ILC – Enabling Technology

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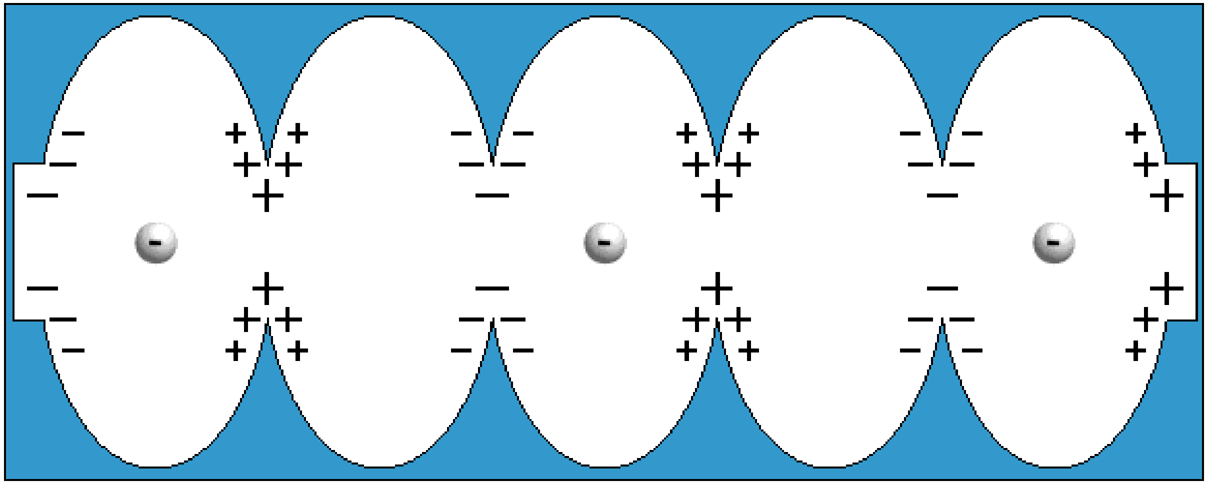
Superconducting Radio Frequency Technology (SRF)

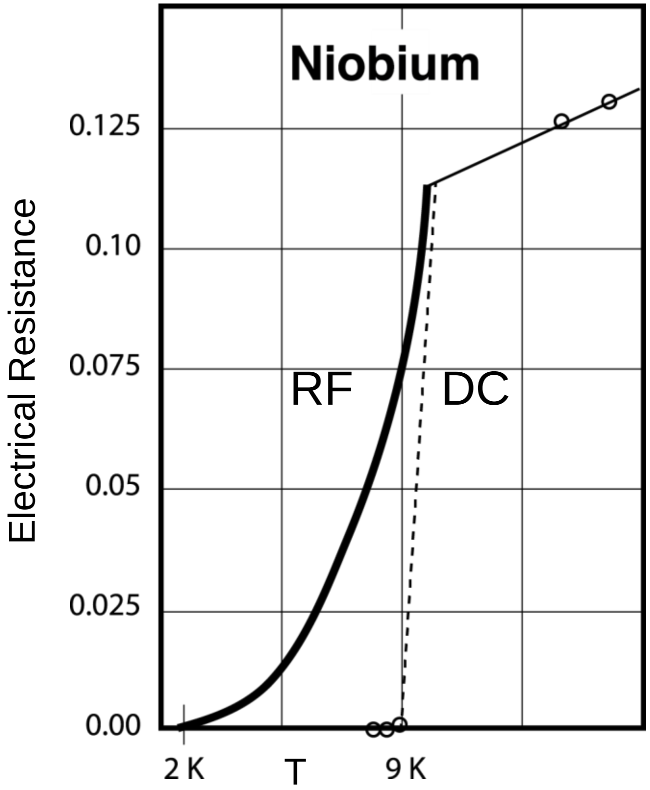
Topics

- Principle of the devices
- Basics of RF Superconductivity
- Examples of operating facilities using SRF
- Examples of facilities in planning that would use SRF
- Potential of new superconducting materials for the future

Accelerating Cavity Principle



Combine with the Fact of Superconductivity

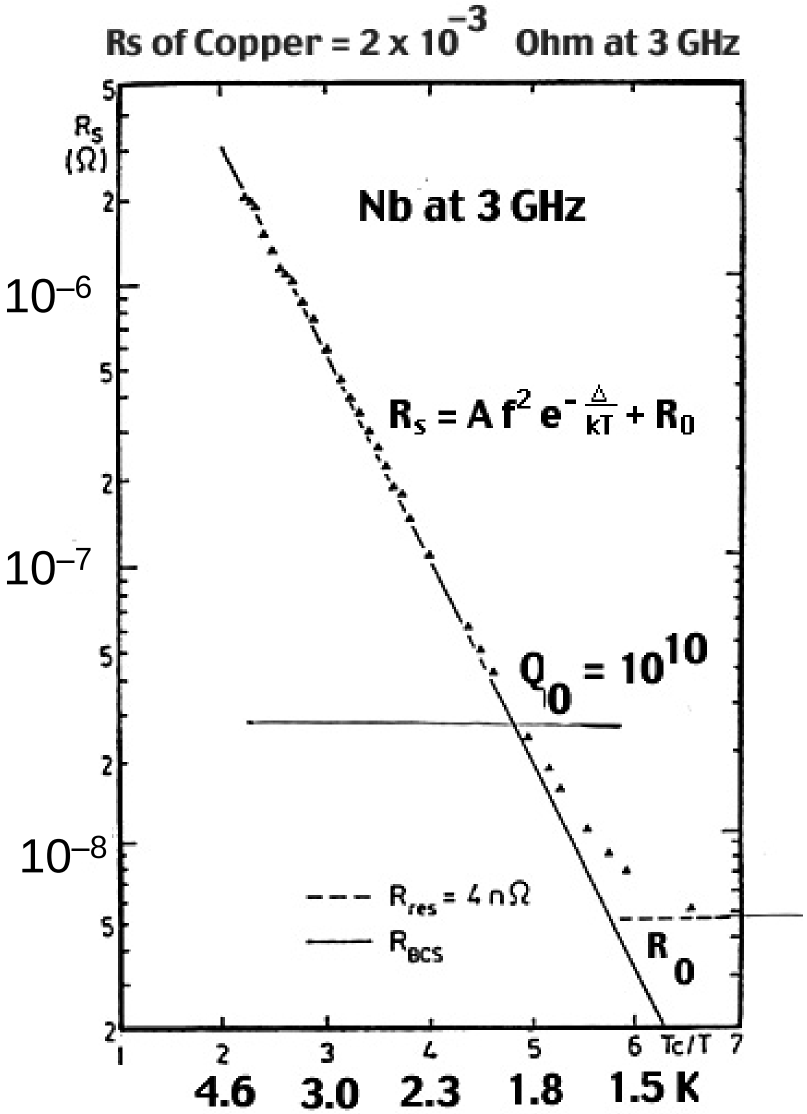


Difference between DC and RF Resistance

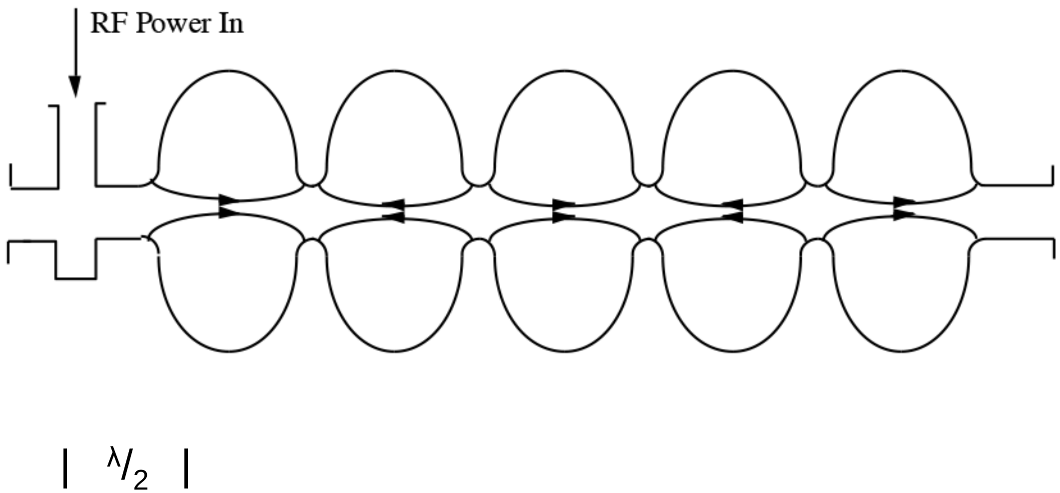
Below a "**transition temperature**" the electric current carried by **Cooper Pairs** with no resistance to their movement
DC Cooper pairs move without resistance in one direction only
RF (AC) Cooper pairs move back and forth to carry the alternating RF currents. They have inertia so moving them back and forth requires an electric field inside the material. Those normal conducting electrons that have not condensed into Cooper Pairs are also accelerated by the electric field and thus the resistance. As the temperature approaches absolute zero more and more of the electrons condense, lowering the resistance.

Leads to
Main Advantages of Superconducting Cavities

- A superconducting cavity reduces the wall dissipation by many orders of magnitude over a copper cavity
- => Affordable higher CW and long pulse gradients
- Larger aperture cavity geometry => for better beam quality

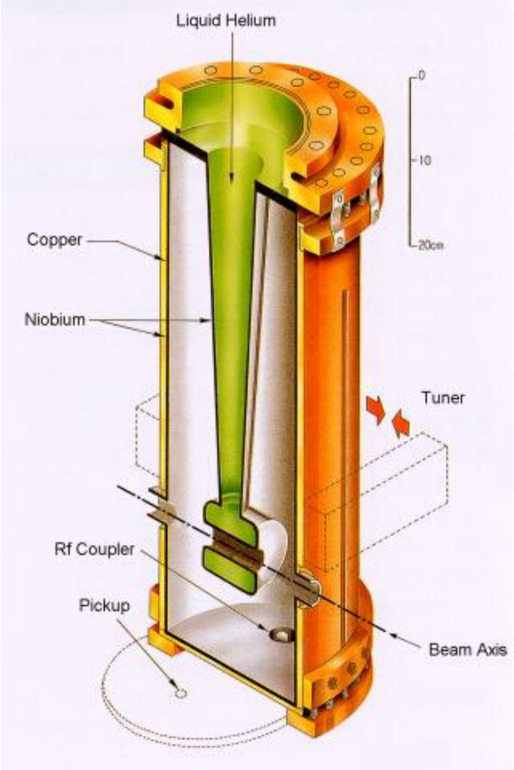


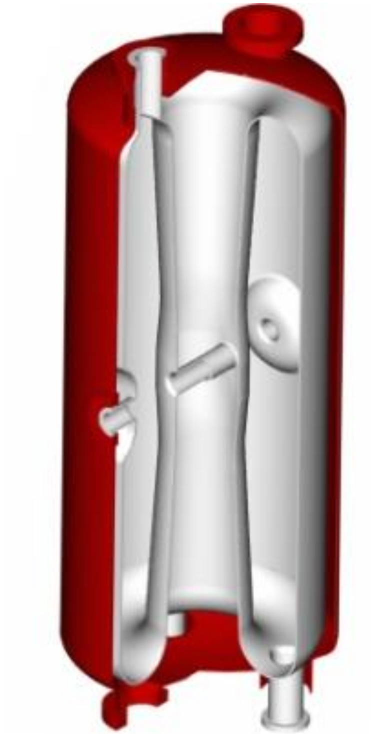
Typical Accelerating Cavity for High Velocity Particles



Typical Accelerating Cavity for Low Velocity Particles

Accelerating Gaps $< {}^{\lambda}/_{2}$





Proven Applications of SRF

- Nuclear Physics
  - Ions (total > 1 GeV)
    - Low Energy
    - Nuclear Astrophysics
  - Electrons (total 12 GeV)
- Light Sources
  - Storage Rings
  - FELs
- Neutron Sources

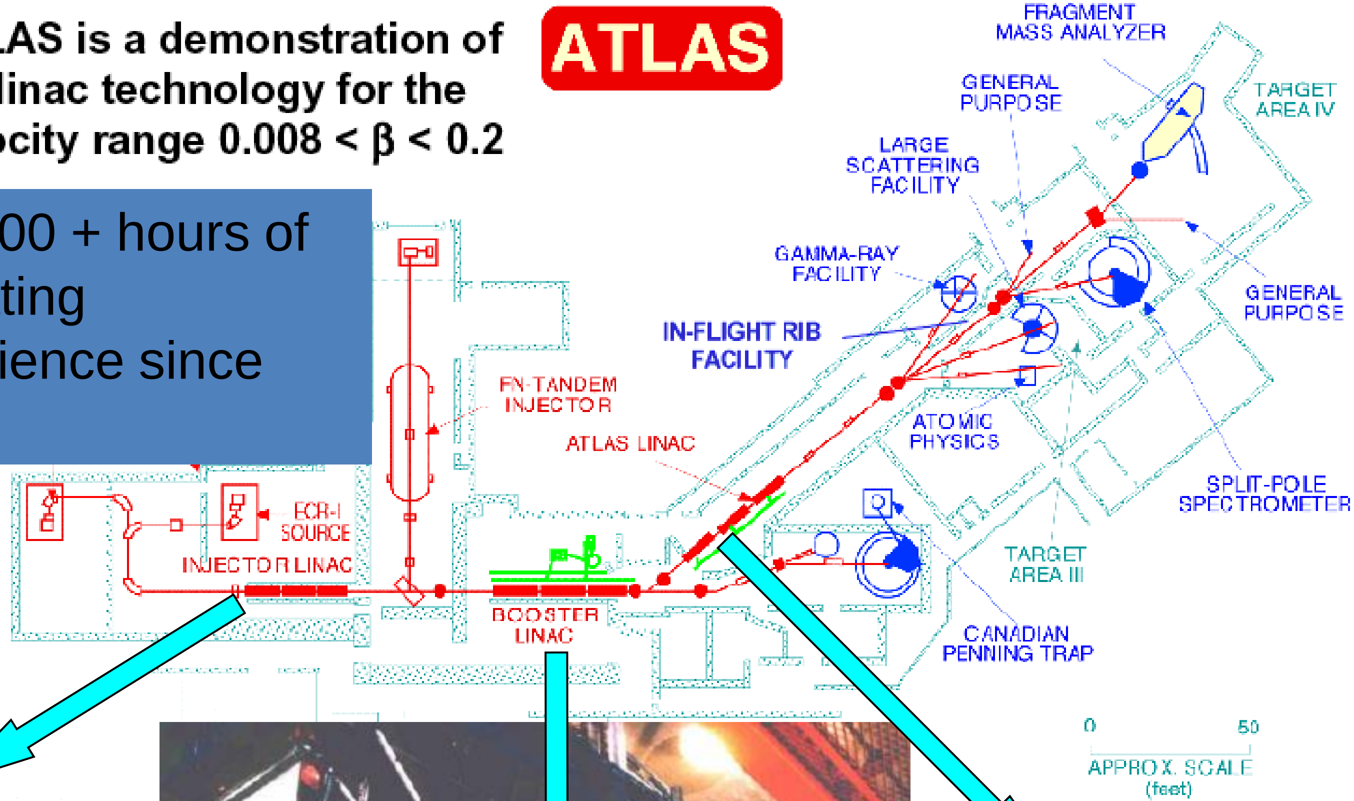
(Examples to be given not a complete list – apologies)

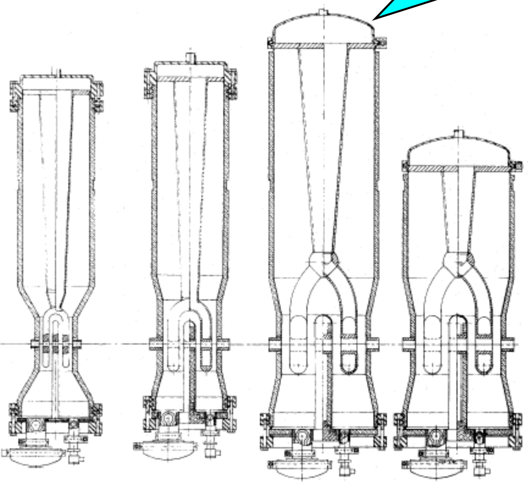
Started in 1978

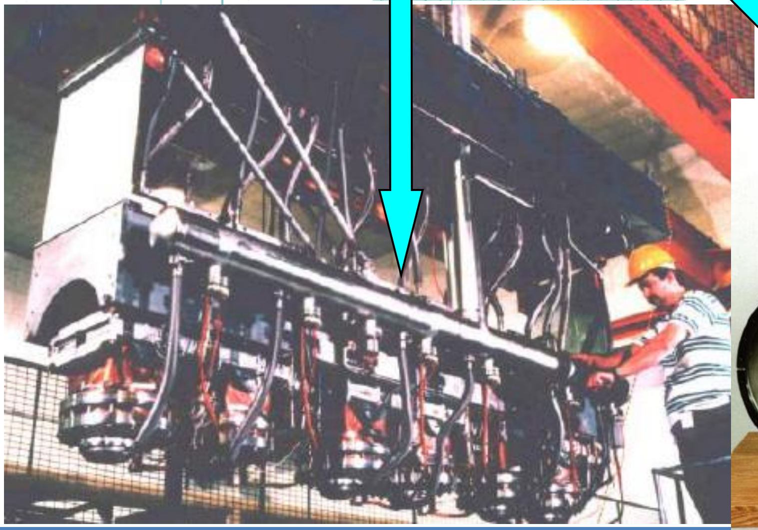
ATLAS is a demonstration of SC linac technology for the velocity range $0.008 < \beta < 0.2$

ATLAS

100,000 + hours of operating experience since 1978



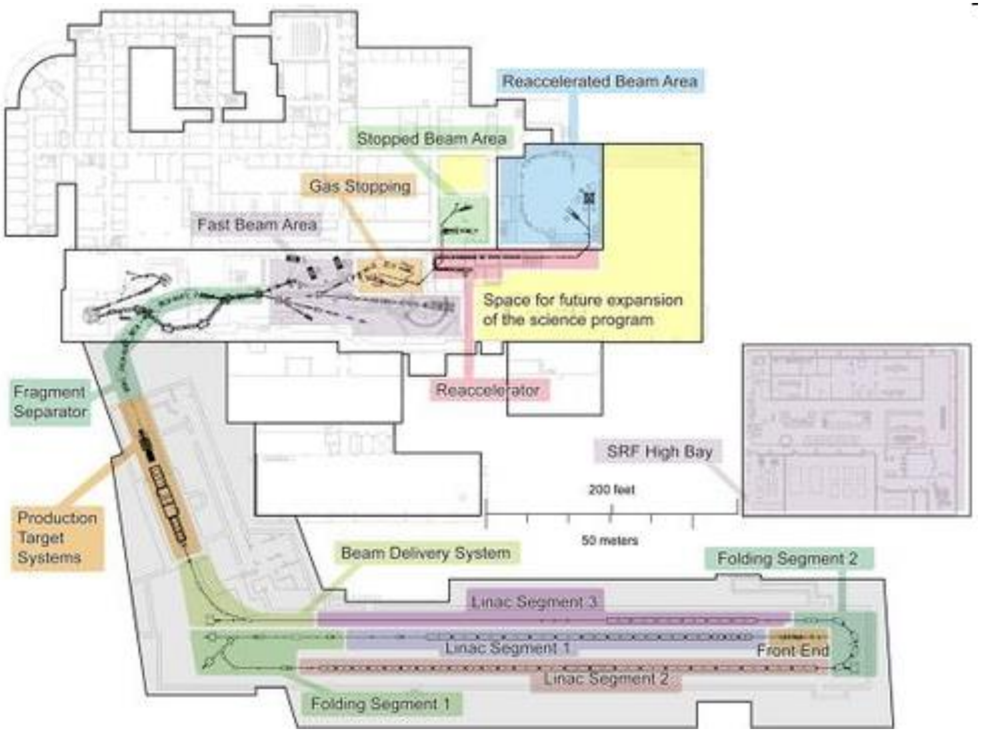


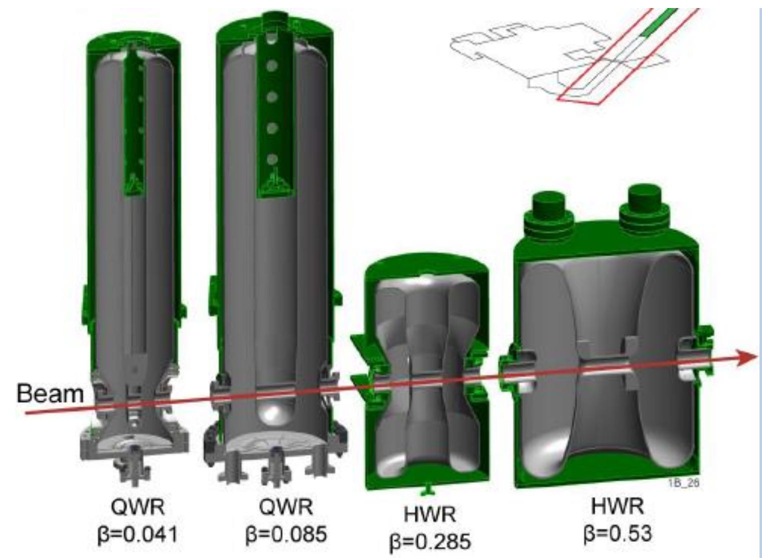


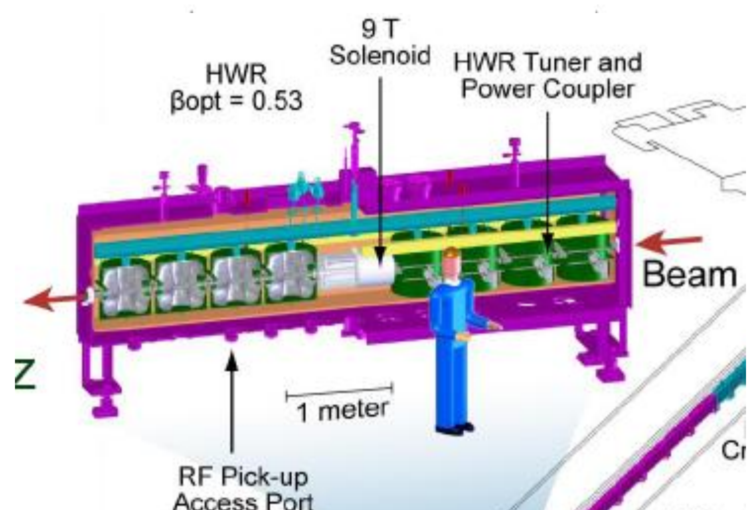
Superconducting Accelerating Structures

FRIB, Facility for Rare Isotope Beams Under Construction at MSU

- 336 Resonators to be built
  - QWR and HWR







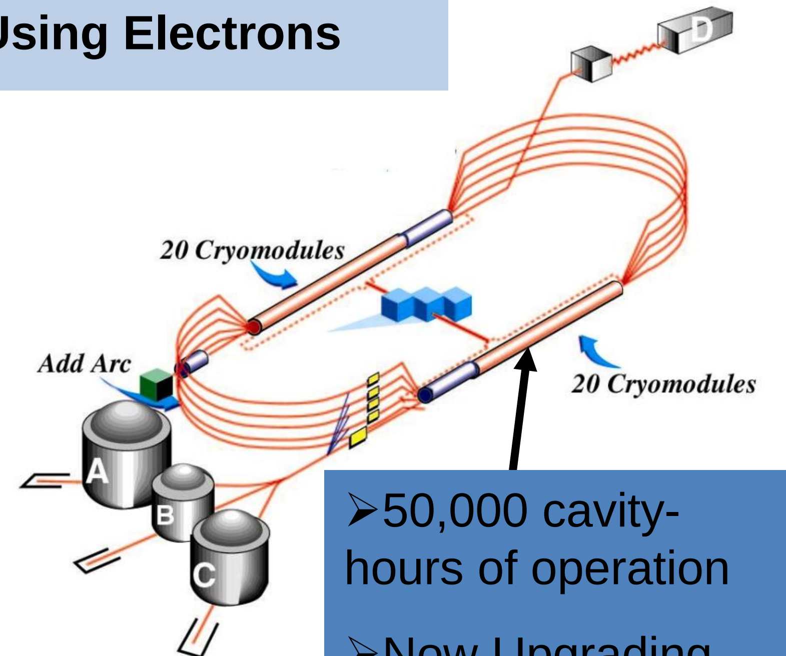
Medium Energy Nucelar Physics

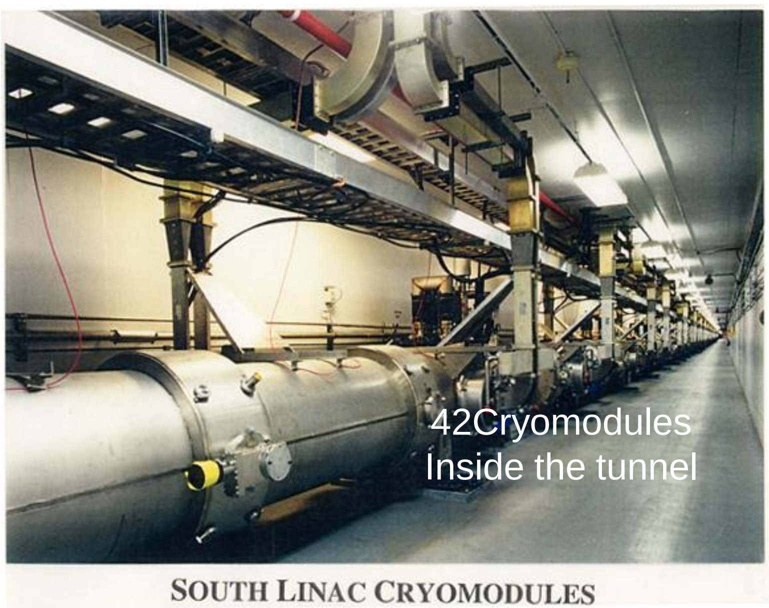
- Understanding the quark-gluon structure of nucleus
- Distribution of nuclear spin

6 -12 GeV Re-circulating Linear Accelerator for Nuclear Physics Using Electrons

380 accelerating structures for Jefferson Lab

7 MV/m





42Cryomodules Inside the tunnel

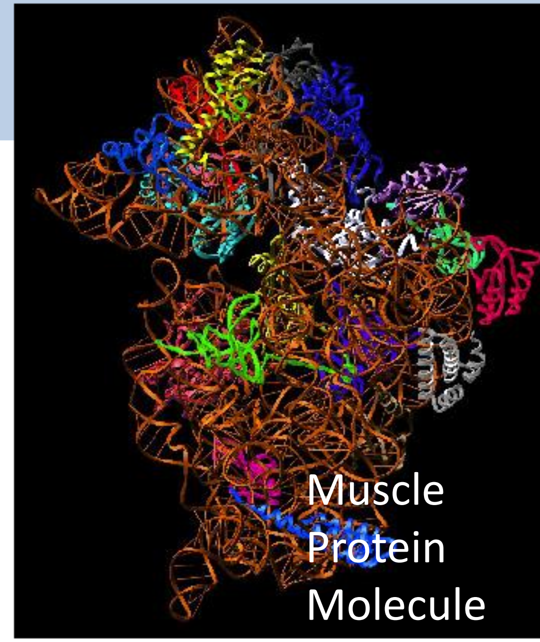
- ➢50,000 cavity-hours of operation
- ➢Now Upgrading
  - ➢to 12 GeV
- ➢18 MV/m

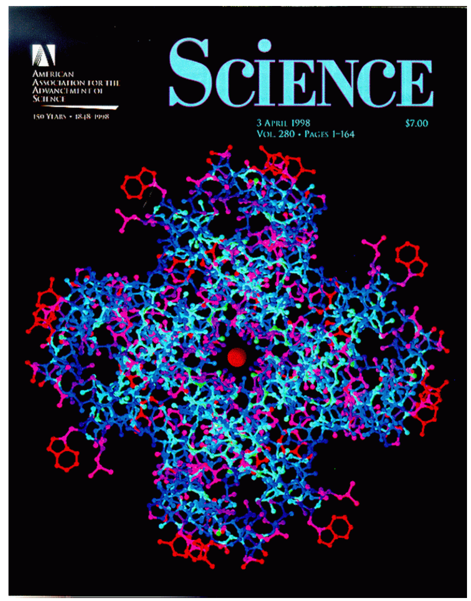
X-Ray Science

X-Ray Science

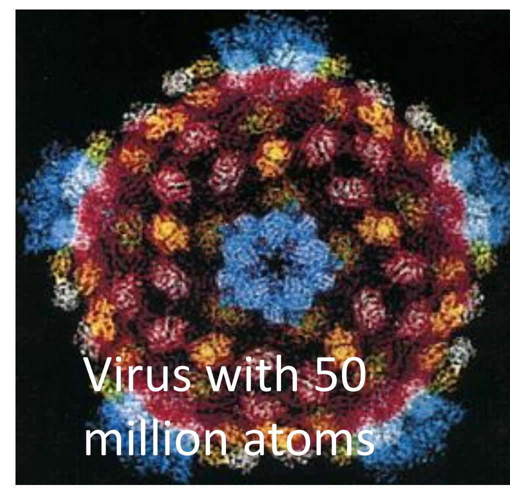
Extremely Broad

Deals with everything from
Fundamental Biology and Medicine to
. . .
Chemistry
Chemical engineering
Metallurgy
Metallurgical engineering
. . .
materials physics
nanoscience
. . .
civil engineering
environmental science



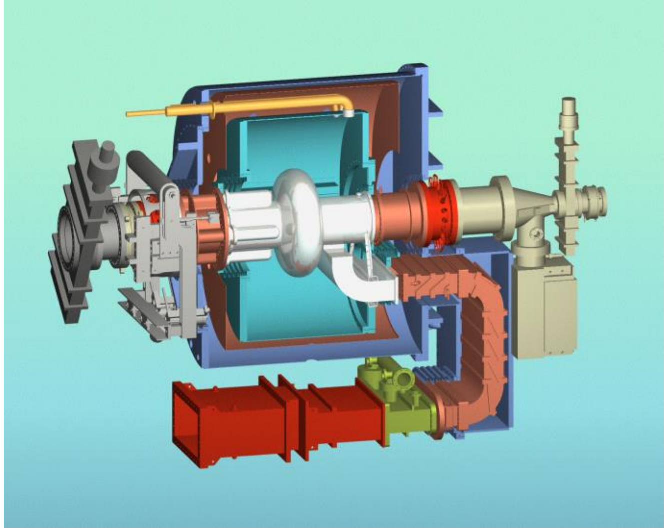


Chemistry Nobel prize



SRF in Electron Storage Rings for X-Rays

- CESR/CHESS (USA)
- Canadian Light Source
- Taiwan Light Source
- DIAMOND Light Source (UK)
- Shanghai Light Source

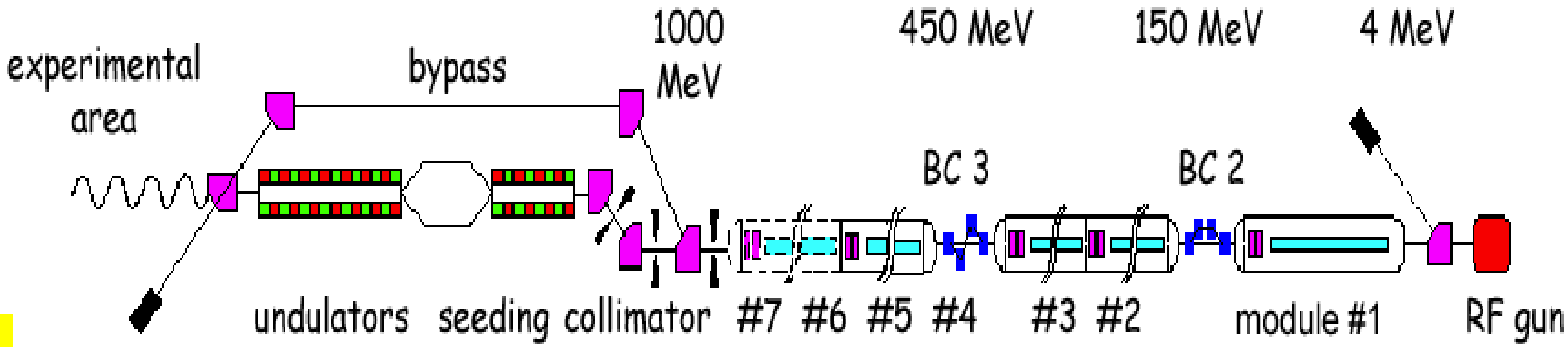


- SOLEIL (France)
- Beijing Tau-Charm Factory
- Swiss Light Source
  - For life time increase
- ELETTRA (Italy)
  - For life time increase
- NSLS2 BNL (USA)
  (under construction)

Free Electron Lasers: Infrared, UV, X-Ray

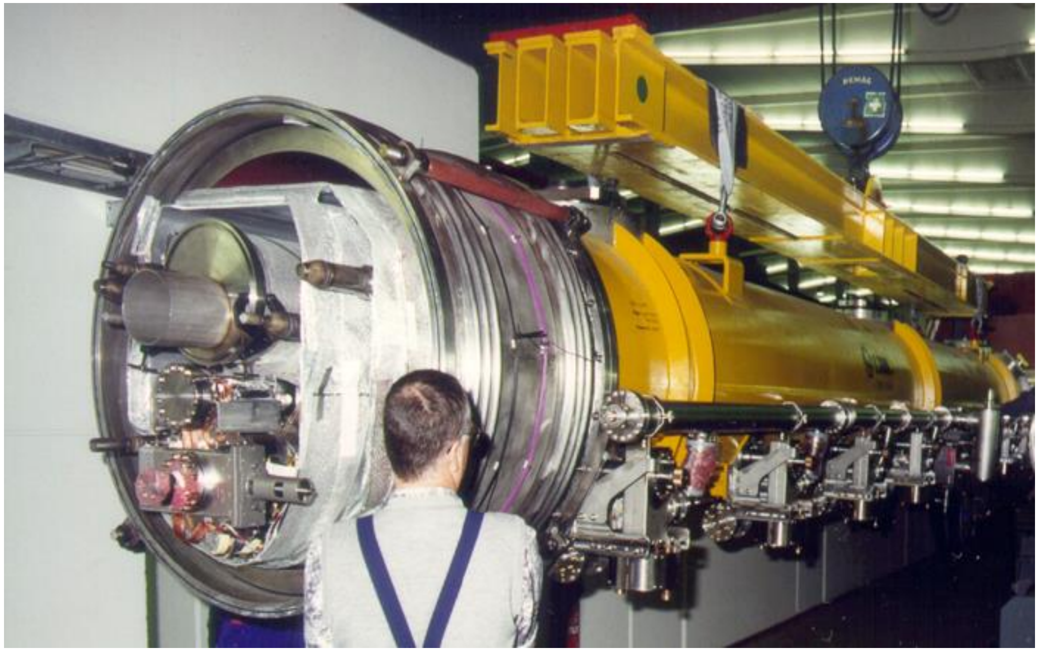
- Jefferson Lab
- JAERI-FEL
- Darmstadt
- DESY (FLASH)

DESY – SASE – FEL FLASH VUV to Soft X-Rays

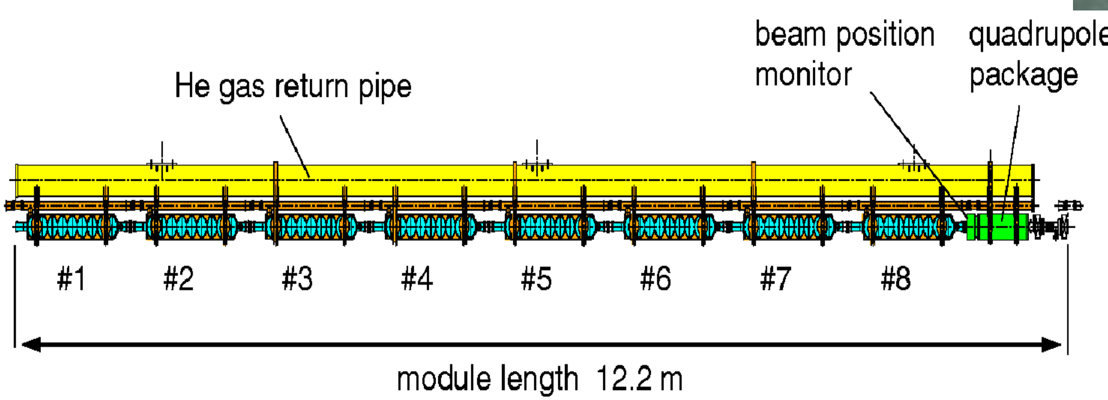


TTF-II

Basis of XFEL, Now Under Construction



8-Cavity Module for FLASH and XFEL



25 MV/m

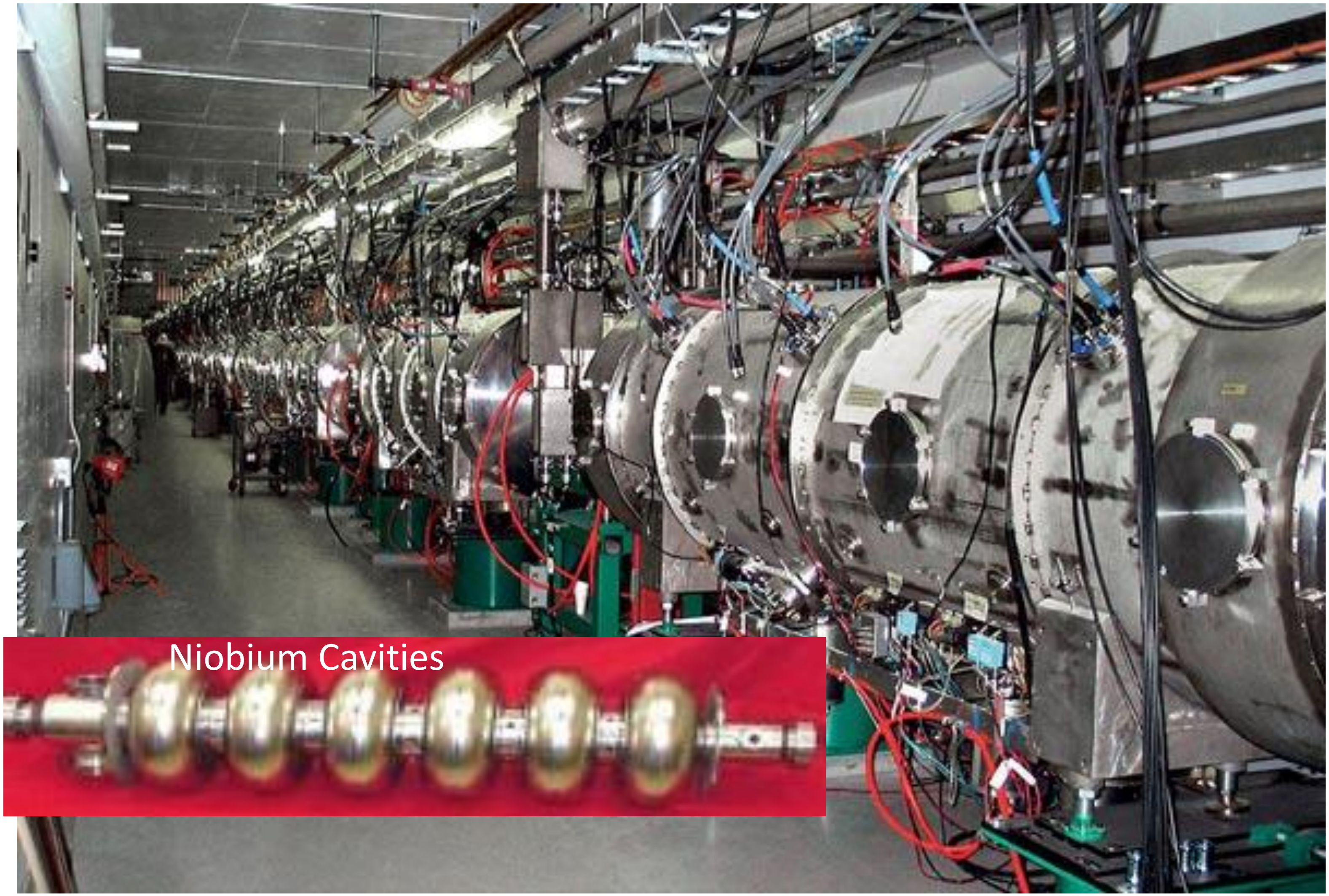
XFEL (18 GeV) Under Construction

The biggest SRF application to date

800 cavities , 24 MV/m, 18 GeV

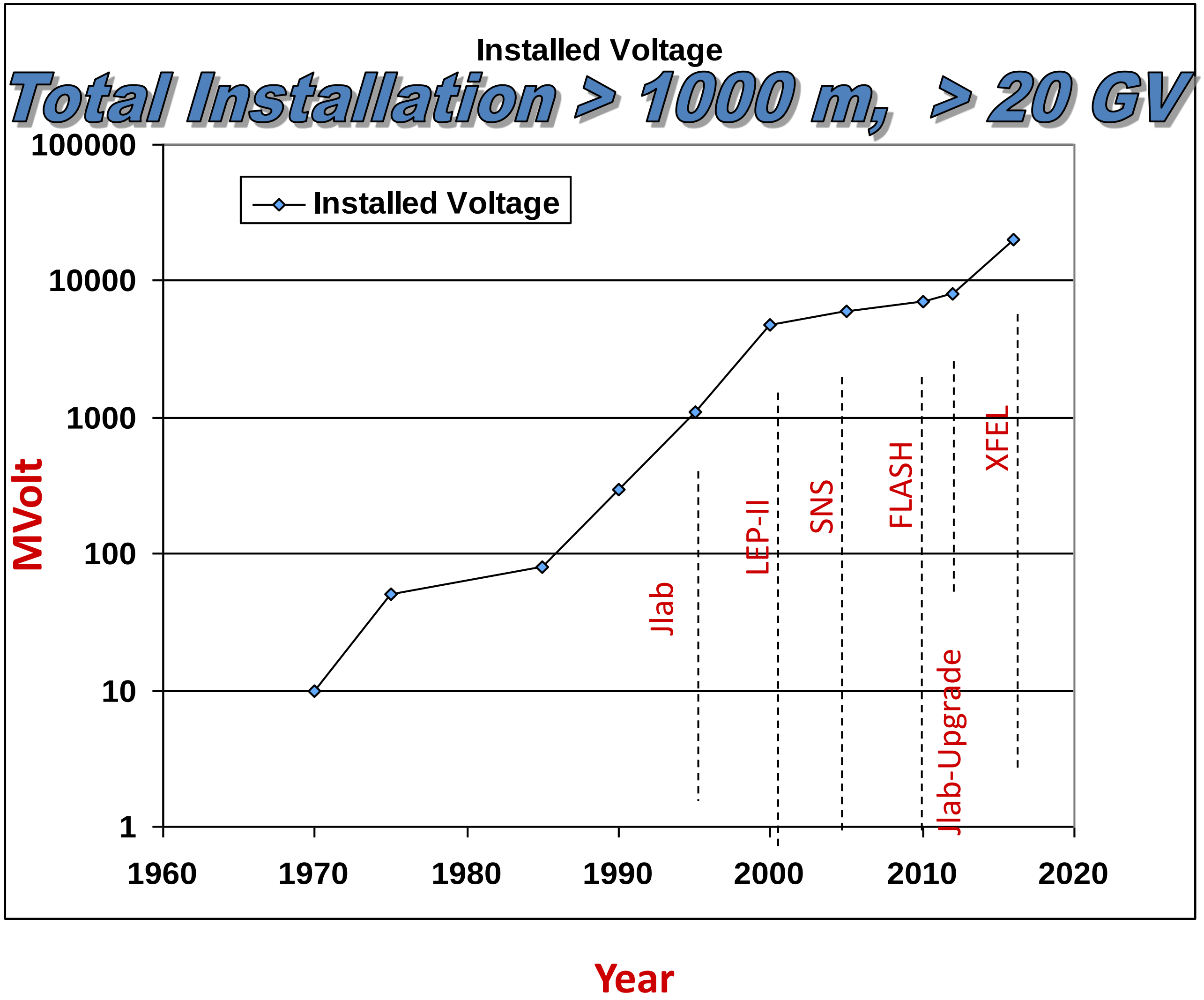

Neutron
Science
Materials design
Drug discovery
Biotechnology
Advanced Engineering
Biology
Material Science
Soft Condensed Matter
Structural Chemistry
Templating of nanostructures
Solid State Physics
Magneto electronics
Fundamental Physics
Liquid and Glasses
Energy Resources
Particle physics cosmology astrophysics
Earth Science
Unveiling ancient technologies
Hydrogen Economy
H2

SNS (1 GeV protons, > 1 MW)
Low Energy Neutrons by Spallation In A Target



50 Yr-Growth of Installed Voltage *for v/c=1 Accelerators*

A "Livingston Plot" for RF Superconductivity

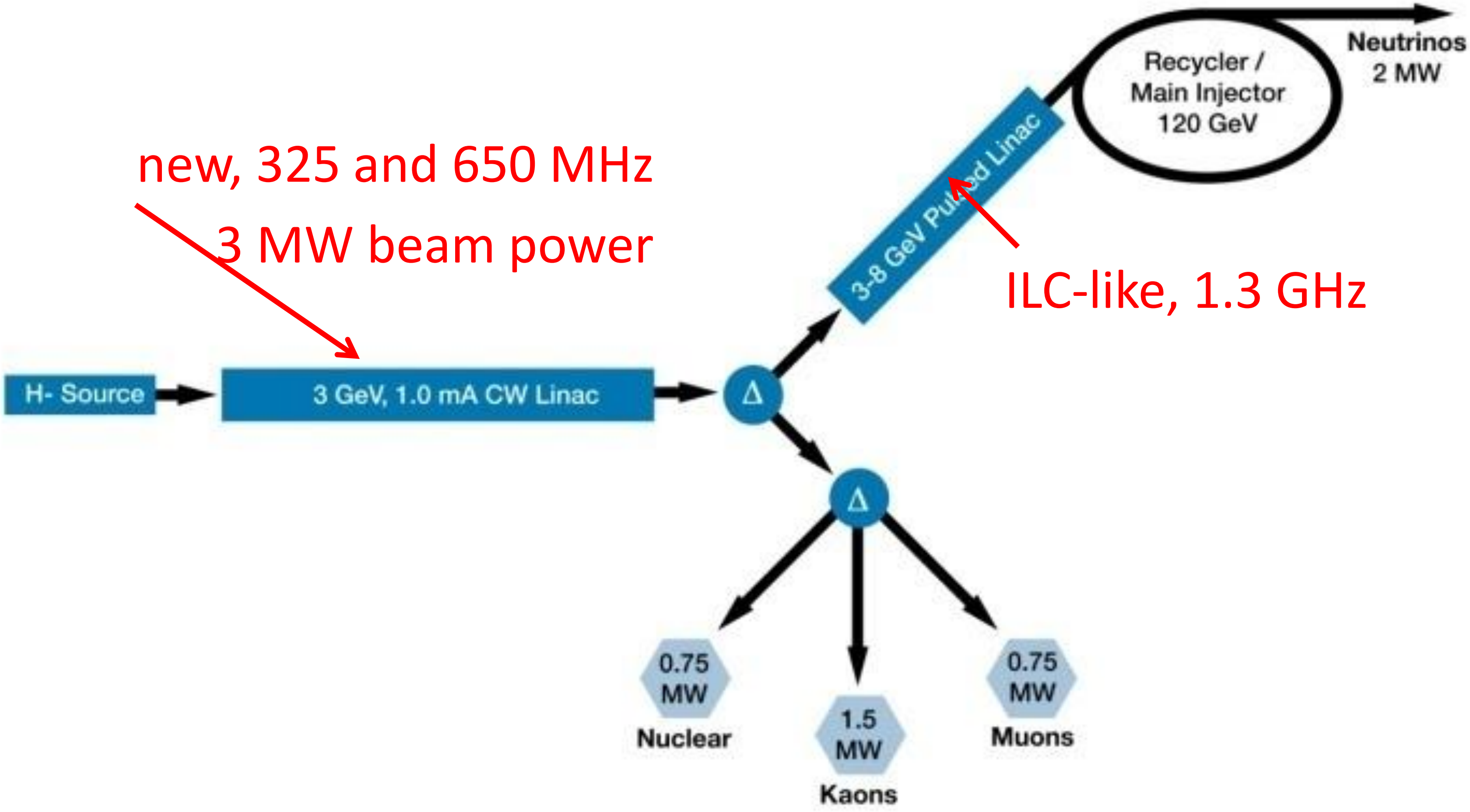


Future Projects Under Study with Prototype Construction *(besides ILC)*

High Intensity Proton Linacs
Beam Power 1–5 MW

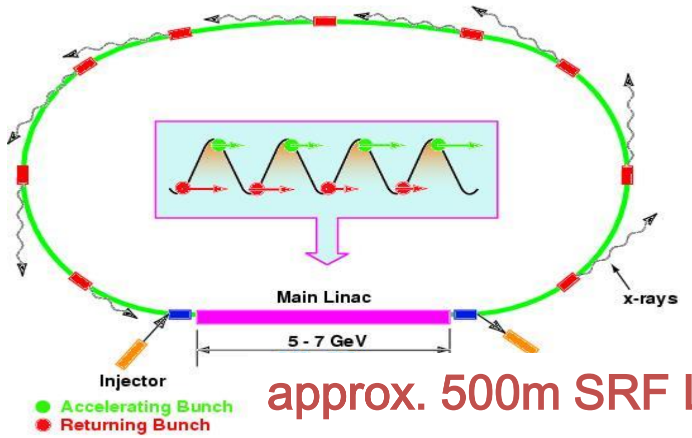
- Anticipated
- ESS
  - European Spallation Source
- CSNS – China
- Proton Drivers
  - Project X (Fermilab)
  - SPL (CERN)
- ADS
  - MYRRAH
  - India
  - Japan
  - China

Future > 2020
Project X Accelerator at Fermilab

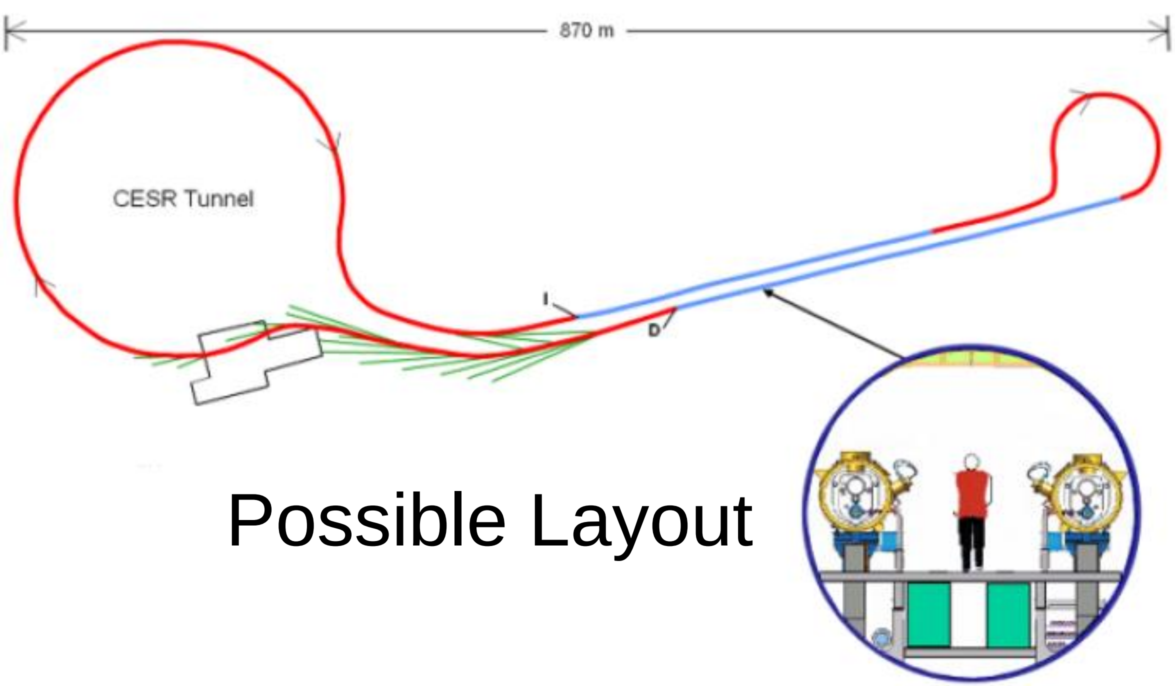


Two accelerator sections comprised of SRF cavities

Energy Recovery Linac
Next Generation Light Sources



approx. 500m SRF Linac

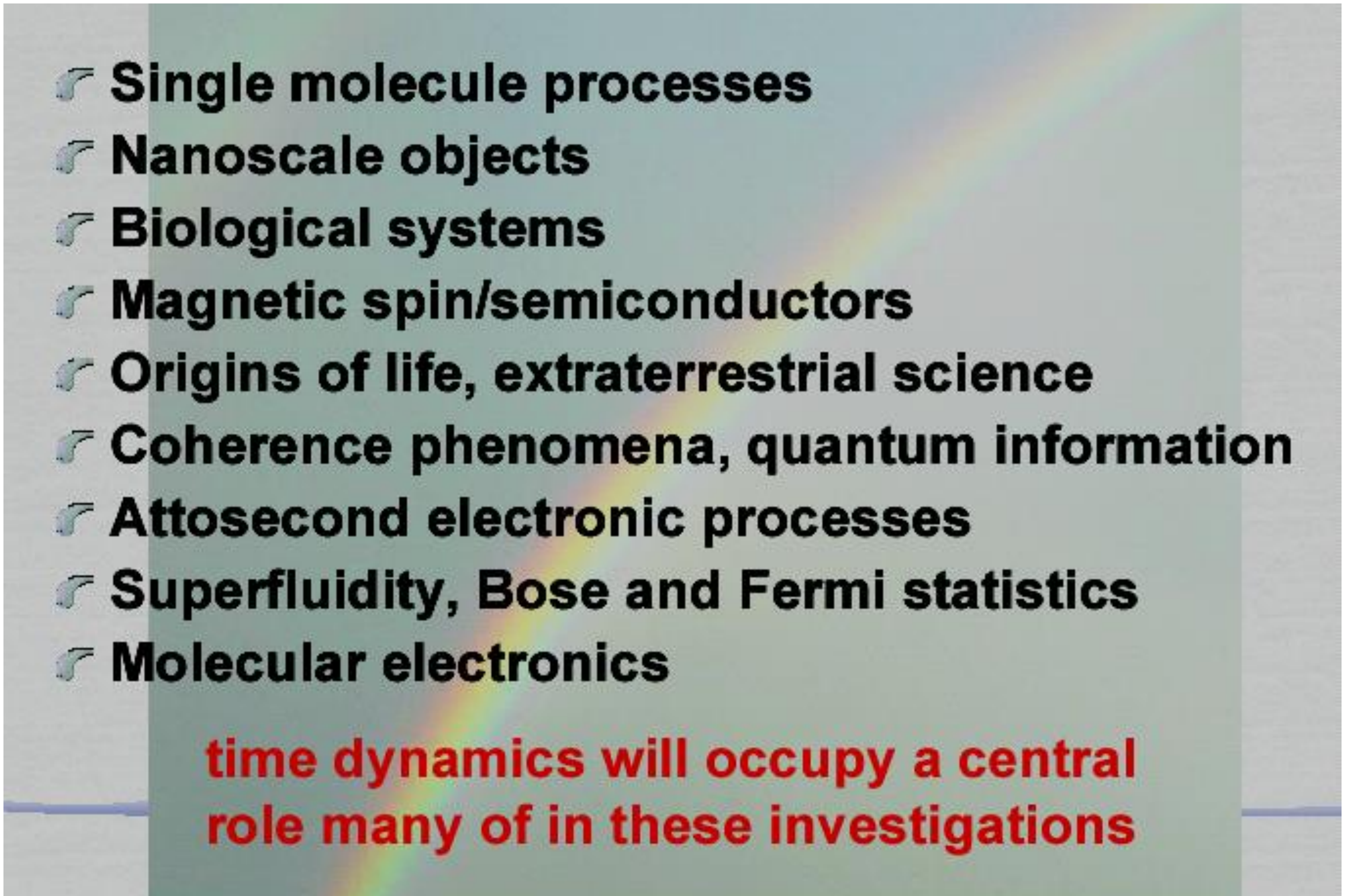


Possible Layout

- BESSY – ERL
- KEK ERL
- BNL
- LBNL – NGLS
  - FEL

Benefits from New Generation of Light Sources

- X-Ray FELs and ERLs



The Future?

- New Materials with higher Eacc limit
  - Nb_3Sn
  - MgB_2

Can We Expect Higher Accelerating Fields than for Nb From New Materials?

- GL theory gives Eacc ~ H_{sh} ~ $0.75H_c$
  - for kappa (λ/ξ) >> 1
  - Nb_3Sn :Tc = 18 K, H_{sh} = 3000 Oe => E_{acc} = 80 MV/m (improved shape cavity)
  - MgB_2:Tc = 38 K, H_{sh} = 6200 Oe => E_{acc} = 172 MV/m (improved shape cavity)

- How do experiments compare with (simple) GL theory?
- Much materials development required!

Best Nb_3Sn Today

R_s ~ nΩ (low field, 2K)

Highest surface field ~ 1300 Oe (→32 MV/m)

(Nb also ~ nΩ, surface field ~ 2000 Oe)

More material development needed

Best MgB_2 Today

- Rs about 1 μΩ
- Highest surface fields ~ 300 Oe (→8MV/m)

  (Nb has reached nΩ and 2000 Oe)

Much material development required

SUMMARY

- SRF Has Become a Core Technology Worldwide for a Variety of Accelerators
- HEP
- Nuclear Physics
- Nuclear-Astrophysics
- Material Science: X-rays
- Material Science: Neutron Sources

Concluding Wish!

May all these “coming attractions” face

ZERO RESISTANCE !!