Beam based monitoring of the RF photo gun stability at PITZ

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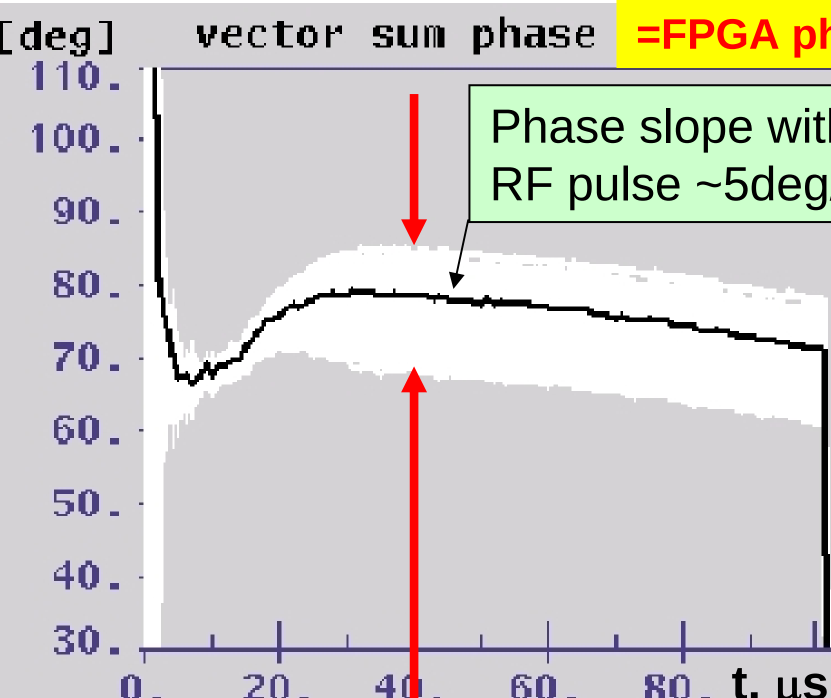
Outlook:

- Motivation: gun stability
- Phase scan for gun stability measurements
- Some experimental tests
- Conclusions

Machine stability problems (2009) – RF gun phase

=FPGA phase, reconstructed from virtual ADC probes

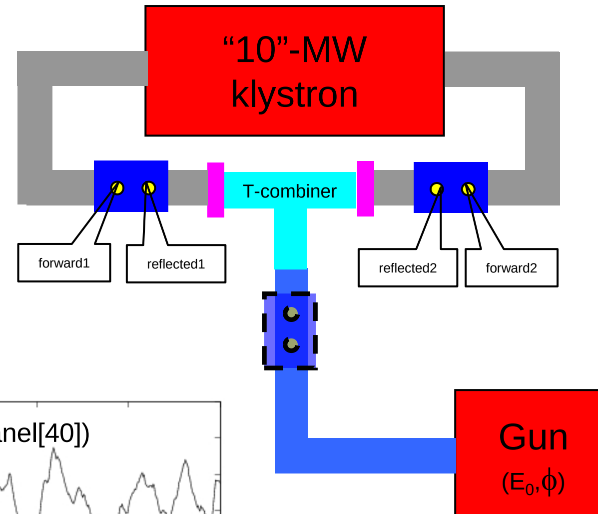


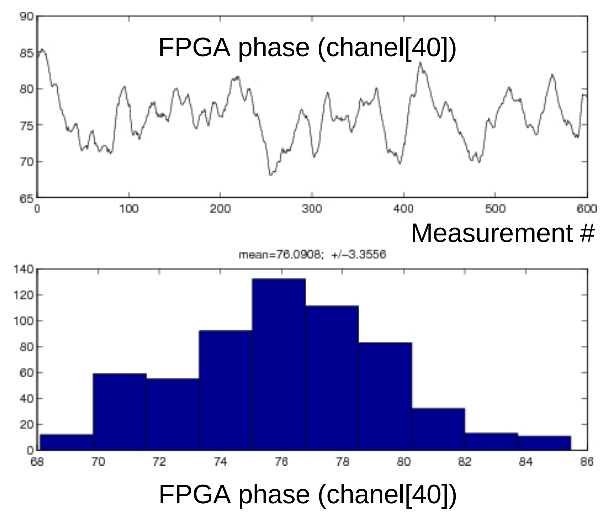
Phase slope within an RF pulse ~5deg/40us

Fluctuations:

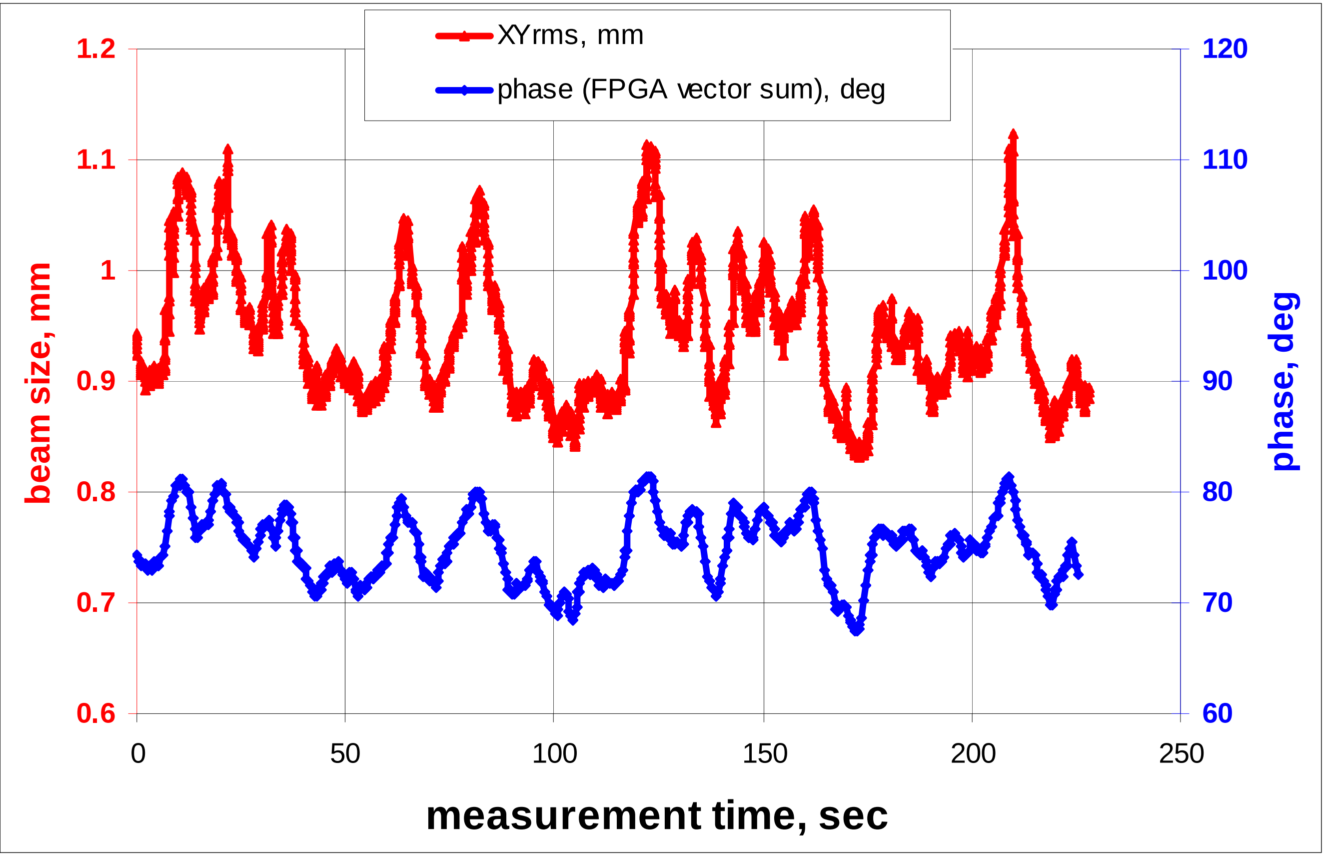
- **10..15 deg (p-p)**
- 2..4 deg (rms)

"10"-MW klystron is working close to saturation, no LLRF regulation!





e-beam size fluctuations at EMSY1



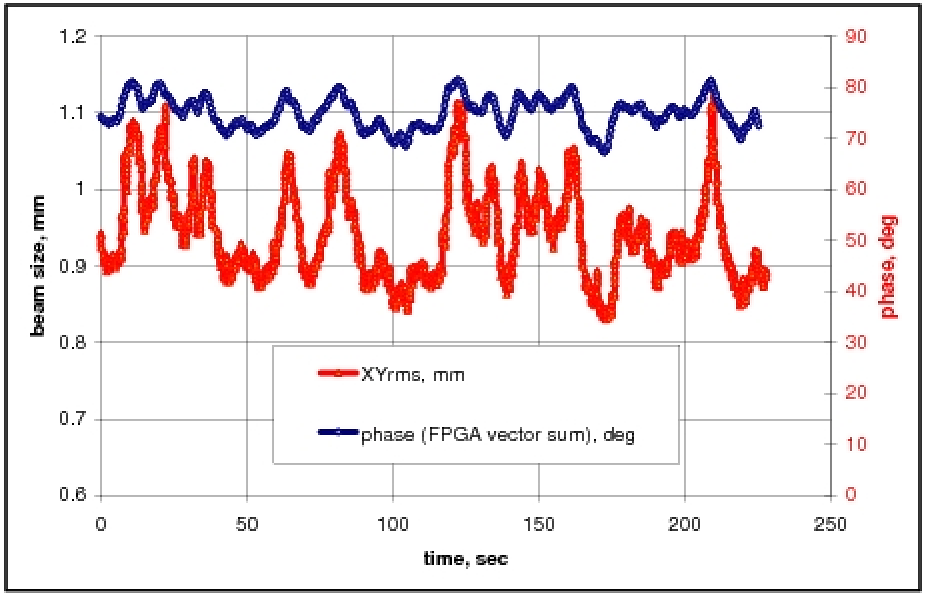
FPGA phase:
14deg(p-p)

XYrms:
7% (rms), **up to >30%(p-p)**

variation in rms beam size at EMSY1

impact on emittance measurements

FPGA phase and beam size at EMSY1

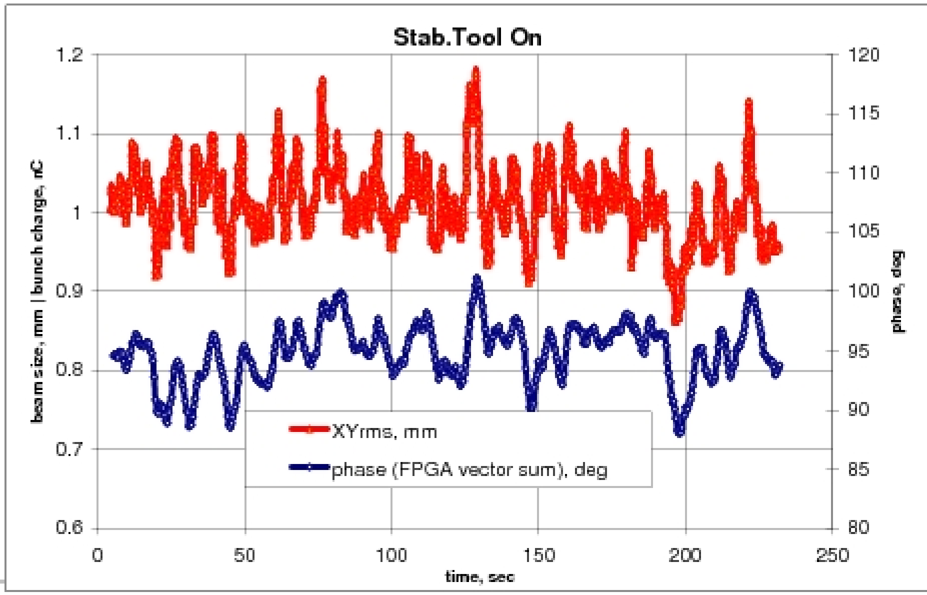


Stab.tool OFF

PITZ 2009 run

FPGA phase:
14deg(p-p)

XYrms:
7% (rms), **38%(p-p)**



Stab.tool ON

FPGA phase:
15deg(p-p)

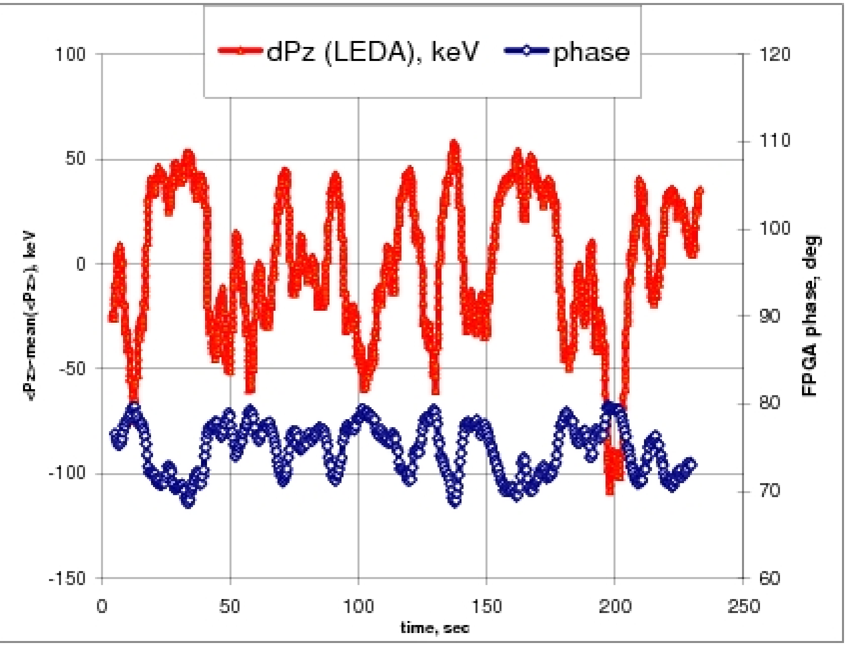
XYrms:
30%(p-p)

does not work properly

FPGA **phase** and **beam momentum** in LEDA

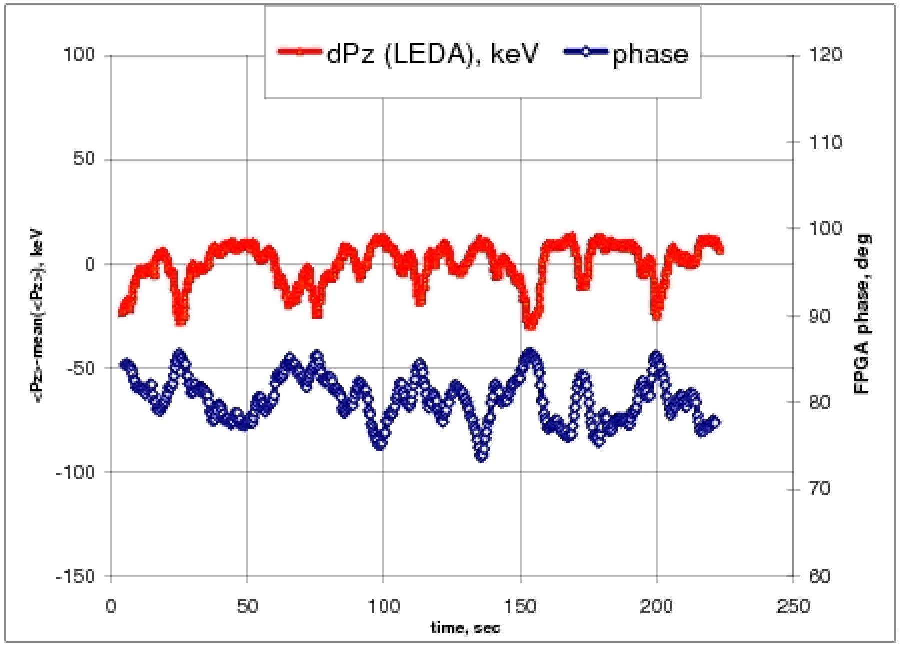
PITZ 2009 run

gun -6deg off-crest



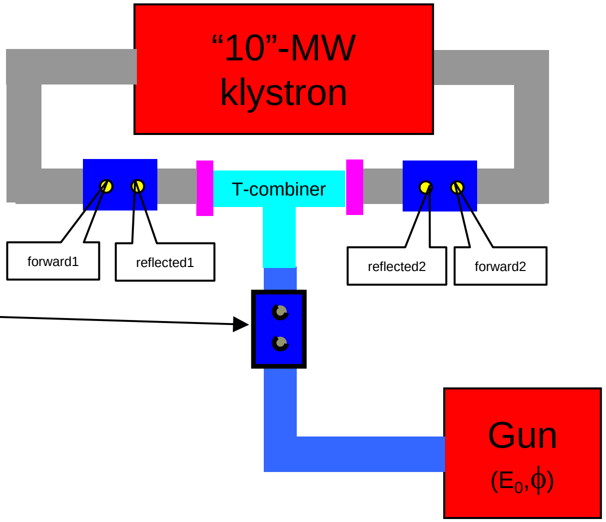
parameter	rms	**peak-to-peak**
FPGA phase	2.9 deg	**11 deg**
dPz	35 keV/c	**166 keV/c**

gun on-crest



parameter	rms	**peak-to-peak**
FPGA phase	2.6 deg	**12 deg**
dPz	9.7 keV/c	**44 keV/c**

Phase stability improvement



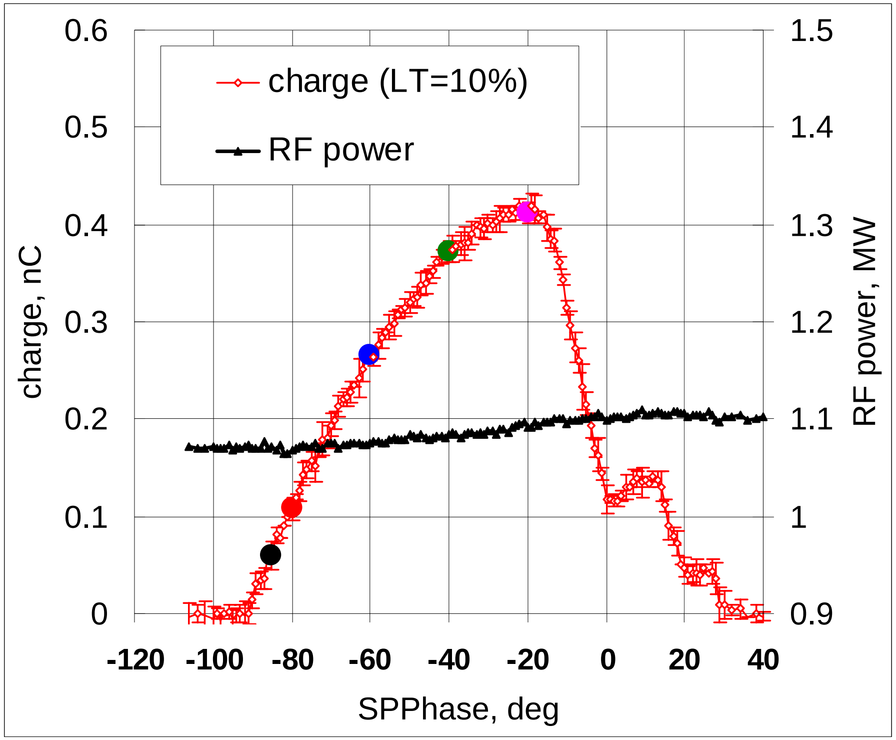
- 10 MW in-vacuum directional coupler
- FB based on signals from it
- Tools for the cross checking?

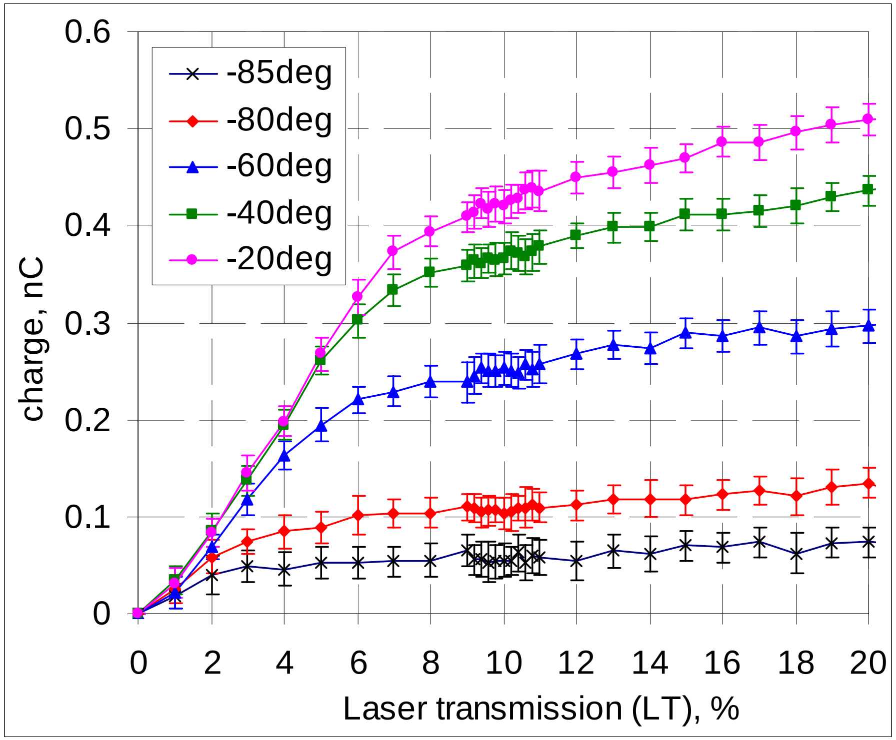
injector XFEL requirements [TDR]:

- RF gun launch phase stability is expected to be in the order of 0.1 deg (RMS)
- shot-to-shot stability in energy of the cathode laser pulses is expected to be:
  - 2% (RMS) for single pulses
  - 1% (RMS) averaged over a pulse train

Phase scan for gun stability measurements

Phase scan = measurement of the accelerated **charge** downstream of the gun as a function of the cathode laser launch phase for a given laser energy

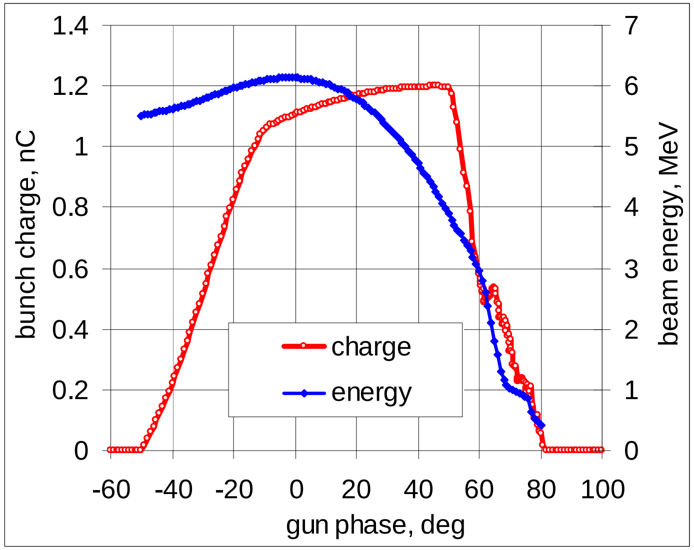




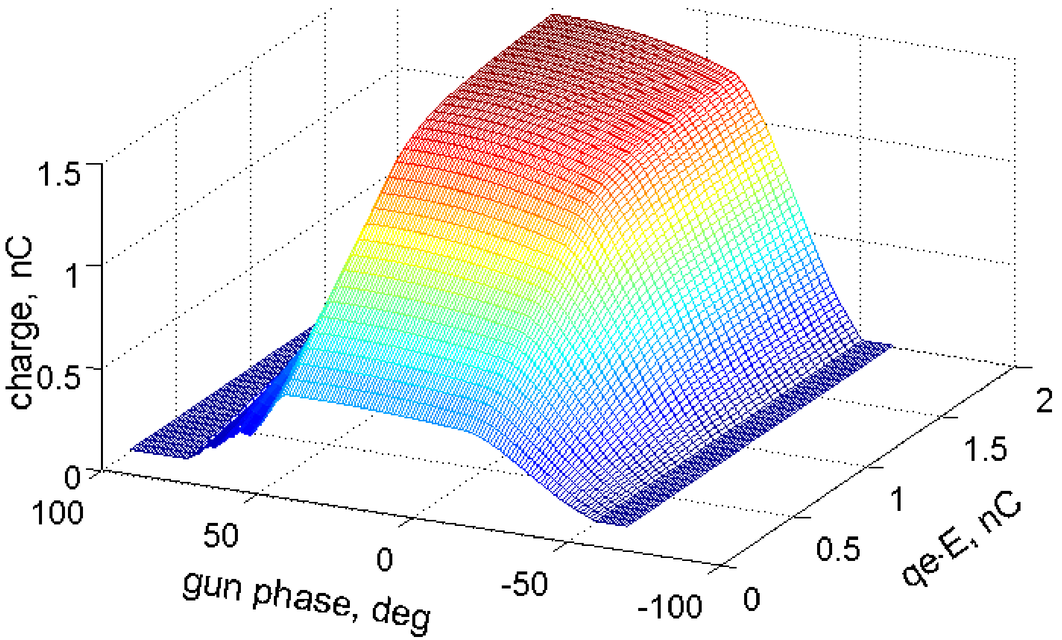
Measurements: April 2010

- The set point RF phase (SPPhase) is used for the horizontal axis. It has an arbitrary (but fixed) offset to the mathematical phase of the gun cavity resonator.
- The laser pulse energy is controlled by a polarizer (laser transmission - LT).
- The first FC (~0.8 m from the cathode) has been used.
- RF peak power is significantly lower that the nominal one, its mean value is ~1.09 MW.
- The main solenoid current of 210 A

Phase scan: simulations



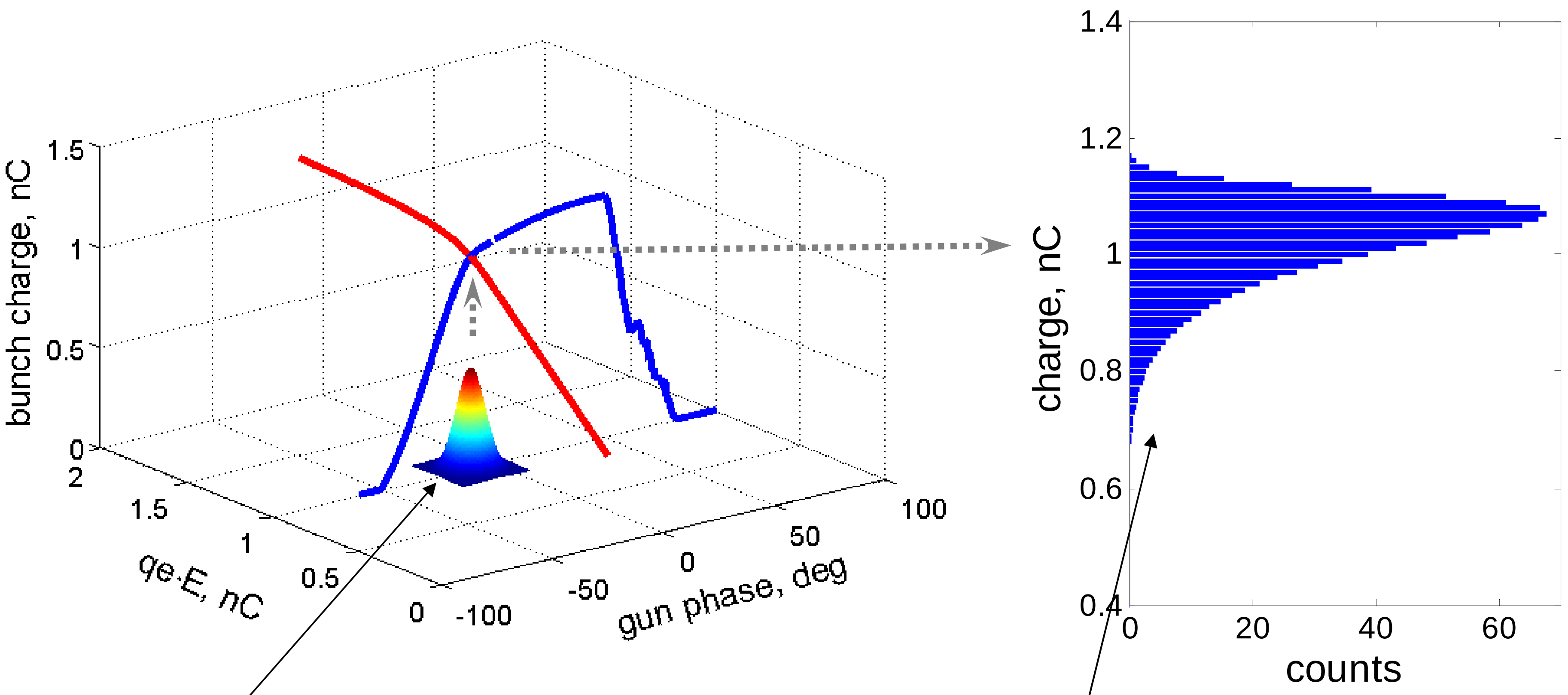
2D scan – bunch charge vs. the RF gun phase and the cathode laser pulse energy



ASTRA simulations:

- 60 MV/m at the cathode
- flat-top cathode laser temporal profile with 20 ps FWHM and 2 ps rise and fall time
- ~0.4 mm RMS laser spot size.
- all other fixed parameters → setup optimized to minimize the beam emittance at EMSY
- Additionally a Schottky constant of 0.005 nC/(MV/m)
- The value qe*E (horizontal axis in 2D scan) can be treated as a charge which could be extracted from the cathode if no space charge or Schottky-like effects would be applied

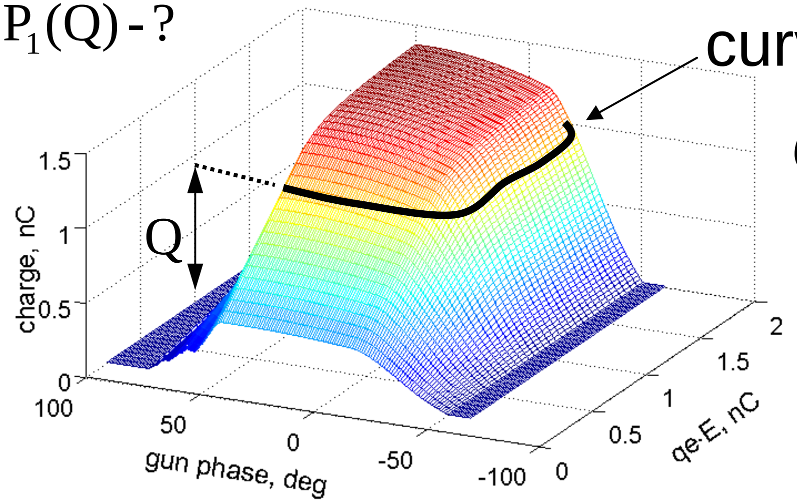
Phase scan for stability measurements



$$P_2(\phi, E) = \frac{1}{2\pi\sigma_\phi\sigma_E}\exp\left(-\frac{\Delta\phi^2}{2\sigma_\phi^2} - \frac{\Delta E^2}{2\sigma_E^2}\right) \Rightarrow P_1(Q)$$

Phase scan for stability measurements

$P_1(Q)$ - ?



$$G(\phi, E) = Q \xrightarrow{\text{parameterization}} \begin{cases} \phi = F_\phi(Q,\xi) \\ E = F_E(Q,\xi) \end{cases}$$

$$P_1(Q) = \int P_2\left(F_\phi(Q,\xi), F_E(Q,\xi)\right) \cdot \sqrt{\left(\frac{\partial F_\phi}{\partial \xi}\right)^2 + \left(\frac{\partial F_E}{\partial \xi}\right)^2} d\xi$$

Phase scan for stability measurements

$G(\phi, E) = \text{Q}$ → rough estimation ➔ the Taylor expansion up to linear terms:

$$Q = \left.\frac{\partial Q(\phi,E)}{\partial \phi}\right|_{(0)} \Delta\phi + \left.\frac{\partial Q(\phi,E)}{\partial E}\right|_{(0)} \Delta E$$

In this case $P_1(Q)$ is Gaussian with RMS width

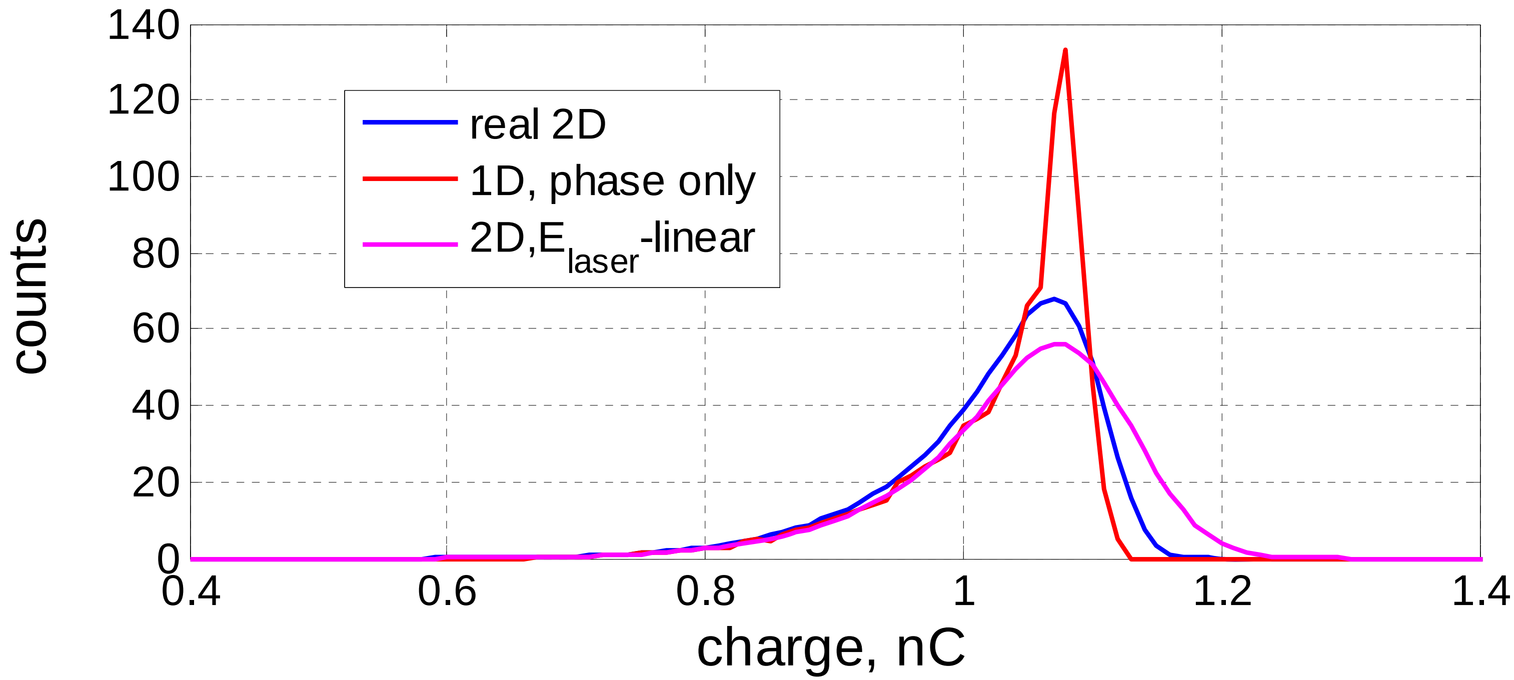
$$\sigma_Q = \sqrt{\left(\left.\frac{\partial Q(\phi,E)}{\partial \phi}\right|_{(0)}\right)^2 \sigma_\phi^2 + \left(\left.\frac{\partial Q(\phi,E)}{\partial E}\right|_{(0)}\right)^2 \sigma_E^2}$$

In principle, two measured points are sufficient to resolve the linear system:

$$\begin{pmatrix} \left(\left.\frac{\partial Q}{\partial \phi}\right|_{01}\right)^2 & \left(\left.\frac{\partial Q}{\partial E}\right|_{01}\right)^2 \\ \left(\left.\frac{\partial Q}{\partial \phi}\right|_{02}\right)^2 & \left(\left.\frac{\partial Q}{\partial E}\right|_{02}\right)^2 \end{pmatrix} \times \begin{pmatrix} \sigma_\phi^2 \\ \sigma_E^2 \end{pmatrix} = \begin{pmatrix} \sigma_{Q1}^2 \\ \sigma_{Q2}^2 \end{pmatrix}$$

, BUT…

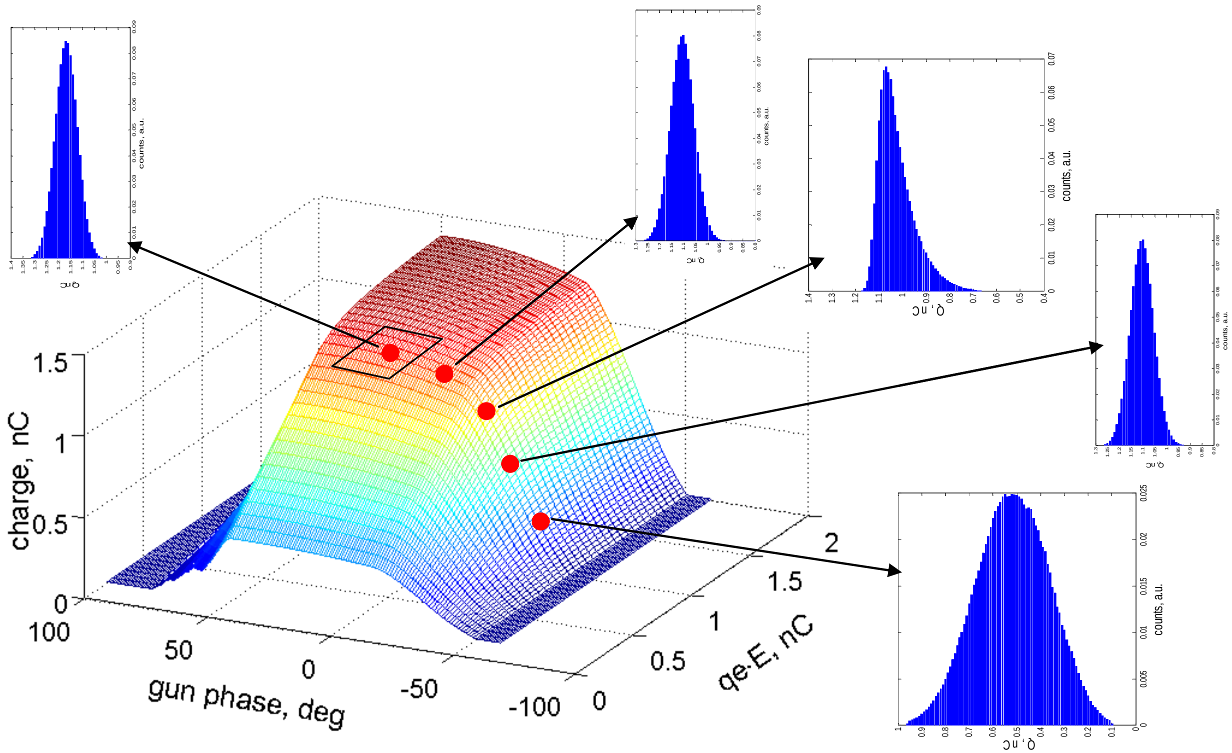
Simulated charge histograms



real 2D	**using full nonlinear charge dependence**	**=> goal histogram**
1D, phase only	**no laser pulse energy jitter assumed**	**overestimation of the phase jitter**
2D, E_{laser}-linear	**only linear slope of charge vs. laser energy assumed**	**underesimation of phase and laser energy jitter**

General Approach

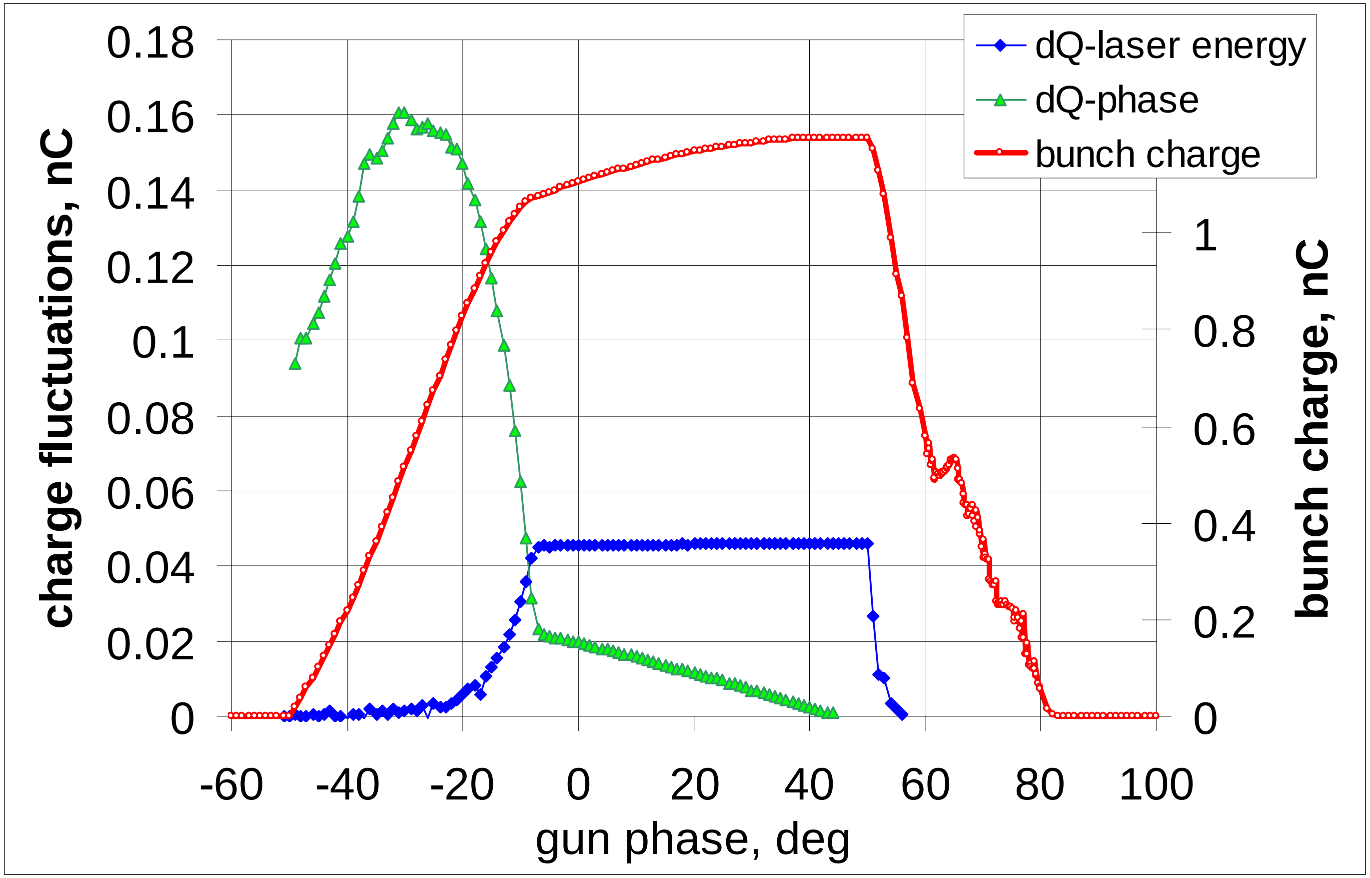
= simultaneous simulations of the measured charge histograms at various points



$$\Phi(\sigma_\phi, \sigma_E) = \sum_n w_n \cdot \int \left| QH_n^{meas} - QH_n^{sim} \right| dq \Rightarrow \min$$

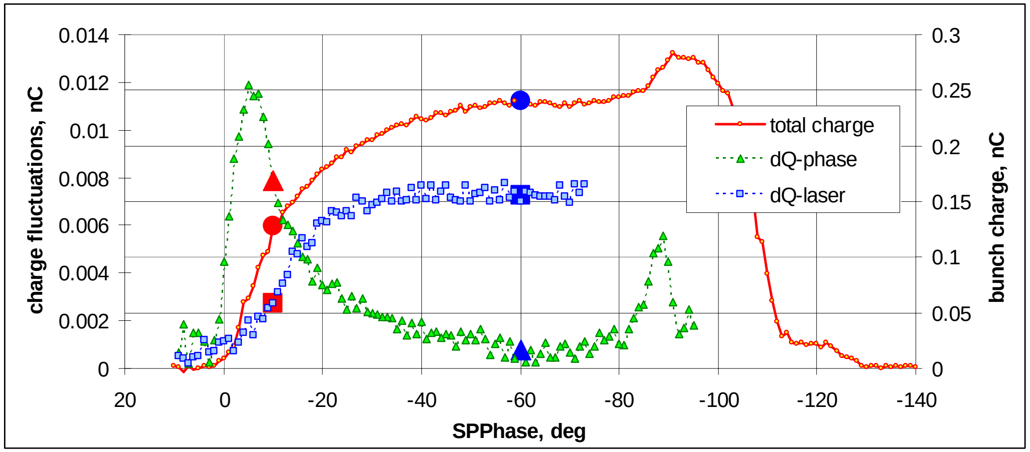
Choice of points

Simulated linear contributions to charge fluctuations from phase and laser pulse energy jitters



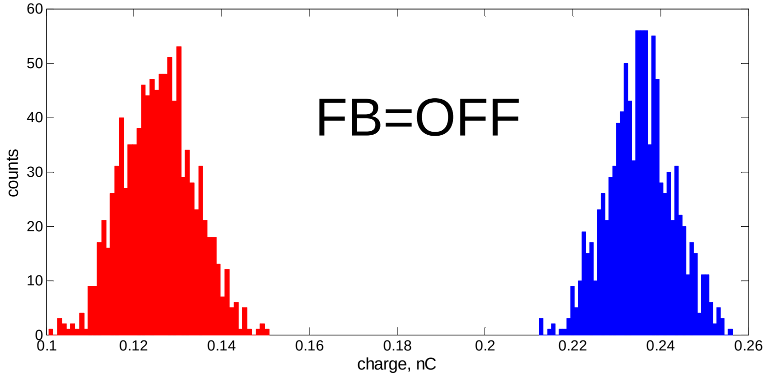
$$dQ\_phase = \frac{\partial Q(\phi, E)}{\partial \phi}\sigma_{\phi}; \quad dQ\_laser = \frac{\partial Q(\phi, E)}{\partial E}\sigma_{E}$$

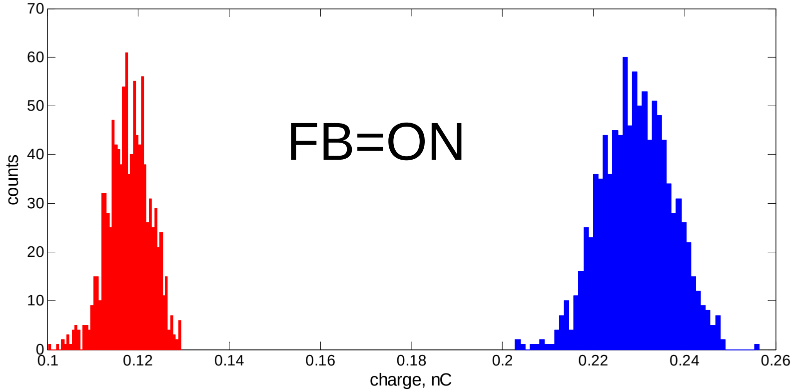
Experimental tests (Feb.2010)



Measurements:

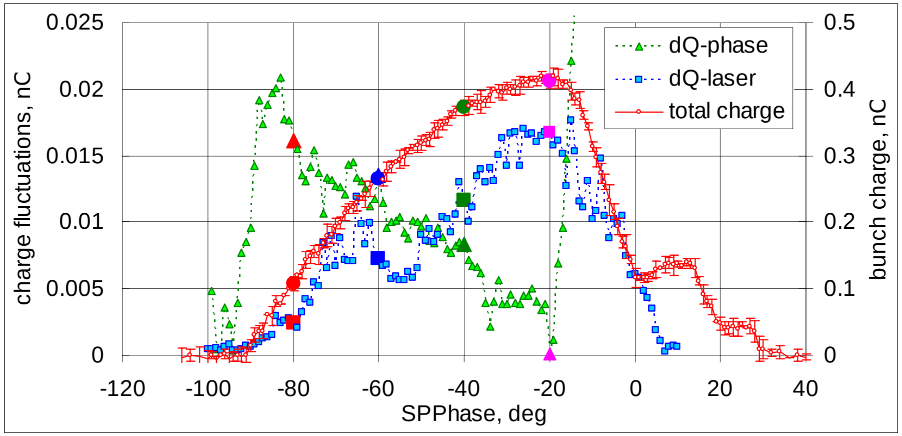
- ~0.85 MW
- no solenoid applied
- short Gaussian laser pulses
- first tests of the LLRF with closed FB loop



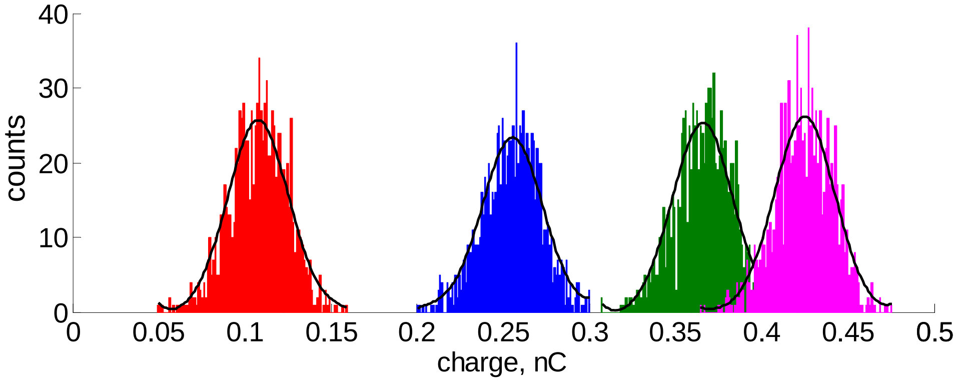


Feed Back (FB)	Laser pulse RMS jitter	RF phase RMS jitter	
		from charge measurements	from directional coupler
OFF	11%	0.82 deg	0.43 deg
ON	11%	0.32 deg	0.16 deg

Experimental tests (April 2010)

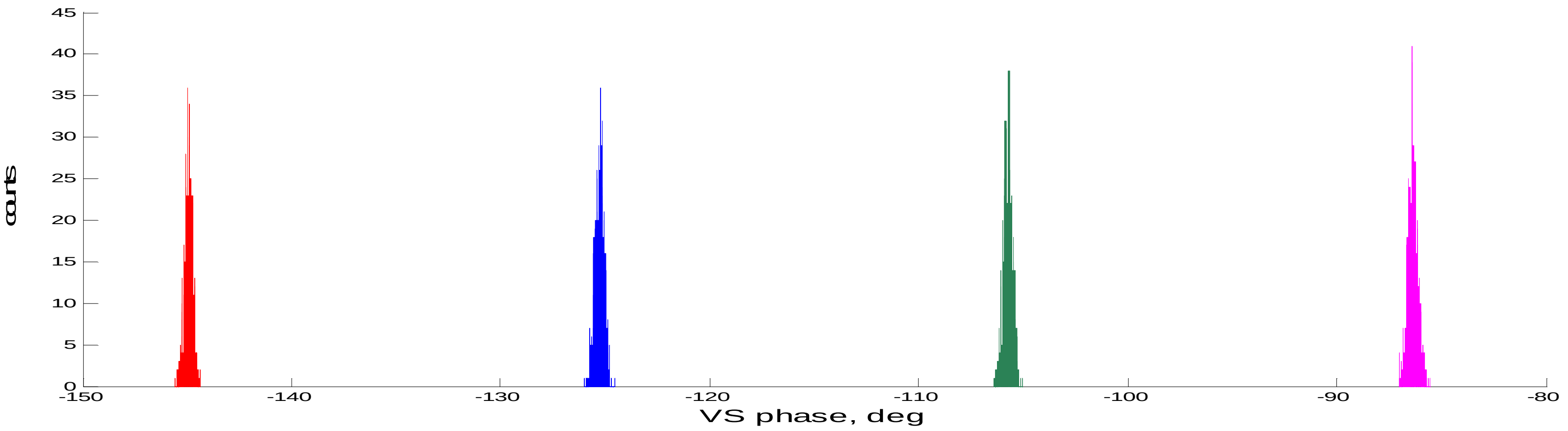


Charge histograms have been fitted at 4 phases (SPPhase=-80;-60;-40;-20 deg).

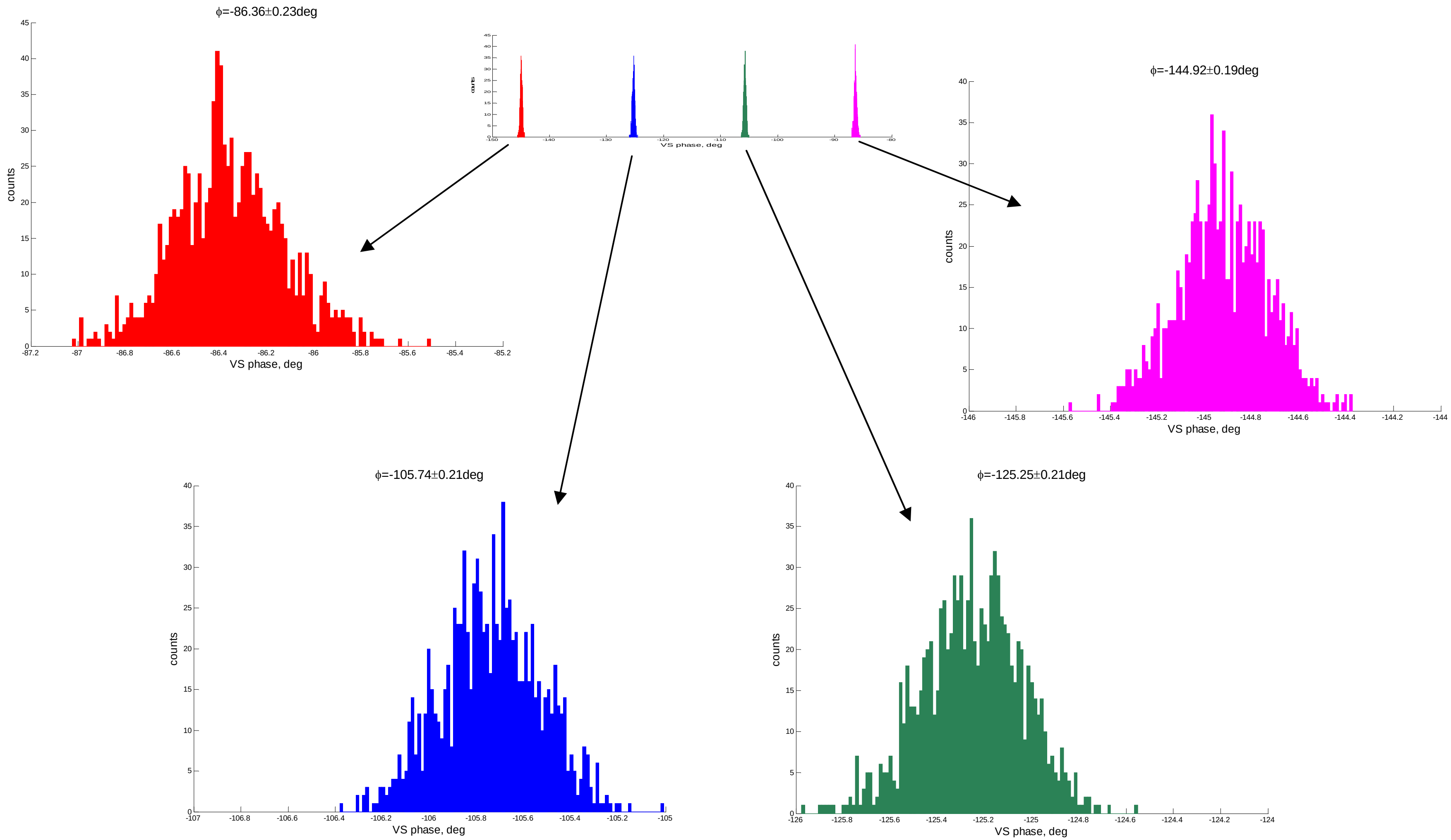


The applied method yielded an RMS jitter of **1.77 deg** for the RF phase and 12.5% for the laser pulse energy.

RF phase jitter measured using VS from the 10-MW in-vacuum coupler → 0.21 deg (only!)



10-MW in-vacuum coupler measurements



Measured phase jitter (VS) → (0.21±0.02) deg contradicts 1.8 deg obtained from charge based method!

Systematic limitation of the technique

- The bunch charge measurements using FC or ICT with a scope readout is usually disturbed by the noise of the scope base line and by the jitter of the background due to the dark current fluctuations.
  - A method to reduce the signal dependence on the dark current intensity can be based on a dark current envelope fitting corresponding to the actual peak power in the gun. This has to be tested in future when the nominal power level in the gun (7MW) will be achieved.
  - A dependence of the extracted charge on the RF gradient in the gun is not included in the above described method. However for some conditions when the electric field at the cathode plays a significant role in the emission process the RF field jitter (e.g. due to the resonance temperature fluctuations) could contribute in the bunch charge jitter as well.
  - This can also include the klystron nonlinearity – namely the dependency of the output RF power on the set point RF phase, which can be a substantial effect by the operation of the klystron close to saturation. If RF gradient in the gun is well controlled by the LLRF system these effects are assumed to be rather small.
- Another factor limiting the method performance is the laser timing synchronization to the MO, which are intrinsically included in the measured phase jitter. Using measurements from the directional coupler it should be possible to estimate this jitter as well.
- Scope readout to DOOCS – hanging (to be solved soon)

Conclusions

- Technique for the gun stability monitoring has been developed and tested at PITZ
- Some improvements on the procedure are still needed, including routine usage implementation
- The discrepancy with direct phase measurements from 10 MW in-vacuum coupler is to be clarified