Lasers for CTF3 and outlook for CLIC

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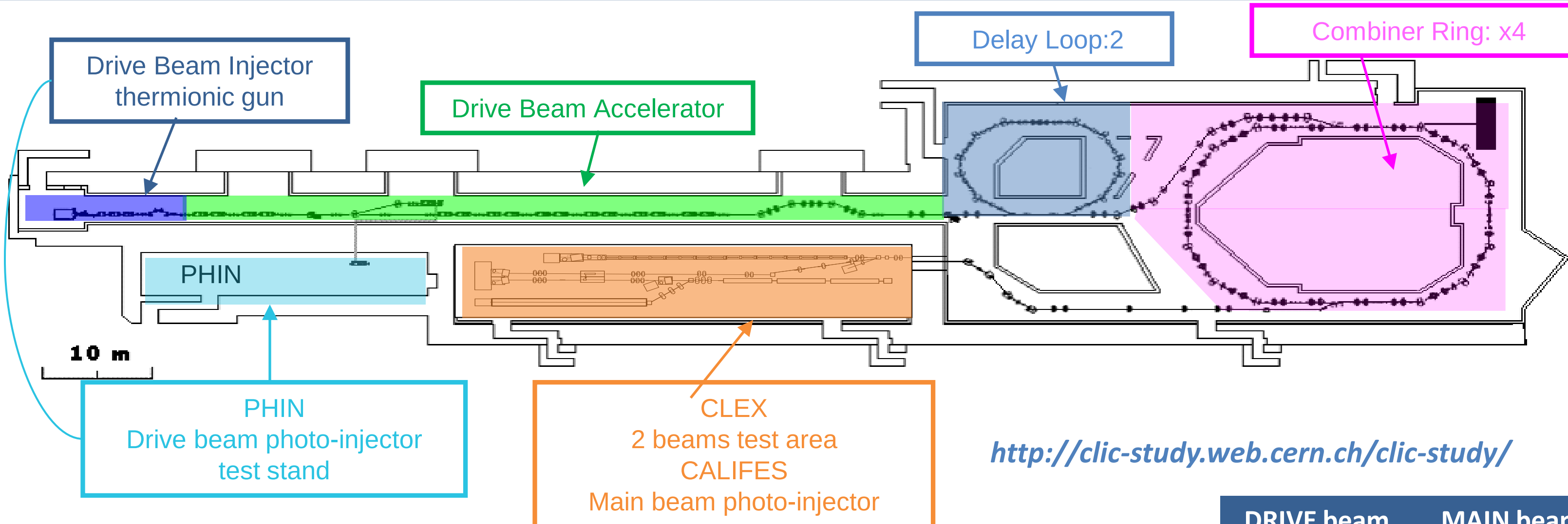
Outline

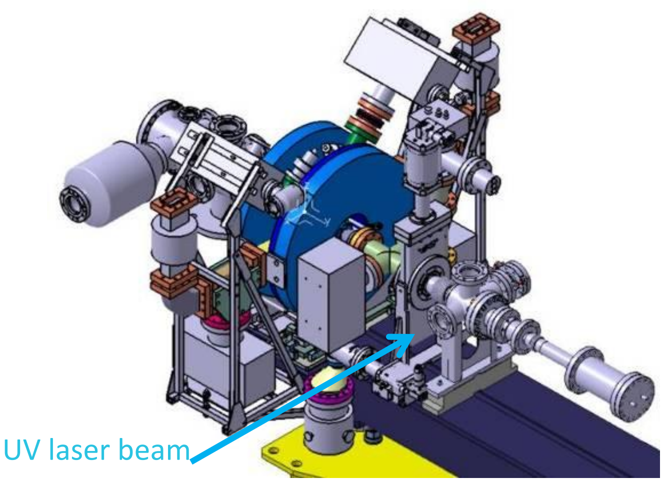
- Photo-injectors for CTF3
- Current laser setup
- Phase coding
- Stability
- Feedback stabilization
- Laser for CALIFES
- Challenges for CLIC drive beam

Photo-injectors for CTF3



Possible change over in next few years

http://clic-study.web.cern.ch/clic-study/



		DRIVE beam	MAIN beam
		PHIN	**CALIFES**
Electrons	**charge/bunch (nC)**	2.3	0.6
	Number of subtrains	**8**	NA
	Number of pulses in subtrain	**212**	NA
	gate (ns)	**1272**	20-150
	bunch spacing(ns)	0.666	0.666
	bunch length (ps)	10	10
	Rf reprate (GHz)	1.5	1.5
	number of bunches	1802	32
	machine reprate (Hz)	**5**	5
	margine for the laser	**1.5**	1.5
	charge stability	**<0.25%**	<3%
	QE(%) of Cs2Te cathode	**3**	0.3

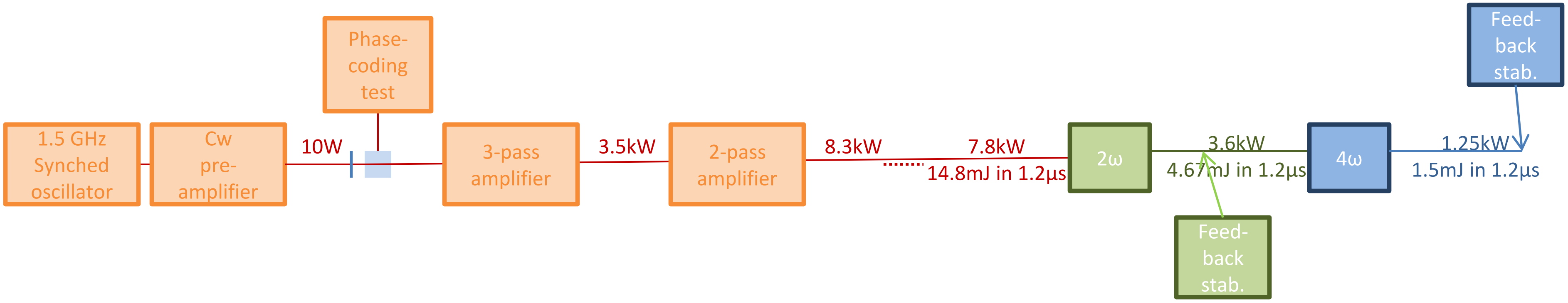
Machine parameters set the requirement for the laser

Laser requirements

	PARAMETERS	PHIN	CALIFES
Laser in UV	laser wavelegth (nm)	262	262
	energy/micropulse on cathode (nJ)	>363	947
	energy/micropulse laserroom (nJ)	544	1420
	energy/macrop. laserroom (uJ)	9.8E+02	4.1E+01
	mean power (kW)	0.8	2.1
	average power at cathode wavelength(W)	0.005	2.E-04
	micro/macropulse stability	<0.25%	<3%
Laser in IR	conversion efficiency	0.1	0.15
	energy/macropulse in IR (mJ)	9.8	0.3
	energy/micropulse in IR (uJ)	5.4	9.5
	mean power in IR (kW)	8.2	14.2
	average power on second harmonic (W)	0.49	1.E-03
	average power in final amplifier (W)	9	15

Achieved

Not yet reached



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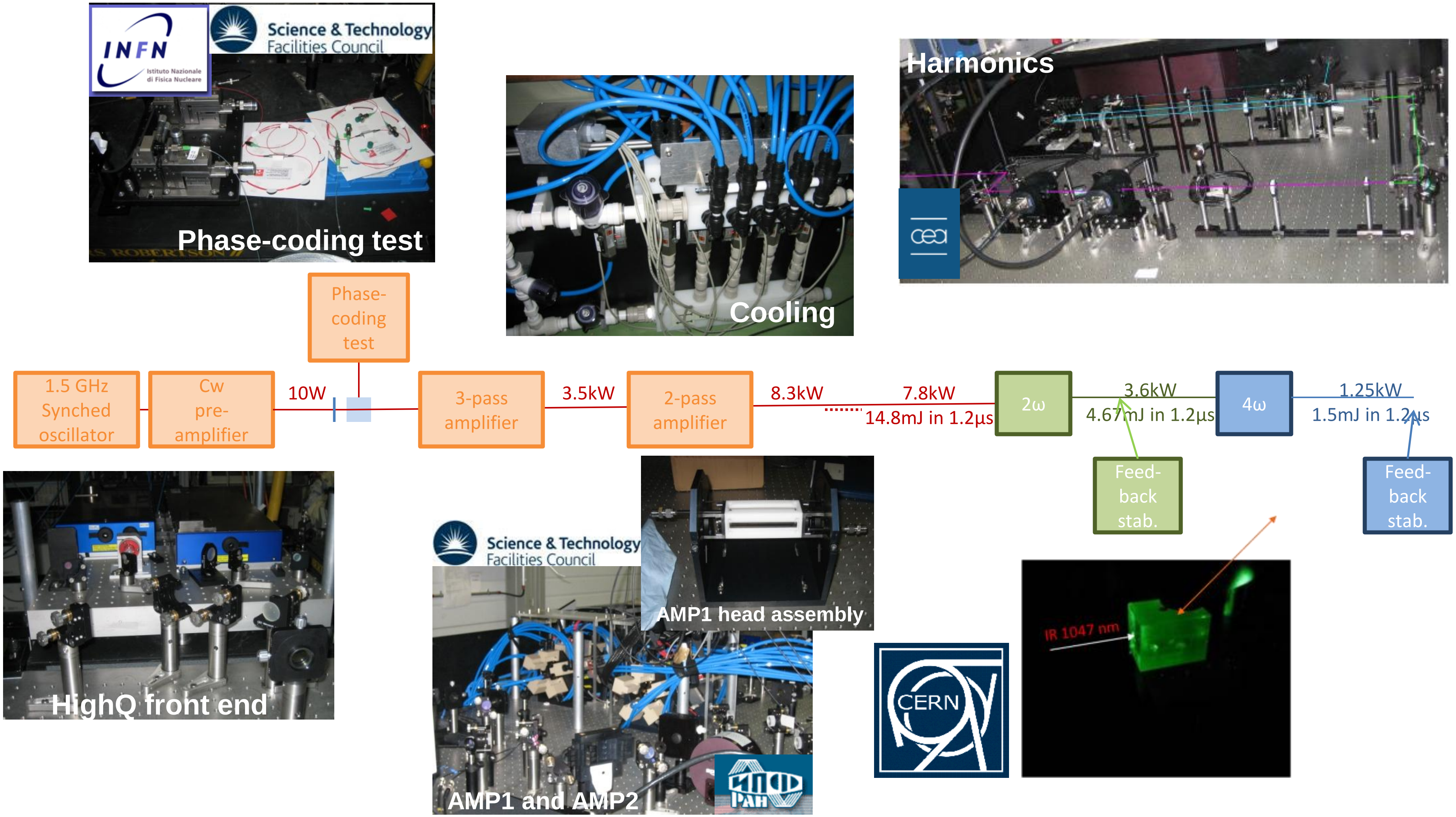
Laser setup



Phase-coding test
Cooling
Harmonics
Phase-coding test
1.5 GHz Synched oscillator
Cw pre-amplifier
10W
3-pass amplifier
3.5kW
2-pass amplifier
8.3kW
7.8kW
14.8mJ in 1.2μs
2ω
3.6kW
4.67mJ in 1.2μs
4ω
1.25kW
1.5mJ in 1.2μs
Feed-back stab.
Feed-back stab.
AMP1 head assembly
HighQ front end
AMP1 and AMP2
IR 1047 nm

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Phase-coding

✓Slow switching demonstrated
✓Recombination and delay measured

•Damage due to the high input power

•Only 10mW output (3% transmission)

•Unstable bias controller

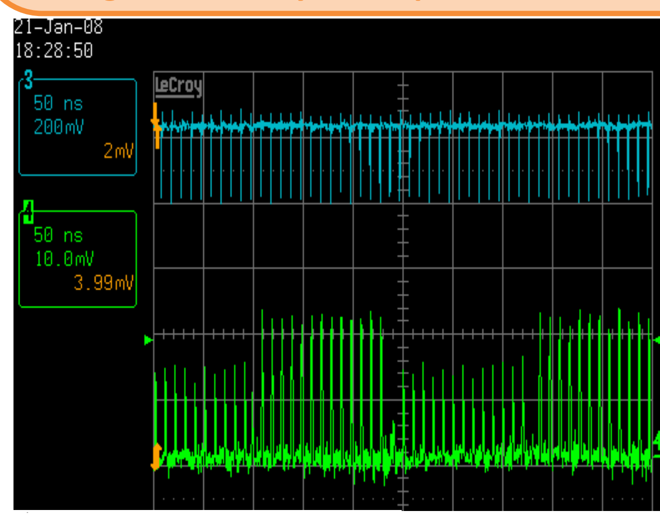
•Long 140ns delay is temperature sensitive (1.92ps/K)

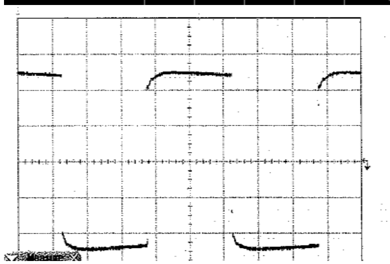
•RF driver amplifier is not up to our specification (see picture)

•3GHz signal when no modulation

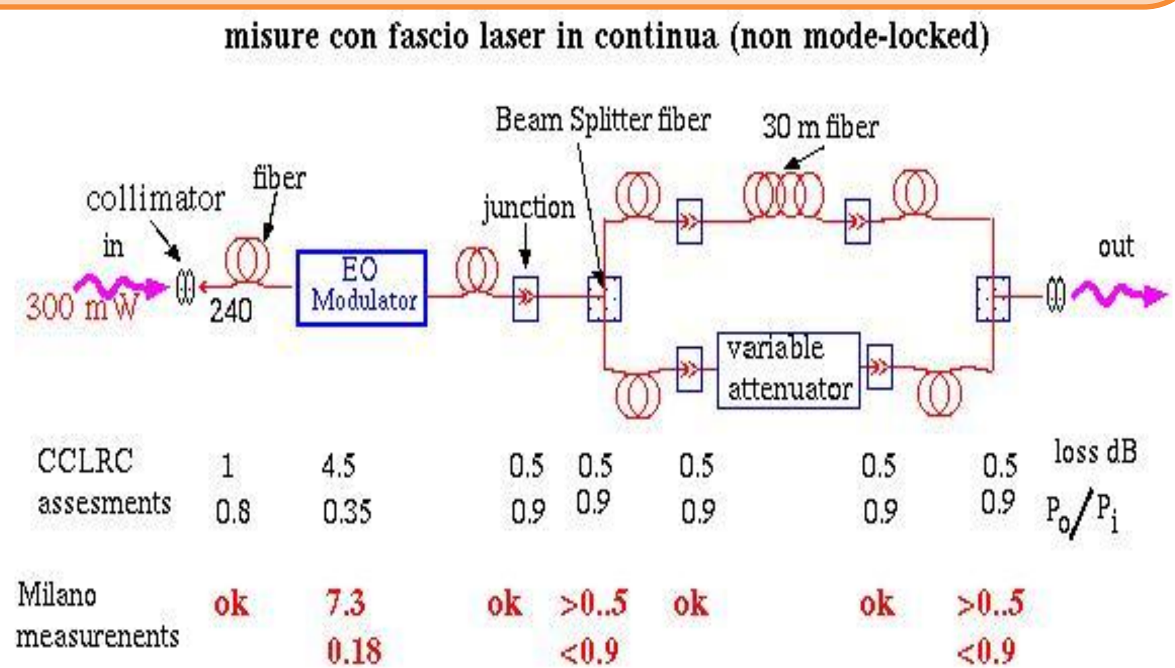
•Trigger only delivered for 1.3µs

→ Unstable amplification later in the system



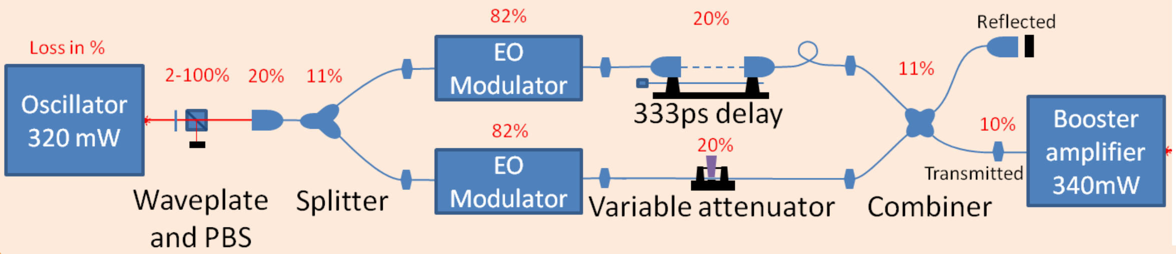


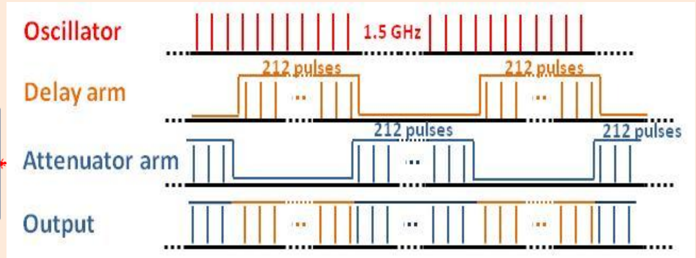
Driver response to
to square input
(voltage applied to
modulator)

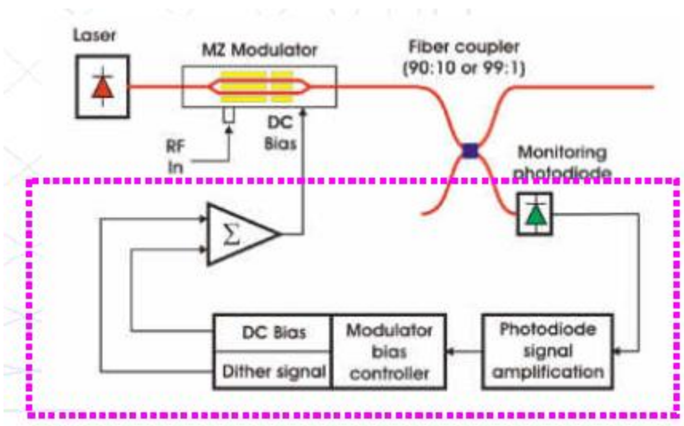


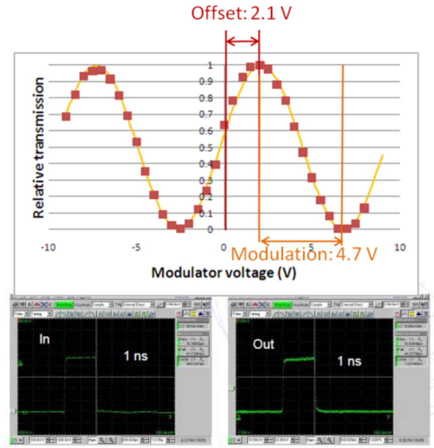
Phase-coding

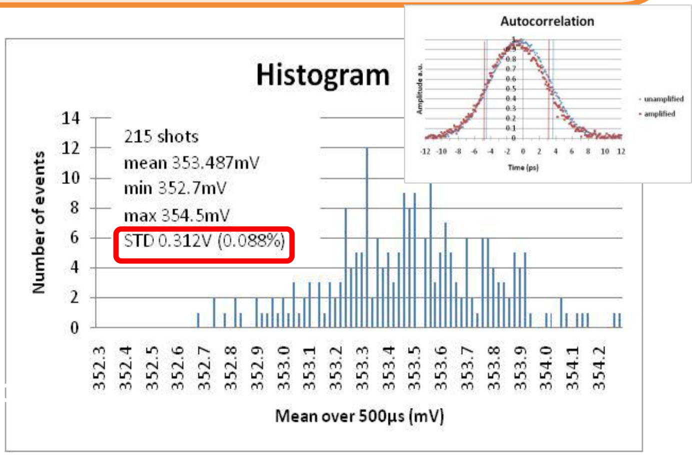
NEW scheme









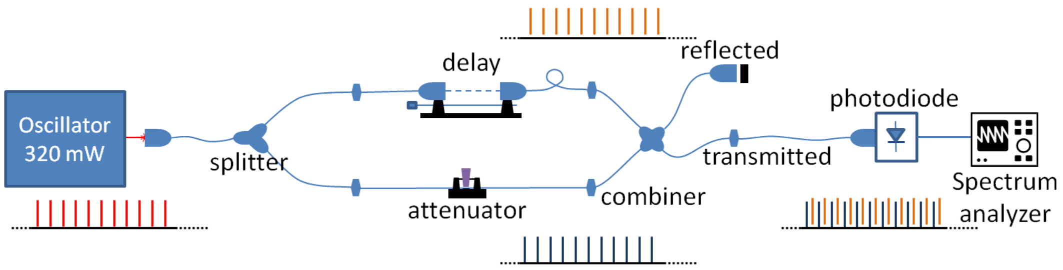


- 2 modulator scheme will be safer against power damage
- Better temperature stability with the 333ps delay
- 1.5 GHz when no modulation applied
- Installed booster amplifier to reach oscillator power

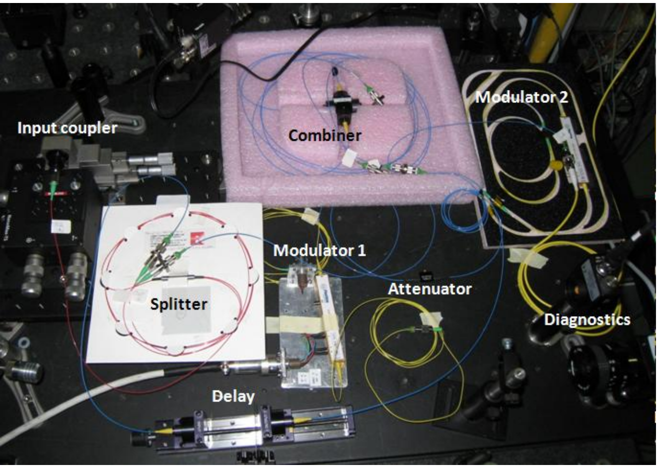
Still missing:

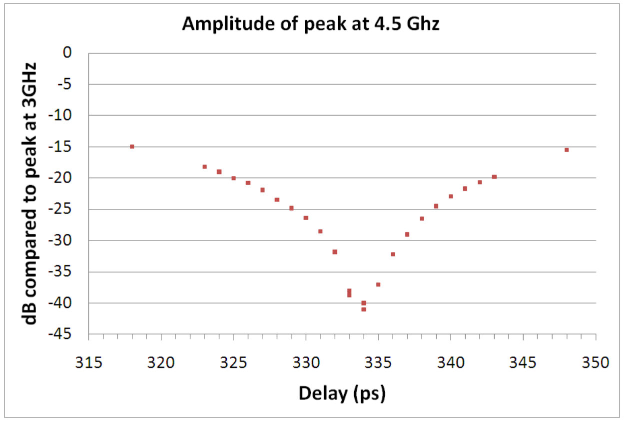
- Fully adjustable timing system for amplification window (any time)
- External photodiode for more stable bias control (ordered)
- Driver amplifier with flat output response (ordered)

Phase coding alignment measurement



- Measurement without modulators (or modulators at 50% bias)
- Delayed and un-delayed signals overlaid on top of each other
  -> 3 GHz signal instead of 1.5 GHz
  -> Peaks in spectrum at odd multiples of 1.5 GHz disappear
- Measured peak at 4.5 GHz on spectrum analyzer sensitive to both amplitude and delay





Achieved accuracy between arms:

•0.2 ps in delay

•0.1% in amplitude

Provides easy setup for the phase-coding

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Stability

Amplitude

In laser room

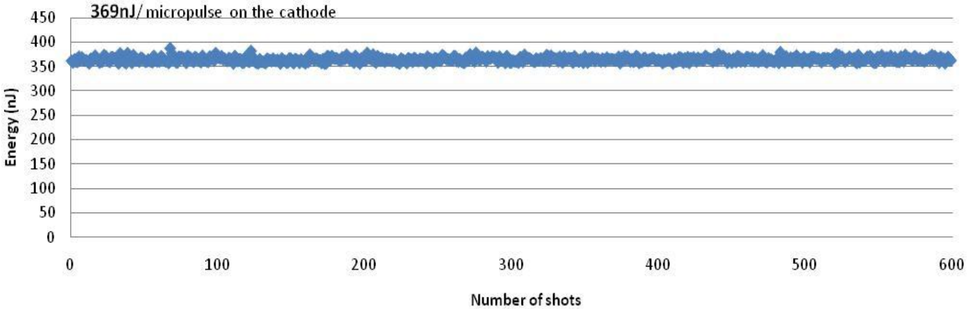
Macrop	IR	Green	UV
RMS stability	0.23%	0.8%	1.3%

Nonlinear conversion increases noise and causes amplitude variations along the train

In PHIN

Laser RMS	Current RMS	Train length(ns)	
1.3% RMS	0.8% RMS	1250	best
2.6%	2.4%	1300	worst

Laser energy over 600 shots
1.3% RMS

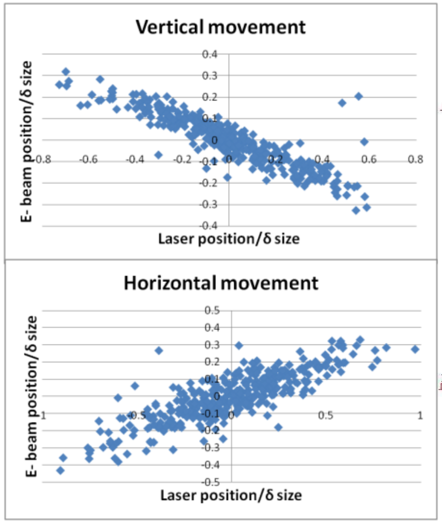


We need 0.1% RMS stability

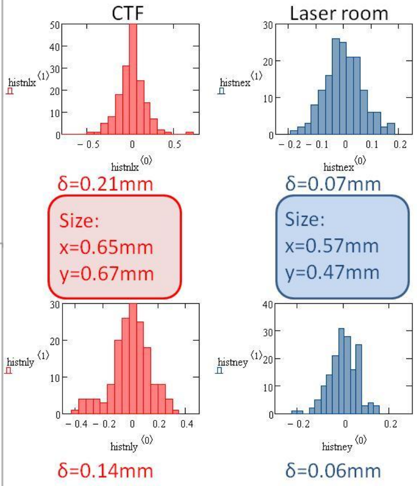
- Exceptional stability without feedback stabilization!
- Noise characterization ongoing
- Fast feedback planned for Spring 2011

Position

CLEX (CALIFES)



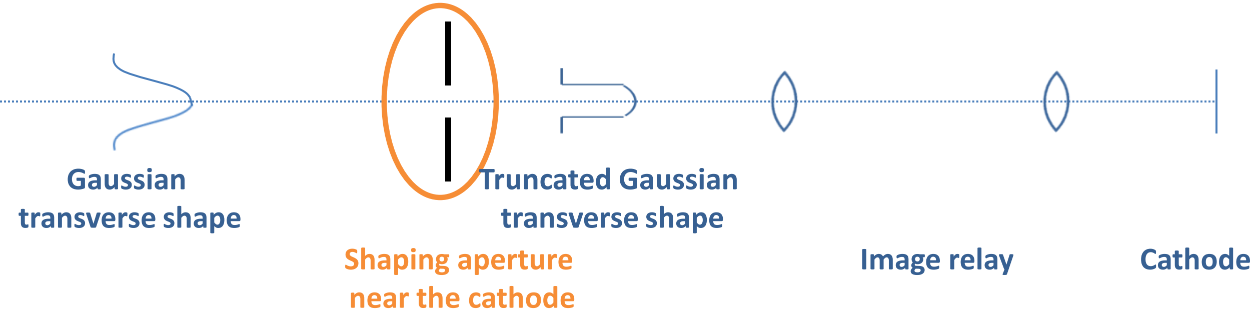
CTF2 (PHIN)



	RMS V movement /size	RMS H movement /size
Laser room Without laser cover	13%	12%
PHIN (11.4m transport)	32%	21%
Laser room With laser cover	7.5%	5%
CALIFES (70m transport)	25%	16%

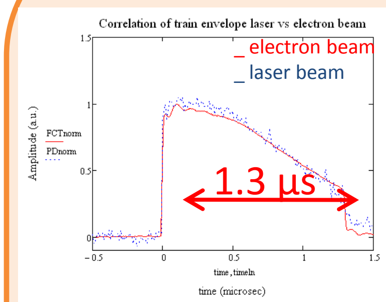
- Pointing instabilities improved by laser cover
- Windows will be installed on laser room floor to avoid airflow

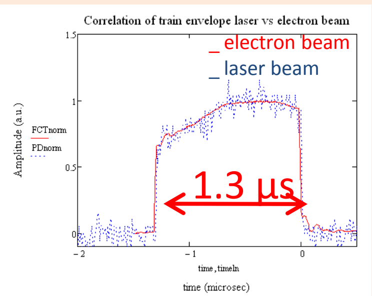
Pointing stability (solution?)



- Can be placed near to the cathode
- Cathode always sees the aperture position and not the beam position
- Transverse movement translates to amplitude instabilities→
- Aperture size/beamsize has to be small →
- Need X10 more laser energy

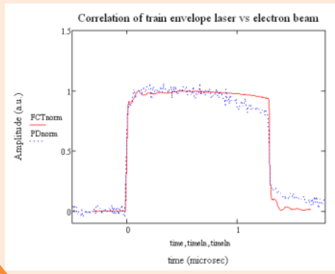
Beam shaping in PHIN

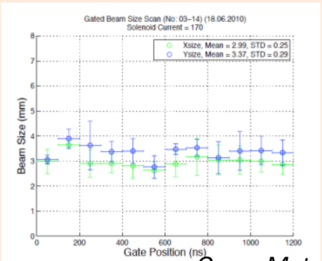




Iris at centre Iris at edge

of the beam

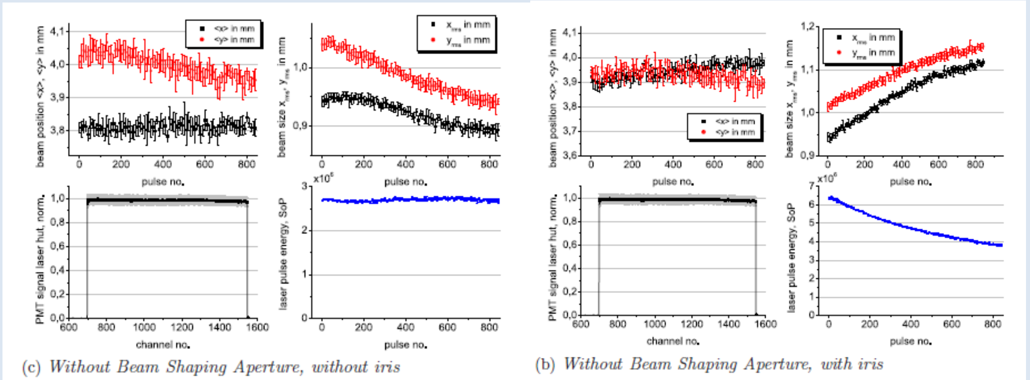




Oznur Mete

No iris

Beam shaping at PITZ

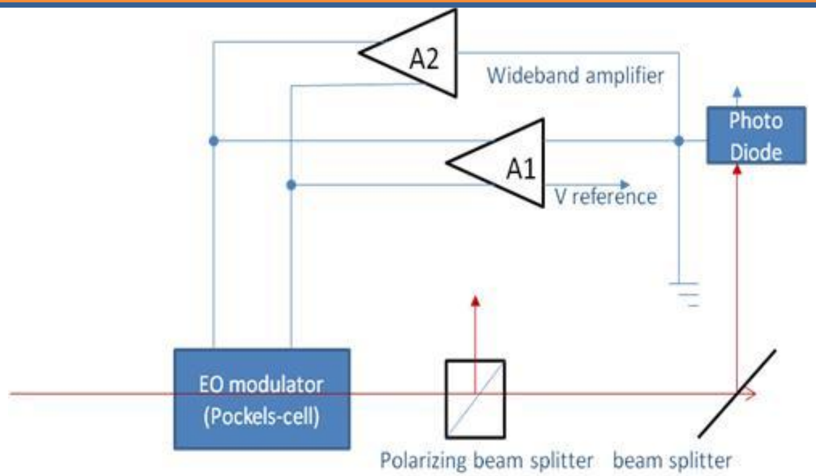


(c) *Without Beam Shaping Aperture, without iris* (b) *Without Beam Shaping Aperture, with iris*

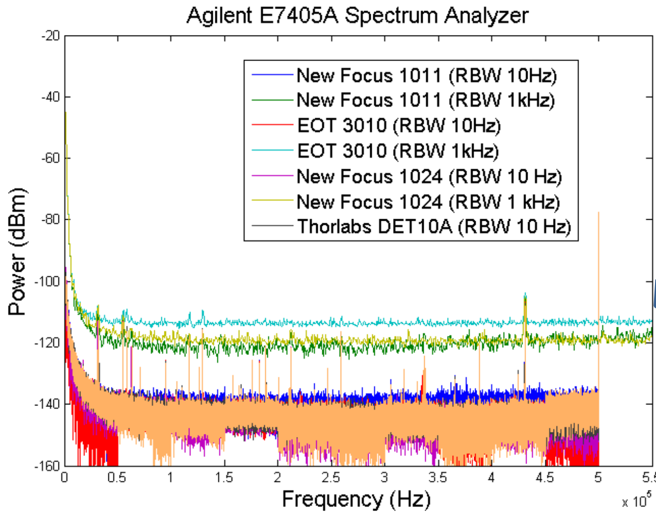
Marc Hänel Dissertation Hamburg 2010

- The effect is though to be from thermal lensing
- In our case detuning of the conversion crystal (see slide 21)
- Beam size variations to be investigated with gated camera in 2011
- Even if we act on amplitude variations, we might still be left with beam size variations

Scheme to improve stability



In TESLA this system was invented by I. Will and his group
0.7% rms stability was achieved from 3% with 70% transmission



- **We need 0.1% rms stability**
- **Amplifiers provide stabilization for noise <10kHz with steady-state (see slide 27)**
- **Commercial LASS-II by Conoptics at green wavelength**
  1/1@ 500kHz (Int. Ref. Mode) ,5/1 @ 100kHz ,18/1 @50kHz ,100/1 @10kHz , 200/1 @1kHz,250/1 @200hz
- **New fellow Sebastian Gim to work on 'in house' solution**
- **Detailed noise measurement on the laser system started**
- **Comparison of different detectors**
- **12bit AD card to perform high dynamic range measurements purchased**
- **Pockels-cells purchased for test**

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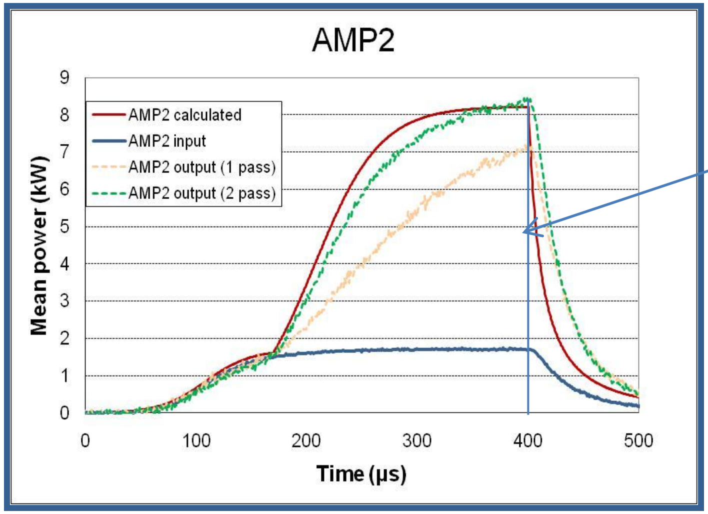
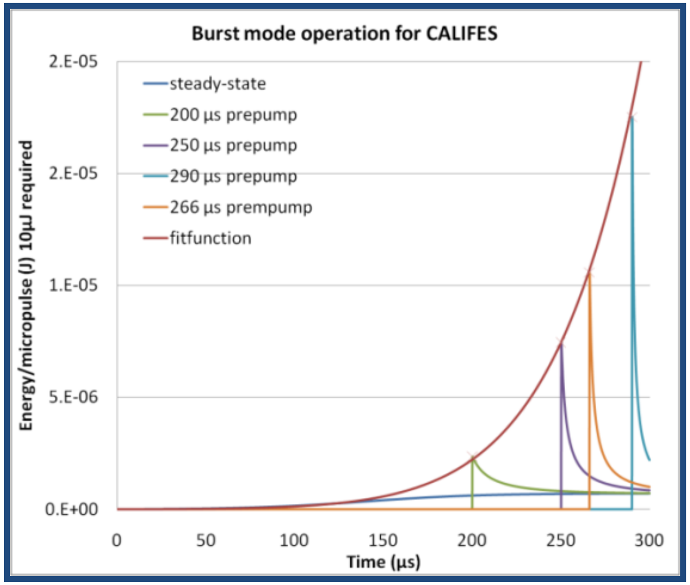
Independent laser system for CALIFES

- Laser design was for long trains of the CLIC drive beam
- CALIFES requires only up to 226 pulses (160ns)
- 1µJ in the UV is necessary for short train, which have not been delivered yet
- CALIFES will be used as a diagnostic test bench until 2015 at least



This is how long the CALIFES train is



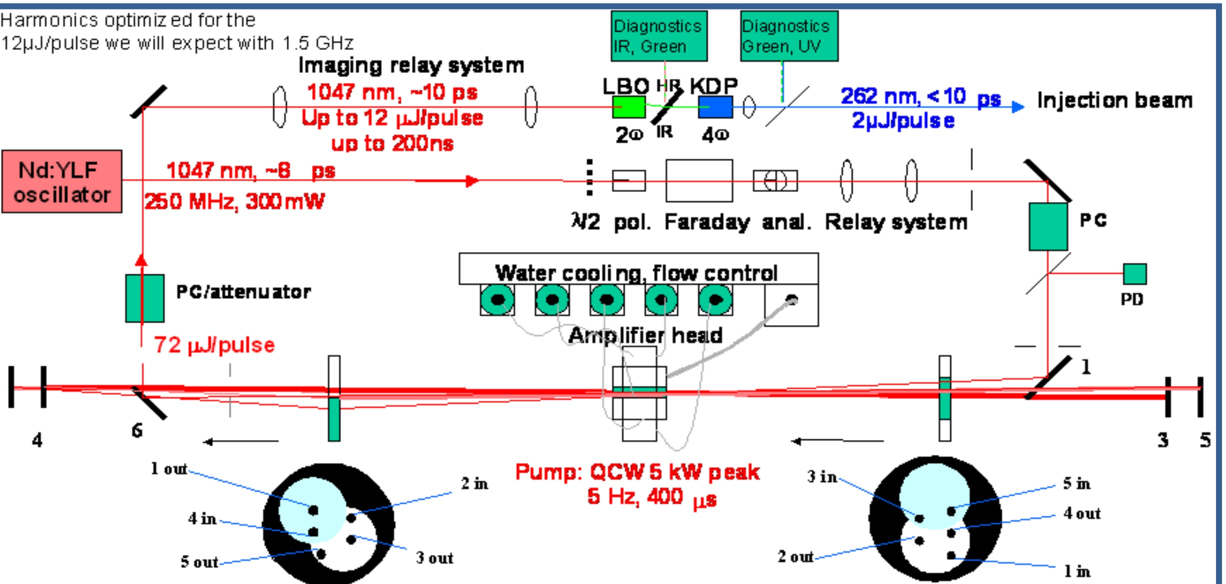
Allow the amplifier to store the energy before pulses arrive

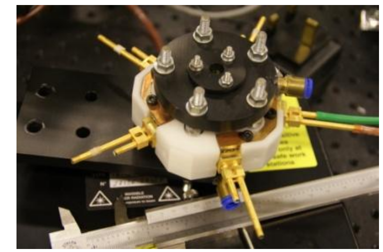
↓

Higher energy can be reached
Stability needs to be investigated

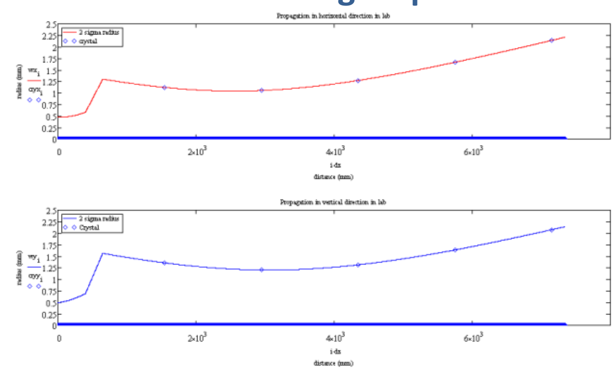
- Refurbishment of PILOT laser tested on CTF2
- Small footprint
- Simpler setup
- Lower pump power

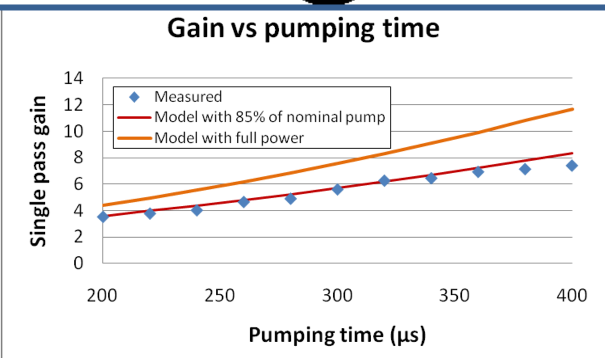
Independent laser system for CALIFES

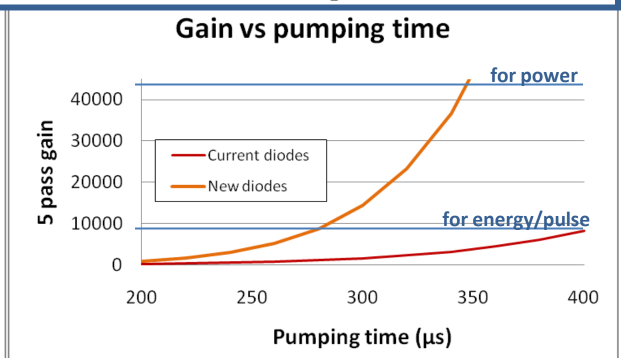




Beam through 5 passes







- Test oscillator at 250MHz 400mW requires much higher gain to reach the CALIFES parameters
- Old diodes have less pumping power

- New diodes arrive for middle of December
- Full commissioning planned for Spring 2011

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Lasers for CLIC

DRIVE beam for CLIC							POLARIZED SOURCE FOR CLIC		
current	Feas Study	CLIC	in green				CLIC	SLAC	
	I.Ross (2001)			Electrons	electrons (*10^9)	Electrons	3.72	60	
2.3	8.4	8.4	8.4		charge (nC)		0.6		
1200	91600	140371	140371		gate (ns)		156	300	600
0.666	2.13	1.992	1.992		bunch spacing(ns)		0.5	cw	
1.5	0.5	0.5	0.5		Rf reprate (GHz)		2	cw	
1802	43005	70467	70467		number of bunches		312		
5	100	100	100		machine reprate (Hz)		100	120	120
1.5	2.9	2.9	2.9		beamshaping/feedback/efficiency/transport				
3	2.3	3	2		QE(%)		0.3	0.3	
262	262	262	532	Laser	laser wavelegth (nm)	Laser	780	865	
363	1729	1325	979		energy/micropulse on cathode (nJ)		317.9		
544	5013	3843	2839		energy/micropulse laserroom (nJ)		476.9	NA	
9.8E+02	2.2E+05	2.7E+05	2.0E+05		energy/macrop. laserroom (uJ)		148.8	500	0
0.8	2.4	1.9	1.4		mean power (kW)		1.0	1.7	
0.005	22	27	20		average power at cathode wavelength(W)		14.88	60	
1.30%	<0.5%	<0.1%	<0.1%		micro/macropulse stability		1%	<0.5%	
0.1	0.05	0.1	0.35		conversion efficiency				
	0.6	0.6	0.6		IR beamtransport/chopping				
9.8	7185.6	2708.1	571.6		energy/macropulse in IR (mJ)				
5.4	100.3	38.4	8.1		energy/micropulse in IR (uJ)				
8.2	47.1	19.3	4.1		mean power in IR (kW)				
0.49	431	271	57		average power on second harmonic (W)				
9	659	405	86		average power in final amplifier (W)				

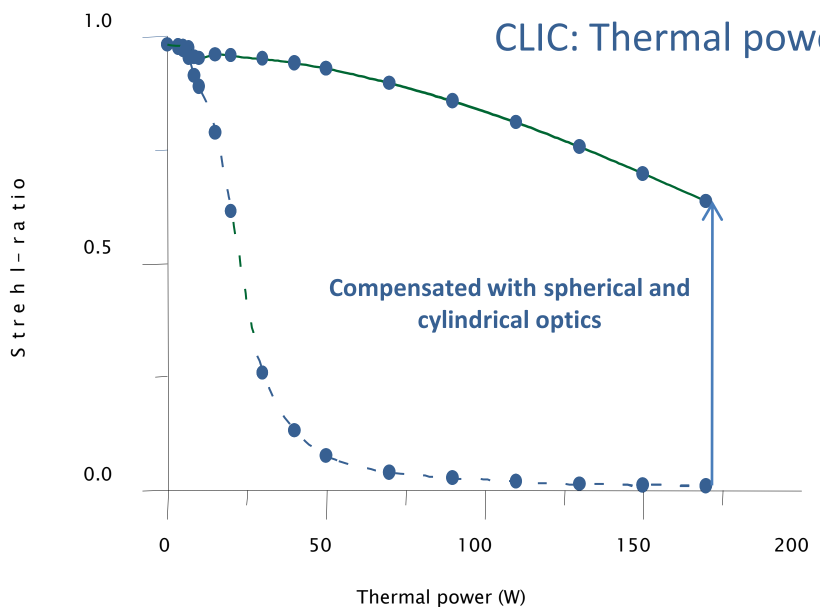
Massimo Petrarca's talk
Wednesday WG1 5:30pm
Room 19 floor "3"

Amplifiers

High average power, thermal management

- **Thermal lensing, Nd:YLF is one of the best materials**
- **Fracture, maximum 22W/cm for rod geometry**

CLIC: Thermal power ~170 W at 50Hz



$f \sim D^2/P_{th}$

Vertical aberration f=15 cm

Horizontal aberration f=-60 cm

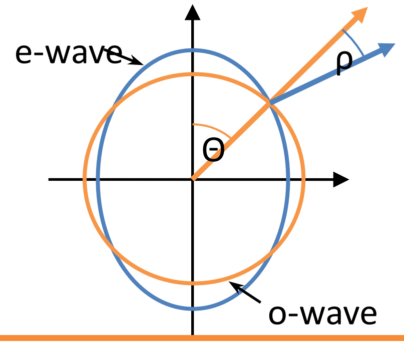
Strehl ratio 0.012

- More thermal lensing measurement to be done on PHIN laser at 50Hz
- Maximum length for rod is 18cm→in a single amplifier we can only get 28kW out →
- 2 amplifiers or slab geometry could be the answer

UV generation (harmonics)

Refractive index depends on

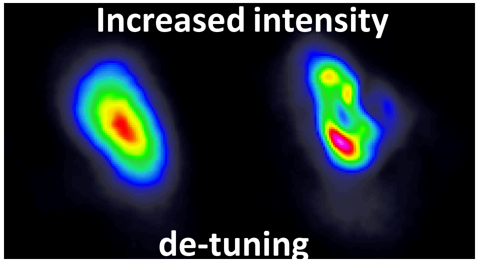
Temperature
Angle of the beam
Wavelength
Polarization

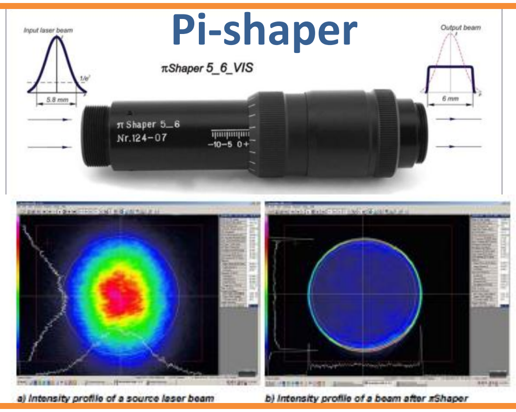


Conversion efficiency depends on

Temperature
Angle and divergence of the beam
Wavelength and spectral bandwidth
Intensity
Crystal length
Polarization

•Inhomogeneous temperature distribution due to laser beam profile





•Maximum average power demonstrated 100W at 532nm 25W in UV (similar to what is required for CLIC, but in cw train)
•400W the absorption will start to become a problem (CLIC mean power is 30kW)

Bastian Gronloh Fraunhofer-Insitut für Lasertechnik ILT

•Investigation of heat effect with long train planned for December 2010
•Investigation of heat with high repetition rate after CALIFES laser commissioning
•Test with homogeneous beamprofile

Cathode at visible wavelength

QE= #electrons/#photons

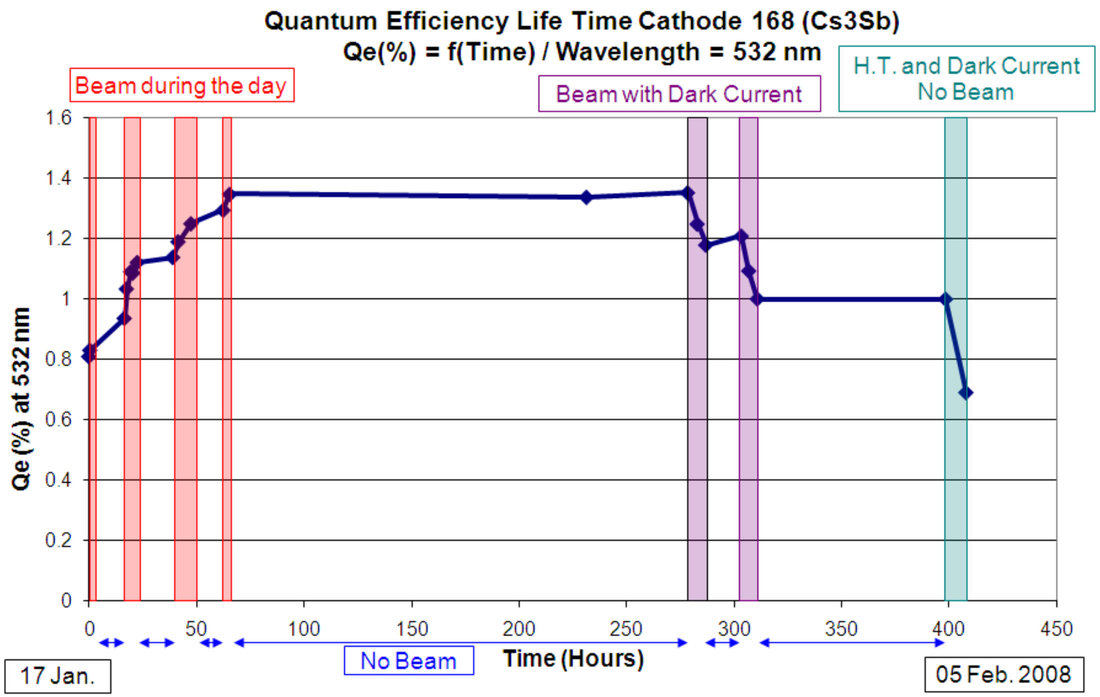
At visible:

The photon energy is half
The laser energy is X4

Number of photons X8

QE is expected to be the same

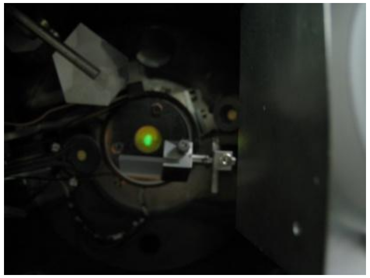
X8 of the charge with the same laser



Preliminary Test done in 2008 (E.Chevallay / K. Elsener)
Co-evaporation process on Cu plug, Lack of Sb

Cs_3Sb Photocathode test planned

- Co-evaporation
- Qe optimalization during fabrication at 532 nm
- Online measurements and computing available
- Better vacuum pressure

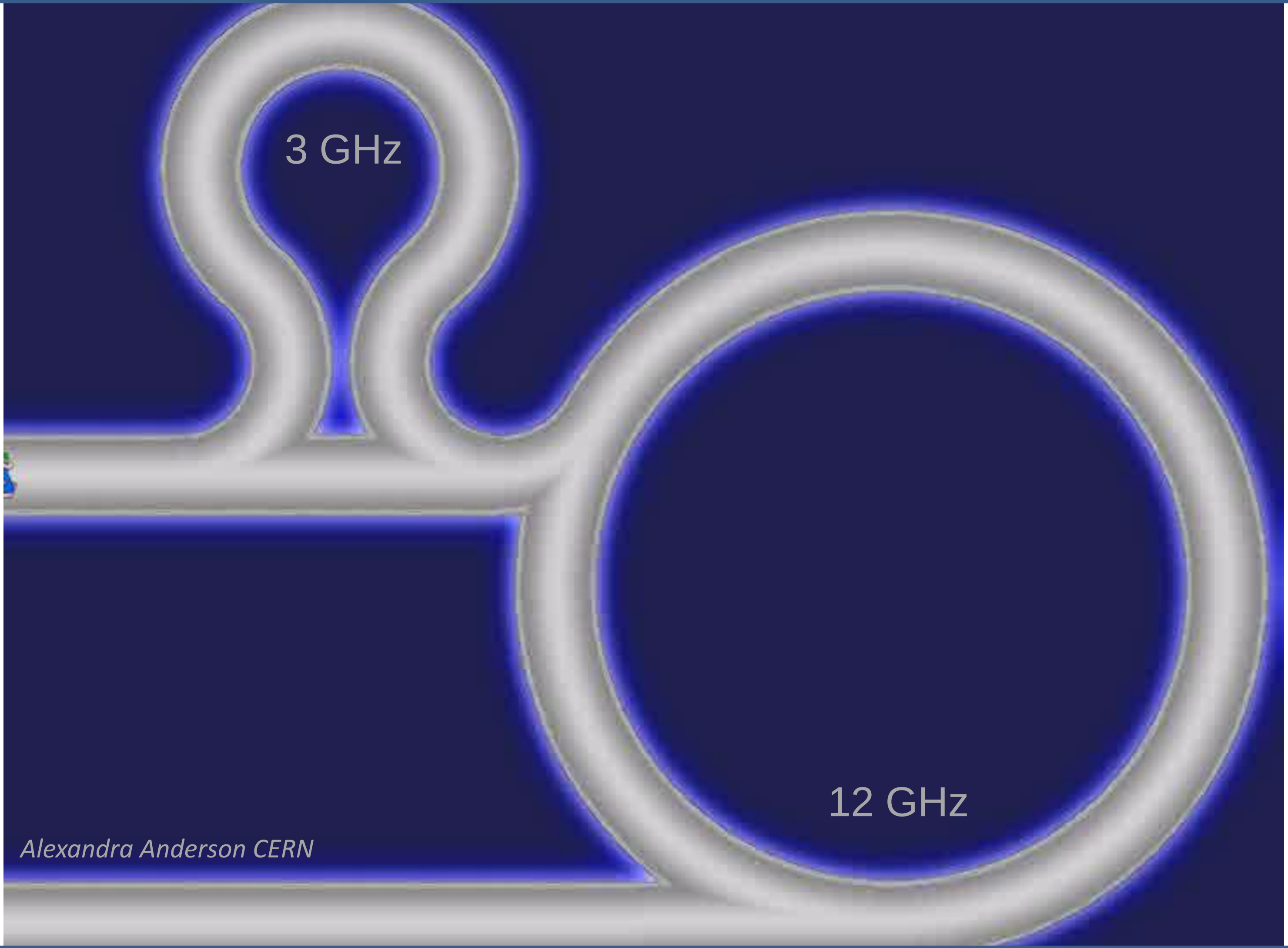


Summary/Outlook

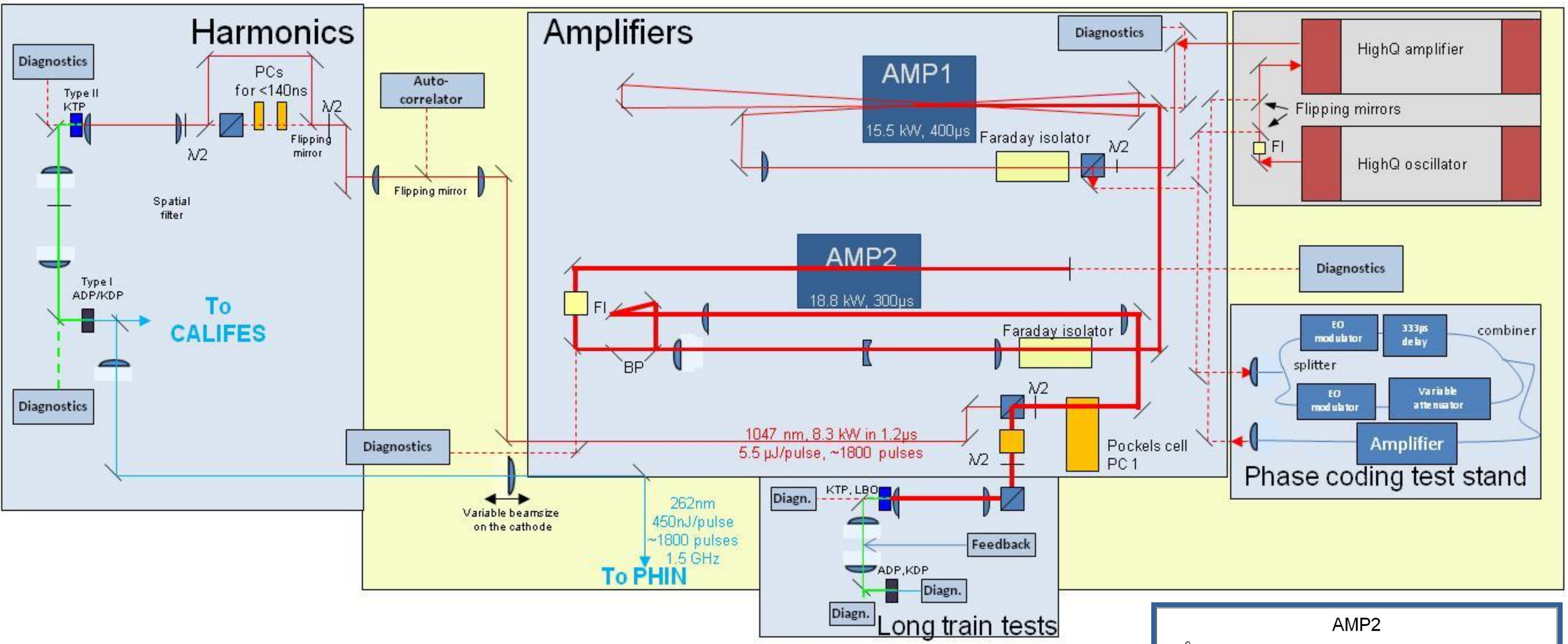
- **Phase-coding** for begging of next year →full timing flexibility
- **Long train harmonics** test December 2010 →140 µs for CLIC
- **Feedback stabilization** in 2011 →0.1% rms charge stability
- **Independent CALIFES laser** to reach nominal charge and to allow **high repetition rate tests** on PHIN laser →high average power
- **Amplifier development** on PHIN to reach nominal parameters →rod amplifier feasibility
- New front end at **500MHz for PHIN development** →8.4nC/bunch for CLIC
- Feasibility study for **CLIC drive beam laser** with collaborators working on most important issues planned →study all the challenging parts for the drive beam laser

Time structure requirement

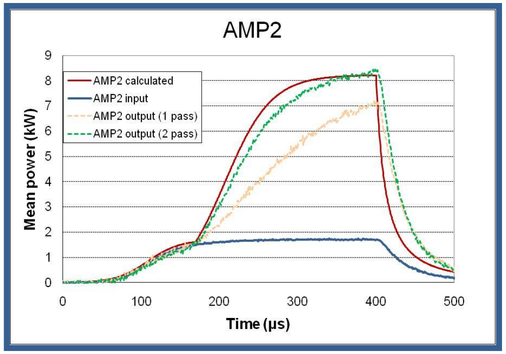
Combiner ring and Delay loop



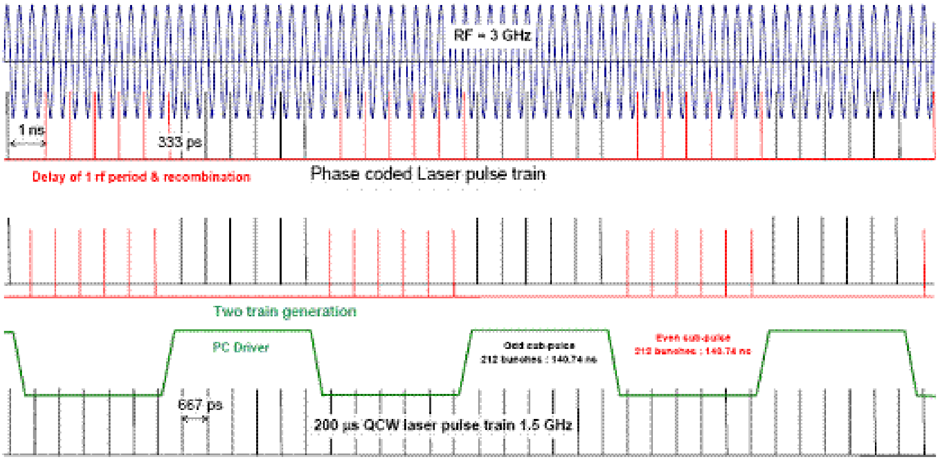
Laser setup



- •Using 'leakage' wherever we can
- •No interruption to operation

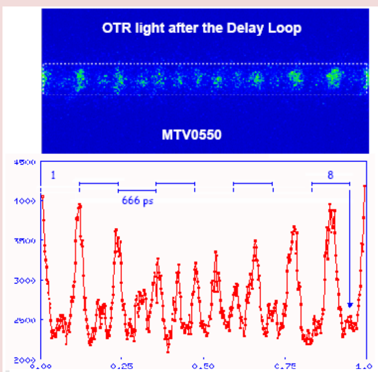


Time structure requirement

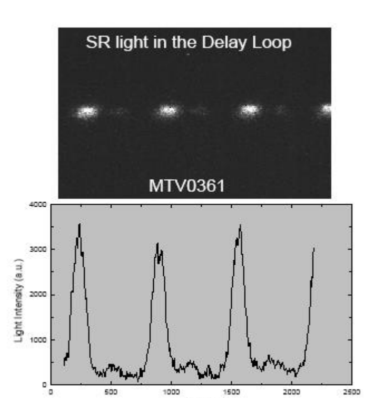


	PHIN	CALIFES
Micropulse repetition rate	1.5GHz	1.5Ghz
Macropulse repetition rate	1-5 Hz	1-5Hz
Number of pulses	2332	1-226
Gate length	1200 ns	0.5-150ns
Number of subpulses	11	-
Length of subpulse	140.7ns	-

With thermionic gun



Phase switch is done within eight 1.5 GHz periods (~ 5 ns)



Satellite bunch population was estimated to ~ 7 %

R. Corsini (12th March 2010)

- Flexibility in timing structure is a real advantage
- Single PC arrangement for long train
- Double PC for <200ns

Steady-state MOPA

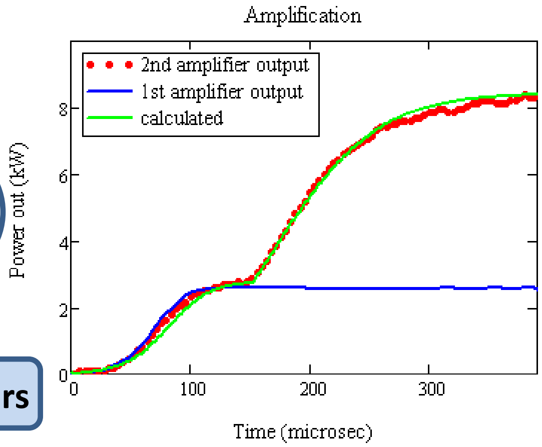
How is the output power affected by the input parameters?

Pumping diodes
Current overshoot <1%
Ripples <1%
Temperature

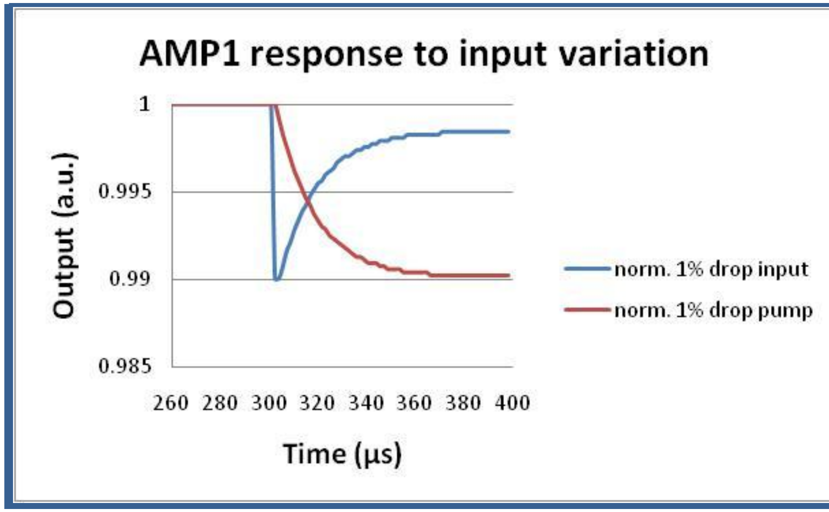
$$P_{out} - P_{in} = \eta_p P_{abs} - \frac{\pi D^2}{4} F_{sat} \ln G \frac{(1+B)}{\tau_{fl}}$$

Oscillator and preamp from HighQ
< 0.2 % rms above the 100 kHz noise region
<1% rms below the 100kHz noise region

Interlinked with all the others

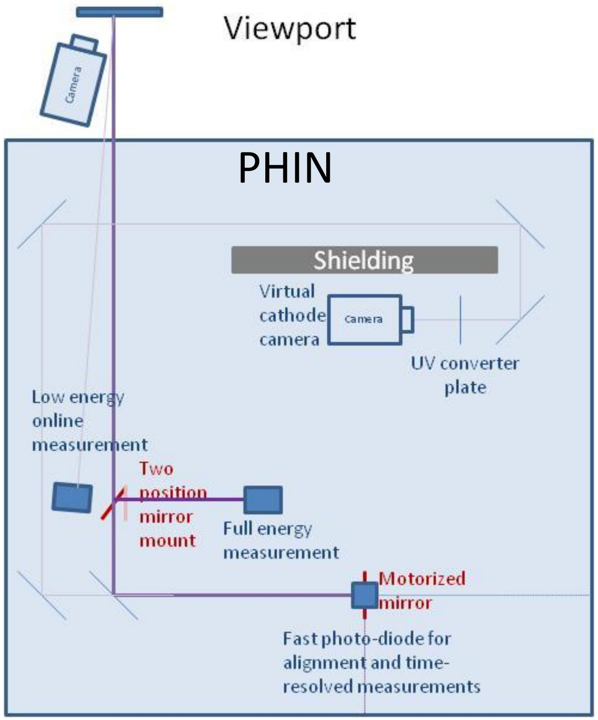


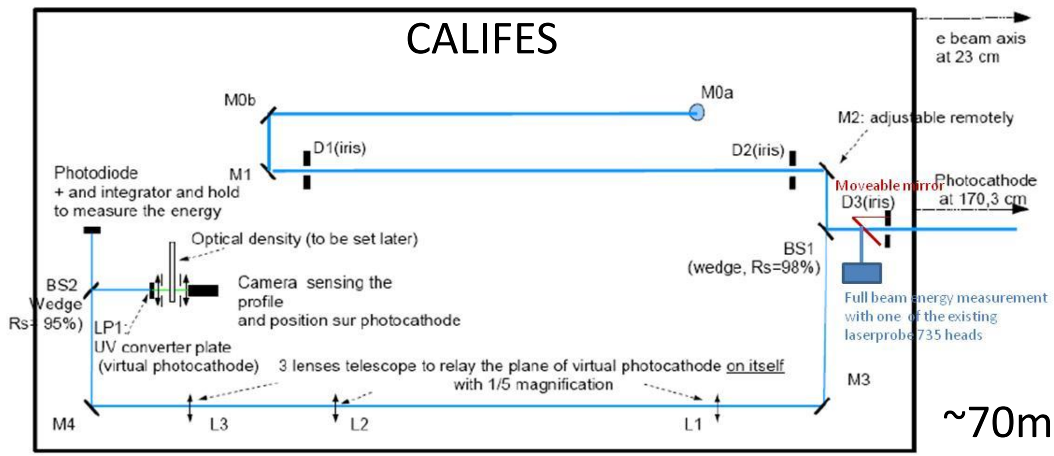
- The best technology for the time was bought
- We are more sensitive to pump variation
- Stabilized diode technology should be investigated
- 0.33% RMS stability is measured in the IR



Science & Technology Facilities Council

Laser diagnostics

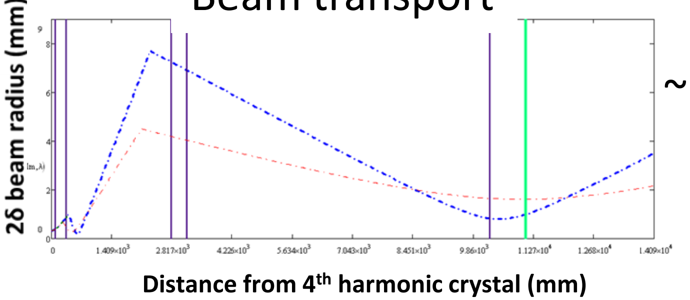




~70m

- •The imaging lenses removed and UV converter changed to a 30mm diameter one.
- Install remote flip mirror for full energy measurement

Beam transport



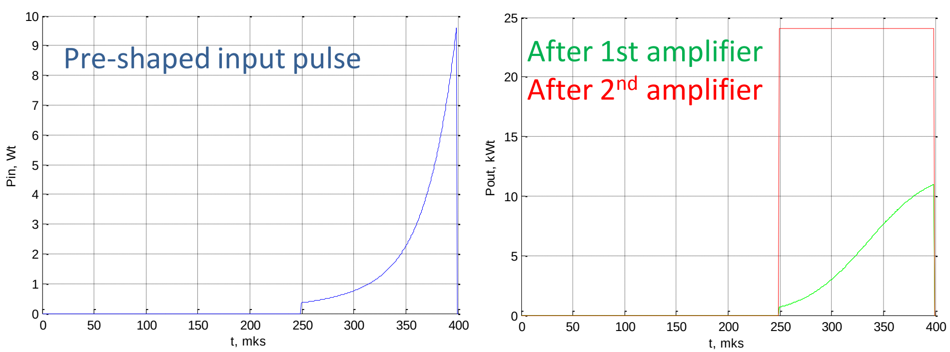
~11m

- •Transmission is low for CALIFES line
- •Pointing instabilities are high due to long distances
- •Automated measurement system needed

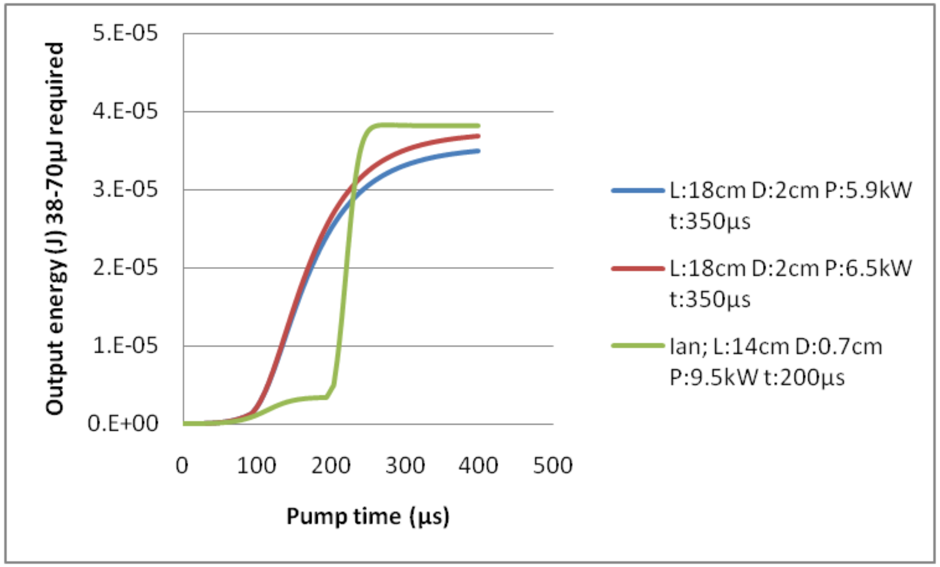
Feasibility for CLIC laser

Current amplifiers in a pre-pumped mode with a pre-shaped pulse

Steady state operation with an additional amplifier



By Mikhail Martyanov from IAP



Possible collaboration with MBI (Berlin), IAP (Russia) and Advanced Laser Development Group JAEA (Japan)