Ultrafast High Power Lasers, Accelerators & Plasma

Viviana Vlăduţescu, PhD

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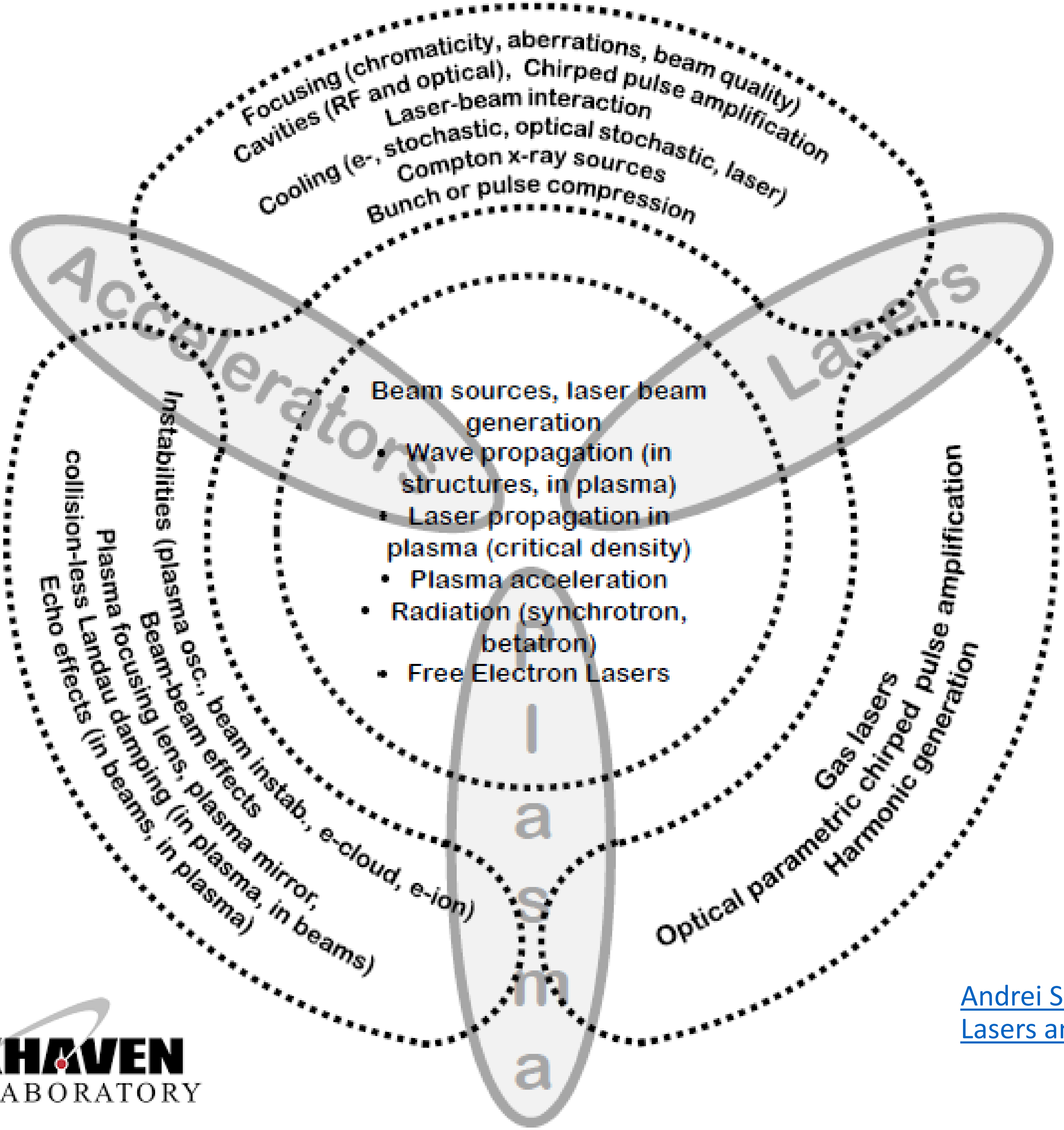
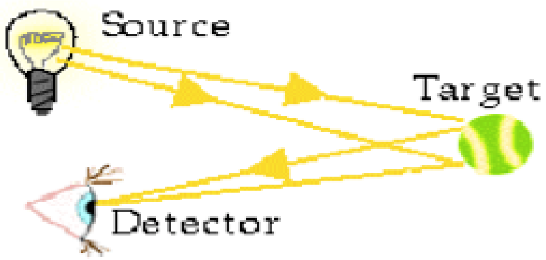


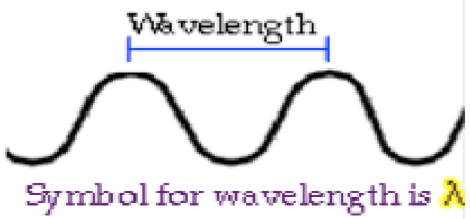
[Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016]

Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

Interaction of Radiation with Matter



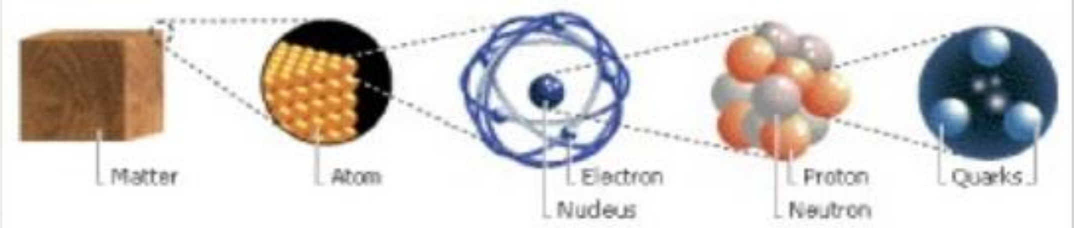
The smaller the wavelength, the smaller the features observed.



de Broglie suggested that particles can exhibit properties of waves.

$$\lambda = h/mv$$

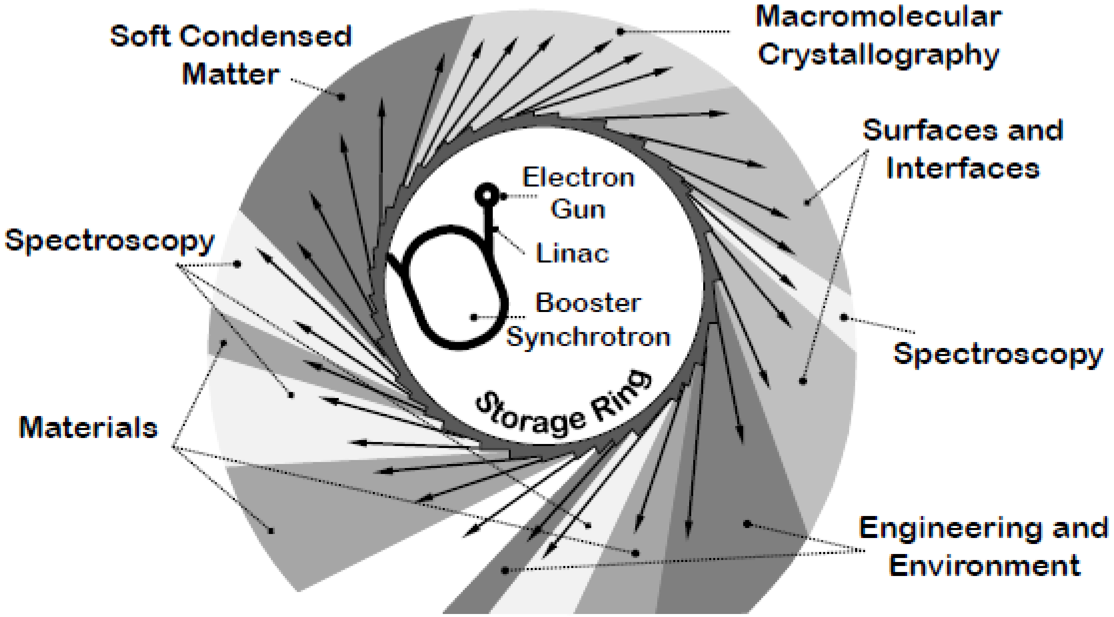
λ is wavelength,
h is Planck's constant,
m is the mass of a particle, moving at a velocity v.



To examine smaller structures need increasingly high energy

1,000 eV	1,000,000 eV	1,000,000,000 eV
keV	MeV	GeV

Particle Acceleration
Synchrotron Light Sources



Andrei Seryi, “Unifying Physics of Accelerators, Lasers and Plasma”, CRC Press, 2016

NSLS II, BNL, US

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Example of Electron Beam source and Booster

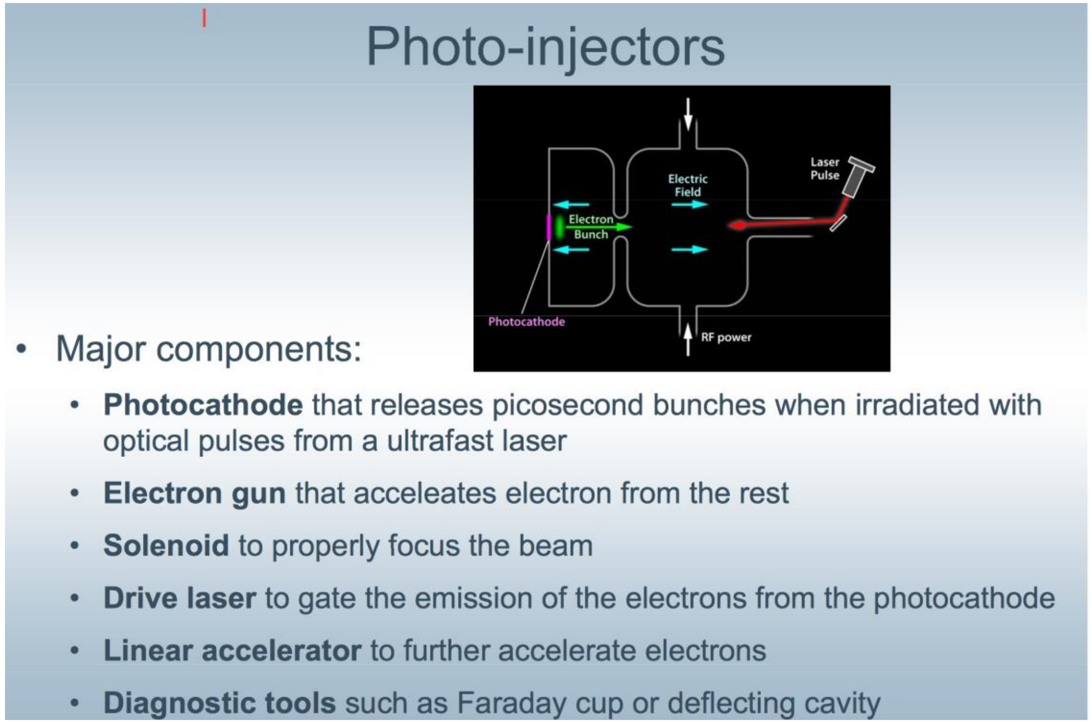
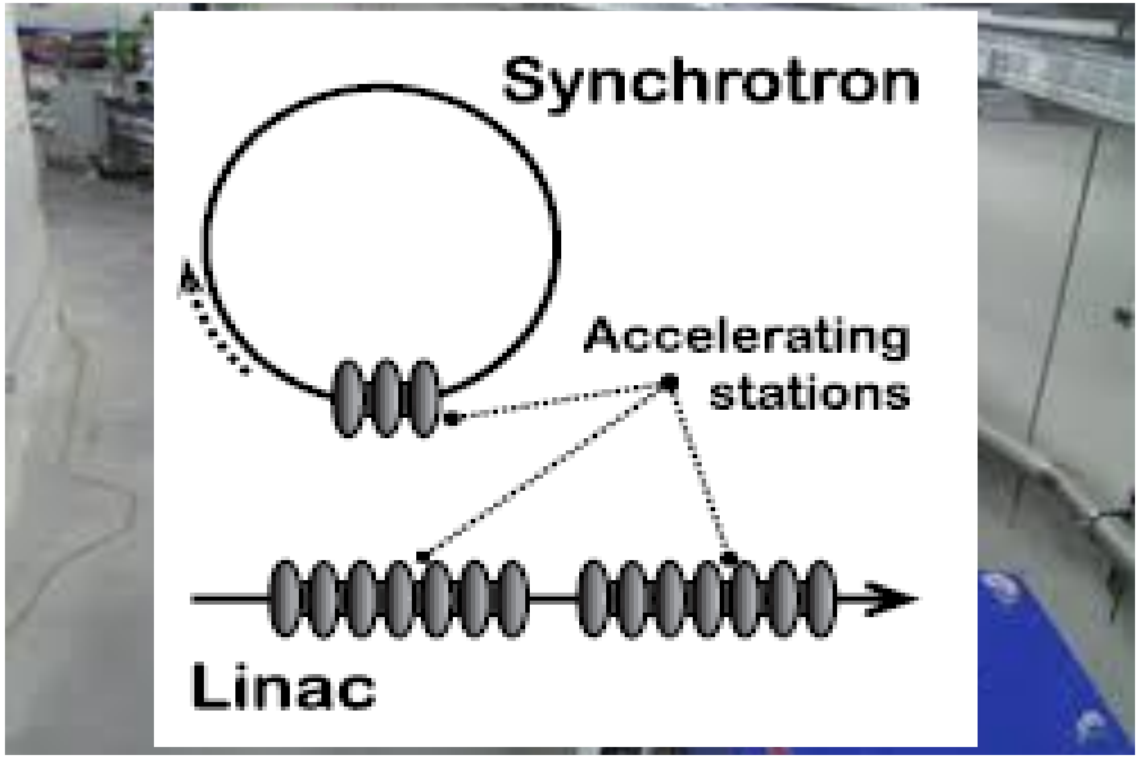


Photo-injectors

- Major components:
  - **Photocathode** that releases picosecond bunches when irradiated with optical pulses from a ultrafast laser
  - **Electron gun** that acceleates electron from the rest
  - **Solenoid** to properly focus the beam
  - **Drive laser** to gate the emission of the electrons from the photocathode
  - **Linear accelerator** to further accelerate electrons
  - **Diagnostic tools** such as Faraday cup or deflecting cavity



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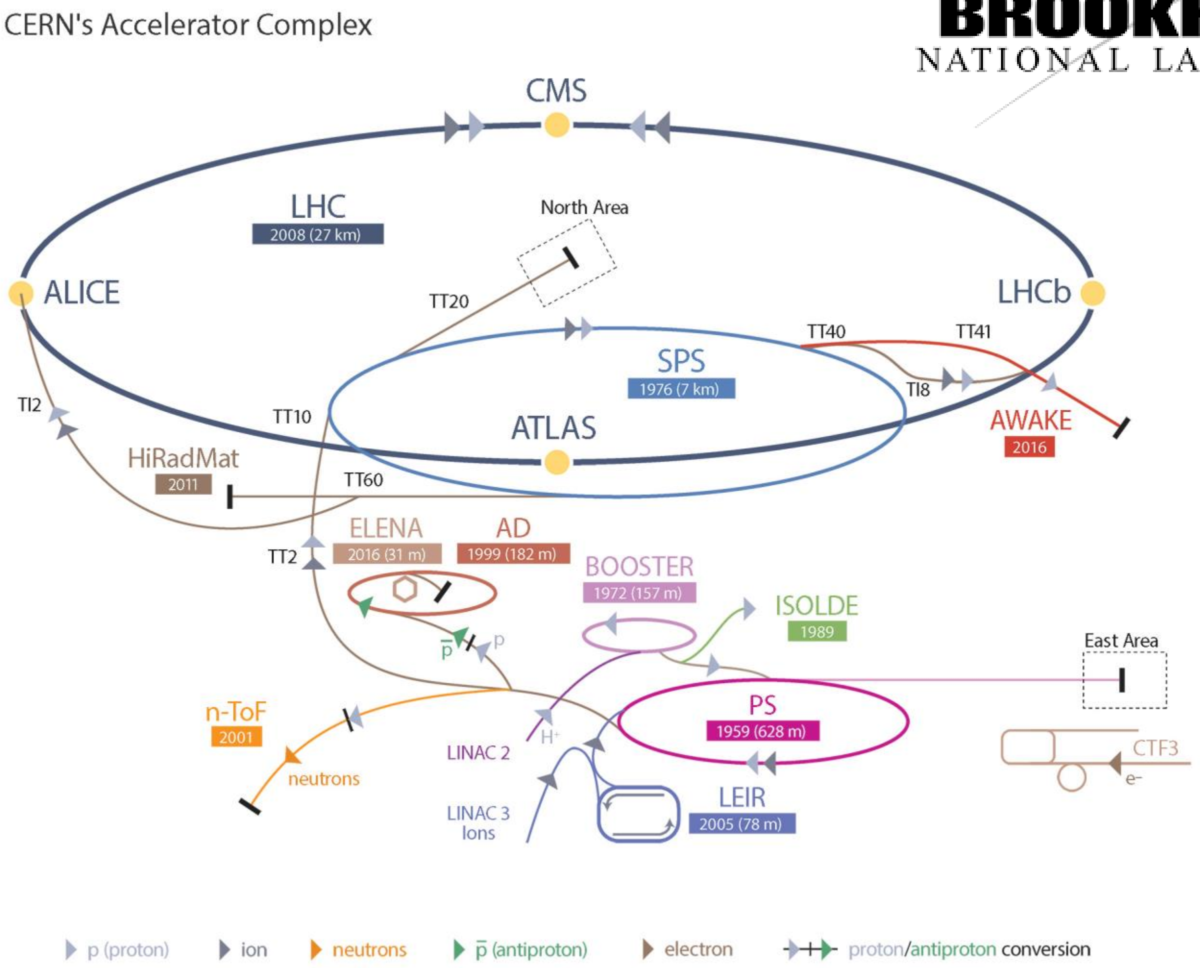
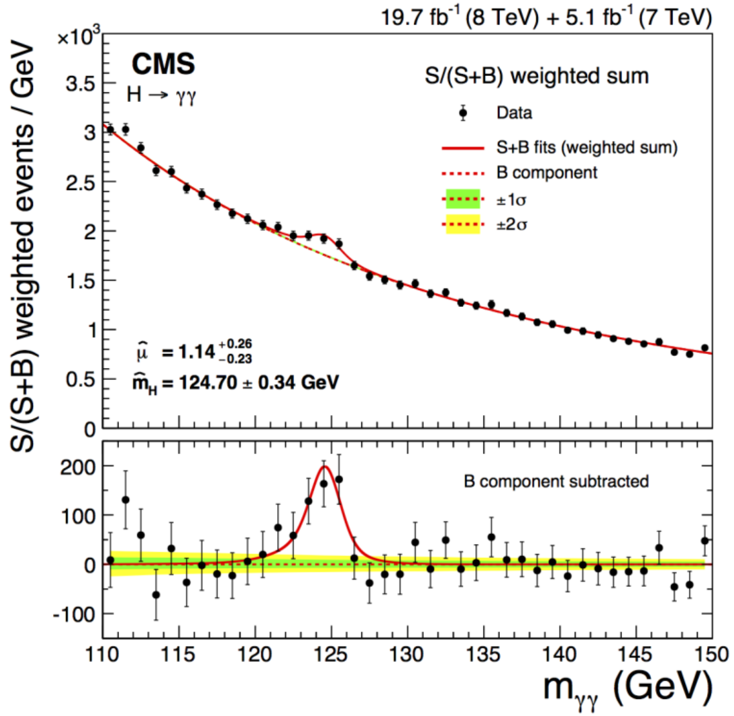
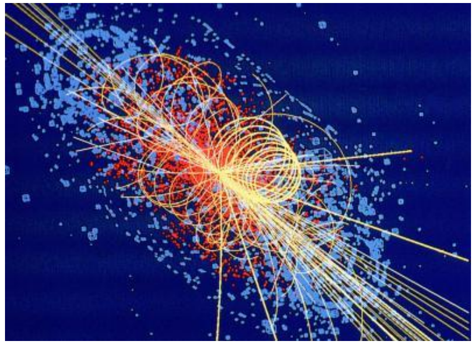




Discovery of Higgs Boson

The Higgs boson with a rest mass of 125 GeV/c^2 is the latest subatomic particle discovery enabled by particle accelerators and colliders

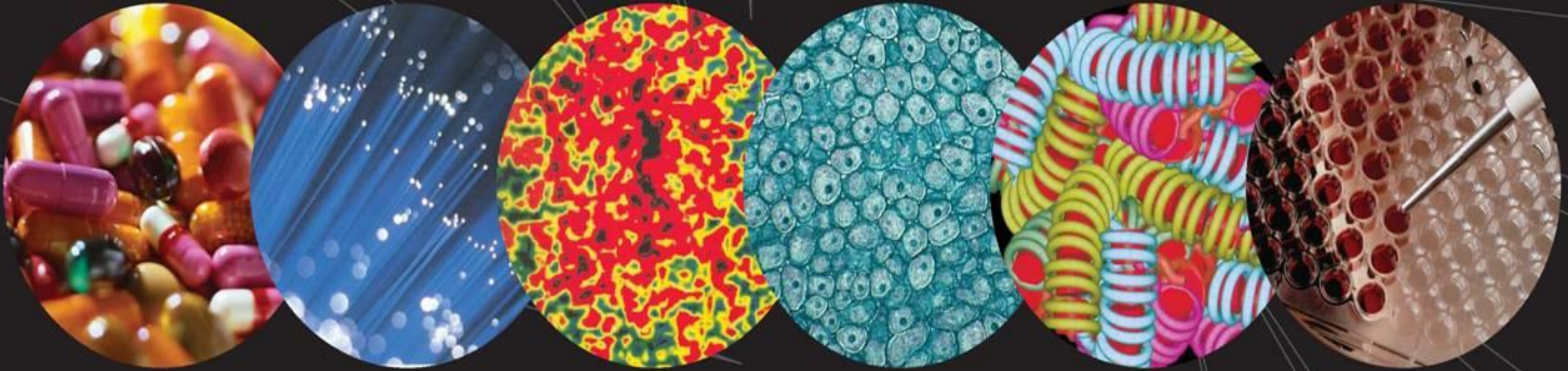


Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

Viviana Vladutescu, PhD,

IEEE LICN, March 5th, 2020

Synchrotron Light



CHEMISTRY

X-ray analysis of chemical elements allows diversification of methods and improvement of production processes for adhesives and lubricants, anti-corrosion coatings, surface electro-chemical preparations, hydrophobic coatings and many others.

MATERIALS SCIENCE

By means of non-destructive image formation one can establish the three dimensional structure of non-crystalline materials, where their behaviour depends on the presence of nano-crystalline phases or chemical impurities (doping) that cannot be studied by traditional means, and which are nevertheless extremely important in the material's performance.

Synchrotron Light is also used, for example, in the study of: special alloys for use in aerospace technology; the electronic and atomic structure of catalysts; semiconductors; superconductors; and how these

MAGNETISM

Techniques exclusive to synchrotron light sources, such as soft X-ray magnetic circular dichroism, are used to image the magnetic domains in thin films and mono-layers. These are essential in sensors and data storage devices. In addition, Synchrotron Light is used for "in situ" detection of magnetic microstructures.

LIFE SCIENCES

Time-resolved X-ray diffraction, unique to Synchrotron Light, is routinely used to study the structural/functional changes undergone by, for example, DNA, proteins and macromolecules in solution, as well as structural/functional studies of hormones, enzymes and viruses.

For example, muscles, and other biological systems, convert chemical energy into force or motion. Muscle molecules undergo subtle and rapid conformational changes that only Synchrotron Light is capable of detecting. It is thanks to such techniques that we can understand the

MACROMOLECULAR CRYSTALLOGRAPHY

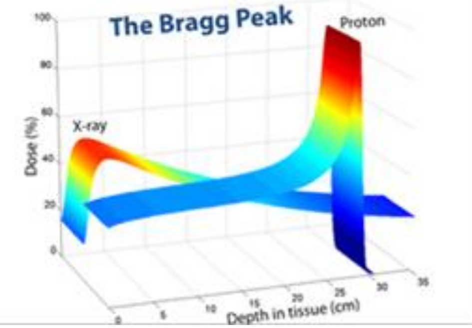
This is currently an area of intense activity, both academically and in industry. As a result of the completion of the Human Genome Project it is now possible to crystallize many biological macromolecules intimately involved in a given biological target. Synchrotron Light has solved the atomic structure of many biological macromolecules and will continue to do so until all the protein structures (in excess of 50,000) derived from the knowledge acquired in the Human Genome Project are solved. One important recent example is the atomic structure of the biological

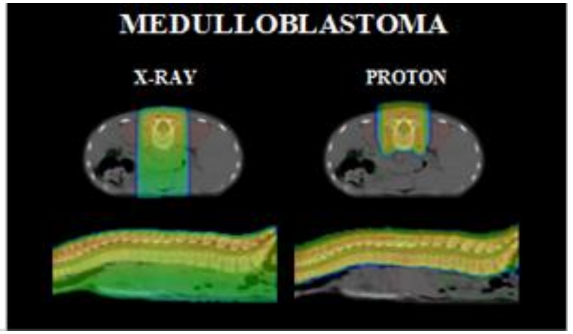
INDUSTRY

In the past, many industrial processes, such as polymer and ceramics production, depended on the skill of the experts and on chance. Great control and predictability has now been acquired in these processes following research carried out with Synchrotron Light.

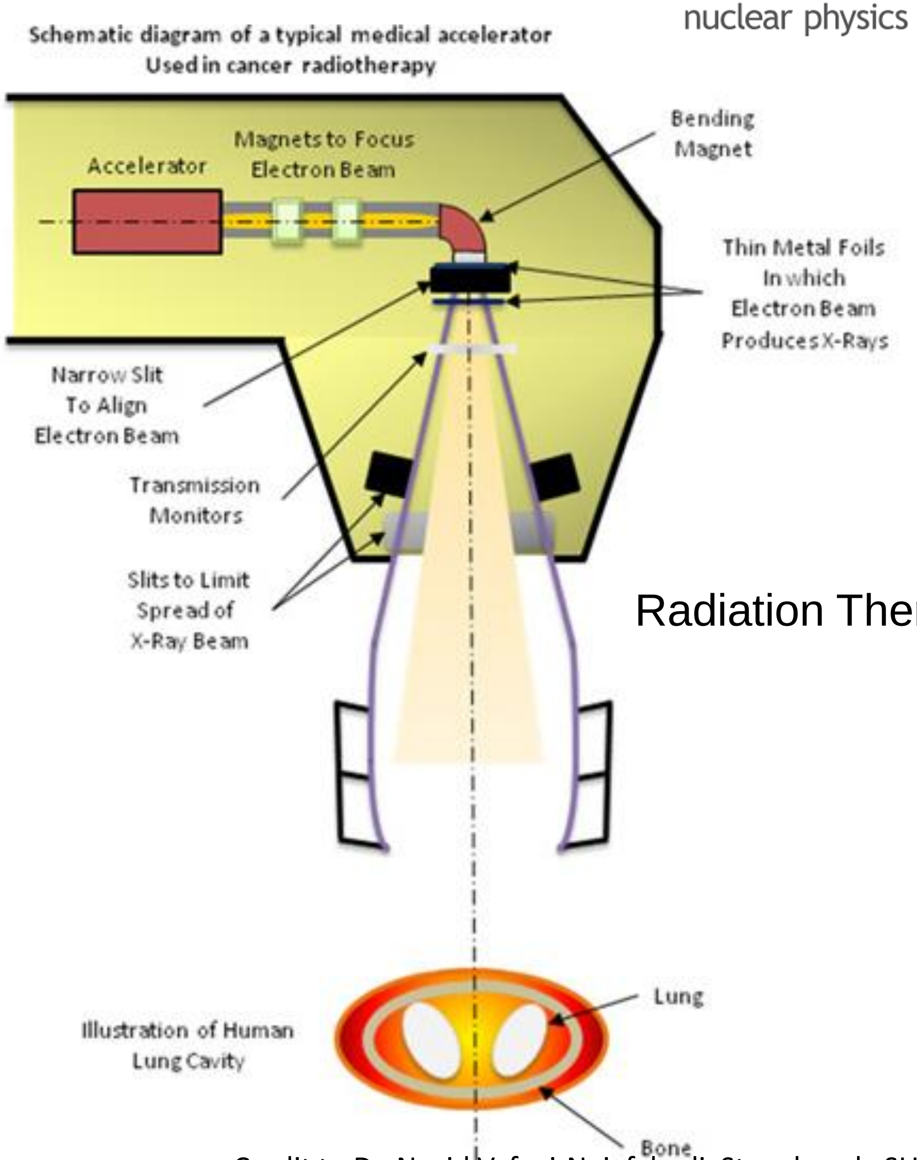
Other industrial applications are in areas such as electronics (e.g., chip manufacture), micro-mechanics (e.g., manufacture of sub-micron devices used in medical or sensor applications), aerospace industry (e.g., detector calibration), pharmaceuticals (e.g., structural/functional studies of

Accelerators in Medicine





Particle and radiation beams are used for imaging, diagnosis, and therapy



Radiation Therapy

Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

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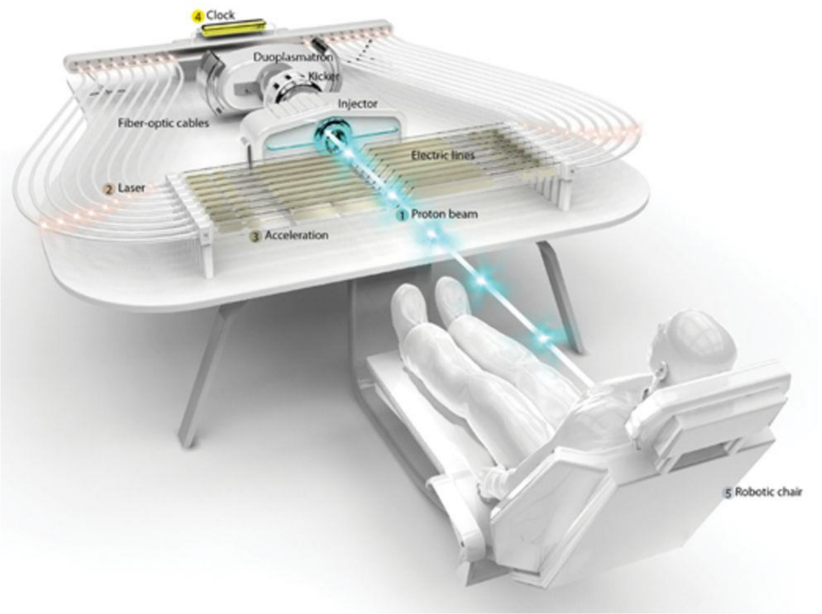
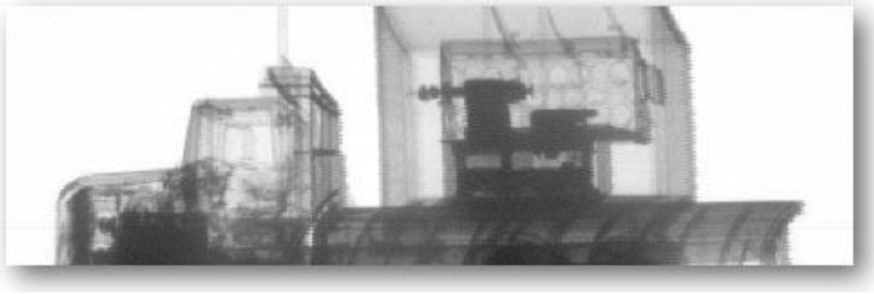
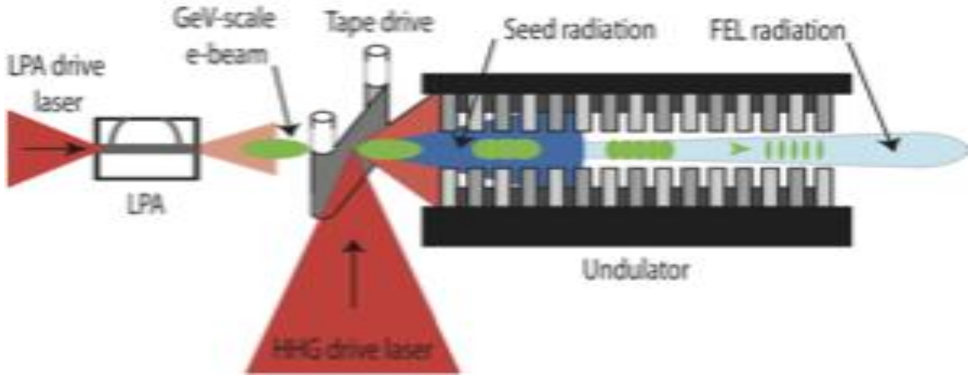
Applications of Table Top Plasma Accelerators



Medicine



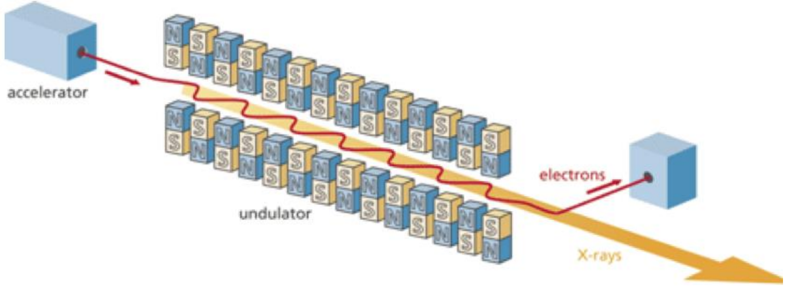
Security



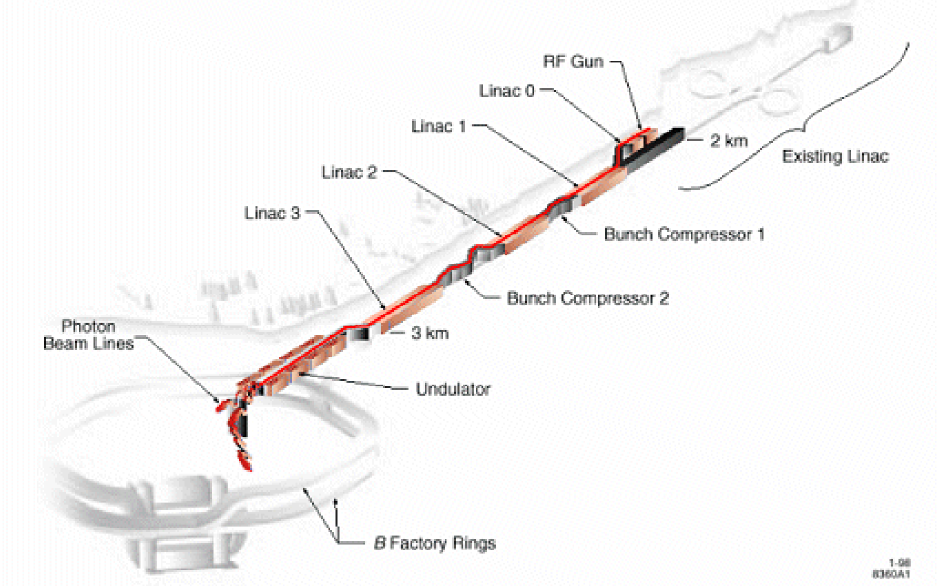
[Free Electron Laser]

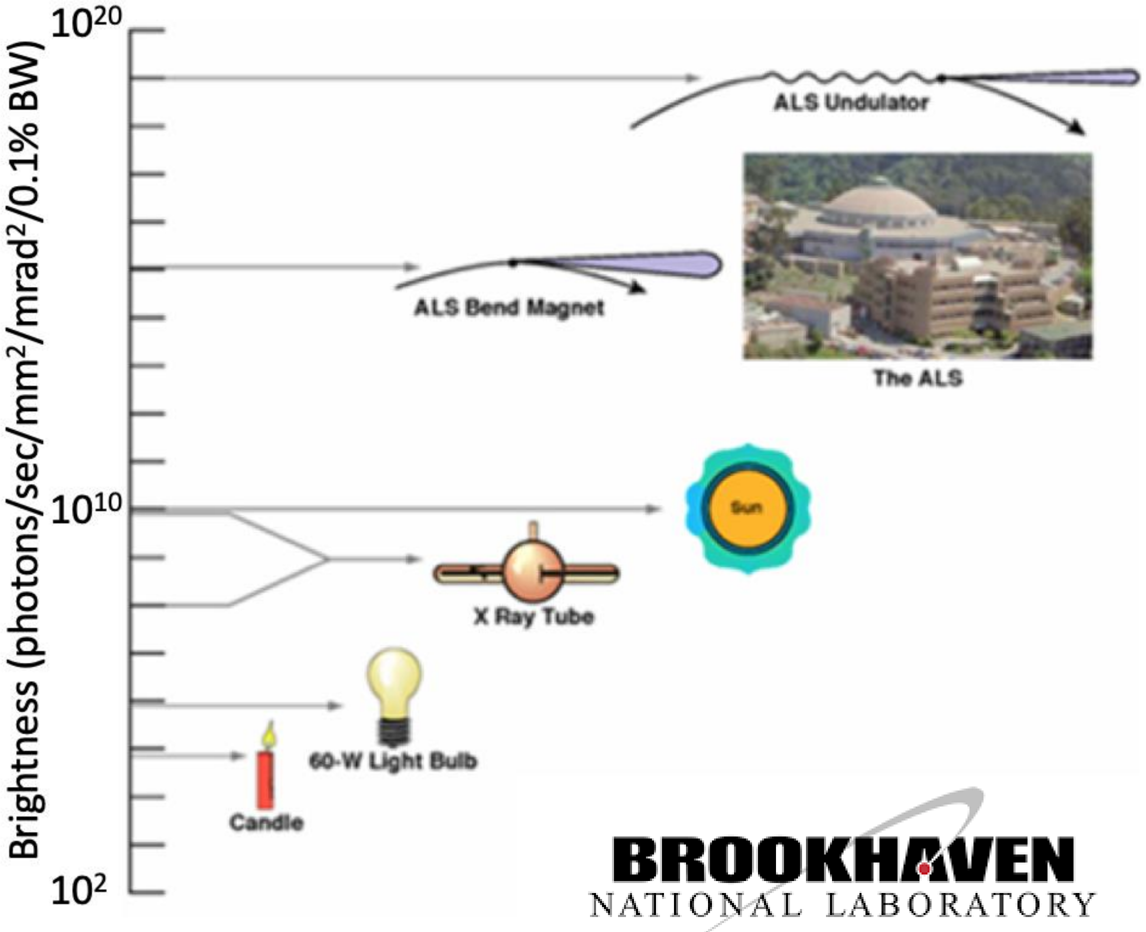
Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

Accelerator Light Sources



The LCLS
(Linac Coherent Light Source)





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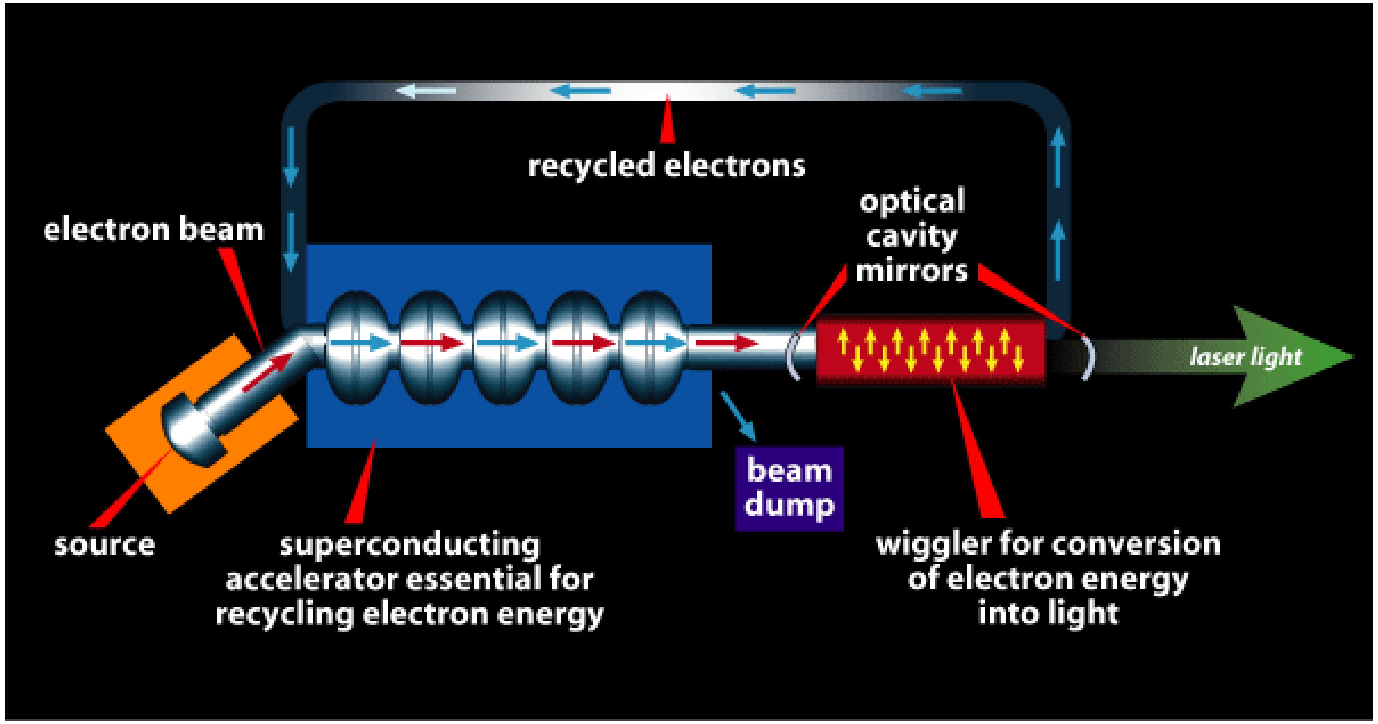
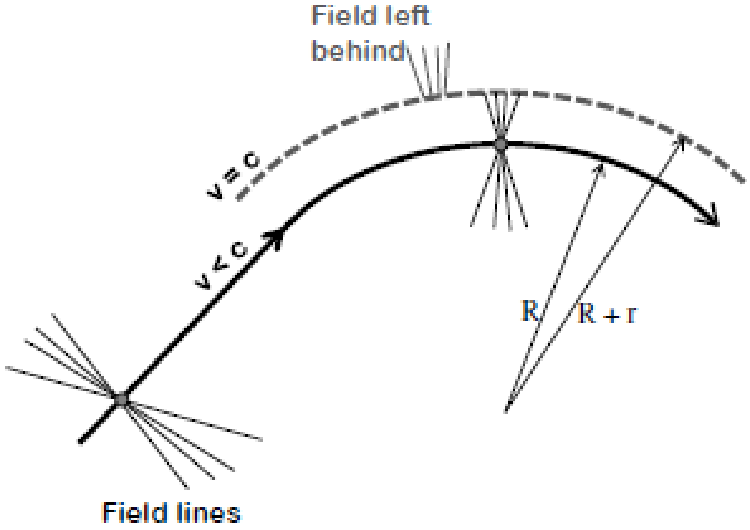
Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

Free Electron Lasers

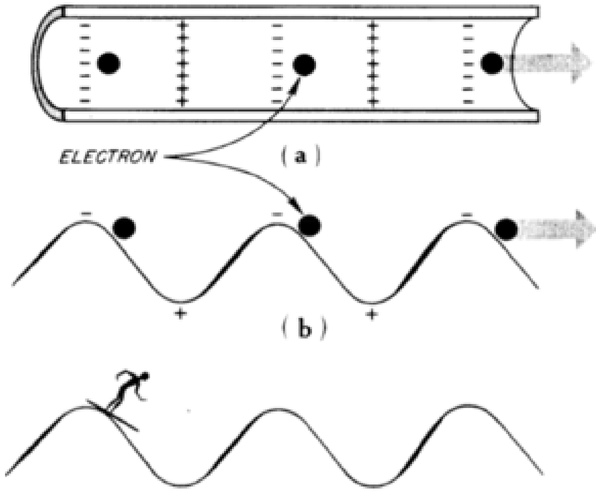


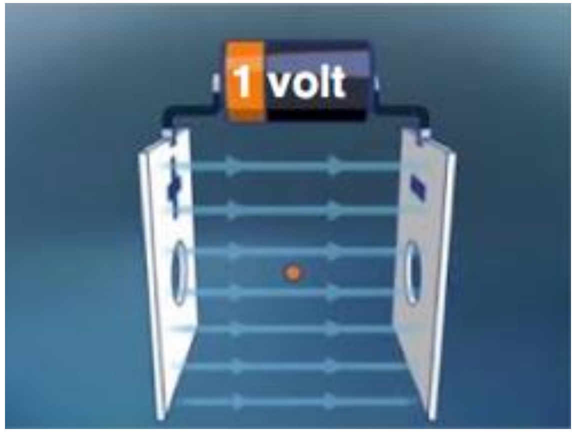


https://www.youtube.com/watch?v=RKqof77pKBc

Conventional particle acceleration

Copper structure with irises
Structure diameter ~ 10 cm
Energy gain ~ 20 MeV/m

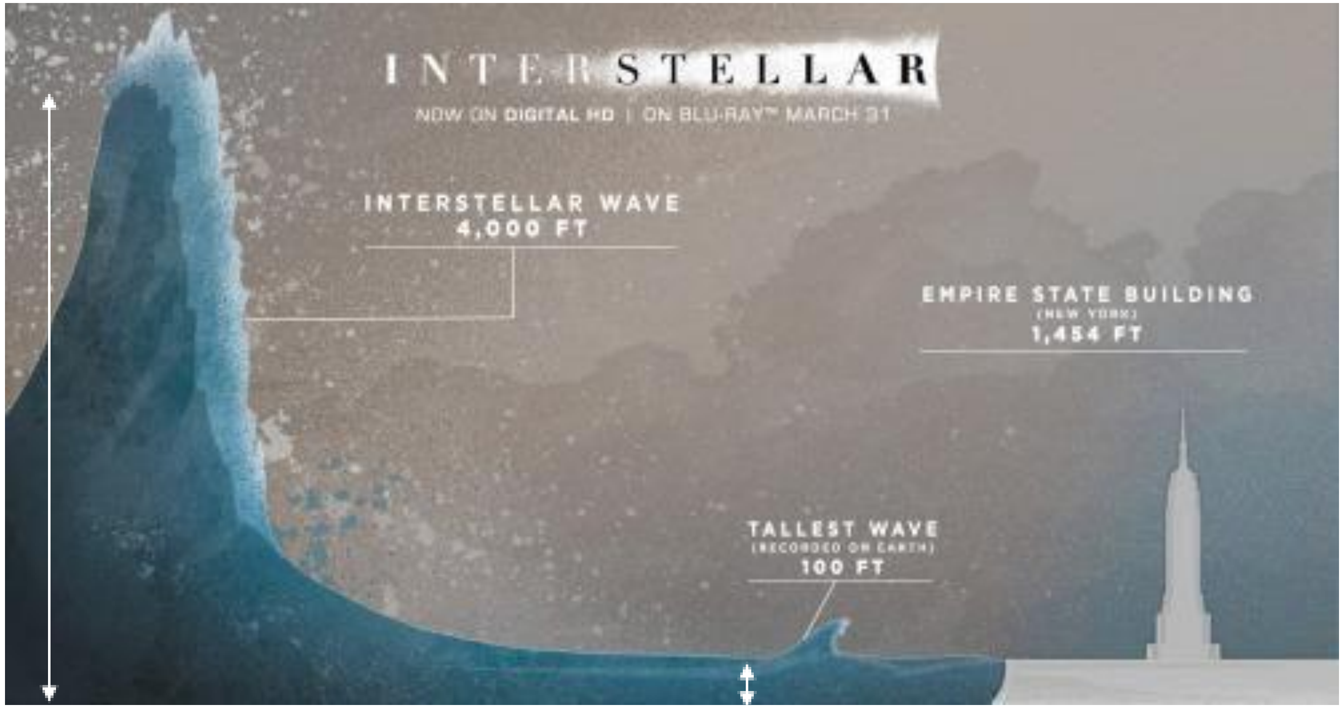




E(MeV)	E(J)	v (e^-)
3	4.8E-19	0.985 c
300	4.8E-17	0.9999985 c

Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

Getting a Larger Wave for Electrons to Ride



Plasma Wave(40 GeV/m) EM Wave in Copper Structure (100 MeV/m)

By getting the electrons a large potential wave to ride, colliders of the future could get hundreds of times smaller LHC: 27 km circumference -> ~70 m in length

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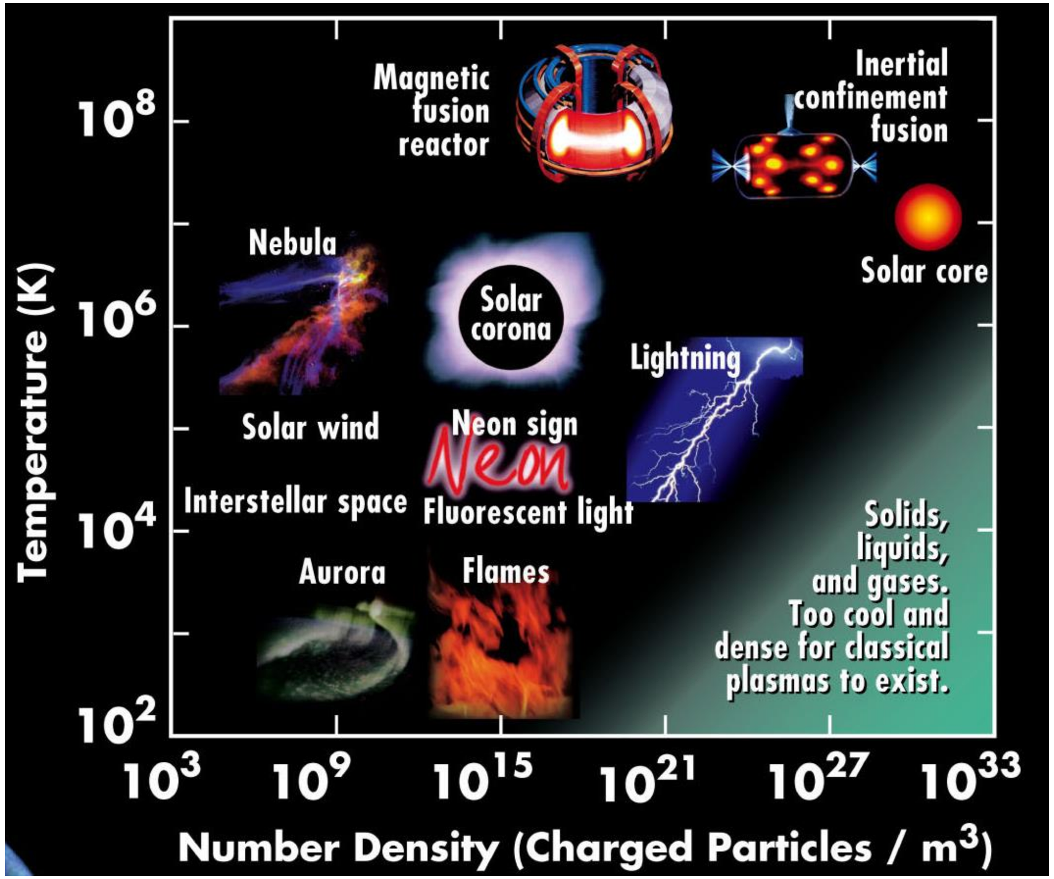
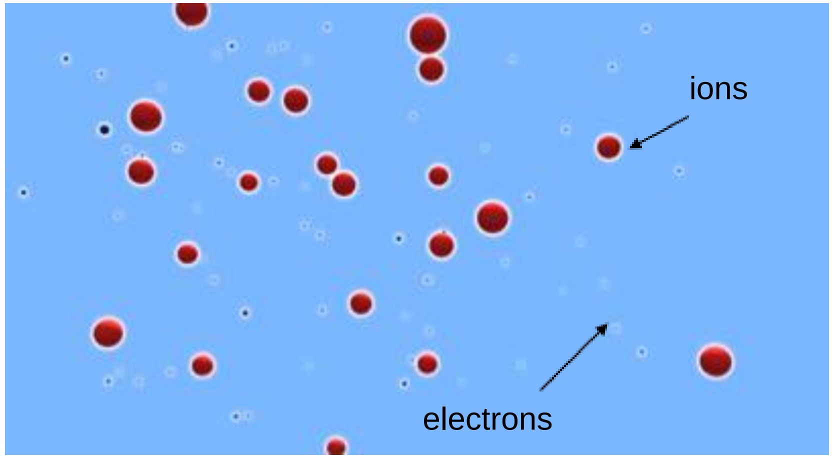
Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

Plasma



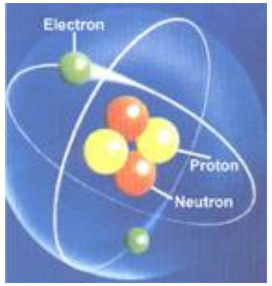
Contemporary Physics Education Project

- Most of the universe exist in the state of plasma
- A plasma is a collection of electrons and ions that are not bound to each other
- The mass of the ions are several thousand times greater than the mass of the electrons.



Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

How to make plasma



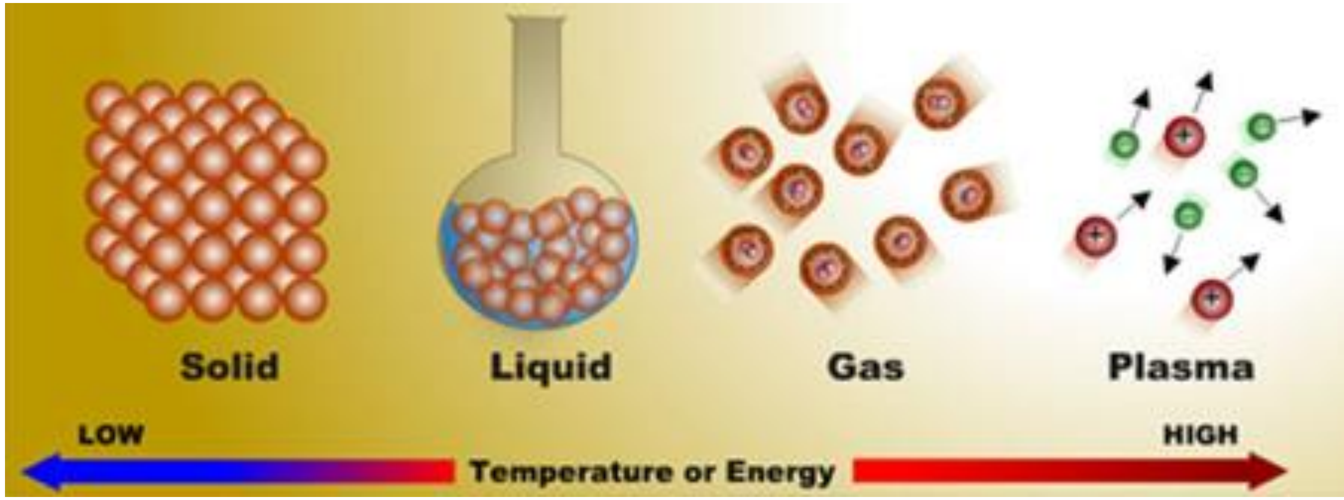
Energy → Ionization

Must provide energy for the electron to overcome the ion's electric attraction

1. Use heat $$\frac{n_i}{n_n} = 2.4 \times \frac{10^{21} T^{3/2}}{n_i} e^{-U_i/KT}$$

e.g. for air at room temperature,
$n_i/n_n \sim 10^{-122}$

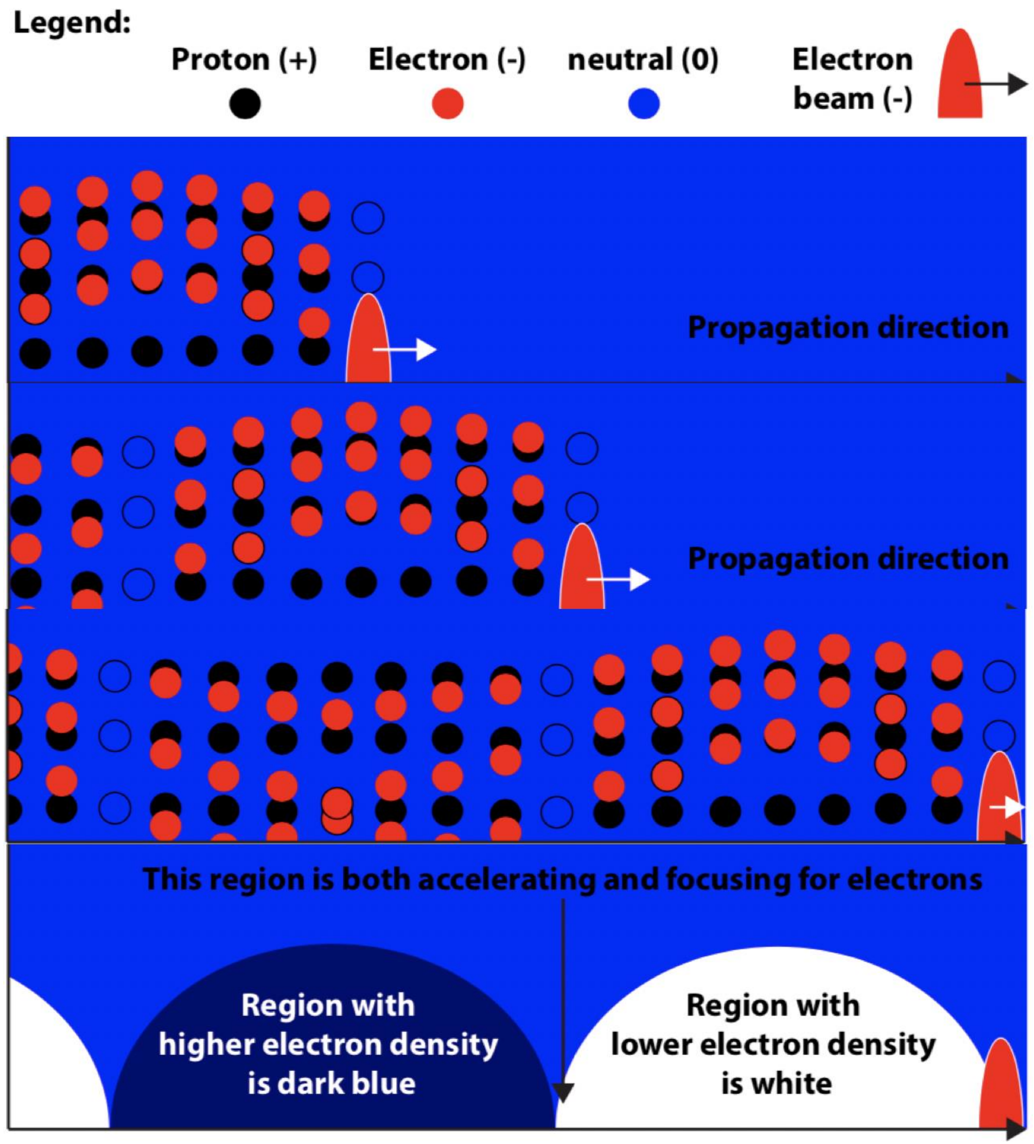
2. Use stronger electric field
   a. Light (laser)
   b. particles (electron beam)



Dimensionless Physical Quantities in Science and Engineering
By Josef Kunes

Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

Plasma Wakefield



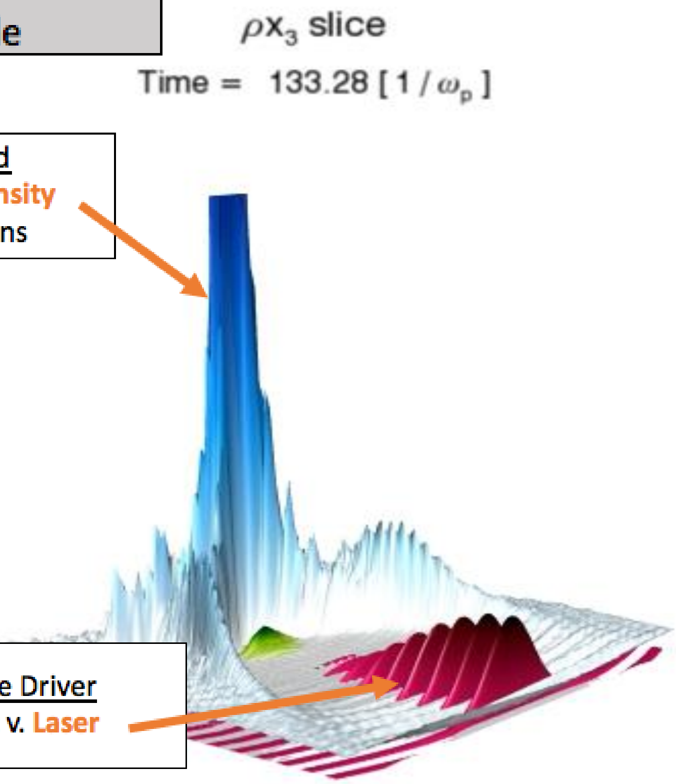
Density perturbations due to a powerful driver results in high amplitude accelerating field

Credit to Dr. Navid Vafaei-Najafabadi, Stonybrook, SUNY

It’s Like Wake Surfing, But With a Laser/Beam Driver

Wake in Water
Meter-Scale

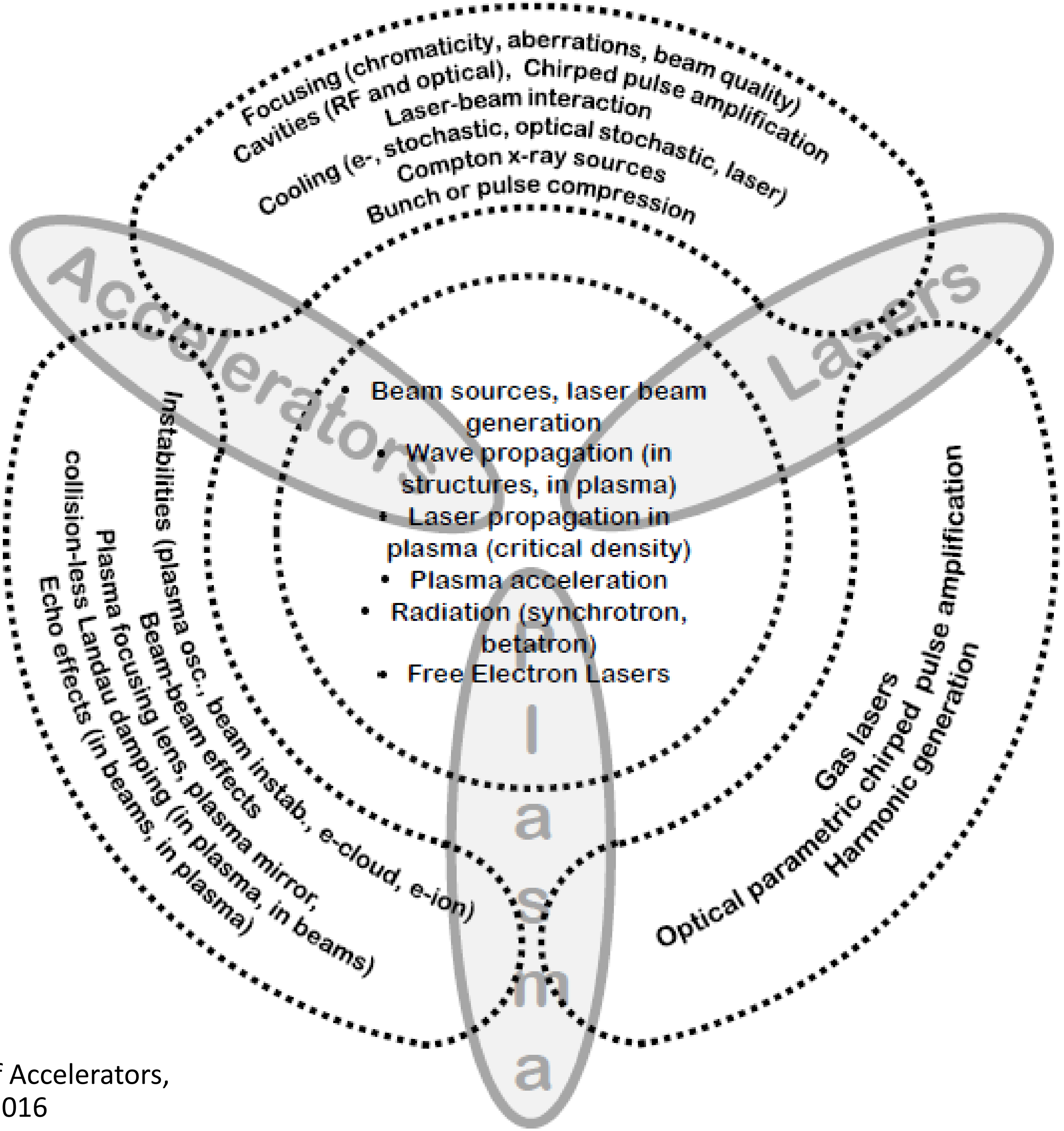
Wake in Plasma
Micron-Scale



<u>Wakefield</u>
Height v. Density
Modulations

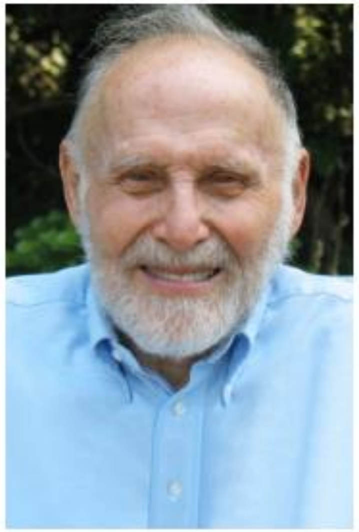
<u>Wake Driver</u>
Boat v. Laser

Credit to Dr. J. L. Shaw, LLE, Rochester



Andrei Seryi, “Unifying Physics of Accelerators, Lasers and Plasma”, CRC Press, 2016

Ultrafast High Power Lasers



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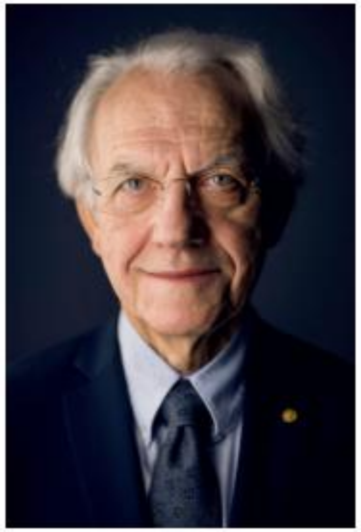

© Nobel Media AB. Photo: A. Mahmoud
Gérard Mourou
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© Nobel Media AB. Photo: A. Mahmoud
Donna Strickland
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The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to Arthur Ashkin "for the optical tweezers and their application to biological systems", the other half jointly to Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses."

Chirped-pulse amplification (CPA) concept

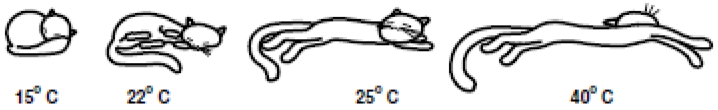
Volume 56, number 3 OPTICS COMMUNICATIONS 1 December 1985

COMPRESSION OF AMPLIFIED CHIRPED OPTICAL PULSES ☆

Donna STRICKLAND and Gerard MOUROU

Laboratory for Laser Energetics, University of Rochester, 250 East River Road, Rochester, NY 14623-1299, USA

Received 5 July 1985



We have demonstrated the amplification and subsequent recompression of optical chirped pulses. A system which produces 1.06 μm laser pulses with pulse widths of 2 ps and energies at the millijoule level is presented.

Volume 56, number 3 OPTICS COMMUNICATIONS 1 December 1985

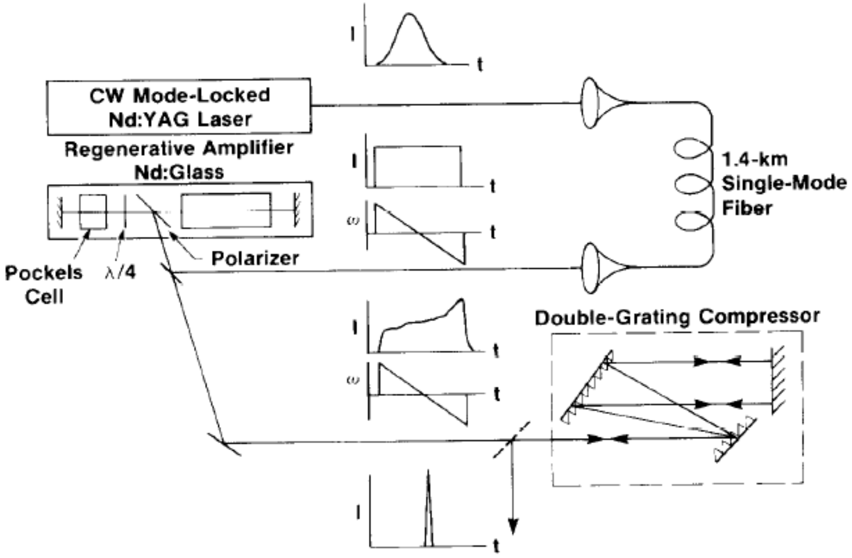


Fig. 1. Amplifier and compression system configuration.

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APS NEWS

Winners of 2018 Nobel Prize in Physics Announced

Three researchers receive honors for laser science

October 2, 2018 | Leah Poffenberger

The Royal Swedish Academy of Sciences has announced this year's winner of the Nobel Prize in Physics. Recipients of 2018 prize, awarded "for groundbreaking inventions in the field of laser physics," are Arthur Ashkin (formerly at Bell Laboratories), Gérard Mourou (École Polytechnique, France, and the University of Michigan, Ann Arbor, United States) and Donna Strickland (University of Waterloo, Canada). Strickland is the third female physicist to receive this award, and the first to do so since 1963.

Photos: Ashkin: A. Ashkin, Mourou: ELSA Lab, Strickland: Univ. of Waterloo

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New Journal Launch: Physical Review Research

Set to open for submissions soon, the new open access journal published by APS will cover the full spectrum of research topics of interest to the physics community

Five Institutions Join the PhysTEC 5+ Club

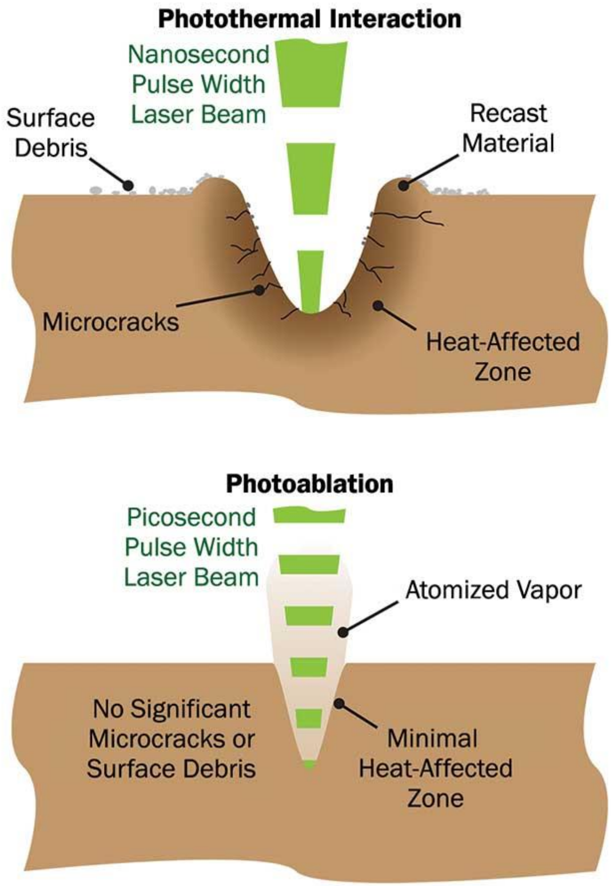
PhysTEC announces the colleges and universities that graduated 5 or more physics teachers in the 2017-2018 academic year.

Applications of UFHPL

Applications exploiting the very high **peak power**:

- industrial laser material processing of small parts (micromachining) or with very high quality,
- medical applications such as **eye surgery** and other forms of **microsurgery**.
- **laser-induced breakdown** spectroscopy (LIBS).
- **nonlinear frequency conversion** of light pulses, e.g. for high-power RGB displays (→ **RGB sources**) and for **laser spectroscopy**

Particularly extreme optical intensities are used in some fundamental science experiments and in laser fusion research.

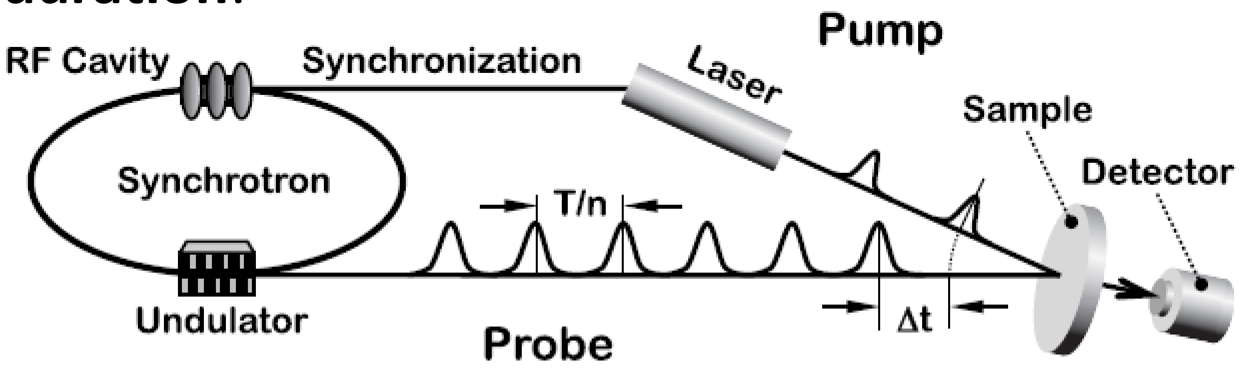


https://www.rp-photonics.com/ultrafast_lasers.html

Applications of UFHPL

Applications exploiting the ultrashort **pulse duration**:

- **pump–probe measurements**,
- **distance measurements with lasers** with the **time-of-flight** method,
- **electro-optic sampling**,
- the generation and detection of **terahertz radiation**,
- **optical fiber communications** with **soliton** pulses.



https://www.rp-photonics.com/ultrafast_lasers.html

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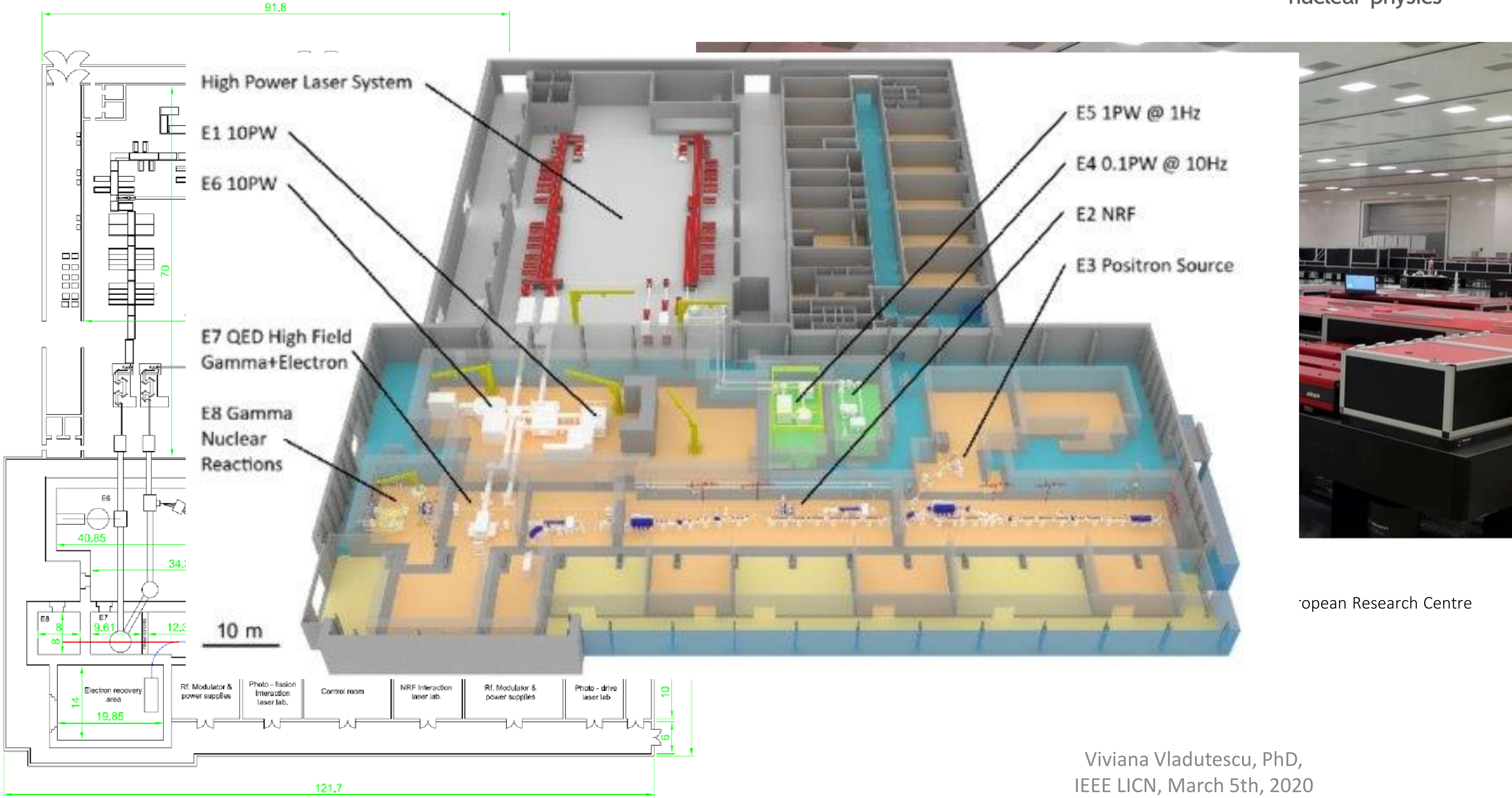
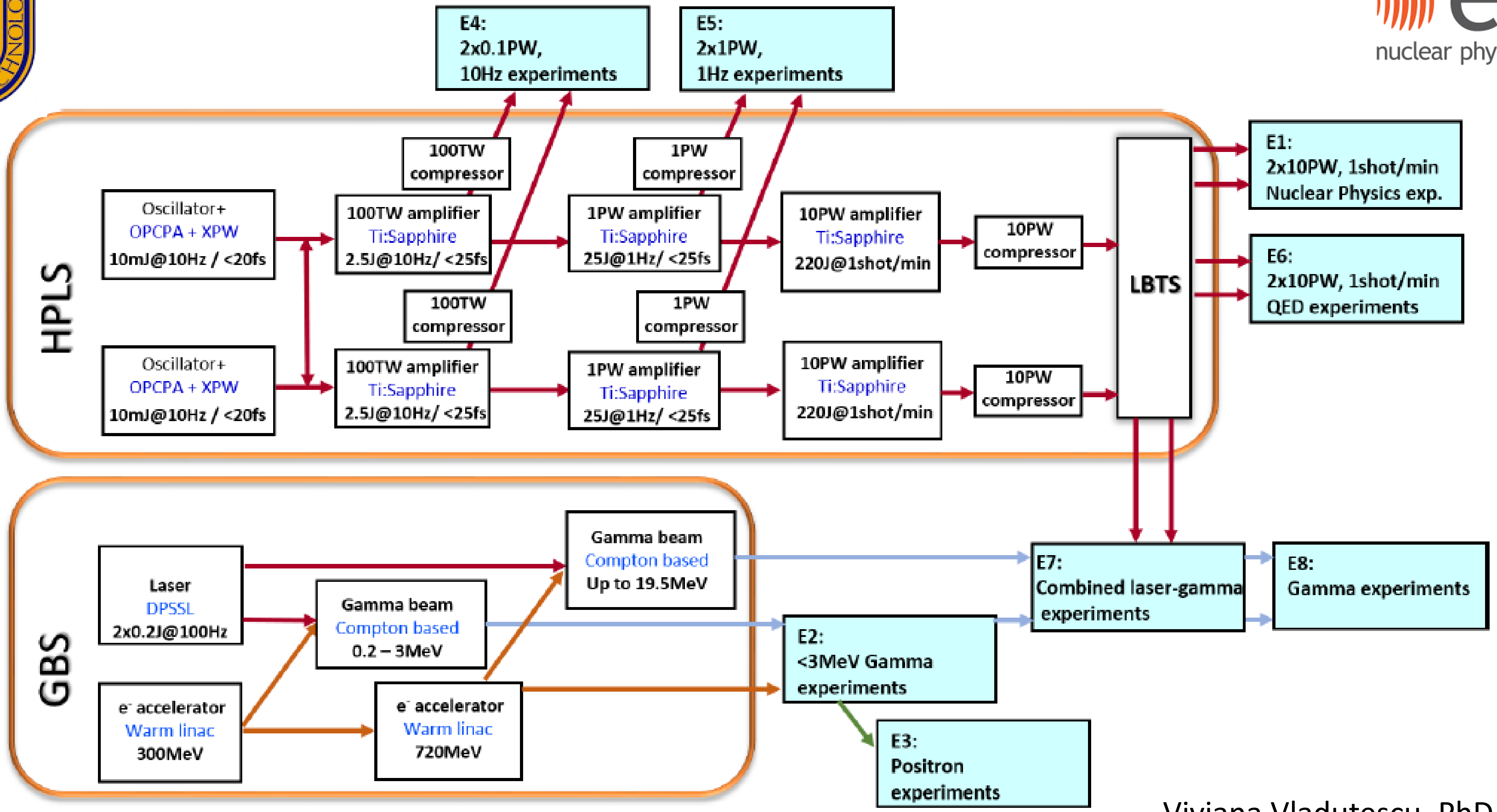
IEEE LICN, March 5th, 2020

ELI-NP Facilities- HPLS and GBS



opean Research Centre



S.Gales et al., The Extreme Light Infrastructure Nuclear Physics (ELI-NP) Facility: New Horizons in Physics with 10-PW ultra-intense Lasers and 20-MeV brilliant Gamma beams, March 2019

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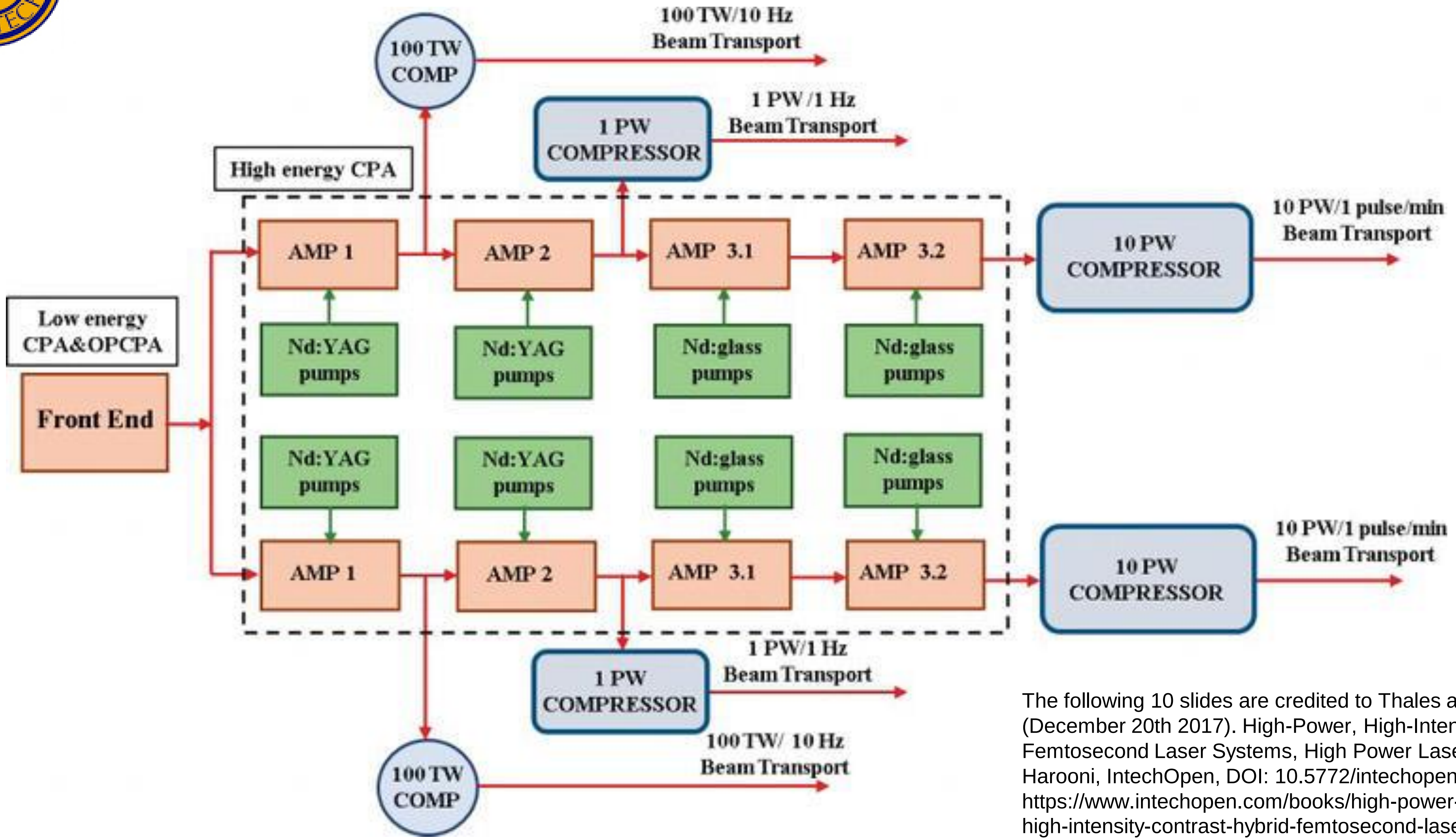
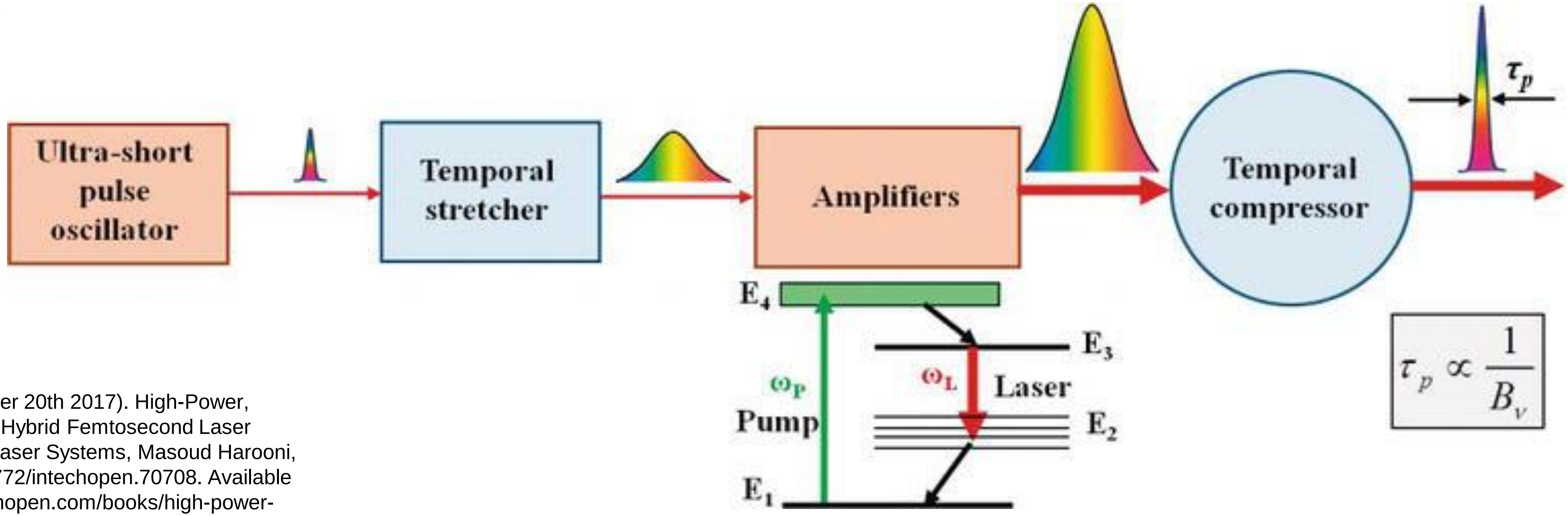
IEEE LICN, March 5th, 2020

HPLS @ ELI



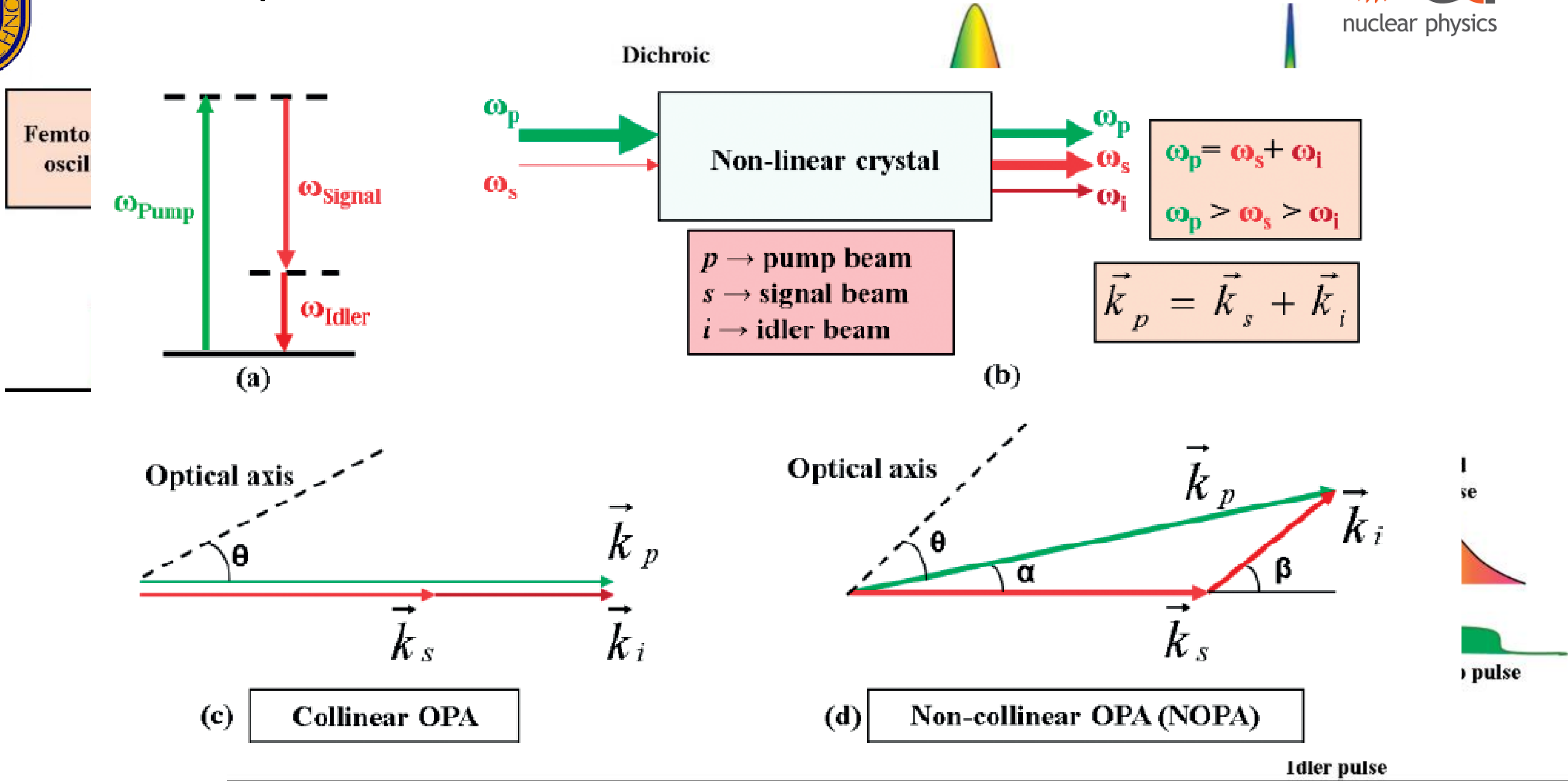
The following 10 slides are credited to Thales and Dr. Razvan Dabu (December 20th 2017). High-Power, High-Intensity Contrast Hybrid Femtosecond Laser Systems, High Power Laser Systems, Masoud Harooni, IntechOpen, DOI: 10.5772/intechopen.70708. Available from: https://www.intechopen.com/books/high-power-laser-systems/high-power-high-intensity-contrast-hybrid-femtosecond-laser-systems

CPA systems

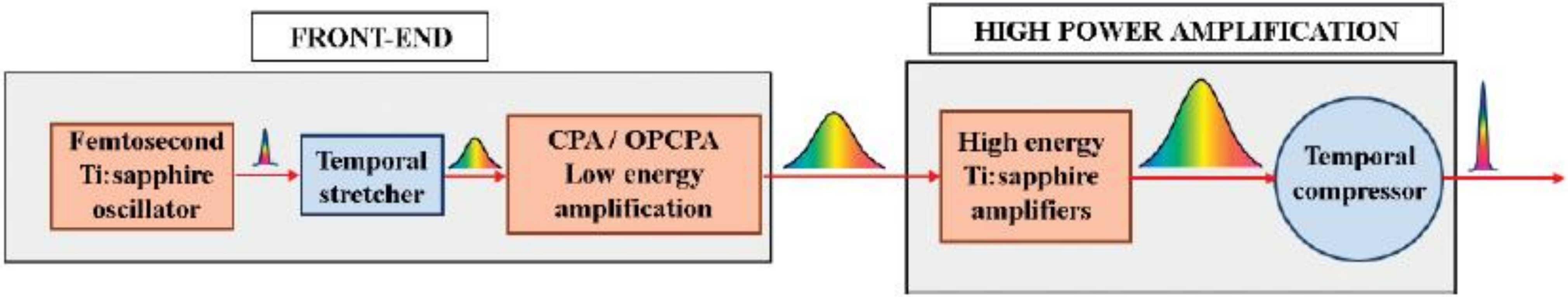


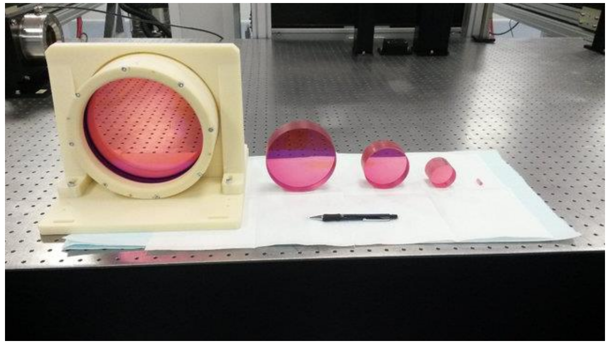
Razvan Dabu (December 20th 2017). High-Power, High-Intensity Contrast Hybrid Femtosecond Laser Systems, High Power Laser Systems, Masoud Harooni, IntechOpen, DOI: 10.5772/intechopen.70708. Available from: https://www.intechopen.com/books/high-power-laser-systems/high-power-high-intensity-contrast-hybrid-femtosecond-laser-systems

Amplification Process



Basic configuration of a hybrid chirped pulse amplification laser system.





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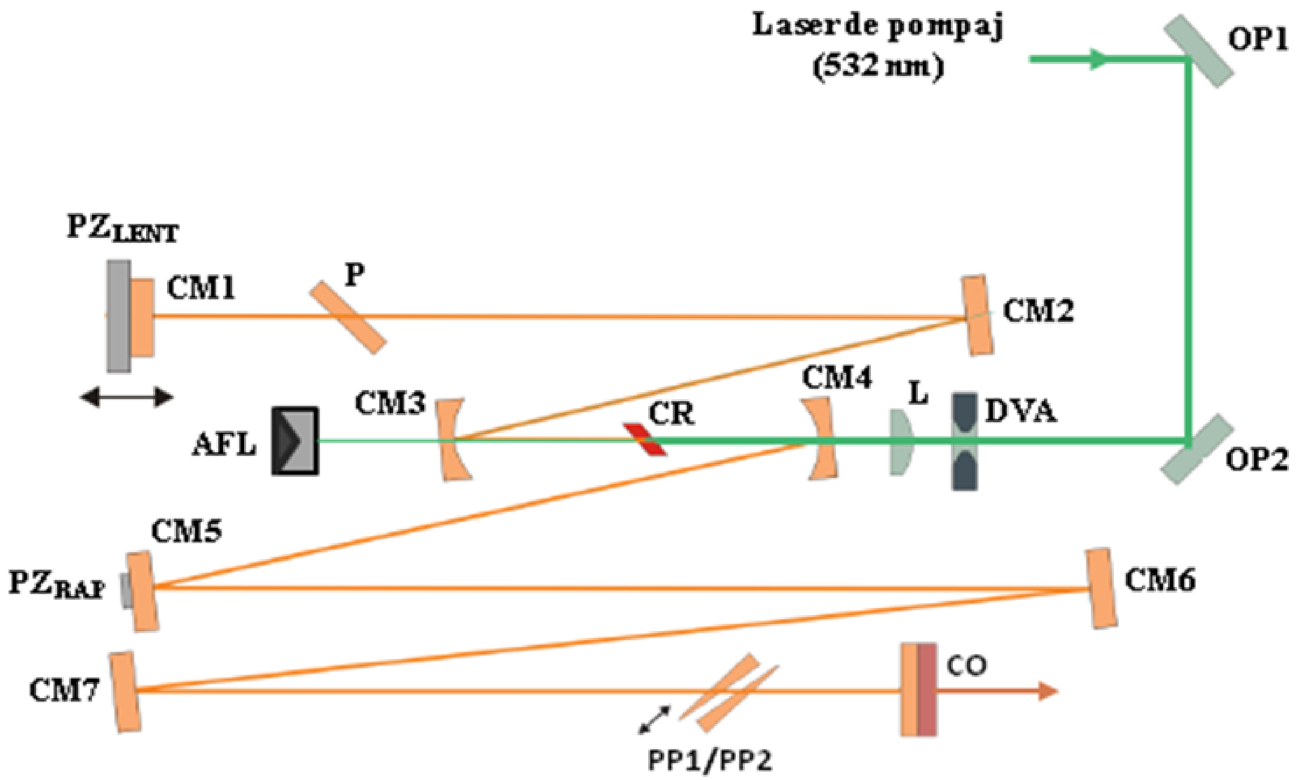
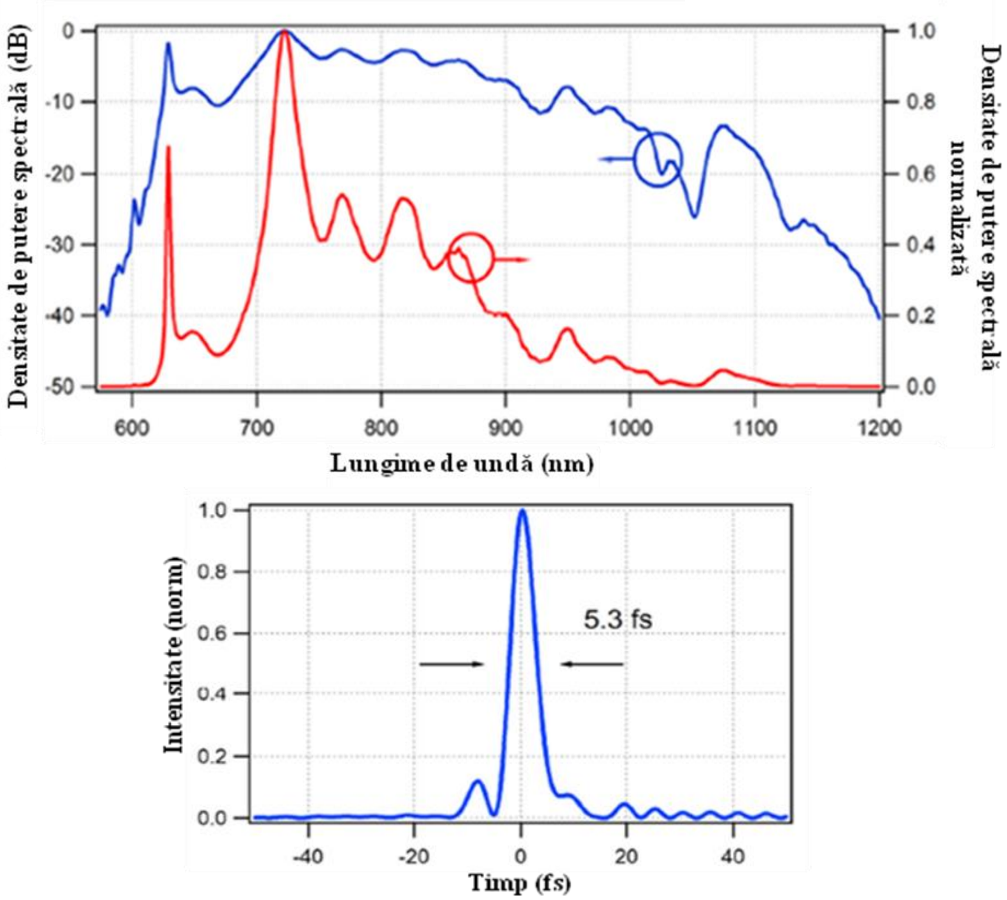
Advanced Ti:sapphire laser oscillator (VENTEON)





Spectral intensity and temporal intensity profiles of the VENTEON Ti:sapphire oscillator

Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

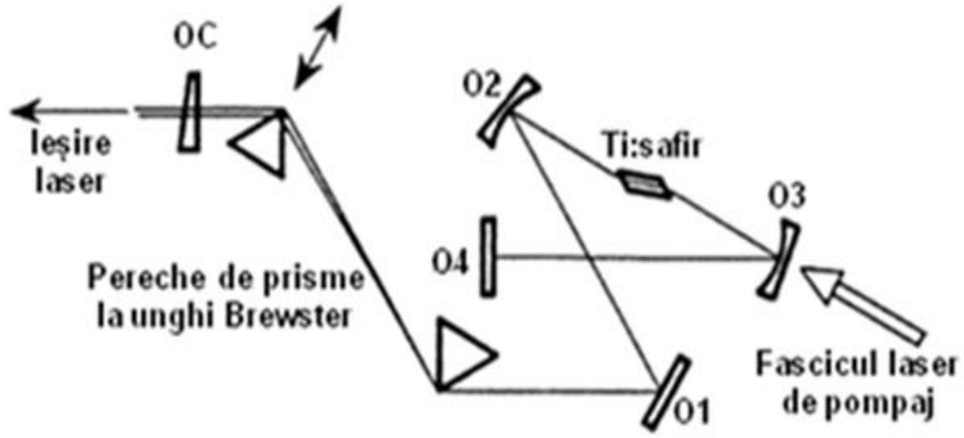
Femtosecond oscillators

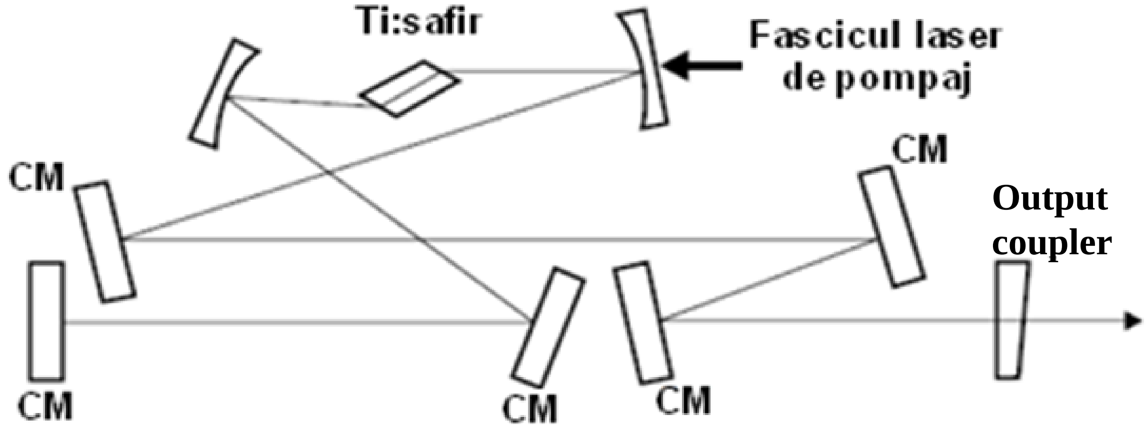
$$\phi(\omega)=\phi(\omega_0)+\left(\frac{d\phi}{d\omega}\right)_0(\omega-\omega_0)+\frac{1}{2!}\left(\frac{d^2\phi}{d\omega^2}\right)_0(\omega-\omega_0)^2+\frac{1}{3!}\left(\frac{d^3\phi}{d\omega^3}\right)_0(\omega-\omega_0)^3+\ldots$$

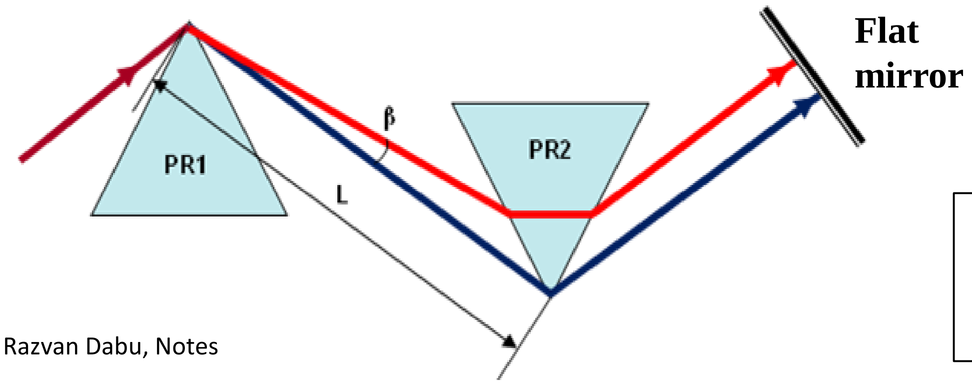
Group delay (GD)

Linear group delay dispersion (GDD), linear "chirp"

Quadratic GDD, quadratic "chirp"



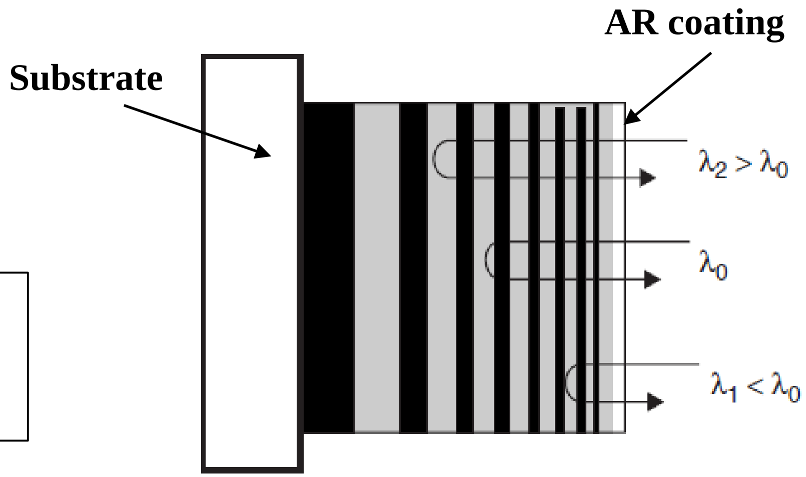




Dr. Razvan Dabu, Notes

Pair of Brewster angle prisms

Negative dispersion:
dT/dλ > 0,
T, propagation time



Chirped mirror

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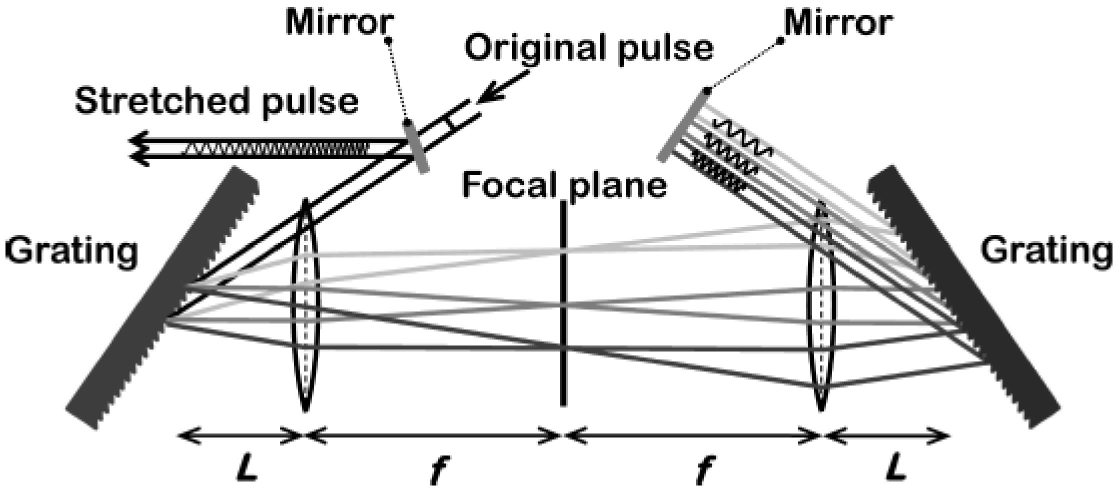
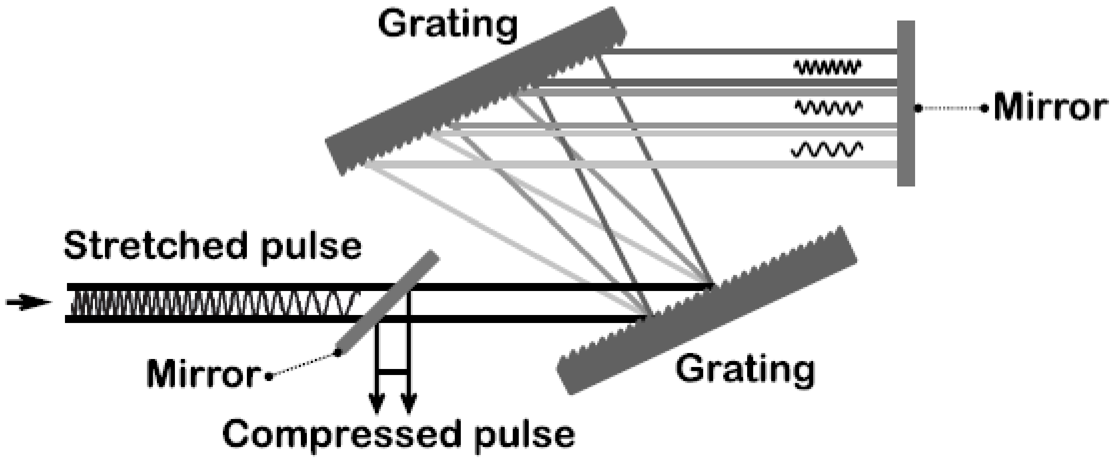
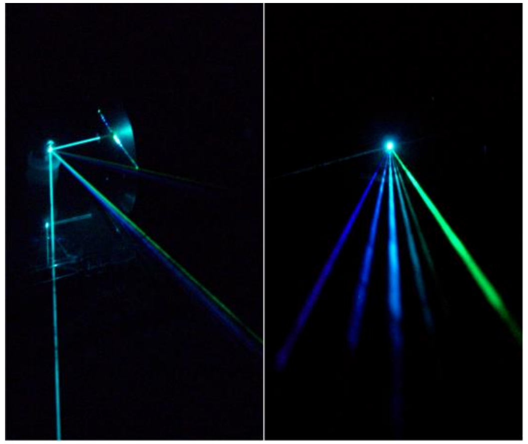
IEEE LICN, March 5th, 2020

Stretching and Compressing Process





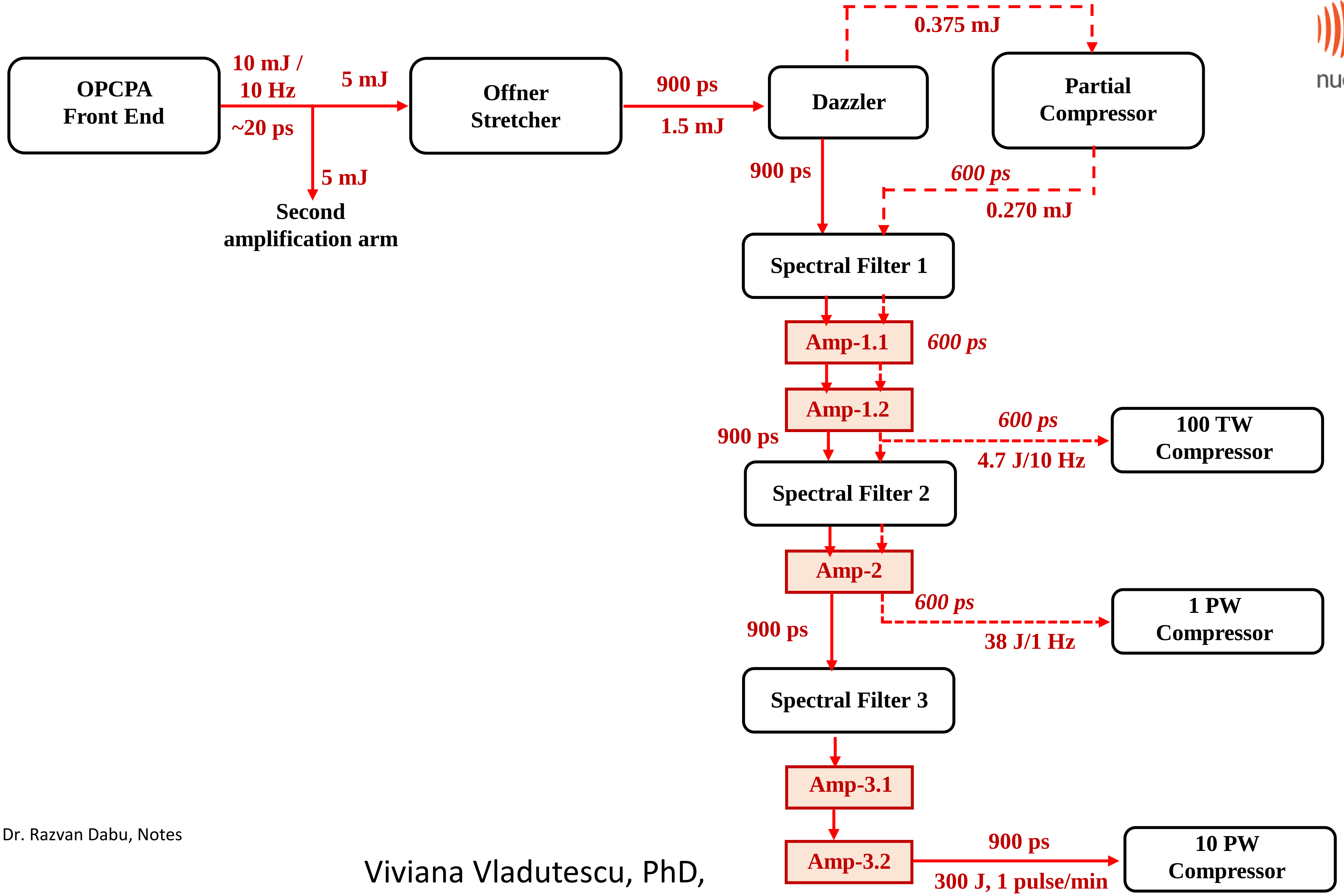
The optical telescope placed inside the pulse stretcher is needed in order to provide a "negative distance" between the gratings.



Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

High energy amplification



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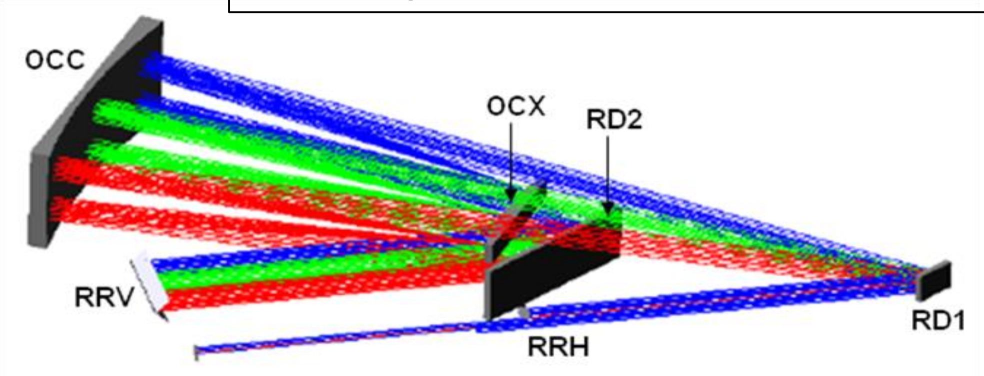
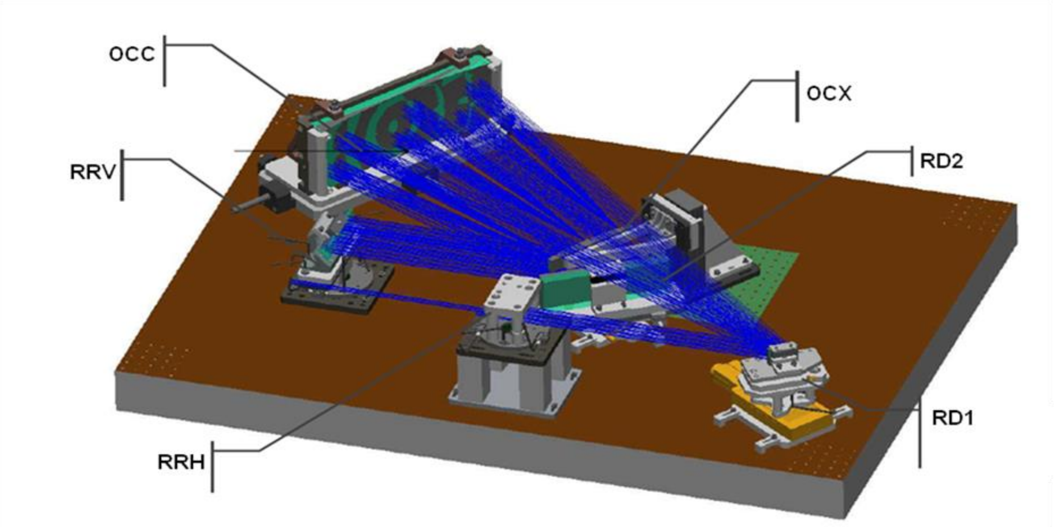
Offner stretcher with two parallel gratings.
10 PW HPLS stretcher

Large stretching ratio is required to get 900 ps pulse duration (about 14 ps/nm)
If a single grating stretcher is used, to get such a large stretching ratio, the grating has to be located far away from the Offner optical system center of curvature. This leads to high amounts of spherical aberrations and spatial chirp.
First grating, located at the center of curvature, spreads the whole spectrum without introducing spherical aberrations, because the Offner triplet is stigmatic for an object point located near the center of curvature. Optical aberrations are minimized.





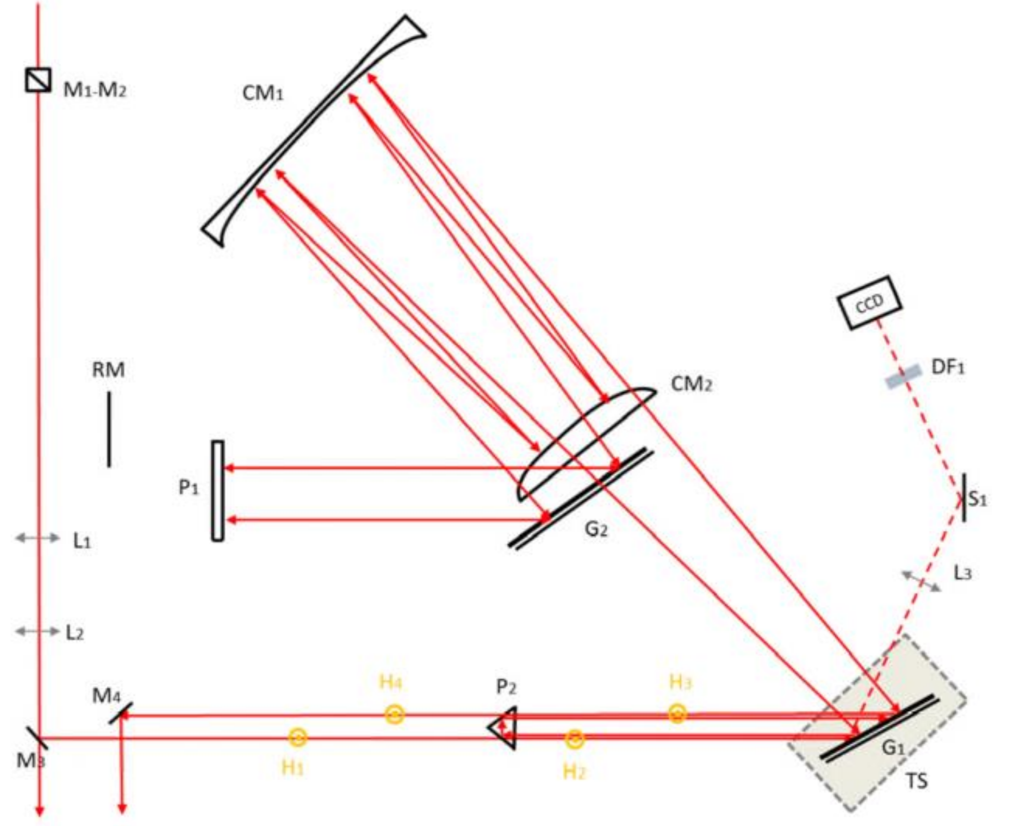


Figure 14 STRETCHER 10PW optical layout

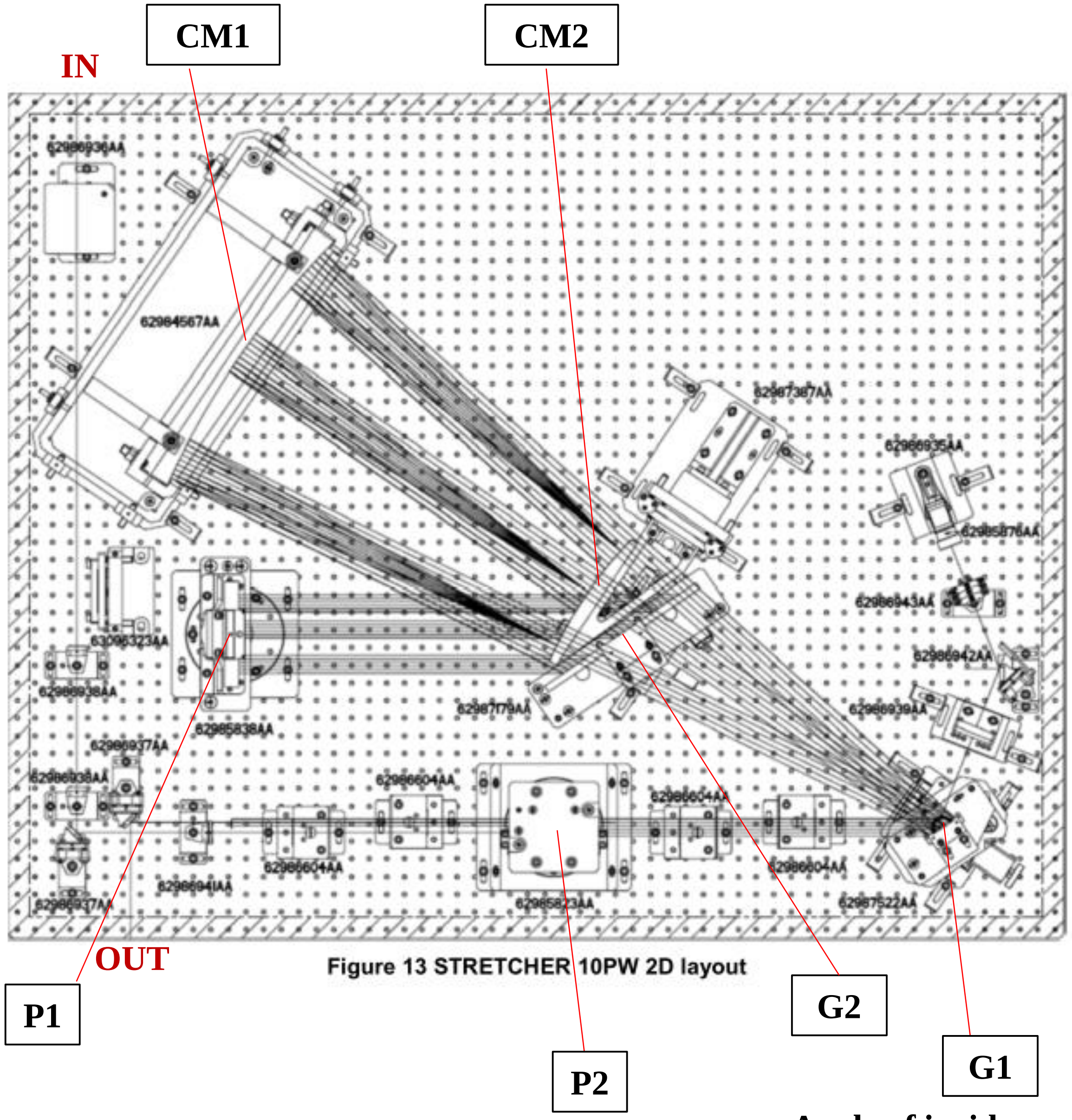
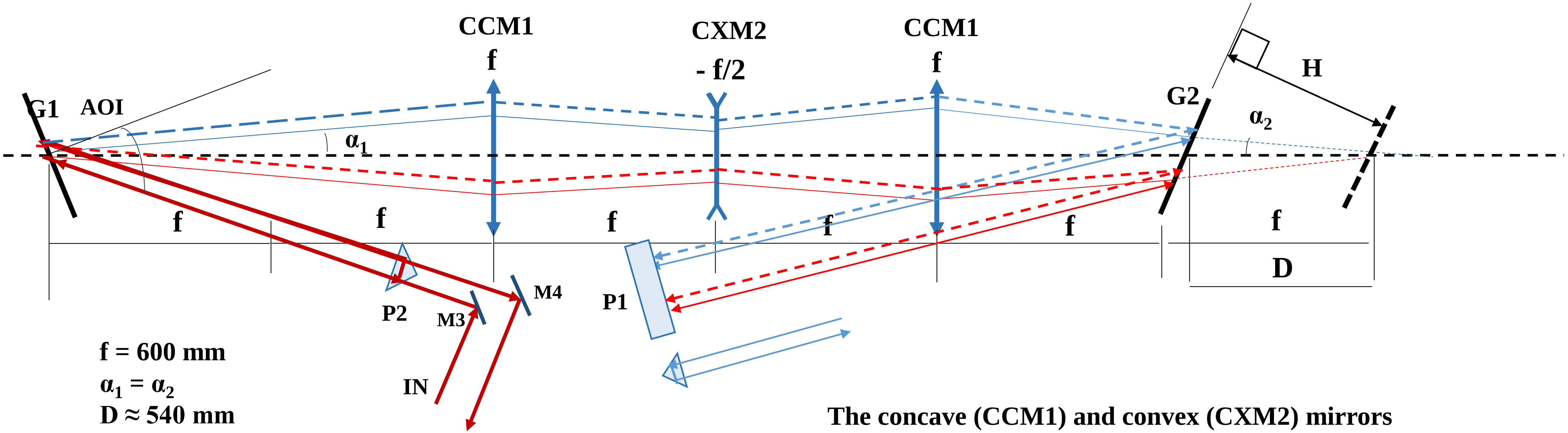


Figure 13 STRETCHER 10PW 2D layout

Angle of incidence: 54.7^0

Code	Part No.	Description	Qty.
Stretcher Function			
L2	62429704	LENS 700-900 F-100 D25	1
M1-M4	62984116	MIRROR 45^0 750-870 D25	4
CM1	62985242	MIRROR CONCAVE R1200	1
CM2	62985244	MIRROR CONVEXE R600	1
P1	62985352	PRISM D1	1
P2	62985353	PRISM D2	1
L1(*)	62987687	LENS 700-900 F+300 D25	1
	62987689	LENS 700-900 F+250 D25	1
WP1	6701858	HALF WAVEPLATE 800 D15	1
RM	91879941	Reference MIRROR	1
G1	91950510	Grating G1	1
G2	91950514	Grating G2	1
TS	91958993	TRANSLATION STAGE	1
Diagnostic Function			
S1	62535289	WEDGE 1.5'	1
D_L1	91957660	LENS 700-900 F+65 D50	1
DF1	91920615	FILTER	1
CCD	62985876	KIT CAMERA	1

Schematic drawing of the 10 PW stretcher



f = 600 mm
$\alpha_1 = \alpha_2$
D ≈ 540 mm
AOI = 54.7^0
N =1430 mm^{-1}

The concave (CCM1) and convex (CXM2) mirrors compose an afocal telescope system with 1 magnification

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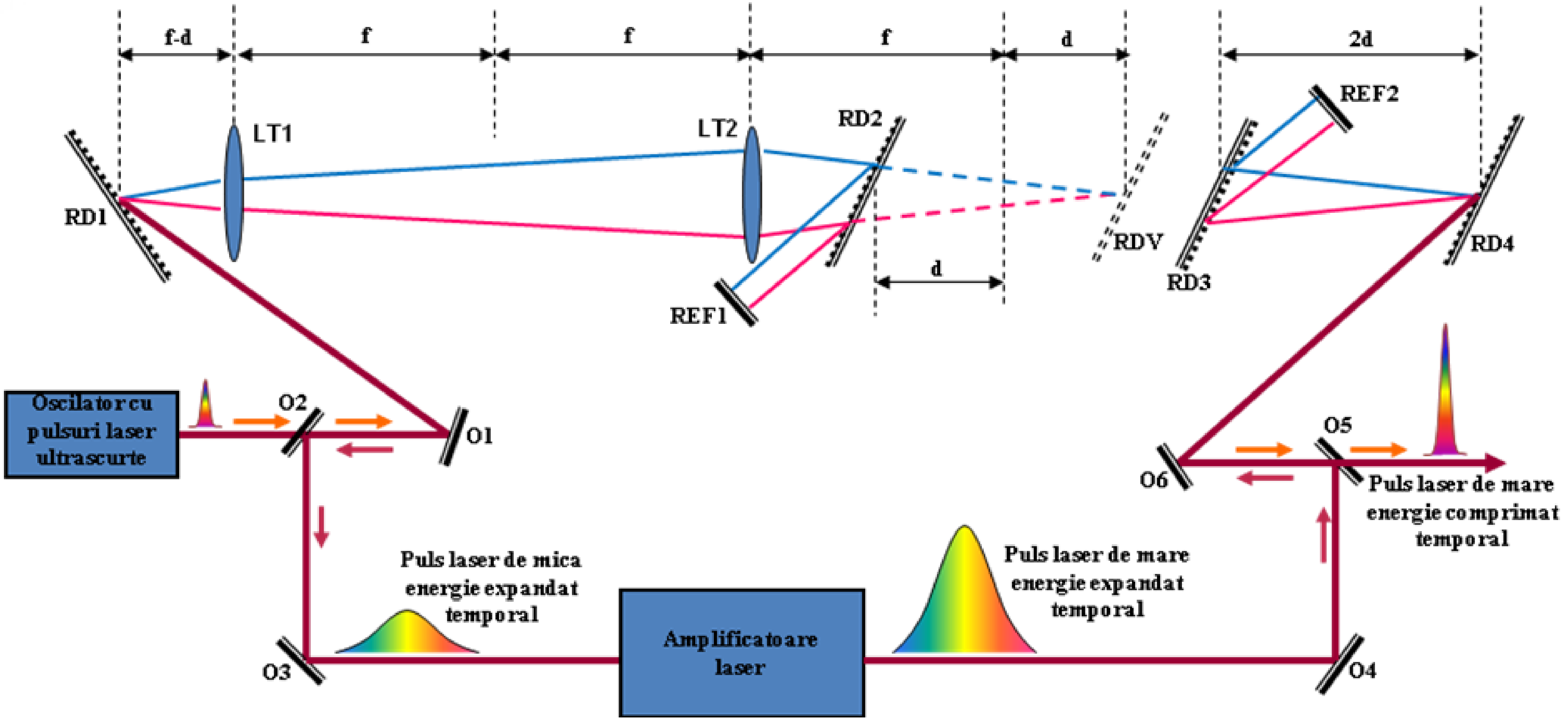
IEEE LICN, March 5th, 2020

Stretcher-Compressor
Spectral Phase Compensation



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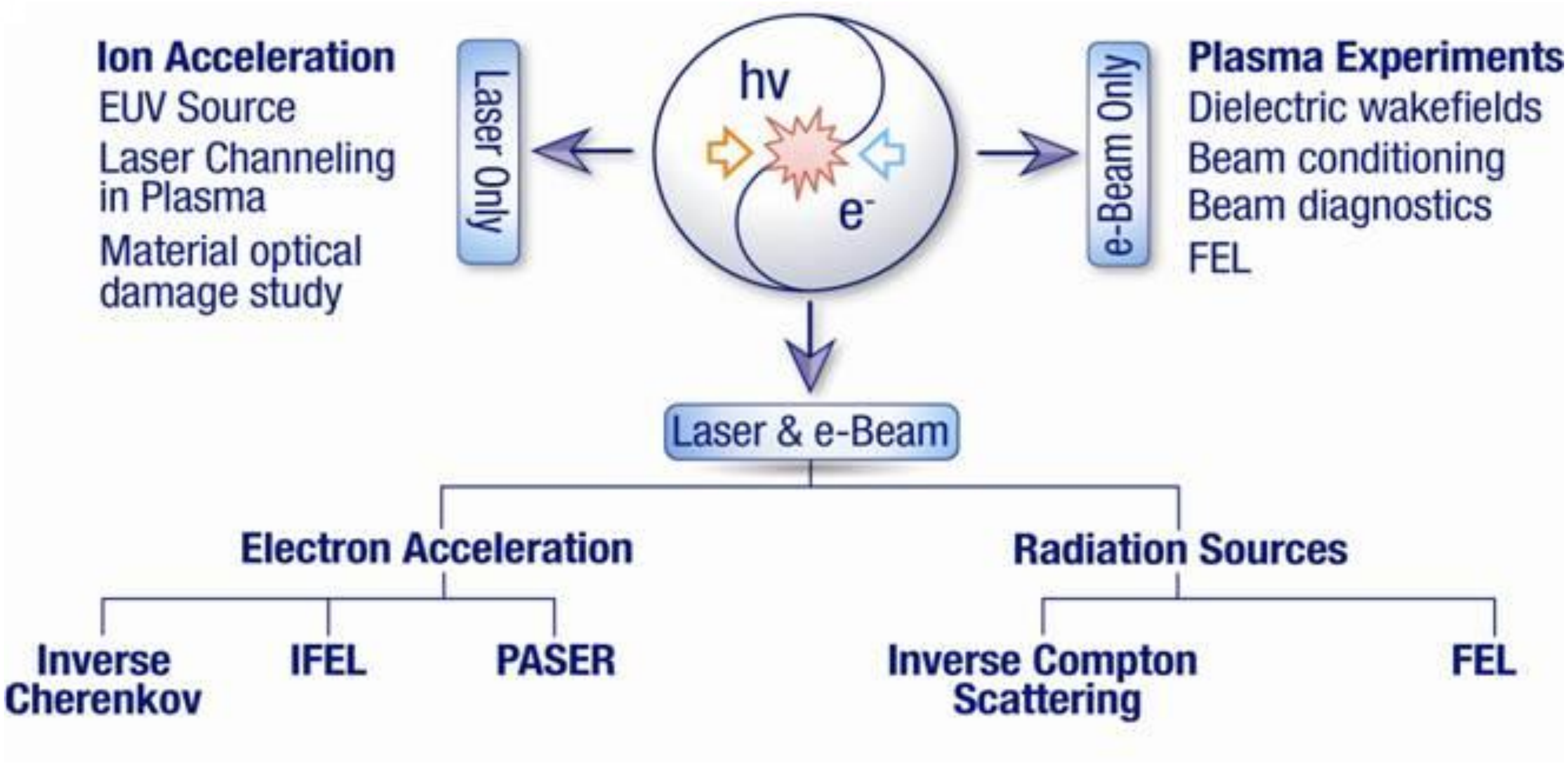
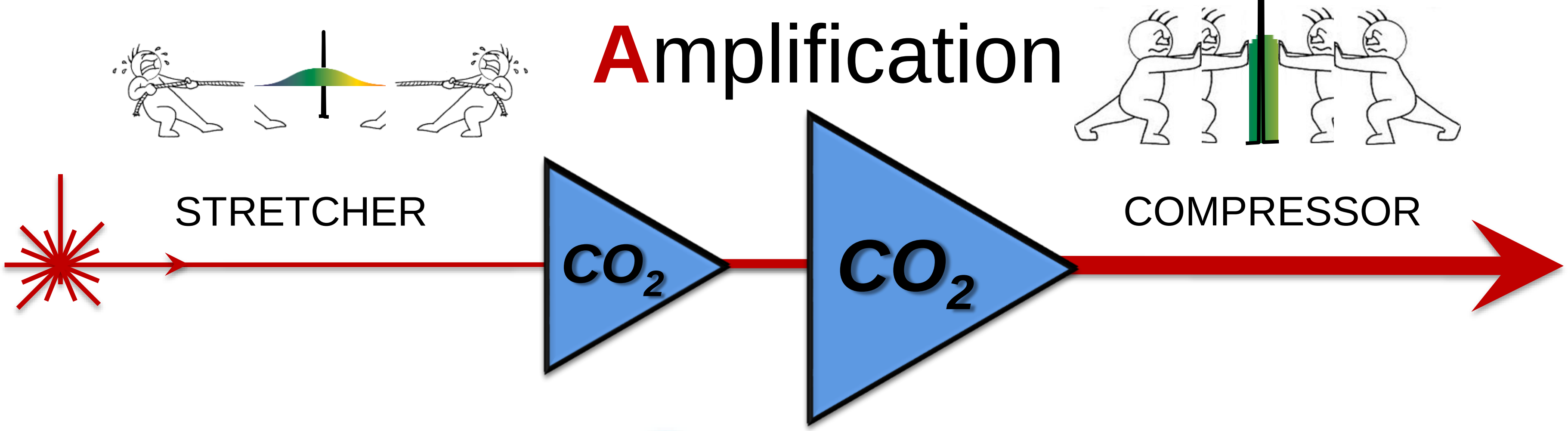
BNL ATF



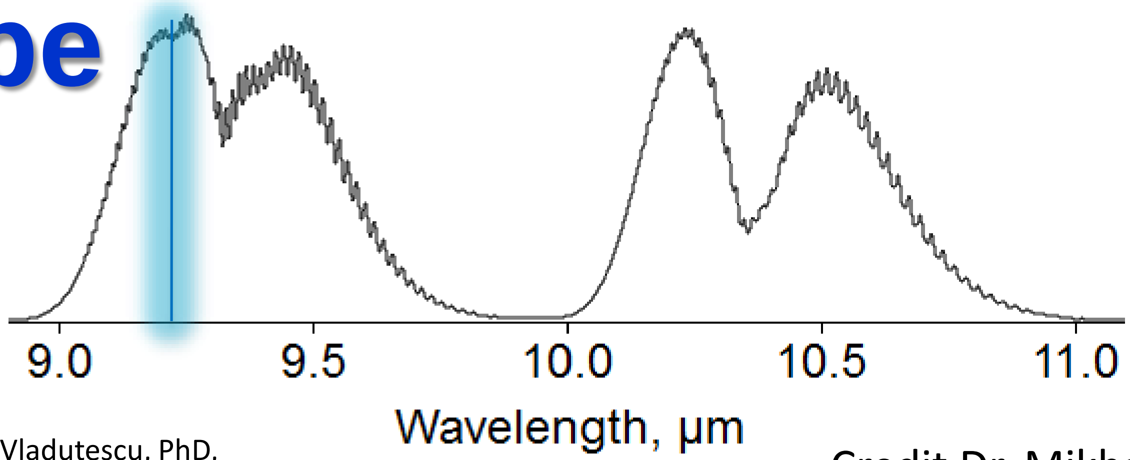
Ion Acceleration
EUV Source
Laser Channeling in Plasma
Material optical damage study
Laser Only
hv
e-
e-Beam Only
Plasma Experiments
Dielectric wakefields
Beam conditioning
Beam diagnostics
FEL
Laser & e-Beam
Electron Acceleration
Radiation Sources
Inverse Cherenkov
IFEL
PASER
Inverse Compton Scattering
FEL

ATF BNL UFHPL

Chirped
Pulse
Amplification



Mixed-isotope
active
medium



Credit Dr. Mikhail (Misha) Polyanski

10um UFHPL Applications

Military applications

- gas-sensing,
- chemical analysis,
- targeting and tracking,
- countermeasure systems.

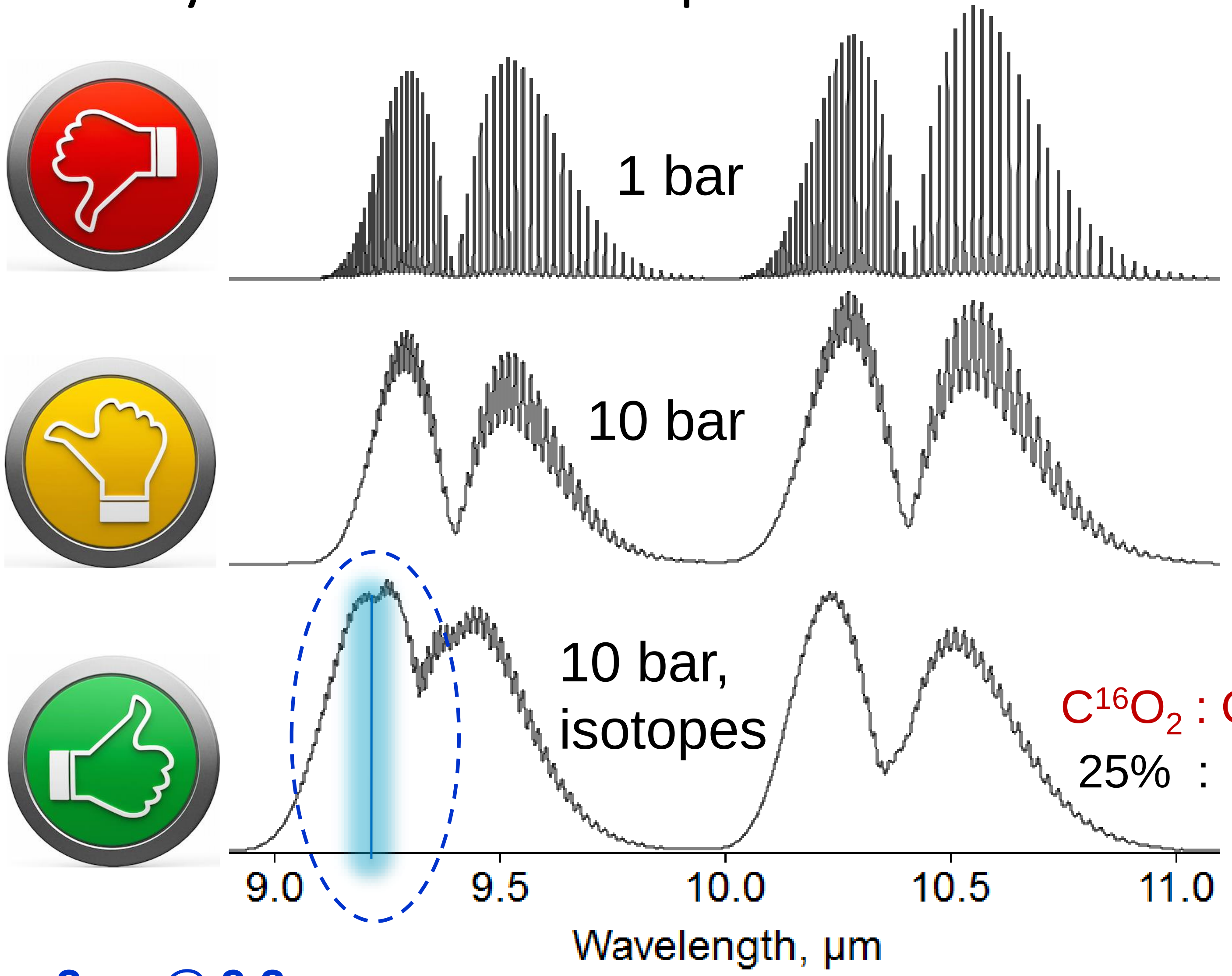
Industry & basic research.

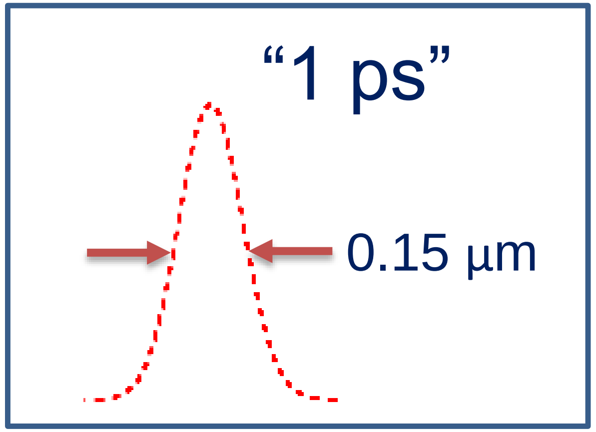
- high-resolution molecular spectroscopy, ultra-low loss optical fiber (fluoride-based glasses),
- communication,
- trace gas monitoring,
- air pollution analysis (since a variety of molecules, including all hydrocarbons have strong absorption lines in this band), medical diagnostics.

Most of the toxic chemicals included in the CAAA have strong absorption features in the 3.3- to 4.2-micron and 8- to 13.3-micron atmospheric window regions where absorption by water vapor and carbon dioxide is minimal

Grant W. et al, Optical Remote Measurement of Toxic Gases
https://www.tandfonline.com/doi/pdf/10.1080/10473289.1992.10466965

Why mixed-isotope active medium?





$C^{16}O_2 : C^{16}O^{18}O : C^{18}O_2$

25% : 50% : 25%

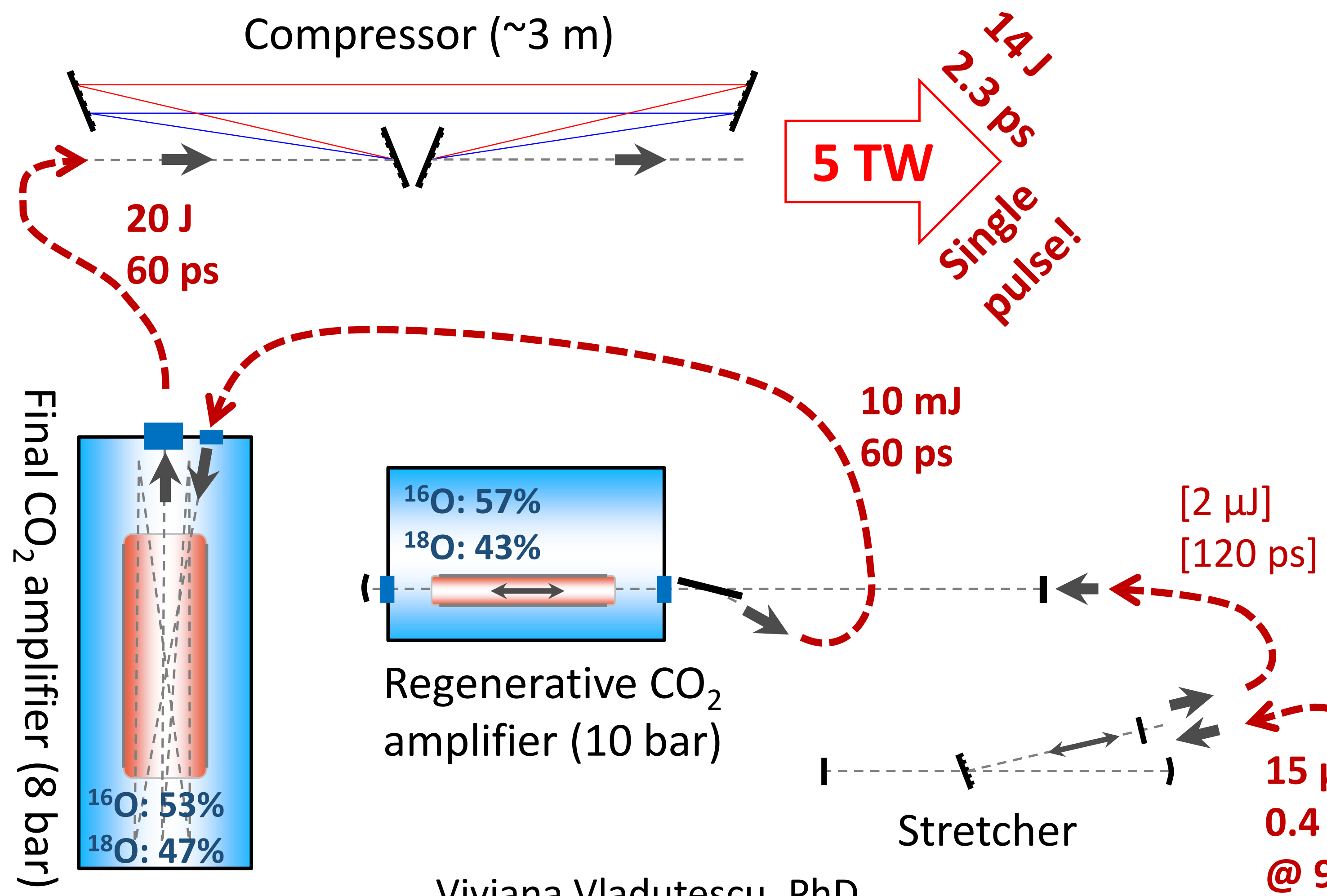
2 ps @ 9.2 µm

Credit Dr. Mikhail (Misha) Polyanski

Simulations: `co2amp`

Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

ATF's **5 TW** Long-Wave IR (**9.2 μm**) Laser



ATF's know-how

- First mixed-isotope picosecond CO_2 laser
- First gas laser with CPA
- Solid-state seed laser

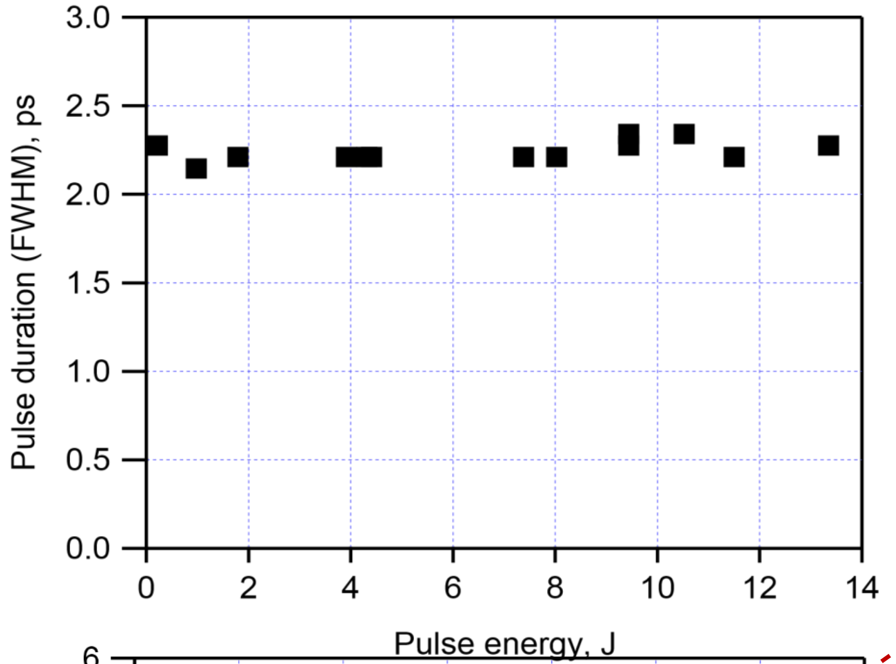
Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

Credit Dr. Mikhail (Misha) Polyanski

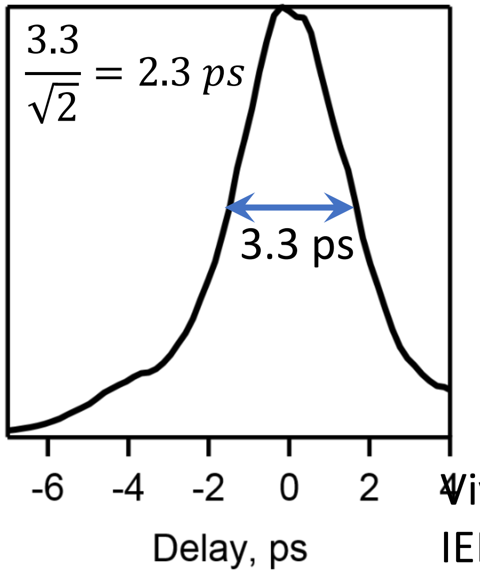
5 TW

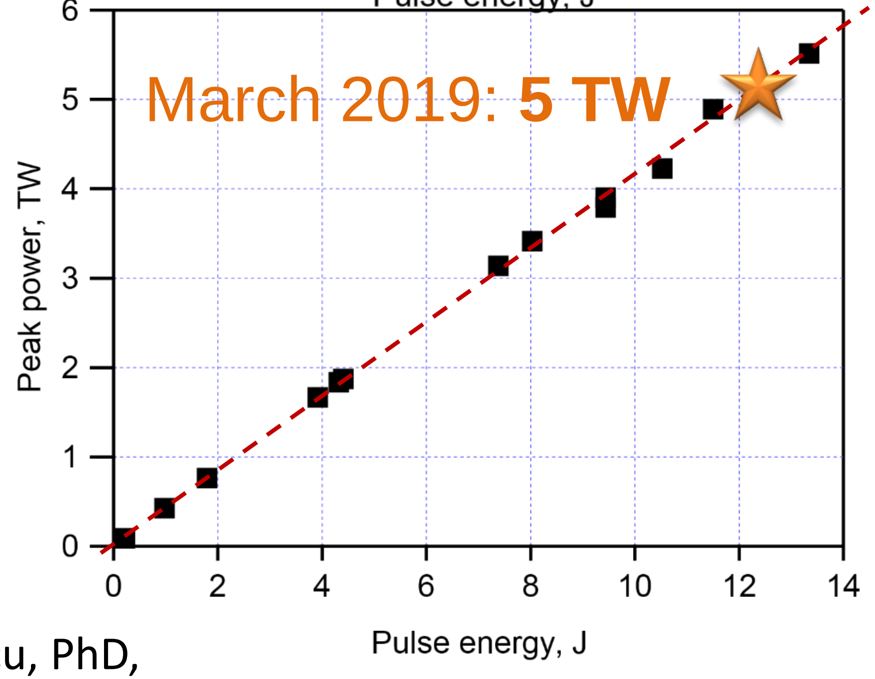
New compressor gratings

Line density:	75 → 100 lines/mm
Coating:	Al → Au
Blaze wavelength:	10.0 → 9.3 µm
Efficiency:	84 → 92 %
Efficiency (4x):	50 → 70 %
Damage threshold:	0.5 → 2 J/cm^2



Autocorrelation (single-shot)



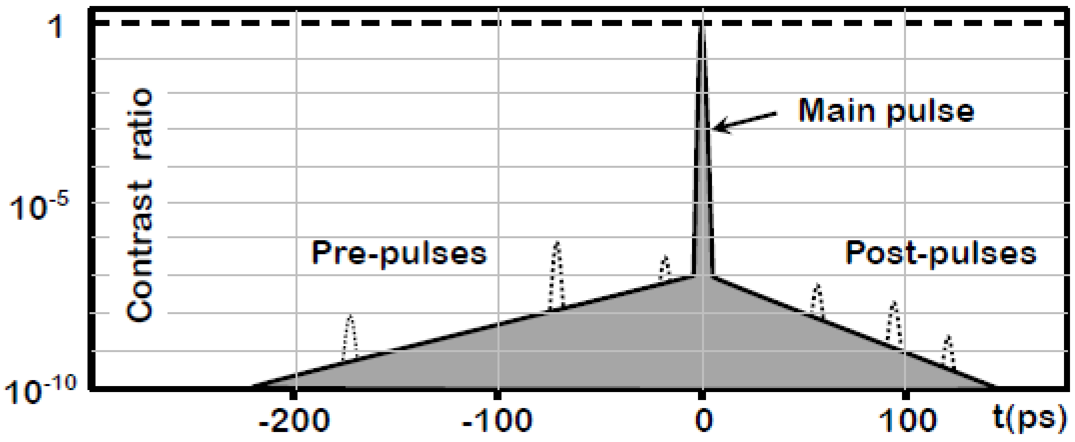


Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

Credit Dr. Mikhail (Misha) Polyanski

Beam Parameters
Laser Contrast Ratio

The ***spatial contrast*** — the ratio of intensity at the laser focus to the intensity outside of the focus — is a standard concept intuitively known to everyone from everyday life.

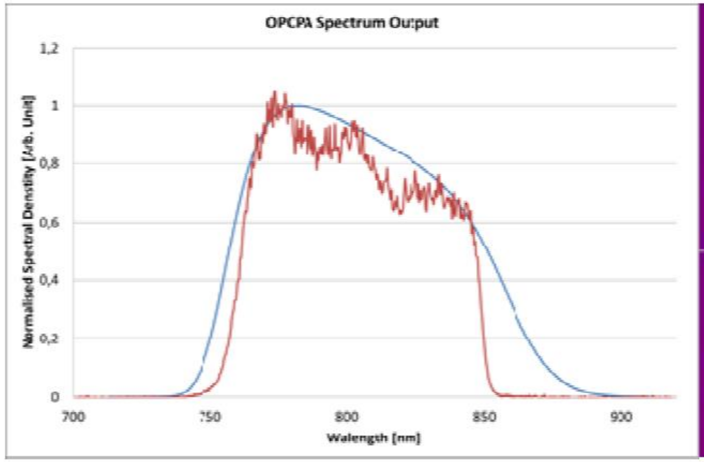


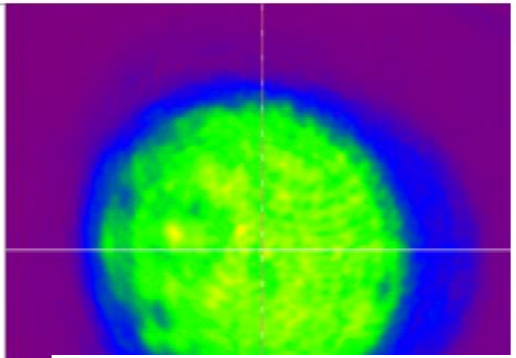
For CPA-compressed pulses, which involve manipulations and exchanges between energy and longitudinal phase space coordinates, it is appropriate to introduce the notion of the temporal ***contrast ratio*** — a function of time given by the ratio of the peak laser intensity to the intensity in the front or back of the pulse.

Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

Beam Metrology

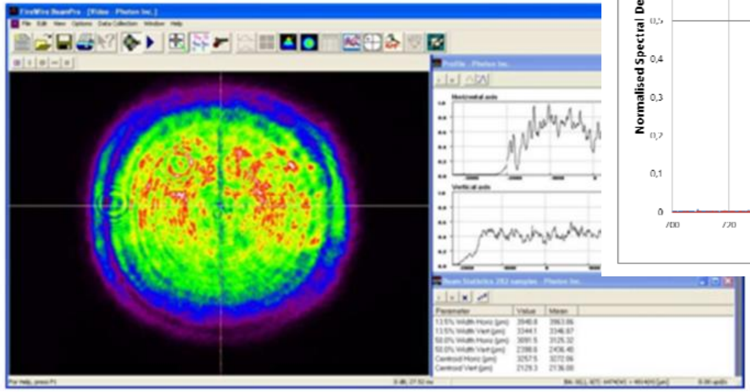
OPCPA Spectrum and Intensity Profile

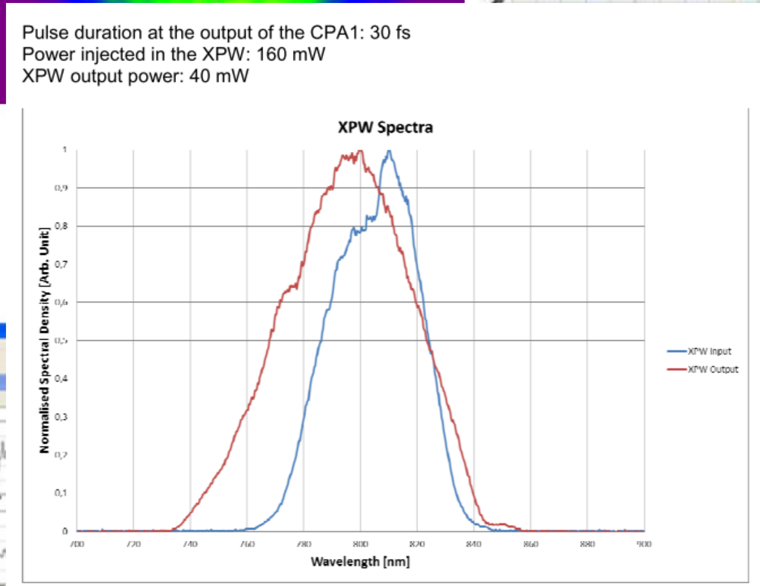




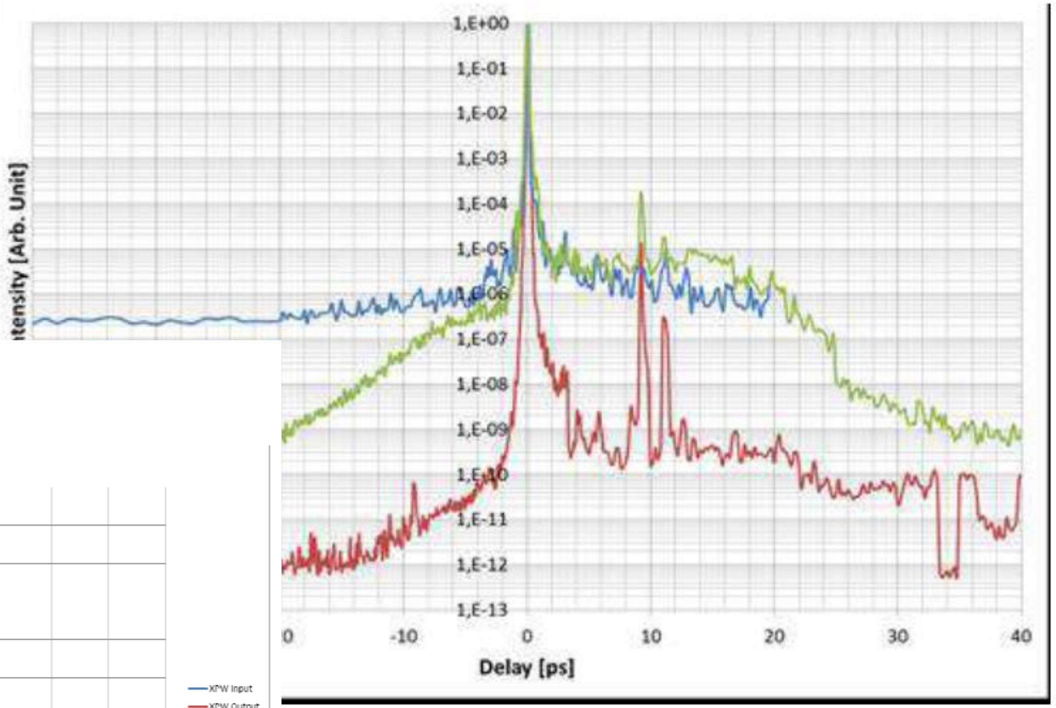
Pump Laser

- **Beam profile Super-gaussian**
- **Energy 80mJ**
- **Pulse duration 25ps**



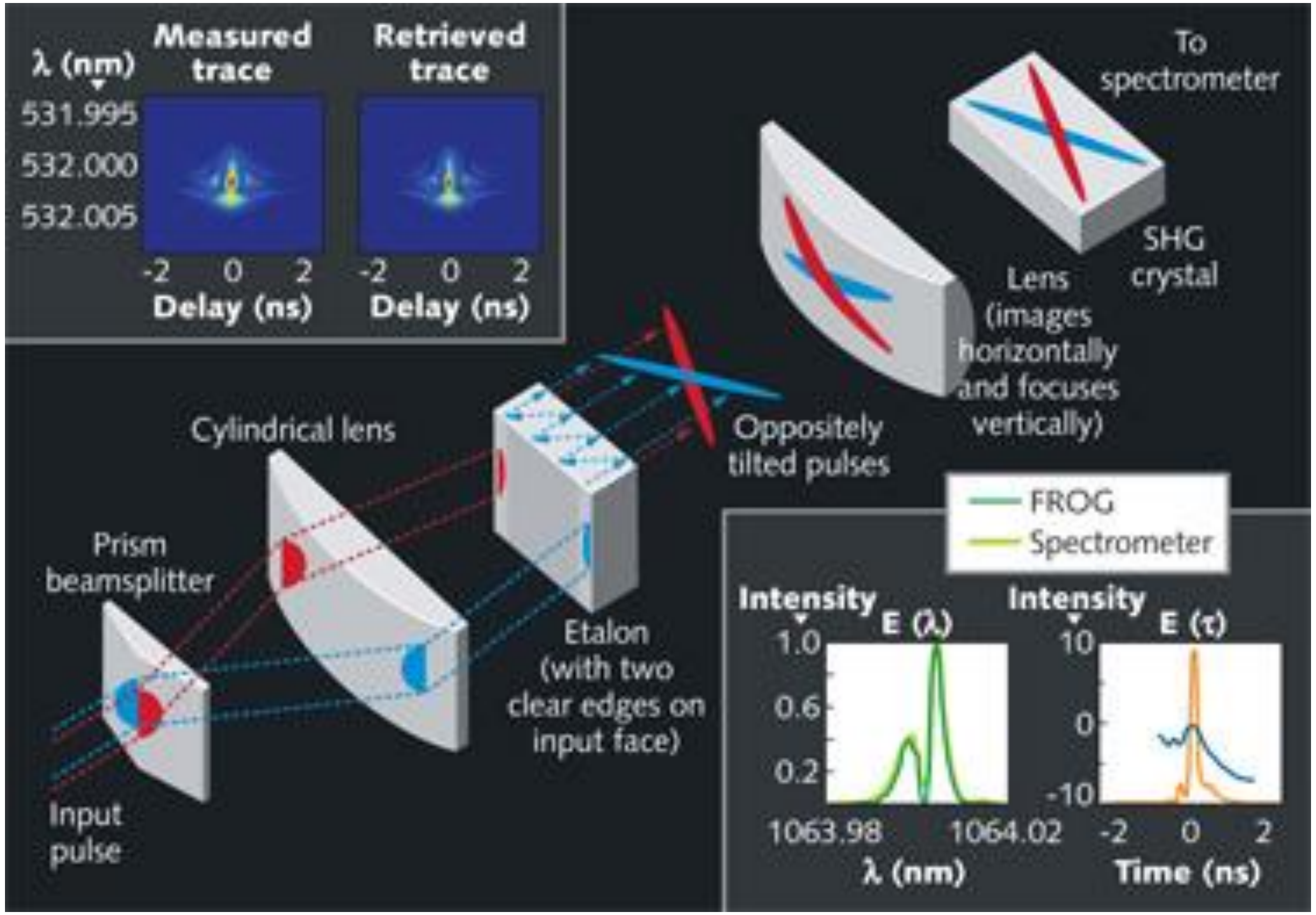


Intensity Contrast of the Front End



ontrast recorded with the Ti:Sapphire stage alone.
he contrast recorded with the Ti:Sapphire stage and the OPCPA stage
ent of the contrast of more than three orders of magnitude is obtained
lse duration.
contrast measurement of the full Front End system which is clearly limited
rement tool.

Laser Beam Metrology



A technique called autocorrelation emerged, involving splitting the pulse into two replicas, variably delaying one, overlapping them in a nonlinear-optical medium, and measuring the generated nonlinear-optical pulse energy vs. delay.

https://www.laserfocusworld.com/articles/print/volume-50/issue-01/features/ultrafast-pulse-characterization-from-femtosecond-to-nanosecond-laser-pulse-measurement-is-all-about-the-single-shot.html

Schwinger Intensity Limit

- A laser of high enough intensity can generate *e+e-* pairs from a vacuum. According to the time-energy uncertainty principle $\Delta E\,\Delta t \geq \frac{\hbar}{2}$ a virtual *e+e-* pair (thus $\Delta E \sim m_e c^2$) can appear for a short duration of time $\Delta t \sim \hbar/(m_e c^2)$
- If an electric field E_S acting on the pair during Δt increases the momentum of *e+* or *e-* by about *mc* (i.e. $\Delta t \cdot e E_S \sim mc$), the particles then become real and thus materialize from the vacuum thanks to the laser field.
- The corresponding laser field (ignoring factors of two in the estimations) is hence given by $$E_S = \frac{m_e^2 c^3}{e\hbar} \approx 1.3 \cdot 10^{18} \ \ \mathrm{V/m}$$
- and is called a *Schwinger limit* field — the scale above which the linear electrodynamics become invalid. The corresponding laser intensity is $$I_S \approx 2 \cdot 10^{29} \ \ \mathrm{W/cm^2}$$

Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

BROOKHAVEN NATIONAL LABORATORY

Accelerator Test Facility

U.S. DEPARTMENT OF ENERGY

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A user facility for advanced accelerator research

The Accelerator Test Facility (ATF) is a proposal driven, Program Advisory Committee reviewed facility that provides users with high-brightness electron- and laser-beams. The ATF pioneered the concept of a user facility studying properties of modern accelerators and new techniques of particle acceleration over 25 years ago. It remains a valuable resource to the user community. ATF serves the U.S. Dept. of Energy Accelerator Stewardship program.

Contact Us

Electron/Laser Facility

High-brightness, 80 MeV, sub-picosecond, 3 kA electron bunches are being delivered to the experimental hall where user experiments are parked in three beam lines. The experiment beam lines are fully equipped with beam manipulation and diagnostic and special insertion devices to support diverse user requirements. The ATF unique capabilities include the possibility to combine the electron beam with synchronized high-power CO_2 laser.

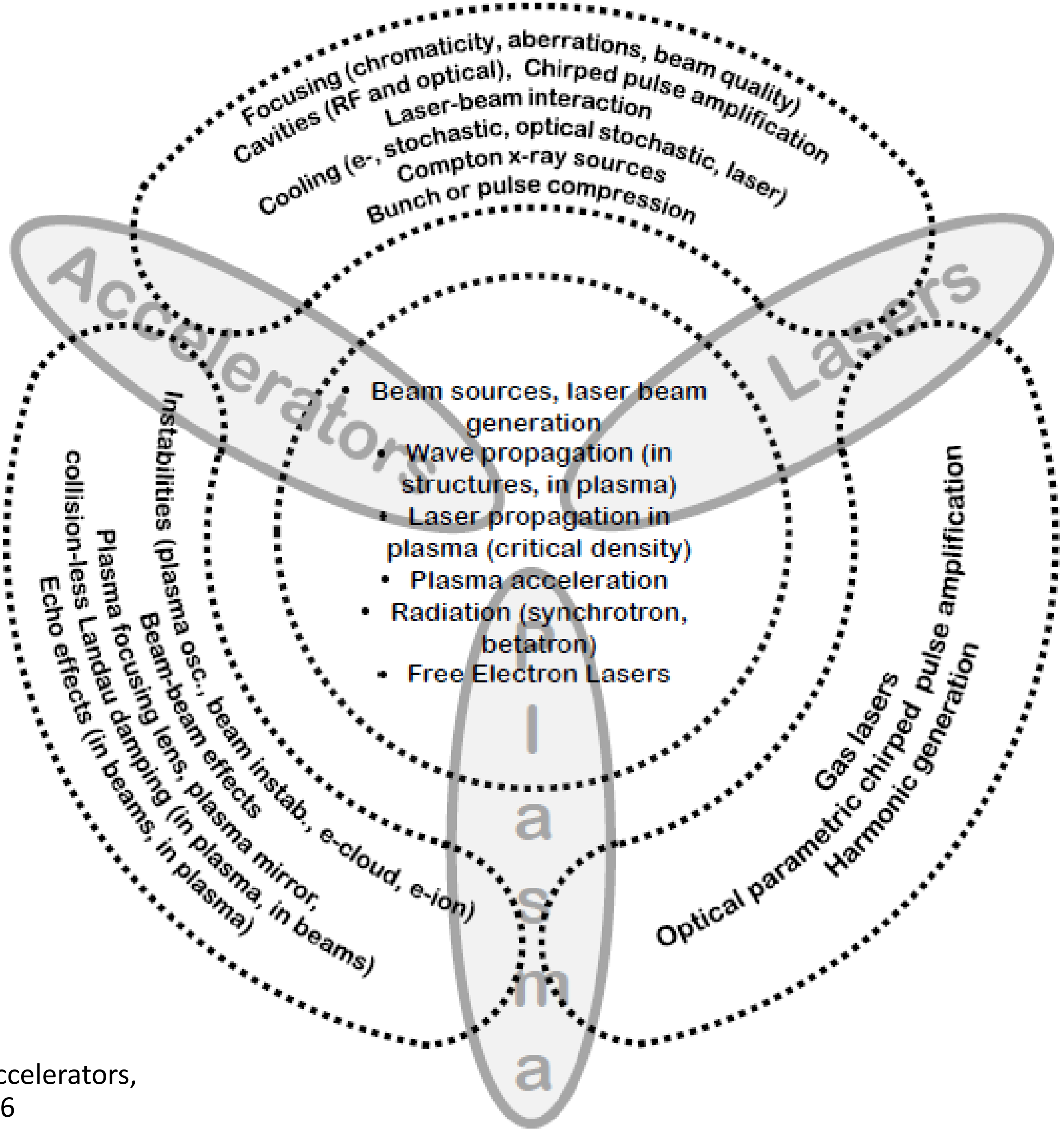
CO_2 Laser

ATF's one-terawatt, picosecond, IR (10 μm) carbon dioxide laser is unique in the world. With it, the ATF users explore long-wavelength scaling of various physical processes and new approaches to particle acceleration and x-ray generation. A next-generation ultra-fast CO_2 laser based on chirped pulse amplification in isotopic gas mixtures is under construction. This laser will open the long-wavelength spectral domain to exploring strong-field phenomena at a_0=10.

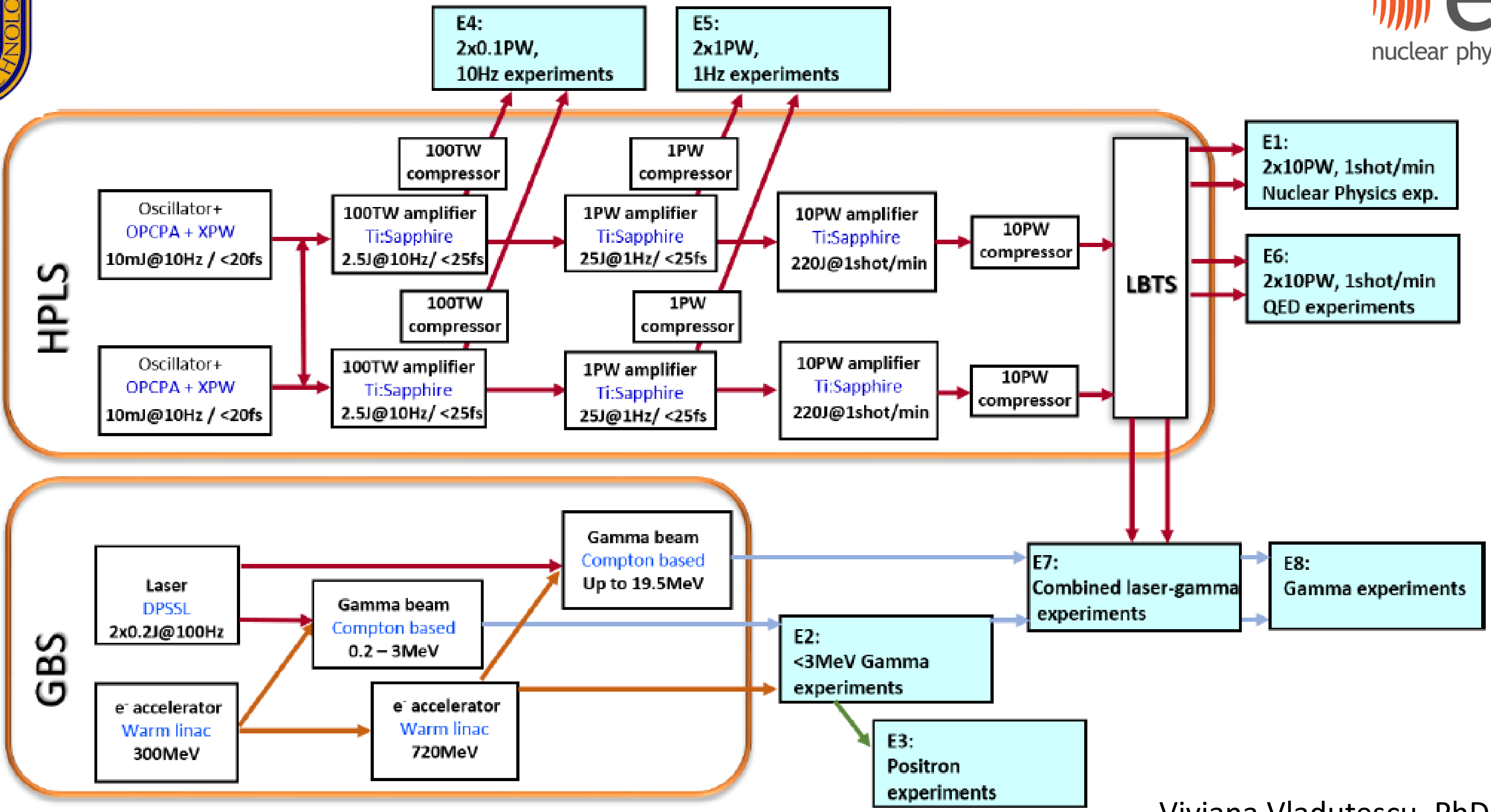
News & Announcements

- 22nd ATF Users Meeting - December 3-5, 2019
- ATF Science Planning Workshop 2019
- In Memory of Christina Swinson-Cruz
- Meet the Director: Mark Palmer, Accelerator Test Facility
- 21st ATF Users Meeting - November 14 - 16, 2018
- ATF Scientific Needs Workshop Report - November 2017

eli nuclear physics



Andrei Seryi, “Unifying Physics of Accelerators, Lasers and Plasma”, CRC Press, 2016



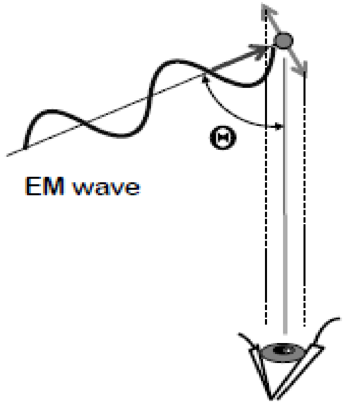
S.Gales et al., The Extreme Light Infrastructure Nuclear Physics (ELI-NP) Facility: New Horizons in Physics with 10-PW ultra-intense Lasers and 20-MeV brilliant Gamma beams, March 2019

Thomson scattering

The elastic scattering of an electromagnetic plane wave by an electron at rest (or low energy *E*) with mass m_e and charge *q*, is a process known as *Thomson scattering*.

The total cross section of a classical Thomson scattering is given by the following equation:

$$\sigma_{Th} = \frac{8\pi}{3} r_e^2 \approx 0.665 \cdot 10^{-28}\ [m^2]$$



And the differential cross section, is equal to $$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_e^2 \left(1 + \cos^2\theta\right)$$

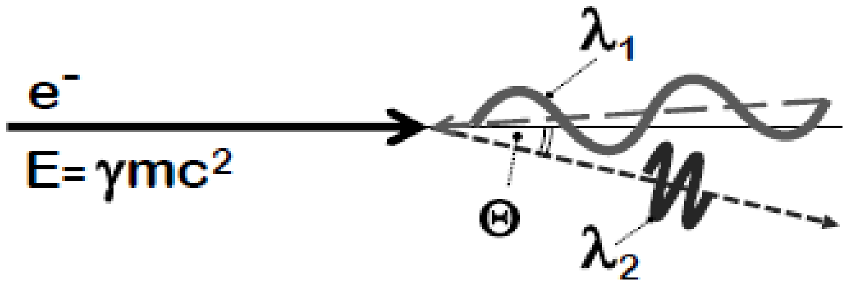
Thomson scattering is an approximation of an elastic process— the energies of the particle and photon are the same before and after the scattering (i.e., the recoil of the electron can be neglected, in contrast to the Compton scattering).

Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

Compton scattering

Compton scattering describes the inelastic process where we can no longer neglect the transfer of energy between the particle and the photon.

We are, in particular, interested in the instance when a collision between a high-energy electron and a low-energy photon results in a substantial fraction of the electron energy being transferred to the photon.



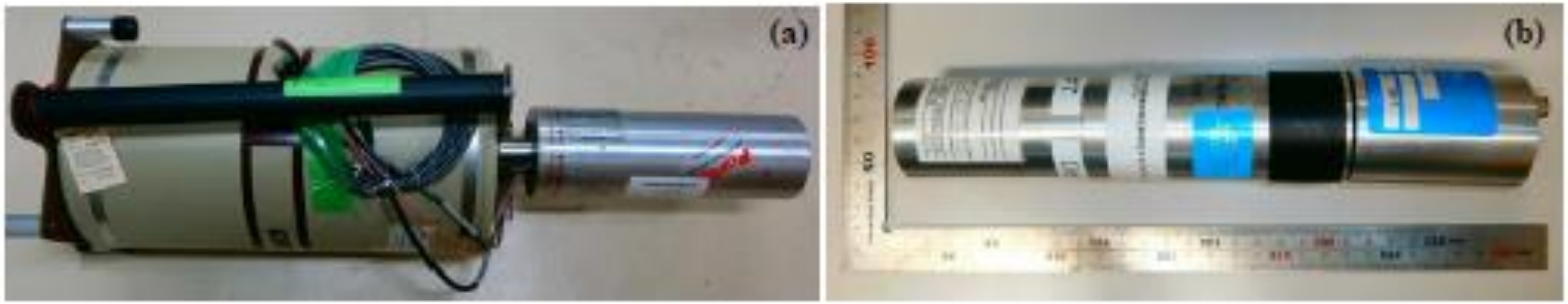
$$\lambda_2 = \lambda_1 \left(1 + \theta^2\gamma^2\right) / \left(4\gamma^2\right)$$

In the laboratory reference frame, this manifests as backscattering of the photon with a significant energy boost; this process is known as *Compton backscattering* (or inverse Compton scattering), as illustrated

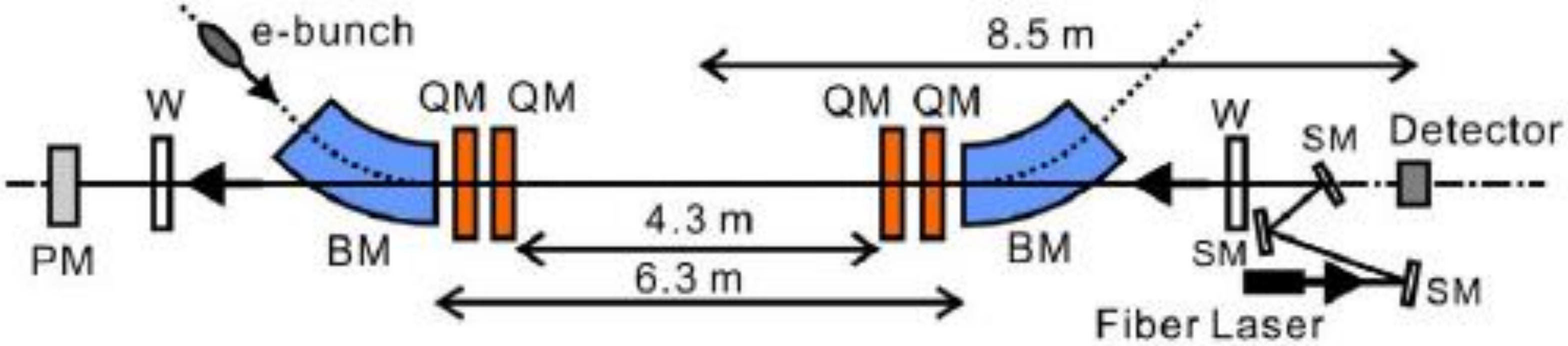
Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020

Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

Gamma beam generation and detection



HPGe Detector and $LaBr_3$(Ce) Scintillation Detector



Schematic Diagram of Experimental Geometry
QM: Quadrupole Magnet in Storage Ring, BM: Bending Magnet in Storage Ring,
W: Quartz Window, SM: Silver Mirror, PM : Laser Power Meter

Heishun Zen et al, Generation of High Energy Gamma-ray by Laser Compton Scattering of 1.94-µm Fiber Laser in UVSOR-III Electron Storage Ring, Energy Procedia, Volume 89, June 2016, Pages 335-345, https://doi.org/10.1016/j.egypro.2016.05.044

Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

GBS Applications

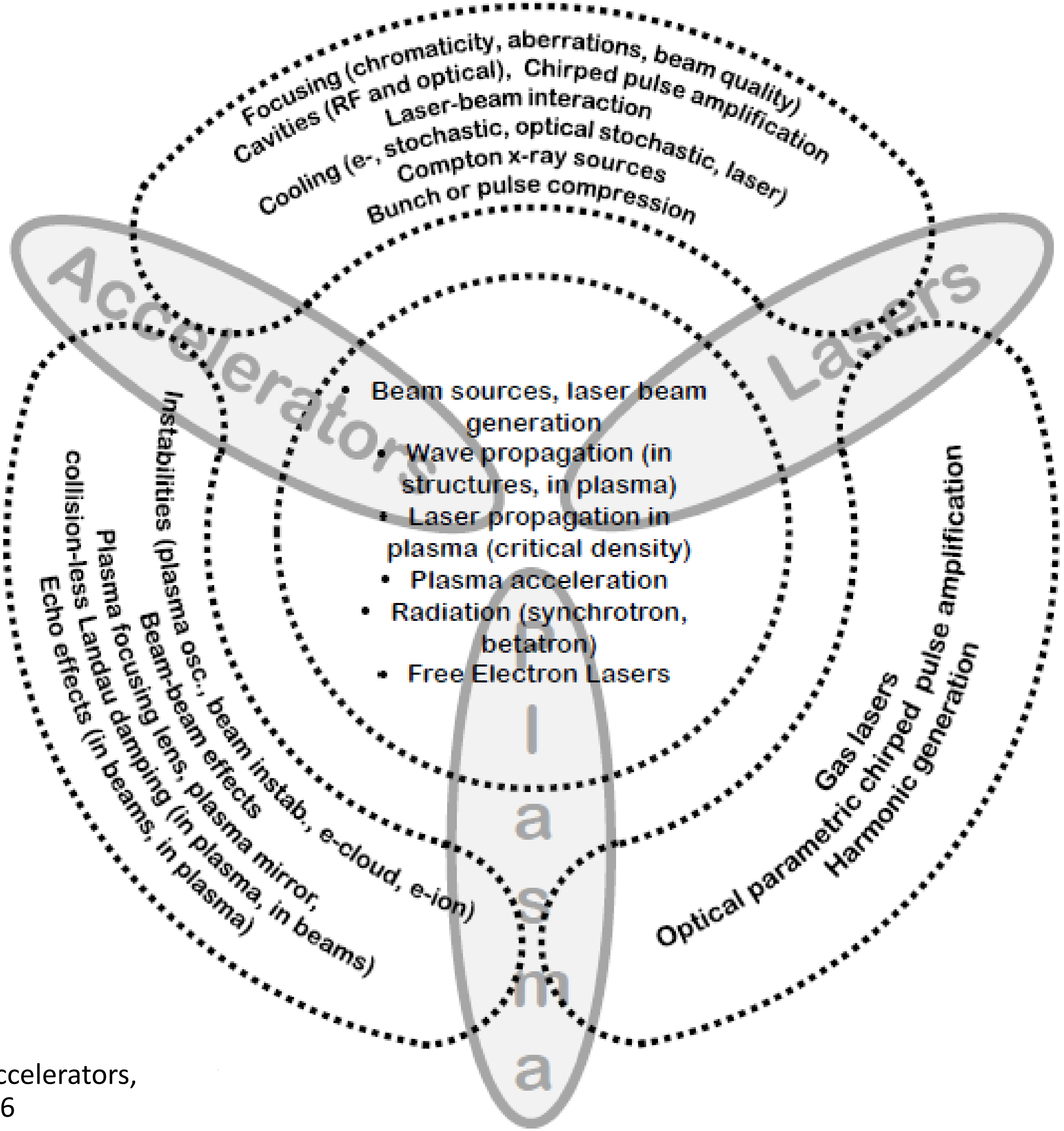
- fundamental physics of perturbative and non-perturbative high-field quantum electrodynamics,
- high-resolution nuclear spectroscopy and astrophysics of the r-, sand p-processes in nucleosynthesis.
- photonuclear reactions related to nuclear astrophysics, as well as to photofission studies.

The new extremely performing γ beam opens new possibilities for high resolution spectroscopy at higher nuclear excitation energies. They will lead to a better understanding of nuclear structure at higher excitation energies with many doorway states, their damping widths, and chaotic behavior, but also new fluctuating properties in the time and energy domain.

- The detailed investigation of the pygmy dipole resonance above and below the particle threshold is essential for nucleosynthesis in astrophysics.

GBS Applications

- developing Nuclear Resonance Fluorescence (NRF) for nuclear materials and radioactive waste management, brilliant gamma, X-ray, neutron, positron and electron microbeams in material and life science, and techniques of laser acceleration and of a brilliant gamma beam.
- new production schemes of medical isotopes (e.g., 99Mo – currently used in therapies, 195mPt – nuclear imaging to determine efficiency of chemotherapy, 117mSn – emitter of low energy Auger electrons for tumor therapy) via (γ,n) processes are also among the proposed areas of study of ELI-NP.
- investigation of new methods to produce thermal neutrons, through photonuclear reactions (γ,n). These will be used in the study of bio-proteins, nanocomposites, fullerenes, and magnetic materials, to name a few.
- creation of an intense positron source by means of the (γ,e+ e -) reaction, very useful in materials science.



Andrei Seryi, "Unifying Physics of Accelerators, Lasers and Plasma", CRC Press, 2016

END

Viviana Vladutescu, PhD,
IEEE LICN, March 5th, 2020