WG1 – Injectors
Summary

A. Bartnik (Cornell)

T. Kamps (HZB)

Main Themes

From our charge:
Explore recent work in injectors, especially...

- RF, SRF, DC guns
  - Performance, limitations, operational experience
- Cathode development
  - Black magic or science?
  - Roughness
  - Operational experience / frustrations
- Laser development
  - Power (more or less) solved
  - Need: Stability, synchronization, reliability
  - Shaping

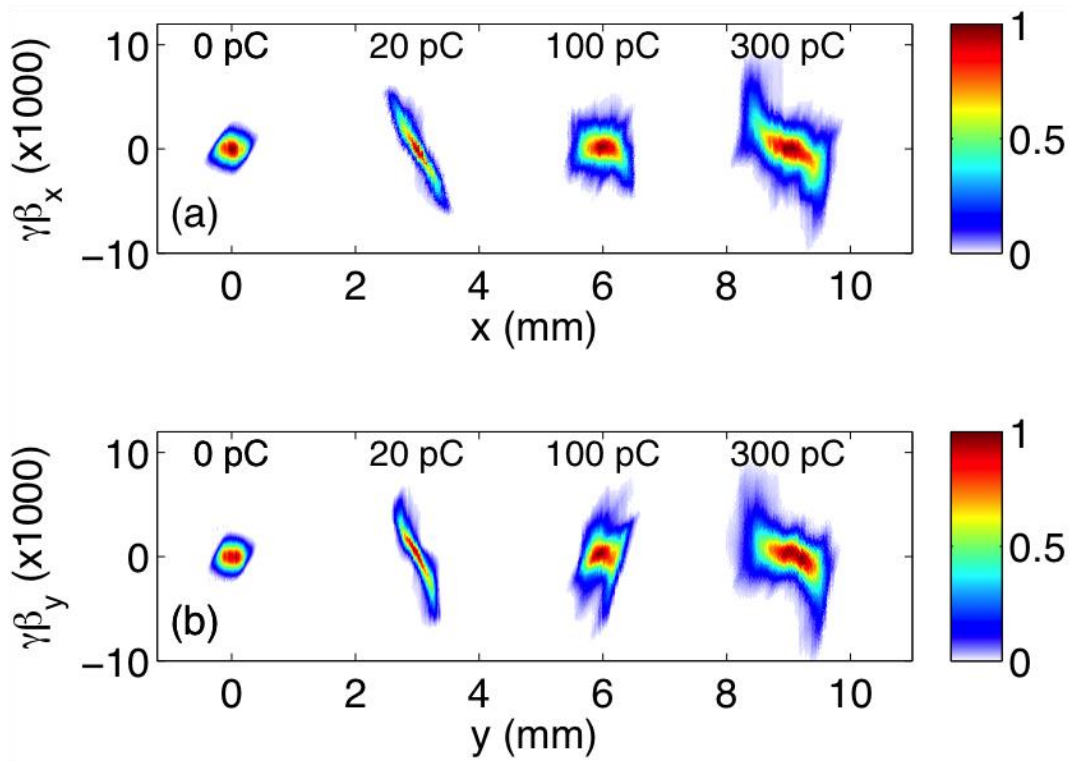
Performance of DC and SRF guns

Performance of DC gun

- DC gun concept mature and robust → works really well
- Cornell work on LCLS-II parameter shows versatility of DC gun system.
- JAEA and KEK are both working on the high voltage and high gradient frontiers.
- Interesting idea with Funneling to maximise cathode standing time

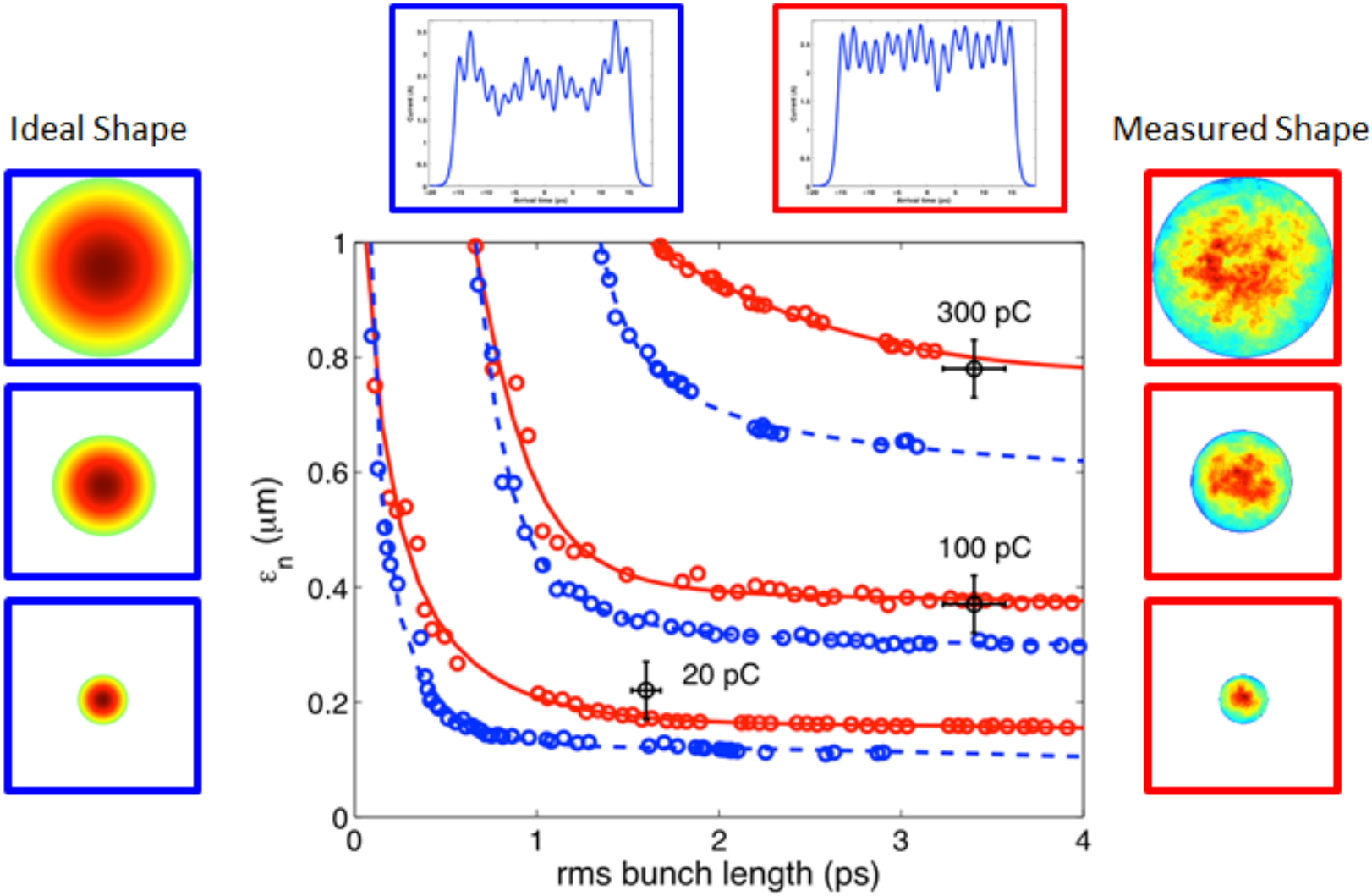
A. Bartnik (Cornell) - DC Gun / Injector
Met specification for LCLS-II FEL Injector

- No emittance asymmetry
- Met LCLS-II spec at all charges
- Same SRF settings for all charges



Q (pC)	I_{peak} Target (A)	I_{peak} (A)	ε_n Target (95%, μm)	ε_n (95%, μm)	$\varepsilon_{n,th}/\varepsilon_n$
20	5	5	0.25	**H: 0.18, V: 0.19**	**60%**
100	10	11.5	0.40	**H: 0.32, V: 0.30**	**80%**
300	30	32	0.60	**H: 0.62, V: 0.60**	**70%**

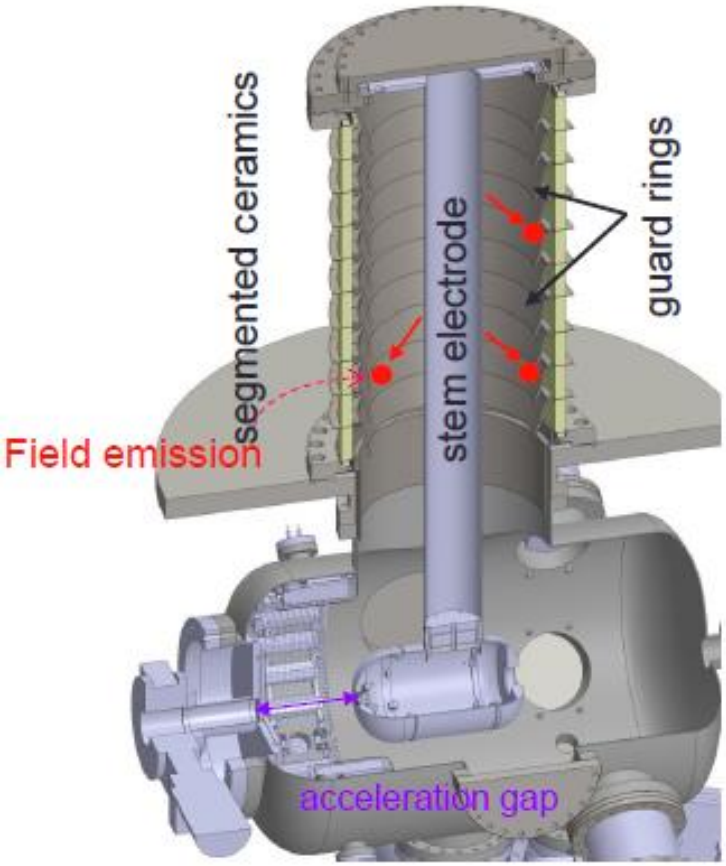
Cornell DC Gun / Injector
Good agreement when using real laser profile

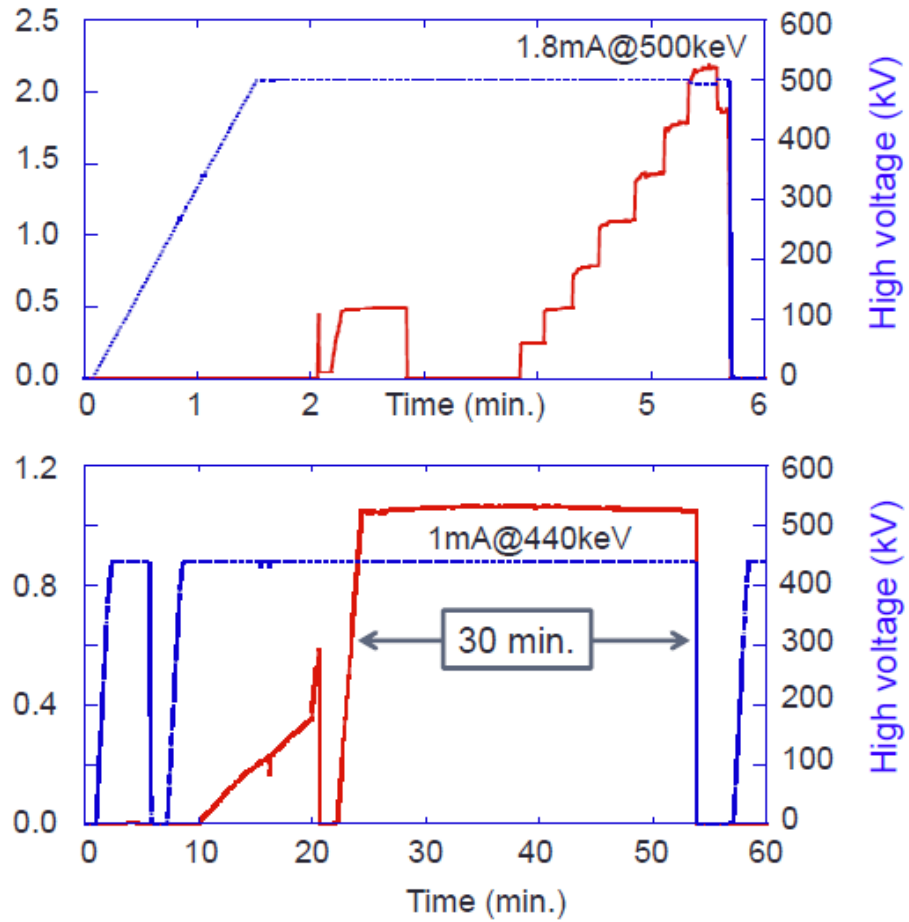


N. Nishimori (JAEA) – DC gun for cERL
Pushing the limit of DC voltage

500keV beam generation

N. Nishimori et al., APL 102, 234103 (2013)



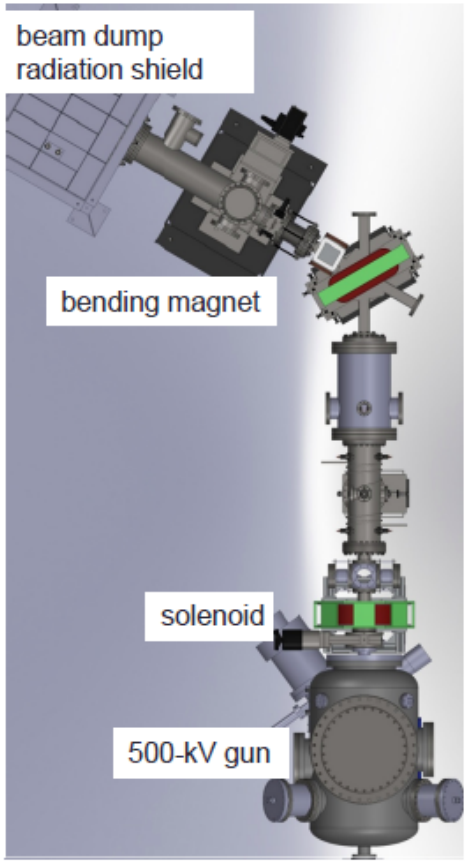


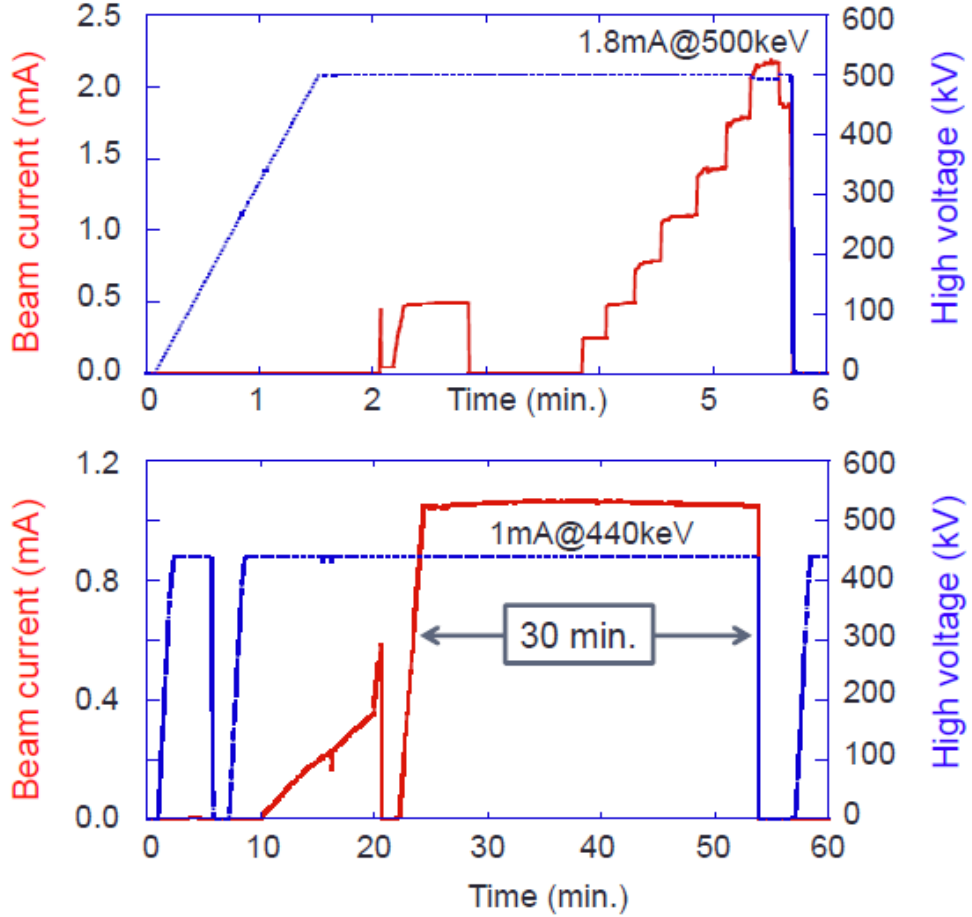
N. Nishimori (JAEA) – DC gun for cERL
Pushing the limit of DC voltage

June 9, 2015 N. Nishimori ERL15 at Stony Brook University 6

500keV beam generation

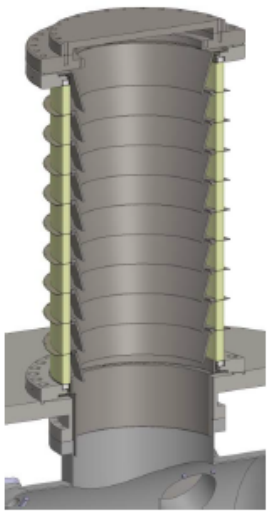
N. Nishimori et al., APL 102, 234103 (2013)

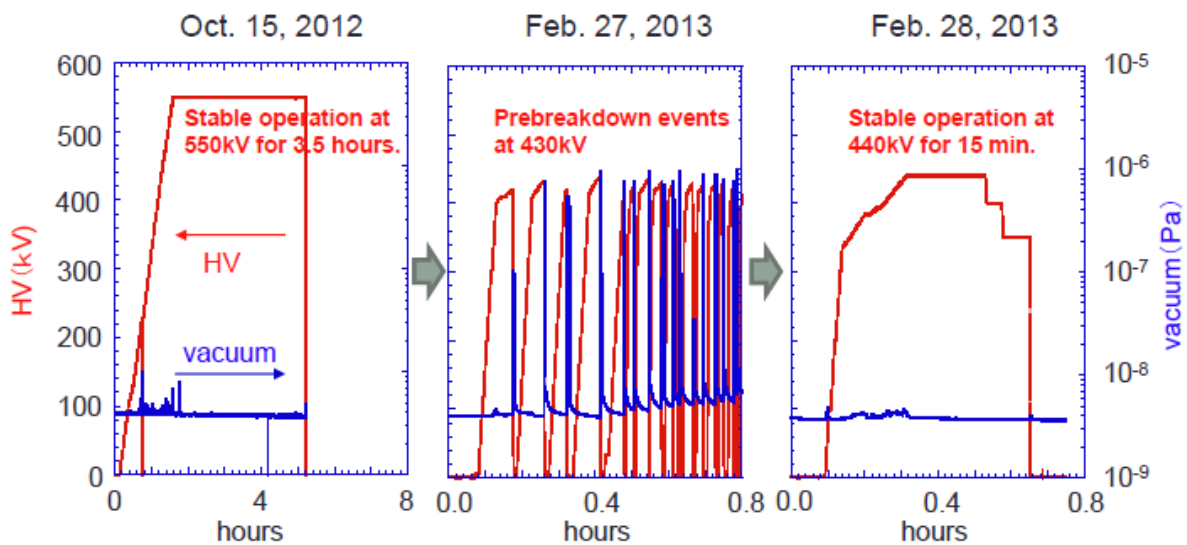




The gun is now running reliable for two years for cERL at 390 kV and generated electrons for LCS exp

Why 390kV operation ? (Exp. with insulator only)





at JAEA
No problem

at KEK
A problem happened.

at KEK
Top and bottom ceramics are short-circuited.
8 segments operation

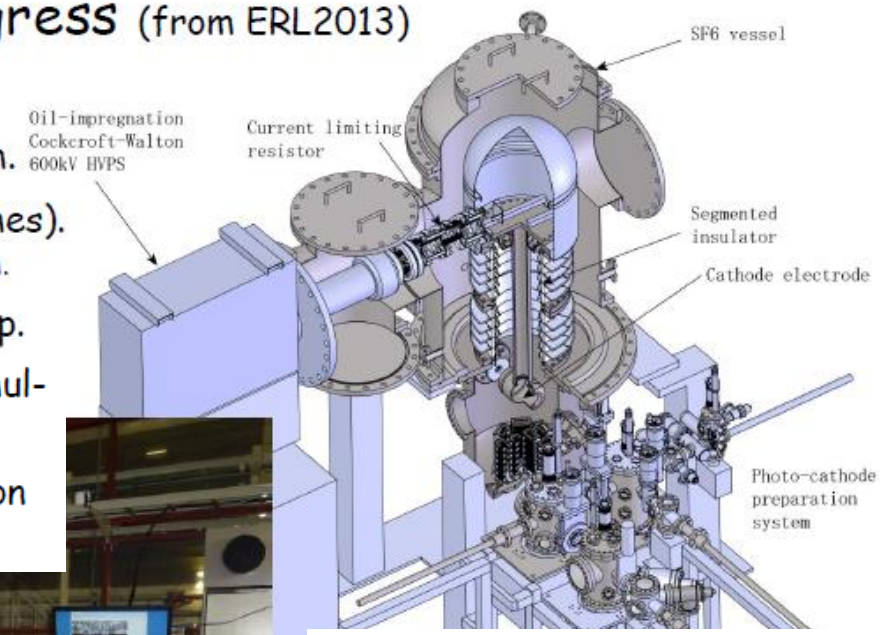
Future work

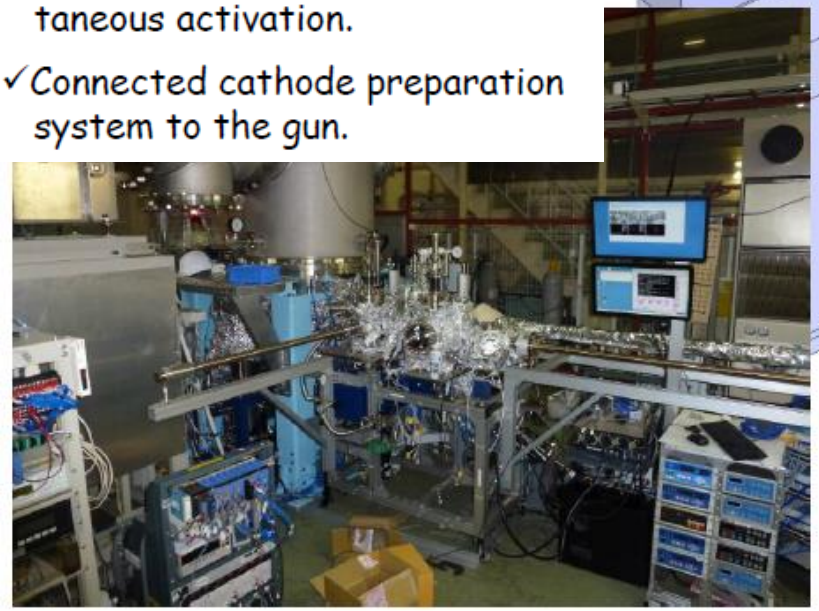
- Install additional ceramic insulator for 500 kV operation at the cERL
- Develop a photocathode appropriate for high current operation

M. Yamamoto (KEK) – Small(est) 70 mm gap DC gun for 6.9 MV/m gradient

Last 2 years progress (from ERL2013)

- ✓Baking with main pump system.
- ✓HV conditioning in XHV (4 times). 2014/May, /Jul, /Aug, 2015/Jan.
- ✓Beam transport & Dump set up.
- ✓Demonstrated 3 cathodes simultaneous activation.
- ✓Connected cathode preparation system to the gun.



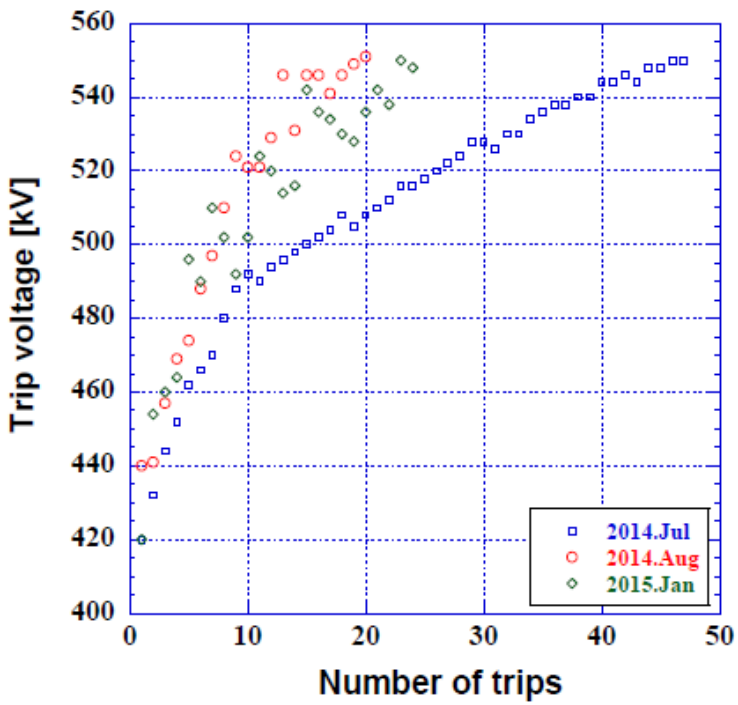


Now & Feature plan

- 400 keV beam study is just started.
- Preparations for mA class high current cw-beam operation are underway.
  - Radiation shield
  - Water cooled beam dump
  - Fast interlock system

Experimental observation of a trip voltage memory phenomenon

HV conditioning repeatability (2014/Jul ~ 2015/Jan)



2014/Jul. HV Conditioning
(reached 550 kV after 48 trips)

~3 weeks shutdown
~1 week for XHV establish

2014/Aug. HV Conditioning
(reached 550 kV after 20 trips)

~3.5 months shutdown
~1 week for XHV establish

2015/Jan. HV Conditioning
(reached 550 kV after 23 trips)

Almost trip events were hardly detected emission current (≤1 nA) just before trip happened. Almost trip voltage increased continuously as if the trip voltage was memorized. How we can explain this ?

Possible model to explain memory effect, stimulated desorption

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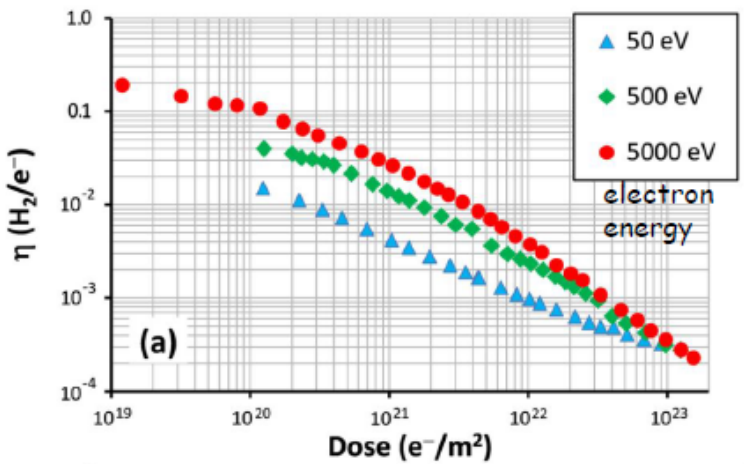
Model of trip voltage memory phenomenon

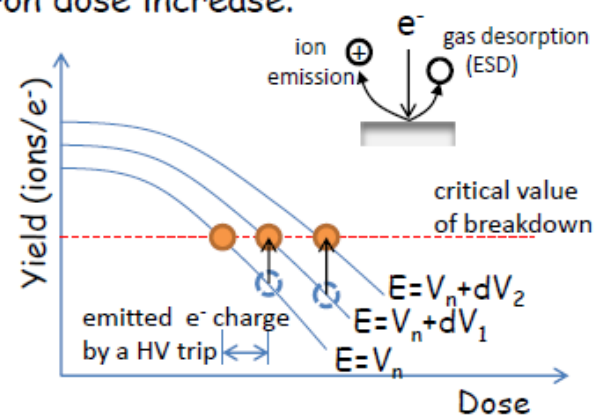
Electron induced ion (H^+,H_2^+,etc.) emission is probably related electron stimulated desorption (ESD) phenomenon.
ESD yield is decrease drastically by electron dose increase.

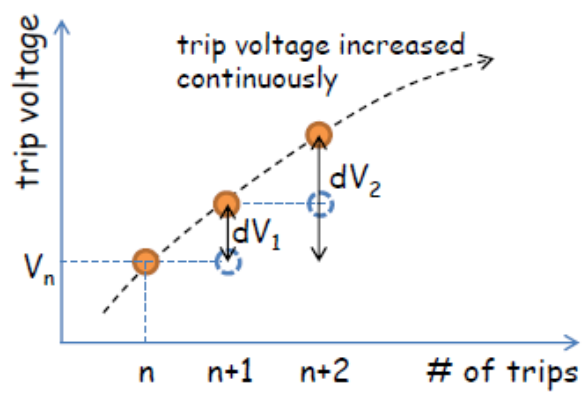
Hydrogen desorption from SUS316L



Oleg B.Malyshev et al., J.Vac.Sci.Technol.A 31 (2013) 031601

✓ ESD property of anode surface may give a important hint to know a limitation of breakdown voltage.

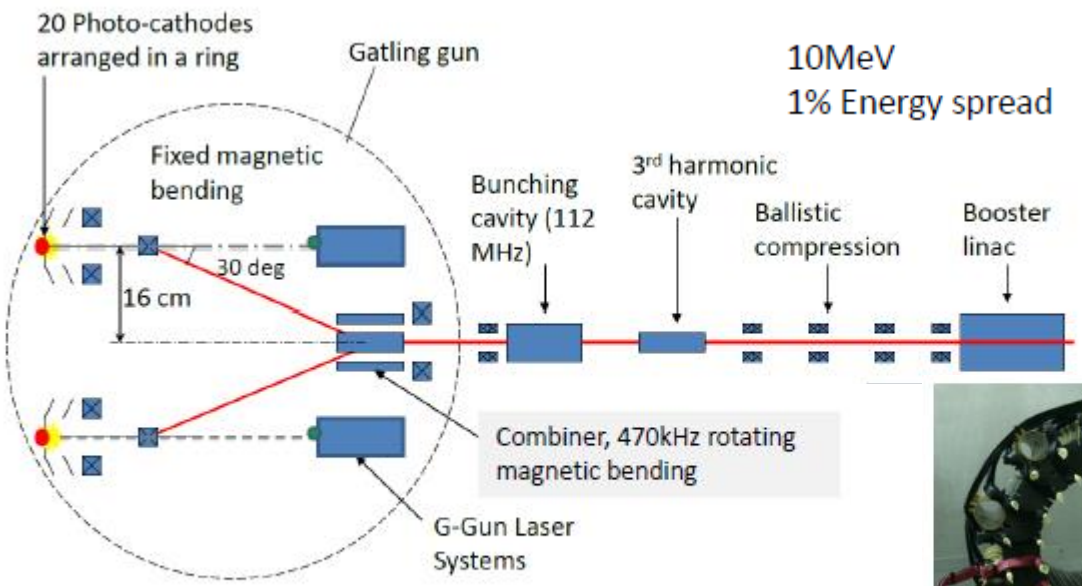


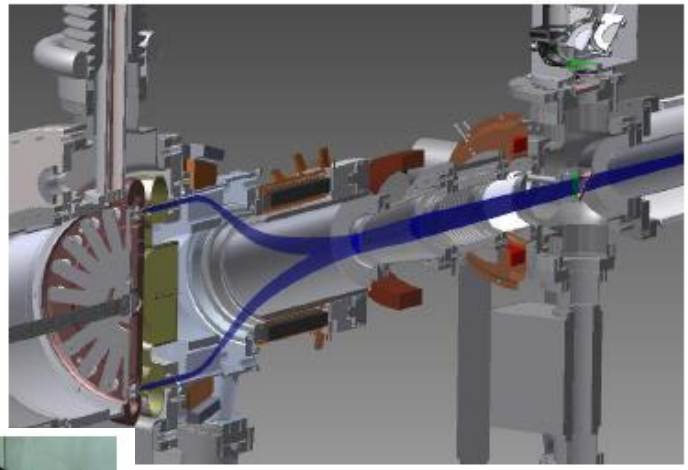


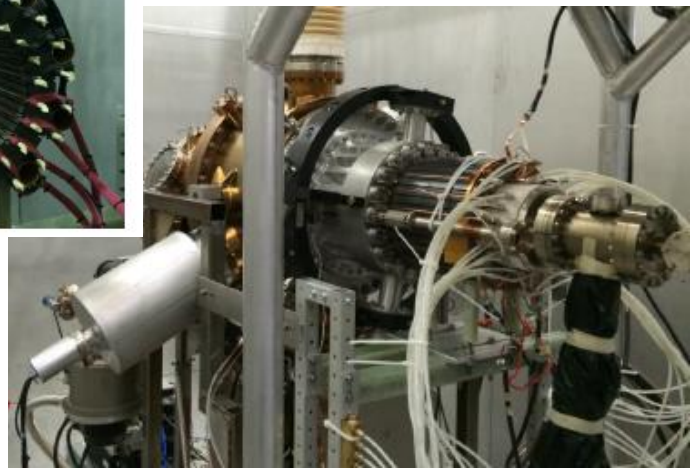
Funneling

E. Wang (BNL) – Demo for a Funneling DC gun at 50 mA to maximise cathode standing time

Single cathode:470 KHz*5.3nC=2.5mA
After funneling:9.4 MHz*5.3nC=50mA







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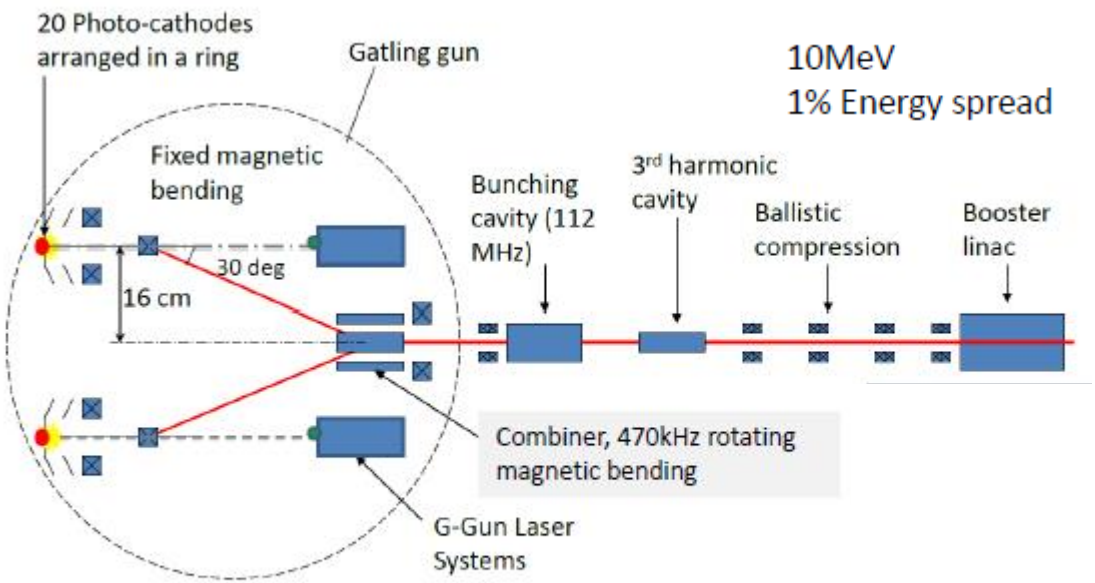
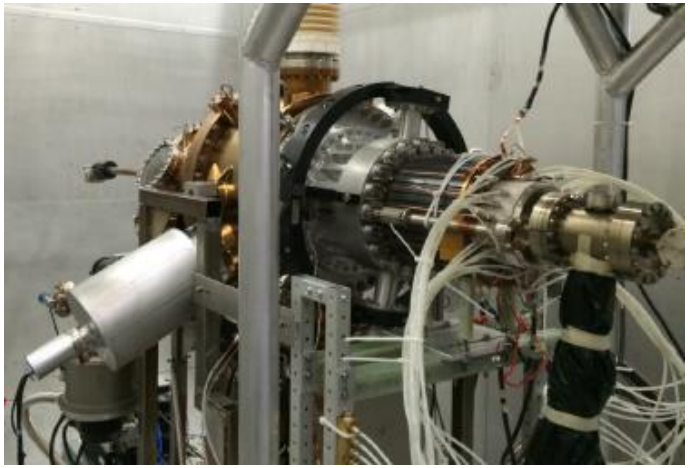




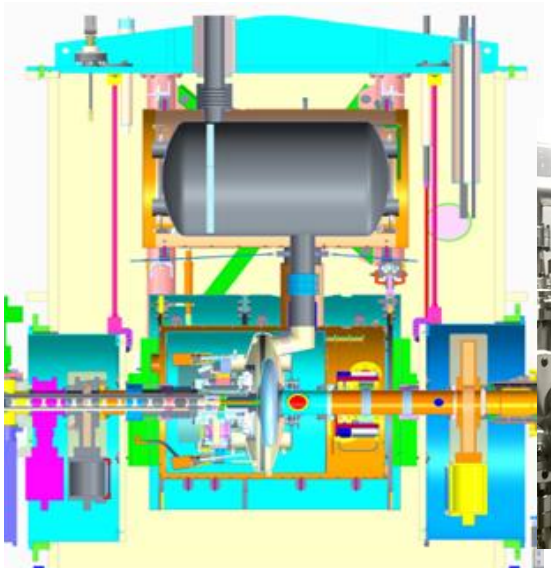
- Gun fabricated, assembled and tested by industry.
- Two low current beams were combined.
- At a few hundreds nano-amper current level, the test indicates #1 beam will not affect #2cathode lifetime. No cathode cross talk observed.
- Current status: Initial beam test done, the system has been shipped to our laboratory for high-current tests.

SRF guns

SRF guns

- while DC guns show robust performance with ERL parameters, SRF gun concept still lacking demo at high current and/or low emittance
- Progress at BNL on solving multipacting issues → generation of first beam with 704 MHz gun
- Progress at HZDR on reaching high gradients in SRF guns → valid stable source for ELBE user facility driving multiple experiments
- What do we need to do to get reproducible SRF performance at high gradient → low emittance?

W. Xu (BNL) - Commissioning of 704 MHz gun and MP-free cathode stalk design



Building up:

Mid. 2010: vertical cavity test in Jlab, reached 2.9 MV w/o cathode stalk.

2.9 MV/0.082 m = 35 MV/m

Commissioning:

Nov. 2012 to Mar. 2013: Commissioned SRF gun cavity w/o cathode stalk inserted.

→Demonstrated the SRF gun to be able to operate at 2.0 MV CW.

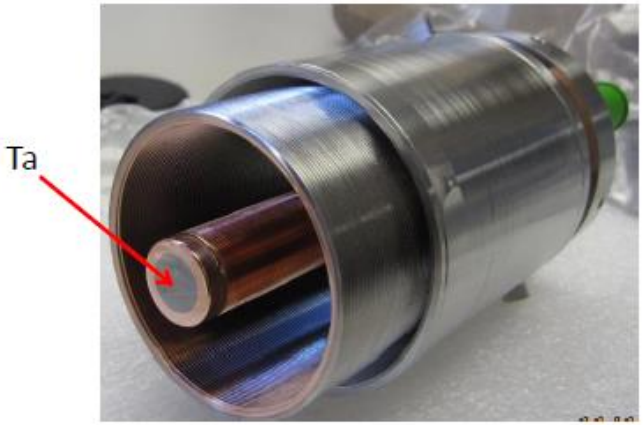
→The amplitude stability is 2.3e-4 rms and the phase stability is 0.035 deg rms.

Aug. to Oct. 2013: Commissioned SRF gun cavity with copper cathode stalk inserted.

→Found operational parameters: 1.85 MV, 180 ms, 1 Hz - limited by multipacting in the stalk.

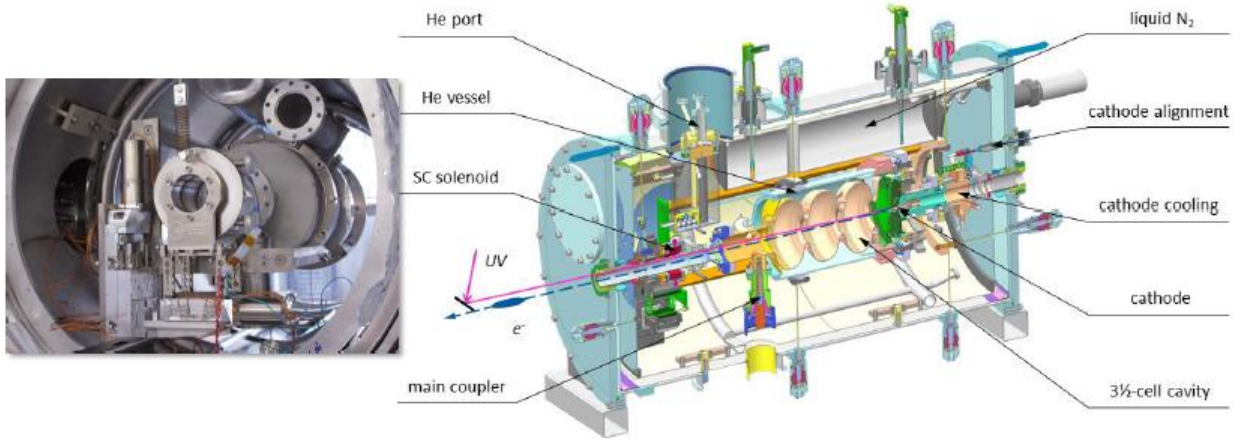
→Design a new multipacting-free cathode stalk with Ta tip for high QE => high current electron beam.

Design, construction of a new, MP-free cathode stalk with Ta cathode tip → beam ops



- Cathode: K_2CsSb photocathode, 3.8% of QE on the fresh cathode stalk and stay the same up before inserting into the gun.
- RF: 0.85 MV, pulse mode due to multipacting. The reason for multipacting is because the surface was contaminated during cathode growth. With a better mask, the issue can be resolved.
- The highest bunch charge reached 0.55 nC per bunch (0.85 MeV) in June 2, 2015.
- There is no sign of cavity degradation due to operating with photo-cathode.

J. Teichert (HZDR) – Results from beam measurements with SRF gun II at ELBE

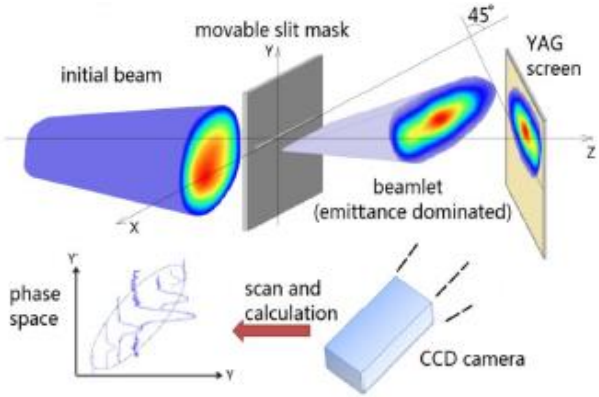


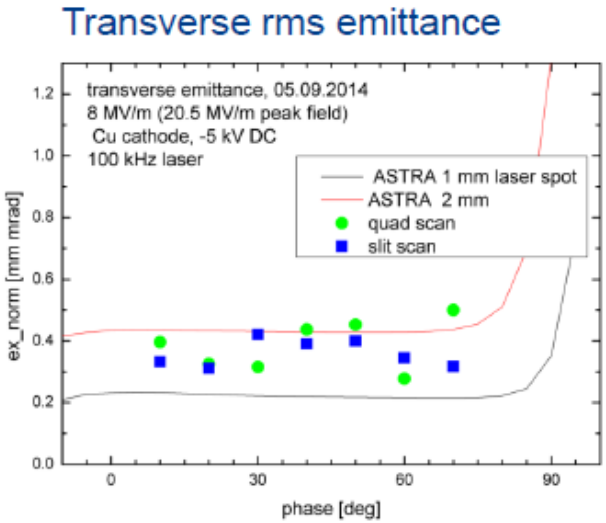
1. SRF Gun II with 7 MV/m acceleration gradient will improve user operation at ELBE
   - Cu cathode measurements show very reproducible and promising results
   - simulation predicts operation up to 500 pC despite the lower gradient

2. The photo cathodes are the bottle neck at present
   high qualitiy & clean photocathodes
   - test of Mg full metal cathodes
   - than Cs2Te photo cathodes

3. A next SRF Gun with high gradient
   - Refurbishment of old SRF gun cavity at DESY within MaT/ARD
   - Cavity design for improved SRF gun cavity and fabrication of new cavities (2017 …)

Results from thermal emittance and longitudinal phase space measurements





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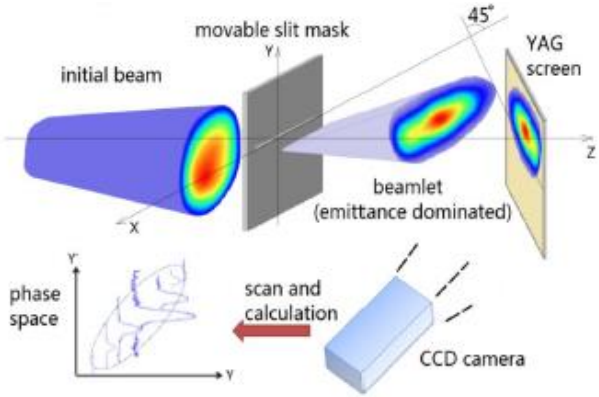
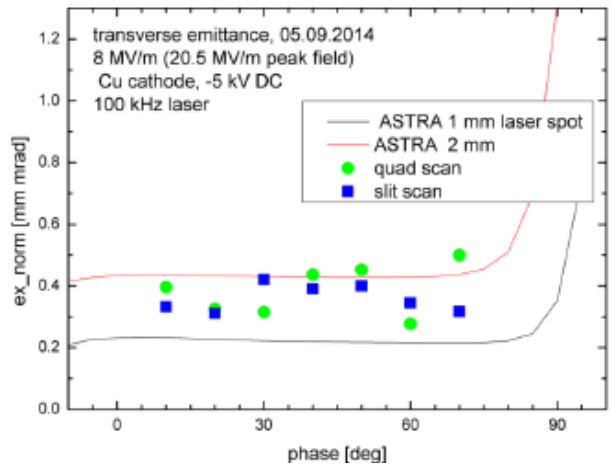
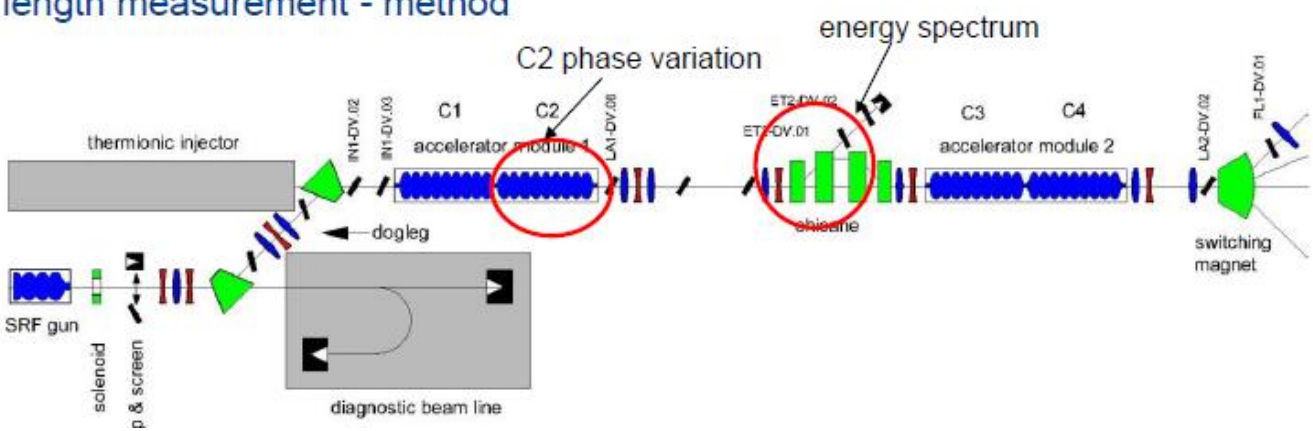


Transverse rms emittance



Bunch length measurement - method



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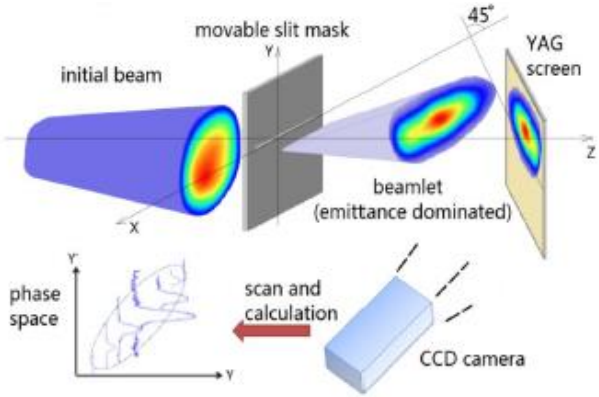

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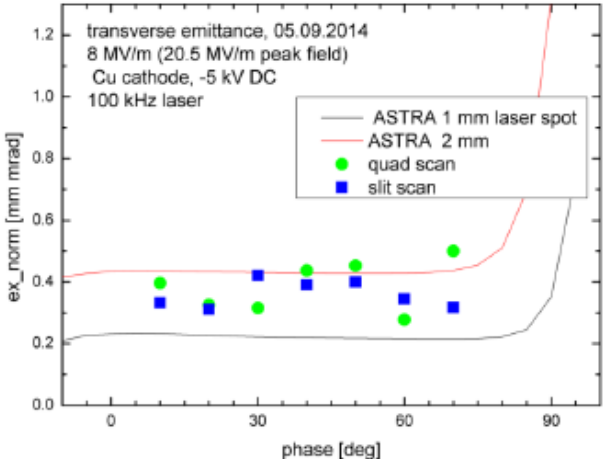
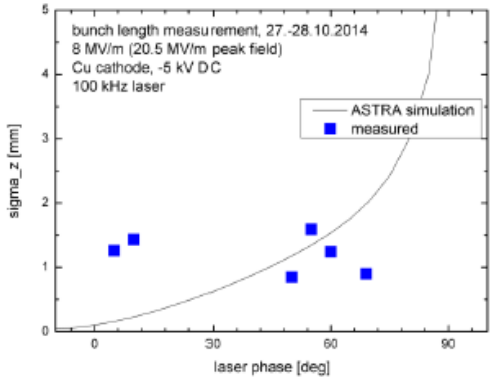
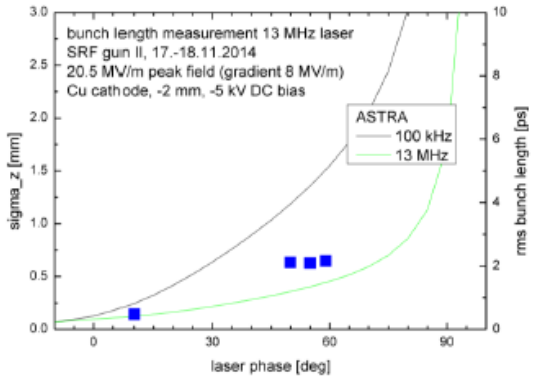


Bunch length measurement

10 ps FWHM laser



3 ps FWHM laser (13 MHz)

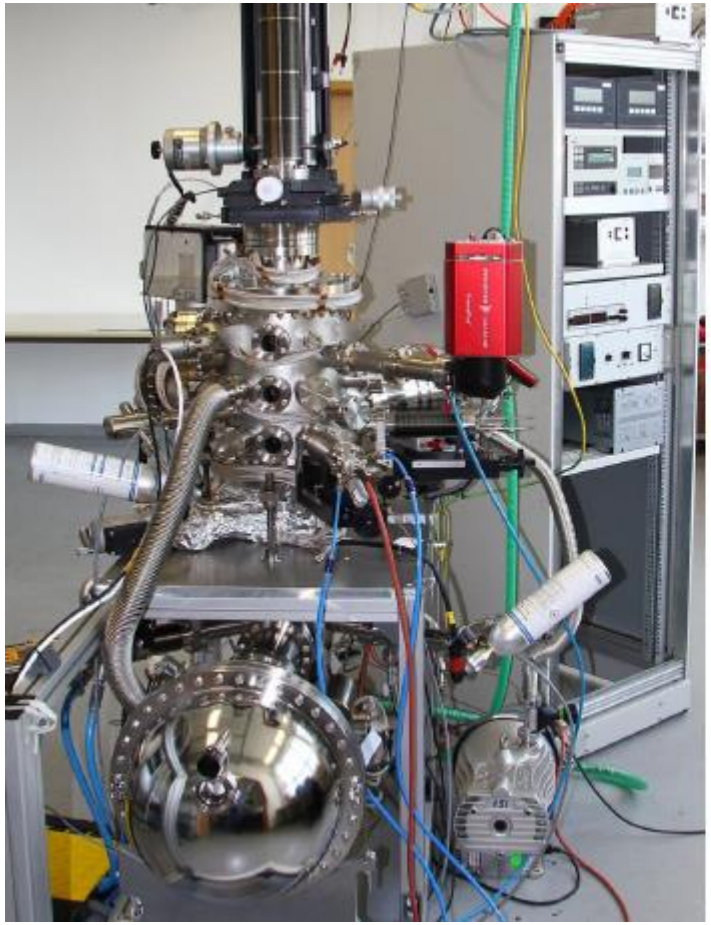


Subsystems - Photocathodes

Photocathodes

- Main goals related to photocathodes:
  1. Correlate growth and performance
  2. Prepare reproducible performance
  3. Mitigate degrading effects
- All this by employing state-of-the-art material science techniques in-situ and in-operando at synchrotron radiation sources
- Popular
  - substrates are Mo, Ta
  - cathode materials are Cs2Te, CsK2sb, NaKSb (S20) during ops and Cu and Mg for commissioning (→ need multiple drive laser wavelengths)
- Industry interested in producing off-the-shelf cathodes, sealed CsK2Sb cathode from Photonis ($$$$ USD) and triode like gated therminonic emitter from Far-Tech.

M. Schmeißer (HZB) – Photocathode R&D for 100 mA, low emittance SRF gun for bERLinPro



Preparation chamber:
- effusion cell for Sb, dispenser sources for K and Cs
- co-deposition of K and Cs or K and Sb

Quantum efficiency:
- Spectral response
- Spatial distribution

Intrinsic Emittance:
- Resolved in a drift-space spectrometer - Momentatron

See IPAC14 mopri019

Surface Analysis chamber:
- X-ray photoelectron spectroscopy (XPS)
- Low Energy Ion Scattering (LEIS)

Now commissioned and ready for experiments
- First Sample in April '15
- XPS system calibrated
- Both chambers in 10^{-10} mbar UHV

Preparation of first CsKSb photocathode with in-situ XPS to reveal chemical composition of film

PHOTOCATHODES – FIRST SAMPLE

HZB Helmholtz Zentrum Berlin bERLinPro

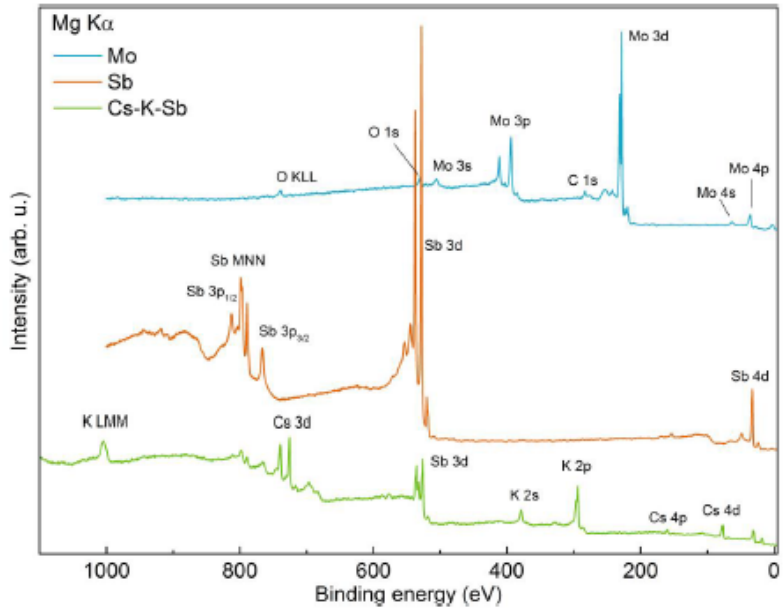
Sequential growth recipe

- Mo substrate, annealed at 450°C for 1h, sputter cleaned with Ar^+, 3kV for 30min
- Substrate is relatively clean, O and C impurities probably from the material (99.9%)

- Sb deposition at $1*10^{-7}$ vapour pressure, 0.5 A/s
- Very clean Sb film

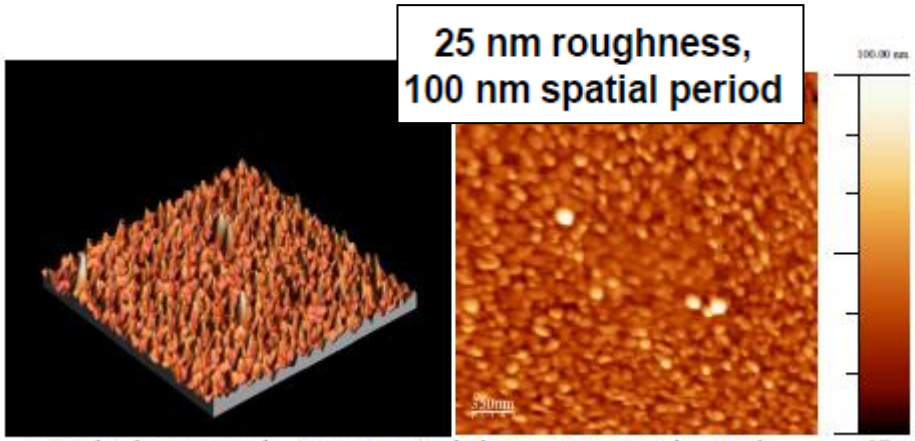
- K and Cs deposition from SAES dispensers
- Alkalis are hardly resolved in the mass spectrometer
- During K deposition, partial pressures of H_20 $2*10^{-9}$ mbar, O_2 and CO < 10^{-10}
- Cs dispenser operated above its rated heating current to obtain a rate reading on quartz balance
- Cr and O impurities in the final Cs-K-Sb spectrum

- QE < 1%

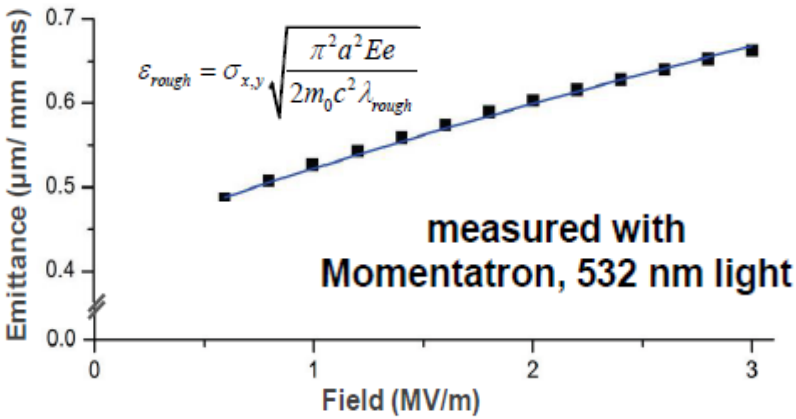


Martin Schmeißer ERL Workshop 06-09-2015 6

J. Smedley (BNL) - Solving the surface roughness problem of alkali antimonide photocathodes



S. Schubert et al., APL Materials 1, 032119 (2013)

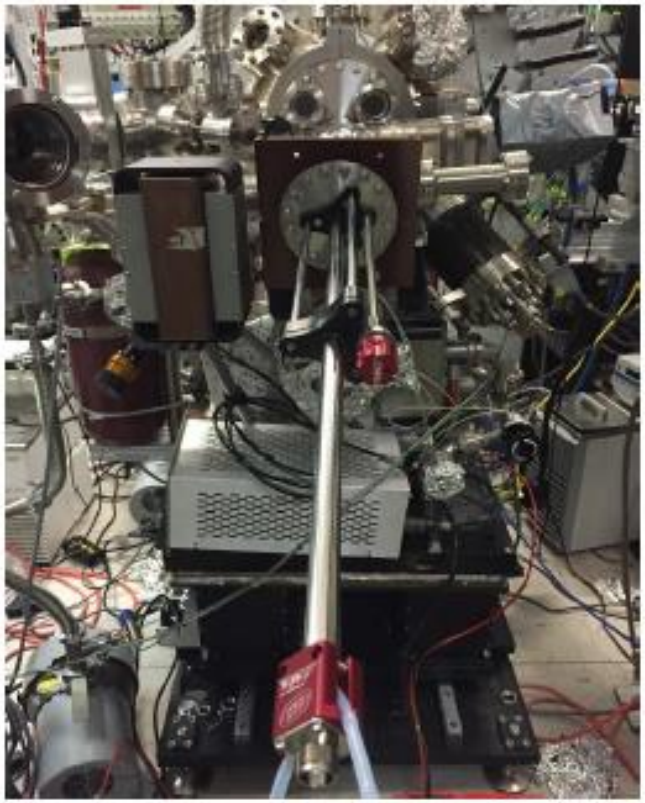


T. Vecchione, et al, Proc. of IPAC12, 655 (2012)

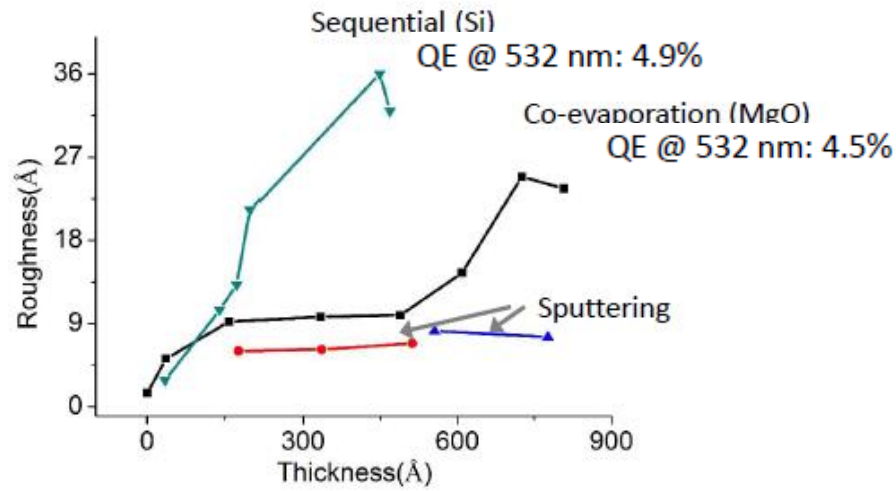
- XRD (and XRF) provide information on formation chemistry of these materials during growth, XRR (and GISAXS) give roughness
- Traditional cathodes are *very* rough… but we are learning to make them smoother – More in the next talk!

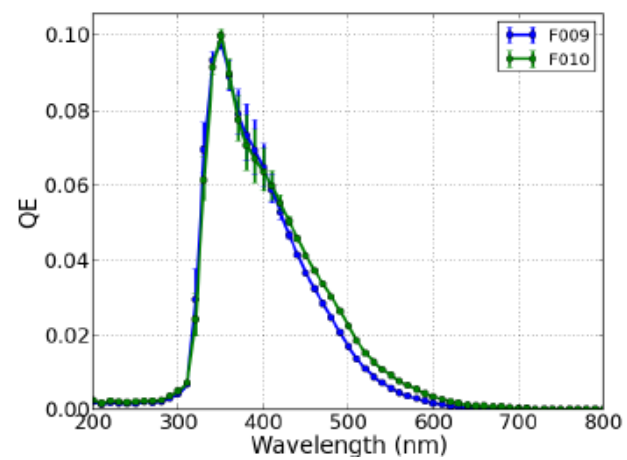
goal < 1 nm

Z. Ding (Stony Brook) – In-situ XRR to reveal surface roughness of sequential, co-deposition and sputter grown CsK2Sb photocathodes



In-situ growth chamber with sputter system installed at G3, CHESS





QE at 532 nm for sputtered cathode

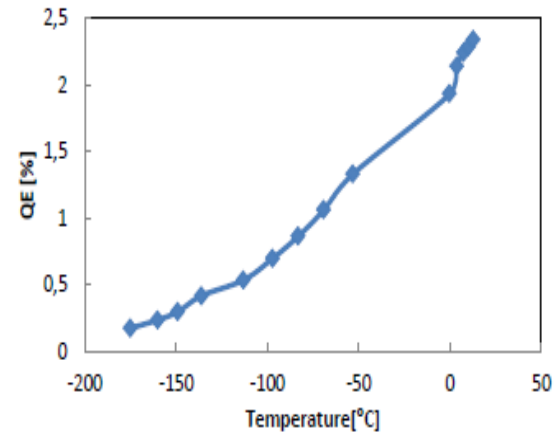
Z. Ding (Stony Brook) – In-situ XRR

- Summary:
  - X-ray reflectivity is a useful in-situ technique in characterizing the roughness, thickness and density of CsK_2Sb in this study, stoichiometry information obtained from XRF analysis helps the XRR simulation.
  - Co-evaporated CsK_2Sb may end up in a smoother surface with almost the same quantum efficiency compared to sequentially-evaporated CsK_2Sb in previous study.
  - Sputtered CsK_2Sb exhibits the best surface roughness, in trade of quantum efficiency

- Future work:
  - To increase quantum efficiency while maintaining excellent surface roughness of sputtered CsK_2Sb.
  - Demonstrate Cs_3Sb sputtering (should avoid K deficiency problem) – Starting next week @ CHESS.
  - If ready, gun test in the Cornell ERL in the future!

E. Wang (BNL) – Multi alkali photocathodes at cryogenic temperature for BNL 114 and 704 MHz SRF guns

- We observed that the cathode QE will drop when cooled down. We carried out multiple cooling tests and saw the QE will drop factor of 8~10 (at 532nm) when the cathode cools down to LN_2.
- In the SRF gun, the cathode is either cooled by LN_2 or water.
- QE could fully recovery if the cathode warms up back to room temperature.



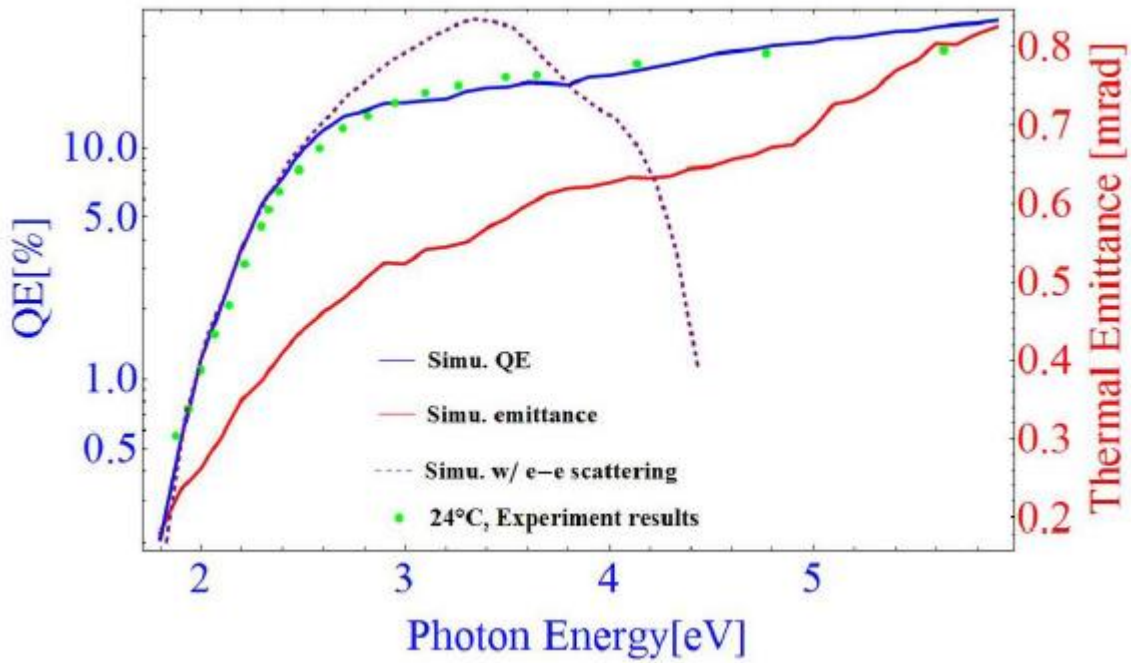
Why does the QE decay?

- Increase in work function due to change in lattice structure at low temperature.
  - Band gap change from 1.42eV to 1.5eV while cathode cool down to LN2 temperature measured by Spectral photoluminescence.

V. Beguchev J. Phys. 0: Apl. Phys. 26 (1993) 4499-4502.

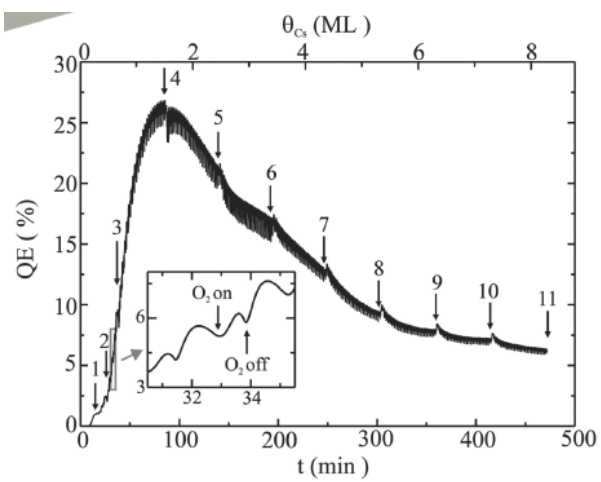
E. Wang (BNL) – modeling emission from cathode

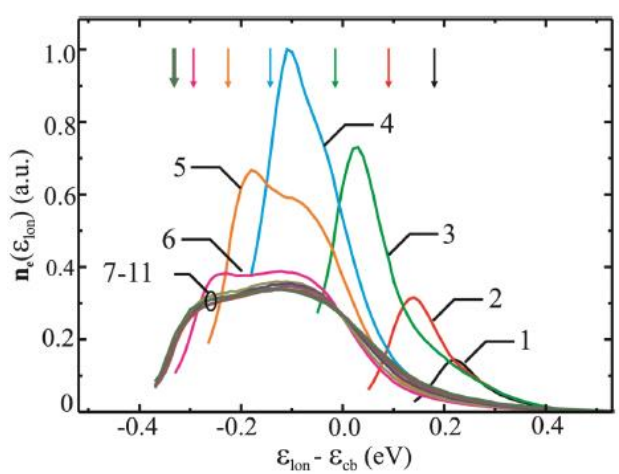
To understand the K_2CsSb photocathode photoemission, we developed a python-based 2D Monte-Carlo simulation code based on Spicer's three step model.

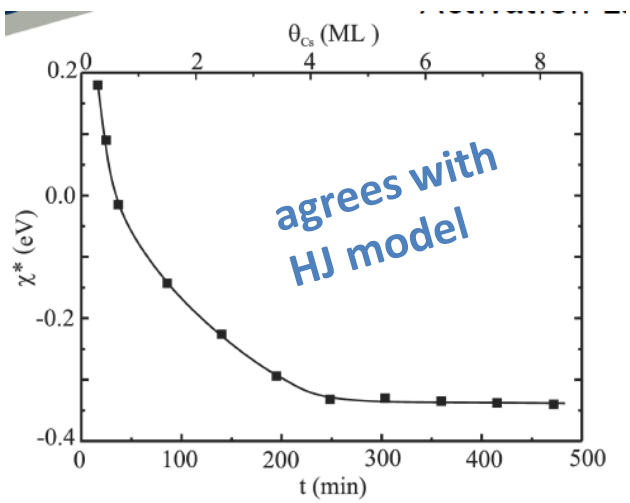


L. Jones (ASTEC) – Understanding of the p-GaAs(Cs,O) activation layer with energy spread measurents

- Several layer models proposed:
  - Dipole Layer (DL) model, applicable to 'thin' layers, and the
  - Hetero Junction (HJ) model, applicable to 'thick' layers
- Method: Very slowly activate cathode, interrupt and measure long. energy distribution with a parallel plate retarding analyzer





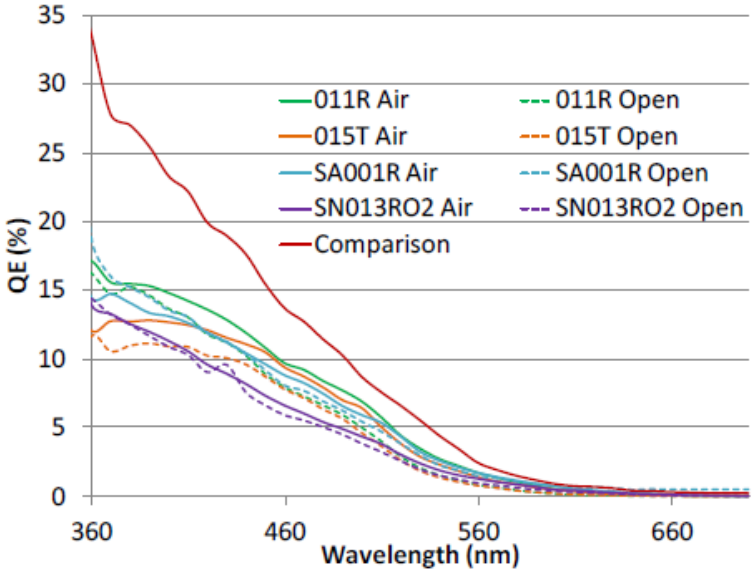


J. Smedley (BNL) – CsK2Sb cathodes from Photonis

Photonis USA, using detector growth process

Shelf life of months at least

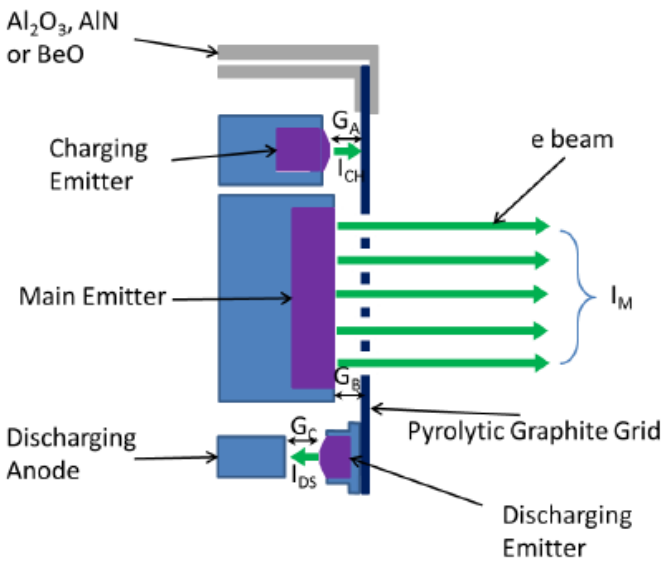
NaK_2Sb available



X. Chang (Far-Tech) – high peak/average current source based on triode like thermionic cathode

FAR-TECH's Proposed Thermionic RF Gun Without BB & Section II Beam: Step II

Step II, use a floating grid cathode.



A floating grid thermionic cathode

- $E_{grid\text{-}Main\ Emitter} = E_{DC} + E_{RF}$
- E_{DC} is determined by the geometry of the floating grid and net charge on it.
- The floating grid net charge can be adjusted by changing the emission of charging / discharging emitters through changing their operating temperatures or apply bias fields.

FAR-TECH Proprietary 13

Subsystems – Drive Laser

S. Zhang (JLAB) - Drive Laser Challenges

- The state-of-the-art laser techniques can provide enough average and peak power for 100s of mA photoguns,
- Still need better:
  - Stability

    long term phase drift, pointing
  - Versatility

    more flexiable rep rate & pulse structure control

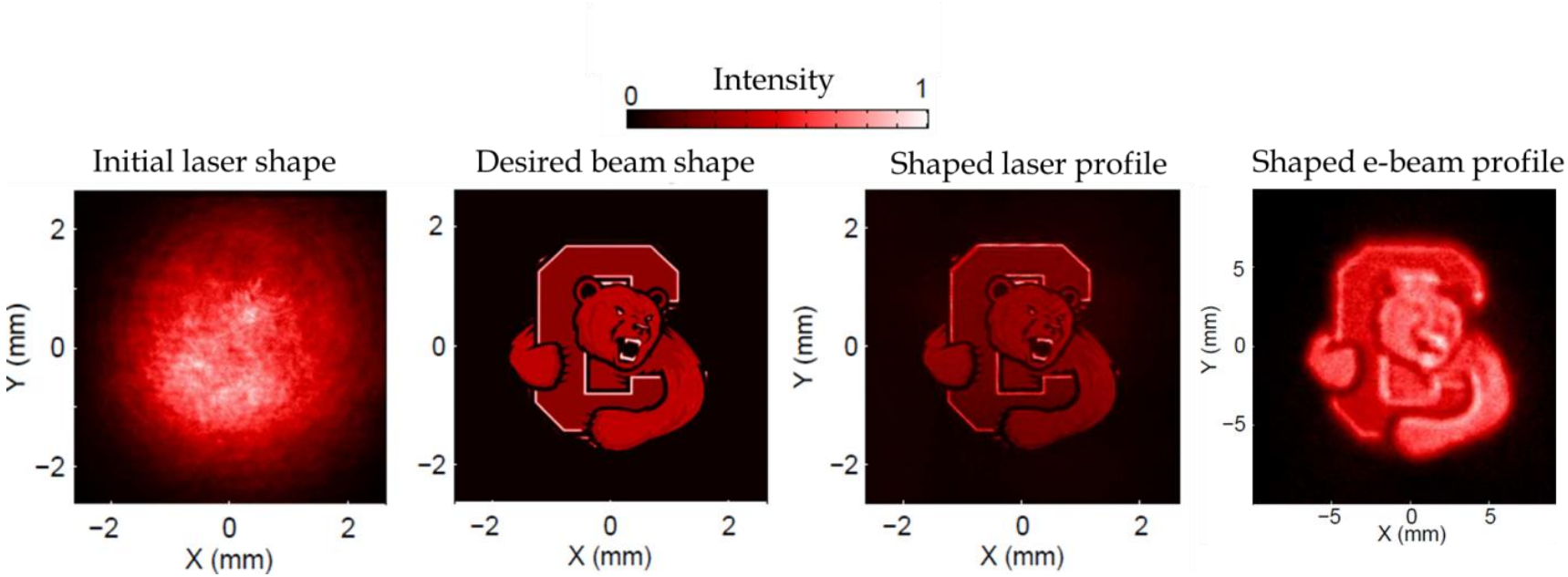
    e-beam noise control by optical modulation
  - Spatial/temporal shape

    robust, high power (passive and active) shaping technique
  - Reliability

    run 24/7, resistance to environmental disturbances

J. Maxson (Cornell) - Laser shaping with SLM

- Simple shaping method demonstrated
- High current -> more work needed to surpass thermal damage threshold (e.g., just cool it?)



Conclusions

- There is a robust choice for an ERL class injector → DC gun
- We need more demo and test experiments to push limits of the SRF gun concept
- Photocathode R&D is now strongly benefitting from material science methods → departing from alchemy
- From the drive laser we expect more results on control of laser parameters in the future.

Thanks

- to all speakers, participants, the LOC and PC…