EMMI Workshop on High-Power Laser Interactions at GSI, 30.09 – 02.10.2013

Attempt of a Summary and a Recommendation

- Status of high-power laser-matter interaction
- Perspective for basic science and for applications
- What is the relevance of the Workshop for FAIR-GSI?
- PHELIX Upgrade in the European concert
- A recommendation to Directorate and Management Board of FAIR

●High-power laser-matter interaction

A representative cross section given at the Workshop:

Dense Plasma production

ns – fs interaction with I = $10^{16} - 10^{23}$ W/cm², density $10^{19} - 10^{24}$ cm^{-3}, contrasts & prepulses

Particle acceleration mechanisms

Fast electron production, wake field acceleration (bubble)

Ions: TNSA $> \approx 10^{20}$, 200 MeV, BOA > 1 GeV, light sail, RPA ≈ 10^{21}.

Harmonics & Attophysics

Coherent and incoherent X rays > 10 fs

Radiation damping, hard γ production: $I > 10^{23}$

„Vacuum“ optics: pair production and γ avalanges

Laser-matter interaction has started with hydrodynamics at modereate intensities.

With intensities increasing enormous ramification has occured

Superhigh intensities means the triumph of the photon, the most noble kind of matter.

● *Is there any new physics that deserves the full attention of the ambitious young researchers?*

Applications:

New concepts and schemes for accelerators

Intense ion beams for medical applications

Fast & ultrafast diagnostics: probing chemical reactions, evolution into thermal equilibrium in dense matter, phase transitions dynamics

Basic science:

Probing the vacuum, application of QED in the strong field regime & exploring its limits

Strong field induced ionization dynamics in atoms & molecules (“multiphoton physics”)

Nuclear physics: Interplay electron shell ↔ nulear transitions, nuclear level fine tuning

(nuclear Stark effect)

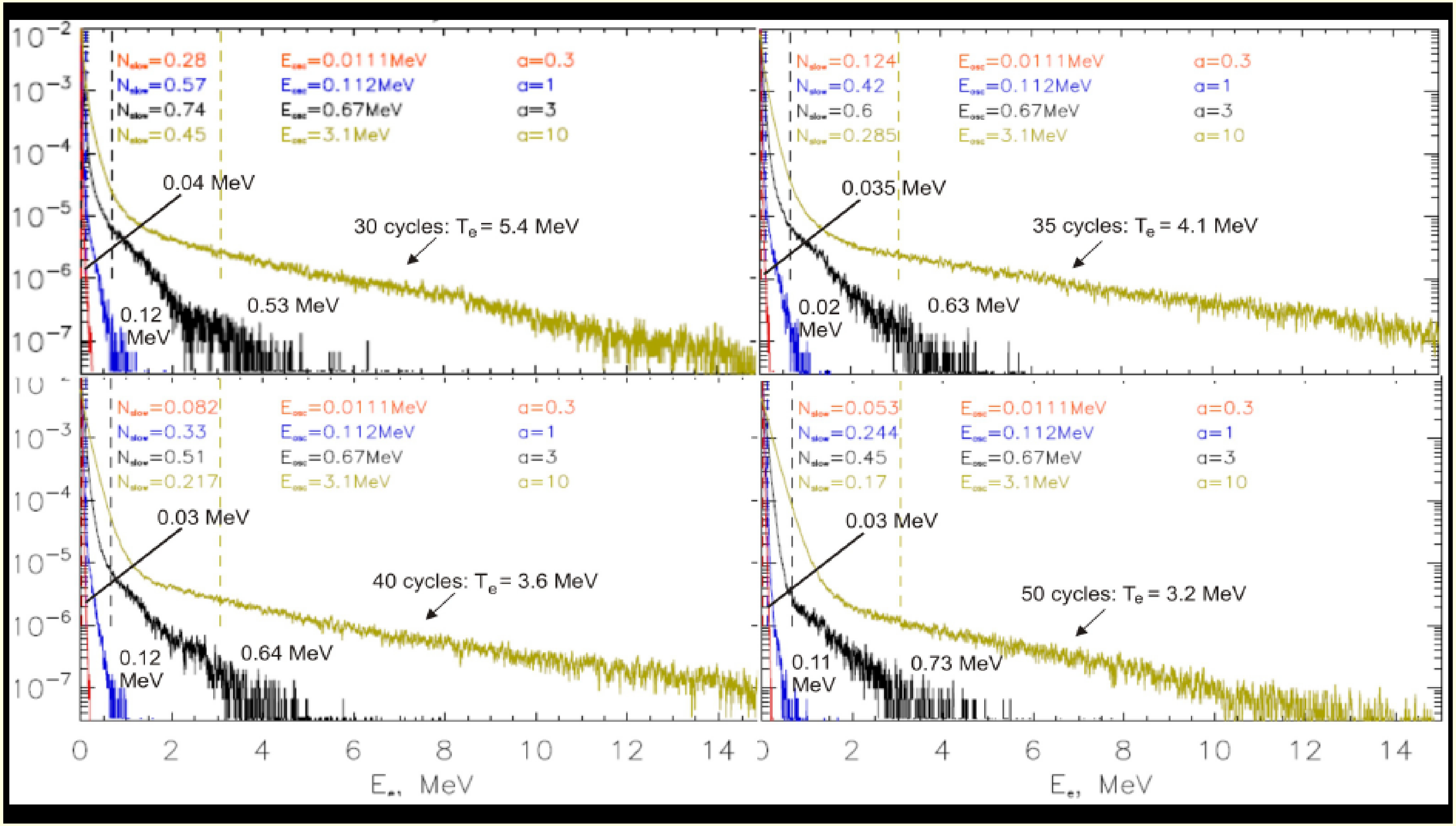
Collective plasma dynamics

Development of simulation methods, e.g. 3D Vlasov

Example: Collisionless laser beam absorption? Fast electron spectra?

Formation of Maxwellian tail & scaling

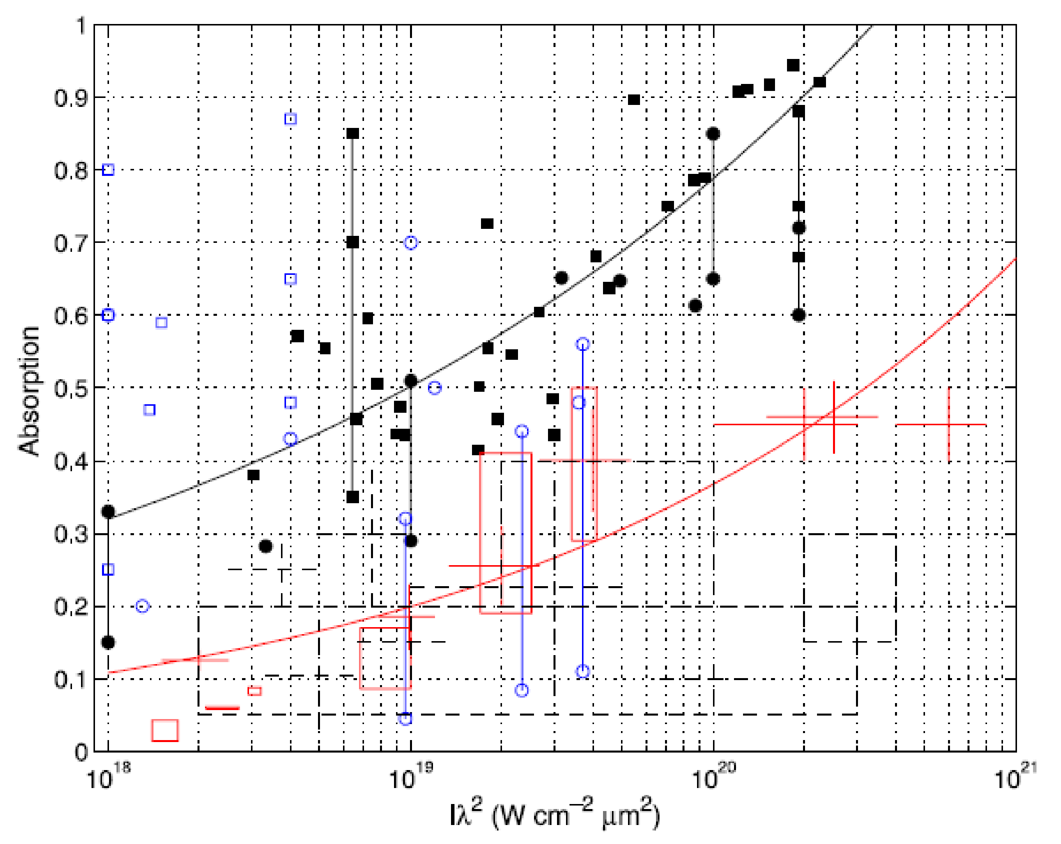
Gaussian laser pulse, FHW = 50 cycles, α = 45°, mobile ions, ne/nc = 81 (court. T. Liseykina)



$k_B T_e = (m_C - m_e)c^2$: T_{hot} decreases during laser pulse

m_C averaged electron mass in center of momentum system. Target thickness 40 – 60μm

Collisionless absorption: Experiments & simulations



J.R. Davies, Plasma Phys. Control. Fusion **51**, 014006 (2009)

normal incidence ● (exp. + num.), ○ (num.)

Oblique incidence (30°, 45°)■ (exp. + num.), □ (num.)

Nova results ┼ , solid line: fit to Nova exp.; solid line: fit to experiments and sim.,

Collisionless absorption

Demands on the mechanism:

Origin of the phase shift between ***j*** and ***E*** in cycle-averaged ***jE***

Poynting's theorem $\nabla S = -jE \sim \sin(\omega t + \varphi)\cos\omega t$

cycle averaged $\overline{\sin(\omega t + \varphi)\cos\omega t} = \frac{1}{2}\sin\varphi$

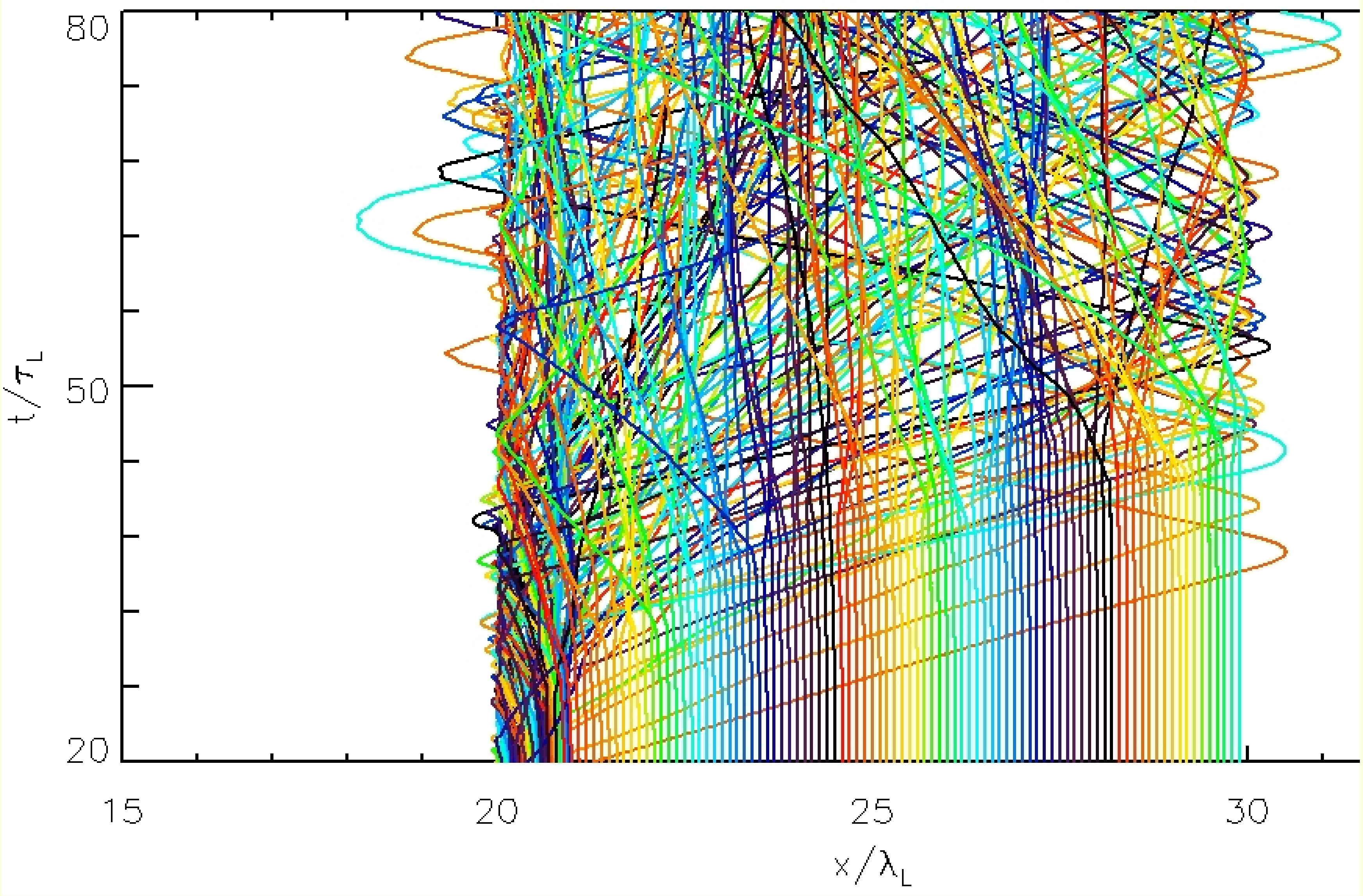
$$\overline{jE} = \varepsilon_0 \omega_p^2 \frac{\nu}{\omega^2 + \nu^2} |E|^2 \qquad \nu = 0 \Rightarrow \varphi = 0 \Leftrightarrow \overline{jE} = 0$$

If there is no friction, only inertia can provide for phase shift (dynamic origin of φ)

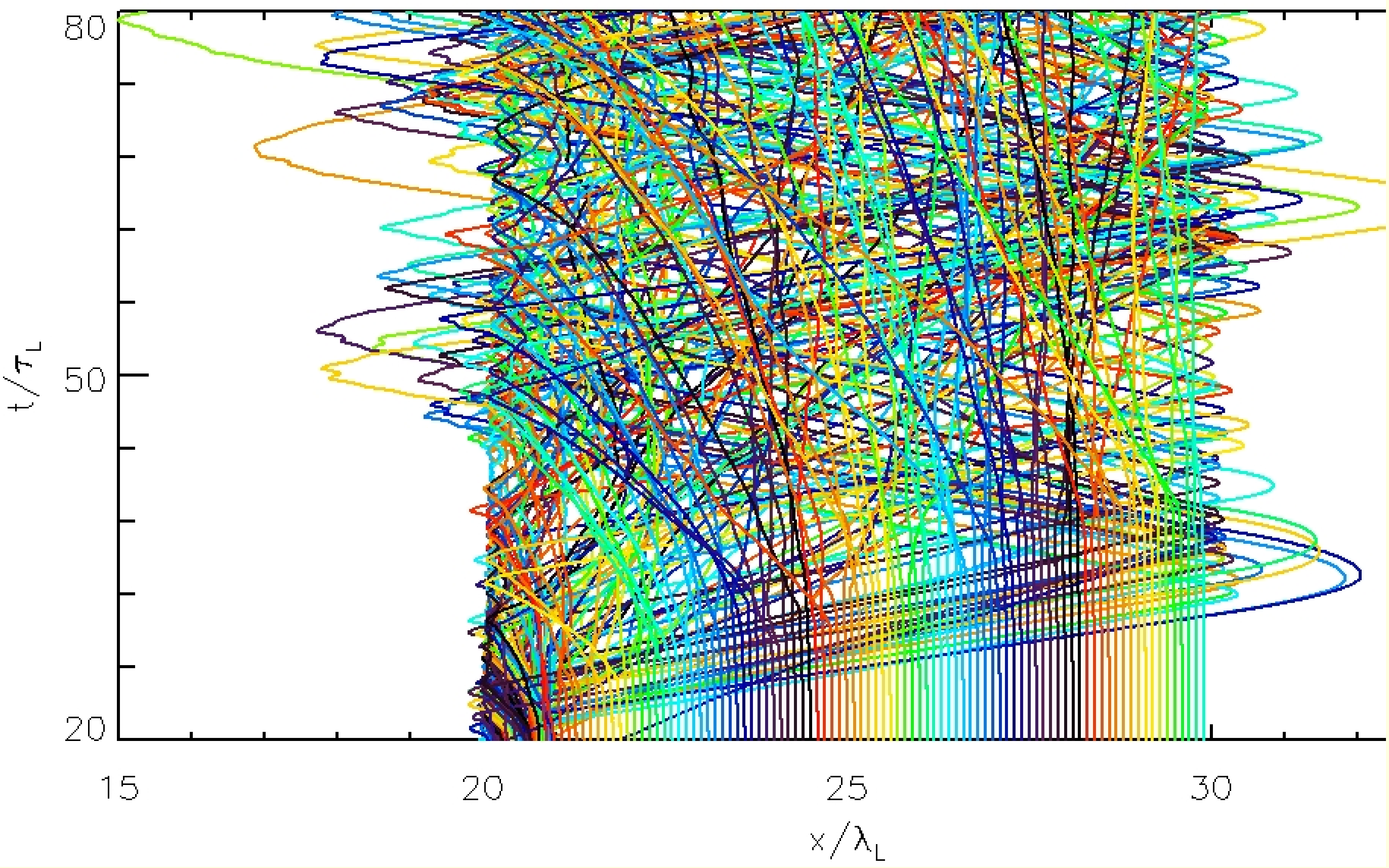
- Prompt generation of fast electrons, almost without delay ?
- Or stochastic heating: $\sim t^{1/2} \Longrightarrow$ slow ?
- Maxwellian tail contains a significant fraction of energies exceeding E_{os} many times

Taken for granted: Phase shift from space charge fields induced by laser

***Example*:Constant electric field E_0** yields per electron **$\langle jE \rangle = 2\pi e^2 E_0^2/me\omega \neq 0$**



a =0.3



$a = 1.0$

Highlights?

A very personal choice:

- Pair production and avalanche of γ's starts at 5 x 10^{22} (H. Ruhl)
- Beyond ***I*** = 1024 hand over energy to protons $\Longrightarrow$ photons (A. Pukhov)

• What is the relevance of the Workshop for FAIR-GSI?

High-power laser is complementary to FAIR accelerator:

Macroscopic samples of **warm** dense and **compressed** matter (WDCM)

Fine dense matter diagnostic by proton radiography (D. Varentsov)

FAIR limitations: T < 20 eV. Laser: almost no limitation in T ⟹ **H**DCM

time ≥ 50 ns. Laser: **atto**second & intnese electron pulses

Necessity of fast diagnostics: **Laser is indispensable**

High flexibility of laser

Accelerator is the scientific machine of the **20th century**

Laser is the scientific machine of **our century**

- **PHELIX Upgrade in the European concert**

V. Bagnoud and his study group have shown in a convincing way that GSI has got the knowhow to build PHELIX upgrade

P. Neumayer et al. from the GSI plasma physics group have shown to be ready with a whole variety of diagnostic tools for FAIR-PHELIX physics

FAIR NEEDS PHELIX Upgrade

Recommendation to FAIR Management

Plasma physics is one of the pillars in the scientific programme at FAIR

Thanks to the FAIR Director **Boris Sharkov** for his continuous support and interest for the plasma physics group at GSI.

Herewith the GSI plasma physics group expresses its hope for support and interest in the forthcoming years

Thanks to the organizer of the EMMI Workshop

Olga Rosmej