Expected Radiation in FLASH with 3rd Harmonic Module

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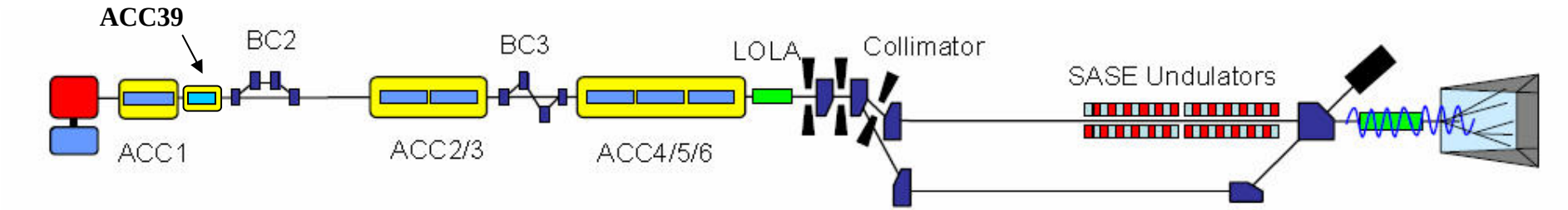
BD meeting, DESY

Layout and main parameters

Present layout + ACC39 is considered in the talk.
Energy 1 GeV.
Radiation wavelength ~ 6.5 nm.
Bunch charges 1nC, 0.5 nC, 0.25 nC.



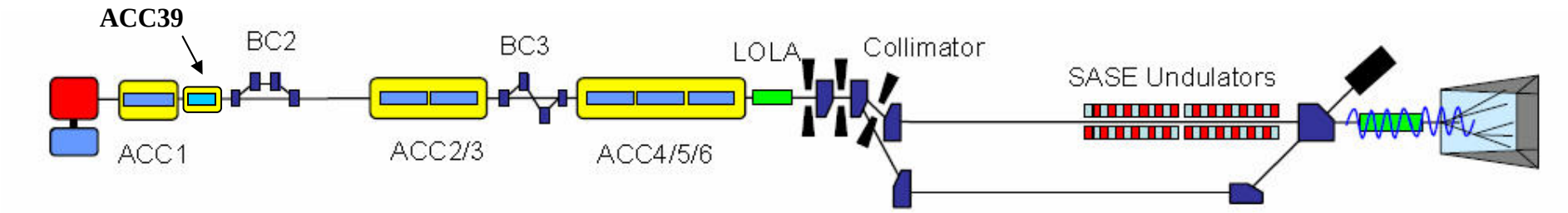
$E_1 = 127\text{MeV}$
$r_{56} = -0.1808\text{[m]}$
$t_{566} = 0.295198$
$u_{5666} = -0.437737$

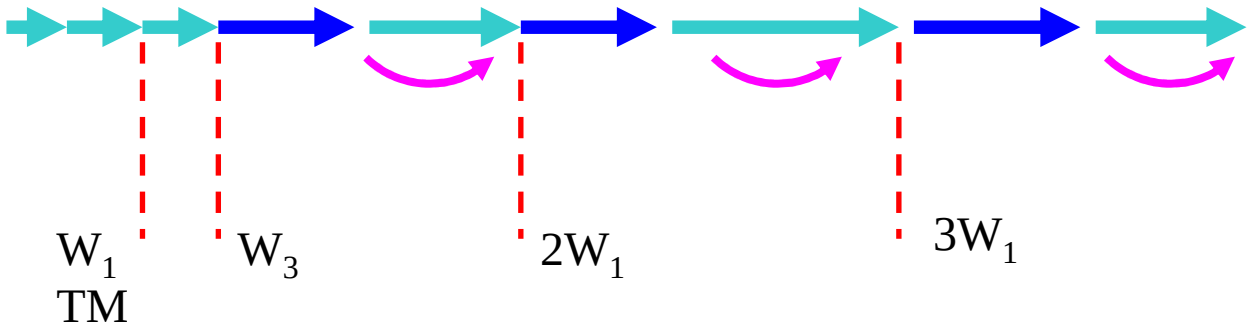
$E_2 = 470\text{MeV}$
$r_{56} = -0.048669\text{[m]}$
$t_{566} = 0.0733141$
$u_{5666} = -0.0982712$

$E_3 = 1\text{GeV}$
$r_{56} = 5.585\text{e-}4\text{[m]}$
$t_{566} = 0.0588$
$u_{5666} = -0.6417$

3D simulation setup

M. Krasilnikov - Input Desk for ASTRA gun simulations for 1nC, 0.5 nC, 0.25nC
N. Golubeva – MAD optics (V2, V2+) for 1 GeV





ASTRA (m=0 solver, on axis bunch)

CSRtrack (1D model)

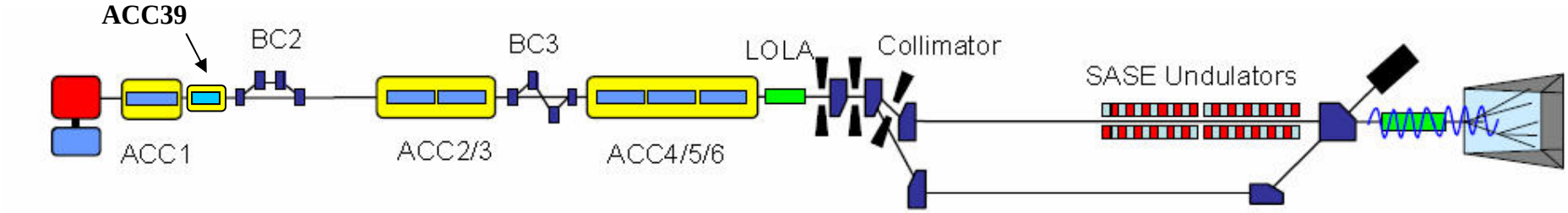
Linear Transformation (slice centers)

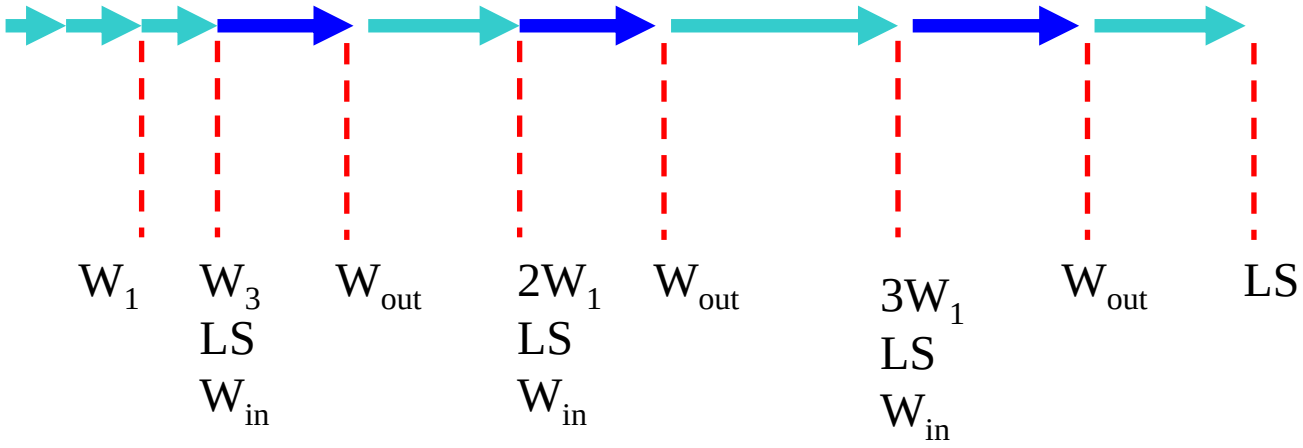
W_1-TESLA cryomodule wake

W_3- ACC39 wake

TM- transverse matching to the design optics

1D (longitudinal phase space) simulation setup





accelerator

$$E_1(s_1) = E_0(s_0) + V\cos(ks_0 + \varphi)$$
$$s_1 = s_0$$

compressor

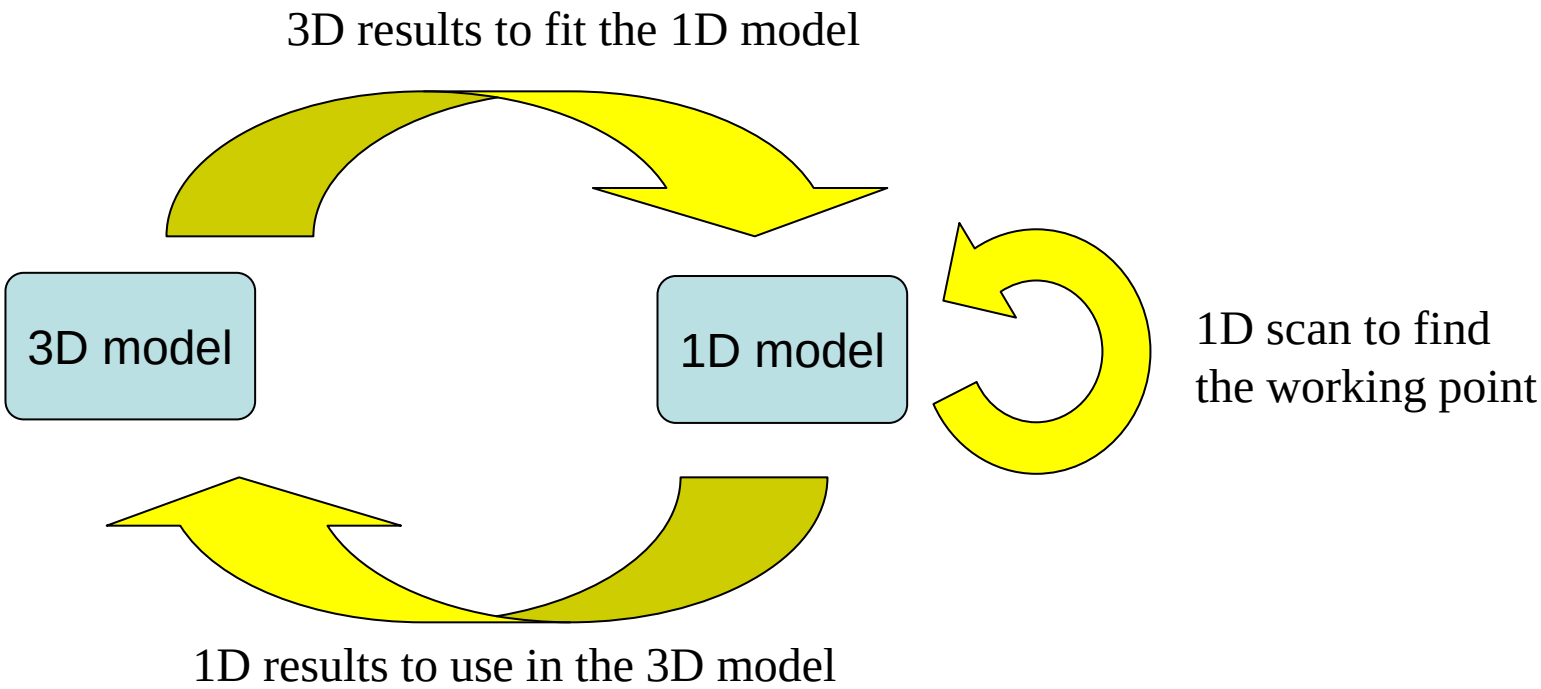
$$E_1(s_1) = E_0(s_0(s_1))$$
$$s_1(s_0) = s_0 - \left(r_{56}\delta_0^{\,1} + t_{566}\delta_0^{\,2} + u_{5666}\delta_0^{\,3}\right)$$

W1 -TESLA cryomodule wake
W_3 - ACC39 wake
LS - space charge wake
W_{in}, W_{out} - wakes to simulate CS and edge radiation in BCs

3D and 1D simulations with self fields.

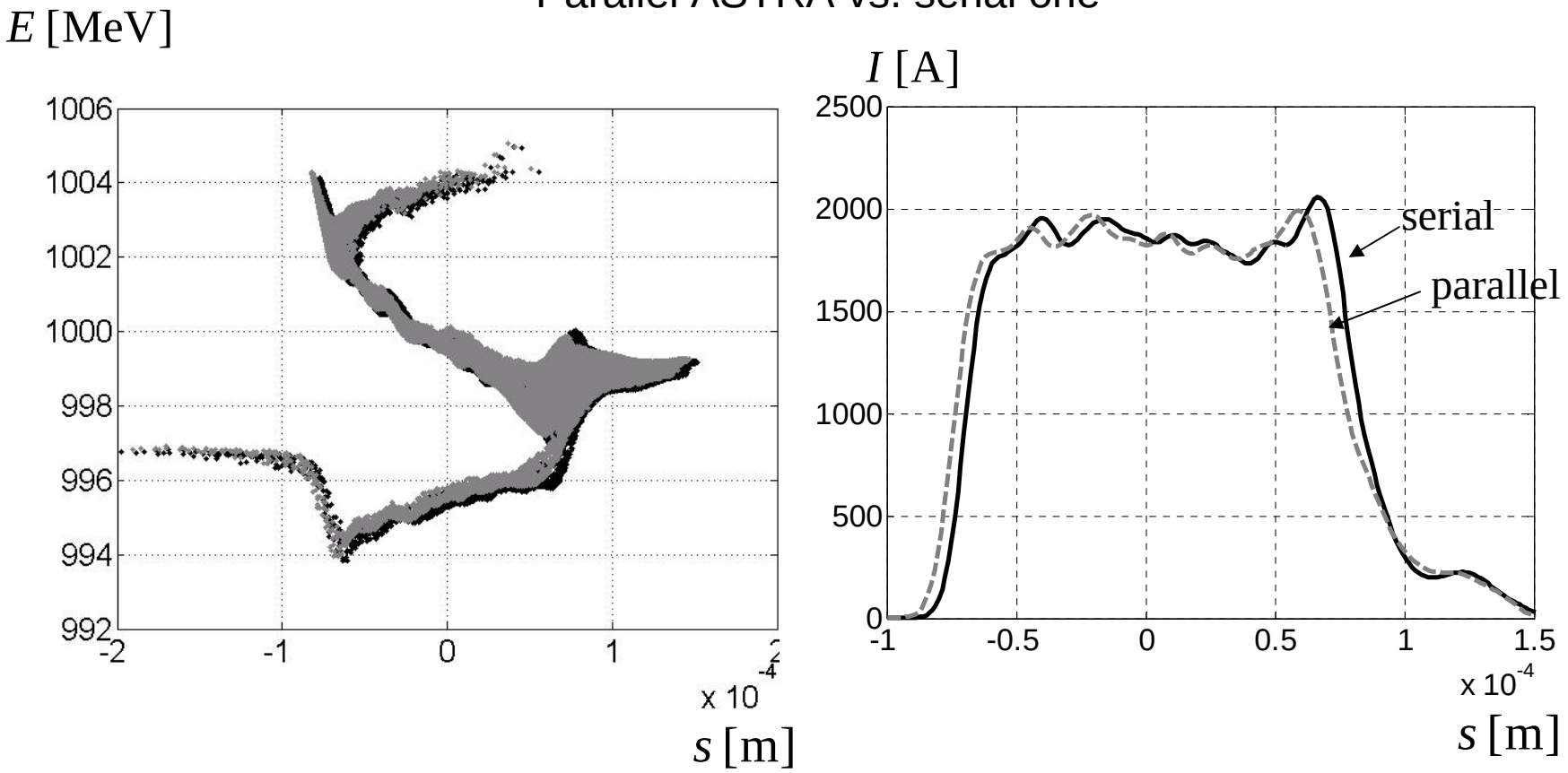
space charge +cavity wakes + self fields in BCs

1D model was checked through 3D.
Working points are found by optimization in 1D and then checked by 3D.
Finally, 1D model is used to estimate the RF tolerances.



Accuracy check of the results for 1nC presented in January

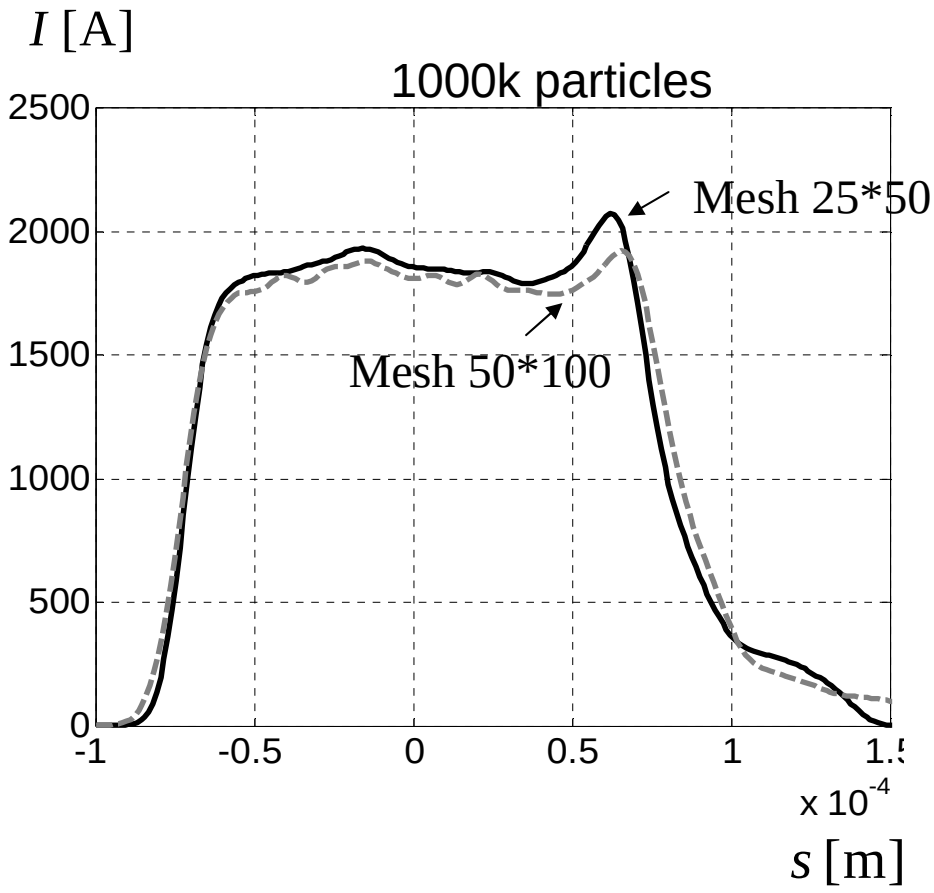
Parallel ASTRA vs. serial one

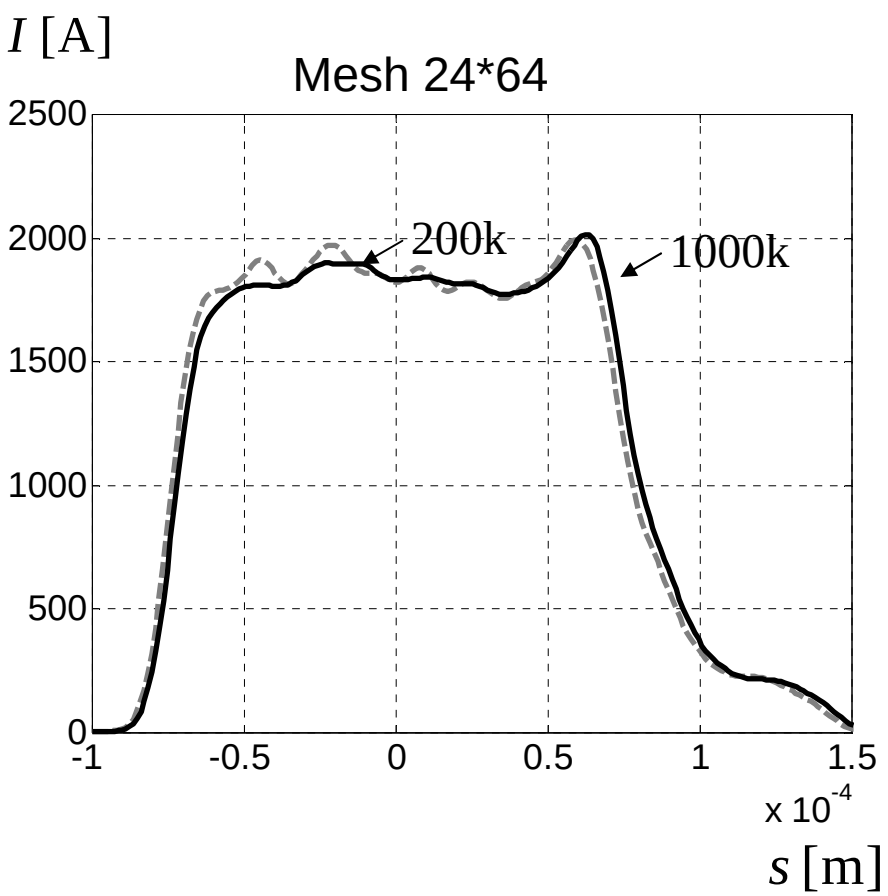


Have I started **exactly** with the same distribution from the cathode?

Accuracy check of the results for 1nC presented in January

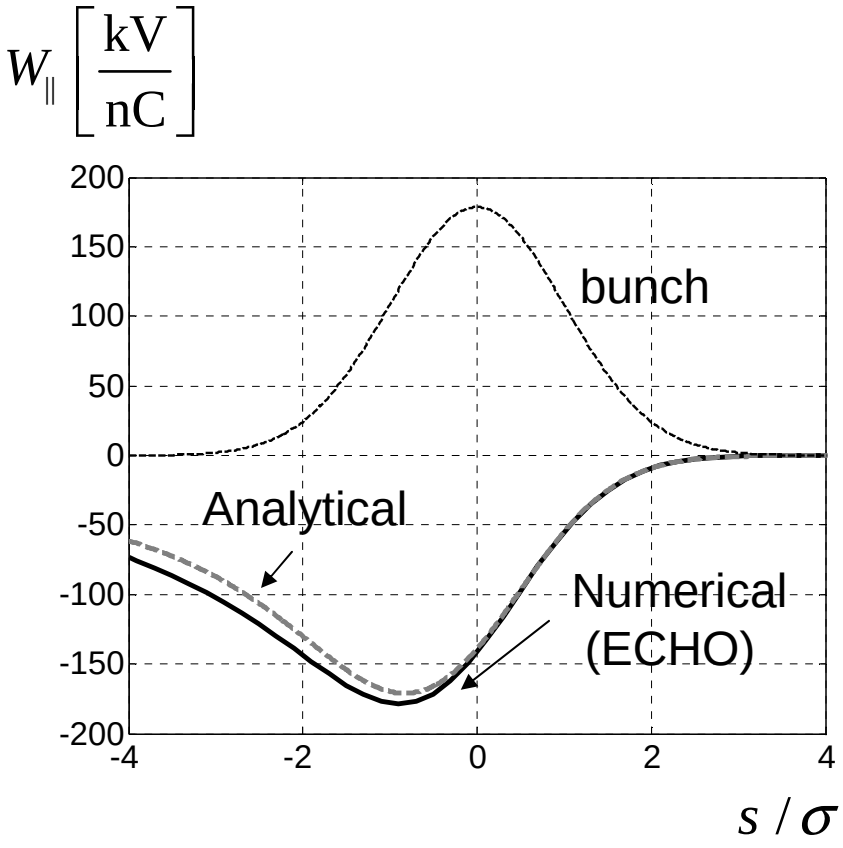
Different number of particles and mesh lines in ASTRA

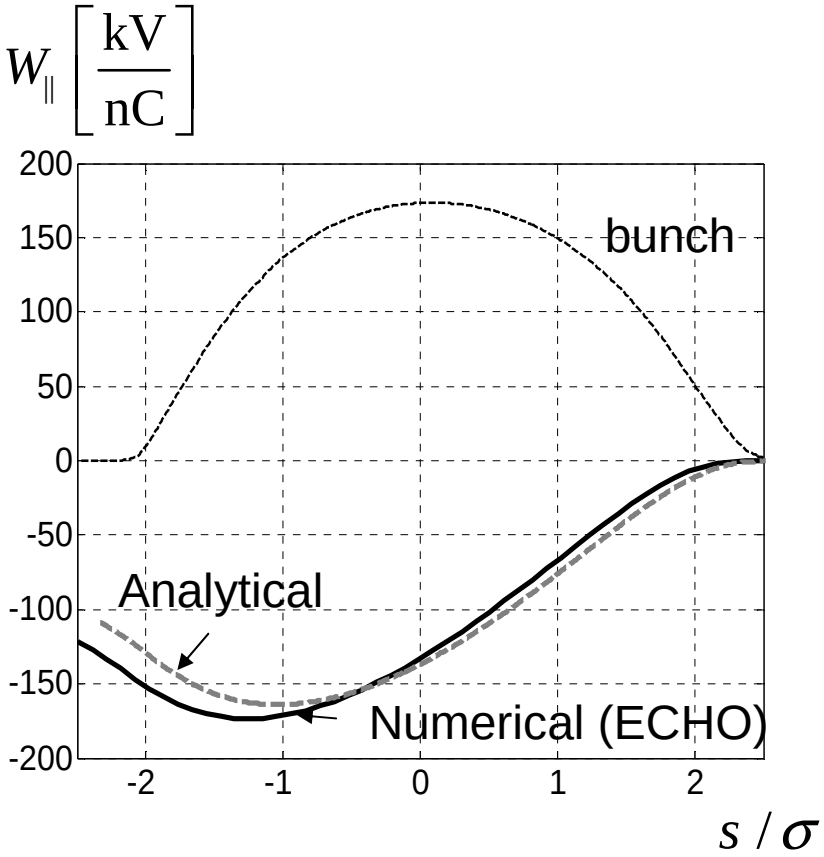




Accuracy check of the results for 1nC presented in January

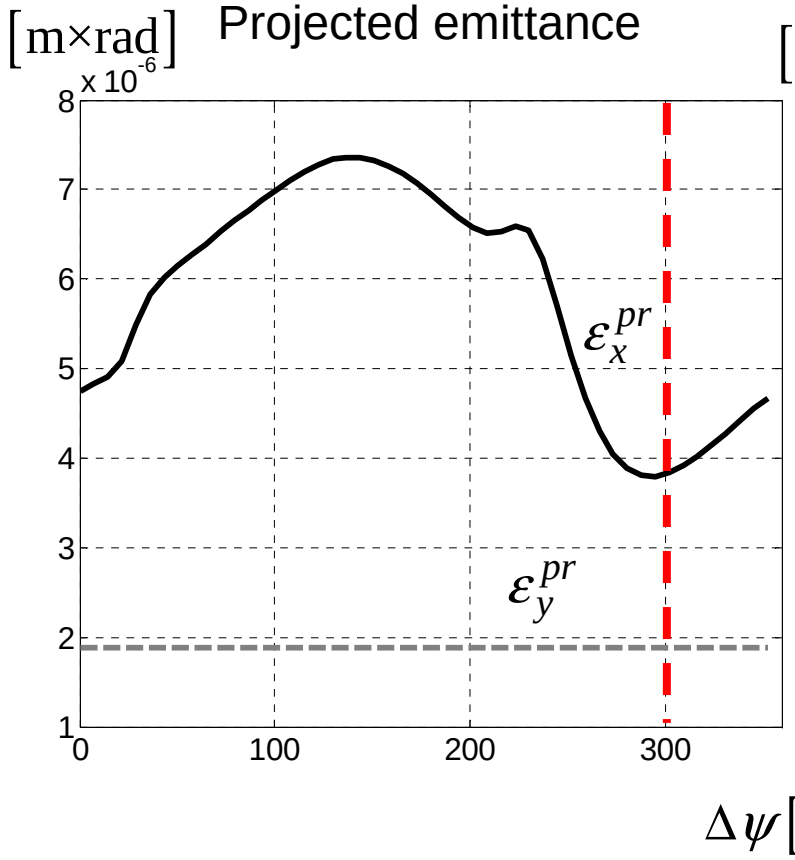
Check of the wakefield model from the gun up to BC2



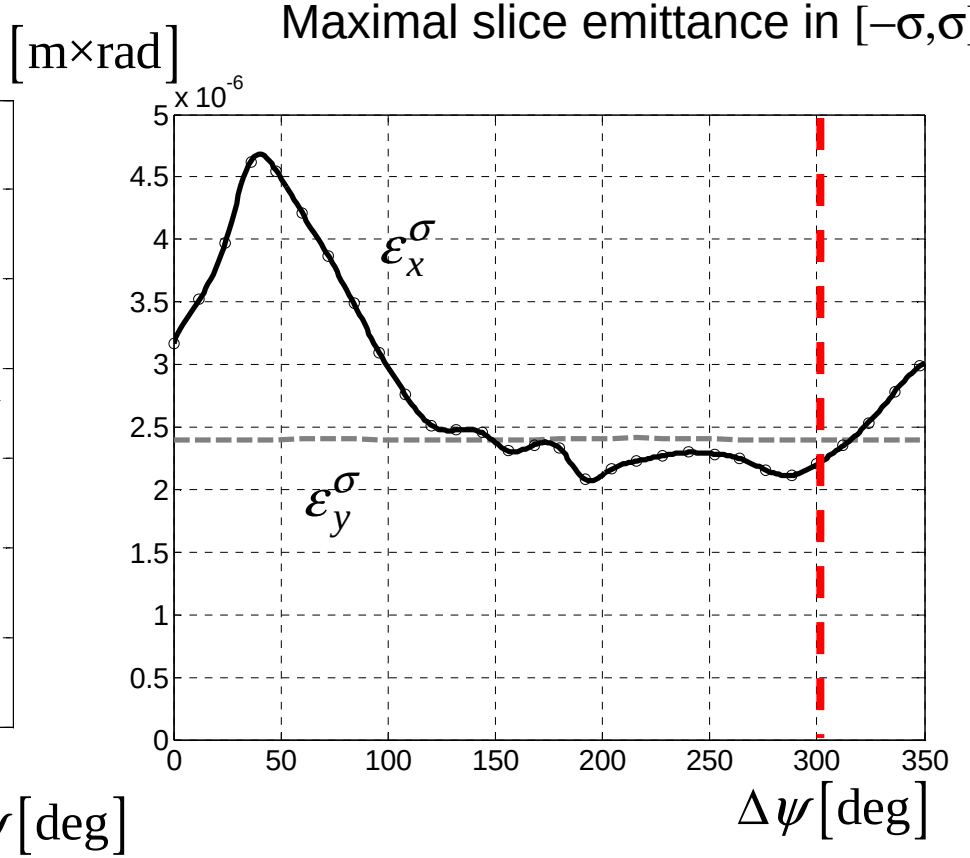


Phase shift between BCs (Q=1nC, optics V2).

Projected emittance



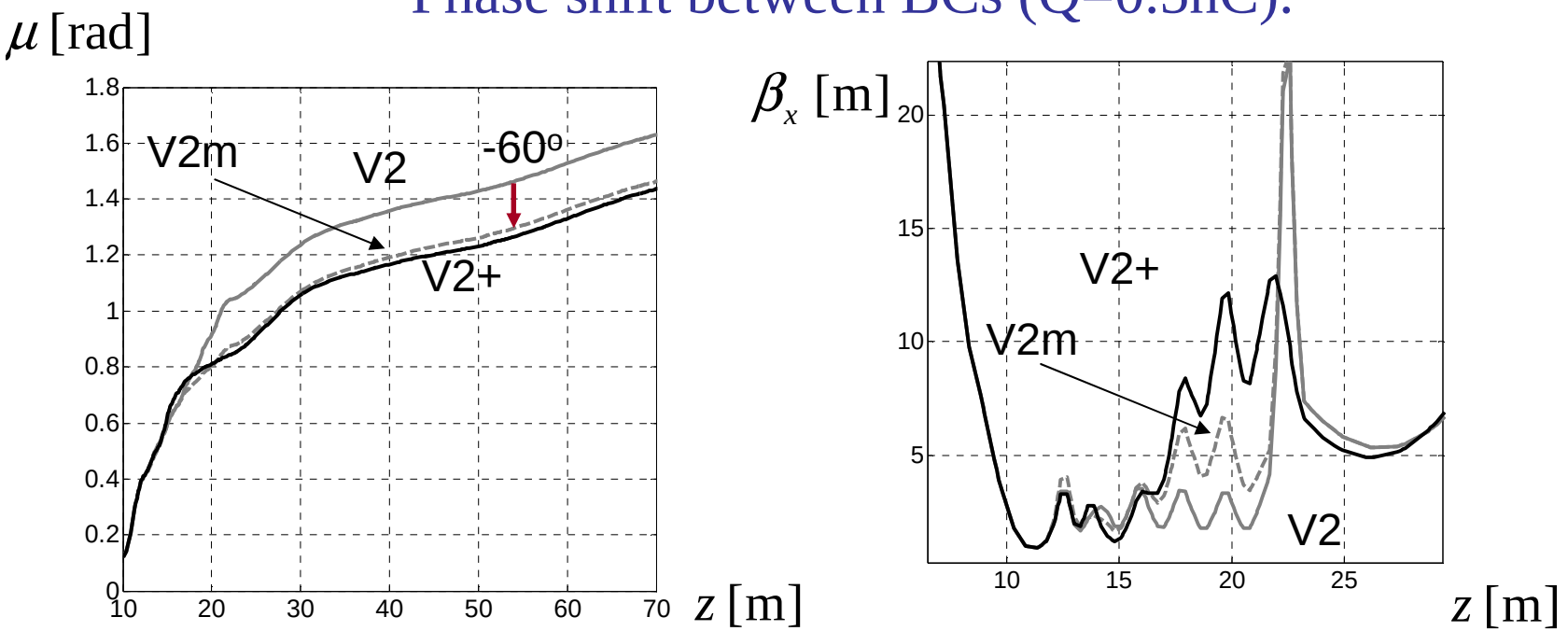
Maximal slice emittance in [–σ,σ]

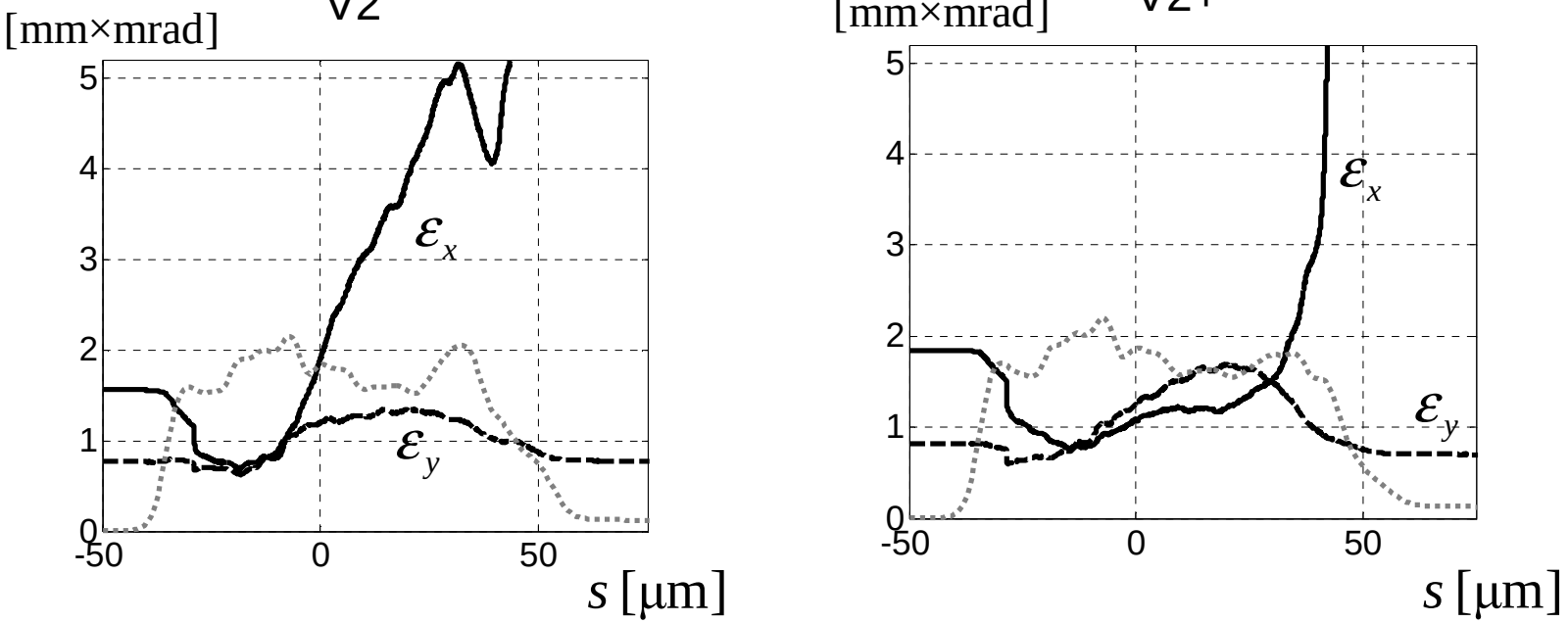


$$\Delta\psi = -60[\text{deg}] - ?$$

$$\varepsilon^{\sigma} = \max_{s\in[-\sigma,\sigma]} \varepsilon^{sl}(s)$$

Phase shift between BCs (Q=0.5nC).

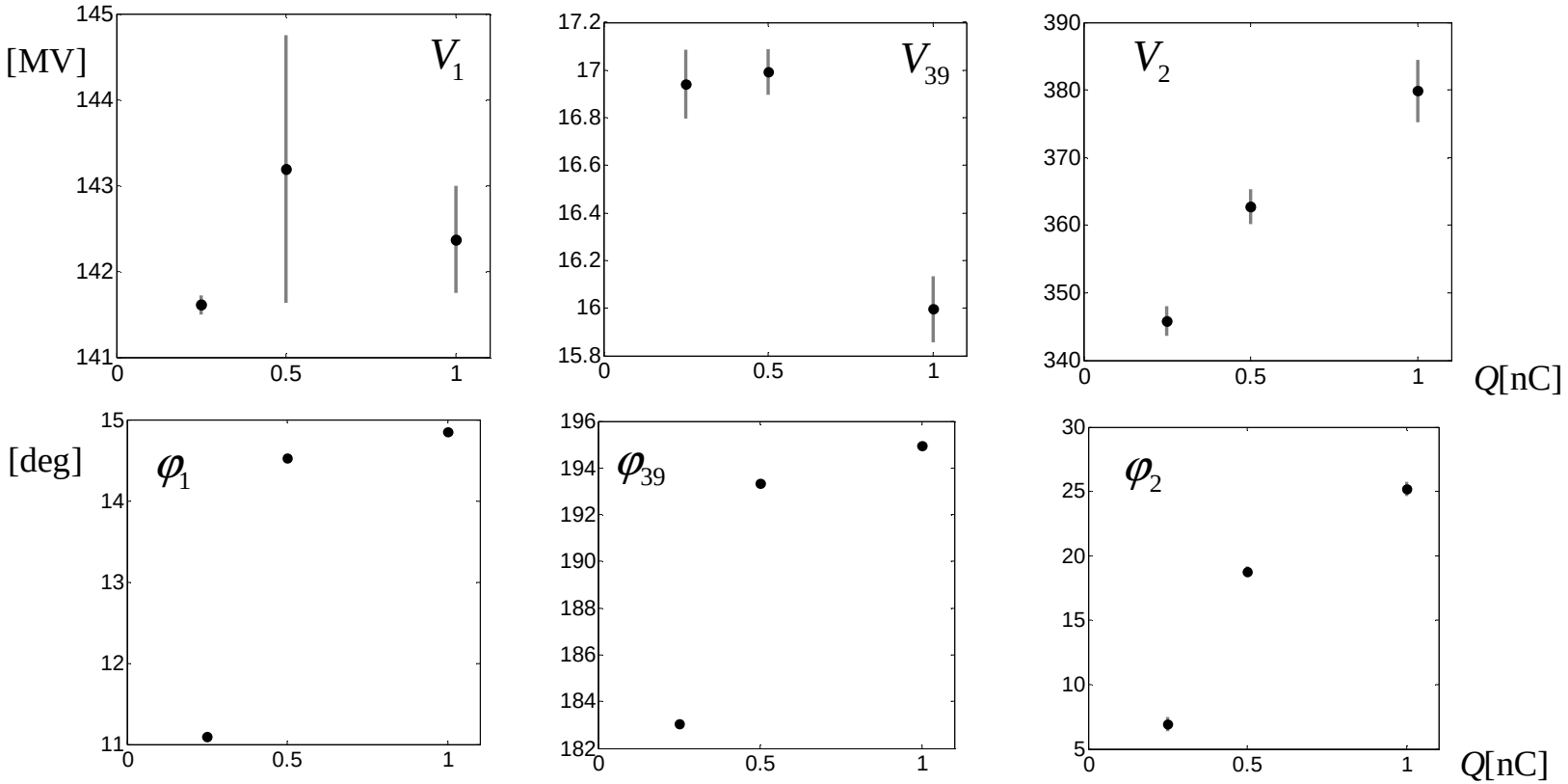




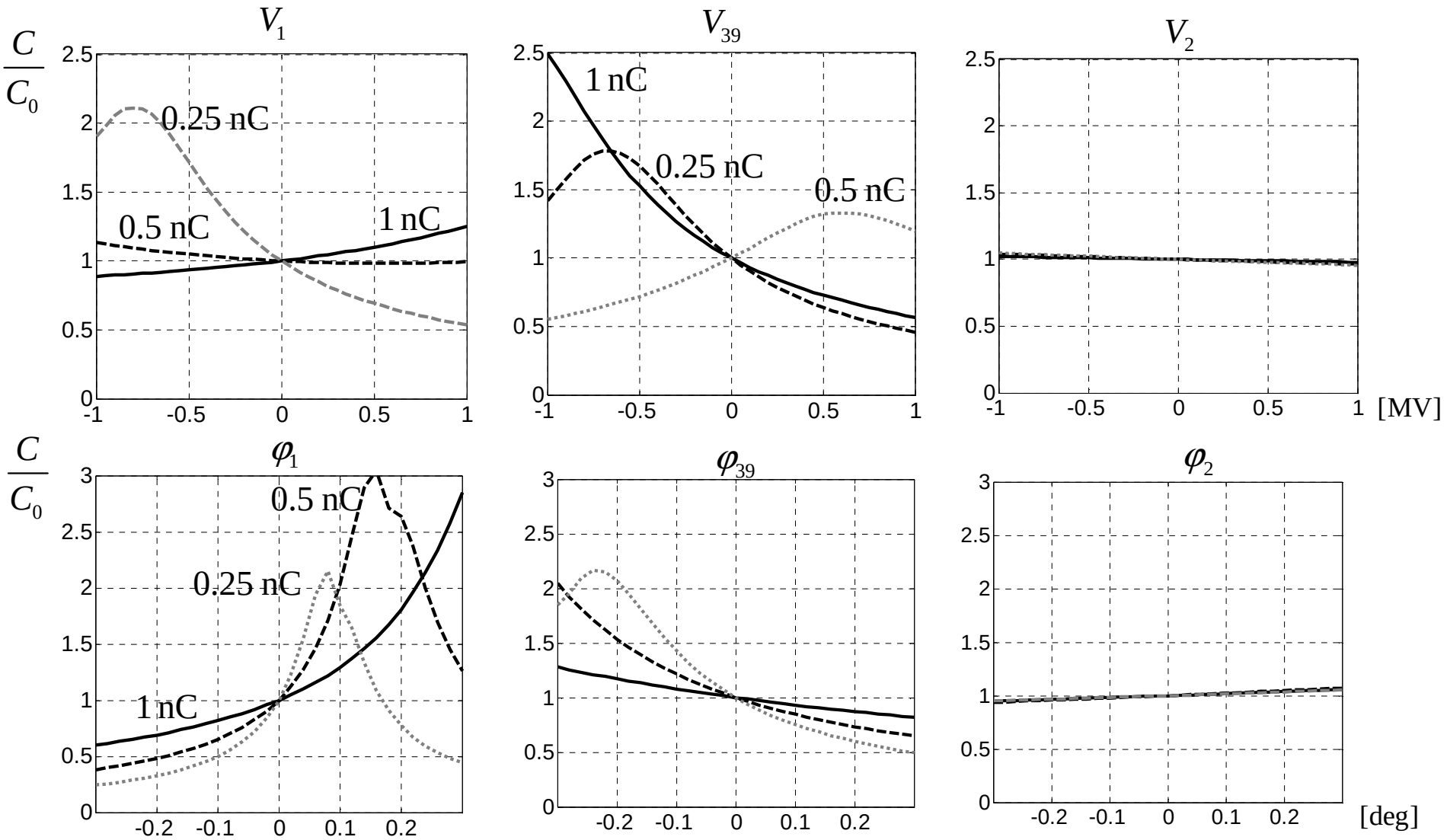
Work points (Track1D)

$$\min\left[0.25\frac{\varepsilon_s}{\varepsilon_{s0}}+\frac{2\left|I(\sigma)-I(-\sigma)\right|+3\left|I(0)-I_0\right|+\left|\max I(s)-I_0\right|}{I_0}\right],\ I_0=1809A$$

Charge, nC	V_1, [MV]	φ_1, [deg]	V_{39}, [MV]	φ_{39}, [deg]	V_2, [MV]	φ_2, [deg]	V_3, [MV]	φ_3, [deg]
1	142.372	14.848	15.996	194.963	379.867	25.198	531.845	0
0.5	143.193	14.521	16.993	193.356	362.722	18.771	531.261	0
0.25	141.611	11.098	16.9413	183.034	345.81	6.932	530.937	0



Tolerances (Track1D)

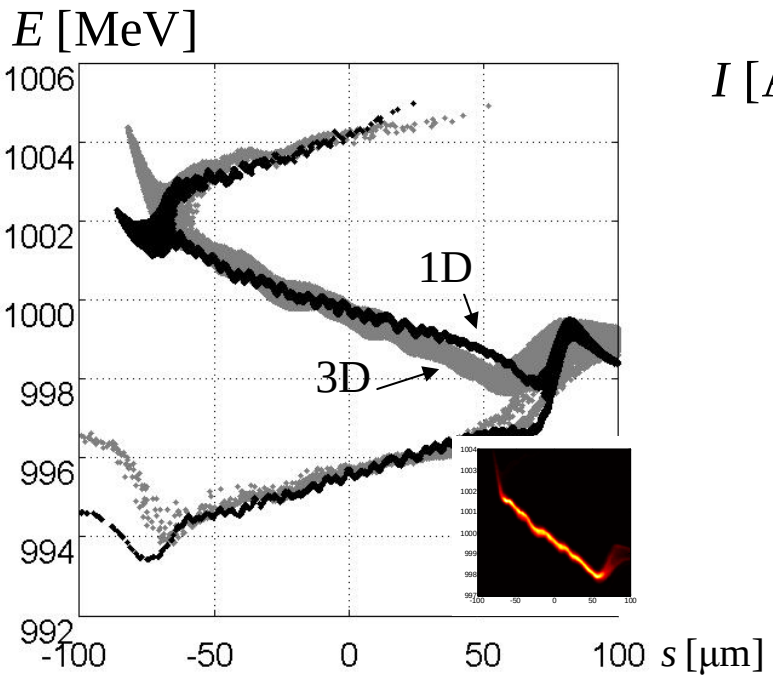


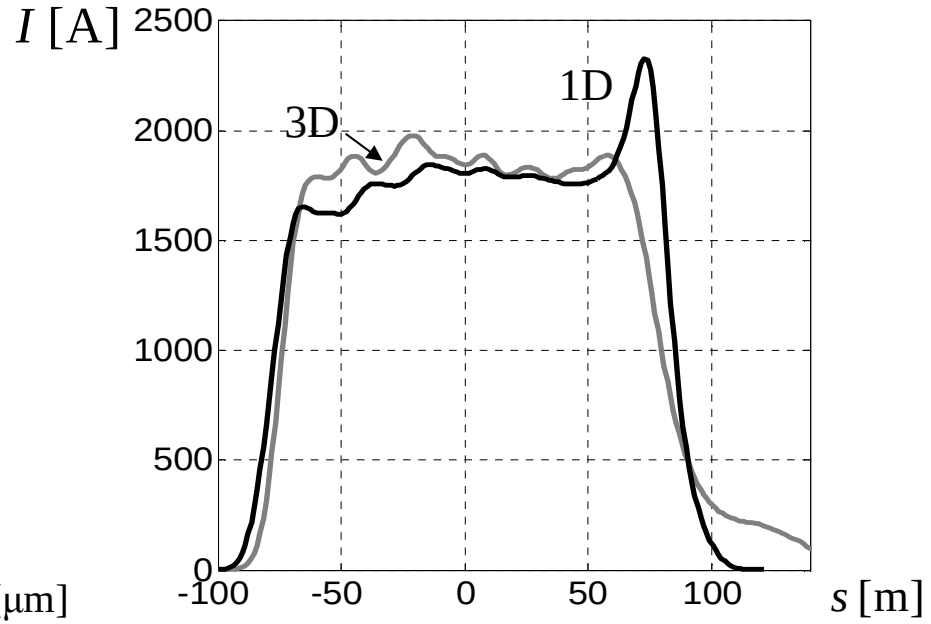
Tolerances

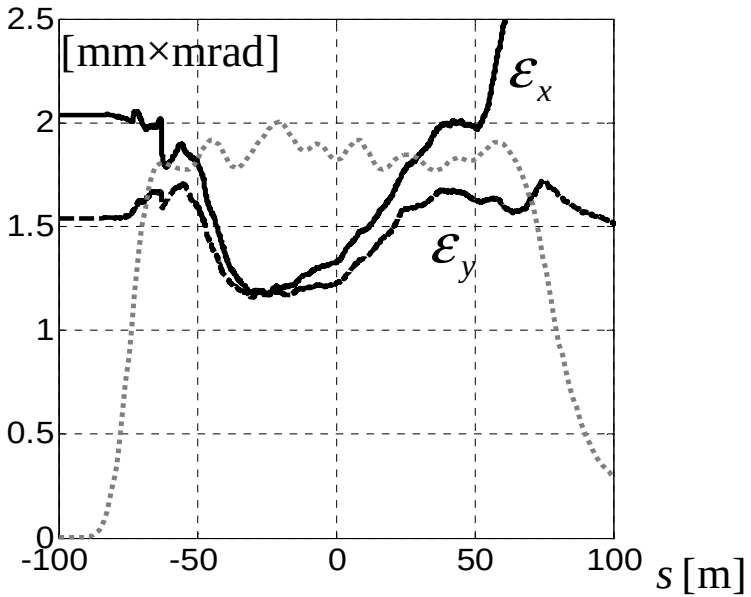
Tolerances (10 % change of compression)

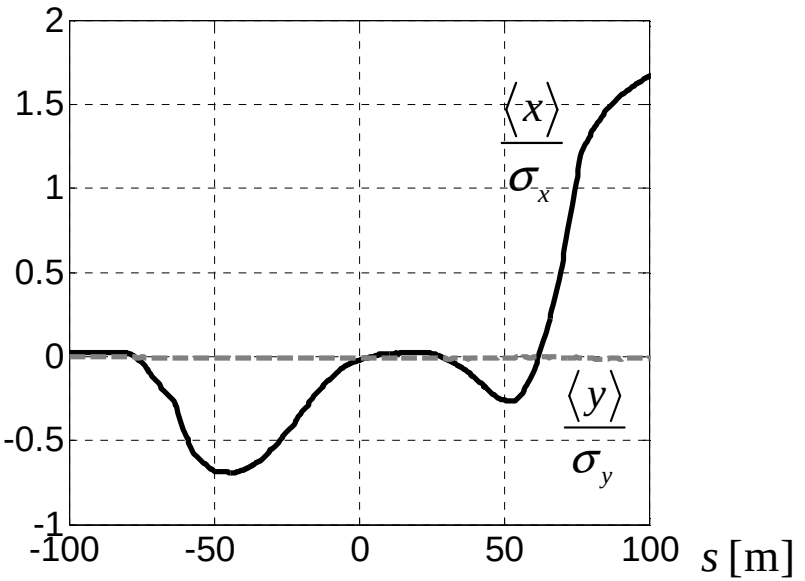
	Charge, nC	Phase, degree	V, MV
ACC1	1	0.05	0.62
	0.5	0.02	1.56
	0.25	**0.01**	0.11
ACC39	1	0.14	0.14
	0.5	0.06	**0.10**
	0.25	0.03	0.14
ACC2	1	0.56	4.6
	0.5	0.44	2.6
	0.25	0.58	2.2

Q=1nC (S2E)

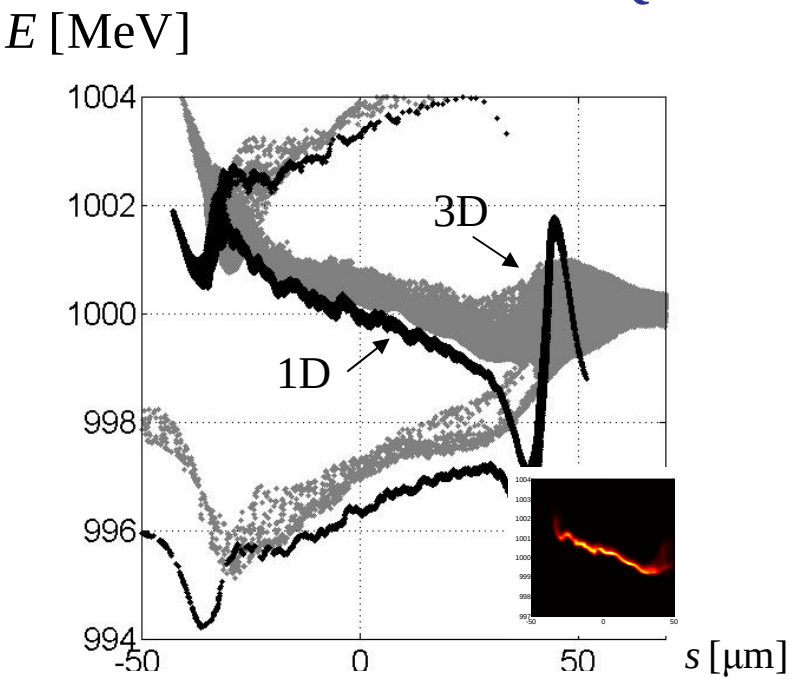

E [MeV]
1006
1004
1002
1000
998
996
994
992
1D
3D
-100
-50
0
50
100
s [μm]

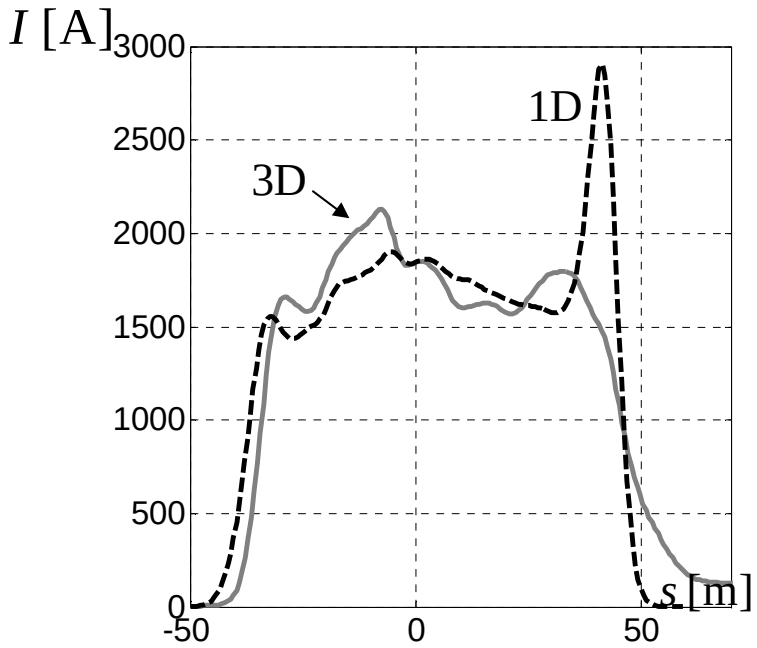

I [A]
2500
2000
1500
1000
500
0
1D
3D
-100
-50
0
50
100
s [m]

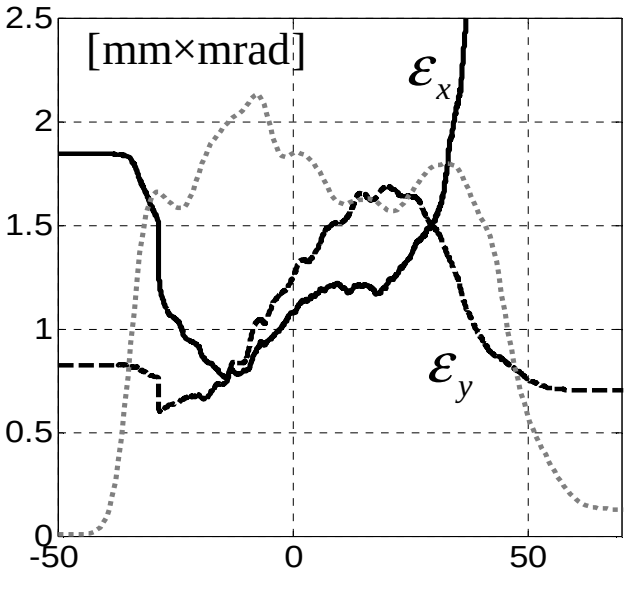

2.5
[mm×mrad]
2
1.5
1
0.5
0
ε_x
ε_y
-100
-50
0
50
100
s [m]

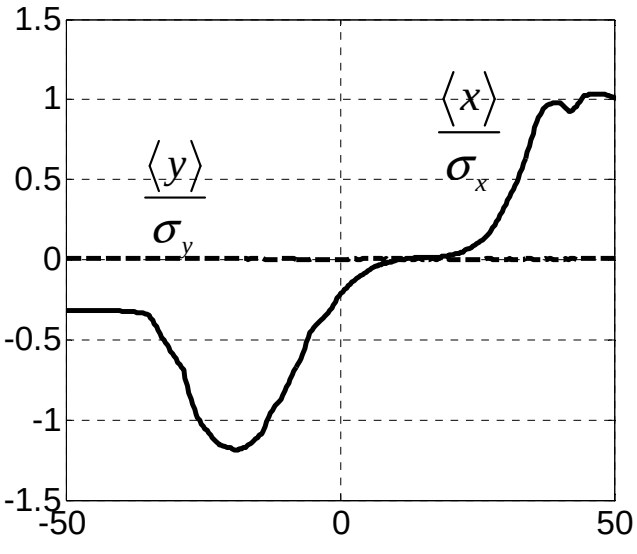

2
1.5
1
0.5
0
-0.5
-1
$\frac{\langle x \rangle}{\sigma_x}$
$\frac{\langle y \rangle}{\sigma_y}$
-100
-50
0
50
100
s [m]

Q=0.5nC (S2E)

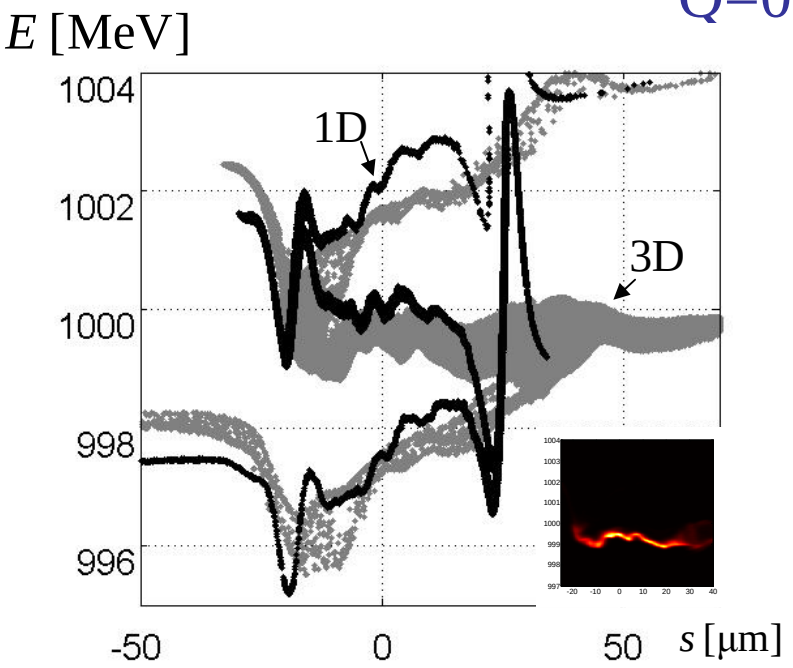

E [MeV]
1004
1002
1000
998
996
994
-50
0
50
3D
1D
s [μm]

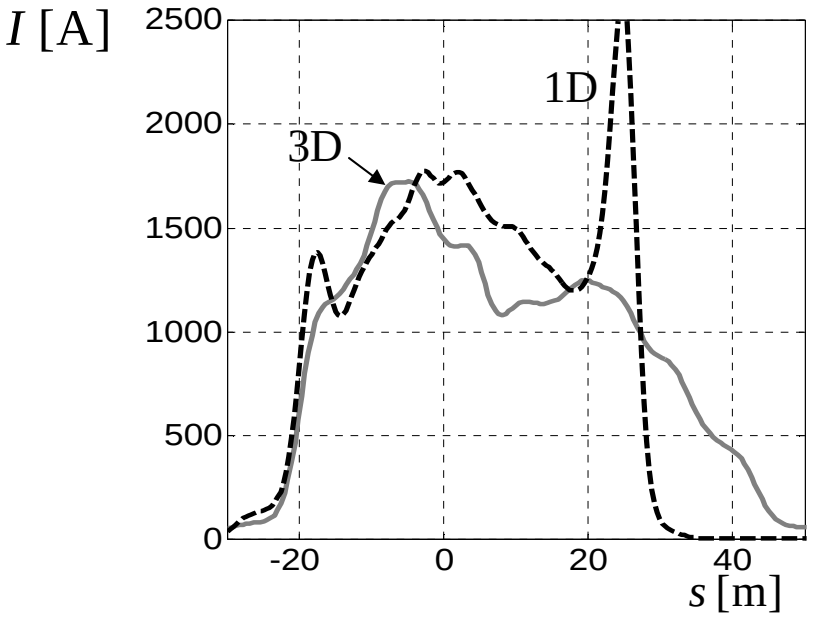

I [A]
3000
2500
2000
1500
1000
500
0
-50
0
50
1D
3D
s [m]

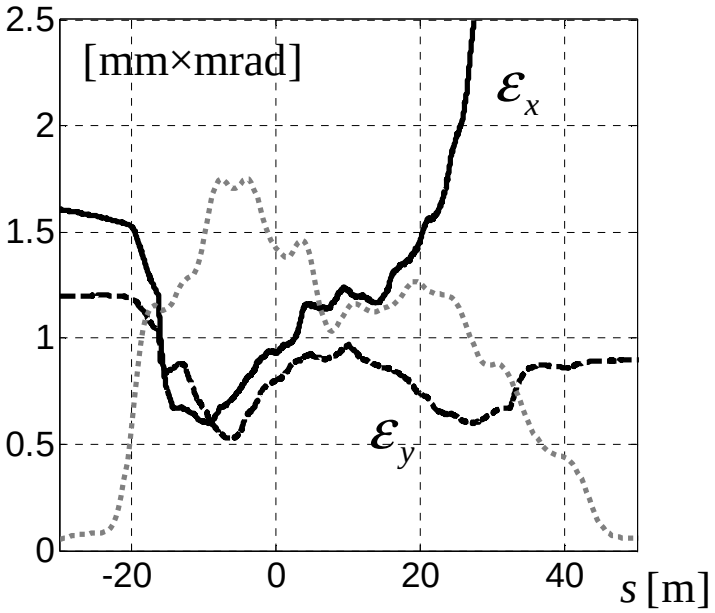

2.5
2
1.5
1
0.5
0
-50
0
50
[mm×mrad]
ε_x
ε_y
s [m]

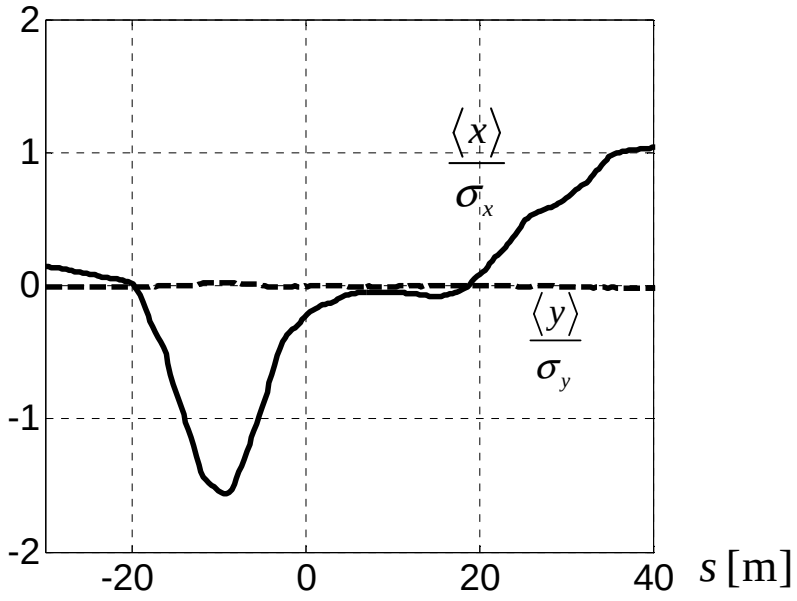

1.5
1
0.5
0
-0.5
-1
-1.5
-50
0
50
$\frac{\langle x \rangle}{\sigma_x}$
$\frac{\langle y \rangle}{\sigma_y}$
s [m]

Q=0.25nC (S2E)

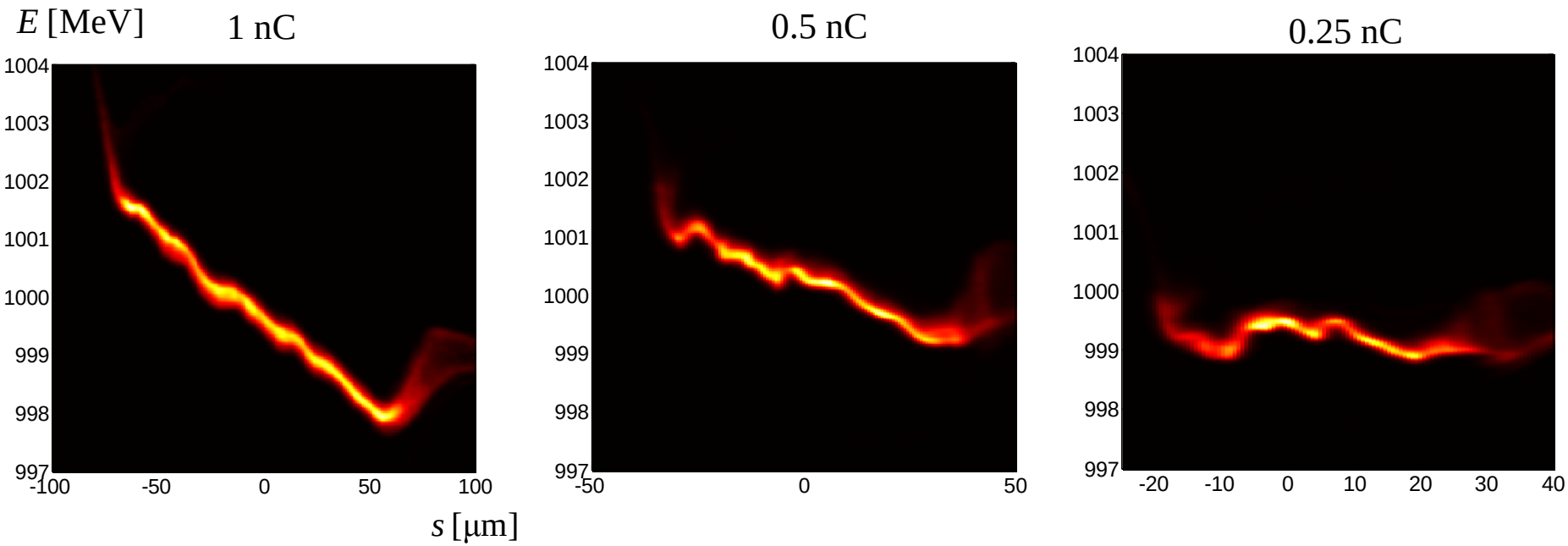

E [MeV]
1004
1002
1000
998
996
1D
3D
-50
0
50
s [μm]


I [A]
2500
2000
1500
1000
500
0
1D
3D
-20
0
20
40
s [m]

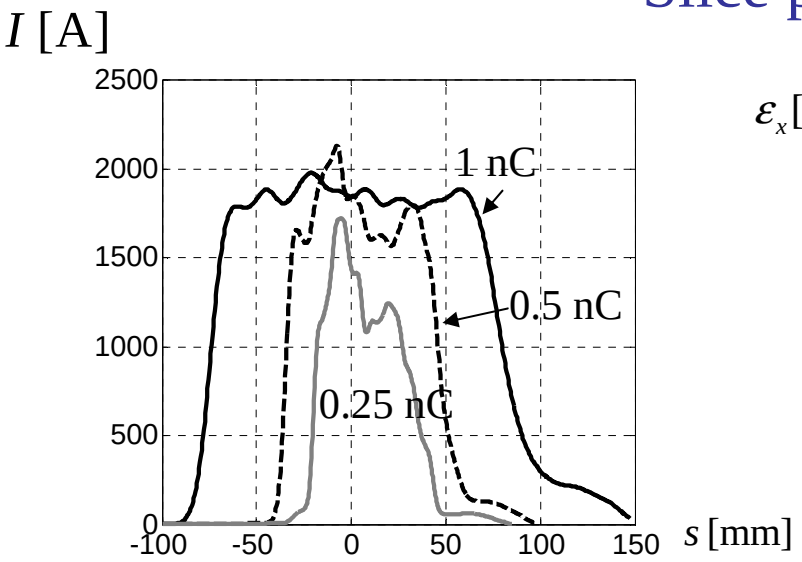

2.5
2
1.5
1
0.5
0
[mm×mrad]
ε_x
ε_y
-20
0
20
40
s [m]

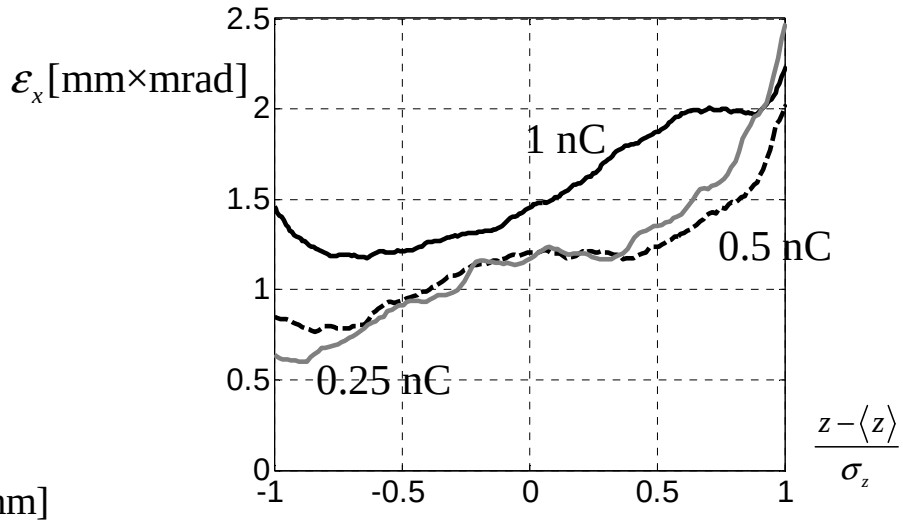

2
1
0
-1
-2
$\frac{\langle x \rangle}{\sigma_x}$
$\frac{\langle y \rangle}{\sigma_y}$
-20
0
20
40
s [m]

Density function $\rho(s, E)$

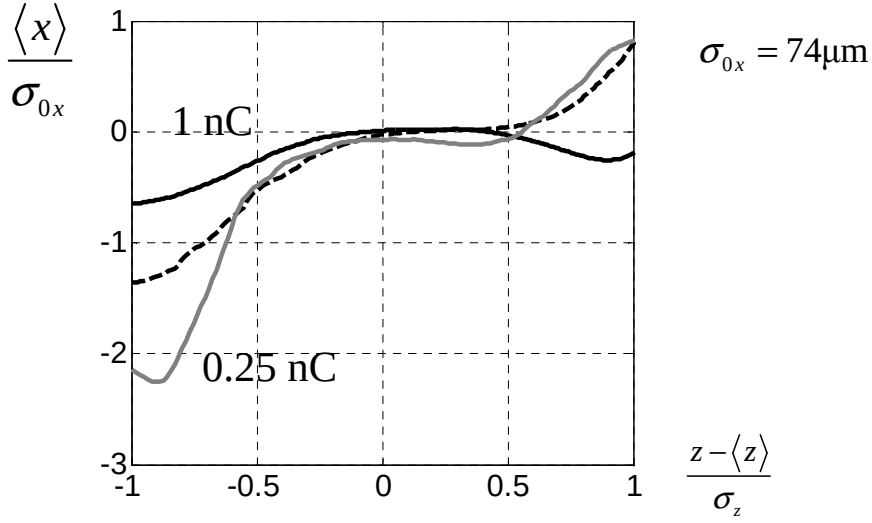


Slice parameters





Q,nC	1	0.5	0.25
FWHM, mkm	154	79	49
σ_z, mkm	49	26	19
σ_x, mkm	74	85	107
σ_y, mkm	65	75	61



$\sigma_{0x} = 74\mu m$

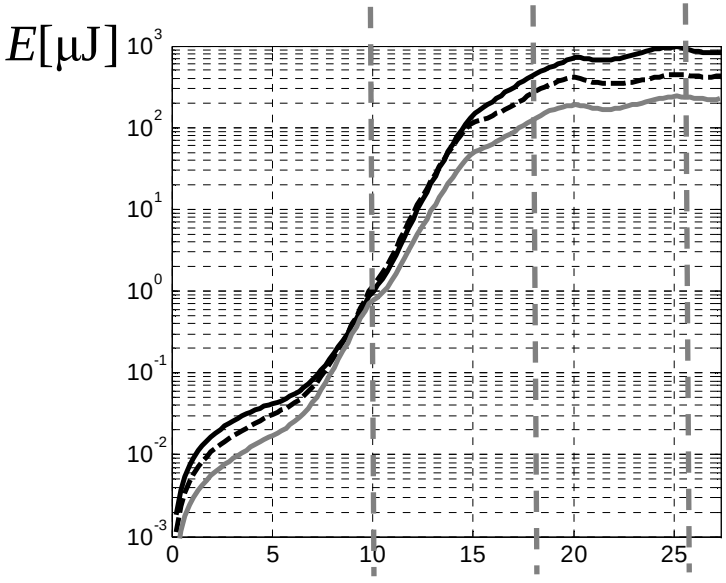
Slice parameters extracted from S2E simulations

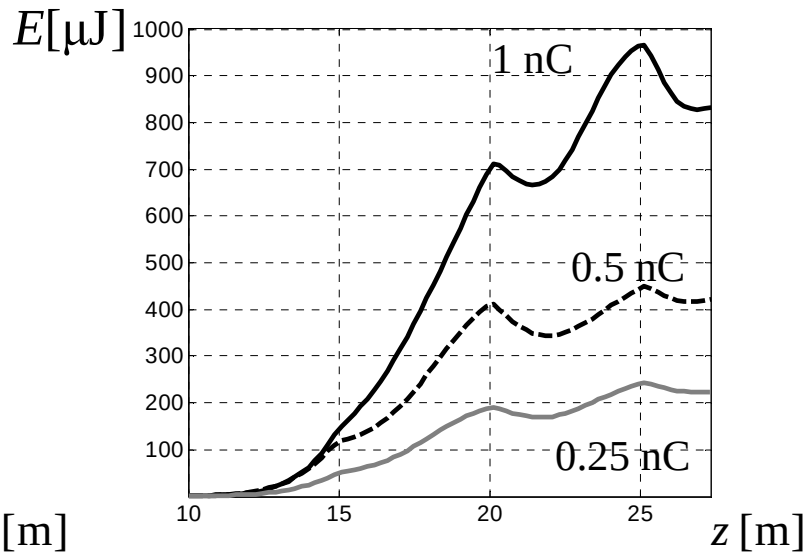
$$\gamma \quad \Delta\gamma \quad \varepsilon_x \quad \varepsilon_y \quad \beta_x \quad \beta_y \quad \langle x\rangle \quad \langle y\rangle \quad \langle x'\rangle \quad \langle y'\rangle \quad \alpha_x \quad \alpha_y \quad I$$

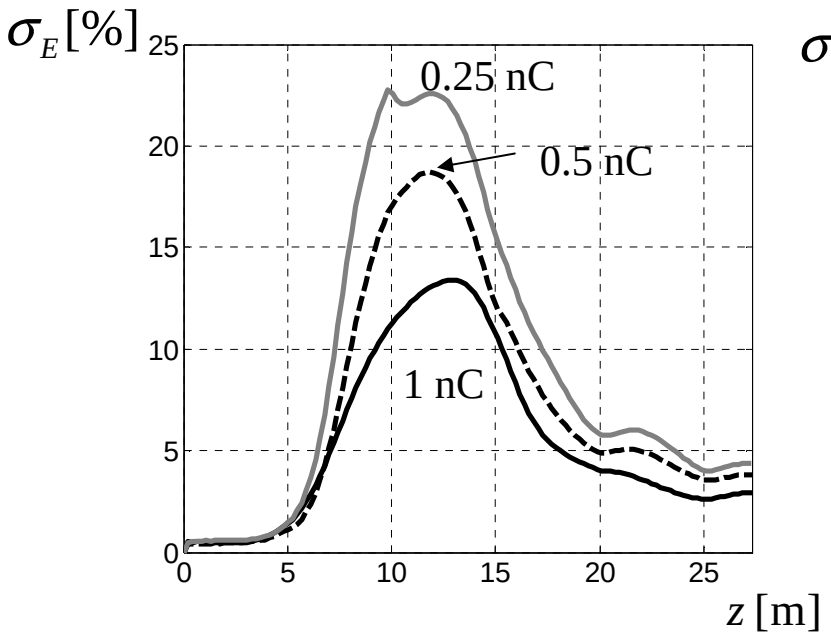
FEL code ALICE

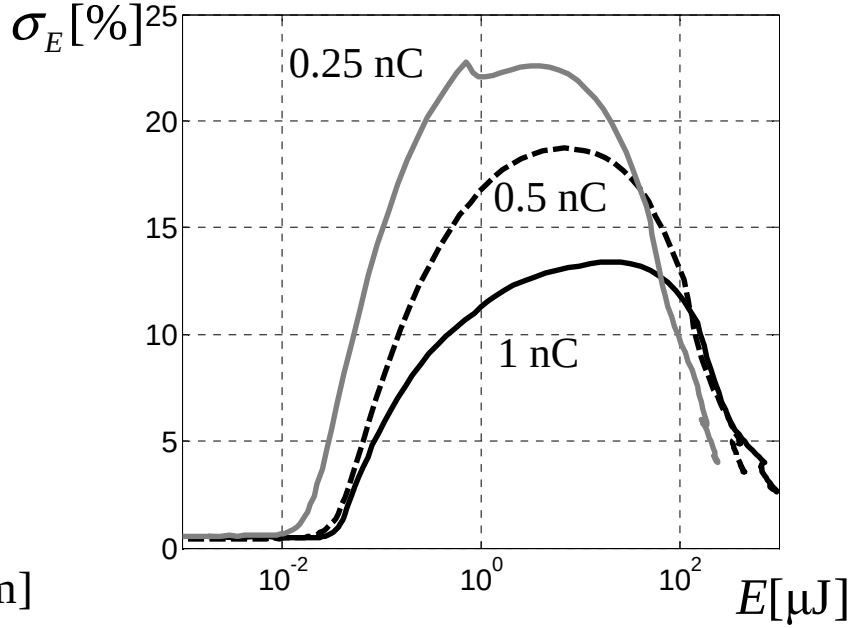
- 1D/2D/3D
- 3D azimuthal field solver (Neumann)
- Leap-Frog integrator
- **Perfectly Matched Layer**
- **transverse motion**
- simplified model
- **parallel (MPI)**
- tested on examples from the book of E.L. Saldin at al "The Physics …", and by comparison with code Genesis 2.0 of S. Reiche

Radiation energy statistics (700 runs)

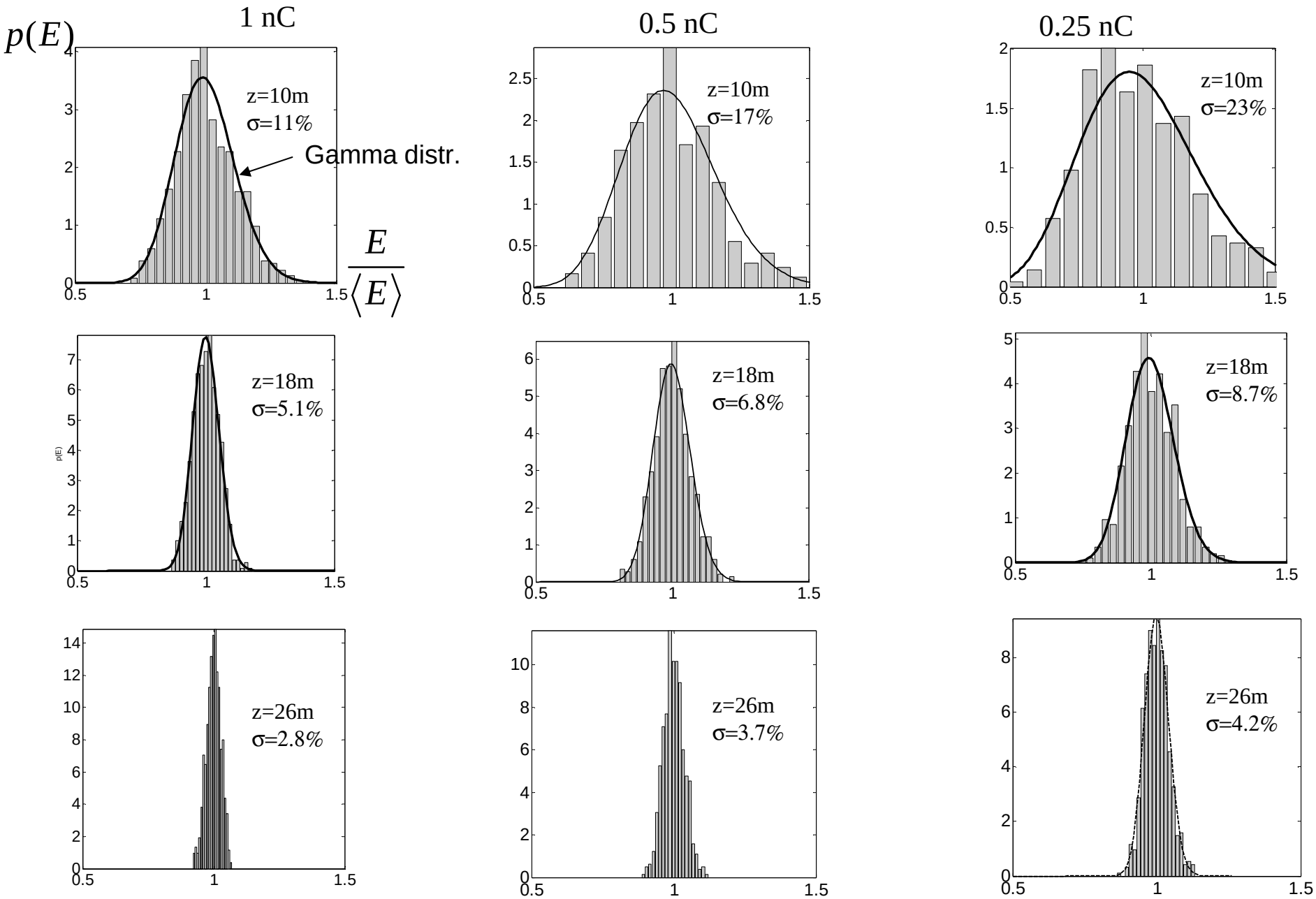




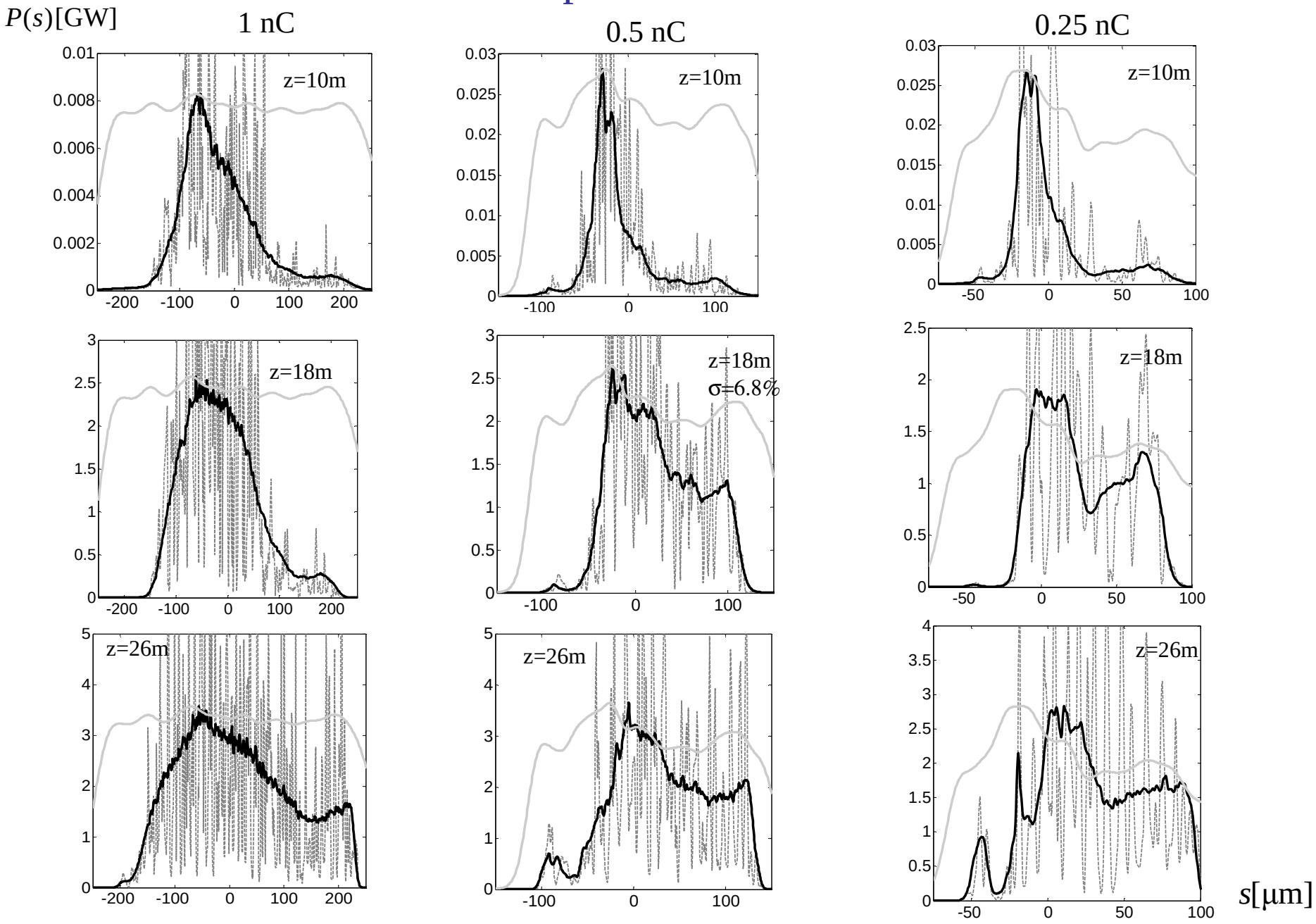




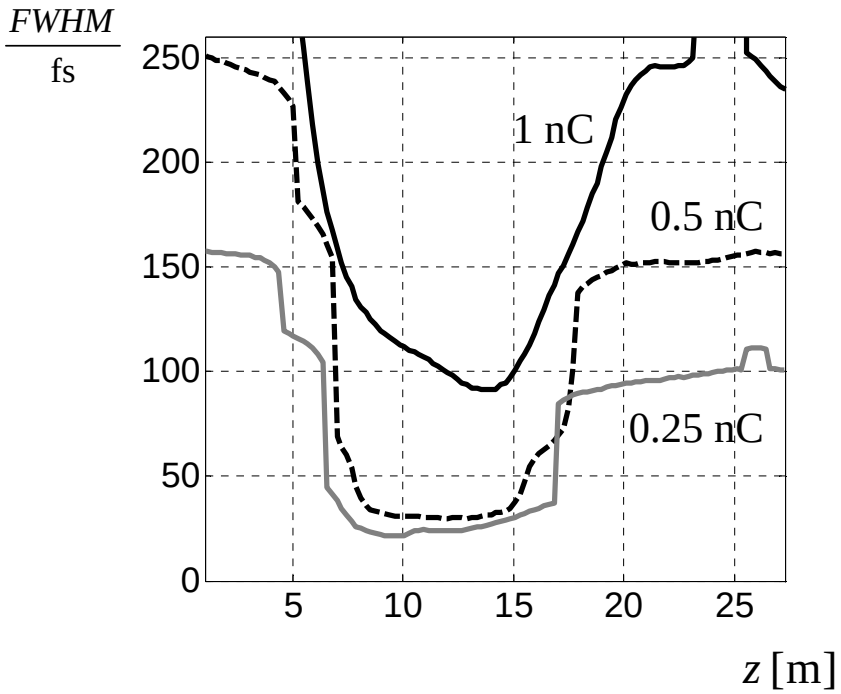
Radiation energy statistics

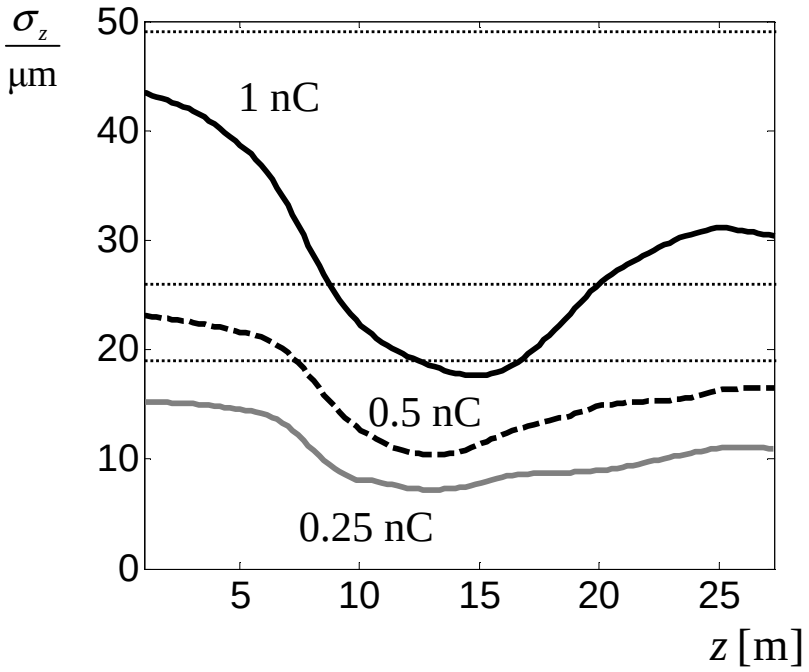


Temporal structure

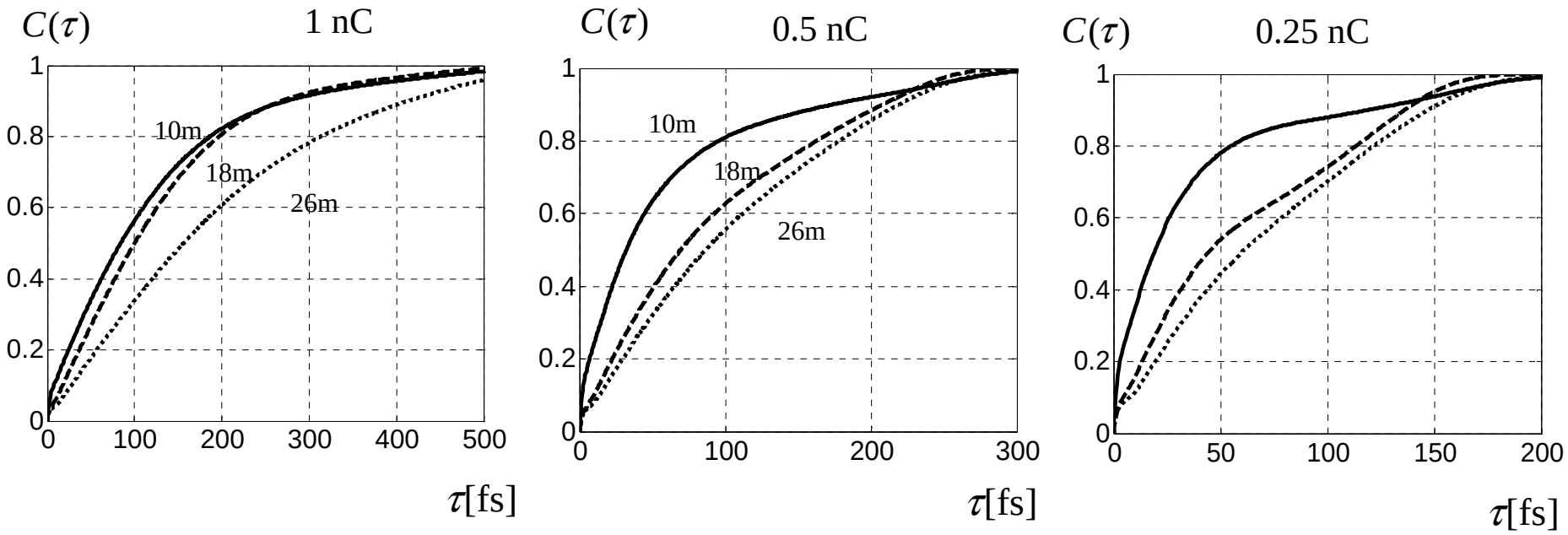


Temporal structure



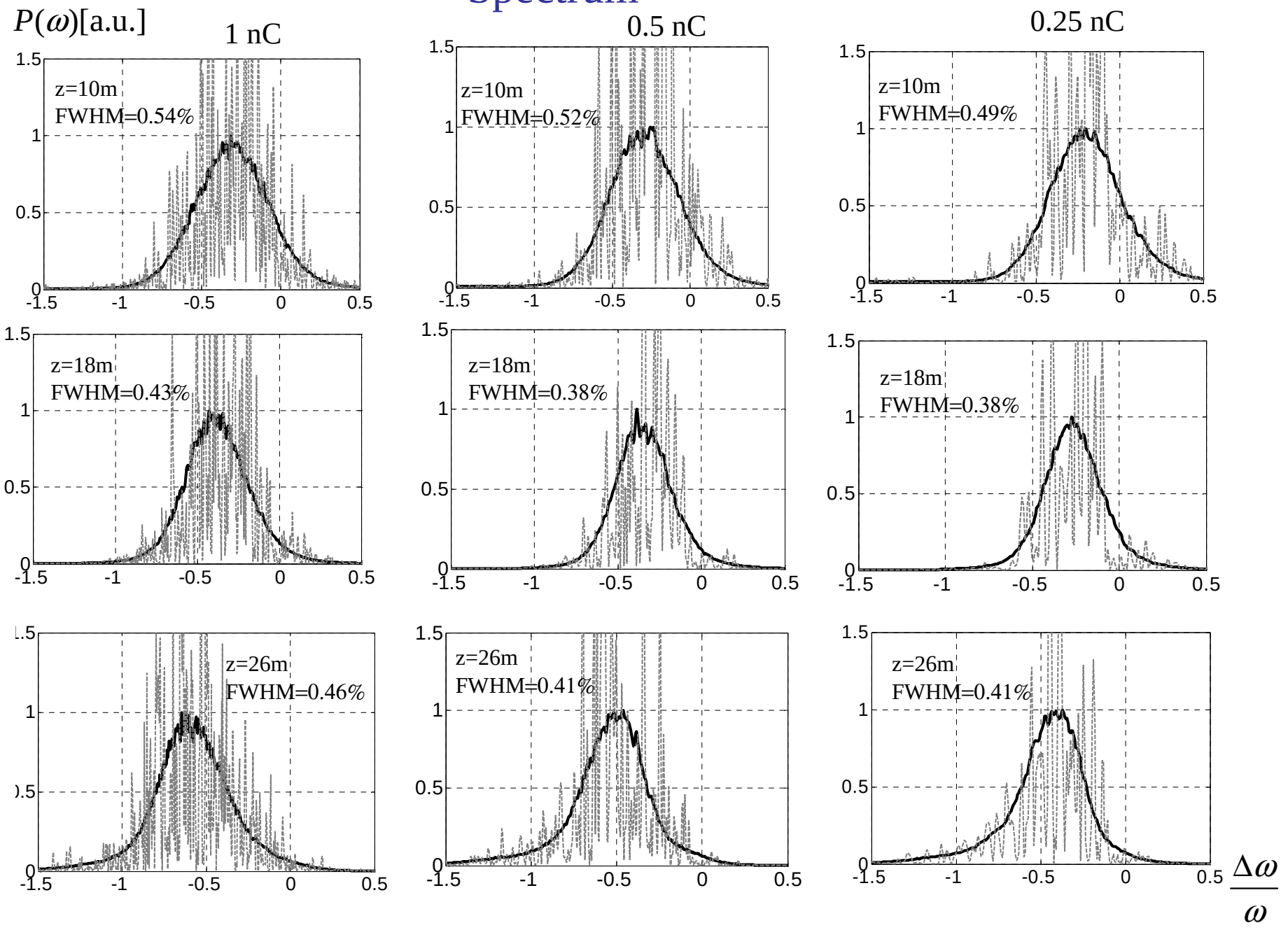


Temporal structure. Degree of contrast.

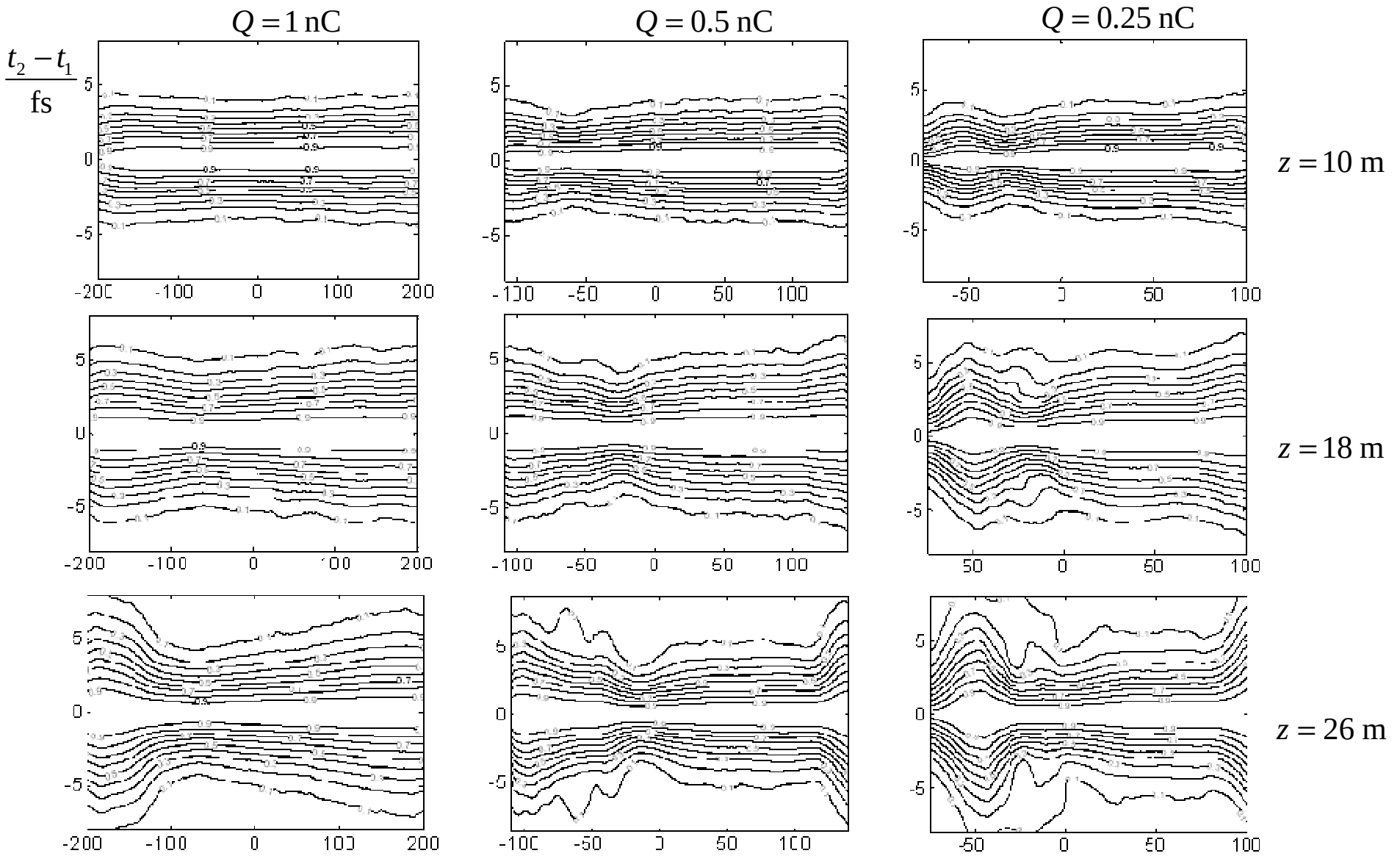


$$C(\tau) = \left\langle \int_{-0.5\tau}^{0.5\tau} P(t)dt \left(\int_{-\infty}^{\infty} P(t)dt \right)^{-1} \right\rangle$$

Spectrum

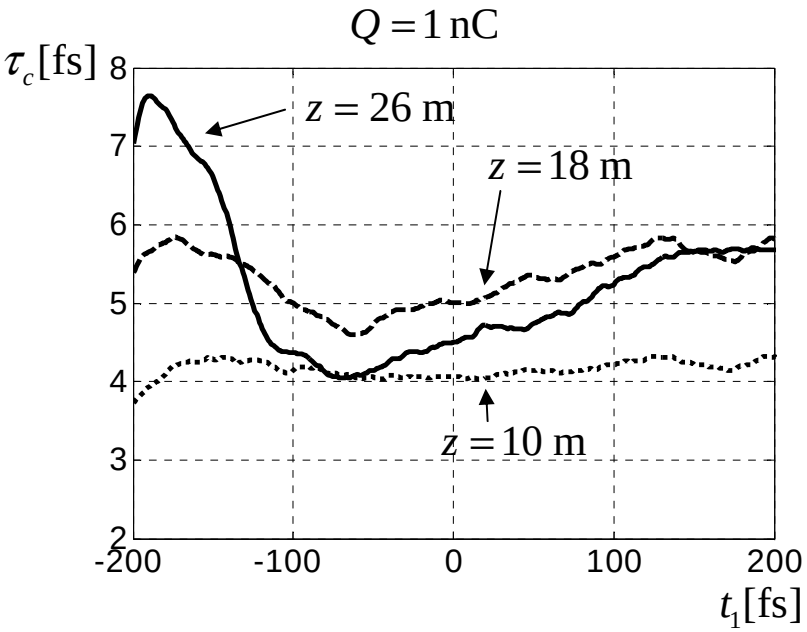

$P(\omega)$[a.u.]
1 nC
0.5 nC
0.25 nC
z=10m
FWHM=0.54%
z=10m
FWHM=0.52%
z=10m
FWHM=0.49%
z=18m
FWHM=0.43%
z=18m
FWHM=0.38%
z=18m
FWHM=0.38%
z=26m
FWHM=0.46%
z=26m
FWHM=0.41%
z=26m
FWHM=0.41%
$\frac{\Delta\omega}{\omega}$

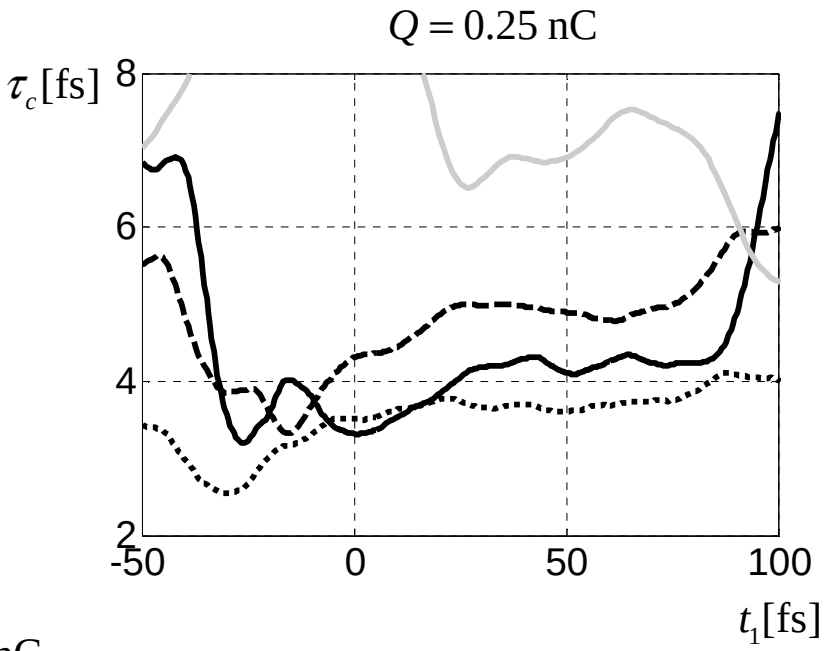
First order correlation $\left|g_1(t_1, t_2 - t_1)\right|$

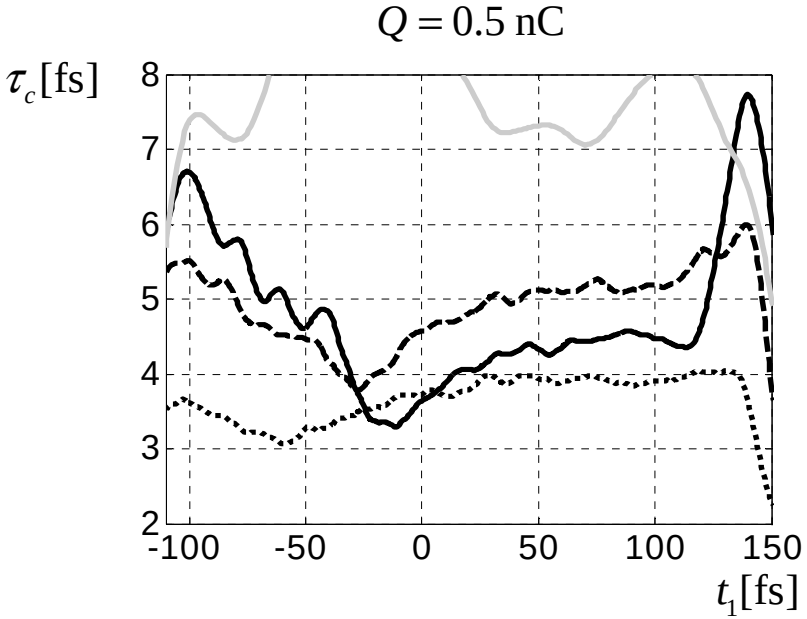


$$g_1(t_1, t_2) = \frac{\left\langle \tilde{E}(t_1)\tilde{E}^*(t_2) \right\rangle}{\sigma_E(t_1)\sigma_E(t_2)}$$

Coherence time $\tau_c(t) = \int |g_1(t,t')|^2 \, dt'$







Summary

	with harmonic module			without*
Bunch charge, nC	1	0.5	0.25	0.5-1
Wavelength, nm	6.5			6
Beam energy, MeV	1000			1000
Peak current, kA	2	2	1.7	1.3-2.2
Slice emmitance,mm-mrad	1.2-2	0.7-2	0.6-2	1.5-3.5
Saturation length, m	20			22-32
Energy in the rad. pulse, mkJ	700	400	200	50-150
Radiation pulse duration at 80% of contrast, fs	200-300	100-200	50-140	
Radiation pulse duration FWHM, fs	100-250	35-150	25-100	15-50
Averaged peak power, GW	3			2-4
Spectrum width, %	0.4-0.5			0.4-0.6
Coherence time, fs	4-5			

*) E.L.Saldin at al, Expected properties of the radiation from VUV-FEL at DESY, TESLA FEL 2004-06, 2004.

Summary

ASTRA – tracking in stright sections with SC
CSRtrack – tracking through dipoles
MAD 8 – optics matching
GlueTrackM – master script for 3D S2E
Track1D – semi-analytical tracking of long. phase space
ECHO – wake fields
ALICE – FEL process

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