Beam Generation at the DESY II Test Beam Facility

Test Beam Coordinators:
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HELMHOLTZ

beamline for schools
cern.ch/bl4s
Powered by CERN & DESY

DESY.

Basics

Particle Acceleration

- The basics:
  - Acceleration in electric fields

    $$F = q \cdot U$$

  - Lorentz Force, bending the beam in a magnetic field

    $$F = q\, v \times B$$

- In reality many additional effects play a role
  - Relativity
  - Real fields etc. are not ideal
  - ...

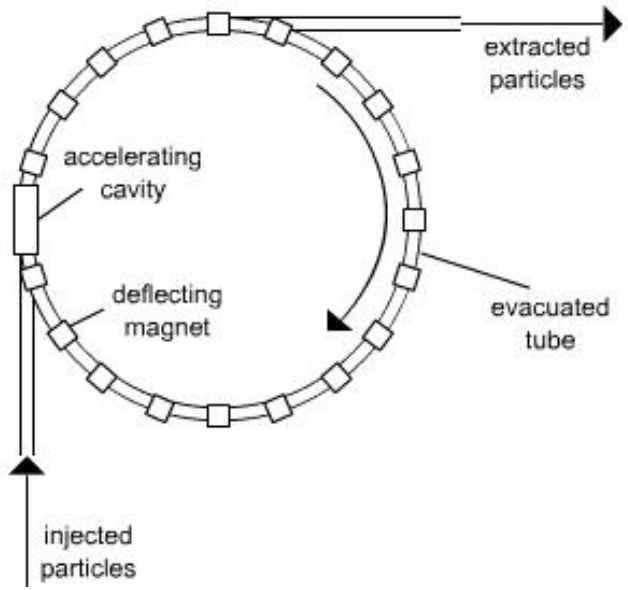
… let's ignore the "details" for now

Source: Wikipedia

Accelerating the Beam

Synchrotron

- “Classic design” for a circular machine
  - Particle beam travels around a fixed closed-loop path
  - Magnetic field bending the particle beam increases with time **synchronized** to the increasing kinetic energy of the particles
- Ingredients
  - Injector
  - Evacuated beam pipe
  - Accelerating cavities
  - Bending magnets (dipoles)
  - Focusing magnet (quadrupoles)

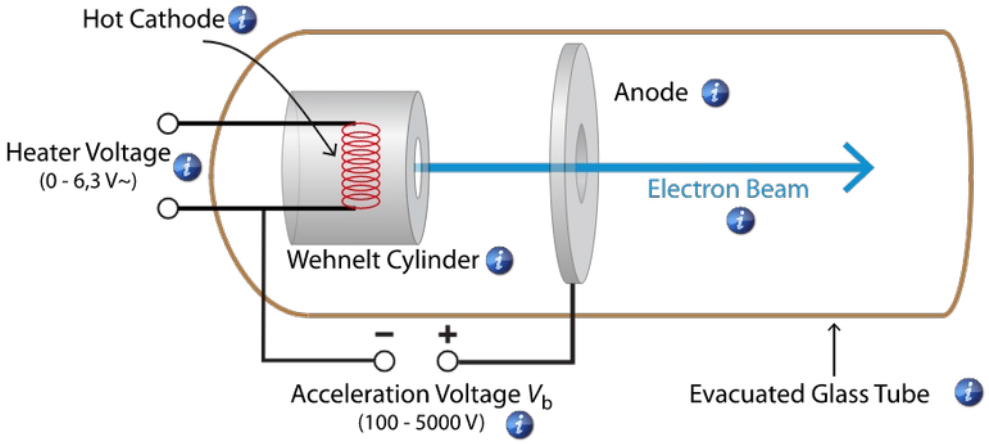


- Can be build for electrons/positrons, protons...
- Most frequently used accelerator type: DESY II, PETRA, LHC are all synchrotrons

Accelerating the Beam

Producing Electrons

- Before accelerating electrons, we need to produce them
- Most commonly used source: "*Electron Gun*"
- Most well-known is the Cathode Ray Tube
  - Thermionic emission of electrons
  - Emitter size is (a few) mm^2
- The guns at DESY
  - Just a "bit" bigger and stronger
  - Emitter size 28 cm^2
  - Each pulse has with several 10^9 electrons
- Electrons leave the gun section with 100 / 150 keV



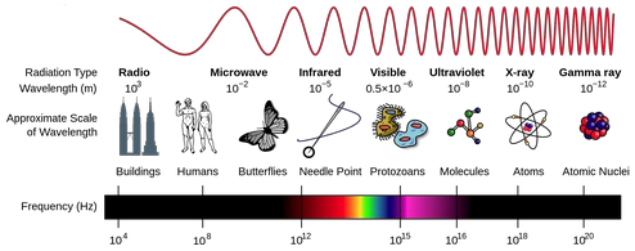
from https://virtuelle-experimente.de

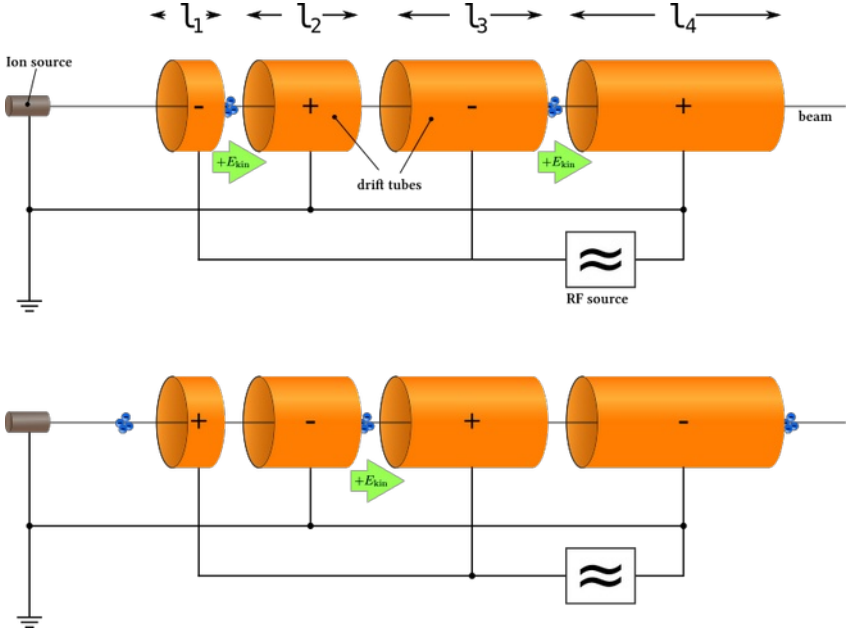
Accelerating the Beam

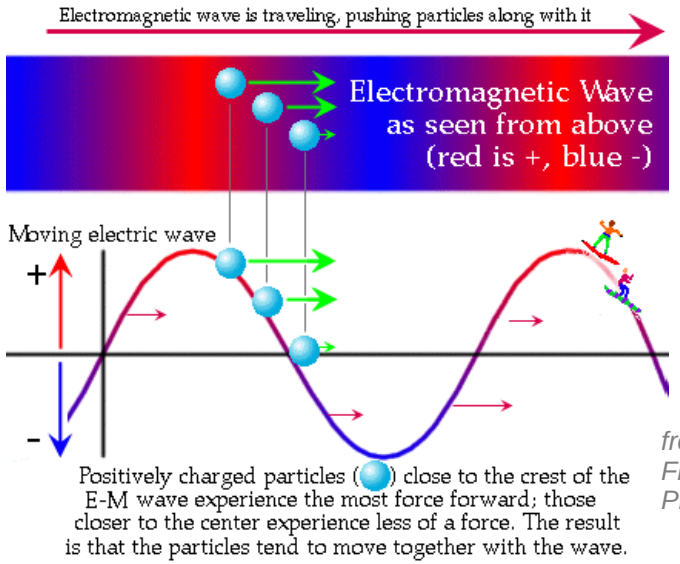
Linear Acceleration

- As magnets cannot cycle very well from 0 to several T field, after their production, the electrons are accelerated first in a linear accelerator: here the Linac II
- Acceleration principle:
  - Particle ride on a “wave”
- LINAC II
  - 12 accelerator modules:
    - 6 to accelerate from 100 keV to 450 MeV energy
    - 2 to adjust beam energy precisely
    - 4 spares
  - 70 meters in total, gradient 17 MV/m
- At the end of the Linac II:
  the electrons reached a momentum of 450 MeV

Cavity radio frequency: Microwaves
(1 mm – 1 m, 300 GHz – 300 MHz)





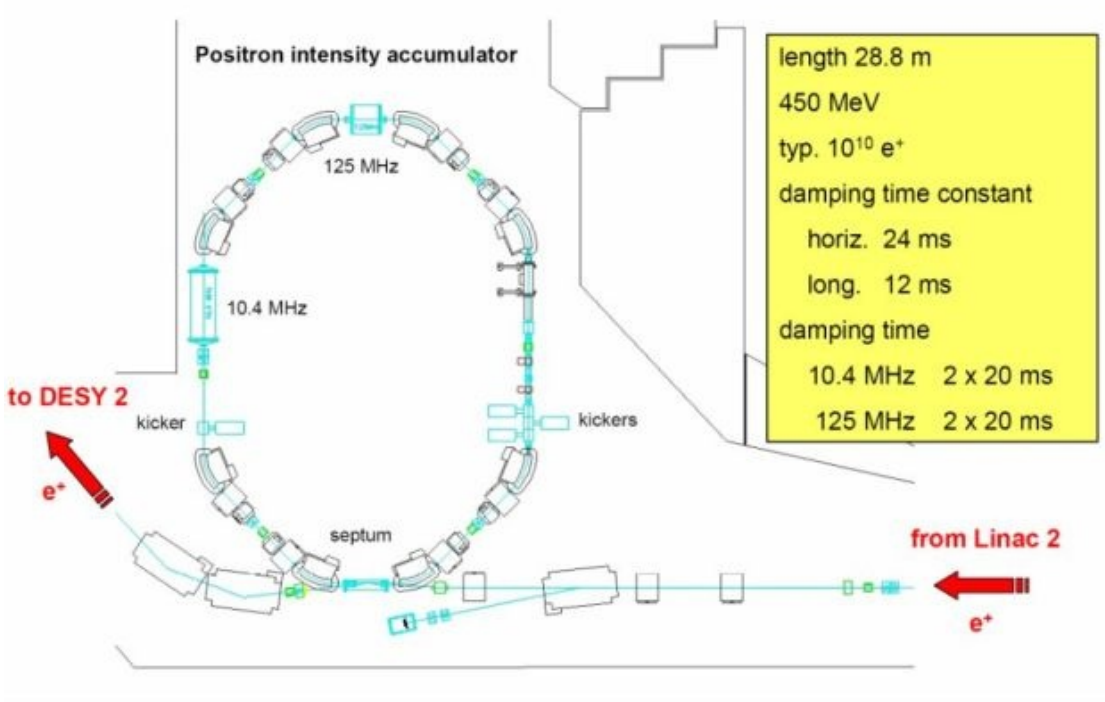


from: “Overview of Accelerators: From CRTs to Colliding Beams” Prof. Robin D. Erbacher, UC, Davis

Accelerating the Beam

PIA - Positron Intensity Accumulator

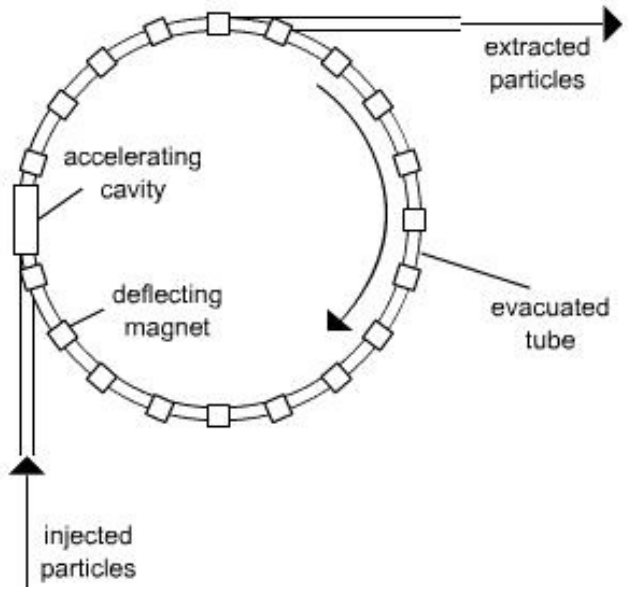
- In principle one can go from the linac to the synchrotron
- At DESY II, we have a tiny synchrotron in-between:
  PIA - Positron Intensity Accumulator
  - Circumference 28 m
  - Collects several bunches from the LINAC II and merges them (increase intensity)
  - Adjusts bunch structure (damping, compression) so it suits the DESY II synchrotron
- After this we finally are ready for the main synchrotron



Accelerating the Beam

Synchrotron

- “Classic design” for a circular machine
  - Particle beam travels around a fixed closed-loop path
  - Magnetic field bending the particle beam increases with time, synchronized to the increasing kinetic energy of the particles
- Ingredients
  - Injector
  - **Evacuated beam pipe → no losses, scattering with gas molecules**
  - Accelerating cavities
  - Bending magnets (dipoles)
  - Focusing magnet (quadrupoles)



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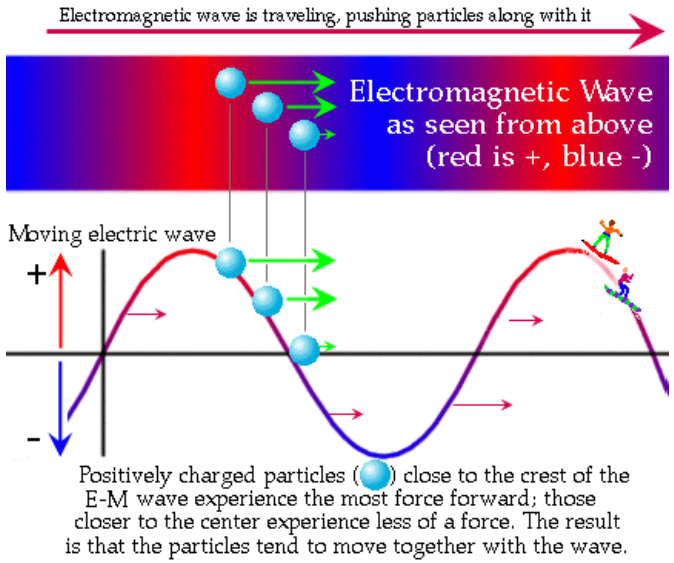
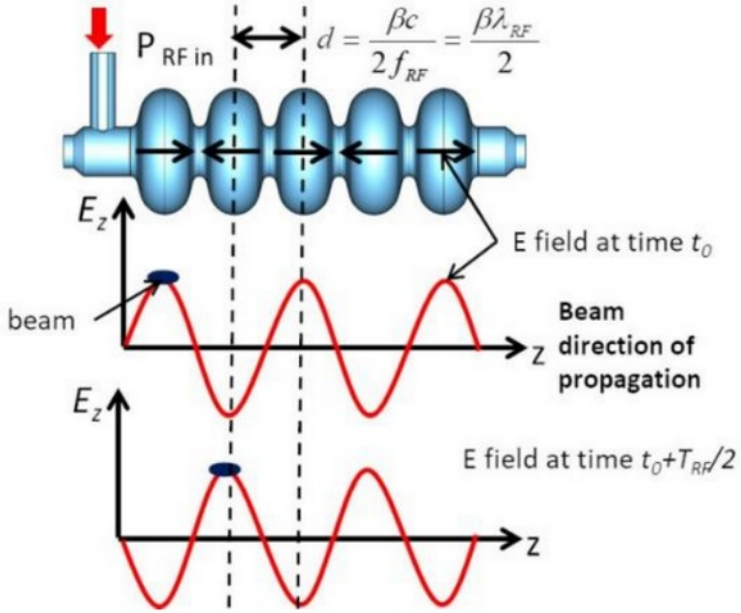
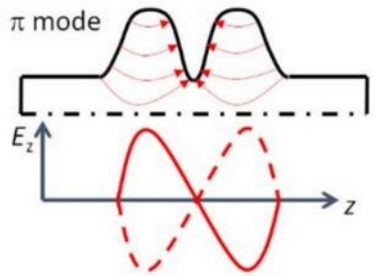




From Proceedings of the CERN–Accelerator–School course: ”Introduction to Accelerator Physics LINAC” by D. Alesini



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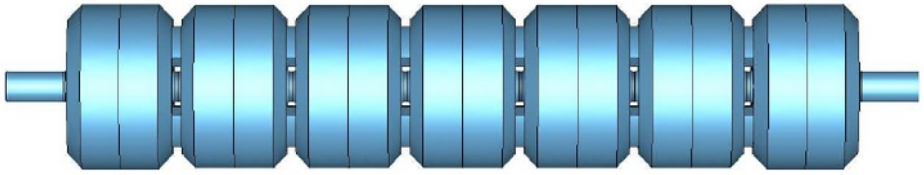
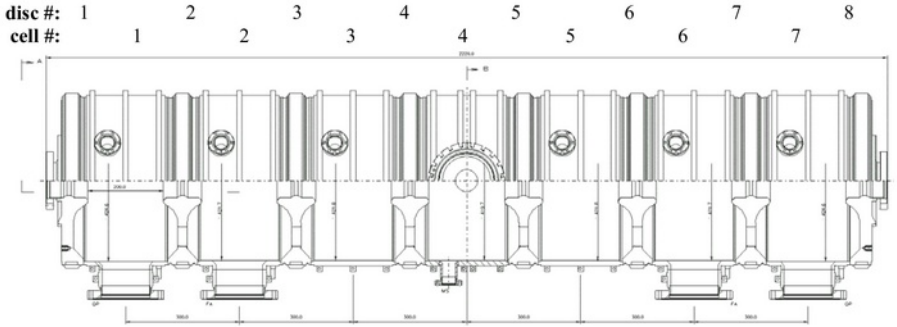
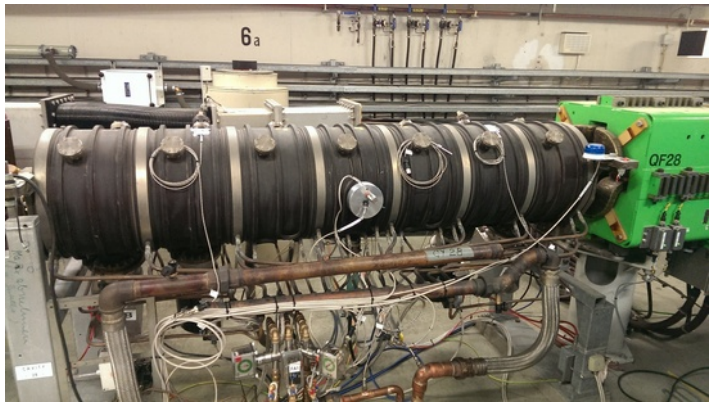


Figure 2: The PETRA 7-cell cavity (500 MHz) with beam tubes.





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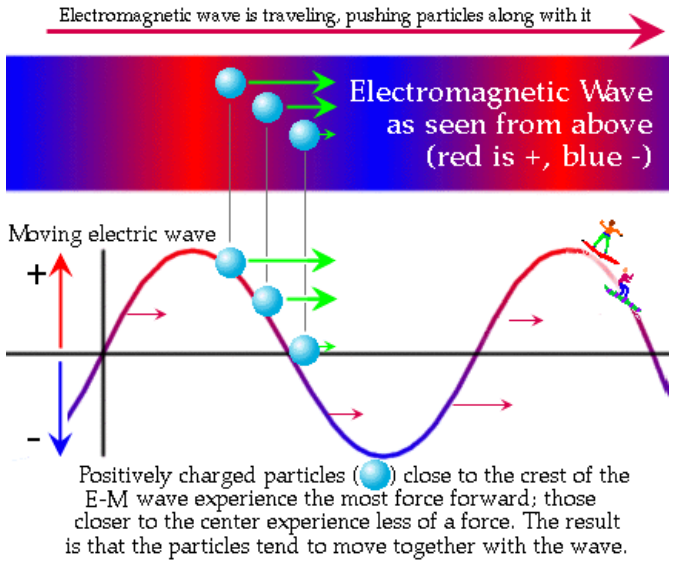
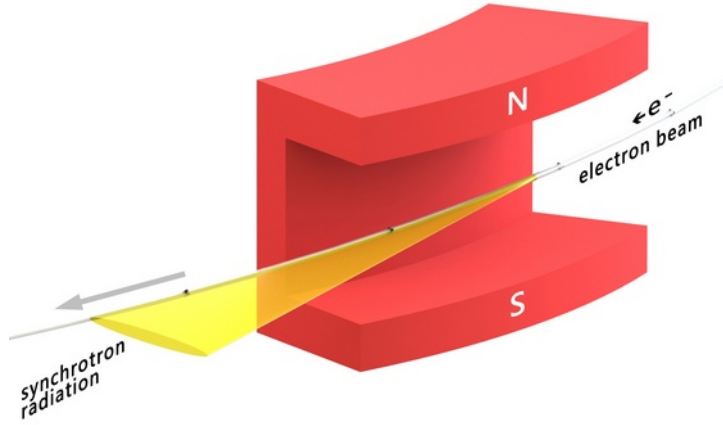


Acceleration cavities to get a more energetic beam:
450 MeV → 6.3 GeV.
But also to even out losses due to synchrotron radiation: emitted when relativistic charged particles are subject to an acceleration perpendicular to their velocity (a ⊥ v)



from https://www.nsrrc.org.tw

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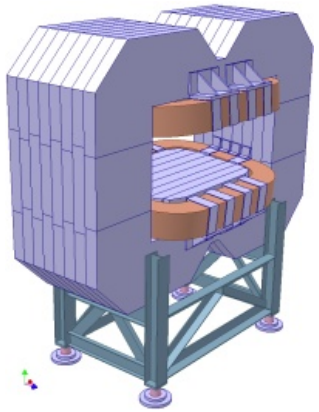
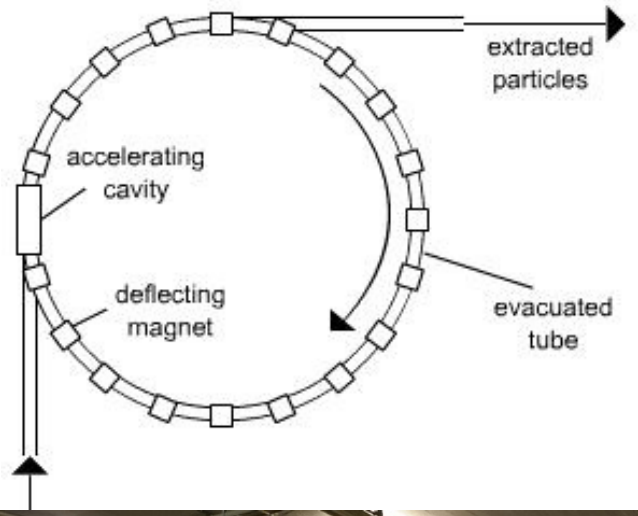


from https://panda.gsi.de/

$$F = q\, v \times B$$



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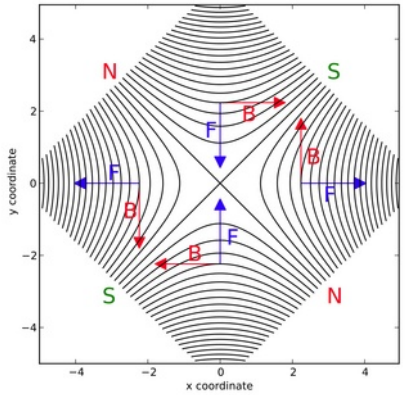
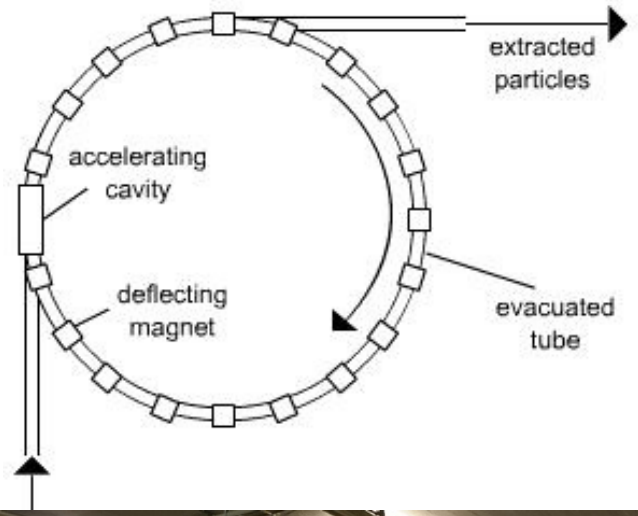


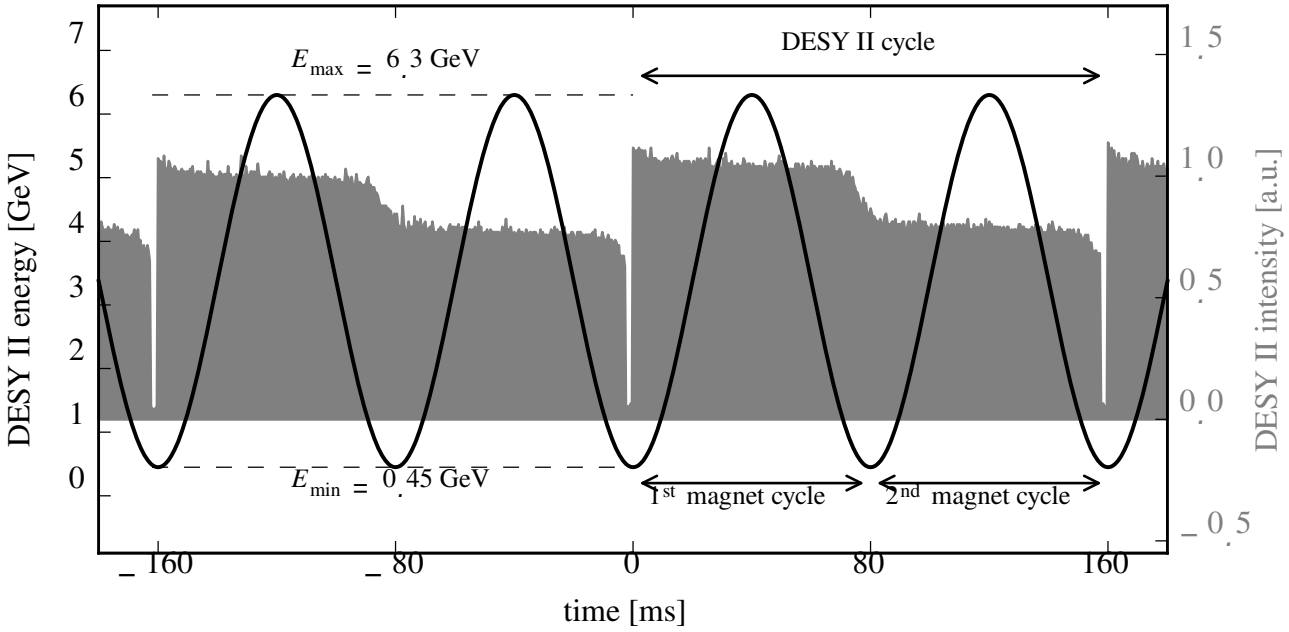


from Wikipedia

Accelerating the Beam

The DESY II Synchrotron

- Circumference: 292.8m
- Continuously cycling at 12.5 Hz
  (a quarter of the power grid frequency of 50 Hz),
  this means all magnets ramp up and down
  with this frequency (80 ms magnet cycle)
- Extraction at any time and any energy
  - e.g. 3 or 6 GeV particles for PETRA
  - 4.5 GeV particle for DORIS (when it still existed)
- Injection at 450 MeV from the L-Weg (PIA)
  happens usually every second cycle
- Very flexible … but
  - The beam quality suffers after the deceleration (increased multiple scattering at lower energies)
  - In its current configuration, it can't run stable at a certain energy

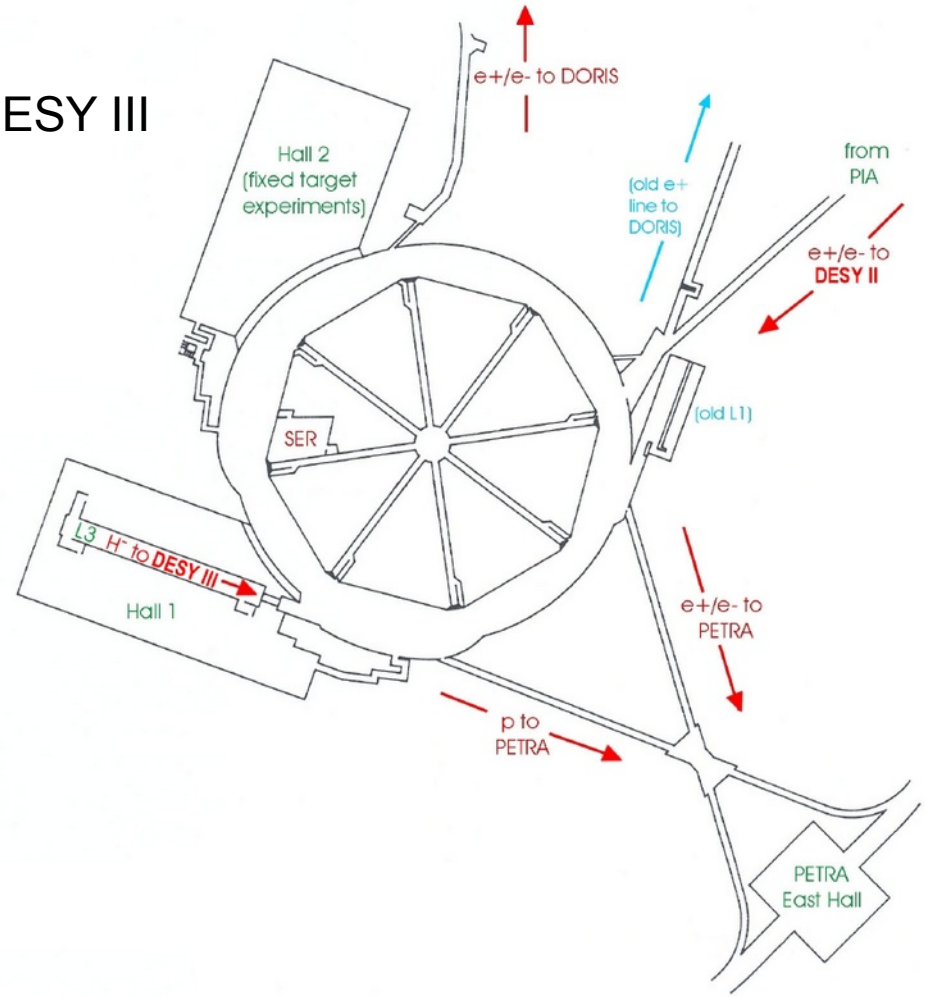


Accelerating the Beam

The DESY II Synchrotron

- 1985: first run tests of DESY II (electrons beam up to 10GeV)
- 1986: DESY I switched off and converted into proton synchrotron DESY III
- 1987: DESY II takes over and delivers beam to DORIS (→2013), PETRA and the test beam area
- Main objective today: Injector & top-up for Petra III

- DESY II Test Beam Facility runs parasitically
  - Low beam intensity during PETRA top-up, high otherwise
  - Mix depends on PETRA III operation mode and needs
- High demands on the availability by photon science community
  - 2017 Run : 99.25% availability
  - So there is beam for users whenever needed



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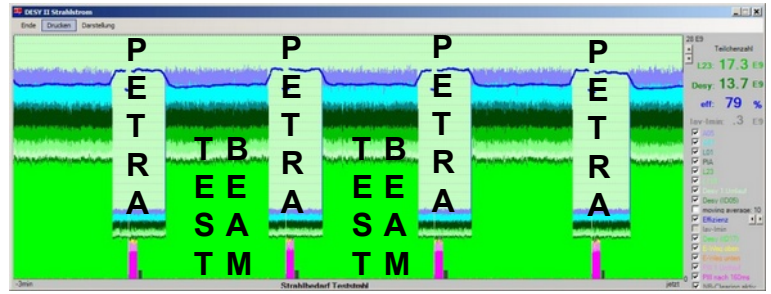
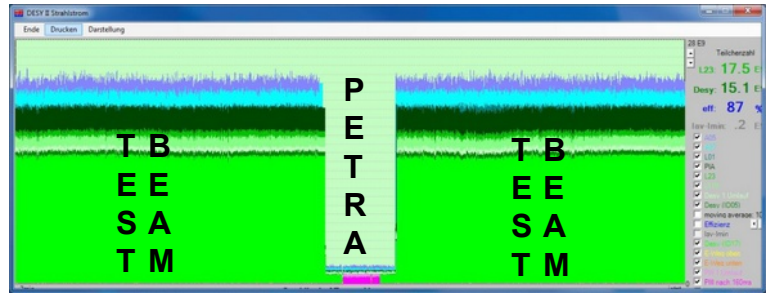
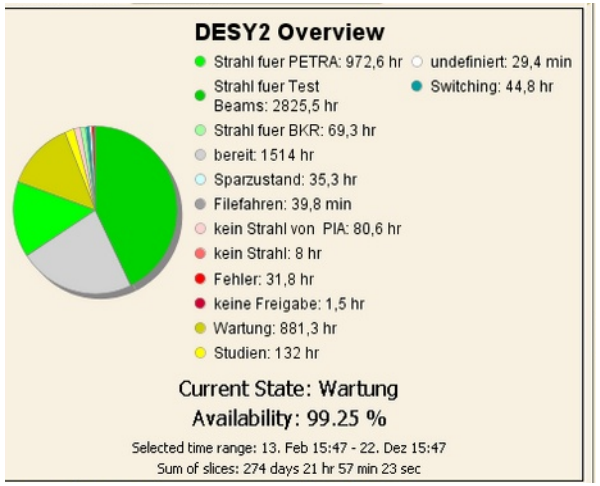




3 minutes



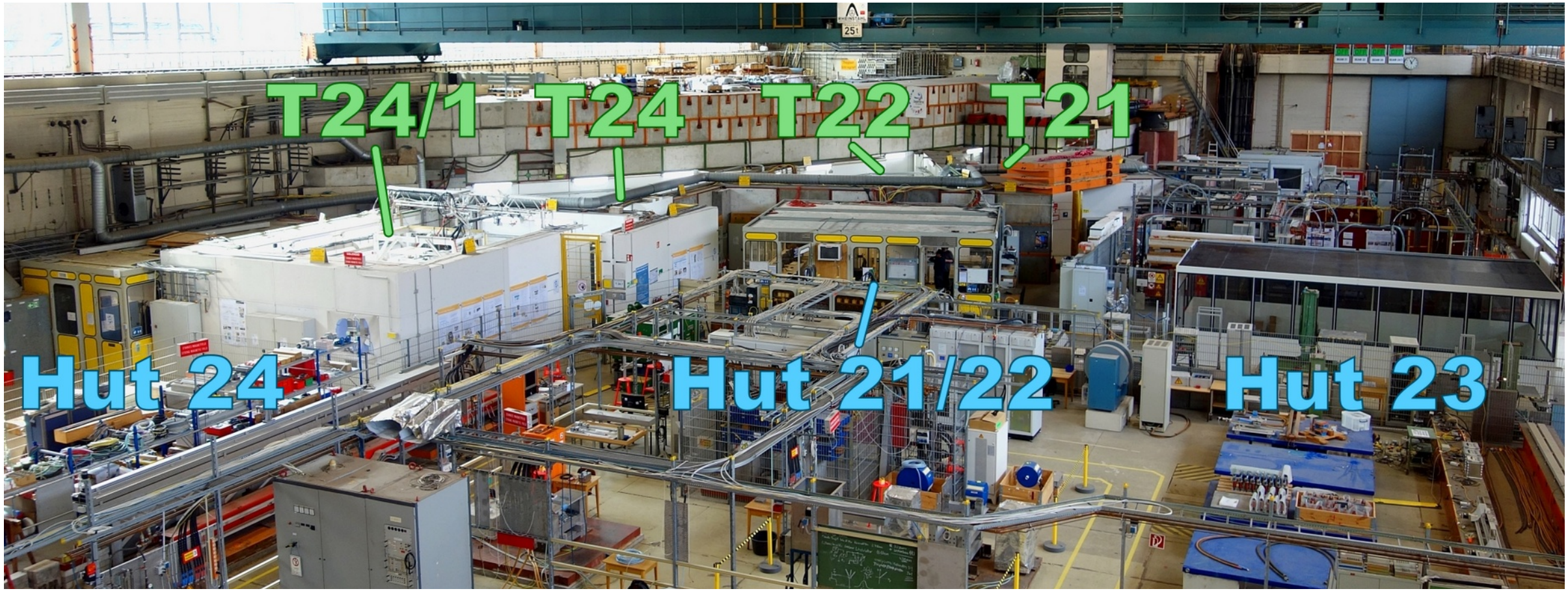
Testbeam Facilty

Overview and Beam Generation

Test Beam Hall

Overview

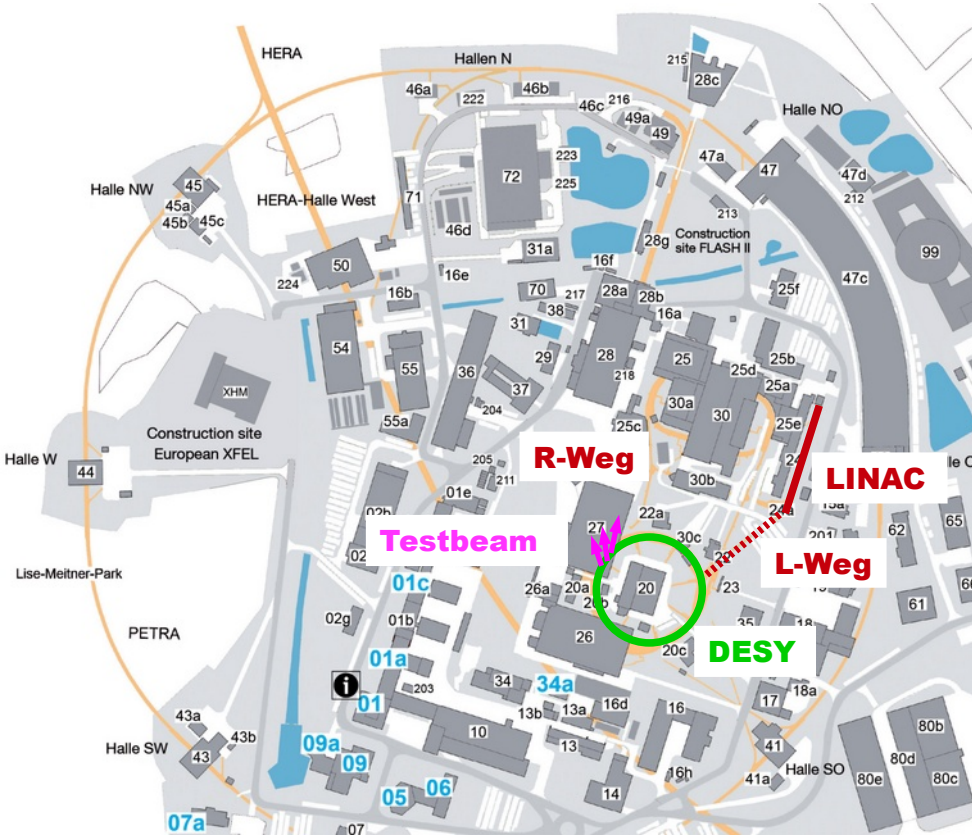
- Three beamlines feeding 4 beam areas located in *Hall II* (building 27), in the center of the DESY campus



Facility and Beam Generation

Overview

- Facility parasitically fed by DESY II synchrotron
  - 1 bunch per fill
  - 1 MHz circulation frequency



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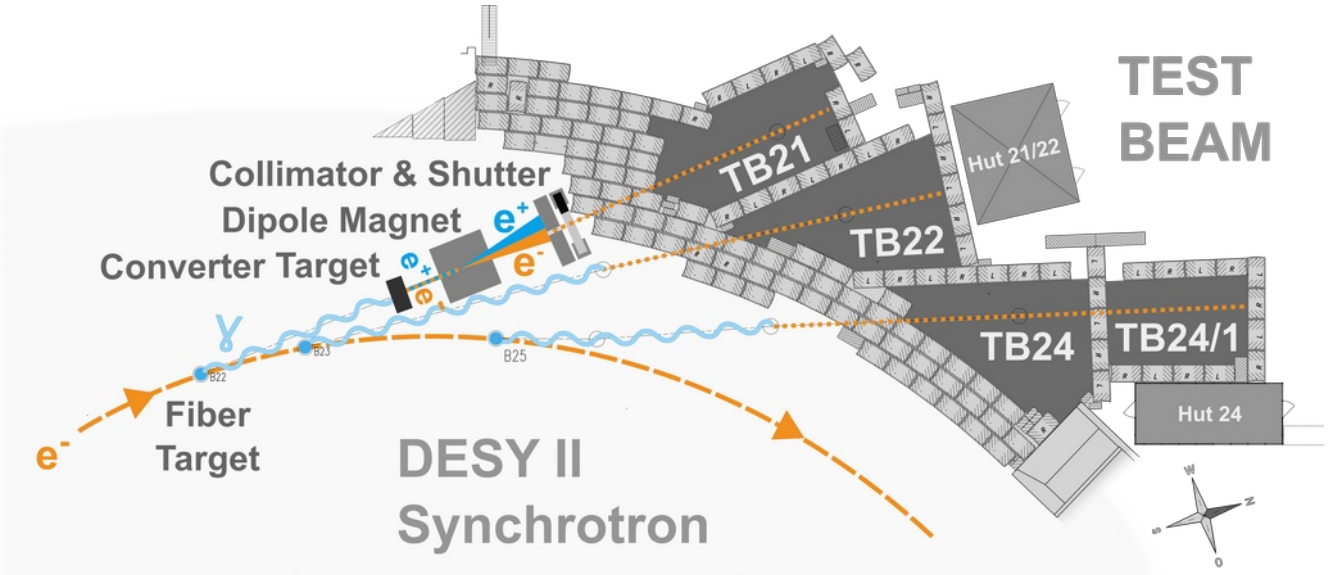
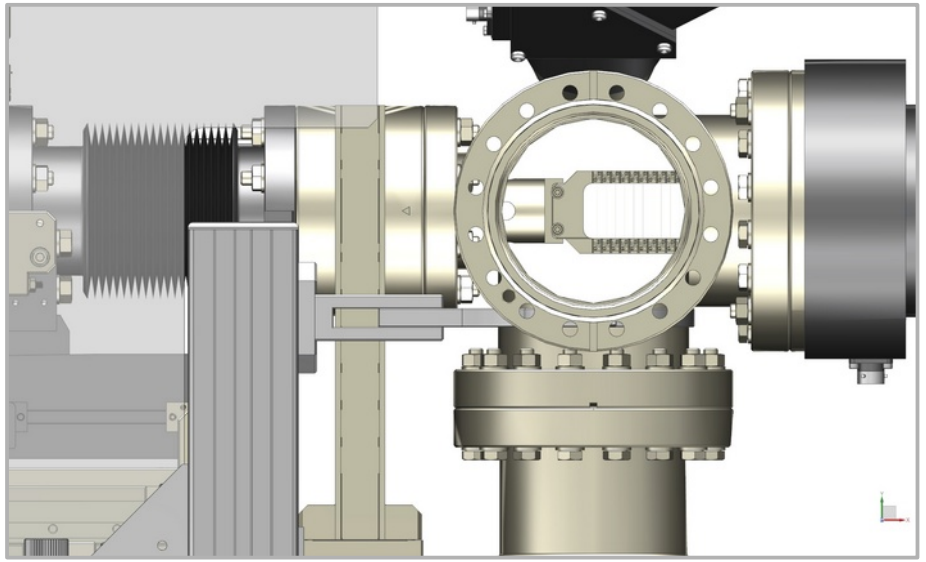


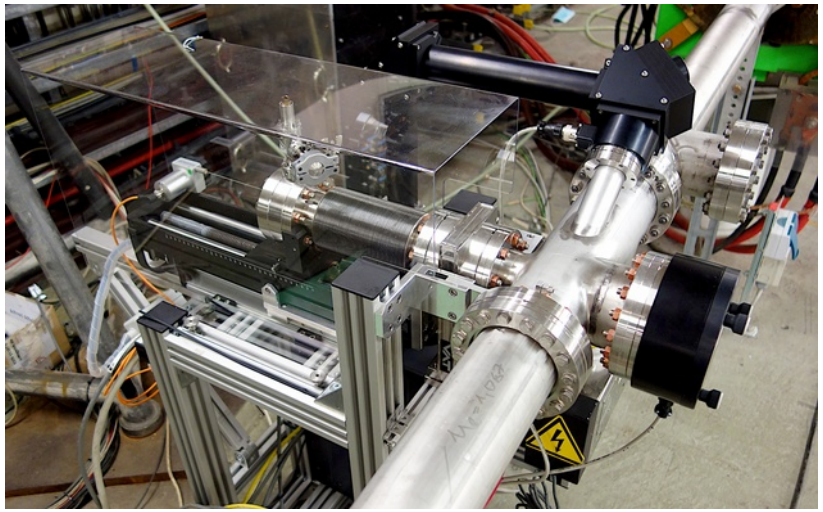
- Test beam generation:
  - 3 primary carbon fiber targets generate bremsstrahlung photons
  - Conversion at secondary target to e^+/e^- up to 6 GeV
  - Energy selected with dipole / collimator combination

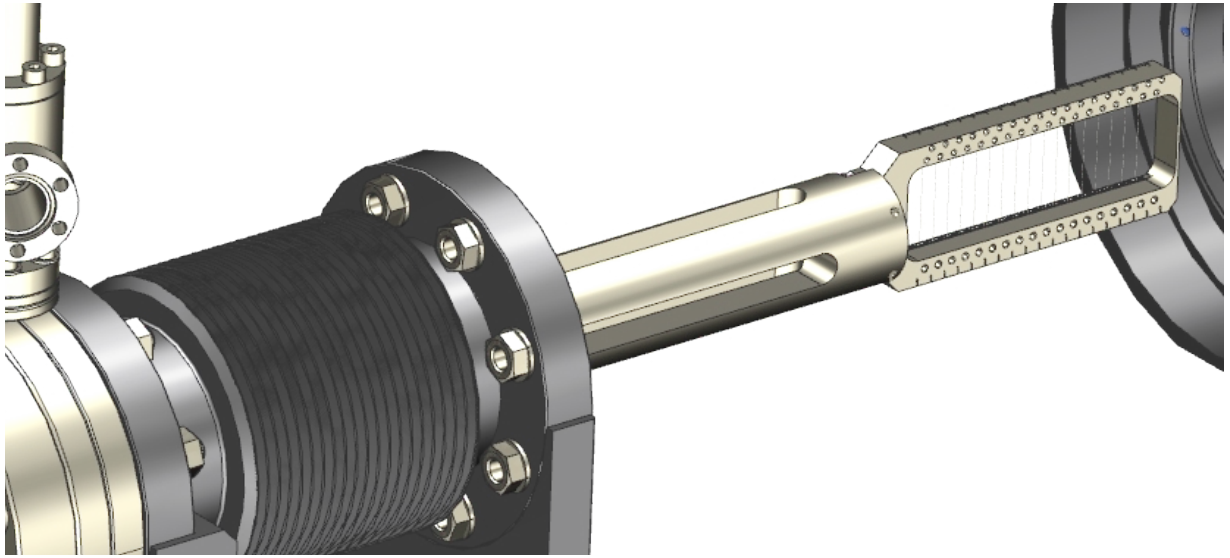
Facility and Beam Generation

Primary Target



- In the primary target station there's a "harp" with ten carbon fibers, 7 µm thick
- One the these is driven into the electron beam in DESY II
- When an electron hits the fiber, there can be Bremsstrahlung (= "*braking radiation*"): deceleration of the electron leads to energy loss which is emitted by photon radiation (similar to synchrotron radiation)





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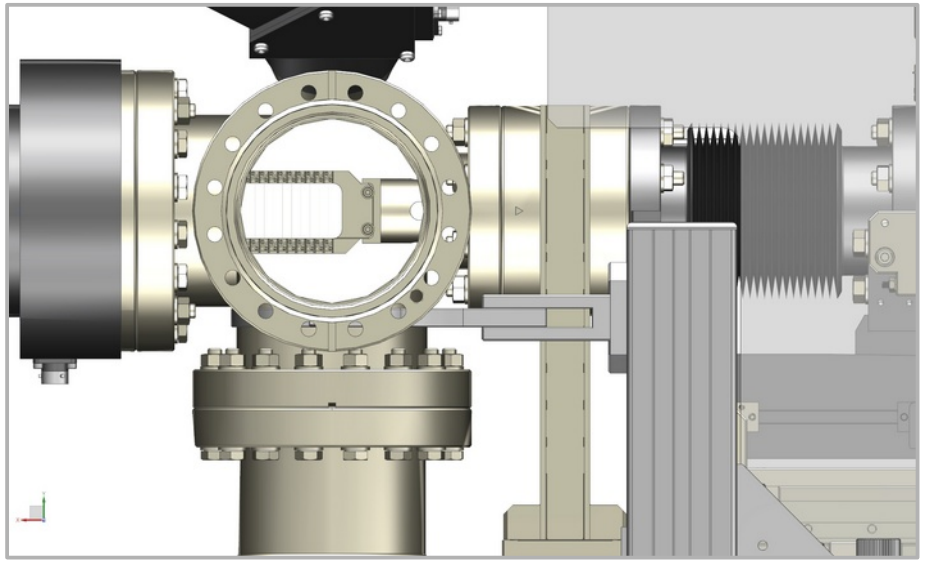
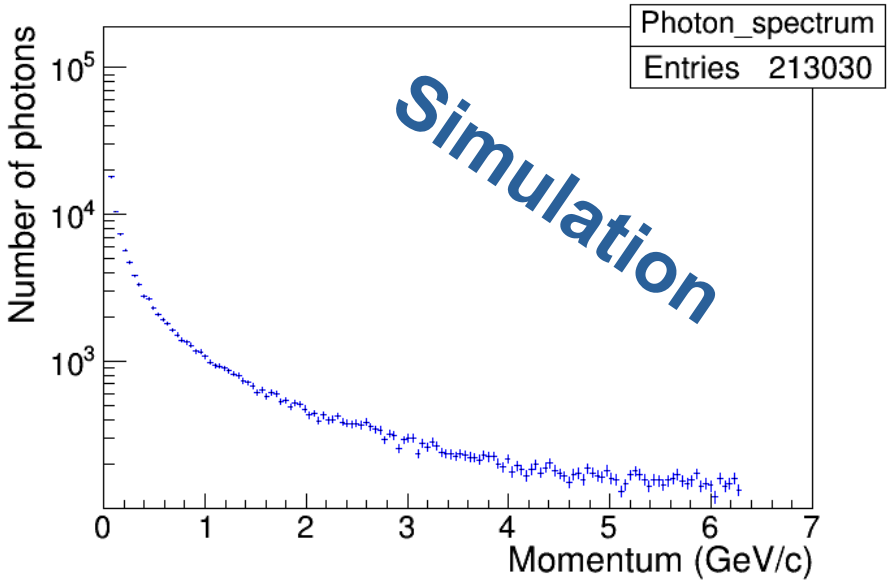
- Bremsstrahlung spectrum
  - Steeply falling of … but still lots of photons per bunch hitting the secondary target.
  - Maximum energy of the photon depends on the beam energy
  - Due to cycling, makes it a bit complicated

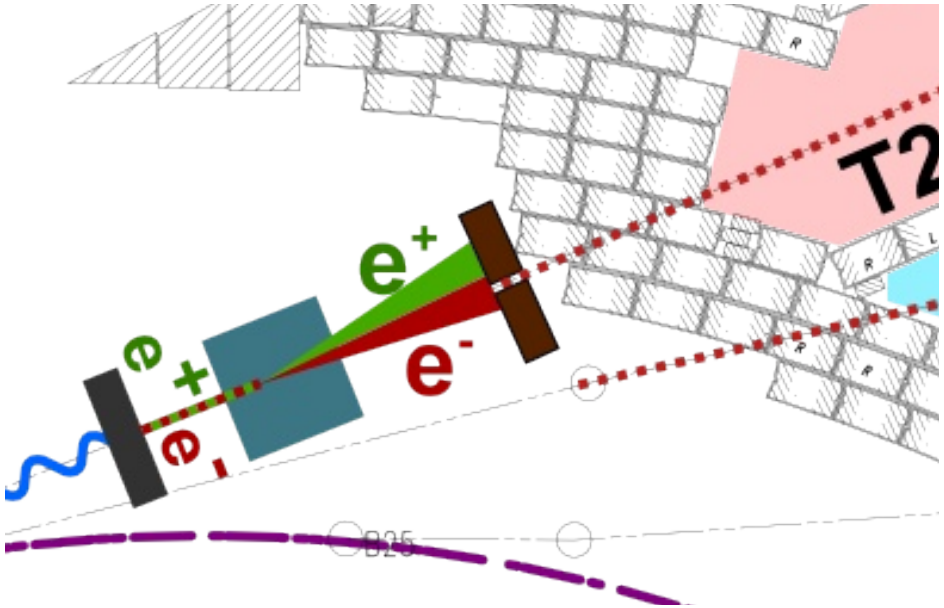


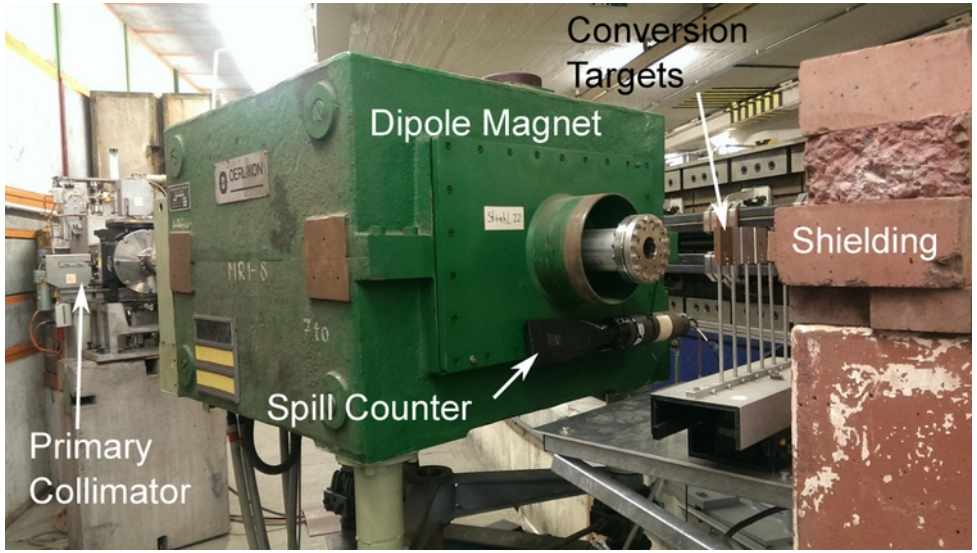


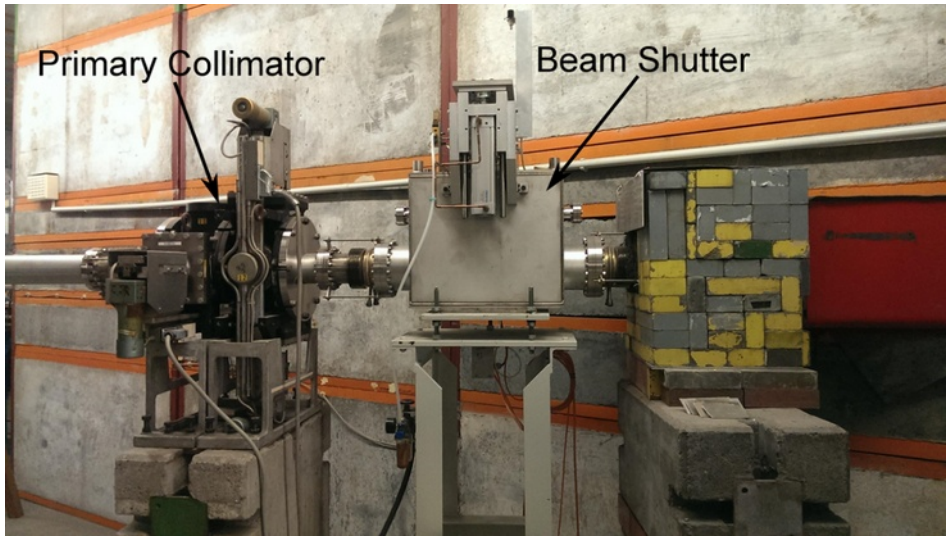
Facility and Beam Generation

Secondary Target

- Bremsstrahlung photons from the primary target hit a secondary target: thin metal plate
  - Here they can do pair production: $\gamma \rightarrow e^+e^-$
- So now we have electrons and positrons (energy distribution rather flat)
- The collimator is at a fixed position
- By adjusting the magnet power, we can choose the electron energy





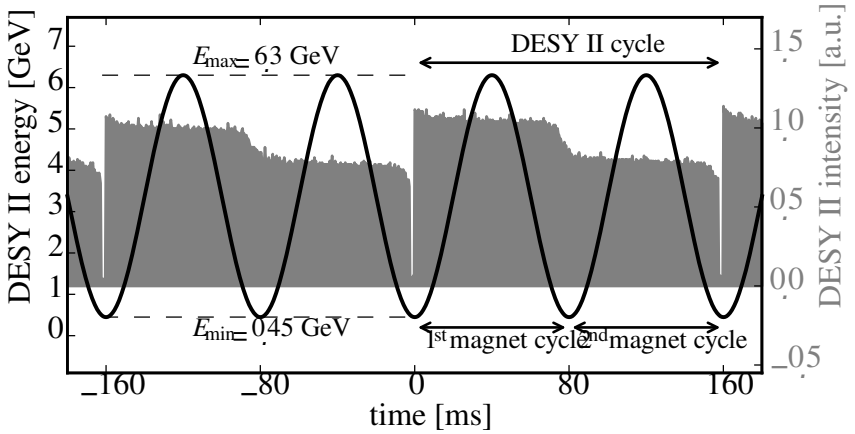


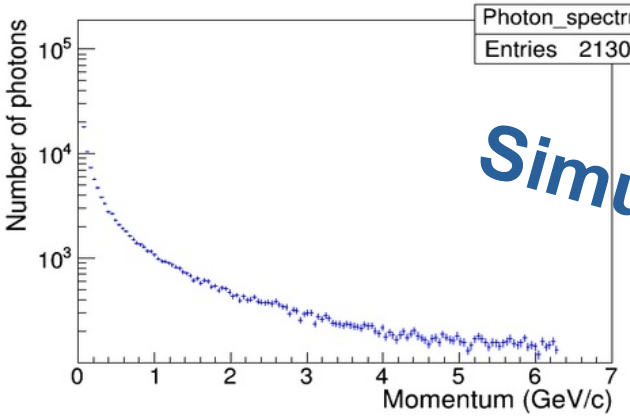
Facility and Beam Generation

Beam Properties

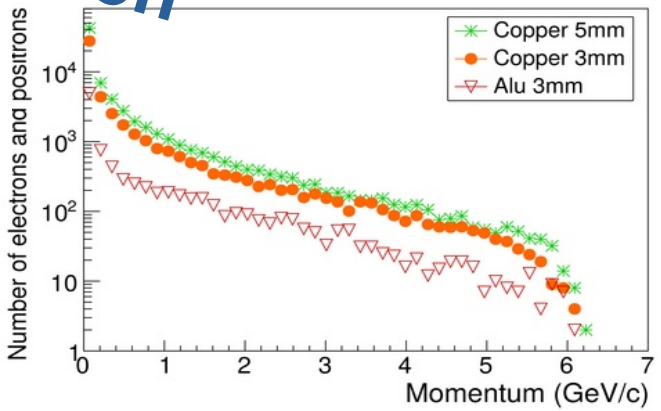
- Physicists are usually interested in: rate, energy (precision)
- Tricky to determine:
  - DESY II synchrotron cycles energy, intensity can vary
  - Bremsstrahlung spectrum (energy dependent) also depends how well the target is positioned in the beam (which is also not 100% stable) and the resulting photon beam has some divergence
  - Pair production spectrum (energy dependent)
  - Which energy is choosen
  - Collimator opening

… not as trivial as one would've hoped for





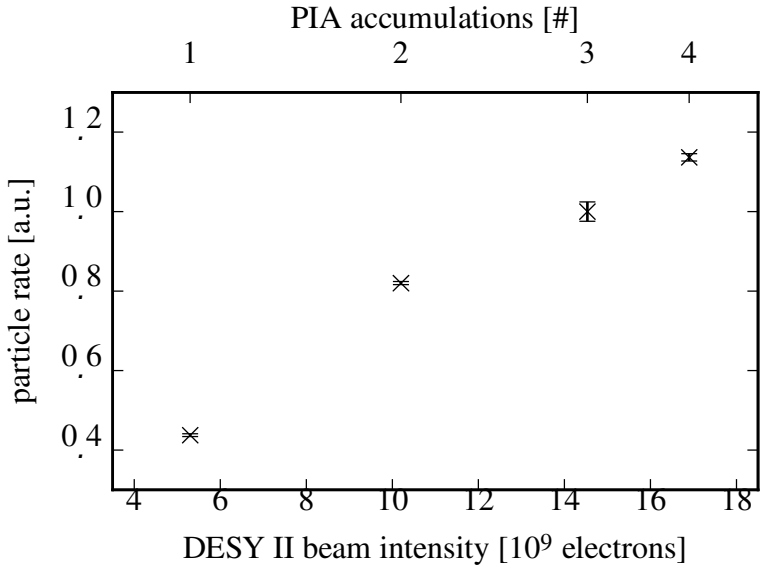
Simulation

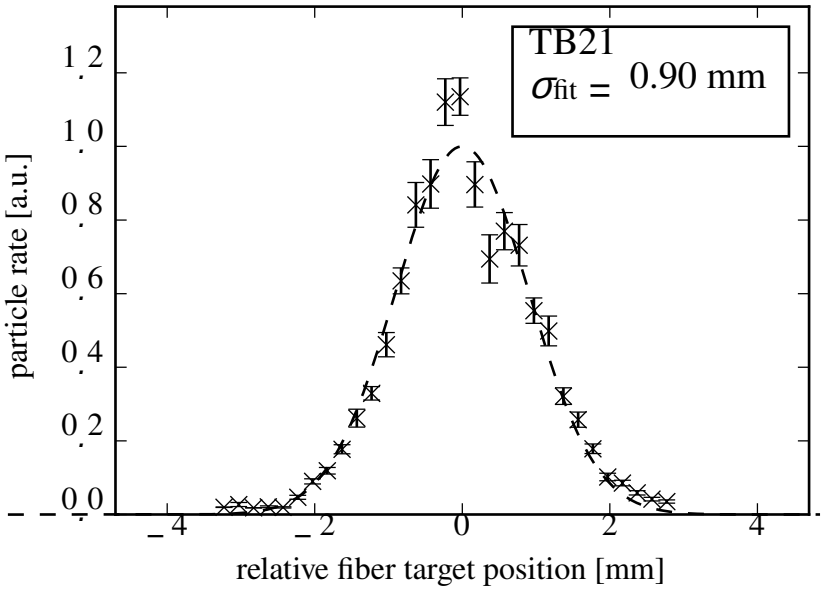


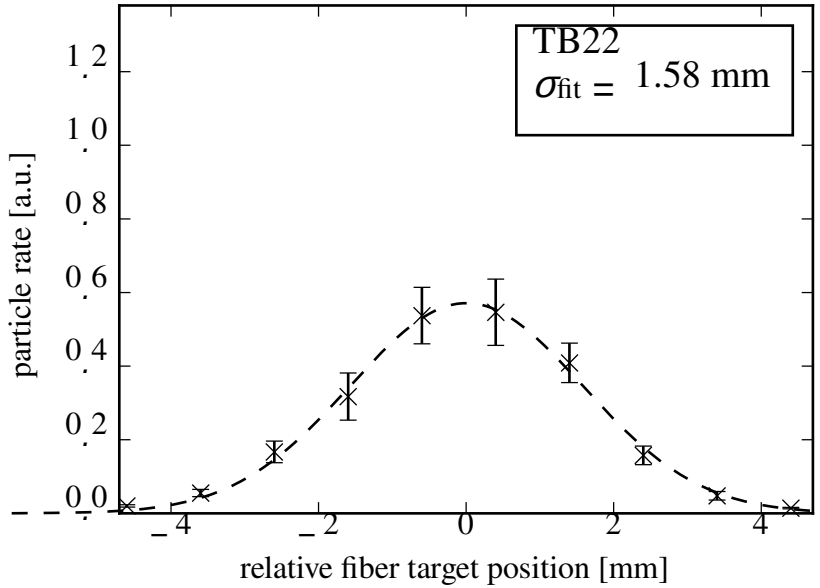
Facility and Beam Generation

Beam Properties

- A few measurements to get an idea of the dependencies
  - DESY II synchrotron intensity
  - How well the target is positioned in the beam
    + which beamline + how many targets are in overall



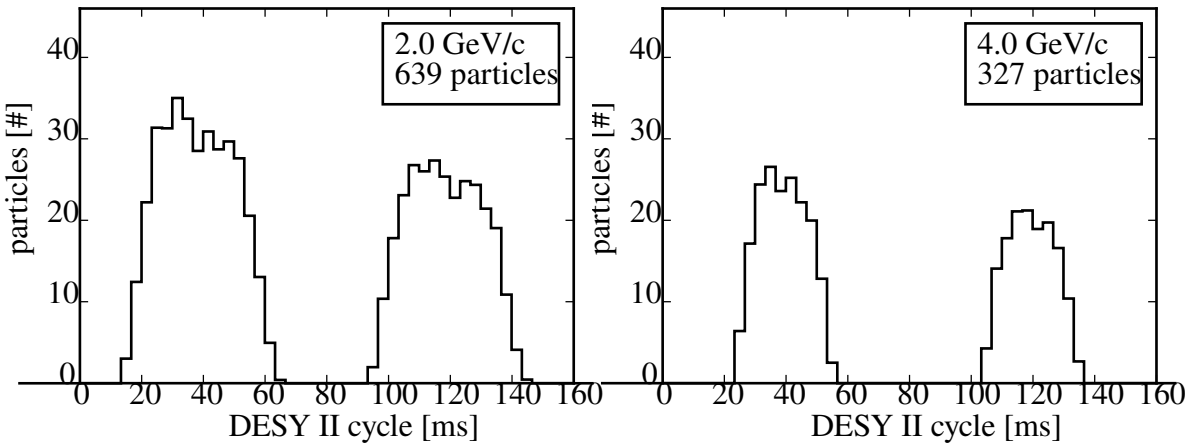


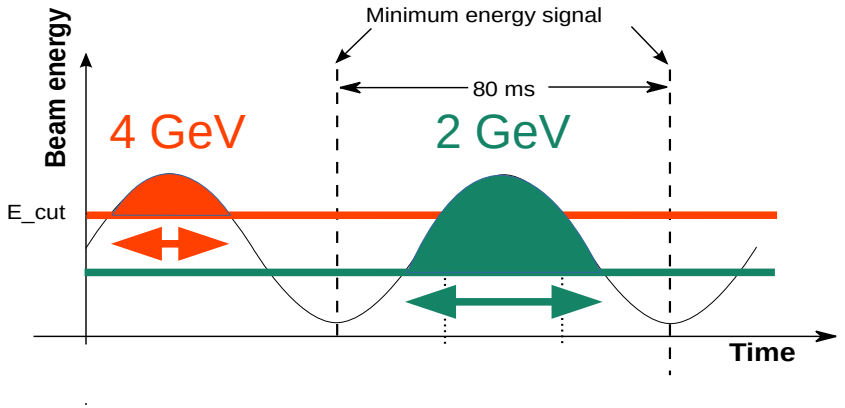


Facility and Beam Generation

Beam Properties

- A few measurements to get an idea of the dependencies
  - DESY II synchrotron intensity
  - How well the target is positioned in the beam
    + which beamline + how many targets are in overall
  - Energy dependence

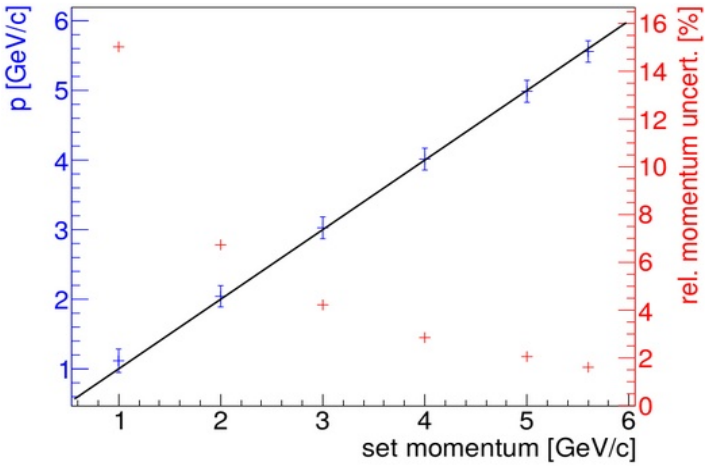


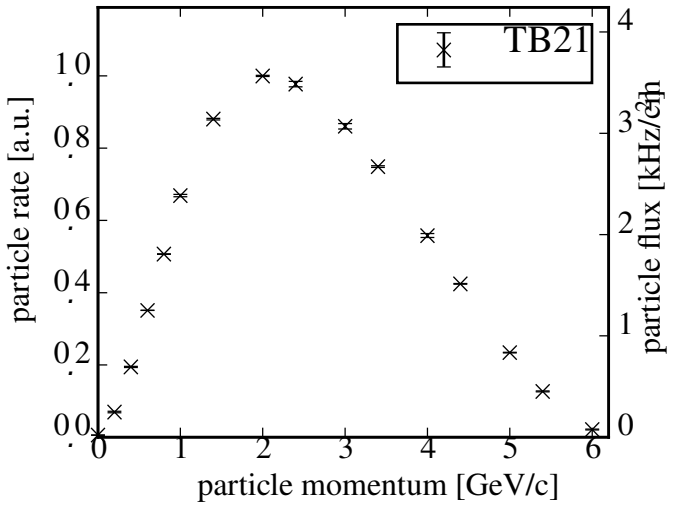


Facility and Beam Generation

Beam Properties

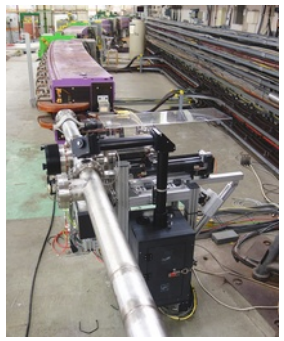
- A few measurements to get an idea of the dependencies
  - DESY II synchrotron intensity
  - How well the target is positioned in the beam + which beamline + how many targets are in overall
  - Energy dependence
  - Energy precision: Offset very small
    - Absolute spread rather independent of energy → relative spread smaller at higher energies
    - Can be influenced by the collimator setting (but less spread also means less rate, so you need to decide what's more important)
- In the end we arrive from 1 MHz bunch frequency in DESY II to a rate from several 10 Hz to several 10 kHz single electrons at a beam line



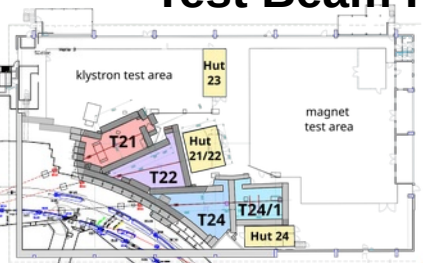


Overview

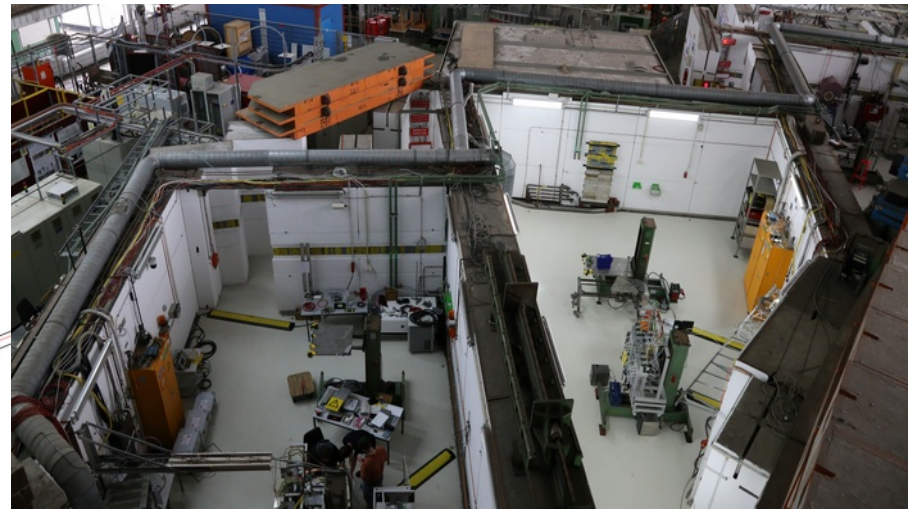
From Electron Gun to Beam Area



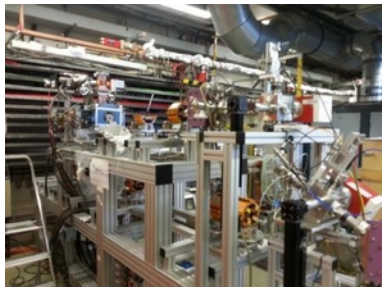
Test Beam Hall



Test Beam Generation



DESY II



Electron “Gun”

PIA

LINAC II