The MariX FEL
Preliminary 3d simulations

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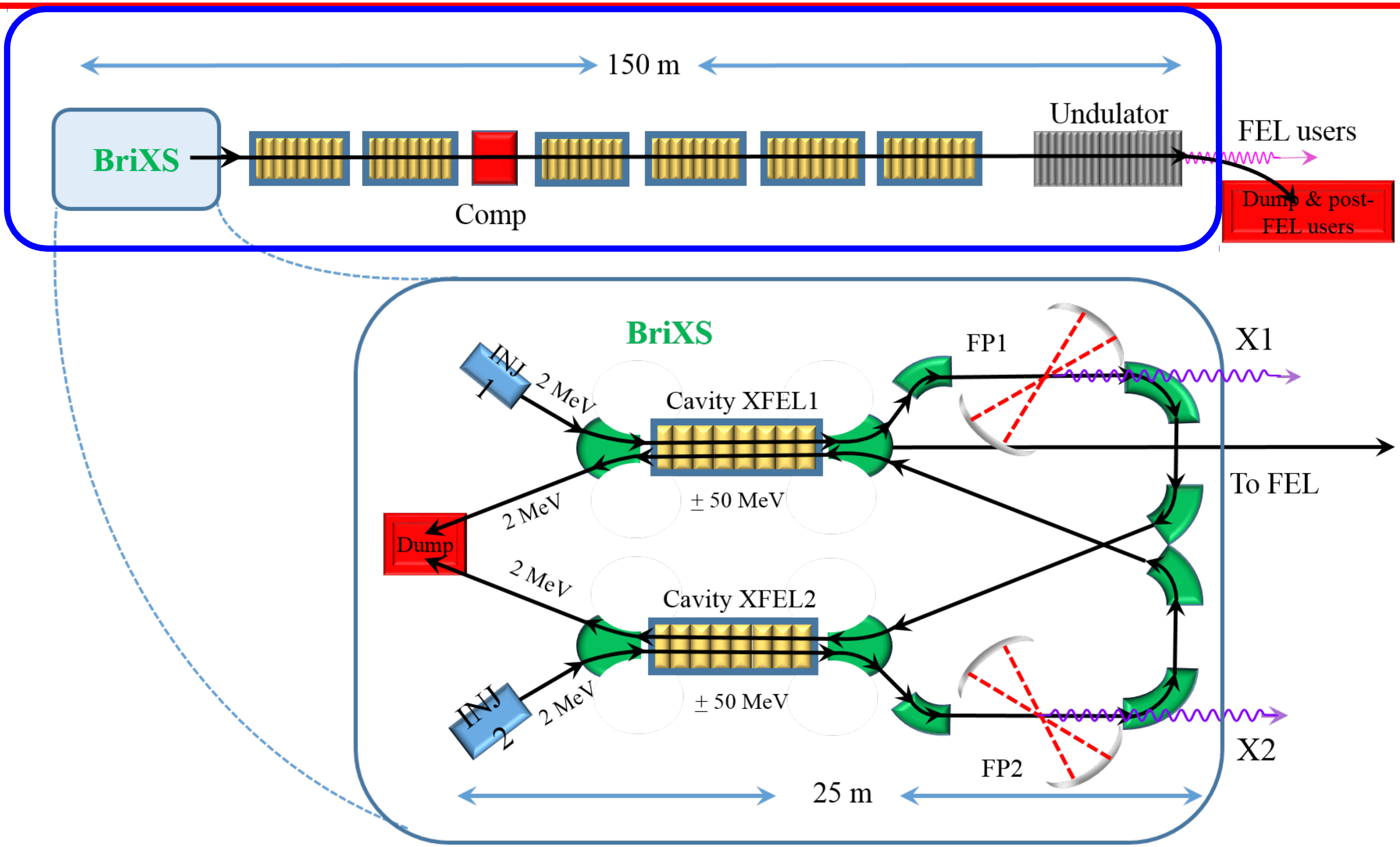
FEL scheme

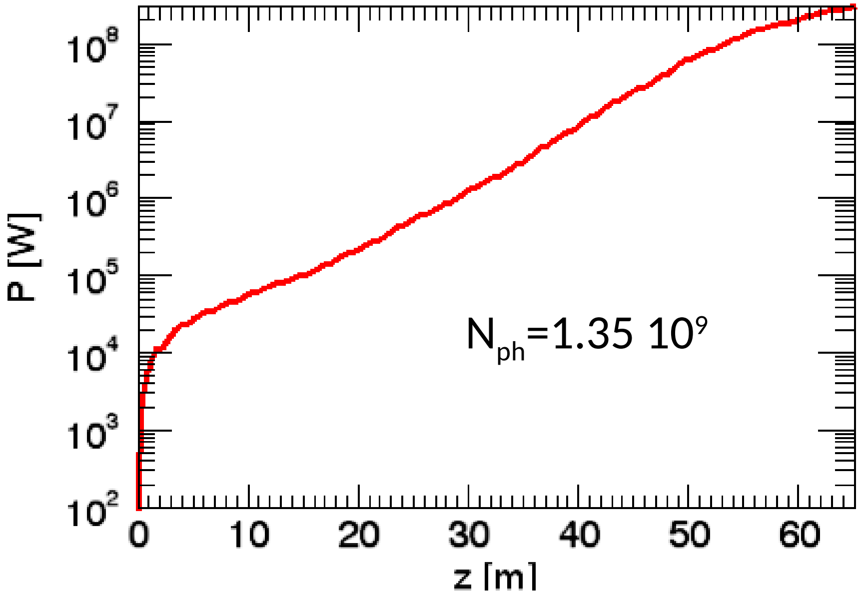

150 m
BriXS
Undulator
FEL users
Comp
Dump & post-FEL users
BriXS
INJ 1
2 MeV
Cavity XFEL1
FP1
X1
± 50 MeV
To FEL
2 MeV
Dump
2 MeV
Cavity XFEL2
INJ 2
2 MeV
± 50 MeV
X2
FP2
25 m

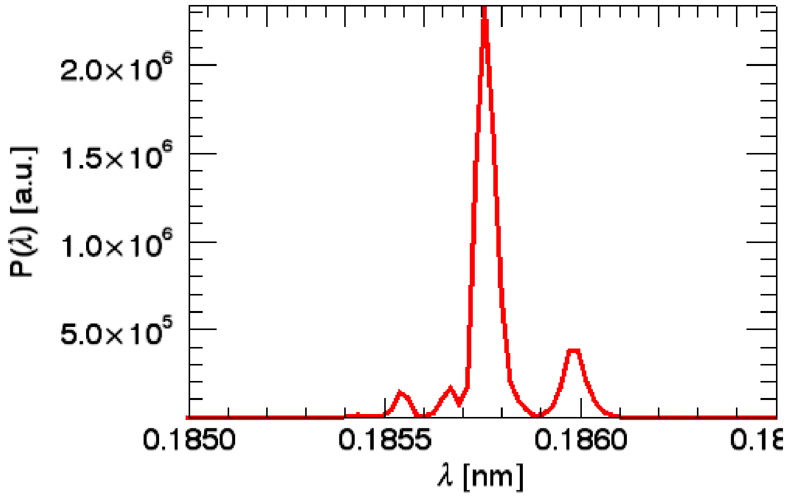
Imagine

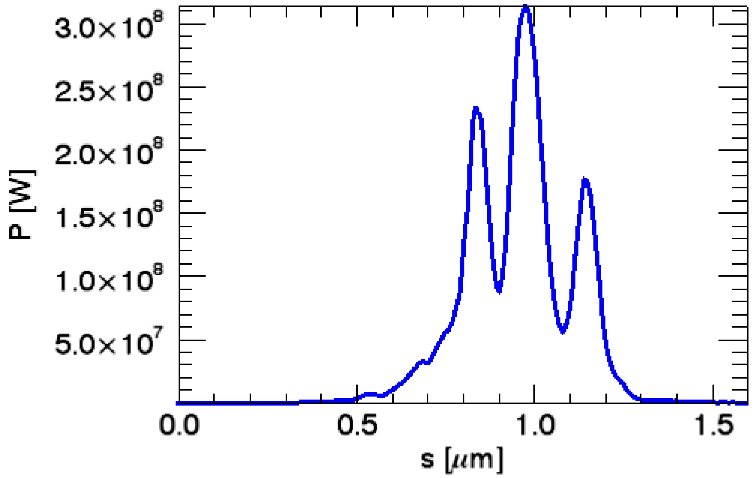
…to want to project a FEL in the Angstrom's.

What to do?

Take a linac, the longest and strongest possible, making, say, 3.5 GeV or more and an undulator, robust, already tested with, say, 1.4 cm of period, align them, put transfer line, quadrupoles, diagnostics, photon lines and try.



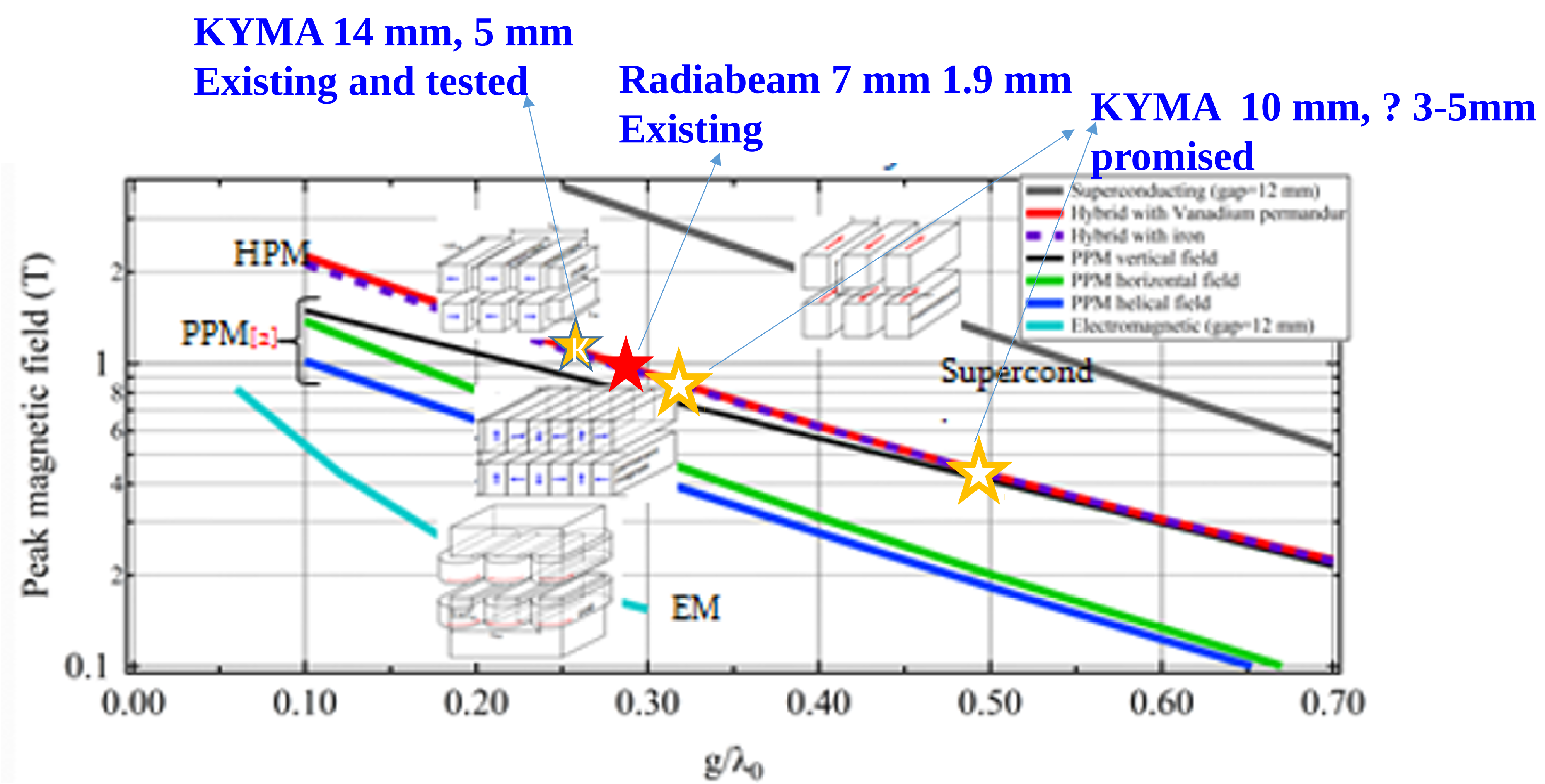




Desires and constraints (December ‘17)

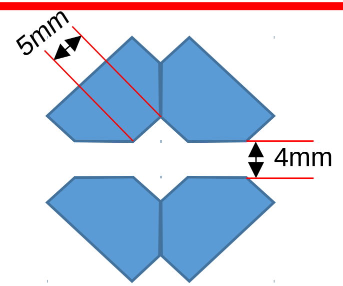
- **Value of the wavelength** (down to 2.5 Å)
- **Flux** (10^8-10^9 photons per shot)
- **Coherence** (transverse and longitudinal)
- **Final Energy of the electrons** (last evaluation: <2.4 GeV)
- **Total length of the apparatus** (?)

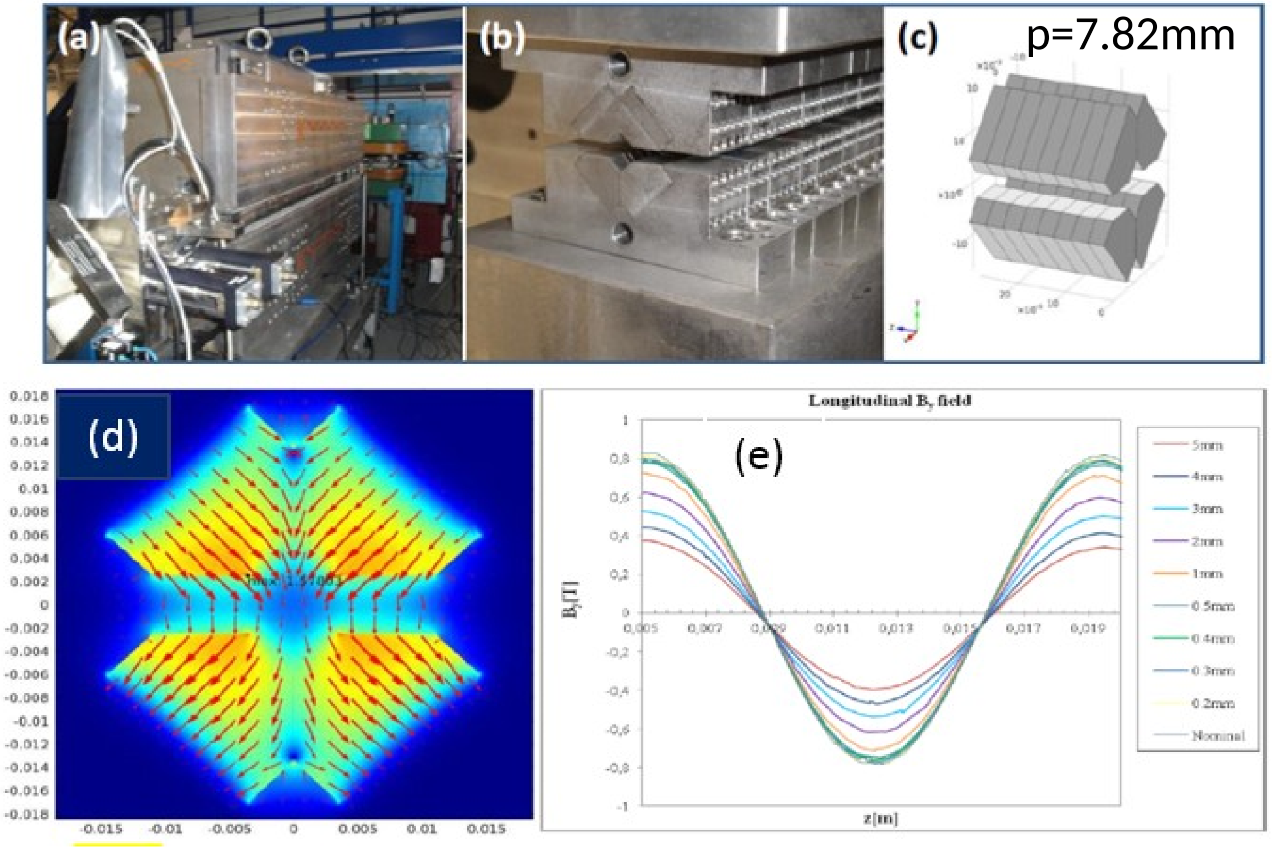
Comparing different undulator technologies

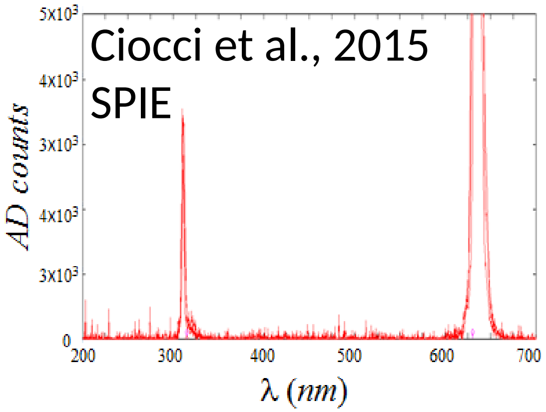


Courtesy of Pino Dattoli

Undulator KYMA, existing and tested







λ_w=14 mm

Gap=5 mm

B=1-1.1 T

a_w=0.7-0.8

Immediate Upgrade

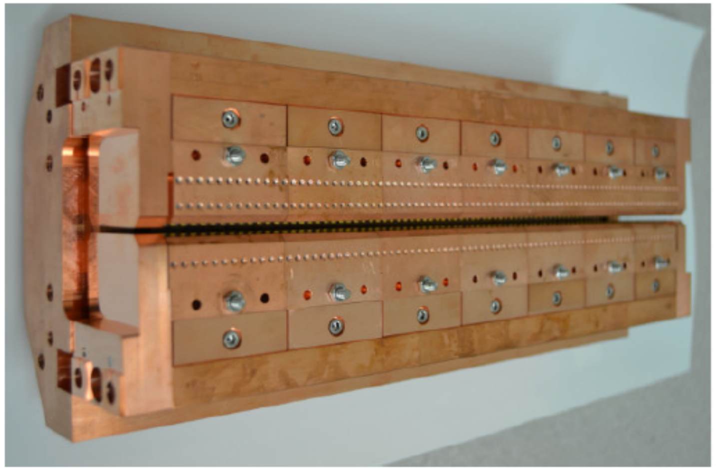
λ_w=10 mm

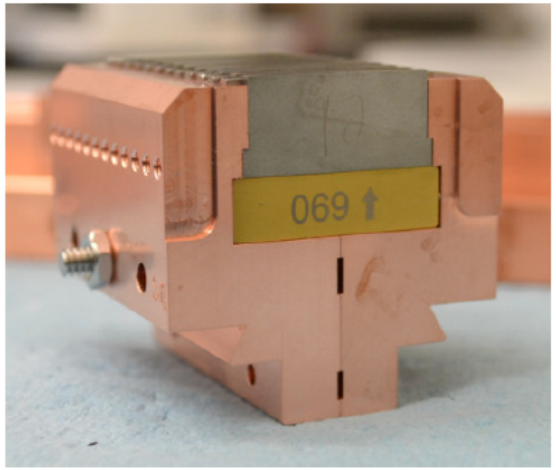
Do we want a variable gap?

We can have it!

'… la nostra determinazione di realizzare MariX non ha prezzo,…per tutto il resto c'è Mastercard'

RadiaBeam, existing and to be tested





Prototype Parameter	Value
Period length	7 mm
Field strength (room temp.)	1.1 T
Full gap height	1.9 mm
Undulator Parameter, K_U	0.72
Number of periods, N_u	42
Magnet material	PrFeB
Pole material	Vanadium Permendur

Where could we test it? At SPARC! M.F. and P.D. agree.

What can we do with E<2.4GeV ? Not much.

Period	Wavelength	Gap	B peak	aw	gamma	E-Energy	?
14 mm	5 A	5 mm	0.76 T	0.7	4567	2.33 GeV	OK
		3 mm	1.1 T	1.011	5320	2.72 GeV	NO
	2.5 A	5 mm		0.7	6459	3.3 GeV	NO
		3 mm	1.1 T	1.011	7527	3.85 GeV	NO

Working points at 5 Å

Period	Wavelength	aw	gamma	rho3d (10^{-3})	L_{gain} (m)
14 mm	5 A	0.7	4567	0.62572	1.0280
10 mm	5 A	0.2628	3269	0.23584	1.9481
		0.5913	3673	0.53037	0.8663
7 mm	5 A	0.5059	2964	0.4405	0.7301

The electrons (Gaussian ideal beam):

ε_x (mm mrad)	0.5	ε_y (mm mrad)	0.5	$\Delta E/E$	1-7 10^{-4}
Q (pC)	6-60	I(kA)	2.5	$\Delta\tau_{beam}$(fs)	1-10

Three-dimensional simulations

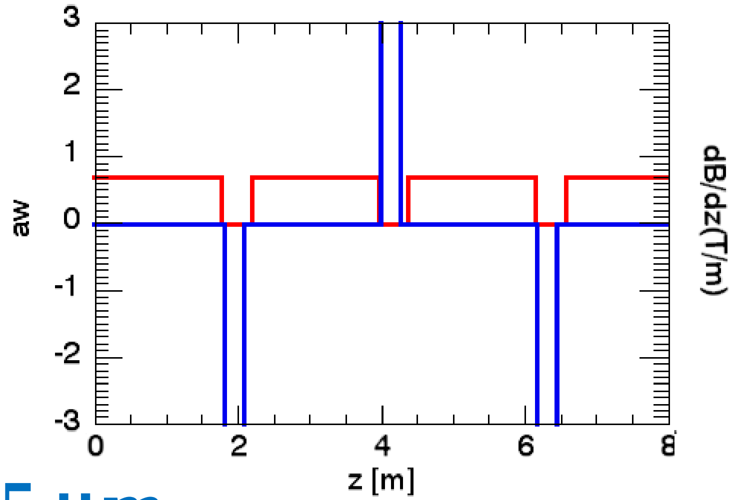
Simulations have been done with GENESIS 1.3, released by S. Reiche.

3-D FEL code in the time dependent mode, with the best possible precision options.

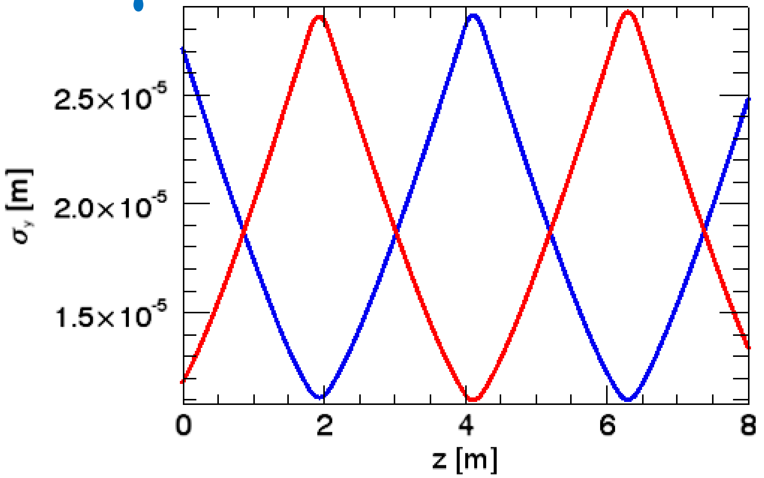
In the non-paralellized version, on my PC, each run takes 5-12 hours.

For the cascade, more than 2 days.

Undulator KYMA 14 mm+FODO, matching



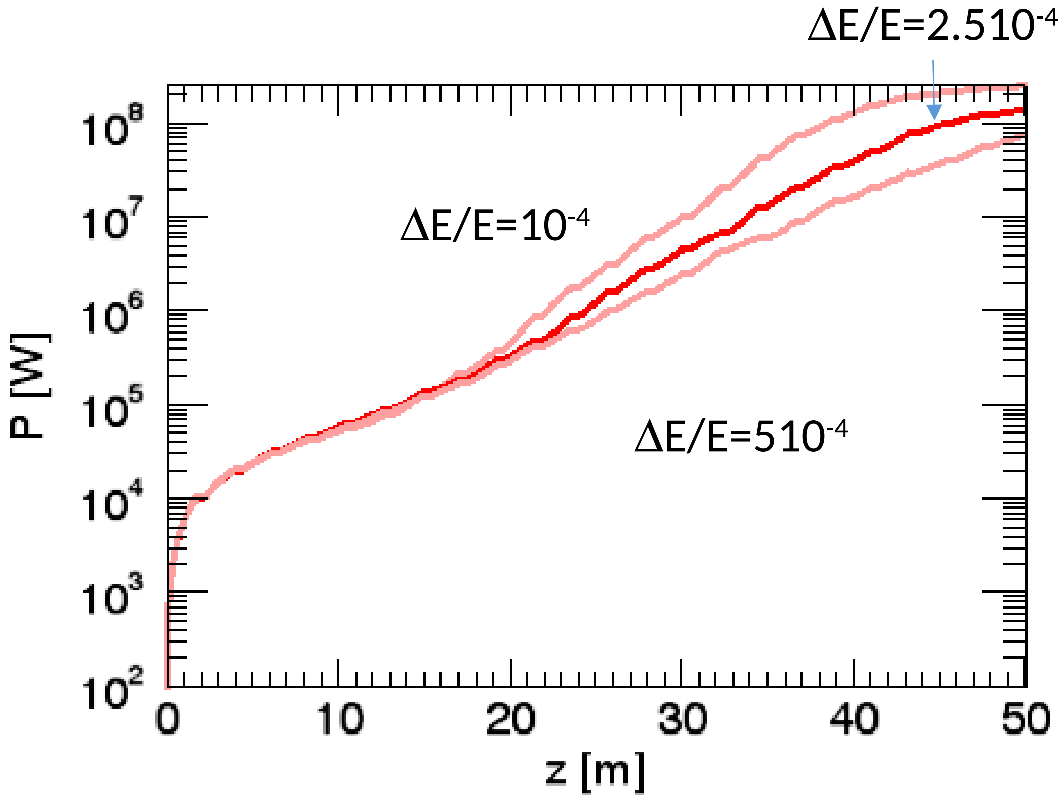
ε=0.5 μm

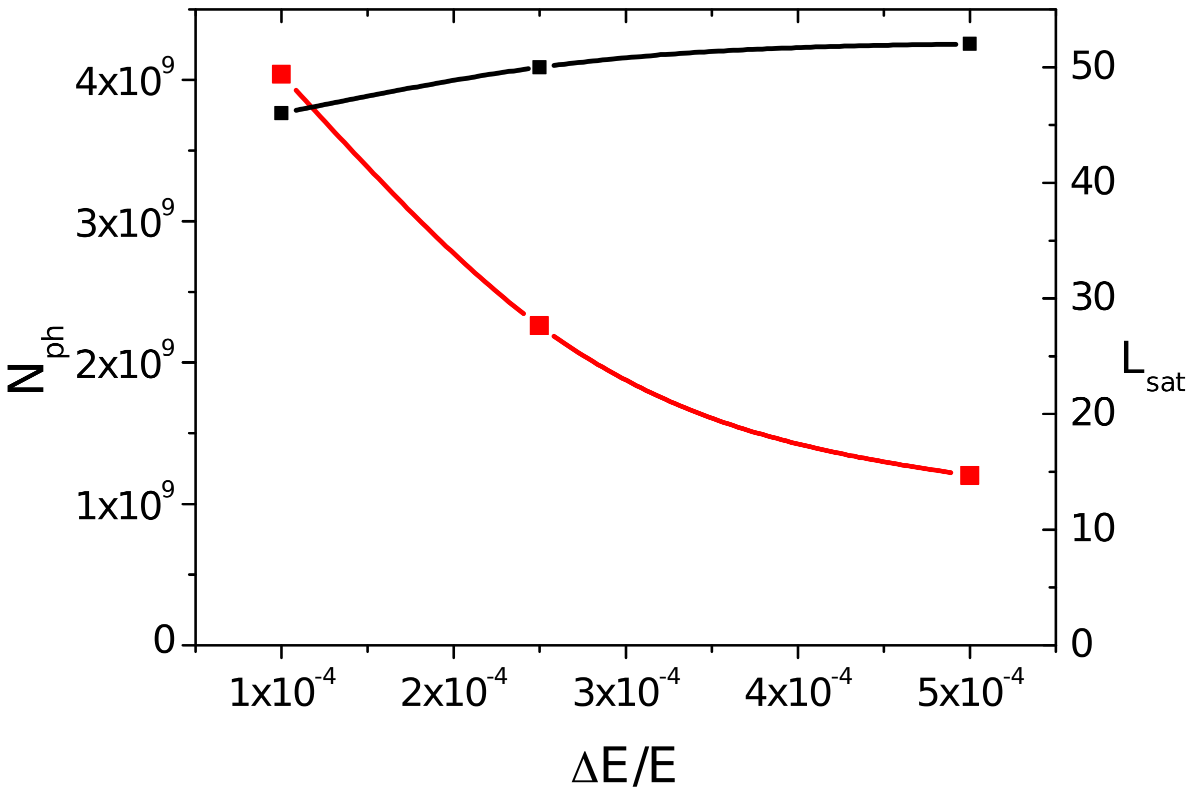


Period	Wavelength	aw	gamma
14 mm	5 A	0.7	4567

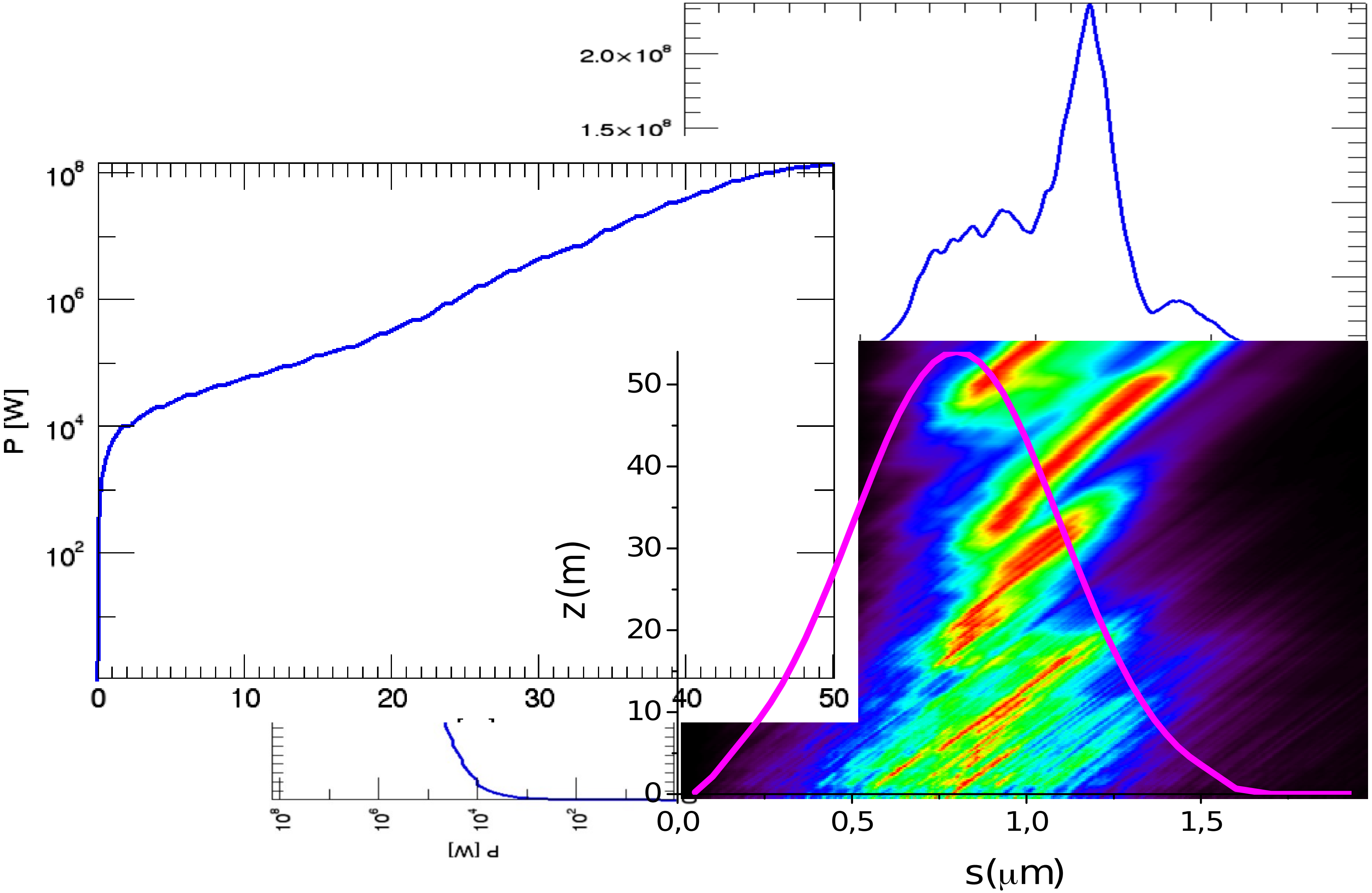
dB/dz (T/m)	ε(μm)	σ_x(μm)	σ_y(μm)	α_x	α_y
20	0.5	27.1	11.8	2.5	-0.64
20	0.8	34.27	14.9	2.5	-0.64

KYMA 14 mm, a_w=0.7 5 Å, ε=0.5 µm, energy spread

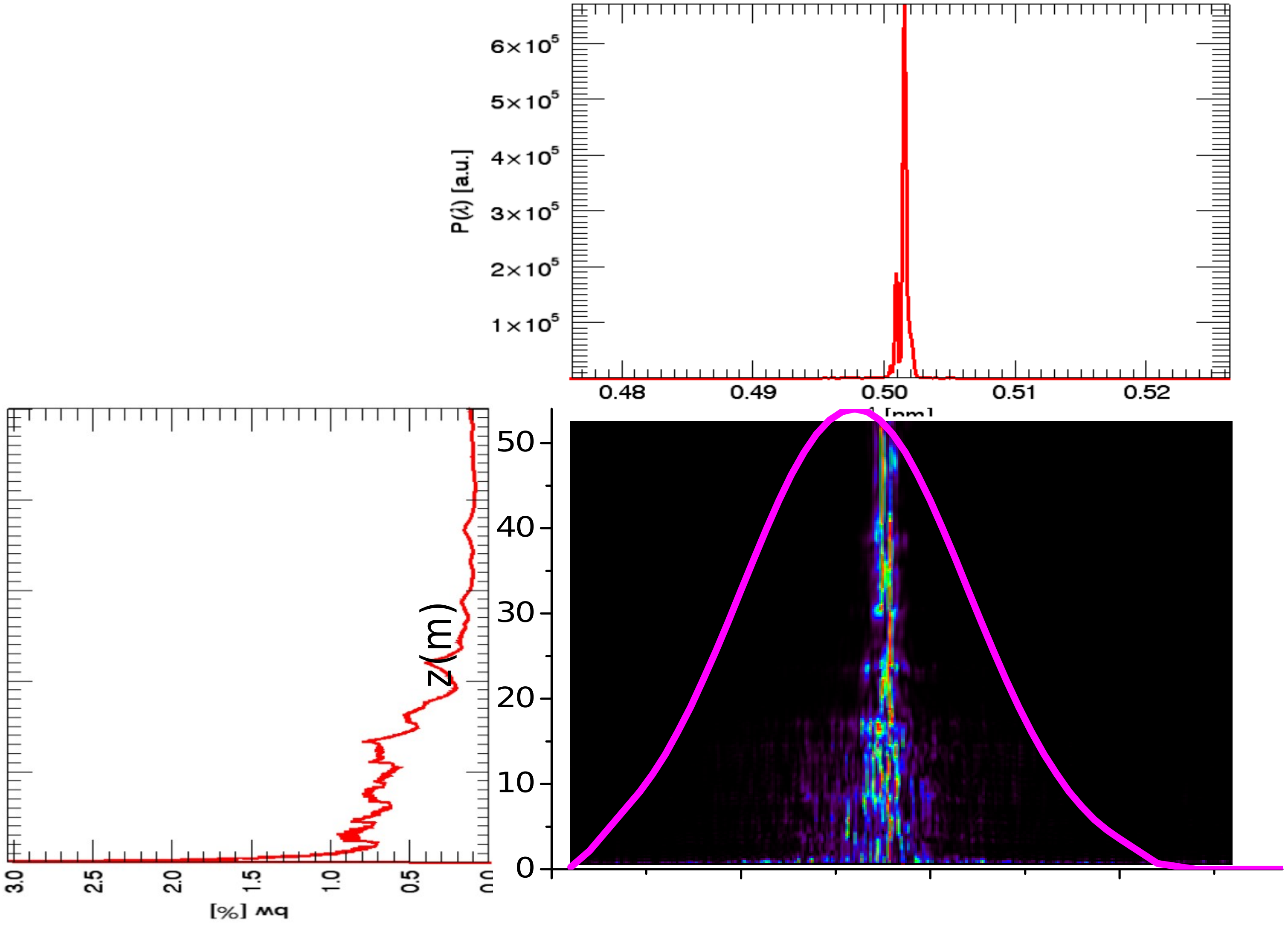




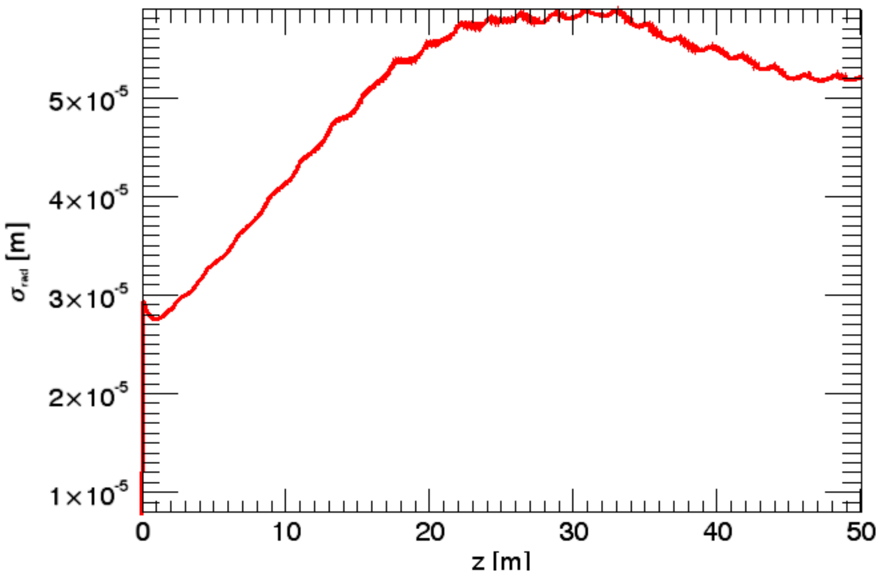
Growth KYMA 14 mm 5 A, power, ΔE/E=2.5 10^{-4}

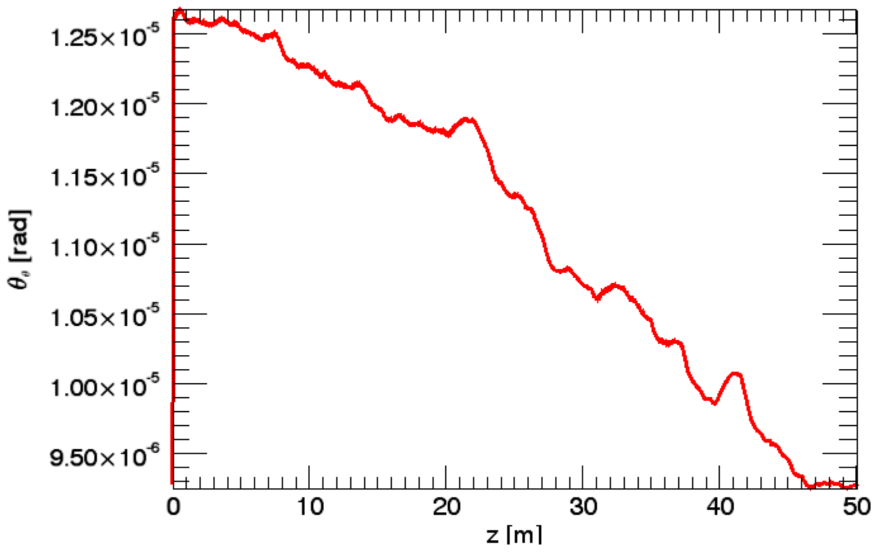


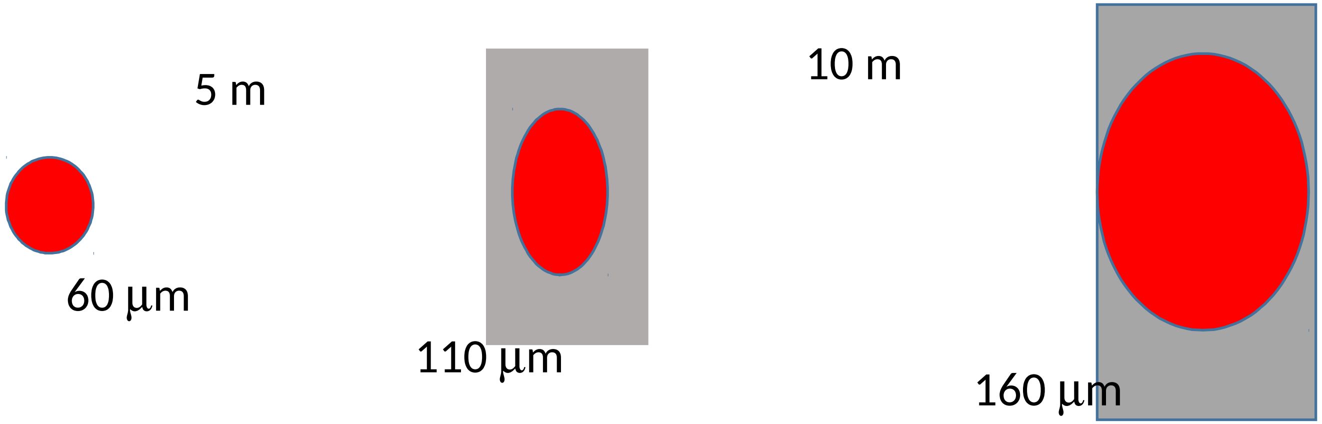
KYMA 14 mm 5 A, spectrum, $\Delta E/E=2.5\ 10^{-4}$



KYMA 14 mm 5 A, rad size and divergence





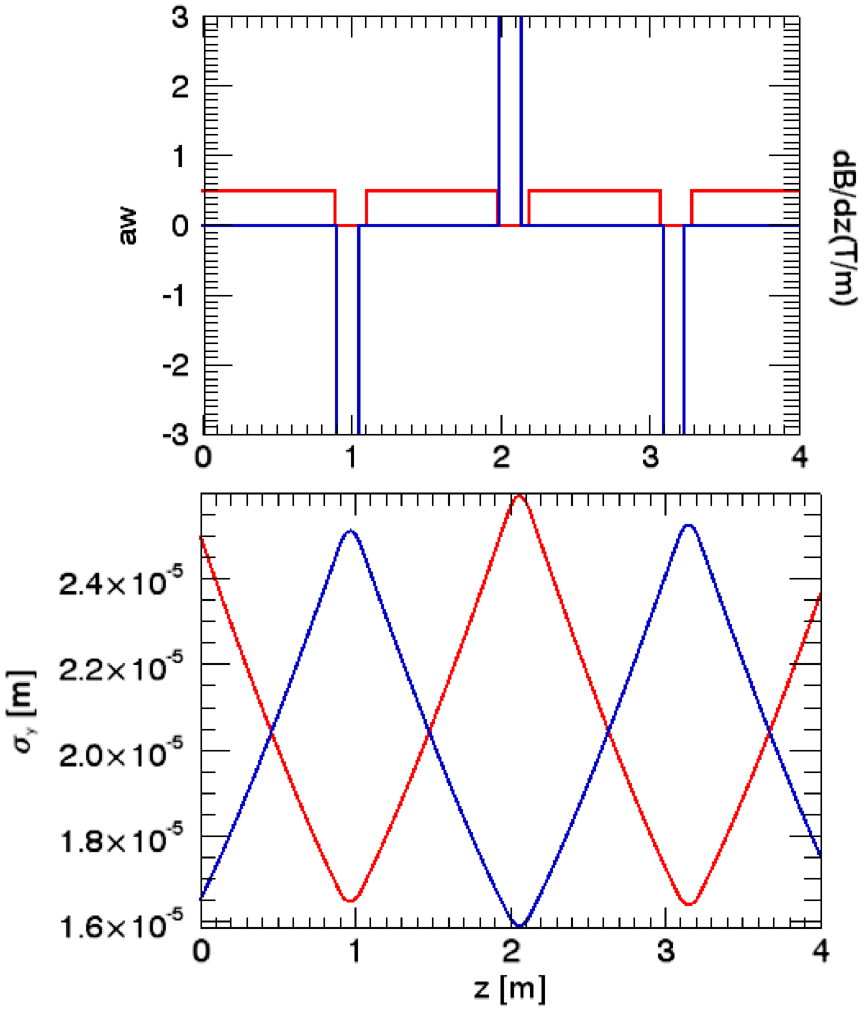


KYMA 14 mm, summary

With the constraint at E<2.4 GeV, we can do only 5 Å

γ	$\Delta E/E$	ε (μm)	N_{ph}	L_{sat}(m)	bw	Rad size(μm)	Div(μrad)
4567	$1\ 10^{-4}$	0.5	$4\ 10^{9}$	45	$0.8\ 10^{-3}$	50	9
	$2.5\ 10^{-4}$	0.5	$2.2\ 10^{9}$	48	$0.9\ 10^{-3}$	52	9.3
	$5\ 10^{-4}$	0.5	$1.2\ 10^{9}$	51	10^{-3}	58	10.8
	$2.5\ 10^{-4}$	0.8	$1.9\ 10^{9}$	55	$1.5\ 10^{-3}$	130	11

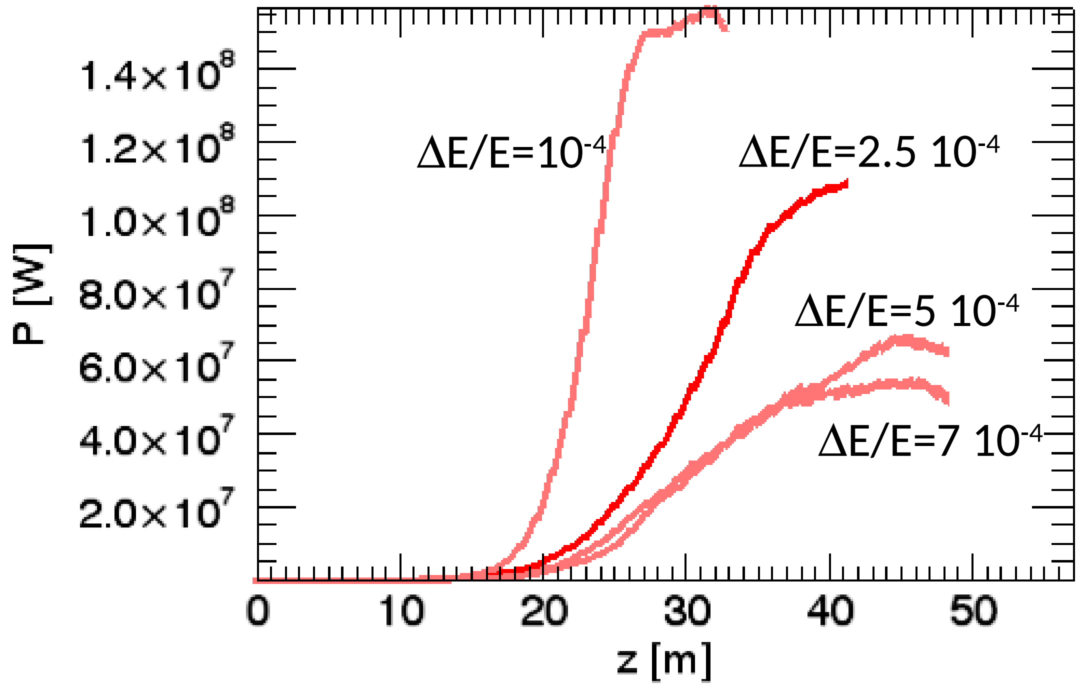
Undulator RadiaB+FODO, 5 Å, matching at ε=0.5 μm

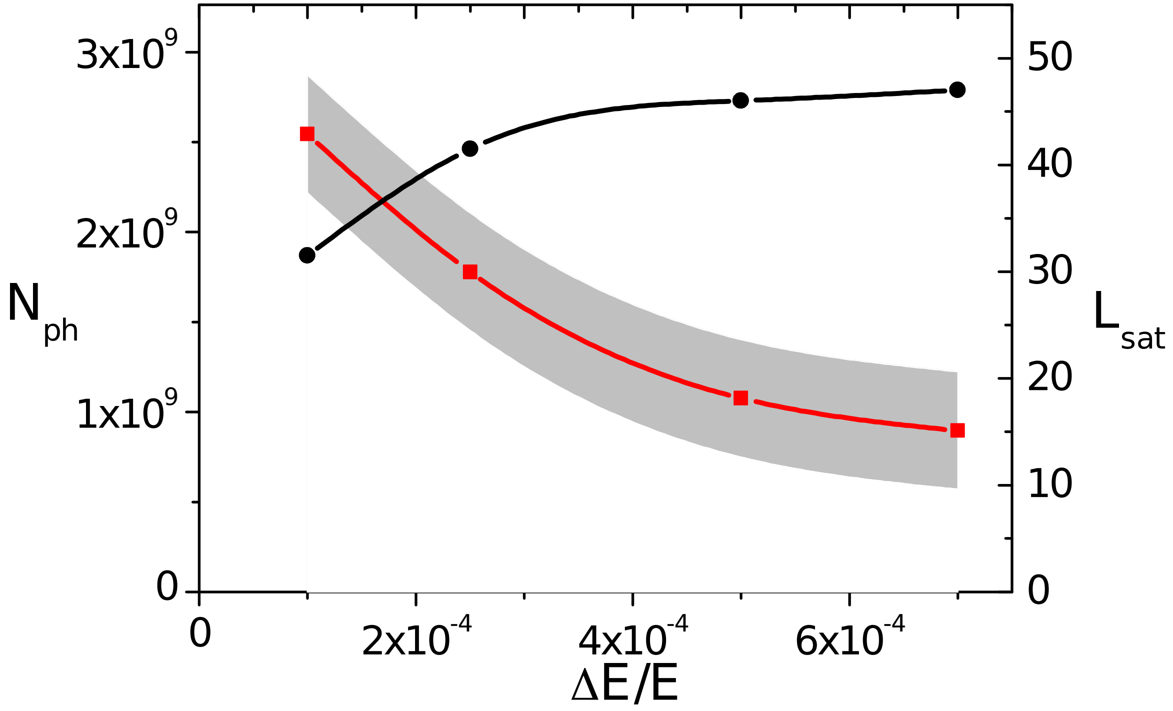


Period	Wavelength	aw	gamma
7 mm	5 A	0.5059	2964

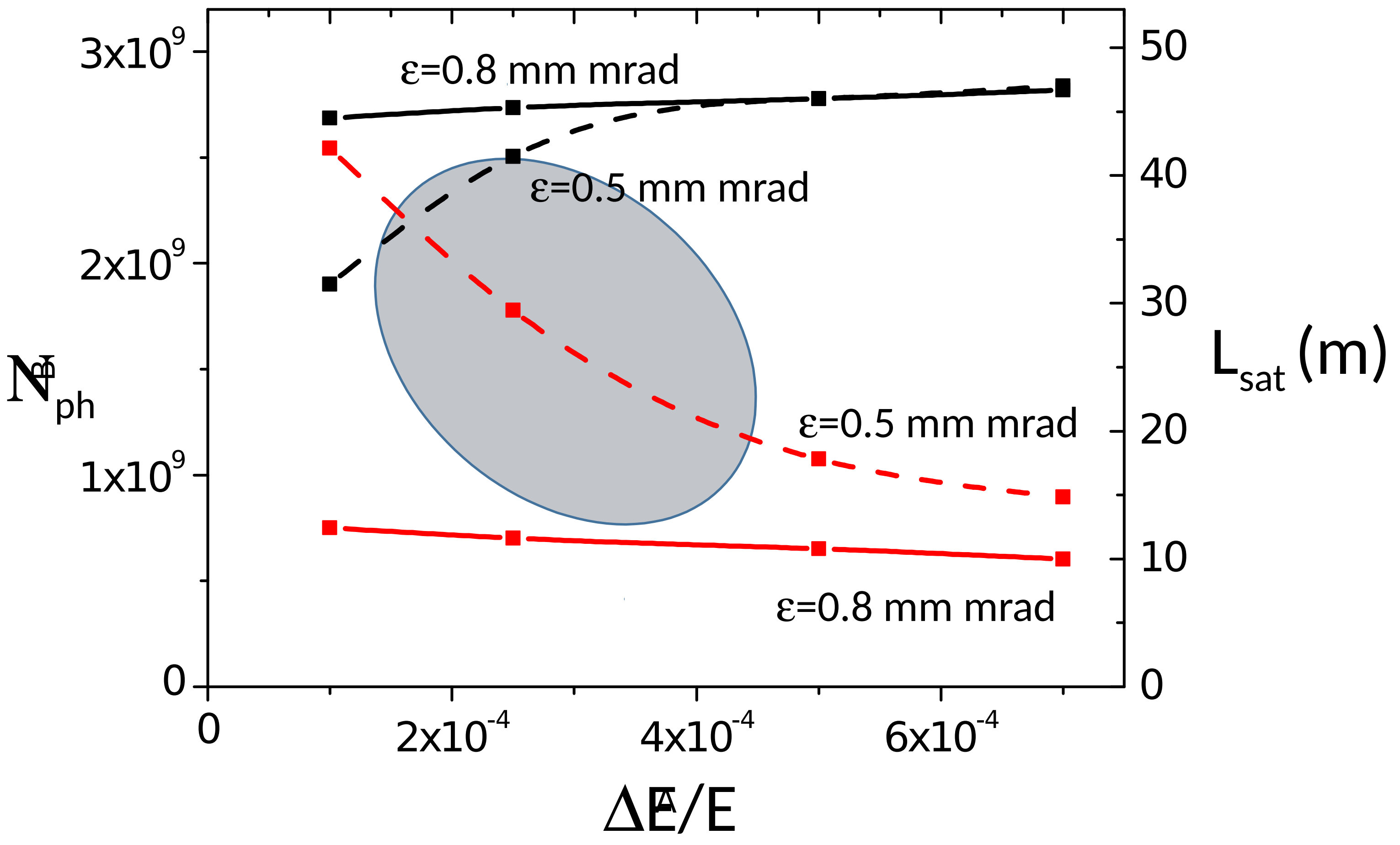
dB/dz (T/m)	ε(μm)	σ_x(μm)	σ_y(μm)	α_x	α_y
30	0.5	25	16.5	1.55	-0.73
30	0.8	31.6	21	1.55	-0.73

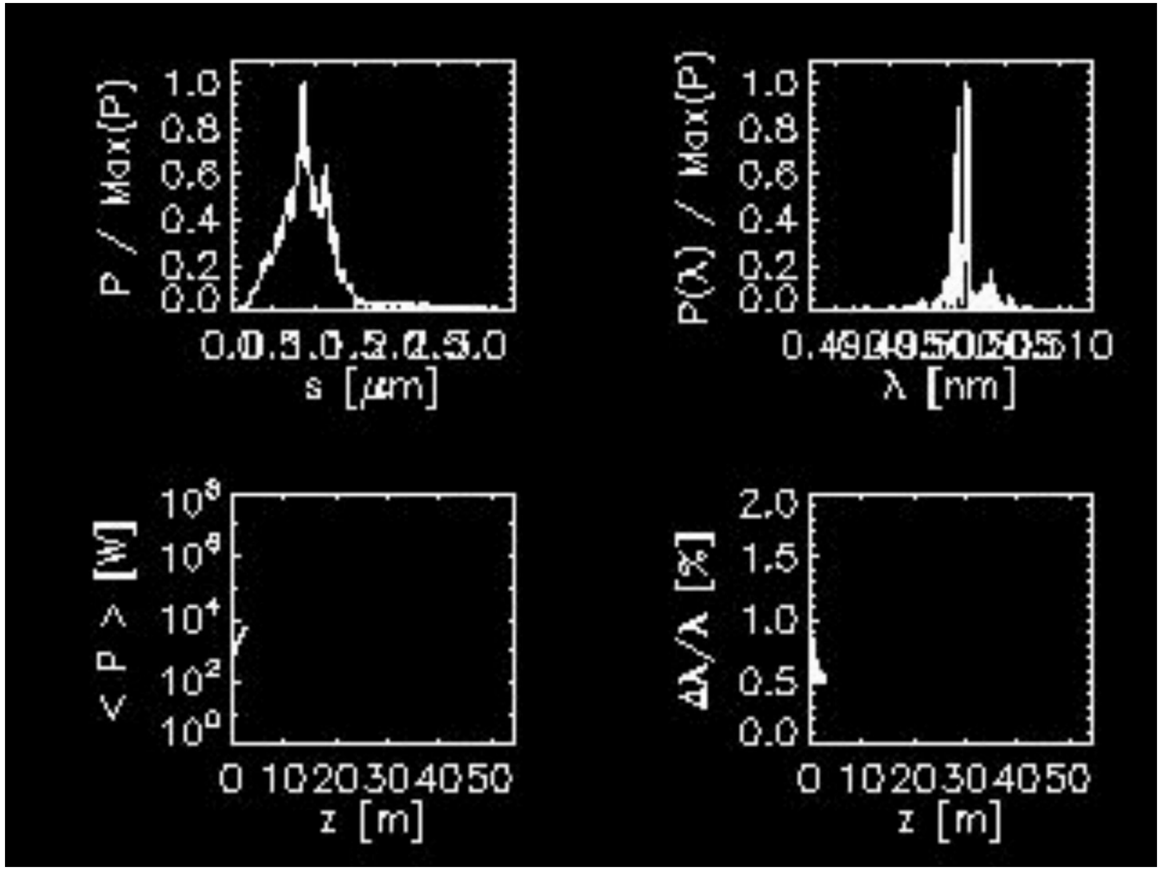
Growth RadiaB, 5 Å, energy spread





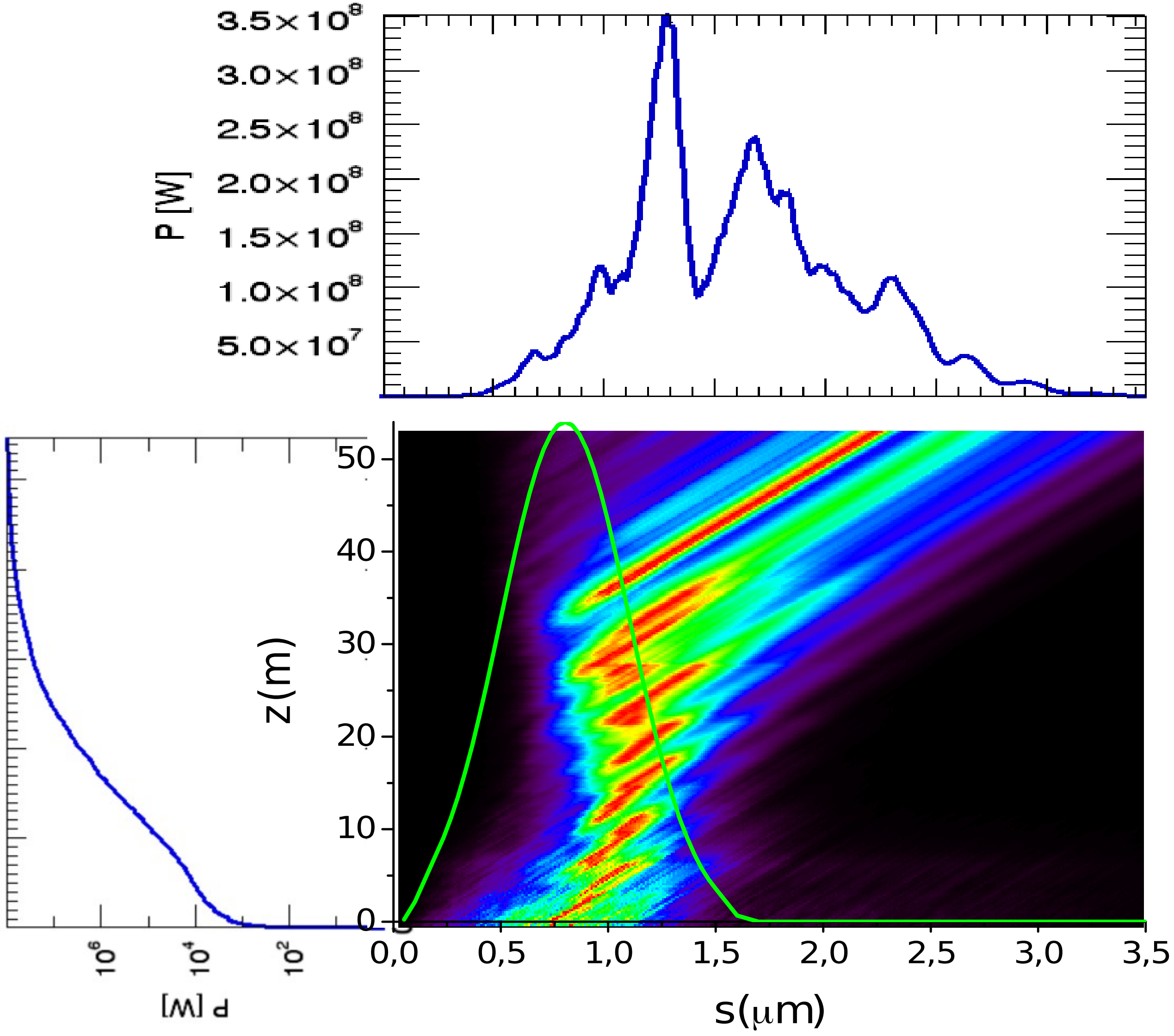
Growth RadiaB, 5 Å, emittance



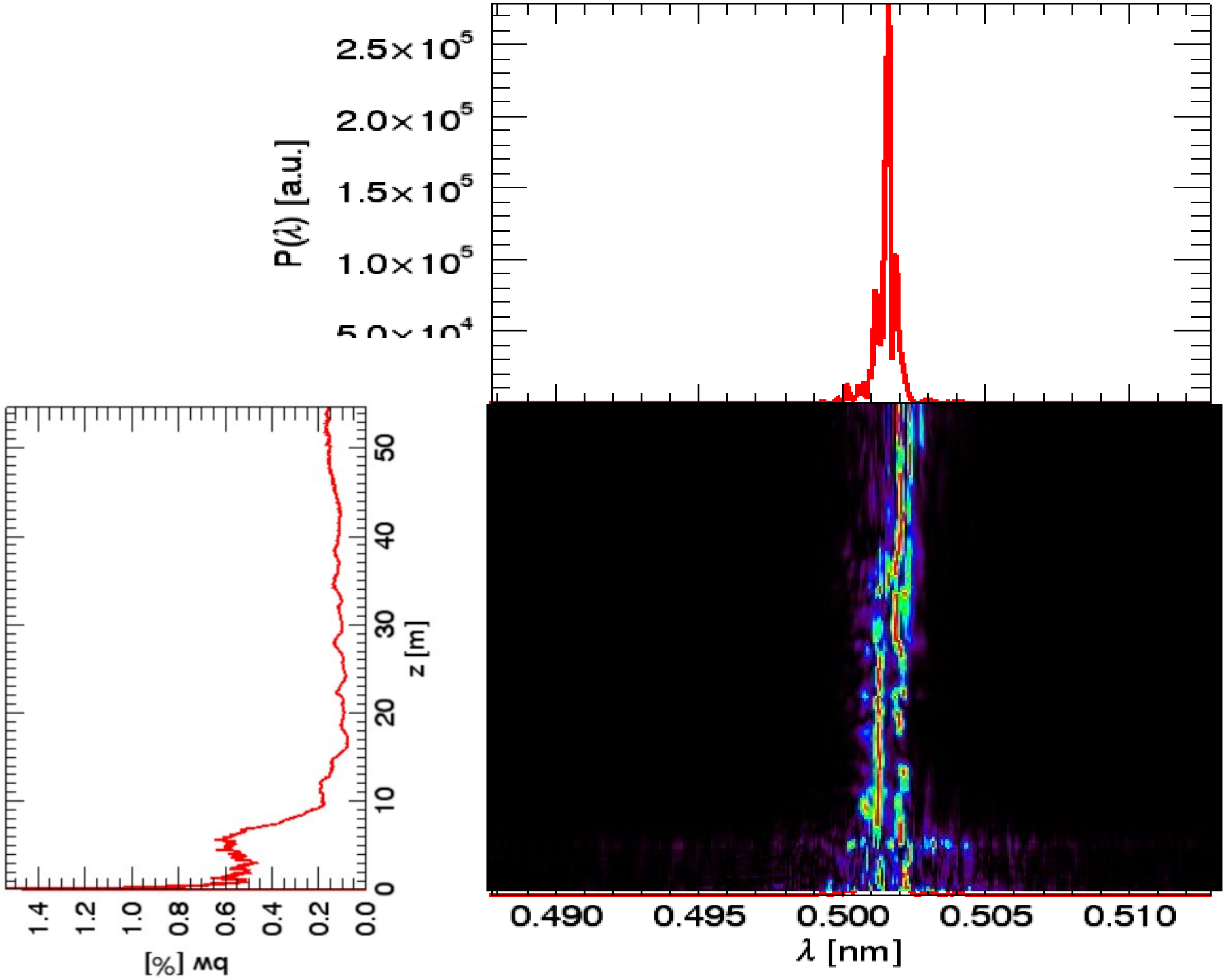


P / Max(P)
1.0
0.8
0.6
0.4
0.2
0.0
s [μm]
P(λ) / Max(P)
λ [nm]
< P > [W]
z [m]
Δλ/λ [%]
2.0
1.5
1.0
0.5
0.0
0 10 20 30 40 50
z [m]

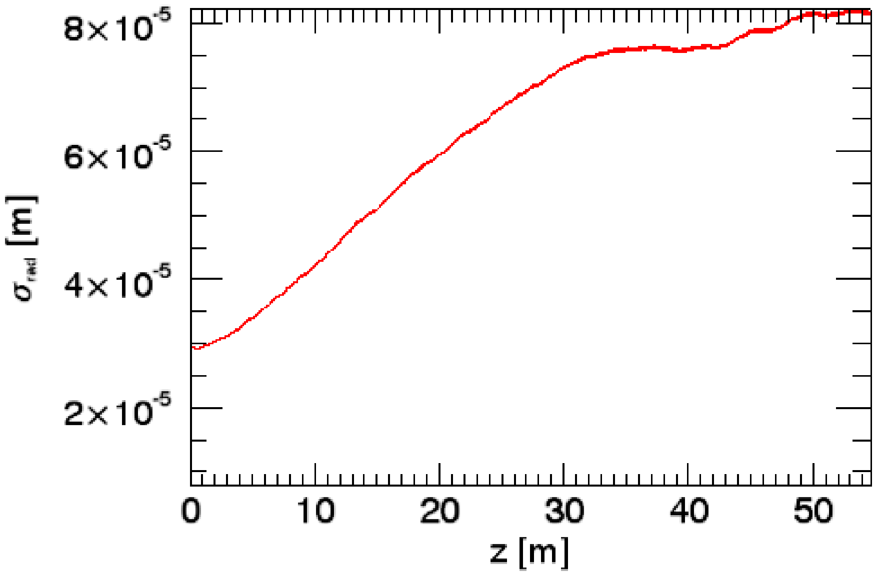
RadiaB, 5 Å, power

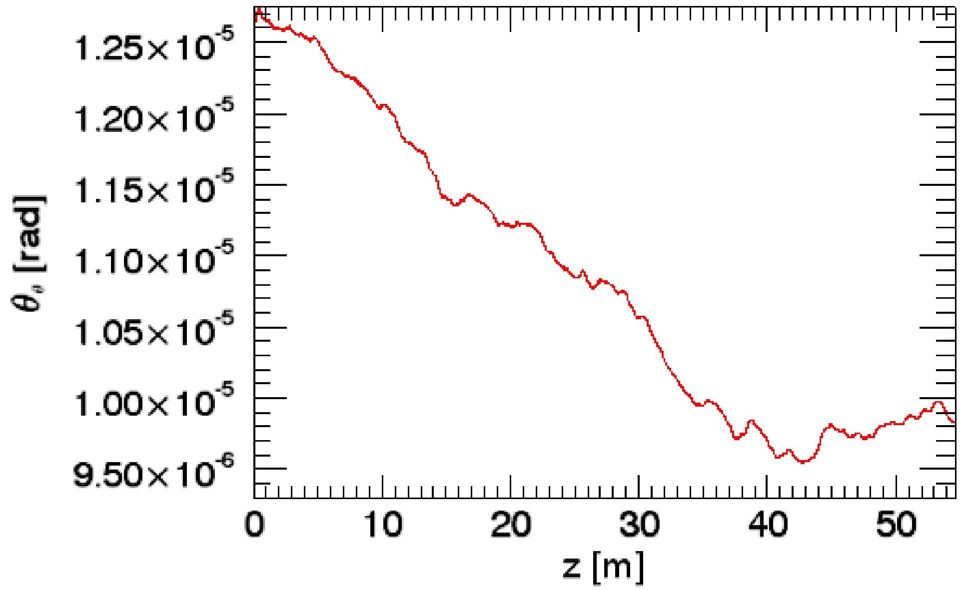


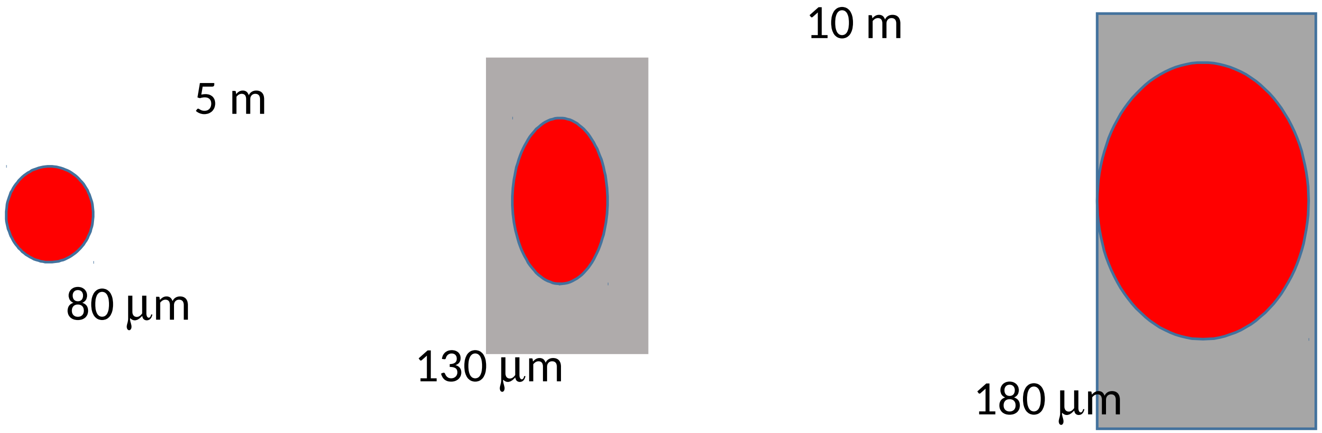
RadiaB, 5 Å, spectrum



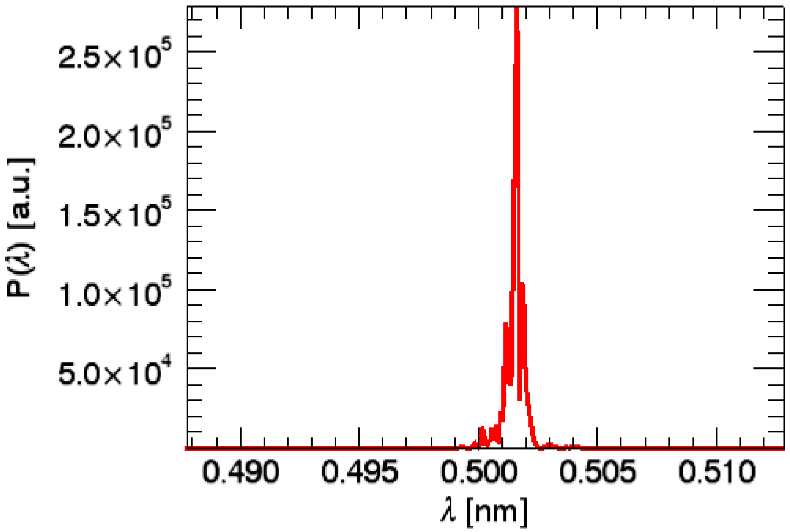
RadiaB, 5 Å, rad size and divergence





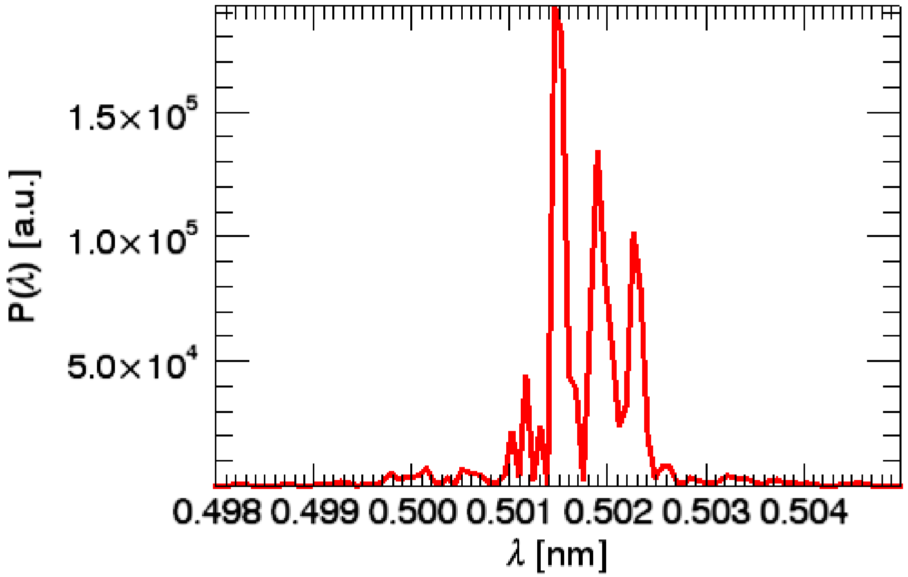


Why so few electrons?



Q=6 pC

Q=60 pC



RadiaB, 7 mm, 5 Å , summary

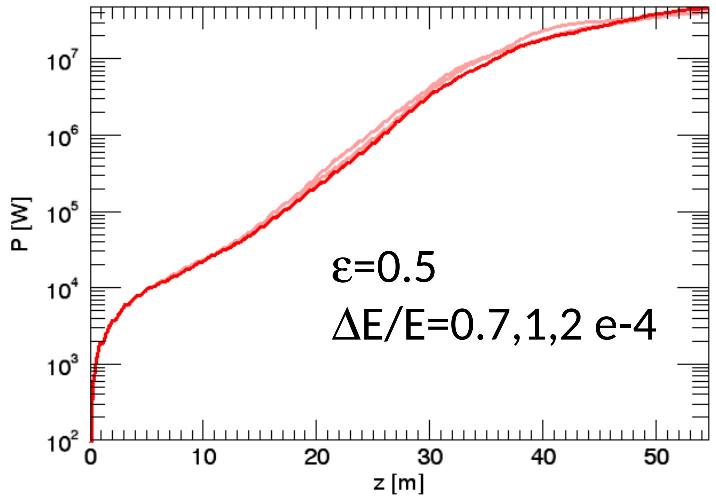
γ	ΔE/E	ε (μm)	σ (μm)	N_{ph}	L_{sat}(m)	bw	Rad size	div
2964	1e-4	0.5	25-16.5	$2.7\ 10^{9}$	27	10^{-3}	35	8.2
	2.5 e-4	0.5	25-16.5	$1.91\ 10^{9}$	42	$1.3\ 10^{-3}$	40	10
	5 e-4	0.5	25-16.5	$1.13\ 10^{9}$	45	$1.5\ 10^{-3}$	45	11
	7e-4	0.5	25-16.5	$0.94\ 10^{9}$	47	$2\ 10^{-3}$	46	11.5
	1e-4	0.8	31-21	$0.75\ 10^{9}$	44	$1.2\ 10^{-3}$	45	11.5
	2.5 e-4	0.8	31-21	$0.67\ 10^{9}$	46	$1.8\ 10^{-3}$	46	12
	5 e-4	0.8	31-21	$0.64\ 10^{9}$	47	$2\ 10^{-3}$	47	12.5
	7e-4	0.8	31-21	$0.6\ 10^{9}$	48	$2\ 10^{-3}$	47	12.5

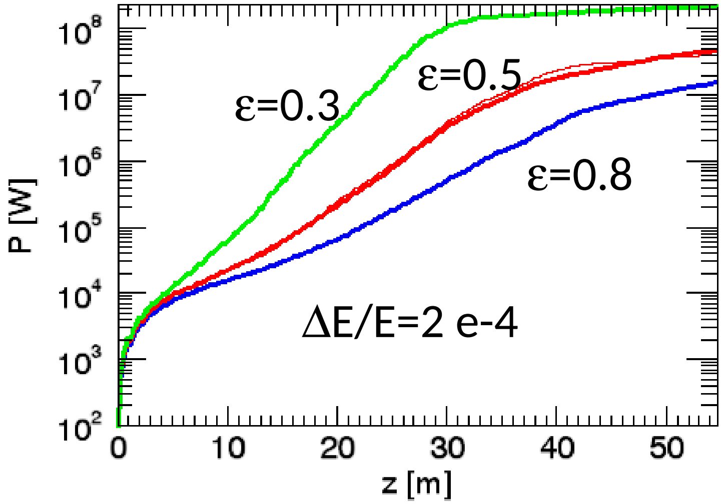
Working point RB at 2.5 Å

Period	Wavelength	aw	gamma	rho3d (10^{-3})	L_{gain} (m)
10 mm	2.5 A	0.2628	4623	0.12151	3.7812
7 mm	2.5 A	0.5059	4193.21	0.25694	1.2517

dB/dz(T/m)	ε(μm)	σ_x(μm)	σ_y(μm)	α_x	α_y
30	0.3	16.26	10.75	1.55	-0.73
30	0.5	21	13.88	1.55	-0.73
30	0.8	26.56	17.55	1.55	-0.73

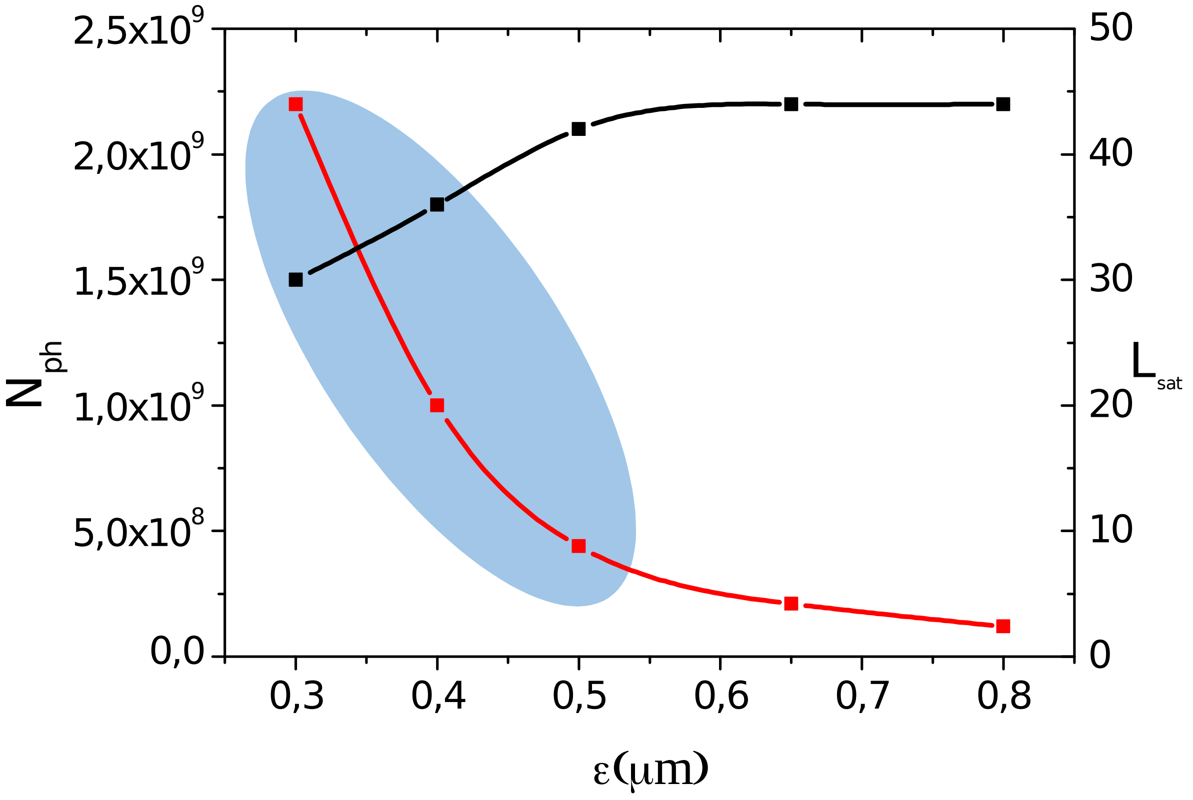
RadiaB, 2.5 Å, growth, energy spread and emittance



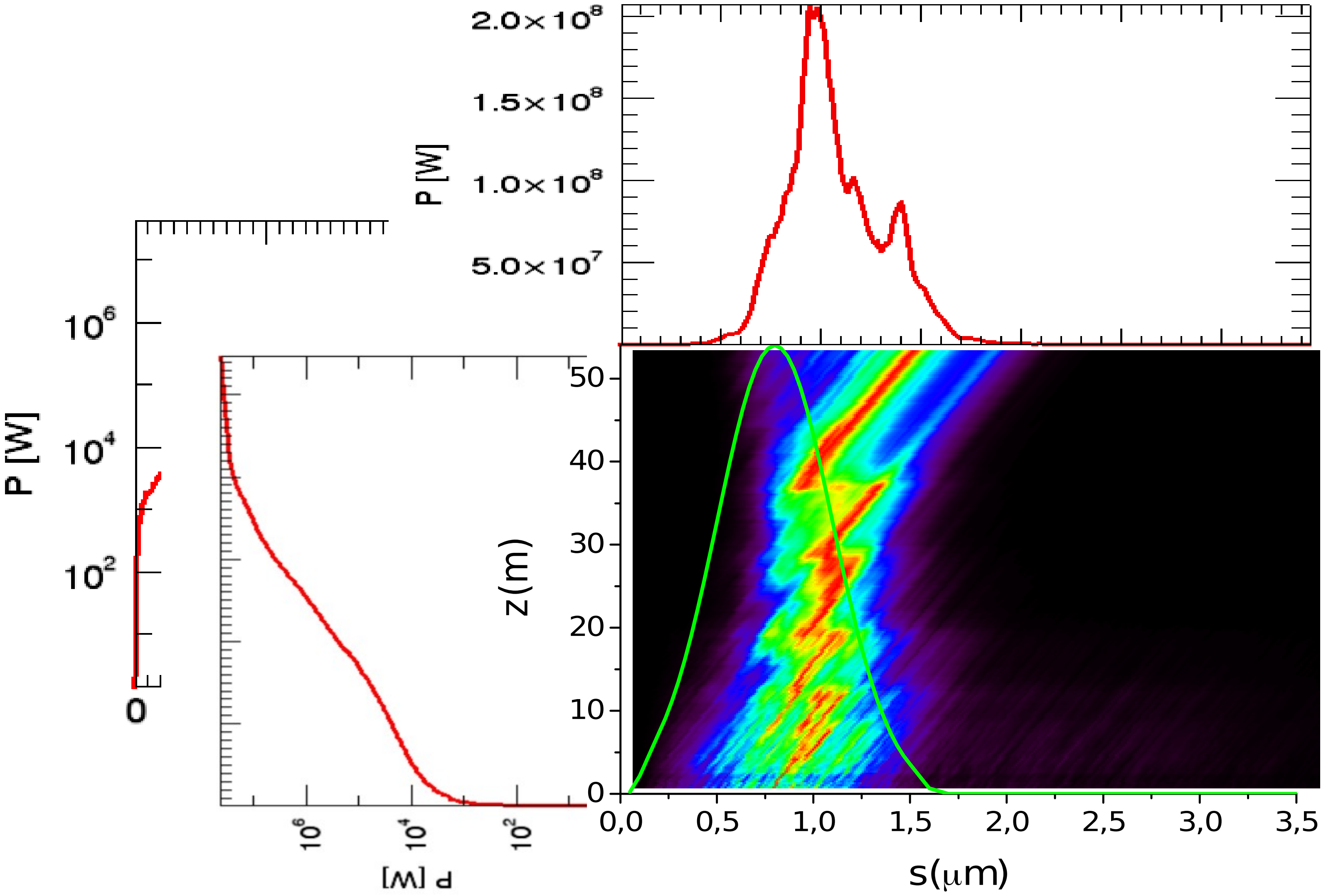


γ	ΔE/E	ε (μm)	Nph	L_{sat}(m)	bw	Size (μm)	Div(μrad)
4193	0.7e-4	0.5	$4.6\ 10^{8}$	42	$0.65\ 10^{-3}$	60	5.5
	1 e-4	0.5	$4.4\ 10^{8}$	42	$0.65\ 10^{-3}$	60	5.5
	2 e-4	0.5	$4.4\ 10^{8}$	42	$0.68\ 10^{-3}$	60	5.5
	2e-4	0.8	$1.2\ 10^{8}$	44	$0.8\ 10^{-3}$	62	5.7
	2e-4	0.3	$2.2\ 10^{9}$	30	$0.5\ 10^{-3}$	40	5

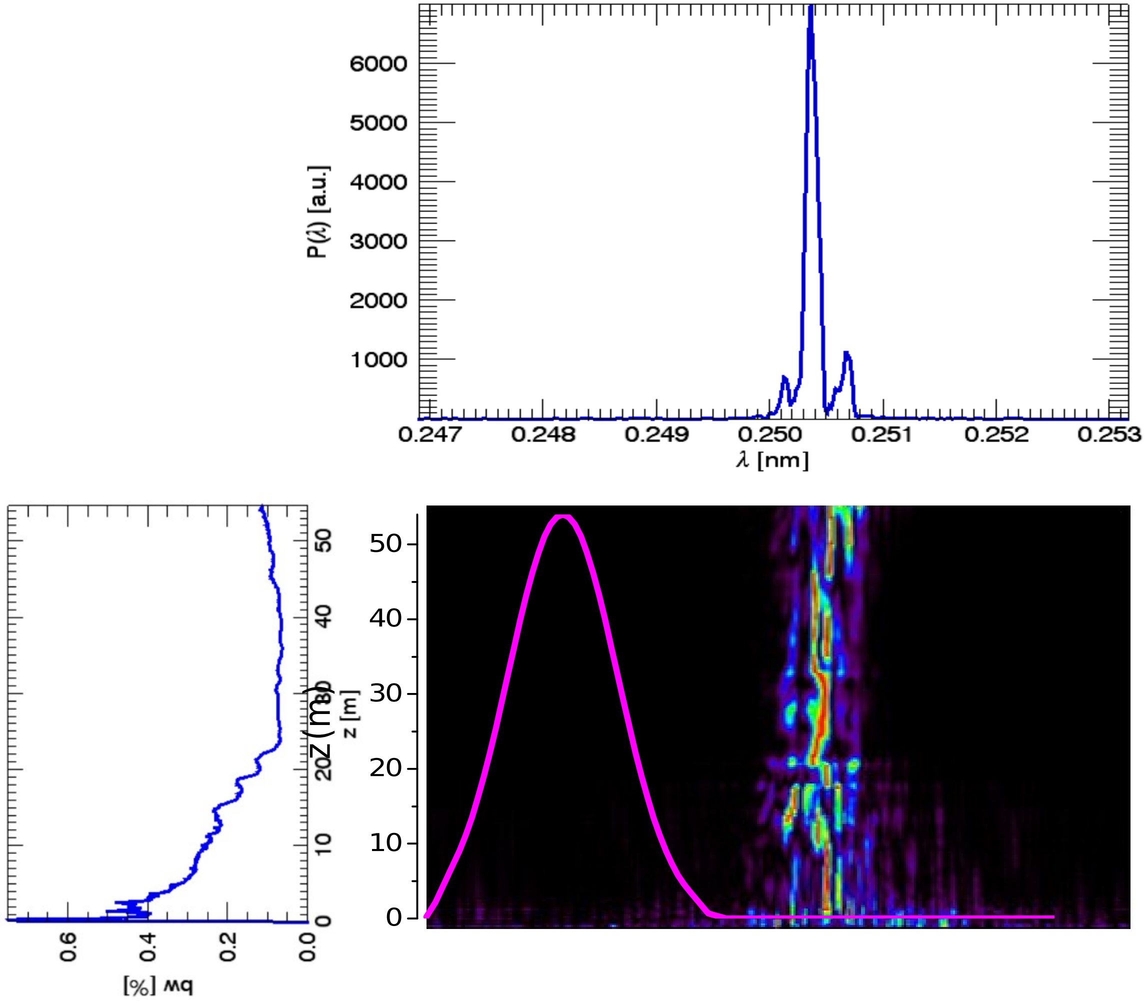
RB at 2.5 Å, emittance



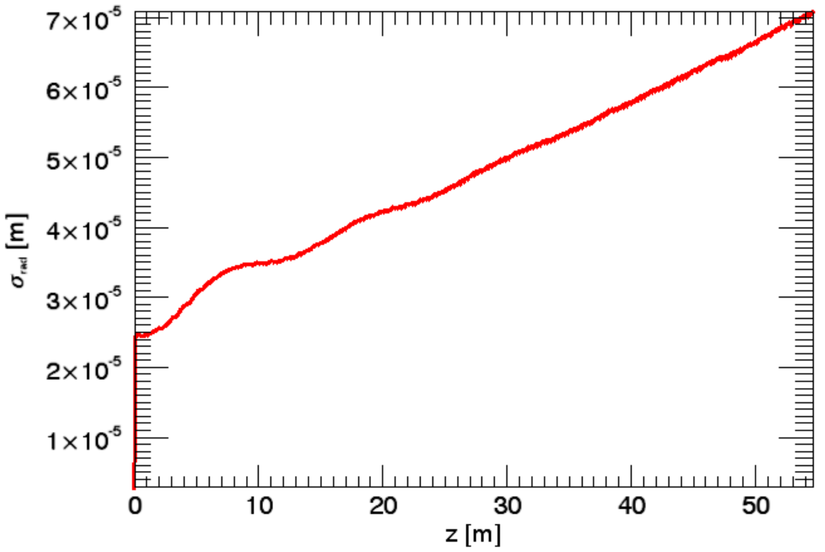
RadiaB, 2.5 Å, power, ε=0.5 μm, ΔE/E=10^{-4}

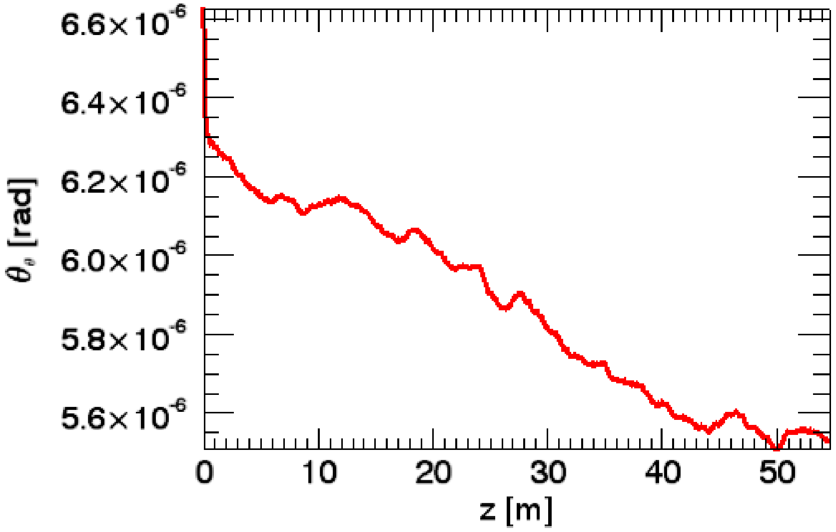


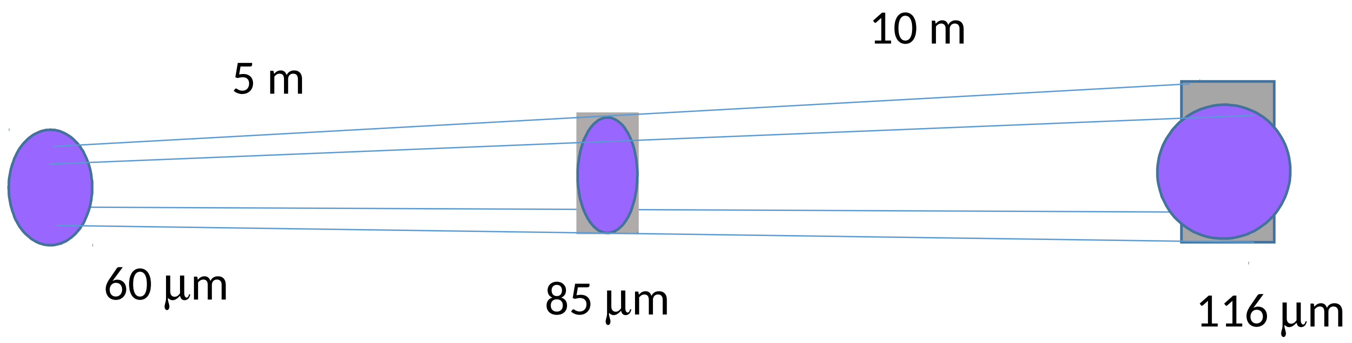
RadiaB, 2.5 Å, spectrum, ε=0.5 μm, $\Delta E/E=10^{-4}$



Diverg. and rad. size RB 2.5 Å, ε=0.5 μm, ΔE/E=10^{-4}







Problem with coherence

SASE single spike vs **seeded pulse** (here the pulses are two)

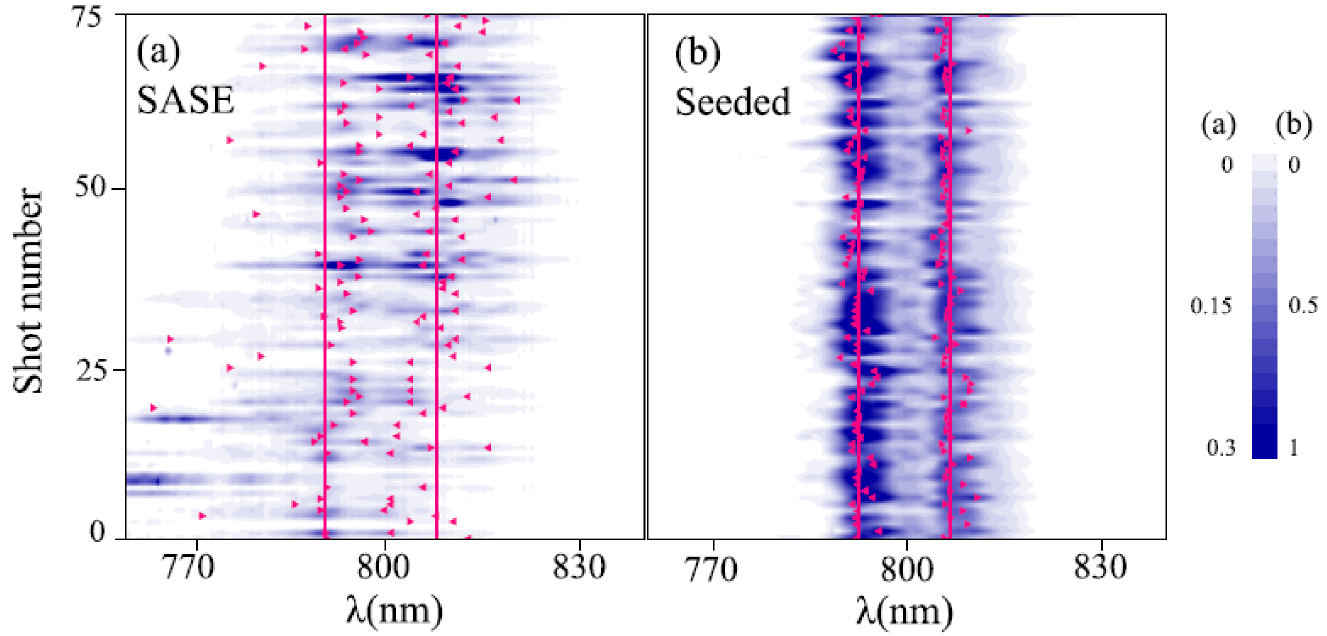
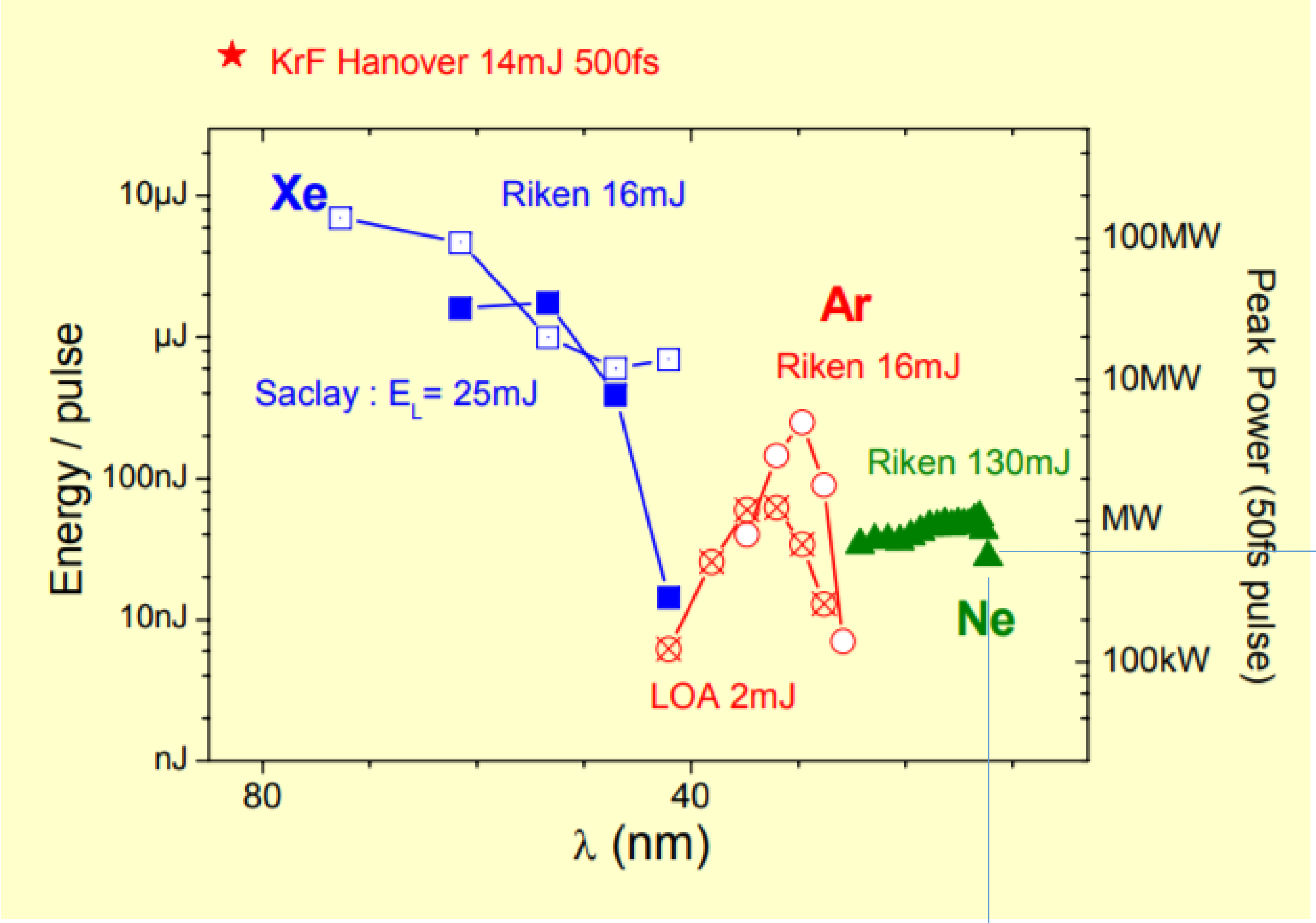


Figure 4: Spectral intensity vs wavelength, sequence of shots without (left) and with (right) seed. Pink lines: average wavelength $\langle \lambda_{1,2} \rangle$, pink triangles: peak values of each shot.

High order harmonics generated in gases



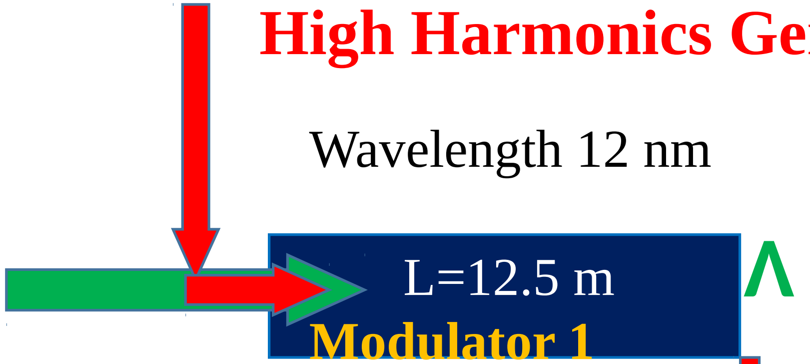
25 nJ

12 nm

Seeding: double cascade with fresh bunch technique. Se7en

High Harmonics Generation in Gas: **first attempt**: 20 nanoJ at 12 nm, 60 pC

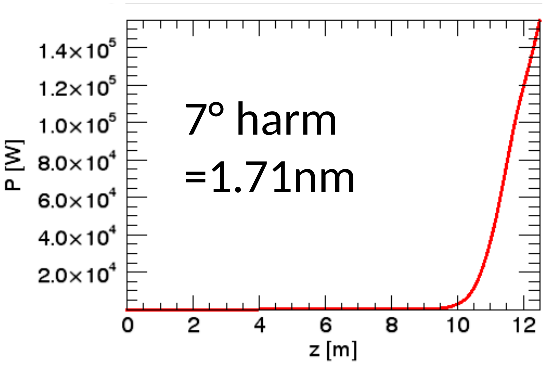
Wavelength 12 nm

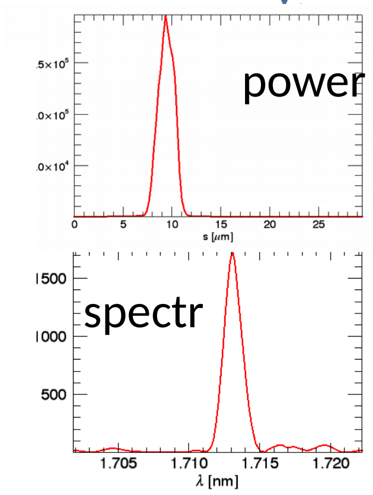


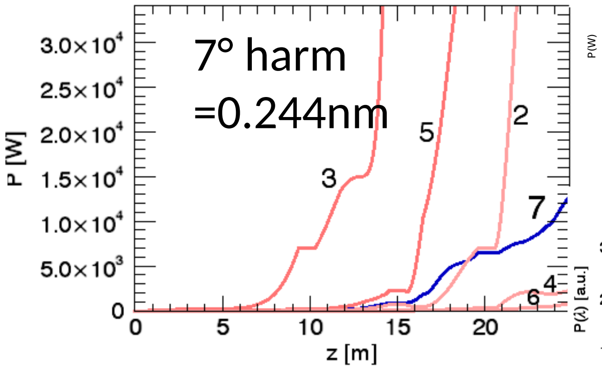
Und. Period 5 cm

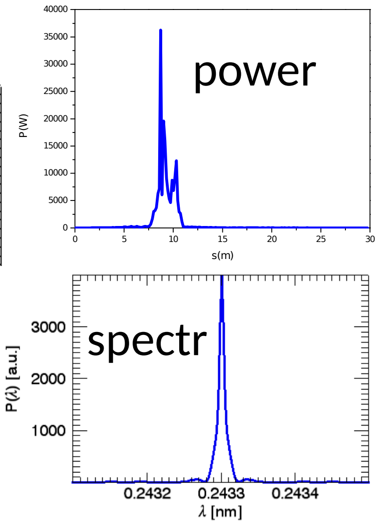
a_w=3. γ=4567

e-Energy=2.3 GeV







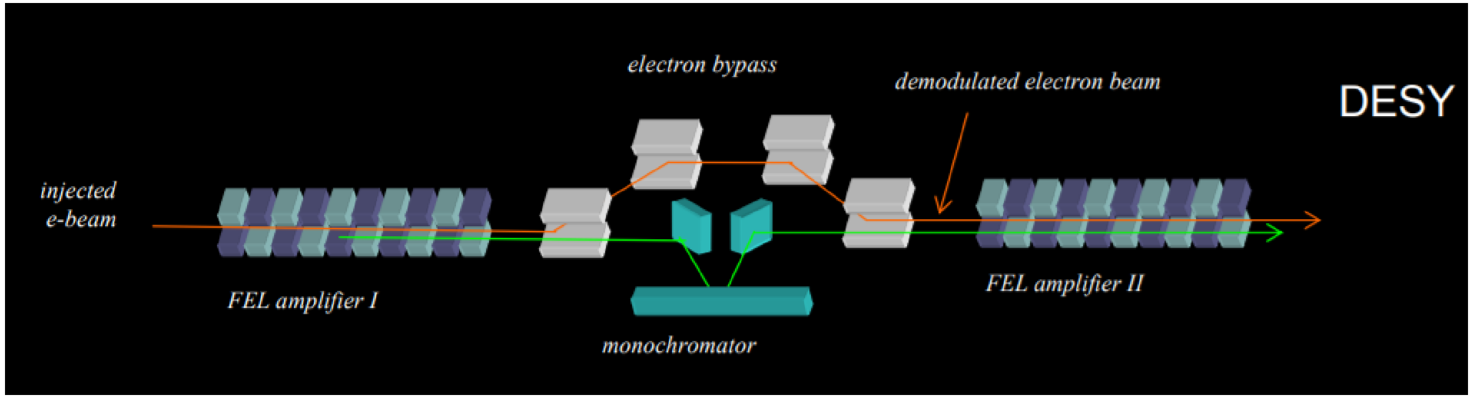


To be studied:

Dispersive section in the cascade with fresh bunch technique.

12 nm	1.71 nm	Disp sec few m	1,71nm	2.4 A

Self seeding: regenerative amplifier



pSASE

Conclusions and perspectives

Going down towards the Angstrom: Mission impossible

Start to end simulations: Desperately seeking a good electron bunch.

RadiaBeam undulators: a new hope?
KYMA: when?

Flux: 10^8 on the target? What news from users?

Coherence: Mission impossible II

Needed young people, hard work and good ideas.