# Generation of Ultrashort X-Ray Pulses Using 20 TW Laser System at PALS Facility

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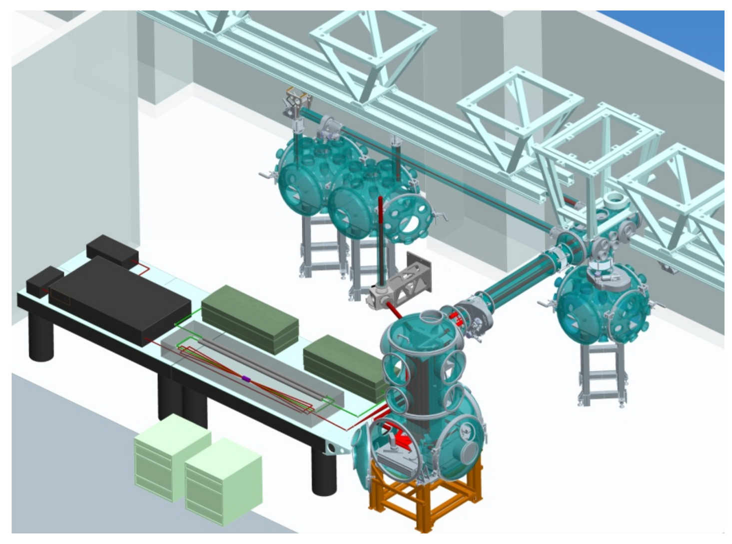
## Introduction

- Relativistic electron beams can be generated after interaction of ultrashort (*tens of fs*) intense ($\mathbf{a_0} \gtrsim \mathbf{2}$) laser pulse with underdense plasma ($\mathbf{n_e} = \mathbf{10^{18}}$–$\mathbf{10^{19}}$ cm$^{-3}$ for $\boldsymbol{\lambda} = \mathbf{810}$ nm).
- Ion cavity appears when bubble regime of laser wakefield acceleration occurs.
- Strong electric field accelerates electrons injected to the rear part of the ion cavity.
- Injected electrons oscillate in transverse direction and emit X-ray radiation.
- **Simulations:** Trajectories of oscillating electrons were *tracked* during 2D PIC simulations. It enabled to calculate electric field in the far distance using theory based on *Lineard -Wiechert potentials*. Radiation spectra were obtained by *Fourier transform*.
- **Experiment:** Initial experimental campaign will be performed at PALS facility in November 2015 with the intention to handle diagnostics of electron beams and x-ray properties.

## PALS Ti:sapphire laser system

Located in PALS Research Centre in Prague.

- $\mathbf{E_{main}} \approx 1$ J
- $\mathbf{E_{aux}} \approx 0.1$ J
- $\boldsymbol{\lambda} \approx 0.810$ $\mu$m
- $\boldsymbol{\tau} \approx 40$ fs
- $\mathbf{P} \approx 20$ TW
- $\mathbf{f}_{1\,\mathrm{J}} \approx 10$ Hz
- $\mathbf{f}_{1\,\mathrm{mJ}} \approx 1$ kHz



## PIC simulations of electron acceleration in laser plasma

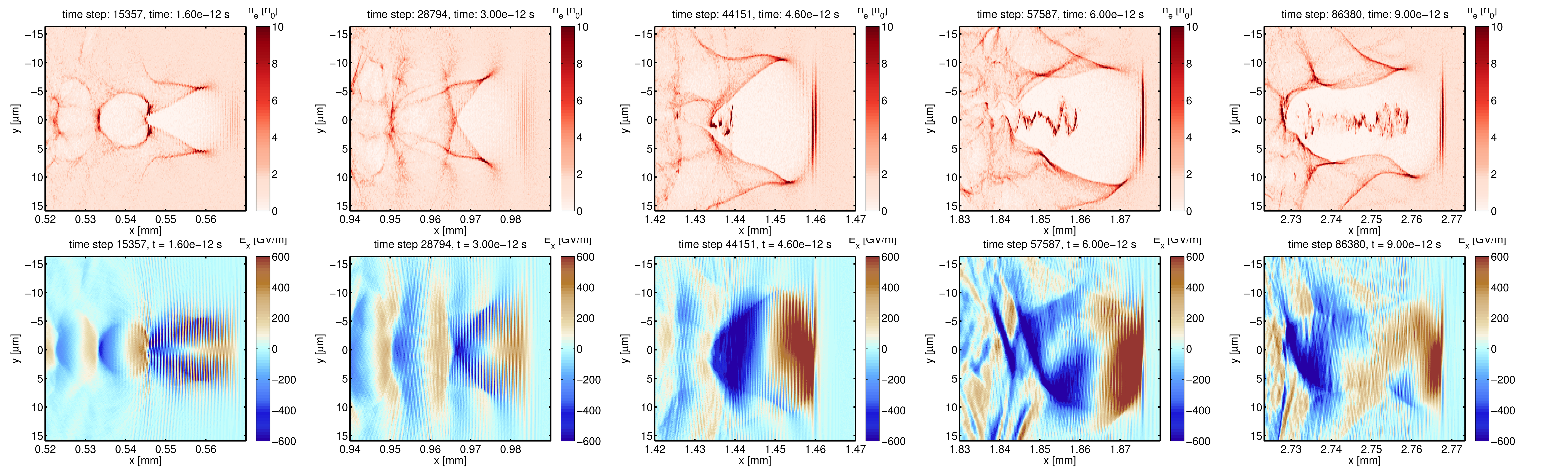
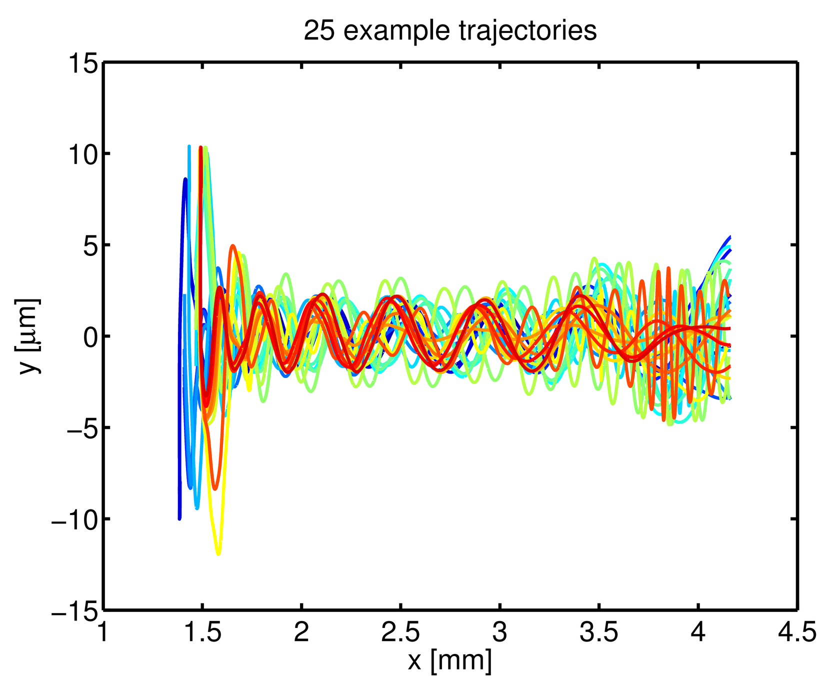
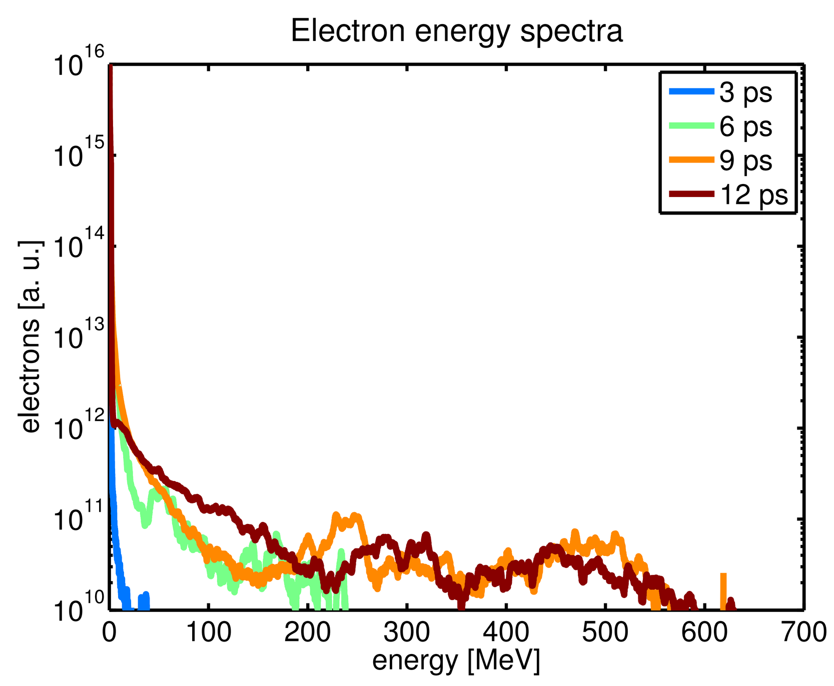



Figure: Results of 2D PIC simulations. Electron densities $\mathbf{n_e}$ (upper graphs) and electric fields $\mathbf{E_x}$ in direction of initial laser pulse propagation (lower graphs). Initial electron density $\mathbf{n_0} = \mathbf{7} \times \mathbf{10^{18}}$ cm$^{-3}$. Parameters of laser pulse: $\mathbf{E} = \mathbf{0.5}$ J, $\boldsymbol{\lambda} = \mathbf{0.8}$ $\mu$m, $\boldsymbol{\tau} = \mathbf{40}$ fs, $\mathbf{w_0} = \mathbf{7}$ $\mu$m. Simulated using 2D code EPOCH.




## Conclusion of PIC simulations

PIC simulations were carried out with the various initial parameters ($\mathbf{w_0}$, $\mathbf{n_0}$). The typical result is presented. Generation of ion cavity, development of its properties, *continuous self injection* of the electrons in the rear side of the target and the acceleration and oscillation of injected electron beam is observable. Energy spectrum of trapped electrons reaches hundreds of MeV.
The trajectories of several injected electrons were tracked and investigated. Electrons perform around *3–10 oscillations* on 1 mm distance with the amplitude around *1.5* $\mu$*m*.

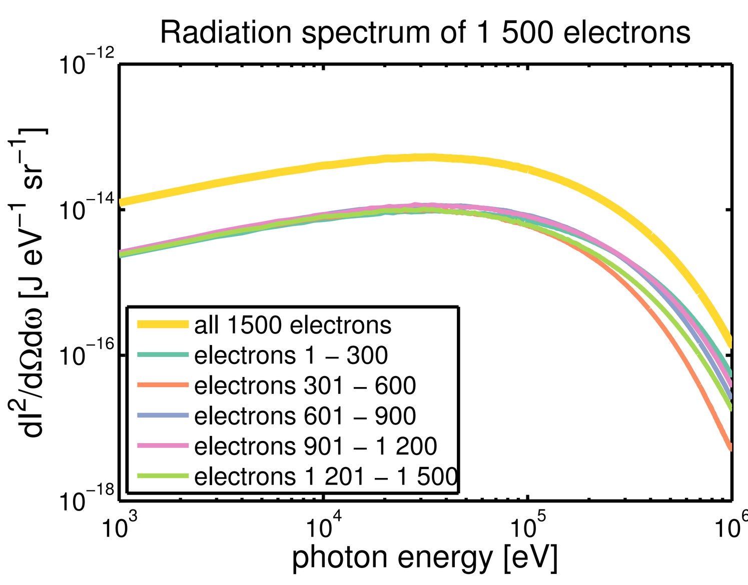
## Betatron emission from laser plasma

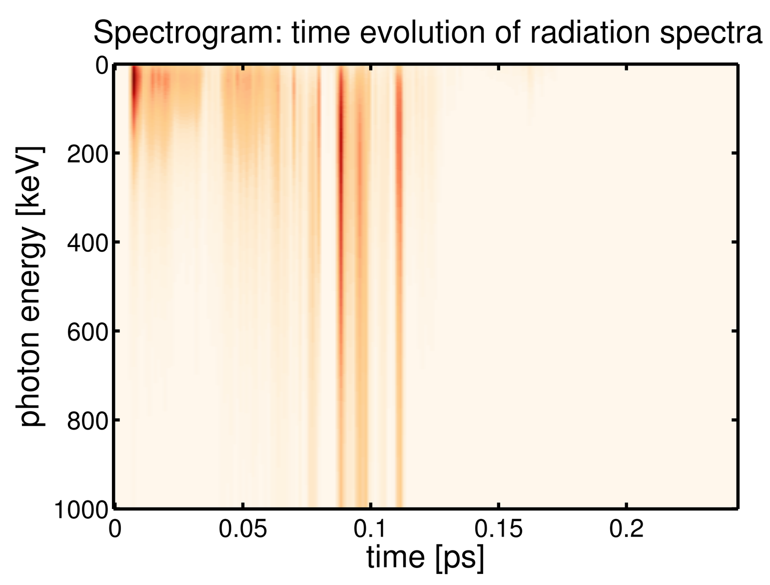
Electric field in the far distance and intensity of radiation *gererated by one moving electron* was calculated according to theory based on Lineard-Wiechert potentials

$$\mathbf{E_{rad,i}(x,t)} = \frac{\mathbf{q}}{\mathbf{4\pi\varepsilon_0}} \left[ \frac{\mathbf{n_i} \times [(\mathbf{n_i} - \boldsymbol{\beta}_i) \times \dot{\boldsymbol{\beta}}_i]}{\mathbf{c}(1 - \mathbf{n_i} \cdot \boldsymbol{\beta}_i)^3 \mathbf{R_i}} \right]_{\mathbf{ret}}$$

Radiated X-Ray spectrum was obtained via *Fourier transform*

$$\frac{\mathrm{d}^2\mathbf{I_i}}{\mathrm{d}\Omega \mathrm{d}\omega} = \frac{\mathbf{c}\varepsilon_0}{\pi} |\mathcal{F}[\mathbf{E_{rad,i}R_i}]|^2$$

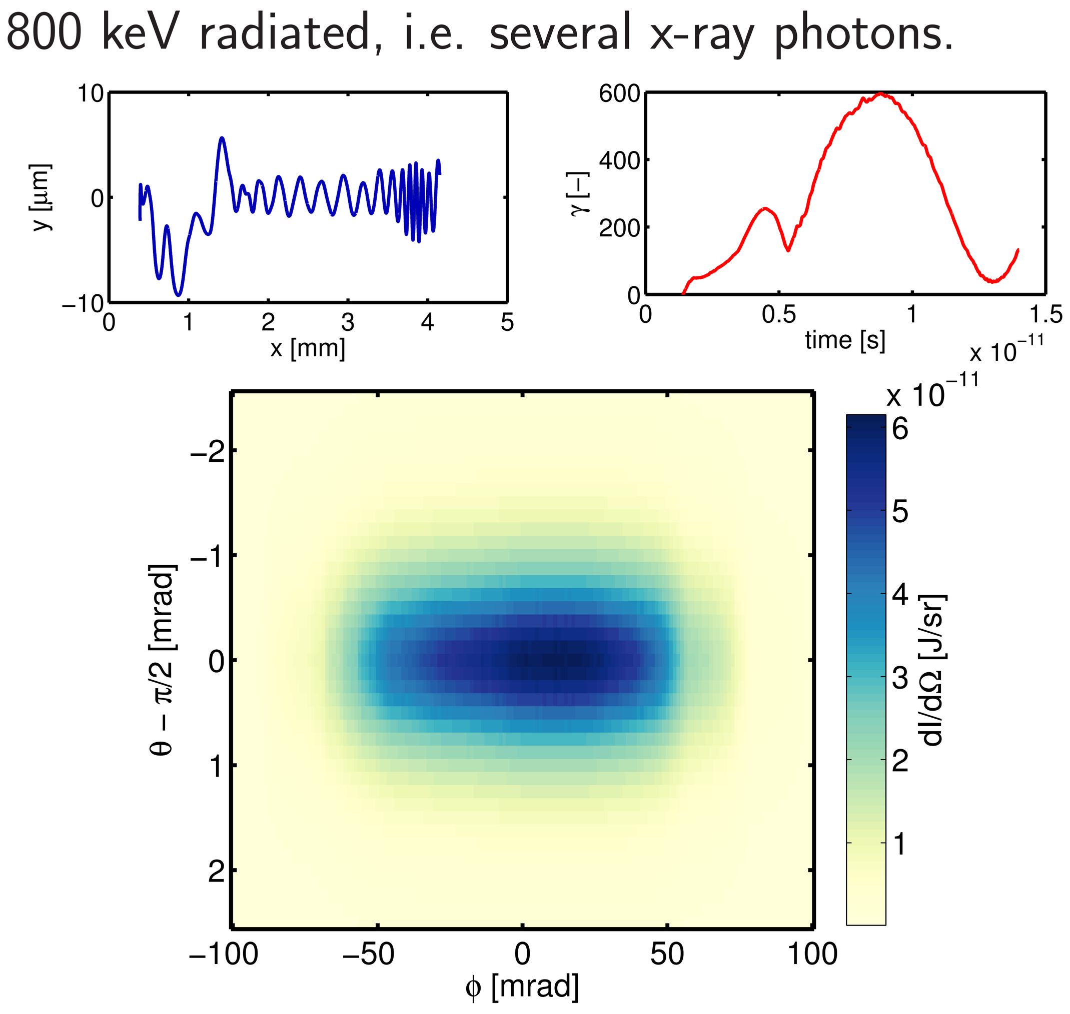



Spectra calculated on the axis of incoming laser beam. Single spectra of 1 500 trapped electrons summed up. Number of electrons trapped into ion cavity is usually of the order of $\mathbf{10^{8-9}}$ [Corde]. 2D simulation does not provide quantitative prediction.
Time values are not the same as those by PIC results.

## Angular spectrum

- Angular distribution of radiated energy by one electron moving in 2D space.
- Electron energy up to 300 MeV, accelerated within 4 mm distance.
- 800 keV radiated, i.e. several x-ray photons.

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