Introduction to Accelerator Physics

Part 1

Pedro Castro / Accelerator Physics Group (MPY)
Zeuthen, 8th August 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

	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.

10th, 11th Aug.: Photoinjector PITZ, Namra Aftab

Today and tomorrow: focus on synchrotrons

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

1. Overview of charged particle accelerators

A historical overview of particle accelerators?

CERN summer student lecture: Particle Accelerators, Michaela Schaumann

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

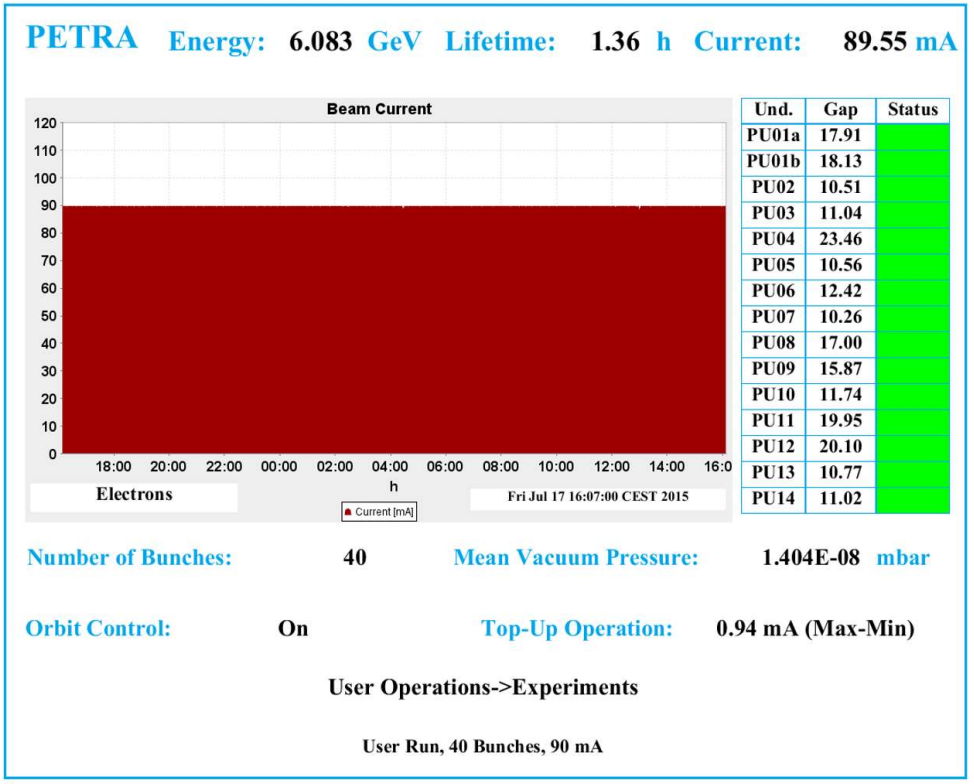
Scope of this lecture:

1. The four most important applications of accelerators
2. Main accelerators at DESY

} Part 1, 30 min.

3. Working with accelerators in the control room Part 2, 60 min.

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

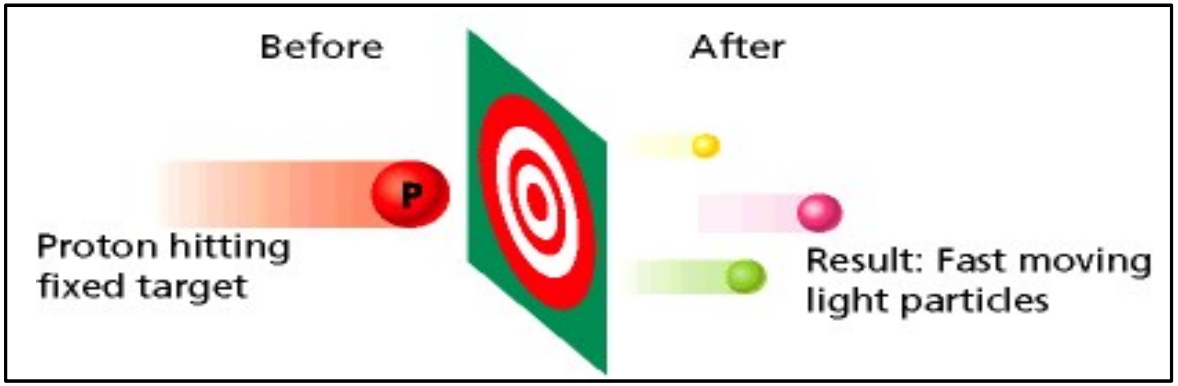
   } Part 4, tomorrow

   - Quadrupole magnets to focus beams Part 2
2. Synchrotrons and Linear Accelerators:
   - Acceleration using radio-frequency electomagnetic fields Part 3, tomorrow

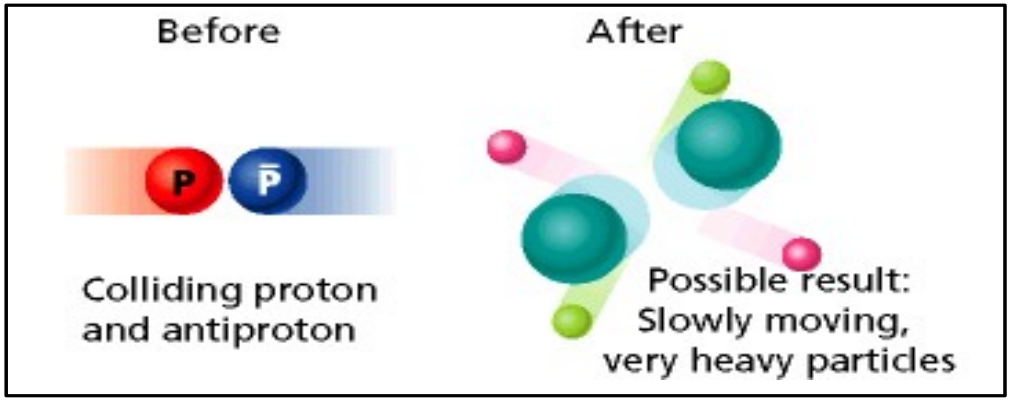
Applications of Accelerators (1)

Particle colliders for High Energy Physics (HEP) experiments

Fixed target experiments



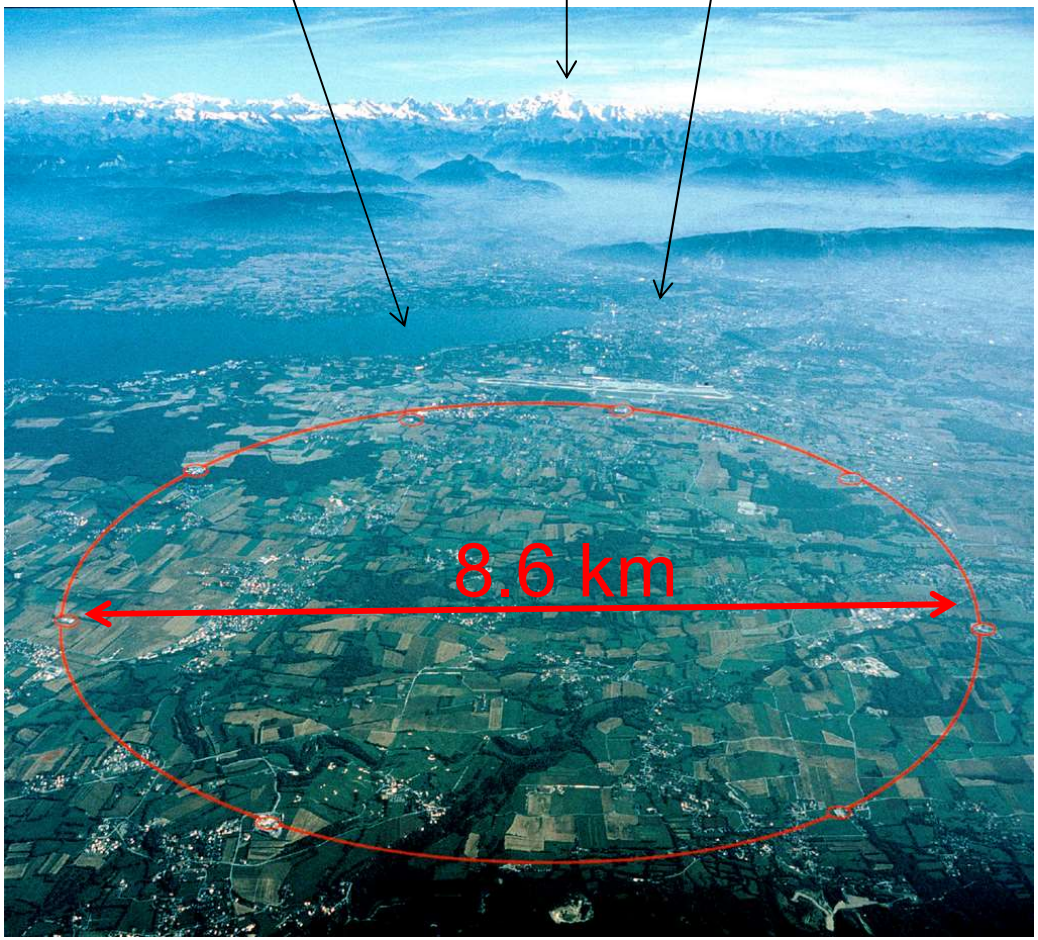
Two beams collider experiments

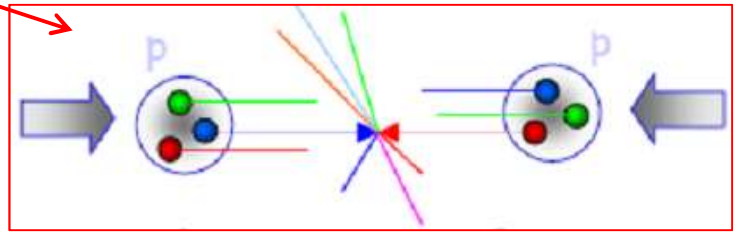


Applications of Accelerators (1)

Particle colliders for High Energy Physics experiments

Example: the Large Hadron Collider (LHC) at CERN



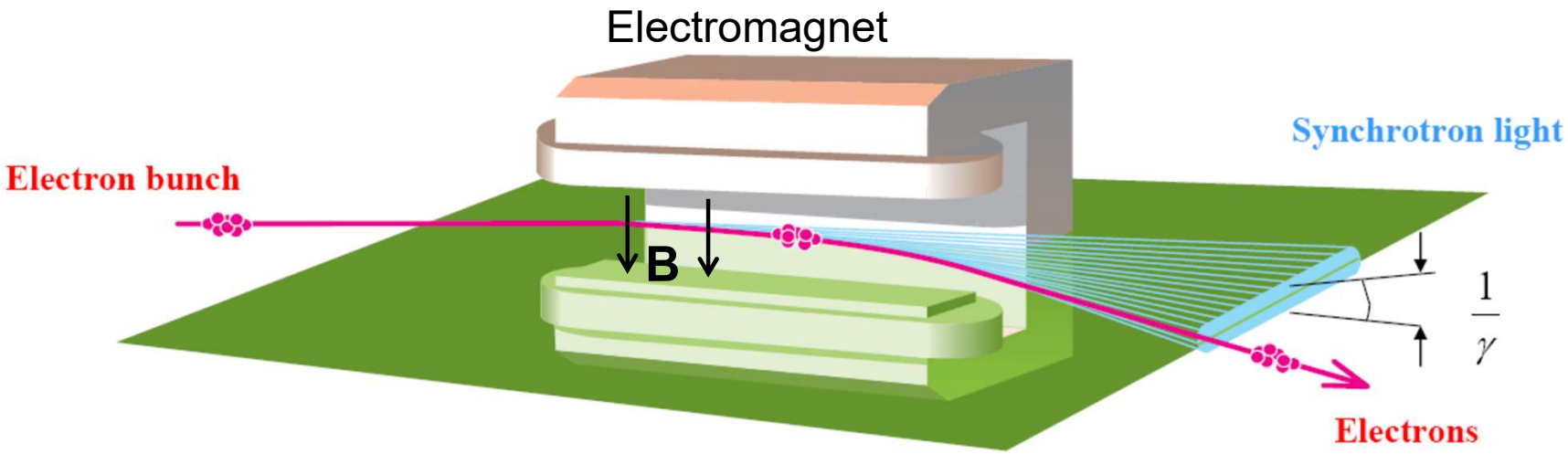


built between 2001 and 2009
Higgs discovery: July 2012

superconducting magnets
(inside a cryostat)

Applications of Accelerators (2)

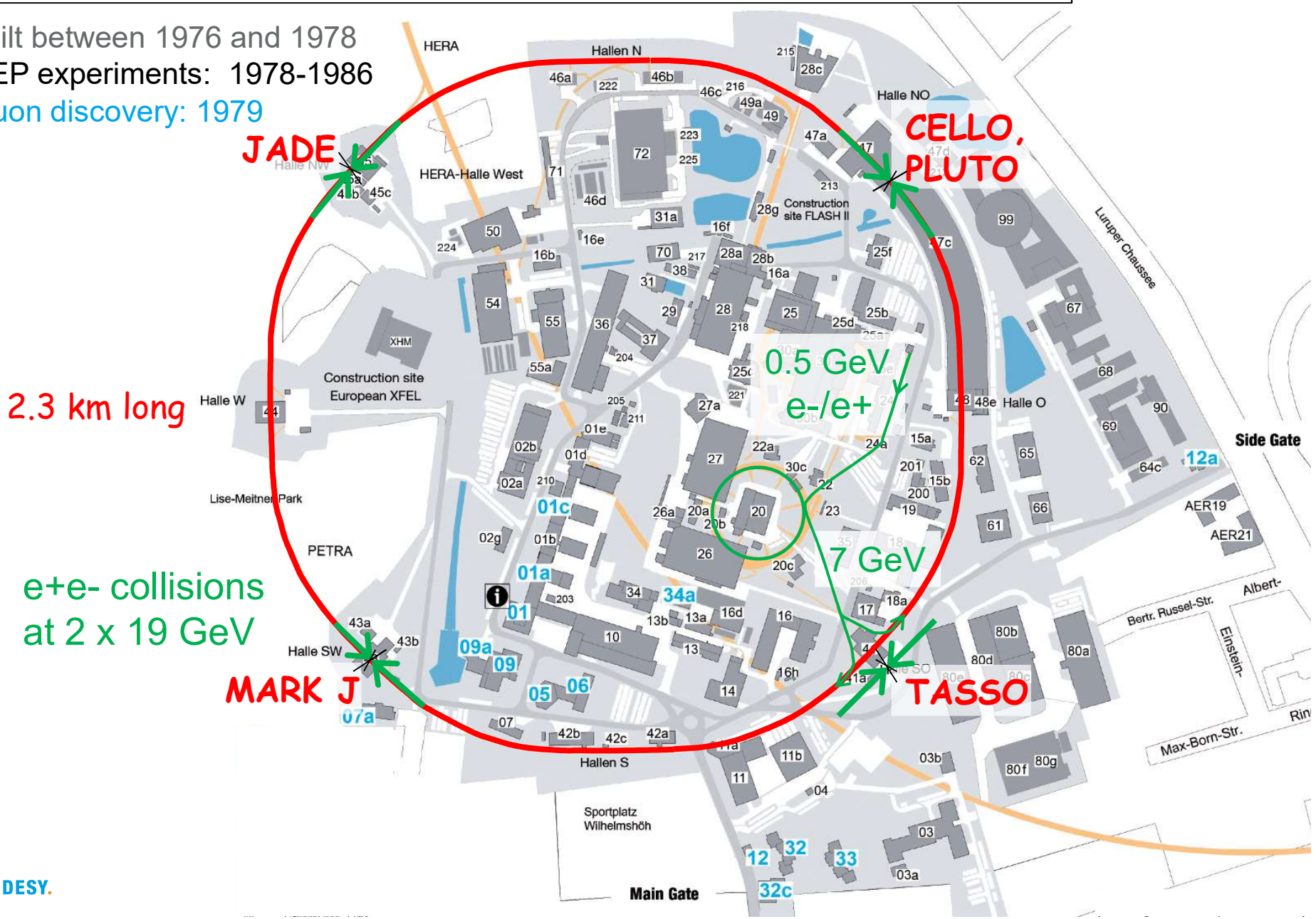
Light sources for biology, physics, chemistry… experiments



- 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



DESY.

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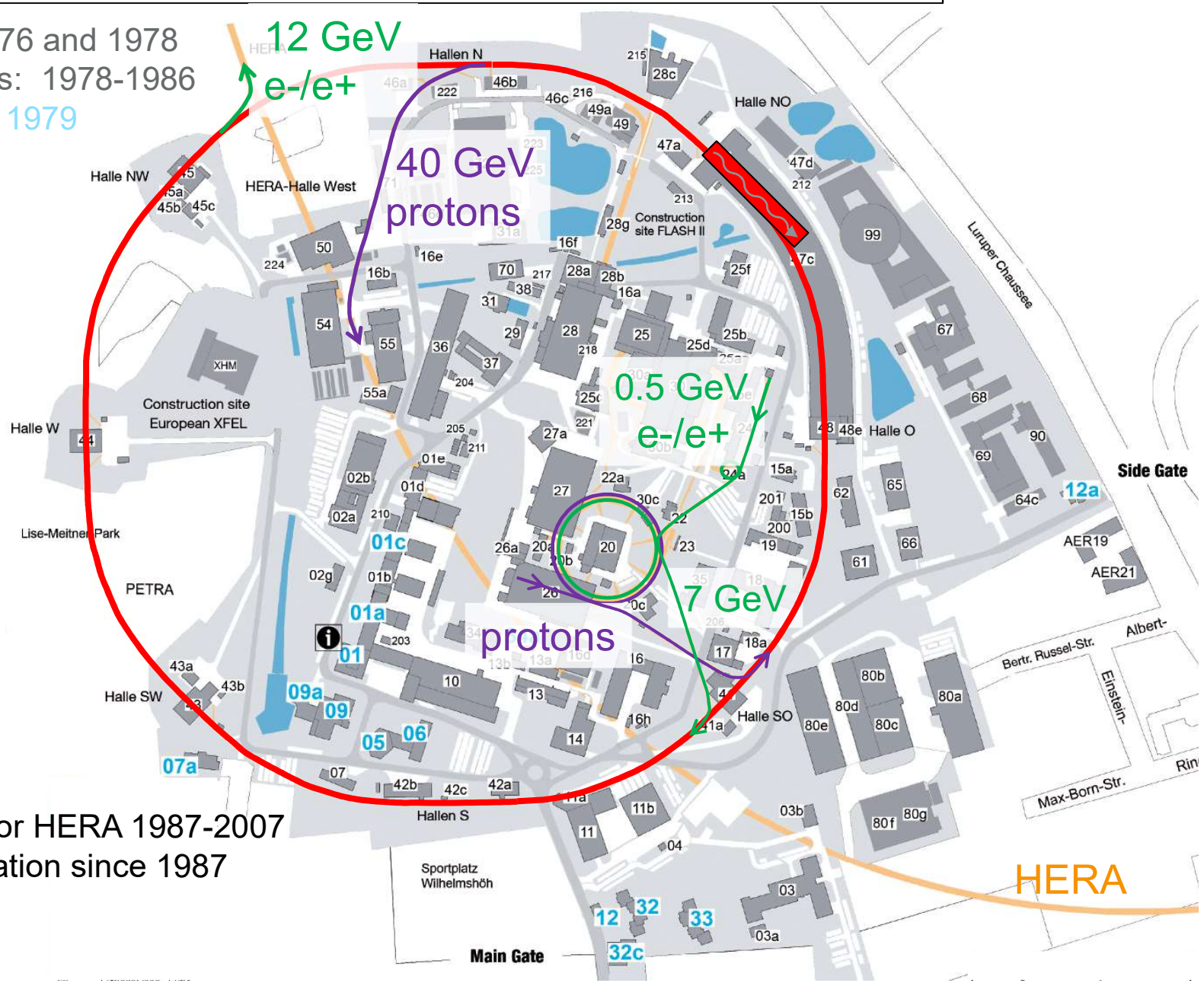

pre-accelerator for HERA 1987-2007
synchrotron radiation since 1987

DESY.

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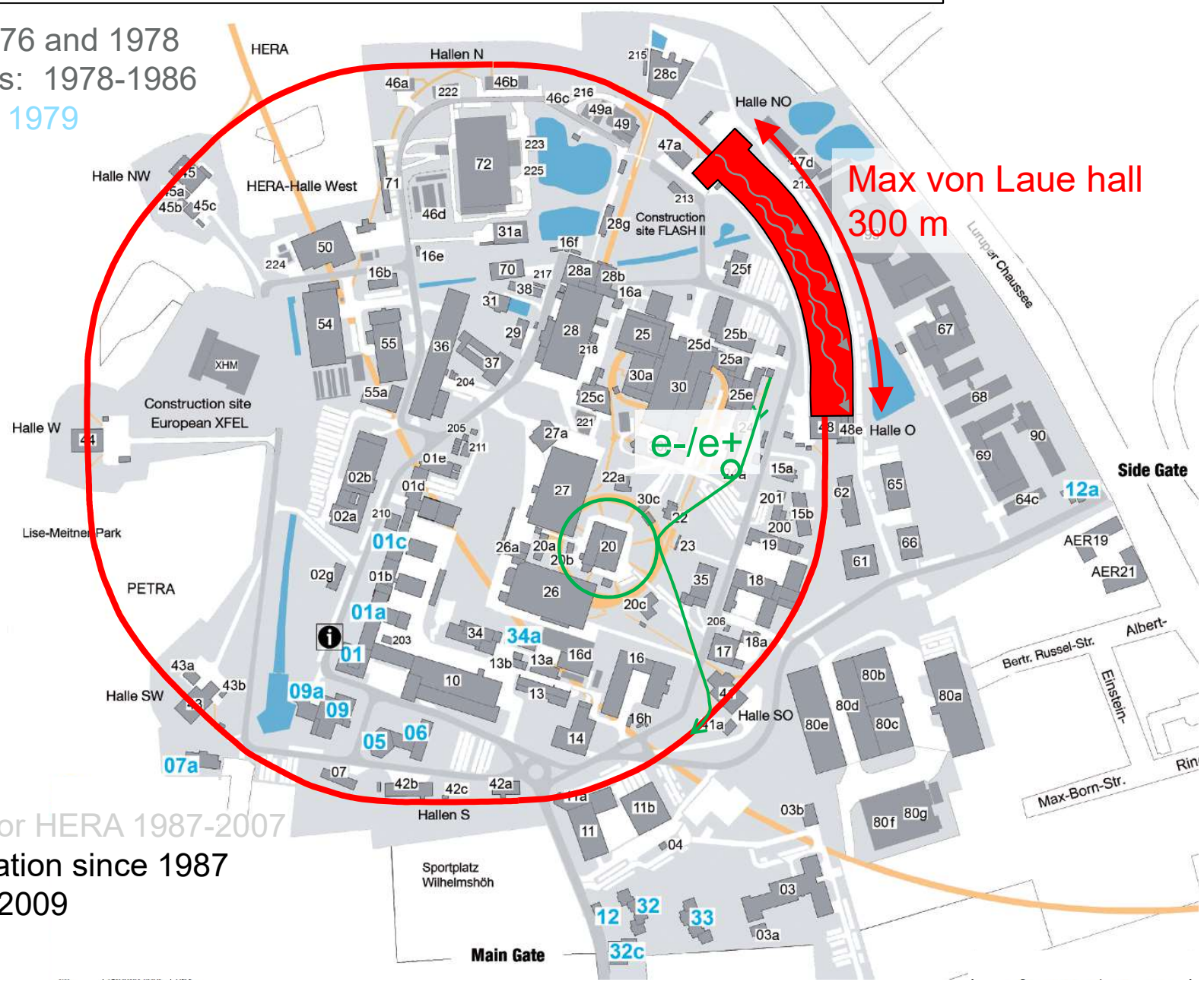
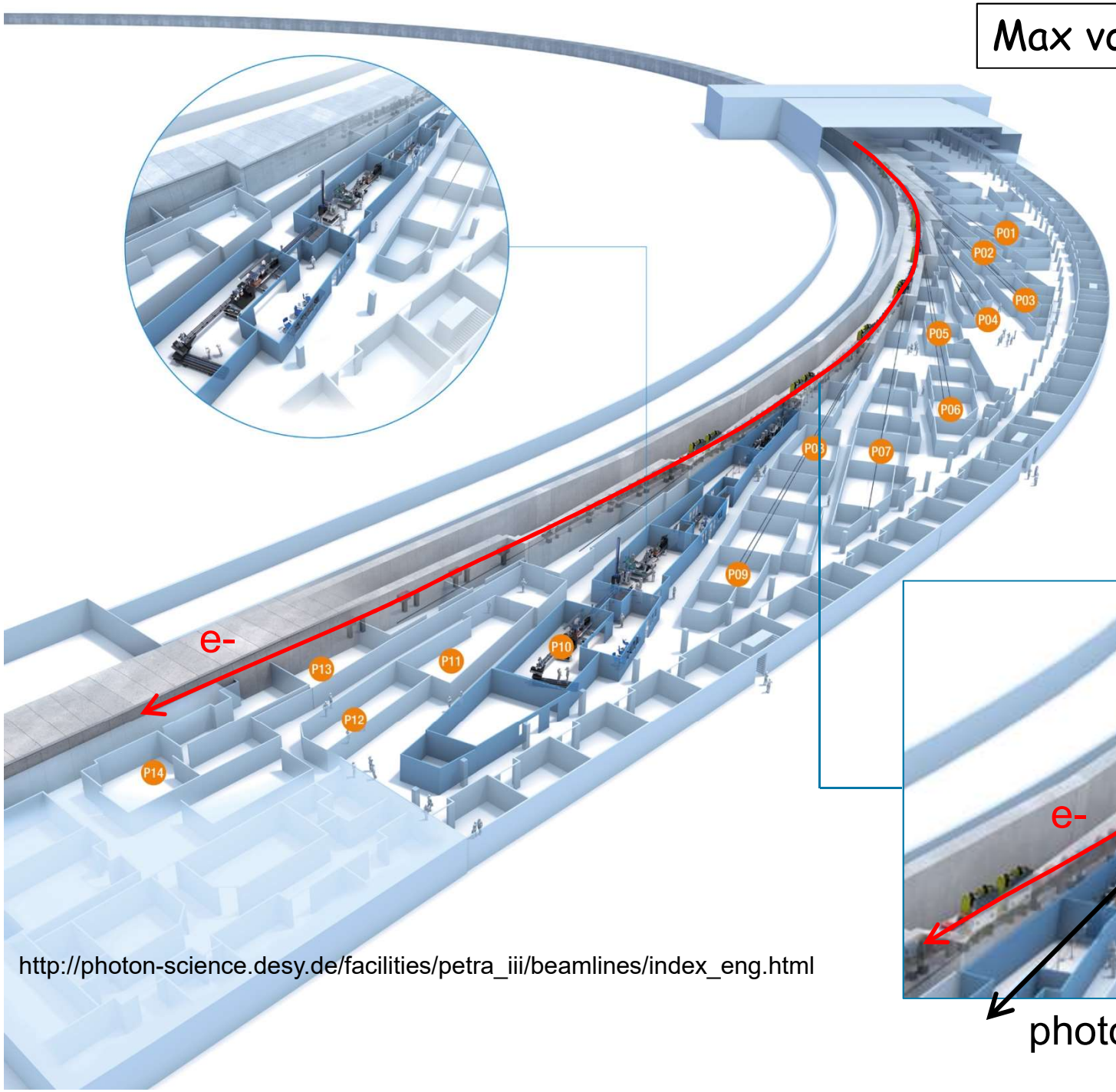


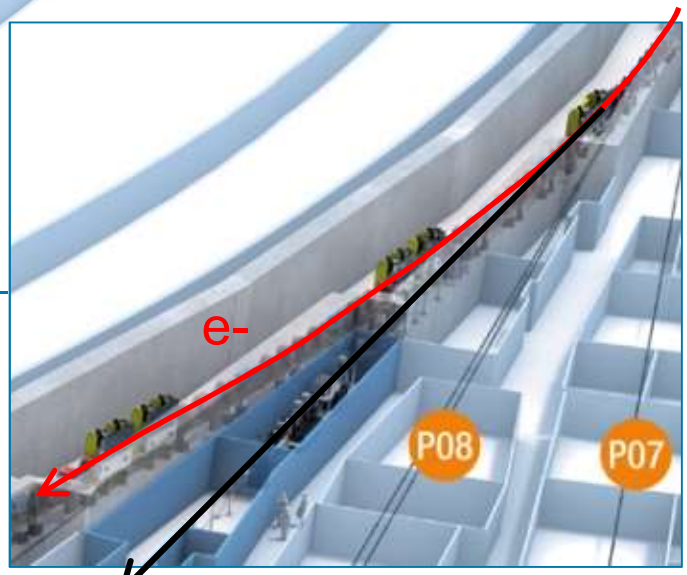
pre-accelerator for HERA 1987-2007
synchrotron radiation since 1987
PETRA III since 2009

DESY.

Max von Laue hall

14 beamlines
30 exp. stations





photons

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

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

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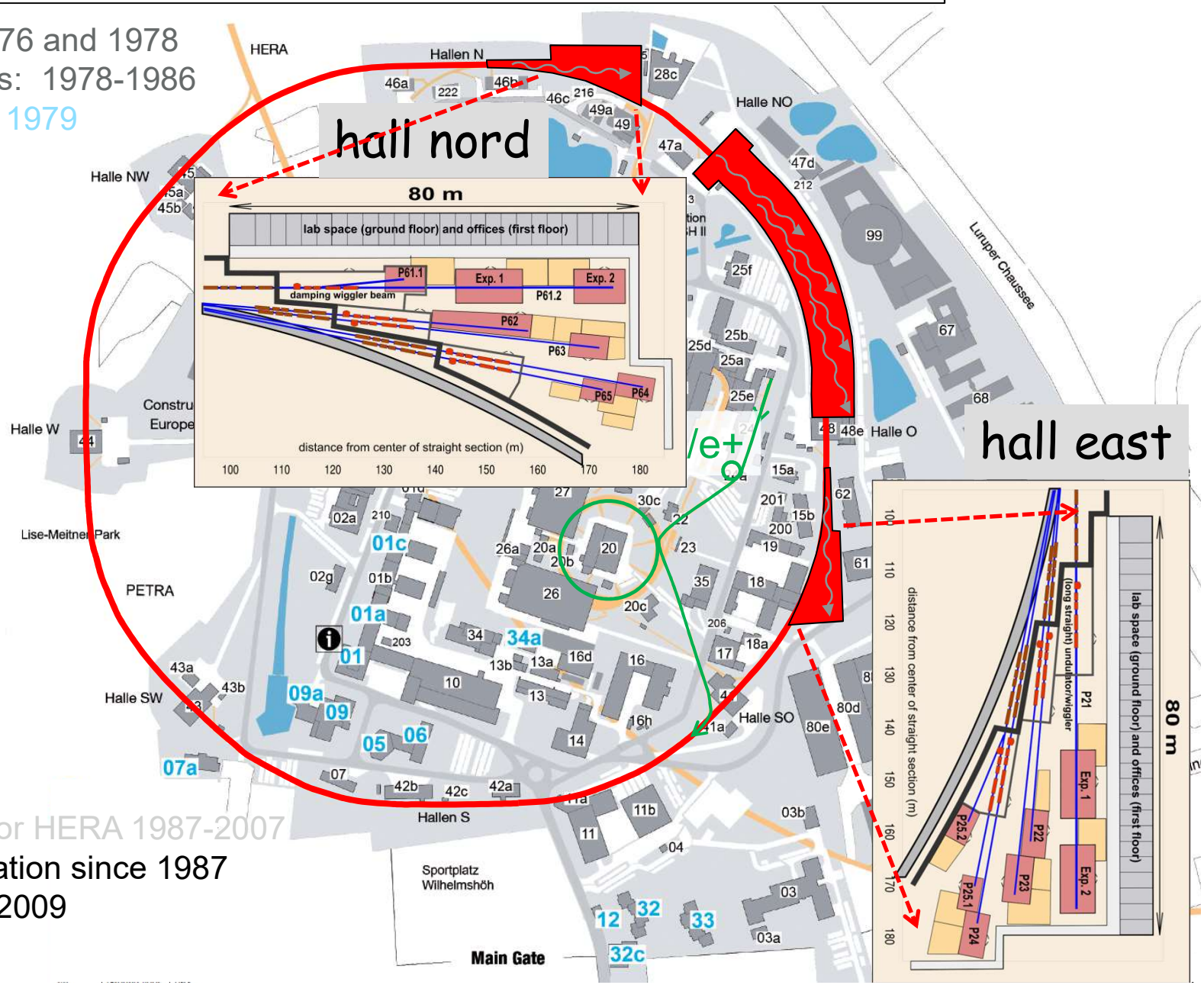
2.3 km long



pre-accelerator for HERA 1987-2007
synchrotron radiation since 1987
PETRA III since 2009

DESY.

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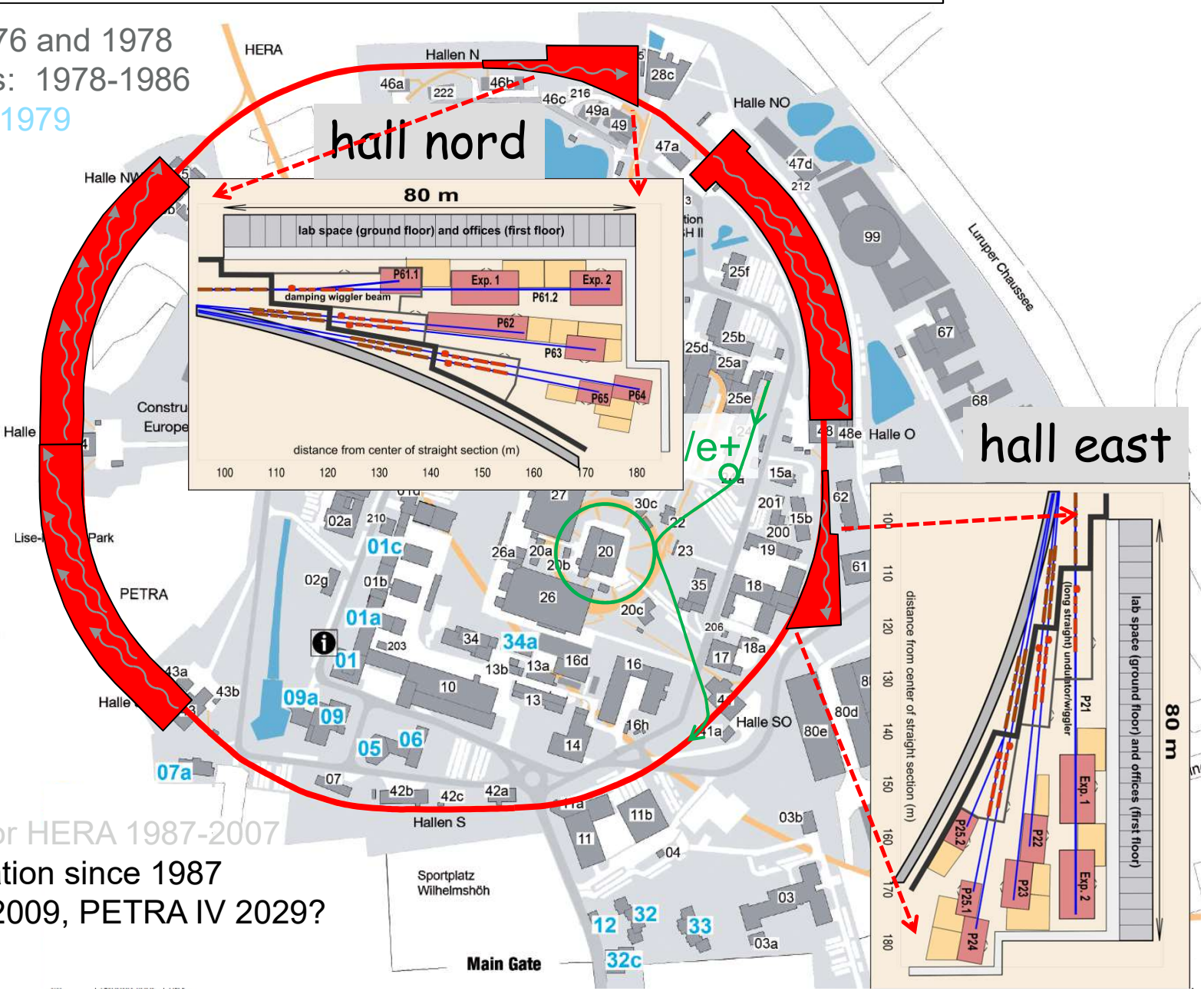


pre-accelerator for HERA 1987-2007
synchrotron radiation since 1987
PETRA III since 2009, PETRA IV 2029?

DESY.

Applications of Accelerators (3)

Accelerators in medicine

For radioisotope production

proton beam + stable isotope $\xrightarrow{\text{transmutation}}$ radioactive isotope

For radiotherapy and radiosurgery:

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

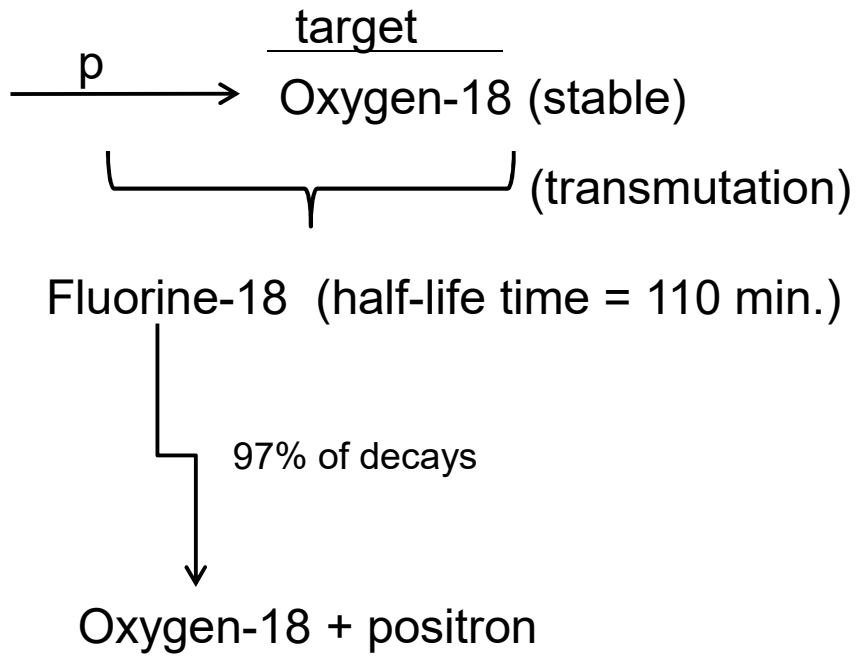
Applications of Accelerators (3)

Accelerators in medicine

For radioisotope production

For example:

18 MeV proton accelerator



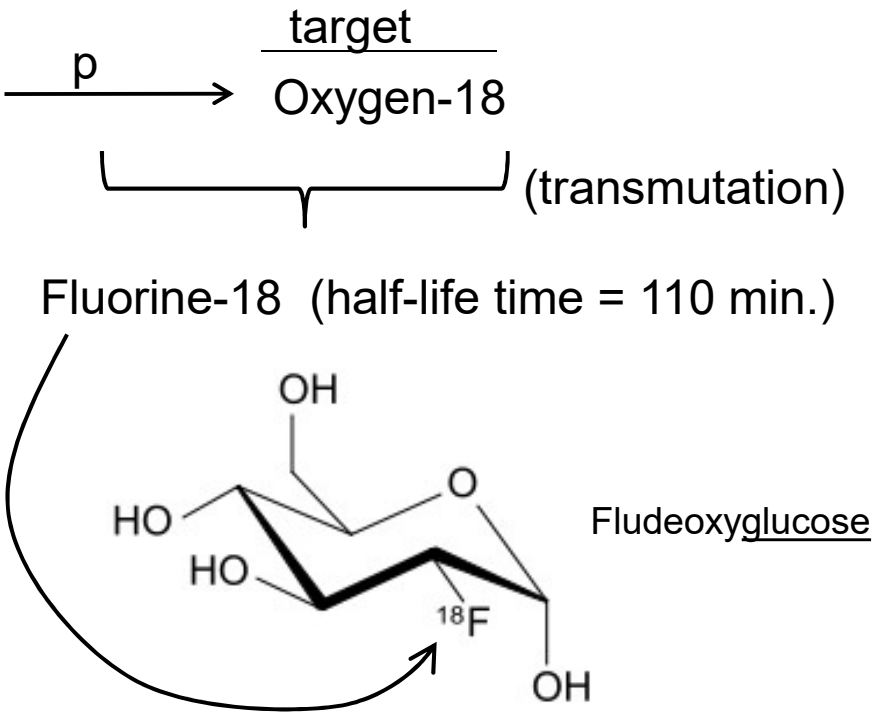
Applications of Accelerators (3)

Accelerators in medicine

For radioisotope production

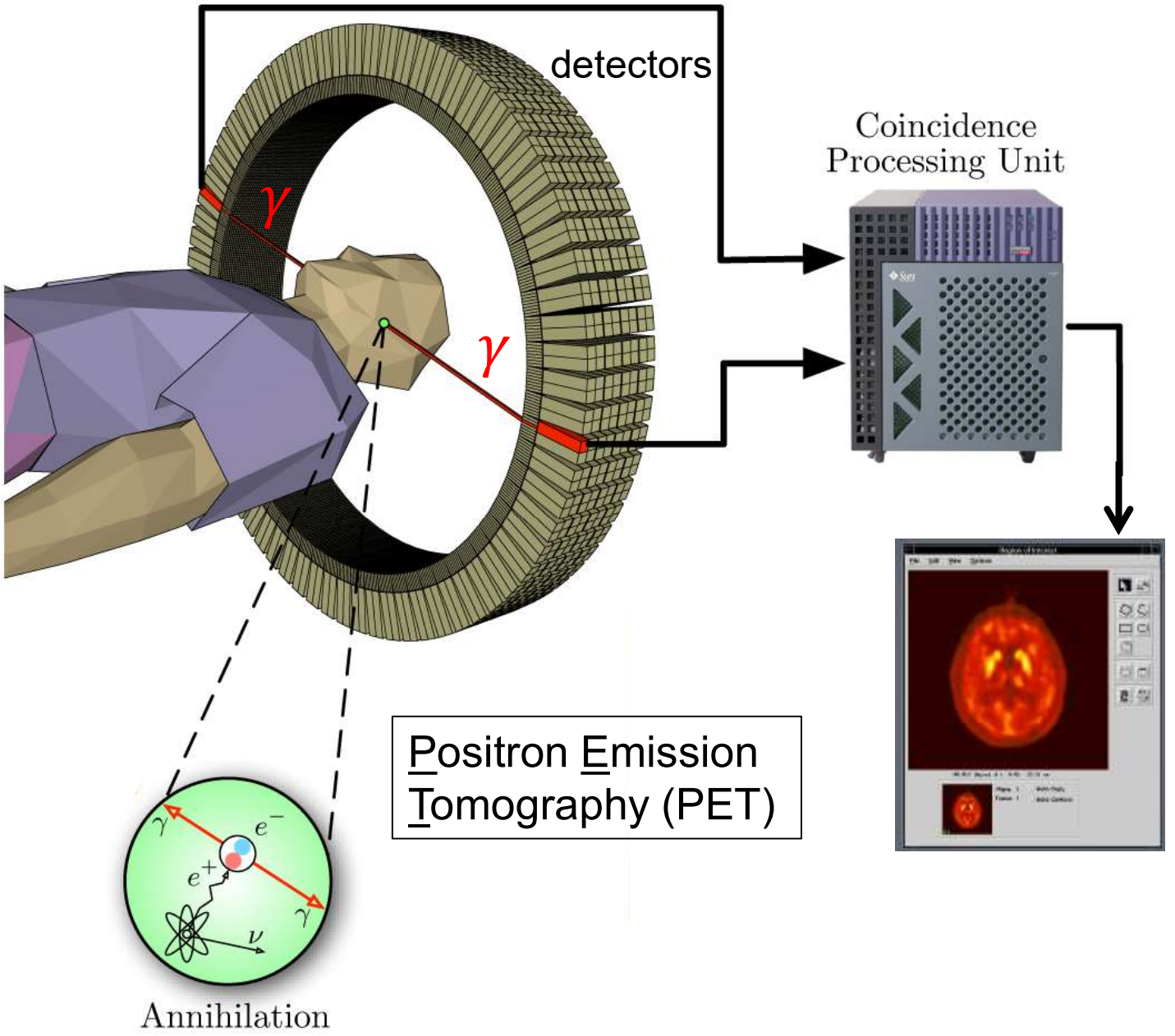
For example:

18 MeV proton accelerator

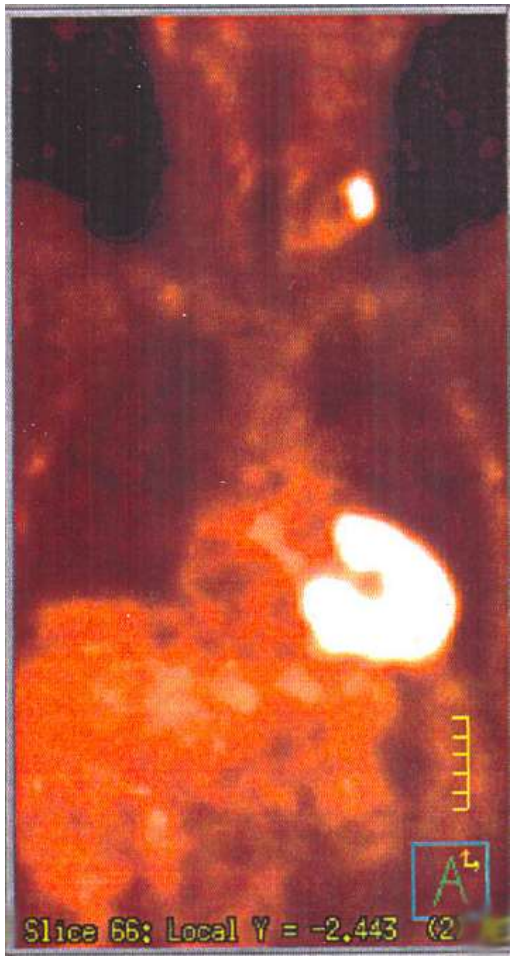


Fludeoxyglucose (^{18}F)

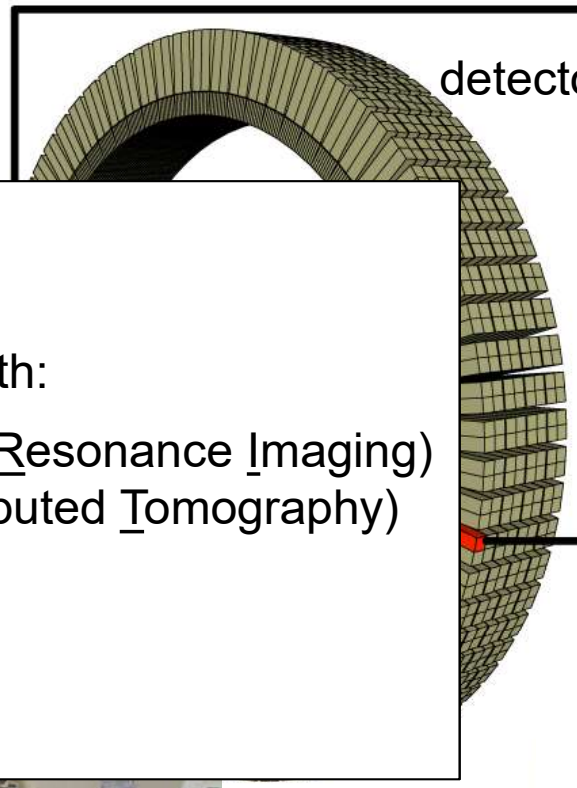
Applications of Accelerators (3)



PET



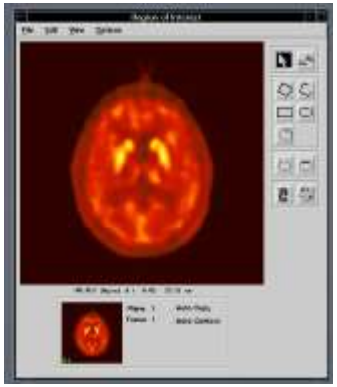
Applications of Accelerators (3)



Coincidence Processing Unit

not to be confused with:

- MRI (Magnetic Resonance Imaging)
- CT (X-ray Computed Tomography)



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

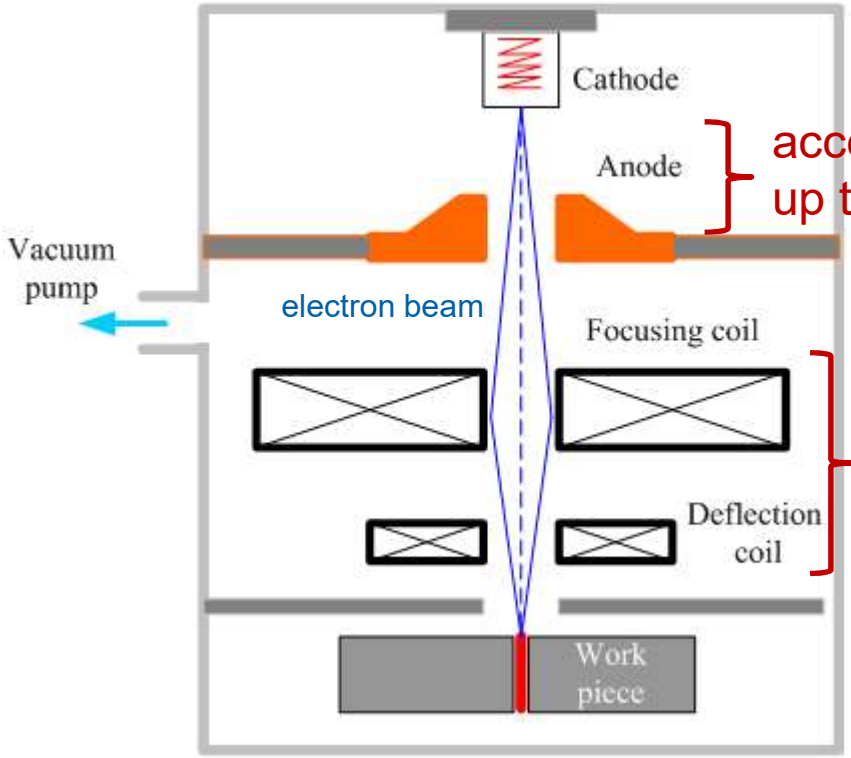
approx. numbers from 2007 (worldwide)

with energies up to 15 MeV

Applications of Accelerators (4)

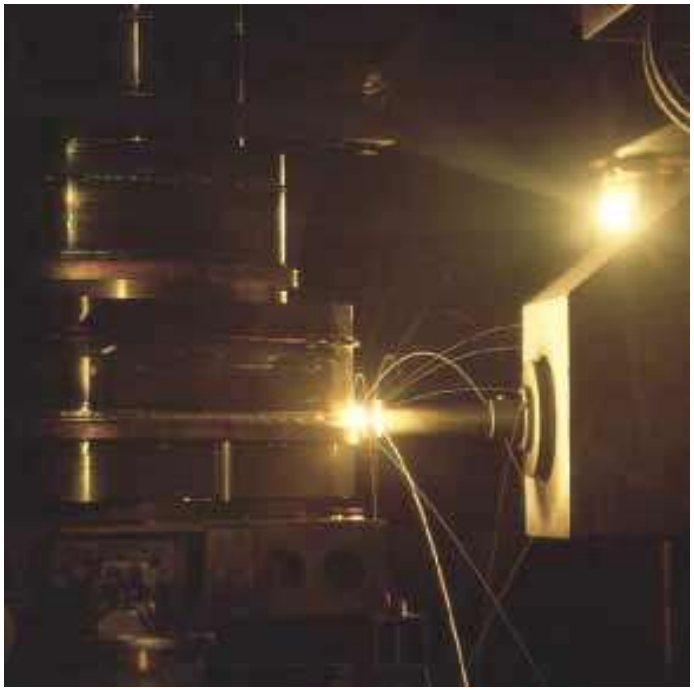
For industrial applications:

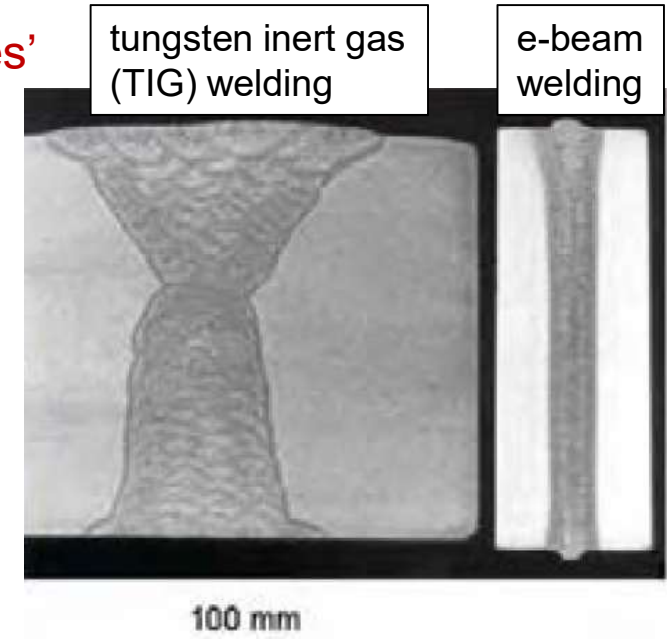
an example: electron beam welding



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 …

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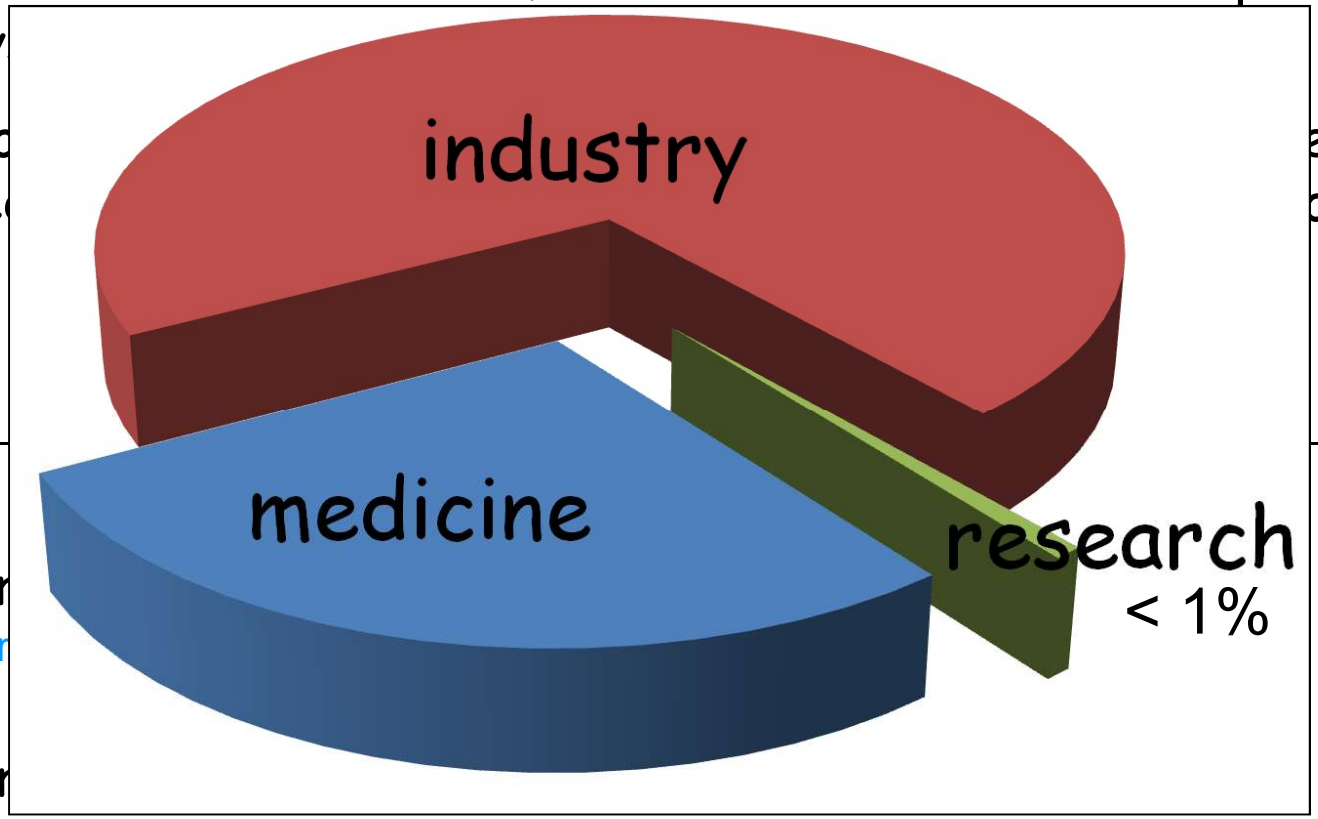
- Abo elerators use burces')



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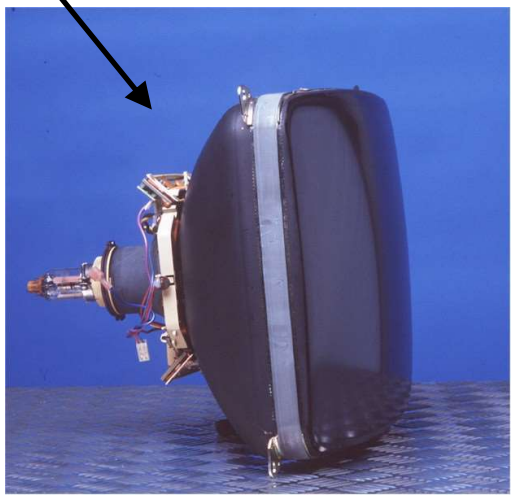
ion implantation (>9,000) , electron cutting and welding (>4,000) …

Applications of Accelerators (5)

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

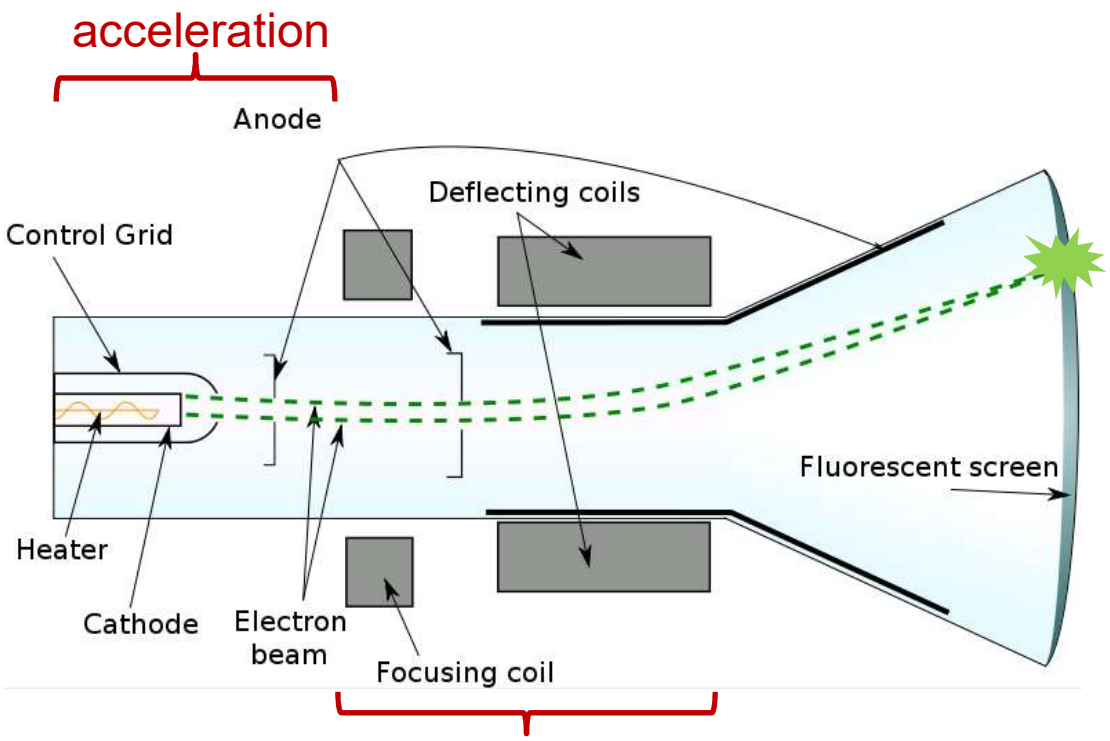
TV

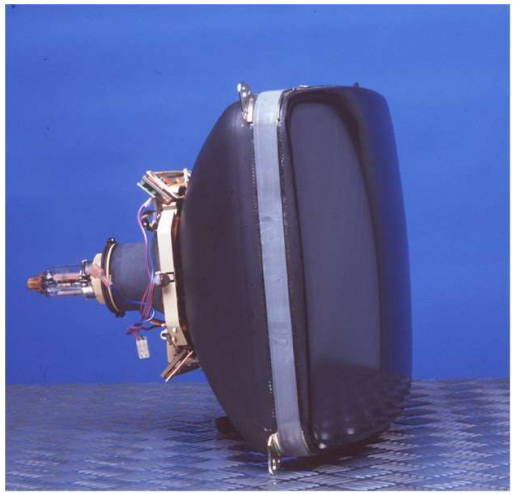


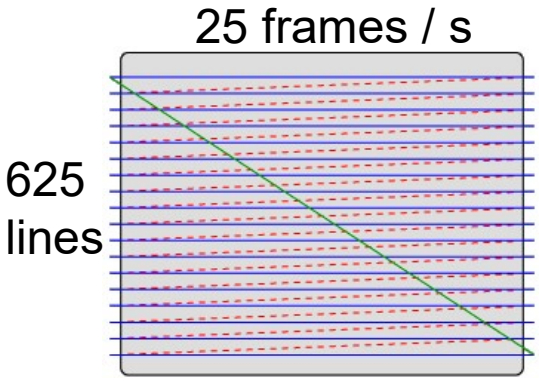
oscilloscope

Applications of Accelerators (5)

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

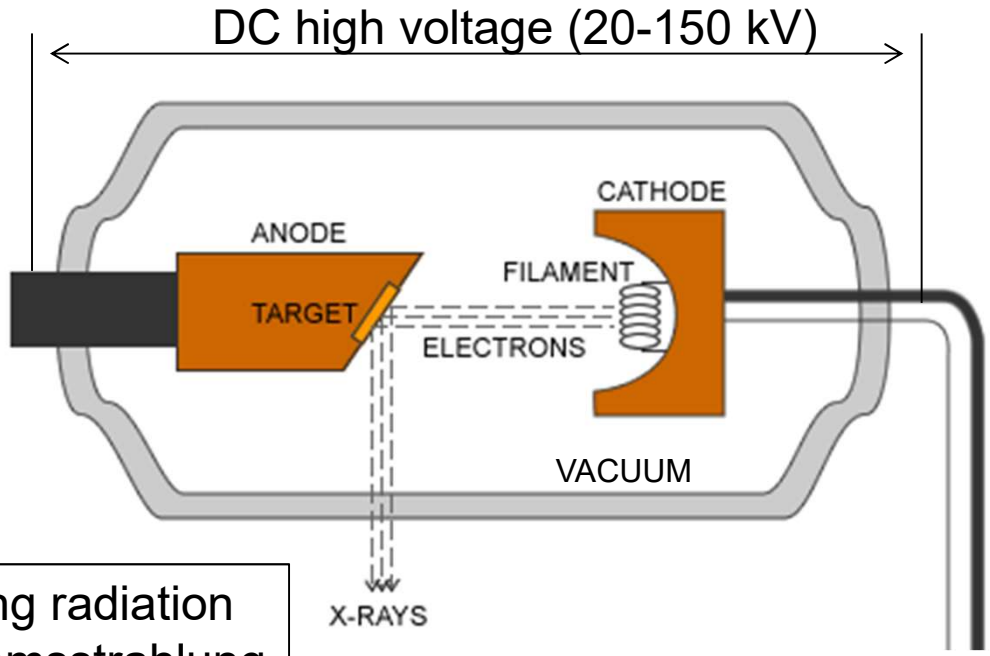






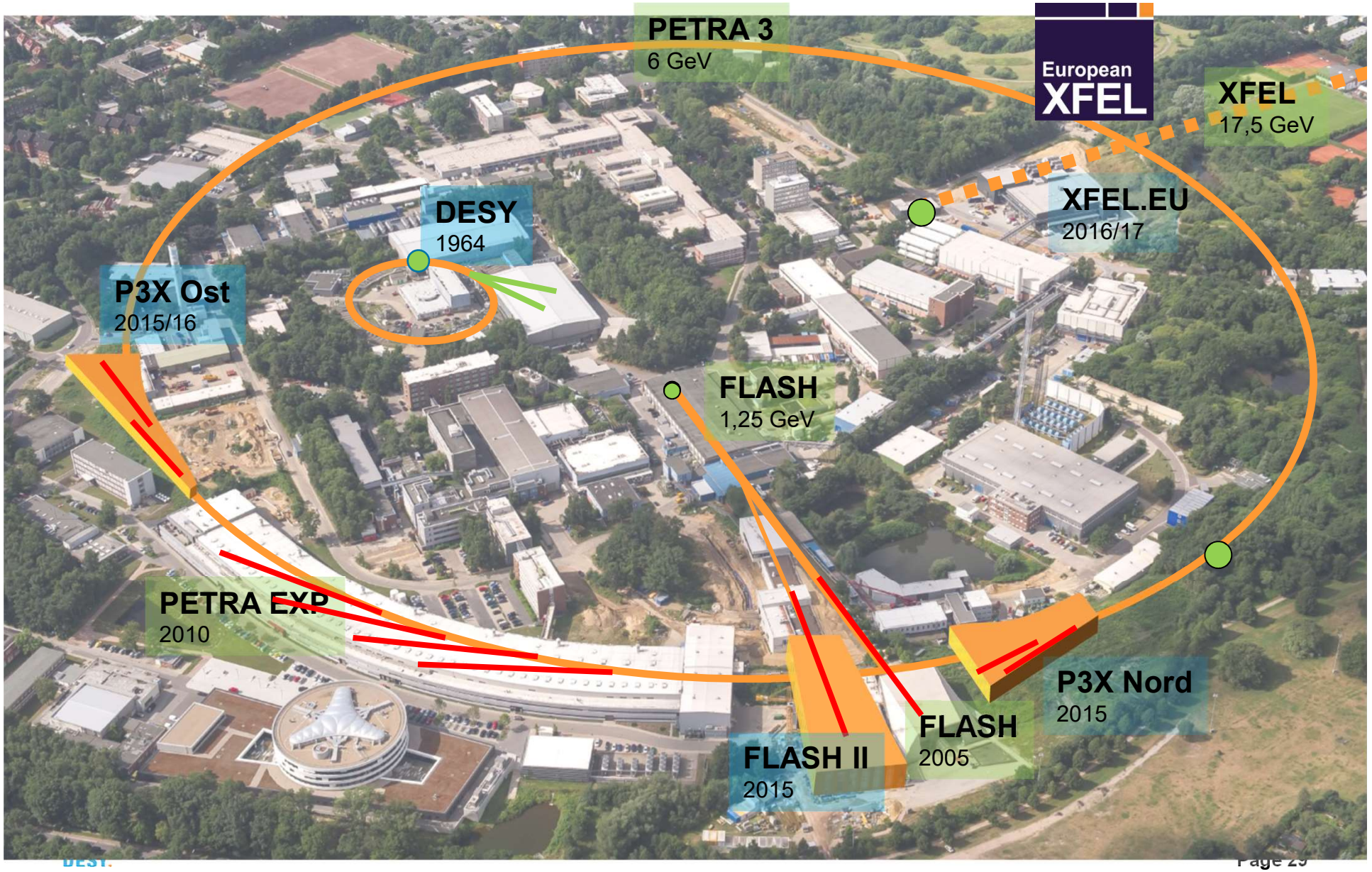
Applications of Accelerators (6)

X-ray tubes

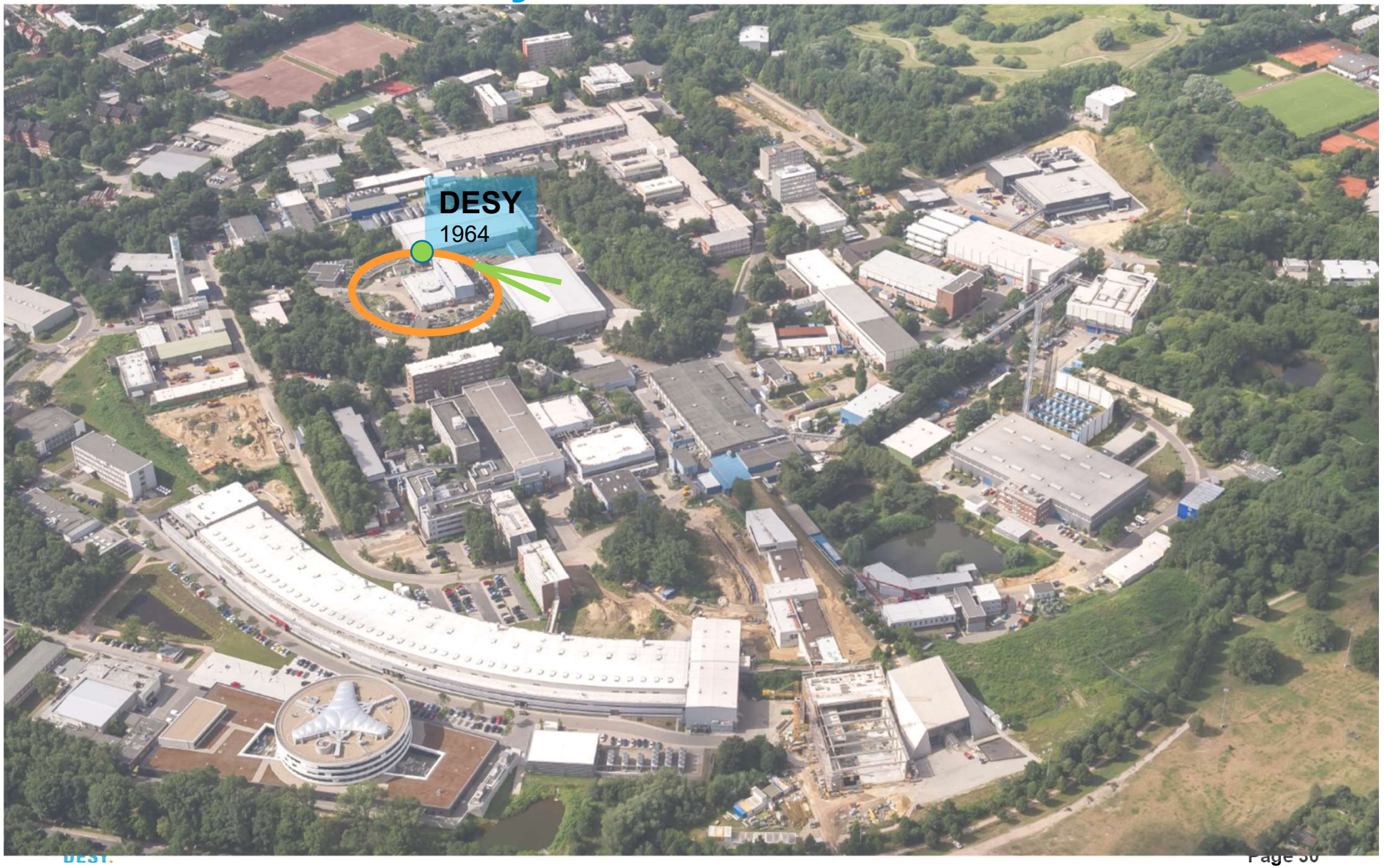


braking radiation
or bremsstrahlung

Main accelerators at DESY



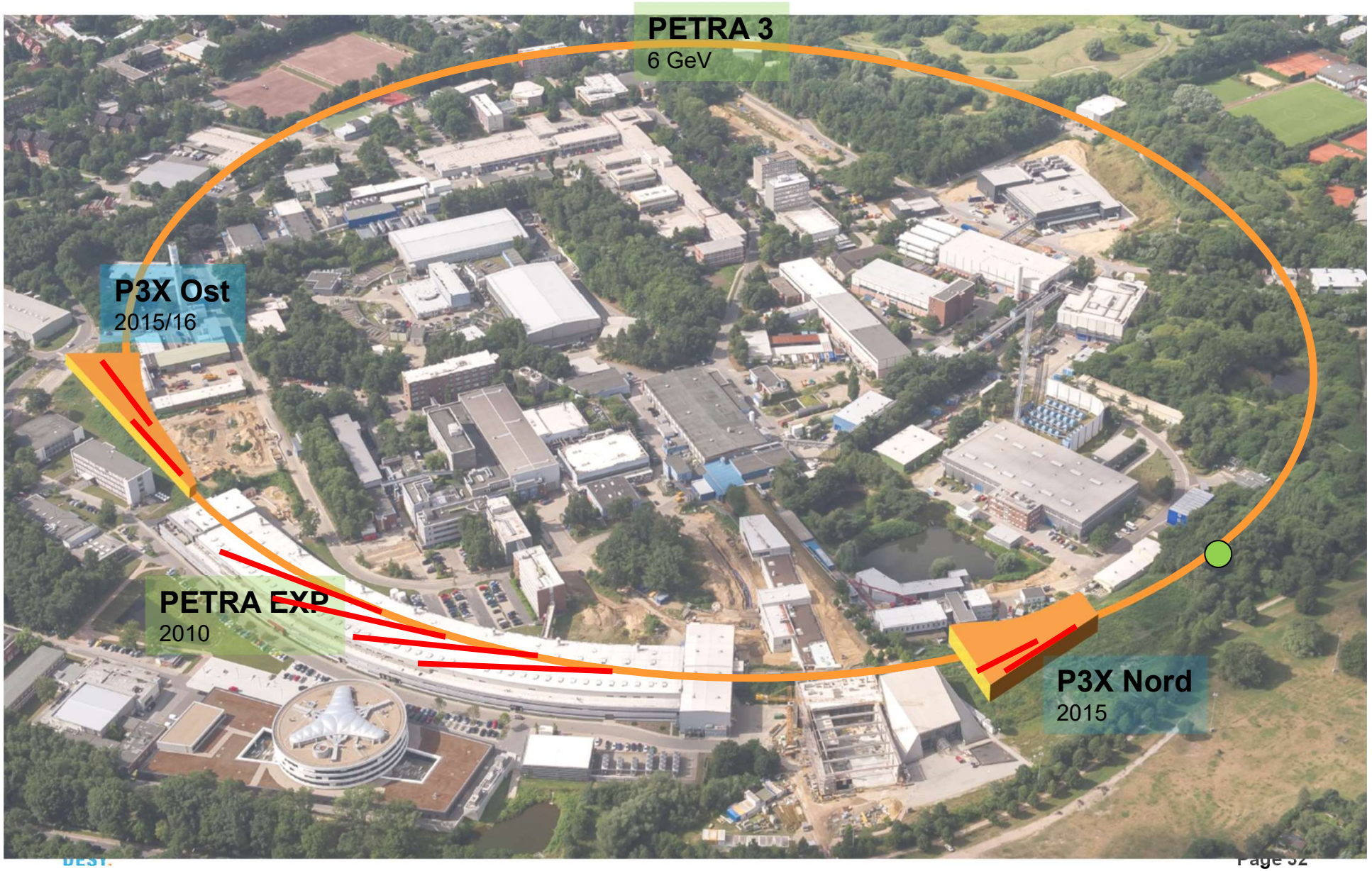
DESY (Deutsches Elektronen Synchrotron)
German electron synchrotron



DESY (Deutsches Elektronen Synchrotron)
German electron synchrotron

1964, 7.4 GeV

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



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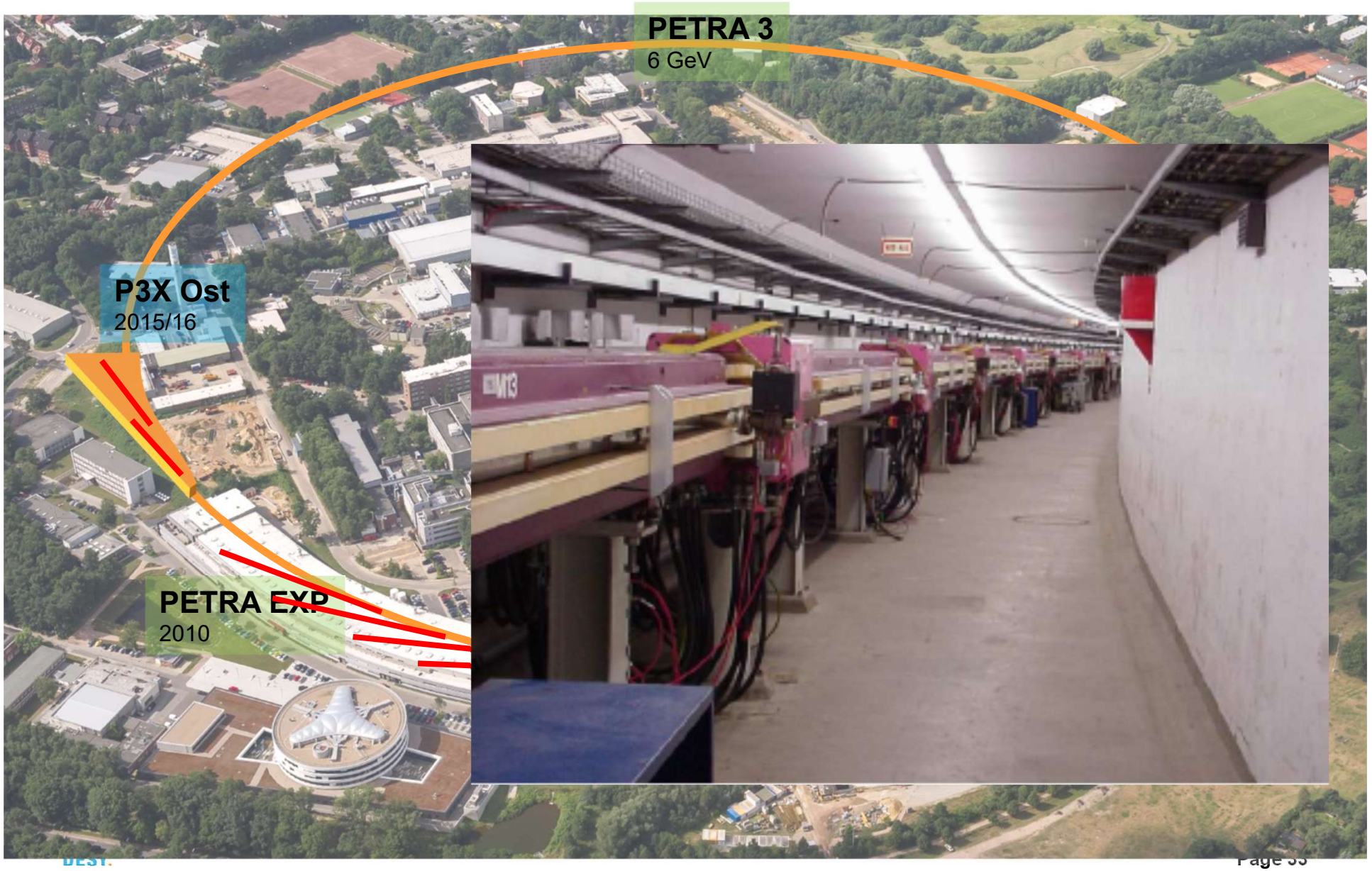
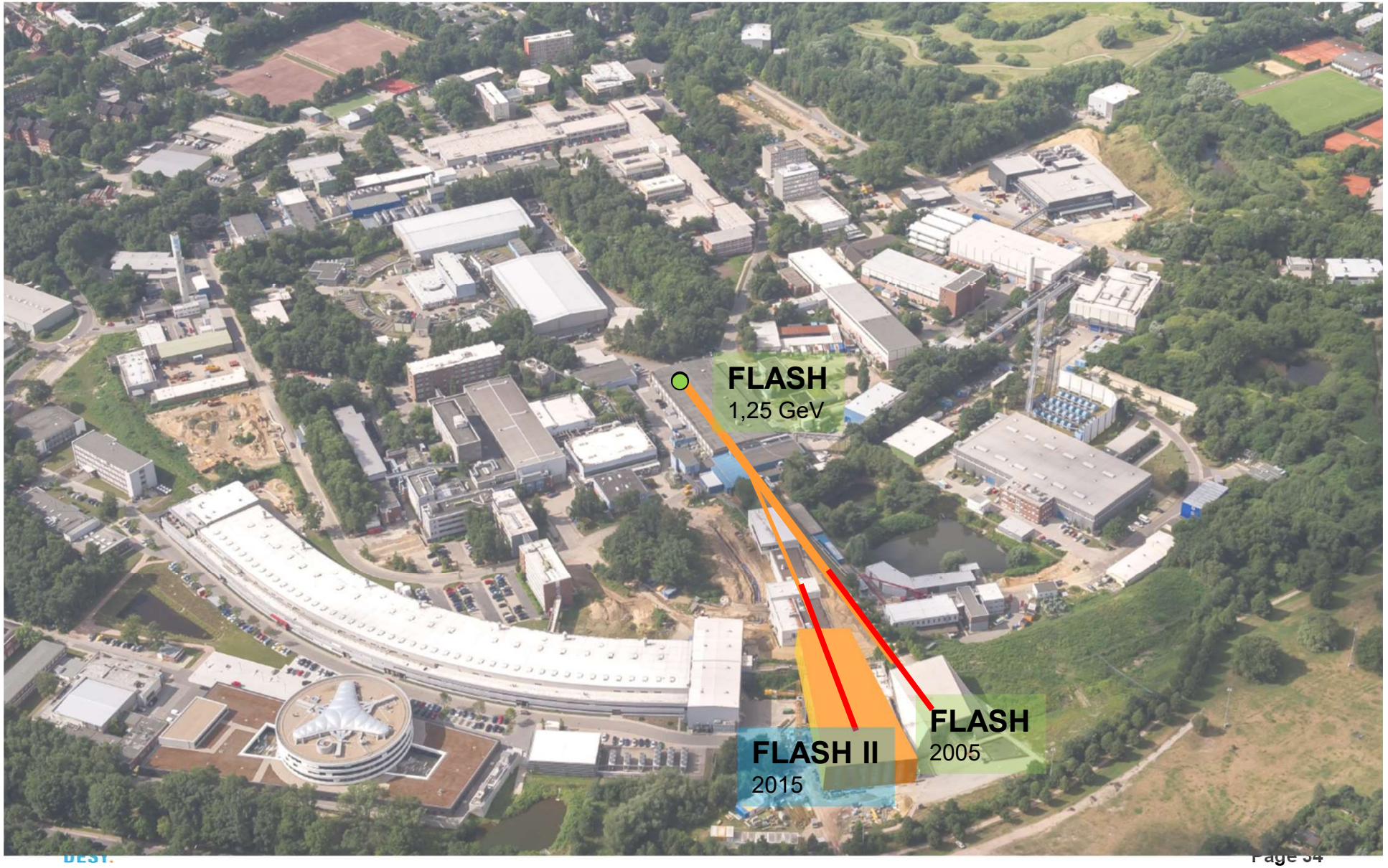


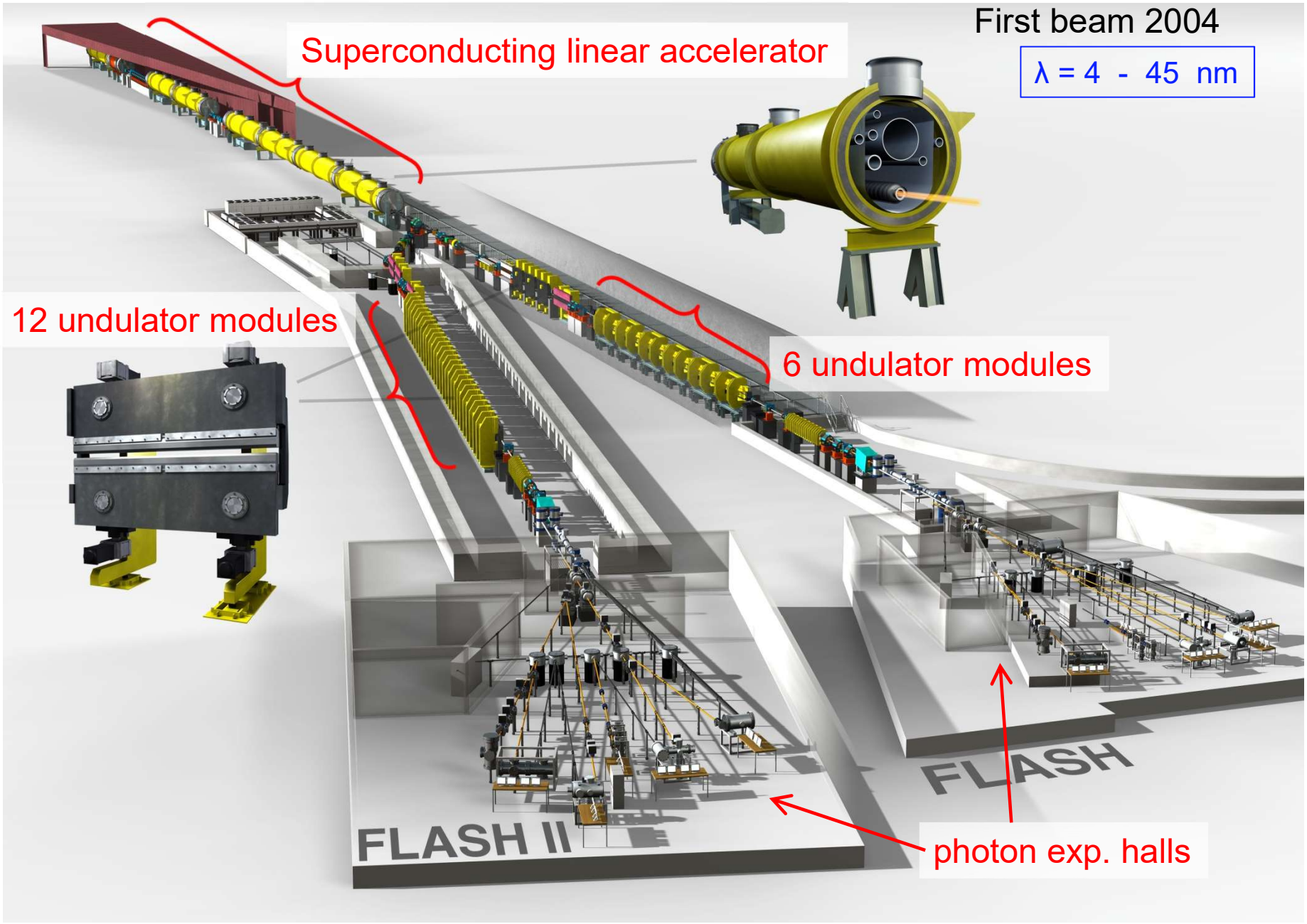
Free-electron LASer in Hamburg (FLASH)



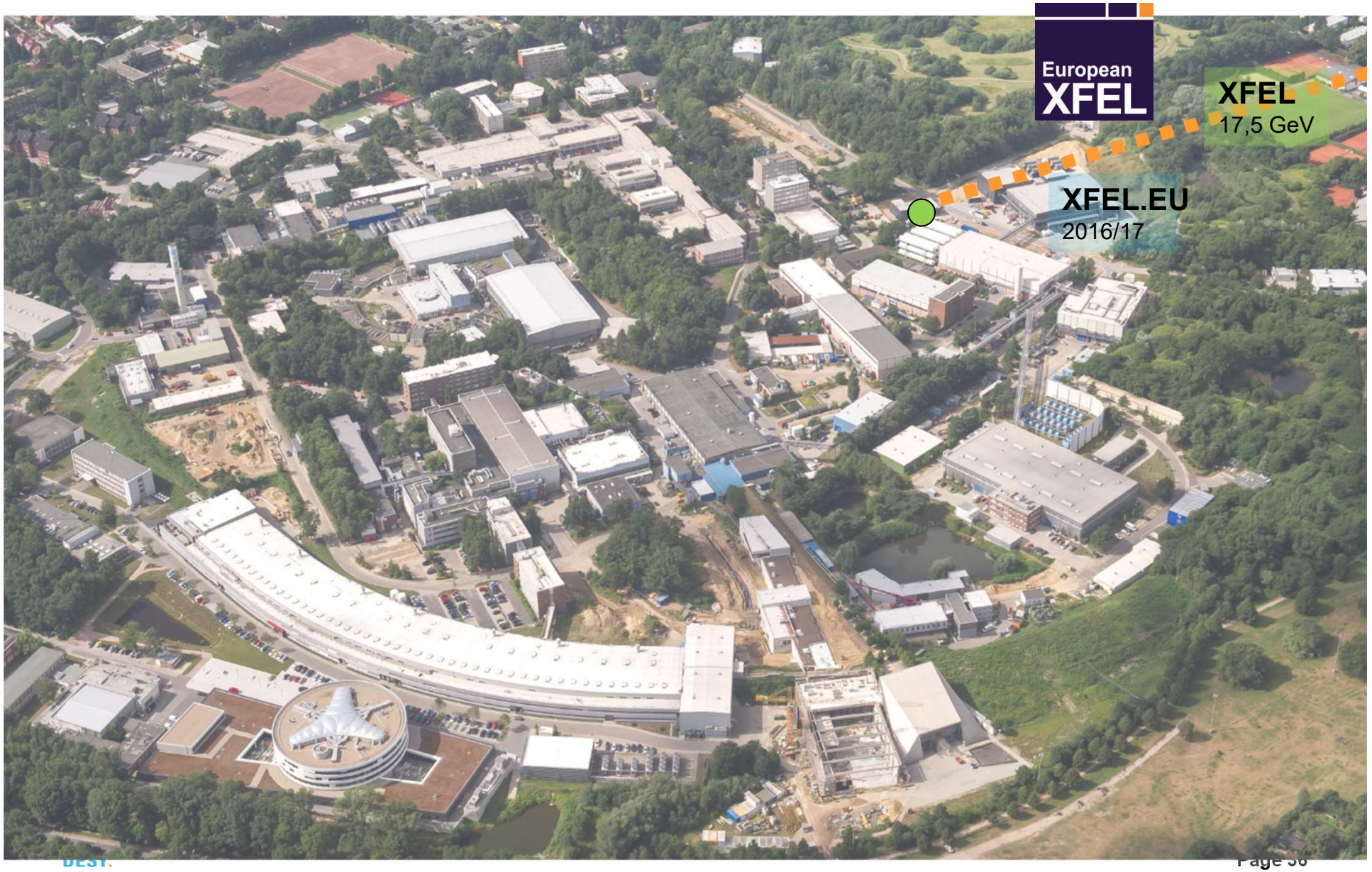
Free-electron LASer in Hamburg (FLASH)

300 m long, 1.2 GeV
First beam 2004

$\lambda = 4 - 45$ nm



European X-ray Free-Electron Laser (XFEL)



European X-ray Free-Electron Laser (XFEL)

European XFEL

2 km superconducting linear accelerator

Undulators and experiments

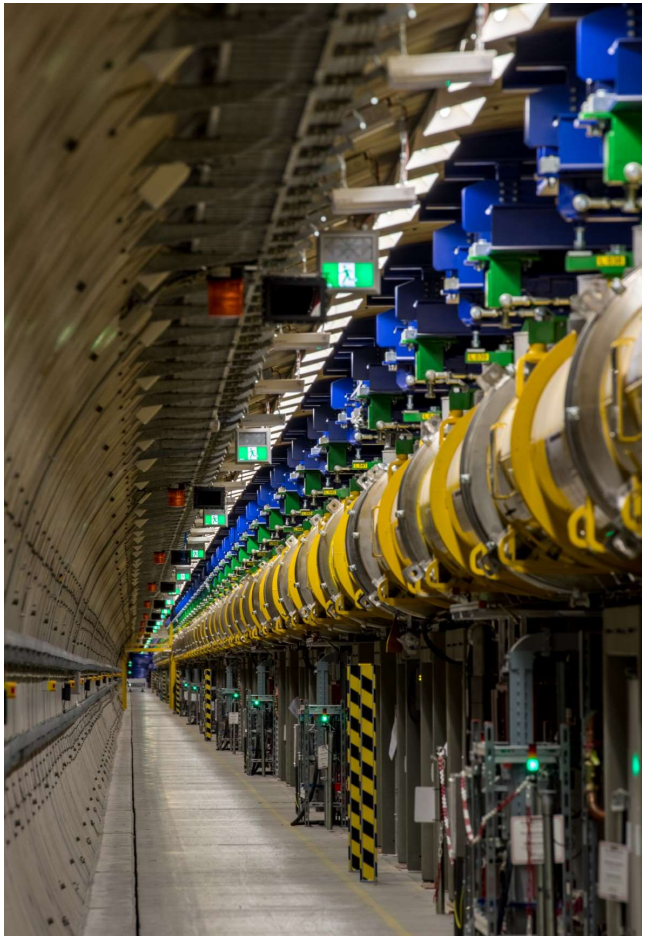
DESY.

European XFEL

3 km long 17,5 GeV

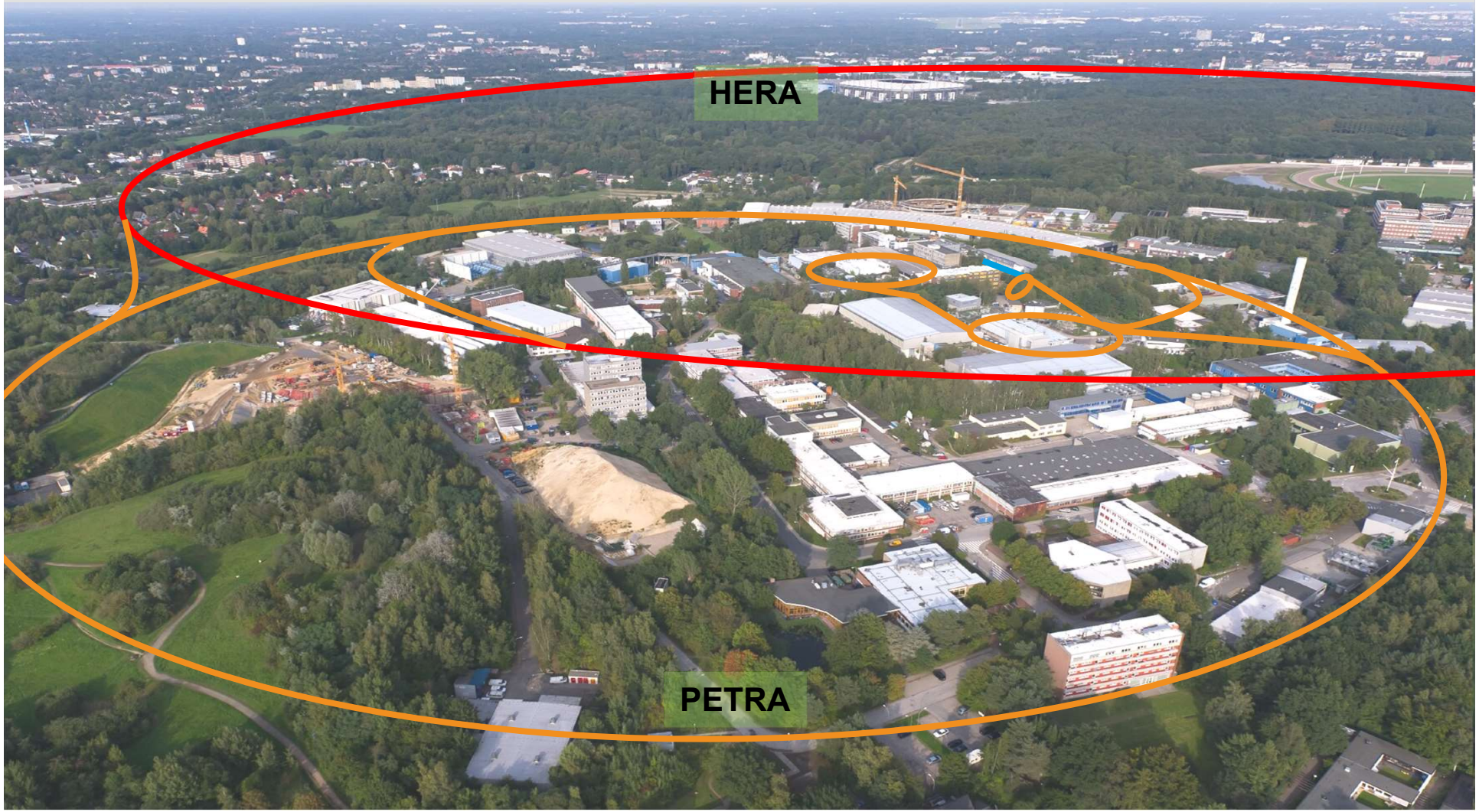
First beam 2016

$\lambda = 0.05 - 6$ nm



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

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



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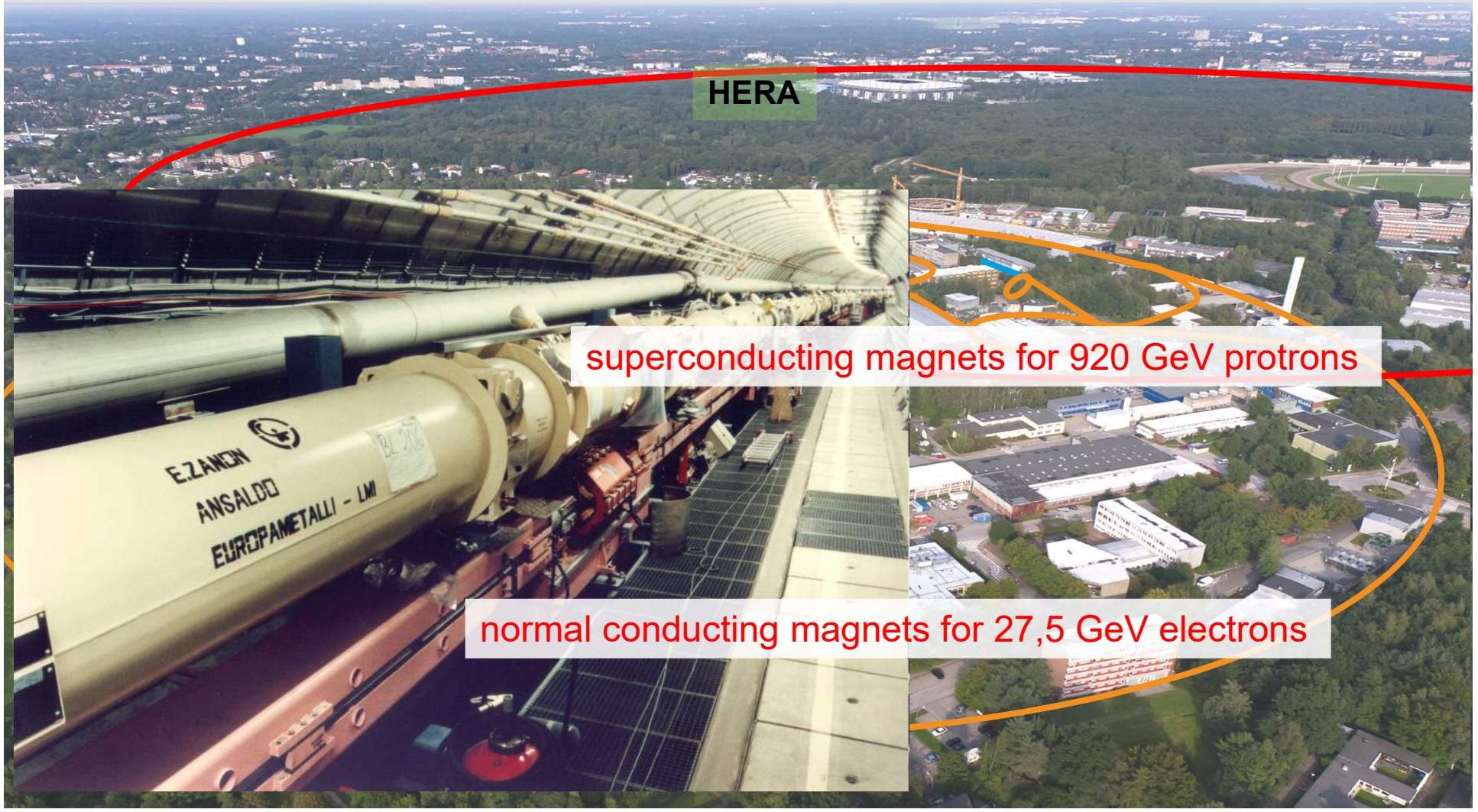

Discussion time / exercise

Do you know any accelerator from your university / town / country ?

Which kind of accelerator is it? (cyclotron, synchrotron, linear accel.)
Which application area is it dedicated to? (HEP, synchrotron radiation, medicine)
and
Which are the main parameters that describe it ? (particle type, energy, current…)

if no ➔ pick up an accelerator from CERN or DESY (see table)

hint: you may search in internet ...