POST ACCELERATION CONCEPT FOR THE

LOW EMITTANCE GUN PROJECT

- The PSI X-Ray FEL concept behind LEG

(if LEG works what shall we do?)

- "RF-gun" structure for post acceleration

(compensation of the RF contribution to the emittance dilution)

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Leg.web.psi.ch

The Physics and Applications of High Brightness Electron Beams, Erice, Italy, October 9-14, 2005

X-ray FELs are expensive machine the main driving cost being:

- The Linac energy
- The undulator length

Two basic condition to fulfill*

$$\lambda_s = \frac{\lambda_u}{2\gamma^2}\left(1 + K_{rms}^2\right)$$

Resonant condition

With usually K_{rms}~1

$$\varepsilon_n < \frac{\beta}{L_G}\frac{\gamma\lambda_s}{2\pi}$$

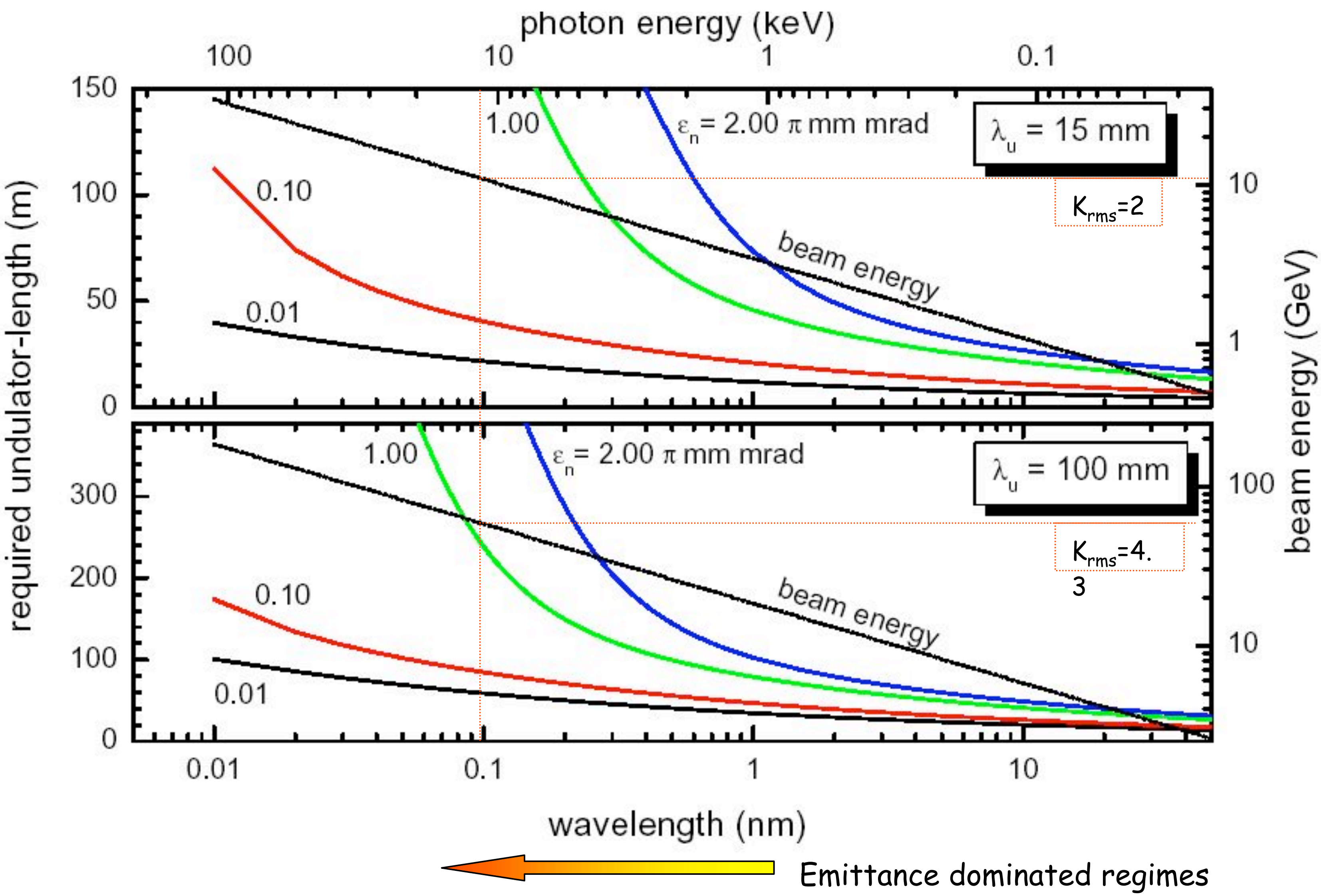
~Diffraction limit strongly affect the FEL ρ parameter.

$$L_g \approx \frac{\lambda_u}{4\pi\rho(\varepsilon_n)}$$

Reduction of the normalized emittance leads to a reduction of the linear accelerator and undulator length.

Cost reduction would allow medium size research institute to realize FEL based light sources at wavelength down to 0.1 nm.

*For much more on theory see: S. Reiche / R. Bonifacio / L. Giannesi contributions to this workshop



Goal 0.1nm radiation wave length (12.4 keV)

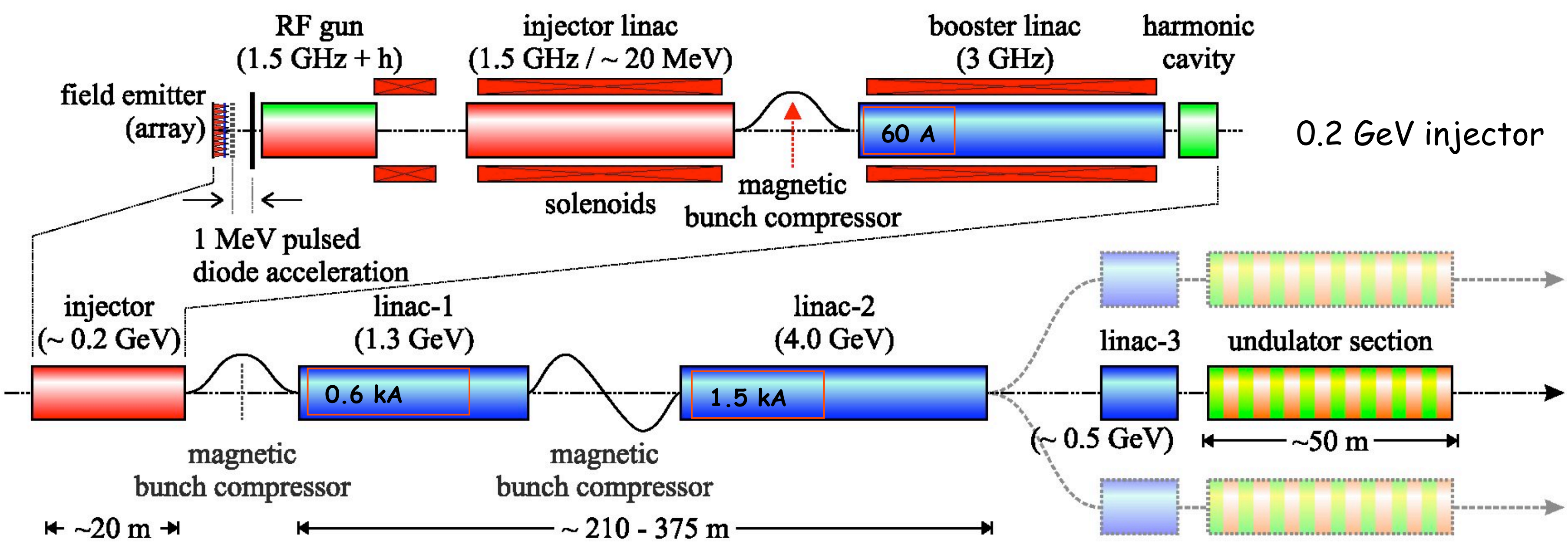
Economic x-ray FEL at PSI - first concept based on LEG

Gun parameters

Peak current	I	≥ 5	A
Pulse duration (FWHM)*	τ	35	ps
Bunch charge*	Q	0.2	nC
Beam energy	E	1.0	MeV
Energy spread (FWHM)	σ_E	0.5	eV
Emittance (normalized)	ε_n	0.05	mm mrad
Repetition rate	f	10	Hz

* defined by parametric FEL studies [5].

[5] http://leg.web.psi.ch/public/xfel/proposal.html



Parameters at the undulator

Wavelength	λ_{rad}	0.1	nm
Photon energy	$\hbar\omega_{rad}$	12.4	keV
Electron Beam			
Beam energy	E	5.8	GeV
Peak current	I	1.5	kA
Bunch charge	Q	0.2	nC
Norm. Emittance[a]	ε_n	≤ 0.1	mm mrad
Energy spread[a]	σ_E	≤ 0.6	MeV/ ps
Undulator Section			
Undulator period	λ_u	15 (12)	mm
Undulator type		planar	-
Undulator strength	K	1.19	-
Average β-function	β	15	m
FEL Performance[b]			
Pierce parameter	ρ_{1D}	$5.4 \cdot 10^{-4}$	-
Gain length	L_g	1.0	m
Saturation Length	L_{sat}	20	m
Peak power	P	6	GW
Pulse Energy	E_{ph}	0.4	mJ
Peak brilliance	B	$1.1 \cdot 10^{33}$	$-^c$
Photons per pulse	N	$1.9 \cdot 10^{11}$	-

[a] Slice parameters
[b] Based on analytical estimates [5]
[c] photons/sec/mm^2/mrad^2/0.1% bw

Chicanes and <linac parameters

	BC_2	BC_3	
Length	14	14	m
Bending angle	3	2.9	deg
Compression factor	10	2.5	
$\sigma_{E_0}{}^a$	0.5	0.16	eV
$\sigma_{E_c}{}^b$	0.7	7.2	eV/ps
$\Delta\varepsilon_n{}^c$	≤ 0.05	≤ 0.02	mm mrad

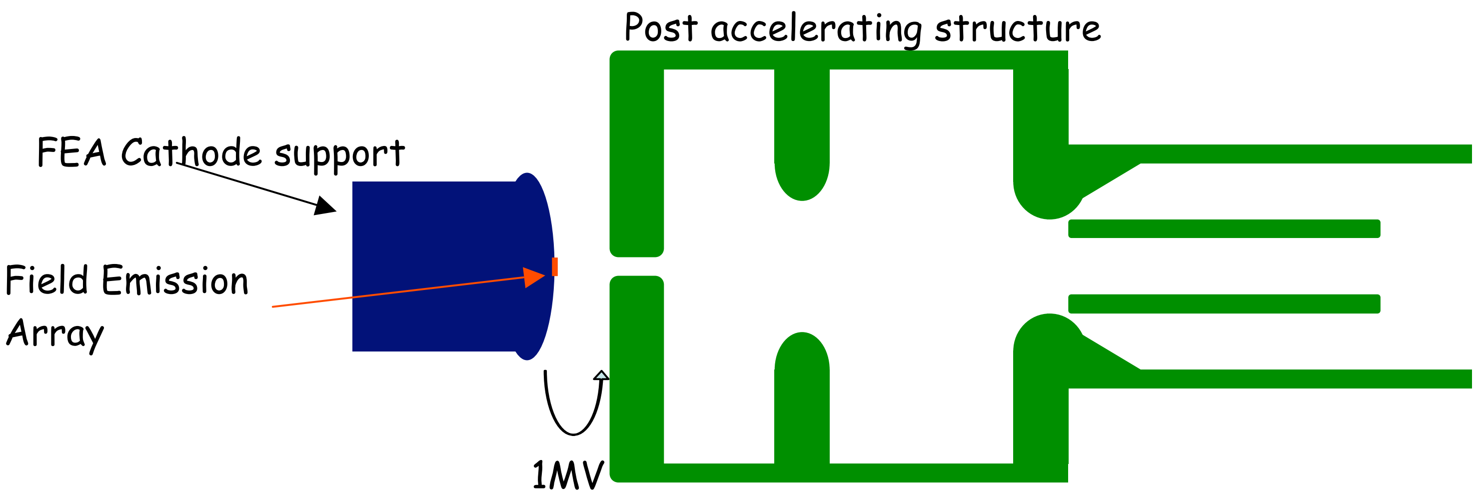
	Linac-1	Linac-2	
Initial Energy	0.2	0.8	GeV
Final Energy	0.8	5.8	GeV
Length	32.5	364	m
Mode	$2\pi/3$	$2\pi/3$	rad
Average β	8	7.5	m
Number of cavities	10	96	
Injection phase	40	5	deg

[a] Uncorrelated energy spread
[b] Correlated energy spread
[c] Absolute slice emittance growth

See as well: Leg.web.psi.ch

LEG-RF Gun design for post acceleration

[J.-Y. Raguin et al, FEL 05 proceedings, Stanford (2005)]



BASIC PARAMETERS

- Long pulses: L-band 1.5 GHz
- Structure: here 1.5 Cells RF-gun like
- Two frequency scheme for RF time dependent forces compensations *

DESIGN CRITERIA

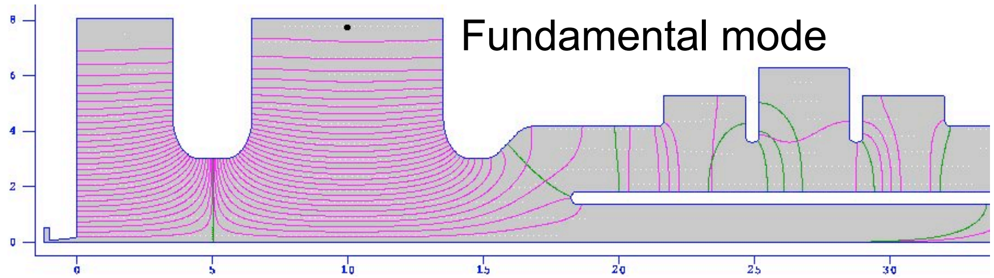
- Large π–O mode separation **
- Reduced peak surface E field
- Balanced field profile (fund. & fund.+harm.)
- Coax feed for critical coupling

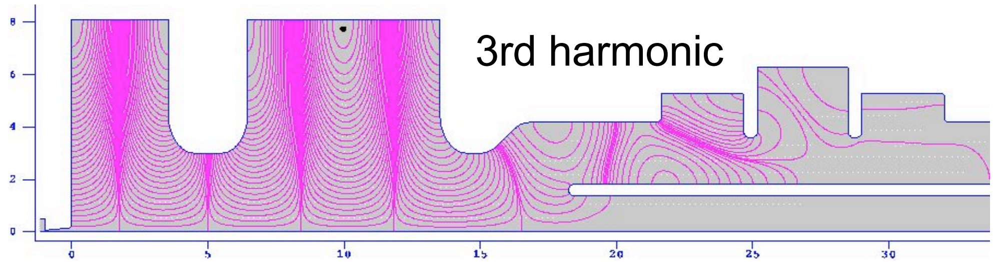
* L. Serafini at al, Nucl. Instr.and Meth., A318 (1992), pp301-307 (early proposal for RF compensation)

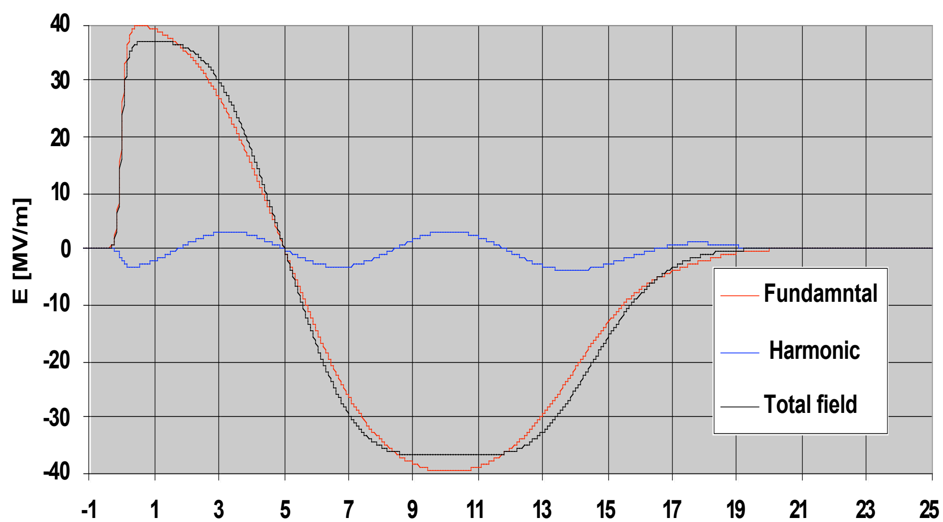
* D.H. dowell et all, Nucl. Instr.and Meth., A528 (2004), pp316-320 (S-band simulations)

** See J. Schmerge presentation this workshop and published paper.

Two freq. RF gun *1.5 GHz – 4.5 GHz* - RF design



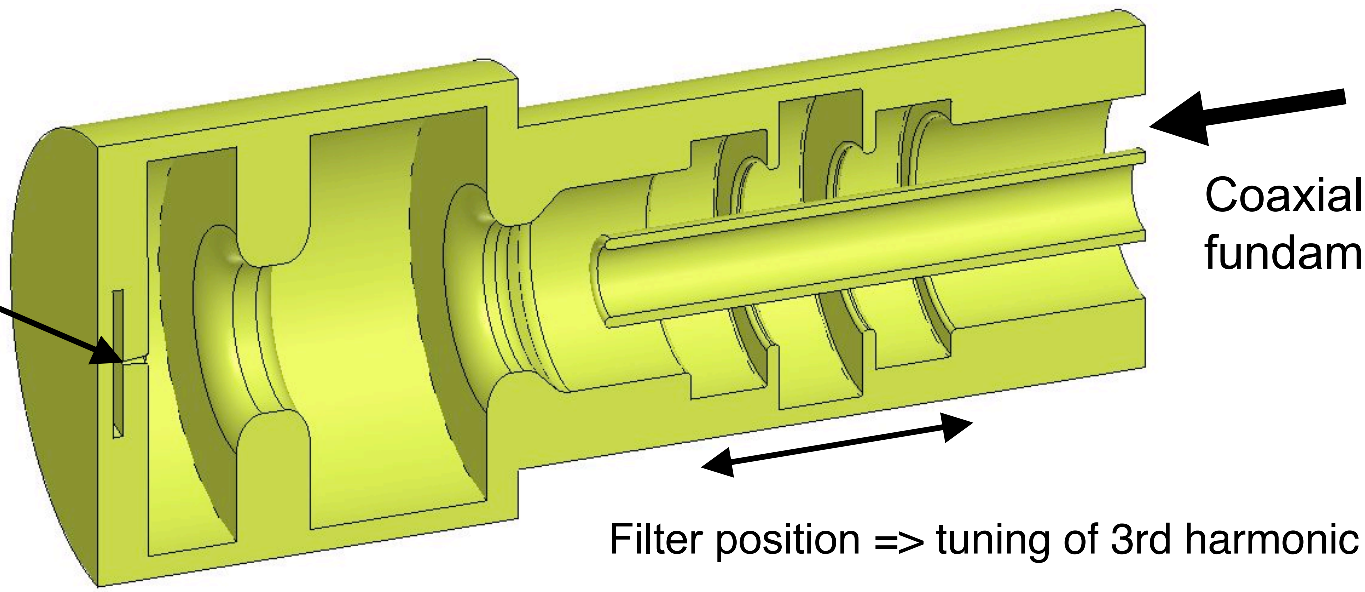


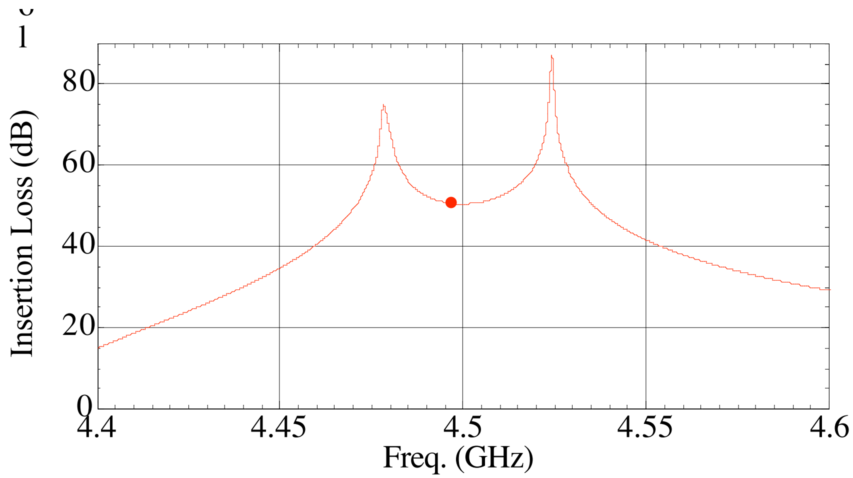


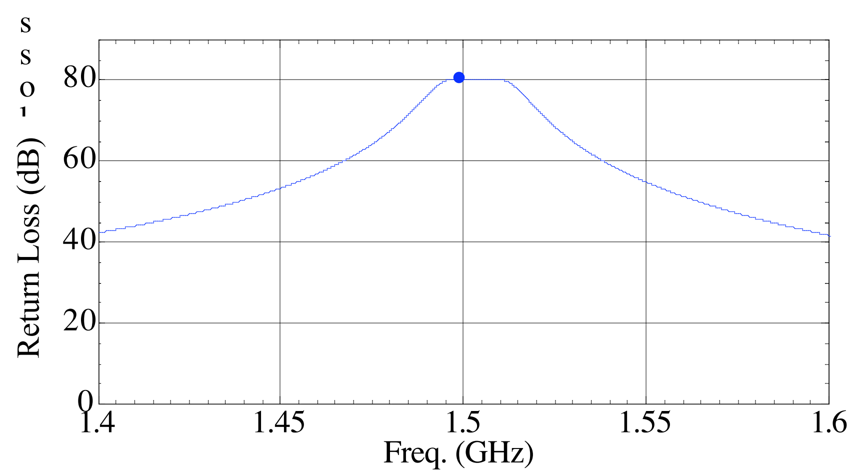
SUPERFISH simulations

Fundamental freq. (MHz)	**1498.956**
π-O mode separation (MHz) *(Optimized for large mode separation)*	**12**
Qo fundamental O mode	**11260**
Q loaded fund. π mode	**9340**
Qo harmonic (~TM_{012})	**19840**
Peak on axis field (MV/m)	**40**
Peak surface field (MV/m)	**48.1**
Peak input power π mode (MW)	**3.3**
Peak input power harmonic (kW)	**280**

Coaxial coupling with 3rd harmonic filter – RF design







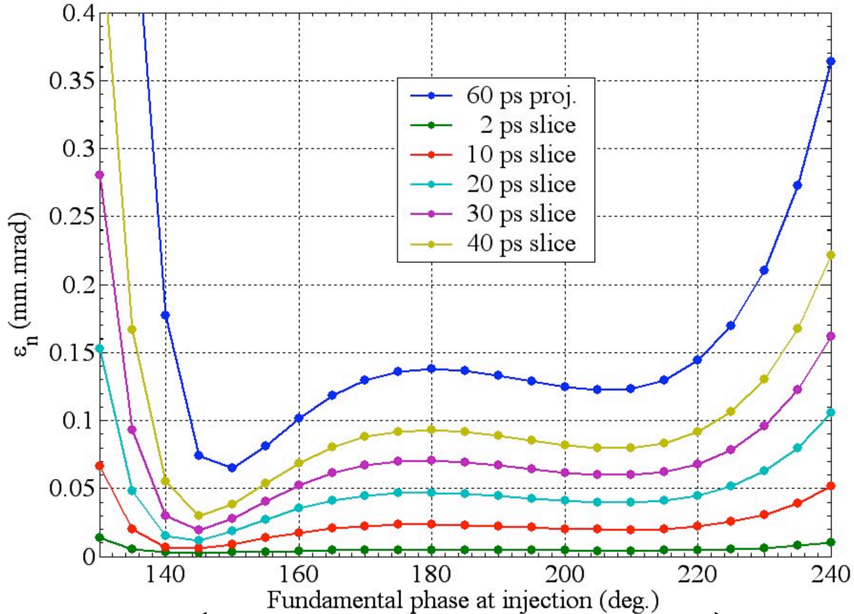
Parmela simulation 1 - Zero current
Gun and Beam parameters

- Diode gap: 4 mm
- Diode voltage: 1 MV (β=0.94*)
- Iris length: 10 mm
- Total pulse duration: 60 ps
- Emitter Radius: 0.25 mm
- Peak RF Voltage: 40 MV/m
- Uniform longitudinal distribution
- Uniform transverse distribution
- No focusing to compensate the iris defocusing

* close to "on crest" injection possible => allowing higher acceleration

Parmela simulation 1 - Zero current RF ε dilution for long pulses

Fundamental alone

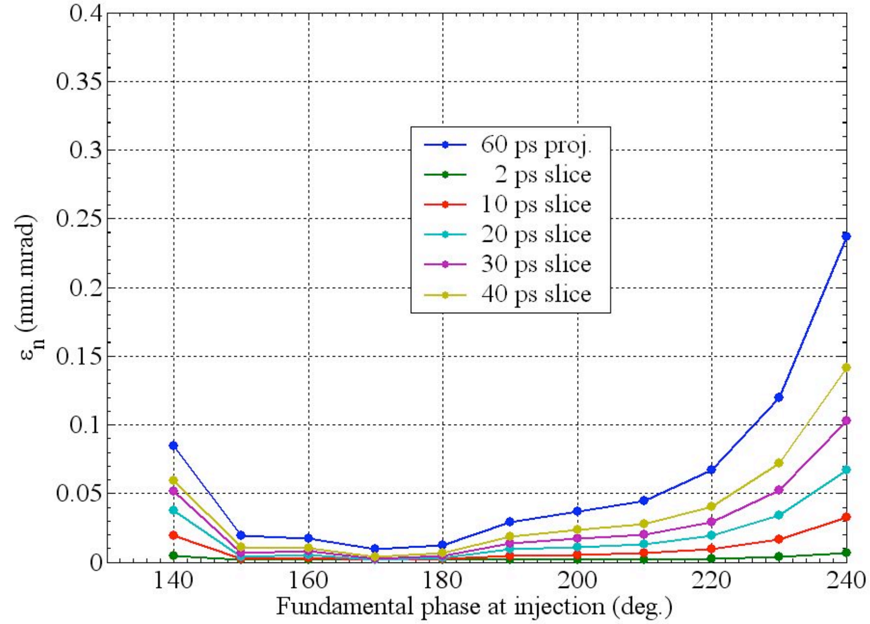


Bunching

De-bunching

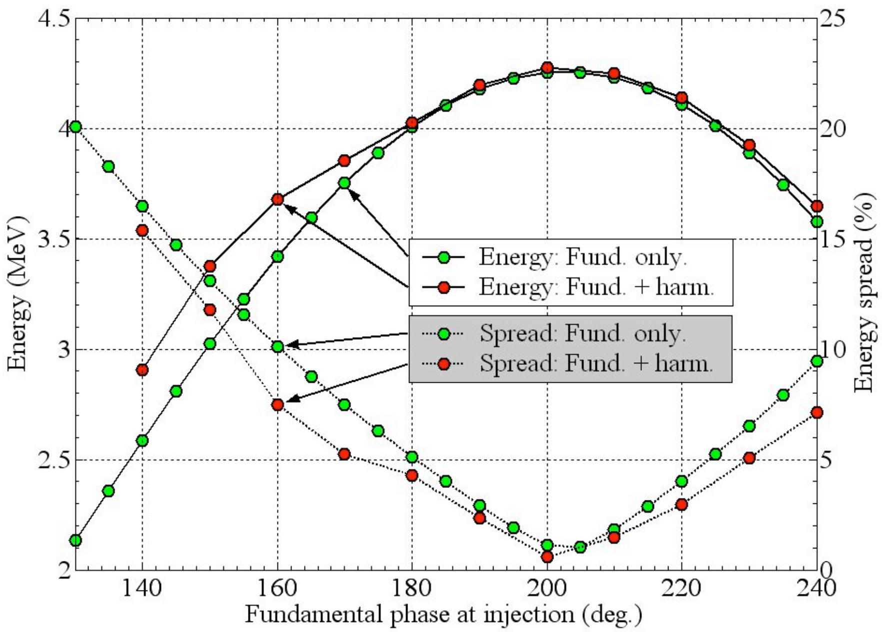
Injection phase ≡ theRF phase of the fubdamental when the first particle of the 60 ps pulse is entering the diode Transit angle for the bunch center to reach the cavity backplane is 26.5 deg.

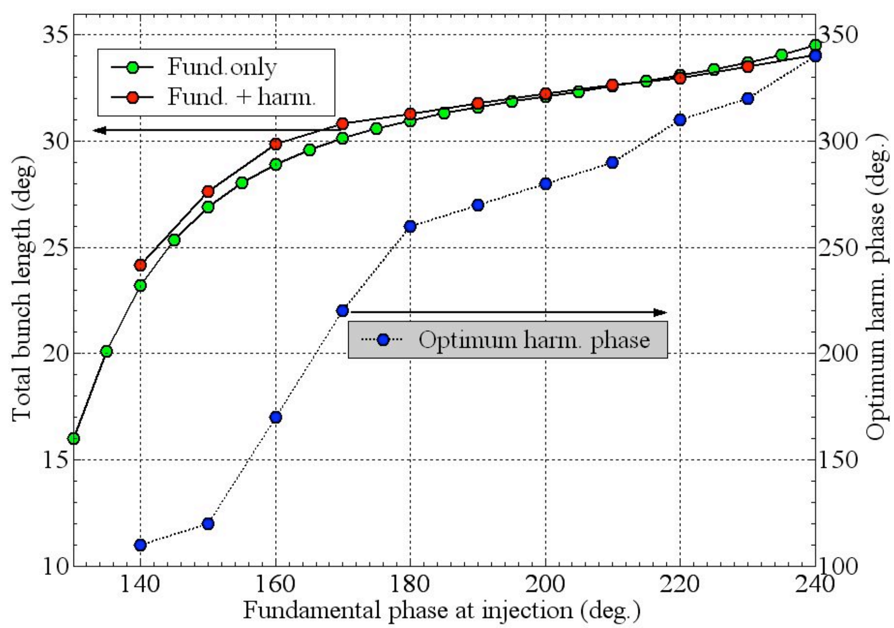
Fundamental + optimized 3rd harm.



The emittance dilution due to the RF with long pulses can be compensated. The third harmonic make the bunching regime accessible from the emittance point of view.

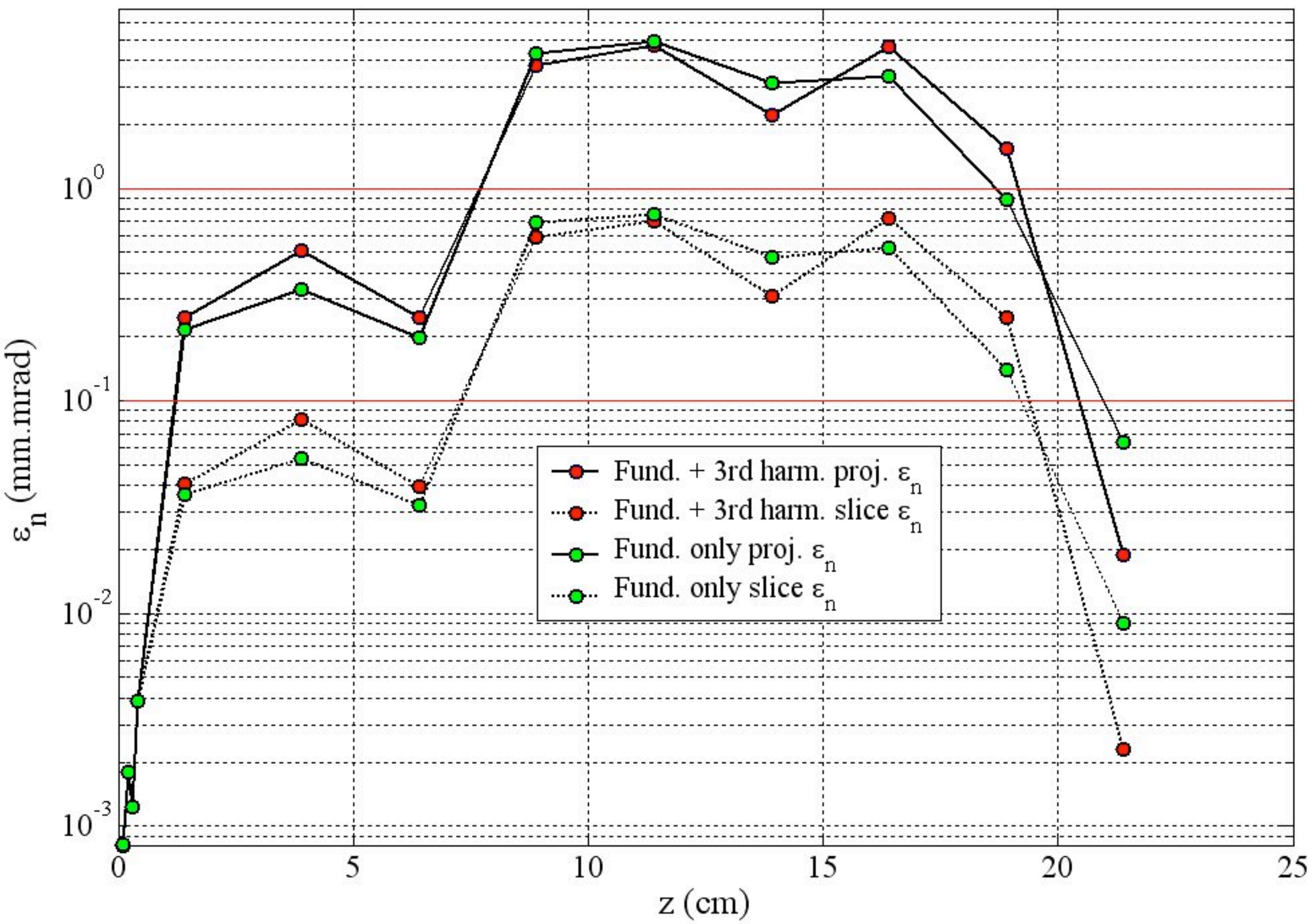
Parmela simulations 1 - Zero current
Energy and energy distribution



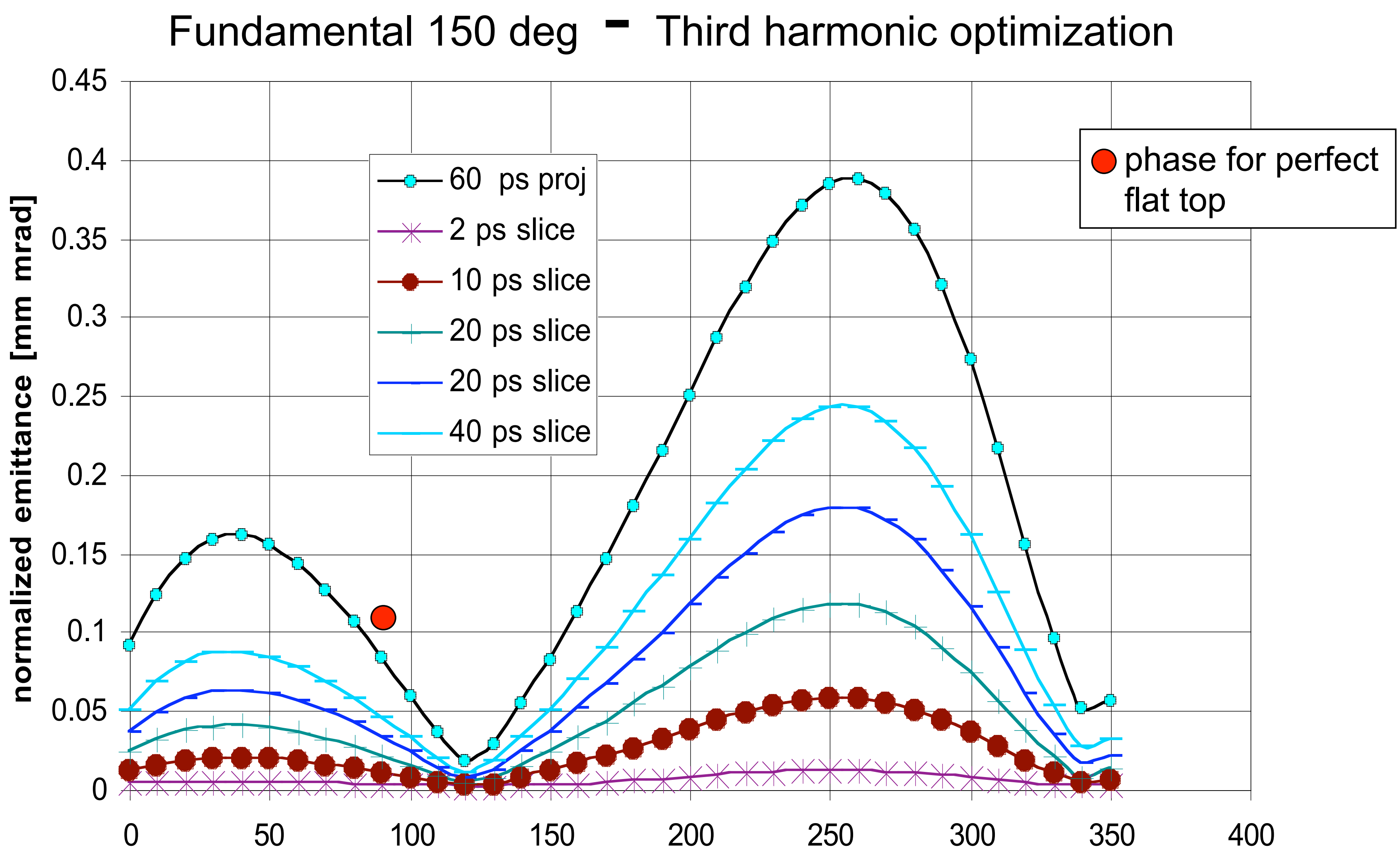


Parmela simulations 1 - Zero current

$\_{norm}$ profile – Fund. Phase 150 deg - harmonic phase 120 deg projected and 10ps slice emittance



Parmela simulations 1 - Zero current

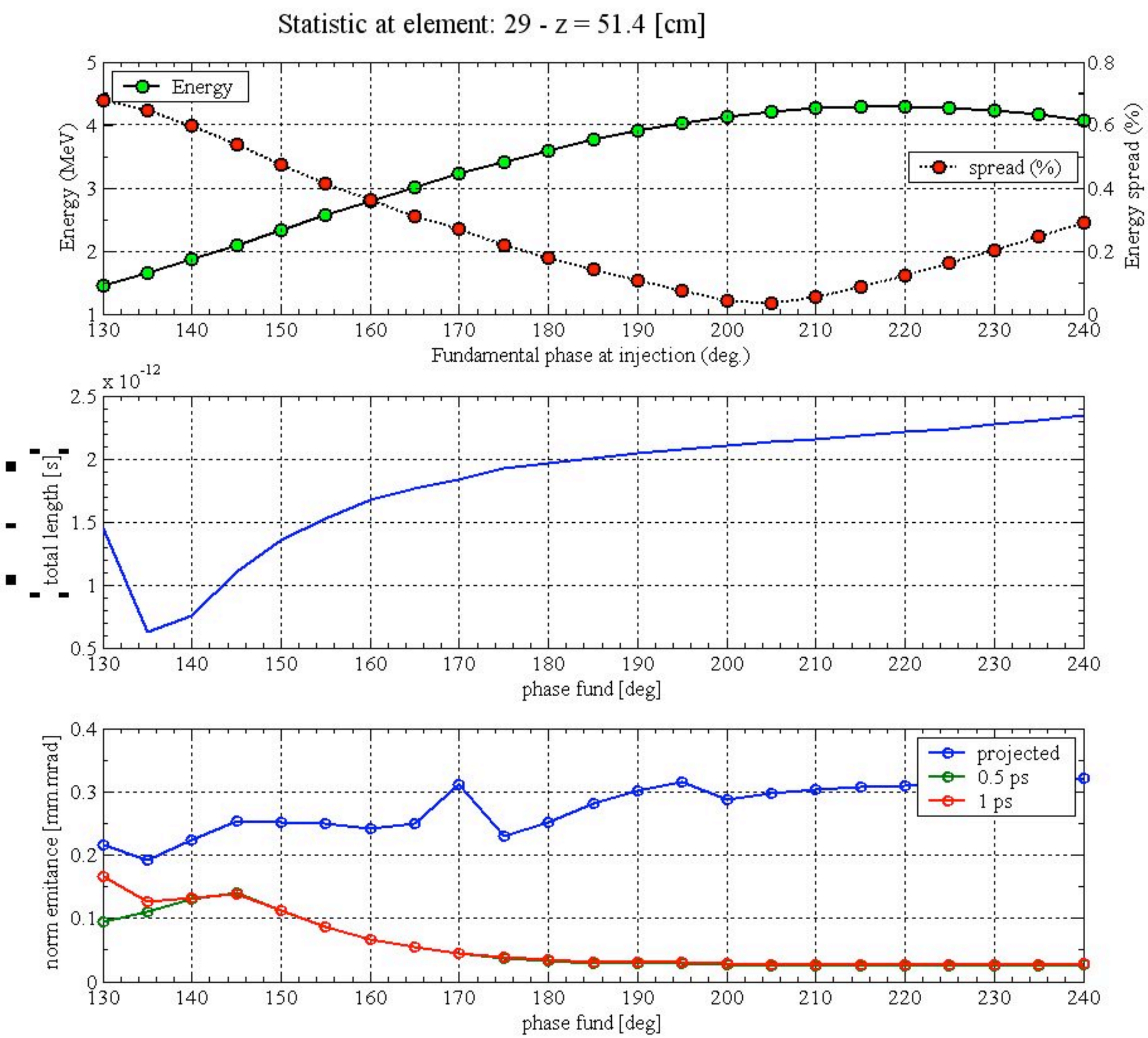


Only a restricted fund. Ph. range around 140-150 deg where two minima of ~ the same magnitude are present.

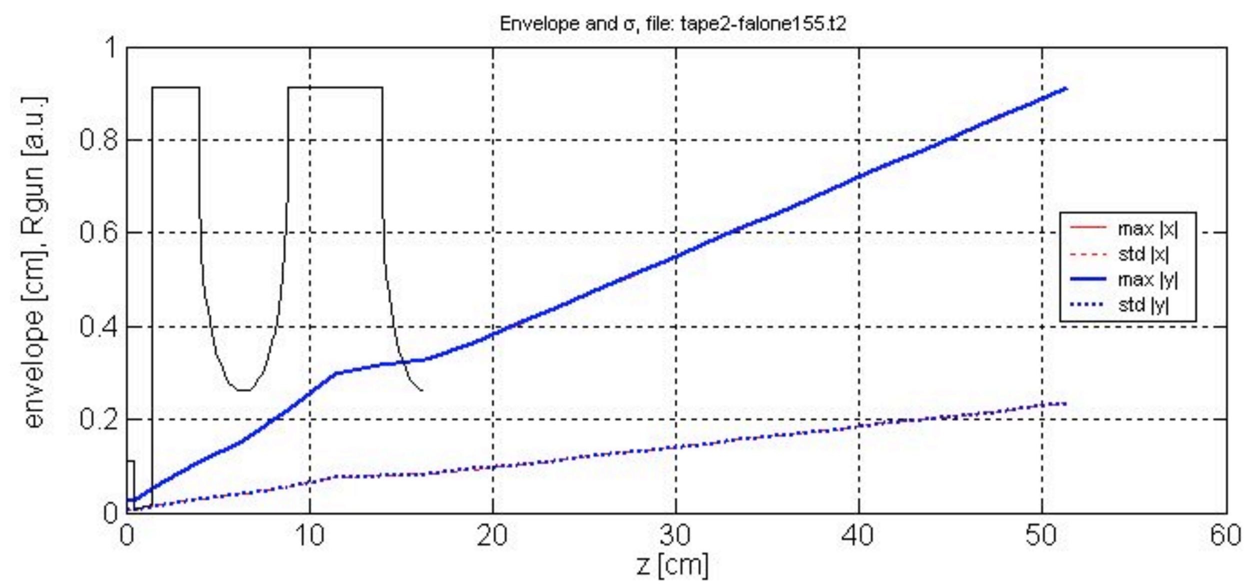
Parmela simulations 2 – 5.5A

Fundamental 150 deg - Third harmonic optimization

- Diode gap: 4 mm
- Diode voltage: 1 MV
- Iris length: 10 mm
- Total pulse duration: **2** ps
- Beam current: **5.5** A
- Emitter Radius: 0.25 mm
- Peak RF Voltage: 40 MV/m
- Uniform transverse distribution
- No focusing to compensate the iris defocusing and/or the emittance dilution due to space charge.
- Fundamental alone
- Uniform longitudinal distribution

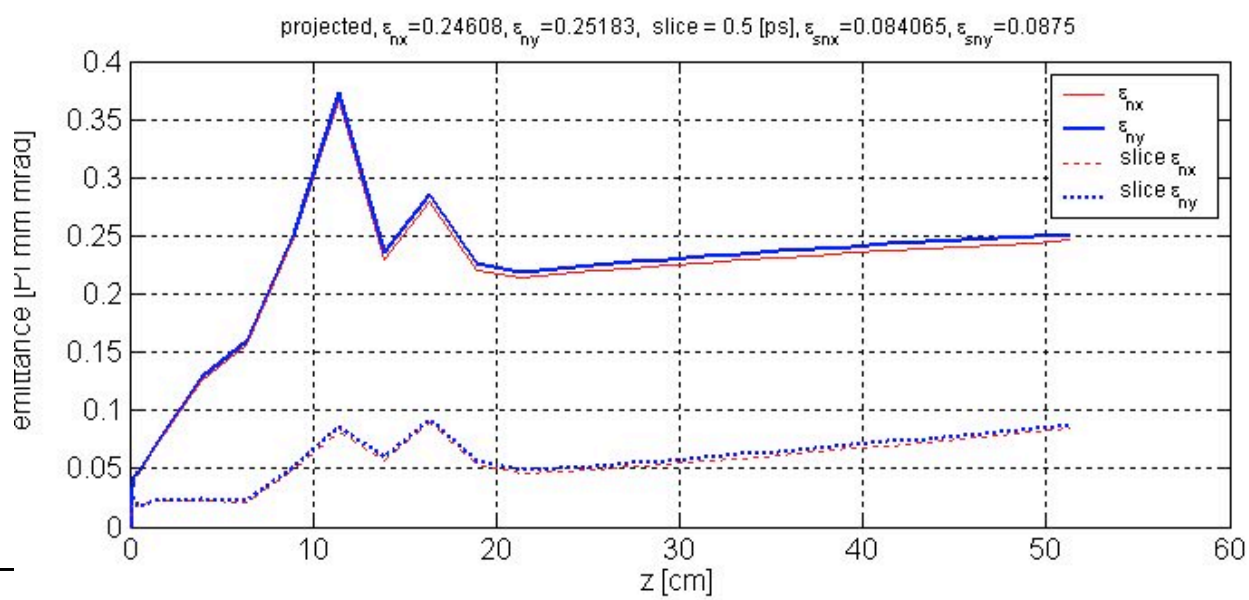

Statistic at element: 29 - z = 51.4 [cm]
Energy
spread (%)
Energy (MeV)
Energy spread (%)
Fundamental phase at injection (deg.)
x 10^-12
total length [s]
phase fund [deg]
norm emitance [mm.mrad]
projected
0.5 ps
1 ps
phase fund [deg]

Beam dynamic 2 – 5.5A Fund. alone – inj. phase = 155 deg



Without focusing the size of the beam explode.

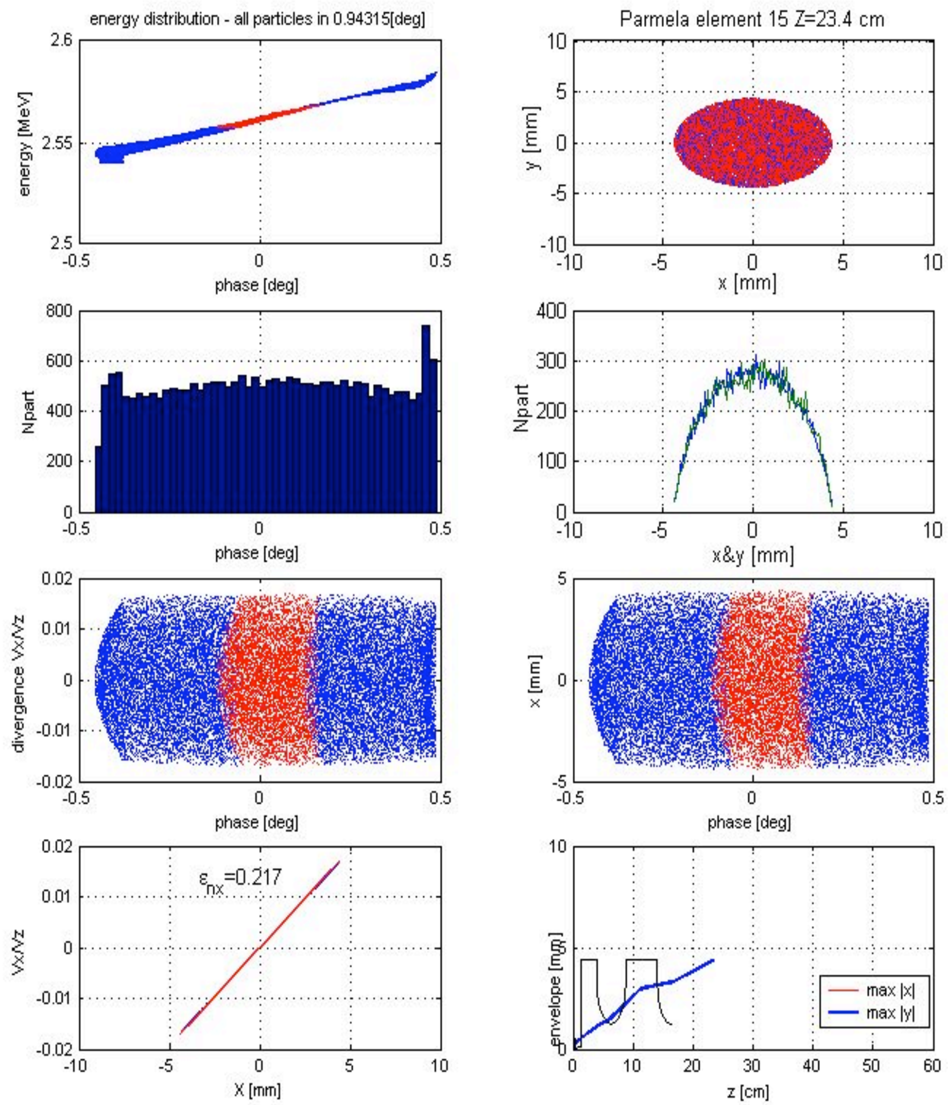
Solenoid around 20 cm needed for re-focusing and emittance compensation.

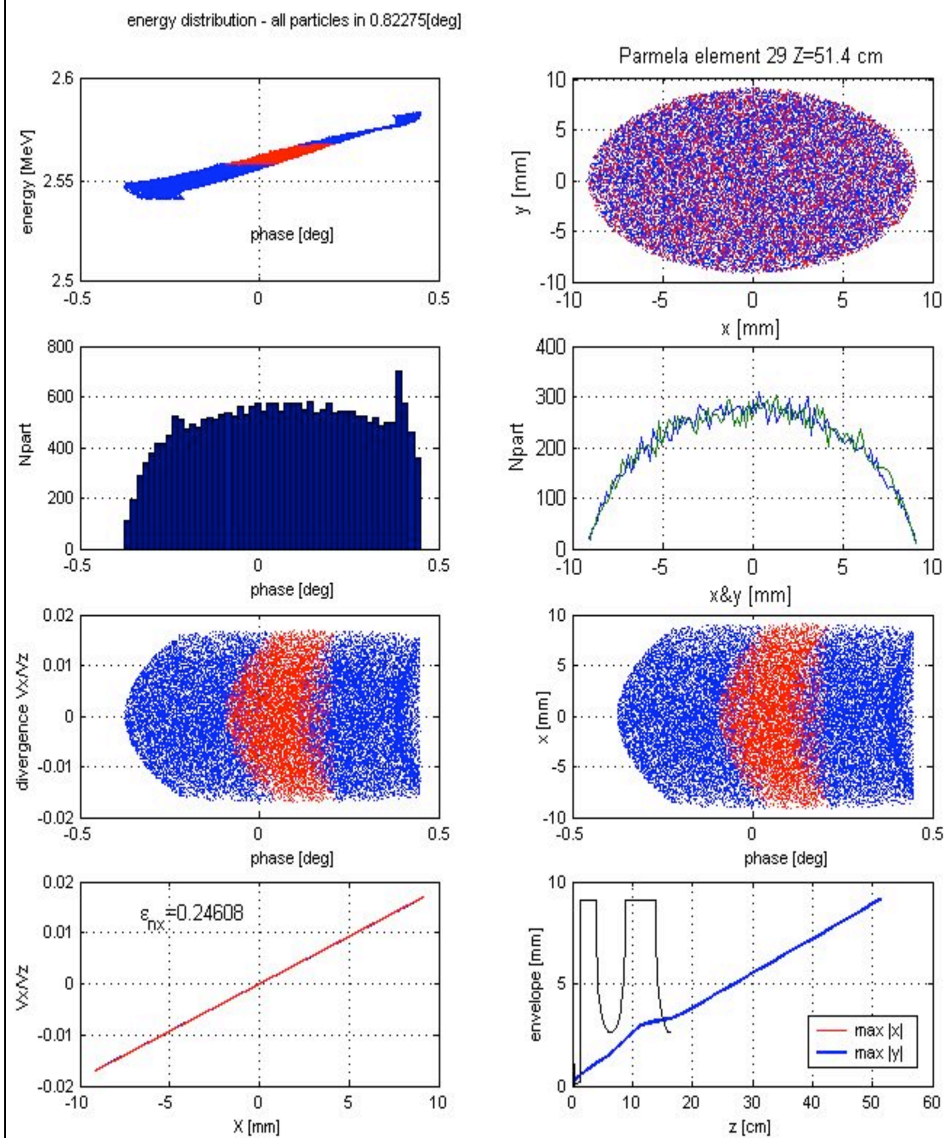


Slice definition here:
All particle within 0.5 ps with respect to the pulse center at the injection. Those particles are then monitored down to the end.

Beam dynamic 2 – 5.5A

Phase space - Injection phase = 155 deg





Conclusions

•Emittance dilution due to time dependent RF forces can be compensated over a large range of input phase (zero current case)

• More flexibility with a two frequency scheme (better for bunching)

• First simulations with space charge are promising. Optimisation with third harmonic and space charge compensation scheme must be introduced.

• Cavity with 1.6 up to 2 cell will be designed to study the benefit of the RF focusing in the first cell.

• Presently investigated the possibility to implement a pulsed solenoid in the input iris.