Lecture:

Accelerator Physics

Heidelberg WS 2014/15

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Physikalisches Institut der Universität Heidelberg

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: Mathis Kolb)
  “hands on” computer exercises (Python)
- First date October 15 (**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

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

Dates: Wednesday 11:15-13:00
Place: room 2.403, INF 227 (KIP)

Date	Topic Wednesday (Link)
15.10.12	Introduction and Basic Definitions
22.10.12	Accelerating Structures
29.10.12	Optics with Magnets 1
05.11.12	Optics with Magnets 2
12.11.12	Equations of Motion
19.11.12	Phase Ellipses and Magneto-Optical Systems
26.11.12	Transverse Beam Dynamics
03.12.12	Transverse Beam Dynamics and Beam Stability
10.12.12	Longitudinal Beam Dynamics
11.12.12	Phase Space and Beam Cooling
07.01.13	Space Charge and Beam-Beam Dynamics
14.01.13	Colliders
21.01.13	New Accelerator Technologies
28.01.13	no lecture
04.02.13	no lecture

“Leistungskontrolle”

Tutorials (Mathis Kolb):

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

sign up here: https://uebungen.physik.uni-heidelberg.de/v/497

Excursions

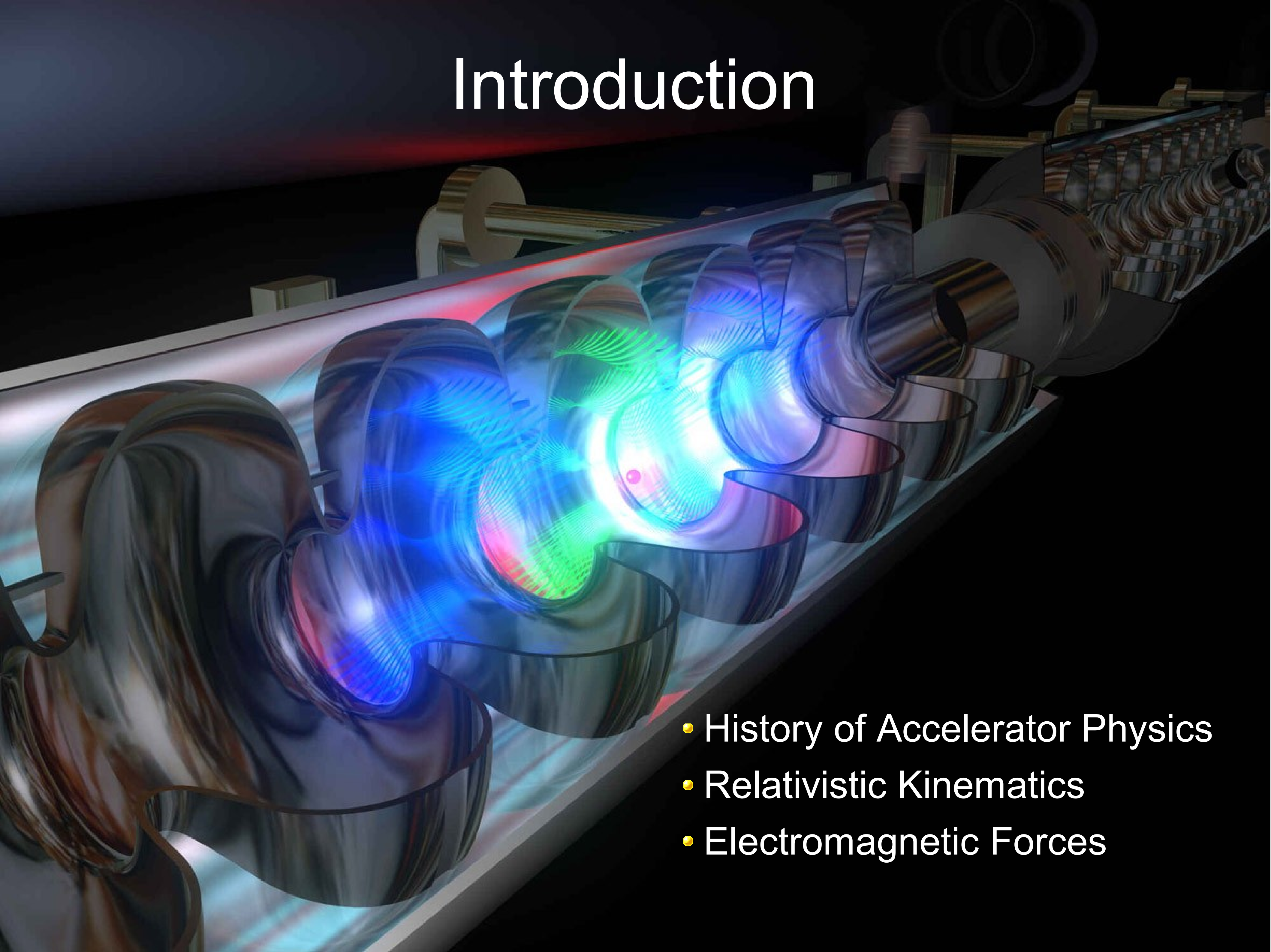
We could organise excursions to

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

depending on interest?

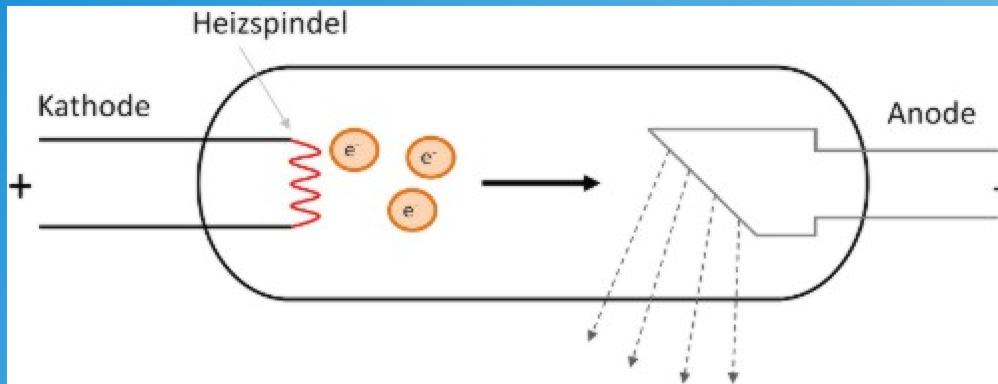
Feedback!

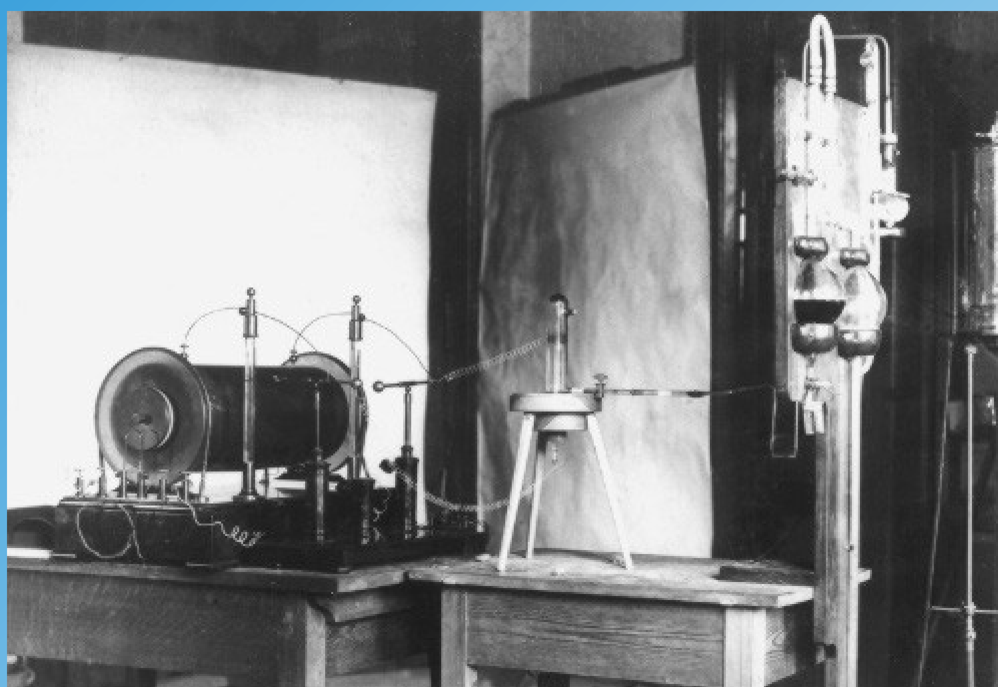
Introduction



- History of Accelerator Physics
- Relativistic Kinematics
- Electromagnetic Forces

First electron accelerator



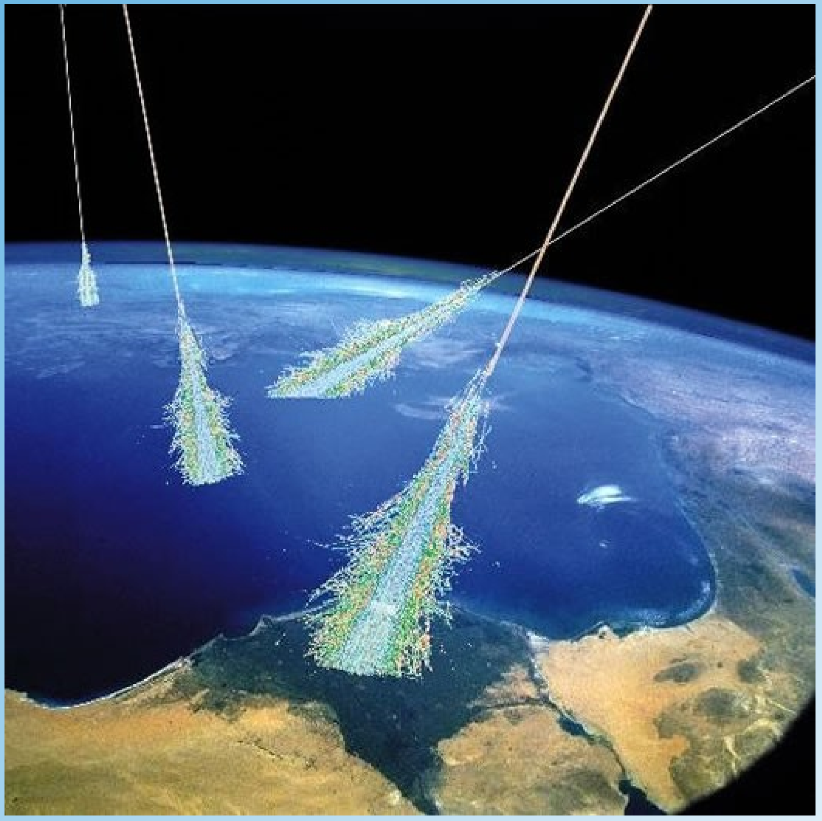


Wilhelm Conrad Röntgen (1895)

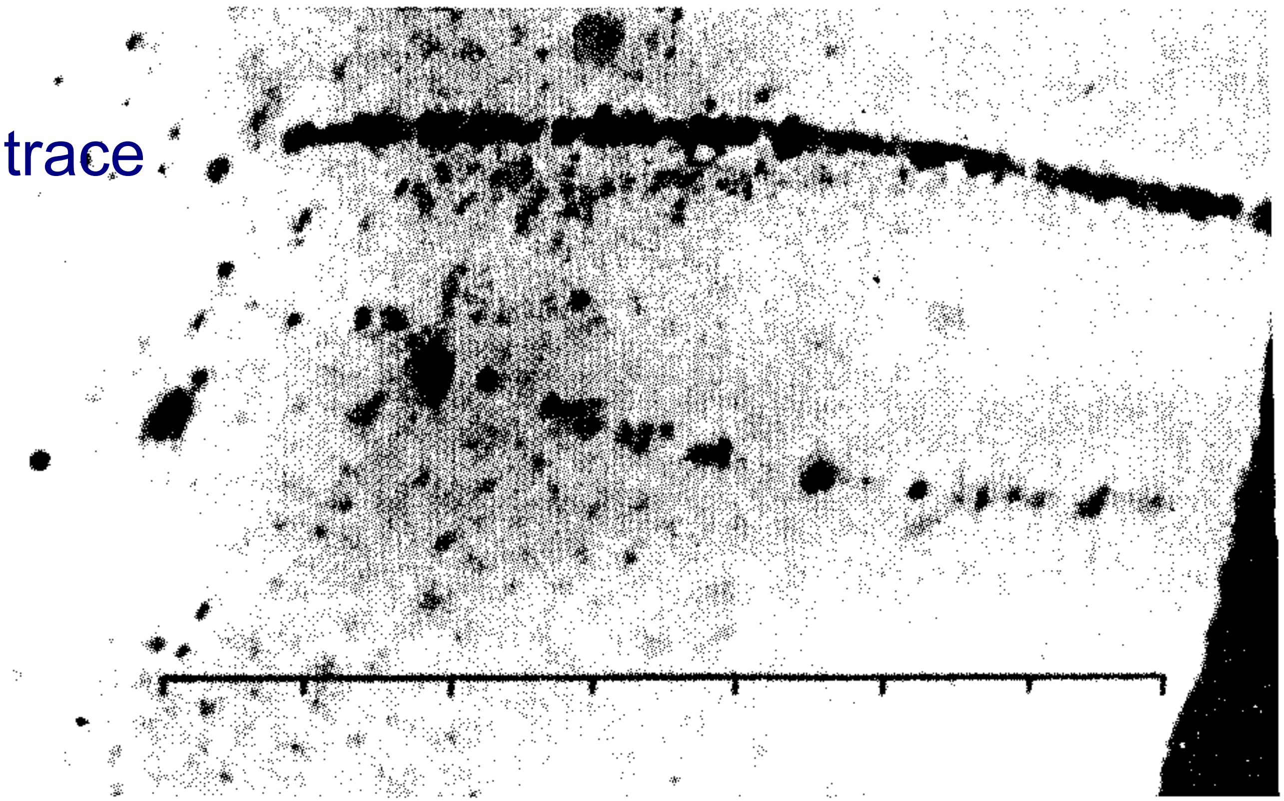
Cosmic Rays

Particle Acceleration in Universe

Victor Hess, 1912



Discovery of Muons in Cosmic Rays

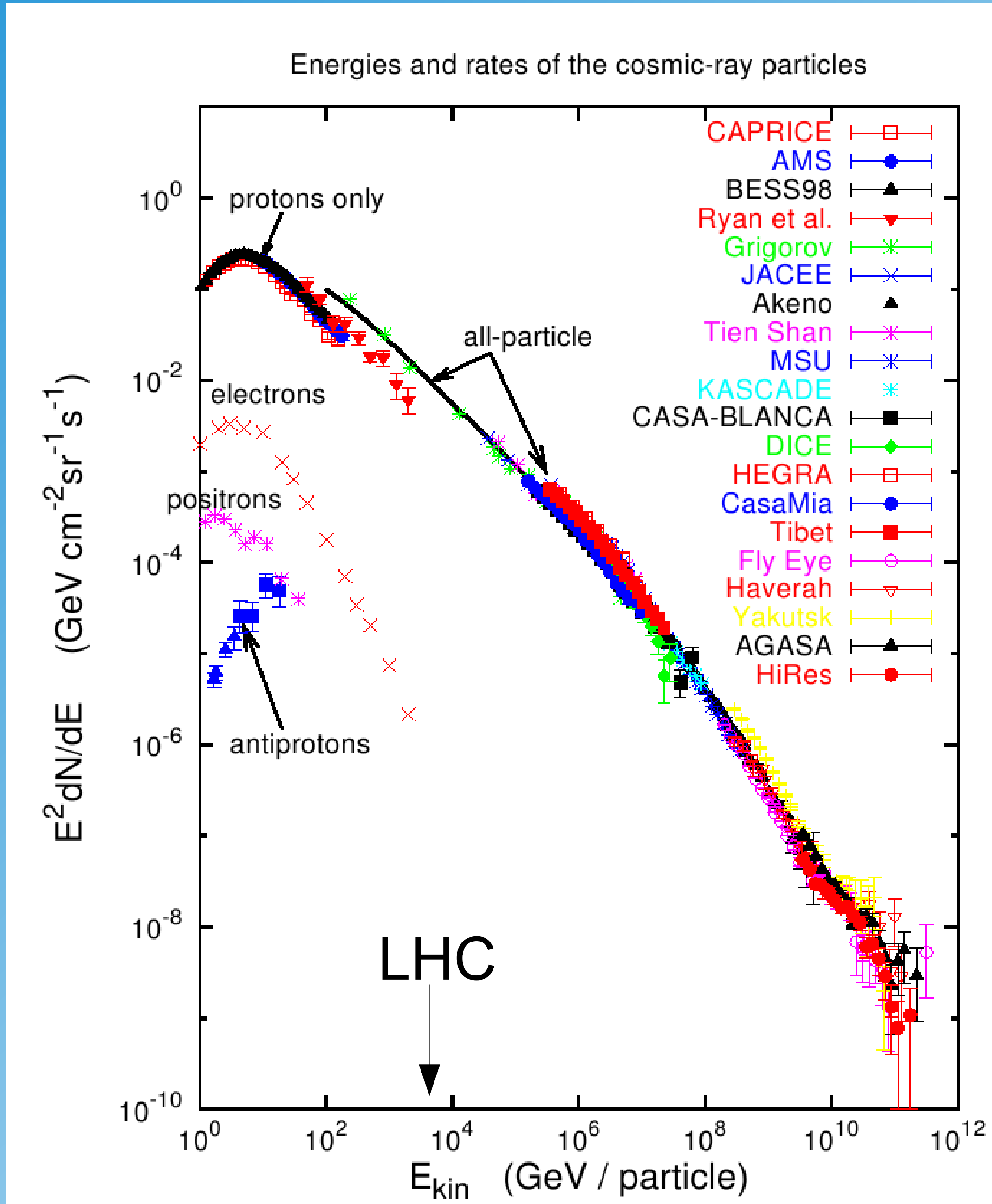


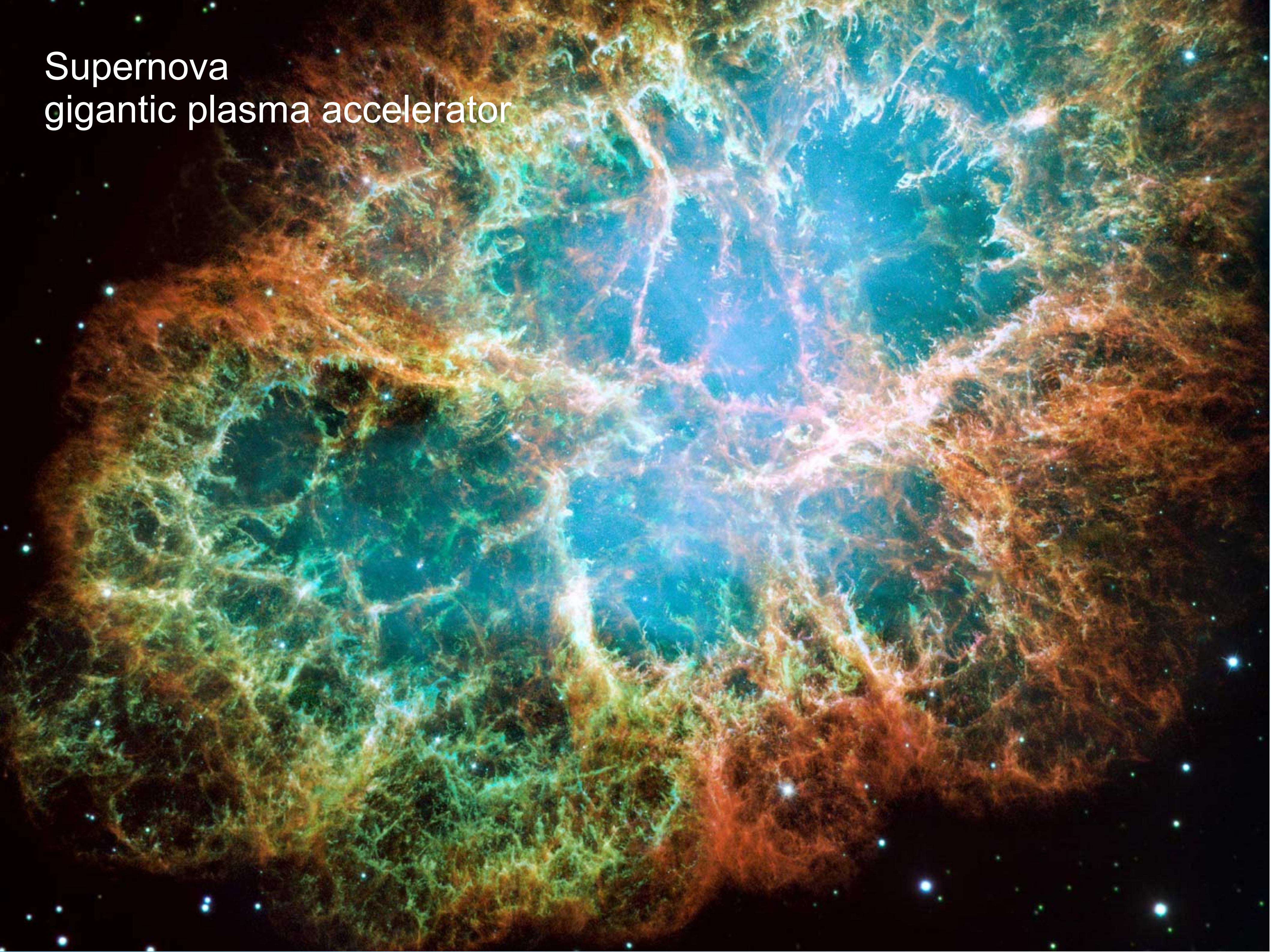
muon trace

"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 whith 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

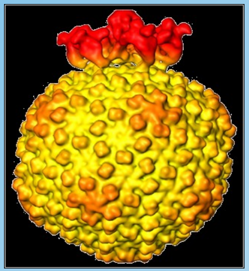
<u>"Natural" colliders:</u>
cosmic rays in the universe: supernova (shock waves, plasma accelerators)

<u>Humans</u> start to think about accelerating particles (electrons) more than 100 years ago.

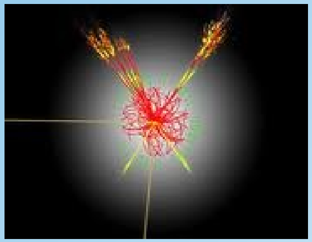
First Applications: X-Rays
(cathode ray tubes, Conrad Röntgen)

Applications of Accelerators

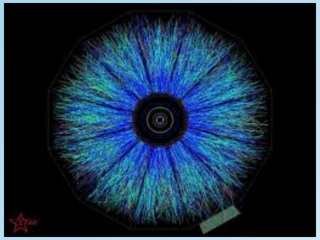
Investigation of small structures
(scattering experiments)



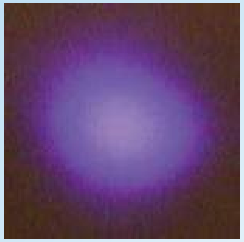
Excitation of atoms, nuclei, baryons
(spectroscopy)
production of new particles (Higgs Boson)



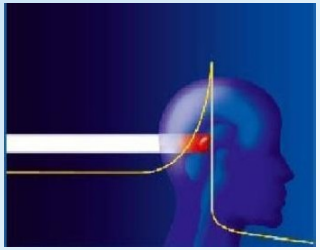
Exotic states of matter
(Quark-Gluon Plasma)



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

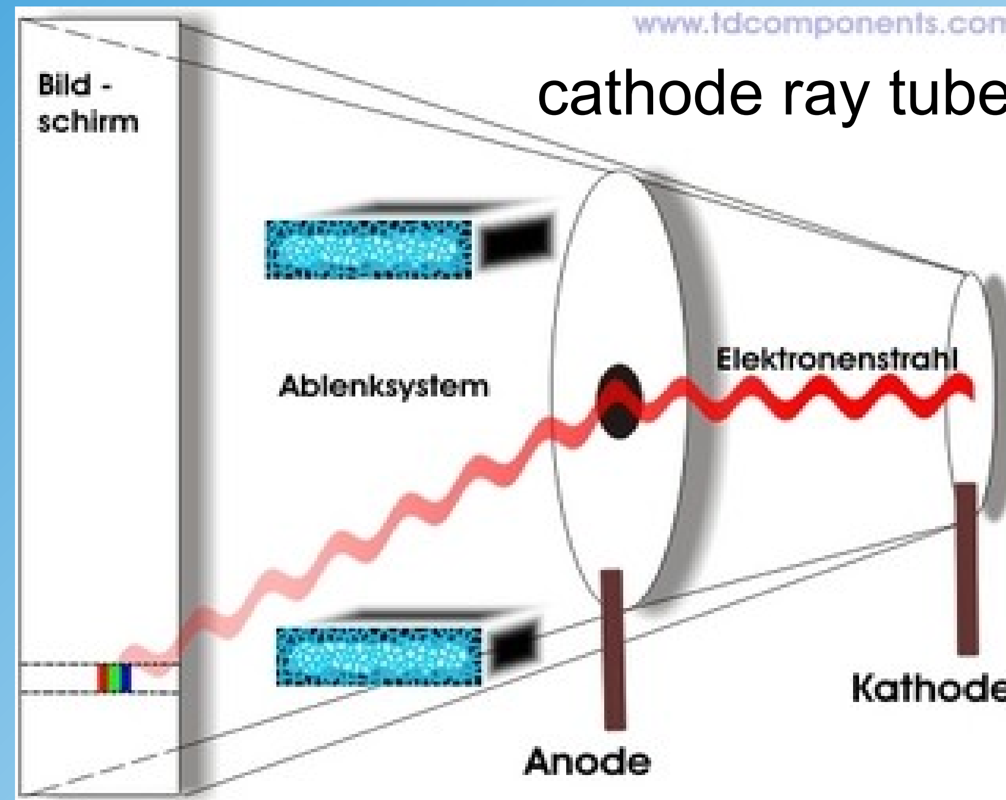


Radiation Therapy



Technical Applications
(e.g. production of isotopes)

The Principle



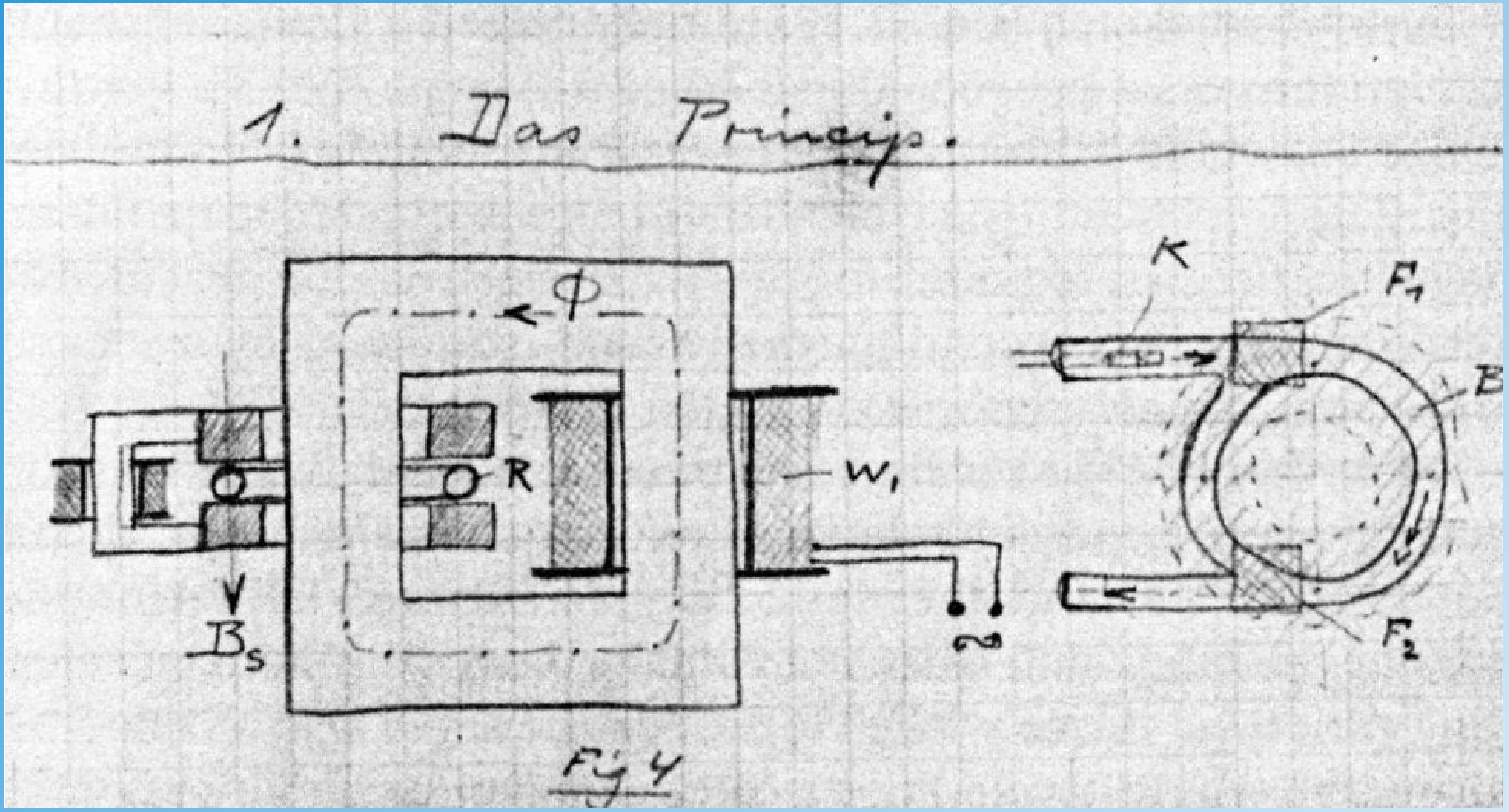
Monitors (cathode ray tubes) have the same components like accelerators:

- electron gun
- acceleration structure
- beam steering system

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

Ray Transformer
(ring accelerator)

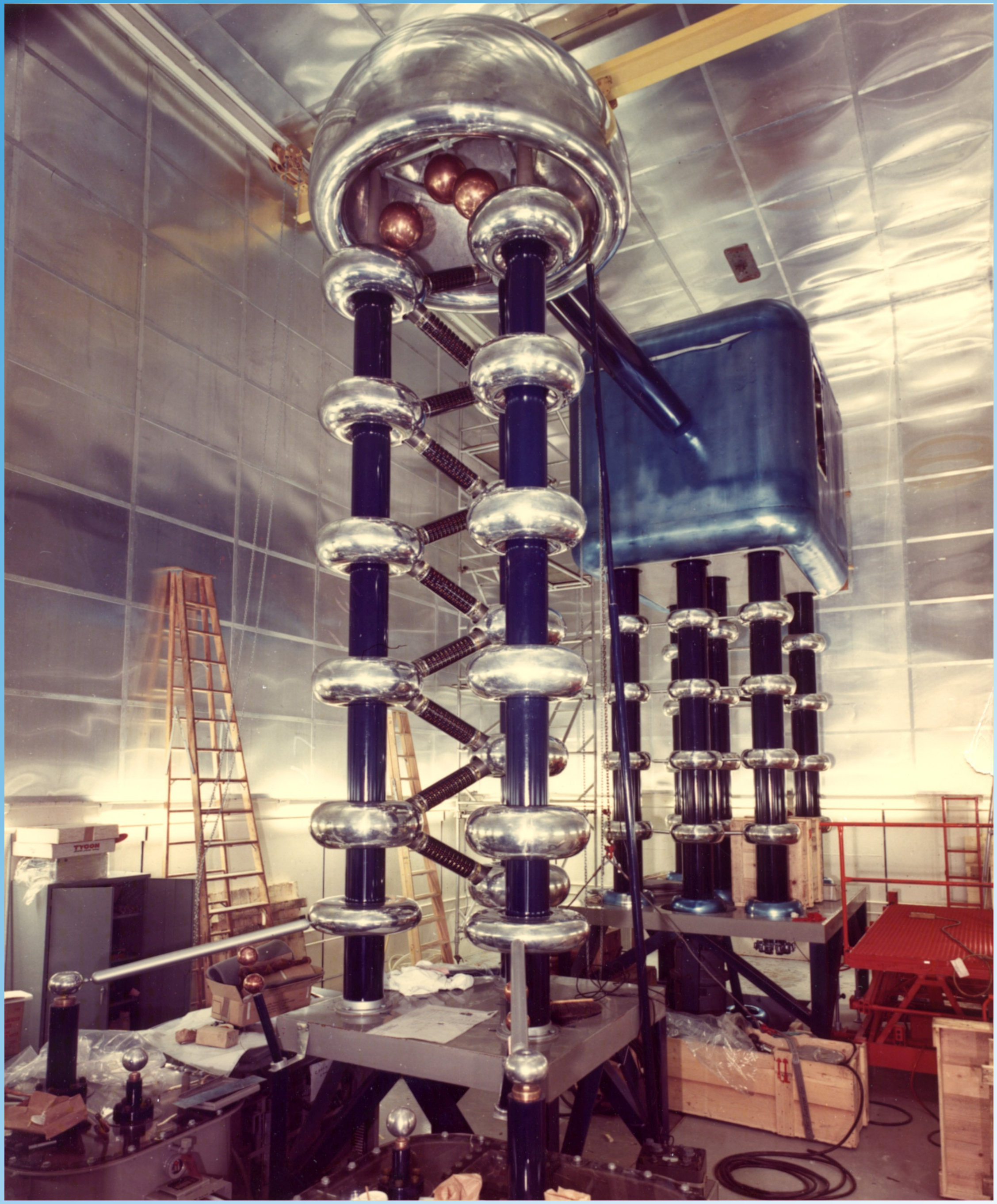
Rolf Wideröe (1928)



particle beam as “second winding” → later Betatron

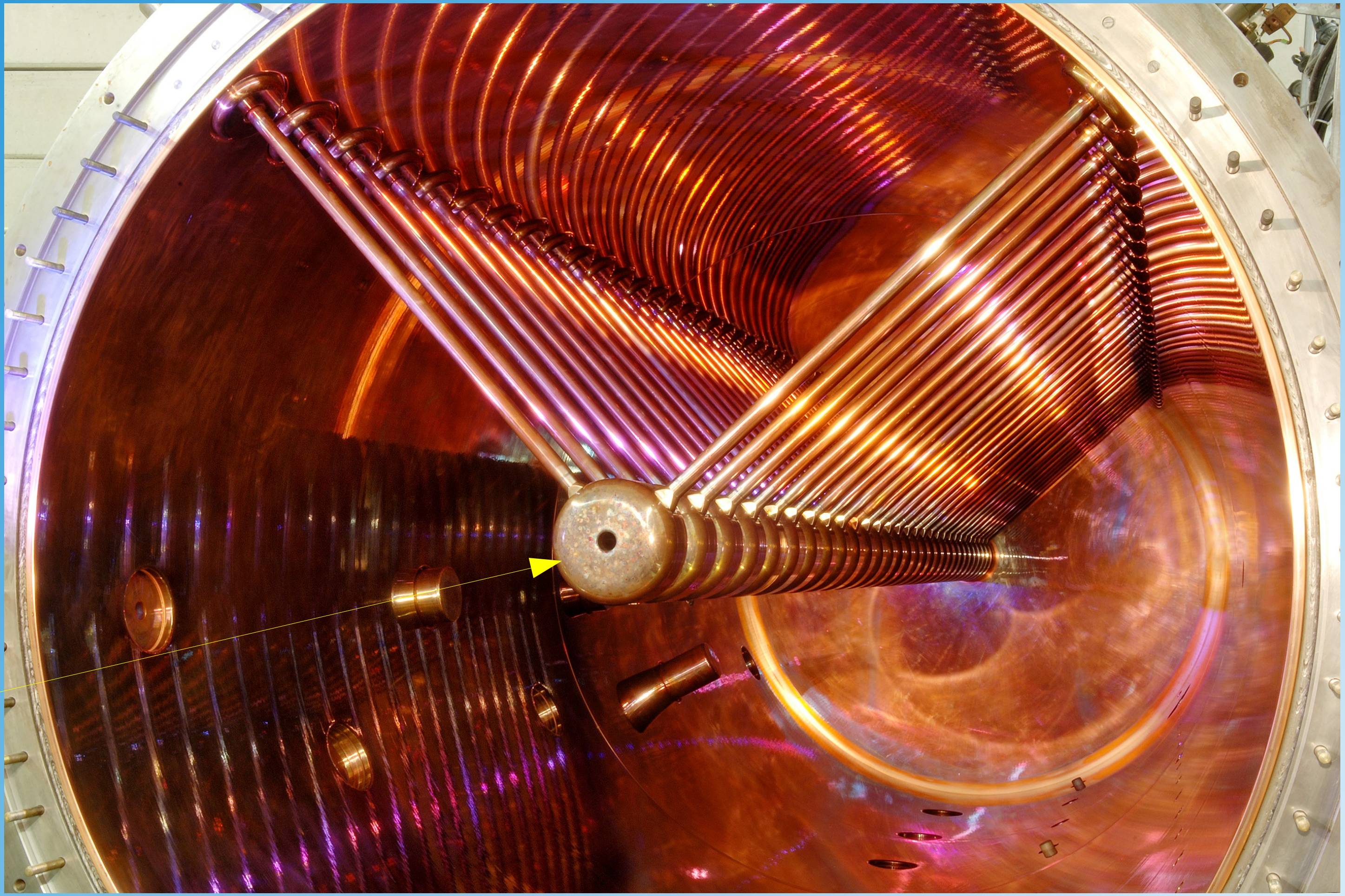
Cockcroft-Walton Generator

(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 nulcear 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

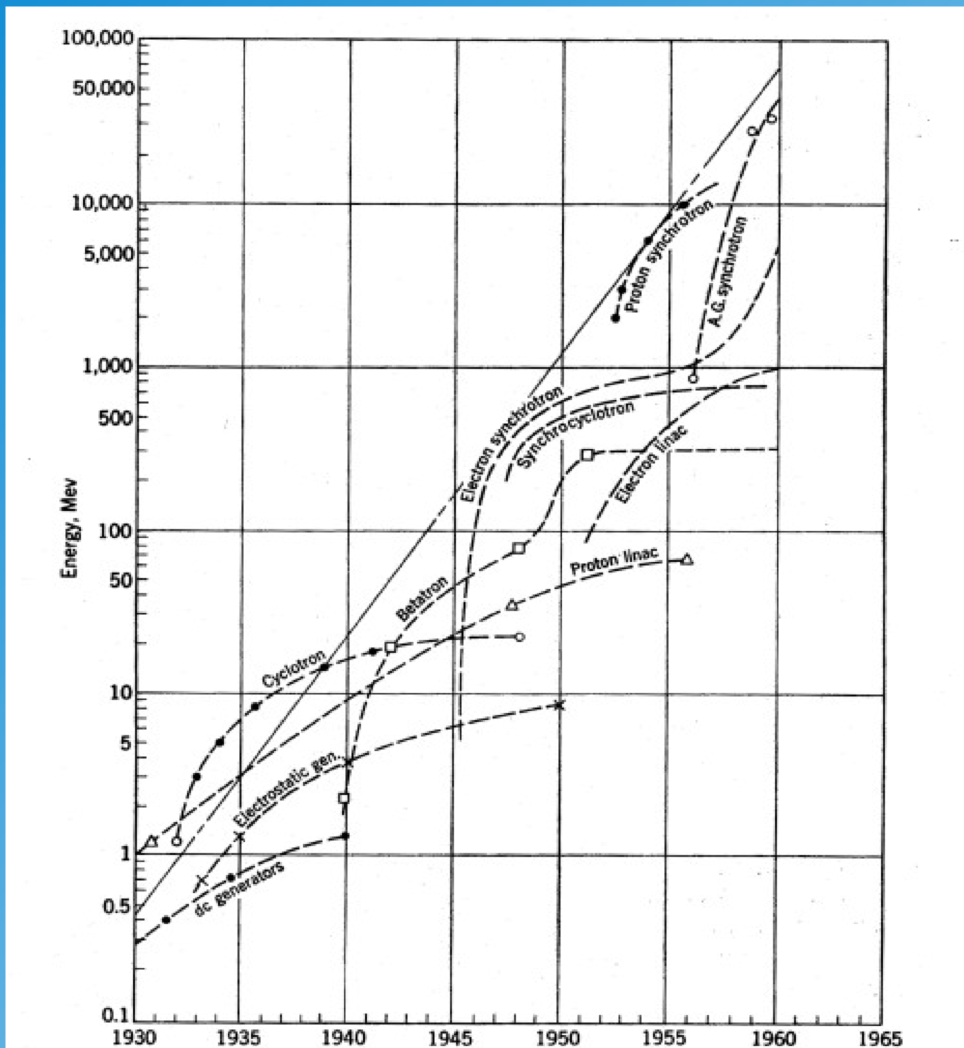
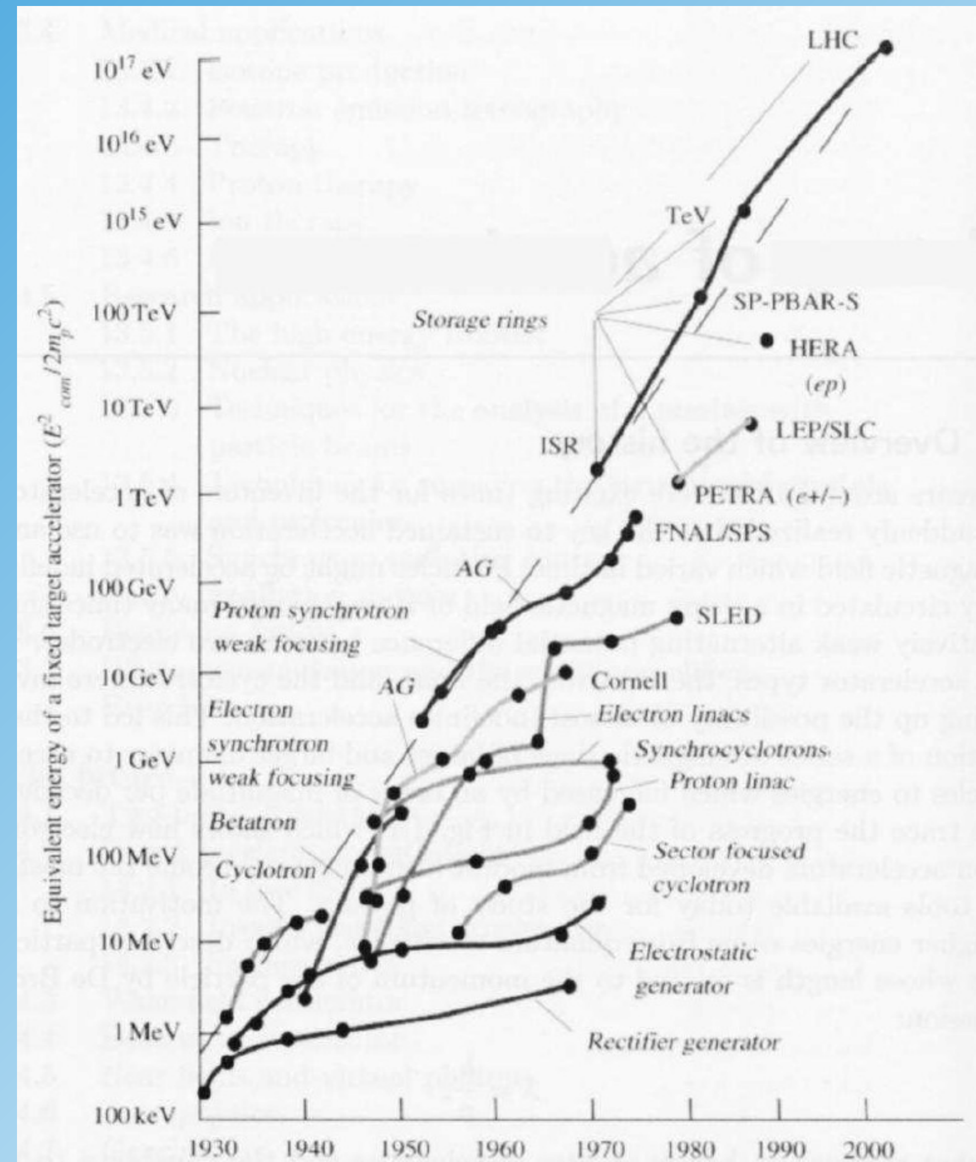
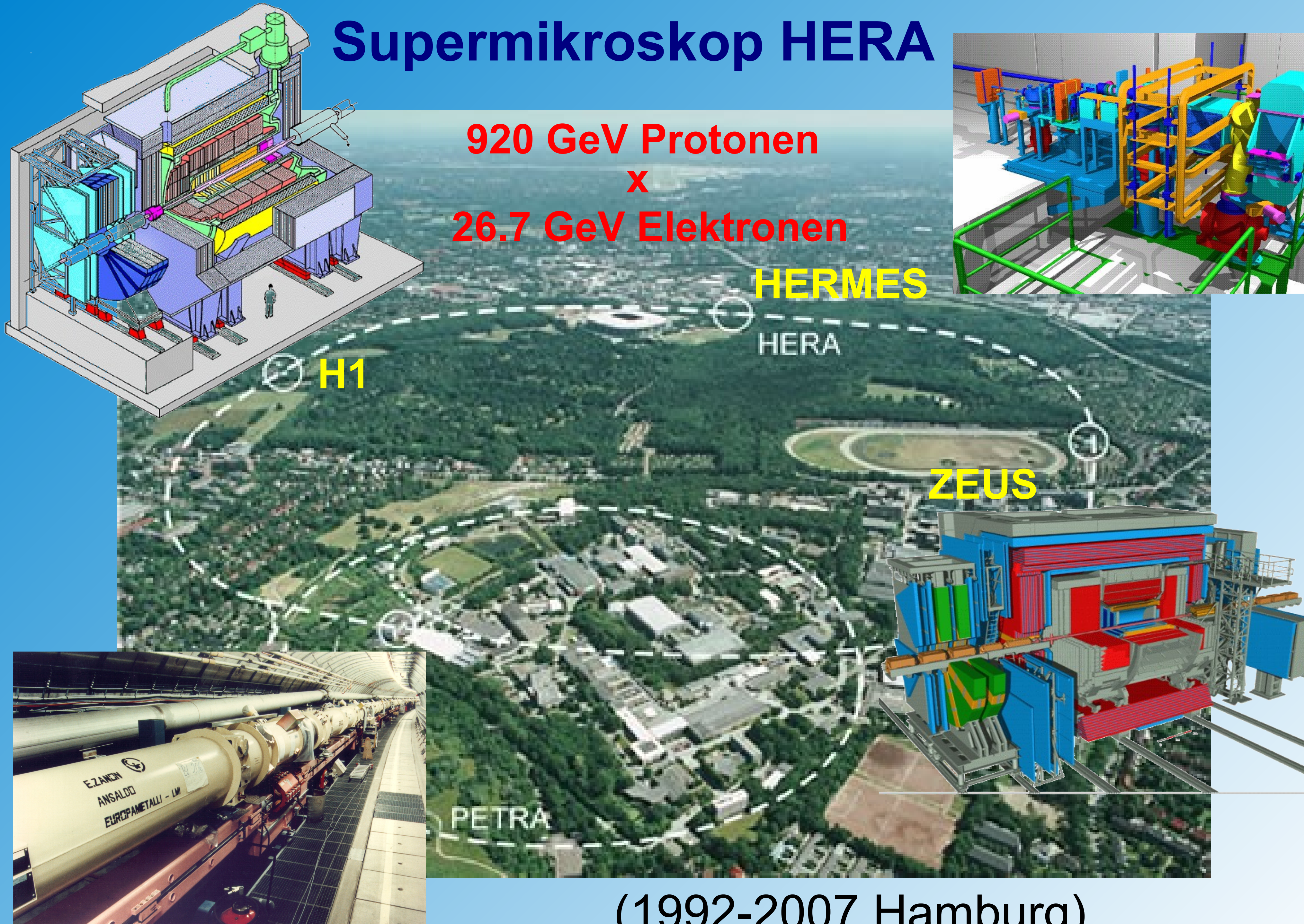


Fig. 1-1. Energies achieved by accelerators from 1930 to 1960. The linear envelope of the individual curves shows an average tenfold increase in energy every six years.



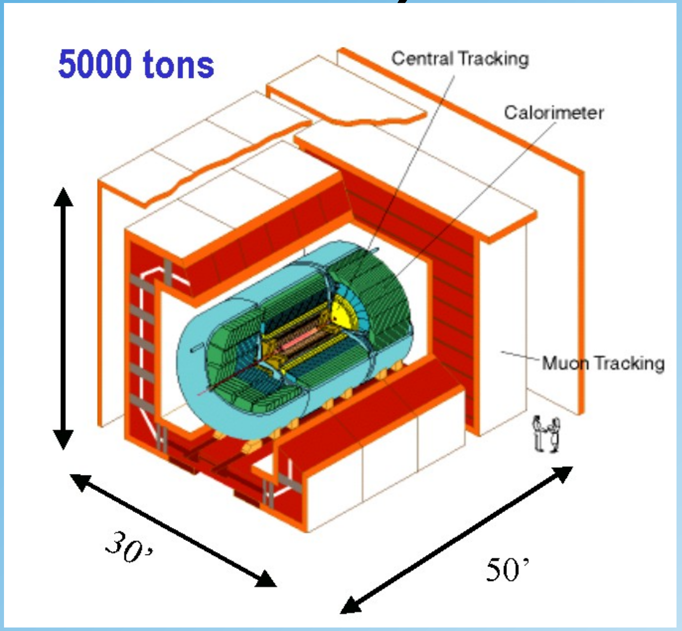
Supermikroskop HERA



(1992-2007 Hamburg)

Tevatron (Fermilab, USA)

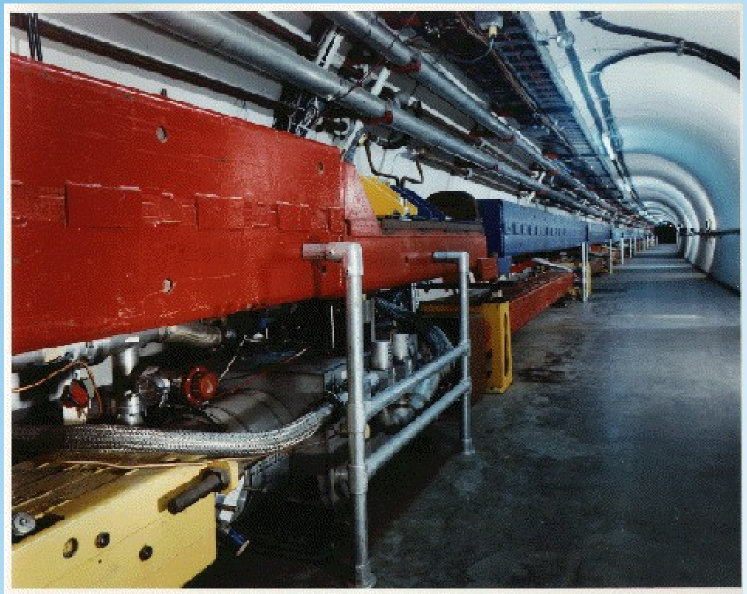
terminated September 2011



D0 Experiment

Proton-Antiproton Collider

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



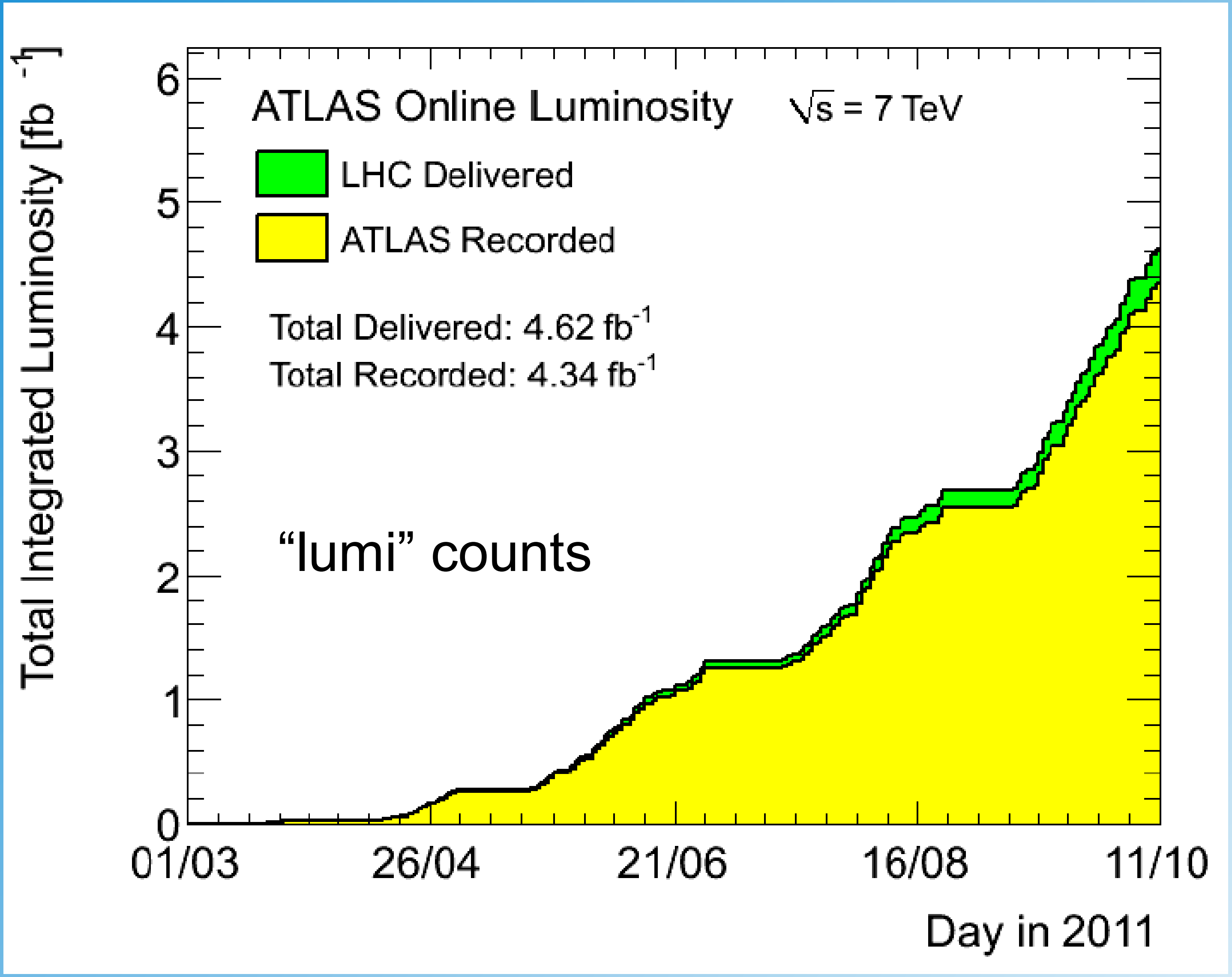
Large Hadron Collider (CERN)

LHC (pp) 8(14) TeV

- operation started 2009
- restart 2015 at 13 TeV

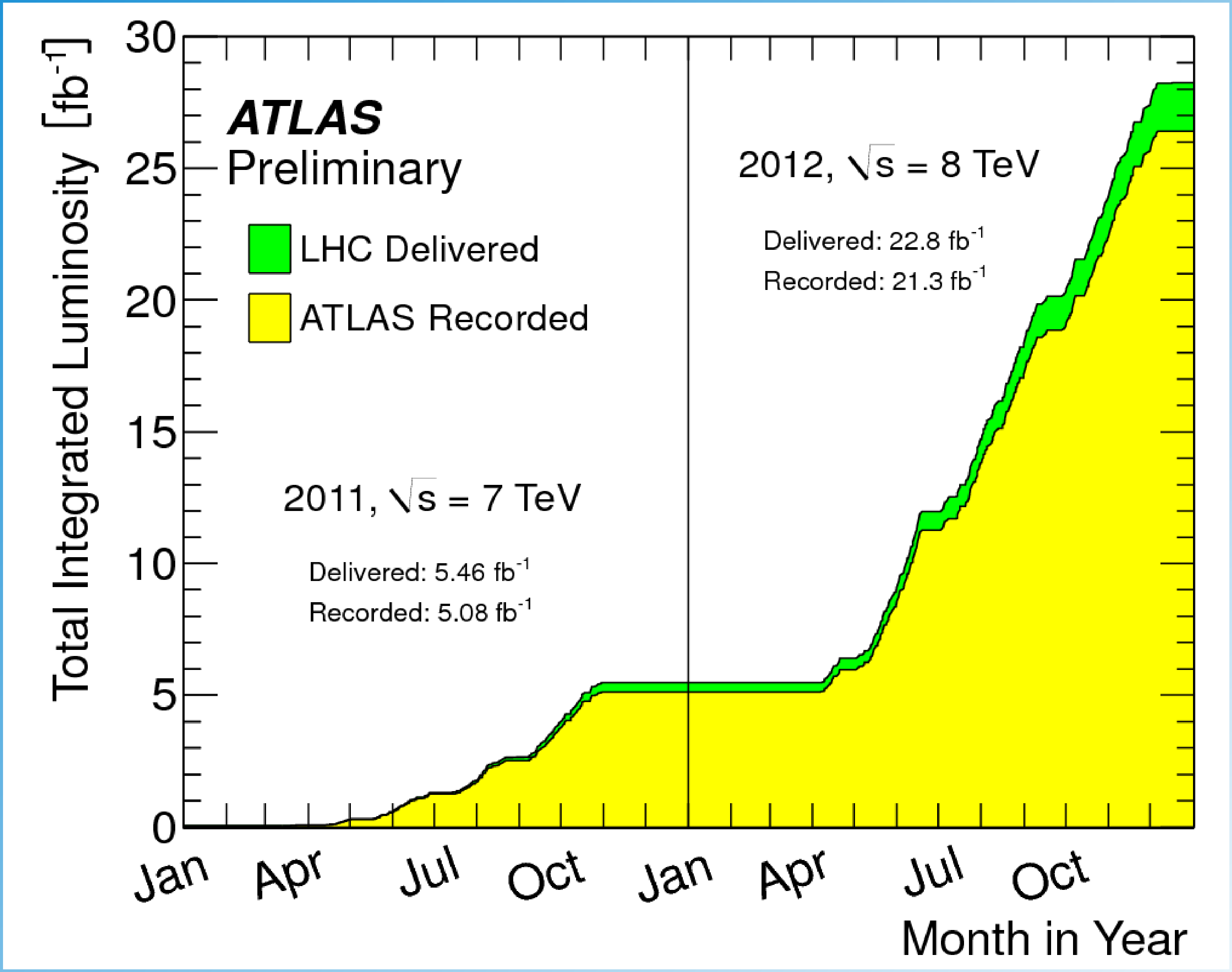
26.7 km circumference!

LHC Integrated Luminosity 2011



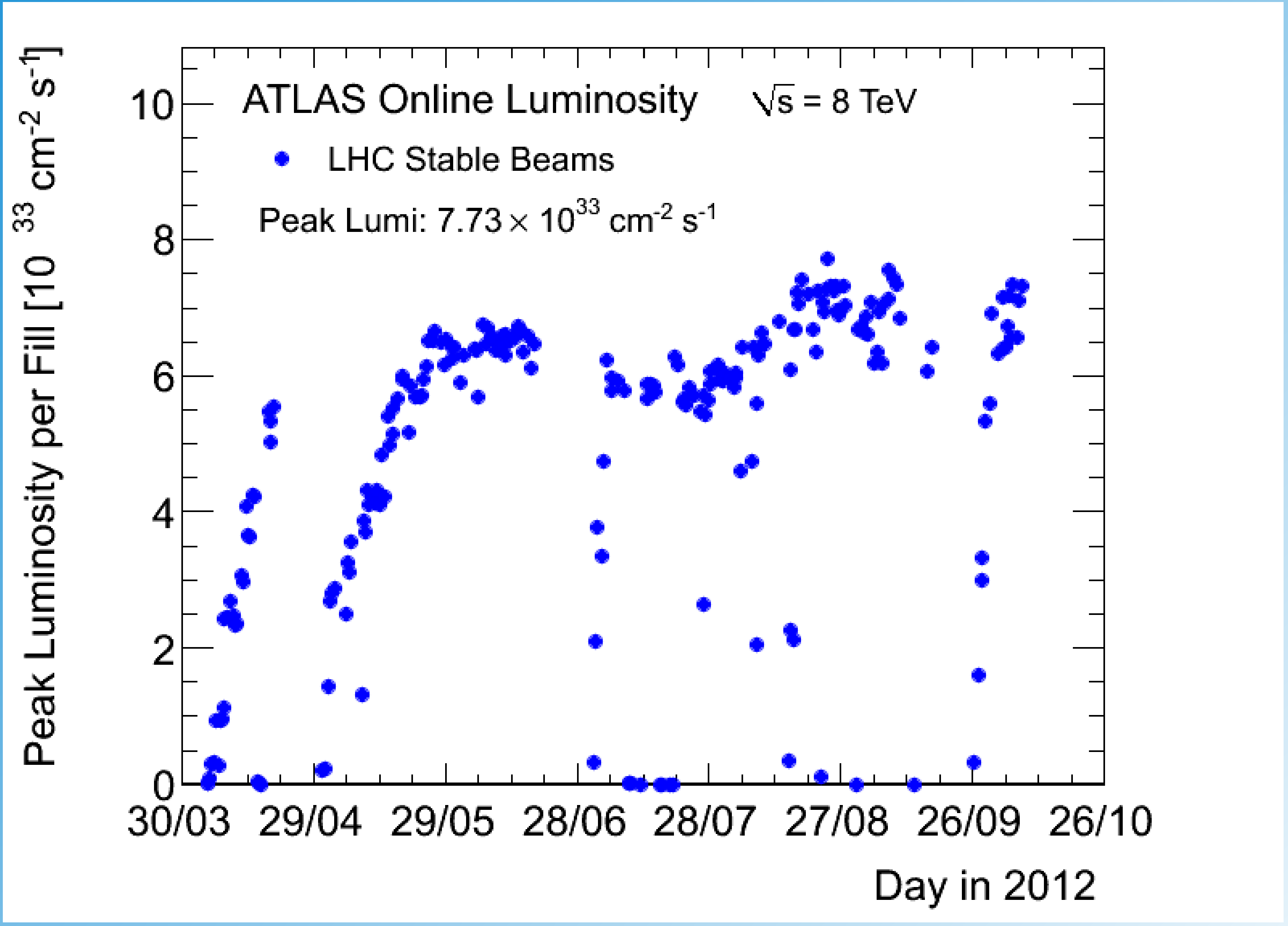
- extremely successful opration in 2011 (2012)
- lead to the discovery of the Higgs boson in 2012

LHC Integrated Luminosity 2012



Peak Luminosity

Design lumi value is 10^{34} $cm^{-2}s^{-1}$



Future e^+e^- and pp Circular Colliders

Future Circular Collider (FCC)

100 km circumference

- year > 2035
- first $e^+ e^-$ collider
- then pp collider (100 TeV)

Accelerators in Medicine

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

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

→ ionisation loss in materials (tumors)