Report from HOPE and SINEMP meeting on 21-22.06.2016

- **HOPE** - Hochbrillante photoinduzierte Hochfrequenz-Elektronenquellen
- **SINEMP** - Entwicklung einer Multipacting-freien Kathodeneinheit für supraleitende Hochfrequenz-Photoinjektoren (SRF-Guns)

Igor Isaev
PPS, 30.06.2016

HELMHOLTZ | ASSOCIATION

DESY

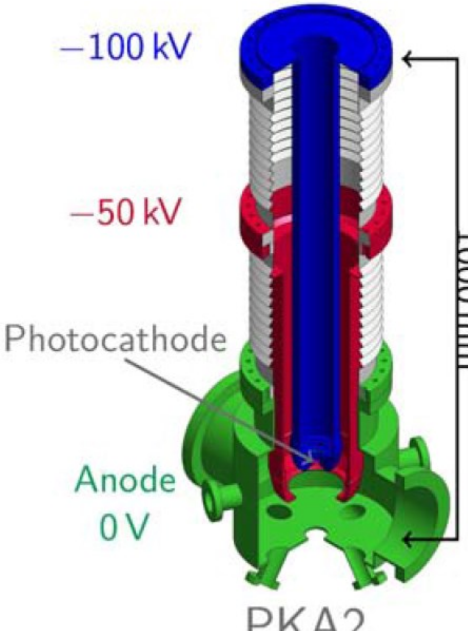
Program HOPE und SINEMP Meeting

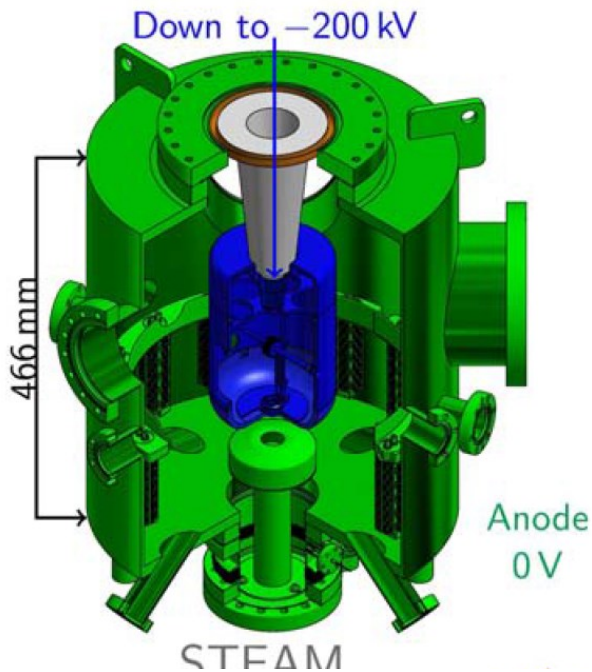
- Andre Arnold, Rossendorf:
  - First Operational Experience of SRF Gun II
- Ye Chen, Darmstadt:
  - Electron Emission Modeling and Simulation using Enhanced QE Models
- Simon Friedrich, Mainz:
  - The new 200kV Electron Source at Mainz
- Thorsten Staedler, Siegen:
  - Carbon Coatings for Superconducting RF Guns
- Igor Isaev, Zeuthen:
  - Beam Imperfections Studies at PITZ
- Eden Tafa Tulu, Rostok:
  - Multi-Dimensional Optimization of Groove Parameters for the Cathode Tip

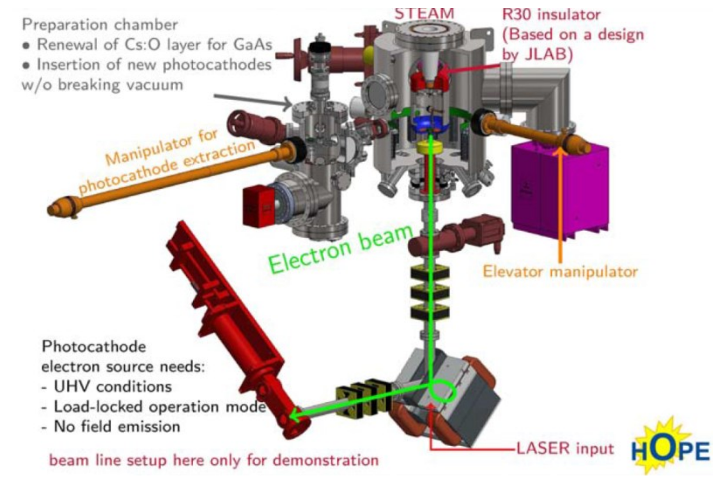
This talk sequence

1. Simon Friedrich, Mainz:
   - The new 200kV Electron Source at Mainz
2. Thorsten Staedler, Siegen:
   - Carbon Coatings for Superconducting RF Guns
3. Eden Tafa Tulu, Rostok:
   - Multi-Dimensional Optimization of Groove Parameters for the Cathode Tip
4. Andre Arnold, Rossendorf:
   - First Operational Experience of SRF Gun II

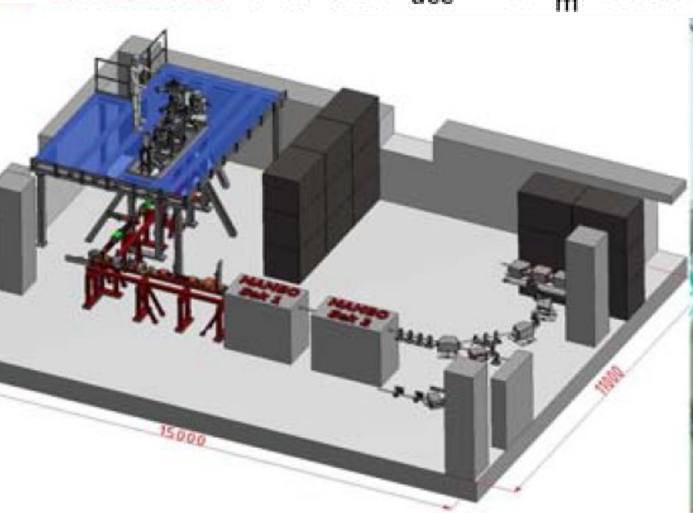
Simon Friedrich: The new 200kV Electron Source at Mainz

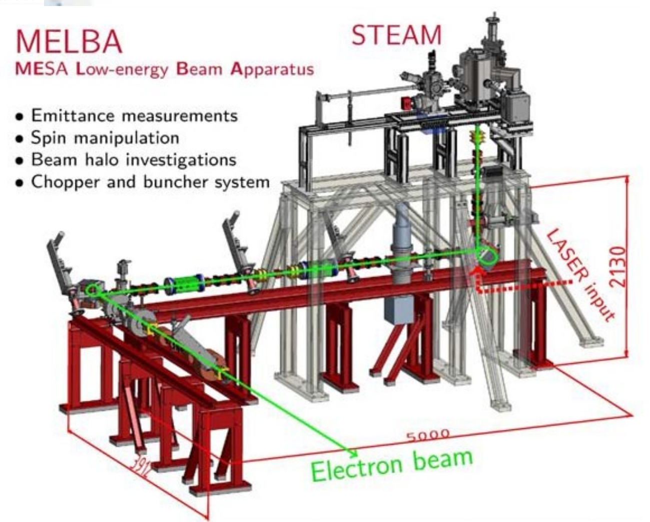






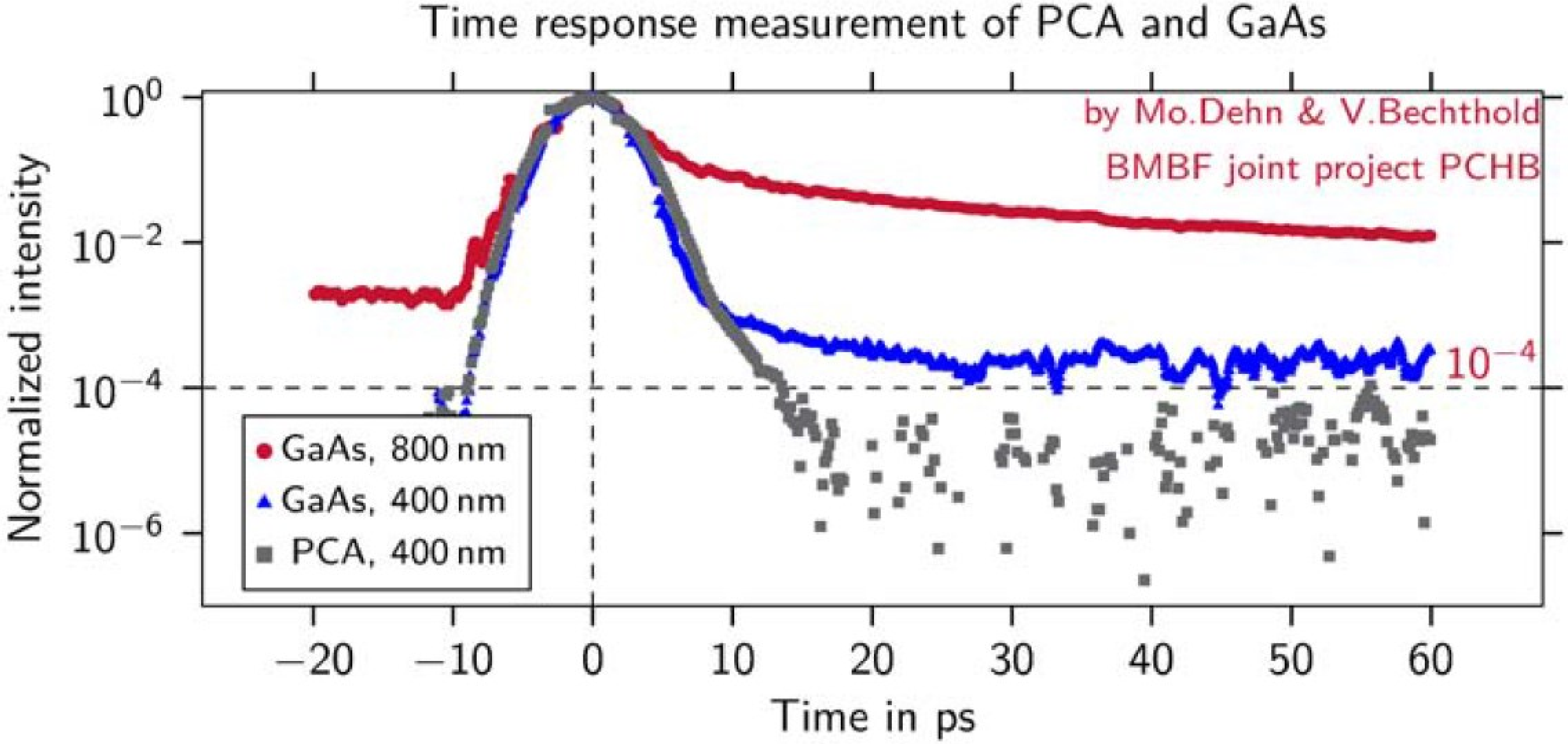
Difference: PKA2: $E_{acc} \approx 1\,\frac{\mathrm{MV}}{\mathrm{m}}$@100 kV, STEAM: $E_{acc} \approx 2.5\,\frac{\mathrm{MV}}{\mathrm{m}}$@100 kV





Simon Friedrich: The new 200kV Electron Source at Mainz

Recent Achievements in Synthesizing new Photocathodes
K_2CsSb Photocathodes



Potassium Cesium Antimonid (PCA) versus GaAs photocathodes

PCA photocathodes promise **high quantum efficiency**, **fast response time** and **low thermal emittance** while being **100 fold** more robust.

Simon Friedrich: The new 200kV Electron Source at Mainz

Summary & Outlook

Recent achievements

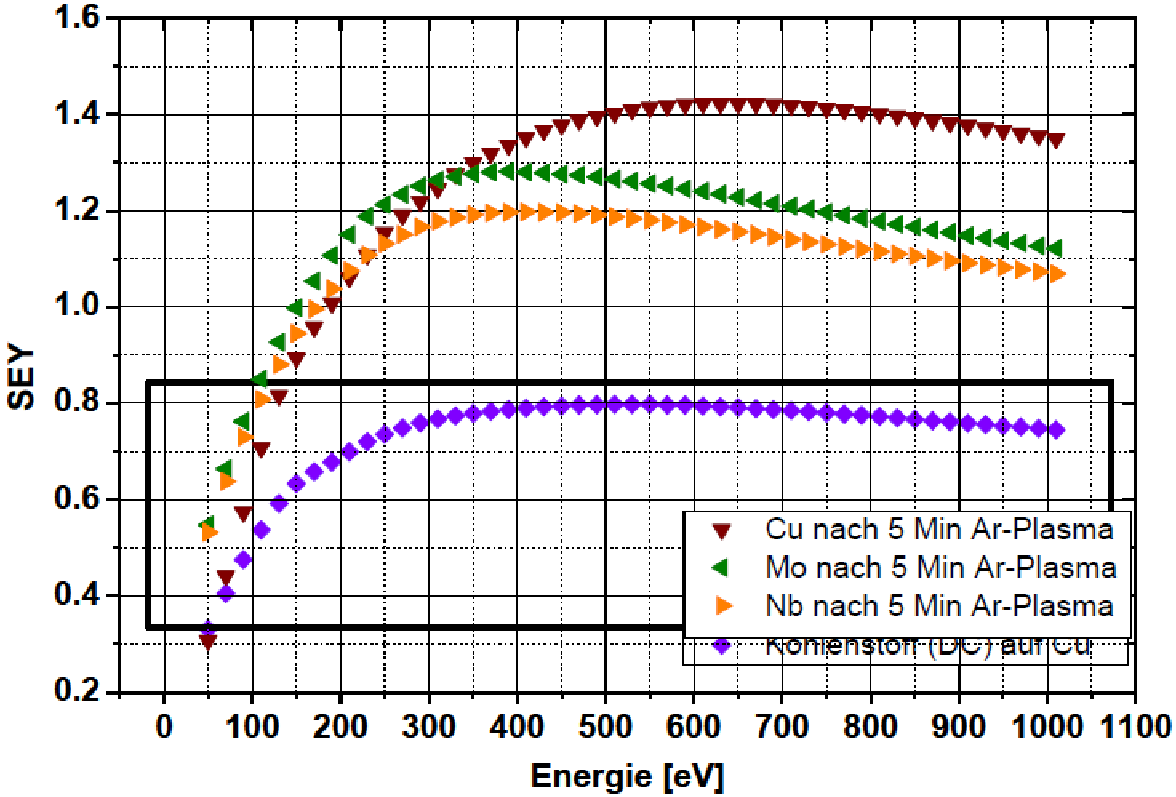
- STEAM fully assembled and ready to be baked out
- Platform was built up and further assembling can begin
- Some parts of diagnostic beam line were ordered or are currently being built
- Some infrasturcture (e.g. cooling water) ready to use
- Progress in developing PCA photocathodes

Further tasks

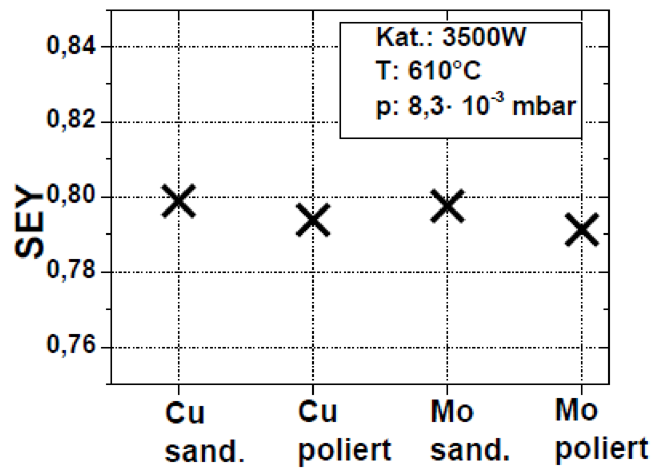
- After STEAM bake out: high voltage processing (based on JLAB technique)
- Testing high voltage cable and power supply at small test stand beforehand
- Setting up control system for MELBA
- Operating laser (first comissioning with diagnostic laser)

C- SEY-Measurements

SEY-Substrate measurements +
Change through C-coatings

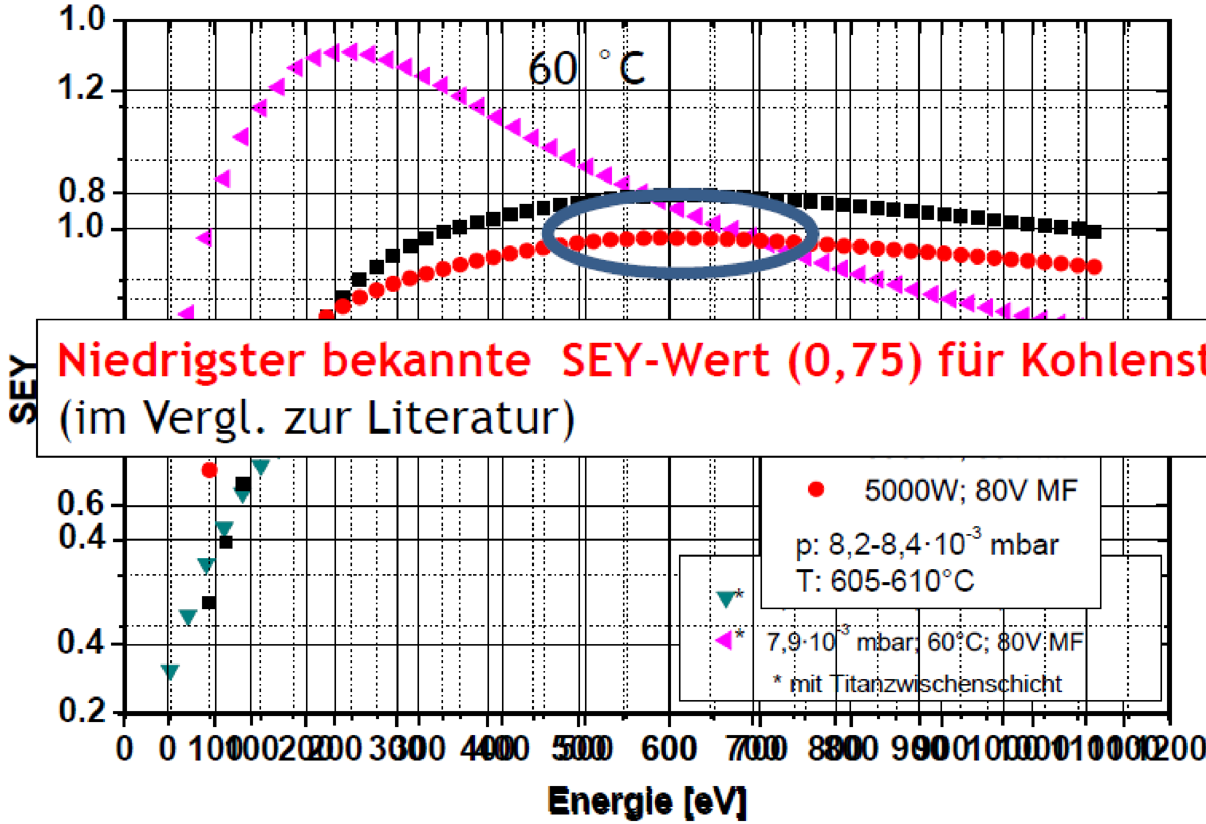


SEY of C:
substrate independent:



C- SEY-Measurements

SEY-Messungen für verschiedene Herstellungsparameter



Niedrigster bekannte SEY-Wert (0,75) für Kohlenstoffschichten (im Vergl. zur Literatur)

		SEY
Leistung	↑	↓
	MF	↓
(BIAS)	ohne	↘
	DC	→
Temperatur	↑	↓
(Druck)	↓	↓

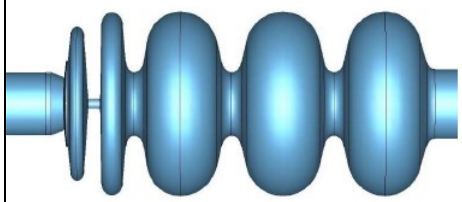
Thorsten Staedler: Carbon Coatings for Superconducting RF Guns

My notes:

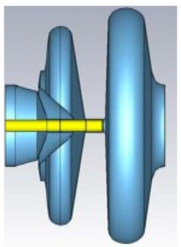
- Carbon coatings are produced
- SEY for carbon is always lower than 1: the best is 0.75
- C coating is well known in industry
- Also measured SEY for Cu, Mo, Nb
- Coating thickness of C is ~200..300nm
- C coating is very stable
- Ti is used as intermediate layer for C coating, but plays no role on SEY of layer
- C layer is very good for sliding

Eden Tafa Tulu: Multi-Dimensional Optimization of Groove Parameters for the Cathode Tip

A very simplified model

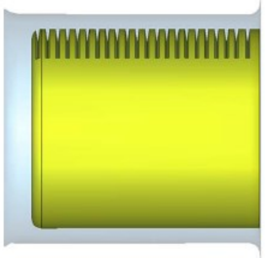


Choke filter, cathode and 3 ½ cells Tesla-like cavity



Choke filter, cathode and half-cell

Cathode and half-cell

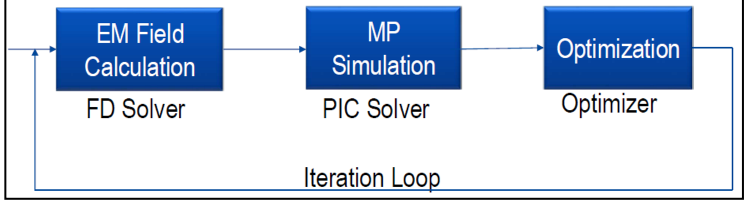


Cathode

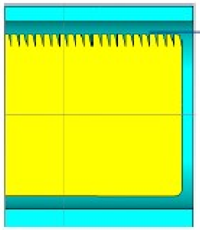
Coaxial model: Better EM field resolution (high accuracy) and faster simulation time

The groove‘s edges are blended in order to avoid field emission effect

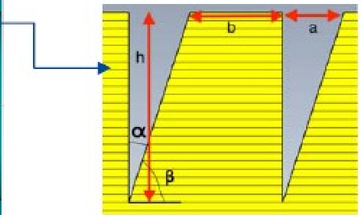
Work flow for Multi-dimensional Optimization



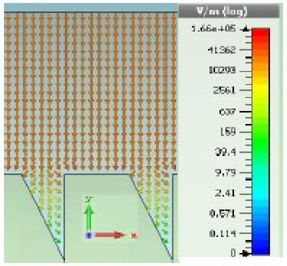
EM Field Calculation in the Sawtooth Groove Model



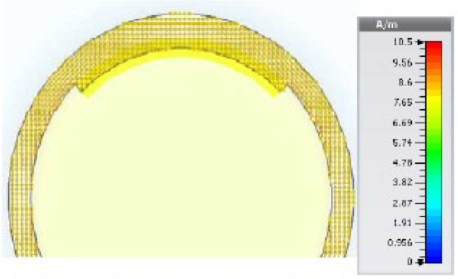
~2.1 G mesh cells



sawtooth groove, $\alpha + \beta = \frac{\pi}{2}$



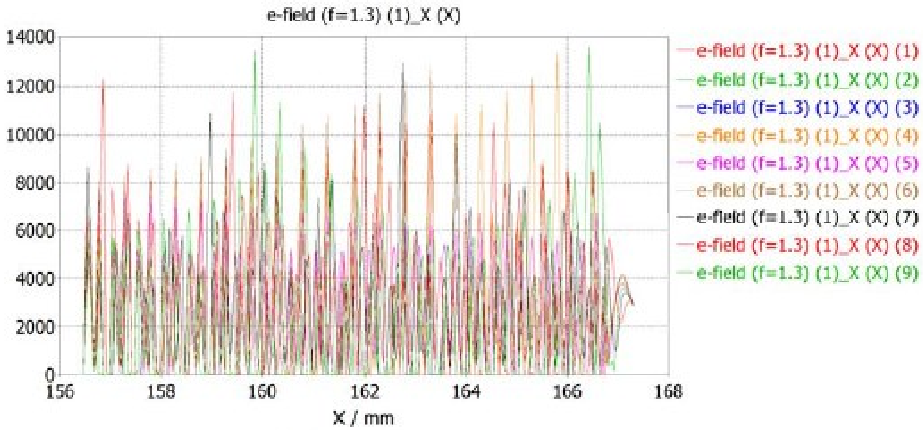
E-field distribution in sawtooth grooves



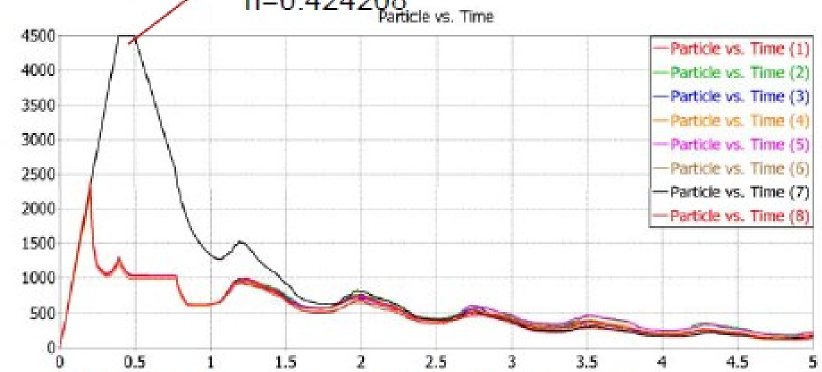
H-field distribution in sawtooth grooves

Eden Tafa Tulu: Multi-Dimensional Optimization of Groove Parameters for the Cathode Tip

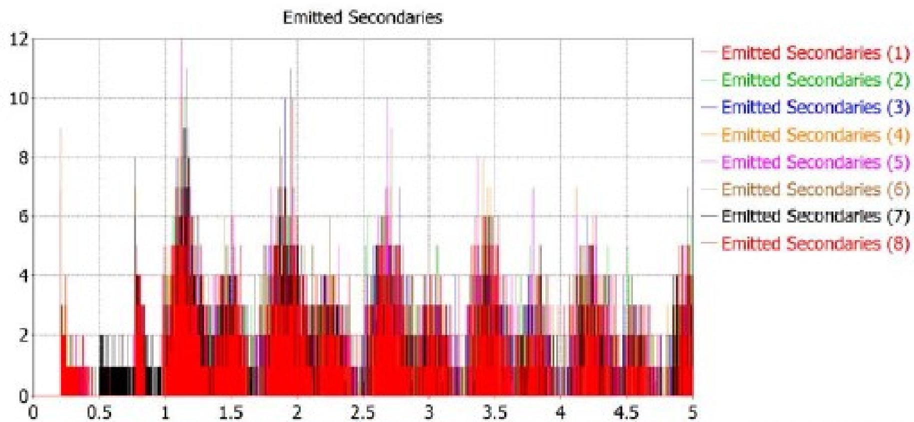
Multi-dimensional Optimization for Sawtooth Model

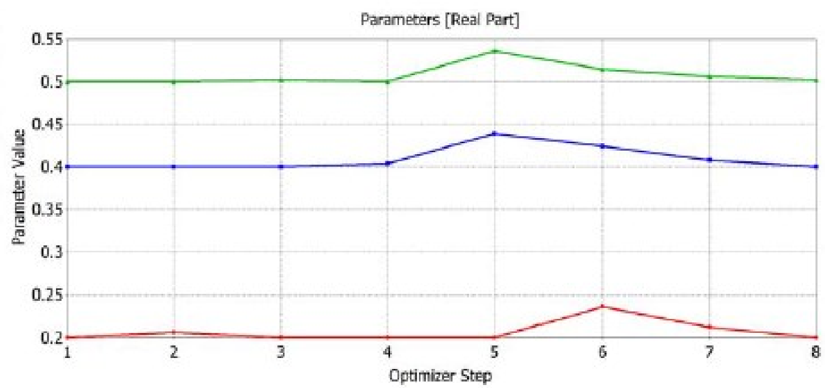


a=0.236313
b=0.514104
h=0.424208



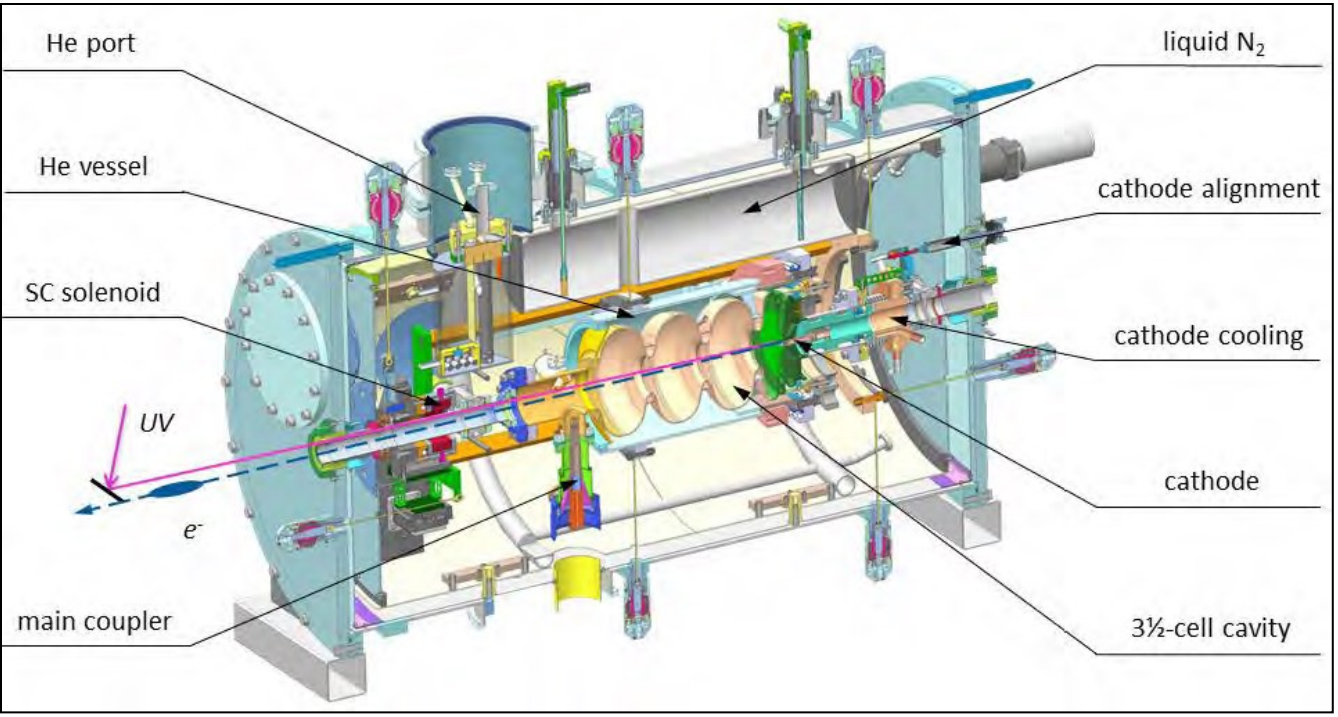
Total evaluation time (for 8 iterations):



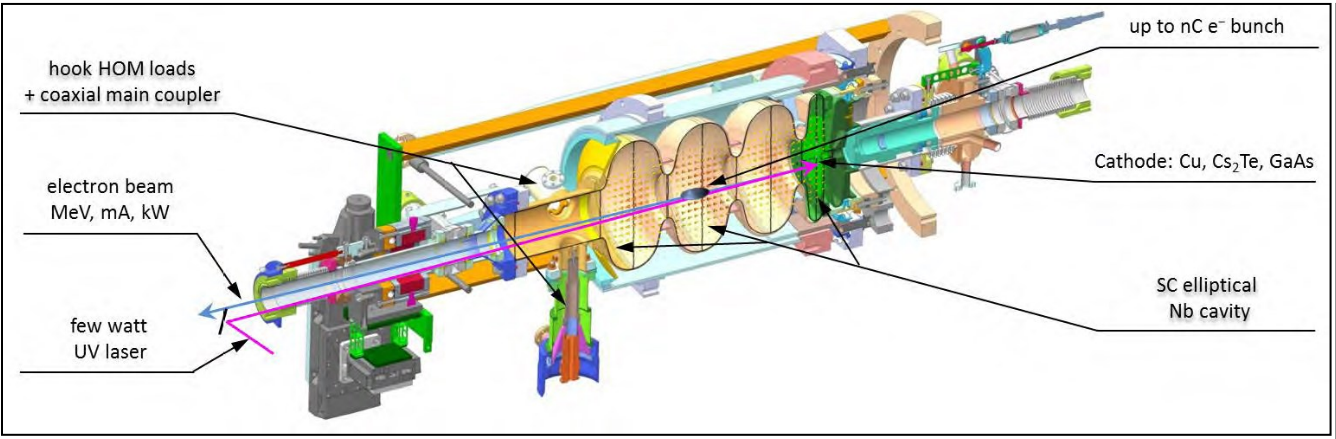


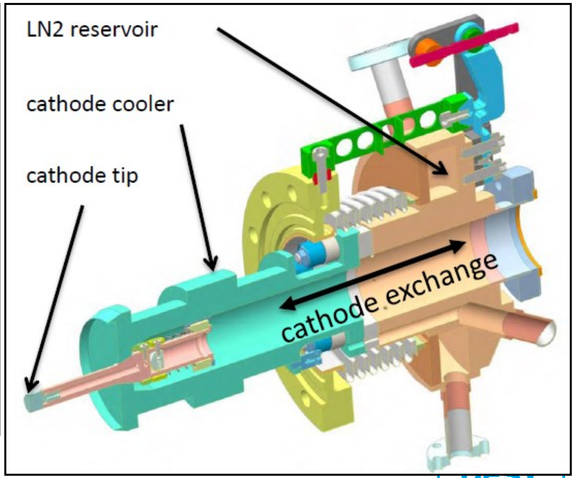
Lower/upper parameter bounds are set to ±10 % of initial value in order to modify quickly
Setting a broader range might be necessary in order to obtain an optimum (accurate) result by more evaluations

Andre Arnold: First Operational Experience of SRF Gun II

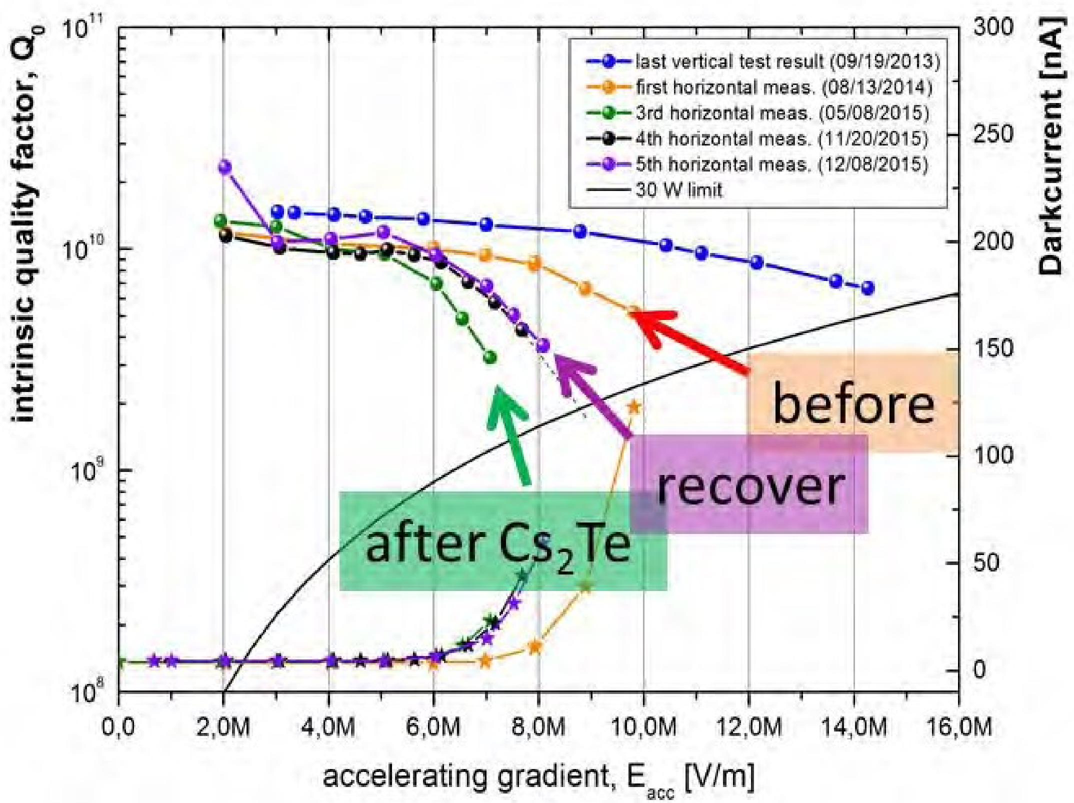


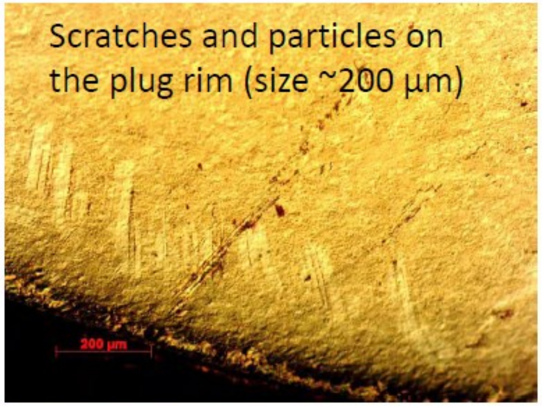
- Cs2Te, Cu, GaAs, Mg cathode
- cooled by LN2 to 77 K
- therm. and electr. isolated from cavity
- DC bias up to 7 kV for MP suppression
- moveable (±0.6 mm) by remote stepper for best RF focusing
- tiltablefor axis alignment by hand
- cathode exchange in cold gun

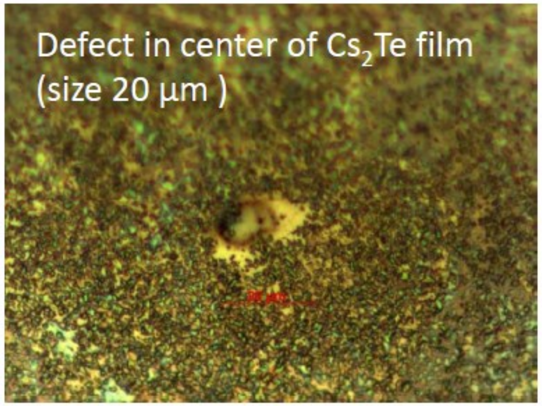


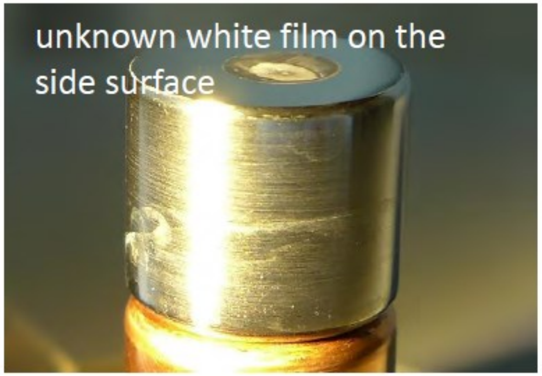


Andre Arnold: First Operational Experience of SRF Gun II









- no further degradation with Cu cathode
- **but** 1stCs2Te cathode in Feb. 2015 failed in gun, leading to **contamination, dark current and tremendous RF loss**
- Probably caused by particle moved from cathode to first iris → **Contamination risk by cathodes is not eliminated** Performance

Move on and focus on first user operation

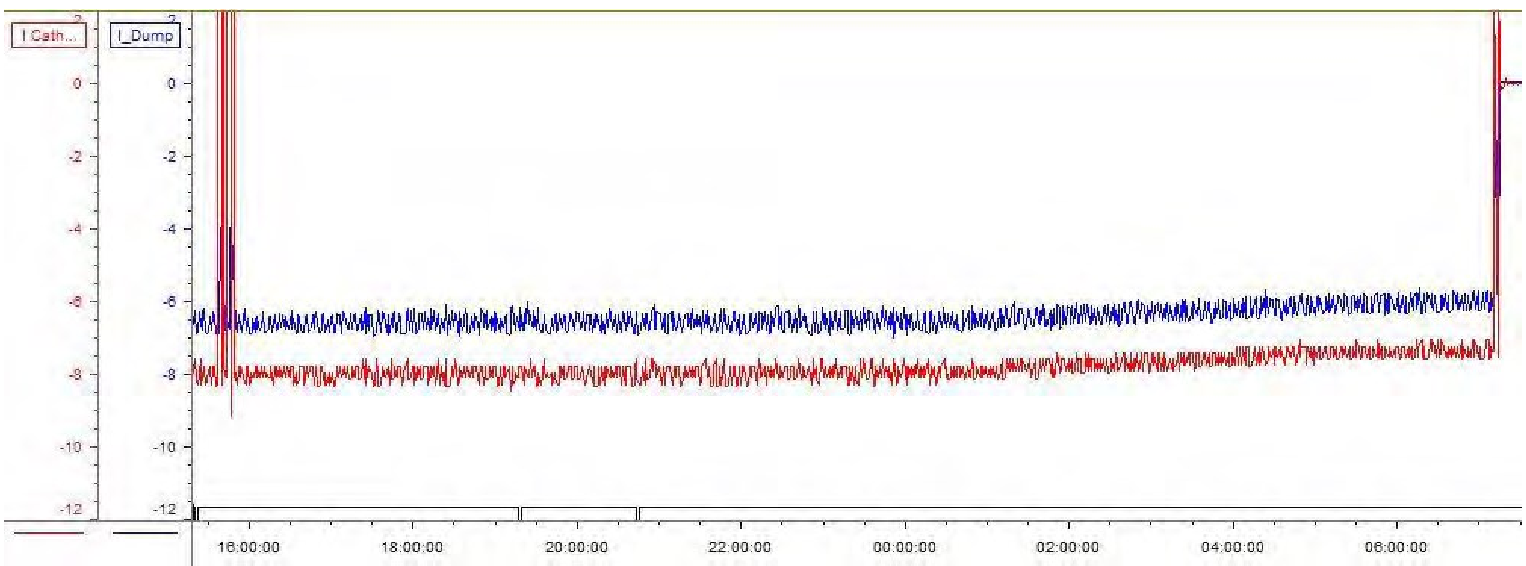
Motivation: to search for a „Clean“ (Cs-free) cathode for SRF gun

Mg photocathode
ϕ = 3.6 eV
QE = 0.1 – 0.2 %

user application	bunch charge	Rep. rate	average current
IR FELs	77 pC	13 MHz	1 mA
Neutrons	500 pC	100 kHz	50 µA
Positrons	200 pC	500 kHz	100 µA
THz radiation	350 pC	100 kHz	35 µA
CBS x-rays	450 pC	10 Hz	4.5 nA

First user operation

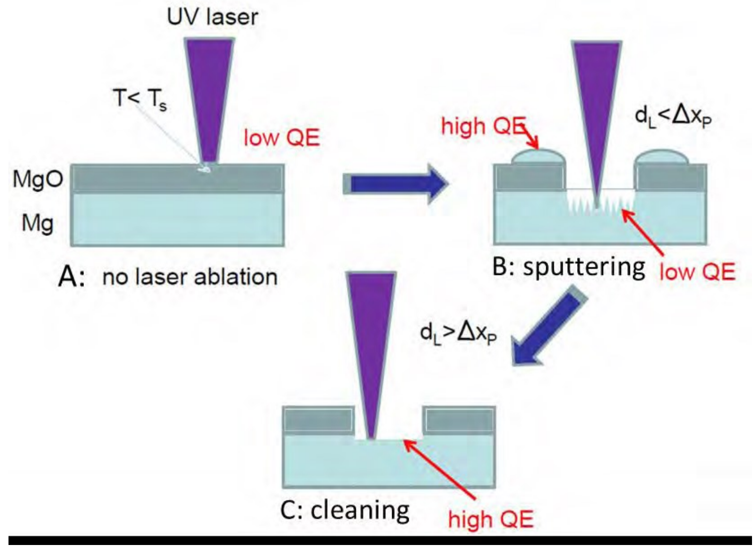
- several 12h-shifts for user setting preparation, test, and measurement with 100 kHz CW and 80 -200 pC
- optimization of beam transport without beam loss
- **stable ~80 hour** user operation with 80pC and 30 MeV for time of flight neutrons generation (total charge 2C)
- so far Mg cathode worked in the gun for three months and ~350h beam time without QE degradation



Andre Arnold: First Operational Experience of SRF Gun II

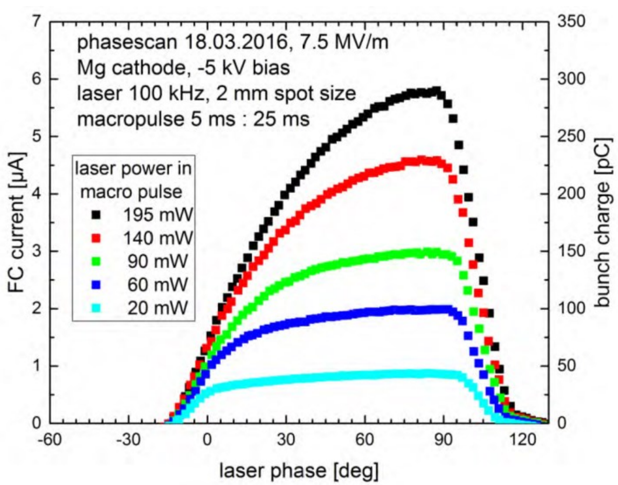
Mg photocathodes preparation

- turning of the Mg tip
- diamond polishing (Ra ~10nm)
- de-oxidized (Glycol-HNO3etching)
- cleaned (water free)
- stored in N2
- laser cleaning done in transport chamber right next to the gun
  - UV: 263 nm (4.7 eV)
  - rep. rate: 100 kHz
  - ultra short pulse: 7 ps
  - mean power: 100 mW
  - min. spot: r=30 µm
- QE depends on power density and illumination duration



Mg photocathode in operation

	Initial CW RF 2014	with beam at present
acceleration field	10 MV/m	8 MV/m
peak field on axis	25.6 MV/m	20.5 MV/m
cathode field	15.4 MV/m	12.3 MV/m
kinetic energy	5 MeV	4 MeV



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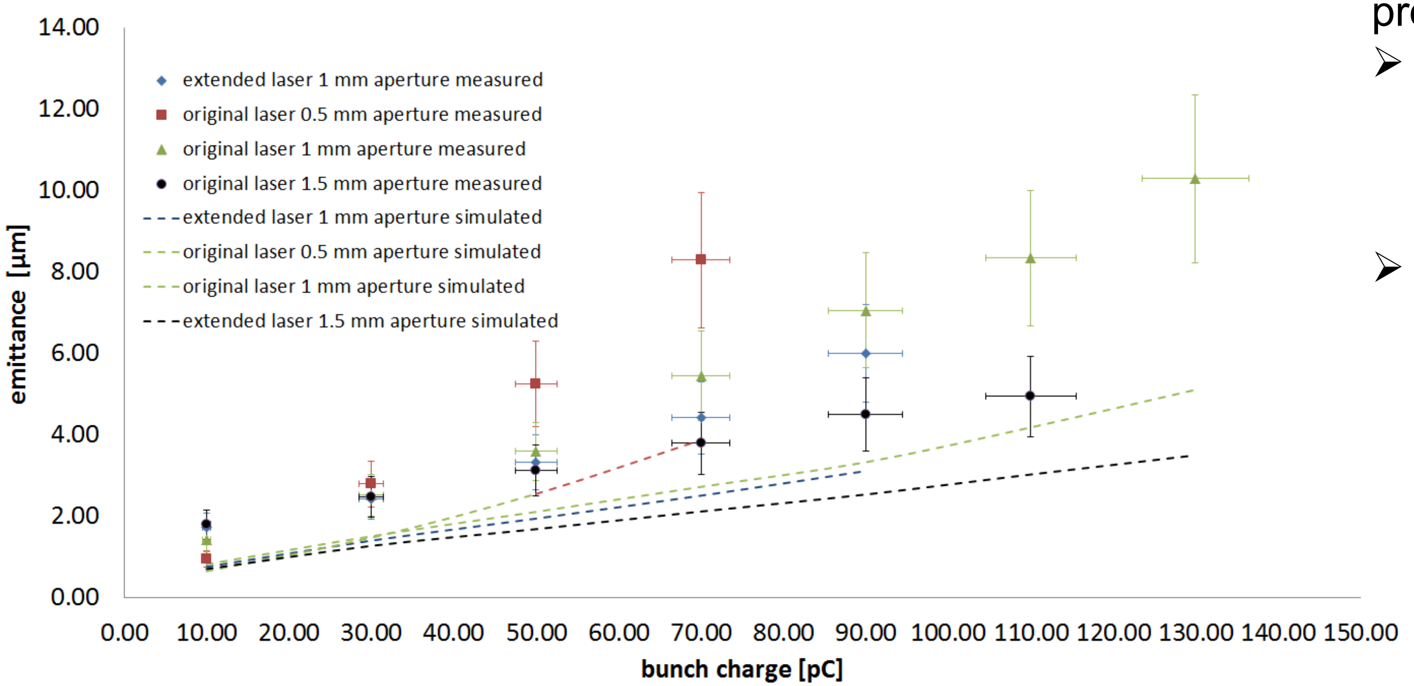
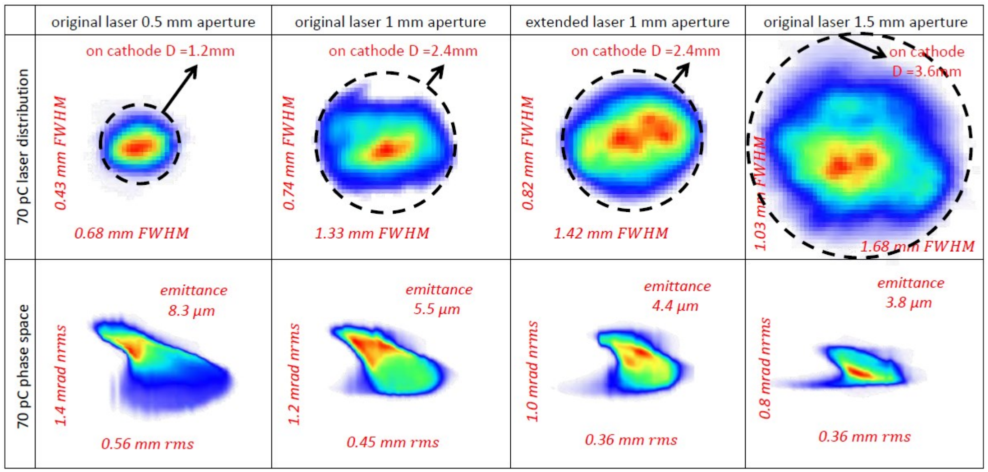
Andre Arnold: First Operational Experience of SRF Gun II

Beam characterization



Trying to understand the properties of the gun e.g.:

- strong difference in emittance btw. measurement and simulation
- the smaller the laser spot the bigger the difference



- one reason is very likely the transverse laser intensity profile
- near future a spatial light modulator will be used to great a flat top

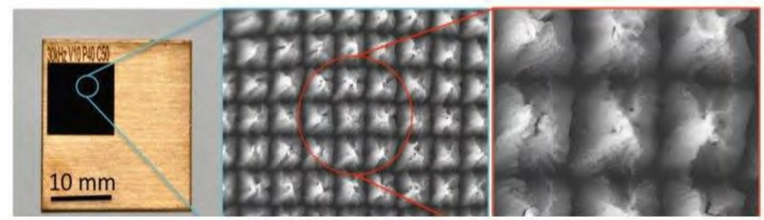
Andre Arnold: First Operational Experience of SRF Gun II

Cathodes properties

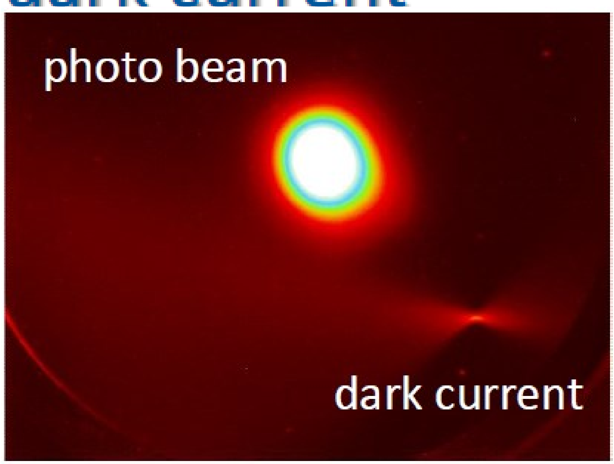
- **Cs2Te**: Strong MP effects, required a permanent adoption of cathode bias (-1 … -7 kV)
- **Cu** & **Mg**: **no** MP, one of the advantages of metal cathodes?

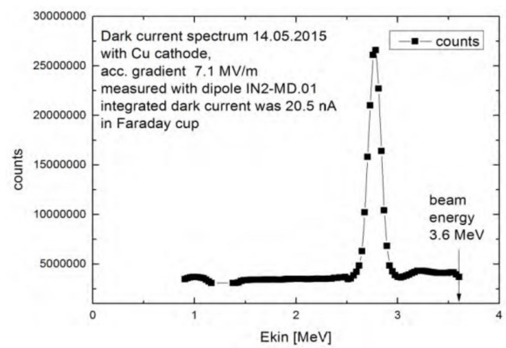
<u>Approaches of MP suppression for Cs2Te cathodes:</u>

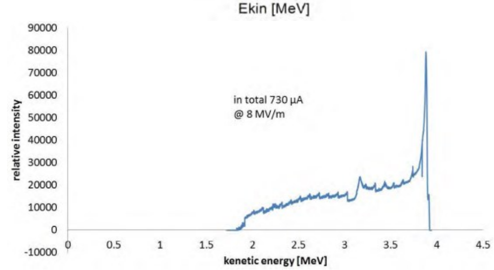
- sub-mm structuring of cathode tips based on simulation results University of Rostock (HOPE)
- surface coatings based on investigations of University of Siegen (HOPE)
- laser treatment of tip side walls based on laser-engineered surface structures

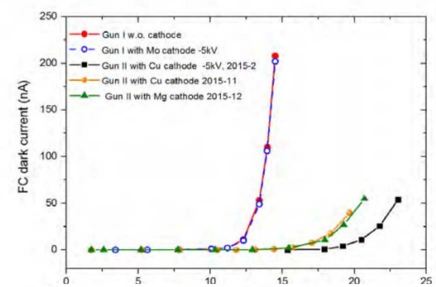


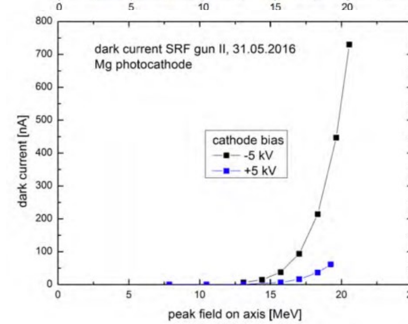
dark current











DESY

Andre Arnold: First Operational Experience of SRF Gun II

Summary and Outlook

- The SRF Gun II cavity reached 25.6 MV/m on-axis peak field in CW
  - still far away from first specifications of 50 MV/m for <1 µm @ 1 nC but close to 30 MV/m of recent CW test of X-FEL and ELBE modules
  - cavity and RF work very reliable and stable over days without any trips
- Exchange and operation of normal conducting cathodes is still very risky
  - improved quality management before cathode goes in the gun
  - improve exchange and handling mechanics to avoid particles
- Mg cathodes more save and suitable for medium current application
  - cathode preparation is well understood, QE of 10^{-3}
  - first successful 80h user operation demonstrated
- Outlook:
  - beam characterization and optimization at high bunch charges
  - further user beam time with higher bunch charge
  - insertion of Cs2Te photo cathodes (QE>1%) for high average current
  - refurbish SRF Gun I cavity in collaboration with DESY for higher gradients

Thank you for your attention.

My notes about First Operational Experience of SRF Gun II

- SFR gun 2: 3.5 cells
- CW operation
- Cathode possiblae to move by +-5mm
- Mg cathode now, was tested Cu and Cs2Te(contaminated the gun and Q dropped down)
- Cs2Te production should be improved
- Cathode is fixed by mechanism like photo objectives
- Ecath/Eacc = 1.53 Epeak /Eacc=2.56
- Problem with Lorenz forces
- Gun was put to user operation with Mg cathode (or Mo)
- Laser cleaning by the same PC laser -> must be done more careful in order avoid cathode surface damage (2.04 W/mm^2 laser energy which could be used)
- Emittance 1..4 um
- Trouble with Pc laser transverse profile
- Last weekend 1st user experiment
- 8pc 12 hours, but the gun is able to run for longer time
- Critical cathode properties:
  - MP for Cs2Te, bias needed
  - Cu and Mg no MP
- DC:
  - 200nA max – Gun1
  - 2.8MeV -> beamE=3.6MeV
  - 50uA – gun2 -20..24MW/m on axes
  - But recently new FE appared – 800uA at 20MV/m –the same as beam -> it is cathode
- Gun2 reached 25.6MV/m – spec 50MV/m
- RF is very stable
- Dry-Ice is not used for Niobium, but HPWR instead
- Spatial light modulator is going to be used to get rid of laser profile undesirable features
- Maybe compensate QE roughness by laser transverse shaping