Интенсивные лазерные источники гамма-излучения и частиц высоких энергий

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Heinrich-Heine-Universität Düsseldorf
ITEP SRC
Lebedev Physical Institute of RAS
Institute of Applied Physics of RAS

7 – 13 ноября, 2022, Институт прикладной физики РАН, Нижний Новгород

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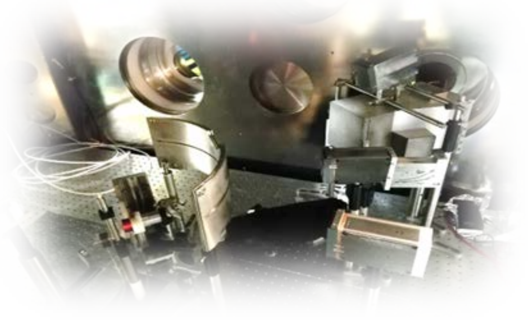

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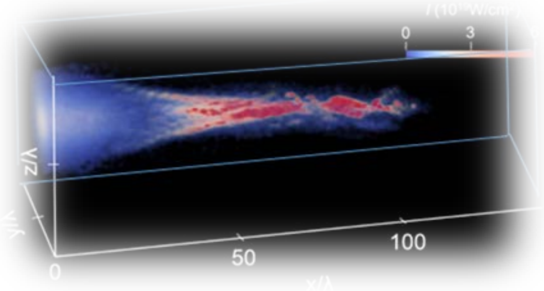


OUTLINE

Motivation:

Approach to enhance performance of laser-based sources of MeV particles and radiation for HED research

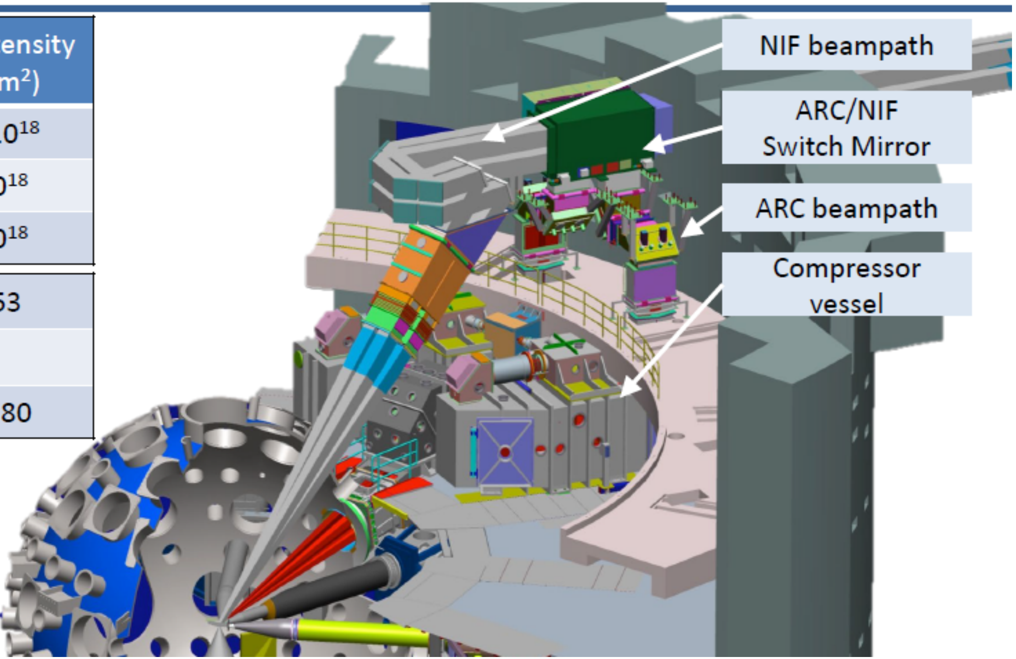
- ❑ Generation of super-pondreromotive electrons at sub-ps and fs laser facilitates:
  - Direct Laser Acceleration in NCD plasma
  - Production of sub-mm long NCD plasma with foams
  - Experiments on generation of high-current well-directed beams of super-ponderomotive electrons
  - 3D PIC simulations for PHELIX-up-grade, PEAR and XSELS
- ❑ Application of foams for interdisciplinary research with lasers:
  - Ultra bright betatron radiation
  - Production of ultra-bright tens of MeV BS sources
- ❑ Summary

NIF's short pulse laser, the advanced radiographic capability (ARC)

Largest amount of available short pulse energy in the world (up to 4 kJ) but is delivered at quasi-relativistic intensities (I_L < =10^{18} W/cm^2)

Energy/ beamlet (kJ)	Pulse Duration (ps)	Peak Intensity (W/cm^2)
1.0	30	0.3×10^{18}
0.6	10	1×10^{18}
0.25	1	2×10^{18}

Wavelength (um)	1.053
Number of beams	4
Spot Size Radius (um^2)	40 x 80

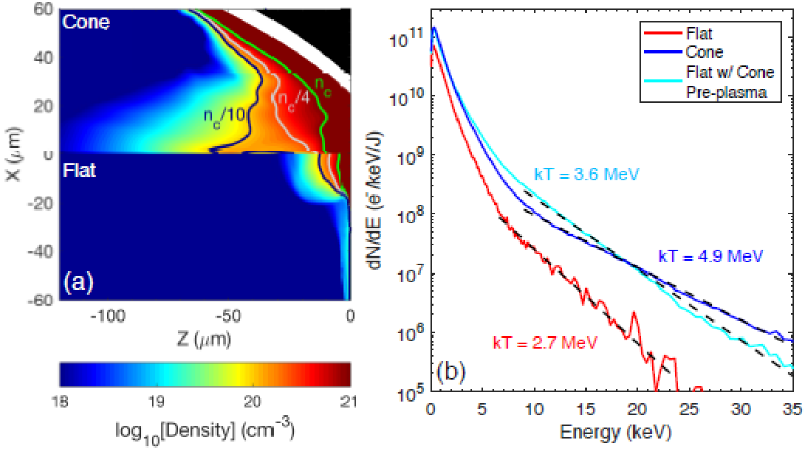


From: Development of a Self-Modulated Laser Wakefield Accelerator Platform with a 10 keV to 1 MeV Hyper Spectral Photon Source for HEDS. PI: C. Joshi

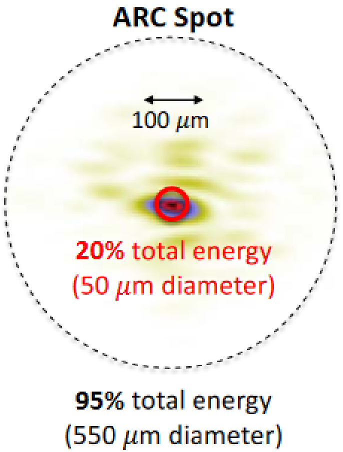
There is the need for a high energy broadband x-ray source for High-Energy Density Science

Modern approach to laser sources of relativistic electrons for high energy density research at Livermore

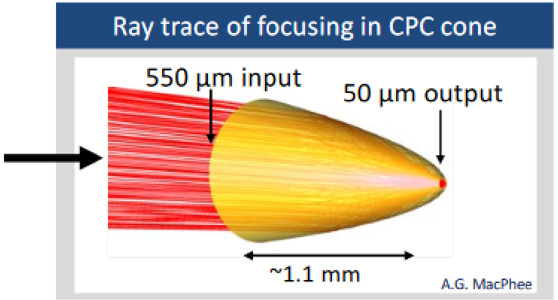
Compound Parabolic Concentrator (CPC) at the Advanced Radiographic Capability laser system at LLNL's National Ignition Facility (ARC)



(a) Density maps from hydrodynamic simulations for cone (upper) and at (lower) targets with contours corresponding to nc, nc=4, and nc=10. White region shows the initial location of the cone wall. (b) Electron spectra from cone, flat, and flat with cone preplasma.



A. G. MacPhee et al., Optica Vol. 7, Issue 2, pp. 129-130 (2020)



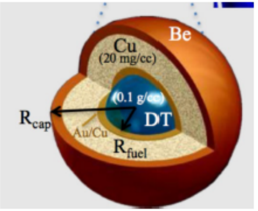
There is the need for a high energy broadband x-ray source for High-Energy Density Science

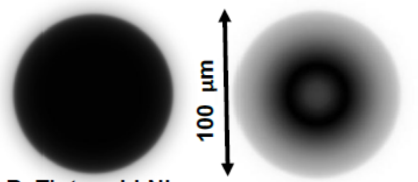
Applications

MeV radiography:

NIF capsule | 0.2 MeV radiography | 1 MeV radiography

- Double shell capsule at NIF, 1800 g/cm³, 10 μm radius

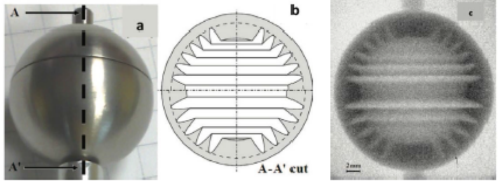




R. Tipton, LLNL

Fully imploded

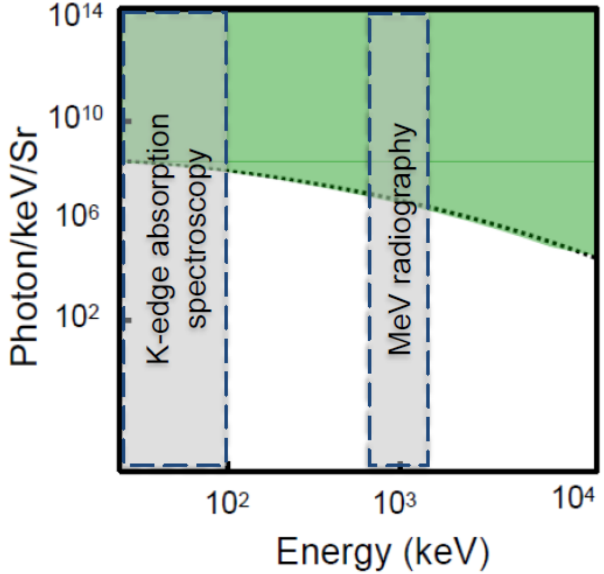
- High-Z complex targets



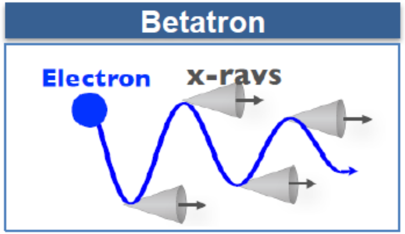
Ben Ismail, et. al., Nucl. Instrum. Methods Phys. Res. A 629 382–6

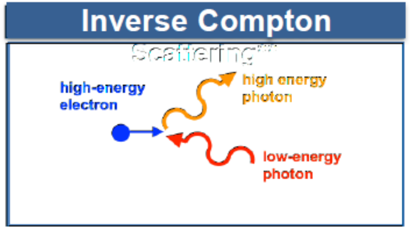
- Opacity in hot-dense plasmas
- K-edge absorption spectroscopy of high-z materials

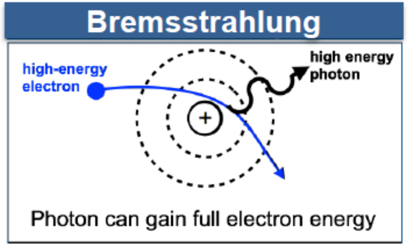
Necessary X/Gamma-ray spectrum

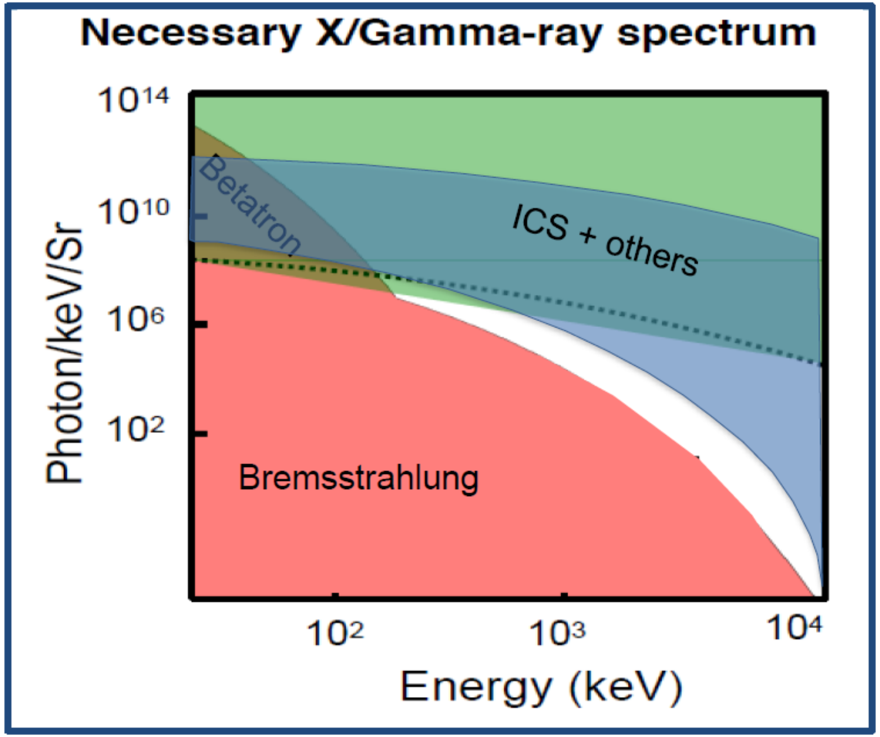


Relativistic electrons are used to created x-rays through Inverse Compton Scattering and bremsstrahlung radiation

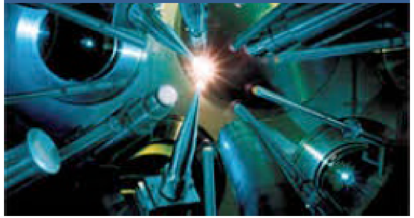








Development of a Self-Modulated Laser Wakefield Accelerator Platform with a 10 keV to 1 MeV Hyper Spectral Photon Source for HEDS **PI:** C. Joshi, NIF

Titan, LLNL	OMEGA-EP, LLE	NIF – ARC, LLNL	LMJ – PETAL, CEA
			

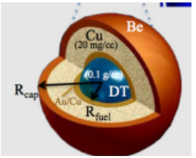
2015 → 2016 → 2017 → 2018 → 2019 → 2020 → 2021

- **Titan** – SMLWFA electrons, Betatron radiation (2015)
- **Titan** – Compton scattering/Bremsstahlung (2016–2017)
- **Titan** – Radiography (2018–2019)
- **Titan** – Shock Compression (2020–2021)
- **OMEGA-EP** – SMLWFA electrons (2018)
- **OMEGA-EP** – X-ray sources (2019)
- **OMEGA-EP** – Radiography + shocks (2020–2021)
- **NIF - ARC** – SMLWFA electrons (2019–2020)
- **NIF - ARC** – X-ray sources (2020–2021)
- **LMJ – PETAL** – SMLWFA electrons (2021)

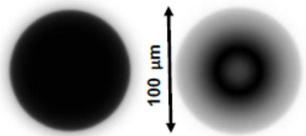
MeV radiography:

- **Double shell capsule at NIF, 1800 g/cm^3, 10 µm radius**

NIF capsule



0.2 MeV radiography **1 MeV radiography**

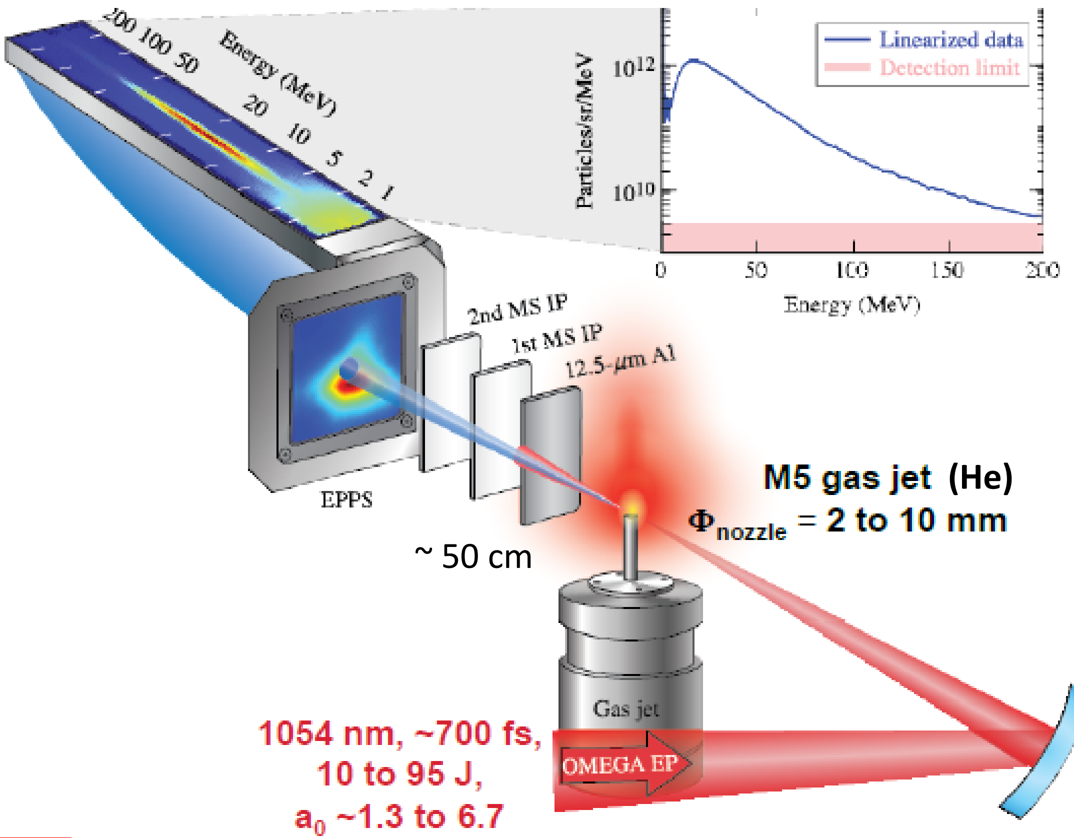


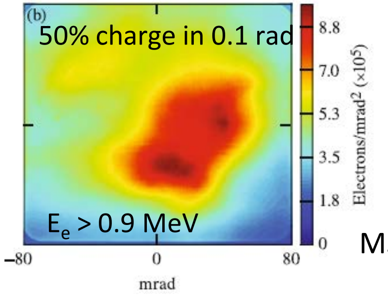
R. Tipton, LLNL

New Developments in Laser Wakefield Acceleration at the Laboratory for Laser Energetics

OMEGA EP

SM-LWFA-based LPA





MS IP after 37 μm Al

M5 gas jet (He)

Φ_{nozzle} = 2 to 10 mm

~ 50 cm

1054 nm, ~700 fs,
10 to 95 J,
a_0 ~1.3 to 6.7

f/2 OAP
apodized to
f/5 to f/10

Results for a_o= 6.6

n_e=8x10^{18} cm^{-3}, Φ_{nozzle}= 6 mm

P/P_c= 3-4

Charge 700±420 nC (1-200 MeV)
conversion efficiency (18 MeV) ~ 11%

J. Shaw *et al*, Sci. Reports 2021

UR LLE

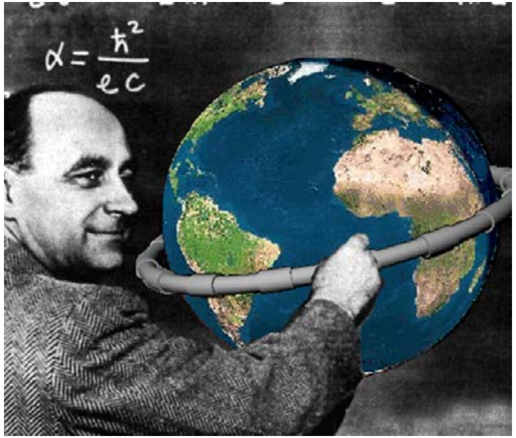
Problems of reproducibility

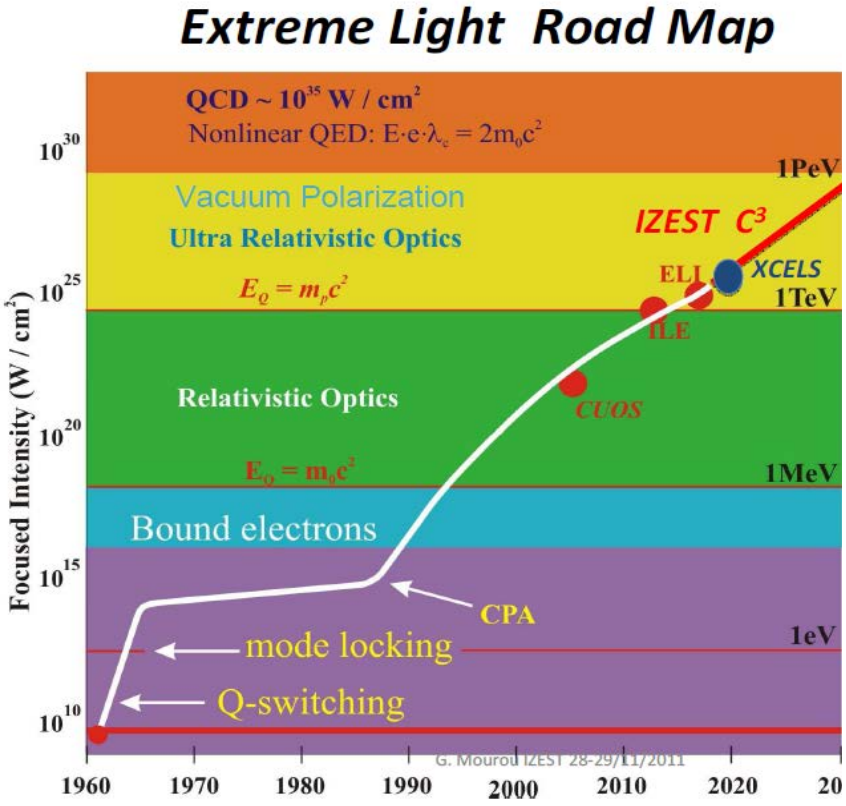
- The nature of SMLWFA means that there is variation in the reproducibility of the electron beam quality.
- The divergence of the electron beams will be affected by the plasma density profile and uniformity, the laser focal spot quality and size, the phase front of the laser, and the interaction between the laser and the plasma, including the coupling of the laser into the plasma and the subsequent laser evolution (modulation and self-focusing).
- **For all but three of the 23 high-plasma-density** ($n_e > 1.9 \times 10^{19}$ cm^{-3}) shots in this experiment, the **produced electrons did not form a defined beam**, and instead, the transverse charge profile was distributed across the entire solid angle collected by the EPPS.
- **For those three shots, all were produced in 10-mm nozzles**, which suggests that having **longer plasmas, and therefore longer distances for laser evolution, may help** maintain the transverse beam profile.
- For the remainder of the **49 shots with charge ≥ 50 nC**, the shots were either single-peaked **with higher divergence** or **had multiple peaks**.

Laser Acceleration of Electrons

At 10^{23} W/cm^2 , E = 0.6 PV/m,
it is SLAC (**50GeV**, 3km long) on **10 µm**

The size of the Fermi **PeV** accelerator will only be **one meter**
(accelerator will go around the globe, based on conventional technology).



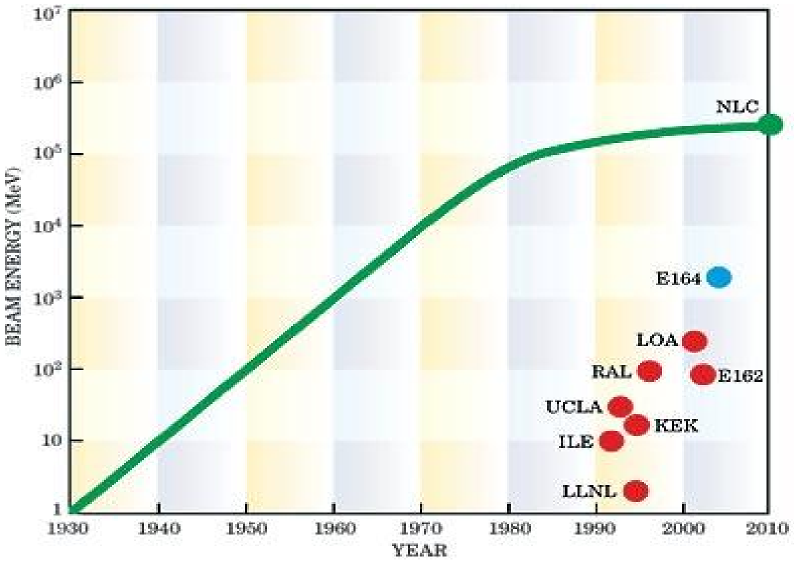


Motivation…

maximum of accelerating gradient in traditional accelerators (RF linac):

E_{RF} ~ 10 - 100 MV/m

Exponential growth of "the Livingston curve" began tapering off around 1980



Electric field of plasma wave (*with phase velocity ~ c,* $\lambda_p = 2\pi c/\omega_p$):

$$E_P\,[\mathrm{V/m}] \approx 10^2\, \alpha \;(\, n_e\, [\mathrm{cm}^3]\,)^{1/2}$$

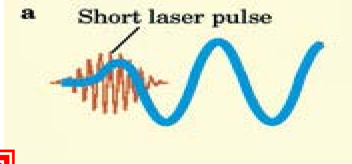
A. I. Akhiezer and R. V. Polovin, "Theory of wave motion of an electron plasma," *Sov. Phys. JETP,* vol. 3, pp. 696-705, 1956
J. M. Dawson, "Nonlinear electron oscillations in a cold plasma," Phys. Rev., vol. 133, pp. 383-387, 1959.

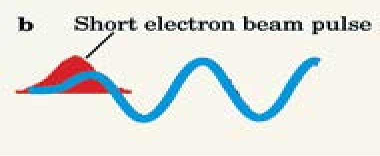
α = $\delta n / n_0$ – *plasma wave amplitude; at* α = 0.3÷1.0, $n_e = 10^{17} \div 10^{18}$ cm^{-3}:

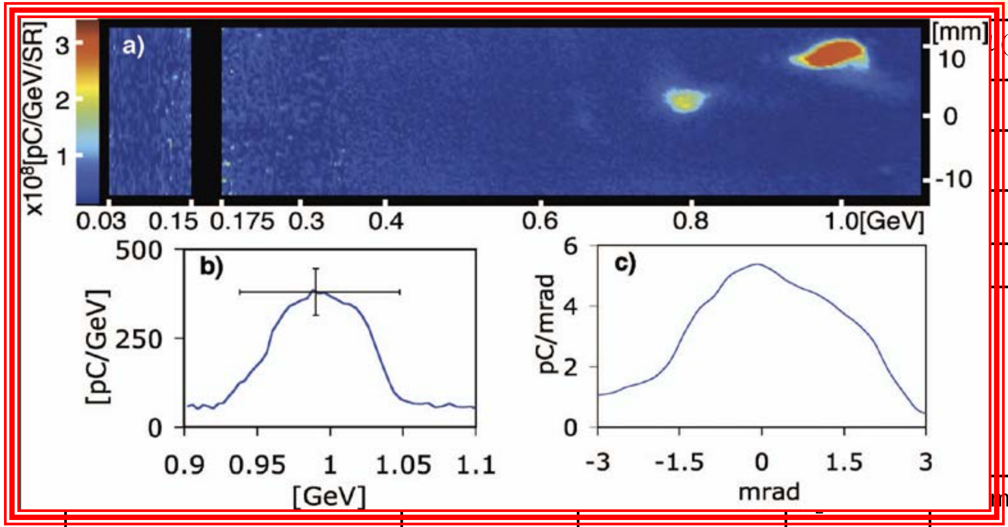
E_P = 10 ÷100 GV/m

Parameters and results of some experiments

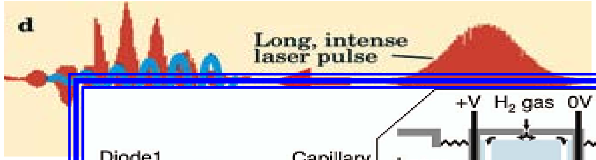
for **standard LWFA** scheme $c\tau_L \approx \lambda_p/2$



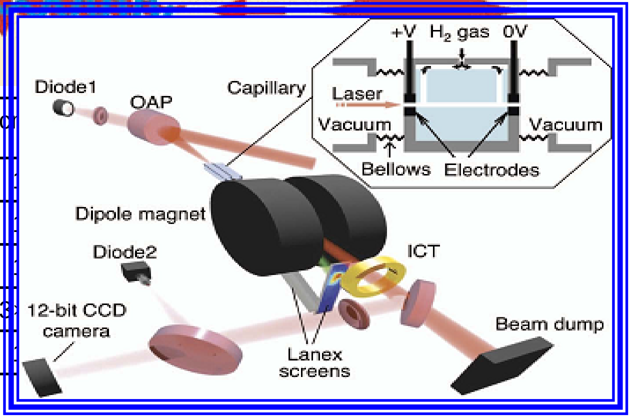




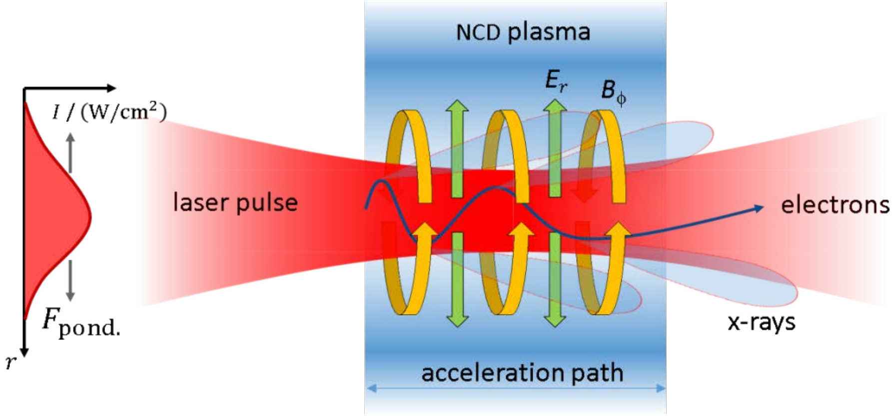
(μm)	N_e (cm^{-3})	ΔE (MeV)	E_{ac} (GV/m)
1.05	10^{15}	5	0.7
1.05	2×10^{16}	1.5	1.5
0.8	10^{18}		20
0.8	**2.5×10^{19}**	**200**	**200**



				m)	N_e (c
UK (RAL)	25	10^{19}	0.8	1.05	
France (CEA)	5	10^{19}	0.3	1.05	
USA (CUOS)	4.5	10^{18}	0.4	1.05	
USA (NRL)	2.5	4×10^{18}	0.4	1.05	3
Japan (KEK)	3	10^{17}	1.0	1.05	



Sub-mm length of NCD plasma provides a long acceleration path



A. Pukhov *et al.*, PoP **6**, N7 (1999)

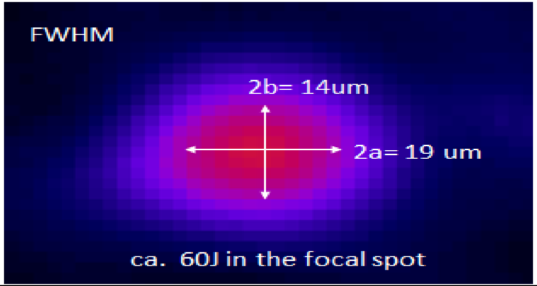
$$\omega_\beta = \left(1 - \frac{v_x}{v_{ph}}\right)\omega_L$$

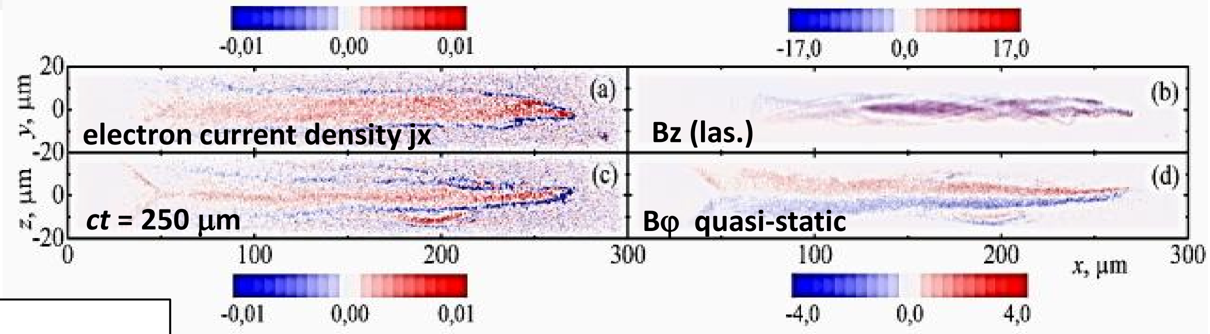
- self-focusing : $P_L > P_c = 17$ GW × n_c / n_e ~ 17 GW in NCD (high aspect ratio channel)
- ponderomotive force expels background plasma electrons from the laser channel
- **quasi-static radial E-field is produced** that has a focusing polarity for electrons
- current of relativistic electrons generates a **quasi-static B azimuthal** that traps electrons in the plasma channel
- electrons undergo **transversal betatron oscillations** and gain energy from laser field if coming in resonance.

FULLY RELATIVISTIC 3D PIC-SIMULATIONS (VLPL)

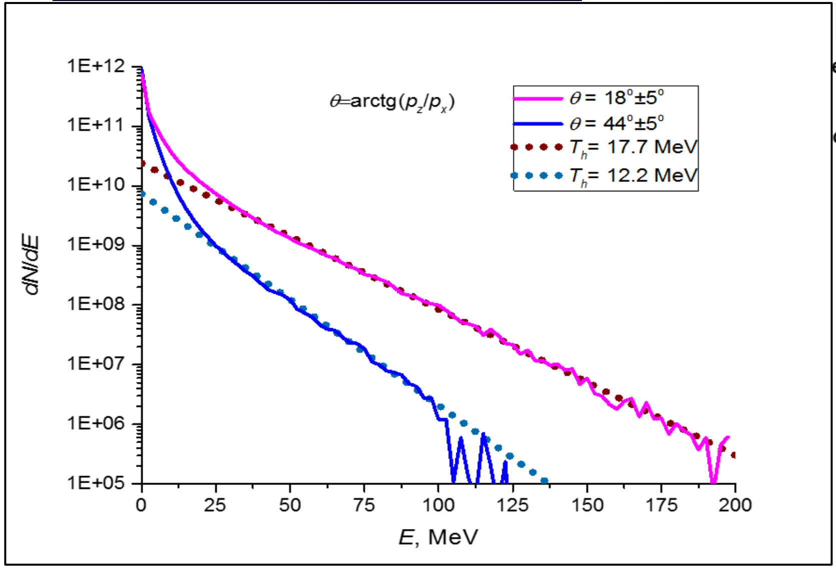
Laser: 4.4×10^{19} W/cm^2 (a_L = 5.67), 50 J

target: fully ionized CHO plasma 10^{21}cm^{-3}, x=500μm





ectron current density j_x normalized to $n_{cr}ec$ in the plane $z=0$ (a)
= 0 (c); b_z contains mainly a laser field strongly increased by the
cusing effect. Dimensionless magnetic field $|b|$ = 1 corr. to 108 MG.



electron angular distribution in a horizontal plane

super ponderomotive electrons (E>12 MeV)

Current of super-ponderomotive electrons (E > 3 MeV) reaches 2 MA, charge 2 μC, Magnetic field in a plasma channel 200 MG

The number, charge and energy of accelerated electrons which leaved the target with $p_x > 0$ at $ct = 550$ mm

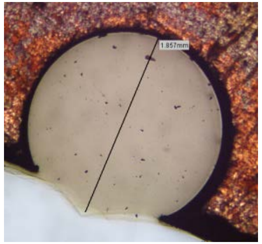
Energy range, MeV	Number of electrons	Charge of electrons, μC	Percent of laser energy
(0.5, ∞)	3.22×10^{13}	5.15	40%
(3, ∞)	1.15×10^{13}	1.84	31%
(3, 12)	9.09×10^{12}	1.45	14.8%
(12, ∞)	2.38×10^{12}	0.381	16.3%
(30, ∞)	4.85×10^{11}	0.078	6.4%

O N Rosmej, N E Andreev, S Zaehter, N Zahn, P Christ, B Borm, T Radon, A Sokolov, L P Pugachev, D Khaghani, F Horst, N G Borisenko, G Sklizkov, V G Pimenov. 2019 New J. Phys. 21 043044

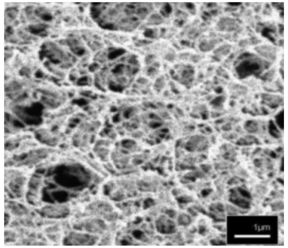
Generation of NCD plasma in interaction of ns-laser pulse with polymer foam

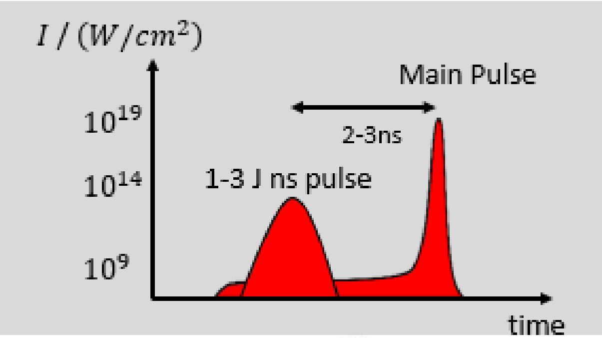
foam ionization is triggered by well-defined ns-pulse with parameters adjusted to the foam density and thickness

CHO: 2 mg/cc (2×10^{20} at/cm^3)



3D aerogel structure





50-100 nm solid (0.1g/cc)+ ca. 1 μm evacuated pore

sub mm thick foam provides increased interaction path

> 500 μm thick NCD plasma "target" (Ne $\lesssim 0.7 \times 10^{21}$ cm^{-3}) is created by a 10^{13}-10^{14} W/cm^2 ns pulse.

O. N. Rosmej et al, New J. Phys. **21**(2019) 043044

O. N. Rosmej et al Plasma Phys. Control. Fusion **62** (2020) 115024

PHELIX beam-time P176, 2019

PHELIX system:

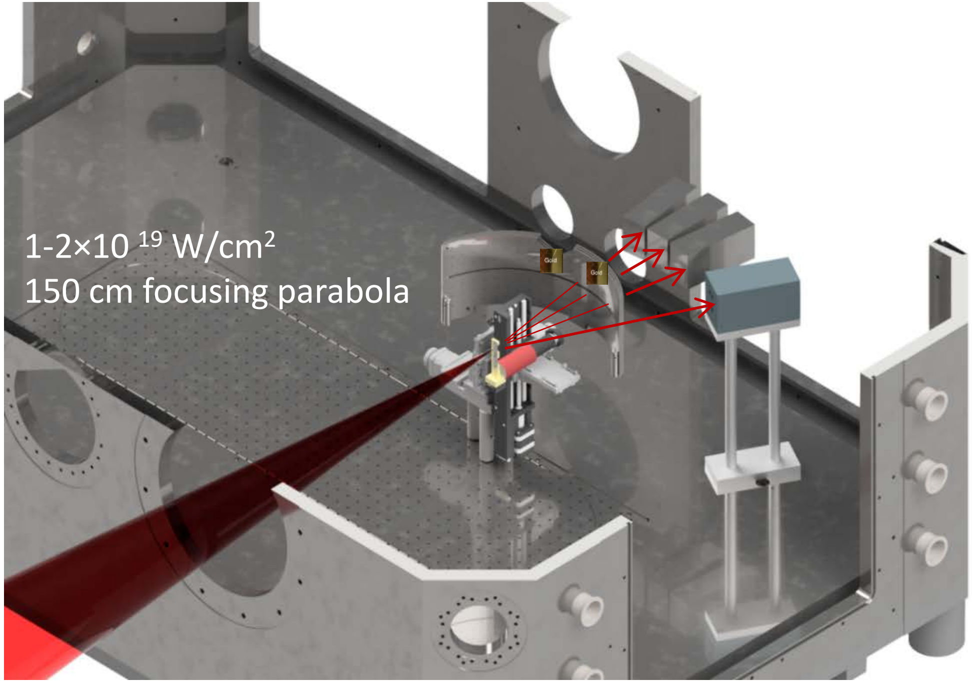
Nd:glass λ=1.053μm, s-polarized
main pulse:

- τ=700± 250 fs
- 10^{19} W/cm^2 (20J , d=15 μm)
- 10^{21} W/cm^2 (40J , d=3 μm)
- ns contrast better than 10^{-11}

ns pulse: 1 J, 1.5 ns , Δt=2-3 ns

Targets:

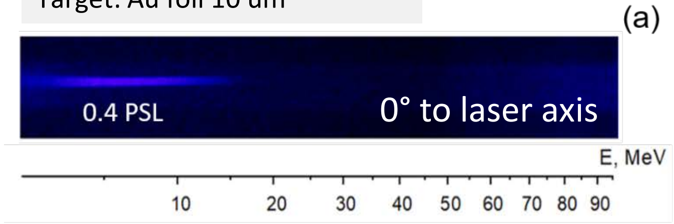
- 10 μm thin Ti, Au-foils
- mm-thick Au convertor
- low density polymer foams
  ρ=2 mg/cc (1.7 × 10^{20} at/cm^3)
- combination foam+foil

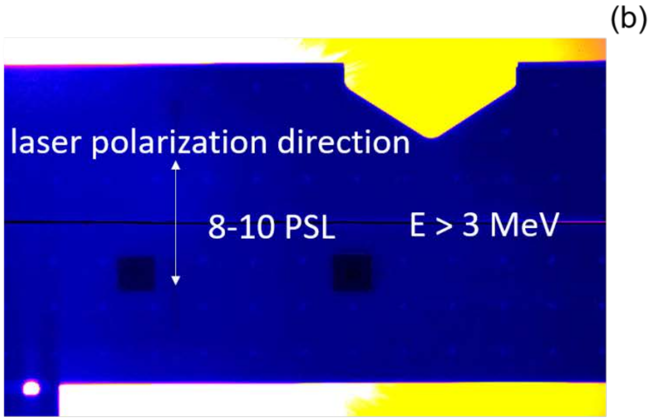


Detailed measurements of the angular distribution of energy and the number of electrons using an multilayer IP cylinder

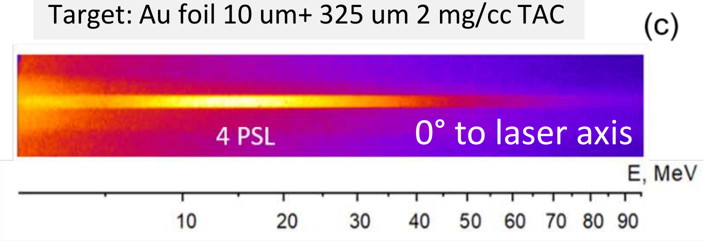
DLA in pre-ionized foam: raw electron spectra from PHELIX 20J, 10^{19}W/cm^2

Shot 40: 700 fs, 10^{19} W/cm^2
Target: Au foil 10 um

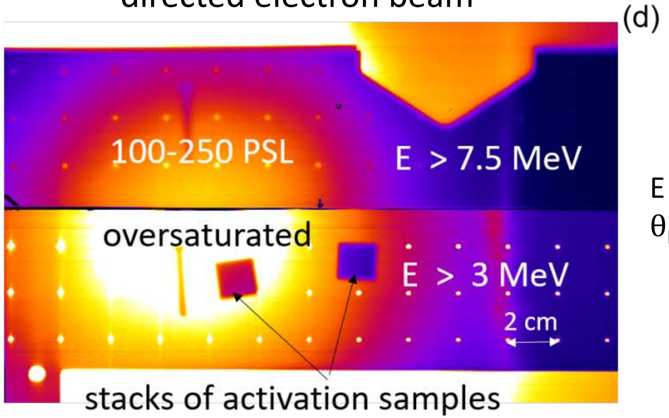




Shot 42: 700 fs, 10^{19} W/cm^2
Target: Au foil 10 um+ 325 um 2 mg/cc TAC

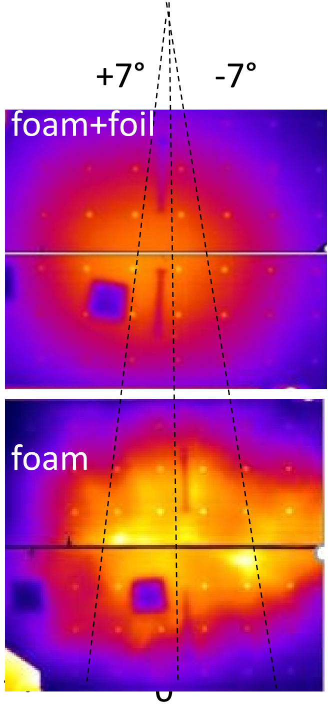


directed electron beam

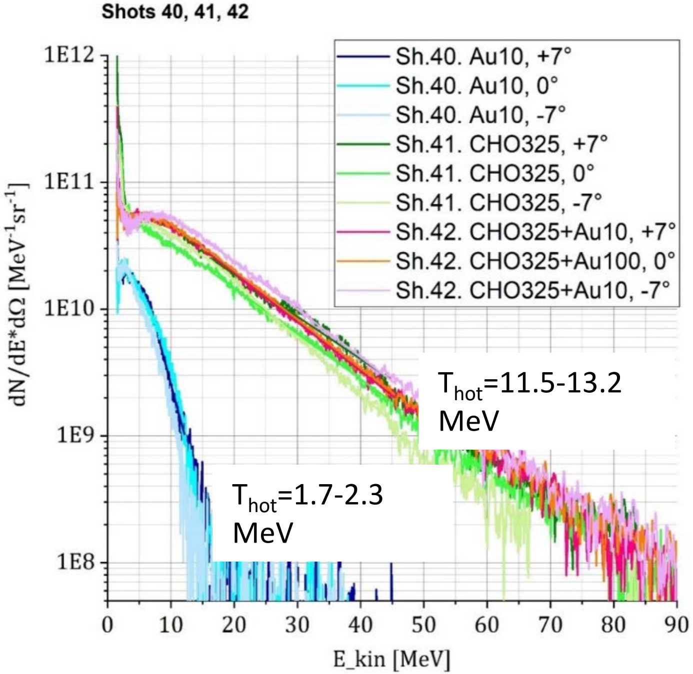


E > 3 MeV,
θ_{FWHM} = 160 msr

Energy and number of MeV-electrons inside the divergence cone



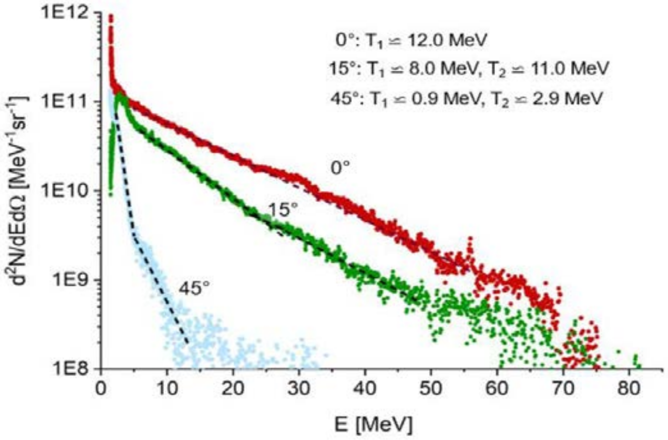
5 % current is in filaments



M. Gyrdymov

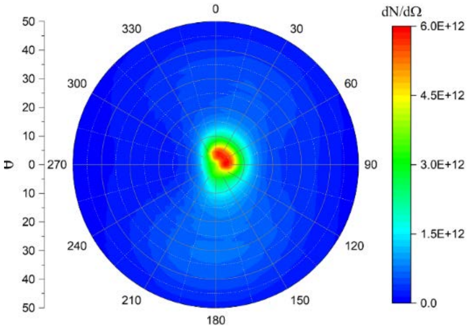
3D PIC Simulations (VLPL) for PHELIX and Comparison with experiment:

Measured angular dependent energy distributions



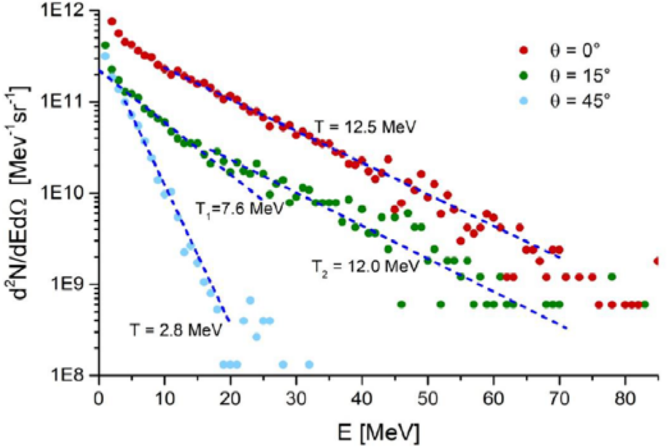
measured for a shot onto the pre-ionized foam layer at 2×10^19 W cm^-2 laser intensity

Angular distribution of electrons with E > 7 MeV



½ θ at FWHM ~ 10° (experiment ~ 13°)

Modeled angular dependent energy distributions



leave the simulation box at t = 2.5 ps

O. N. Rosmej, M Gyrdymov, M M Günther, N E Andreev, P Tavana, P Neumayer, S ZËahter, N Zahn, V S Popov, N G Borisenko, A Kantsyrev, A Skobliakov, V Panyushkin, A Bogdanov, F Consoli, X F Shen, and A Pukhov. Plasma Phys. Control. Fusion **62** (2020) 115024

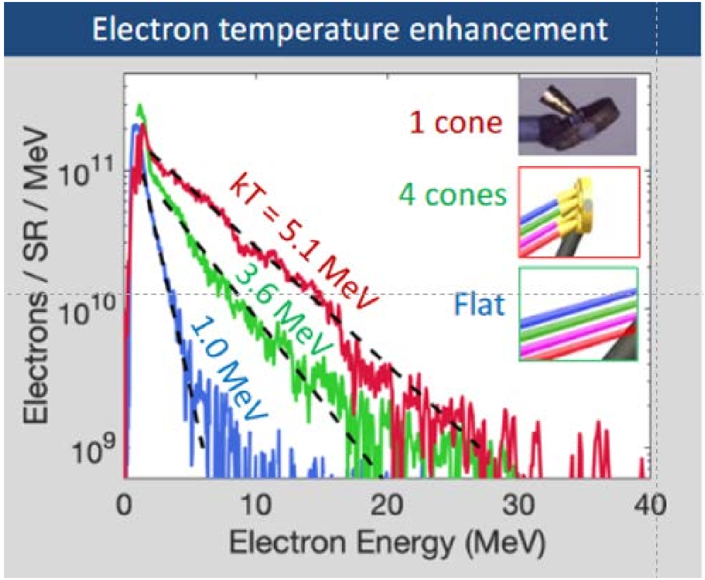
ARC at NIF versus PHELIX at GSI-FAIR

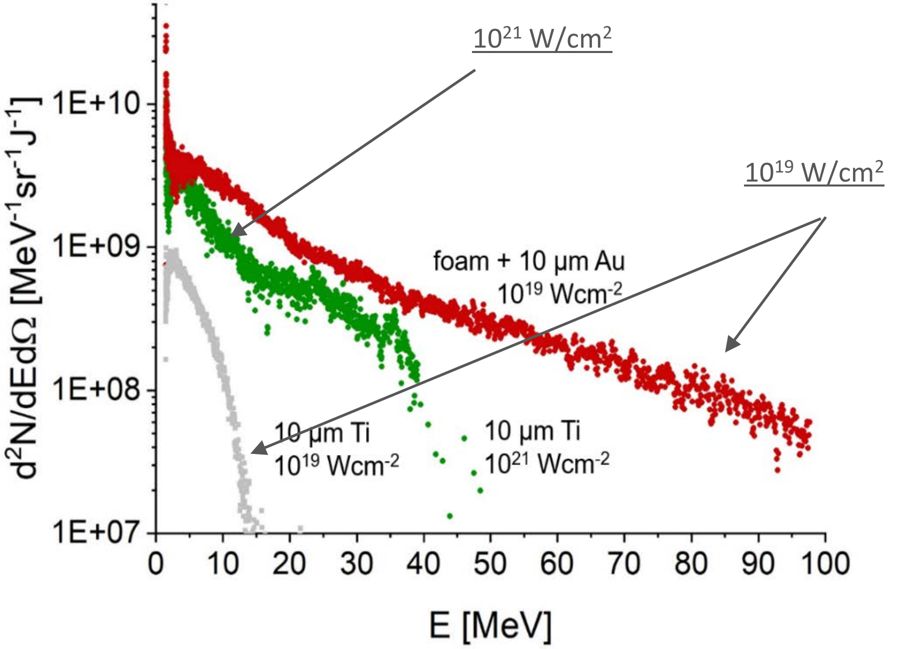
ARC: **4 kJ**, $10^{18} \rightarrow 10^{19}$ W/cm^2

gold foil target coupled with a CPC

PHELIX: **80 J (20 J)**, 10^{19} W/cm^2

gold foil attached to a foam (NCD plasma)

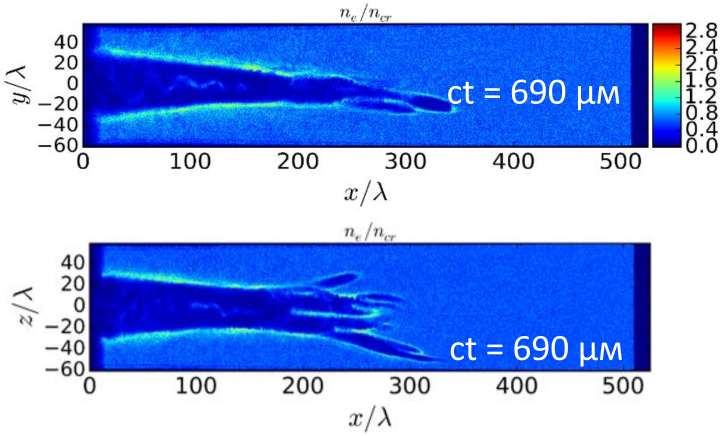




3D PIC simulations for 200 J PHELIX up-grade

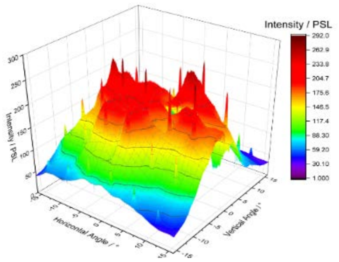
electron density in plasma channel,

XY and *XZ* -planes



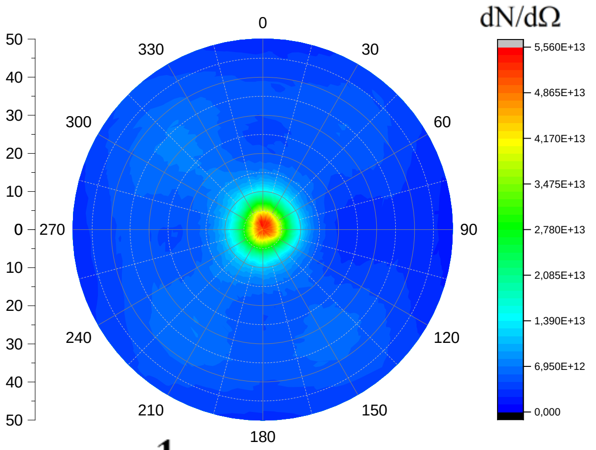
filamentation and hosing of the laser pulse and electron current

λ=1 μм
700 fs
waist 25 μм (FWHM)
200 J (FWHM)
pulse length 178. μм
foam length 500 μm
a_0=7.44
7.587 × 10^{19} W/см²



Experiment, PHELIX 20 J:
5% of the current is in filaments

angular distribution of electrons with *E* > 7.5 MeV



$$\frac{1}{2}\theta_{FWHM} = 6.8^{\circ}$$

V. Popov, N. Andreev, JIHT, Moscow
3D VLPL A. Pukhov

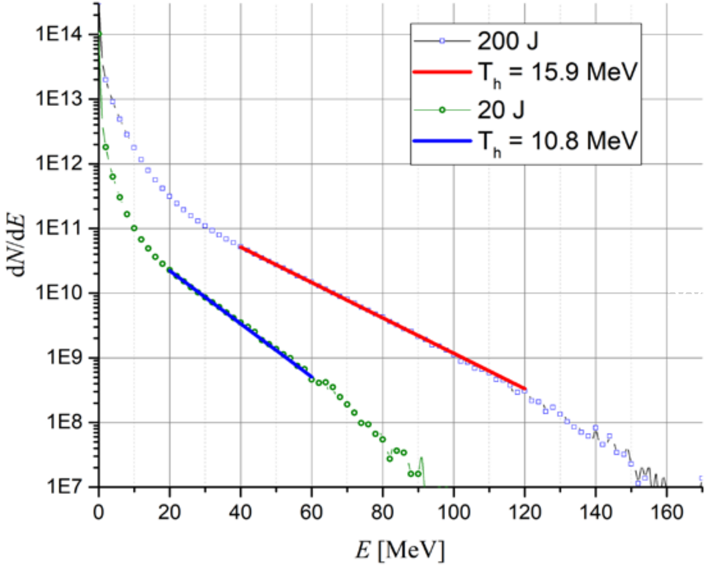
Limitations on Transport of accelerated electrons in vacuum

***N** $_{super\text{-}pond}$* **in NCD plasma grows with** E_{las} **and** I_{las}
compensated electron beam transport is limited by the Alfven current: $\gamma \times 17.5$ **kA, with** $\gamma = E/mc^2$

Charge of electrons with > 7.5 MeV ($\gamma=15$) is limited by 260nC (1ps)

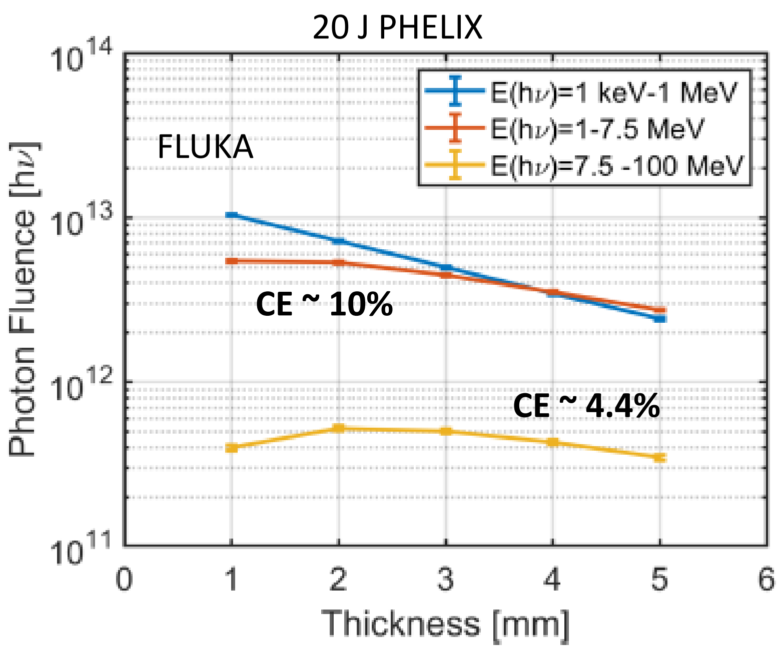
	E > 2 MэB		E > 7 MэB
20 J	4.5e+12/ **0.7 μC in 2π**		1.2e+12/ **0.2 μC in 2π**
200 J	6.4e+13**/ 10 μC in 2π** Only **3%** propagates in ½ θ=7°		1.9e+13**/ 3 μC in 2π** **10%** propagates in ½ θ=7°

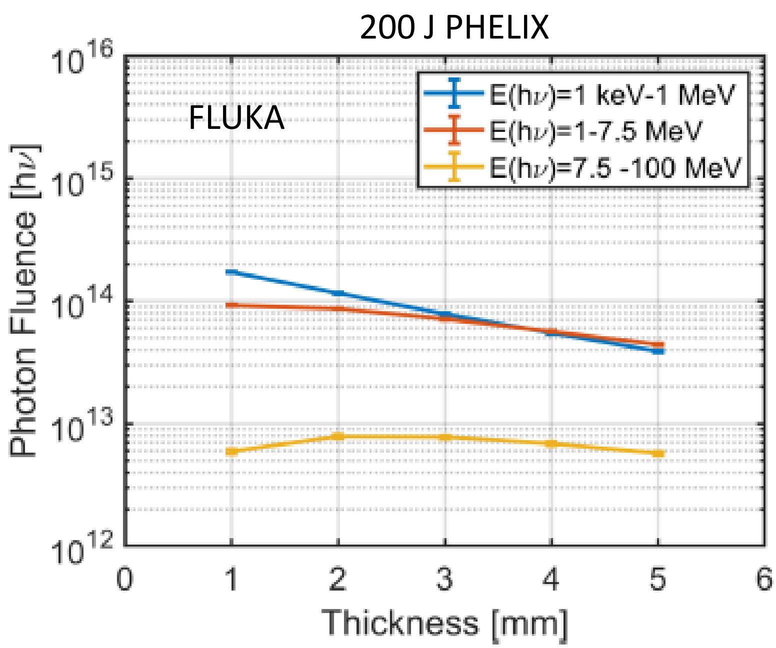
3D PIC 200J: expected T_{hot} ~ 21 MeV, simulated T_{hot} ~ 16 MeV



Solution: vacuum-less contact between NCD plasma and foil/convertor

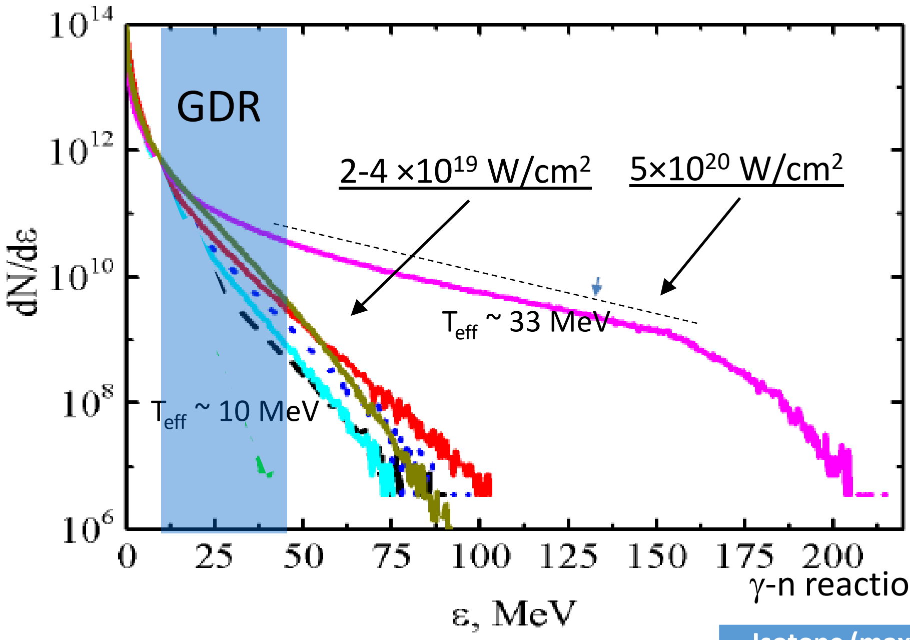
FLUKA simulations of ultra-bright source of MeV-photons via interaction of DLA electrons with Au-convertor





Number of bremsstrahlung photons for different aplications: E < 1 MeV – radiography of HED matter;
E > 1 MeV – e-e+ pair producton; E > 7.5 MeV (GDR) gamma-driven nuclear reactions, isotope production, neutrons

Increase of the laser intensity (5×10^{20} W/cm^2)



E_{FWHM}= 56 J, 700fs, **5×10^{20} W/cm²**

d=4 μm; 350 μm NCD-plasma

1. More charge (up to 0.9 μC) can be transported
2. increase of the betatron $\omega_c \sim \gamma^2$.
3. higher energies of bremsstrahlung gammas
4. no win in the neutron production by GDR

γ-n reaction yield caused by electrons propagating in **1x1x1cm³ Au**

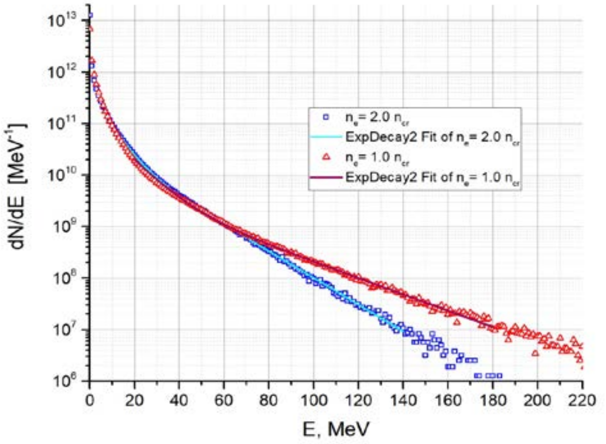
Isotope (max GDR)	Yield, 5x10²⁰ W/cm², 60 J	Yield, 2x10¹⁹ W/cm², 20J
196Au (14 MeV)	3,00E+09	1,10E+09
194Au (32 MeV)	4.62E+07	7,62E+06
192Au (50 MeV)	4.44E+06	5,80E+05

GEANT4 , A. Skobliakov, ITEP

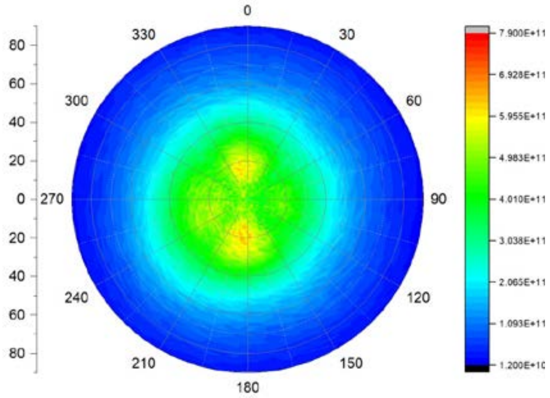
Pugachev L P and Andreev N E
2019 *J. Phys.: Conf. Ser.* **1147** 012080

Direct Laser Acceleration by ultraintense fs laser pulses in NCD plasmas at PEARL (*for experiment at IAP, November 2022*)

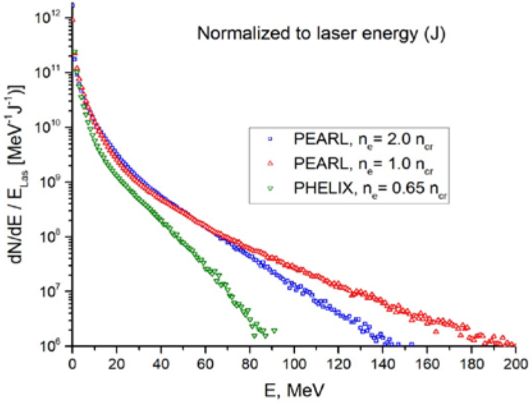
E_L = 7.5 J in D_{FWHM} = 4.12 μm, τ_{FWHM} = 60 fs, $I_0 = 1.2\times10^{21}$ W/cm², a_0 = 30



$n_e = 1.0\ n_{cr}$: $T_1 \approx 9$ MeV, $T_2 \approx 27$ MeV
$n_e = 2.0\ n_{cr}$: $T_1 \approx 6$ MeV, $T_2 \approx 17$ MeV



angle distribution for E > 7 MeV
PEARL, $Ne = 2.0\ n_{cr}$

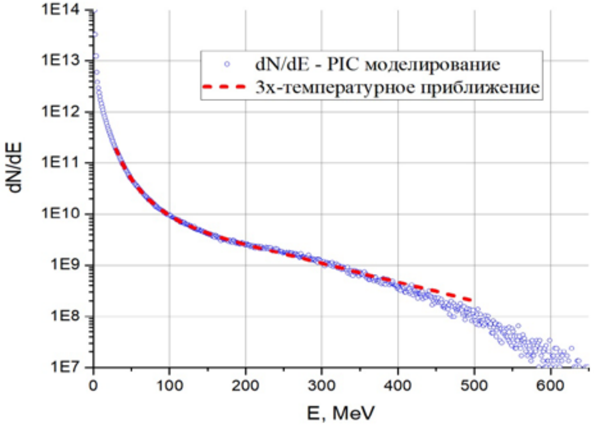


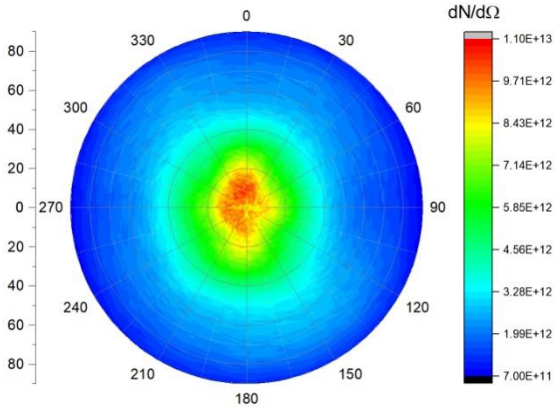
Energy spectra of electrons per 1 J laser energy for PEARL and PHELIX

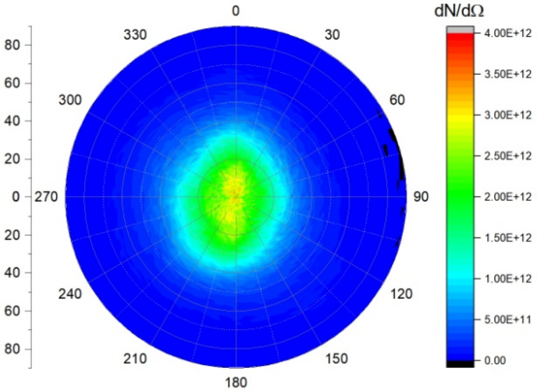
N.E. Andreev, V.S. Popov, O.N. Rosmej, A.A. Kuzmin, A.A. Shaykin, E.A. Khazanov, A.V. Kotov, N.G. Borisenko, M.V. Starodubtsev, A.A. Soloviev. Efficiency improvement of the femtosecond laser source of superponderomotive electrons and X-ray radiation due to the use of near-critical density targets. *Quantum Electronics* 51 (11) 1019 – 1025 (2021) https://doi.org/10.1070/QEL17648

Direct Laser Acceleration of electrons by ultraintense fs laser pulses in NCD plasmas **at XCELS**

E_L =150 J in D_{FWHM} = 10 μm, τ_{FWHM} = 60 fs, $I_0 = 4.1\times10^{21}$ W/cm^2, a_0 = 55







3 – temperature approximation:

T_1 = 8.3, T_2 = 22.7, T_3 = 118 MeV

Angular distributions of accelerated electrons with energies

E > 7 MeV E > 40 MeV

N. E. Andreev, I.R. Umarov, V. S. Popov, Quantum Electronics, in press (2022)

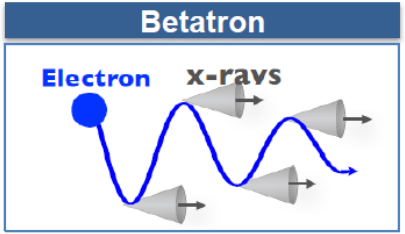
Direct Laser Acceleration of electrons by ultraintense fs laser pulses in NCD plasmas **at PEARL and XCELS**

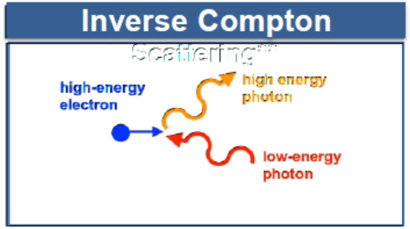
PEARL: E_L =7.5 J in D_{FWHM} = 4.12 μm, τ_{FWHM} = 60 fs, I_0 = 1.2×10^{21} W/cm^2, a_0 = 30
XCELS: E_L =150 J in D_{FWHM} = 10 μm, τ_{FWHM} = 60 fs, I_0 = 4.1×10^{21} W/cm^2, a_0 = 55

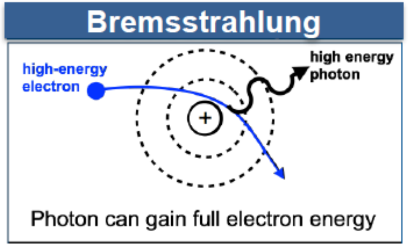
Parameters	Energy range of accelerated electrons (MeV)	PHELIX (17.5 J) $n_e = 0.65\ n_{cr}$	PEARL (7.5 J) $n_e = 2.0\ n_{cr}$	PEARL (7.5 J) $n_e = 1.0\ n_{cr}$	XCELS (150 J) $n_e = 1.0\ n_{cr}$
Number of electrons per 1 J laser energy	E>3	1.96×10^{11}	3.4×10^{11}	3.5×10^{11}	3.1×10^{11}
	E>7	**0.72×10^{11}**	**1.7×10^{11}**	**1.5×10^{11}**	**1.4×10^{11}**
	E>30	0.62×10^{10}	1.7×10^{10}	1.7×10^{10}	2.5×10^{10}
	E>100	0	2.3×10^{8}	7.5×10^{8}	5.0×10^{9}
	E>300	0	0	0	6.5×10^{8}
Full charge (nC)	E>3	510	408	420	7340
	E>7	**187**	**203**	**180**	**3374**
	E>30	15	22	20	592
	E>100	0	0.3	0.9	120
	E>300	0	0	0	16
Conversion efficiency of laser energy	E>3	27%	57%	56%	68%
	E>7	**17%**	**44%**	**41%**	**56.5%**
	E>30	3.6%	13%	13.5%	31%
	E>100	0	0.43%	1.6%	15.6%
	E>300	0	0	0	3.9%

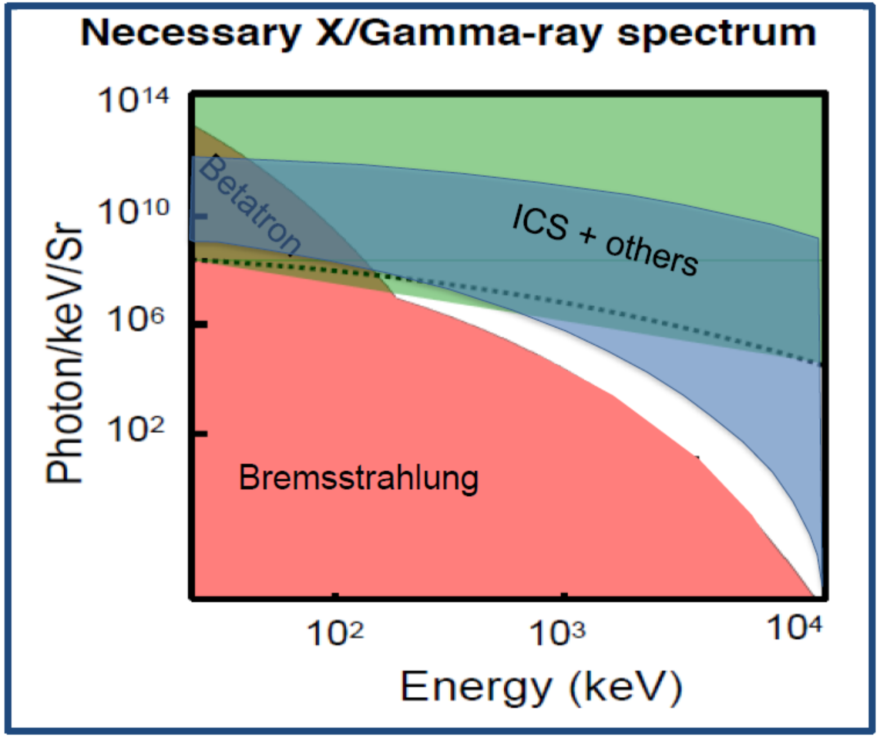
PHELIX: 2.5×10^{19} W/cm^2 (a_0 = 4.28), 17.5 J

Relativistic electrons are used to created x-rays through Inverse Compton Scattering and bremsstrahlung radiation









Applications:

Ultra-intense betatron radiation

Betatron Radiation: PHELIX: a_0= 2.5, 20 J, E_c = 5 keV , 7×10^{11} photons with E = 1-30 keV

PETAL 1 kJ , SM-LWFA (a_0= 7.5, n_e= 10^{18} cm^{-3}, E_e~ 1 GeV) 7×10^{11} photons with E_c = 10 keV,

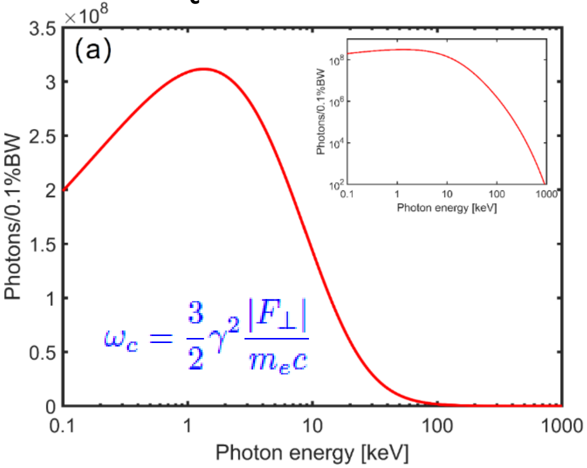
Ferri et al, PHYS. REV. ACCELERATORS AND BEAMS 19, 101301 (2016)

- Broad spectrum, large photon number:
- **6×10^{11} (1-10 keV)**, ~ 10^{11} (10-30 keV)

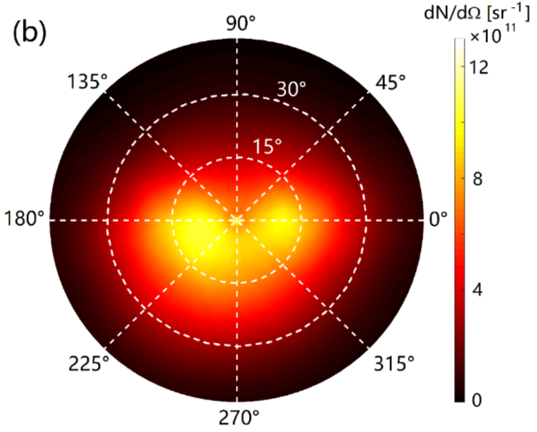
- **opening angles**: 360 mrad (y, laser polarization) and 270 mrad (z) RMS (root mean square)
- **source size**: 3,5µm - 4µm (RMS)

PIC code VLPL, A. Pukhov

E_c = 5 keV



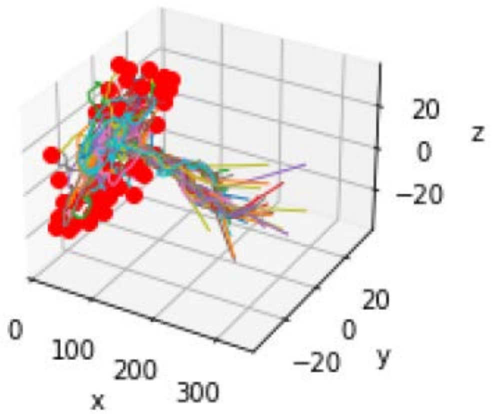
$$\omega_c = \frac{3}{2}\gamma^2 \frac{|F_\perp|}{m_e c}$$

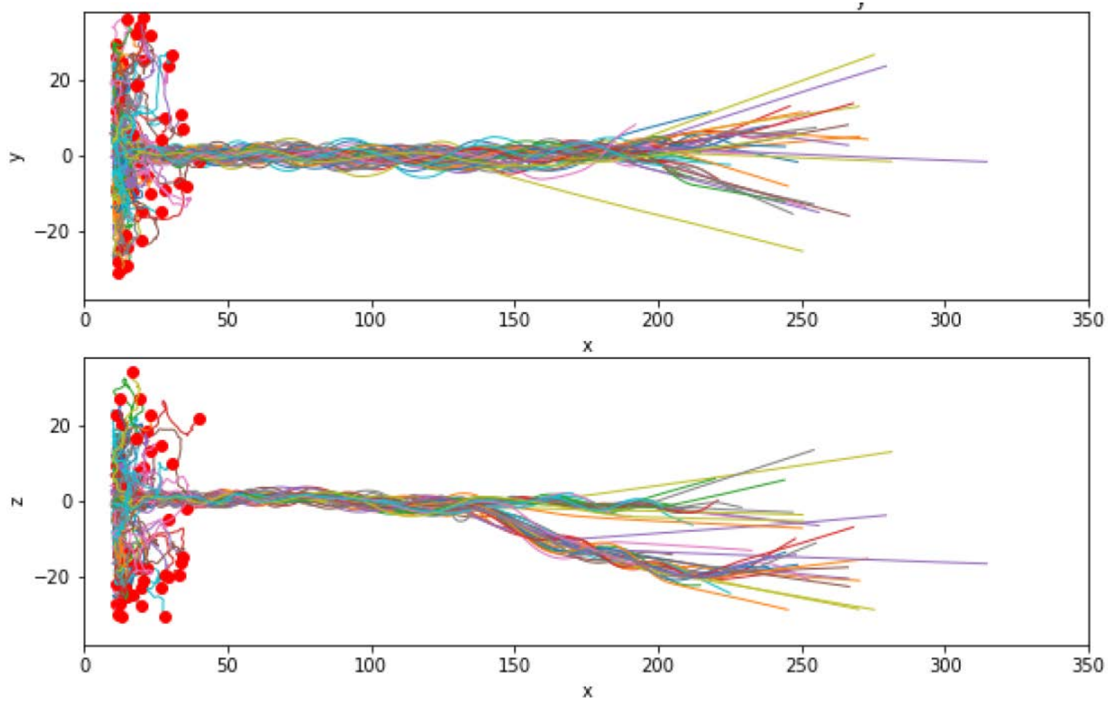


Ultra-bright betatron radiation based on direct laser acceleration of electrons in plasma of near critical density

O. N. Rosmej, X. F. Shen, A. Pukhov, L. Antonelli, F. Barbato, M. Gyrdymov, M. M. Günther, S. Zähter, V. S. Popov, N. G. Borisenko, and N. E. Andreev , Matter Radiat. Extremes 6, 048401 (2021)

Betatron radiation (PHELIX): trajectories of DLA electrons in plasma channel



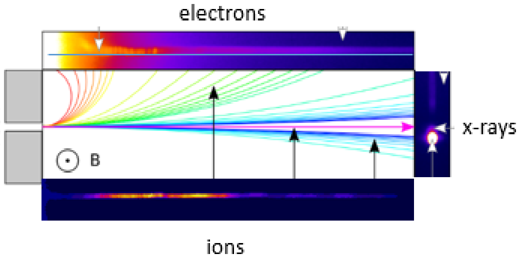


L.P. Pugachev, VLPL code A. Pykhov

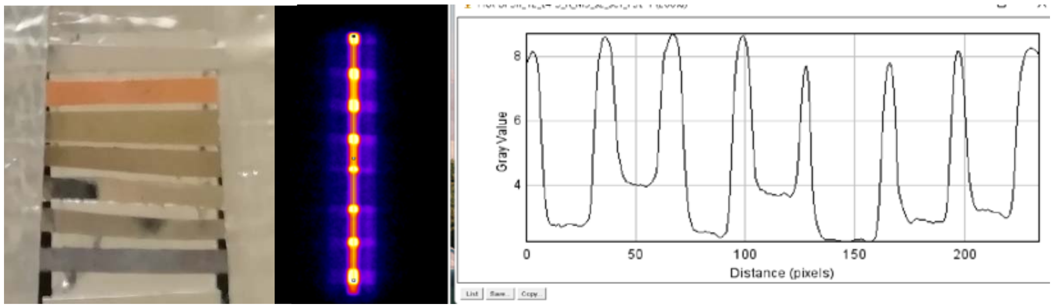
Measurements of the betatron radiation at PHELIX 2022

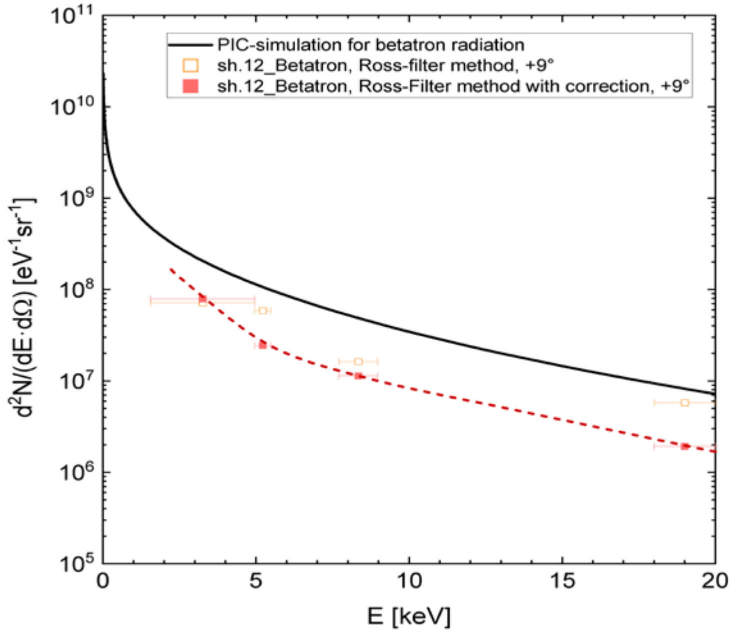
M. Gyrdymov, U-Frankfurt

Spatial separation of electron, proton, BS and betatron sources in magnetic spectrometer



7 Ross-filters





Applications:

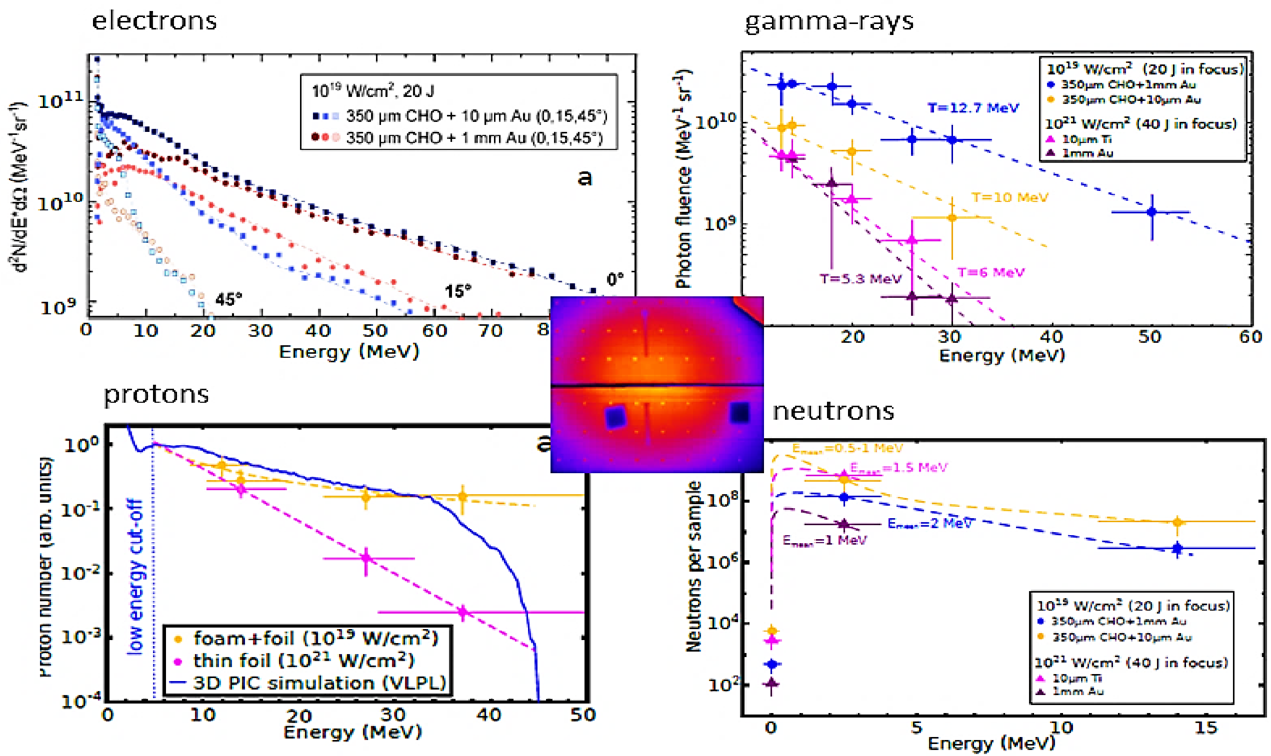
Ultra-bright sources of MeV BS and neutrons

Forward-looking insights in laser-generated ultra-intense gamma-ray and neutron sources for nuclear applications and science

Nat Commun 13, 170 (2022)

M. M. Günther, O.N. Rosmej, P. Tavana, M. Gyrdymov, A, Skobliakov, A. Kantsyrev, S. Zähter, N.G. Borisenko, A. Pukhov, and N.E. Andreev.

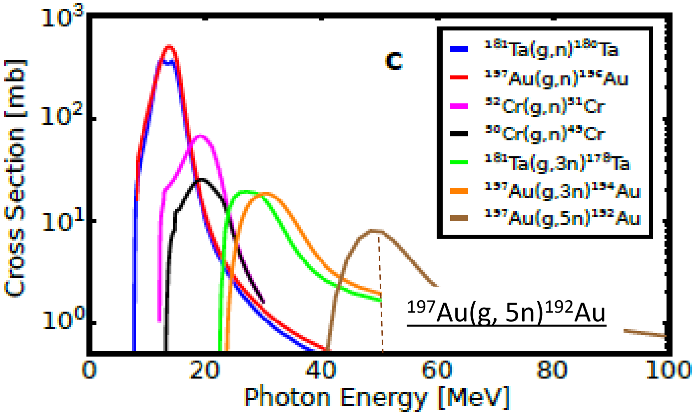
Enhanced generation of MeV electrons, protons, gamma-rays and neutrons at 10^{19} W/cm^2 intensity by irradiation of low density polymer aerogels.



Electrons propagate in high Z converter and generate BS with 10´s of MeV photon energy

10^{12}/sr photons with E > 7.5 MeV, T_{eff} =10 -13 MeV

Nuclear activation-based diagnostics: takes use of resonances in γ,n reactions in different materials. The yields of the produced isotopes are used to evaluate BS spectrum.

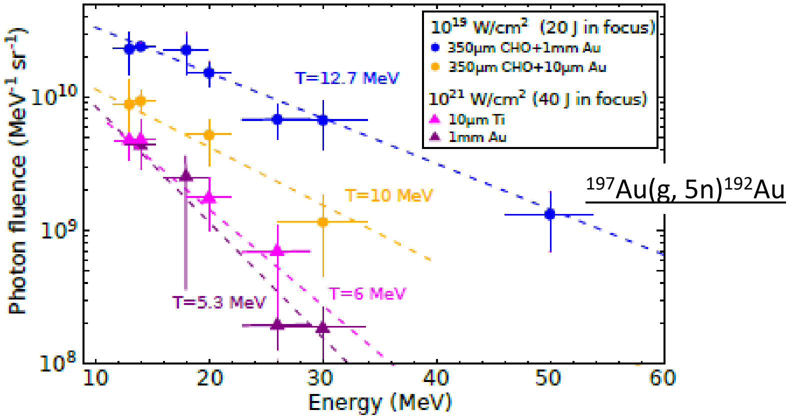


Record-breaking conv. eff. into BS > 7.5 MeV

Giant Dipole Resonance

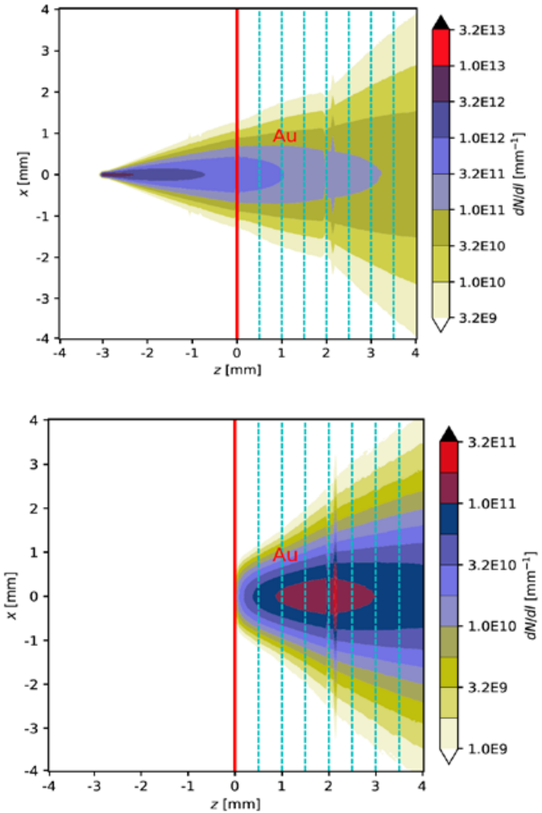
PHELIX, 10^{19} W/cm^2 : 1.7±0.4% (GDR)

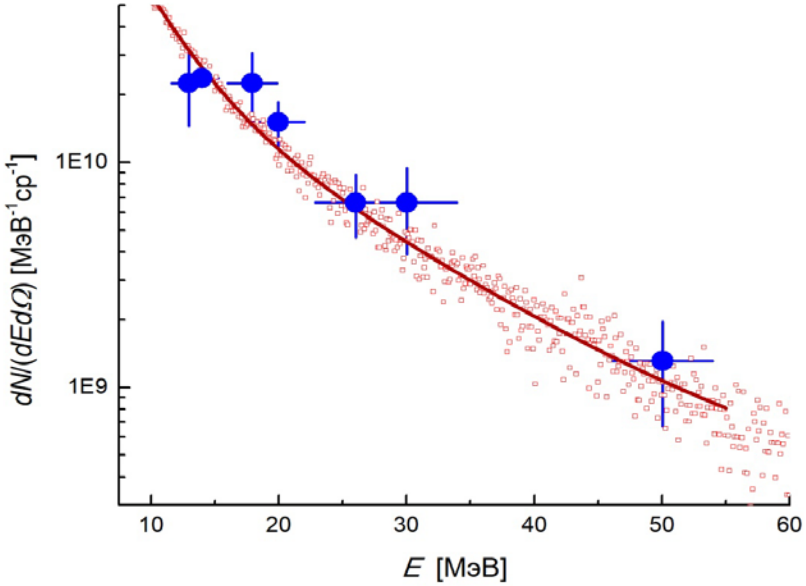
VULCAN at 10^{20} W/cm^2: 0.2 % (GDR)



10^{19} W/cm^2 with foam vs. 10^{21} W/cm^2 foil: two times higher effective temperature and 10 times higher photon number (Eγ > 7 MeV)

PIC (DLA electrons in NCD plasma) and GEANT4 (gamma-rays) modeling in GDR – comparison with experiment



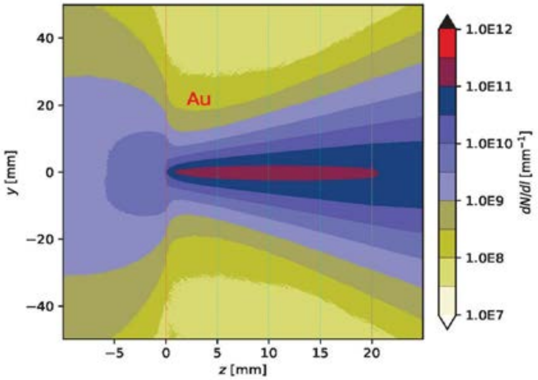


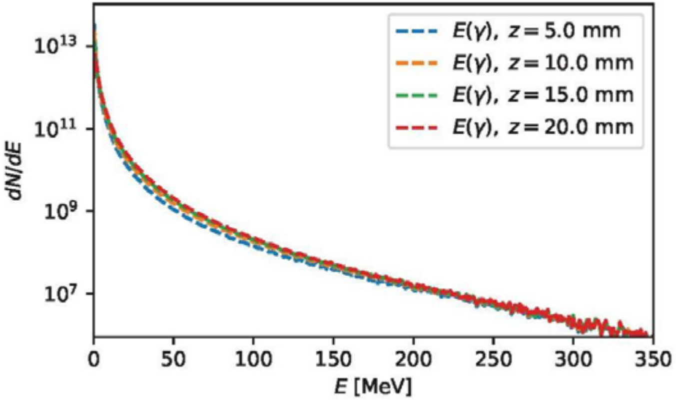
Generation of MeV- bremsstrahlung radiation at different laser facilitates

LASER, target	e-source	convertor	gammas	conversion
VULCAN, 10^{19} W/cm^2 Pb [Norreys, PoP 1999]	pondertomotiv e E_e=1-13 MeV	Pb, 3mm	10^{10} E > 10 MeV E_{mean}~ 13 MeV *nuclear activation*	**20 mJ 0.2%** > 10 MeV (GDR)
NOVA **LLNL** 3x10^{20}W/cm^2 Au [Stoyer, RSI 2001]	ponderomtive + super-ponderomotive tail with E≤ 100 MeV	Au , 1mm	8-25 MeV T_{bs} =5.3 MeV, 2x10^{11}/MeV/sr > 25 MeV T_{bs} = 9.5 MeV, 10^9/MeV/sr div. angle= 105° *nuclear activation*	**0.18 %** > 10 MeV (GDR)
PHELIX ~ 10^{19}W/cm^2 CHO-foam [NatComm_2022]	DLA super-ponder. T_{hot} ~ 14 MeV E_e ≤ 100 MeV	Au , 1mm	> 7.5 MeV ~ 2x10^{11} T_{bs} ~ 10-12 MeV div. angle= 40° *nuclear activation*	**1.7±0.4%** > 10 MeV (GDR)

Gamma-bremsstralung XCELS (PIC+GEANT4 , QE_2022)

XCELS: E_L =150 J in D_{FWHM} = 10 μm, τ_{FWHM} = 60 fs, $I_0 = 4.1\times10^{21}$ W/cm², a_0 = 55





Диапазон энергий	количество гамма квантов	конверсия лазера в гамма излучение	расходимость гамма излучения (1/2 θ_{FWHM})
E > 1 МэВ	1.1×10^{13}	5.22%	≈ 26°
E >7 МэВ	1.6×10^{12}	2.63%	≈ 20°
E >30 МэВ	1.3×10^{11}	0.73%	≈ 15.5°
E >100 МэВ	7.8×10^{9}	0.12%	≈ 12°
E>300 МэВ	1.2×10^{8}	<0.01%	--

New level of interdisciplinary research with sub-kJ, sub-PW lasers

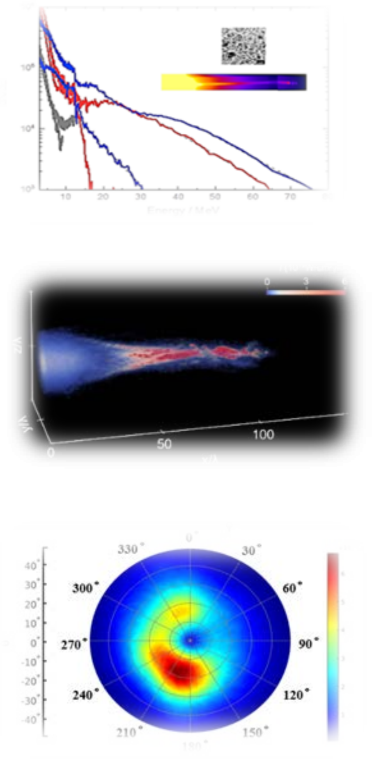
<u>Application of foams provides a strong boost of the parameters of laser driven sources of particles and radiation</u>

<u>Universal character of foam targets:</u>
No high laser contrast, no ultra-high laser intensity, no pointing stability, no changes in the experimental set-up are required.

<u>Plasma Physics, HED-research:</u>
foam and foam stacked with thin foil:
- Ultra-intense betatron and THz radiation,
- Well-directed beams of super-ponderomotive electrons
- Protons: enhanced TNSA

<u>Nuclear Physics:</u>
foam stacked with thick high Z convertor or thin foil:
- High yield (γ,n) and (p,n) reactions in GDR region (Isotope production)
- High fluence/ flux MeV gamma sources and gamma /proton-driven neutron sources with record breaking conversation efficiency

<u>Biophysics:</u>
- Ultra-high dose-rate (20-50 TGy/s) of ionizing radiation for investigation of the FLASH-effect



With thanks for collaboration to all participants of the

Project "Interaction of relativistic laser pulses with near critical plasma for optimization of the laser based sources of photons and particles"

Olga Rosmej, Marc Günther and Students of the Plasma Physics Group

Helmholtzzentrum GSI Darmstadt and Goethe University Frankfurt, Germany

Thank you for your attention!

participants:

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