

Radiation damage studies in scCVD diamond material with protons and heavy ions



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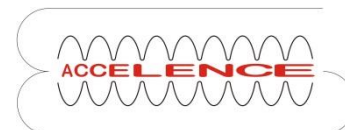
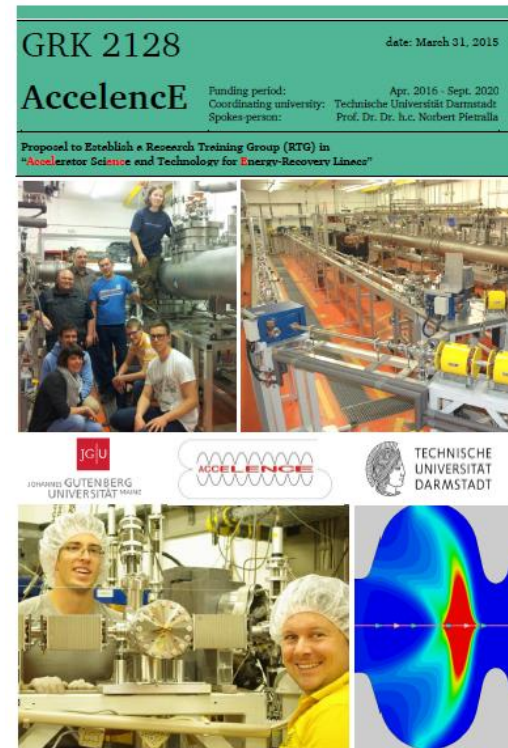


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Content

- Introduction
- Radiation damage studies of diamond material
- Future Outlook: Diamond detectors for beam diagnostics at the S-DALINAC of TU Darmstadt

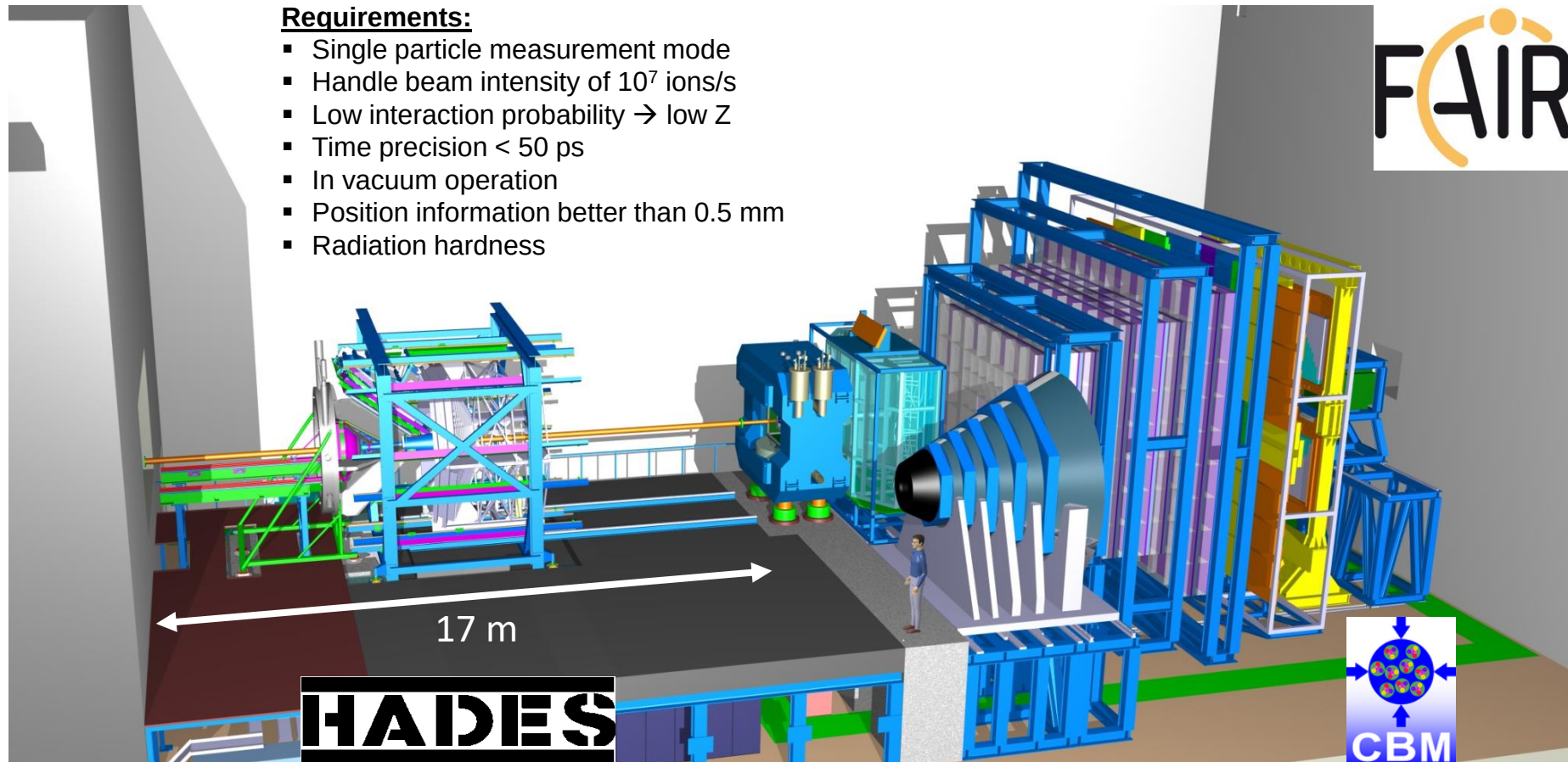
Diamond detectors in the HADES and CBM experiments at SIS100 (FAIR)

Diamond detector applications:

- T0 determination → ToF measurements
- Beam monitoring: beam profile in X and Y, beam HALO measurement
→ Fast Beam Abort System

Requirements:

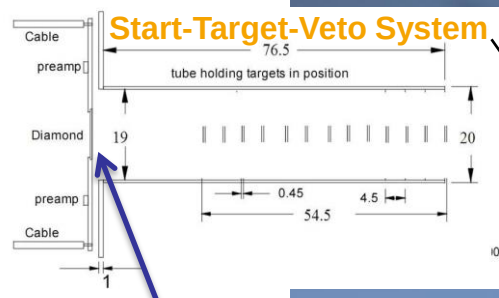
- Single particle measurement mode
- Handle beam intensity of 10^7 ions/s
- Low interaction probability → low Z
- Time precision < 50 ps
- In vacuum operation
- Position information better than 0.5 mm
- Radiation hardness



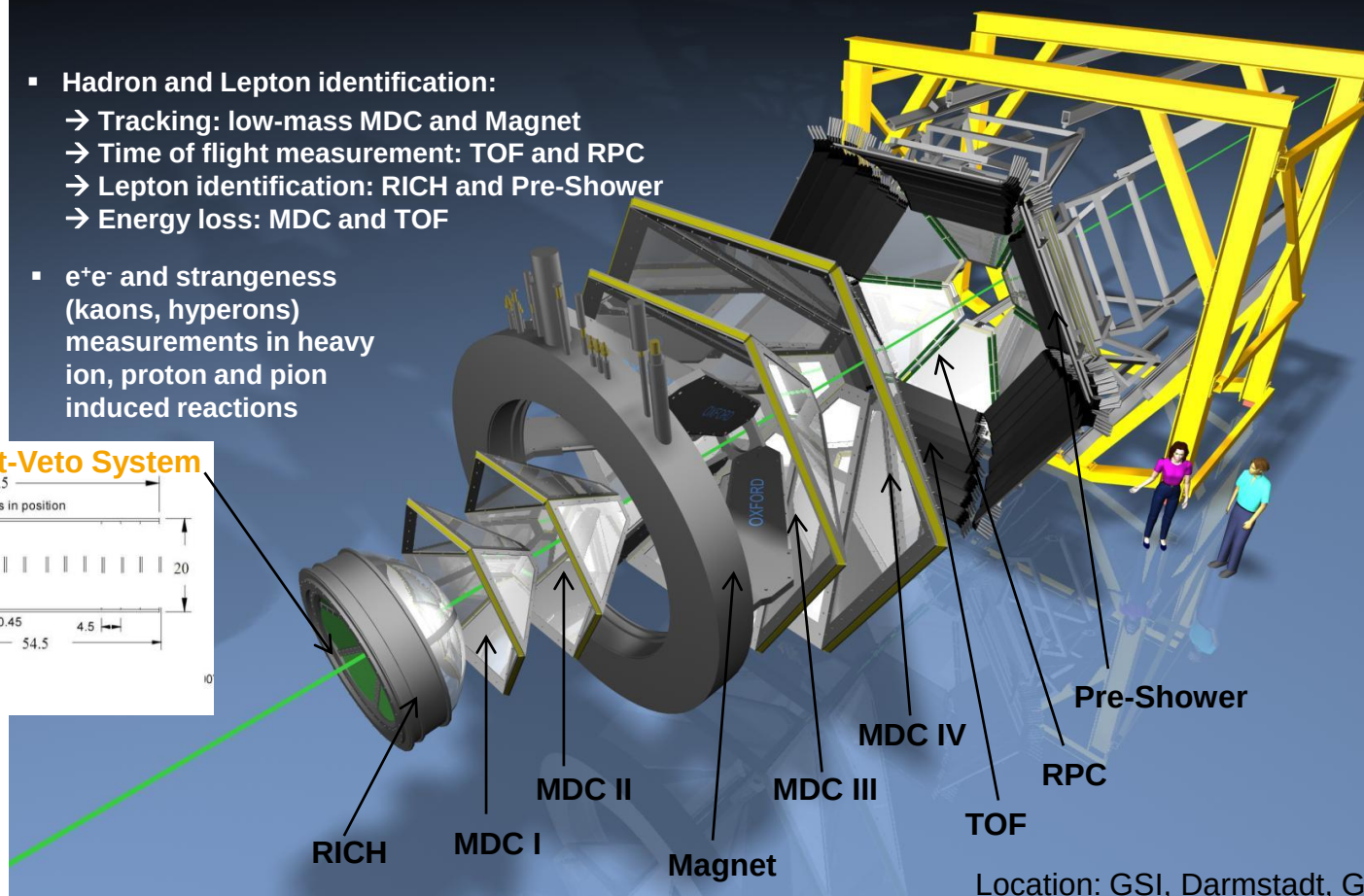
The HADES at GSI:

High-Acceptance Dielectron Spectrometer

- Acceptance: 2π in ϕ ; $18^\circ < \theta < 85^\circ$
- e^+e^- pair acceptance: $\sim 35\%$, mass resolution: $\sigma_M(\omega) = 2\%$
- Hadron and Lepton identification:
 - Tracking: low-mass MDC and Magnet
 - Time of flight measurement: TOF and RPC
 - Lepton identification: RICH and Pre-Shower
 - Energy loss: MDC and TOF
- e^+e^- and strangeness (kaons, hyperons) measurements in heavy ion, proton and pion induced reactions

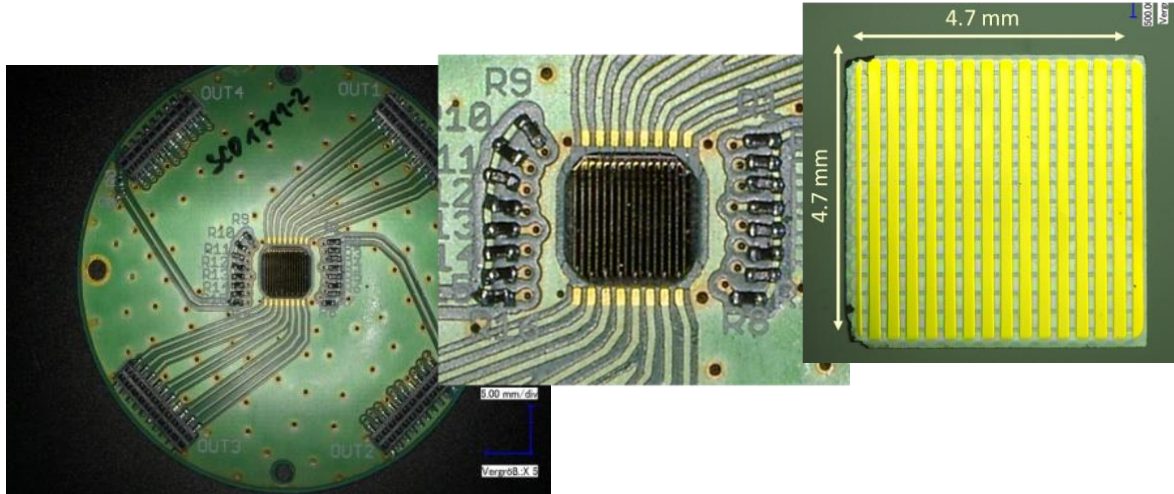


Start detector
(scCVD diamond)



Location: GSI, Darmstadt, Germany

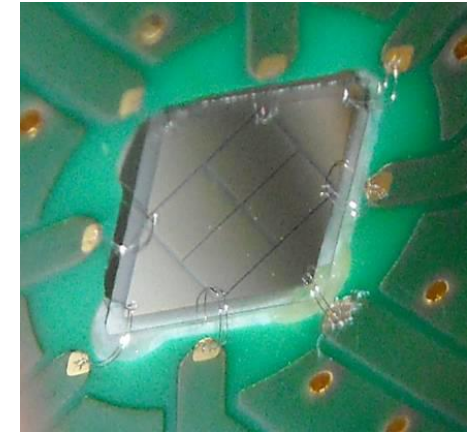
Diamond detectors used in HADES for Au beam (1.25 A GeV)



Multi-strip detector

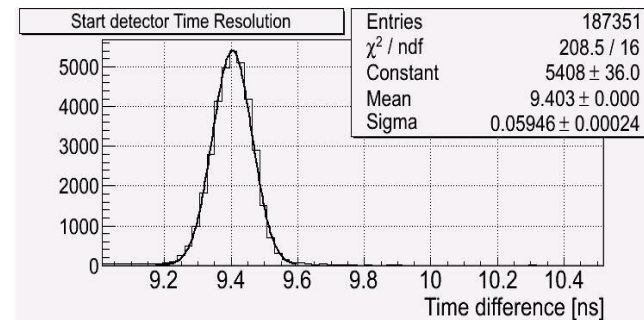
- 16 stripes on each side (width: 200 μm , gap: 90 μm)
- detector thickness: $\sim 60 \mu\text{m}$
- detector time precision: $\sim 50 \text{ ps}$

→ dedicated electronics: Multihit TDC (17 ps RMS)
→ Single particle mode: up to 10^7 ions/s per channel
(limited by TDC: 10^6 hits/s)



8 segment detector

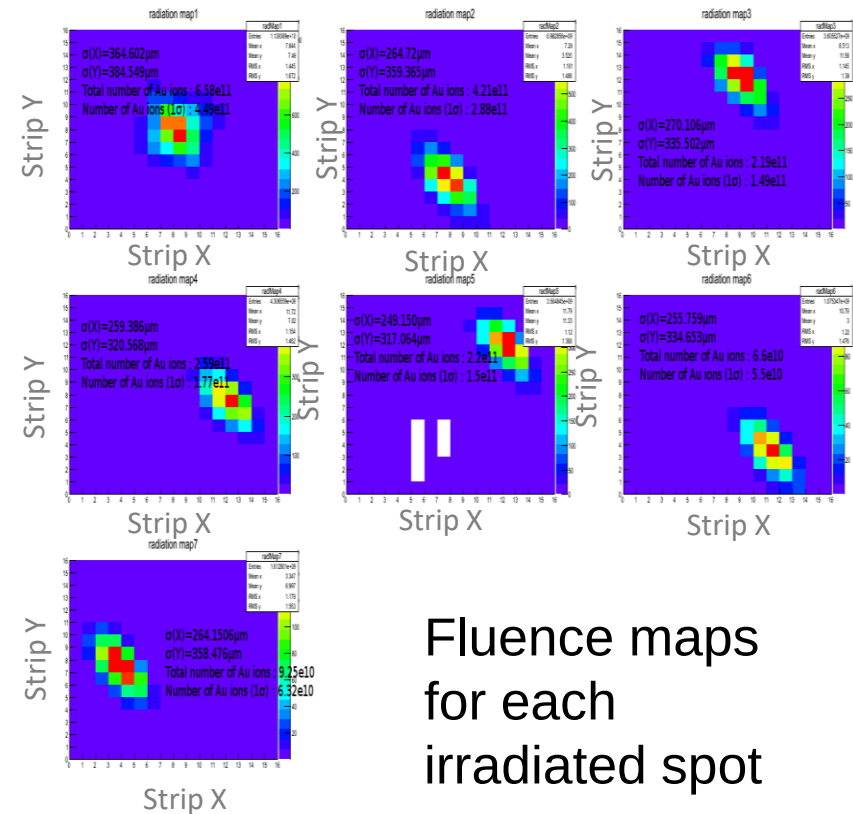
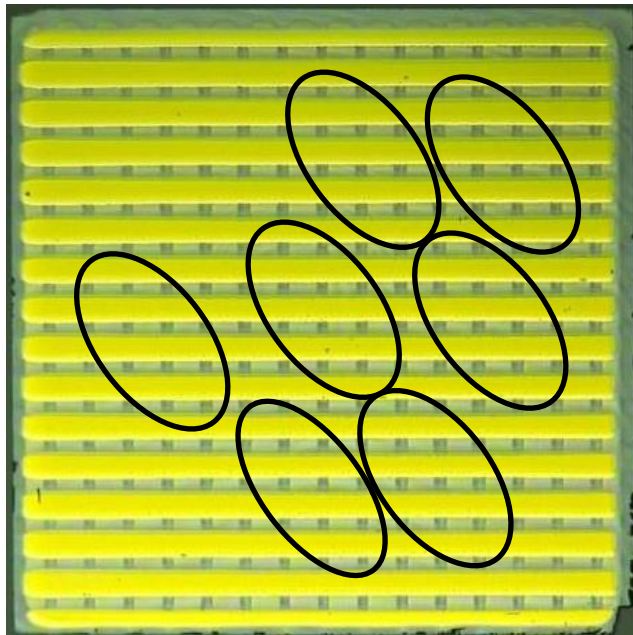
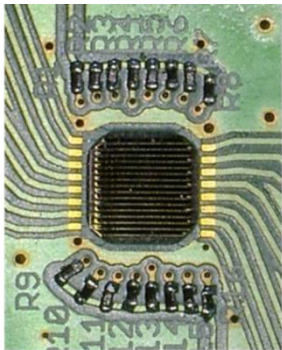
- size: 4.5 mm x 4.5 mm
- detector thickness: 70 μm
- detector time precision: $\sim 50 \text{ ps}$



Irradiation of the multi-strip detector

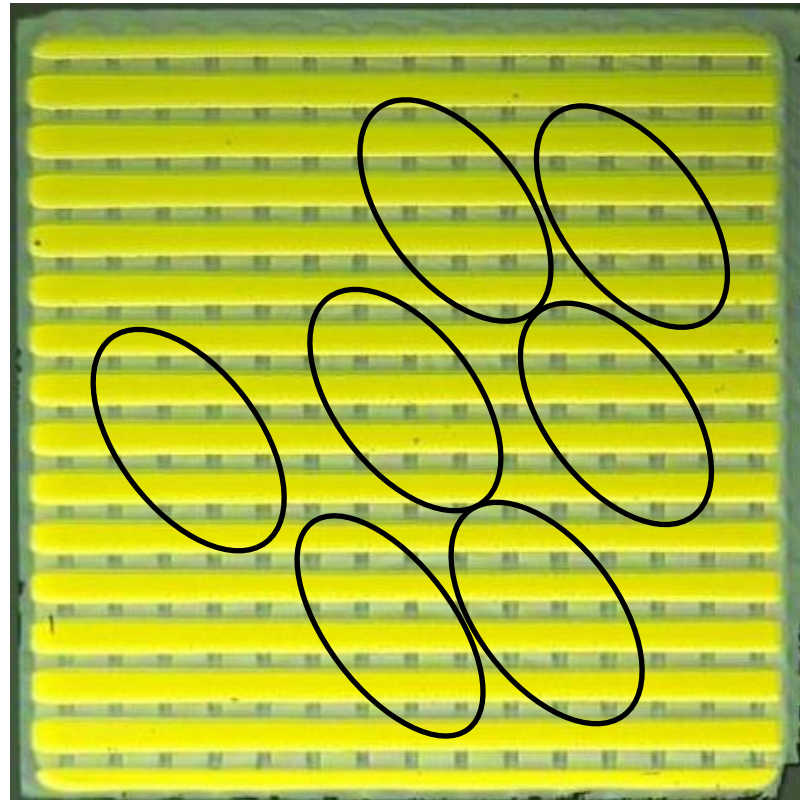
$^{197}\text{Au}^{69+}$ beam:

- Energy 1.23 AGeV
- Beam size (3σ) $1.3 \times 0.8 \text{ mm}^2$
- Intensity $\approx 10^6$ ions/s



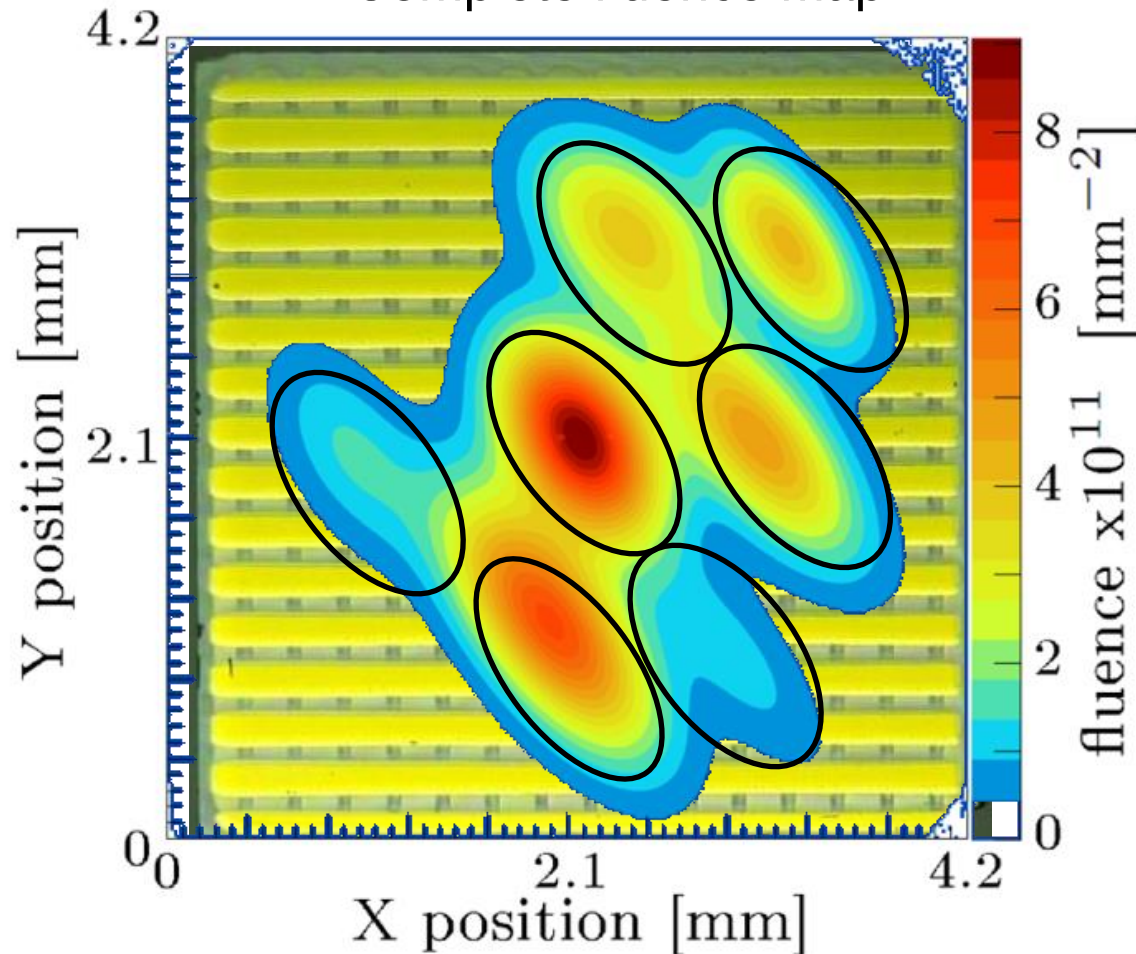
Fluence maps
for each
irradiated spot

Fitting the fluence distribution with seven 2D Gaussian functions



Fitting the fluence distribution with seven 2D Gaussian functions

Complete fluence map



Analysis of signal degradation in Zagreb

IBIC is perfect method of choice:

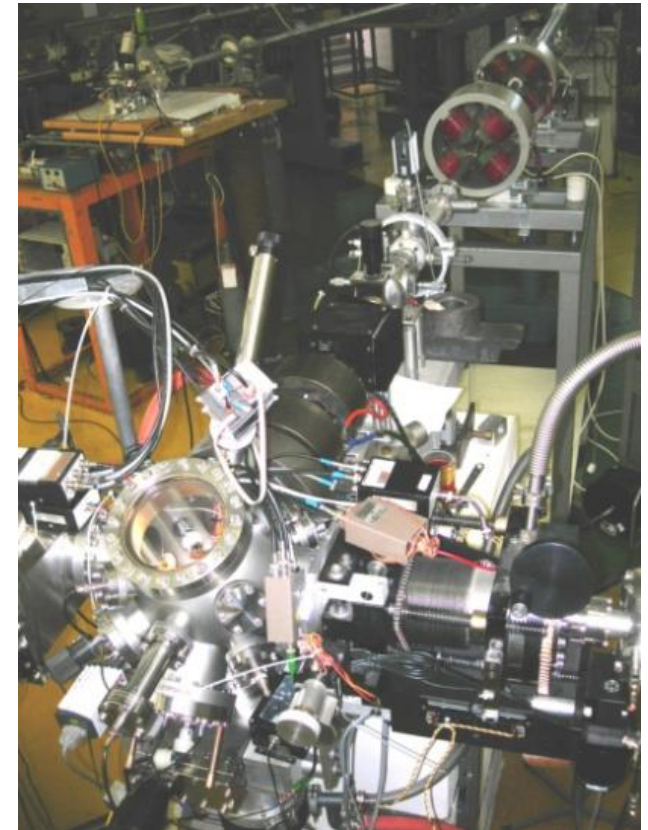
- Signal decrease corresponds to the amount of damage produced
- Spatial resolution retained through the whole device
- Theory already well established

Possible problems:

- Diamond polarization
- Limited scan size

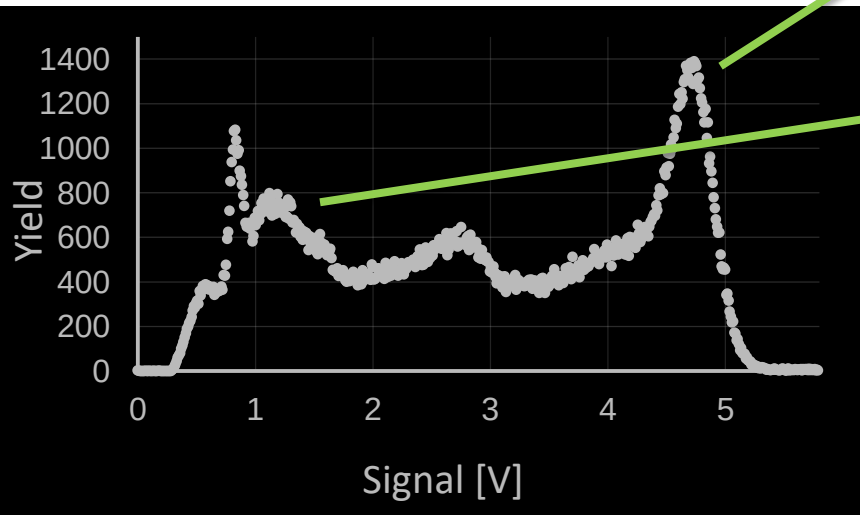
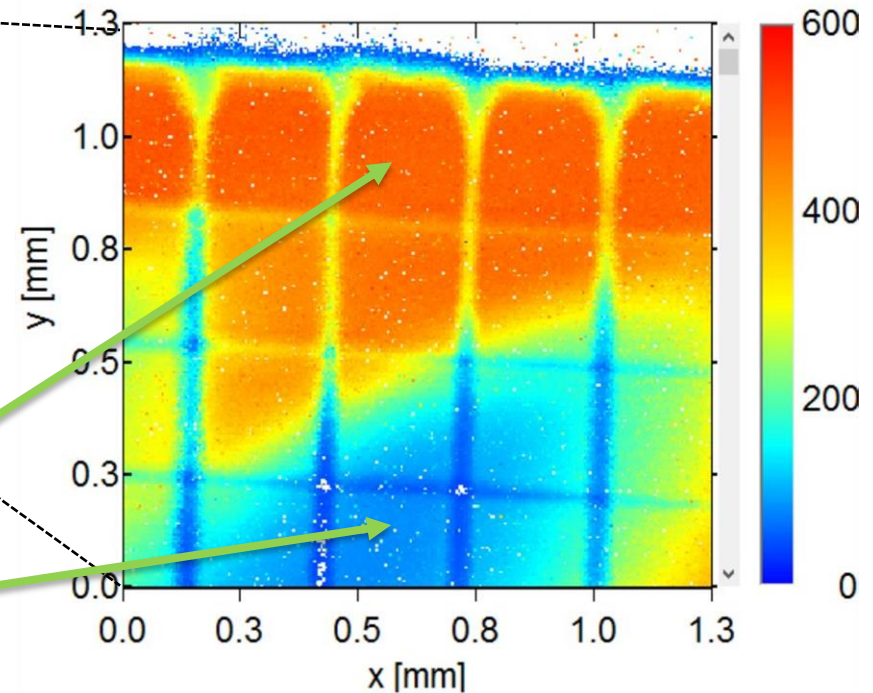
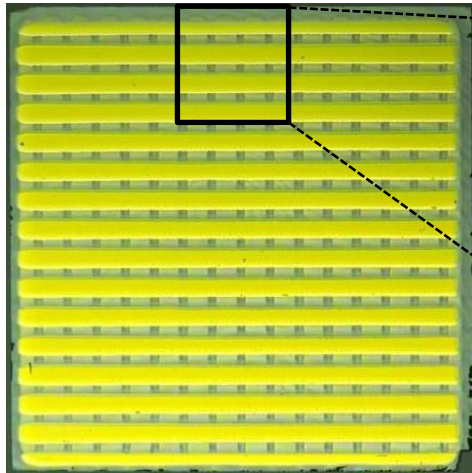
Proton μ -beam:

- **Energy 4.5 MeV**
- **Spot size $\approx 1 \times 1 \mu\text{m}^2$**
- **Max. scan $\approx 1.3 \times 1.3 \text{ mm}^2$**



Zagreb microbeam line

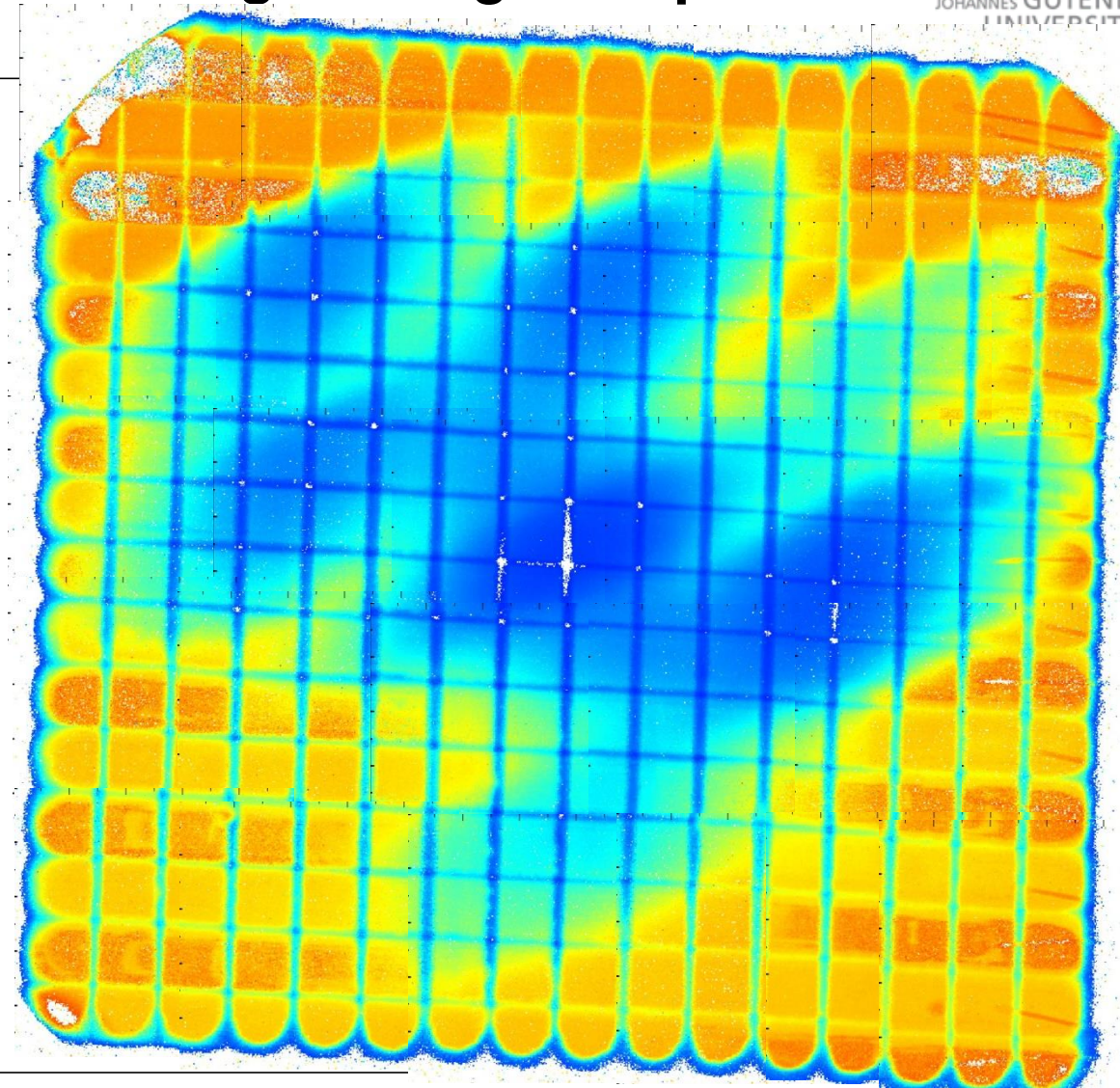
Analysis of signal degradation by scanning with μ -beam and measuring ADC amplitude



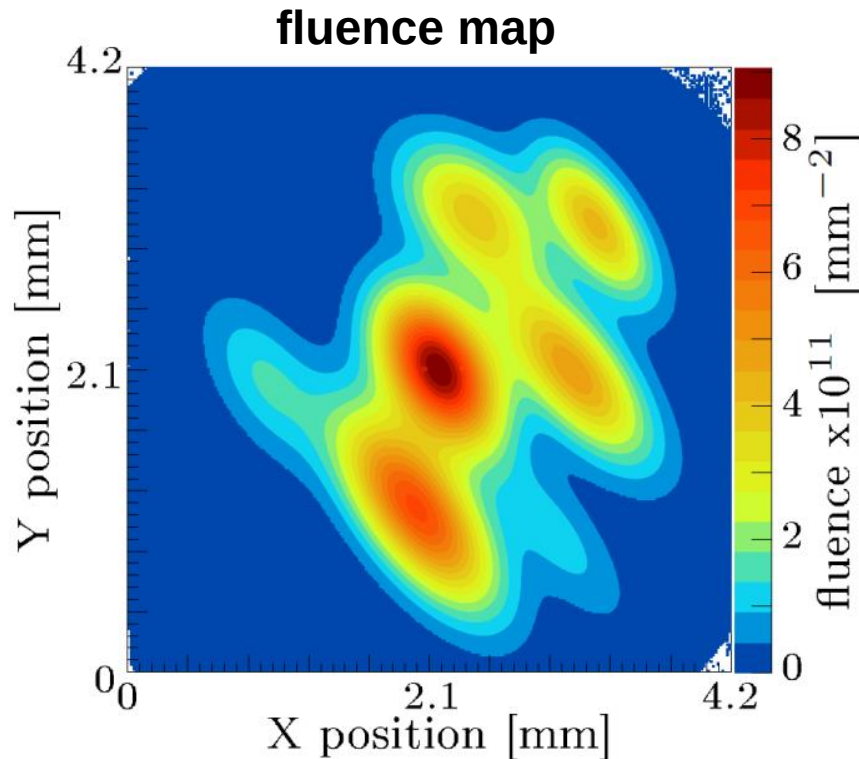
Proton μ -beam:

- Energy 4.5 MeV
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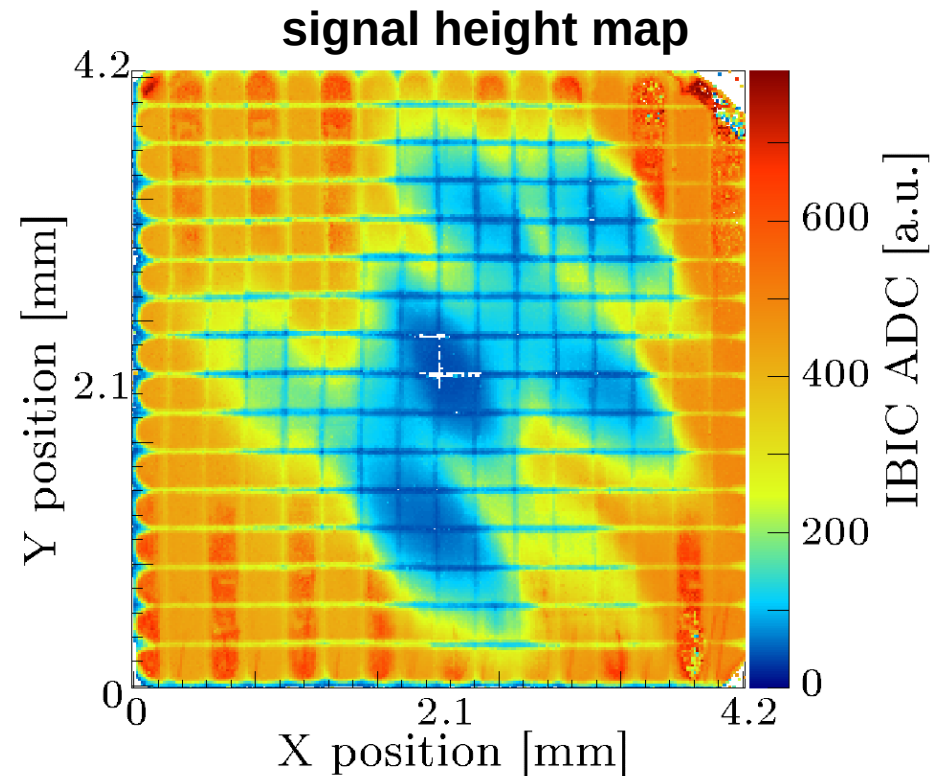
→ Full IBIC signal height map



Correlating fluence and degradation

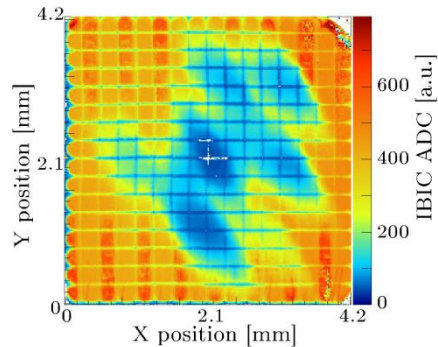


**2D fitting of the Au hit
distribution**



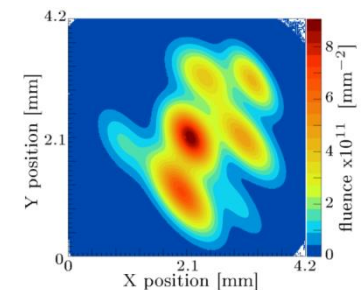
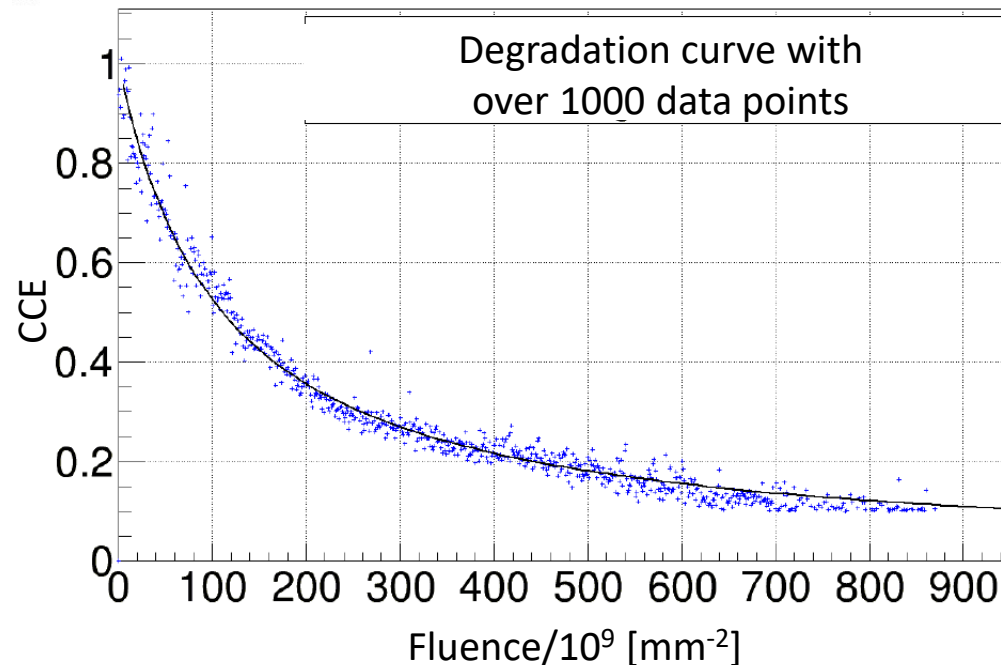
**IBIC imaging
with protons**

Final CCE degradation curve



$$\text{CCE} = Q/Q_0$$

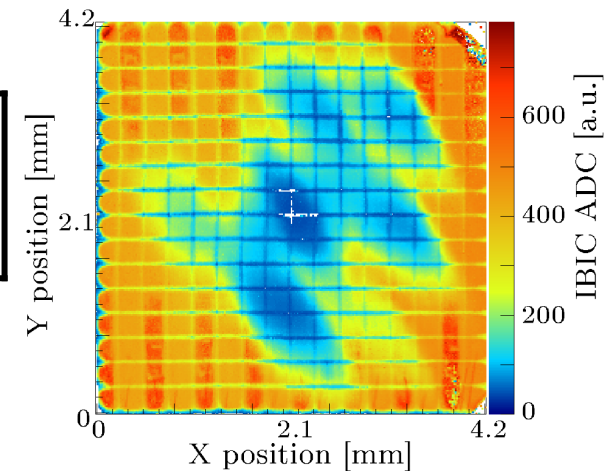
- CCE is macroscopic property
 - Detector thickness dependence
 - CCE fits assume low level damage
- mfp should be used



Comparison with proton damage

1.

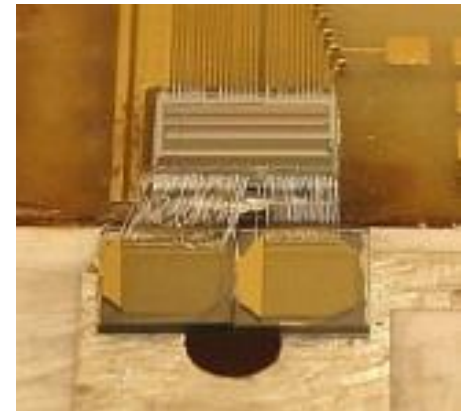
**4.5 MeV protons
Zagreb, μ -beam irradiation**



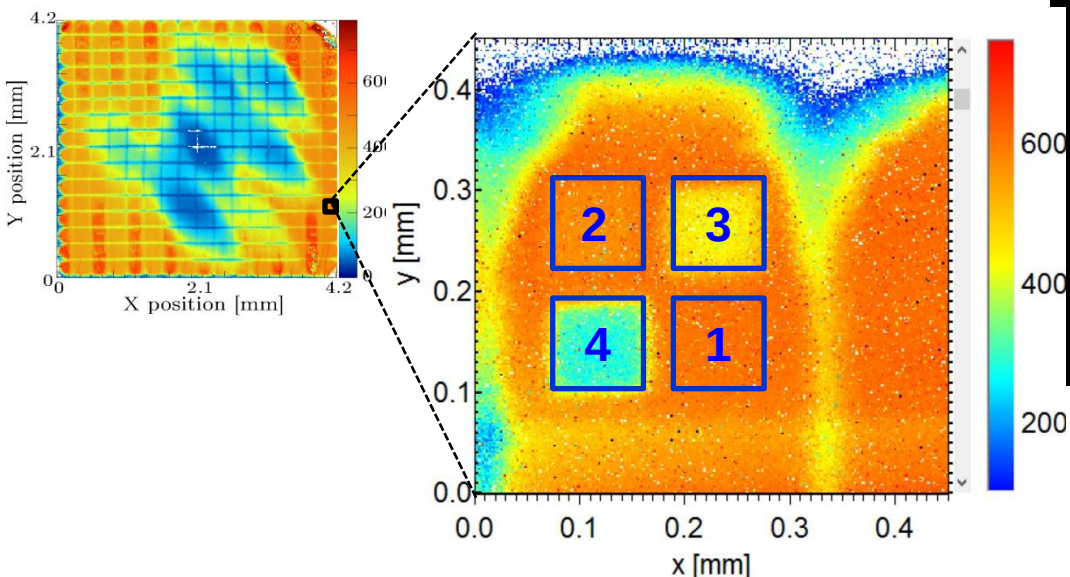
2.

**24 GeV protons
RD 42 collaboration, CERN-PS**

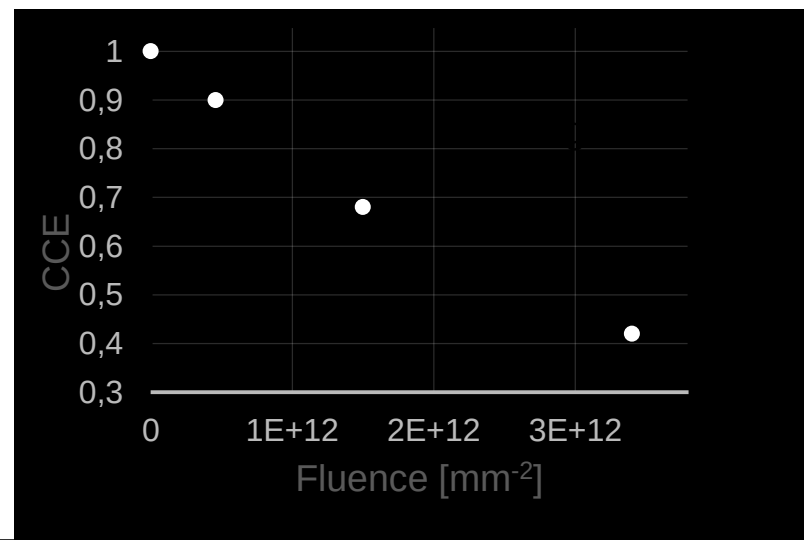
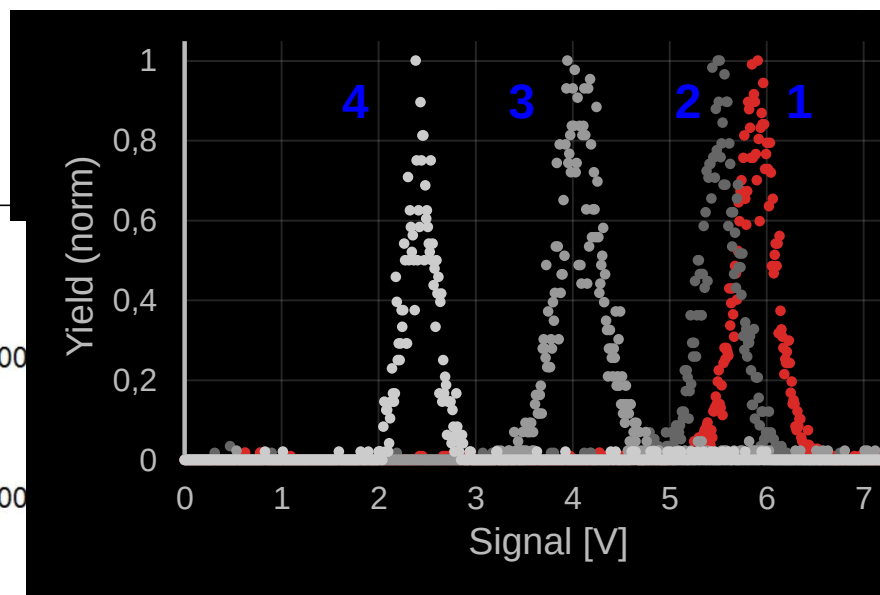
*RD42 Collaboration (Kagan H. et al.)
Nucl.Instrum.Meth. A636 (2011) S125-S129)*



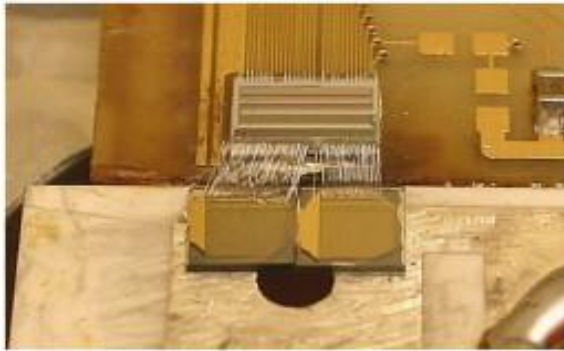
4.5 MeV protons Zagreb, microbeam irradiation



	Fluence [mm ⁻²]	ADC [MeV]	CCE
1	0	2.35	1
2	4.6E11	2.12	0.90
3	1.5E12	1.60	0.68
4	3.4E12	0.99	0.42



24 GeV protons RD 42 collaboration

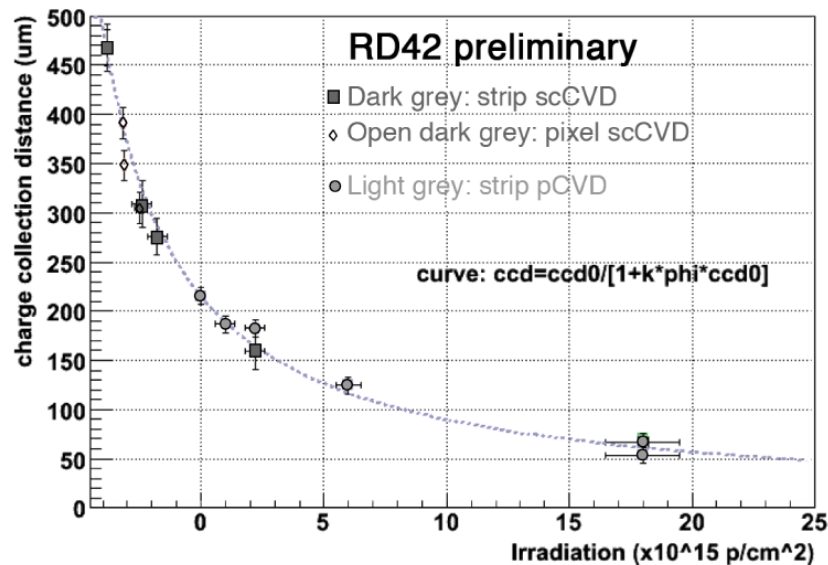


Diamond detector:

- scCVD
- 2880 pixels
- Thickness 475 μm

Irradiation:

- 24 GeV p at CERN PS



RD42 Collaboration (Kagan H. et al.) Nucl.Instrum.Meth. A636 (2011) S125-S129)

Mean Free Path $\leftrightarrow$ CCE

Decrease of τ and mfp with radiation:

$$\frac{1}{\tau} = \frac{1}{\tau_0} + N_{rad} \times \sigma \times v_{th} \quad \Rightarrow \quad \frac{1}{mfp} = \frac{1}{mfp_0} + K \times \Phi$$

Connection between mean free path and CCE:

$$CCE = \frac{mfp_e}{d} \left[1 - \frac{mfp_e}{d} (1 - e^{-\frac{d}{mfp_e}}) \right] + \frac{mfp_h}{d} \left[1 - \frac{mfp_h}{d} (1 - e^{-\frac{d}{mfp_h}}) \right]$$

With the assumption $mfp_e = mfp_h = mfp$:

$$CCE = 2 \frac{mfp}{d} \left[1 - \frac{mfp}{d} (1 - e^{-\frac{d}{mfp}}) \right]$$

Mean free path:

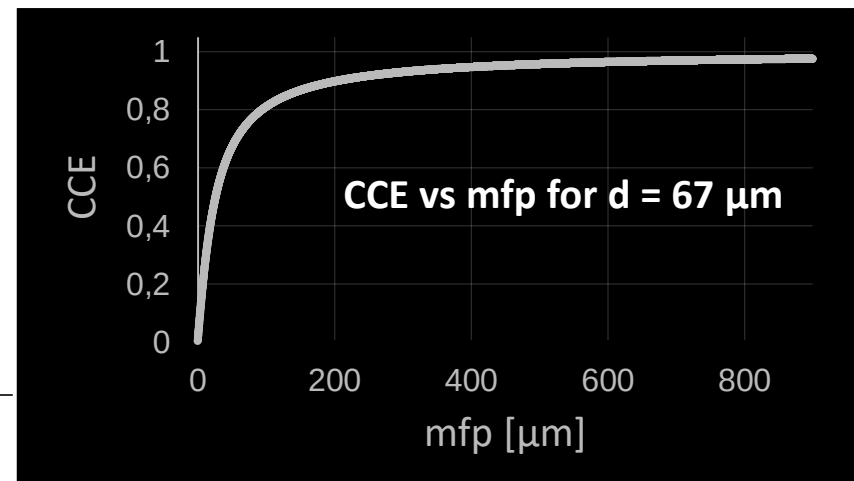
$$mfp = \tau \times v_d$$

Lifetime:

$$\tau = \frac{1}{N \times \sigma \times v_{th}}$$

$$N = N_0 + N_{rad}$$

$$N_{rad} \sim \Phi$$



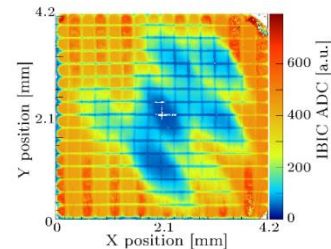
Comparison with proton damage

CCE → mfp (mean free path)

$$\frac{1}{mfp} = \frac{1}{mfp_0} + K \times \Phi \quad K = \sigma \times k \times \frac{v_{th}}{v_d}$$

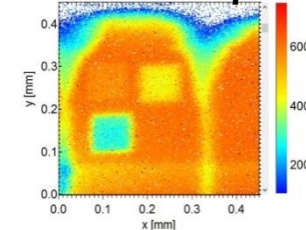
k is number of traps produced by 1 ion

246.25 GeV Au



$$K = 3.4 \times 10^{-7} \mu\text{m}$$

4.5 MeV p

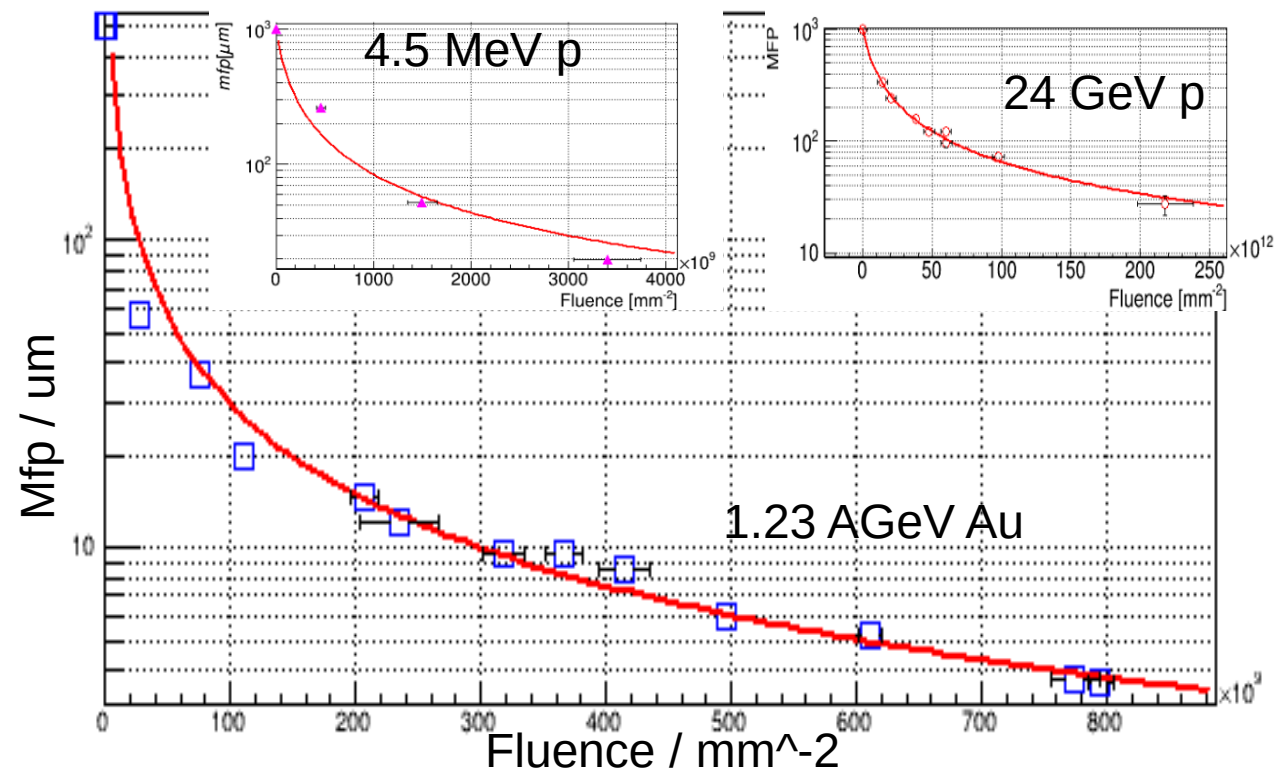


$$K = 1.1 \times 10^{-8} \mu\text{m}$$

24 GeV p

RD42 Collaboration

$$K = 1.4 \times 10^{-10} \mu\text{m}$$



Results summary

mfp from Au fit: 880 μm

Au @ 1.23 A GeV

mfp ₀ [μm]	500	1000
K [μm]	3400×10^{-10}	3450×10^{-10}

p @ 4.5 MeV

mfp ₀ [μm]	500	1000
K [μm]	114×10^{-10}	110×10^{-10}

p @ 24 GeV

mfp ₀ [μm]	500	1000
K [μm]	1.4×10^{-10}	1.4×10^{-10}

Number of traps:

$$\text{Au} / p_{4.5\text{MeV}} / p_{24\text{GeV}} = 1 / 30 / 2430$$

$$p_{4.5\text{MeV}} / p_{24\text{GeV}} = 81$$



Contents lists available at ScienceDirect

Nuclear Instruments and Methods in
Physics Research A

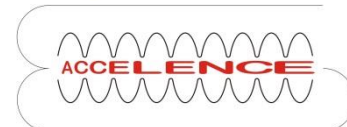
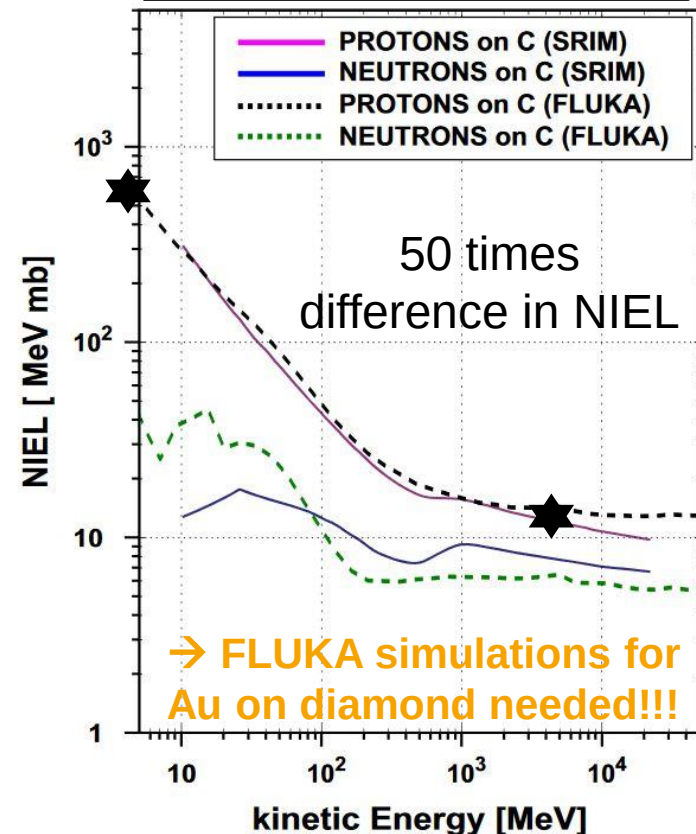
journal homepage: www.elsevier.com/locate/nima

Simulation of beam induced lattice defects of diamond detectors
using FLUKA

Moritz Guthoff^{a,b,*}, Wim de Boer^a, Steffen Müller^{a,b}

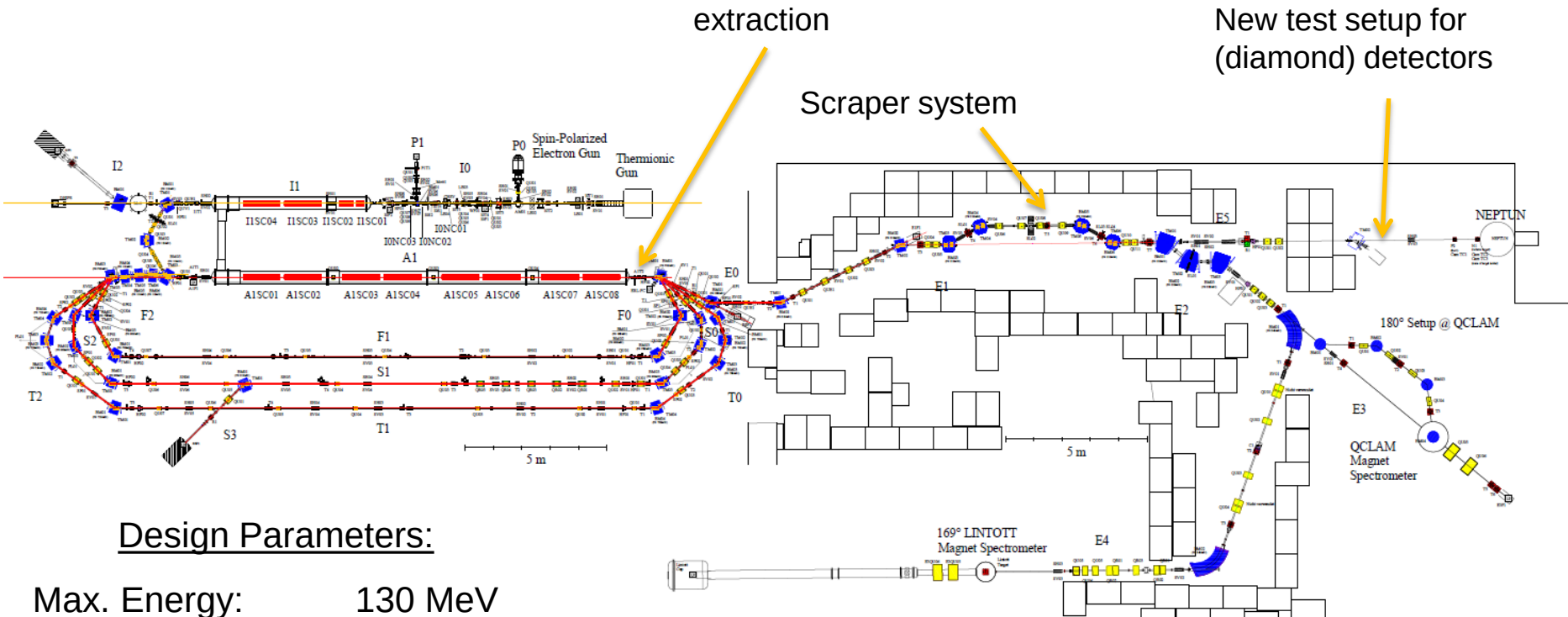
^a Institut für Experimentelle Kernphysik, Karlsruhe Institute of Technology, Campus Süd, P.O. Box 6980, 76128 Karlsruhe, Germany
^b CERN, CH-1211 Geneva 23, Switzerland

FLUKA simulations



Outlook: Diamond detectors for beam diagnostic at the S-DALINAC

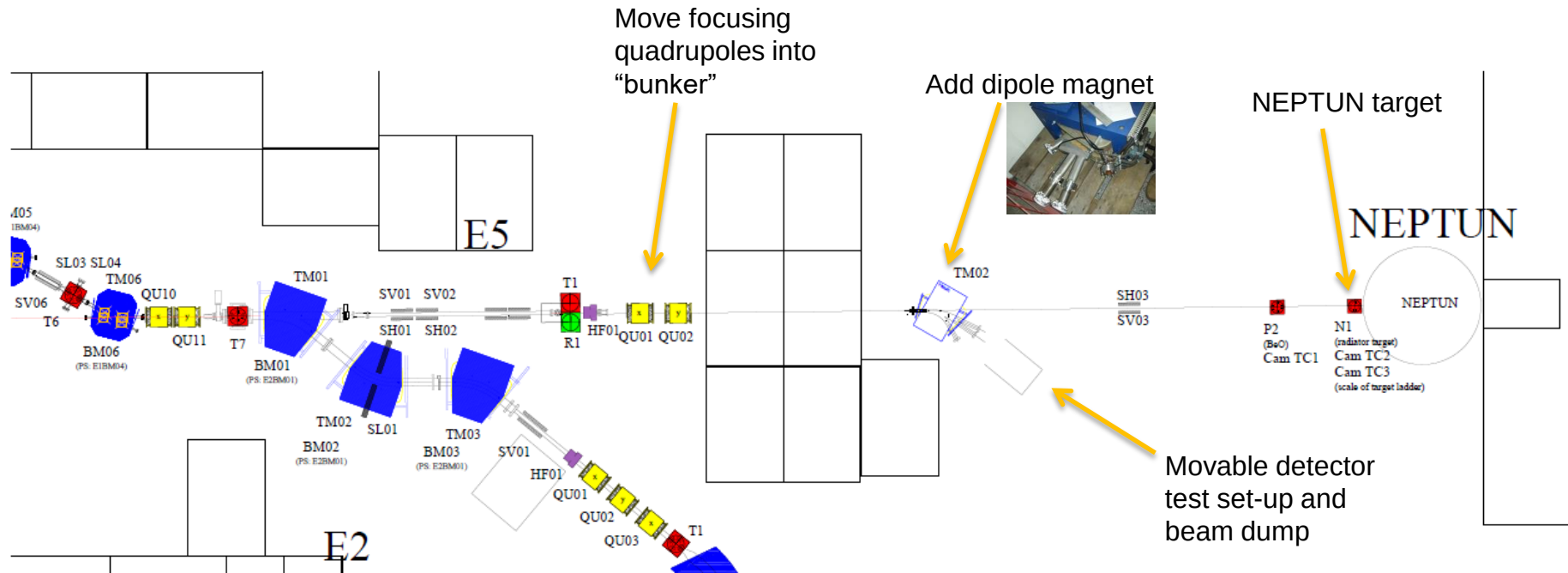
(Superconducting Darmstadt electron linear accelerator of TU Darmstadt)



Design Parameters:

Max. Energy:	130 MeV
Beam Current:	20 μ A
Duty cycle:	cw
Frequency:	3 GHz
RF-power/cavity:	500 W

Diamond detector test set-up



Investigation for diamond detector developments for MIPs and HI:

- time resolution
- amplitude measurements
- studies of radiation damage
- read-out electronics test

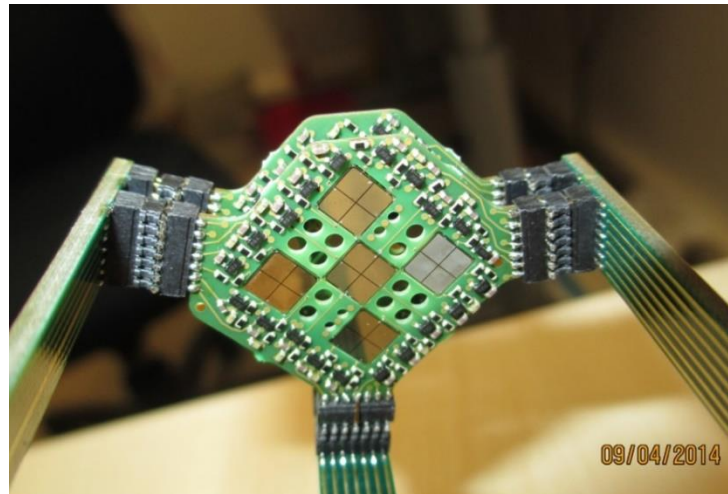
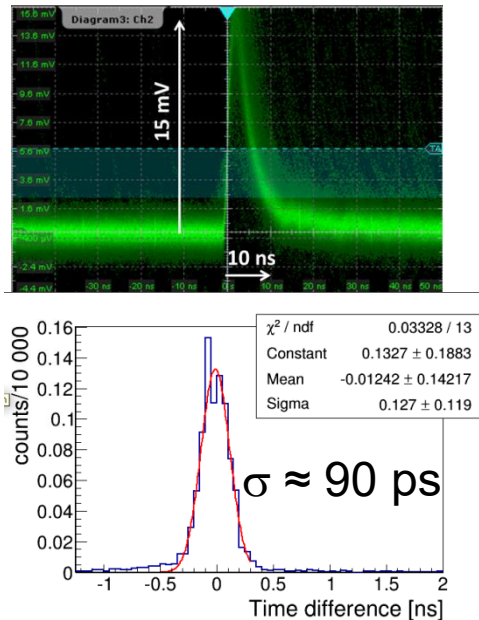
Beam parameters:

- Beam current: $\sim \text{nA}$ ($\sim 10^9 \text{ e}^-/\text{s}$), higher currents desirable $\rightarrow$ radiation safety!?
- Beam diameters: $\sim 0.1 \text{ mm} - 1 \text{ cm}$
- Max. Energy: 130 MeV

Diamonds for MIPS

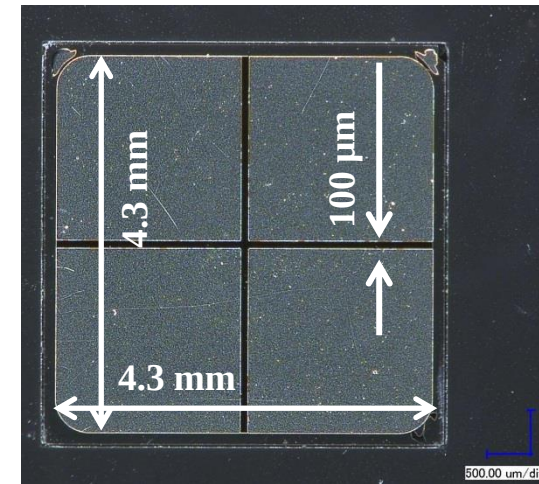
Expected / measured diamond detector performance for MIPS ($10^6/s$)

- stable long term operation
- time resolution below 100 ps (σ)



HADES mosaic diamond detector used in pion production beam time in 2014

- pion T0 detector 4×10^5 pions/s
- time. res. 200 ps only



TRB3 platform

FPGA TDC and multi purpose DAQ

Time precision
10 ps RMS

4 FPGAs with
260 TDC channels

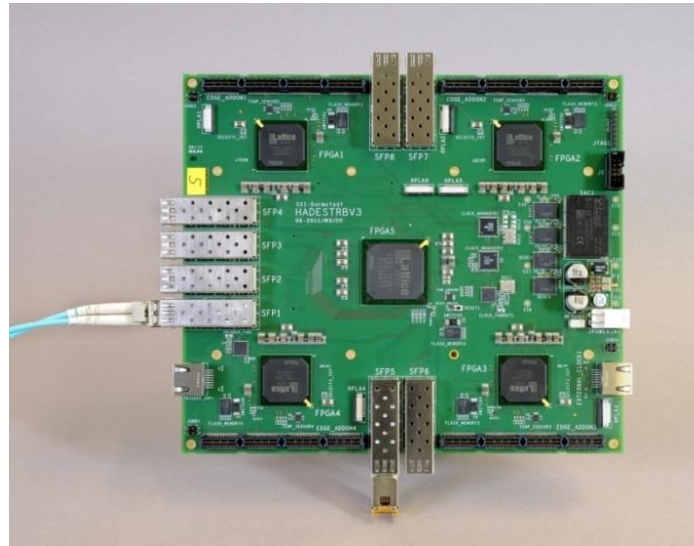


Single edge & ToT
measurements

Usable in large systems
& stand alone

50 MHz hit rate
per channel

Only 48 V and GbE
needed to take data



Internal trigger system
and slow control

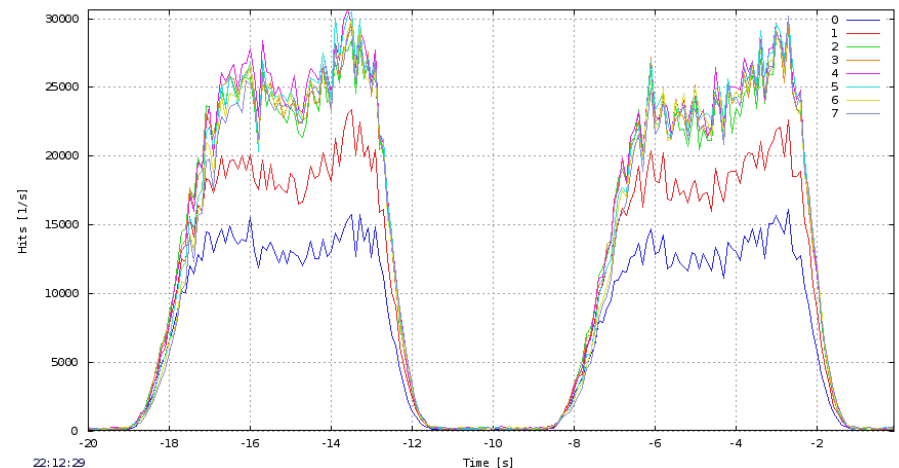
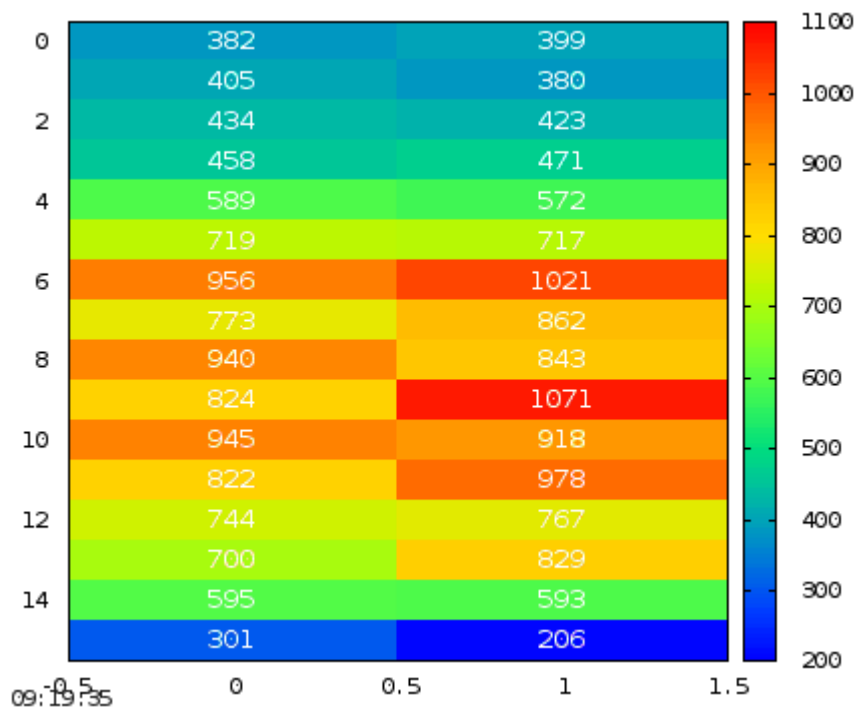
Expendable by Add-Ons and
FEEs → i.e. PaDiWa



(developed at GSI, see: <http://trb.gsi.de/>)

TRB3 based Online Beam Monitoring System

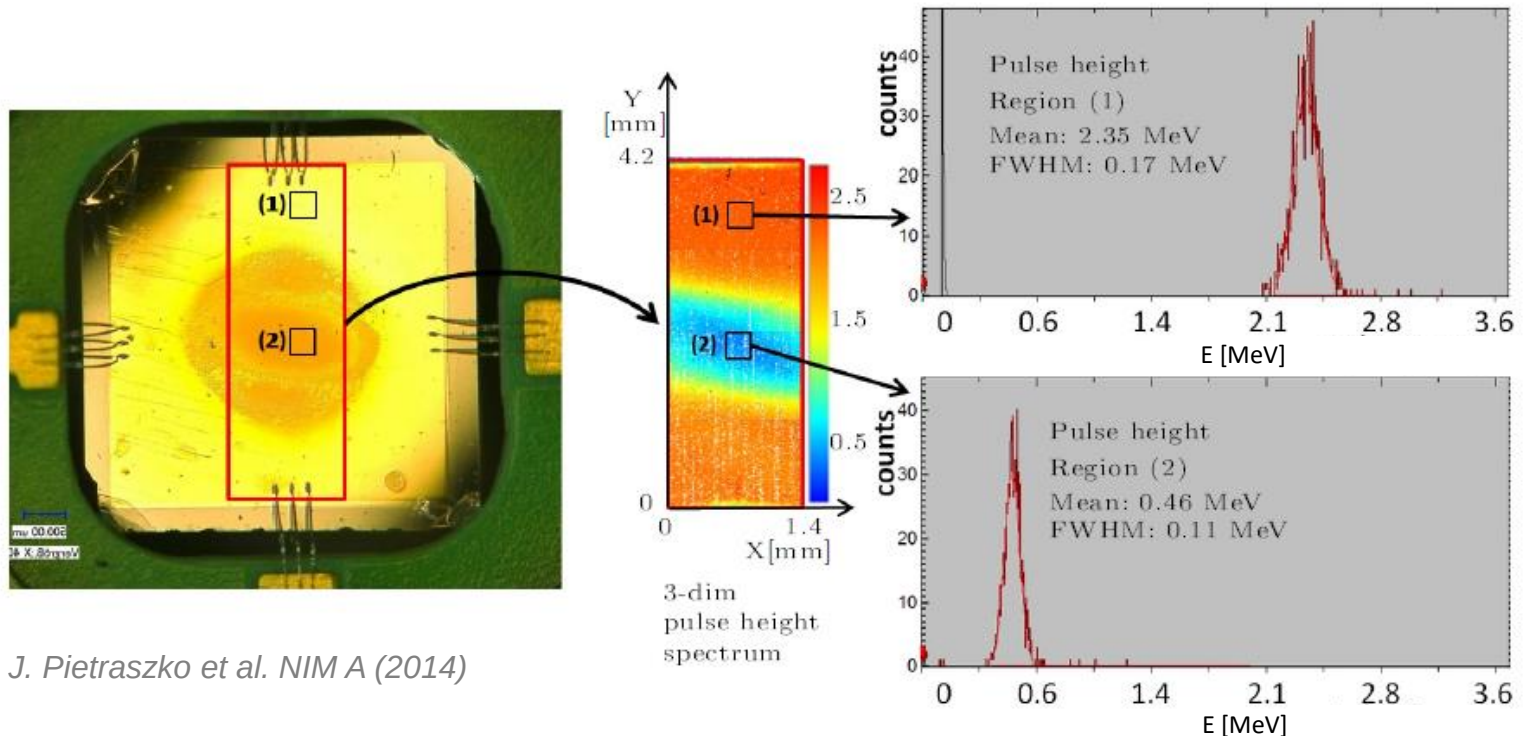
- 32 TDC input channels (direct LVDS or PaDiWa Discriminator AddOn board)
- Sampling period 1 s – 100 ns with maximum depth of 8192 words
- visualization in web-browser via gnuplot



Thank you for you attention!!!!

Analysis of signal degradation of the 8 segment detector

- Pulse height scan with 4.5 MeV μ -beam of protons



J. Pietraszko et al. NIM A (2014)

- Pulse height reduced by a factor of 5.1 in the middle of the damaged area
- To few information on fluence distribution → **Systematic study needed!!!**