LWFA Simulations at GeV-Energy on Curie

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Outline

- **Investigation tool: CALDER-CIRC**
- **Case study: A. Beck et al., NIMA 2014**
  - Results from the original paper
  - Simulation Setup with Anticherenkov
- **Preliminary Results with Anticherenkov scheme**
  - Laser evolution
  - Bunch @ 0.7 cm, 1 GeV
  - Bunch @ 1.3 cm, 2 GeV
- **Conclusions**
- **Discussion**

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Investigation tool: CALDER-CIRC

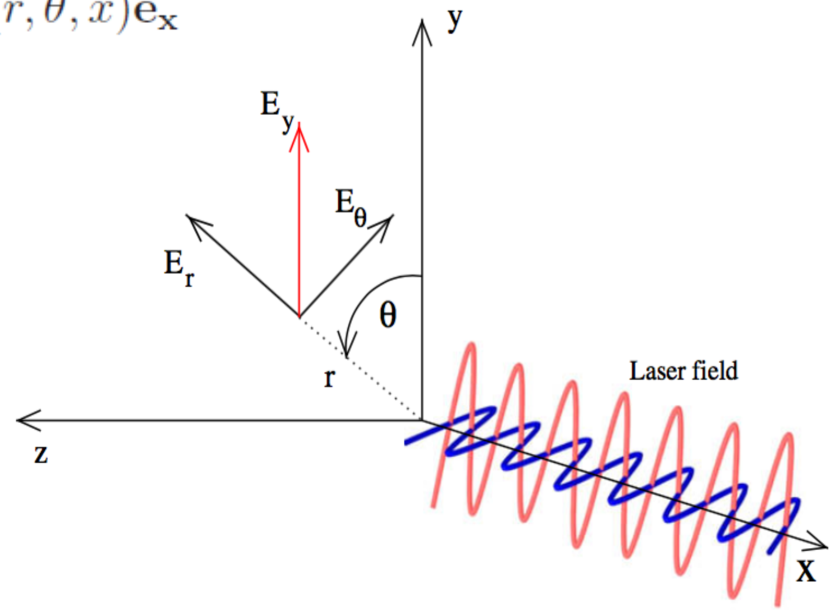
- Cylindrical coordinates are used for the fields:

$$\mathbf{E}(r,\theta,x) = E_r(r,\theta,x)\mathbf{e_r} + E_\theta(r,\theta,x)\mathbf{e}_\theta + E_x(r,\theta,x)\mathbf{e_x}$$

- Fourier decomposition is used in the azimuthal coordinate

$$F(r,\theta,x) = \sum_{m=-\infty}^{+\infty} \hat{F}^m(r,x)e^{-im\theta}$$

$$\hat{F}^m(r,x) = \frac{1}{2\pi}\int_0^{2\pi} F(r,\theta,x)e^{im\theta}d\theta$$



- Often for LWFA only few azimuthal modes are needed

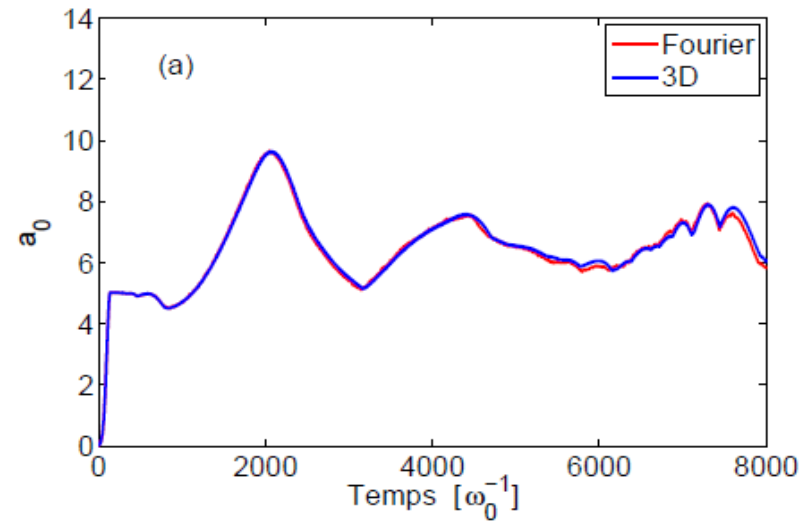
- Neglecting all but the first N modes, cost is approximately equal to N 2D simulations

A. Lifschitz et al, Journal of Computational Physics 228 (2009)
X. Davoine et al. "New Algorithms for Cylindrical PIC code" (1st EAAC - 2013)

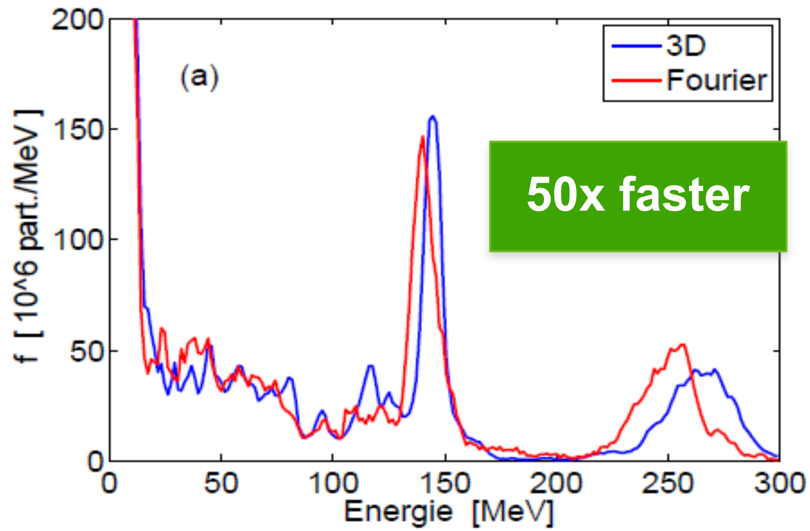
Azimuthal Fourier decomposition: comparisons of CALDER-CIRC with full 3D code

Laser and plasma parameters

- λ_0 = 0.8 μm
- τ_0 = 30 fs
- w_0 = 9 μm
- a_0 = 5
- ne = 0.007 nc



CALDER-CIRC:
12h on 6 processors for 1 mm



Images from

X. Davoine et al. "New Algorithms for Cylindrical PIC code" (1st EAAC - 2013)

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Results from A. Beck et al., NIM A 740 (2014)

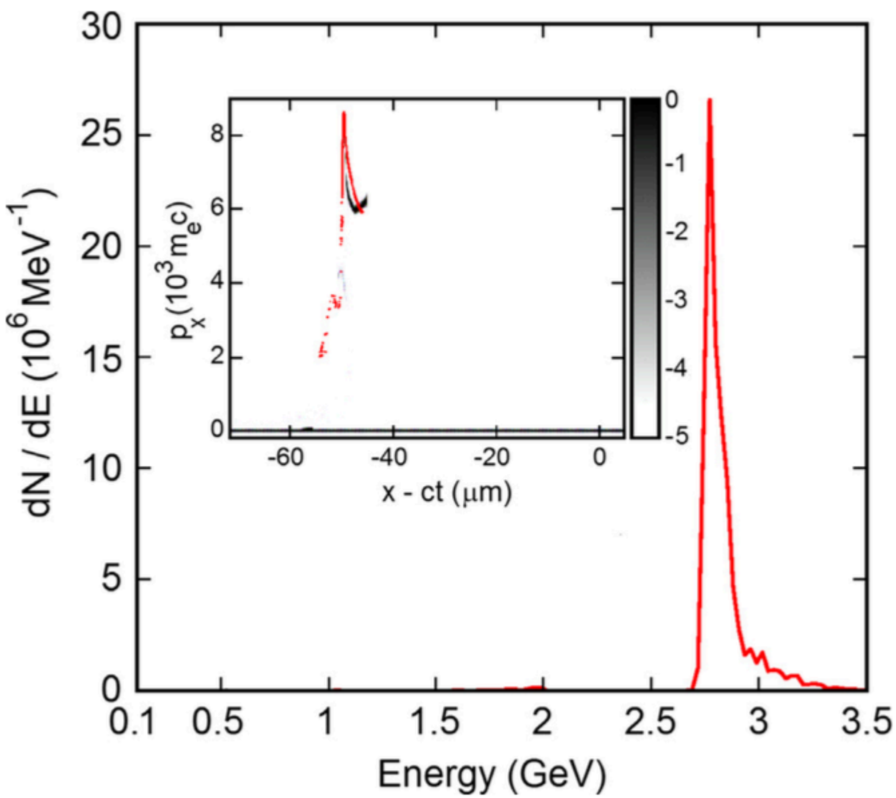


Fig. 7. Electron energy spectrum at $x = 1.86$ cm (CALDER-Circ simulation). Inset: longitudinal phase space of electrons reaching $x = 1.86$ cm. Grayscale shows the logarithm of the phase space density from the CALDER-Circ simulation. Red (gray) markers are the WAKE test particles.

Bunch Parameters @ 1.86 cm

Q = 0.43 nC

E = 2.85 GeV

w_0 = 3.57 μm

$\Delta\gamma/\gamma$ (rms) = 4.3 %

$\Delta\theta$ (rms) = 4.9 mrad

ε_n = 98 mm-mrad

Simulation Parameters

50 particles per cell

No Anticherenkov-stencil

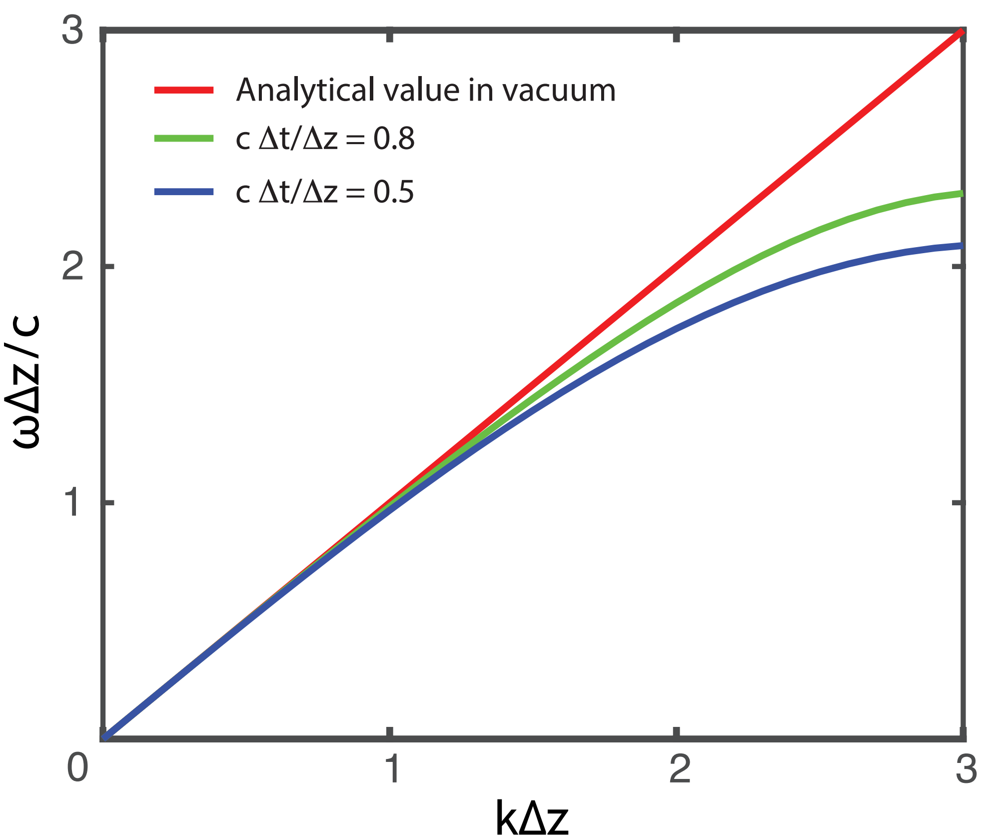
(not implemented yet)

A. Beck et al., Nuclear Instruments and Methods in Physics Research A 740 (2014) 67-73

Boosted frame: numerical Cherenkov instability

Numerical dispersion in standard PIC codes (e.g. FDTD scheme) slows down radiation, radiation deflects particles, generated current induces more radiation

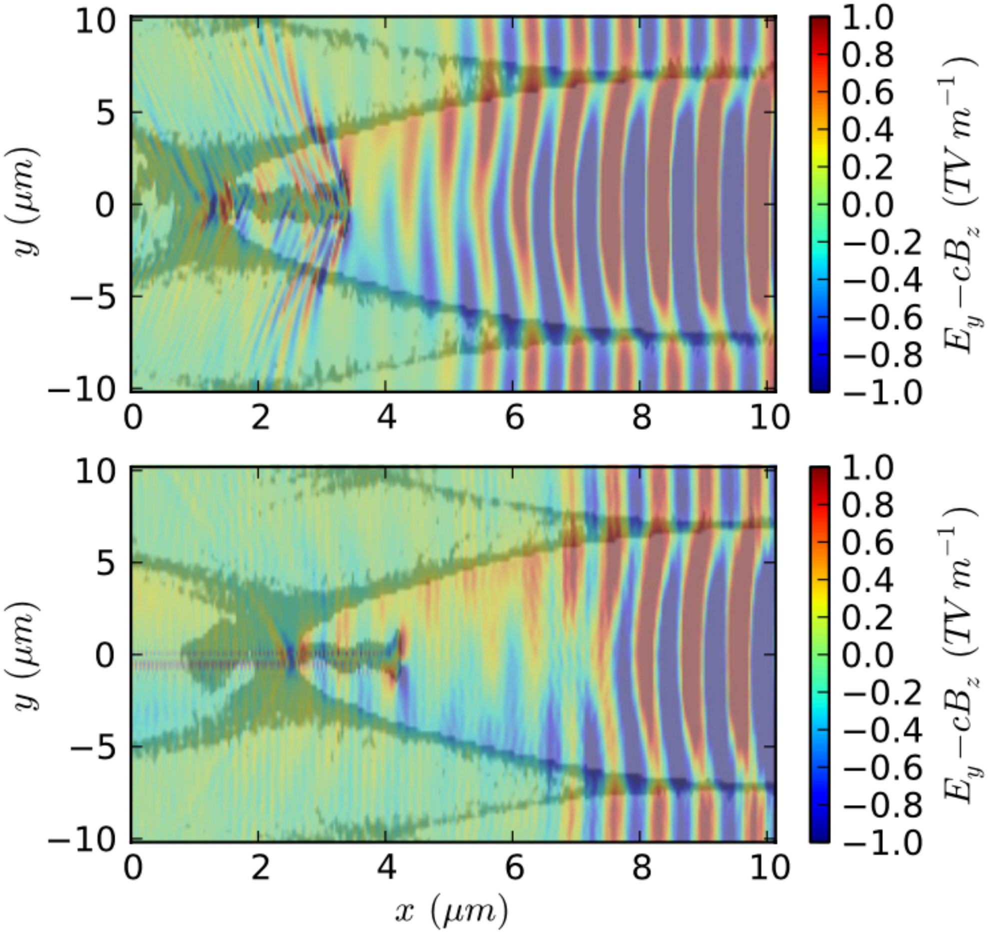
B. B. Godfrey, “Numerical Cherenkov instabilities in electromagnetic particle codes”, *J. Comput. Phys.* **15** (1974)



Anticherenkov scheme

Numerical dispersion in standard PIC codes (e.g. FDTD scheme) slows down radiation, radiation deflects particles, generated current induces more radiation

R. Lehe et al., "Numerical growth of emittance in simulations of laser-wakefield acceleration", PRSTAB 16, 021301 (2013)



Anticherenkov off

Anticherenkov on

Simulation Setup with Anticherenkov

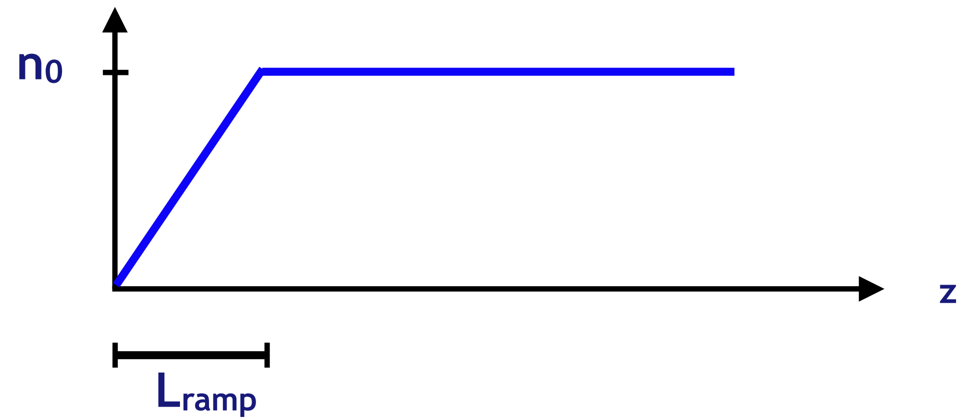
Parameters from **A. Beck et al., Nuclear Instruments and Methods in Physics Research A 740 (2014) 67-73**

Plasma

L_{ramp} = 0.5 mm

n_0 = 0.0005 nc = 8.62*10^{17} cm^{-3}

Plasma density profile (a.u.),
hydrogen only, transversely uniform



Laser Pulse

a_0 = 4.3

λ = 0.8 μm

w_0 = 30 μm

L_{FWHM} = 25 fs

E = 15J

P = 0.6 PW

Simulation Parameters

Δx = 0.016 μm

Δr = 0.2 μm

Δt = 0.05 fs

Azimuthal modes 0,1

Window size (z-r):

85 μm x 120 μm

35 particles per cell

Anticherenkov on

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Laser Evolution from original article

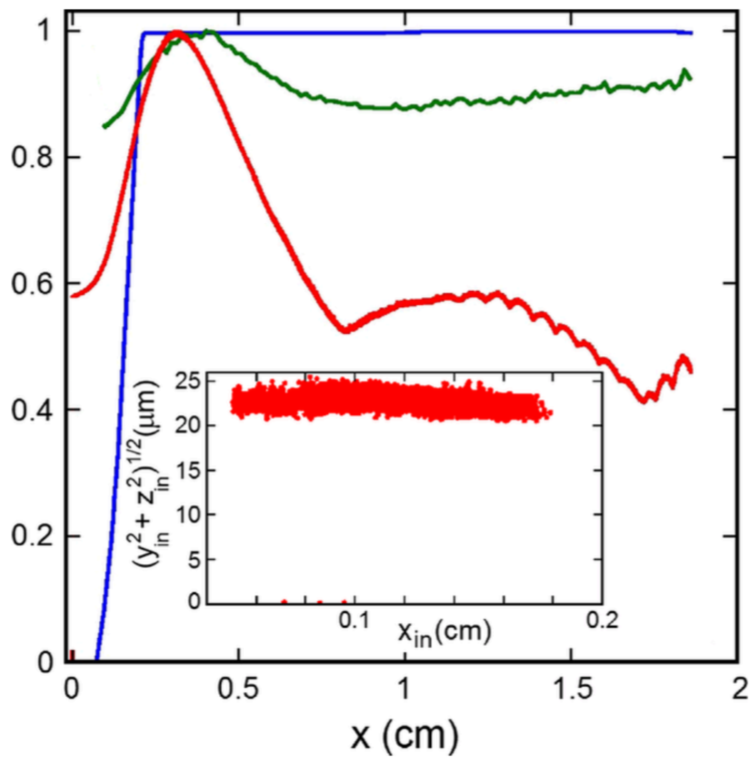

Fig. 5. Evolution of the laser pulse peak amplitude a [red (gray)], injected charge Q [blue (dark gray)], and the length of the rear half the bubble L_b [green (light gray)]. L_b is defined as the length of the accelerating phase on axis (the interval of negative electric field inside the bubble). All quantities are normalized to their respective global maximum values: $Q_{max} = 0.43$ nC, $L_{b\ max} = 29.2$ μm, and $a_{max} = 7.36$. Inset: initial positions of self-injected electrons. (CALDER-Circ simulation).

Bunch Parameters @ 1.86 cm

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ε_n = 98 mm-mrad

Simulation Parameters

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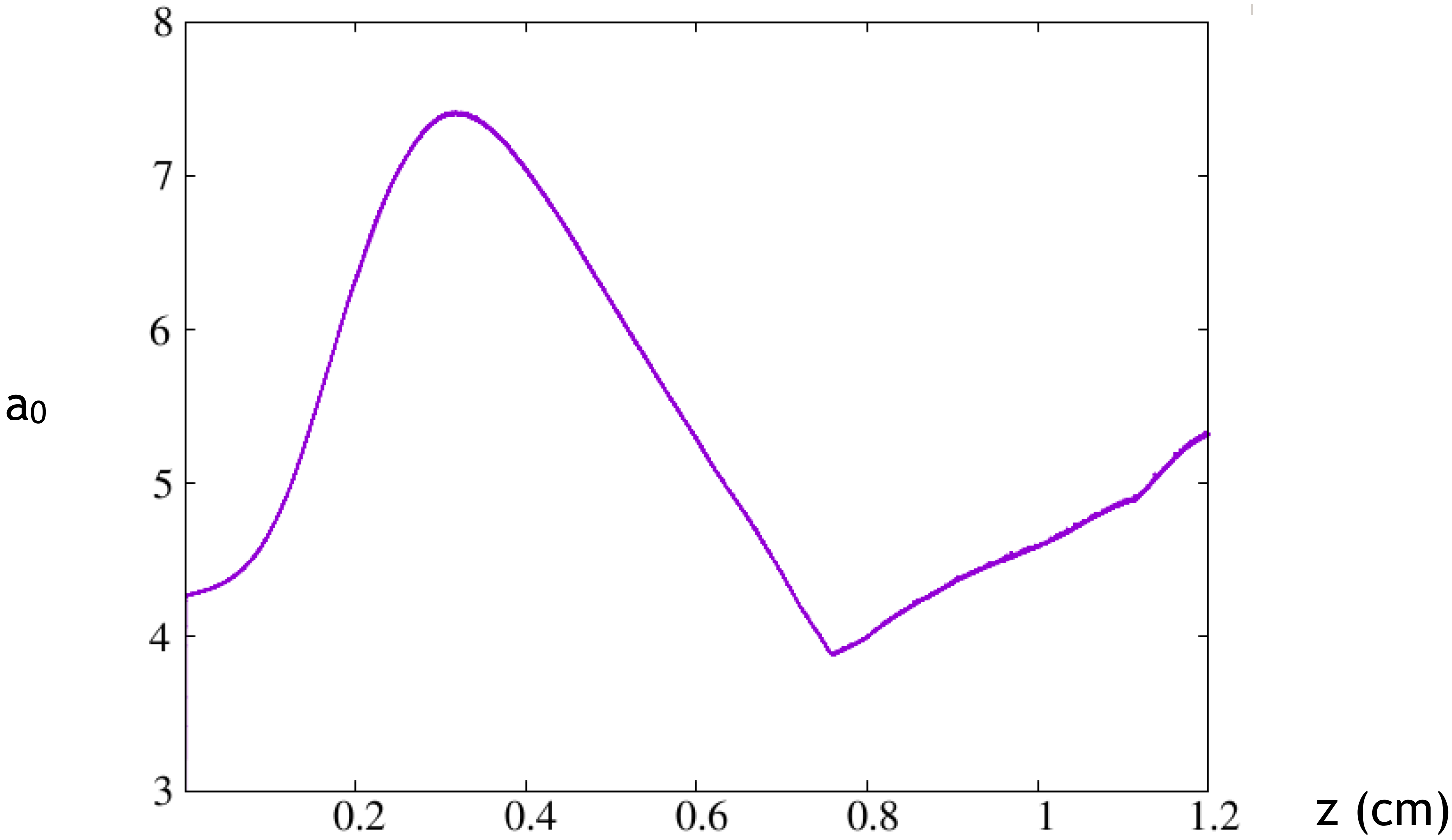
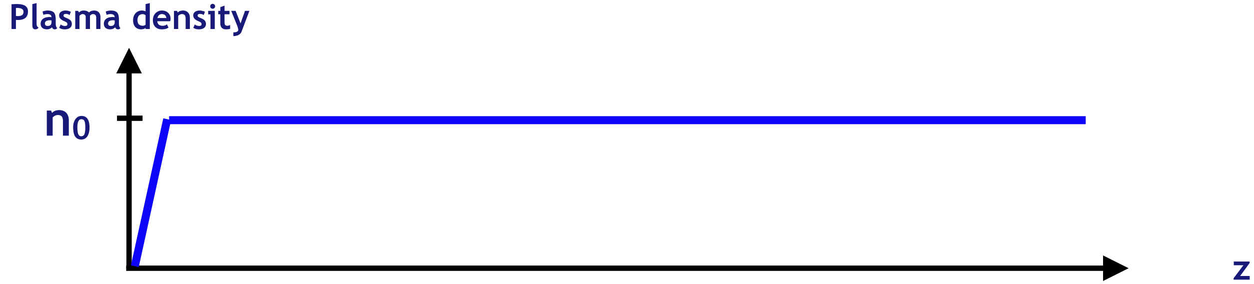
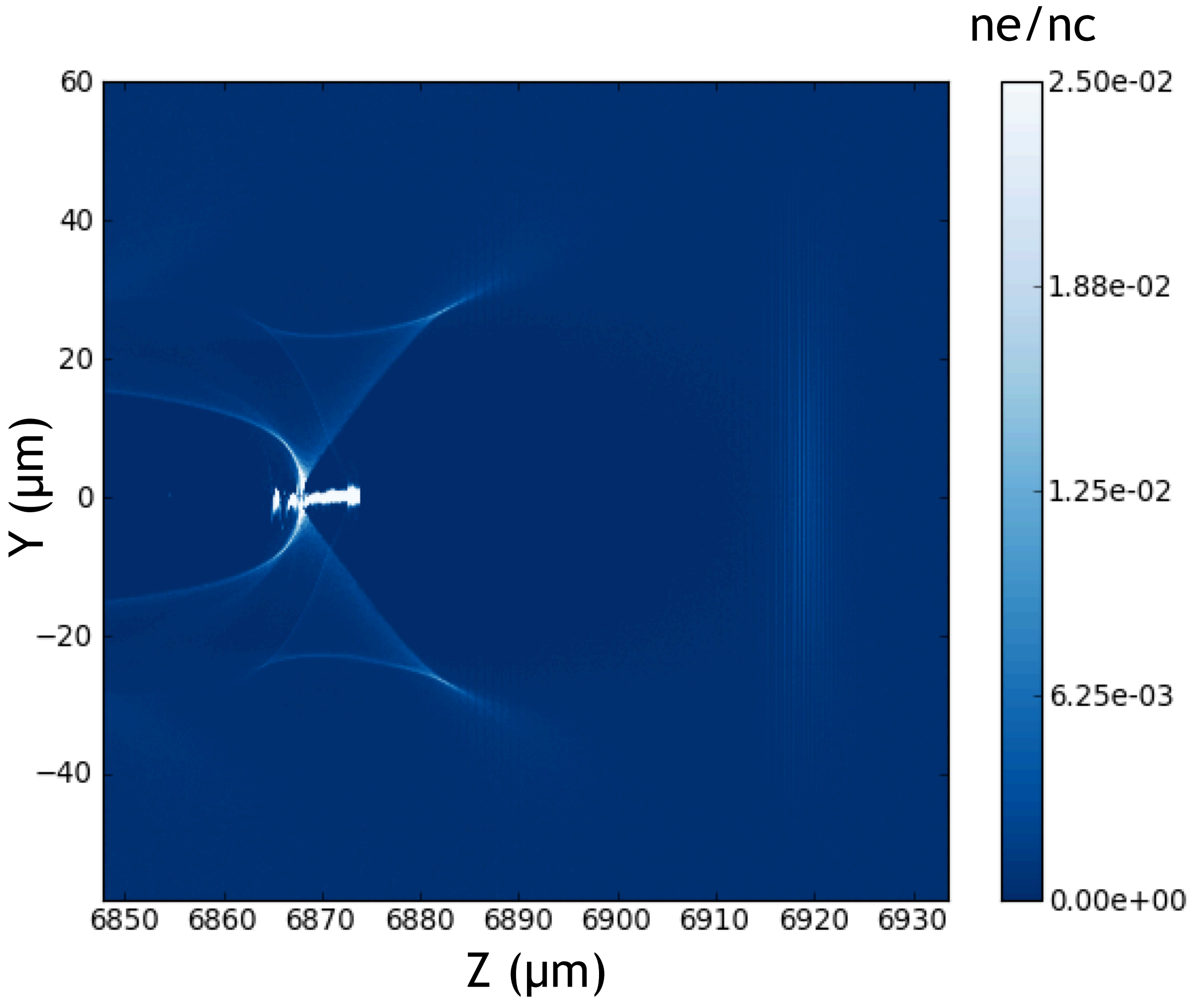
Laser Evolution with Anticherenkov





Bunch Parameters with Anticherenkov @ 0.7 cm: 1 GeV



Q = 0.61 nC

E = 1.16 GeV

$w_{0y} = w_{0x}$ = 1 μm

L_{FWHM} = 11.2 fs

$\Delta\gamma/\gamma$ (rms) = 6.6 %

$\Delta\theta_y$ (rms) = 1.5 mrad

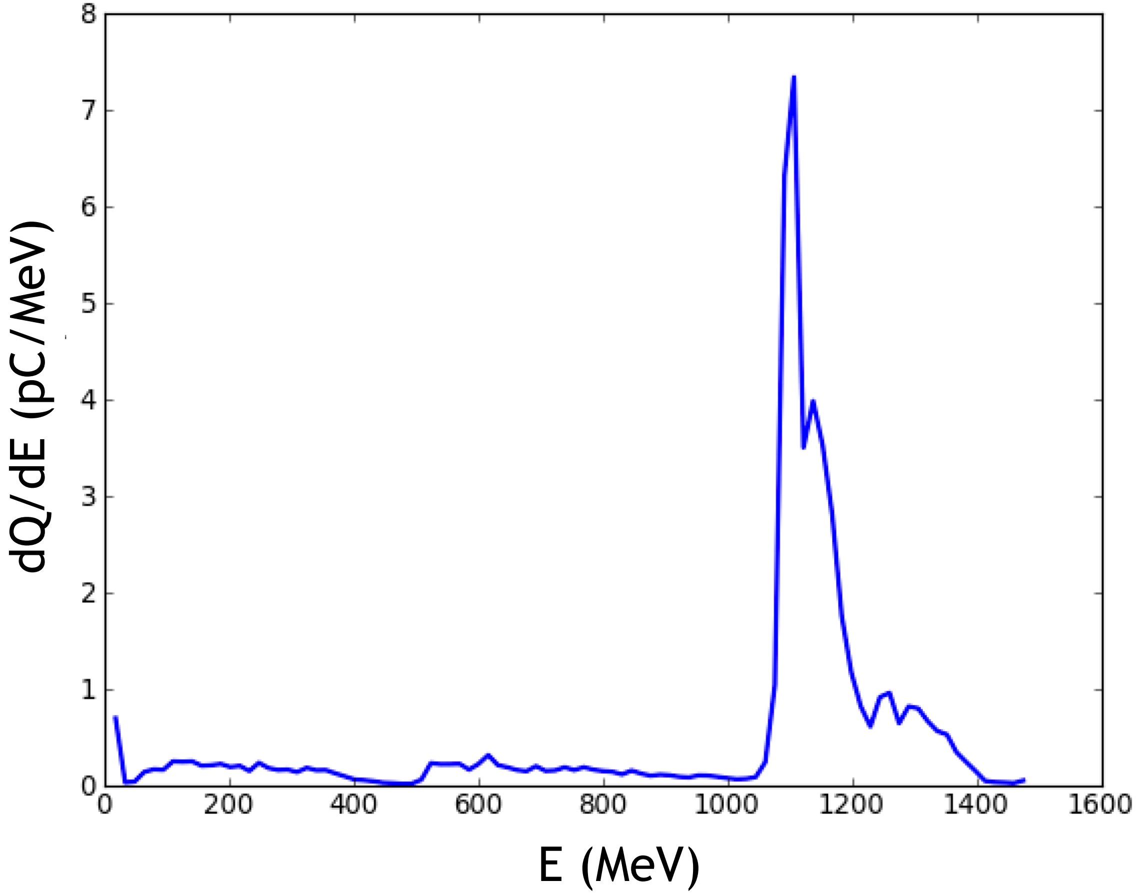
$\Delta\theta_x$ (rms) = 1.4 mrad

ε_{ny} = 1.5 mm-mrad

ε_{nx} = 1.5 mm-mrad

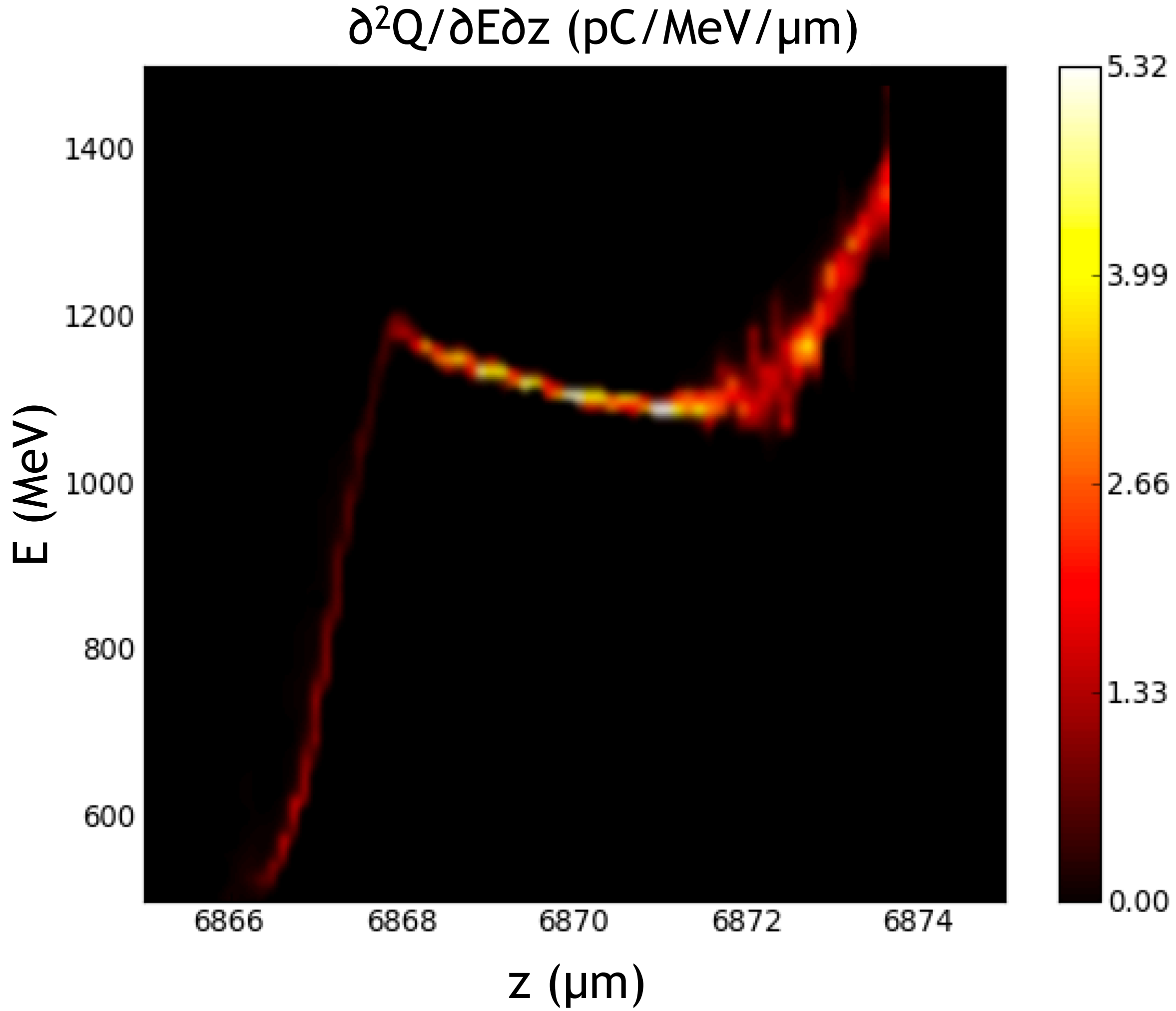
Particles in the diagnostics:
iteration 440000, R<100 c/ω_0 = 12.73 μm, E > 1 GeV

Bunch Parameters with Anticherenkov @ 0.7 cm: 1 GeV



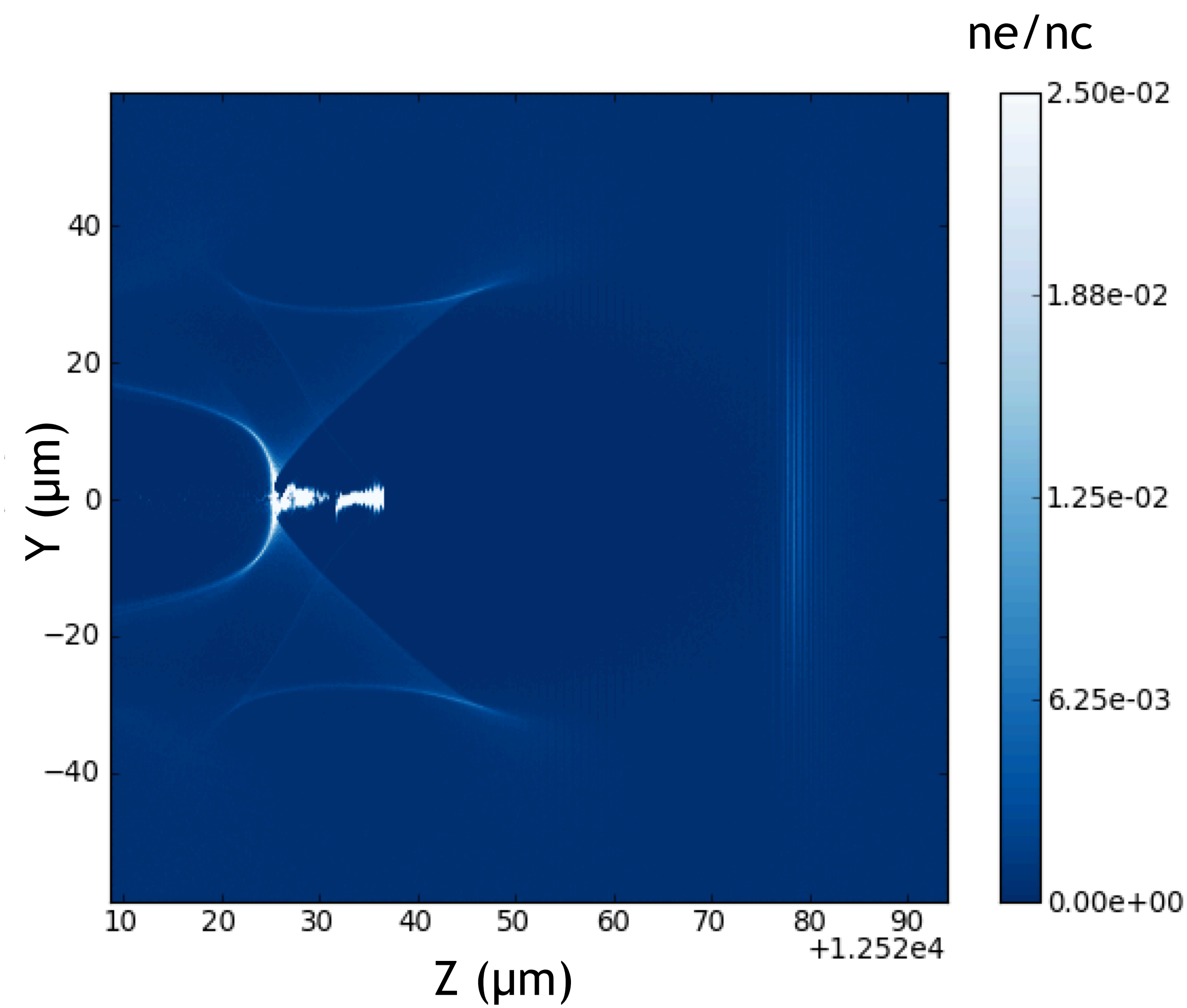
Particles in the diagnostics:
iteration 440000, R<100 c/omega0 = 12.73 um, E > 10 MeV

Longitudinal Phase Space with Anticherenkov @ 0.7 cm : 1 GeV



Particles in the diagnostics:
iteration 440000, R<100 c/omega0 = 12.73 um, E > 500 MeV

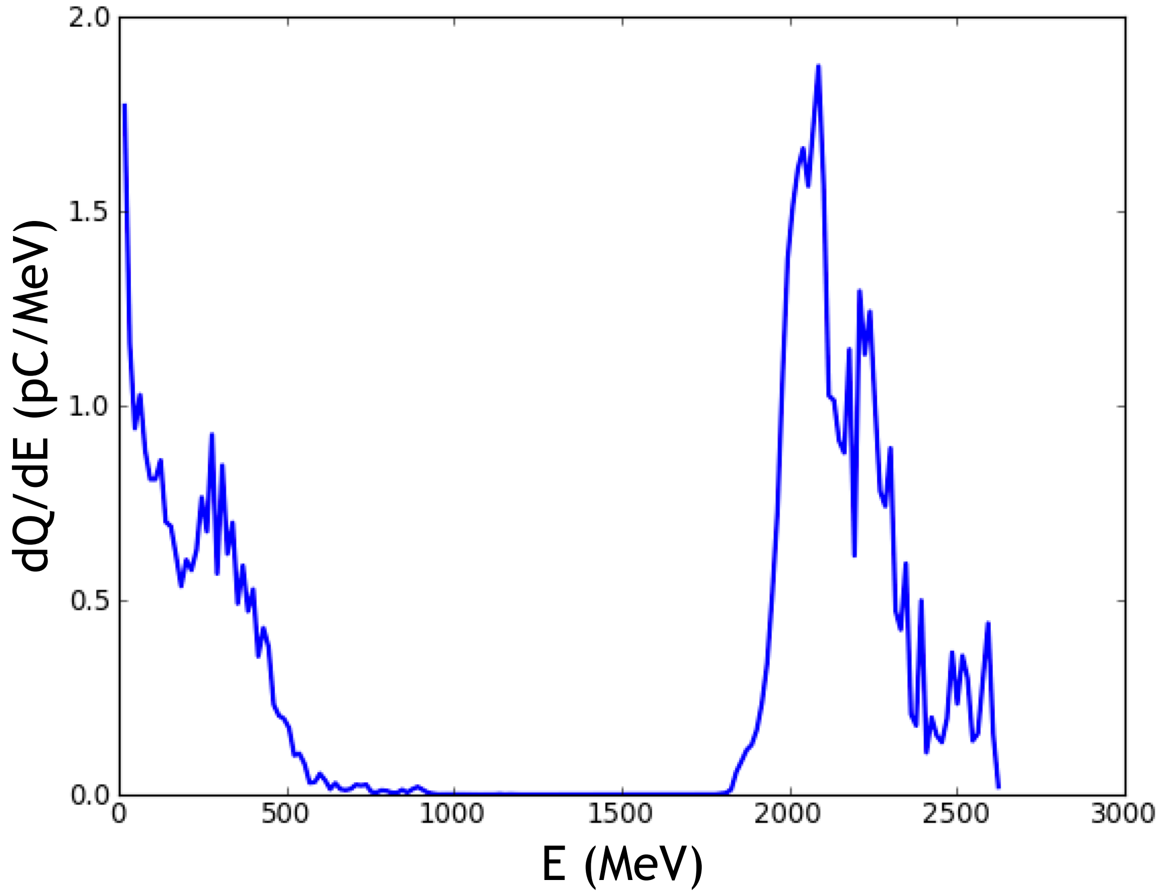
Bunch Parameters with Anticherenkov @ 1.26 cm: 2 GeV



Q	= 0.53 nC
E	= 2.16 GeV
$w_{0y} = w_{0x}$	= 0.9 μm
L_{FWHM}	= 8.7 fs
$\Delta\gamma/\gamma$ (rms)	= 7.5 %
$\Delta\theta_y$ (rms)	= 0.9 mrad
$\Delta\theta_x$ (rms)	= 0.8 mrad
ε_{ny}	= 1.7 mm-mrad
ε_{nx}	= 1.5 mm-mrad

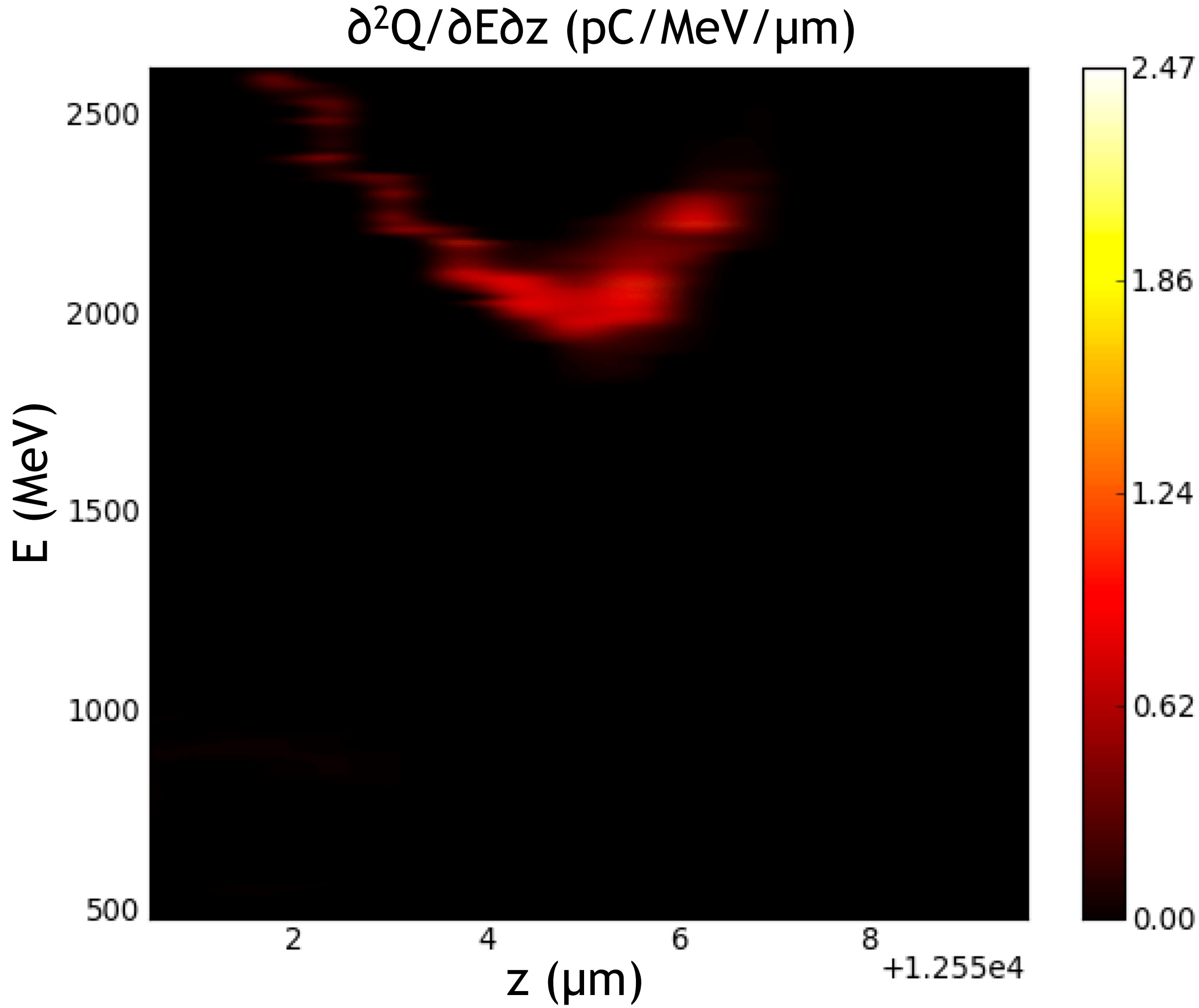
Particles in the diagnostics:
iteration 800000, R<100 c/ω_0 = 12.73 μm, E > 1.5 GeV

Bunch Parameters with Anticherenkov @ 1.26 cm: 2 GeV



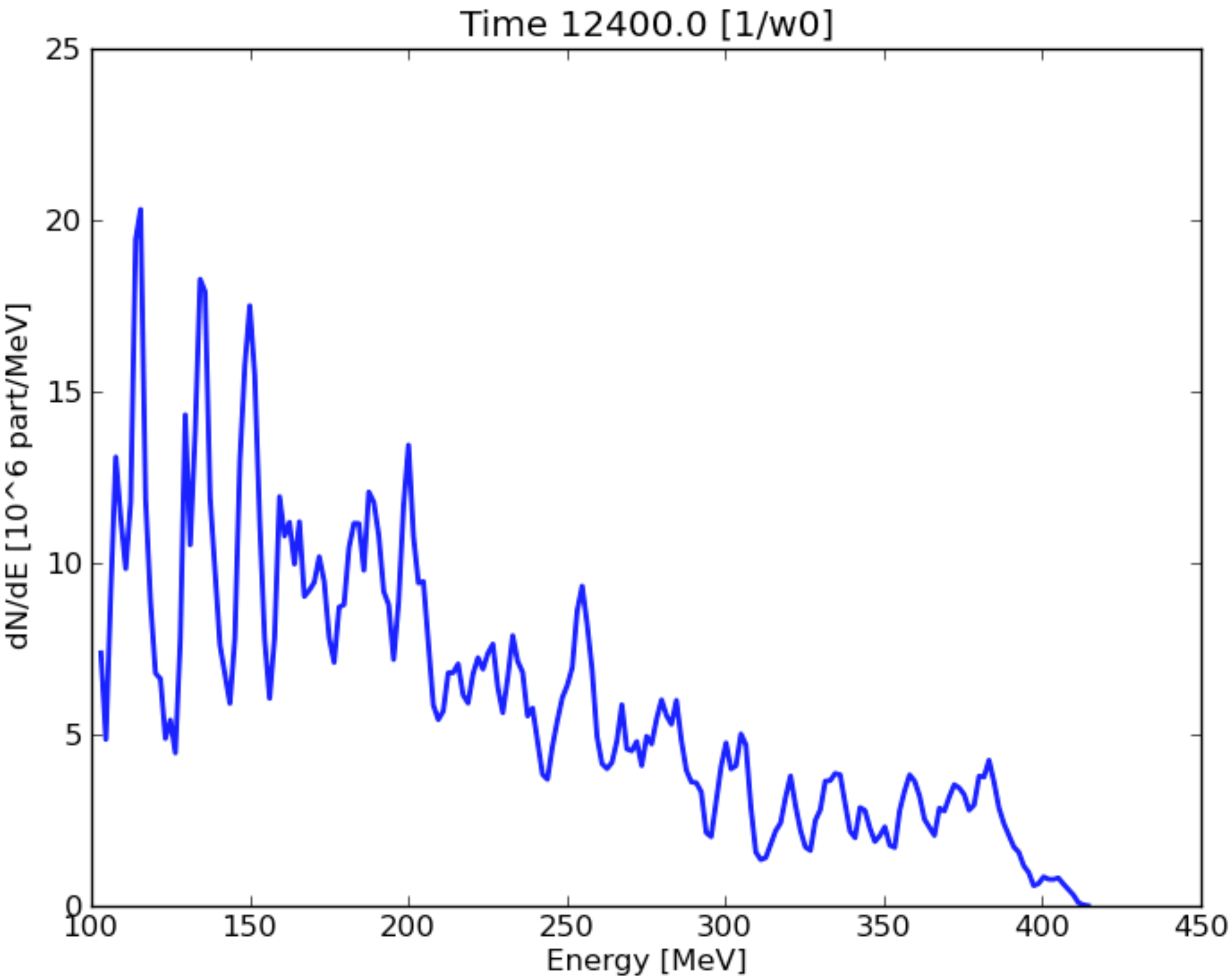
Particles in the diagnostics:
iteration 440000, R<100 c/omega0 = 12.73 um, E > 10 MeV

Longitudinal Phase Space with Anticherenkov @ 1.26 cm: 2 GeV



Particles in the diagnostics:
iteration 800000, R<100 c/ω_0 = 12.73 μm, E > 500 MeV

Energy Spectrum Evolution



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Conclusions

- LWFA simulations based on a working point found by A. Beck et al., NIMA 2014 performed on Curie
- Found preliminary results at 1GeV and 2GeV, with interesting beam qualities
- Further studies are necessary with more particles

Acknowledgements

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