Cathode Laser Pulse Shaping For High Brightness Electron Sources (PITZ Experience)

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ICFA Workshop on Future Light Sources, *March 5-9, 2012*
Thomas Jefferson National Accelerator Facility, Newport News, VA

Content:

- Photo cathode laser system at PITZ
- Temporal pulse shaping – flat-top profile:
  - rise/fall time impact
  - flat-top modulations studies
- Transverse laser distribution influence
- Advanced pulse shaping of the cathode laser: 3D ellipsoid
- Summary

HELMHOLTZ | ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

DESY

PITZ Photo cathode laser (Max-Born-Institute, Berlin)

Yb:YAG laser at PITZ with integrated optical sampling system

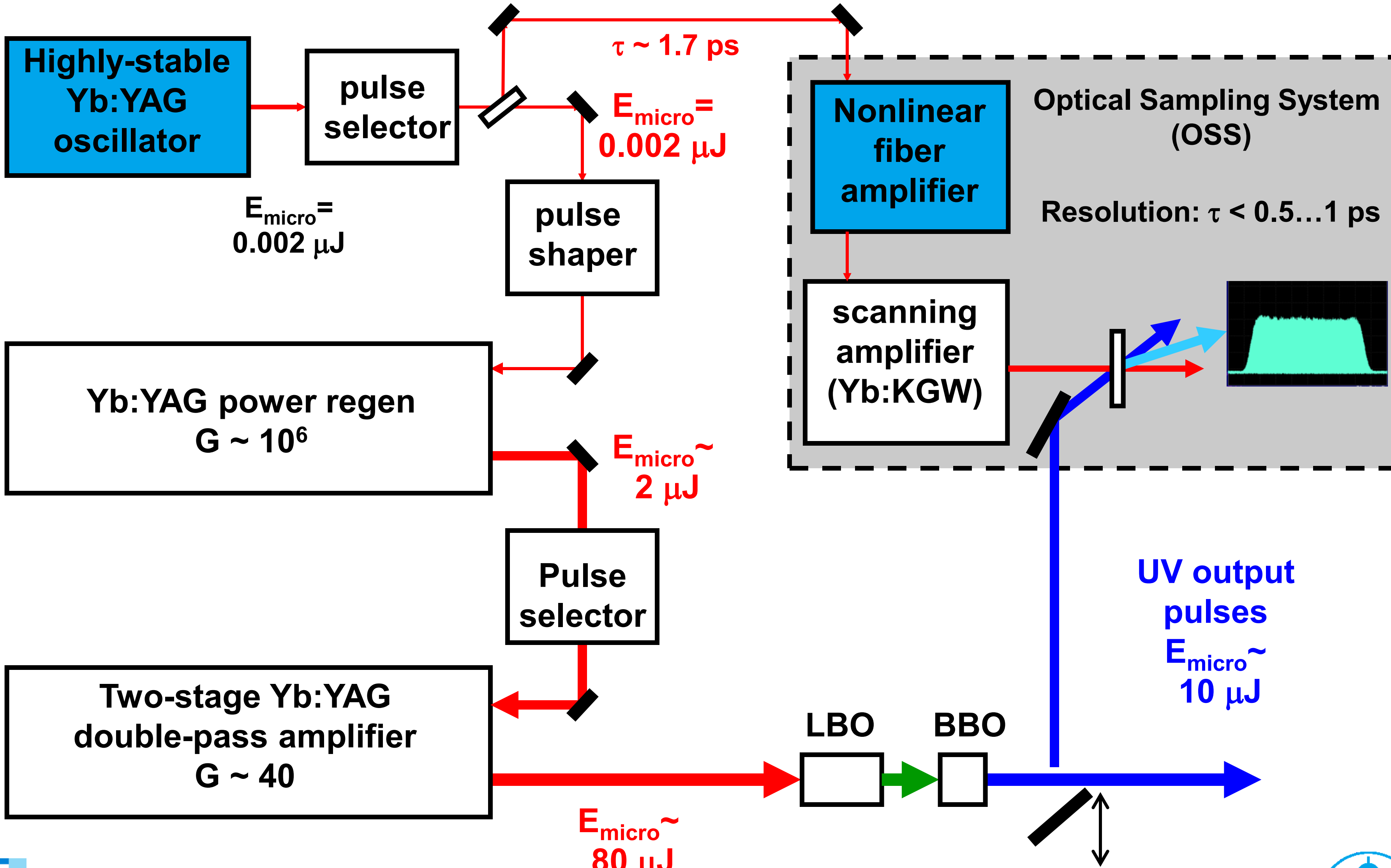
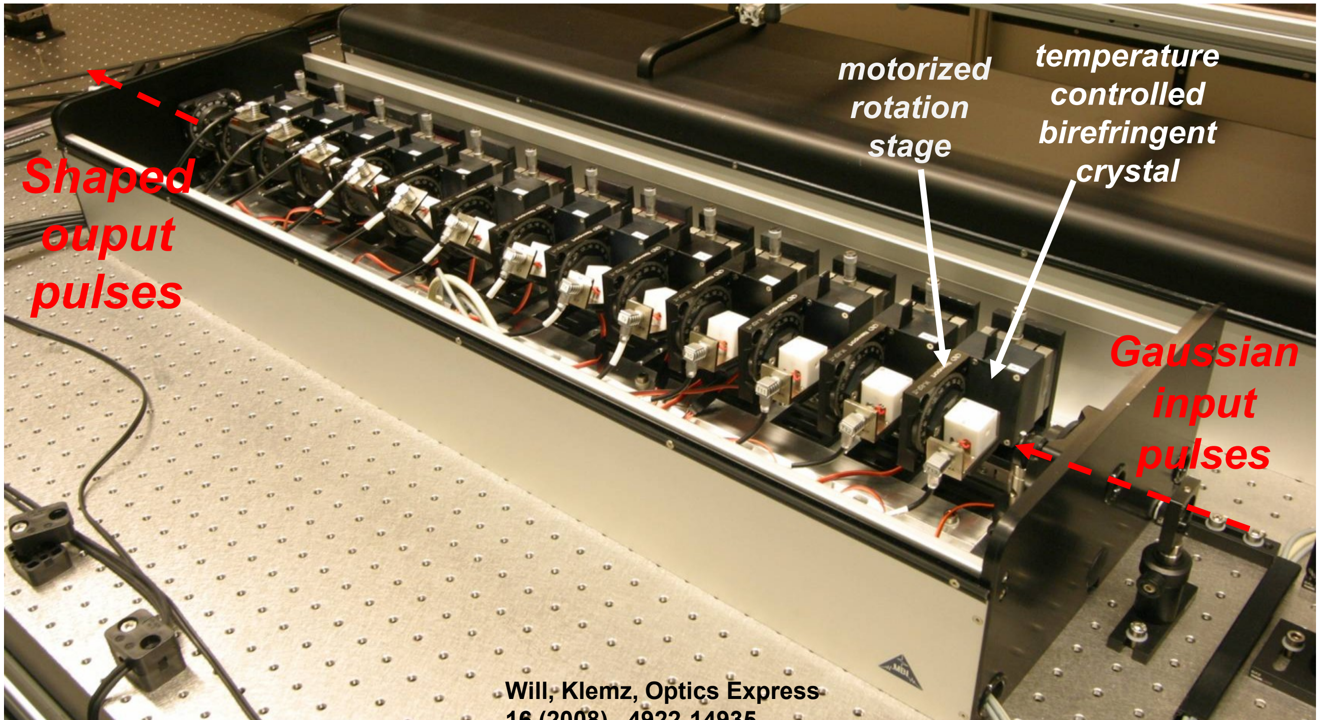


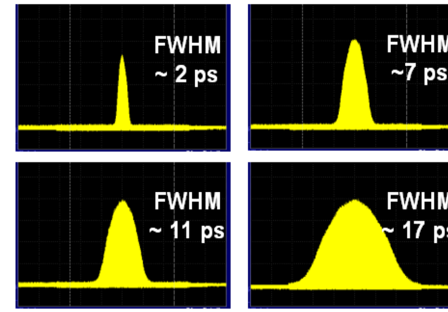
Photo cathode laser: temporal pulse shaping

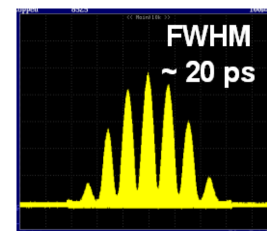
Multicrystal birefringent pulse shaper containing 13 crystals



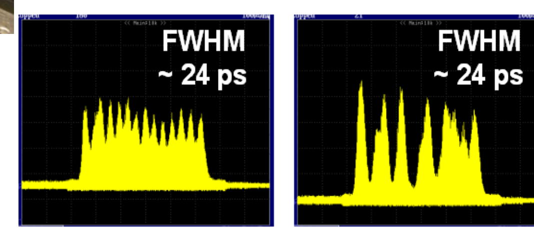
Will, Klemz, Optics Express
16 (2008) , 4922-14935

Gaussian:





Simulated pulse-stacker



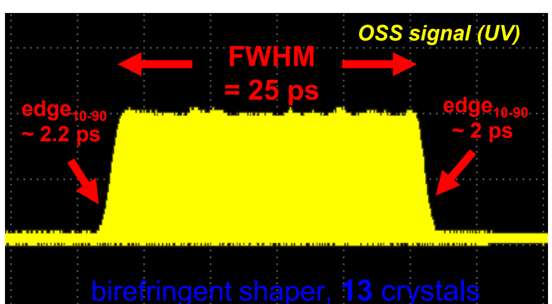
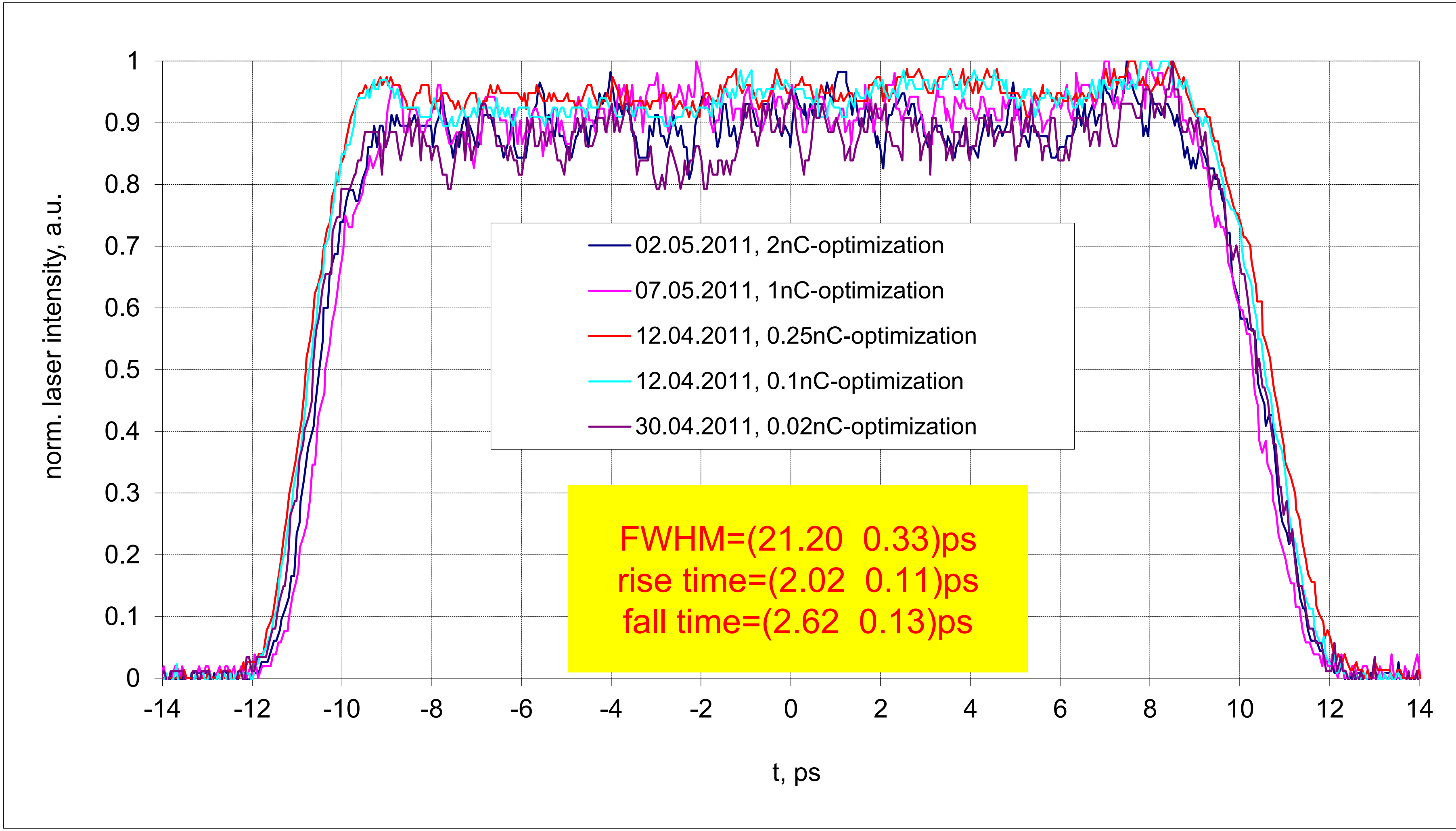
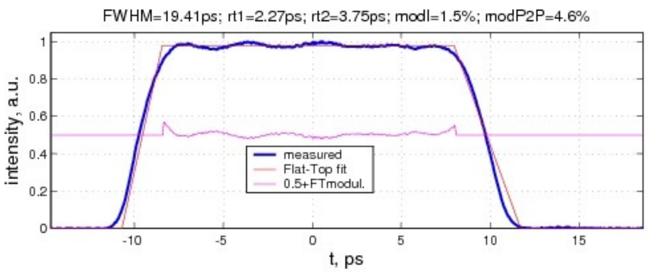


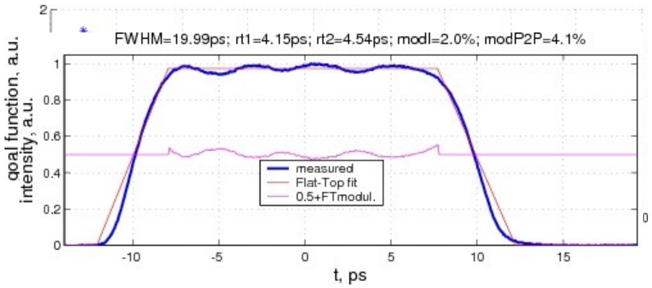
Photo cathode laser: flat-top temporal pulse profiles

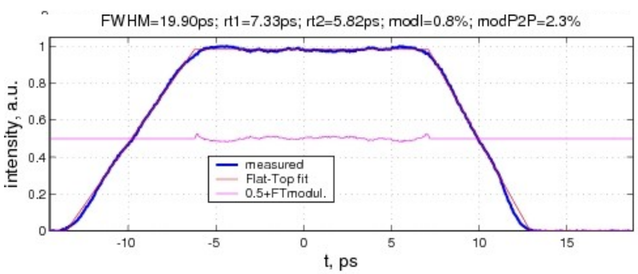
Laser temporal profile used for the emittance optimization at various bunch charge levels

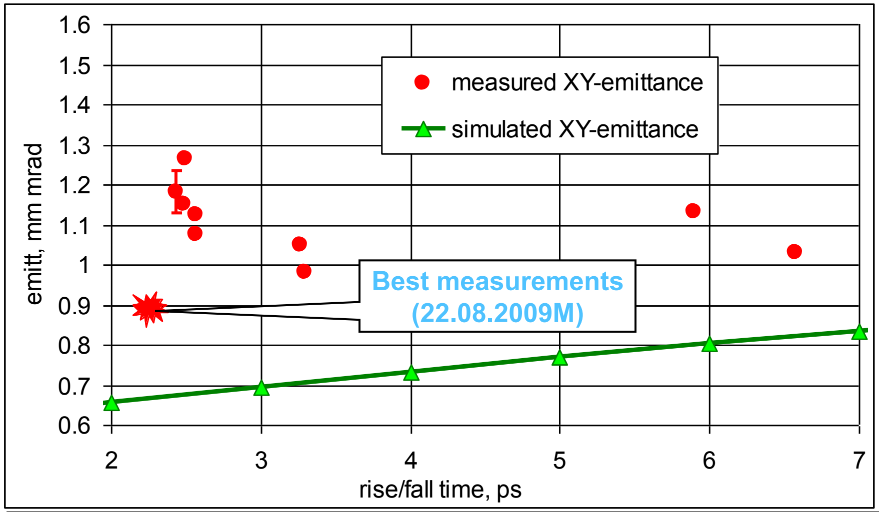


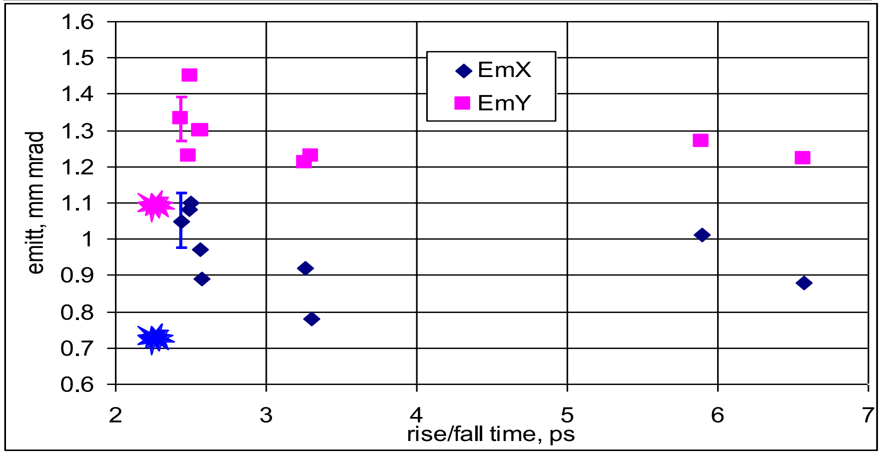
Check effect on rise/fall time – results of 2009







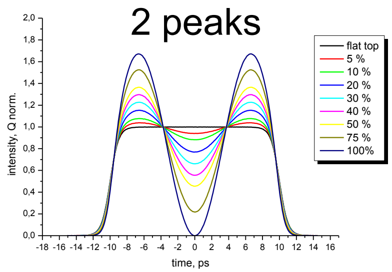


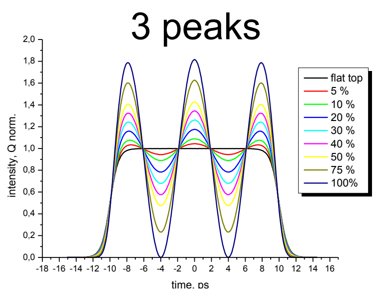


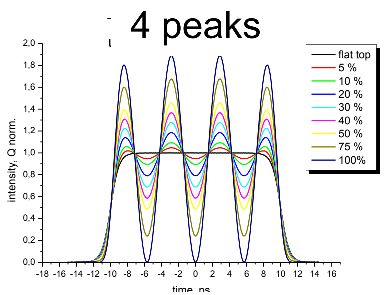
- Q=1nC
- Imain➔optimized
- Gun: +6deg off-crest
- Booster: on-crest
- Laser: temp FWHM~20ps, BSA=1.5mm

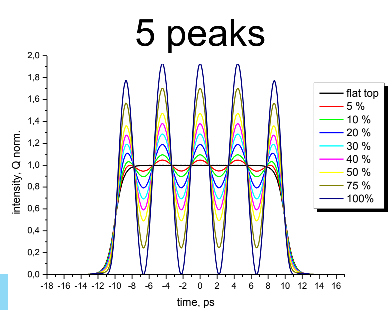
- **In 2009 it was not possible to measure the effect with current machine stability**
- **After the improvement of the phase stability the effect is planned to be rechecked (this year)**

Various laser temporal flat-top modulations
Simulations

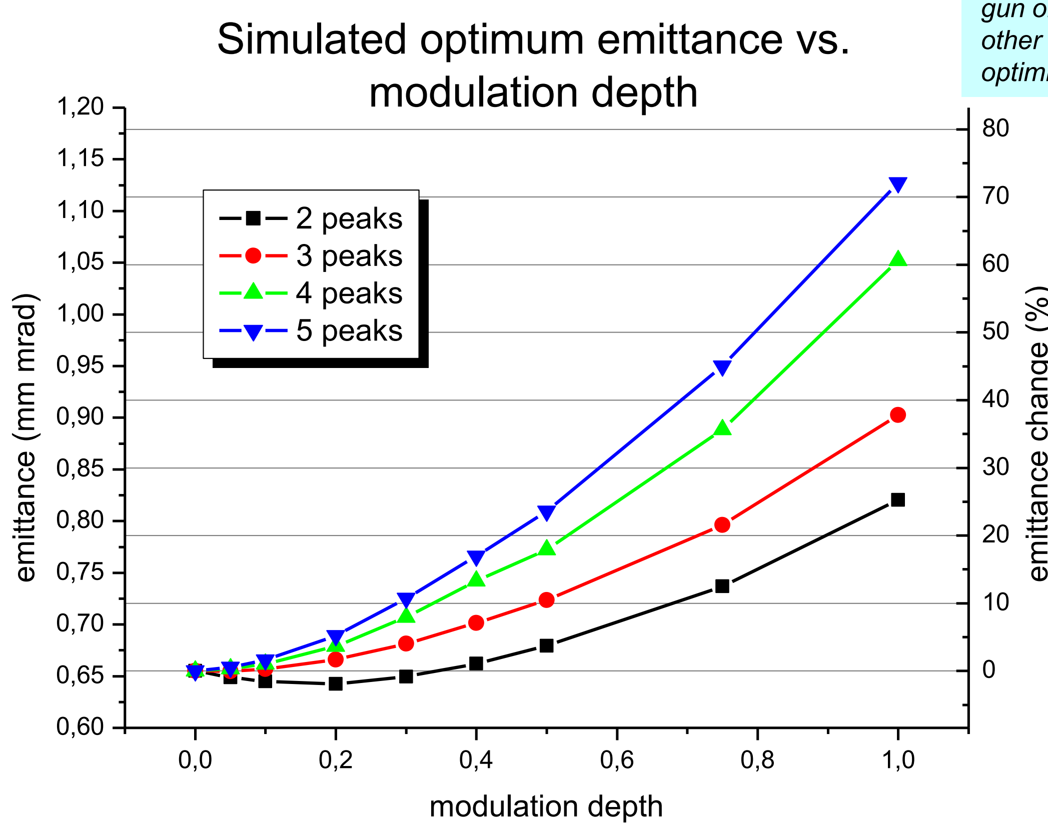








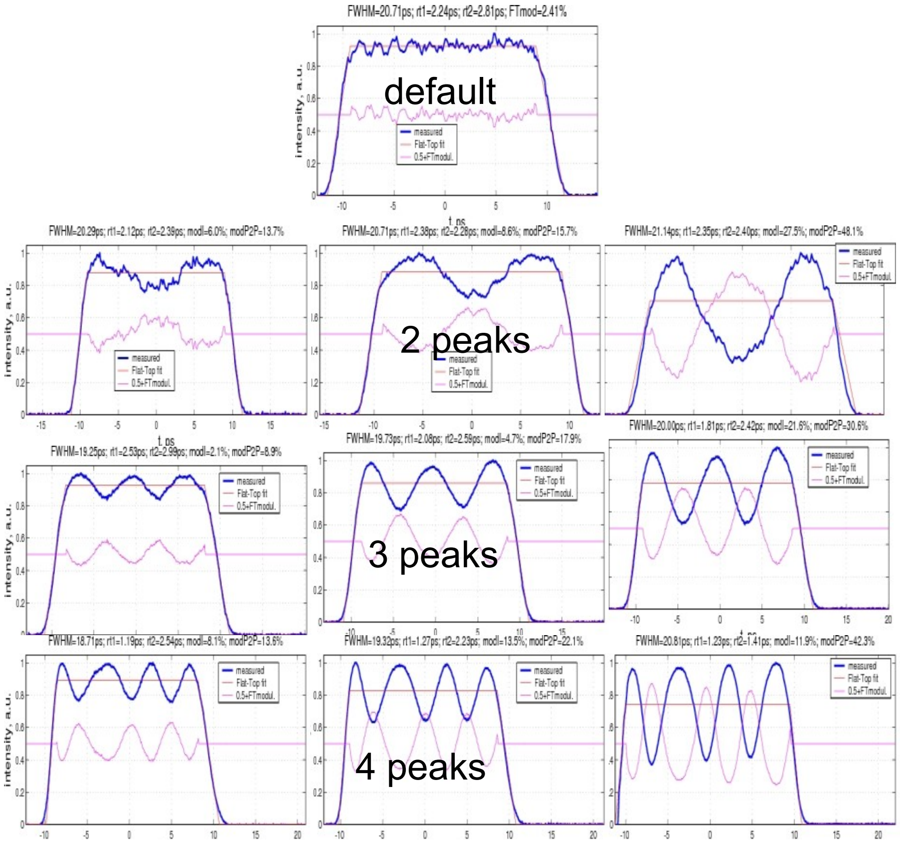
simulations with gun on-crest, other parameters optimized



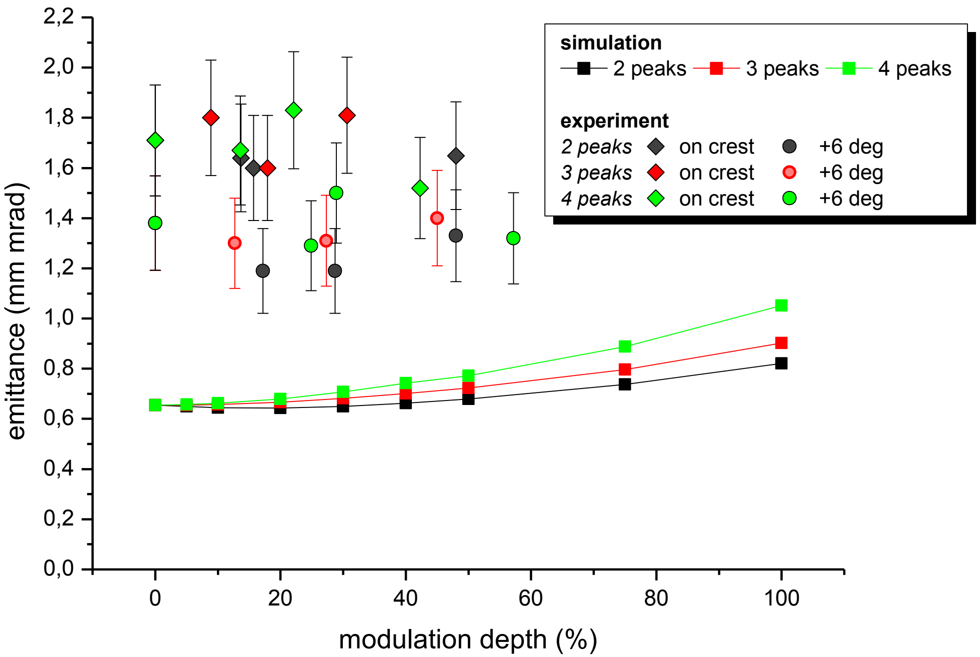
- higher modulation frequency ➔ larger emittance growth rate
- reliable simulations for modulations with >5 peaks are difficult

Laser temporal profile modulations

Experiment: measurements in 2009



Experimental results compared to simulations

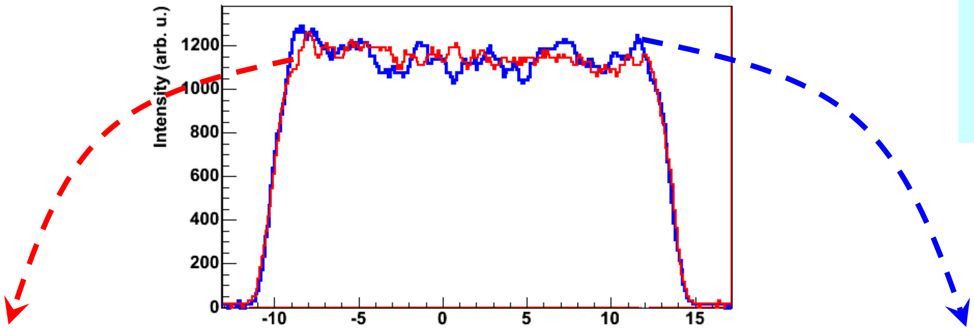


In 2009 it was not possible to measure the effect with the current machine stability

Measurements with / without modulations on the temporal laser distribution

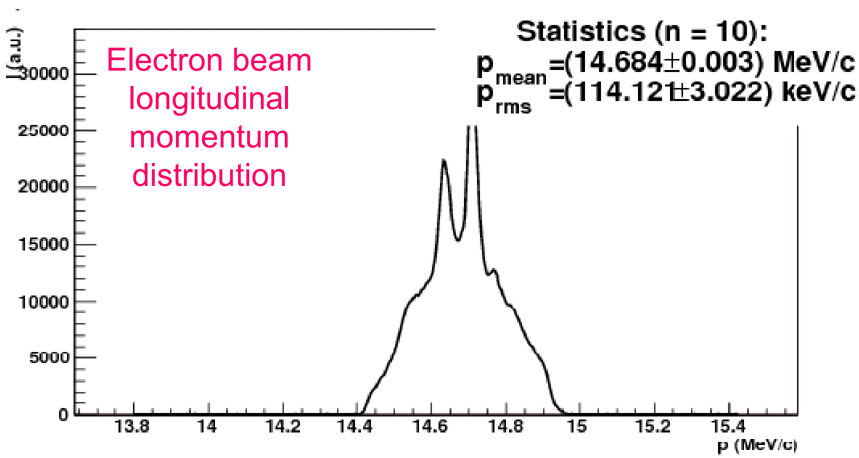
Approach → detuning of an aligned pulse shaper, i.e. by purpose introducing modulations on the flat-top of the temporal laser distribution and measuring momentum distribution in HEDA

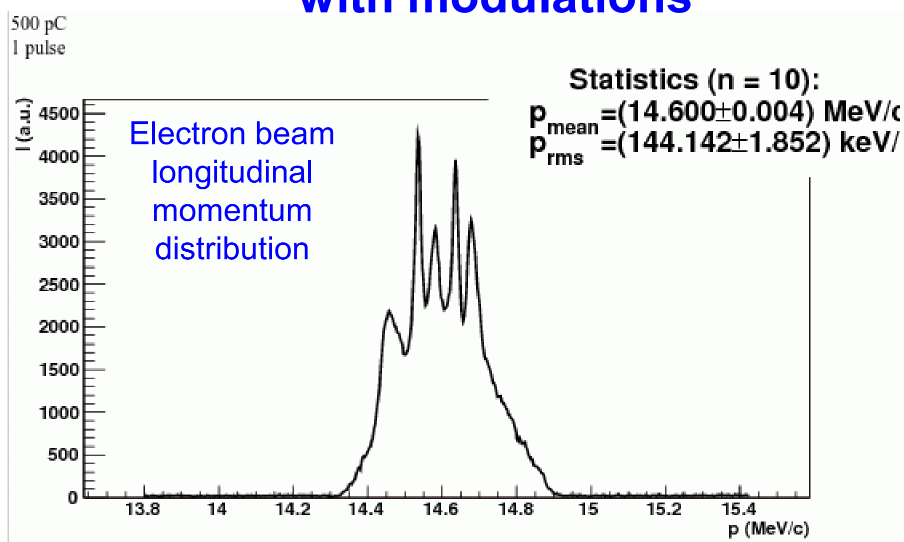
Machine conditions:
- gun: on-crest
- booster: +10deg off-crest
- bunch charge: 500pC



without modulations

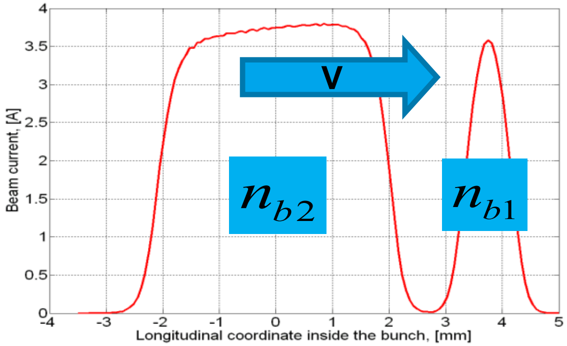
with modulations





Studies for Particle Driven Plasma Acceleration @PITZ

- **Self-modulation with seed pulse:**



Output parameters for 2 sub-bunches @6.28m from cathode:

Gauss: $Q = 10\,pC,\ \sigma_z = 0.311\,mm$, $\sigma_{xy} = 83.25\,\mu m,\ \varepsilon_{xy} = 0.471\,mm\ mrad$ $\Big\}\ n_{b1}[cm^{-3}] = 3.69 \cdot 10^{12}$

Flat-top: $Q = 50\,pC,\ L_b = 4.05\,mm$, $\sigma_{xy} = 48.45\,\mu m,\ \varepsilon_{xy} = 0.448\,mm\ mrad$ $\Big\}\ n_{b2}[cm^{-3}] = 1.05 \cdot 10^{13}$

- **Self-modulation without seed but with flat-top modulation:**

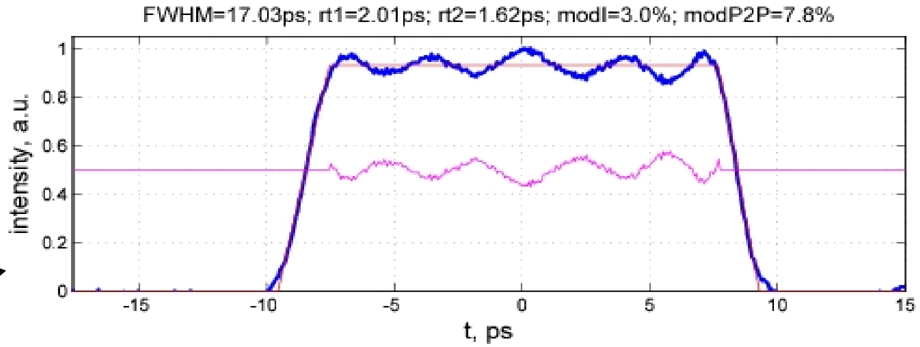
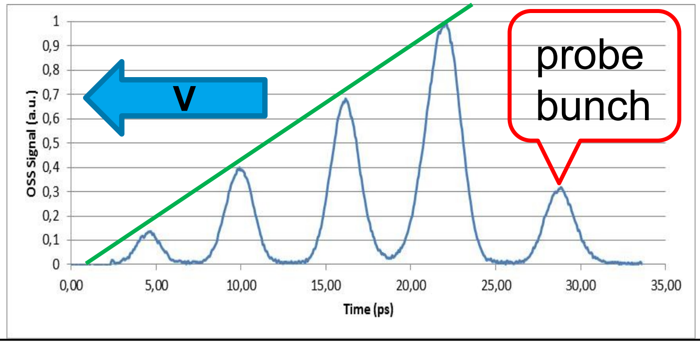


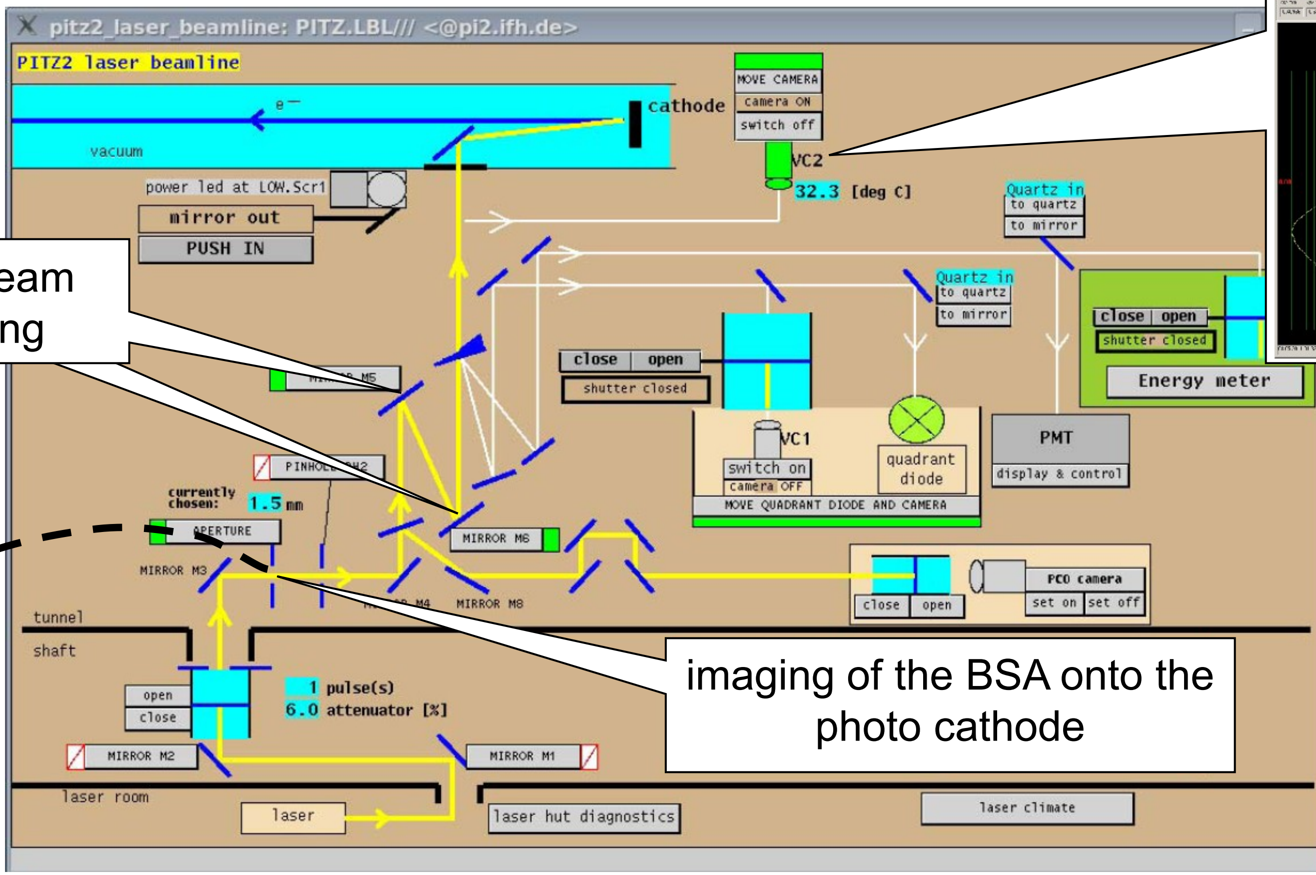
Photo cathode laser distributions

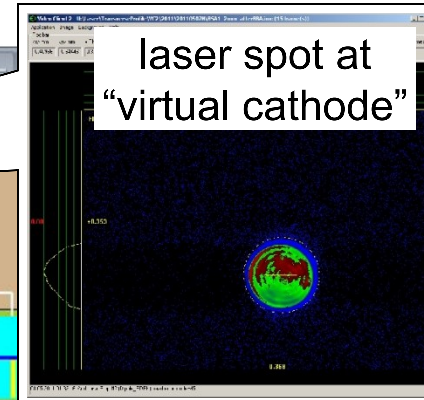
- **Resonantly driven plasma wave → high tranformation ratio → 5 Bunchlets inside the bunch:**



to be sent to bunch compres-sor

Photo cathode laser: transverse pulse shaping

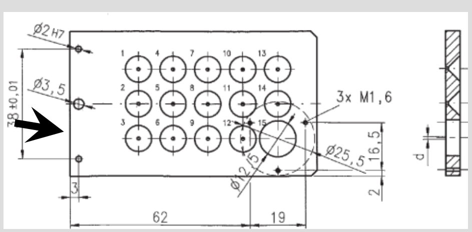




laser spot at “virtual cathode”

laser beam steering

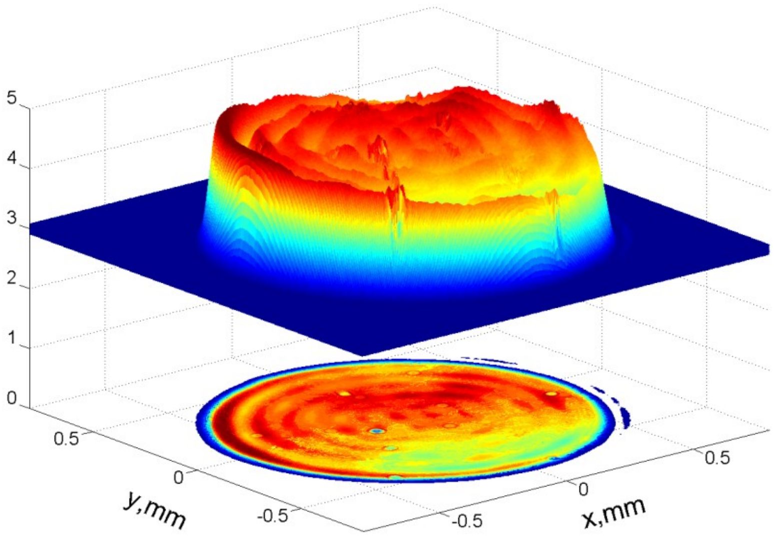
imaging of the BSA onto the photo cathode



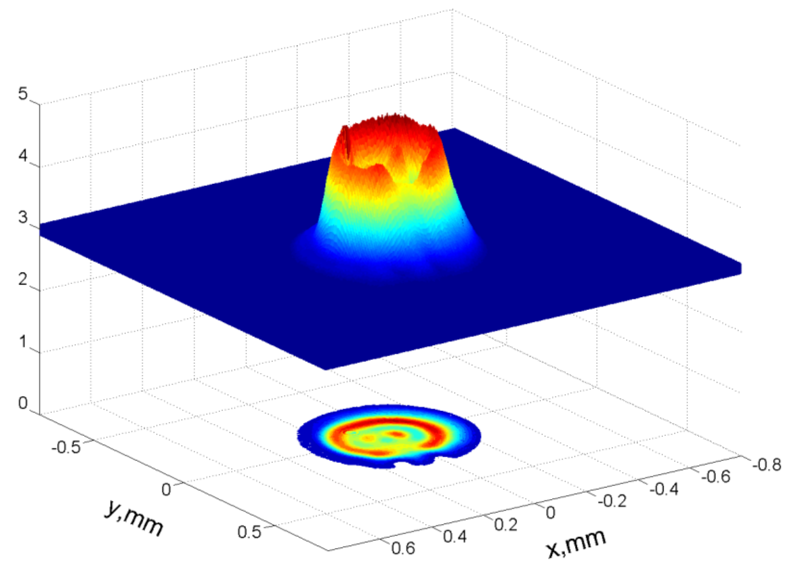
Beam Shaping Aperture (BSA) plate is now replaced by an iris with remotely tunable opening

Photo cathode laser: transverse distributions

BSA=1.2mm (1nC)



BSA=0.5mm (0.1nC)



RMS sizes (no Gaussian fit!)
σ_x=0.30 mm and σ_y=0.29 mm

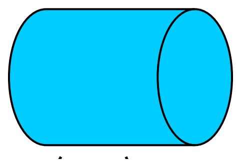
RMS sizes (no Gaussian fit!)
σ_x=0.13 mm and σ_y=0.12 mm

Laser pulse shaping studies for further improvement of the electron beam quality in a photo injector

$$\varepsilon = \sqrt{\varepsilon_{cath}^2 + \varepsilon_{RF}^2 + \varepsilon_{SpCh}^2}$$

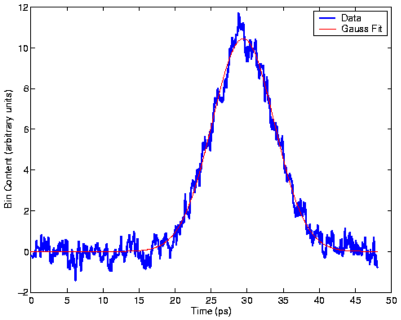
$$\text{cathode laser shape} : \varepsilon_{SpCh} \rightarrow \min$$

cylindrical

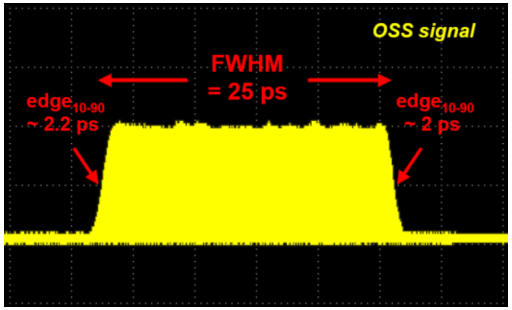


temporally

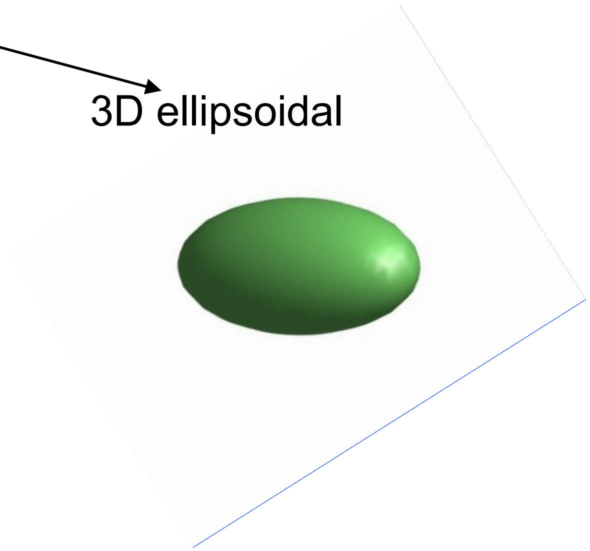
Gaussian
(e.g. FLASH)
Trms=4.4ps



Flat-top
(e.g PITZ)
FWHM~20ps, rt~2ps

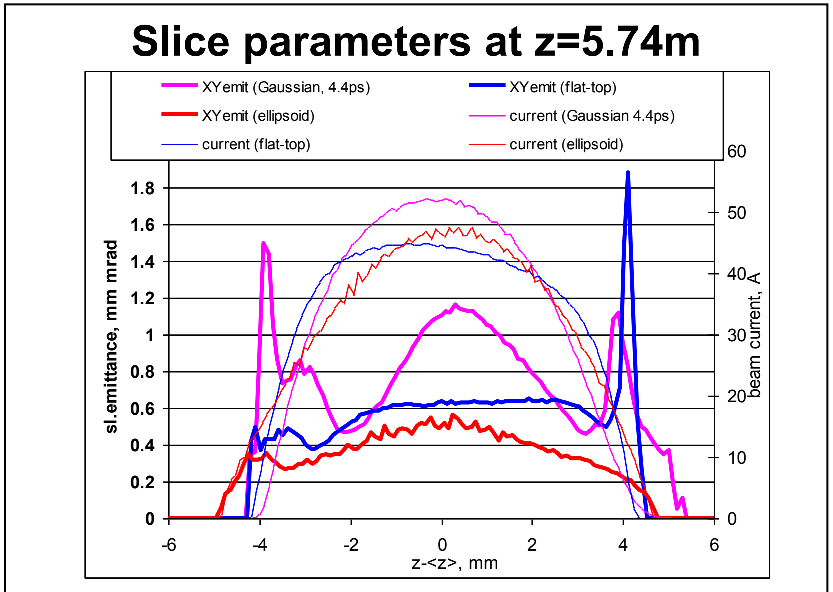


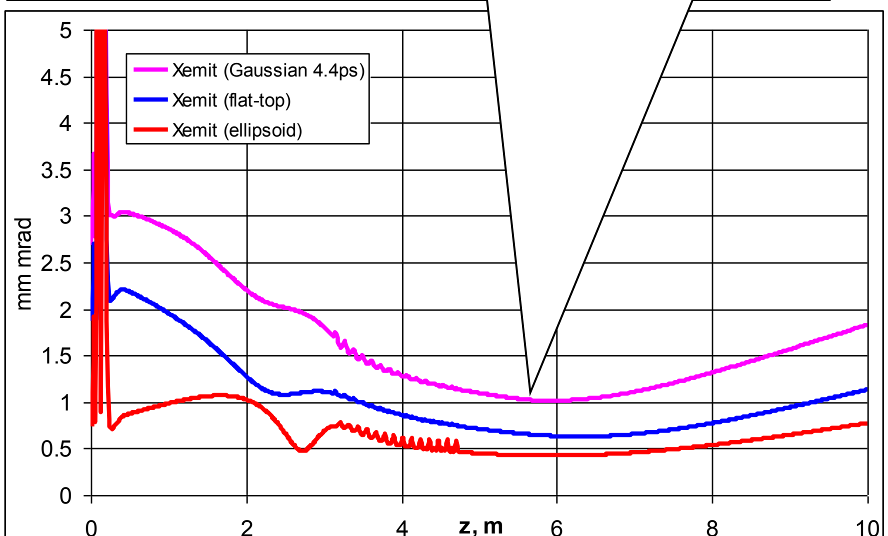
3D ellipsoidal

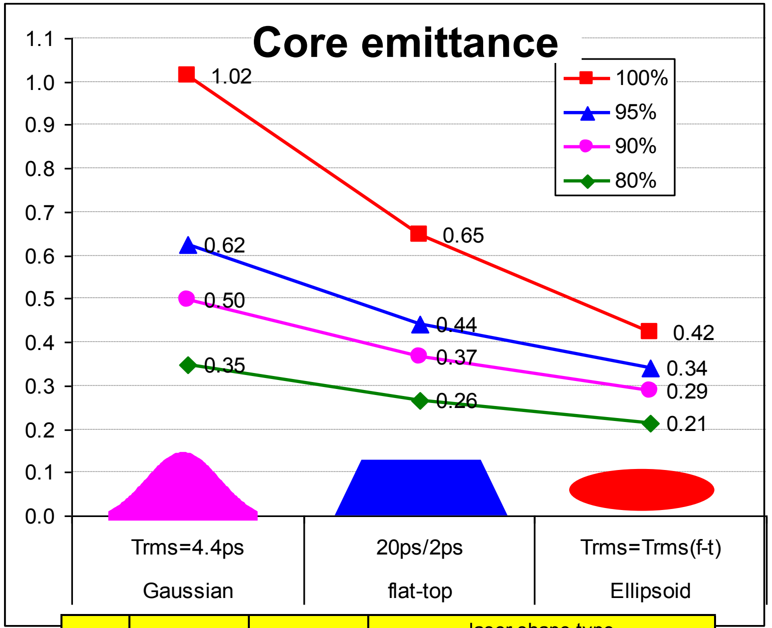


Beam dynamics (ASTRA) simulations for PITZ-1.8 setup

BD simulations for bunch charge 1 nC

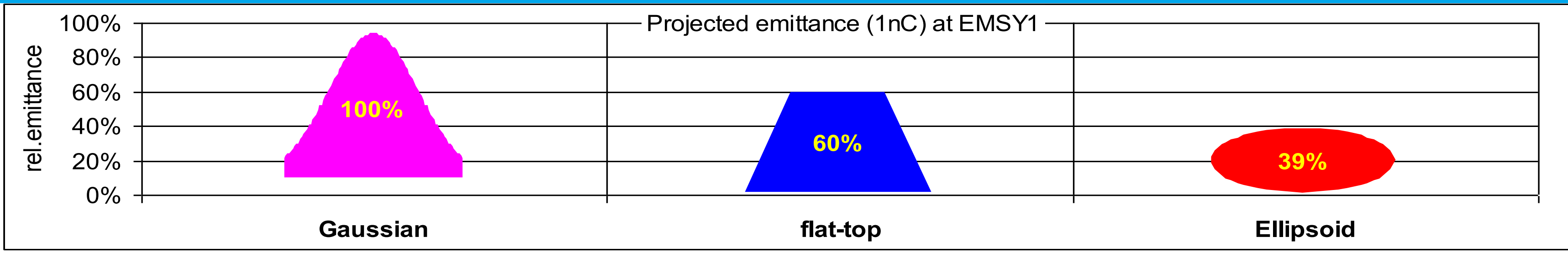




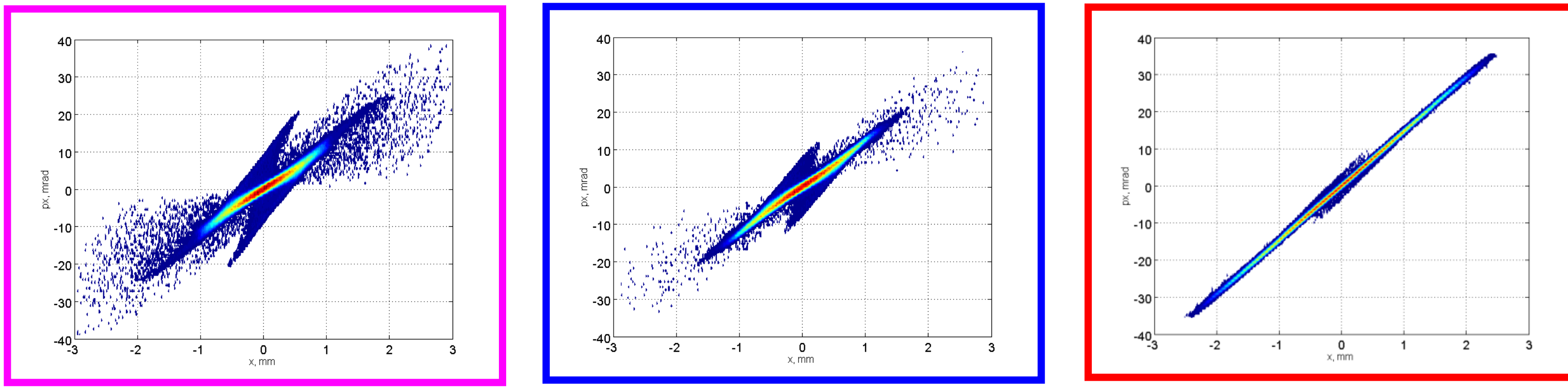


	parameter	unit	laser shape type		
			cylindrical		3D ellipsoidal
cathode laser	temporal	profile	Gaussian	Flat-top	3D ellipsoidal
	transverse	distribution	radial homogen.		
	Trms	ps	4,4	5,8	5,8
	XYrms	mm	0,427	0,415	0,389
	Ek	eV	0,55		
	th.emit.	mm mrad	0,36	0,35	0,33
RF-gun	Ecath	MV/m	60		
	phase	deg	-3,1	-1,9	-2,8
	maxBz	T	-0,2253	-0,2258	-0,2277
CDS boost	maxE		18,5	19,1	19,1
	phase	deg	0		
e-beam @EMSY1	charge	nC	1		
	energy	MeV	22,3	22,7	22,8
	proj.emit.	mm mrad	1,02	0,65	0,42
	th./proj.em.	%	36%	54%	78%
	<sl.emit.>	mm mrad	0,82	0,58	0,41
	B~Ipeak/em^2		51	106	270

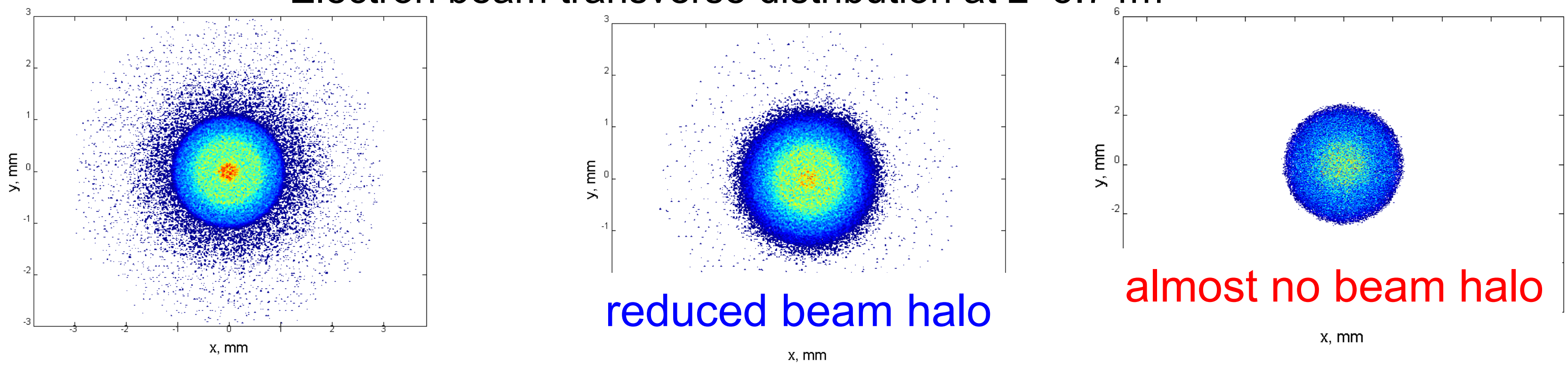
BD simulations for bunch charge 1 nC



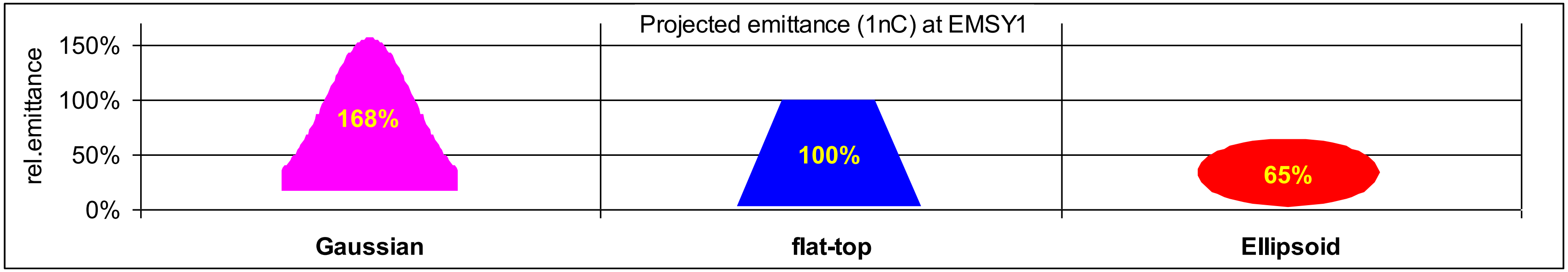
Transverse phase space at z=5.74m



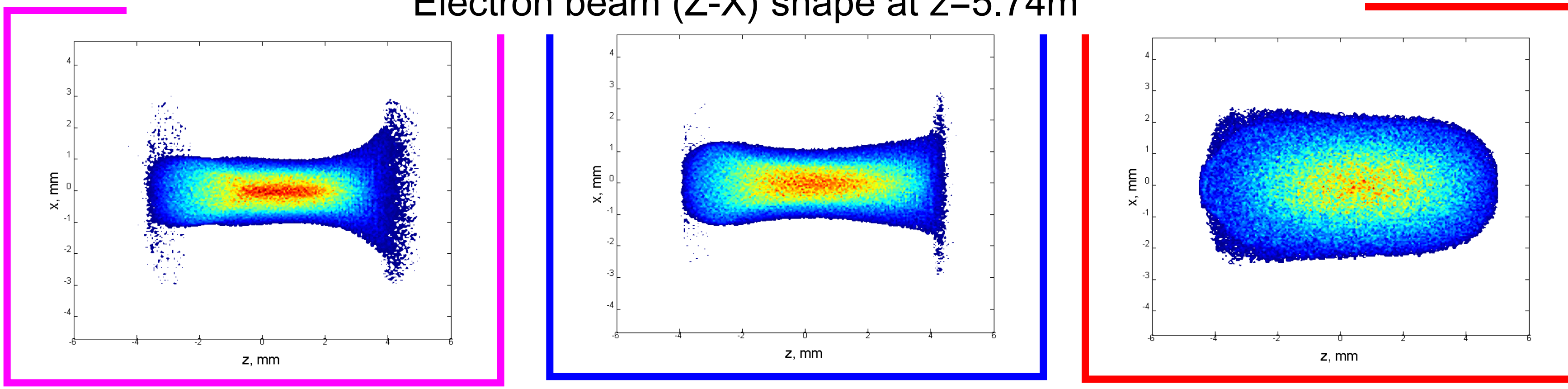
Electron beam transverse distribution at z=5.74m



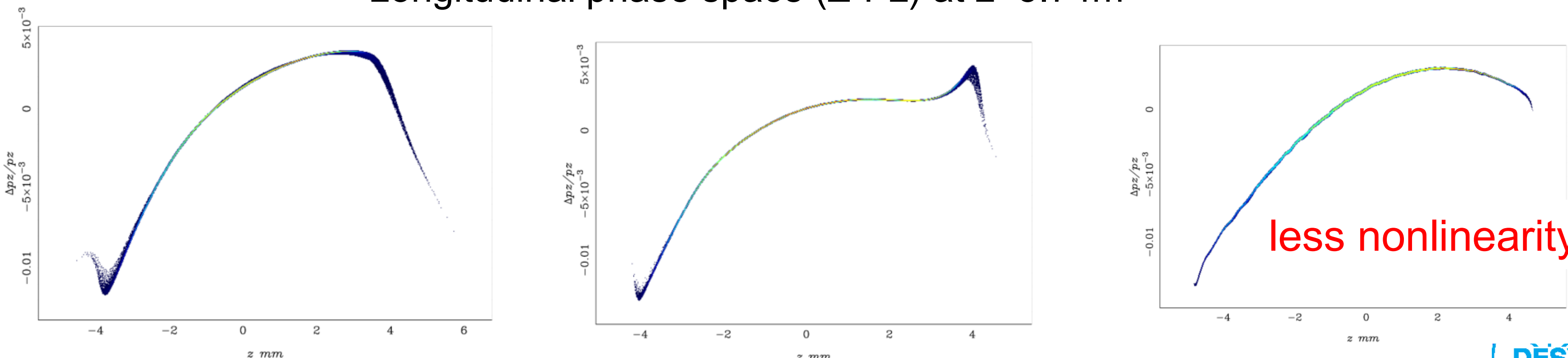
BD simulations for bunch charge 1 nC



Electron beam (Z-X) shape at z=5.74m



Longitudinal phase space (Z-Pz) at z=5.74m



Conclusions

- Cathode laser pulse shaping is one of the key parameters for a high brightness photo injector
- Nominal temporal pulse shape at PITZ – a flat-top of ~ 20ps FWHM
  - Short rise/fall time, first trials were performed in 2009, to be checked soon
  - Flat-top modulations: no large impact onto the transverse phase space, but longitudinal phase space modulations
- Transverse laser distribution:
  - Laser transport and imaging to the cathode
  - "Fresh cathode" effect → homogeneous emission area
- Beam dynamics simulations applying a **3D** pulse shaping (ellipsoid) for the PITZ injector yield :
  - significant reduction in beam projected and slice emittance
  - reduced beam halo and less sensitivity to machine parameters
  - less nonlinear longitudinal phase space

practical realization → BMBF project with IAP, Nizhniy Novgorod, Russia