Polarized photocathode R&D

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Outline

- Major parameters – cathode requirements
- Recent polarized cathode R&D at SLAC GTF
  - To improve baseline cathode GaAs/GaAsP
  - To explore alternate cathode AlInGaAs/AlGaAs
  - To measure and extend QE lifetime
  - To analyze cathode material with XRD and SIMS
- Summary

ILC and CLIC vs SLC e- sources

Parameters	ILC	CLIC [1]	CLIC [2]	SLC
Electrons/μbunch (@cath)	5nC	0.96nC	300 nC	12 nC
# of μbunches (@cath)	2625	312	1	2
Width of μbunch (@cath)	1.3 ns	100 ps	156 ns	2 ns
Time bet. μbunches (@cath) Time bet. μbunches (@inj)	~360 ns ~360 ns	500 ps 500 ps	- 0.5 ns	58.5 ns 58.5 ns
Width of macropulse	1 ms	156 ns	156 ns	~64 ns
Macropulse repetition rate	5 Hz	50 Hz	50 Hz	120 Hz
Charge per macropulse	13125 nC	300 nC	300 nC	24 nC
Average current from gun	66 μA	15 μA	15 μA	2.9 uA
Peak current of microbunch	4.0 A	9.6 A	1.9 A	6 A
Current intensity (r=1 cm)	1.3A/cm^2	3.0A/cm^2	0.6A/cm^2	1.9A/cm^2
Polarization	>80%	>80%	>80%	>80%

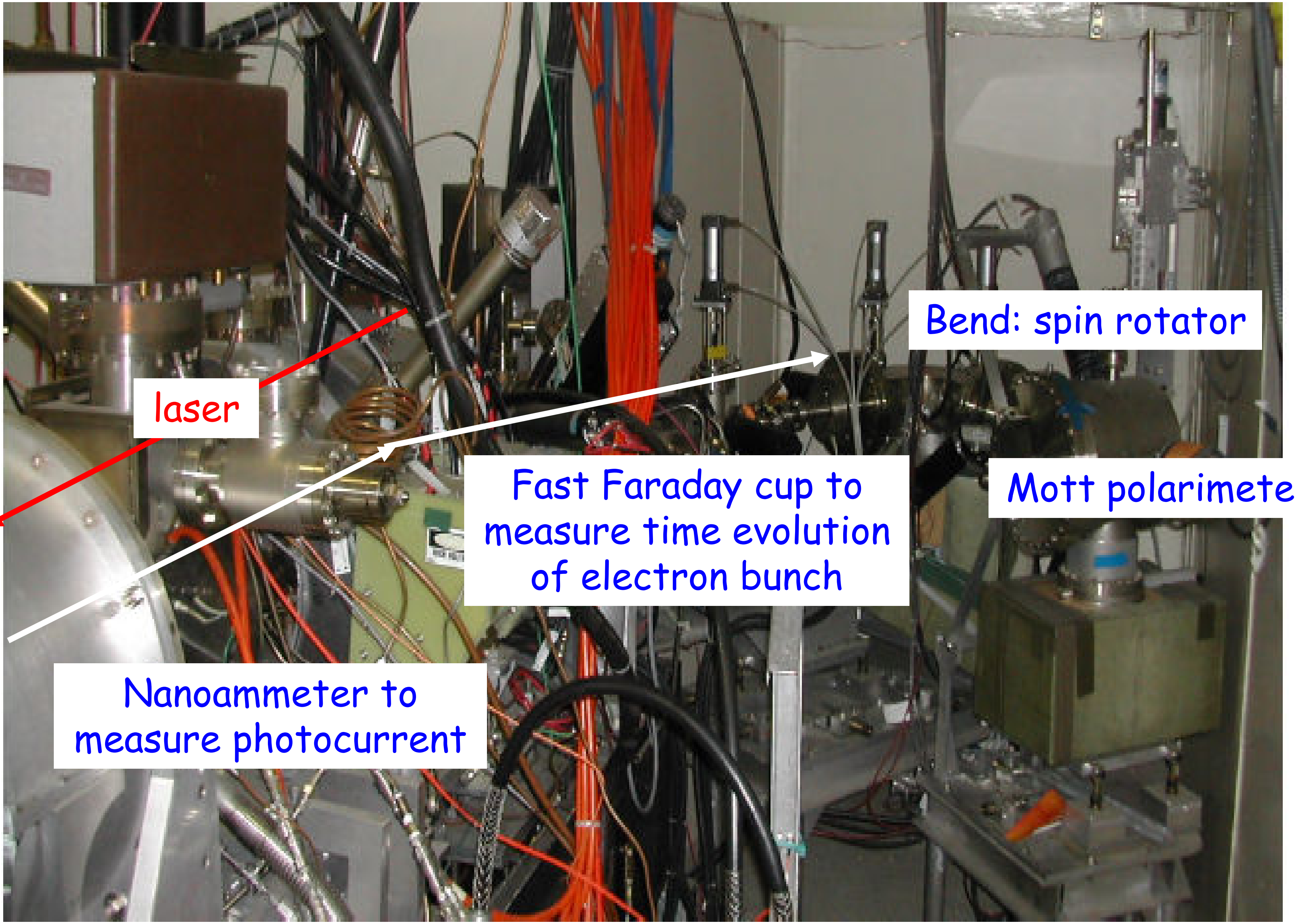
[1] by CERN colleagues, 2007.
[2] by SLAC team, 2009.

Cathode requirements for ILC and CLIC e-sources

- Less charge limit (surface charge and space charge)
- High polarization
- High QE and,
- Long QE lifetime

Worldwide unique dedicated Gun Test Facility (GTF) at SLAC for studies of polarized cathodes: capability to completely study the above four things.

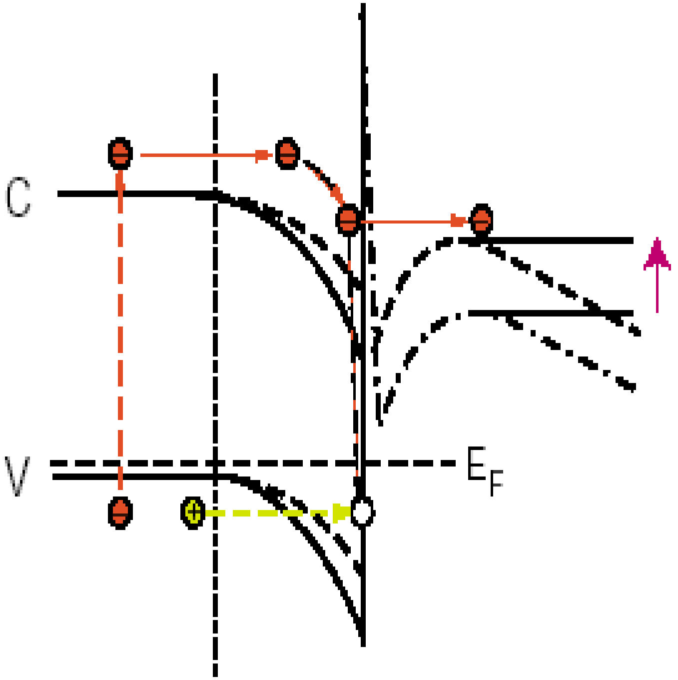
SLAC GTF



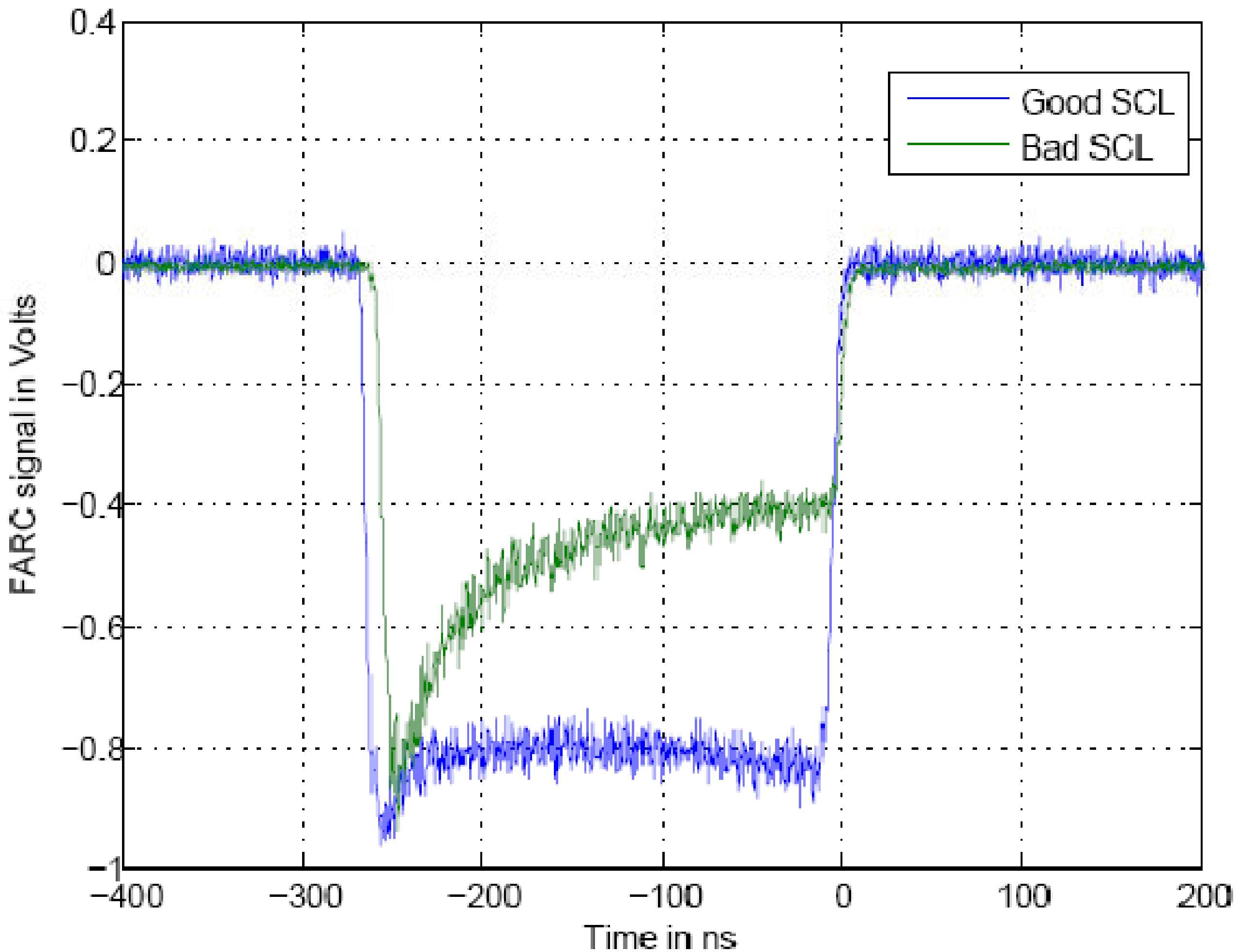
laser
Bend: spin rotator
Fast Faraday cup to measure time evolution of electron bunch
Mott polarimeter
Nanoammeter to measure photocurrent

Surface charge effect at NEA cathode

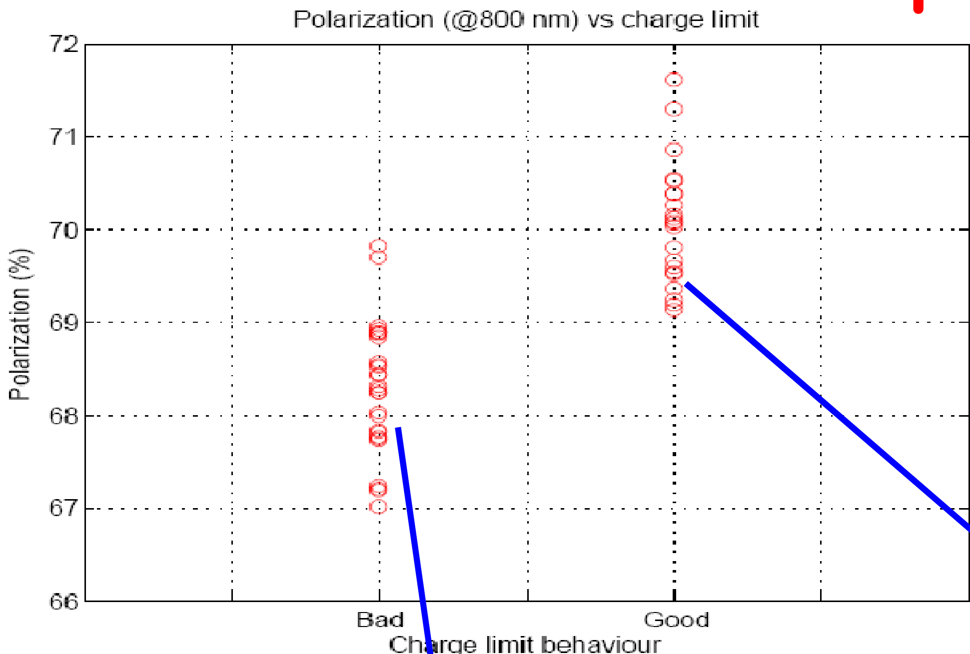
- Photon absorption excites electrons to conduction band
- Electrons can be trapped near the surface
- Electrostatic potential from trapped electrons raised affinity.
- Increased affinity decreases emission probability.



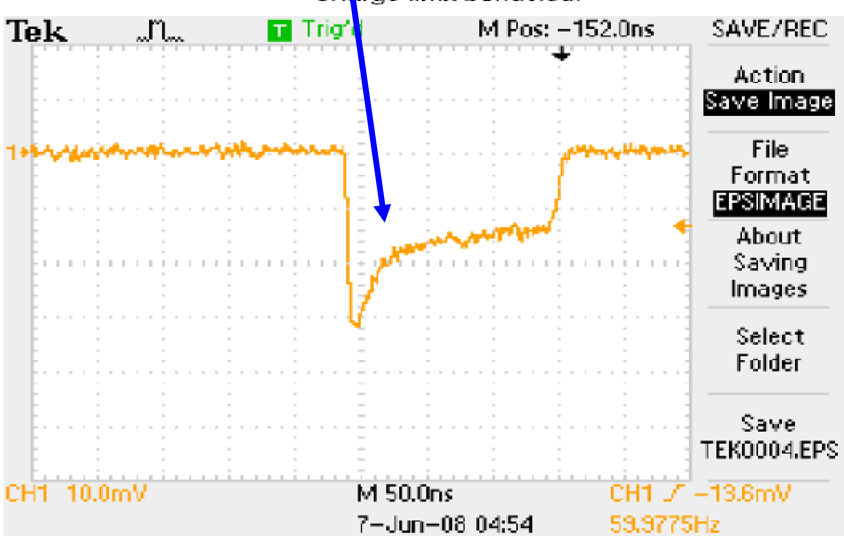
Good vs bad surface charge limit: observed at GTF

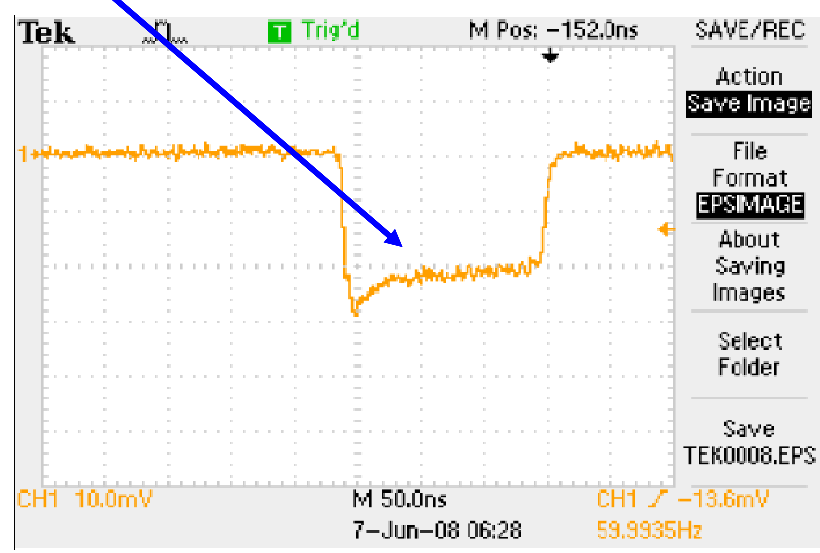


1st observation of charge limit effect on polarization



- The cathode is driven into saturation, electrons photoexcited into CB can still escape if they diffuse to a non-saturated region.
- But, these electrons spent long time inside structure so it is likely that they suffer spin relaxation.





Charge limit at ILC and CLIC sources

- Charge limit @ILC:
  - Individual 1.3ns microbunch's surface charge limit is ok but it may be accumulated along 1ms of 2625 microbunches. 1ms surface charge limit is not concluded yet until ILC beam is generated and characterized at SLAC GTF.
  - Space charge (Child law): $\sim V^{3/2}/d^2$, 14 A/cm^2 @ 140kV and d=3cm.
  - 1.25 A/cm @1cm laser radius
- Charge limit @CLIC (original scheme):
  - Surface charge limit unknown
  - Space charge limit 3A/cm^2 @1cm laser radius
- Charge limit @CLIC (SLAC scheme):
  - Surface charge is well understood.
  - Space charge 0.64 A/cm^2 @1cm laser radius

How to improve baseline cathode GaAs/GaAsP?

Optimum Polarization

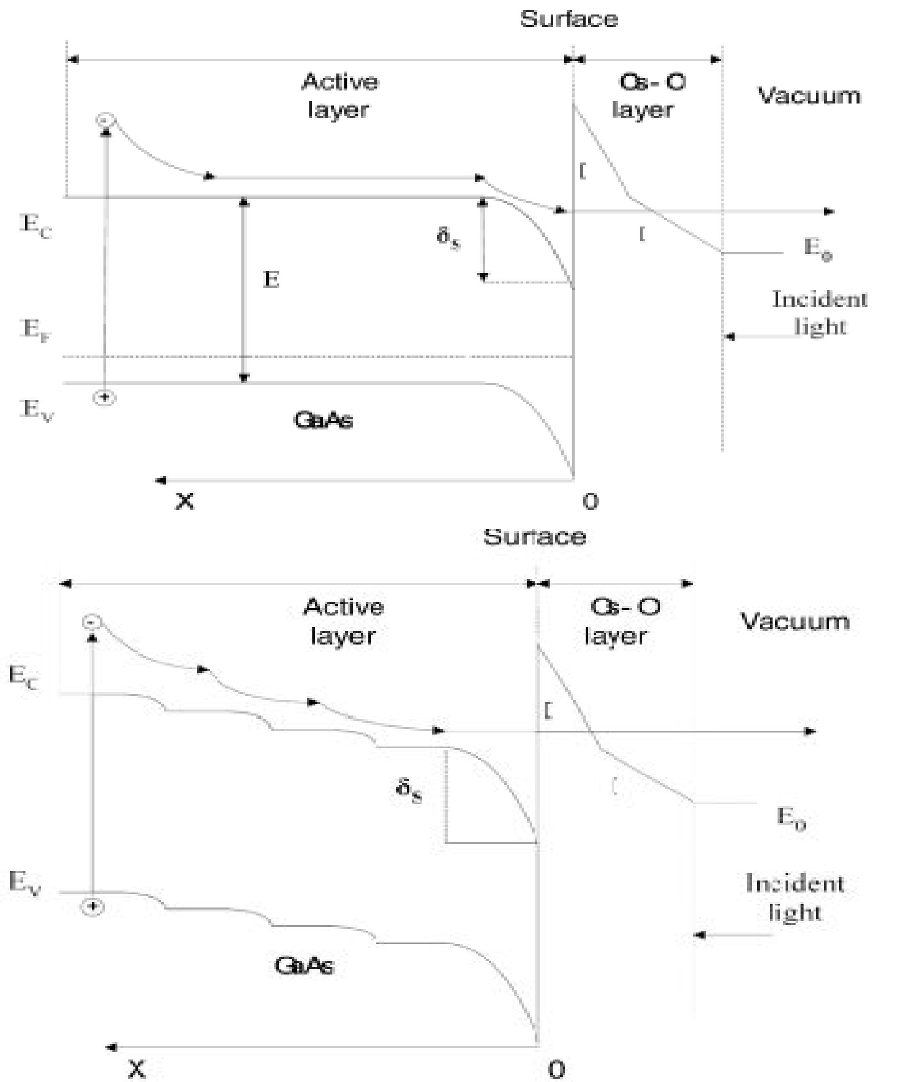
- Large valence band splitting E_{hh-lh}> 60 meV
- High strain splitting and offsets in valence band
- Effective electronic transport along SL axes
- High quality SL, uniform layer composition and thickness
- Low doping in SL

Optimum QE

- High NEA value
- Thick working layer
- Heavy doped BBR layer

Gradient doping technique in active layers

- Gradient doping in active layer $5x10^{17}$ cm^{-3} to $1x10^{17}cm^{-3}$ (next to surface) instead of constant $5x10^{17}$ cm^{-3}
- Electrons can be accelerated when getting through BBR: higher QE and polarization are expected.
- For the test run, we used AlGaAs/GaAs. SVT samples already delivered to be installed and tested at GTF in next months.

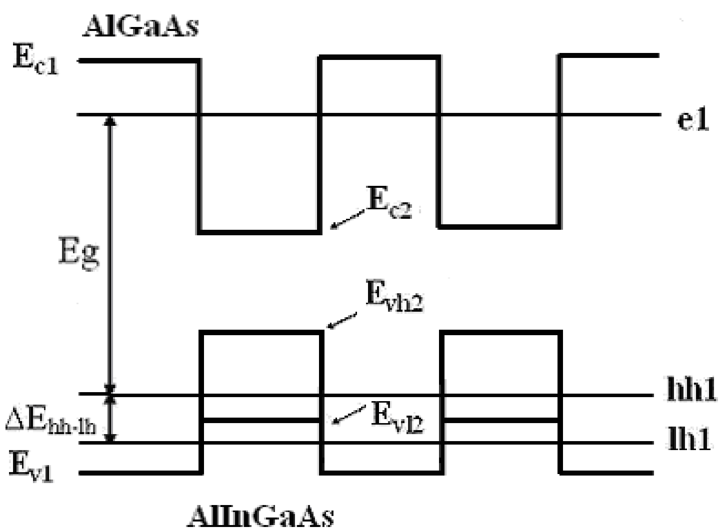


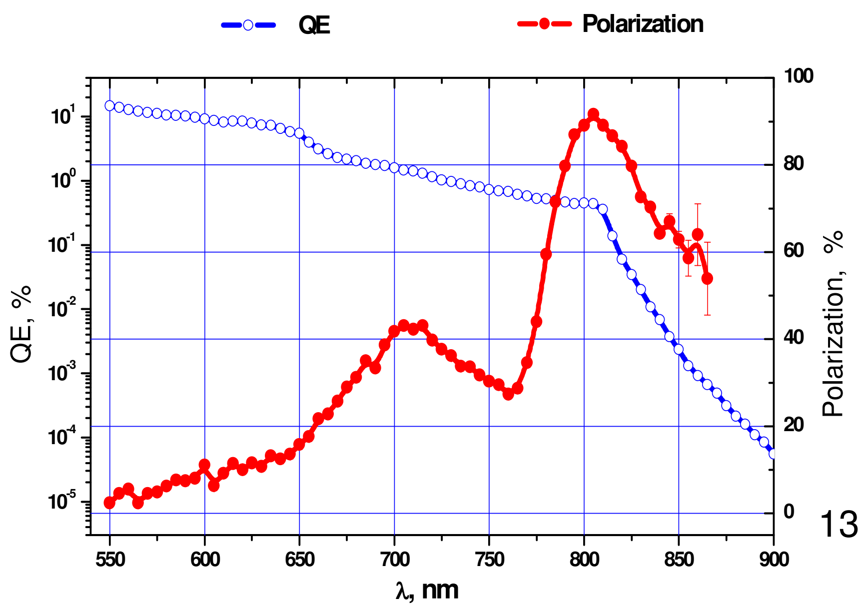
Doping profiles in active and surface layers

- Optimize doping in the active layer and surface to increase polarization:
  - Surface doping study: fixed doping in active layer to $1x10^{17} cm^{-3}$, measure QE, polarization and surface charge limit as surface doping level.
  - Active layer constant doping study: fixed doping in the surface, to determine doping level in the active layer w/o depolarization spin.
- With gradient doping technique and optimization of doping in surface and active layer, it is expected to increase QE and polarization without surface charge limit.
- All samples to be delivered by SVT in the next few months (support under SBIR phase II).

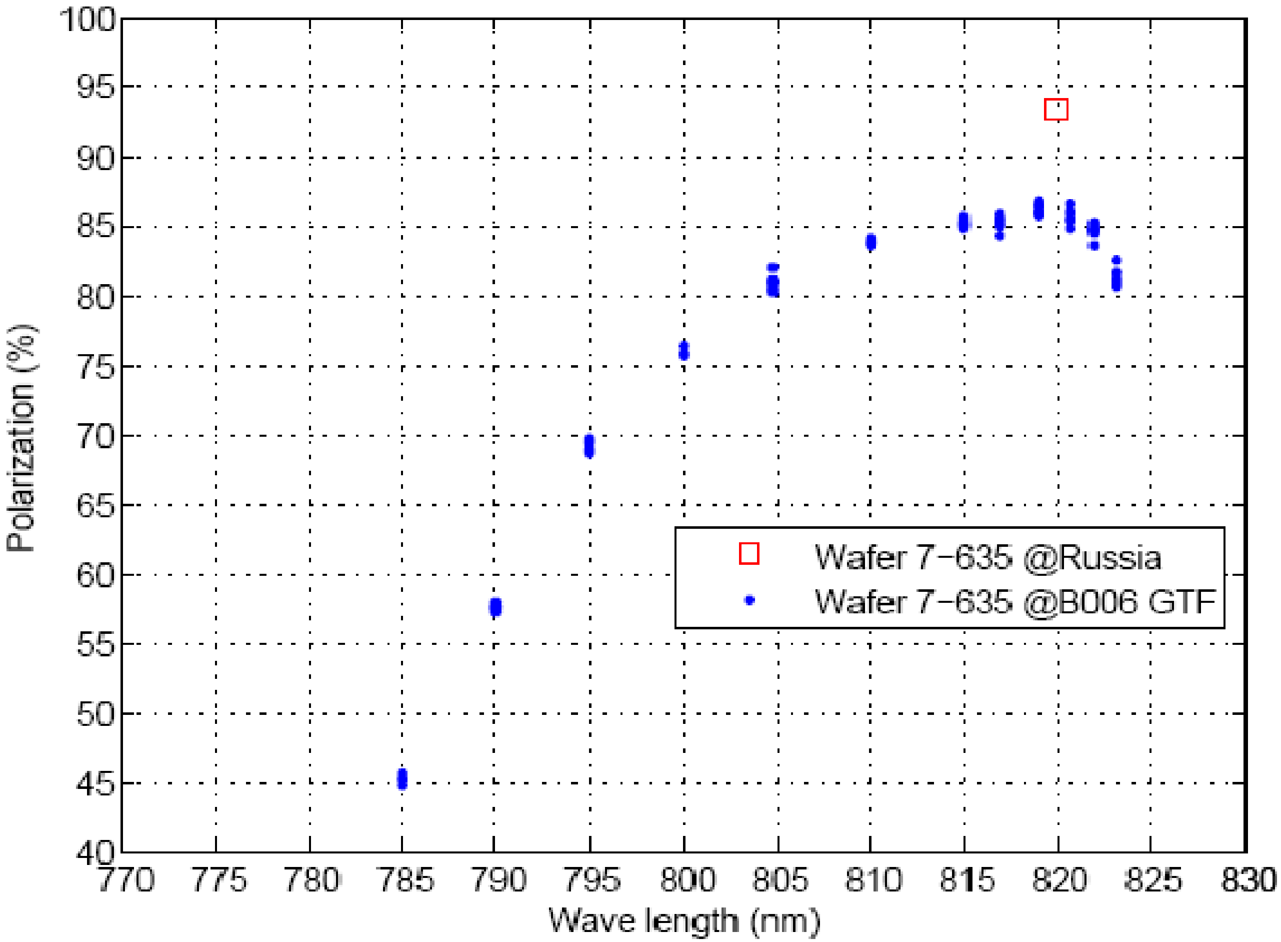
To explore alternate cathodes

- Strained-well InAlGaAs/AlGaAs manufactured in Russia:
  - Large VB splitting (~60 meV) due to combination of deformation and quantum confinement effects in QW.
  - BBR engineering
  - Reasonable-thick working layer without strain relaxation

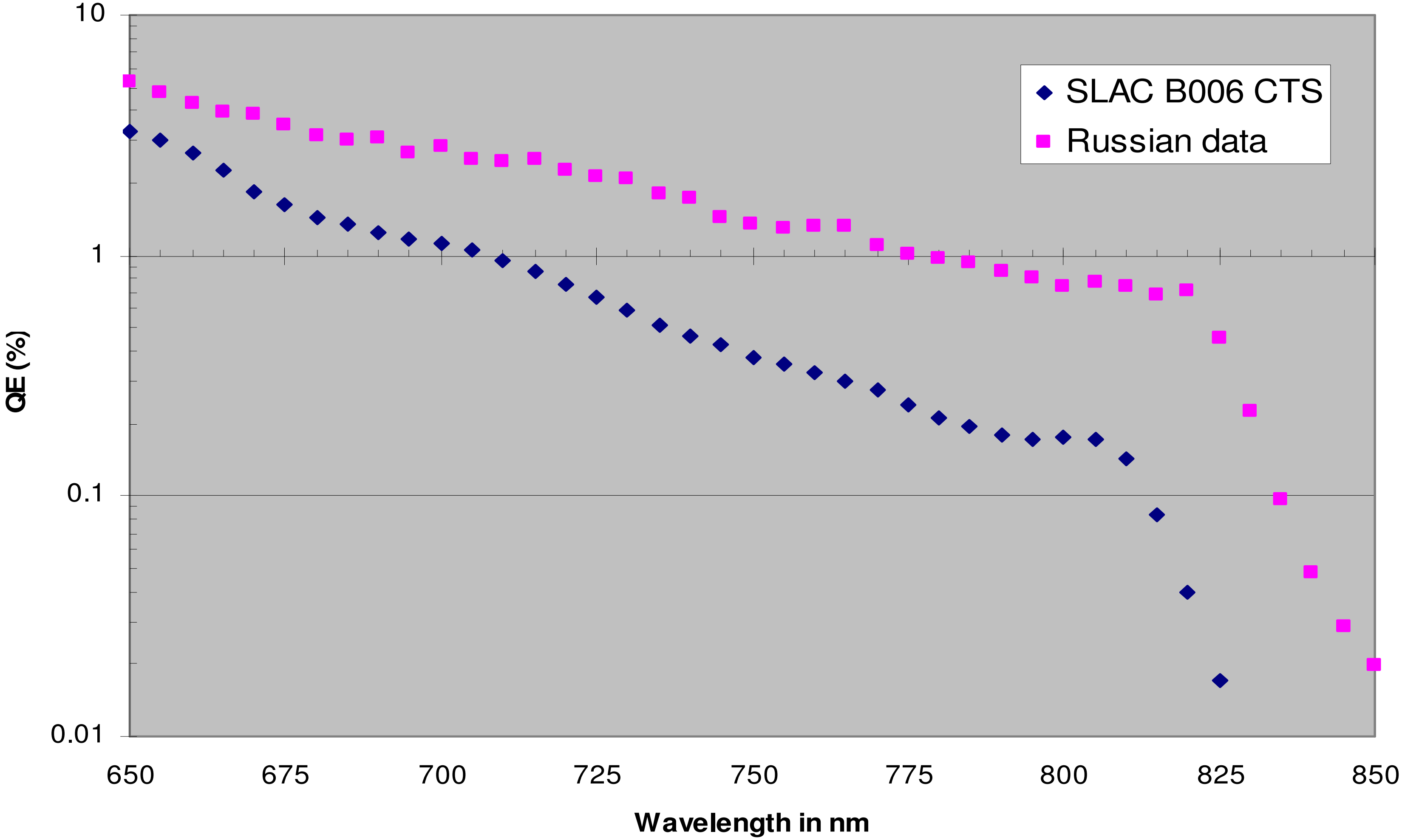




Polarization of AlInGaAs/AlGaAs in Russia and SLAC GTF

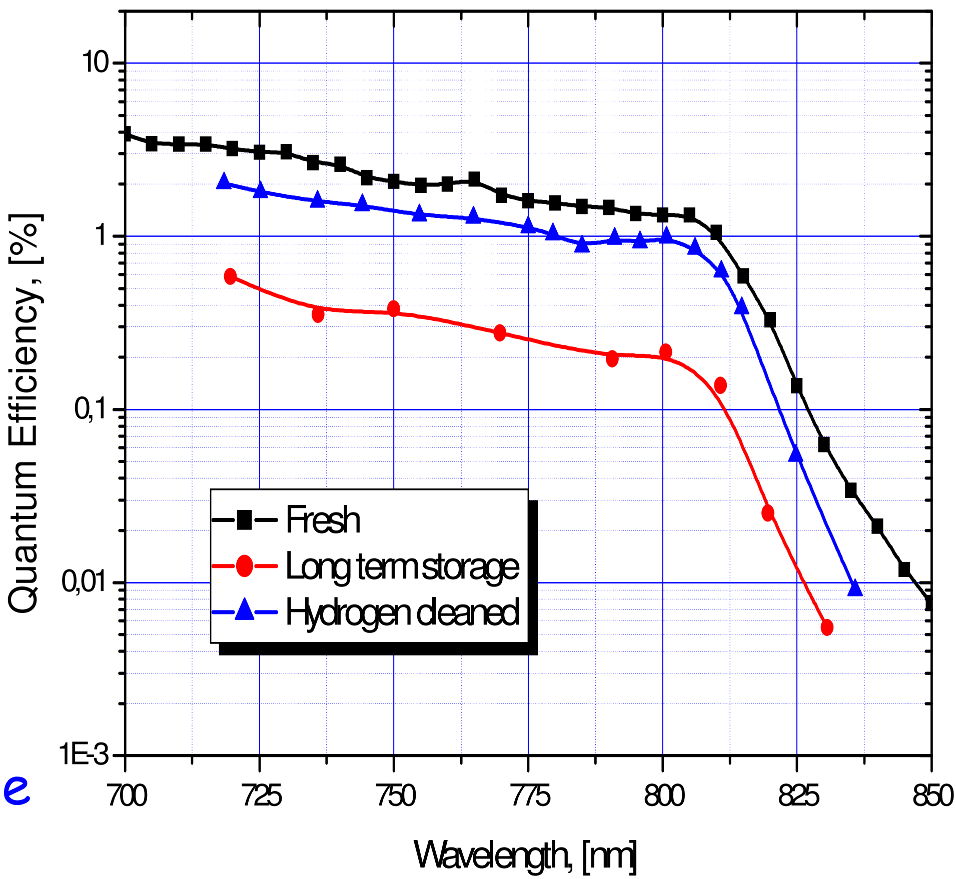


- Its QE drops by a factor of 5 at SLAC compared with Russian data, 0.8%. Only difference of the cathode: the one used in Russian is fresh while our one was stored for a few months.



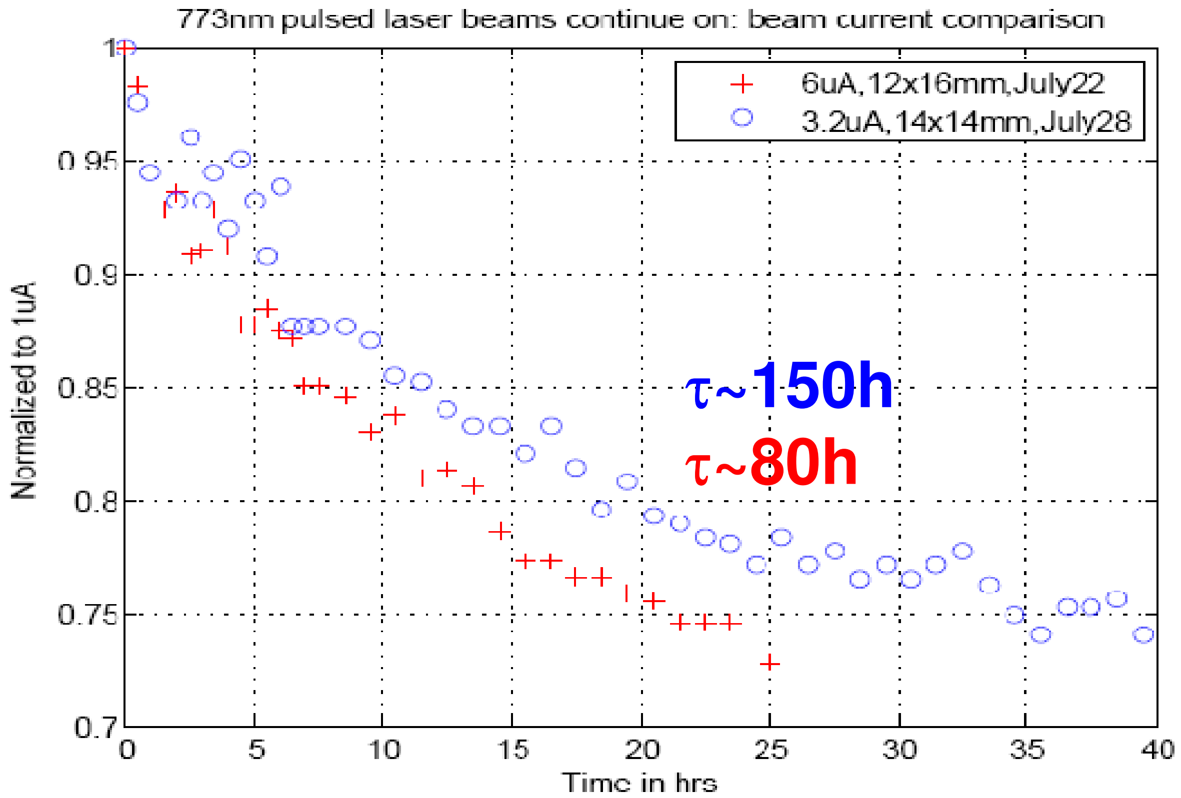
Its QE recovered by AHC - Atomic hydrogen cleaning

- QE drop after months of storage: probably due to insufficient As on the surface - oxide may transfer As→Ga.
- Some oxides (Ga_2O_3-like) and carbides can't be removed by conventional heating temperature but removed by AHC (see plot).
- Our AHC source: RF dissociating molecular hydrogen in a tube and atomic hydrogen passed through a 1mm hole and travelled 25cm to cathode.
- We will process the Russian cathode using AHC, and expect to recover its QE.
- To apply SBIR for further studies



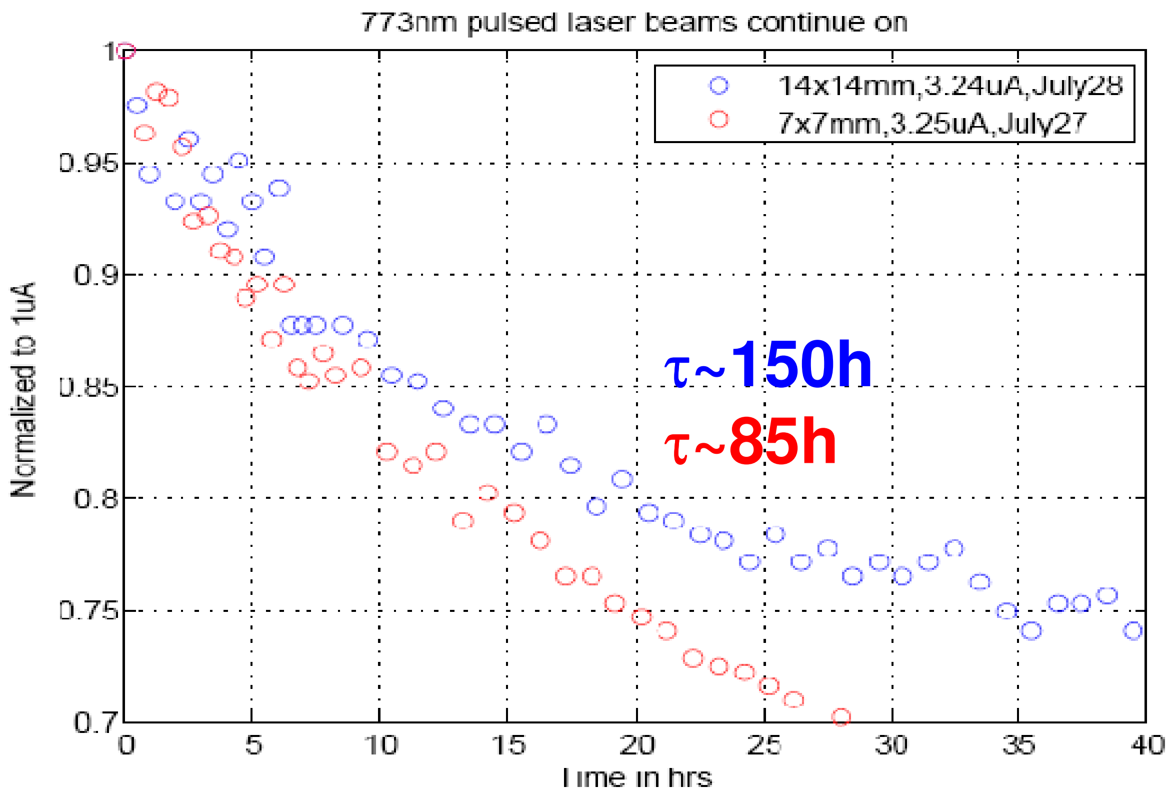
Mainz data in PESP2008

QE lifetime vs beam current



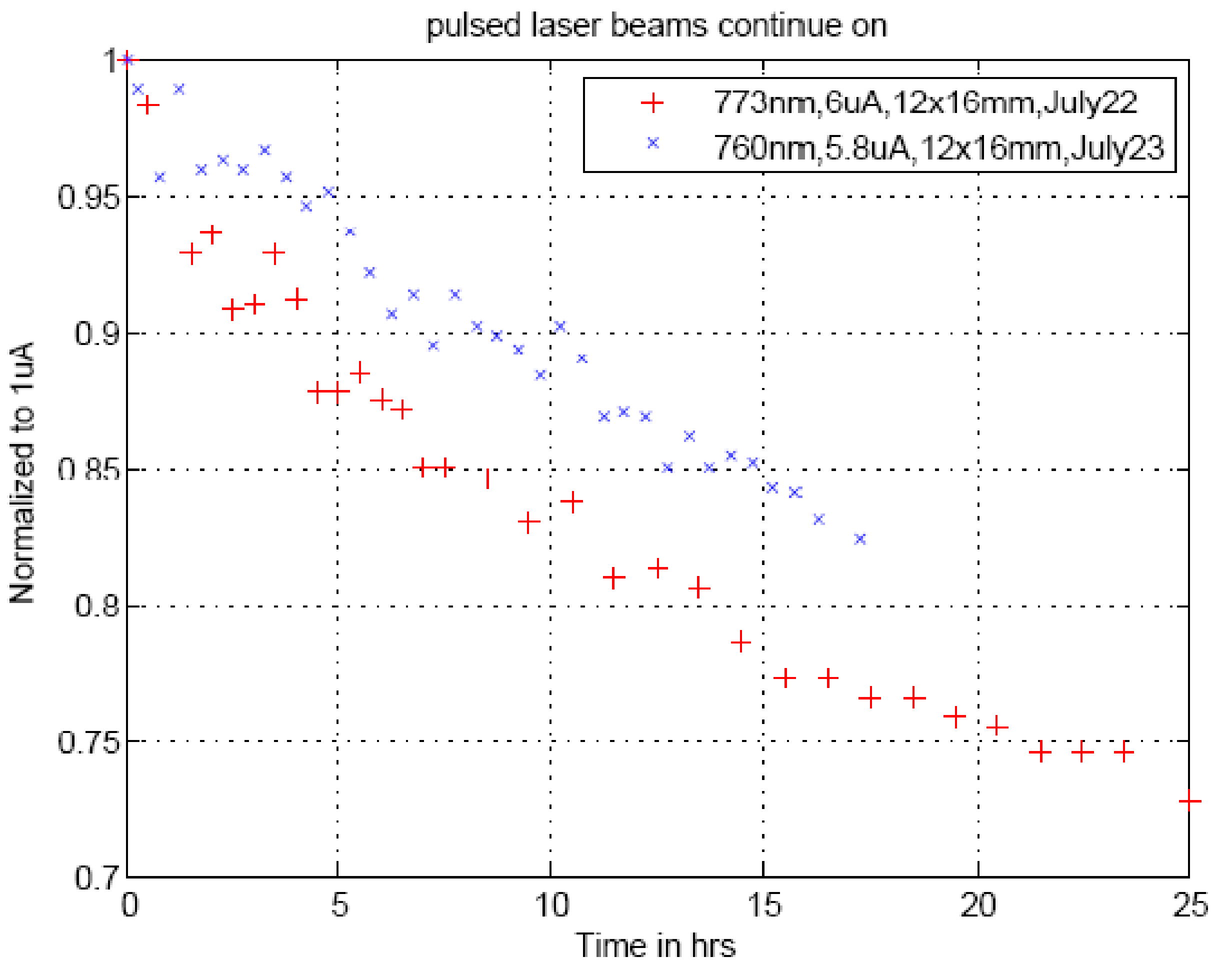
- Beam current: larger beam current naturally has more ions
- ILC average current is 25 times more than SLC. Beam lifetime probably is of concern.

QE lifetime vs laser size



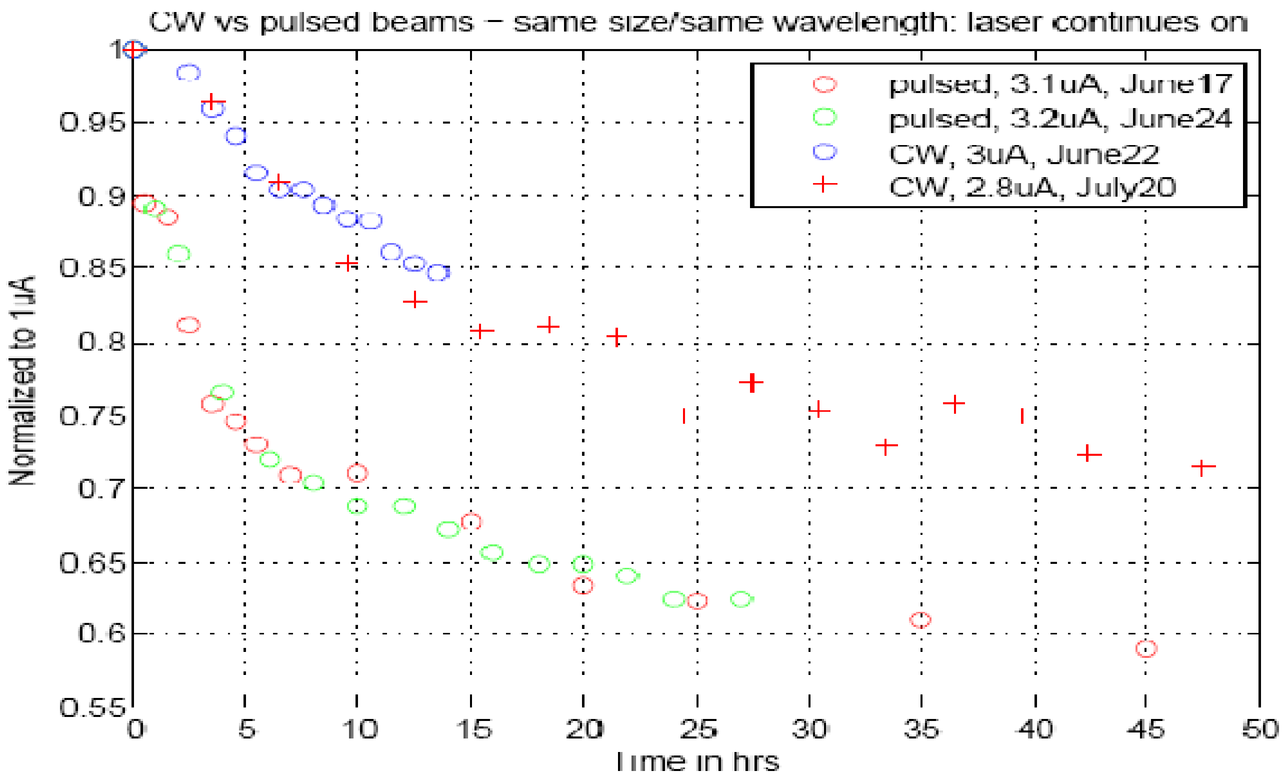
- Residual gases ionized by electrons are accelerated back to cathode, resulting in ion damage to cathode or sputter away Cs.
- If the larger laser size, ion intensity becomes lower (# of ions is constant for smaller vs larger size if without charge limit).
- Ion dynamics actually depends on ion trajectory and stopping depth.

QE lifetime vs wavelength



Electrons at short wavelength may be more mobile than at long wavelength, and may be less contamination in vacuum.

QE lifetime: CW vs pulse



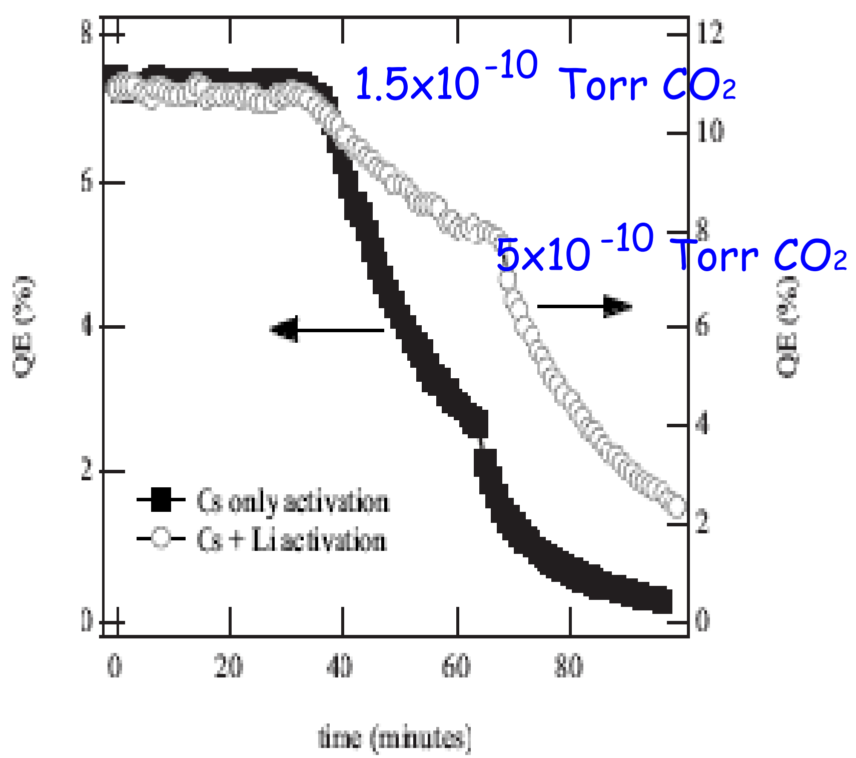
- If only ion back-bombardment effects, QE lifetime for CW and pulse beam should be same. Detail mechanics for the phenomena needs to be further understood.
- Current confidence of ILC beam (70uA) lifetime mostly relies on CEBAF CW data. Our some data show that pulse beam lifetime is worse than CW even if their average current is same.
- To make solid conclusion we need to take more data.

To improve QE lifetime: new activation Cs+Li

- Regular activation consists of the deposition of Cs, with an oxidizer NF_3 onto surface to obtain the lowest affinities.
- New activation technique Cs+Li initiated by Mulhollan at SAXET, provides good opportunity to significantly extend beam lifetime:
  - With Cs, the layer is amorphous, due in part to the large covalent radius of Cs.
  - Initial oxidizer absorption sites are between Cs atoms. If access to underlying oxidizer and GaAs surface could be blocked following activation process, then absorbed gas induced decay could be inhibited.
  - The covalent radius of Li is smaller than Cs. Thus, a 2nd smaller covalent radius alkali can be used to block atoms, then enhance beam lifetime.

To implement Cs+Li technique into SLAC GTF

- Beam lifetime comparisons (SAXET)
- Polarization is verified at SLAC CTS (Maruyama and SAXET)
- We are planning to apply the Cs+Li into GTF:
  - Need to establish mature activation recipes since it seems system dependence. We will play SAXET chamber with Cs+Li to further study the recipes.
  - To integrate the technique into GTF (it is not trivial)
  - Check surface charge with Cs+Li
  - Measure beam lifetime in a practical machine.



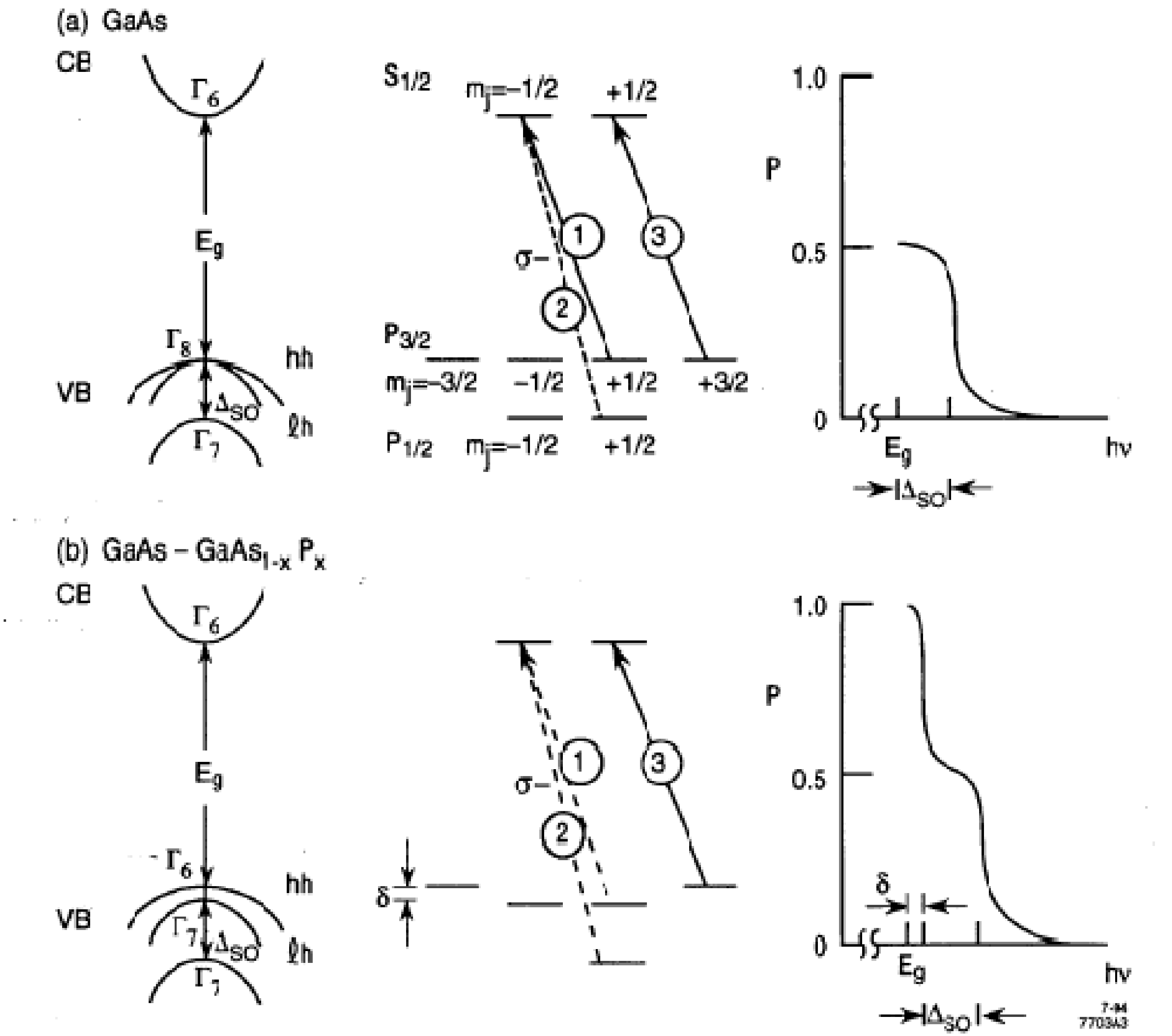
Mulhollan and Bierman, J. Vac. Sci. Tech. A , 2008

To establish steps to analyze cathode materials

- GaAs/GaAsP for full CLIC beam demonstration at GTF:
  - Charge 1600nC/pulse, a factor of 5 more than CLIC goals.
  - no surface charge limit
  - Polarization ~85%.
  - QE~0.7%
- Planning to establish cathode analysis: X-ray diffraction and SIMS diagnostics to analyze structure thickness, strain, compositions, and layer doping, etc., to understand the structure in comparison to the design parameters.

Summary

- Aggressive work to improve baseline cathode GaAs/GaAsP performance is under way – both QE and polarization enhancements are expected.
- Exploring alternate cathode AlInGaAs/AlGaAs: to get 90% polarization and 1% QE is very promising.
- QE lifetime dependences on parameters are studied. And implementing a new activation Cs+Li at GTF to significantly extend beam lifetime is planned.
- Planning to establish cathode material analyses: XRD and SIMS.
- Full beam demonstrations at GTF
  - Full CLIC beam has been demonstrated and all parameters are met with the requirements.
  - ILC beam to be demonstrated soon to study charge limit, to study individual bunch polarization, and QE lifetime at 70uA.


(a) GaAs
CB
Γ6
Eg
Γ8
hh
VB
ΔSO
ℓh
Γ7
S1/2
mj=−1/2
+1/2
σ−
1
2
3
P3/2
mj=−3/2
−1/2
+1/2
+3/2
P1/2
mj=−1/2
+1/2
1.0
P
0.5
0
Eg
hν
|ΔSO|
(b) GaAs – GaAs1-x Px
CB
Γ6
Eg
Γ6
hh
VB
Γ7
ΔSO
ℓh
Γ7
σ−
1
2
3
δ
1.0
P
0.5
0
δ
Eg
hν
|ΔSO|
7-94
7703A3