About Injector Characterization Program

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XFEL Beam Dynamics Meeting

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Why do we need simulations?

- To predict the electron and photon beams **parameters which can be measured**.
- To predict the electron and photon beams **parameters which can not be measured**.
- **To optimize the setup** of the real machine: “working points”.
- To model and **study a special scenarios** which are yet not possible in the real machine.

We need a physical/mathematical model which reproduces the electron/photon beam properties measured in the “real” machine.

What is a “good” simulation?

- One that predicts expected “good” beam properties? No.
- One that agrees with the measurements and reproduces different actuator – detector dependences.

What is a “good” measurement?

- Not one point but a whole actuator – detector dependence.
- We know what is measured: we know a detector response function to do a “deconvolution” or simulate the measurement.
- We know estimation of systematic and statistical errors of the detector/the measurement.
- We know the states of other parameters which impact the measurement and which depend on the actuator during the measurement.
- Reproducibility.

Motivation for the current injector studies

- To reproduce the measured beam properties in the simulations
- To create a computer model of electron beam with the measured properties before the injector dogleg

Approach

- To measure and to calibrate the “hardware” parameters used in the simulations
- To measure the beam properties vs scans of the calibrated hardware parameters

“Hardware” parameters

- Photocathode laser longitudinal and transverse profiles
- Gun solenoids fields
- Gun RF field
- Gun quadrupoles fields
- A1 module field
- AH1 module field
- TDS cavity field
- Quadrupole fields
- Laser heater fields

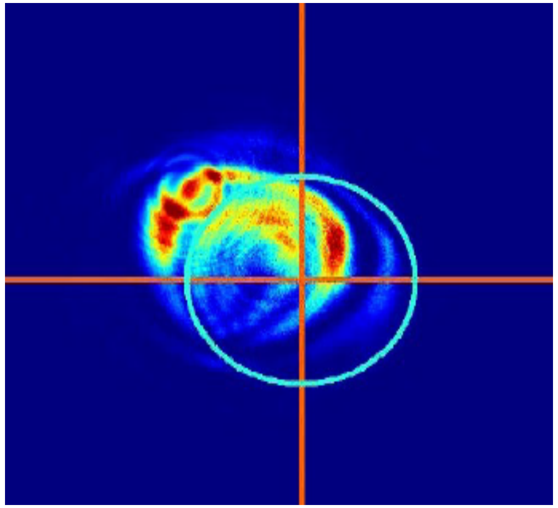
Beam parameters

- Beam charge vs laser pulse energy
- Beam charge vs gun phase
- Beam energy vs RF gun phase
- Beam size vs solenoid strength
- Beam size vs gun quad strength
- Longitudinal phase space, current and energy profiles vs RF parameters
- Projected and slice emittances
- Correlated and uncorrelated energy spreads

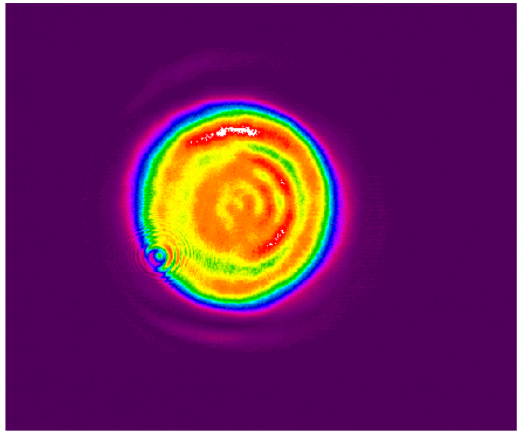
“Hardware” parameters

- Photocathode laser **transverse** distribution

Laser 2, 29.10.19



Laser 2 (last winter)
from Frank Brinker

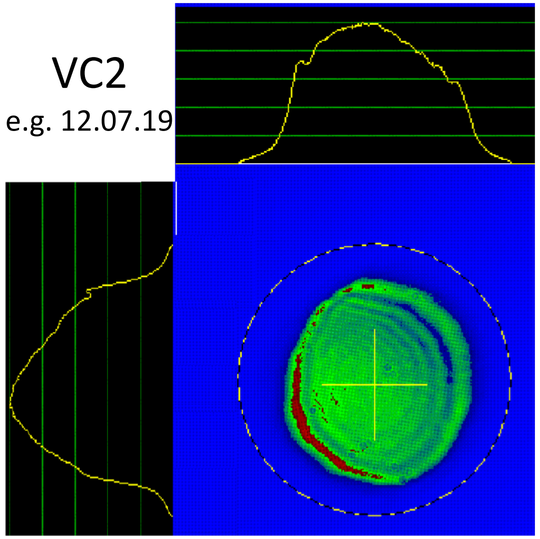


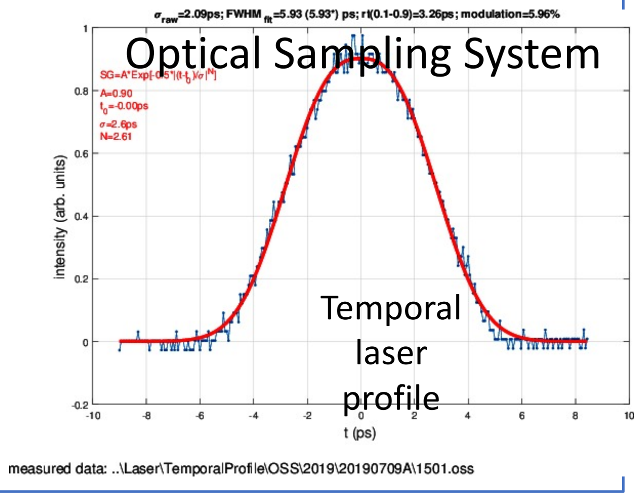
- Photocathode laser **temporal** profile

XFEL in October 2019 → measurements not available

PITZ

VC2
e.g. 12.07.19



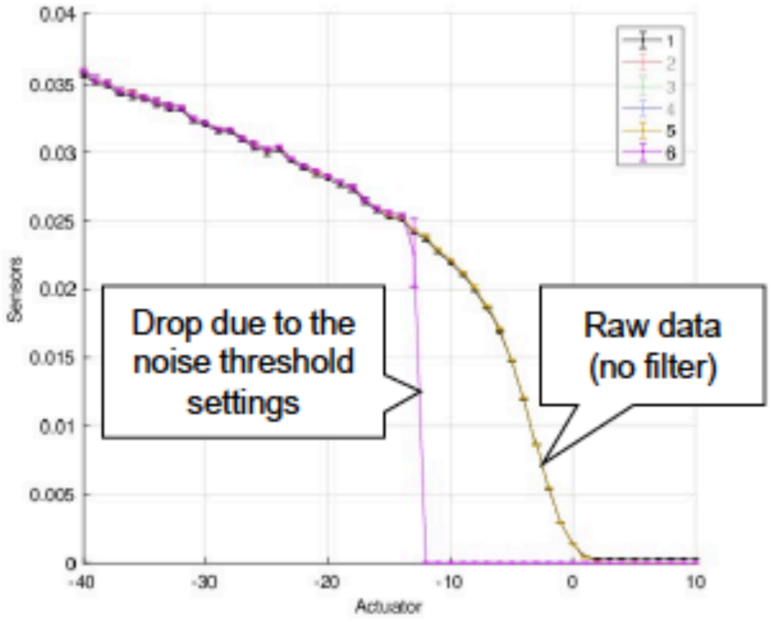


“Hardware” parameters

- Photocathode laser **longitudinal** and transverse profiles

Schottky scans: bunch charge vs. gun SP phase using BPMG.24.I1 (BSA=1mm, PfwdSP=55.6)

We hope to estimate the longitudinal laser profile from these scans



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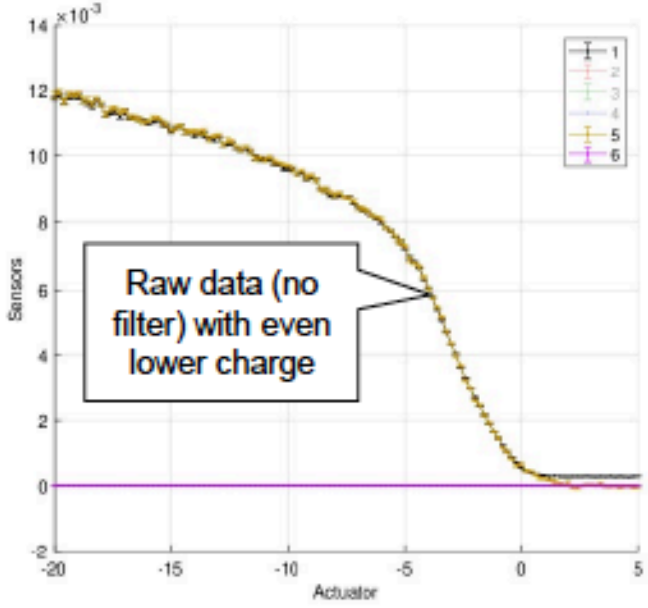
Duration: 2019-10-29 12:37:19 - 12:39:28
Samples/point: 10
Scan from: Scan Tool version 2019-01-25

Actuator: XFEL.RF/LLRF.CONTROLLER/CTRL.GUN.I1/SP.PHASE
Sensor 1: XFEL.DIAG/CHARGE.ML/BPMG.24.I1/CHARGE_RAW.ALL
Sensor 2: XFEL.RF/LLRF.CONTROLLER/VS.GUN.I1/PHASE.SAMPLE
Sensor 3: XFEL.RF/LLRF.CONTROLLER/VS.GUN.I1/AMPL.SAMPLE
Sensor 4: XFEL.DIAG/ORBIT/BPMG.24.I1/X.ALL
Sensor 5: XFEL.DIAG/CHARGE.ML/TORA.25.I1/CHARGE_RAW.ALL
Sensor 6: XFEL.DIAG/CHARGE.ML/TORA.25.I1/CHARGE.ALL



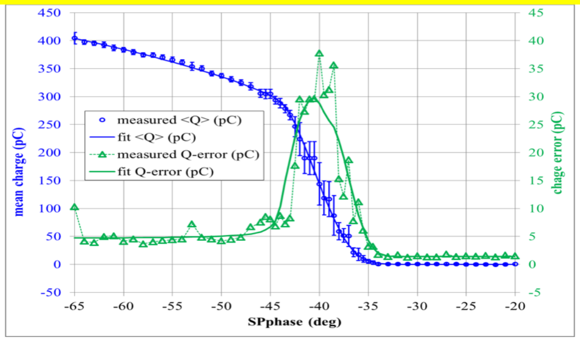
File: /home/xfeloper/data/scantool/2019-10-29T124152.mat
Duration: 2019-10-29 12:41:54 - 12:46:50
Samples/point: 10
Scan from: Scan Tool version 2019-01-25

Actuator: XFEL.RF/LLRF.CONTROLLER/CTRL.GUN.I1/SP.PHASE
Sensor 1: XFEL.DIAG/CHARGE.ML/BPMG.24.I1/CHARGE_RAW.ALL
Sensor 2: XFEL.RF/LLRF.CONTROLLER/VS.GUN.I1/PHASE.SAMPLE
Sensor 3: XFEL.RF/LLRF.CONTROLLER/VS.GUN.I1/AMPL.SAMPLE
Sensor 4: XFEL.DIAG/ORBIT/BPMG.24.I1/X.ALL
Sensor 5: XFEL.DIAG/CHARGE.ML/TORA.25.I1/CHARGE_RAW.ALL
Sensor 6: XFEL.DIAG/CHARGE.ML/TORA.25.I1/CHARGE.ALL

$$\varphi = SPPhase - \Phi_0$$

$$Q_{fit}(SPPhase) = Q_{bkg} + A \cdot F_{schottky}(\varphi) \cdot \{1 - Erf[C \cdot \varphi]\}$$

$$F_{schottky}(\varphi) = \begin{cases} \left(1 + S \cdot \sqrt{\sin\left(-\frac{\pi\varphi}{180}\right)}\right)^2, & if\ \varphi \le 0 \\ 1, & if\ \varphi > 0 \end{cases}$$



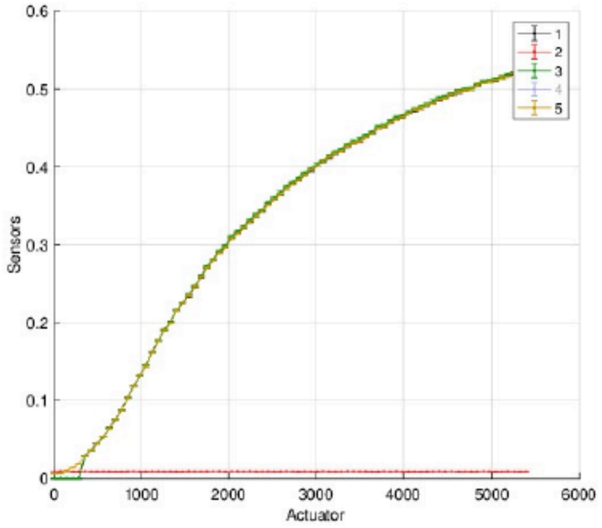
Fit for the mean charge fit Q_{fit}:
Φ_0 - zero crossing phase
Q_{bkg} - background charge (dark current)
A – scaling factor → max bunch charge
S - constant in Schottky factor $F_{schottky}(\varphi)$
C – scaling factor in the error function argument
$\sigma = \frac{1}{\sqrt{2}C}$ - rms length (in deg) of the derived Gaussian

M. Krasilnikov, “Improved beam-based method for RF photo gun stability measurements”, ARD ST3 meeting, 2015

Beam parameters

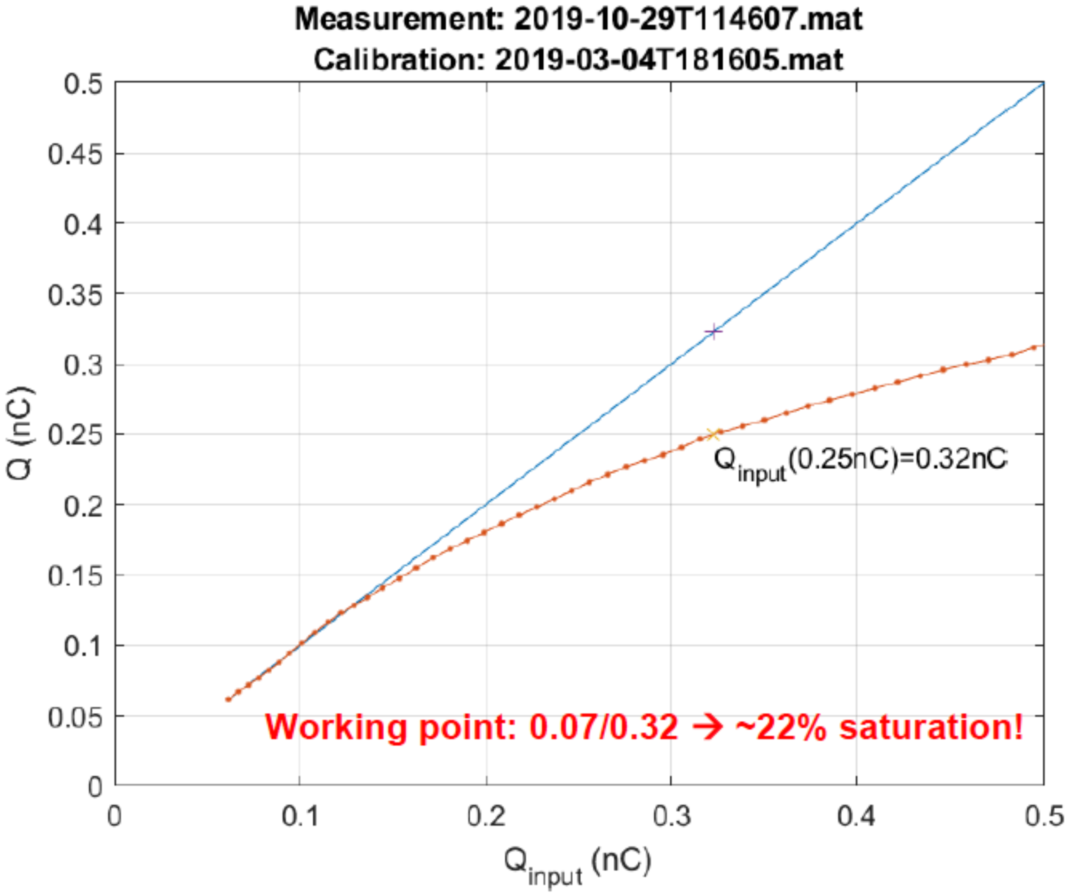
- Beam charge vs laser pulse energy

Bunch charge vs. laser pulse energy (PfwdSP=55.6, SPPhase=MMMG=-45deg, BSA=1mm)



Laser1, 1.0mm, 5.4MW, -45degr, Photocathode Quantum Efficiency Measurem

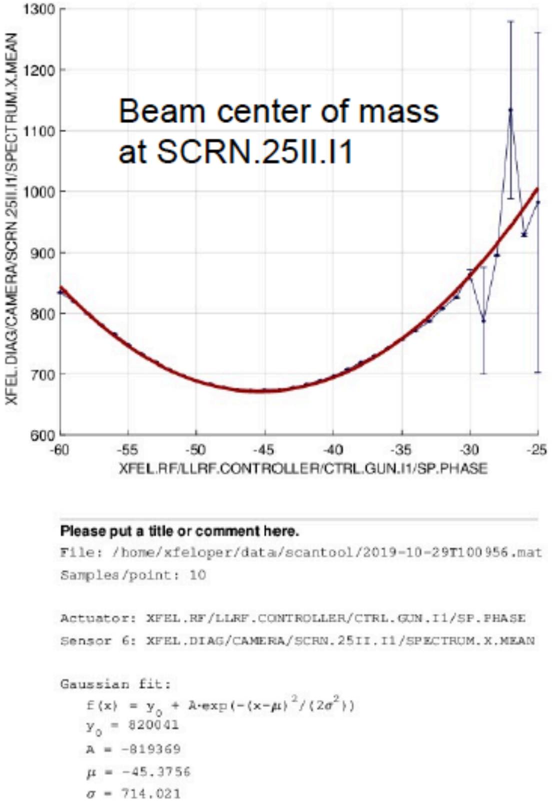
File:	/home/xfeloper/data/scantool/2019-10-29T121159.mat
Duration:	2019-10-29 12:12:03 - 12:16:15 (scan aborted)
Samples/point:	6
Scan from:	Scan Tool version 2019-01-25
Actuator:	XFEL.UTIL/LASER.MOTORS/MOTOR4.GUN.I1/POS.SET
Sensor 1:	XFEL.DIAG/TOROID/TORA.25.I1/CHARGE.ALL
Sensor 2:	XFEL.DIAG/DCM/DCM.25.I1/CHARGE.SA1
Sensor 3:	XFEL.DIAG/BPM/BPMG.24.I1/CHARGE.ALL
Sensor 4:	XFEL.DIAG/LASER.PULSEENERGY/GUN.I1.UV/PULSEENERGY.MEAN
Sensor 5:	XFEL.DIAG/CHARGE.ML/TORA.25.I1/CHARGE_RAW.ALL

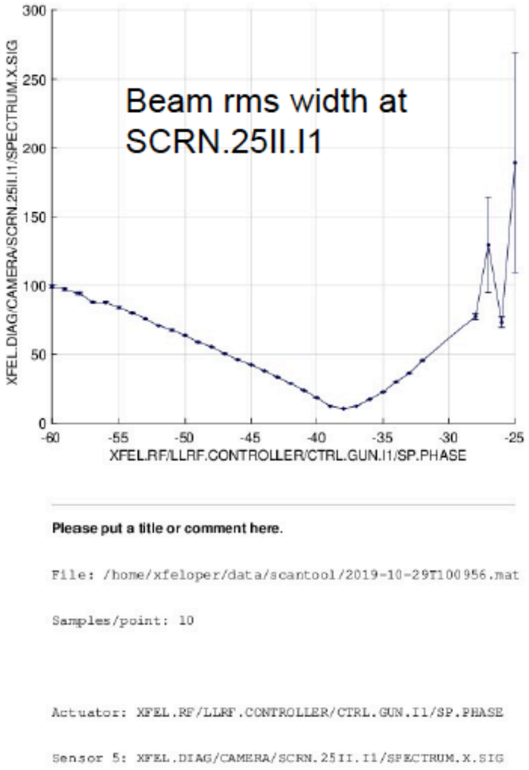


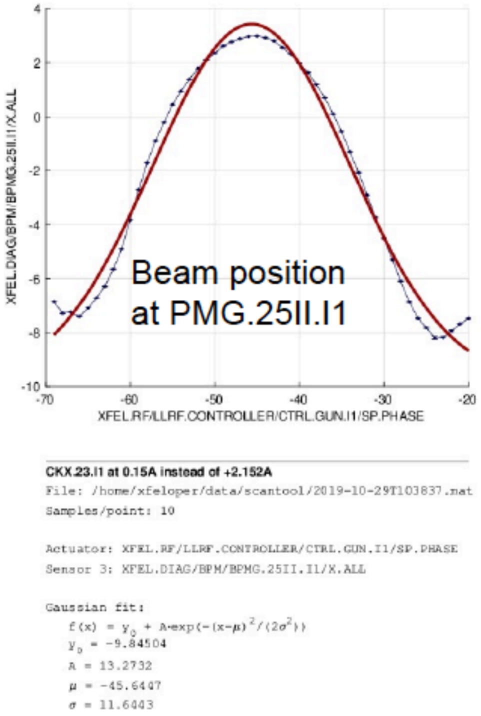
Beam parameters

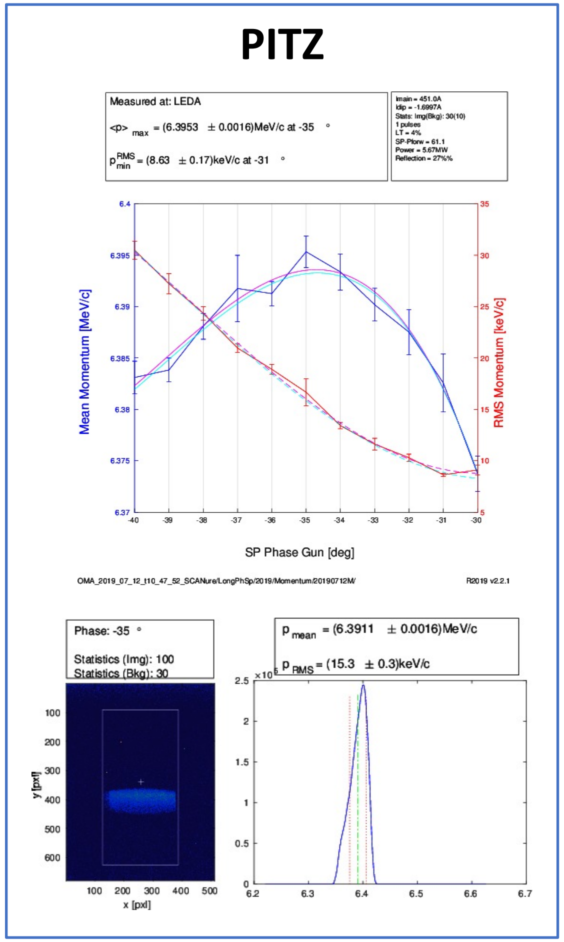
- Beam energy vs RF gun phase

Beam position (~momentum) in the low energy dispersive arm (PfwdSP=55.6)









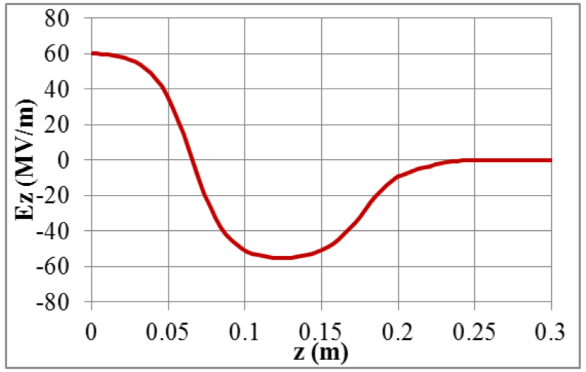
“Hardware” parameters

	method	parasitic	29/30.10.1019	older	wanted
Laser transverse profile	virtual cathode	yes/no	+	+	Realistic 2D distribution
Laser longitudinal profile	UV Cross-correlator, streak camera, low charge Schottky scan Q(gun phase)	no	+		UV cross-correlator with resolution < 0.5ps
Gun solenoid field	E-beam size vs solenoid current	no	+	+	Calibration: strength vs current
Gun quad field	E-beam size vs quads currents	no			
RF gun field	Beam energy vs gun phase	no	+		
	Beam energy vs gun gradient	no	+		
A1 module field	Beam phase space with TDS	no	+		
AH1 module field	Beam phase space with TDS	no	+		
TDS cavity field					
Quadrupole fields					
Laser heater fields					

See next slide

Measurements: PITZ Gun-4.6

Mean momentum and Maximum Mean Momentum Gain (MMMG) phase



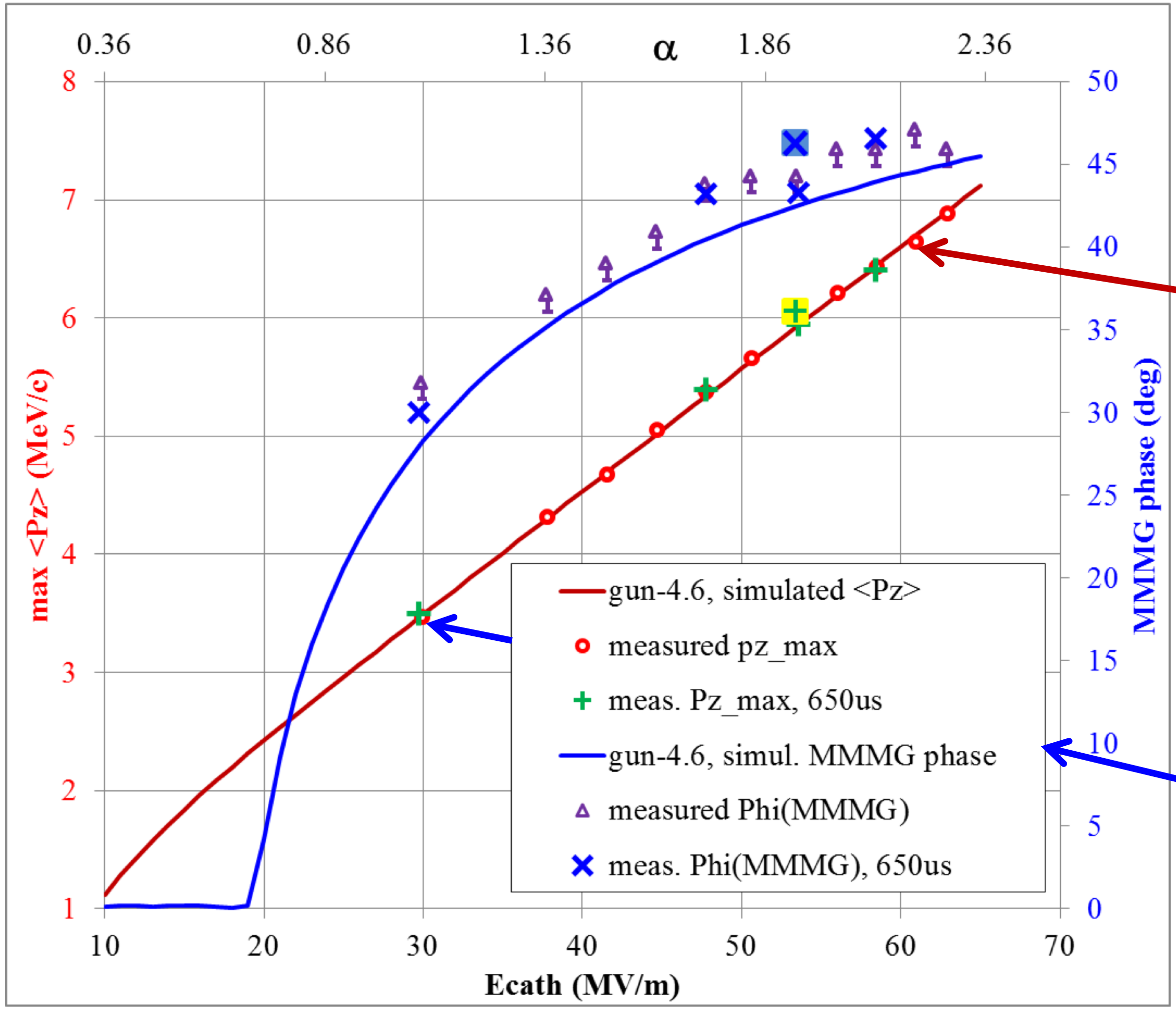
$$\langle P_z \rangle = \beta_z \gamma \cdot 0.511 \frac{MeV}{c}$$

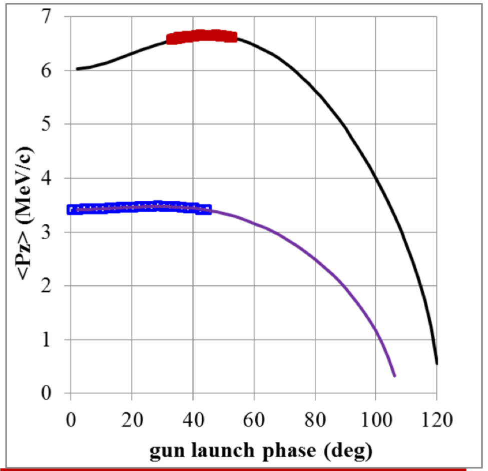
$$\beta_z = v_z/c$$

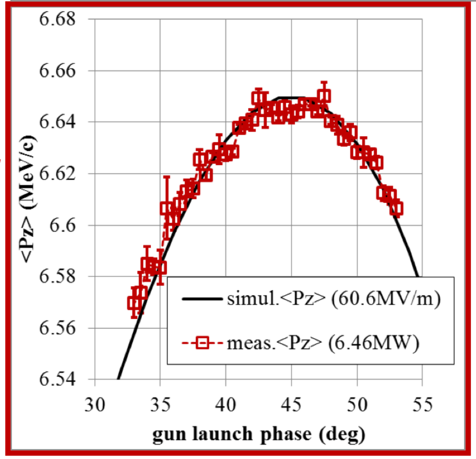
$$\gamma = \frac{1}{\sqrt{1-\beta_z^2}}$$

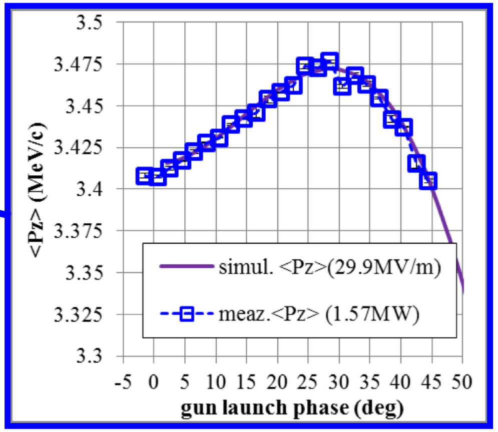
$$\frac{1}{\beta_z} = \frac{\gamma}{\sqrt{\gamma^2 - 1}}$$

Measurements vs. Simulations







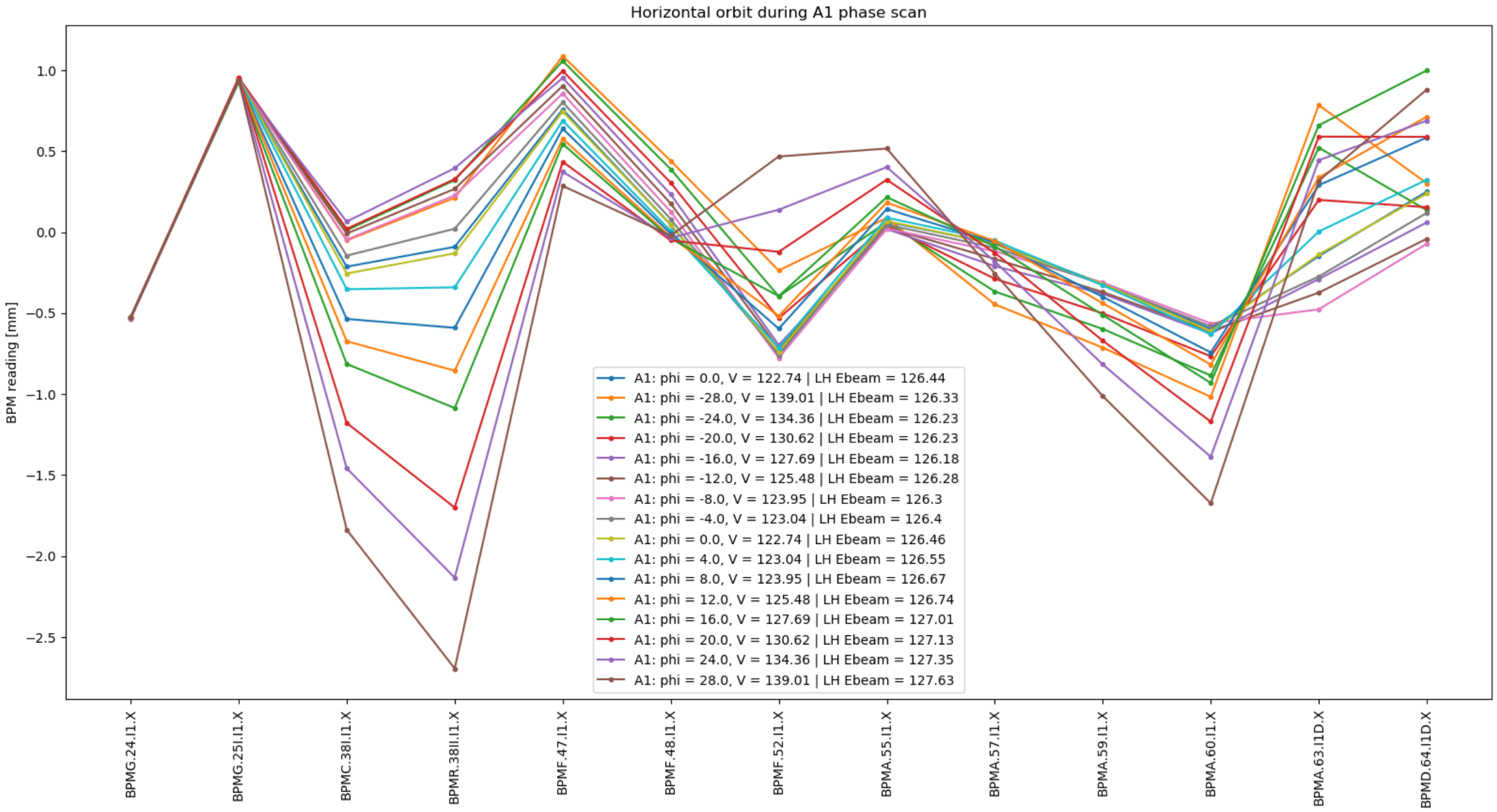


$$P[MW] = 0.00176 \cdot (E_{cath}[MV/m])^2$$

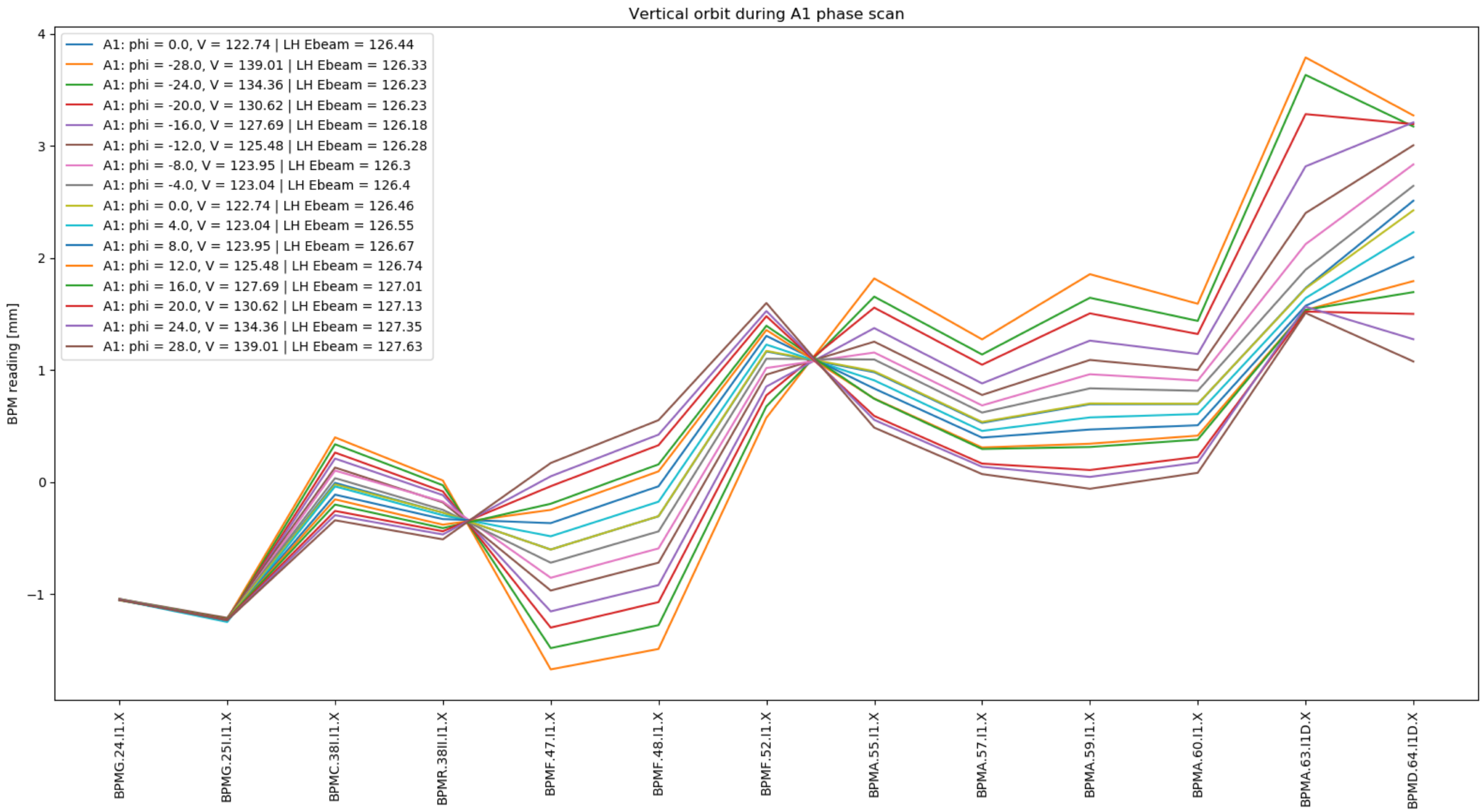
Beam parameters

	diagnostics	29/30.10.1019	older	Wanted
Beam charge vs laser pulse energy		+		
Beam charge vs gun phase	BPMG.24.I1	+		
Beam energy vs RF gun phase		+		Beam momentum (absolute) and momentum distribution
Beam size vs main solenoid strength/current		+		
Beam size vs gun quads strength/current				
Longitudinal phase space, current and energy profiles vs A1 parameters	TDS	+		Good matching for the best time and energy resolution
Longitudinal phase space, current and energy profiles vs AH1 parameters	TDS	+		Good matching for the best time and energy resolution
Projected and slice emittance		+		
Correlated and uncorrelated energy spreads				

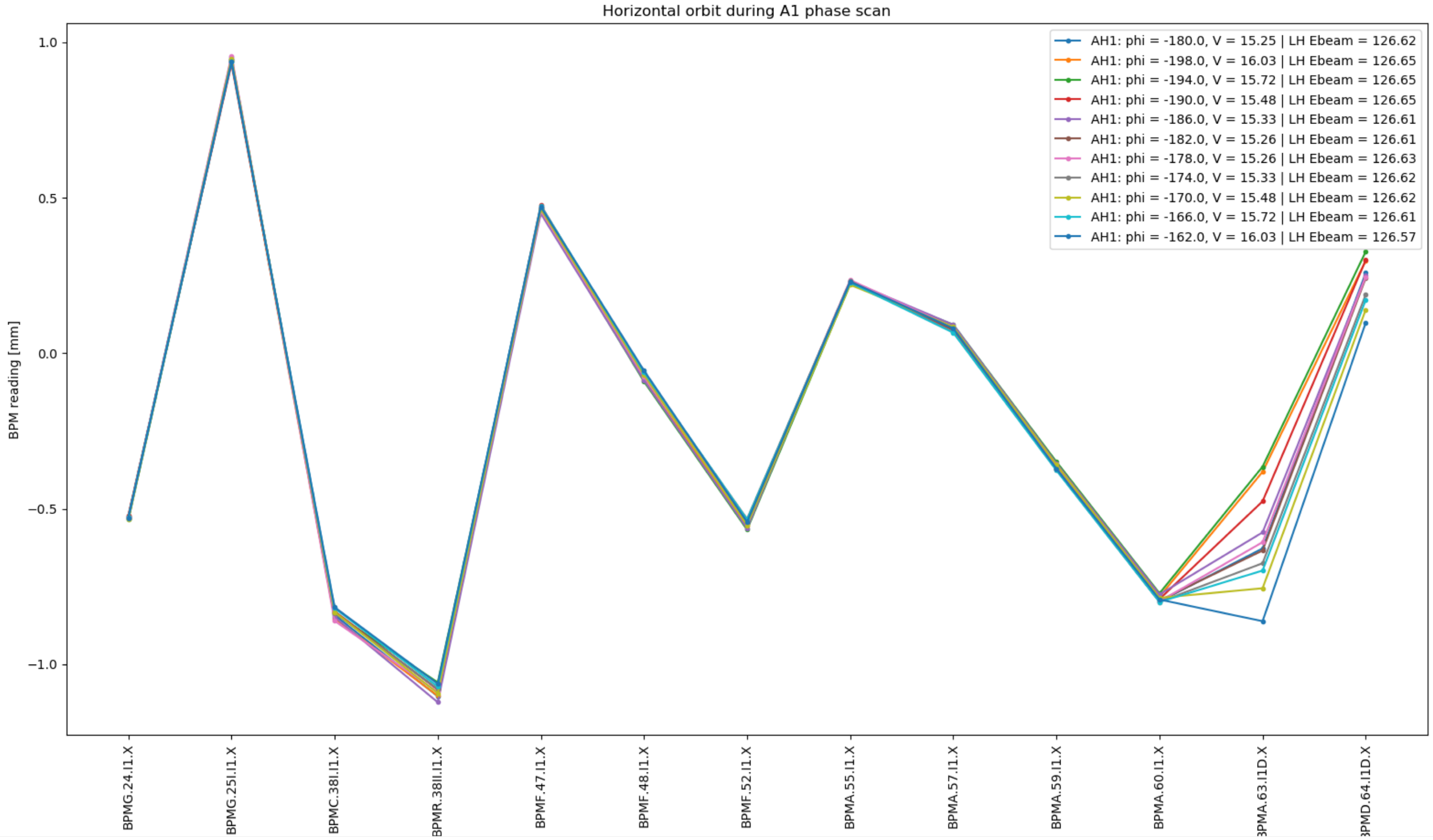
Horizontal orbit change during A1 phase scan with the "constant" beam energy (S. Tomin).



Vertical orbit change during A1 phase scan with the "constant" beam energy (S. Tomin) .



Horizontal orbit change during AH1 phase scan with the “constant” beam energy (S. Tomin).



Vertical orbit change during AH1 phase scan with the “constant” beam energy (S. Tomin).