Beamline for Schools

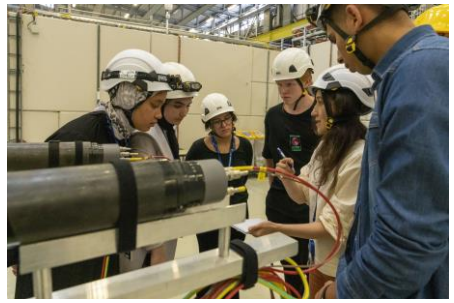
A world-wide physics competition for high-school students

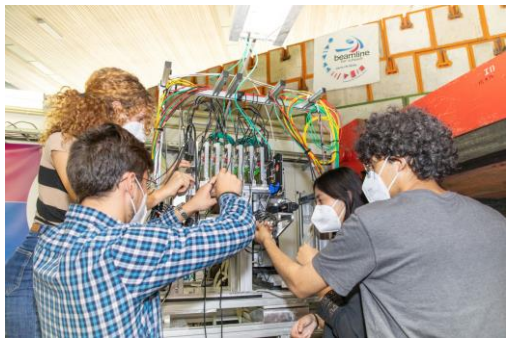
Beamline for Schools – The basic idea

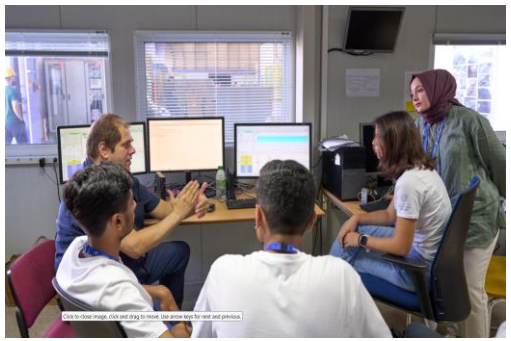
Teams of high-school students can propose an experiment to be performed at the beam facility of a particle accelerator

It is a great opportunity for them to get in touch with the world of physics research

Students can interact with scientists from CERN and DESY (and many other institutions around the world)







The venues

In the past, some participating teams have been invited to extended visits to Fermilab and INFN institutes.

We are in contact with other physics labs but there is no concrete collaboration yet.

My vision / wish: establish BL4S as a “brand” with a head quarter at CERN and “franchises” in other institutes.

The team

- CERN
  - Core team:
    - Project manager
    - Technical coordinator
    - Two support scientists
  - Helped by volunteers:
    - ~40: Proposal evaluation
    - ~60: National contacts
    - ~5: Data analysis
    - ~2: TDAQ and simulations

- DESY
  - One support scientist
  - Administration
  - Volunteers for data analysis

More volunteers wanted….

The BL4S 5-season year

- October / November: Publicity
  - Posts on CERN and DESY social media
  - E-mails to many e-groups (previous BL4S participants, alumni of CERN teacher programs, etc.)
  - Messages to other networks (e.g. IPPOG, alumni of teacher programmes) and Web sites
  - Celebrities
  - Permanently looking for additional channels for publicity
- November to April
  - Student teams are forming and work on their proposals (and videos). We are answering tons of questions
  - On-line events
- April to June
  - Evaluation of the proposals and selection of the winners
- June to September
  - Preparation of the winning experiments (including test beam)
- September
  - Winners come to CERN / DESY

The financial side of the business….

- Main expenses:
  - Salaries of support scientists (CERN / DESY)
  - Travel and subsistence of the winners (CERN / DESY)
  - Prizes for the shortlisted teams as well as shipping and customs (CERN)
    - …and shipping of the prizes
  - Materials for the winning experiments (CERN / DESY)

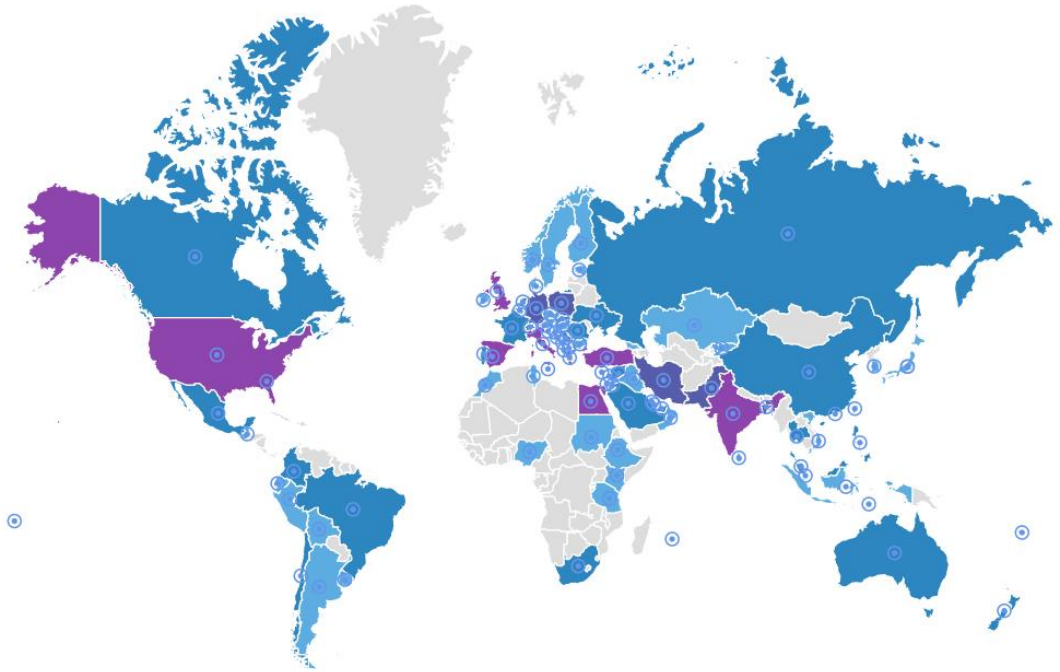
- Main income:
  - CERN / DESY
    - Staff: Institute
    - Rest: 3rd party money via the CERN & Society foundation
- Total cost per year (only 3rd party money): ~CHF 150.000 – 200.000

CERN & Society Foundation

Impact – Statistics 2014 to 2024

Year	Number of teams
2014	292
2015	119
2016	150
2017	180
2018	192
2019	178
2020	198
2021	289
2022	304
2023	379
2024	461

Total number of countries: 108
Total number of teams: 2750
Total number of students: >20.000
Hours spent per team on the research for their proposal: ~30

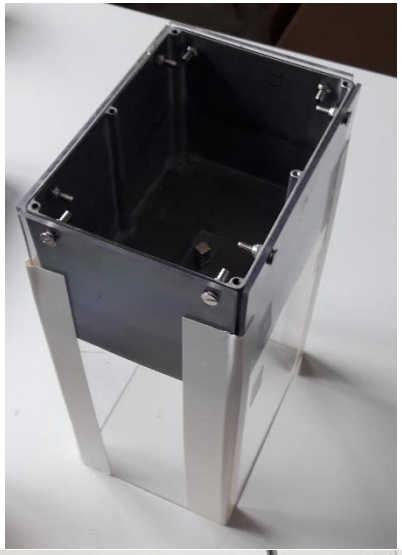


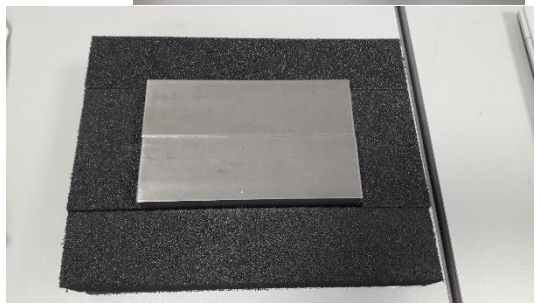
Practical information

- Teams: min 5, max 9 people, ≥ 16 years old (if invited to CERN/DESY)
- Enrolled in high-school in the current school year
- Each team has to be led by an adult, «coach », max 2 per team

Prizes:

- Three teams will perform their experiments at CERN (2 teams) or DESY (1 team)
- About 10% of the teams will be shortlisted and get:
  - T-shirts, USB sticks
  - Cloud chambers, radiation detectors
- Special awards for the best video
- Up to 10-15 «physics outreach » awards offered by «Stars shine for everyone » (SSVI)
  - Optical telescopes
- Participation certificates for all participants





Experiment proposal

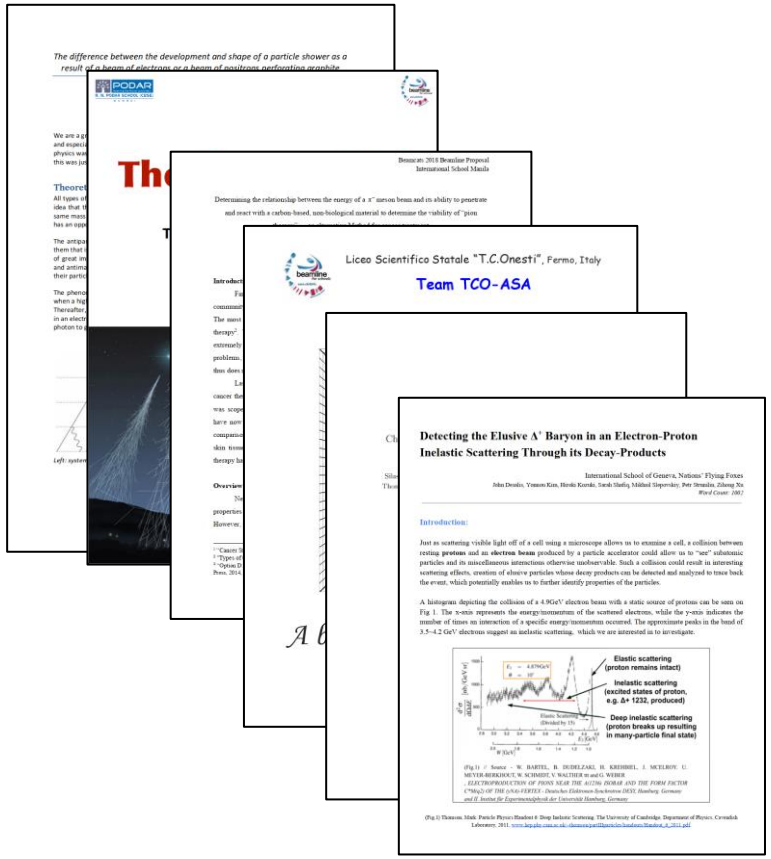
Written proposal (~1000 words):

- Motivation (~ 100 words)
- Proposal of a physics experiment (~800 words)
- What the students hope to take away from this experience (~100 words)

Optional:

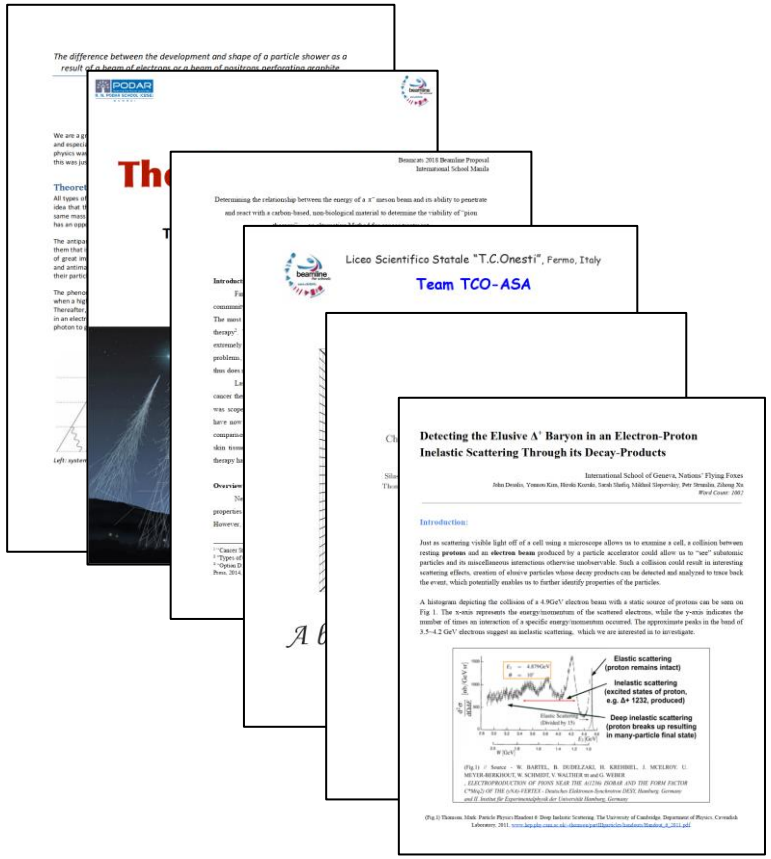
A creative video of 1 minute to explain the experiment or to present the team

Submissions accepted from January to April



Experiment proposal - II

All proposals are evaluated by scientists, engineers and other specialists



Evaluation Criteria:

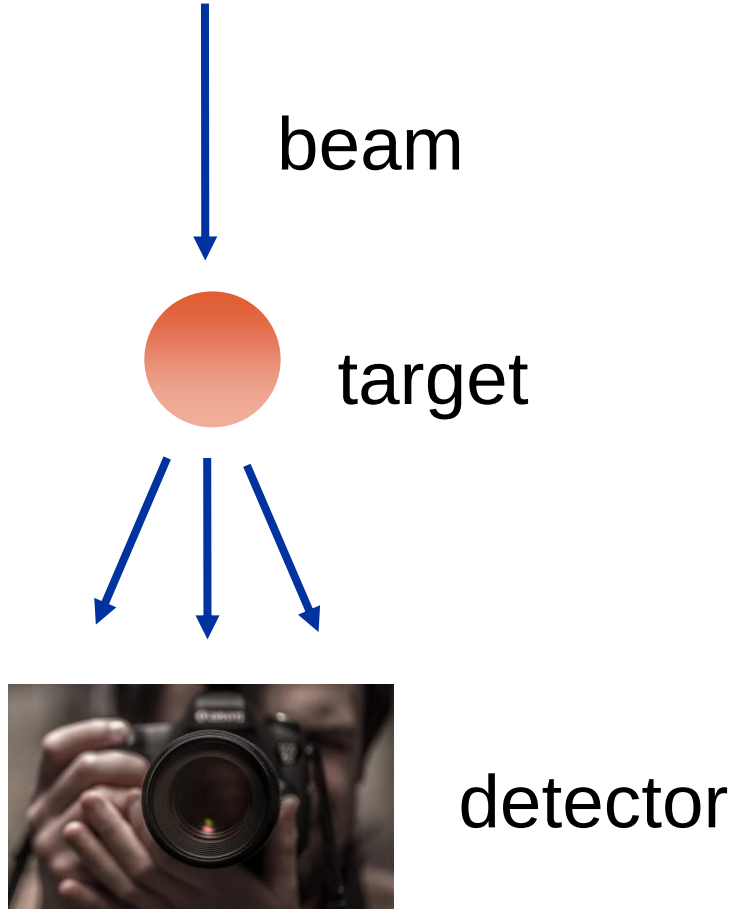
- Feasibility of the experiment
- Motivation of the experiment
- Creativity of the experiment
- Ability to follow the scientific method

Students are not alone!

Students and team coaches can get in touch with national contacts or the BL4S team : bl4s.team@cern.ch

Experiment requirements

- The proposal has to be designed for a test-beam facility in fixed target configuration
- Experiment design:
  1. Beam
  2. Target
  3. Detectors
  4. Trigger/readout



Proposal Extension

Participants can describe (~200 extra words) an outreach/education activity that they plan to organize for promoting science in an inclusive way!

Target audience: a part of the student's community usually less exposed to science

This extra proposal will give students access to the optical telescopes offered by SSVI

SSVI

Sterren Schitteren Voor Iedereen (Stars Shine For Everyone)
An Astronomy Project for children with disabilities and underserved communities around the world

”*All children in special education and vulnerable people should have the opportunity to admire the starry sky with the help of a telescope*.”

This is the starting point of the founder of the project Jean-Pierre Grootaerd.

https://www.ssvi.be

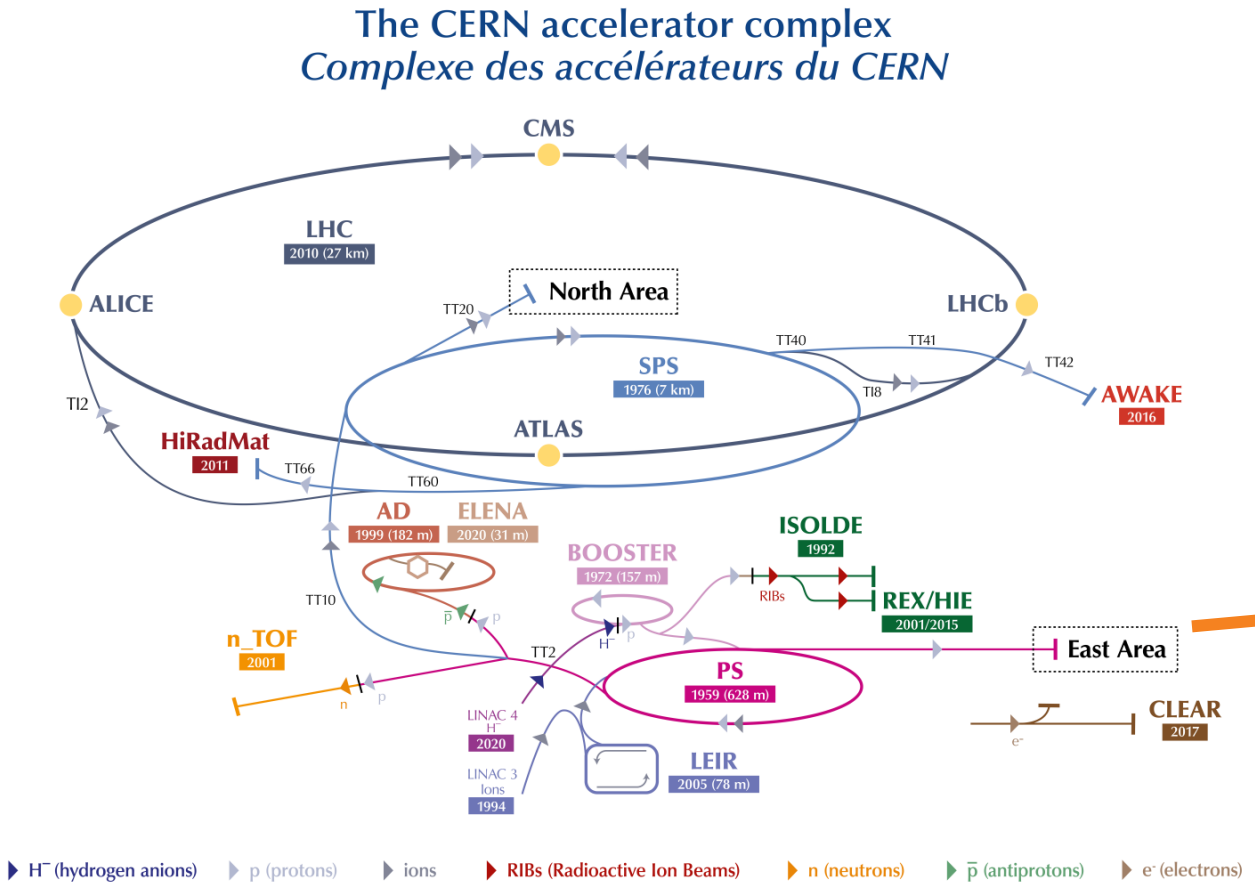
Additional content created by BL4S

- BL4S is organizing a series of on-line Zoom events for the participants of the competition. Individuals are invited as well as complete school classes
- Each event is repeated twice (9:00 and 17:00 CERN time)

- Program:
  - Introduction to CERN and DESY
  - Introduction to BL4S
  - Virtual visit to the ATLAS experiment
  - Virtual visit to the antimatter factory
  - 3rd party content. E.g. Life of an astronaut, engineering at CERN, astrophysics, etc.
- On-line participants are given time for questions
- Sessions are recorded for offline viewing

Schedule for 2025:
https://indico.cern.ch/category/19008/

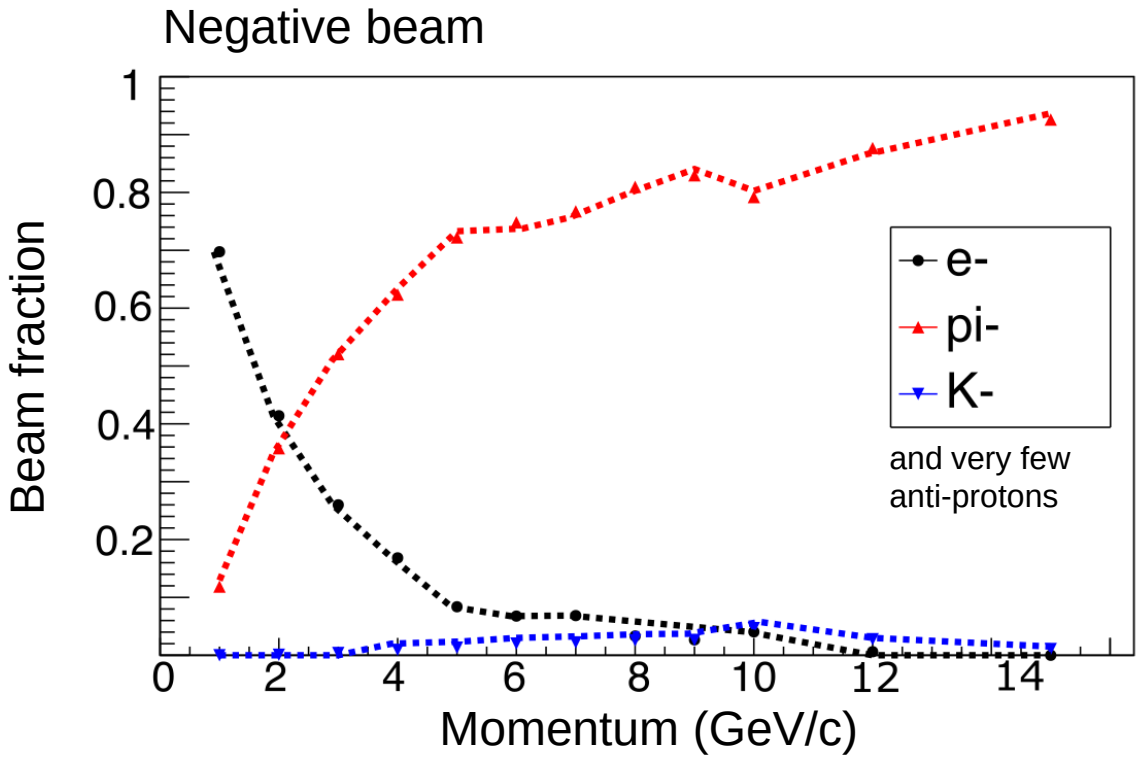
At CERN: Proton Synchrotron

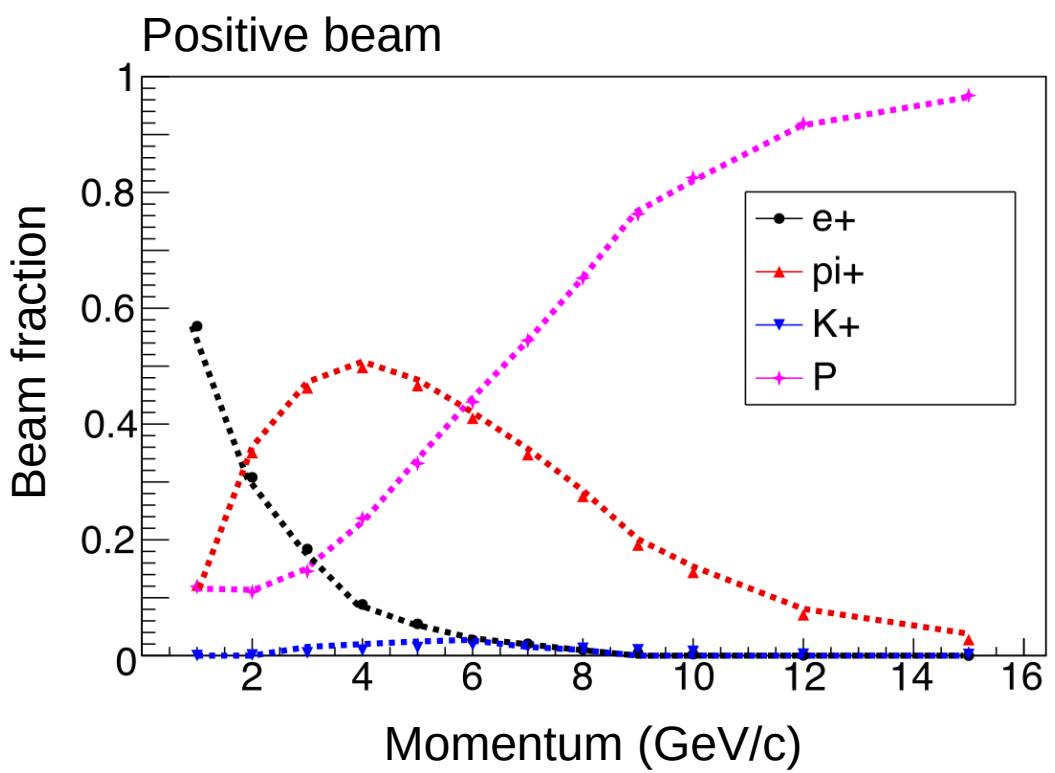


Beam properties at CERN

- Protons accelerated by the PS (up to 26 GeV) are smashed into a target
- The secondary particles (proton, kaon, pion, muon, electron) from this interaction are available in the experimental area
- Users can select the particle polarity (positive or negative) and momentum as well as the opening of the collimator
- Beam-spot size: diameter of ~ 2 cm

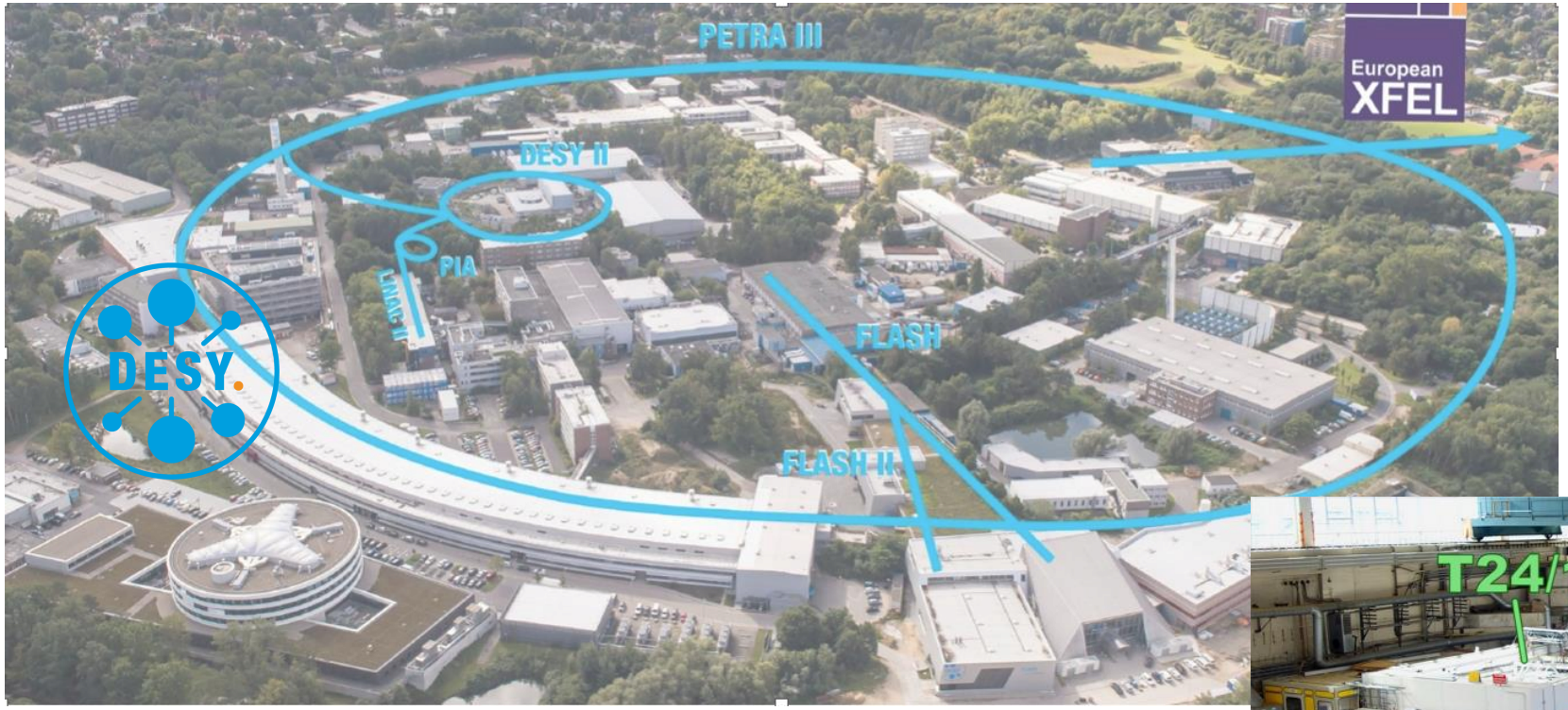
Beam properties at CERN





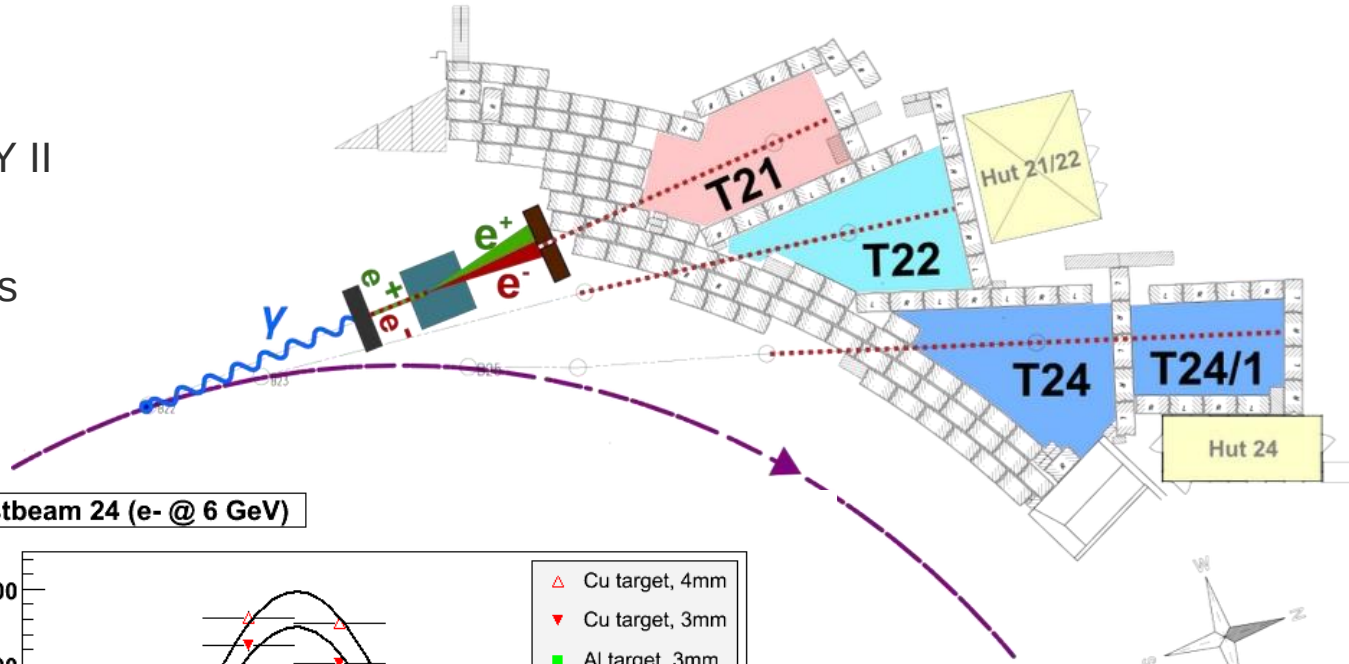
Energy range : 0.4-10/15 GeV
10^5 – 10^6 particles per spill of 400 ms
+ some muons

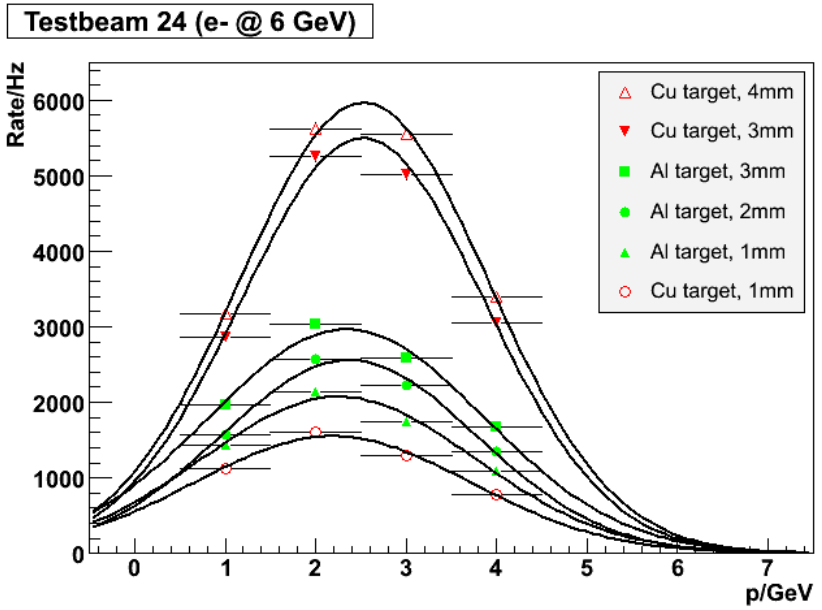
At DESY: DESY-II



Beam properties at DESY

- Photons produced by electrons accelerated by the DESY II up to 10 GeV and smashed into a target
- Electron/positron pairs are produced at different energies
- The user can select the particle polarity (positive or negative) and momentum as well as the opening of the collimator
- Beam-spot size: diameter of ~ 2 cm
- Beam momentum: 1 – 6 GeV/c



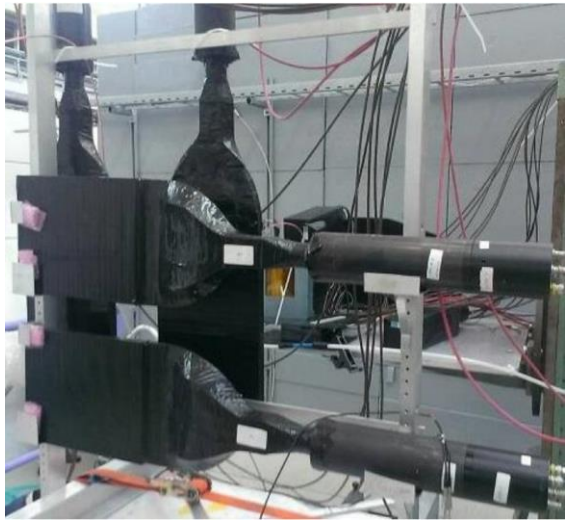


Detectors

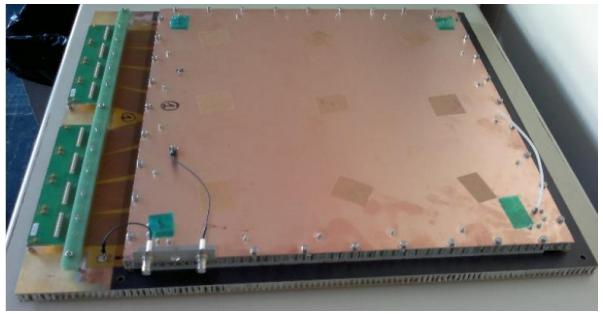
- Different detectors are available for BL4S
- The choice depends on the requirements of the proposed experiment and the lab (CERN/DESY)
- Each detector has its specific readout system
- The data-acquisition systems controls all the detectors and the experiment

Detectors - II

- Scintillators + photomultipliers – particle counting, trigger, TOF measurements
- CERN: Delay Wire Chamber – 2D tracker – active area 10x10 cm, resolution 200-300 um
- DESY: Beam telescope, 6 planes of pixel sensors



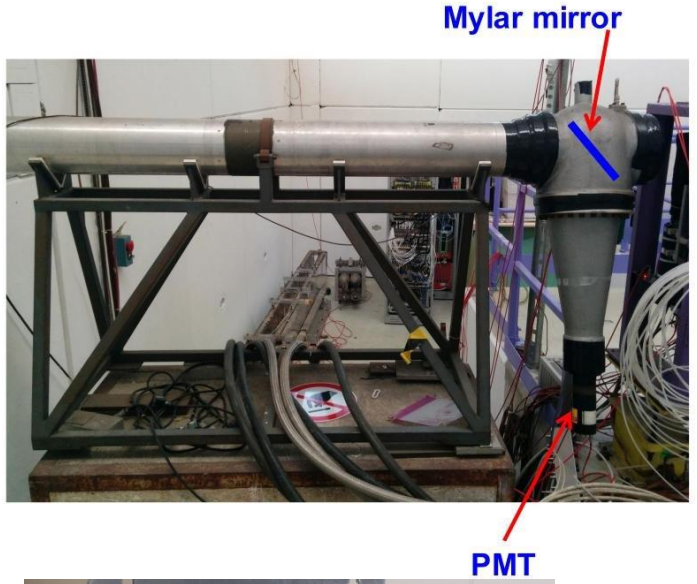
- MediPix Silicon pixel detectors – 2D tracker – 2x2 cm, resolution ~ um
- MicroMegas detectors – 1D tracker – 40x40 cm, resolution 200 um



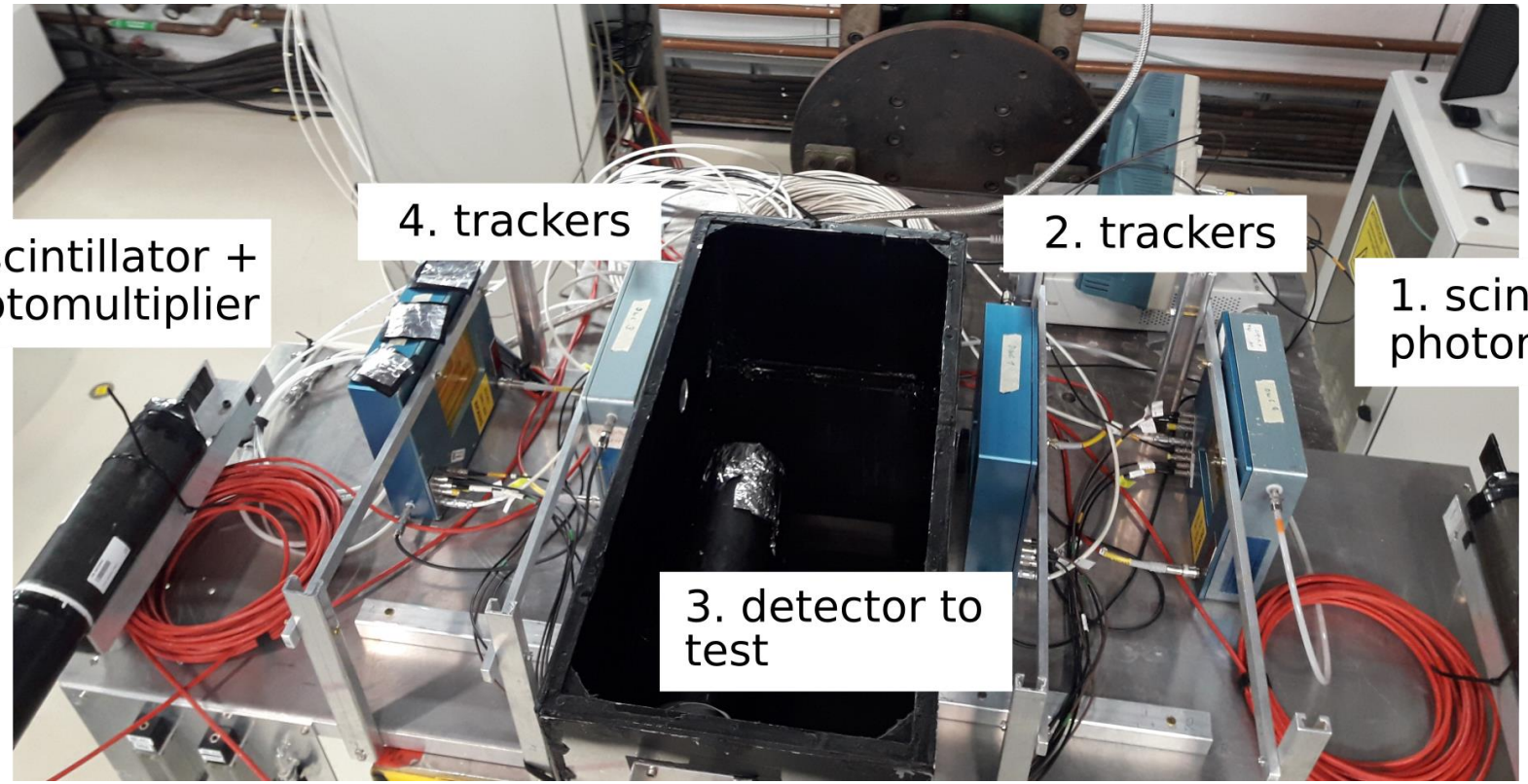
Detectors - III

- CERN: Cherenkov detectors. Filled with gas at variable (but limited) pressure. For particle identification
- Lead crystal calorimeter – Energy of particles
- Neutron detector (WENDI) - spallation
- Muti-gap resistive plate chambers (MRPC)- trackers – 30x30 cm, suitable for time of flight measurements (particle speed), time resolution 100 ps

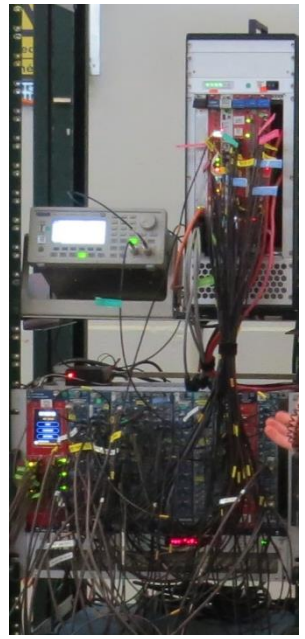
- Students are free to build and test their own detectors!



A typical experimental setup



The BL4S TDAQ

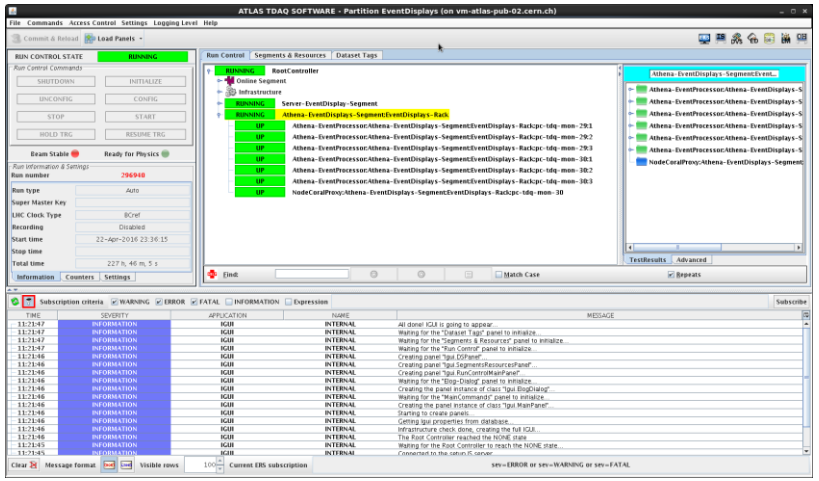


We are using the (RCD) TDAQ system of ATLAS

- Very scalable
- VMEbus well integrated
- Lost of useful features: GUI, databases, monitoring
- Access to experts from ATLAS
- Performance: 2-4 kHz event rate

For special experiments we have used:

- UDP module in RCD to acquire data from MMFE8 cards (MicroMegas)
- EUDAQ (in combination with the DESY beam telescope)
- Data recording on high-end oscilloscopes (with a common trigger)
- Ad-hoc code (e.g. to read out MediPix via USB)

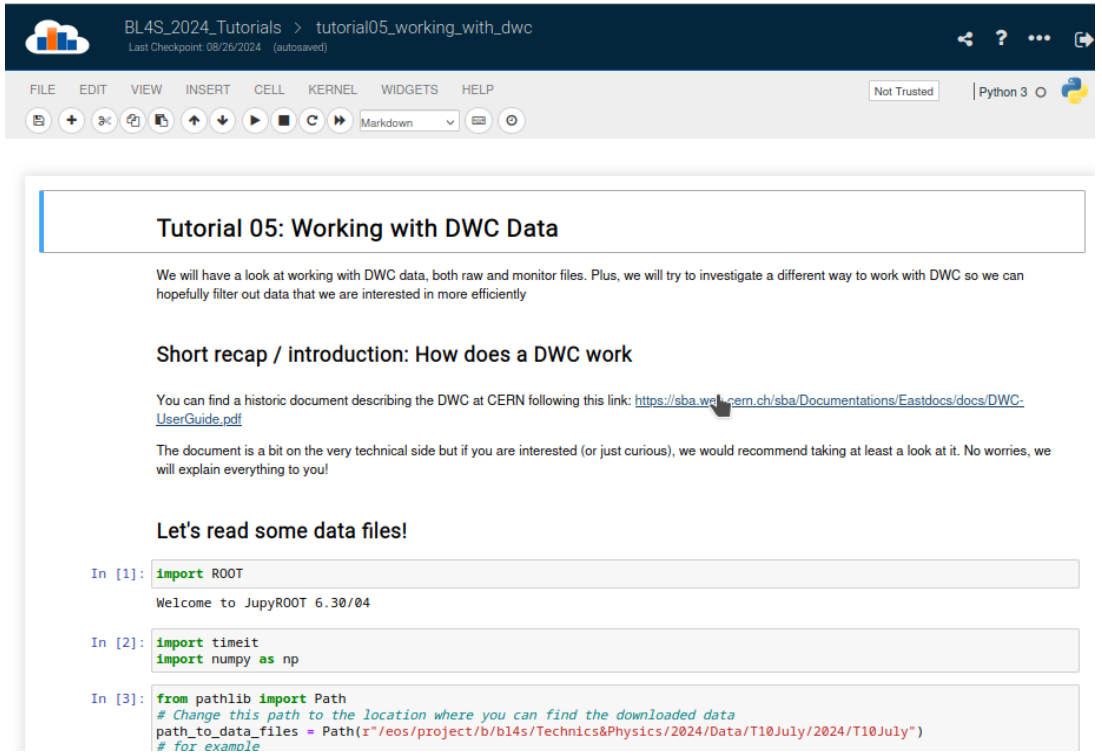


Setting up the TDAQ system is one of the main challenges of the support scientists

Data analysis

- Students have a very diverse background in programming and computing, both within and across different winning teams
- Some students usually know a little bit of Python and maybe have done some data analysis with frameworks such as numpy, scipy, pandas, etc.
- The BL4S TDAQ software provides data in the form of ROOT Tree files
  - Students usually not familiar with this quite complex and domain specific software framework!
- The BL4S Support Scientists work with the students over the summer (~ June to September) to introduce them to the required tools & prepare them for the data analysis tasks they will perform during their on-site visit

- Main tool: Jupyter Notebooks using PyROOT



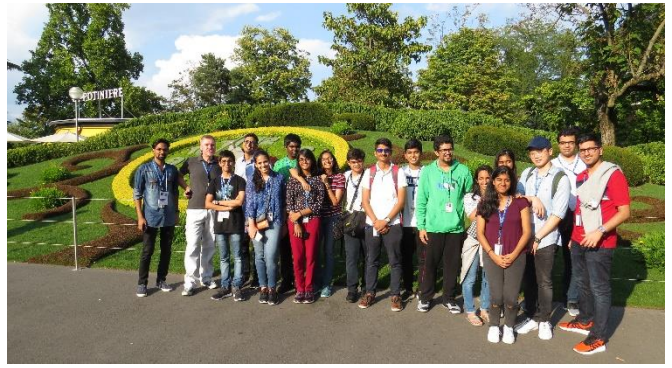
- Depending on the experiment also Geant4, BDSim, finite element solvers, 3D visualization, etc.

A typical day of a winner at CERN/DESY

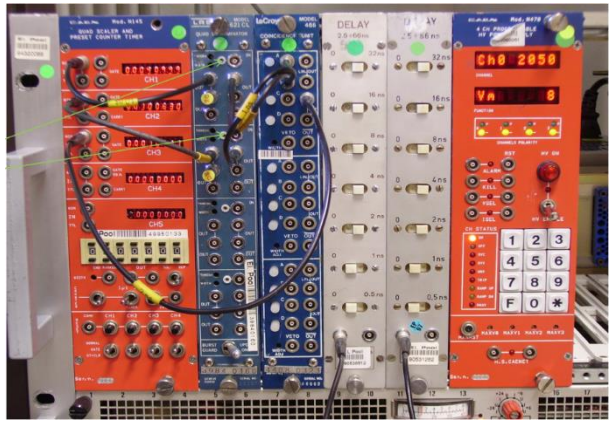
8:00:	Breakfast
9:00 – 9:30:	Daily meeting
9:30 – 12:00:	Data taking shift in the control room
12:00 – 13:00:	Lunch
13:00 – 15:00:	Playgound (CERN only)
15:00 – 15:30:	Break
15:30 – 17:30:	Data analysis

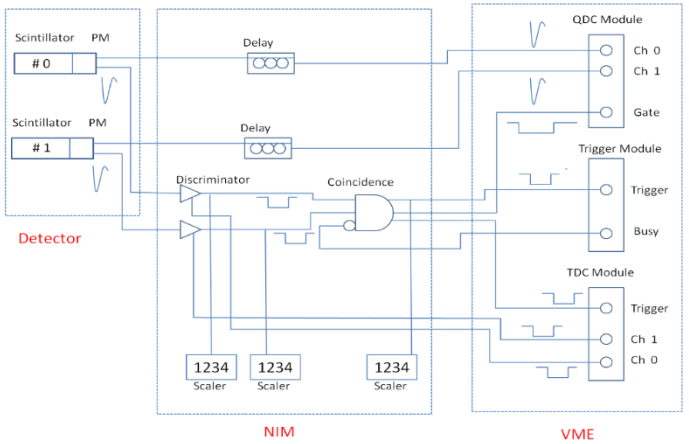
In addition:
- A full day safety briefing
- Introductory lectures
- VIP day (sponsors, ambassadors, other officials)
- Visits to points of interest at CERN / DESY
- Social activities (sightseeing, official dinner)
- Final presentation (preliminary results)
- Homework (for their school or university)

→ We go to the limits of what teenagers can cope with … and they enjoy it!



A COVID lesson … the BL4S playground





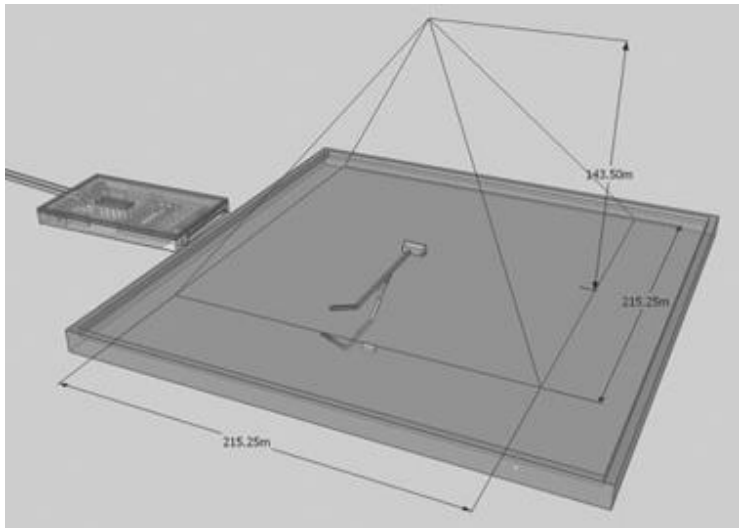
The “playground” is a supervised lab where the students can do some “hands-on work” on a simple cosmic muon detection set-up. It helps them a lot in understanding the equipment that they are using in the experimental area

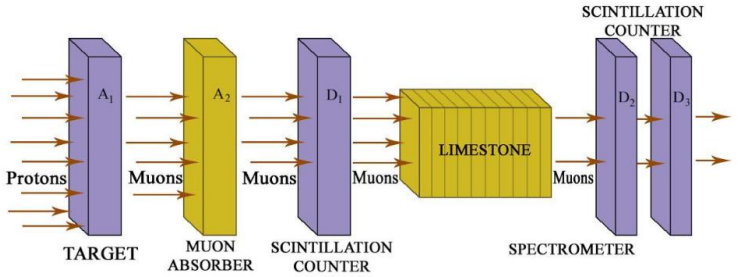
It is also an opportunity to get to know the students better (many of them ask us for letters of reference when they apply at universities)

Past experiments – I (proposal)

2016 – Pyramid hunters, Poland

- Use muon radiography to find hidden chambers in a pyramid
- “Knowing the magnitude of fluctuations in the number of muons coming out of the rocks we can prove that there is an invisible Pharaoh chamber between 62° and 72°”.

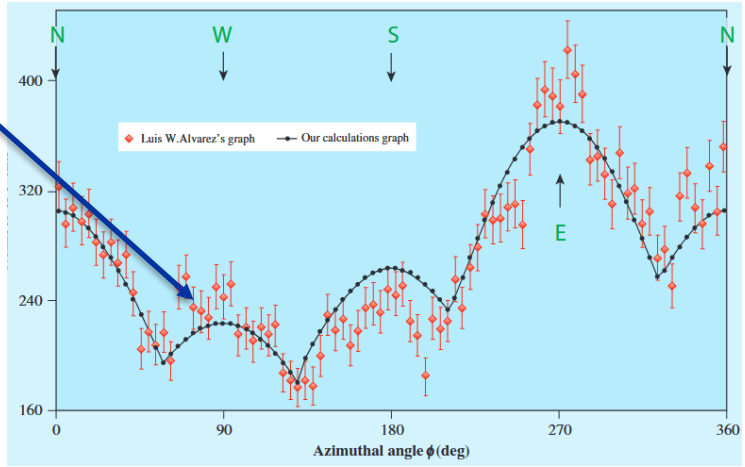




Theoretical data for standard rock[3]

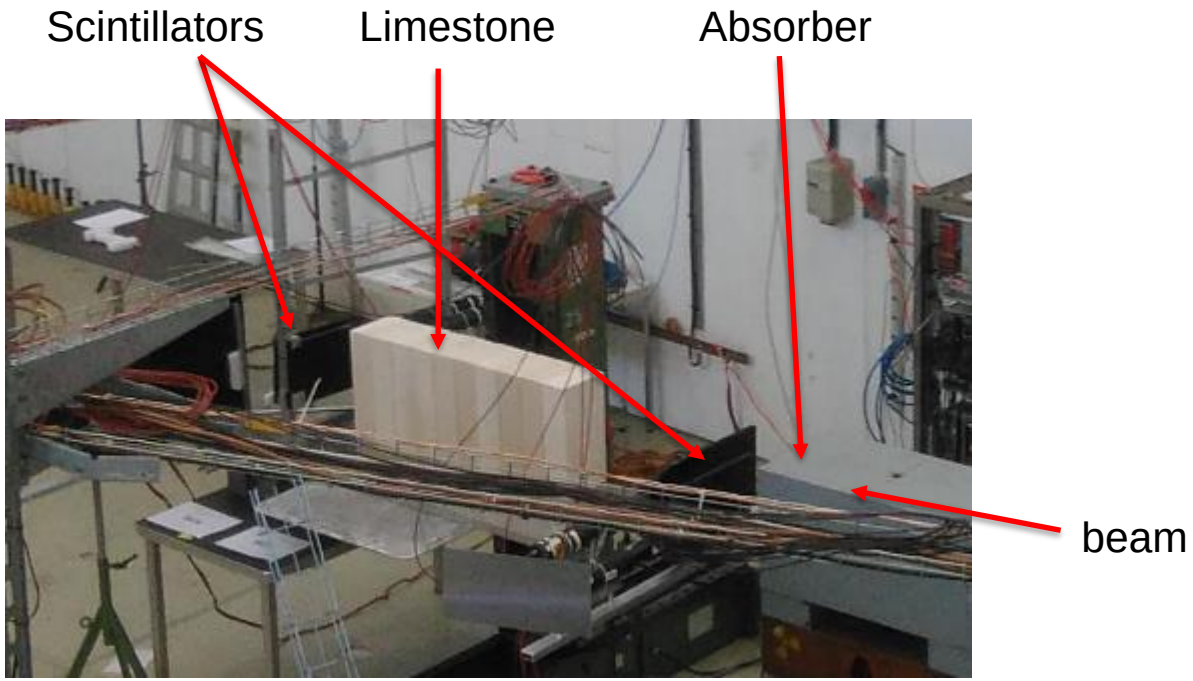
Muon momentum [MeV/c]	Range [g/cm^2]
176,4	36,96
286,8	93,32
391,7	152,4
494,5	211,5
891,5	441,8

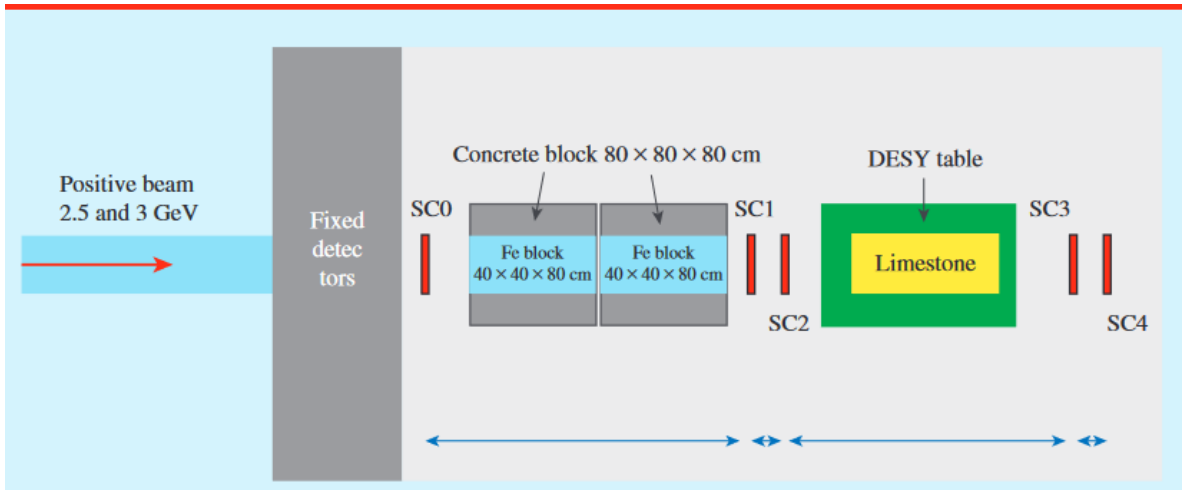
From the original proposal

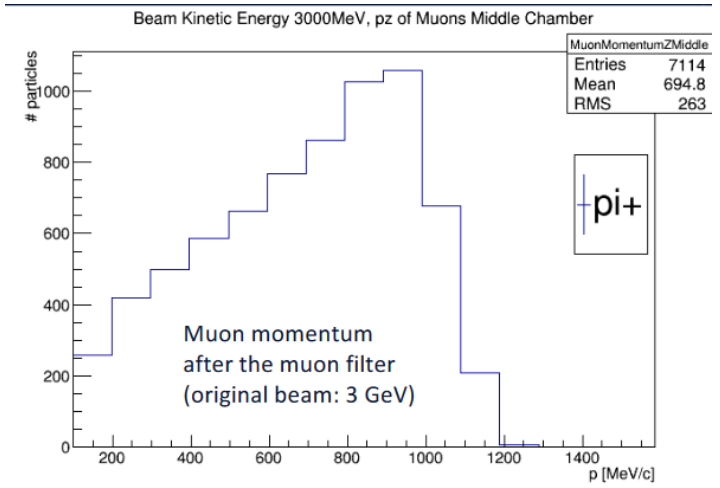


Past experiments – I (realization)

Setup at CERN







Challenges:

- Who is selling pyramids?
- How can we make a muon beam with sufficient intensity but low momentum (< 1 GeV)

Past experiments – I (result)

Publication:

https://iopscience.iop.org/article/10.1088/1361-6552/aab85c

OPEN ACCESS

Phys. Educ. **53** (2018) 045011 (8pp)

The secret chambers in the Chephren pyramid

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Abstract
In 2016, we (seven high school students from a school in Plock, Poland) participated in the CERN Beamline for Schools competition. Together with our team coach, Mr. Janusz Kempa, we submitted a proposal to CERN that was selected as one of two winning proposals that year. This paper describes our experiment from the early days of brainstorming to the trip to Geneva.

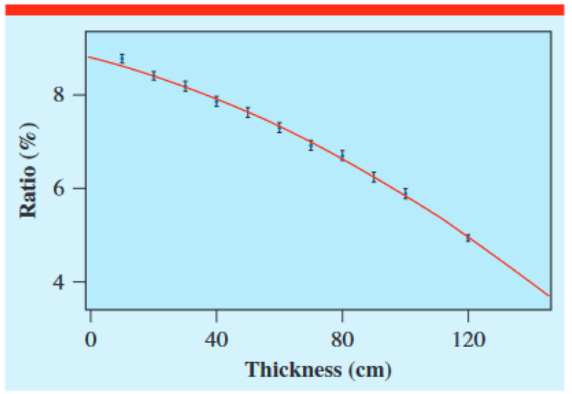


Figure 9. Ratio of muons that passed through the limestone over the initial number of muons, as a function of thickness of limestone for 2.5 GeV/c.

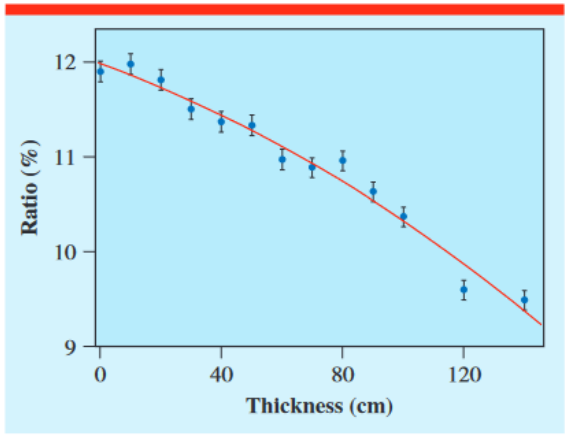
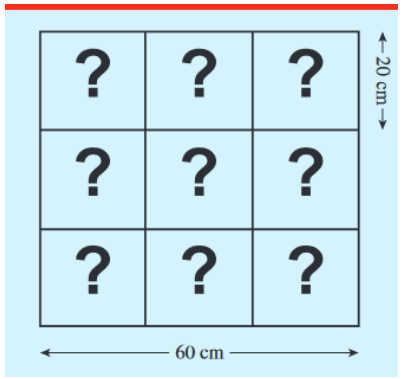
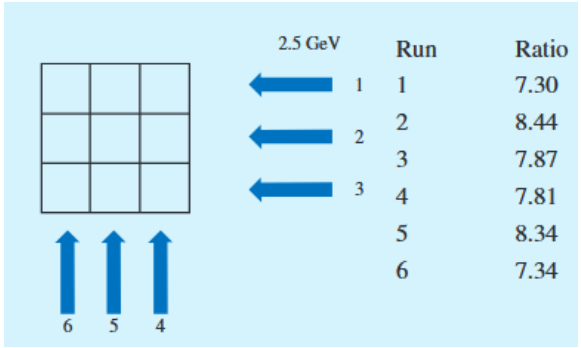
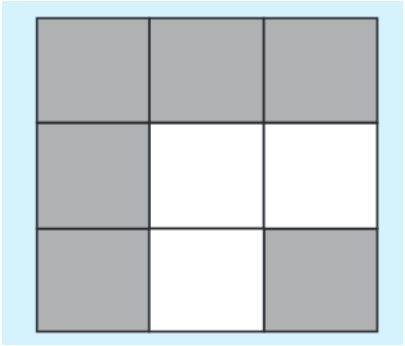


Figure 10. Ratio of muons that passed through the limestone over the initial number of muons, as a function of thickness of limestone for 3 GeV/c.





Run	Ratio
1	7.30
2	8.44
3	7.87
4	7.81
5	8.34
6	7.34

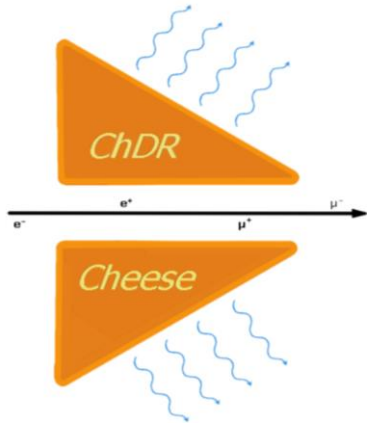


Past experiments – II (proposal)

2020 – ChDR Cheese, Germany

- Use Cherenkov diffraction radiation for beam diagnostics

Beam diagnostics are crucial for smooth accelerator operations. Approaches in the past have mainly focused on technologies where the beam properties are significantly affected by the measurement. Recently, groups have performed experiments for non-invasive beam diagnostics using Cherenkov Diffraction Radiation (ChDR). Unlike regular Cherenkov Radiation, the charged particles (e.g. electrons and positrons) do not have to move inside of the medium, but it is sufficient for them to move in its vicinity as long as they are faster than the speed of light in the medium. Changes to the beam properties due to ChDR-measurements are negligible and therefore ChDR could be used for non-invasive beam diagnostics in future colliders.
In our experiment we want to focus on the ChDR emitted by electrons and positrons, monitor the beam properties and compare the results.



From the original proposal

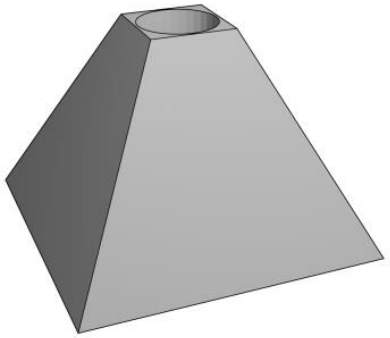
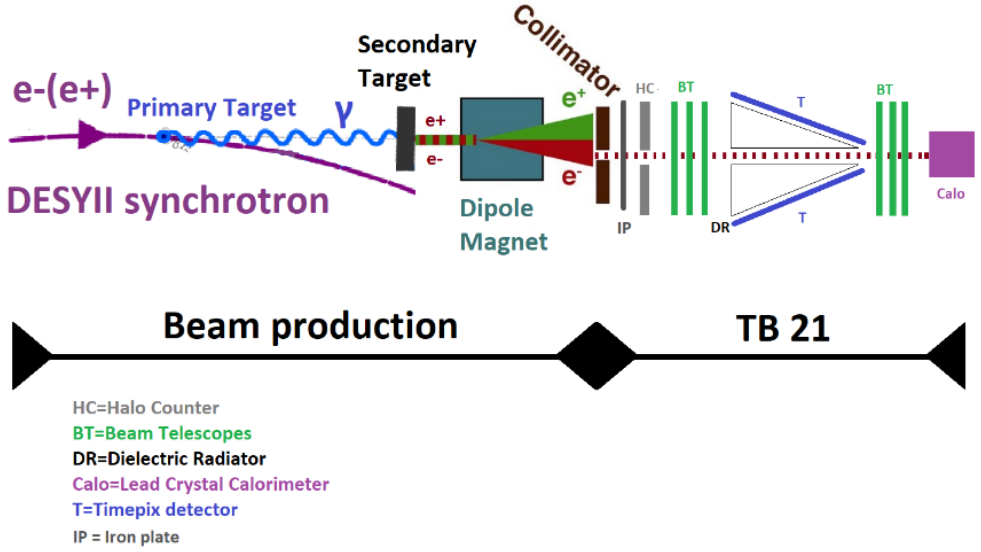
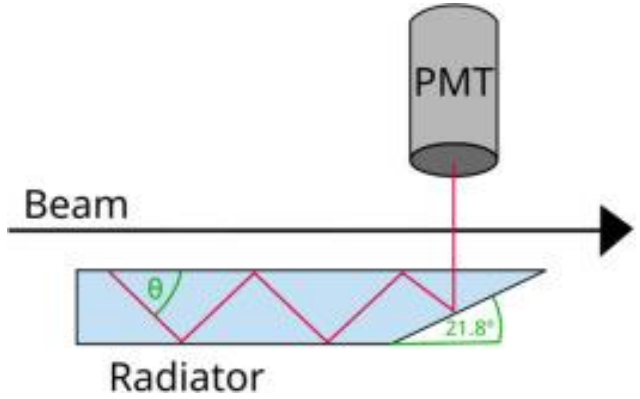


Figure 5: 3D-model of the dielectric radiator (not to scale)

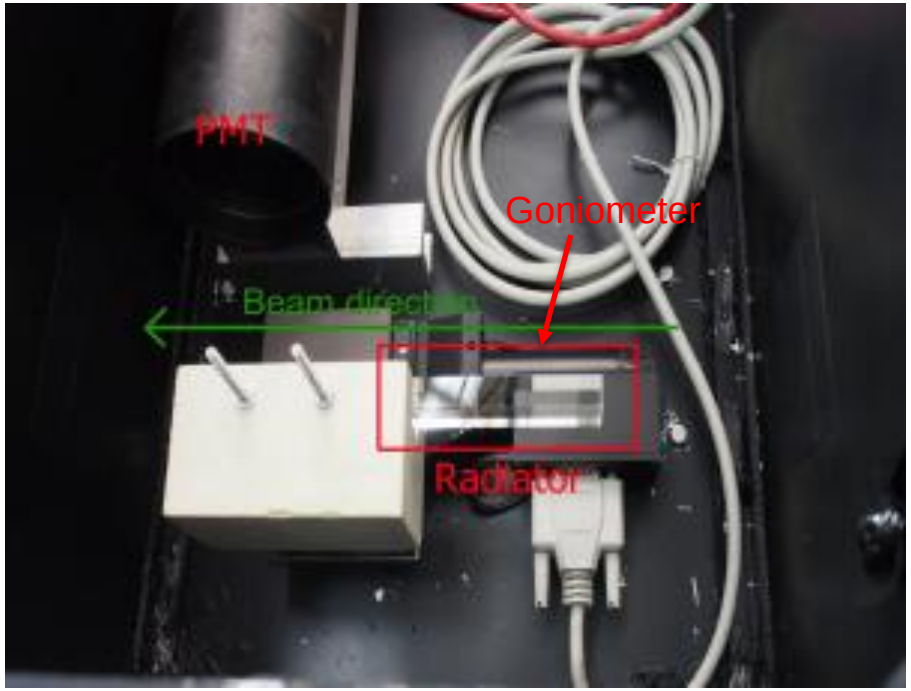


Past experiments – II (realization)



Challenges:

- We need a radiator of fused silica with a custom geometry and a coated surface
  - Radiators: CERN (on loan) and Heraeus (offered to BL4S)
  - Coating: CERN
- Mechanics and alignment
  - Design a holder for the radiator and guarantee alignment with the opening of the PMT while still allowing to rotate the radiator to fine tune the alignment with the beam.
  - Beam telescope (radiography)
- Data analysis
  - Select only particles which travelled parallel to the radiator surface
  - Select only particles which are close to the surface, and not inside the radiator



Past experiments - II (result)

Publication:

https://www.sciencedirect.com/science/article/pii/S0168900223002772?via%3Dihub

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

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Full Length Article

Cherenkov diffraction radiation emissions from single electrons and positrons on a fused silica radiator

Silas Ruhrberg Estevez [a], Tobias Baumgartner [a], Johann Bahl [a], Thomas Lehrach [a], Tobias Thole [a], Benildur Nickel [a], Philipp Loewe [a], Lukas Hildebrandt [a], Cristóvão Beirão da Cruz e Silva [c], Paul Schütze [b], Markus Joos [c]

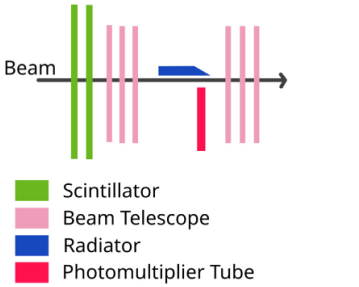


Fig. 1. Sketch of the experimental setup at the DESY II Test beam facility showing the relative positions of the detectors used and the radiator.

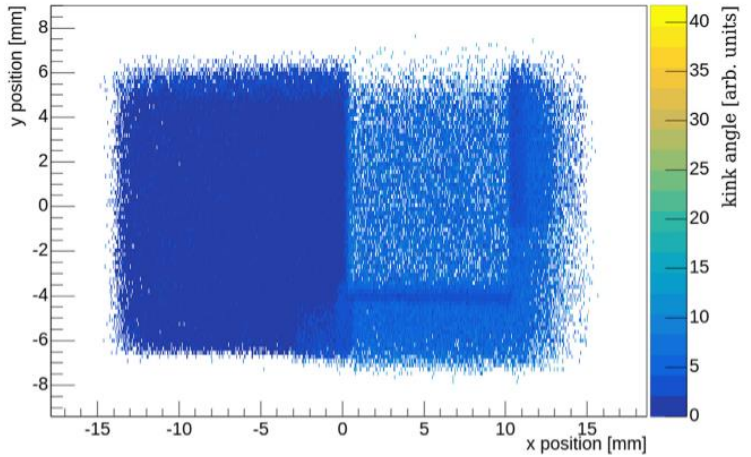
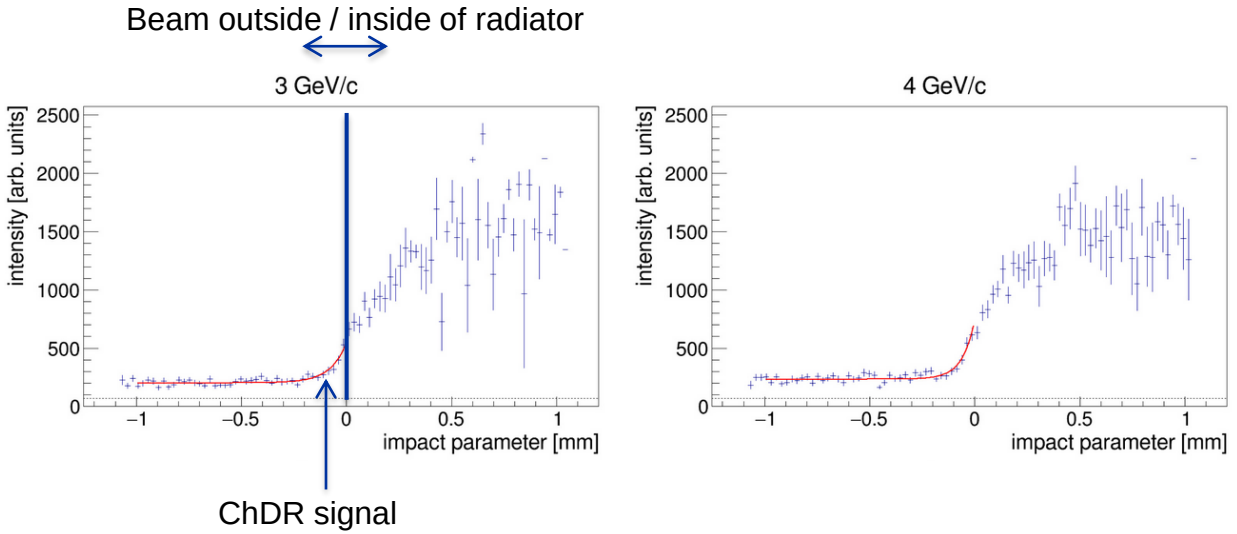
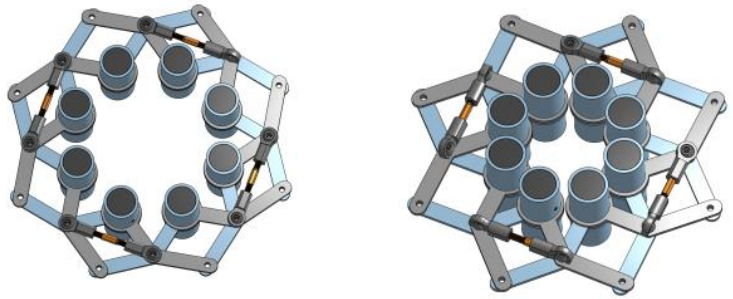


Fig. 4. X–Y projection material budget image of the beam profile kink angle.



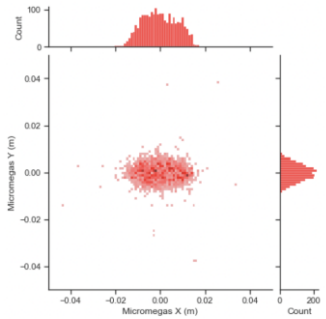
Past experiments – III (proposal)



2023 – Myriad Magnets, USA

- Design of a versatile Halbach magnet

Excessive energy usage is a major contributor to climate change, a pressing world issue. Electromagnets used at accelerator facilities can consume large quantities of energy – it is therefore worthwhile to investigate alternative technologies that provide the same capabilities



(c) Quadrupole configuration with radial arrangement of $d = 7.0$ cm ($g = 6.1$ T/m)

Figure 9: GEANT4 simulation: position distributions of 1500 electrons on a tracking detector 4.9 m from the mangle. The plots were simulated using a circular particle source 2 cm in diameter and a simplified detector volume for the tracking detector.

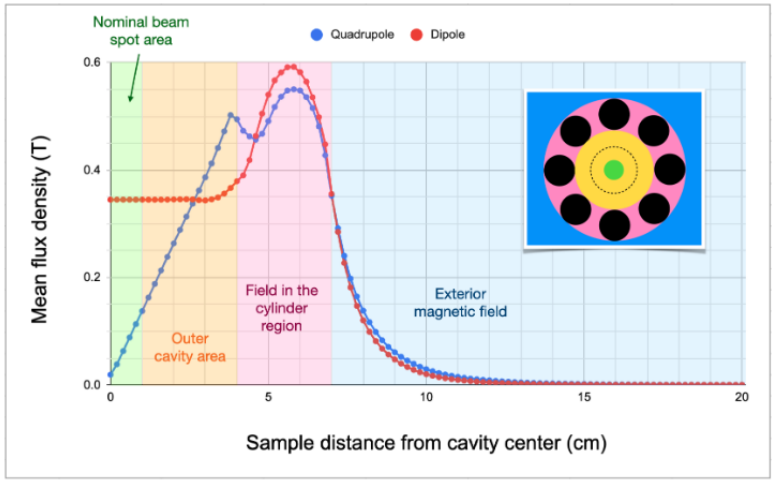
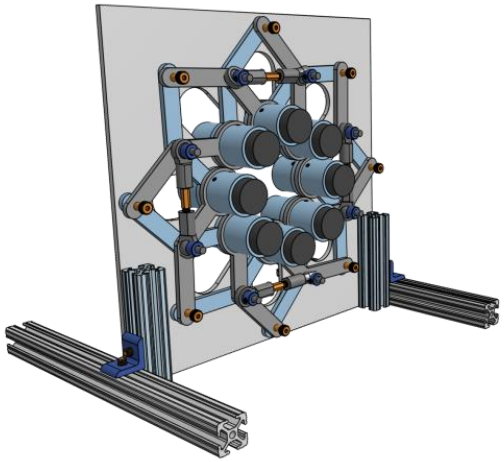
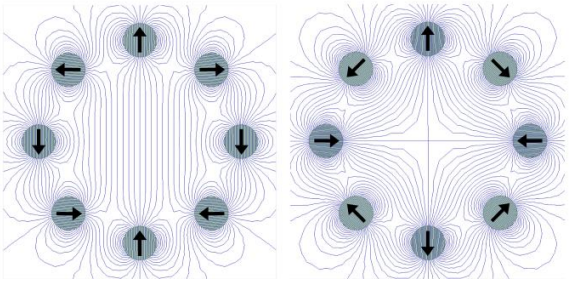


Figure 5: Mean flux density at a given radial sample distance from the cavity center for dipole and quadrupole configurations with $d = 5.5$ cm. As shown by the dotted black line in the top right diagram, the mean flux density at a given radial distance is found by uniformly sampling points around a circular ring and averaging the flux density. As seen in the blue region, the exterior flux density decreases to about 0.2 mT within 20 cm from the cavity center – this is a level considered safe for most electronic devices.

From the original proposal

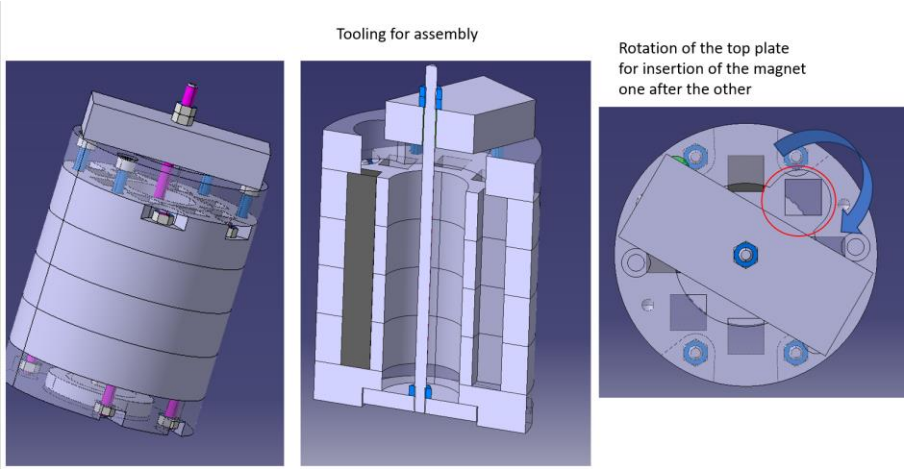


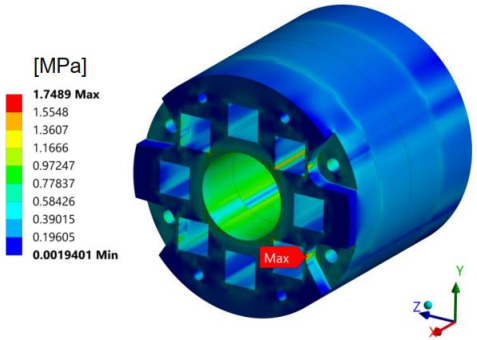


Past experiments – III (realization)

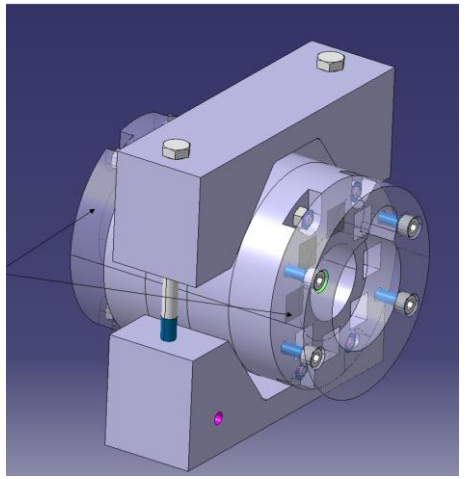
Challenges:

- The magnets (15 x 15 x 50 mm) are very strong (~330 N). A 3D printed plastic mangle is too weak and the assembly of the array is dangerous
- The CERN mechanical workshop has done simulations and designed a mounting structure that was made from aluminum in our workshop
- The deflection of the beam was measured with DWCs. Calibrating and aligning them is a pain…..





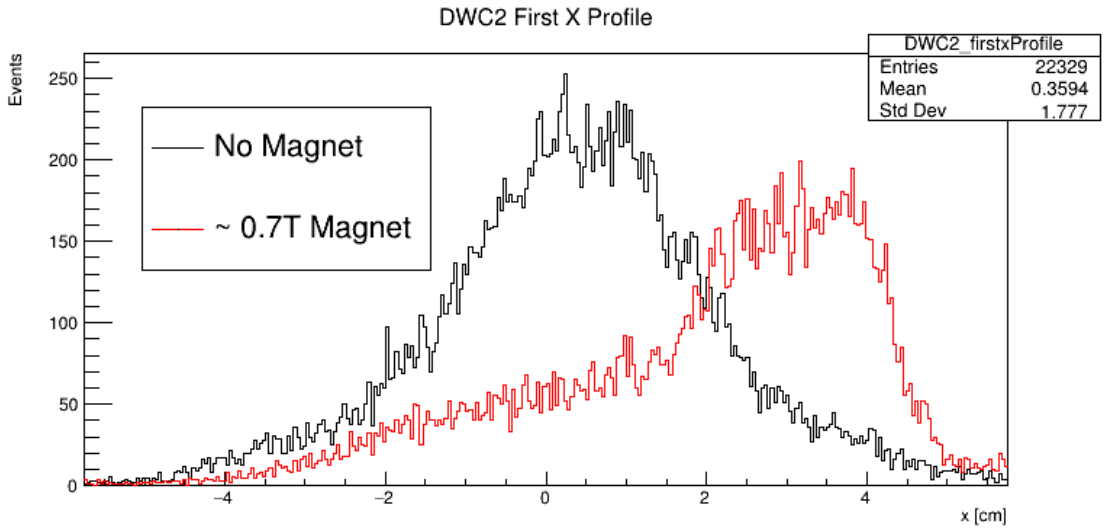
Von Mises stress distribution and peak for *Configuration 'open' with forces per quadrant* (worst case).

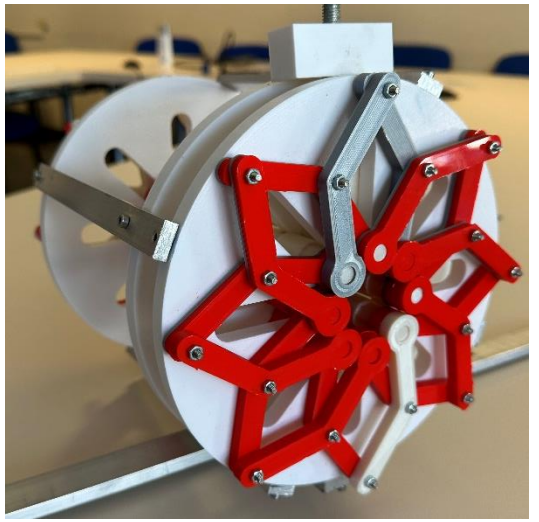


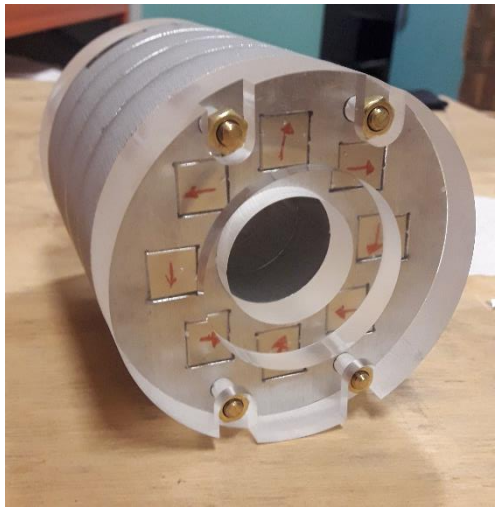
Past experiments – III (result)

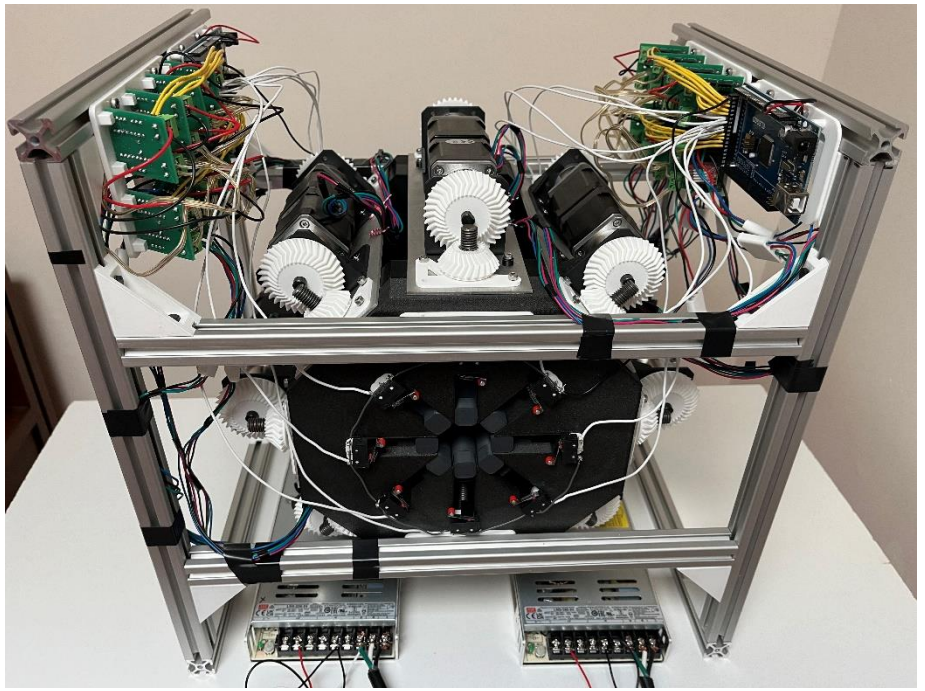
- No publication yet
- ….but one student is still very active

- A 3D printed mangle with weaker magnets works fine
- Magnetic field measurements done in two dipole configurations
- Main Challenges:
  - Alignment of DWC and Magnet relative to the beam centroid
  - Noise and reflections in the DWC
  - Off-Centre particles scattering off the magnet structure









Challenges for the future

- Funding
  - We need roughly CHF / EUR 150.000 – 200.000 per year
  - Many donors only make one-year commitments
- Access to beam lines
  - LS3 of CERN approaching
  - Situation at DESY unclear due to PETRA-IV
- Support scientists
  - Need specialists with a variety of skills
  - Can only keep them busy for 6 months / year
- Detectors
  - “Lost” some detectors (MicroMegas, MRPC). Looking for alternatives
- Volunteers
  - Some of the key players are 70++

The Outreach challenge in a nutshell….

Teenagers with an interest in STEM

Outreach activities of CERN (selection)

- Science Gateway
  - Open Tue-Sun, free access, interactive exhibition and hands-on sessions (reservation required)
  - Capacity: 300.000+ visitors per year
- Regular visits
  - Mon-Sat, 2 to 3 hours, reservation required
  - 130.000 visitors per year (but many more requests)
- Arts at CERN
- Programmes for High School Teachers
- CERN-Solvay Education Programme

Educational activities of CERN

https://isotdaq-schools.web.cern.ch/

- CERN Accelerator School (https://cas.web.cern.ch/)
  - Bachelor/Master/PhD/Postdoc - training courses in Accelerator Physics
- CERN Computing School (https://csc.web.cern.ch/)
  - postgraduate (min. Bachelor)
- CERN Schools of Physics (https://physicsschool.web.cern.ch/)
  - Master/PhD/Postdoc
- CERN-Fermilab Hadron Collider School (https://hcpss.web.cern.ch/)
  - Phd/Postdoc
- DRD1 Gaseous Detectors School (https://indico.cern.ch/event/1384298)
  - Phd/Postdoc

- ESIPAP, JUAS: Not “CERN” schools but held close to CERN: https://www.esi-archamps.eu/our-schools/

Career options at CERN

Main portal: https://careers.cern/

- Lots of offers:
  - Summer students
    - 8-12 weeks at CERN (also for students from non-member states)
  - Graduates (2+1 years):
    - Origin: BsC and MsC with up to 2 years of experience
    - Quest: MsC with 2-6 and PhD with at least 3 years of experience
    - Research: PhD with up to 3 years of professional experience
  - Technical students
    - 4-12 months, interesting for engineers and computer scientists
  - Doctoral program
  - Staff
    - Limited duration contracts: 5+3 years

Outreach activities of DESY

- Visits can be arranged for groups of 15-60 visitors
  - Individuals can join registered groups
  - Visits are possible Monday through Friday and last for 3 hours
  - Public visit one Saturday per month (registration required)
  - Content: Overview of DESY, Photon science, Particle physics, design and construction of accelerators
  - Access to (small) gift shop

- Coming soon (end 2025): New DESYUM visitor centre. Permanent exhibition about research at DESY, gift shop, open 7/7, free entrance

- Public events agenda: Öffentliche Vorträge - Deutsches Elektronen-Synchrotron DESY

Educational activities of DESY

- For high school students:
  - Schülerlabore - Deutsches Elektronen-Synchrotron DESY
- For teachers:
  - Lehrerfortbildung - Deutsches Elektronen-Synchrotron DESY
- Internships:
  - Praktikum - Deutsches Elektronen-Synchrotron DESY

Career options at DESY

- Dual studies (5 professions):
  - Das Duale Studium bei DESY - Deutsches Elektronen-Synchrotron DESY
- Professional training (9 professions):
  - Ausbildung - Deutsches Elektronen-Synchrotron DESY
- Portal for job vacancies:
  - Stellenangebote (desy.de)
- Further information:
  - Karriereprogramme - Deutsches Elektronen-Synchrotron DESY

Thank you very much for your attention

beamline for schools

cern.ch/bl4s