Evolution of ELLA

Progress and Development

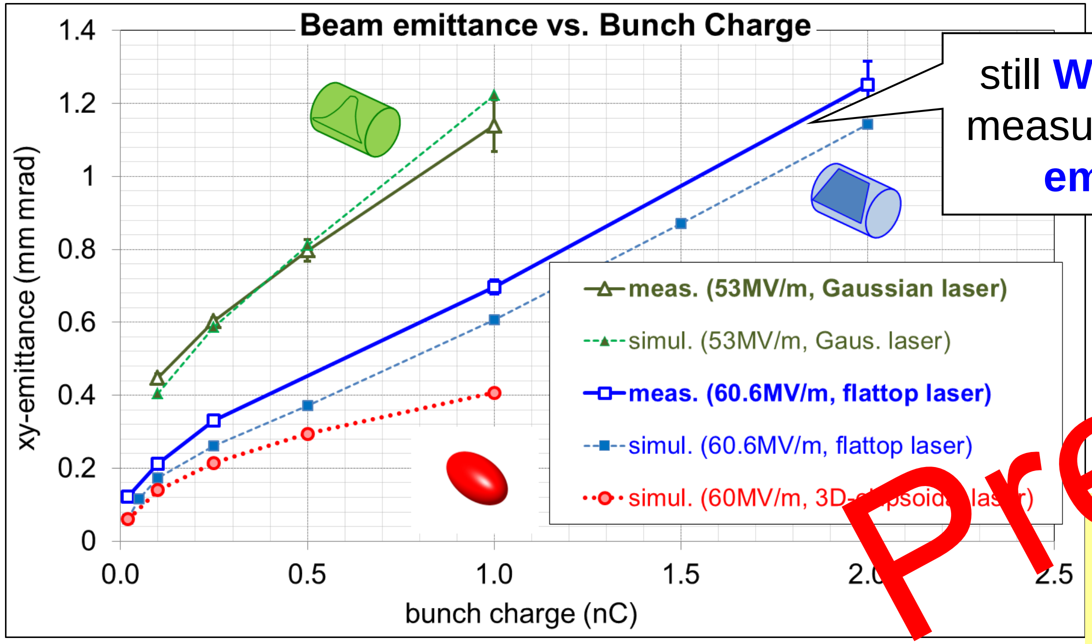
It’s OK to be smart: What is Impossible in Evolution?
https://www.youtube.com/watch?v=YkS1U5lfSRw

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

PITZ Photo Injector Test Facility Zeuthen

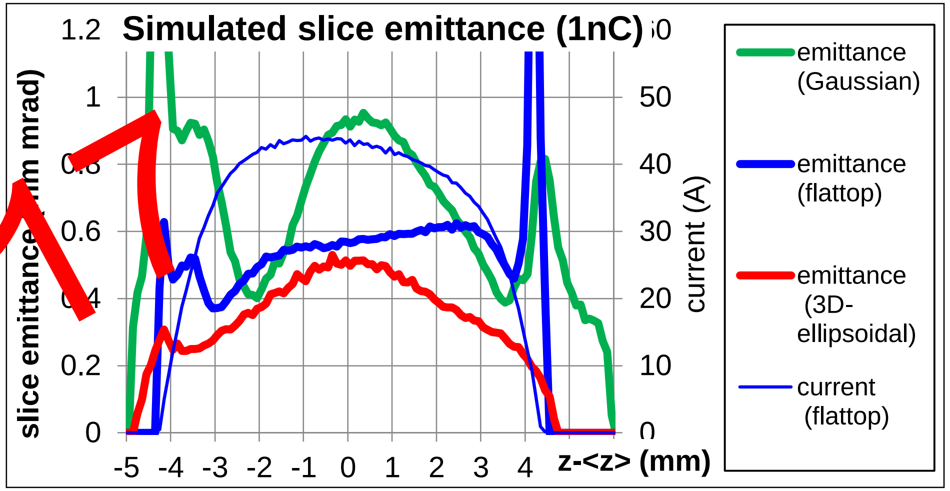
DESY

Towards ultimate low emittance beams → 3D ellipsoidal pulses



still **WR** on **lowest** measured projected **emittances**

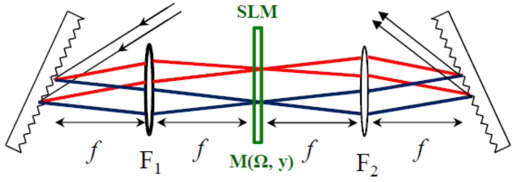
Pre 2017



- Laser shaping → **key** for optimizing photoinjector **brightness**.
- Ellipsoidal laser shaping benefits **high bunch charge** beams or **CW guns** (lower gun gradients).

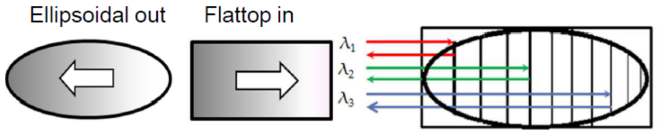
- Two methods to generate 3D ellipsoidal photo cathode laser pulses are under study:
  - Mironov et al., *Appl. Opt*. **55**, p. 1630 (2016)
  - Mironov et al., *Laser Phys. Lett.* **13**, p. 055003 (2016)

Spatial Light Modulator (SLM) shaper

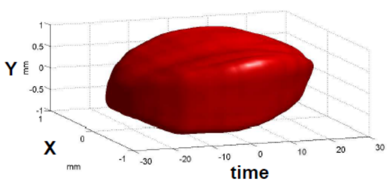


Collaboration with IAP, JINR

NEW: 3D Volume chirp Bragg grating

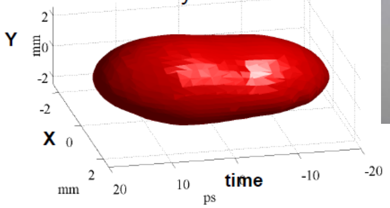


no rotational symmetry



IR cross correlation measurements

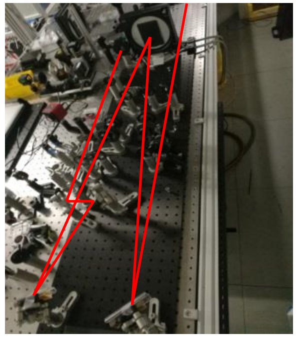
rotational symmetric



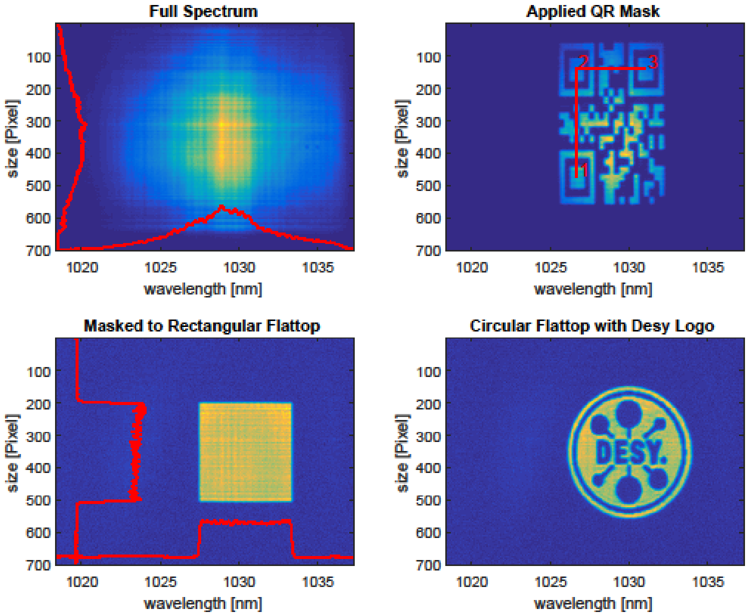
Developing 3D ellipsoidal laser pulses → result of 2018

Christian Koschitzki[1], James Good[1], Matthias Gross[1], Sergey Mironov[2], Tino Lang[3], Lutz Winkelmann[3]
1: PITZ / Zeuthen , 2: IAP RAS, 3: DESY HH

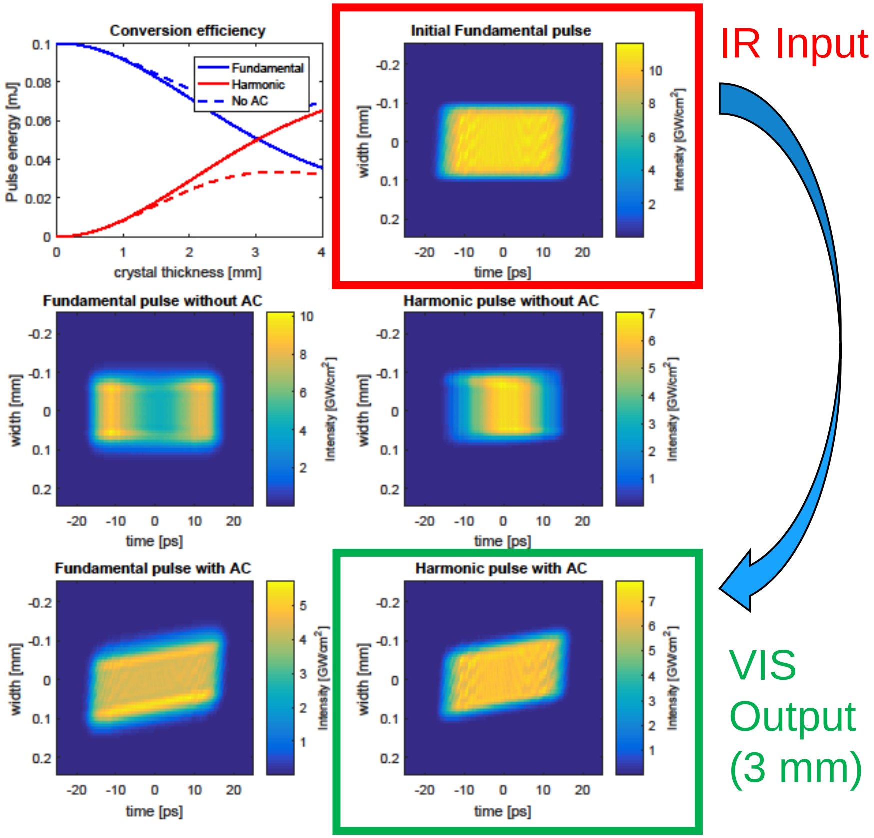
1: SLM Shaper



- **First** shaping unit **finished**
- Shaping with feedback from spectrograph has been demonstrated
- Second unit under construction (full 3D)
- temporal measurements with cross correlation coming up



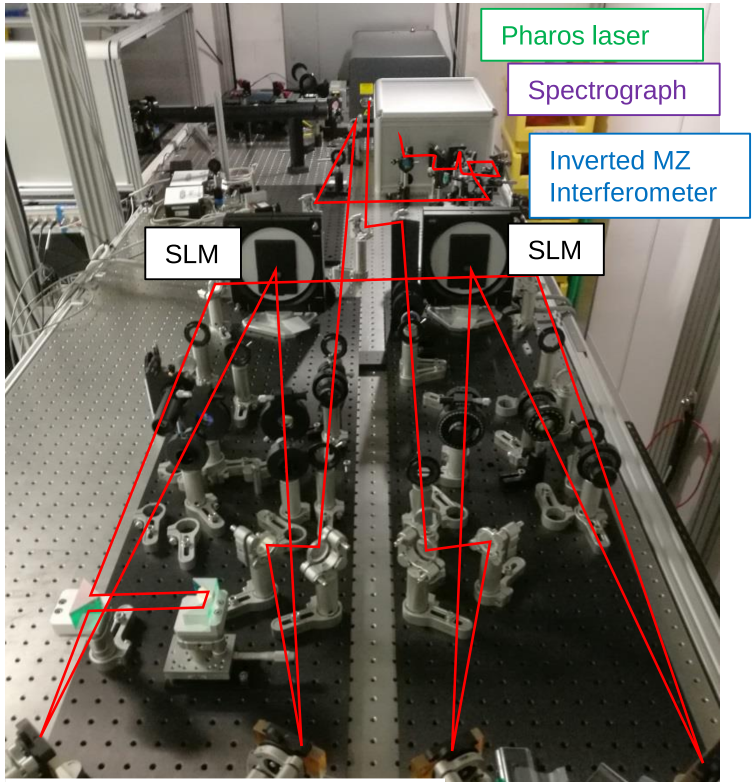
2: Design of shape preserving UV-Conversion



IR Input

VIS Output (3 mm)

- Simulations (Chi23d) show **feasibility** of shape preserving conversion **with angular chirp (AC)**
- More work needed



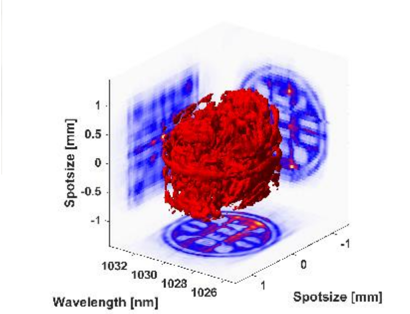
Pharos laser

Spectrograph

Inverted MZ Interferometer

SLM

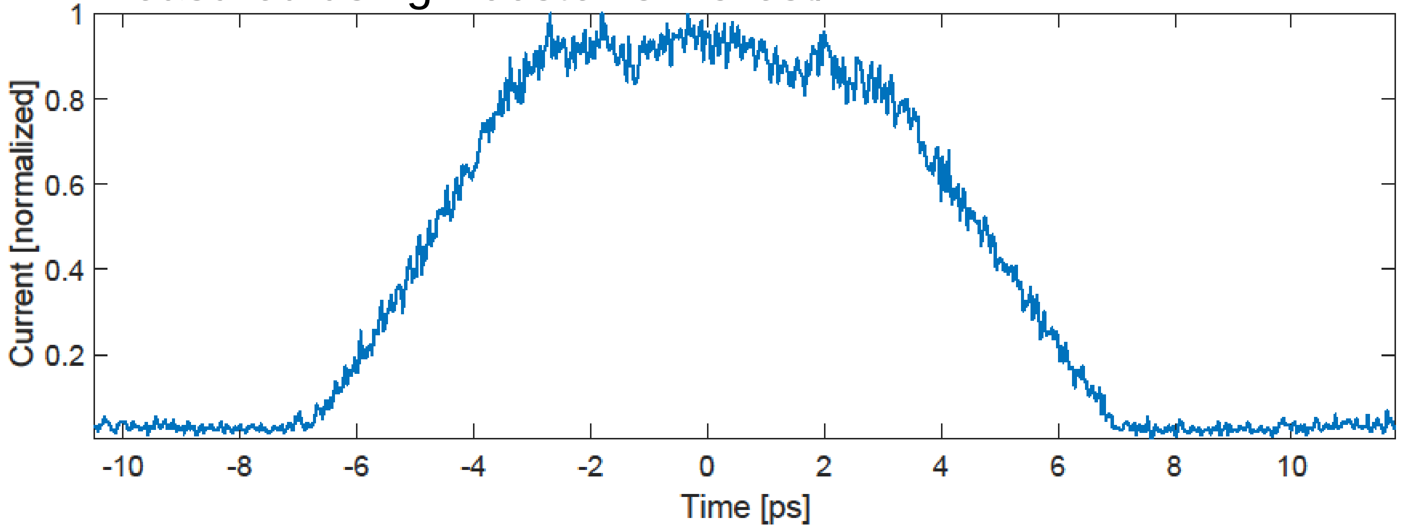
SLM



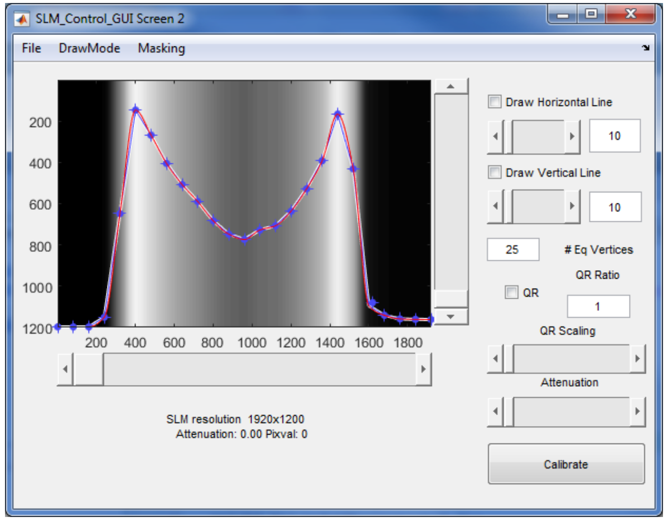
Status 2019

Conversion Section and first operation

Bunch length 9.5 ps @ 102 pC & 1mm BSA.
Measured using Booster Off Crest/ HEDA



Matlab Calibration- and Shapermanager

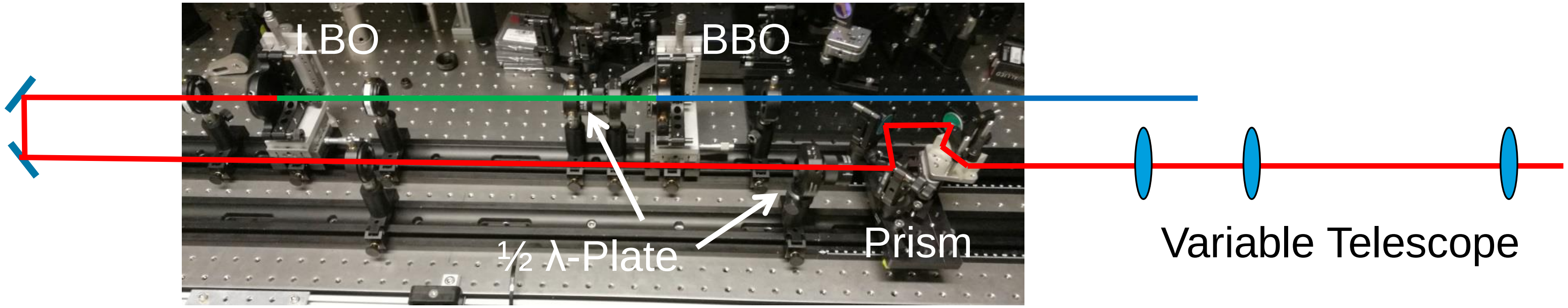


☐ Draw Horizontal Line
10
☐ Draw Vertical Line
10
25 # Eq Vertices
QR Ratio
☐ QR
1
QR Scaling
Attenuation

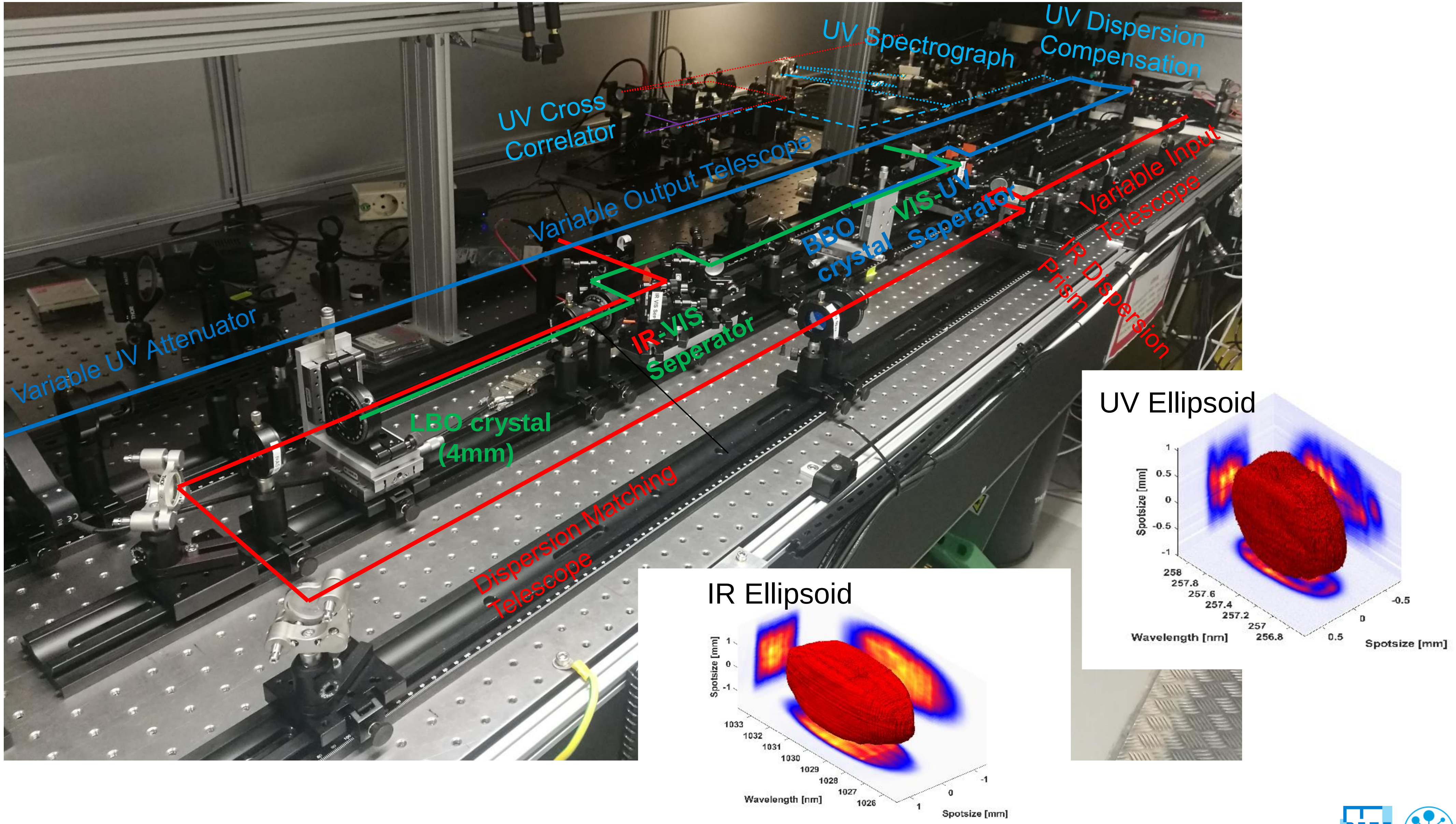
SLM resolution 1920x1200
Attenuation: 0.00 Pixval: 0

Low Noise RF Amplifier for Synchronisation

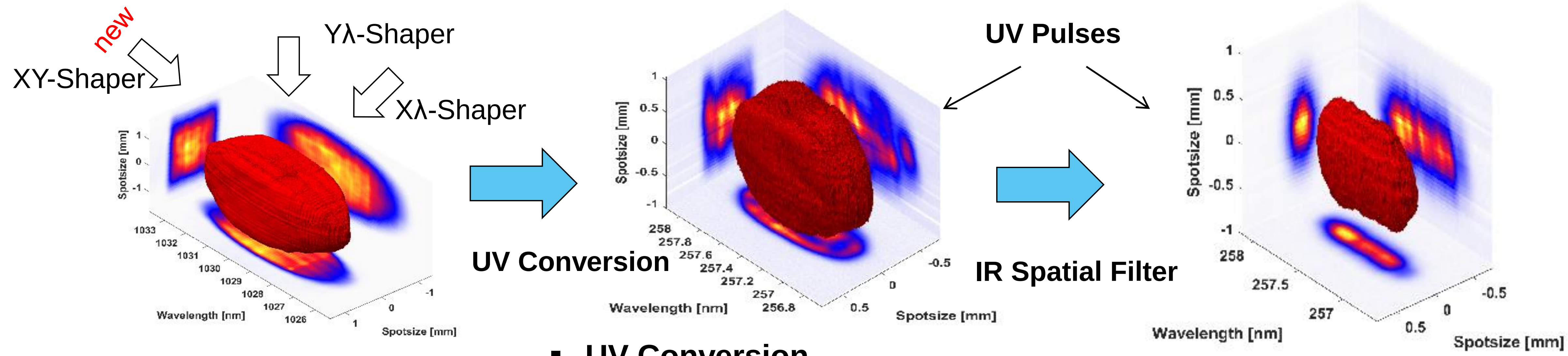
Conversion with double SHG and dispersive Matching



UV Conversion and Diagnostics upgrades 2020



Developing 3D ellipsoidal laser pulses



XY-Shaper

Yλ-Shaper

Xλ-Shaper

UV Conversion

UV Pulses

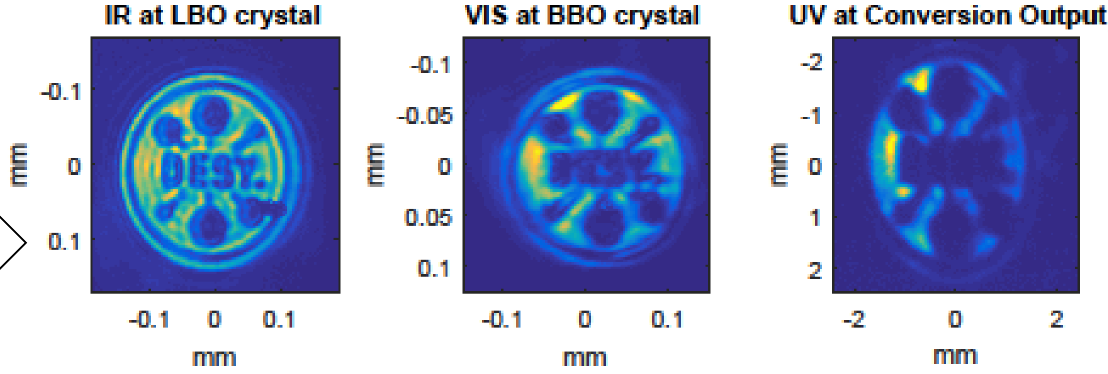
IR Spatial Filter

- **IR Shaping**
  - 3 SLM Shapers allow for shaping of all 3 projections
  - Direct feedback loops with IR-Spectrograph allow high quality shaping

- **UV Conversion**
  - 4th harmonic nonlinear conversion heavily exaggerates small non-uniformities
  - Possibly insufficient optical resolution

- **Spatial Filtering**
  - With spatial filtering non-uniformities are removed
  - Temporal/spectral shaping still possible. Some emittance reduction possible in this mode.

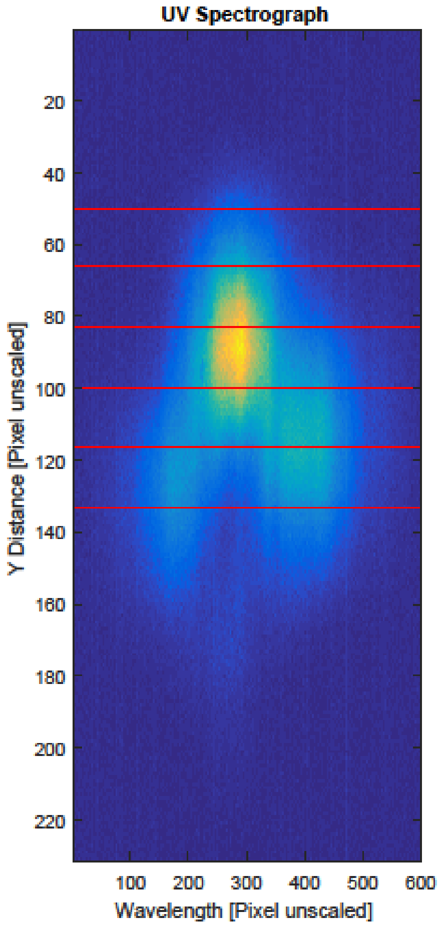
Transverse Shaping through conversion


IR at LBO crystal

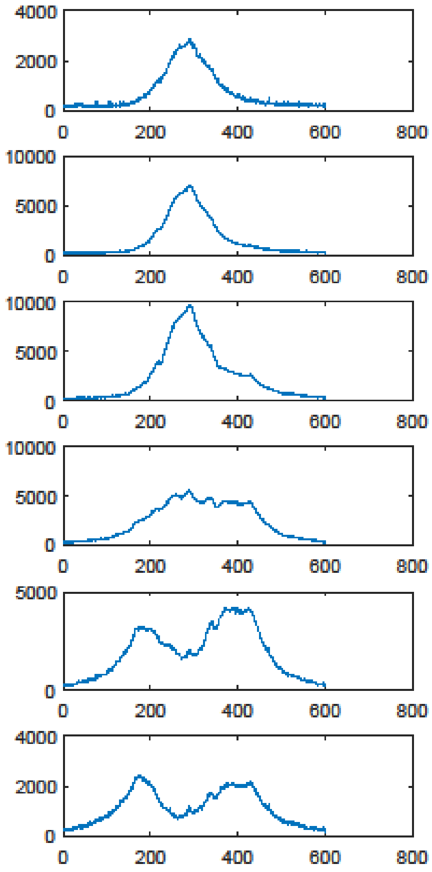
VIS at BBO crystal

UV at Conversion Output

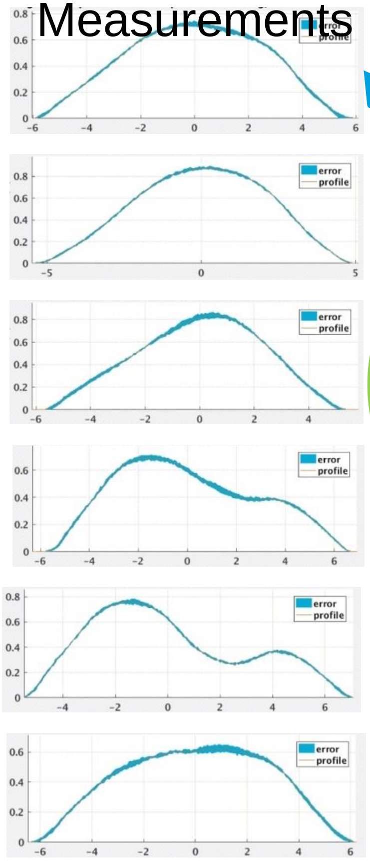
Symmetrie problems with “simple beams”


UV Spectrograph

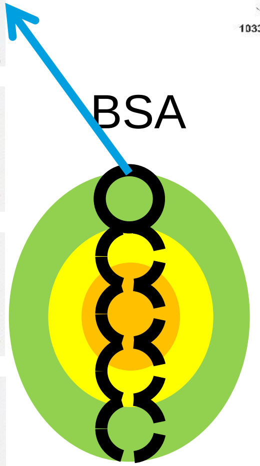
Spectral Slices



TDS Measurements

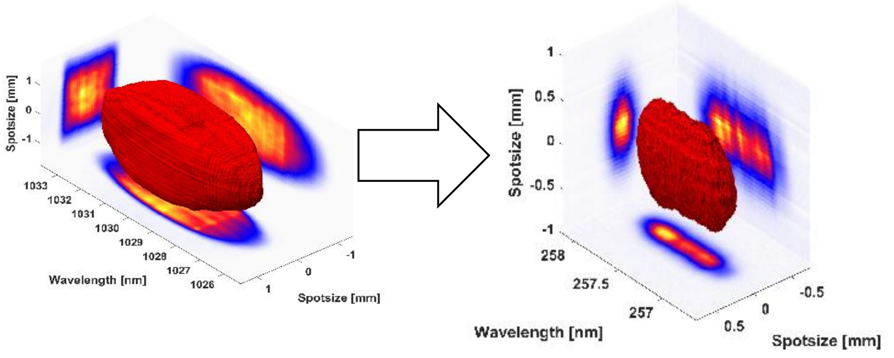


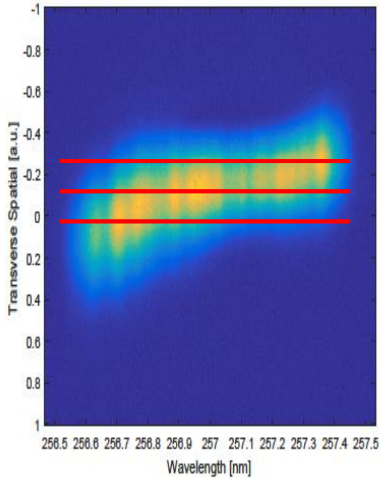
BSA

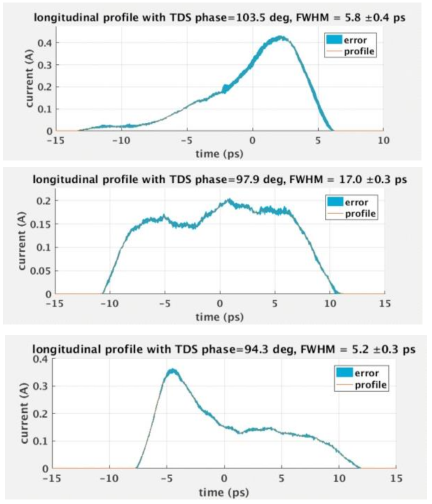


Laser Beam Profile

IR Spatial Filter






longitudinal profile with TDS phase=103.5 deg, FWHM = 5.8 ±0.4 ps

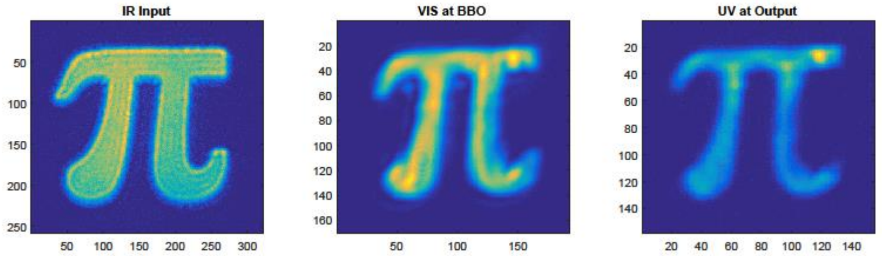
longitudinal profile with TDS phase=97.9 deg, FWHM = 17.0 ±0.3 ps

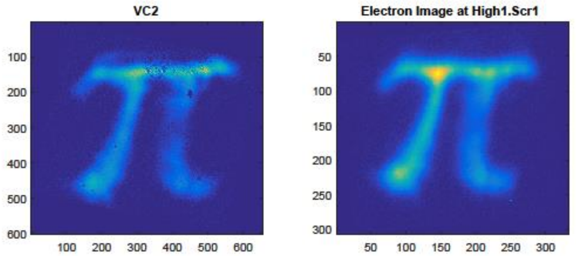
longitudinal profile with TDS phase=94.3 deg, FWHM = 5.2 ±0.3 ps

Separating transverse and longitudinal

Lessons learned:

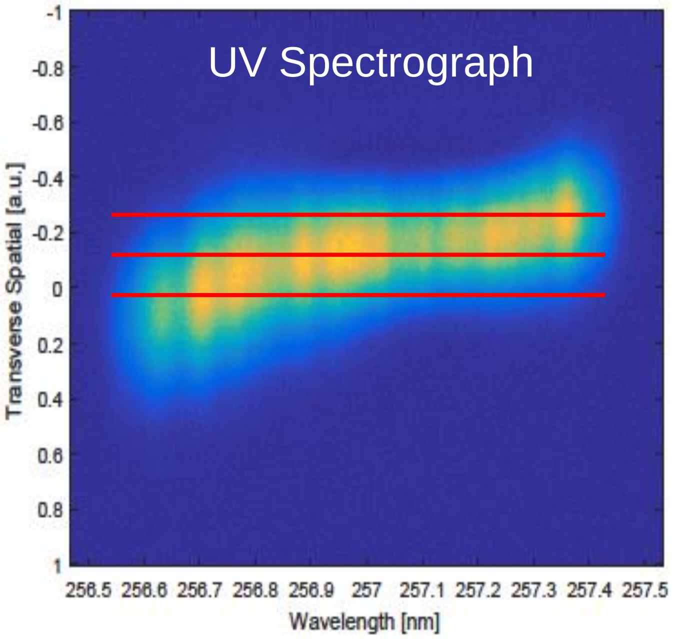
- Resolution issues with image transport
- Nonlinear depth of field effect in LBO

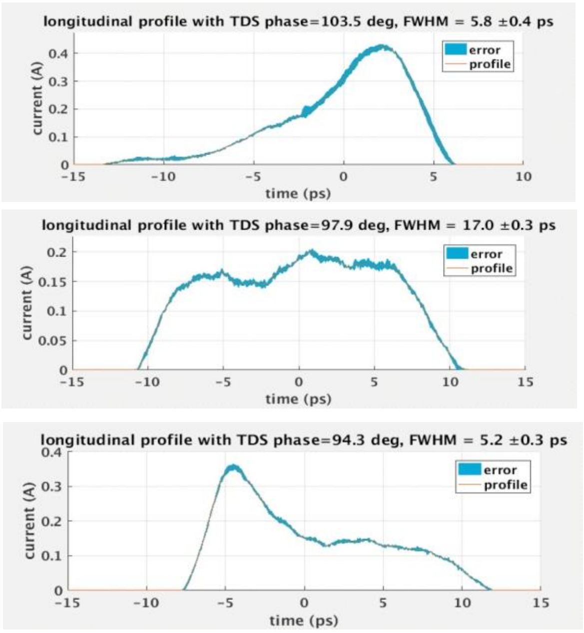


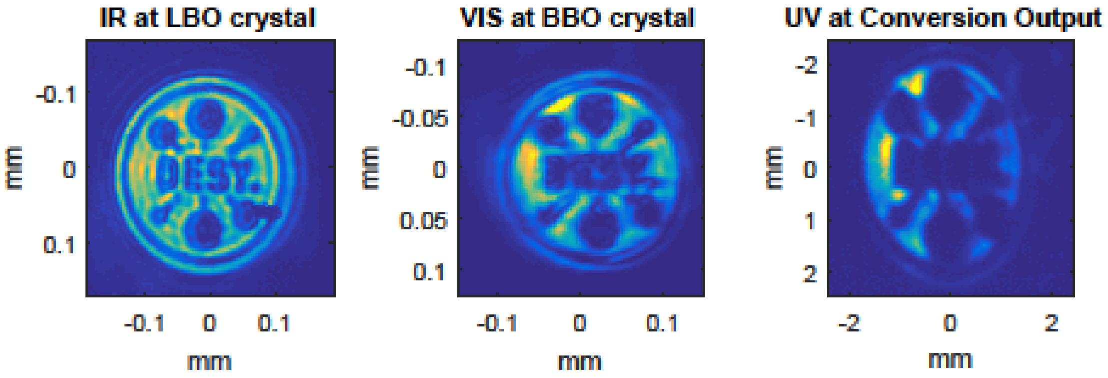


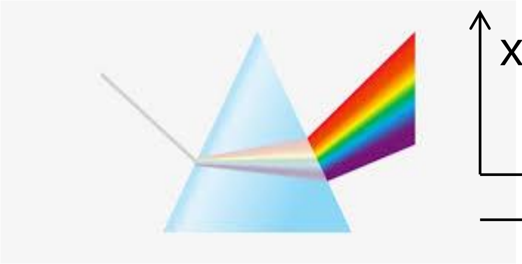
Electron imaging

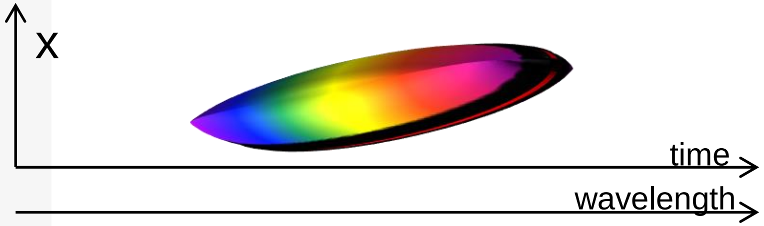
Transverse Preservation
Low charge (20 pC)
Short pulse (1.6 ps)
Very thin nonlinear crystals
LBO (2mm)/ BBO (0.1mm)



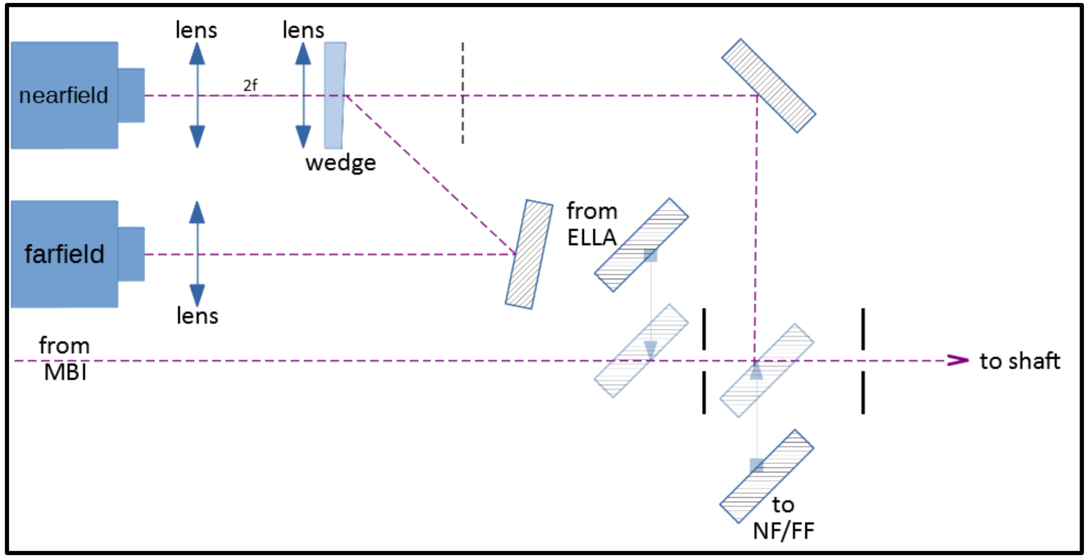


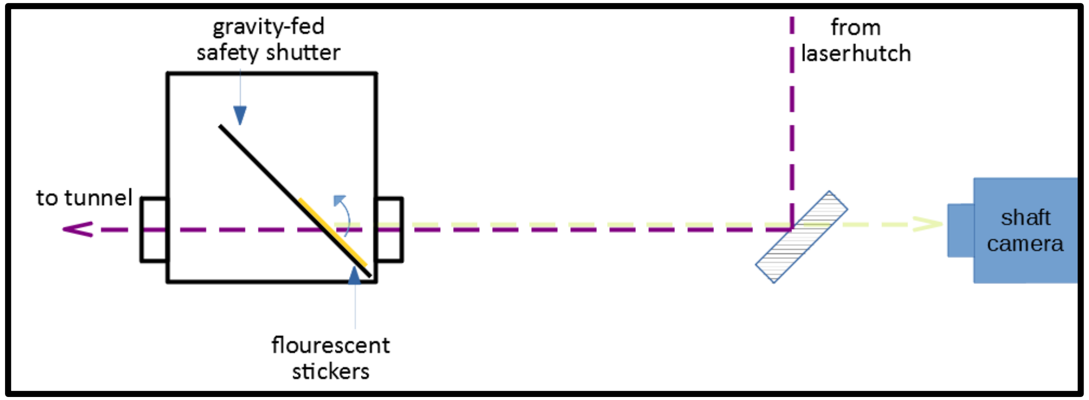


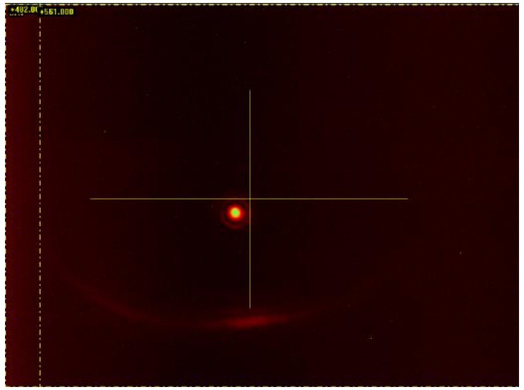




UV beamline diagnostics



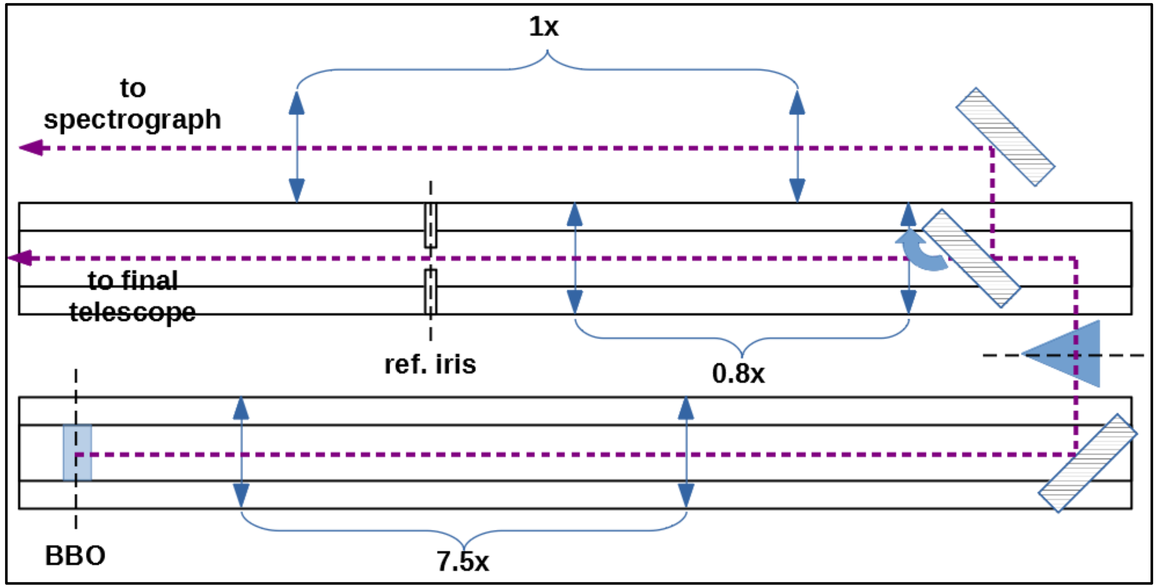


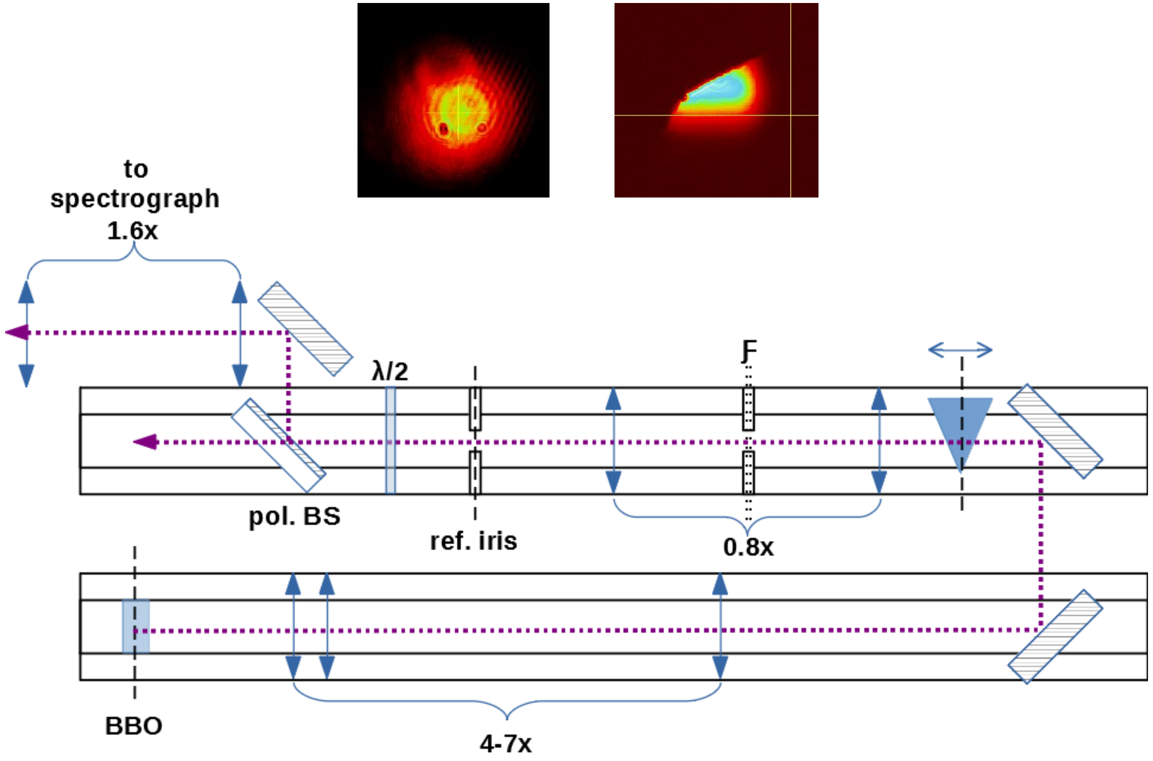


Multi-system <?> for co-linear alignment

- Multi-system:
  Near-/far- field cameras for position/angle
  Shaft camera as redundancy cross-check
- Available for MBI & ELLA (co-linear alignment!)
  Remove lens steering
- Precise: 5 um /5 urad resolution
- Shaft is parasitic

UV beamline reconstruction





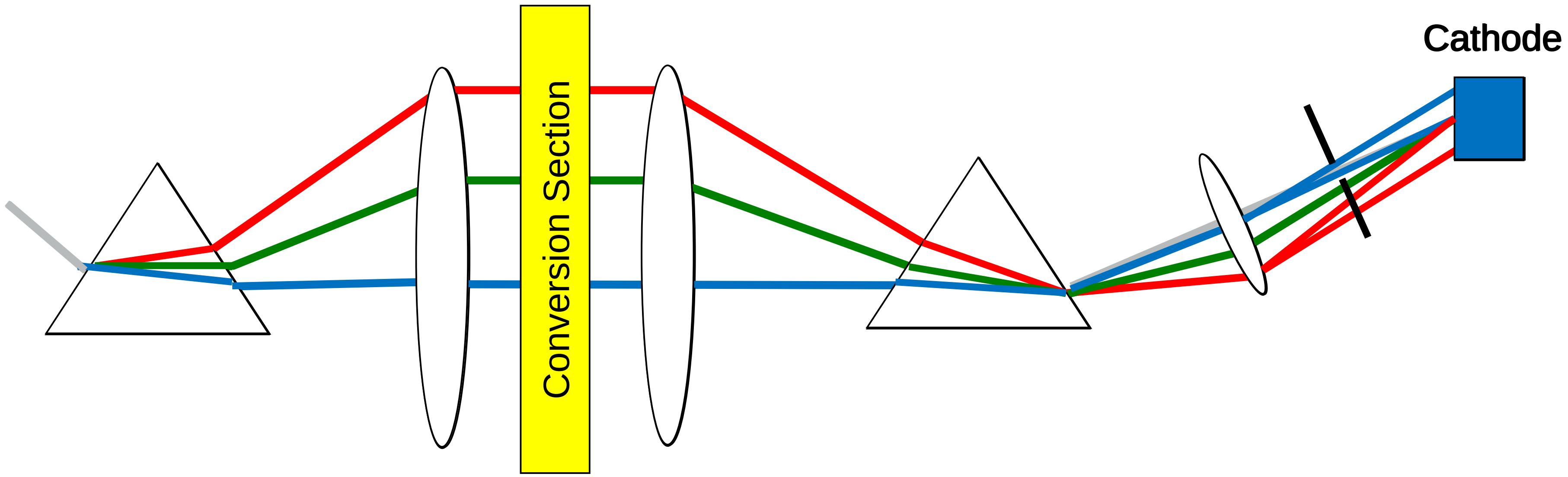
United single-stream UV beamline

- Variable coupling telescope
- Translatable prism
- Variable spatial filter (old BSA plates)
- Improve LT controller
- Dual-band (257+515 nm) mirrors (downstream)

Parasitic diagnostic beamsplitter arm

- Spectrograph (improved spatial res.)
- Imaging cross-correlator
- Gregor Michealson?
- (drawings: O:\0_Documentation\laser hut\Nearfieldfarfield)

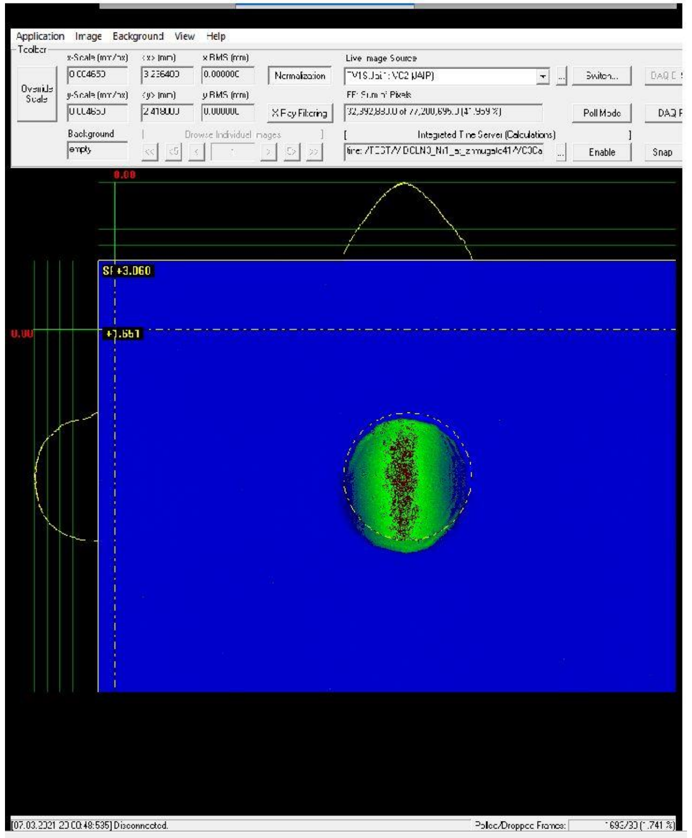
Dispersion in the UV Section



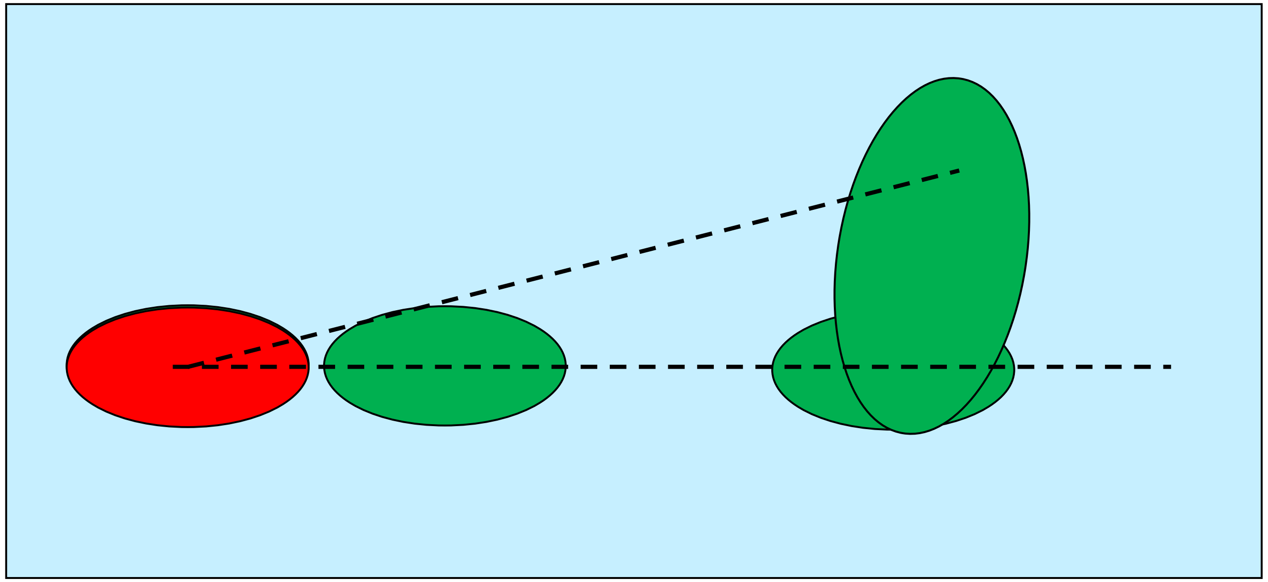
Prisms are needed to have spectrally broadband conversion. Due to the problems however, it is planed for the next beam time to operate without prisms.

Con: Only thin BBO crystals and thus low charge / narrow spectrum and thus short pulses
Pro: No dispersion and thus can use spatial filter and cross correlator

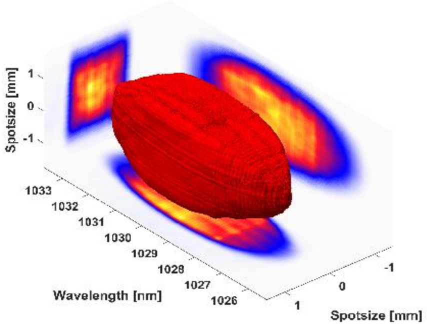
Thin crystal VS thick crystal

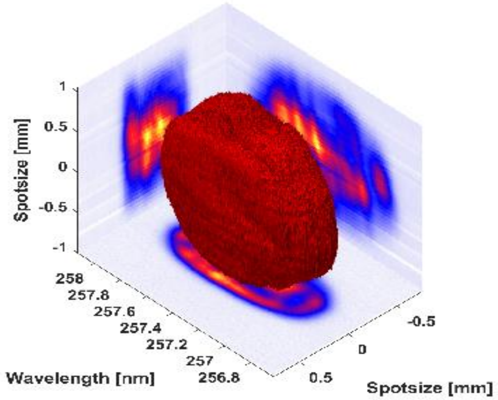


x-Scale (mm/px): 0.004650
<x> (mm): 3.236400
x RMS (mm): 0.000000
y-Scale (mm/px): 0.004650
<y> (mm): 2.418000
y RMS (mm): 0.000000
Background: empty
Live Image Source: TV1S.Jai1 : VC2 (JAIP)
FF: Sum of Pixels: 32,392,830.0 of 77,200,695.0 (41.959 %)
[07.03.2021 23:00:48:535] Disconnected.



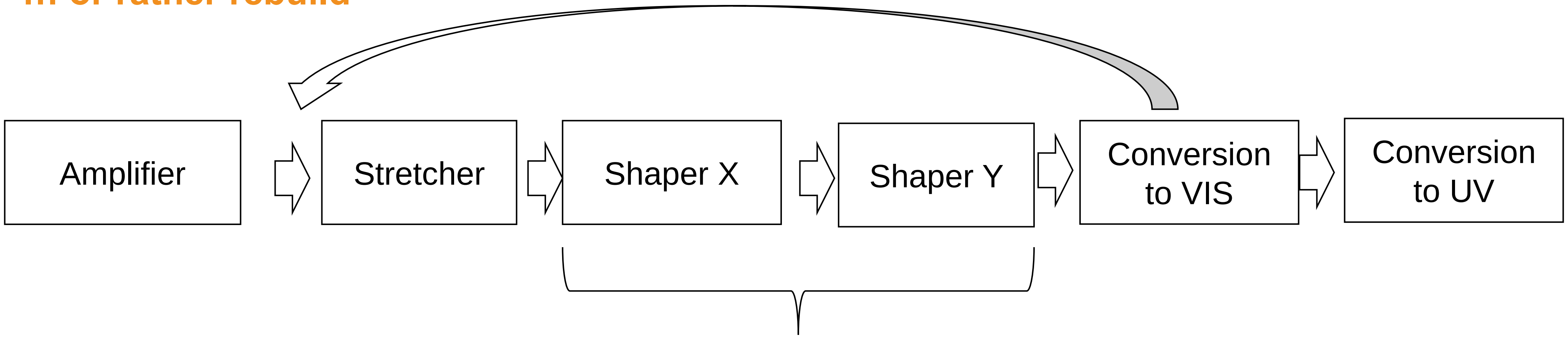
Emittance of 0.9 -1.2 in case of thin crystal





Rearrange ELLA Setup

… or rather rebuild



Amplifier

Stretcher

Shaper X

Shaper Y

Conversion to VIS

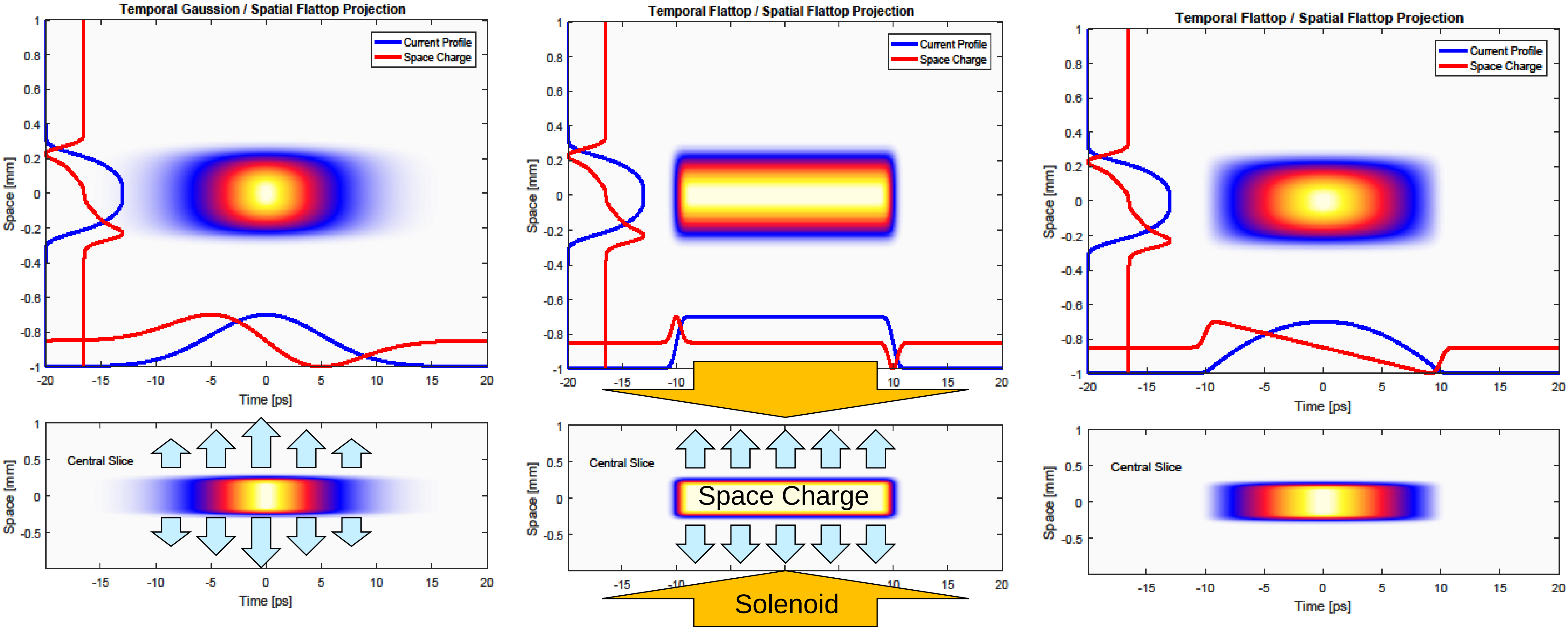
Conversion to UV

Build from scratch

Rebuild with VIS optics

Theoretical expectation for laser shaping influence

Longitudinal



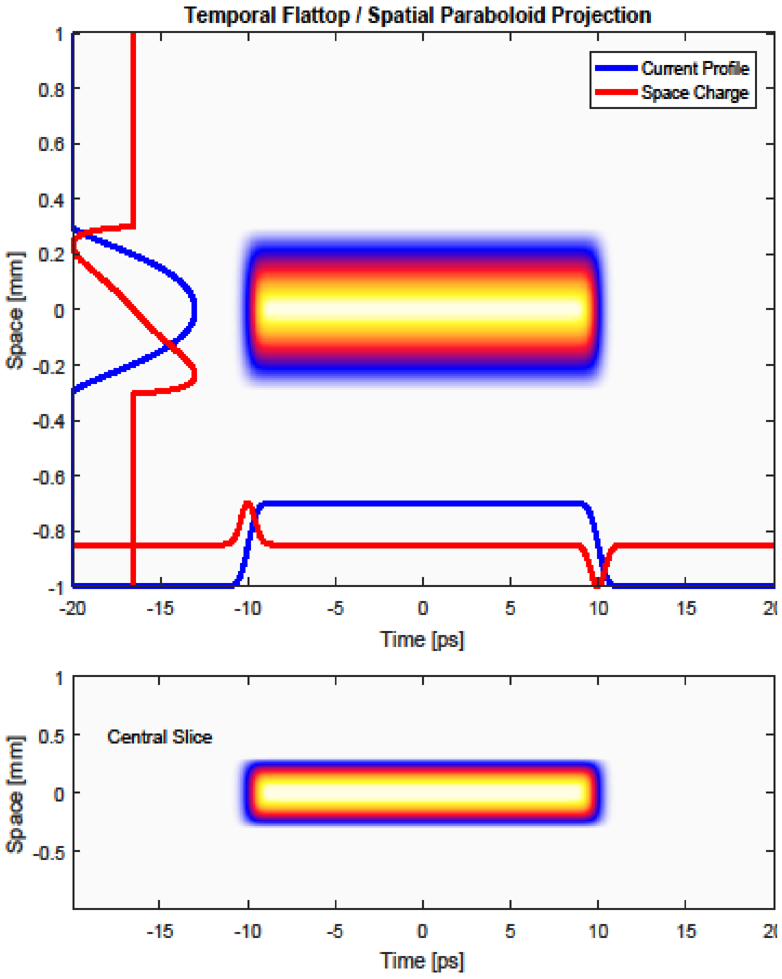
Temporal Gaussion / Spatial Flattop Projection

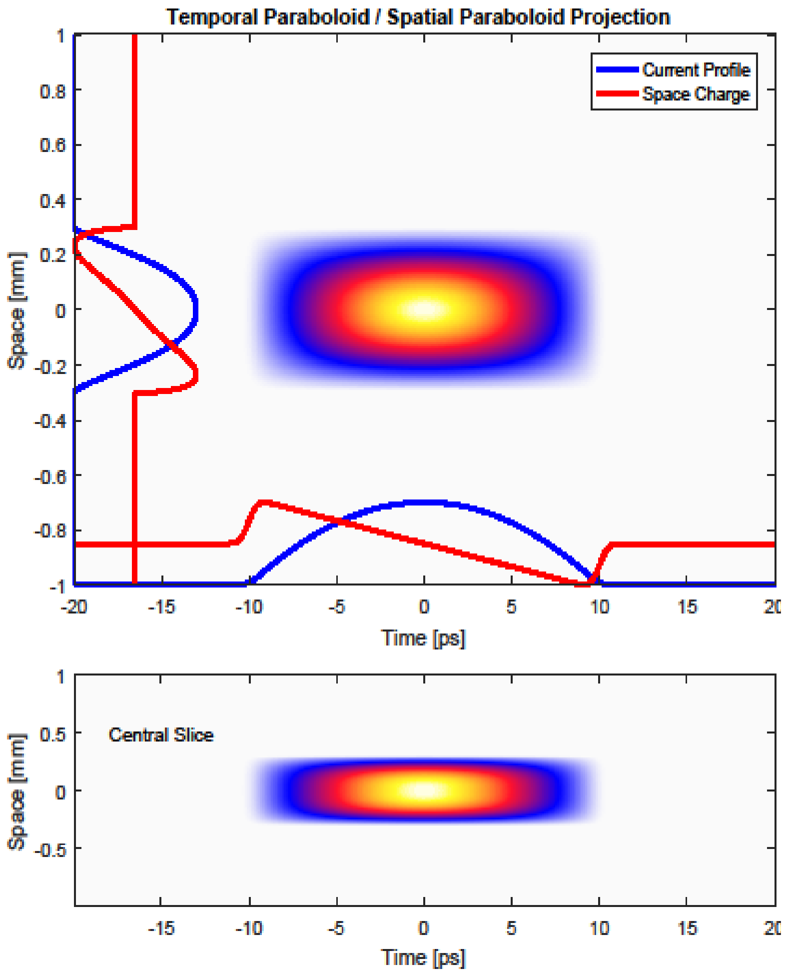
Temporal Flattop / Spatial Flattop Projection

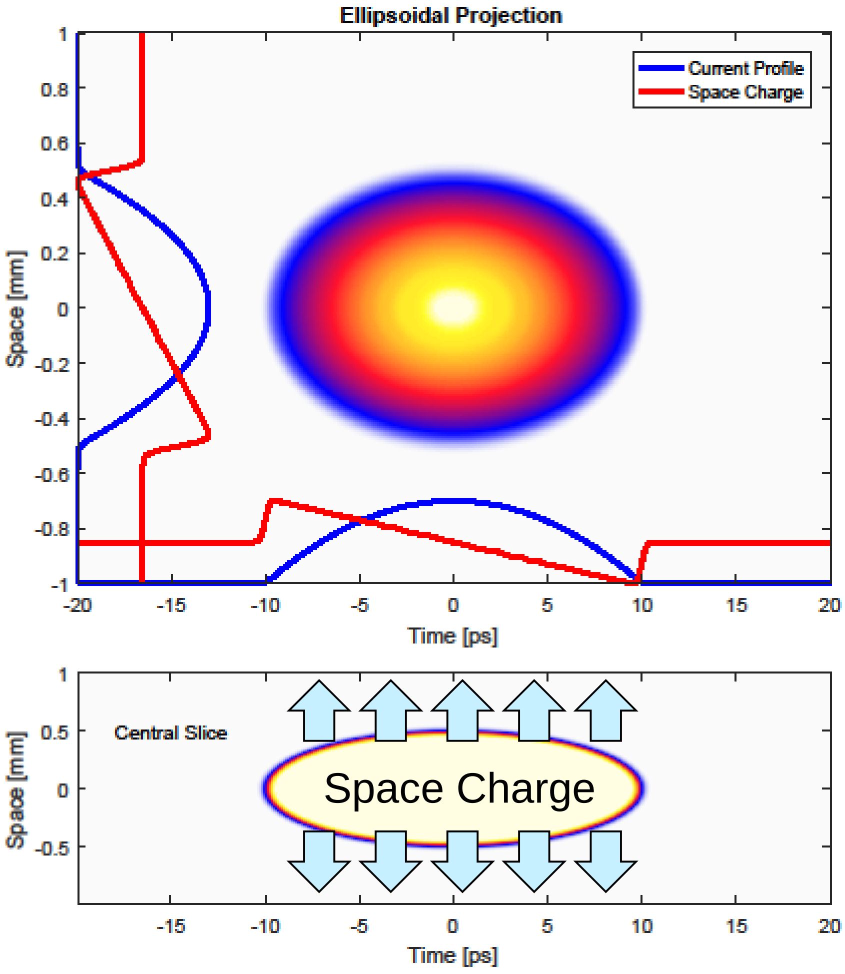
Temporal Flattop / Spatial Flattop Projection

Theoretical expectation for laser shaping influence

Spatial & Spatial Temporal shapes


Temporal Flattop / Spatial Paraboloid Projection

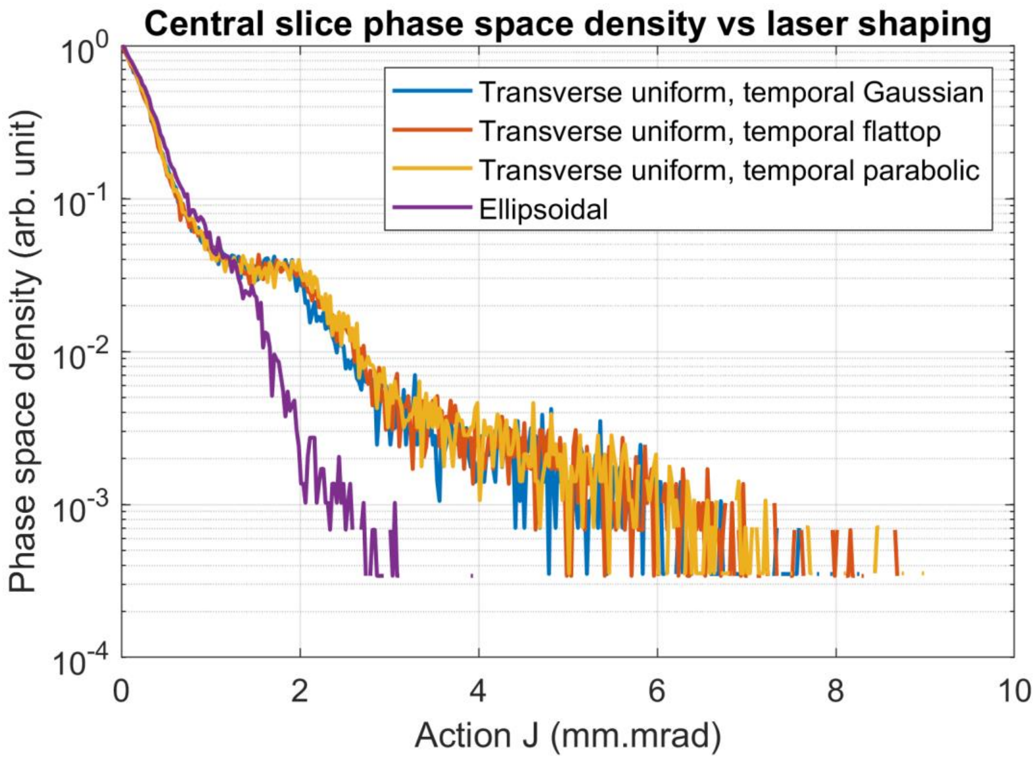

Temporal Paraboloid / Spatial Paraboloid Projection

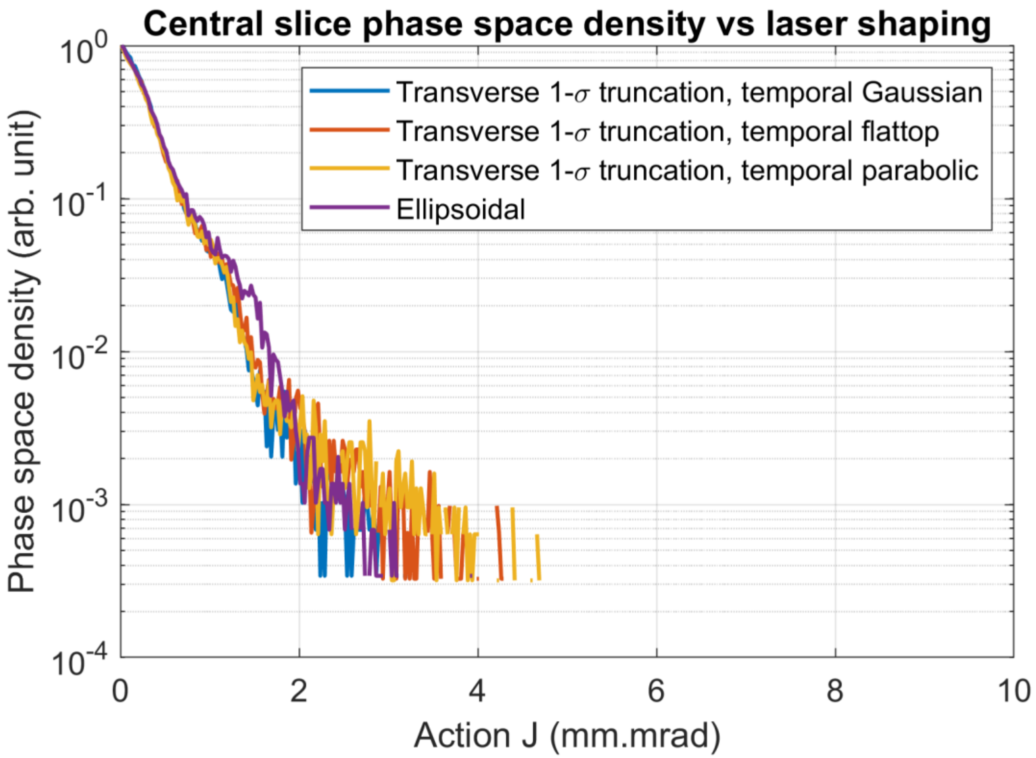

Ellipsoidal Projection

Central slice phase space

250 pC, XFEL working point

- ☐ Transverse Gaussian truncation is very effective in reducing central slice emittance, but also improving 'halo' brightness.
- ☐ Both ellipsoidal and gaussian truncation slightly degrades core emittance.
- ☐ Beam core brightness is same as photoemission for uniform case.



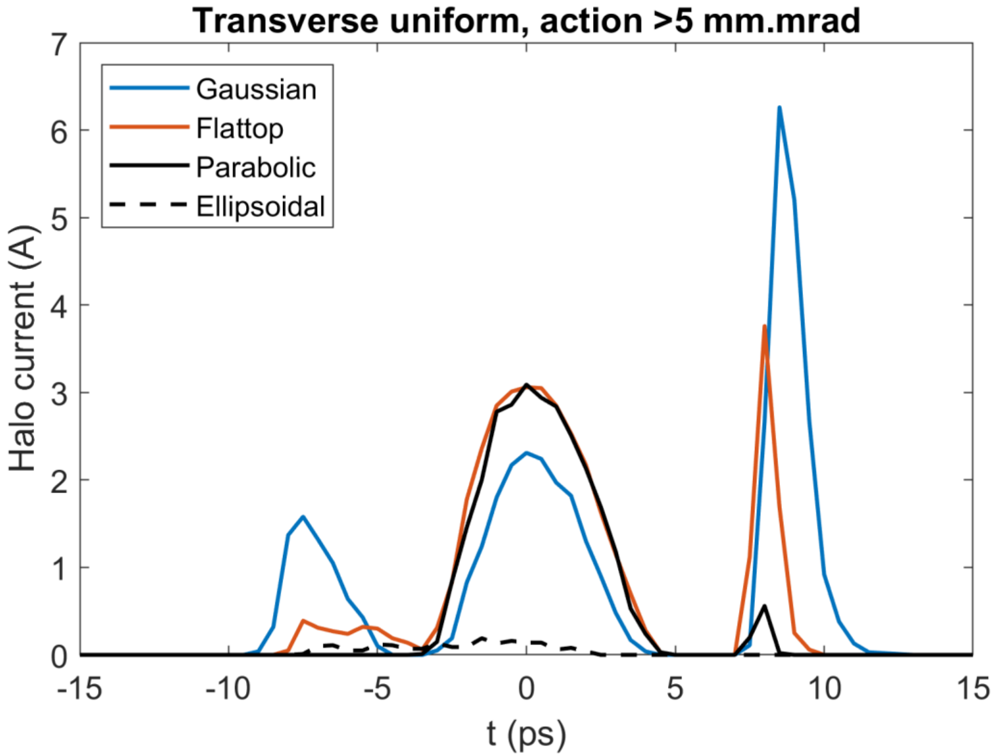


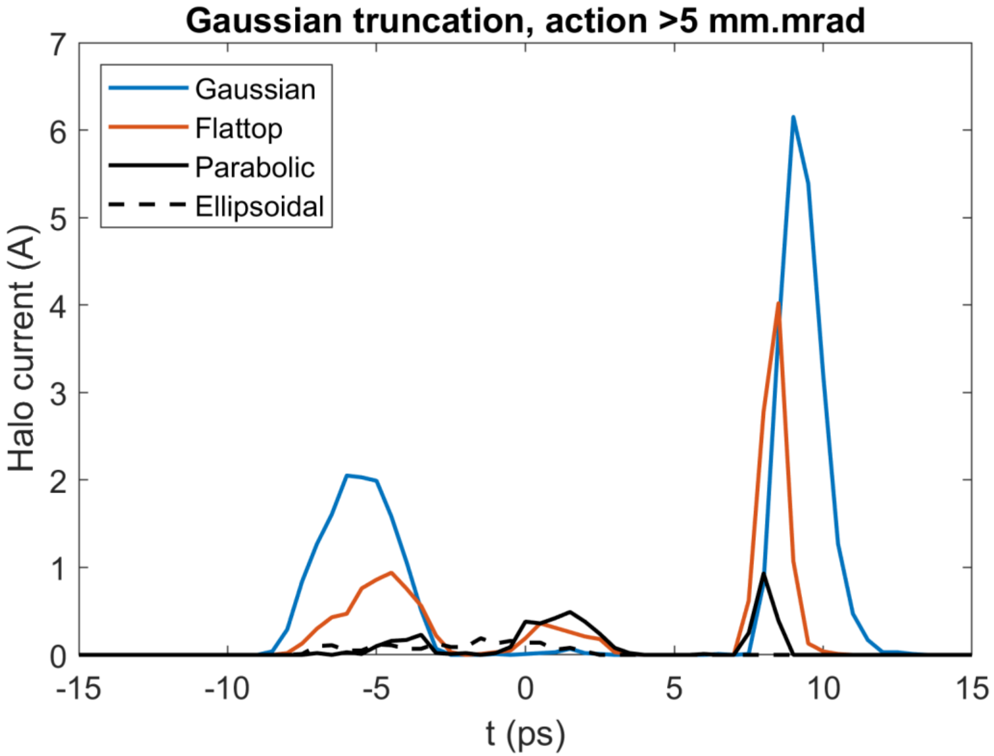
laser shapes	100% emit	95% emit	Action < 2 Emittance	Action < 2 percentage	core emit
Gauss	0.53	0.38	0.38	94.8%	0.26
Flattop	0.56	0.40	0.37	93.6%	0.25
Parabolic	0.57	0.40	0.37	93.3%	0.26
Elliptical	0.34	0.28	0.33	99.7%	0.30

laser shapes	100% emit	95% emit	Action < 2 Emittance	Action < 2 percentage	core emit
Gauss-2	0.31	0.25	0.30	99.6%	0.28
Flattop-2	0.33	0.26	0.31	99.3%	0.28
Parabolic-2	0.33	0.26	0.30	99.1%	0.28
Elliptical	0.34	0.28	0.33	99.7%	0.30

Halo formation

With respect to truncation

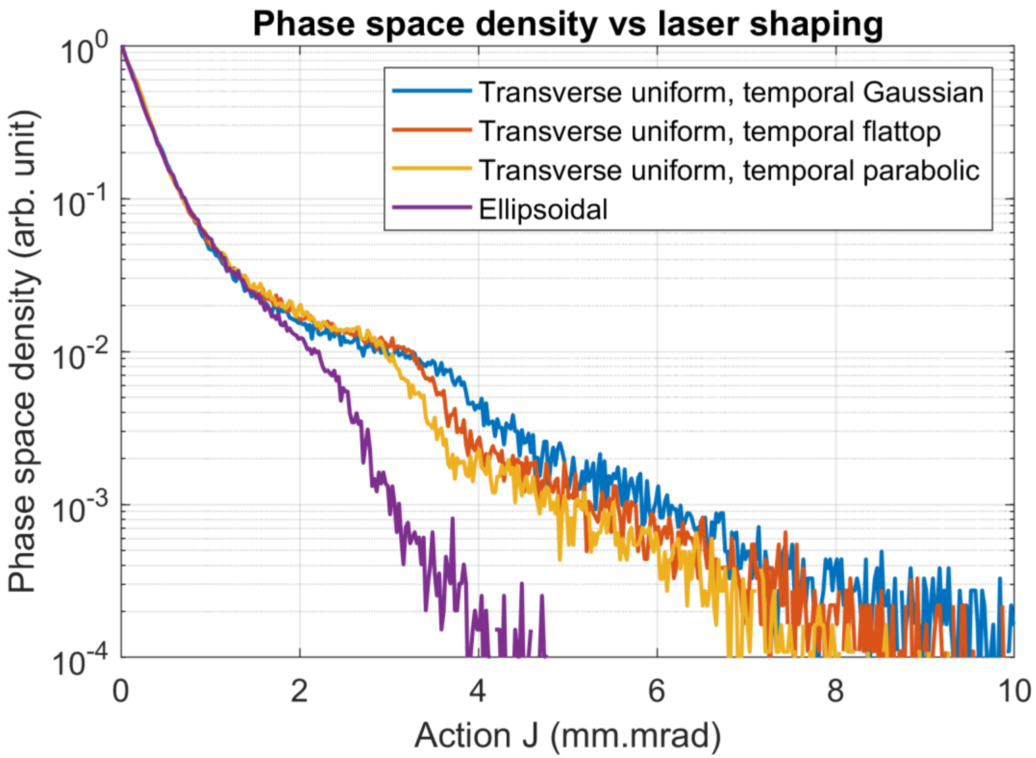


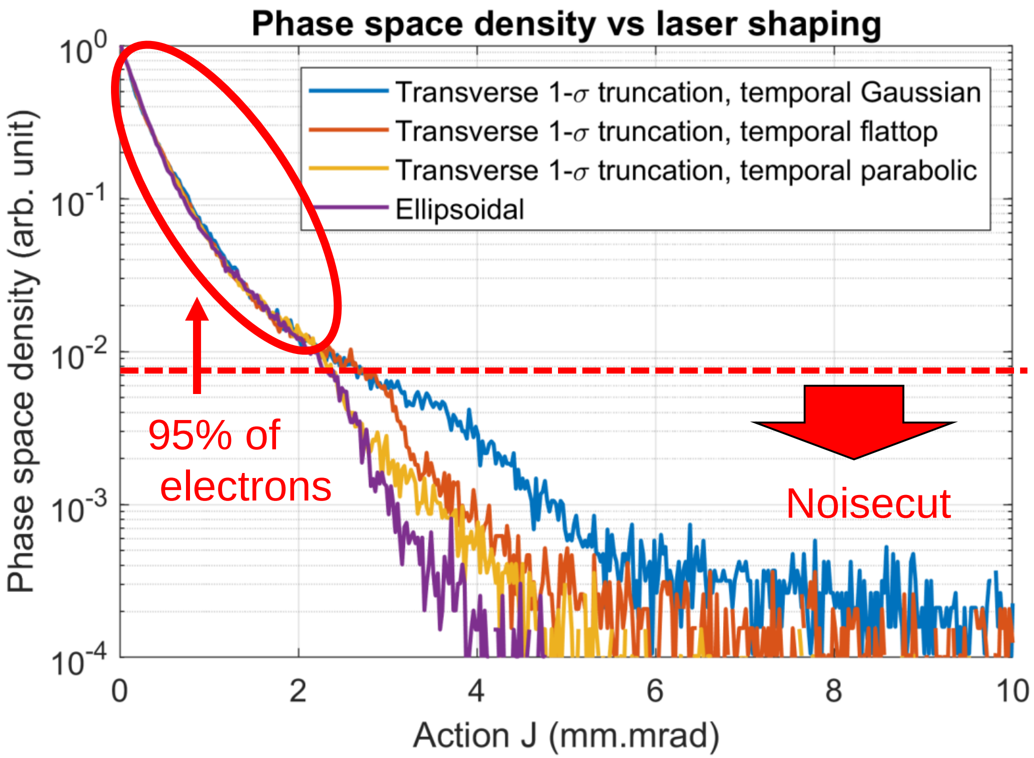


Projected phase space

250 pC, XFEL working point

- ❑ Core emittance is same for all laser shapes, Laser shaping optimizes ‘halo’ brightness. Actual beam brightness improvement is much smaller than expected by emittance.
- ❑ 100% emittance is not a good figure of merit for beam brightness, too much affected by halo particles. 95% emittance is a better compromise between core and halo particles.

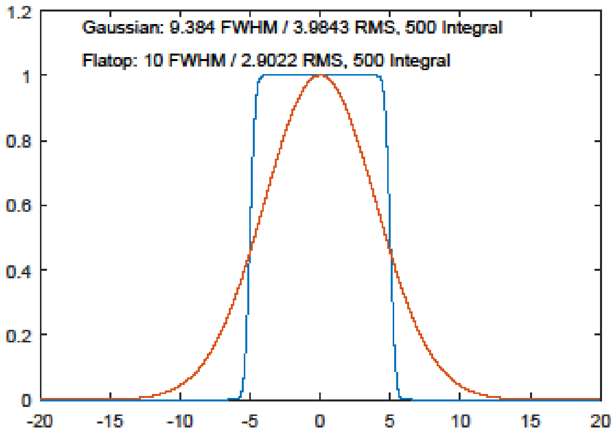




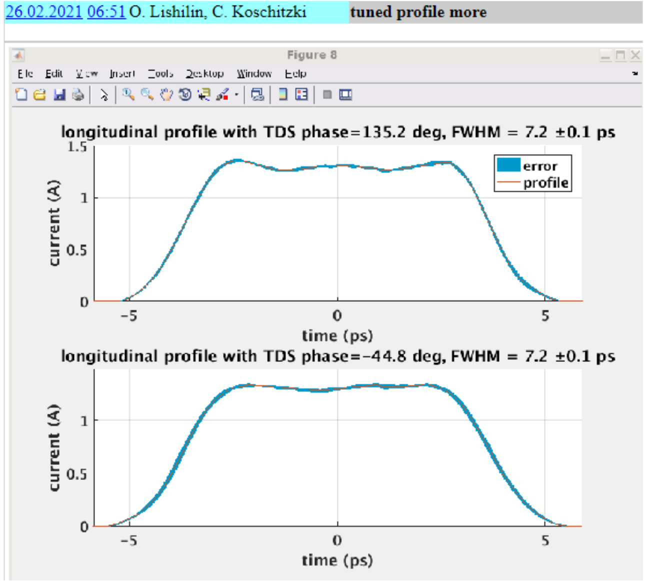
laser shapes	100% emit	95% emit	Action < 2 Emittance	 percentage	core emit
Gauss	0.70	0.42	0.36	92.0%	0.29
Flattop	0.61	0.41	0.37	92.9%	0.28
Parabolic	0.53	0.39	0.37	93.9%	0.28
Elliptical	0.40	0.32	0.36	98.0%	0.29

laser shapes	100% emit	95% emit	Action < 2 Emittance	 percentage	core emit
Gauss-2	0.66	0.37	0.36	94.4%	0.30
Flattop-2	0.53	0.34	0.36	96.0%	0.30
Parabolic-2	0.43	0.33	0.37	97.5%	0.30
Elliptical	0.40	0.32	0.36	98.0%	0.29

Measuring emittance

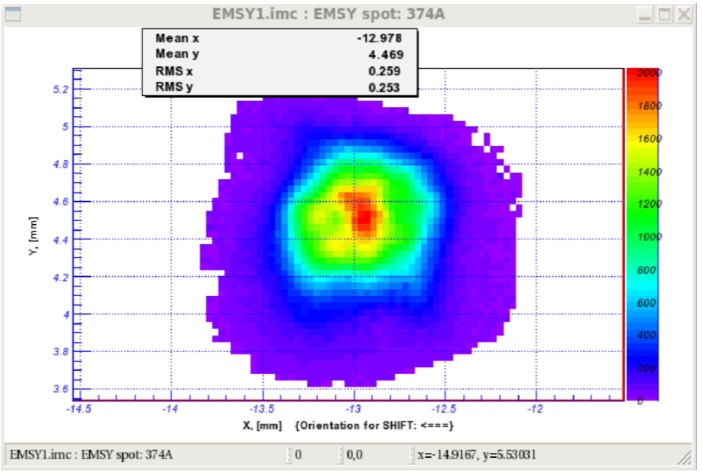


Ratio Flattop/Gauss:
1.07 FWHM
0.73 RMS



26.02.2021 06:51 O. Lishilin, C. Koschitzki **tuned profile more**

PHAROS ~10 psflattop, 374A

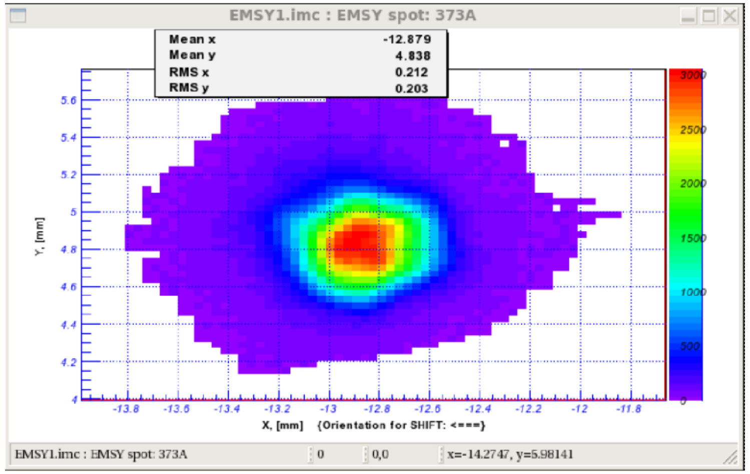


EMSY1.imc : EMSY spot: 374A

Mean x	-12.978
Mean y	4.469
RMS x	0.259
RMS y	0.253

EMSY1.imc : EMSY spot: 374A 0 0,0 x=-14.9167, y=5.53031

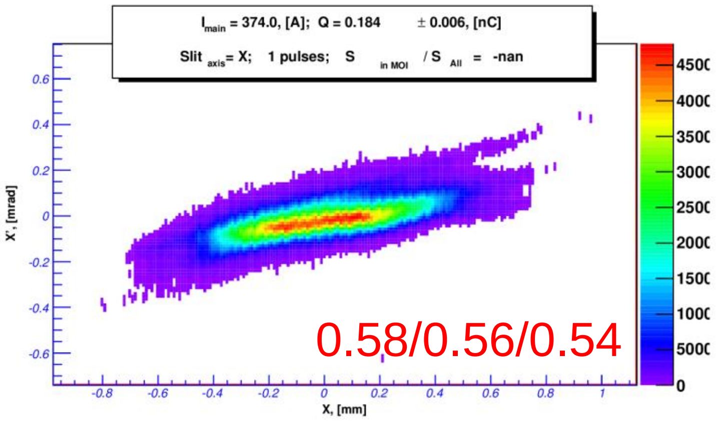
MBI ~8 psGaussian, 373A



EMSY1.imc : EMSY spot: 373A

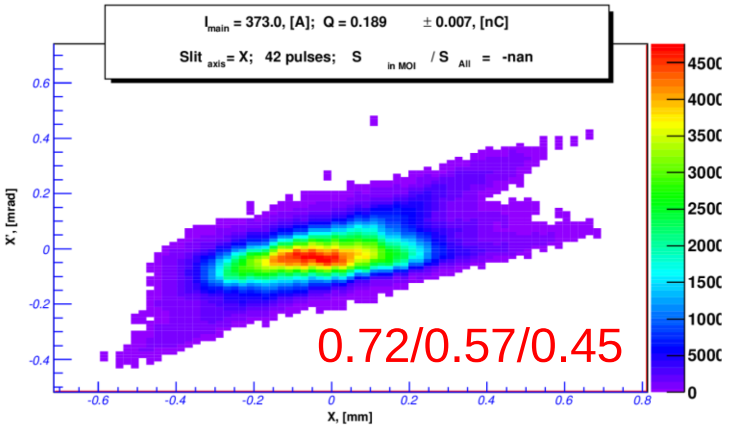
Mean x	-12.879
Mean y	4.838
RMS x	0.212
RMS y	0.203

EMSY1.imc : EMSY spot: 373A 0 0,0 x=-14.2747, y=5.98141



I_{main} = 374.0, [A]; Q = 0.184 ± 0.006, [nC]
Slit $_{axis}$= X; 1 pulses; S $_{in\ MOI}$ / S $_{All}$ = -nan

0.58/0.56/0.54



I_{main} = 373.0, [A]; Q = 0.189 ± 0.007, [nC]
Slit $_{axis}$= X; 42 pulses; S $_{in\ MOI}$ / S $_{All}$ = -nan

0.72/0.57/0.45

20% charge cut

PHAROS emittance study

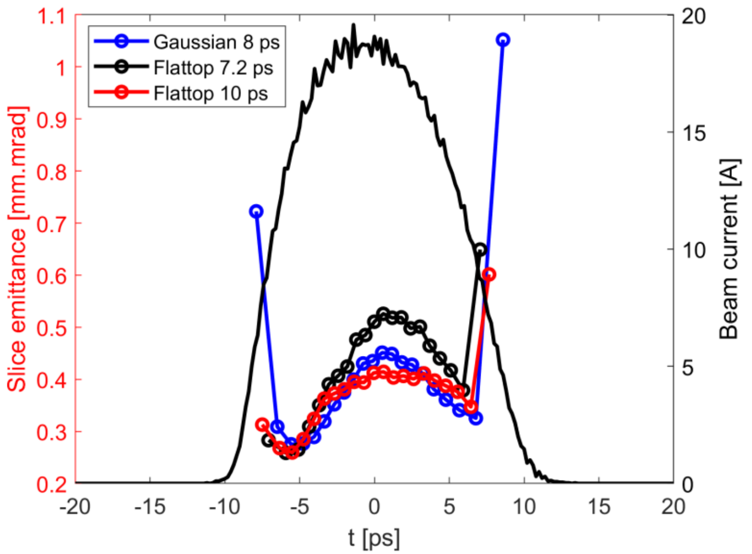
250 pC BSA1mm, 6.3 MeV/c

- 10 nm cathode, ‘4 nC’ steering, MBI vs Pharos flattop shaping

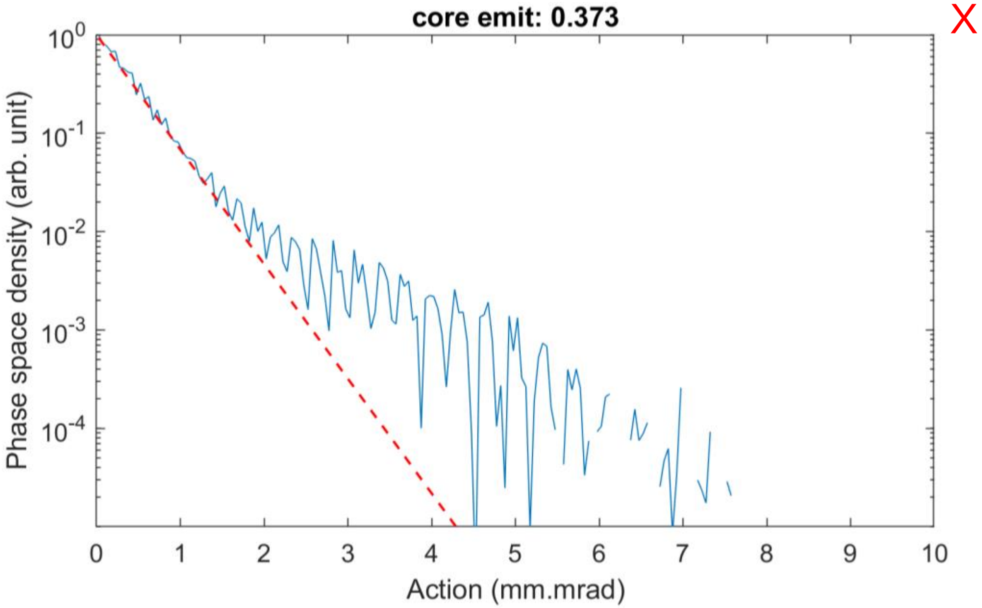
Scale2	Scale1	unscaled	EMSY1	Scaling factor	steering	Slit width	cathode	Gun quads	date	Charge
	MBI ~8 ps Gaussian									
0.72	**0.57**	**0.45**	**0.21**	**1.26**	4 nC steering	10 um	10 nm	Optimization from history	16.03.2021N	250
	Flattop ~9.4 ps									
0.58	**0.56**	**0.54**	**0.25**	**1.04**	4 nC steering	10 um	10 nm	Optimization from history	17.03.2021N	250

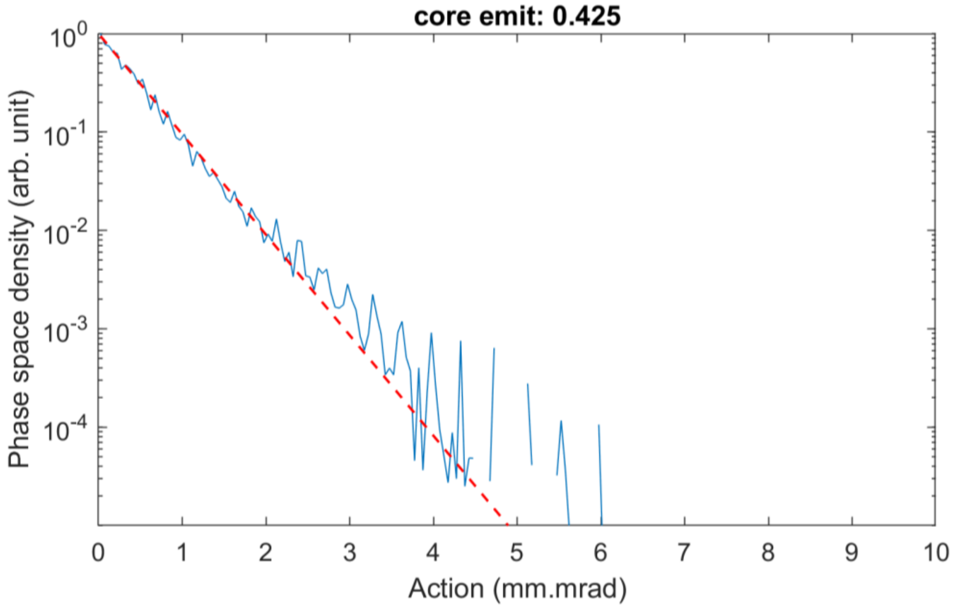
- Shaping effect: scale2 reduce by ~20%, scaling factor reduce by ~20%, but scale1 similar, unscaled higher by 20%
- Ideal simulations
  - Pro: flattop shaping helps phase space in tails, reducing halos
  - Con: flattop shaping distorts more LPS due to sharper edges

	Proj (100%)	slice	Mismatch	dE
Gaussian	0.75	0.42	0.60	3.6
Flattop7	0.58	0.43	0.37	6.3
Flattop10	0.52	0.38	0.35	7.3



X phase space



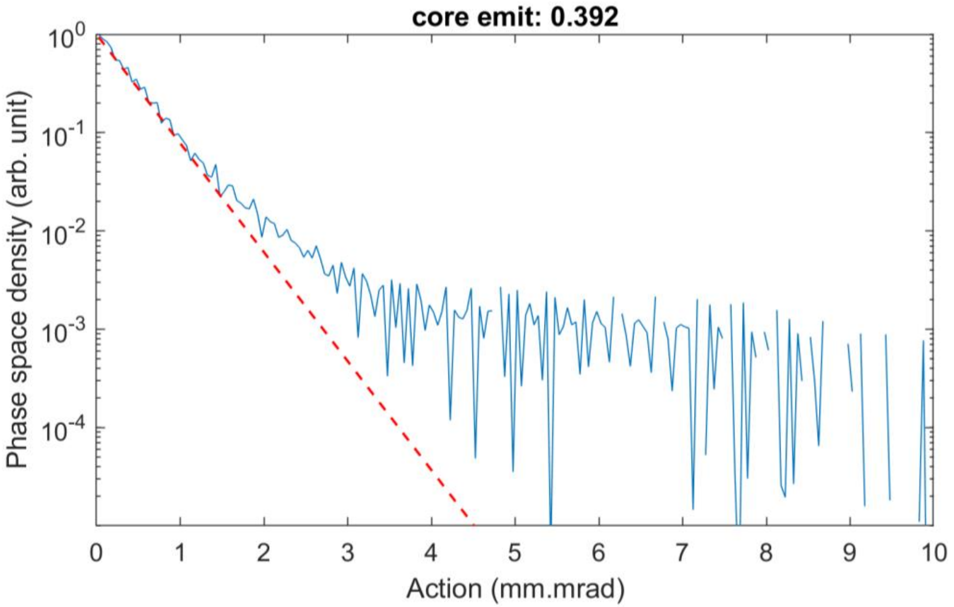


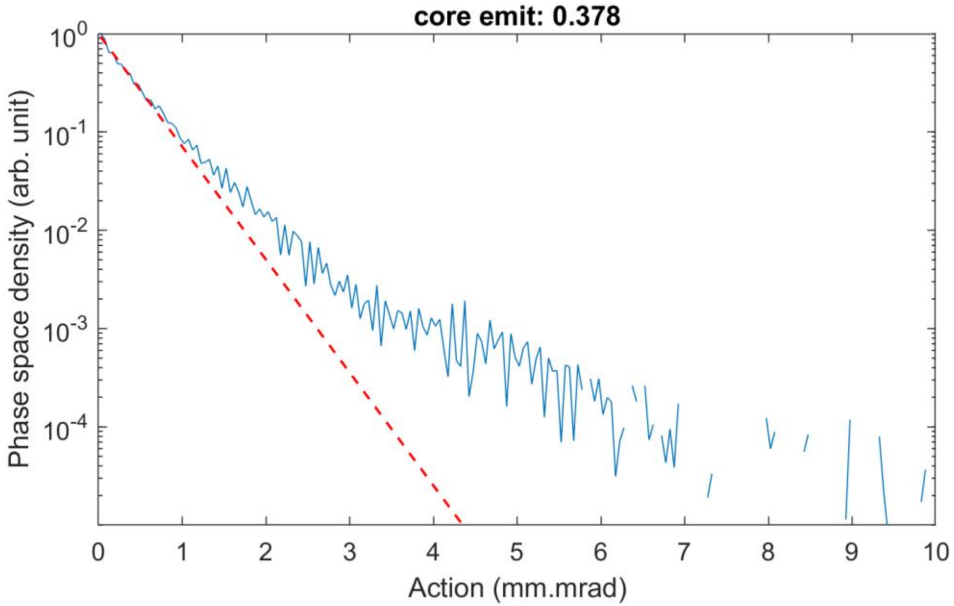
Unscaled: 0.46
Scaled: 0.55

Unscaled: 0.45
Scaled: 0.52 (scale 0.59)

MBI 20210316N

Y phase space

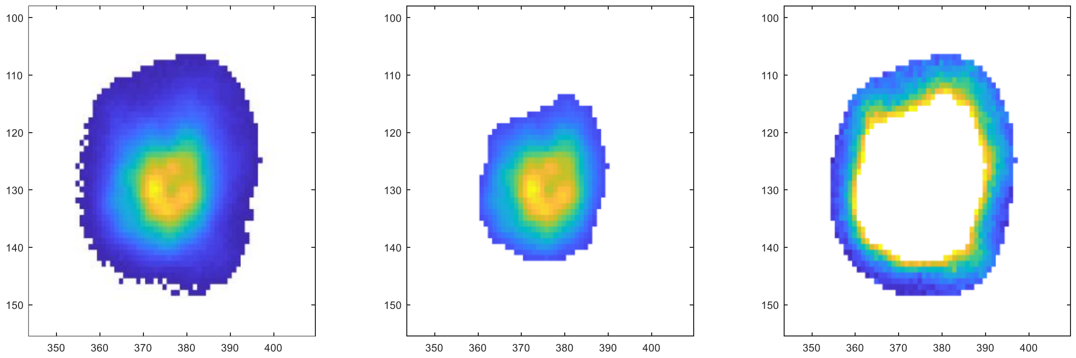




Laser Shaping Experiments: Halo

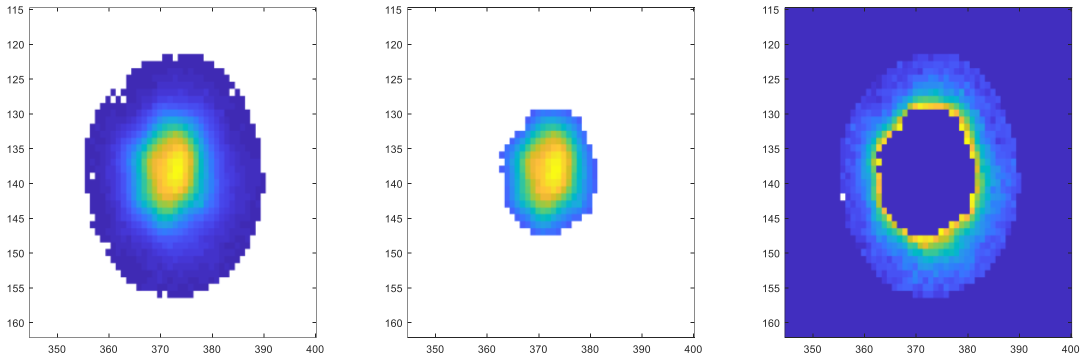
Example from Mikhail Krasilnikov

PHAROS ~9 psflattop, 374A



Chargecut 13% → Skaling factor 1.04

MBI ~8 psGaussian, 373A



Chargecut 21% → Skaling factor 1.26

1. **Emittance**
   - Measure consistent low core emittance

2. **Halo**
   - Find comparable definition for Halos

2. **LPS linearity**
   - Hasn’t been compared experimentally

Good Emittance + small Halo + good linearity = good beam

Laser Shaping Experiments: Longitudinal phase space

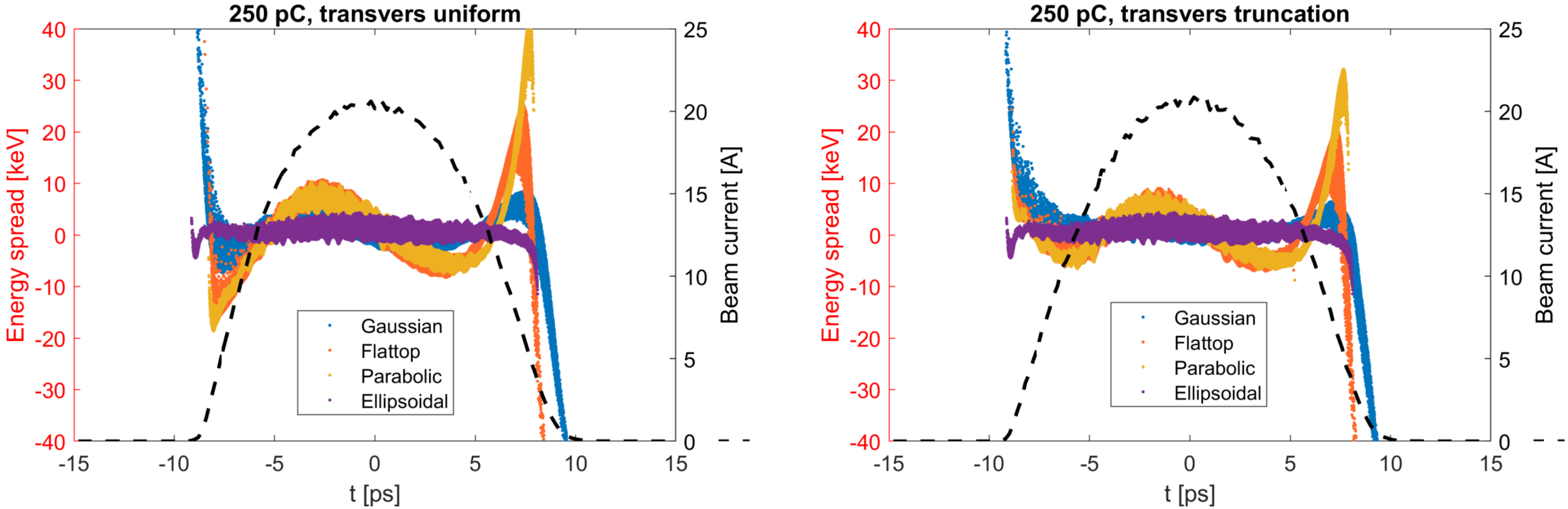
250 pC, after removing 1st and 2nd order energy chirp

Transverse uniform case

2.4/5.4/4.7/0.8 keV rms

Transverse truncation case

1.5/4.4/3.9/0.8 keV rms



Summary

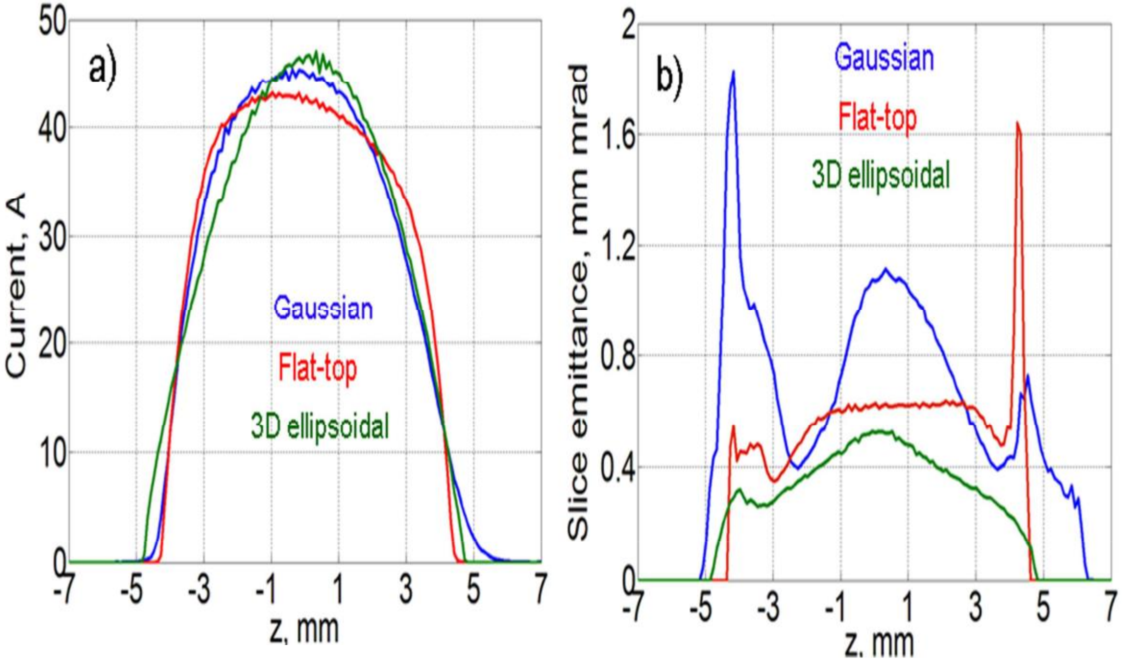
Achievements

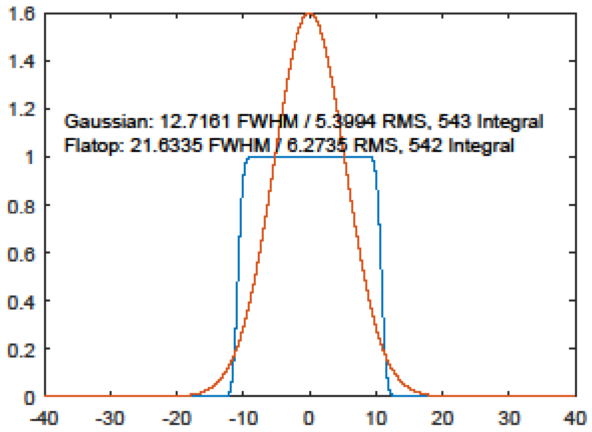
- Theoretically predicted (good) emittance achieved for thick crystal
- Long pulse, high current modulated beams
- Relatively short setup times

TO DO

- Fix dispersion matching in Conversion section
- Investigate homogeneity issues from conversion
- Rebuild Setup in VIS

Old comparison metric





	Temporal	profile	cylindrical		3D ellipsoidal
			Gaussian	Flat-top [fixed to reference [4]]	3D homogeneous
Cathode laser	Transverse	distribution	radial homogeneous		3D homogeneous
	Trms	ps	5.4	6.272	6.1
	XYrms	mm	0.385	0.401	0.39
	Th. emit.	mm mrad	0.326	0.339	0.33
RF gun	Ecath.	MV/m	60.58		
	Phase	deg	on-crest		
	MaxBz	T	0.2275	0.2279	0.2297
CDS	CDS starting point	m	3.07		
	MaxE	MV/m	19.76		
E-beam @ EMSY1	Charge	nC	1		
	Momentum	MeV/c	23.96		
	Proj. emittance	mm mrad	1.08	0.639	0.419
	Th. / proj.	%	30	53	79
	<Sl. emit.>	mm mrad	0.778	0.572	0.392
	Rms bunch length	mm	2.163	2.163	2.162
	Peak current	A	45.4	43.2	46.8
	Long. emittance	pi keV mm	106.7	98.2	88

varied parameters

min emittance at EMSY1

← same