Photocathode R&D at Cornell University

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Outline

- Motivations
- The photocathode laboratory
- Alkali antimonide
- MBE grown GaAs
- Perspective and future developments

Motivations

- What we want from a photocathode?
  - High Quantum Efficiency in IR-VIS
  - Low thermal (or intrinsic) emittance
  - Sub-ps response time
  - Long lifetime
- Which are the actual candidates?
  - Alkali antimonide
  - GaAs activated to NEA

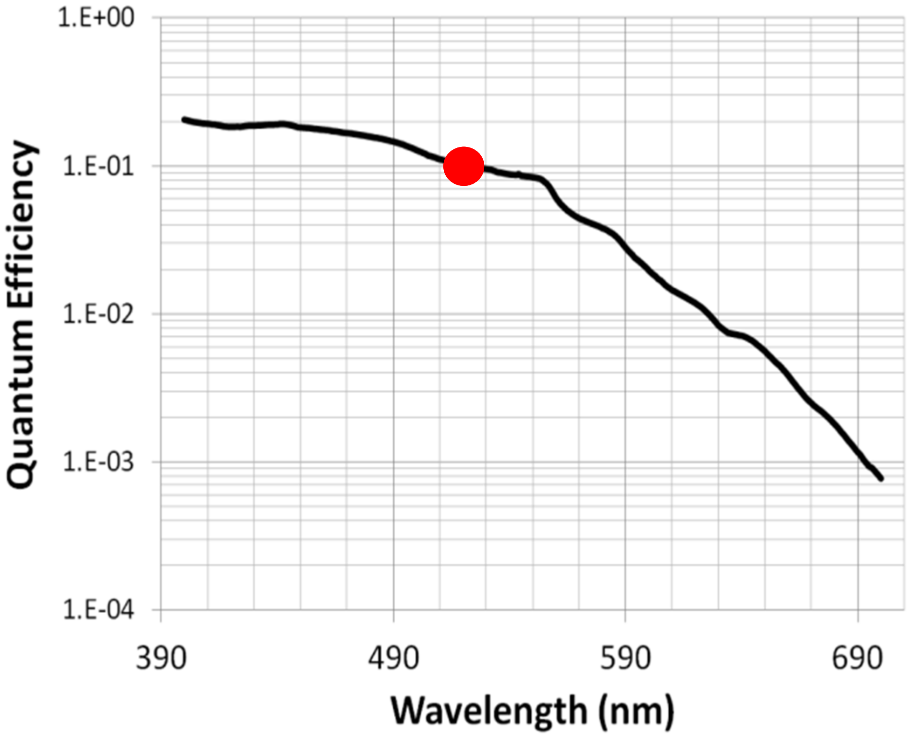
Motivations

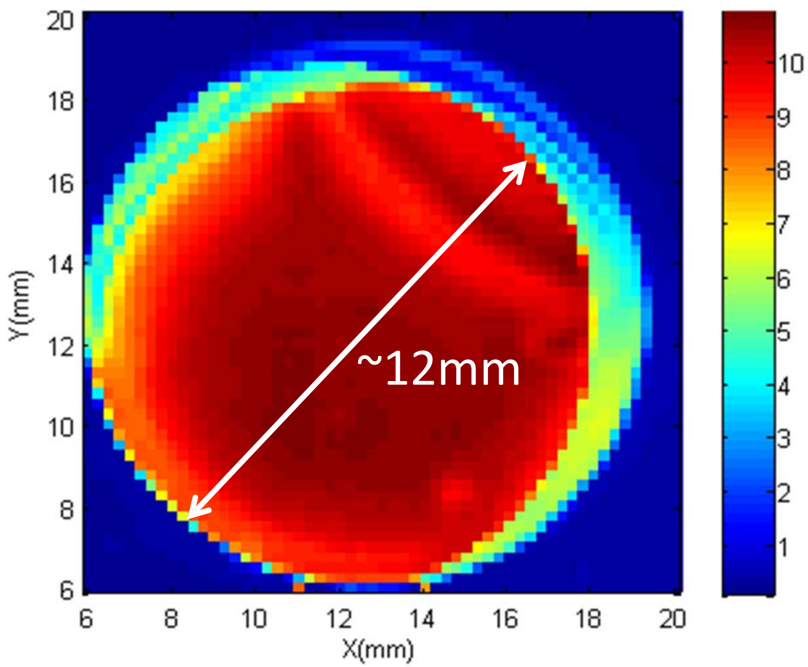
Cathode Type	Cathode	Typical Wavelength, λ_{opt}(nm), (eV)	Quantum Efficiency (electrons per photon)	Vacuum for 1000 Hrs (Torr)	Gap Energy + Electron Affinity, $E_A + E_G$ (eV)	Thermal Emittance (microns/mm(rms))	
						Eqn. [7]	Expt.
PEA: Mono-alkali	Cs_2Te	211, 5.88 264, 4.70 262, 4.73	~0.1 - -	10^{-9} - -	3.5 [42] " "	1.2 0.9 0.9	0.5±0.1 [35] 0.7±0.1 [35] 1.2 ±0.1 [43]
	Cs_3Sb	432, 2.87	0.15	?	1.6 + 0.45 [42]	0.7	?
	K_3Sb	400, 3.10	0.07	?	1.1 + 1.6 [42]	0.5	?
	Na_3Sb	330, 3.76	0.02	?	1.1 + 2.44 [42]	0.4	?
	Li_3Sb	295, 4.20	0.0001	?	?	?	?
PEA: Multi-alkali	Na_2KSb	330, 3.76	0.1	10^{-10}	1+1 [42]	1.1	?
	$(Cs)Na_3KSb$	390, 3.18	0.2	10^{-10}	1+0.55 [42]	1.5	?
	K_2CsSb	543, 2.28	0.1	10^{-10}	1+1.1 [42]	0.4	?
	$K_2CsSb(O)$	543, 2.28	0.1	10^{-10}	1+<1.1 [42]	~0.4	?
NEA	GaAs(Cs,F)	532, 2.33 860, 1.44	~0.1 -	? ?	1.4±0.1 [42] "	0.8 0.2	0.44±0.01 [44] 0.22±0.01 [44]
	GaN(Cs)	260, 4.77	-	?	1.96 + ? [44]	1.35	1.35±0.1 [45]
	GaAs(1-x)Px x~0.45 (Cs,F)	532, 2.33	-	?	1.96+? [44]	0.49	0.44±0.1 [44]
S-1	Ag-O-Cs	900, 1.38	0.01	?	0.7 [42]	0.7	?

Dowell et al., *NIM-A*, **622**, (2010) 685-697

Motivations

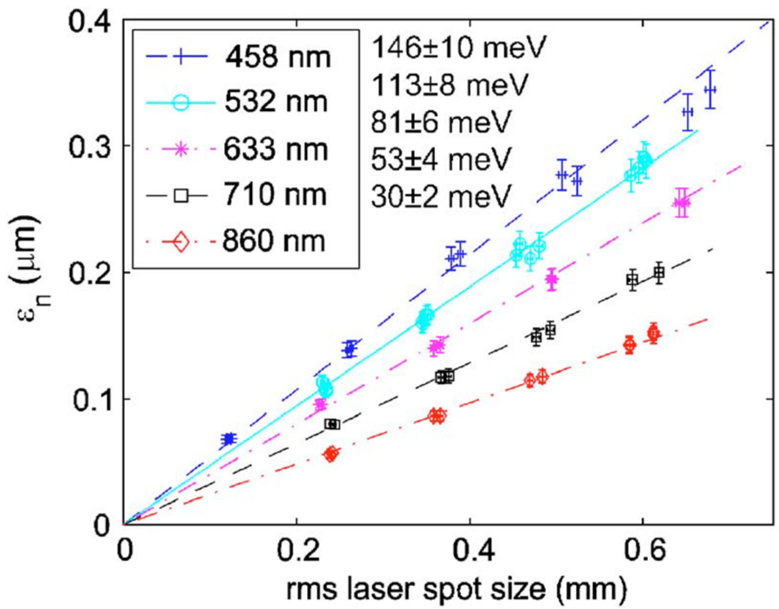
- What we know
  - Alkali antimonide and GaAs give routinely more than 10% QE in the "green"

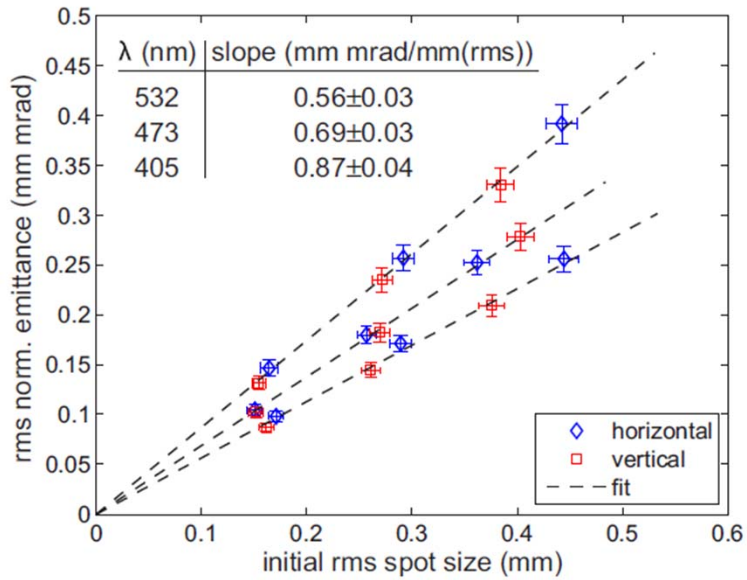




Motivations

- Thermal emittances are comparable





GaAs

CsK_2Sb

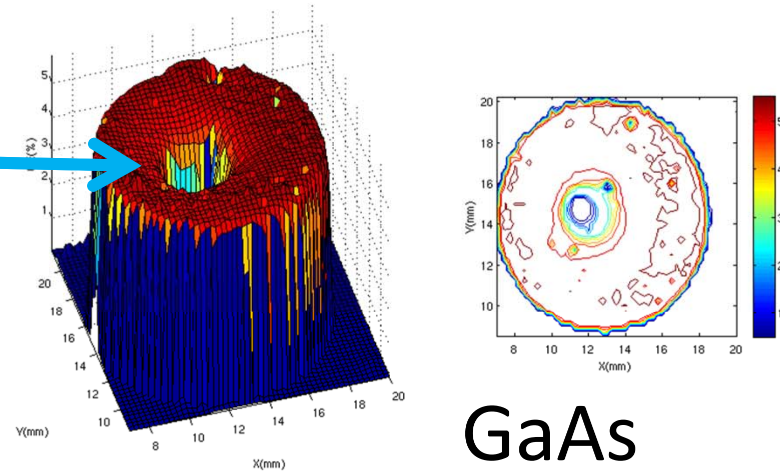
$$\epsilon_{nx} = \sigma_x \sqrt{\frac{MTE}{mc^2}}$$

2 mm diameter "flat top" laser transverse distribution result in a thermal emittance rms values of
~0.25 mm mrad for GaAs
~0.3 mm mrad for CsK_2Sb

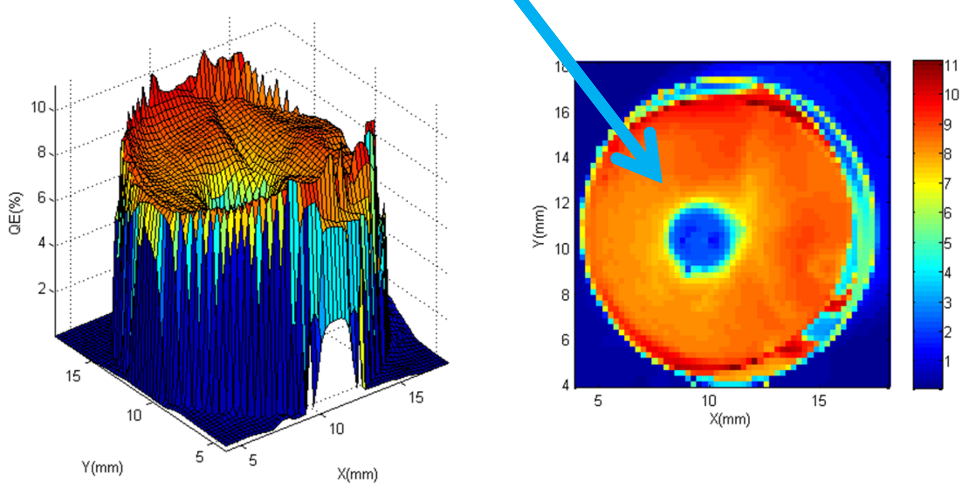
Motivations

- What we know
  - Both suffer from ion back bombardment

After high current operation (> 5 mA)
Irreversible QE decay
Electrostatic centre



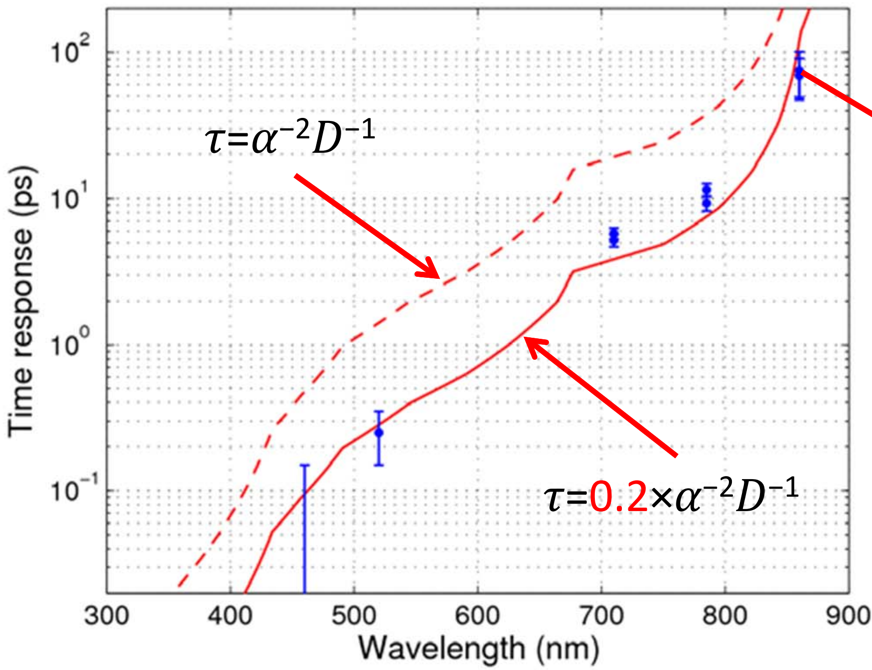
GaAs



CsK_2Sb

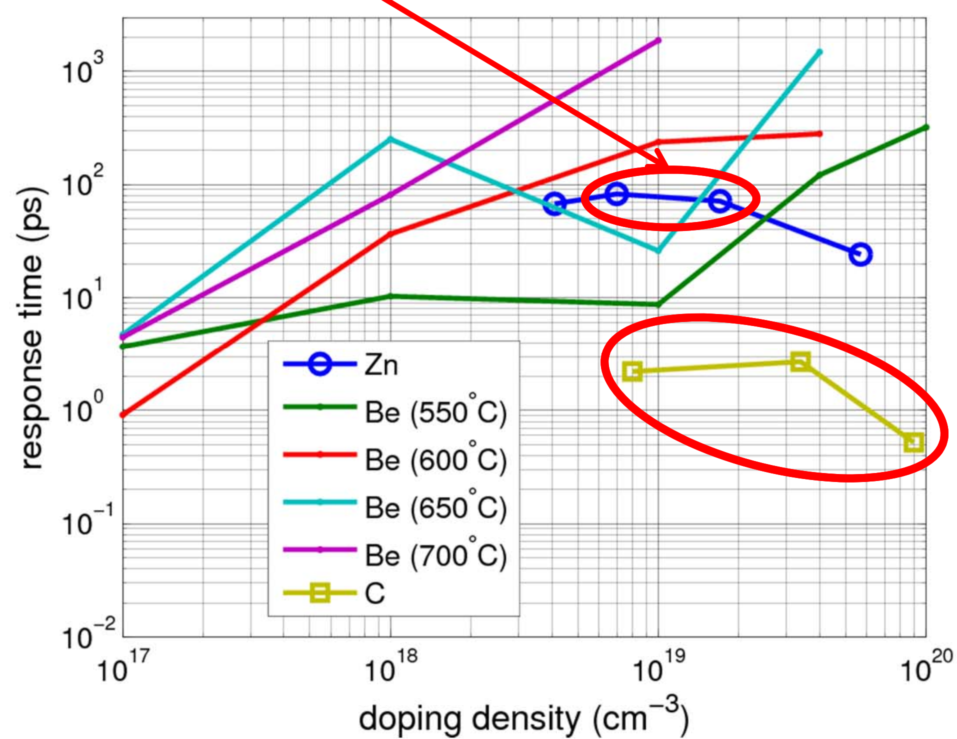
Motivations

- What we don't know



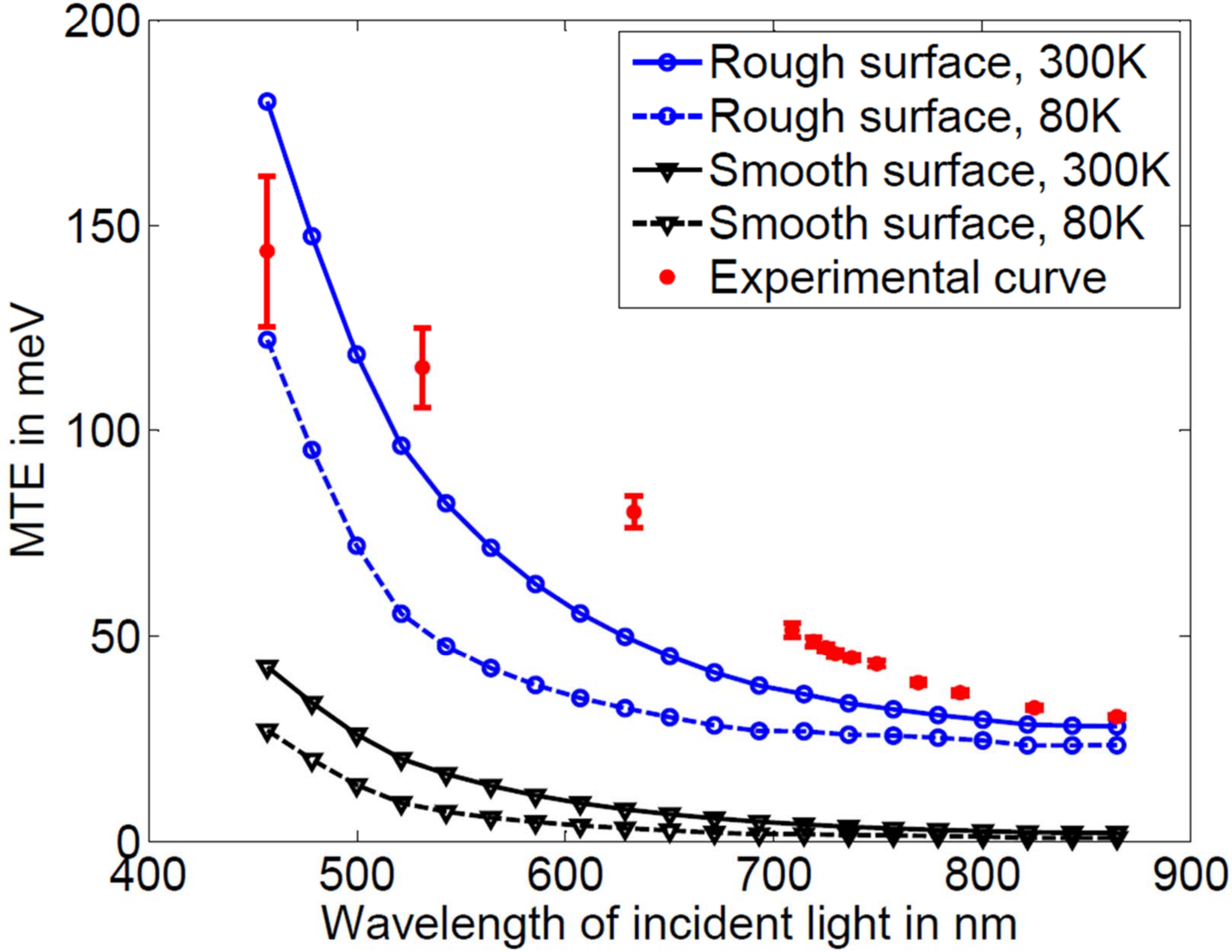
Zn p-doped GaAs wafers
(between 6.3×10^{18} and 1.9×10^{19} cm^{-3})

Photons just above band gap
Same model on using other dopants
(between 1×10^{17} and 9×10^{19} cm^{-3})



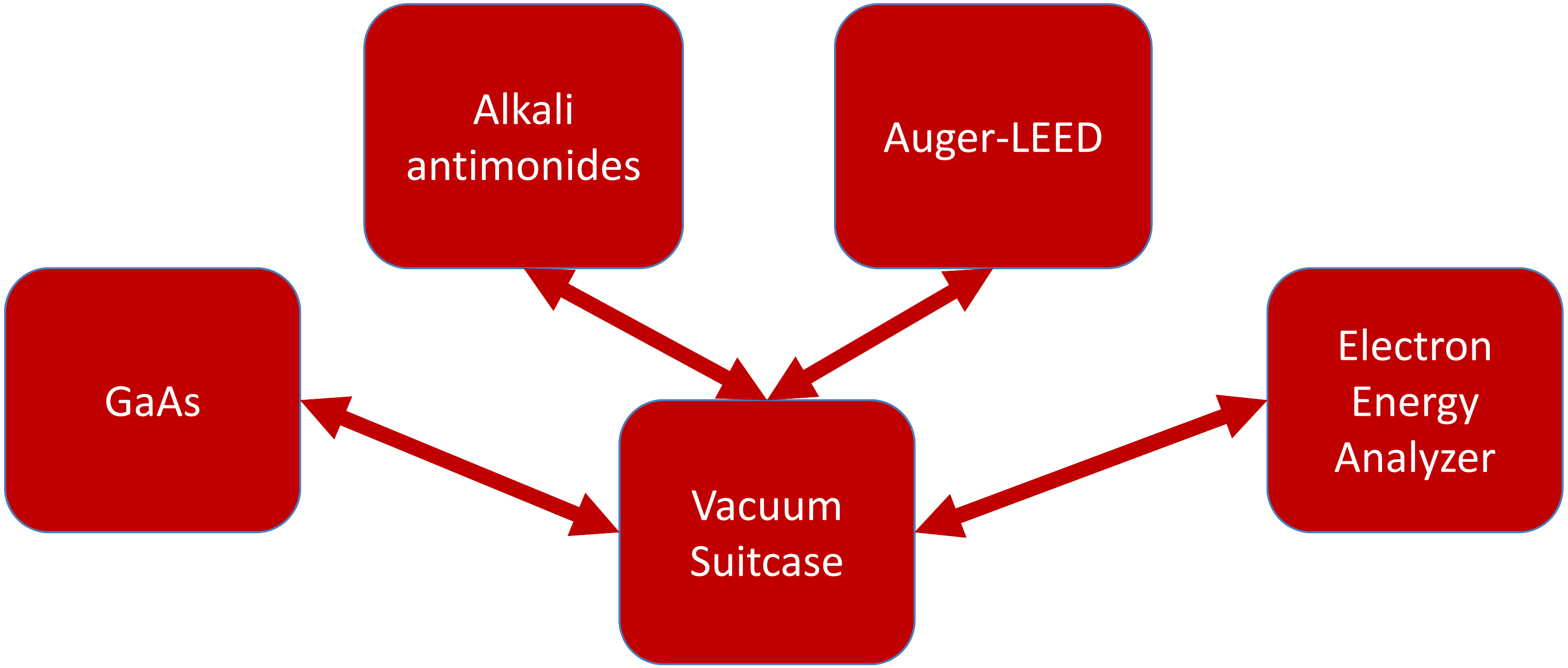
Motivations

- What we don't know



The photocathode lab

- During last years we have been designing and realizing different separated UHV chamber:



Extremely time consuming
Vacuum not good enough for GaAs

→ Build a permanent UHV connection!!

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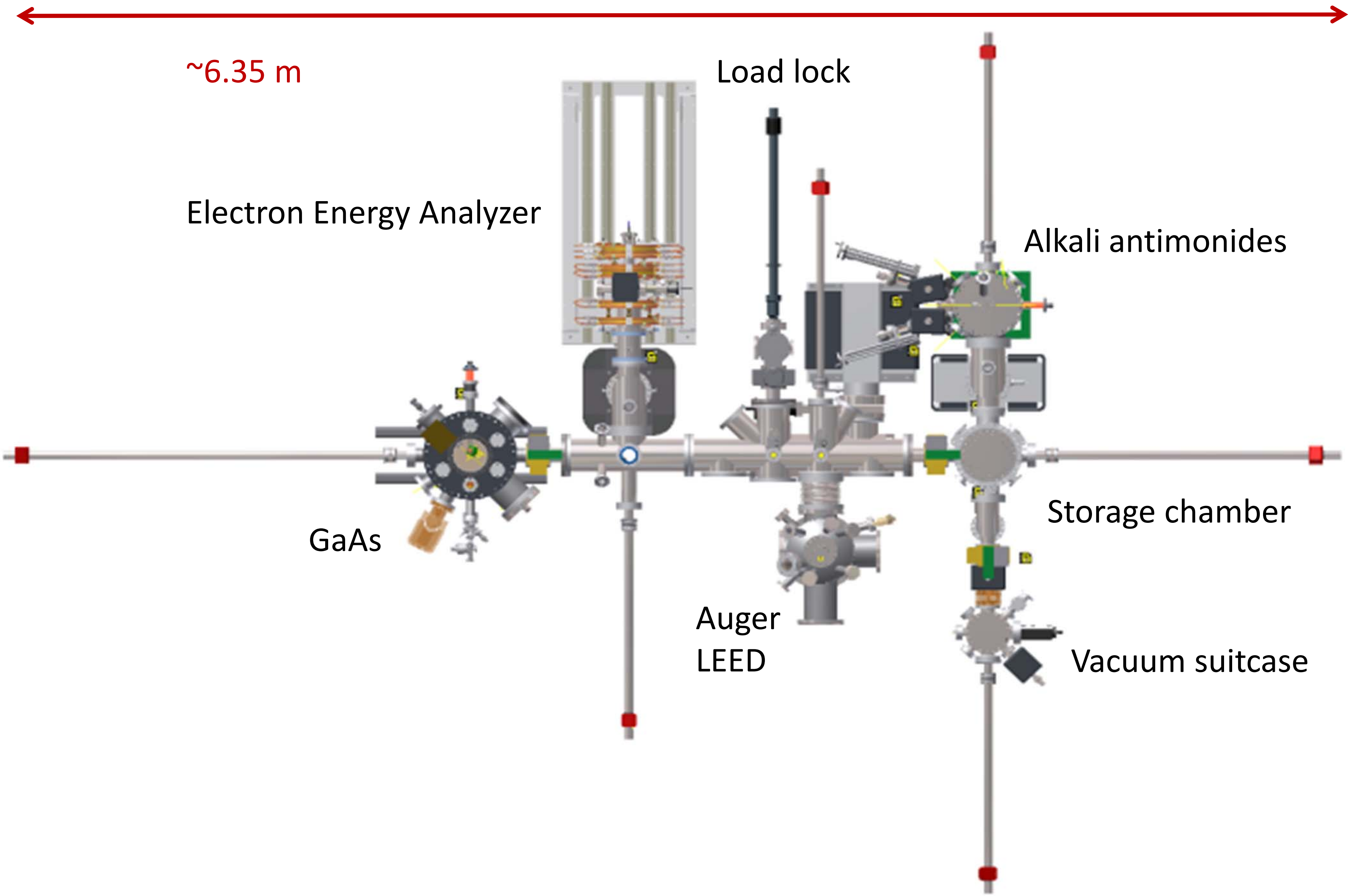
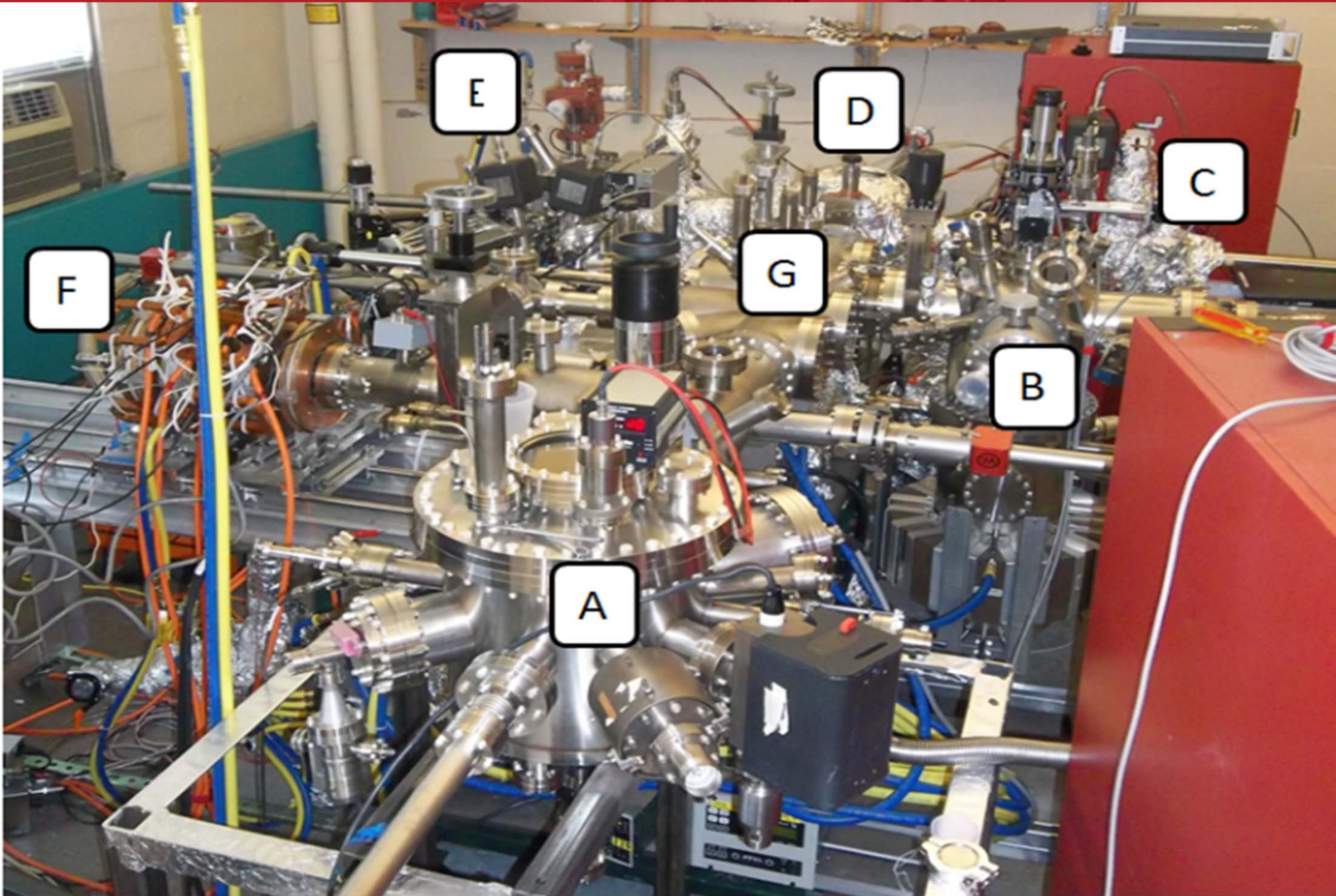
The photocathode lab

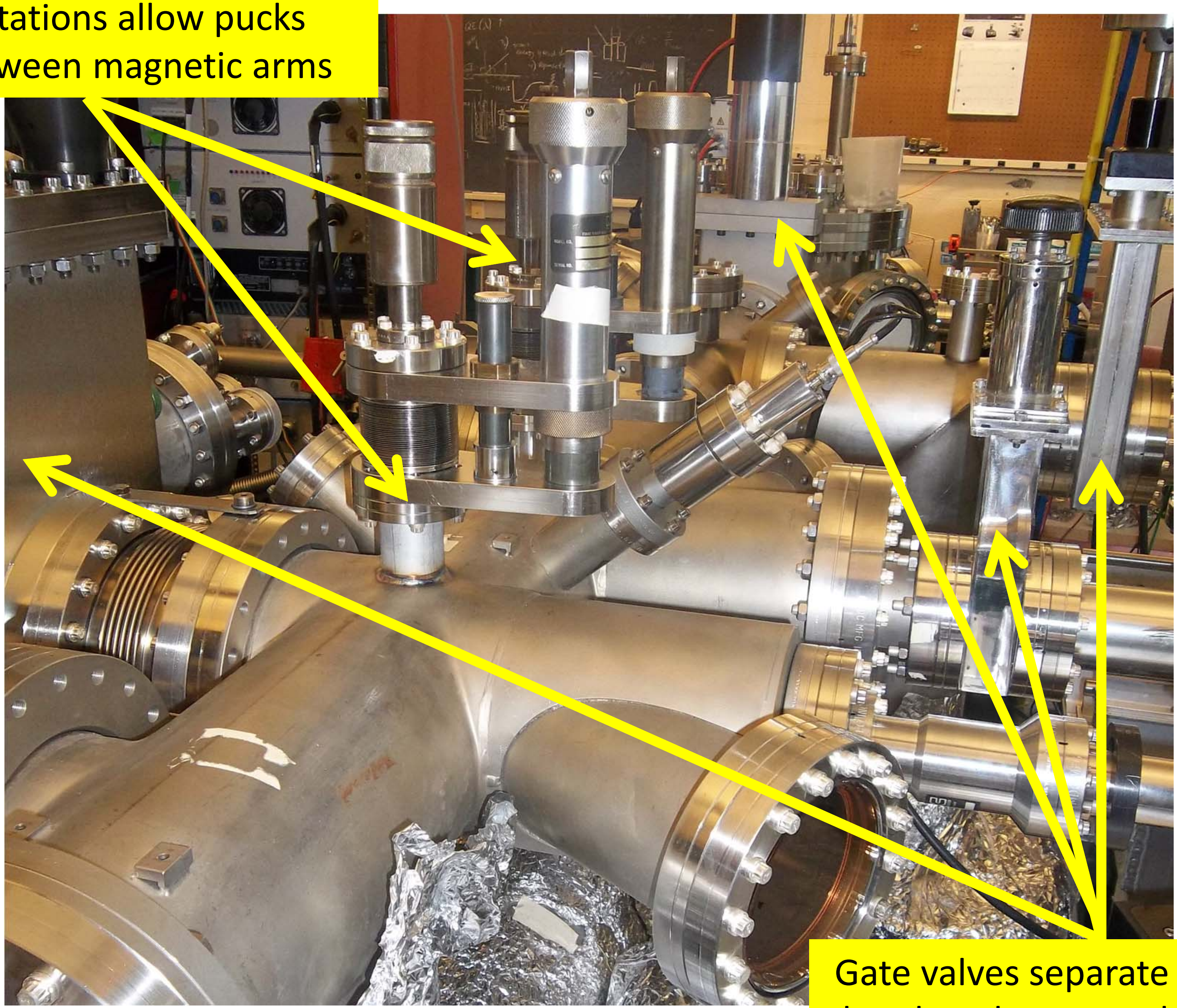


The photocathode lab



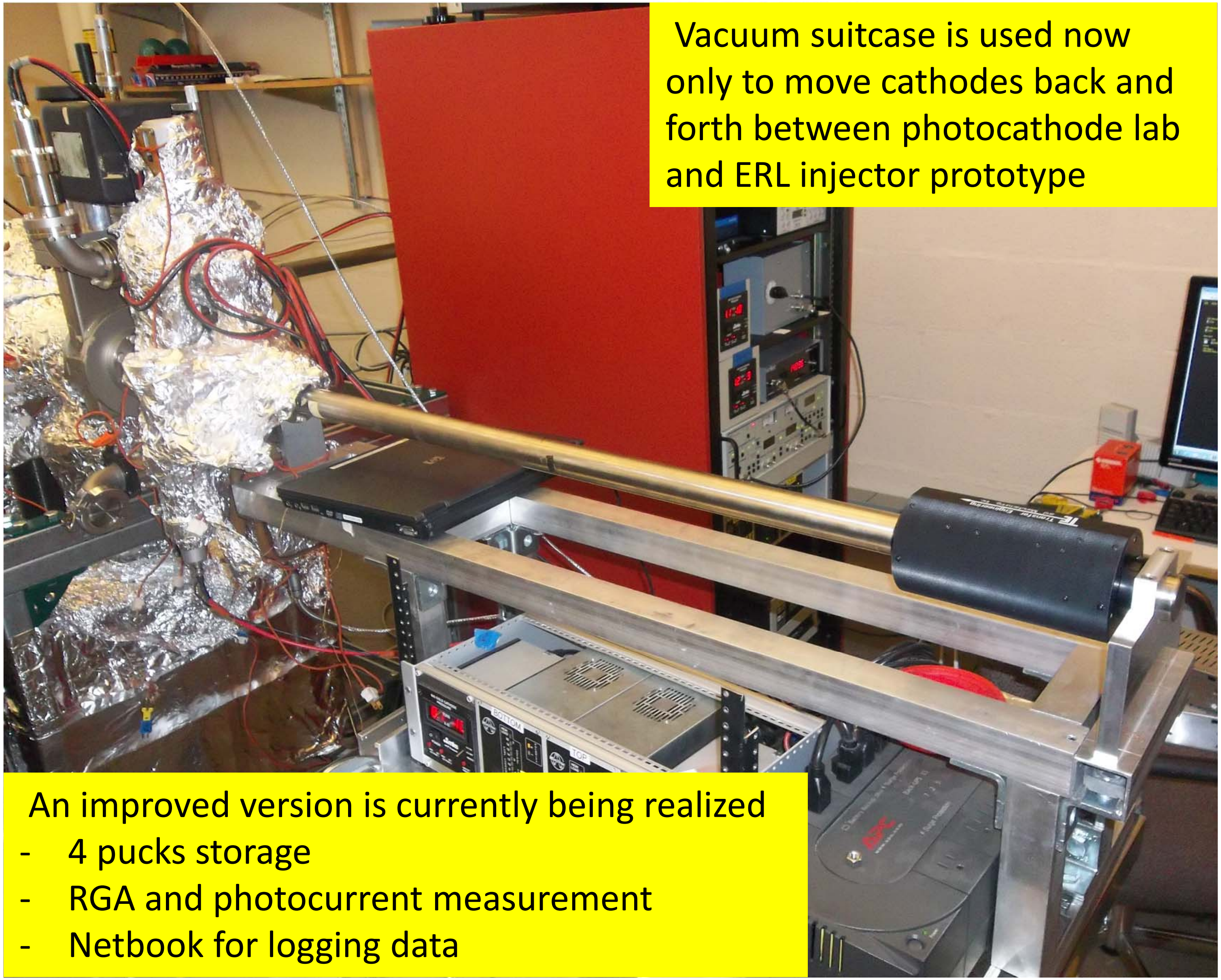
The photocathode lab

Exchange stations allow pucks moving between magnetic arms



Gate valves separate different chambers between them

The photocathode lab

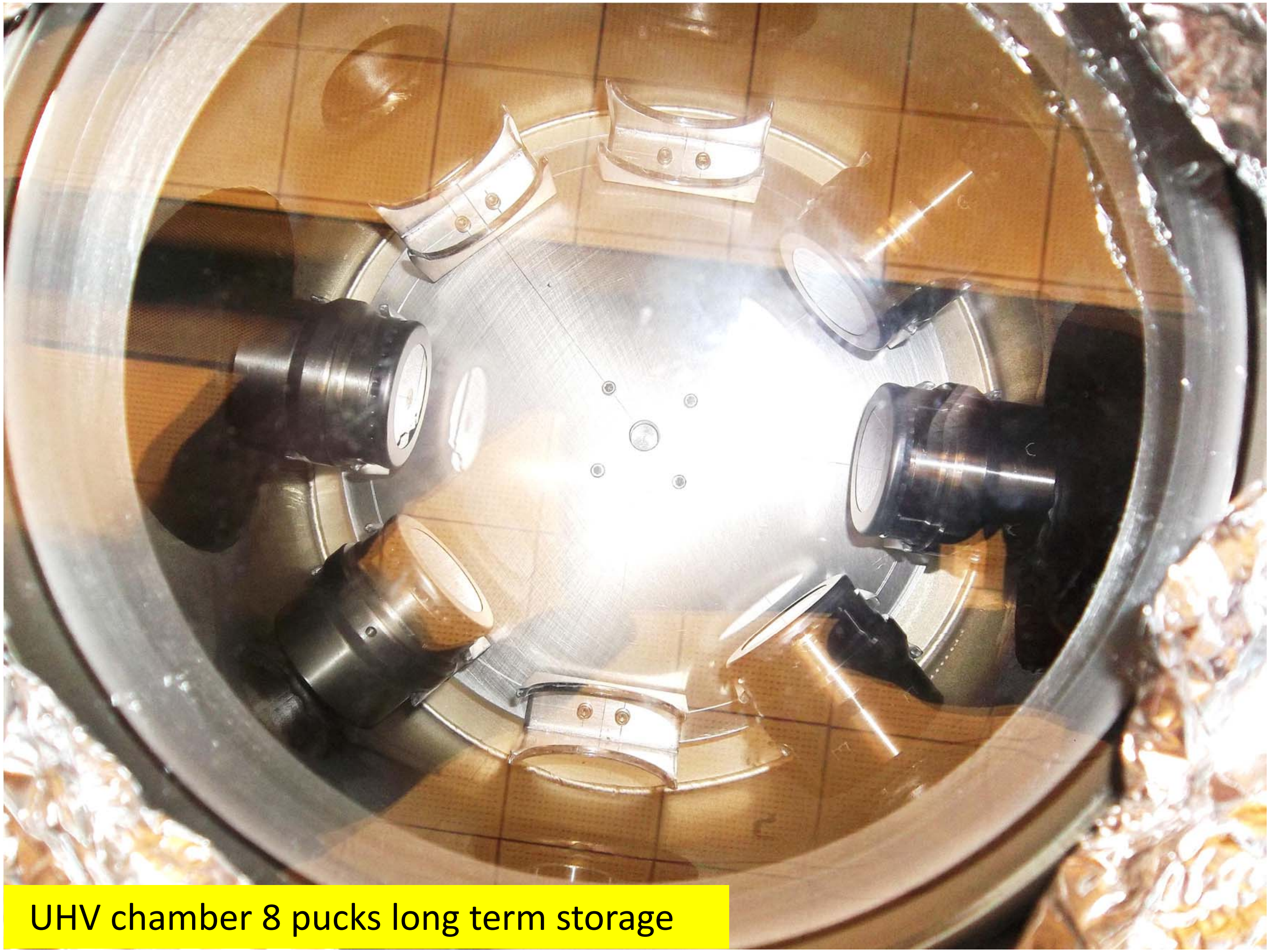


Vacuum suitcase is used now only to move cathodes back and forth between photocathode lab and ERL injector prototype

An improved version is currently being realized

- 4 pucks storage
- RGA and photocurrent measurement
- Netbook for logging data

The photocathode lab



UHV chamber 8 pucks long term storage

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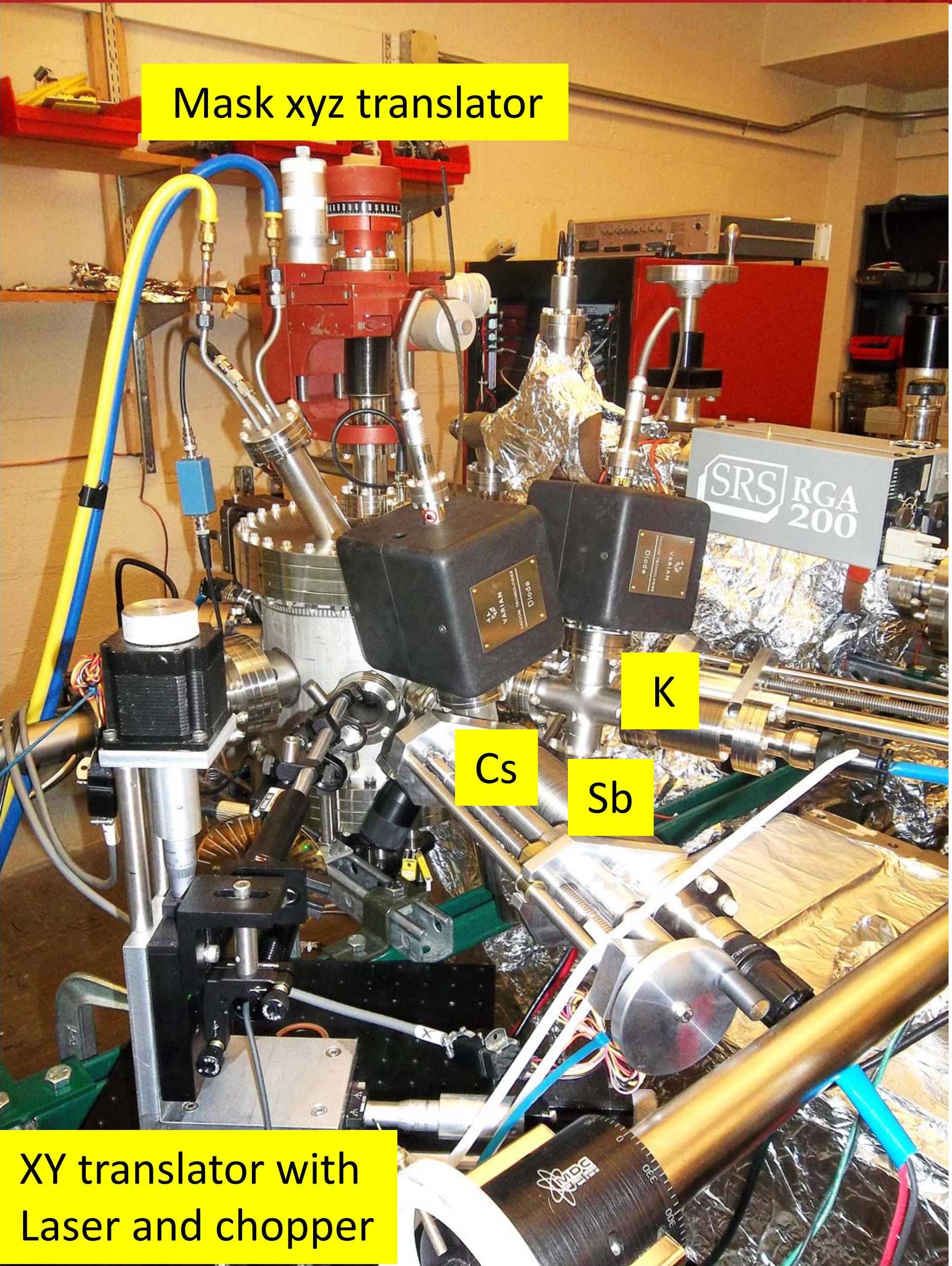
Alkali Antimonides

IPAC12



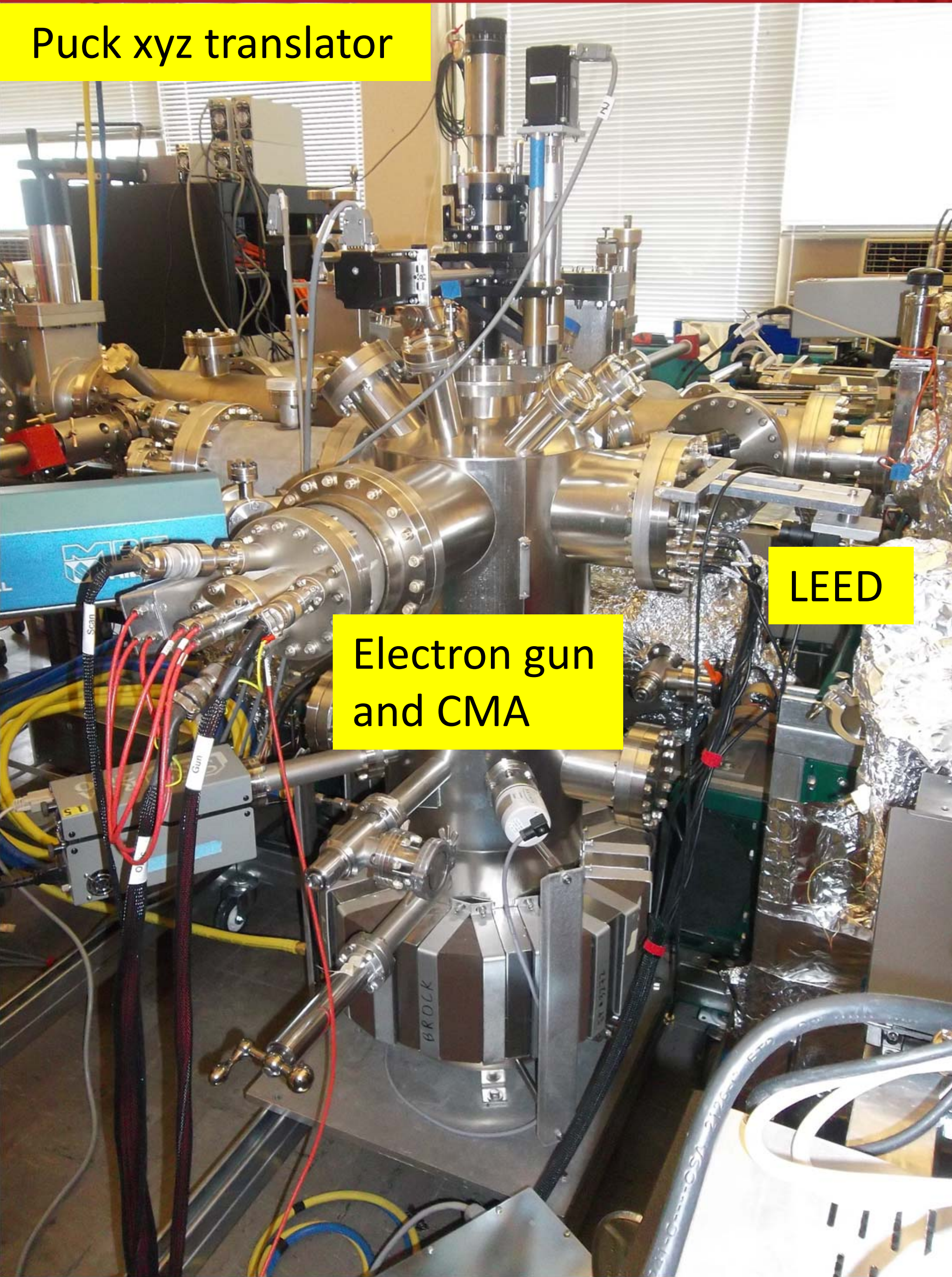
Labview® based software to control the growth

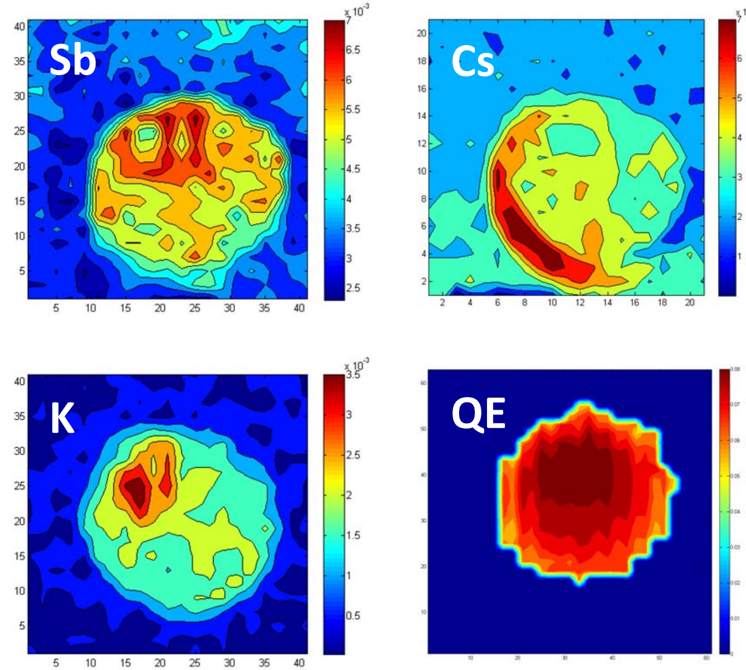
New optimized recipe for CsK_2Sb

- 20 nm of Sb when T goes below 175°C
- when T goes below 150°C K until photocurrent peaks
- when T goes below 120°C Cs until photocurrent peaks

QE of about 10% at 520 nm are now routinely achieved

2D scanning Auger





We are working towards the measure of the stoichiometry of our photocathodes

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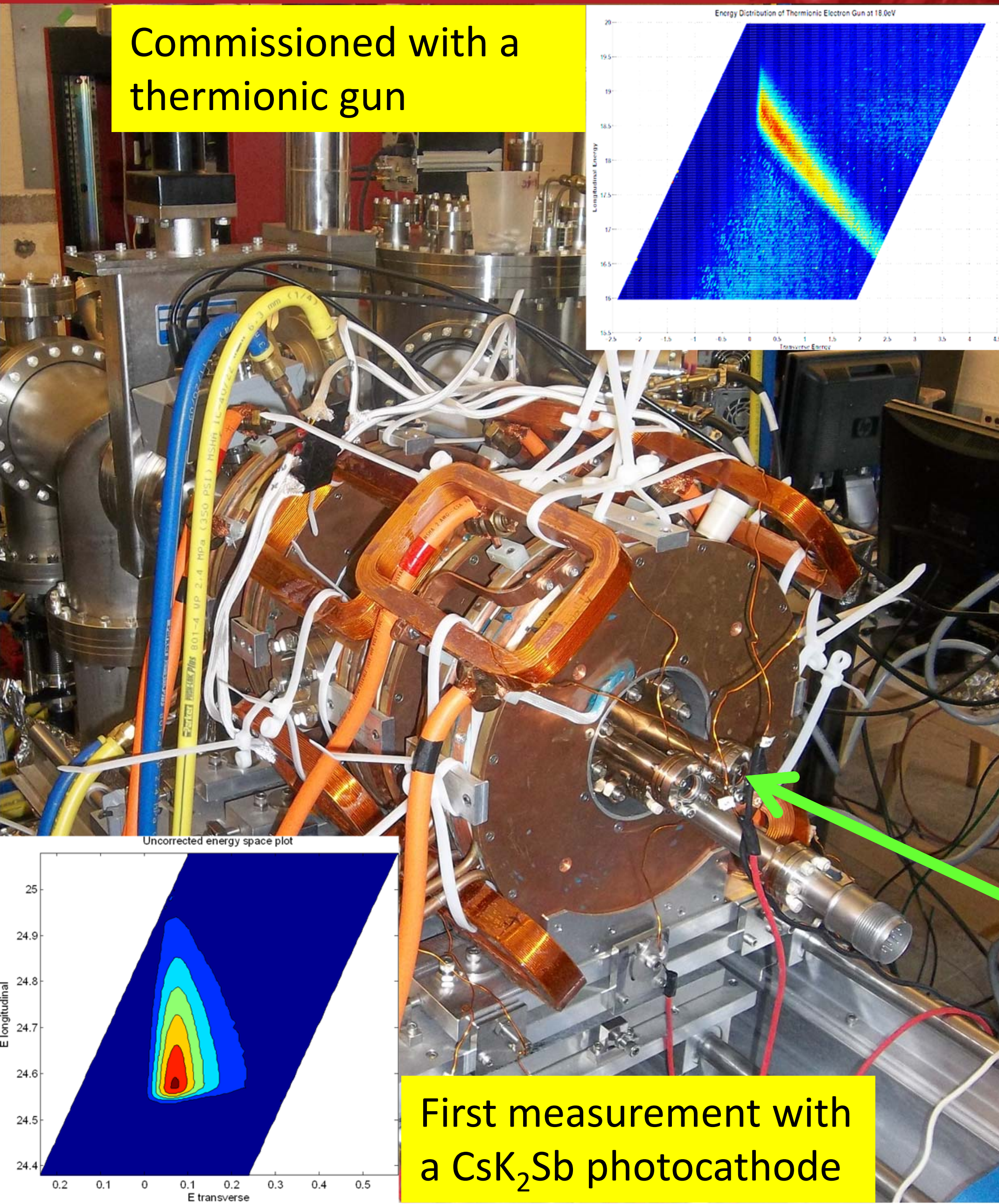
Electron Energy Analyzer

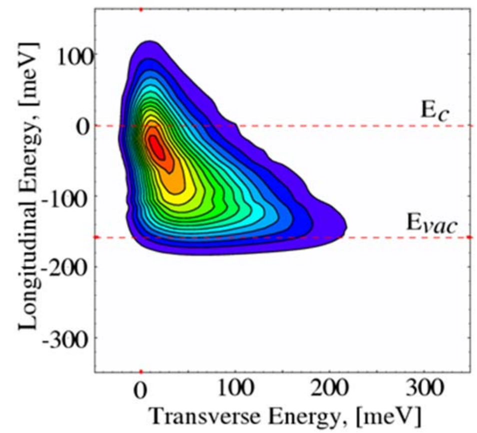
IPAC12

Commissioned with a thermionic gun



First measurement with a CsK_2Sb photocathode

Based on similar device designed and operated at Max Plank Institute

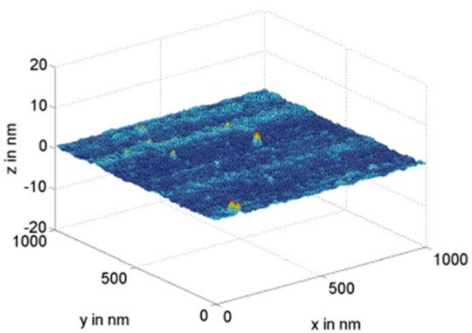


D. A. Orlov et al., Appl. Phys. Lett. 78 (2001) 2721

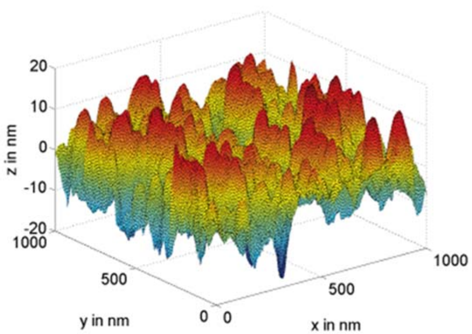
The EEA is now under commissioning. It will allow to evaluate the intrinsic emittance of photoelectrons without the need for them of being generated in the injector gun.

MTE of GaAs: a mystery?

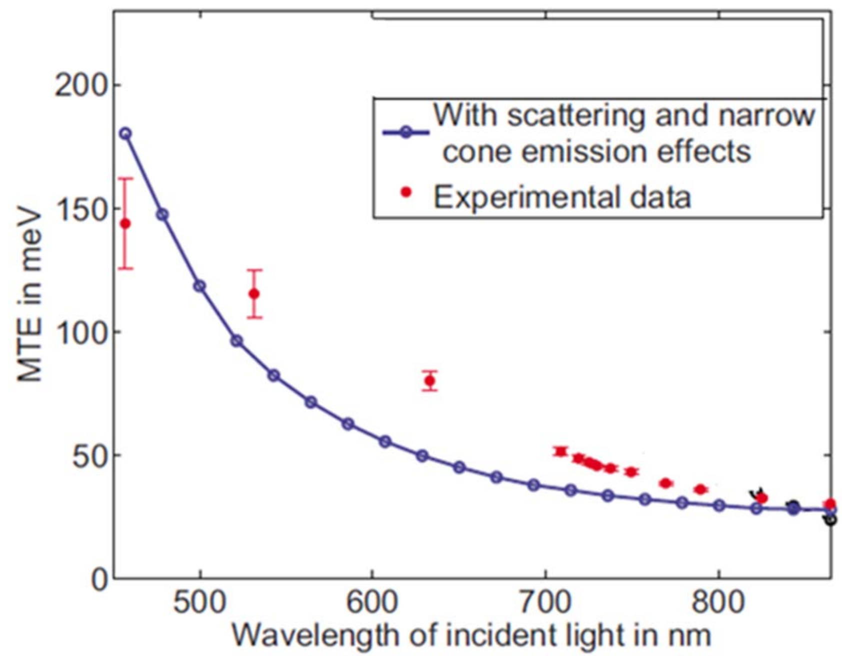
- Small effective mass of electrons in Γ valley, should result in very low MTE
- We have not yet been able to measure "narrow cone"
- Surface roughness? Strong scattering in active layers?



(a) Surface of atomically polished GaAs crystal before heat cleaning (smooth surface)



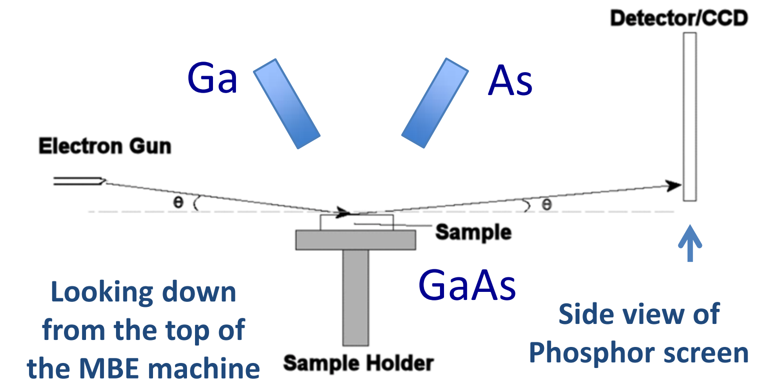
(b) Surface of heat cleaned and activated GaAs crystal used in the Cornell dc photoemission gun (rough surface)

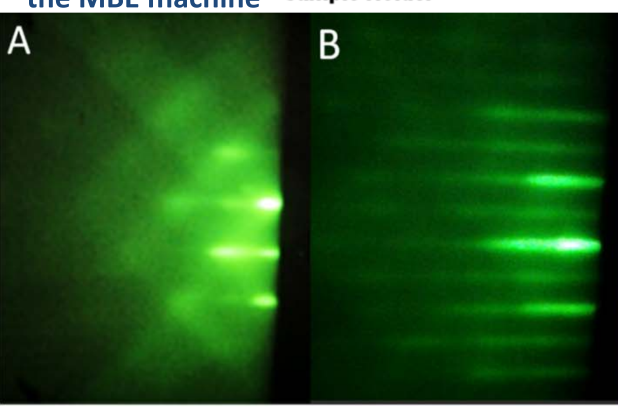


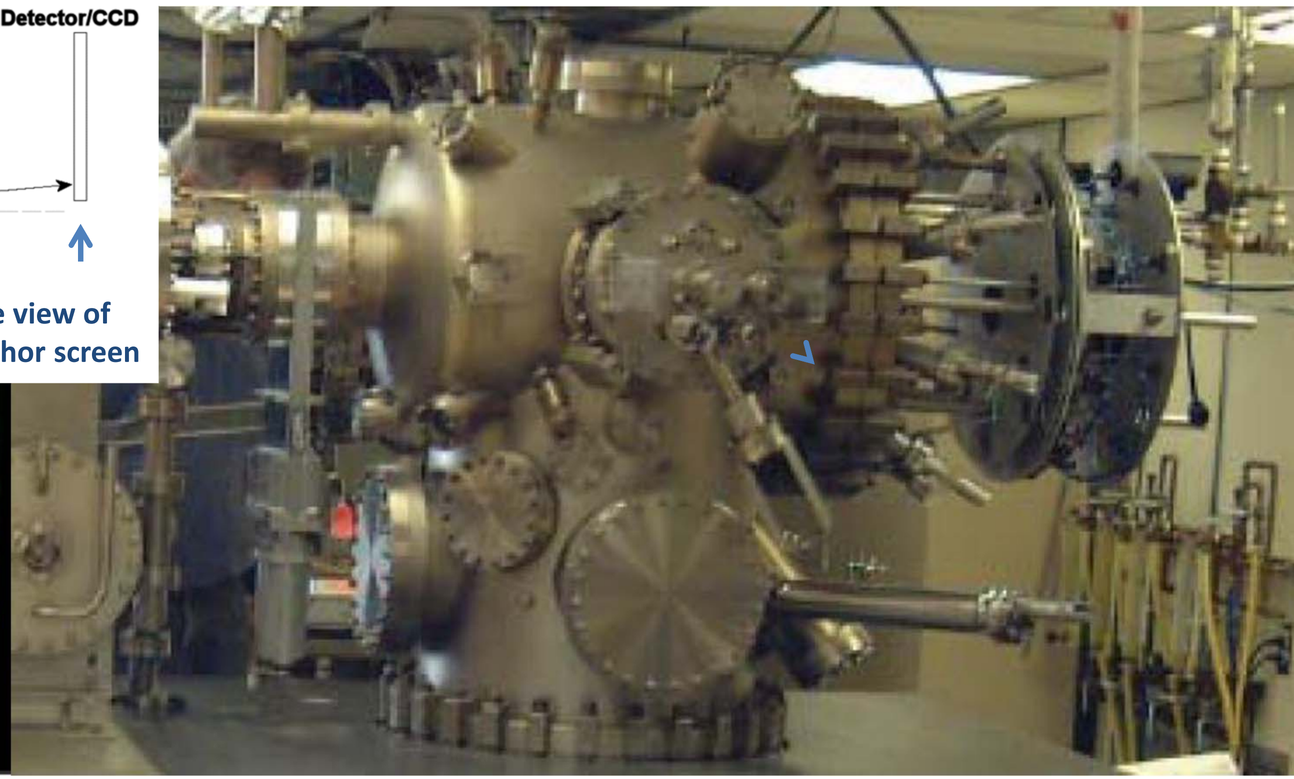
GaAs grown by MBE

Why not to design ourselves the GaAs layers we want to investigate?

- Non conventional dopant
- Choice of doping profiles



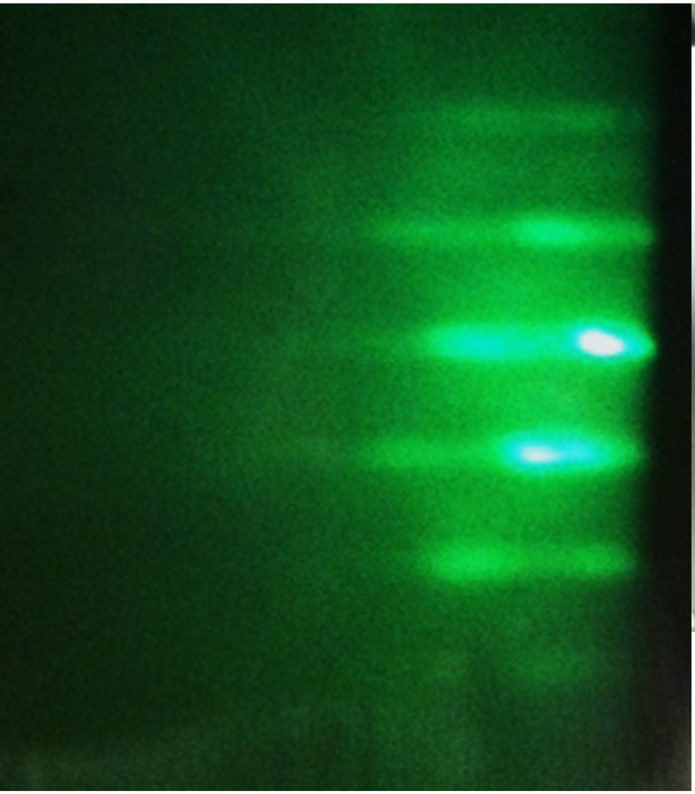




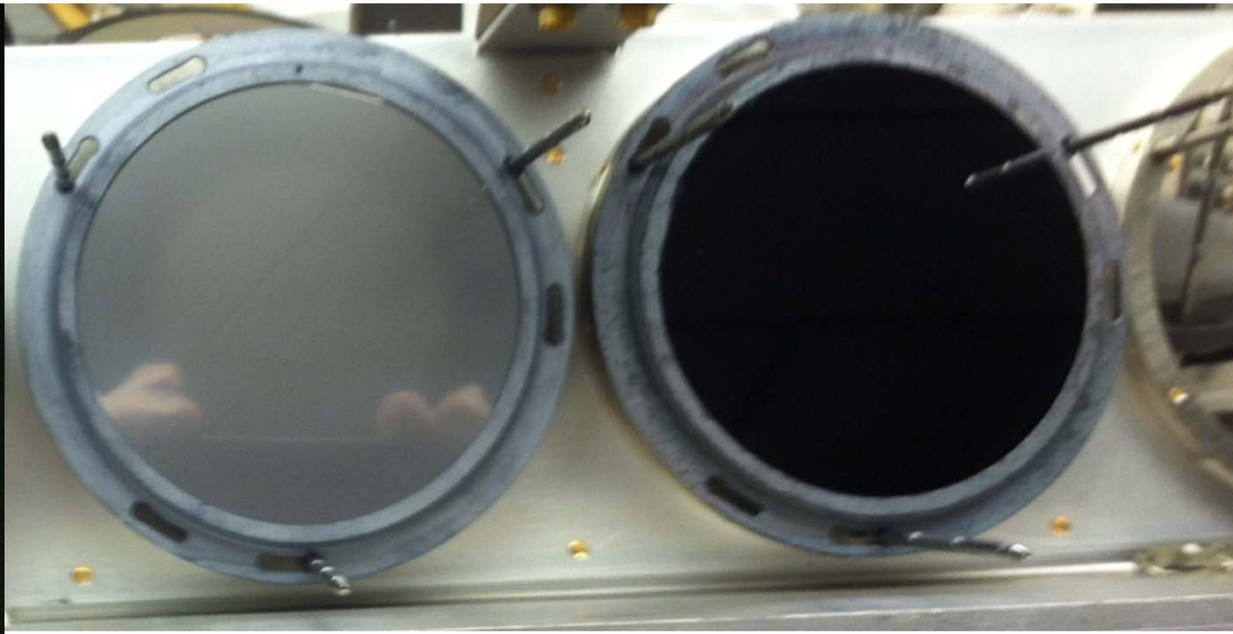
MBE lab of Department of Electrical and Computer Engineering at Cornell University

Arsenic capping

As capped wafers exposed to air for 64hours then heated for growth



Thin film grown over std Zn p-doped GaAs wafer



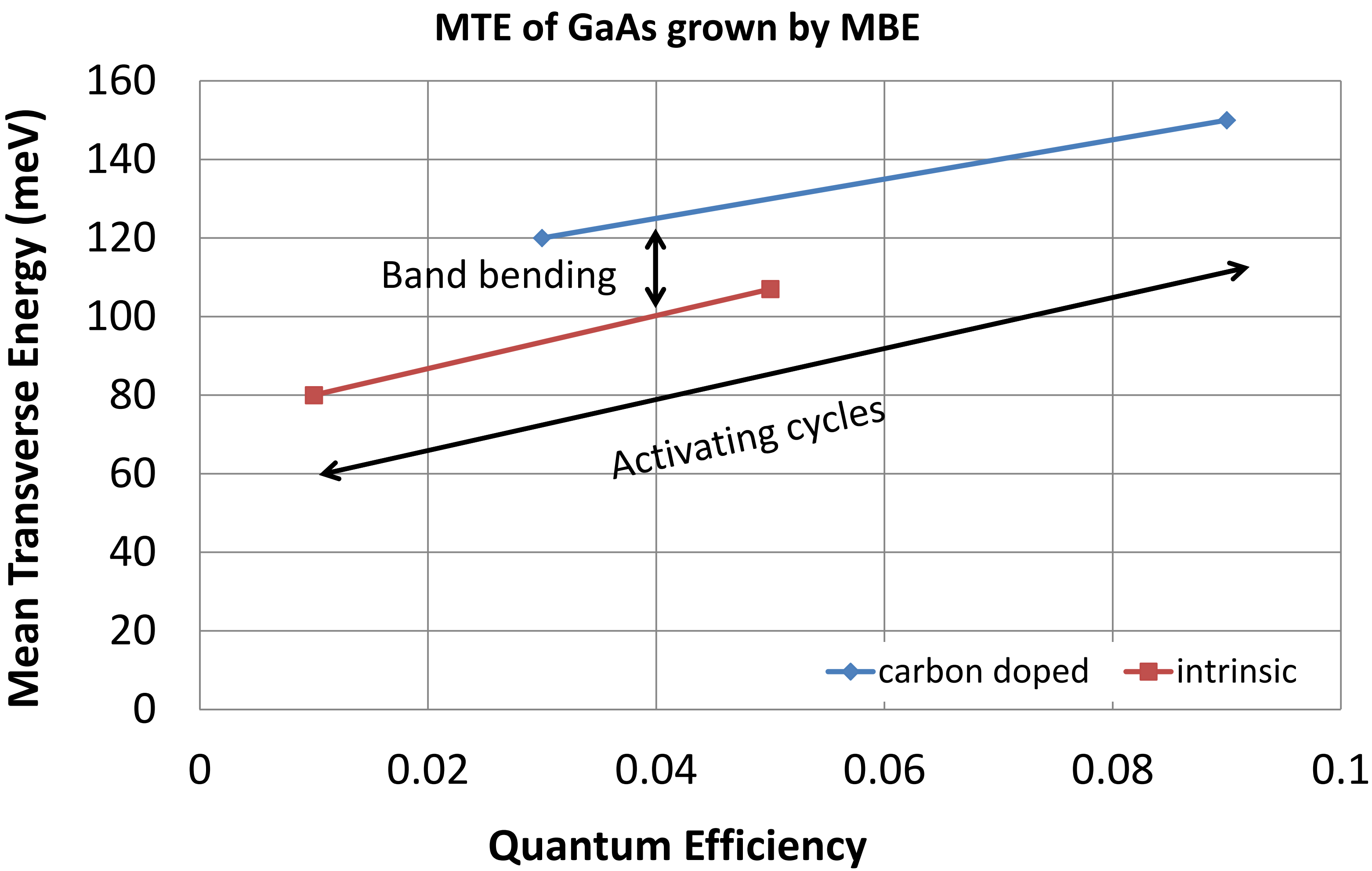
G20191
Warm cap

G20189
No cap

Results:

	G20191	G20189
Results:	Oxide-free	Thick Oxide
	Flat surface	Rough surface

GaAs MTE results



Preliminary results seem to indicate that an important role in MTE is due to

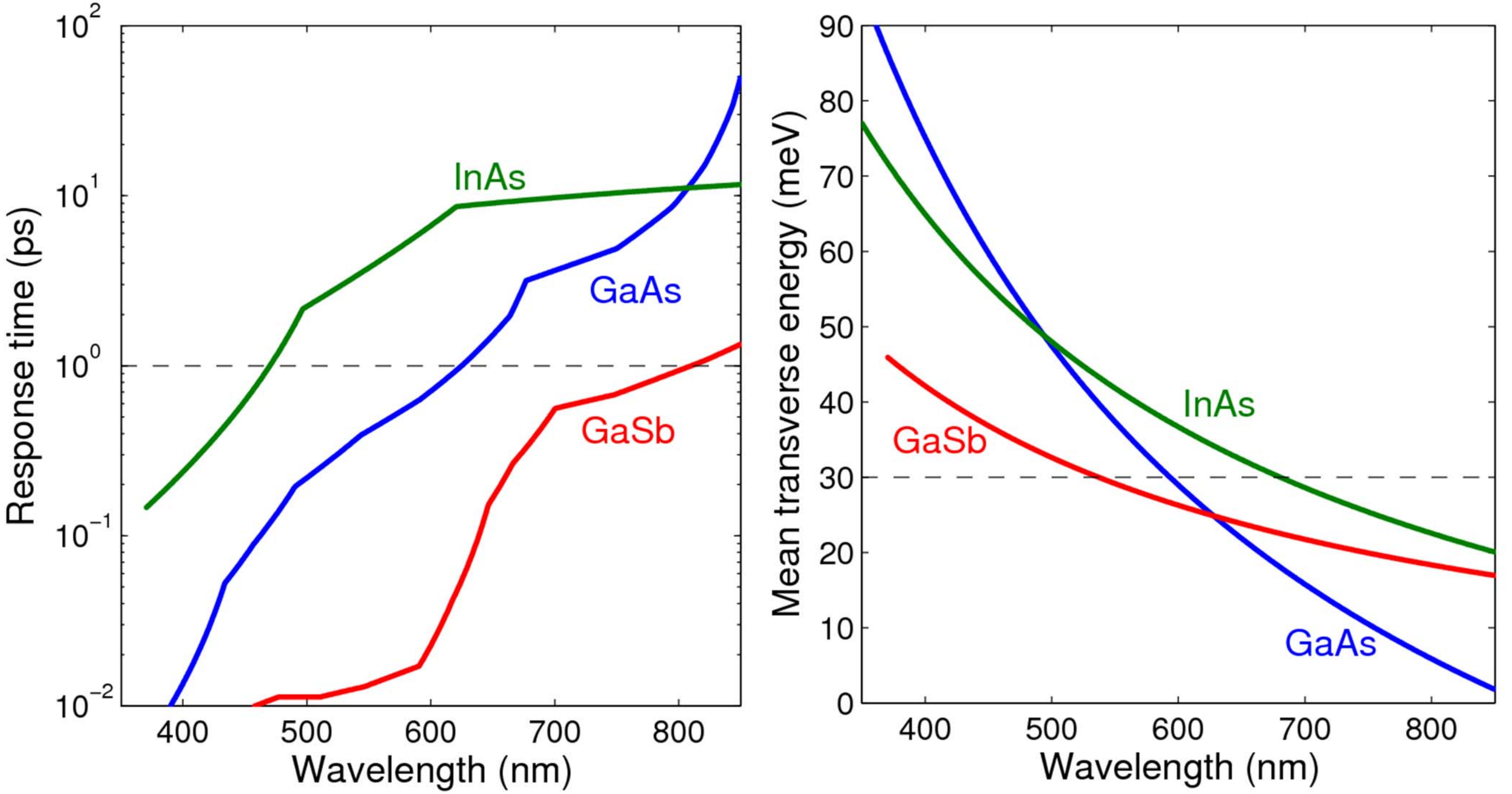
- band bending at the surface (C-doped vs intrinsic)
- Scattering at the surface Cs/F activating layer (low QE vs high QE)

The future

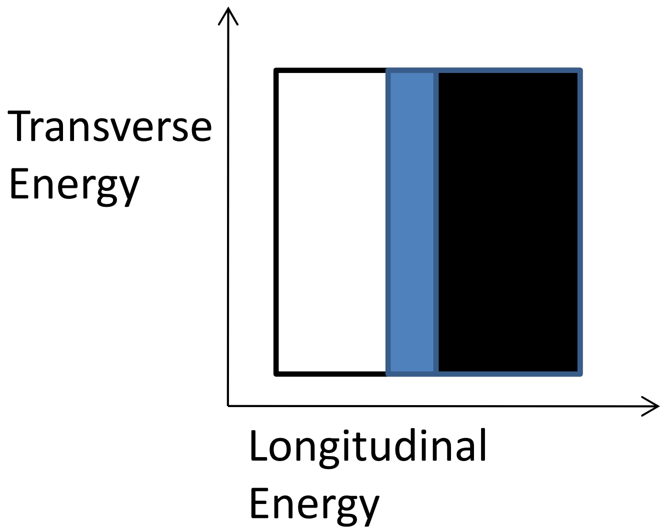
- Continue to provide experimental data to fill the voids on the table
  - new materials will be grown
- Modularity of the UHV system allow implementing additional non destructive techniques
- Investigating the photoemission process with numerical simulations based on MonteCarlo techniques

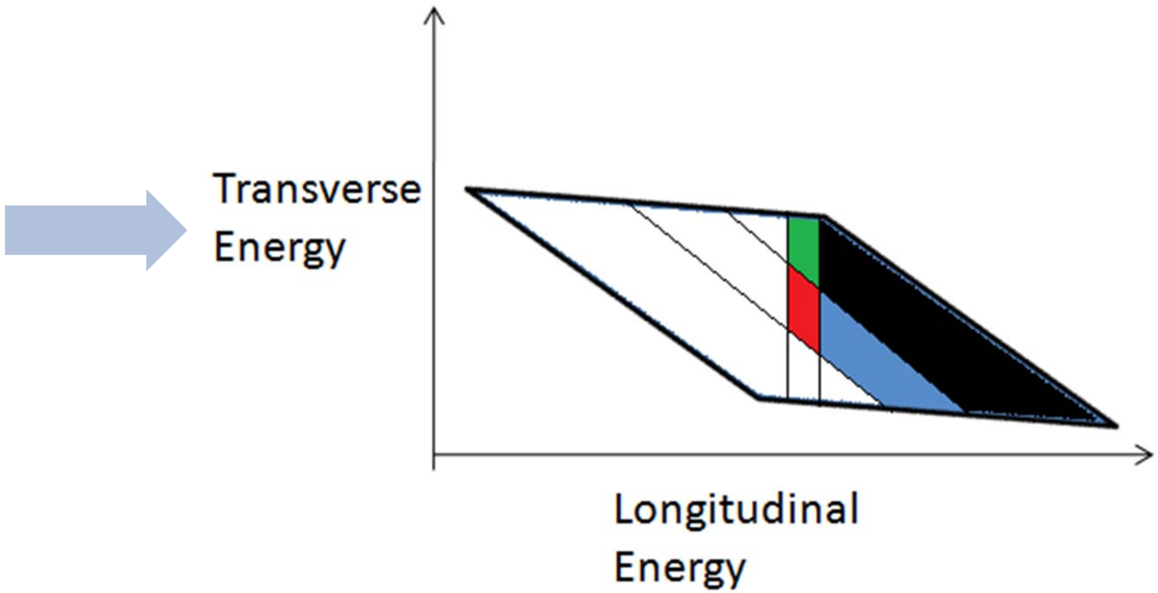
Thank you!

Other III-V semiconductors



Electron Energy Analyzer





- Adiabatic invariant and energy conservation:

$$E_t + E_l = const \qquad \frac{E_t}{B} = const$$

- So for marking electrode voltages V_1, V_2:

$$E_l = eV_1 \qquad E_t = \frac{e(V_2 - V_1)}{1 - B_2 / B_1}$$