Polarized cathode developments and future plans

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SLAC

Thank J. Clendenin and other colleagues for their contributions

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Outline

- Major cathode R&D goals for future LCs:
  - To demonstrate full charge productions (highly polarized) for linear colliders, and
  - To develop high performance cathodes.
- Recent measurements on InAlGaAs/AlGaAs:
  - Measurements at SLAC's Cathode Test System (CTS)
  - Measurements at SLAC's Gun Test Lab (GTL)
- Summary for the measurements and future plans

Major parameters of ILC and CLIC e- sources

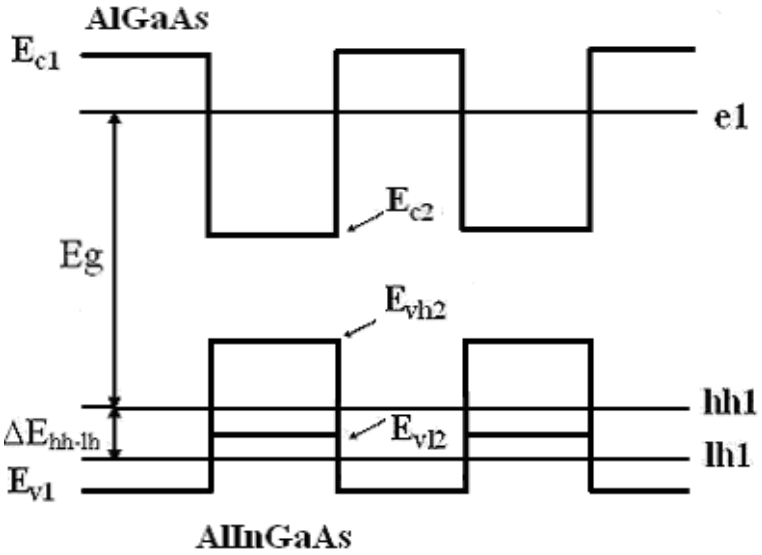
Parameters	ILC	CLIC
Electrons/microbunch	~3E10	6E9
Number of microbunches	2625	312
Width of Microbunch	**1 ns**	**~100 ps**
Time between microbunches	**~360 ns**	**500.2 ps**
Width of Macropulse	**1 ms**	**156 ns**
Macropulse repetition rate	5 Hz	50 Hz
Charge per macropulse	**~12600 nC**	**300 nC**
Average current from gun	63 μA	15 μA
Peak current of microbunch	4.8 A	9.6 A
Current density (1 cm radius)	**1.5 A/cm^2**	**3.0 A/cm^2**
Polarization	**>80%**	**>80%**

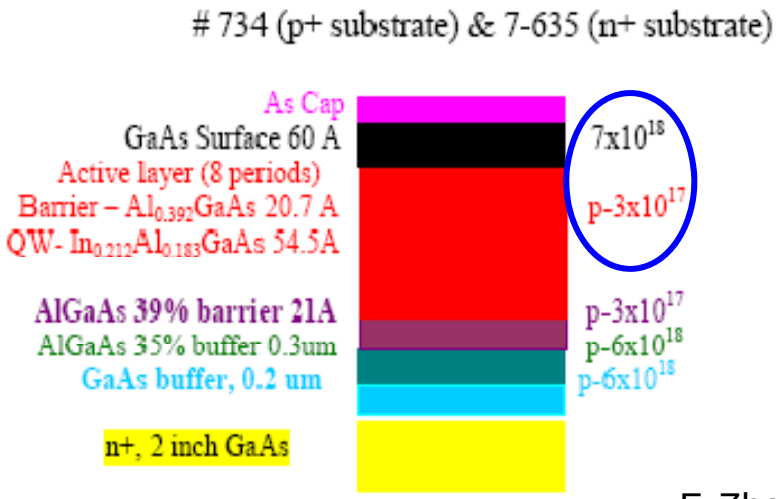
Challenges

- Full charge production limited by space charge and surface charge:
  - Lasers to demonstrate production of polarized electron beam with ILC and CLIC time structures
  - Good polarized cathodes to overcome surface charges with high QE and polarization
  - H.V. gun to overcome space charge, and ultra high vacuum to overcome contamination.
- Cathode candidates for linear colliders:
  - Less charge limit (surface charge and space charge)
  - High polarization (>85%)
  - High QE and QE lifetime

InAlGaAs/AlGaAs

- Strained-well InAlGaAs/AlGaAs structures designed and grown by St. Petersburg in Russia:
  - Large valence band splitting (~60 meV) due to combination of deformation and quantum confinement effects in quantum well.
  - Good BBR engineering
  - Thick working layer without strain relaxation
  - ~1% QE and 88%-93% polarization (Russia)

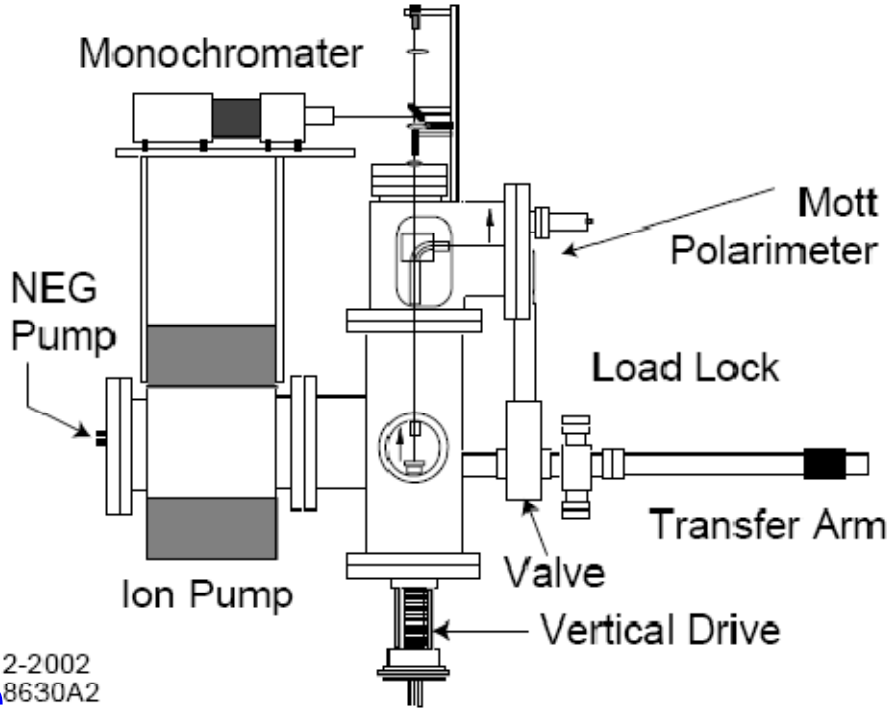




F. Zhou/SLAC

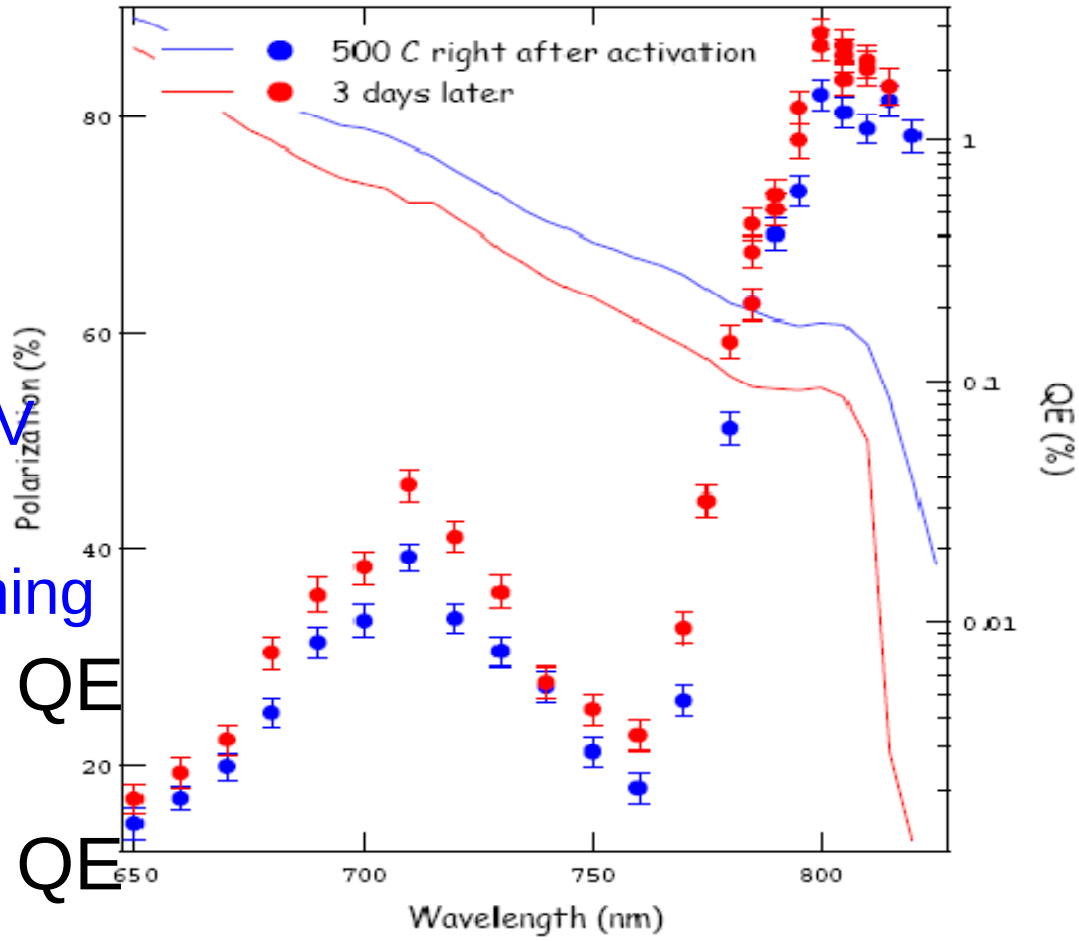
Capabilities at SLAC's Cathode Test System (CTS)

- Cathode preparation and cleaning processes
- QE and polarization measured at 20 KV
- QE and polarization of Cathode can be quickly characterized in few days.
- Drawback: unable to characterize surface charge limit (time evolution of bunch).

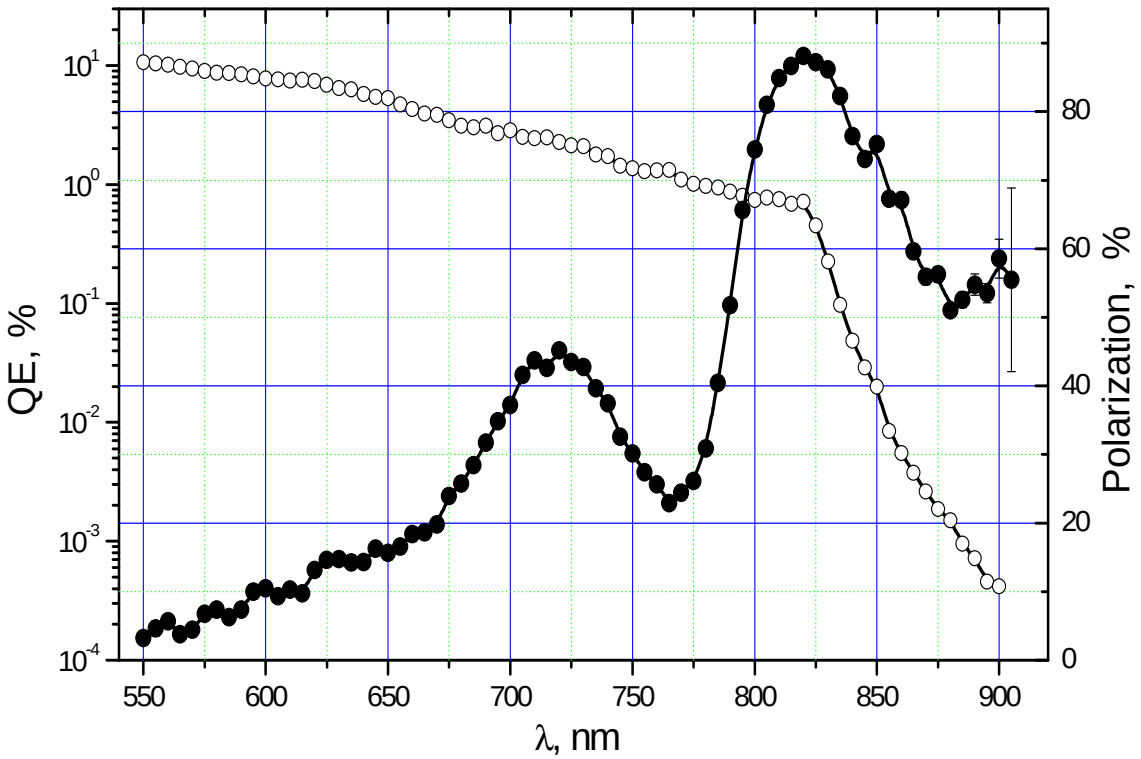


InAlGaAs/AlGaAs @ CTS

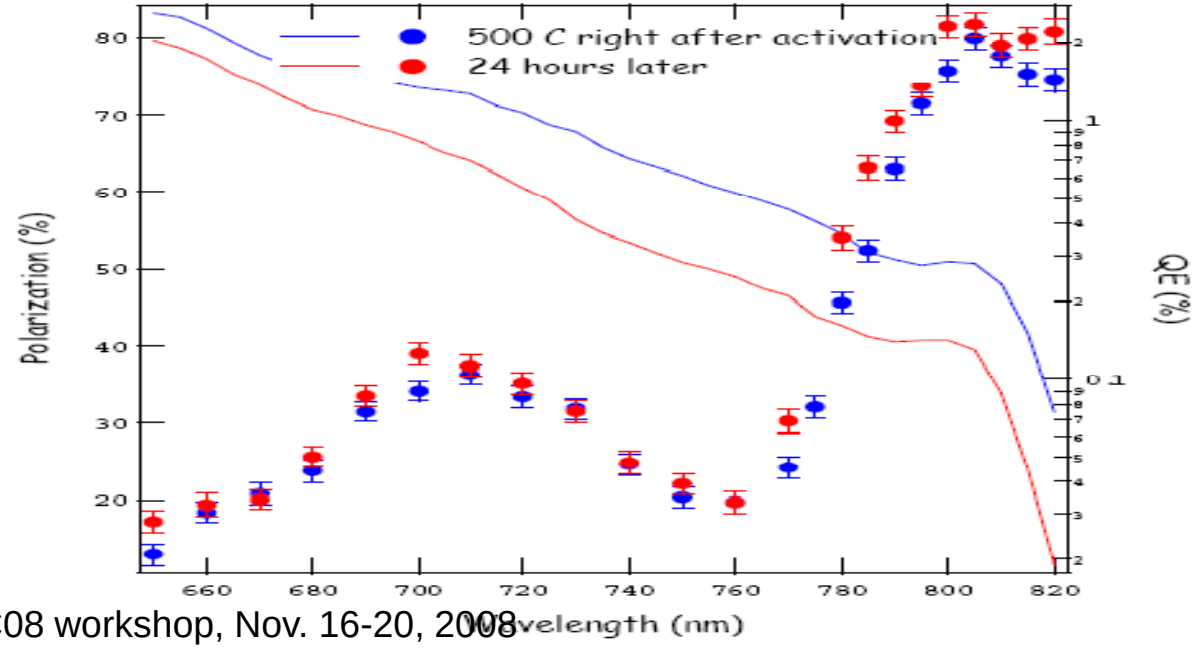
- Polarized cathode measurements:
  - Cathode preparation
  - Chemical cleaning
  - Load lock system to change cathode in UHV
  - Heat cleaning
  - Atomic hydrogen cleaning
- Sample 7-632: ~0.3% QE and 82% polarization.
- Sample 7-635: ~0.2% QE and 87% polarization.



Sample 7-635



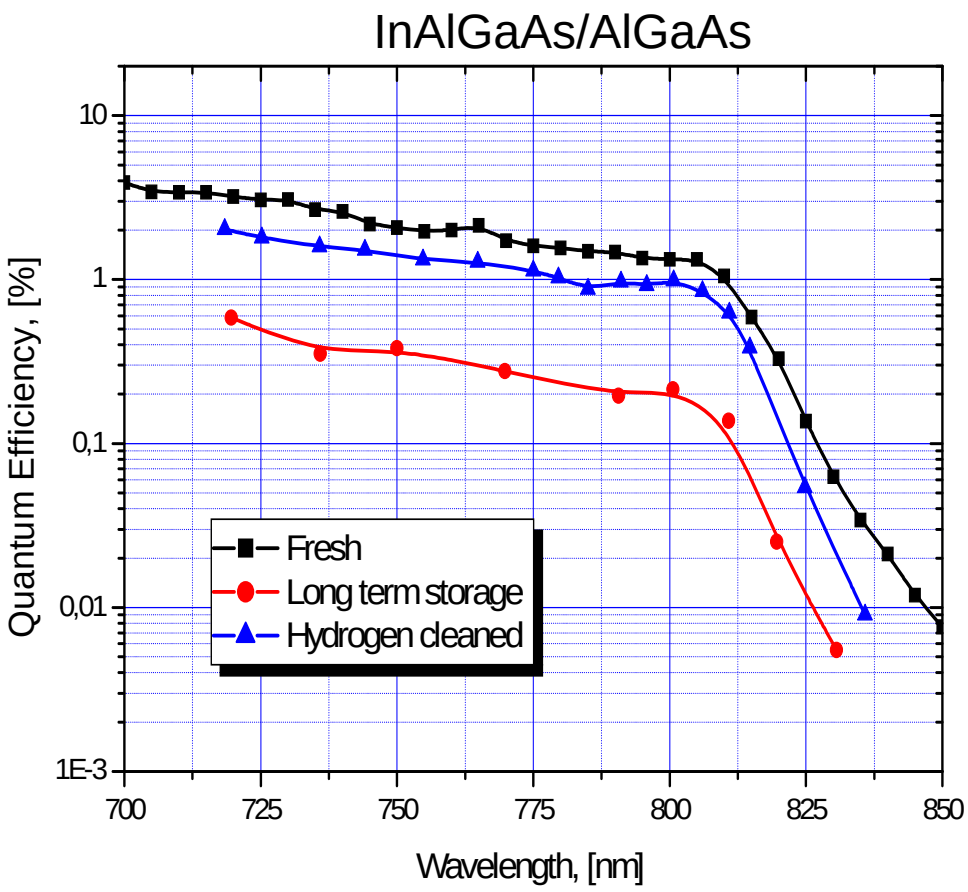
Sample 7-632
Russian data:
0.8% QE and
88% Polarization



Sample 7-632
CTS/SLAC data:
0.3% QE and
82% Polarization

1% of QE recovered by AHC

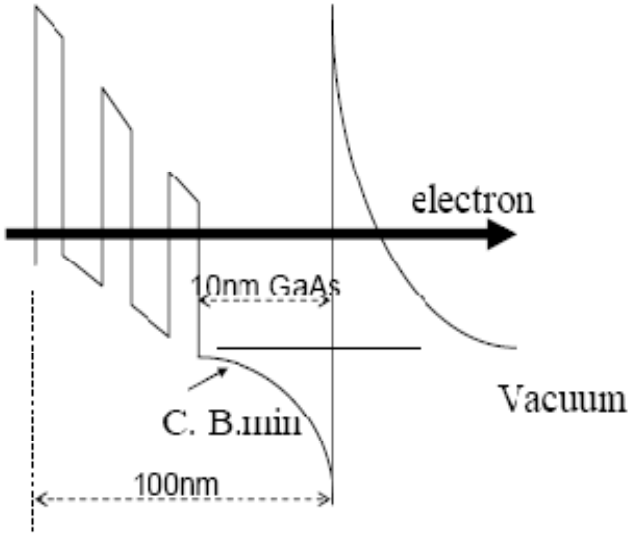
- Probably due to insufficient As-passivation of surface; possible reason: oxide transfer As→Ga after some time storage.
- Oxides were not removed by conventional heating. But atomic hydrogen cleaning can significantly improve QE for same kind of Russian cathode in Germany.

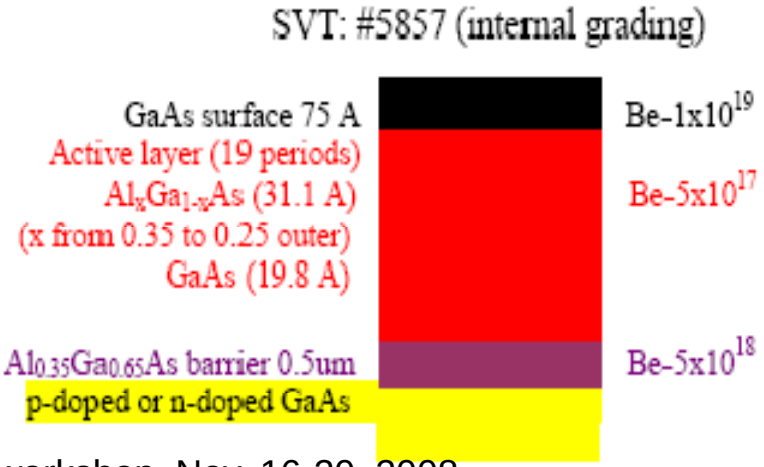


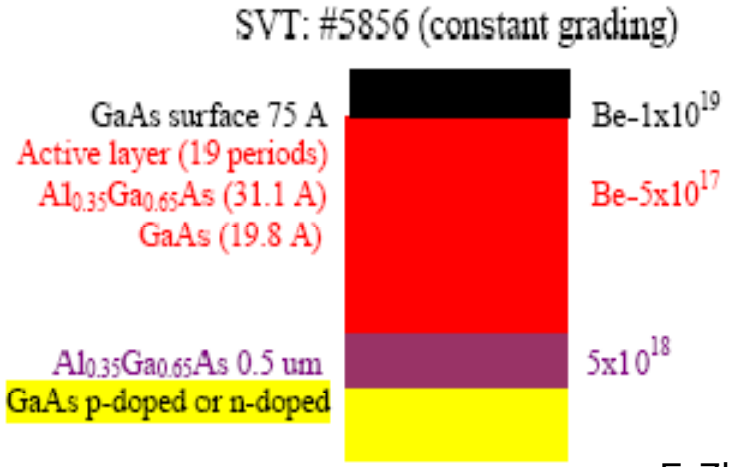
V. Tioukine, MAMI (PESP2008)

SBIR graded $Al_xGa_{(1-x)}As/GaAs$ (Grown by SVT)

- The graded bandgap active region provides an internal accelerating field for the photo-generated electrons in the conduction band. QE is increased by the field.
- But, the polarization is decreased; need to tune the structure parameters in SBIR phase II.



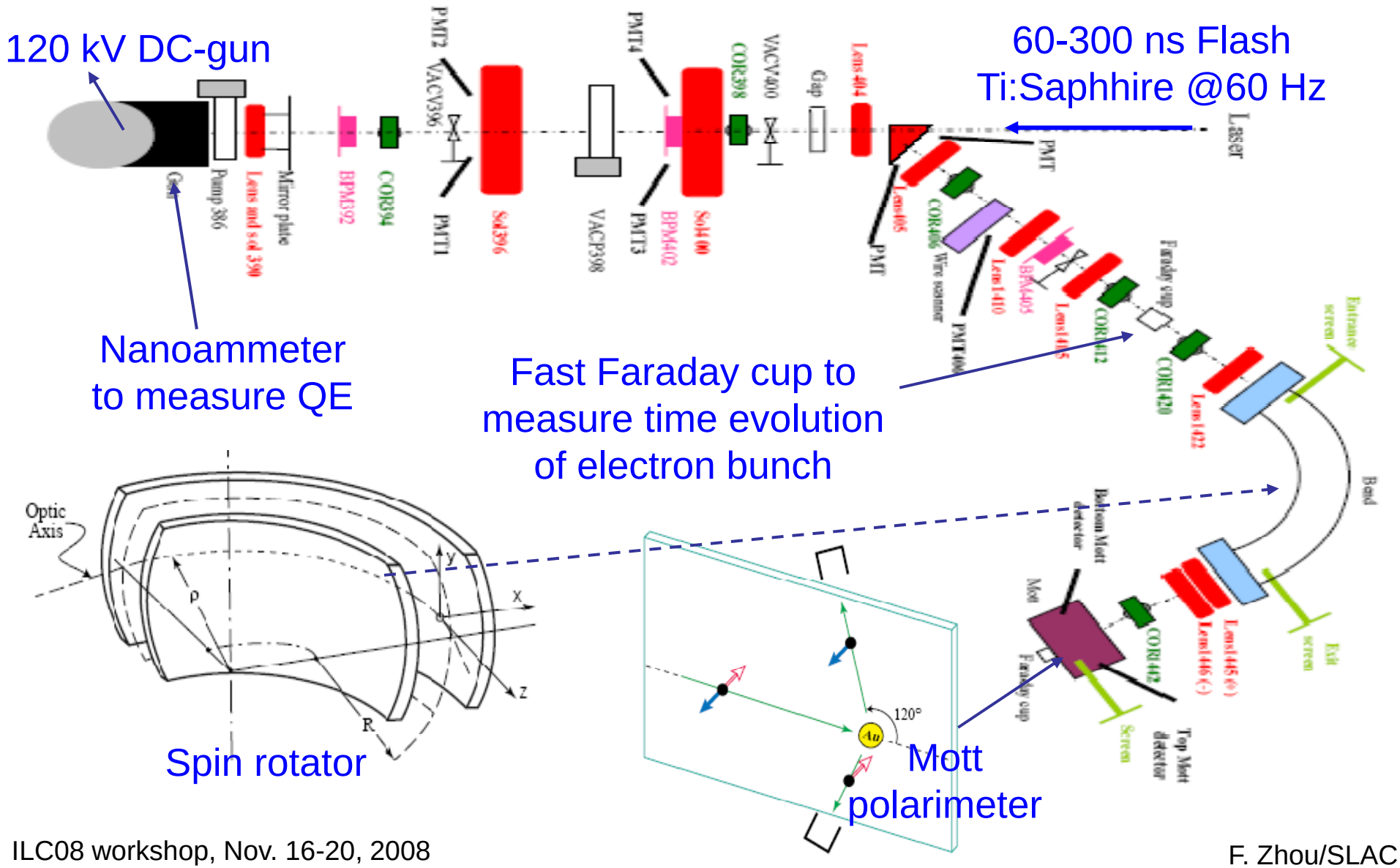




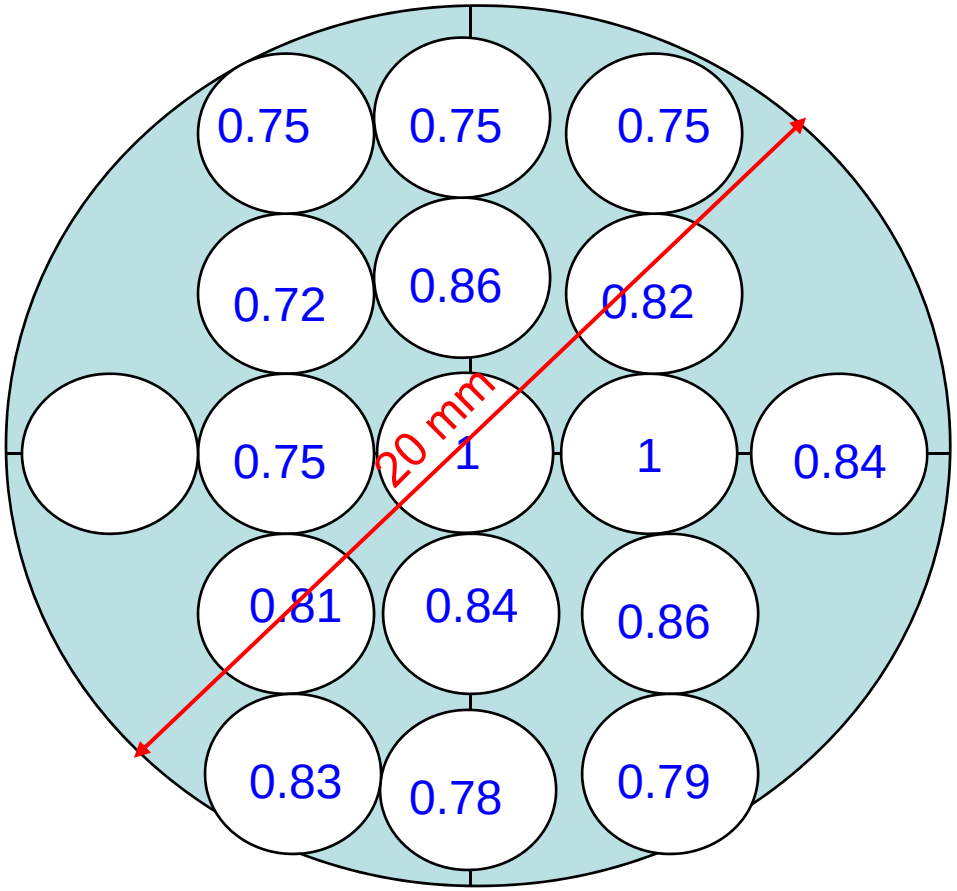
Capabilities at SLAC's Gun Test Lab

- Re-established all measurements at GTL after three-year down time:
  - Surface charge limit (time evolution of bunch)
  - QE and QE lifetime
  - Polarization
- Recent/future activities at SLAC's GTL:
  - Samples of InAlGaAs/AlGaAs (measurements done)
  - Internal graded sample $Al_xGa_{(1-x)}As/GaAs$
  - To demonstrate full charge production once it is mated to ILC and CLIC lasers
  - Funded R&D programs on new cathodes
- GTL is also available for other R&D projects, such as test different electrodes and guns.

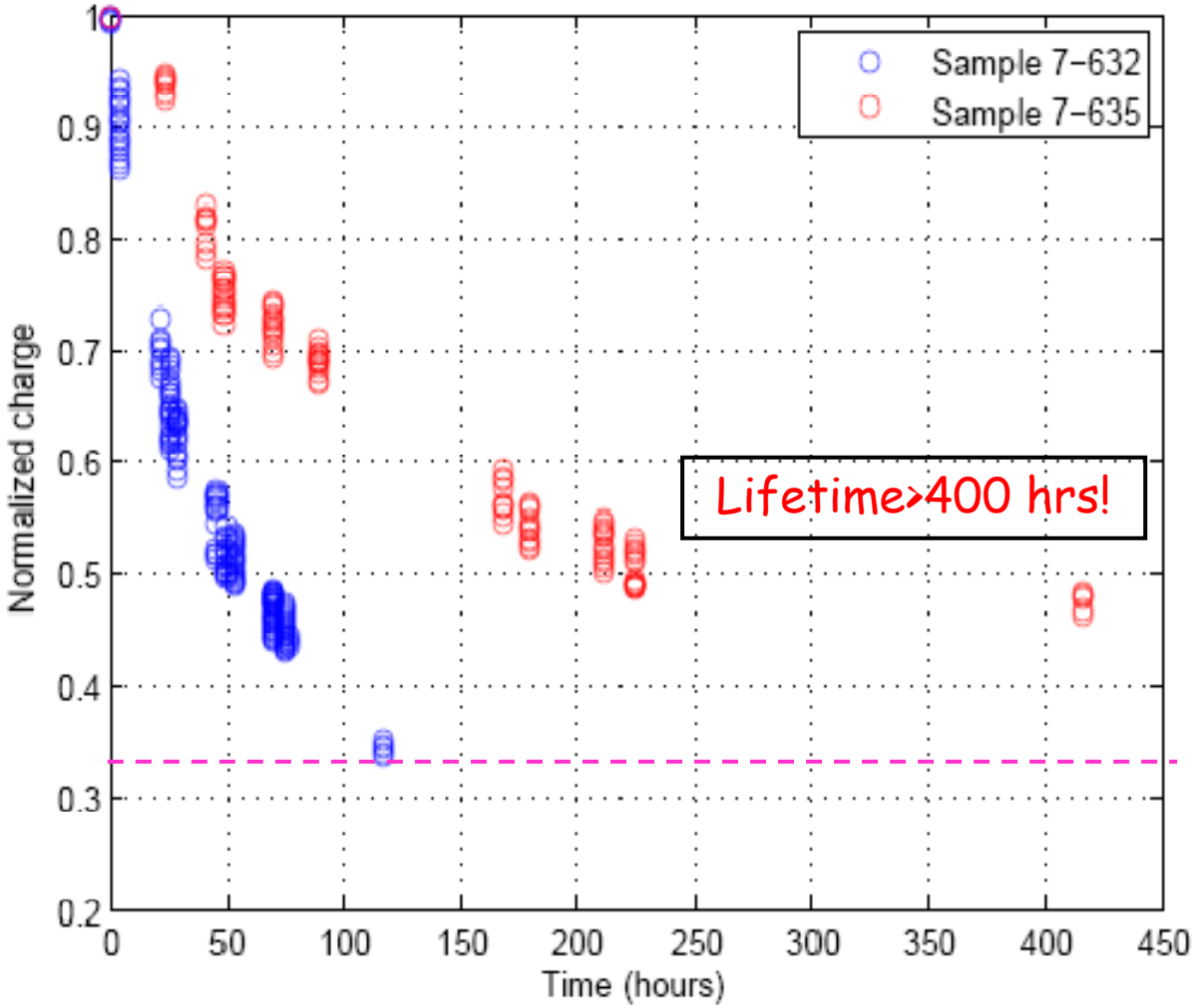
SLAC's GTL layout



InAlGaAs/AlGaAs: QE uniformity



InAlGaAs/AlGaAs: QE lifetime

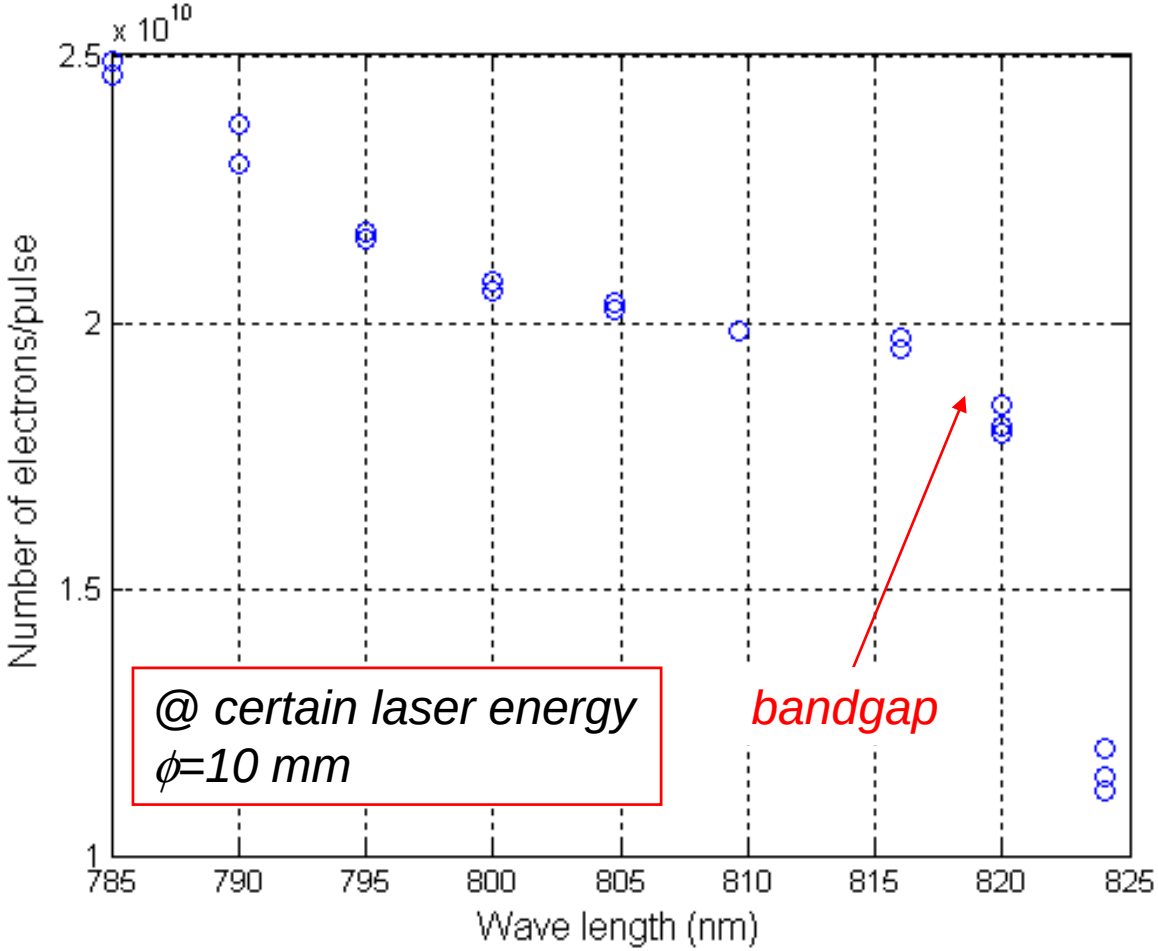


Only difference:

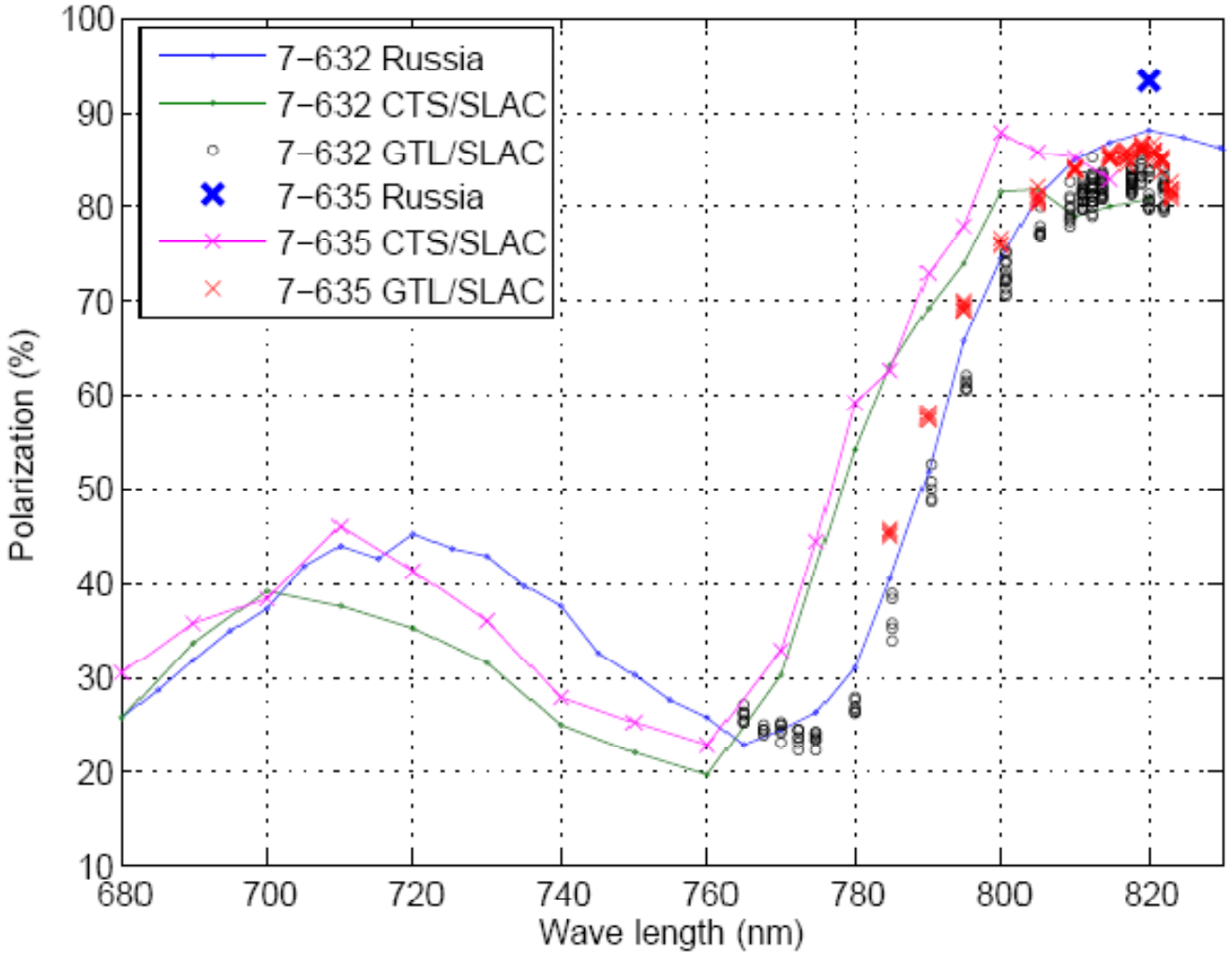
7-632 12 periods active layers

7-635 8 periods of active layer

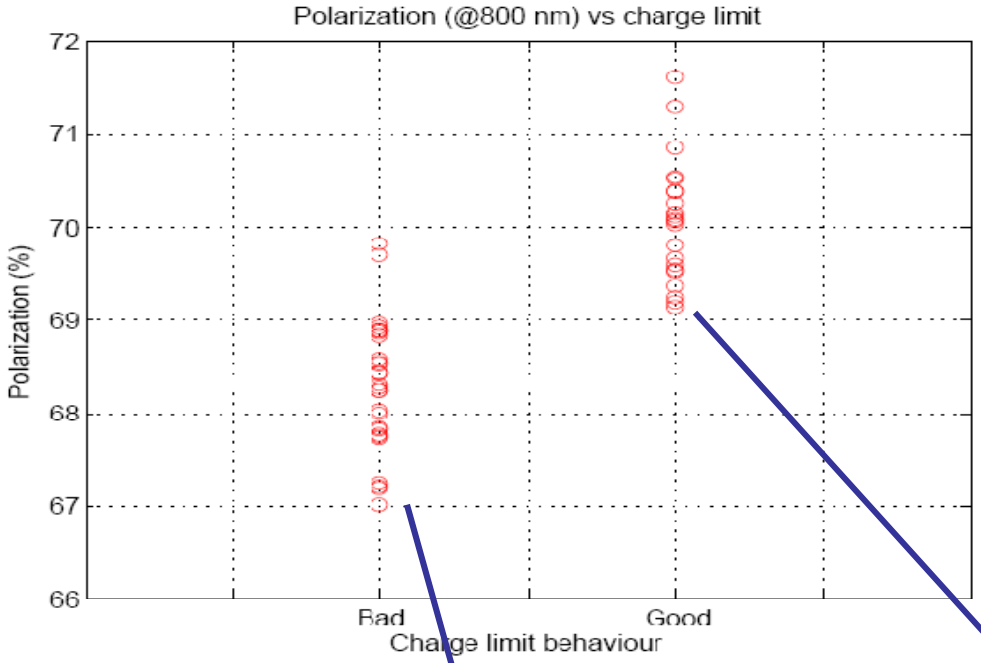
InAlGaAs/AlGaAs: bandgap



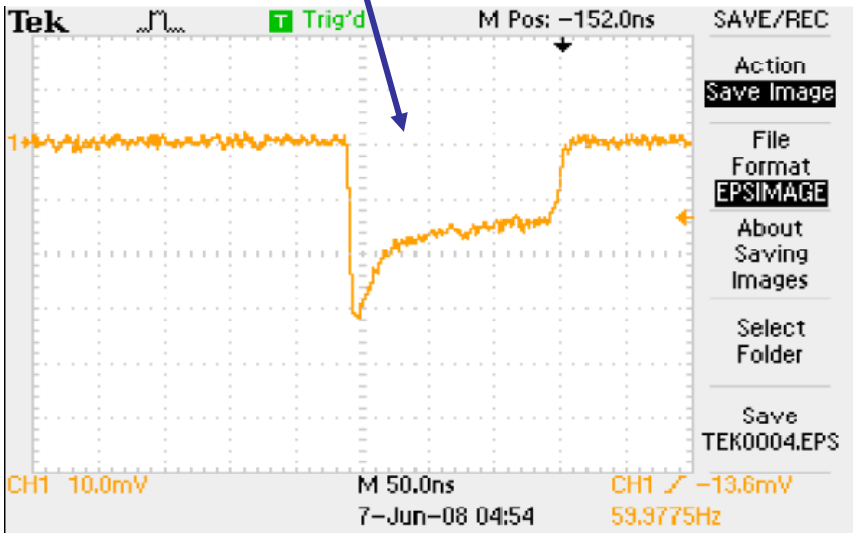
InAlGaAs/AlGaAs: polarization measurements

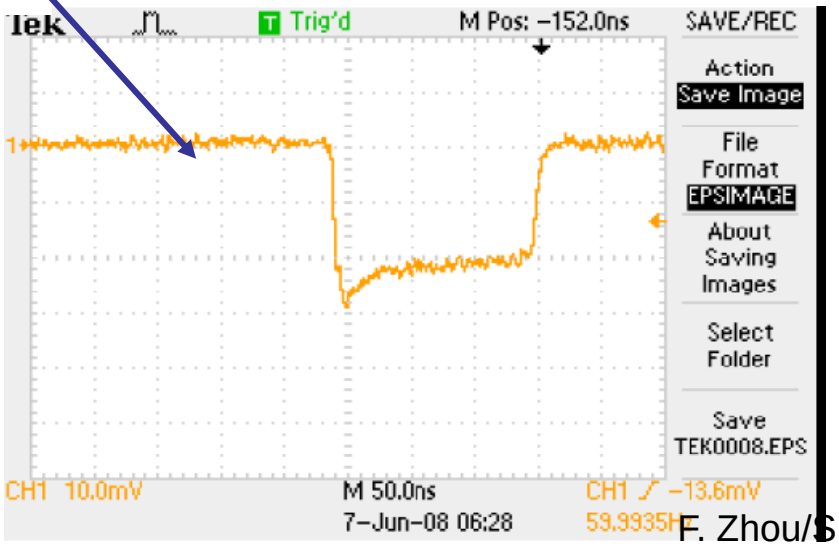


InAlGaAs/AlGaAs: polarization vs surface charge limit



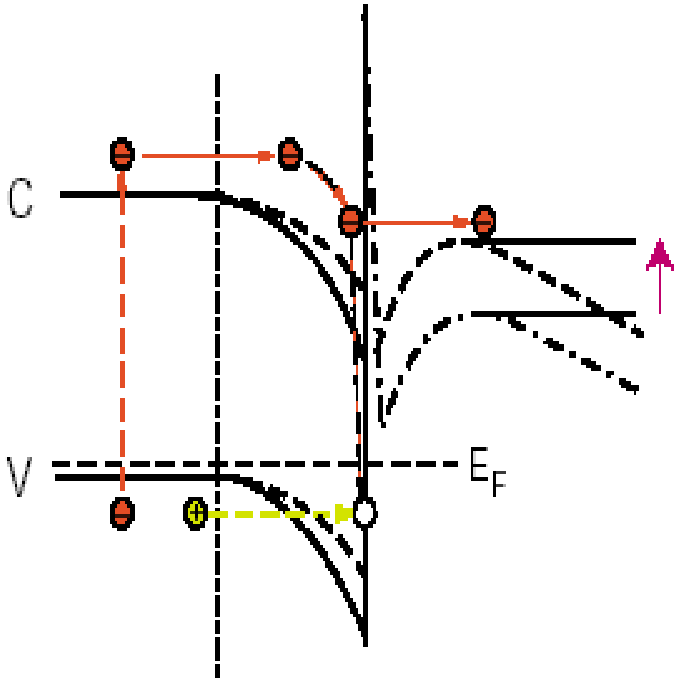
- The cathode is driven into saturation, electrons photoexcited into conduction band can still escape if they diffuse to a non-saturated region.
- But, these electrons spend long time inside structure so it is likely that they suffer spin relaxation.



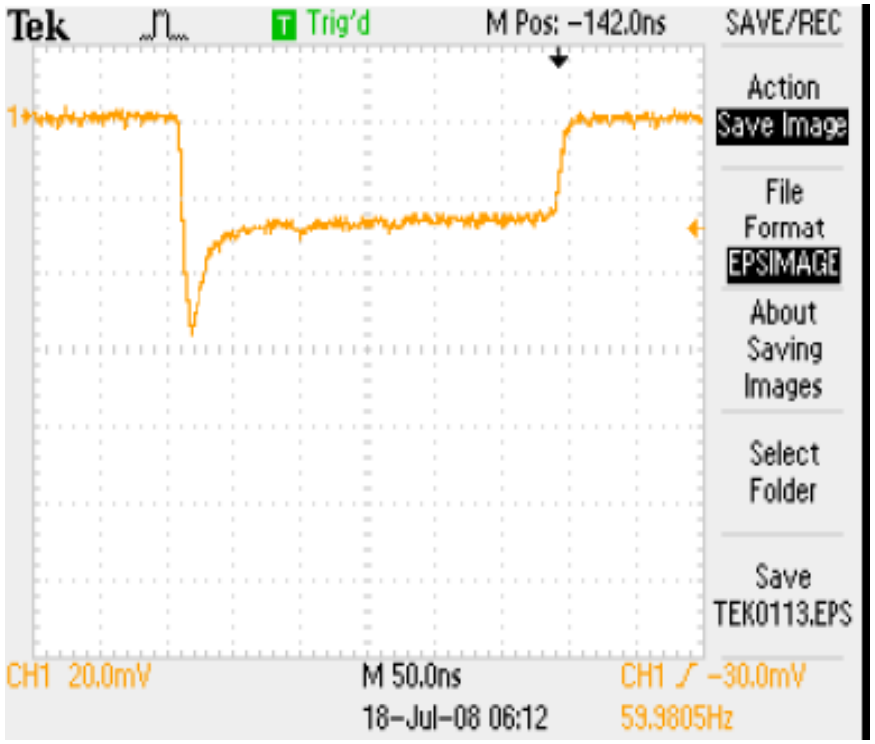


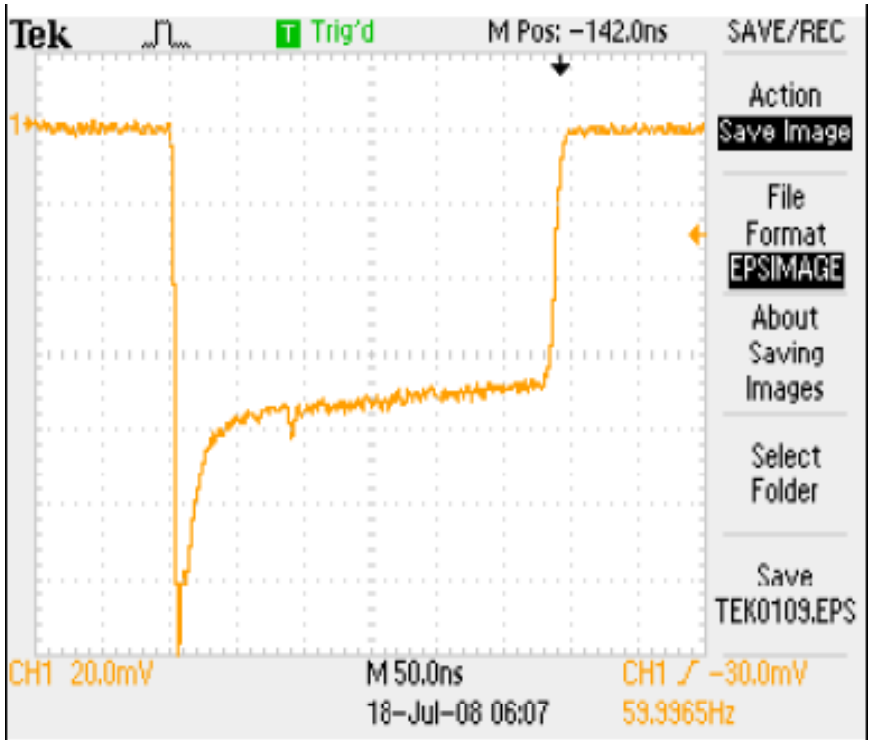
Surface photovoltaic effect – surface charge limit

- 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.



Surface charge: laser energy

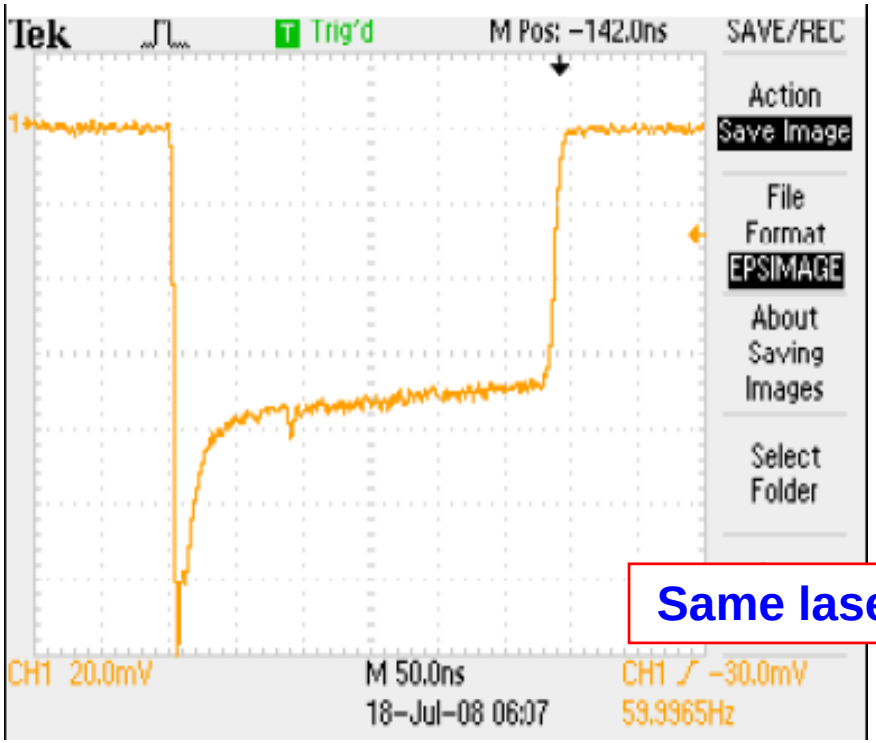


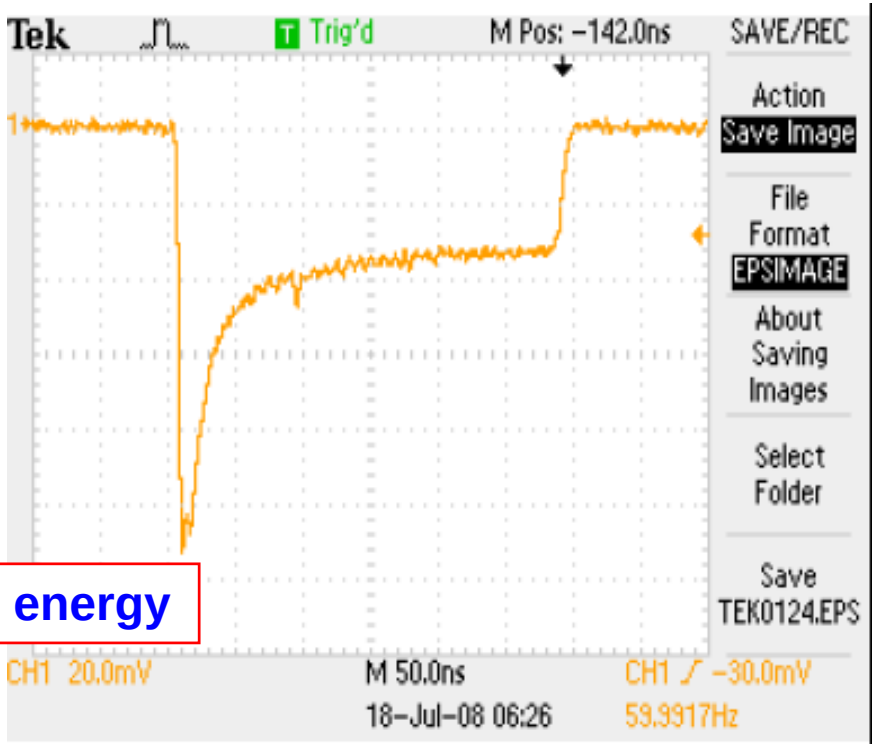


0.73x10^{10} e- @ 1x laser energy
10 mm full size

2.5x10^{10} e- @ 8x laser energy
10 mm full size

Surface charge: laser location



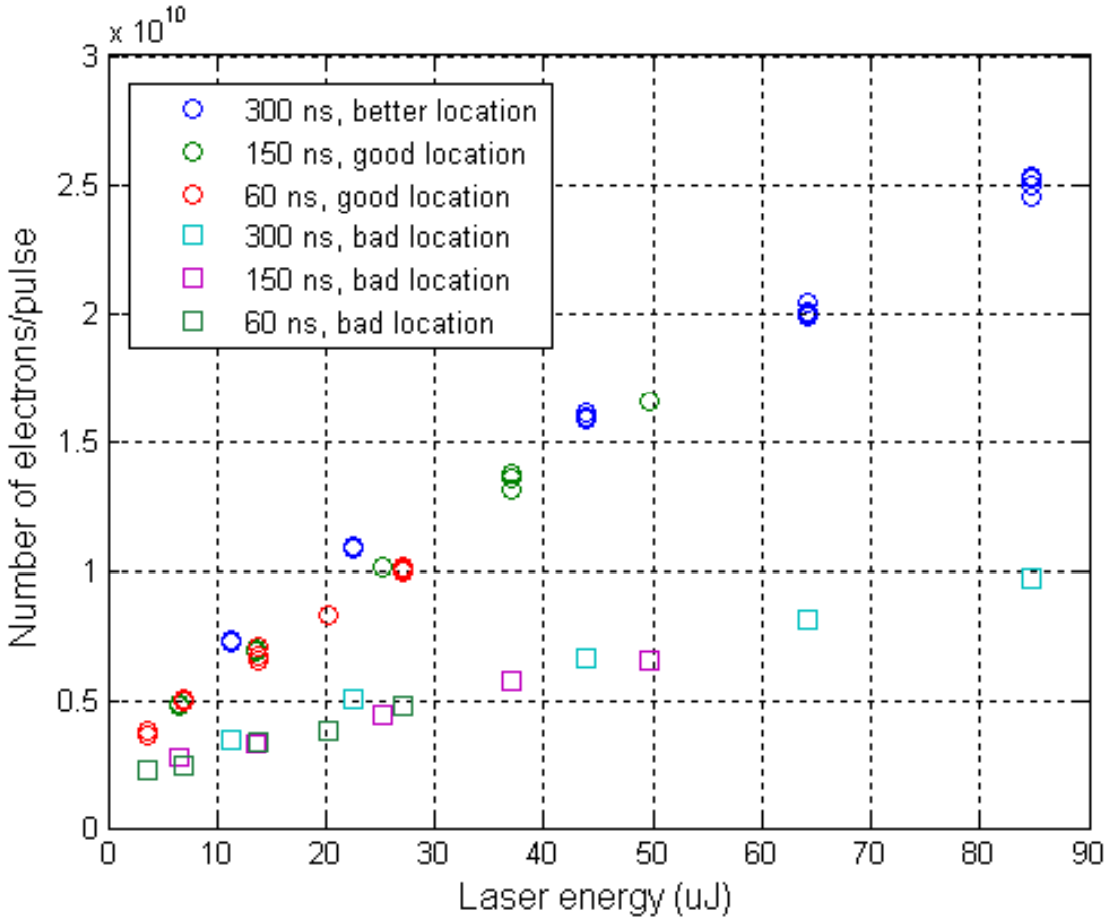


Same laser energy

2.5x10^{10} e- production
10 mm full size @ good location

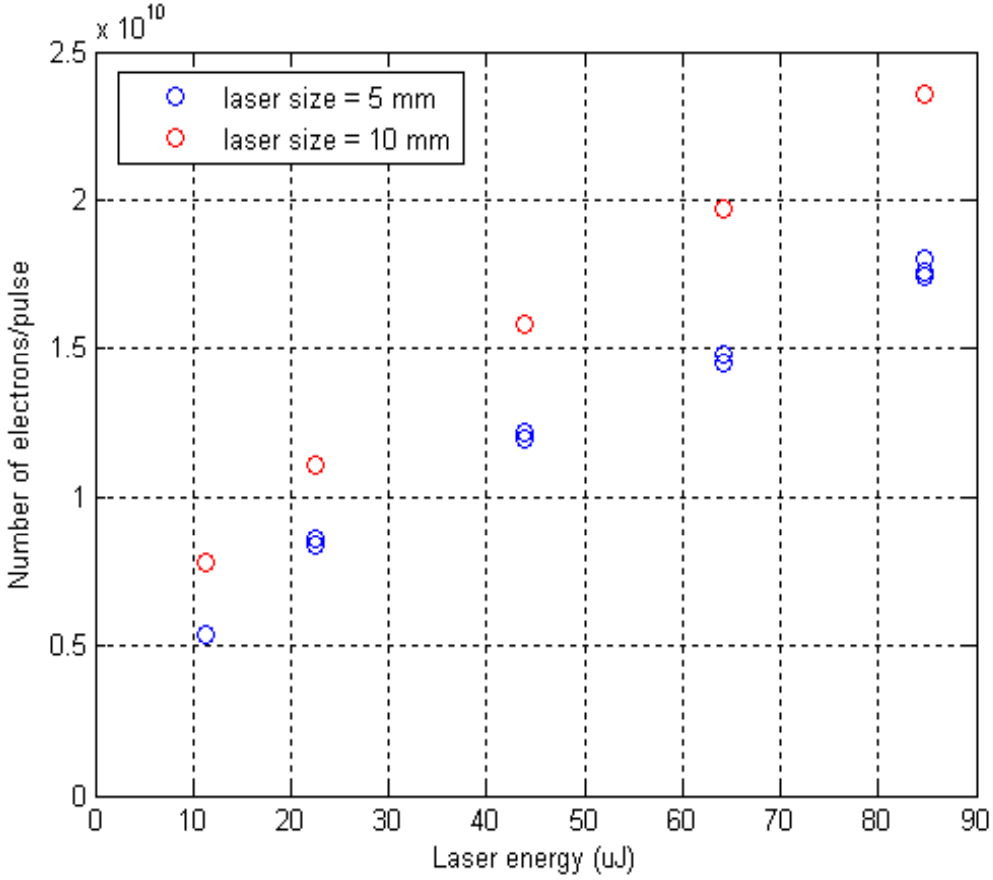
1.4x10^{10} e- production
10 mm full size @ bad location

Charge limit: laser energy



10 mm laser full size

Charge limit: beam size

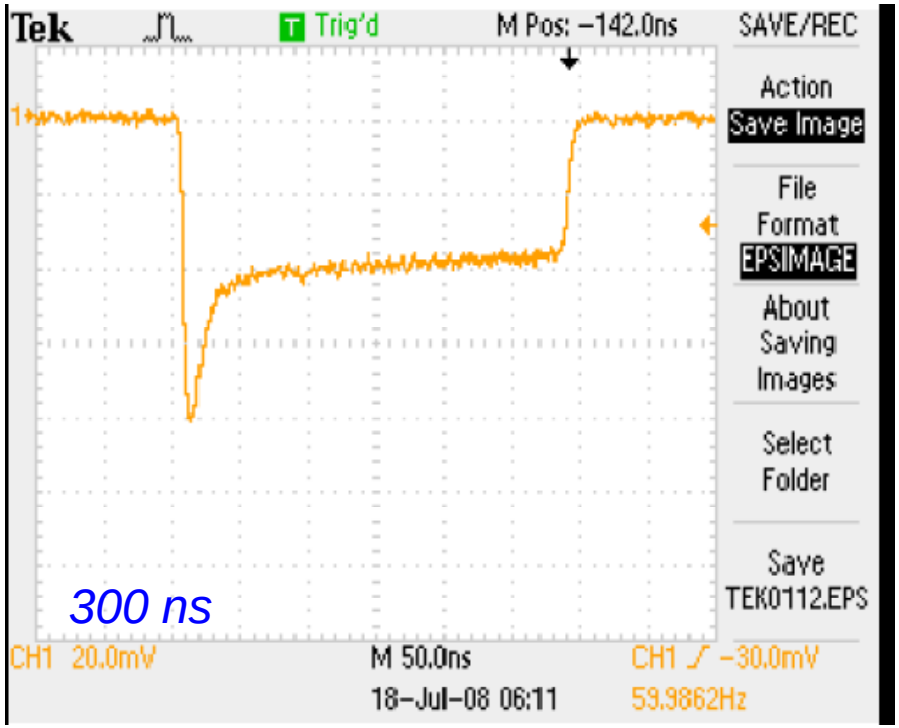


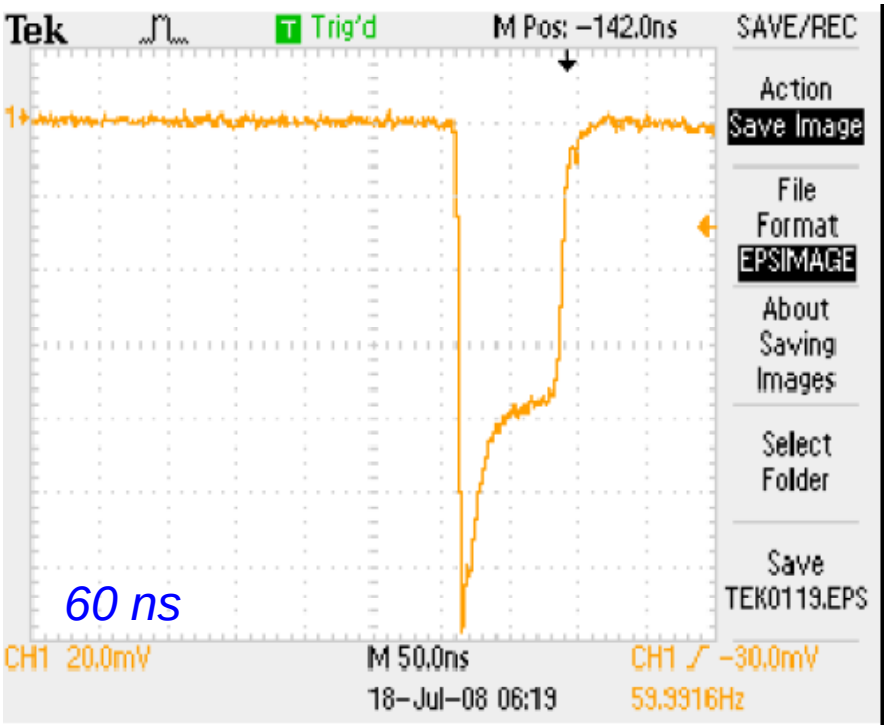
- Space charge (Child's law)

  $J_0=(2.33\text{x}10^{-6})V^{3/2}/d^2$

  J_0 =10 A/cm^2 @ GTL gun
- Take beam parameters d=5mm, Q=3.75 nC, 300 ns, J_0 =0.06 A/cm^2
- Space charge negligible at current conditions; thus surface charge limit dominates at smaller size with 7x10^{18}/cm^3 of doping at the surface layer.

Surface charge: pulse length





same laser energy
10 mm laser full size

And what about at 1 ns?

What's the possible indications from the measurements for ILC and CLIC: surface charge & space charge?

	ILC	CLIC
Microbunch	300 ns →1 ns Surface charge better Space charge worse	300 ns → 100 ps Surface charge better Space charge much worse
Macropulse	1 ms (360 ns spacing) Accumulated surface charge may be much worse?	156 ns (0.5 ns spacing) Surface charge may accumulate
Current intensity (r=1cm)	1.5 A/cm^2 Surface charge and space charge combined; Surface charge may be serious in macropulse?	3.0 A/cm^2 Space charge serious; Surface charge may accumulate in macropulse

Summary and plans

- Measurements for InAlGaAs/AlGaAs cathode at SLAC:
  - **0.2-0.3% QE but can be increased to 1% level after Atomic hydrogen cleaning.**
  - **QE lifetime is very long >400 hrs!**
  - **86% polarization compared with 93% of Russian data**
  - **However, surface charge limit is observed, current intensity 0.06 A/cm^2 @ 7x10^{18}/cm^3 of doping in surface. We need to tune the cathode parameters.**
  - **First observation of polarization dependence on surface charge limit.**

Summary and plans (con't)

- To demonstrate full charge production (surface charge and space charge) for the ILC once its laser ready. The ILC laser expected ready in the early of next year.
- To improve baseline cathode GaAs/GaAsP in the next few yrs with SBIR supports:
  - Study doping level in the structure of GaAs/GaAsP
  - Gradient doping in the active layer
  - Apply both techniques into GaAs/GaAsP
- To study alternate cathodes: tune InAlGaAs/AlGaAs parameters

Doping level in GaAs/GaAsP

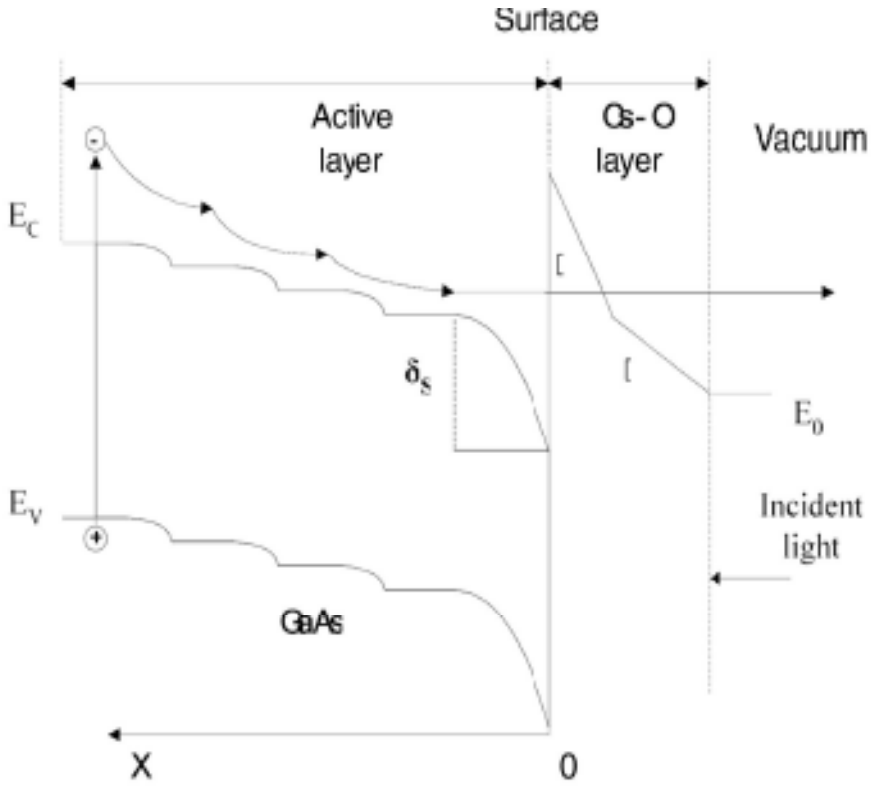
- Doping level at least affects:
  - Smearing band edge and broadening hole spectrum
  - Spin relaxation in transport stage; BAP process - one of major mechanisms -, exchange interaction between electrons and holes:

$$\frac{1}{\tau_s} = N_h \sigma_{BAP} v$$

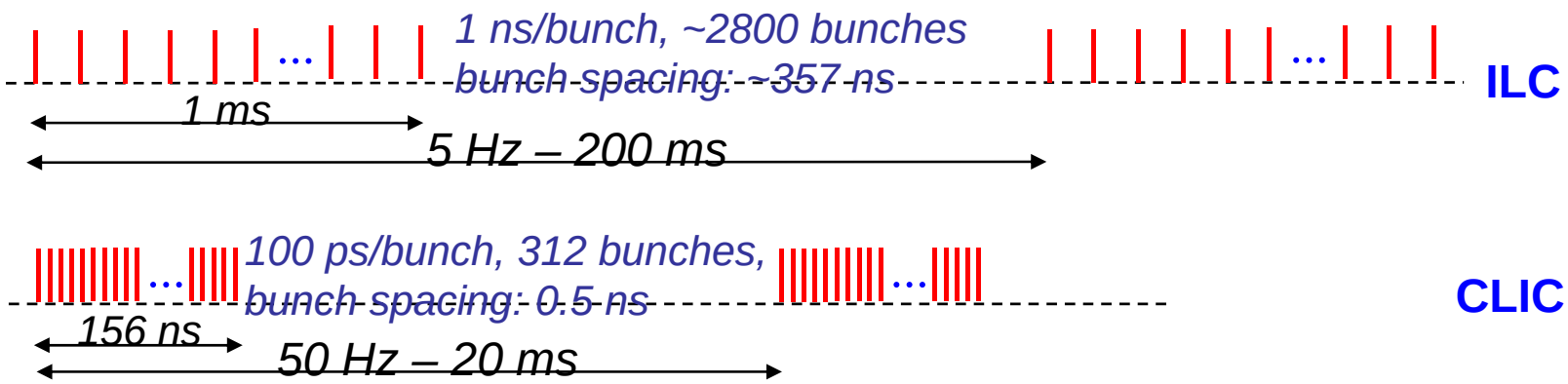
  - Spin relaxation in BBR
  - Surface charge limit

Gradient doping in the active layer

- Electrons are accelerated when getting through band-bending regions
- High QE expected
- Much interest in gradient doping in the active layer of SL structure.



Summary and plans (con't)



- To demonstrate CLIC-like beam production by using existing 76 MHz ML oscillator (13 ns spacing) or real CLIC laser.
- SLAC's dc-Gun Test Lab with multi-lasers is a worldwide unique diagnostic to characterize polarized photocathodes for both ILC and CLIC: charge limit, polarization, QE, and QE lifetime.