

Introduction to Accelerator Physics

Part 1

Pedro Castro / Accelerator Physics Group (MPY)
Hamburg, 1st February 2023



	length	lab	run	particles	energy	dipole field
PETRA	2.3 km	DESY	1978-1986	e-/e+	2x19 GeV	0.33 T
PETRA II	2.3 km	DESY	1987-2007	e- or e+ p	12 GeV 40 GeV	0.21 T 0.7 T
PETRA III	2.3 km	DESY	2009- ?	e-	6 GeV	0.10 T
HERA	6.3 km	DESY	1992-2007	e- or e+ p	27.5 GeV 920 GeV	0.274 T 5 T
LEP	27 km	CERN	1989-2000	e-/e+	2x105 GeV	0.135 T
LHC	27 km	CERN	2010- ?	p/p	2x7000 GeV	8.3 T
FLASH	0.3 km	DESY	2004- ?	e-	1.2 GeV	
XFEL	3 km	DESY	2016- ?	e-	17.5 GeV	
ILC	30 km	?	?	e-/e+	2x250 GeV	

DESY

CERN

Accelerator lectures framework in Summer Student Prog.

22nd Feb.: Plasma wakefield acceleration, J. Osterhoff

Today and on Friday: focus on present day and last 50 years accelerator technology

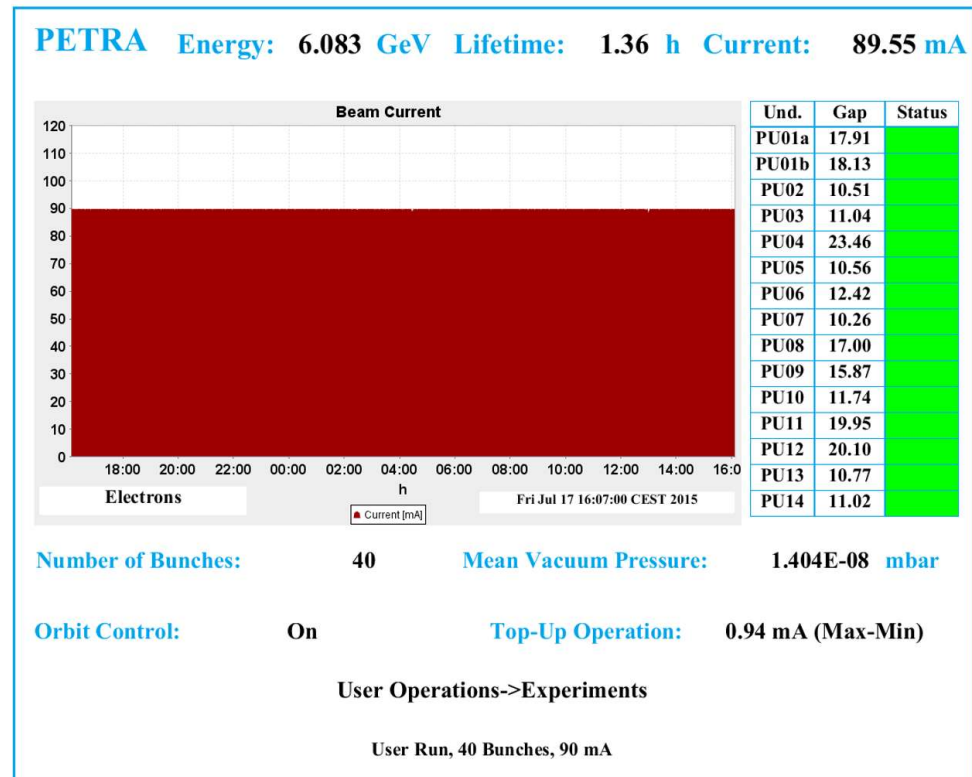
synchrotrons: machines for discoveries

Facility	Particle(s) discovered	Year of discovery	Nobel Price
SPEAR	charm quark	1974	1976
SPEAR	tau lepton	1975	1995
PETRA	gluon	1979	
S \bar{p} pS	W^{\pm}, Z bosons	1983	1984
SLC, LEP	$N_{\nu} = 3$		
Tevatron	top quark	1995	
LHC	Higgs	2012	2013

Scope of this lecture:

1. The four most important applications of accelerators } Part 1
2. Main accelerators at DESY }
3. Working with accelerators in the control room Part 2

The Main Accelerator Control Room



Scope of this lecture:

1. Synchrotrons: key components and their challenges to reach high energies:

- Dipole magnetic fields
 - Superconducting dipoles
 - Quadrupole magnets to focus beams
- Part 4, Friday
- Part 2

2. Synchrotrons and Linear Accelerators:

- Acceleration using radio-frequency electromagnetic fields
- Part 3, Friday

1. Overview of charged particle accelerators

A historical overview of particle accelerators?

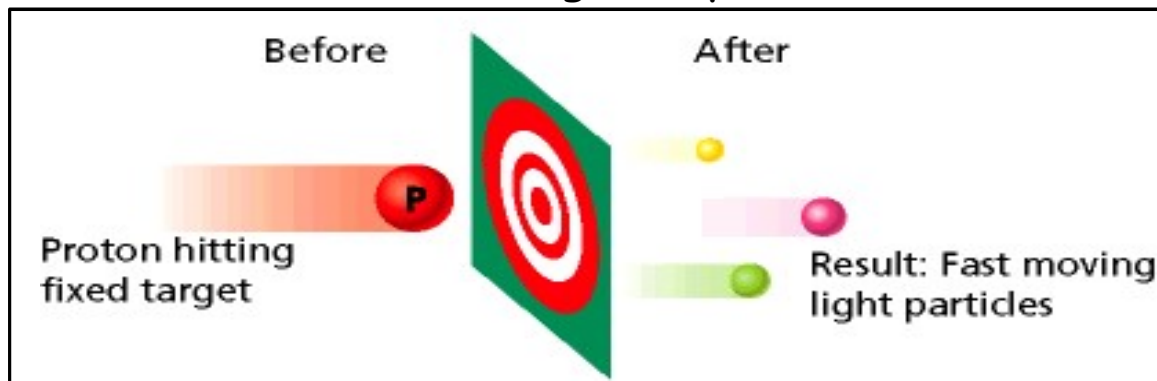
CERN summer student lecture: Particle Accelerators, M. Schaumann

<https://indico.cern.ch/event/1132543>

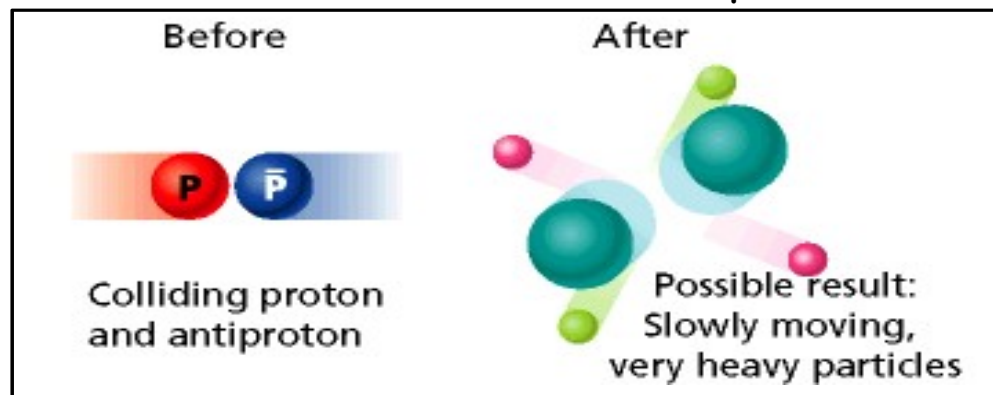
Applications of Accelerators (1)

Particle colliders for High Energy Physics (HEP) experiments

Fixed target experiments



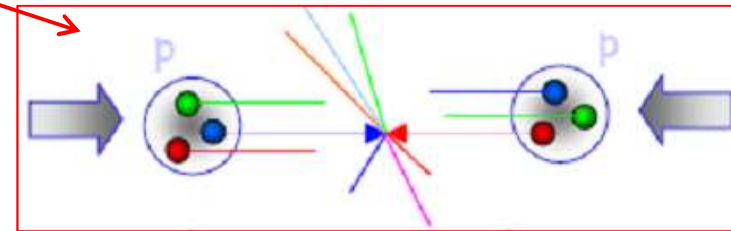
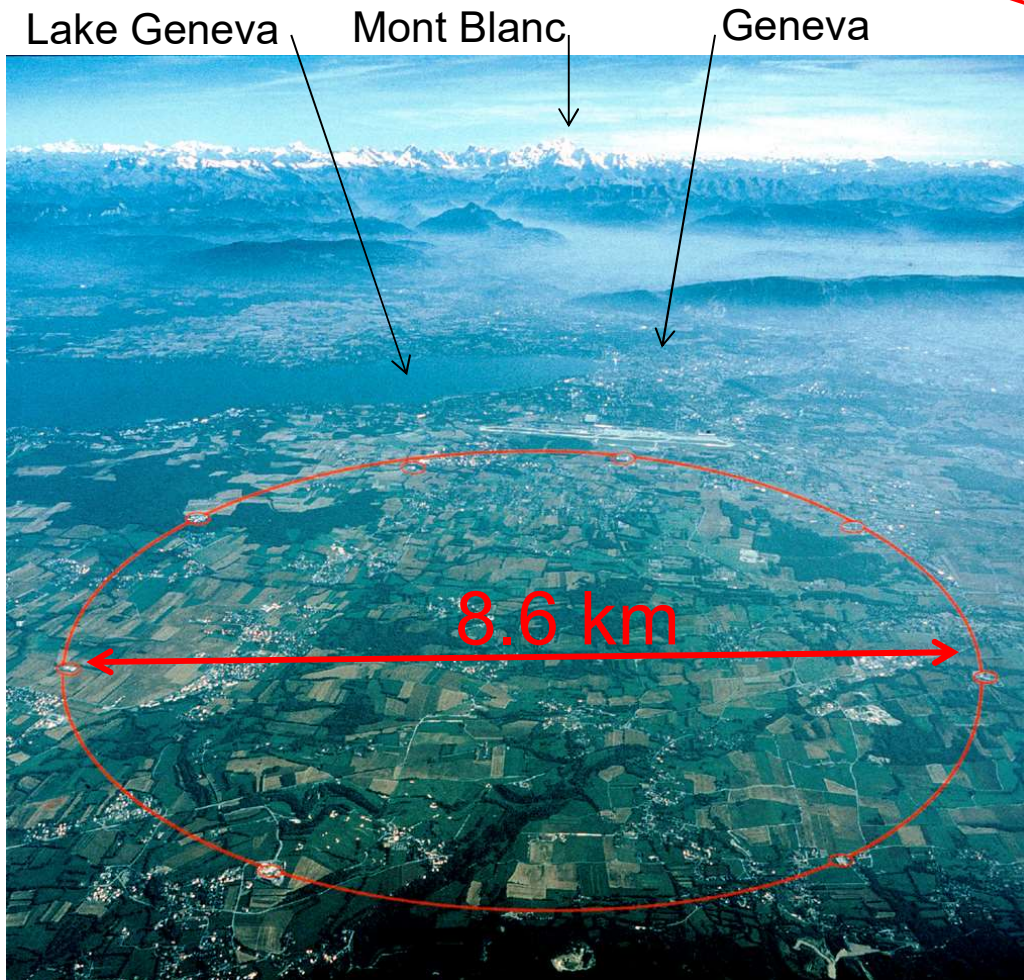
Two beams collider experiments



Applications of Accelerators (1)

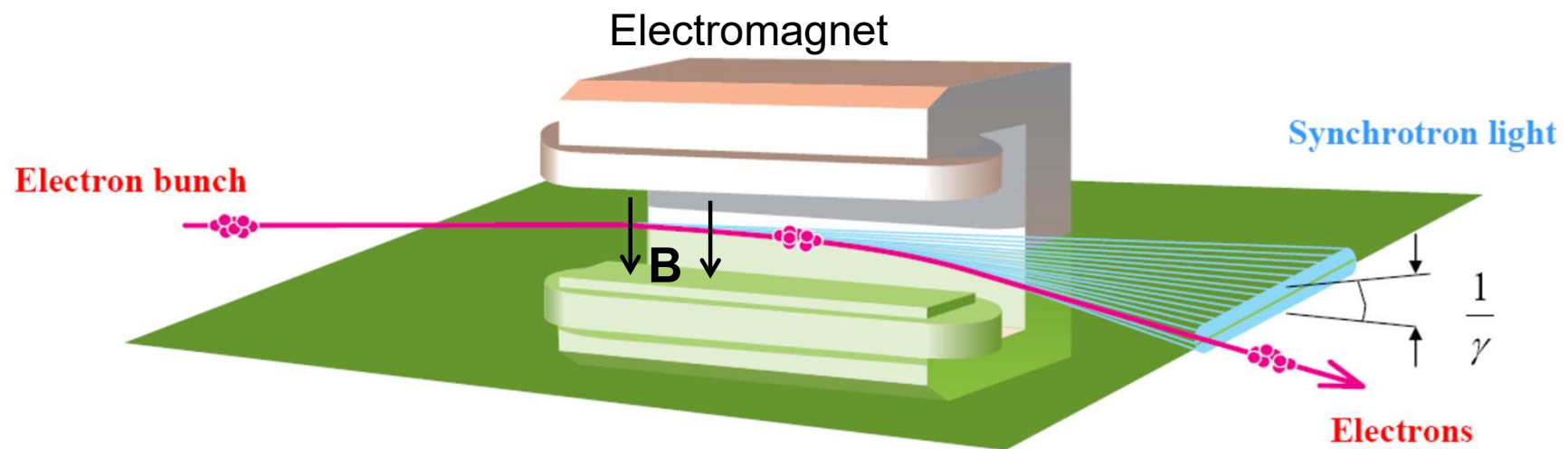
Particle colliders for High Energy Physics experiments

Example: the Large Hadron Collider (LHC) at CERN



Applications of Accelerators (2)

Light sources for biology, physics, chemistry... experiments



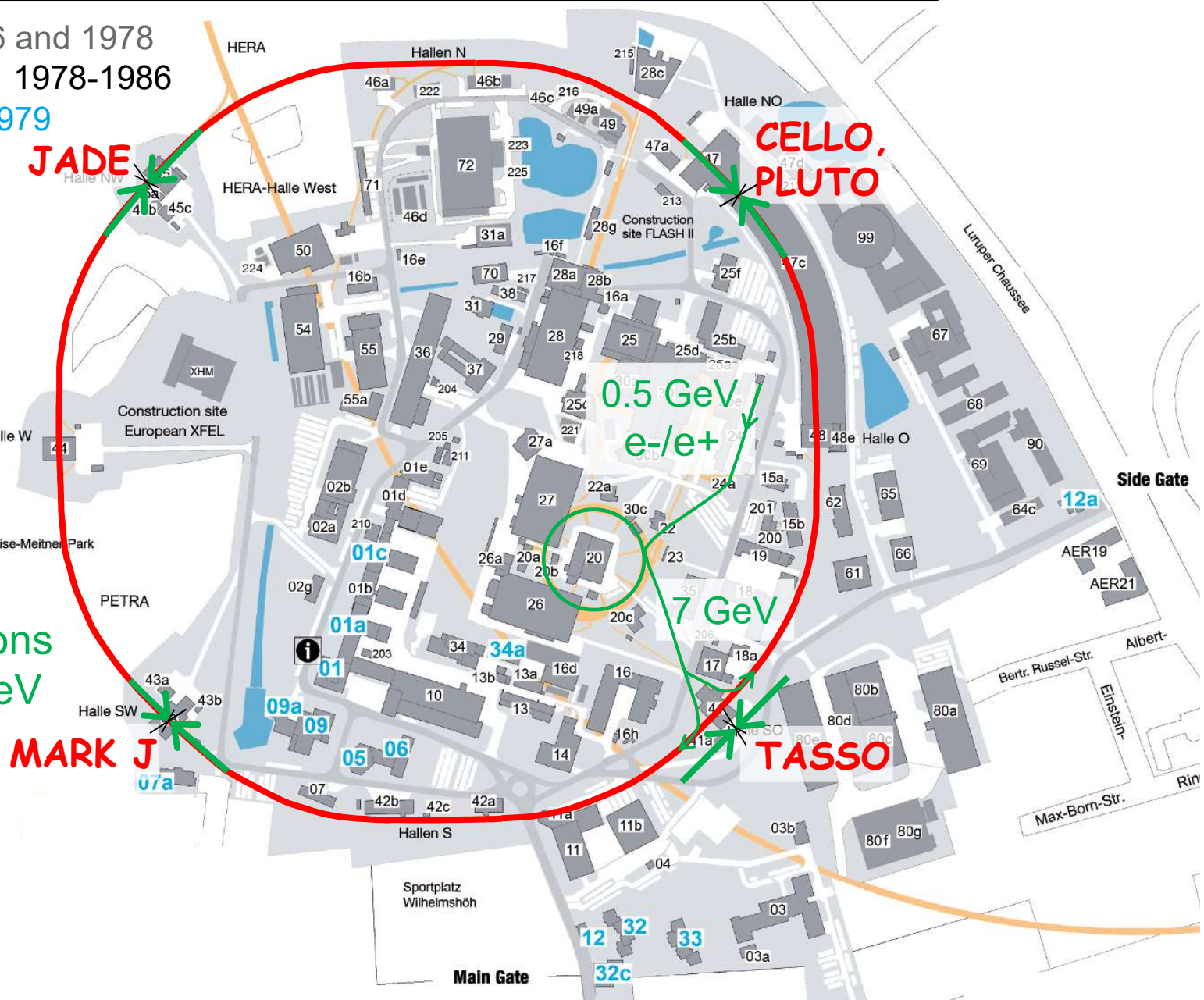
- structural analysis of crystalline materials
- X-ray crystallography (of proteins)
- X-ray microscopy
- X-ray absorption (or emission) spectroscopy
- ...

Example: Positron-Elektron-Tandem-Ring-Anlage (PETRA) 'positron-electron tandem ring accelerator' at DESY

built between 1976 and 1978
HEP experiments: 1978-1986
gluon discovery: 1979

2.3 km long

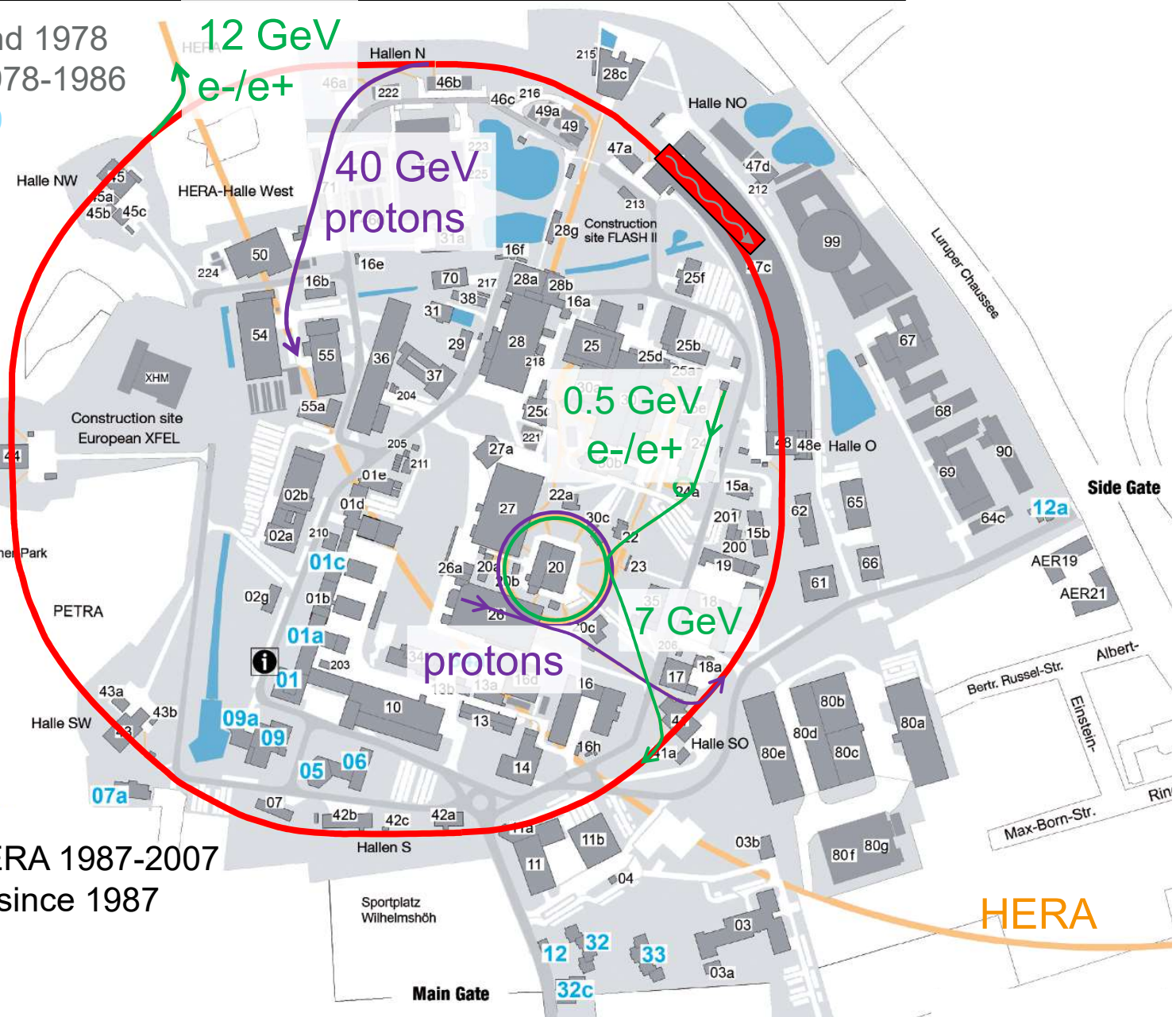
e^+e^- collisions
at 2×19 GeV



Example: Positron-Elektron-Tandem-Ring-Anlage (PETRA) 'positron-electron tandem ring accelerator' at DESY

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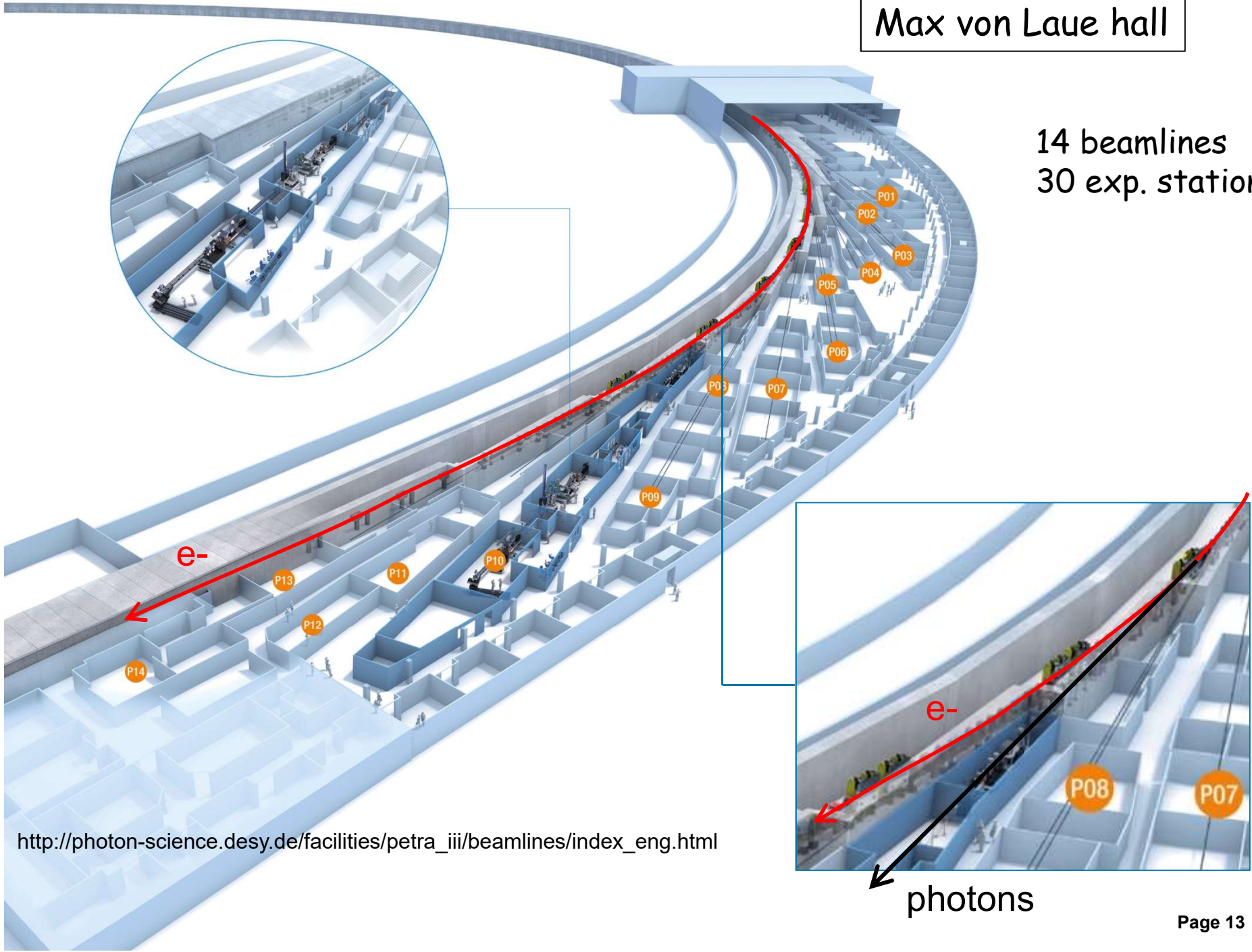
2.3 km long



pre-accelerator for HERA 1987-2007
synchrotron radiation since 1987

Max von Laue hall

14 beamlines
30 exp. stations

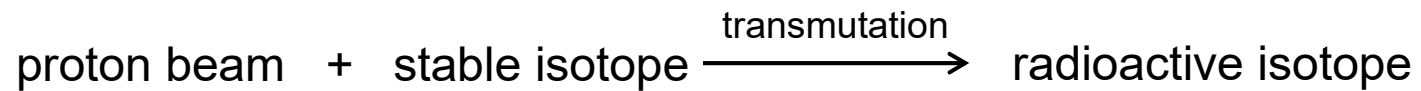


http://photon-science.desy.de/facilities/petra_iii/beamlines/index_eng.html

Applications of Accelerators (3)

Accelerators in medicine

For radioisotope production



For radiotherapy and radiosurgery:

- x-rays and gamma-rays
- ions (from protons to atoms with atomic number up to 18, Argon)
- neutrons

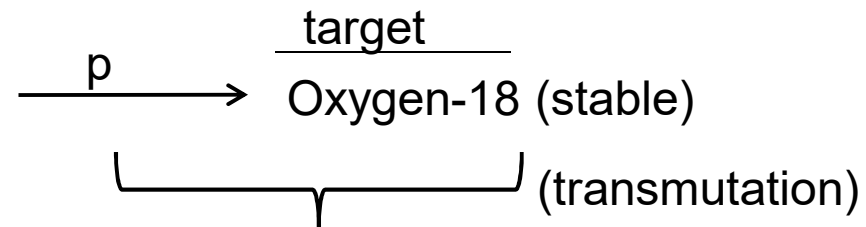
Applications of Accelerators (3)

Accelerators in medicine

For radioisotope production

For example:

18 MeV proton accelerator



Fluorine-18 (half-life time = 110 min.)

97% of decays

Oxygen-18 + positron

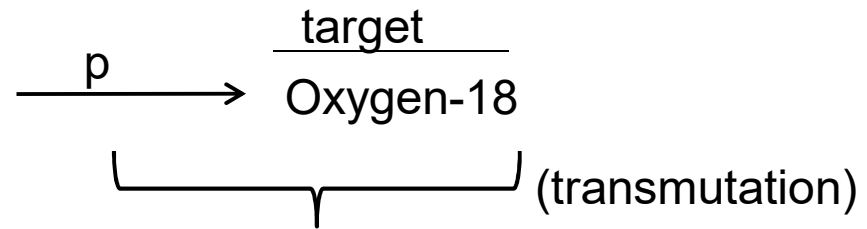
Applications of Accelerators (3)

Accelerators in medicine

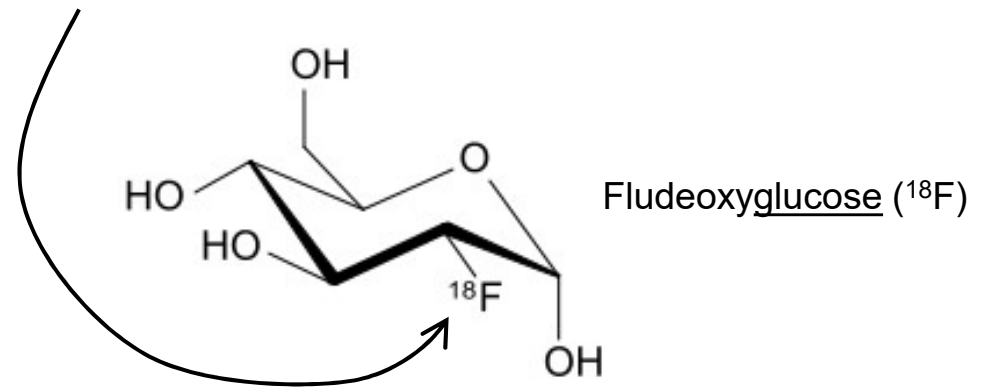
For radioisotope production

For example:

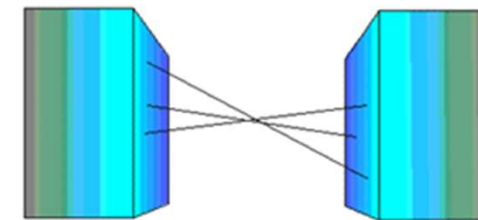
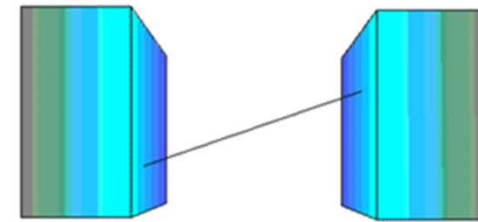
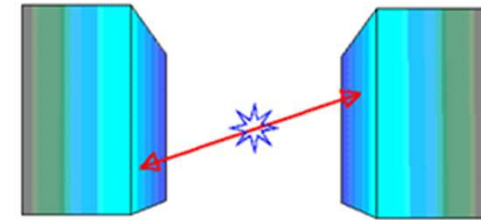
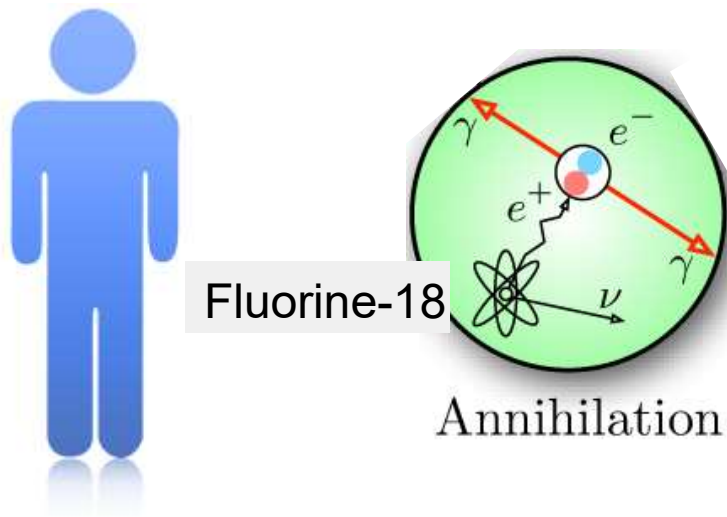
18 MeV proton accelerator



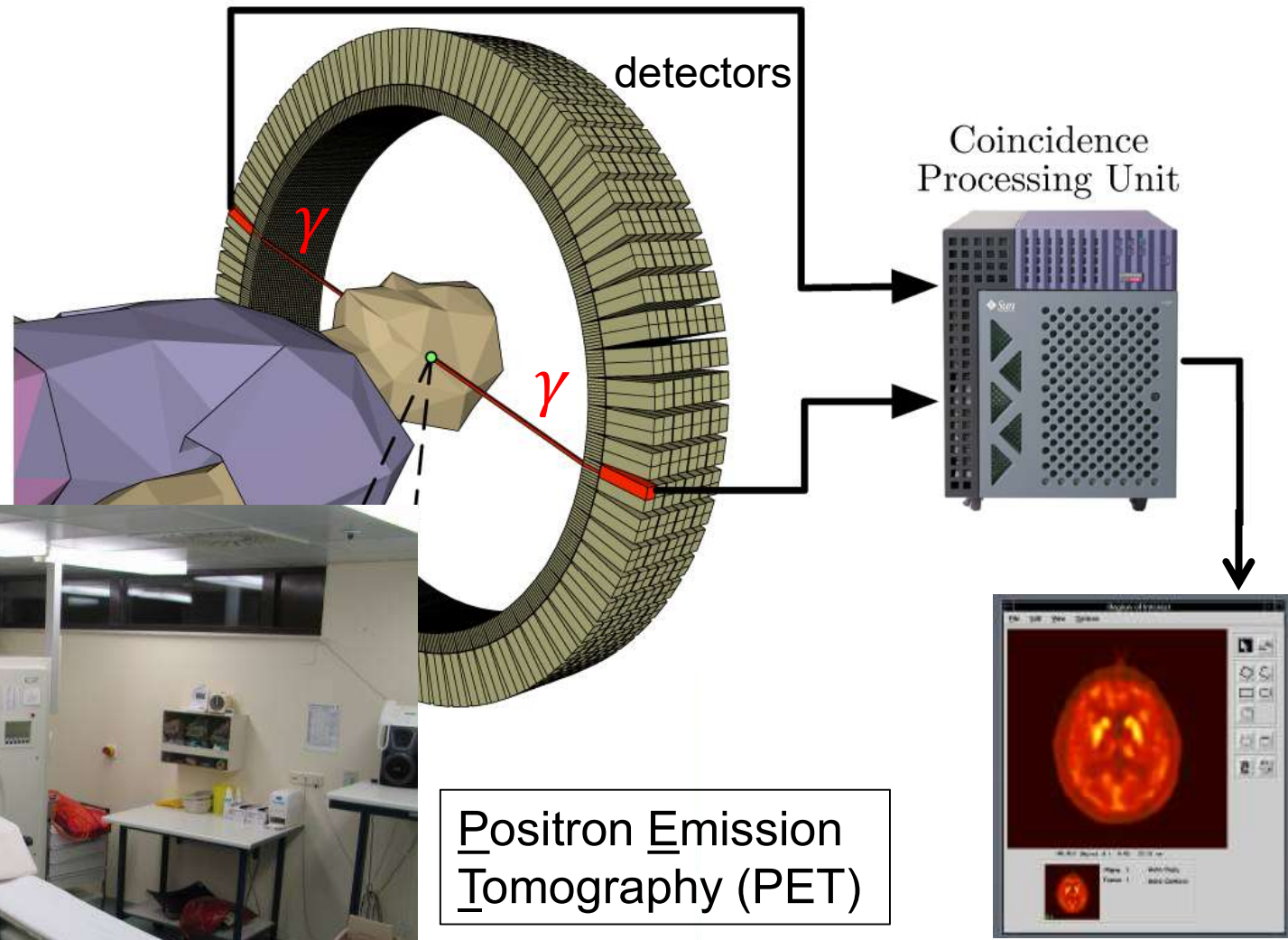
Fluorine-18 (half-life time = 110 min.)



Applications of Accelerators (3)



Applications of Accelerators (3)



Positron Emission
Tomography (PET)

Applications of Accelerators (4)

For industrial applications:

Application	
Ion implantation	~ 9500
Electron cutting and welding	~ 4500
Electron beam and x-ray irradiators	~ 2000
Ion beam analysis (including AMS)	~ 200
Radioisotope production (including PET)	~ 900
Nondestructive testing (including security)	~ 650
Neutron generators (including sealed tubes)	~ 1000

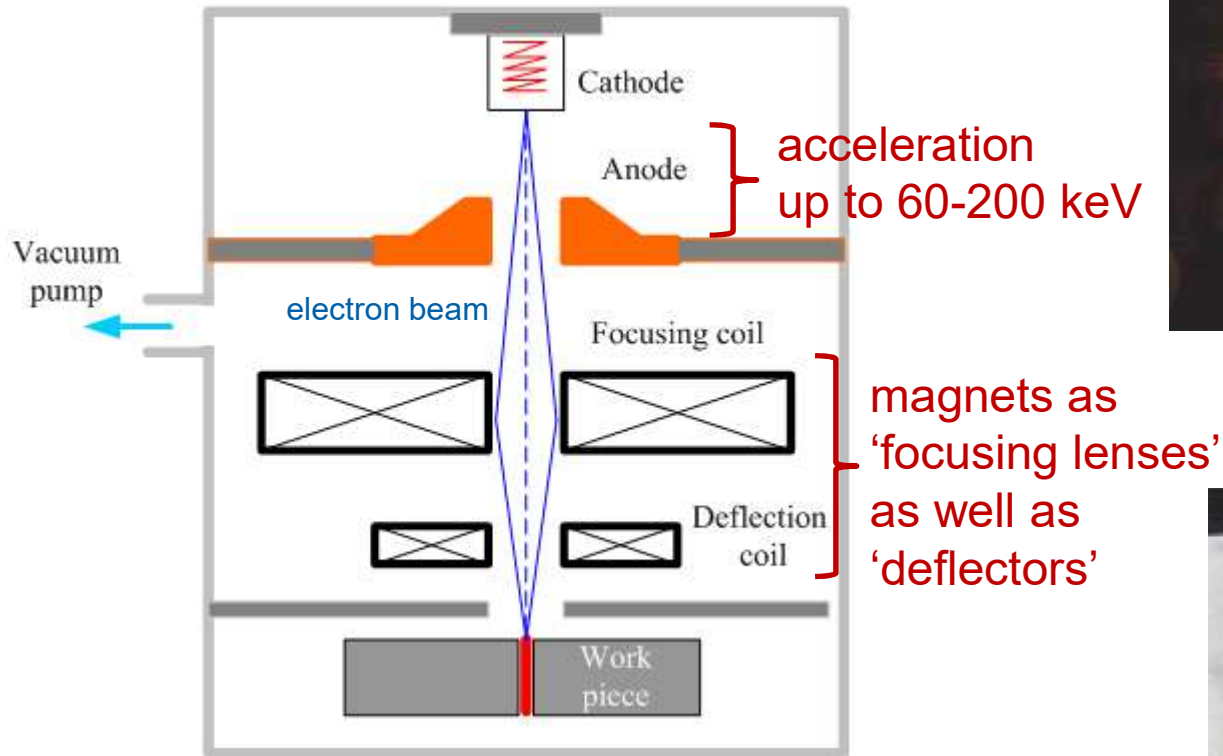
approx. numbers from 2007 (worldwide)

with energies up to 15 MeV

Applications of Accelerators (4)

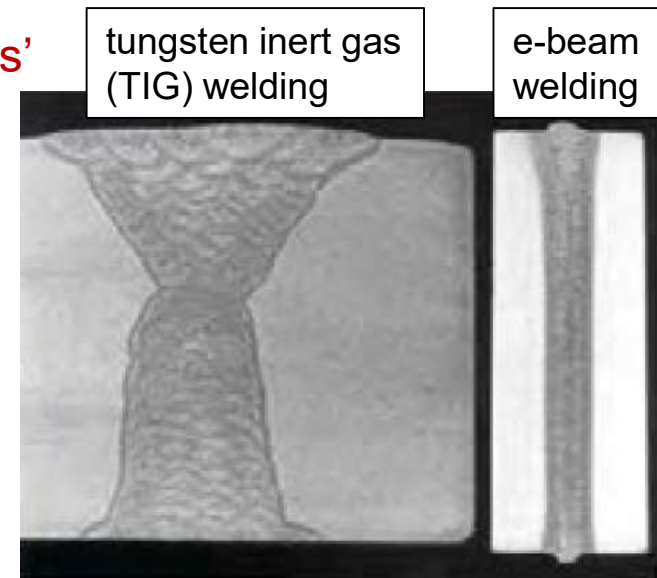
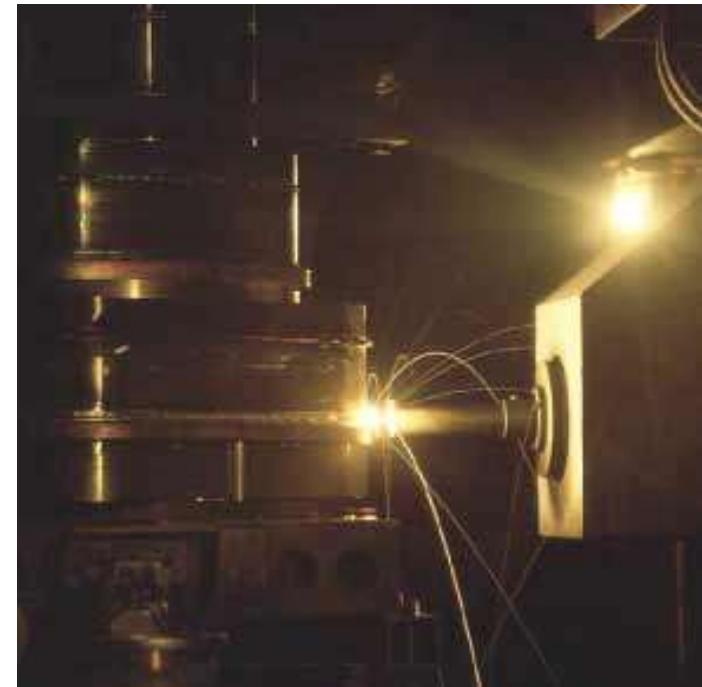
For industrial applications:

an example: electron beam welding



up to 15 cm

'deep welding effect'



Worldwide ...

- > About 120 accelerators for research in "nuclear and particle physics"
- > About 70 electron storage rings and electron linear accelerators used as light sources (so-called 'synchrotron radiation sources')

-
- > More than 7,000 accelerators for medicine
radiotherapy (>7,500), radioisotope production (200)
 - > More than 18,000 industrial accelerators
ion implantation (>9,000) , electron cutting and welding (>4,000) ...

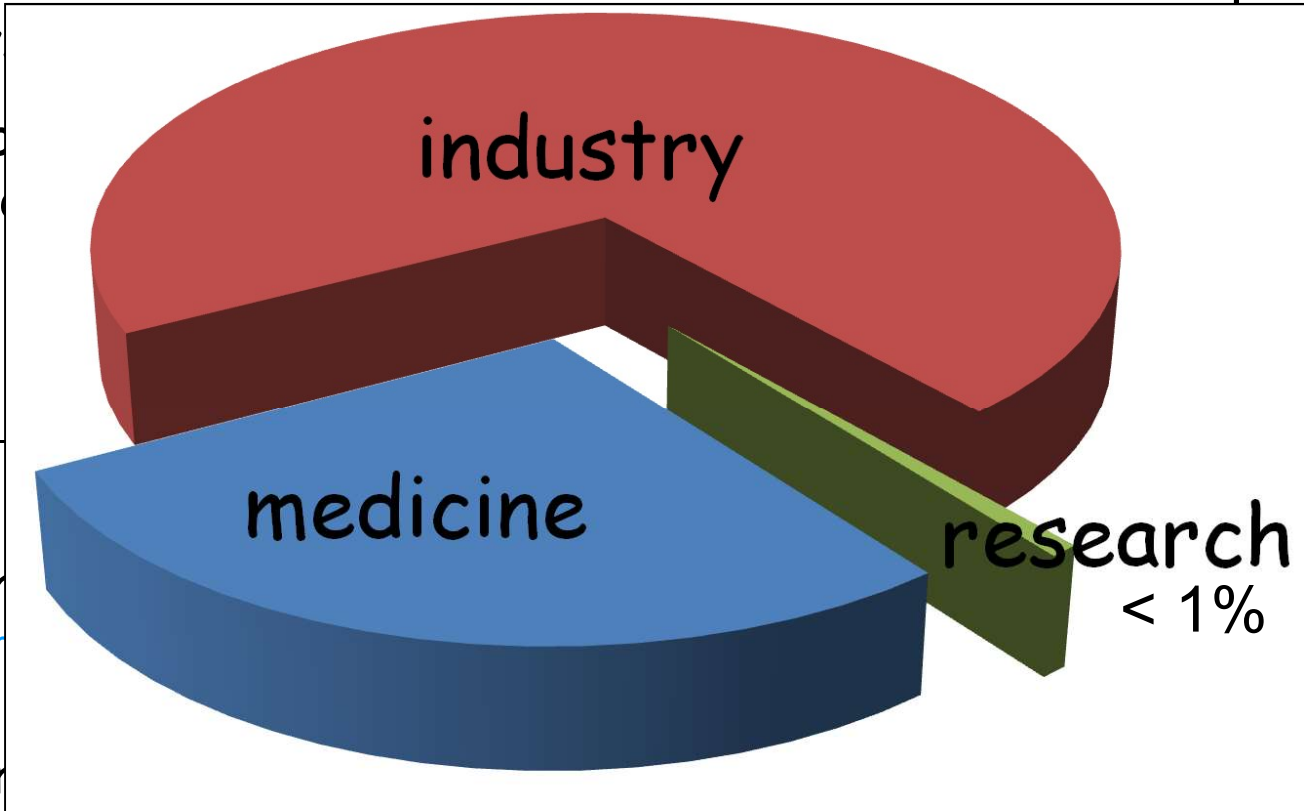
Worldwide ...

> About 120 accelerators for research in "nuclear and particle physics"

> About 1000 accelerators for other uses

> More than 1000 accelerators for medicine

> More than 1000 accelerators for industry



accelerators for other uses ('sources')

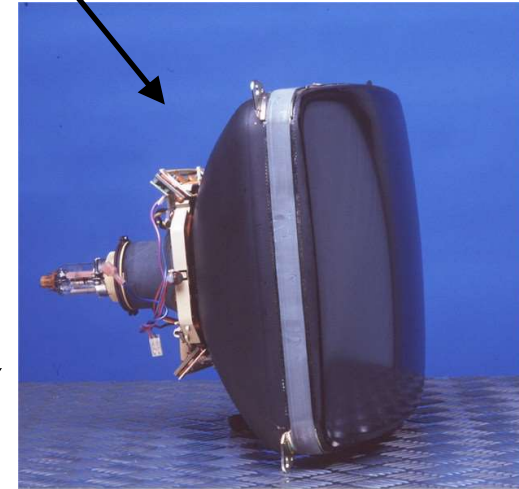
ion implantation (>9,000) , electron cutting and welding (>4,000) ...

Applications of Accelerators (5)

Many millions of television sets, oscilloscopes using CRTs (Cathode Ray Tube)



TV

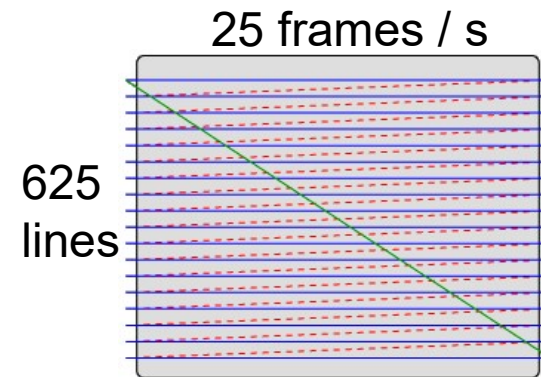
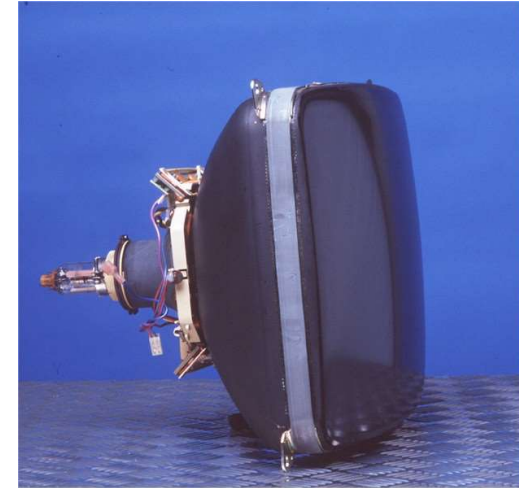
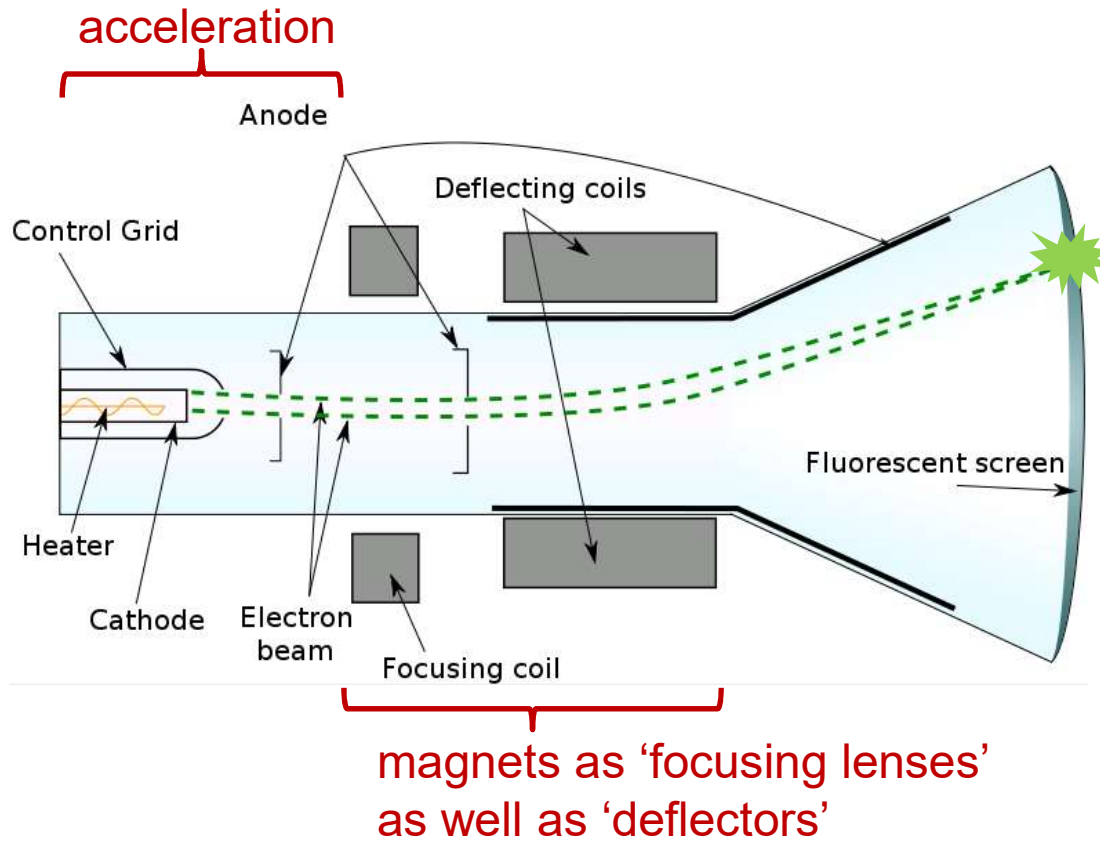


oscilloscope



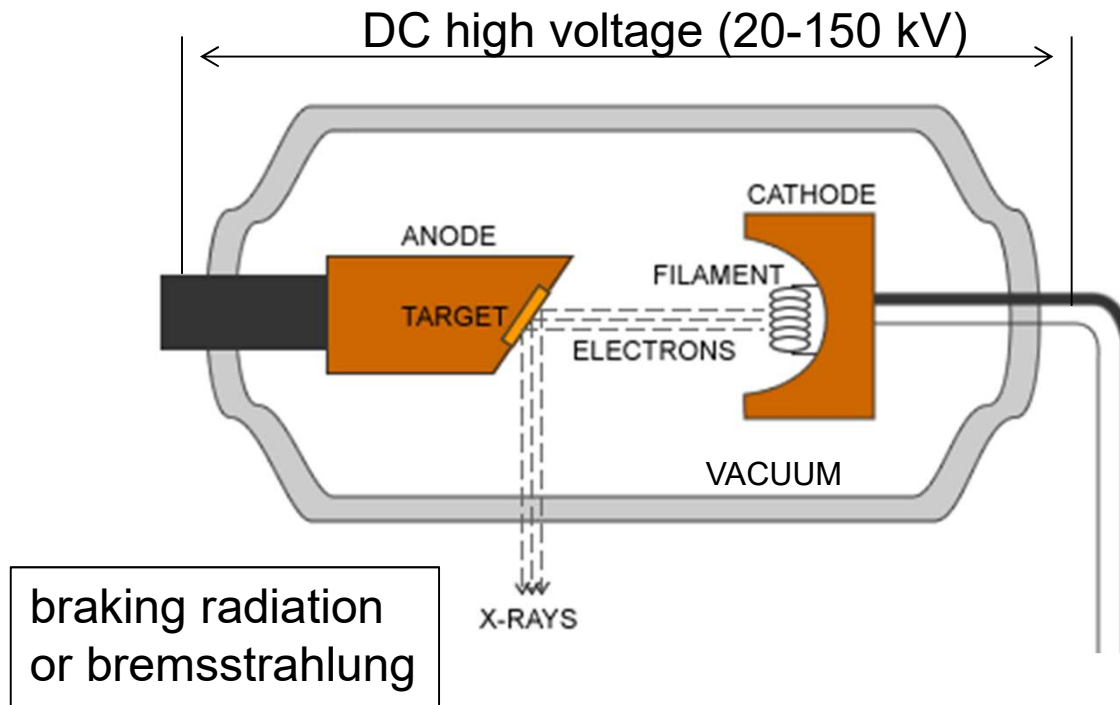
Applications of Accelerators (5)

Many millions of television sets, oscilloscopes using CRTs (Cathode Ray Tube)

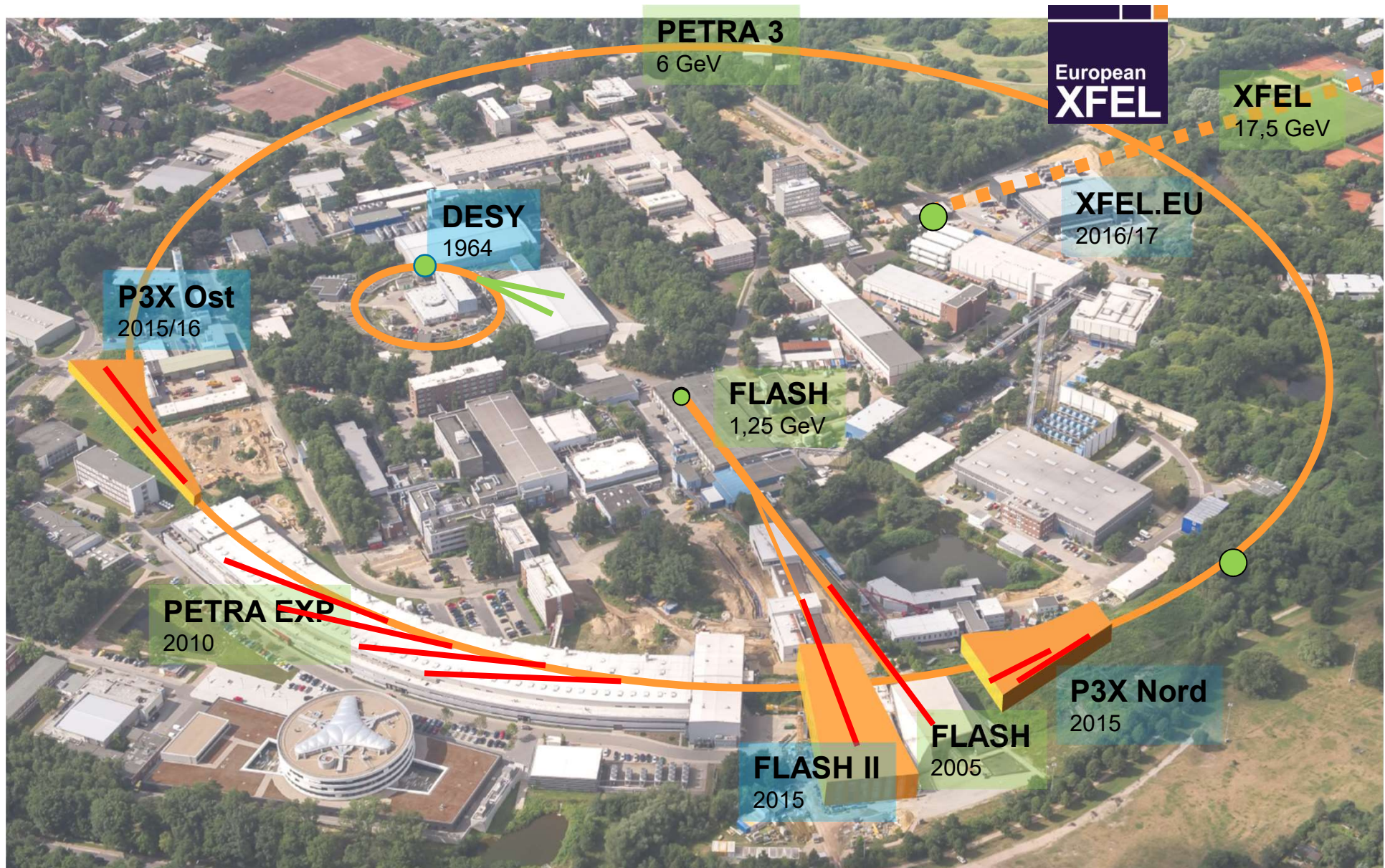


Applications of Accelerators (6)

X-ray tubes



Main accelerators at DESY

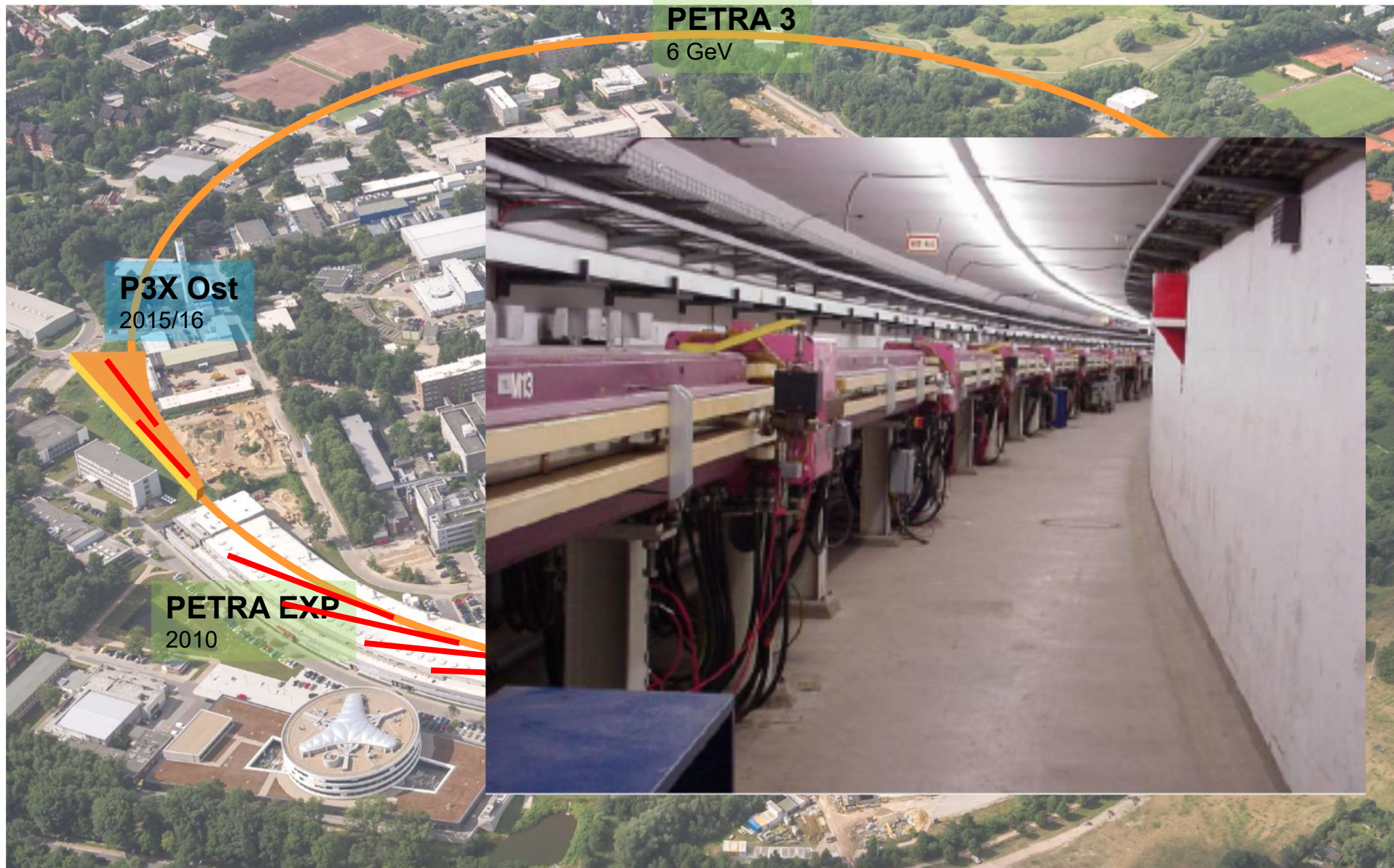


DESY (Deutsches Elektronen Synchrotron) German electron synchrotron

1964, 7.4 GeV



Positron-Elektron-Tandem-Ring-Anlage (PETRA) 'positron-electron tandem ring accelerator'



PETRA 3
6 GeV

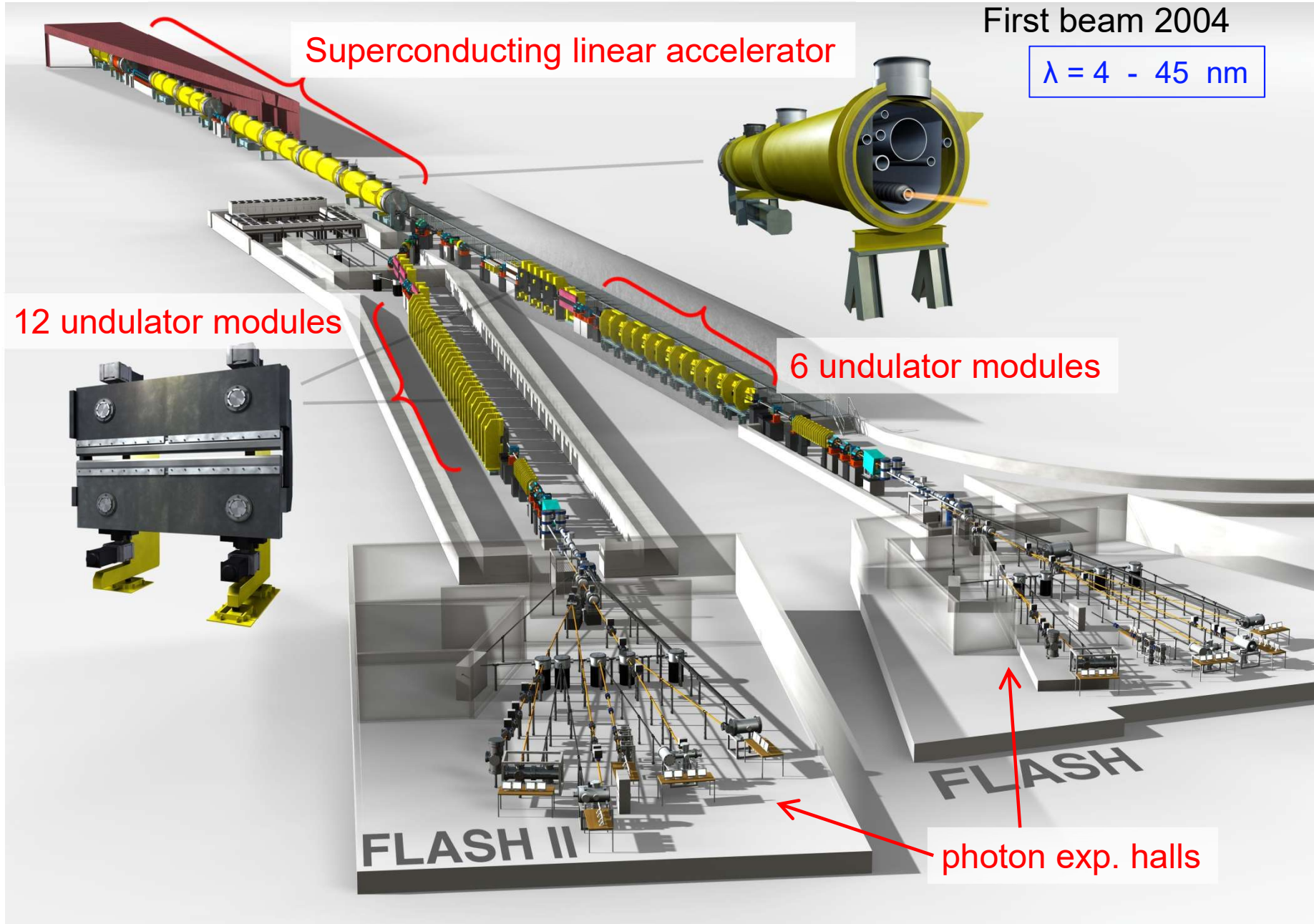
P3X Ost
2015/16

PETRA EXP
2010

Free-electron LASer in Hamburg (FLASH)

300 m long, 1.2 GeV
First beam 2004

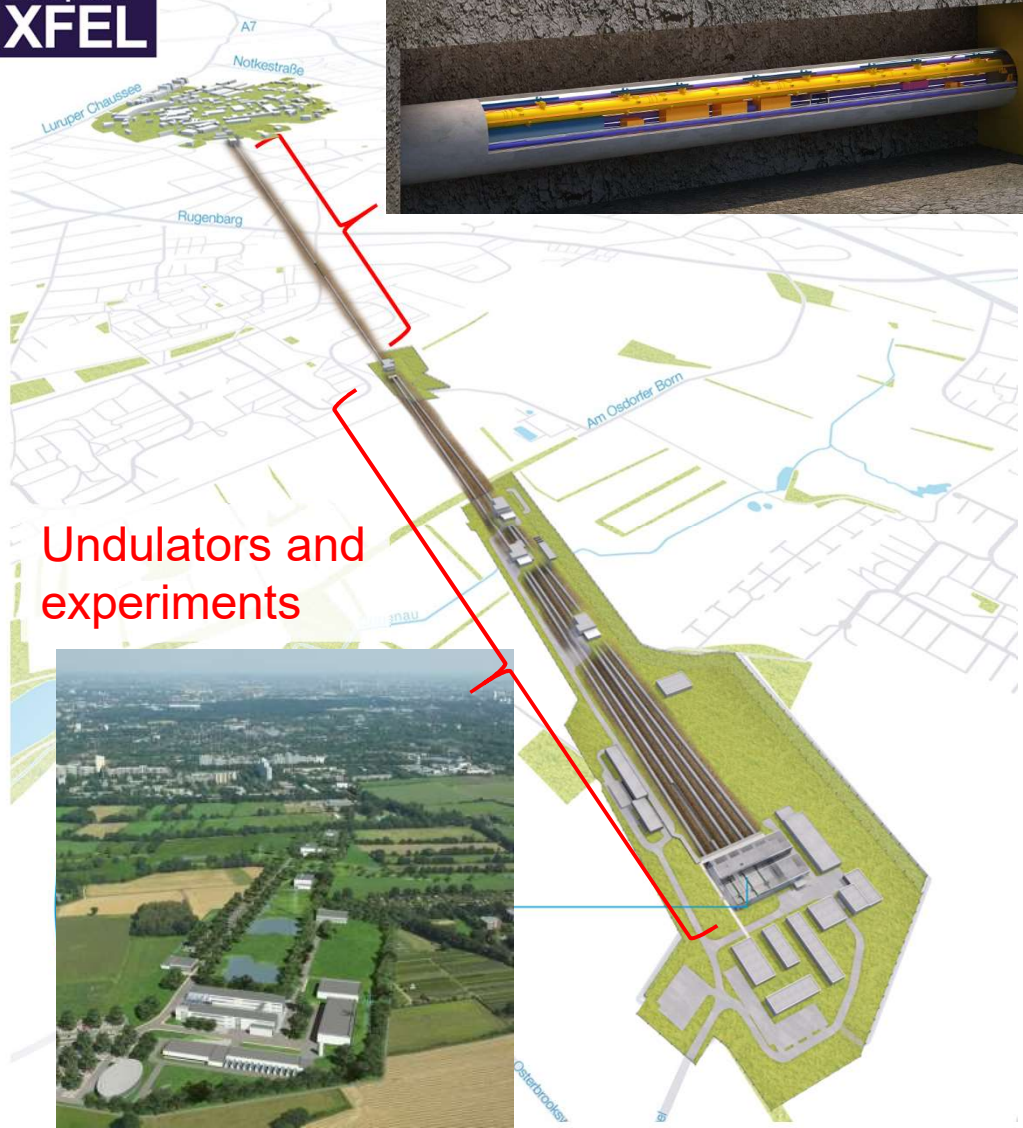
$$\lambda = 4 - 45 \text{ nm}$$



European X-ray Free-Electron Laser (XFEL)



2 km superconducting linear accelerator



Undulators and experiments



DESY

European XFEL

3 km long 17,5 GeV

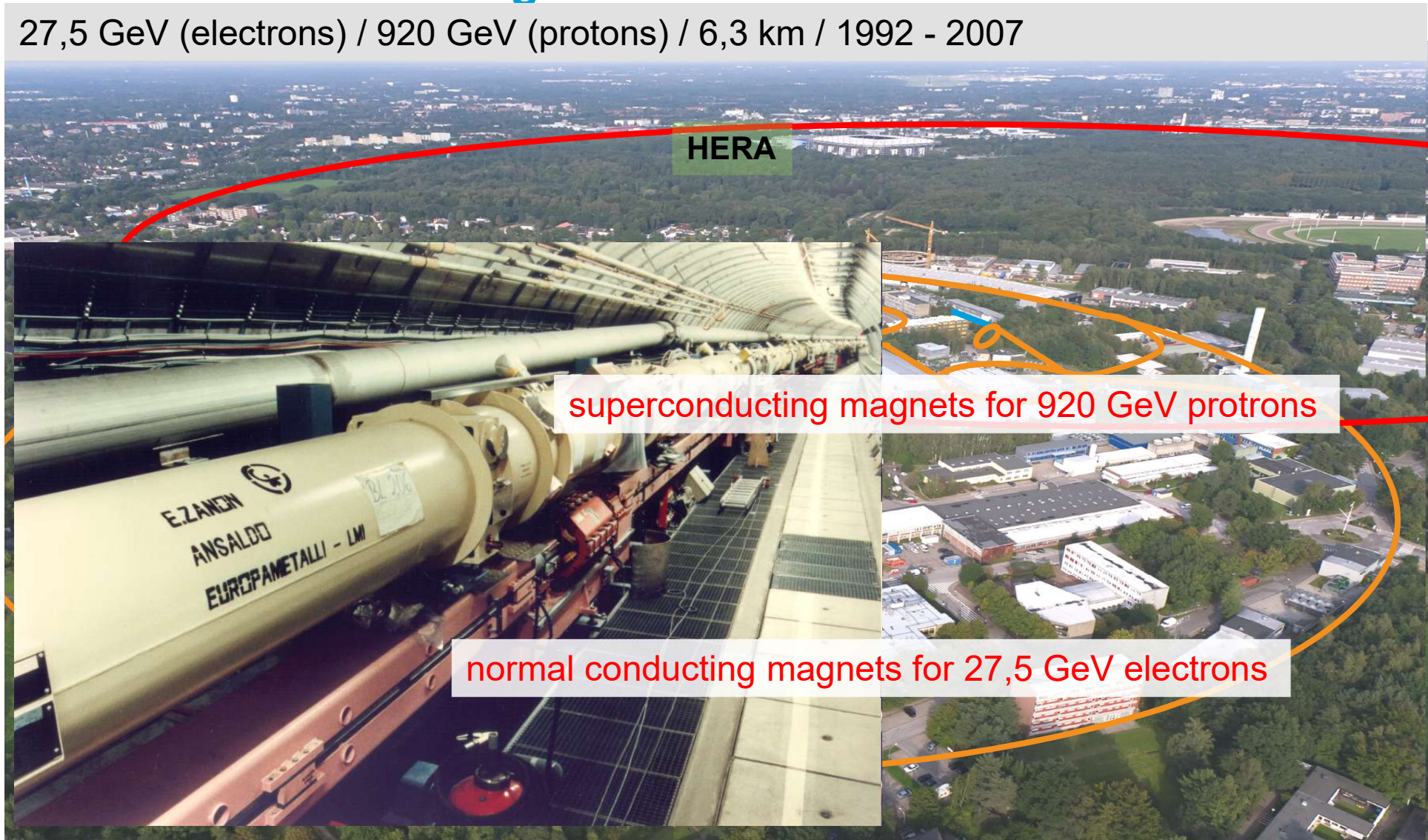
First beam 2016

$\lambda = 0.05 - 6 \text{ nm}$



HERA (Hadron-Elektronen-Ring-Anlage) Hadron-electron ring accelerator

27,5 GeV (electrons) / 920 GeV (protons) / 6,3 km / 1992 - 2007



HERA

superconducting magnets for 920 GeV protons

normal conducting magnets for 27,5 GeV electrons