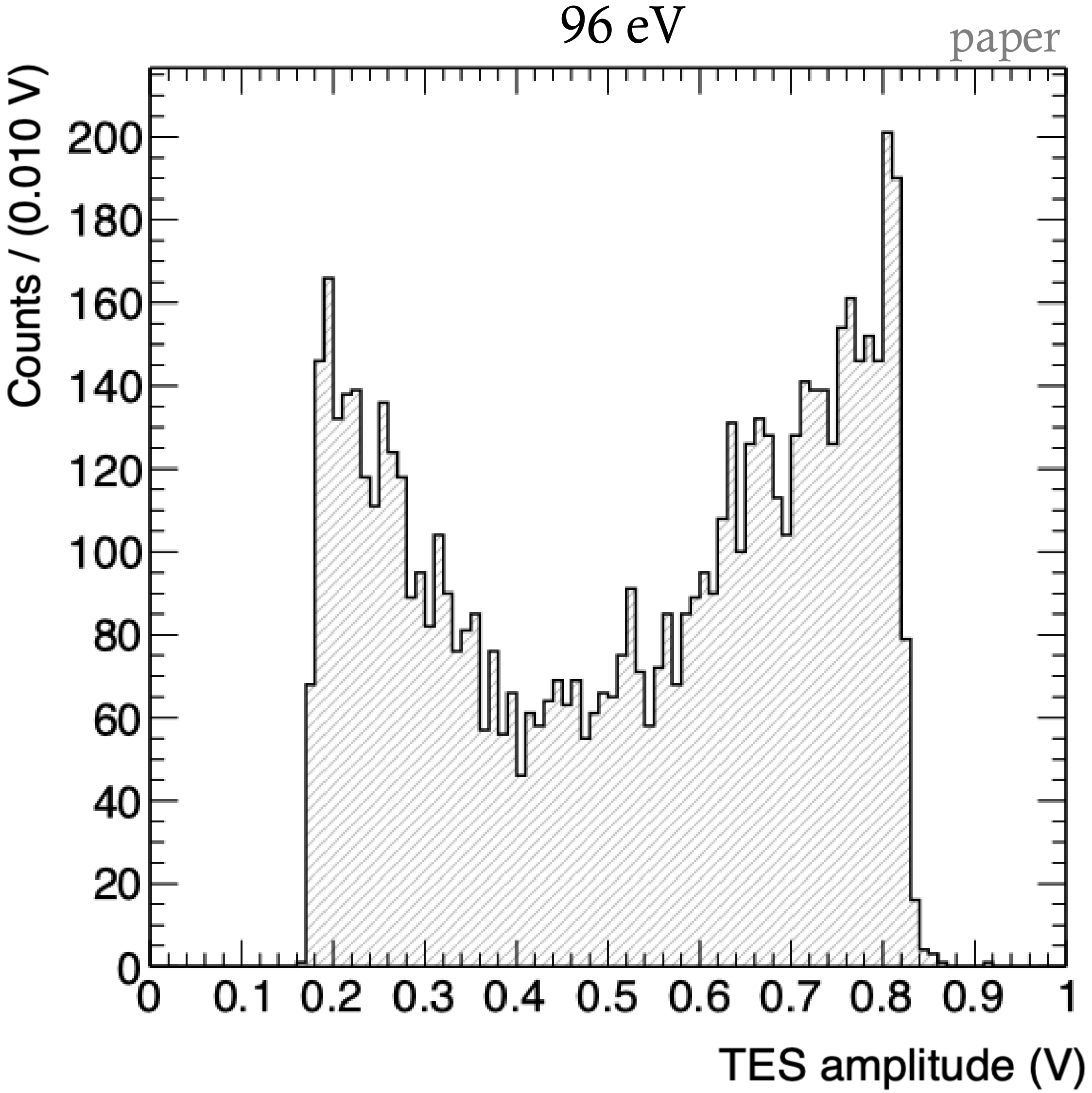


CHARGE 96 eV

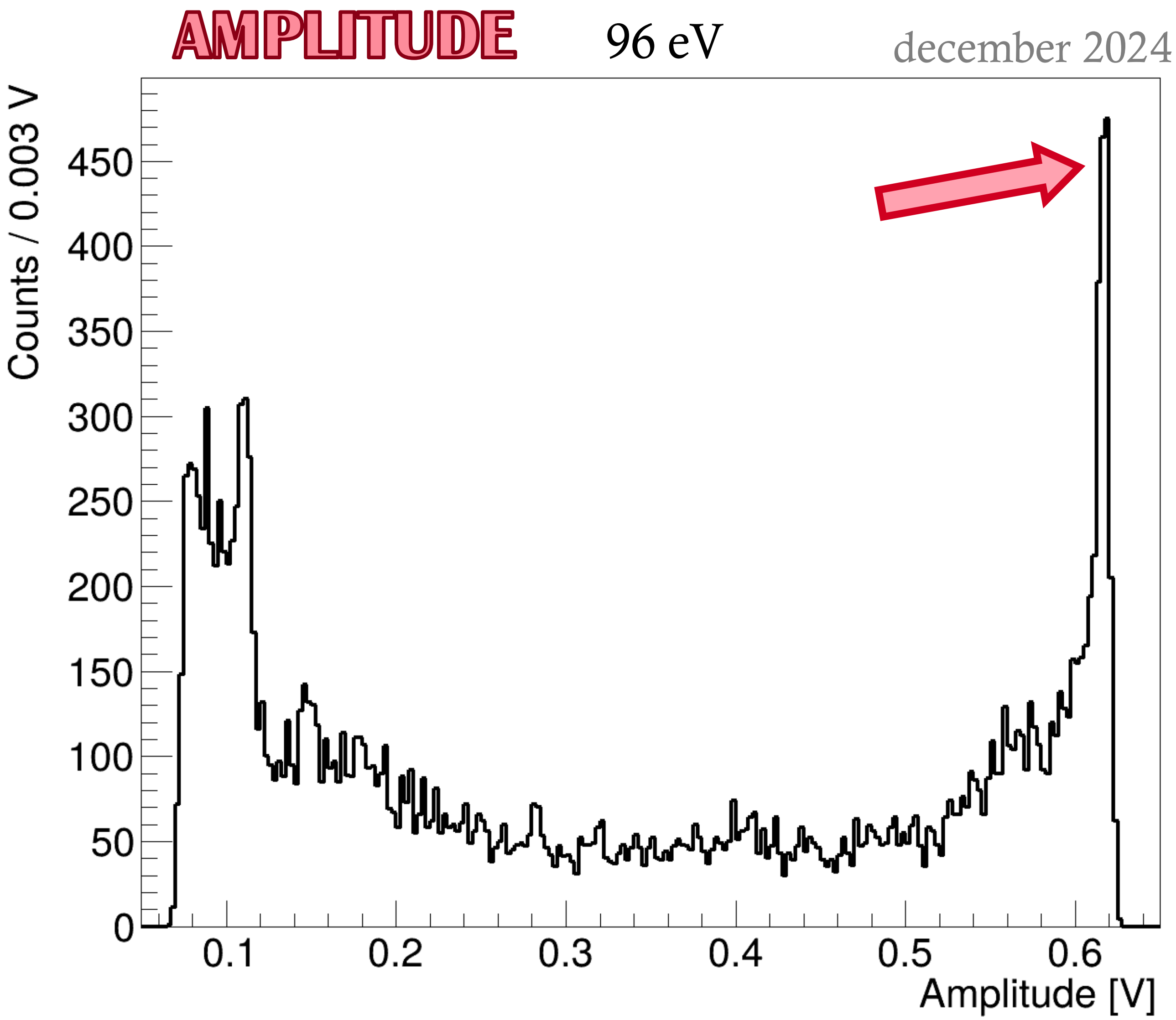


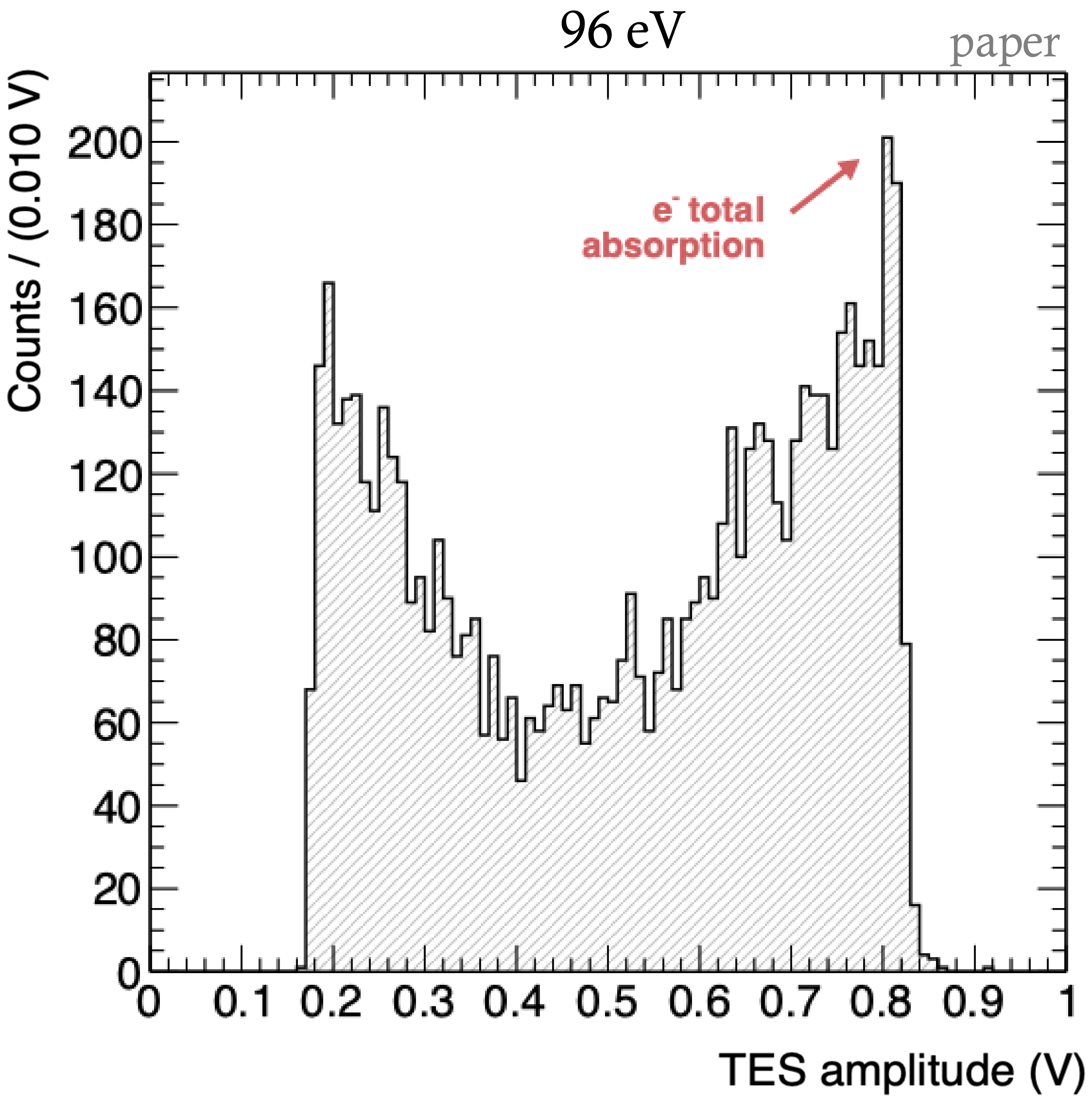
What Did we Achieve?





High-Amplitude Peak is Narrower!





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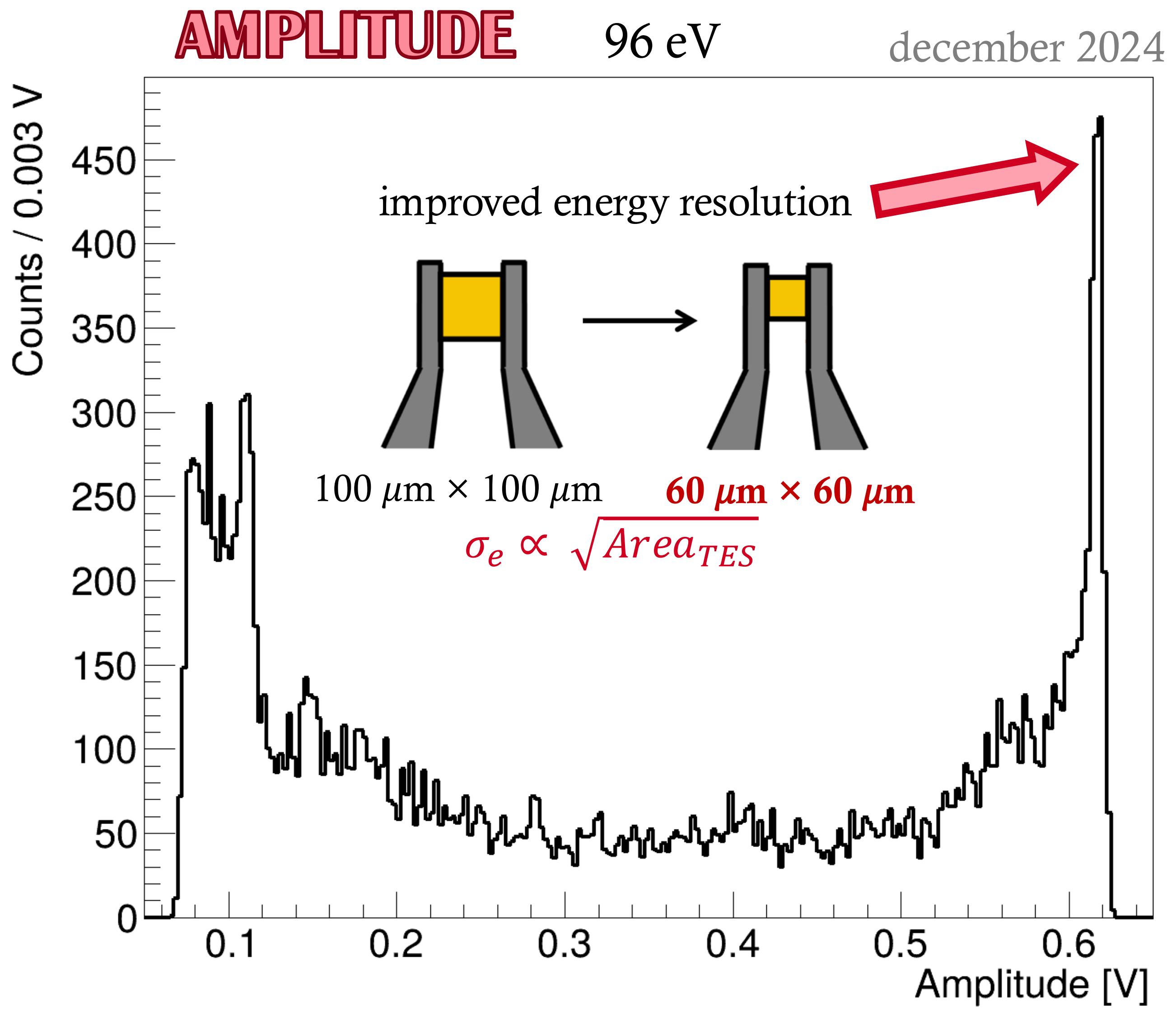
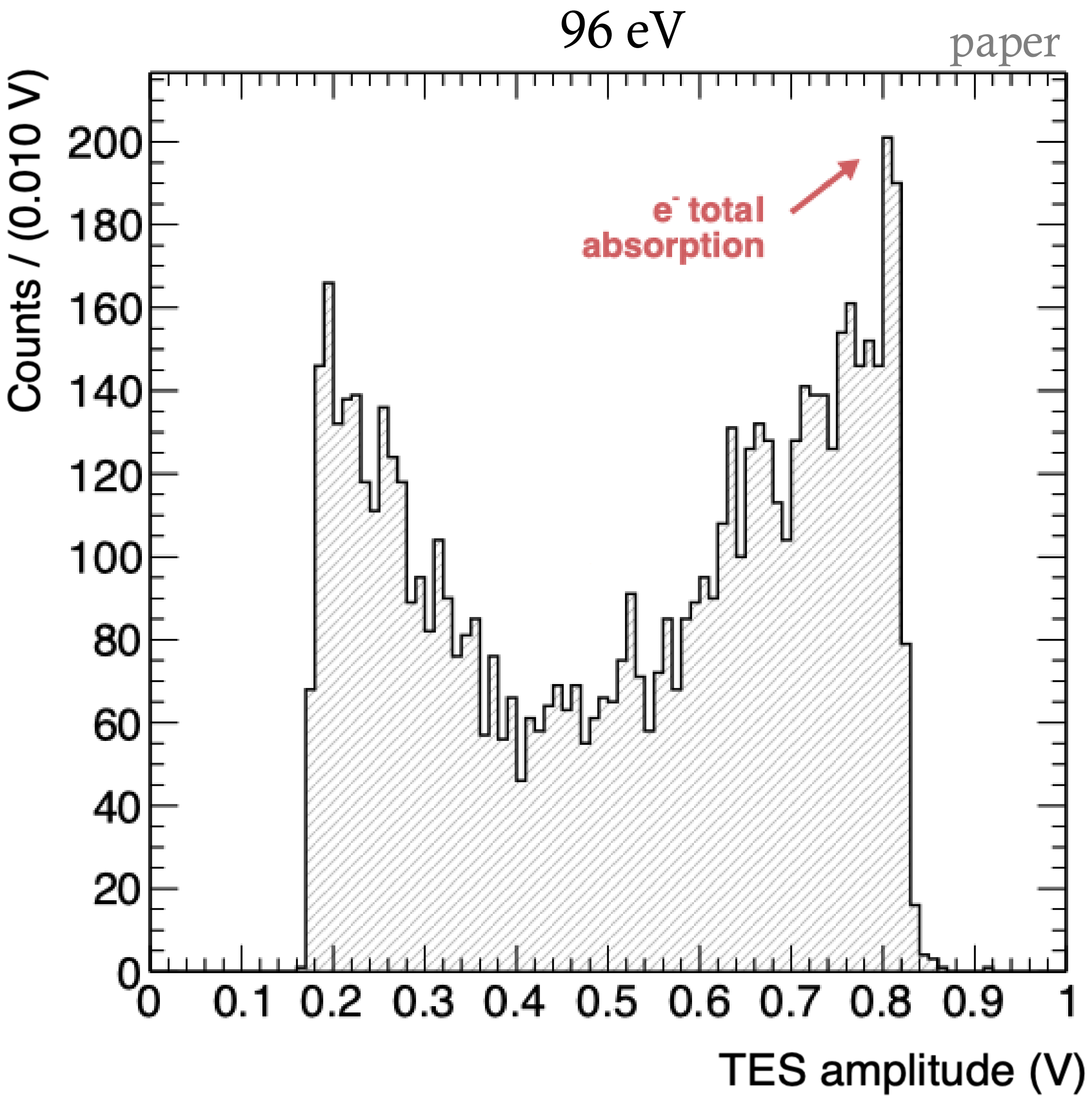
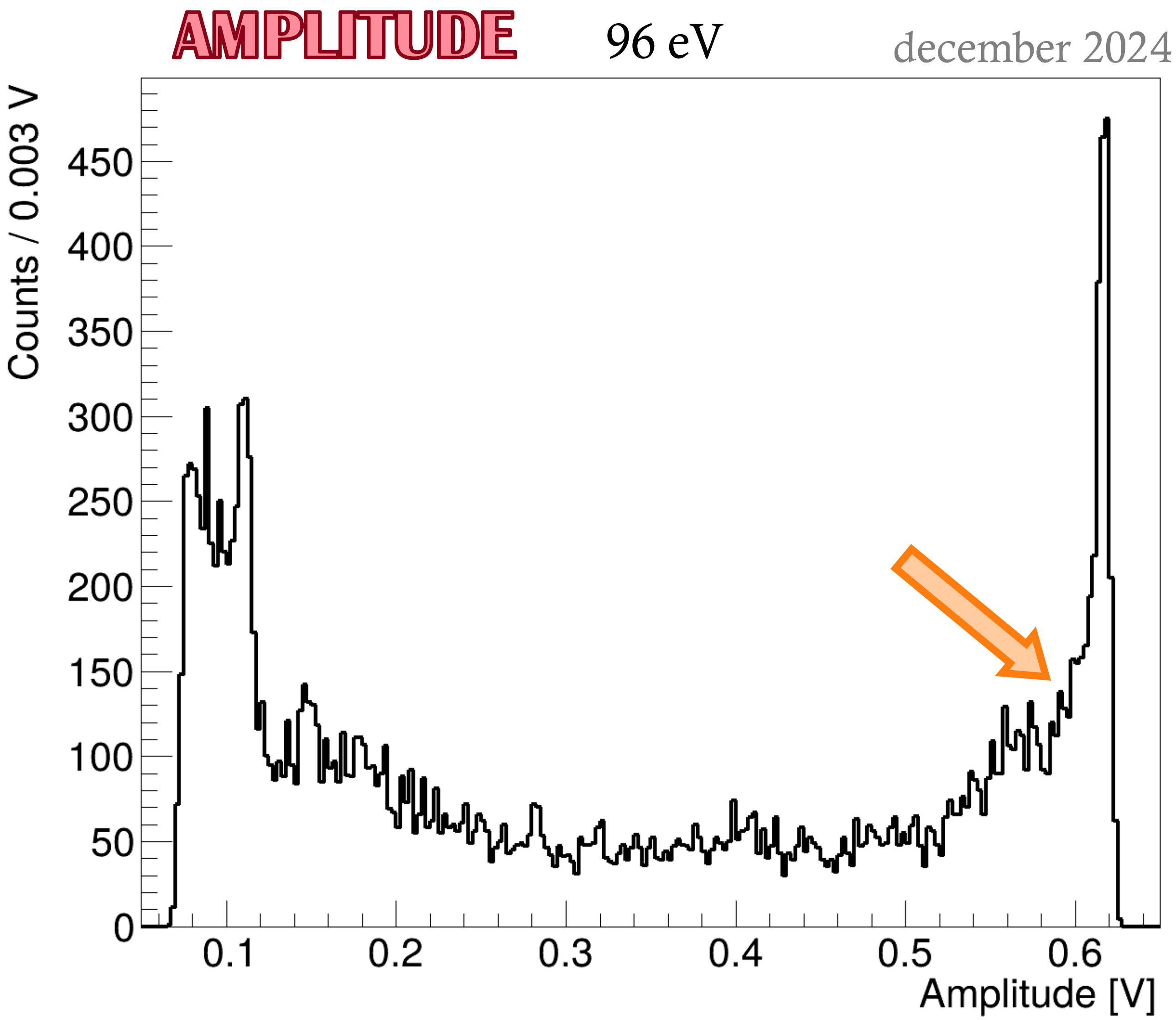
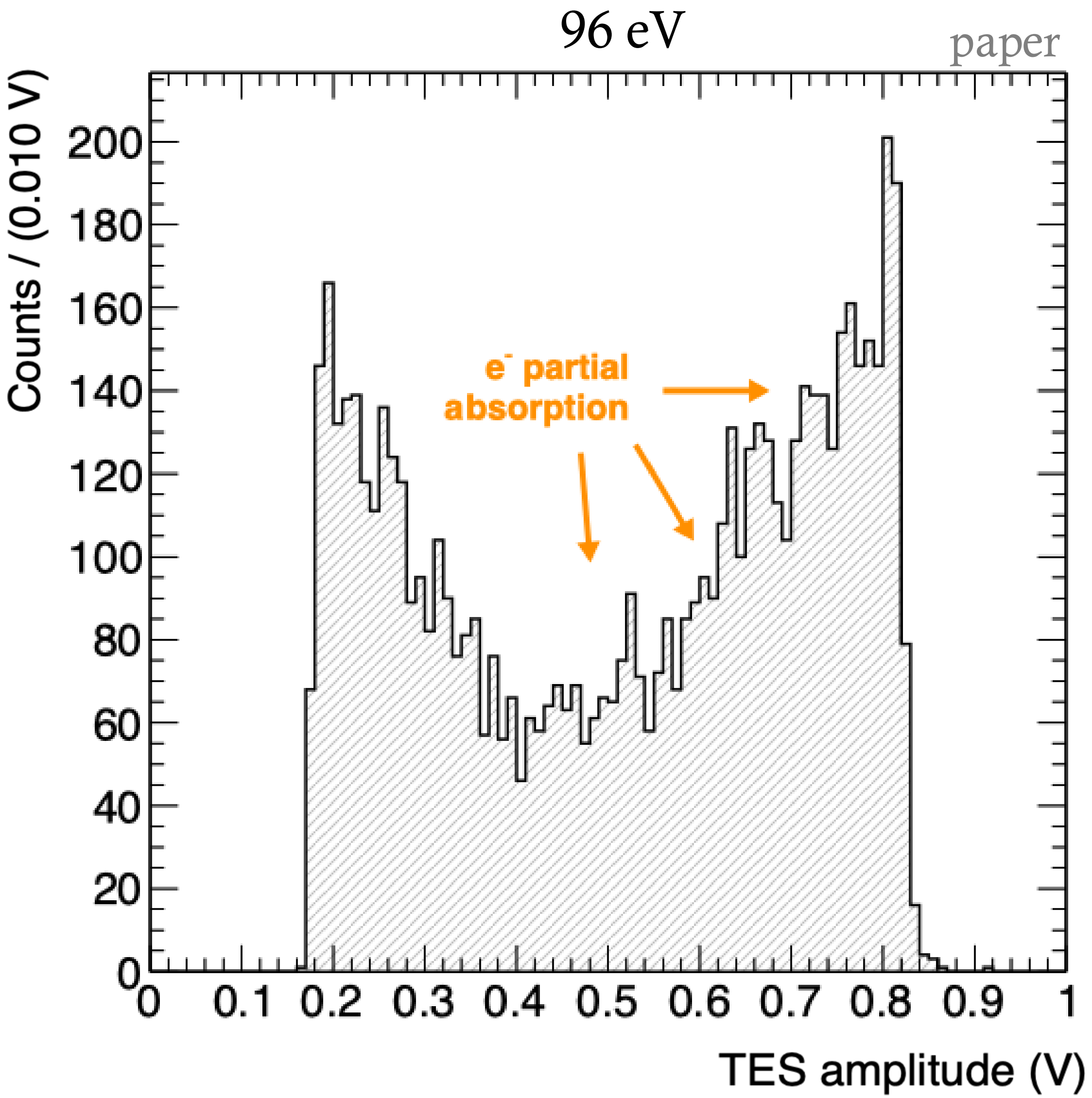




Left Tail of High-Amplitude Peak is Reduced!





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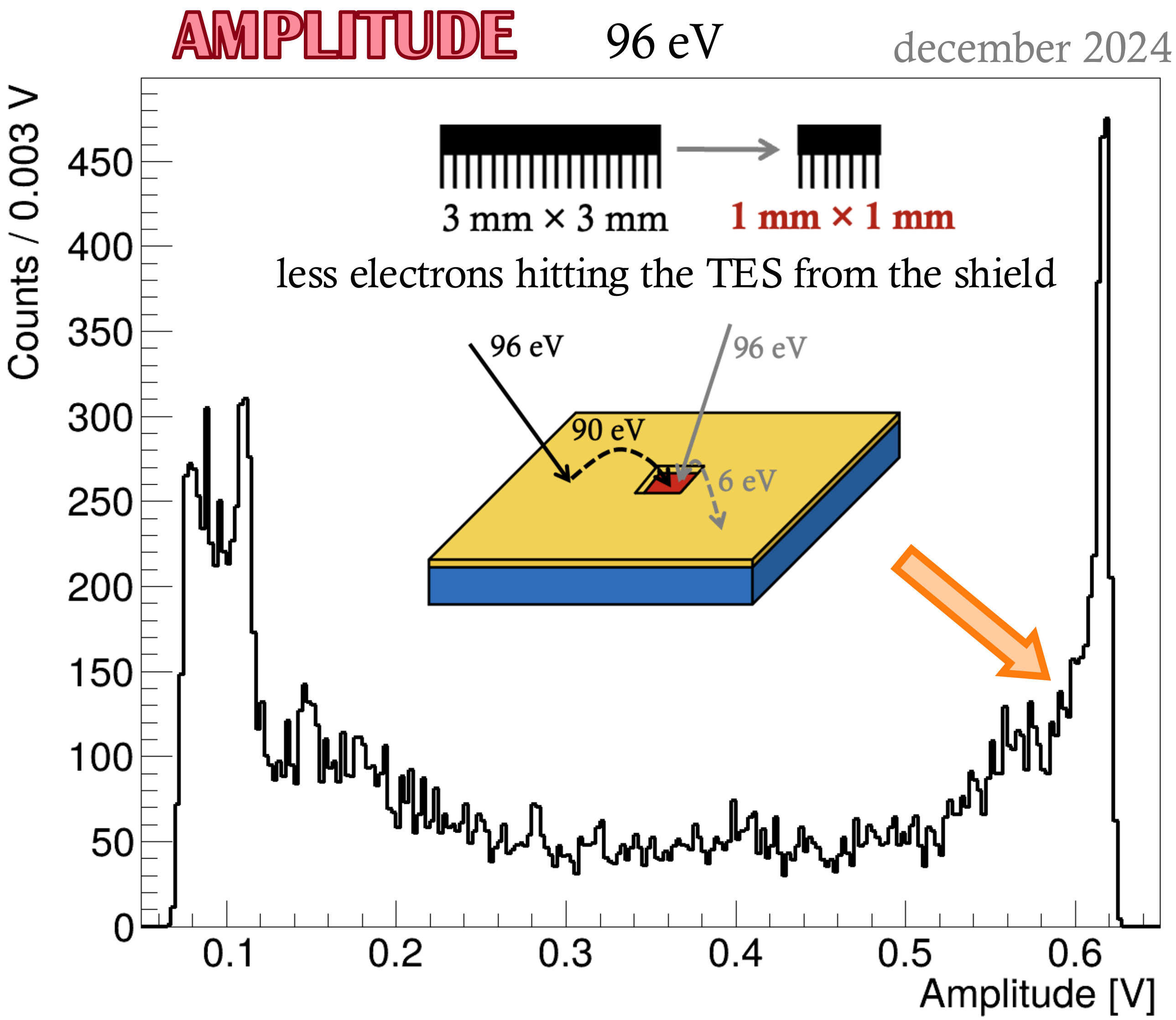
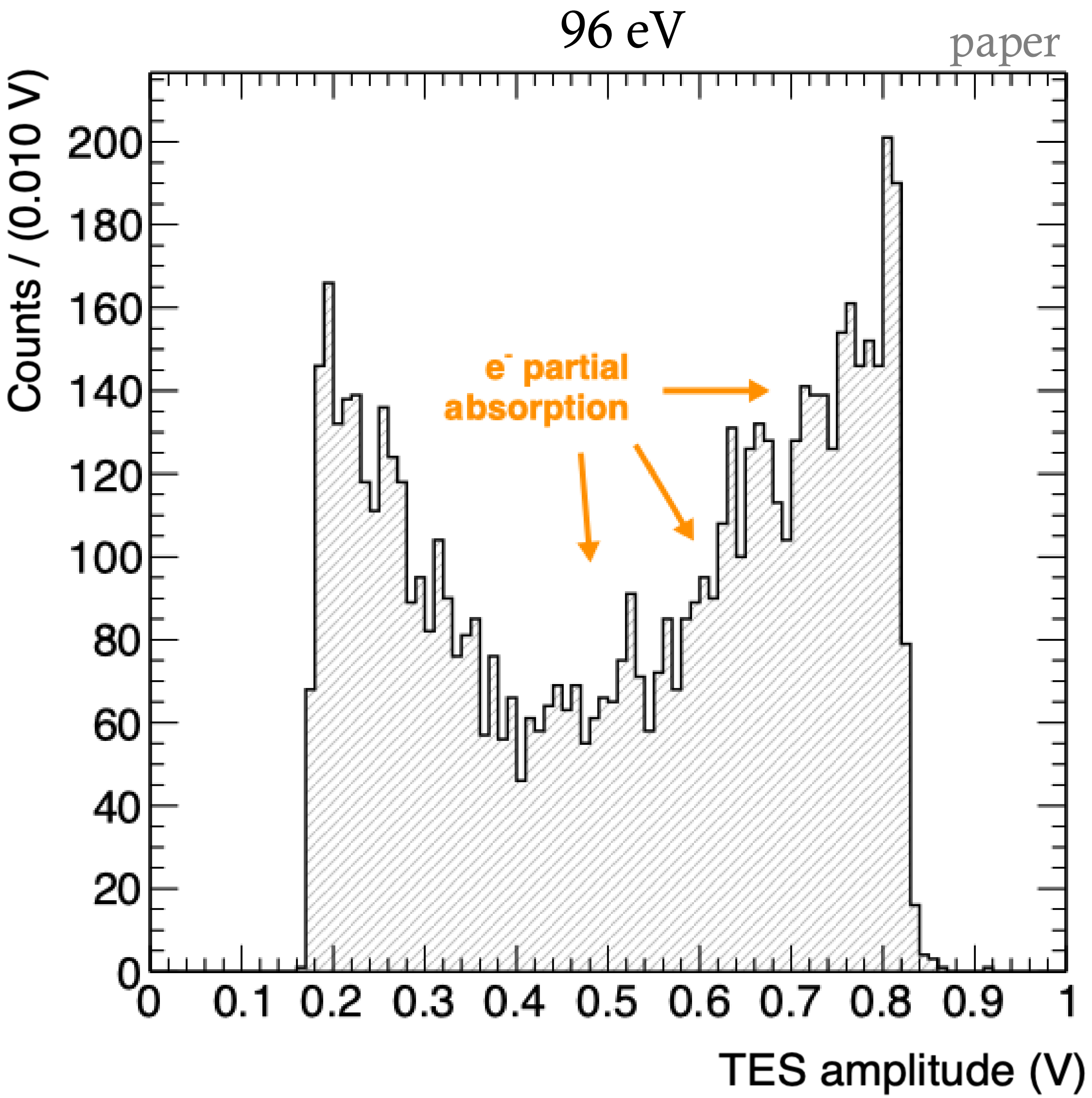
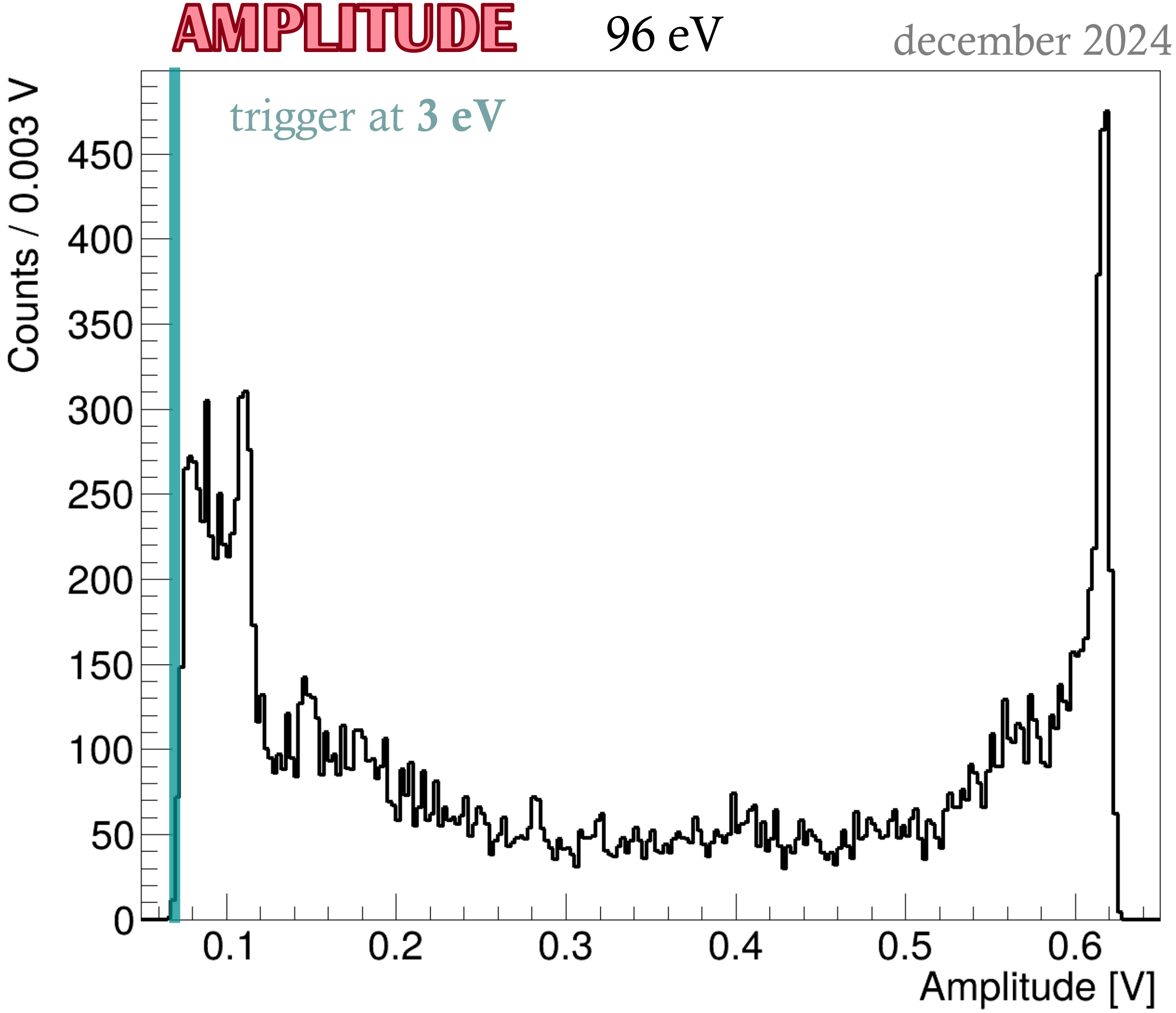
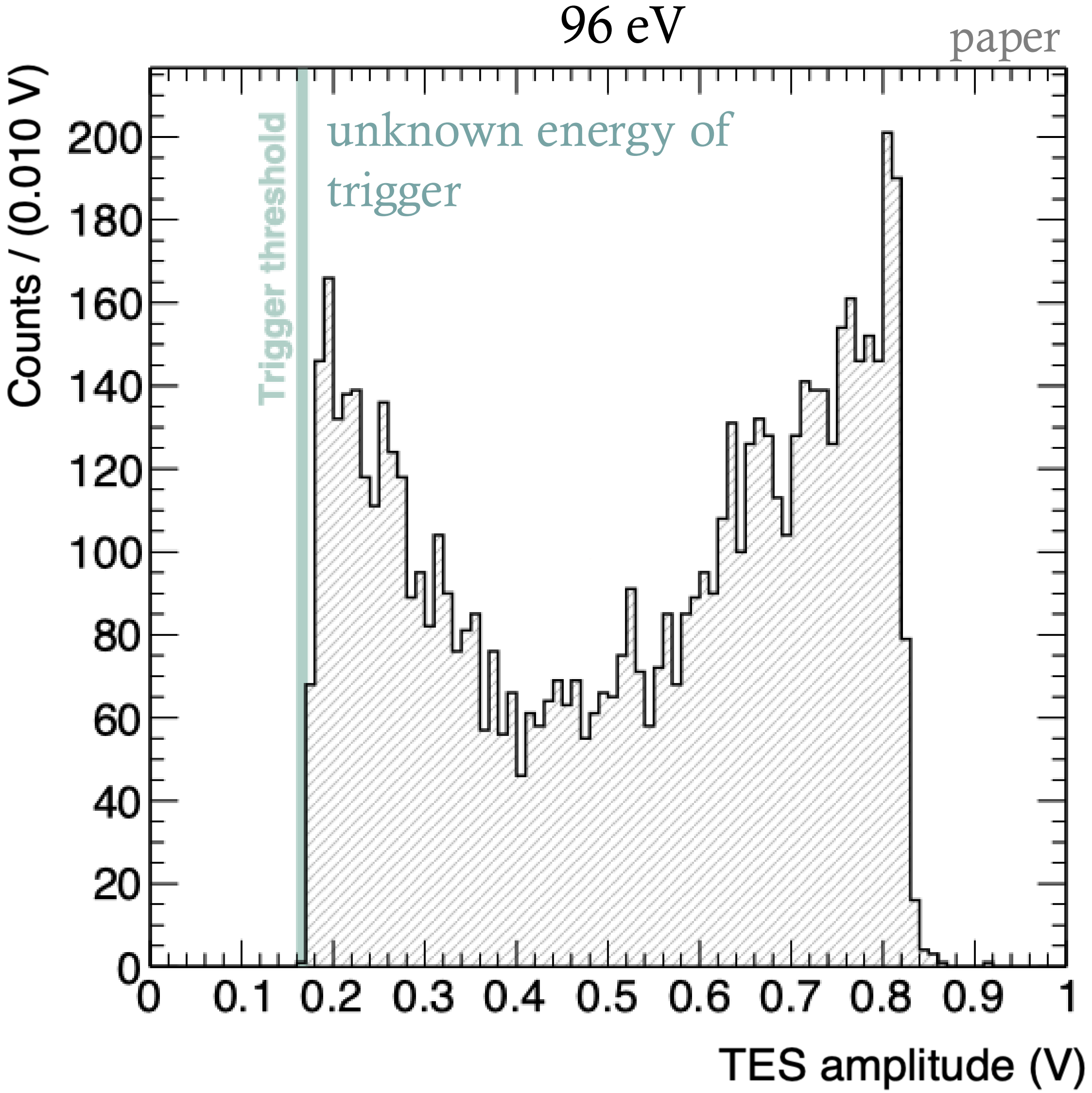




Trigger Threshold is Known in Energy!

AMPLITUDE





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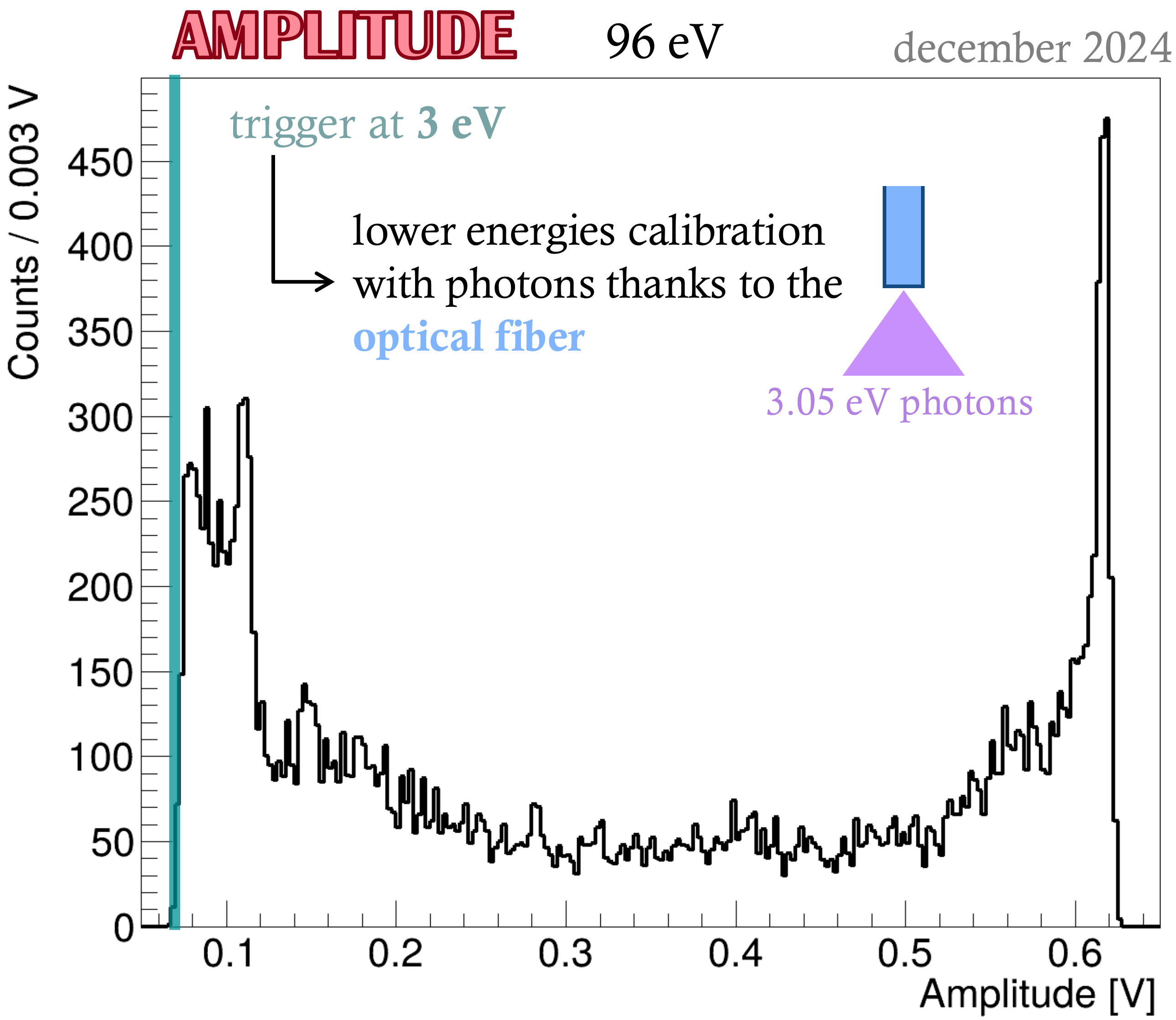

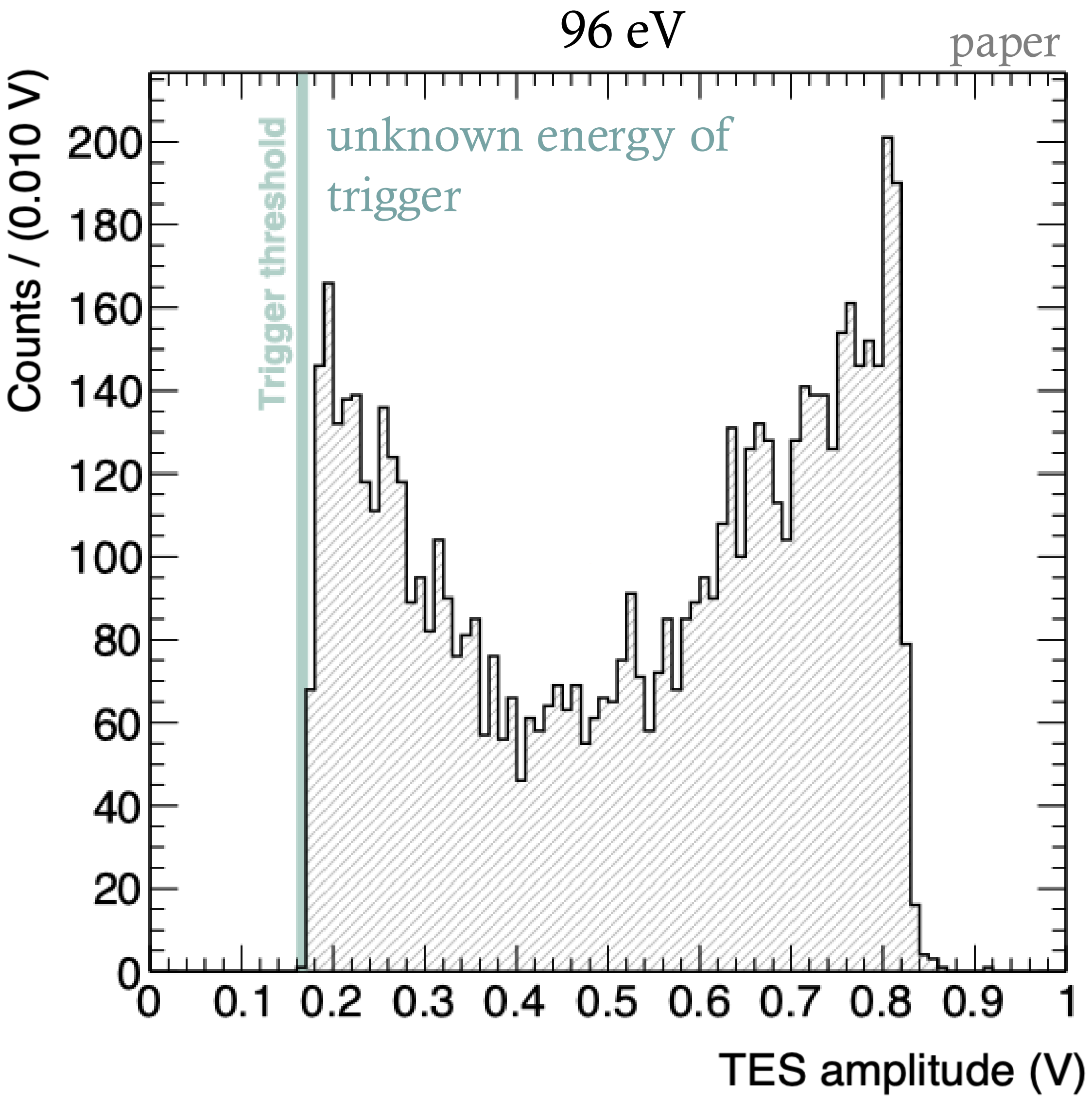

Low-Energy Calibration with Photons

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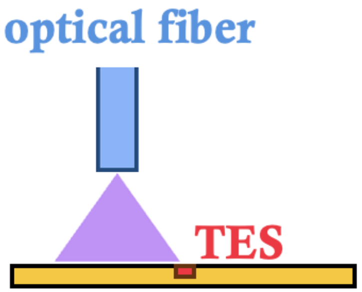

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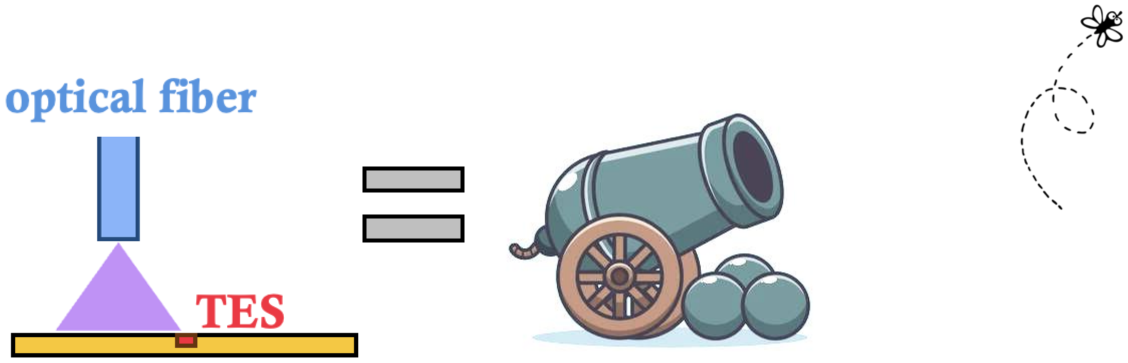

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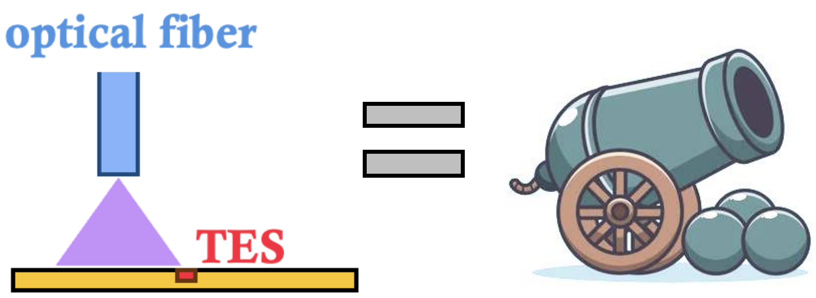


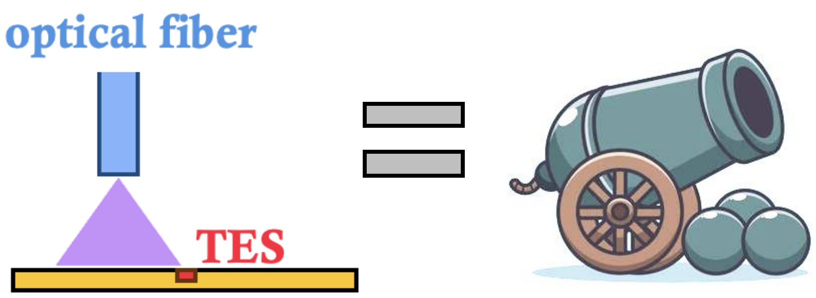
Fiber could not be aligned

we are sending a lot of photons towards the TES and we can see at most 2 or 3 simultaneous photons on the TES (last time we calibrated the TES up to ~ 45 photons!)

↓

increasing the laser power we steadily heat the TES

Low-Energy Calibration with Photons



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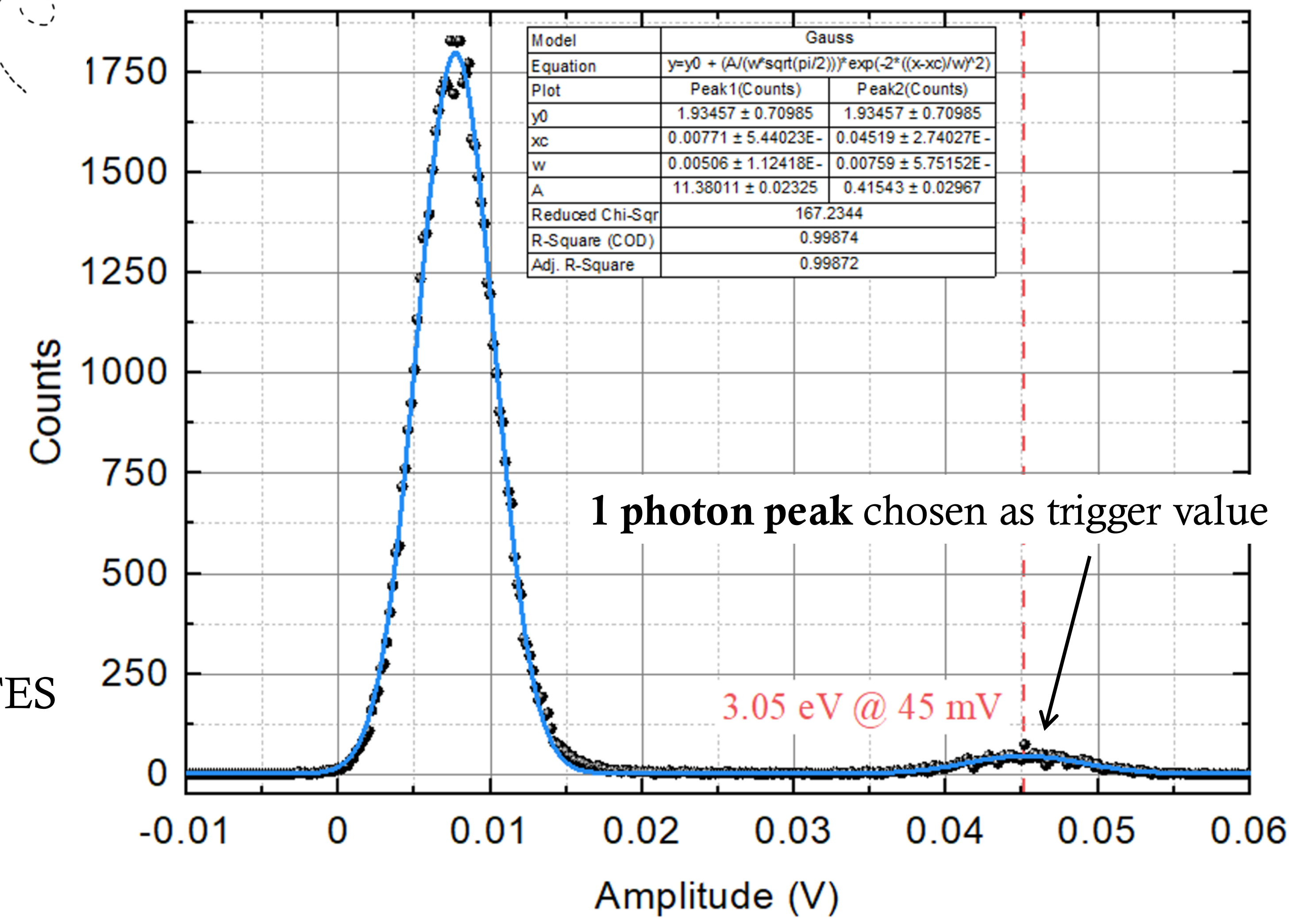
3.05 eV photons



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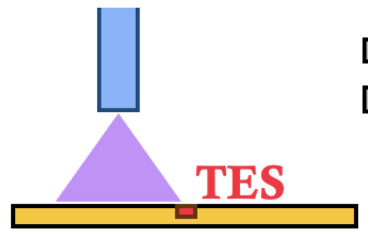

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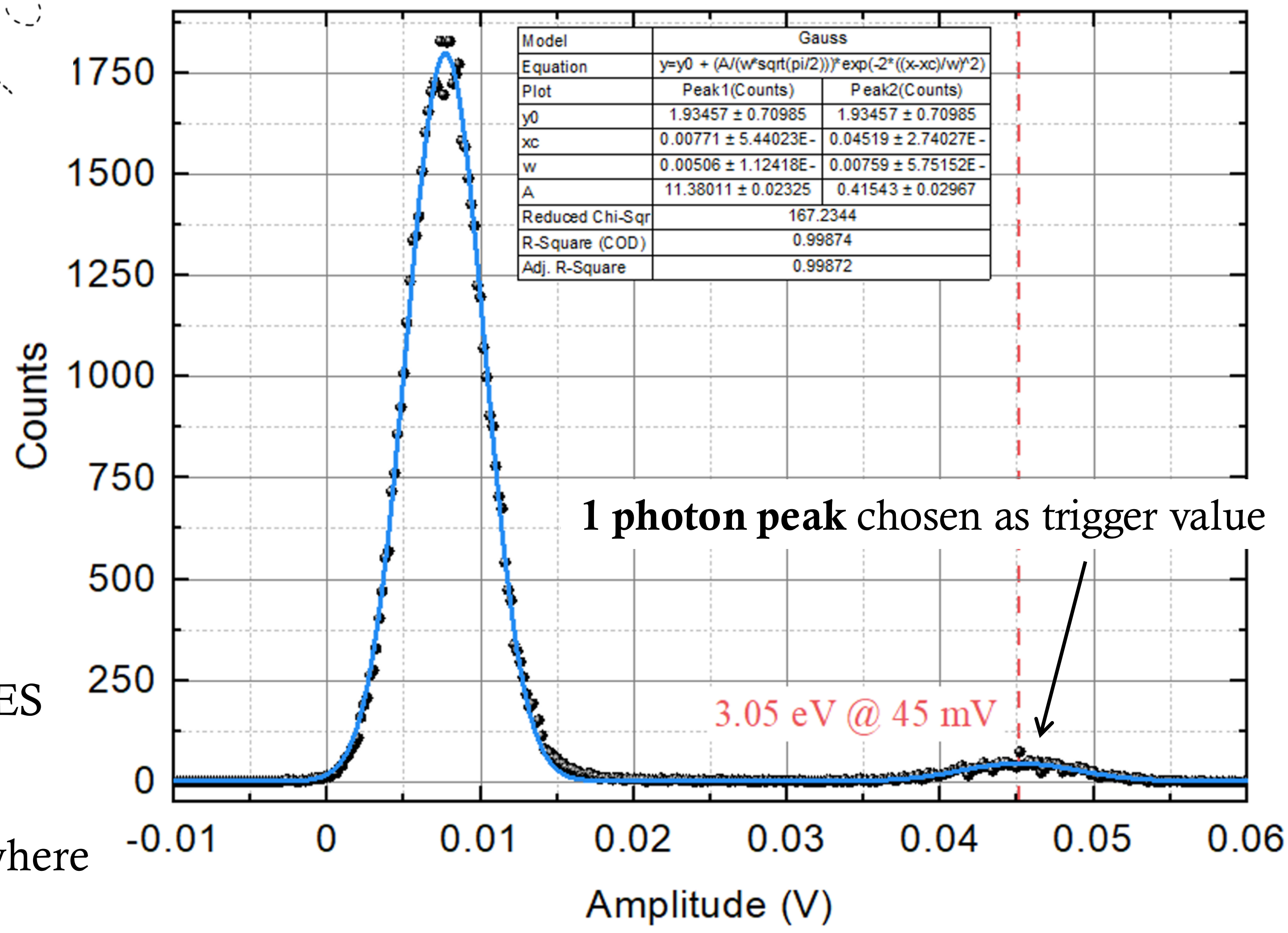
increasing the laser power we steadily heat the TES

- **Energy calibration** up to 3 photons (**~ 9 eV**) where the TES can be considered linear in response

3.05 eV photons

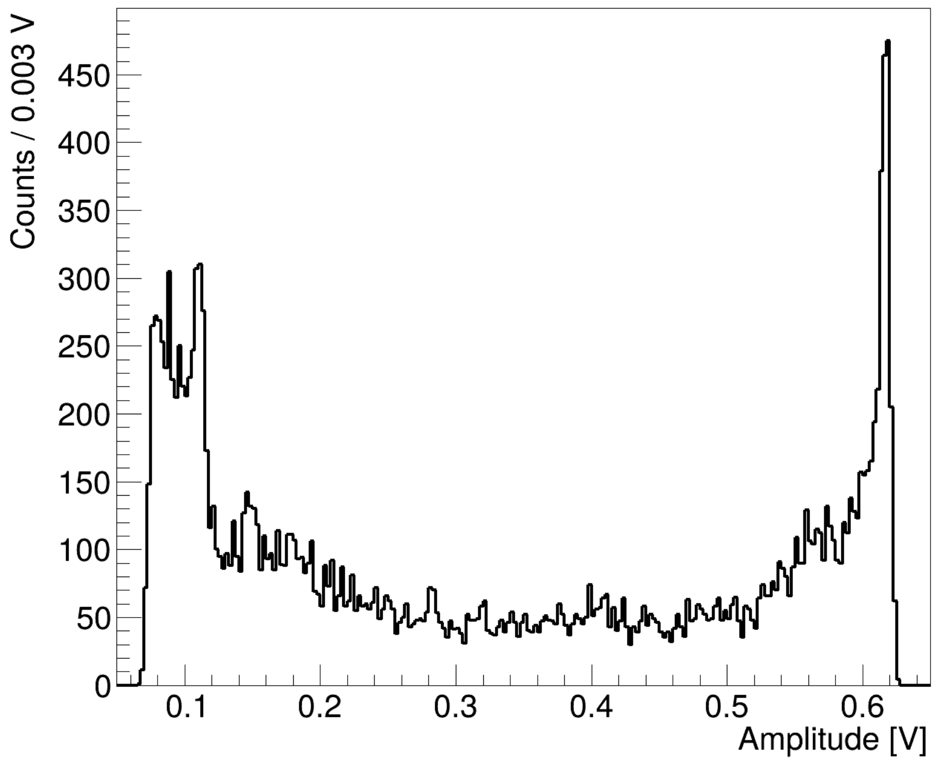


Model	Gauss	
Equation	y=y0 + (A/(w*sqrt(pi/2)))*exp(-2*((x-xc)/w)^2)	
Plot	Peak1(Counts)	Peak2(Counts)
y0	1.93457 ± 0.70985	1.93457 ± 0.70985
xc	0.00771 ± 5.44023E-	0.04519 ± 2.74027E-
w	0.00506 ± 1.12418E-	0.00759 ± 5.75152E-
A	11.38011 ± 0.02325	0.41543 ± 0.02967
Reduced Chi-Sqr	167.2344	
R-Square (COD)	0.99874	
Adj. R-Square	0.99872	

More Defined Peak is much Easier to Fit

- Asymmetric Gaussian fit on the high-amplitude peak

$$f(x) = \begin{cases} A \cdot exp\left(-\frac{(x-\boldsymbol{\mu})^2}{2\sigma_L^2}\right) & x < \mu \\ A \cdot exp\left(-\frac{(x-\boldsymbol{\mu})^2}{2\boldsymbol{\sigma}_{\boldsymbol{R}}^2}\right) & x > \mu \end{cases}$$



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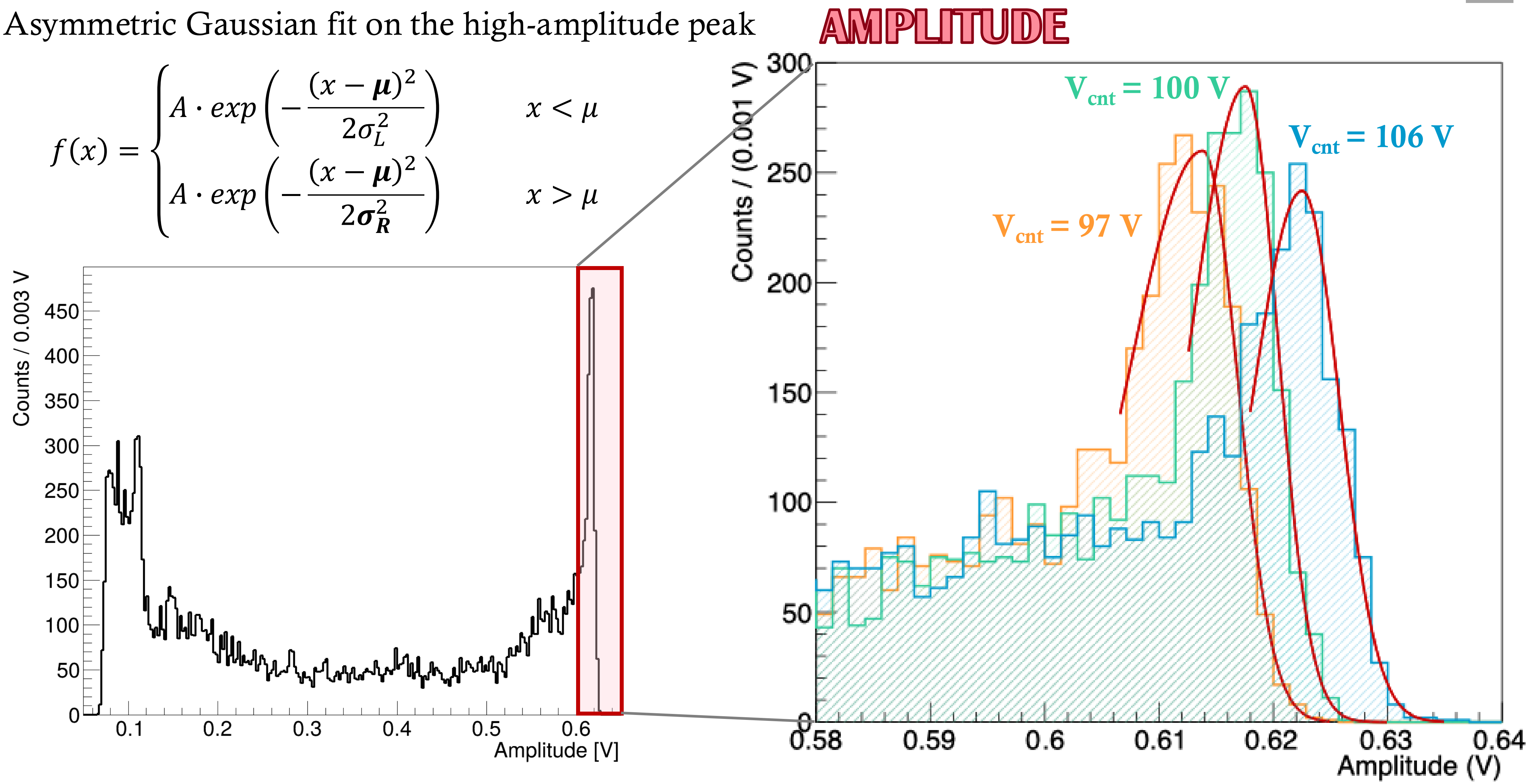
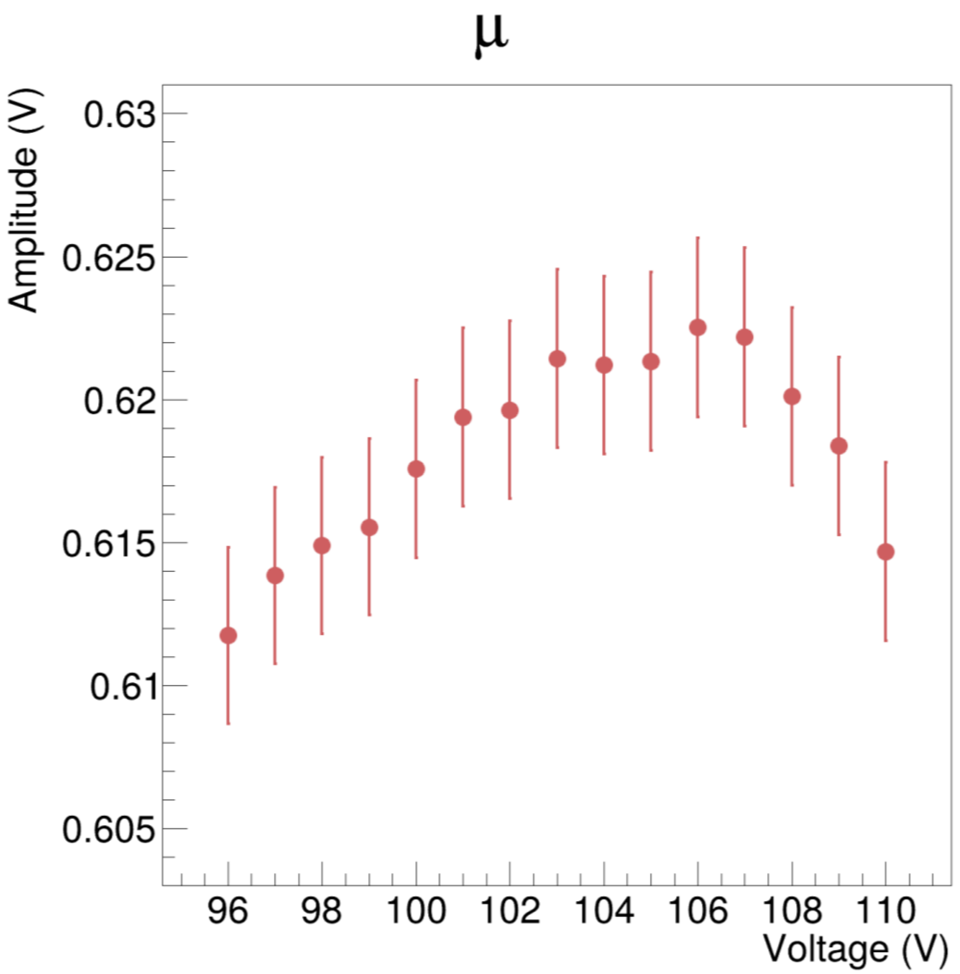
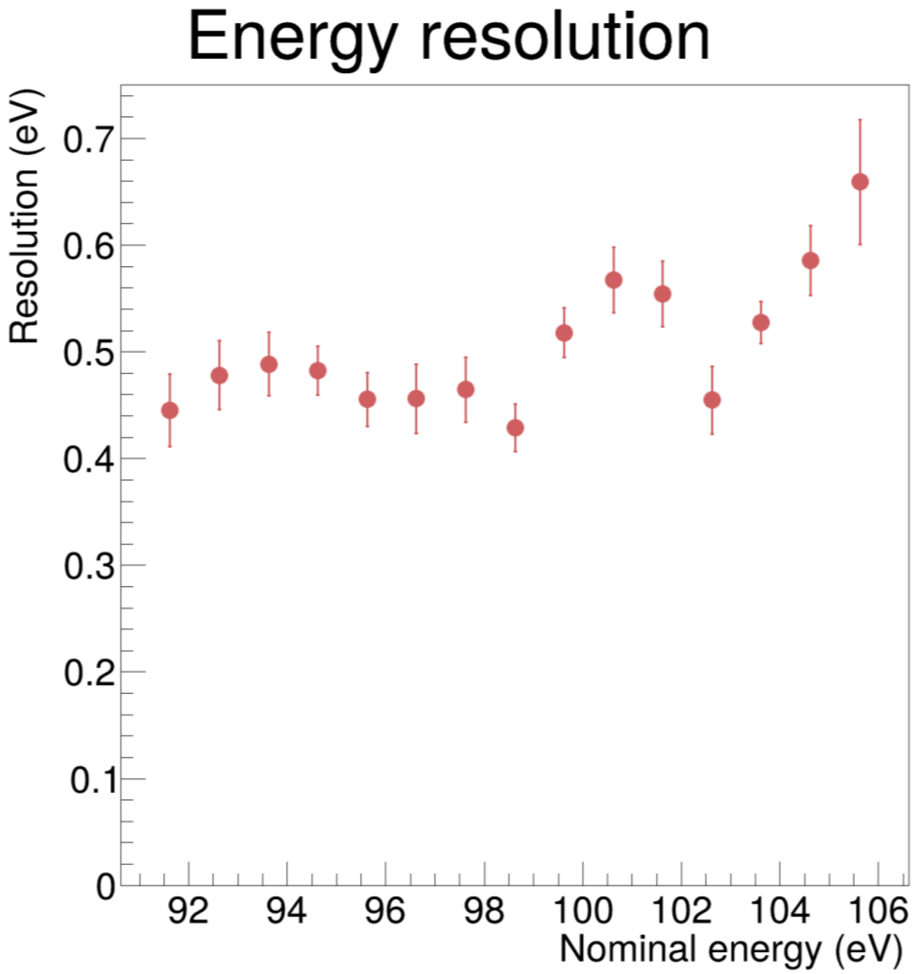


The TES saturates in amplitudes





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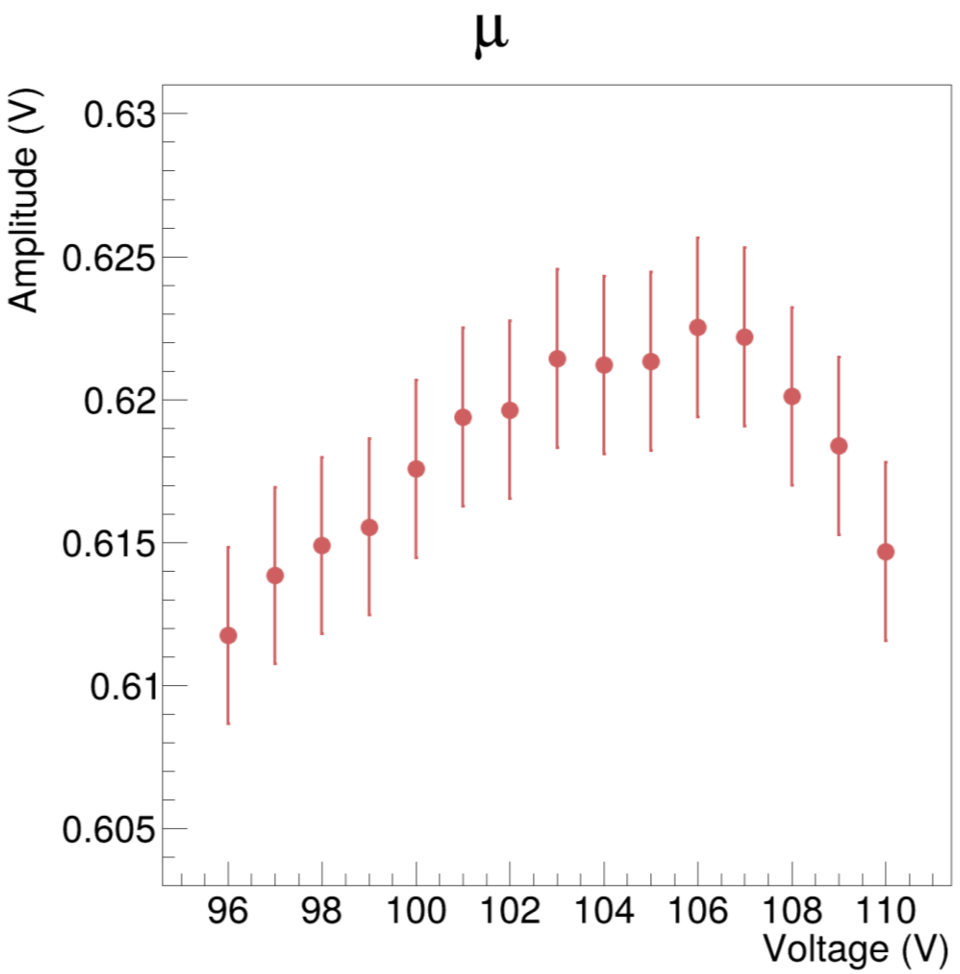

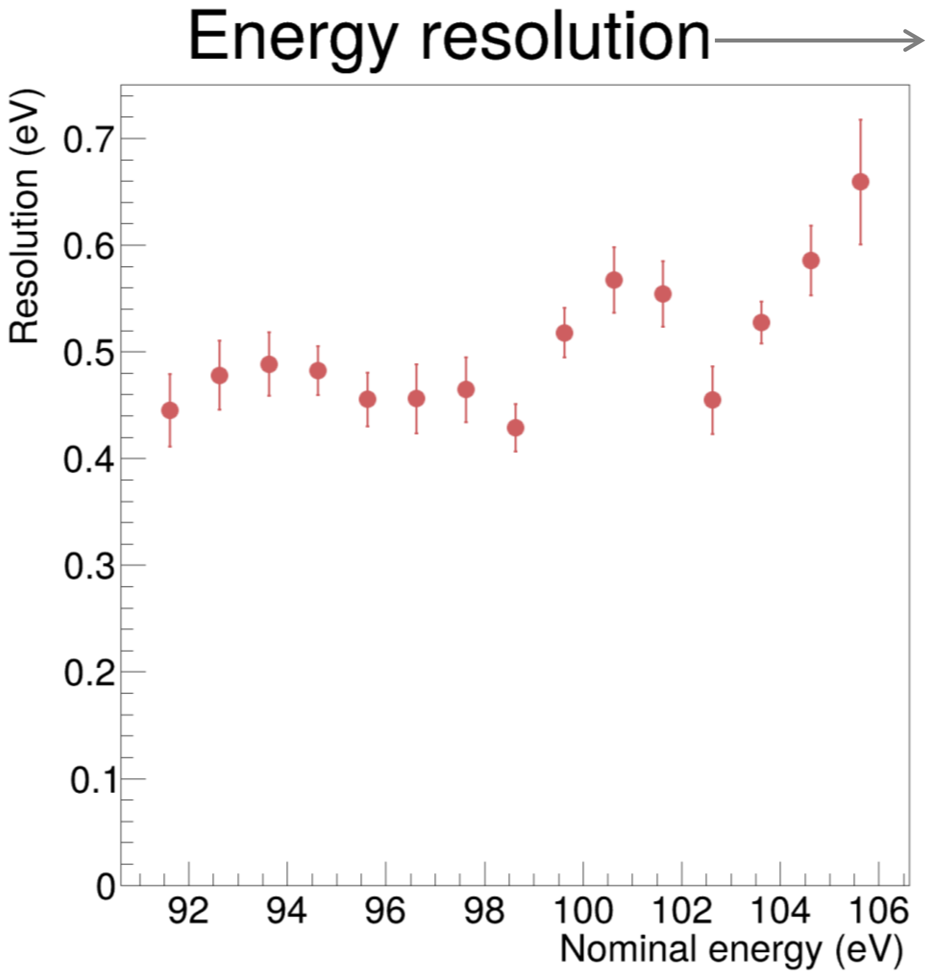

$$\sigma_e(E) = \frac{\sigma_{right}}{\mu} \boldsymbol{E_e}$$

fit parameters

electron nominal energy

$$\boldsymbol{E_e} = eV_{cnt} - \varphi_{tes} = eV_{cnt} - 4.4 \text{ eV}$$

(measured @ LASEC lab in Roma Tre)

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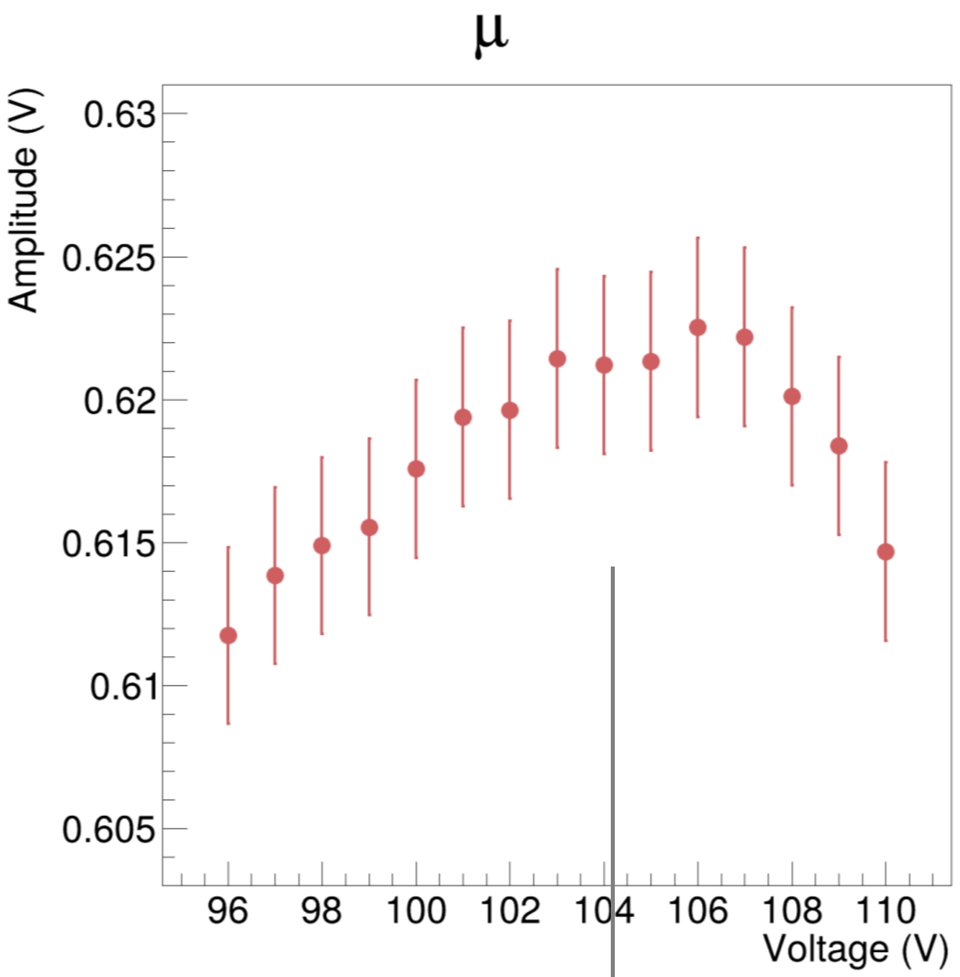

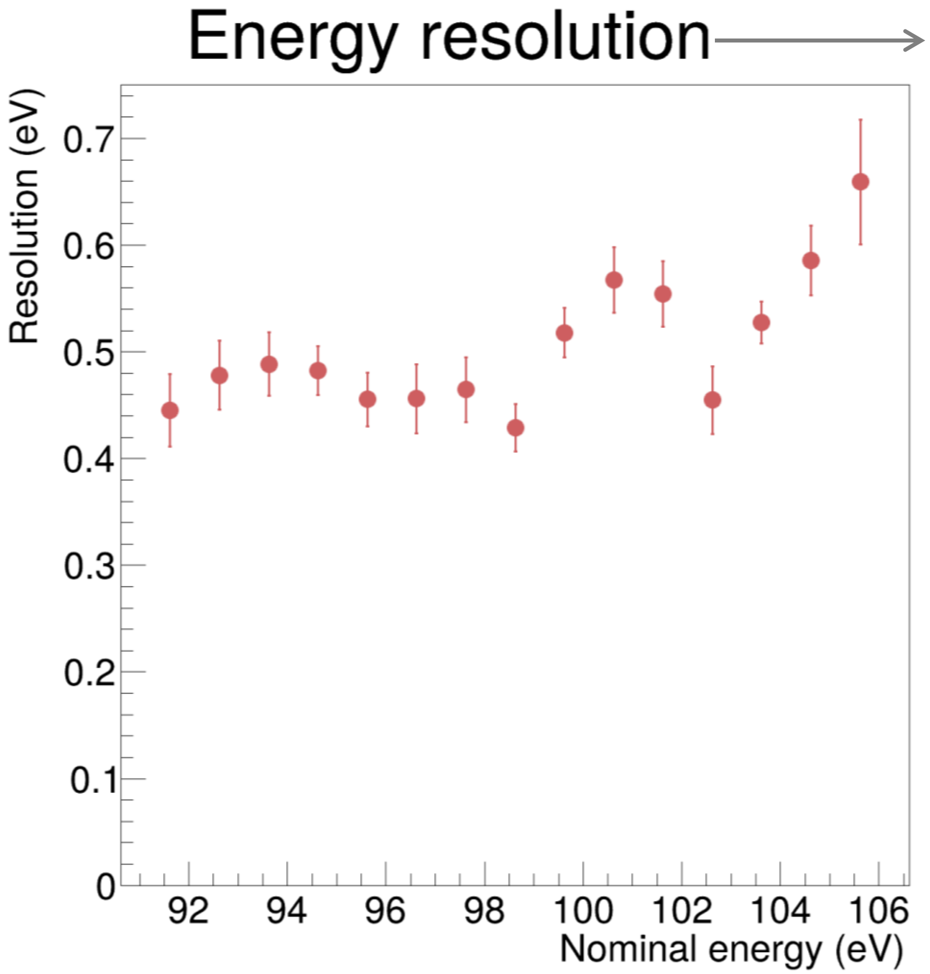

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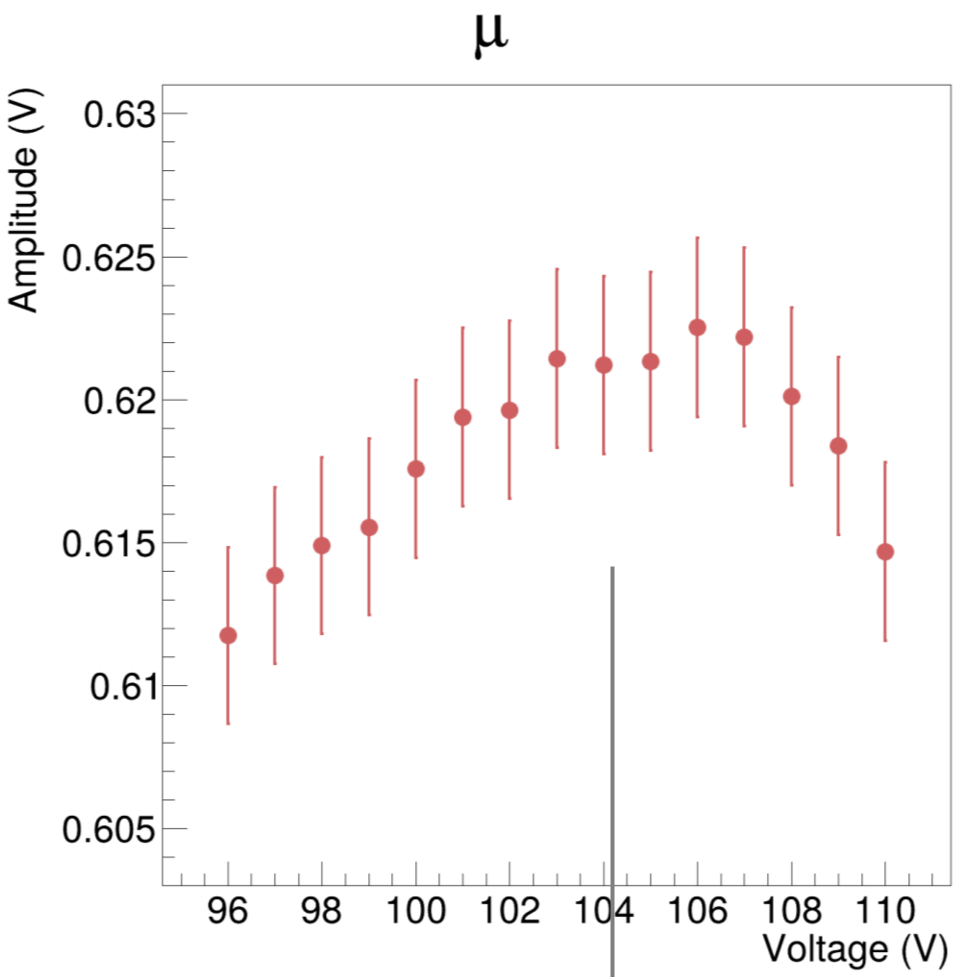

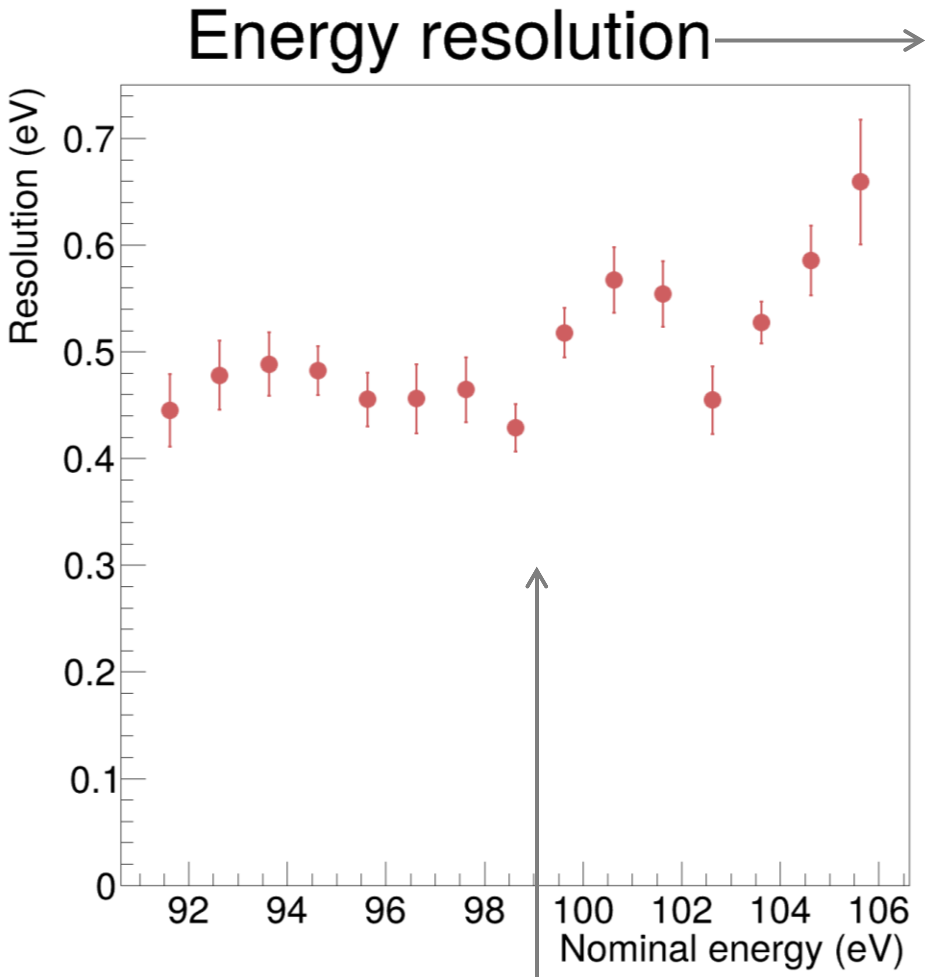

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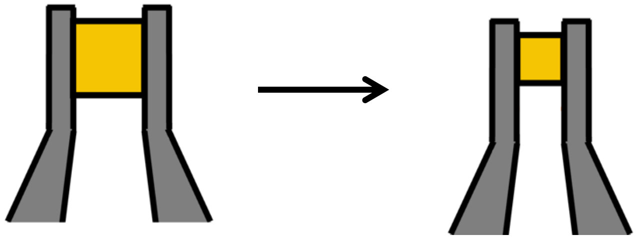
energy resolution evaluated from amplitude is **unrealiable** in such saturation condition

Signal Charge Preferred to Amplitude

Reducing the TES from 100 μm × 100 μm to
60 μm × 60 μm, it **saturates** in energy at ~ 100 eV!



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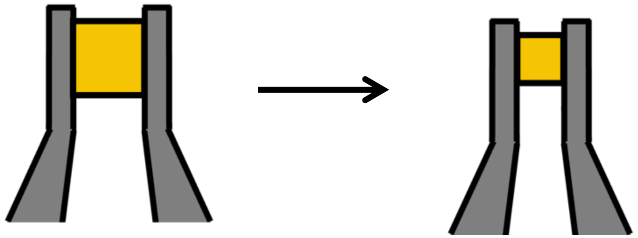

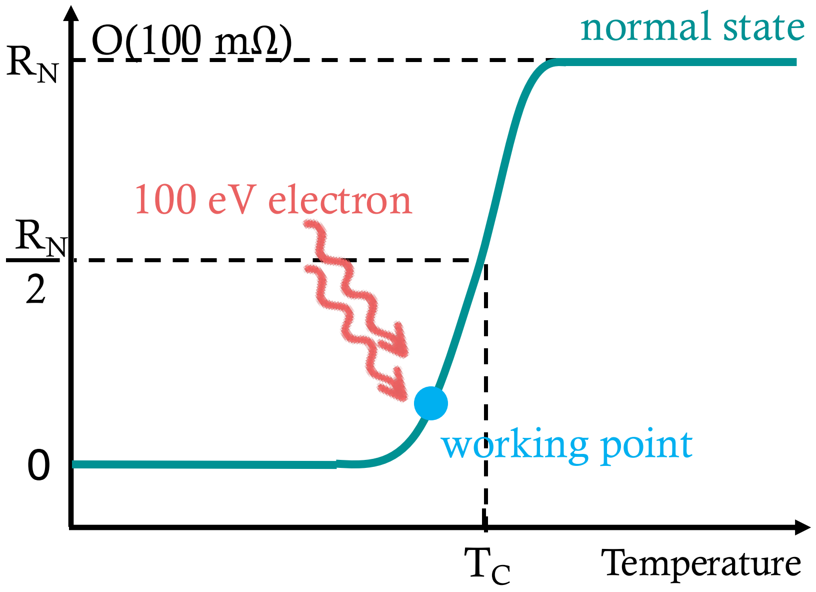

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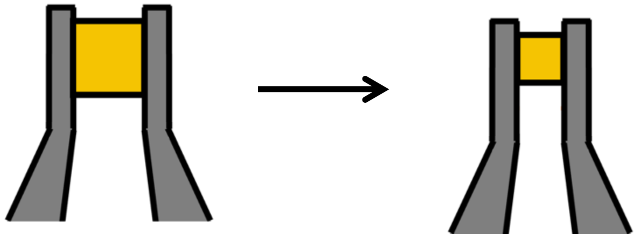

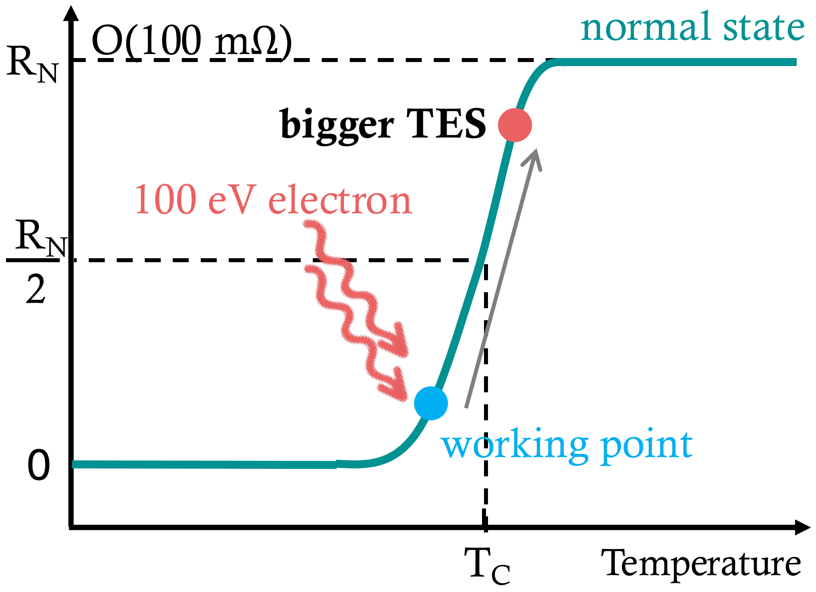

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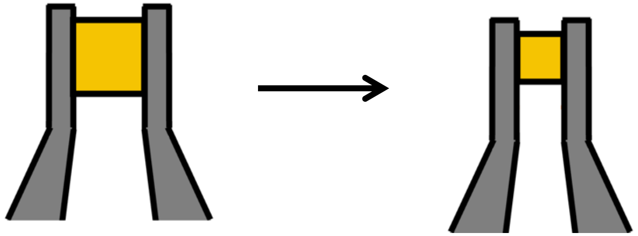

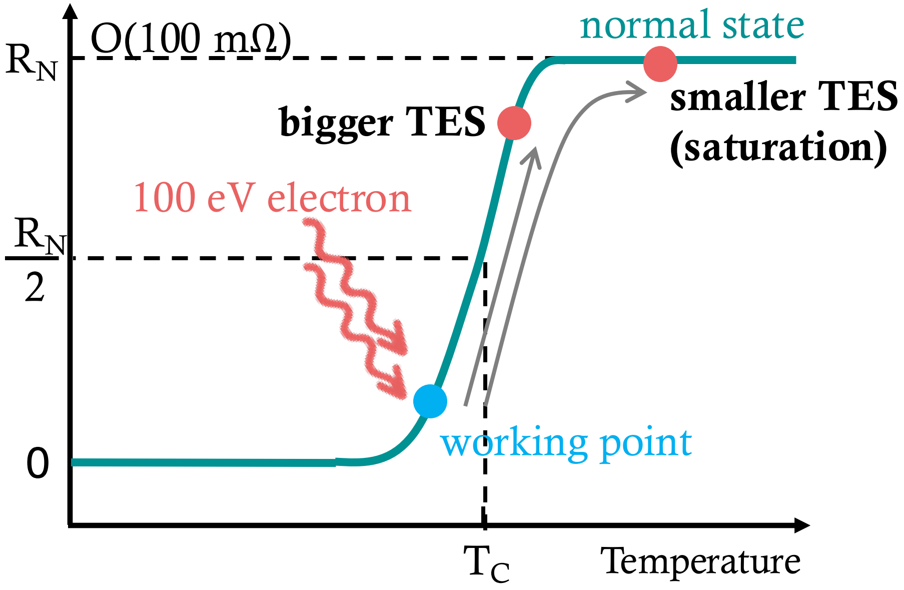

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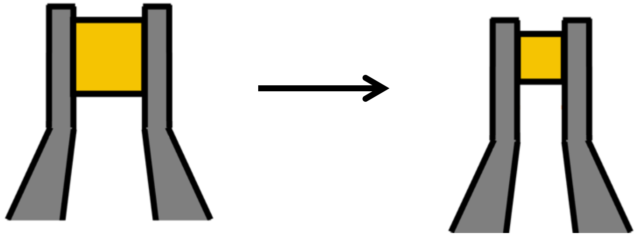

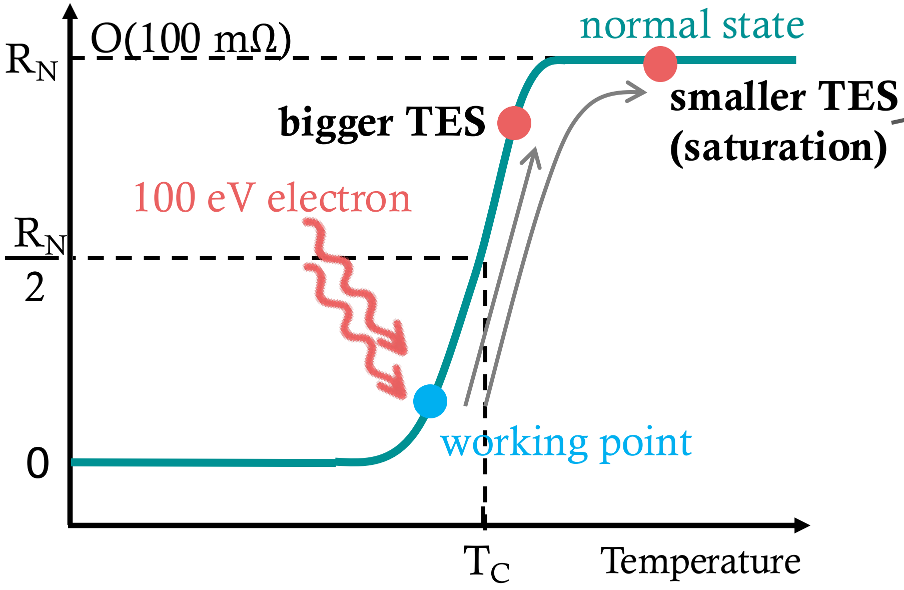

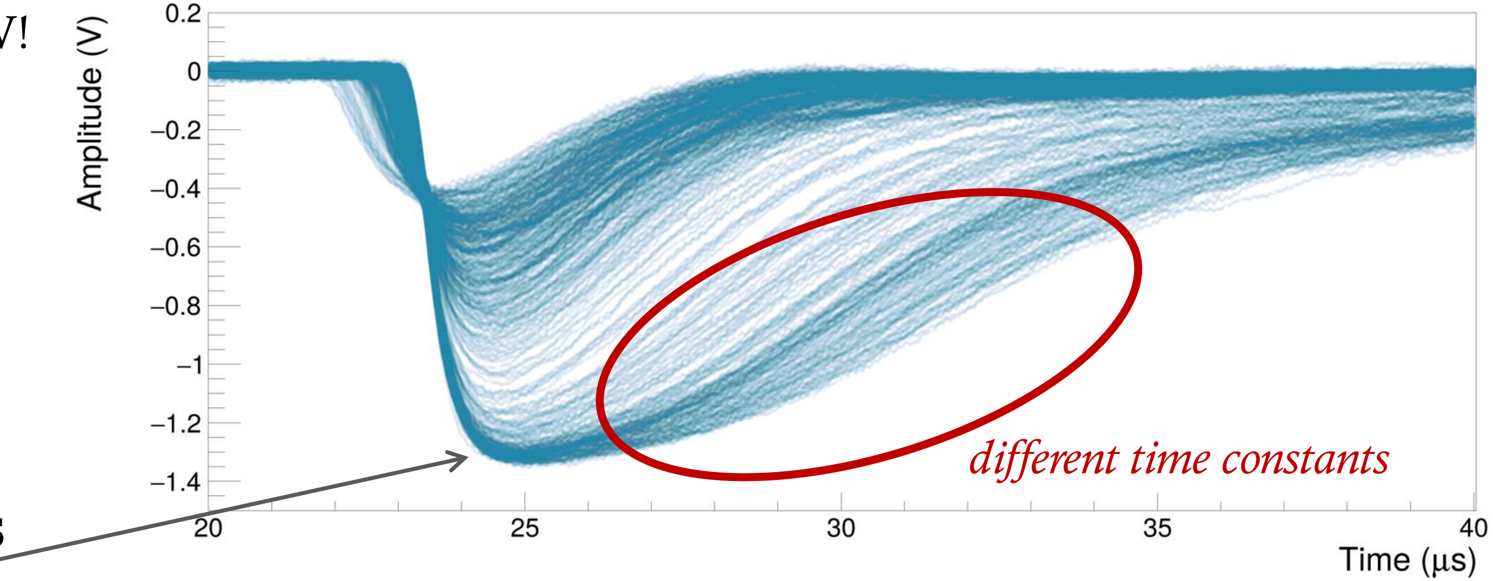

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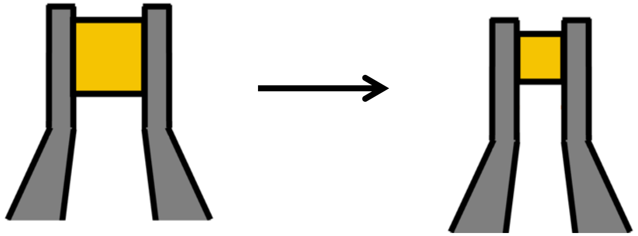

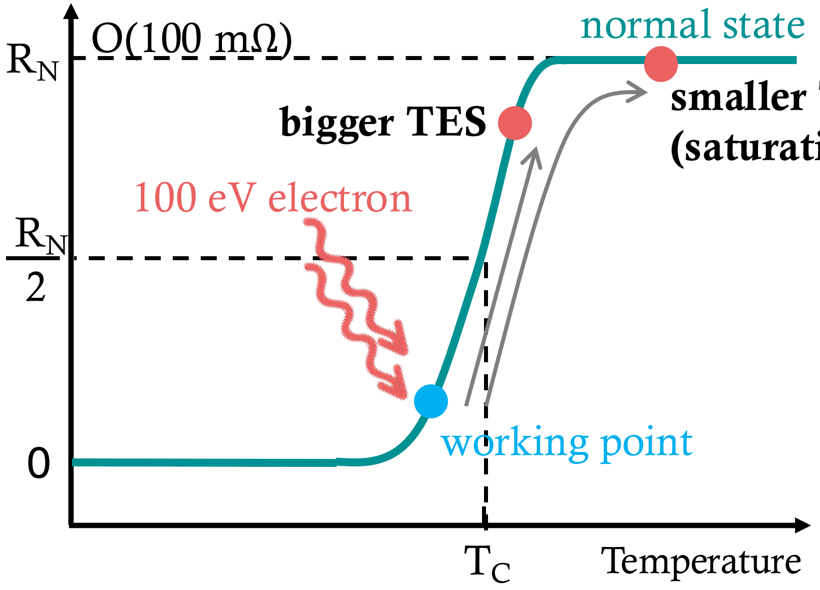

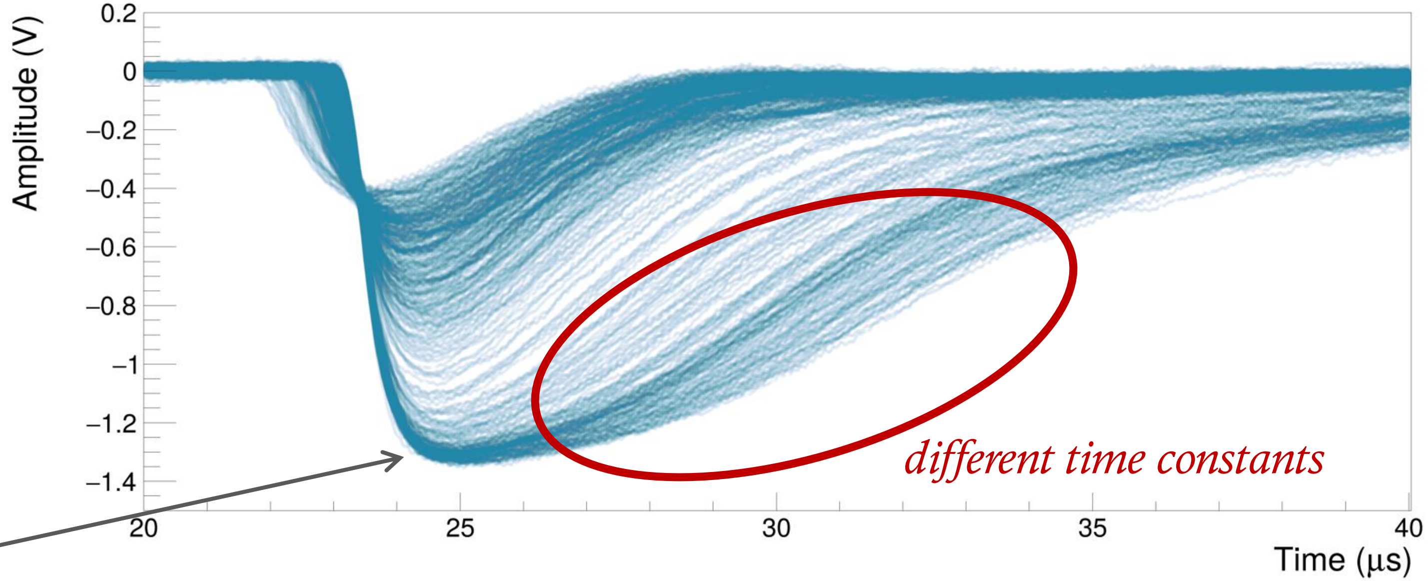

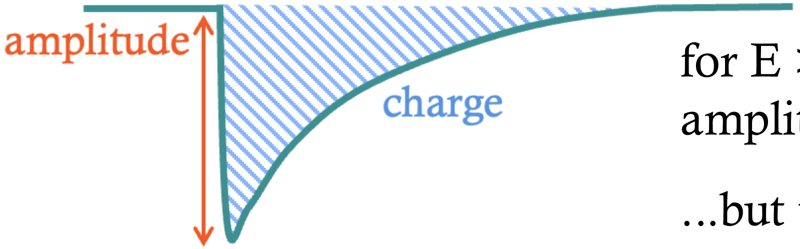

for E > $E_{saturation}$ the signal amplitude remains the same…

…but the **charge** varies due to wider signal shapes!

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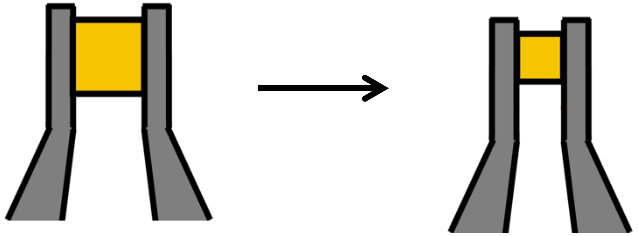

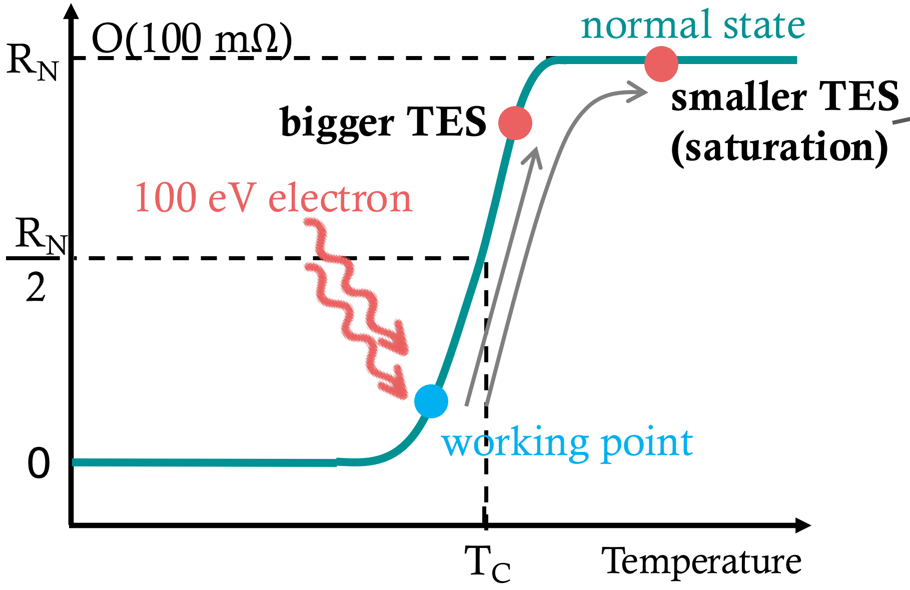

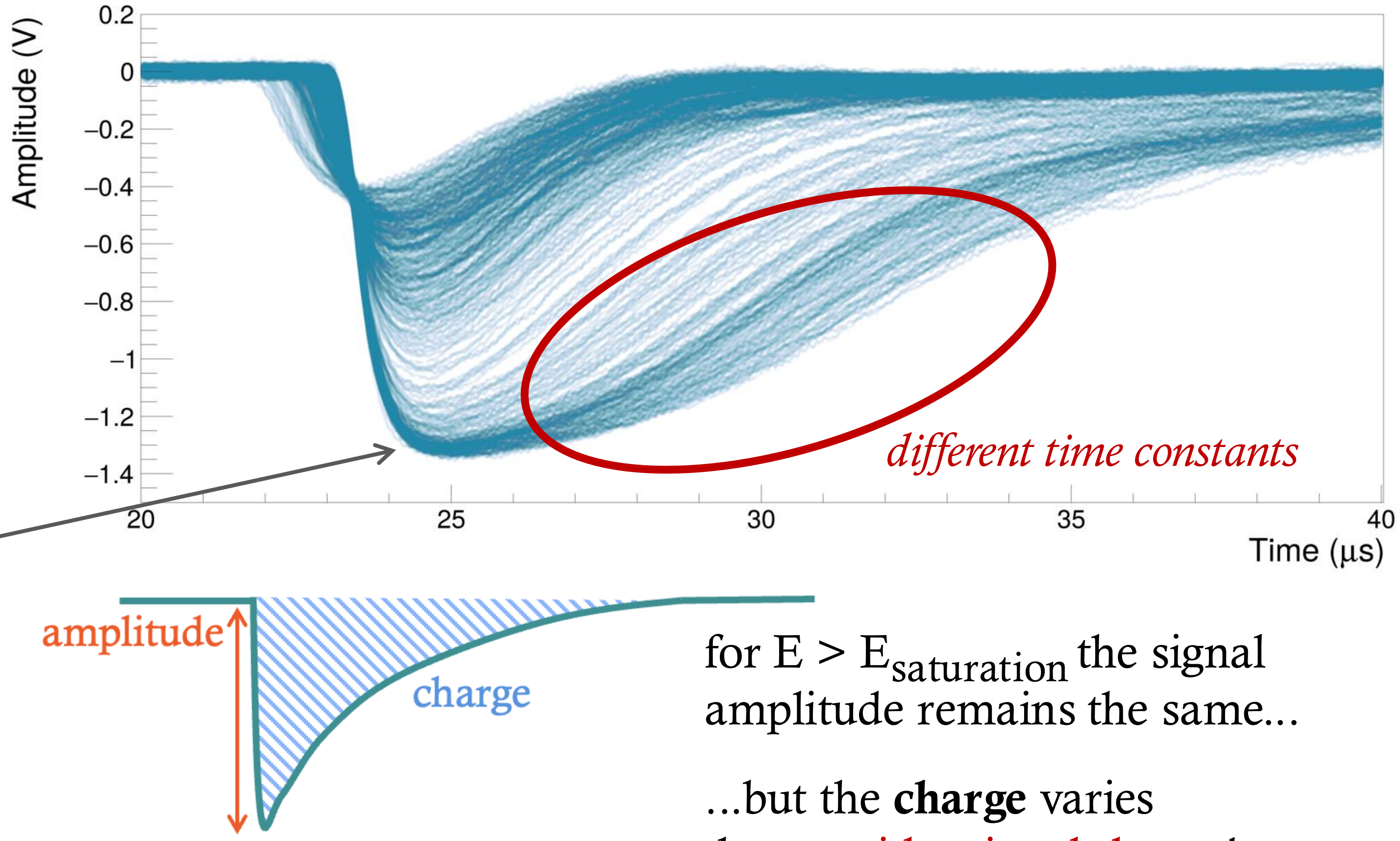

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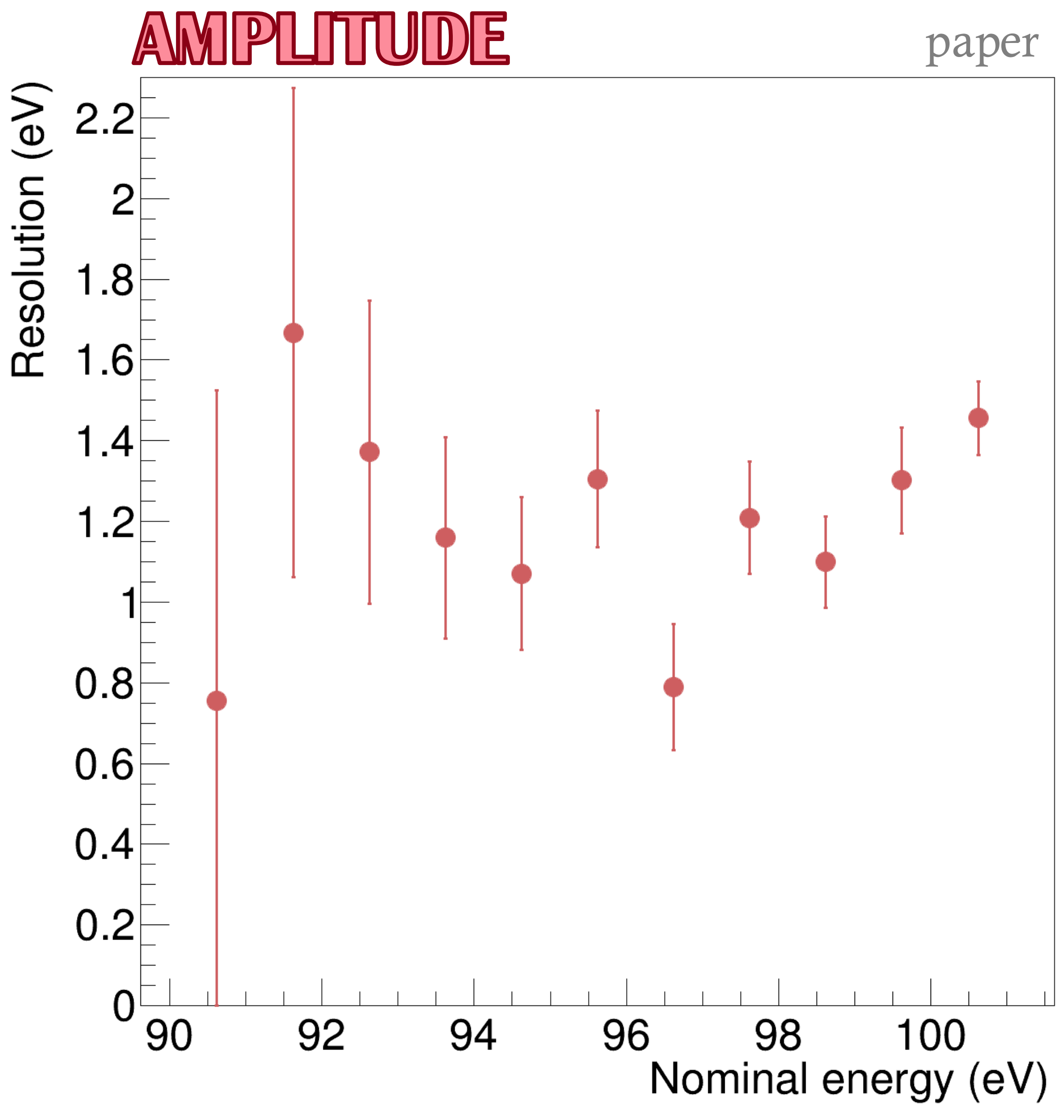
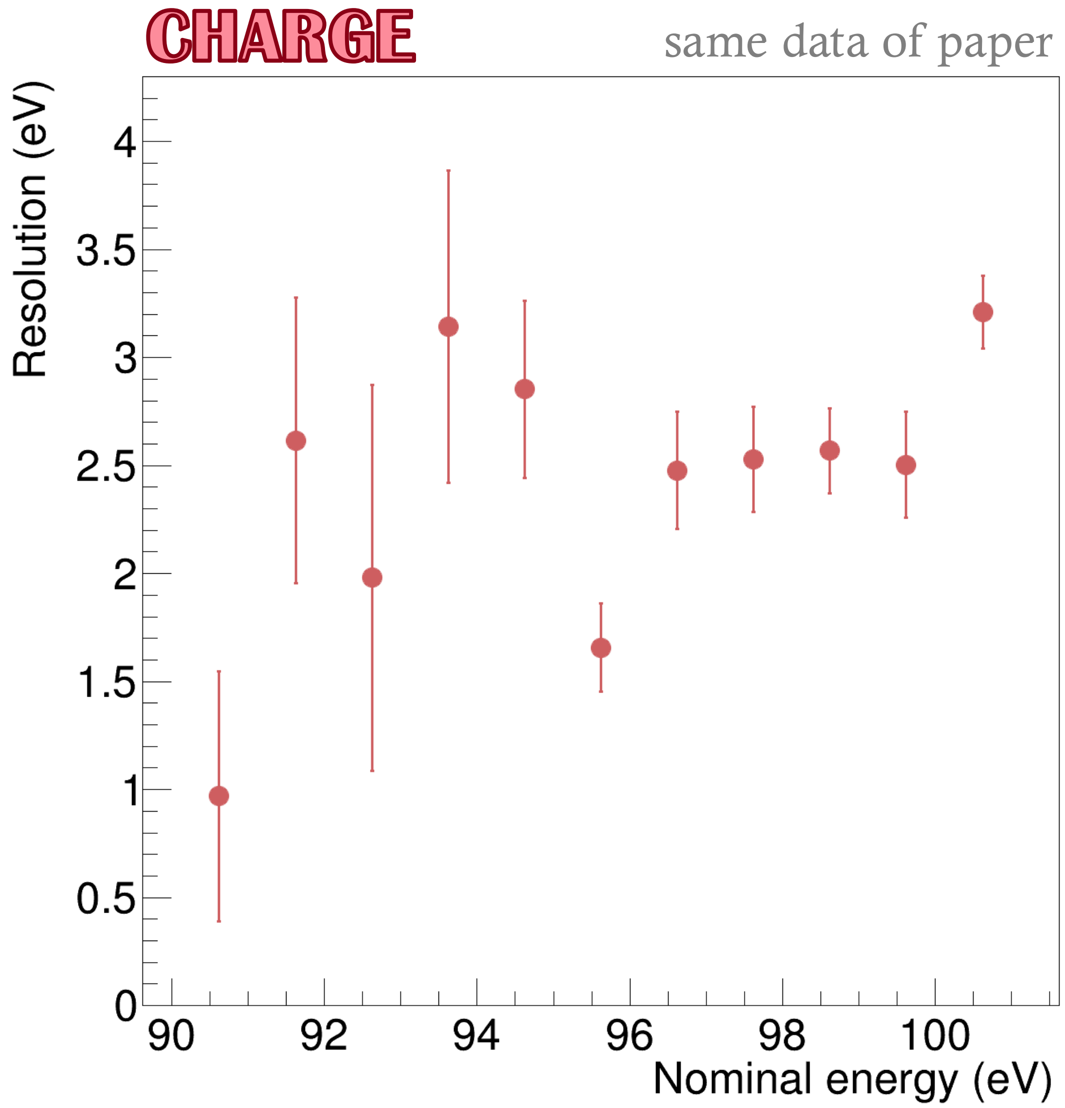
⇨ energy resolution studied on charge

Charge has Worse Resolution than Amplitude





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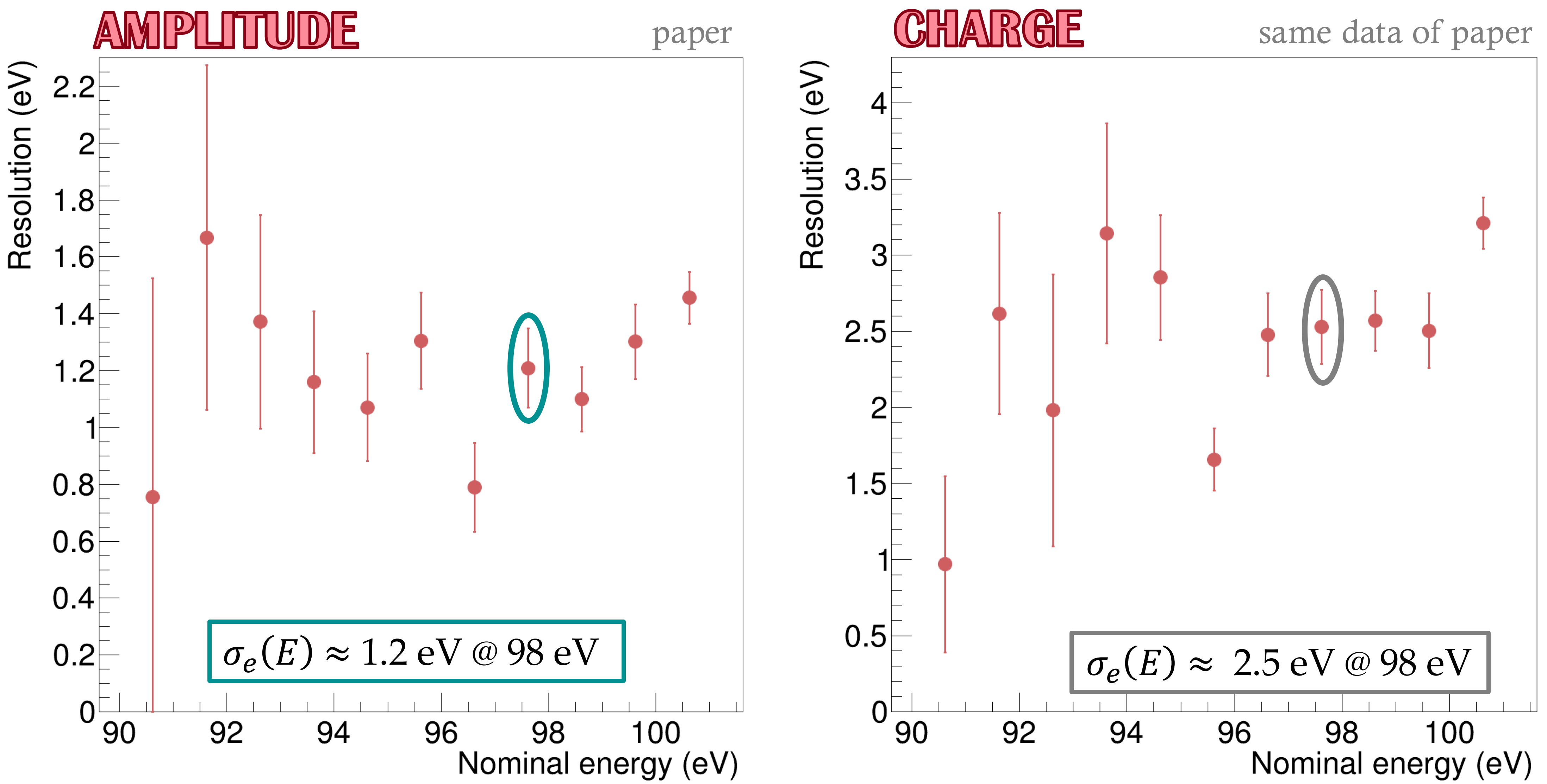

Same Fit on Charge Distributions

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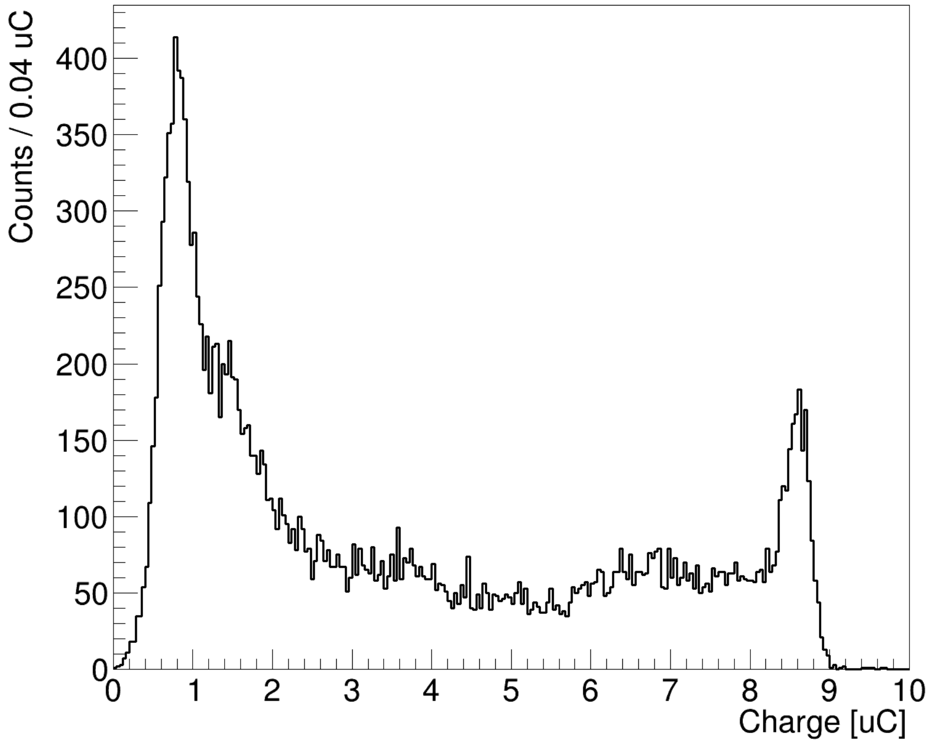

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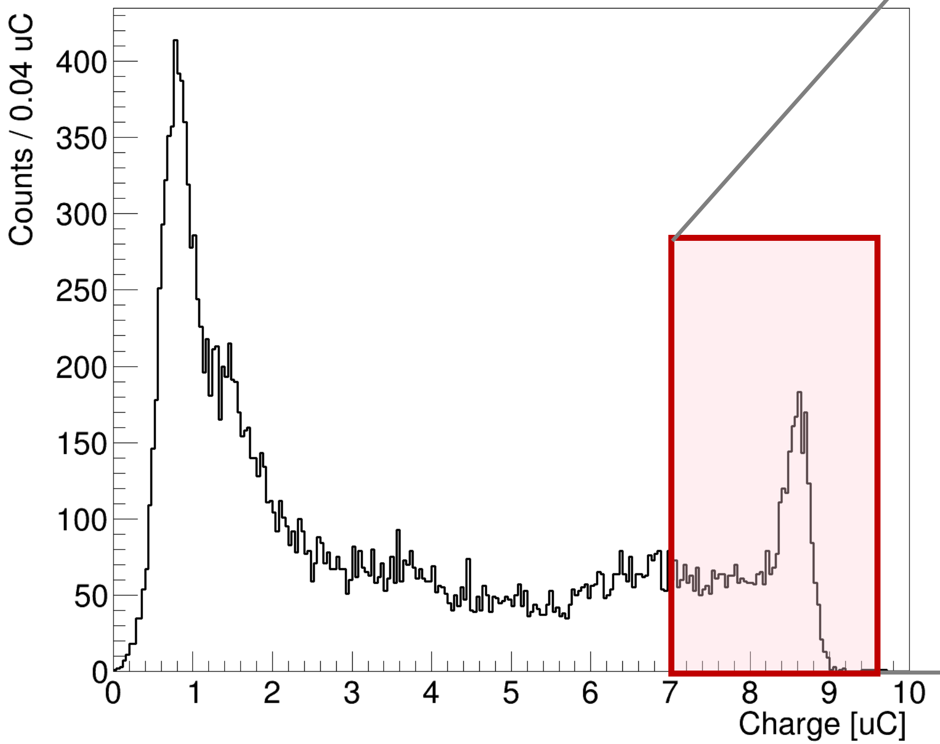
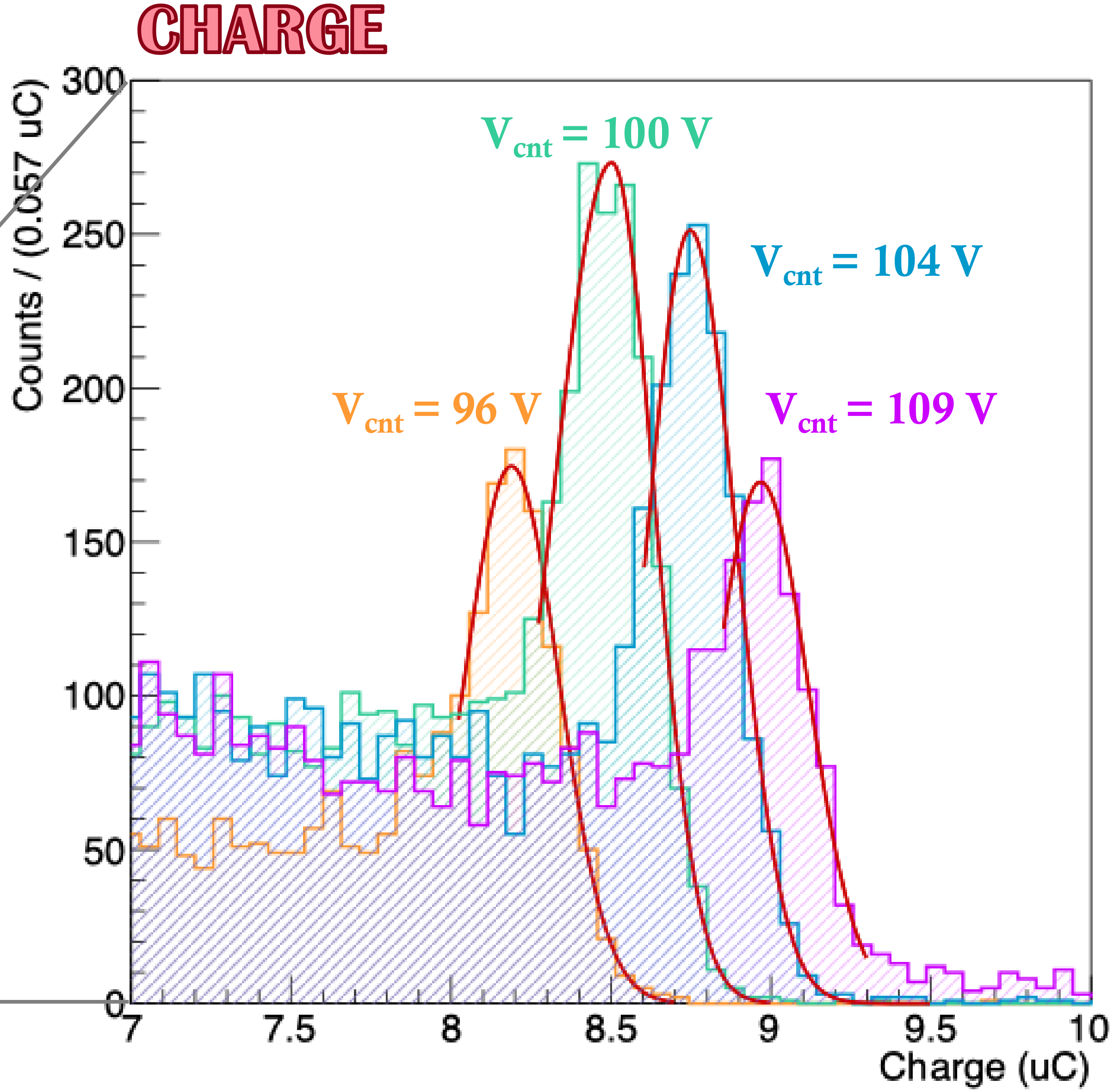
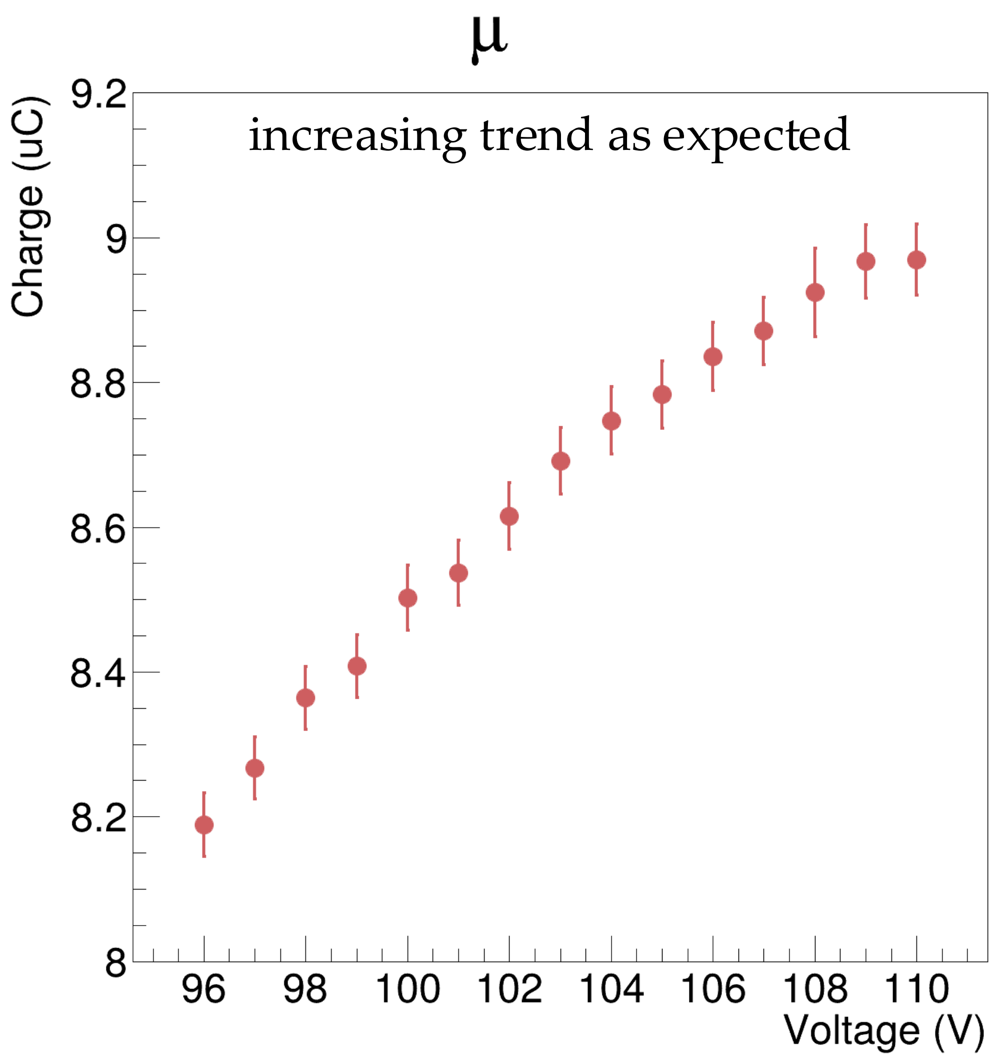
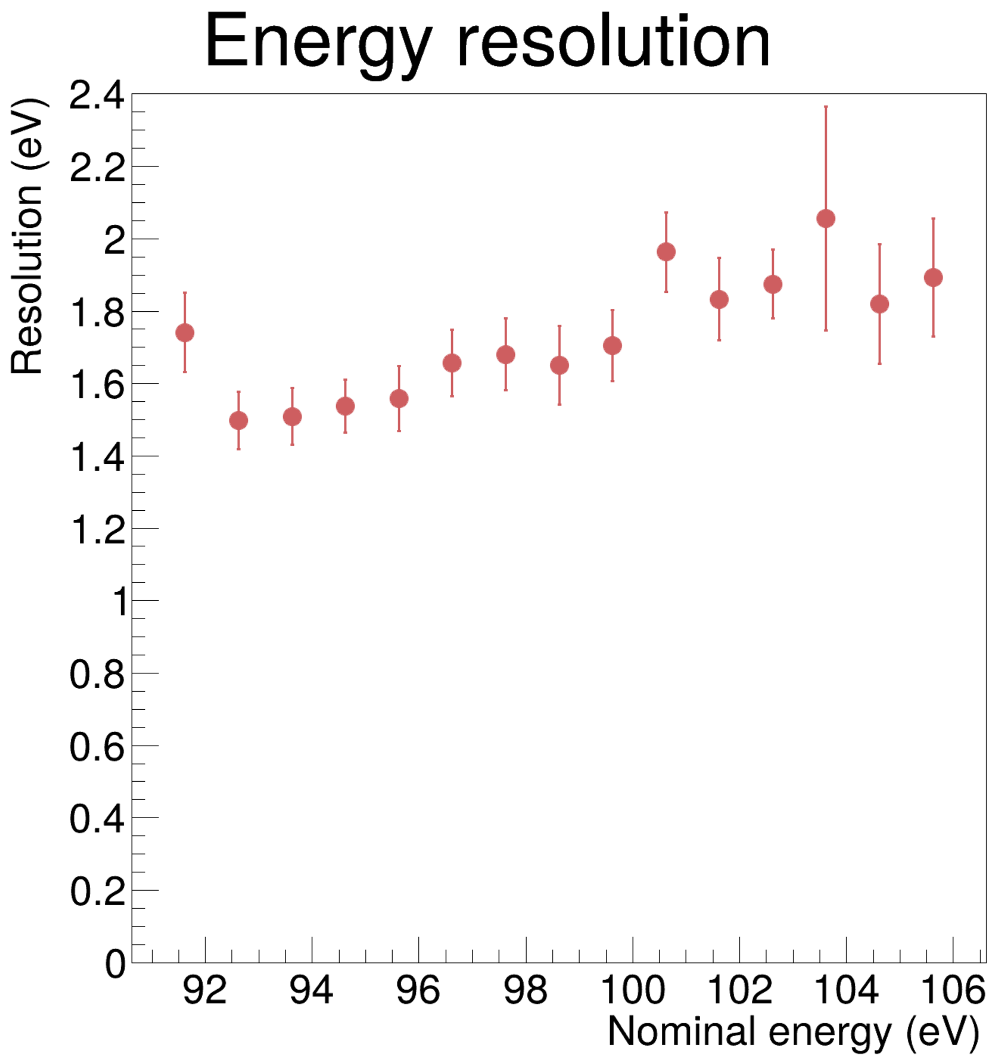




$1.5\ \text{eV} \lesssim \sigma_e^{charge}(E) \lesssim 2.0\ \text{eV}$ for 92 - 106 eV Electrons





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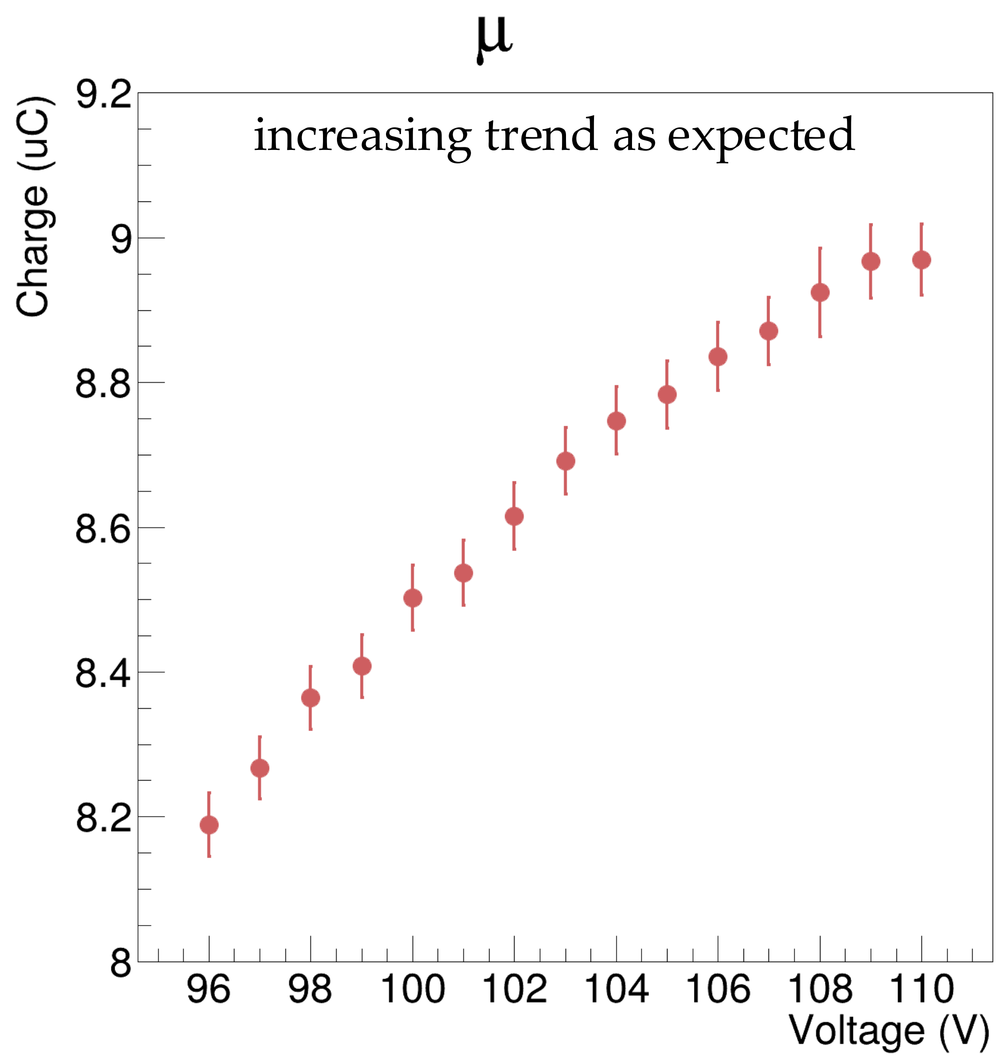

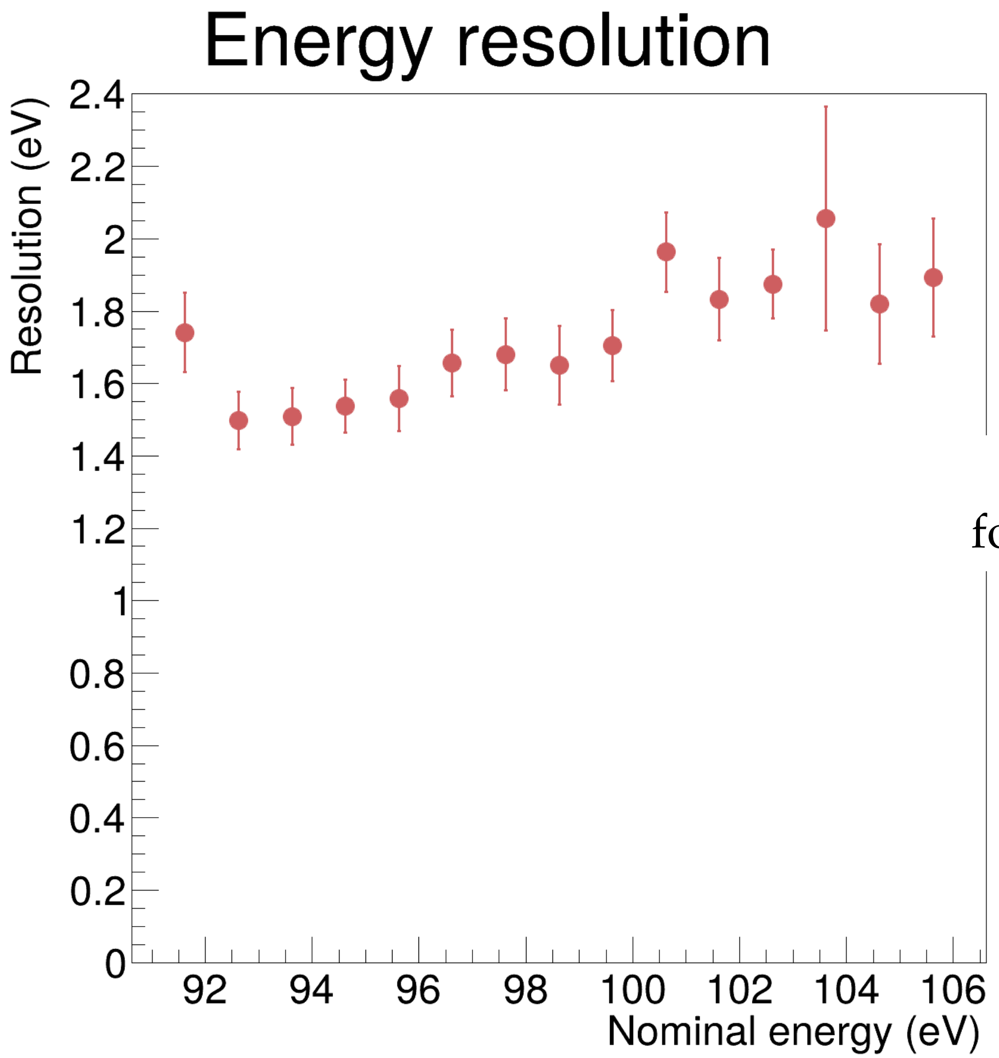

CHARGE

paper data

$\boldsymbol{\sigma_e(E) \approx 2.5}$ **eV**

for 98 eV electrons

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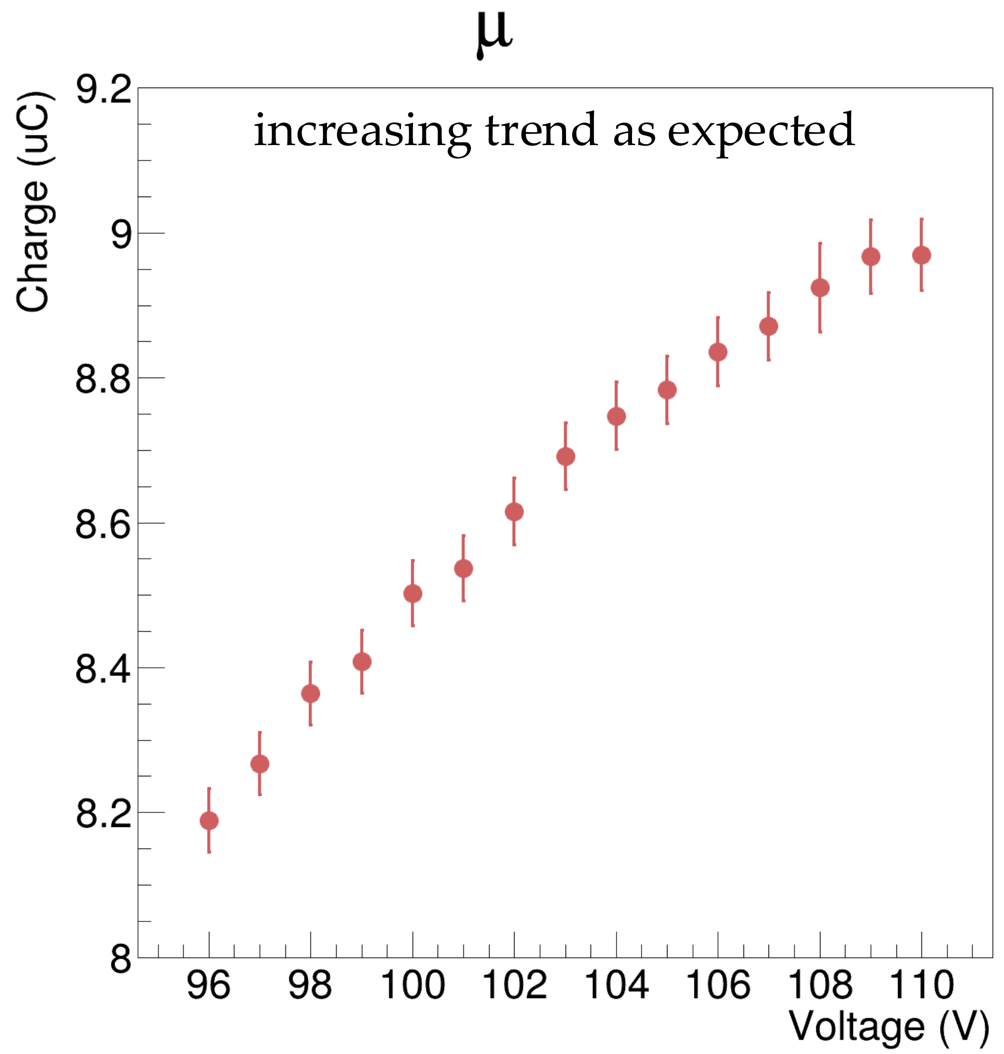

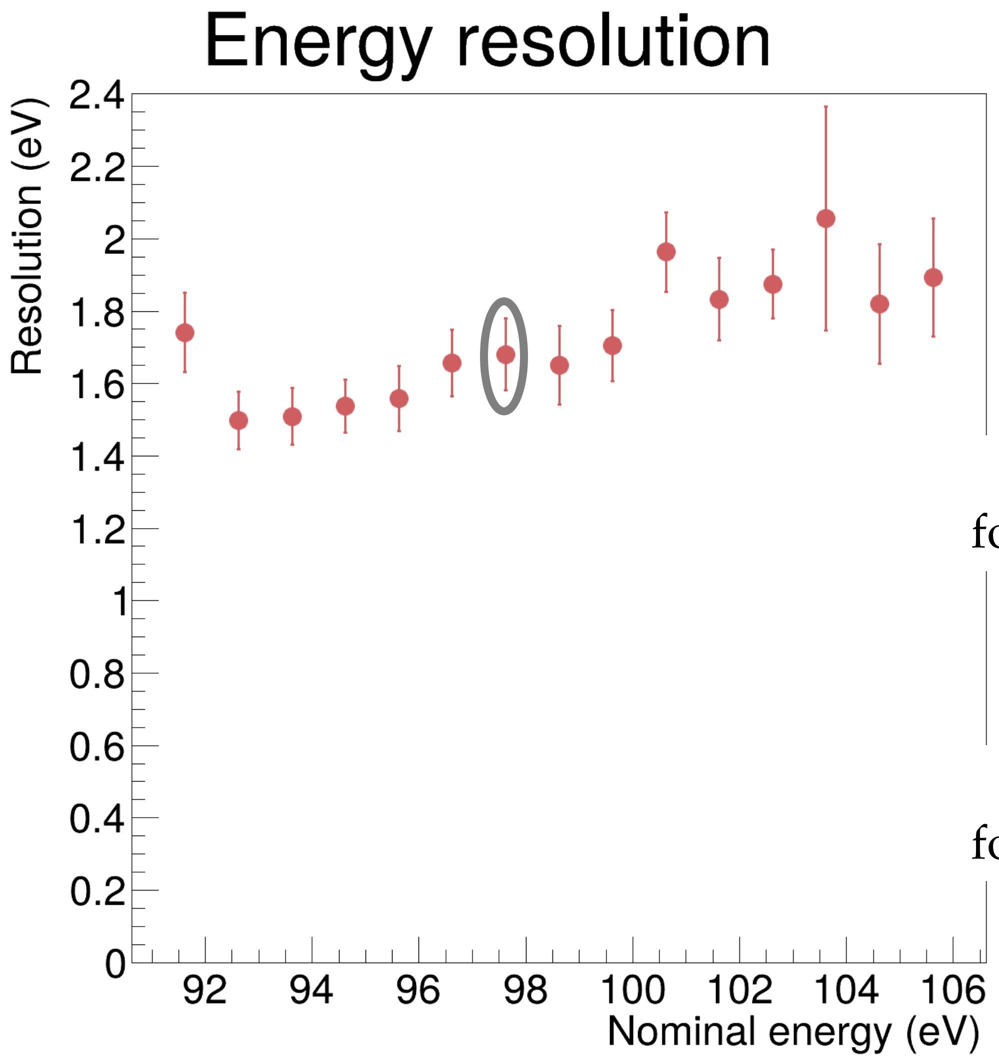

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improvement

dec 2024

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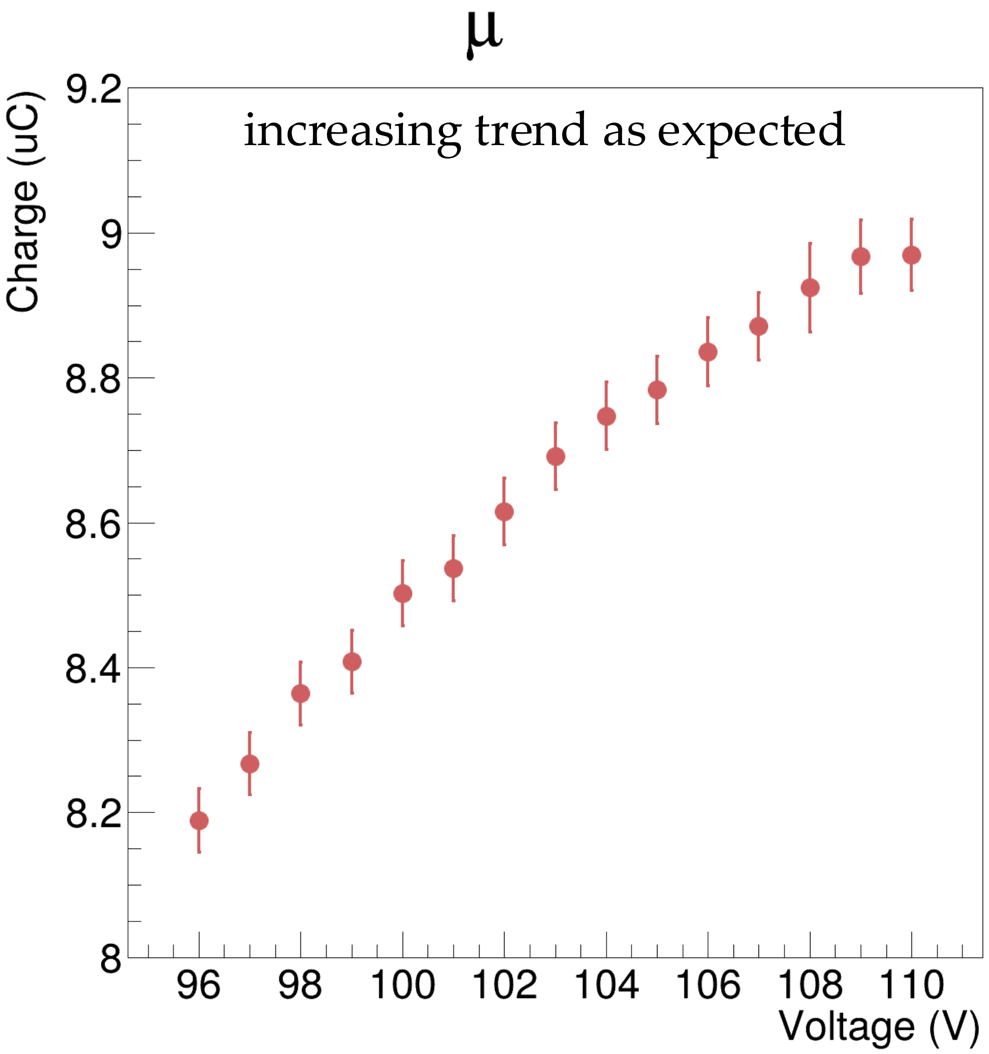

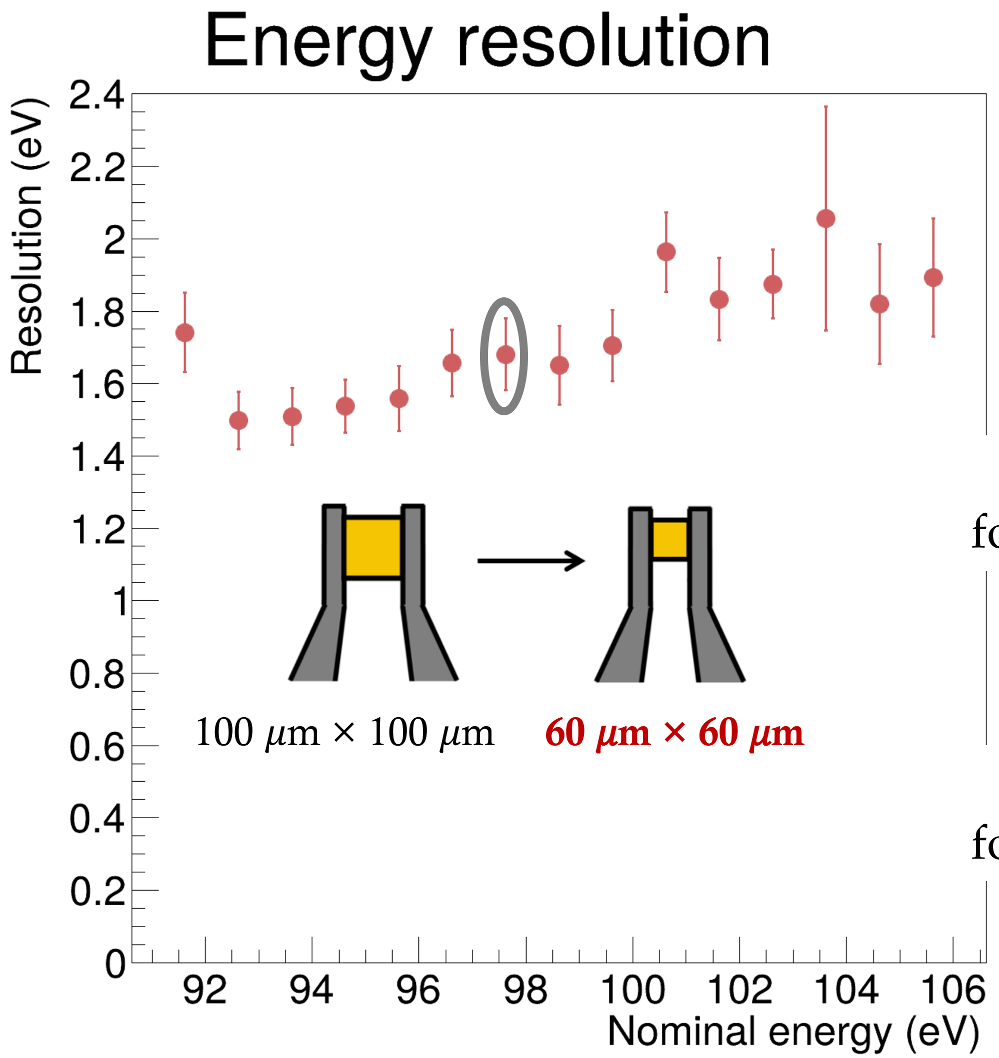

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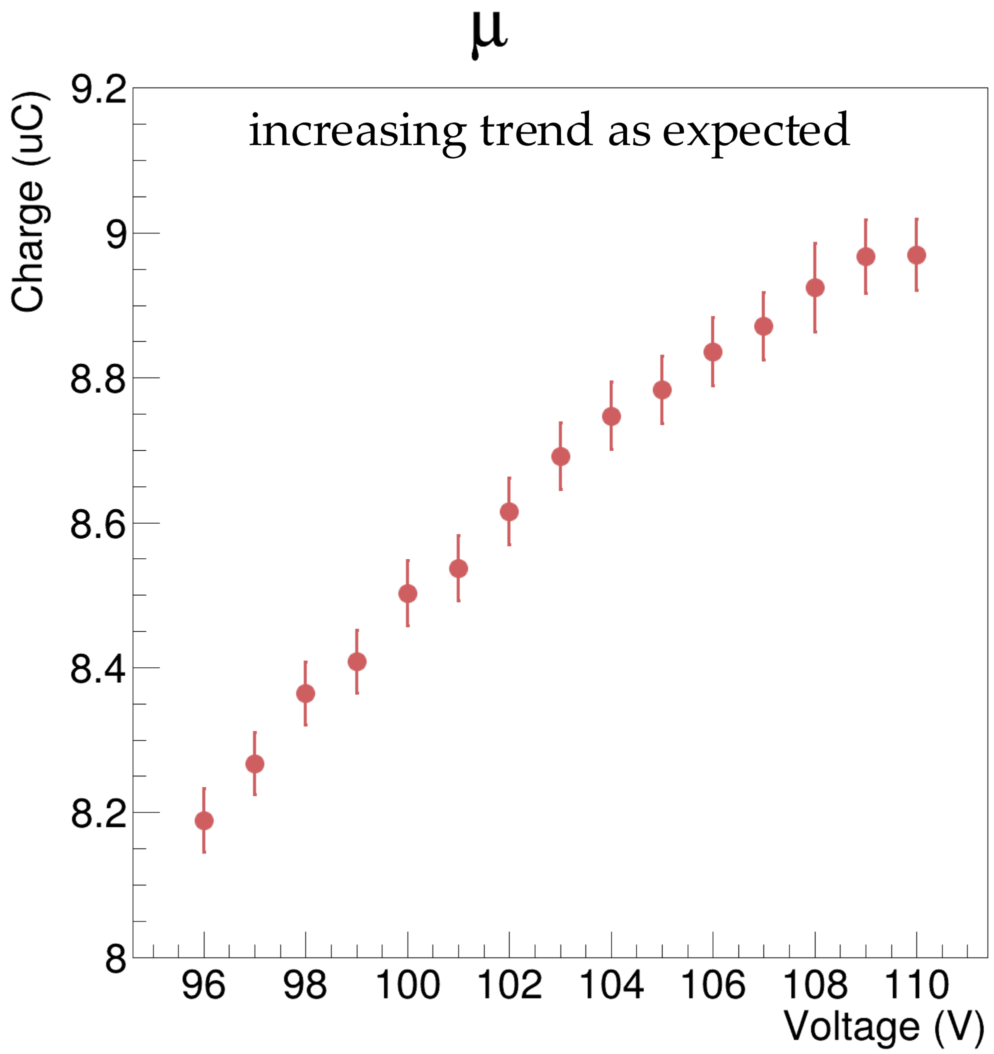

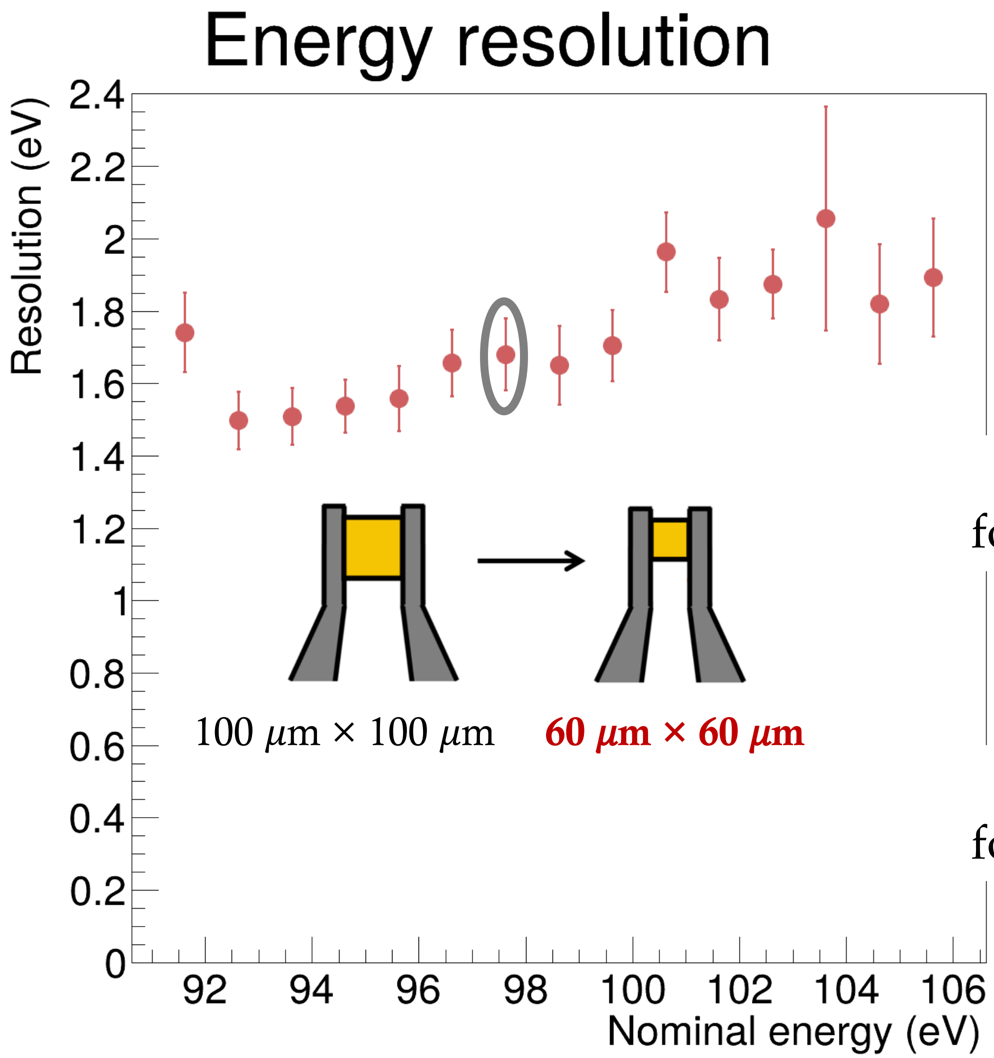

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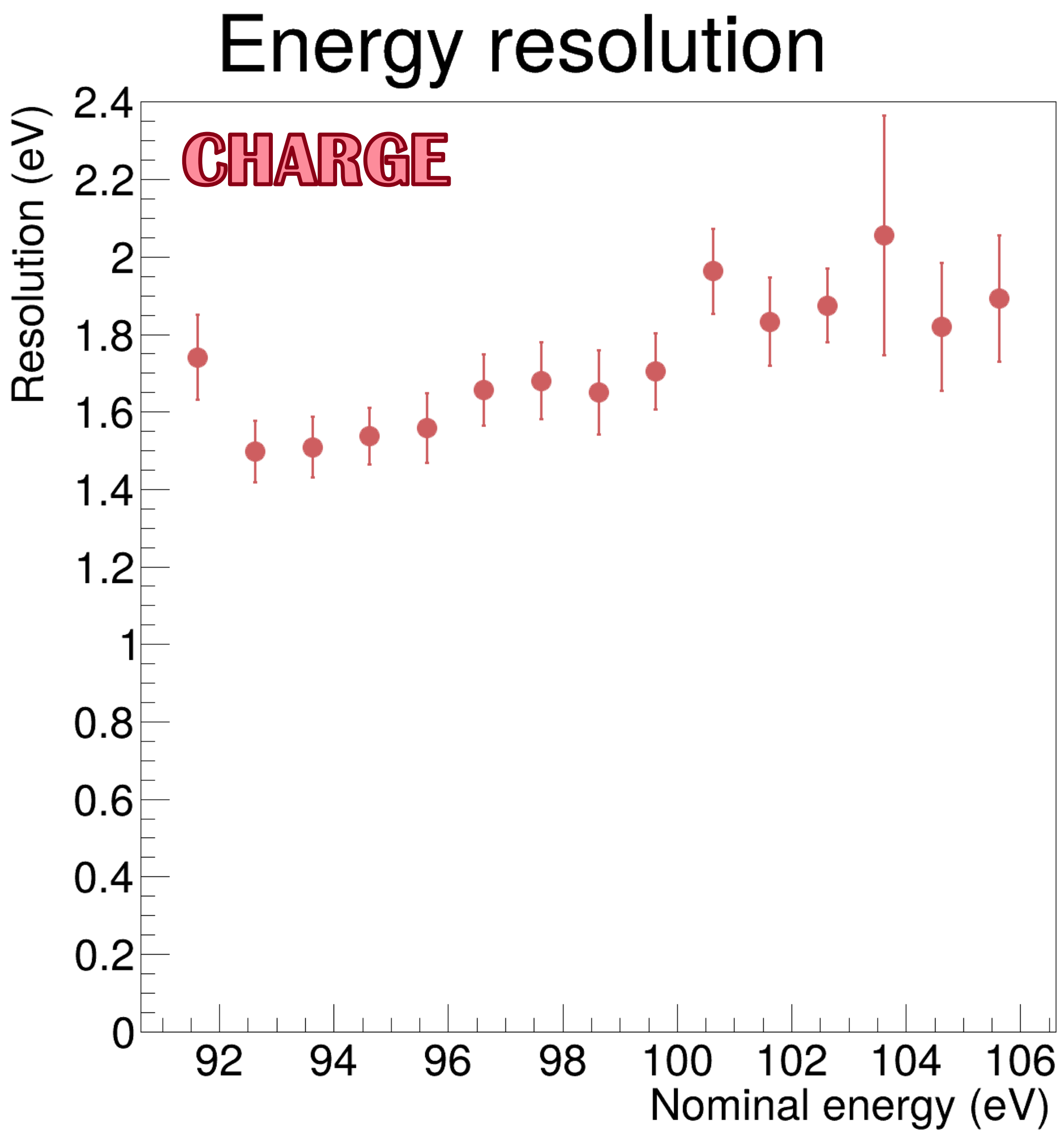
factor 0.6 gained

Optimistic Conjectures on Resolution :D



Comparing results we found:

CHARGE $\Longrightarrow$ $\dfrac{resolution\ (\text{december 2024})}{resolution\ (\text{paper data})} \sim 0.6$

if we <u>impose</u> that:

AMPLITUDE $\Longrightarrow$ $0.6 = \dfrac{resolution\ (\text{december 2024})}{resolution\ (\text{paper})}$

if we say that the paper energy resolution is 1 eV,
we <u>would obtain</u> an energy resolution on amplitudes of

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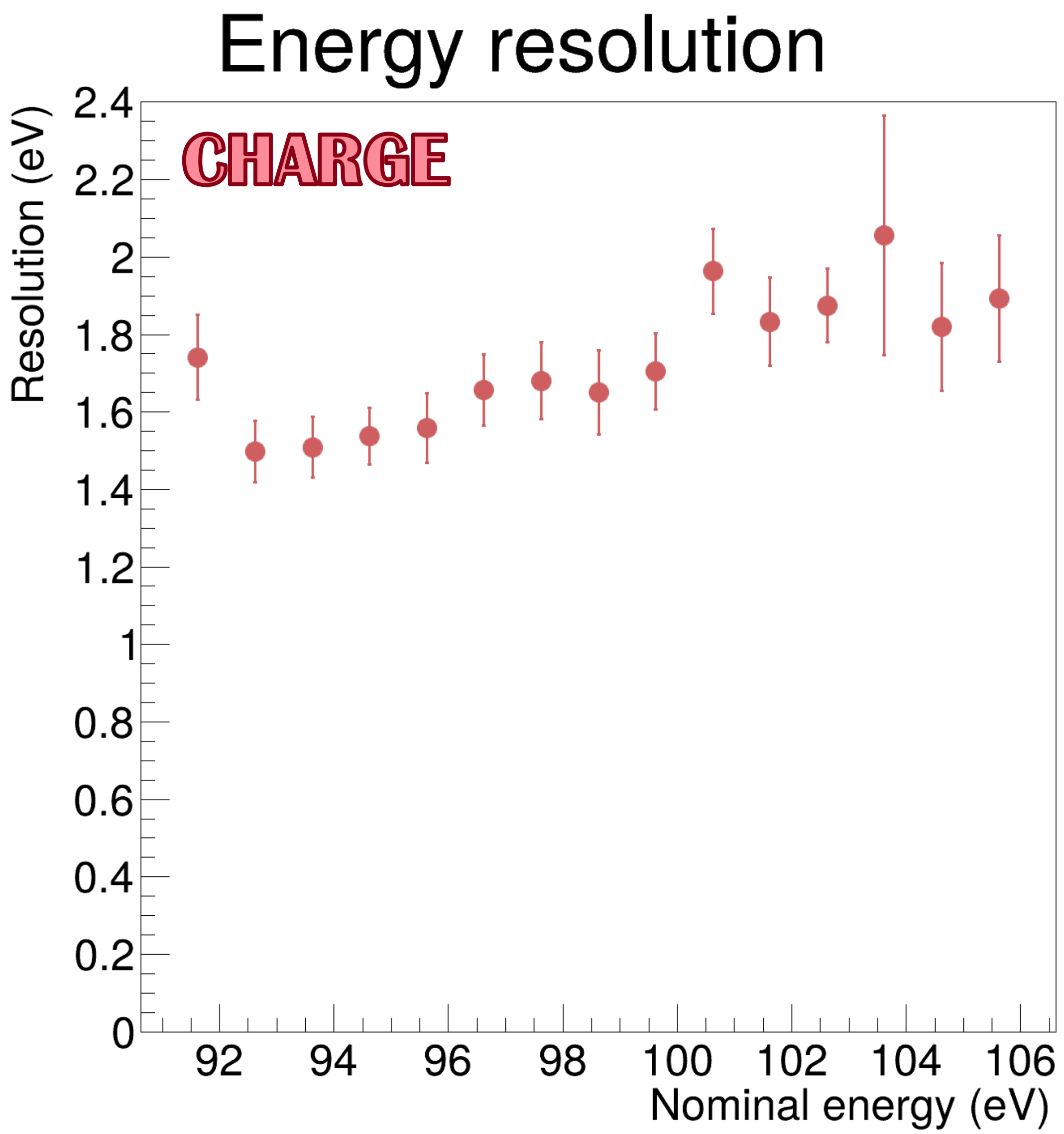

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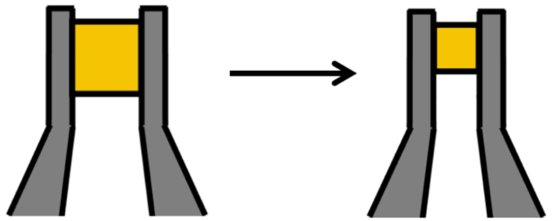
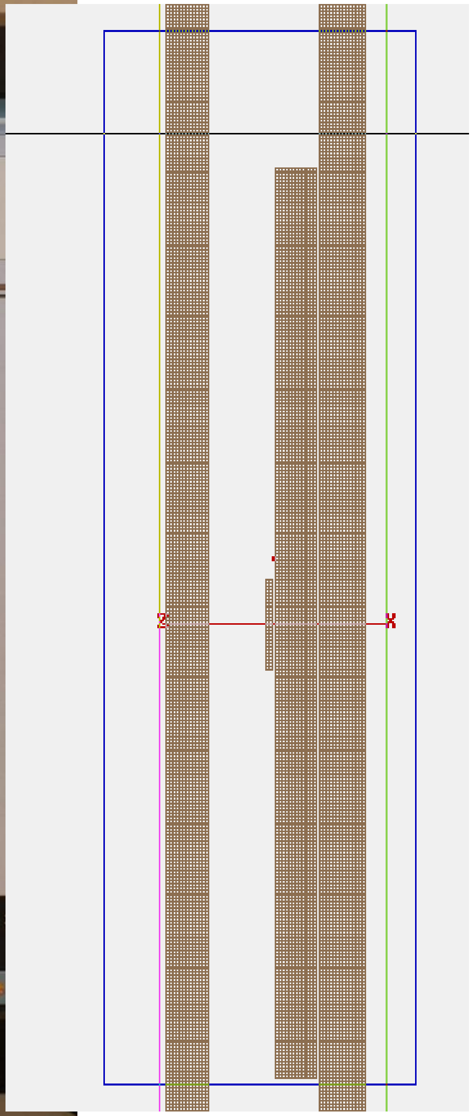


$100\ \mu m \times 100\ \mu m$ **$60\ \mu m \times 60\ \mu m$**

compatible with the **expected** energy resolution improvement of 40%!

Simulations on how to Improve the Setup Ongoing

these were the only pictures I had :')



Conclusions

WHAT DID WE LEARN?

Conclusions

WHAT DID WE LEARN?

- **Reduction** of **CNTs**

3 mm × 3 mm **1 mm × 1 mm**

Conclusions

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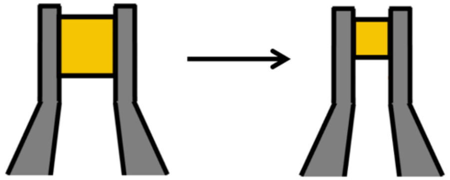

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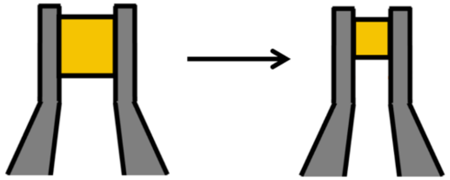

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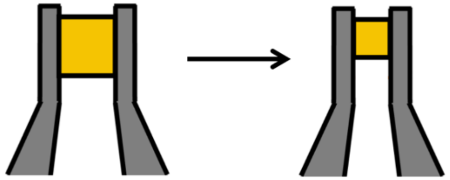

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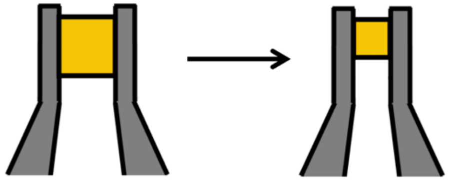

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NEXT STEPS:

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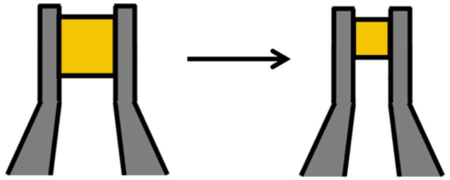

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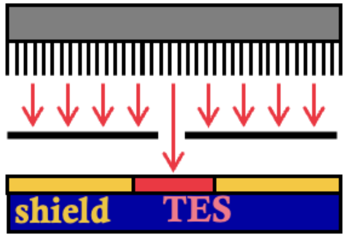
→ improvement of 40% as **expected**!

NEXT STEPS:

- keep **reducing** the CNT active area →



pinhole to stop electrons

Conclusions

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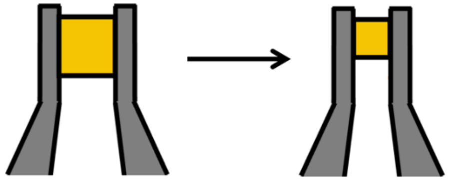
→ left tail of high-energy peak much **reduced**

- **Reduction** of **TES**



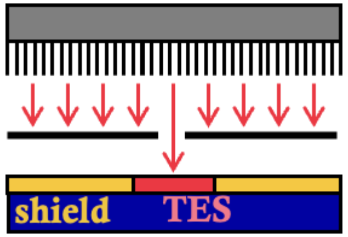
100 μm × 100 μm → **60 μm × 60 μm**

→ **better** energy resolution on charge

→ improvement of 40% as **expected**!

NEXT STEPS:

- keep **reducing** the CNT active area →
- **simulations** to optimize the electron collection on the TES

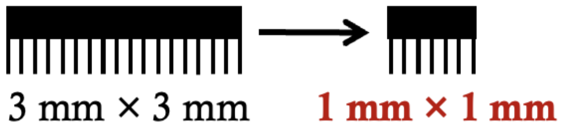


pinhole to stop electrons

Conclusions

WHAT DID WE LEARN?

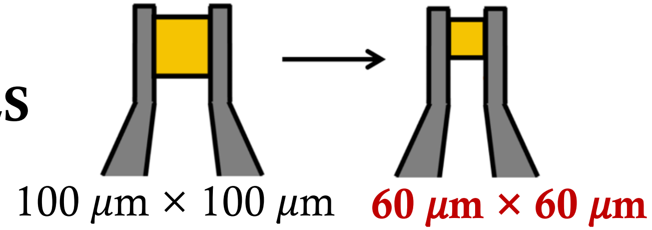
- **Reduction** of **CNTs**



→ TES shows **stable** working conditions

→ left tail of high-energy peak much **reduced**

- **Reduction** of **TES**



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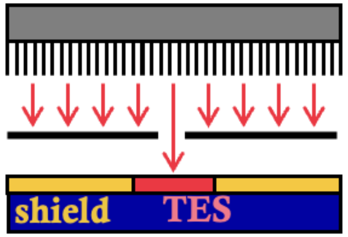
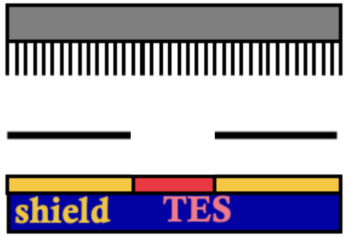


- **simulations** to optimize the electron collection on the TES
- **lower the energies** not to saturate the TES



Conclusions

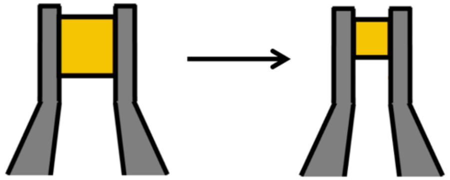
WHAT DID WE LEARN?

- **Reduction** of **CNTs**

3 mm × 3 mm → **1 mm × 1 mm**

- TES shows **stable** working conditions
- left tail of high-energy peak much **reduced**

- **Reduction** of **TES**

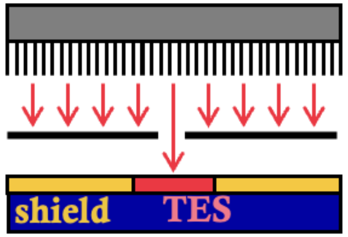


100 μm × 100 μm → **60 μm × 60 μm**

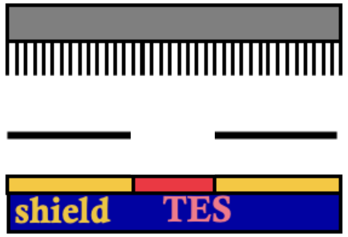
- **better** energy resolution on charge
- improvement of 40% as **expected**!

NEXT STEPS:

- keep **reducing** the CNT active area → pinhole to stop electrons
- **simulations** to optimize the electron collection on the TES
- **lower the energies** not to saturate the TES



pinhole to stop electrons



decelerating plate

-5 V
+95 V
0 V

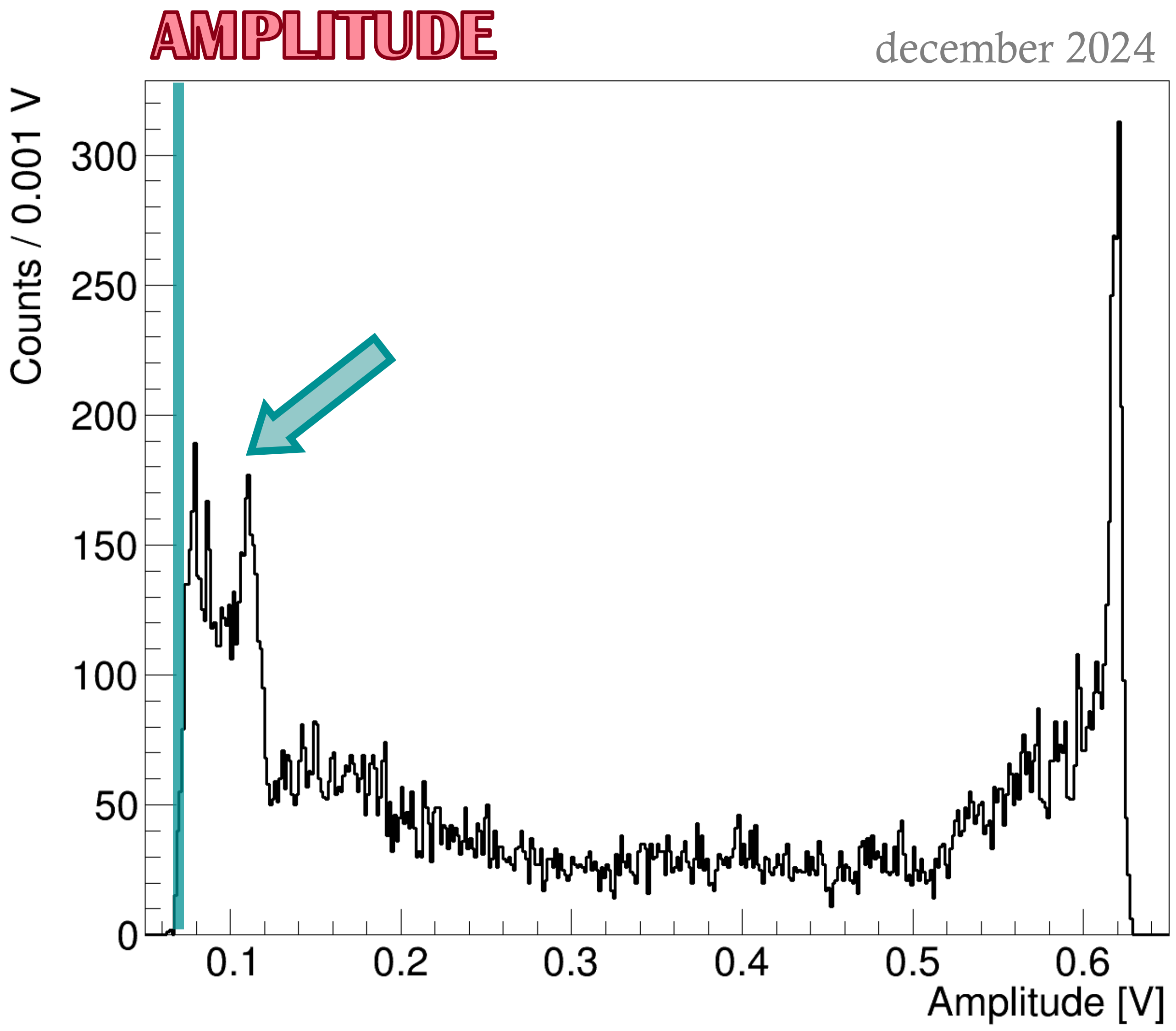
ΔV = 100 V to extract electrons

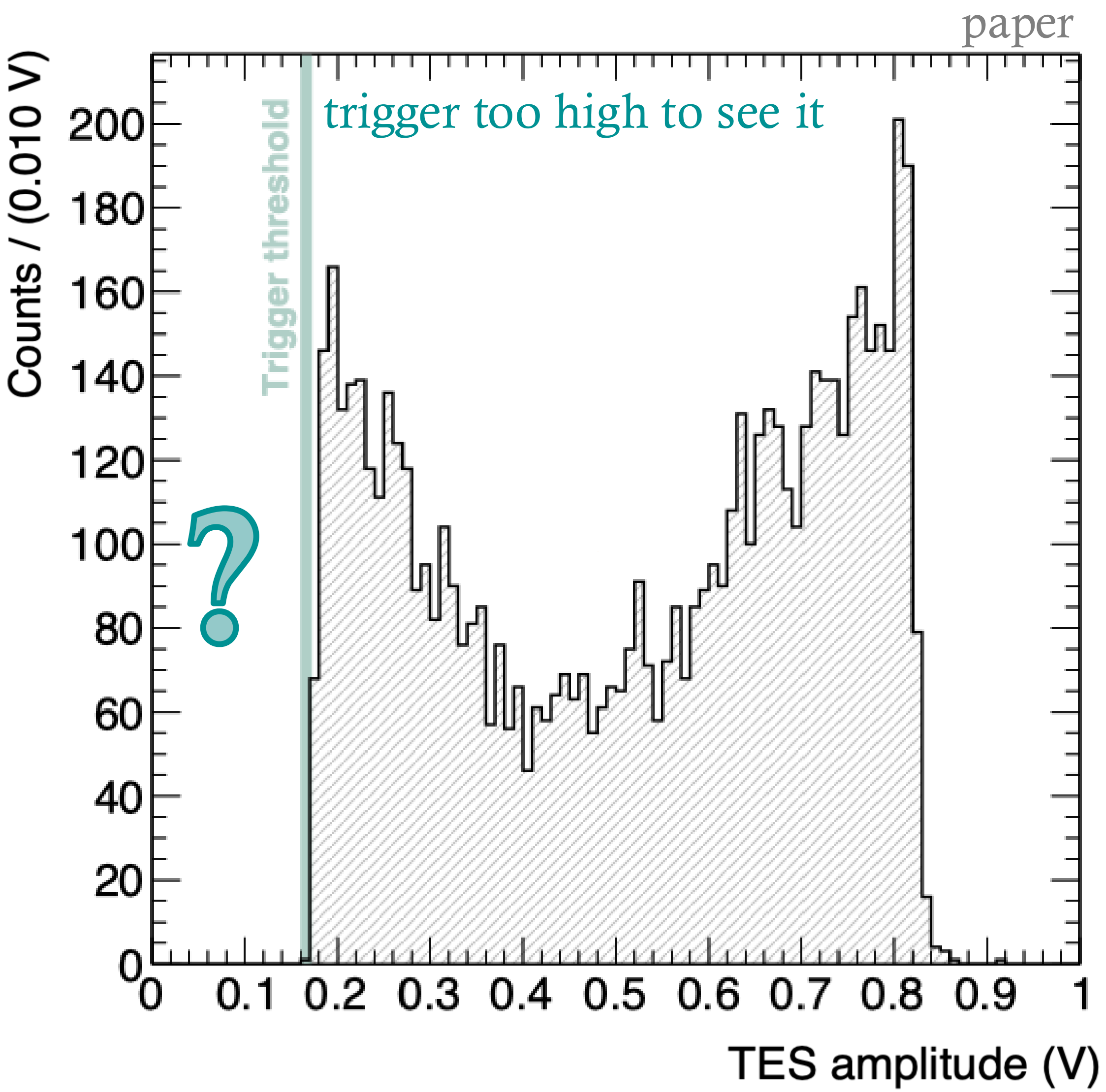
ΔV = - 95 V to obtain 5 eV electrons

Backup Slides

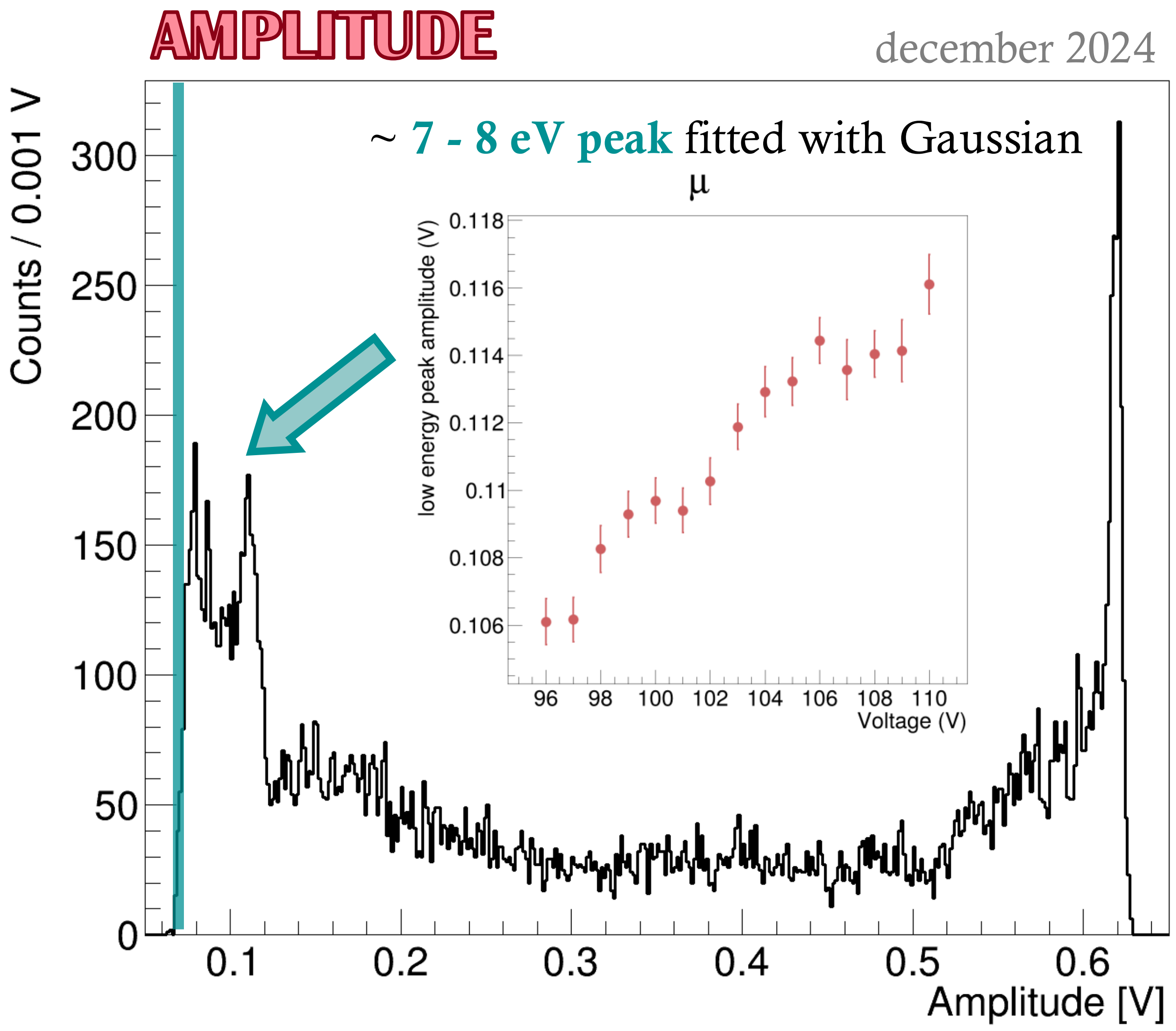
Low Amplitude Peak not Reached Before

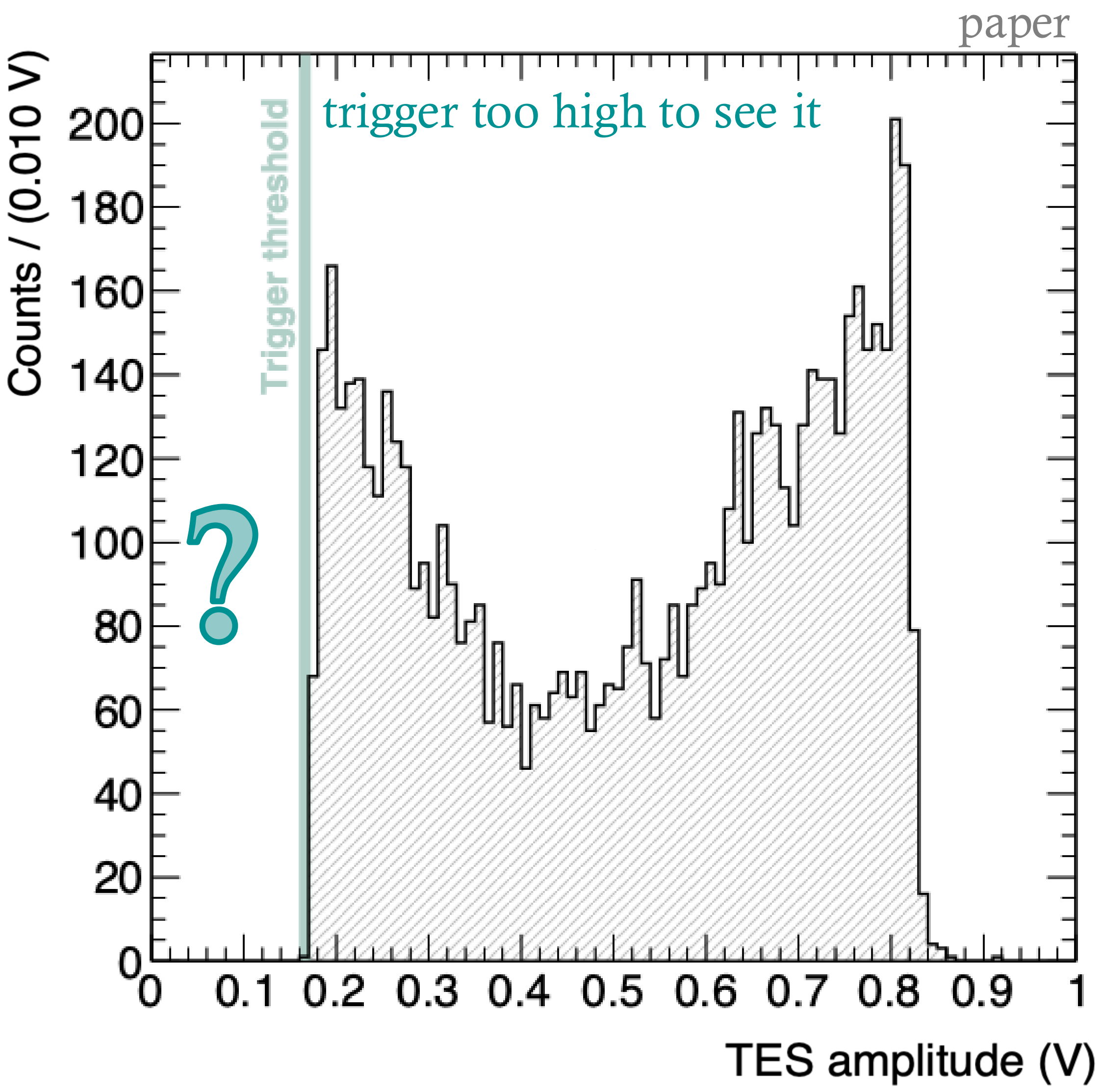
A





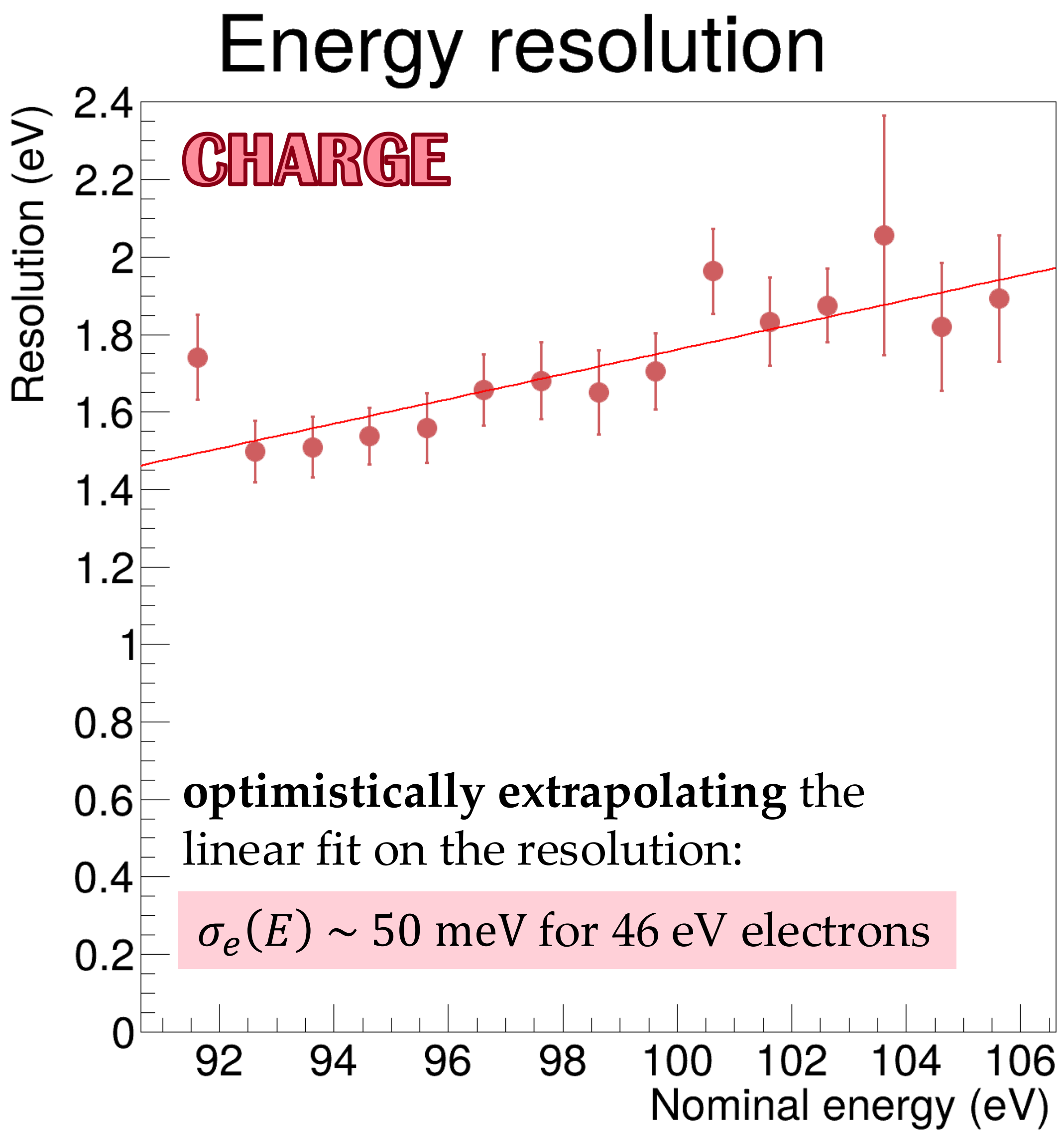
Low Amplitude Peak not Reached Before





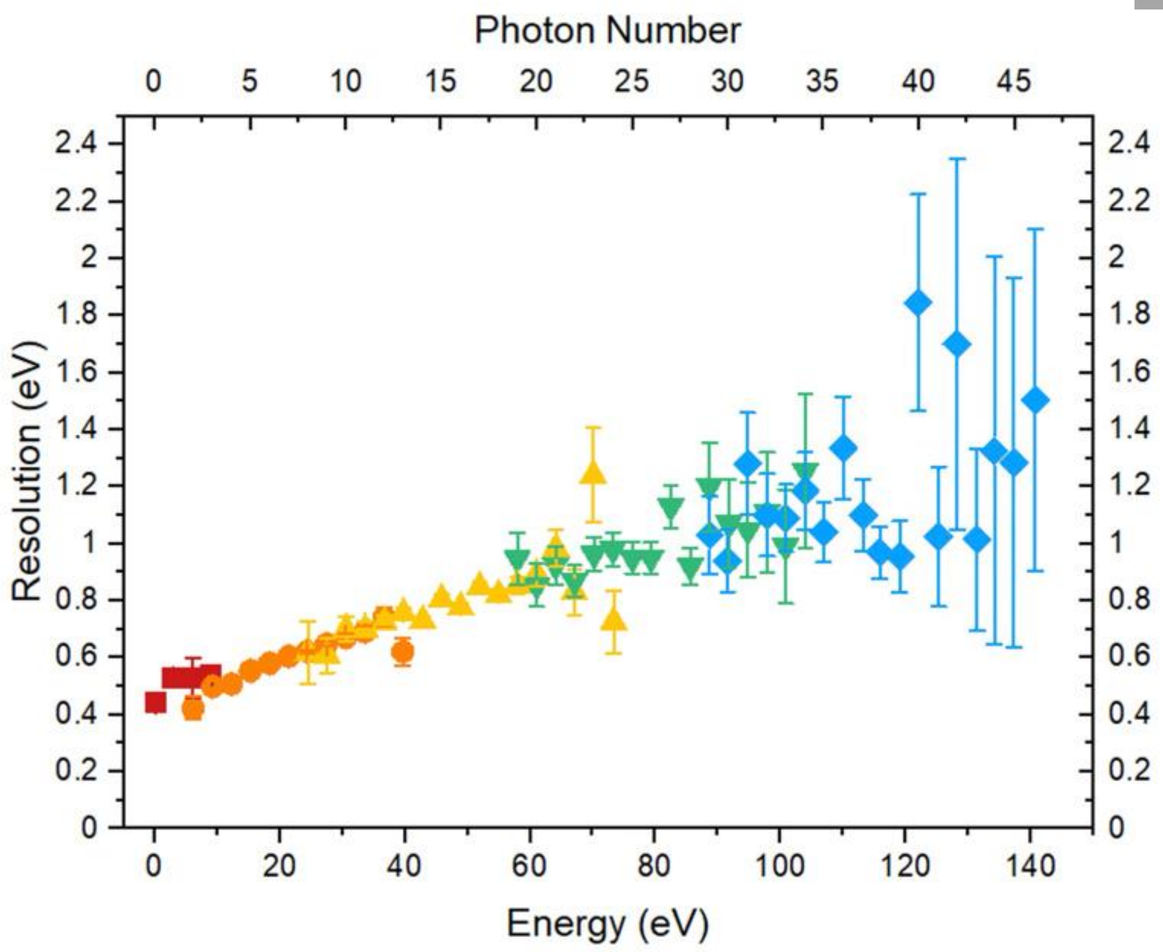
Optimistic Conjectures on Resolution :D

B



optimistically extrapolating the linear fit on the resolution:

$\sigma_e(E)$ ~ 50 meV for 46 eV electrons



factor ~ **2.3** between amp and charge of PTL4e D100
factor ~ **0.6** between PTL4e D100 and PTL4e3 B60

Workfunctions Play a Role in Electron Kinetic Energy

C

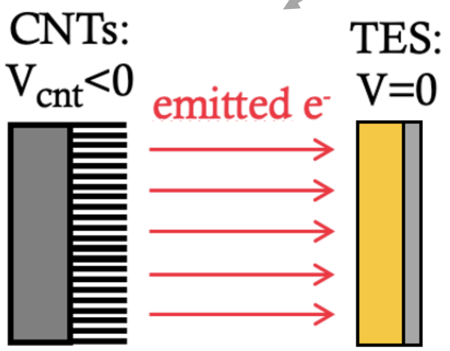
$$E_e = (eV_{\mathrm{cnt}} - \varphi_{\mathrm{cnt}}) + (\varphi_{\mathrm{cnt}} - \varphi_{\mathrm{tes}}) = eV_{\mathrm{cnt}} - \varphi_{\mathrm{tes}}$$

Workfunctions Play a Role in Electron Kinetic Energy

C

$$E_e = (eV_{cnt} - \varphi_{cnt}) + (\varphi_{cnt} - \varphi_{tes}) = eV_{cnt} - \varphi_{tes}$$

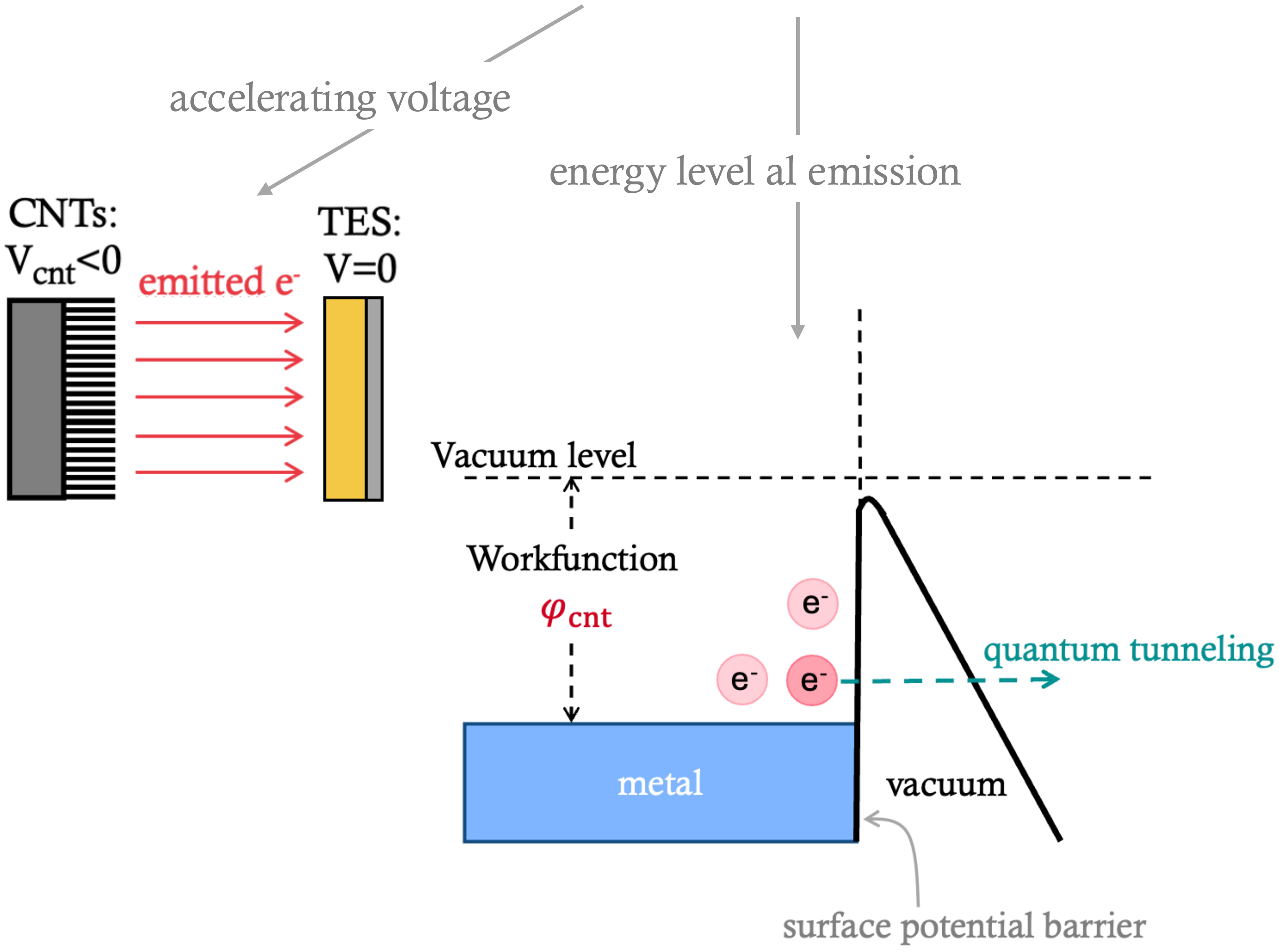
accelerating voltage



Workfunctions Play a Role in Electron Kinetic Energy

C

$$E_e = (eV_{cnt} - \varphi_{cnt}) + (\varphi_{cnt} - \varphi_{tes}) = eV_{cnt} - \varphi_{tes}$$



Workfunctions Play a Role in Electron Kinetic Energy

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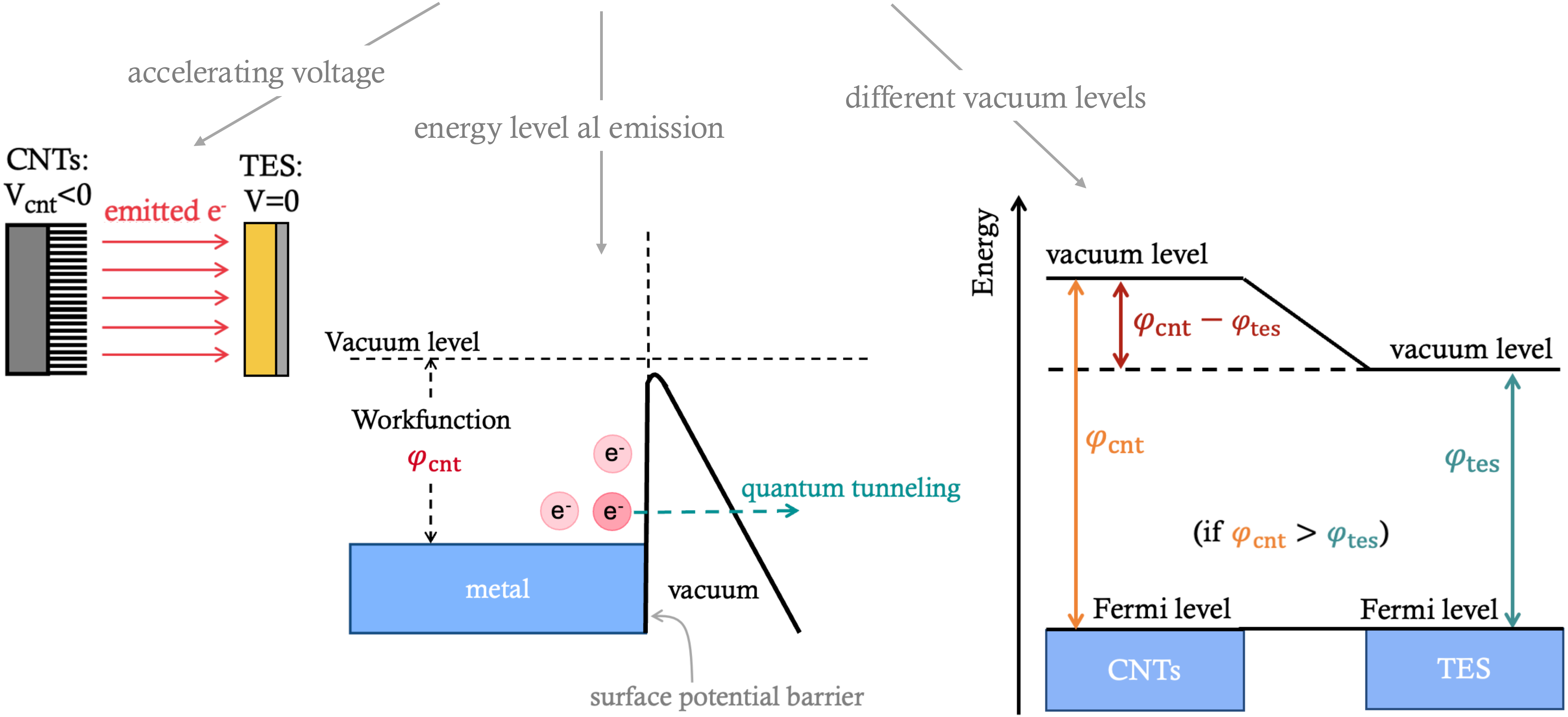


Workfunctions Play a Role in Electron Kinetic Energy

C

4.4 eV @ LASEC lab in Roma Tre

$$E_e = (eV_{cnt} - \varphi_{cnt}) + (\varphi_{cnt} - \varphi_{tes}) = eV_{cnt} - \varphi_{tes}$$

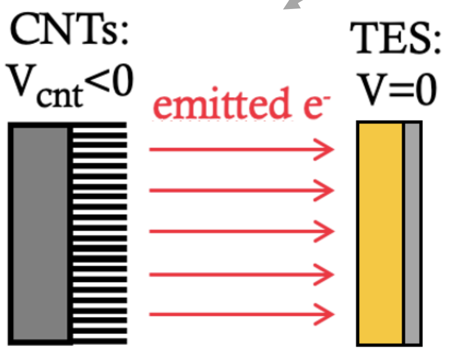
accelerating voltage

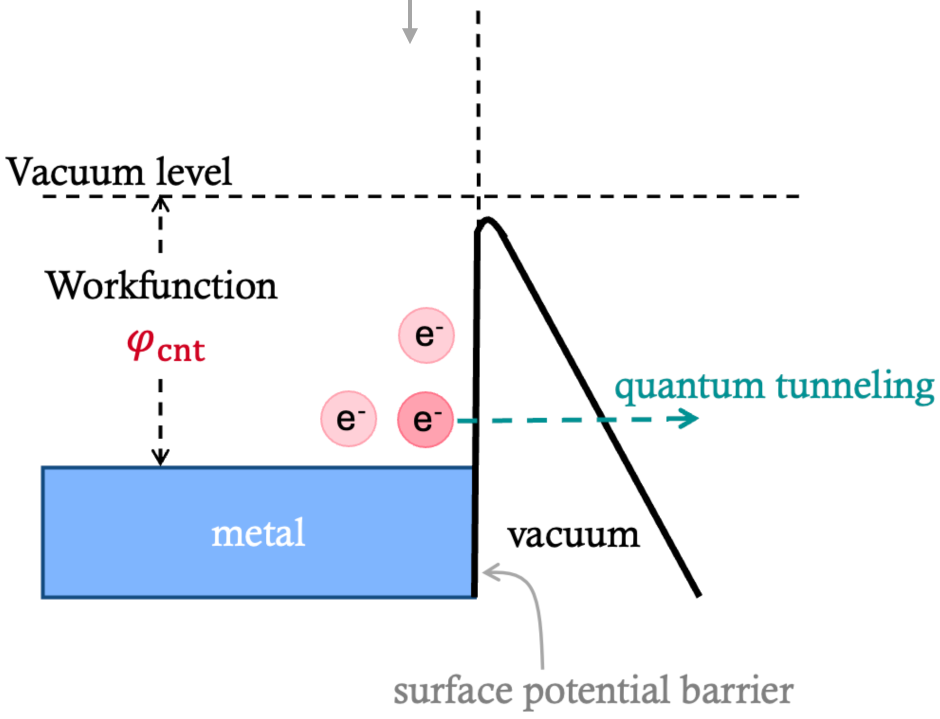
energy level al emission

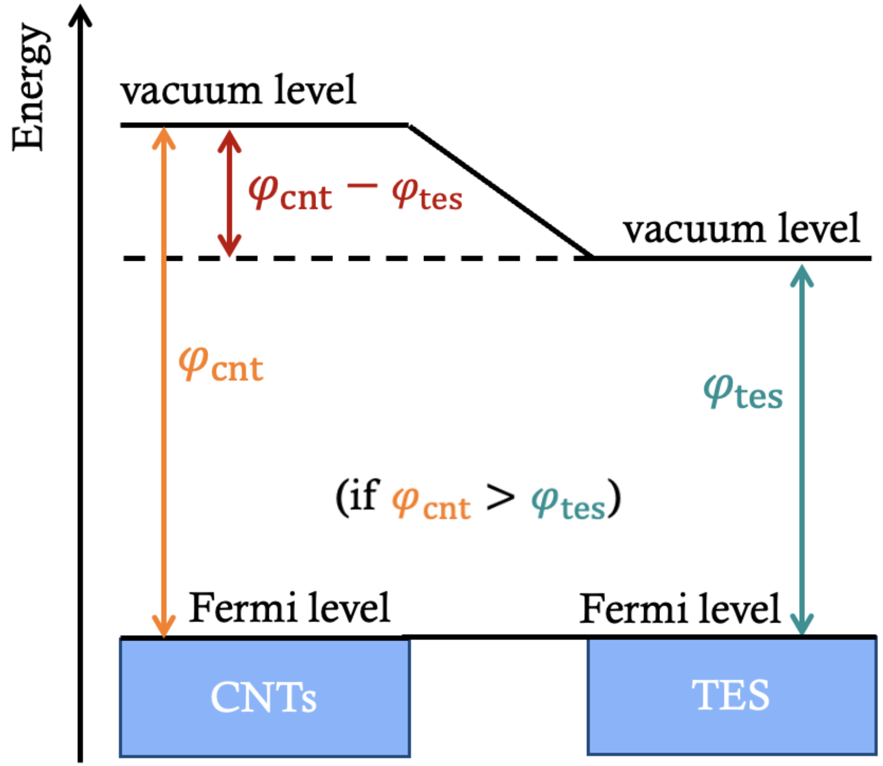
different vacuum levels

$96 \text{ V} < V_{cnt} < 110 \text{ V}$

$\mathbf{91.6 \text{ eV} < E_e < 105.6 \text{ eV}}$







TES Detection Performance

D

$$\tau_{eff} = \tau_{th}\left\{1 + \frac{\alpha}{n}\left(1 - \frac{T_{bath}^n}{T_c^n}\right)\right\}^{-1} \approx \frac{n}{\alpha}\tau_{th} \approx \frac{C}{G} \propto T_c^{-3}$$

effective time response

$$\Delta E_{FWHM} = 2.36\sqrt{4k_B T_c^2 \frac{C}{\alpha}\sqrt{\frac{n}{2}}} \propto T_c^{3/2}$$

energy FWHM

$$E_{sat} = C\Delta T_{sat} = \frac{C}{\alpha}\frac{\Delta R_{sat}}{R}T_c \propto T_c$$

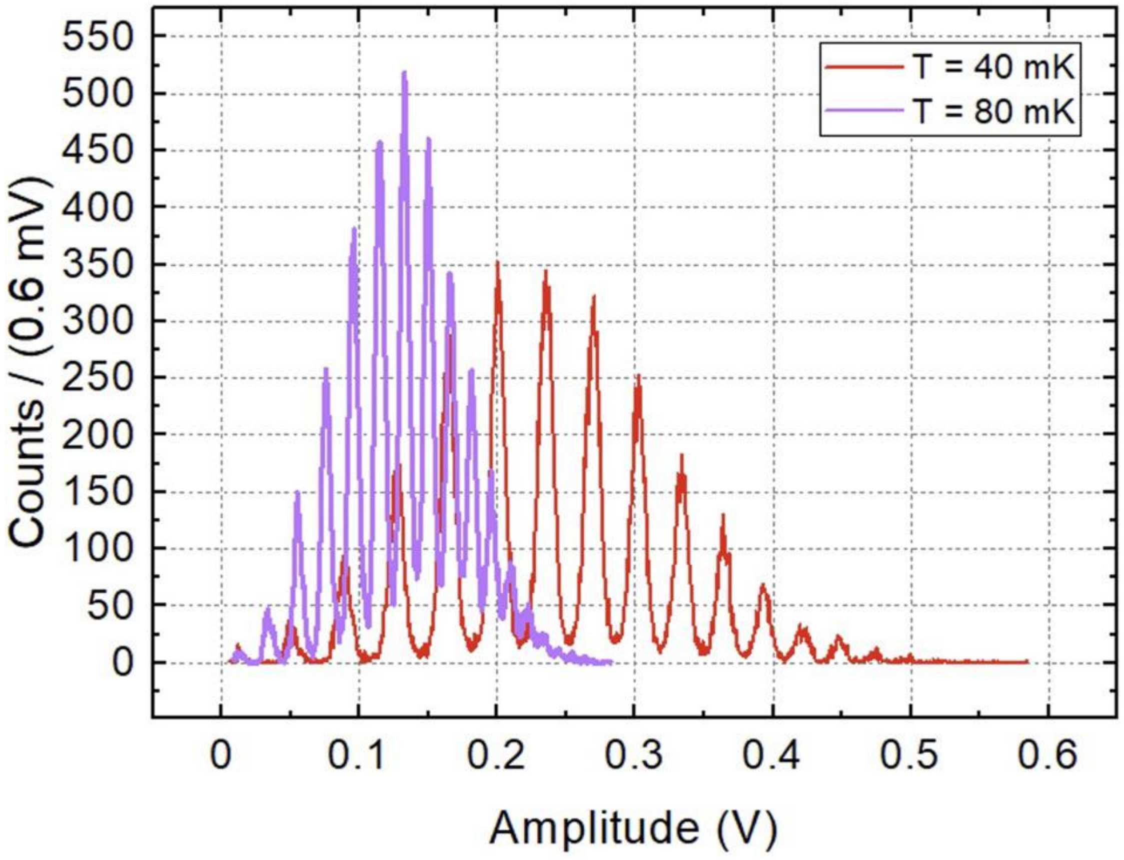
energy saturation

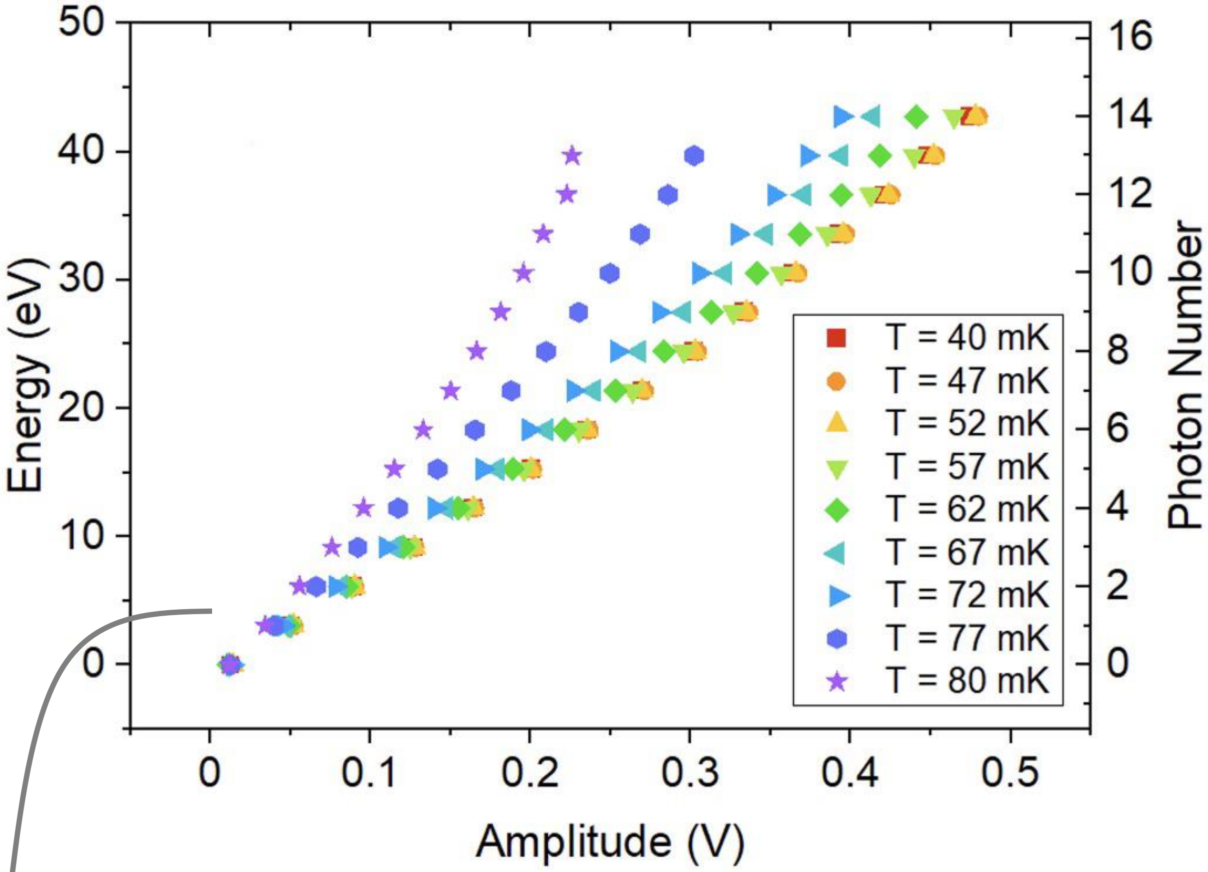
$$\alpha = \frac{T}{R}\frac{dR}{dT}$$

transition sharpness

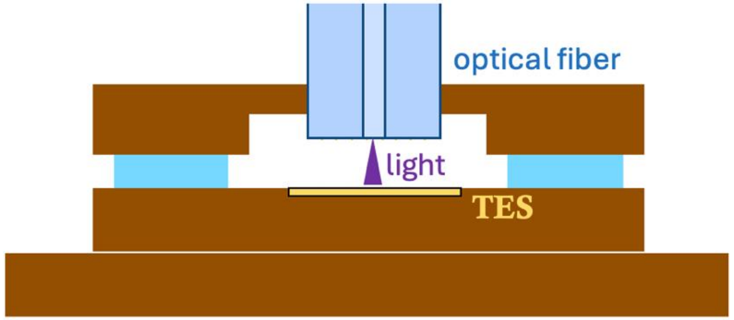
Temperature Effects on Signal Amplitude

E



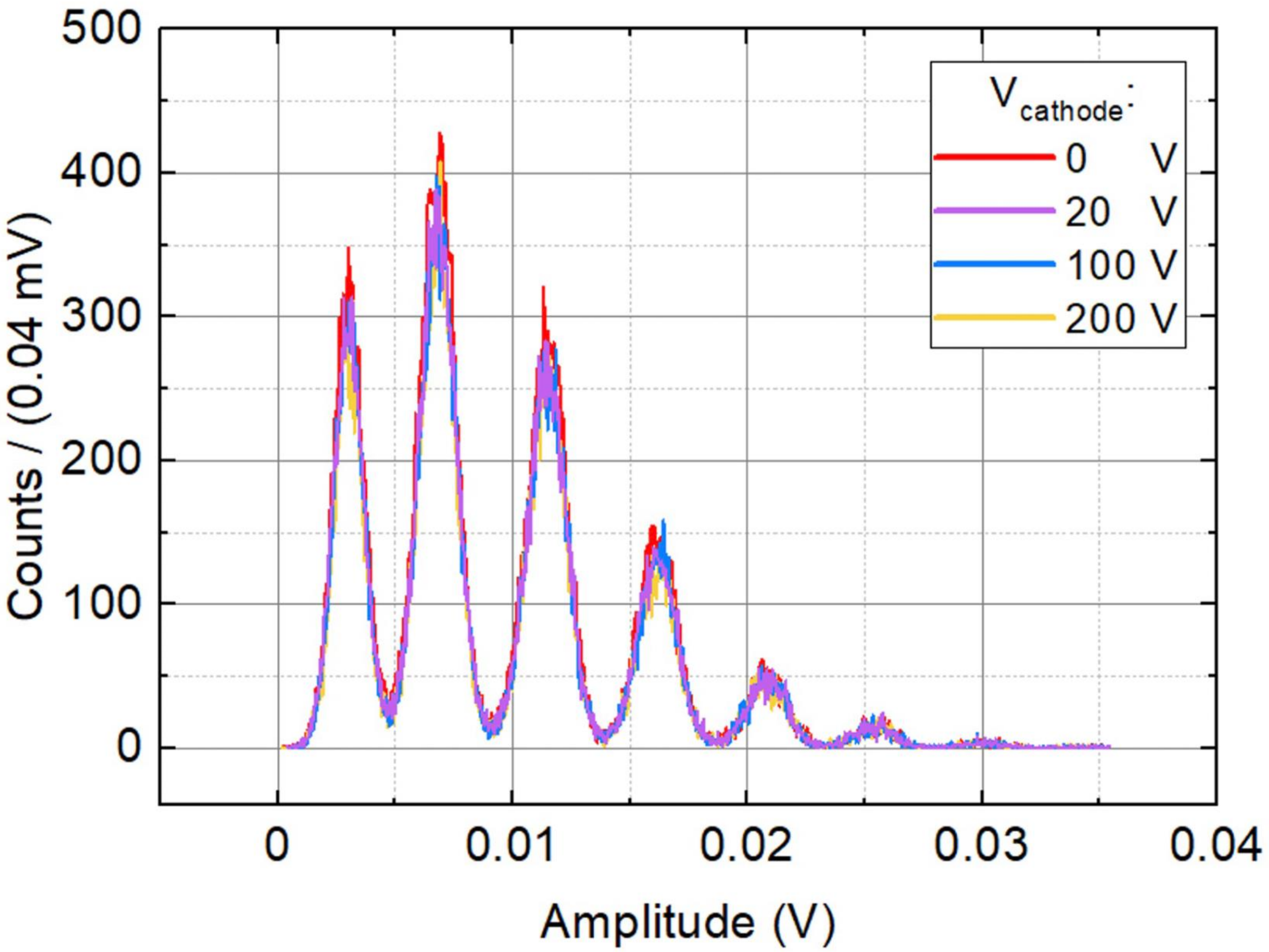


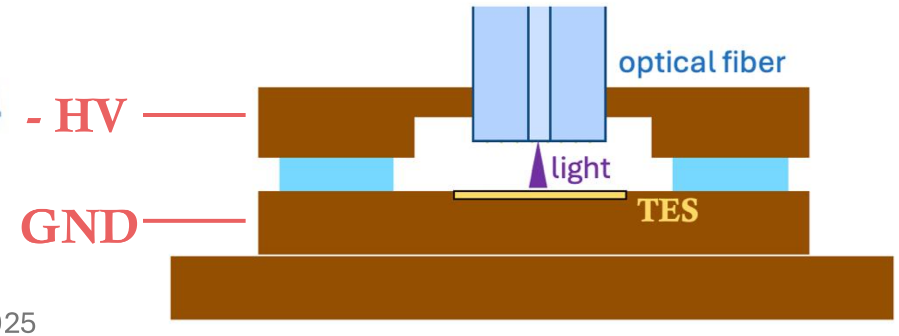
Need for a **different calibration** for each TES **different temperature** working condition!



Electric Field does not have Relevant Effect

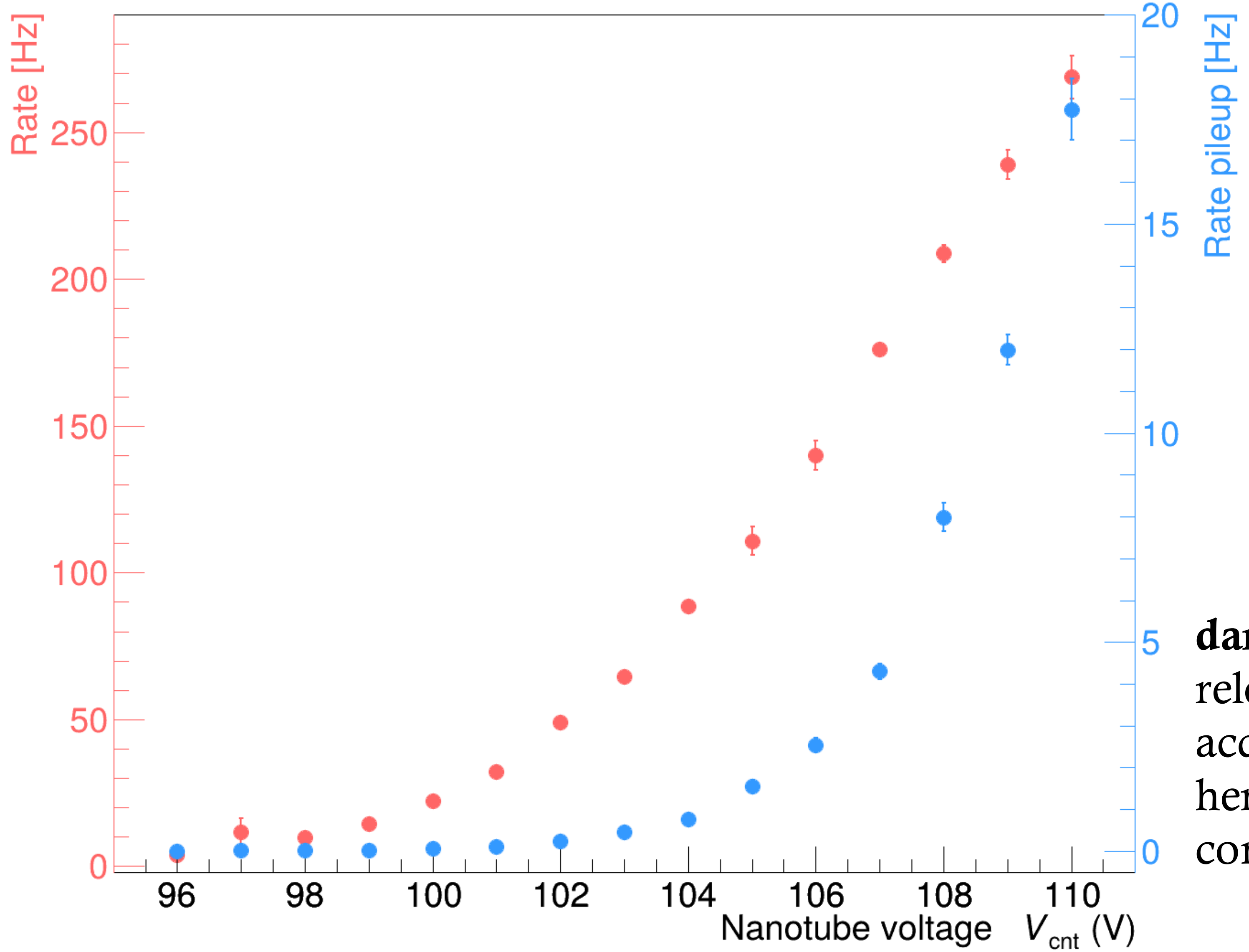
F





Rate of Signals Follows FE expectation

G



dark counts seem not to have relevant rates but they were acquired with different trigger, hence they have a rate not comparable to the signal one