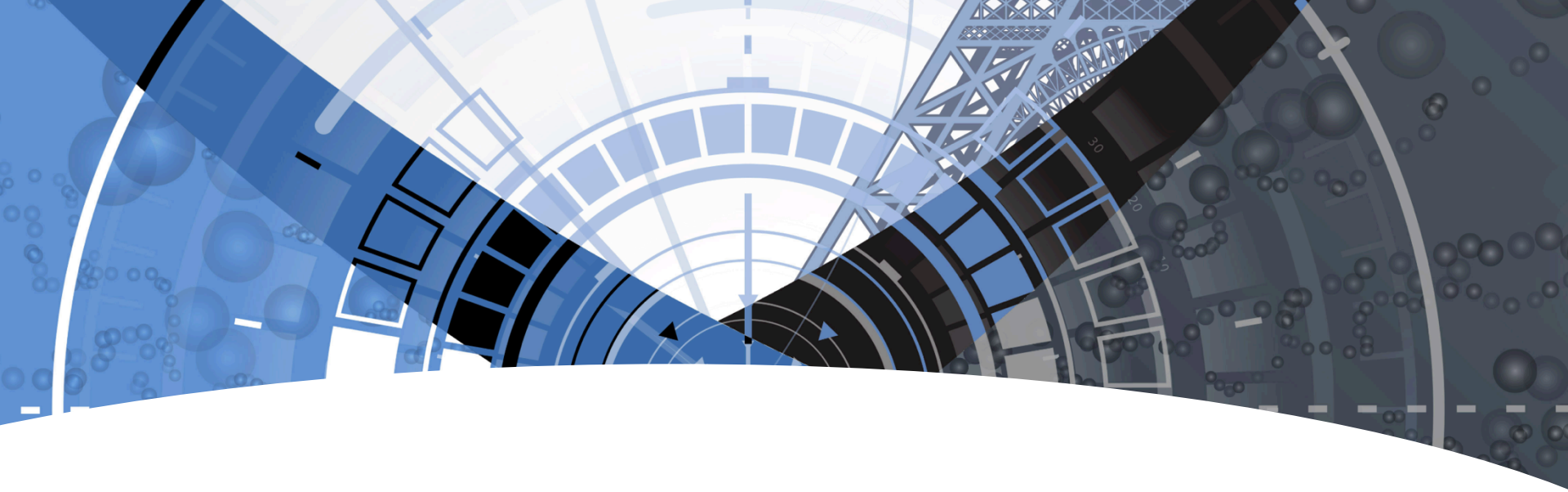


Production of electron beams using lasers at CERN: research, development and operation.

V. Fedosseev, E. Chevallay, F. Friebel, E. Granados, C. Hessler, S. Gilardoni

EN-STI-LP

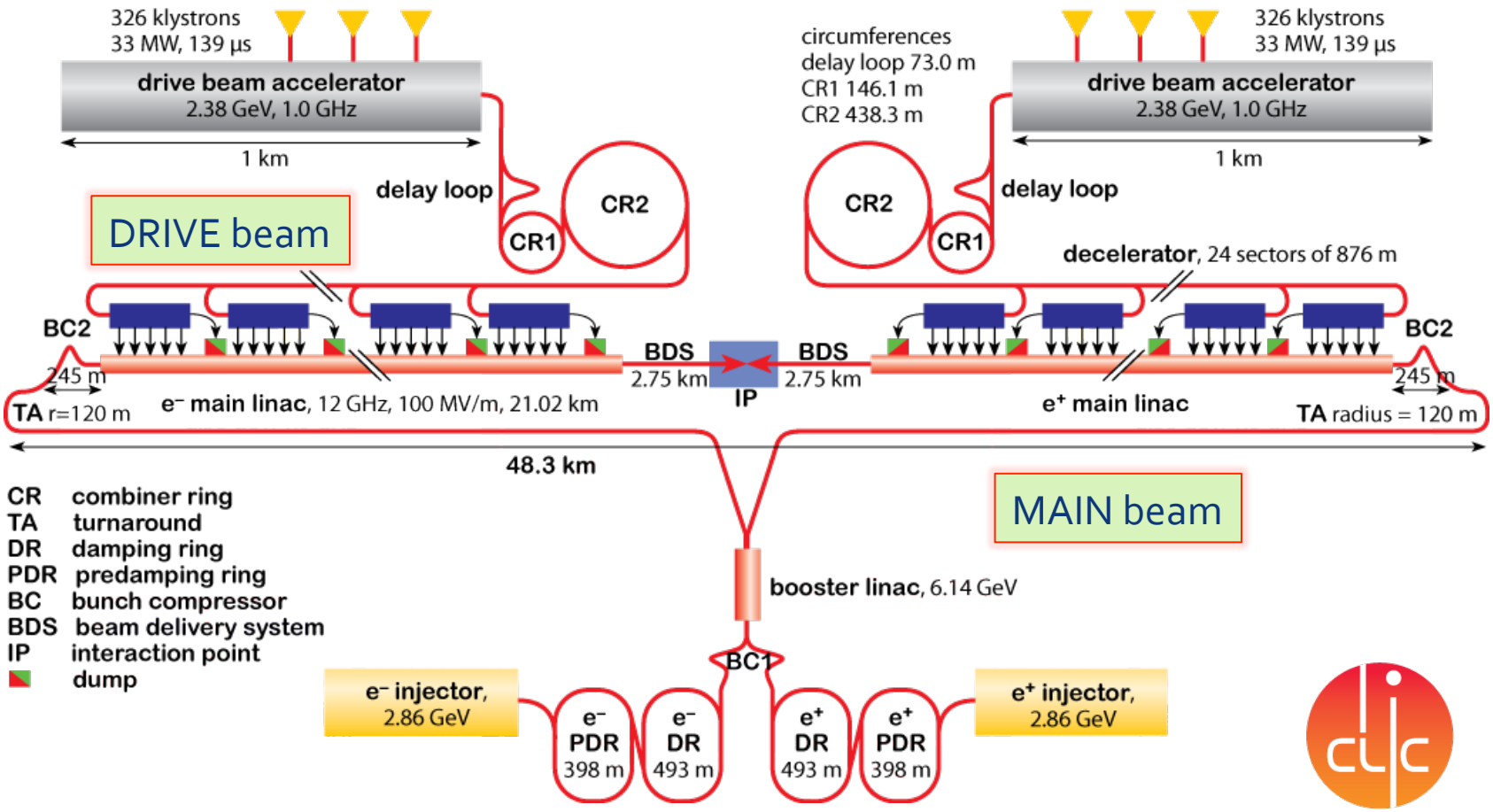
CERN | EN ENGINEERING DEPARTMENT

LHeC/FCCeh and PERLE Workshop, 27-29 June 2018

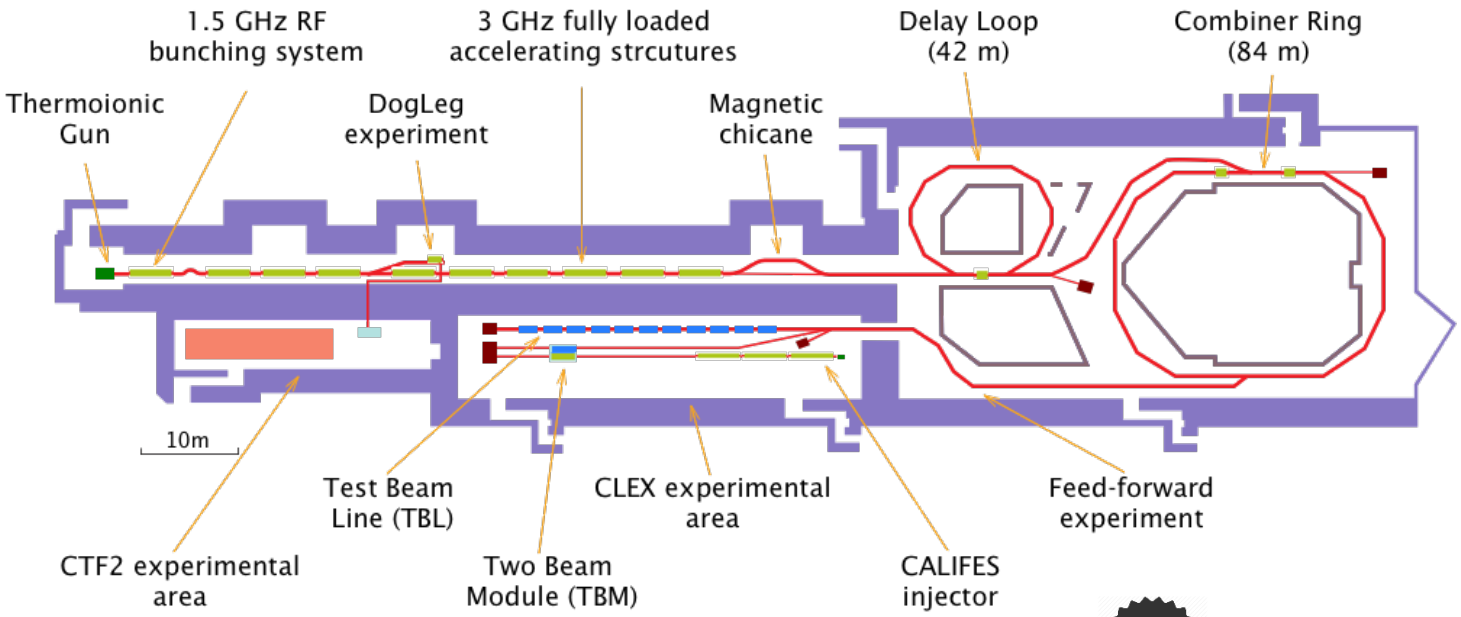
Outline

- Overview on CERN photoinjector activities
  - CTF3 / CLEAR Facilities
  - AWAKE experiment
  - Laser upgrades for photoinjectors
- Photocathode preparation facility at CERN
  - Development of co-deposition of Cs_2Te and Cs_3Sb photocathodes
- Lifetime studies in RF and DC guns
- XPS surface analysis
- Conclusions and outlook

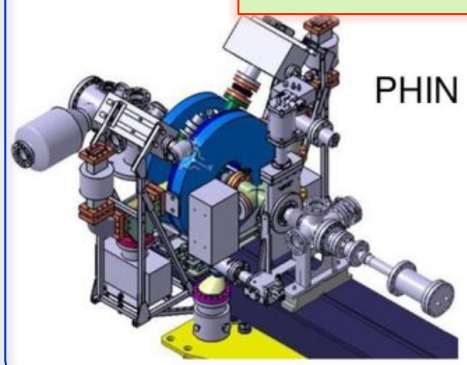
CLIC Concept



Photoinjectors at CTF3



DRIVE beam



PHIN

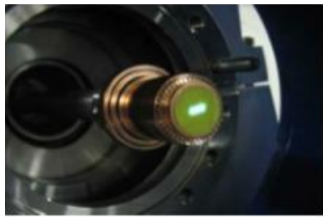
Cs_2Te / Cs_3Sb
Co-deposition

Now at:

AWAKE

MAIN beam

Cs_2Te @ CALIFES
In-situ, dual layer



NEW clear

Test facility for:

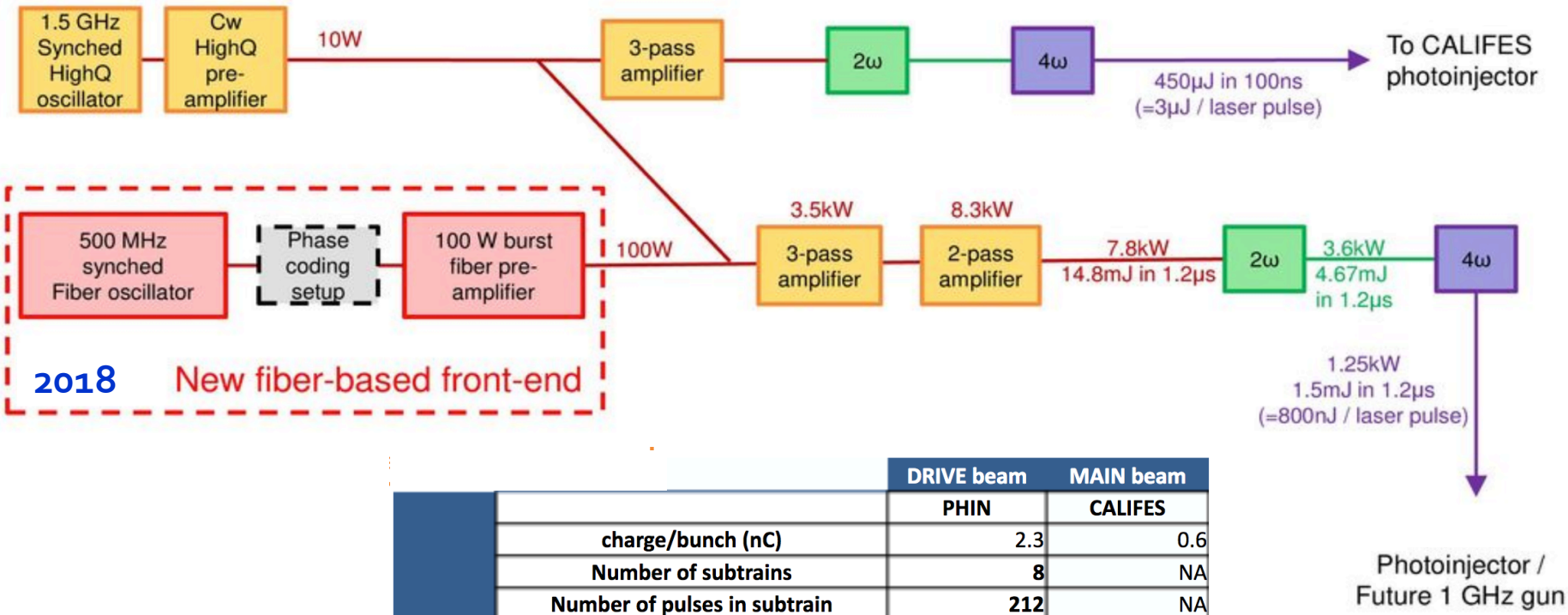
- X-band technology
- Bunch compression
- Advanced beam dynamics
- Plasma lens, AWAKE…
- Wakefield physics
- Radiation studies

CLIC / CTF3 requirements for e- guns

	Main beam	Drive beam	
Parameter	**CALIFES (CTF3)**	**PHIN (CTF3)**	**CLIC requirem.**
Charge per bunch (nC)	0.6	2.3 (9.2)	8.4
Macro pulse length (μs)	<0.2	1.2 (1.6)	140
Bunch spacing (ns)	0.66	0.66	2.0
Gun RF / bunch rep. rate (GHz)	3 / 1.5	3 / 1.5	1 / 0.5
Number of bunches in macro pulse	1 – 300	1800 (2400)	70000
Macro pulse rep. rate (Hz)	5	5 (5)	50
Charge per macro pulse (μC)	<0.18	4.1 (5.5)	590
Beam current in macro pulse (A)	0.9	3.5	4.2
Bunch length (ps)	10	10	10
Charge stability	<3%	<0.25% (<1%)	<0.1%
Cathode lifetime (Cs_2Te)	1 y (QE>0.3%)	>50 h (QE>3%) (>300 h)	>150 h (QE>3%)
Cathode type	Cs_2Te (in-situ, dual layer)	Cs_2Te, Cs_3Sb (co-deposition)	To be defined
Norm. emittance (μm)	<20	<25 (14)	<100

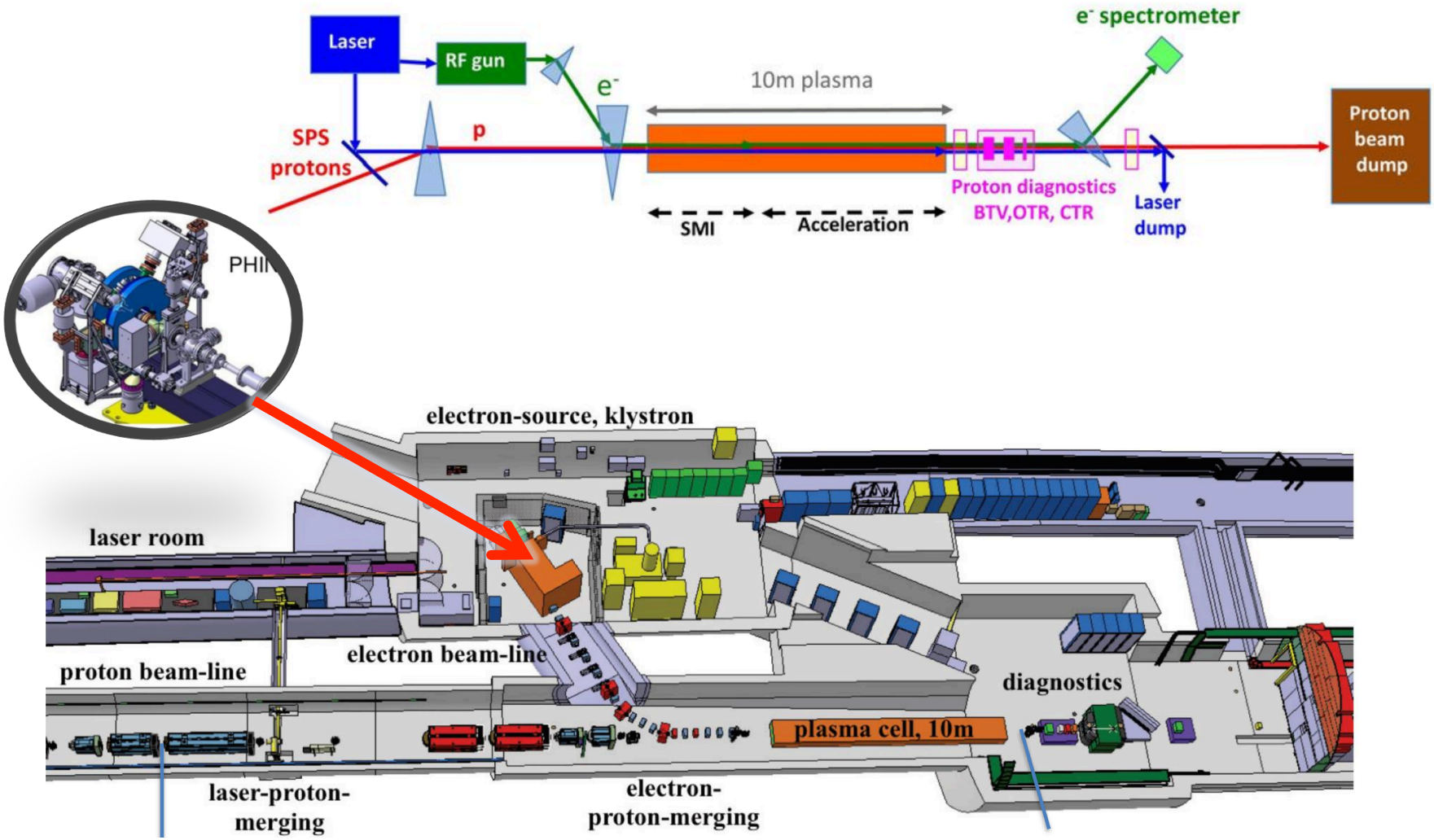
O. Mete et al., "Production of long bunch trains with 4.5 μC total charge using a photoinjector", Phys. Rev. ST Accel. Beams 15 (2012), 022803.

CALIFES and PHIN lasers at CLEAR



		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

AWAKE experiment at CERN



Recap Photocathodes Properties and Materials

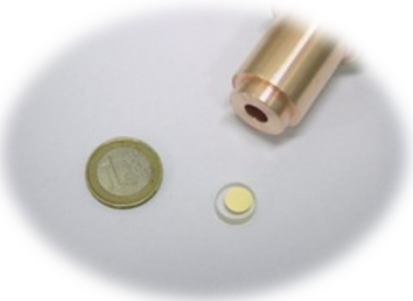
Class	Material	QE	Wavelength	Gun	Application
Normally conducting metals	Cu, Mg	10^{-5} - 10^{-4}	UV	NC-RF	Low Rep rate FELs (LCLS, SwissFEL…)
Super-conducting metals	Nb, Pb	10^{-5} - 10^{-4}	UV	SC-RF	High Rep rate FELs
Positive electron affinity semiconductor	Cs_2Te, Cs_3Sb , K_2CsSb …and others…	0.1 – 0.2	Visible – UV	NC-RF, DC	FELs, ERLs
Negative electron affinity semiconductor	GaAs, etc	0.1-0.35	IR – Visible	DC (XHV)	Polarized sources, ERLs (ALICE)

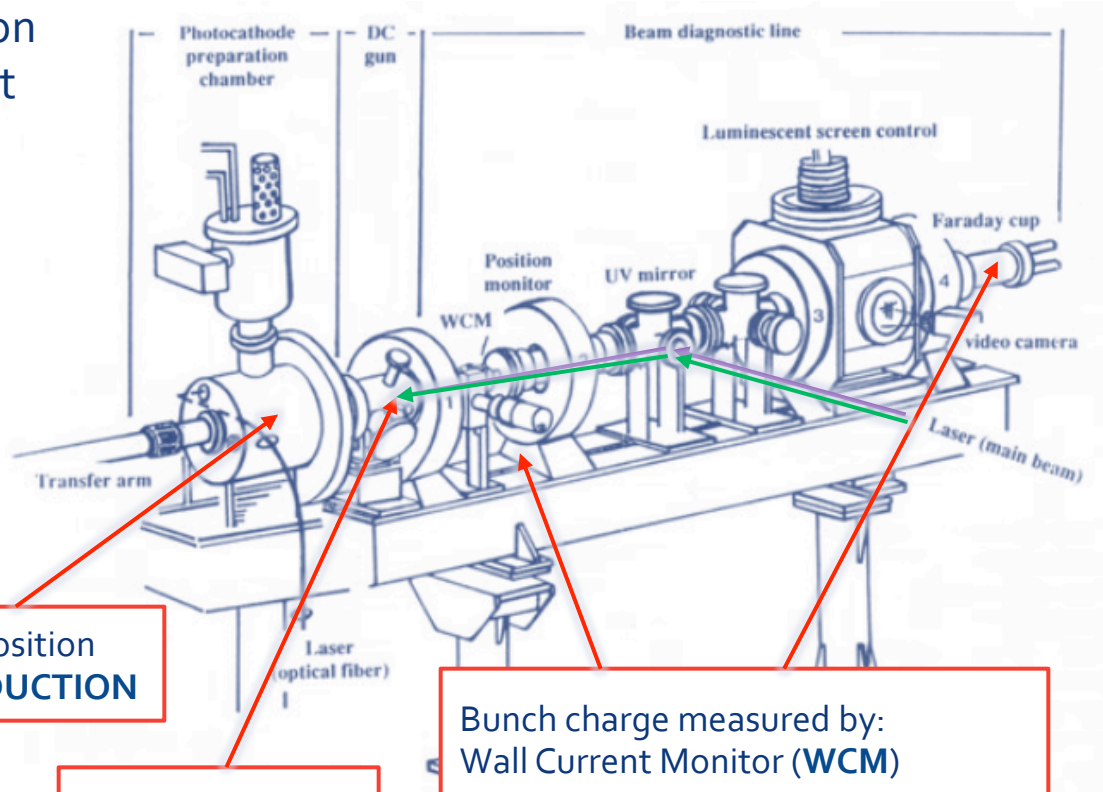
- **Metals**
  - Low quantum efficiency -> requires high power lasers -> plasma is formed
  - Robust and simple
- **Semiconductors**
  - High quantum efficiency at extended wavelength range.
  - More difficult to maintain – ions can cause decomposition and surface damage, vacuum…
  - Cs_2Te is quite standard, but requires UV

Photocathode Preparation Facility at CERN

Originally designed for producing photocathodes for the CLIC project:

- CERN Photocathode Preparation Facility has been working without interruption since >25 years.
- Focus on development of manufacturing techniques for Cs_3Sb and Cs_2Te photocathodes.





Cathode position during **PRODUCTION**

Cathode position during **TEST**

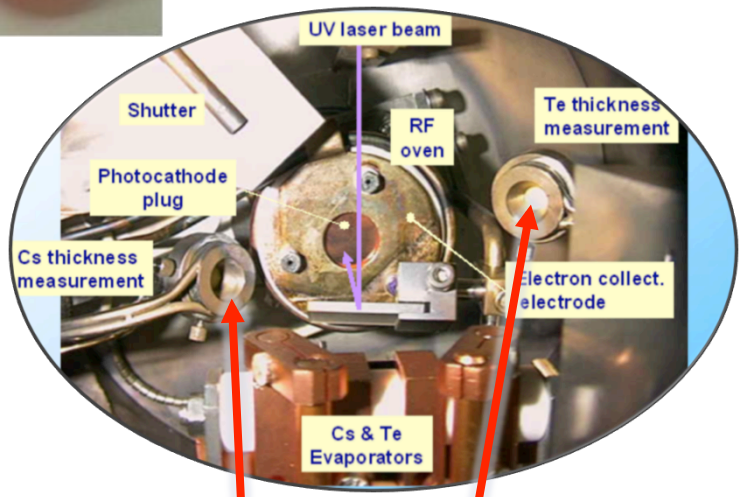
Bunch charge measured by:
Wall Current Monitor (**WCM**)
Fast Current Transformer (**FCT**)
Faraday Cup (**FC**)

Photocathode preparation by co-deposition

Co-Deposition setup

- **Substrate**: Copper with diamond powder polished surface
- **Good isolation** for each quartz
- **Substrate is heated** to 125 C for Cs_3Sb, and not heated for Cs_2Te.
- **Thickness monitors**: Quartz microbalances for Cs and Te/Sb.
- **Mask** allow to measure both evaporation rates separately.
- **Online QE measurement**: Main tool for optimizing the deposition process -> Mandatory for co-deposition.

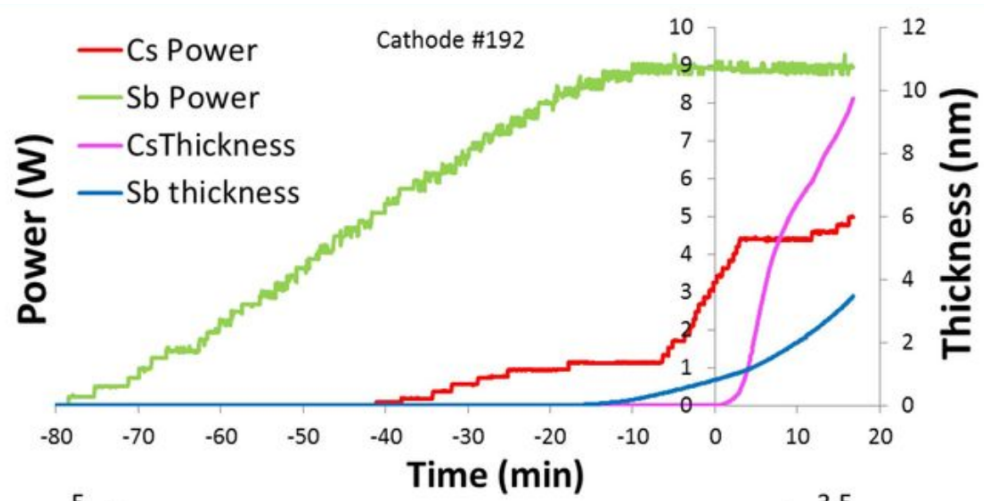
Copper plug

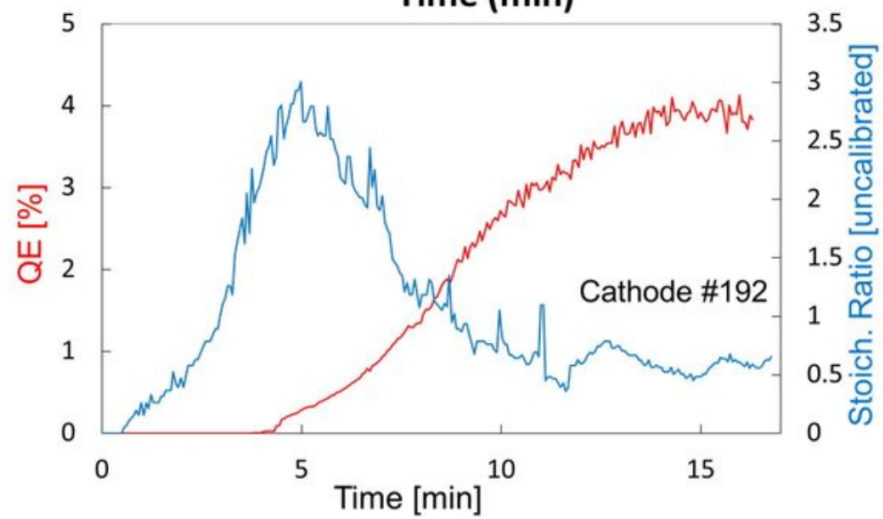


	Quartz1 (Cs) (nm)	Quartz2 (Te) (nm)	Isolation Factor
Te (S64)	0.25	40.05	**160**
Cs (S68)	23.12	0.16	**145**

Co-deposition process

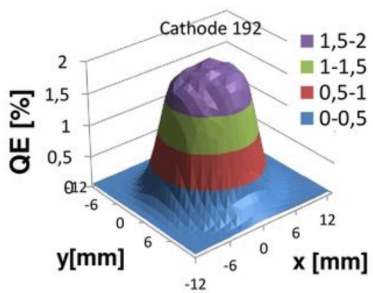
- Co-deposition: Cs and Sb (or Te) evaporated at the same time. The metallic elements can mix together in the vapour phase.
- The evaporators power is adjusted in order to reach a maximum value of QE.
- Average pressure during the process is 1e-8 mbar.
- Tricky business, depends on the skills of the operator (and experience).

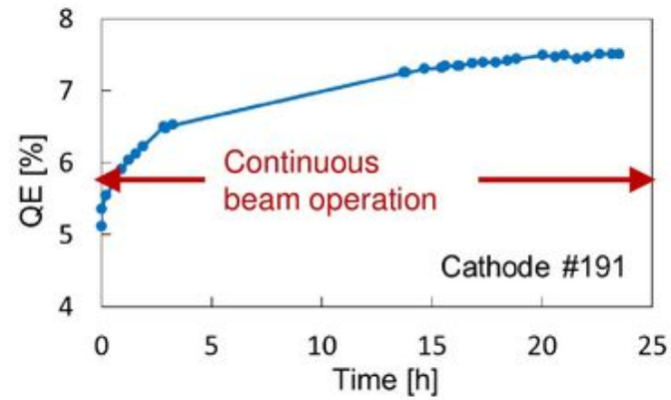




Example: Deposition results for Cs_3Sb

- In contrast to the Cs_2Te results, the QE of Cs_3Sb cathodes initially continues **to increase during beam production** in DC gun.
- Reason for this behavior still unclear, but maybe due to re-organization of Cs and Sb atoms.
- Maximum QE achieved is 7.5 % (measured in DC gun)

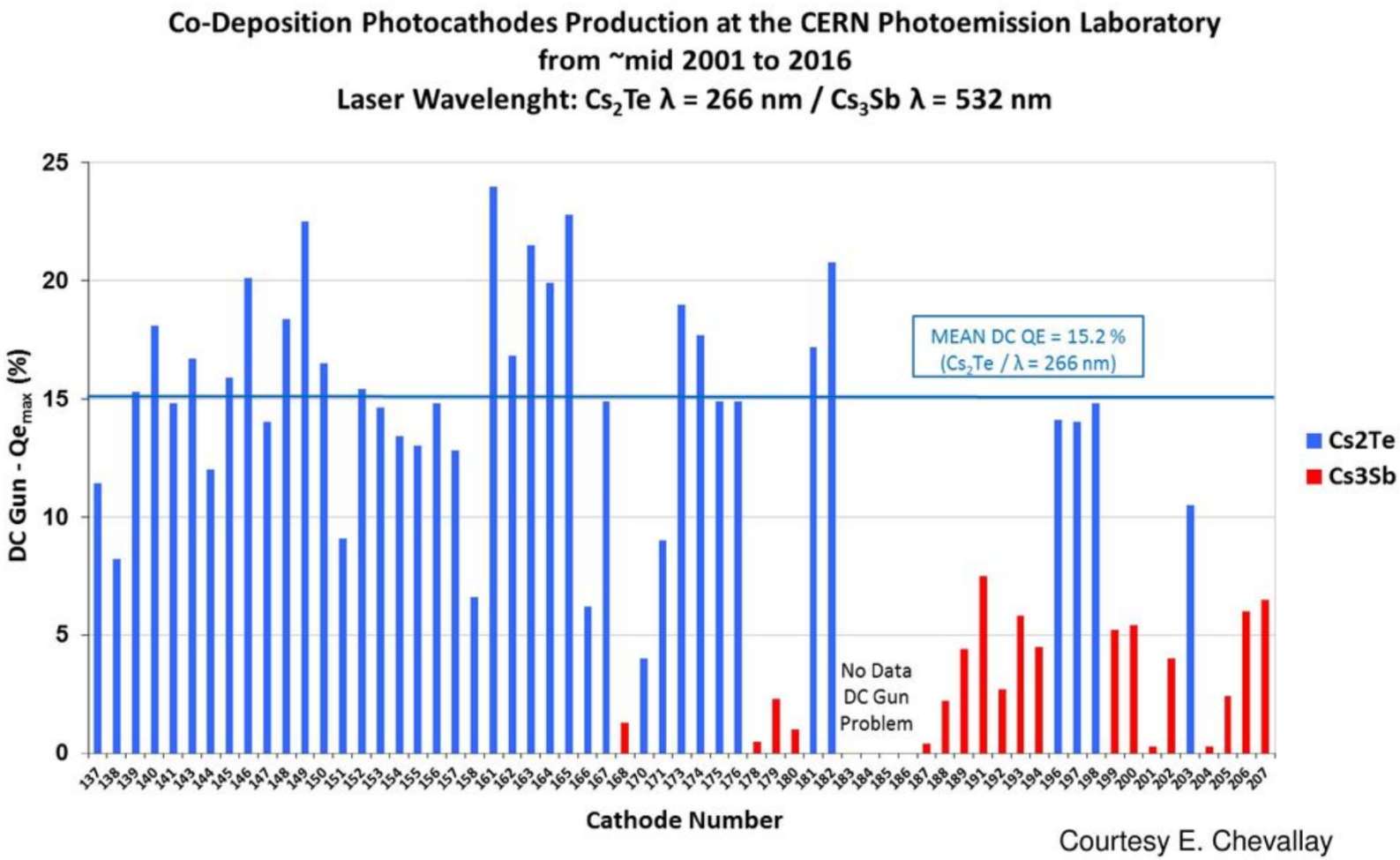




No.	Initial QE (%)	Max QE (%)	Evaporated Cs (nm)*	Evaporated Sb (nm)*	Final stoich. ratio*
178	0.3	0.5	120	18.4	2.9
179	1.4	2.3	156	24.5	1.74
180	0.6	1.0	52	14.4	3.1
187	0.3	0.4	67.6	4.7	18.9
188	1.3	2.2	152	17.8	8.84
189	2.3	4.4	64	15	1
191	5.4	7.5	156	14	1.7
192	2.0	2.7	9.7	3.5	0.66
193	4.2	5.8	10.8	7.6	0.65
194	2.7	4.5	18.7	20.7	0.9
199	3.5	5.2	269	22.7	2.9
200	3.4	5.5	83.3	23.5	0.98

Courtesy I. Martini

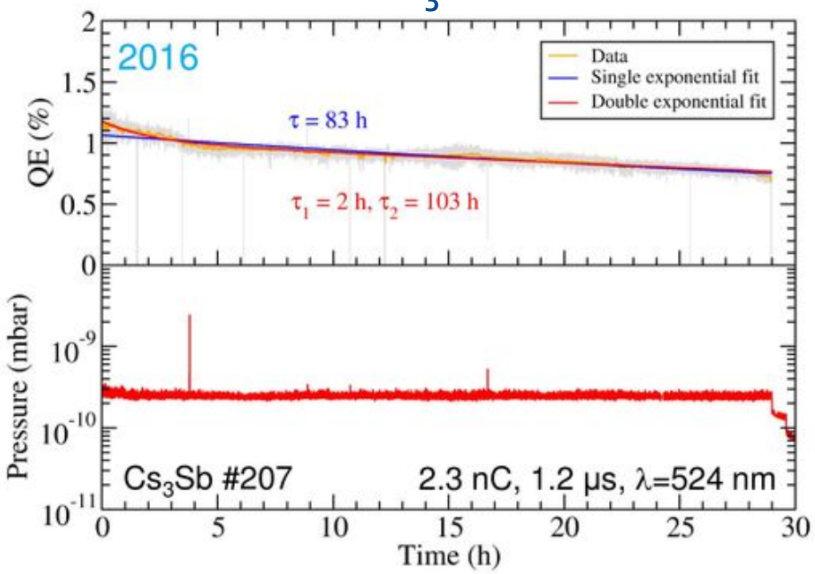
Cs_3Sb vs Cs_2Te (QE comparison)



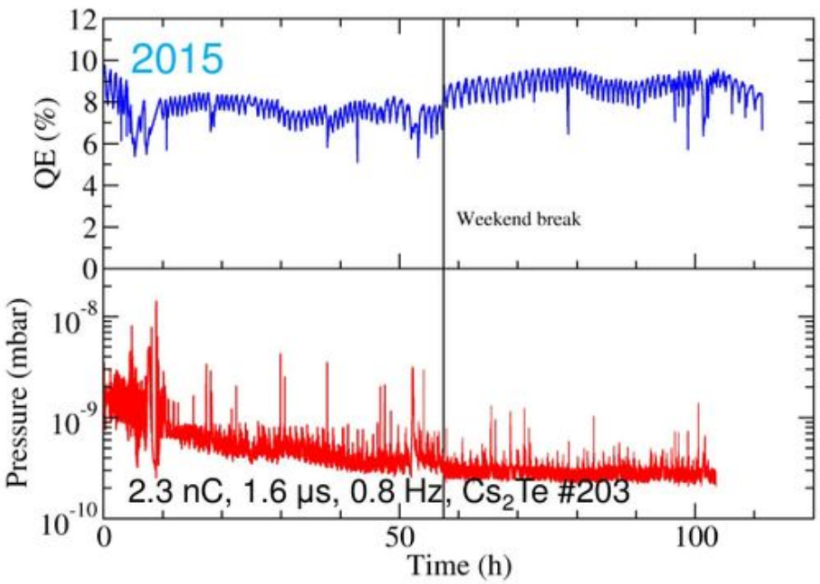
Cs_2Te / Cs_3Sb photocathode lifetime studies

- Operation with 1.6 µs, 2.3 nC/bunch at 0.8 Hz repetition rate.
- **Vacuum** at the exit of the gun stayed low e-10 mbar range.
- No real decrease of the QE visible over >100h of beam operation.

Cs_3Sb



Cs_2Te

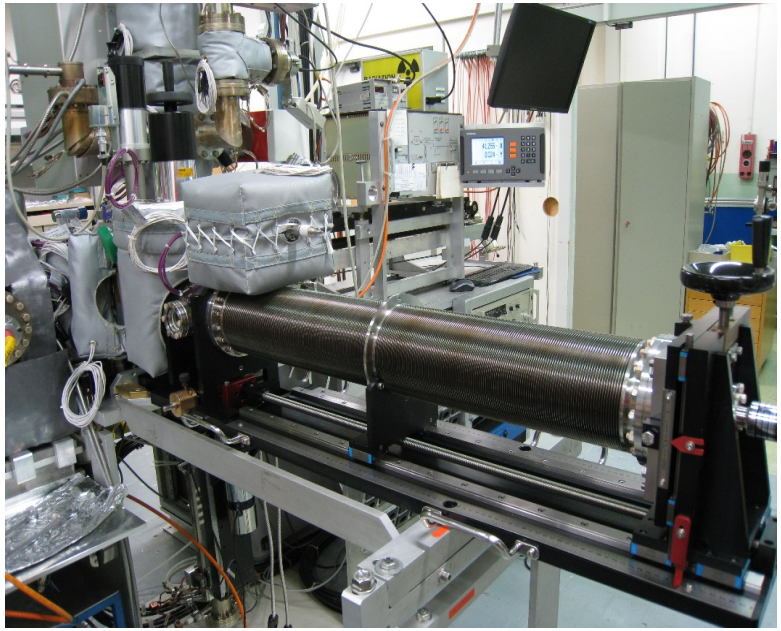


- 1/e lifetime ~100 hours, corresponding to a lifetime of ~170h above QE = 0.5%

C. Hessler et al., "Study of the Performance of Cs2Te Cathodes in the PHIN RF Photoinjector using Long Pulse Trains", Proc. of IPAC'16, Busan (2016), p. 3960.

Photocathode transport vessel

- Collaboration with **LAL** to construct **UHV carrier vessel** allows transfer of photocathodes from production laboratory to other facilities and laboratories.
- Successful transfer to **XPS laboratory** at CERN.
- XPS allows material **characterization of the surface**.
- Aim: Study the **correlation** between the chemical composition and the QE.



XPS Surface analysis of photocathodes

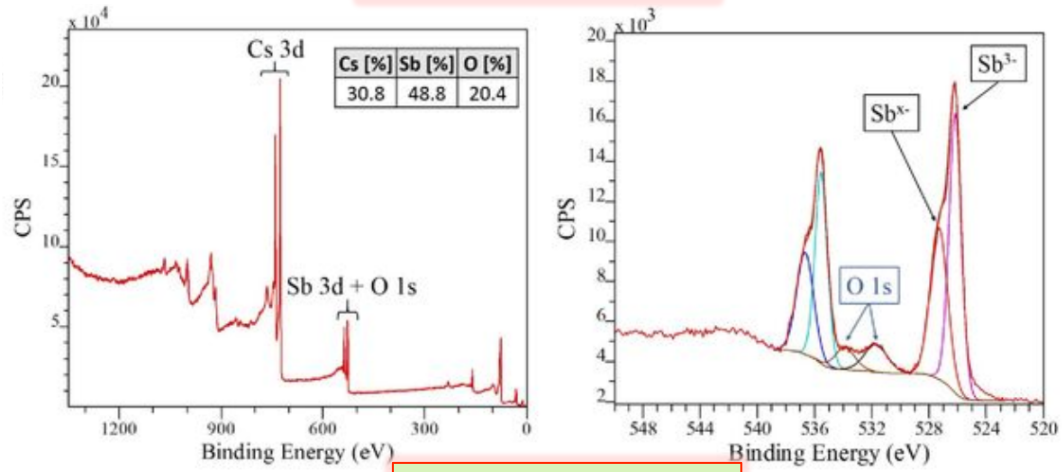
Fresh Photocathode:

- Sb-rich phase
- O 1s peaks could be explained by Cs_3O_{11} and H_2O

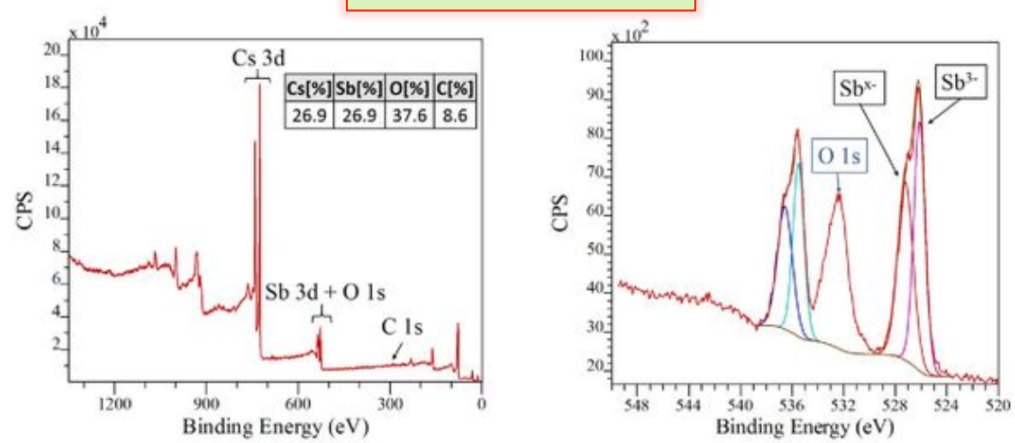
Used Photocathode:

- Sb-rich peak has increased.
- Oxygen and carbon contamination is present and can be explained by CO_3^{2-}
- Results indicate that perhaps Cs probably reacted with CO_2 to produce Cs_2CO_3
- Cs_3O_{11} or H_2O not excluded.

Fresh Photocathode



Used Photocathode



Some conclusions related to Cs_3Sb

- Cs_3Sb seems to be **less robust** than Cs2Te and more sensitive to non-optimal operation conditions.
- For obtaining good lifetimes with Cs_3Sb cathodes it is important to have the following conditions:
  - Excellent vacuum
  - Very stable phase between RF and laser
  - Linear charge extraction regime of the gun. Otherwise non-extracted e- can cause desorption in the gun -> bad lifetime.
  - Good laser beam shape characteristics
- More studies are needed, but mature technology with great potential for high charge production in ERLs for example.

Conclusions & Outlook

- CTF3 was closed at the end of 2016. But since 2017 the CLEAR facility makes use of the existing e- accelerator for a variety of tests:
  - X band technology.
  - Plasma lens development.
  - Novel diagnostics based on THz…
  - Instrumentation development.
- The production of photocathodes at CERN continues, in particular alkali antimonide and telluride.
- Capability of adapting photocathode design to specific projects, including future accelerators such as LHeC and FCC-eh.

Thanks for your attention!

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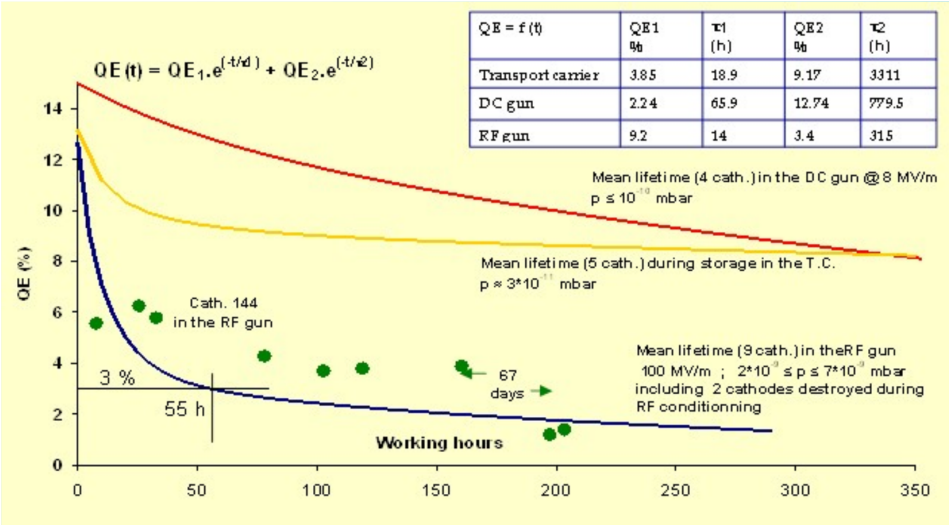
Example 1: Cs_2Te Photocathodes for CLIC (CTF3)

- Photocathodes produced by co-evaporation seem to be quite sensitive to the quality of vacuum

Achieved quantum efficiency (QE):
>20% (Cs_2Te), 7.5% (Cs_3Sb)

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



QE = f (t)	QE1 %	τ1 (h)	QE2 %	τ2 (h)
Transport carrier	3.85	18.9	9.17	3311
DC gun	2.24	65.9	12.74	779.5
RF gun	9.2	14	3.4	31.5

Photocathode	Min QE	Mean QE	Max QE
Cs2Te (20 u.)	8.2 %	14.9 %	24 %