

Lecture:
Accelerator Physics

Heidelberg WS 2013/14

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Introduction

Goal of this Lecture

Introduction to Accelerator Physics:

- experimental aspects:
 - accelerator components
 - collider concepts
- theory:
 - beam optics
 - linear beam dynamics
 - simulation of beam particles (→ exercises)

Organisation

Prerequisites:

Knowledge: Electrodynamics, special relativity, Quantum Mechanics

Lectures: Experimental Physics I-V

Addressing:

Master Students (Bachelor Students)

Accompanying Tutorials:

- Wednesday 16h15, CIP Pool – PI (Tutor: Sebastian Schmitt)
“hands on” computer exercises (Python)
- First date October 16 (**today!**)

More Information on the Web:

<http://www.physi.uni-heidelberg.de/~schoning/Vorlesungen/Accelerator/>

Literature Accelerator Physics

No script!

Frank Hinterberger: Physik der Teilchenbeschleuniger und Ionenoptik (Taschenbuch)

Klaus Wille: Physik der Teilchenbeschleuniger und Synchrotronstrahlungsquellen. Eine Einführung (Broschiert) Teubner Verlag 2001, also in English, Oxford University Press; book is difficult to get!

E.Wilson: An Introduction to Particle Accelerators, Oxford University Press 2001

Helmut Wiedemann Particle Accelerator Physics, 3. Auflage, Springer 2007, ISBN 3540490434

J.D.Jackson, Classical Electrodynamics, also in German

Lecture Dates

Dates: Wednesday 9:15-11:00

Place: Conference 1-3 , INF 226

Date	Topic Wednesday (Link)
16.10.12	Introduction and Basic Definitions
23.10.12	Accelerating Structures
30.10.12	Optics with Magnets 1
06.11.12	Optics with Magnets 2
13.11.12	Equations of Motion
20.11.12	Phase Ellipses and Magneto-Optical Systems
27.11.12	Transverse Beam Dynamics
04.12.12	Transverse Beam Dynamics and Beam Stability
11.12.12	Longitudinal Beam Dynamics
18.12.12	Phase Space and Beam Cooling
08.01.13	Space Charge and Beam-Beam Dynamics
15.01.13	Colliders
22.01.13	New Accelerator Technologies
29.01.13	Synchrotron Facilities and FELs
05.02.13	no lecture

“Leistungskontrolle”

Tutorials (Sebastian Schmitt):

- 11 series of exercises
- a series has typically one exercise (mostly computational)
- exercises are checked and corrected
- working in small groups allowed
- target is 60% of the total score → certificate (Master)
- number of credit points = 4
- no grades given (only “pass”)

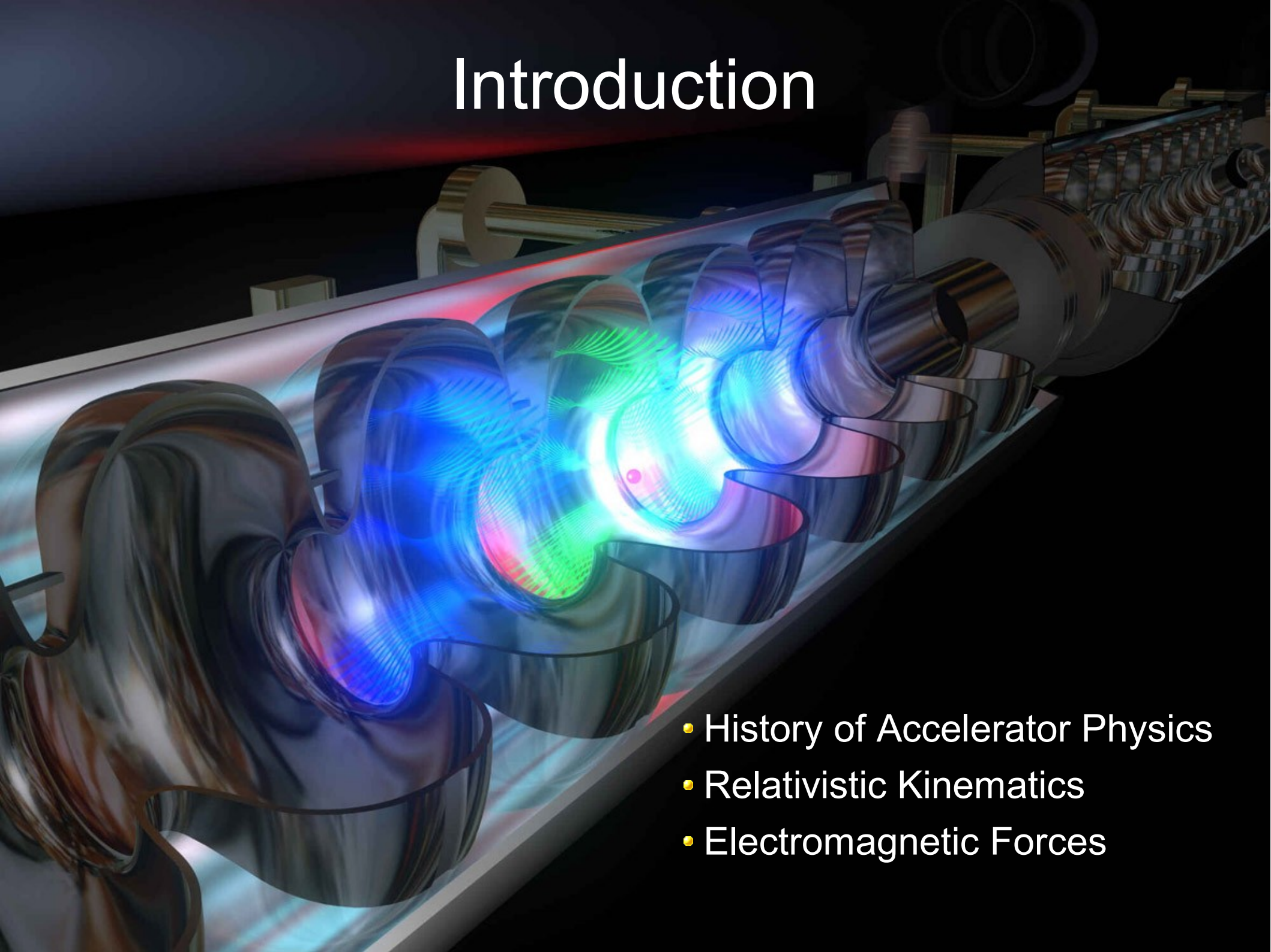
Excursions

We could organise excursions to

- HIT (Heidelberg Ion Therapy)
- MPI-Kernphysik, (TSR for Ions, others)
- Anka (KIT Karlsruhe), Synchrotron

Feedback!

Introduction



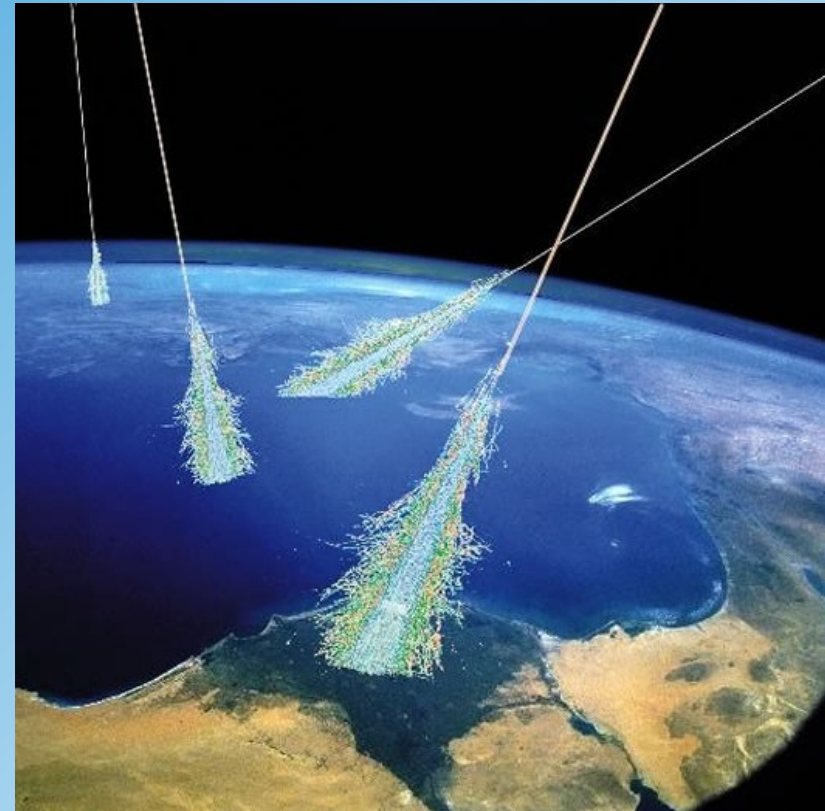
- History of Accelerator Physics
- Relativistic Kinematics
- Electromagnetic Forces

Cosmic Rays

Particle Acceleration in Universe

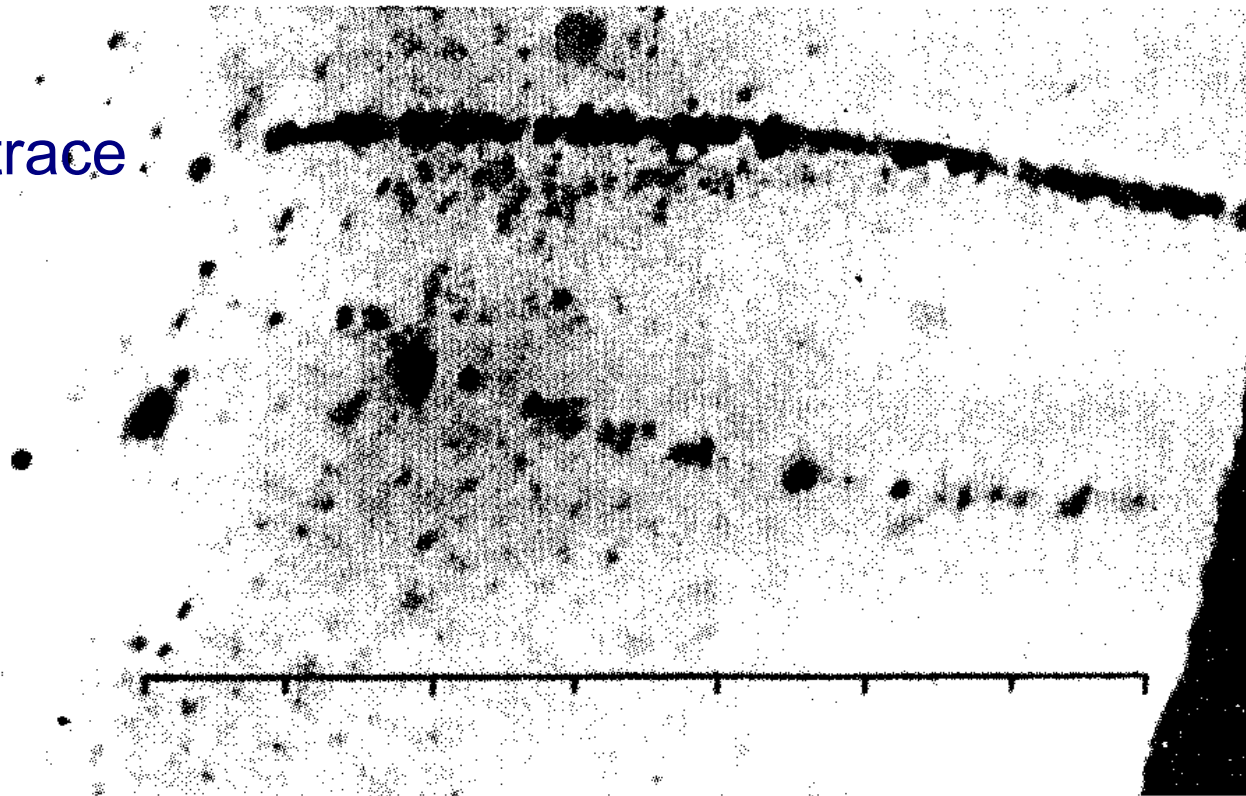


Victor Hess, 1912



Discovery of Muons in Cosmic Rays

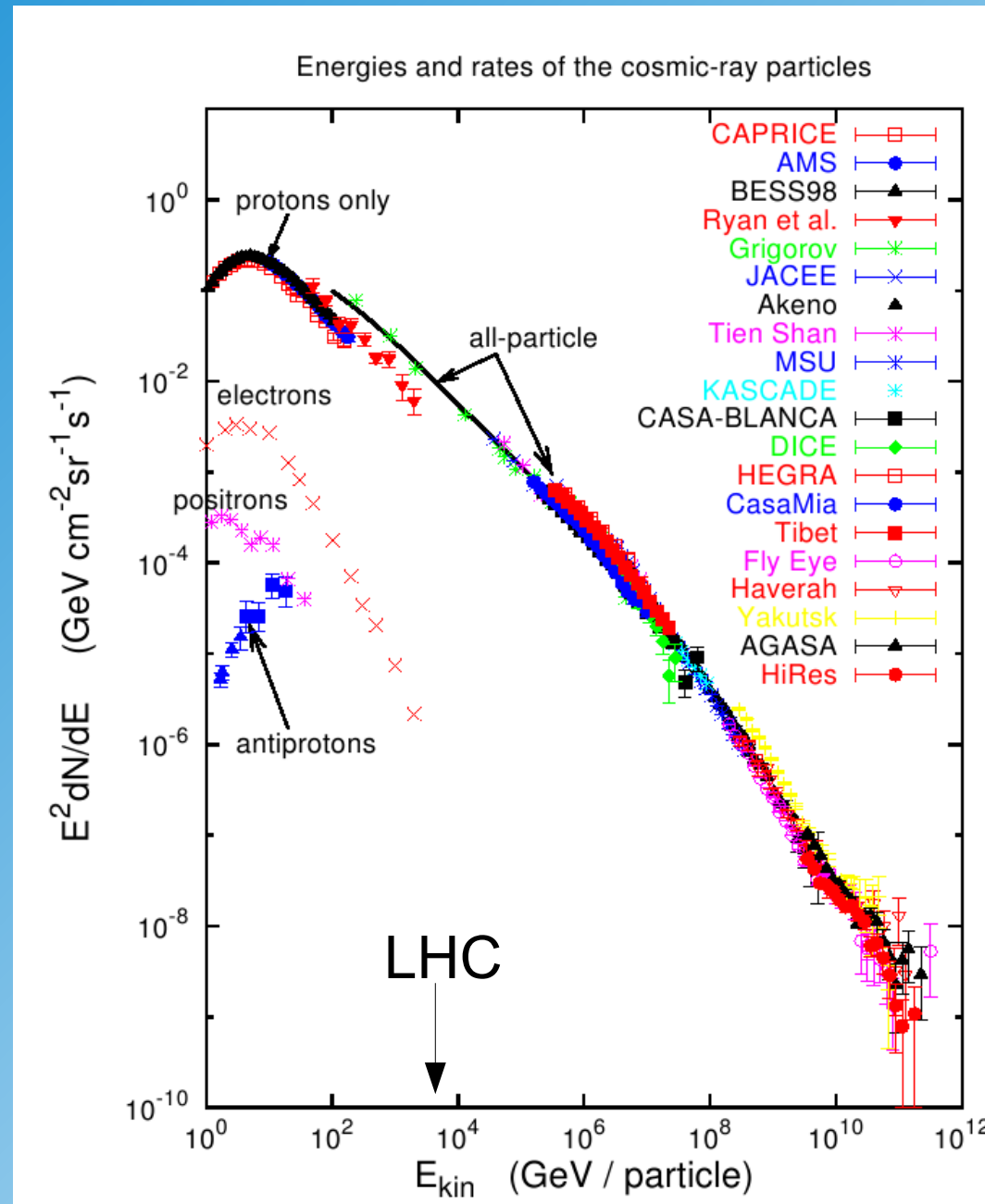
muon trace



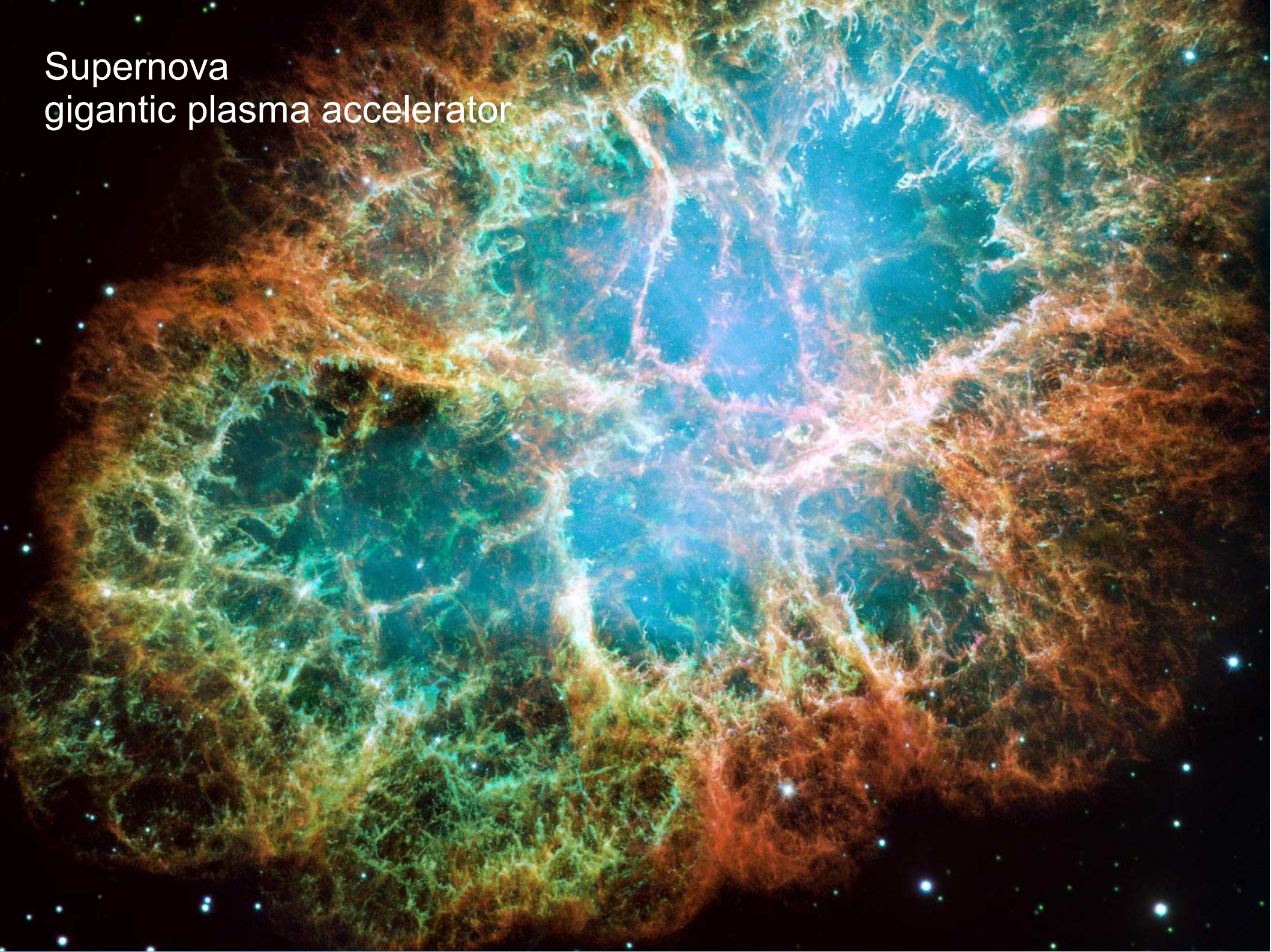
"The other double trace of the same type (figure 5) shows closely together the thin trace of an electron of 37 MeV, and a much more strongly ionizing positive particle with a much larger bending radius. The nature of this particle is unknown; for a proton it does not ionize enough and for a positive electron the ionization is too strong. The present double trace is probably a segment from a "shower" of particles as they have been observed by Blackett and Occhialini, i.e. the result of a nuclear explosion".

Kunze, P., Z. Phys. 83, (1933) 1

The Cosmic Accelerator(s)



Supernova
gigantic plasma accelerator



History

Natural colliders:

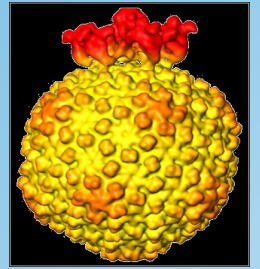
cosmic rays in the universe: supernova (shock waves, plasma accelerators)

Humans start to think about accelerating particles (electrons) more than 100 years ago:

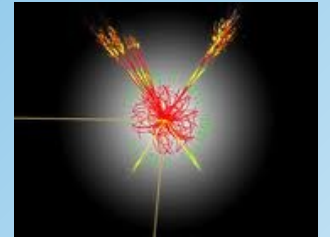
First Applications: X-Rays
(cathode ray tubes, Conrad Röntgen)

Applications of Accelerators

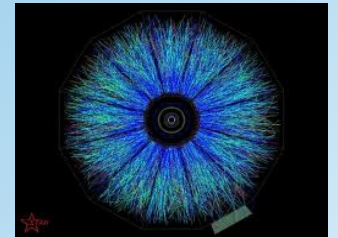
Investigation of small structures
(scattering experiments)



Excitation of atoms, nuclei, baryons
(spectroscopy)
production of new particles (Higgs Boson)



Exotic states of matter
(Quark-Gluon Plasma)

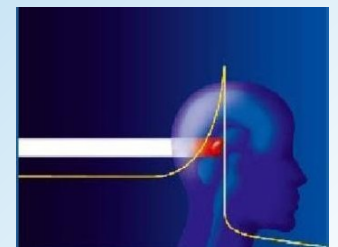


Synchrotron light / Free electron light
sources for experiments:
diffraction, spectroscopy, microscopy,
lithography, metrology, etc.

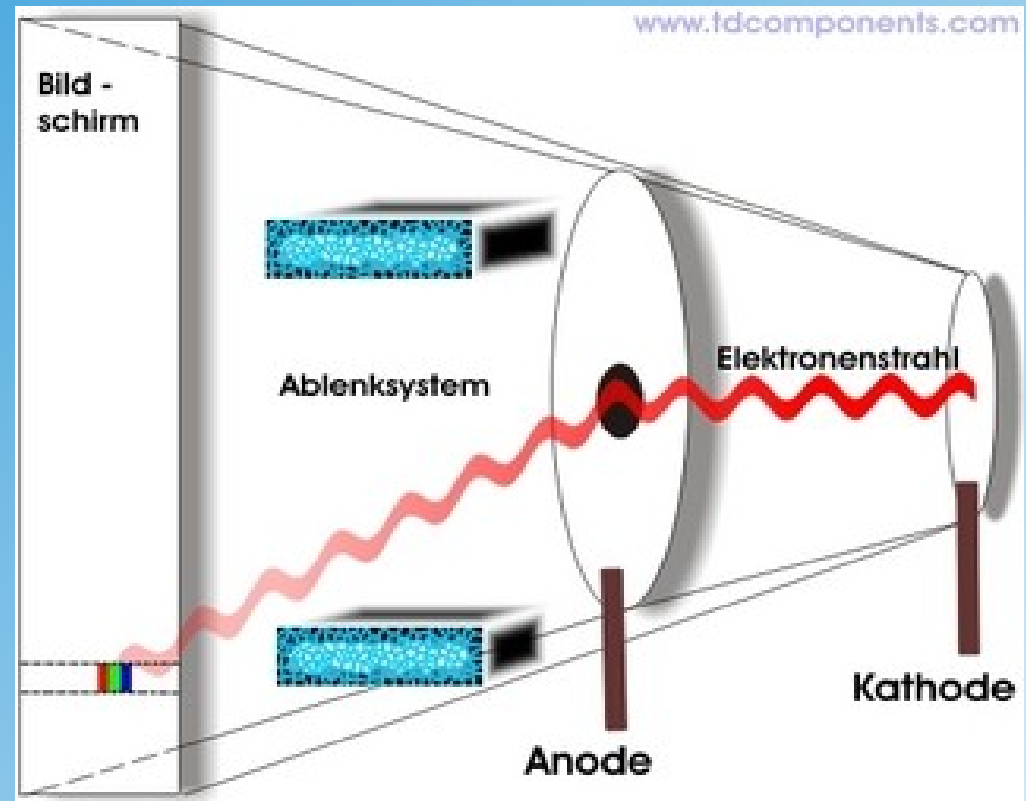


Radiation Therapy

Technical Applications
(e.g. production of isotopes)



The Principle



Monitors have the same components like accelerators:

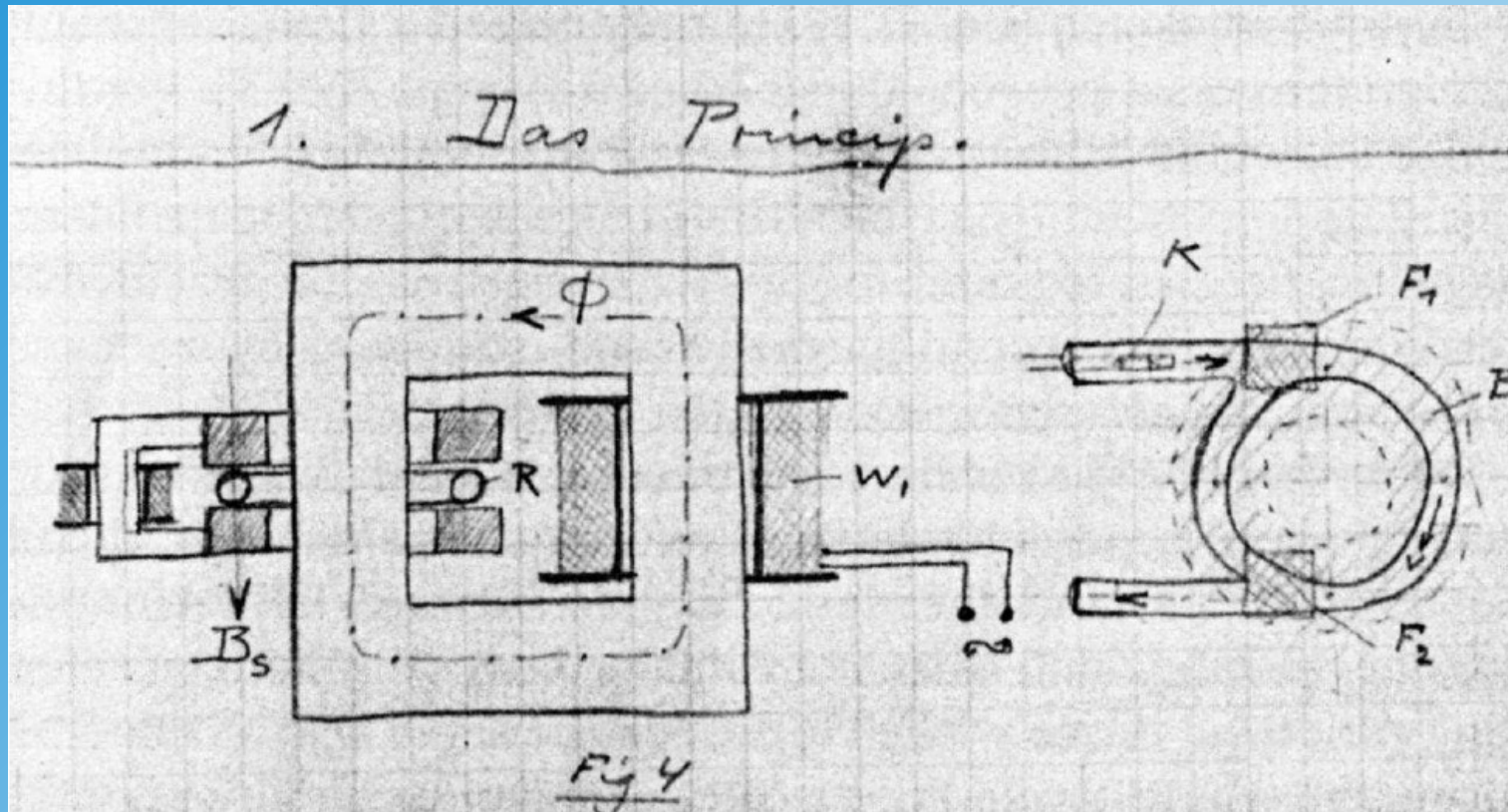
- electron gun
- acceleration structure
- beam steering system

$$\text{kinetic energy: } E_{\text{kin}} = e U$$

Ray Transformer

(ring accelerator)

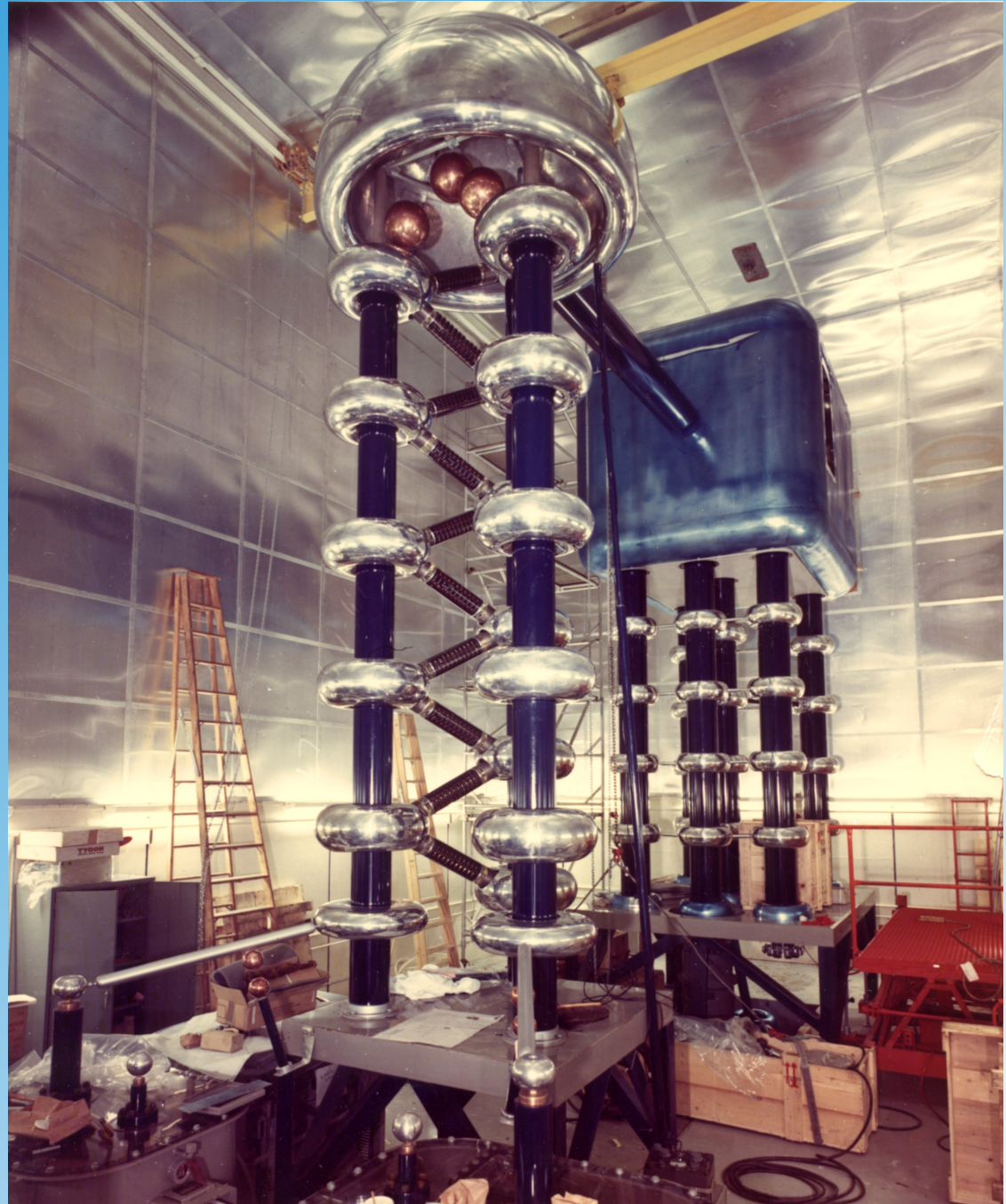
Rolf Wideröe



particle beam as “second winding” → later Betatron

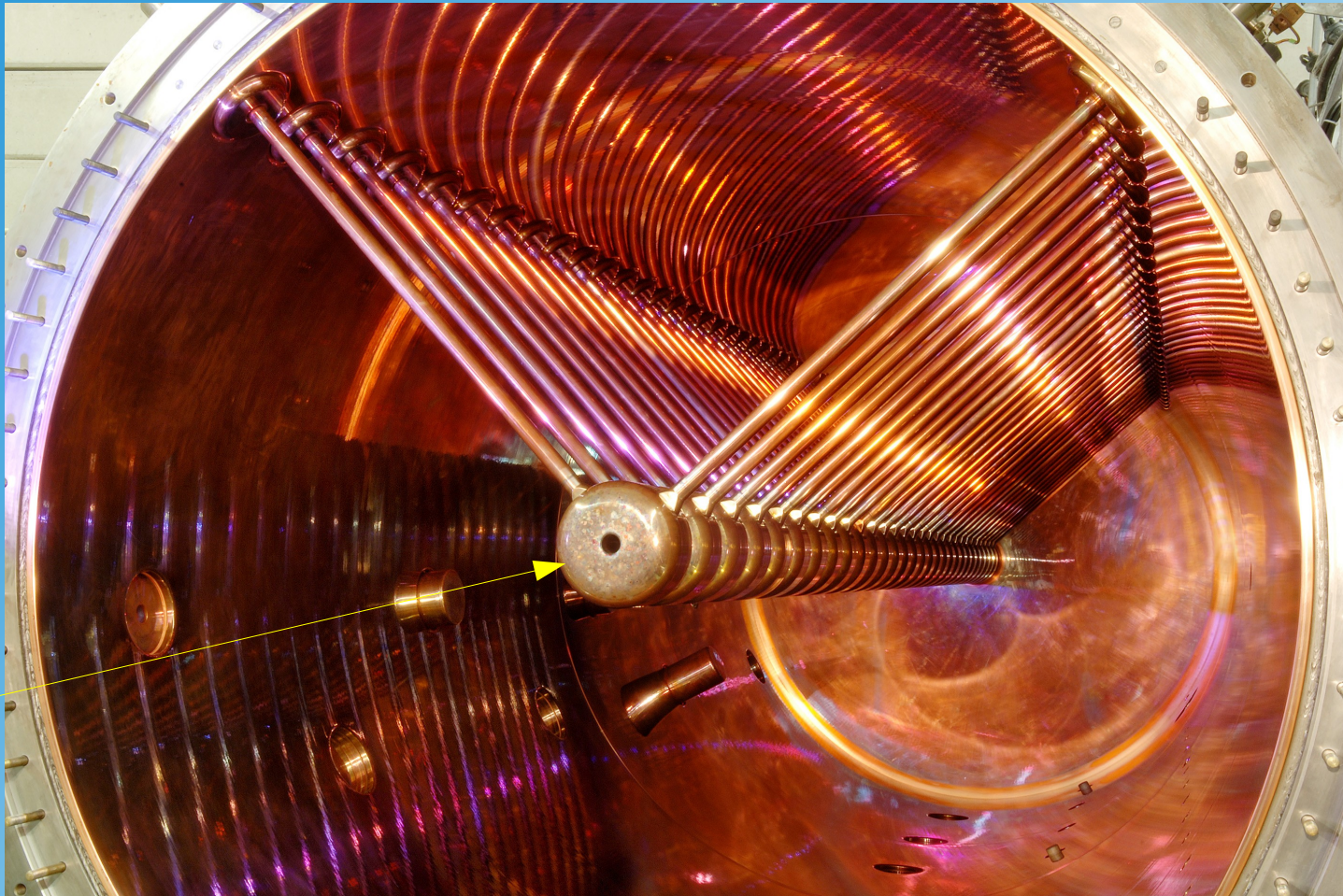
Cockcroft-Walton Generator

(electrostatic accelerator)



Unilac (Darmstadt)

(linear accelerator)



resonator
cell

Alvarez- Structure

Milestones in Accelerator Physics

- 1920 *first cascade generator* (H.Greinacker)
- 1922 *patent for betatron idea* (J.Slepian)
- 1924 *linear accelerator invented* (G.Ising)
- 1928 *first linear accelerator in Aachen* (R.Wideröe)
- 1929 *cyclotron main principle* (E.Lawrence, N. Edlefsen)
- 1931 *first Van-de-Graaf Generator* (van des Graaf)
- 1931 *first cyclotron* (E.O.Lawrence, M.S Livingston)
- 1932 *Cockcroft-Walton-Generator, first nuclear reaction* (J.Cockcroft, E Walton)
- 1939 *invention of klystron* (W.W. Hansen, K.Varian, S.Varian)
- 1941 *first Betatron* (D.W.Kerst, R.Serber)
- 1943 *principle of storage ring patented* (R.Wideröe)
- 1944 *principle of microtron* (V.I.Veksler)
- 1945 *principle of synchrotron* (E.M. Mc Millan, V.I.Veksler)
- 1946 *first electron synchrotron* (F.K.Goward, D.E.Barnes)
- 1947 *first electron linear accelerator* (E.L. Ginzton et al.)
- 1947 *study about proton linear accelerator* (L.Alvarez, W.K.H.Panofsky)
- 1947 *study about proton synchrotron* (M.L.Oliphant)
- 1949 *320-MeV electron synchrotron in Berkeley* (E.M.McMillan)
- 1950 *“Strong focussing” principle* (N.Christophilos)
- 1952 *first proton synchrotron in Brookhaven* (G.K.Green et al.)
- 1961 *first electron positron storage ring AdA in Frascati* (B.Touschek)
- ...
- 2006 *1GeV electrons with Laser-Plasma acceleration* (W.Leemans)

Livingston Plot

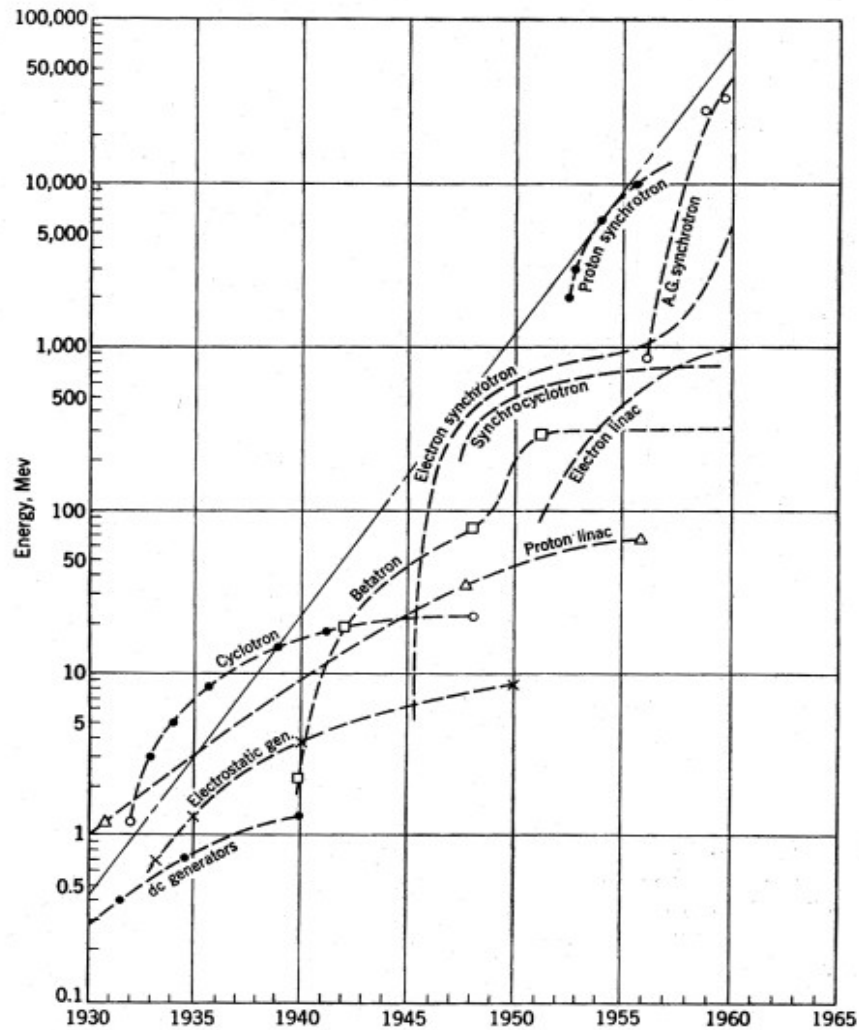
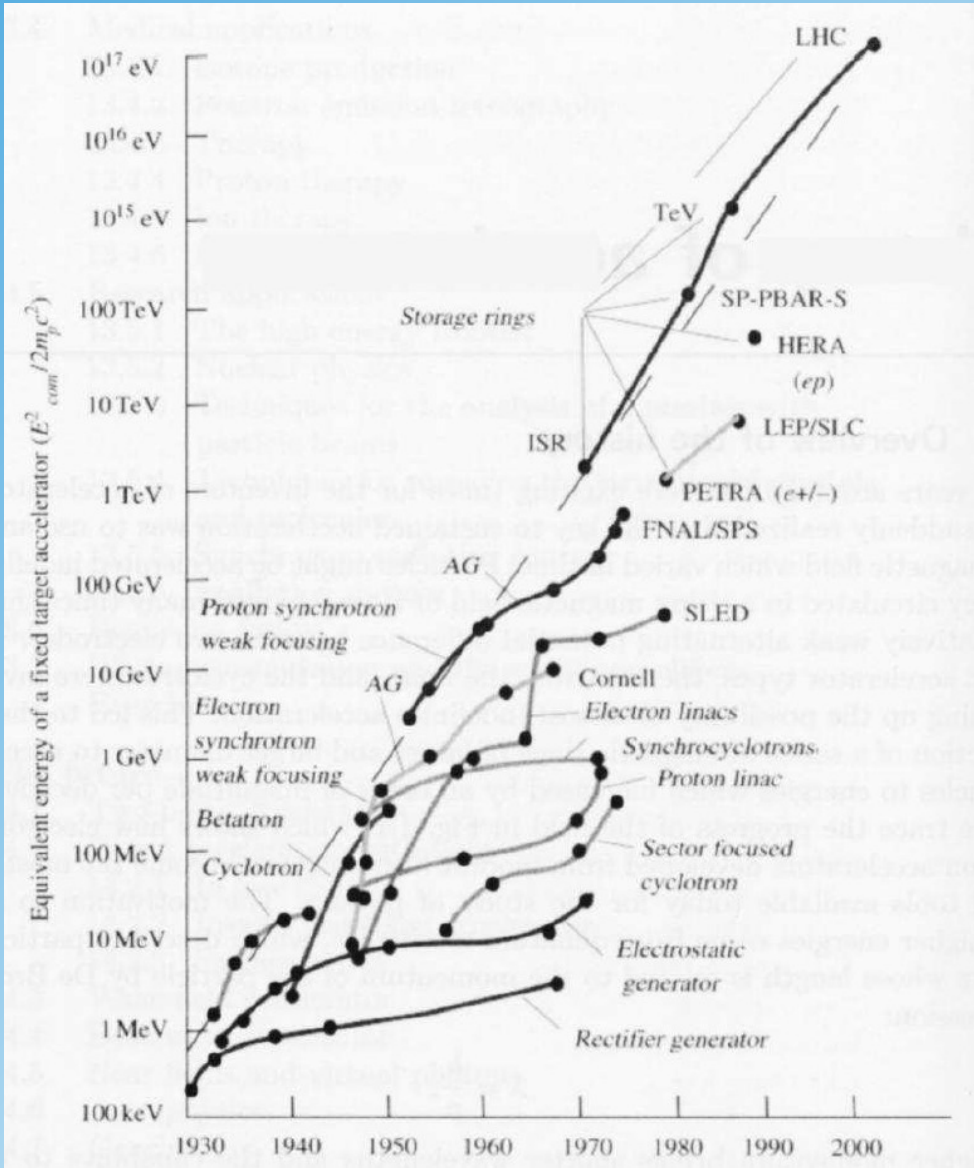
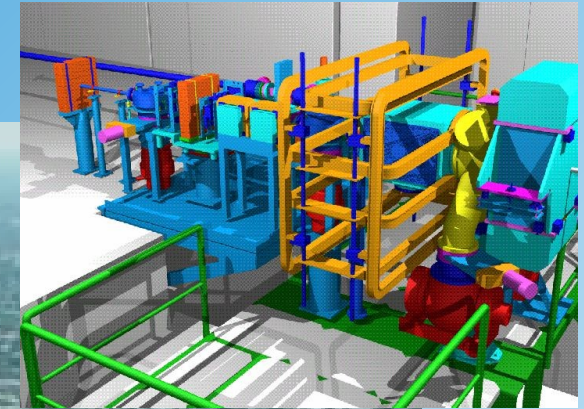
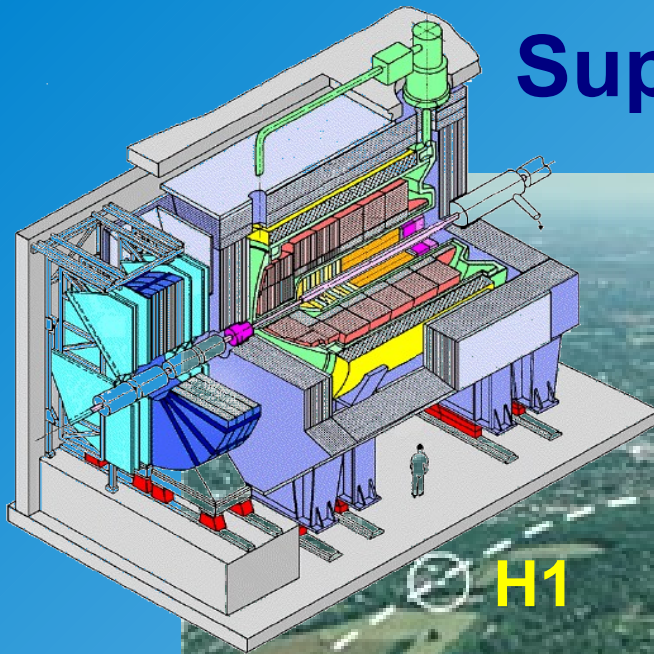


Fig. 1-1. Energies achieved by accelerators from 1930 to 1960. The linear envelope of the individual curves shows an average tenfold increase in energy every six years.



Supermikroskop HERA

920 GeV Protonen
x
26.7 GeV Elektronen

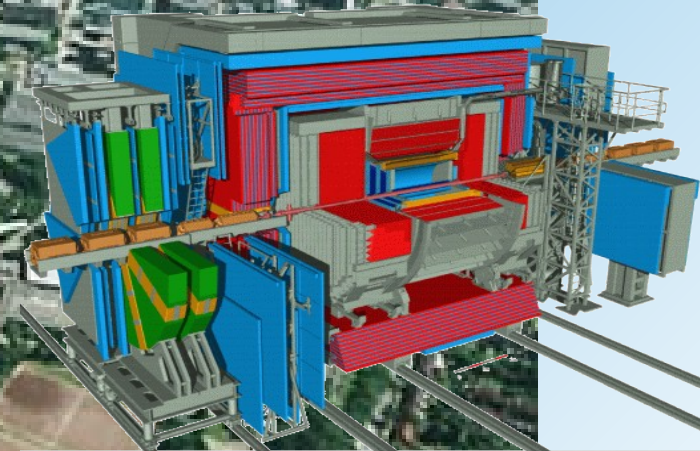


HERMES

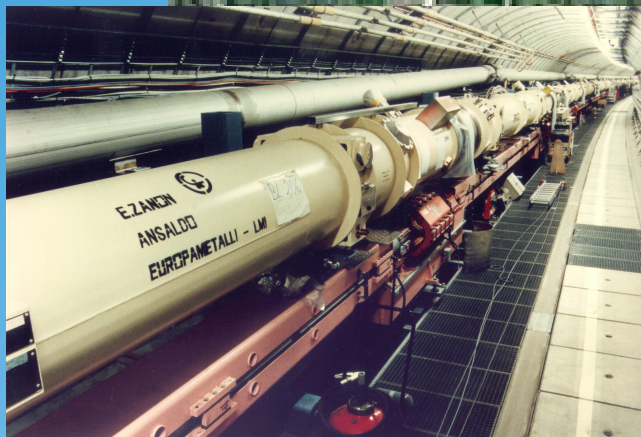
HERA

H1

ZEUS



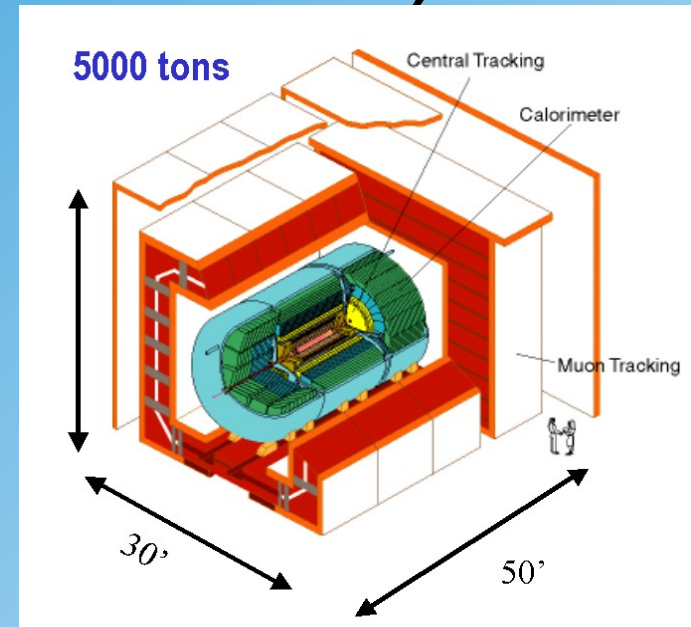
PETRA



(1992-2007 Hamburg)

Tevatron (Fermilab, USA)

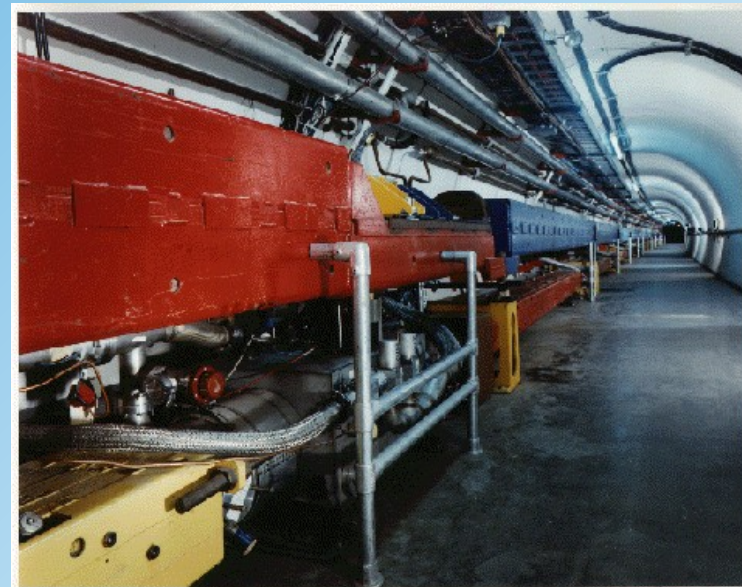
terminated September 2011



D0 Experiment

Proton-Antiproton Collider

$$s^{1/2} = 2 \text{ TeV}$$



Large Hadron Collider (CERN)



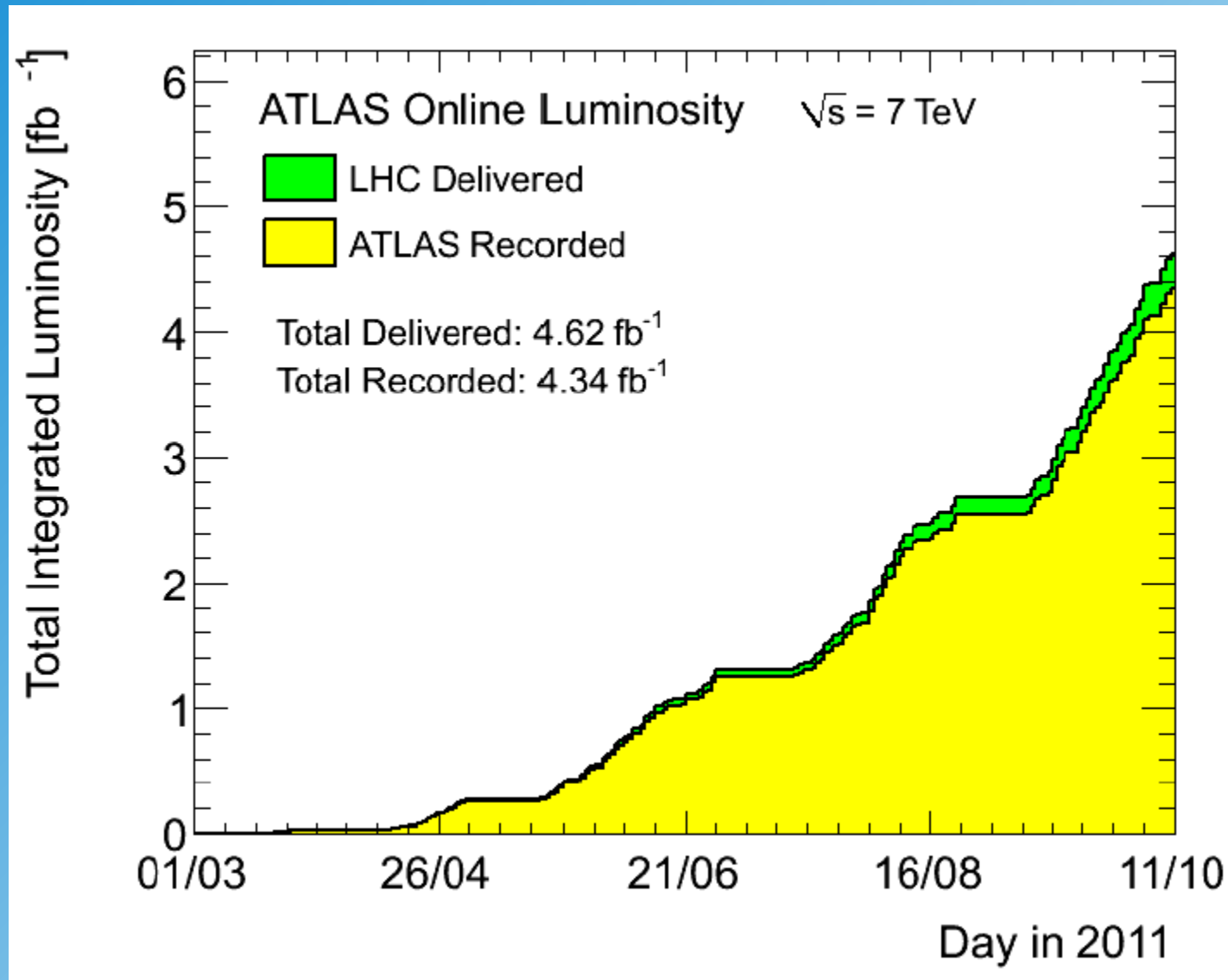
LHC (pp) 8(14) TeV

operation started 2009

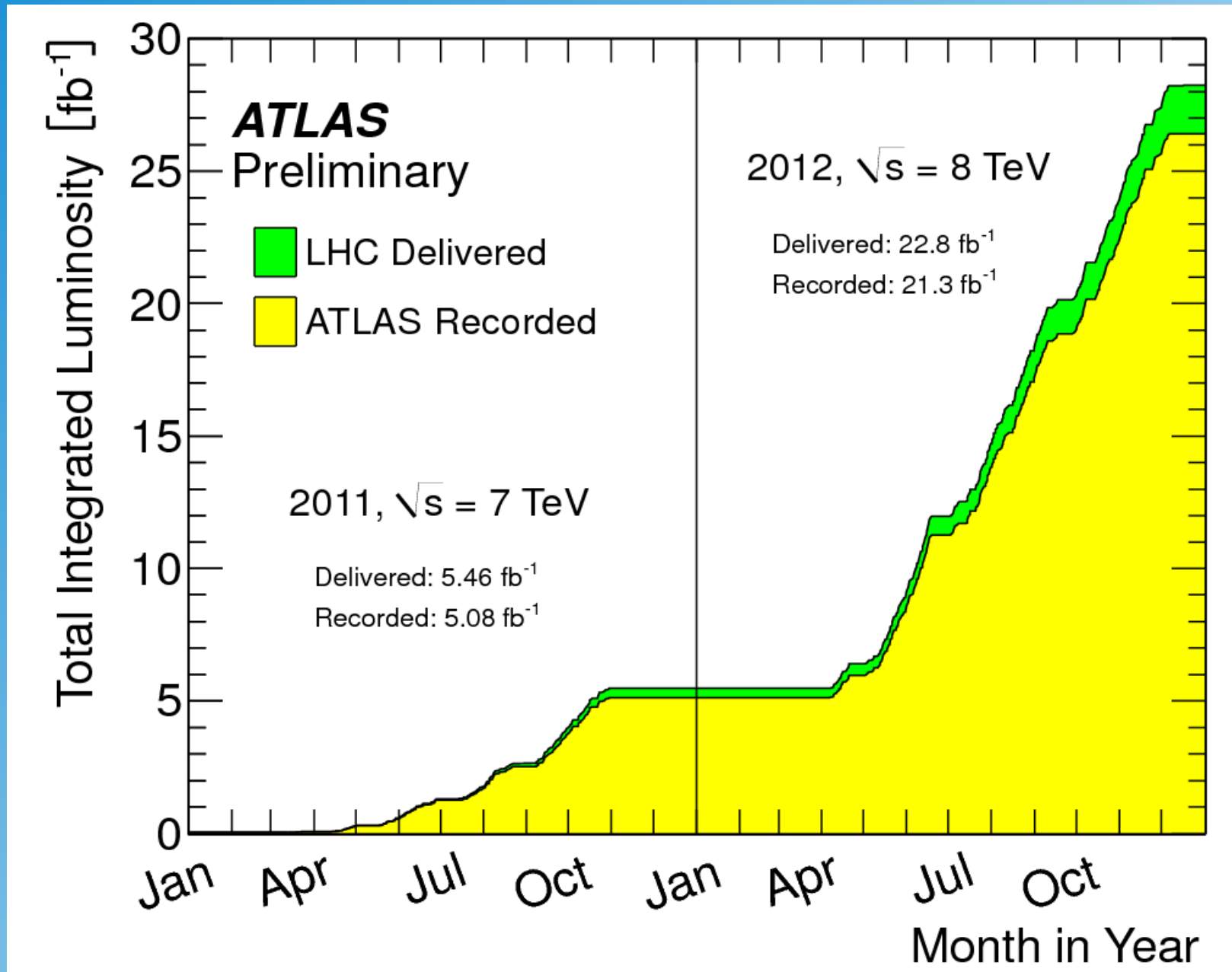


26.7 km circumference!

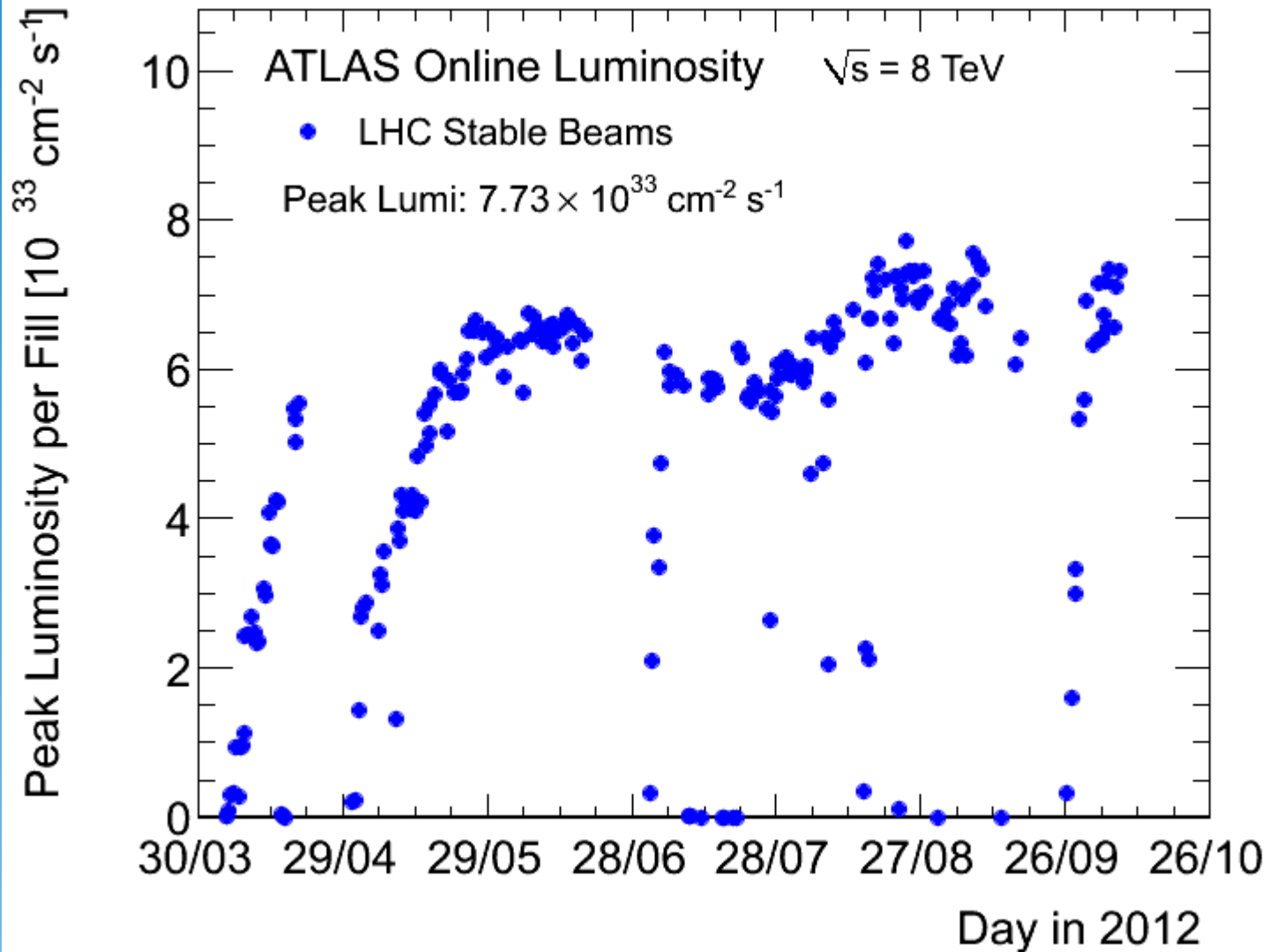
LHC Integrated Luminosity 2011



LHC Integrated Luminosity 2012



Peak Luminosity



Accelerators in Medicine

- X-ray therapy
- proton therapy (tumor treatment)

Berlin, Darmstadt, Erlangen, Heidelberg, Munich, PSI (Switzerland), ...



→ ionisation loss in materials (tumors)

