Future Challenges

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Part I – Accelerator challenges:

- high energy physics;
- spallation neutron sources;
- synchrotron radiation sources;
- accelerators for medical use.

Part II – Resulting demands on Power Converters:

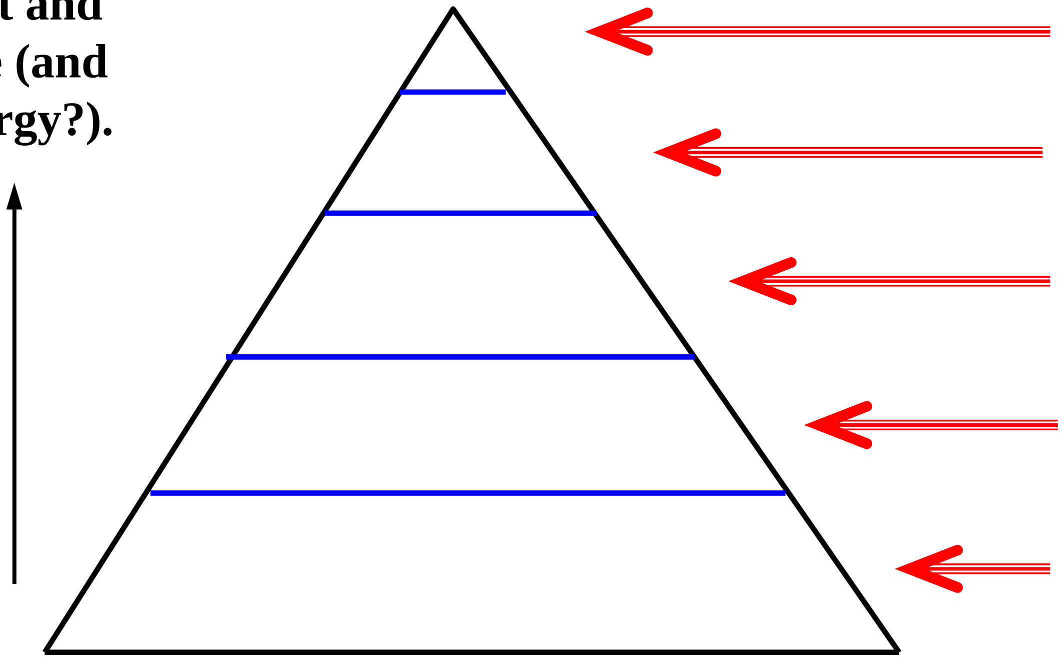
- cycling accelerators;
- dc &ac converter performance;
- speed of response;
- digital control systems;
- reliability;
- environmental issues.

The Future.

Part I

Accelerator developments and requirements over the next decade.

The Accelerator ‘Triangle’



cost and size (and energy?).

high energy (particle) physics

nuclear physics

‘materials’ science – s.r. and n sources

industrial & commercial

health – diagnostics and treatment.

number of accelerators

High Energy (Particle) Physics

Present ‘giant’ machines – LHC, Tevatron and LEP (deceased) are probably the last big circular accelerators to be built for HEP.

at ultra-relativistic energies ($E_{kinetic} >> m_0c^2$), particles with curved trajectories in a field B radiate excess synchrotron radiation.

$$E_{sr} \propto B^2 E_{kinetic}^2 ;$$

future ‘cutting edge’ HEP accelerators will be linear.

Linear Colliders

One International Linear Collider (ILC) is planned;
Work is underway on three possible candidates:

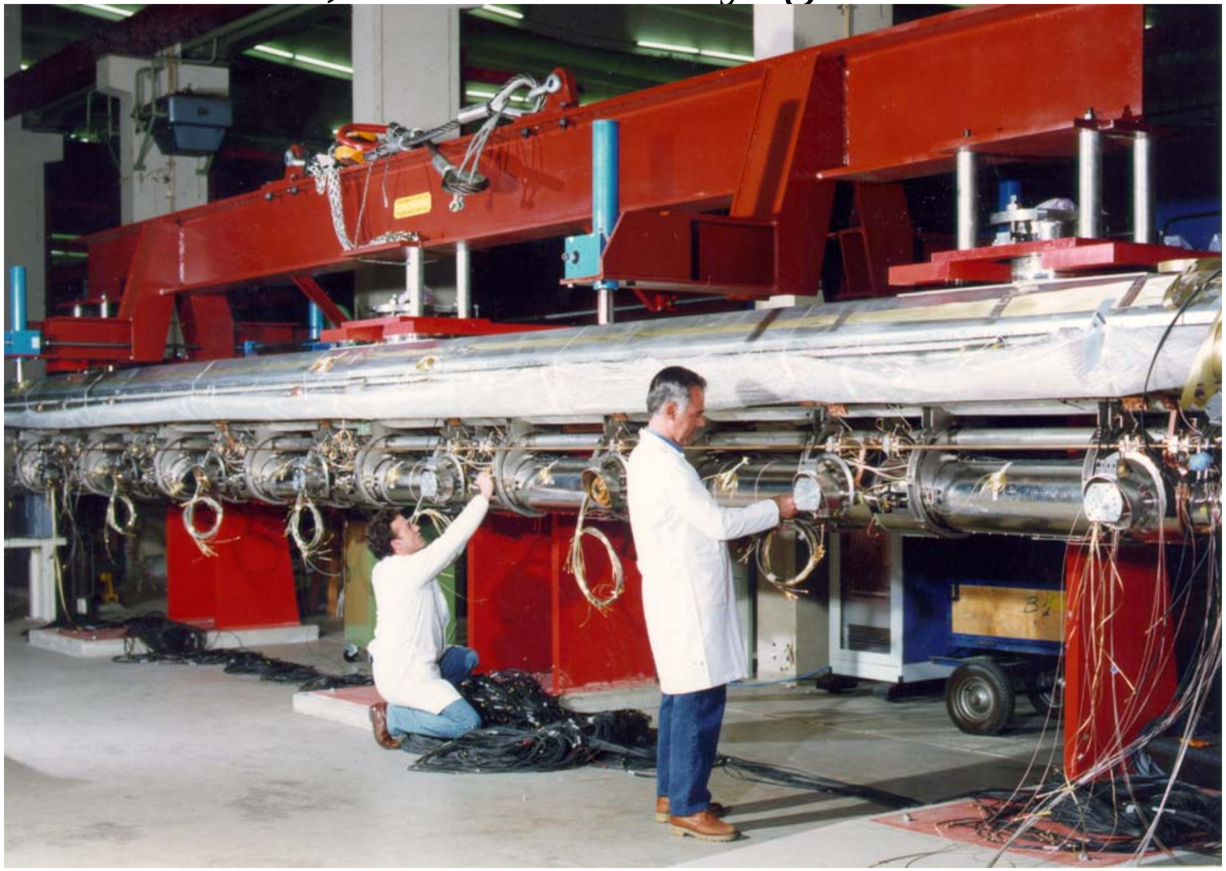
- TESLA (at DESY);
- NLC/GLC (Stanford/KEK);
- CLIC (CERN);

The ILC will be:

- 0.5 – 1.0 TeV electron/positron linear collider;
- ~ 30 km in length
- composed of s.c or conventional r.f. cavities, damping rings, beam-lines & interaction region;
- cost 3 – 4 x 10^9 €.

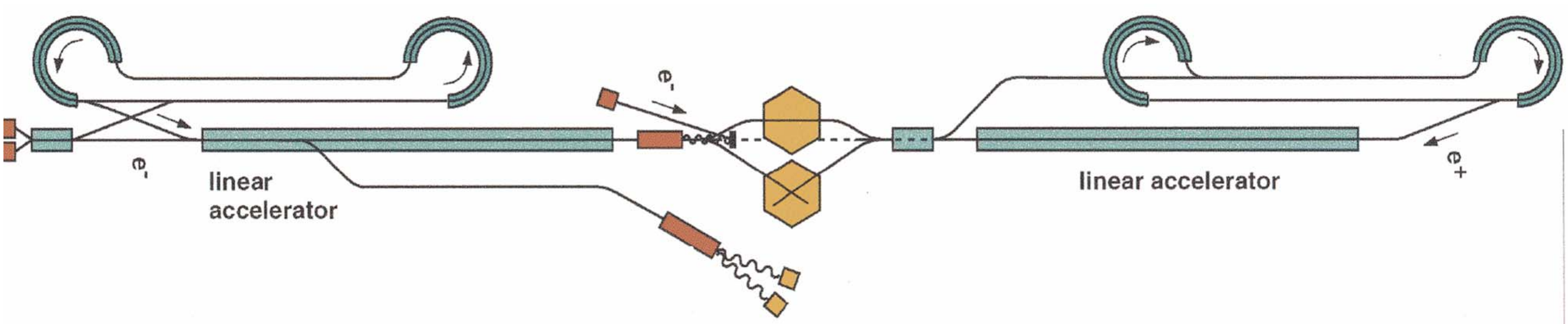
TESLA data

Length: 33 kilometers; Inner diameter of tunnel: ~5 m;
Depth: 10 - 30 meters; Number of cryogenic halls: 7



Map of Tesla location

Tesla layout



TESLA Technical data

- e^-/e^+ collision energy: 500 GeV :
- number of 1-m s.c. resonators: 21 024;
- alignment precision: 0.5 mm;
- e-/e+ beam size at interaction: 40 nm;
- installed load: 195 MVA;
- power (normal operation): 155 MW;
- number of bunches per pulse: 2820;
- number of particles per bunch: 2 x 10^{10}.

Collider Challenges

Design challenges:

- many (~ 10^3) magnets and power converters;
- very high luminosity
  → very small beam at intersection;
- very high energy density in beam
  → equipment/personnel safety issues;
- interaction control to 40 nm;
- magnet response time << 1 µs.

Other H.E.P. prospects.

Other specialised particle physics possibilities:

- ‘exotic’ sources – B, μ and K mesons, etc. ;
- neutrino factories.

These will be lower energy than the ILC but will have similar demands:

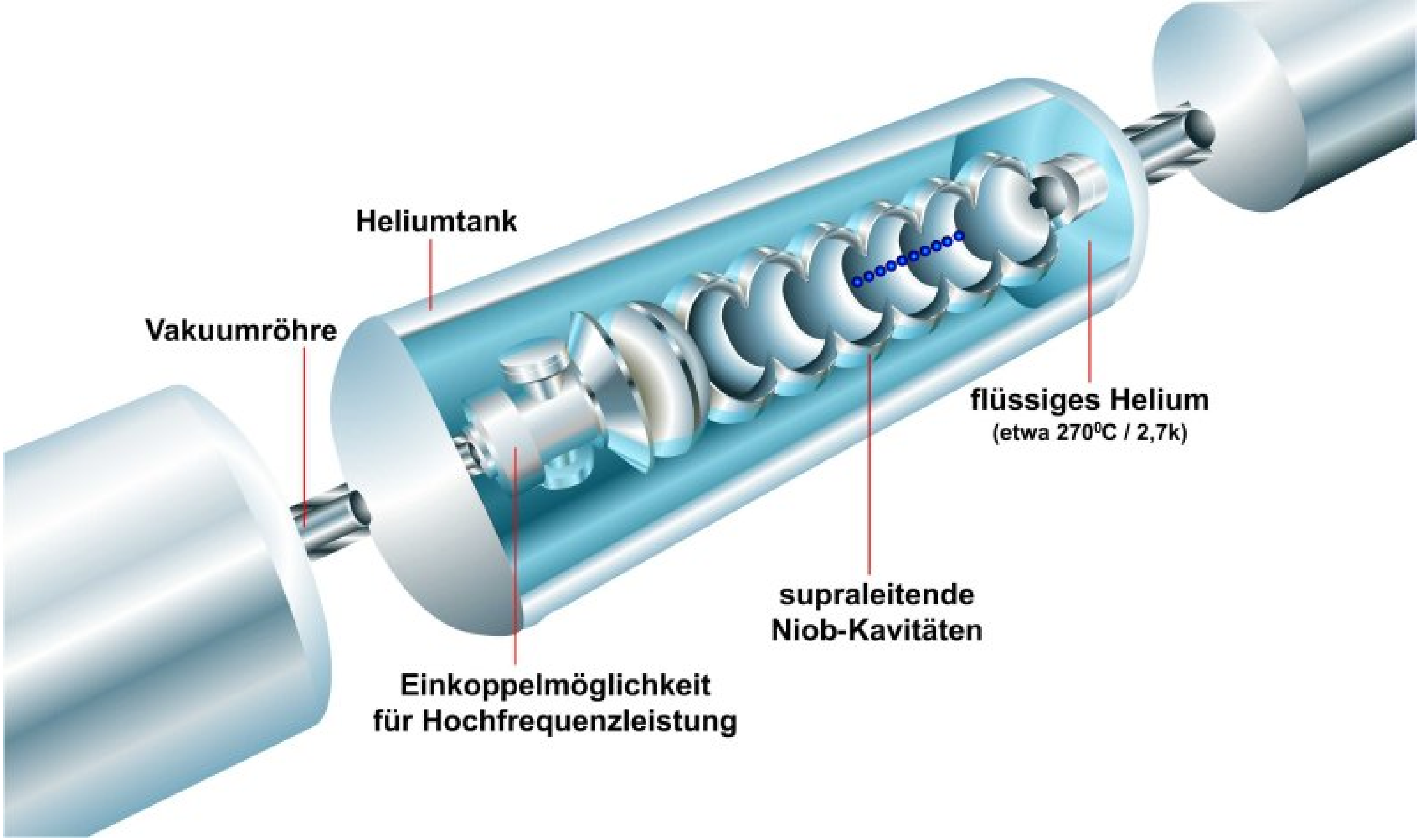
- multi GeV fast cycling accelerators;
- strong control on beam position and size;
- high particle currents - high reliability;
- rapid safety reactions.

Spallation neutron sources

A high current proton synchrotron bombards a uranium target to produce a high flux of neutrons for nuclear physics and materials science.

The construction of a European Spallation Source **(ESS)** is currently being studied by partner laboratories:

Forschungszentrum Jülich plans for the ESS.

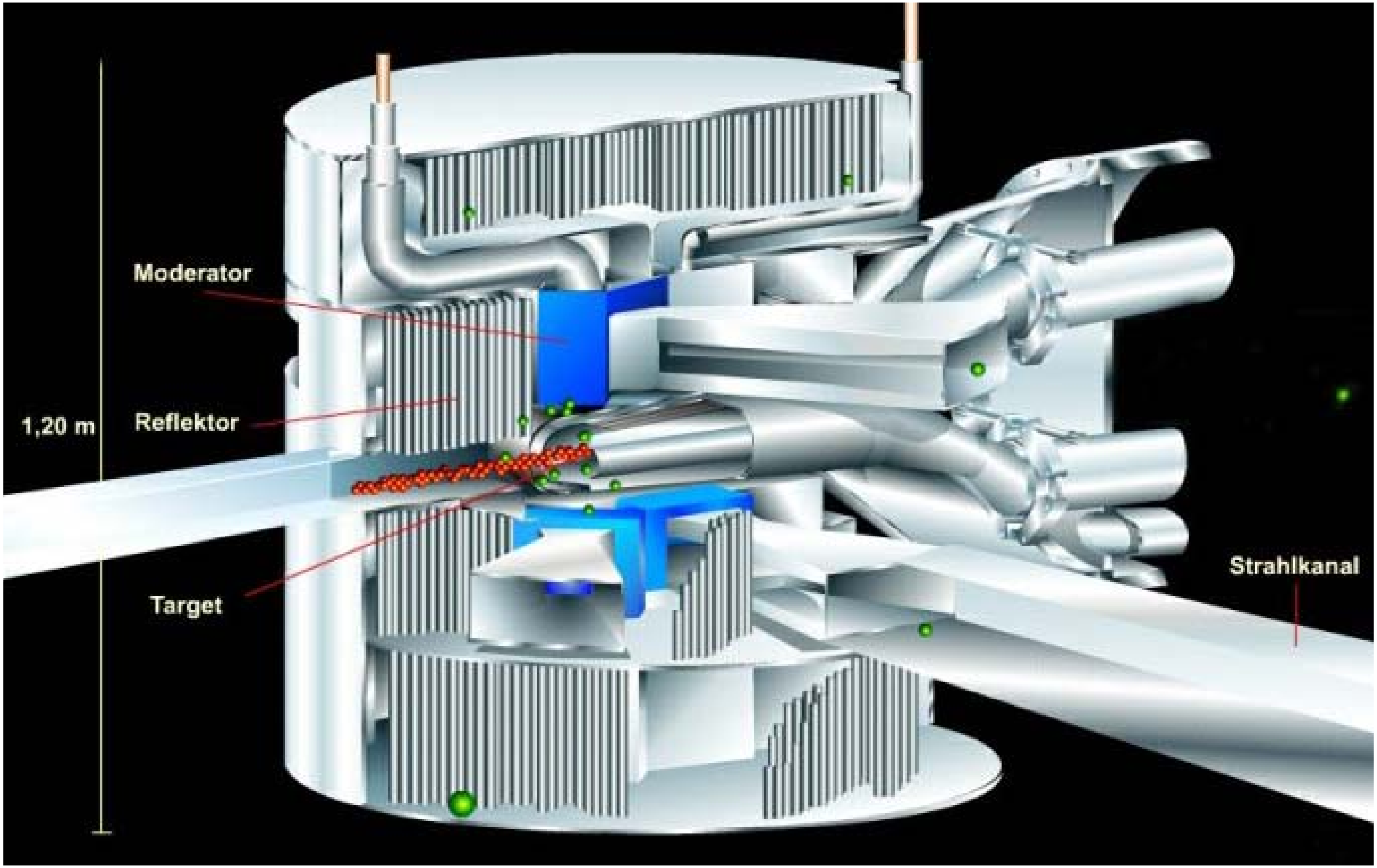


FZJ ESS Data

Linearbeschleuniger: 1334 MeV;
Strahlleistung : 2 x 5 MW;
Neutronenfluss : 3,1 x 10^{14} n/cm^{2}s;
Langpuls-Target: Pulsfrequenz: 16.66 Hz;
Neutronen-Pulsdauer:2 ms;
Leistung: 5 MW;
max.fluss: 1 x 10^{16} n/cm^{2}s;
Kurzpuls-Target: Pulsfrequenz: 50 Hz;
N Pulsdauer:~100 µs;
Leistung: 5 MW;
max.fluss: 1,3 x 10^{17}n/cm^{2}s;

Layout of two target stations.

Target station details



ESS Accelerator Requirements

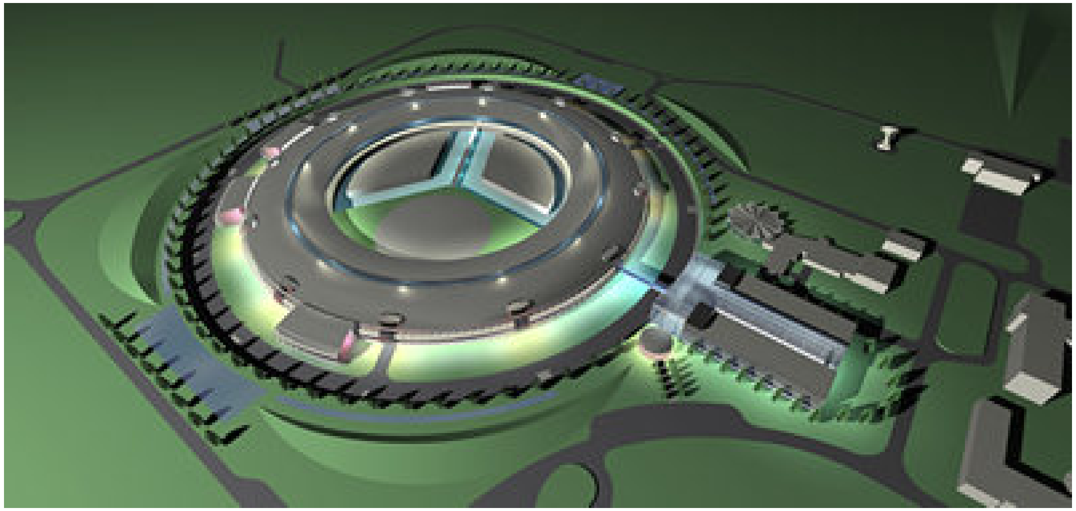
Demands:

- beam steering and focusing in the linac;
- a pulse compressor ring;
- accurate beam steering onto the targets;
- high reliability – safety implications;
- rapid reaction to safety commands.

Synchrotron Light Sources

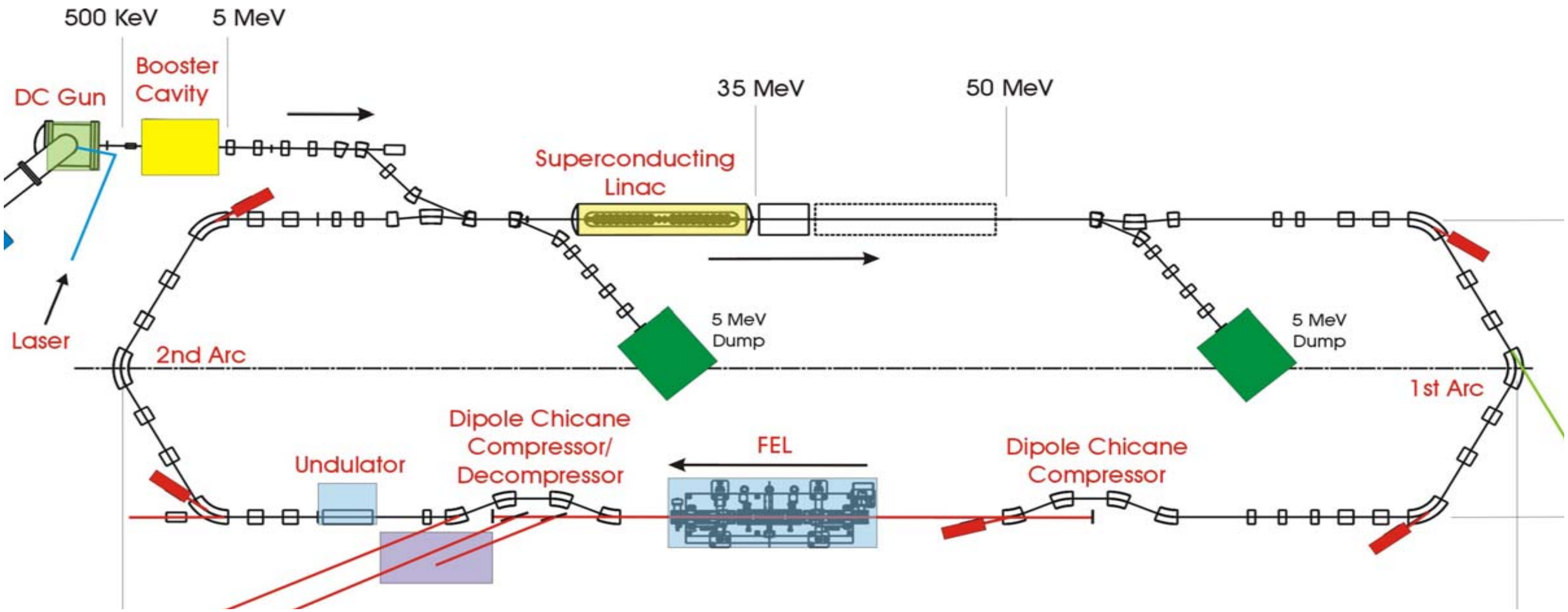
Many s.r. sources based on storage rings are now operating in the 2 – 6 GeV range; more are being built:

- Australian light source;
- Barcelona light source;
- Soleil (F);
- Diamond (UK):



S.R. Sources (cont)

In addition to storage rings, future s.r. sources will be free electron lasers with linear accelerators supplying electron - ‘Fourth Generation Light Sources’. Prototype for the Daresbury ‘4GLS’:



Demands of S.R. Sources.

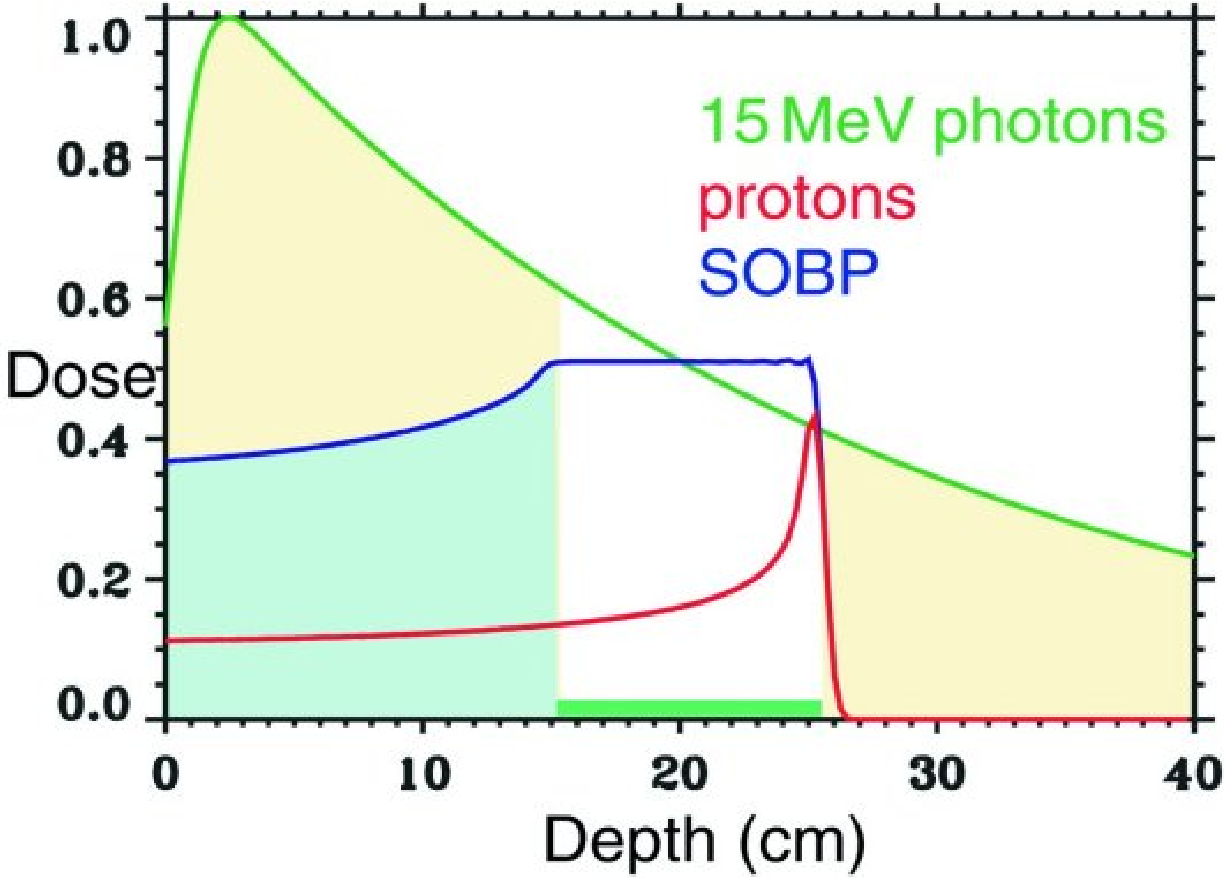
The development of storage rings and FELs represent an ever increasing achievement of:

- greater source 'brilliance' (photons/s/mm^2/m rad/1% bandwidth);
- smaller electron beam cross-section <<1mm^2;
- highly stable e$^-$ and photon beam position (~ 50 μm);
- independent control of beam dimensions around the lattice (control of β values).

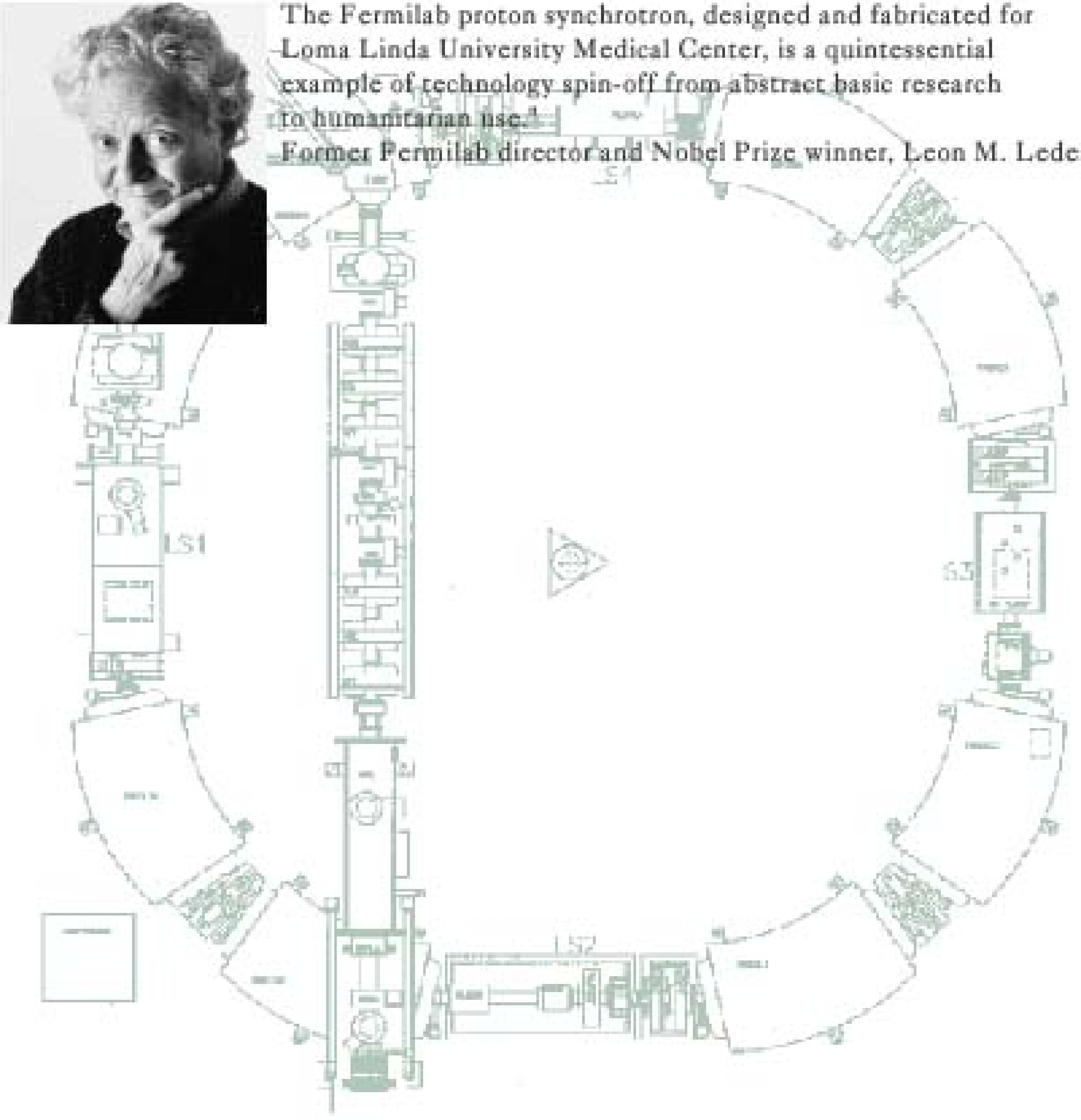
Accelerators for therapy

It is now understood that protons (up to 250 MeV from a cyclotron or small synchrotron) are very effective for cancer therapy.

By selecting the proton energy, the Bragg peak of irradiation can be positioned at the centre of the tumour.



The Loma Linda (CA, USA) Proton Therapy Unit



The Fermilab proton synchrotron, designed and fabricated for Loma Linda University Medical Center, is a quintessential example of technology spin-off from abstract basic research to humanitarian use.[1]

Former Fermilab director and Nobel Prize winner, Leon M. Lederman, Ph.D.

Loma Linda treatment

‘Three of the four treatment rooms use gantries to deliver the proton beam. The 90-ton, three-story gantries can be rotated 360 degrees to deliver the beam at the precise angle prescribed by the physician. Most of the gantry is concealed by the walls and floor of the treatment room--the patient, lying within the gantry, only sees the front of the proton nozzle rotating prior to treatment.’

High energy p treatment development

Examples of therapy and research centres:

- Loma Linda;
- TRIUMF (Canada);
- PSI (Switzerland);
- Massachusetts General Hospital;
- Clatterbridge Centre for Oncology (UK);
- Rinecker Proton Therapy Centre, Munich (under construction);

‘There are treatment centres in Canada, France, Germany, Japan, Russia, South Africa, Sweden, Switzerland, the United Kingdom, and the United States’. (CERN Courier)

Requirements for Therapy facility

Therapy has stringent requirements:

- full 360° control of entry angle;
- high stability of beam position;
- high stability of beam amplitude;
- high stability of beam energy;
- very high reliability, minute to minute, day to day, month to month;
- rapid and effective control for patient safety.

Part II

Resulting Challenges to Power Converters for Accelerators.

Cycling accelerators – choice of converter

Present choice of cycling converter:

- large (slow cycling) systems: **direct connection;**
- large fast cycling systems: **White circuit**;
- small and medium sized, medium rep rate: **capacitor/inverter**.

Will we see the capacitor/inverter system increase in VA and rep rate to completely replace the White circuit (say for a 3 to 6 GeV synchrotron cycling at 50 Hz)?

Component changes needed for capacitor/inverter system.

To fully replace the White circuit by the capacitor/inverter circuit, we need to see:

- IGBT ratings → 10kV; 2 kA average; switching at >50 kHz;
- E storage capacitors → 10 kV peak; 2 kA pulse; 50 Hz pulse duty;
- modules series connected (multiple magnet cells).

All ‘economically’ available – catalogue items, not ‘special developments’.

Challenges for HV Power ToDs

Dr Carroll gives details of the following challenges for the active devices:

- **High voltage devices present following challenges:**
  - **Dynamic Avalanche ruggedness (for reliable operation)**
  - **Short Circuit Failure Modes (IGBT) and fault interruption (IGCT)**
  - **Design Trade-off between Losses and SOA**
  - **Critical Punch-Through voltages (for controllable voltage, low EMI)**
  - **High DC link voltage (leakage stability, cosmic ray withstand)**
  - **Large inductance and overshoot voltages in HV power systems**
  - **High frequency (limited by losses, T_J)**

Challenges for this decade

- **10 kV switches with 1 kHz snubberless operation**

  (for the 6.9 kV$_{RMS}$ MV line for drives and power conditioners)

- **Snubberless series operation**

  (static and dynamic for MV lines > 6.9 kV$_{RMS}$)

- **Power supply free operation**

  (autogenous power supply for series connection)

- **System cost-reduction**

  (e.g. pay-back times $\approx$ 1 year for MV Drives)

- **Reduced thermal resistance and increased T_J**

- **Reduced losses?**

Challenges from Dr Benfatto

- **Development of the following 1 MV DC components:**
  - **step up transformers;**
  - **gas insulted transmission lines;**
  - **bushings – air/pressurised gas, oil/air, oil/pressurised gas;**

- The fabrication and testing of an IGBT valve, combining the functions of a protective switch and modulator;

- Revise the component design taling account of emerging new technologies (eg: application of HVDC light® or HVDC plus®).

DC and cycling – converter performance

Today:

- $1:10^4$ is ‘commonplace’;
- $1:10^5$ is exceptional but often specified;
- $1:10^6$ is difficult but achievable.

Future:

- $1:10^5$ to be normal for many applications?
- $1:10^6$ to be frequently asked for?
- $1:10^7$ needed?

Possible for stability and repeatability? Possible for accuracy?

Future challenges from Gunnar

Relevant to previous slide:

- Create a better burden resistor
- Create a better current-to-voltage converter

Speed of response

Greater stability (as on previous slide) calls for increased servo bandwidth – MHz for linear colliders (pulsed magnets)!

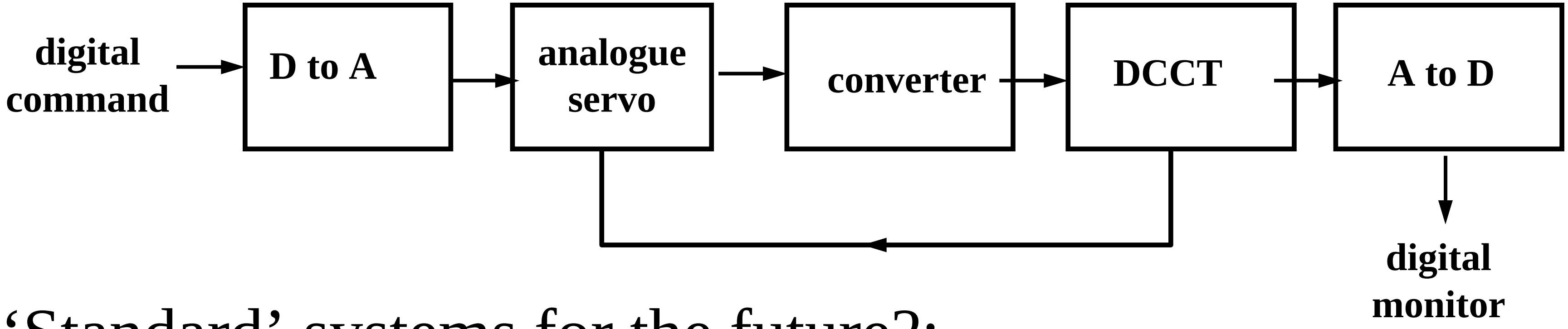
Requirements for safety and control →

- fast response in level control
- fast switch-off;
- fail to safety (beam!).

Solved by the switch mode chopper's increase in frequency?

Digital control systems

‘Standard’ systems 5 years ago (today?):



digital command

D to A

analogue servo

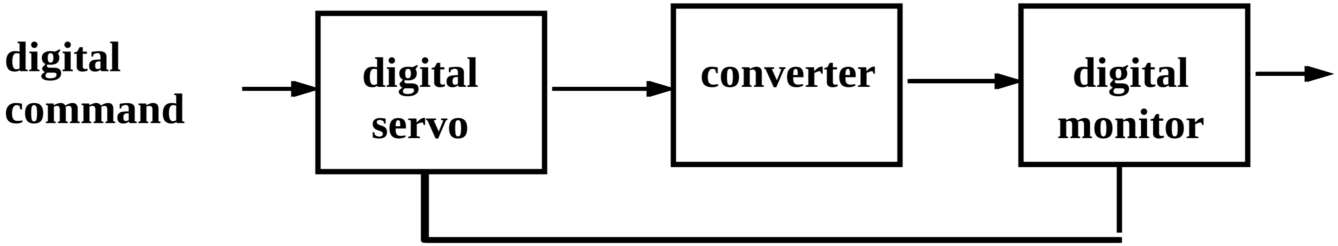
converter

DCCT

A to D

digital monitor

‘Standard’ systems for the future?:



digital command

digital servo

converter

digital monitor

Gives: speed; servo flexibility; economy.

Future challenges from Gunnar

Relevant to previous slide:

- Create a truly digital DCCT

Converter Controls

From Quentin:

For "extreme" machines, we need solutions to:

- Extreme precision requirements
- Extreme environments (radiation, inaccessibility)
- Extreme loads (very long time constants)
- Very large numbers of converters
- Large distances between installations
- Very high reliability requirements
- Long project lifetimes

Converter Controls

For “simple” machines:

- Fast development times
- Low cost

For all systems:

- Component obsolescence
- Documentation
- Long term maintainability
- Reducing cabling and connectors

Reliability

Increasing demand for

- efficiency to meet schedule >> 90%;
- operational predictability day/week/month.

Obvious solutions:

- increase component mean time to failure;
- under-rate components or whole systems;
- more U.P.S.s for auxiliaries.

Radical solutions (?):

- introduce redundancy of vital modules (rectifiers/choppers/controls);
- automatic ‘hot’ switching between modules;
- ‘hot’ maintenance/repair;
- use U.P.S.s for main power source (!?).

Environmental issues – power budget

Environmental pressure (global warming) to substantially reduce facility power consumption:

- reduce current density in magnets ?
- improve converter power efficiency (possible?);
- recycle ‘waste’ power into heating systems ?

Is increased capital cost justified?

Environmental issues – e.m. noise.

Increased sensitivity and speed of experimental detectors will place further stringent limits on e.m. noise.

Alain Charoy asks:

- Expertise: how to manage & limit EMC Risks before a machine fires up ?
- Coordination : How to avoid as many EMC Policies as physical experiments ?
- Anticipation : How to plan for EMC Fixes in a “dirty” machine ?

The Future

Many more accelerator systems:

- more complexity!
- more challenges!
- more work!
- more professional commitment!
- greater contribution to society!

The future promises an exciting and fascinating career for accelerator scientists and engineers.