Calculations with Genesis and ALICE of XFEL Performance at 0.1nm (SASE2)

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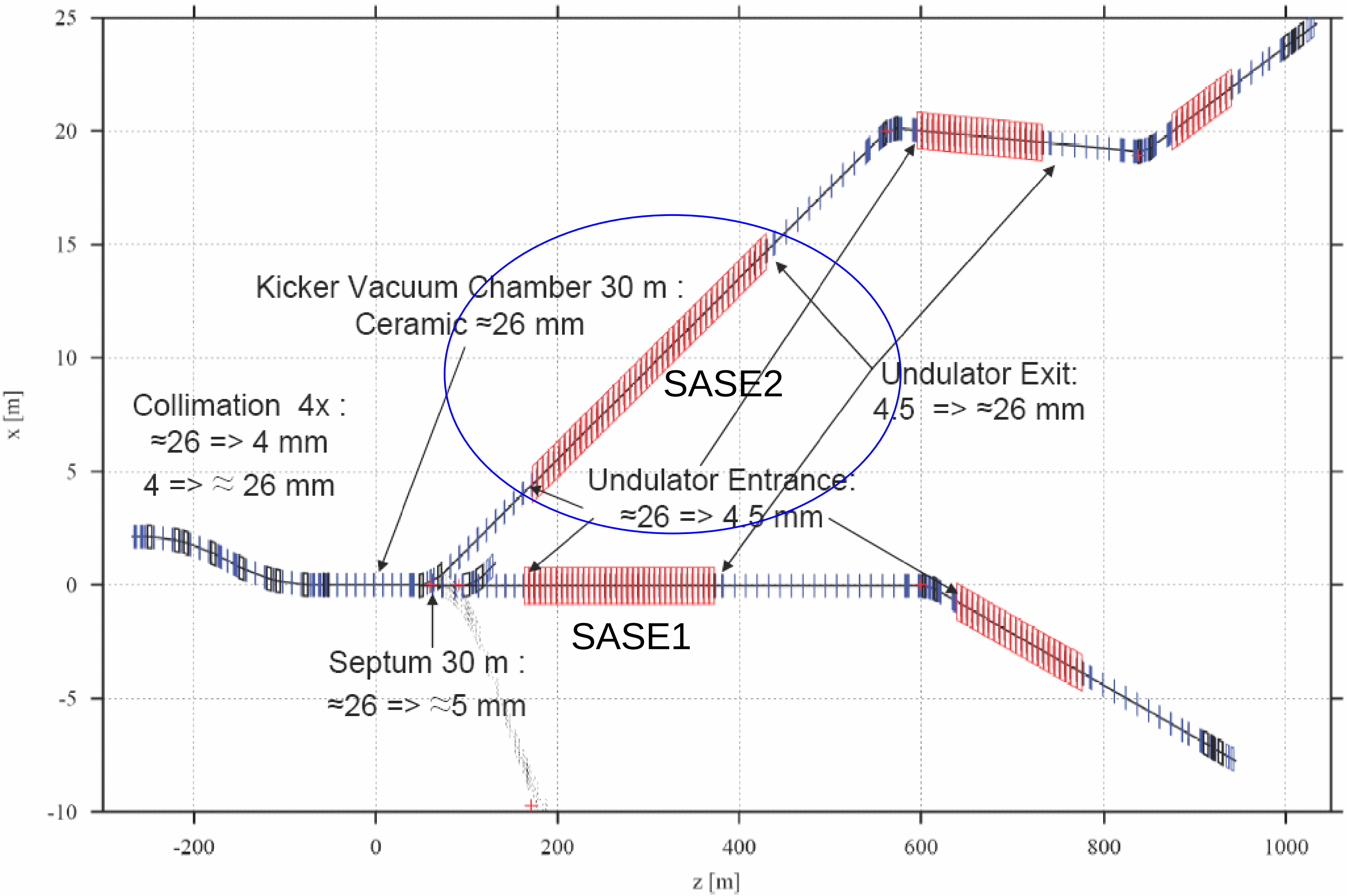
Beam Dynamics Group Meeting

15.01.07


Kicker Vacuum Chamber 30 m :
Ceramic ≈26 mm
Collimation 4x :
≈26 => 4 mm
4 => ≈ 26 mm
SASE2
Undulator Exit:
4.5 => ≈26 mm
Undulator Entrance:
≈26 => 4.5 mm
SASE1
Septum 30 m :
≈26 => ≈5 mm
x [m]
z [m]
25
20
15
10
5
0
-5
-10
-200
0
200
400
600
800
1000

W.Decking

XFEL Source Parameters

General properties of XFEL sources

- Operation at fixed electron energy 17.5 GeV
- Continuos covering of design wavelength range with three SASE FELs

Electron beam

	Units	
Energy	GeV	17.5
Bunch charge	nC	1
Peak current	kA	5
Bunch length (rms)	μm	25
Norm. emittance (rms)	mm-mrad	1.4
Energy spread (rms)	MeV	1.5
# bunches p. pulse	#	3250
Repetition rate	Hz	10

Undulators:

	λ_r nm	λ_u mm	L_W m
SASE1	0.1	35.6	200
SASE2	0.1–0.4	48	260
SASE3	0.4–1.6	65	130
Possible XUV option			
SASE4	1.6–6.4	110	80

Normalized FEL model
(~Saldin et al, 2000 „The Physics …“, 1D normalization)

$$\frac{d\psi_i}{d\hat{z}} = \hat{P}_i + \hat{C}$$

$$\hat{E}_z(\psi_i, \vec{r}_i^{\perp}) = \frac{\hat{\Lambda}_p^2(\vec{r}_i^{\perp})}{j^{(0)}(\vec{r}_i^{\perp})} \sum_{n=1}^{\infty} \frac{j^{(n)}(\vec{r}_i^{\perp})}{n} \sin(n\psi_i + \psi^{(n)}(\vec{r}_i^{\perp}))$$

$$\frac{d\hat{P}_i}{d\hat{z}} = \hat{u}(\vec{r}_i^{\perp})\cos\left[\psi_i + \psi_r(\vec{r}_i^{\perp})\right] - \hat{E}_z(\psi_i, \vec{r}_i^{\perp})$$

$$\left[\frac{1}{2iB}\Delta_{\perp} + \frac{d}{d\hat{z}}\right]\hat{u}(\vec{r}_i^{\perp}) = -2a^{(1)}(\vec{r}_i^{\perp})$$

$$\Gamma = \sqrt[3]{\frac{\pi j_0 \theta_s^2 \omega A_{JJ}^2}{\gamma_0 \gamma_z^2 I_A c}}$$

$$\hat{\Lambda}_p^2 = \frac{4\pi j_0}{\omega \theta_s E_0}$$ - space charge parameter

$$\rho = \frac{c\gamma_z^2 \Gamma}{\omega}$$

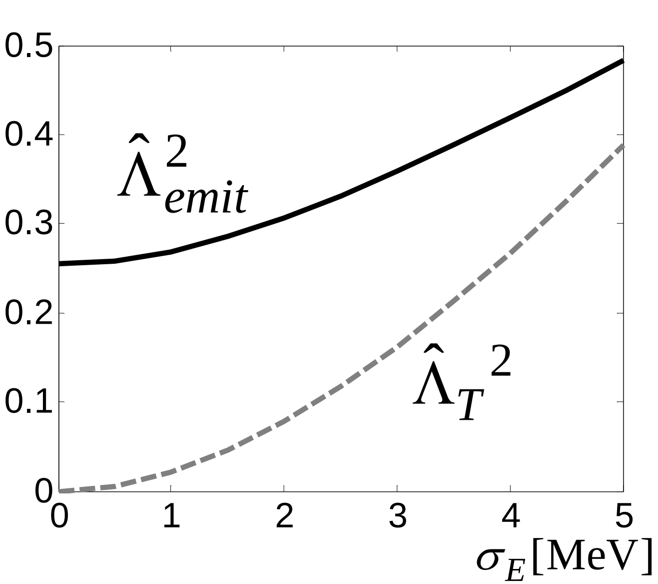
$$\hat{\Lambda}_T^2 = \frac{\sigma_\varepsilon^2}{\rho^2 \varepsilon_0^2}$$ - energy spread parameter

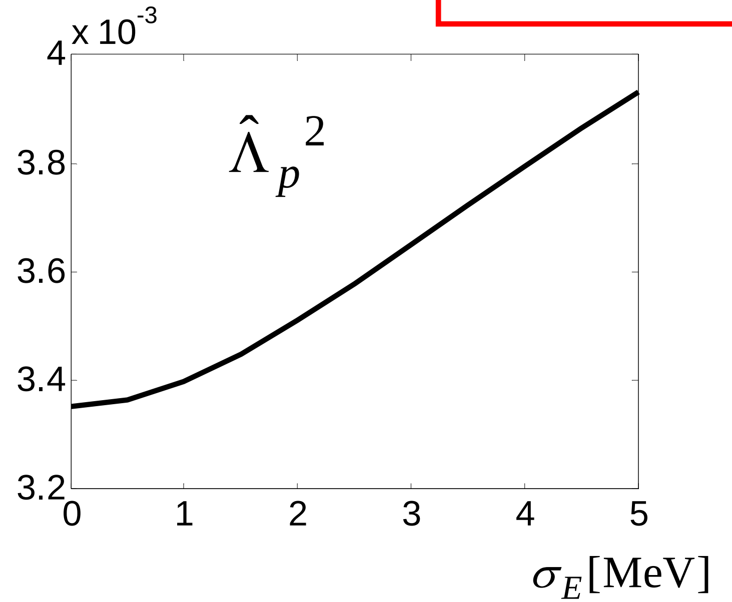
$$\hat{\Lambda}_{emit}^2 = \frac{\gamma_{z0}^4 \varepsilon^2}{\rho^2 \beta^2}$$ - effective energy spread (emittance) parameter

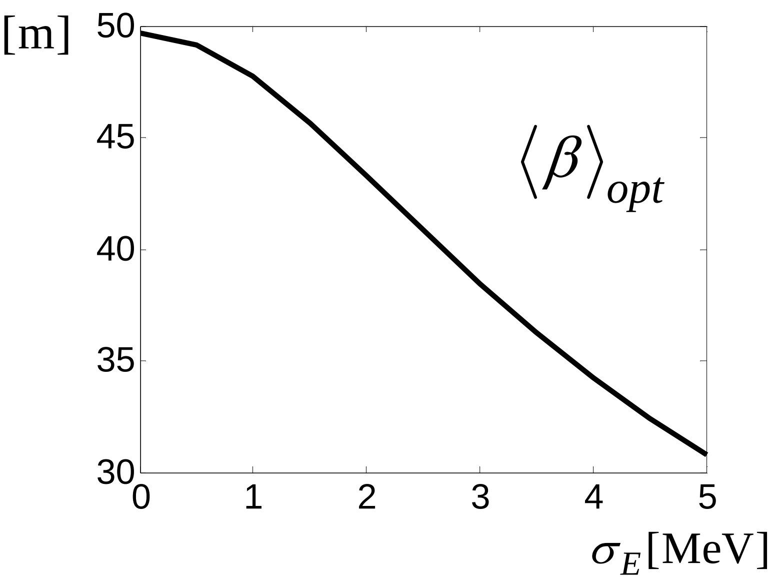
$\lambda = 0.1\text{nm}$

Normalized parameters

$\varepsilon_n = 1.4\,\text{mm}\times\text{mrad}$







$$\beta_{\text{opt}} \simeq 11.2 \left(\frac{I_A}{I}\right)^{1/2} \frac{\epsilon_n^{3/2}\lambda_{\text{w}}^{1/2}}{\lambda_r K A_{JJ}} (1+8\delta)^{-1/3}$$

$$\delta = 131\ \frac{I_A}{I}\ \frac{\epsilon_n^{5/4}}{\lambda_r^{1/8}\lambda_{\text{w}}^{9/8}}\ \frac{\sigma_\gamma^2}{(KA_{JJ})^2(1+K^2)^{1/8}}\ .$$

DESY 04-012

January 2004

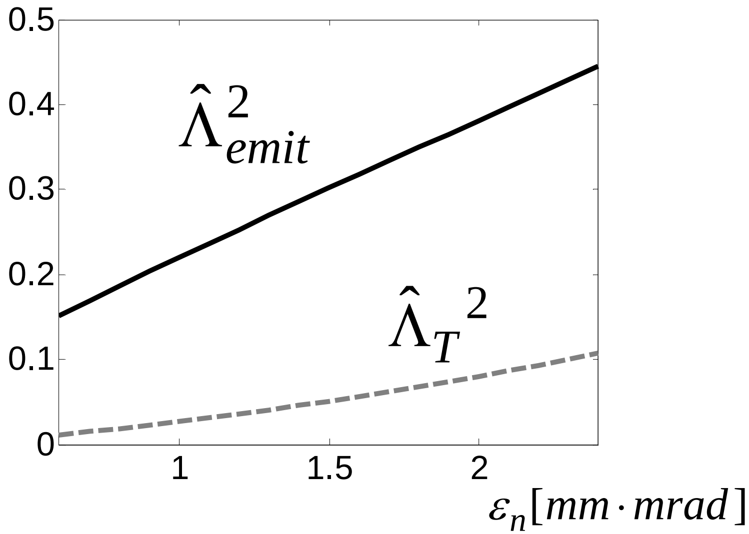
Design formulas for short-wavelength FELs

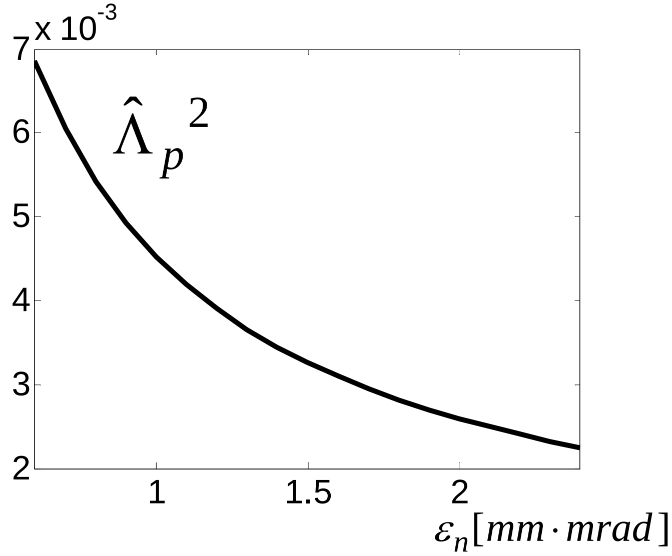
E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov

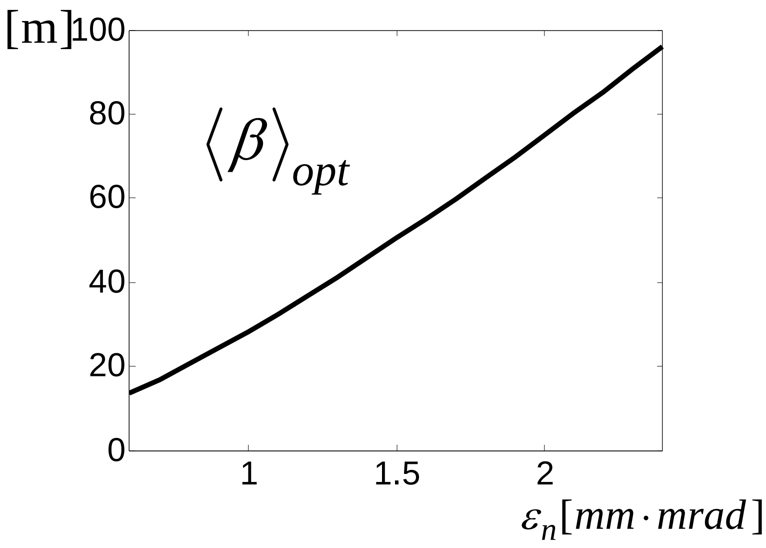
$\lambda = 0.1\,\mathrm{nm}$

Normalized parameters

$\sigma_E = 1.5\,\mathrm{MeV}$



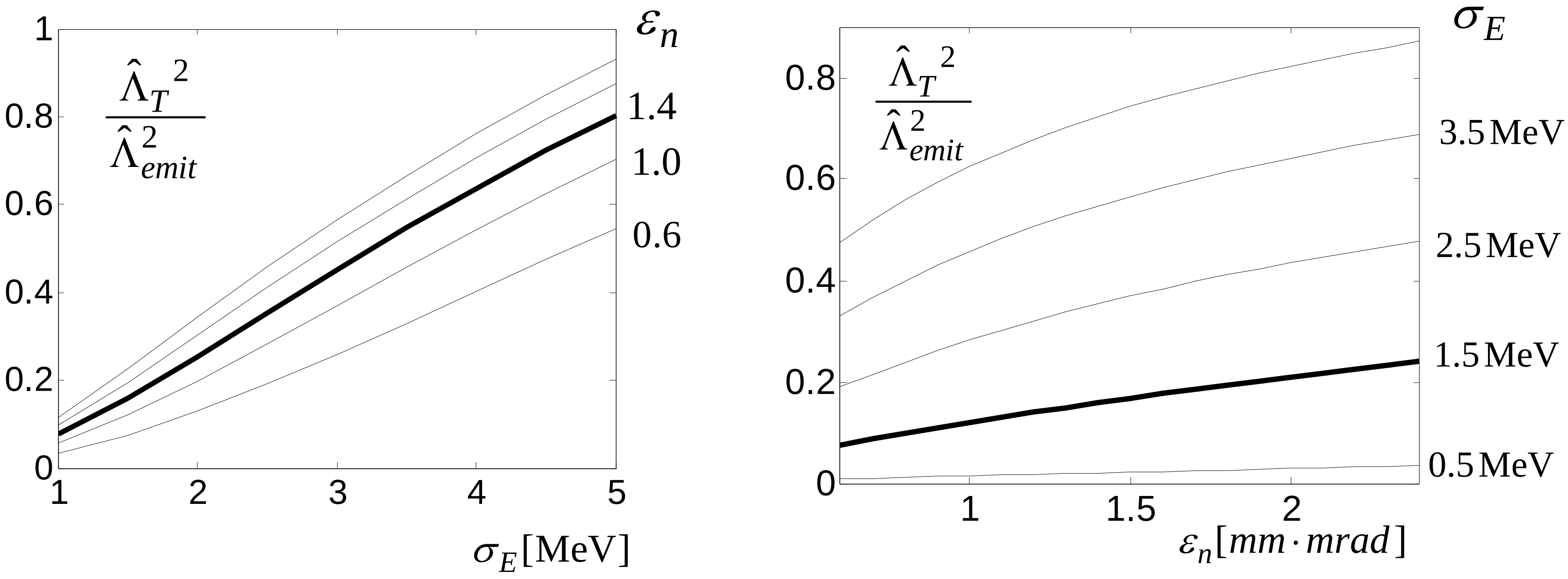




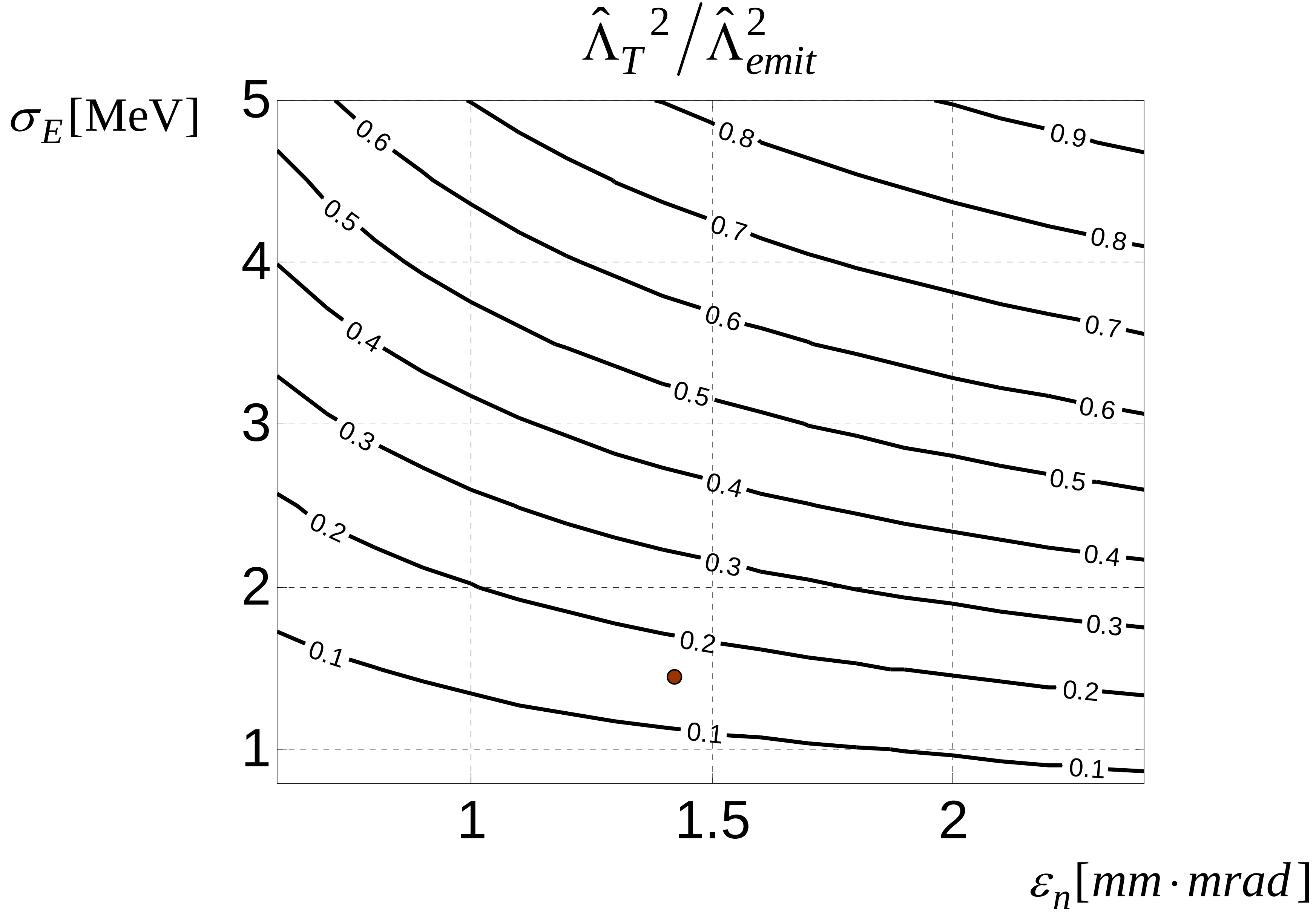
- Most important is effect of emittance.
- Longitudinal space charge field can be neglected

Normalized parameters

$$\lambda = 0.1\text{nm}$$

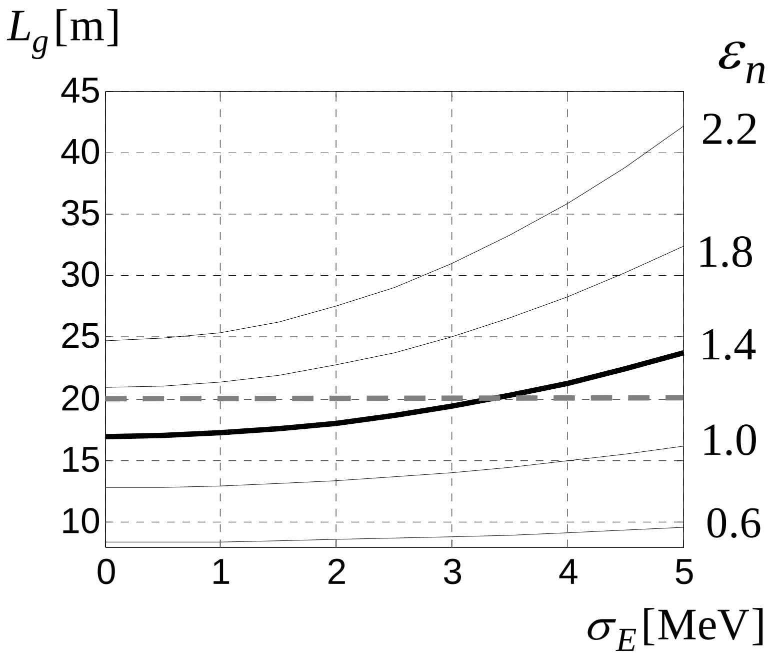


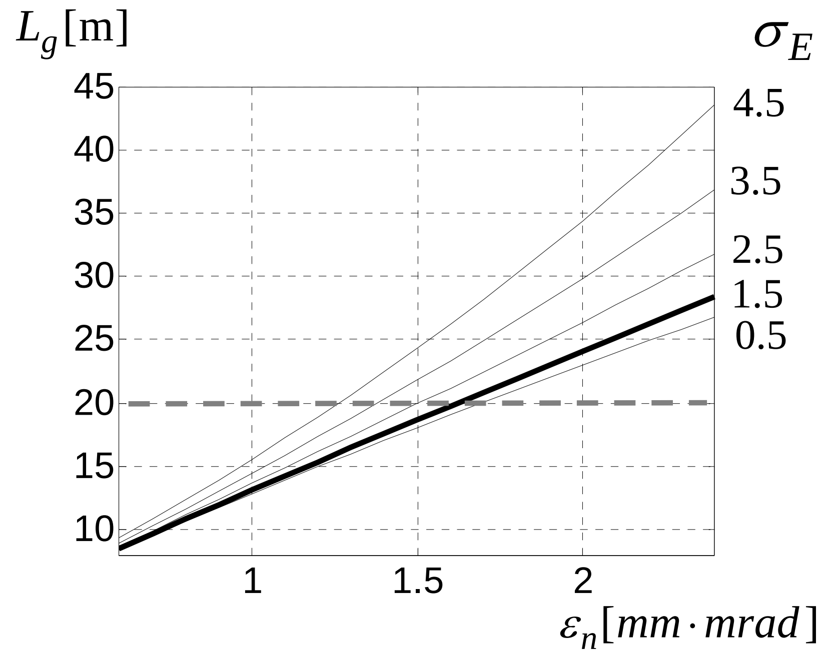
Normalized parameters



Gain length scan

$\lambda = 0.1\text{nm}$





$$L_g \simeq L_{g0}\,(1+\delta)\ ,$$

$$L_{g0} = 1.67\left(\frac{I_A}{I}\right)^{1/2}\frac{(\epsilon_n\lambda_{\rm w})^{5/6}}{\lambda_r^{2/3}}\ \frac{(1+K^2)^{1/3}}{KA_{JJ}}\ ,$$

$$\delta = 131\ \frac{I_A}{I}\ \frac{\epsilon_n^{5/4}}{\lambda_r^{1/8}\lambda_{\rm w}^{9/8}}\ \frac{\sigma_\gamma^2}{(KA_{JJ})^2(1+K^2)^{1/8}}$$

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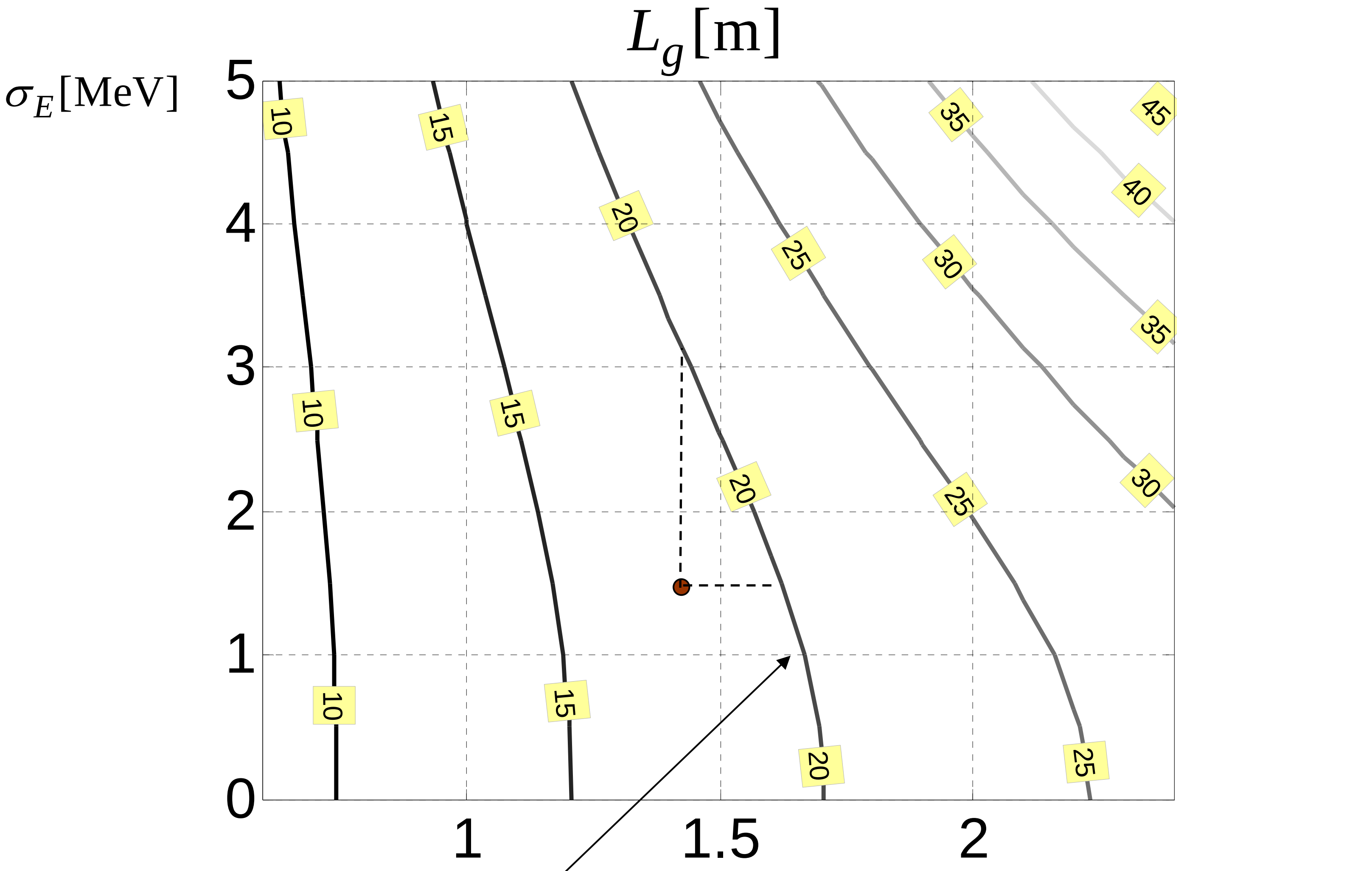


$L_g \simeq 0.1 L_{sat}$

Genesis

- only 3D
- 3D Cartesian field solver (ADI)
- Runge-Kutta integrator
- Dirichlet boundary conditions
- **transversal motion**
- many other physics

$$\frac{d\psi_i}{d\hat{z}} = k_w - \frac{1 + K^2 + p_x^2 + p_y^2 + \ldots}{2\gamma^2}$$

ALICE

- 1D/2D/3D
- 3D azimuthal field solver (Neumann)
- Leap-Frog integrator
- Perfectly Matched Layer
- **parallel motion**
- tested by me on the examples from the book of SSY

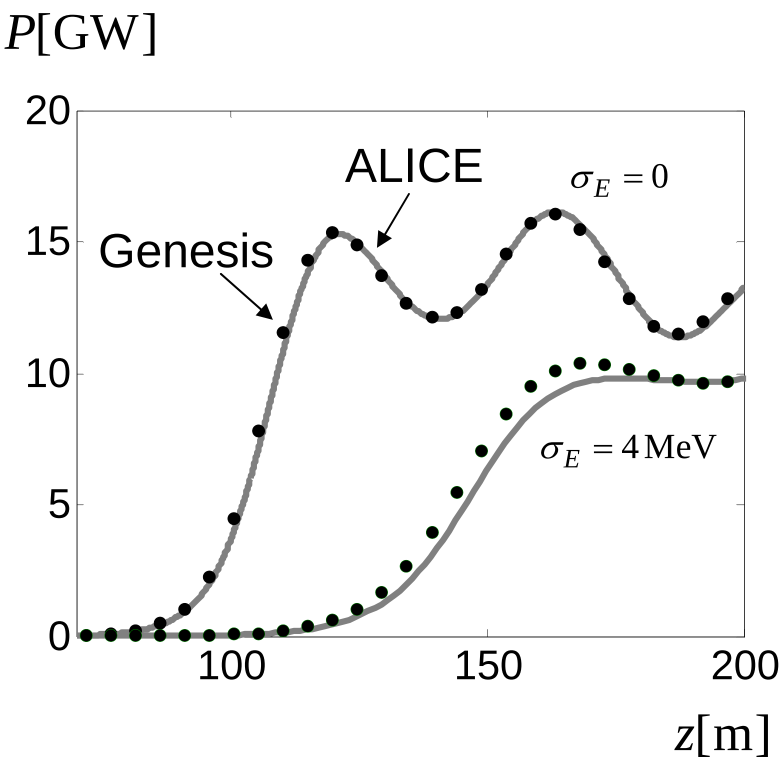
(~Saldin et al, 2000 „The Physics …“,)

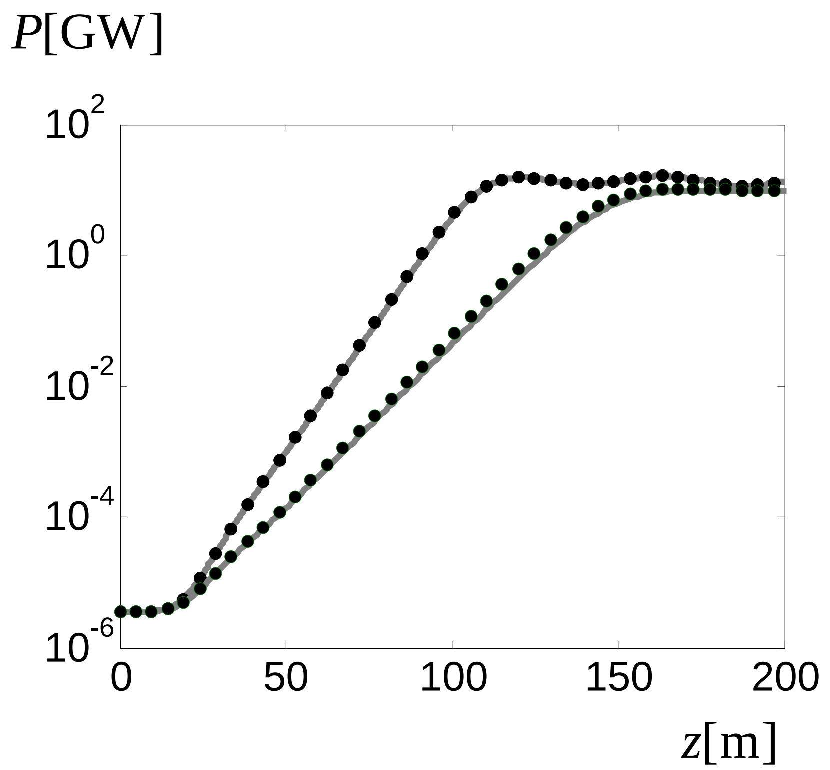
$$\frac{d\psi_i}{d\hat{z}} = \hat{P}_i + \hat{C}$$

$$P = \varepsilon - \varepsilon_0$$

$$C \equiv k_w + \frac{\omega}{c} - \frac{\omega}{v_z(\varepsilon_0)}$$

Genesis vs. ALICE / Energy Spread
(round Gaussian beam, Gaussian energy spread, **parallel motion only**)





$$C = 0$$

$$\sigma_r = 4.4038\text{e-}005\text{m}$$

How to simulate emmitance with parallel particle motion only?

$$\hat{\Lambda}_T{}^2 = \frac{\sigma_\varepsilon{}^2}{\rho^2 \varepsilon_0{}^2} \qquad \hat{\Lambda}_{emit}{}^2 = \frac{\gamma_{z0}^4 \varepsilon^2}{\rho^2 \beta^2}$$

$$\boxed{\hat{\Lambda}_{T,eff}^2 = \hat{\Lambda}_T^2 + a\hat{\Lambda}_{emit}^2}$$

$a = \frac{1}{4}$ -E. Saldin et al, TESLA-FEL 95-02 (1995);
S.Reiche PhD Thesis (1999).

$a = 1$ - E. Saldin et al, The Physics of Free Electron Lasers (2000)

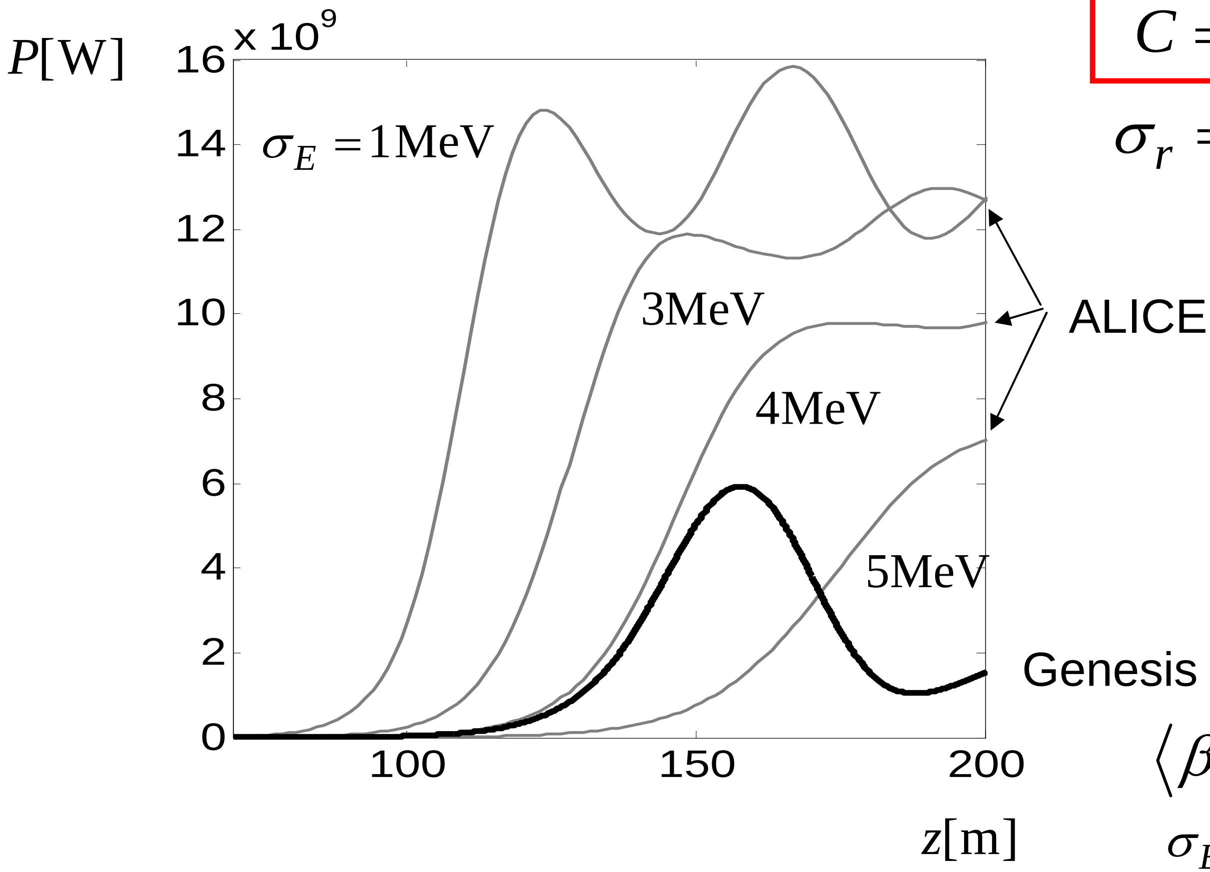
$a = 2$ - E. Saldin et al, DESY 05-164 (2005)

$\varepsilon_n = 1.4\ \text{mm}\times\text{mrad}$

Genesis vs. ALICE / Emmitance
(round Gaussian beam, Gaussian energy spread)

$C = 0$

$\sigma_r = 4.4038\text{e-}005\text{m}$



$\langle\beta\rangle = 47.44\text{m}$

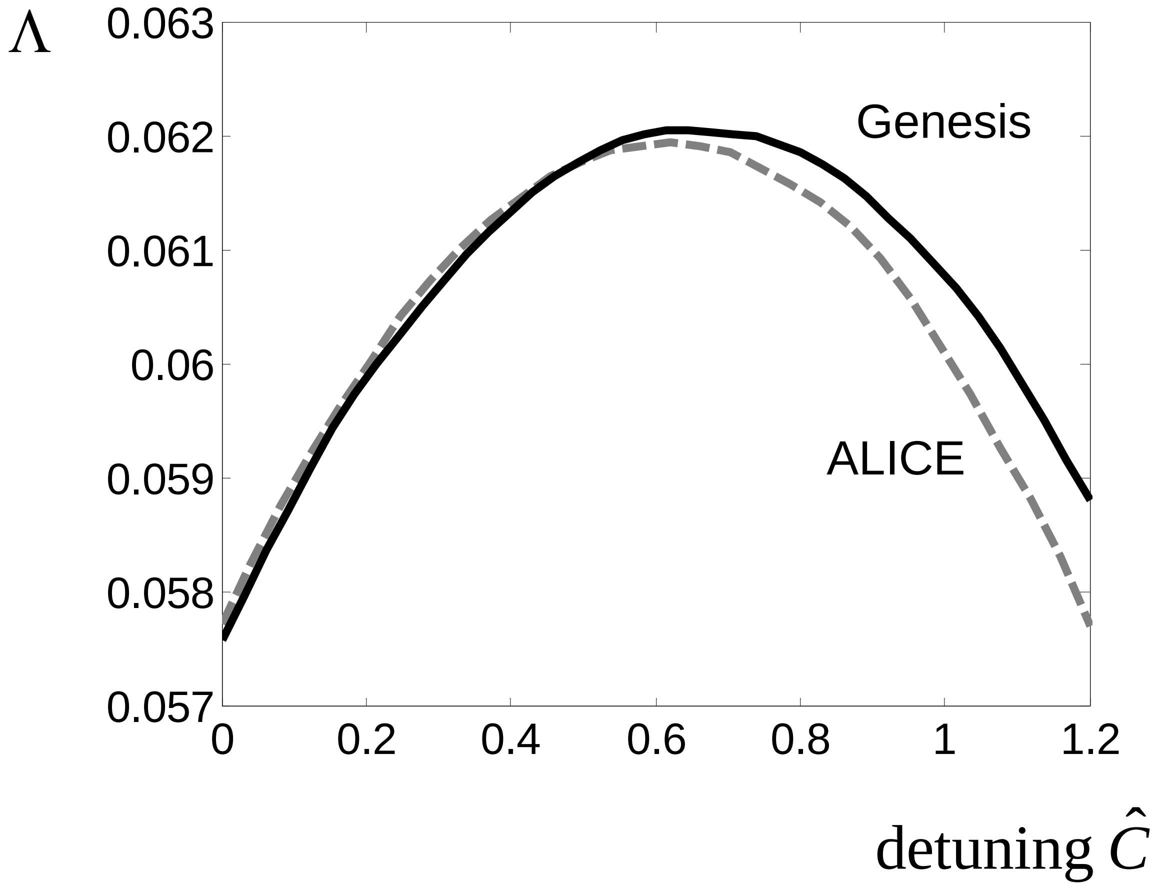
$\sigma_E = 1\text{MeV}$

$\varepsilon_n = 1.4\ \text{mm}\times\text{mrad}$

Genesis vs. ALICE (emittance parameter fit)

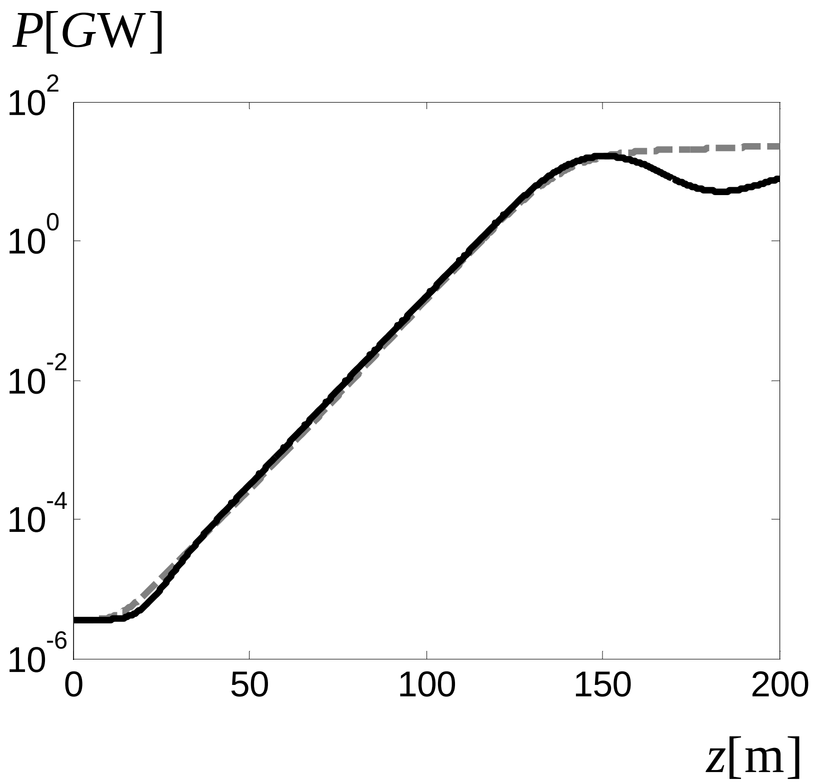
$$a = 1.1$$

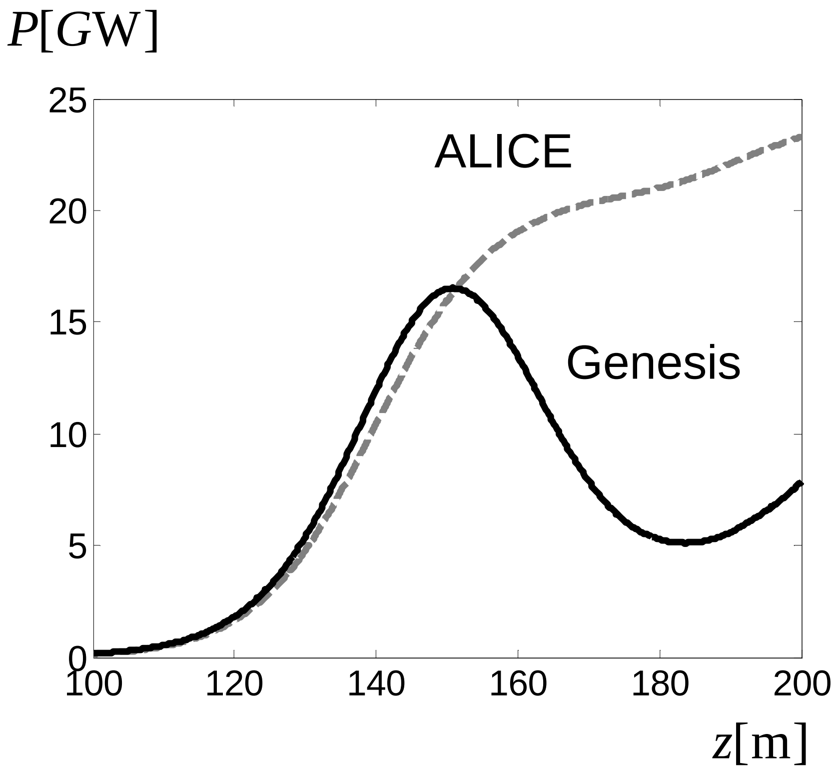
Field growth rate



Genesis vs.ALICE (emittance models)

$$a = 1.1$$

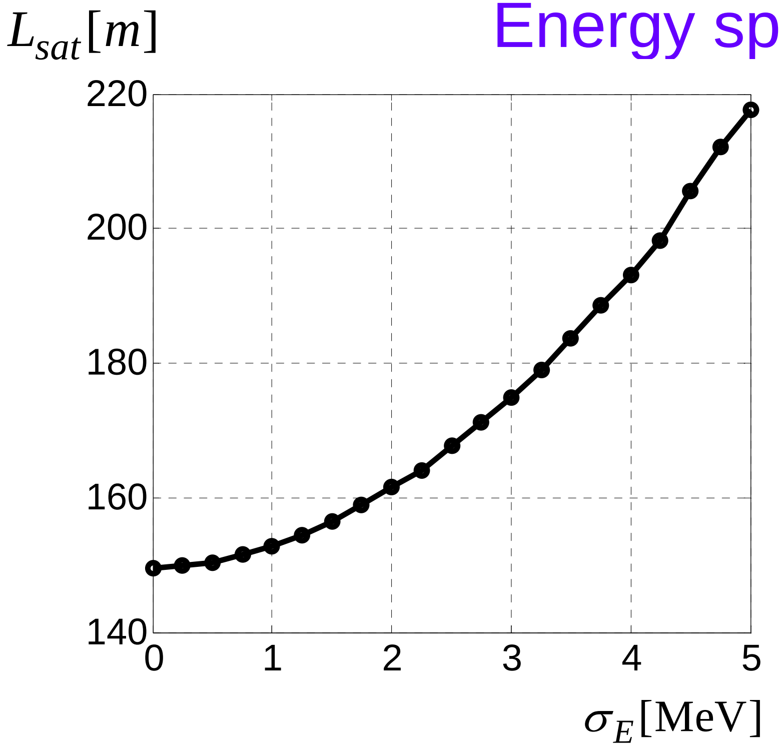


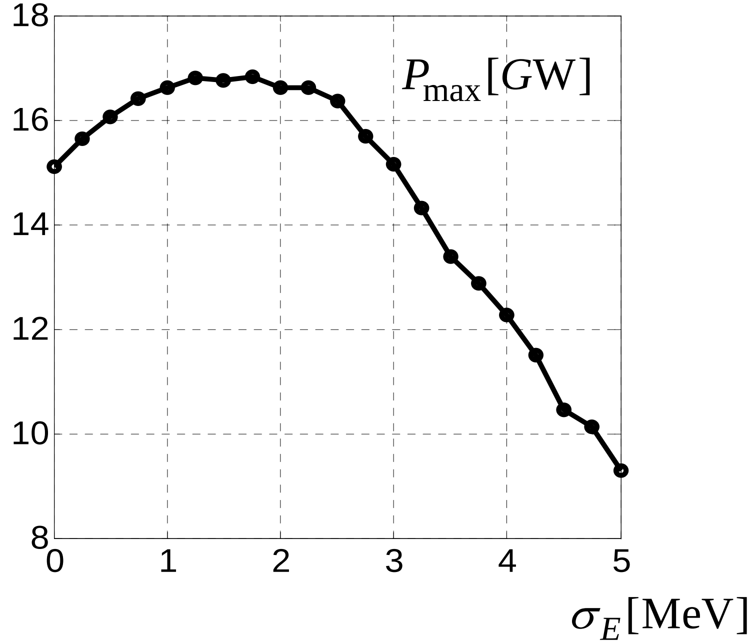


Detuning corresponds to maximal growth rate in linear regime

$$\Lambda(C_0) = \max_{C} \Lambda$$

Energy spread scan (Genesis)





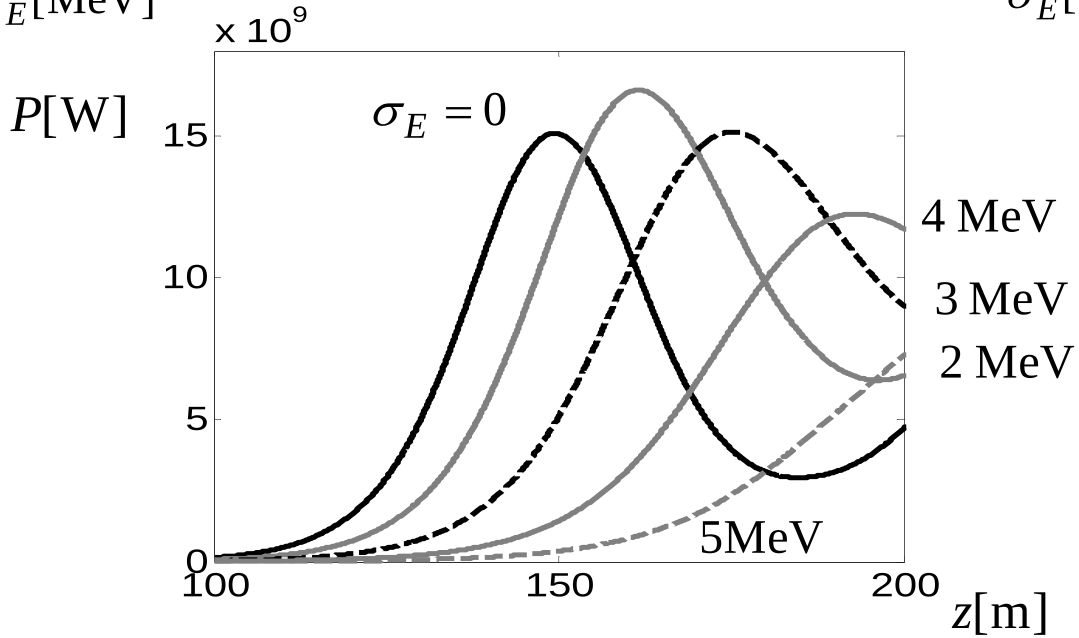
$\varepsilon_n = 1.4$ mm×mrad

$$\Lambda(C_0) = \max_C \Lambda$$

$$\langle\beta\rangle = 47.44\text{m}$$

Should be

$$\langle\beta\rangle = \langle\beta\rangle_{opt}$$



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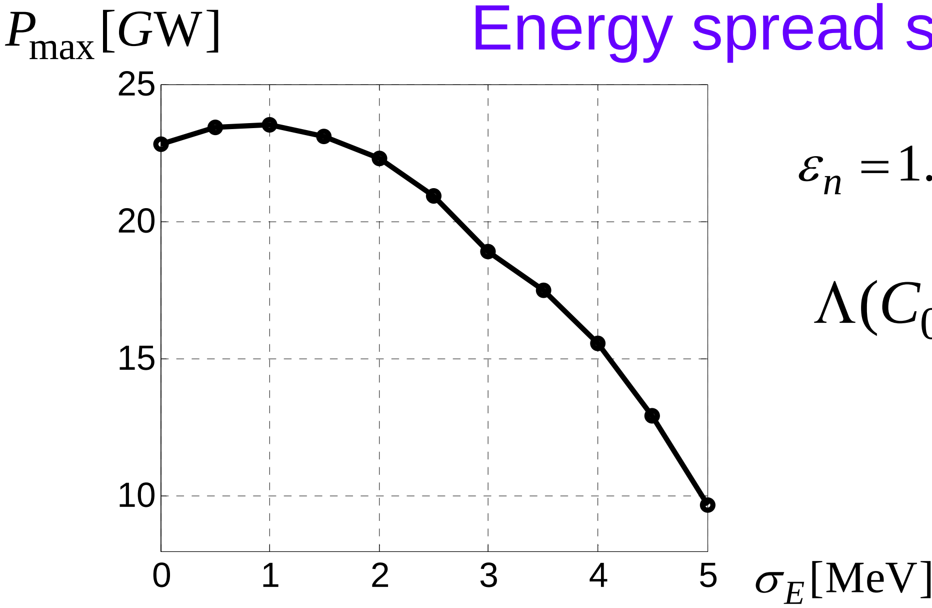

$$\varepsilon_n = 1.4\ \mathrm{mm}\times\mathrm{mrad}$$

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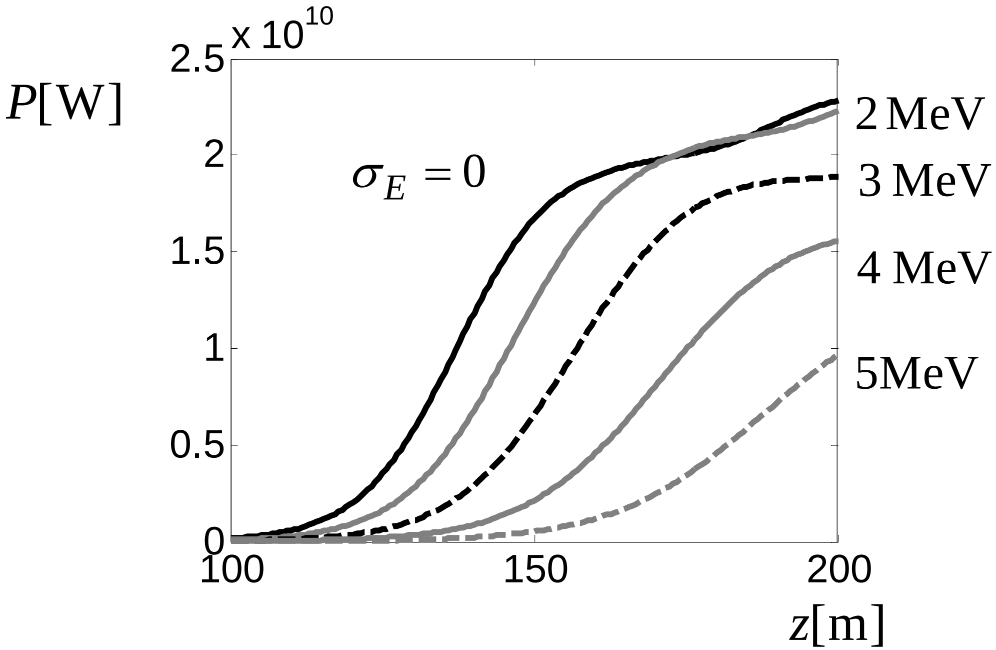
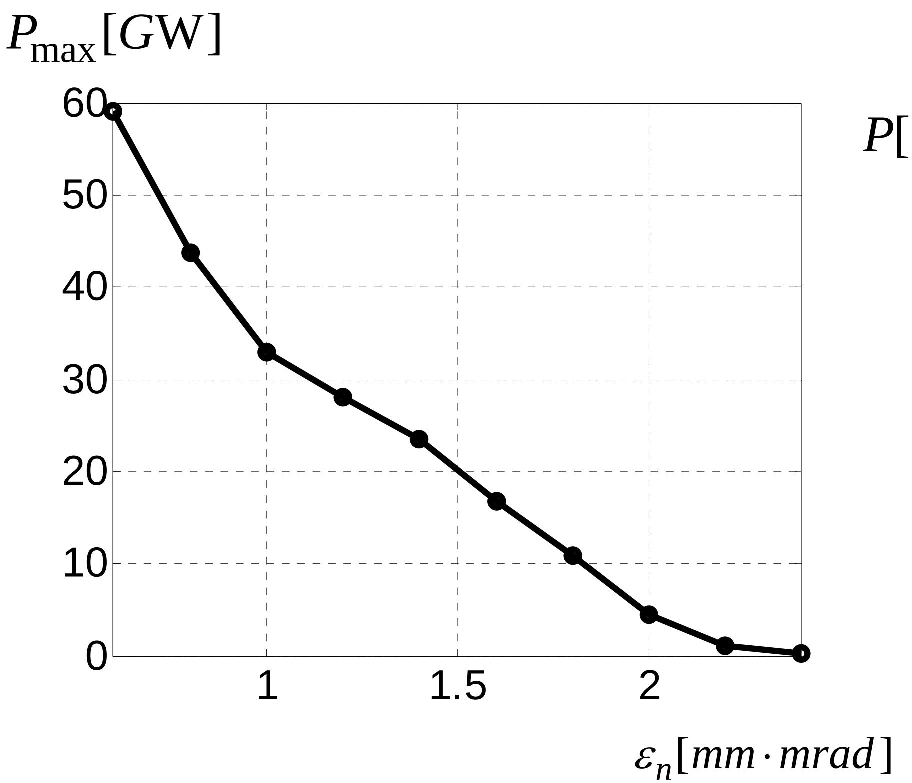
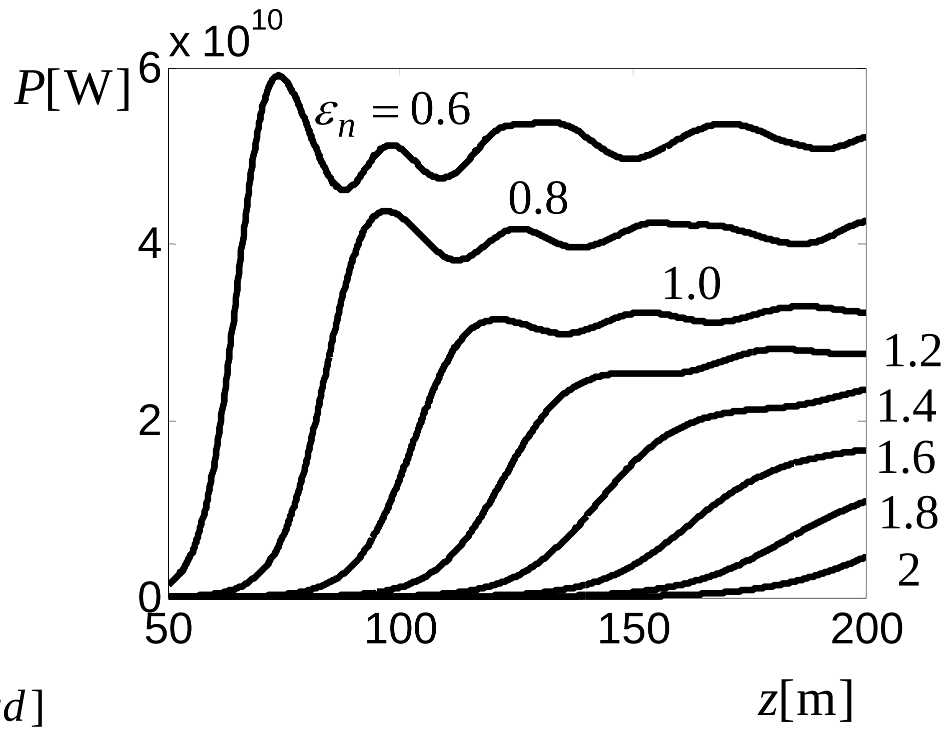


Emittance scan (ALICE)



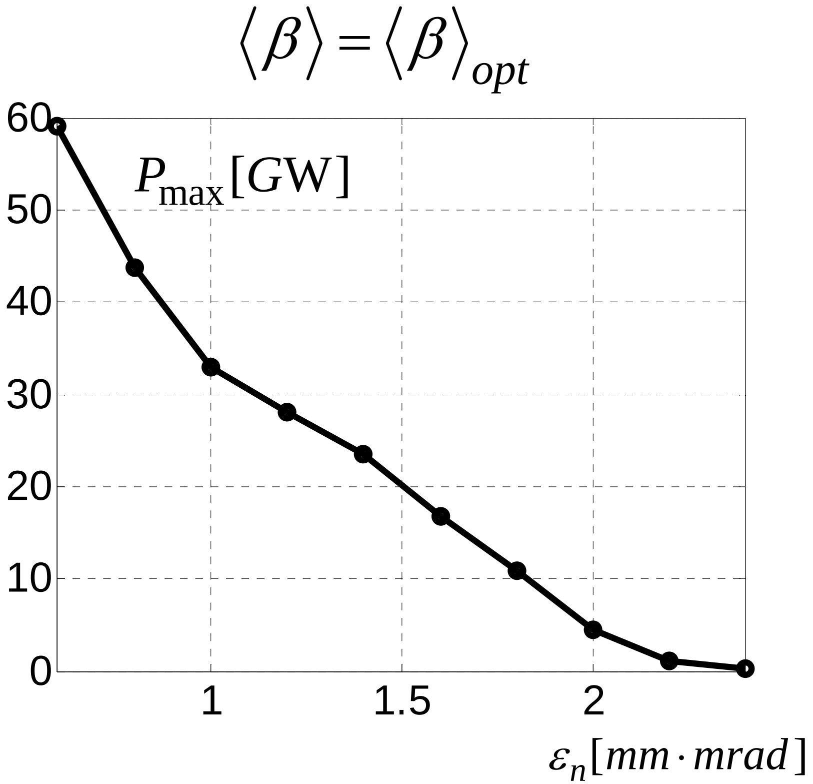


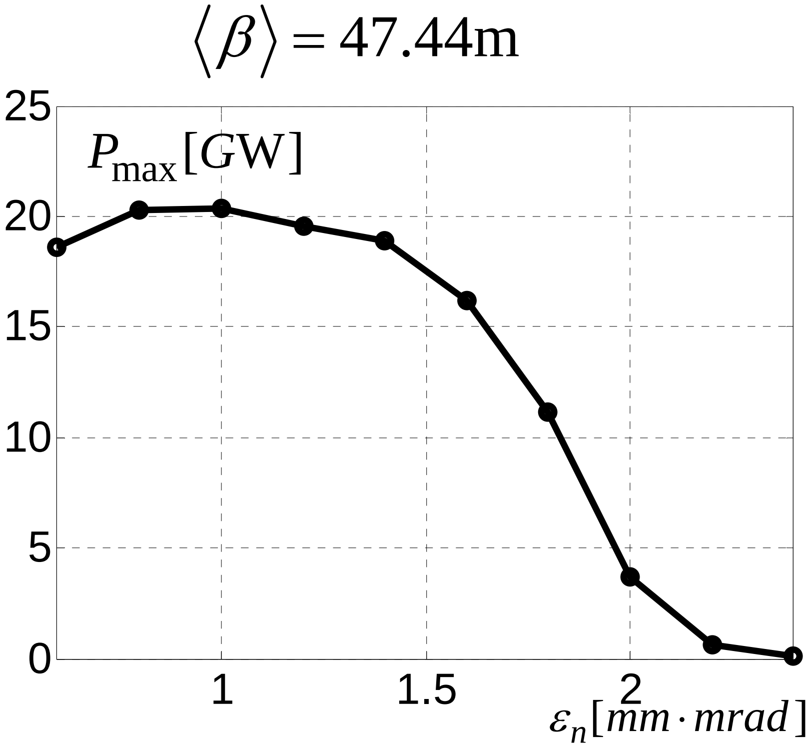
$$\sigma_E = 1.5\,\mathrm{MeV}$$

$$\langle\beta\rangle = \langle\beta\rangle_{opt}$$

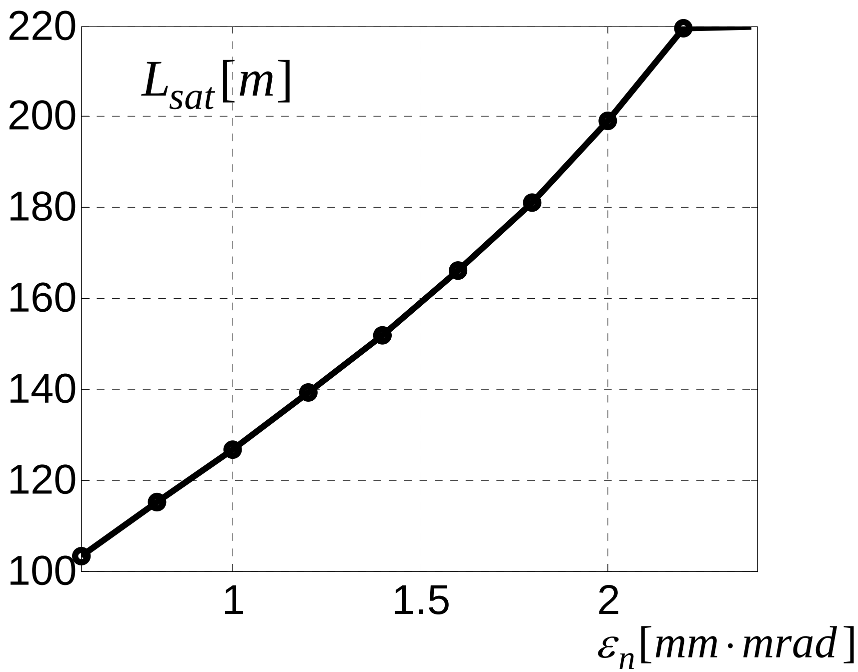
$$\Lambda(C_0) = \max_C \Lambda$$

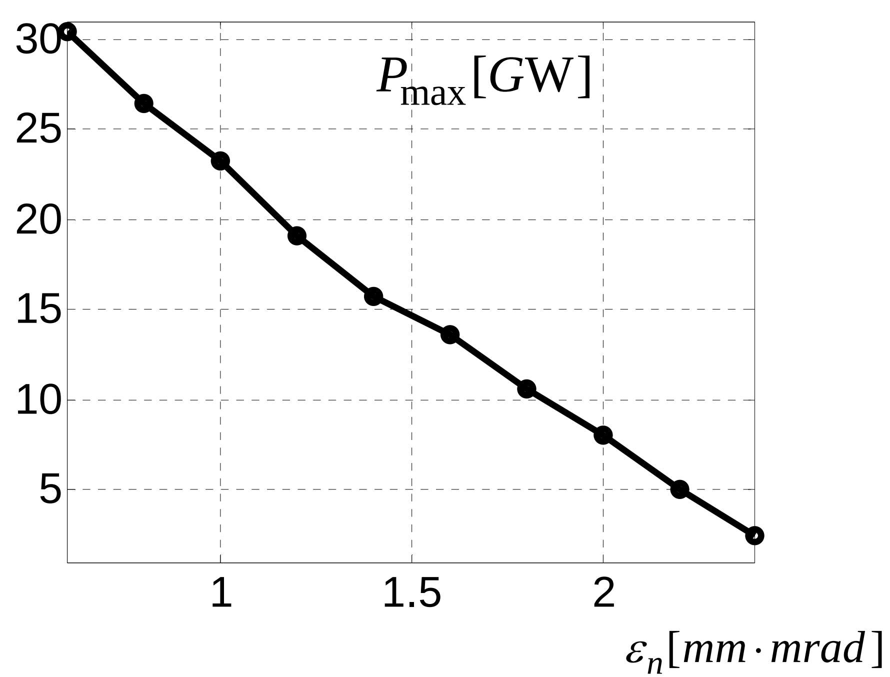
Emittance scan (ALICE)





Emittance scan (Genesis)





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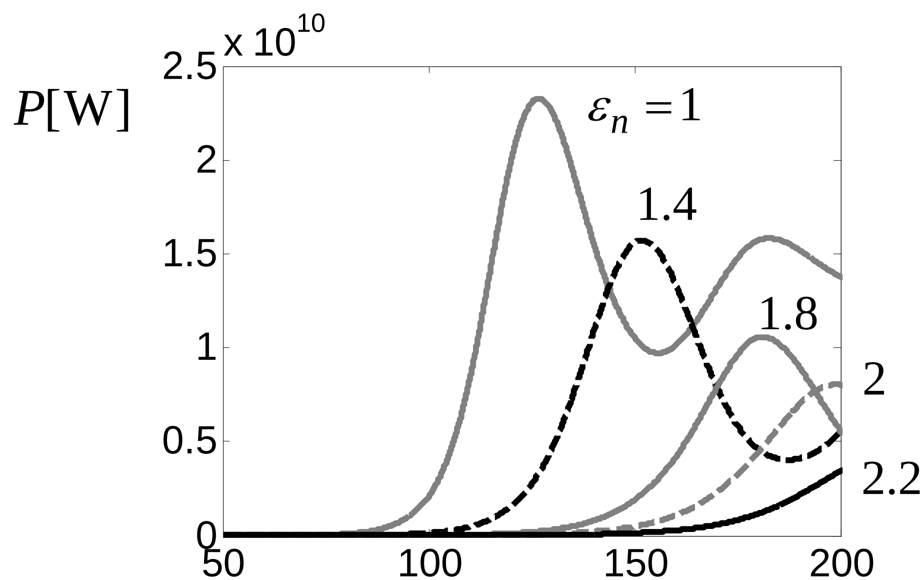

Conclusion

- The effective undulator length (200m) and the design emmitance (1.4 mm*mrad) allow the energy spread up to 4MeV
- transverse motion has to be realized in ALICE
- estimation of the emittance impact requires yet additional efforts (with optimal beta function etc.)
- spectrum?