Photoinjector Activities at CERN

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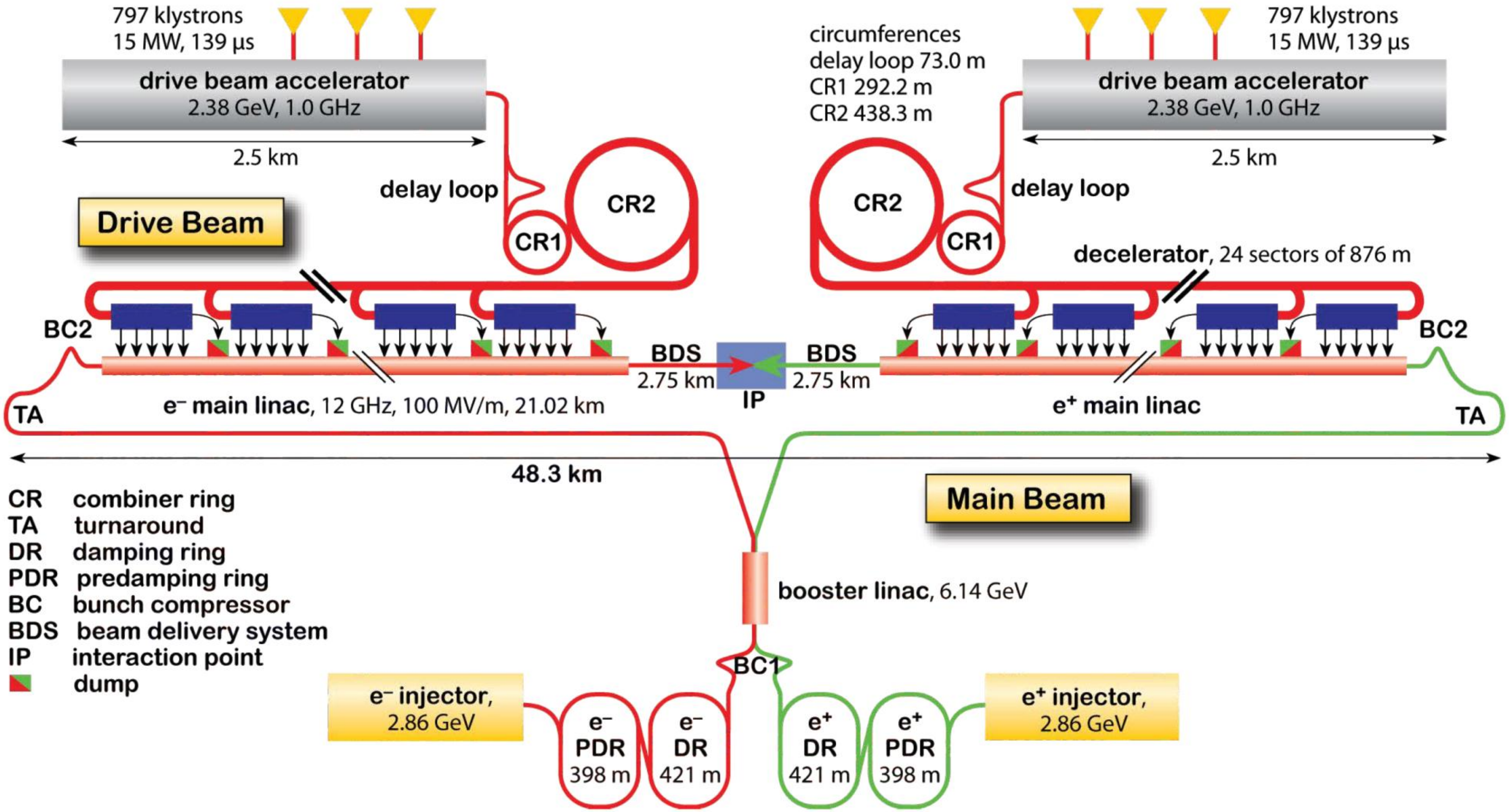
1st Topical LA3NET Workshop on Laser Particle Sources, CERN

Outline

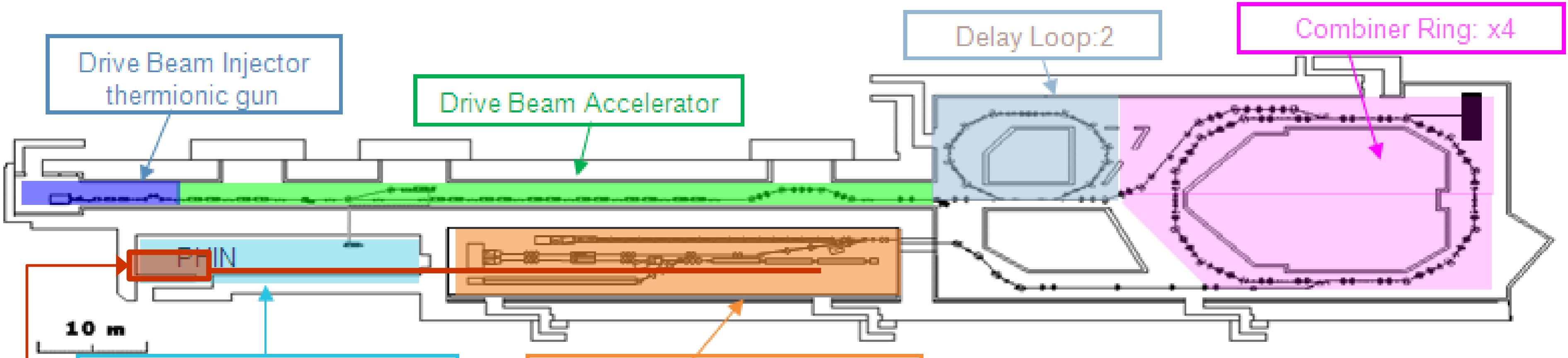
- Introduction
- Photoinjector laser system
- Photocathode production
- Beam measurements at the PHIN Photoinjector
- Conclusion and outlook

CLIC



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
🟥	dump

Photoinjectors at CTF3



Drive Beam Injector
thermionic gun

Drive Beam Accelerator

Delay Loop:2

Combiner Ring: x4

PHIN
Drive beam photo-injector
test stand

CLEX
2 beams test area
CALIFES
Main beam photo-injector

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

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

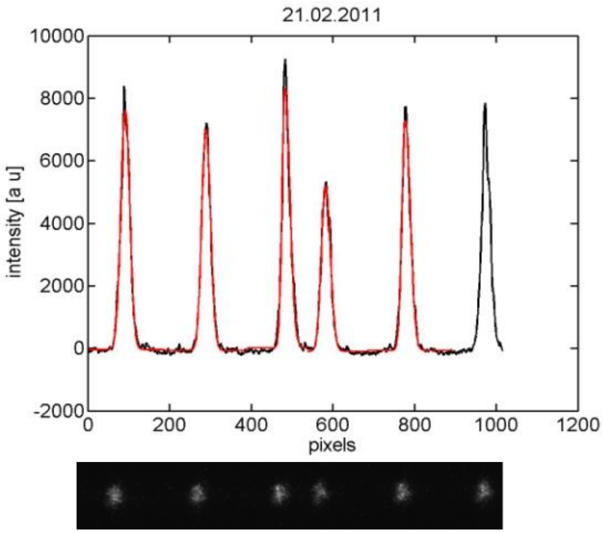
		DRIVE beam	MAIN beam
		PHIN	**CALIFES**
Electrons	**charge/bunch (nC)**	2.3	0.6
	Number of subtrains	**8**	NA
	Number of pulses in subtrain	**212**	NA
	gate (ns)	**1272**	20-150
	bunch spacing(ns)	0.666	0.666
	bunch length (ps)	10	10
	Rf reprate (GHz)	1.5	1.5
	number of bunches	1802	32
	machine reprate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

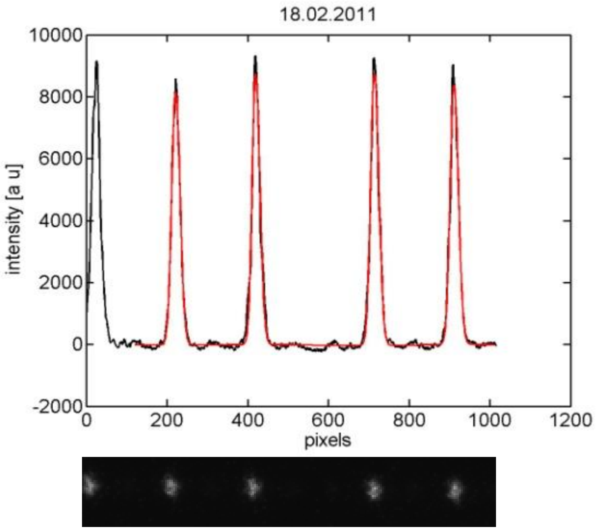
Motivation for a Drive-Beam Photoinjector

- To generate the 12 GHz time structure, several fast 180 degree phase switches are needed, which is presently done by a sub-harmonic bunching system.
- However, 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 the phase-coding can be done on the laser side and only the needed electron bunches are produced with the needed time structure.

Laser-based Phase Coding Demonstration

- Time structure: CTF3/CLIC drive beam requires several fast 180 degree phase-switches for beam combination (so-called phase coding).
- Satellite-free beam production at PHIN using laser phase-coding based on fiber-modulator technology has been demonstrated in 2011.
- Results:
  - Streak camera measurements of Cerenkov light:





⇒ switching time < 300ps

⇒ Satellites <0.1%

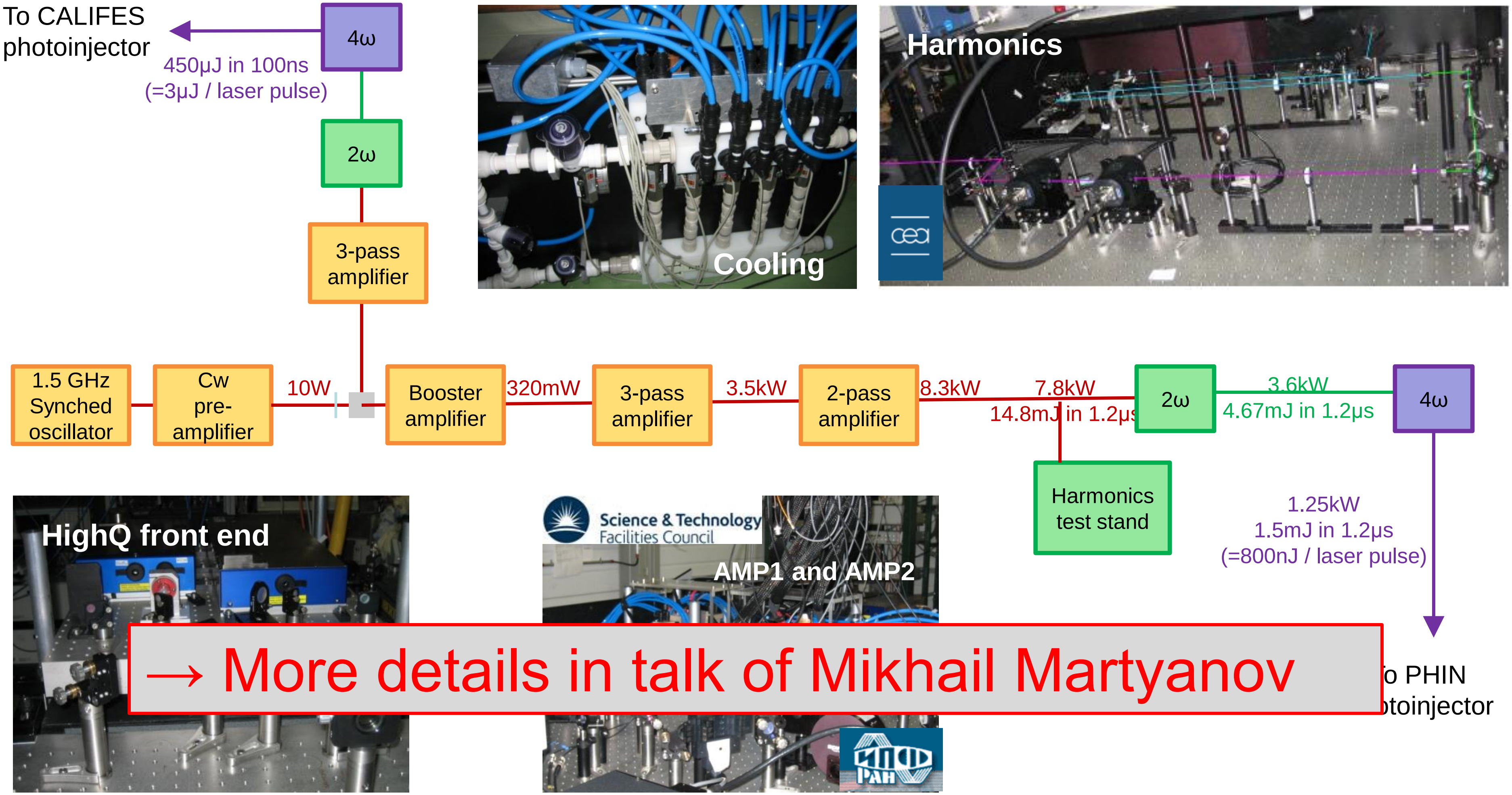
M.Csatari Divall et al., “Fast phase switching within the bunch train of the PHIN photo-injector at CERN using fiber-optic modulators on the drive laser”, Nucl. Instr. And Meth. A 659 (2011) p. 1.

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

Main issues:
- Long cathode lifetimes with high bunch and average charges
- Laser system for CLIC parameters (UV generation, 50 Hz operation, stability)

Laser System



To CALIFES photoinjector

450µJ in 100ns
(=3µJ / laser pulse)

4ω

2ω

3-pass amplifier

1.5 GHz Synched oscillator

Cw pre-amplifier

10W

Booster amplifier

320mW

3-pass amplifier

3.5kW

2-pass amplifier

8.3kW

7.8kW
14.8mJ in 1.2µs

Harmonics test stand

2ω

3.6kW
4.67mJ in 1.2µs

4ω

1.25kW
1.5mJ in 1.2µs
(=800nJ / laser pulse)

o PHIN
otoinjector

Cooling

Harmonics

HighQ front end

Science & Technology Facilities Council

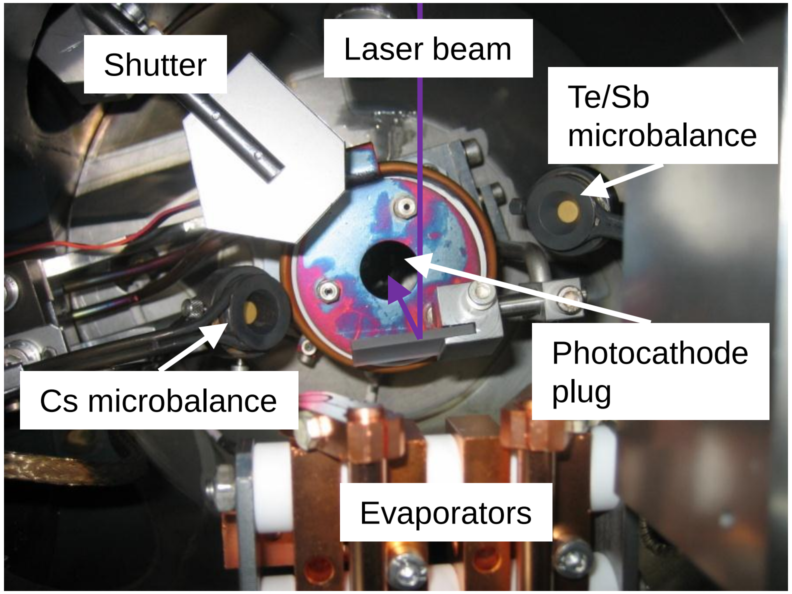
AMP1 and AMP2

→ More details in talk of Mikhail Martyanov

M. Petrarca et al., “Study of the Powerful Nd:YLF Laser Amplifiers for the CTF3 Photoinjectors”, IEEE J. Quant. Electr. 47 (2011), p. 306.

Photocathode Production

- Co-evaporation of Cs and Te/Sb
- Monitoring of each component by a separate microbalance (other component is shielded by a mask)
- DC gun + diagnostic beam line for measuring the photocathode properties
- Achieved QE: ~20% (Cs_2Te), 7.5% (Cs_3Sb)



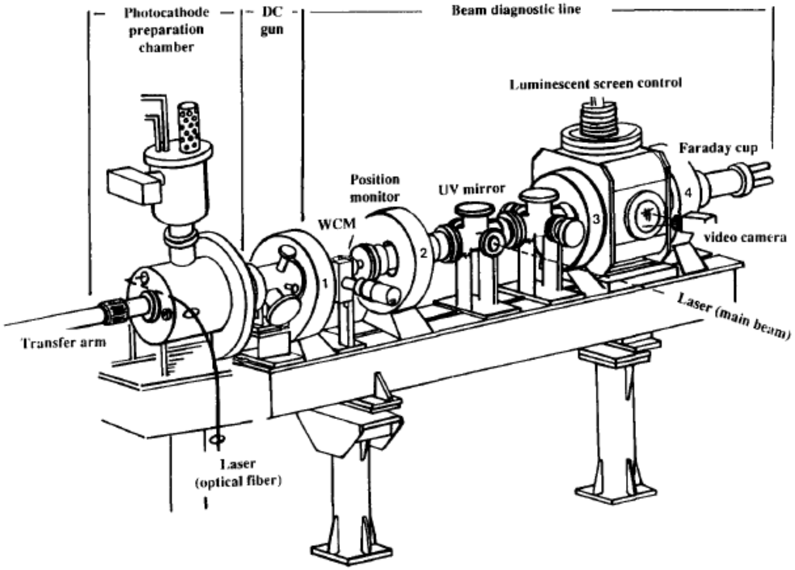
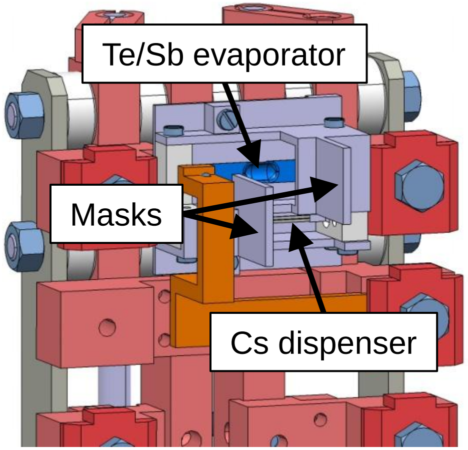
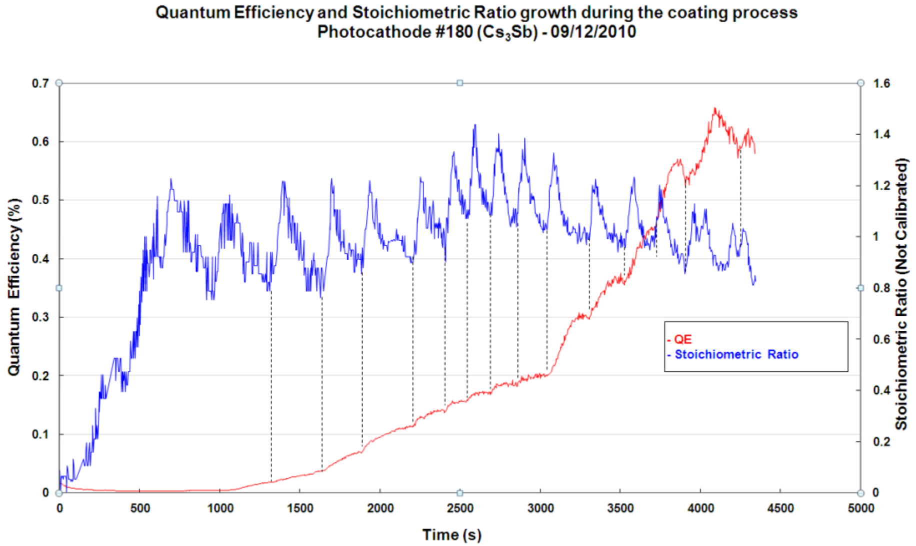


Fig. 1. The dc test bench.

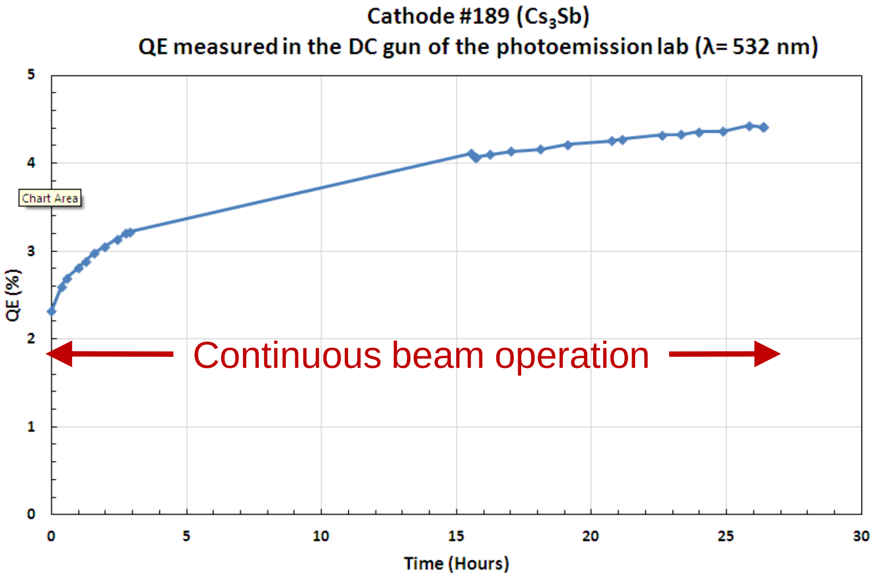


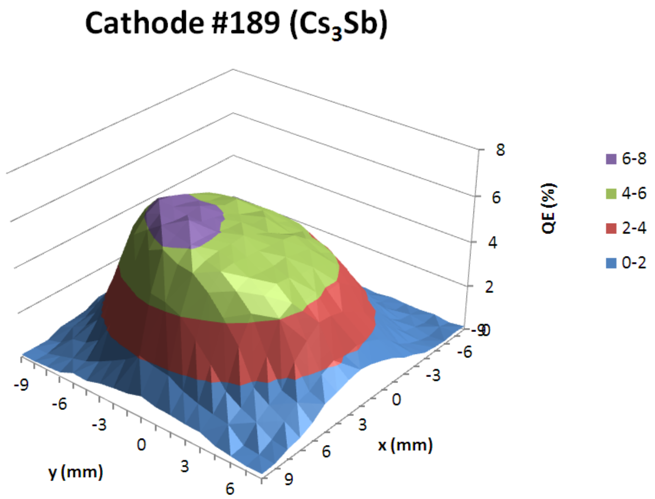
E. Chevallay, “Experimental Results at the CERN Photoemission Laboratory with Co-deposition Photocathodes in the Frame of the CLIC Studies”, CTF3 Note 104, submitted

Co-deposition Cs_3Sb Photocathodes


Quantum Efficiency and Stoichiometric Ratio growth during the coating process
Photocathode #180 (Cs_3Sb) - 09/12/2010

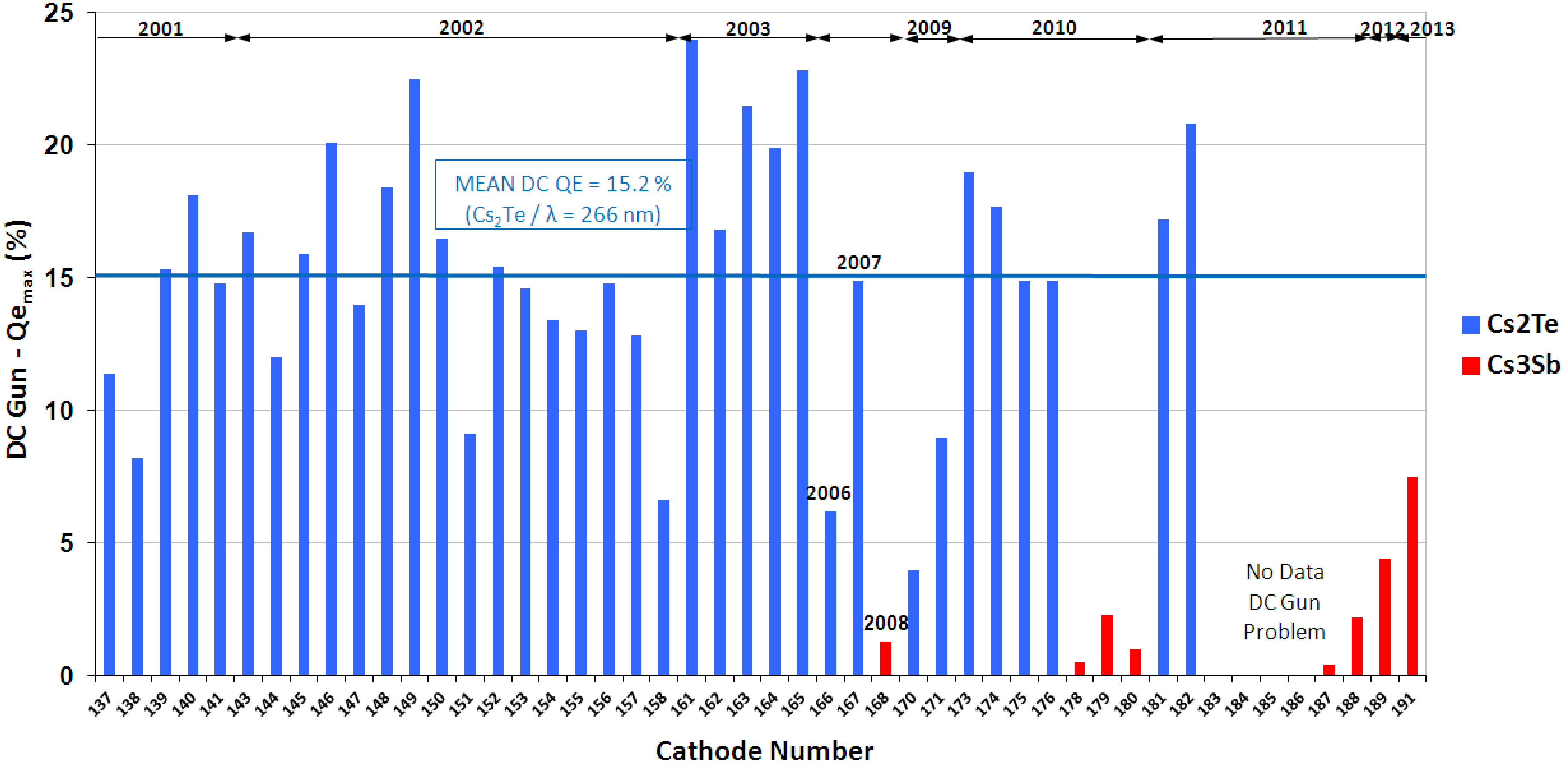
- After stopping the evaporation, the QE first continues to increase during beam production.
- Reason for this behavior still unclear, maybe due to re-organization of Cs and Sb atoms.
- Maximum achieved QE: 7.5%


Cathode #189 (Cs_3Sb)
QE measured in the DC gun of the photoemission lab (λ= 532 nm)


Cathode #189 (Cs_3Sb)

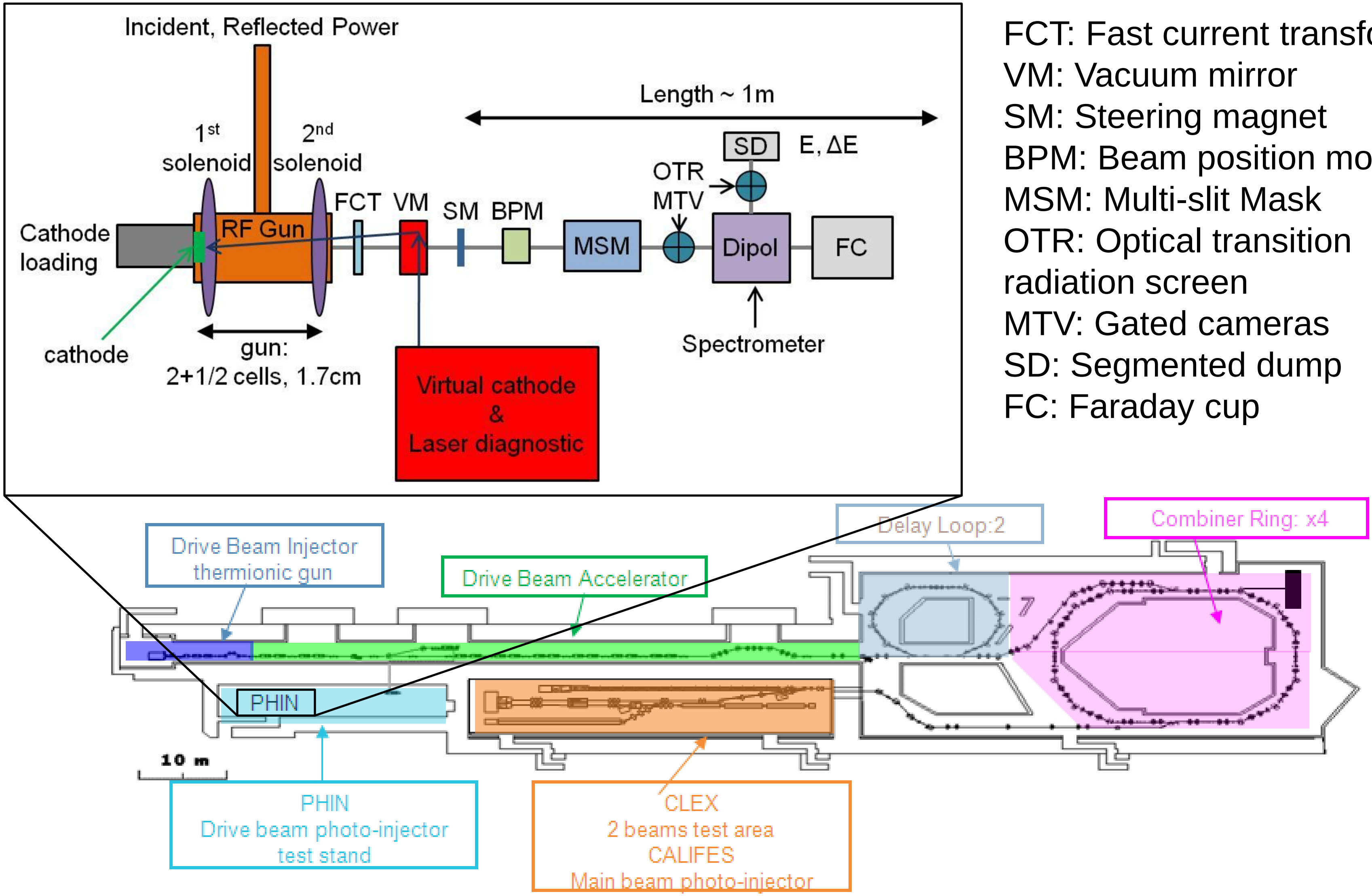
Photocathode History

Co-Deposition Photocathodes Production at the CERN Photoemission Laboratory
from ~mid 2001 to beginning 2013
Laser Wavelenght: Cs_2Te λ = 266 nm / Cs_3Sb λ = 532 nm



MEAN DC QE = 15.2 %
(Cs_2Te / λ = 266 nm)

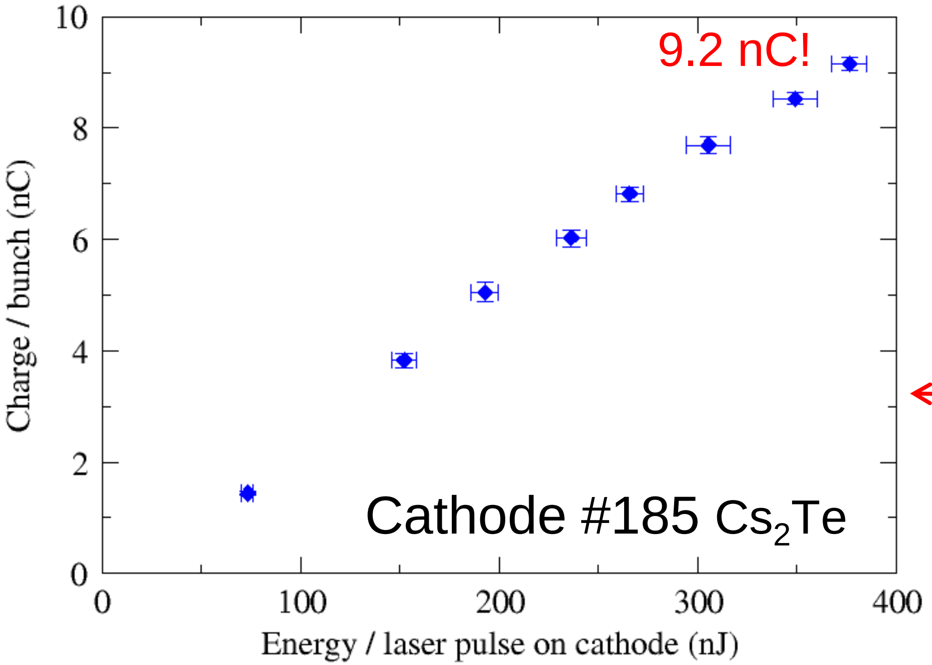
PHIN Layout

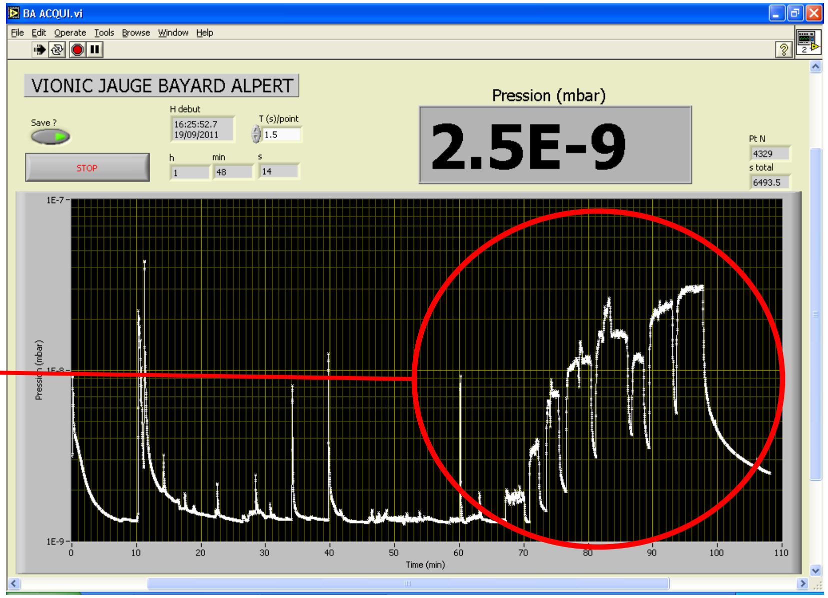


FCT: Fast current transformer
VM: Vacuum mirror
SM: Steering magnet
BPM: Beam position monitor
MSM: Multi-slit Mask
OTR: Optical transition radiation screen
MTV: Gated cameras
SD: Segmented dump
FC: Faraday cup

High Charge Production (Cs_2Te)

- Charge vs. laser energy scan with 50 ns long trains
- Linear response up to 5 nC
- Record bunch charge of 9.2 nC above CLIC requirements!
- Close to the theoretical limit of Q_{max}=9.47 nC for a beam size of 1.8 mm σ x 1.25 mm σ





VIONIC JAUGE BAYARD ALPERT

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h: 1 min: 48 s: 14

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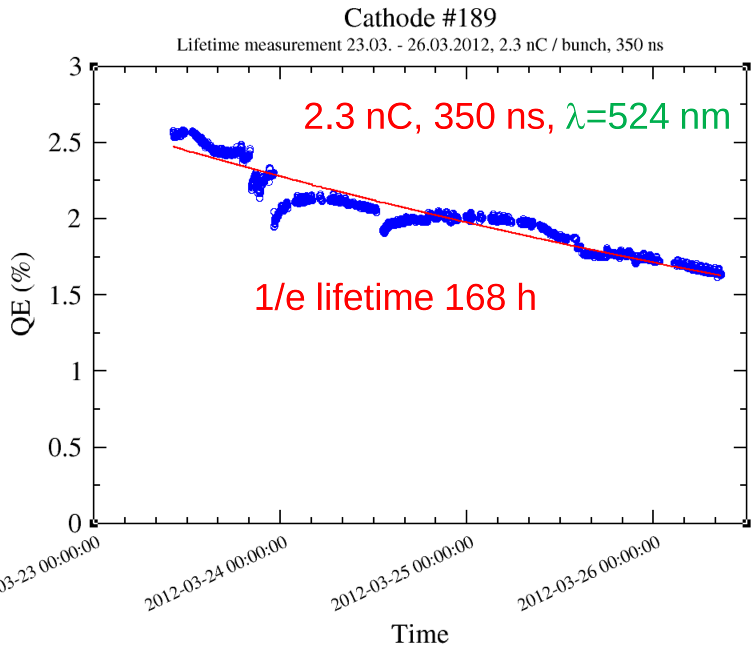
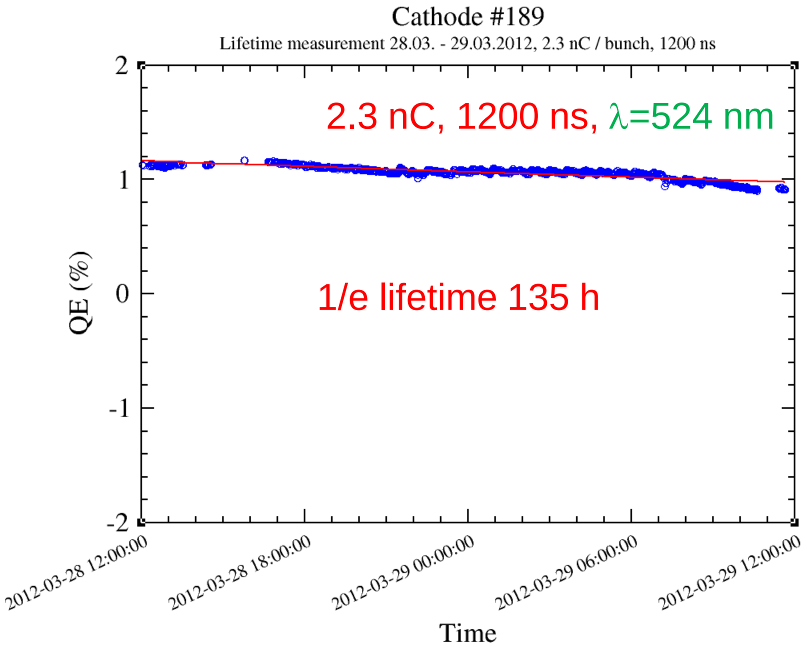
Lifetime studies of Cs_3Sb cathodes with green light

- Measurements taken during PHIN run March 2012
- Excellent lifetimes obtained, much better than expected.
- Long-time operation over 10 days with one cathode!
- Operation of 1.2 µs long trains yield similar lifetime as for short trains.



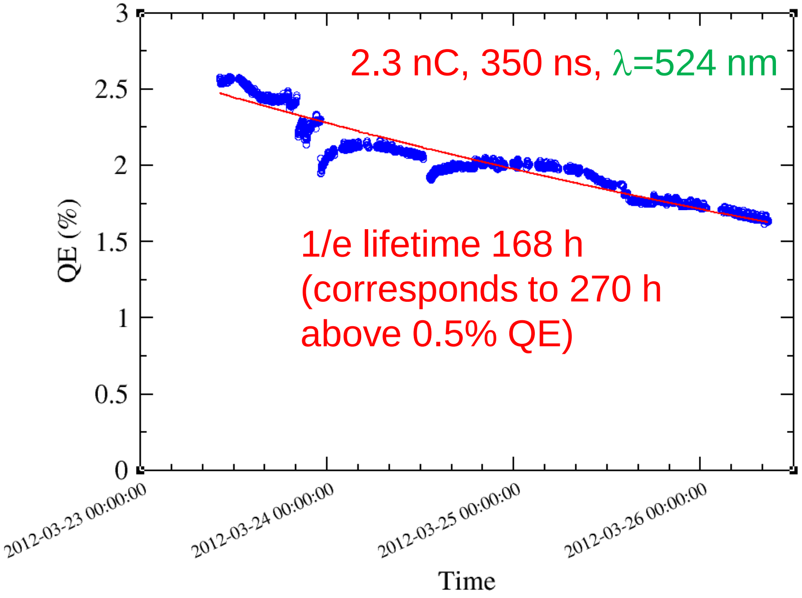


Lifetime Cs_3Sb vs. Cs_2Te Cathodes

- Comparison with earlier lifetime measurements of Cs_2Te cathodes.
- Lifetimes are similar and within CLIC specifications.
- For Cs_3Sb a factor 6 less of QE is needed as for Cs_2Te cathodes, due to the different wavelength and the absence of 4th harmonics conversion stage

$$QE = \frac{124 \times Q[\mathrm{nC}]}{\lambda[\mathrm{nm}] \times E[\mu\mathrm{J}]}$$

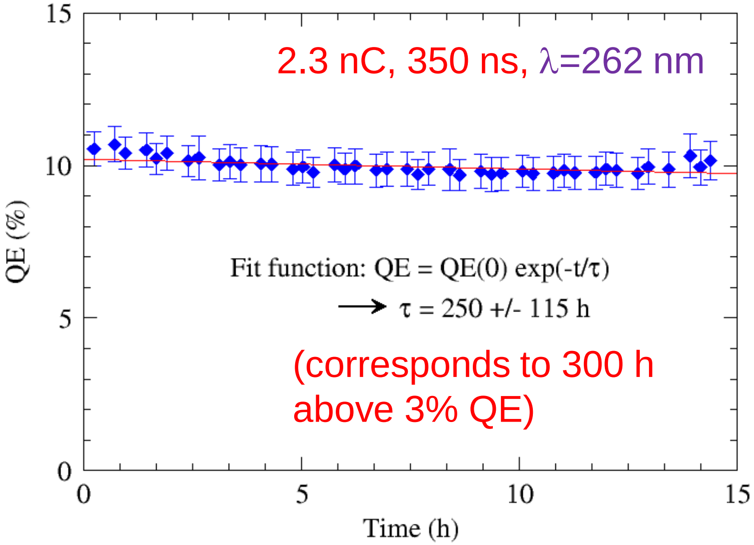
Cathode #189 (Cs_3Sb)



2.3 nC, 350 ns, λ=524 nm

1/e lifetime 168 h
(corresponds to 270 h
above 0.5% QE)

Cathode #185 (Cs_2Te)



2.3 nC, 350 ns, λ=262 nm

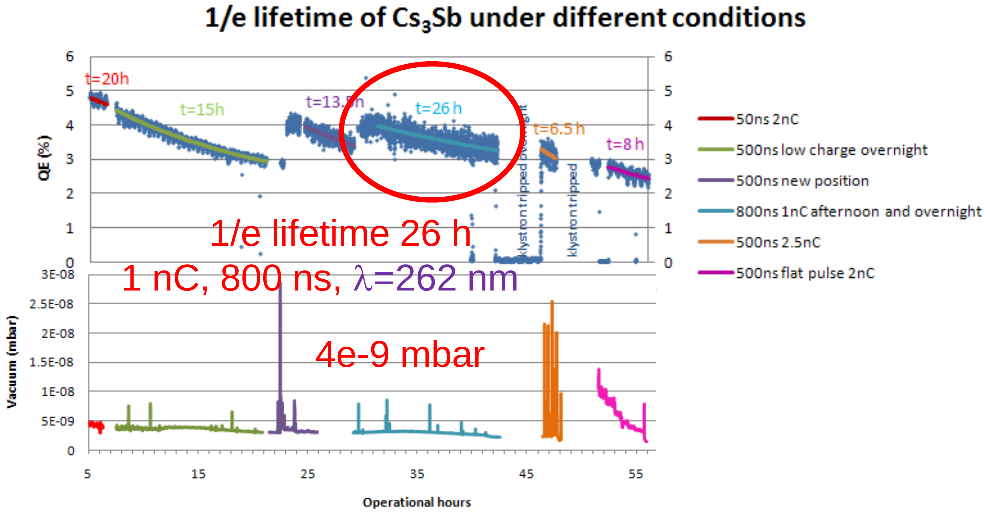
Fit function: QE = QE(0) exp(-t/τ)
→ τ = 250 +/- 115 h

(corresponds to 300 h
above 3% QE)

Impact of Vacuum on Cs_3Sb Cathode Lifetime

- Comparison with earlier measurements of Cs_3Sb cathodes with UV light and worse vacuum conditions (same beam parameters).
- Lifetime has drastically improved from 26 to 185 h.
- Improved vacuum condition due to activation of NEG chamber around the gun.

March 2011



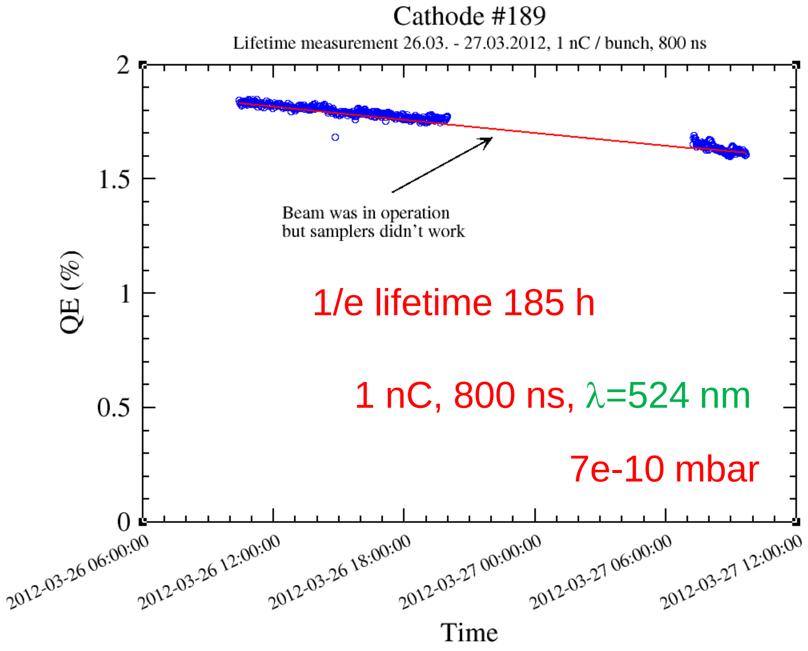
1/e lifetime of Cs_3Sb under different conditions

1/e lifetime 26 h

1 nC, 800 ns, λ=262 nm

4e-9 mbar

March 2012



Cathode #189

Lifetime measurement 26.03. - 27.03.2012, 1 nC / bunch, 800 ns

Beam was in operation but samplers didn't work

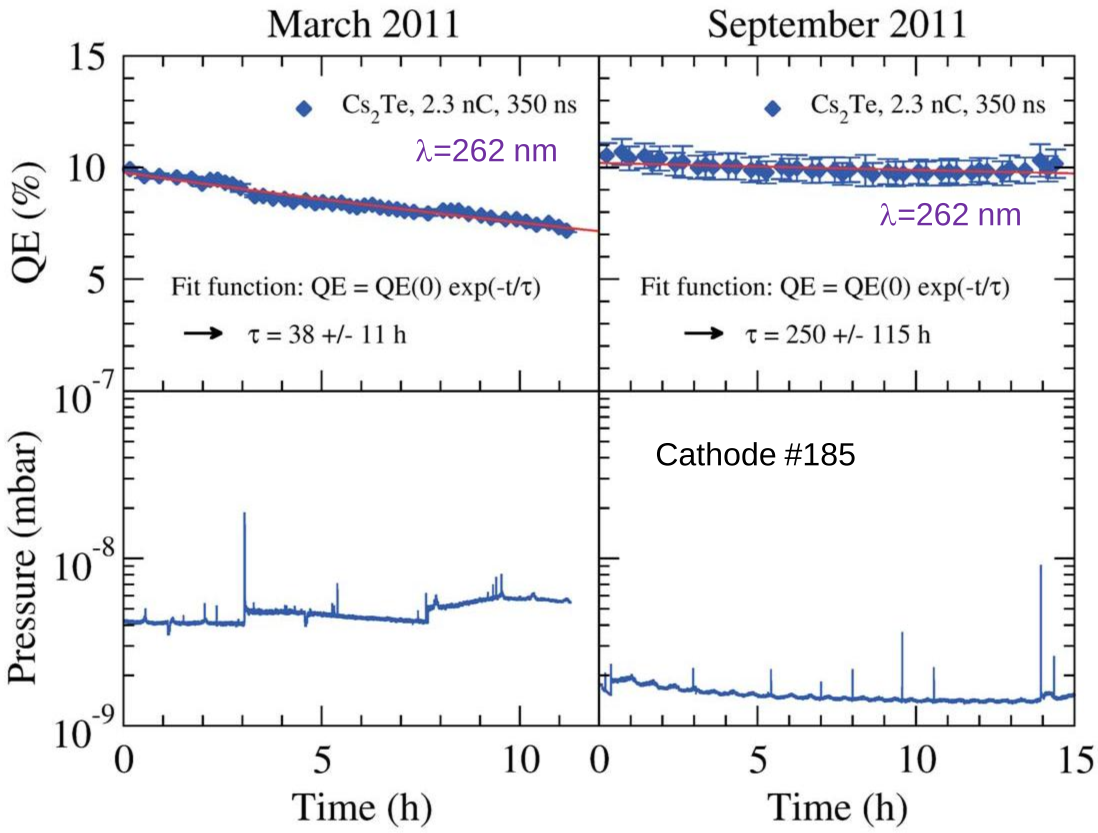
1/e lifetime 185 h

1 nC, 800 ns, λ=524 nm

7e-10 mbar

Impact of Vacuum on Cs_2Te Cathode Lifetime

Comparison of lifetime measurements with same beam properties but different vacuum conditions:



- Substantial improvement of dynamic vacuum level has resulted in drastic increase of 1/e lifetime from 38 to 250 h.
- Corresponds to total cathode lifetime of 300 h above 3% QE.

Conclusion

- Cs_3Sb photocathodes successfully operated at PHIN RF photoinjector with **green laser light**.
- Similar lifetimes obtained as for Cs_2Te cathodes.

  ⇒ Good candidate material for further studies
- Good vacuum is mandatory for a good lifetime.
- Cathode production process (co-evaporation) seems to be important for obtaining good lifetimes for Cs_3Sb cathodes .

Outlook (1)

Photocathode R&D:

- Continue studies on new cathode materials sensitive to visible light at the photoemission lab and later at PHIN:
  - Cs_3Sb
  - Multi-alkali photocathodes like e.g. K_2CsSb, Na_2KSb, …
- Integrated charge studies with Cs_3Sb cathodes and green light
  → New laser system installed
- XPS surface analysis studies of photocathodes to get a better understanding of surface deterioration effects and the cathode life time
  → New transfer arm built in collaboration with LAL
- Design and implementation of a load-lock system for fast cathode plug and evaporator exchange to increase availability of photoemission lab.

Outlook (2)

PHIN studies:

- Continue studies of Cs_3Sb cathodes using a green laser beam.
- Push parameters as far as possible towards CLIC requirements (5 µs long pulse trains, 5 Hz repetition rate).
- Further improvement of vacuum (Installation and activation of a new NEG pump).
- Feedback tests with electron beam.

Beyond PHIN:

- However, the final proof of feasibility of a photoinjector for CLIC drive beam cannot be achieved with PHIN.
- New 1 GHz RF gun specially designed for the CLIC requirements needed.
- Looking for collaboration for designing this gun.

Acknowledgement

Collaborating institutes:

LABORATOIRE
DE L'ACCÉLÉRATEUR
LINÉAIRE

cea

Science & Technology
Facilities Council

ИПФ
РАН

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MARIE CURIE ACTIONS

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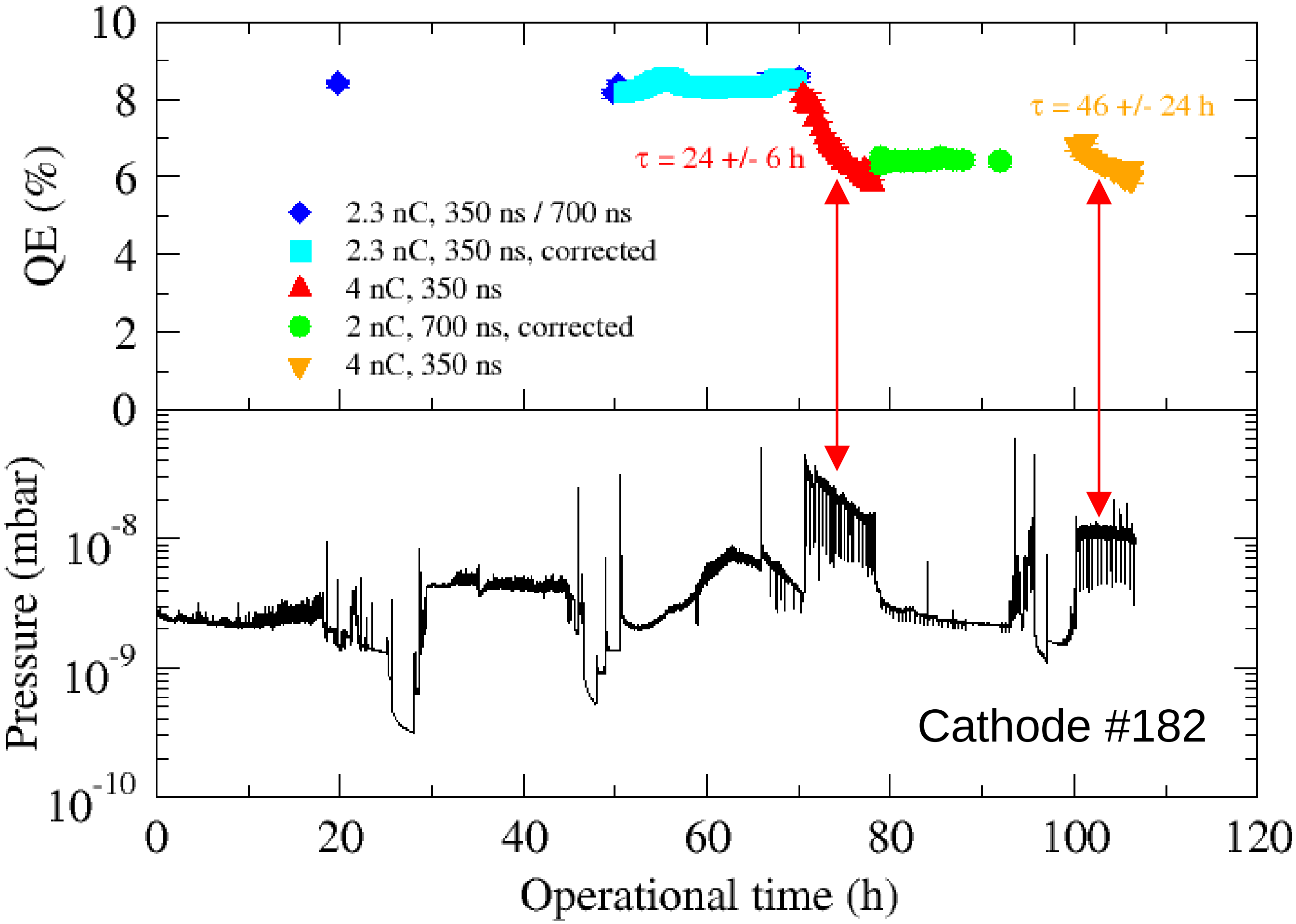
… and thank you for your attention!

Lifetime Studies of Cs_2Te Cathodes

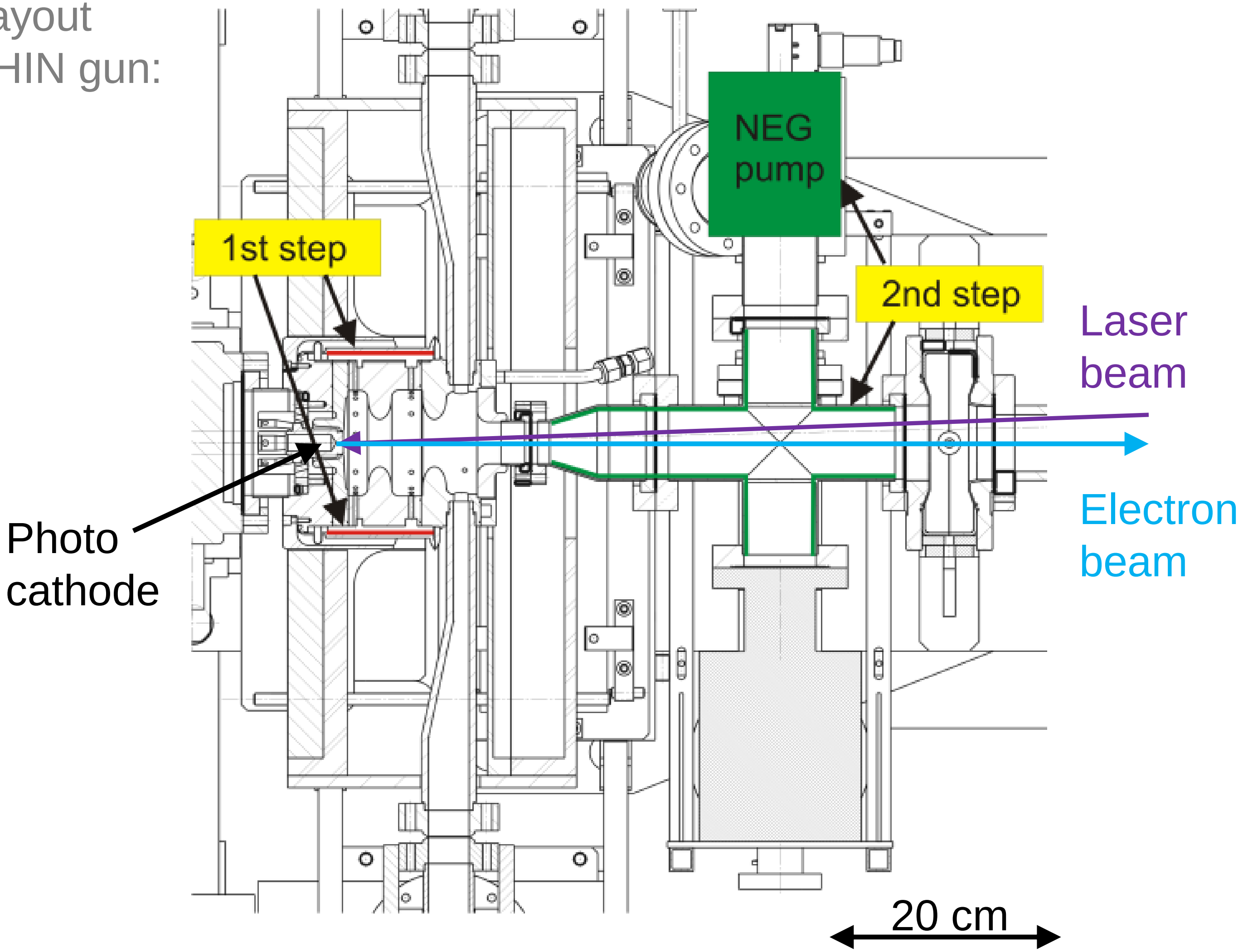
- Cathode lifetime vs. vacuum



- Correlation between lifetime and vacuum.
- In high e-9 mbar/ low e-8 mbar < 50h lifetime was measured.
- When vacuum is kept at low e-9 mbar lifetime is within specification.

Improvement of PHIN Vacuum System

Layout PHIN gun:

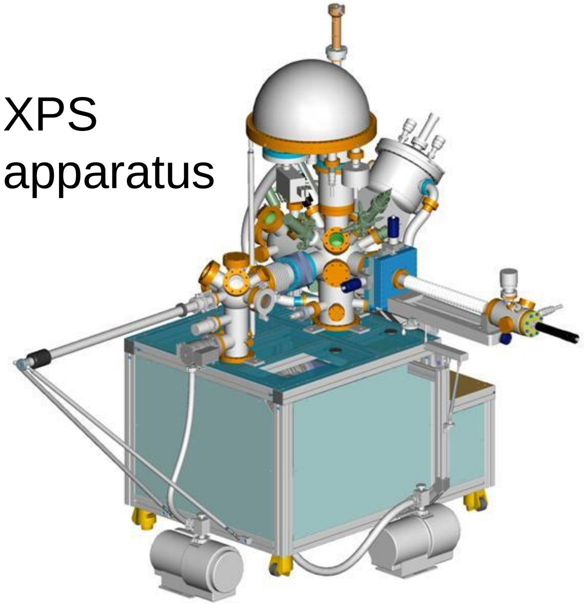


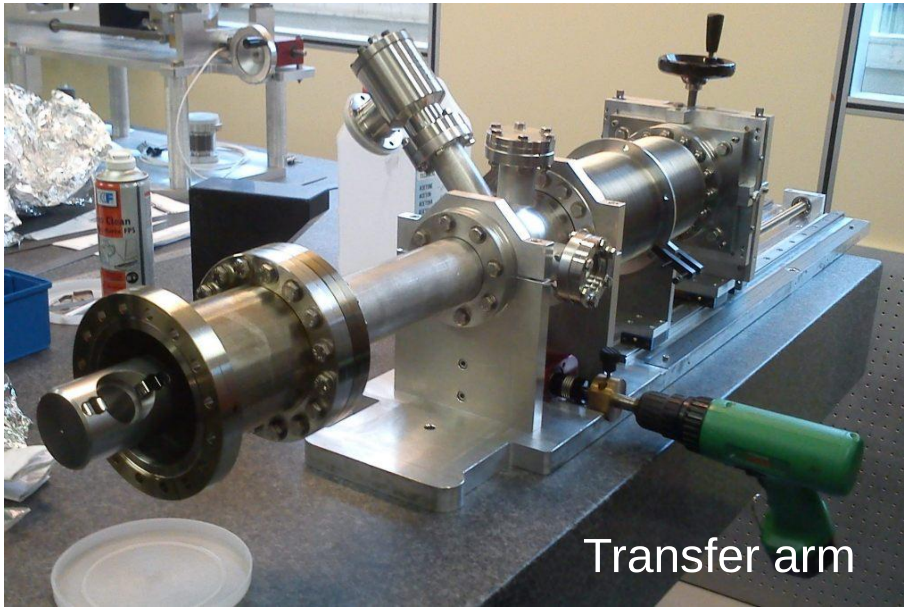
Plan to improve vacuum in two steps:

- Activation of existing NEG coated chamber around the gun (already done)
- Activation of existing NEG coating in beam line and installation of additional NEG pump.

XPS Surface Analysis Studies

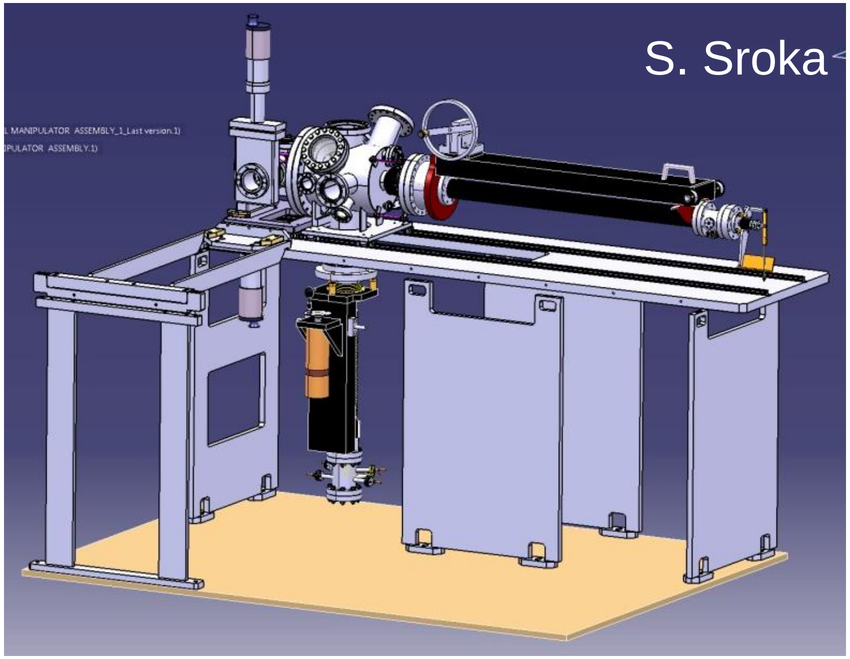
- Investigation of surface deterioration of photocathodes and its effect on quantum efficiency and lifetime
- Planned to be performed in collaboration with CERN vacuum group
- For the photocathode transfer to XPS lab a new transfer arm has been built in collaboration with LAL (Orsay) and will be ready soon:


XPS apparatus

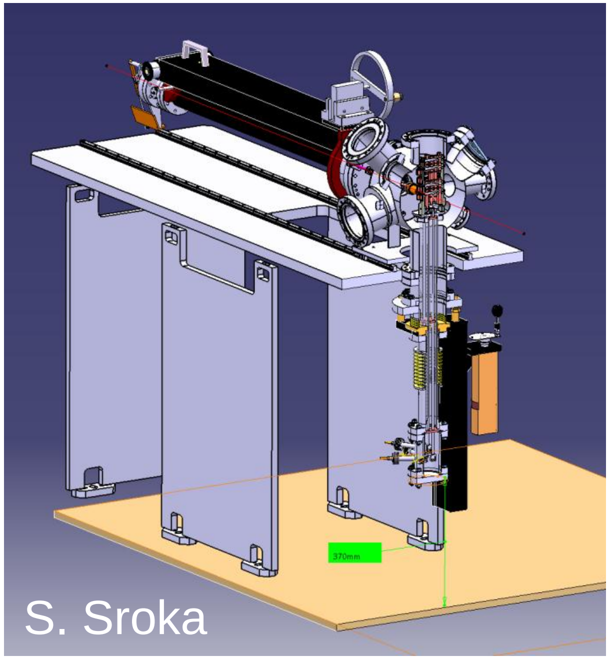

Transfer arm

Studies for Load-Lock System in the Photoemission Lab

- Implementation of existing horizontal and vertical manipulators for moving the cathode plug and the evaporator setup into a 3D CATIA model:



S. Sroka



S. Sroka

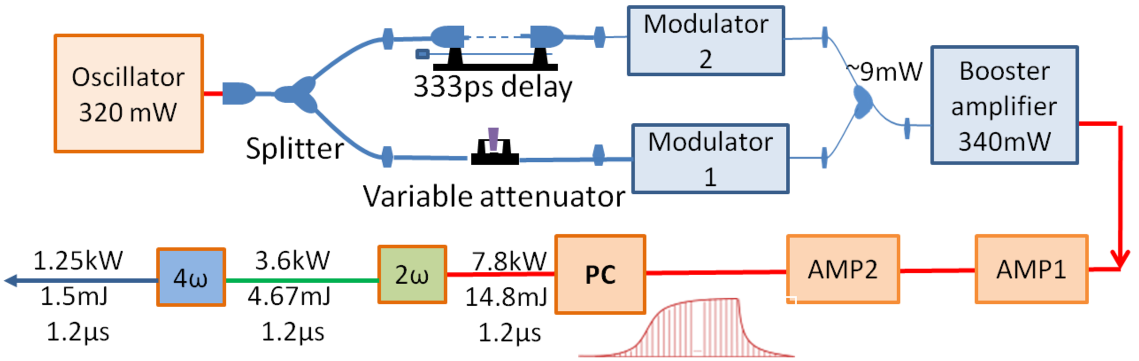
- The next step is to implement a new vertical manipulator and a valve, which separates the evaporator setup from the preparation chamber. This will avoid the need of breaking the vacuum in the preparation chamber during an exchange of the evaporators.
- Second step: Find a solution exchange cathode plugs without breaking the vacuum in the preparation chamber.

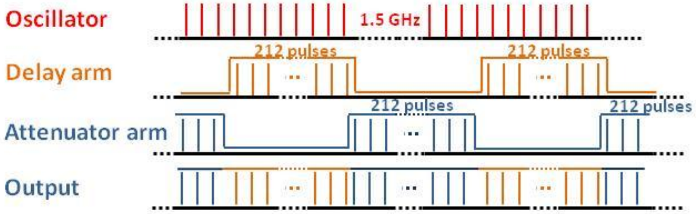
PHIN and CLIC Parameters

		DRIVE beam	
		PHIN	CLIC
Electrons	charge/bunch (nC)	2.3	8.4
	train length (ns)	1200	140371
	bunch spacing(ns)	0.666	1.992
	bunch length (ps)	10	10
	bunch rep rate (GHz)	1.5	0.5
	number of bunches	1802	70467
	machine rep rate (Hz)	5	100
	margine for the laser	1.5	2.9
	charge stability	<0.25%	<0.1%
	Cathode lifetime (h) at QE > 3%	>50	>150
Laser in UV	laser wavelegth (nm)	262	262
	energy/micropulse on cathode (nJ)	363	1988
	energy/micropulse laserroom (nJ)	544	5765
	energy/macrop. laserroom (uJ)	9.8E+02	4.1E+05
	mean power (kW)	0.8	2.9
	average power at cathode wavelength(W)	0.005	41
	micro/macropulse stability	1.30%	<0.1%
Laser in IR	conversion efficiency	0.1	0.1
	energy/macropulse in IR (mJ)	9.8	4062.2
	energy/micropulse in IR (uJ)	5.4	57.6
	mean power in IR (kW)	8.2	28.9
	average power on second harmonic (W)	0.49	406
	average power in final amplifier (W)	9	608

Phase Coding Demonstration

- Motivation
  - CTF3/CLIC drive beam requires several fast 180 degree phase-switches for beam combination.
  - With currently used thermionic DC gun and sub-harmonic bunching satellites are produced, which could cause radiation problems.
- Aim to provide an alternative satellite-free solution using laser phase-coding based on fiber-modulator technology and an RF photo-injector.
- Setup:

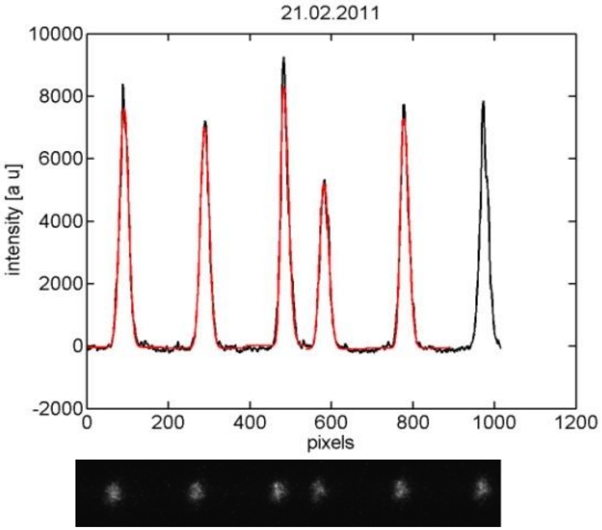


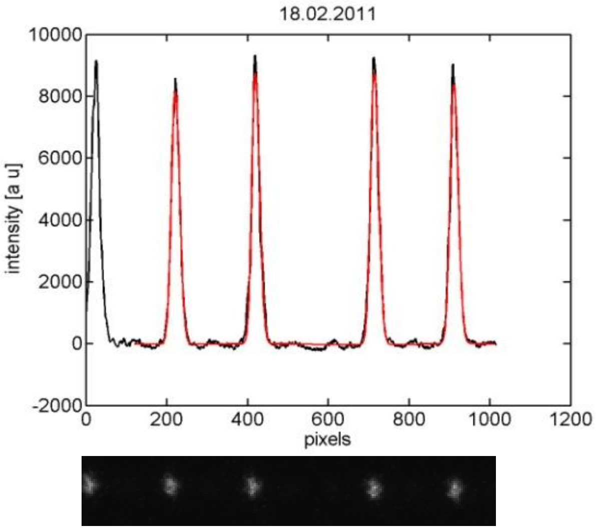


M.Csatari Divall et al., “Fast phase switching within the bunch train of the PHIN photo-injector at CERN using fiber-optic modulators on the drive laser”, Nucl. Instr. And Meth. A 659 (2011) p. 1.

Phase Coding Demonstration

- Results:
  - Streak camera measurements of Cerenkov light

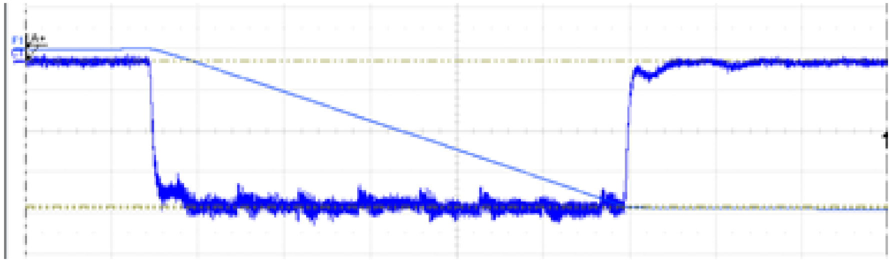




⇒ switching time < 300ps

⇒ Satellites <0.1%

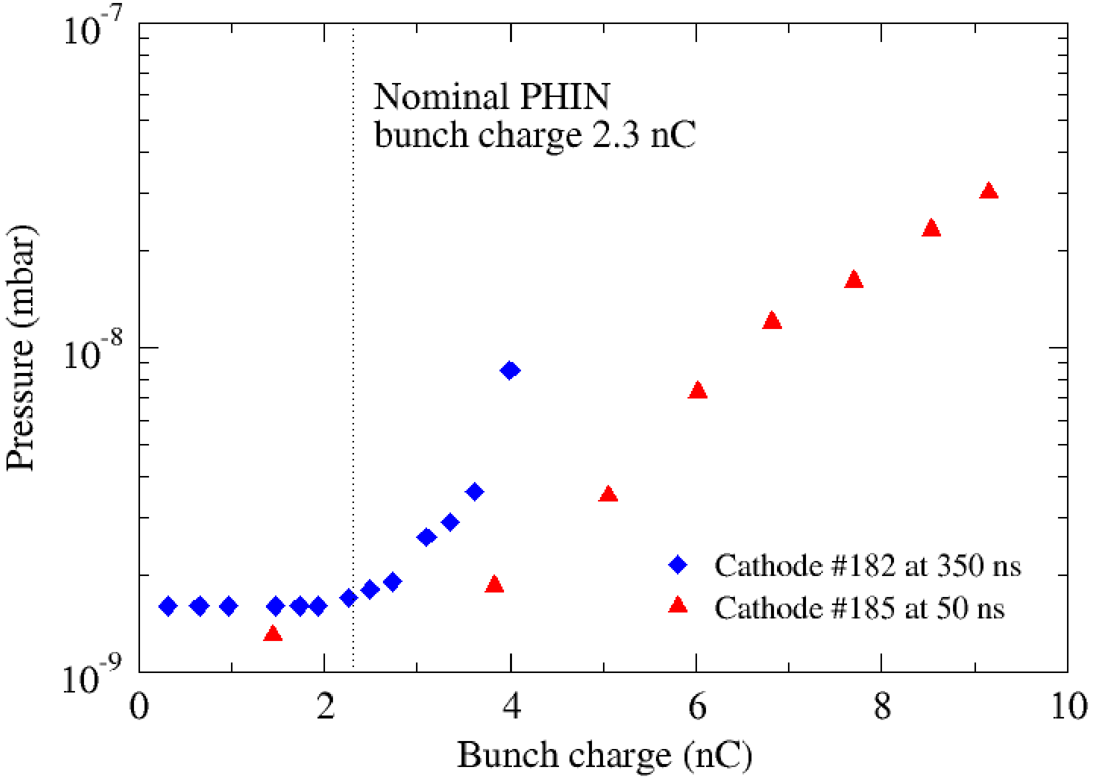
  - Beam observation on fast current transformer:



⇒ No beam degradation due to switching

Impact of Bunch Charge on Vacuum

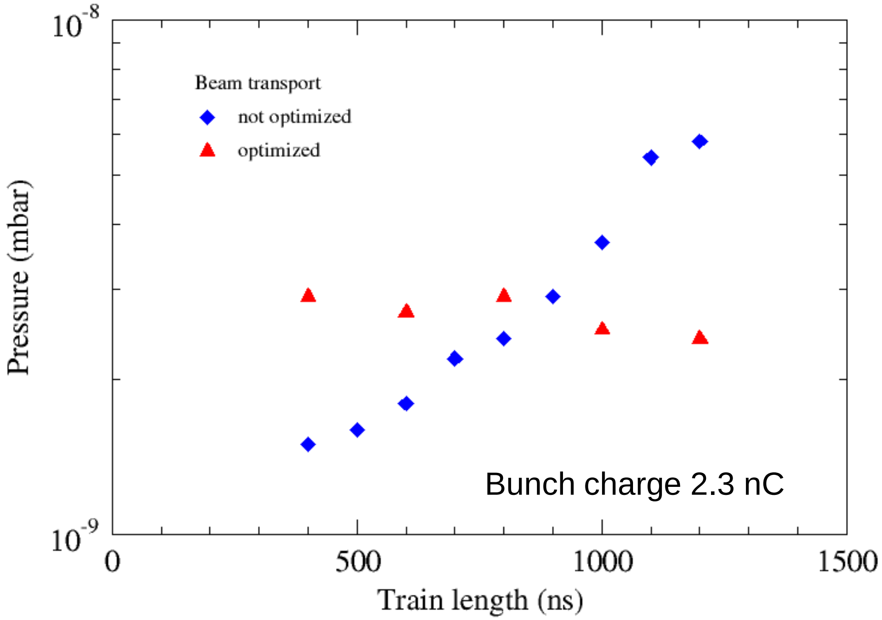
Vacuum vs. bunch charge



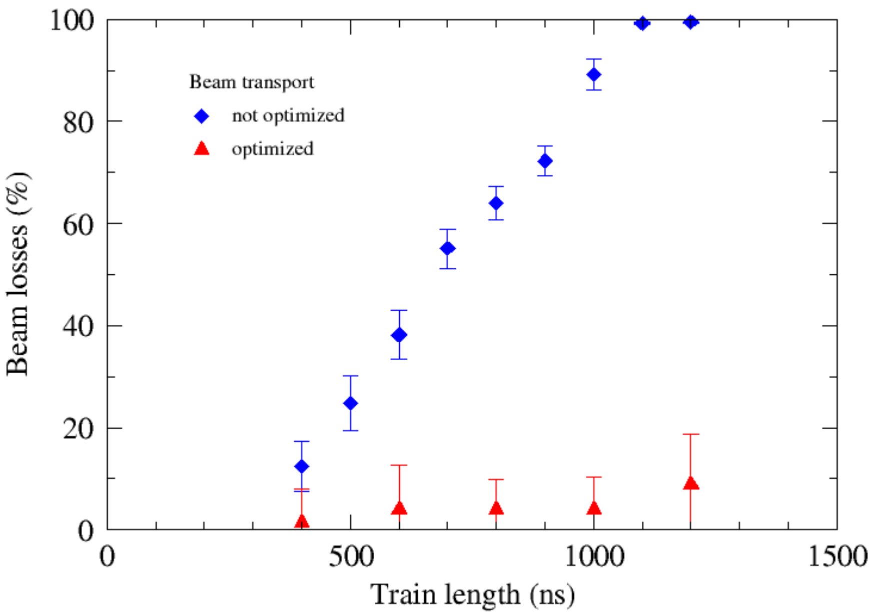
- Vacuum can be maintained up to nominal bunch charge of PHIN of 2.3nC.
- Pressure increase above nominal bunch charge probably due to losses inside gun.
- A 1 GHz gun specially designed for CLIC might be able to maintain the vacuum up to a higher bunch charge due to larger apertures.

Impact of Train Length on Vacuum

Vacuum vs. train-length



Corresponding beam losses
Between FCT and Faraday cup



- Vacuum correlated to beam losses in the beam line
- When beam is optimized for good transport, the vacuum can be maintained with increasing train length