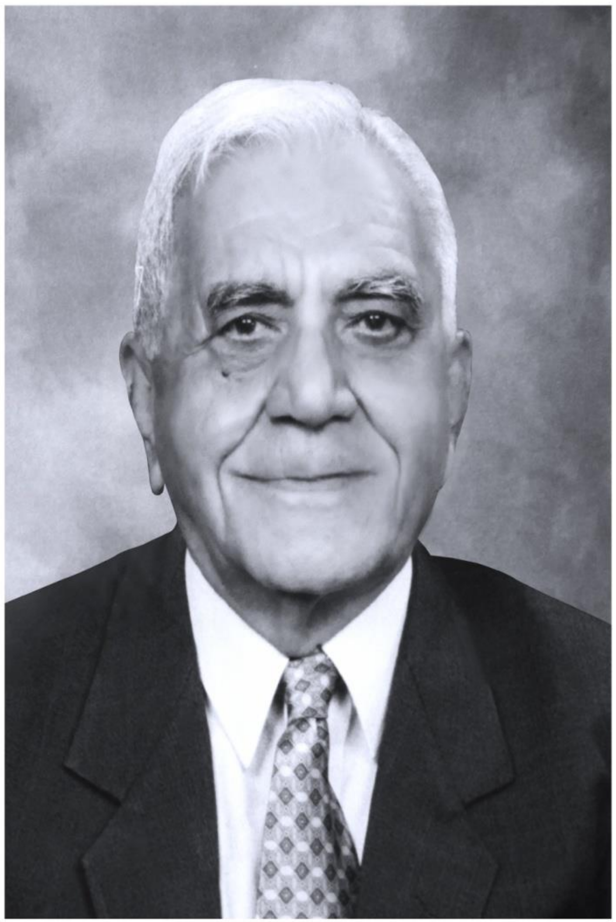
Prof. H S Hans :

A great visionary, world-class researcher and scientific team leader, excellent teacher , exemplary motivator . . . . .




INSAC-2012
Nuclear Society
Construction
Power Plants
400094
INDIAN NUCLEAR SOCIETY
r. R.K. Sinha
S.K. Sharma

Annual Convocation of Panjab University, Chandigargh 1971

I owe a great deal to Prof. Hans .. ..

I recall with great pleasure my two years at Physics Hons. School during 1970-72.

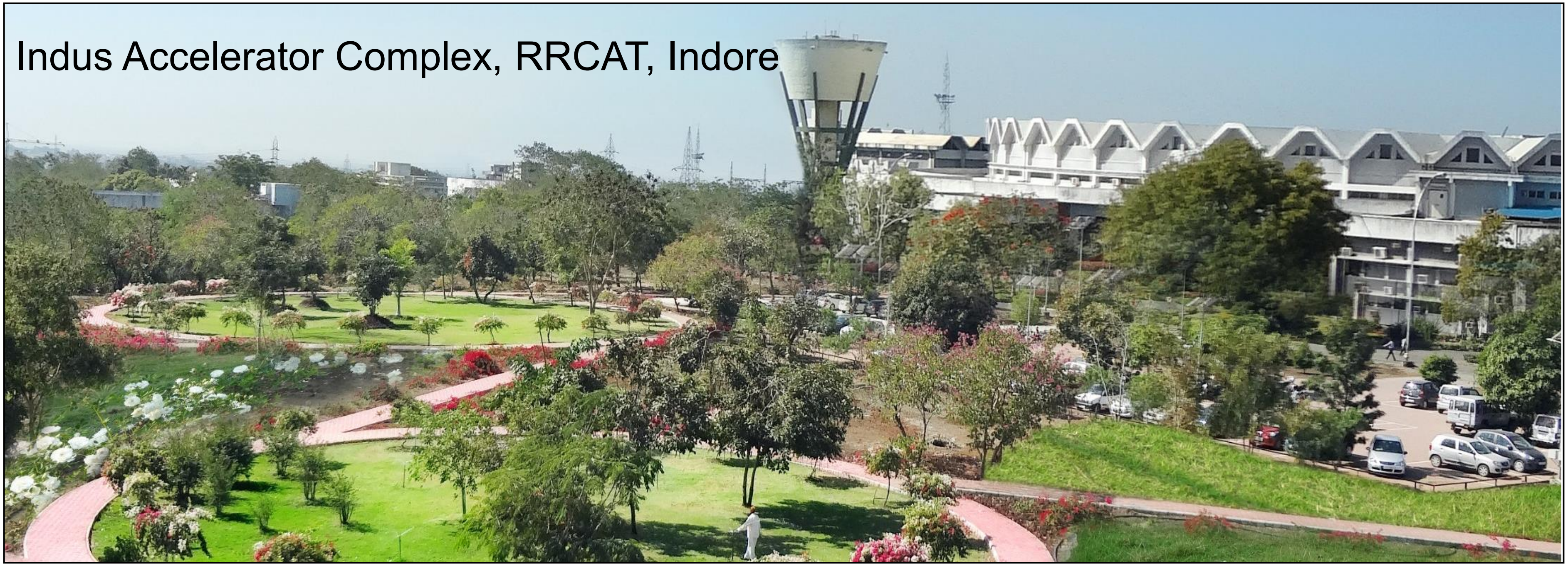
- My heartfelt regards to my all teachers : Prof Pathak, …..
- Wonderful group of batchmates Prof. Arun Grover, Prof. Ajay Sood, Prof. Manmohan Gupta ....
- Great environment of Physics Hons. School and Panjab University Campus at Physics Hons. School

We all take great pride in the stupendous accomplishments of Physics Department and Panjab University, making world-class contribution to the Research Program at Large Hadron Collider, and being the top University on the National Level.

Synchrotron Radiation and Intense Laser Beams for Innovative Research and Applications

P. D. Gupta

Homi Bhabha National Institute, Mumbai



First H. S. Hans Memorial Lecture

Department of Physics, Panjab University Chandigarh

March 24, 2017

In this lecture :

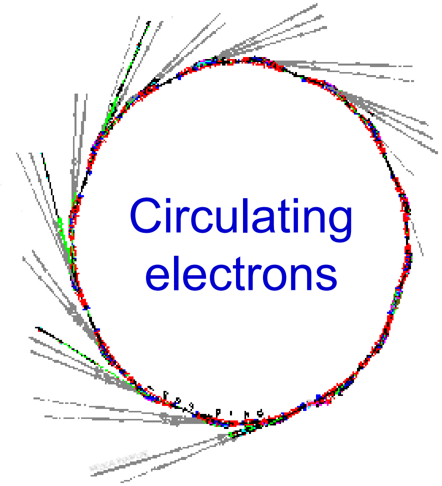
- Storage rings for generation of synchrotron radiation
- Challenges involved : Physical insight
- Indus accelerators
- Synchrotron beamlines and their utilization
- Ultra-intense / high power laser beams

  - Realizing extreme parameters on a table-top
- Laser driven electron / ion acceleration
- Laser material processing : Strategic applications
- Looking ahead : Next generation HBSRS, PW laser, ISNS, LIGO-India

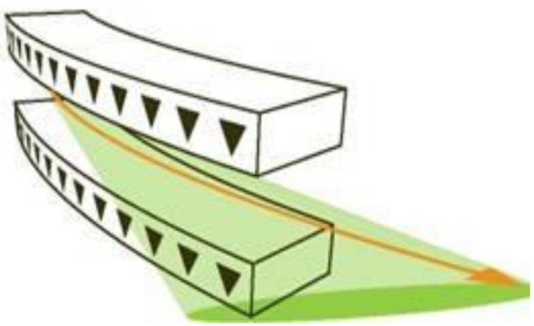
Accelerators & Synchrotron Radiation Sources

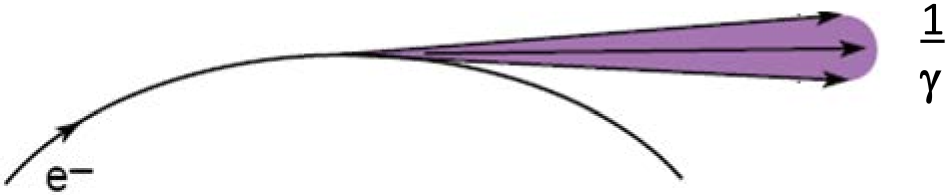
When a charged particle undergoes acceleration it emits radiation.

Radiation emitted by high energy electron beams traversing closed orbits is called synchrotron radiation.



$$E = \gamma m_0 c^2$$





Synchrotron radiation was first observed (accidently) from a 70 MeV circular accelerator of the General Electric Co. in USA in 1947.

For many years this was considered parasitic. Later, dedicated accelerators were set up by many laboratories to produce this radiation.

Properties of Synchrotron Radiation

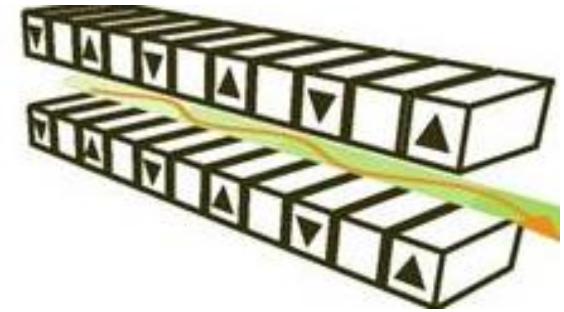
- Broad spectrum : from infrared to hard x-ray
- Wide tunability in photon energy
- High brightness (photons / sec - mm^2 - $mrad^2$ - 0.1% BW)
- Highly collimated : divergence angle $\propto 1 / \gamma$
- Highly polarized : linear, circular, elliptical
- Pulsed time structure : 10's of picosecond pulses

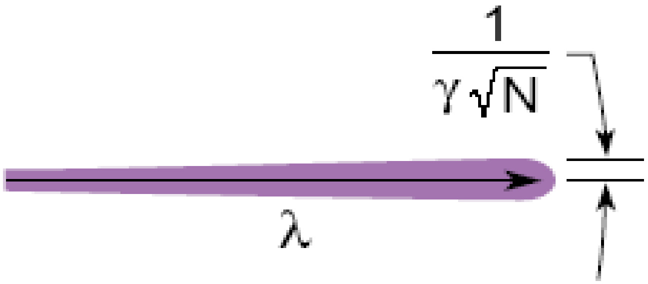
Insertion Devices

- An insertion device has a periodic magnetic field of alternately reversing polarity designed to make the electron trajectory wiggle and generate intense synchrotron radiation.

- Superposition of radiation emitted at different bends results in an intense beam of synchrotron light, several orders of magnitude more intense than that from bending magnets.

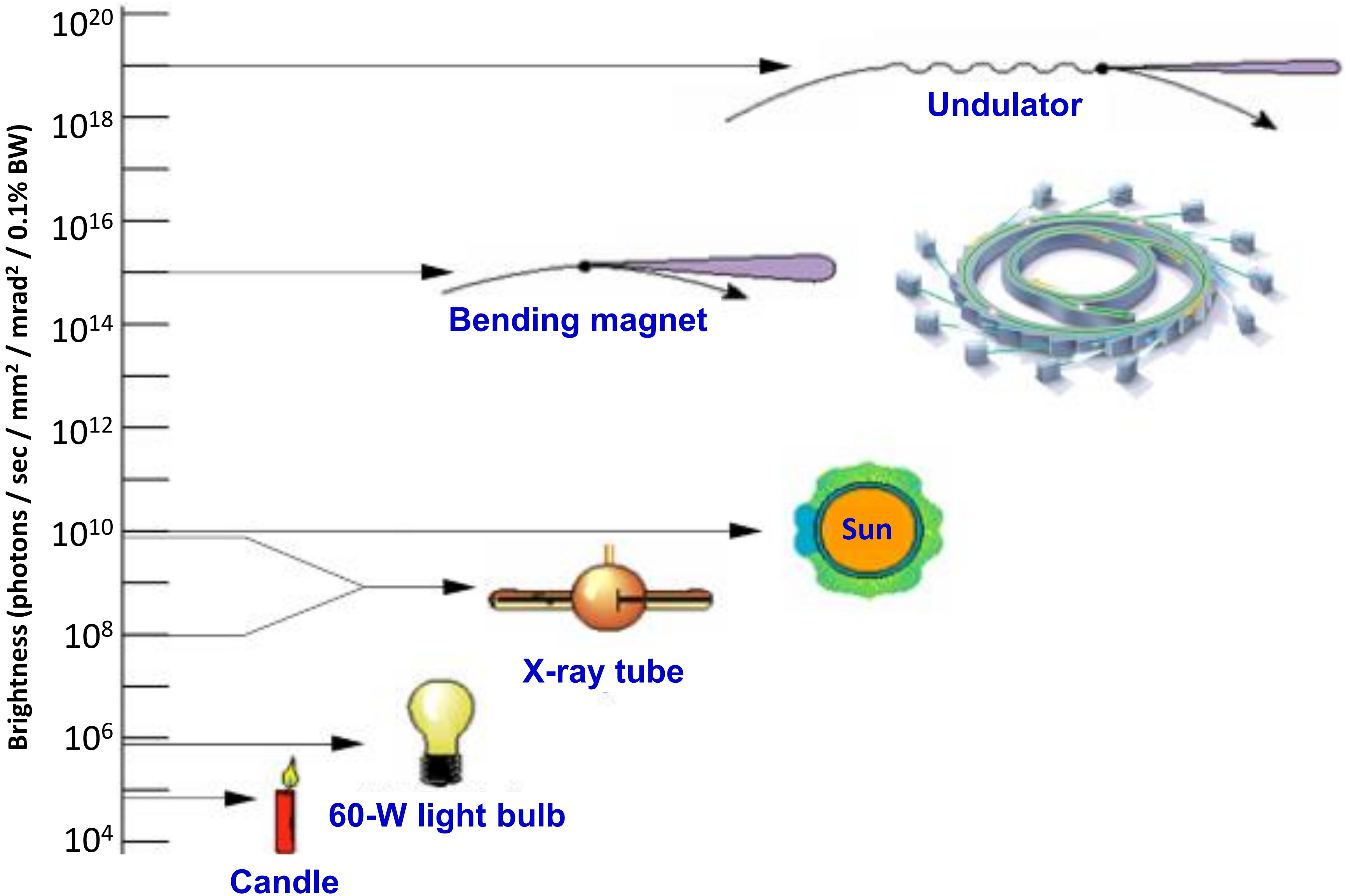
- The radiation appears at discreet frequencies in a narrower cone.





- Photon energy is tuned by changing the pole gaps
- Spectral brightness is $\propto N^2$

A Comparison of Some Light Sources



Synchrotron Radiation Facilities (In Operation)

Asia-Oceania : 26, Europe : 25 , America : 18

www.lightsources.org

Centre for Advanced Technology

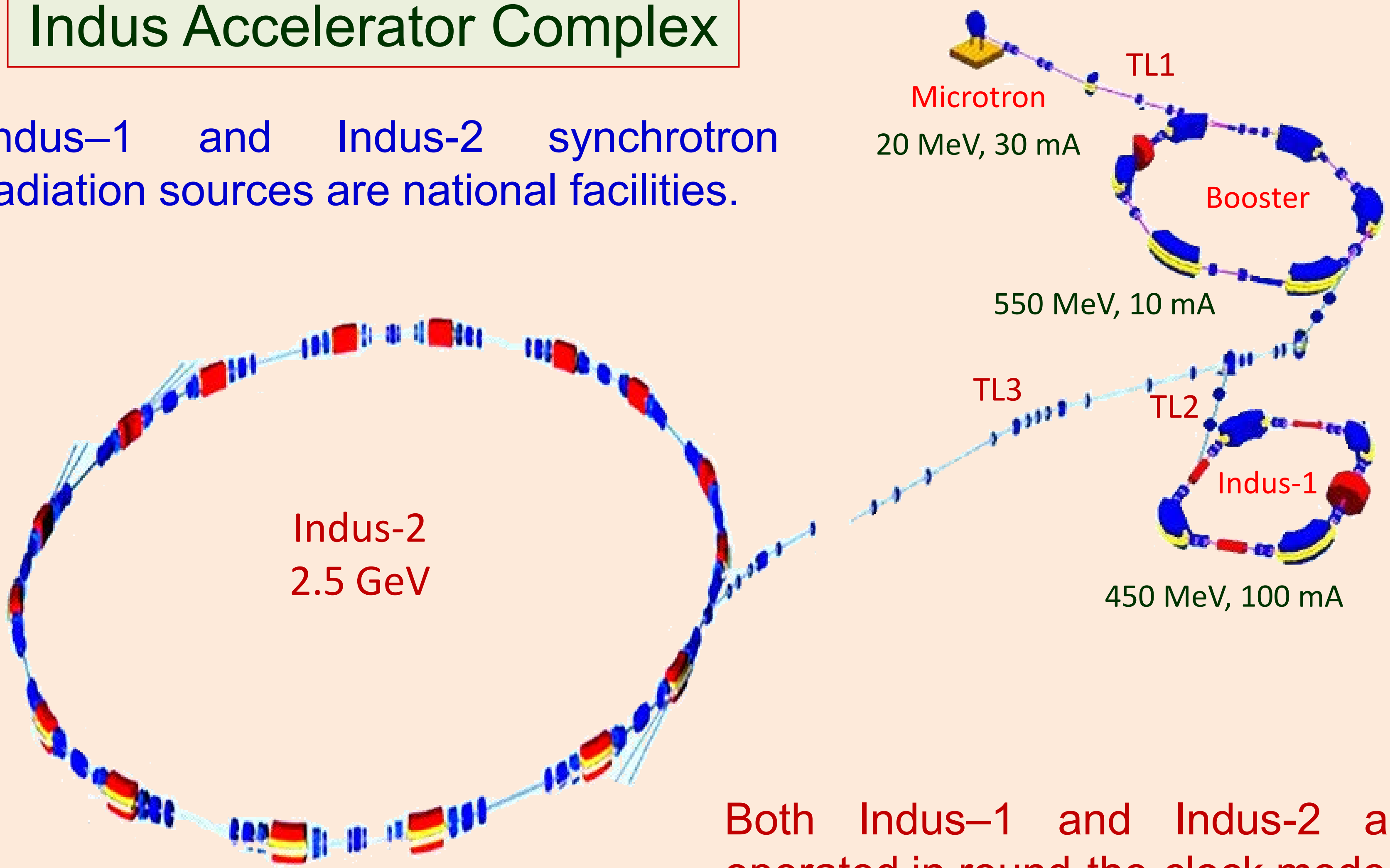
- R&D programmes in frontline areas of lasers and accelerators, related advanced technologies and applications.
- A site was acquired around an heritage building in February 1984 and scientific activities commenced from 1987.
- The Centre renamed after Dr Raja Ramanna on December 17, 2005.

RRCAT is now established as a premier national laboratory on high brightness light (radiation) sources.

DAE Diamond Jubilee Structure at RRCAT

Indus Accelerator Complex

Indus–1 and Indus-2 synchrotron radiation sources are national facilities.

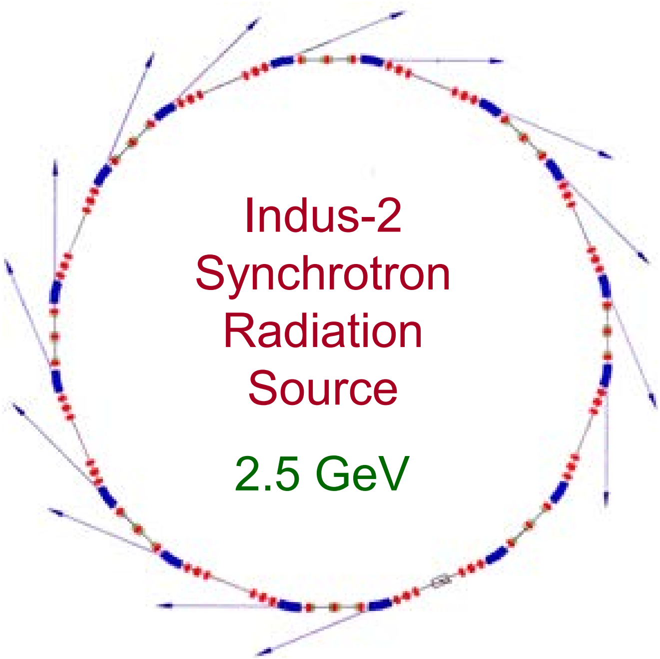


Both Indus–1 and Indus-2 are operated in round-the-clock mode.

Indigenous Design, Development, Commissioning and Operation of Indus Accelerators

Indus-2 is the largest size accelerator built in the country and of highest energy, with many sub-systems developed for the first time in the country.

Indus-2 is a conglomeration of several advanced technologies



- Dipole, Quadrupole, Sextupole magnets
- Magnet power supplies
- Injection magnets
- Control System
- RF System
- UHV System
- Beam Diagnostics
- Survey & Alignment
- Radiation Safety
- LCW / Precision temperature control

- About 400 scientists, engineers and technical staff have worked on its development for more than 10 years.

Indus-2 Storage Ring

A section of Indus-2 tunnel (172.5 m circumference)

- The electron beam (sub-mm) makes 17 lakh revolutions / sec.
- Ultrahigh vacuum in the range of 10^{-10} mbar.

Precision Magnet Optics

- Electron beam stored in the ring is of size ~ 200 µm (H) x 50 µm (V).
- Orbit distortion should be much smaller than the beam size and should be corrected dynamically.

Dipole magnets
weighing 7 ton each

Machined to 50 µm accuracy

Precision magnet
positioning system

Positioning accuracy 50 µm

- Precision temperature control (0.1 ^{0}C RF cavity / 1 ^{0}C magnets)
- Power supply current for the electromagnets required to be precise in the range of 1 part in 5000.

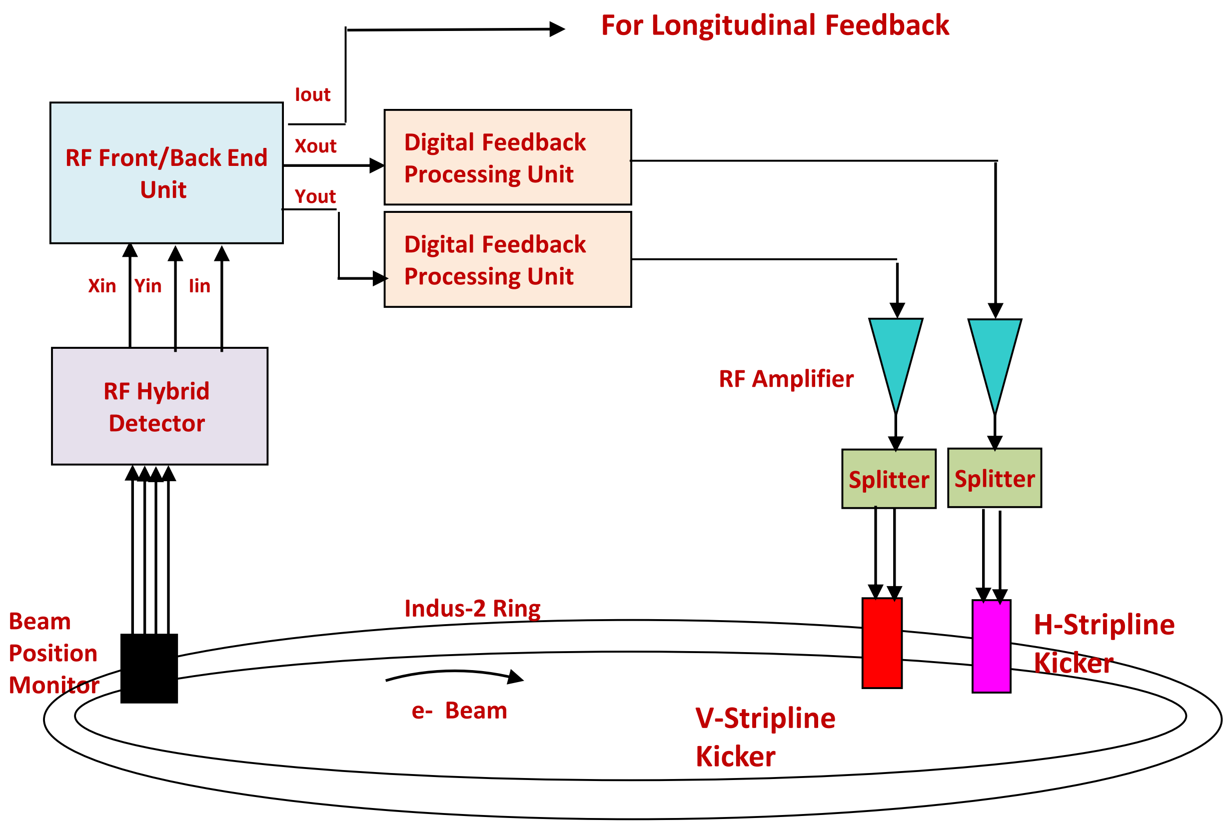
Indus Control System

- Indigenous and in-house developed control system
- About 10,000 parameters under constant monitoring, control, data logging and alarm handling, with 1 sec data refresh rate

- Beam orbit variation in both horizontal and vertical planes were controlled to 2-3 microns rms using global slow and fast orbit electronic feedback systems.

Controlling Transverse Instabilities in Indus-2

- At high currents, transverse instabilities get excited in the circulating electron beam.
- A bunch-by-bunch feedback system for Indus-2 has been installed for controlling these instabilities in Indus-2.



What is the energy content of electron beam circulating in a storage ring ?

- Let us take Indus-2 example : 2.5 GeV beam, 200 mA current
- No. of electrons in 200 mA beam = 7.2×10^{11}
- Energy content in the beam = $2.5\ \text{GeV} \times 7.2 \times 10^{11}$

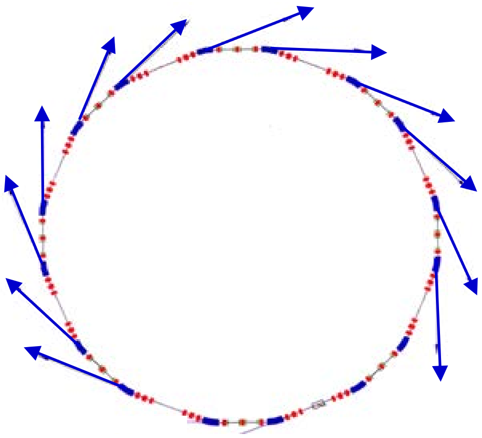
  = 290 J
- How much energy is needed to boil a cup of water ?

  = $150\ \text{gm} \times 4.18\ \text{J / gm / }^{o}\text{C} \times 80\ ^{o}\text{C}$

  ~ 50,000 J
- Thus the energy of electron beam circulating in the storage ring is not enough to even boil even a teaspoon of water.

Need for High Power RF Sources

- The synchrotron radiation loss per revolution is 70 mJ.
- Revolution frequency of electron beam is 17 million per second
- Synchrotron radiation of about 120 kW is emitted continuously.



RF Cavities

- This radiation loss from the beam needs to be compensated by feeding electrical radio-frequency (RF) power to the electron beam through accelerating cavities.
- High power RF sources of a few hundred MHz frequency (few 100 kW power) are required.

Klystron based RF Power system for Indus-2

- Indus-2 has four RF cavities which were earlier energized by a klystron each of 60 kW power at 505.8 MHz.

- Two klystrons had failed and no replacements were available due to export control restrictions.
- New technology of solid state RF amplifiers developed to replace klystrons.

High Power RF Amplifiers for Indus-2

- Starting from development of single modules of 200W power of solid state amplifiers, a large number of them were combined to make RF power stations of 75 kW.

- Total RF power of solid state amplifiers = 300 kW.
- Highest power of solid state amplifiers operating at frequency > 500 MHz in round-the-clock mode.
- This has eliminated dependence on klystrons.

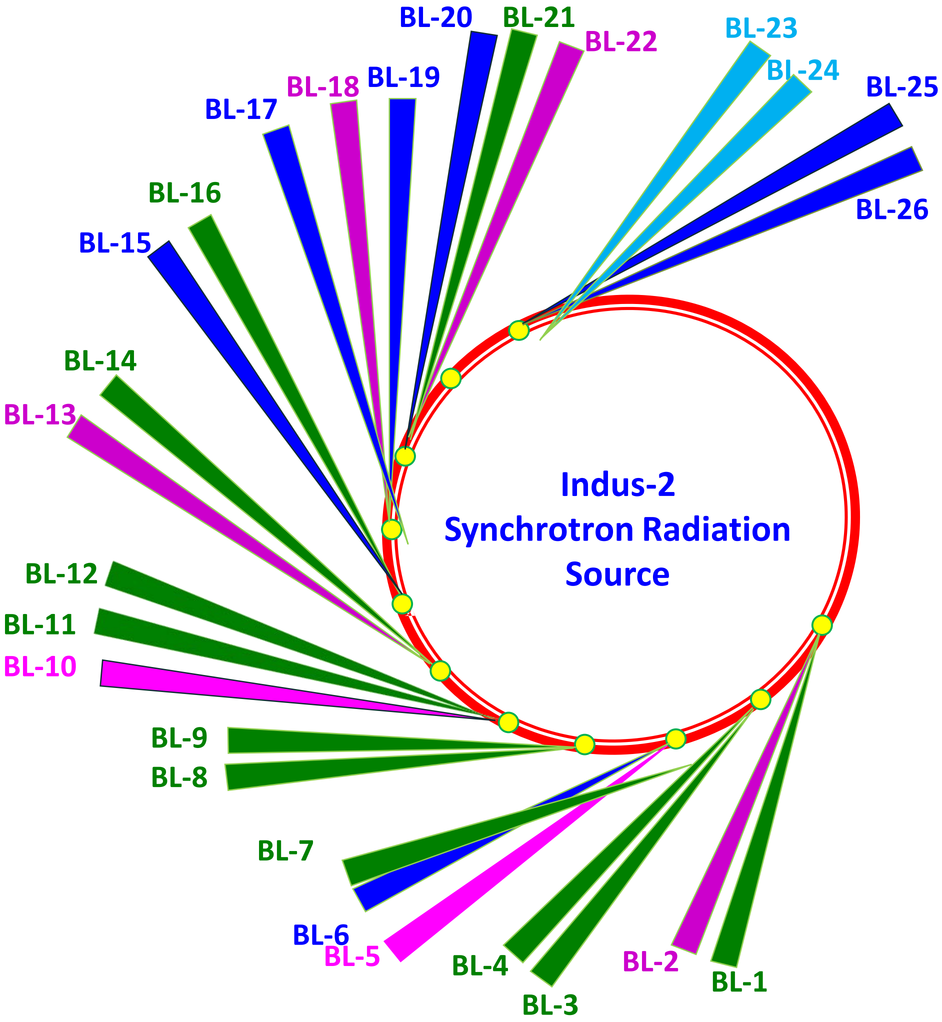
Indus-1 Synchrotron Radiation Source

- Indus-1 is regularly operated at 450 MeV, 100 mA round-the-clock.
- 6 beamlines are operational and made available to users.

Circumference 18.96 m

- Soft X-ray Reflectivity
- Angle Integrated Photoelectron Spectroscopy
- Angle Resolved Photoelectron Spectroscopy
- Photophysics
- High Resolution VUV
- Infrared Spectroscopy

Indus-2 beamlines



Operational beamlines (13)

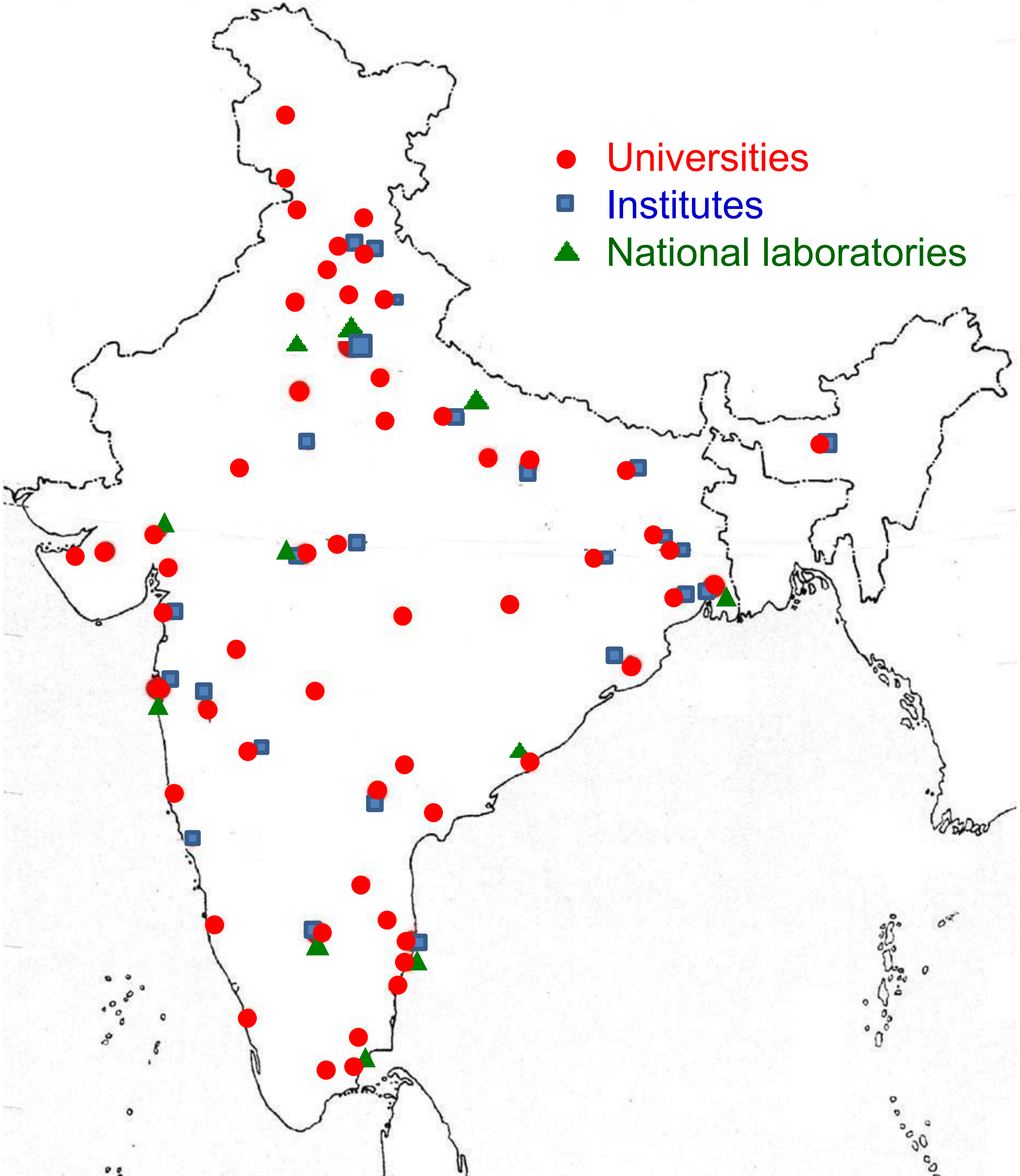
- Soft X-ray Absorption Spect. (BL-1)
- Soft X-ray Reflectivity (BL-3)]
- X-ray Imaging (BL-4))
- X-ray Lithography (BL-7)
- Dispersive EXAFS (BL-8)
- Scanning EXAFS (BL-9)
- Extreme Conditions AD/ED XRD (BL-11)
- Angle Dispersive XRD (BL-12))
- X-ray Photo-Electron Spect. (BL-14)
- X-ray Fluorescence Microprobe (BL-16)
- Protein Crystallography (BL-21)
- Visible Diagnostic (BL-23)
- X-ray Diagnostic (BL-24)

Under construction (6)

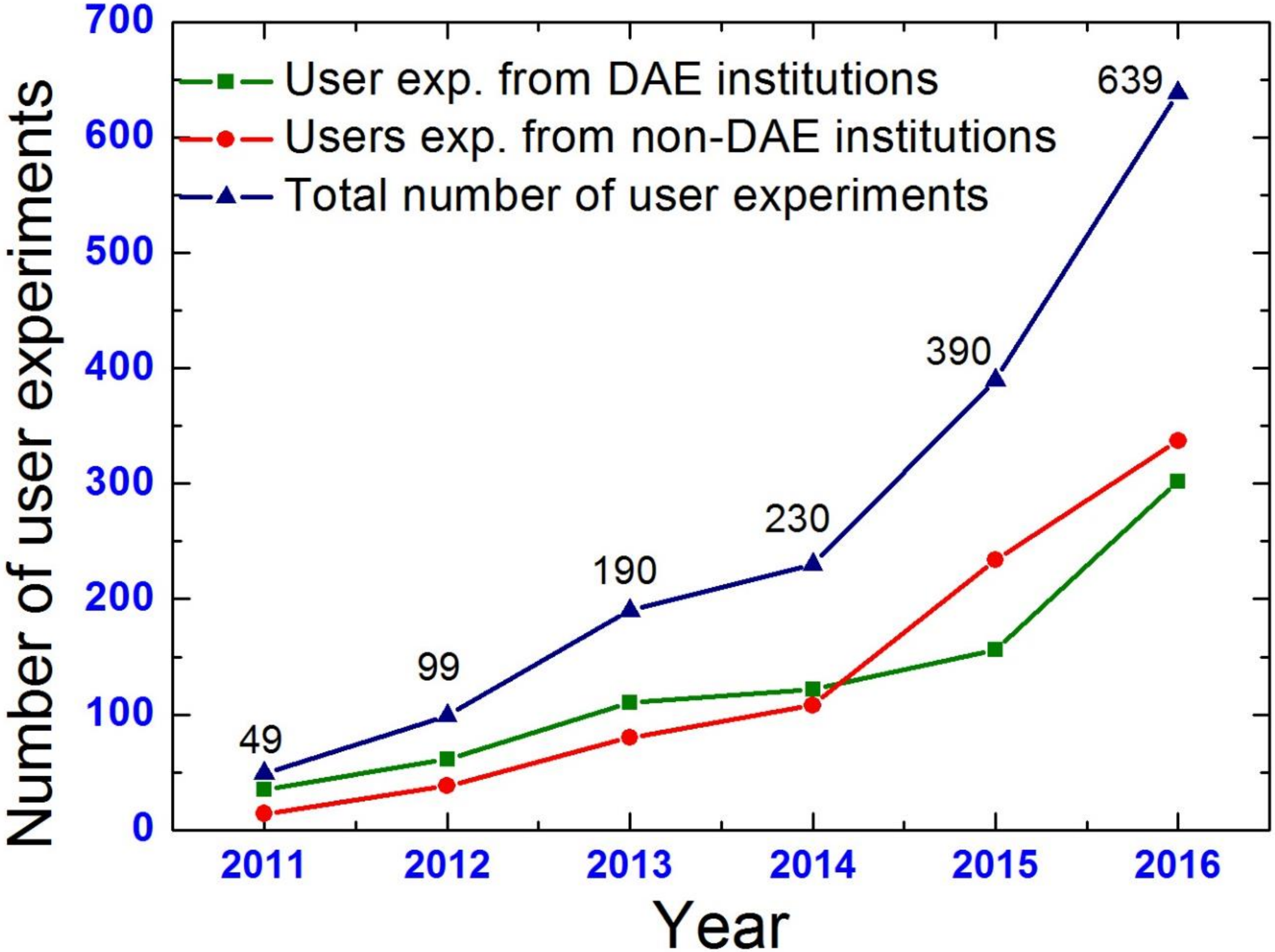
- Engg. Appl. beamline (BL-02)
- AMOS beamline on U-1 (BL-05)
- ARPES beamline on U-2 (BL-10)
- Grazing Incidence X-ray Scatt. (BL-13)
- Small and Wide Angle X-ray Scatt. (BL-18)
- Photo-Emission Ele. Microscopy (BL-22)

Indus-2 SRS Experimental Hall

- The Indus beamlines are being increasingly used by researchers from various universities, national laboratories and research institutes (140).
- Indus Beamlines Online Booking Portal : www.rrcat.gov.in


Universities
Institutes
National laboratories

Indus Synchrotron Radiation Sources : Utilization



Users from Private Industry

Commercial allotment of Indus beamlines to users from private industry at Rs 7,500 per hour, per beamline.

- EXAFS studies of Fe based drug samples (2016)

  Lupin Ltd., Research Park, Pune.

- EXAFS studies of Ni based catalytic samples (2016)

  Johnson Matthey Chemicals India Pvt. Ltd, Raigad, Maharashtra.

- Experiment using Protein Crystallography beamline (2016)

  Jubilant Biosys, Bengaluru.

- *Lupin Ltd.* has come for the second time (13^{th} Feb. 2017).

- Reliance R&D Labs (Mumbai) have expressed interest in using the EXAFS, XRF, and XRD beamlines.

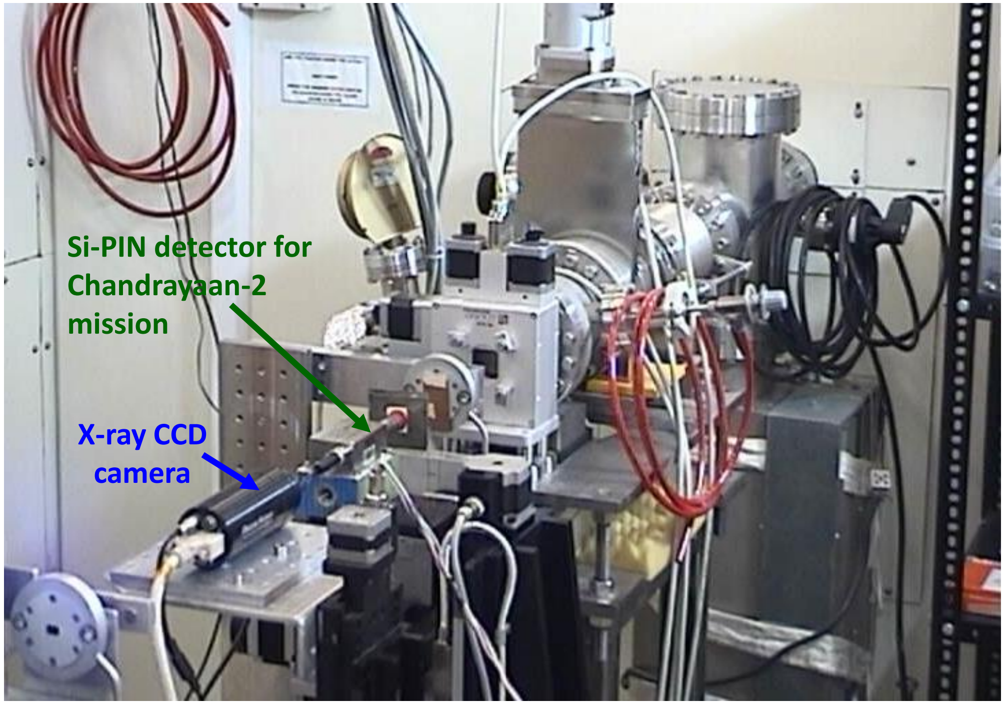
Characterization of Lyman-alpha Photometer for Mangalyaan

- ❖ Mangalyaan (Mars Orbiter Mission) launched by ISRO on November 5, 2013, and successfully accomplished on September 24, 2014.
- ❖ One of the experimental payloads in Mangalyaan was Lyman-α photometer to measure the relative abundances of H and D in the Martian atmosphere.

- ➢ The ratio is useful for estimation of the amount of water lost to outer space from the Martian surface.
- ➢ Calibration of this photometer was carried out using the HRVUV beamline of Indus-1.

Calibration of a Si-PIN detector for Chandrayaan-2 mission

Detector calibration and validation of the methodology for finding the lunar surface elemental abundance, before sending it on the Chandrayaan-2 mission in 2018.



Experimental setup used for characterization of Si-PIN detector on BL-16

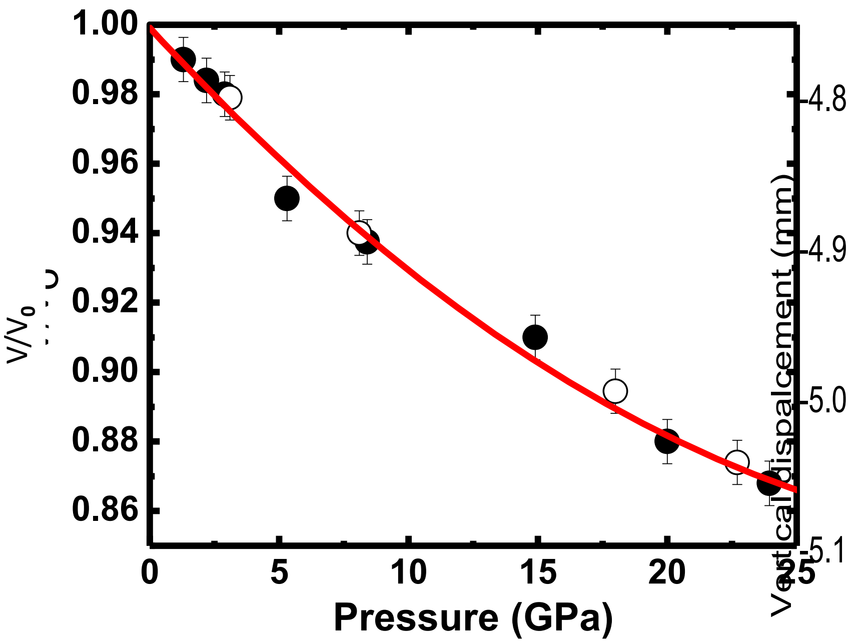
Calibration of a Si-PIN detector for the x-ray energies 5 to 12 keV has been carried out on BL-16.

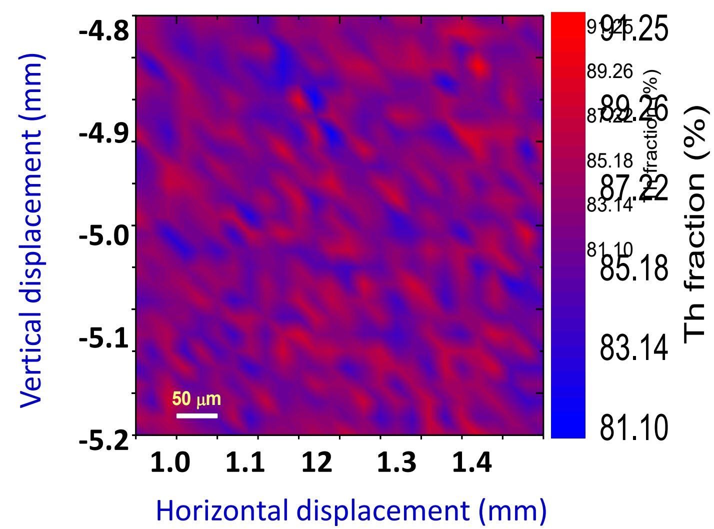
This calibration is needed for the Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) to globally map the abundances of the major rock forming elements on the lunar surface.

Strategic and Applied Research Using Indus-2 Beamlines

Determination of the equation of state of natural uranium

Composition distribution of uranium and thorium in fuel pellets for AHWR





X-ray Spectrometry, 42, 4, 2012

-5.2

50 µm

1.0 1.1 1.2 1.3 1.4

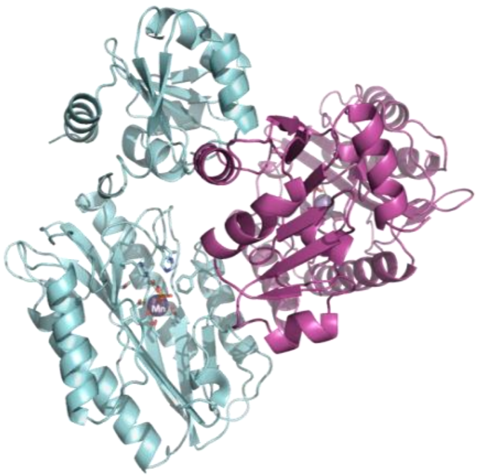
Understanding the Structure of Proteins : Key to better life

- Proteins are the building blocks of all living organisms.

  They are large biological molecules composed of low-Z elements like C, H, N, O, S.

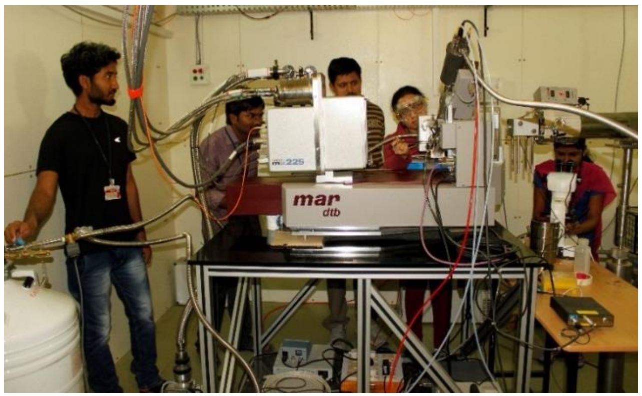
- Functionality of proteins is governed by their structure. Typically few hundred to several thousand atoms are present in one protein.

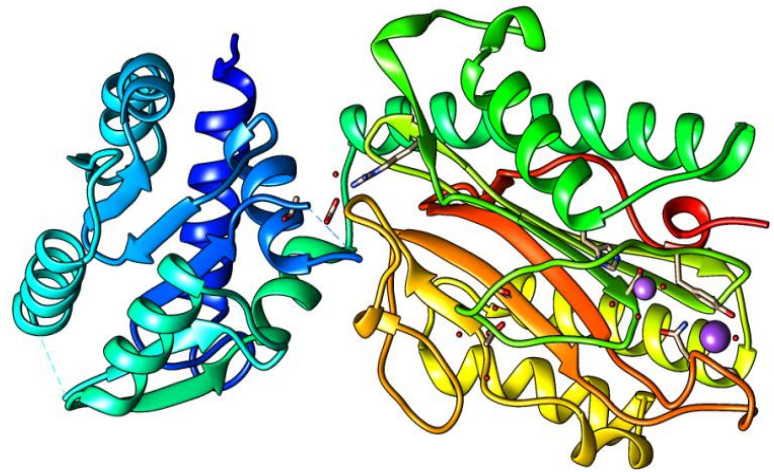
- Knowledge of protein structure is useful in a variety of applications :
  - Design of new antibiotics
  - Development of new drugs for cancer
  - Proteins for degradation of pesticides
  - Development of protein based bio-sensors
  - Photosynthetic complex for future green energy



Studies of Novel Protein Structures

- Protein Crystallography beamline extensively used for protein crystal structure determination.





WORLDWIDE
wwPDB
PROTEIN DATA BANK

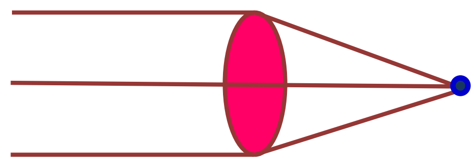
is the single world-wide repository of information about the 3D structures of large biological molecules including proteins and nucleic acids.

Based on the data collected at the Indus-2 protein crystallography beamline, the total number of structures submitted to wwPDB is 31.

IISc-Bengaluru, IICB-Kolkata, NCL-Pune, AIIMS-New Delhi, SINP-Kolkata, BARC

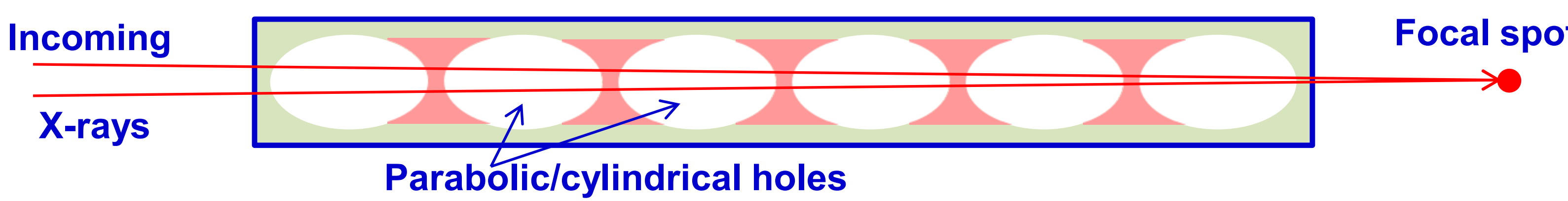
Development of X-ray Lenses using Lithography Beamline

Focusing lens : Glass refractive index ~ 1.5



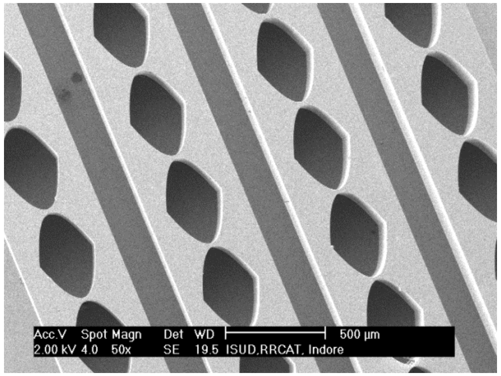
- Unlike lenses to focus visible light, it is a big challenge to make x-ray lenses.
- Refractive index of materials for x-rays is : $n = 1 - \delta - i\beta$
- A series of parabolic refracting surfaces allowing high transmission are required to serve as an x-ray lens.

Refractive lenses

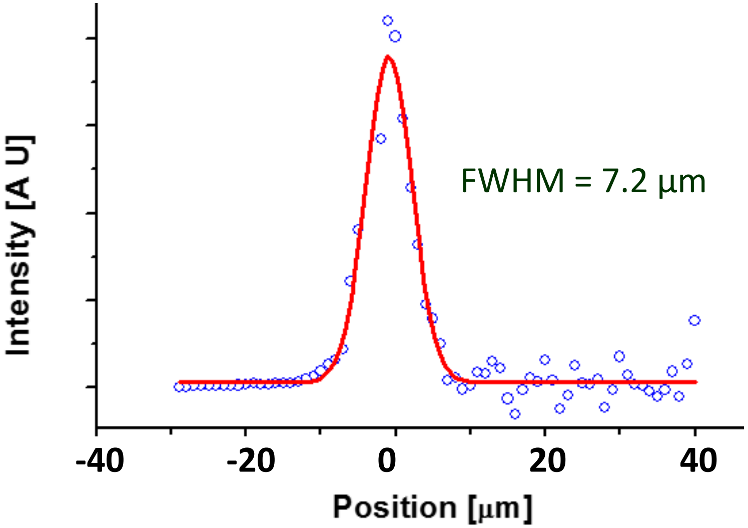


Development of Hard X-ray Lenses using X-ray Lithography Beamline

- X-ray lenses are high aspect ratio structures which can be manufactured by x-ray lithography on suitable photo-resist.
- X-ray lenses have been developed from SUEX material (antimony-free).



SEM image of SUEX lenses



X-ray lenses suitable for focusing x-rays of energy > 30 keV have been developed.

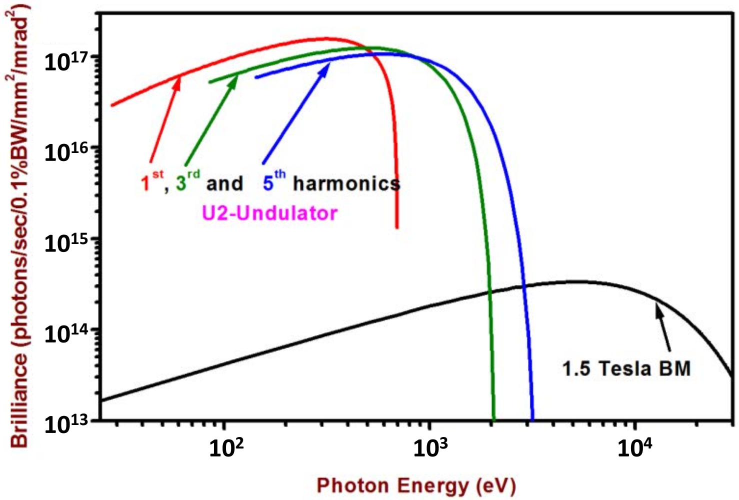
Progress with Installation of Insertion Devices

U1 planar undulator
commissioned in January 2015

U2 planar undulator
commissioned in January 2015

U3 helical undulator
installed in November 2015

Computed spectral brightness of U2



Work is in progress to build beamlines for the above undulators.

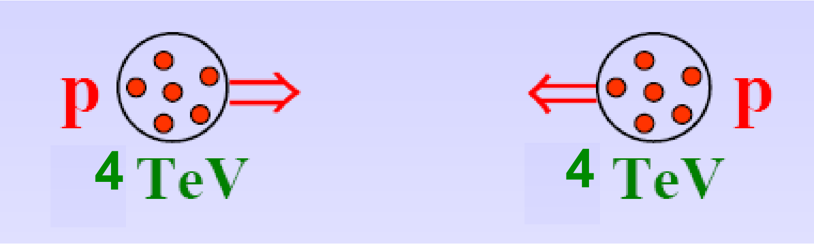
World's Biggest Accelerator Large Hadron Collider (LHC)

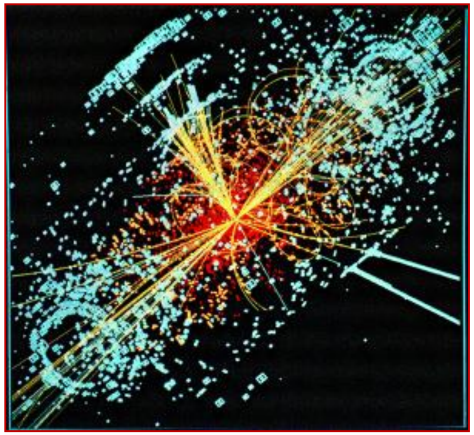
- LHC has been constructed with worldwide collaboration.
- Installed in a tunnel of ~26.6 km circumference ~100 m below the ground.
- RRCAT has been the nodal institute for DAE-CERN Collaboration for LHC.

- India was accorded "Observer State" status in 2002 by CERN. India has now become Associate Member of CERN.

The Grand Success of Large Hadron Collider

- Conditions existing 1-100 ps after the big bang (beginning of universe 13.7 billion years ago)





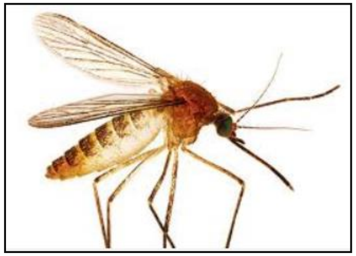
Signature of Higgs Boson seen on July 4, 2012 at LHC.

2013 Nobel Prize in Physics awarded to Francois Englert and Peter W. Higgs

- Indian Collaborators are proud of their partnership and contributions to LHC.

What is the energy / energy density involved ?

How does the energy of a 4 TeV proton in LHC compare with kinetic energy of a flying mosquito ?



Energy of a 4 TeV proton $= 4.0 \times 10^{12} \times 1.6 \times 10^{-19}$ J

$= 6.4 \times 10^{-7}$ J

K. E. of a flying mosquito $= \frac{1}{2} \times 5$ mg $\times (0.5$ m / s$)^2$

$= 6.2 \times 10^{-7}$ J

But the energy in a proton is confined to a very small dimension ($\sim 10^{-15}$ m) compared to a mosquito (~ few mm). The energy density is therefore much higher in case of 4 TeV proton in LHC.

Invention of Laser : Theodore Maimen – May 16, 1960

Light Amplification by Stimulated Emission of Radiation

"Stimulated Optical Radiation in Ruby"
T.H.Maimen,
Nature Vol 187, p493 August 6, 1960

Theodore Maiman promptly submitted a short report of the work to the journal Physical Review Letters, but the editors turned it down. He then submitted it to Nature who published it.

Editor of Physical Review Letters at the time, has said that he turned down this historic paper because Maiman had just published, in June 1960, an article on the excitation of ruby with light, and the new work seemed to be simply more of the same.

Characteristics of Lasers

- Coherence :
  - Spatial coherence (small divergence)
  - Temporal coherence (highly monochromatic)
- Short pulse duration
- High peak power
- High focusability
- High intensity

Compact Terawatt Laser Systems (fs pulses)

GEKKO Laser

5 TW, 5 kJ, 1 ns beam

Ti:Sapphire Laser

10 TW, 0.5 J, 50 fs beam

- Compact terawatt lasers have rejuvenated research in several fields including ultra-intense laser-plasma interaction

Ultra - Intense Laser Beams

- 10 TW – 1 PW lasers (pulse duration 15 – 50 fs)
- Focused intensity 10^{18} – 10^{20} W/cm^2
- Peak electric field : 10^{10} – 10^{11} V/cm
- Instantaneously produces a plasma with very high ionization
- Strong field science
- For $I_L = 10^{18}$ W/cm^2 , energy of oscillating electron ~ 0.5 MeV ~ $m_o c^2$
- Relativistic interaction
- Force experienced by electrons in the laser field is

$$F = e [E + (v \times B) / c]$$

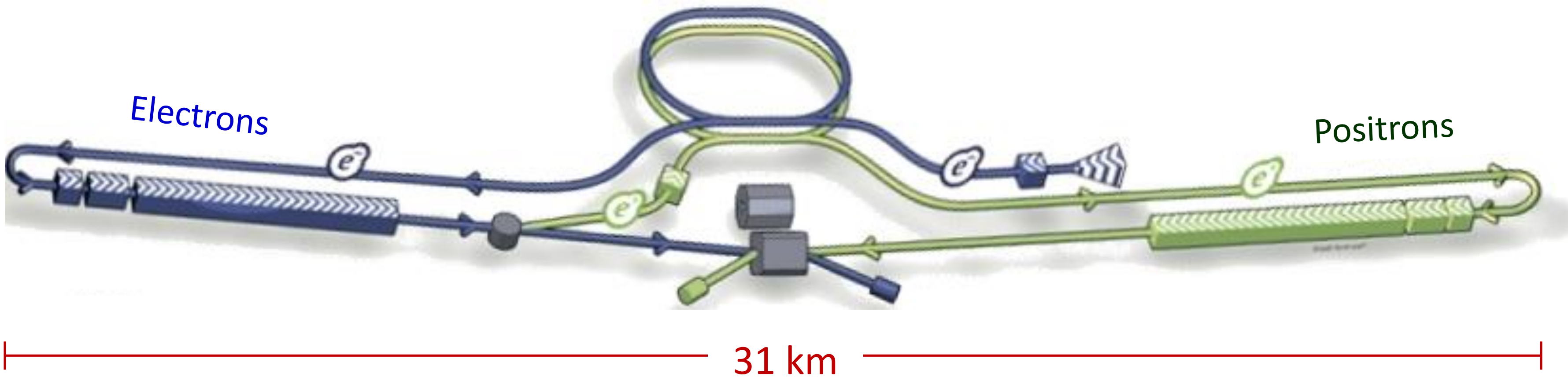
- Electron motion is highly non-linear

Ultra-short Pulse, Ultra-intense Laser Matter Interaction

- Electron acceleration
- Proton / ion acceleration
- Femtosecond monochromatic x-ray source
- X-ray lasers
- Table-top nuclear reactions
- Intense x-ray beam (photon energy ~ MeV)
- Fast ignition drive of inertial confinement fusion

Why Interest in Laser Driven Acceleration ?

- Conventional accelerator : RF cavities (electric fields < 50 MV/m)
- Large accelerators of TeV energy LHC (27 km circumference)
- Proposal for International linear collider (ILC) of 0.5 to 1 TeV CM energy (Estimated cost US$ 20 B).



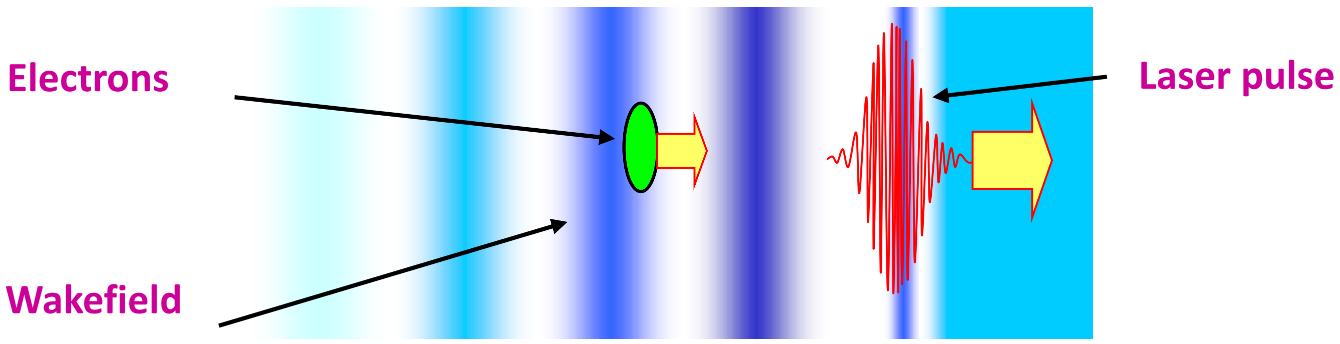
- Possibility of making big accelerators as very compact and much cheaper devices using laser driven acceleration.

Laser Beams : Drivers for Particle Acceleration

- 10 TW – 1 PW lasers (pulse duration 15 – 50 fs)
- Focused intensity $10^{18} – 10^{20}$ W/cm^2
- Peak electric field : $10^{10} – 10^{11}$ V/cm

- High electric fields ($\geq$ 100 GV/m) are available with intense laser beams, but being transverse, they can not be effective for acceleration
- For the above high fields, accelerating structure would breakdown and get ionized
- Plasma (an ionized medium) supports longitudinal electric fields as electron plasma-waves
- Ultrashort high intensity laser pulses to produce plasma medium and excite electron plasma waves of high amplitudes (100 GV/m).

Laser Wakefield Electron Acceleration

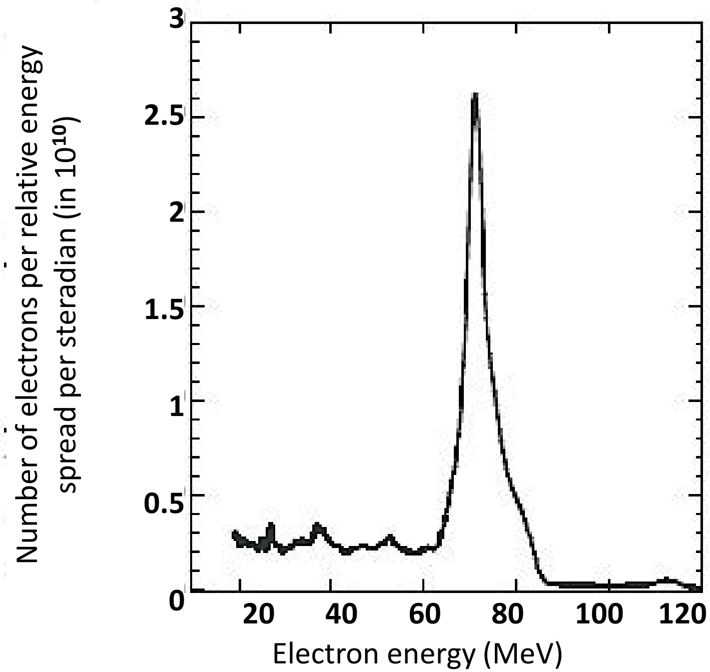


Wake created by a boat

- Phase velocity of the laser wakefield is equal to group velocity of the laser pulse (~ c)
- Electrons of velocity ~ V_{ph} will get accelerated

The Dawn of Compact Particle Accelerators

30 September 2004

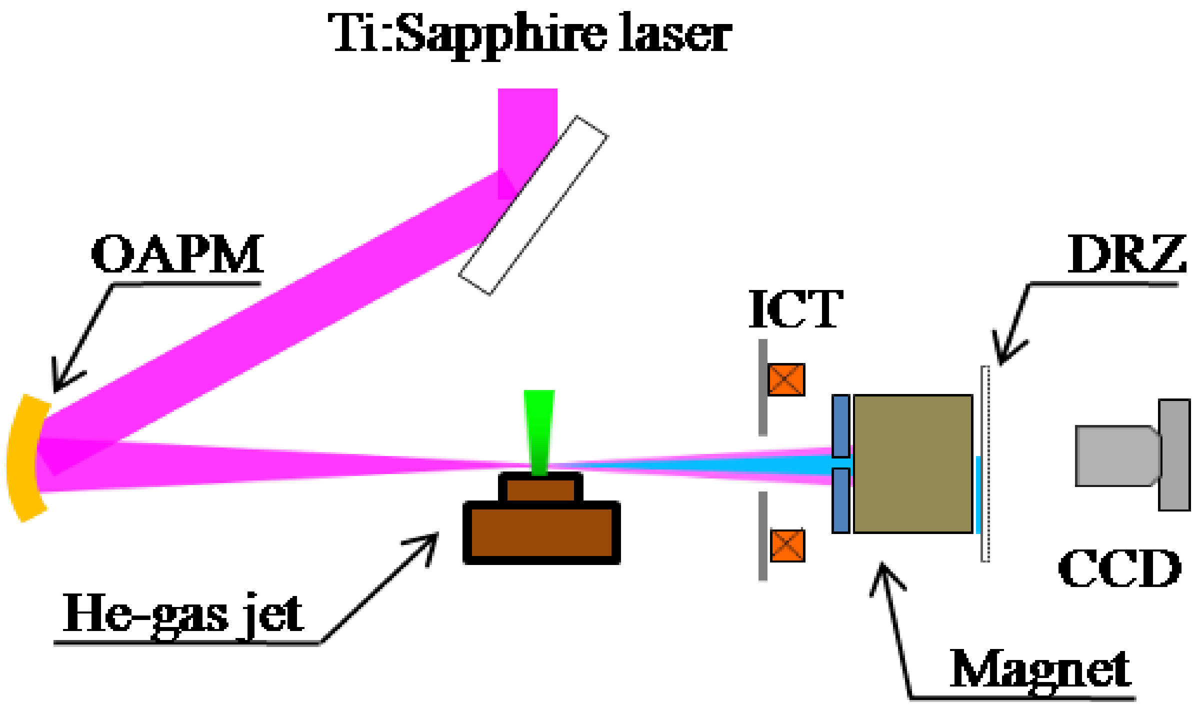


Mono-energetic beam spectrum measured by S P D Mangles et al

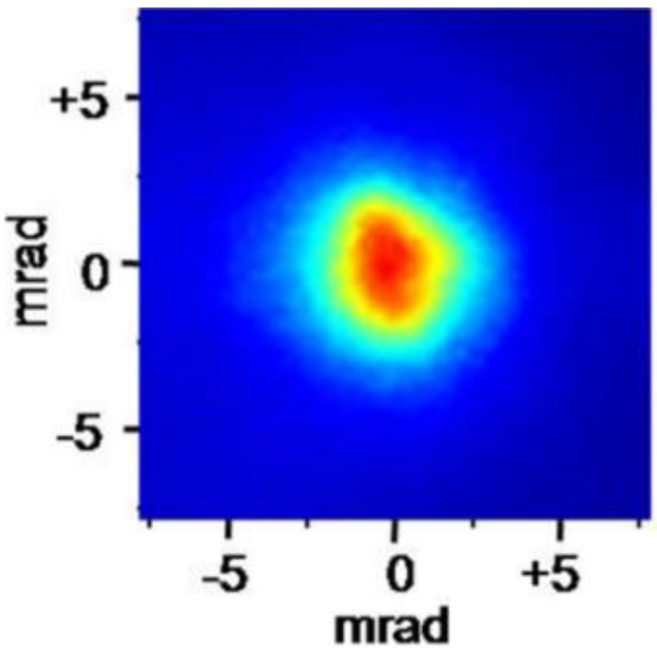
- Monoenergetic beam : Energy spread ~ 10%

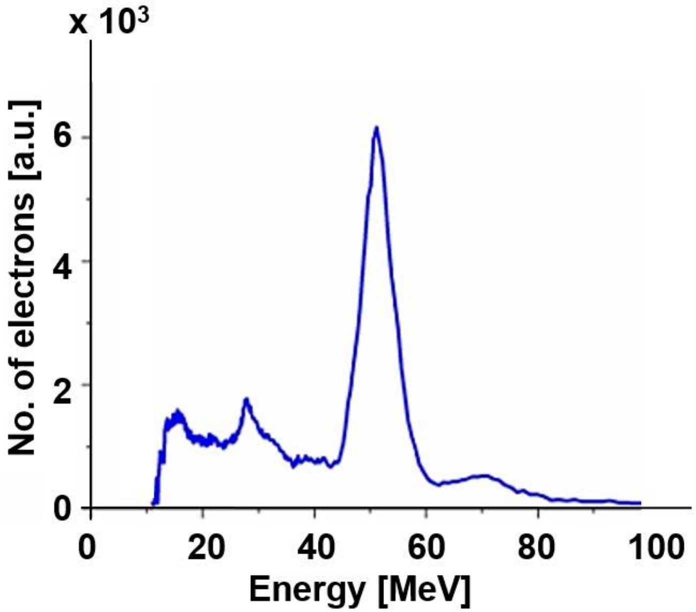
Electron Acceleration : Gas-jet Target

- Laser : 10 TW, 45 fs and 150 TW, 25 fs (Ti:Sapphire)
- Slit-type supersonic nozzle (helium gas jet 2 ms duration)



Laser accelerated mono-energetic 50 MeV electron beam





Physics of Plasmas 18, 93104 (2011)

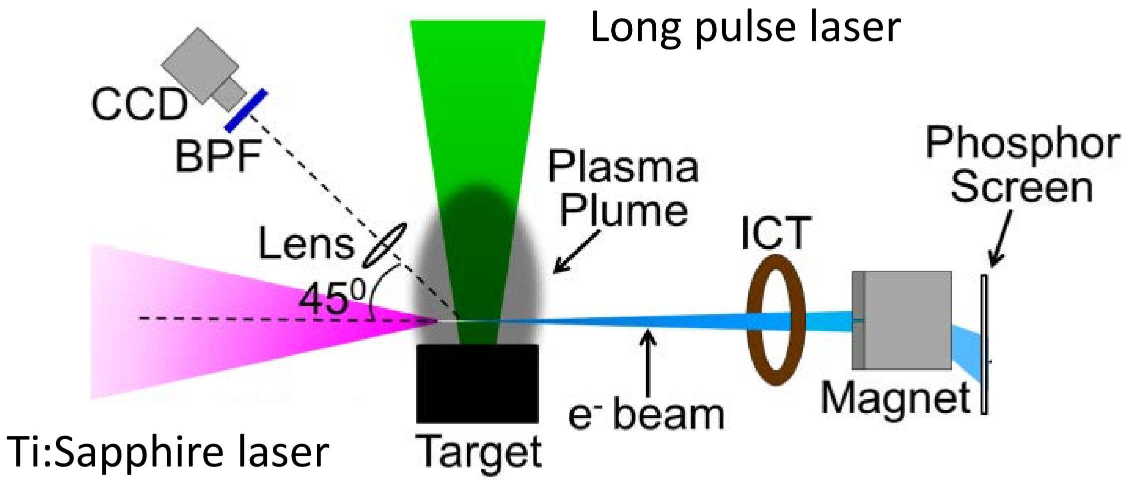
Phys. Rev. STAB 16, 091301 (2013)

Appl. Phy. Lett. 102, 231108 (2013)

Phys. Rev. STAB 17, 011301 (2014)

New Scheme for High Rep. Rate Operation

- Uses plasma plume instead of gas-jet.
- Plasma plume is produced by long laser pulse.



Appl. Phy. Lett. 102, 231108 (2013)

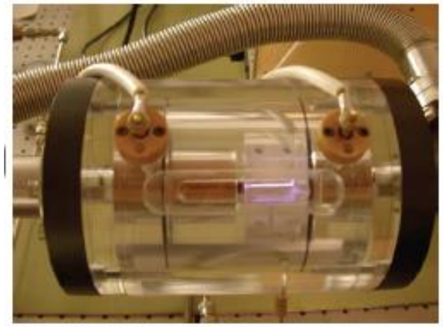
- The scheme enables high repetition rate (kHz) operation.
- The new setup is simple, low cost, and offers wide variety of targets for optimization of electron beam parameters.

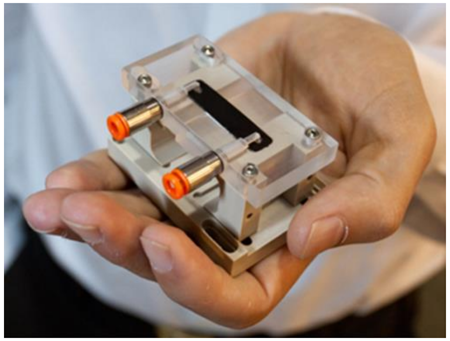
Laser Driven GeV Electron Beam

❖ Higher intensity laser

❖ Larger acceleration length

Use capillary discharge plasma channel as waveguide





Observed 1GeV beam of Q ~ 50-100 pC

LBNL, Berkeley, USA

40 TW, 35 fs Ti: sapphire laser
3.3 cm long gas filled capillary column

Nature Physics, 2, 696 (2006)

Using 0.3 PW laser pulse and 9 cm plasma channel : Electron beam 4.2 GeV.

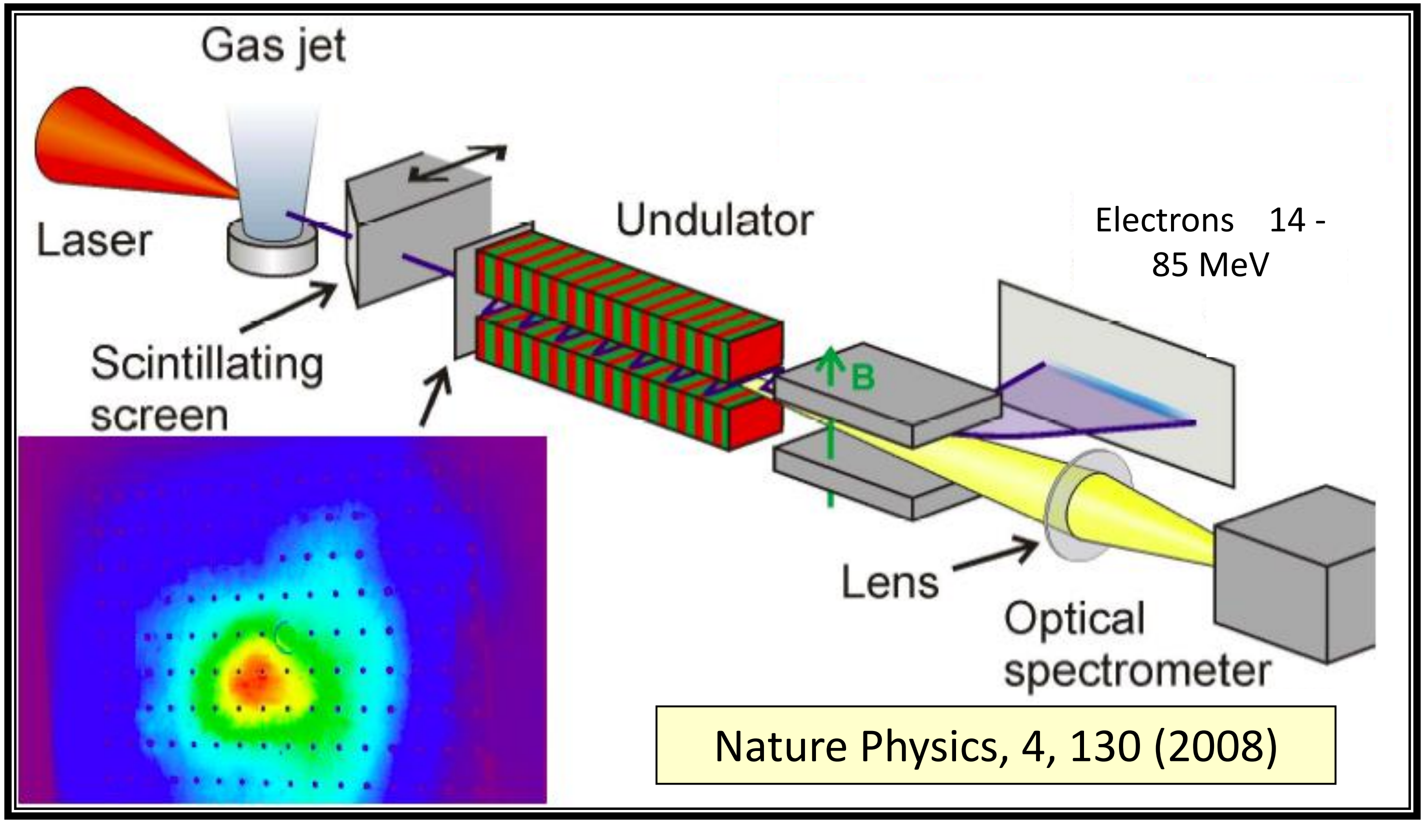
W. Leemans et al., Phys. Rev. Lett. 113, 245002 (2014)

Undulator Radiation from Laser-Accelerated Electron Beam

IOQ, JENA, Germany and University of Strathclyde, UK

Laser : 5 TW, 85 fs Ti: sapphire, 5 x 10^{18} W/cm^2, n_e = 2 x 10^{19} cm^{-3}

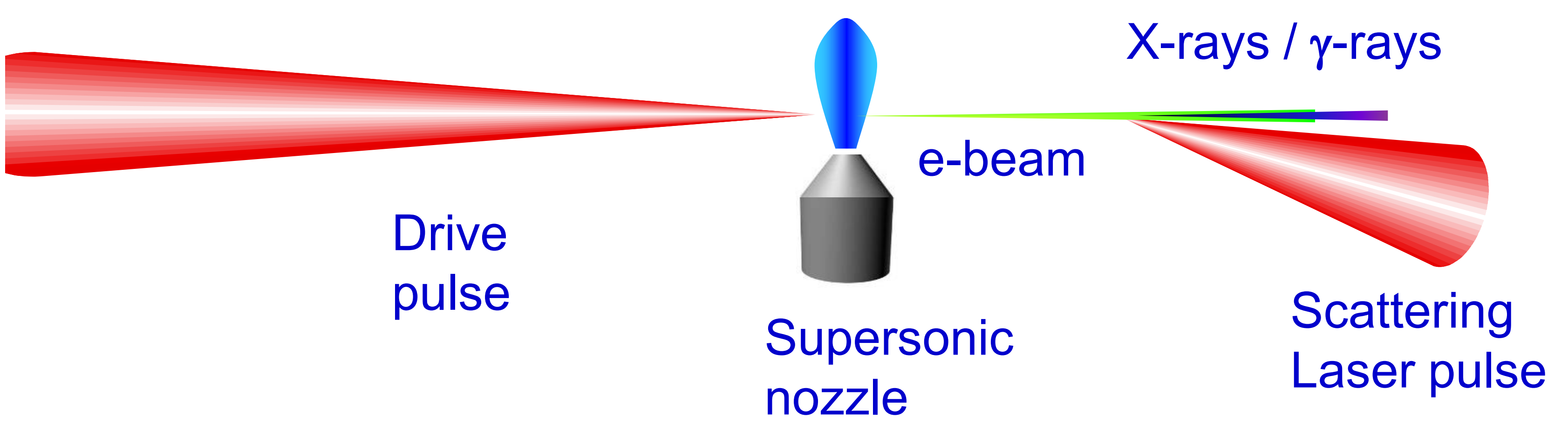
Undulator : 2 cm period, 50 periods, 10 mm pole gap, B_{max} = 0.33 T



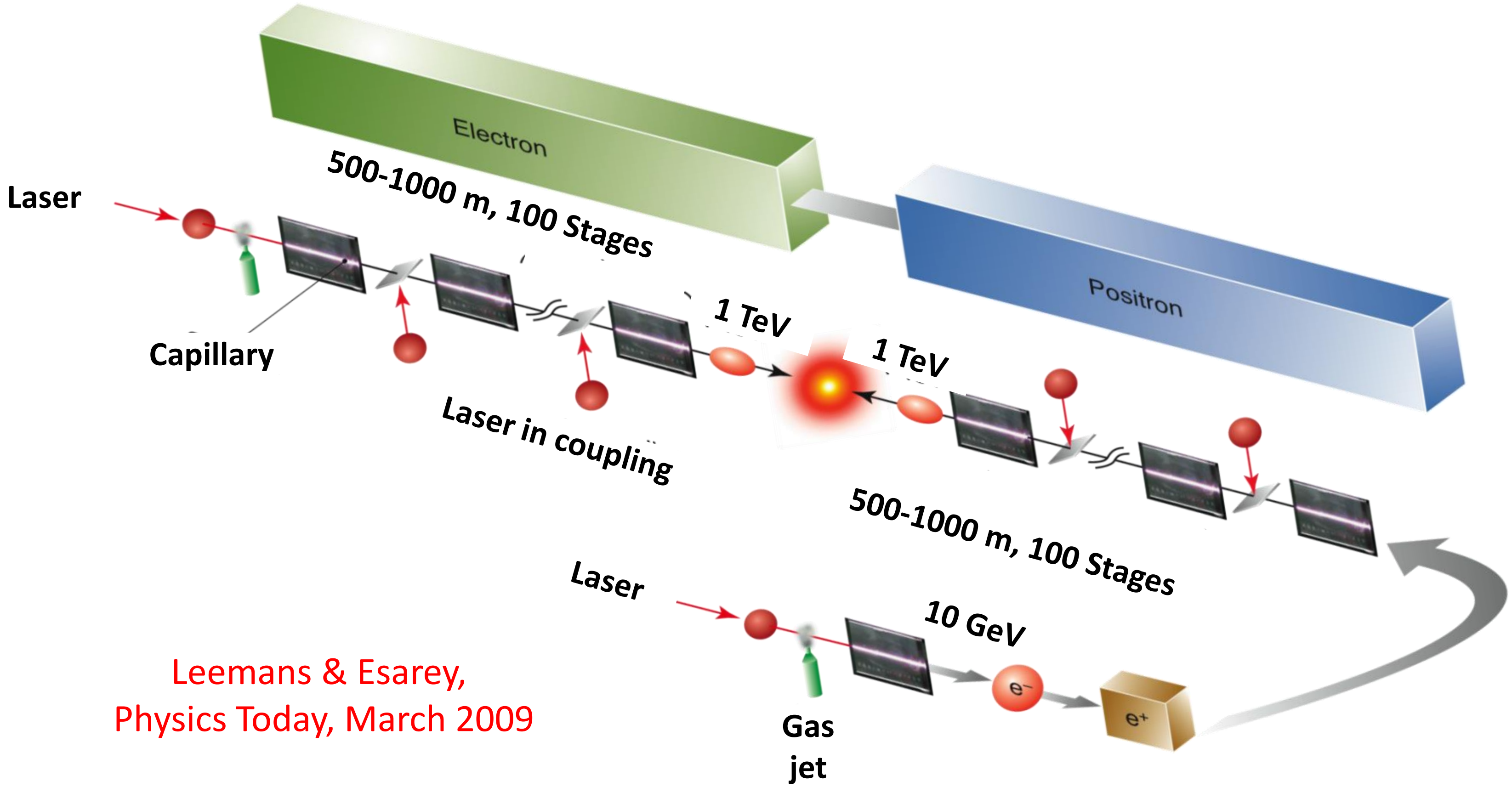
Nature Physics, 4, 130 (2008)

Scattering of intense light by a counter propagating electron beam

- Scattering of an ultra-intense laser pulse off a laser-produced electron beam can be used to generate high energy x-ray
- Doppler upshift (~$4\gamma^2$) provides necessary frequency shift to convert visible (eV) photons to x-ray/γ-ray (keV-MeV) photons.



Conceptual 1 TeV Electron-Positron Collider

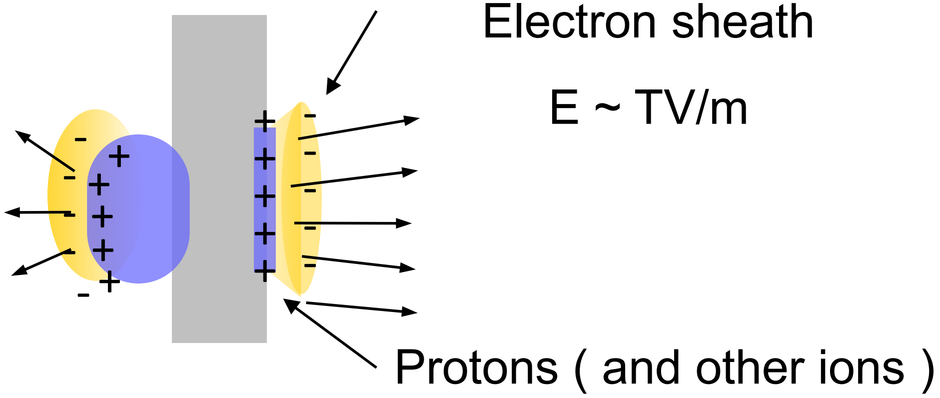


Leemans & Esarey,
Physics Today, March 2009

Electrons to be accelerated to 1 TeV using 100 laser-plasma modules, each consisting of a 1-m long preformed plasma channel (10^{17} cm^{-3}) driven by a 40 J laser pulse giving a 10 GeV energy gain.

Laser Driven Ion Acceleration

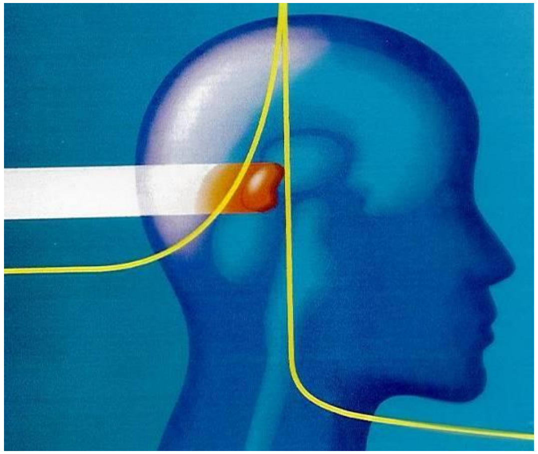
Target Normal Sheath Acceleration (TNSA)

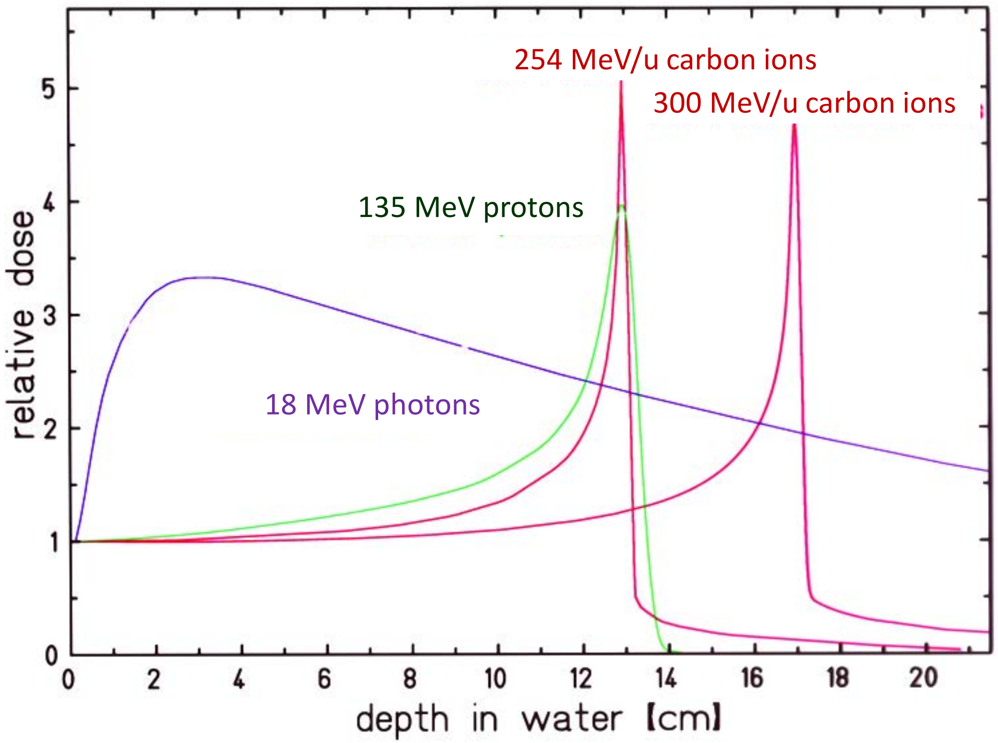


- Quasi – mono energetic ion beams, ultra low emittance
- LLNL PW Laser : Laser intensity 3 x 10^{20} W/cm^2
- 2 x 10^{13} protons / pulse, Max. proton energy 58 MeV

Laser-driven Proton Oncology - A New cancer Therapy ?

- Proton beams : Deep longitudinal penetration, deposition of energy near Bragg- peak, and small lateral penumbra

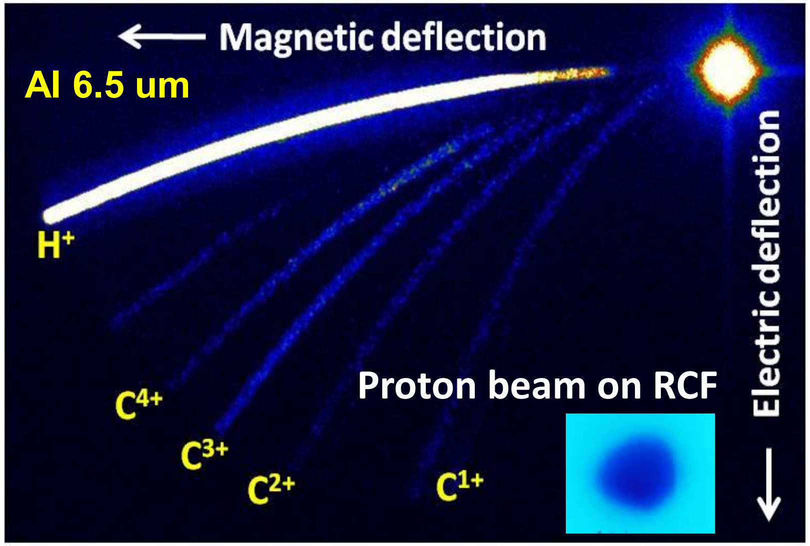


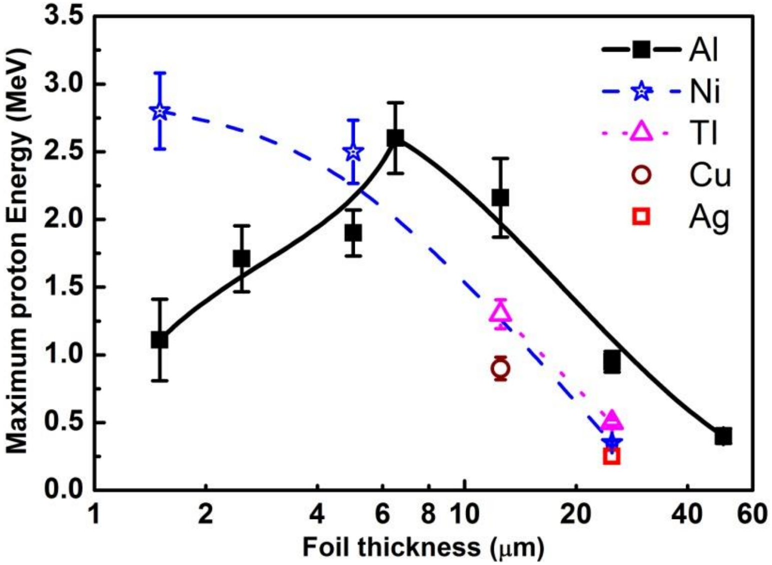


- Laser-driven proton therapy offers compact and low cost alternative to cyclotrons
- 10^9 -10^{10} ions per fraction but perferct control (spectrum, stabilty, pointing)

Proton / Ion Acceleration from Thin Foils

Ion acceleration with 10 TW Ti: Sa laser system using thin foil targets.

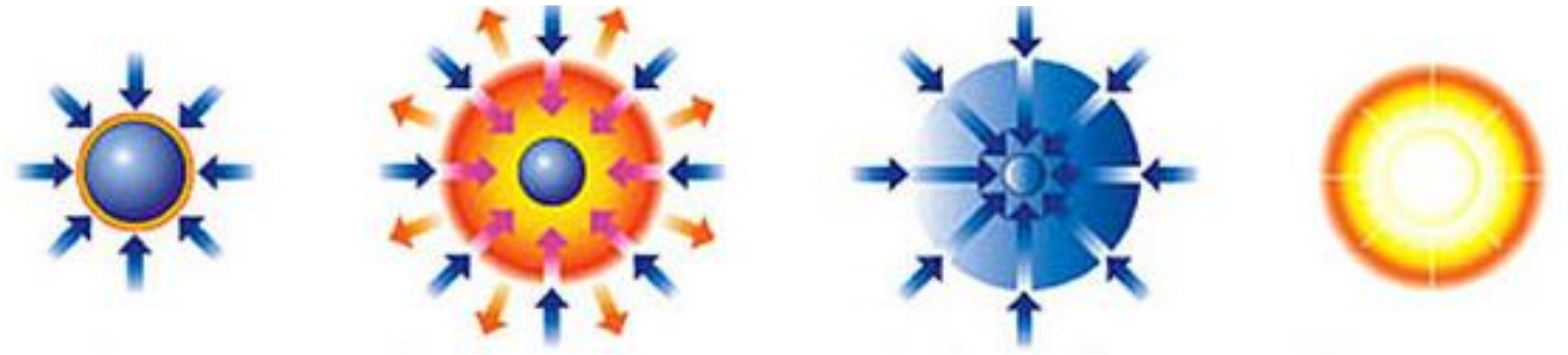




M. Tayyab et al, Phys. Rev. E, 90 023103 (2014)

Laser Driven Inertial Confinement Fusion

Laser irradiation | Plasma blow-off & compression | Convergence & ignition | Thermonuclear burn

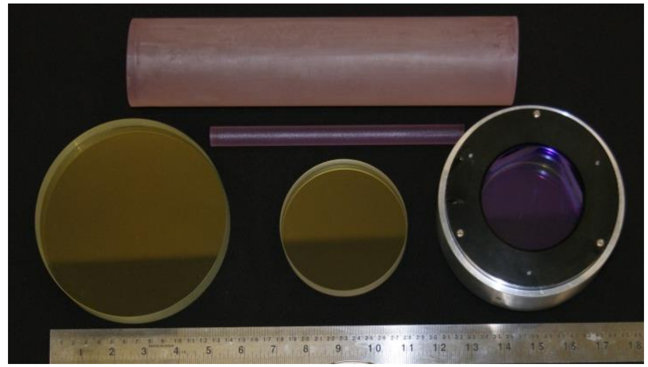


- High power ns-pulse laser beams irradiation in spherical symmetry
- Compression ~ 10^4 Temperature ~ 10 keV
- Simultaneous convergence of sequence of shocks
- Central spark ignition, keeping the rest of the compressed fuel cold

High Power Nd: Glass Laser Chain

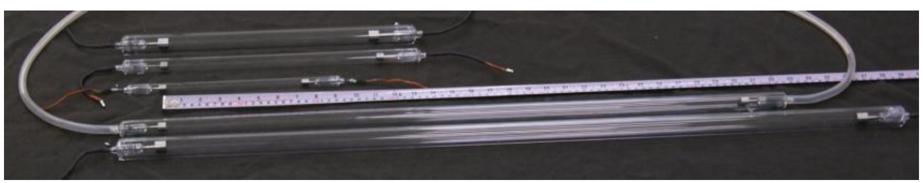
Indigenization of Components for Nd:glass Amplifiers for High Power Lasers

Nd:phosphate glass rods/discs from CGCRI

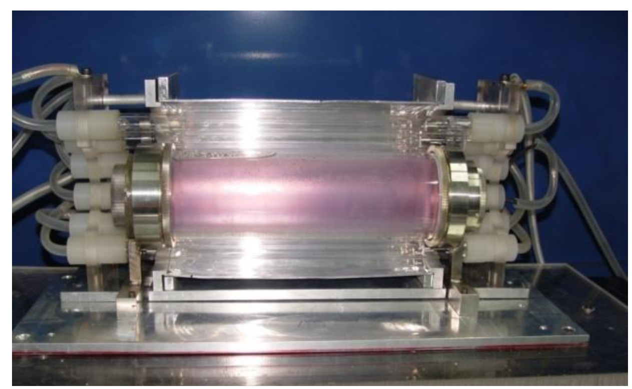


AR coated large dia. glas blanks, lenses, laser rods and KDP crystals

Energy storage capacitor

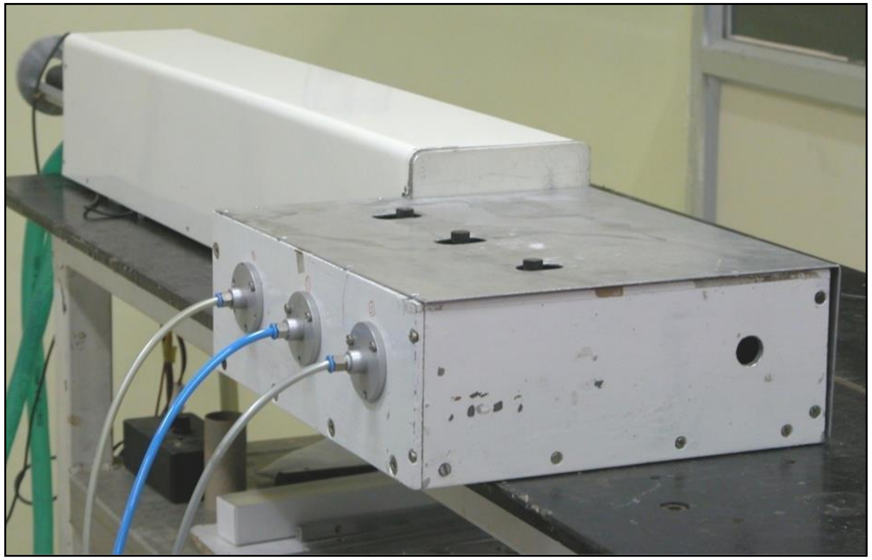


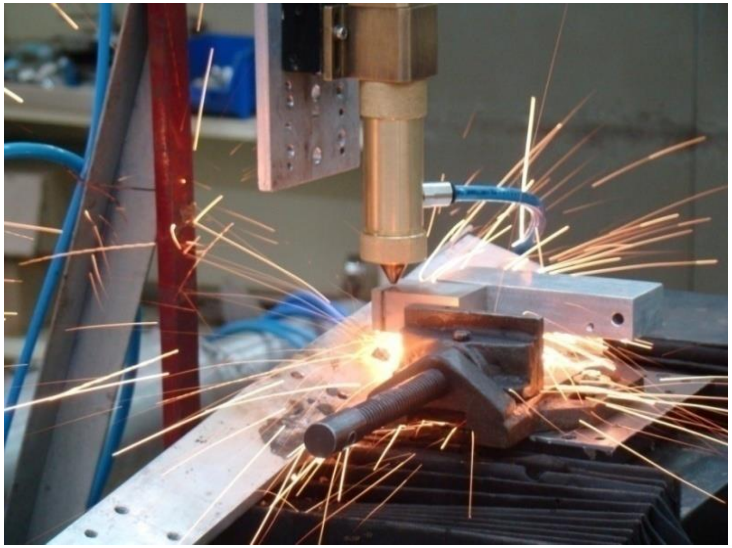
Xenon Flashlamps of arc length 200 to 900 mm developed in India with M/s Litex Ltd., Pune



Laser Material Processing : Strategic Applications

RRCAT has developed high power Nd:YAG lasers along with fiber optic delivery system with remote control operation





- Cutting up to 35 mm thick SS and weld depth up to 2.5 mm
- 20 such laser systems have been commissioned in different DAE units for various cutting and welding operations.

En-masse Coolant Channel Replacement in PHWRs

Matrix of 306 coolant channels
Radiation field ~100 mR

- Laser used for cutting of bellow-lip joints during en-masse coolant channel replacement campaigns for three PHWRs
- Time taken for one reactor : 1 week (c/f 2-3 months for manual operation)

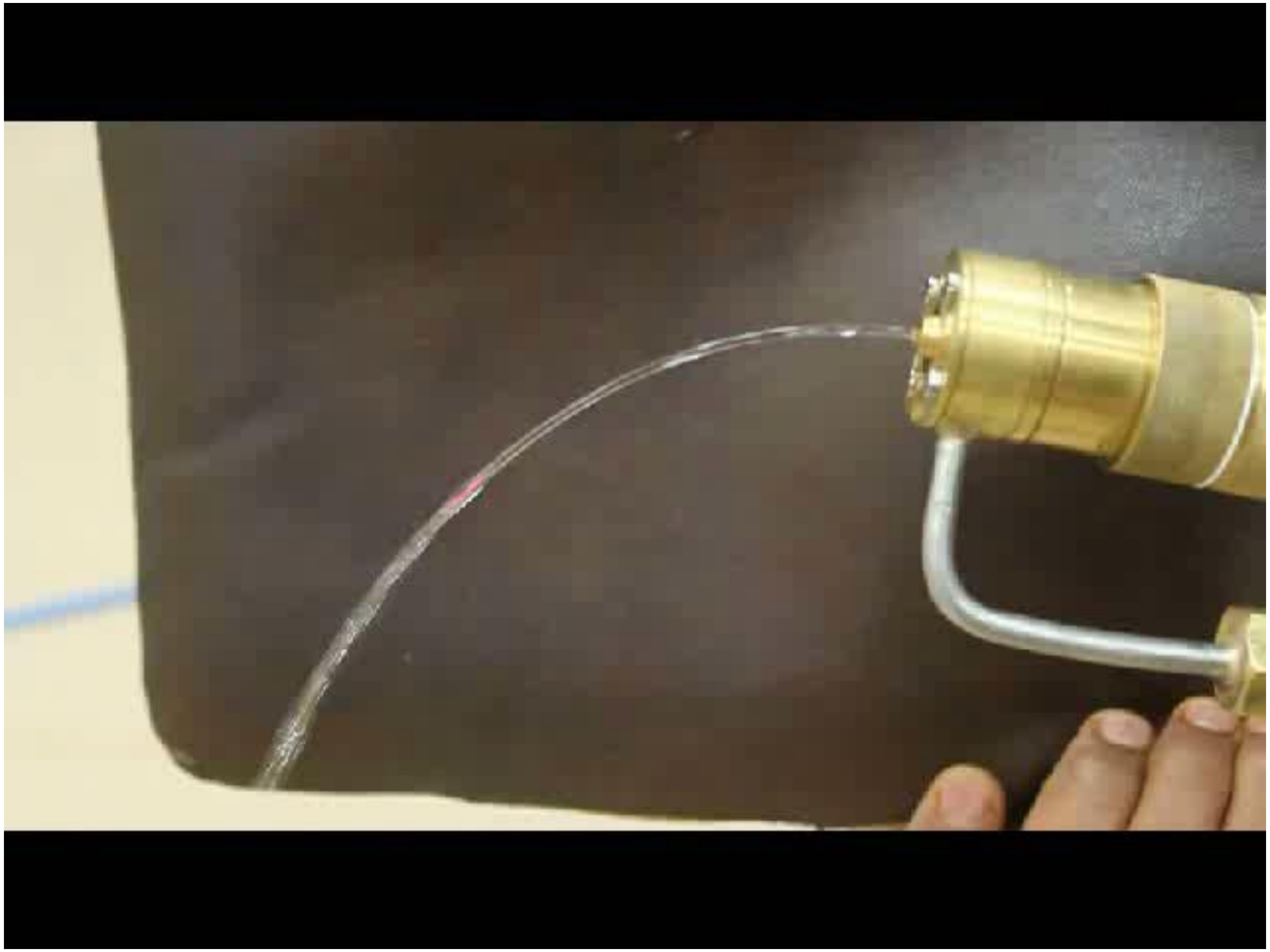
Laser cutting mock-up for bellow lip

- Reduction in radiation exposure by ~ 40 times
- Cost saving > Rs1 Crore per day

Water-jet Assisted Underwater Laser Cutting

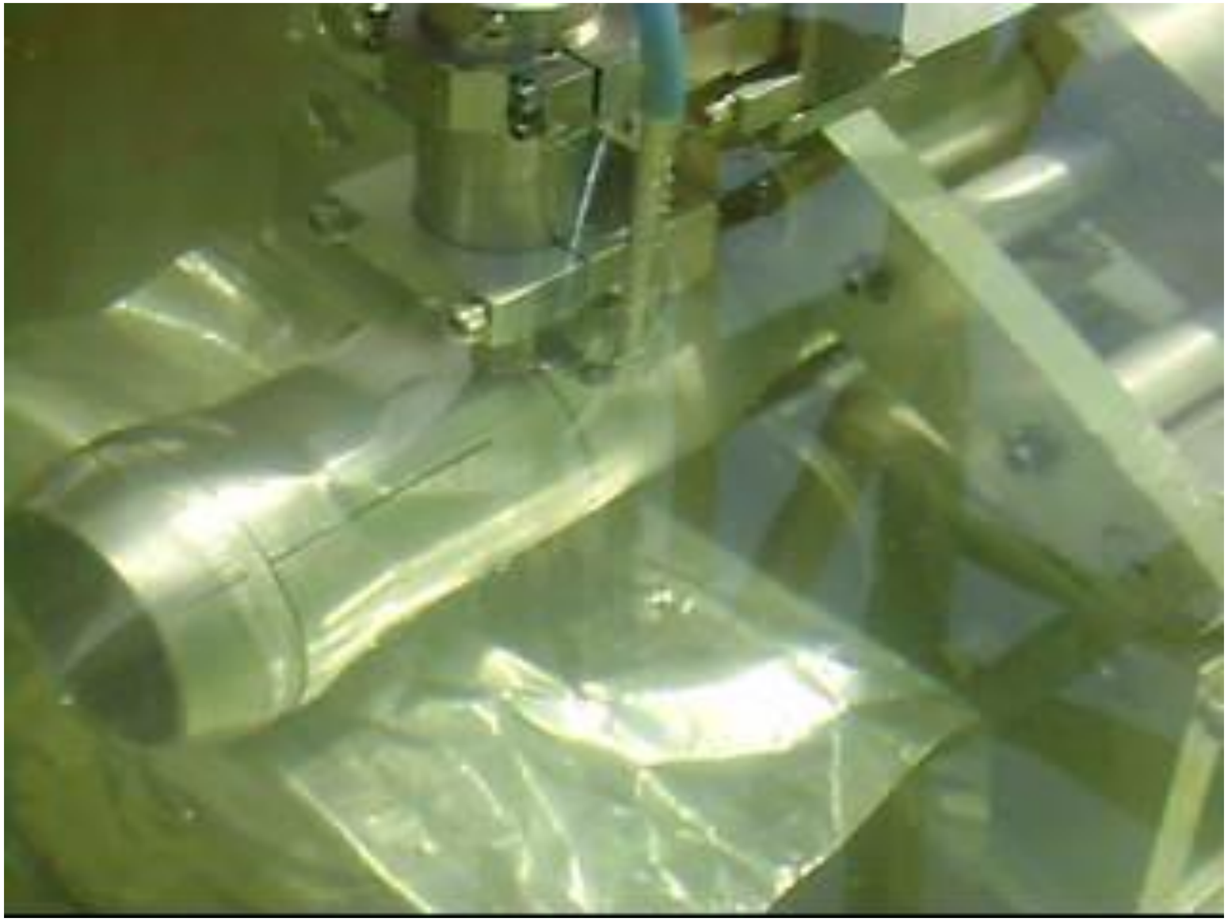
- For cutting of Al fuel tubes stored in water pool of 5 m depth in Dhruva reactor

Water jet Guide for Laser Beam



Underwater Laser Cutting in Dhruva Reactor

- Innovative tool and technology developed for underwater water-jet assisted laser cutting.



Fibre-coupled remotely controlled Nd:YAG laser of 10 kW peak power.

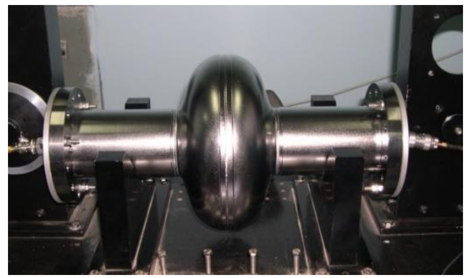
Eight flared aluminium spent fuel tubes stored in water pool of 5 m depth in Dhruva reactor have been successfully cut in.

Laser Welding of Niobium Superconducting RF Cavities

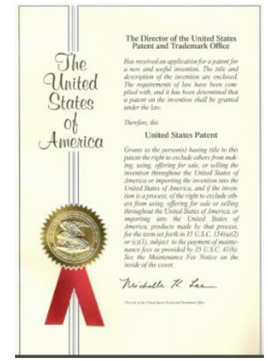
A technological innovation of fabricating superconducting cavities using laser welding has been made by RRCAT.

Japanese Patent

Patent No. JP5632924
grant date Oct 17, 2014



First laser-welded
single-cell 1.3 GHz niobium cavity



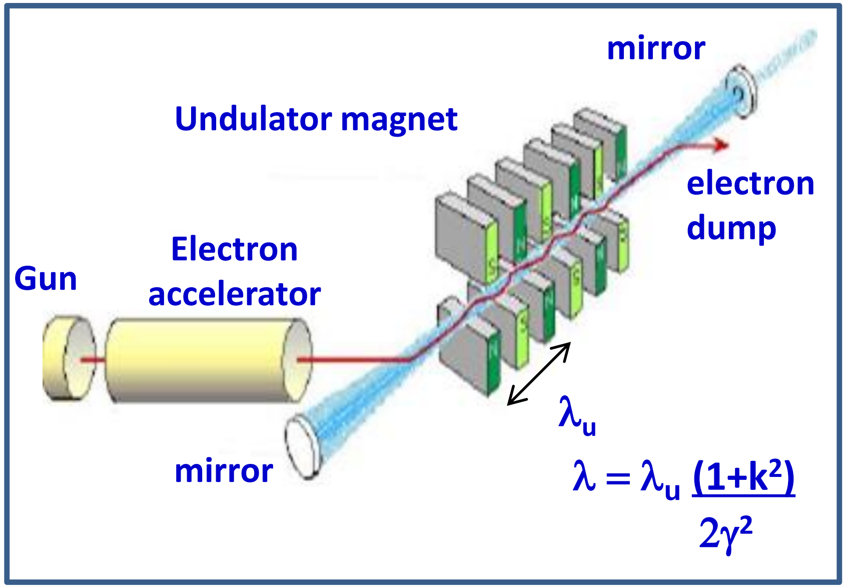
US Patent

Patent No. US 9352416 B2
grant date May 31, 2016

- After successful fabrication and testing of laser welded single cell 1.3 GHz SCRF cavity, first multi-cell laser welded cavity has been fabricated at RRCAT.

Free-Electron Laser Activity

- Combines two technologies : Laser and Accelerator
- A beam of relativistic electrons propagates through a spatially varying periodic magnetic field and emits radiation, which builds up coherently.



- Compact Ultrafast THz FEL (CUTE-FEL) λ : 80 – 200 μm
- Infra-Red FEL (IR-FEL) λ : 12.5 – 50 μm

Infra Red Free Electron Laser

A 60 m long shielded tunnel (width 5 m, height 3.5 m and 1.5 m thick walls) has been built to house the infra red free electron laser.

- An 18 MeV electron beam from linac transported through an undulator.
- Infra-red radiation was detected by a liquid helium cooled bolometer.
- First observation of lasing in the IR-FEL with an estimated gain of 10^4 over expected spontaneous emission at λ = 34.4 μm.

Technology Development for Low Emittance Storage Ring

- Several technologies have been indigenously developed for Indus-2.

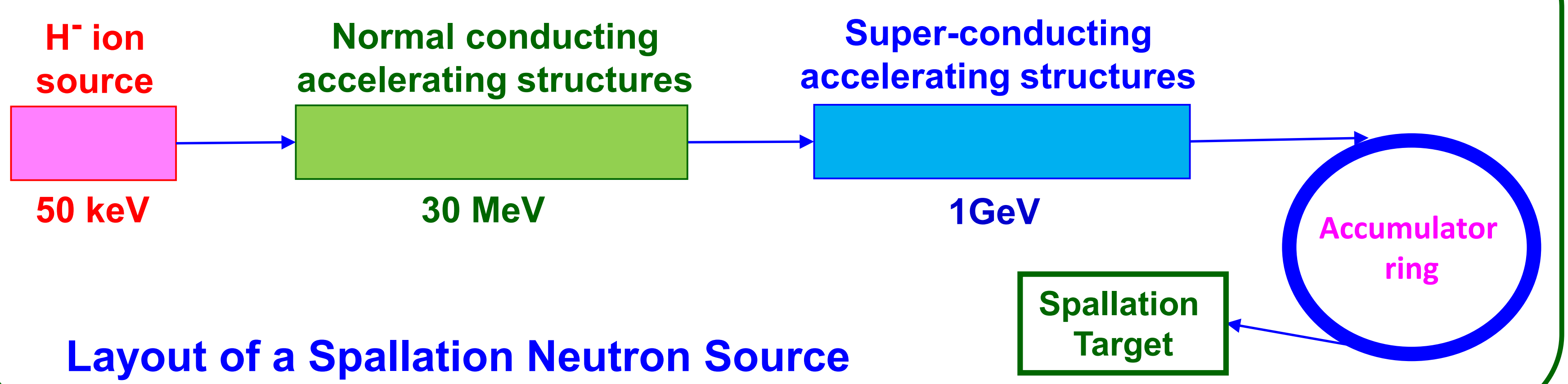
Parameters	Indus-2	Next Synchrotron (Typical values)
Beam orbit stability	3 μm	0.3 μm
Magnetic field uniformity	5 in 10^4	1-2 in 10^4
Power supply stability	50 ppm	10 ppm
Beam position resolution	1 μm	0.1 μm
Tunnel temperature stability	1 ^{0}C	0.1 ^{0}C
RF field amplitude stability	0.5 %	0.1 %
RF field phase stability	0.5^o	0.1^o

- R&D efforts are underway to bridge the technology gaps w.r.to low emittance storage ring.

High energy pulsed proton linac for Indian Spallation Neutron Source

DAE has a long term program on developing a 1 GeV CW proton accelerator (with power > 10 MW) for Accelerator Driven Subcritical System (ADSS).

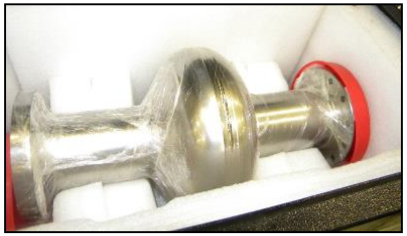
A pulse proton linac based Spallation Neutron Source (to be built at RRCAT) is an intermediate step towards building a CW proton linac.



Layout of a Spallation Neutron Source

A comprehensive infrastructure for covering all steps from fabrication to testing of superconducting RF cavities has been set up at RRCAT.

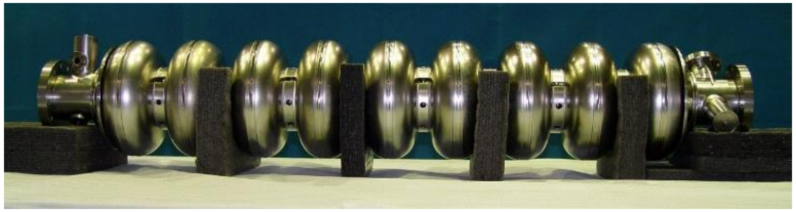
Superconducting RF Cavity Development



Single-cell 1.3 GHz cavity

1.3 GHz five-cell cavity

Single-cell 650 MHz cavity

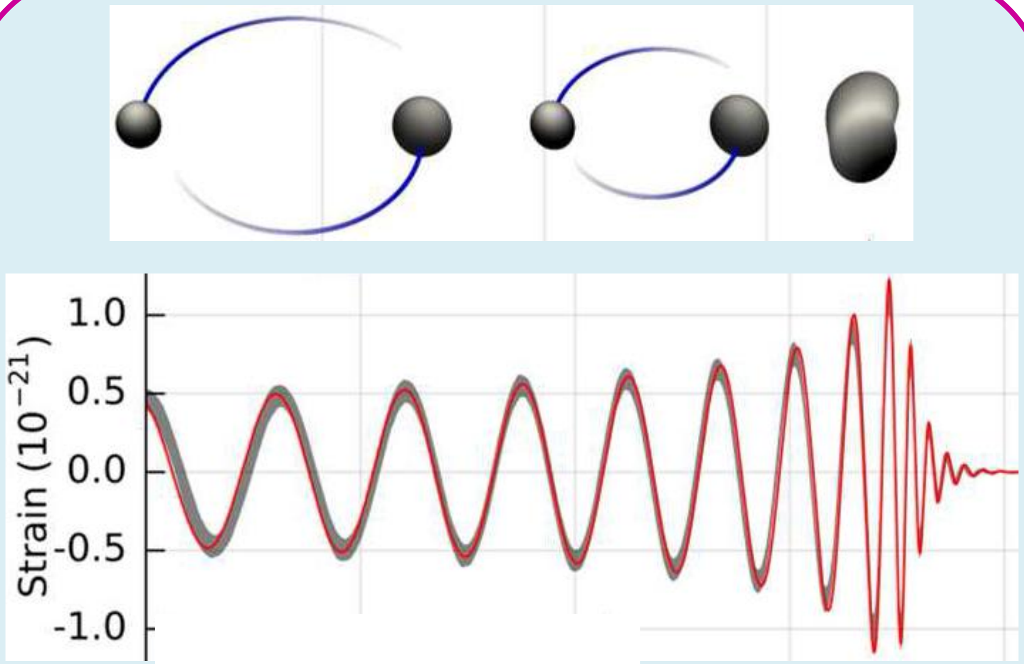


1.3 GHz nine-cell cavity

- 100's of such cavities will be required in high intensity proton accelerators for DAE's programme on SNS and ADS.
- About 18,000 number of 9-cell SCRF cavities will be required in ILC (electron-positron collider, 31 km long).

Detection of Gravitational Waves from a Binary Black Hole Merger

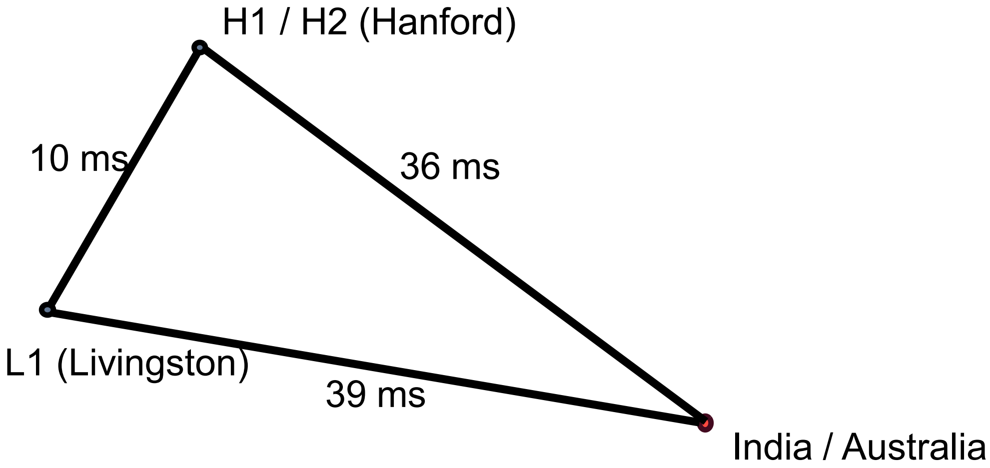
- On February 11, 2016, NSF announced detection of gravitational waves due to merger of two black holes of 36 and 29 solar mass 1.3 billion years ago.
- This detection was done by two LIGO detectors (laser interferometer gravitational wave observatory) at Hanford and Livingston.

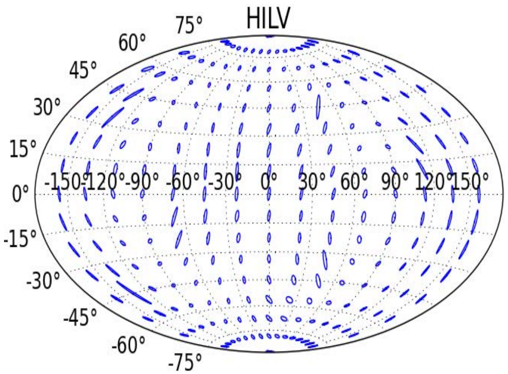


- These laser detectors are extremely sensitive and can detect strain to the order of 10^{-21}.
- This discovery has heralded the start of a new era in astronomy : 'Gravitational wave astronomy'.

LIGO India Mega Project

- Adding the third LIGO detector in India to the two existing in USA at Hanford and Livingston will improve sky localization of the origin of gravitational wave.

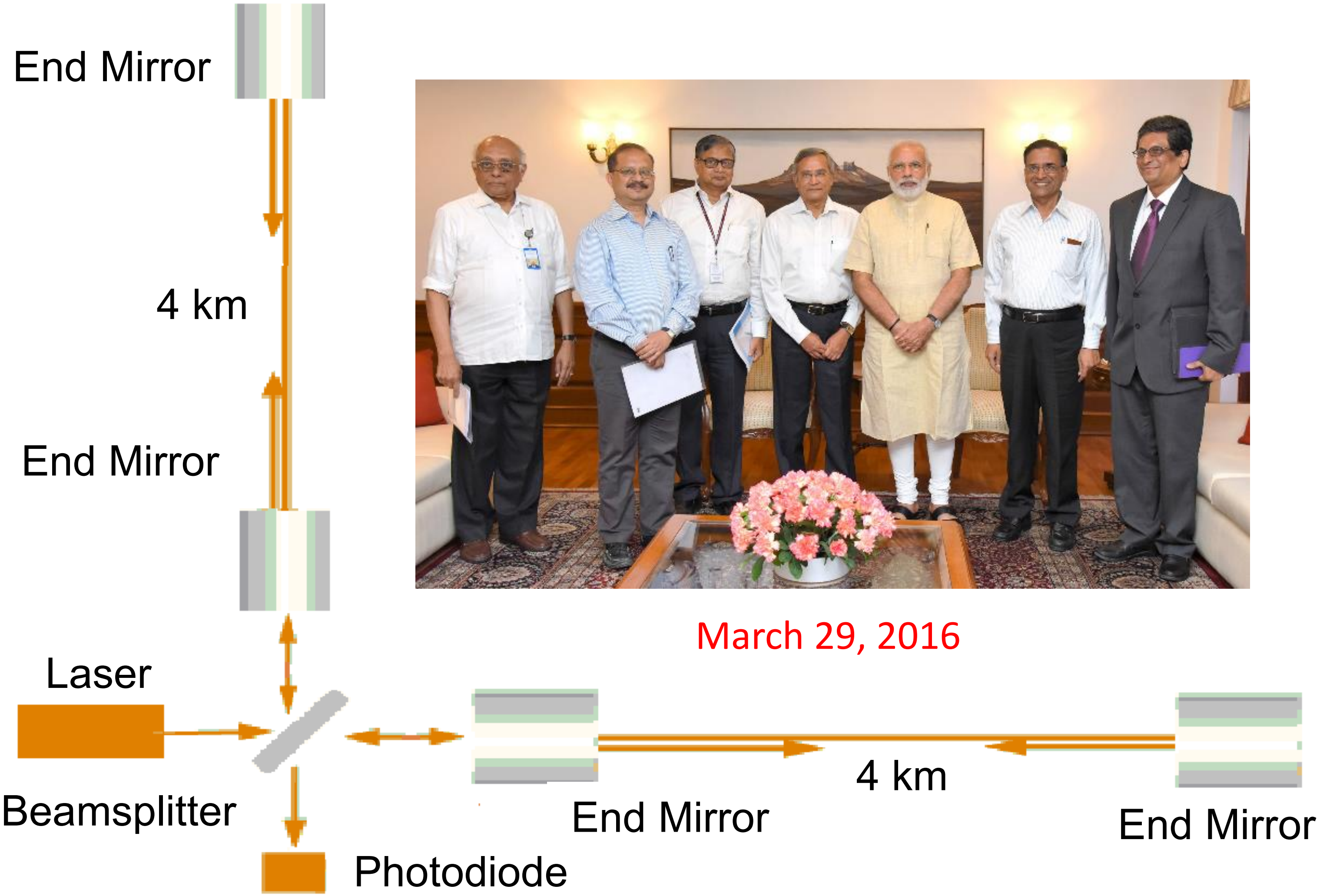




- Recently, Government of India has given in-principle approval to set up LIGO-India with a project cost of Rs 1260 Cr (185 M US$).
- Project in collaboration with LIGO-US.
- Participating institutions : RRCAT, IPR, IUCAA, DCSCM.

LIGO-India : Laser Interferometer Gravitational Wave Observatory

RRCAT Indore : Laser detector and optics



March 29, 2016


Thank You