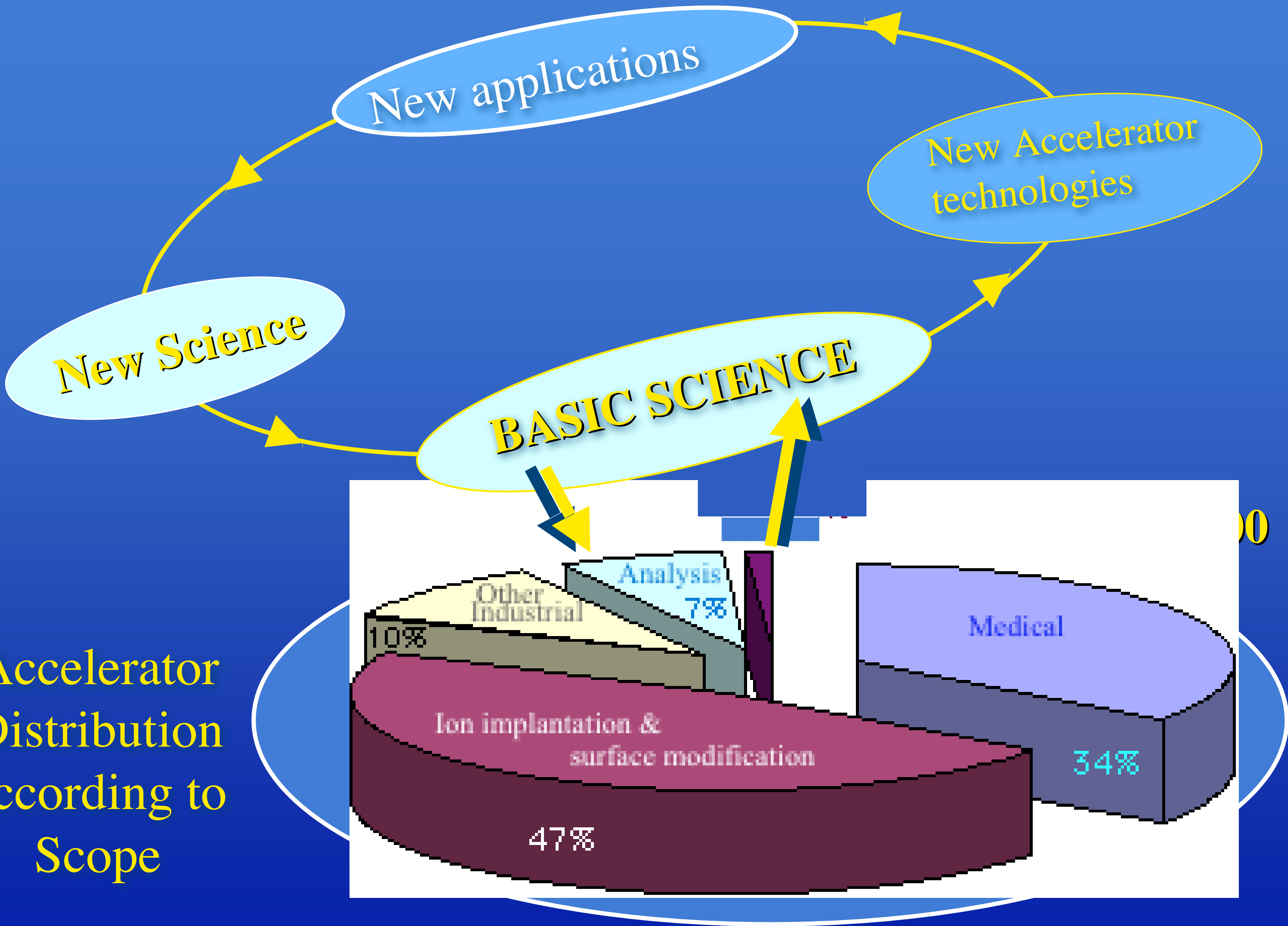
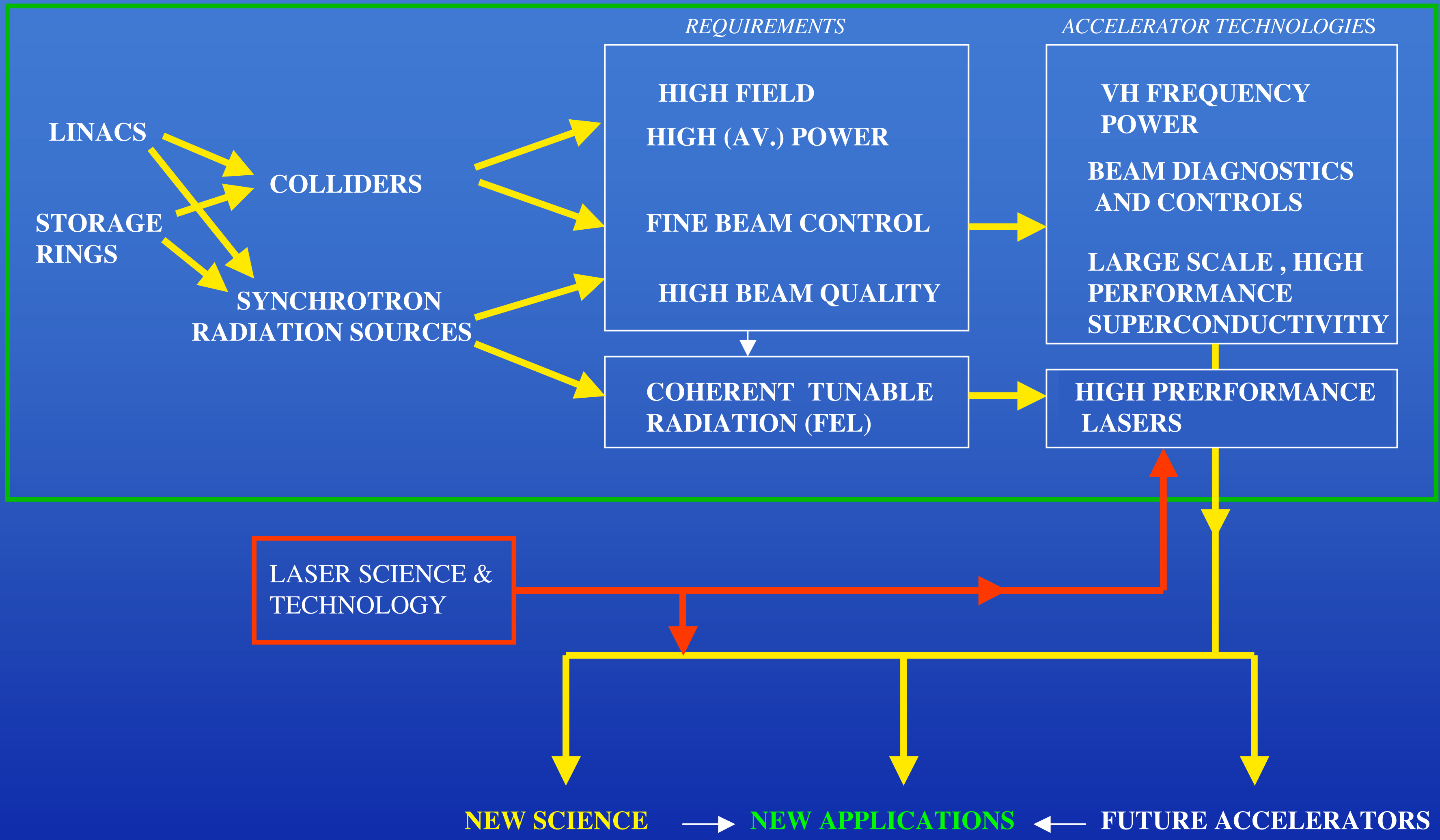


Accelerator Distribution according to Scope

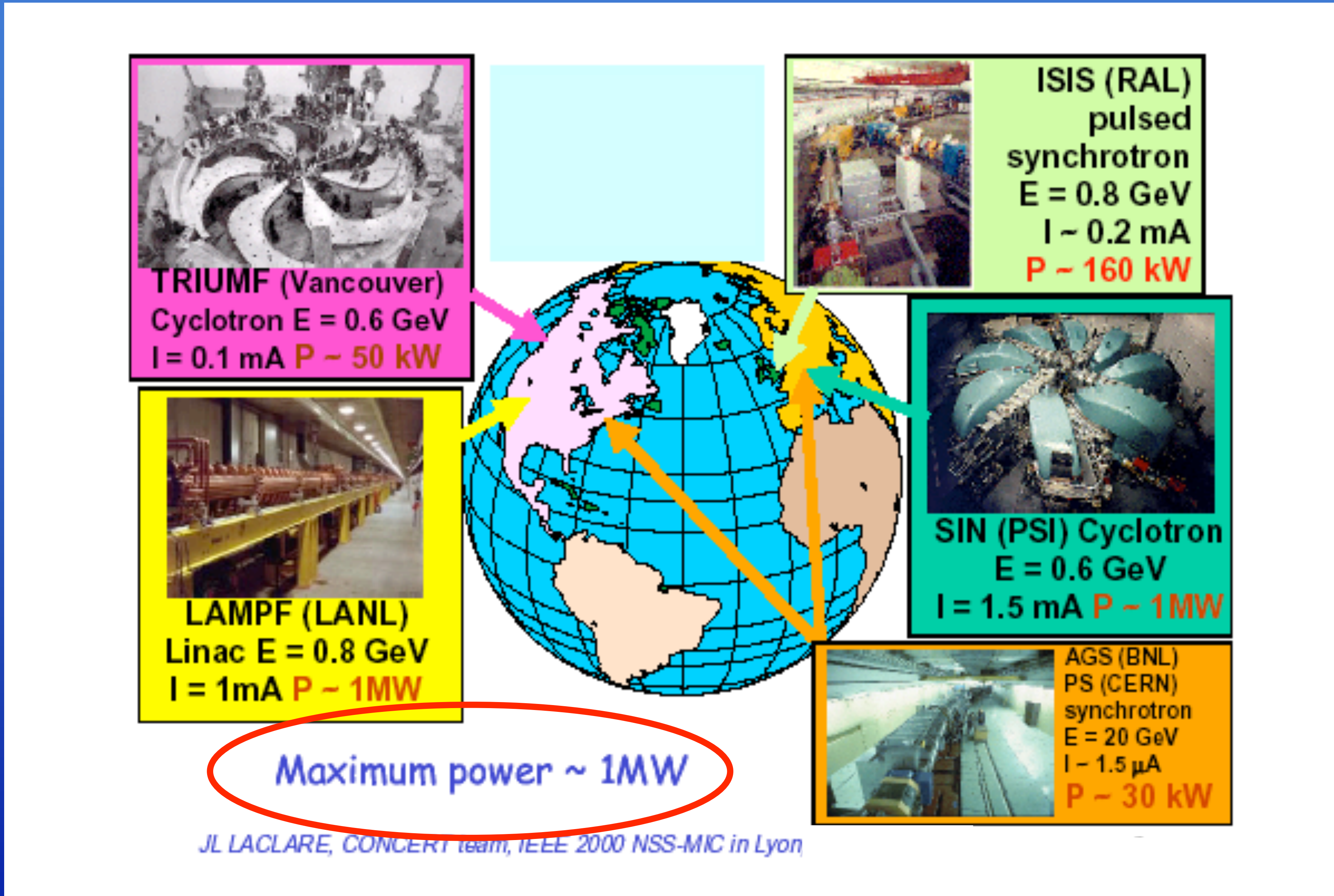
Simplified genealogy



High Average Power
(MW)
Hadron Beams

APPLICATIONS

Present Generation of HP Hadron Accelerators



Main technology advances exploited for High Power Hadron Beams

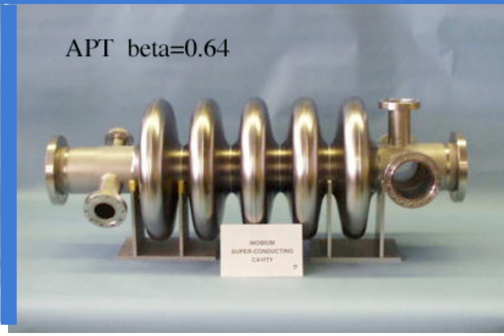
- **Superconductivity:**
  RF cavities : low β , **reliability** of large **high field** systems as tested in HE installations, optimization of warm-cold cavity mix

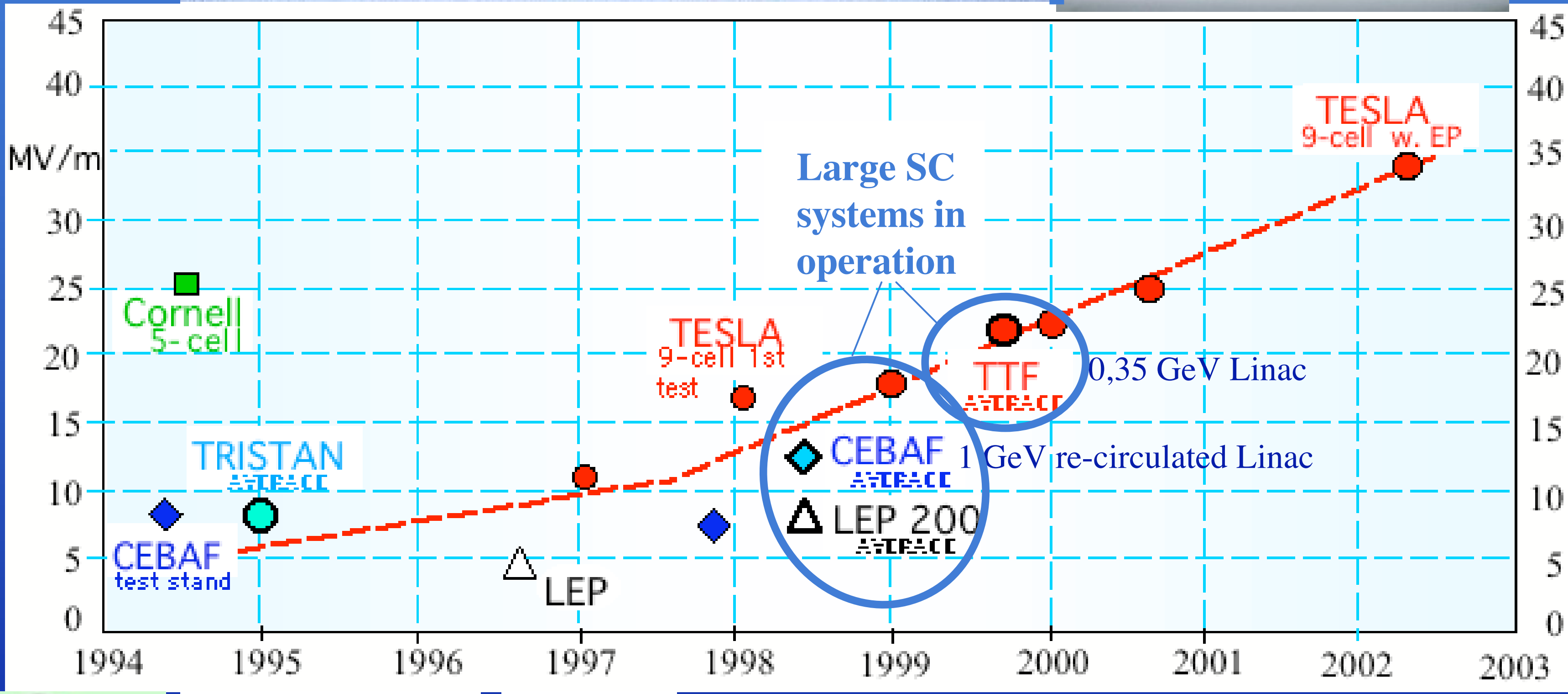
  RF Power Generators : HP, HF components (Klystrons..) developed and tested for Colliders

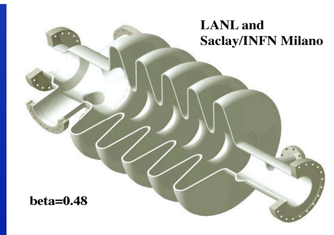
  RFQs : low β, high efficiency and brightness **SC** preinjectors (first prototypes under test)

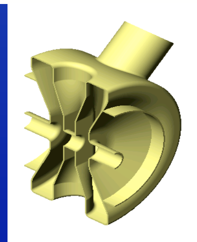
- **ION Sources**: high current, high brightness

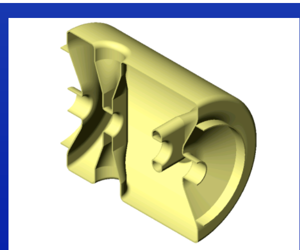
Progress in SC RF gradient

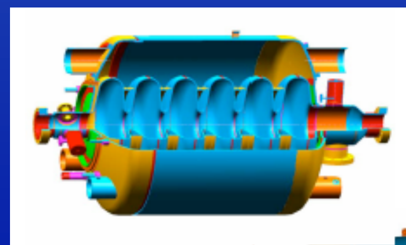






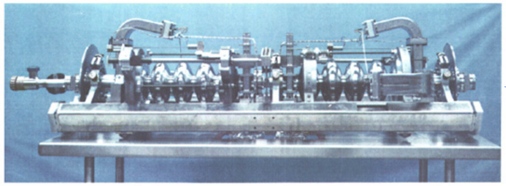


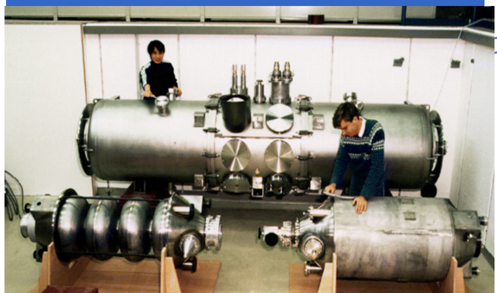


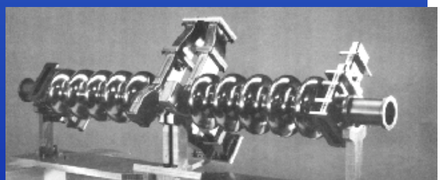


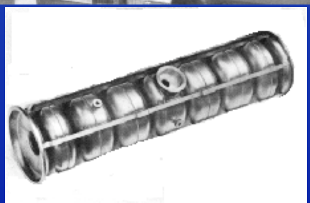
Total “SC voltage” installed on accelerators in operation

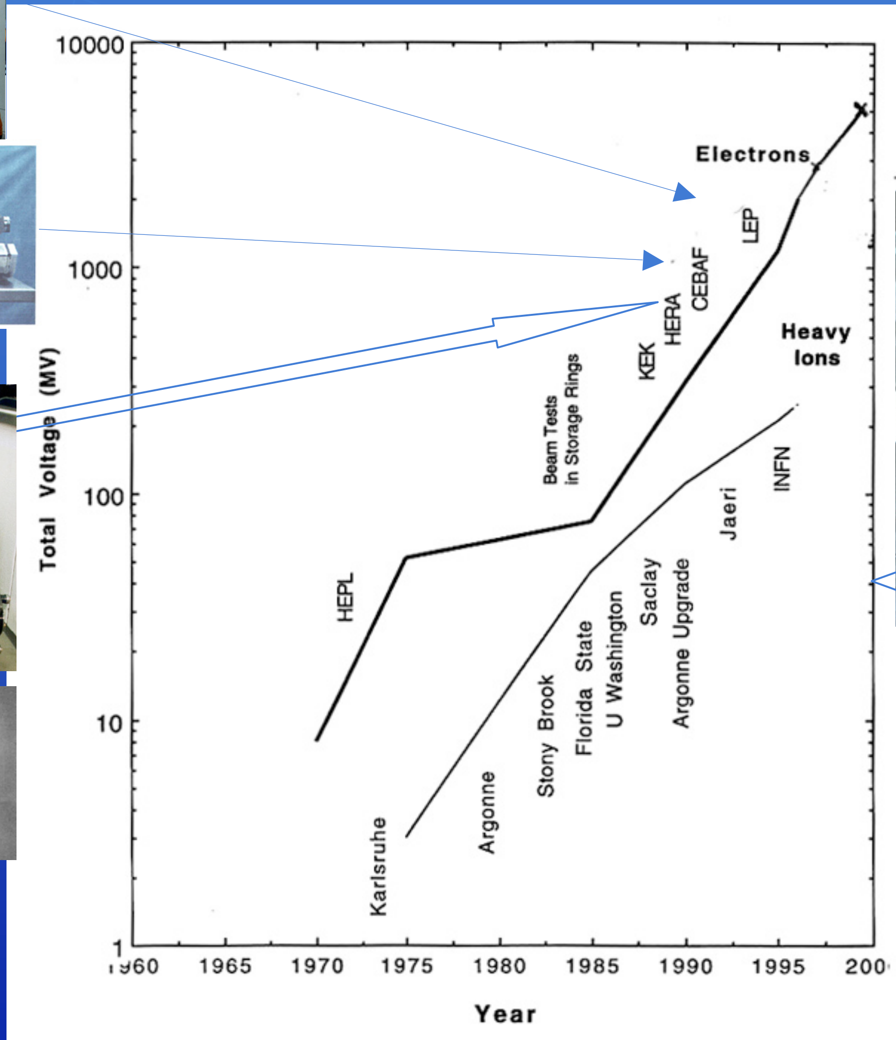
Nb/Cu Technology

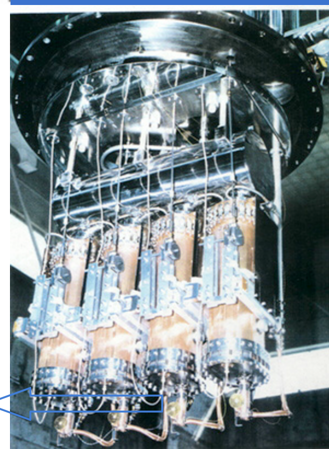










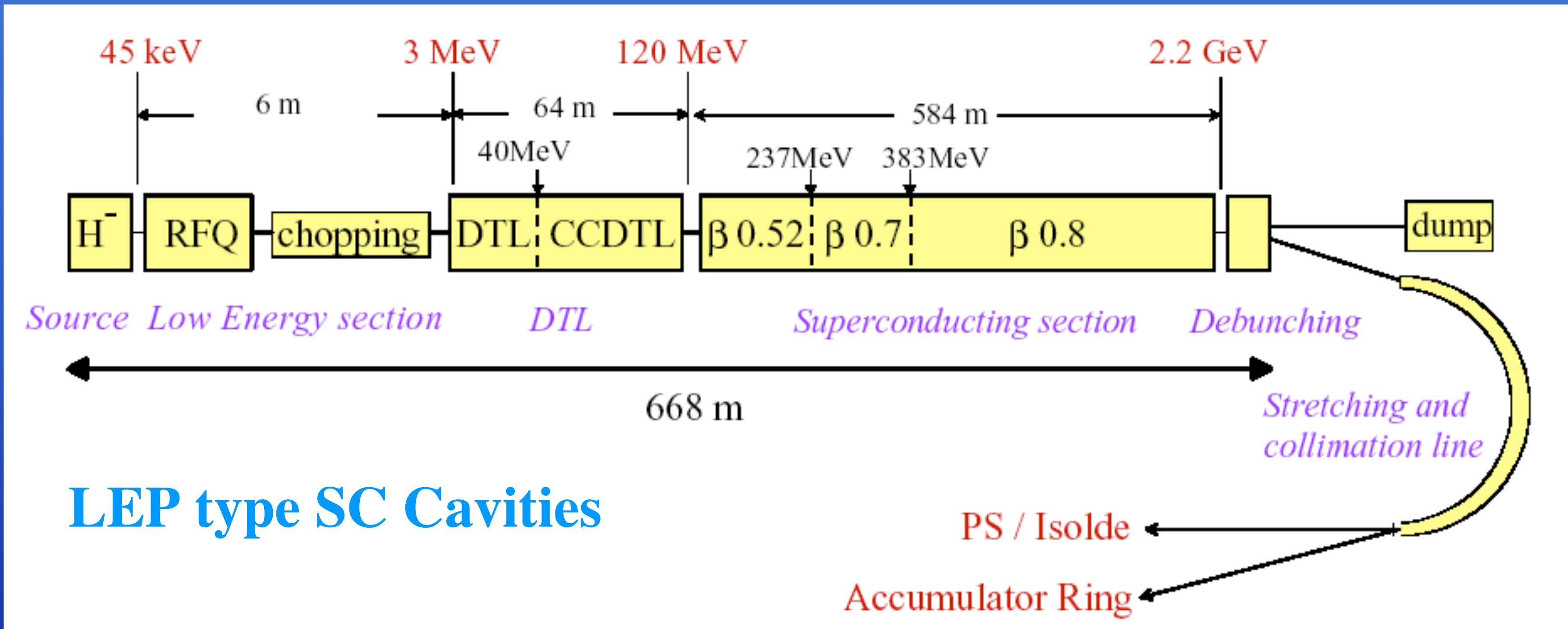


Courtesy of H. Padamsee

CORNELL UNIVERSITY

Typical SC Linac Schematic Layout

ν Factory CERN SC Linac design



LEP type SC Cavities

SUPERCONDUCTIVITY

HP Hadron Beams Applications

- Spallation neutrons
- Radioactive Ions
- Waste Treatment
- Inertial Fusion
- Energy Production
- Materials Irradiation

WHY NEUTRONS ?

Properties of Neutrons

Neutrons are NEUTRAL particles. They

- are highly penetrating,
- can be used as nondestructive probes, and
- can be used to study samples in severe environments.

Neutrons have a MAGNETIC moment. They can be used to

- study microscopic magnetic structure,
- study magnetic fluctuations, and
- develop magnetic materials.

Neutrons have SPIN. They can be

- formed into polarized neutron beams,
- used to study nuclear (atomic) orientation, and
- used for coherent and incoherent scattering.

The ENERGIES of thermal neutrons are similar to the energies of elementary excitations in solids. Both have similar

- molecular vibrations,
- lattice modes, and
- dynamics of atomic motion.

The WAVELENGTHS of neutrons are similar to atomic spacings. They can determine

- structural sensitivity,
- structural information from 10^{-13} to 10^{-4} cm, and
- crystal structures and atomic spacings.

Neutrons "see" NUCLEI. They

- are sensitive to light atoms,
- can exploit isotopic substitution, and
- can use contrast variation to differentiate complex molecular structures.

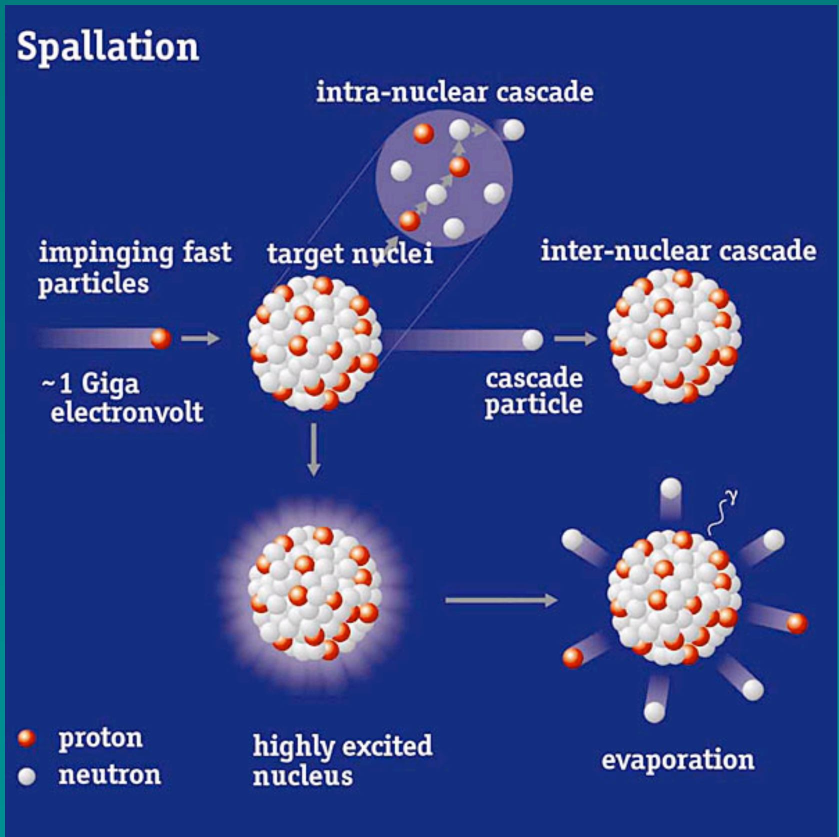
Nobel Laureate Clifford Shull was among the ORNL researchers who pioneered neutron scattering by using neutrons from the Laboratory's Graphite Reactor.

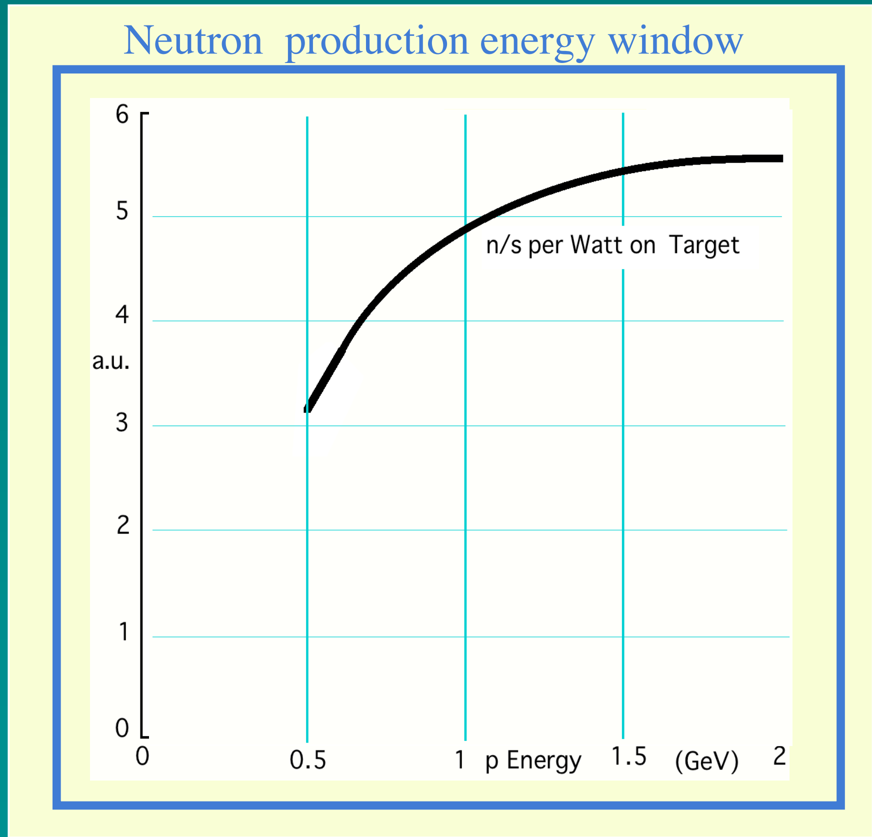
http://www.sns.gov/new/aboutsns/index.shtml

Neutrons: Panorama

Neutron Production by Spallation

needs
high peak current,
high brightness p, H^-
or heavy ion beams





SNS

1.4 MW

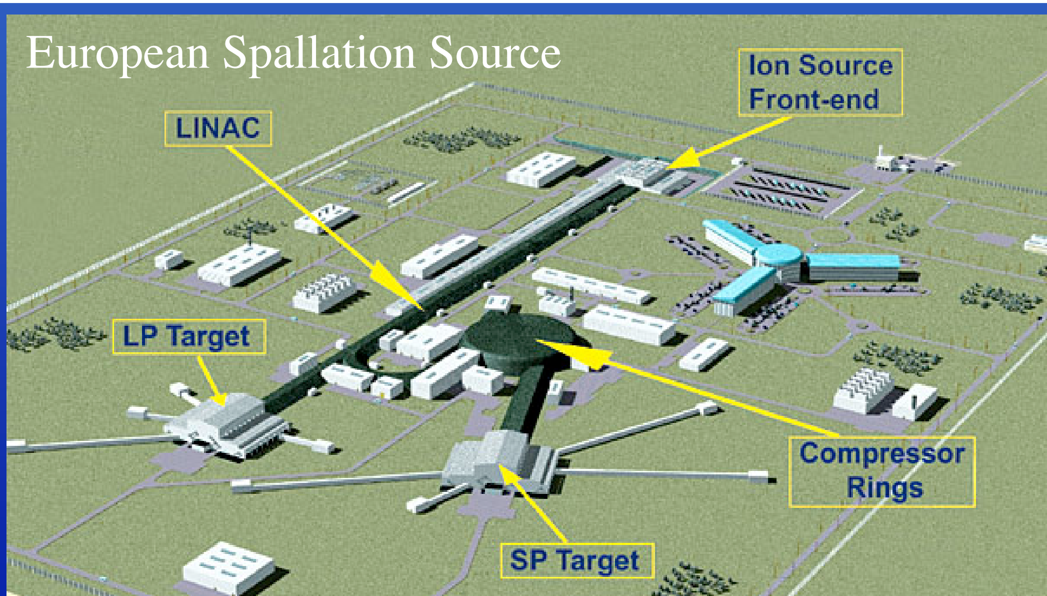
Superconducting Linac

Apr 2006
Successfully commissioned

2007 Fully operational

http://neutron.neutron-eu.net/n_ess/n_ess_documentation

ESS



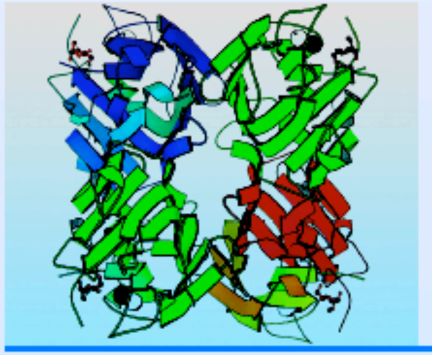
2 x 5 MW

Superconducting
Linac

Design ready
Approval pending

http://www.sns.gov/

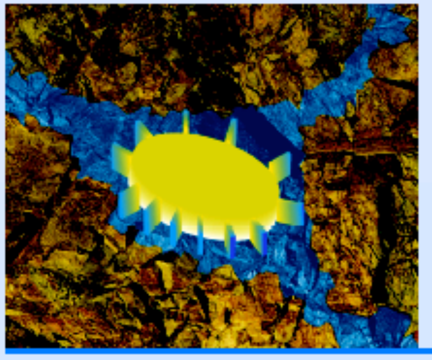
Science with neutrons 1



Biology and Biotechnology

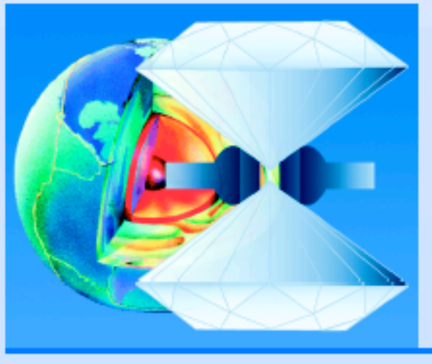
Neutrons are particularly sensitive to the dynamics of molecules and single atoms. The relevant instrumentation at the ESS promises large gain factors, up to three orders of magnitude above what is available today. This will allow an unprecedented increase in experimental sensitivity, which, in combination with bio-simulation, will be applied to the study of atomic and molecular structure and dynamics in many fields of biology.

DNA



Polymers and Soft Matter

Complexity is one of the most common characteristics of soft condensed matter. The properties are often determined by key components that are dilute. Instrumentation at the ESS will allow the observation of such components under both equilibrium and transient conditions. One example is the exploration of the structure, dynamics and phase behaviour of multicomponent complex fluids in porous media, preparing the way for e.g. tertiary oil production or the remediation of soil contamination.

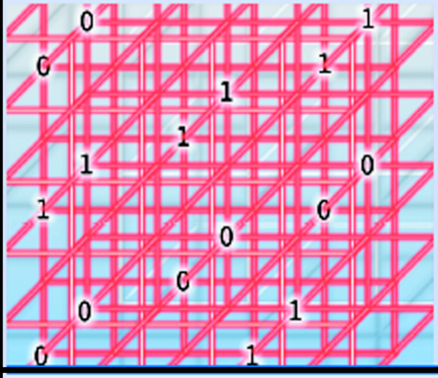


Earth and Environmental Science

Geological activity in the earth's upper mantle is responsible for geo-hazards such as earthquakes and volcanic eruptions. At the ESS, high temperature and high pressure studies of the structure and dynamics of minerals and magmas under earth mantle conditions will lead to significantly improved predictions of earth dynamics and the related geo-hazards.

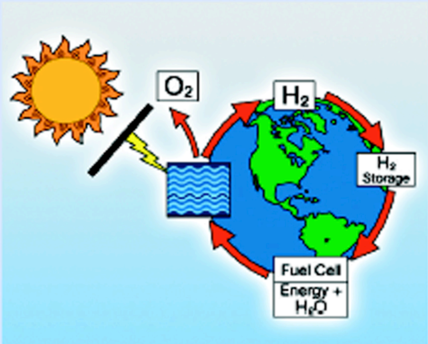
ESS Scientific Case http://neutron.neutron-eu.net/n_ess/n_ess_documentation

Science with neutrons 2



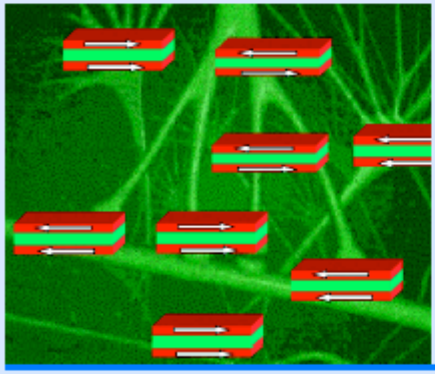
Holographic Laser Discs

Liquid crystalline polymers with photosensitive side groups can undergo pronounced photo-induced structural rearrangements that could be exploited, for instance for three dimensional holographic laser discs with storage capacities of the order of 1000 GB. Structural and dynamical neutron studies at the ESS will help to direct systematic searches for new optimum formulations that meet the demands of a wide variety of applications.



Hydrogen Energy Economy

Hydrogen is an ideally clean carrier of energy. A future hydrogen based energy economy will need substantially better ways of storing hydrogen in a safe, light and affordable manner. Metal hydrides, and ionic compounds of the lighter elements, appear promising candidates. Their relevant structural and dynamical properties can only be clarified by neutron scattering. The ESS will provide the means to study kinetic loading and unloading cycles in-situ, aging processes and associated diffusion mechanisms. This knowledge will be of great importance for rational materials design.



Magnetic Neural Networks

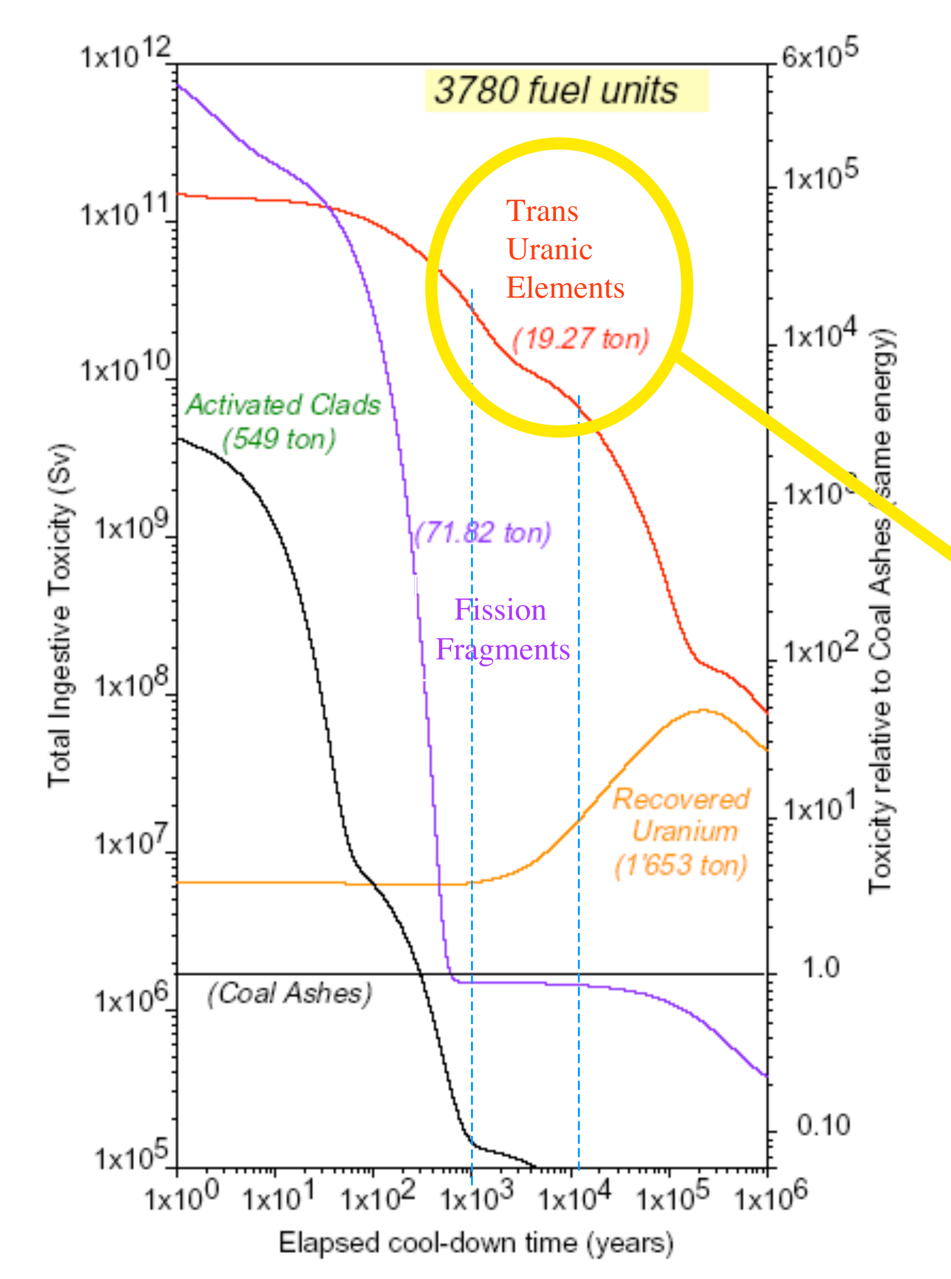
GMR, together with the Exchange Bias (EB) effect that pins the direction of magnetic moments in a certain direction, allows the construction of spin valves, which are essential components of magnetoelectronics. On this basis, smart micro-magnetic-media can be envisaged that could become prototypes for magneto-neural-networks. The ESS will be an invaluable tool for the structural and dynamical evaluation of such systems.

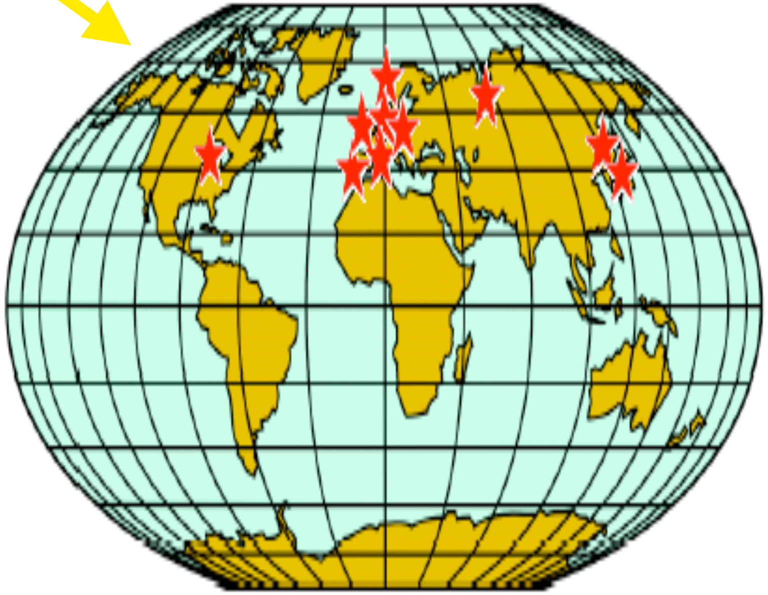
http://lpsc.in2p3.fr/gpr/houch96/houch96.html

CERN/AT/95-44 (ET)

ATW

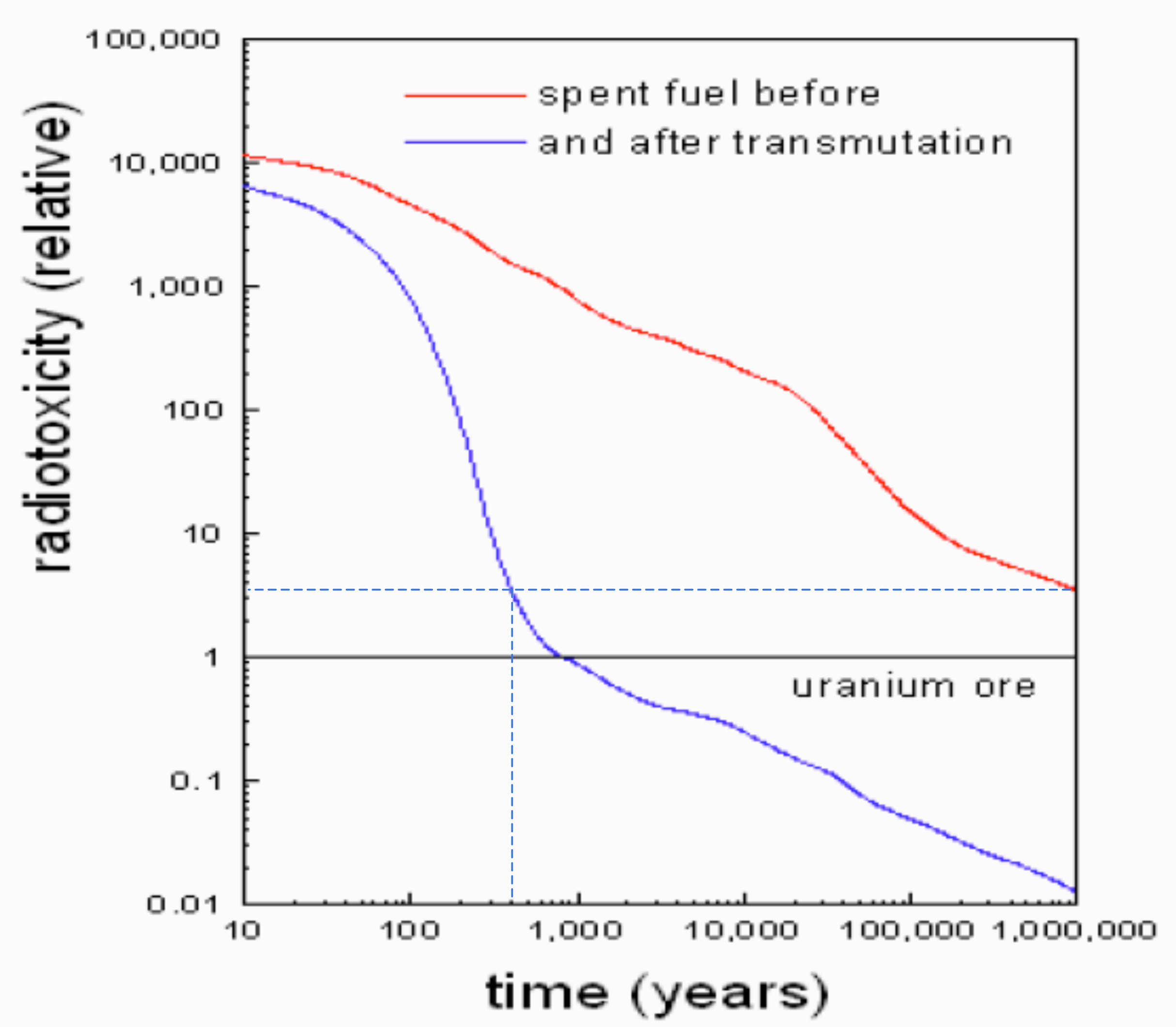
Waste composition





Waste before and after transmutation

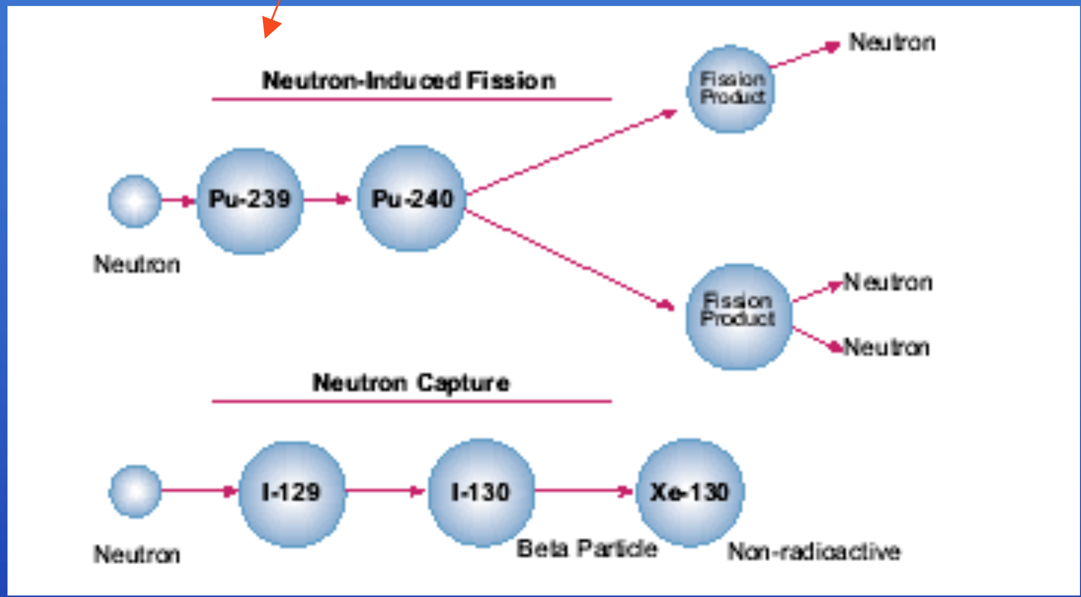
ATW



H. Aït Abderrahim,"*MYRRHA a Multipurpose Experimental ADS, for R&D objectives* ", Proc. *EPAC 2004*, Luzern *(CH)*

Accelerator Transmutation of Waste

• A **HP proton accelerator** produces **spallation neutrons** in a heavy metal **target.**



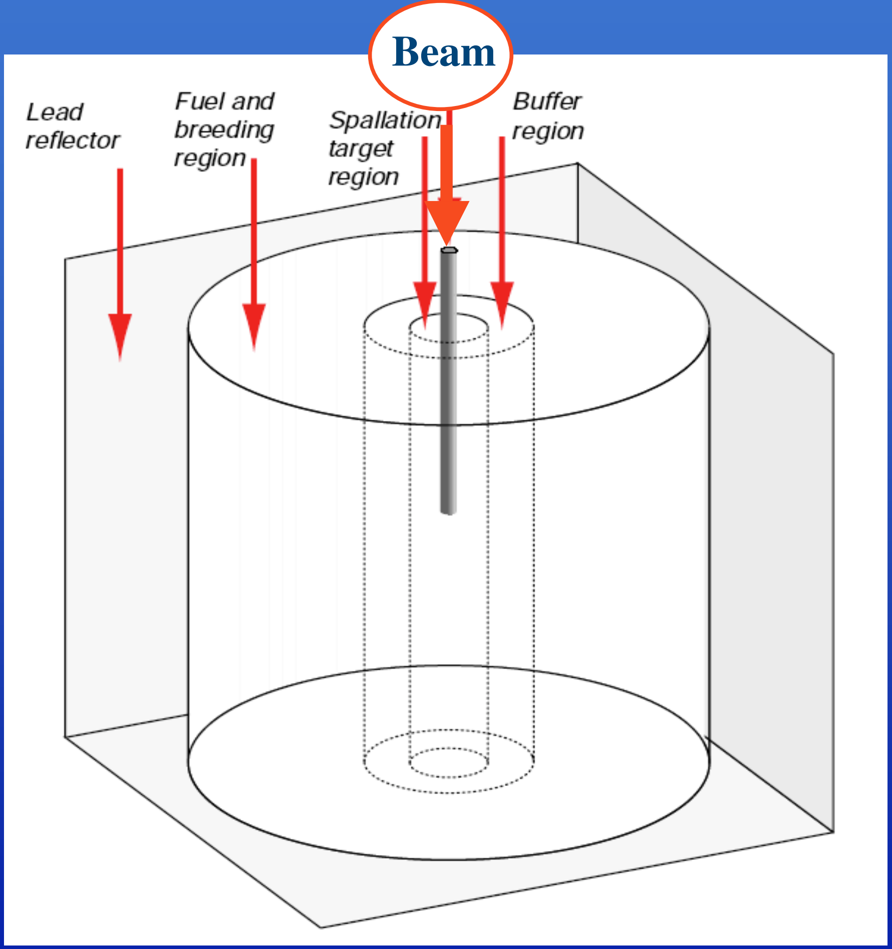
- The **target** is at center of "blanket" region ("**transmuter**") filled with chemically separated **long-lived transuranics** and fission products

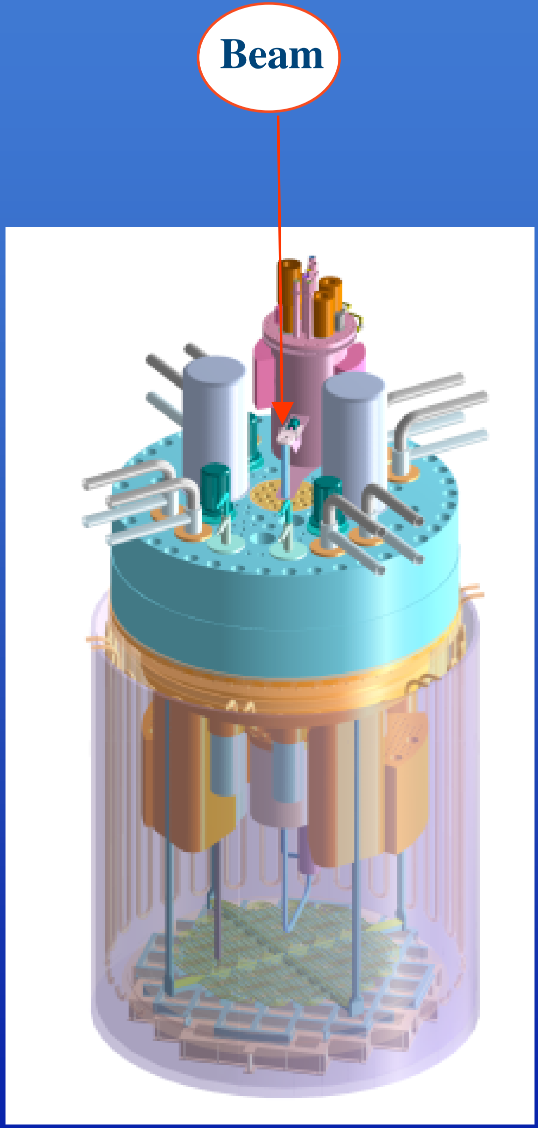
- Subcritical *!!* : fissionable transuranics arranged such that chain reactions cannot be sustained without an **external *n* source**

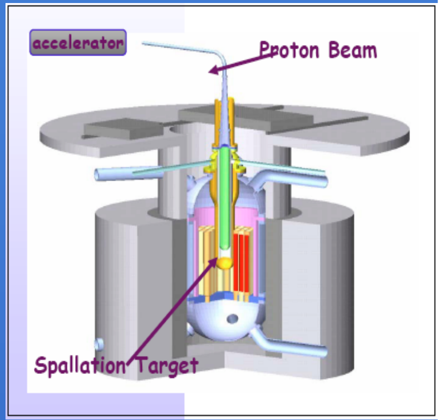
•***ATW has better transmutation performance***
faster, more complete, requires smaller investment

•***ATW has simpler processing requirements***
smaller number of steps, more proliferation resistant, less waste

Principle scheme

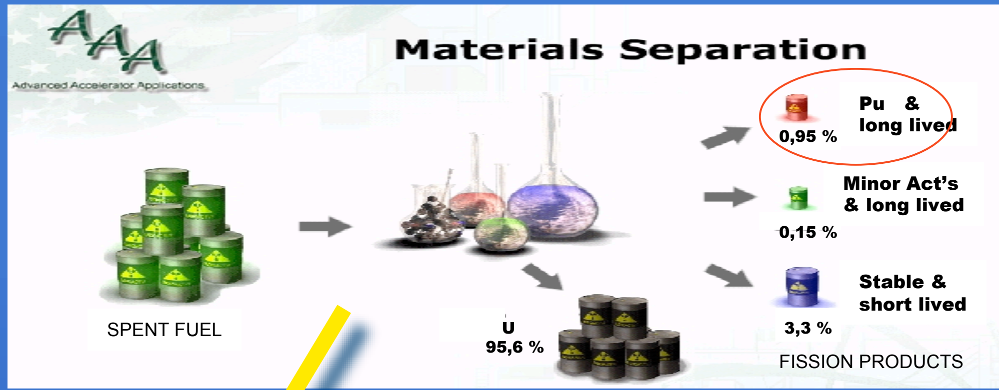


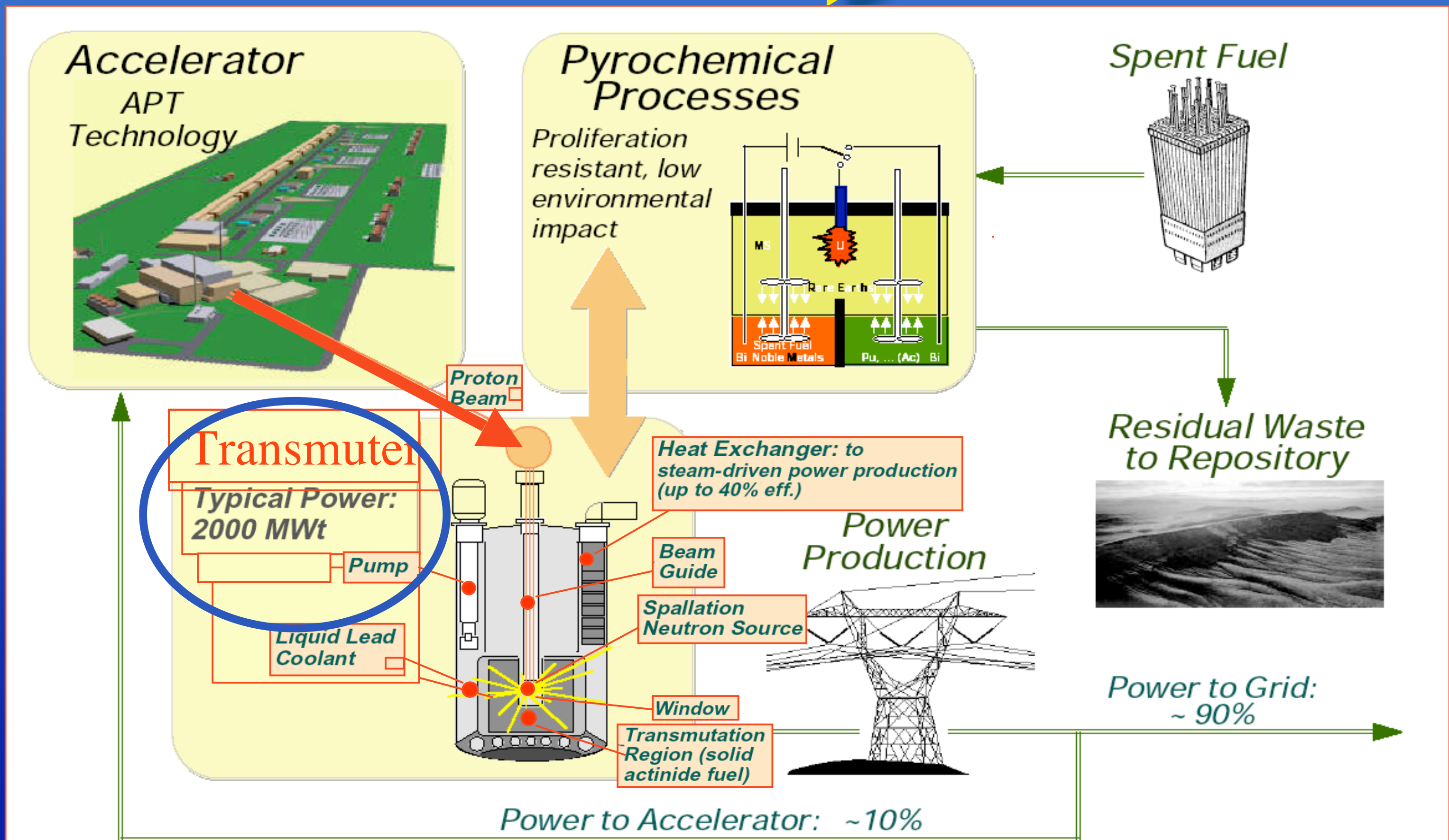




www.sckcen.be/myrrha/

Accelerator Transmutation of Waste





Accelerator Transmutation of Waste

A linac designed to drive an ATW facility should have

- Very high electrical efficiency (ac-power to beam-power)
- Minimum capital and operating costs
- Minimum spatial footprint (short length)
- Capability to adjust beam power on target over a wide range
- High availability and operational flexibility
- Employ the best mix of established technology and anticipate technology advances.

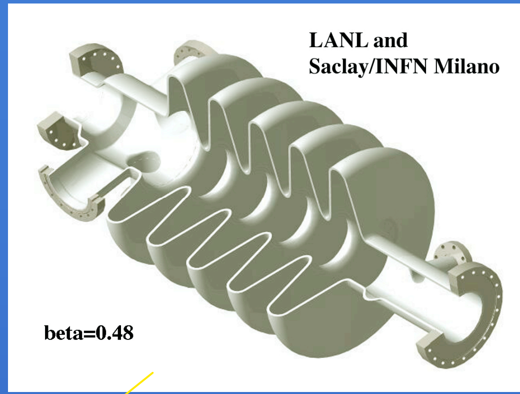
Nominal beam parameters

10 to 40 MW proton beam

1 GeV , 10 to 40 mA, CW

SUPERCONDUCTING !

ADTF
(Accelerator Driven Test Facility)
SC Linac Design



ANL

350 MHz

700 MHz

Injector&
350 MHz
LEDA RFQ

2-gap
spoke
β=0.175

3-gap
spoke
β=0.20

3-gap
spoke
β=0.34

5-cell elliptical
β=0.48

5-cell elliptical
β=0.64

6.7 MeV

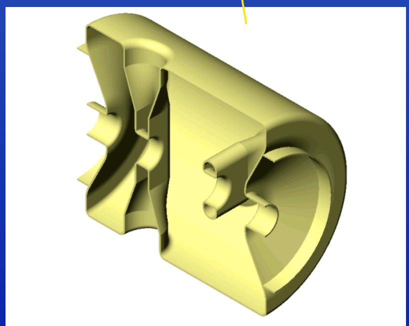
14 MeV

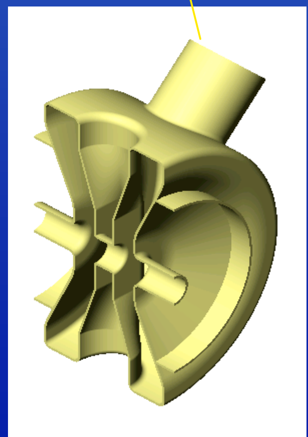
44 MeV

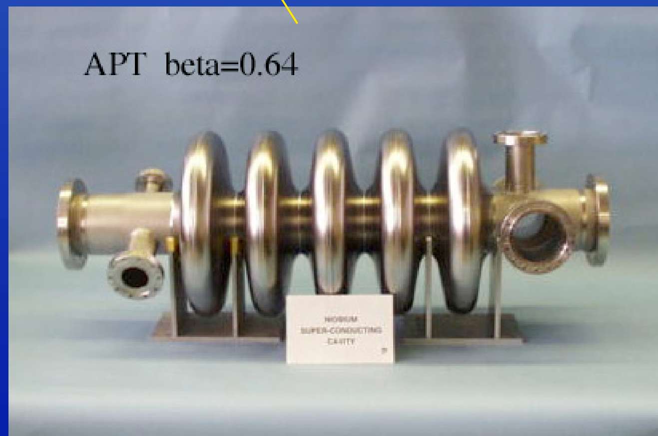
109 MeV

211 MeV

600 MeV
13.3-mA



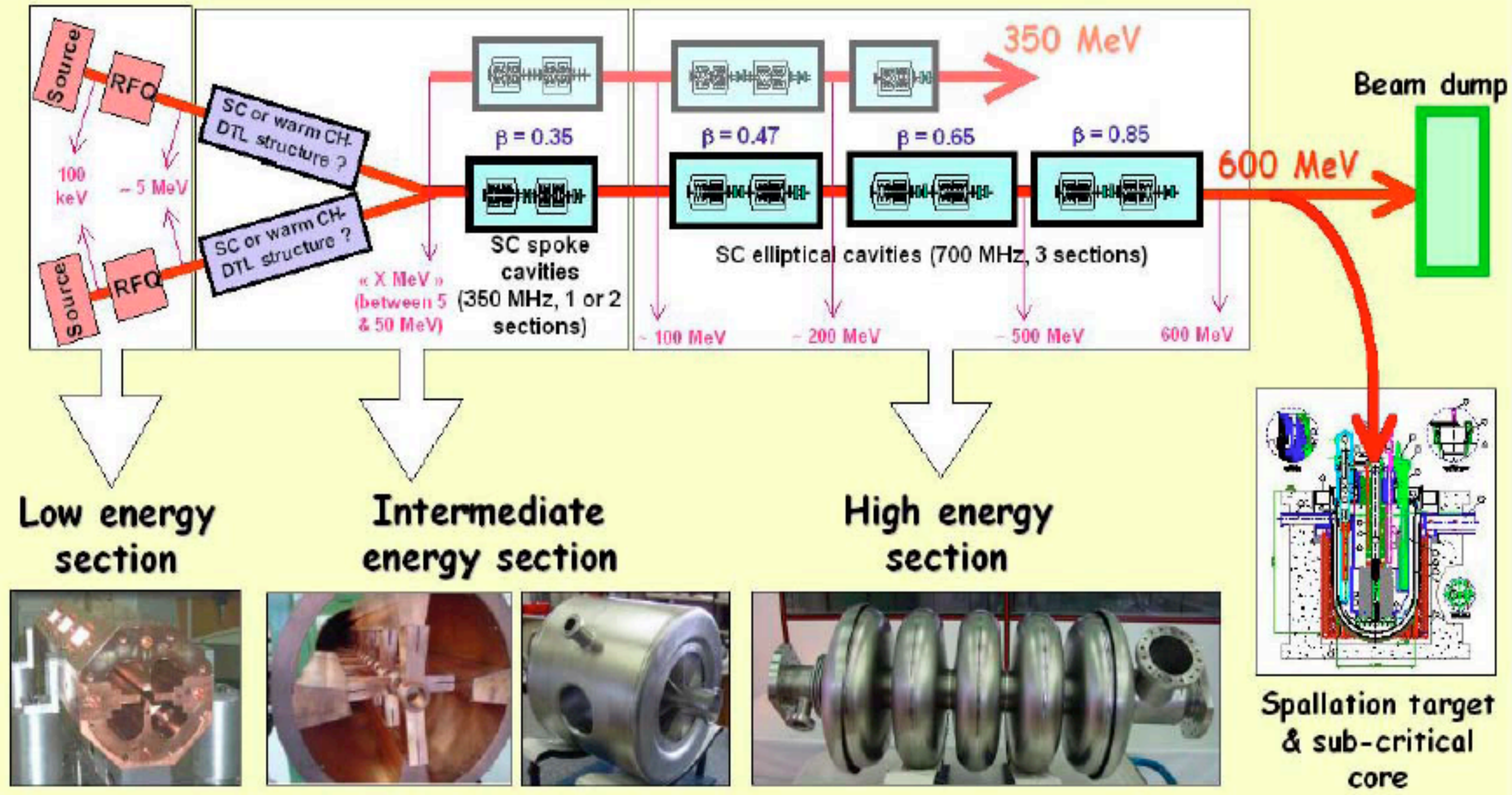




Courtesy C. Pagani

ANL

MYRRHA Present Accelerator LINAC solution

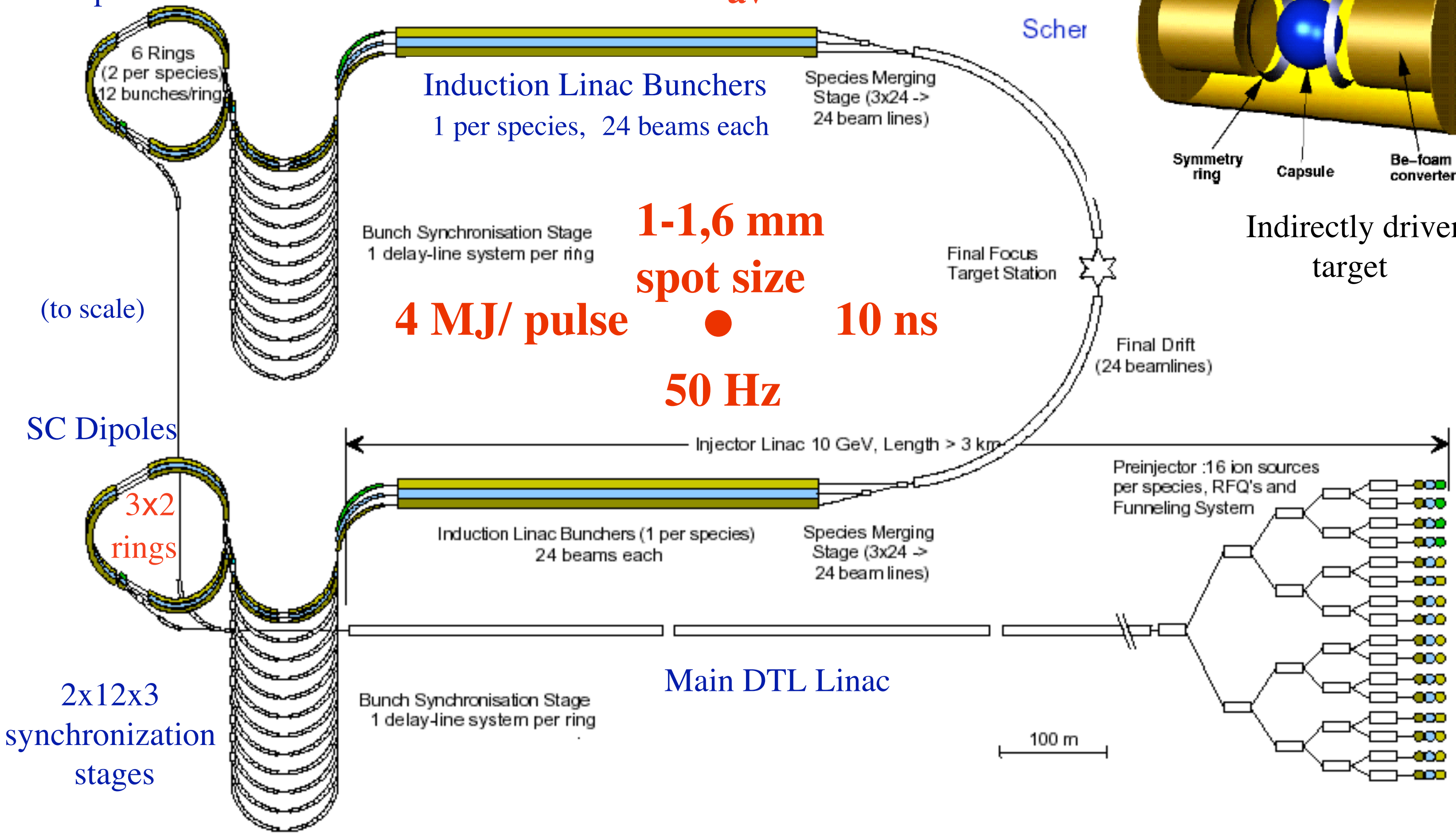


Strong R&D & construction programs for SC linacs underway worldwide for many applications

(Spallation Sources for Neutron Science, Radioactive Ions & Neutrino Beam Facilities, Irradiation Facilities)

High intensity Ion Driven Inertial Fusion

"The ultimate accelerator physics challenge"

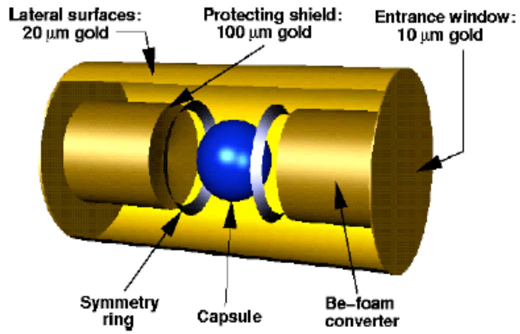


P_{av} ~ 200 MW

1-1,6 mm spot size

4 MJ/ pulse ● 10 ns

50 Hz



Indirectly driven target

HIDIF Study Group

High Power Accelerator Designs

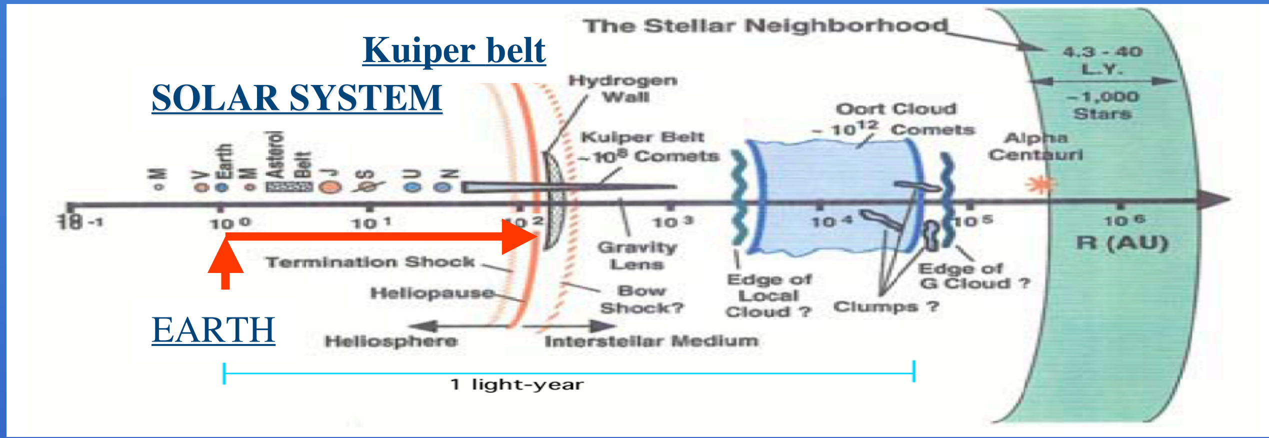
	Radioactive Ions		Neutron Spallation				ν Factory	Multipurpose		ATW	Tritium	Ion driven Fusion
Project	RIA	EURISOL	KEK/ JAERI	AUSTRON	SNS	ESS	SPL	KOMAC	CONCERT	TRASCO	ATF	HIDIF
Based	ANL	Saclay	Tokai	Austria	Oak Ridge	Jülich	CERN	Korea	Saclaly	Italy	Los Alamos	GSI
Beam Power (MW)	0,4	5	0,4	0,5	1.4	2 x 5	4	20	25	30	100	~200
Energy (GeV)	0,9	1	3	1,6	1	1,33	2,2	1	1	1	1	10
Rep Rate (Hz)		CW	25	50	60	50	50	CW	CW	CW	CW	50
Main Accelerator	SC Linac	SC Linac	synchro-tron	synchro-tron	SC linac	DT or SC linac	SC Linac	SC Linac	SC Linac	SC Linac	SC Linac	DT Linac
Status	Start constr. 2004	Ongoing study	Approved	Ongoing study	Operation 2007	Ongoing study	Ongoing study	Ongoing study	Ongoing study	Ongoing study	Ongoing study	Ongoing study

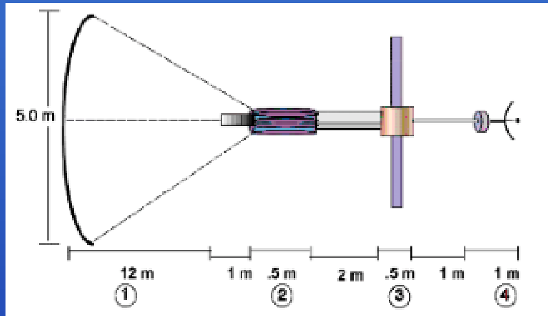
More exotic : Antimatter Driven Sail for Deep Space Missions

Mission: sending a probe to the Kuiper Belt in a transit time of 10 years.

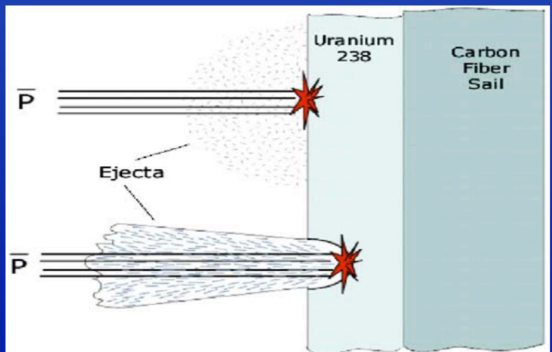
Missions to deep space will require **specific impulses greater than 6000 s** in order to accomplish the mission within the career lifetime of an individual.

System analysis indicates that a 10 kg instrument payload could be **sent to 250 AU in 10 years using 30 milligrams of anti-hydrogen (~6 10^{19} pbar)**.





1. U coated carbon sail 4. 10 Kg payload
2. Solid anti-hydrogen crystal storage
3. Anti-proton driven power supply

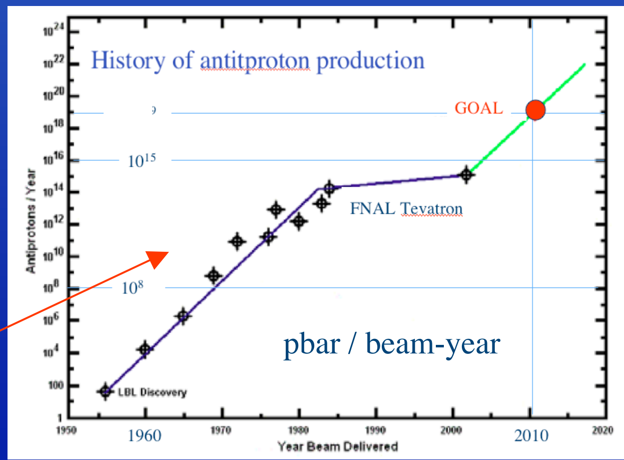


Physics : antimatter incident on uranium foil has a 98% probability of inducing fission.

Two fragments of ~ Palladium-111 are emitted back-to-back with a total energy of ~ 190 MeV. Their velocity is ~1.4×10^{7} m/s and their mass is 1.85×10^{-25} kg/atom.

This equates to a **specific impulse of 1.4 10^{6} *s***.

"At the present time, enough antiprotons are generated to perform millisecond type thrust tests. In order to reach the inventories of antiprotons needed for missions such as the one envisioned in this paper, **it will be necessary to greatly increase the rate of antiproton production** .



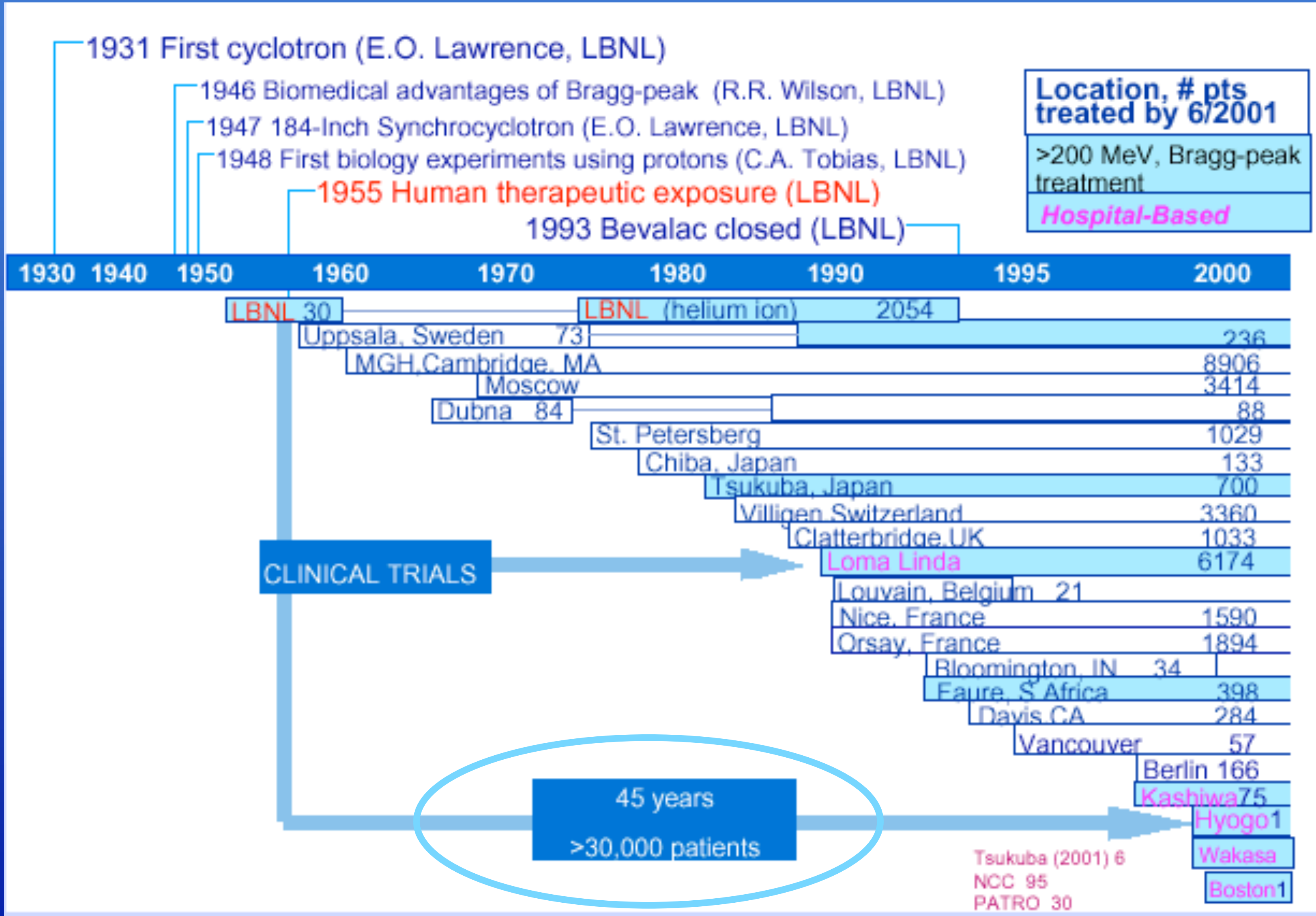
G.P. Jackson & S.D. Howe, "*Antimatter Driven Sail For Deep Space Missions*", Proc. EPAC 2003

Hadron Accelerators for Therapy

Extremely **precisely** controlled beams
Therapy oriented optimization
Economics of running the facility
Hospital level reliability

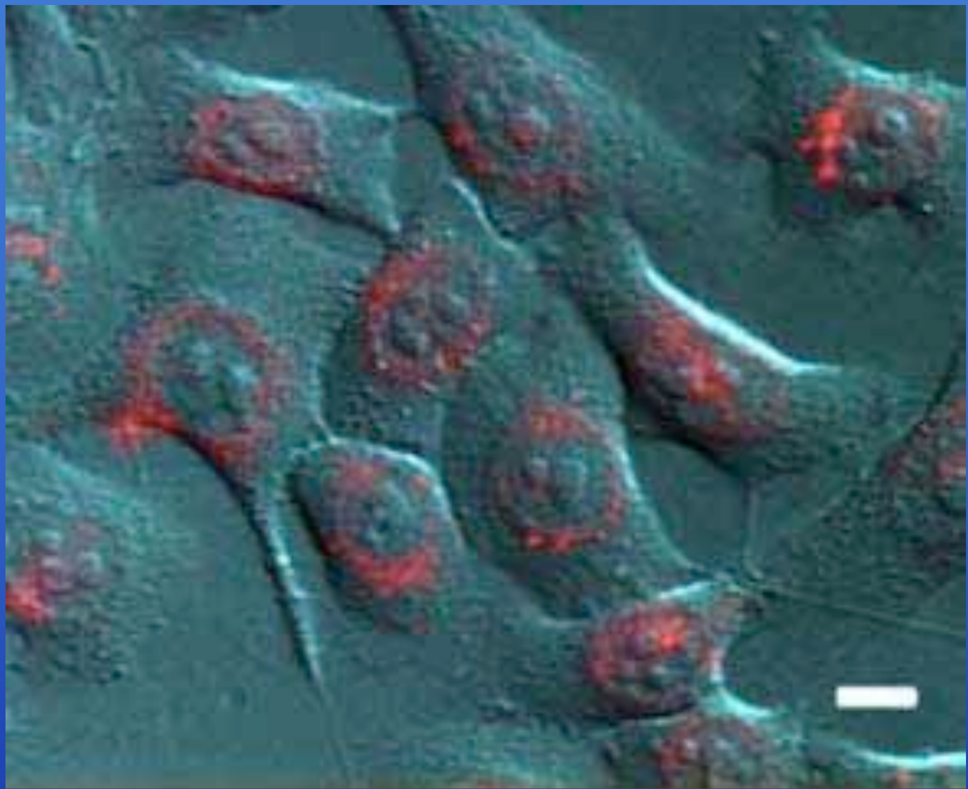
Decades of accelerator physics and engineering know-how

Proton Therapy Milestones



J.W.Kwan, ICFA 20th Advanced Beam Dynamics Workshop, Fermilab, 2002

Neutron Capture therapy



BOPP (shown here in red) is a tumor seeking chemical containing boron which acts like a sponge for neutrons. Inside the brain, BOPP gathers around the nuclei of cancerous tumor cells. When the boron atoms in BOPP absorb neutrons, they emit alpha radiation that destroys the tumor's DNA

BNCT for Glioblastoma Cancer

Step 1: Tumor-seeking drug containing "radiation sponge" administered to patient

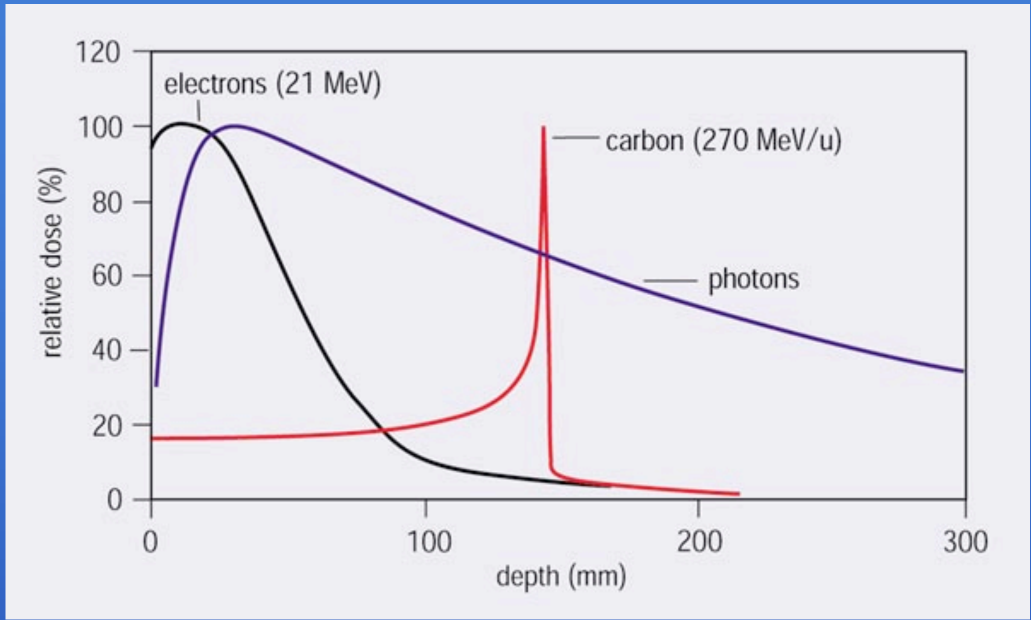
Step 2: Short waiting period while drug fixes in tumor and clears from blood

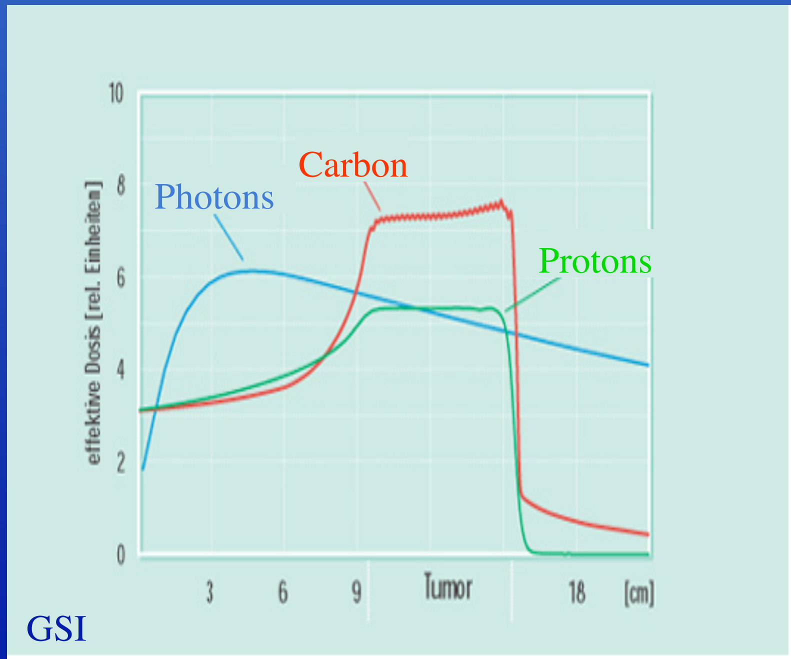
Step 3: Patient receives neutron radiation dose

Step 4: Cell damage concentrated in cancer cells not in healthy tissue

$$^{11}B \Rightarrow {}^{7}Li + {}^{4}He$$

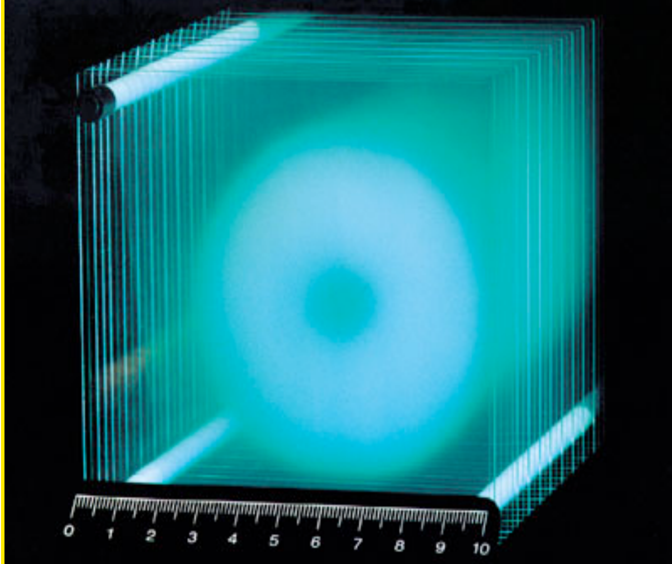
Hadron Therapy worldwide





Courtesy of U.Amaldi

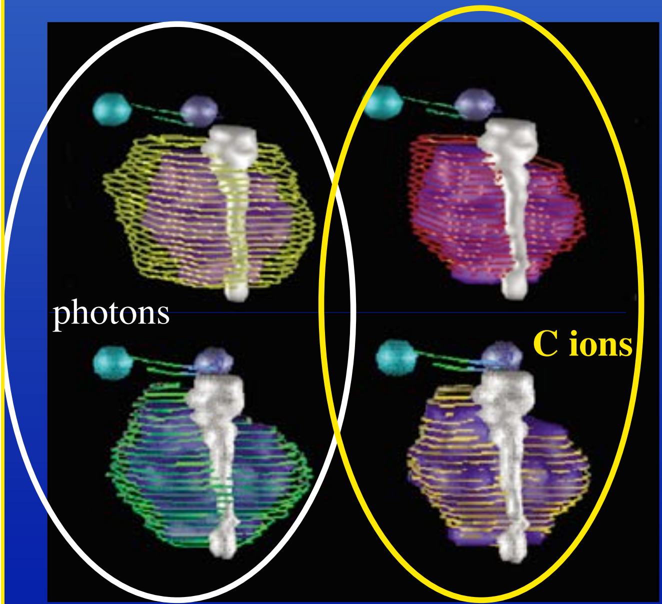
GSI beam-scanning technique: any shape



Plastic sheets immersed in water

E and I changed within a second. An independent control system monitors the **beam position every 100 μs** and **intensity every 10 μs**. If either deviates by > 2% from spec, beam is shut off within 0.5 ms.

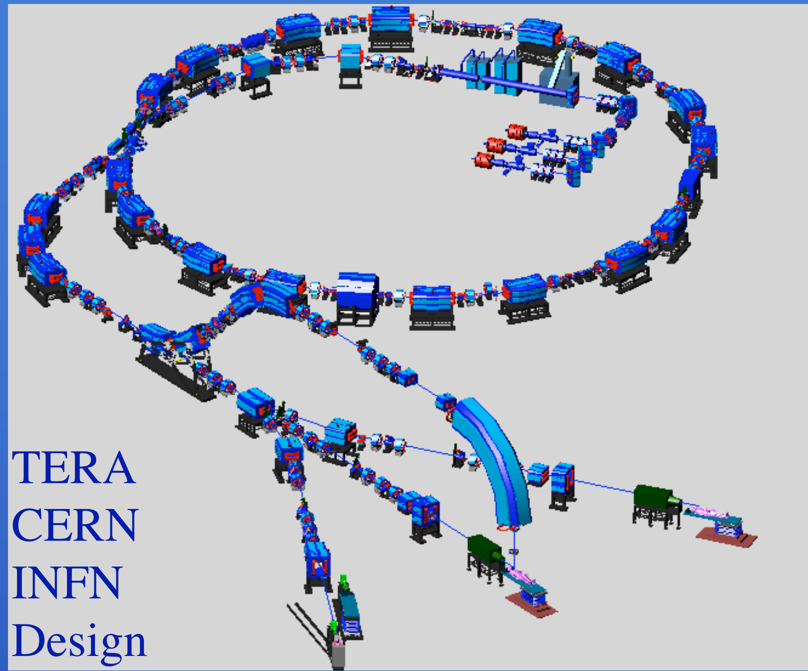
The ions deposit the bulk of their energy in the target volume.



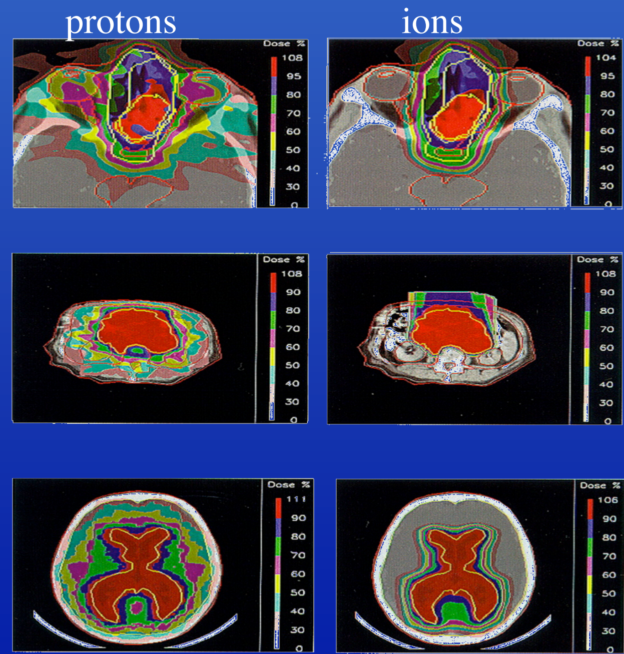
Hadron Therapy

G S I

TERA
CERN
INFN
Design

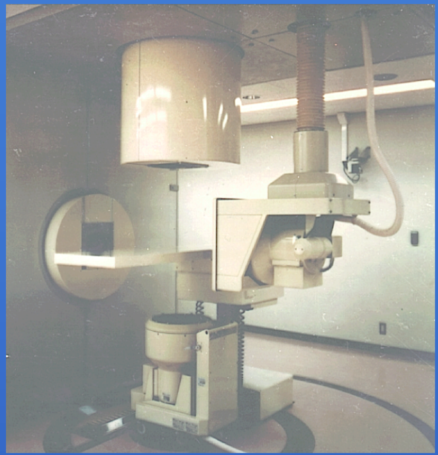


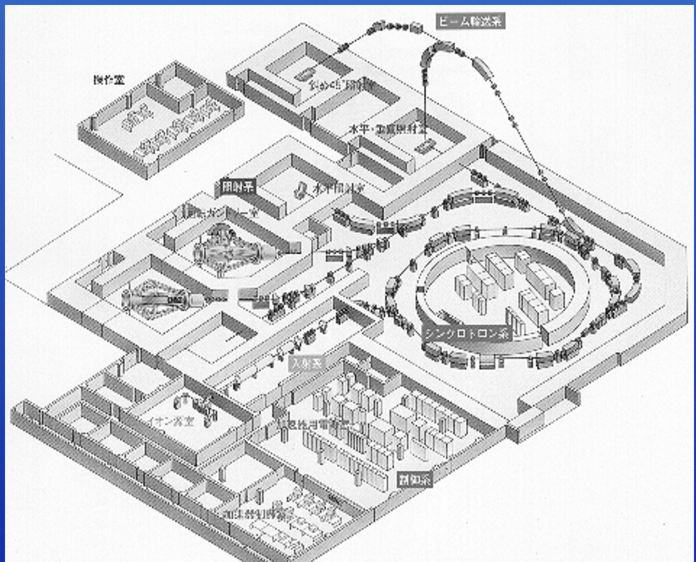
T E R A



s i m u l a t i o n

Shizuoka in Japan





SHIZUOKA FACILITY
Shizuoka (2002)

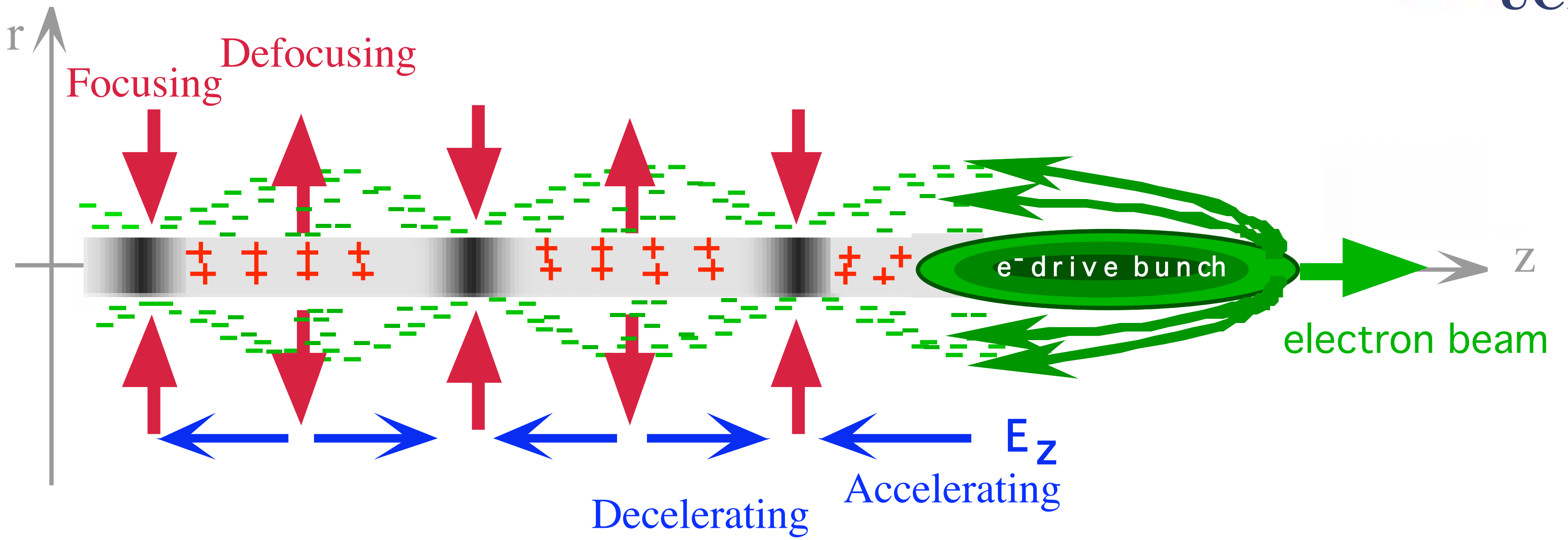
GSI in Darmstadt

GSI Pilot Installation w. C beams
More than 250 patients treated (2005)

Courtesy of U. Amaldi

http://www.gsi.de/portrait/Broschueren/Therapie/index.html

Maximum acceleration with intense beams: Plasma Wakefield Accelerator (PWFA)



- Plasma wave/wake excited by a *single* relativistic electron bunch
- Plasma e⁻ expelled by space charge forces => energy loss, focusing
- Plasma e⁻ rush back on axis, induction field => energy gain
- Plasma Wakefield Accelerator (PWFA) = Beam Energy Transformer
  Booster for high energy accelerator?

Courtesy of J. Rosenzweig (UCLA)

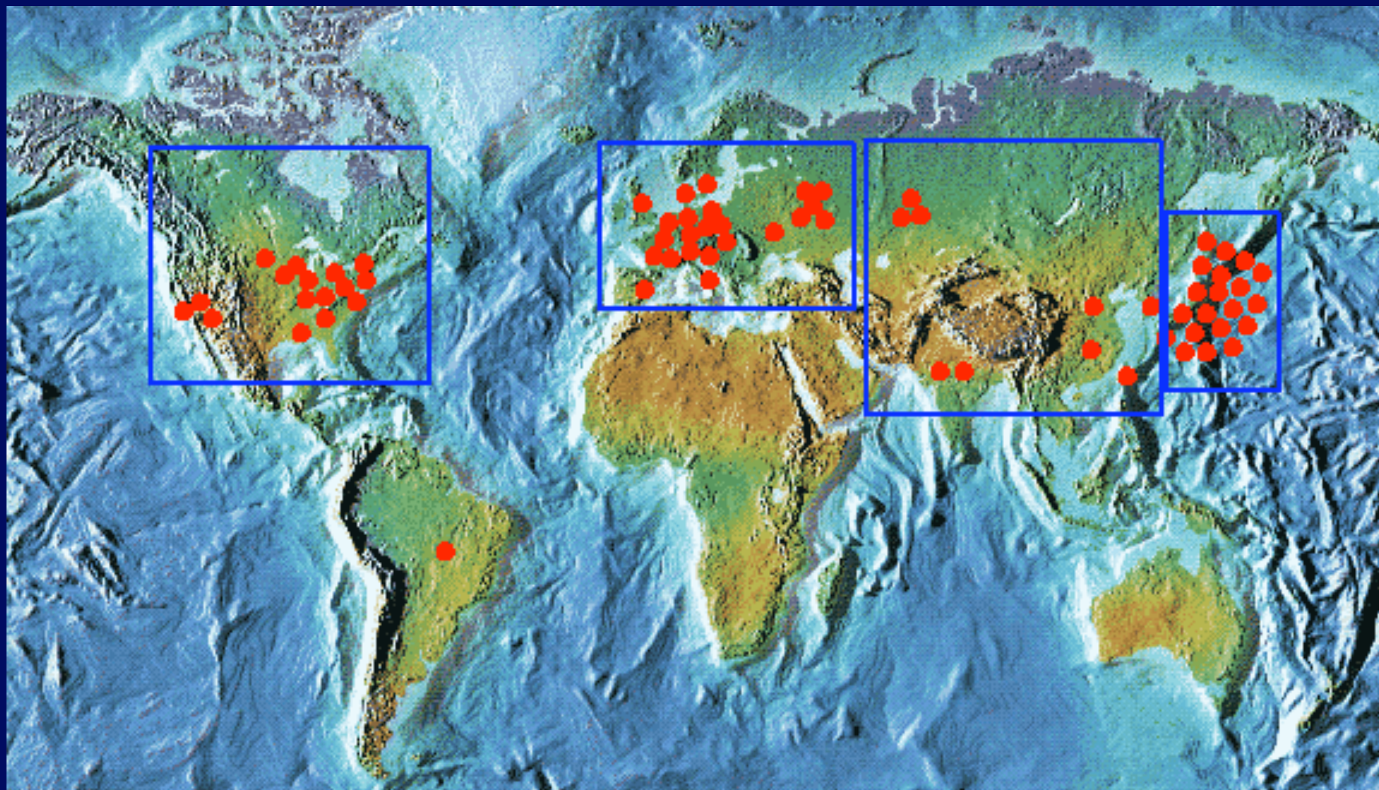
Electron accelerators applications

Synchrotron Radiation

"the most important spin-off of HEP storage rings"

Synchrotron Radiation Sources

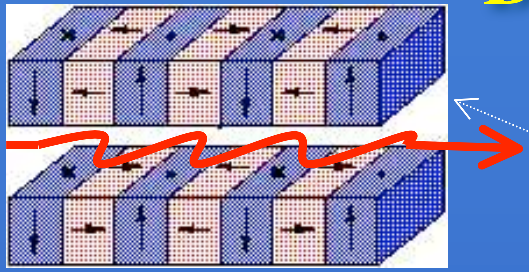
20,000 Users World-wide



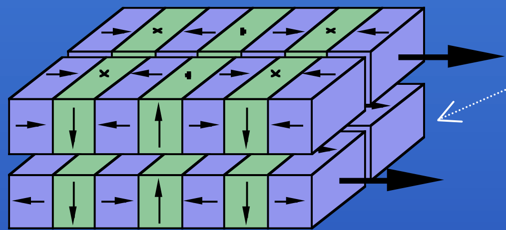
Brilliance and Tunability are the words

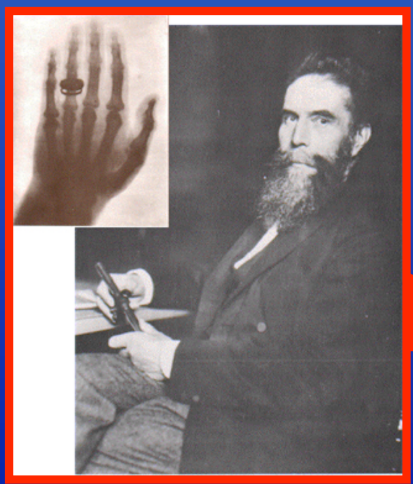
B : photons/mm²/s/mrad²/ 0.1% BW)

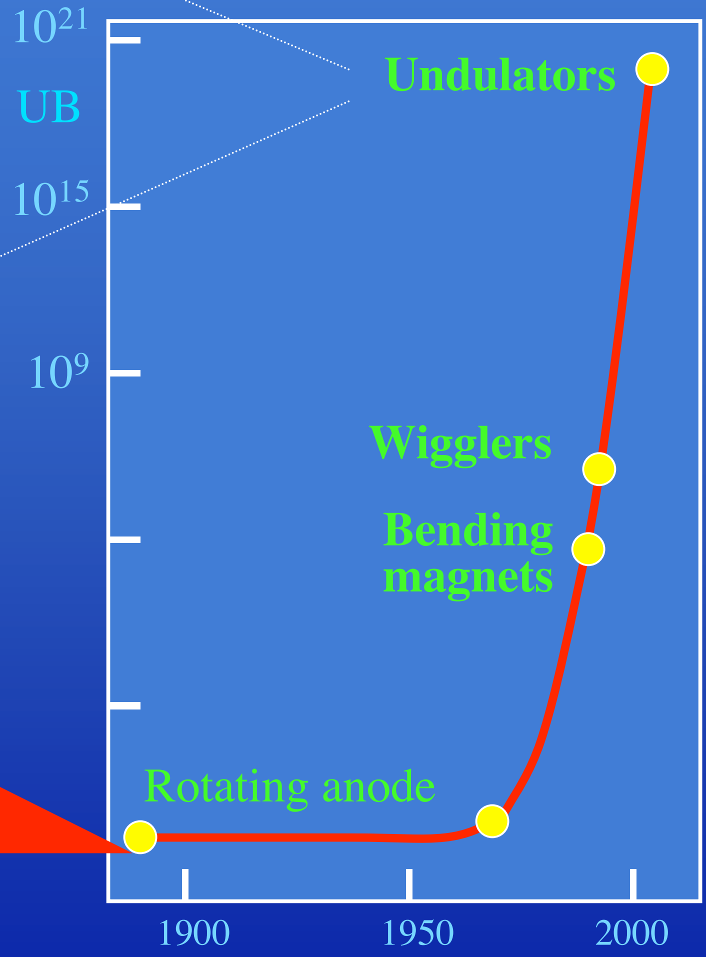
PM Linear undulator



PM Elliptical undulator





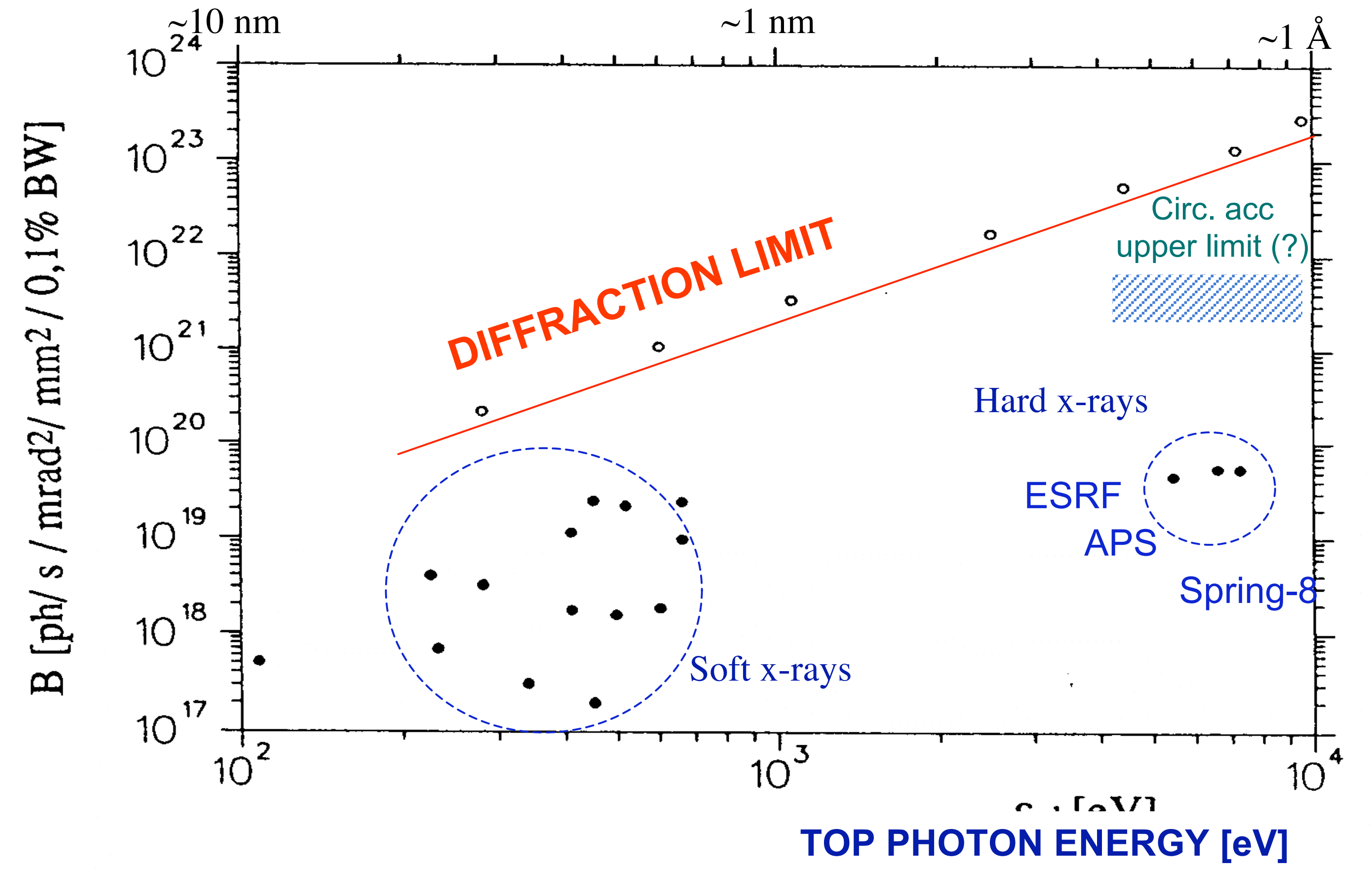


Hard X-rays

Grenoble

Courtesy of Lenny Rivkin, PSI

PERFORMANCE OF 3th GENERATION LIGHT SOURCES



Because of radiation, in circular machines **emittance, bunch length, energy spread** are determined by the lattice,

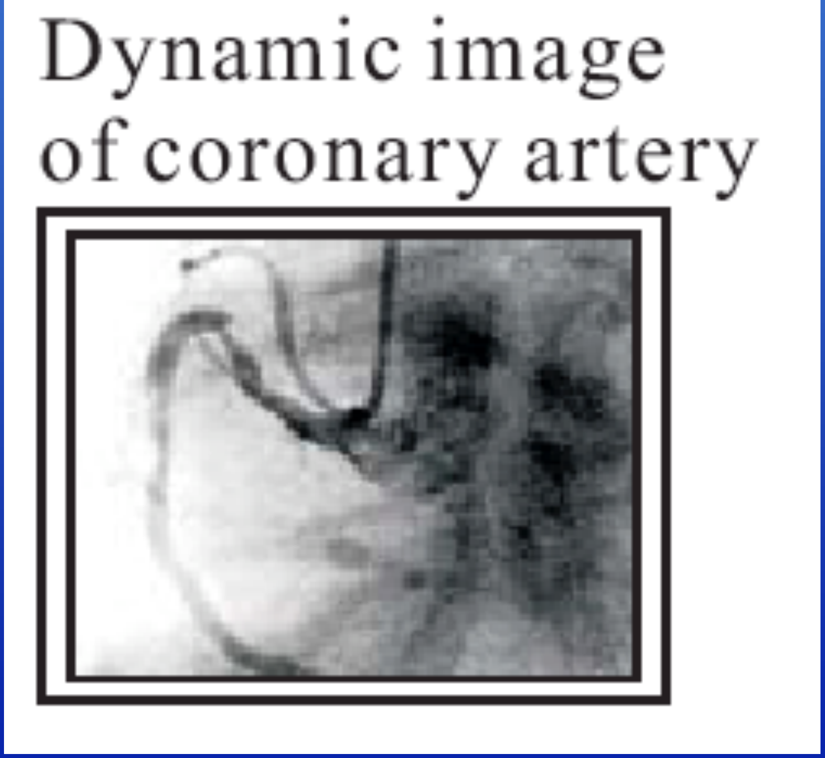
Courtesy of Lenny Rivkin, PSI

Non-invasive Coronaric Angiography

Dynamic IVCAG (Intravenous Coronary Arteriography) using **monochromatic X-rays** produced by *Synchrotron Radiation and monochromators* was clinically tested in various laboratories in Japan and Europe

Clear dynamic images (33 shots/s) of the coronary artery are obtained, with **37 keV X-rays**, **10^{11} photons/s** generated by an undulator at the AR ring (*intravenous contrast agent* applied instead of invasive artery cateter insertion).

Background subtraction is also possible, greatly reducing the needed quantity of contrast agent.



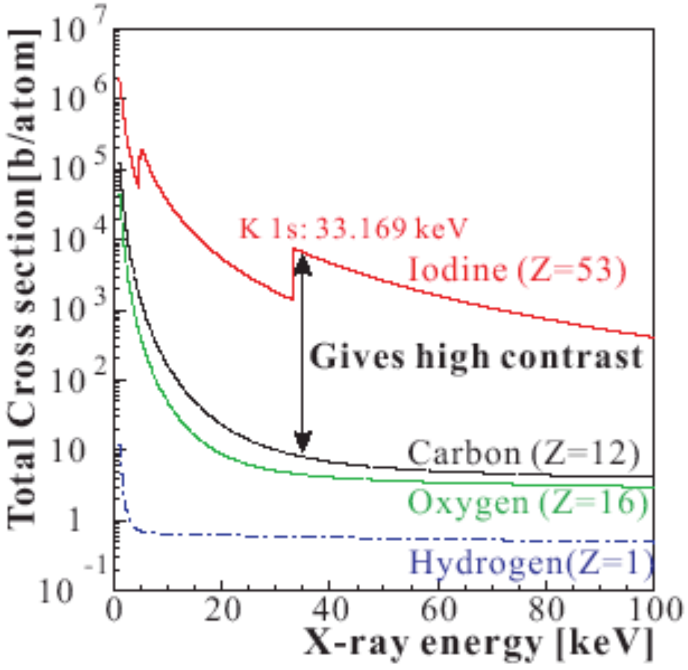
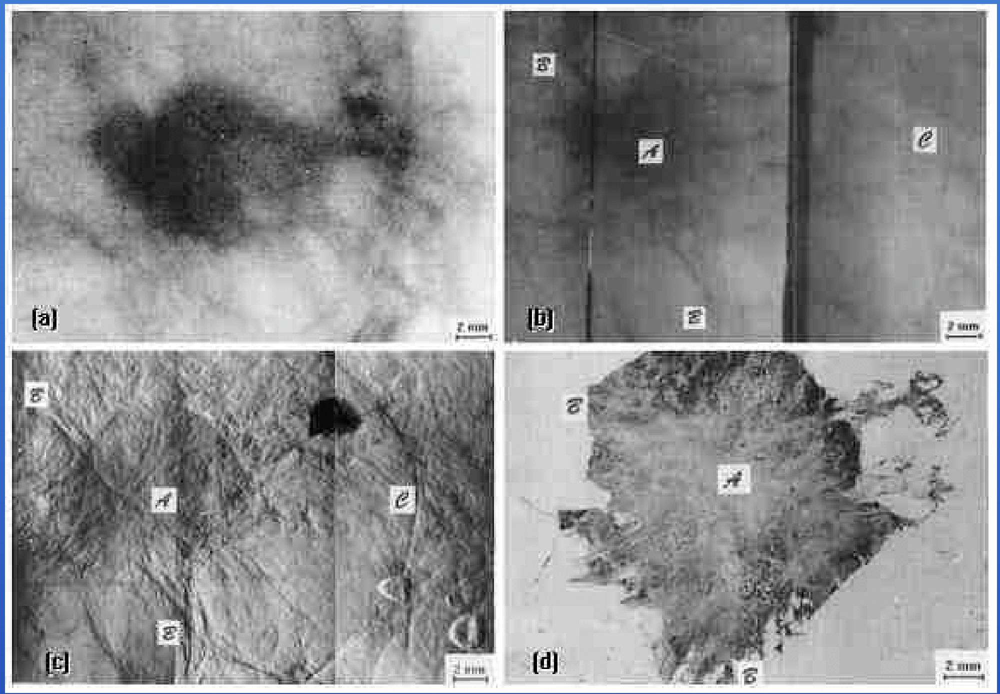


Figure 1: Total attenuation of X-ray for various atoms[1].

Mammography with Mono-chromatic X-Rays



Mammography images of adenocarcinoma. (a) conventional mammogr.; (b) monochromatic beam at 22.2 keV; (c) phase contrasst image; (d) histological section.

The constrast (sensitivity to tissue density variations) goes from 8% to 0.1%, while the spatial resolution goes from 0,15 -0,3 mm to 0.01-0.015 mm. This means the capability to detect a tumor 30 times smaller in volume, i.e. a 2 year earlier detection of the tumor.

Archimedes text recovered

Passages written by the ancient Greek mathematician Archimedes, hidden for nearly 800 years returned to view through x-ray analysis at SSRL of an ancient palinsext prayer book for which a much older parchment had been scraped and re-used.

IMAGING

Brilliant X-rays Reveal Fruits of a Brilliant Mind

Passages written by the ancient Greek mathematician Archimedes, hidden for nearly 800 years, returned to view over the past 2 weeks, thanks to researchers at the Stanford Synchrotron Radiation Laboratory (SSRL) in Menlo Park,

Rare find. This Medieval prayer book conceals seven treatises by Archimedes, two of them unique.

California. The scientists used the synchrotron's hair-thin beam of x-rays to light up the Archimedes text, which was originally copied by a 10th century scribe onto goatskin parchment. Three centuries later, a monk scraped off the Archimedes text, turned the pages sideways, and copied Greek Orthodox prayers onto the recycled pages. Although Stanford's analysis of the text hasn't yet revealed any obvious revolutionary surprises, researchers did find a new geometric drawing as well as several previously missing passages.

"Nothing usually jumps out with Archimedes," says William Noel, the curator of manuscripts and rare books at the Walters Art Museum in Baltimore, Maryland, who is leading the restoration effort. "It takes blood, sweat, toil, and tears to get at what is there." Nevertheless, he adds, "people will be talking about what we are discovering now in 100 years' time and still arguing about it."

Few dispute that Archimedes was one of the world's greatest mathematicians. Today, he's known primarily for the legendary exclamation of "Eureka!" when he realized he could measure the volume of objects by figuring out how much water they displace. But he also helped create a rudimentary form of calculus 20 centuries before Newton and Leibniz put quill to paper. He came up with a way to calculate the value of pi and was the first to tackle the concept of infinity. And Archimedes's understanding of physics helped him invent the catapult and other defenses that his city-state of Syracuse used to repel Roman invaders until 212 B.C.E., when the city was finally overcome and Archimedes was killed.

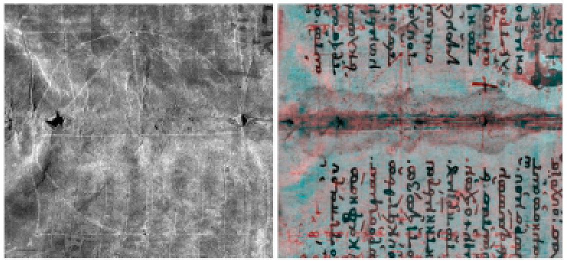
The 174-page hidden manuscript, known as the Archimedes palimpsest, was discovered in 1906 by Danish classics professor John Heiberg, who used a magnifying glass to painstakingly decode the nearly invisible underlying text. But much remained undeciphered, and the book soon disappeared into a private collection. The manuscript resurfaced in October 1998 when it was sold at auction to an anonymous buyer for $2 million. By then it had been severely damaged by mold. Forged gold leaf paintings, completely covering four pages, had also been added, probably in hopes of increasing the prayer book's value.

The day after the book's sale, Noel read about the auction in a *New York Times* article that mentioned the book's dealer. Noel e-mailed the dealer, who eventually put him in contact with the owner, who later agreed to lend the book to the Walters Art Museum for restoration and imaging. Noel says that the owner has paid for the entire project, although the amount spent has not been made public.

Noel and his colleagues from Johns Hopkins University in Baltimore, Maryland, and the Rochester Institute of Technology in New York originally used multispectral imaging to reveal much of the underlying Archimedes text. Although largely successful, the visible and ultraviolet light were unable to peer beneath the forged paintings or to resolve other passages in the faint text. In 2003, Uwe Bergmann, a physicist at SSRL, came up with the idea of scanning synchrotron x-rays over the document to reveal elements such as iron and calcium in the residual ink. The energy of the x-rays is tuned to kick out inner electrons from those elements, Bergmann explains. That disruption triggers outer electrons to drop into the vacancies, giving up their excess energy as x-rays with a characteristic energy for each element, which are then captured by a detector. Computer programs then convert the steady stream of detected x-rays into gray-scale or color-enhanced images to reveal the hidden text.

The current round of imaging was successful, Noel says, and revealed numerous previously hidden passages, which can be viewed at www.archimedespalimpsest.org. In one section on mathematical propositions in a treatise titled *Method of Mechanical Theorems*, for example, Archimedes used infinite numbers to help him calculate volumes of particular objects. Although much of that text had been revealed by multispectral imaging, "there have been gaps in our reading," says Reviel Netz, a historian of ancient science at Stanford University in Palo Alto, California. "It seems the new [x-ray] images will definitely contribute to settling the reading."

The new x-ray technique "is absolutely fabulous" for recovering palimpsest texts, says Nigel Wilson, a classics scholar at Oxford University in the U.K. It's particularly exciting, he says, because many palimpsests remain to be studied. —ROBERT F. SERVICE



Eureka. Synchrotron x-rays tuned to reveal calcium brought to life text and drawings (*left*) that multispectral imaging had shown to be lurking beneath later writings by Byzantine scribes (*right*).

CAS 2006 www.sciencemagazine.org Vol.313, Aug 11 2006

Palinsext : "scraped again "

Why
Hard X-ray
Sources

ERL Sources， SASE FELs

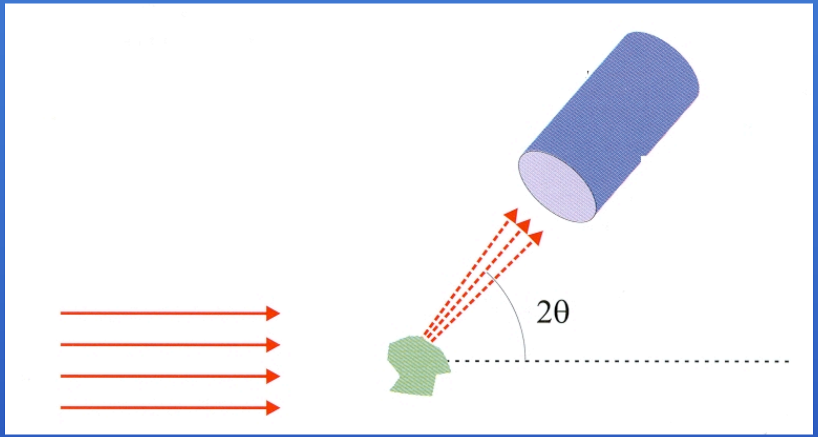
Protein crystallography

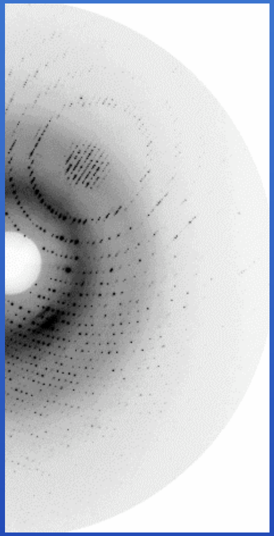
Typical crystal size:
50 µm by 50 µm

Low divergence e.g (0.2 x 0.2 mrad) required for high resolution

very high brilliance

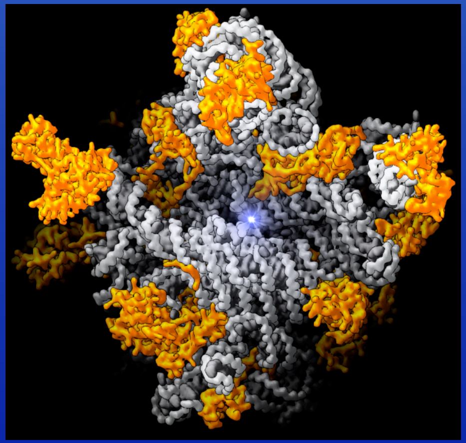
Protein Structure Reconstruction





Diffraction pattern

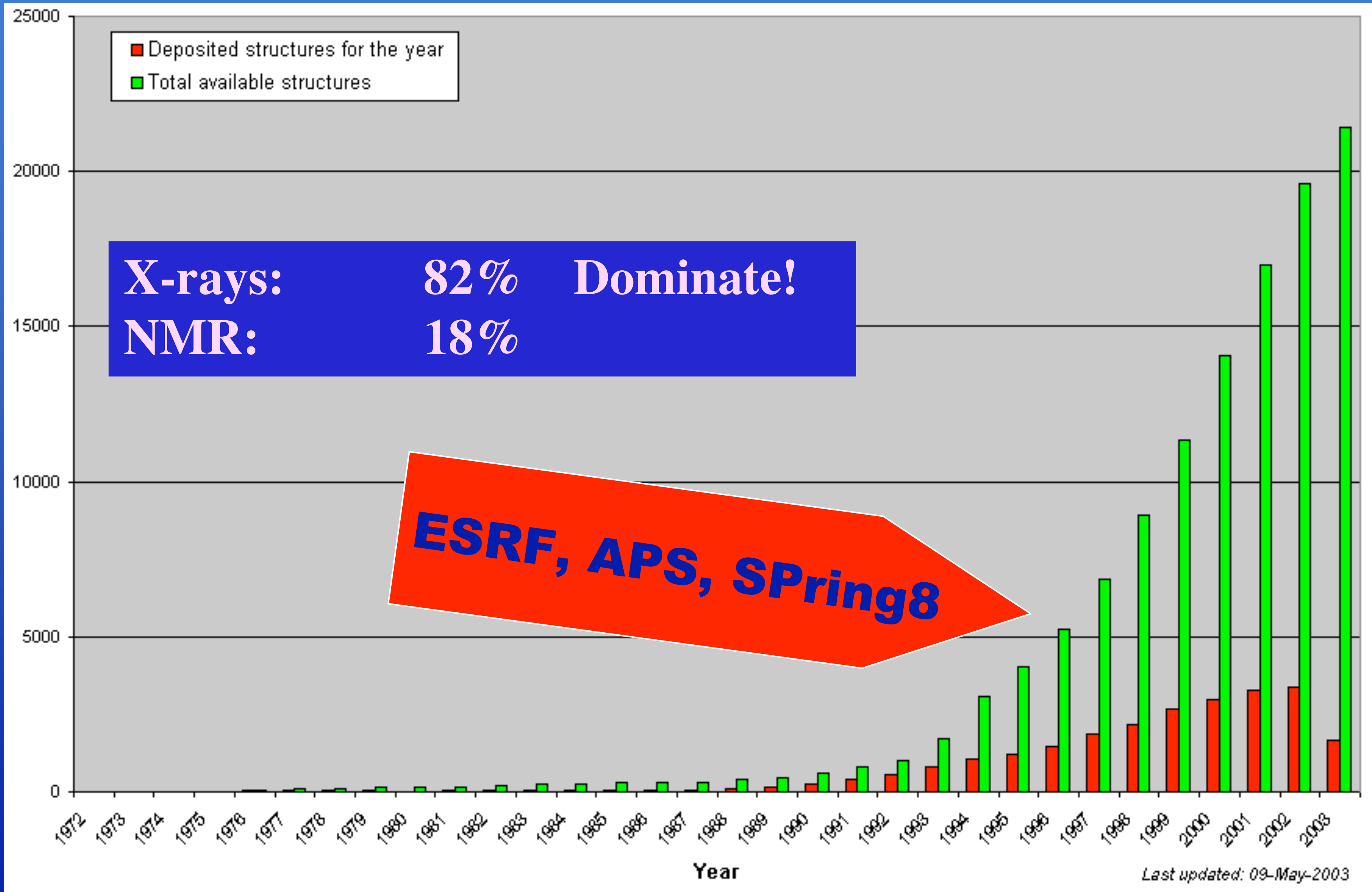
N. Ban et. al.



Part of a Ribosome

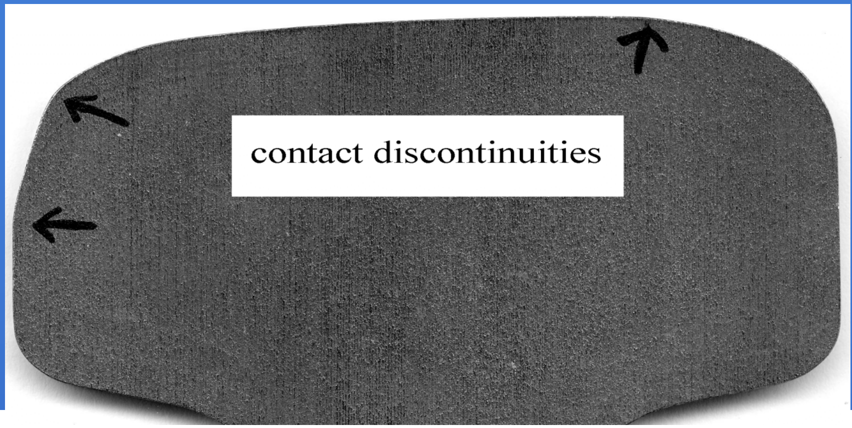
courtesy of L.Rivkin, SLS

Protein Data Bank

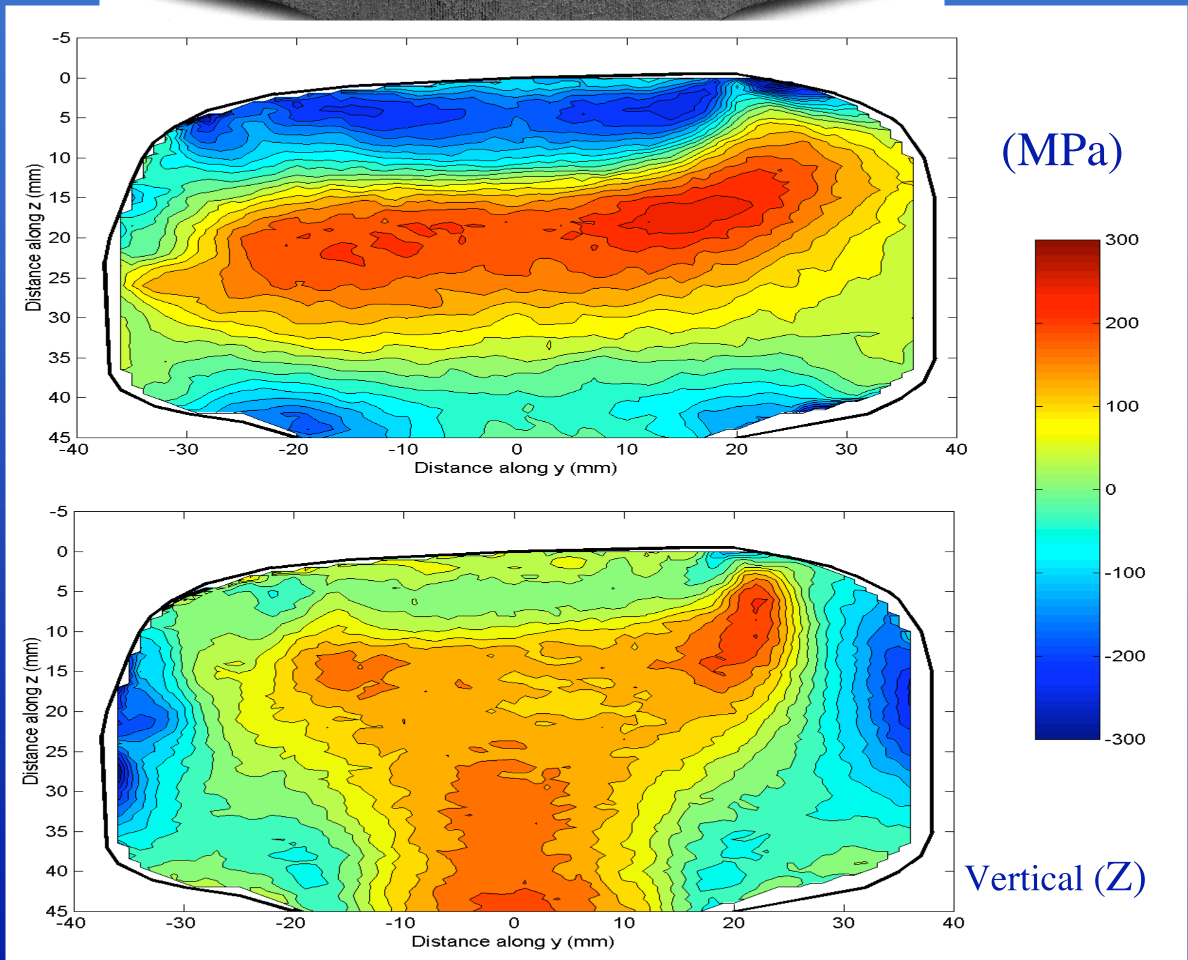


courtesy of L.Rivkin, SLS

...engineering too !



60 KeV X-ray Diffraction study of residual stress profiles in a US railway section.

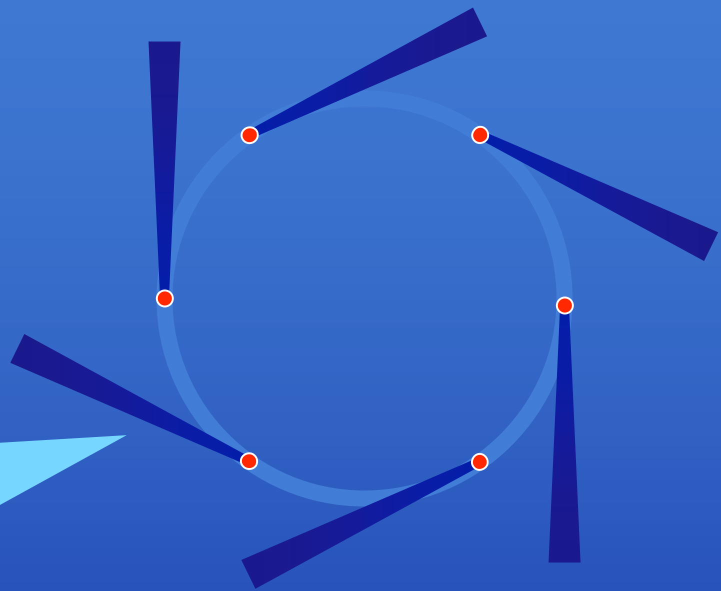


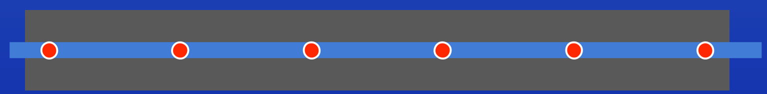
Courtesy of D.J. Hughes
FaME38 (**Fa**cility for **M**aterials **E**ngineering), Grenoble

Linear vs Circular

The brightness depends on the geometry of the source, i.e., on the electron beam emittance

In a storage ring, the electrons continuously emit photons. This "warms up" the electron beam and negatively affects its geometry

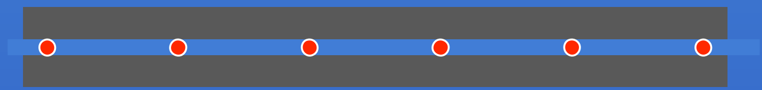




Controlling the electron beam geometry is <u>much easier in a linear accelerator</u>.
Thus, linac sources can reach higher brightness levels

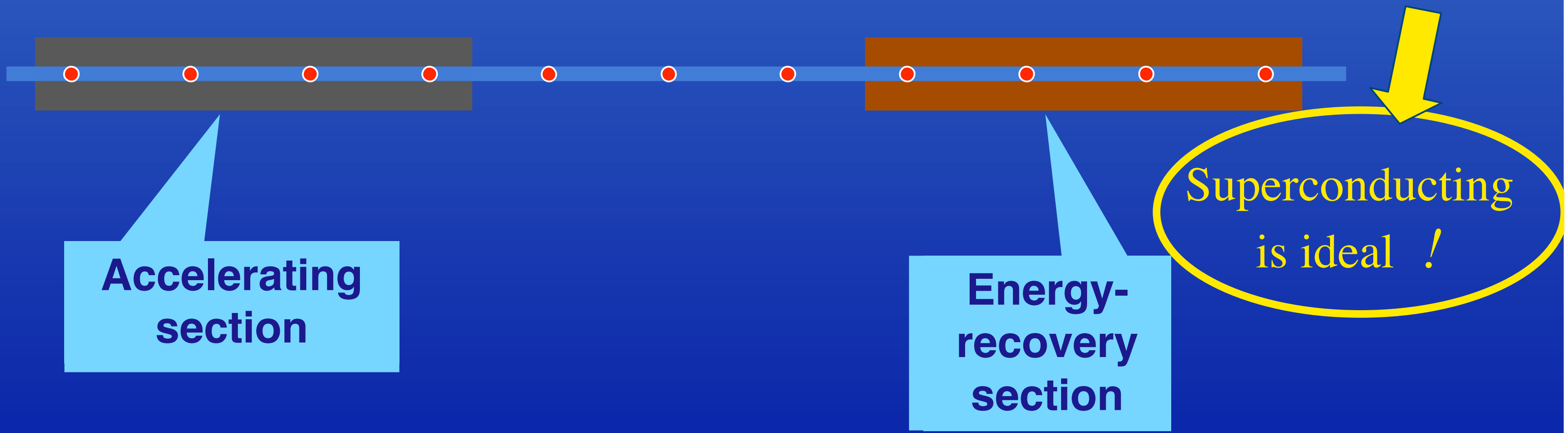
courtesy of L.Rivkin, SLS

Energy-recovery LINAC sources



However, contrary to the electrons in a storage ring, the electrons in a LINAC produce photons only once: the power cost is too high

Solution: recovering energy



courtesy of L.Rivkin, SLS

New Sources

meV

10 KeV

$h\nu$

- FEL oscillators (IR, VUV)
- Inverse-Compton-scattering table-top sources
- Energy-recovery Linac based sources (ERL)
- Self-amplified spontaneous emission (SASE) X-ray FELs

λ

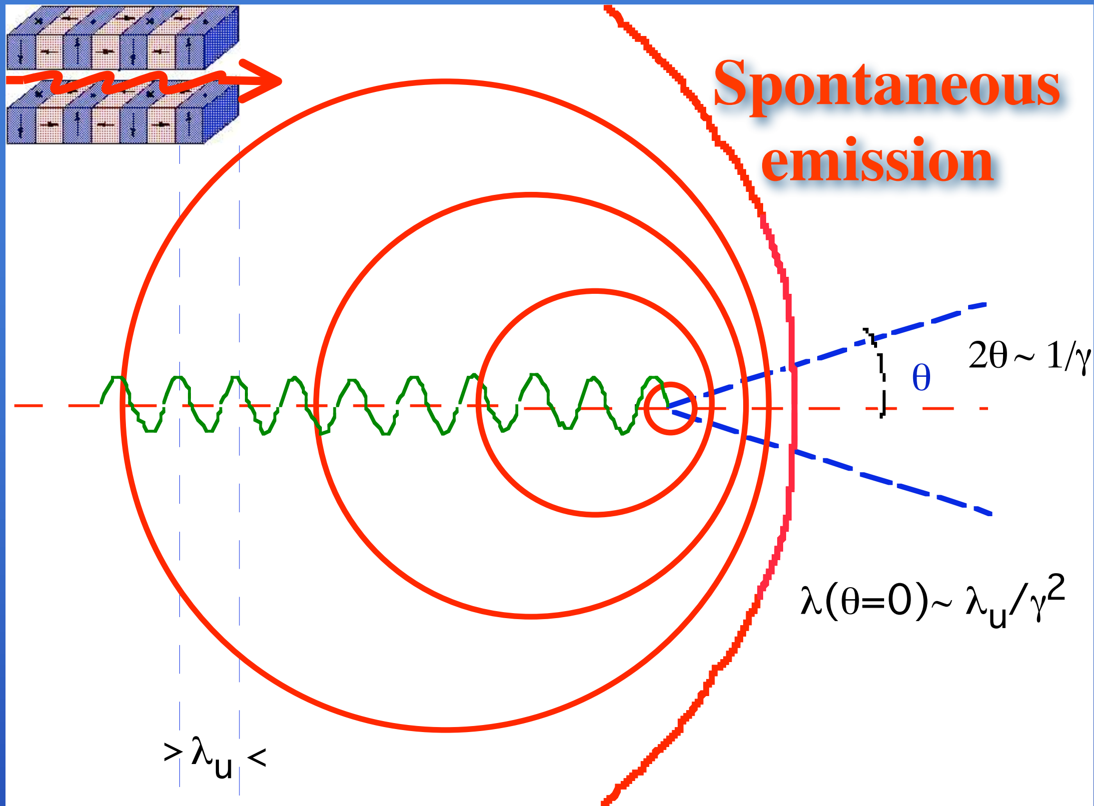
mm

Å

IR, UV
Free Electron Lasers

SR or LINAC
DRIVEN OSCILLATORS.
ENERGY RECOVERY

APPLICATIONS



FEL Oscillator

Principle of operation

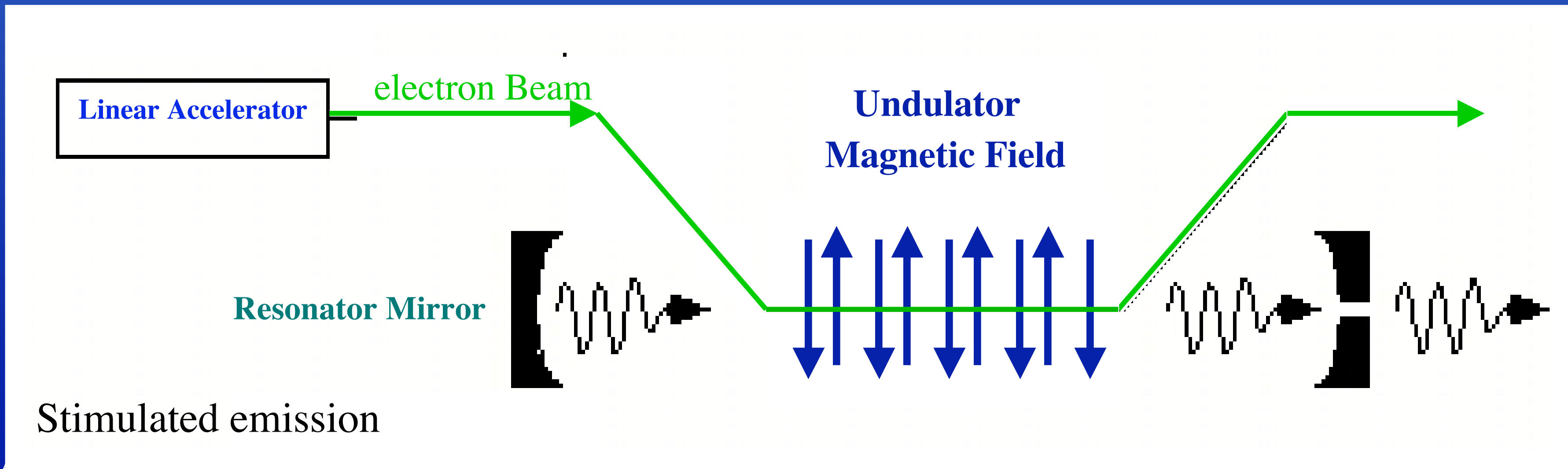
Spontaneous radiation resonance condition: the electron slips back by λ every λ_u because of

e - photon speed difference

$$\lambda \sim \lambda_u/\gamma^2$$

TUNABLE!

(B, γ)



EUFELE

Storage Ring driven FEL Oscillator

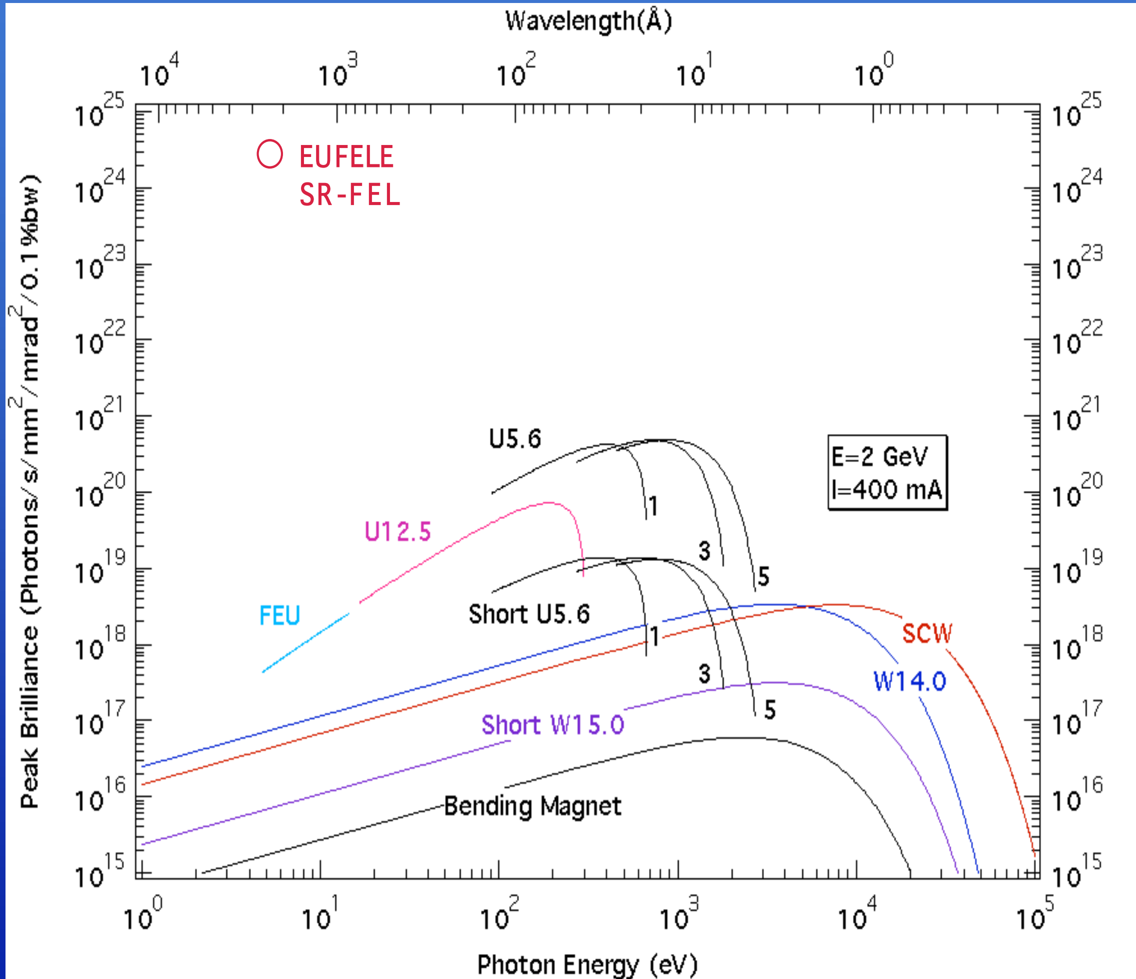
P_{ave} = 500 mW @ 250 nm => B_{peak} ~ 3 ·10^{24} UB (*) , Full spatial coherence

$\Delta\lambda/\lambda$ = 3 ·10^{-4} FWHM

ΔT= 10 ps FWHM-> σ_L= 3 mm

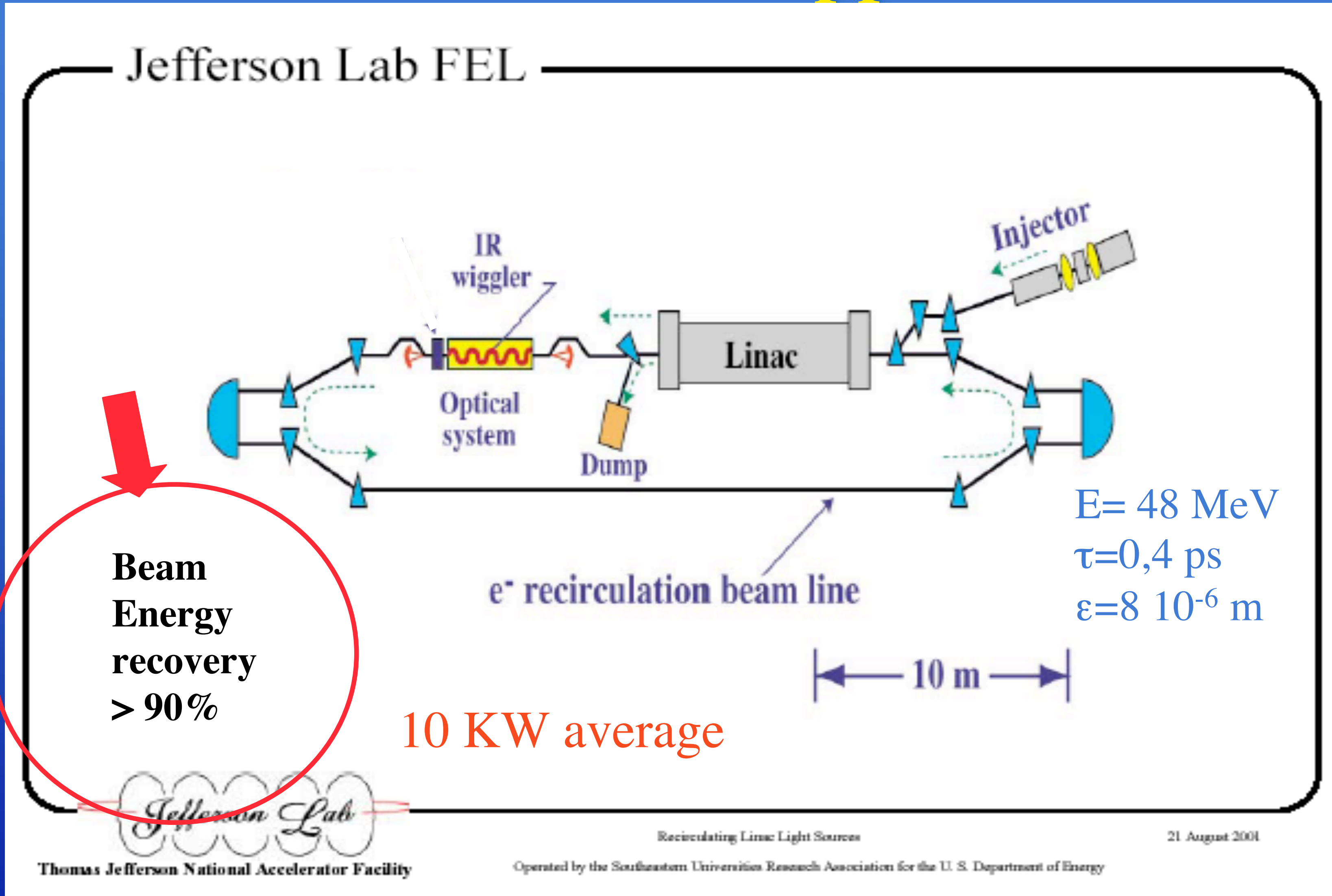
Rep. Rate 4.6 MHz (216 ns)

P_{peak} = 10 kW



Courtesy B. Diviacco (ELETTRA)

FEL for Industrial Applications



Beam Energy recovery > 90%

E= 48 MeV
τ=0,4 ps
ε=8 10^{-6} m

10 KW average

Free-electron lasers
in Surgery (and other medical applications)

- **Most used wavelength band : IR**

Main features that make a FEL a unique tool for surgical and medical applications :

- Tunability

"Tunability is the most important attribute of FEL technology."
(wavelength, power and pulse duration)

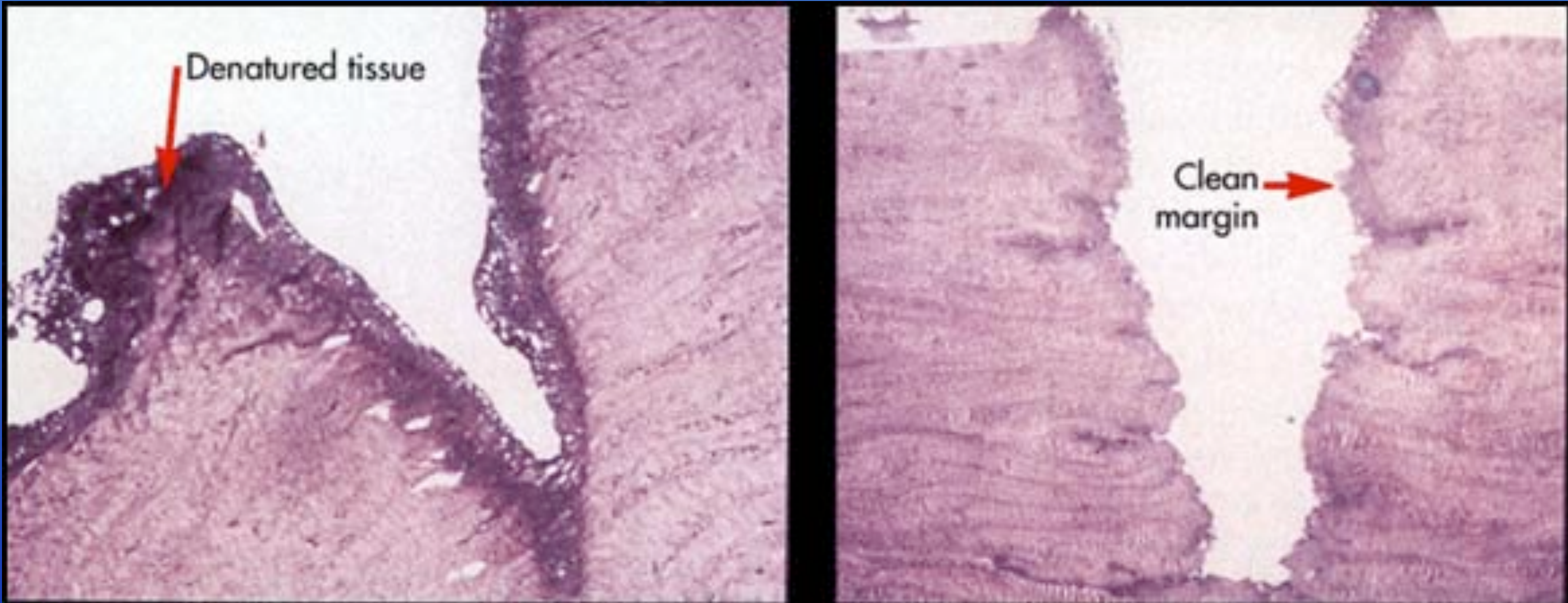
- Coherence (**spot size ...**)

- Time structure

Free-electron lasers 2
in Surgery and Medical diagnostics

- Tunability

Soft tissue vaporization



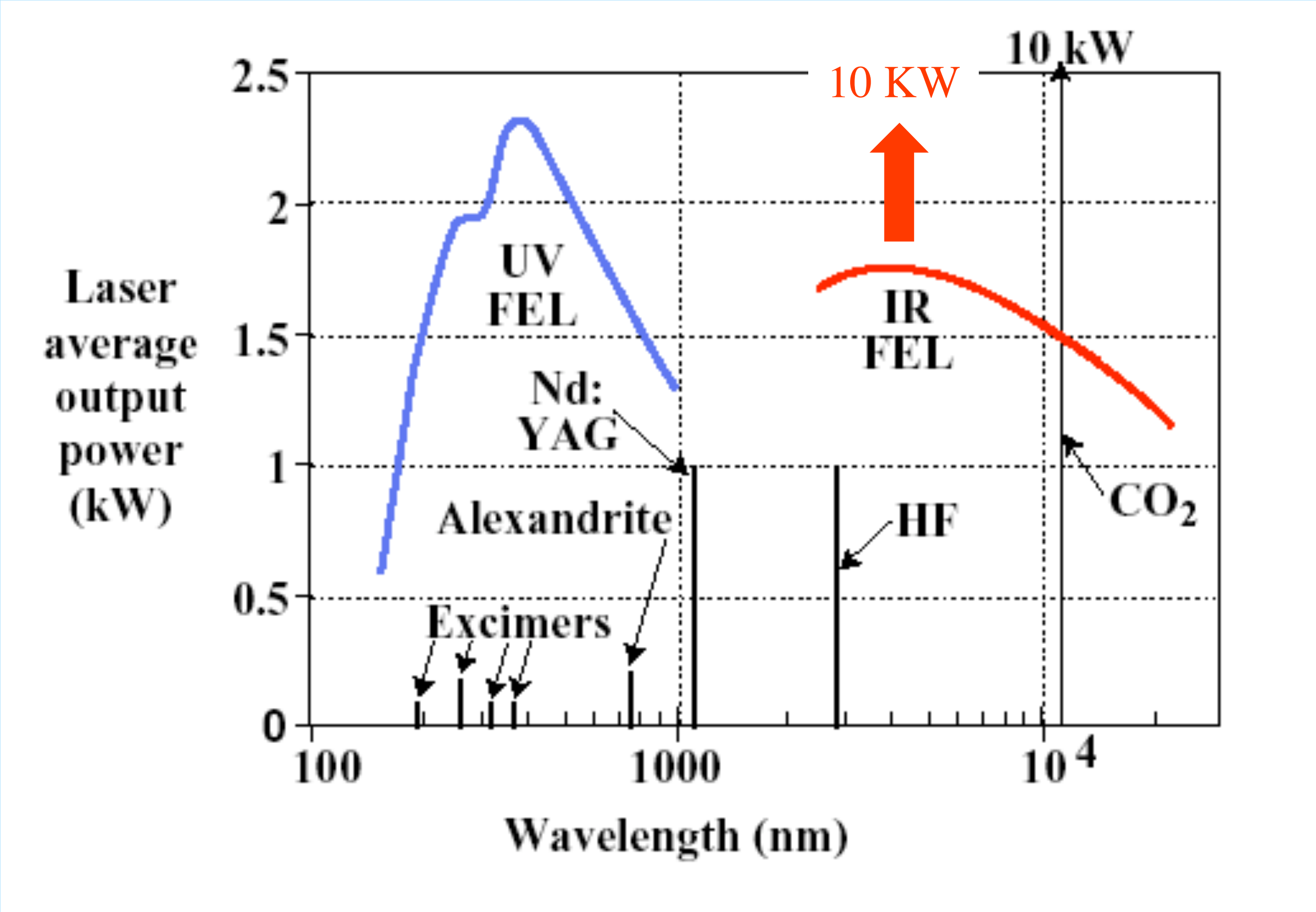
λ 6.45 μm

Two images show how critical proper tuning of the wavelength of the FEL beam is for surgery. The tissue sample on the right was cut with a beam set to 6.45 microns and shows virtually no damage to adjacent tissue. The sample on the left, however, was cut with the beam set at a different wavelength. The darkened areas are result of excessive heat damage.

Photo source: W. W. Keck Free-Electron Laser Center

FEL for Industrial Applications

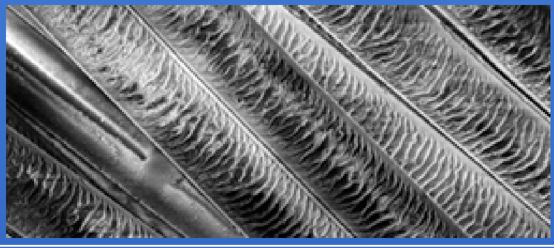
T. Jefferson Laboratory High Power Demo FELs



"Powerful, multipurpose
free-electron lasers (FELs) driven by electron SRF accelerators
prospectively represent substantial, cost-effective
new manufacturing capabilities for industry*." (G.R.Neil, TJ Lab)*

Polymer surface processing:

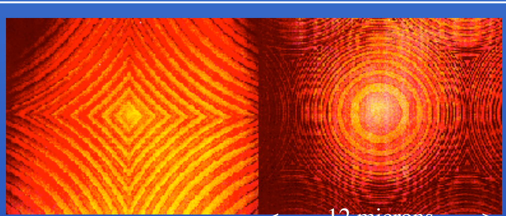
amorphization" to enhance adhesion,
fabric surface texturing, enhanced food packaging
induced surface conductivity.



micrograph of laser treated polyester fabric

Micromachining ,

ultrahigh-density CD-ROM technology
micro-optical components
Micro-Electrical Mechanical Systems (MEMS).



< 12 microns >

Fresnel lens components

Metal surface processing

laser glazing for corrosion resistance and adhesion pre-treatments.

Electronic materials processing

large-area processing (flat-panel displays)
laser-based"cluster tool" for combined deposition, etching, and *in situ* diagnostics.

Carbon nanotubes

Produced 30 times faster than with conventional lasers
aereospace applications

and:

........medical isotope production, fusion, ...

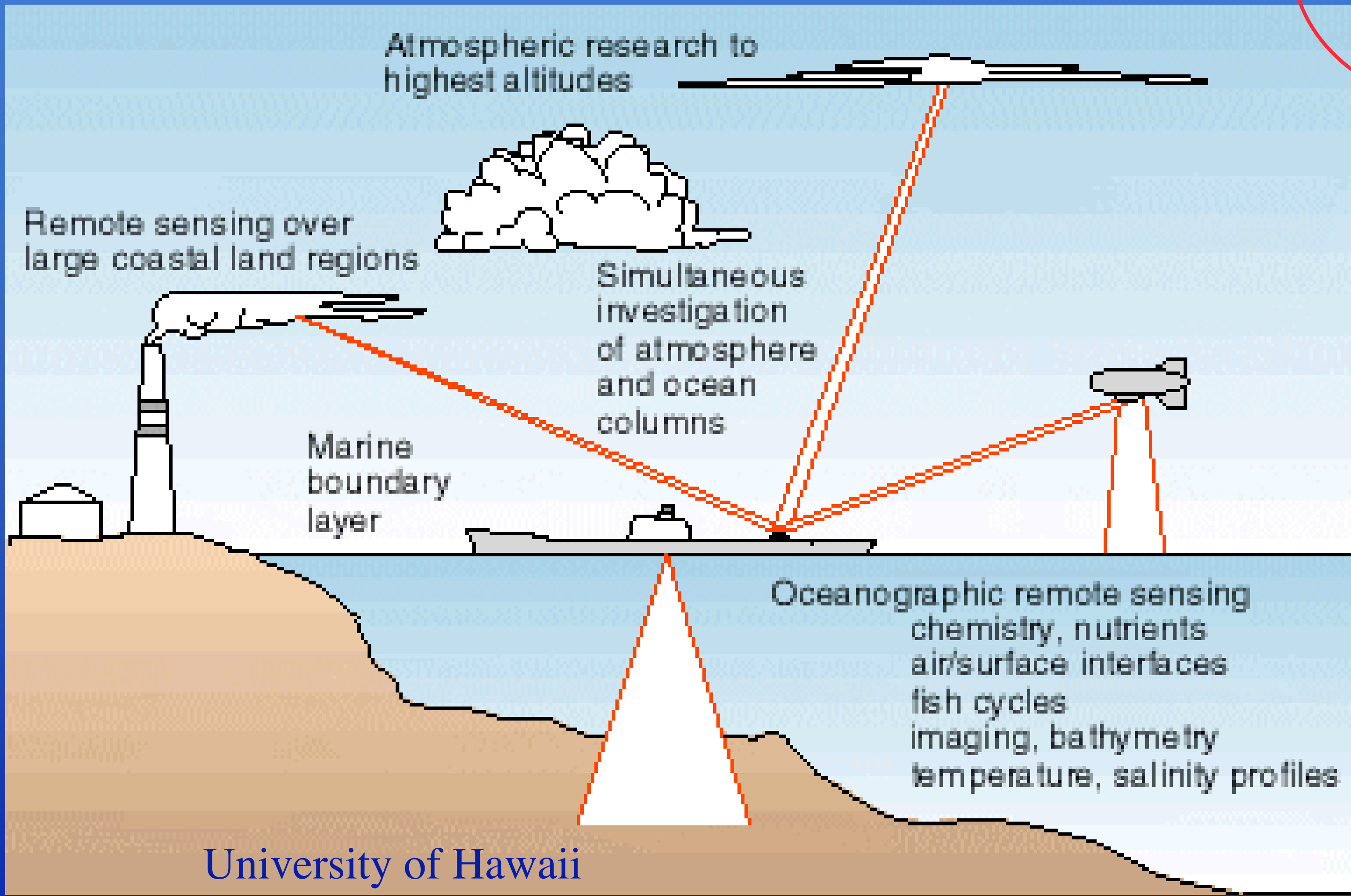
IR-UV Free-electron laser for environmental and atmospheric research

University of Hawaii

Pan-Oceanic
Environmental &
Atmospheric
R esearch
Laboratory

PEARL - Free-electron laser applications in environmental and atmospheric research

LIDAR



University of Hawaii

Pan-Oceanic
Environmental &
Atmospheric
R esearch
Laboratory

Free-electron laser
(less exotic) Space application

Laser-power beaming to generate electricity in satellites is being seriously considered. Compared to solar panels now in operation, the **electrical power deliverable** to a satellite is expected to **increase by** as much as **a factor of ten by using a FEL**.

High-Power Lasers
LASE '99

Towards
X-ray
FEL's

Self-amplified spontaneous emission. X-ray free-electron lasers (SASE X-FEL's)

No mirrors

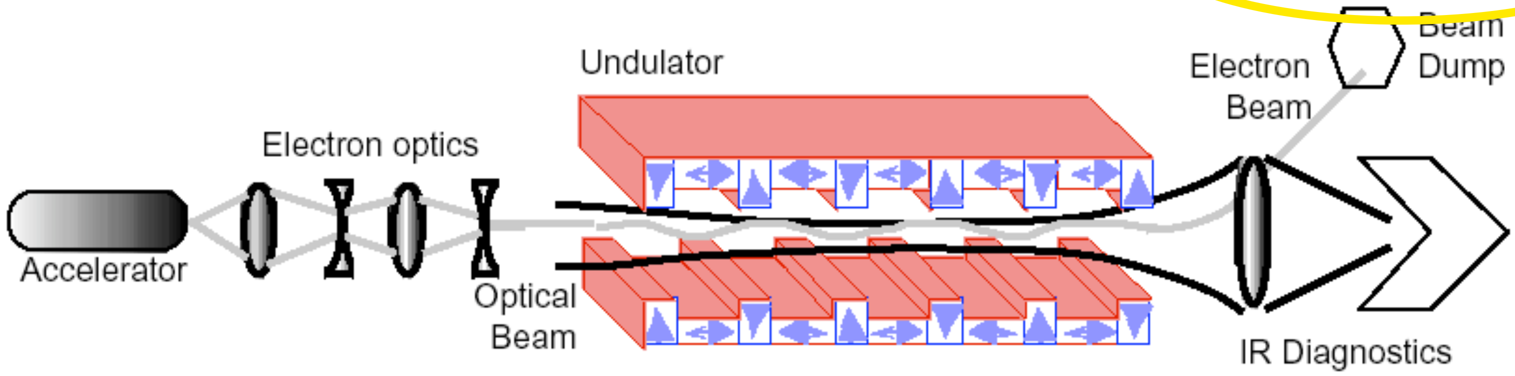
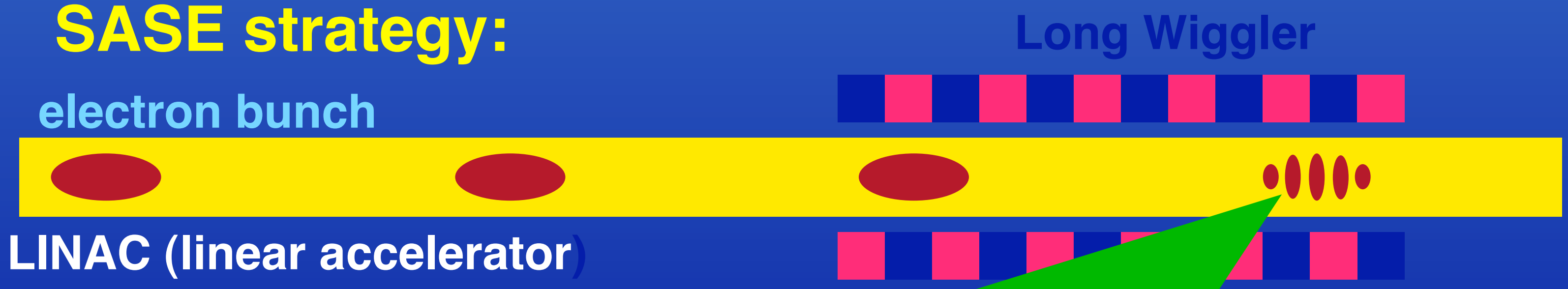


Figure 2.1: The basic components of a single–pass FEL.

R.Bakker

SASE strategy:



"Microbunching increases the local electron density and the amplification and creates very short pulses

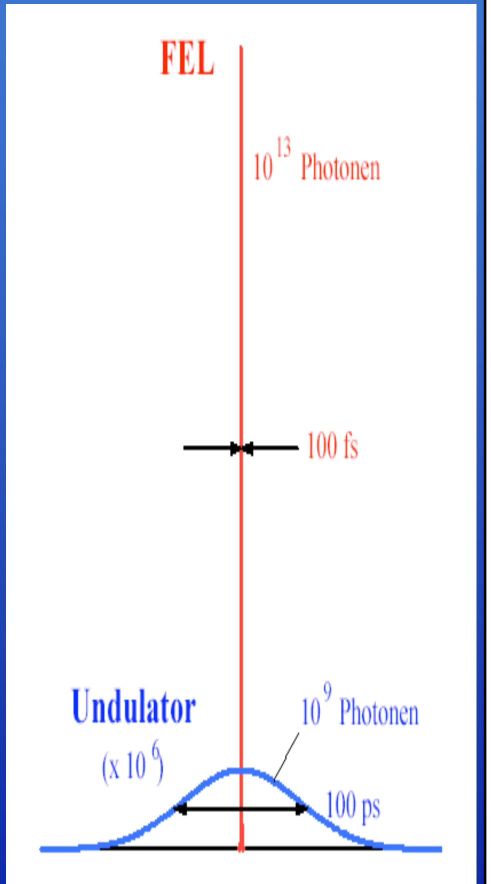
L.Rivkin, SLS

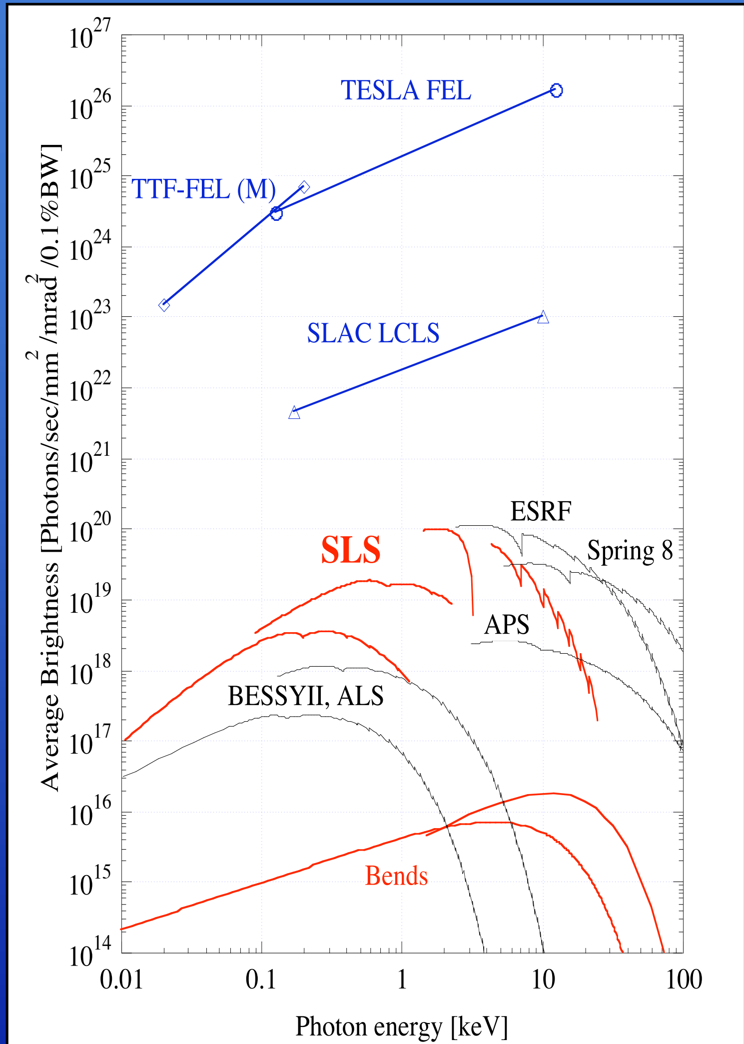
SASE FEL

- **UNBEATABLE BRILLIANCE**
  (10^{30} - 10^{33})

- **HIGH AVERAGE BRILLIANCE**
  (10^{22} - 10^{25})

- **SHORT PULSES**
  (1 ps – 50 fs)

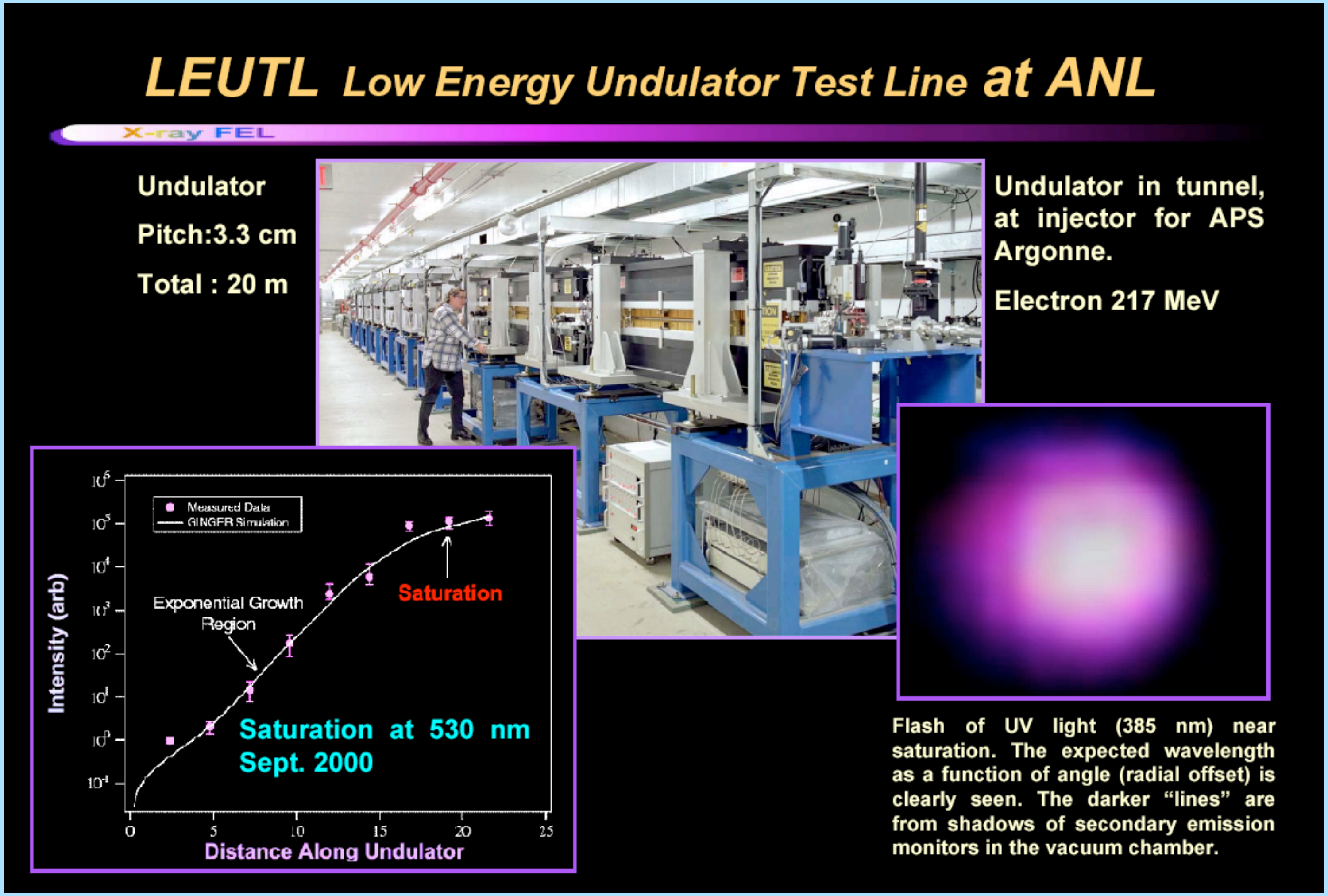




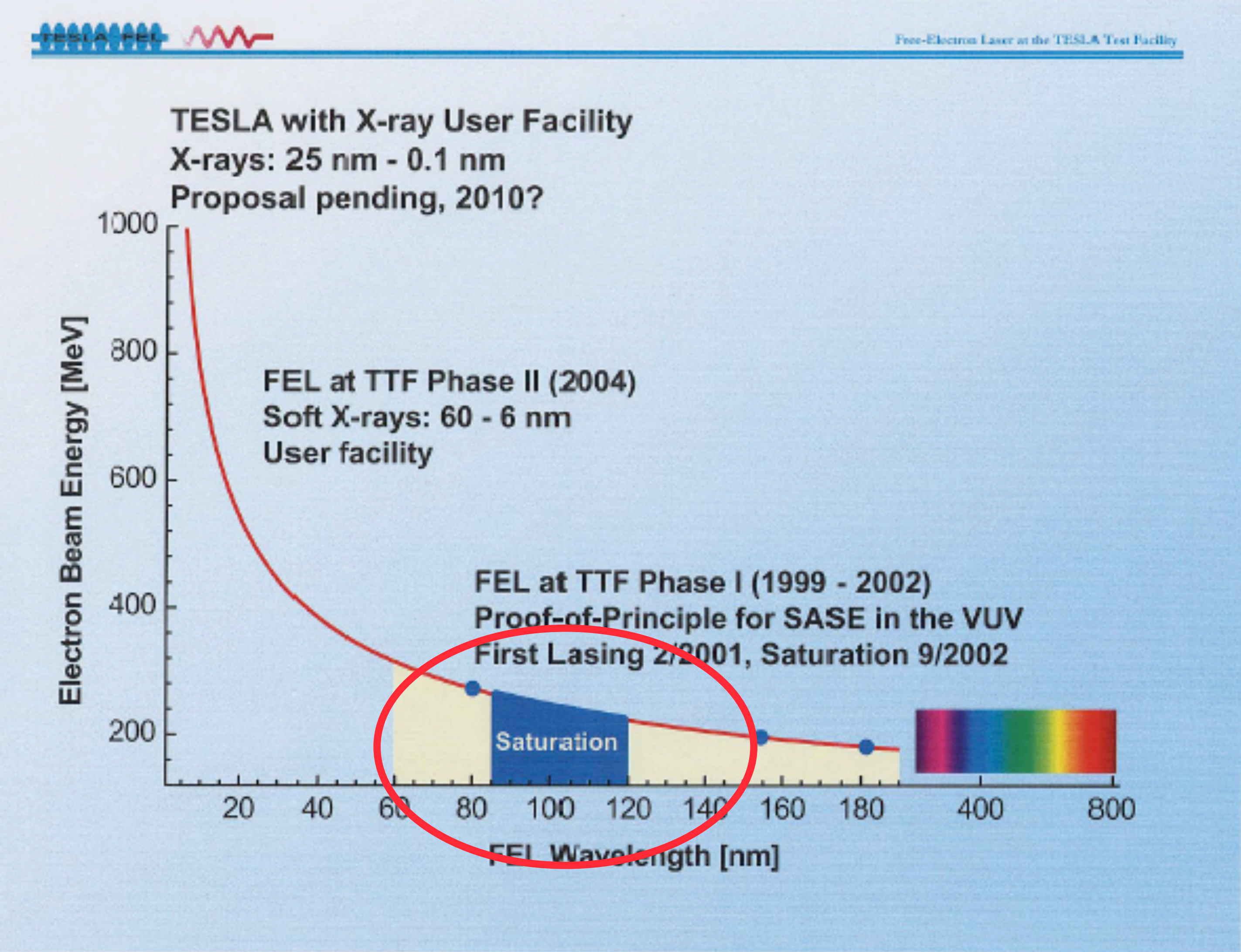
More complex schemes (e.g. seeding) are also being studied

LEUTL (ANL)

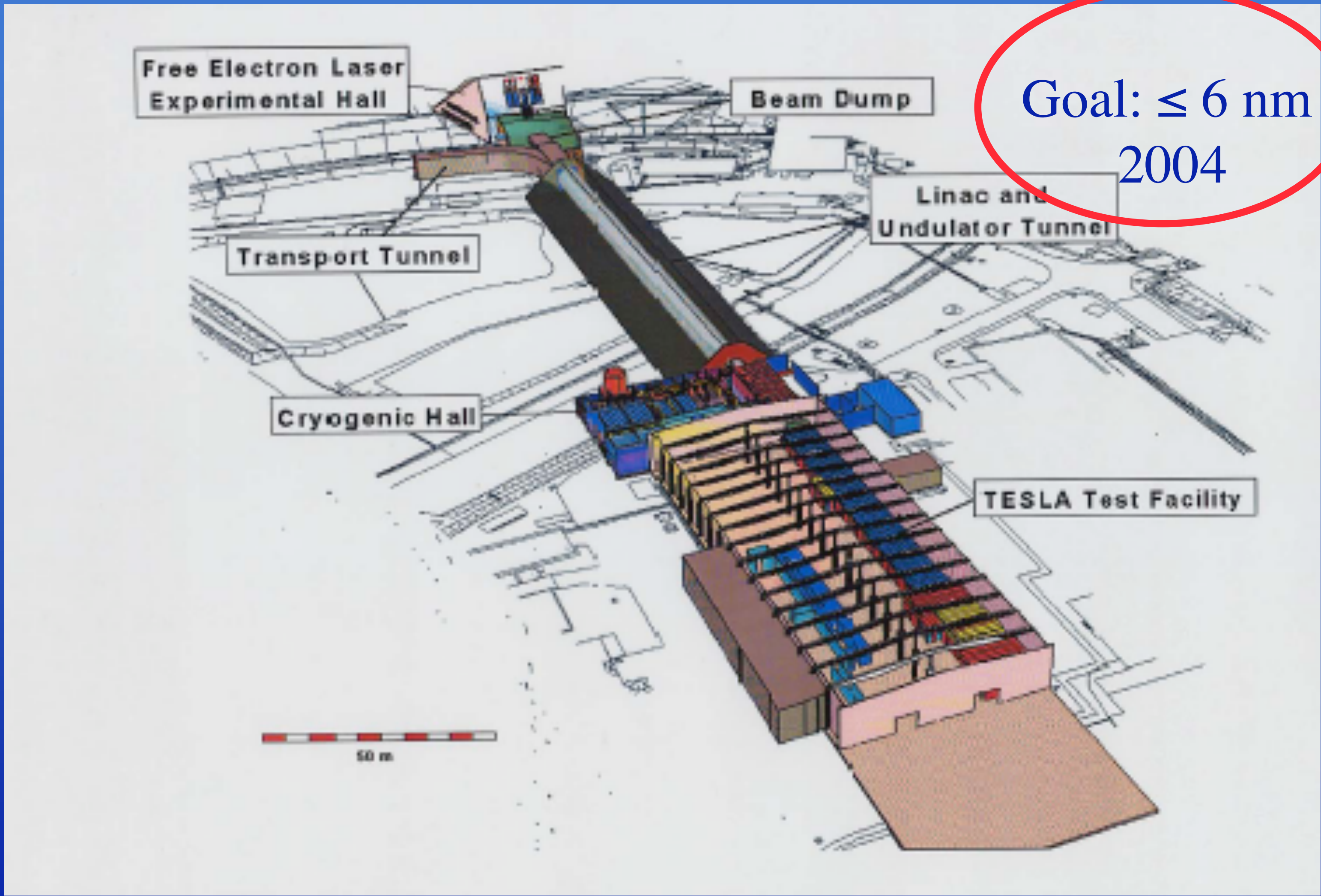
530 nm



TTF SASE FEL


Free-Electron Laser at the TESLA Test Facility
TESLA with X-ray User Facility
X-rays: 25 nm - 0.1 nm
Proposal pending, 2010?
FEL at TTF Phase II (2004)
Soft X-rays: 60 - 6 nm
User facility
FEL at TTF Phase I (1999 - 2002)
Proof-of-Principle for SASE in the VUV
First Lasing 2/2001, Saturation 9/2002
Saturation
Electron Beam Energy [MeV]
1000
800
600
400
200
20
40
60
80
100
120
140
160
180
400
800
FEL Wavelength [nm]

TTF2 (DESY)



Goal: ≤ 6 nm
2004

Many SASE FEL projects are under way ...

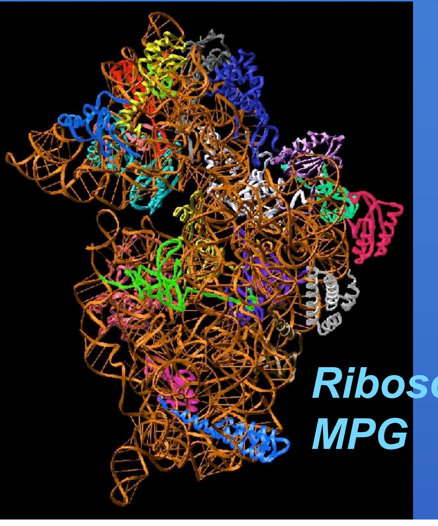
YEAR	NAME	Laboratory	λ [nm]
2000	TTF1	DESY	90
2000	LEUTL	ARGONNE	530
2004	TTF2	DESY	24-6
2006	SCSS	SPRING-8	30-20
2008	LCLS	SLAC	0.15
2008	BESSY	BESSY	100-20
2008	FERMI	ELETTRA	100-10
2011	X-FEL	DESY	0.1

4th Generation
X-ray Sources

OUTLOOK : NEXT GENERATION LIGHT SOURCES

New installations under construction or on the drafting board will allow, for instance:

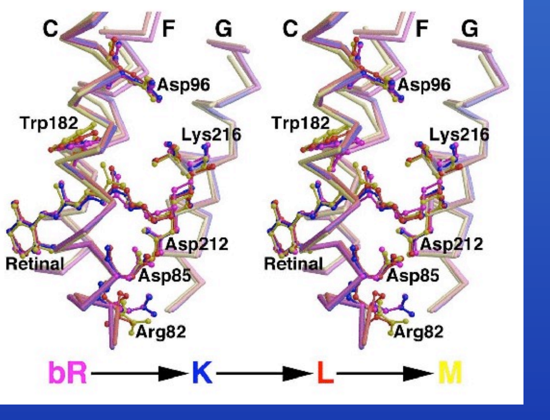
- *to take single-shot photographs of the structure of a single molecule*



Ribosome
MPG

so as to observe its evolution in real time, while chemical reactions are taking place in a living organism.

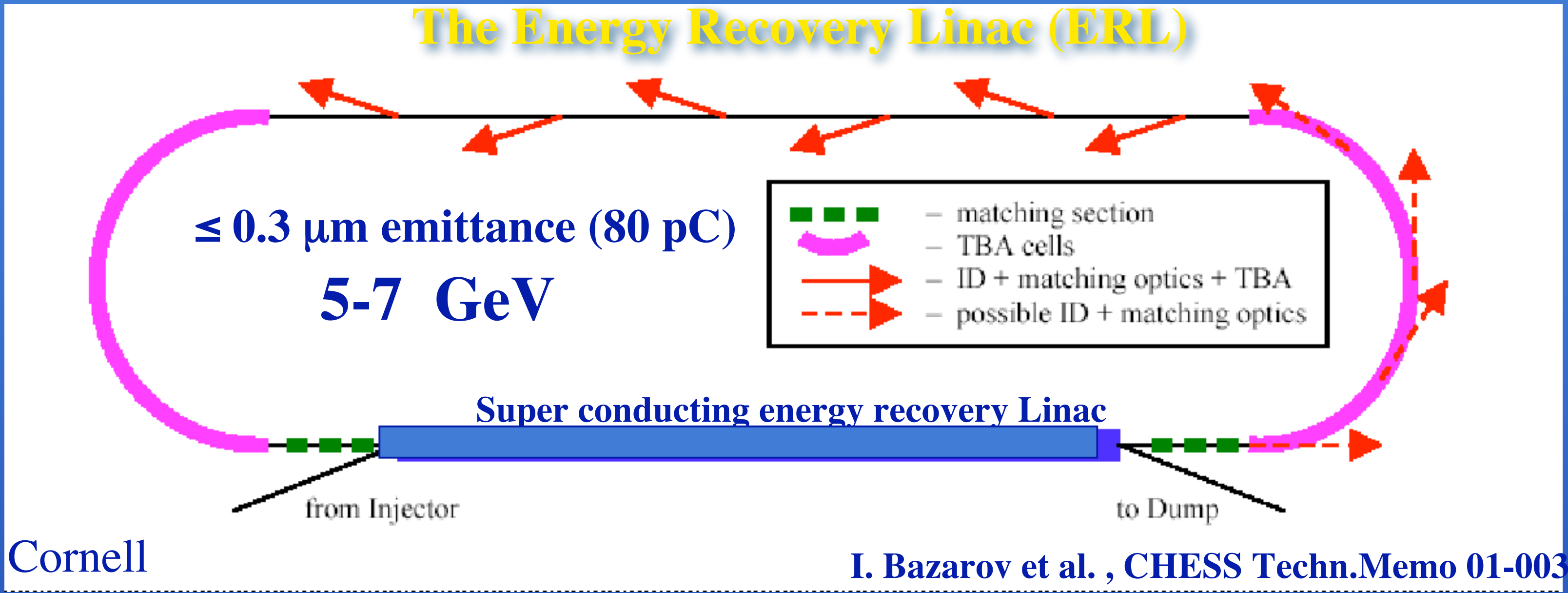
In the figure: Structural changes during a photo-induced chemical reaction



or

- *to produce long enough radiation pulses, i.e. a narrow enough bandwith, to reach the diffraction limit , full coherence*

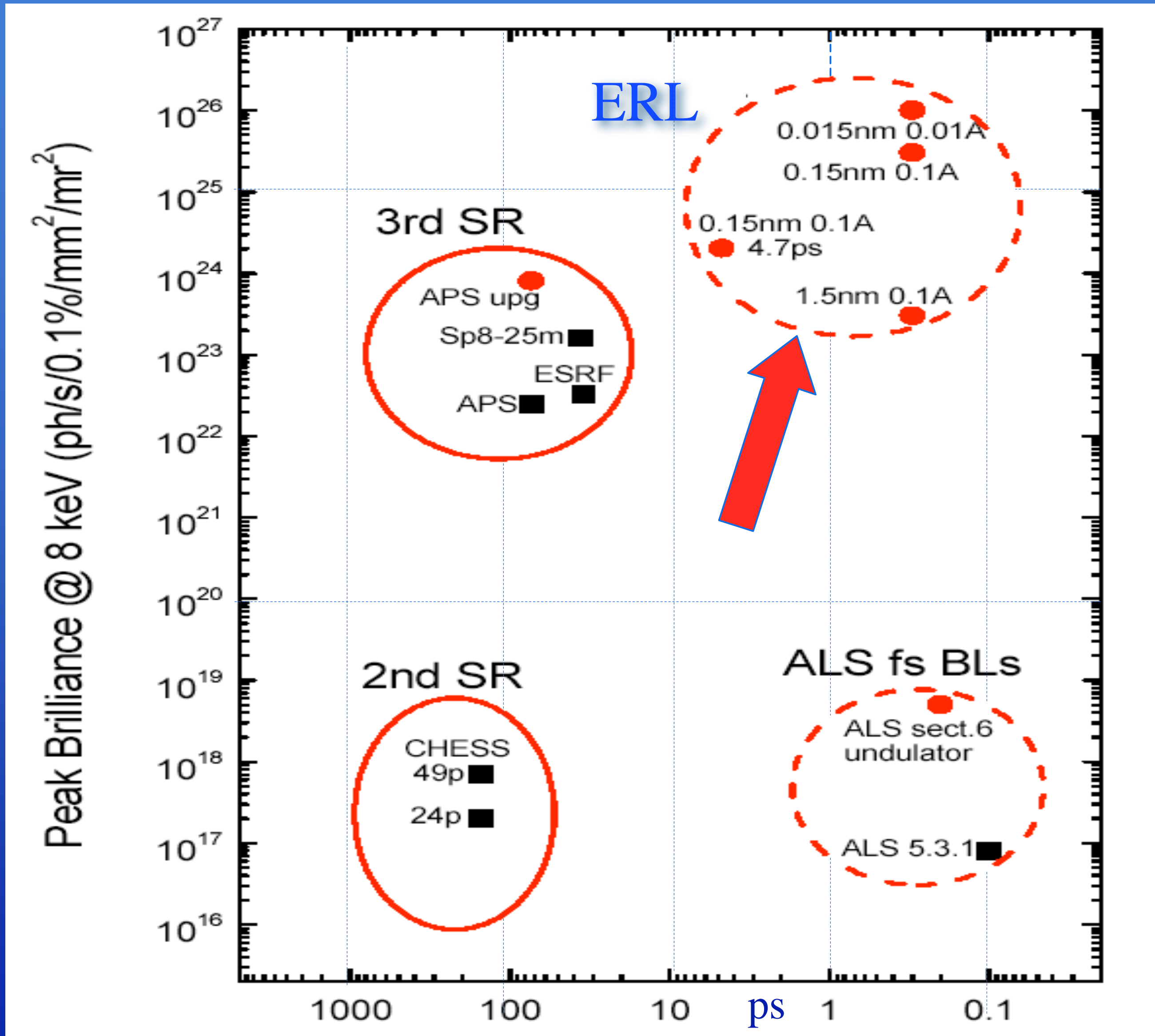
4th Generation X-ray Sources



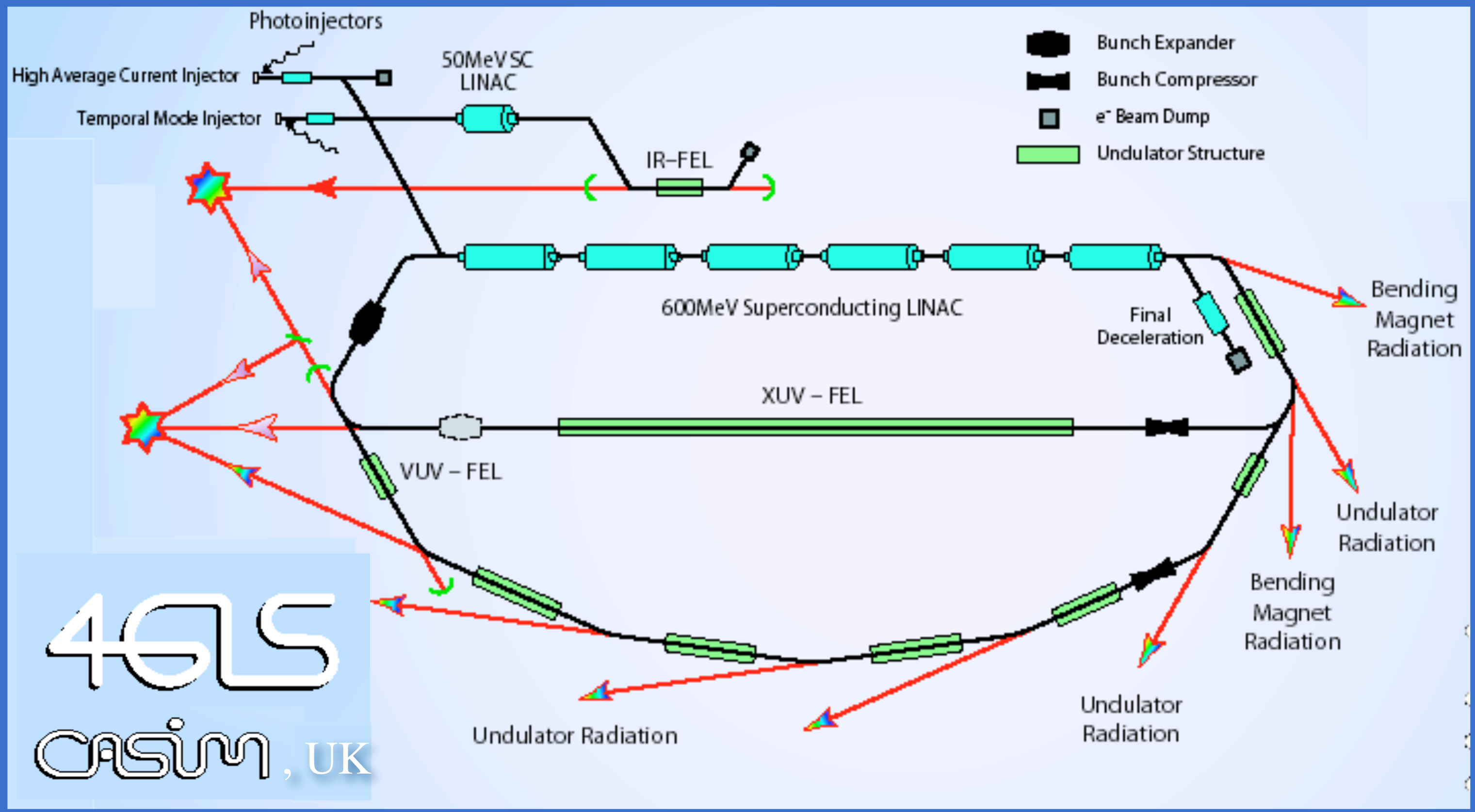
with a SC RF system and energy recovery.
$r = P_{beam} / P_{RF} >$
> 200

- Extraordinary flux.
- Extraordinary brilliance, adjustable via the photo injector.
- Picoseconds bunch lengths.
- Great flexibility in the timing of the bunch sequences.

ERL Short Pulse Performance

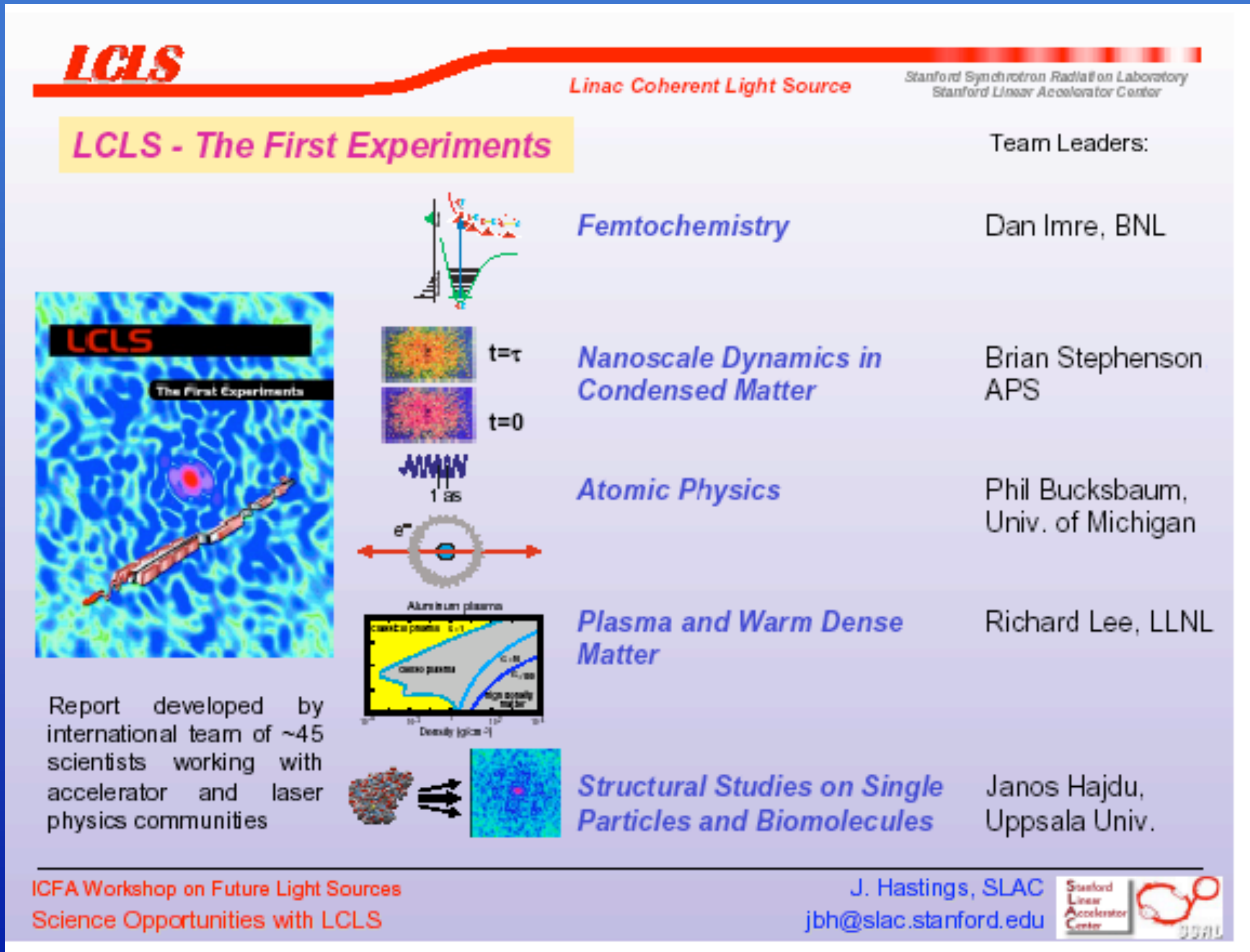


THE UK ERL LIGHT SOURCE DESIGN

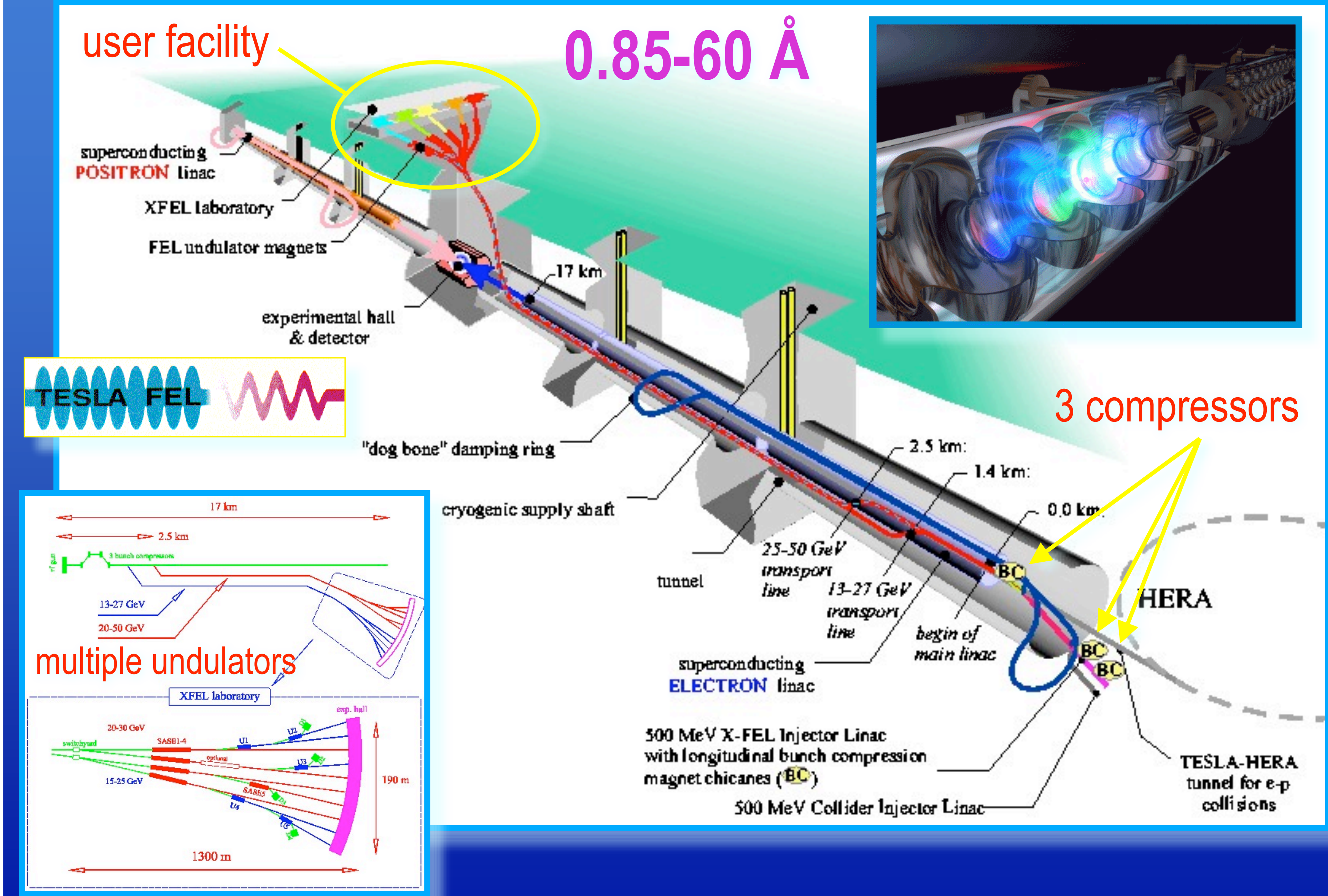


- effectively infinite electron beam lifetime
- very small emittance
- very short pulses
- pulse structure flexibility

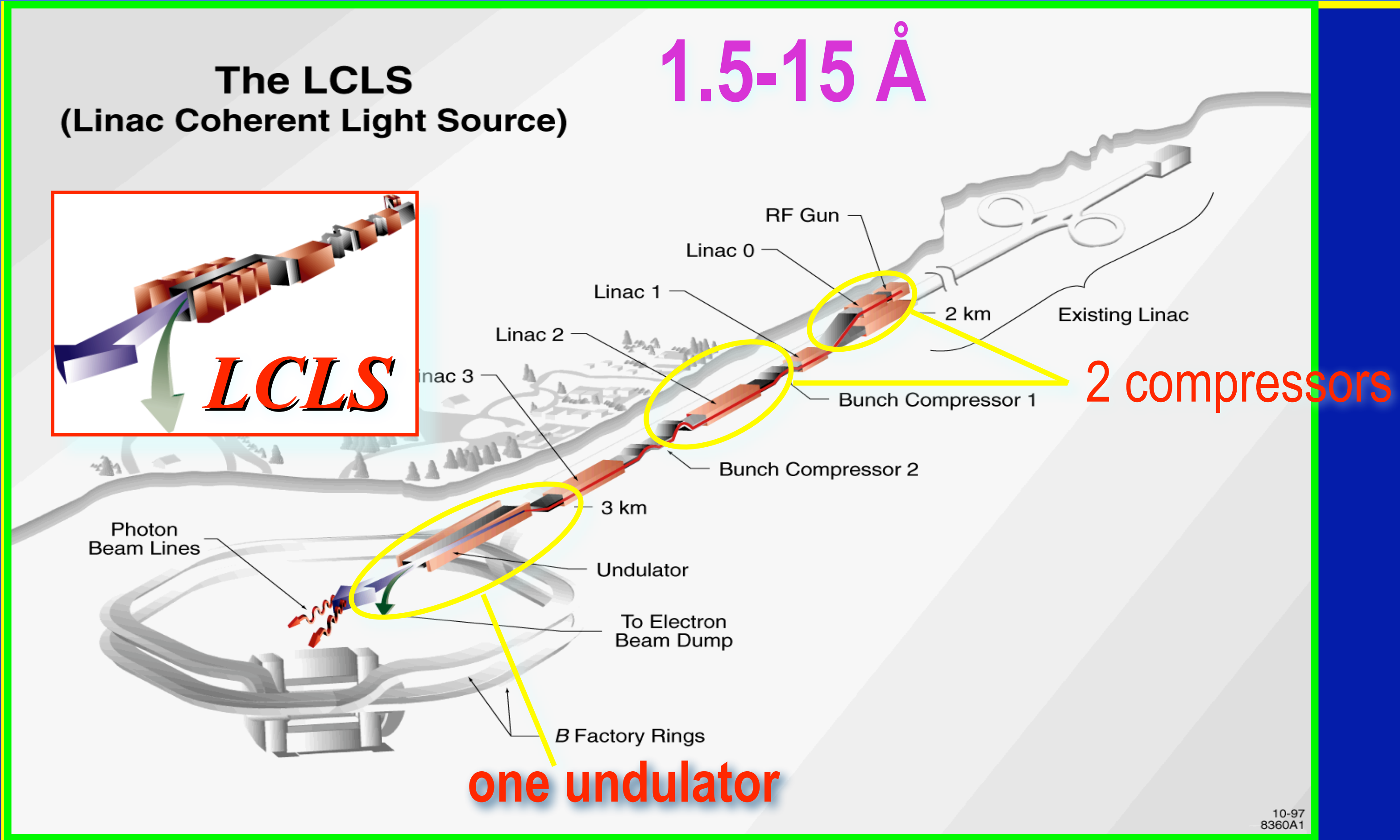
X-ray FEL Scientific Case
(LCLS)



TESLA XFEL at *DESY*



LCLS at *SLAC*



X-FEL based on last 1-km of existing *SLAC* linac

New Acceleration Techniques

"Advancing the Accelerator Art"
(A. Sessler)

The **maximum achievable accelerating field** determines not only the accelerator **cost per GeV**, an all important parameter for VHE LinColl, but also its **physical dimensions**, crucial for most applications (e.g. medical instruments).

- **R&D** on the next generation "warm" LinColl has therefore led to the development of **very high frequency, high field RF systems** and of their **power drivers.**

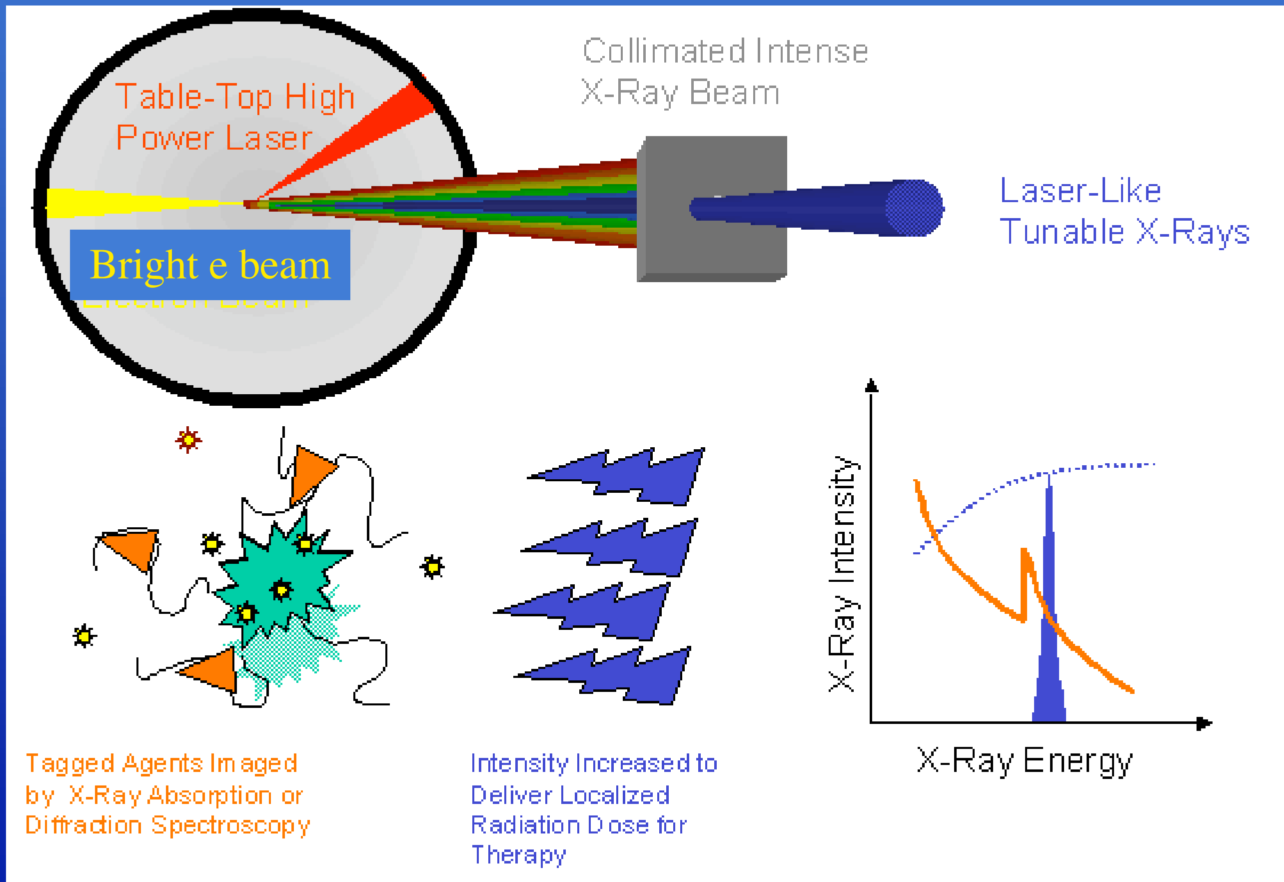
NLC/JLC: 11.4 GHz, **75 MV/m** (unloaded) an its MW Klystrons ⇒ **Application**

CLIC: 30 GHz, **>150MV/m** (unloaded), and a novel **two-beam powering scheme**

CSX Source

Collimated, intense, quasi monochromatic X-ray beam

The electron beam is generated by a 75 MeV/m NLC (15 GHz) type Linac section



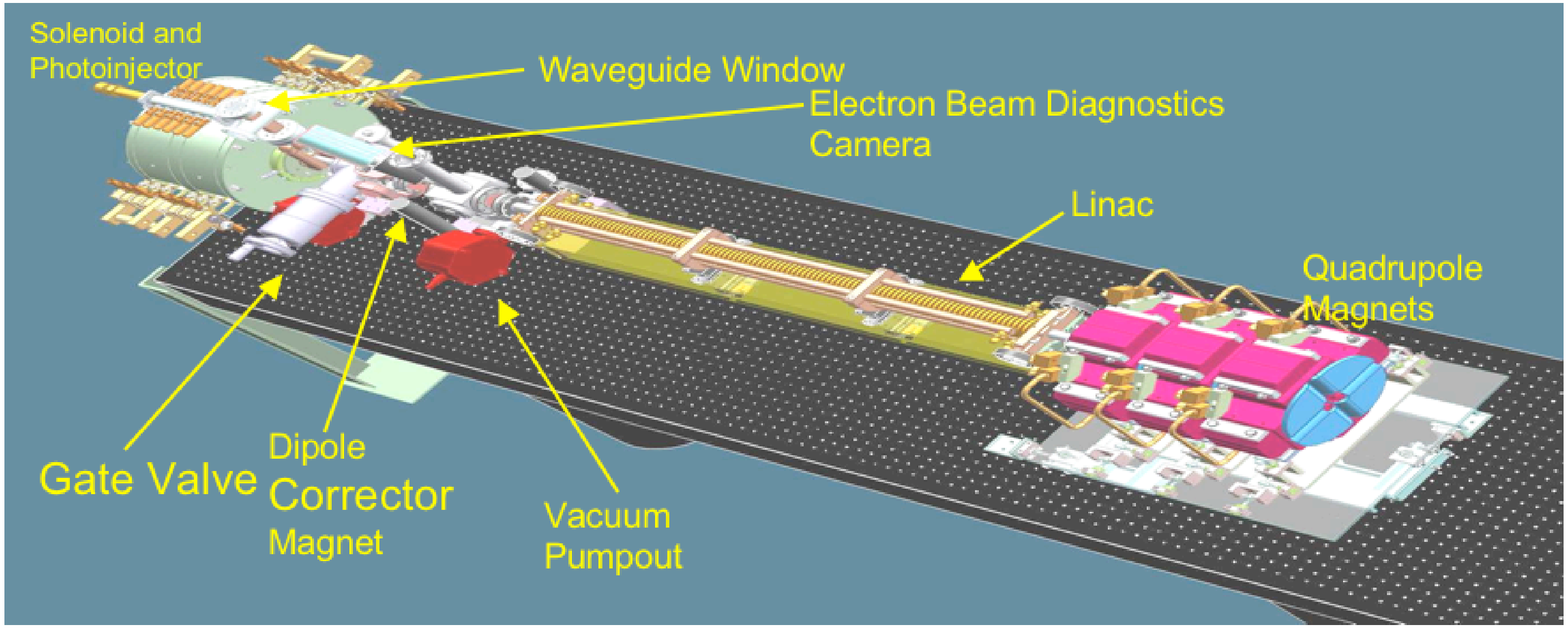
Compton X-Ray Source Development

A.E. Vlieks, D. Martin, G. Caryotakis
Stanford Linear Accelerator Center

D. Price
Lawrence Livermore National Laboratory

C. DeStefano, J.P. Heritage, E.C. Landahl, B. Pelletier, N.C. Luhmann, Jr.
Departments of Applied Science and Electrical and Computer Engineering, University of California, Davis

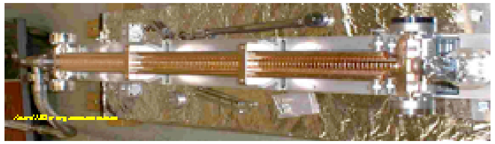
Short pulseTW laser beam off energetic electrons from a **linear accelerator**, producing **x-rays that are tunable between 20 and 100 kV** by changing the energy of the electron beam.

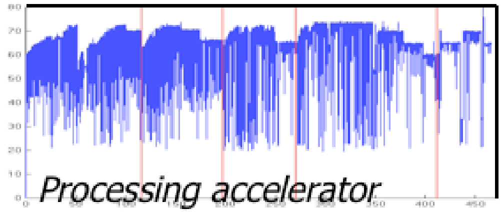


Compton X-Ray Source Development

SLAC Compact X-band Accelerators and Microwave Power Sources

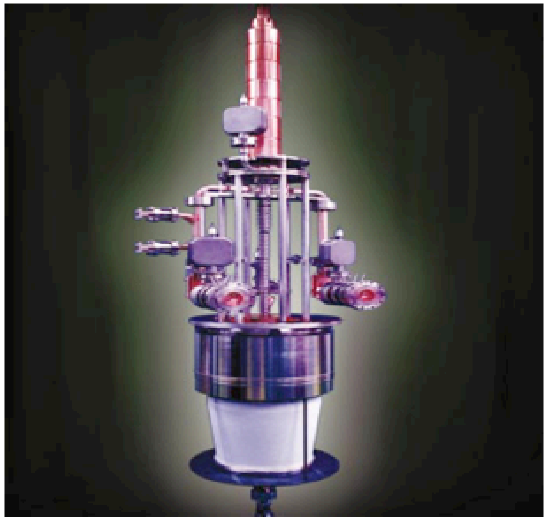
- X-band permits high gradients of up to 75 MV/m
- Four times smaller than conventional technology
- Focusing of ~ kA beam to 30 microns in < 2 meters
- Opens up a new energy and intensity frontier to the medical community



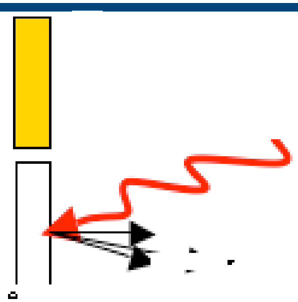


Processing accelerator structure to 75 MV/m

- **X-band klystrons developed for the Next Linear Collider**
- 11.424 GHz
- 1.5 μs pulsewidth
- 60 MW output power
- 420 kV, 327 A
- Two klystrons used for CXS-10; however, the clinical device will use a single source



Compton X-ray source : Laser

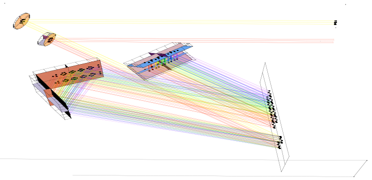


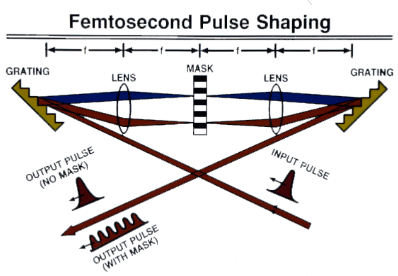
Effect + RF
Acceleration

UV Laser light

1. Emission of electrons from surface is characterized by laser pulse shape and intensity
2. Pulse can be very short. (≈ 0.1-1 ps)
3. Current can be high. (0.5 nC chargeÞ630 A for an 800 fs pulse)
4. Beam size can be small. Size is determined by laser pulse shape.
5. RF fields can be very high. (≈ 200 MeV/m)

Table-Top Terawatt Laser





- The same high field conditions that exist inside a synchrotron x-ray source are generated at the interaction point for only 5 x 10^{-14} seconds
- Ultrashort optics techniques are utilized to synchronize and shape the laser for optimum electron beam and x-ray production

New Acceleration Techniques

"Advancing the Accelerator Art"
(A. Sessler)

- **New technology** (and a great deal of Physics !): Laser or e-beam driven plasma wake fields are in the main R&D line *(triggered originally by dev'pt of table–top TW lasers).* **Field gradients > 150 GV/m** can be reached

Plasma oscillation wavelengths and longitudinal field values can be estimated from

$$\lambda_p \approx \sqrt{\frac{10^{15}\,cm^{-3}}{n_o}} \quad [mm]$$

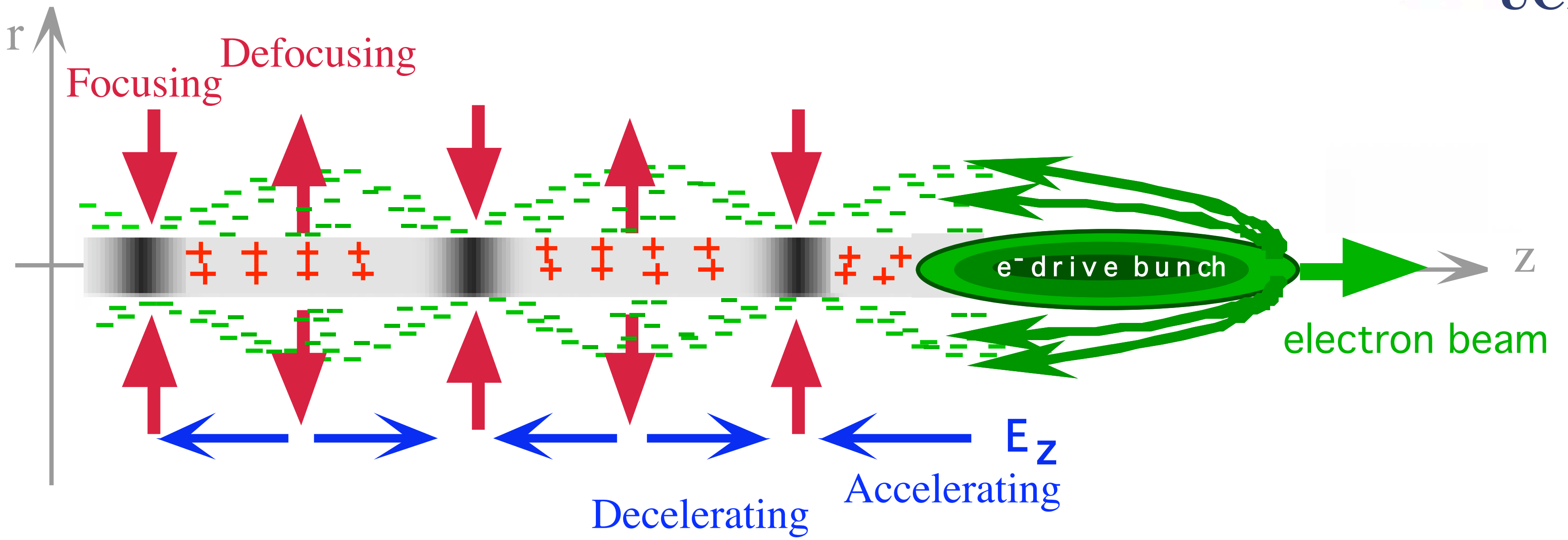
$$E_z \approx 100\sqrt{n_o} \quad [V/m]$$

n_o =plasma density

Peak laser powers today reach up to 100 *TW* with focused intensities of $\approx 10^{20}$ W/cm^2. Future 6 orders of magnitude higher intensities could produce very bright, *TeV*, sub-picosecond intense e^- pulses over a few cm.

HE tabletops : an entirely new generation of applications

Maximum acceleration with intense beams: Plasma Wakefield Accelerator (PWFA)



- Plasma wave/wake excited by a *single* relativistic electron bunch
- Plasma e^- expelled by space charge forces => energy loss, focusing
- Plasma e^- rush back on axis, induction field => energy gain
- Plasma Wakefield Accelerator (PWFA) = Beam Energy Transformer
  Booster for high energy accelerator?

Courtesy of J. Rosenzweig (UCLA)