Status and Recent Developments at the CTF3 Photoinjectors and Laser System

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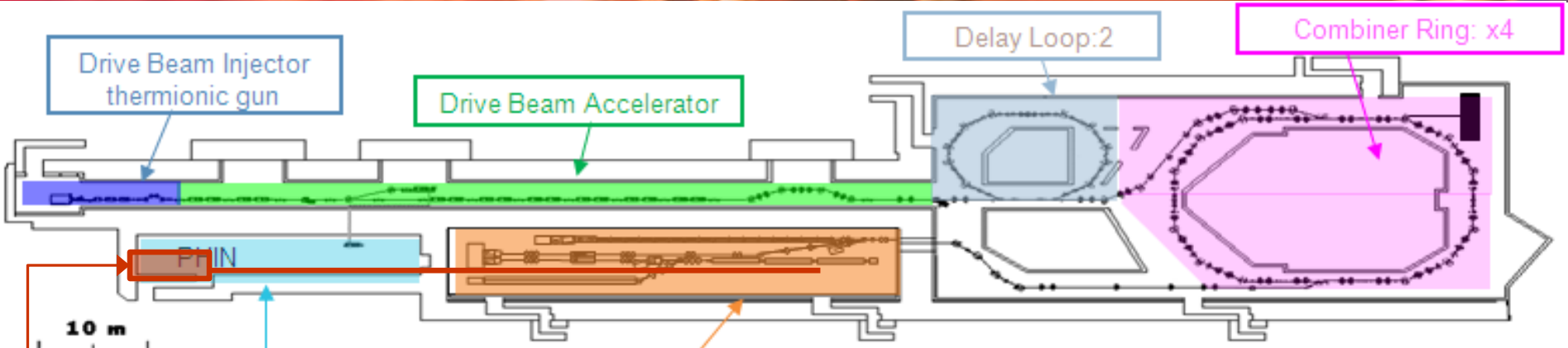
Photoinjectors at CTF3



Photoinjector laser lab (1st floor) and optical transfer lines to PHIN and CALIFES

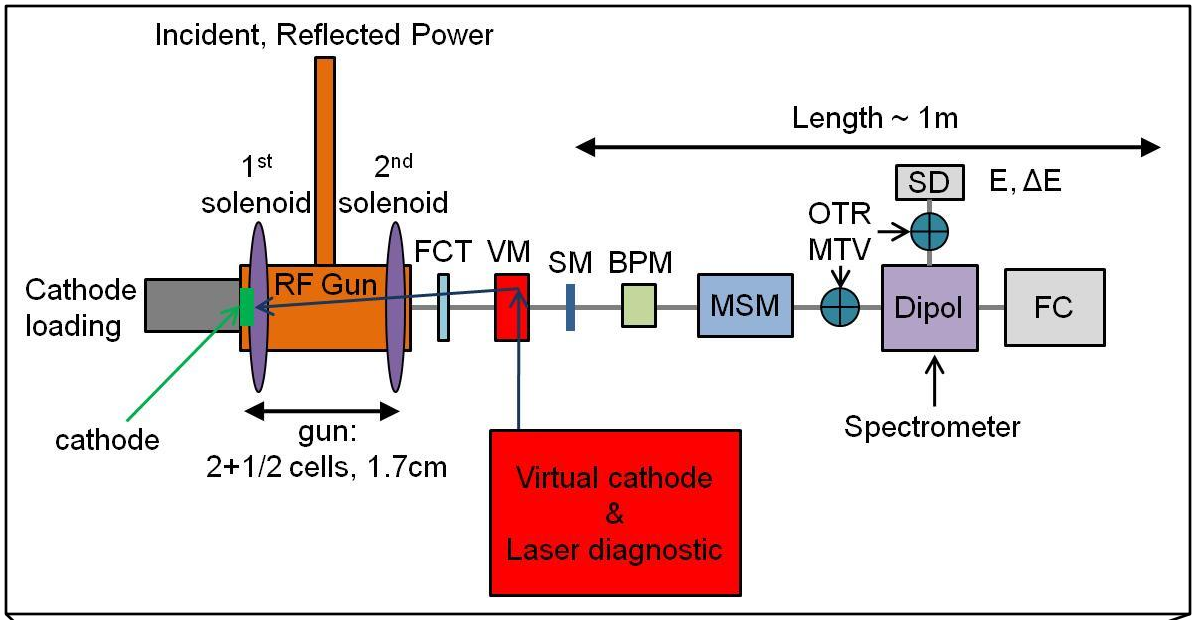
Dedicated photoemission laboratory in Bldg 101 for photocathode production, testing and R&D

		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

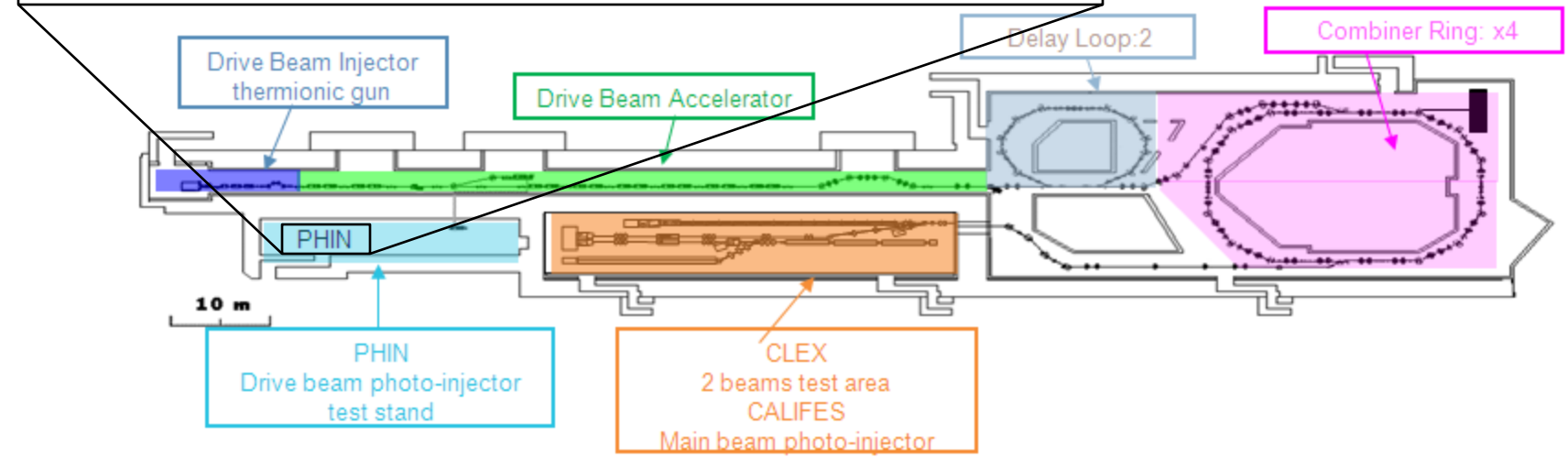
News from CALIFES

- High availability for daily operation in 1st half of 2013.
- Charge requirements fulfilled despite of some degradation of laser beam transmission caused by dust on optical surfaces.
- CALIFES not operational since CTF3 restart in October
  - Failure of the photocathode manipulator
  - Manipulator exchange required bake-out of the ultra-high vacuum system, a re-conditioning of the gun and a preparation of a new photocathode. Work is in progress.
  - 1st major downtime since its commissioning in 2008
    → CALIFES still very reliable
- Upgrade of laser control and diagnostics computers
- Single-pulse picker installed and ready to be tested with beam.

PHIN Layout



FCT: Fast current transformer
VM: Vacuum mirror
SM: Steering magnet
BPM: Beam position monitor
MSM: Multi-slit Mask
OTR: Optical transition radiation screen
MTV: Gated cameras
SD: Segmented dump
FC: Faraday cup



Motivation for a Drive-Beam Photoinjector

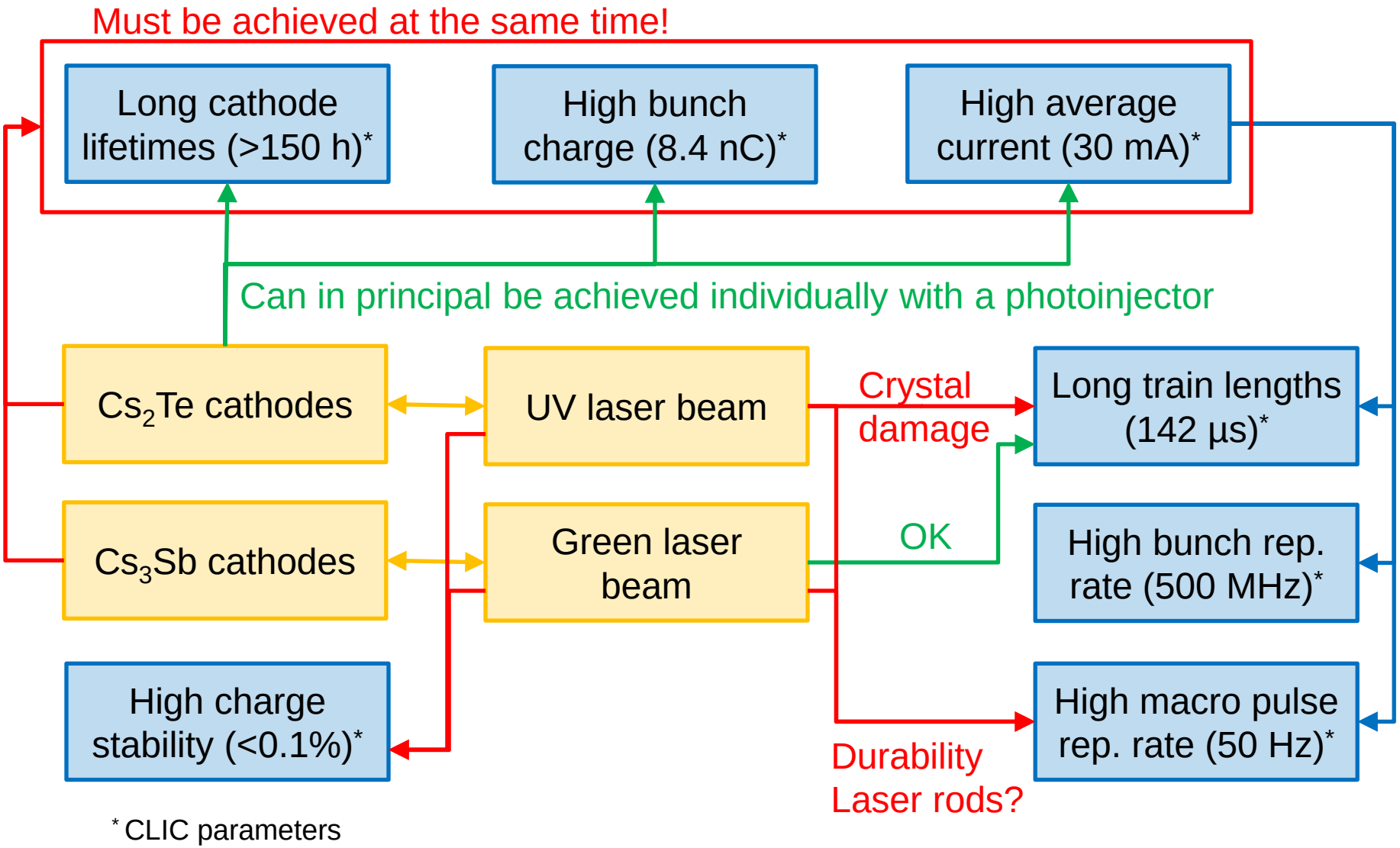
- A conventional system (thermionic gun, sub-harmonic buncher, RF power sources) is not necessarily more reliable than a photoinjector. At CTF3 e.g. the availability of the CALIFES photoinjector is high.

- Present system (thermionic gun, sub-harmonic buncher) generates parasitic satellite pulses, which produce beam losses.
  - Reduced system power efficiency
  - Radiation issues due to the beam losses of the satellite pulses

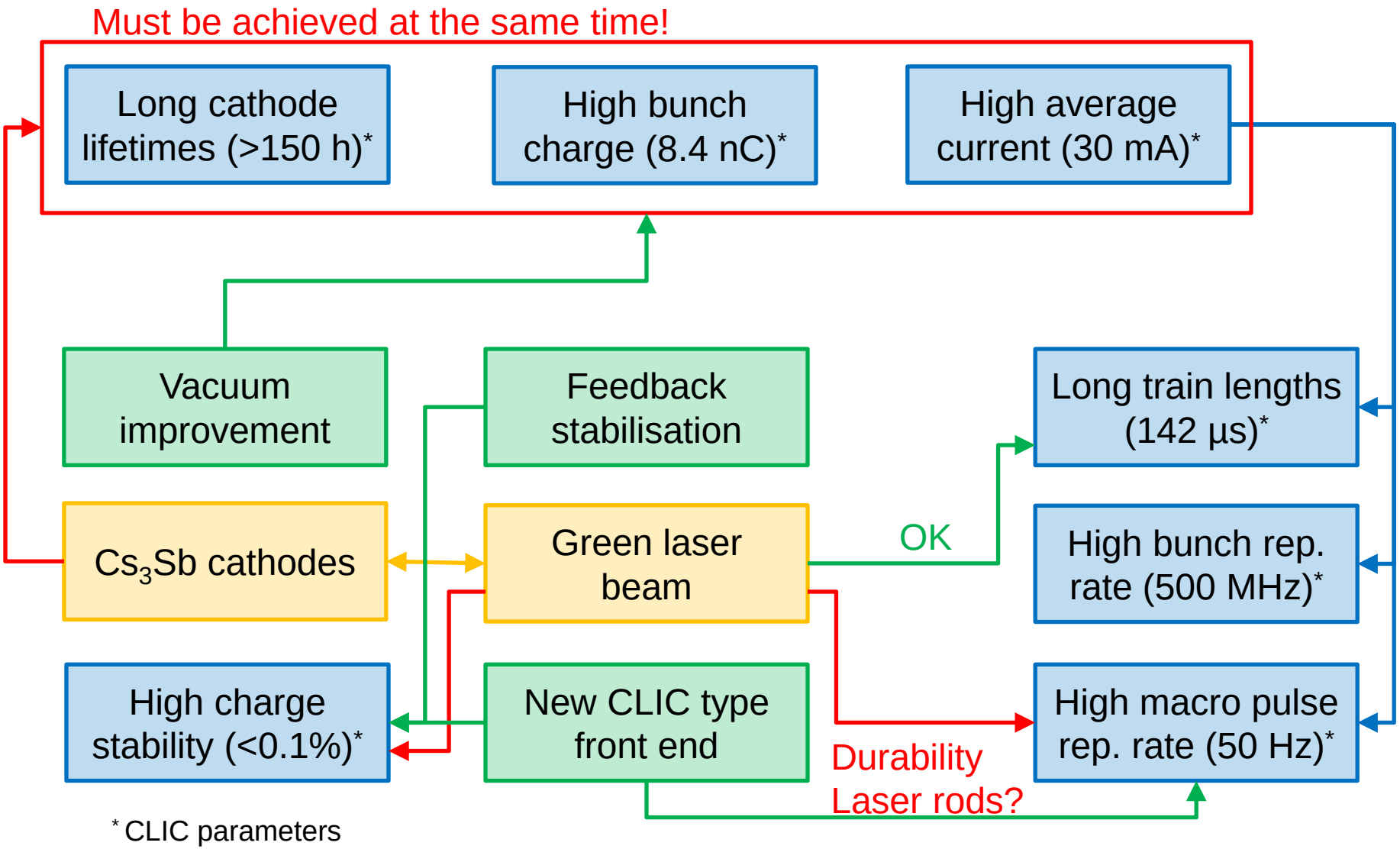
- These problems can be avoided using a photoinjector, where only the needed electron bunches are produced with the needed time structure.
  → Has been demonstrated for the phase-coding in 2011.

M.Csatari Divall et al., “Fast phase switching within the bunch train of the PHIN photo-injector at CERN using fiber-optic modulators on the drive laser”, Nucl. Instr. And Meth. A 659 (2011) p. 1.

Main Challenges for Drive Beam Photoinjector



Strategy to Overcome the Challenges



* CLIC parameters

Improvement of Vacuum in PHIN

March 2011

Dynamic vacuum level: 4e-9 mbar

Activation of NEG chamber around gun

March 2012

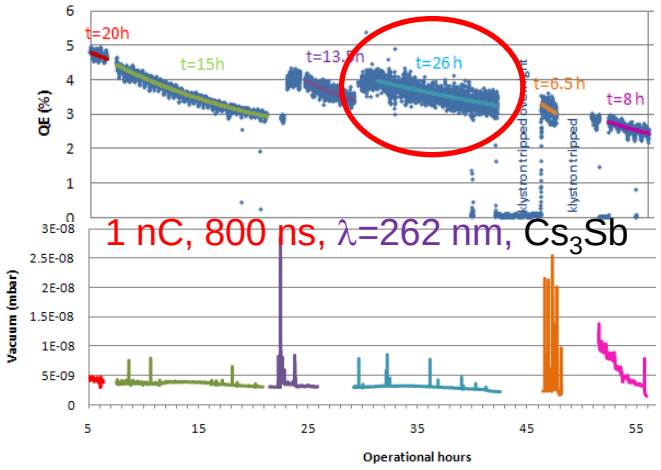
7e-10 mbar

Installation of additional NEG pump

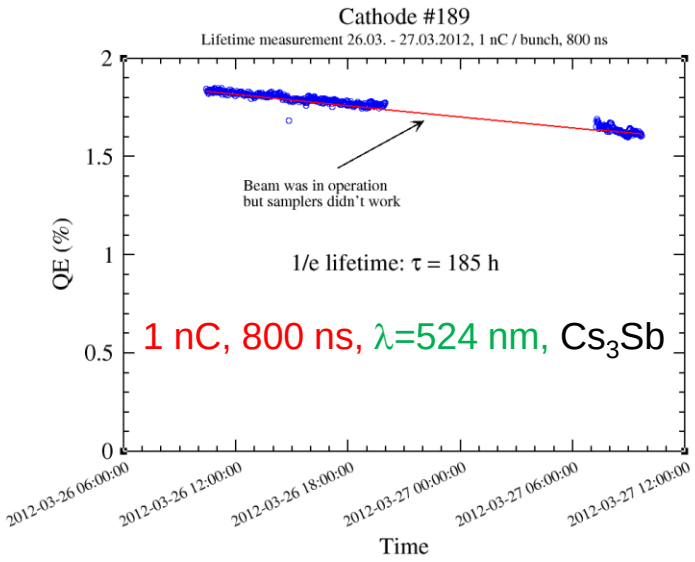
July 2013

<2e-10 mbar

1/e lifetime 26 h



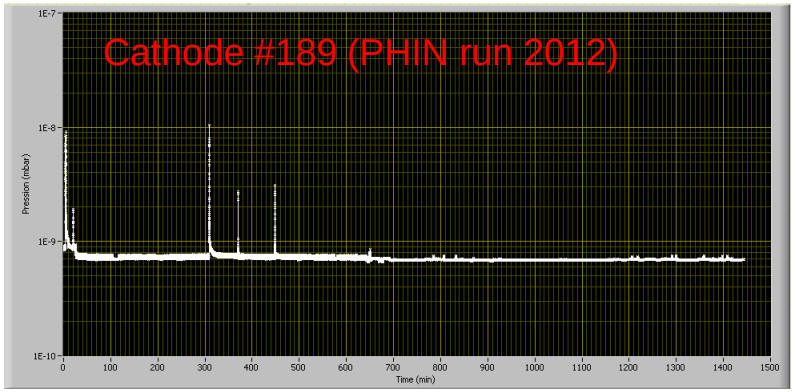
1/e lifetime 185 h

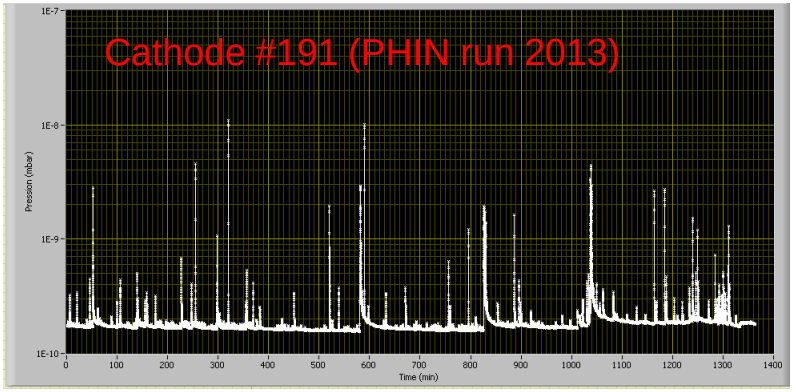


1/e lifetime n/a due to different problems during PHIN run

Problems with Lifetime Measurements

- Despite good QE in DC gun, photocathodes had low QE on arrival in PHIN gun
- Despite good dynamic base vacuum level there were a lot of breakdowns causing desorption spikes:

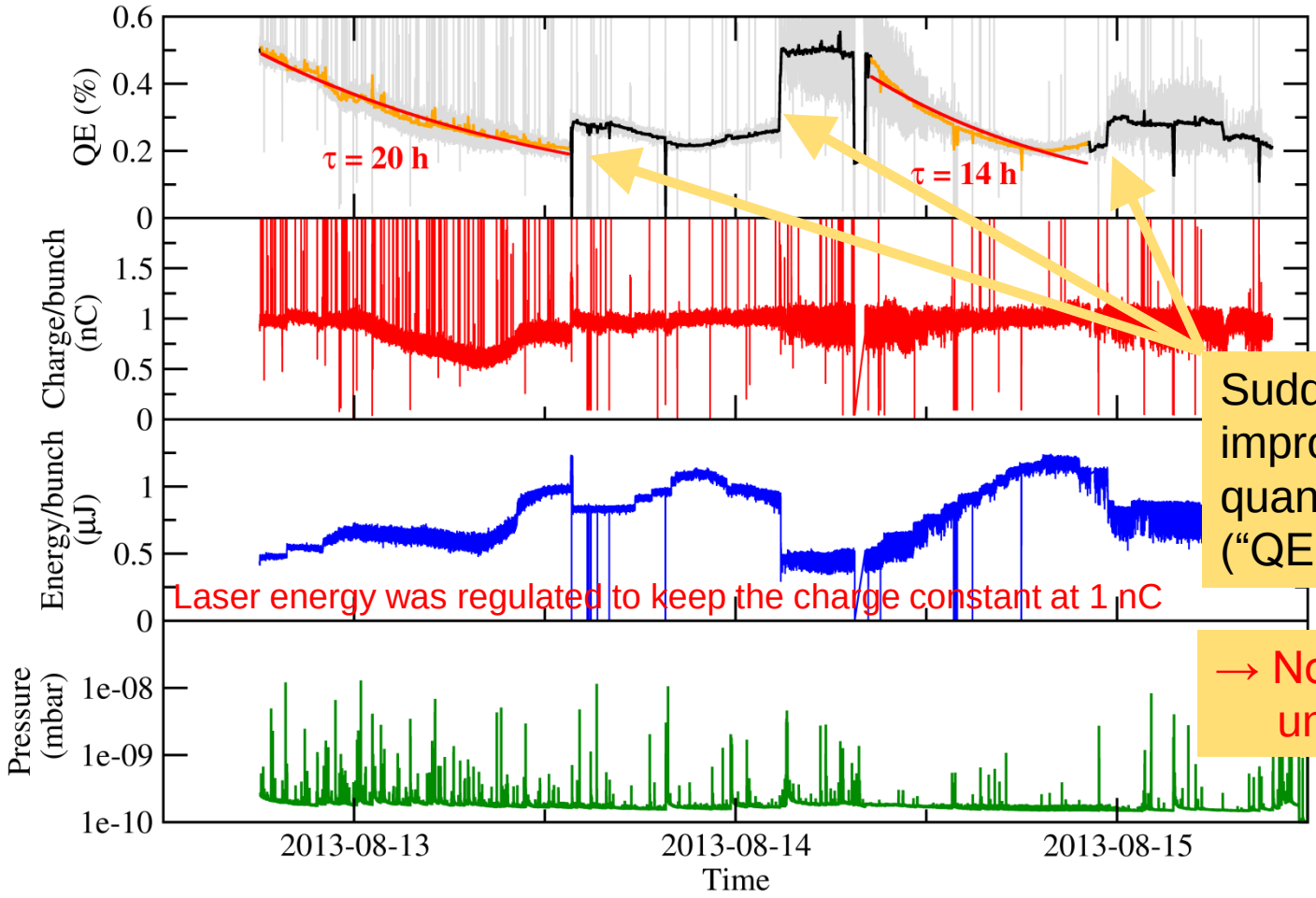




- 24h oscillations on beam current
- Rapidly decreasing QE, (partially) recovering during “QE jumps”

QE Jumps

Cathode #191, Cs_3Sb, train length 800 ns, bunch charge 1 nC



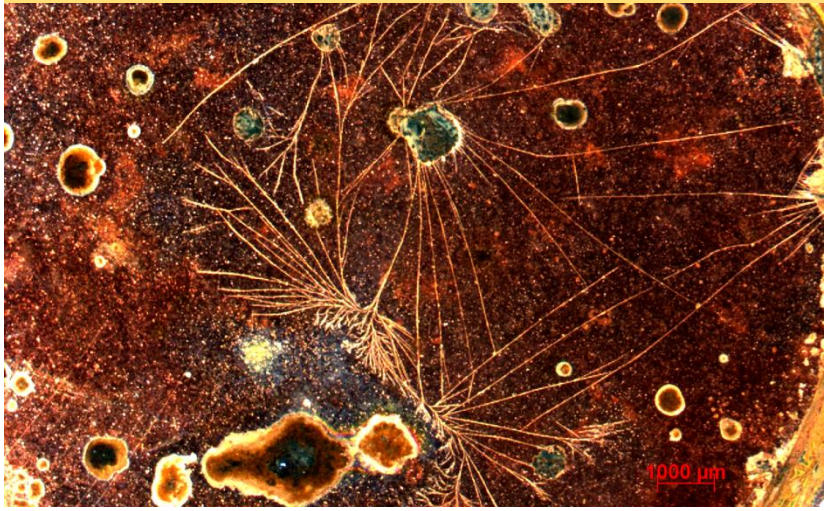
Sudden improvement of quantum efficiency ("QE jumps")

→ Not yet understood!

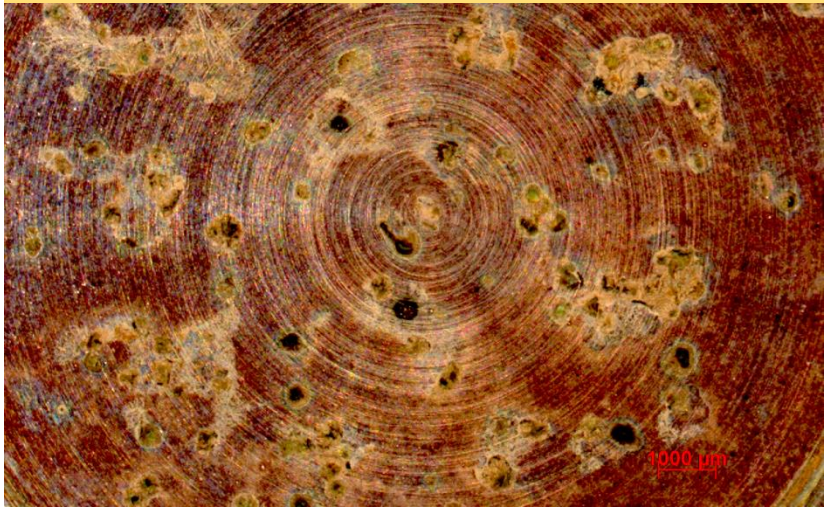
Some Explanations

- Low initial QE and the breakdowns can be partially explained by the fact that Cu plugs of a different batch were used (Photos taken after usage in PHIN):

Cathode #189 (PHIN run 2012)
Surface treatment: Diamond powder polishing



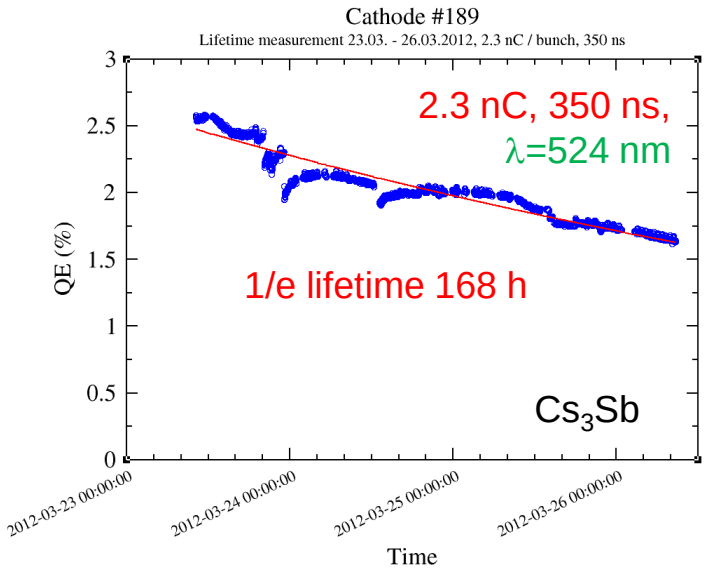
Cathode #193 (PHIN run 2013)
Surface treatment: Diamond turning

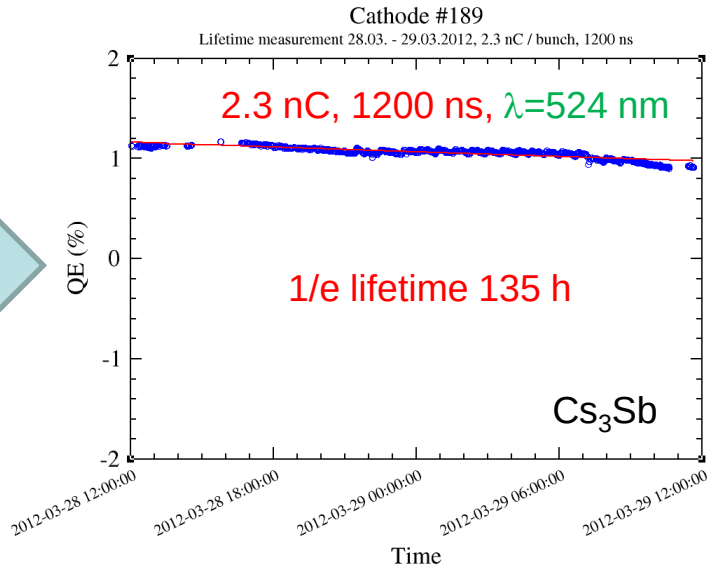


- 24h oscillations probably due to non-working air conditioning in klystron gallery → Phase shift RF reference signal for laser

Operation with Long Trains

- In 2012 measurements with 350 ns and 1200 ns train length were taken, yielding similar lifetimes:





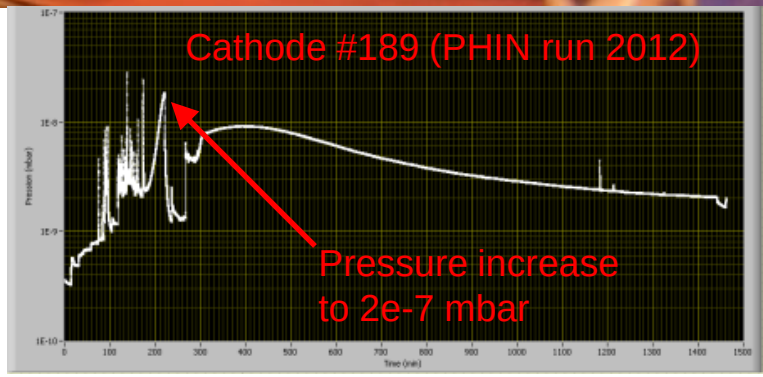
2.3 nC,
5000 ns

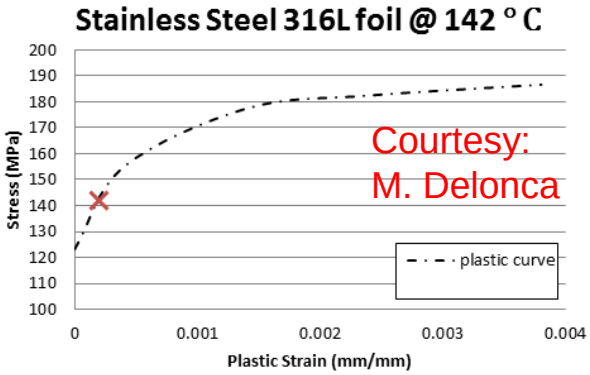
lifetime ?

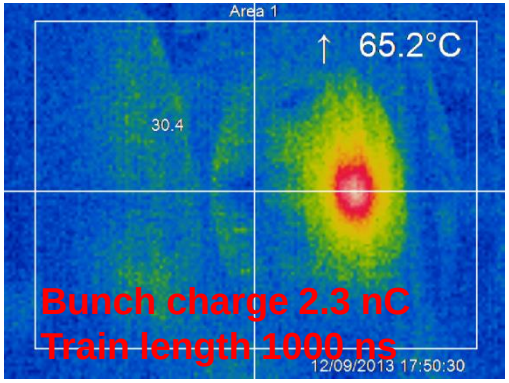
- However, due to low QE of photocathodes and other problems these measurements were not possible during last PHIN run.
- Beam intensity of 5 µs trains is too high for present Faraday cup.

Faraday Cup for Long Trains

- In 2012 strong pressure increase due to Faraday cup heating was observed for relatively high beam intensity.
- Beam power for 5 µs trains with 5 Hz rep rate and 2.3 nC/bunch: 430 W
  → too much for uncooled FC!
- Solution: FC in air + vacuum window
- Only possible material for full intensity: Beryllium
- However, Be must be supported by carbon-composite plate, which might be harmful for photocathodes (outgassing due to beam heating?)
- Solution for intermediate intensities: Stainless steel window + IR camera

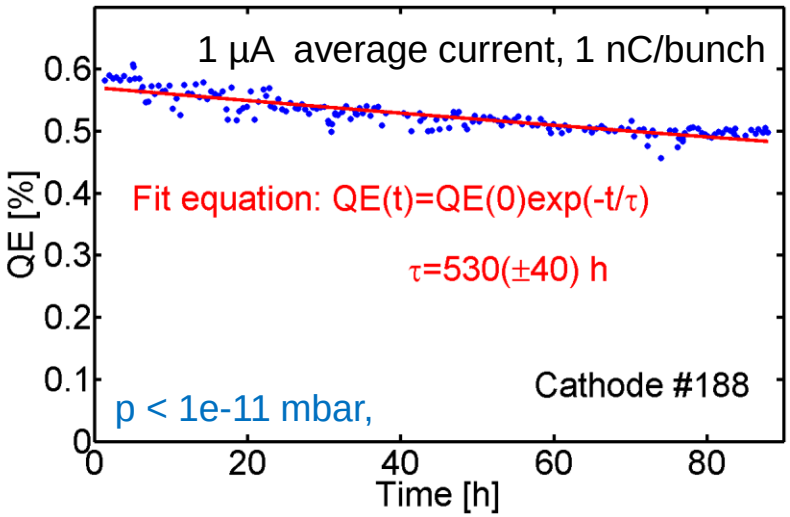


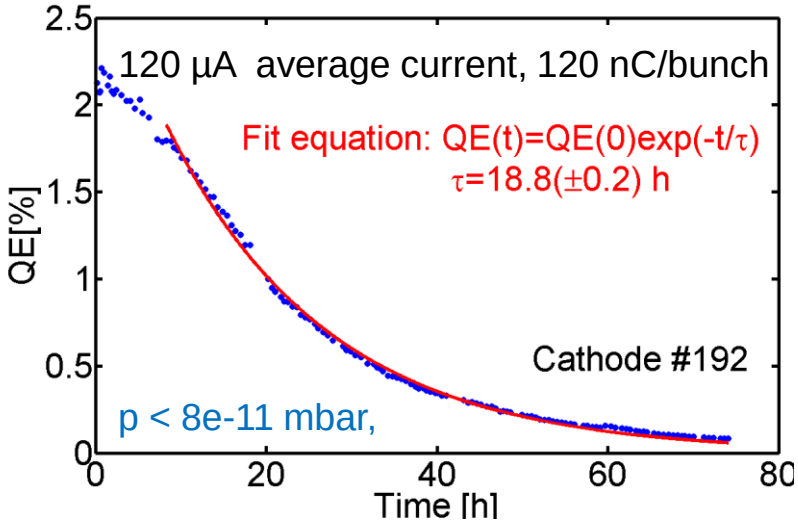




High Charge Studies in Photoemission Lab

- Measurement in DC gun with 1 kHz laser beam and Cs_3Sb cathodes :

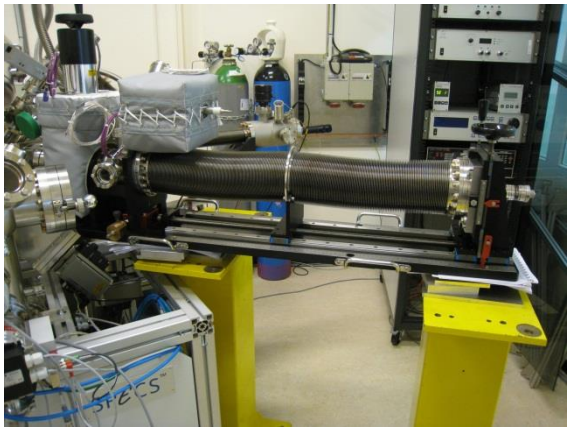




- Total integrated charge produced: 321 mC (cathode #188), 33 C (cathode #192)
- For low charge lifetime is 3 times as long as in PHIN with same average current.
- For high charge vacuum is still good (<8e-11 mbar) but the lifetime is as short as in PHIN under 4e-9 mbar. → Possible reason: Ion back-bombardment in DC gun
- Maybe short lifetime of cathode #192 is due to the very thin photo-emissive layer (13 nm), compared with 170 nm (#188) and 79 nm (#189, PHIN)
- More measurements needed.

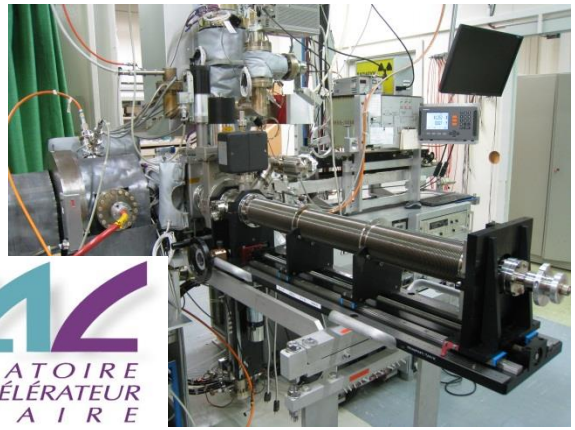
New Cathode Transfer Arms

- Two transfer arms built in collaboration with LAL, Orsay.
- Transfer arm for XPS analysis

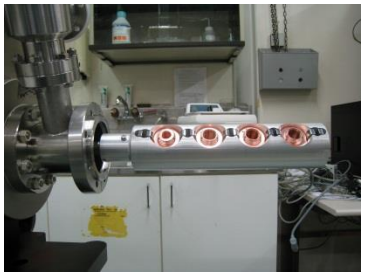


- Cathode transfer under UHV from the photoemission lab to the XPS setup.
- Surface analysis to get a better understanding of production and degradation process.
- New off axis cathode holder will be machined for complete compatibility with XPS setup.

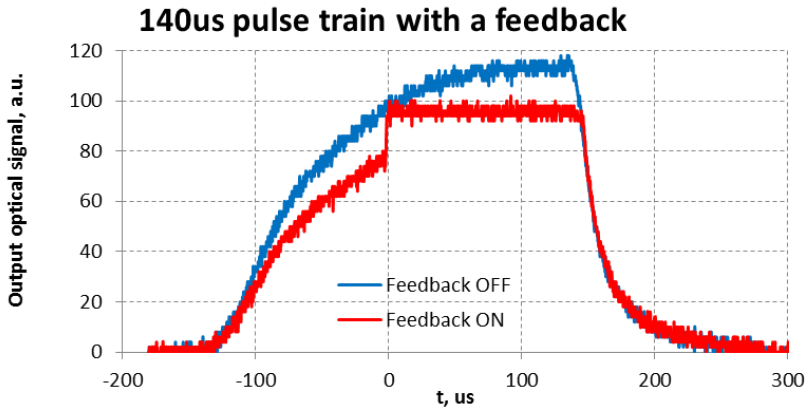
- LAL transfer arm

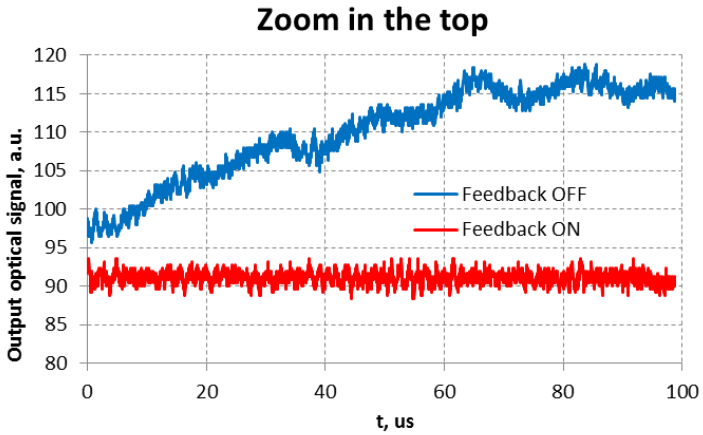


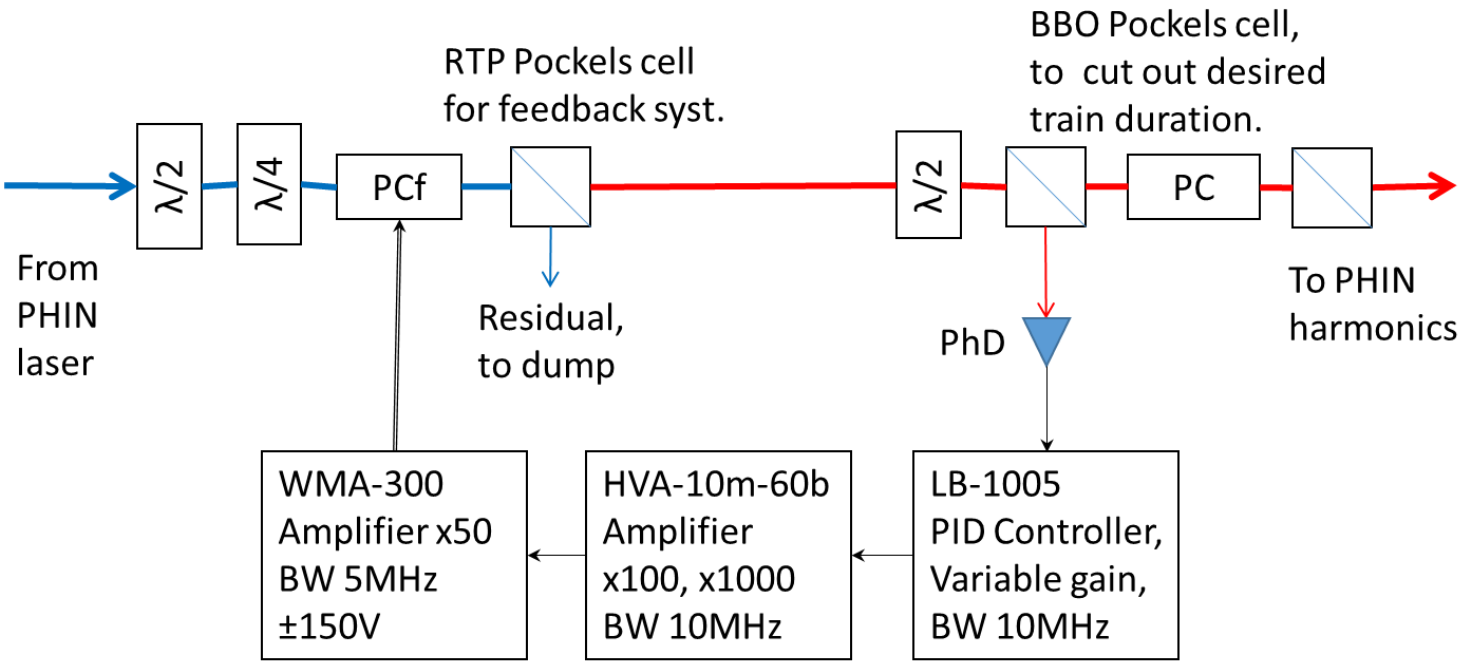
- Up to 4 cathodes can be transferred to LAL after being produced in the CERN photoemission lab.



Feedback Stabilisation Scheme



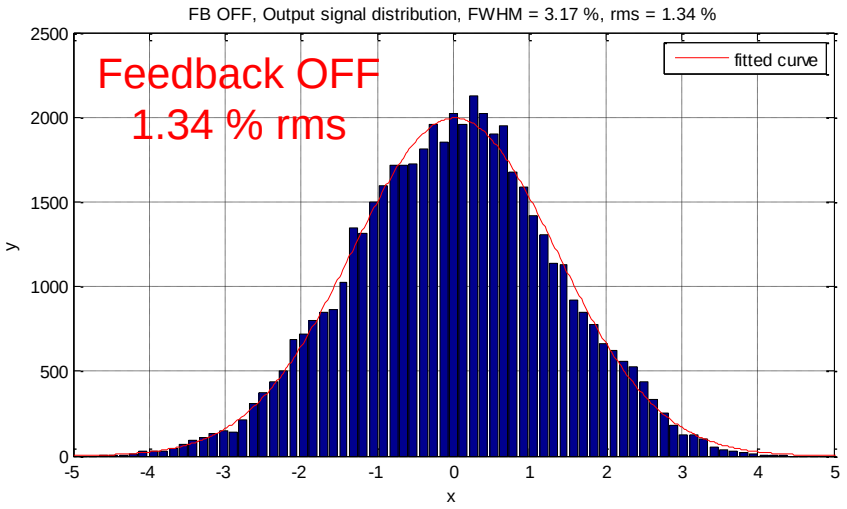


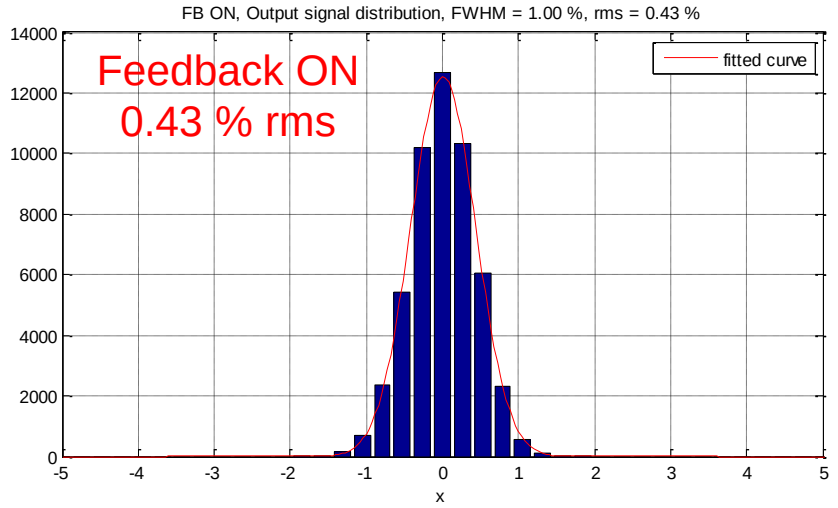


Feedback Stabilisation Tests

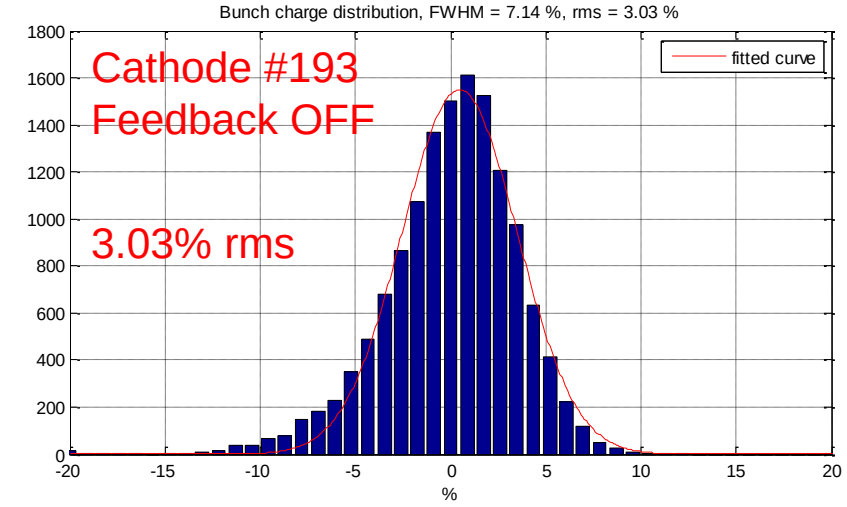
Laser beam

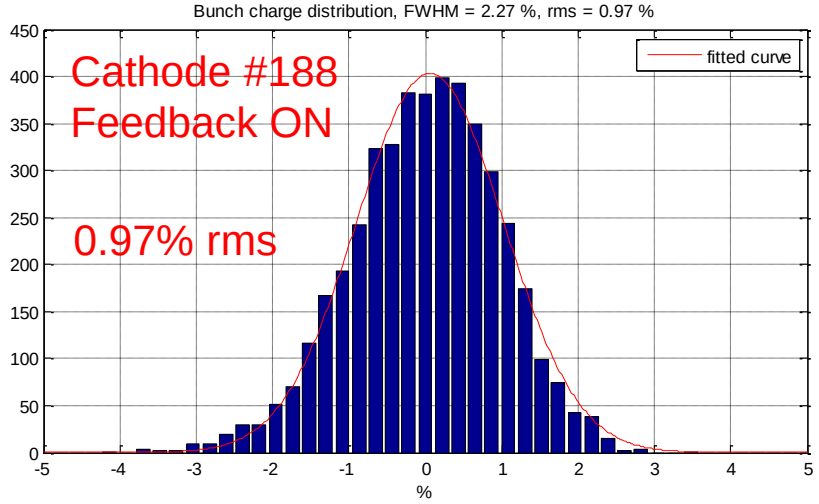
Electron beam





factor 3 improvement !

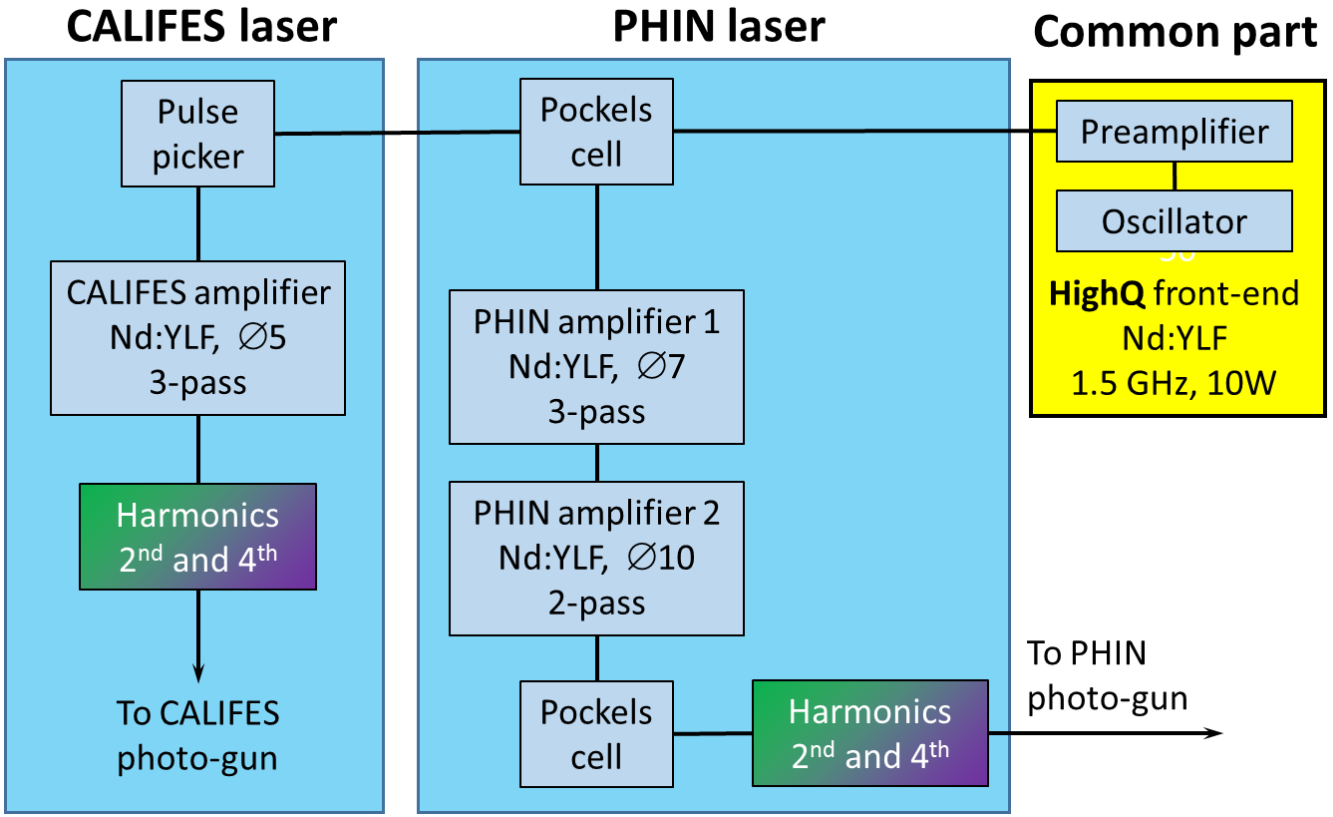




Upgrade of the PHIN Laser System

Current laser setup:

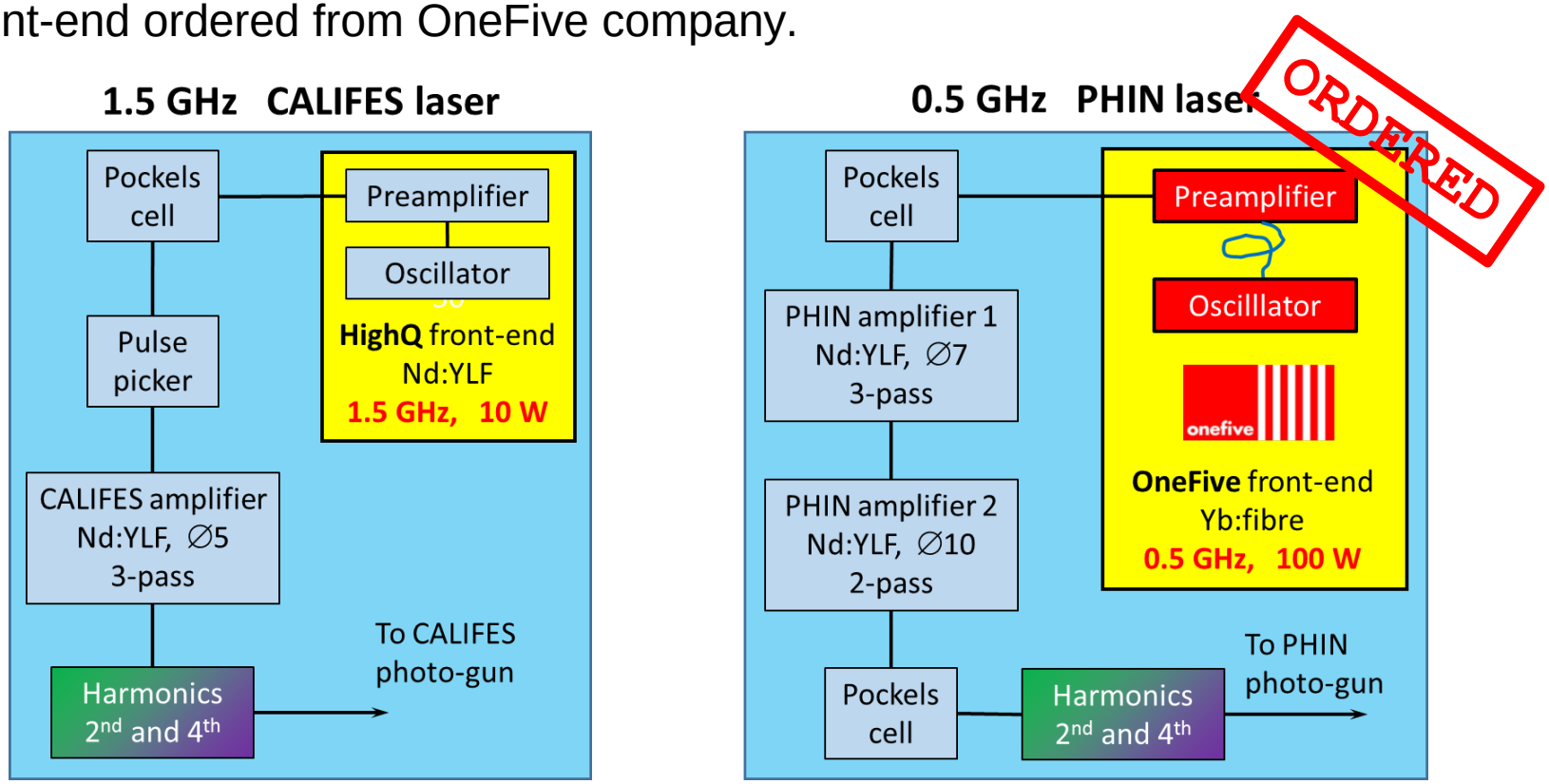
- Common 1.5 GHz, 10 W HighQ front-end
- Simultaneous laser operation of CALIFES and PHIN photoinjectors is possible (with limitations)



Upgrade of the PHIN Laser System

Future laser setup:

- CALIFES and PHIN lasers are completely decoupled
- Simultaneous laser operation of CALIFES and PHIN photoinjectors
- PHIN laser timing parameters pushed towards CLIC requirements due to new front-end ordered from OneFive company.



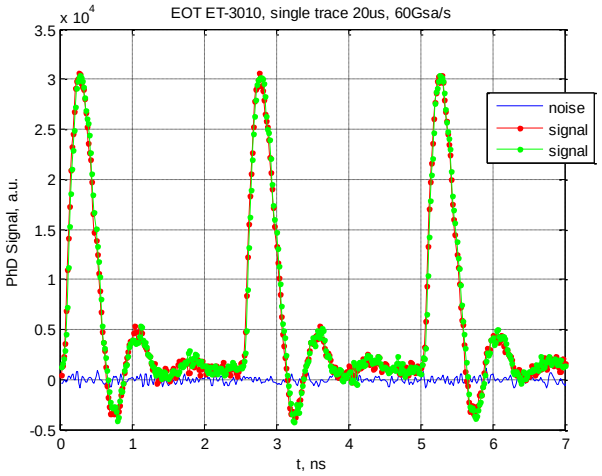
Stability Tests of OneFive Test System

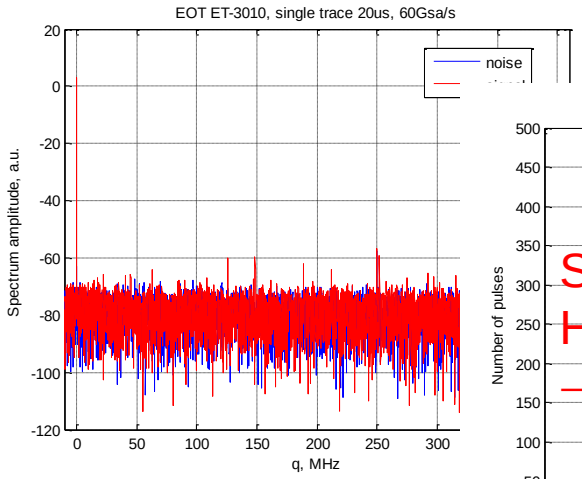
- 400 MHz demo oscillator provided by OneFive for testing.
- 400 000 pulses in the train captured and processed on the pulse-to-pulse basis

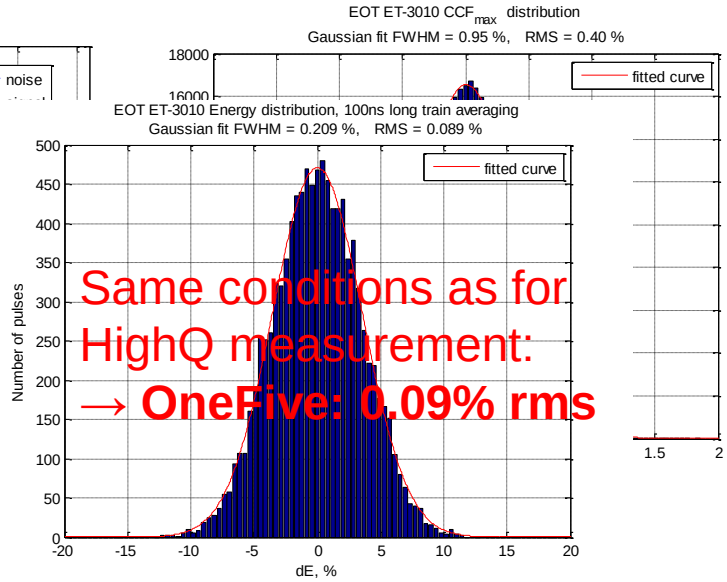
Real time signal digitized with 60 GSa/s

FFT spectrum in 0 to 400 MHz interval **Detected noise 60dB below carrier !**

Pulse-to-pulse energy distribution **0.4% rms !**







Plans for PHIN, Photoemission Lab and Laser System

PHIN:

- Excellent vacuum conditions have been achieved
  → Lifetime studies under these conditions with Cs_3Sb and Cs_2Te cathodes
- Study the effect of surface roughness on cathode lifetime
  → Electro-polished cathode plugs
- Continue studies of Cs_3Sb cathodes using a green laser beam
- Studies with 5 µs long pulse trains and 5 Hz repetition rate
  → Be window needed → separate PHIN run required

Photoemission lab:

- Continue high-charge studies (with different cathode layer thicknesses)
- XPS studies
- Upgrade of cathode preparation system with load-lock system

Laser:

- Study of performance of laser system with CLIC specs (new 500 MHz front end, 50 Hz tests)
- Continue stability studies with new front end

Future Photoinjector Activities for CLIC and at CERN

- CTF3 operation will stop in 2016 → PHIN program will also stop.
- Logical continuation of PHIN program would be an R&D program for a new 1 GHz RF photoinjector with full CLIC specs.
- Due to the budget situation, this is currently not foreseen.
- But the photoinjector activies might continue in the following projects:
  - CALIFES might be used at a new facility in CLEX
  - PHIN or a new photoinjector is planned to be used at the AWAKE facility
- However, these two facilities do not require photocathode R&D.
  → High risk to lose the expertise in photocathode R&D at CERN!
- Possibility to send cathodes to LAL and perform experiments there.
  → However, only single bunch operation possible, not suitable for solving the problems for the CLIC drive beam photoinjector.
- Possibility to focus on photocathodes for polarized electrons for CLIC / ILC
  → However, production technique totally different from Cs_2Te/Cs_3Sb photocathodes and risk to lose expertise still present
- Without an RF photoinjector available for photocathode R&D, the risk to lose the expertise in photocathode production and R&D at CERN is very high!

Acknowledgement

- Controls: Sergio Batuca, Mark Butcher, Mathieu Donze, Alessandro Masi, Christophe Mitifiot
- Load-lock system: Szymon Sroka
- FLUKA simulations: Markus Brugger, Melanie Delonca
- Beam instrumentation: Benoit Bolzon, Thibaut Lefevre
- Vacuum: Paolo Chiggiato, Berthold Jenninger, Esa Paju
- RF: Stephane Curt, Luca Timeo
- Wilfrid Farabolini
- XPS studies: Holger Neupert, Elise Usureau
- Collaborators at LAL and IAP-RAS
- … and many others

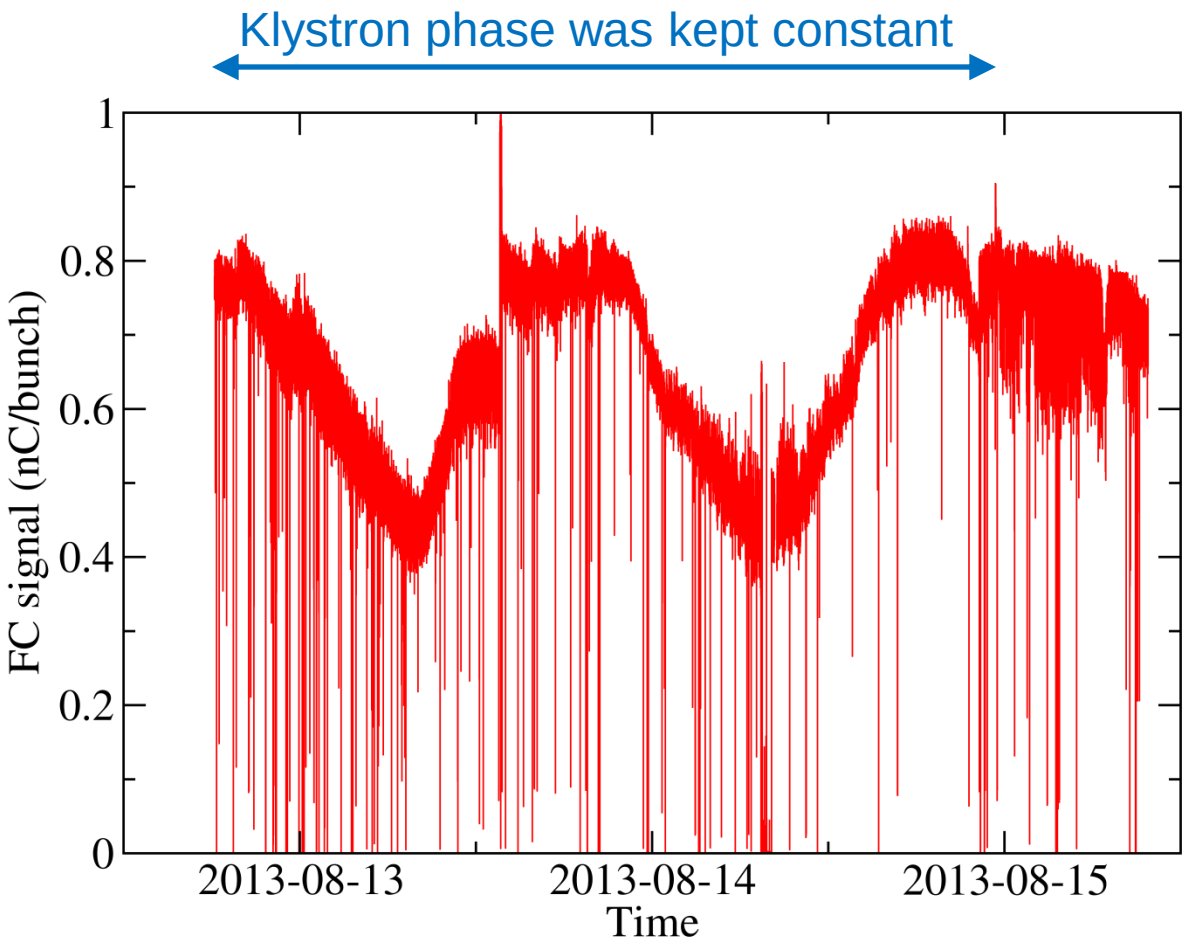
… and thank you for your attention!

PHIN and CLIC Parameters

Parameter	PHIN	CLIC
Charge / bunch (nC)	2.3	8.4
Macro pulse length (μs)	1.2	140
Bunch spacing (ns)	0.66	2.0
Bunch rep. rate (GHz)	1.5	0.5
Number of bunches / macro pulse	1800	70000
Macro pulse rep. rate (Hz)	5	50
Charge / macro pulse (μC)	4.1	590
Beam current / macro pulse (A)	3.4	4.2
Bunch length (ps)	10	10
Charge stability	<0.25%	<0.1%
Cathode lifetime (h) at QE > 3% (Cs_2Te)	>50	>150
Norm. emittance (μm)	<25	<100

24h Oscillations on Beam Current

Beam current measured with the Faraday cup:



24h oscillations probably caused by non-working air-conditioning in klystron gallery:

→ Temperature variation of RF reference signal cable for laser

→ Phase shift of laser with respect to klystron