Introduction to the benchmark problem

M. Krasilnikov (DESY)

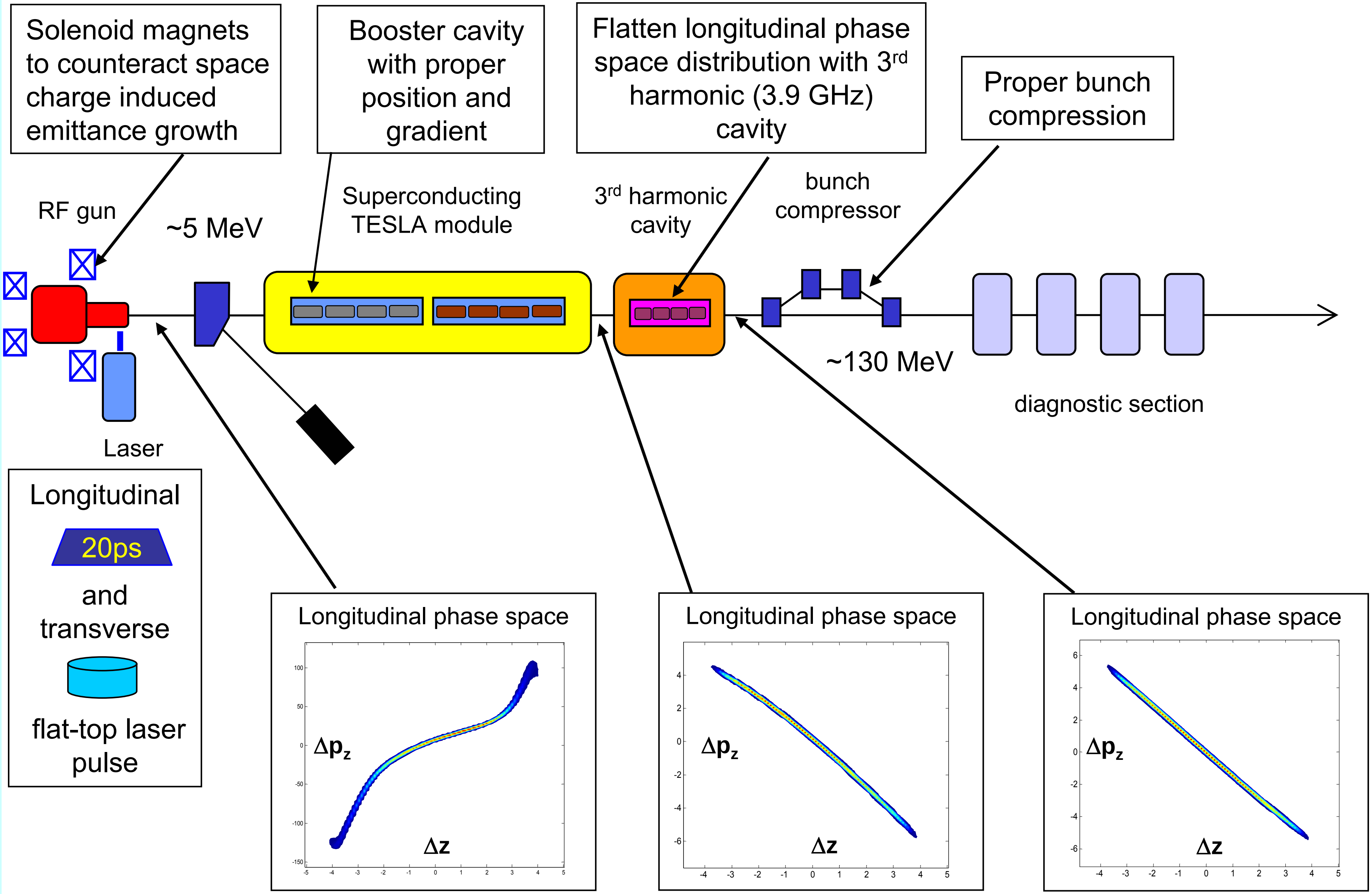
Working group 4: Low emittance electron guns

37th ICFA Beam Dynamics Workshop Future Light Sources 15 – 19 May 2006 DESY, Hamburg, Germany

Outline

- Introduction, **P**hoto **I**njector **T**est facility at **Z**euthen
- PITZ1 benchmark:
  - Motivation
  - Measurements
    - Phase scan for bunch charge
    - Reference phase check – beam size
    - Longitudinal momentum measurements
    - Emittance measurements using slit-scan technique
    - Cathode laser measurements
    - Stability issues
- Possible sources of errors and discrepancies
- Conclusions

Generic photo injector design



Optimization of the XFEL photo injector

ASTRA simulations

			unit	
				1
	remark			optimized
cathode laser	transverse	distribution		homogen.
		XYrms	mm	0.438
	temporal	distribution		flat-top
		Lt	ps	20
		rt	ps	2
		Trms	ps	5.8
	thermal	Ek	eV	0.55
		emittance	mm mrad	0.37
gun	RF	Ecath	MV/m	60
		launch phase	deg	-0.55
	solenoid	z-position	m	0.276
		MaxB(1)	T	-0.22466
		MaxB(2)	T	0.01113
booster	4xTESLA	z-position	m	3.773
		Emax	MV/m	21.53
		phase	deg	-15.72
ACC1	4xTESLA	Emax	MV/m	50
		phase	deg	-15.72
si	ASTRA	number of part.		200000
e-beam	@z=15m	charge	nC	1
		energy	MeV	157
		trans.emittance	mm mrad	0.676
		slice emit.(centre)	mm mrad	0.639
		rms en. spread	MeV	2.1
		long.emittance	mm keV	460
		rms length	mm	2.0

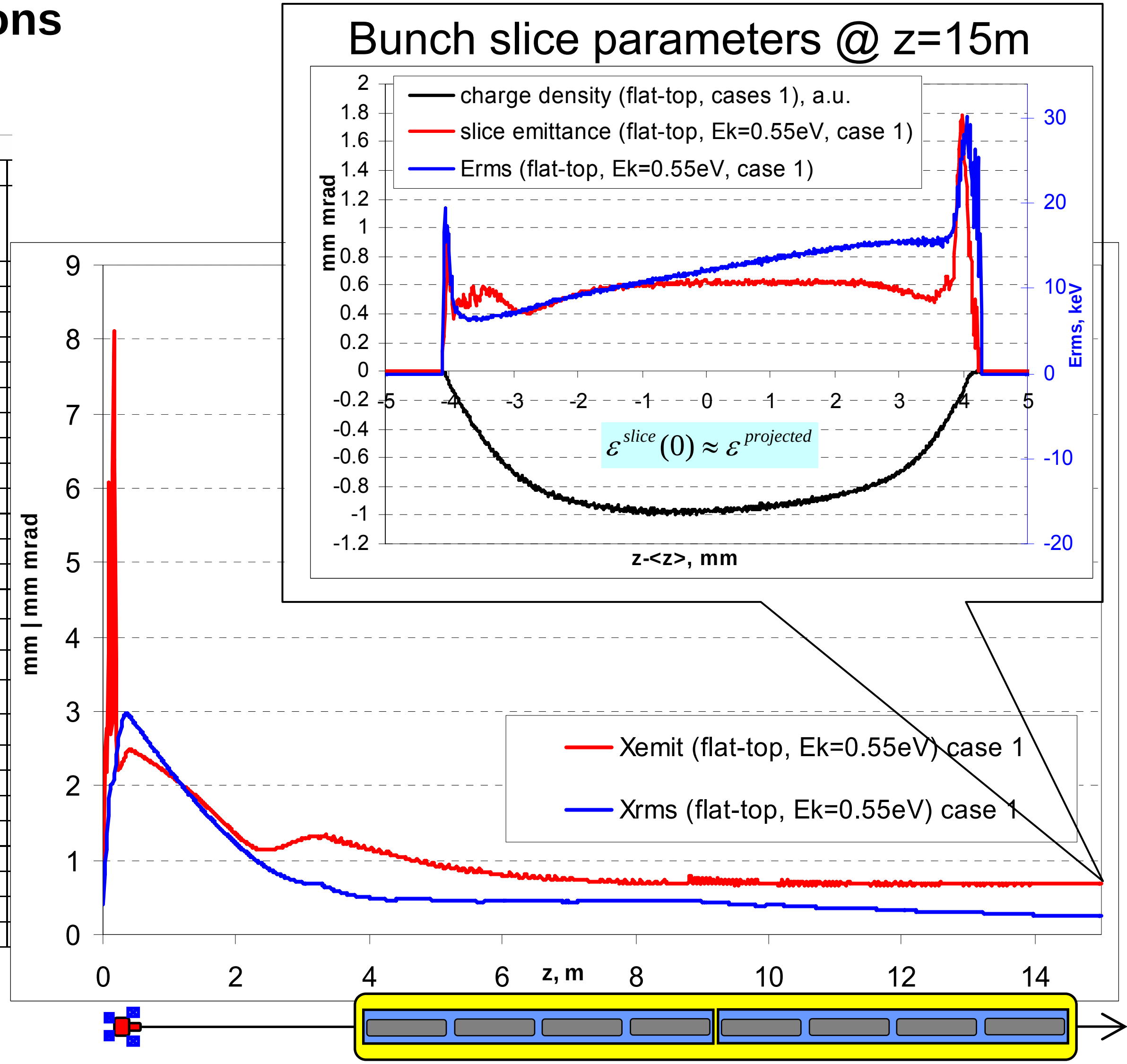


Photo injector layout and PITZ setup

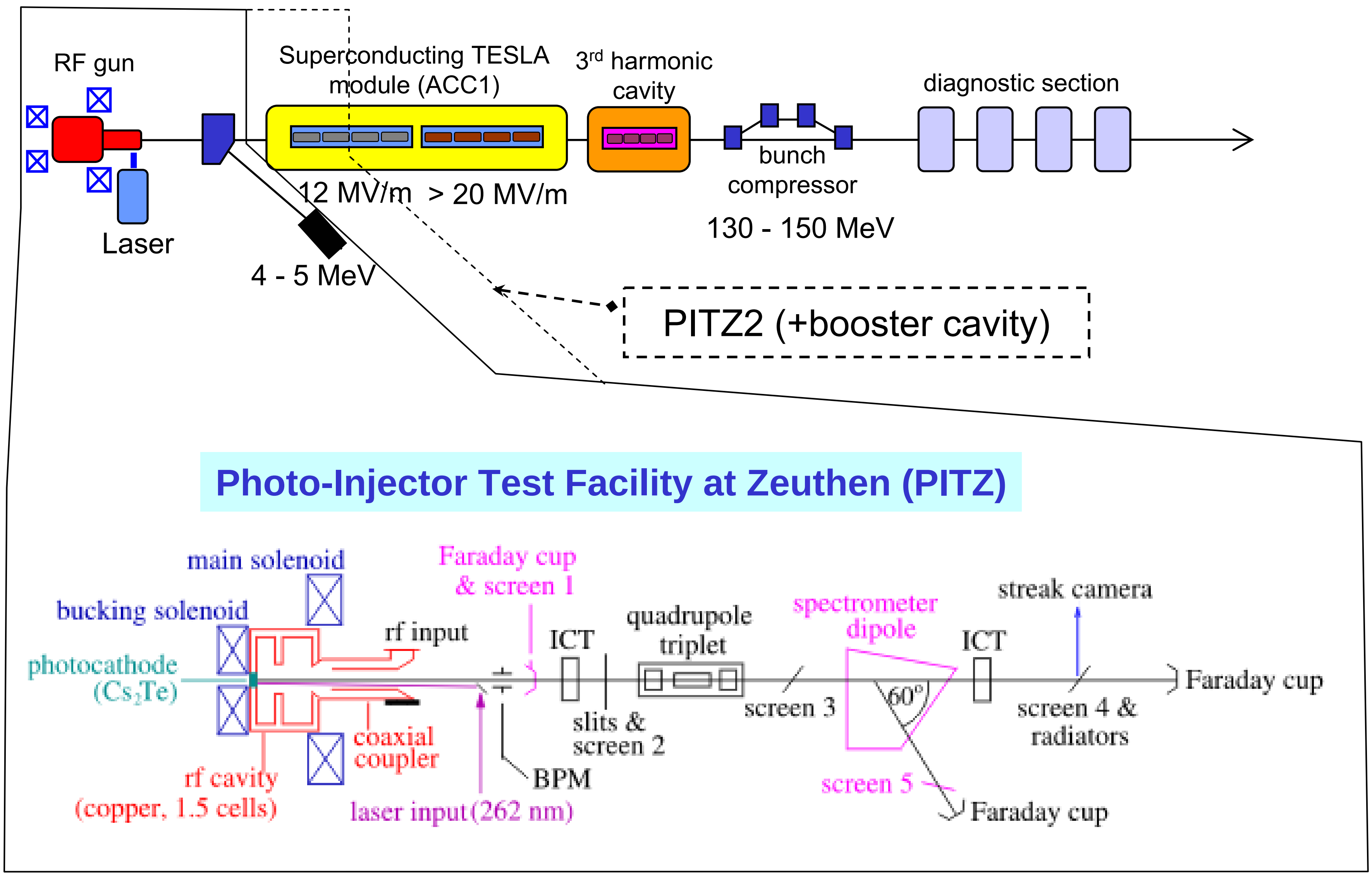
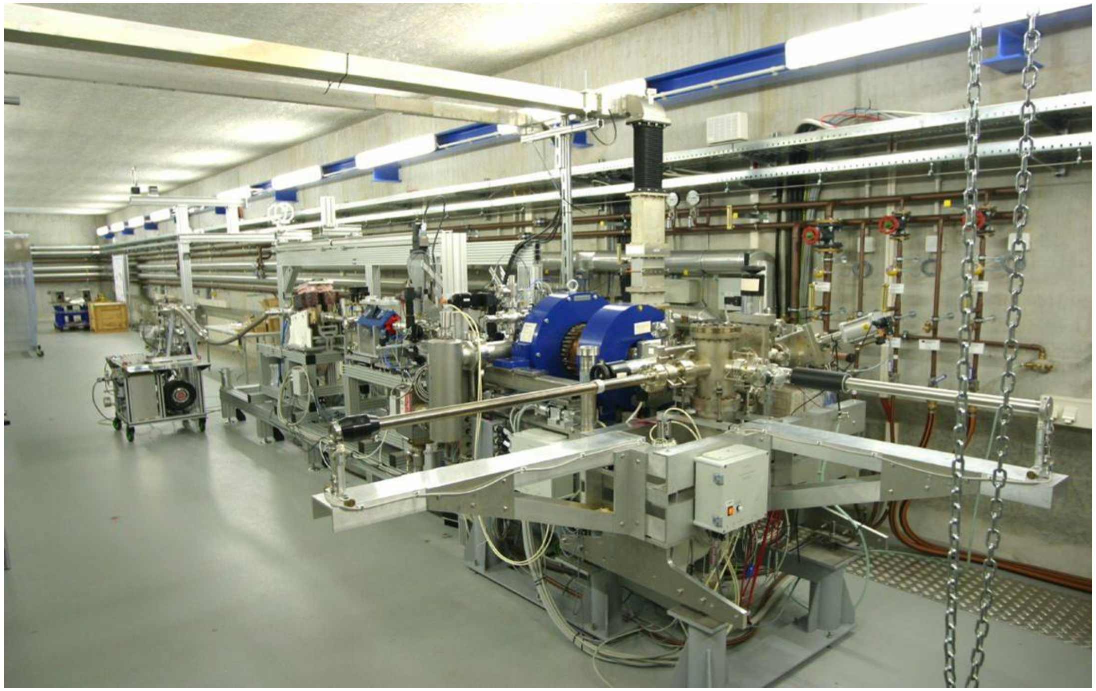


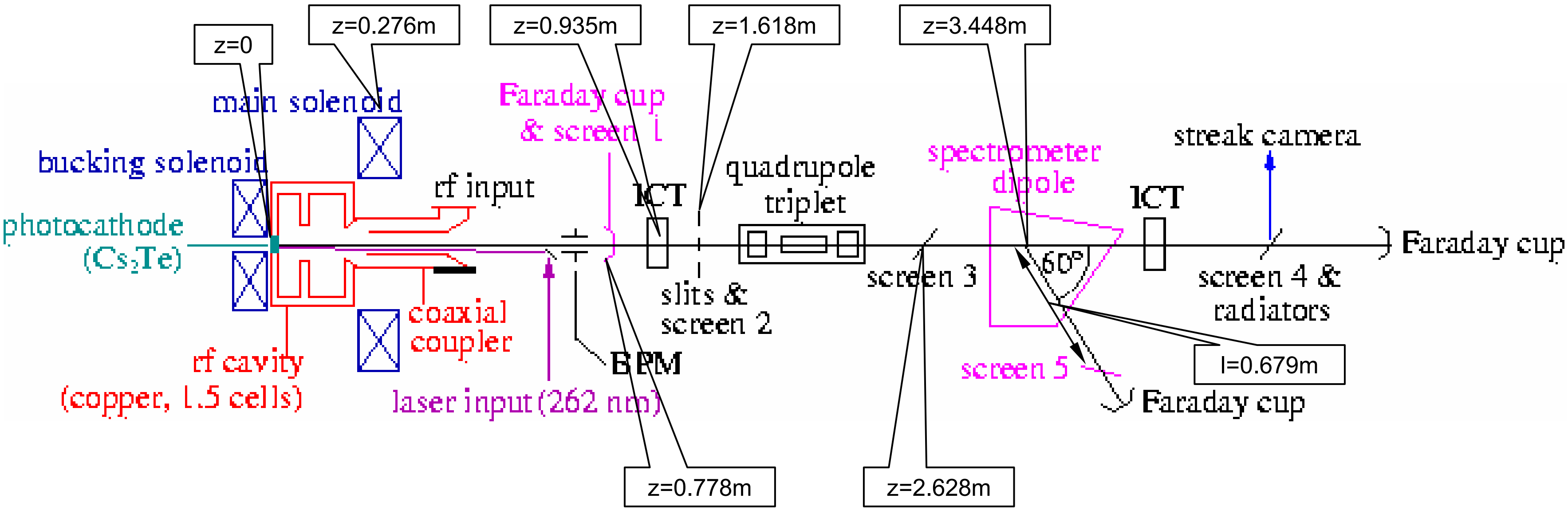
Photo Injector Test Facility at Zeuthen (PITZ)



- test facility for FELs: FLASH, XFEL
  - ⇒ **small transverse emittance (1 mm mrad @ 1 nC)**
  - ⇒ stable production of short bunches with small energy spread
  - ⇒ further studies: dark current, QE, BBA, thermal emittance, …

  + detailed comparison with simulations
- extensive R&D on photo injectors in parallel to FLASH operation
- test and optimize rf guns for subsequent operation at the FLASH and XFEL
- test new developments (laser, cathodes, beam diagnostics)

Diagnostics at PITZ1



component	property	diagnostics
cathode laser	transverse profile	virtual cathode, CCD
	longitudinal	streak-camera
electron beam	charge	FC, ICTs
	beam size	screens 1,2,3,4, CCD
	emittance	EMSY (slit masks), screens 2,3, CCD
	momentum	dipole, screen 5, CCD
	longitudinal profile	radiators(straight)+streak camera
	longitudinal phase space	radiators(straight+dispersive arm)+streak camera

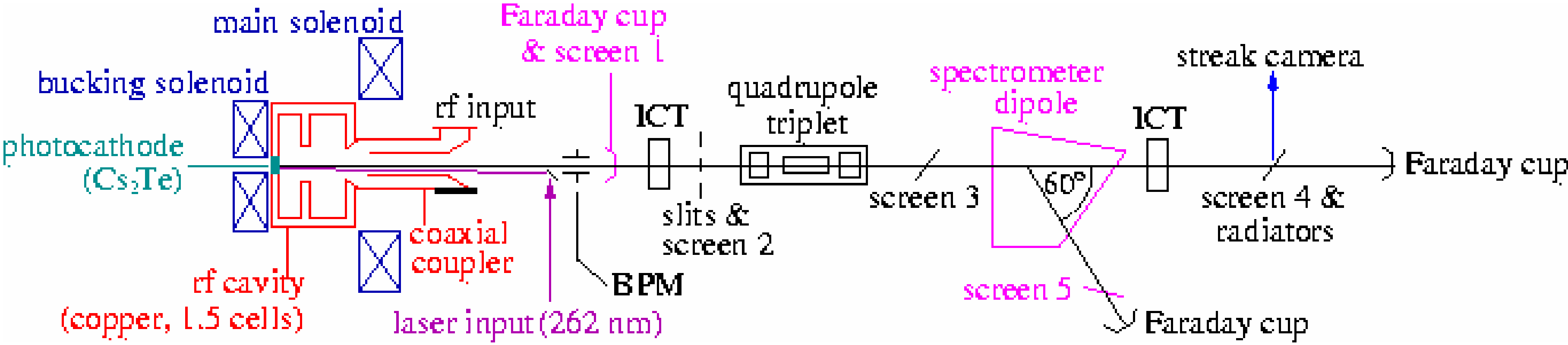
PITZ1 benchmark problem

Simultaneous simulations of a set of the consistent beam measurements (night shift 17.08.2004):

➢Stable machine run (phase drift within <1 deg, cathode laser profiles, measured emittance)

➢Several measurements (laser+electron beam) have been done:

- Phase scan ~1nC, ICT1
- Phase check (several beam size measurements at screen_PP vs. SP Phase)
- Momentum measurements for
  - ✓SPPhase=Phi0+10 deg,
  - ✓SPPhase=Phi0+3 deg (x2),
  - ✓SPPhase=Phi0+5 deg
- Emittance measurements for
  - ✓(SPPhase=Phi0+10 deg) × (Imain=318.5A),
  - ✓(SPPhase=Phi0+3 deg, SPPhase=Phi0+5 deg) ×(Imain=322;324;326:328;330;332A)
- Some stability studies (charge,position)



PITZ1 benchmark problem

Measurements

Beam measurements to be simulates

- **Bunch charge vs. rf phase**
- **Longitudinal momentum**
- **Beam size vs. rf phase**
- **Beam size vs. solenoid**
- **Beam emittance vs. main solenoid current**

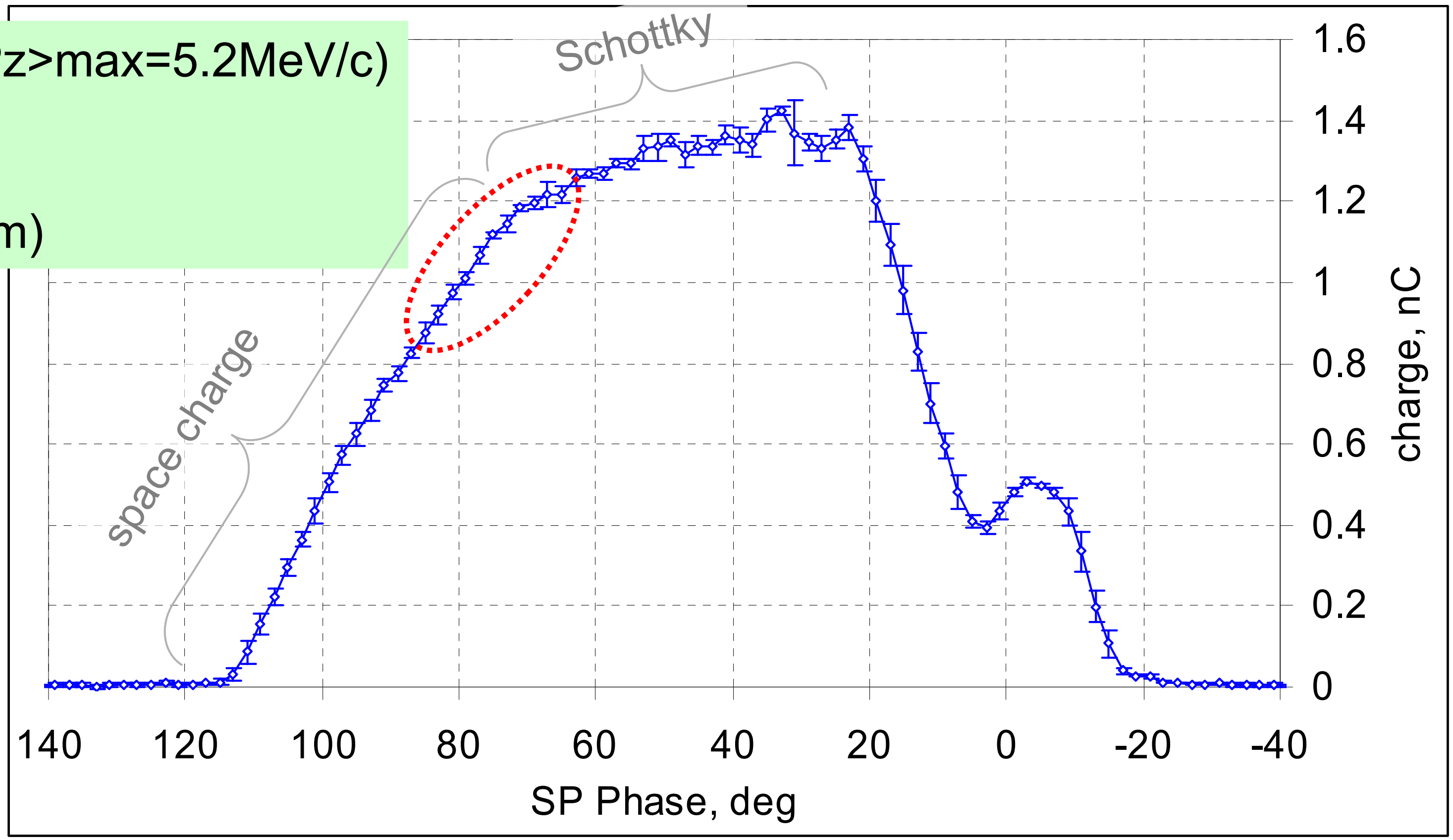
Auxiliary measurements to be used for input

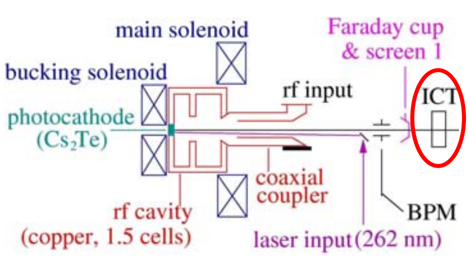
- **Cathode laser transverse intensity distribution**
- **Cathode laser temporal distribution**
- **Bunch charge stability**
- **Cathode laser position stability**

PITZ1 benchmark problem: Phase scan

Bunch charge vs. rf gun launch phase measured with ICT

SPV=33 (<Pz>max=5.2MeV/c)
Imain=320A
Ibuck=24A
ICT(z=0.935m)



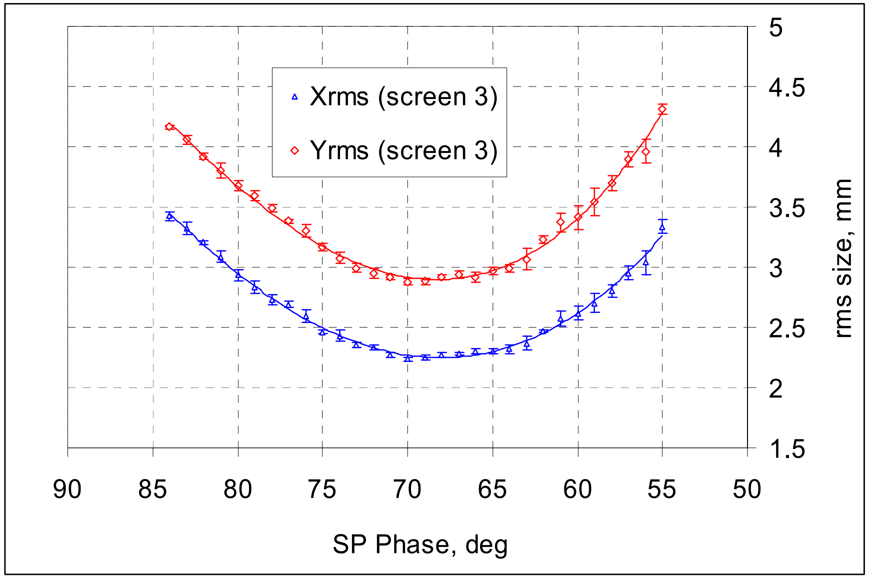


rf phase = PhaseOffset - SP Phase,
PhaseOffset to be found

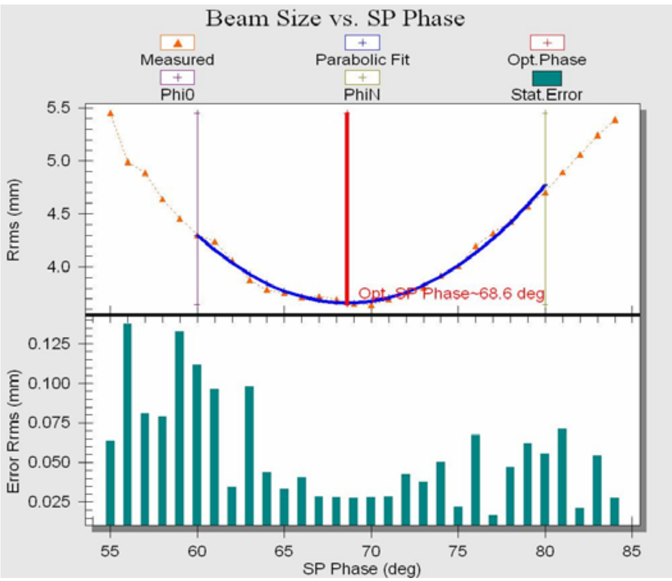
?aperture?
?SE?

PITZ1 benchmark problem: Reference rf phase check

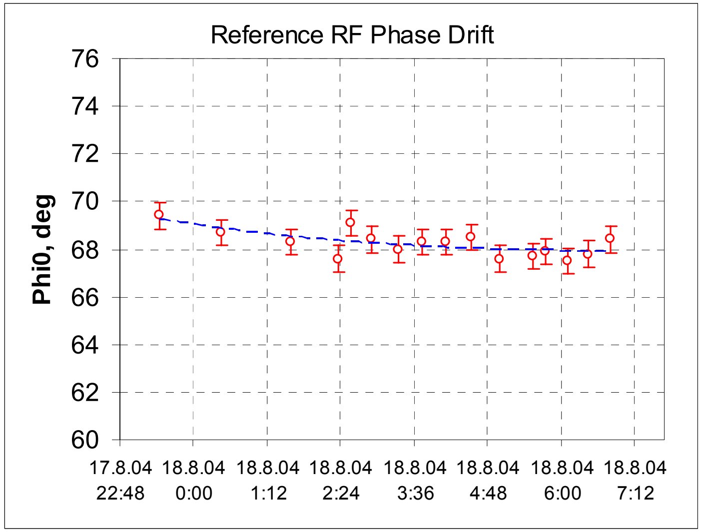
Reference phase ~ rf gun launch phase of maximum momentum gain

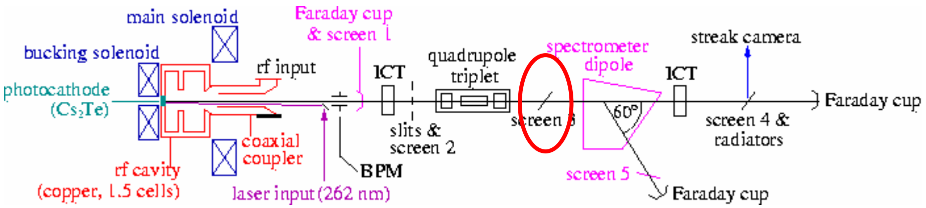


$$R_{rms} = \sqrt{X_{rms}^2 + Y_{rms}^2}$$



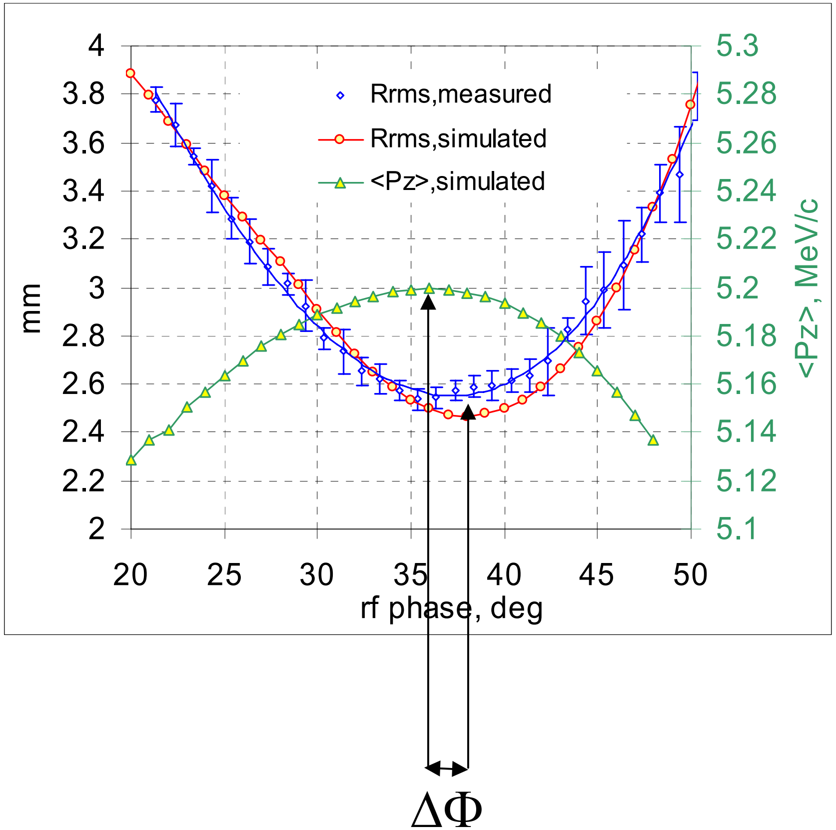
SPV=33 (5.2MeV/c)
Imain=320A
Ibuck=24A
Screen 3 (z=2.628m)



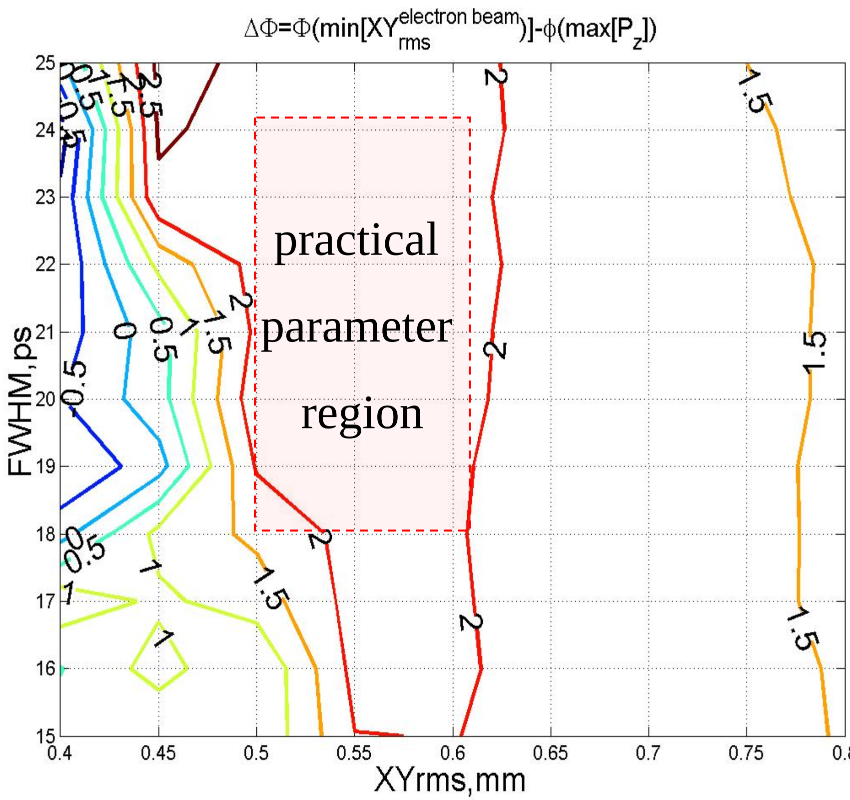


Reference rf phase simulations

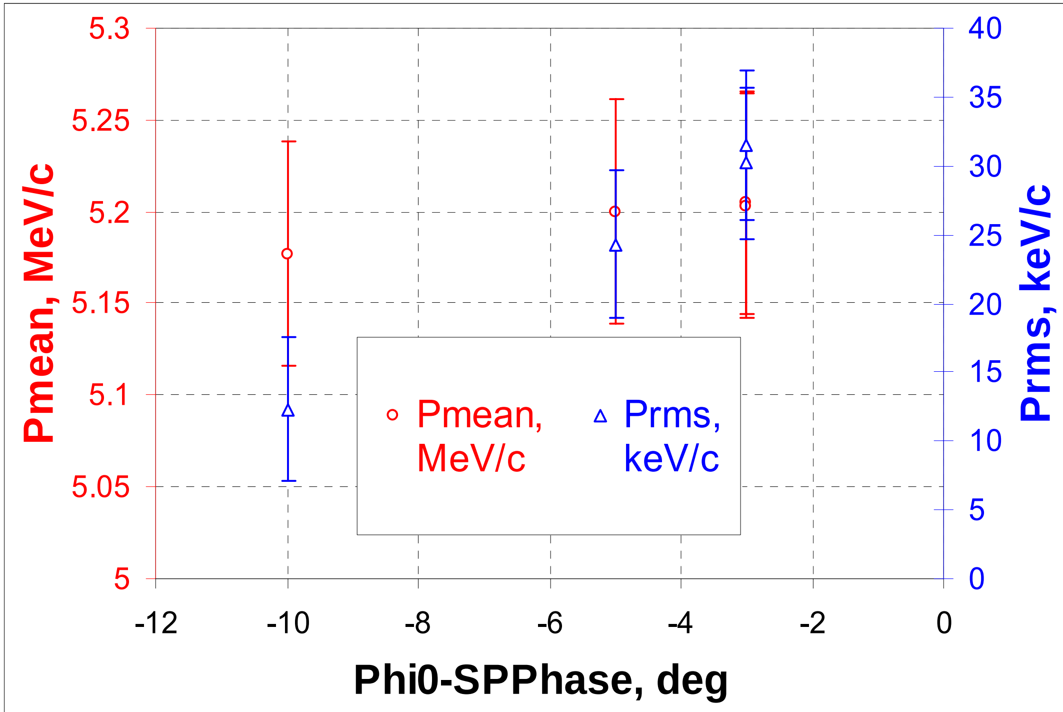
Measurements+Simulations



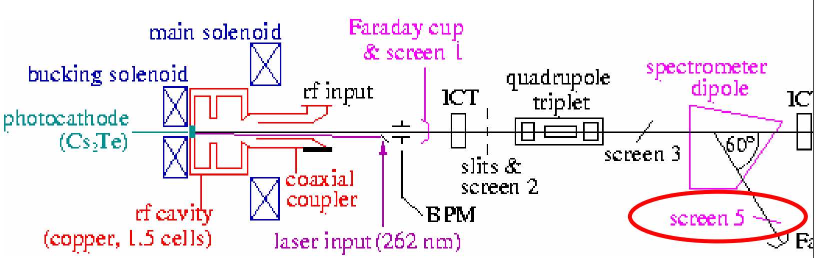
ΔΦ vs. cath. laser parameters

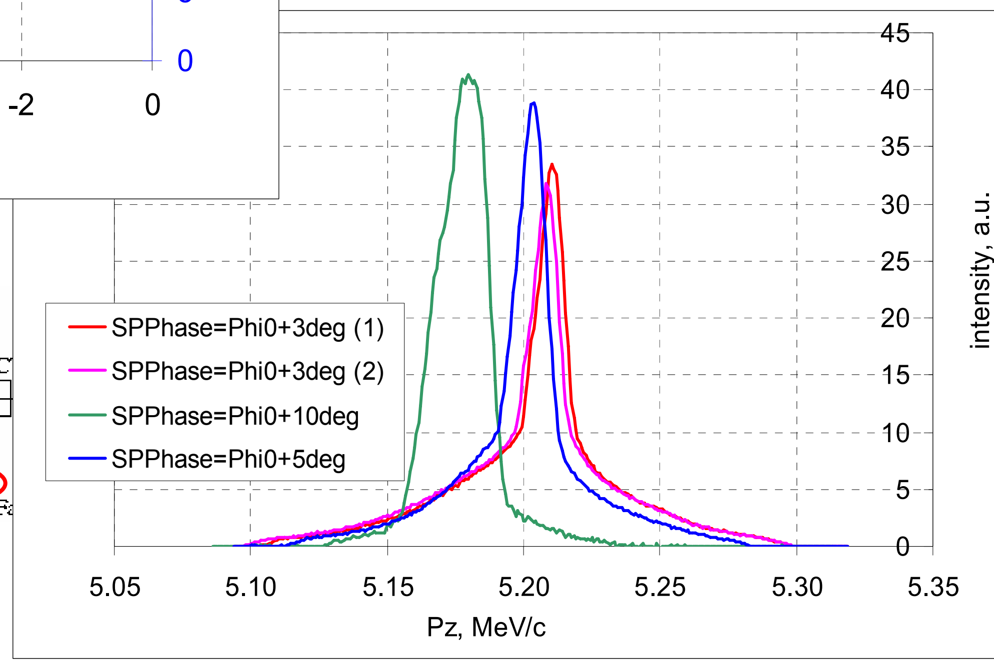


PITZ1 benchmark problem: Longitudinal momentum measurements

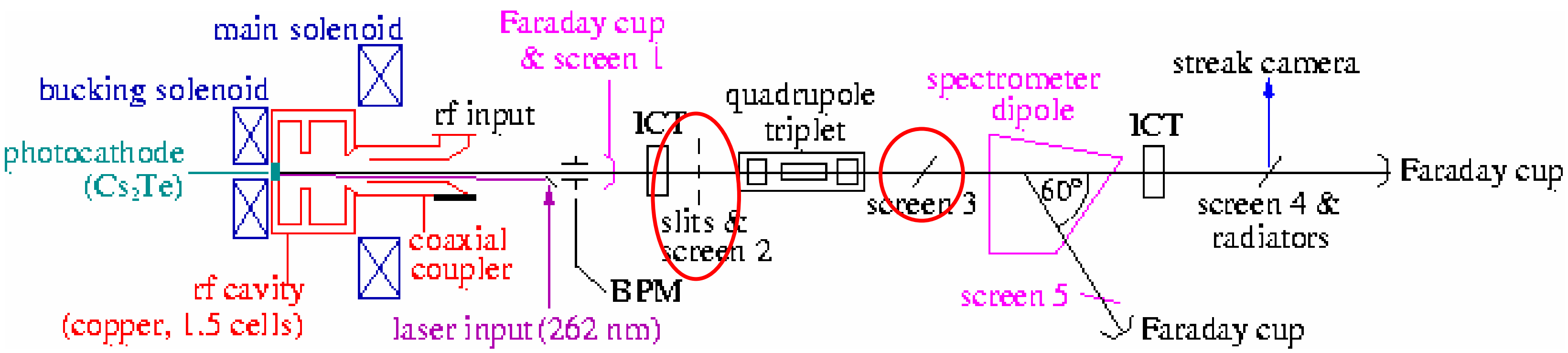


SPV=33 (5.2MeV/c)
Imain=280A
Ibuck=21A
Screen 5 (disp.arm)





PITZ1 benchmark problem:
Emittance measurements using slit scan technique

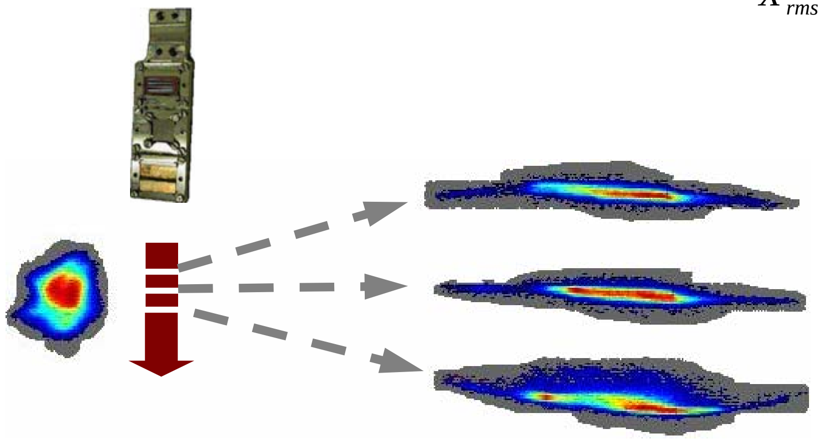


$$\varepsilon_x^n = \beta\gamma \cdot X_{rms} \cdot X'_{rms}$$

$$\varepsilon_y^n = \beta\gamma \cdot Y_{rms} \cdot Y'_{rms}$$

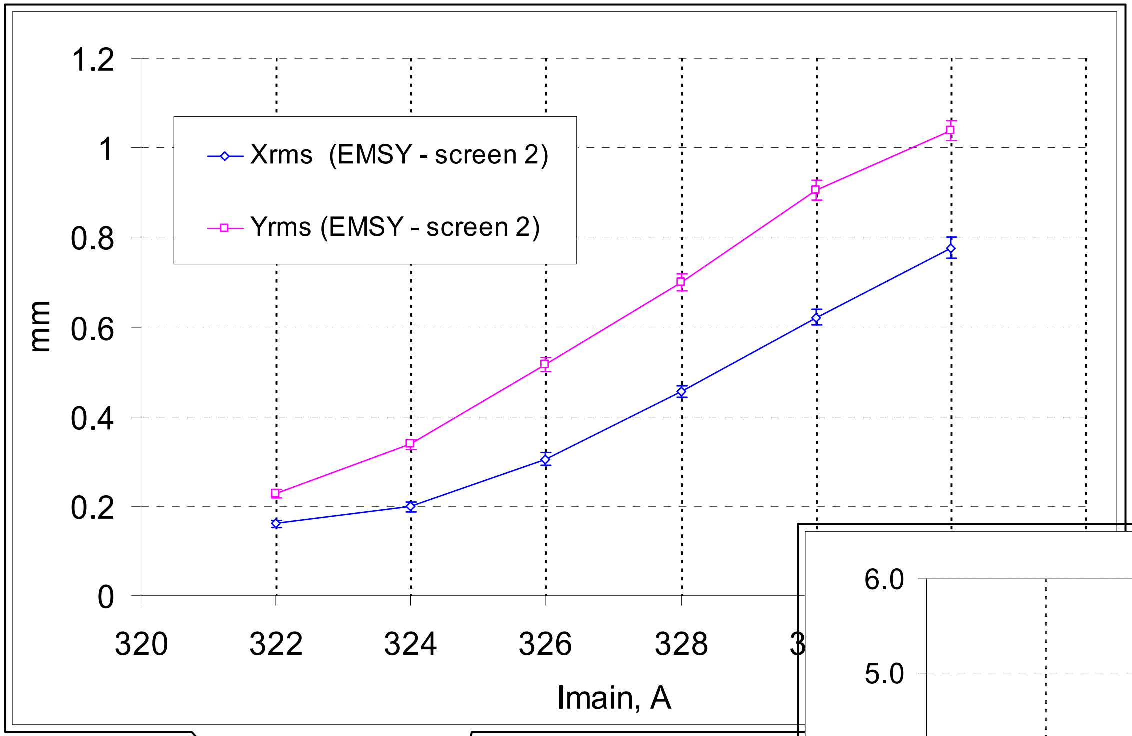
X_{rms} - whole beam rms size at screen2 (z = 1.618m)

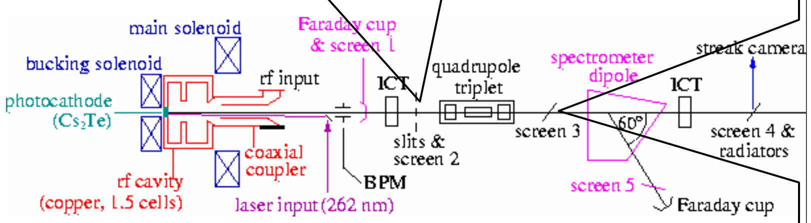
$$X'_{rms} = \frac{1}{L}\sqrt{\frac{\sum_{n=1}^{3} w_n \cdot (X_{rms})_n^2}{\sum_{n=1}^{3} w_n}}, \quad Y'_{rms} = \frac{1}{L}\sqrt{\frac{\sum_{n=1}^{3} w_n \cdot (Y_{rms})_n^2}{\sum_{n=1}^{3} w_n}}, \quad L = 1.01m$$

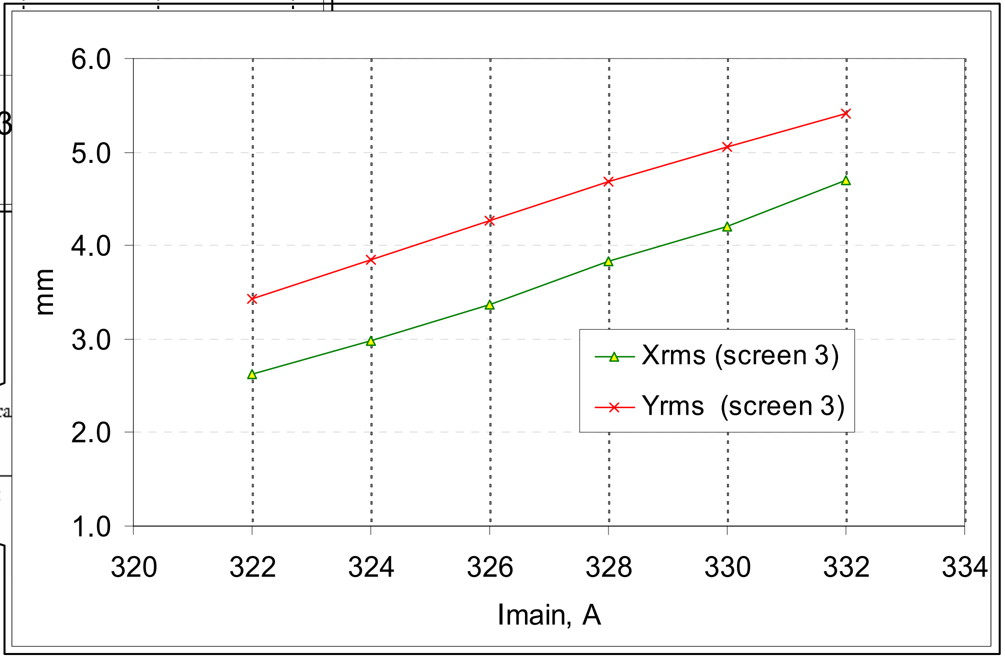


Beamlet #	Slit position-<X>
1	0
2	-0.7·Xrms
3	+0.7·Xrms

PITZ1 benchmark problem:
Emittance measurements. Beam size at screens 2 (EMSY) and 3



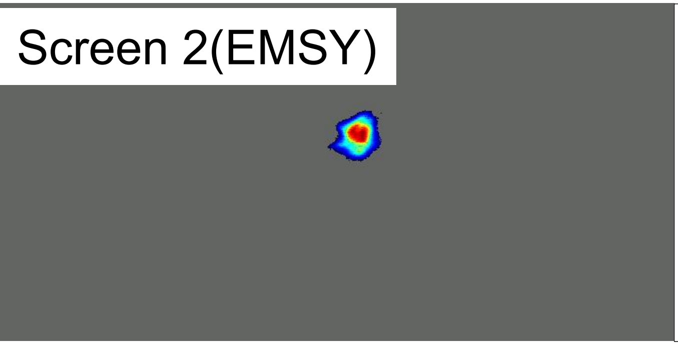


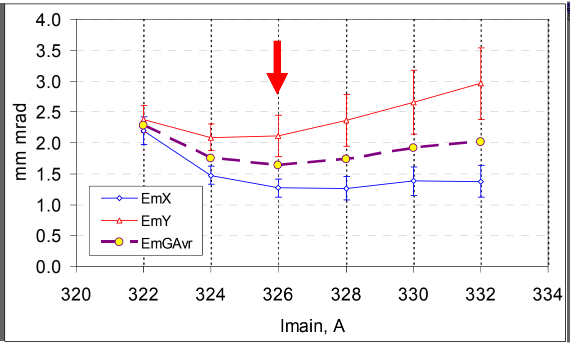


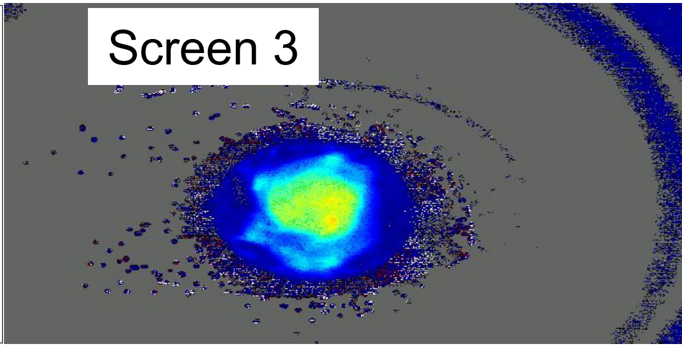
SPV=33 (5.2MeV/c)
SPPhase=Phi0+5deg
Ibuck=0.074847*Imain
Screens: 2 (EMSY), 3

PITZ1 benchmark problem:
Emittance measurements for SP Phase=Phi0+5deg, Imain=326A

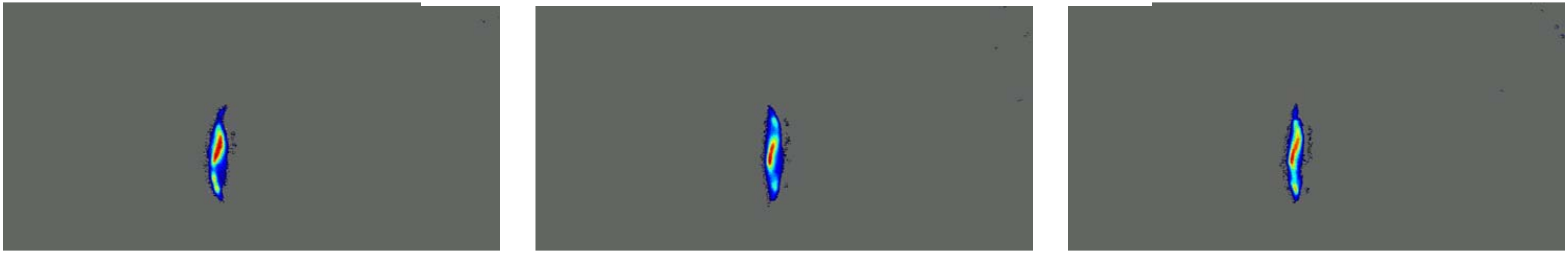
$\varepsilon_x^n = \beta\gamma \cdot X_{rms} \cdot X'_{rms}; \quad \varepsilon_y^n = \beta\gamma \cdot Y_{rms} \cdot Y'_{rms}$ $\quad \varepsilon_{GAvg}^n = \sqrt{\varepsilon_x^n \cdot \varepsilon_y^n}$



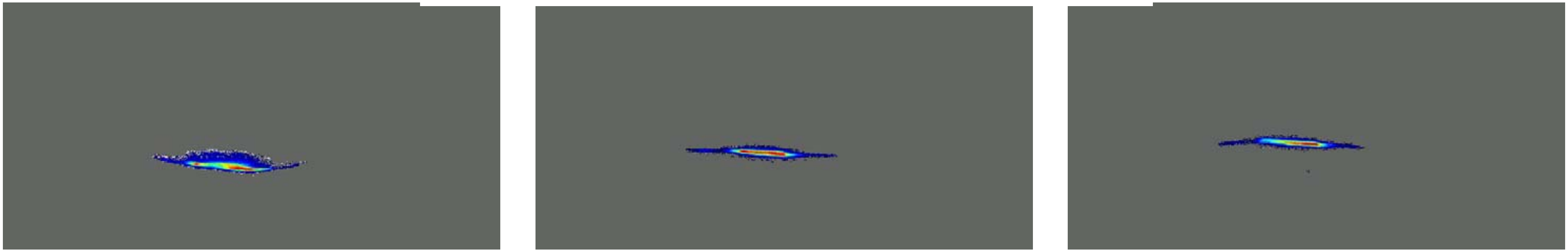




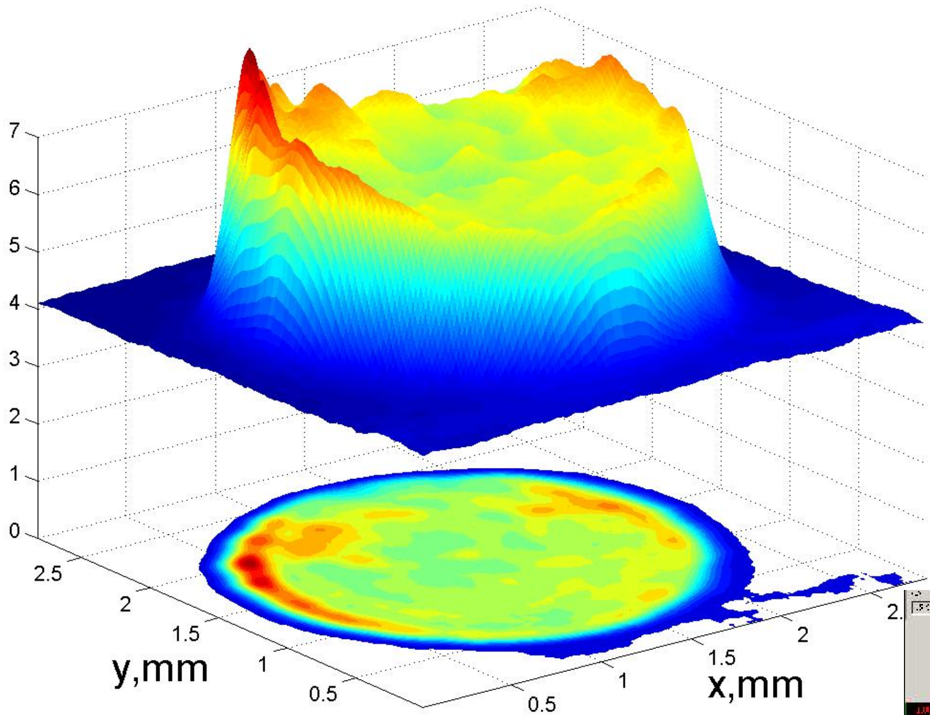
X-beamlets: X= -0.7·Xrms; 0; +0.7·Xrms



Y-beamlets: Y= -0.7·Yrms; 0; +0.7·Yrms

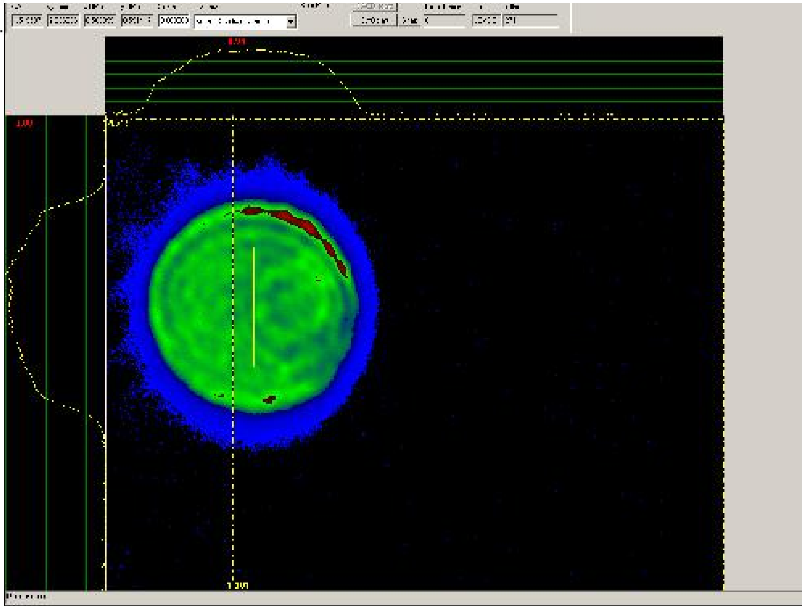


PITZ1 benchmark problem: Cathode laser. Transverse



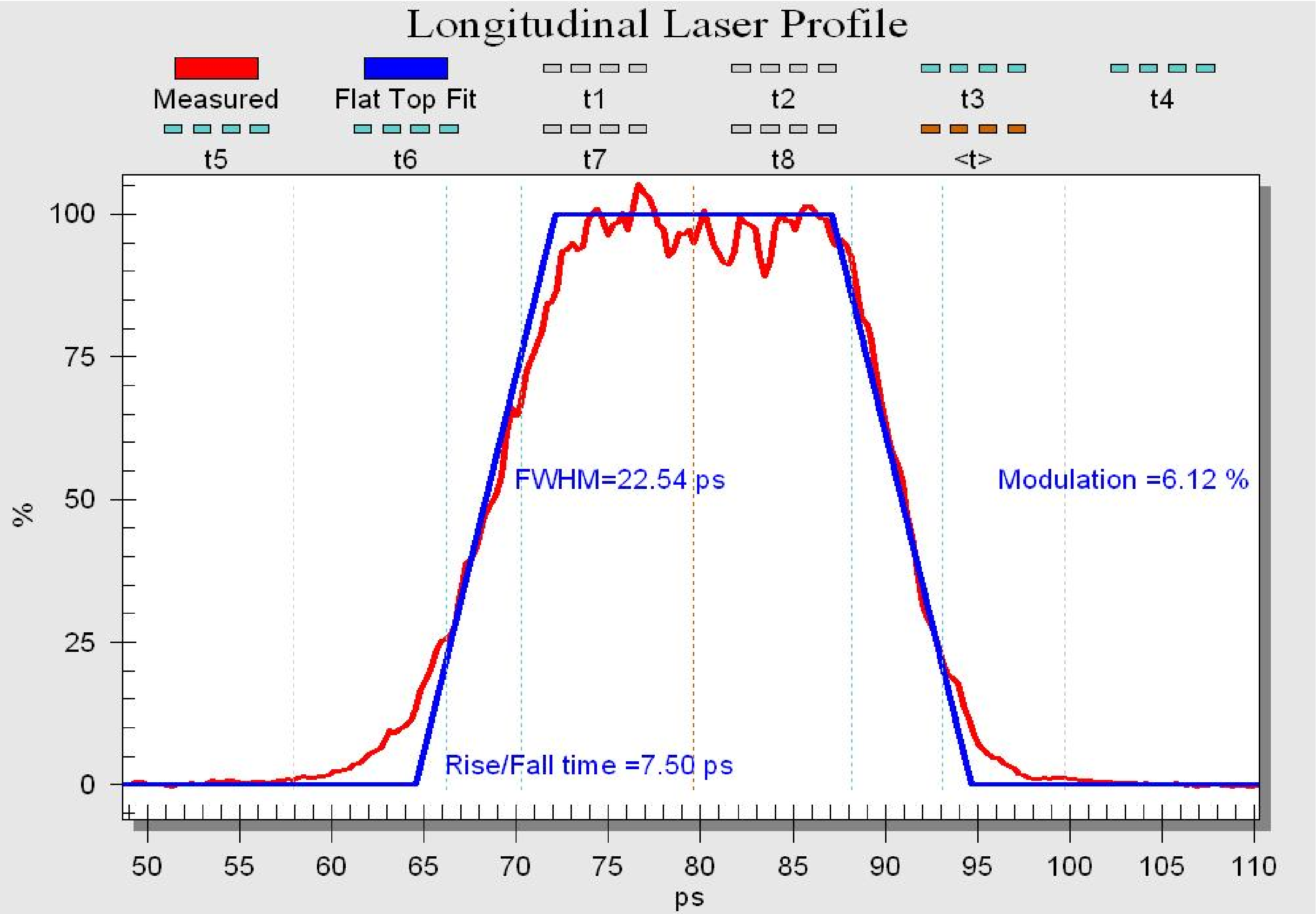
1.5 mm diaphragm:
Xrms=0.54mm
Yrms=0.57mm

Virtual cathode (CCD camera)

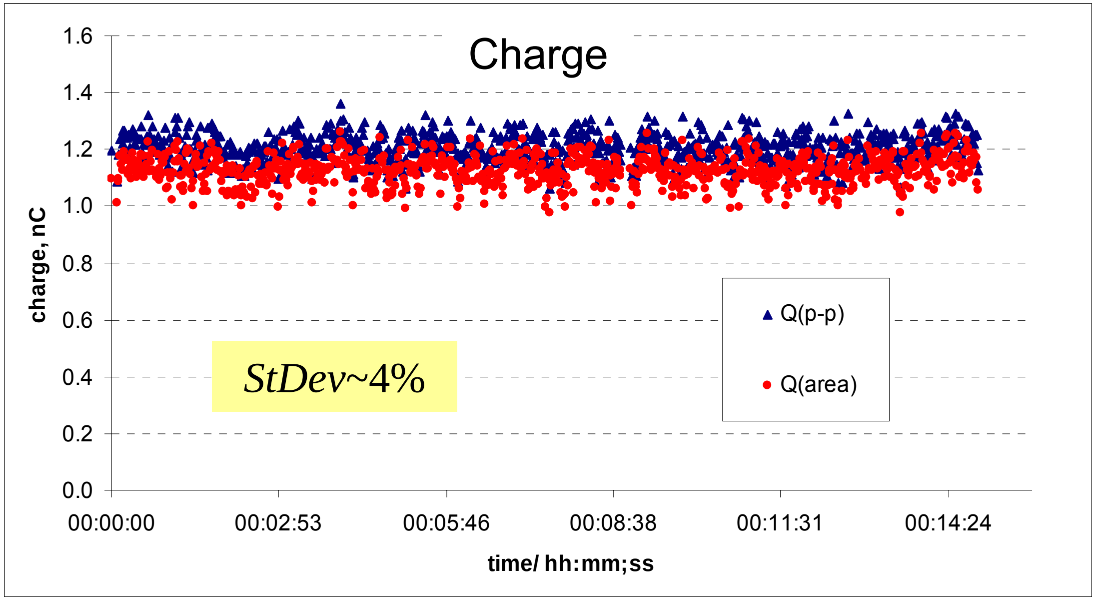


PITZ1 benchmark problem: Cathode laser. Temporal

Streak-camera in UV

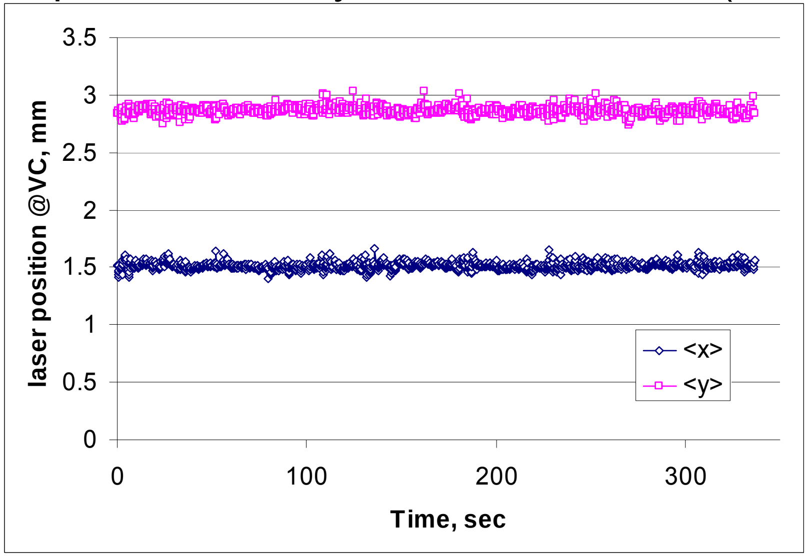


PITZ1 benchmark: Stability



SPV=33 (5.2MeV/c)
Imain=320A
Ibuck=24A
SPPhase=Phi0
ICT1

Laser position stability at Virtual Cathode (19.08.2004)

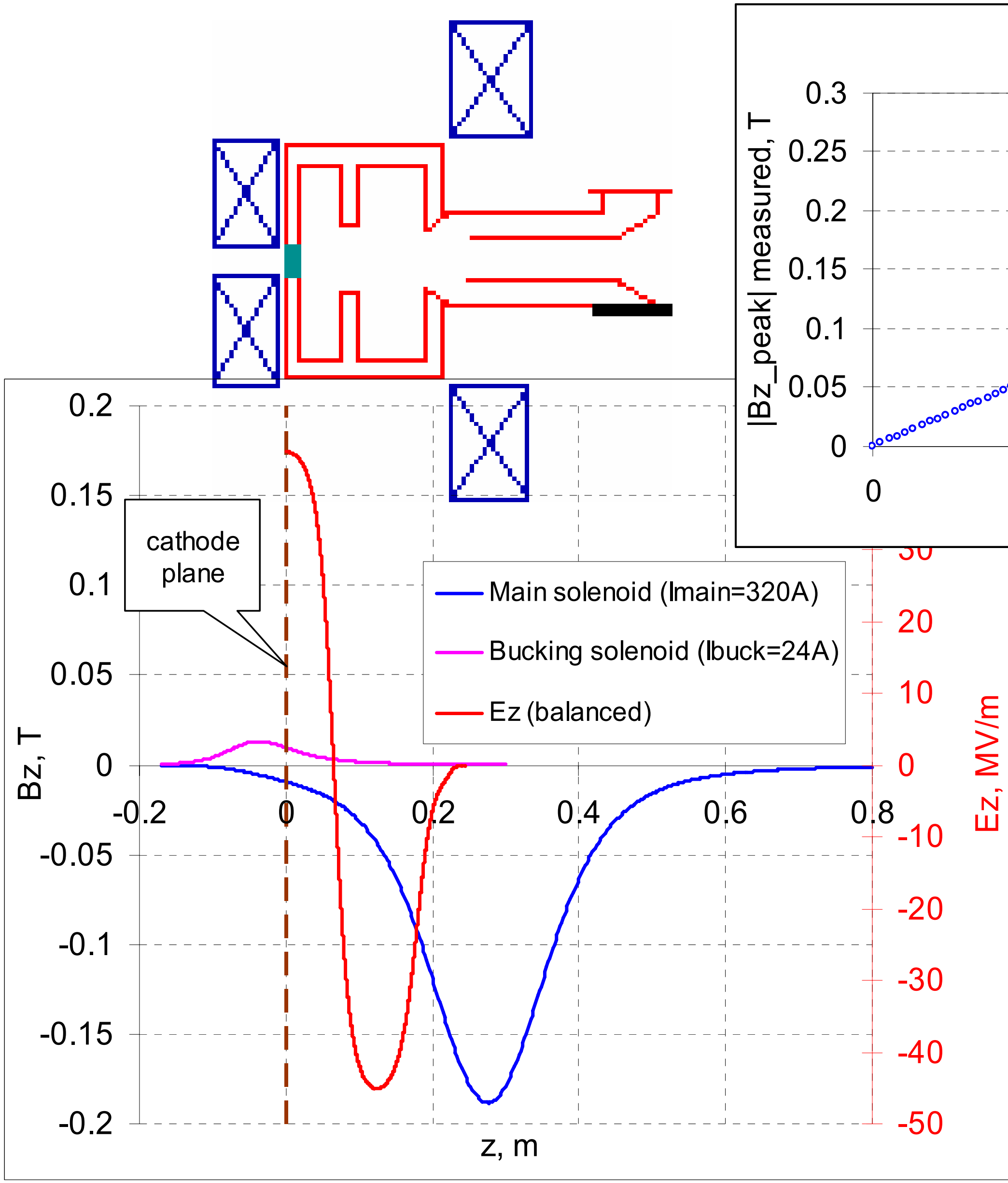


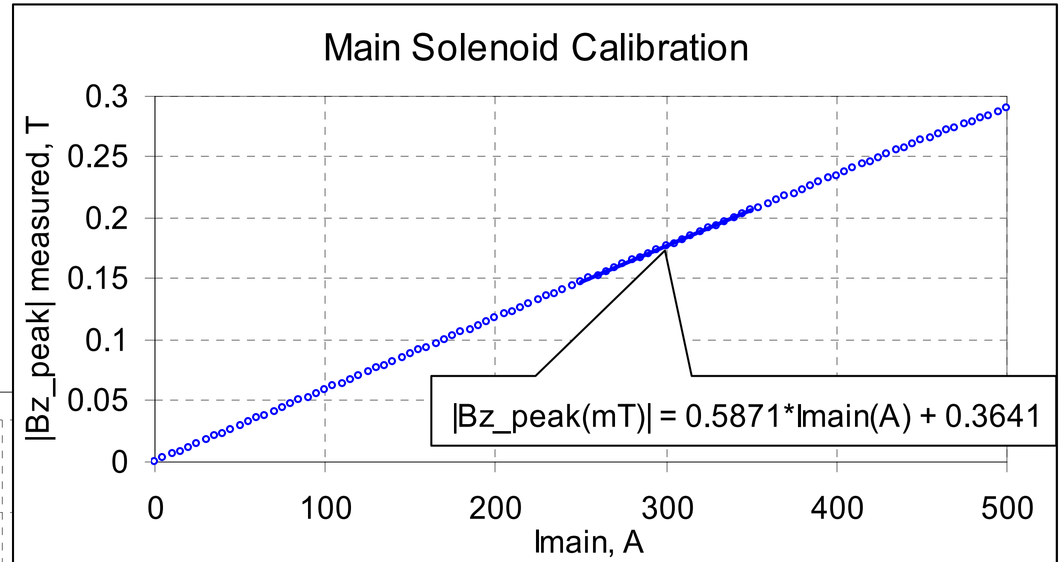
<X>=(1.517±0.028) mm
<Y>=(2.861±0.032) mm
Xrms=(0.560±0.005) mm
Yrms=(0.580±0.004) mm

$$\frac{StDev\left(\langle X\rangle\right)}{\langle Xrms\rangle} \sim \frac{StDev\left(\langle Y\rangle\right)}{\langle Yrms\rangle} \sim 5\%$$

50 frames*→ ~2%

PITZ1 Benchmark Problem: EM Fields





- Field balance in the rf gun cavity
- Solenoid calibration
- MF compensation

  Ibuck=0.074847*Imain

Possible sources of errors and discrepancies

- RF Phase drift and jitter
- Reference phase determination
- Cathode laser power and position jitter
- Field balance (FB=Ecath/Efullcell)
- Solenoid calibration
- Cathode laser measurements
- Beam size measurements using YAG screens
- Influence of the beam line components (i.e.vacuum mirror), misalignment of the components (i.e. DDC)
- …

Conclusions

A set of consistent beam measurements has been proposed as a benchmark for the theoretical understanding (PITZ1 benchmark problem):

- implies simultaneous simulation of measured charge, momentum, beam size at different positions, emittance (beamlet size)
- effects during emission (Schottky, space charge, etc) seem to be of importance for accurate simulations of beam dynamics in photo injector
- various measurements of projected values simulated simultaneously should provide more reliability for simulated slice parameters of the electron bunch

http://www-zeuthen.desy.de/~kras/PITZProblem.html/PITZbenchmark.html