Commissioning results of the HZB SRF Gun for bERLinPro with a Cu cathode

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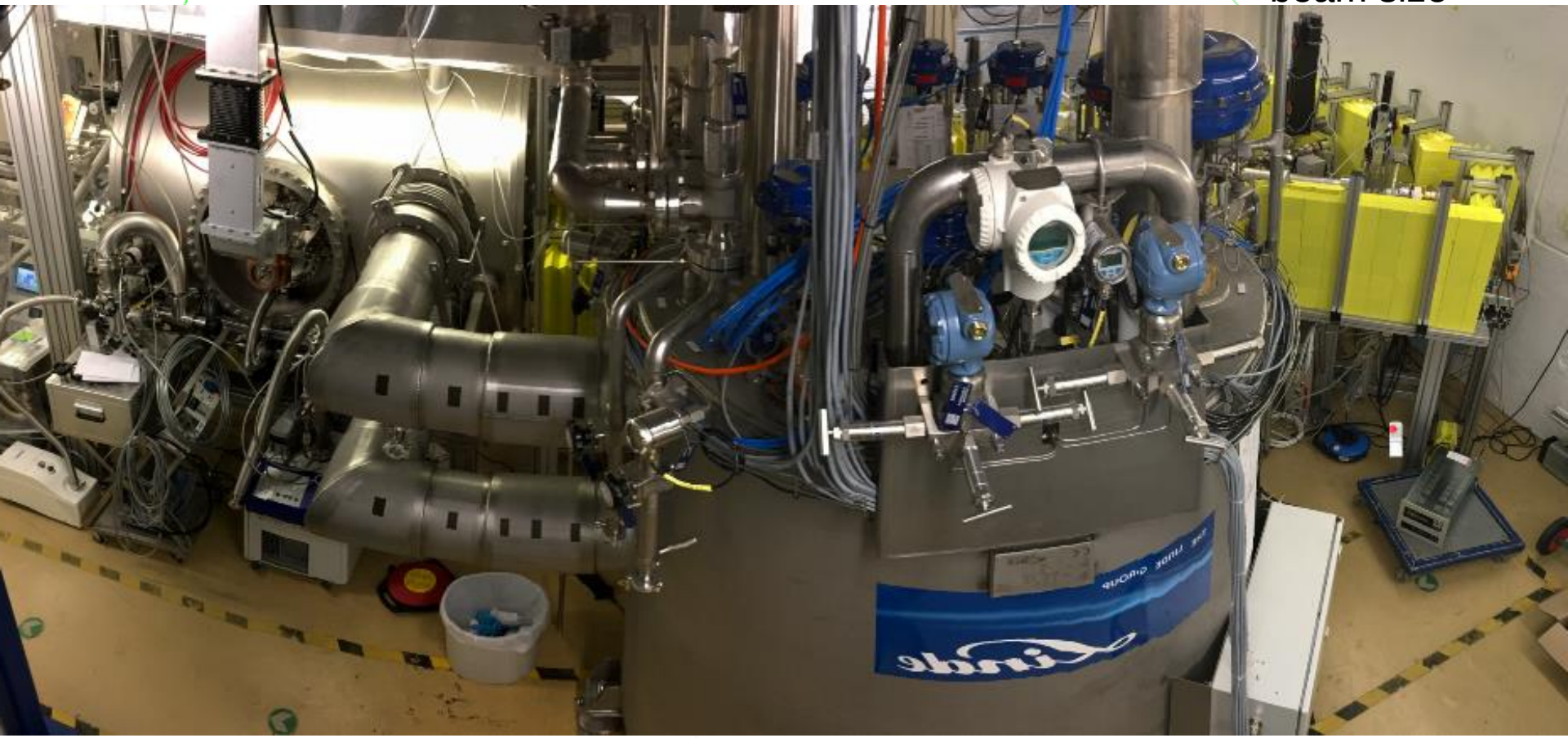
Overview of components & measurements

- **Laser**
  - power, spot size & pulse duration
  - cathode position
- **Cathode**
  - QE scan & map
  - Shottky scan
- **Gun**
  - dark current
  - DC-bias scan
  - RF gradient
- **e^- diagnostics**
  - phase scan for momentum (spread)
  + beam size



Timeline & incidents

- Measurements timeline:

dark current measured

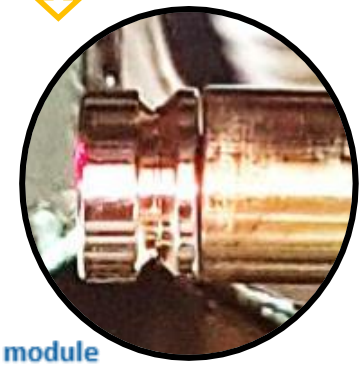
- First RF without cathode: 18–24.08.17
- 1st cathode insertion (inner cathode position): 13.09.17
- Cathode removal, helium processing: 14–15.12.17
- 2nd cathode insertion (outer cathode position): 19.12.17
- laser on: 22.12.17 – 15.01.18 ⇨ e- beam measurements

- solenoid short-circuit observed,
- beam-profile monitor broke,
- cavity accidentally vented

cathode warming frequency change

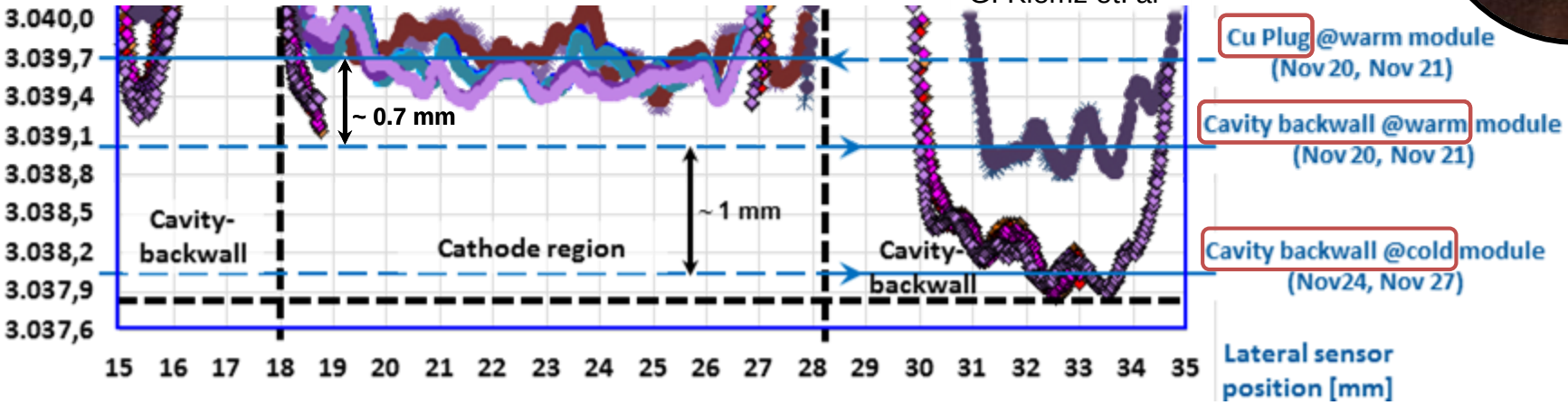
test of coldbox

DC-bias on



- Uncertain: RF calibration, solenoid strength, cathode position and cooling…

Courtesy: G. Klemz et. al

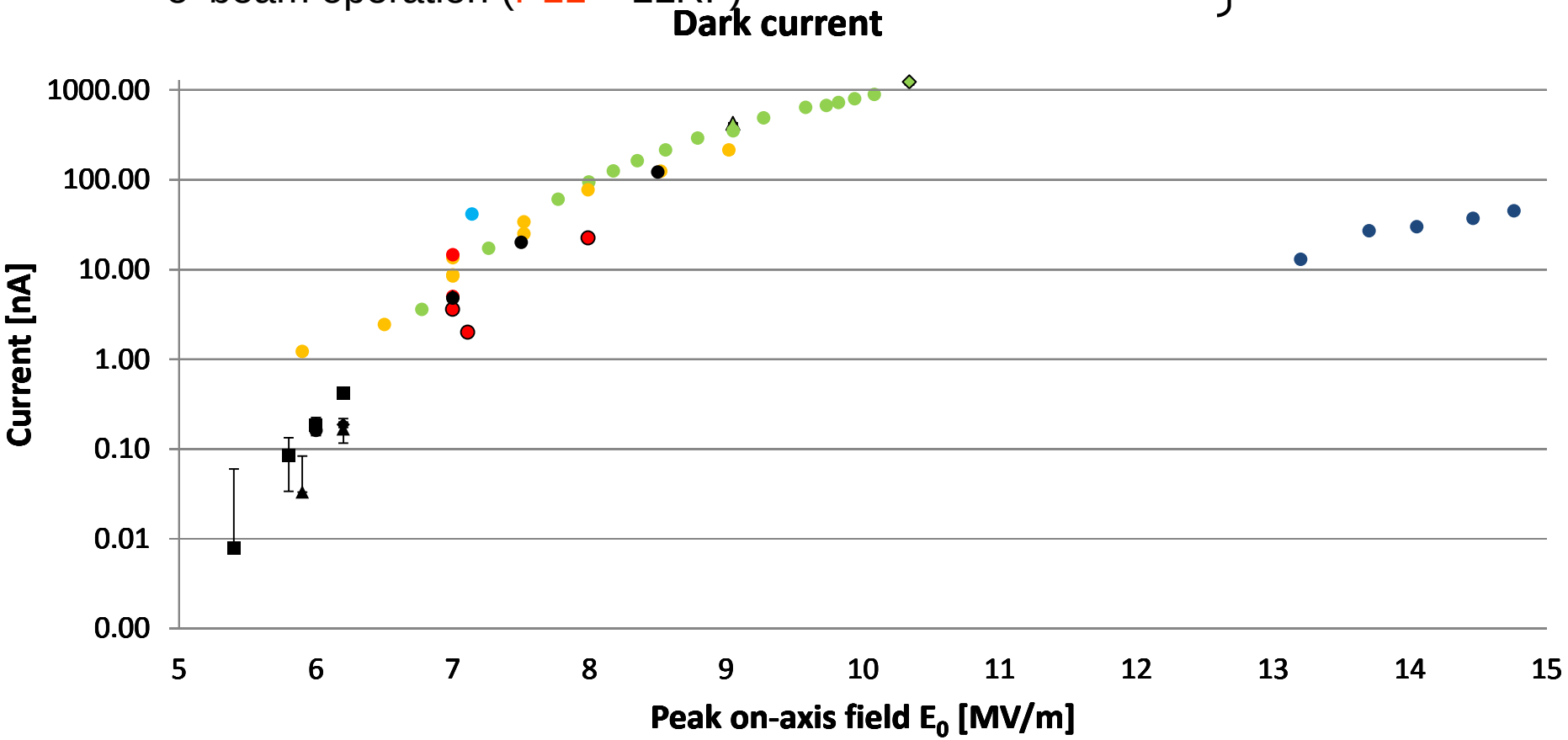


Dark current summary

- First RF without cathode
- 1st cathode insertion (inner cathode position + equipment failures)
- Cathode out & helium processing
- 2nd cathode insertion (outer cathode position)
- e- beam operation (PLL + LLRF)

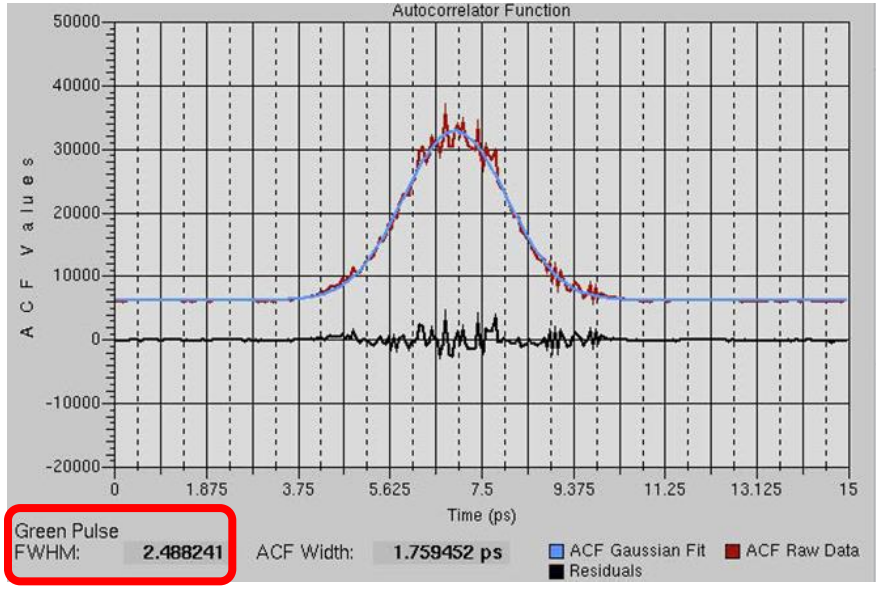
deviation above 8 MV/m due to DC bias / cathode?

measuring different emitters which overlap above 7 MV/m ?



Laser parameters

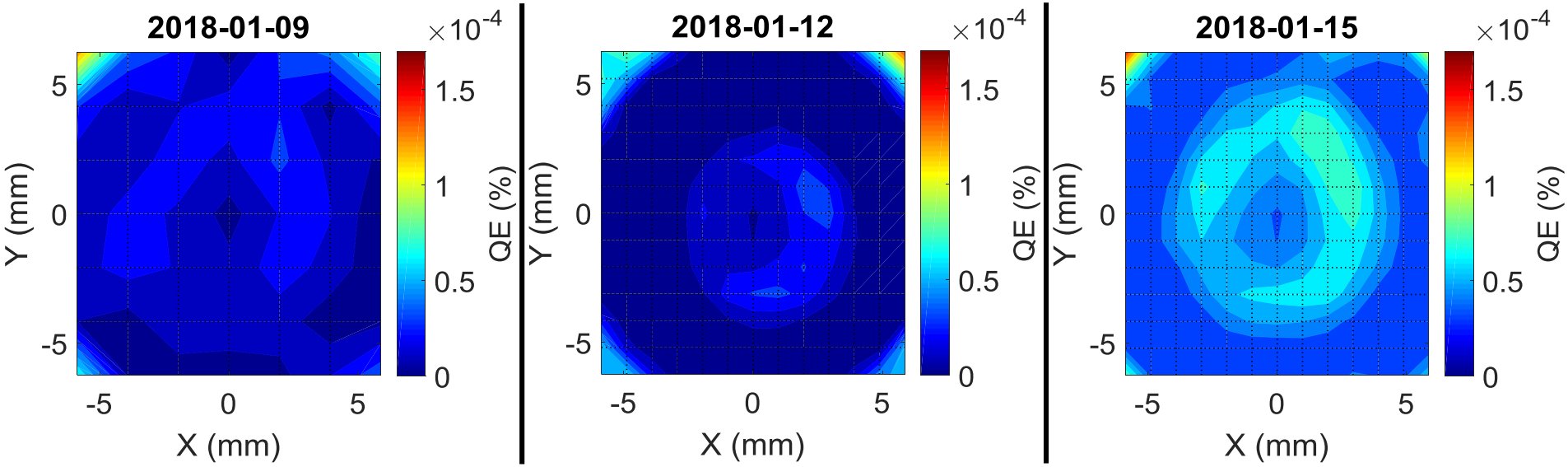
- Power meter:
  - After a cold-start ~10 minutes for stabilization
  - Short-term fluctuation: +/- 0.3 % rms, +/- 1.5 % max
  - Long-term drift: +/- 1.2 % rms, +/- 2.8 % max
- Pulse duration (optical auto-correlator):
  - long-term drift: ~ 4 h to stabilize to 0.6 ps rms (UV)
- Transverse parameters: “virtual cathode” + front camera



Quantum Efficiency maps

Laser: 1.75 mm diameter, 12.1 kHz rep rate

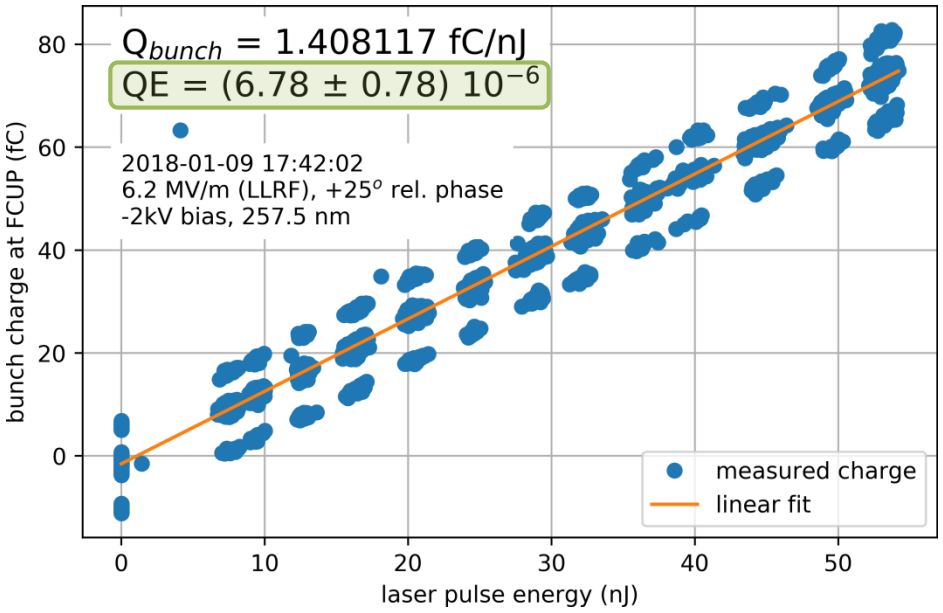
Date	Peak on-axis field (MV/m)	Relative RF phase (deg)	Momentum (MeV/c)	DC bias (kV)	Solenoid (A)
09.01	6.2	+25	0.94	-2	-0.36
12.01	6.0	+60	n/a	-2	-0.40
15.01	7.0	+50	n/a	-2	-0.36

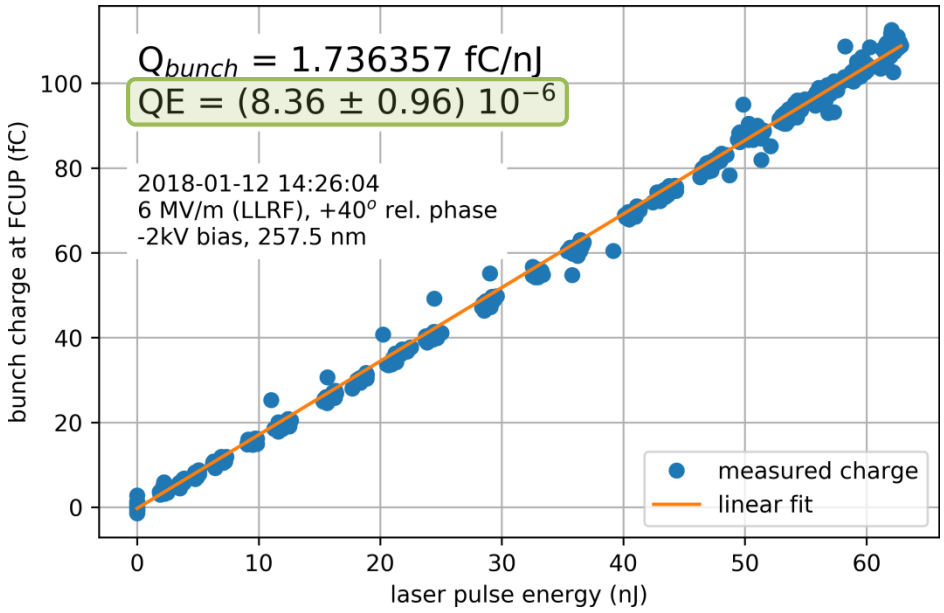


Quantum Efficiency scans

In agreement with Cu measurements from other photo-injectors

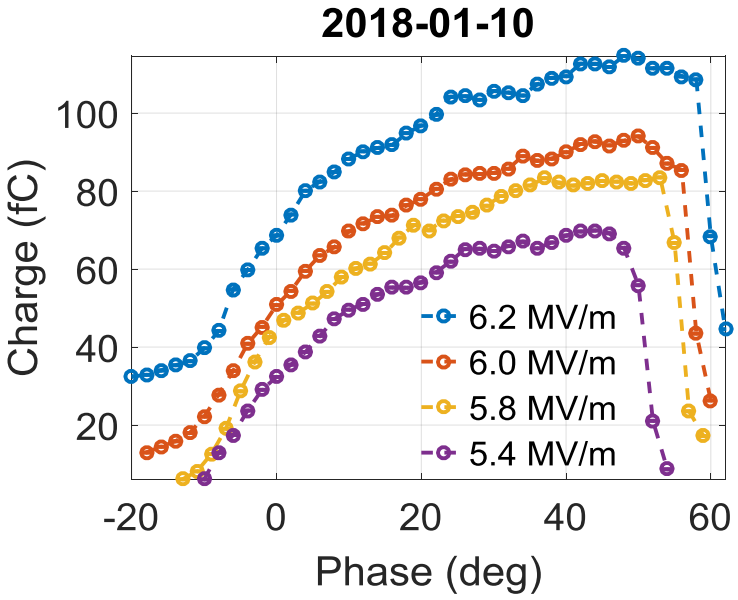
Date	Peak on-axis field (MV/m)	Relative RF phase (deg)	Momentum (MeV/c)	DC bias (kV)	Solenoid (A)
09.01	6.2	+25	0.94	-2	-0.36
12.01	6.0	+40	n/a	-2	-0.40

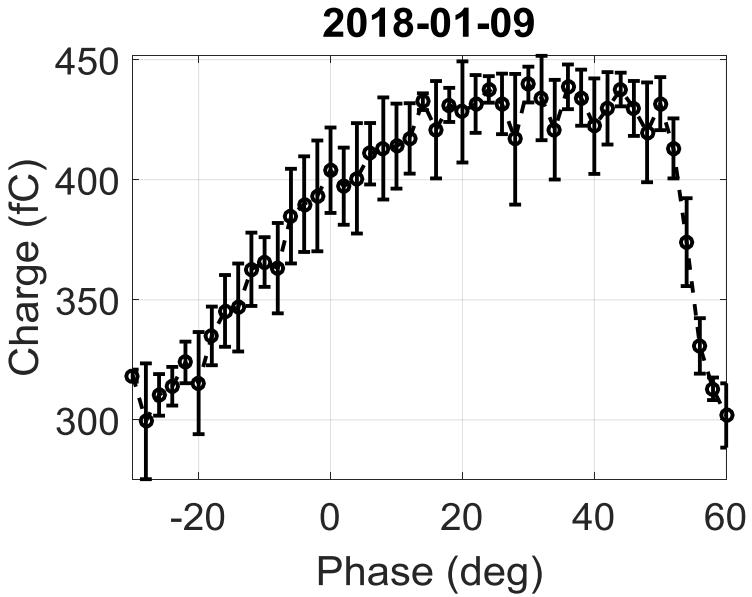


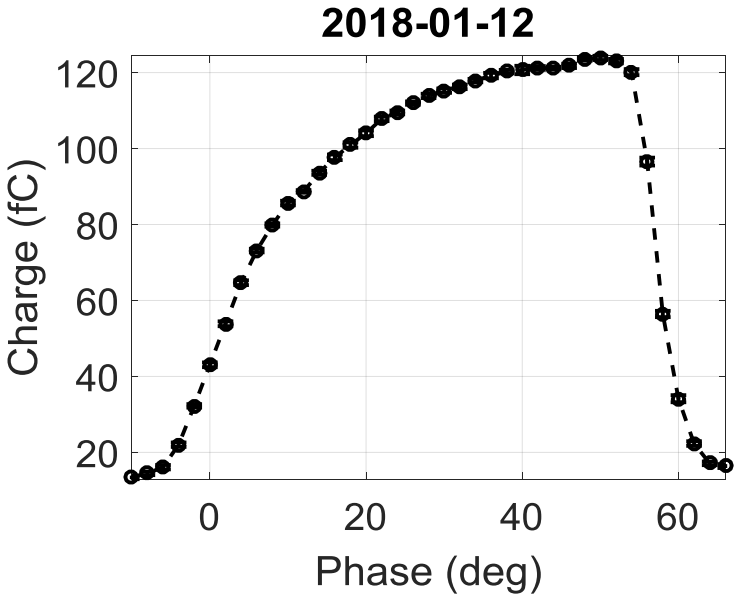


Photoemission scans

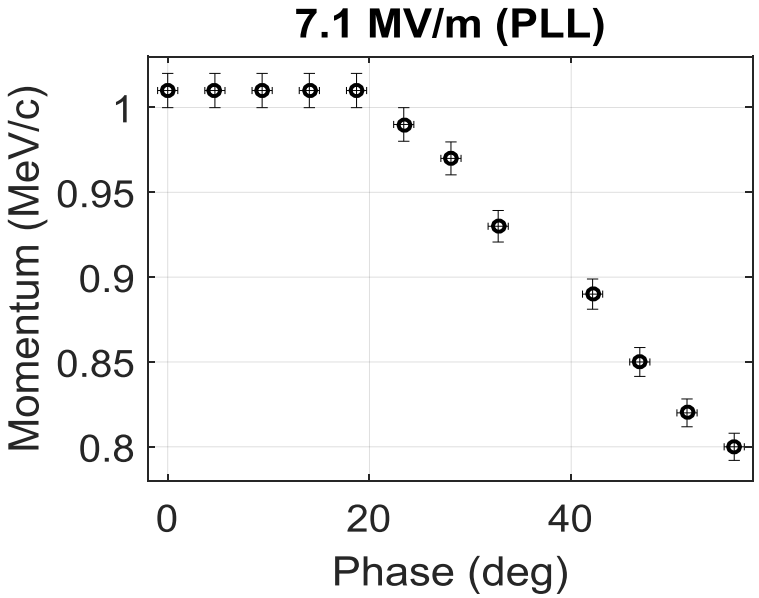
Date	Peak field (MV/m)	Laser power (mW)	DC bias (kV)
09.01	6.2	0.63	-5
10.01	5.4 - 6.2	0.47 - 0.51	-2
12.01	6.0	0.72	-2

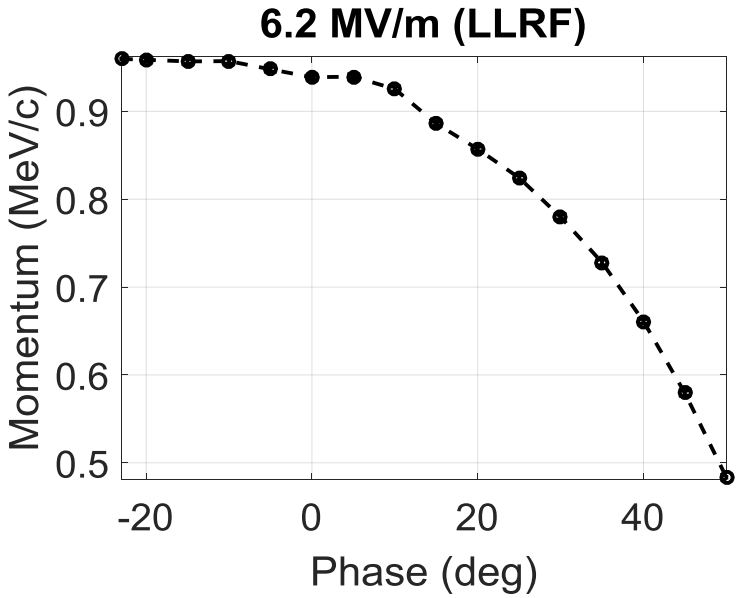


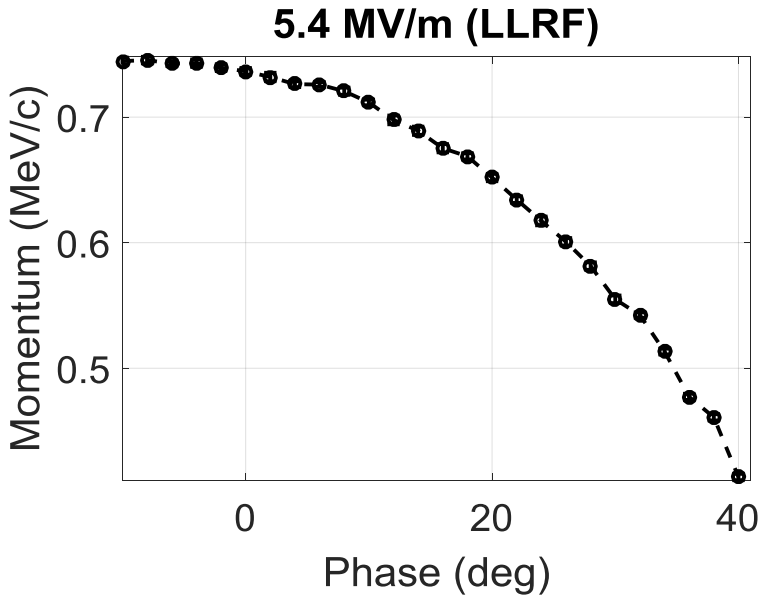


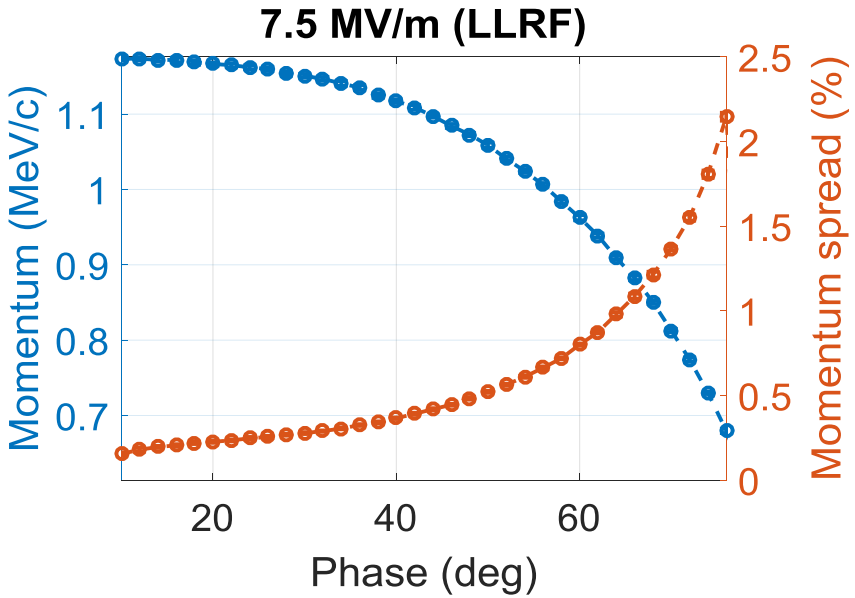


Momentum scans



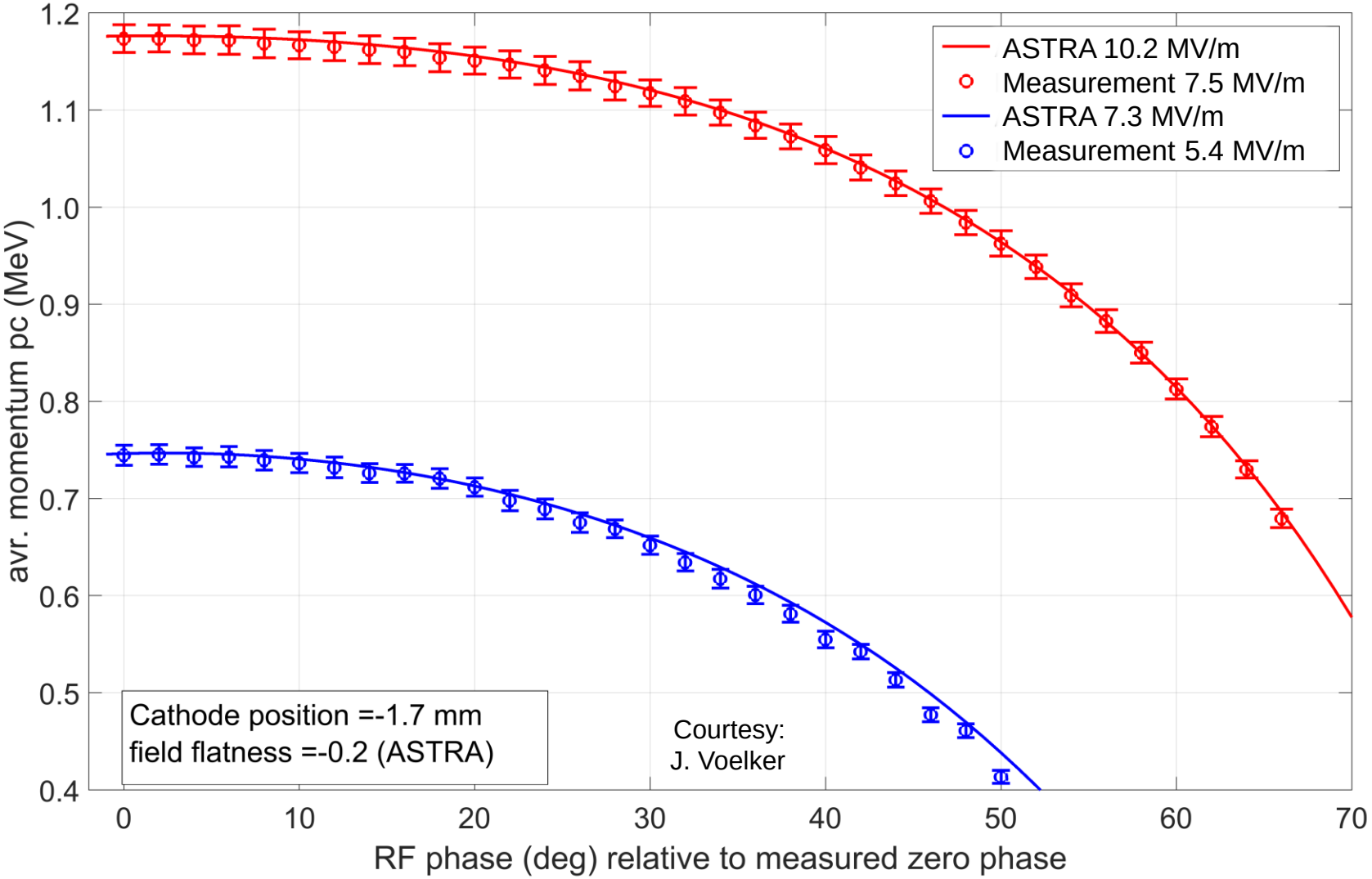






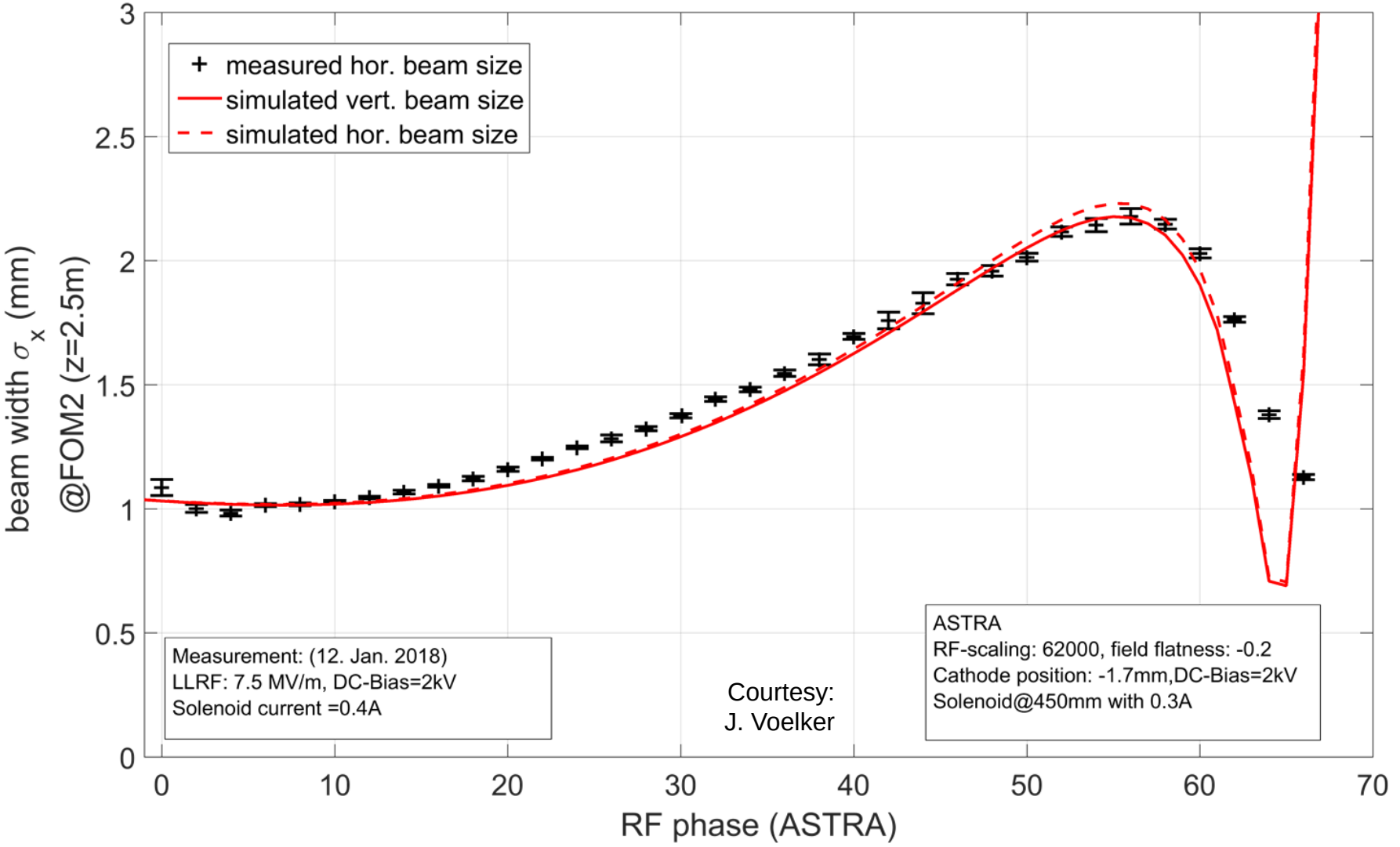
Simulating the measured momentum

ASTRA indicates +35% peak RF field



Simulating the measured beam size

ASTRA indicates -25% solenoid strength

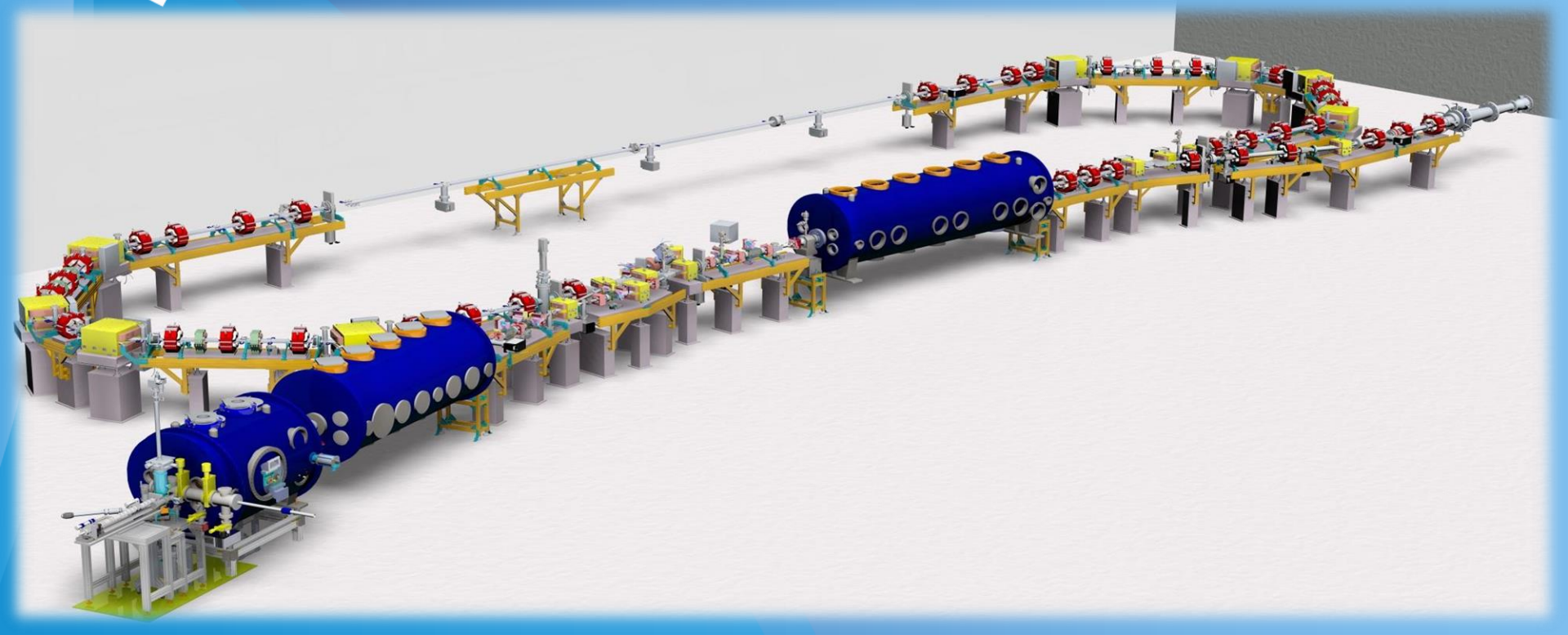


Summary & Outlook

- Valuable experience and data from the commissioning of the SRF injector for bERLinPro with a Cu cathode:
  - Laser performance
  - Cathode position and DC-bias
  - Gun performance & RF parameters
  - Measurement procedures, diagnostics, controls, …
- Consistent beam dynamics simulations – further analysis for (field) emission with DC-bias
- Ongoing tests and improvements regarding:
  - Cryo distribution system
  - Cathode cooling
  - Solenoid
- Next goal: operation with CsK_2Sb cathode at bERLinPro with an online simulation tool for live feedback

HZB Helmholtz Zentrum Berlin
bERLinPro

THANK YOU FOR YOUR ATTENTION



Variable Gun Parameter in ASTRA simulations:

-> Cathode position inside the cavity
-> DC Bias voltage for the cathode insert
-> RF gradient in the the cavity
-> field flatness between the gun cells
-> solenoid postion
-> solenoid strength

field calculation:

-> calculating RF and DC fields of the gun as function of the cathode position
-> field flatness (FF) is calculated by ASTRA

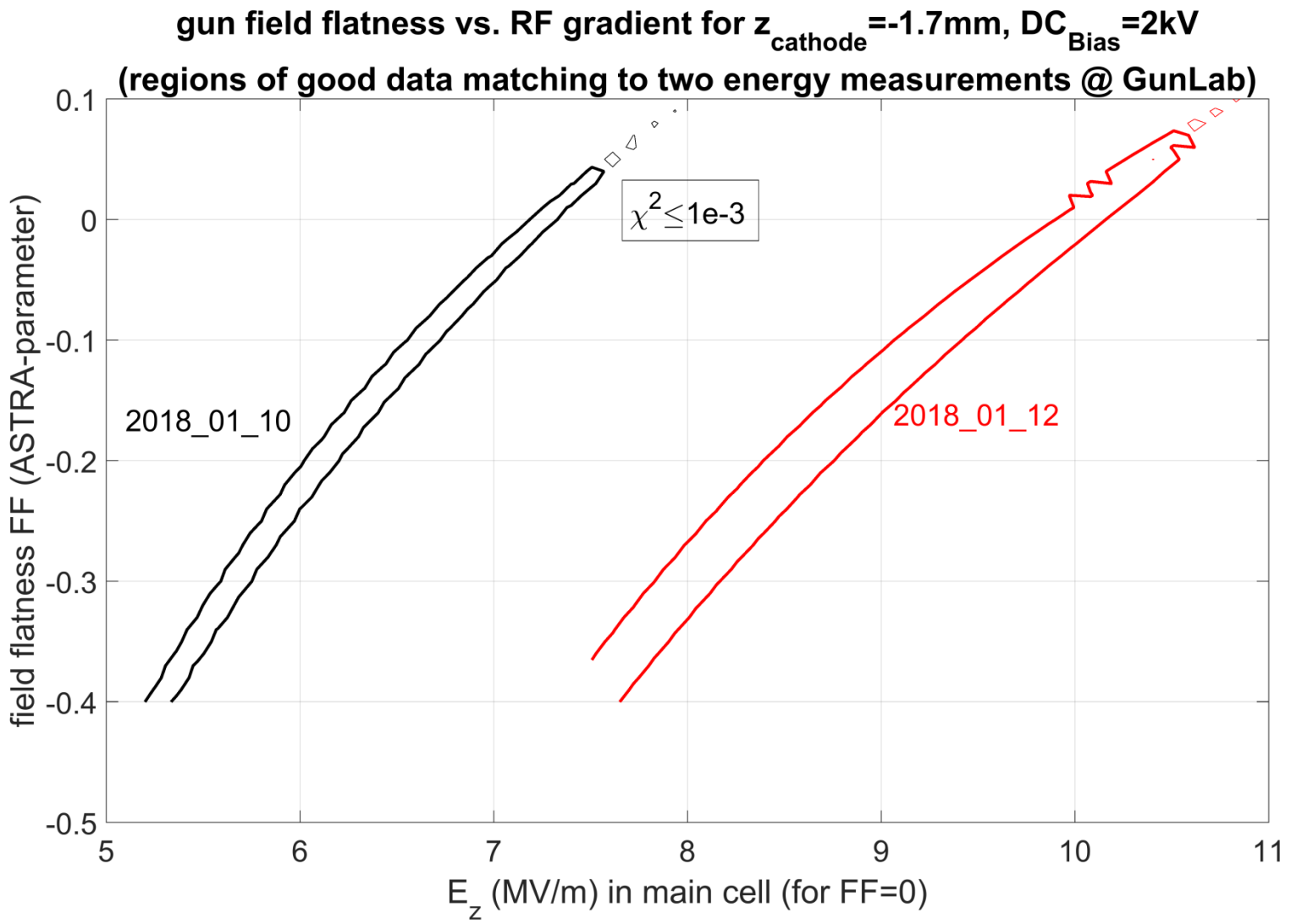
Start with energy calibration:

-> find cathode positions and FF values to describe both
measurements simultaneously , RF gradient free parameter

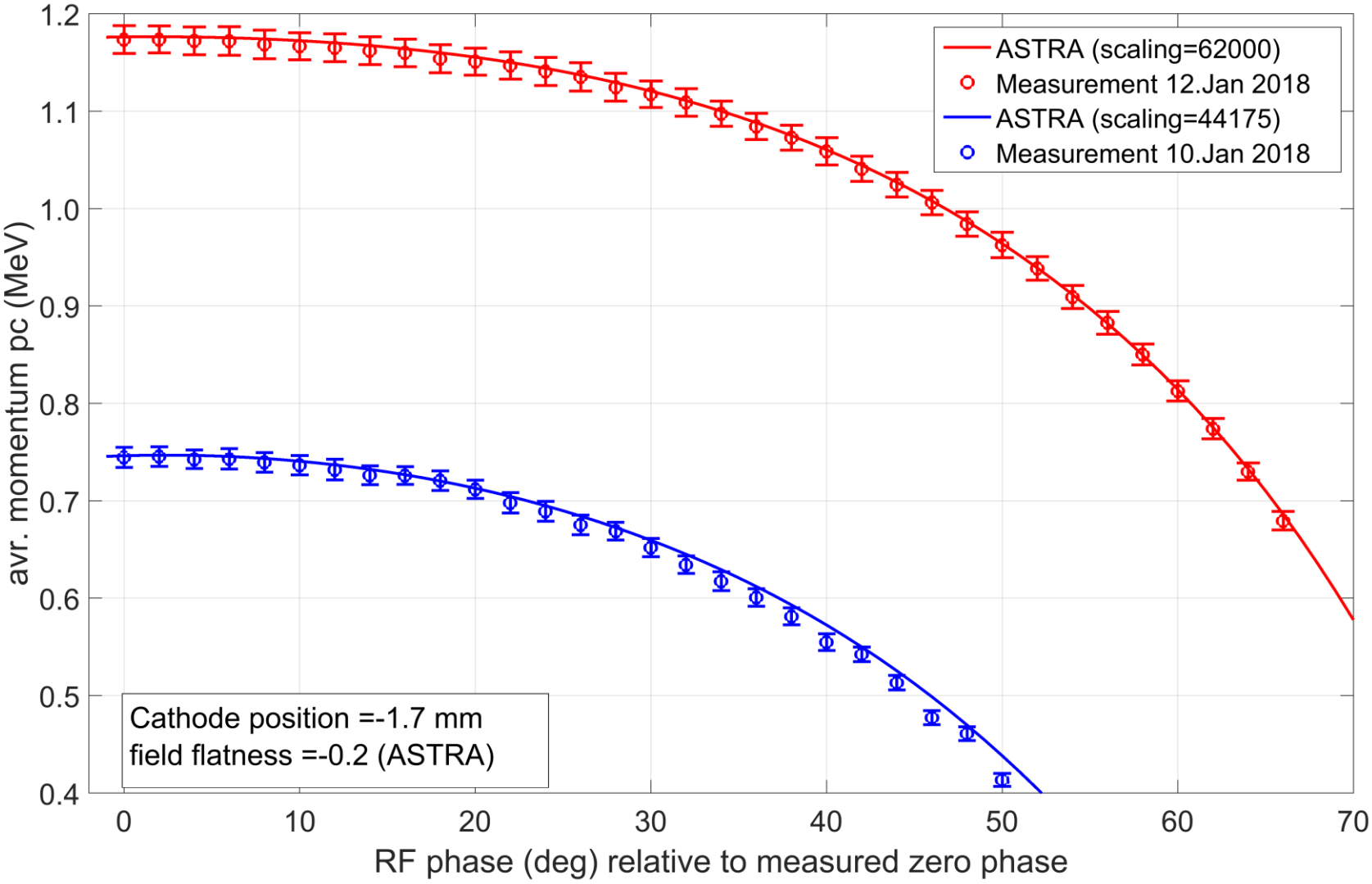
check transverse beam optics:

-> variate solenoid position and strength to achieve the same
beam sizes (as function of the phase) at FOM2 like the measurements

energy calibration -> only for cathode positions of -1.7mm for both measurements
the same FF (FF≈-0.2) can be found to describe both distributions



find the minimal parameter setting with the smallest χ^2 for both measurements:

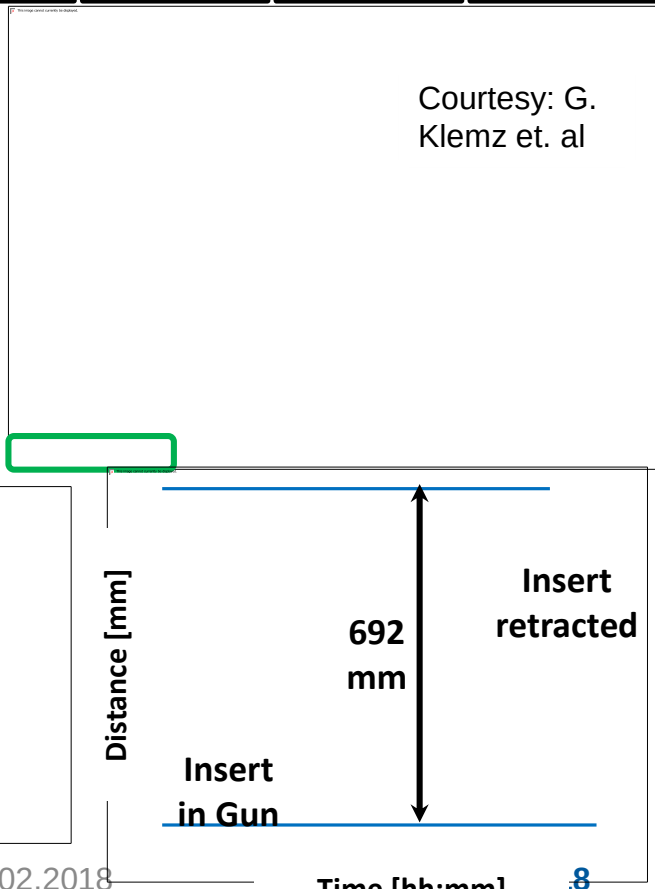


LLRF (measurements)	final ASTRA field (main cell)	final ASTRA field (half cell)	final ASTRA field (cathode)
7.5MV/m	9.433 MV/m	10.177MV/m	7.29MV/m
5.4MV/m	6.721 MV/m	7.251MV/m	5.195MV/m

DC Bias voltage of 2kV results in an additional electric field on the cathode surface of 0.413 MV/m

Laser

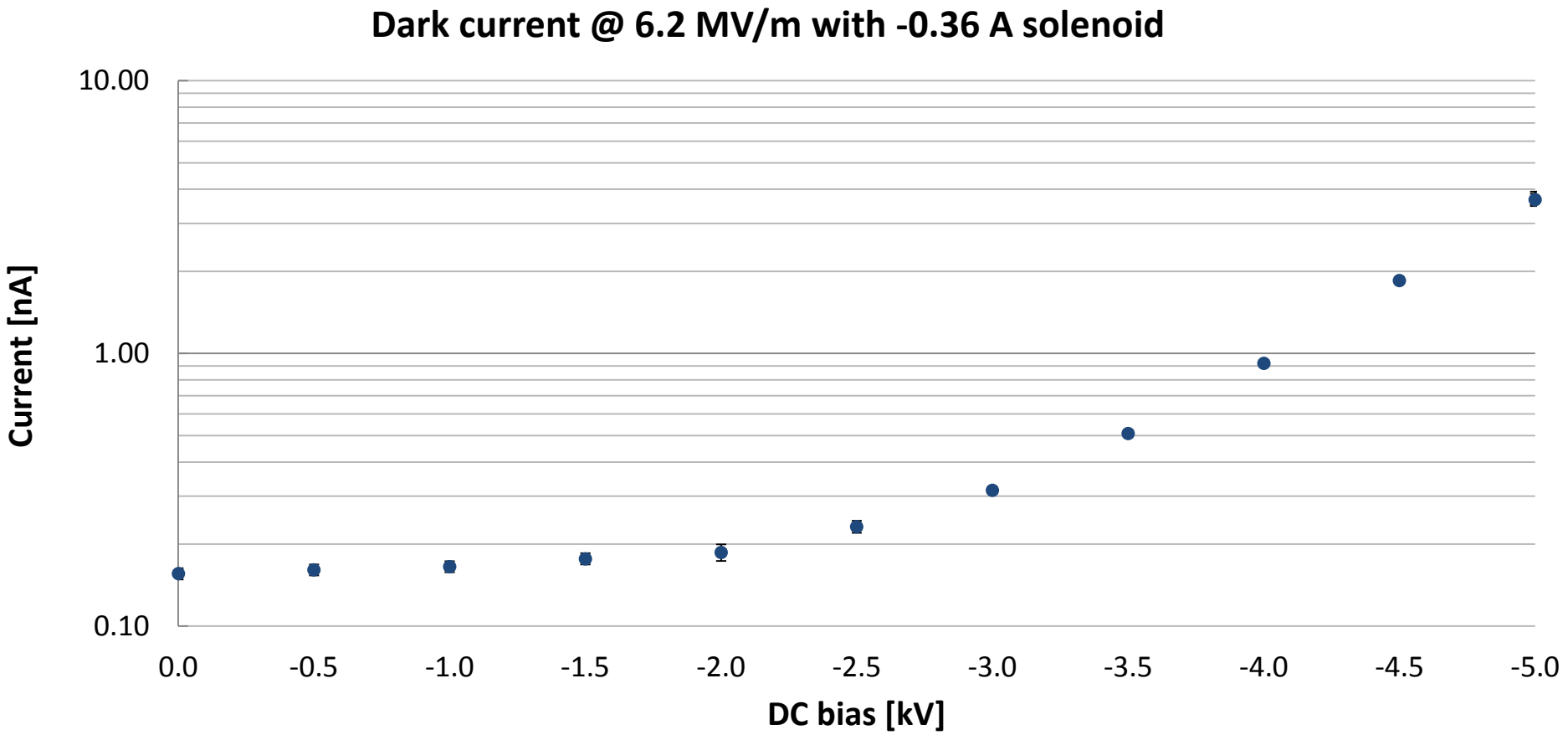
- UV & green wavelengths delivered
- Controlled & measured beam parameters
  - Spot size, location & shape (motorized position & aperture, “virtual cathode”)
  - Pulse energy (λ/2-plate, power meter)
  - Pulse duration (pulse stretcher, optical auto-correlator)
- Cathode position monitoring
  - x3 capacitive sensors (relative measurement, 4 mm range, µm precision)
    → useful during cathode transfer, cool-down, RF-induced heating
  - optical system (visual inspection + absolute position measurement wrt cavity wall, ~ 0.5 mm precision)
    → useful during cathode transfer, with system-related difficulties…



Courtesy: G. Klemz et. al

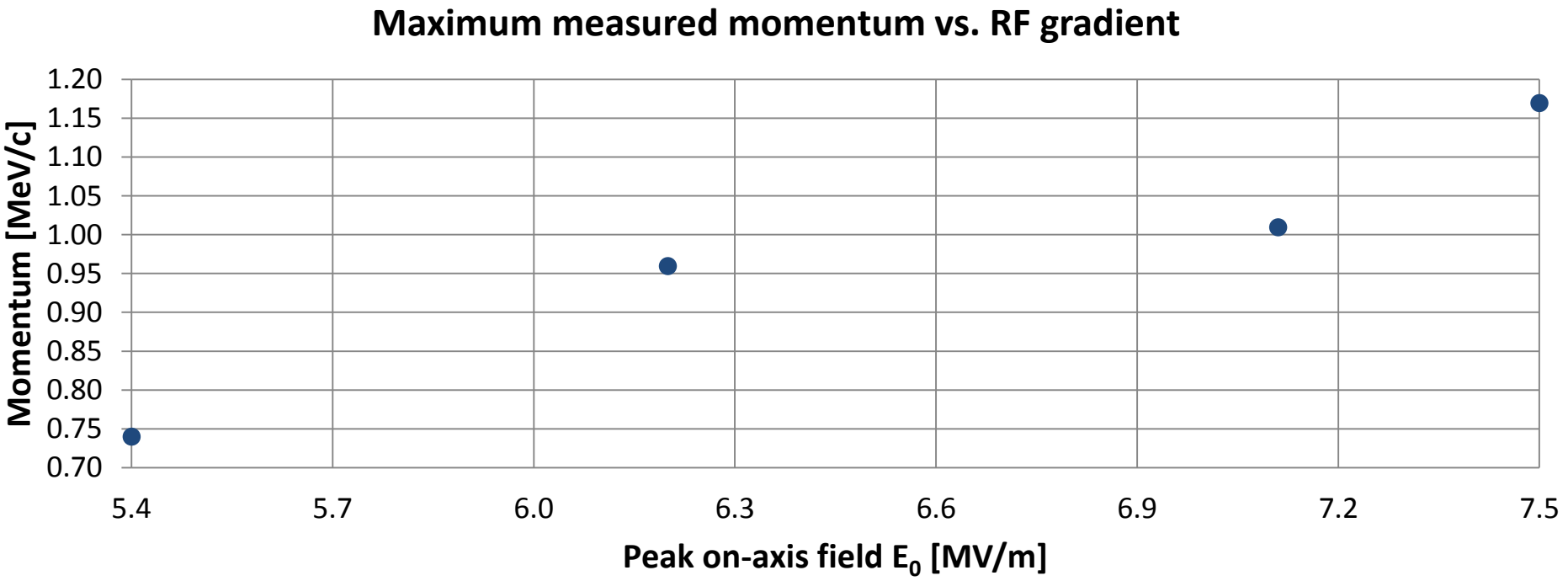
Dark current

- Data not always measured with same machine settings:
  - ~ Solenoid
  - ! DC bias
  - ~ Statistics
  - ! Steerers (emitters)
  - ~ RF feed (PLL / Cornell LLRF)



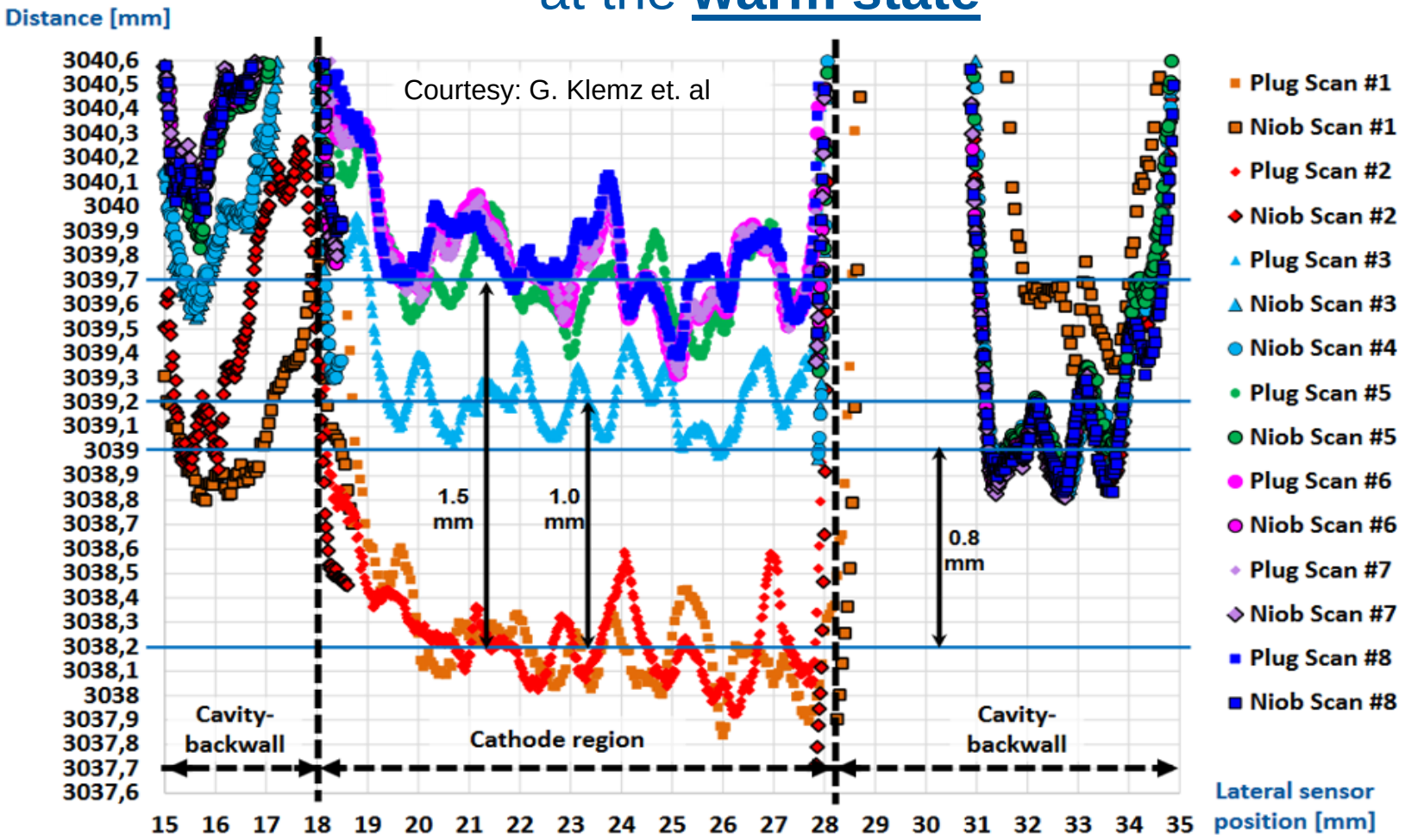
Momentum scans

Date	Peak on-axis field (MV/m)	Max momentum [MeV/c]	DC bias (kV)	Solenoid (A)
27.12	7.1	1.01	-2	-0.35
09.01	6.2	0.96	-2	-0.36
10.01	5.4	0.74	-2	-0.40
12.01	7.5	1.17	-2	-0.40



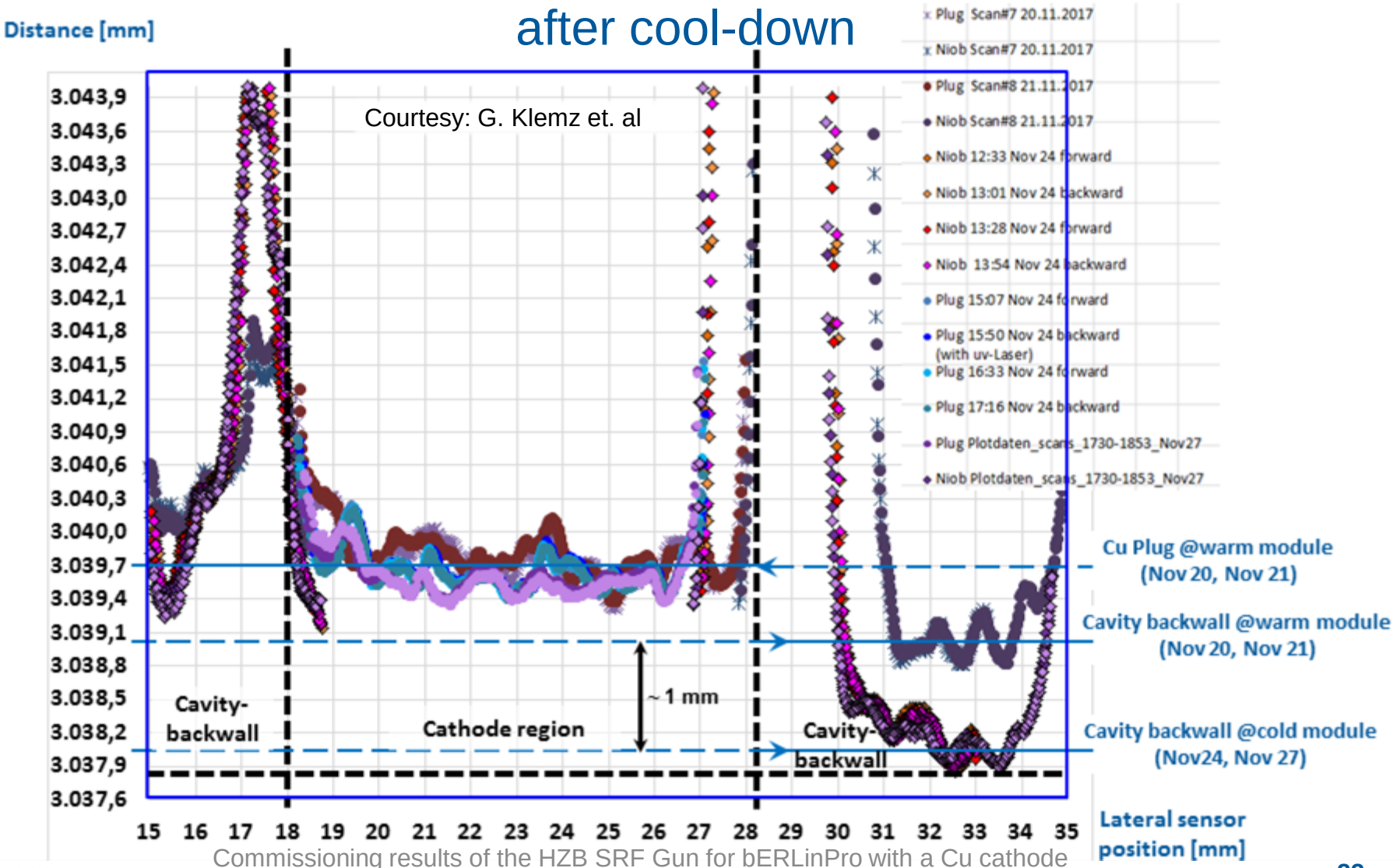
Cathode: -0.7 mm from warm cavity backwall

Cathode was retracted to -0.7 mm behind the cavity backwall at the **warm state**



Cathode: -1.7 mm from cold cavity backwall

Cavity shrinks by ~1 mm away from the cathode holder after cool-down



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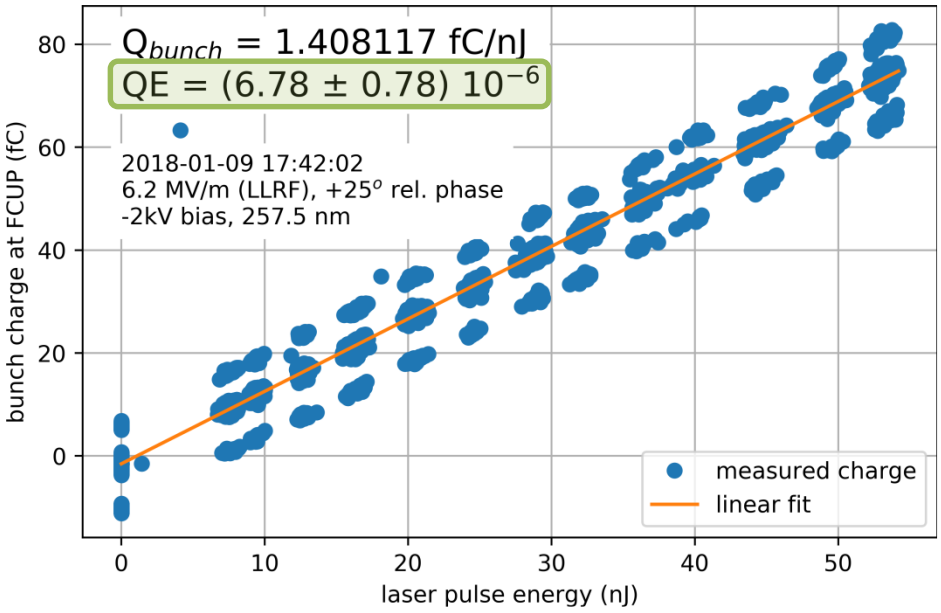
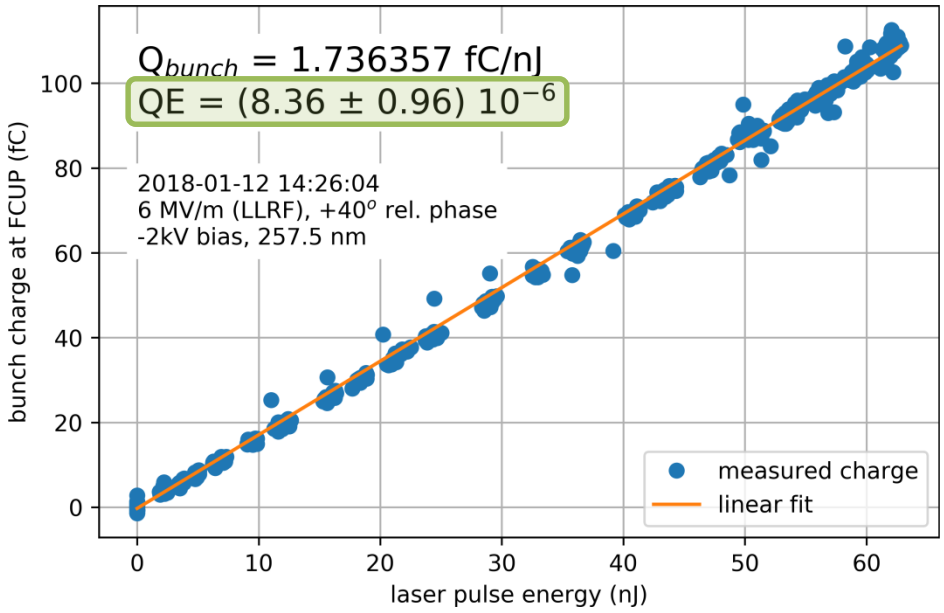


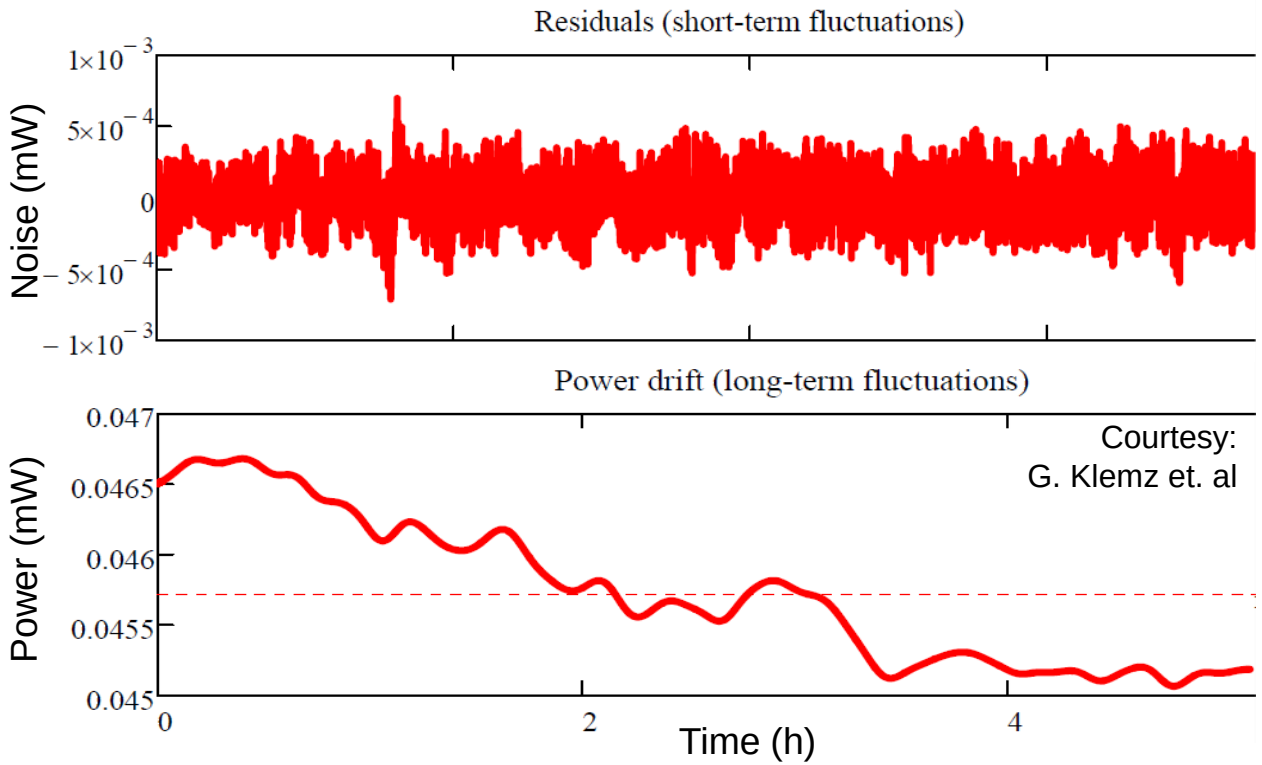


Laser power

- After a cold-start ~10 minutes required for stabilization

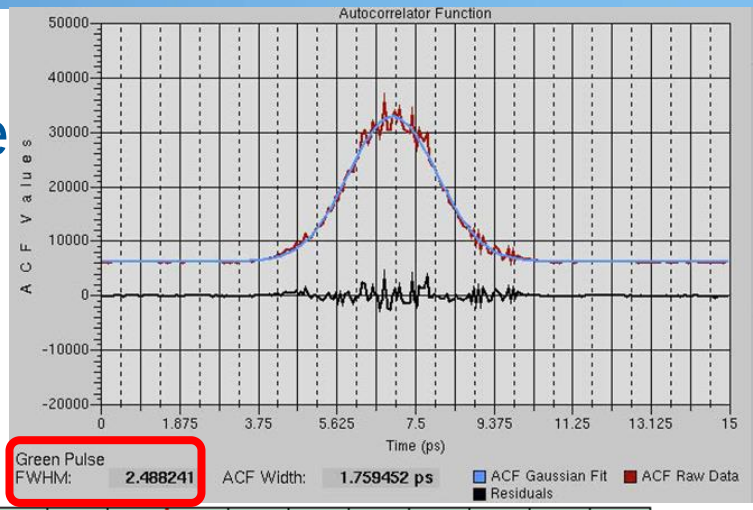
- Short-term fluctuation (noise around 10 min. average):
  +/- 0.3 % rms
  +/- 1.5 % max

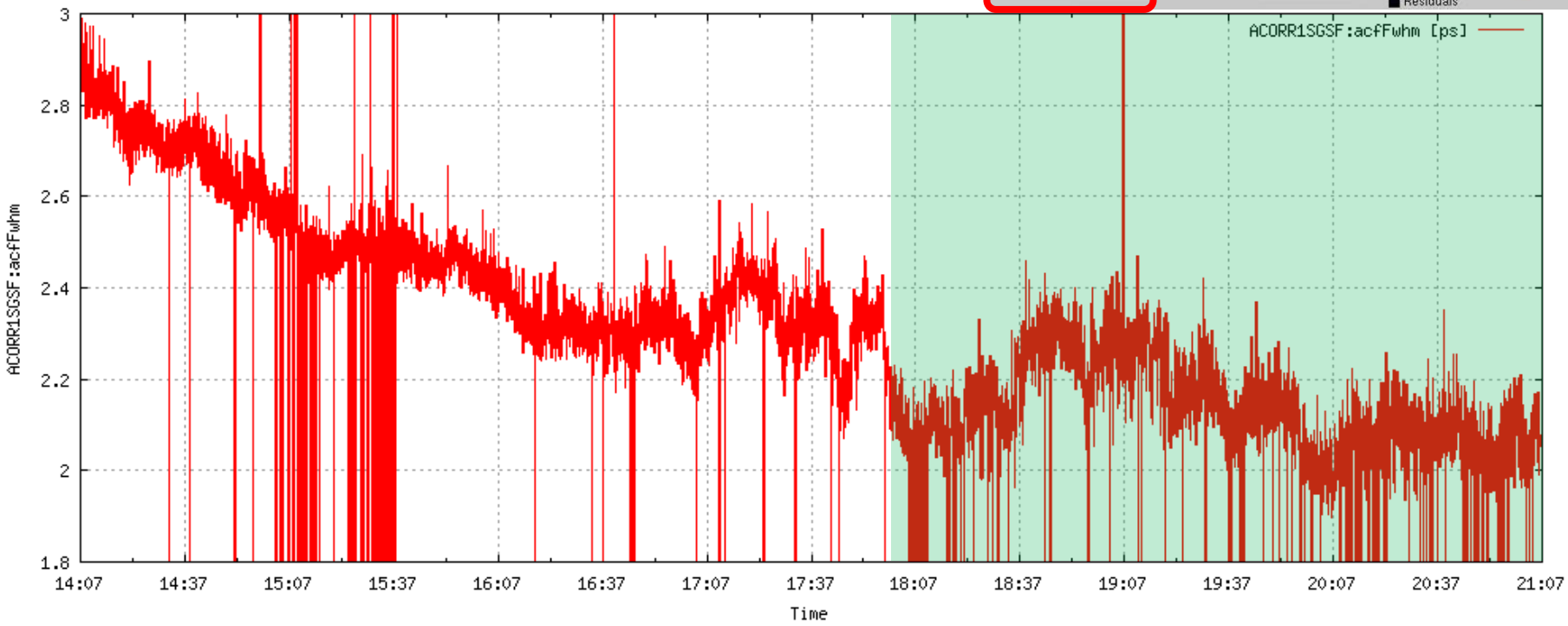
- Long-term drift:
  +/- 1.2 % rms
  +/- 2.8 % max



Laser

- Long-term drift: takes 4 h to stabilize to ~2.1 ps FWHM (green light)
  => 1.5 ps FWHM (UV)
  => 0.6 ps RMS (UV)
- Not archived during measurements





transverse beam optics:

-> no simulation results were found with solenoid currents of 0.4Amp (as used in the measurements)

-> variable solenoid position and current to find the best values:

-> estimated solenoid position: 0.458 m from cathode (0.45m in simulation)

-> defined solenoid current in measurement: 0.4A, (0.3A in simulation)