High rate and photon test beams with the MuPix at MAMI

Alexey Tyukin

Mainz Institute for Nuclear Physics

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter

PRISMA

MAMI MAINZER MIKROTRON

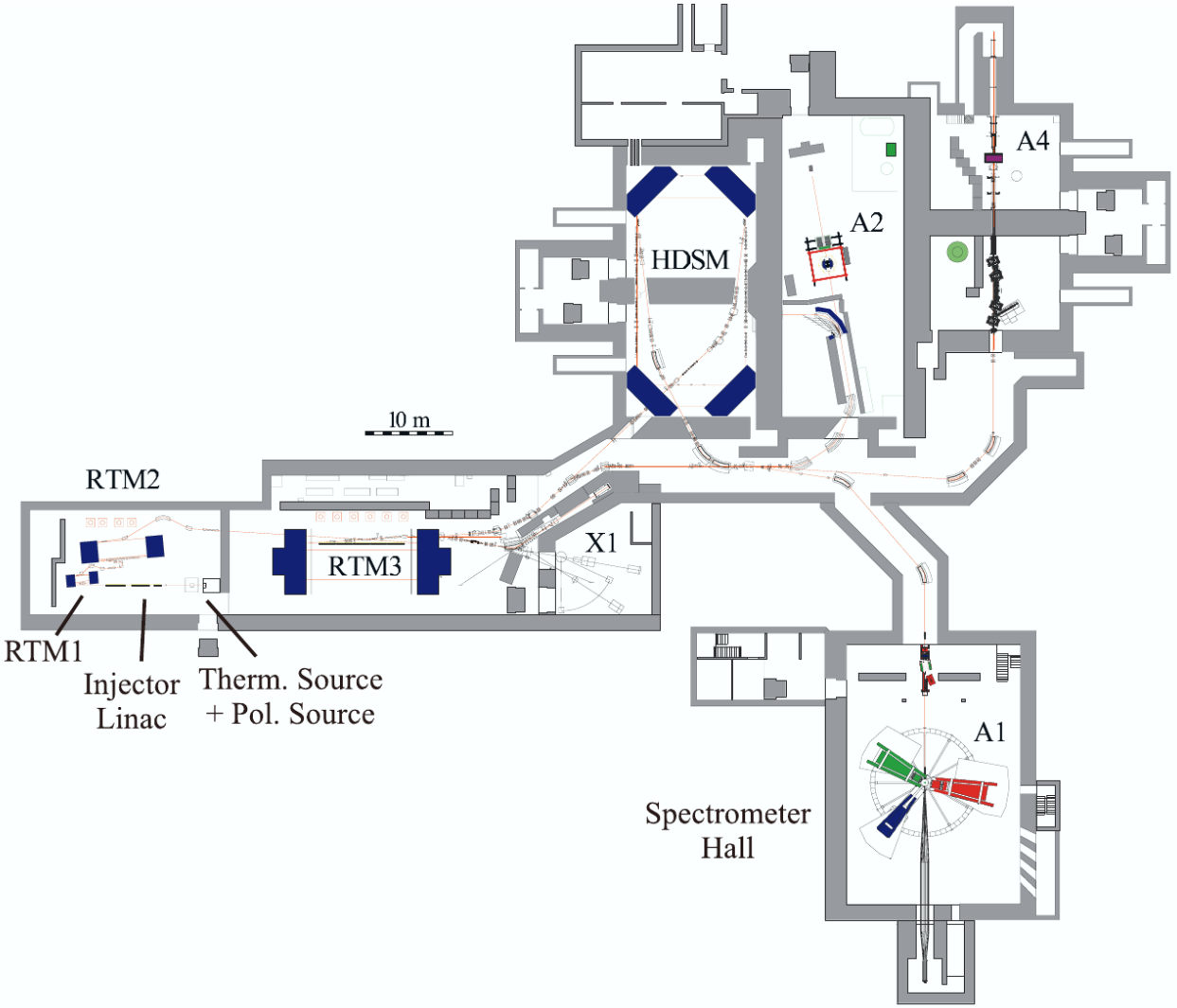
SFB 1044

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Outline

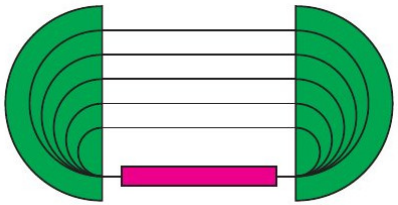
- The MAMI accelerator
- MuPix Chip
- Photon test beam results
- High electron rate results with the MuPix telescope

The Mainz Microton (MAMI)

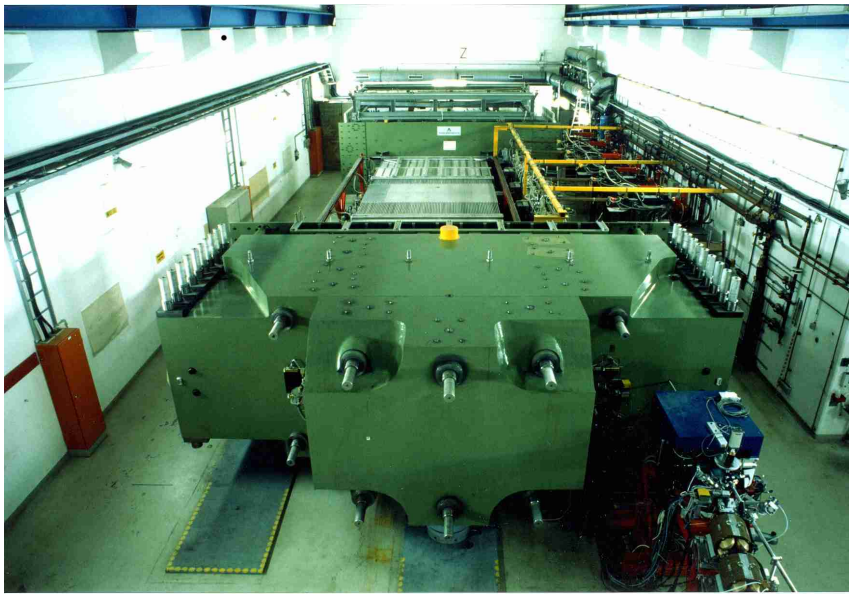


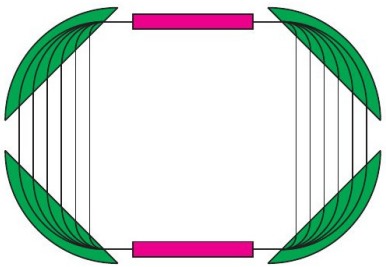
- Electron accelerator up to 1.6 GeV
- Beam current up to 100 µA at 2.45 GHz continuous wave
- Halls for experiments with electrons, high energy photons and x rays

Accelerator Stages

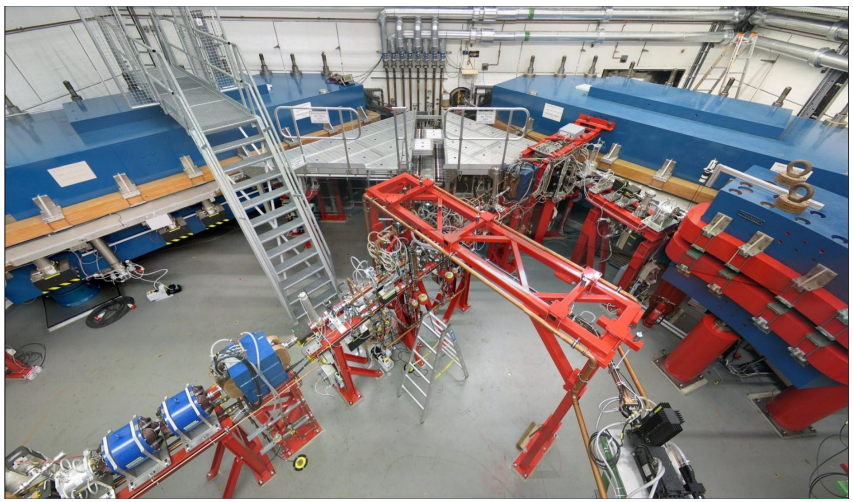


- 3-stage microtron cascade
- Racetrack microtrons
- Output 14, 180, 855 MeV





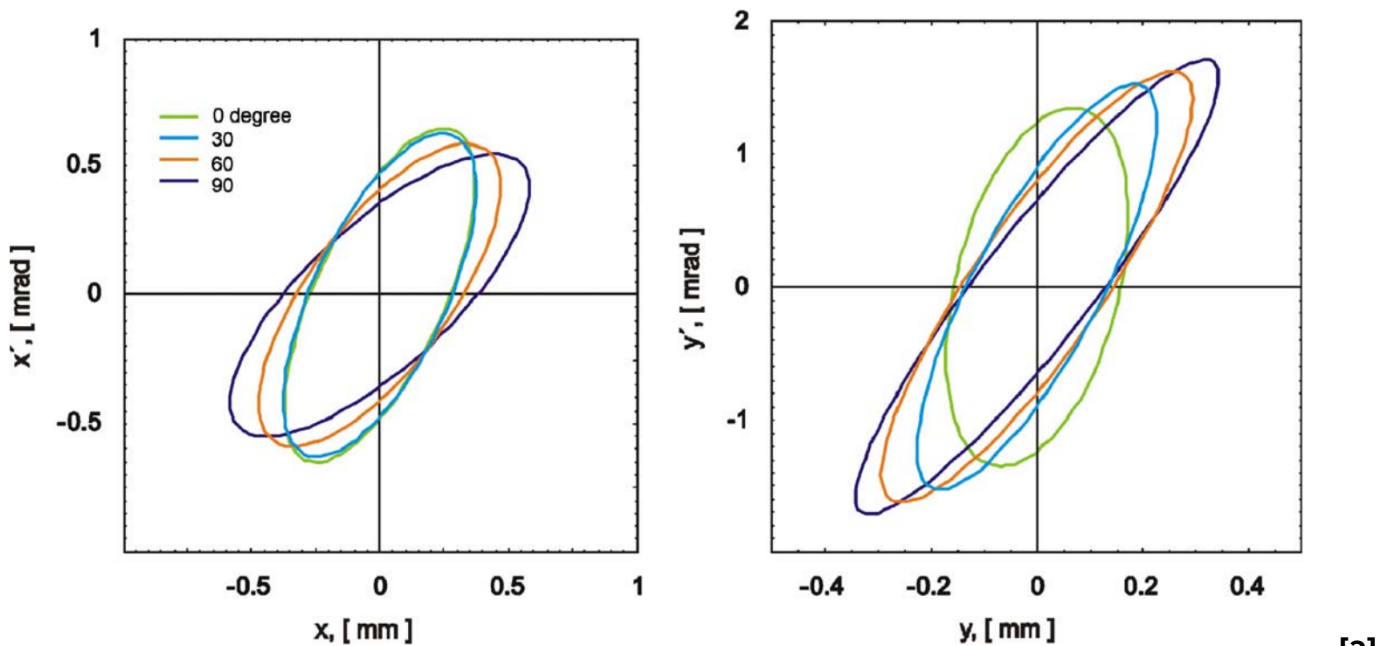
- 4-th stage: double-sided microtron
- 1.6 GeV final energy



[1]

The MAMI beam

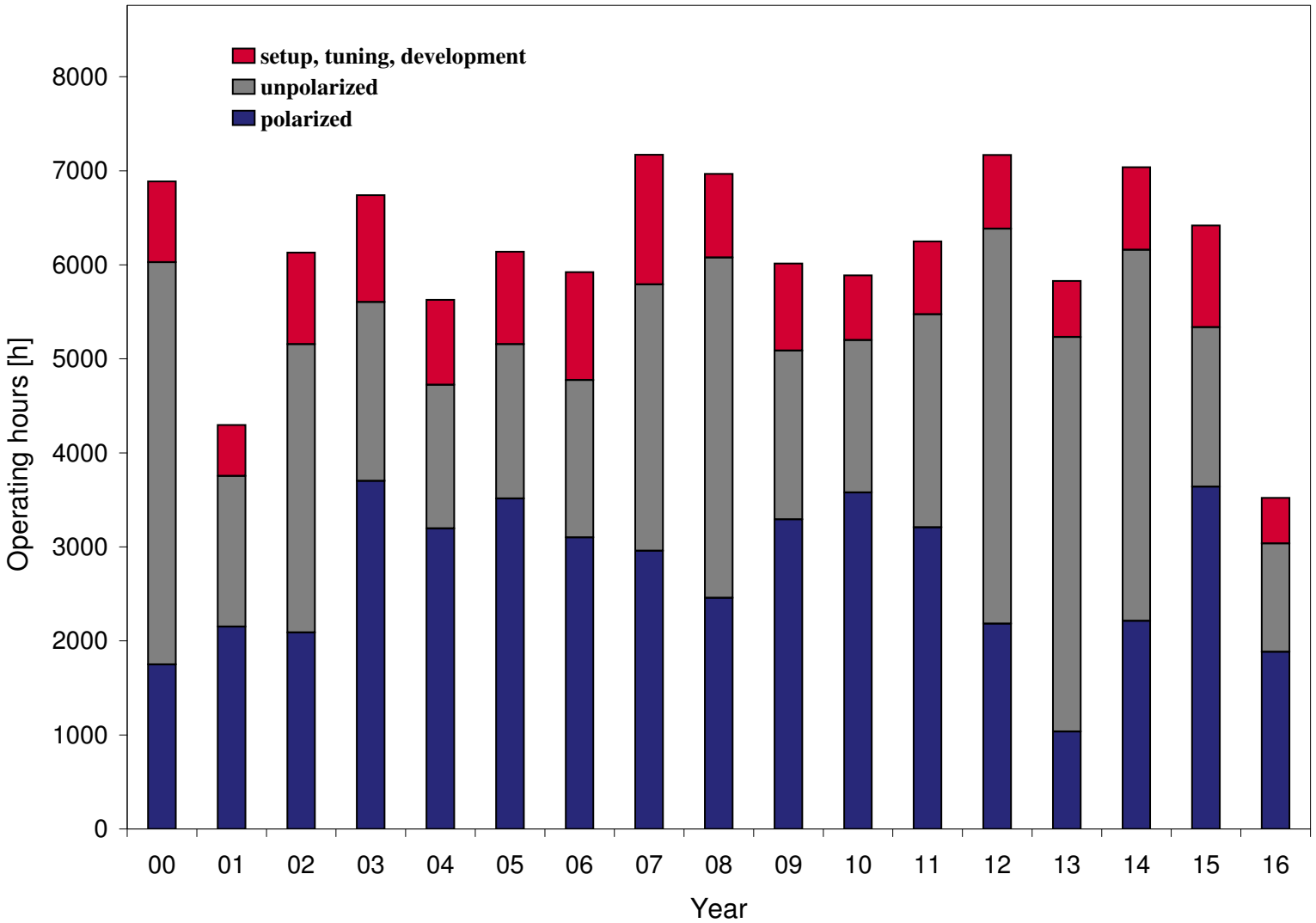
- High quality beam suitable for parity violation experiments
- Typical beam size < 1 mm
- Energy stability to $2 \cdot 10^{-5}$
- Beam can have polarisation of 85%
- Emittance at 855 MeV of 40.8 mm $\cdot$ mrad (hor) and 3.8 mm $\cdot$ mrad (vert)



[2]

Figure: phase space (horizontal and vertical) of the beam for different polarisations at 0.1 MeV. Boundry shows 1 σ area, emittance scales with $\propto \sqrt{E}$

MAMI operation time



- MAMI has a high duty factor of up to 70%
- Proposals for test beam time or experiments with existing detectors welcome!

MESA: a new accelerator near MAMI

Mainz Energy-recovering Superconducting Accelerator planned for 2020

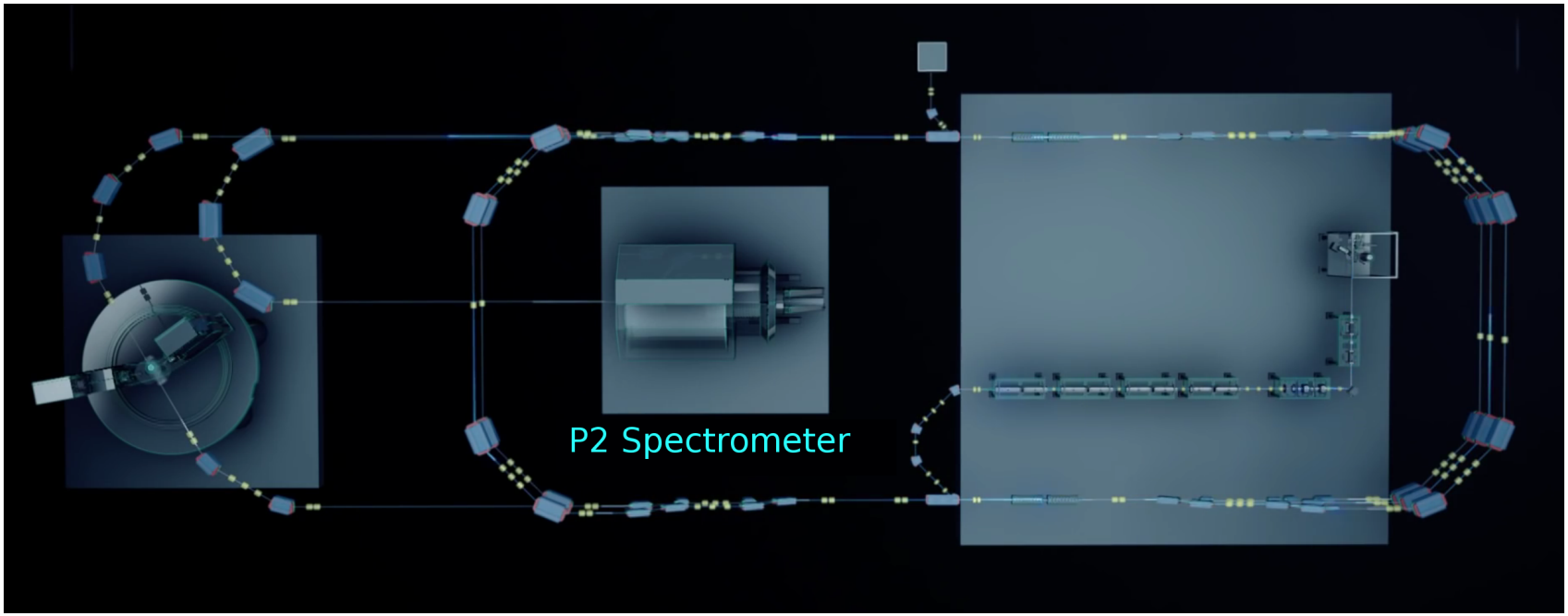
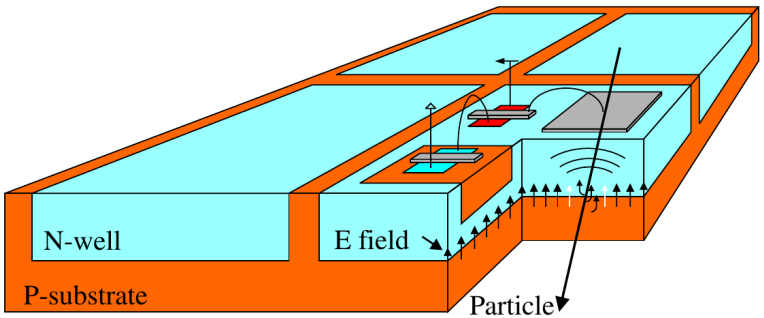


Figure: A new accelerator is being built adjacent to MAMI

- An independent new e^--accelerator up to 155 MeV
- Highly stable beam up to 150 µA for future precision experiments
- Two experiments being planned: **P2** and **MAGIX**
- P2 Experiment requires electron tracker operating in high photon background

The MuPix Chip

The MuPix chip is going to be used in the Mu3e, P2 and PANDA experiment



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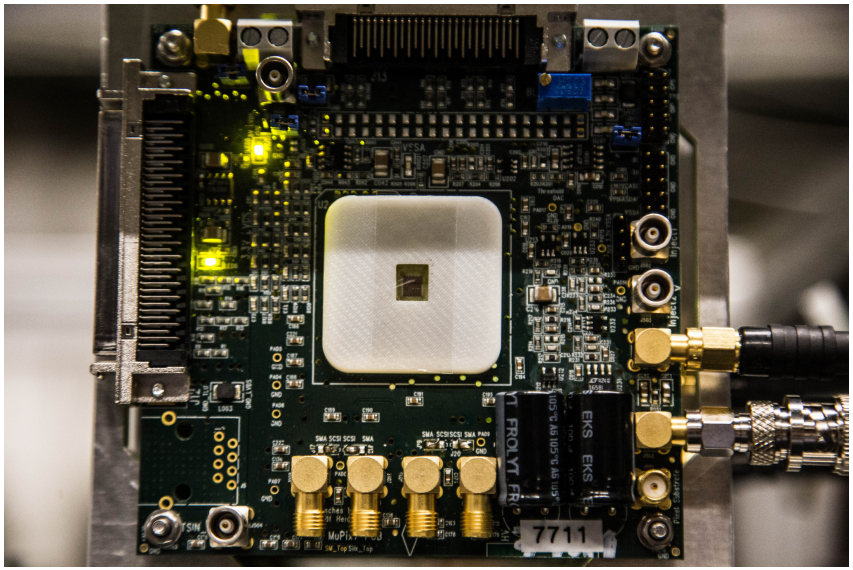
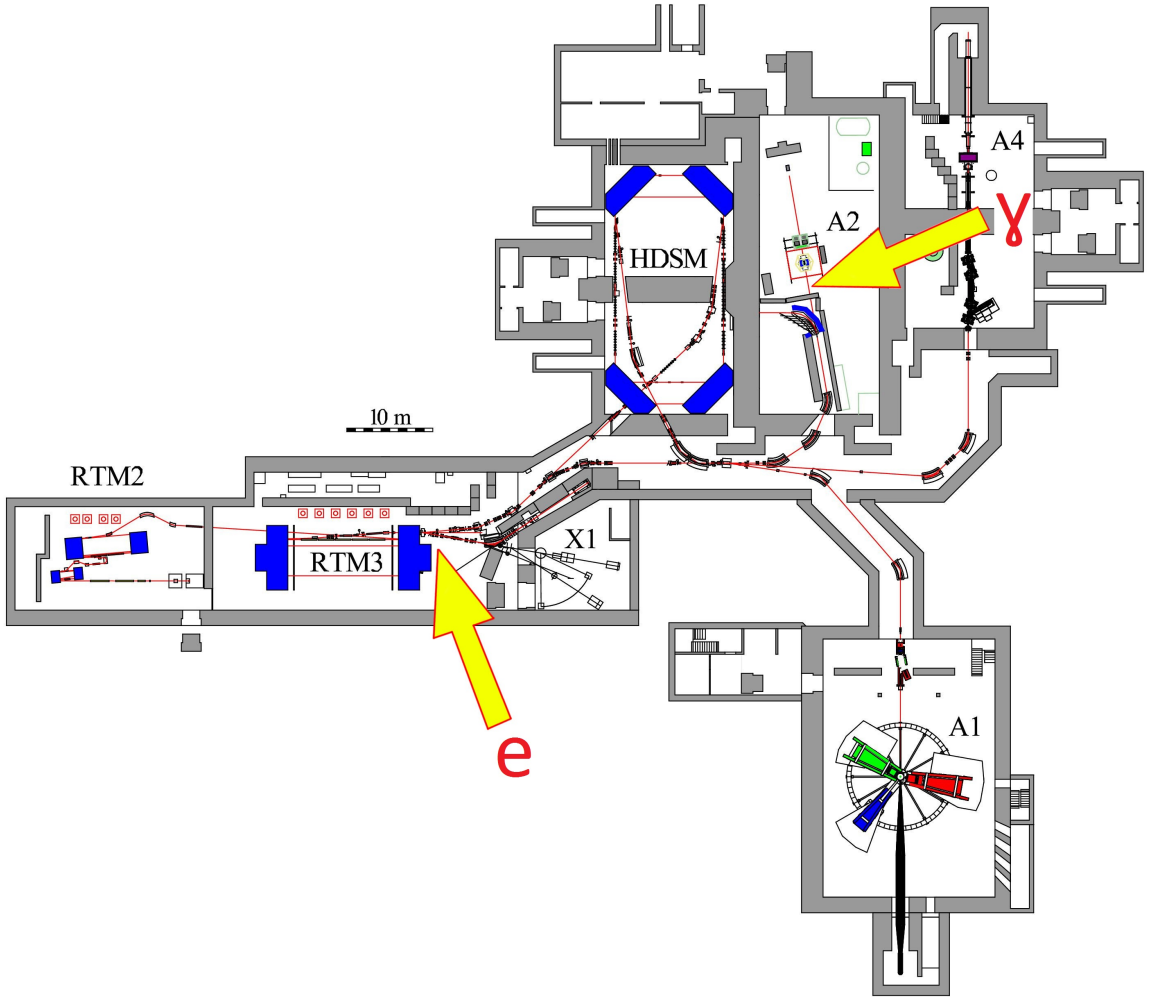


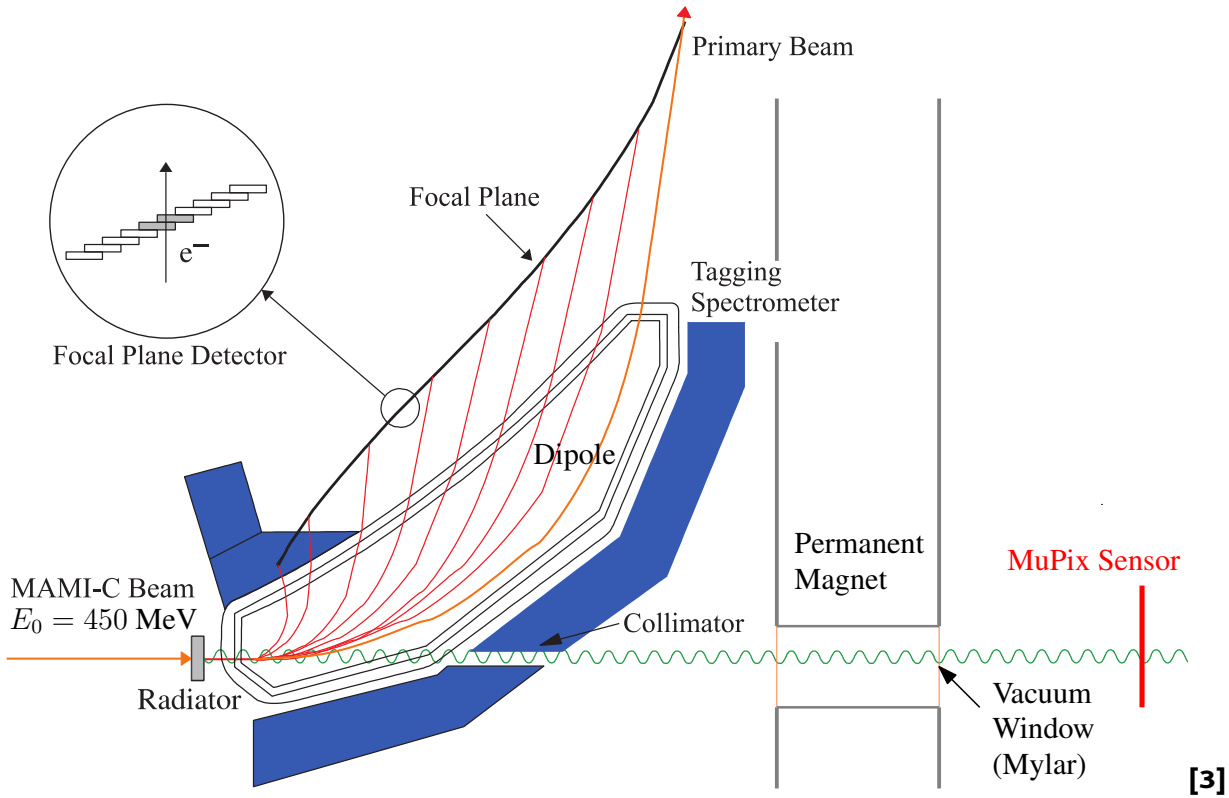
- Originally designed for the **Mu3e** experiment
- Fast, thin high voltage monolithic active pixel sensor (HV-MAPS)
- pixelsize 80x103 µm, time resolution 11 ns
- Currently a 3x3 mm version with 1280 pixels available
- For experiments large area trackers out of MuPix chips planned

Beam test locations



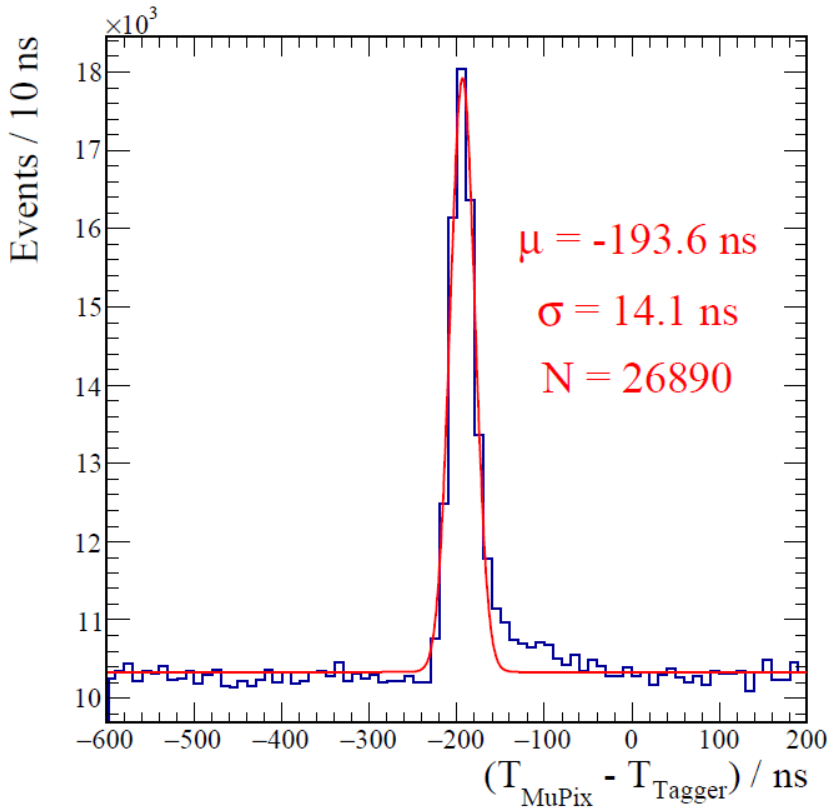
- Direct irradition with the MAMI beam behind RTM3
- Photon test beam location behind A2 Tagger
- Additionally there is space behind the A2 Tagger suitable for tests with the deflected electrons

High energy photon beamtime - A2 Setup

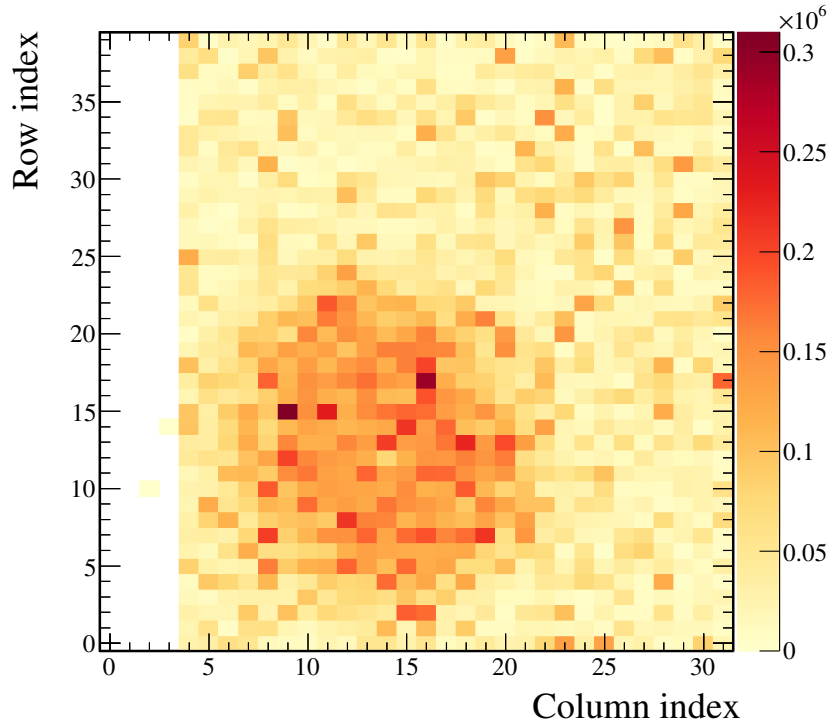


- Efficiency measurement at photon energies from 22.3 to 419 MeV
- Using the photon beam of A2 to irradiate a MuPix chip
- 100 pA of 450 MeV electrons hitting Fe/Cu foil and produce bremsstrahlung photons
- Additional measurement of tagging efficiency with a lead glass detector

High energy photon beamtime - Time coincidende and hitmap



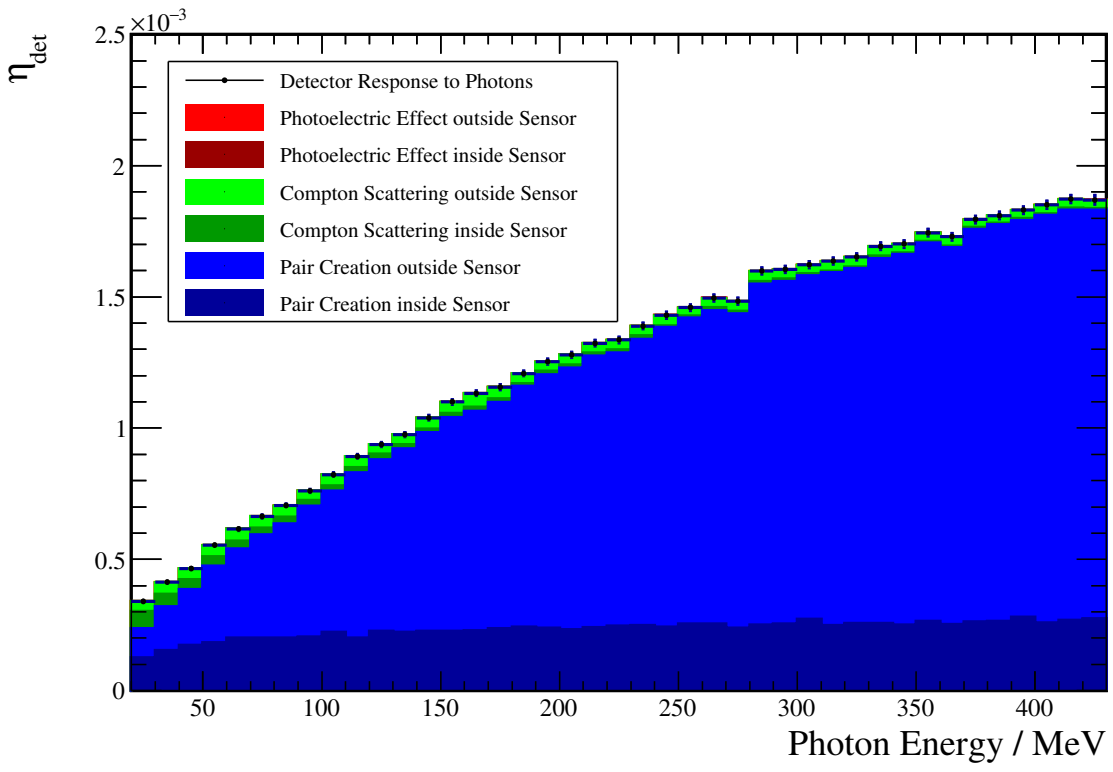
[3]



[3]

- Coicidence between the tagger and the chip
- Photon spot visible in the hitmap
- True photon efficiency can be obtained by correcting for tagging efficiency
- Correction for the sensor size required

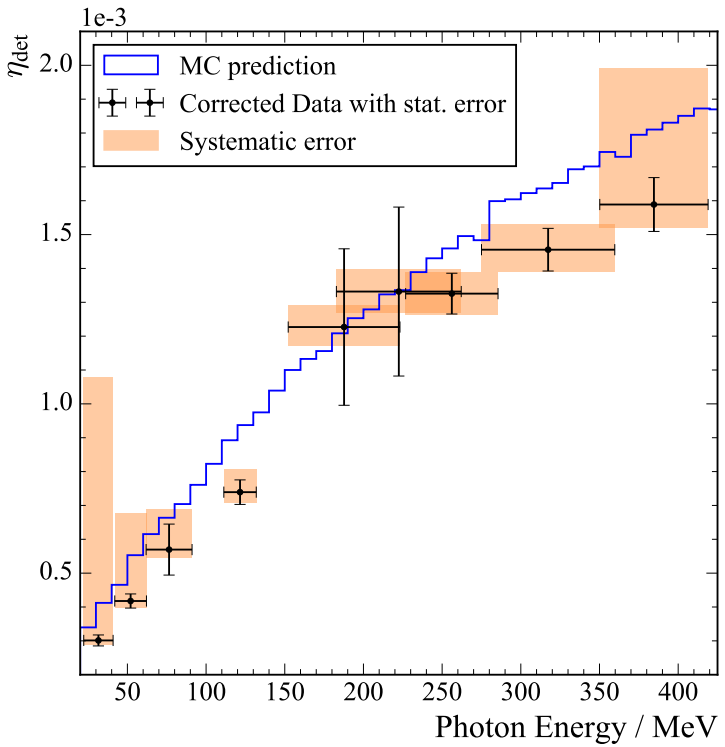
High energy photon beamtime - Simulation



[3]

- Geant4 simulation: main signal contribution from pair production
- Air in front of the chip produced e^+/e^- pairs hitting the chip
- Efficiency η_{det} prediction is between $0.25 \cdot 10^{-3}$ and $1.85 \cdot 10^{-3}$

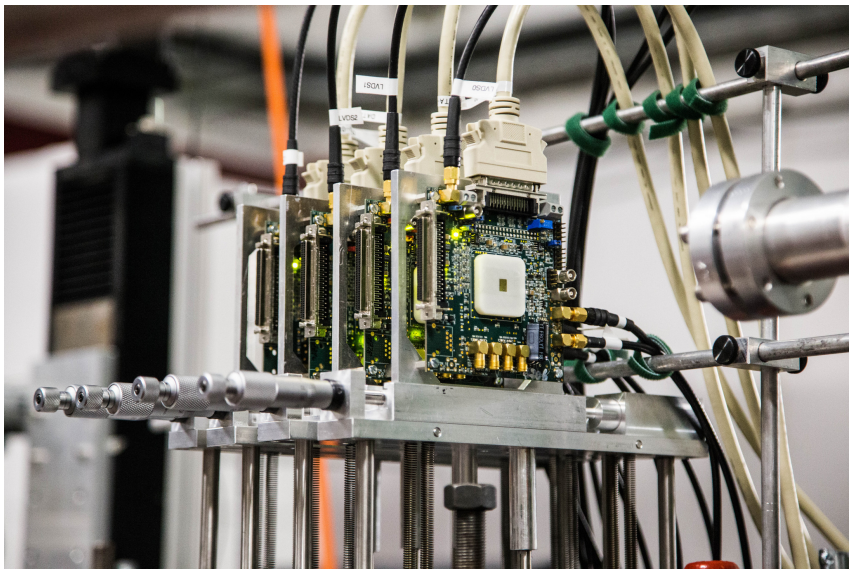
High energy photon beamtime - Result



[3]

- Measured efficiencies agree well with prediction
- More studies at lower photon energies needed
- A magnet in front of the chip could solve the problem of pair production in air

High electron rate beamtimes



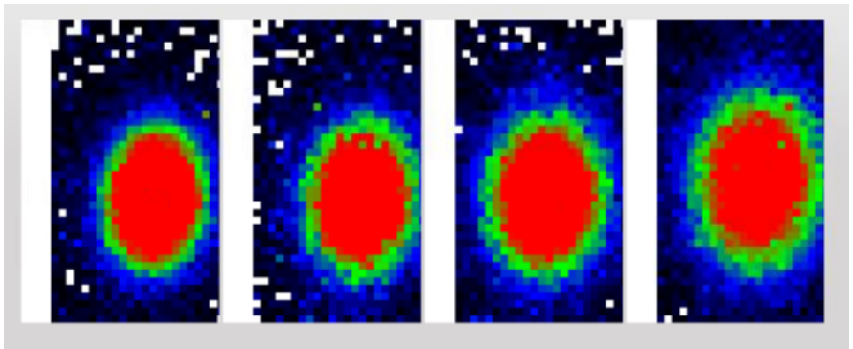
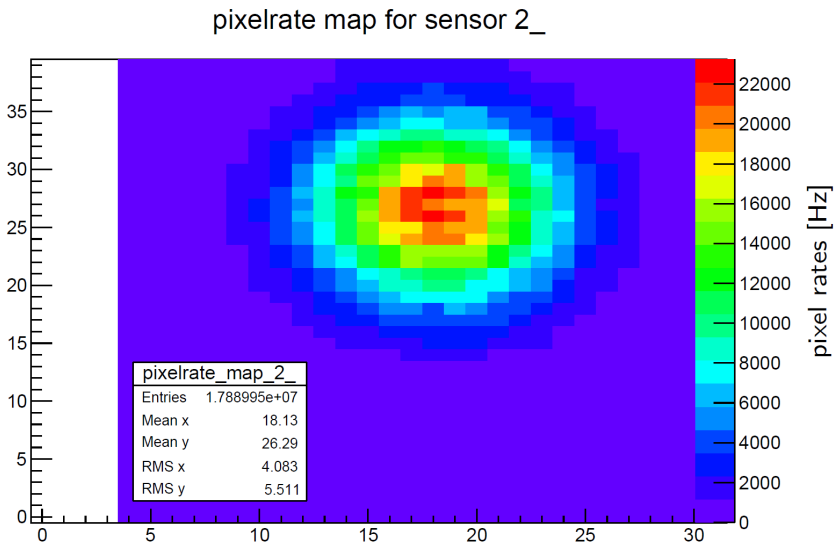


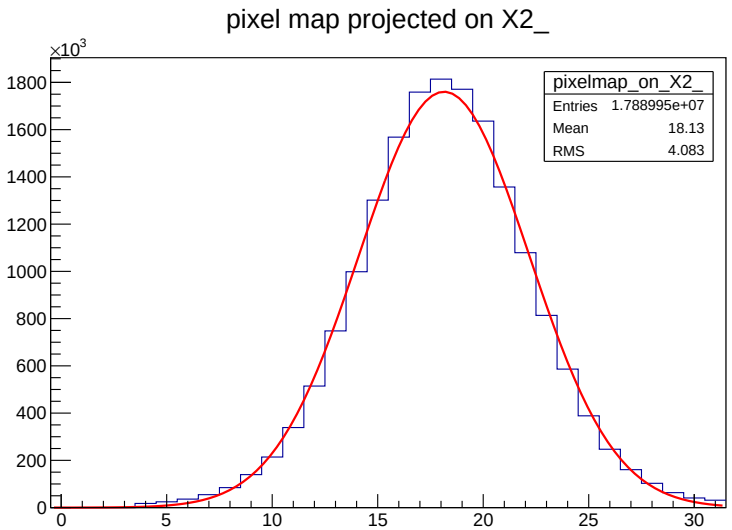
Figure: Beam hitting 4 chips successively

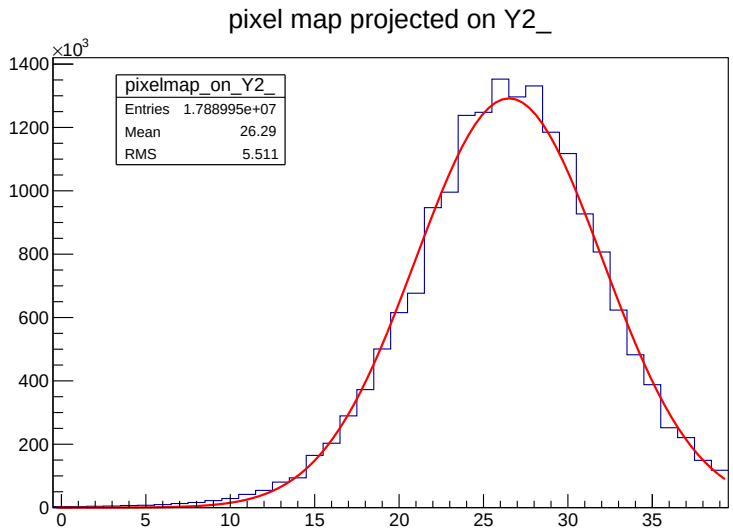
- MAMI beam at 855 MeV hitting a telescope of 4 MuPix chips
- Beam intensity can be chosen arbitrarily low - or full intensity of $6 \cdot 10^{14}\, e^{-}/s$
- Beam profile can be seen in all four chips, if they are aligned well

High electron rate beamtimes - Pixelmap

Pixel rates at 2.8 MHz total rate:

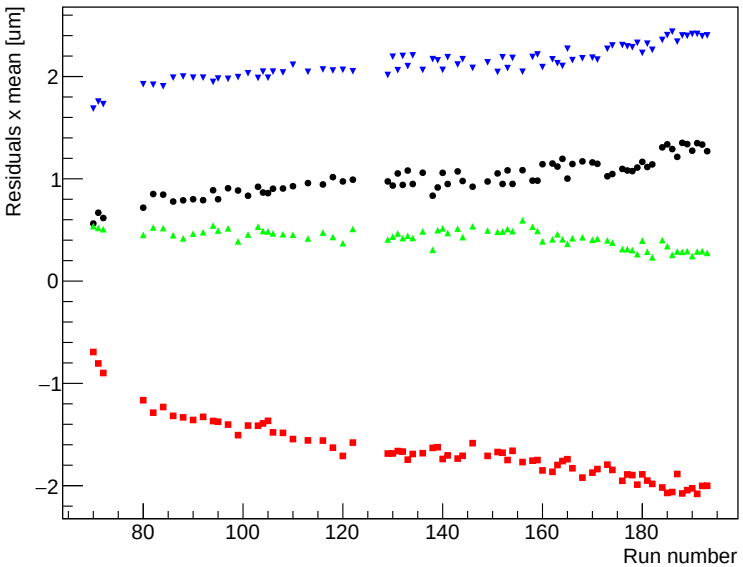


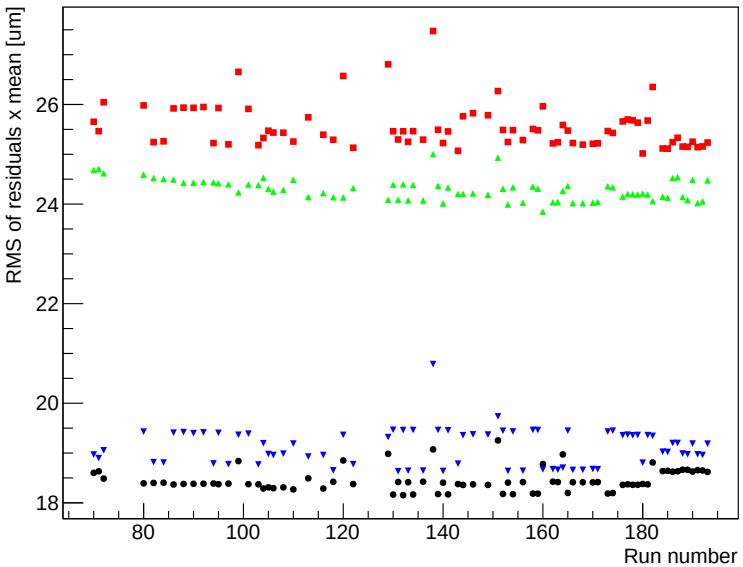




- Beamspot rms after an aluminum window and 1 m of air: 0.42 x 0.44 mm

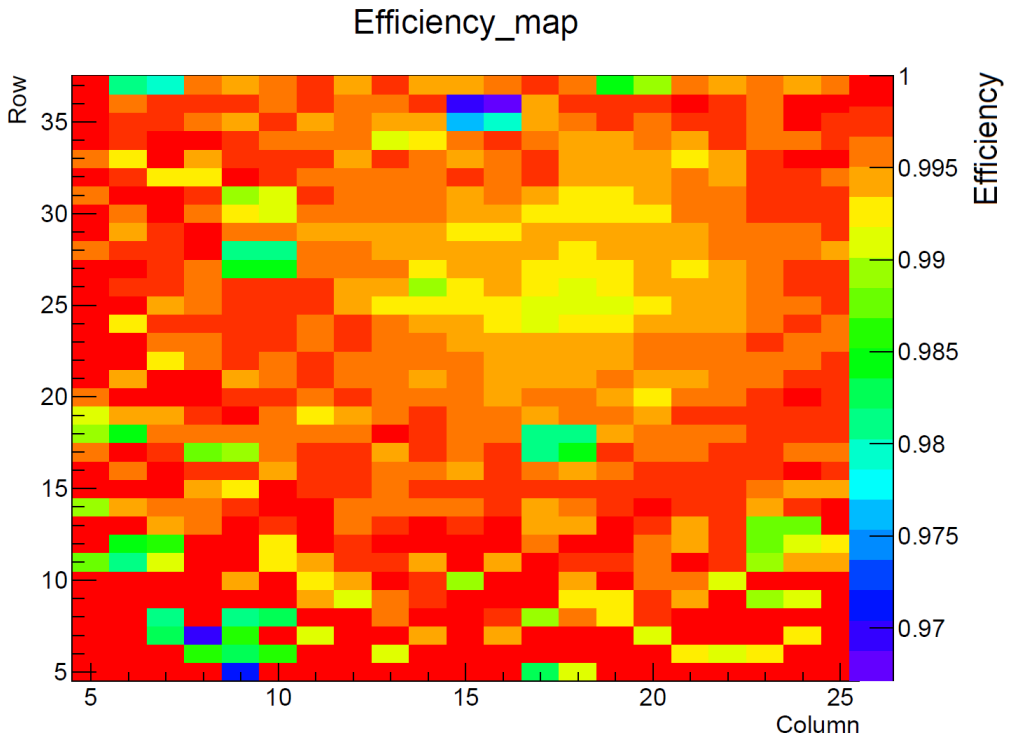
High electron rate beamtimes - Track residuals





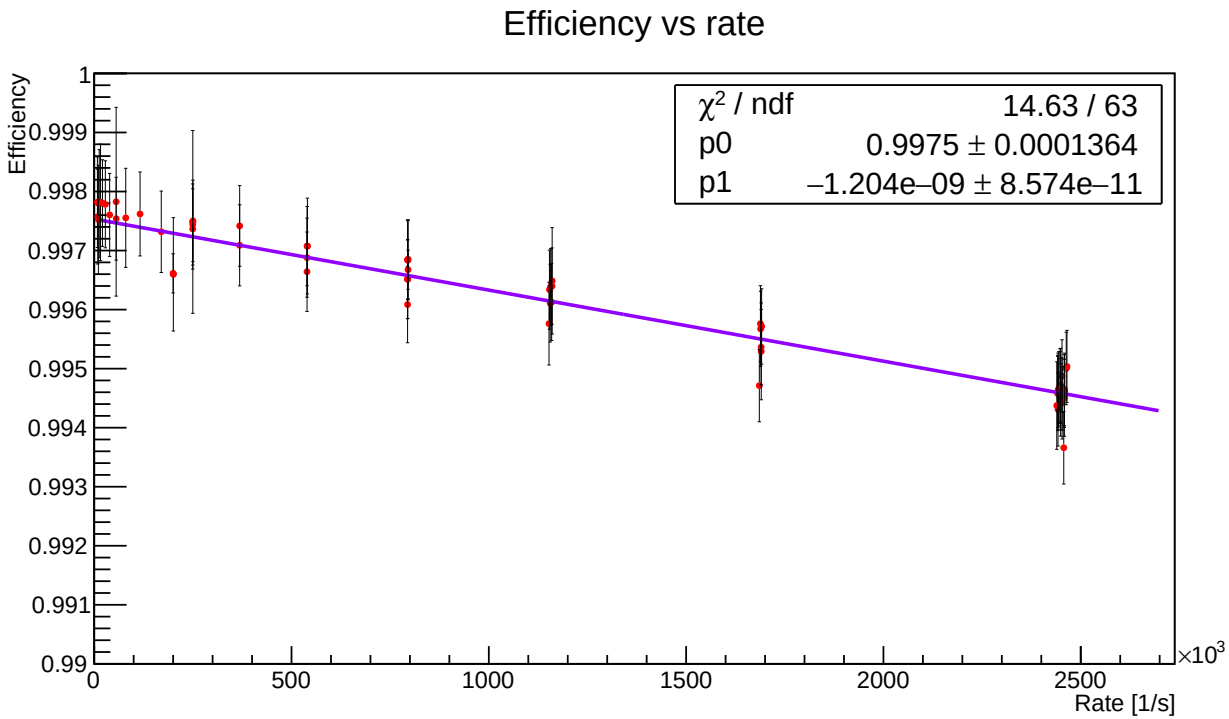
- We can reconstruct tracks when the electrons hit all four chips
- Track efficiency at the chosen cuts was $\approx 45\%$
- Residuals mean changes slighly over time

High electron rate beamtimes - Efficiency map



- The efficiency is mostly constant over the whole chip at low rates
- At high rates we start getting inefficiencies in the highest irradiated pixels
- Deadtimes after each hit of approximatly 600 ns

High electron rate beamtimes



- Efficiency dependence of the beam rate up to 2.5 MHz
- Slope of 0.12% per MHz shows high stability at rates higher than experiment requirements

Summary

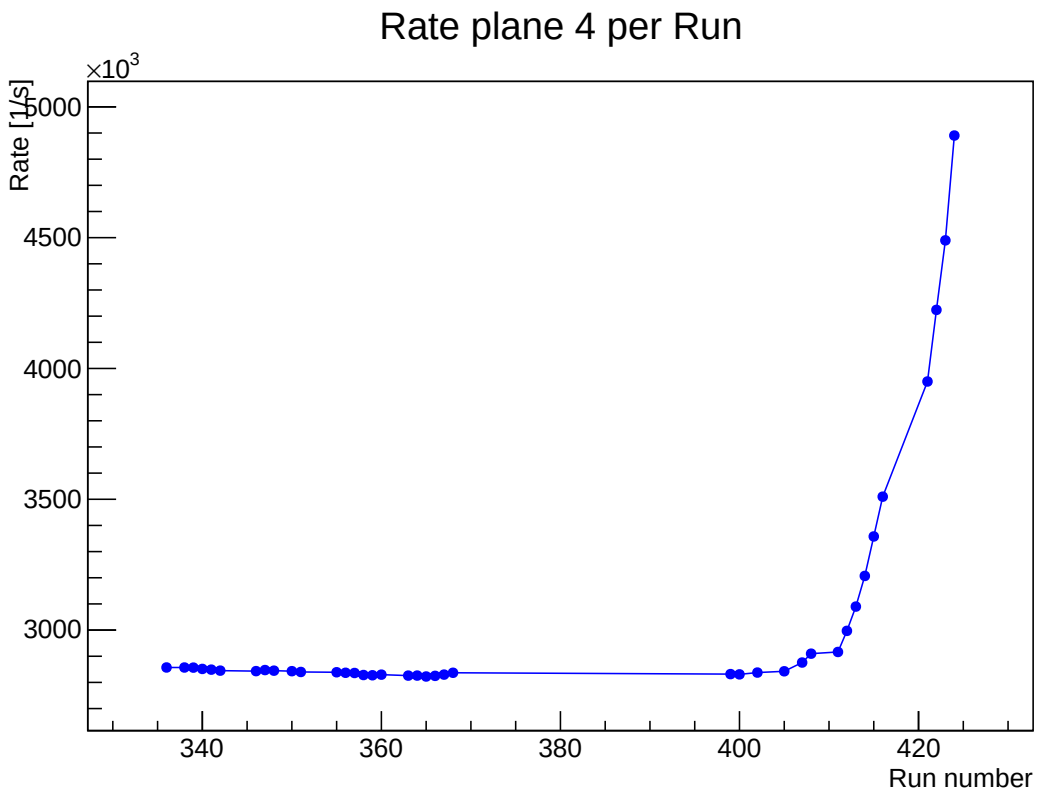
- MAMI is a suitable facility for beam tests with high electron rates and high energy photons
- The narrow high quality electron beam can be extracted at 855 MeV
- Tagged photon beam up to 1.6 GeV
- Photon efficiency upper limit of $0.25 \cdot 10^{-3}$ and $1.85 \cdot 10^{-3}$ between 22.3 to 419 MeV measured with the MuPix chip
- MuPix chip efficiency loss of 0.12% per MHz of 855 MeV electrons

Figure: The Mainz Cathedral

Sources

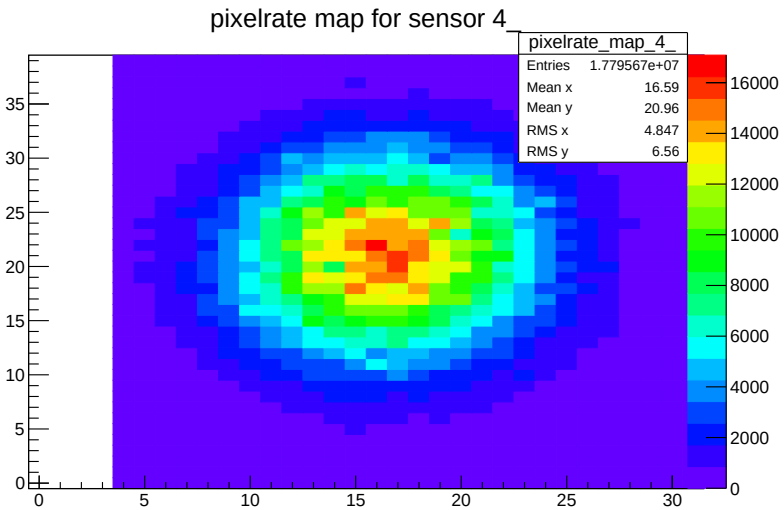
1. Untersuchungen zur Strahldynanik am Harmonischen Doppelseitigen Mikrotron von MAMI-C, Dissertation, Marco Dehn, 2013
2. Operation of the MAMI accelerator with a Wien filter based spin rotation system, V. Tioukine, K. Aulenbacher, Nucl. Inst.a.M. A 568, 2006
3. HV-MAPS Photon Beam Test, Marco Zimmermann, July 11 2016
4. Experimental Study of nucleon resonance contributions to η-photoproduction on the neutron, Dissertation, Dominik Werthmueller, 2014
5. A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology, Ican Peric, Nucl. Inst.a.M. A 582, 2007

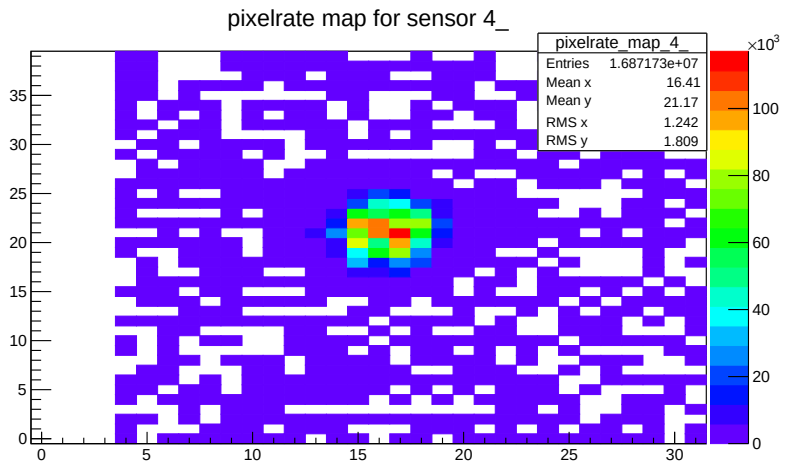
One problem: Beam spots



- Operating the beam at a constant beam current, sometimes a sudden rise in the rate of some chips could be observed.

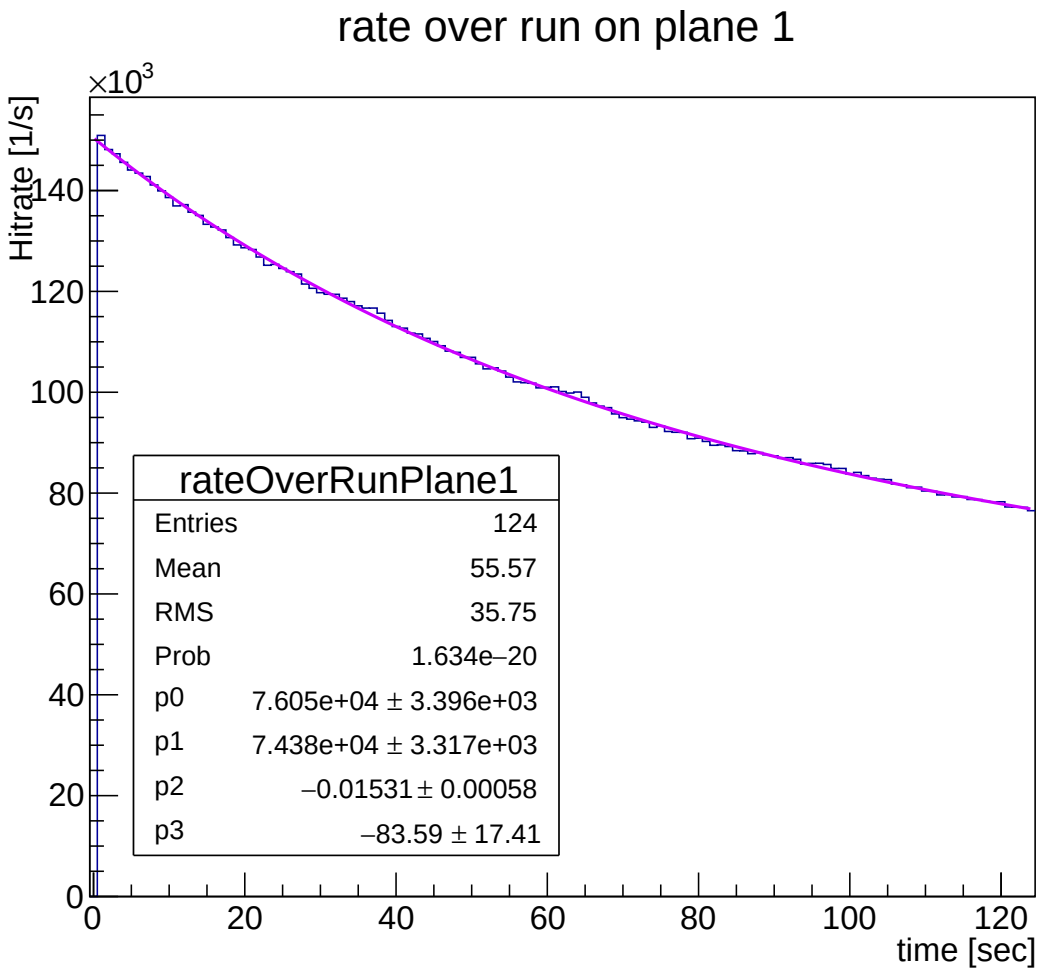
Beam spots





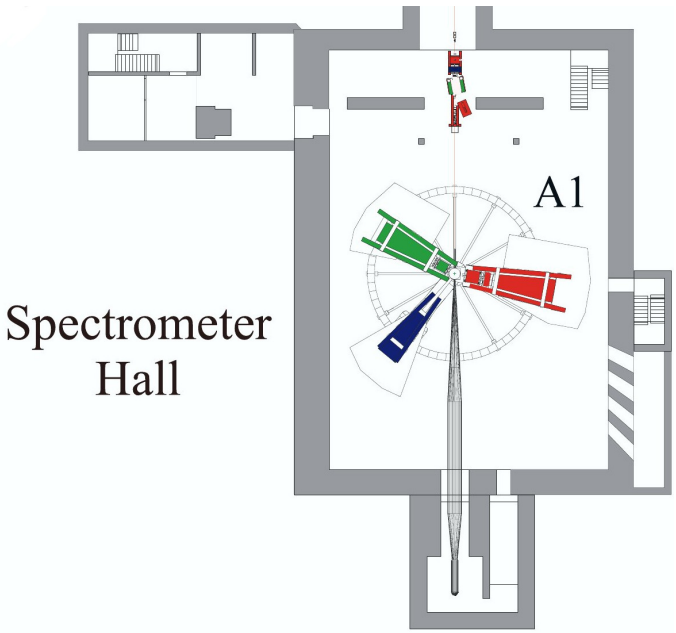
- After switching the beam off, a beamspot was visible in the hitmap. A charge-up effect lead generation of hits without any particles passing through. This would mean severe noise increase in a real experiment.

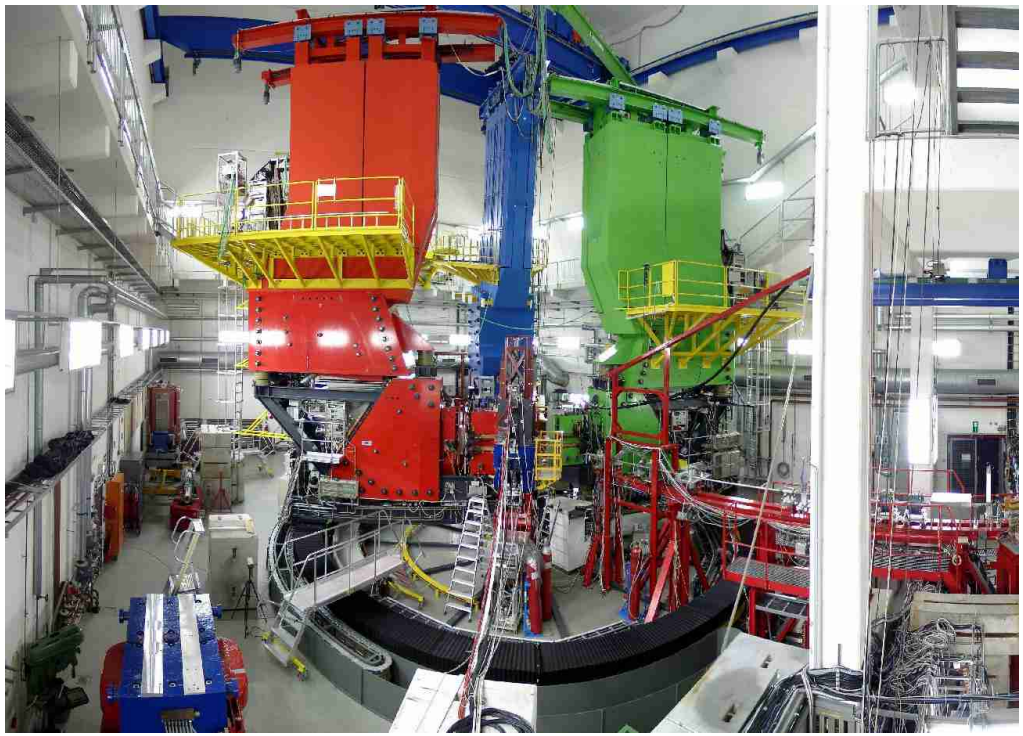
Beam spots



- The beamspot decays with different speeds depening on its intensity.

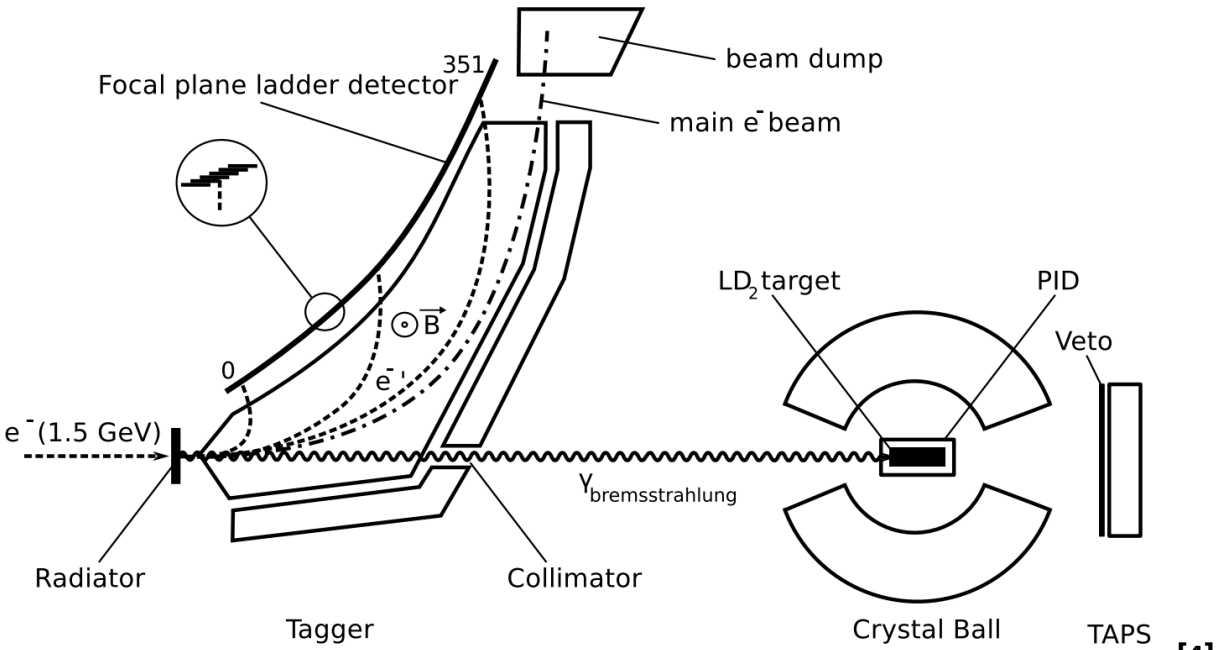
Electron scattering at A1





- Precision electron scattering experiments with 3 rotatable spectrometers
- VDCs with momentum resolution to 10^{-4}
- Electron energy exceeds the production threshold for several Mesons and Hyperons

Photon scattering at A2



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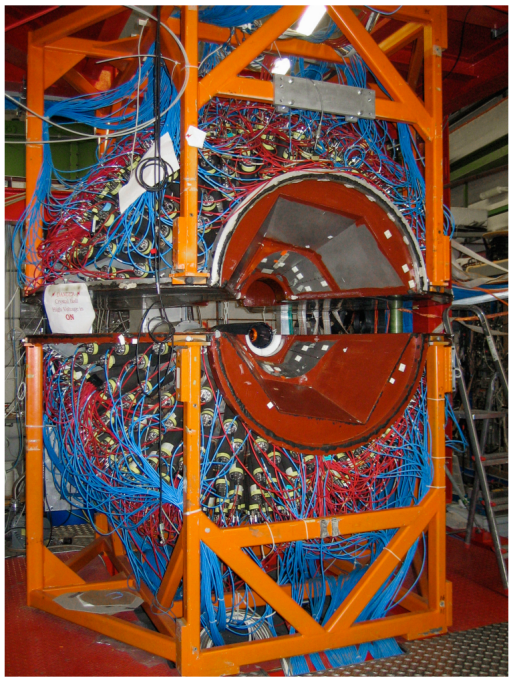

Figure: The Crystal-Ball is a 4π calorimeter around the main target [4]

- Photons between 22-1500 MeV are produced by bremsstrahlung on the radiator
- A dipole deflects the beam electrons and allows momentum measurement in the focal plane detector
- Photons go through a collimator to the main target