Center for
BRIGHT BEAMS
A National Science Foundation Science & Technology Center

BERKELEY LAB

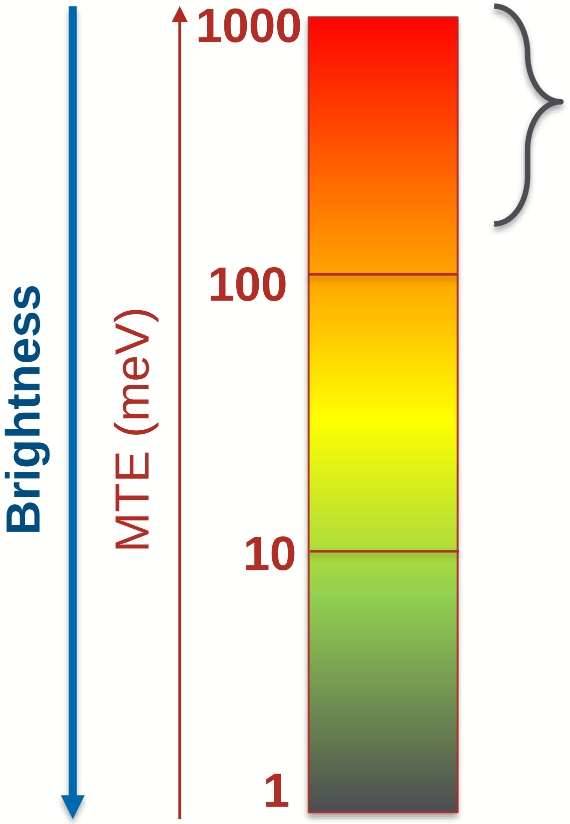
Arizona State University

<10 meV MTE from Cu

- Siddharth Karkare (Department of Physics - ASU)

1. What does MTE depend on?
   - Excess energy, roughness, band-structure
2. Demonstration of sub-10 meV MTE
   - Can be obtained from Cu(100) surface cooled to 30 K
3. How to translate low MTE to high brightness?
   - Defeat electron heating

MTE, Brightness and Emittance



Cathodes Used Today

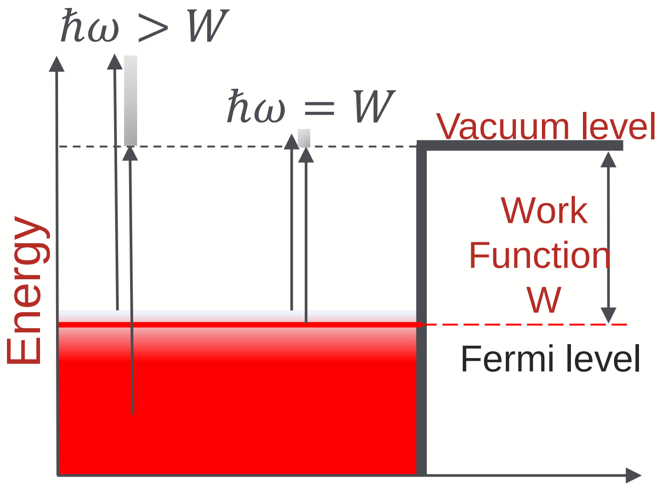
$$B_{4D} \propto \frac{N_{bunch}}{\varepsilon_n^2} \propto \frac{E_z}{\mathrm{MTE}}$$

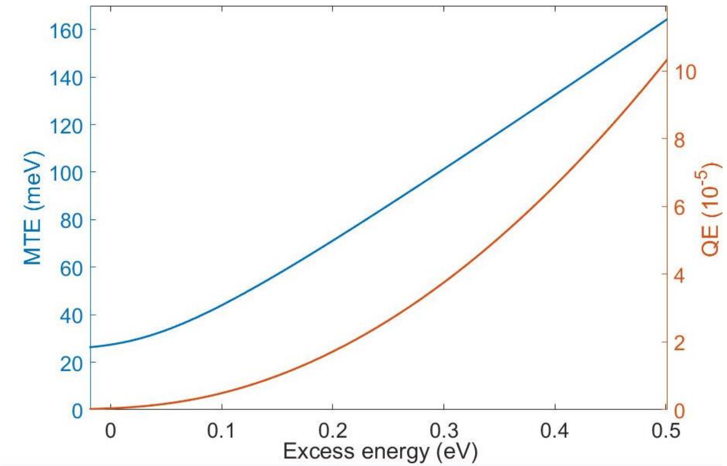
$$\varepsilon_n = \sigma_x \sqrt{\frac{\mathrm{MTE}}{m_e c^2}}$$

$$\mathrm{MTE} = \frac{1}{2} m v_\perp^2$$

I. Bazarov *et al.*, Phys. Rev. Lett. **102**, 104801 (2009)

MTE limiting factors (1) – Excess energy





- Lower photon energy to the work function

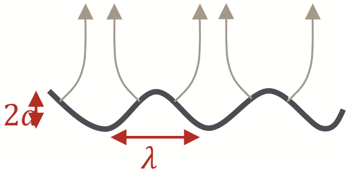
- Cool to low temperature

Limited by kT at threshold

- Penalty for operation is low QE

J. Feng, S Karkare *et al*. APL 107, 134101 (2015)

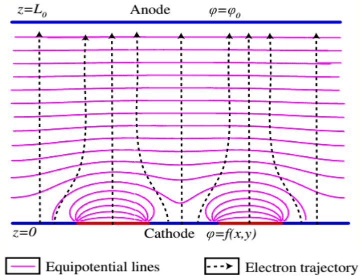
Physical Roughness



$$\mathrm{MTE}_{field} = \frac{\pi^2 a^2 E_0 e}{2\lambda}$$

J. Feng, S. Karkare *et al*, J. Appl. Phys. 121, 044904 (2017)

Chemical Roughness



$$\mathrm{MTE}_{wf} = \frac{\pi^2 h^2 e}{4\sqrt{2} a E_0}$$

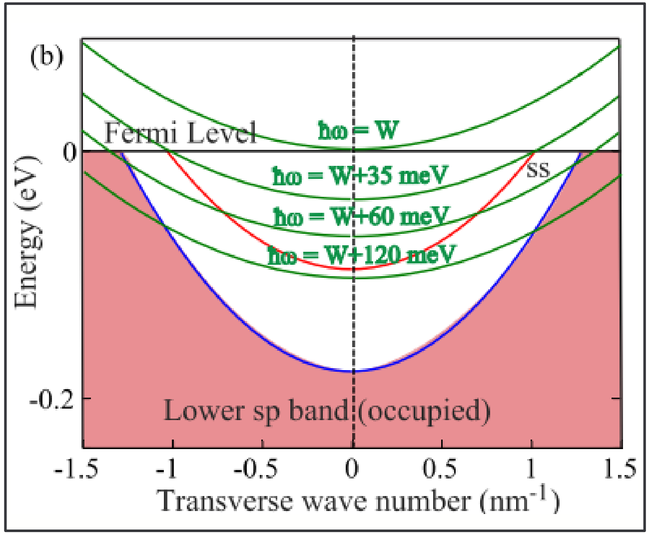
S. Karkare and I. Bazarov, Phys. Rev Applied, 4, 024015 (2015)

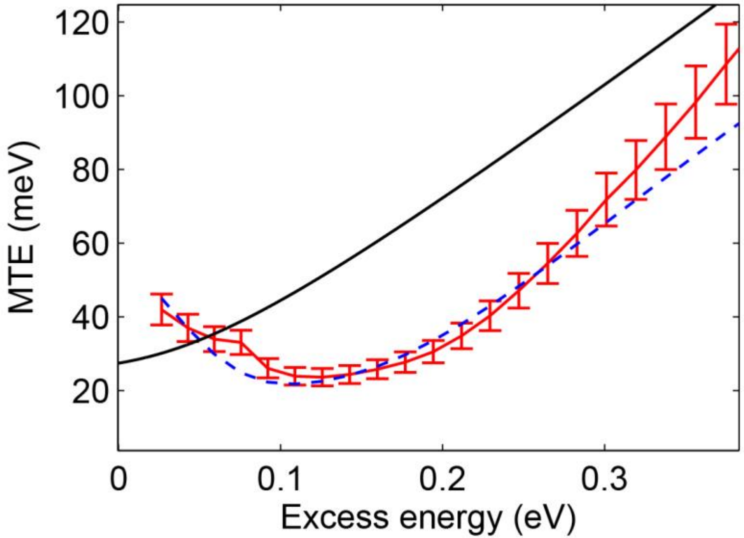
G. Gevorkyan et al. Phys. Rev. ST- Accel and Beams, 21, 093401(2018)

Need single crystal ordered surfaces to minimize MTE

MTE limiting factors (3) – Band structure

Effect surface state of Ag(111)

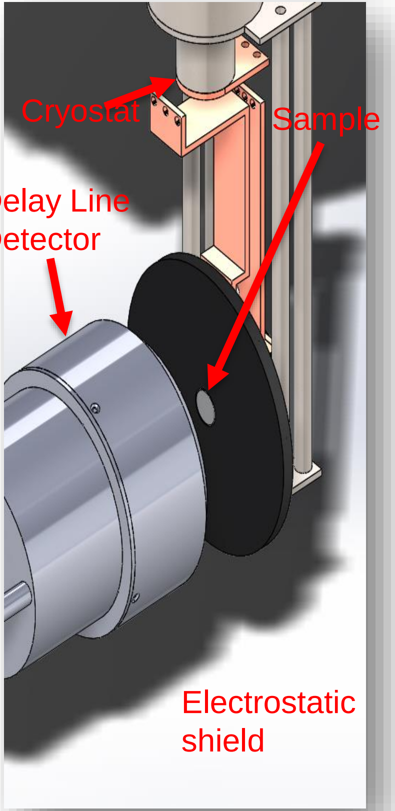


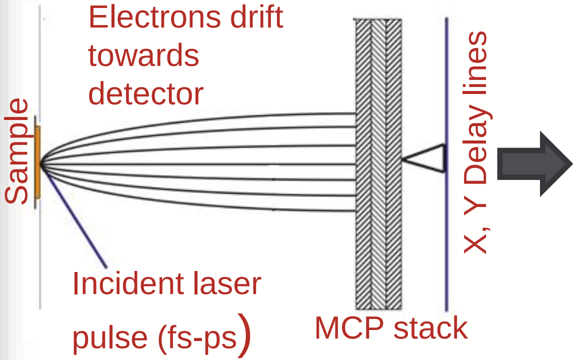


S. Karkare et al. Phys. Rev. B 95, 075439 (2017)

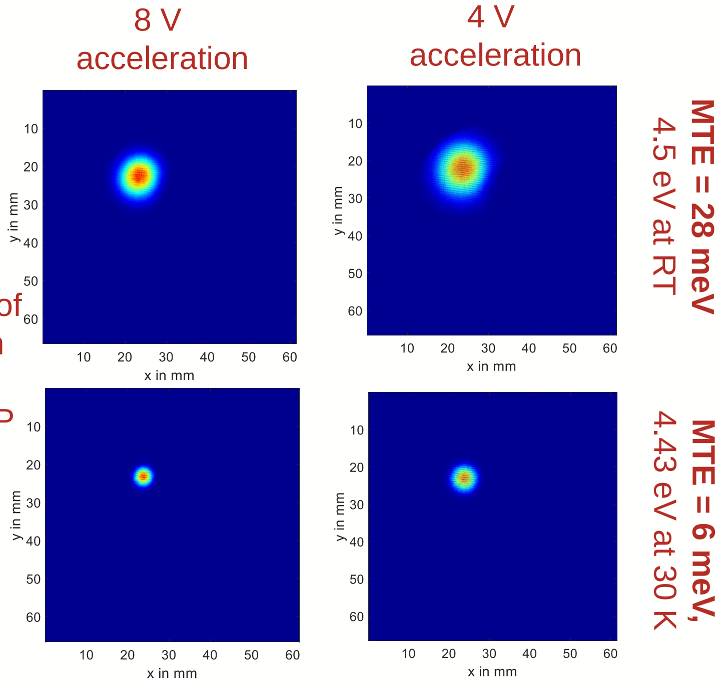
S. Karkare et al. Phys. Rev. Lett. 118, 164802 (2017)

Measuring Low MTE





(x, y, t) of electron hitting the MCP

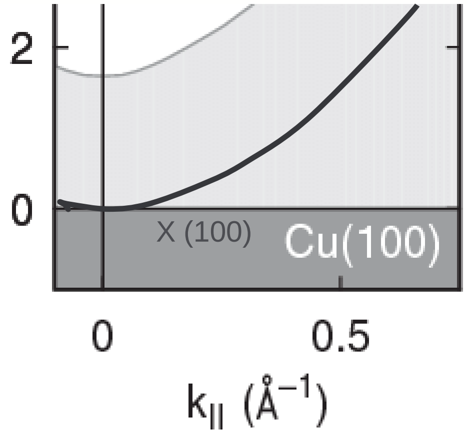


$$p_x = m_e \frac{x}{t} \qquad p_y = m_e \frac{y}{t}$$

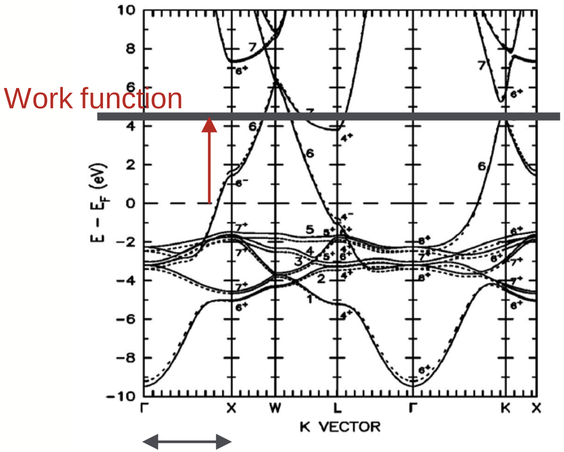
Has sub-meV energy resolution!!!

Can obtain complete energy/momentum distribution

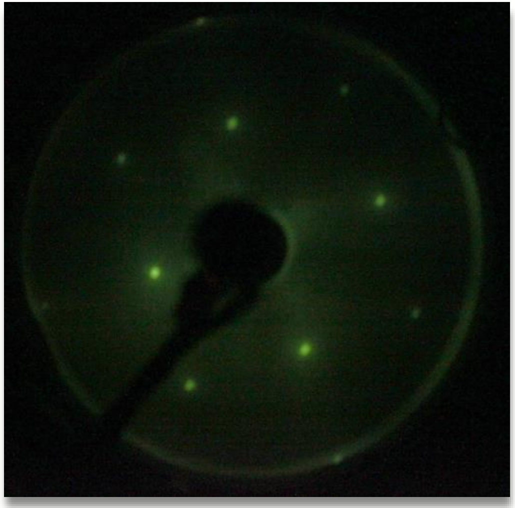
Cu(100) – Ideal for low MTE



Projected band-structure



0 Transverse momentum direction



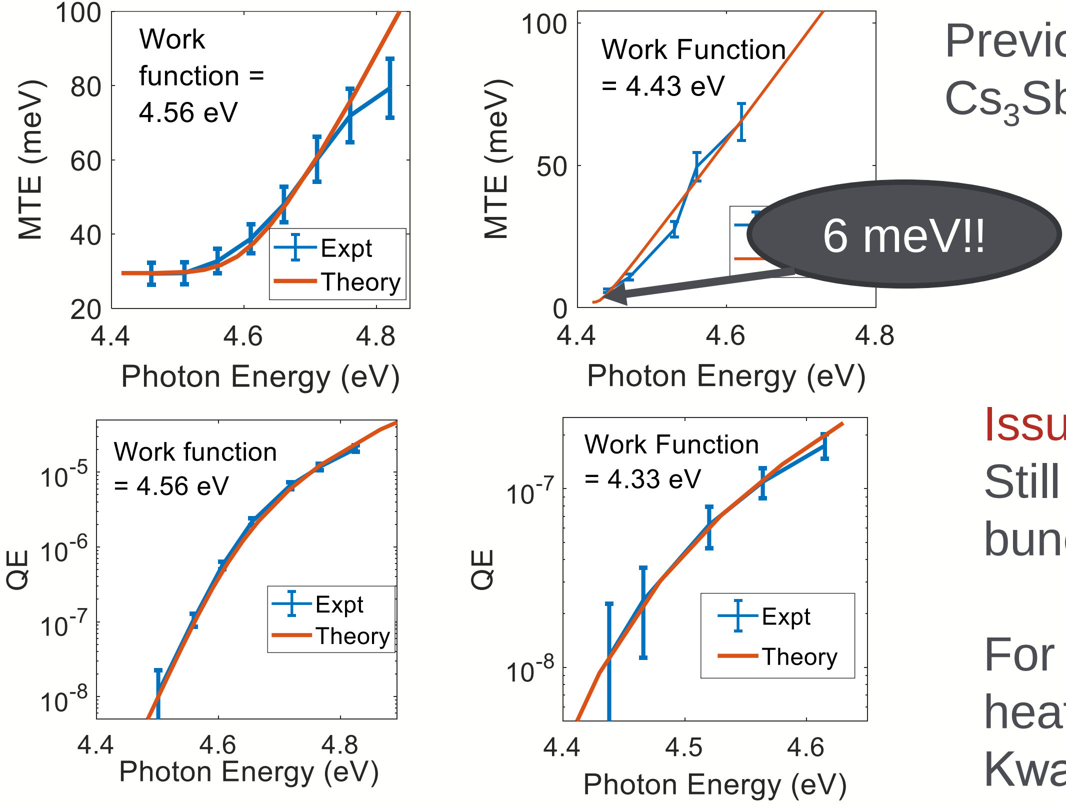
Atomically ordered flat surface

- Photoemission threshold at ~4.5 eV – can be accessed by our laser
- Cooled to LHe (30K)

Cu(100) – Smallest MTE measured

Room Temperature

30K



6 meV MTE measured from Cu(100)
Previous record was 22 meV from Cs_3Sb at 90K

Work function reduced!!! –
first measurement of work function of Cu(100) at LHe temp ??

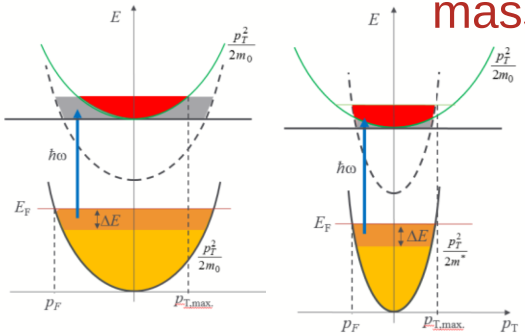
Issue – Very low QE (~10^{-8}) …
Still suitable for single electron/ bunch applications

For large charge densities – electron heating/multi-photon emission – Jai Kwan Bae's talk

Andreas Schroeder's talk on Wednesday for theory description

Beat Electron Heating – CBB efforts

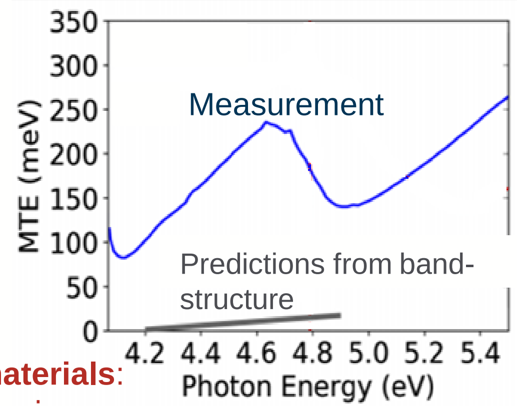
Use single crystals with small effective masses



Small effective masses yield smaller MTE for a given excess energy, $\Delta E = h\nu - \phi$.

Does not work for PbTe(111)!!!

- Kevin Nangoi's talk on Wednesday

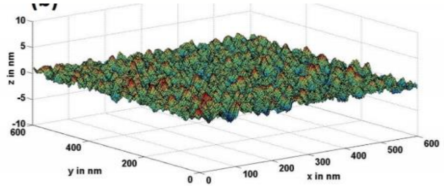


New low effective mass materials:

- Joshua Paul's talk this session
- Chris Pierce's talk next session

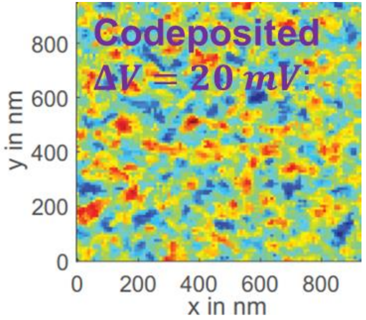
Use Low Electron Affinity semiconductor cathodes – Alkali-antimonides, GaAs(Cs/O)

- Electron heating is mitigated
- Have higher QE even at threshold
- However, roughness is an issue



Will DeBenedetti's talk in next session

Gevork Gevorkyan's talk in next session



Howard Padmore's talk tomorrow

Acknowledgements

LBNL

- Howard Padmore
- Siddharth Karkare (now at ASU)

UIC

- Gowri Adhikari
- Andreas Schroeder

Cornell

- Jared Maxson

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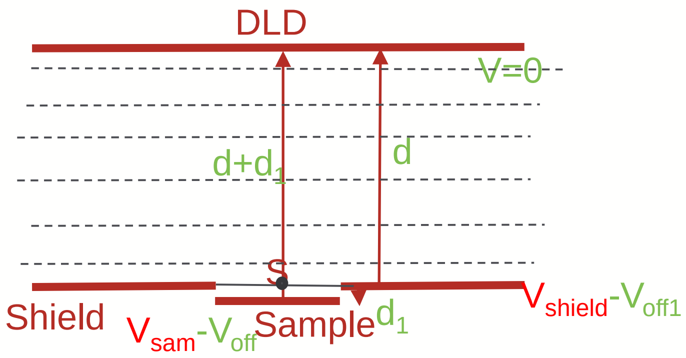
Basic setup and equations



Red → known/can be varied and measured
Green → unknown but constant for one sample

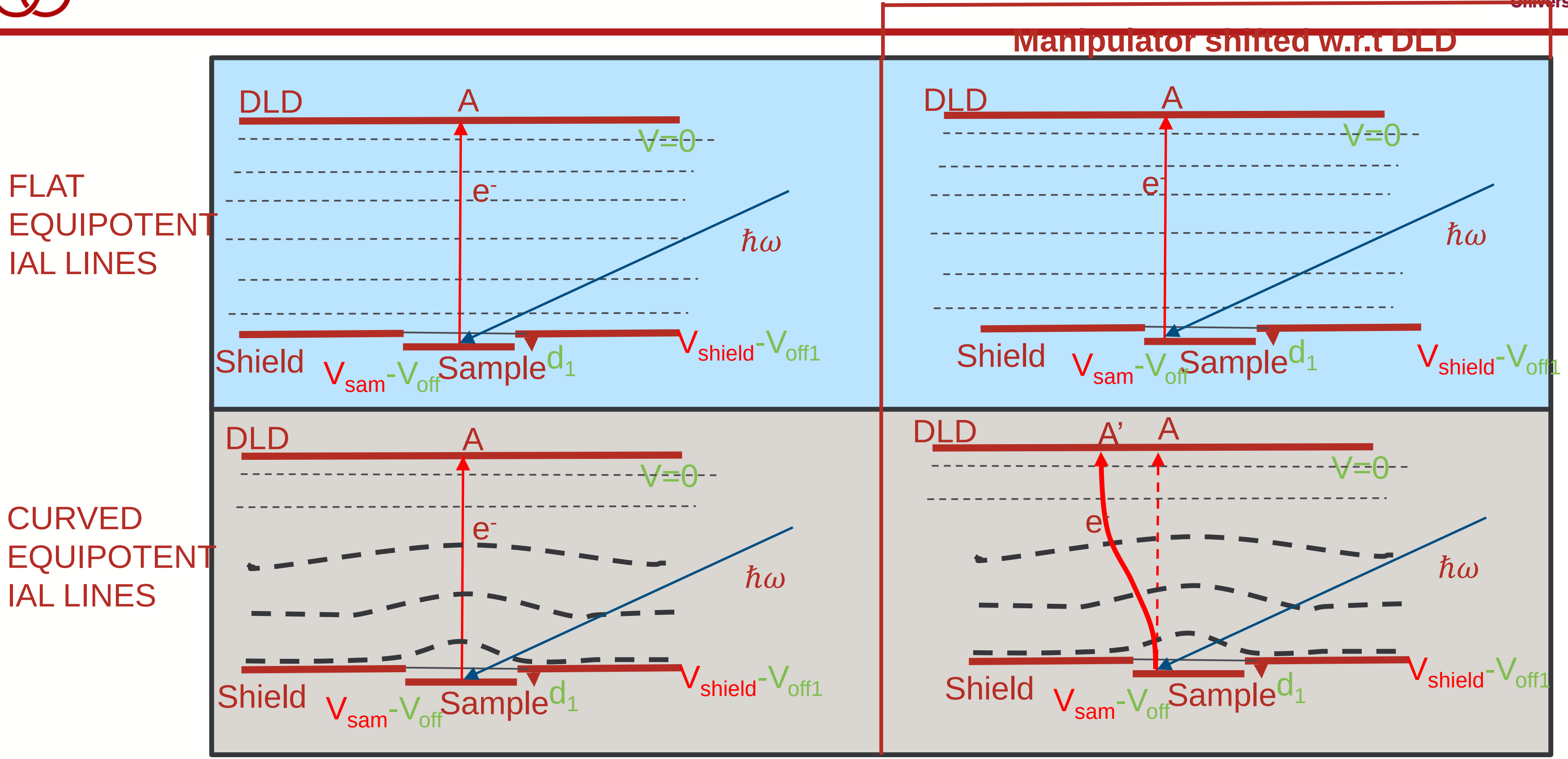
x, y, t are recorded for each electron hitting the DLD

1. $$E_{long}(\text{in meV}) = \frac{1000m_e}{2e}\left(\frac{d+d_1}{t} + \frac{(V_{sam} - V_{off})et}{2m_e(d+d_1)}\right)^2$$

2. $$v_x = \frac{x}{t} \qquad v_y = \frac{y}{t}$$

MTE is calculated by averaging over all detected electrons

Obtaining Flat equipotential lines



If fields are not flat, the shield electrode acts like an non-linear electron lens and the electron spot on the DLD moves when the manipulator (sample+shield) position is changed w.r.t the DLD, keeping the incident laser spot fixed w.r.t DLD