Demonstration of the CLIC Polarized Electron Source
October, 2009

A. Brachmann, T. Maruyama, J. C. Sheppard, F. Zhou
SLAC

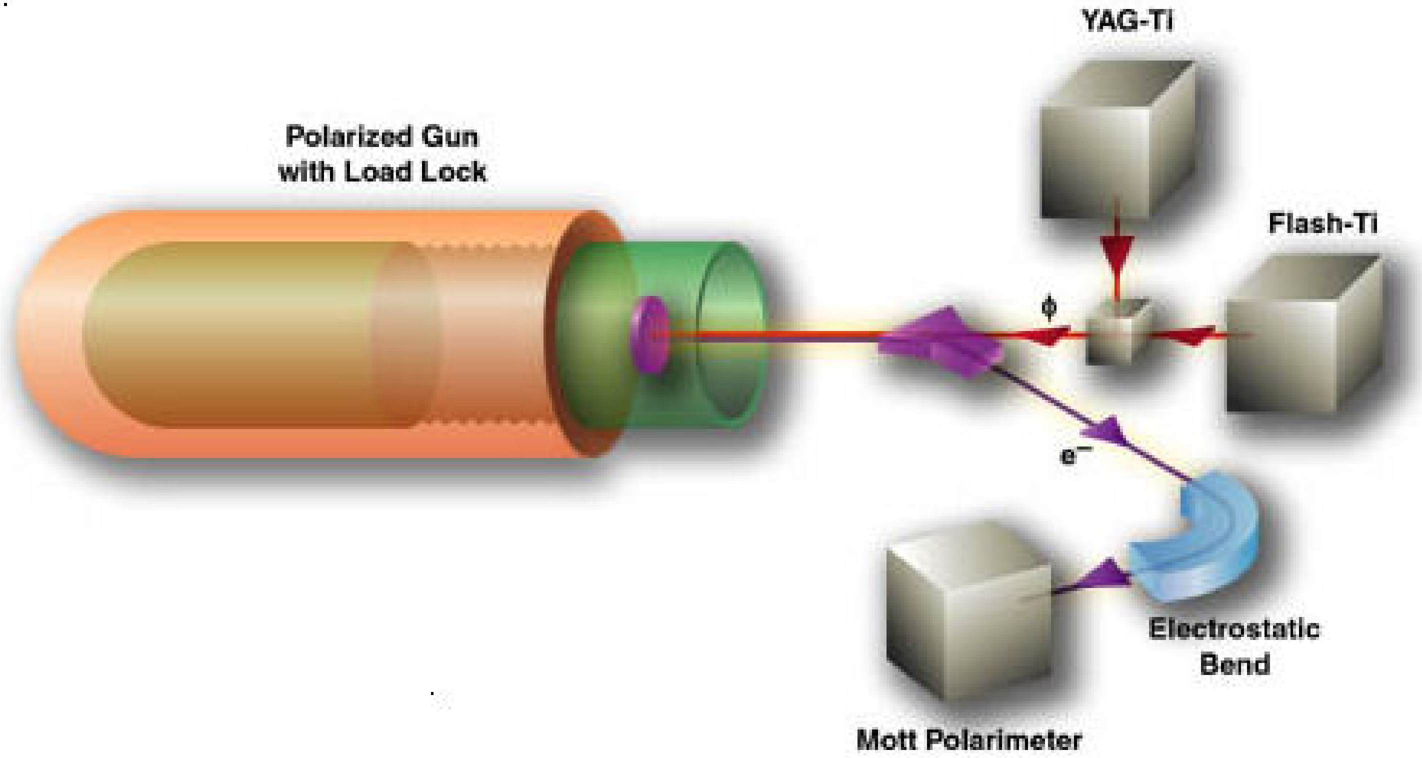
Proposal

It is proposed that SLAC group demonstrate full charge extraction of polarized electrons suitable for use as the CLIC electron source.

Proposal

This work will be accomplished in part by modifying the existing Flash-Ti laser system to produce a 156 ns, cw optical pulse at the requisite power level. The modified laser system will be used to illuminate cathodes in the existing 120 kV dc gun located in the B006 Gun Test Facility.

CLIC Electron Beam Demo



Proposal

In addition, rf capture will be simulated using Paramela to both estimate the overall capture efficiency and to specify the design requirements of the bunching and capture systems. SLAC will work with the CLIC source group to develop performance specifications.

Schedule

Expect to try this before September, 2009 depending on other activities. Need to understand limitations (with existing equipment). If limited, will make corrections in FY2010.

Further along (2012?), will put SLAC cathode and laser together with JLab HV gun.

GOALS

The major goals for photocathode development at SLAC for the ILC and CLIC are:

1) demonstration of full charge production without space charge and surface charge limitation;
2) >85% polarization;
3) ~1% QE and long QE lifetime.

CLIC Electron Beam Demo

TABLE 1). Major parameters of the ILC and CLIC high-current high-polarization electron sources.

Parameters	**ILC**	**CLIC (3GeV)**
Electrons Per Microbunch	$3x10^{10}$	$6x10^{9}$
Number Of Microbunch	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 Dc-Gun	63 μA	15 μA
Peak Current Of Microbunch	4.8 A	9.6 A
Current Intensity (1cm Radius)	1.5 A/cm^2	3.0 A/cm^2
Polarization	>80%	>80%

CLIC Laser Requirements

There are two approaches to the CLIC laser: develop a 2 GHz optical pulse train, chopped and amplified to the proper pulse length and bunch energy or develop a 156 ns cw optical pulse and use an rf system to do all of the electron bunching. The former approach will possibly ease the requirements on the rf bunching system but will not eliminate the need for rf bunching. The CLIC injector linac rf system will run at 2 GHz. This in combination with the damping ring eliminates the concerns of interbunch satellites being generated with the use of a cw optical pulse.

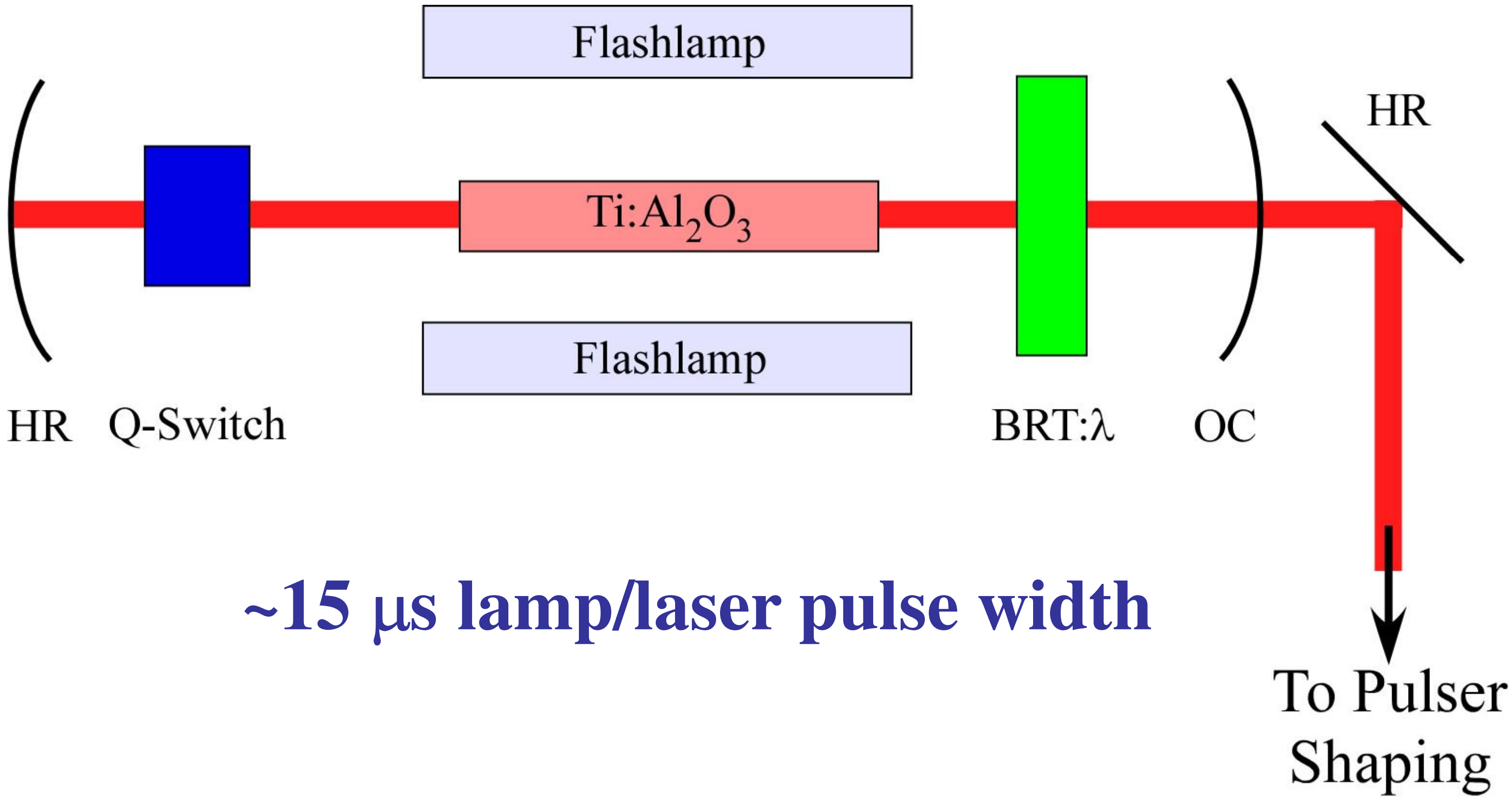
CLIC Electron Beam Demo

Parameter	Symbol	Value	Units	Comments
Electrons per bunch	n_b	6×10^9	#	CLIC spec.
Bunches per pulse	N_b	312	#	CLIC spec.
Pulse length	T_P	156	ns	CLIC spec.
Repetition rate	f_{rep}	50	#	CLIC spec.
Photon energy	$h\nu$	1.6	eV	775 nm
Quantum Efficiency	QE	0.25	%	Optimistic(?)
Capture efficiency	ξ_{rf}	70	%	E158 experience
Overhead factor	f	2	#	Arbitrary

Optical Pulse energy	E_P	548	μJ	
Optical Peak Power	P_P	3.5	kW	
Optical Average Power	P_{avg}	27	mW	

CLIC Electron Beam Demo: Laser

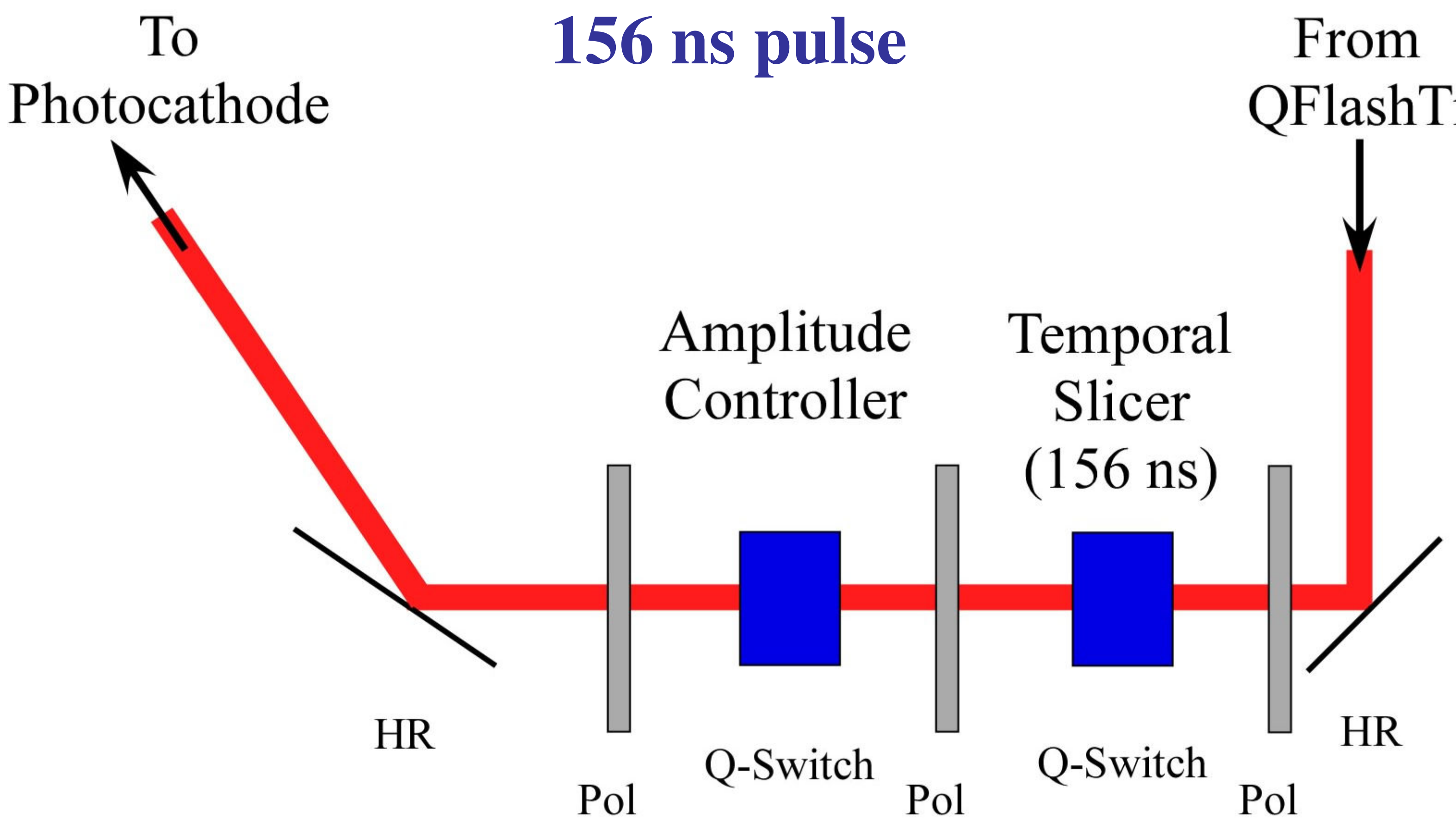
Flash lamped pumped Ti:sapphire laser

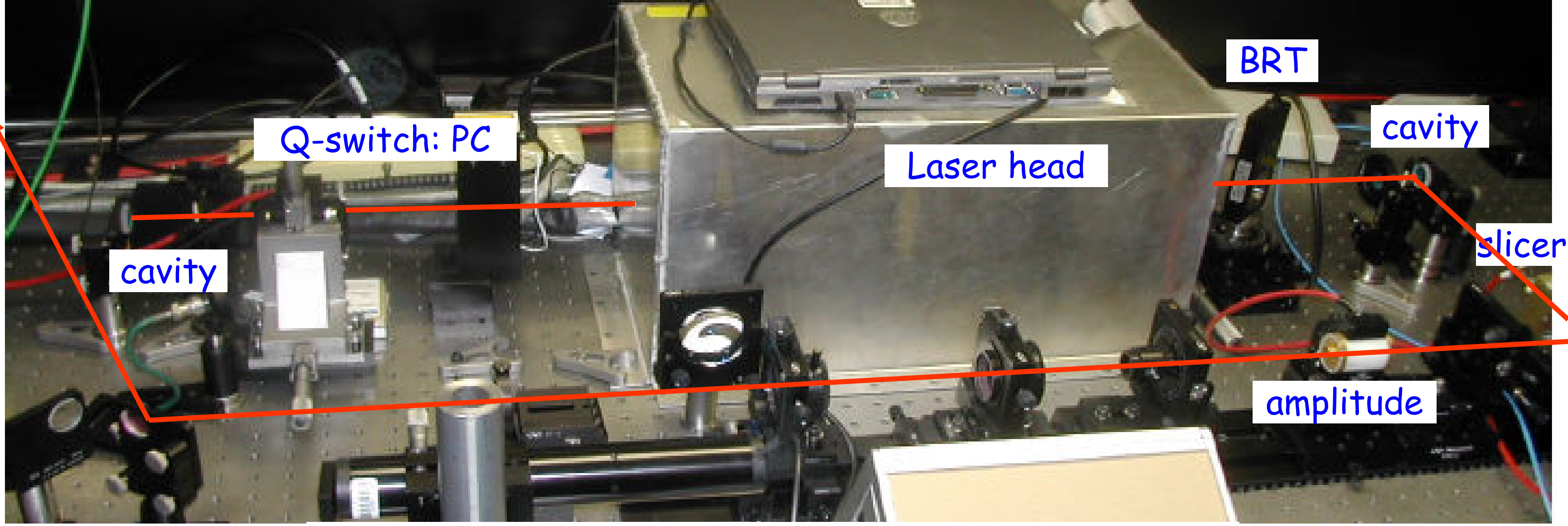


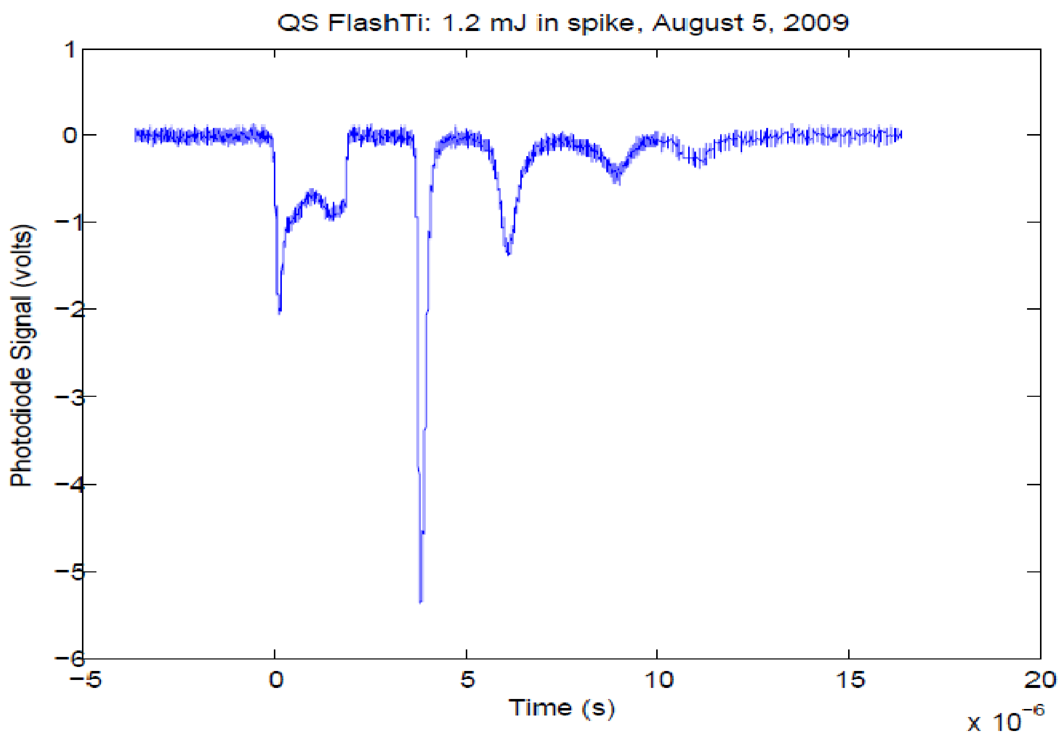
~15 μs lamp/laser pulse width

CLIC Electron Beam Demo: Laser

Pulse Slicing and Amplitude Control







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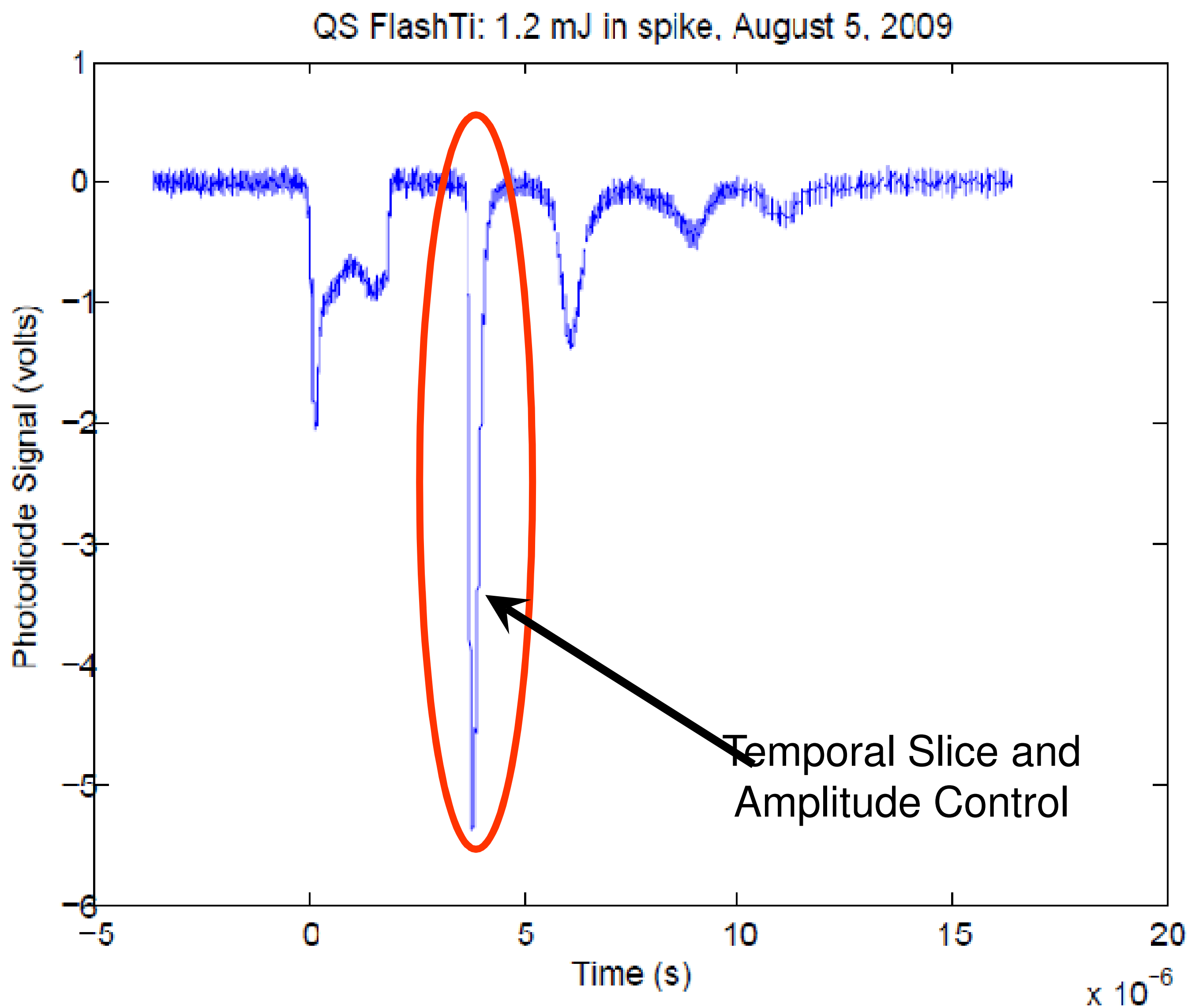
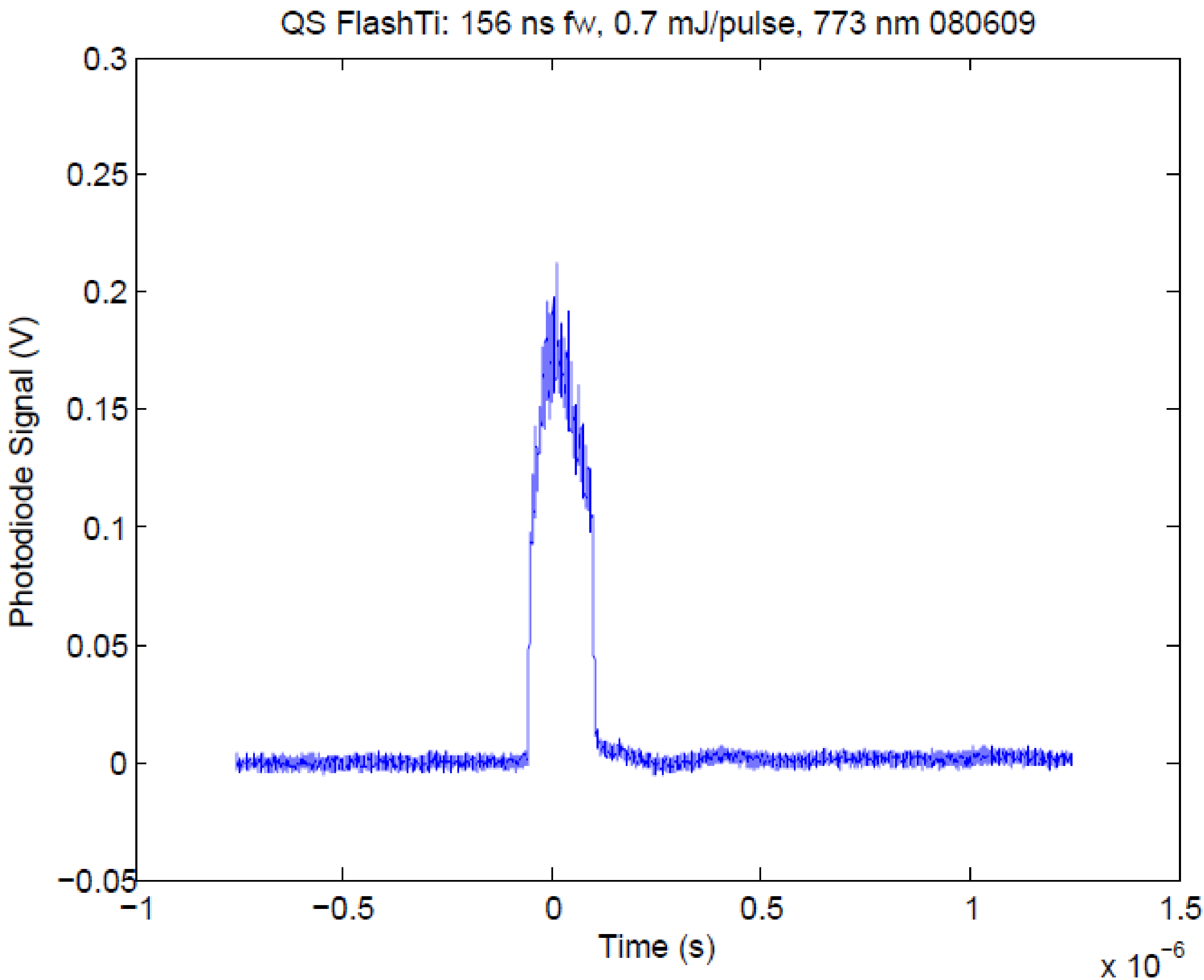
With Brachmann and Sheppard

PPA Particle Physics & Astrophysics

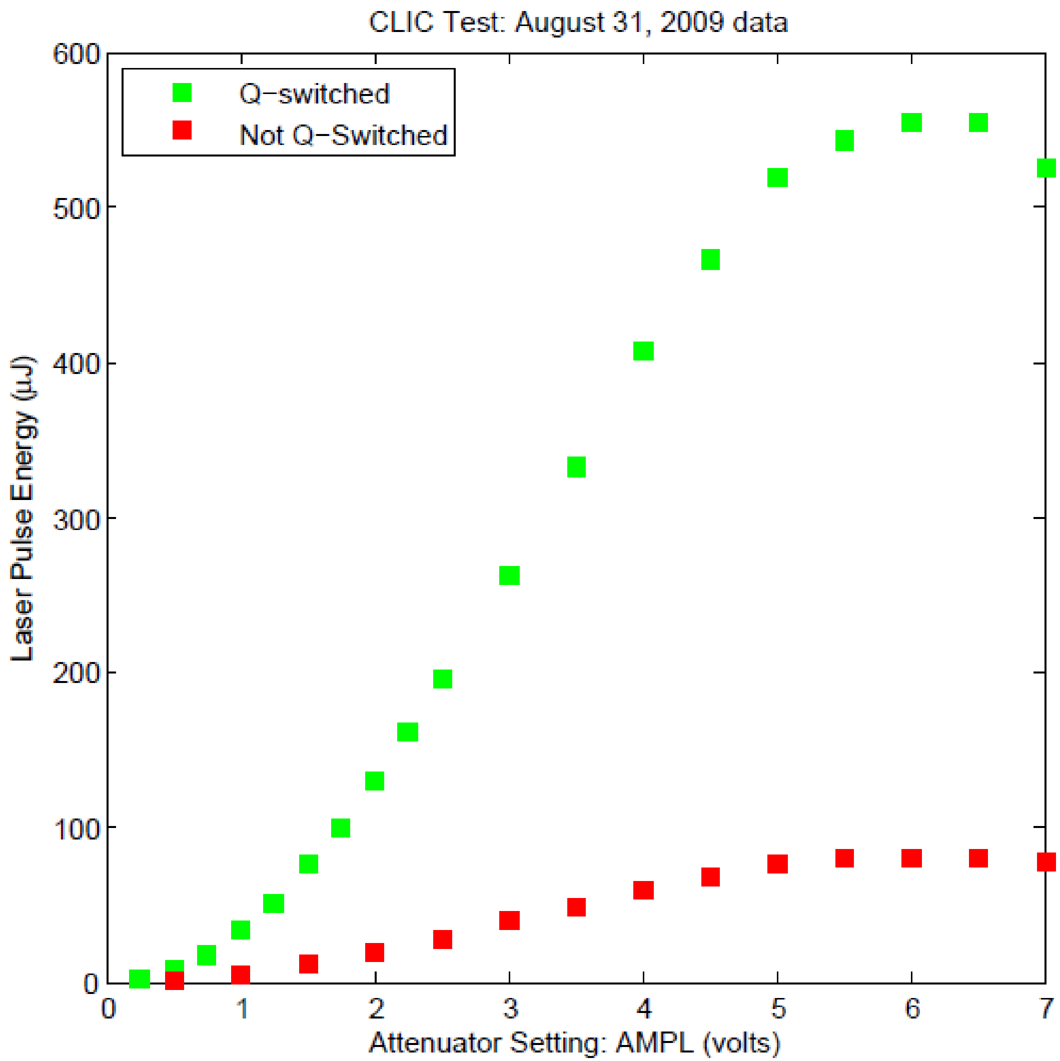
CLIC Electron Beam Demo: Laser



CLIC Electron Beam Demo: Laser



CLIC Electron Beam Demo: Laser



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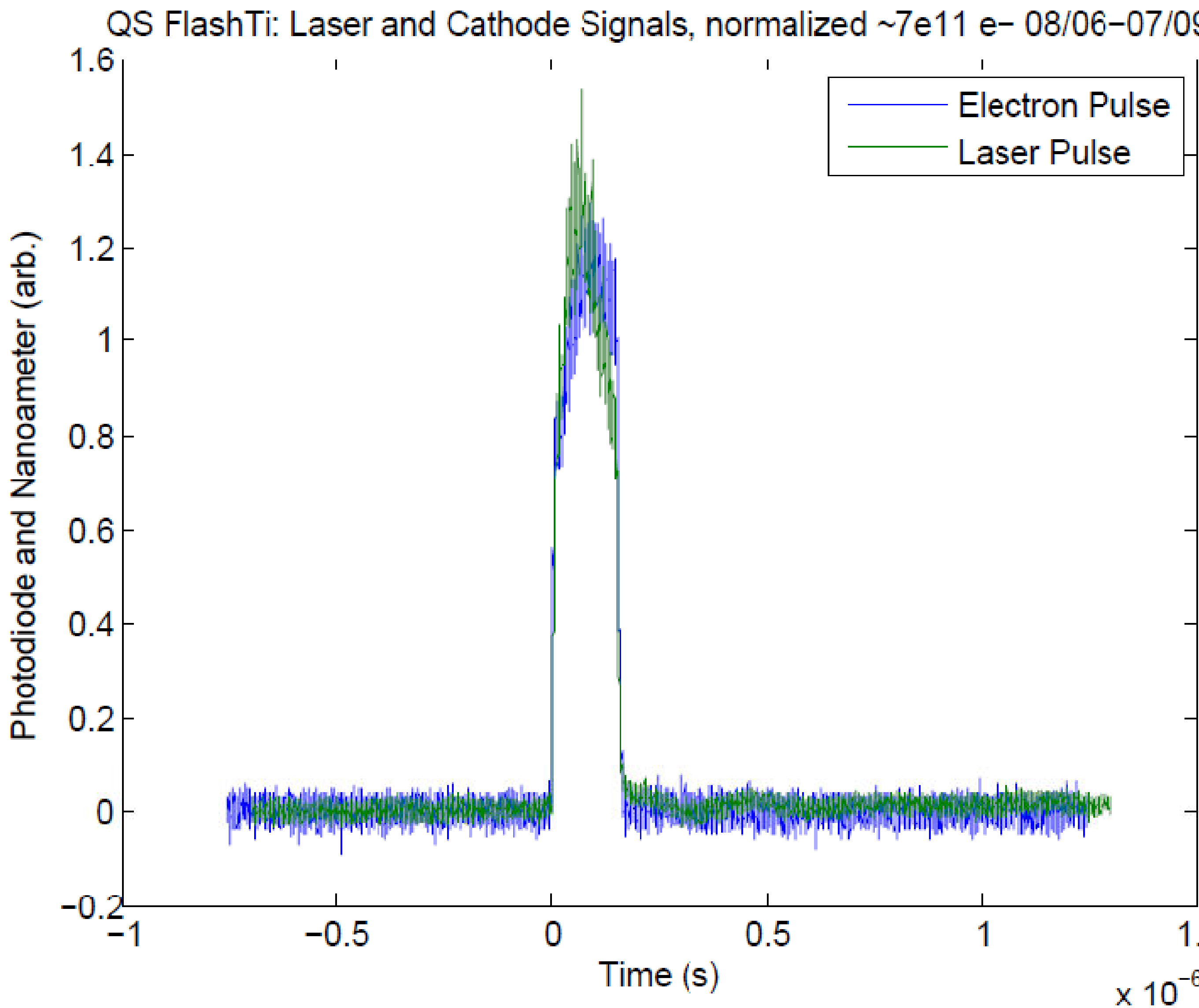
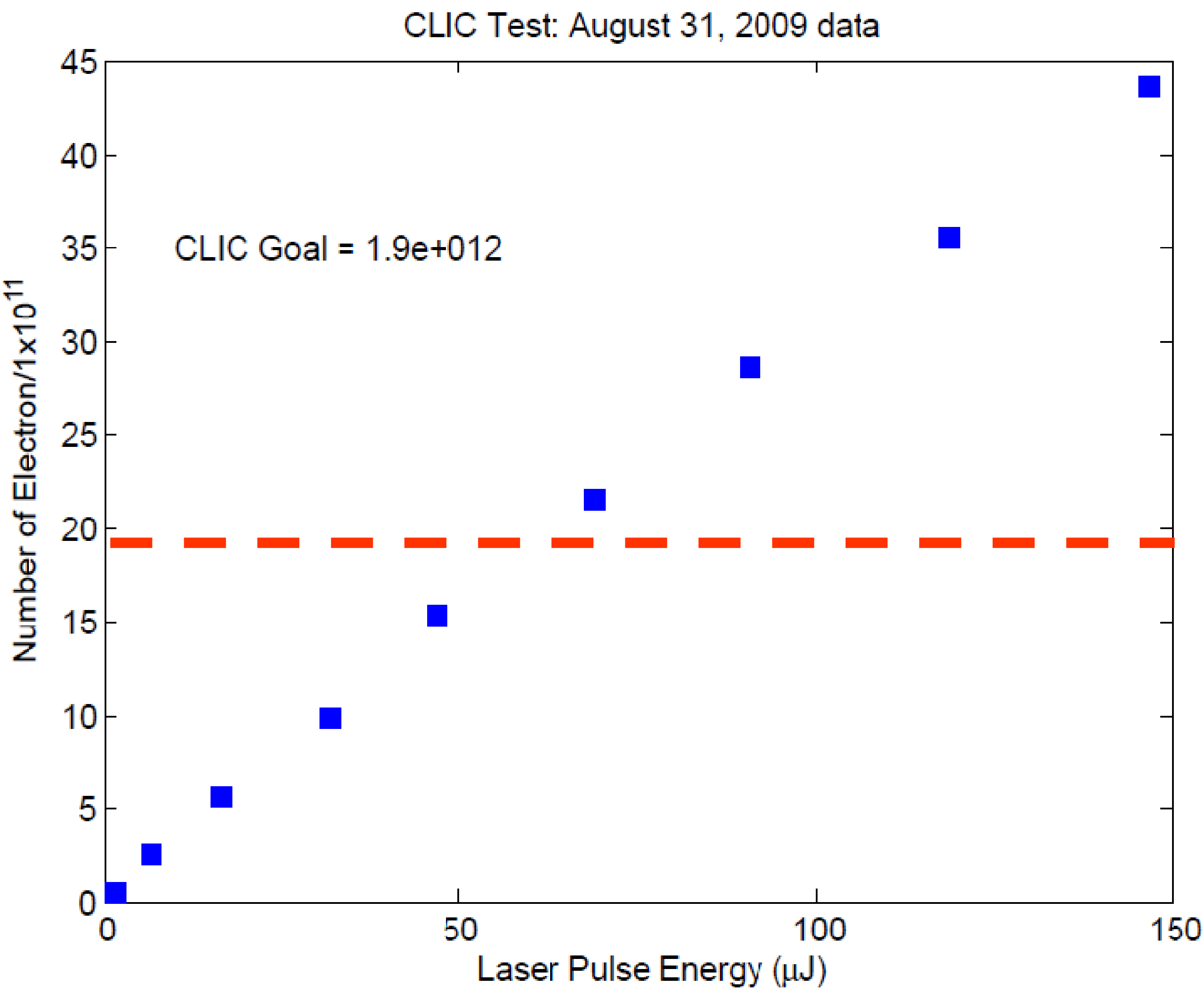
PPA Particle Physics & Astrophysics

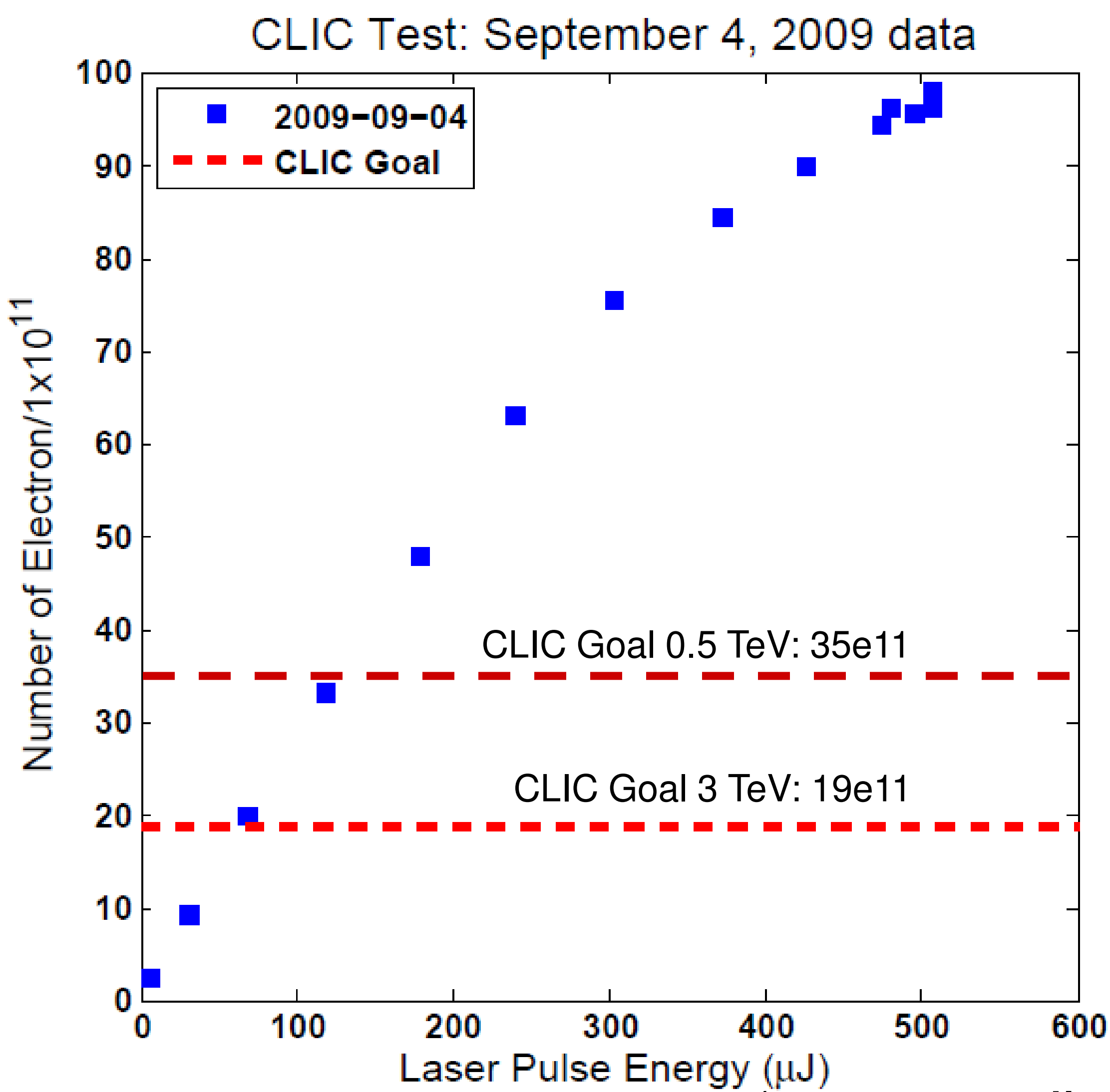
CLIC Electron Beam Demo: Electron Beam



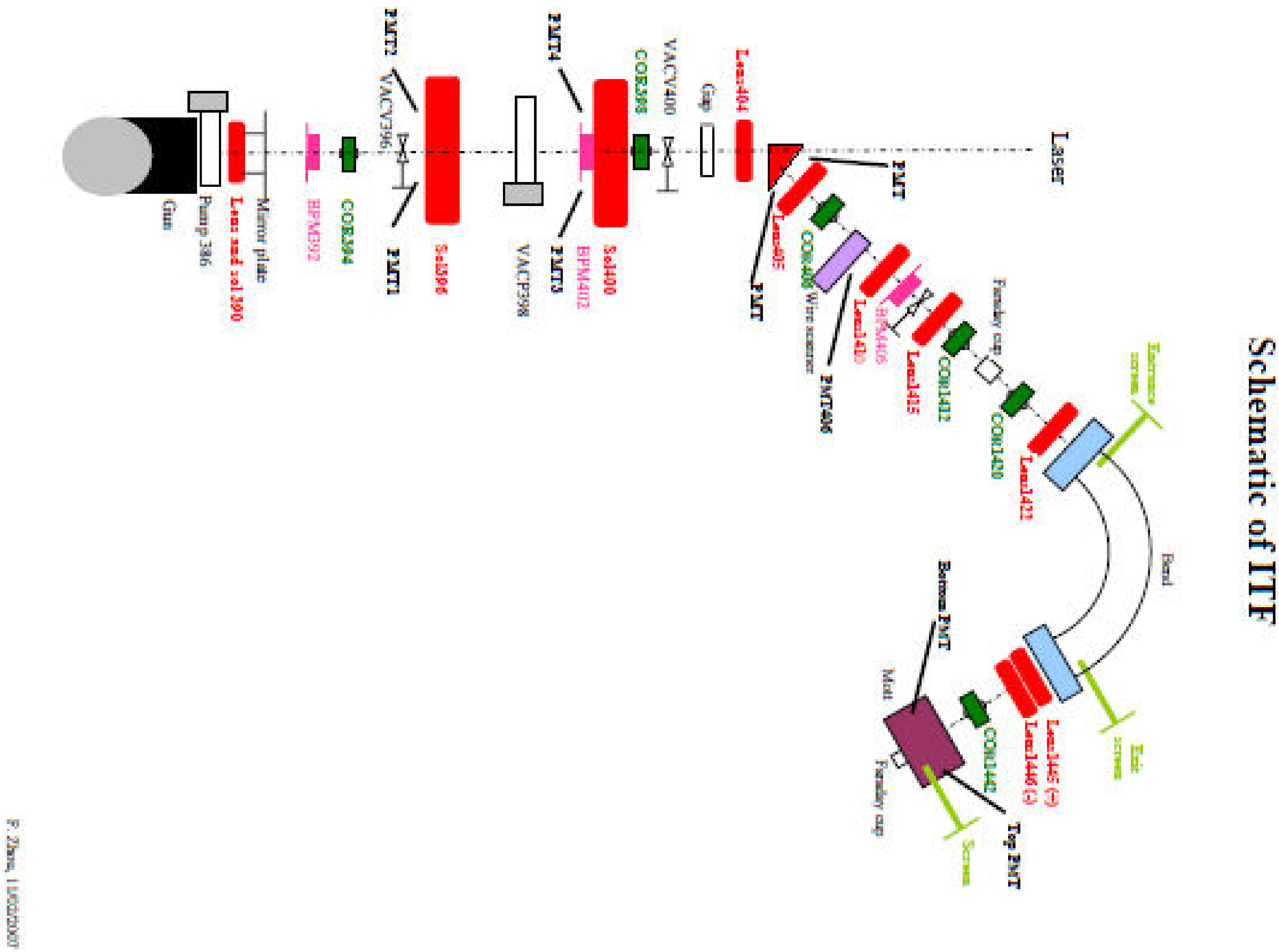
CLIC Electron Beam Demo: Electron Beam



CLIC Electron Beam Demo: Electron Beam



CLIC Electron Beam Demo: Polarization



CLIC Electron Beam Demo: Polarimetry

PROCEEDINGS OF THE ROYAL SOCIETY A | MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Scattering of Fast Electrons by Atomic Nuclei

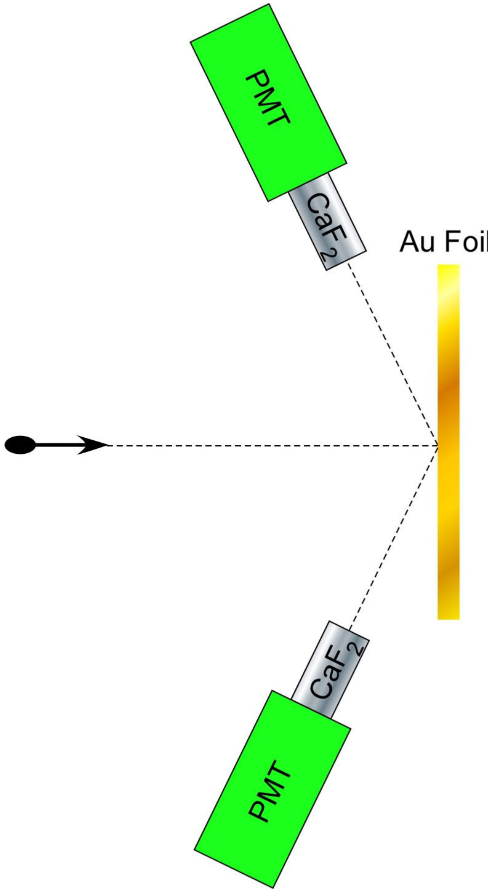
N. F. Mott

Proc. R. Soc. Lond. A 1929 **124**, 425-442
doi: 10.1098/rspa.1929.0127

CLIC Electron Beam Demo: Polarimetry

Mott Polarimetry:

Scatter electrons off a gold foil and measure up-down asymmetry



CLIC Electron Beam Demo: Polarization

Need to say something about polarization measurements

Polarization is ~85%. Measured at low Q. Are exploring how to make a hi Q measurement; difficulties with PMT/DAQ saturation and possibly space charge voltage loading. No previous evidence of polarization decrease with charge

ILC numbers are good from SLC running at 2 ns gun pulses and 7e10/pulse

CLIC Electron Beam Demo: Bunching

slac-pub-13780

Preliminary design of a bunching system for the CLIC polarized electron source

F. Zhou, A. Brachmann, and J. Sheppard
Updated on 09/2/2009

Table I: Major parameters of the ILC and CLIC electron sources

E-source parameters	ILC	CLIC (original) [1]	CLIC (SLAC proposed)
Number of microbunches @cathode	2625	312	1 DC beam
Electrons/(micro)bunch @cathode	5 nC	0.96 nC	300 nC
Number of microbunches @injector	2625	312	312
Width of (micro)bunch @cathode	1.3 ns	~100 ps	156 ns DC
Width of microbunch @injector	20 ps	-	14 ps
Micropulse repetition rate @cathode	3 MHz	2-GHz	-
Microbunch repetition rate @injector	3 MHz	2-GHz	2-GHz
Width of Macropulse	1 ms	156 ns	156 ns
Macropulse repetition rate	5 Hz	50 Hz	50 Hz
Charge per macropulse	13125 nC	300 nC	300 nC
Average current from gun	66 µA	15 µA	15 µA
Peak current @cathode	4.0 A	9.6 A	1.9 A
Current intensity @1cm radius	1.25 A/cm^2	3.0 A/cm^2	0.64 A/cm^2
Polarization	>80%	>80%	>80%

CLIC Electron Beam Demo: Bunching

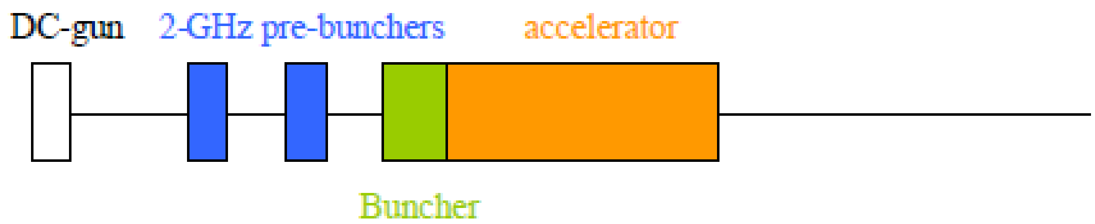


Figure 1: The schematic layout of bunching system for CLIC electron source.

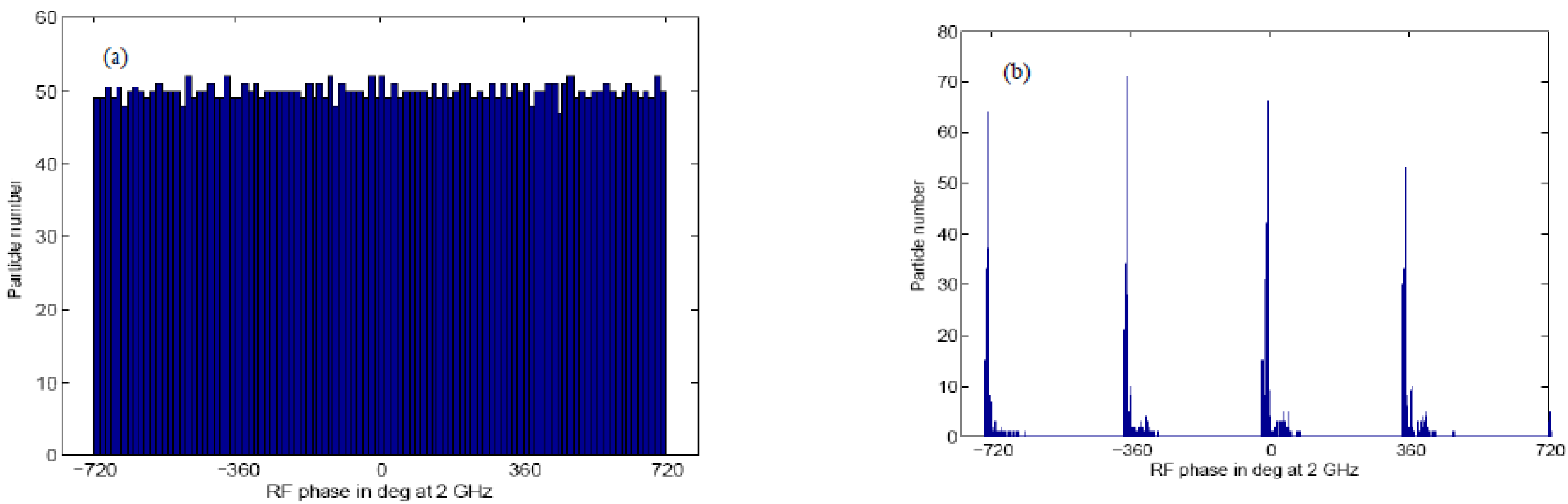


Figure 3: Initial pulse duration (a) on the cathode, and final bunched pulse structure (b) at 19 MeV

CLIC Electron Beam Demo: Bunching

Conclusion and outlook

A bunching system to generate a train of microbunches with 2-GHz repetition rate from a macropulse for the CLIC injector is preliminarily designed and modeled. The tracking shows that 88% of electrons from the DC-gun are captured within a window of 30ps×0.45MeV at 19-MeV. Looking toward the technical design, more detailed work is needed including: (1) adding more RF structures to get energy at about 80 MeV; (2) bunching system optimizations to meet the engineering design; (3) detail definitions of system components.

CLIC Electron Beam Demo: Summary

- Full Q extraction from cathode: 5x 3 TeV and 3x 0.5 TeV specifications
- QE ~1% with "normal" lifetime…..still under study, depends primarily on gun vacuum rather than anything else
- Polarization is ~85%, thinking about how to measure this at full charge
- Bunching simulations show 88% capture of cw beam pulse
- Long term goal is to "marry" cathode, laser, and JLab gun

? QUESTIONS?

Back Up Slides

CLIC Electron Beam Demo

For a cw optical pulse, the pulse energy required is E_P:

$$E_P = fqh\nu \frac{n_b N_b}{\xi_{rf} QE}$$

Wherein f is an arbitrary overhead factor on the order of unity; $h\nu$ is the laser photon energy, n_b is the number of electrons per microbunch, N_b is the number of microbunches per pulse, ξ_{rf} is the capture efficiency of the rf bunching system, and QE is the cathode quantum efficiency for electron emission.

CLIC Electron Beam Demo

The peak optical power from the laser is

$$P_P = \frac{E_P}{T_P}$$

where T_P is the pulse width.

The average laser power is P_{avg}:

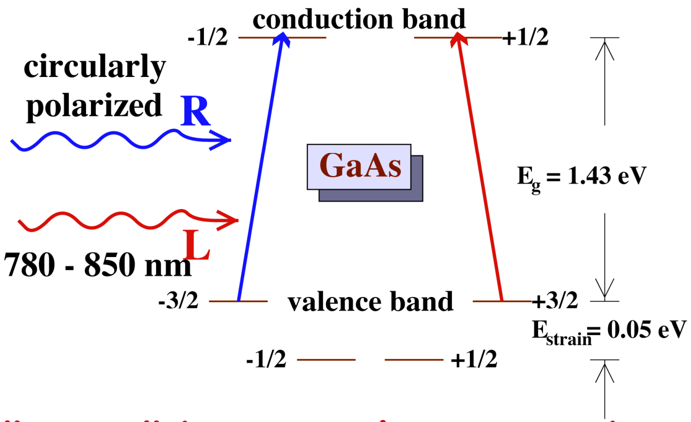
$$P_{avg} = f_{rep} E_p$$

CLIC Electron Beam Demo

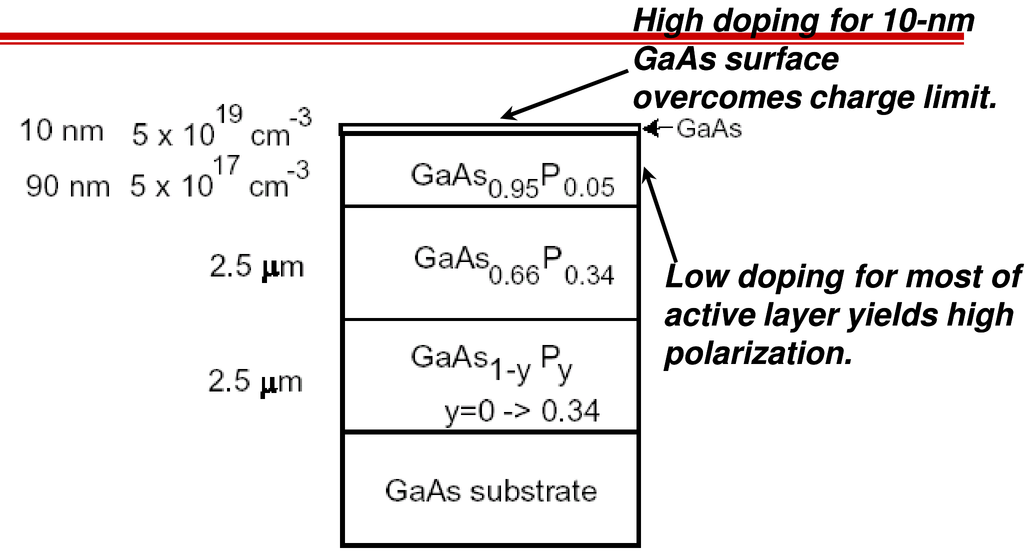
Table 3: 2 GHz optical pulse train requirements

Parameter	Symbol	Value	Units	Comments
Electrons per bunch	n_b	6×10^9	#	CLIC spec.
Bunches per pulse	N_b	312	#	CLIC spec.
Pulse length	T_P	156	ns	CLIC spec.
Repetition rate	f_{rep}	50	#	CLIC spec.
Photon energy	$h\nu$	1.6	eV	775 nm
Quantum Efficiency	QE	0.25	%	Optimistic(?)
Capture efficiency	ξ_{rf}	85	%	Arbitrary Estimate
Overhead factor	f	1.5	#	Arbitrary
Optical microbunch length	t_b	50	ps	1-100 ps
Optical microbunch energy	E_b	0.9	µJ	
Optical peak power	P_b	18	kW	
Optical Pulse energy	E_P	288	µJ	in 156 ns
Optical Peak Power	P_P	1.8	kW	Averaged over 156 ns
Optical Average Power	P_{avg}	14	mW	At 50 Hz

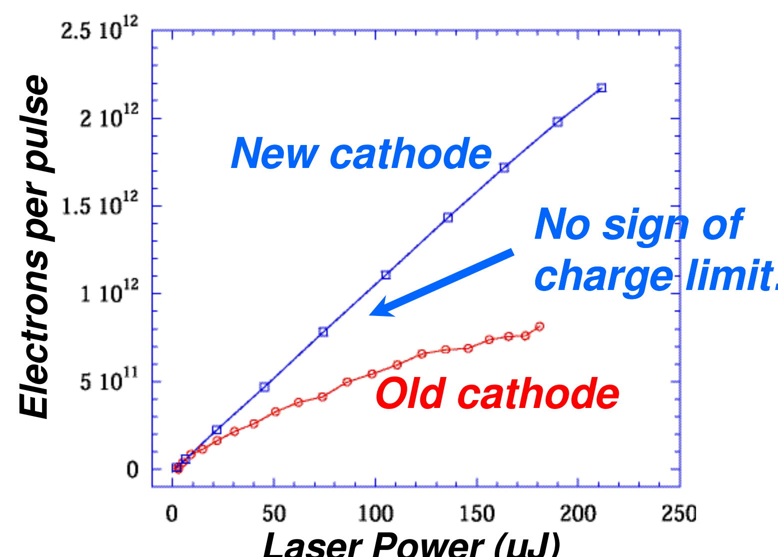
E158: Polarized Beam



"strain" boosts polarization, but introduces anisotropy in response

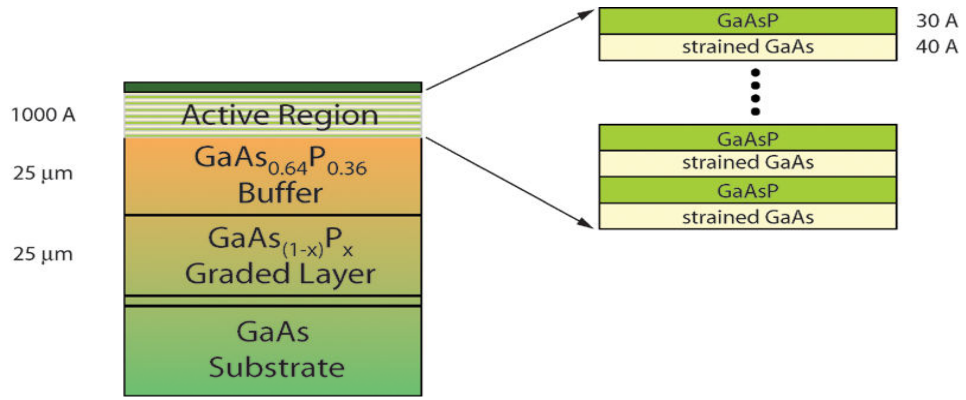


Parameter	E158	NLC-500
Charge/Train	6×10^{11}	14.3×10^{11}
Train Length	270ns	260ns
Bunch spacing	0.3ns	1.4ns
Rep Rate	120Hz	120Hz
Beam Energy	45 GeV	250 GeV
e^- Polarization	80%	80%



Photocathode Research (AB-AAP)

Baseline Design: GaAs/GaAsP



Semiconductor engineering to optimize current designs to ILC conditions:

Composition and layer structure	QE
Doping level	Polarization
Activation technique	Lifetime
	Surface charge limit

V. Conclusion

A Q-switch was successfully performed on the flash lamp pumped Ti:Sapphire laser without inflicting damage upon the laser cavity or other optical elements. The Q-switched laser pulse was characterized for a 250 ns square input pulse of 2 kV to a single Pockels cell. The results suggest that the high voltage pulse to the Pockels cell should be triggered 7.6 μs after the laser is triggered.

This particular arrangement was able to increase the output power of the laser from 0.4 mJ to over 2.3 mJ. The laser pulse generated from the Q-switch demonstrated good stability (< 0.5% jitter) and pulse width of FWHM > 200 ns. This Q-switch technique will be used at SLAC for polarized photocathode R & D as well as future accelerator plans including the Next Linear Collider

CLIC Electron Beam Demo

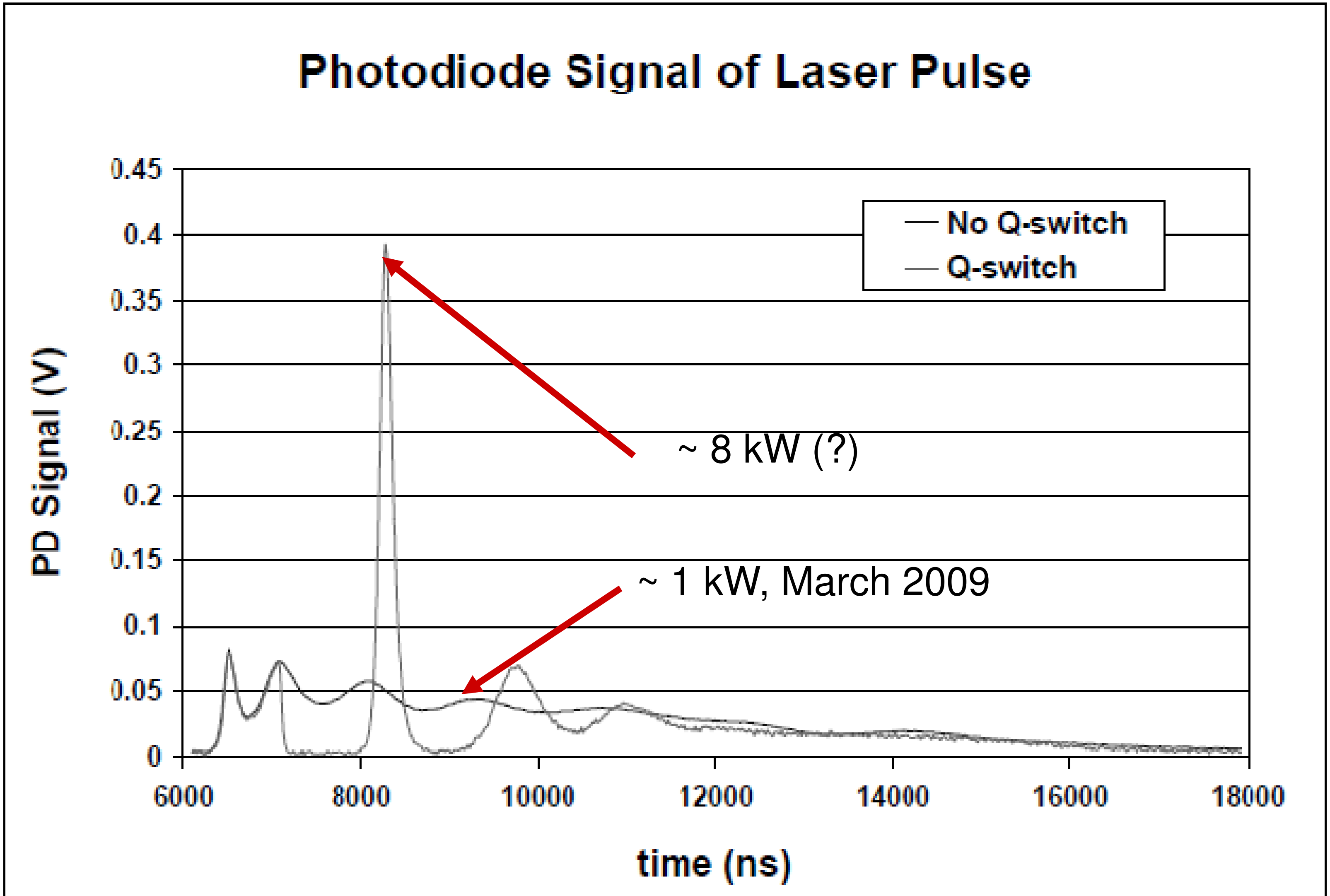
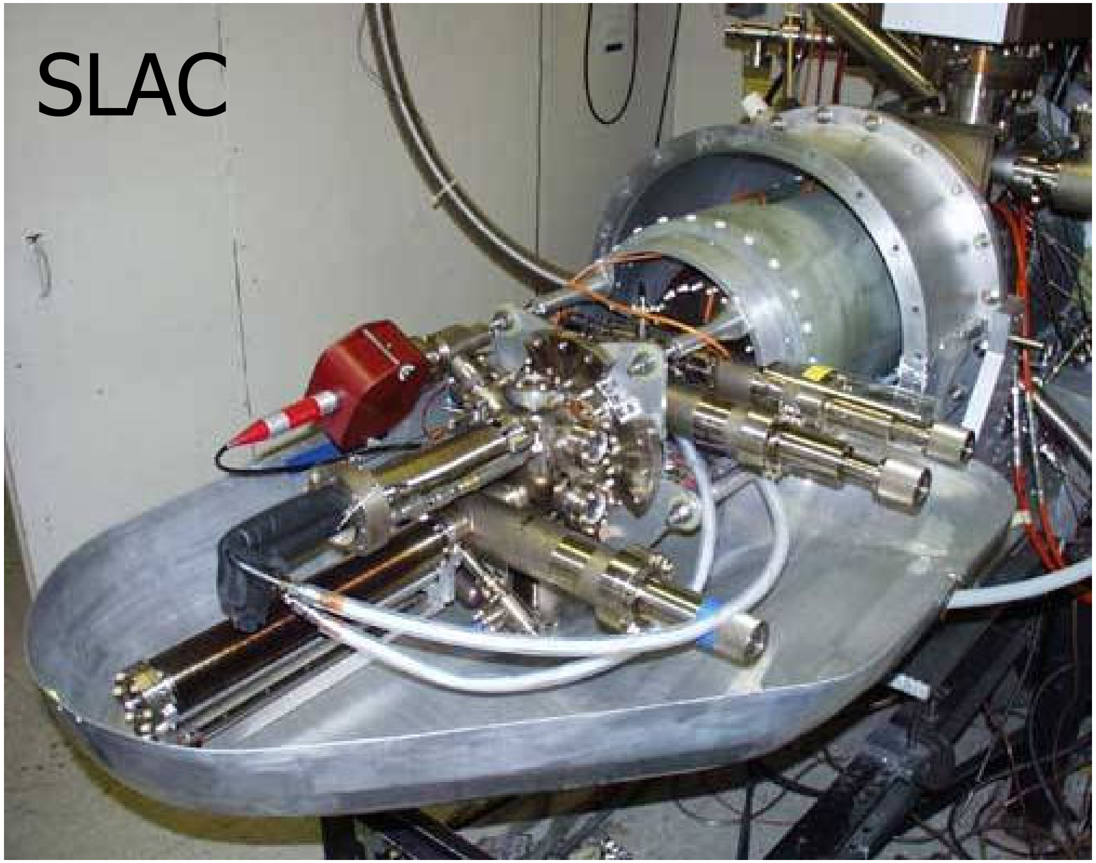
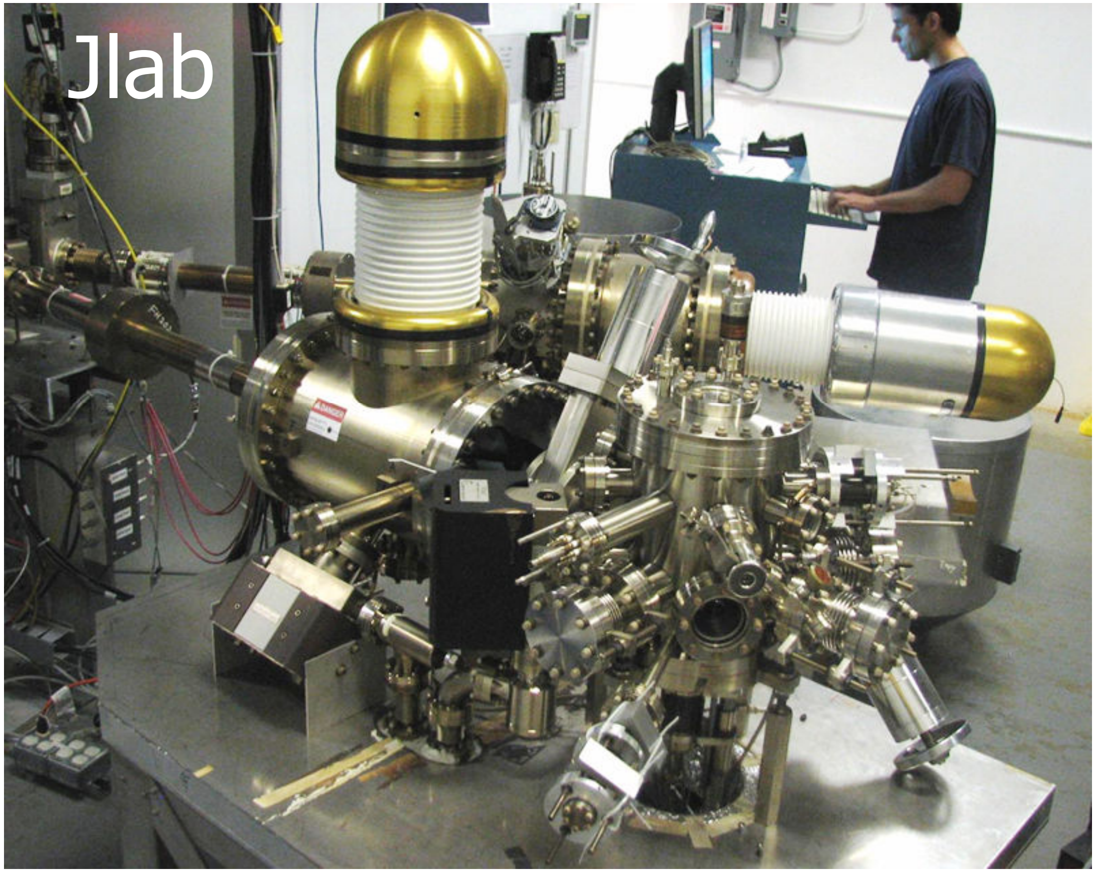


Figure VIII. Comparison of PD signals of laser pulse with and without a Q-switch

SLAC Polarized Electron Gun, GTL



Jefferson Lab Polarized Electron Gun



CLIC Electron Beam Demo

Schedule

Expect to try this before September, 2009 depending on other activities. Need to understand limitations (with existing equipment). If limited, will make corrections in FY2010.

Further along (2012?), will put SLAC cathode and laser together with JLab HV gun.

CLIC e^- Beam Source Parameters

Parameter	Symbol	CLIC
Number Electrons per microbunch	N_e	6 x 10^9
Number of microbunches	n_b	312
Width of microbunch	t_b	~ 100 ps
Time between microbunches	Δt_b	500.2 ps
Microbunch rep rate	f_b	1999 MHz
Width of macropulse	T_B	156 ns
Macropulse repetition rate	f_{rep}	50 Hz
Charge per micropulse	C_b	0.96 nC
Charge per macropulse	C_B	300 nC
Average current from gun (C_B x f_{rep})	I_{ave}	15 uA
Average current macropulse (C_B / T_B)	I_B	1.9 A
Duty Factor w/in macropulse (100ps/500ps)	DF	0.2
Peak current of micropulse (I_B / DF)	I_{peak}	9.6 A

If spot radius = 1 cm

–> challenge for an cathode/anode optics with uniform focusing properties

=> Current density
J = 3 A/cm^2

For 500 GeV option

=> I peak ≈ 20 A
=> Current density
J ≈ 6 A/cm^2