Photo-injector laser for CTF3 and CLIC

Marta Csatari Divall
CERN/EN/STI/LP

CAS Erice
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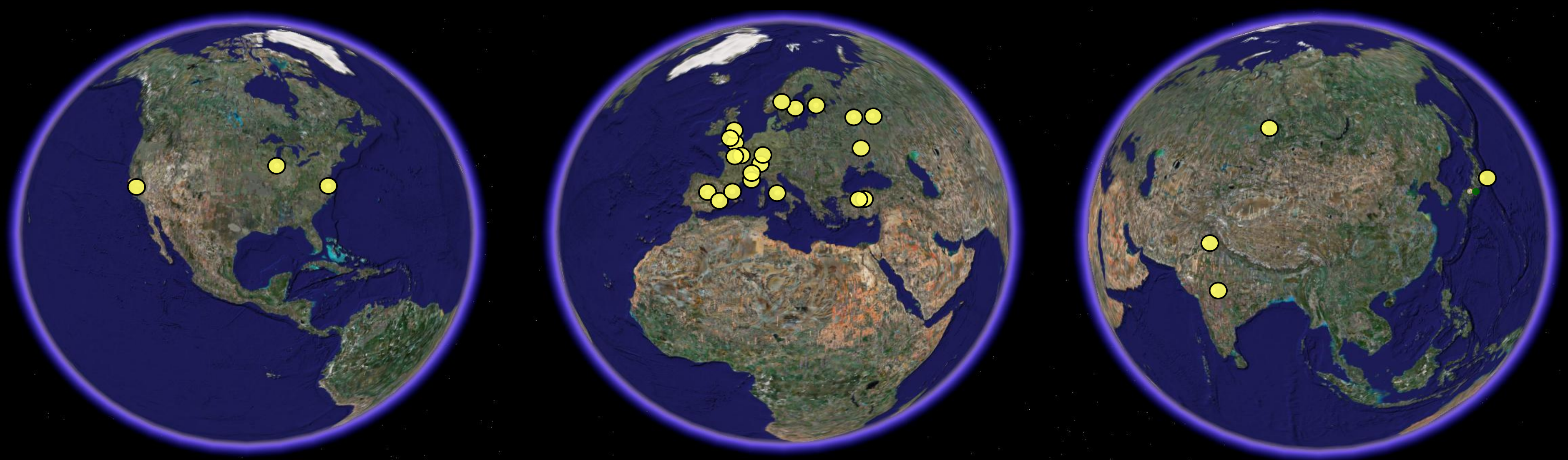
Outline

- CLIC project
- Photo-injectors
- Choice of drive beam
- The laser system
- Time structure/Phase-coding
- The electron beam
- Photo-injector for CLIC/ challenges

The CLIC/CTF3 Collaboration

38 institutes from 19 countries



Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETHZurich (Switzerland)
Gazi Universities (Turkey)

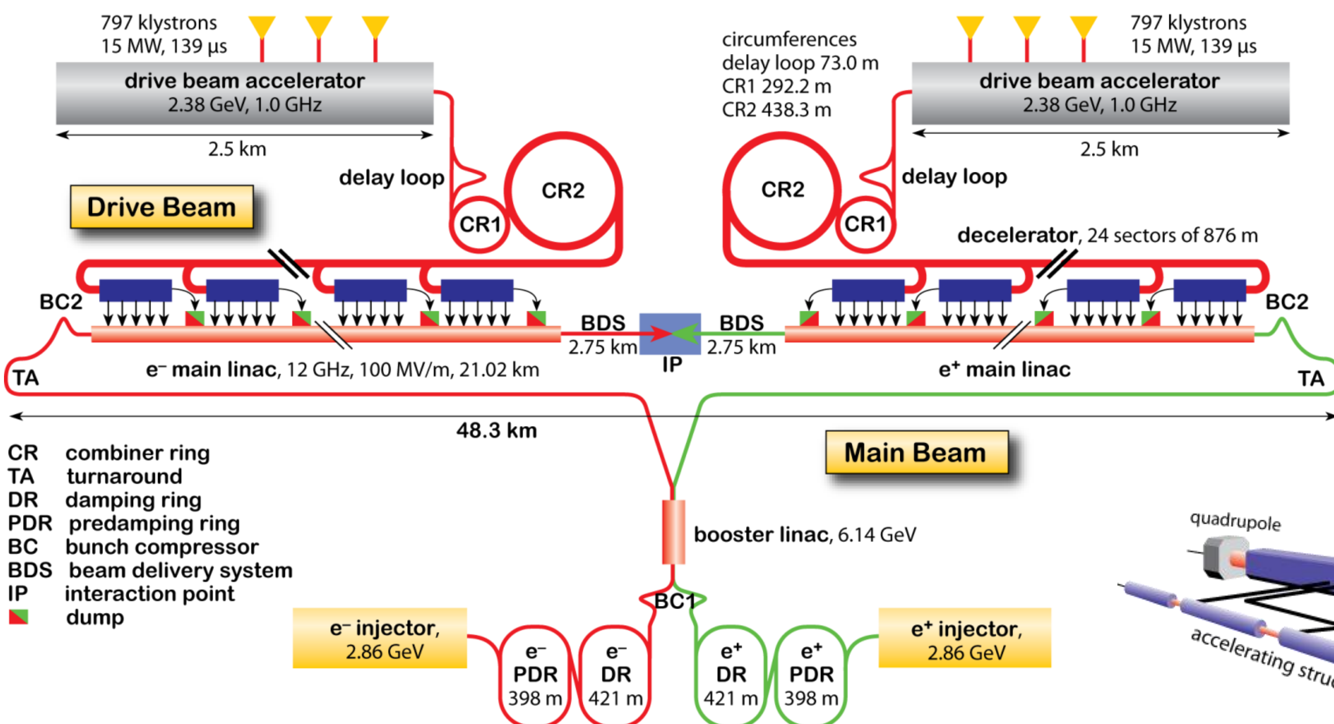
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)

John Adams Institute/RHUL (UK)
JINR (Russia)
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)

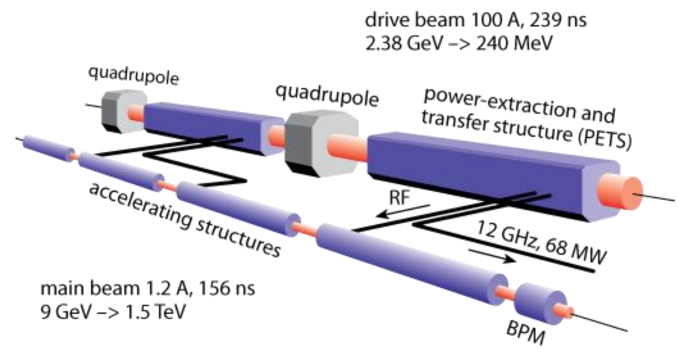
Polytech. University of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
Uppsala University (Sweden)
UCSC SCIPP (USA)

CLIC project

CLIC (Compact Linear Collider) is a study for a future **electron-positron collider** that would allow physicists to study whatever LHC finds and aim at a complementary 0.5-3TeV range. It will be a precision measurement device. *http://clic-study.web.cern.ch/clic-study/*



Designed for collision energy 3 TeV



CLIC relies upon a **two-beam-acceleration concept**, which provides 100 MV/m accelerating gradients: The 12 GHz RF power is generated by a high current electron beam (drive beam) running parallel to the main beam.

Photoinjectors

Since 1985 when the photoinjector concept has been introduced their use has grown substantially

Laser pulses illuminate a photocathode generating e-bunches by photoemission process.
The cathode is placed into an accelerating structure serving to extract the electron bunches.
Multi-cell rf gun cavity with high peak electric field

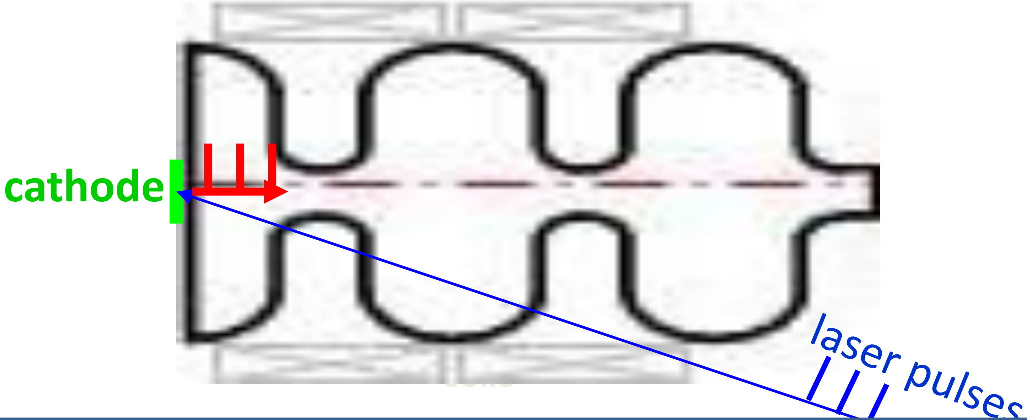
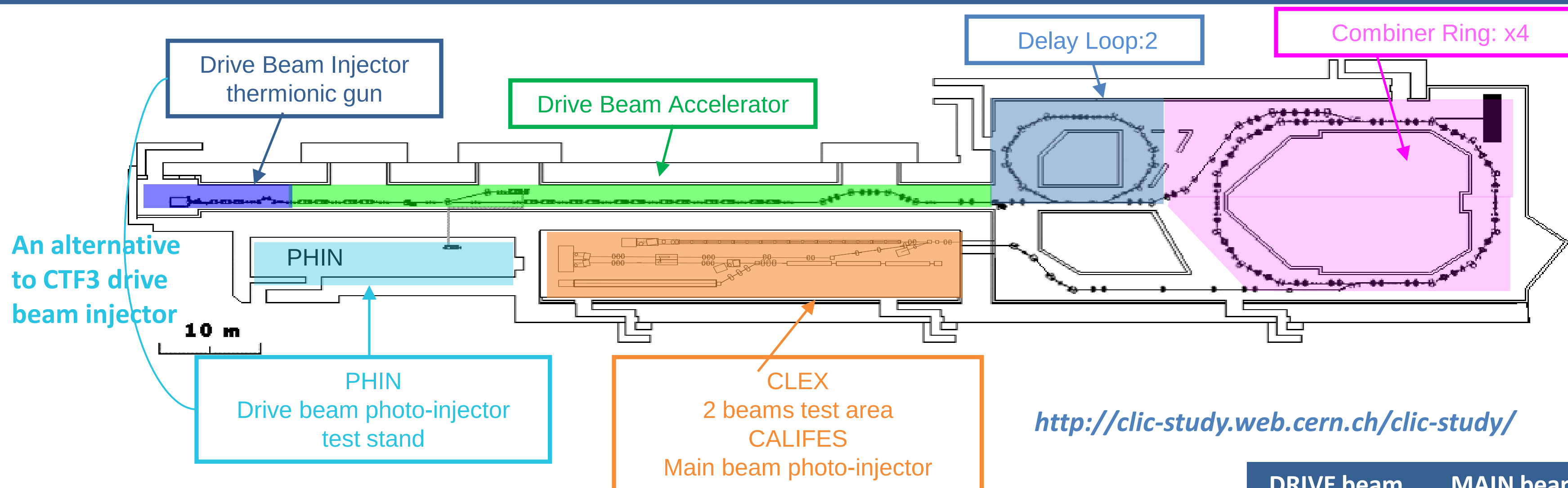
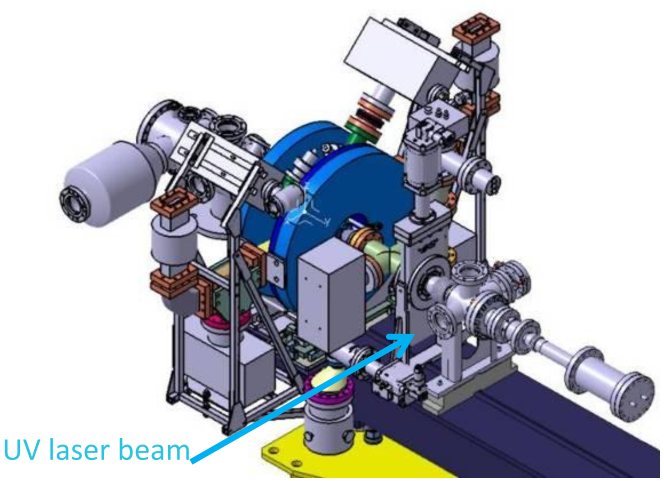


Photo-injectors for CTF3 (CLIC Test Facility 3)



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

Drive Beam injector choice

Baseline: Thermionic gun with 500 MHz sub harmonic bunching and bunch compressor, 1 GHz acceleration

Advantages of a photo injector for the CLIC DB

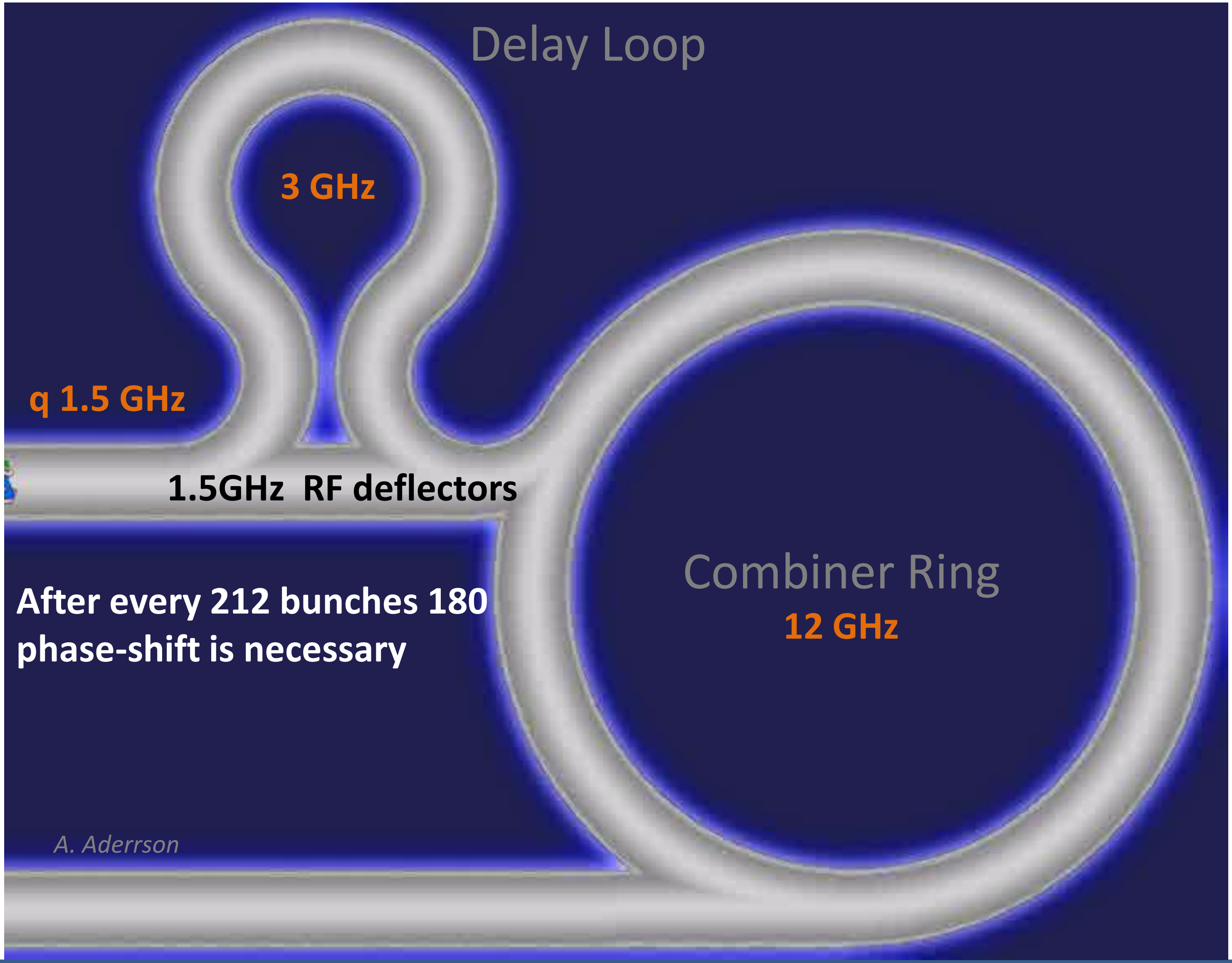
- Time structure already defined by the laser, short bunches
- Satellite-free phase coding, less losses
- No bunching system needed and less bunch compression later on
- Smaller emittance < 10 μm in theory, < 40 μm from PHIN extrapolation

(thermionic gun is specified for < 100 μm)

Disadvantages:

- Potential 'frequent' cathode changes (5 days)
- Amplitude stability of the laser transferred to charge instabilities

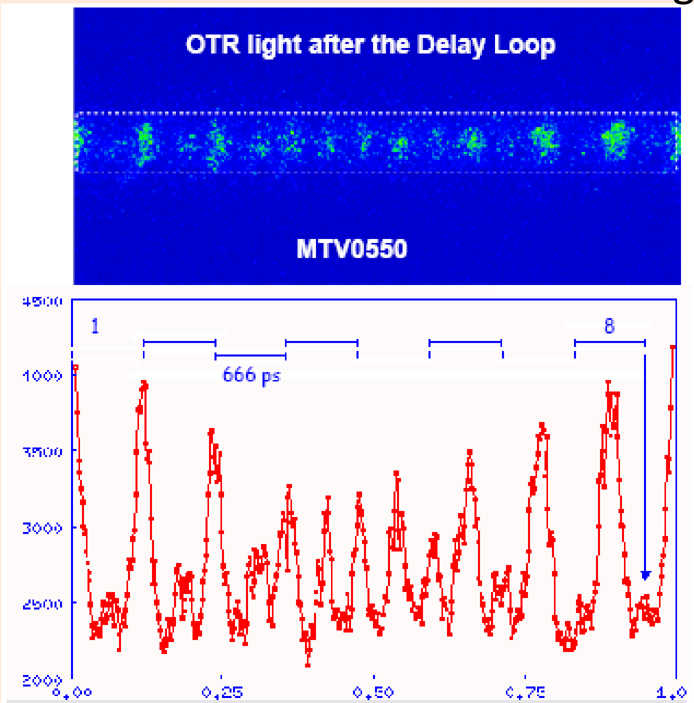
The time structure/beam combination



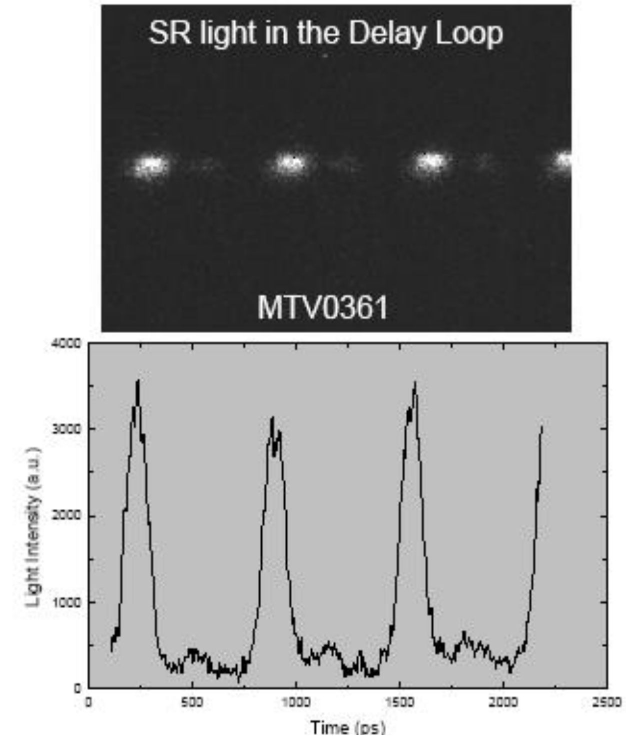
Time structure requirement

With thermionic gun

Sub-harmonic bunching and bunch compression



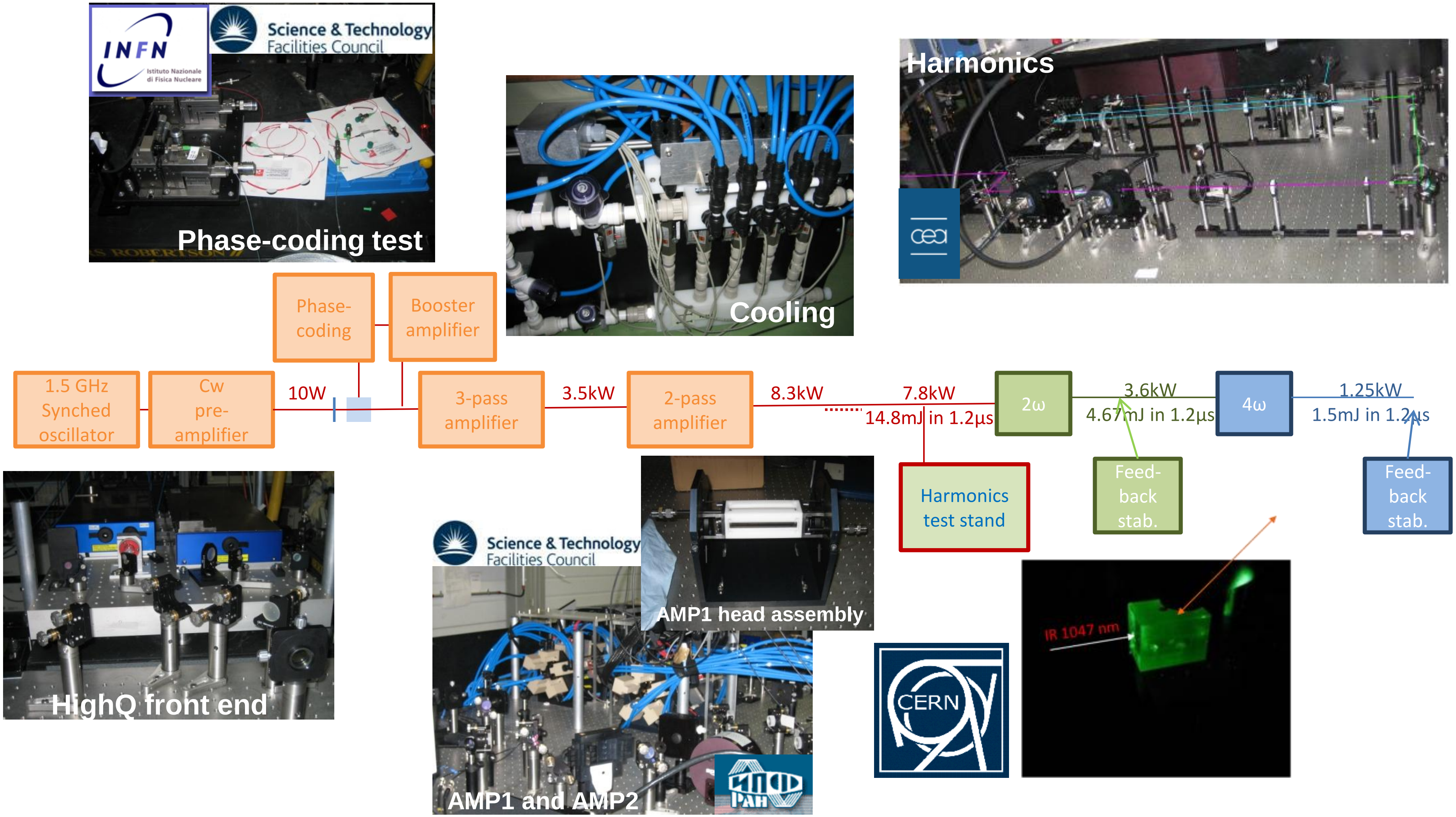
Phase switch is done within 8 of 1.5 GHz periods (~ 5 ns)



Satellite bunch population was estimated to ~ 7 %

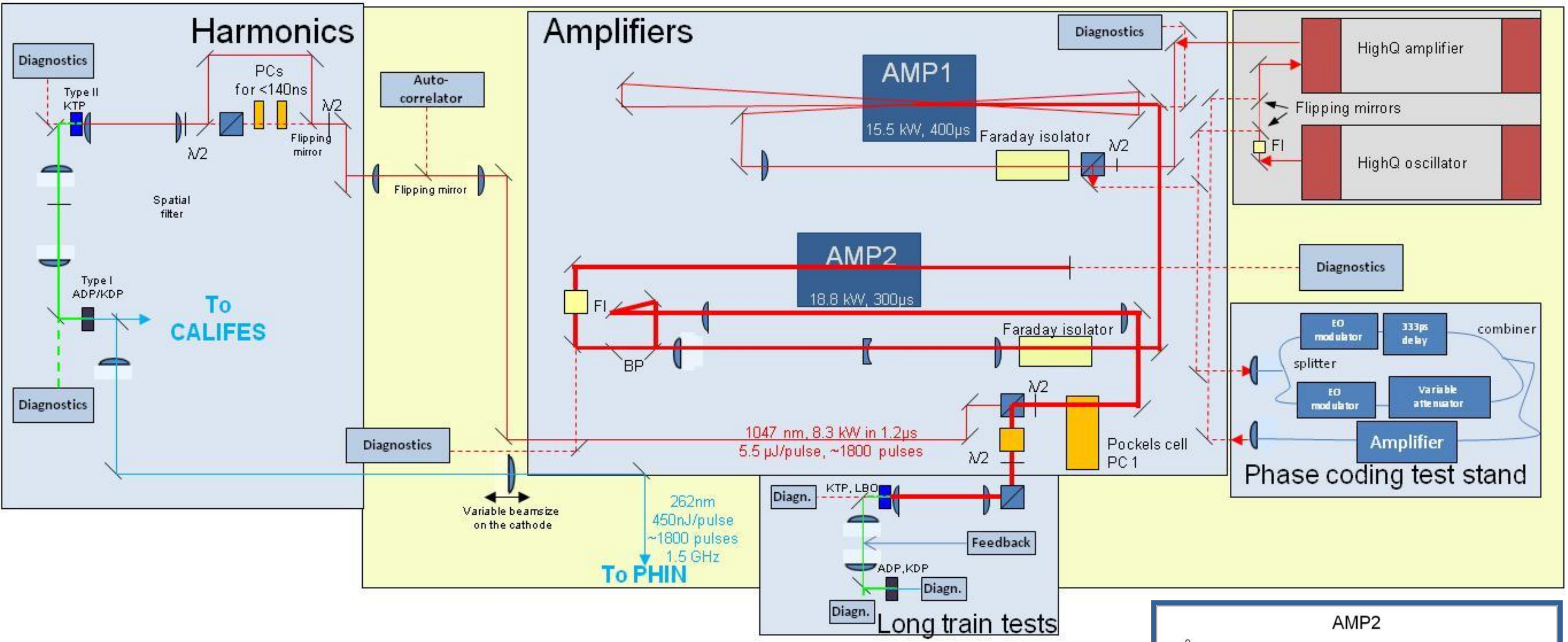
R. Corsini (12th March 2010)

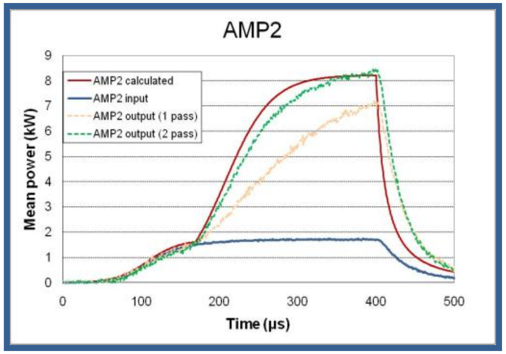
Laser setup



INFN Istituto Nazionale di Fisica Nucleare
Science & Technology Facilities Council
Phase-coding test
Cooling
Harmonics
cea
Phase-coding
Booster amplifier
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
Harmonics test stand
Feed-back stab.
Feed-back stab.
HighQ front end
Science & Technology Facilities Council
AMP1 head assembly
AMP1 and AMP2
CERN
IR 1047 nm

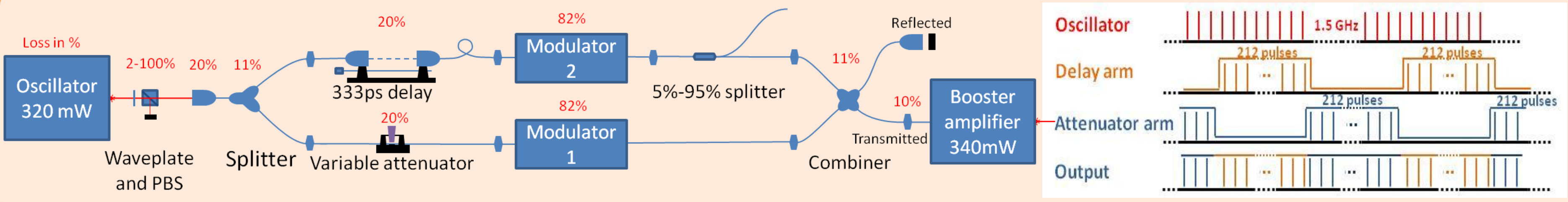
Laser setup

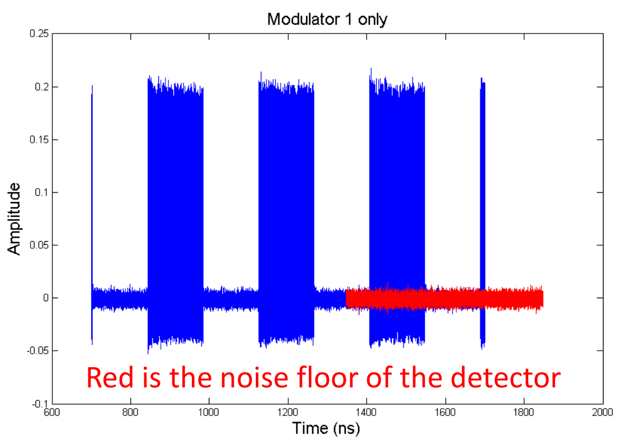


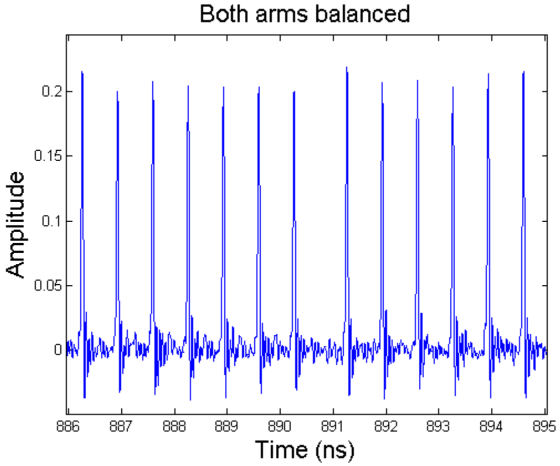


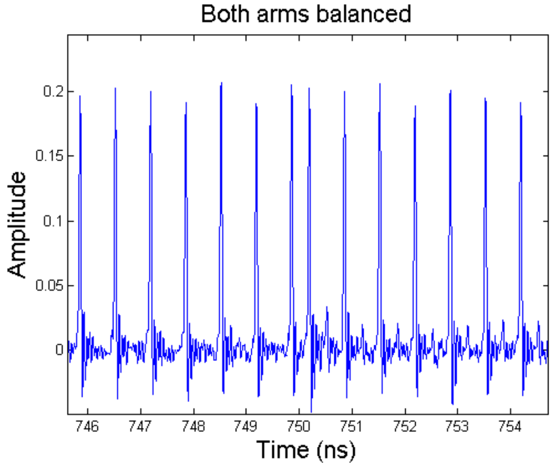
- Using ‘leakage’ wherever we can
- No interruption to operation

Phase-coding



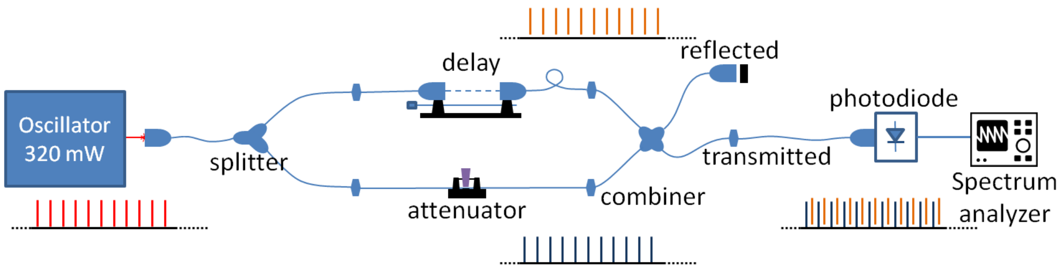




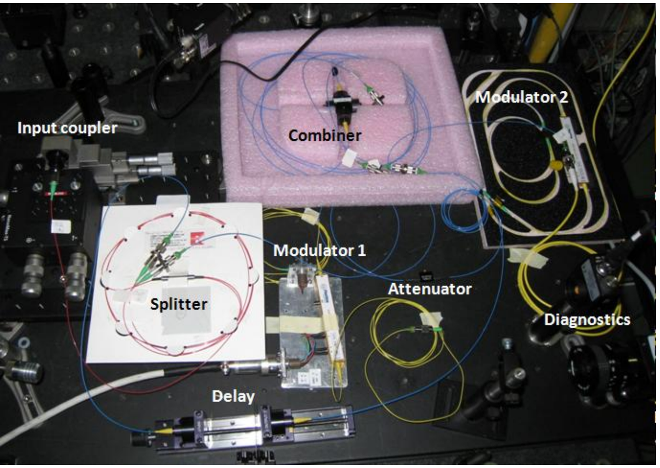


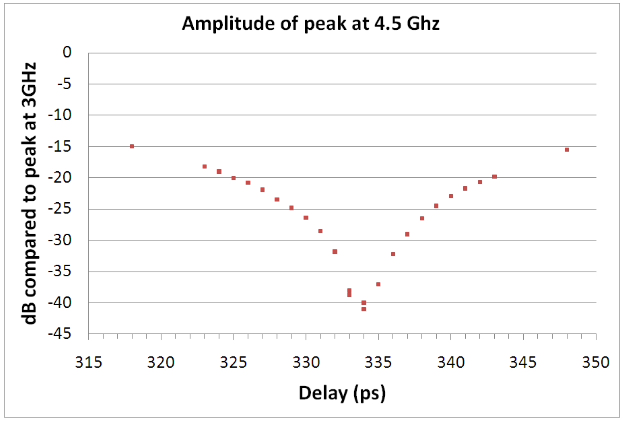
- **Drivers synchronized to 1.5 GHz**
- **Clean cut between pulses**
- **Both modulators give at least 300 extinction ratio, but with the noise floor it is hard to estimate below this**

Phase coding alignment measurement



- Measurement without modulators (or modulators at 50% bias/QUAD point)
- 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





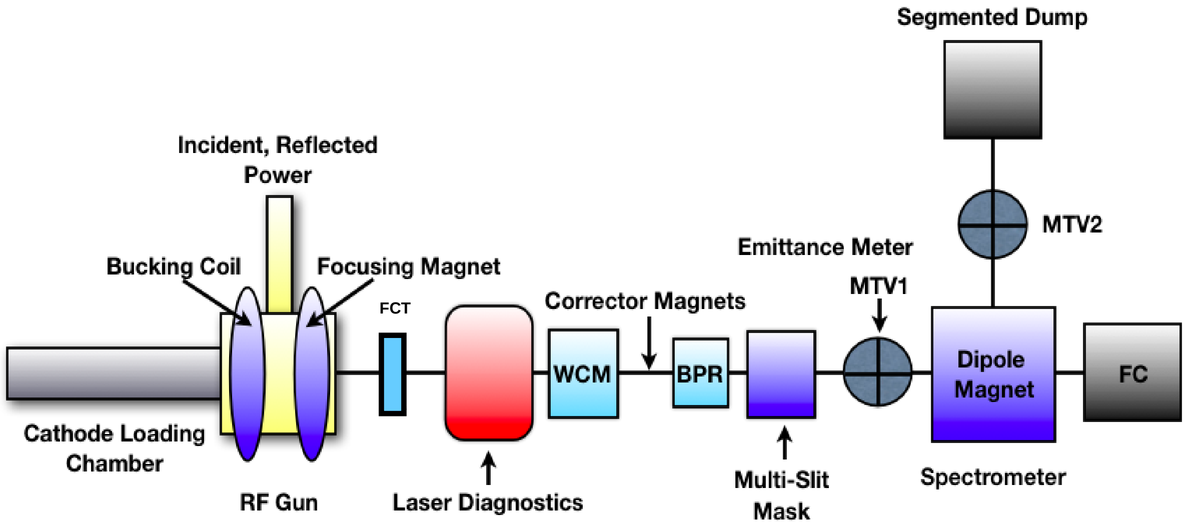
Achieved accuracy between arms:

•0.2 ps in delay

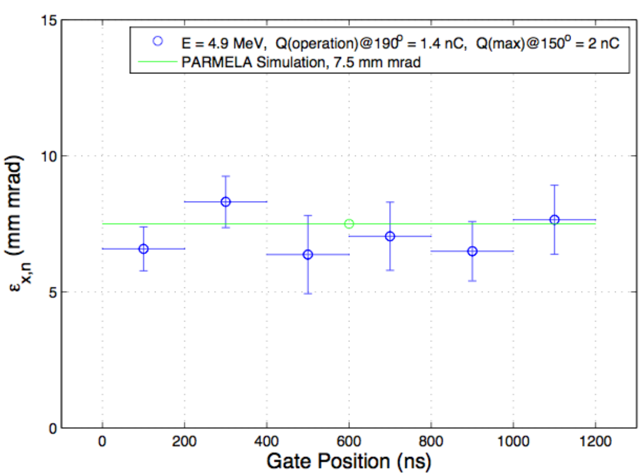
•0.1% in amplitude

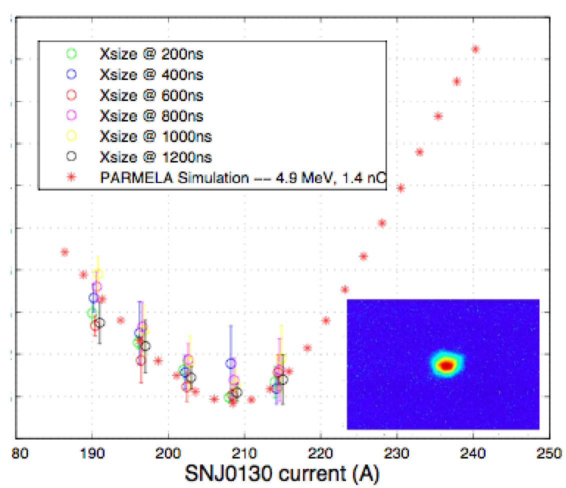
Provides easy setup for the phase-coding

Electron beam characterization



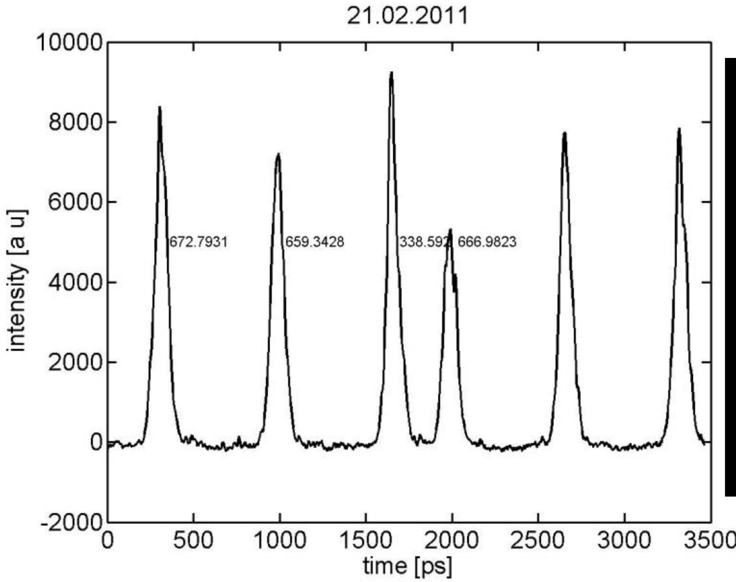
Parameter	Nominal value	Unit
Beam Energy	5.4	MeV
Pulse Length	1.54	μs
Beam current	3.5	A
Bunch charge	2.33	nC
Number of bunches	2310	
Total charge per pulse	5.4	μC
Bunch spacing	0.666	ns
Emittance	14	mm mrad
Repetition rate	5	Hz
Charge variation shot to shot	2	%
Charge flatness on flat top	0.25	%

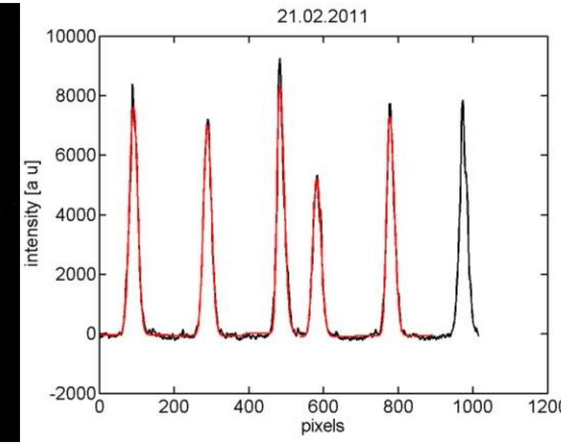


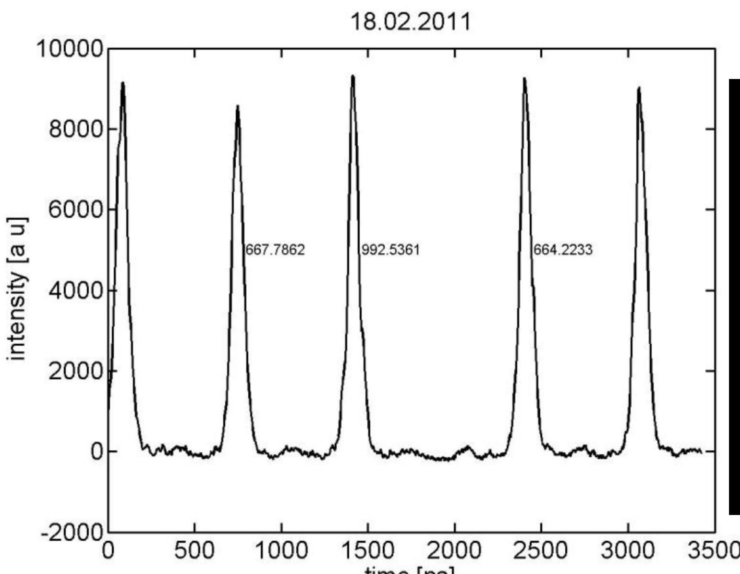


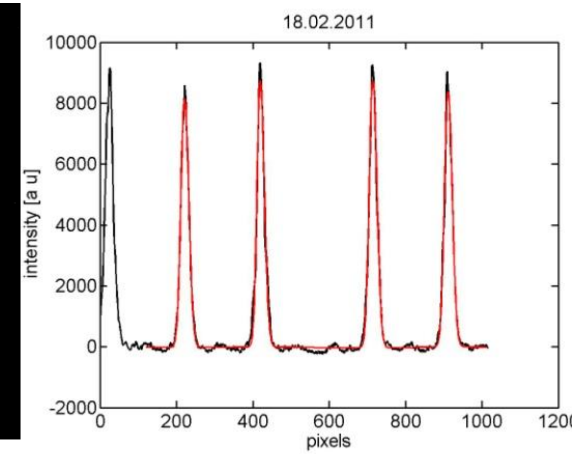
O. Mete

Streak measurements with Cherenkov-line









A.N. Rabiller

CLIC Parameters

		DRIVE beam		MAIN beam
		PHIN	CLIC	CALIFES
Electrons	charge/bunch (nC)	2.3	8.4	0.6
	gate (ns)	1200	140371	19.2
	bunch spacing(ns)	0.666	1.992	0.666
	bunch length (ps)	10	10	10
	Rf reprate (GHz)	1.5	0.5	1.5
	number of bunches	1802	70467	32
	machine reprate (Hz)	5	100	5
	margine for the laser	1.5	2.9	1.5
	charge stability	<0.25%	<0.1%	<3%
	QE(%)	3	2	0.3
Laser in UV	laser wavelegth (nm)	262	262	262
	energy/micropulse on cathode (nJ)	363	1988	947
	energy/micropulse laserroom (nJ)	544	5765	1420
	energy/macrop. laserroom (uJ)	9.8E+02	4.1E+05	4.1E+01
	mean power (kW)	0.8	2.9	2.1
	average power at cathode wavelength(W)	0.005	41	2.E-04
	micro/macropulse stability	1.30%	<0.1%	<3%
Laser in IR	conversion efficiency	0.1	0.1	0.15
	energy/macropulse in IR (mJ)	9.8	4062.2	0.3
	energy/micropulse in IR (uJ)	5.4	57.6	9.5
	mean power in IR (kW)	8.2	28.9	14.2
	average power on second harmonic (W)	0.49	406	1.E-03
	average power in final amplifier (W)	9	608	15

Main challenges

Things we still need to learn about:

LASER

Long train operation for CLIC (140 µs)

High average power operation (100Hz)

Amplitude stability and stabilization

Pointing stability and stabilization

Long term reliability/damage/degradation

CATHODE

Working QE for high integrated charge with reasonable turn over time

Effect of vacuum and possible solutions

Green responsive cathodes

Long term reliability/damage/degradation

The team

BEAM DYNAMICS: *S. Doebert, O. Mete*

DIAGNOSTICS: *B. Bolzon, E. Bravin, A. Dabrowski, D. Egger, T. Lefevre, M. Olvegaard, A.N. Rabiller*

LASER: *V. Fedossev, C. Hessler, M. Martyanov, M. Petrarca*

CATHODE: *E. Chevallay, vacuum group*

PHASE-CODING: *A. Drozdy, S. Livesley, A. Andersson*

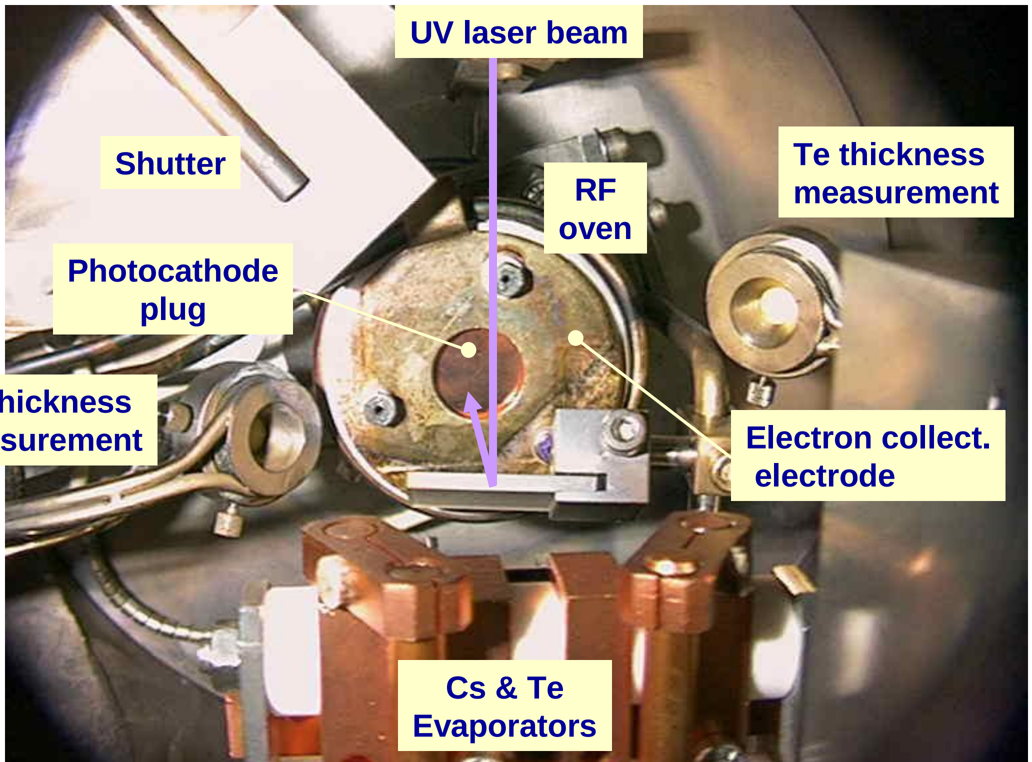
CONTROLS and STABILIZATION: *S. Batuca, M. Donze, A. Massi, M.D'Arco, S. Gim*

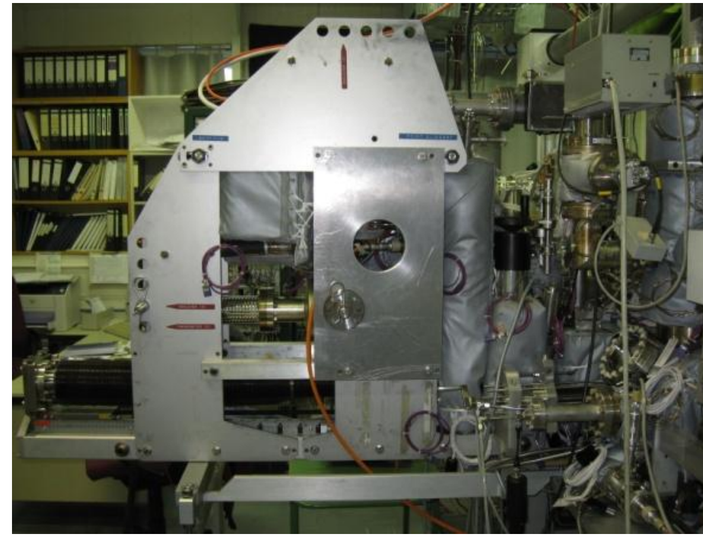
……. and many more

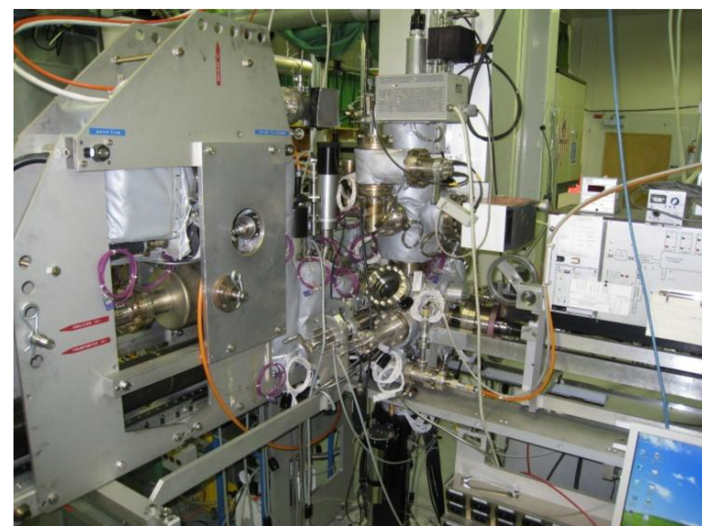
Photocathodes

Cs_2Te photocathodes produced by co-evaporation on Cu substrate under 10^{-10} mbar and transferred to RF gun under 10^{-11} mbar. Active vacuum in RF gun up to 10^{-7}

QE = 10-18% at start







E. Chevallay

Cathode at visible wavelength

QE= #electrons/#photons

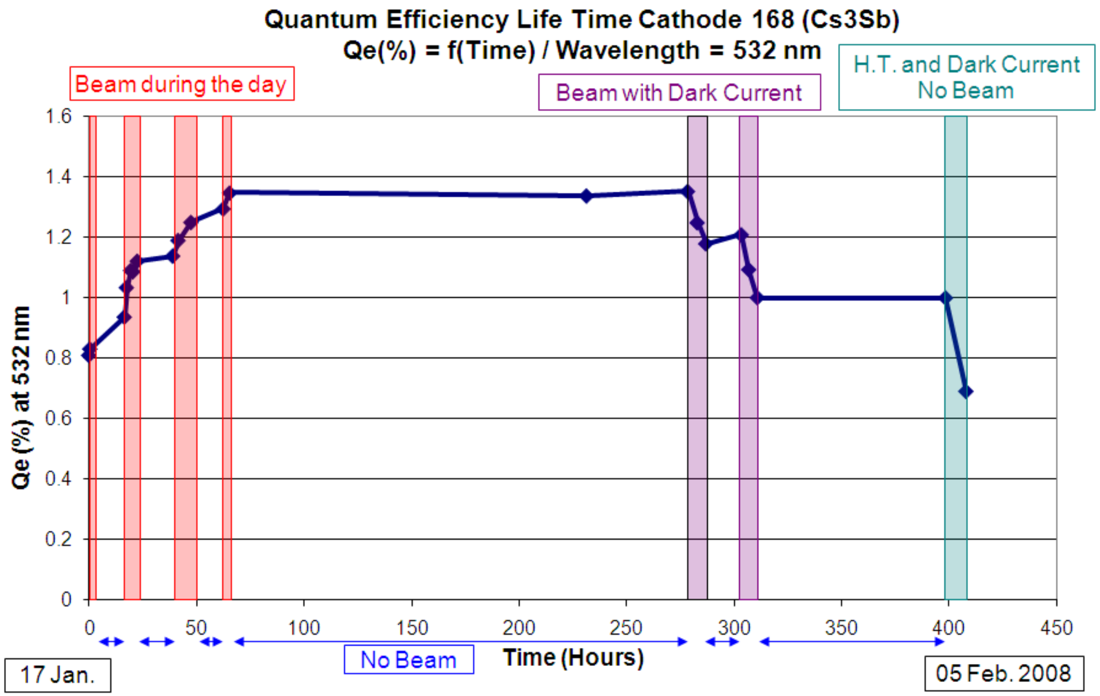
At visible:

The photon energy is half
The laser energy is X4

Number of photons X8

QE is expected to be the same

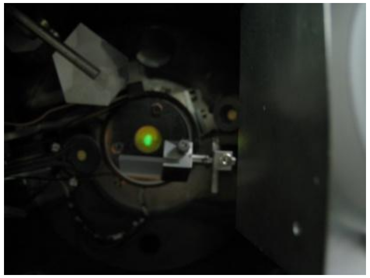
X8 of the charge with the same laser



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

Cs_3Sb Photocathode tests

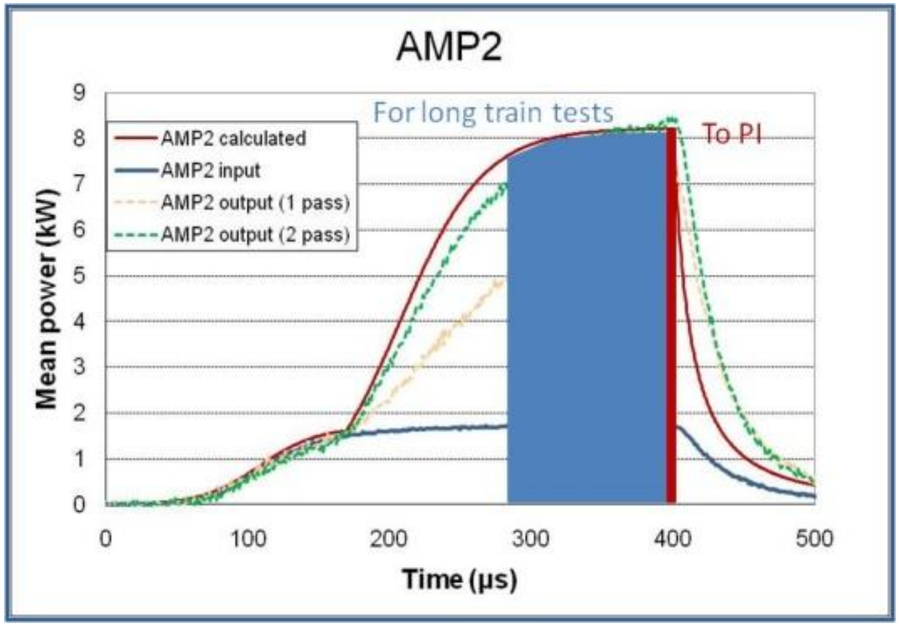
- Co-evaporation
- Qe optimalization during fabrication at 532 nm
- Online measurements and computing available

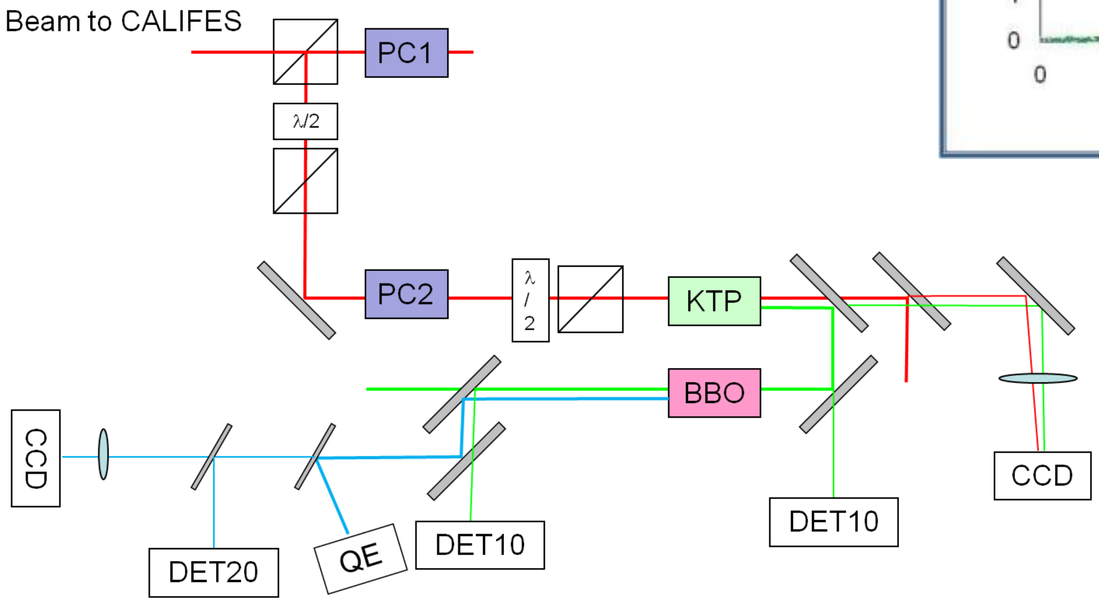


Long train in the UV

<u>Motivation:</u>

- CLIC needs 140 μs long train
- Decay over the train was observed during PHIN run
- Beam profile is degrading with high UV levels
- Damage was observed to crystals with long trains





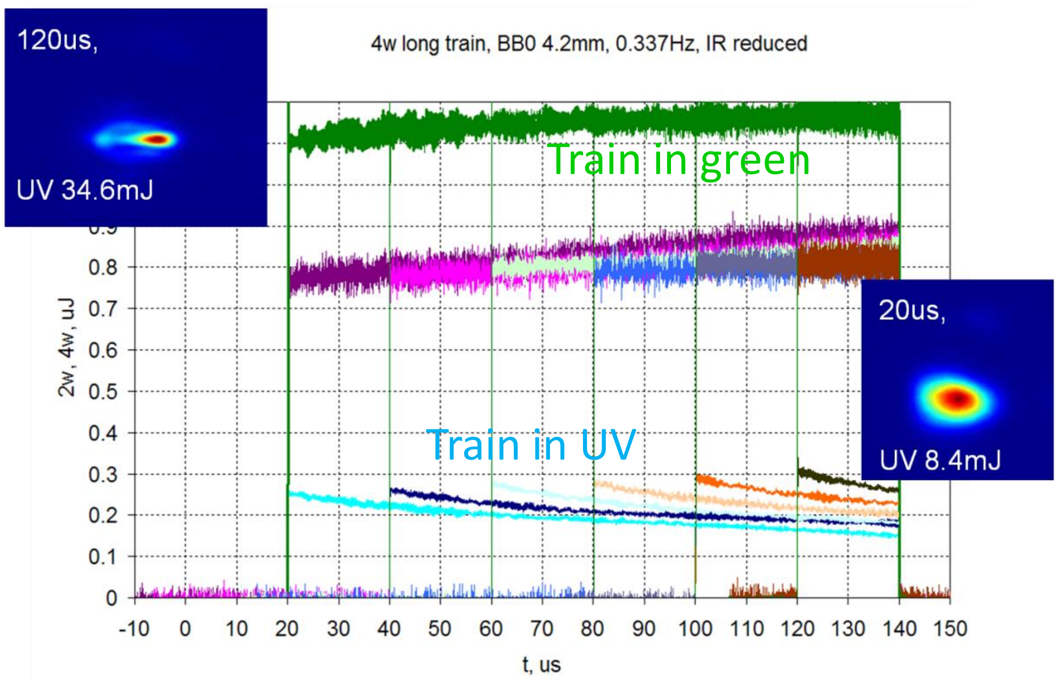
<u>Aim:</u>

- Identify damage levels
- Test response to long trains
- Beam profile meas. along the train
- Tests different crystals for UV
- No interruption to CALIFES

Long train harmonics test

RESULTS

- 140 μs long train in the green with 45% efficiency with comparable energy/pulse to CLIC laser in KTP
- Damage threshold measured and understood to be from aged coating on surface
- BBO as new crystals tested up to 33% efficiency to UV
- 120 μs long train generated in the UV
- Time and spatial profile response measured along the train
- Onset level of beam degradation measured



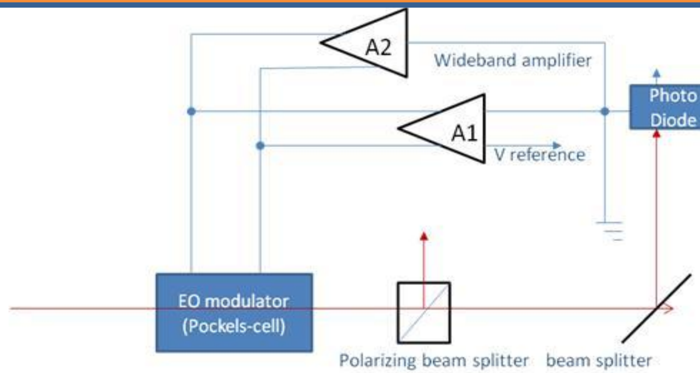
Plans

- Test multi-crystal schemes
- Find best crystal and working point
- Understand thermal load
- Move to higher repetition rate
- Investigation of green responsive cathodes

- Further collaboration with IAP and FI

In collaboration with IAP RAS, Russia; Mikhail Martyanov

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

Noise reduction:
1/1@ 500kHz
5/1 @ 100kHz
18/1 @50kHz
100/1 @10kHz ,
200/1 @1kHz
250/1 @200hz

We need 0.1% rms stability

Stabilization constraints:

- Pockels cell absorptive in UV (control in UV not advisable)
- Laser is in burst mode at all stages after preamp with shorter burst length after Pockels-cell
- Realtime response necessary

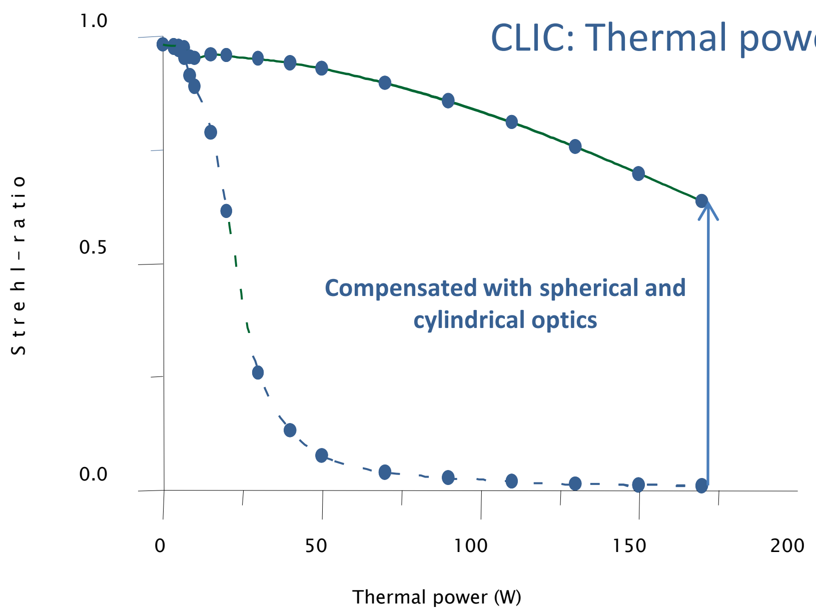
Stabilization options (WIP):

- Feedback control loop at IR or GR using ~Conoptics noise eater. (Market survey needed)
- Feedforward control before 4th harmonic using measurements from earlier stages to determine level correction. (Further studies)
- Hybrid

All options to be investigated in 2011 with tests on laser

High average power

- **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

- 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
- **More thermal lensing measurement to be done on PHIN laser at 50Hz**

Not possible during CALIFES operation