First Beam Characterization of SRF Gun II at ELBE with a Cu Photocathode

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ERL2015, Stony Brook, June 5 -12, 2015

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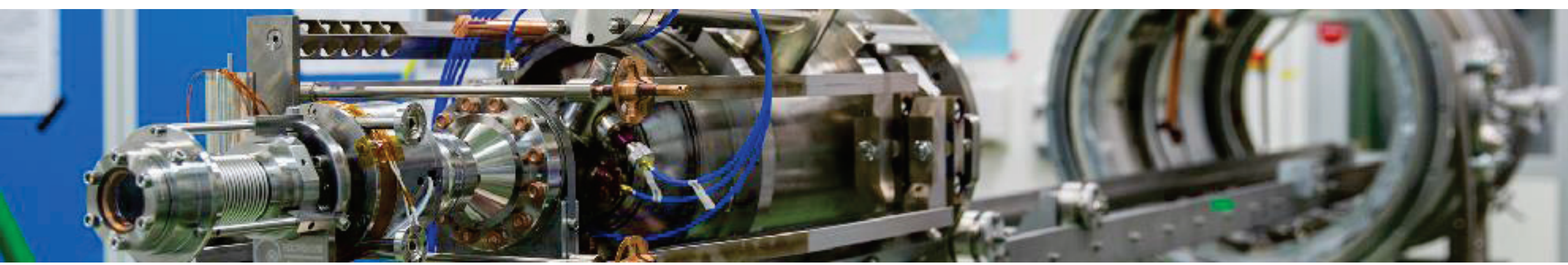
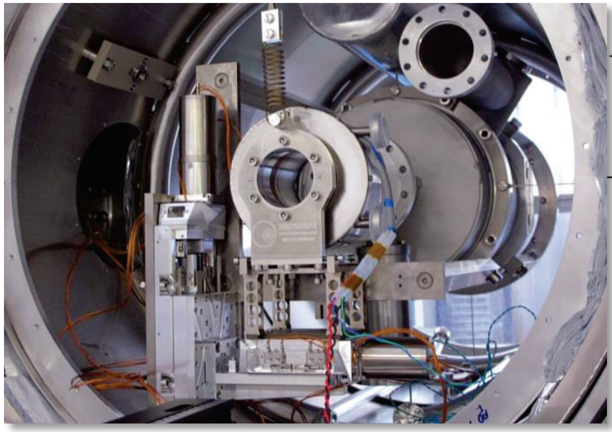
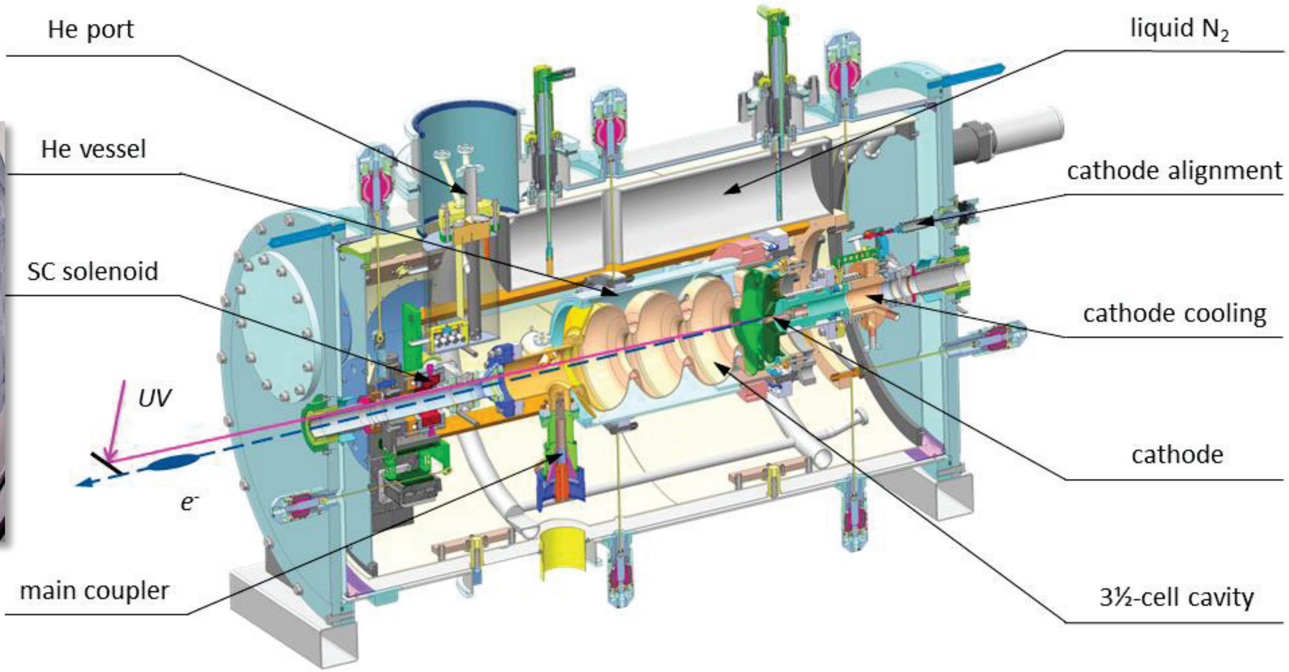
   - Photo Cathodes

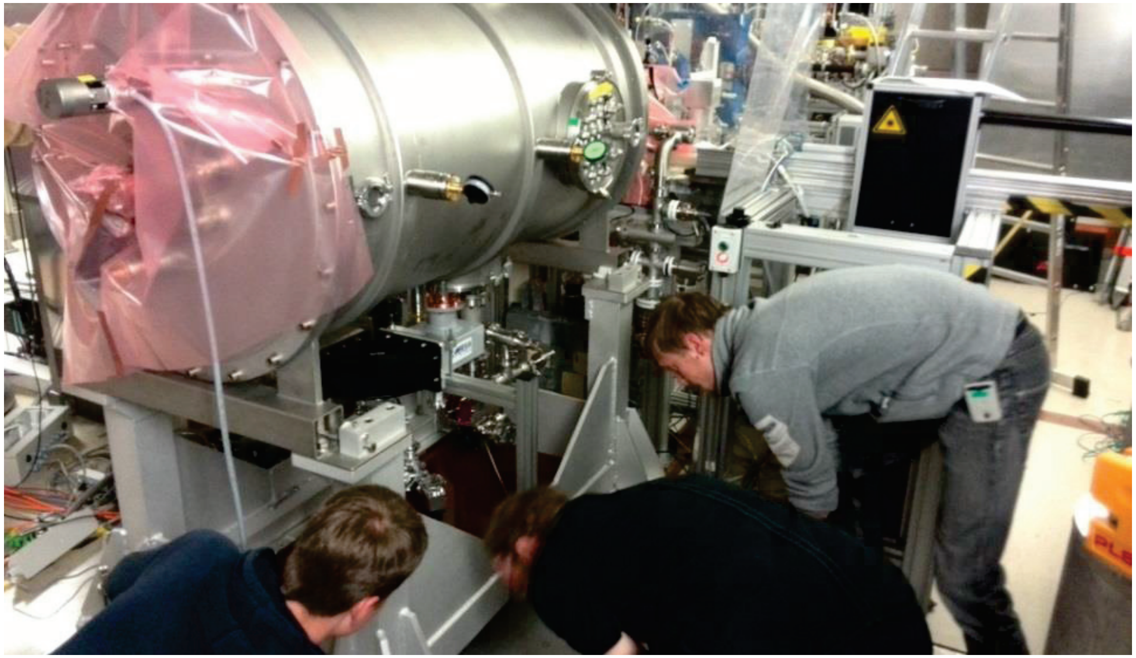


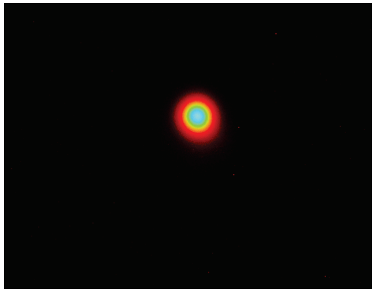
Commissioning of SRF Gun II

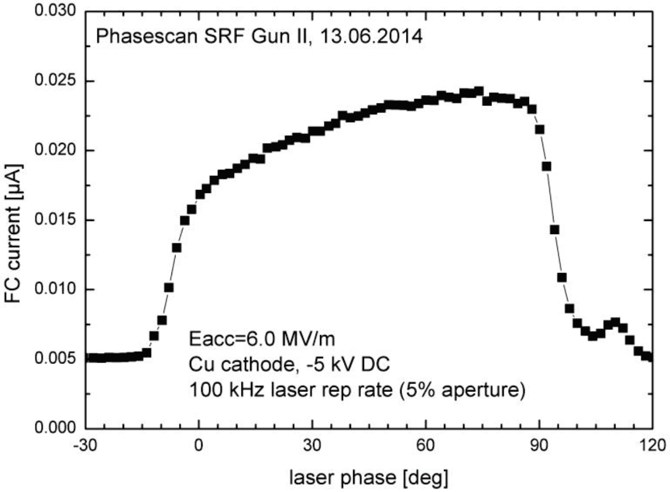




- New cavity - fine grain Nb, produced, treated and tested at JLab
- New cryomodule – 10 cm longer, fabricated and assembled at HZDR
- Integration of a superconducting solenoid

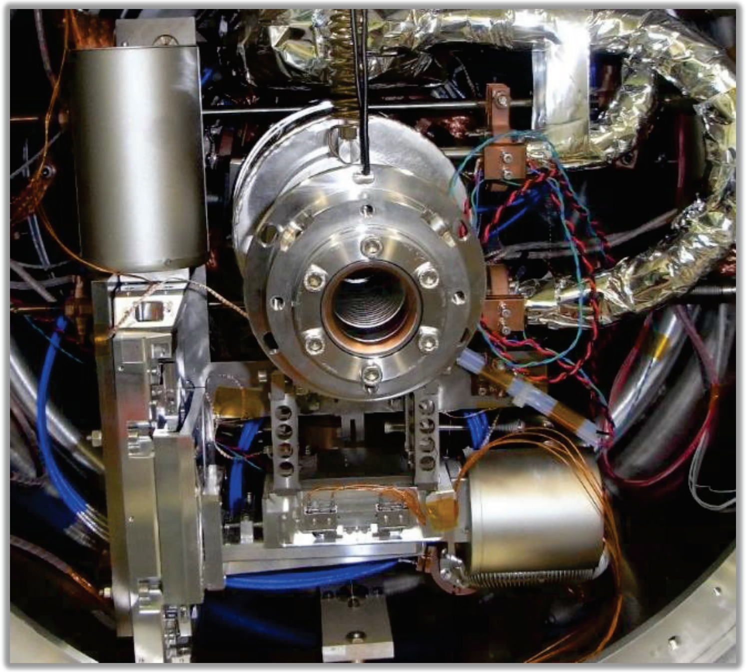


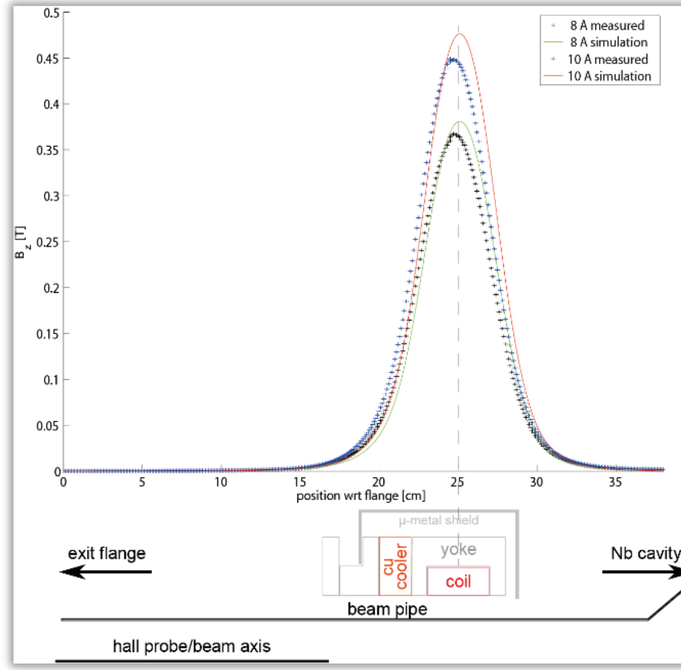




- Gun installation finished on May 16, 2014 without PC transfer system
- First beam with Gun II on June 10, 2014 with Cu photo cathode
- First beam in ELBE on August 12, 2014
  20 nA CW with 100 kHz rep. rate at E_{acc} = 6 MV/m (E_{kin} = 3 MeV)

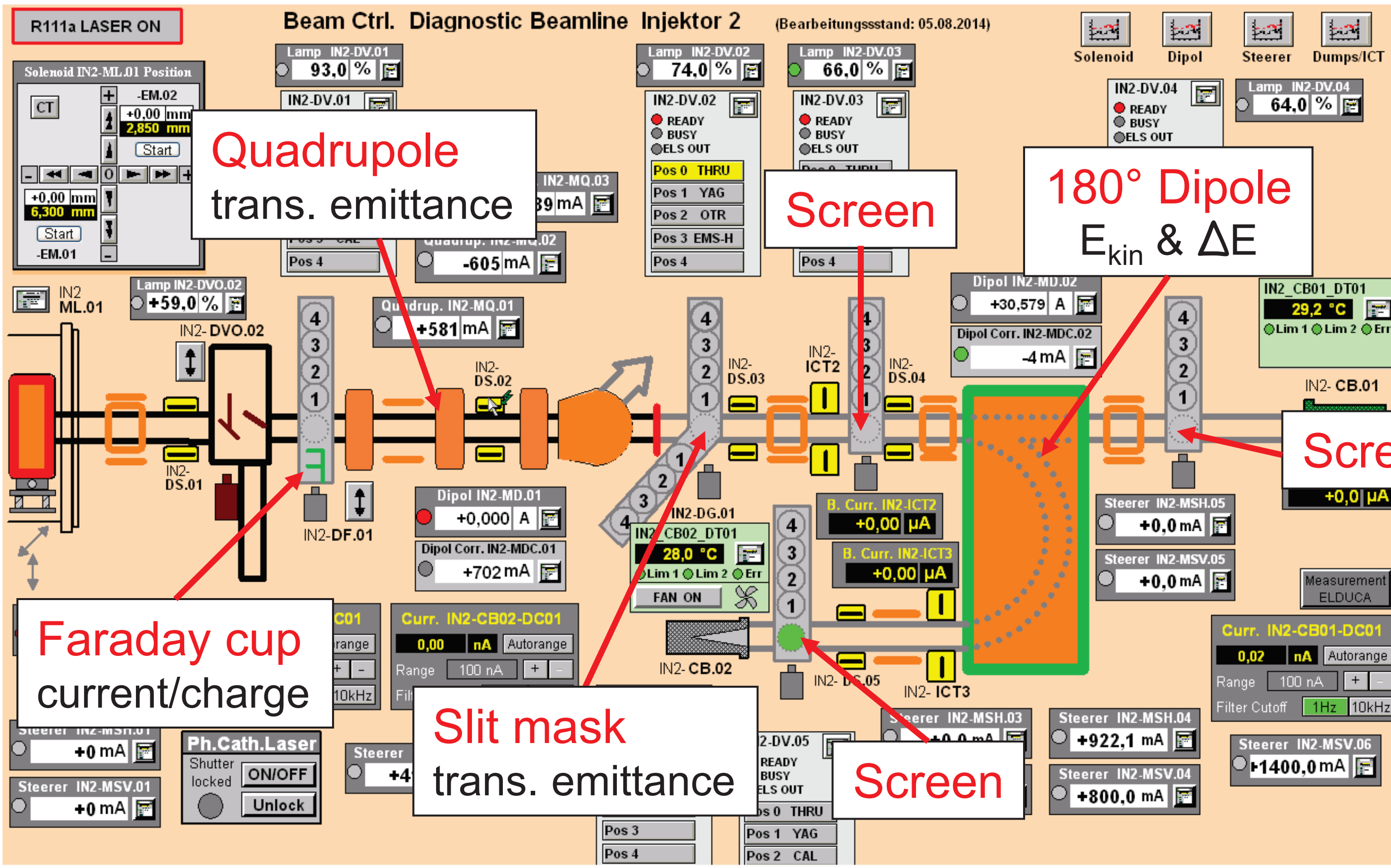
Superconducting Solenoid





- NbTi wire, T_C = 9.2 K, cooled in combination with cavity with 2.0 K liquid He
- on a x-y table with cold motors (70 K)
- μ-metal shielding of solenoid and motors

Diagnostics beamline



Collaboration with HZB Berlin

T. Kamps et al., Rev Sci. Instrum. 79, 093301 (2008)

GUN and RF

- E_{acc} = 6 - 9 MV/m CW (15.5 - 23 MV/m peak field)
- - 5 kV DC bias @ Cathode
- no RF trips,
- sometimes microphonics problems with LN2 filling
- dark current in FC: ≤ 20 nA

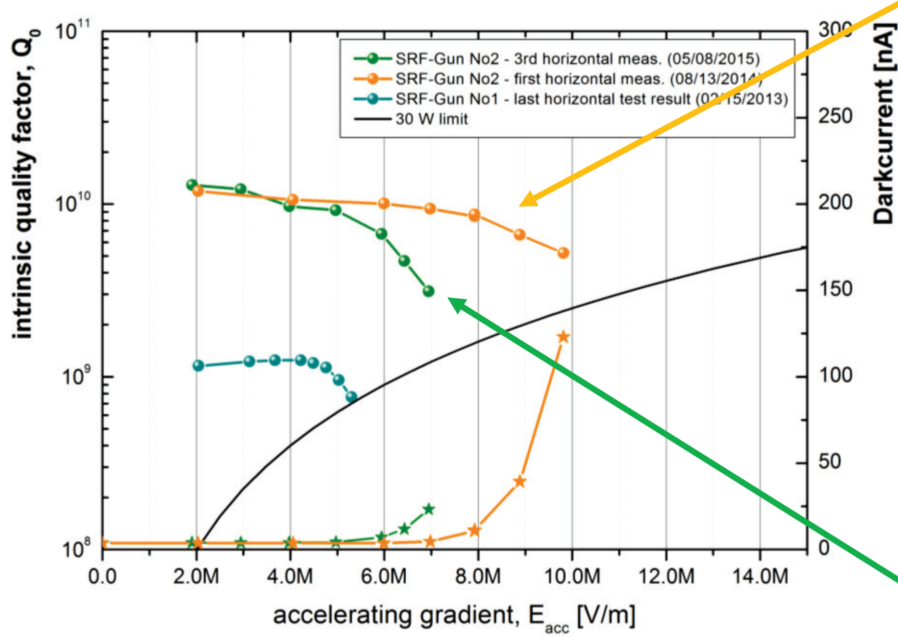
PHOTO CATHODE

- Cu, polycrystalline, mirror-like polished, QE approx. 2×10^{-5} @ 258 nm
- 3 … 300 nA CW beam current (0.03- 3 pC @ 100 kHz rep. rate)
- Cathode ca. 2 mm retracted in half-cell hole

UV LASER

- λ = 258 nm, 200 … 800 mW on laser table, 0.1 & 13 MHz rep. rate, CW
- ca. 5 – 10 % power on cathode (cutting aperture, window & mirror losses)
- longitudinal profile: Gaussian, appr. 10 ps FWHM @ 100 … 500 kHz
  appr. 3 ps FWHM @ 13 MHz
- transverse profile: flat-top 1 - 2 mm diameter

SRF gun II cavitiy performance



June 2014 – Feb. 2015

Cu cathode QE = 2×10^{-5},
low dark current,
no multipacting
acc. gradients: 6 – 9 MV/m

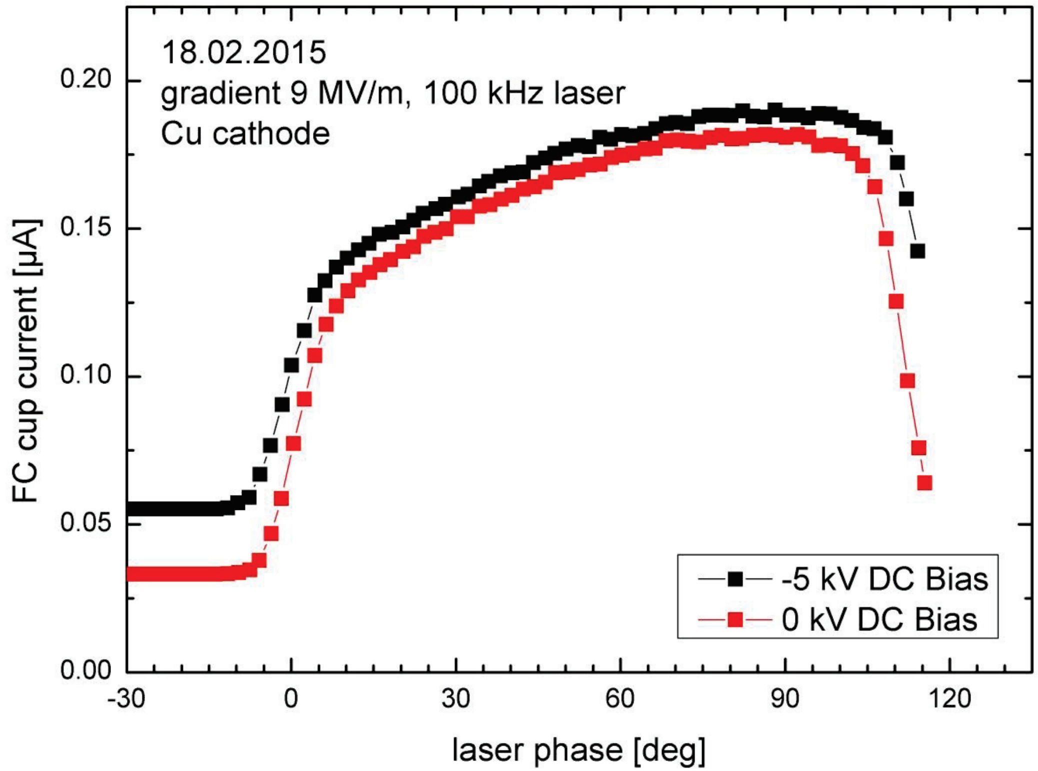
Feb. 2015

first try with Cs2Te
bad cathode

Since May 2015

Cu cathode QE = 2×10^{-5},
higher dark current (20 nA)
higher He losses (13.5 W)
no multipacting
acc. gradient: 7 MV/m

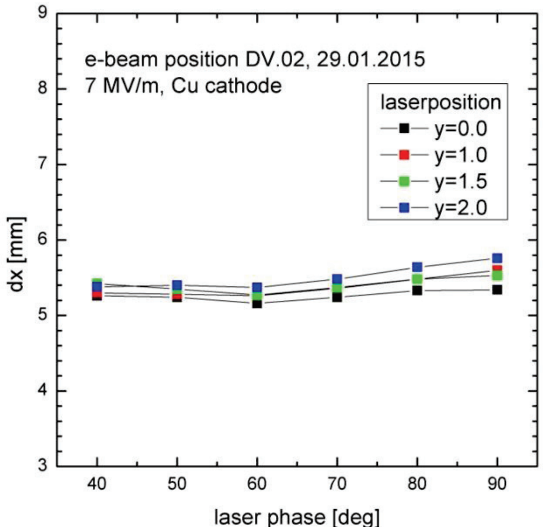
Laser phase scan

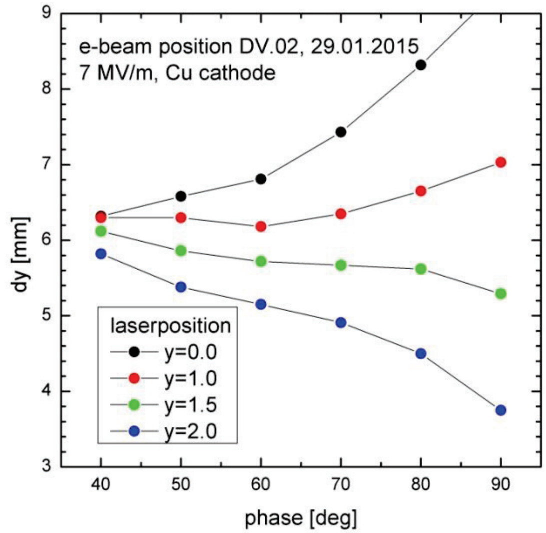


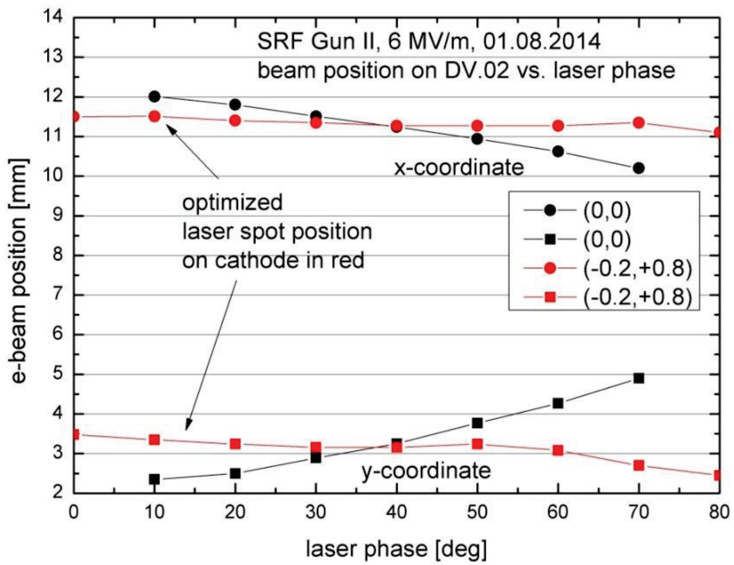
laser phase adjustment with current measurement at low bunch charge

$$E_z = -E_z(0) sin\omega t$$

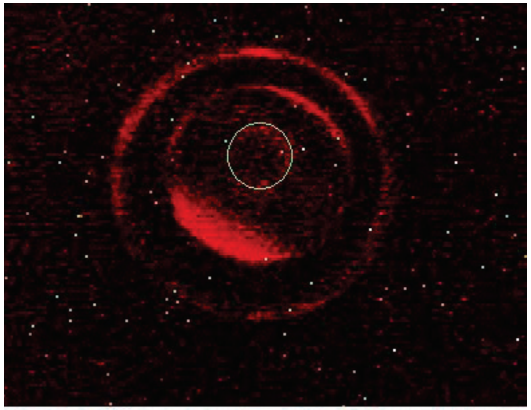
Adjustment of laser spot on photo cathode



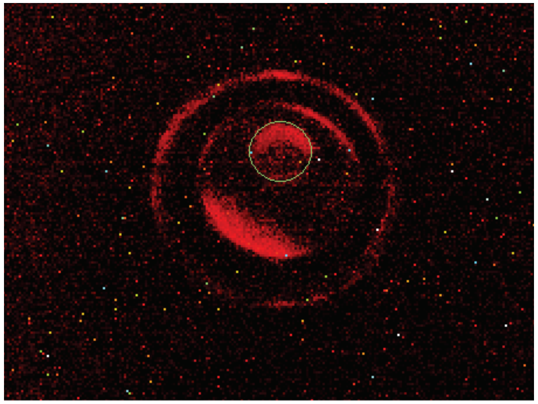




initial



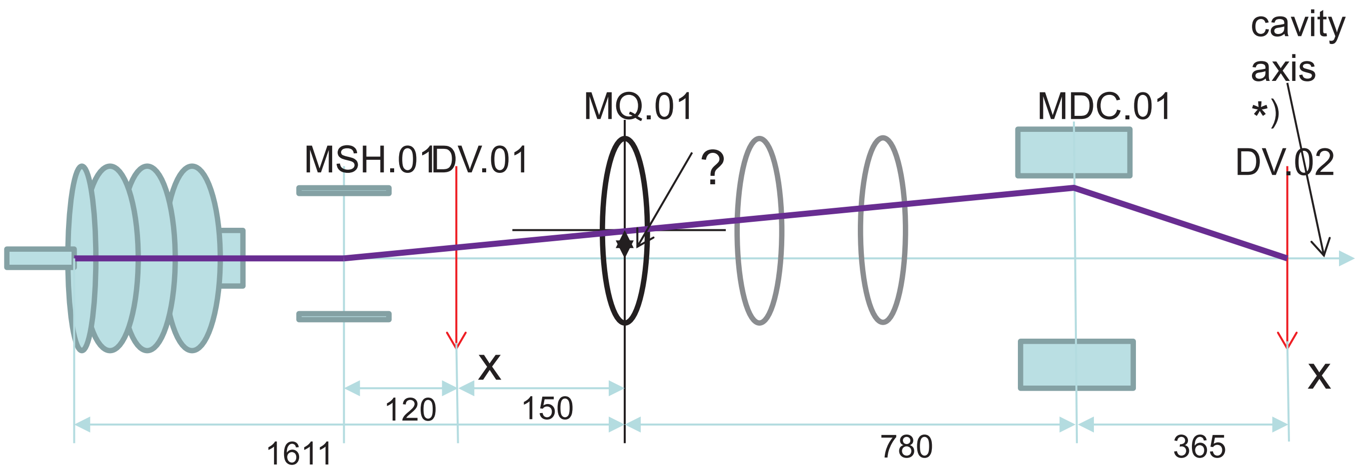
final



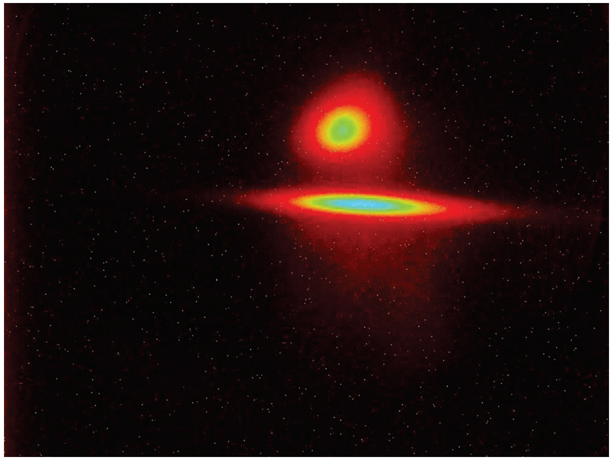
solenoid, quads, steerers are switched of,
accuracy of positioning: ~ 100 µm,
effect on emittance for Δx = 100 µm is less
than measurement accuracy (for Cu with ~ 1 pC)

Cavity axis alignment

Cavity axis is moving in the cryomodule during cool-down
readjustment with respect to the beamline axis using the quadrupole triplet

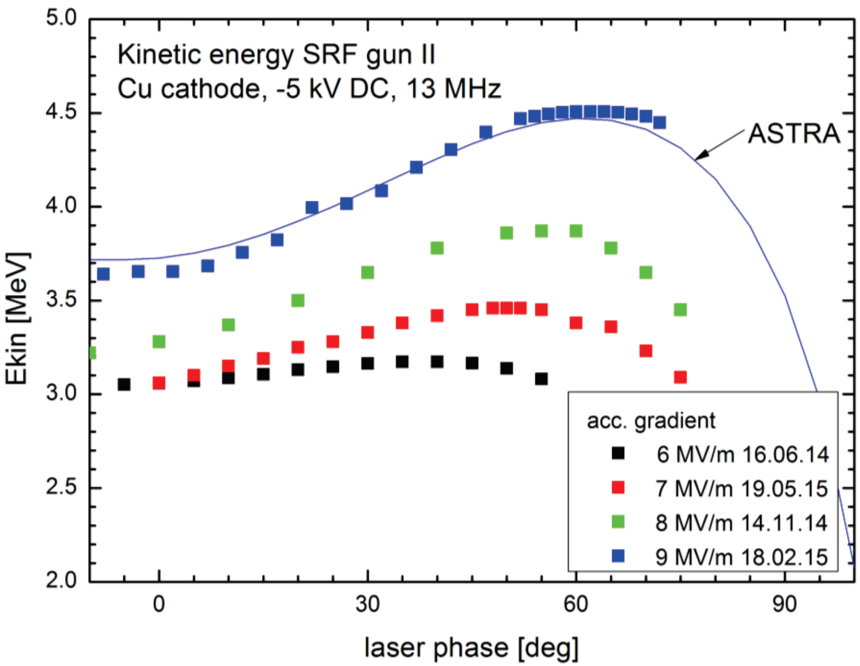


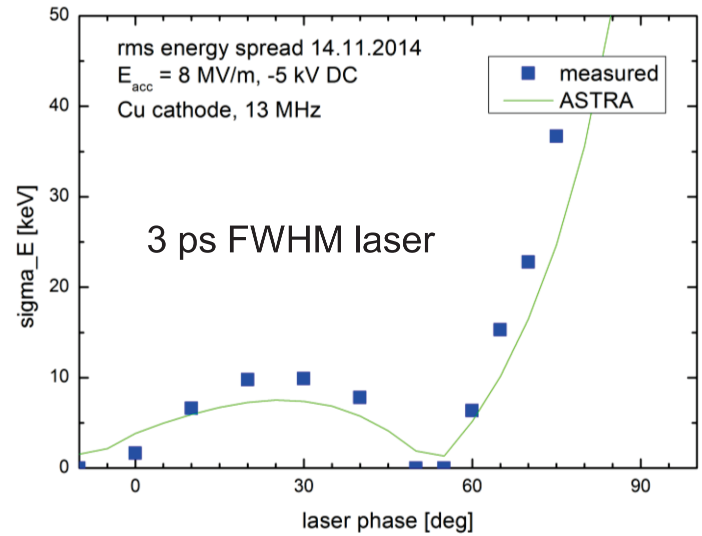
*) defined by
phase scan alignment

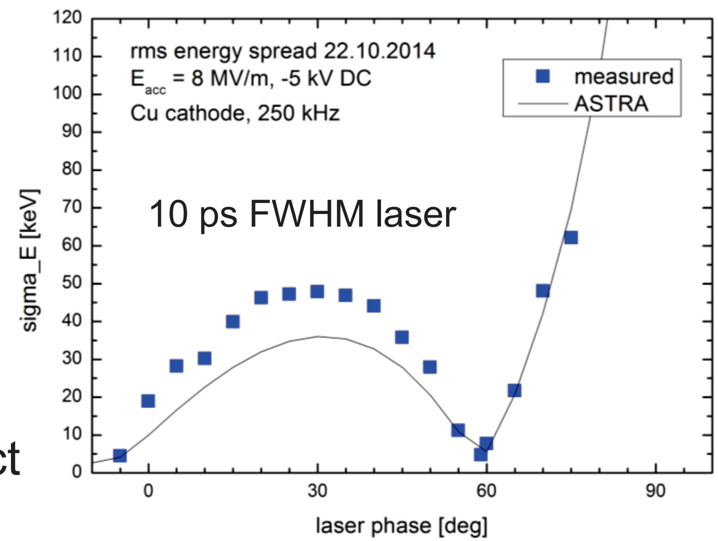


first: Δx = ~4 mm between beam axis and quad center
tilding and shifting cavity and repeating several times
finally: accuracy ~50 µm

Kinetic energy and energy spread

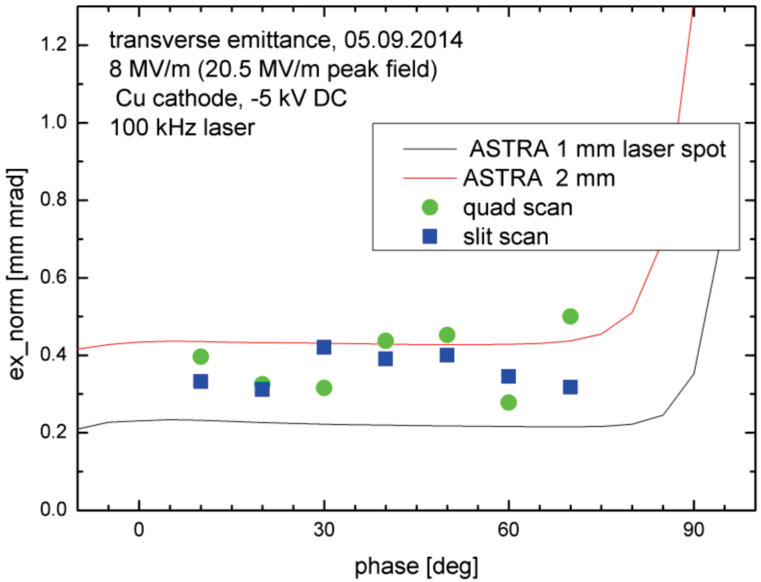


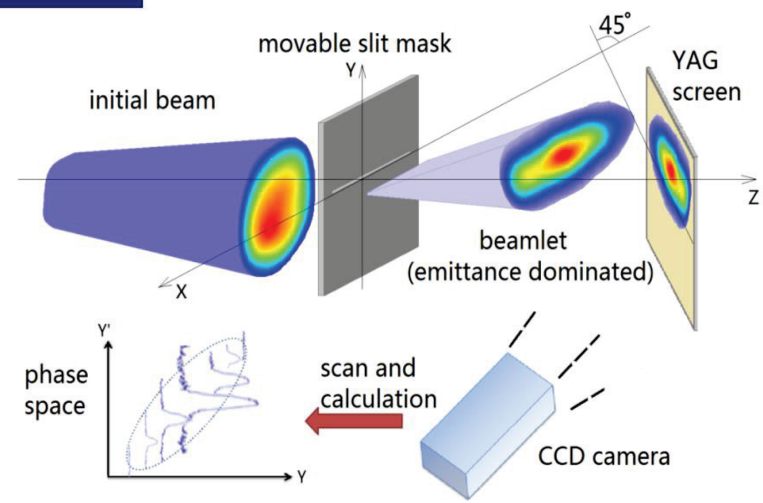




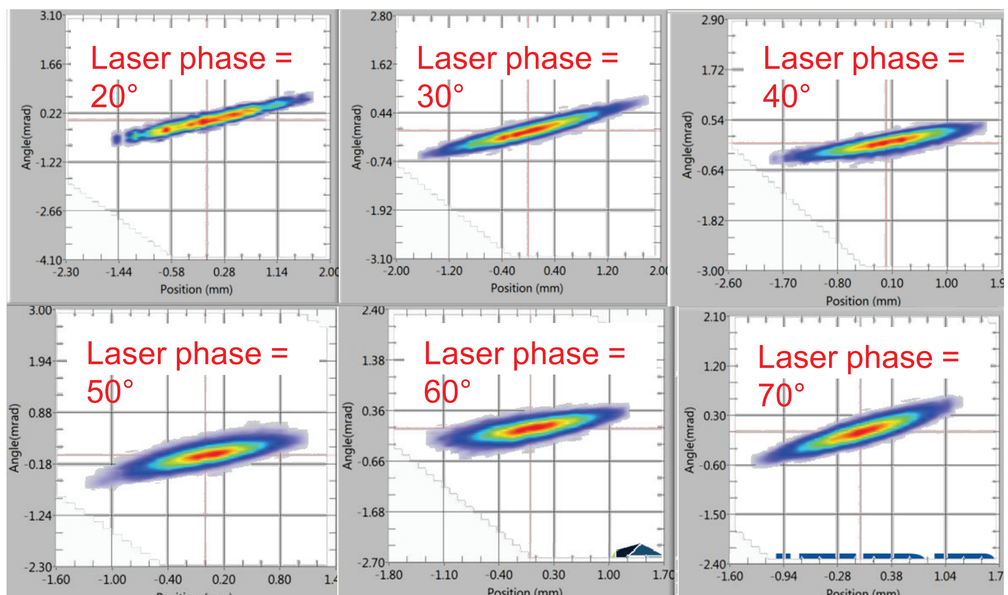
laser phase:
playing with correlated energy spread
- transmission in dogleg
- compensation of long. space charge effect in low-energy beamline to accelerator

Transverse rms emittance





$$\varepsilon_{n,rms} = \beta\gamma\sqrt{\langle x^2\rangle\langle \dot{x}^2\rangle \ldots}$$

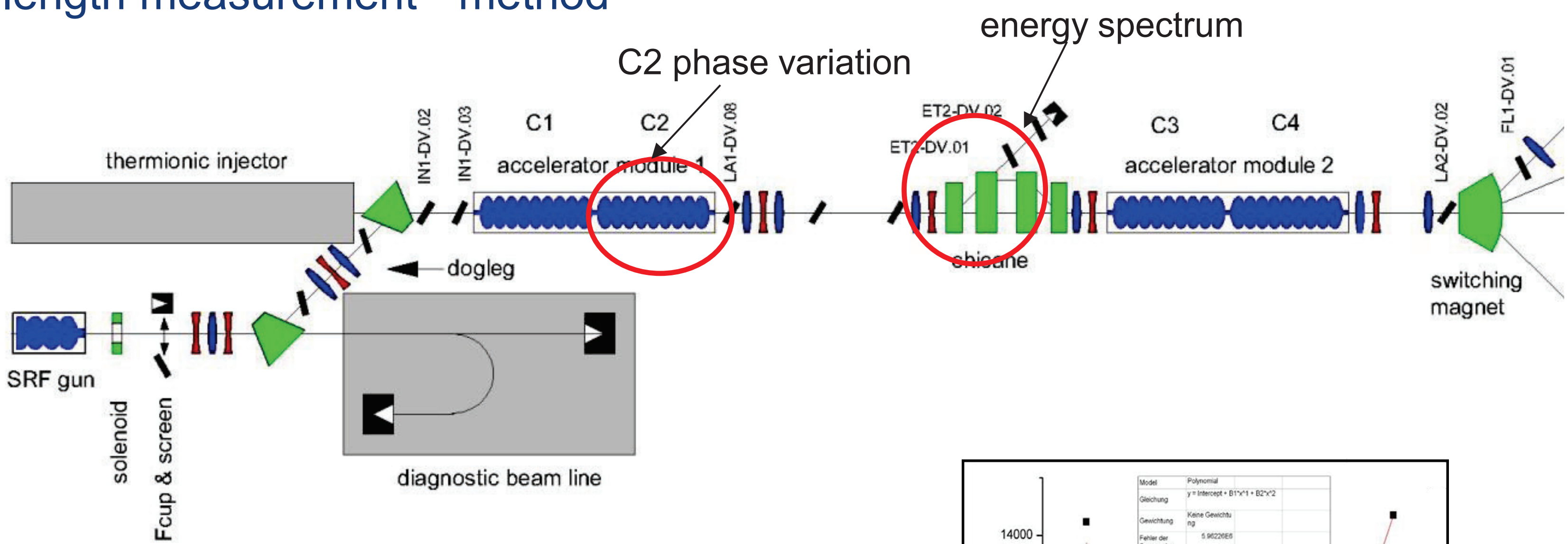


$$\varepsilon_n = \sqrt{\varepsilon_{rf}^2 + \varepsilon_{th}^2 + \varepsilon_{sc}^2}$$

thermal emittance dominates is independent of laser phase

$$\varepsilon_{n,th} = \sigma_{x,laser}\sqrt{\frac{E_k}{mc^2}}$$

Bunch length measurement - method

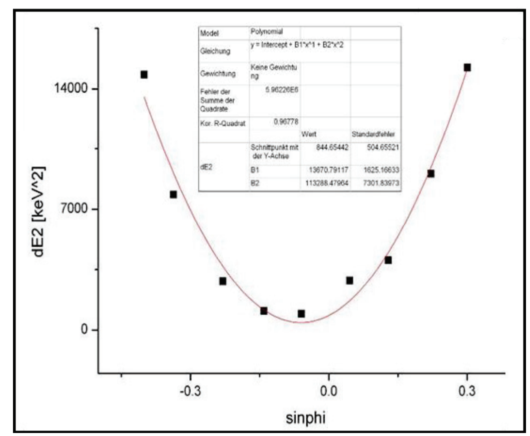


longitudinal beam ellipse

$$\tau = \begin{pmatrix} \tau_{11} & \tau_{12} \\ \tau_{12} & \tau_{22} \end{pmatrix}$$

$$\sqrt{\tau_{11}} = \sigma_t \; rms\ bunch\ length\ (ps)$$

$$\sqrt{\tau_{22}} = \sigma_E \; rms\ energy\ spread\ (keV)$$



$$R_{C2} = \begin{pmatrix} 1 & 0 \\ -\omega_{RF} V_{C2} \sin(\varphi_{C2}) & 1 \end{pmatrix}$$

cavity energy boost :

$$V_{C2} \cos(\varphi_{C2})$$

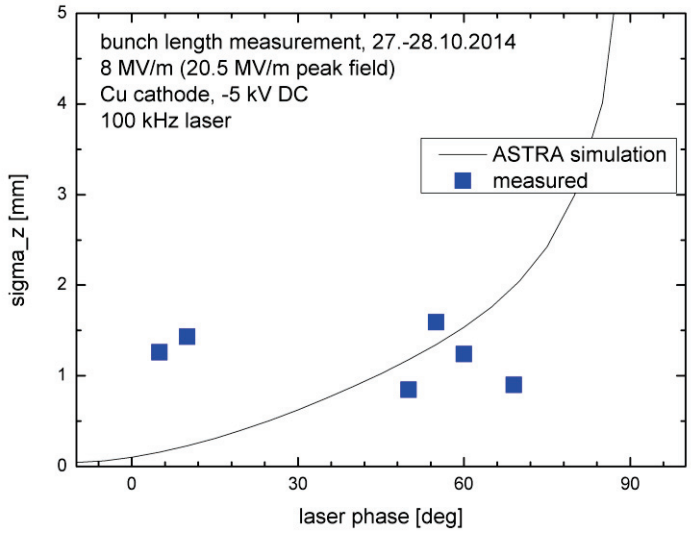
$$\tau(1) = R_{C2} \tau(0) R_{C2}^T$$

from parabola fit

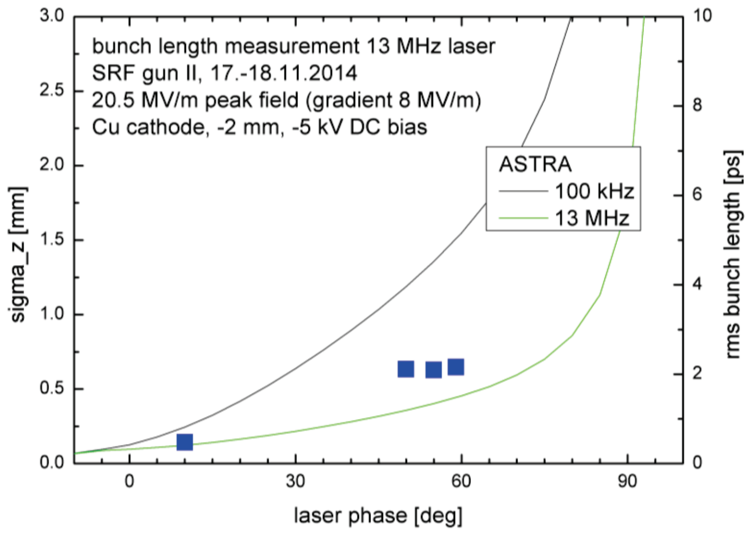
$$\sigma_E^2(1) = \tau_{22}(0) - 2\tau_{12}(0) V_{C2} \sin(\varphi_{C2}) + \tau_{11}(0)(V_{C2} \sin(\varphi_{C2}))^2$$

Bunch length measurement - results

10 ps FWHM laser



3 ps FWHM laser (13 MHz)



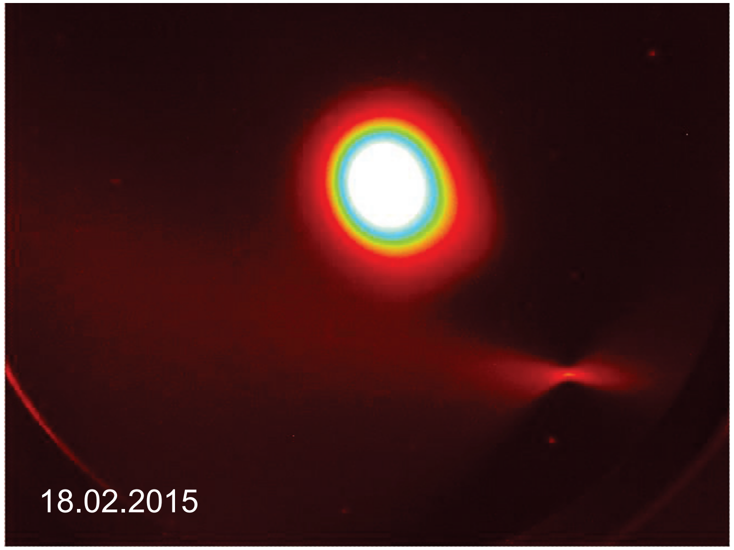
Method need correction due to the beam transport through dogleg: R56 (low energy velocity term $1/\gamma^2$)
longitudinal space charge effect

dark current: field emitters in cavity and on photo cathode

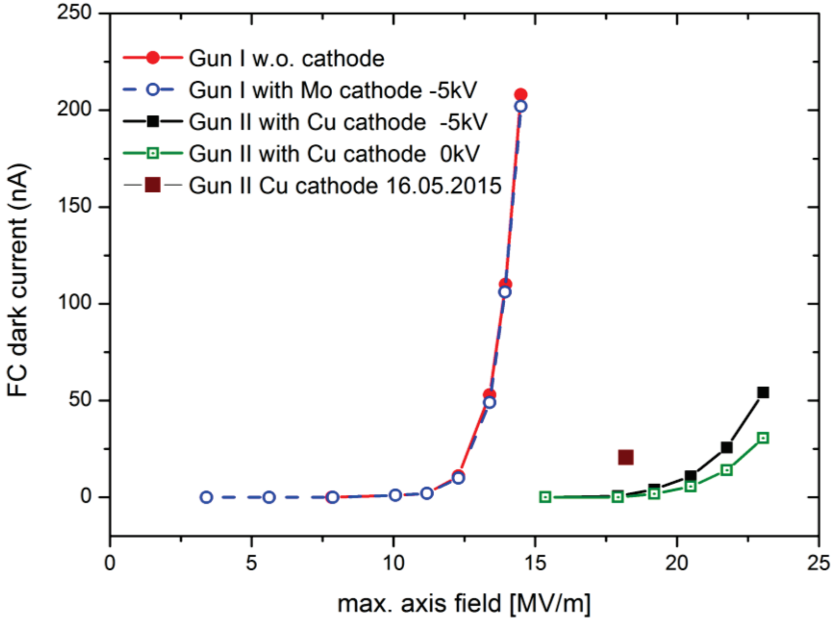
cavity: quality of treatment and cold mass assembly
particle contamination during cathode exchange !
only emitters near cathode and on iris contribute (beam direction &energy)

photo cathode:
emission layer roughness, effects of discharges, coating adhesion, particle pollution
not measured here

comparison of dark current
SRF guns I &II for „clean“ cathodes

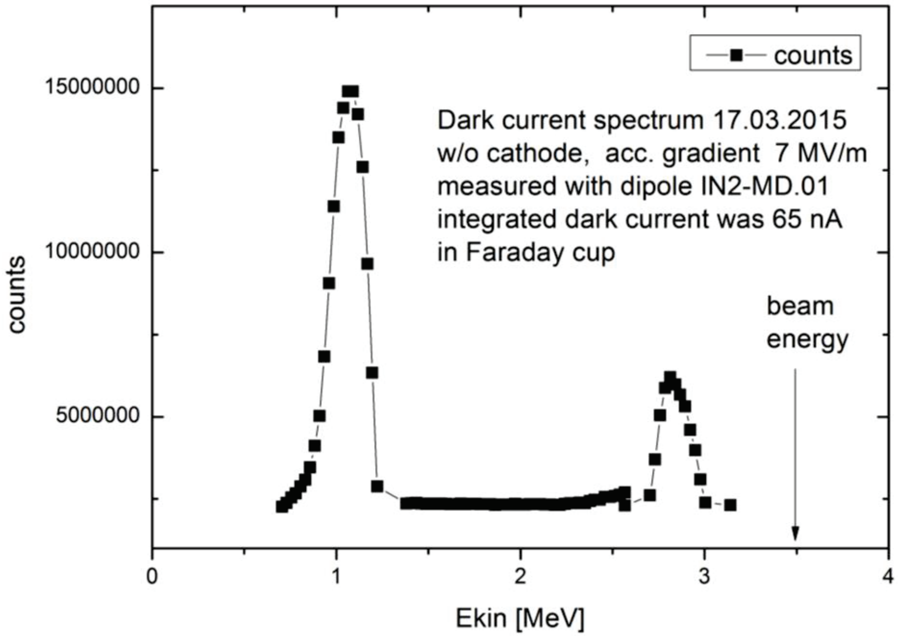


beam spot 200 nA and dark current 53 nA
at 9 MV/m (23 MV/m peak)

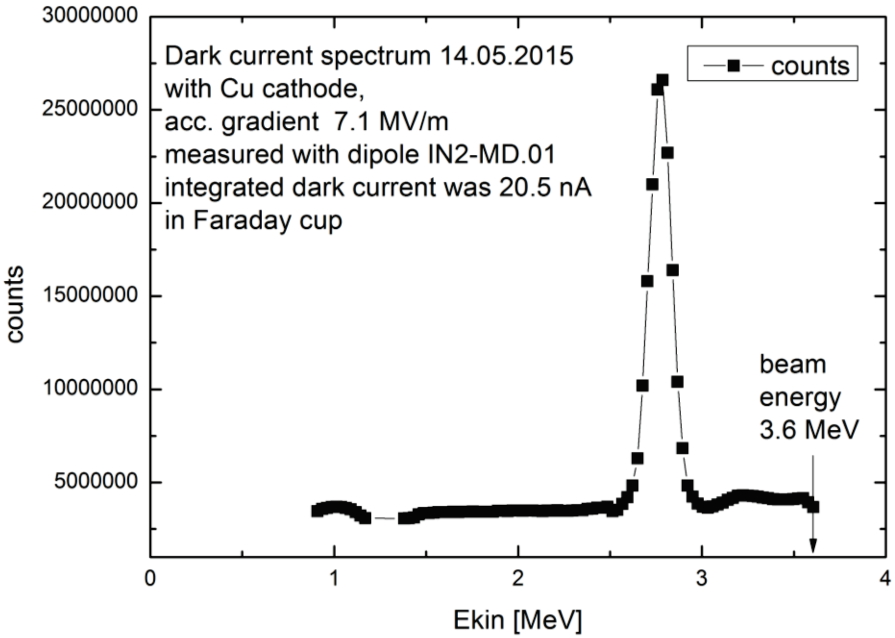


Dark current energy spectra at 7 MV/m

without photo cathode



with Cu photo cathode & after pulsed RF conditioning



Machine safety: dark current of 20 nA sufficient low

User requirements: neutrons, ToF measurements < 1.5 x 10^{-5}

100 µA beam current: 2 x 10^{-4} & further suppression since wrong energy

photo cathode contribution?

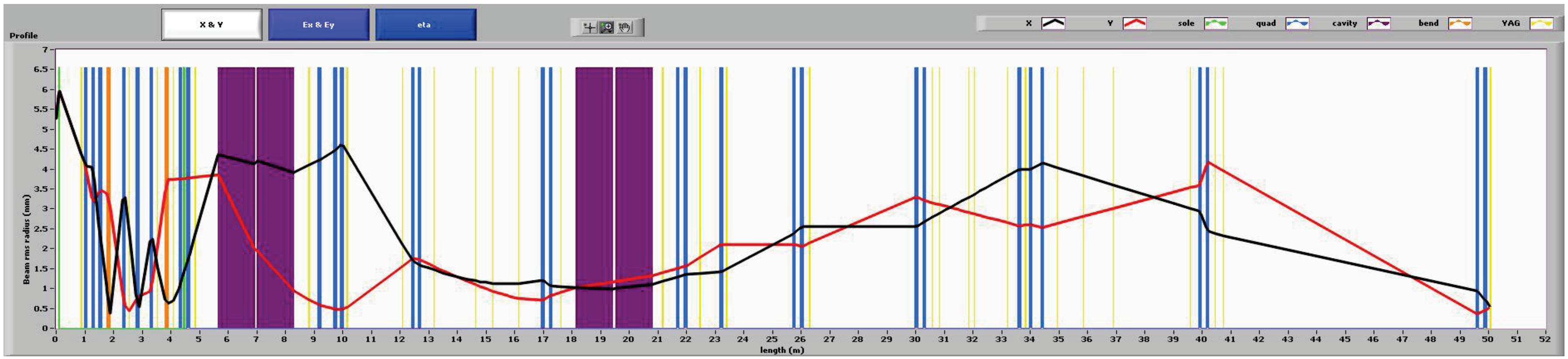
dark current kicker? R. Xiang et al., Phys. Rev. STAB 17, 043401 (2014)

Users require higher bunch charge > 77 pC

Example: neutron production for ToF experiments

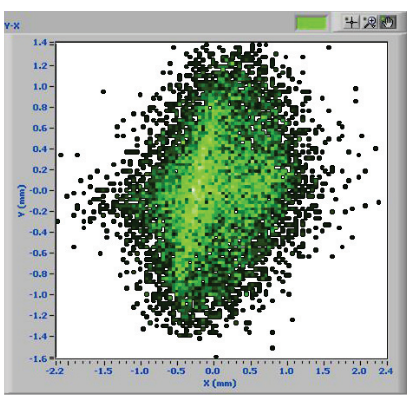
ASTRA + Elegant

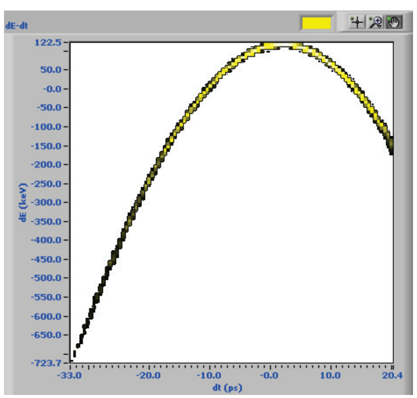
Simulation Results 500 pC, 6 ps, lp 40°, cath. retract. 1.9 mm SRF Gun @7 MV/m:



rms beam profile - x axis, - y axis

parameter	unit	@Gun	@TL1DVO01
E_{tot}	MeV	4.0	27.8
bunch length	ps	10.1	12.1
dE	keV	15.8	140.0
x_{rms}	mm	5.3	0.5
x'_{rms}	mrad	6.8	1.0
ε_x	µm	6.8	13.2





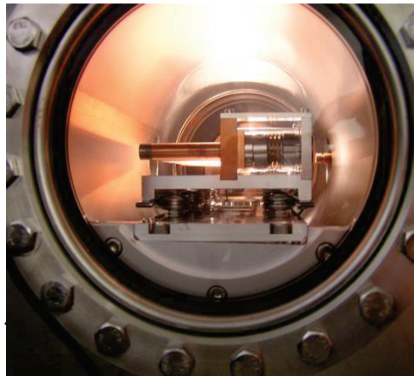
DRESDEN concept

HZDR

Summary ELBE user requirements and simulations at 7 MV/m (E_{kin} = 3.5 MeV)

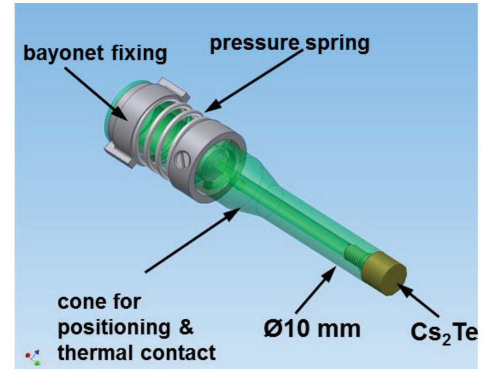
user application	bunch charge	norm trans. emitt.	final bunch length	beam size at IP	average current
IR FELs (13 MHz)	77 pC	2.2 µm	< 1 ps		1 mA
Neutrons (100 kHz)	500 pC				50 µA
Positrons (500 kHz)	200 pC				100 µA
THz radiation (100 kHz)	350 pC		200 fs		35 µA
CBS x-rays (10 Hz)	450 pC		1 ps	30 µm	

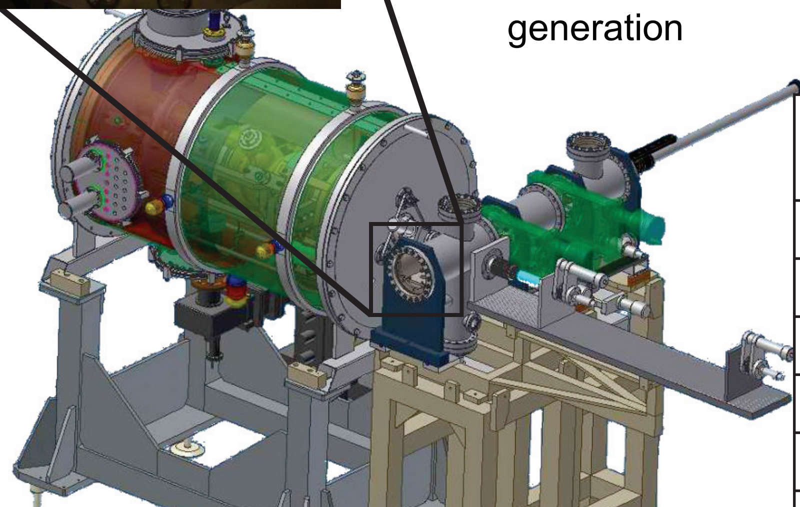
SRF Gun I results: excellent lifetime of Cs2Te PC in SRF gun



Requirements for Transfer:

- Load lock system with < 10^{-9} mbar to preserve QE ≥ 1 %
- Exchange w/o warm-up & in short time and low particle generation





Cathode	Operation days	Extracted charge	Q.E. in gun
#090508Mo	30	< 1 C	0.05%
#070708Mo	60	< 1 C	0.1%
#310309Mo	109	< 1 C	1.1%
#040809Mo	182	< 1 C	0.6%
#230709Mo	56	< 1 C	0.03%
#250310Mo	427	35 C	1.0%
#090611Mo	65	< 1 C	1.2%
#300311Mo	76	2 C	1.0 %
#170412Mo	From 12.05.2012	265 C	~ 0.6 %

- fresh QE 8.5%, in gun 0.6%
- total beam time 600 h
- extracted charge 265 C

01.08.2013

problems: multipacting, QE drop-down during storage

Most importent problem and present activity: Photo cathodes

- Upgrade of the cathode transfer system
  final quality check immediately before use (visual insp., QE, pollution)

- Preparation system upgrade and production of new Cs2Te PC
  identification of QE drop down, prevention of particle contamination

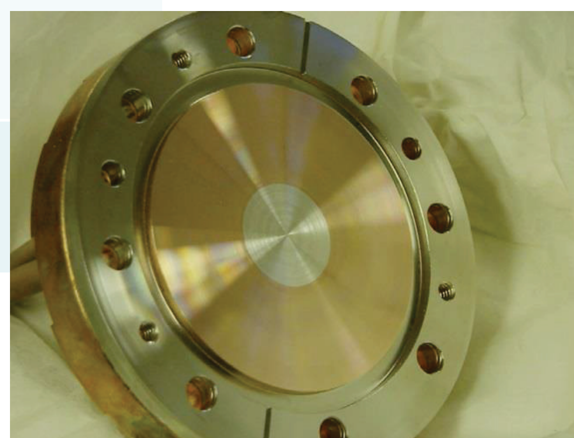
- high QE metallic cathode (no bad layer, no multipacting)
  Mg: QE = 0.002, beam up to 100 µA
  in-situ laser cleaning or ion beam sputtering

Magnesium full metal cathode

Metal	QE (%)	XPS for sample surface(%) O 1s	XPS for sample surface(%) C 1s	Work Function (eV)
Al				
Received				
Ar^+ sputter				
Ag				
Received				
Ar^+ sputter				
Cu				
Received	5.0E-6	32.9	66.2	5.4
Ar^+ sputter	1.1E-5	0	0	5.3
Mg				
Received	6.0E-6	35.2	52.3	3.4
Ar^+ sputter	**1.7E-3**	40.0	0	3.4
Mo				
Received	1.47E-7	24.2	64.9	5.1
Ar^+ sputter	2.48E-6	7.8	17.8	5.2

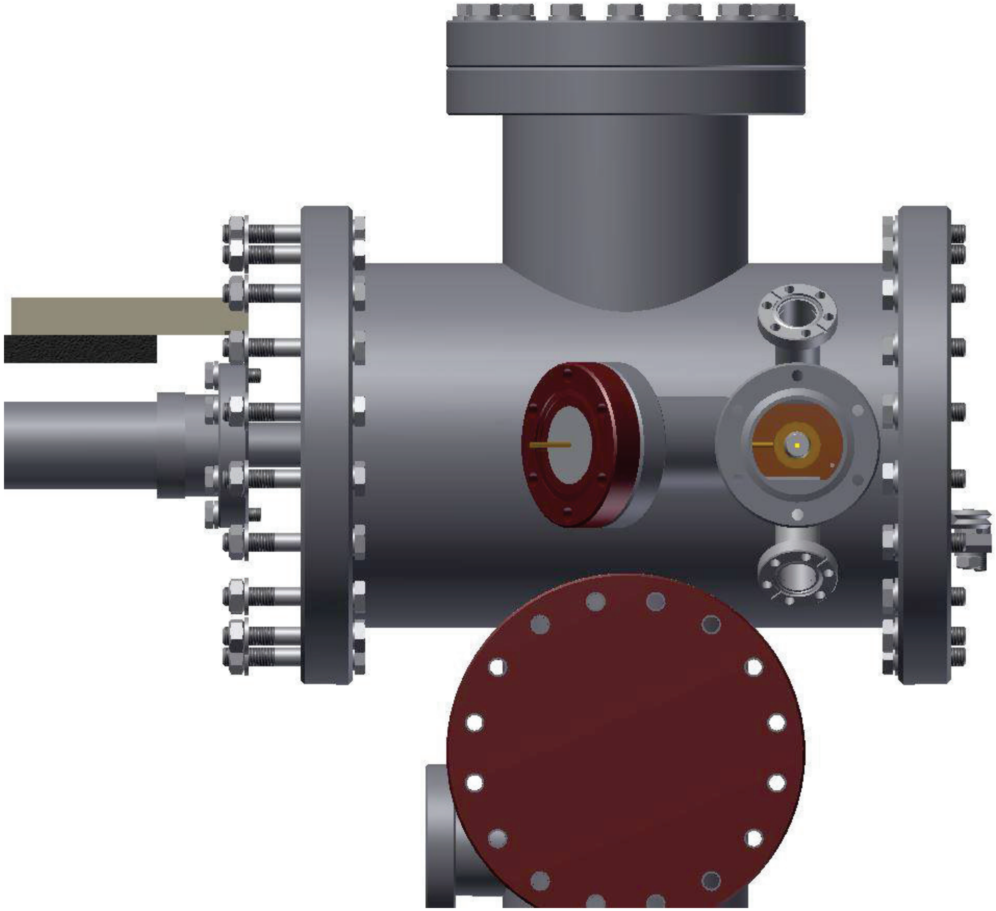
S. Mistry et.al. 2015
ASTeC Daresbury
Results of Ar^+ sputter cleaning of metal PC

- highest QE of a metal of 0.2 % @ 260 nm
- Oxide layer removal by in-situ
  ion beam sputtering, or
  laser cleaning
  (in transfer system of SRF Gun)
- excellent life time in UHV
- low dark current
- Allow e-currents up to 100 µA and up to 500 pC: improve for THz, neutrons, positrons at ELBE)
- „Clean solution“, No cavity contamination by a bad photo layer



Mg photo cathodes in use in NC Rf guns at BNL, Tokyo Uni.

Modification of Cs2Te transport camber



- Visual inspection port
- QE measurement
  UV beam port, anode port
- Particle polution check
  UV lamp, … ?

Summary

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 …)

Thank you for your attention!

Thanks to the ELBE team

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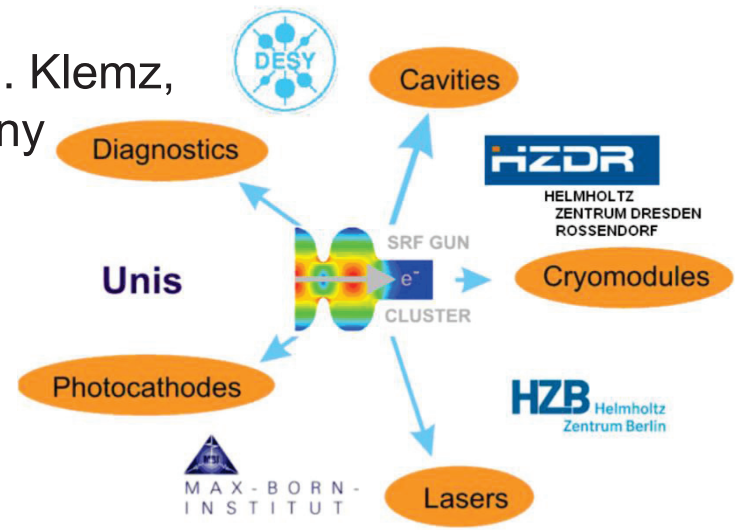

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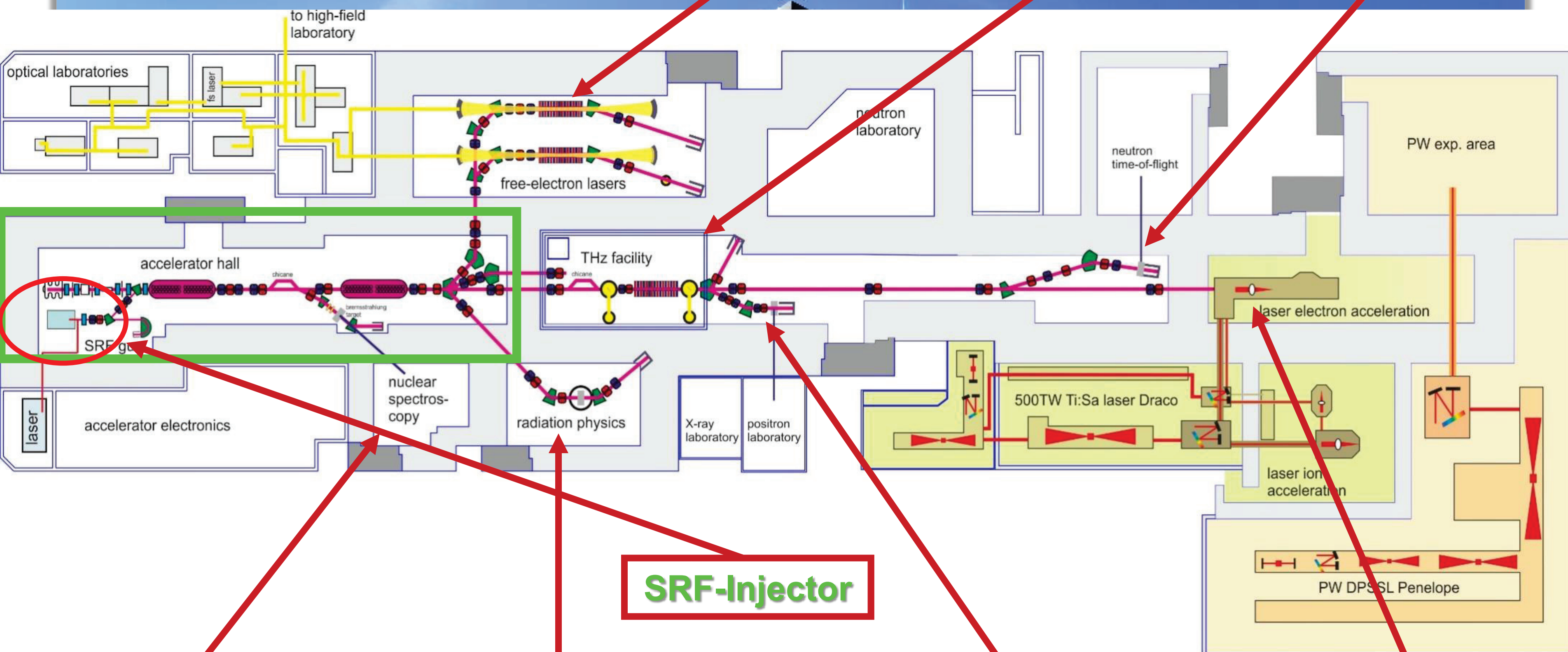
ELBE User Facility

1mA, 40MeV CW electron accelerator

coherent IR-radiation 3 – 230 µm

THz radiation 100 µm – 3 mm

neutron time of flight E_n 0 – 10 MeV



SRF-Injector

Bremsstrahlung 0 – 17 MeV

ELBE elctrons/ monochromatic X-rays 30 – 34MeV/10 – 100 keV

pulsed, mono-energetic positrons 0.2 – 30 keV

electron laser interaction