Lecture:

Accelerator Physics

Heidelberg WS 2012/13

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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: Quantum Mechanics, Electrodynamics, special relativity

Lectures: Physics I-V

Addressing:

Master Students (Bachelor Students)

Accompanying Tutorials:

- Wednesday 16h15, CIP Pool – PI (Tutor Gregor Kasieczka)
  "hands on" computer exercises (Python)
- First date October 17 (**today**!)

More Information on the Web:

http://www.physi.uni-heidelberg.de/~schoning/Vorlesungen/AcceleratorWS12/

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 Electrondynamics, also in German

Lecture Dates

Dates: Wednesday 11:15-13:00

Place: Inf 226, Conference Room 1-3

Date	Topic Wednesday (Link)
17.10.12	Introduction and Basic Definitions
24.10.12	Accelerating Structures
31.10.12	Optics with Magnets 1
07.11.12	Optics with Magnets II
14.11.12	Phase Ellipses and Magneto-Optical Systems
21.11.12	Transverse Beam Dynamics I
28.11.12	Transverse Beam Dynamics and Beam Stability
05.12.12	Longitudinal Beam Dynamics
12.12.12	Phase Space and Beam Cooling
19.12.12	Christmas lecture
09.01.13	Space Charge and Beam-Beam Dynamics
16.01.13	Colliders
23.01.13	New Accelerator Technologies
30.01.13	Synchrotron Facilities and FELs
06.02.13	no lecture

"Leistungskontrolle"

Tutorials (Gregor Kasieczka):

- 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")

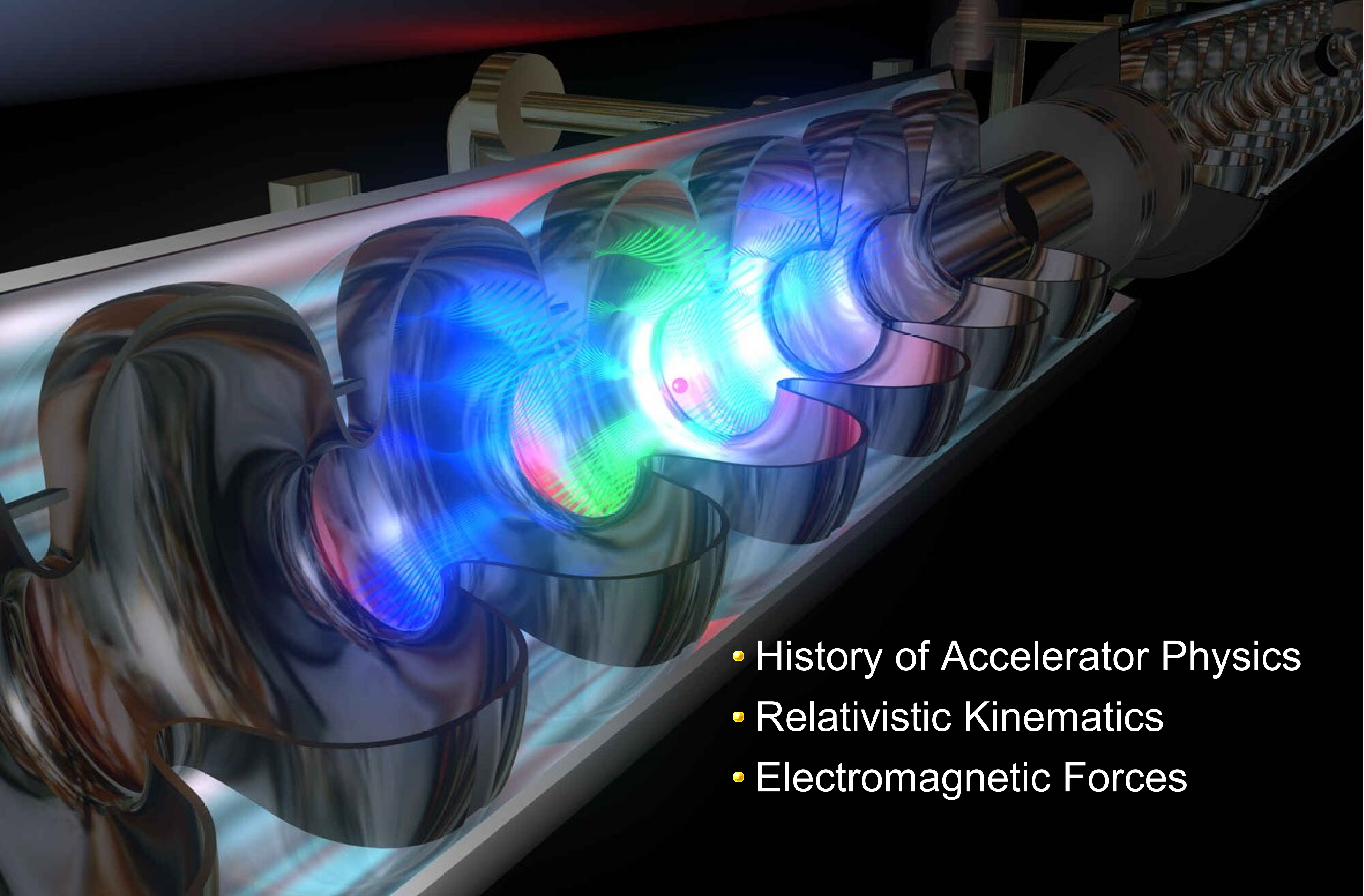
Excursions

We could organise excursions to

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

Feedback!

Introduction

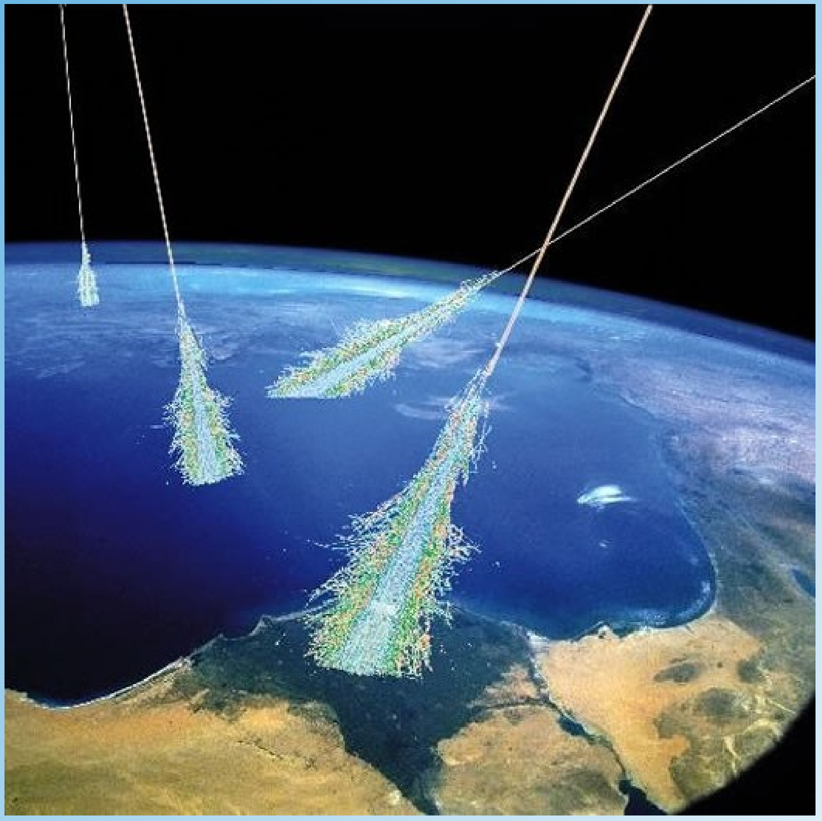


- History of Accelerator Physics
- Relativistic Kinematics
- Electromagnetic Forces

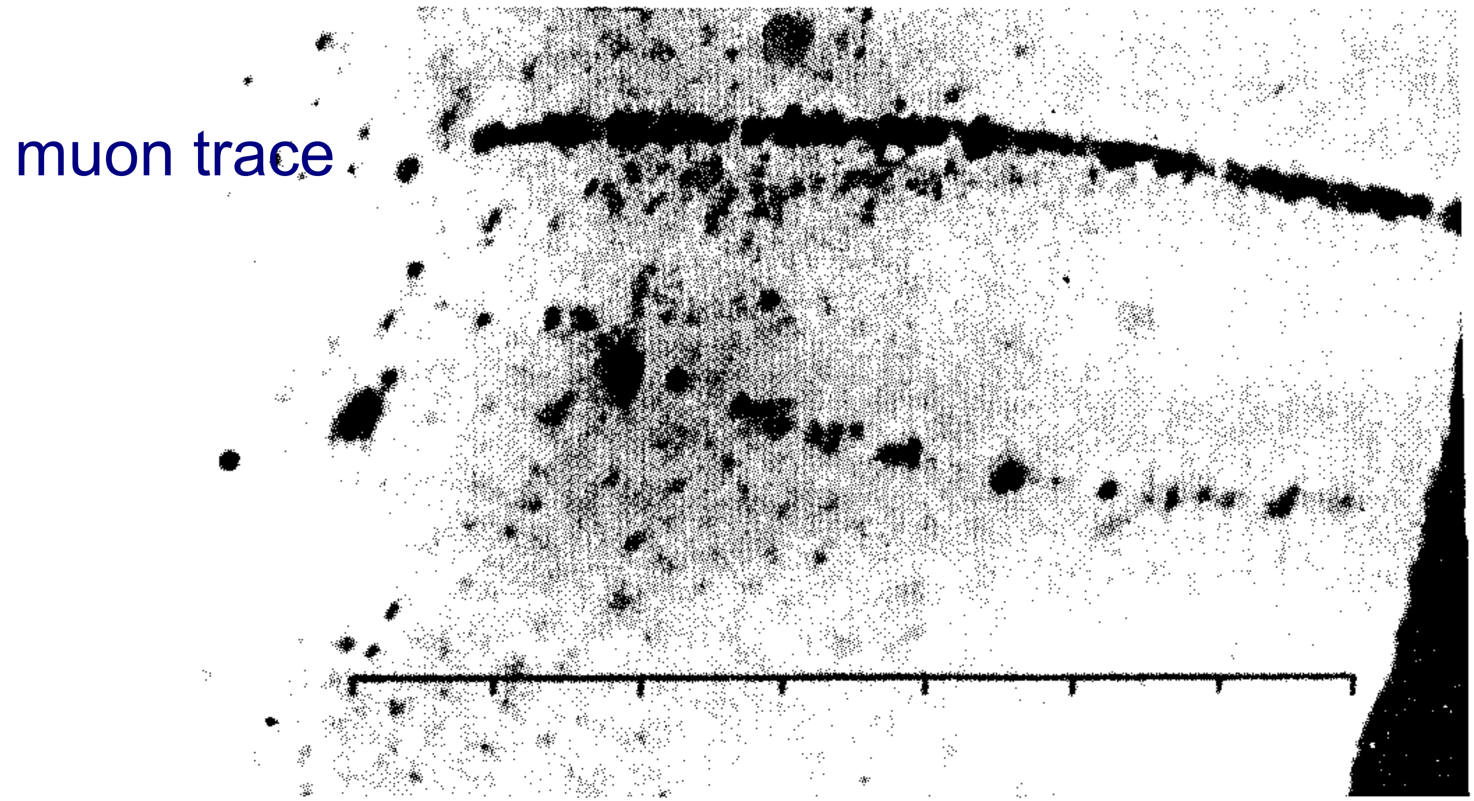
Cosmic Rays

Particle Acceleration in Universe

Victor Hess, 1912



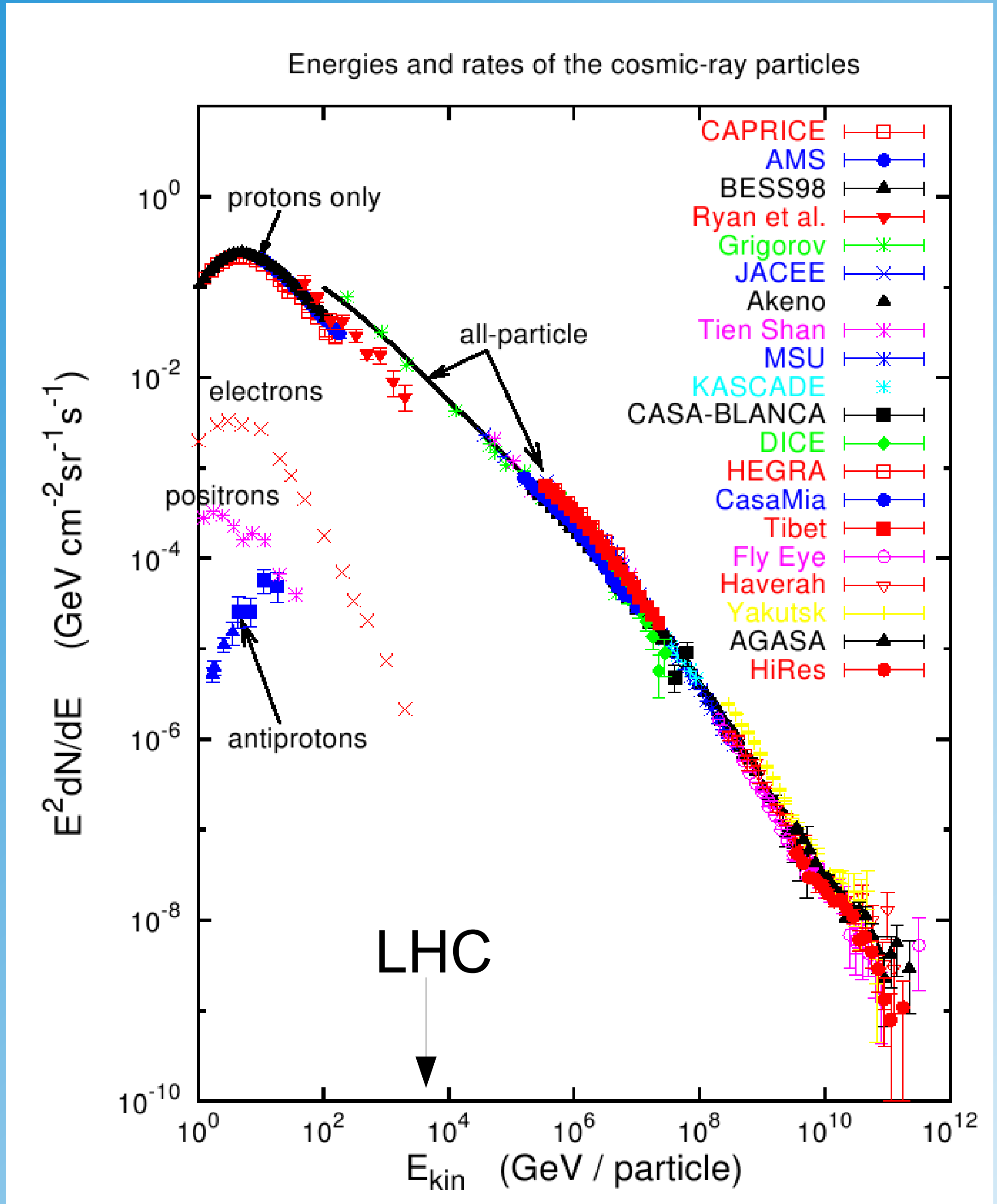
Discovery of Muons in Cosmic Rays

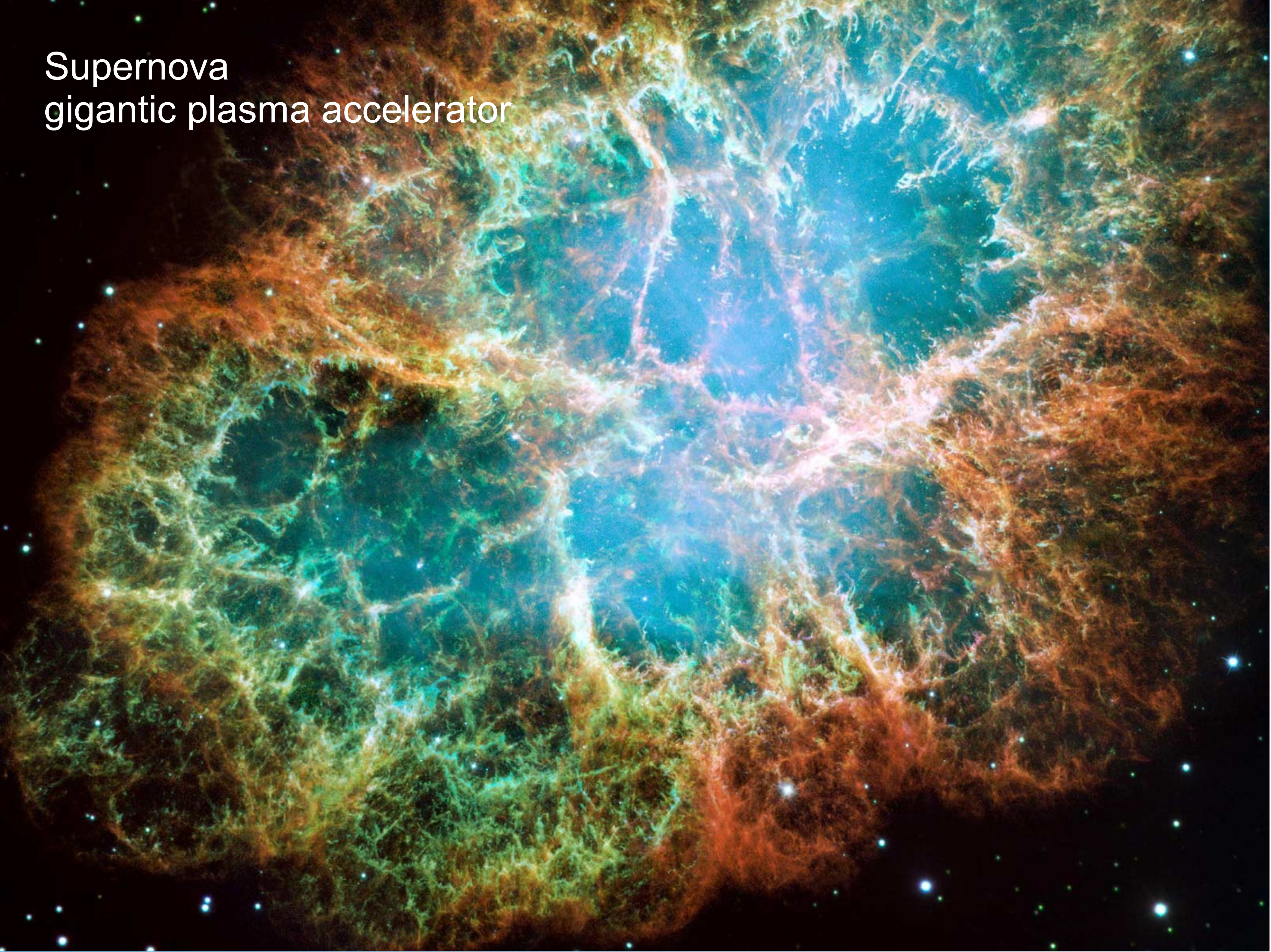


"The other double trace of the same type (figure 5) shows closely together the thin trace of an electron of 37 MeV, and a much more strongly ionizing positive particle whith a much larger bending radius. The nature of this particle is unknown; for a proton it does not ionize enough and for a positive 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

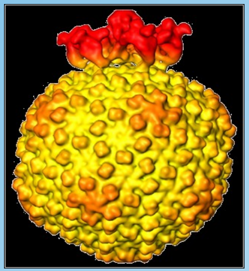
History

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

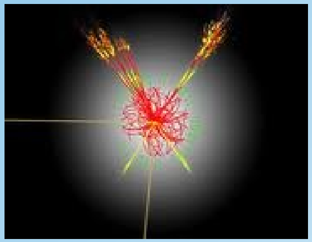
Humans start to think about accelerating particles (electrons) more than 100 years ago:
First Applications: X-Rays
(cathode ray tubes, Conrad Röntgen)

Applications of Accelerators

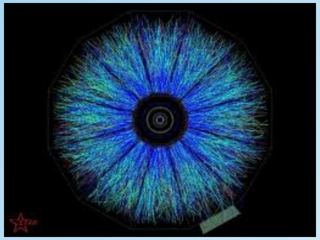
Investigation of small structures
(scattering experiments)



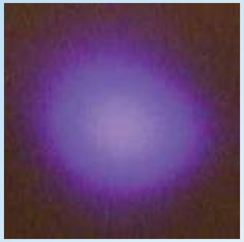
Excitation of atoms, nuclei, baryons
(spectroscopy)
production of new particles (Higgs Boson)



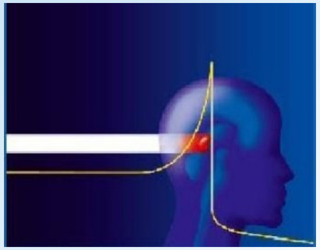
Exotic states of matter
(Quark-Gluon Plasma)



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

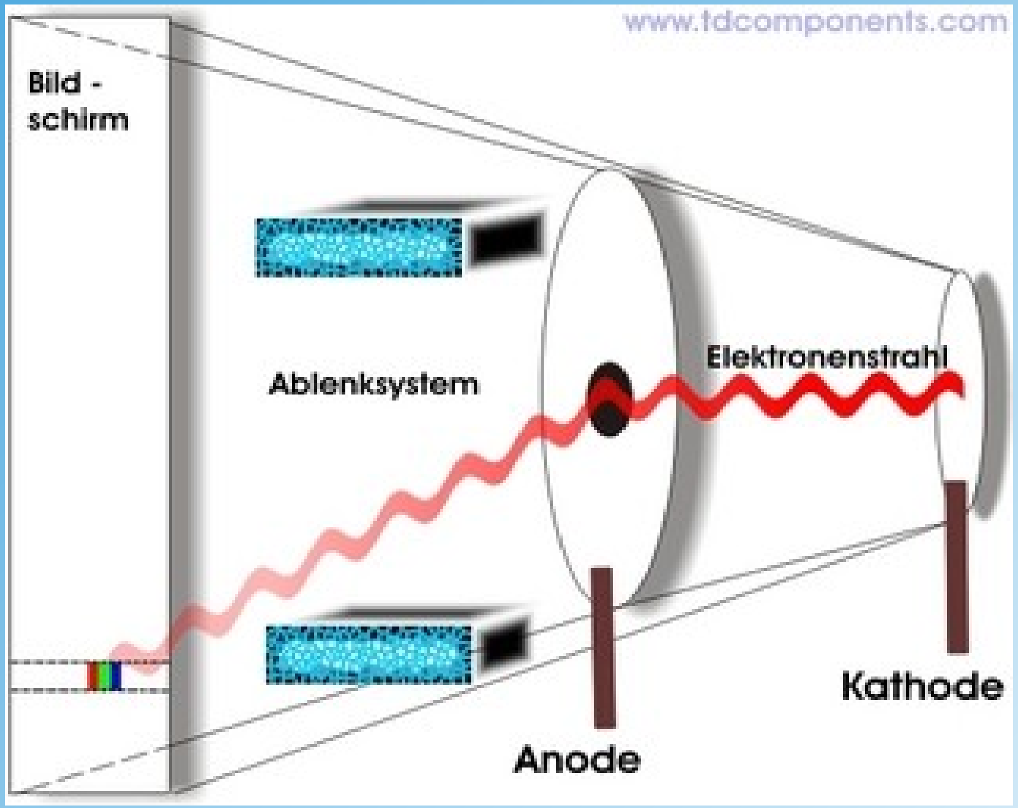


Radiation Therapy



Technical Applications
(e.g. production of isotopes)

The Principle



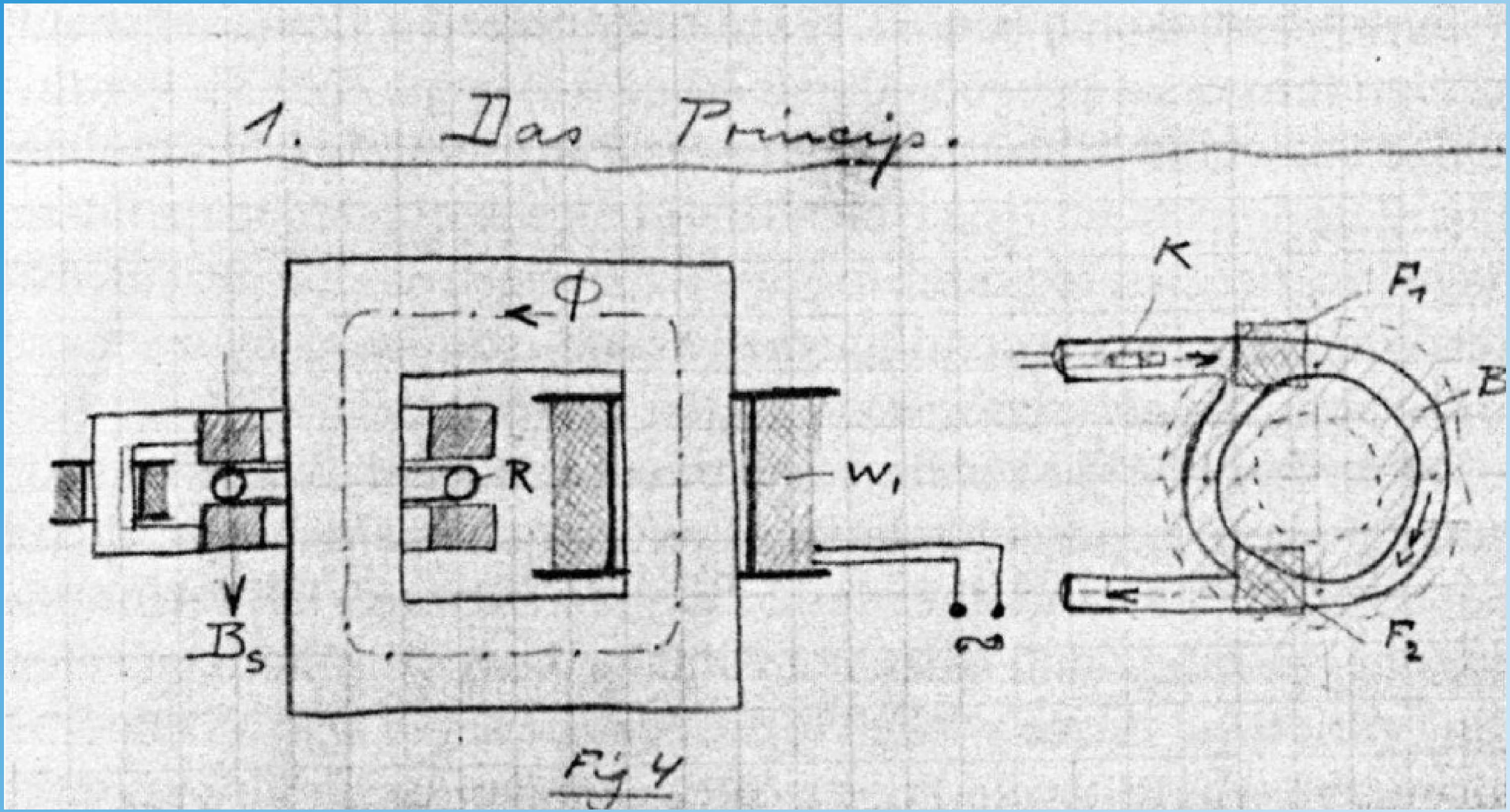
Monitors have the same components like accelerators:

- electron gun
- acceleration structure
- beam steering system

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

Ray Transformer
(ring accelerator)

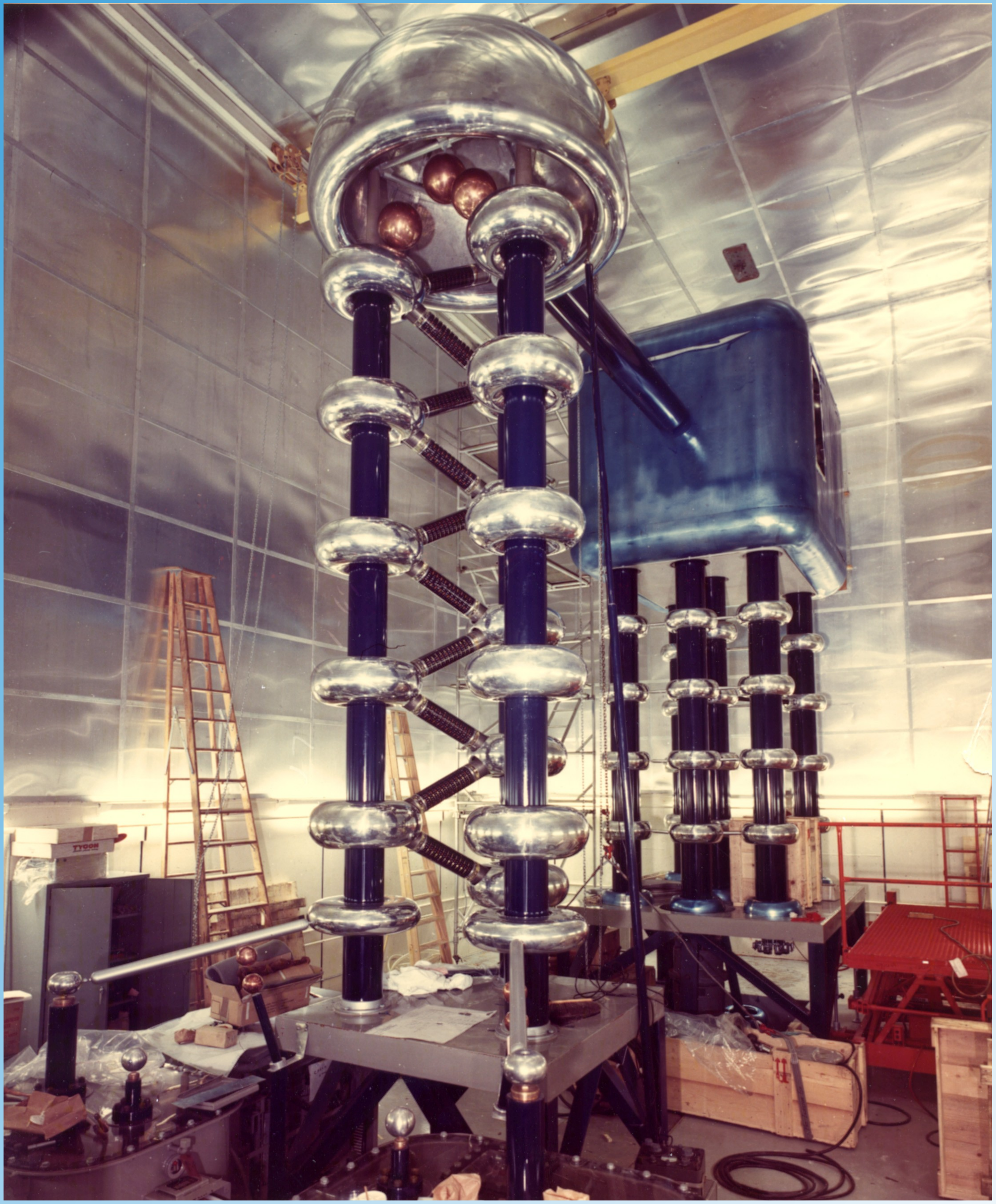
Rolf Wideröe



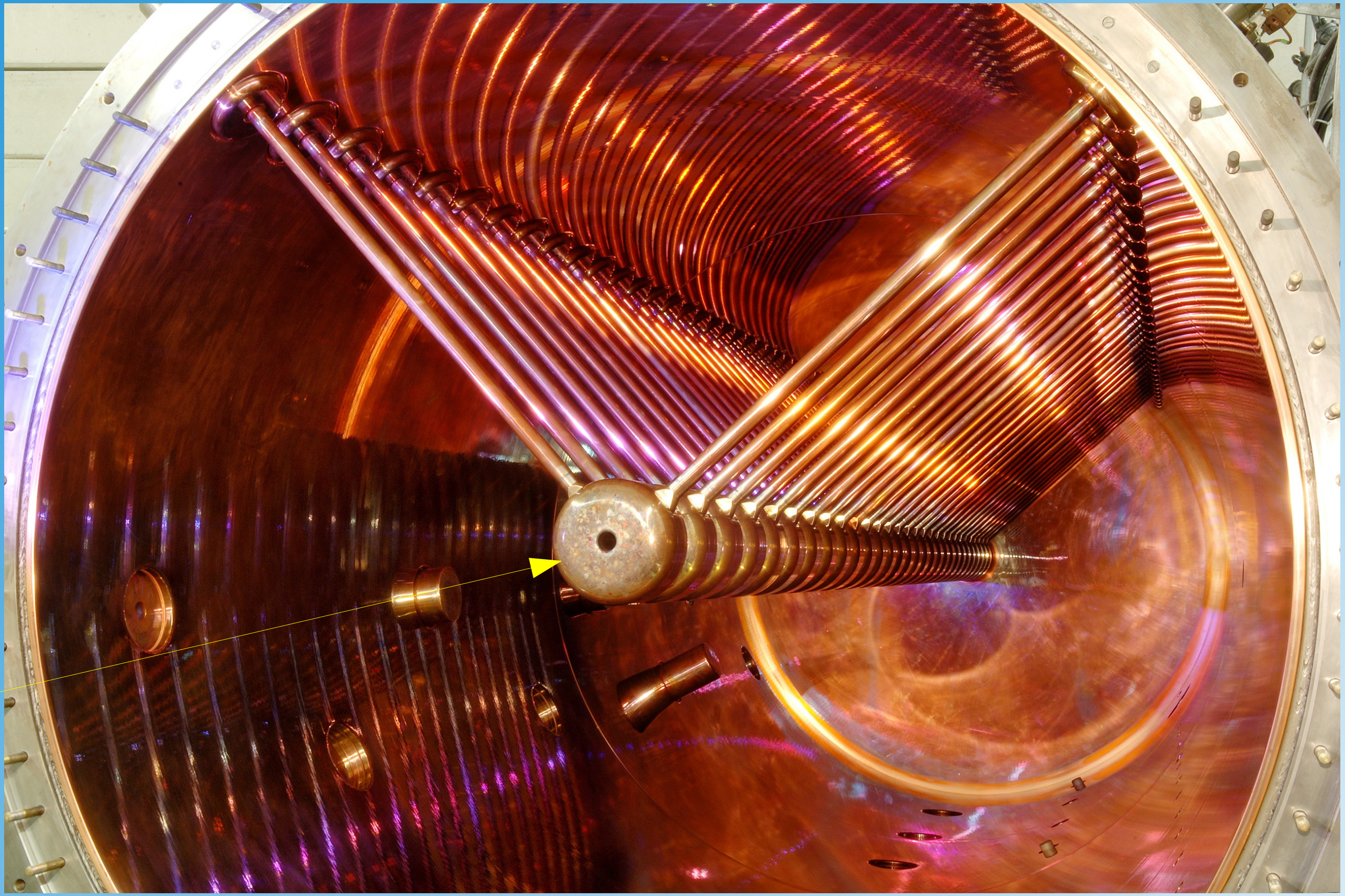
particle beam as “second winding” → later Betatron

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 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

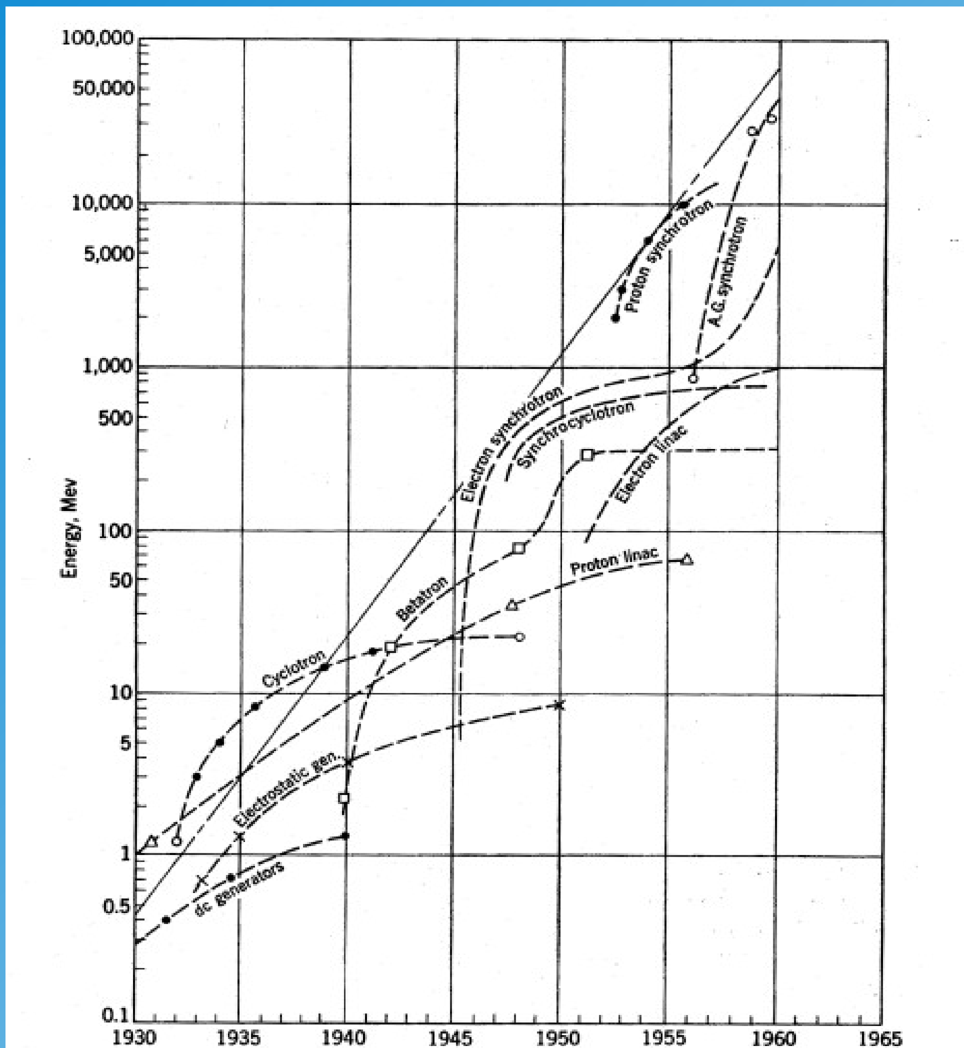
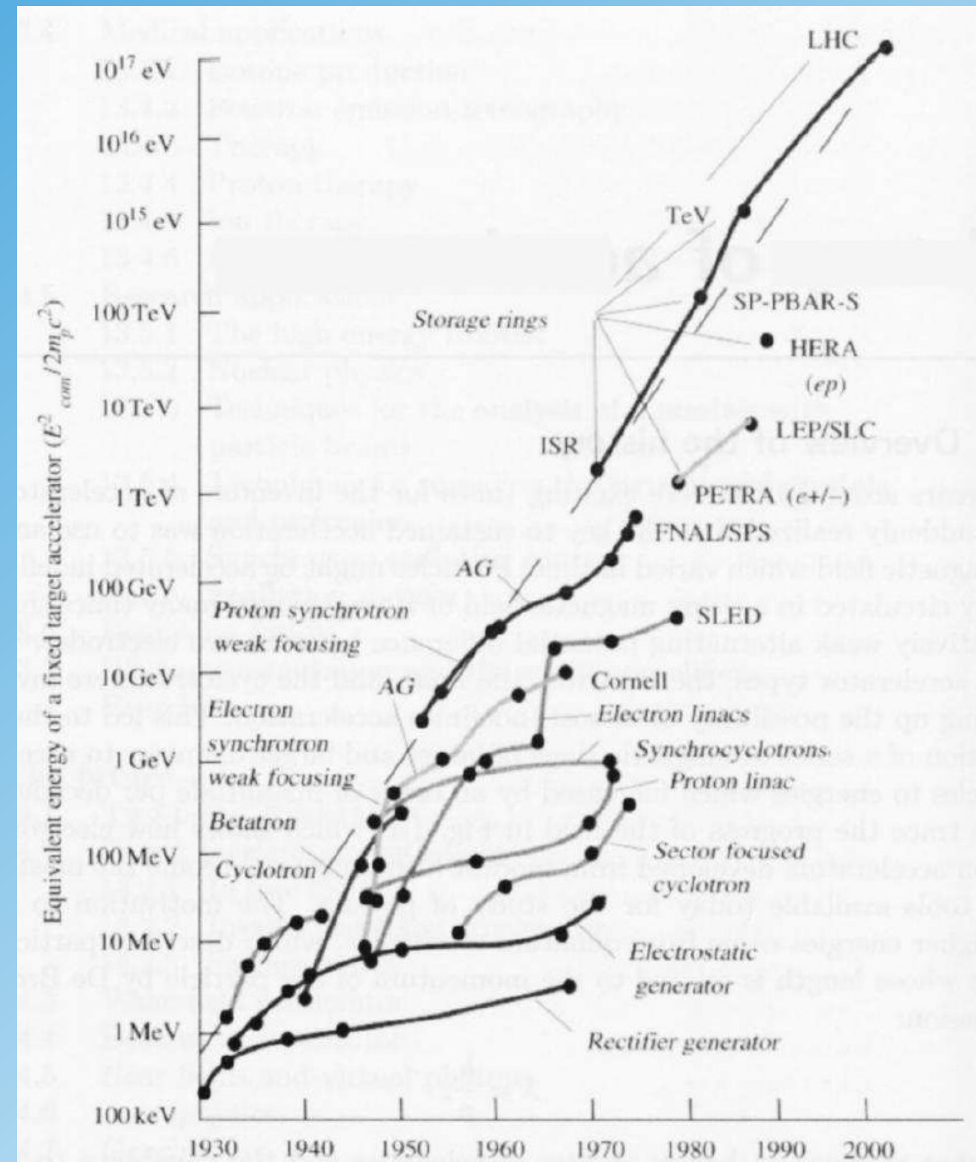


Fig. 1-1. Energies achieved by accelerators from 1930 to 1960. The linear envelope of the individual curves shows an average tenfold increase in energy every six years.

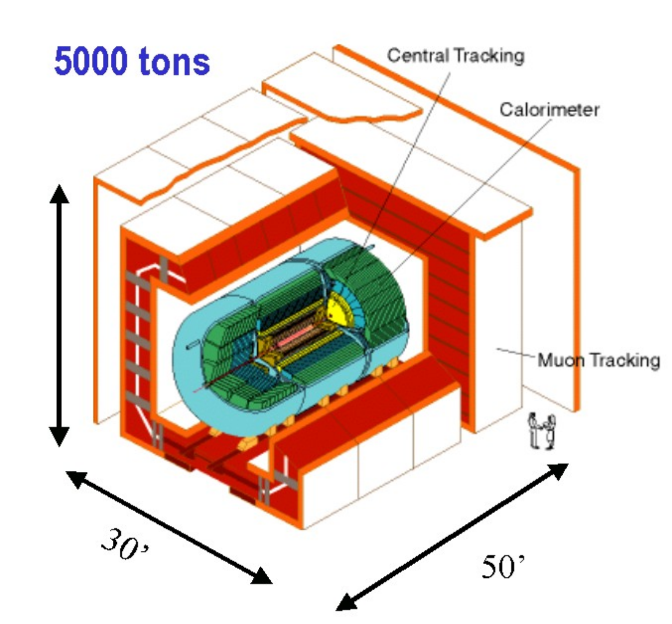


Supermikroskop HERA

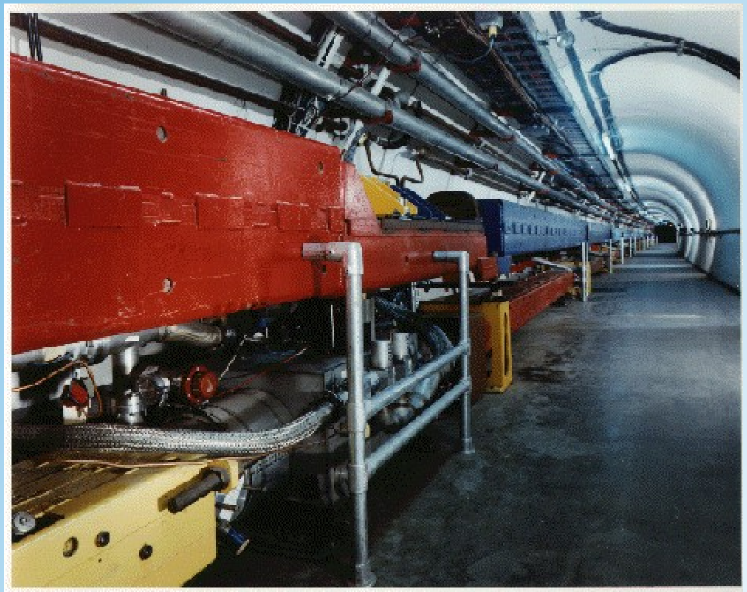
(1992-2007 Hamburg)

Tevatron (Fermilab, USA)

terminated September 2011



D0 Experiment



Proton-Antiproton Collider

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

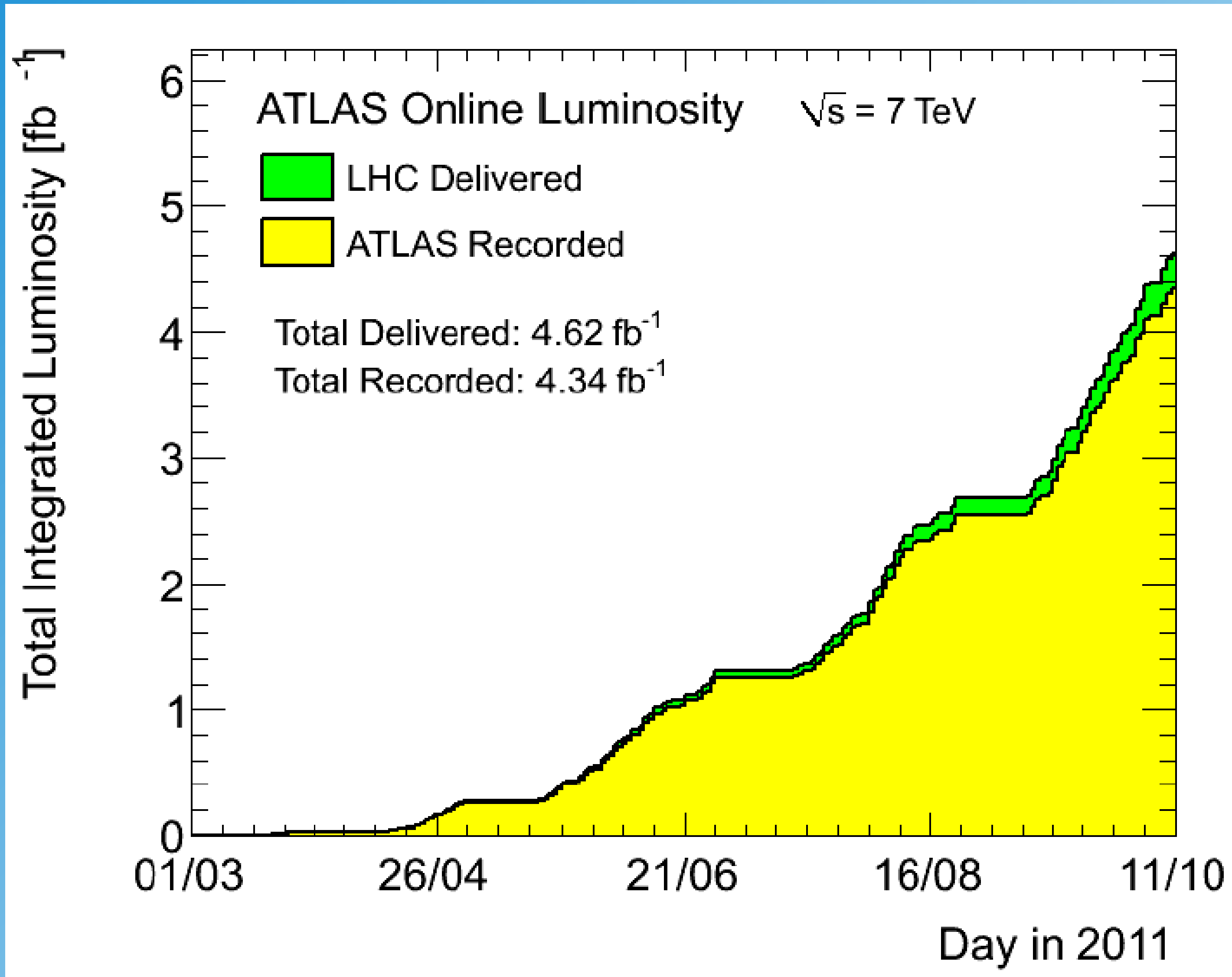
Large Hadron Collider (CERN)

LHC (pp) 7(14) TeV

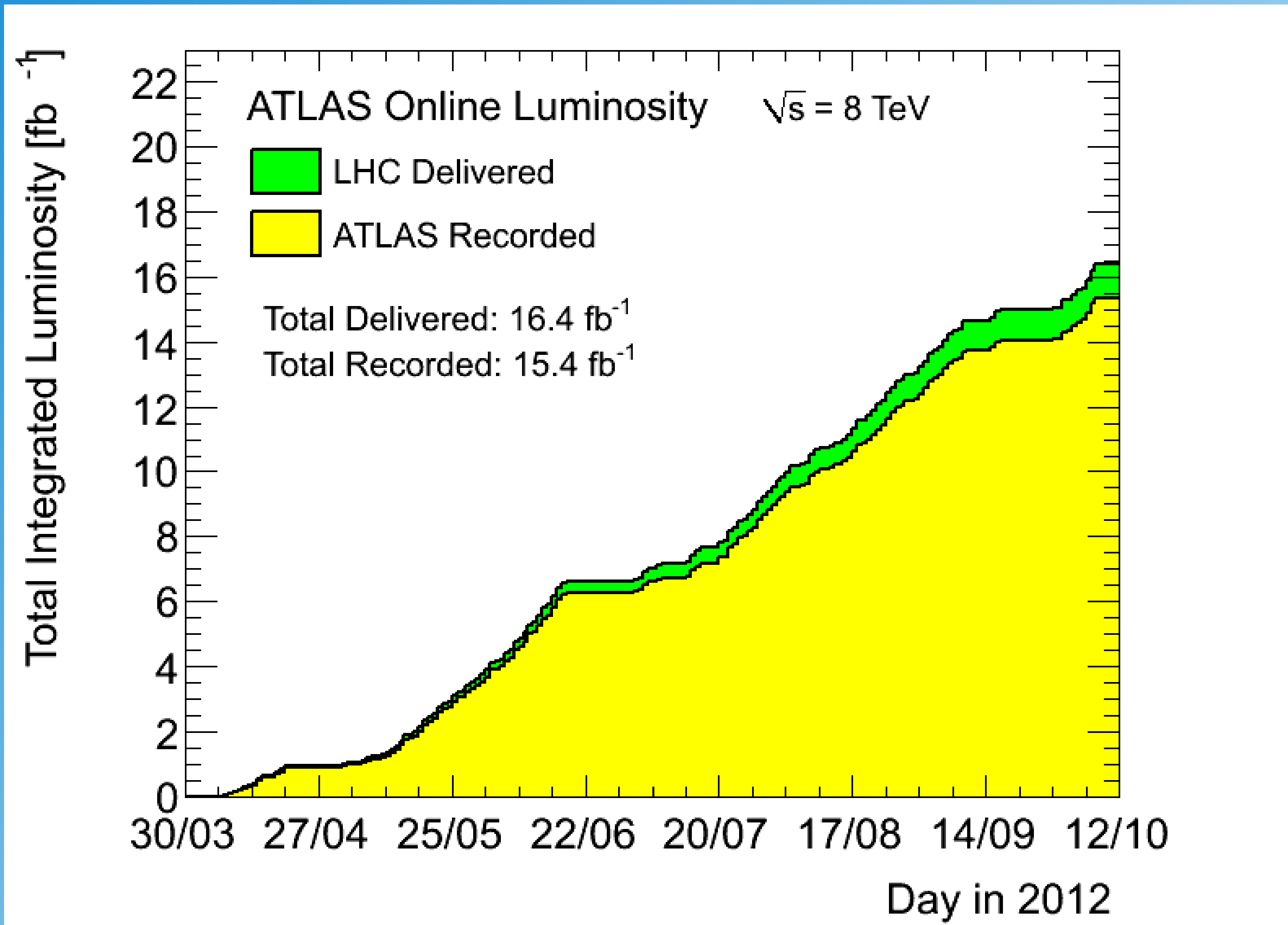
operation started 2009

26.7 km circumference!

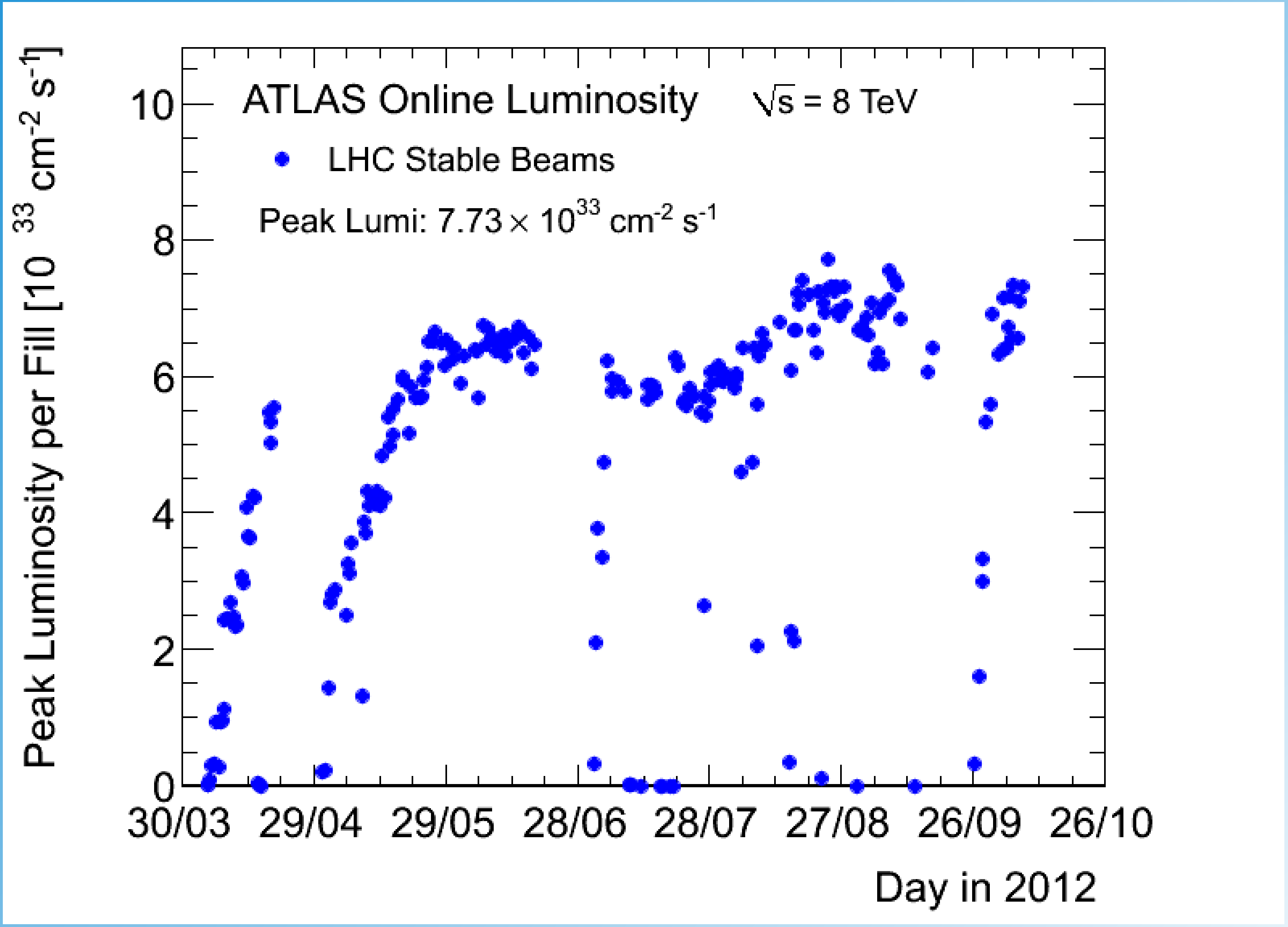
LHC Integrated Luminosity 2011



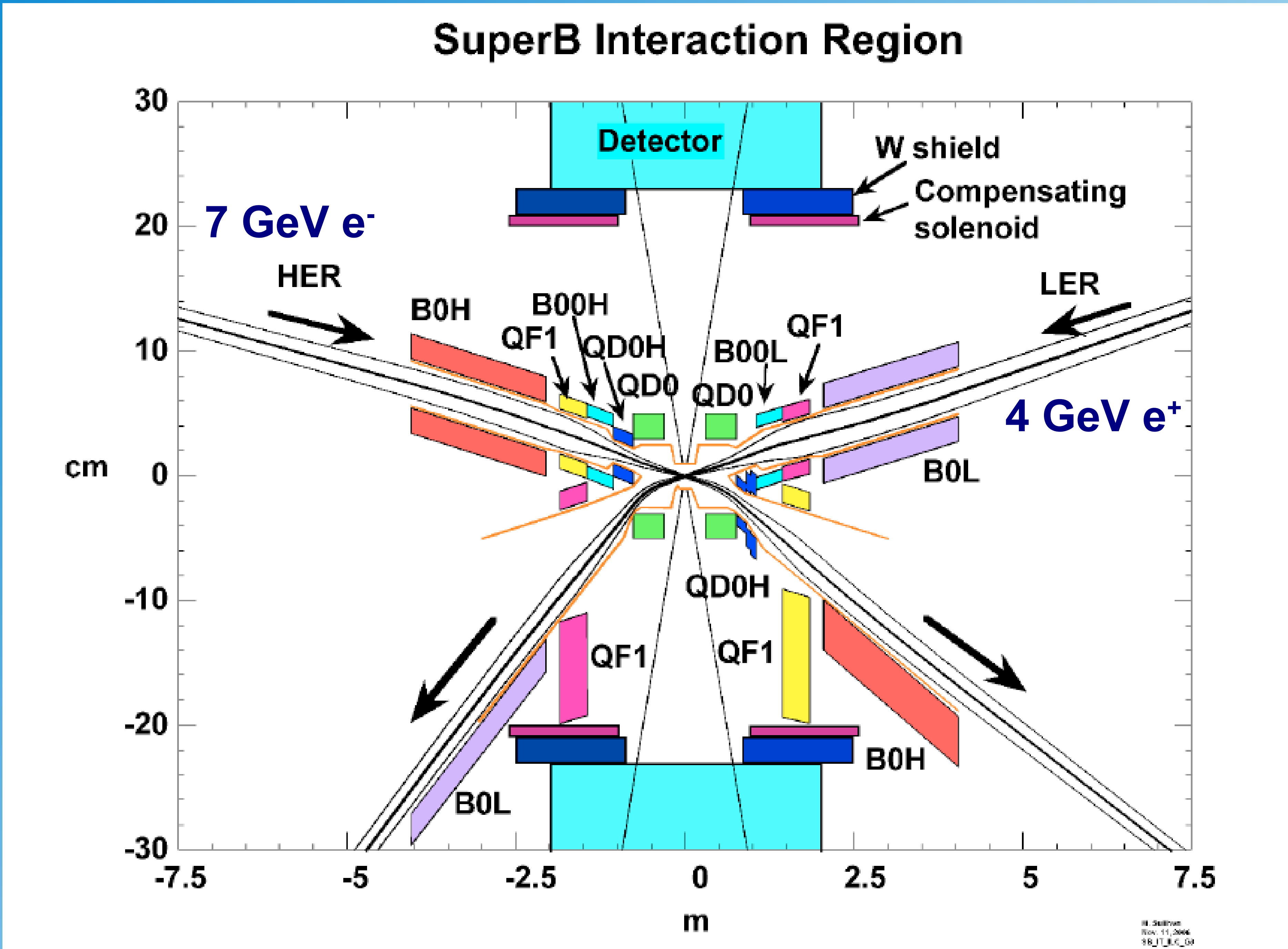
LHC Integrated Luminosity 2012



Peak Luminosity



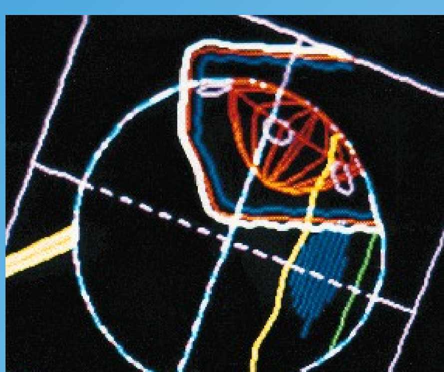
New Project in Italy



Accelerators in Medicine

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

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



→ ionisation loss in materials (tumors)