ADVANCED ACCELERATOR ACTIVITY IN RUSSIA

K.F. Burdonov, V.N. Ginzburg, E.V. Katin, A.V.Kirsanov, V.V. Lozhkarev, G.A.Luchinin, A.N. Mal'shakov, M.A. Martyanov, O.V. Palashov, A.K. Poteomkin,, A.A. Shaykin, A.A. Soloviev, M.V. Starodubtsev, I.V. Yakovlev, V.V.Zelenogorsky and E.A. Khazanov
V.I. Eremin, Yu.A. Malkov, V.V. Korolikhin, A.M. Kiselev, S.A. Skobelev, A.N. Stepanov
A.A. Gonoskov, A.V. Kim, A.V. Korzhimanov, A.M. Sergeev
V.F. Bashmakov, E.N. Nerush, O.R. Zhebrun, I.Yu. Kostyukov

A. Seryi, N. Andreev, S. Kuzikov, A. Kanareykin

EAAC2013, 2-7 June 2013, Isola d'Elba, Italy

Outline

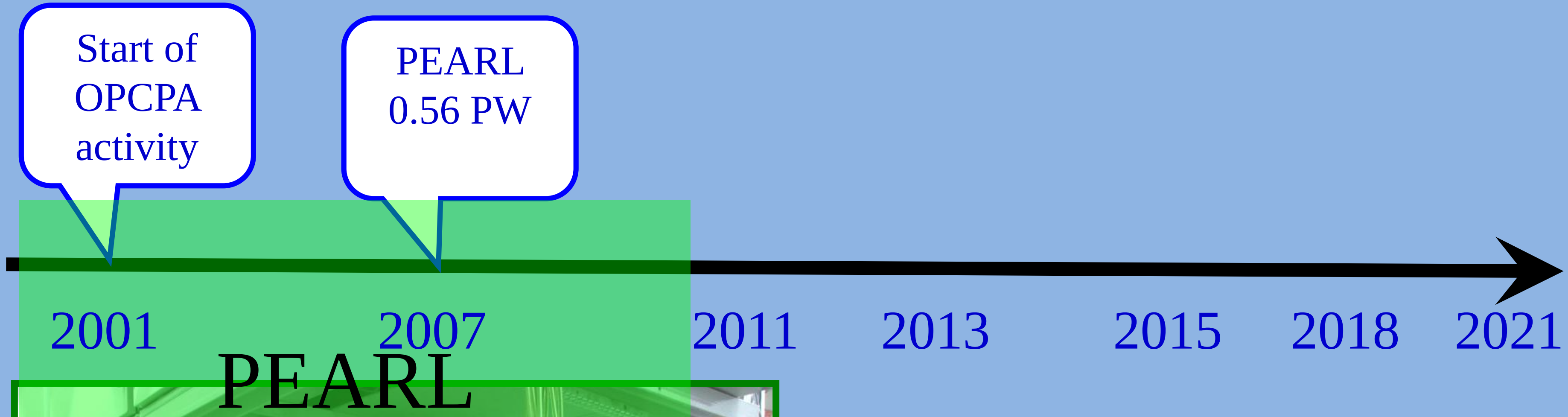
- ✓ Advanced Accelerator Activity in Russia
- ✓ Niznhny Novgorod
- ✓ Moscow region
- ✓ Novosibirsk
- ✓ Sarov and Snezhinsk
- ✓ St. Petersburg
- ✓ Summary

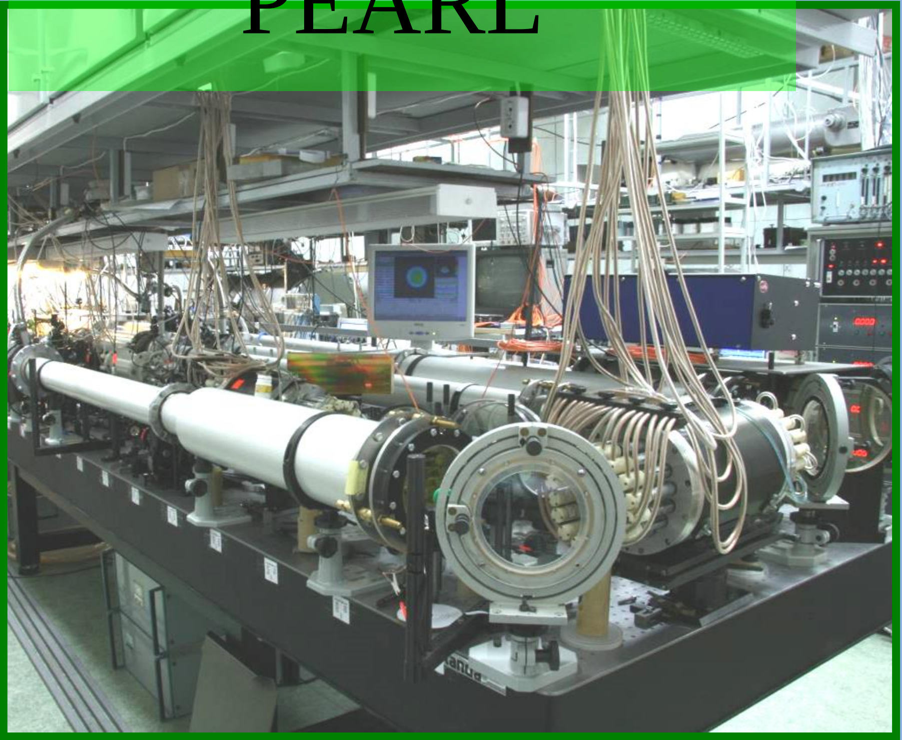
Advanced Accelerator Activity in Russia

Moscow (JIHT RAS, Lebedev Inst., TSNIImash**)**
St. Petersburg (State Electrotech. Univ.**)**
Nizhny Novgorod (IAP RAS**)**
Novosibirsk (Budker Inst., Laser Phys. Inst.**)**
Sarov (VNIIEF**)**
Snezhinsk (VNIITF**)**

INSTITUTE OF APPLIED PHYSIC, RUSSIAN ACADEMY OF SCIENCES (NIZHNY NOVGOROD)

IAP RAS: PEARL Project



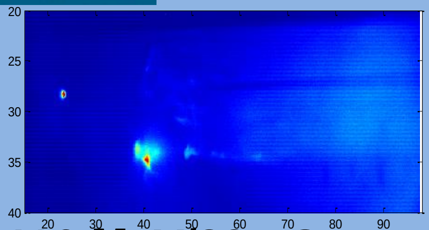


PEARL Project

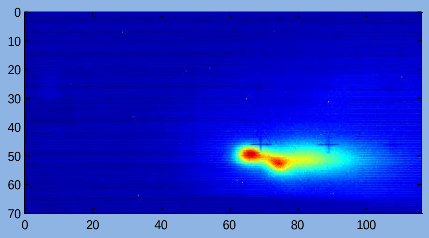
V.V. Lozhkarev, G.I. Freidman, V.N. Ginzburg, E.V. Katin, E.A. Khazanov, A.V. Kirsanov, G.A. Luchinin, A.N. Mal'shakov, M.A. Martyanov, O.V. Palashov, A.K. Poteomkin, A.M. Sergeev, A.A. Shaykin, I.V. Yakovlev, Laser Physics Letters, V. 4, P. 421 – 427 (2007).

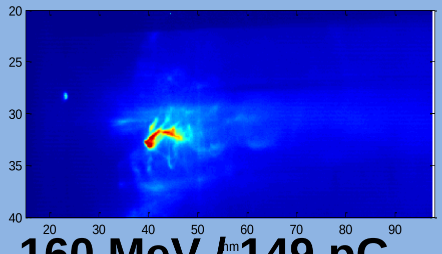
$W=24J,\ \ \tau=43\,fs,\ \ R=12\,\mu m,\ \ P=0.56\,PW,\ \ I=1.1\cdot 10^{20}\,W/cm^2,\ \ \lambda=0.911\,\mu m,\ \ a_0=11.4$

Laser-Plasma Electron Acceleration in IAP RAS in 2008-2010

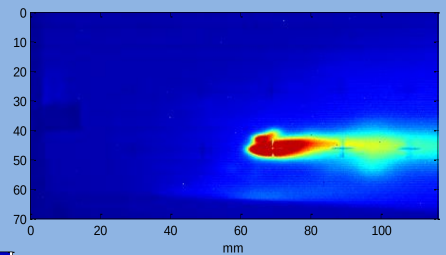


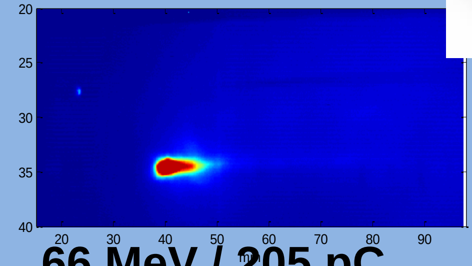
116 MeV/33 pC



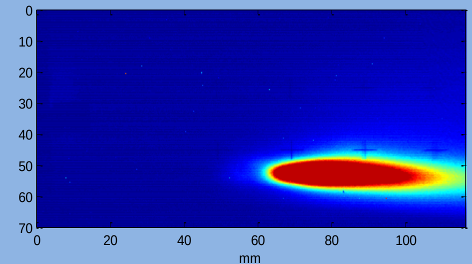


160 MeV / 149 pC

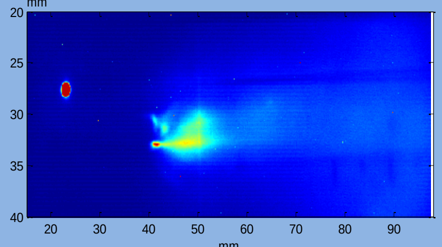




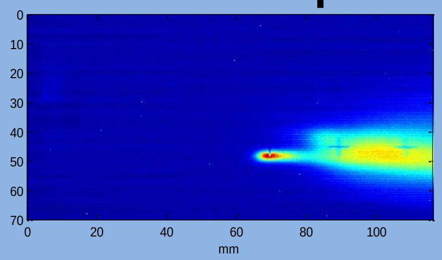
66 MeV / 205 pC

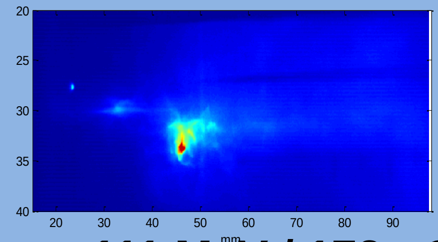


100-200 TW, 50-70fs

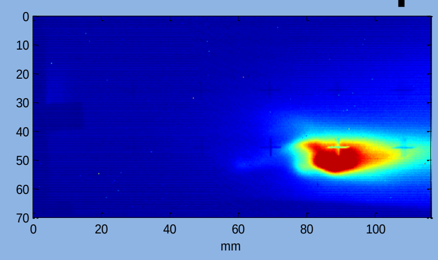


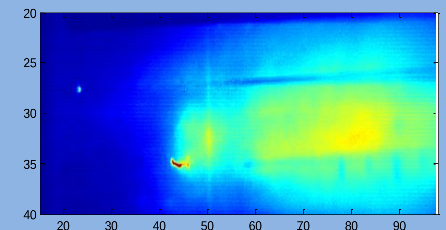
219 MeV/ 14 pC



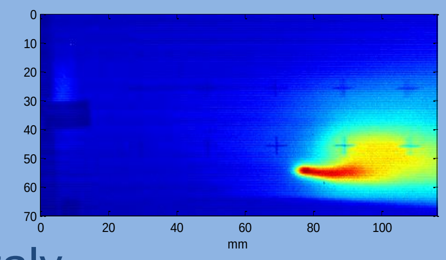


111 MeV / 172 pC

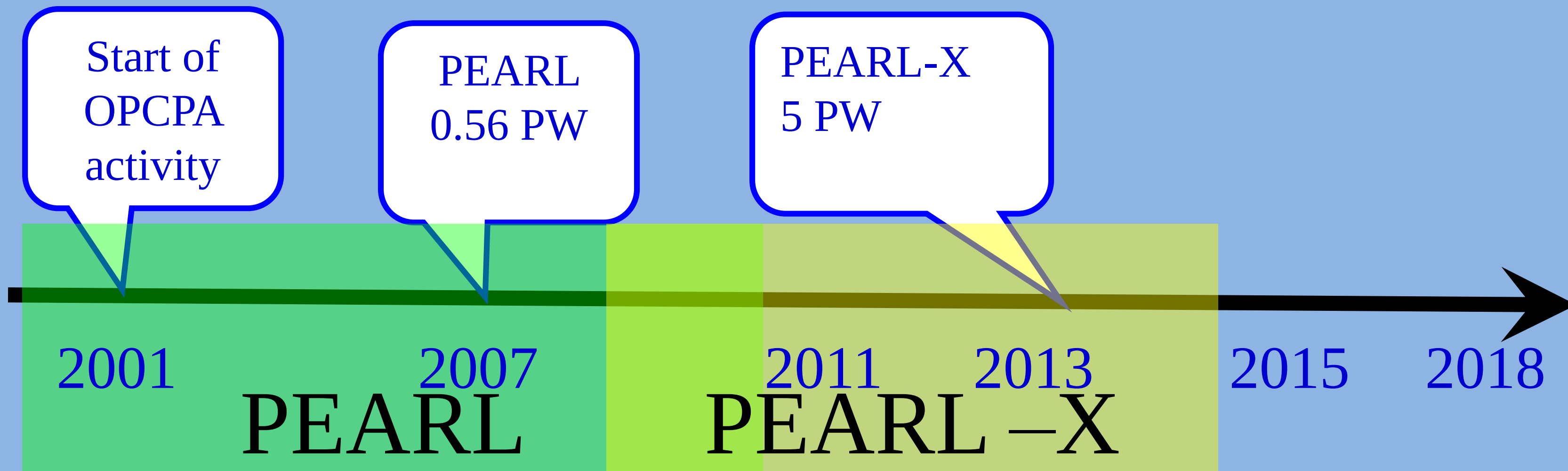


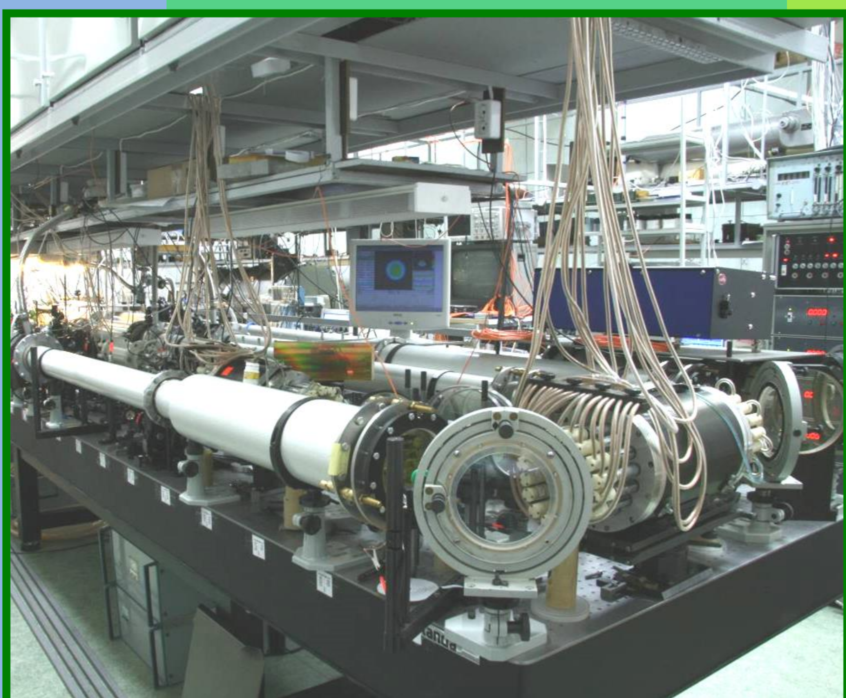


119 MeV / 94 pC

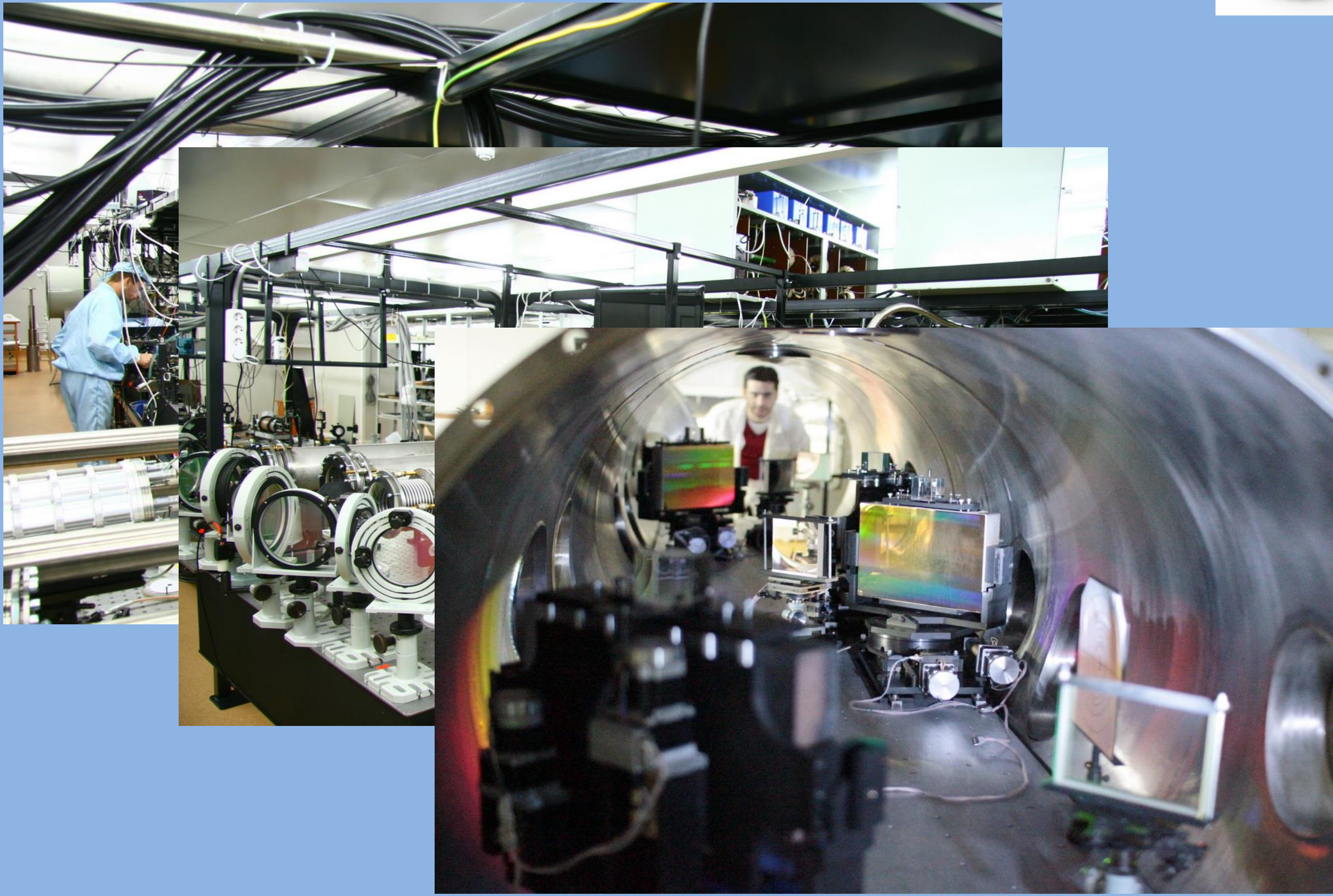


IAP RAS: PEARL Project





IAP RAS: PEARL-X, 2011- …



IAP RAS: PEARL-X

title	PEARL	max	PEARL-X
pulse duration	45 fs	18 fs x 2.5	30fs x 1.5
OPCPA efficiency	20%	40% x 2	33% x 1.65
pump power	180J	600J x 3.3	600J x 3.3
compressor efficiency	66%	76% x 1.2	70% x 1.1
POWER	0,56PW	10PW x 20	5PW x 9
	2007	?	should be done in 2014

IAP RAS: PEARL-X

- **PLANS:**

- PEARL-X will provide power up to 5 PW (fall, 2014).
- The first experiments with power level ~0.5PW will start from the end of 2013.

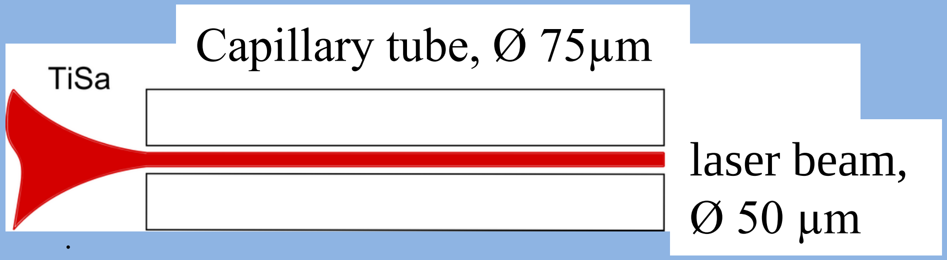
- **GOALS:**

- GeVs electron beam in gas jet in 5 PW regime,
- high-quality GeV electron beam in the regime with external injection

IAP RAS & JIHT RAS: LWFA in Gas- Filled Capillary Tubes

LOW SCALE PROJECTS

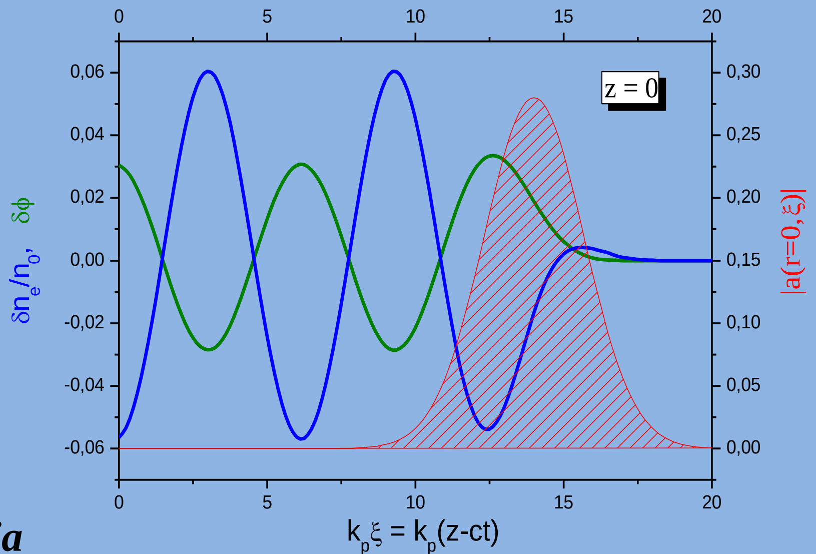
Capillary tube length - several cm
Wake field amplitude
Laser pulse power *P*~ 1TW (10Hz)
Electron energy < 200 MeV



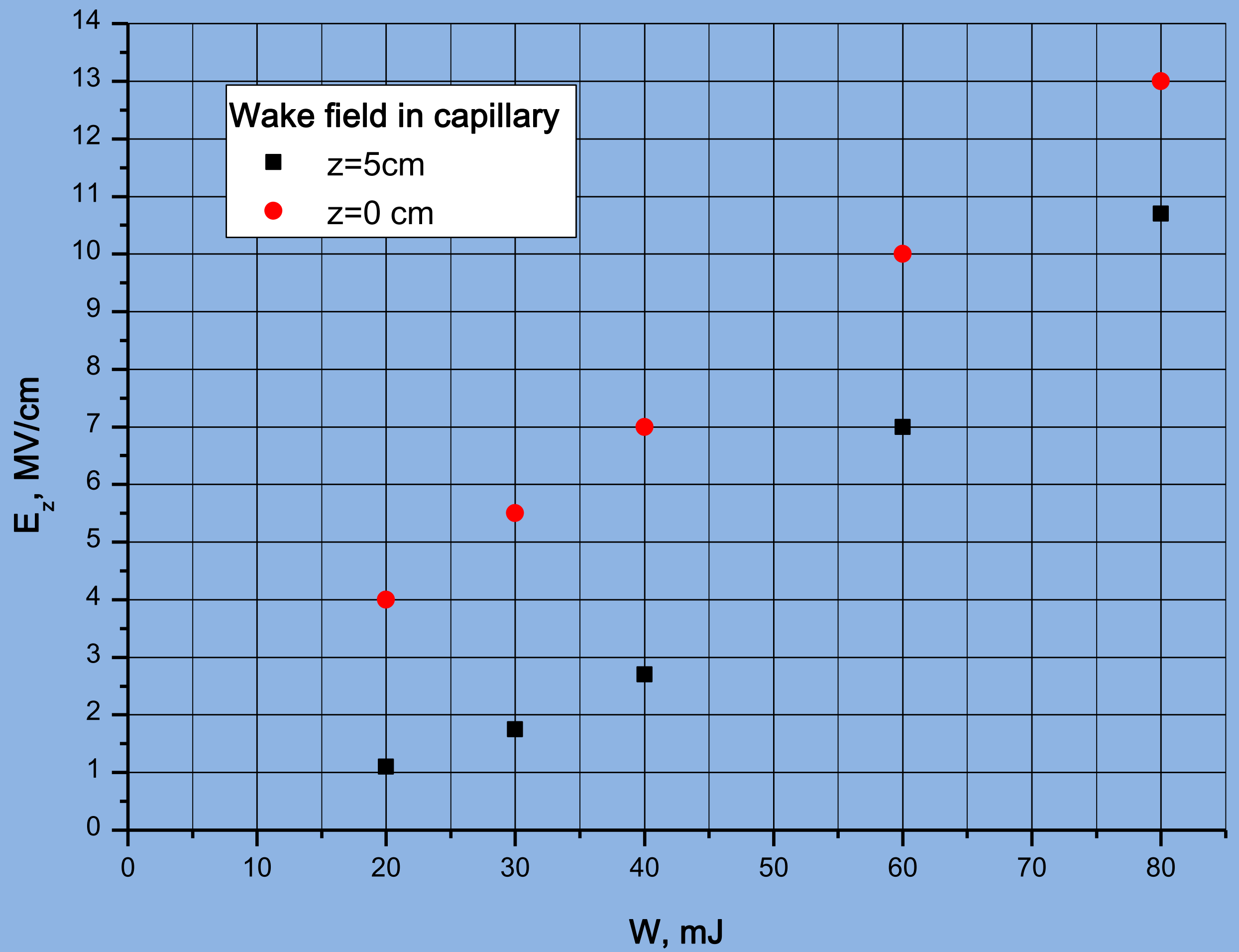
n_e= 6.8×10^{17} cm^{-3} ,
τ≈ 60 fs, W= 98 mJ,
I_L= 1.6×10^{17} W/cm^2

V.I. Eremin, Yu.A. Malkov, V.V. Korolikhin,
A.M. Kiselev, S.A. Skobelev, A.N. Stepanov
Insitute of Applied Physics, Nizhny Novgorod, Russia

L.P. Pugachev, P.R. Levashov, N.E. Andreev
Joint Institute for High Temperatures, Moscow, Russia



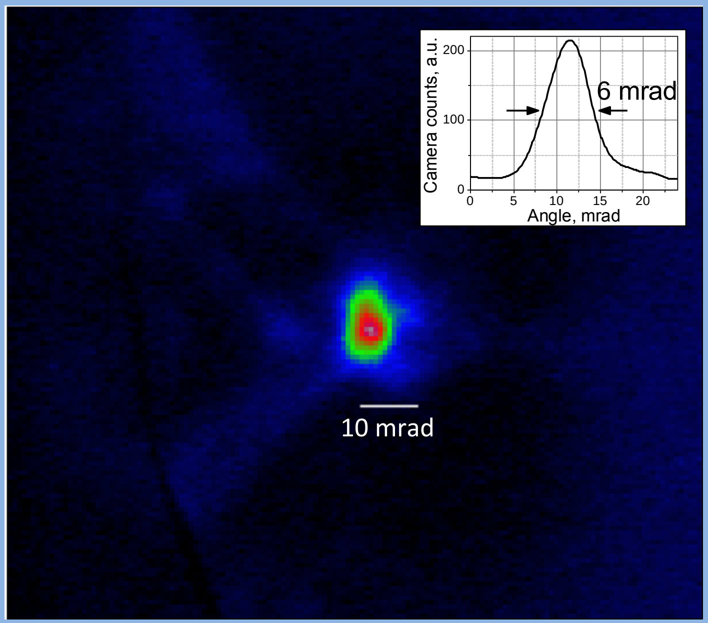
Accelerating Plasma Wakefield In Capillary Tube



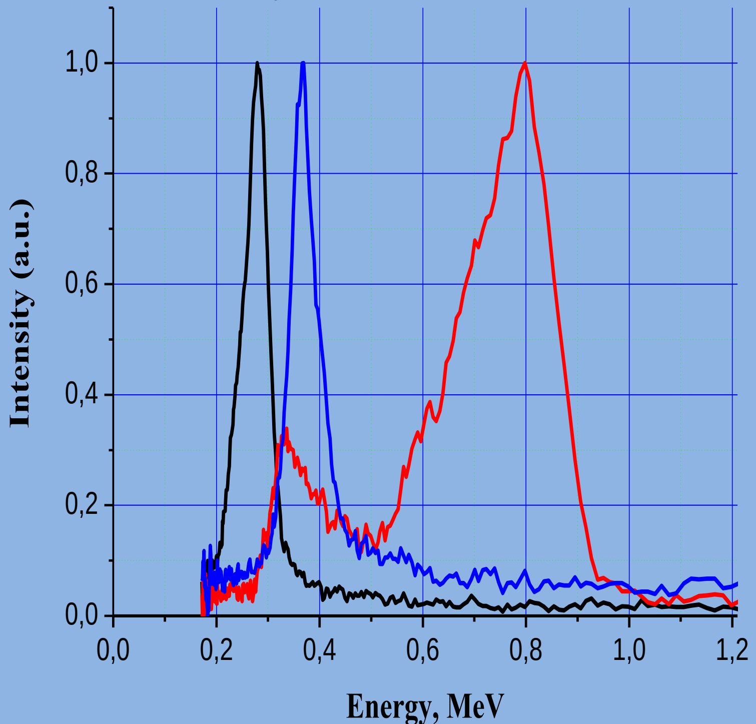
Amplitude of a wake field vs the laser pulse energy

Electron Injector

Angular distribution of electron beam

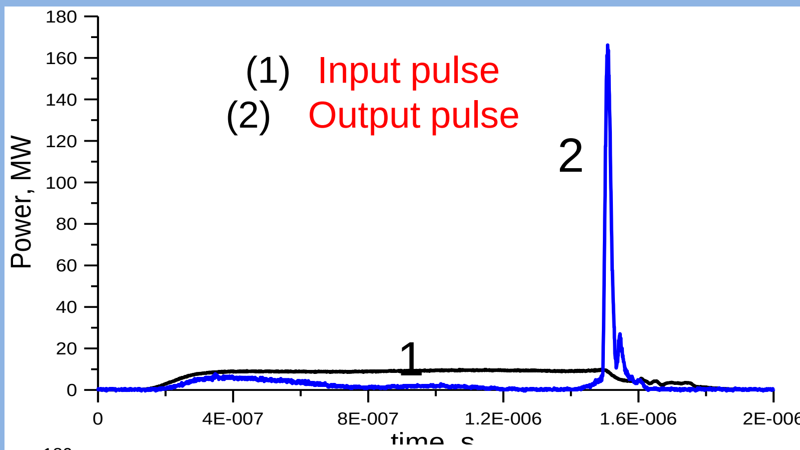


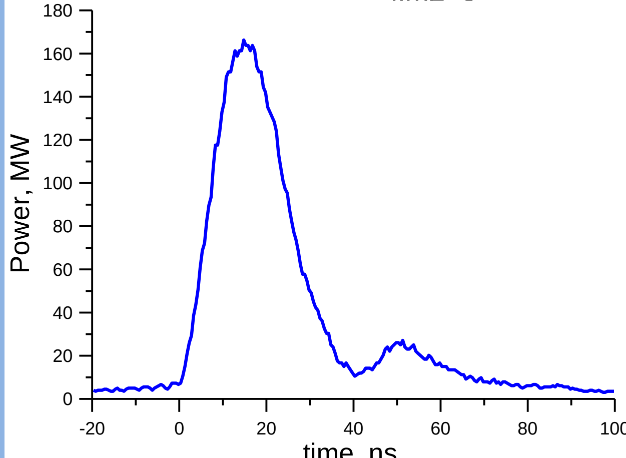
Experimental electron energy spectra



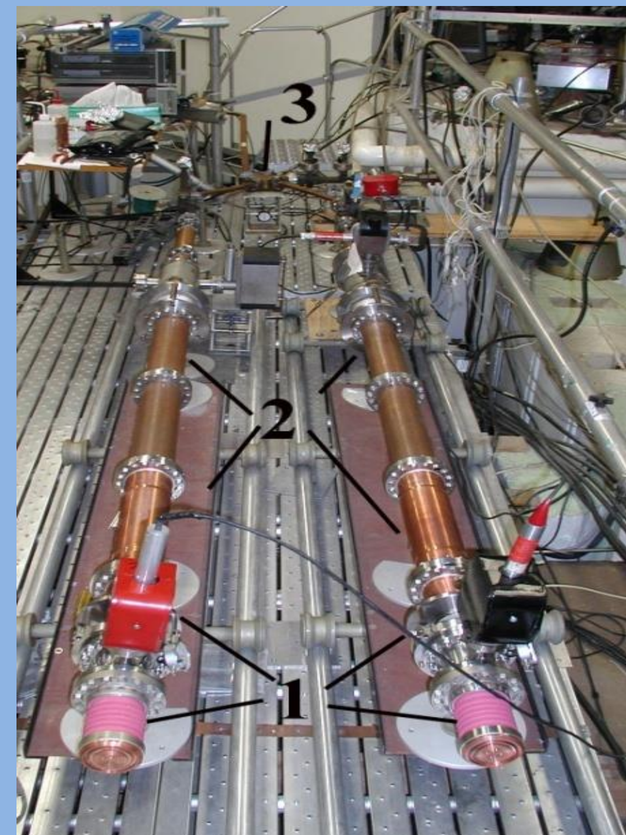
- The plasma wake is excited in gas-filed capillary tube by ~ 1TW laser system.
- The intensity of the accelerating field was up to 13MV/cm.
- Injection is a main issue.
- Promising scheme of laser-foil electron injector is proposed.

High Power RF Compressor For Future Electron-positron Colliders





Pinc= 9.2 MW ,
Pcom= 165 MW,
Power gain = 17.9



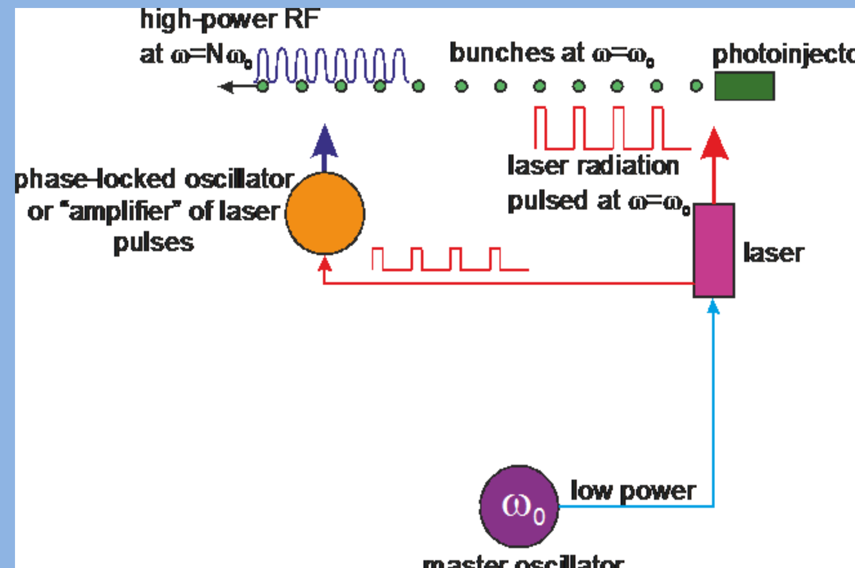
General view of two-channel active pulse compressor: 1 – e-beam switch, 2 – storage resonator, 3 – 3-dB coupler

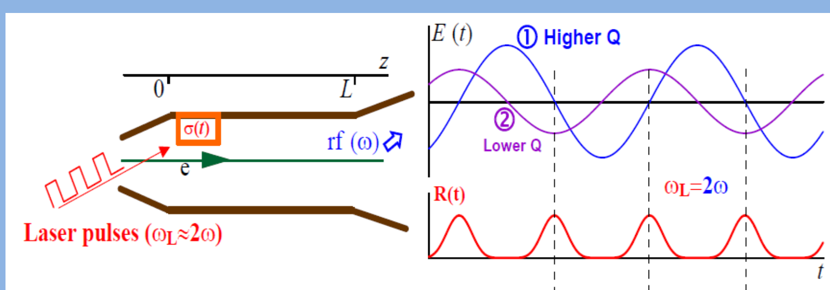
O.A. Ivanov et al., **Phys. Rev. Letters, 110, 115002, (2013)**

Laser Controlled Phase Locked RF Sources

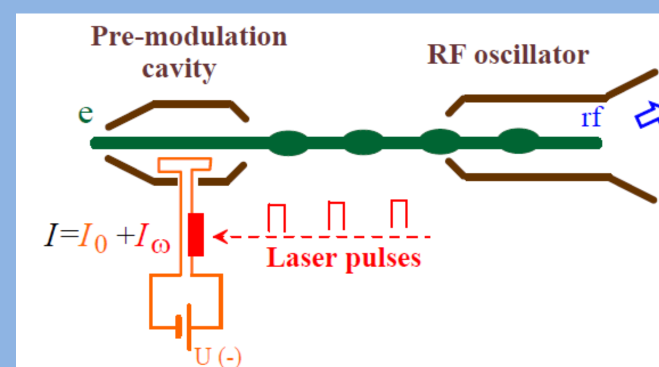
To reduce energy spread in plasma-based accelerators the hybrid schemes are proposed. Schemes combine the conventional accelerator technology with plasma-based technology.

Schemes for electron gun fed by RF source controlled by the same laser which is responsible for photoemission are proposed.





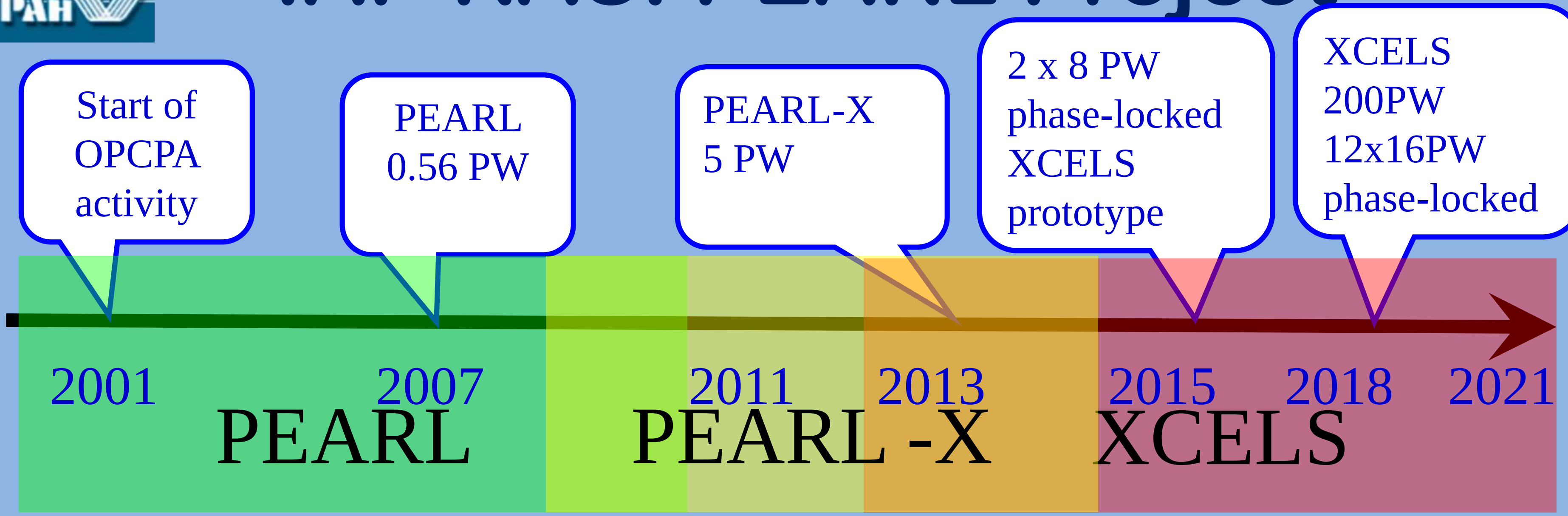
Phase locked RF oscillator

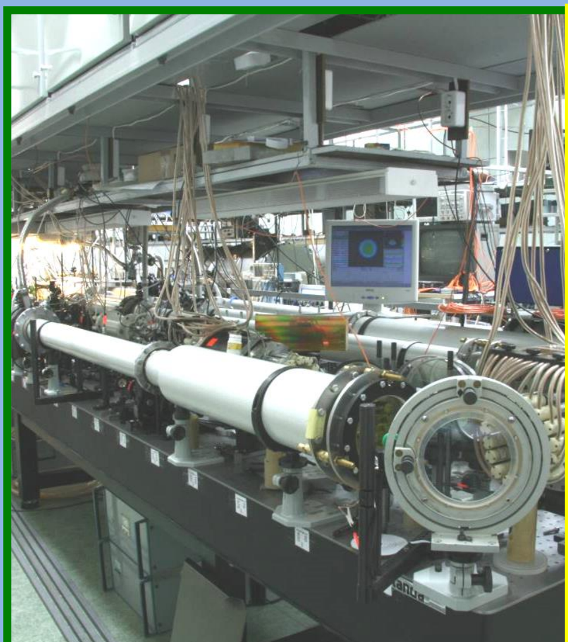


Klystron-type scheme of phase locked RF source

S.V. Kuzikov, A.V. Savilov,
Phys. Rev. Lett. 110, 174801 (2013)

IAP RAS: PEARL Project





IAP RAS: XCELS Project

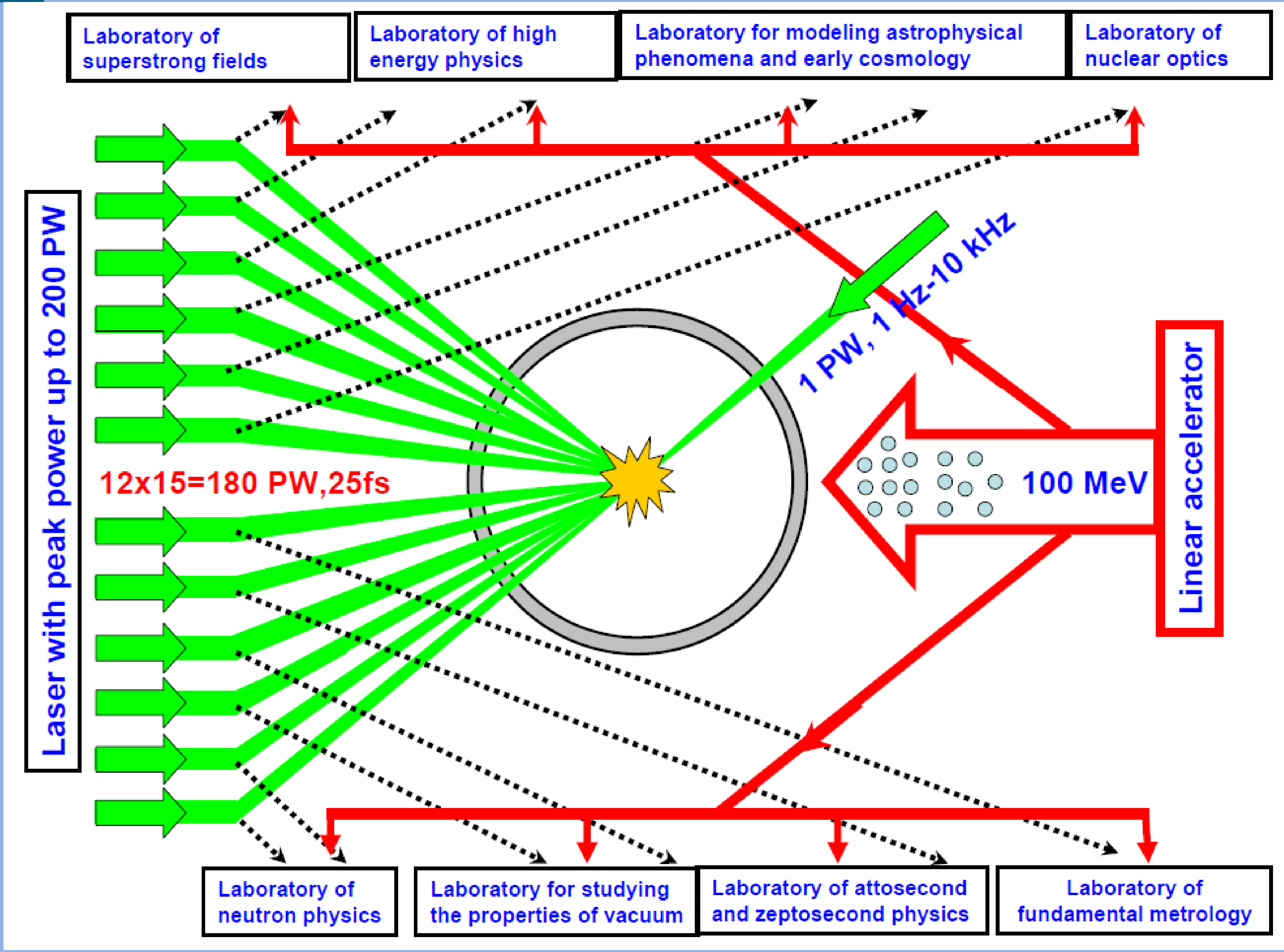
New Mega Science Projects in Russia

1. Tokamak Fusion Reactor IGNITOR /TRINITY,Troitsk,Moscow region/
2. High-Flux Neutrons Research Nuclear Reactor PIK /Inst. Nuclear Physics,Gatchina, St-Petersburg/
3. Fourth-Generation Synchrotron-Radiation Light Source /Kurchatov Inst./
4. Electron-Positron Collider Super C-Tau Factory /Budker Inst/
5. Nuclotron-Based Ion Collider Facility/Dubna,Moscow region/
6. Exawatt Laser Facility XCELS/IAP RAS, Nizhny Novgorod / ~ B €

One of the criteria to select such projects was willingness of over countries to take part in their development (<15% of funding from foreign partners). This could be a proof of scientific significance of the project for Russian Government.

The main contribution of foreign partners is supposed in the form of high-tech research equipment for the laser complex and research laboratories, totaling about 15% of the Project cost.

IAP RAS: XCELS Project



Joint Institute for High Temperatures of the Russian Academy of Sciences (Moscow)

P.N. Lebedev Physical Institute of the Russian Academy of Sciences (Moscow)

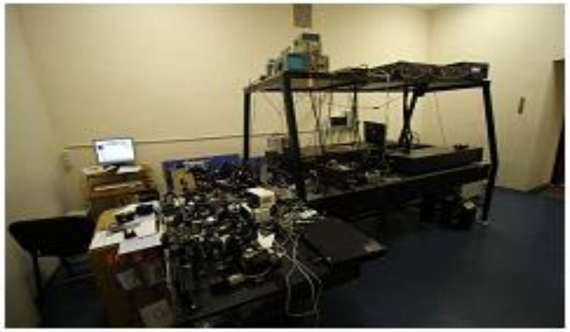
TSNIIMash (Korolev, Moscow region)

Joint Institute for High Temperatures RAS (Moscow)

FEMTOSECOND LASER SYSTEMS at JIHT

Terawatt femtosecond Chrome:Forsterite laser system
1240 nm; 80 fs; 90 mJ; 10 Hz

Subterawatt femtosecond Ti:Sapphire kilohertz laser system
800 nm, 30 fs, 1 kHz, 2,5 mJ



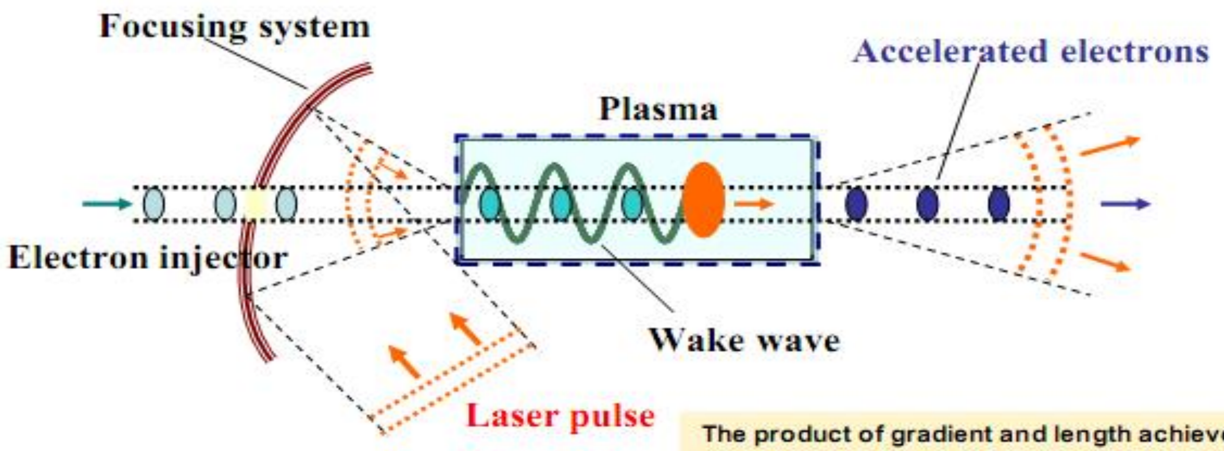
Terawatt femtosecond Ti:Sapphire laser system
800 nm; 40 fs; 10 Hz, to 10 TW

Maximum intensity of focused laser spot 3um in diameter

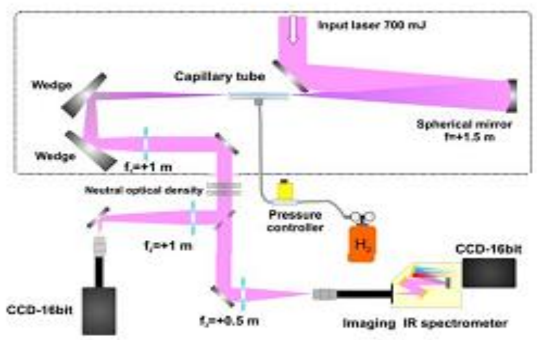
$I_L \approx 10^{19}$ W/cm^2

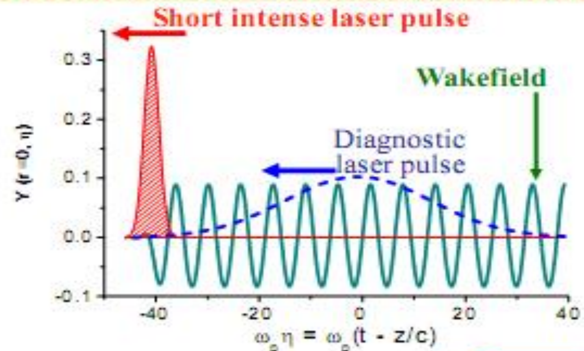
Joint Institute for High Temperatures RAS (Moscow)

Scheme of one cascade of the laser wake-field accelerator



The product of gradient and length achieved in this experiment is 0.4 GV at a pressure of 50 mbar @ 0.12 J, 51 fs





N.E. Andreev, K Cassou, F Wojda, G Genoud, M Burza, O Lundh, A Persson, B Cros, V E Fortov and C-G Wahlstrom, NJP, v. 12, 045024 (2010)

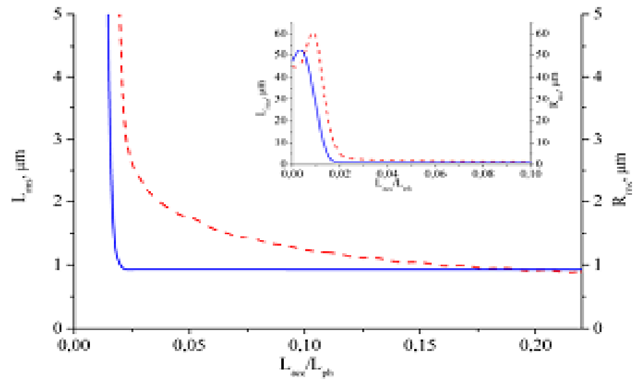
Joint Institute for High Temperatures RAS (Moscow)

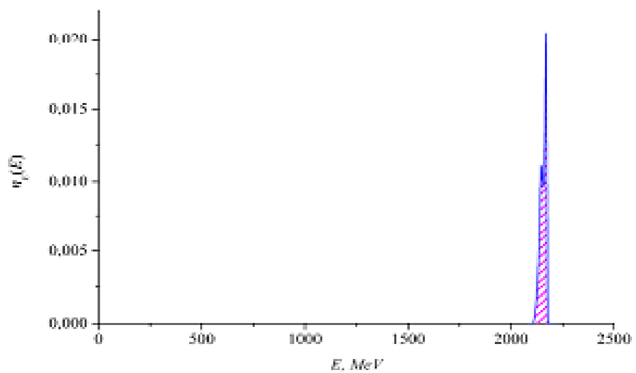
Computer simulation by the code LAPLAC

JIHT of RAS

accelerated electron bunch

the bunch has acquired an energy of **2.2 GeV** with a narrow energy spectrum and low emittance 5.4 mm × mrad





The total trapped and accelerated number of particles in the bunch is about 25% of the injected electrons

$E_{inj} = 3$ MeV $\quad L_{b0} = 2\sigma_z = 47\,\mu m \quad r_0 = 37\,\mu m \quad I_L = 2.7\times 10^{18}$ W/cm^2 $\quad P_L / P_{cr} = 0.35$

$Q_b = 10$ pC $\quad R_{b0} = 45\,\mu m \quad \tau_{FWHM} = 31$ fs $\quad$ laser energy 2.25 J $\quad n_0(0) = 1.1\times 10^{17}$ cm^{-3}

$\varepsilon_{N\perp} = 4 r_{rms} \sigma_{p_\perp / mc} = 1$ mm mrad

$L_b \approx R_b \approx 0.9\ \mu m$

$\Delta E/E \approx 1\%$

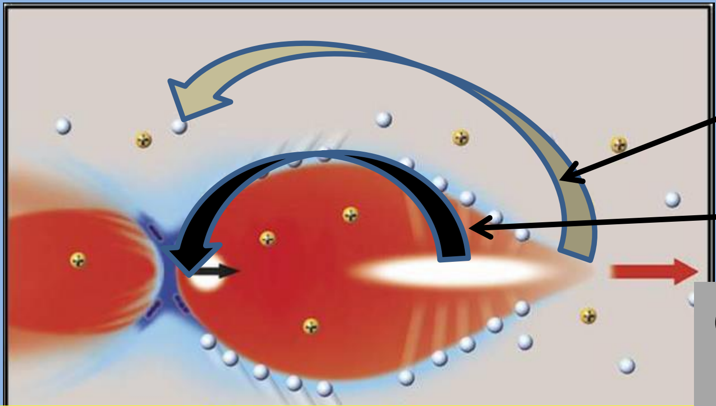
N.E. Andreev, V.E. Baranov, B. Cros, V.E. Fortov, S.V. Kuznetsov, G. Maynard, P. Mora, NIM A (2011)

Lebedev Physical Institute RAS

Ionization Induced Self-Injection in a LWFA

SIMULATION (THEORY) : **Group of Prof. V.Yu. Bychenkov (Lebedev Phys. Inst.) + VNIITF**

EXPERIMENT: **CUOS (Michigan)**

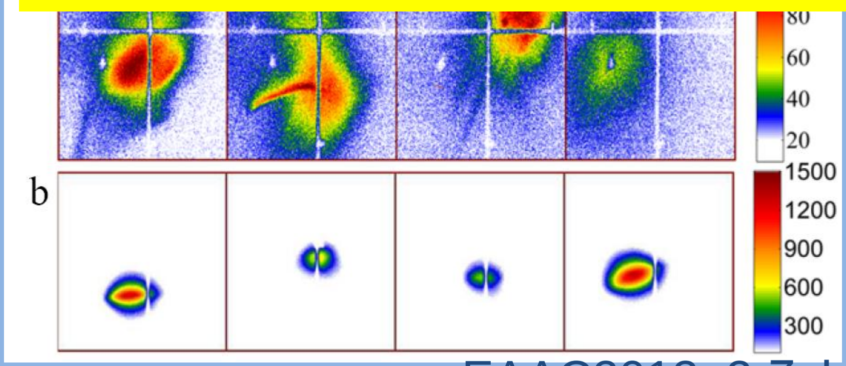


a) Pre-ionized electrons are expelled by laser, most oscillate without trapping, few trapped

b) Electrons born near peak are more likely to become trapped

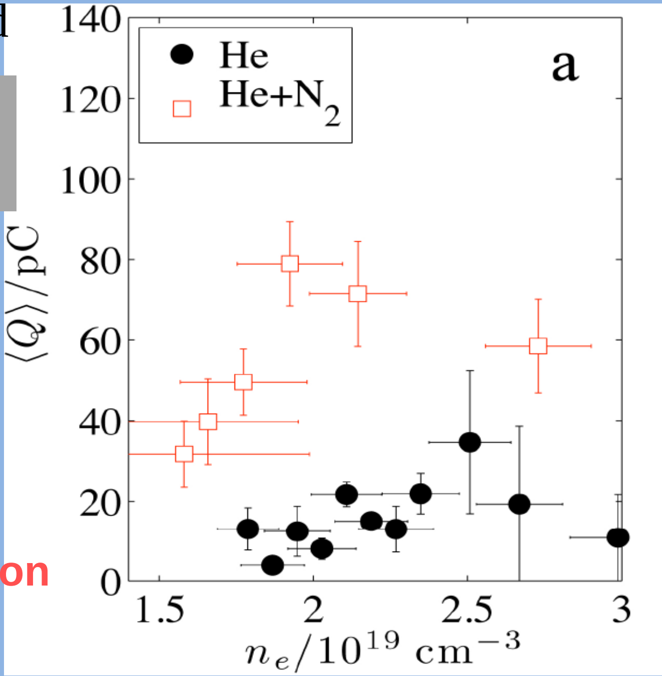
C. McGuffey et al., PRL **104**, 025004 (2010).

→ Better injection → increased charge
→ Lower divergence



→ **Pure helium target**

→ **Helium + argon**



Budker Institute of Nuclear Physics, SB RAS (Novosibirsk)

Novosibirsk State University

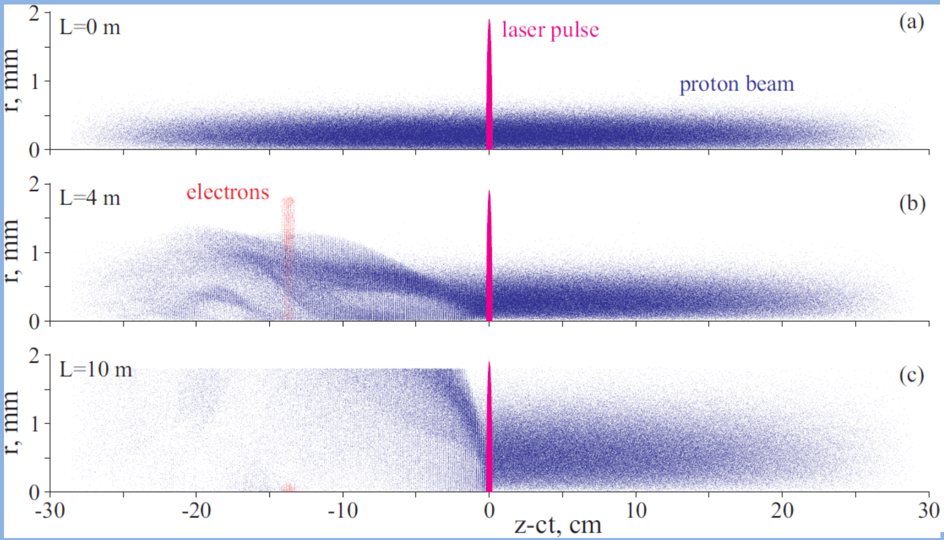
Institute of Laser Physics, SB RAS (Novosibirsk)

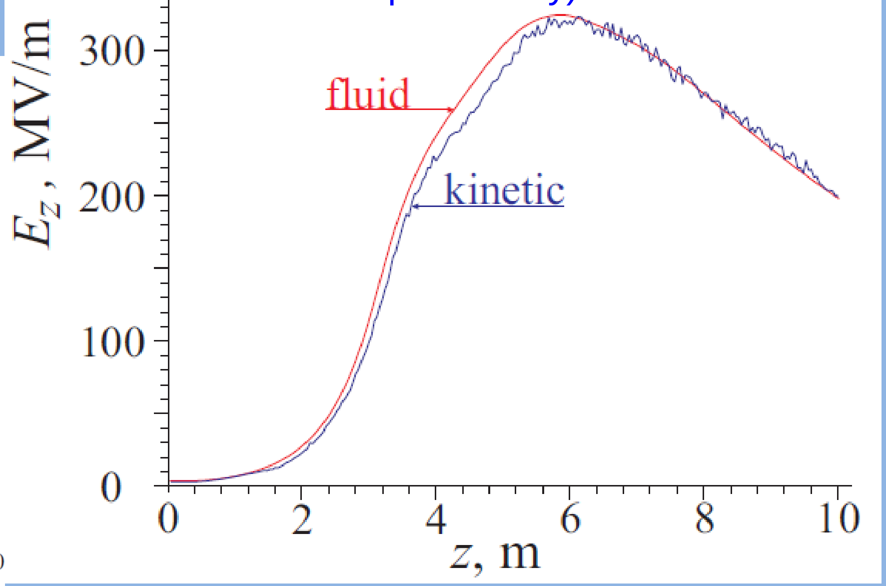
Activity in Novosibirsk: Simulation Codes (NSU)

Features (LCODE):
•2d3V quasi-static
•Specially adapted to long beams and long propagation distances
•Both kinetic and fluid plasma solvers available
•Freely distributed: http://www.inp.nsk.su/~lotov/lcode

Example: self-modulation of the proton beam (AWAKE experiment)

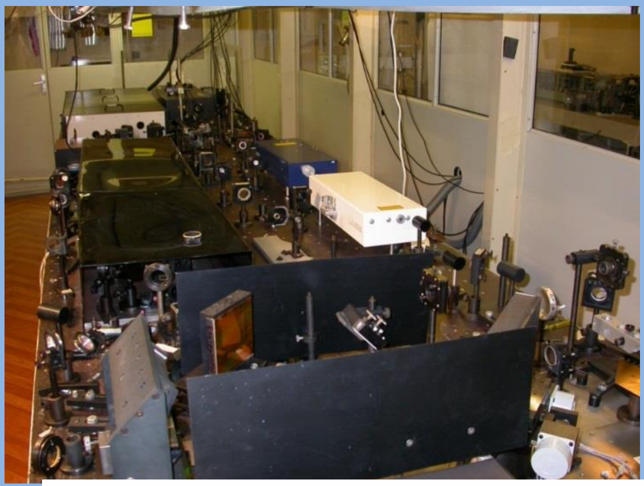
A hard problem for codes:
•Beam 30 cm long (1500 k_p^{-1})
•Energy of beam particles: 5MeV (e) – 400GeV (p)
•Propagation distance 10 m (50000 k_p^{-1})
•Ion motion, wave breaking are important
•Physically unstable process (simulation errors grow up exponentially)

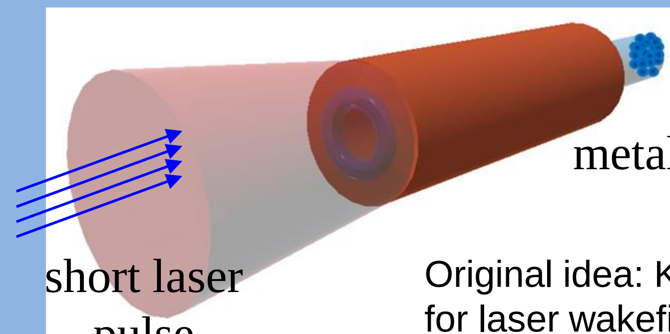




Precision is seen from comparison of two plasma models (at a reduced beam population for the fluid model to work correctly)

Activity in Novosibirsk: LWFA in narrow metal capillaries (Institute of Laser Physics)



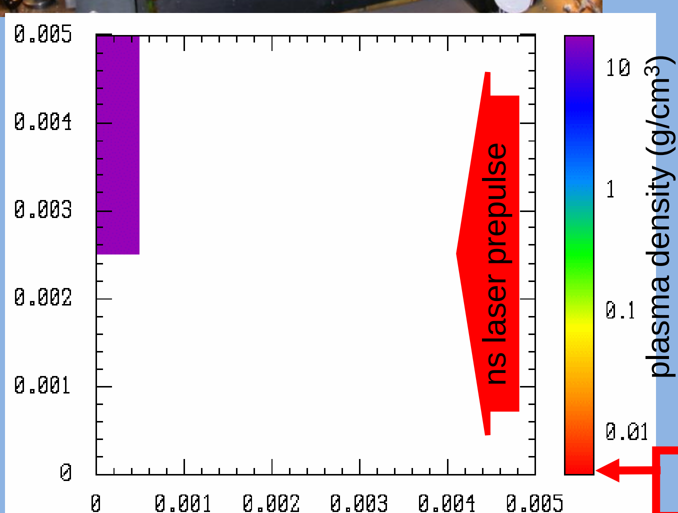


accelerated electrons

metal (copper) capillary, r=15..30 mm

short laser pulse

Original idea: K.V.Lotov, Driver channeling for laser wakefield accelerator, Part. Accel., 1999, v.63, p.139.

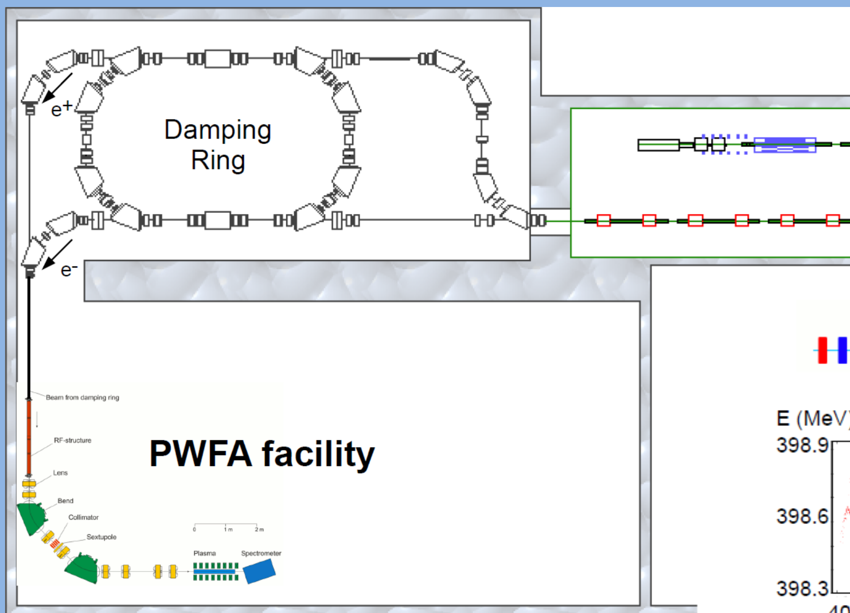


Critical density

Experiments are in preparation.
Problems to be studied:

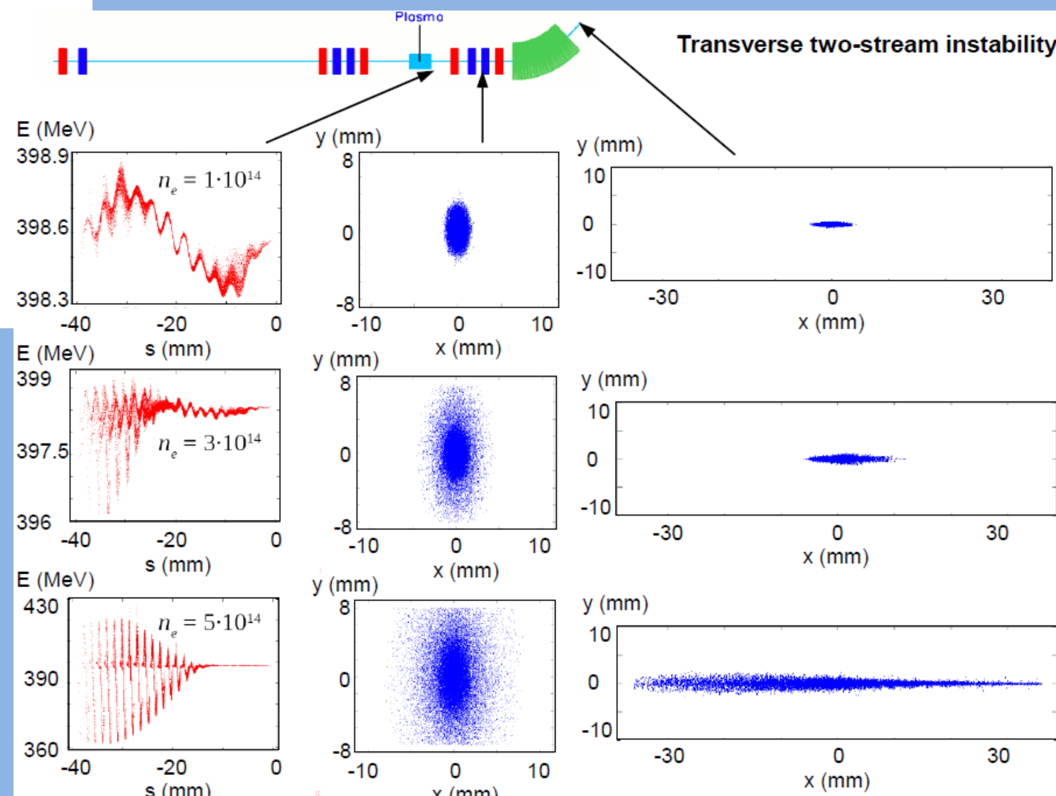
- Capillary manufacturing
- Excitation of a proper waveguide mode
- Blocking the entrance hole by prepulse-generated plasma
- Damping rate of the main pulse
- Lifetime of the capillary
- Stability and reproducibility

Activity in Novosibirsk: Electron driven PWFA (Budker INP)



Experiment with 500 MeV electron beam is in preparation

Full scale construction work is slow, so simplified version is put forward as 1st stage



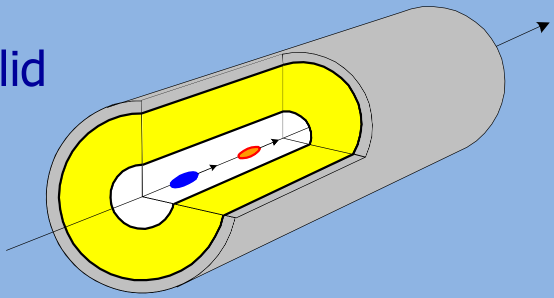
St. Petersburg Electrotechnical University (LETI)

St. Petersburg Electrotechnical University (LETI)

Group of Physics Department of LETI University:

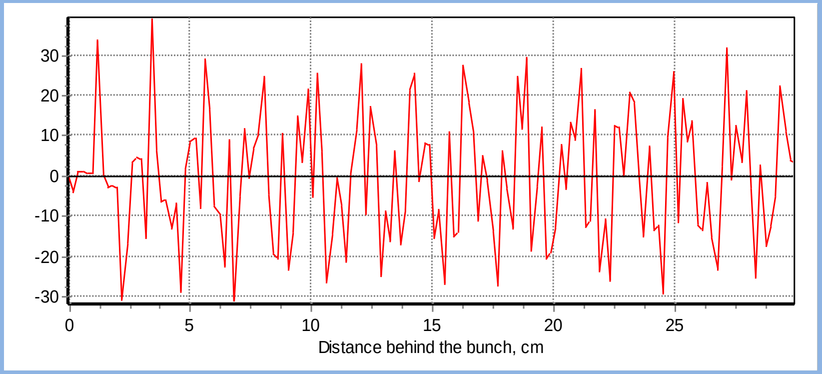
- work since 1992 in close collaboration with ANL and Euclid
- analytical simulations and software development;
- GHz,THz structures design;
- material development and dielectric components fabrication;
- nonlinear ferroelectric development

  for the DLA structure tuning



$$\sigma_r = \left(\frac{\varepsilon_N}{\gamma}\beta\right)^{1/2}$$

$$W_Z(z) \approx \frac{Q}{a^2}\exp\left[-2\left(\frac{\pi\,\sigma_z}{\lambda_n}\right)^2\right]\cos(kz)$$



Accelerating and transverse fields of the DLA (cross-section)

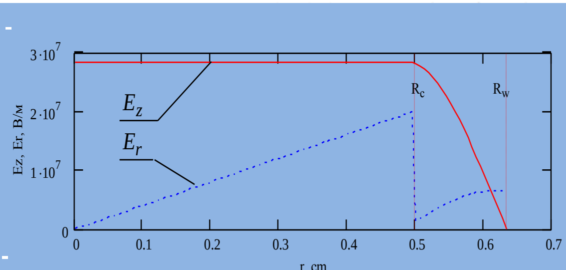
St. Petersburg Electrotechnical University

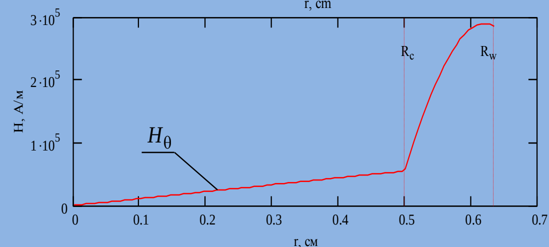
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 051302 (2013)

Transverse operator method for wakefields in a rectangular dielectric loaded accelerating structure

S. S. Baturin,[1,*] I. L. Sheinman,[1] A. M. Altmark,[1] and A. D. Kanareykin[1,2]
[1]*St. Petersburg State Electrotechnical University, St. Petersburg, Russia*
[2]*Euclid Techlabs, LLC, 5900 Harper Road, Solon, Ohio 44139, USA*
(Received 12 February 2013; published 16 May 2013)

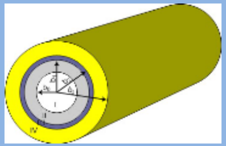
Cherenkov radiation generated by a relativistic electron bunch in a rectangular dielectric-loaded waveguide is analyzed under the assumption that the dielectric layers are inhomogeneous normal to the beam path. We



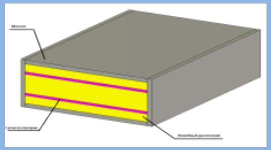


Longitudinal and radial components of electric and magnetic fields in the cross-section

Waveguide

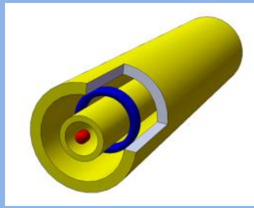


Rectangular

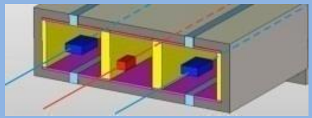


Multibunch

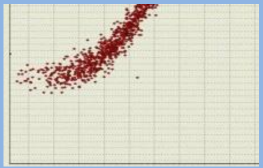
Annular



Multizone.



Beam Breakup (BBU)



SUMMARY

- LASER-DRIVEN ACCELERATION
  - IAP RAS (Nizhny Novgorod) and N. Novgorod University
  - JIHT RAS (Moscow)
  - Lebedev Institute (Moscow)
  - TSNIIMash (Korolev, Moscow region)
  - LPI SB RAS (Novosibirsk)
  - VNIIEF (Sarov)
  - VNIITF (Snezhinsk)

- BEAM-DRIVEN ACCELERATION:
  - Budker Institute (Novosibirsk)
  - Novosibirsk University

- ADVANCENT METHODS FOR CONVENTIONAL ACCELERATORS
  - LETI (St. Petersburg) dielectric-based acceleration
  - IAP RAS (Nizhny Novgorod)
  - Budker Institute (Novosibirsk)
  - JINR (Dubna) ....