High rate and photon testbeams with the MuPix at MAMI

Alexey Tyukin

Mainz Institute for Nuclear Physics

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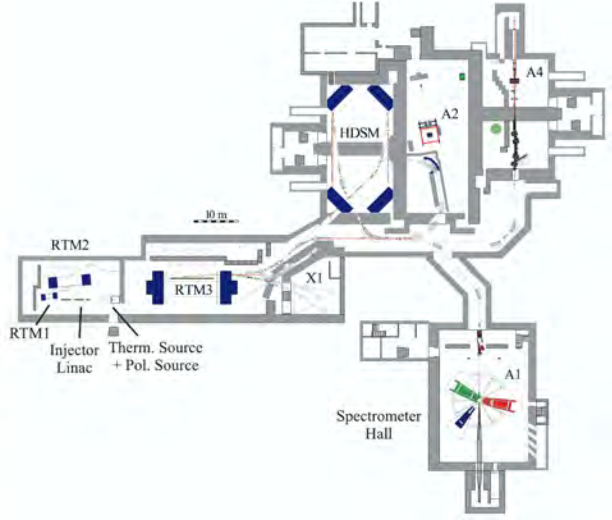
JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U

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

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

The Mainz Microton (MAMI)



- 3 stage RTM up to 855 MeV and HDSM to up 1.6 GeV
- Beamcurrent up to 100 µA as 2.45 / 4.90 GHz continuous wave
- Halls for experiments with electrons, high energy photons and x rays

[1]

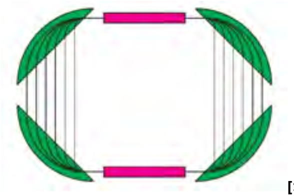
- The first three stages consist of 3 racetrack microtrons
- Acceleration of initial 4 MeV Beam in steps to 14, 180, 855 MeV
- Completed in 1990

The final RTM stage:

- 2 x 450 t Magnets
- 5 Klystrons at 2.45 GHz
- 90 recirculations
- 7.5 MeV / turn
- 855 MeV final Energy

HDSM - Harmonic Doublesided Microtron

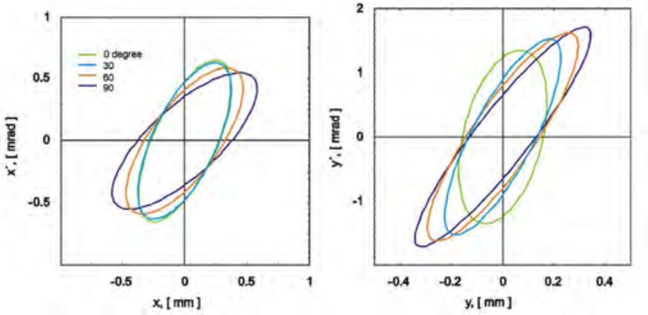
[1]



[1]

- 4 x 250 t Magnets
- 5 Klystrons at 2.45 / 4.9 GHz
- 43 recirculations
- 16.6 MeV / turn
- 1.6 GeV final energy
- Completed in 2006

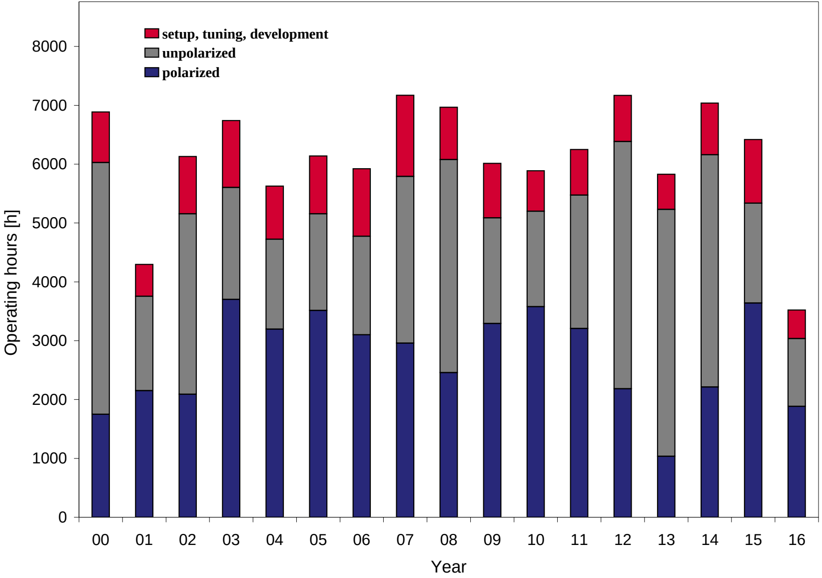
- High quality beam suitable for parity violation experiments
- Typical beam size < 1 mm
- Energy stability to $2 \cdot 10^{-5}$
- Beam can have polarisation of 85%
- Emittance at 855 MeV of 40.8 mm $\cdot$ mrad (hor) and 3.8 mm $\cdot$ mrad (vert)



[2]

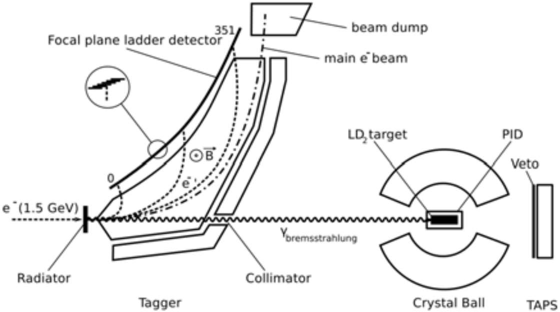
Figure : phase space (horizontal and vertical) of the beam for different polarisations at 0.1 MeV. Boundy shows 1 σ area, emittance scales with $\propto \sqrt{E}$

MAMI operation time



- 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



[4]

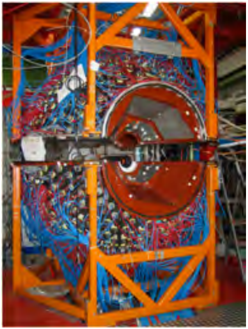


Figure : The Crystal-Ball is a 4π calorimeter around the main target [4]

- Photons between 22-1500 MeV produced by bremsstrahlung on the radiator
- A dipole deflects the beam electrons and allows momentum measurement in the focal plane detector
- Photons are being collimated on the main target
- Lower energetic photons (Hard X-Rays to infrared) are being studied at X1

MESA: a new accelerator near MAMI

Mainz Energy Recovering Superconducting Accelerator planned for 2020+

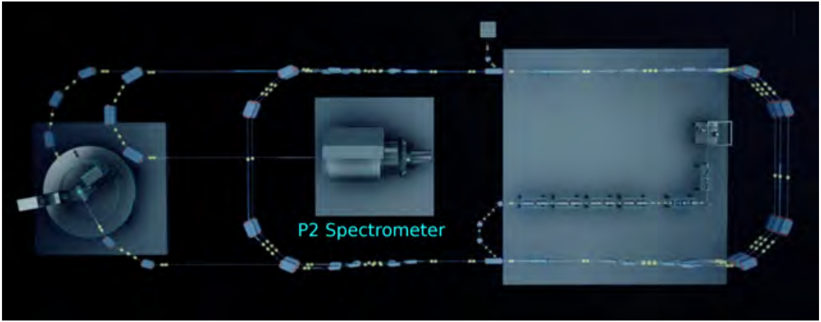
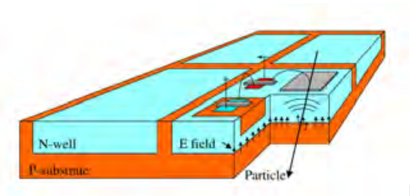
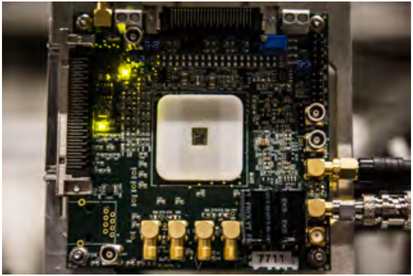


Figure : A new accelerator is being built in the old A4 Hall

- An independent new accelerator for high precision physics up to 155 MeV
- Highly stable beam up to 150 μA for future precision experiments
- Energy recovery mode will allow up to 10 mA beamcurrent
- Two experiments being planned: P2 and MAGIX

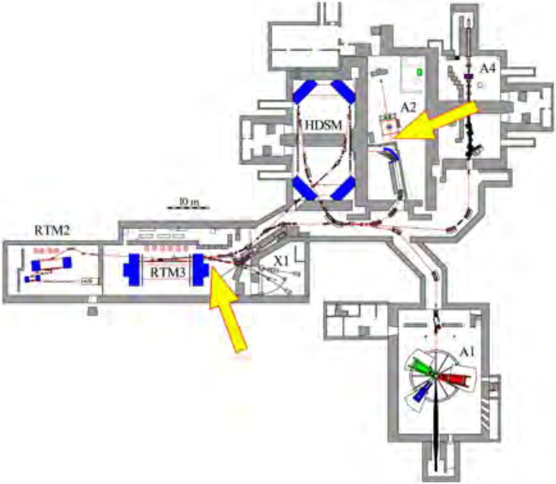


[5]



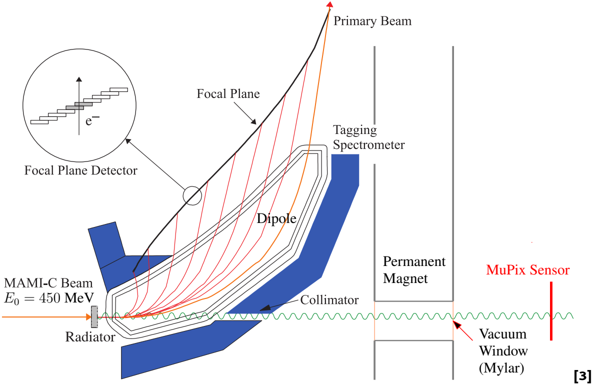
- Originally designed for the Mu3e experiment
- Fast, thin high voltage monolithic active pixel sensor (HV-MAPS)
- pixelsize 80x103 μm, time resolution 11 ns
- Until now a 3x3 mm Version with 1280 pixels available
- In planned experiments large areas need to be covered with MuPix chips

Beam test locations



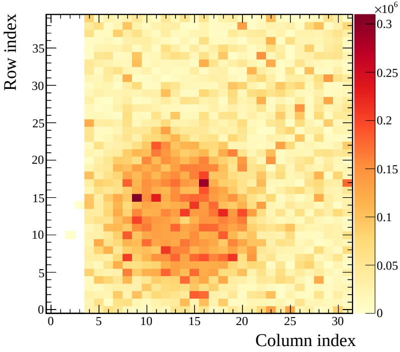
- Behind the RTM3 is a place for any type of setup for direct irradiation with the beam
- Between the A2 Tagger and the Crystall Ball the beamline can be opened to put in a photon test setup

High energy photon beamtime - A2 Setup



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

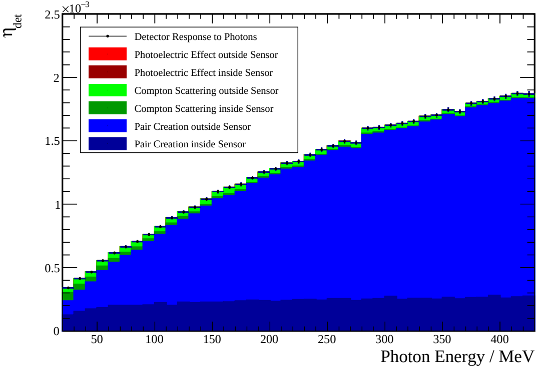
High energy photon beamtime - Hitmap



[3]

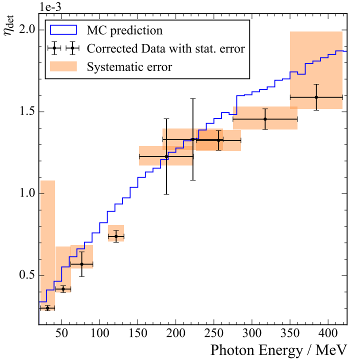
- The hitmap produced a spot which is bigger than the sensor
- Correcting for the sensor position yields total registered photon number
- The actual photon number can be inferred from external lead glass measurement

High energy photon beamtime - Simulation



[3]

- Geant4 Simulation predicted the efficiency η_{det} to be between $0.25 \cdot 10^{-3}$ and $1.85 \cdot 10^{-3}$
- Main problem was 1 meter of air in front of the chip which produced e^{+}/e^{-} pairs hitting the chip
- The efficiency increases mainly because the photon beam is more focused at higher energies



[3]

- Measured efficiencies agree well with prediction
- Background which cannot be reduced affected the measurement
- Lower energies not possible with the A2 tagger

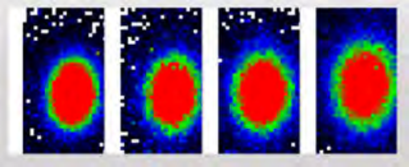


Figure : Beam hitting 4 chips successively

- MAMI beam at 855 MeV hitting a telescope of 4 MuPix chips
- Beam intensity can be chosen arbitrarily low
- Beam profile can be seen in all four chips, if they are aligned well

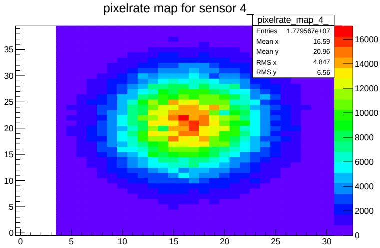
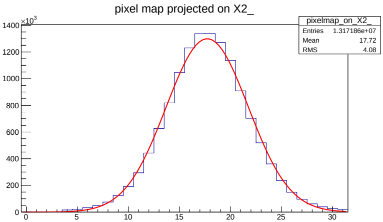
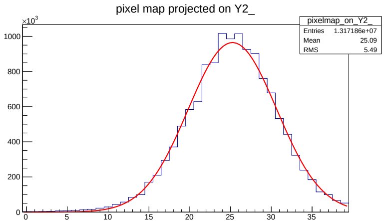


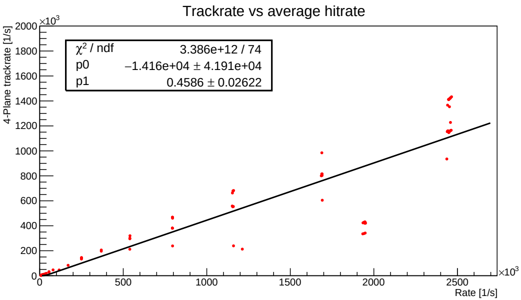
Figure : hit rates [1/s] per pixel at a total chip rate of 2.4 MHz





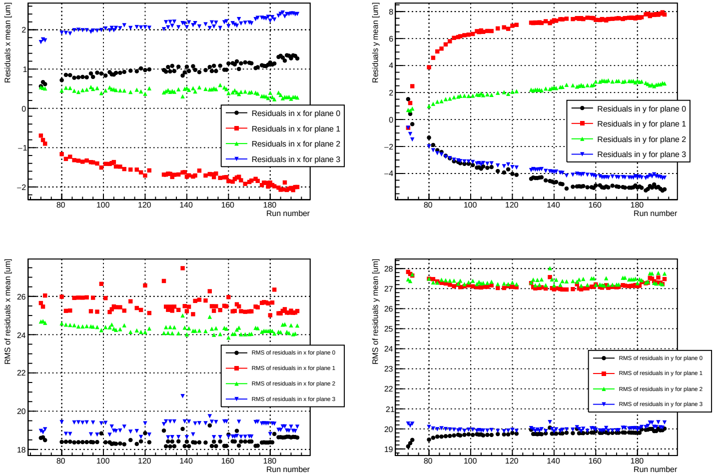
- Beamspot rms after an aluminum window and 1 m of air: 0.42 x 0.42 mm

High electron rate beamtimes

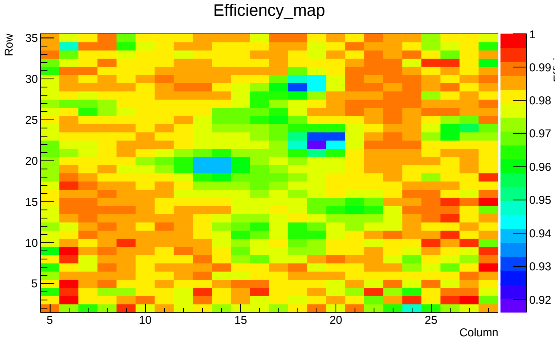


- We can reconstruct tracks when the electrons hit all four chips
- With higher electron rate we can reconstruct proportionally more tracks

High electron rate beamtimes - Track residuals

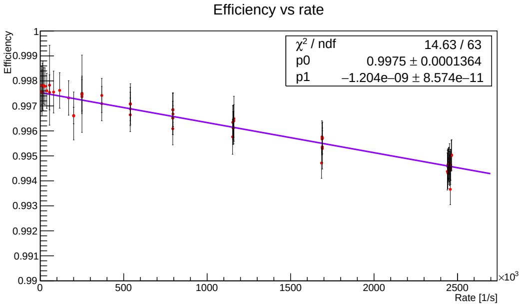


- Residuals mean and width changes slighly over time



- The efficiency is mostly constant over the whole chip al low rates
- At high rates we start getting inefficiencies in the highest irradiated pixels

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 comparable to experiment requirements

Summary

- MAMI is a suitable facility for beamtests with MuPix chips
- Tagged photon beam up to 1.6 GeV available
- The narrow high quality electron beam can be extracted at 855 MeV
- Efficiencies and rate dependencies could be studied

Sources

1 Untersuchungen zur Strahldynanik am Harmonischen Doppelseitigen Mikrotron von MAMI-C, Dissertation, Marco Dehn, 2013

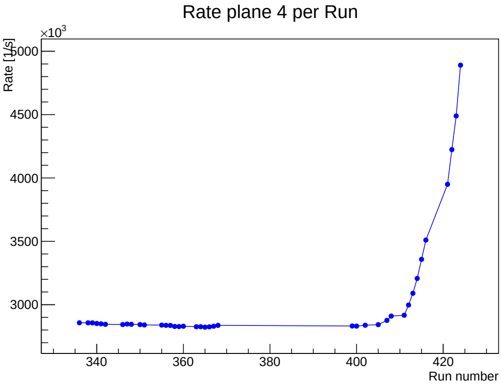
2 Operation of the MAMI accelerator with a Wien filter based spin rotation system, V. Tioukine, K. Aulenbacher, Nucl. Inst.a.M. A 568, 2006

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

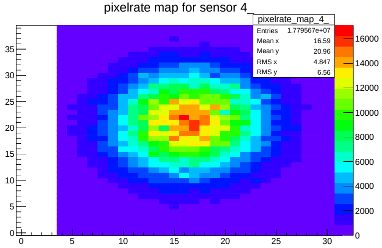
5 A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology, Ican Peric, Nucl. Inst.a.M. A 582, 2007

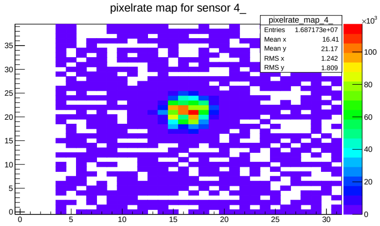
One problem: Beam spots



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

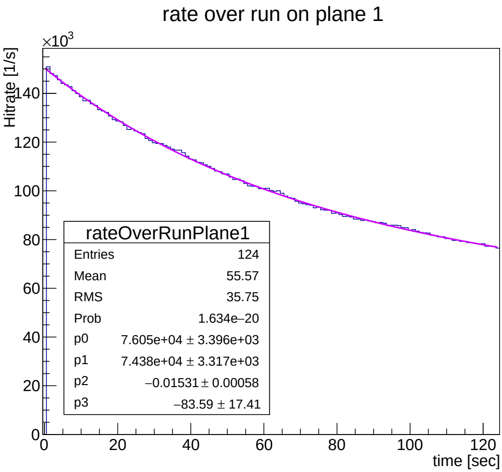
Beam spots





- 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.