Fabrication and rejuvenation of high QE CsTe photocathodes for AWAKE

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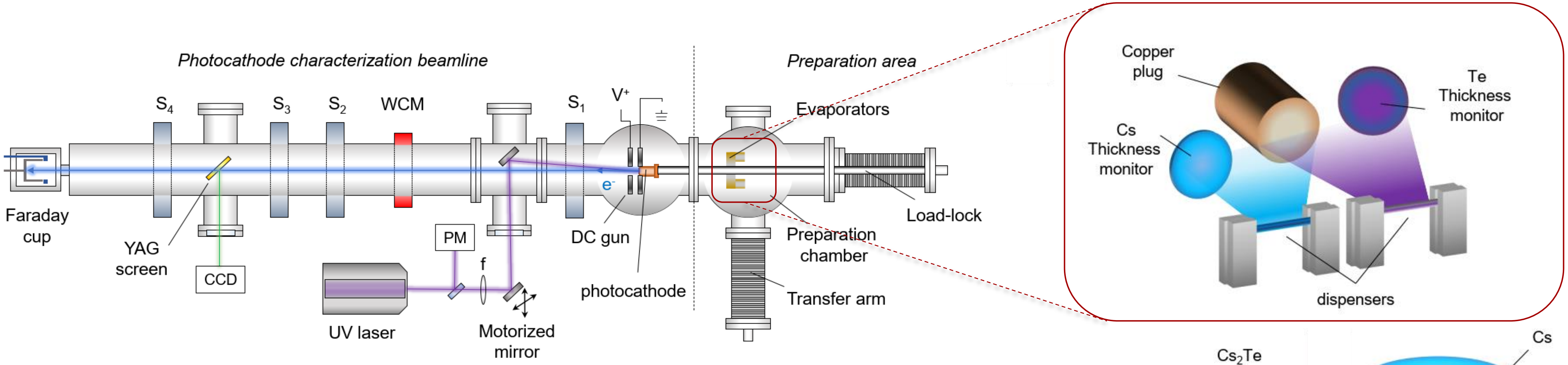
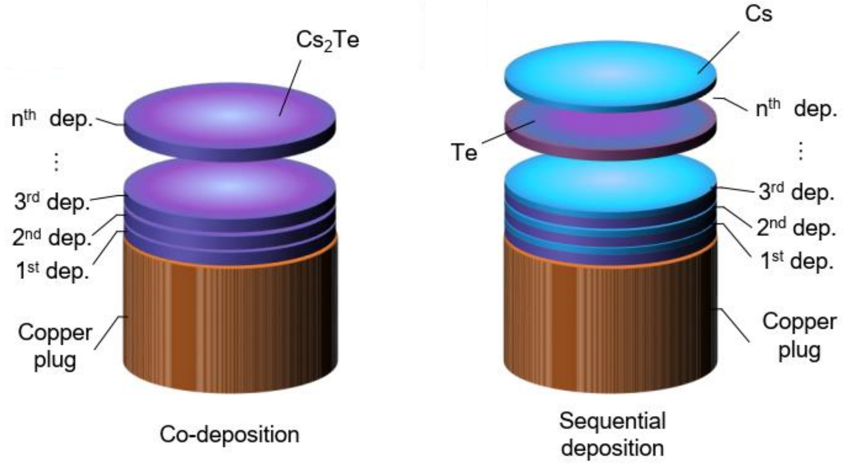
Agenda

- Photocathode production for AWAKE:
  - Photoemission lab setup
  - Cs_2Te thin-film deposition: sequential, co-deposition, rejuvenation.
  - Coating homogeneity.
  - Transport to AWAKE and performance in RF gun.
- Status of AWAKE run 2c photoinjector development:
  - Laser status and performance
  - Integration of Cs_2Te photocathodes in INFN/CTF2 RF gun

Typical arrangement for Cs_2Te photocathode production

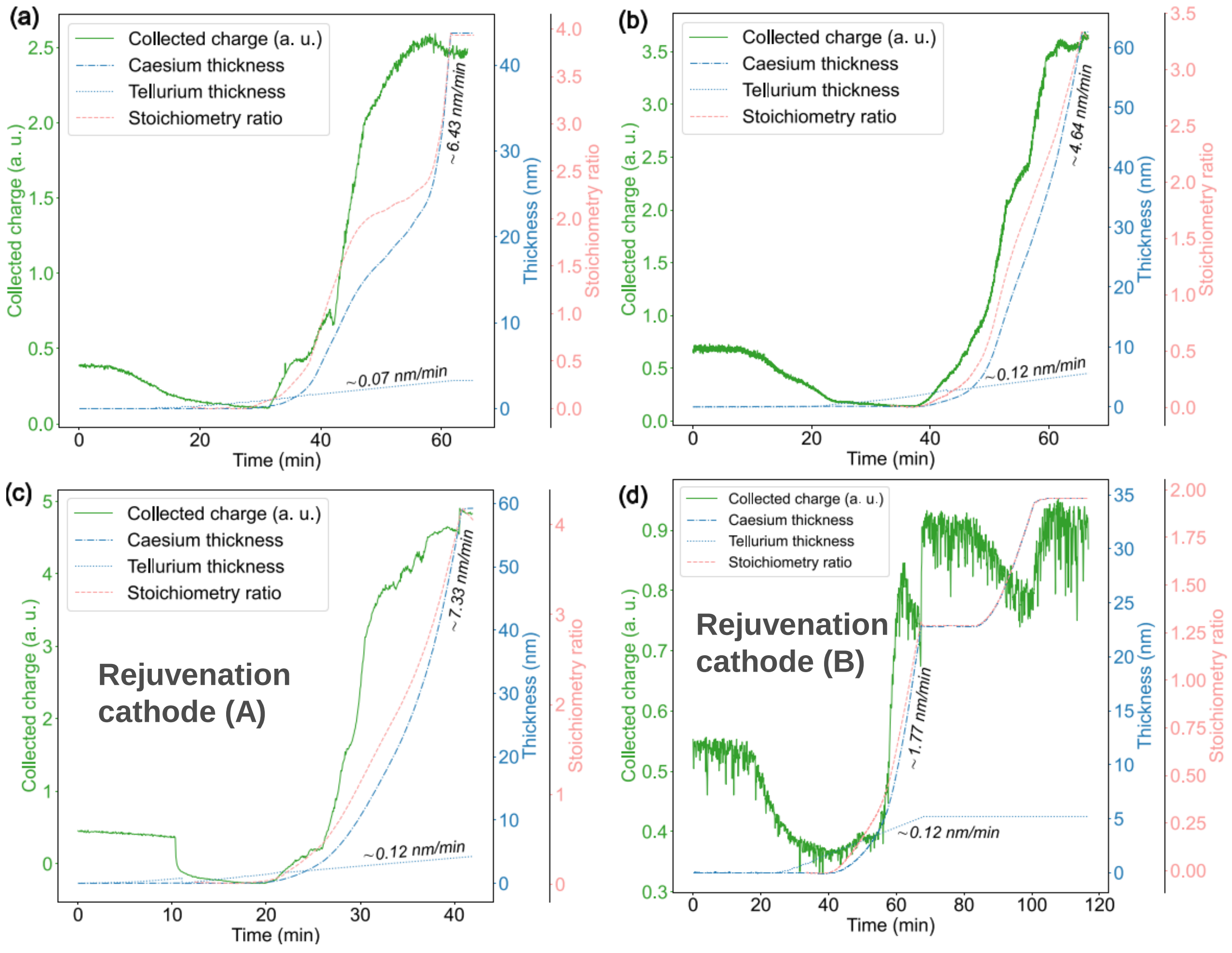


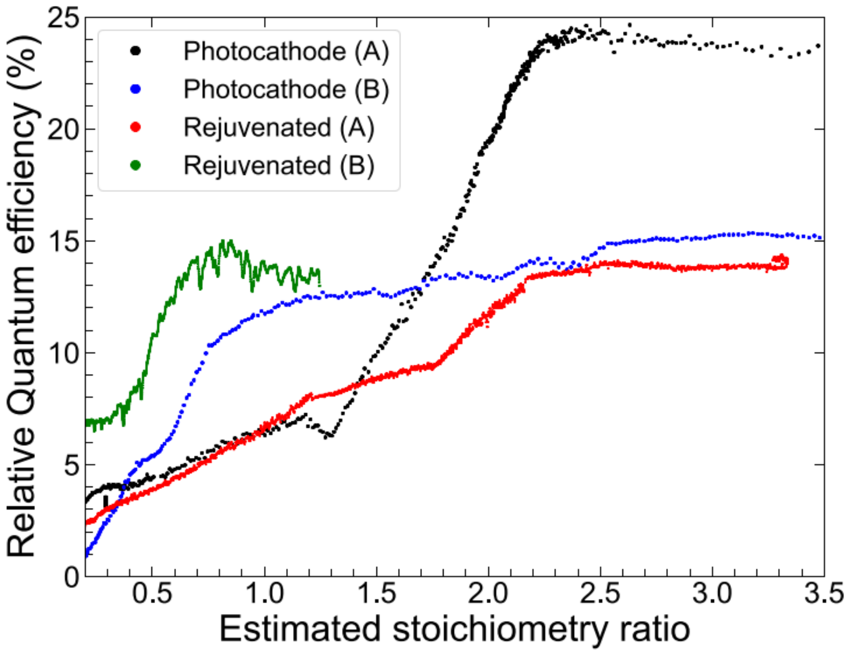


- More than 200 photocathodes produced in ~30+ years
- QE up to 25% demonstrated
- Sequential and co-deposition processing possible
- Now also plasmonic photocathodes!

QE optimization and rejuvenation of AWAKE photocathodes

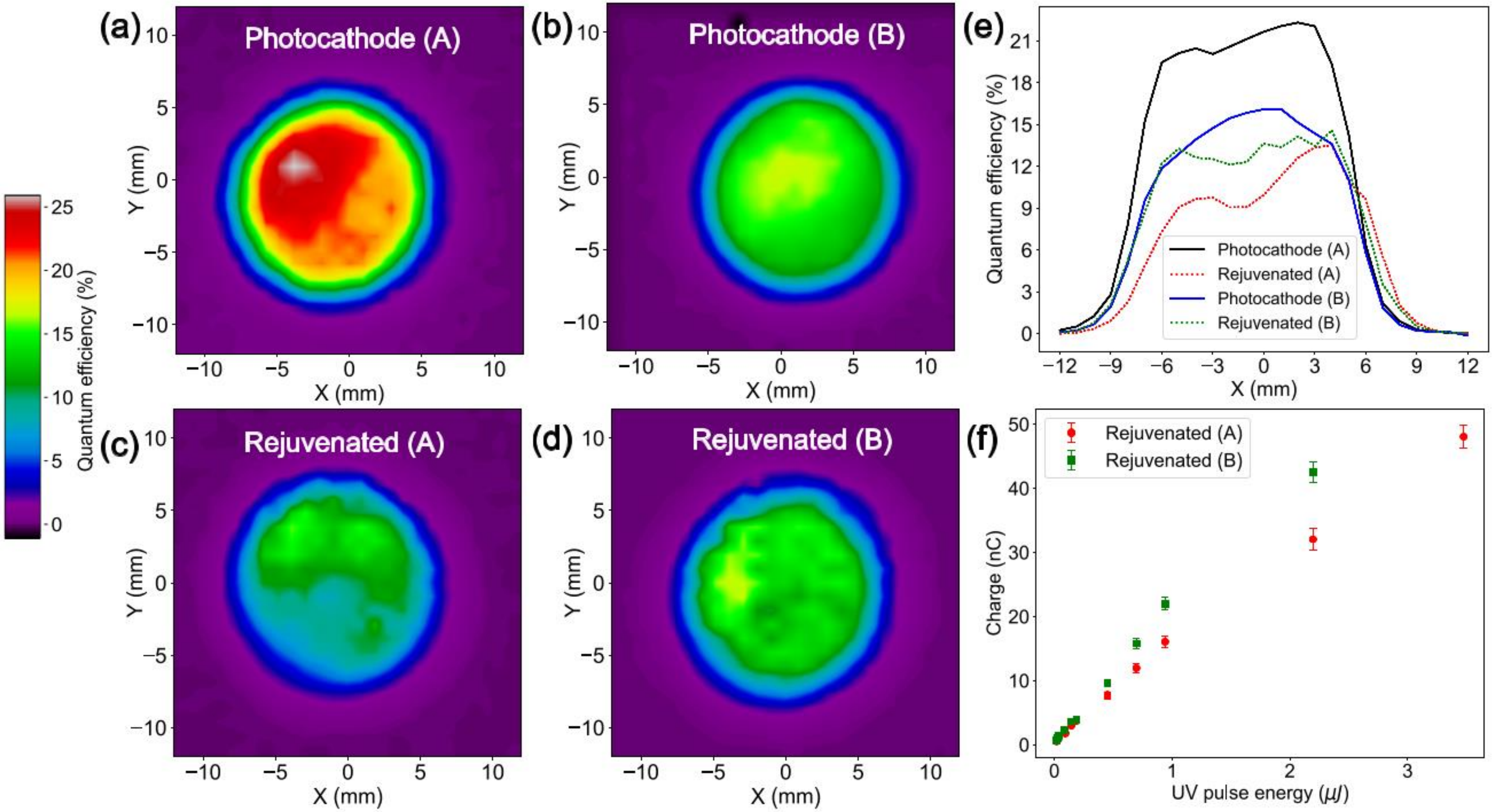
Fresh cathode (A) **Fresh cathode (B)**



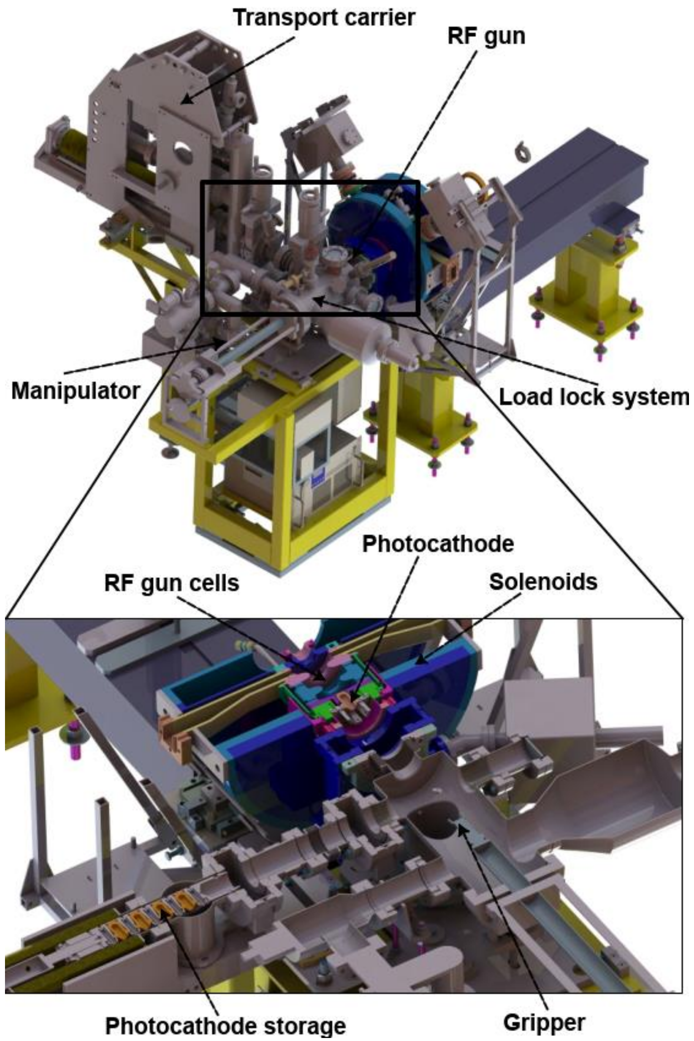


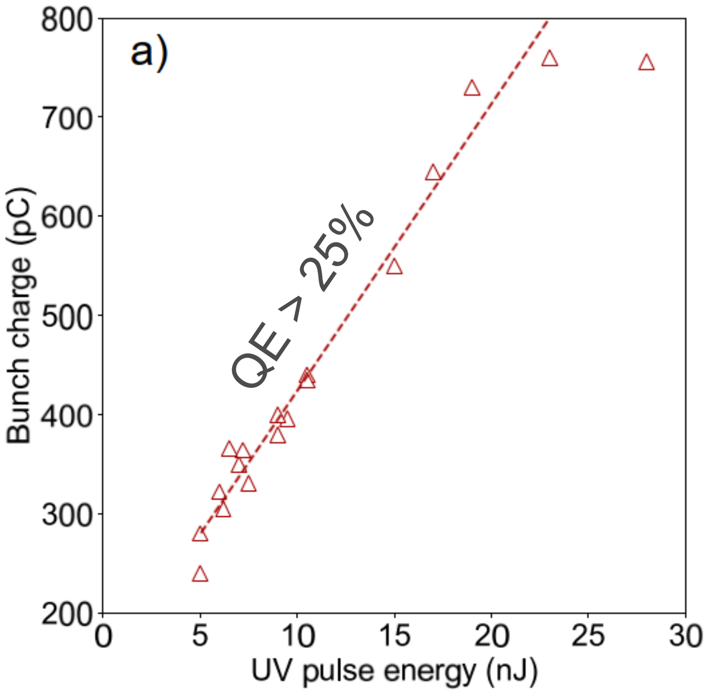
- Photocathode (A) was exposed to air
- Photocathode (B) was heavily used
- Found optimal stoichiometry ratio ~ 2.3

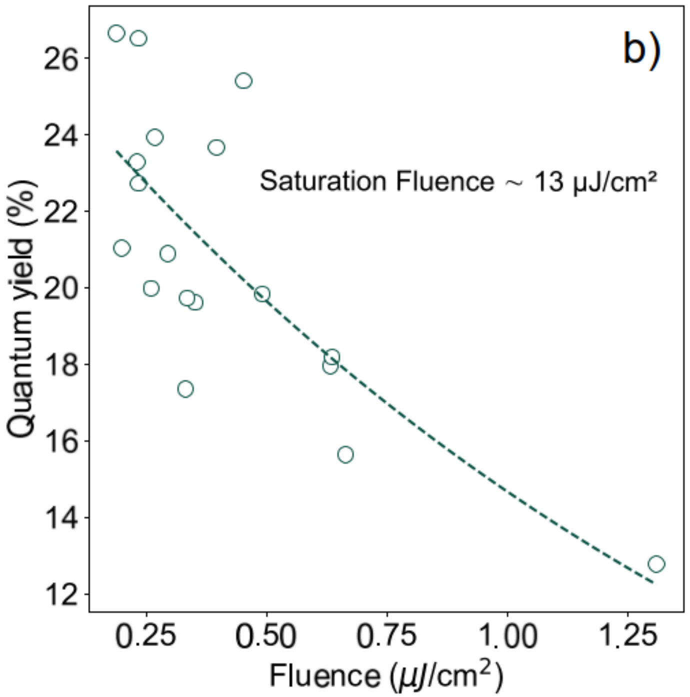
QE map (homogeneity) of rejuvenated cathodes



Photocathode performance at AWAKE photoinjector

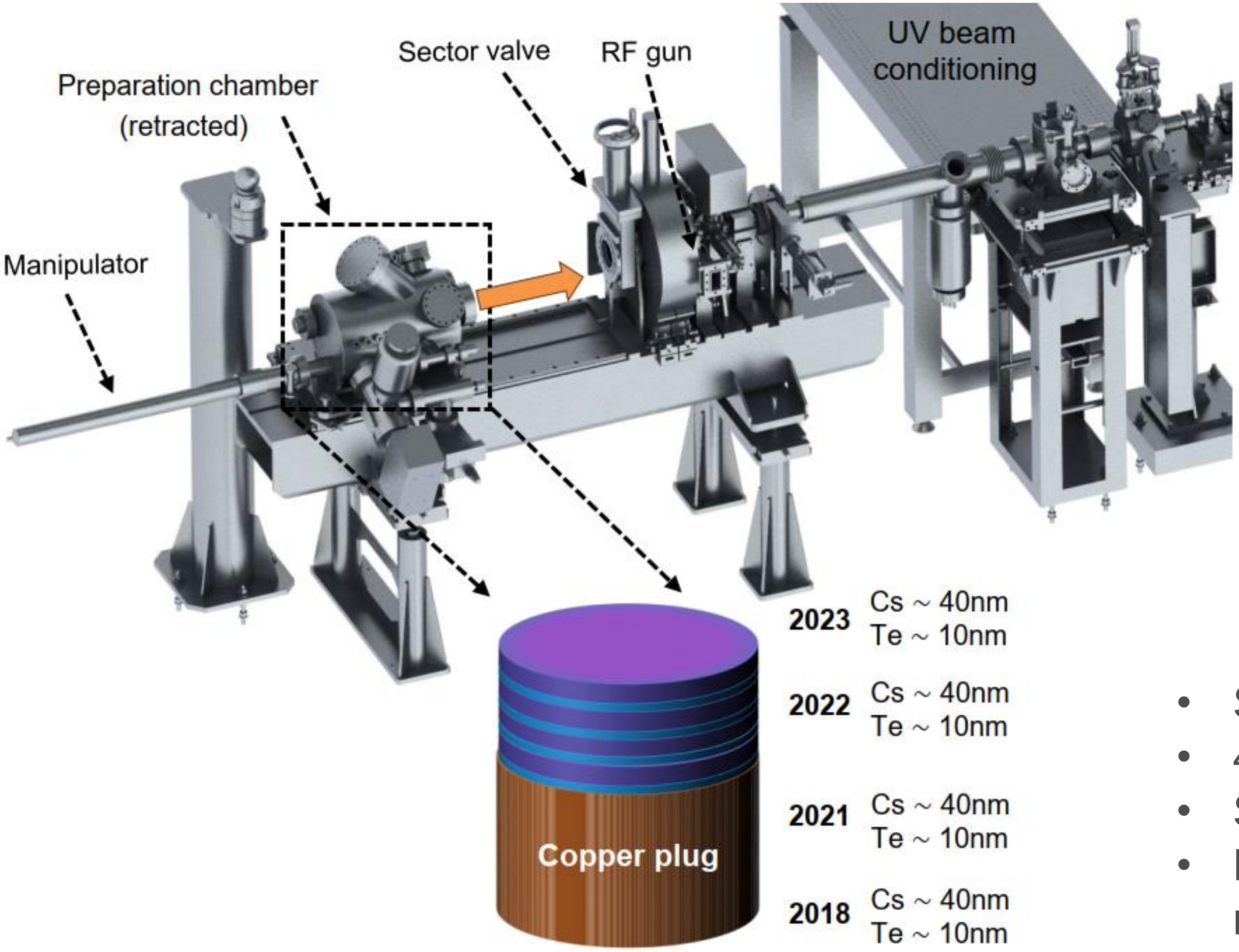


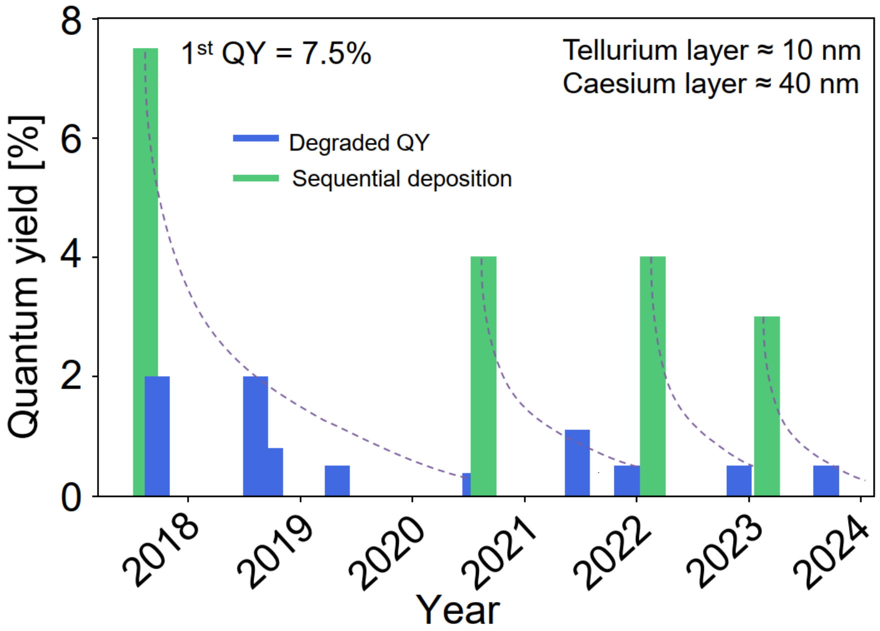




- Results consistent with the ones obtained in the Photoemission lab.
- QE > 25% was demonstrated.
- Emittance below 1 mm mrad achieved with small spot illumination.

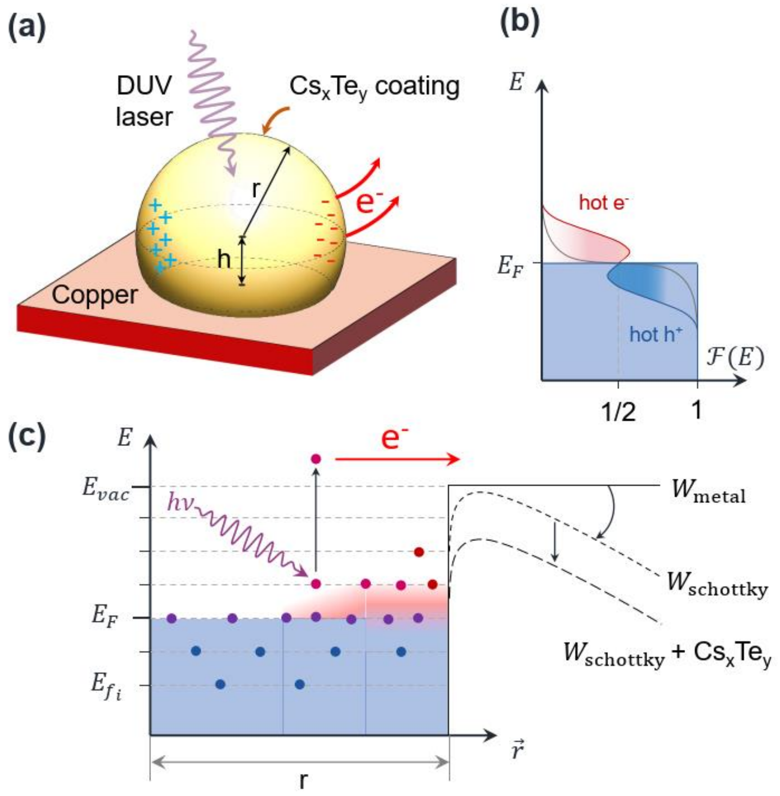
Photocathode rejuvenation at CLEAR

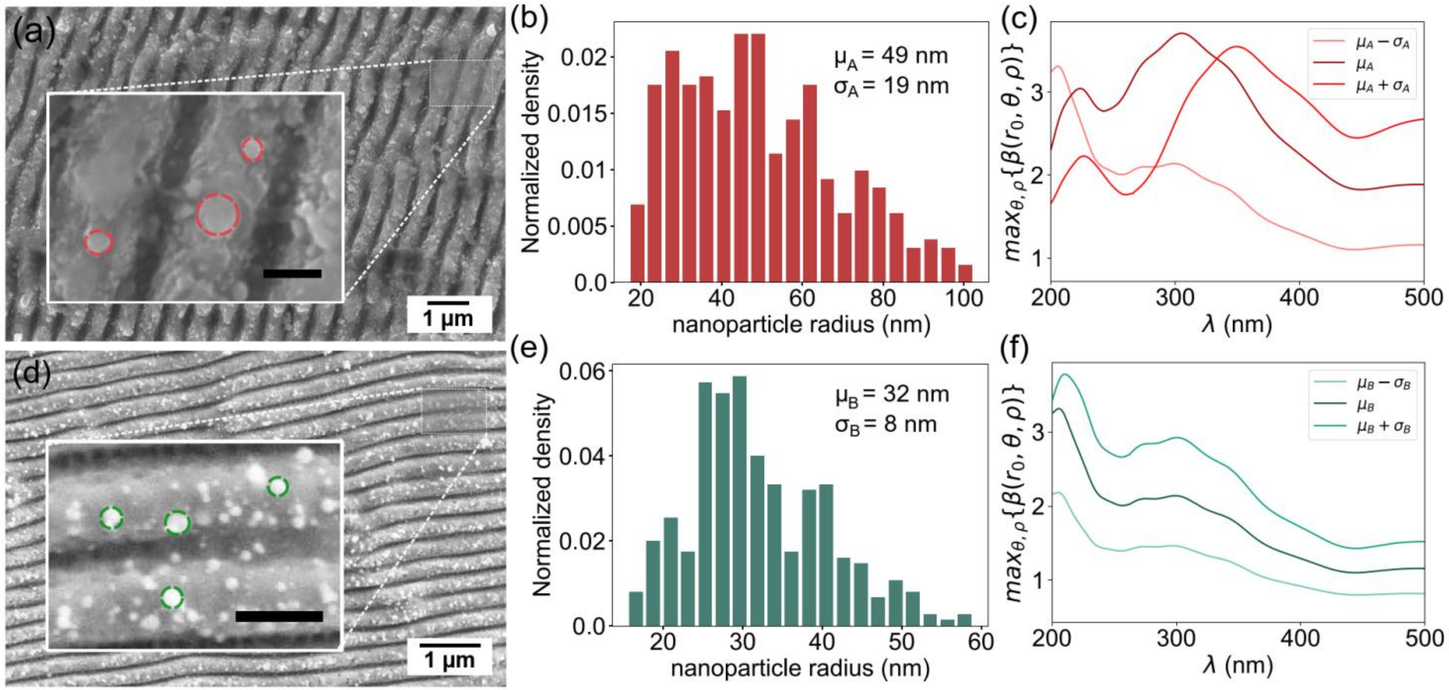




- Sequential deposition is suboptimal.
- 4 rejuvenations carried out successfully.
- Slight decrease of achievable QE.
- Extracted more than 1 Coulomb between rejuvenations.

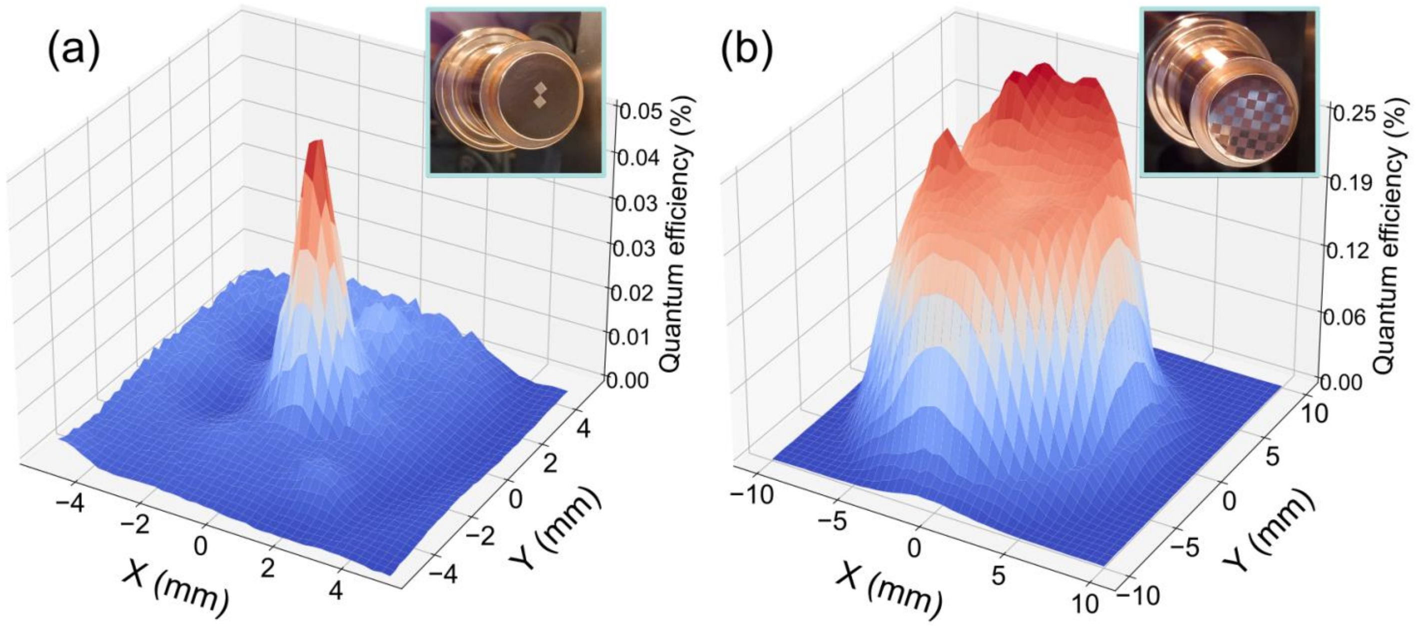
Plasmonic photocathode production

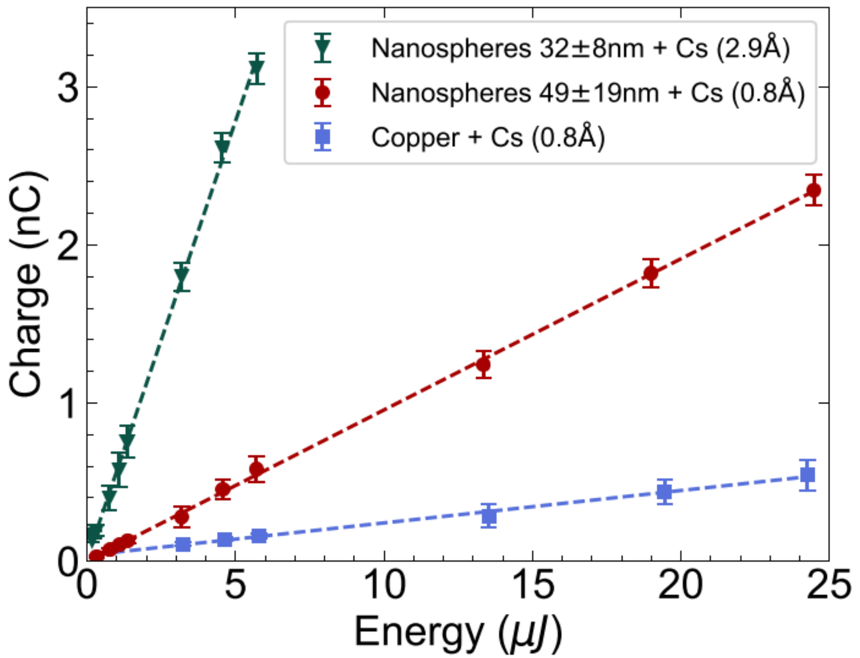




- Nanospheres are produced by interaction of an ultrafast DUV laser with a polished copper surface.
- Depending on illumination conditions, a range of nanospheres can be produced.
- These are DUV plasmonic resonant at around 260 nm, enhancing electric fields by >3x.

Plasmonic photocathode performance



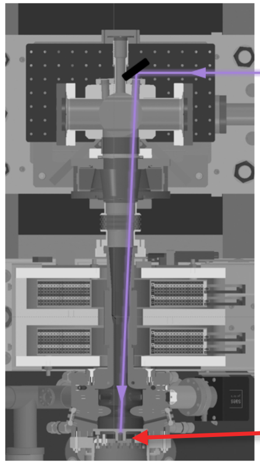


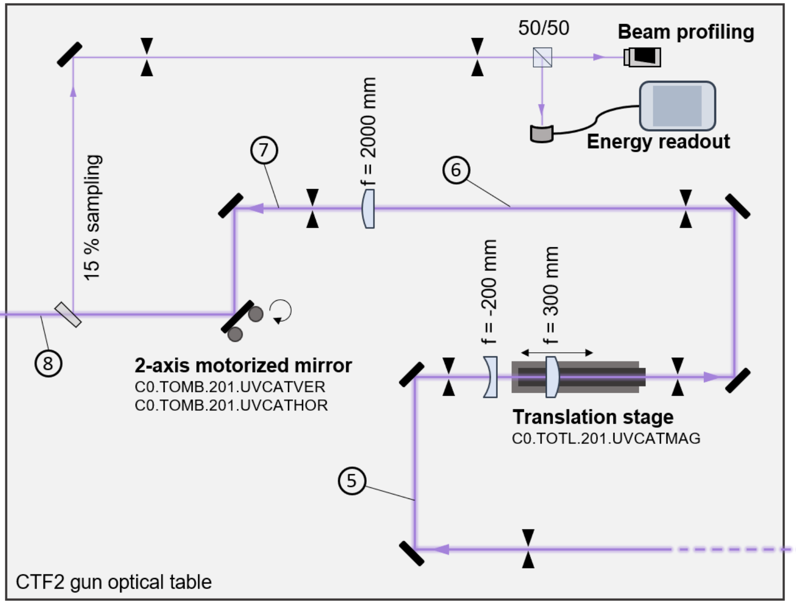
- Cu photoemission improved by a factor of 25x.
- Still, it is 100x QE than our best cesium telluride photocathode.
- Very robust, insensitive to vacuum conditions, durable, and possible of rejuvenation with the photoinjector laser in-situ.
- If performance is further improved, can be a candidate for AWAKE, but emittance studies are to be completed beforehand.

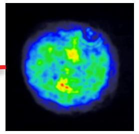
AWAKE run 2c photoinjector

AWAKE run 2c photoinjector laser

CTF2 Gun





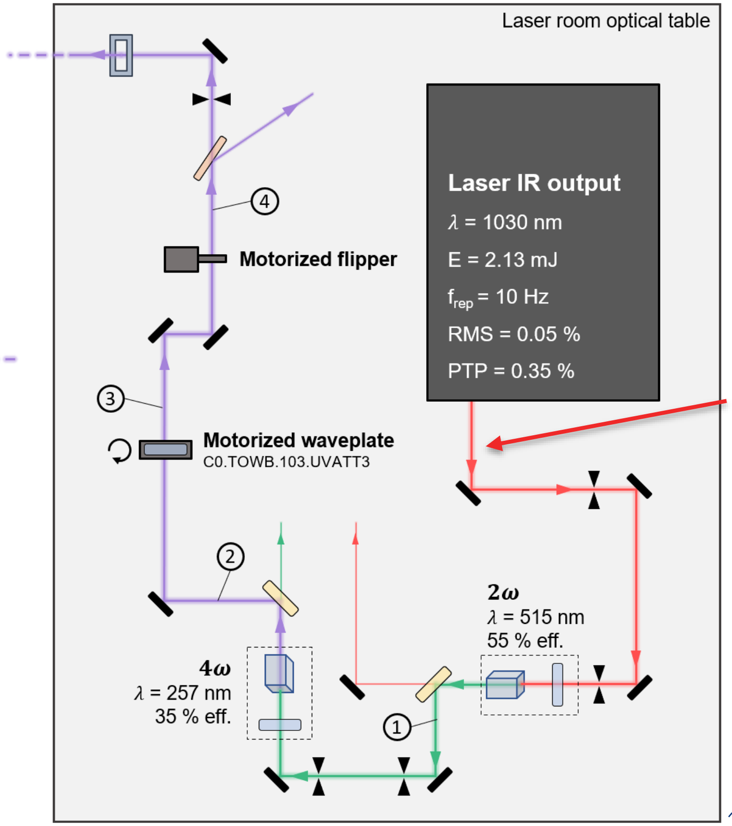


Photocathode

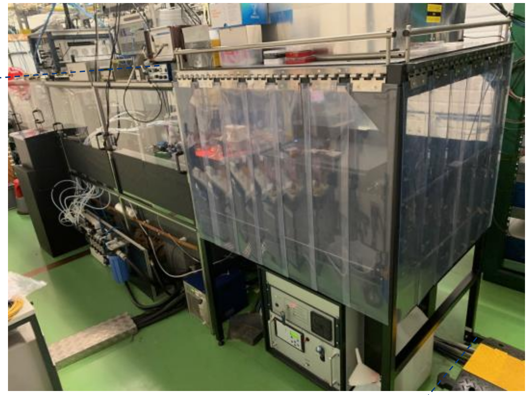
- Dichroic mirror
- β - BBO crystal
- $\lambda/2$ waveplate
- Iris
- Thin Film Polarizer
- Mirror
- Beam splitter
- Plano-concave/ convex lens
- Interlocked shutter

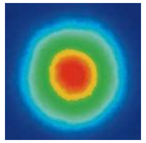
		E (μJ)	RMS (%)	PTP (%)
515 nm	1	1240	0.06	0.48
257 nm	2	480	0.09	0.56
	3	435	0.07	0.53
	4	427	0.07	0.45
	5	369	0.16	0.95
	6	304	0.45	5.39
	7	286	0.61	5.89
	8	245	1.04	11.70

Optical setup of CTF2 Photoinjector laser and energy stability



Dedicated laminar flow tent



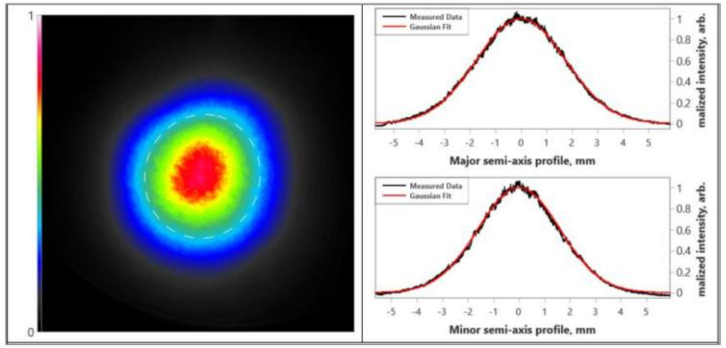


Conversion efficiency:

- IR to green ~60%
- Green to UV ~30%
- Overall ~ **18%**

IR to UV conversion stages

Output at 1030 nm

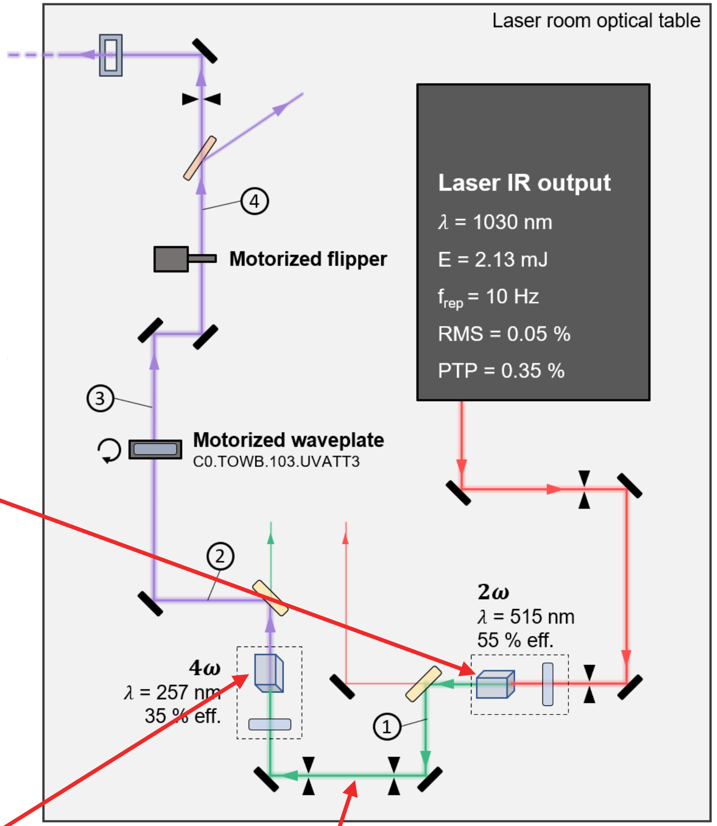


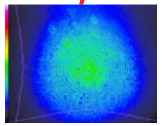
SHG BBO CRYSTALS. Type 1, Thickness = 2.0 mm

Aperture, mm	θ, deg	φ, deg	Coating	Catalogue number	Price, EUR
6x6	23.4	90	AR/AR @ 515+1030 nm	BBO-654H	480
8x8	23.4	90	AR/AR @ 515+1030 nm	BBO-854H	630
10x10	23.4	90	AR/AR @ 515+1030 nm	BBO-1054H	835

BBO FOR 4HG @ 1030 nm

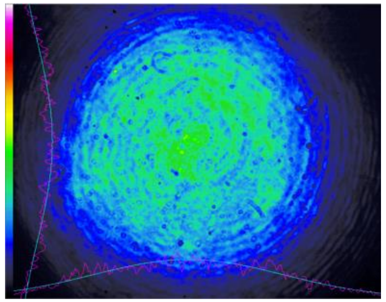
Aperture, mm	Thickness, mm	θ, deg	φ, deg	Coating	Catalogue number	Price, EUR
6x6	0.1	50	90	P/P @ 515/257 nm	BBO-641H	600
6x6	0.15	50	90	P/P @ 515/257 nm	BBO-642H	570
6x6	0.2	50	90	P/P @ 515/257 nm	BBO-643H	550
6x6	0.3	50	90	P/P @ 515/257 nm	BBO-644H	535





Output at 515 nm

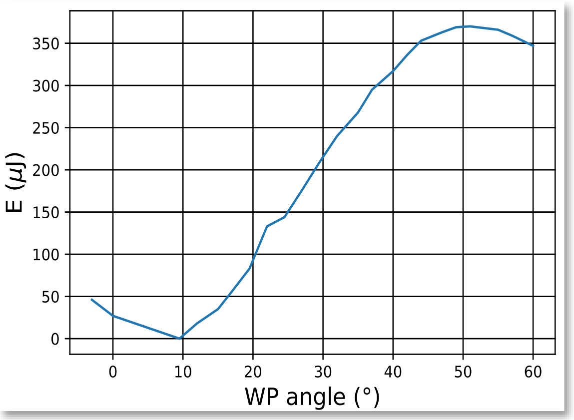
Output at 257.5 nm



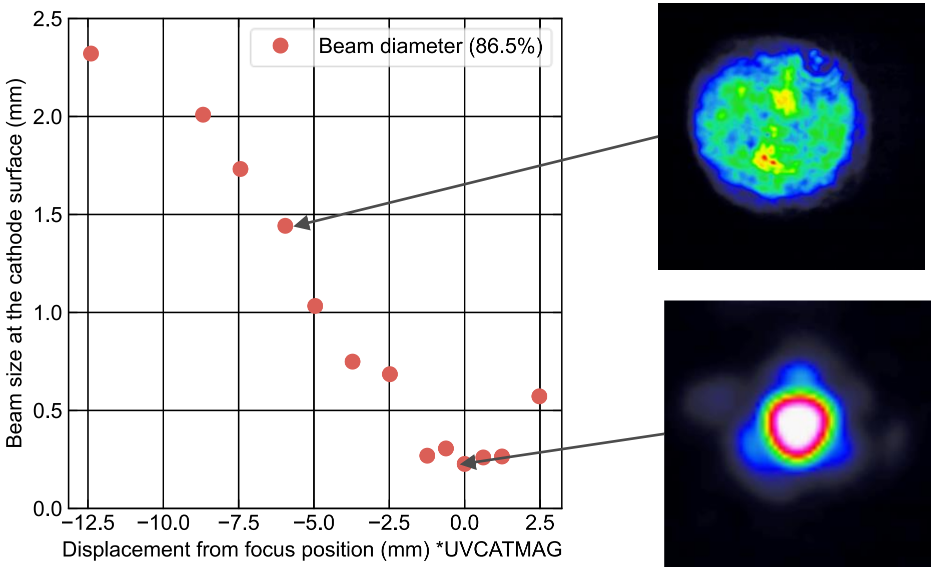
Peak (X,Y)R [µm]	(2351.7, 1554.4) 2819.0
Centroid (X,Y)R [µm]	(4131.2, 3306.5) 5291.5
Peak % Resp. [%]	65.1
Eff. Area [mm²]	16.856
Fluence [J/cm²]	0.803
Eff. Diameter 86.5% [mm]	Invalid
Aper. Diameter 86.5% [mm]	0.066
Knife Edge 84.0% [mm]	7.839, 7.350
Ellipticity	
Major, Minor 86.5% [mm]	7.852, 7.061
Circularity	0.899
Gaussian Fit 86.5%	
Coefficient	0.862, 0.857
Aperture Uniformity	
Min, Mean, Max [digital]	24277.0, 27091.0, 30476.0
Sigma, RMS [digital]	1849.5, 27152.9
Image Uniformity	
Min, Mean, Max [digital]	6.0, 12219.9, 42656.0
Flat Top 14.0%	
Beam Uniformity	0.390
Plateau Uniformity	0.003
Flatness Factor	0.381
Edge Steepness	1.000

Spot on cathode control and performance

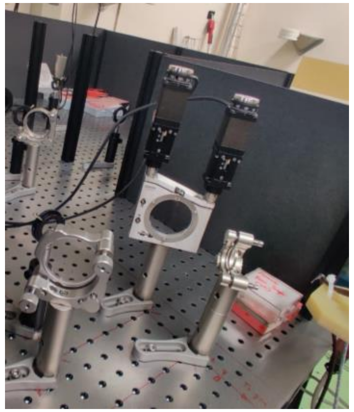
UV pulse energy control



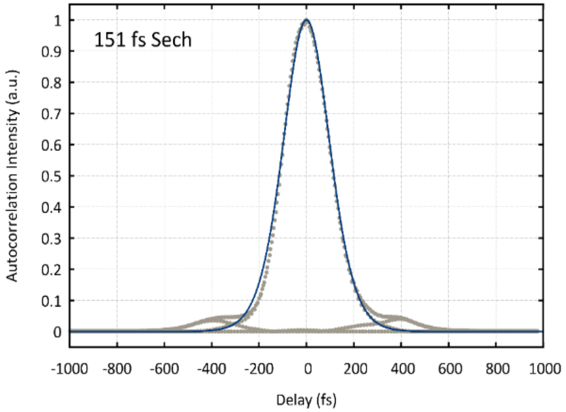
UV spot size control



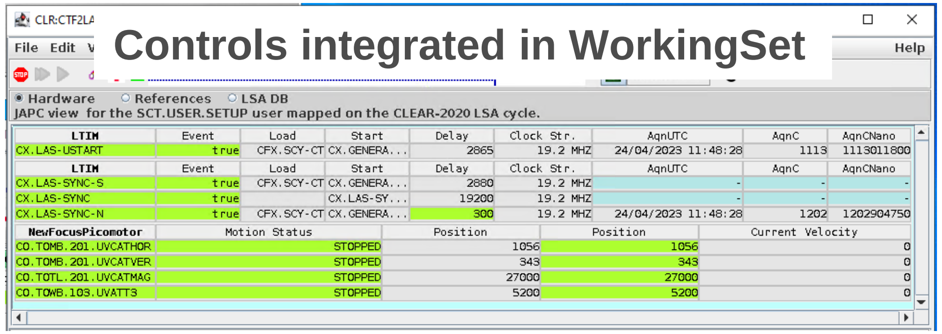
UV position on cathode



UV pulse duration



Controls integrated in WorkingSet

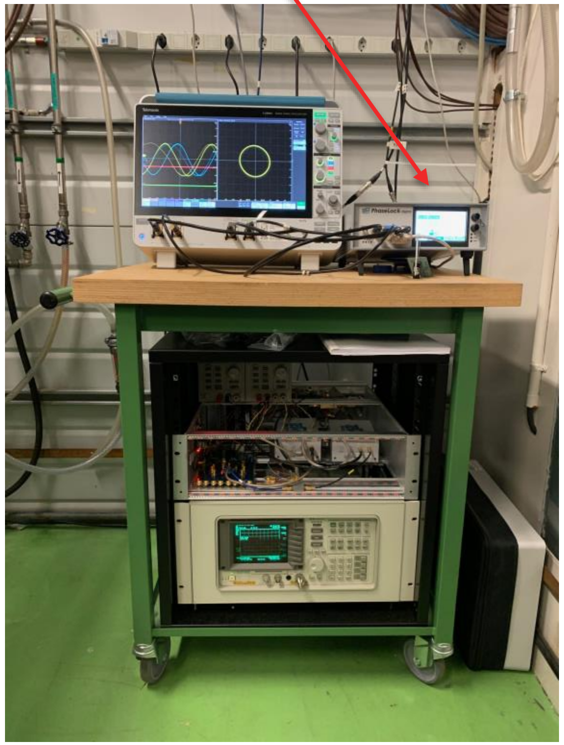


LTIM	Event	Load	Start	Delay	Clock Str.	AqnUTC	AqnC	AqnCNano
CX.LAS-USTART	true	CFX.SCY-CT	CX.GENERA...	2865	19.2 MHZ	24/04/2023 11:48:28	1113	1113011800
LTIM	**Event**	**Load**	**Start**	**Delay**	**Clock Str.**	**AqnUTC**	**AqnC**	**AqnCNano**
CX.LAS-SYNC-S	true	CFX.SCY-CT	CX.GENERA...	2880	19.2 MHZ	-	-	-
CX.LAS-SYNC	true		CX.LAS-SY...	19200	19.2 MHZ	-	-	-
CX.LAS-SYNC-N	true	CFX.SCY-CT	CX.GENERA...	300	19.2 MHZ	24/04/2023 11:48:28	1202	1202904750

NewFocusPicomotor	Motion Status	Position	Position	Current Velocity
CO.TOMB.201.UVCATHOR	STOPPED	1056	1056	0
CO.TOMB.201.UVCATVER	STOPPED	343	343	0
CO.TOTL.201.UVCATMAG	STOPPED	27000	27000	0
CO.TOWB.103.UVATT3	STOPPED	5200	5200	0

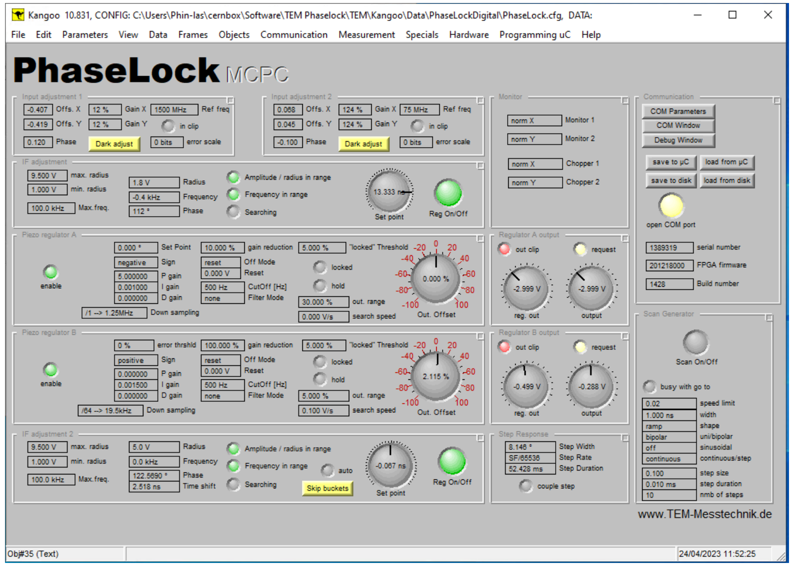
RF synchronization performance

From TEM Messtechnik

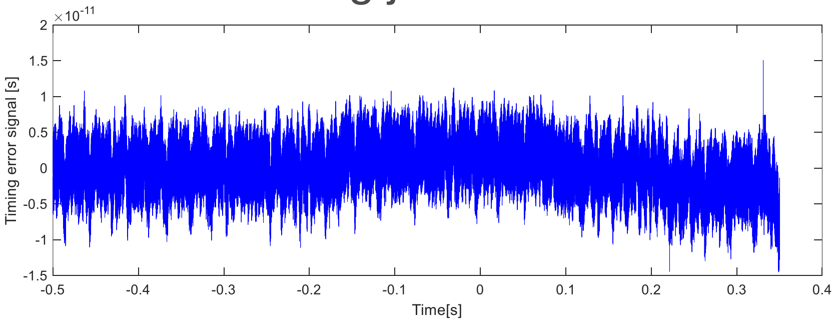


Thanks to Ben Wooley!

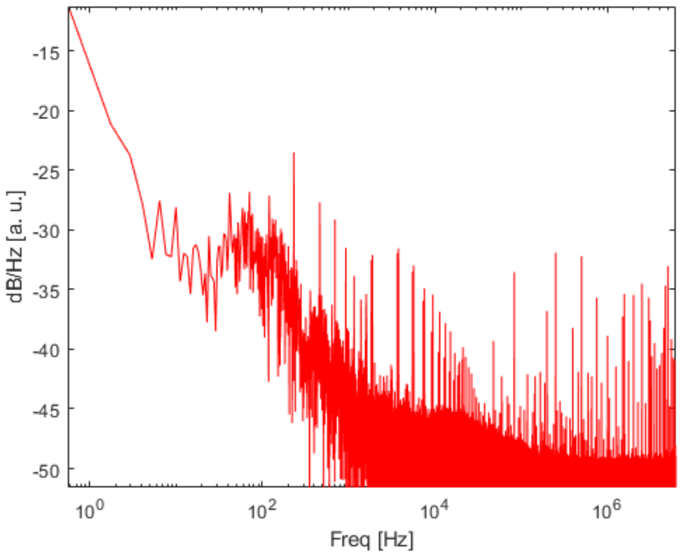
RF locking remote control panel



Timing jitter so far



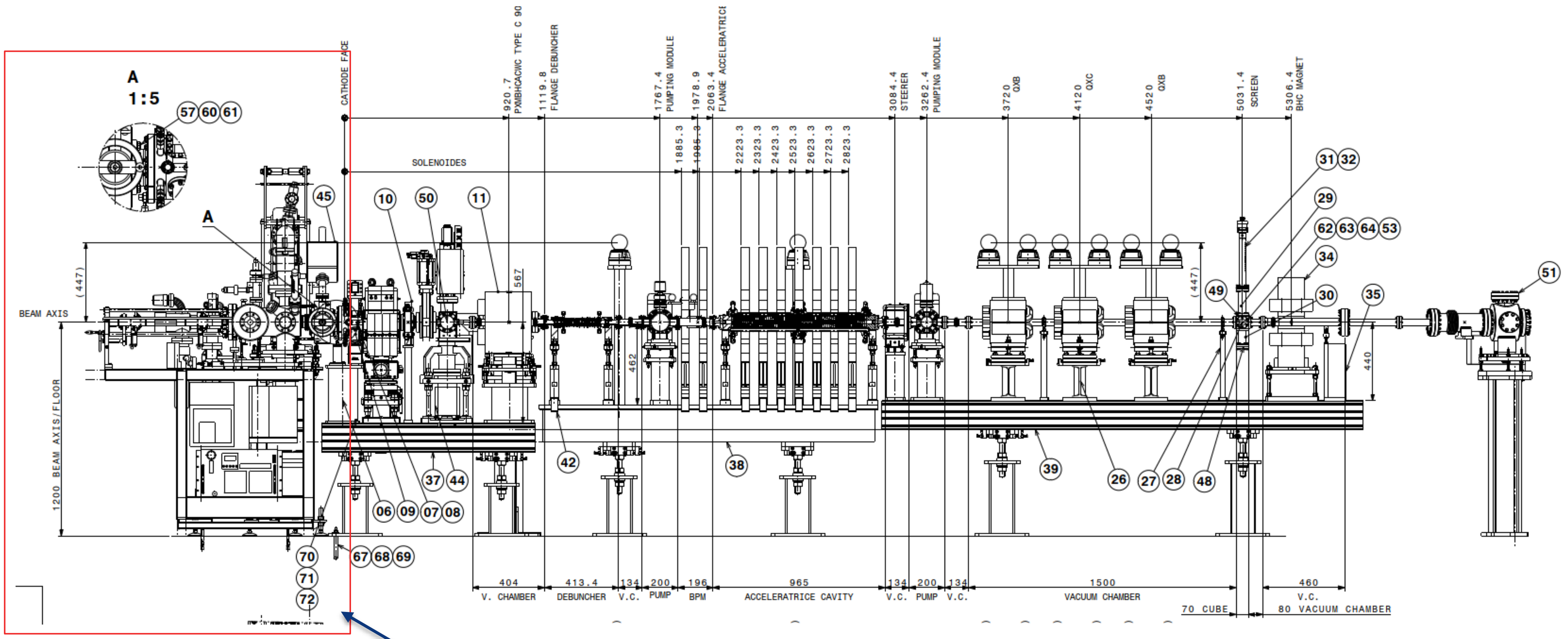
Phase noise spectrum



Integrated 1 Hz – 1 MHz ~ 1.5 ps RMS

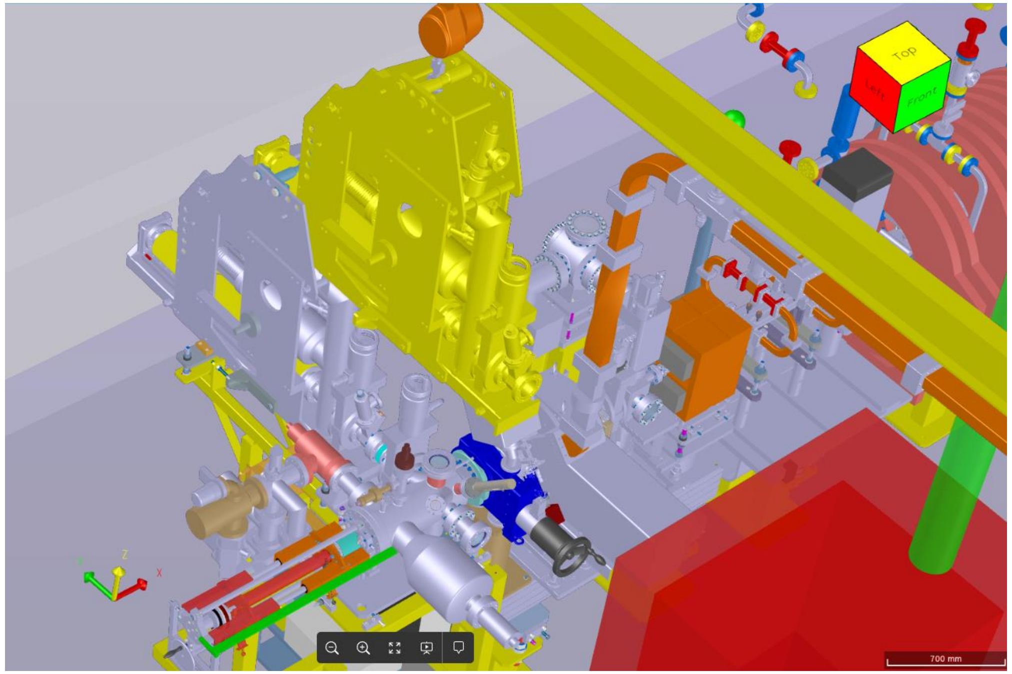
Lots of room for improvement…

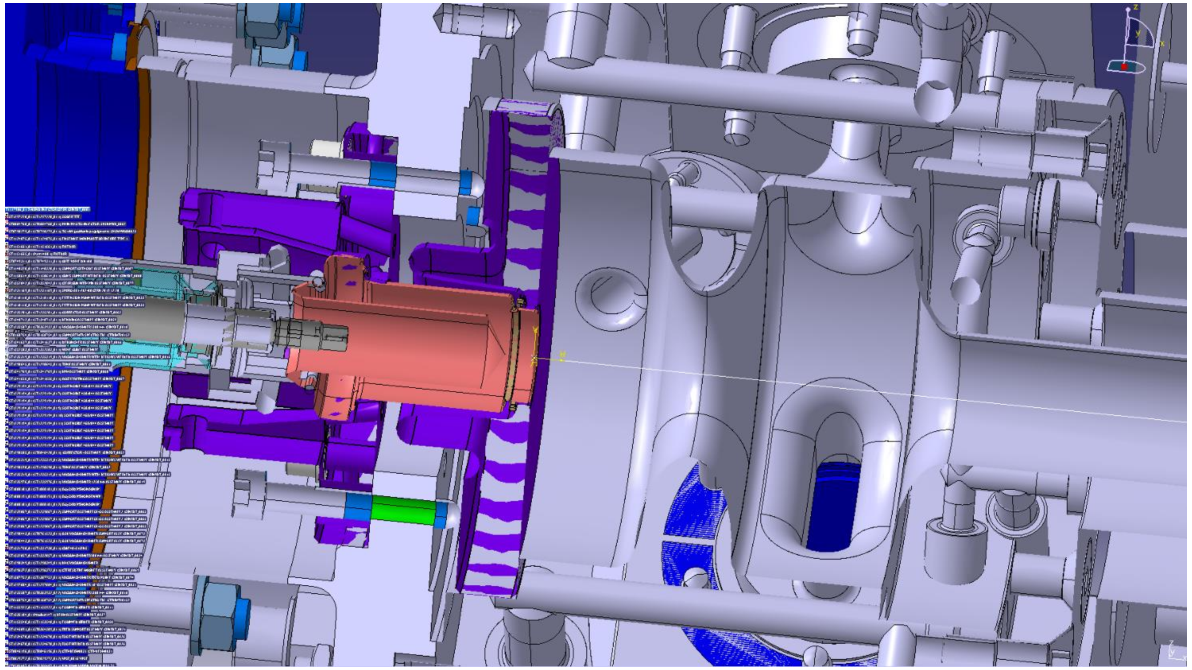
Integration of Cs_2Te photocathodes in CTF2



Replica of existing AWAKE load-lock system

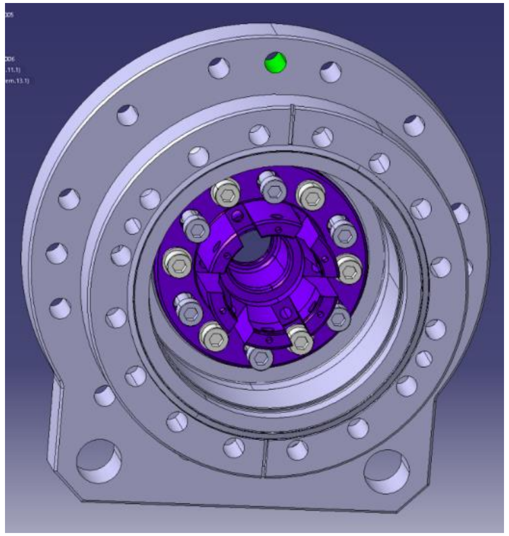
Integration of Cs_2Te photocathodes in CTF2

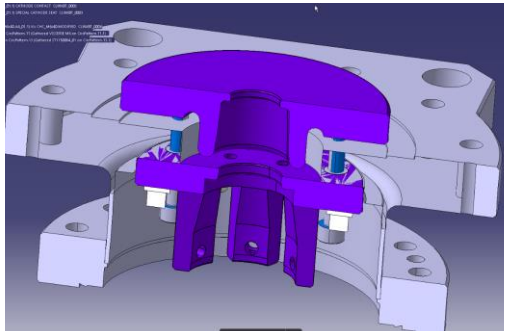


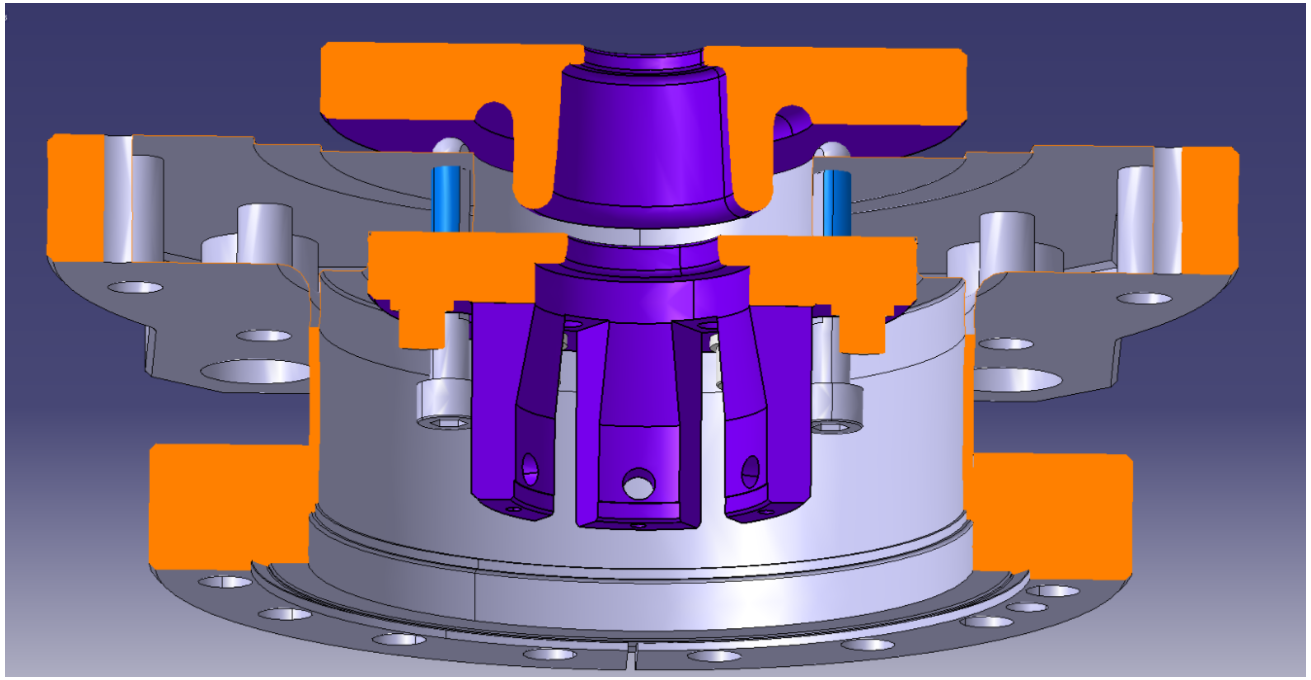


- Initiated study of crane installation and transport carrier handling as well as adapters for load-lock cathodes in the new CTF2 gun. To be done also in TT41.
- The cathodes are to be compatible between both RF guns. A single carrier can transport 4 photocathodes.

Integration of Cs_2Te photocathodes in CTF2







- The main difference between AWAKE, CLEAR and CTF2 load-lock systems is this adapter part.

Conclusions

- Photocathodes:
  - A simple approach to rejuvenate cesium telluride photocathodes is studied, both with co-deposition and sequential deposition schemes.
  - We found that the optimal stoichiometry ratio of 2.3 can lead up to QE > 25%.
  - We study the alternative of employing laser produced plasmonic photocathodes, yielding promising results but more work is necessary.
- AWAKE run2c photoinjector:
  - The photoinjector laser for AWAKE run 2c is ready and operative, alongside with controls and diagnostics.
  - The integration of cesium telluride cathodes at CTF2 is under study, with a view on simplifying the future AWAKE run2c layout and cost.

Thank you for your attention!