BRNO UNIVERSITY OF TECHNOLOGY
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Application of Pixel Detectors in Experimental Physics

Využití pixelových detektorů v experimentální fyzice

Volume of selected author's works (research papers) provided with a commentary

Short Version of Habilitation Thesis

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Charged–particle spectroscopy	Spektroskopie nabitých částic
Particle tracking	Detekce dráhy částic
Nuclear spectroscopy	Jaderná spektroskopie
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Scientists study the world as it is; engineers create the world that has never been.

— Theodore von Kármán

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CONTENTS

1 INTRODUCTION

Advances in technology open new possibilities and extend the frontiers of knowledge in scientific fields such as experimental physics. Significant developments in micro–electronics and data acquisition and processing have brought hybrid semiconductor pixel detectors as a product of integration, miniaturization and continuous downscaling in semiconductor chip technology.

The Habilitation Thesis summarizes the scientific papers of the Author which represent the application of hybrid semiconductor pixel detectors, in particular the Medipix2 detector [1] (see Sec. 1.1), in medical imaging (dental micro–roentgenography [2],[3],[4]), the interdisciplinary area of plasma-nuclear physics (excitation of atomic nuclei by laser–induced plasma [5],[6]) and subatomic physics (spectroscopy of fission fragments [7] and cosmic ray tracking [8]). The latter two projects are reviewed in this Summary Thesis (Chapter 2 and Chapter 3).

1.1 HYBRID PIXEL DETECTORS

Hybrid pixel detectors[1] consist of a semiconductor sensor (radiation sensitive) chip and a bump–bonded integrated–circuit chip which contains readout electronics (amplifier, amplitude discriminators, and a digital counter) on each pixel. This device integrates a signal processing circuit (with hundreds of transistors in every pixel of a CMOS read-out chip) with a radiation sensor chip (of either silicon or other semiconductor material - with thousands of micro-solder bumps). The readout and the sensor chip are manufactured separately which are then connected by a bump–bonding process. This offers the possibility of optimizing the readout electronics and the sensor independently for a number of tasks and applications.

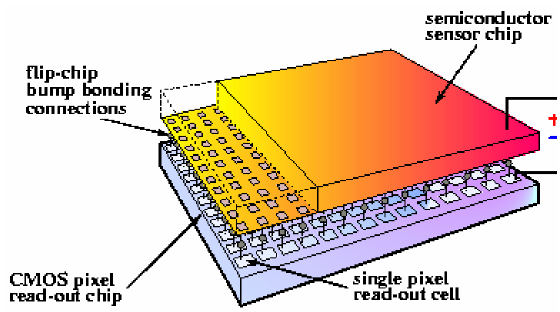

Figure 1, Principle of the hybrid structure of the Medipix2 detector.

1.2 MEDIPIX2

The hybrid position–sensitive semiconductor Medipix2 pixel device[2] [1] consists of a semiconductor sensor chip with 256×256 square pixels of 55 μm size of 1.4×1.4 cm^2 total active area[3] bump-bonded to an integrated circuit readout chip (see Figure 1) which contains an amplifier, two discriminators (high and low threshold) and a 13–bit counter for each pixel. The sensor chip is equipped with a single common back–side electrode and a front–side matrix of

Table 1: Spectroscopic features of Medipix2

active detection (digital, real–time)
multiple radiation detection (X–rays, e$^-$, p, a, t, ion)[#]
position– and energy–sensitive
single–quantum counting
event–by–event spectroscopy
high detection efficiency*
high sensitivity and selectivity
energy sensitive and threshold (counting)
noise discrimination (i.e. no noise, no dark current)
digital integration (single-particle counting)
wide dynamic range
wide (and nearly ideal) linearity
good spatial resolution (pixel pitch size 55 μm)
can be triggered and/or can generate trigger (for coincidence & timing measurements)

[#] Also neutrons – when equipped with suitable neutron converter

* Depending on sensor material and thickness. Also on particle energy – e.g., 100 % for heavy charged particles, light charged particles (E<10’s MeV) and X–rays (E €10–20 keV)

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[1] Other type of pixel detectors are Monolithic pixel detectors where the circuitry is integrated with the detecting elements onto the same substrate.

[2] See also http://www.cern.ch/medipix and http://www.utef.cvut.cz/medipix

[3] A four detector QUAD set array provides a 8 cm^2 total sensor area.

electrodes. Each of the about 65.000 pixels is thus connected to its respective preamplifier, double discriminator and digital counter integrated on the readout chip. The back-side pulse of the detector chip is analyzed by a 13-bit ADC. Running frequency can be 200 MHz for a complete data read–out rate of 200 μs (via 32–bit parallel) or 200 ms (via serial) interface. The hybrid nature of this detector allows its implementation for various radiation and specific applications (X–rays, light– and heavy–charged particles, neutrons). The sensor chip may be manufactured of different materials (Si, GaAs, CdTe or also containing a neutron converter – such as B or Li [9]) and different thicknesses (300, 700, 1000 μm). The main features of this device are summarized in Table 1 presenting a number of advantages for radiation imaging and particle spectroscopy and tracking.

1.3 DIGITAL RADIATION IMAGING

In radiation imaging there are two types of devices with digital output [10]: Charge–integrating devices: in which the ionizing radiation creates a charge which is collected and integrated in small capacitors (CCD, CMOS sensors, Flat panels); and Particle–counting pixel detectors [11]: in which ionizing particle creates charge in a sensitive volume that is compared with a threshold and counted by digital counter. The properties of these two types of systems are compared in Table 2.

Table 2: Comparison of position-sensitive digital detectors for radiation imaging [11].

Charge–integrating devices (CCD, CMOS sensor, flat panels)	Particle–counting pixel detectors (Medipix2)
charge integrating	noiseless integration (counting)
high spatial resolution	good spatial resolution
not energy sensitive	energy sensitive
no noise discrimination	energy/noise discrimination
zero dead time	non–zero dead time
dark current	no dark current
noise	no noise (separated by threshold)
limited dynamic range	broad (unlimited) dynamic range
limited linearity	wide (nearly ideal) linearity (counting)

Both types of devices offer advantages[4] which make them suitable for different applications. Charge–integrating devices are appropriate namely for measurements with high radiation intensity. In cases when the maximum count rate is lower than about 10^6 counts per pixel per second the particle-counting pixel detectors [11] offer better results than charge–integrating devices. All false signals (leakage current and noise) are separated from the useful signal by threshold settings so that there is no false counting. Thus, the dynamic range of pixel detectors is essentially unlimited and it is possible to reach almost any arbitrary signal to (statistical) noise ratio just by exposure time prolongation. The maximal count rate of 10^6 counts per pixel per second is more than sufficient for most radiographic applications [12],[13]. The Medipix2 detector is being successfully implemented for micro–imaging using X–rays [13], light [14] and heavy [15] charged particles as well as neutrons [9].

[4] For comparison, a CCD detector suffers from dark current and count saturation, limited dynamic range, low efficiency and non–continuous data acquisition. X–ray film suffers, in addition to requiring developing and one–time use, namely from saturation, limited range and low contrast.

1.4 RADIATION AND PARTICLE SPECTROSCOPY

Active detectors (i.e., electronic devices with digital output) used for radiation and particle spectroscopy[5] [16] are given namely by spectroscopic solid state devices (i.e., devices which provide information on the radiation/particle energy): scintillating detectors and semiconductor detectors (see Table 3).

Table 3: Comparison of solid state radiation detectors

	Device	Type		Radiation	Advantages/Drawbacks	
I	Scintillating	Inorganic (crystal)		X–ray, γ	Fast response Spectrometric	
		Organic (fluid)		e^-	Fast response Trigger & counting	
II	Semiconductor	Crystal* Ge(Li), HPGe, Si(Li)		X–ray, γ	High count rate digital read-out	Require cooling
		Diodes* (Si)		X–ray, γ, heavy charged particles	High count rate, digital read out	Room temperature operation
		Position–sensitive detectors	Microstrip	X–ray, γ, heavy charged particles	Same as diodes + compact size, small pixel dimension, energy– and position–sensitive spectroscopy, no noise	
			Pixel detectors* (Medipix2)	X–ray, γ, Light and heavy charged particles		

* Suitable also for neutrons (when adapted with neutron converter).

Scintillating detectors are used namely for X–ray and gamma–ray spectroscopy where they provide namely fast response and radiation hardness. However these devices have limited energy resolution (around 7 %), are not suitable for single–quantum counting and are not position–sensitive (e.g., require external collimators). Semiconductor devices are widely used namely as diode Si detectors thanks to their energy resolution (of order 10^{-3} and 10^{-4}) and radiation hardness in addition to small compact size and high quantum efficiency. However, all these devices are essentially only spectroscopic (provide information on the particle's energy) and not position–sensitive (for particle imaging and/or tracking purposes).

As position–sensitive devices[6] serve the hybrid semiconductor pixel devices such as Medipix2 which provides energy– *and* position–sensitive capability. In addition to enhanced energy– and spatial–resolution, these hybrid devices possess also broad (unlimited) range, no dark current (no noise) and thus can operate in spectroscopic and single–quantum counting mode in real time.

1.5 REAL TIME CHARGED PARTICLE TRACKING

In particle tracking[7] there are devices [17] such as bubble chambers, multi wire proportional chambers, time projection chambers, spark chambers, nuclear emulsions which have been used namely in particle physics. These devices make use of gaseous or liquid media where traversing particles generate signals (in the form of bubbles, electric charge) which are collected by sensitive media (photographic film) in the surrounding chamber walls. More recently, solid state trackers,

[5] Radiation spectroscopy aims at measuring namely the energy of the radiation.

[6] Microstrip detectors are generally one-dimensional devices which can have good spatial resolution. However, identification and separation of multiple particles and tracks are difficult.

[7] Particle tracking aims at measuring the trayectory, direction and momentum of particles.

also called silicon trackers, have become available which in addition to providing electronic data and 2D and 3D information, have higher density of the detecting medium (solid state) resulting in higher efficiency (see Table 4). The Medipix2 device possesses in addition a number of advantages as given in the Table 4 and Sec. 1.6.

Table 4: Comparison of radiation tracking devices

	Device	Medium	Advantages/Drawbacks	
I	cloud & bubble chambers	superheated liquid / photographic film	High spatial resolution	Passive detecting and recording media Need of superheated phase (at precise instant) Low density (not massive enough) Path radii of energetic particles too large
II	Nuclear emulsion	photographic plate	High spatial resolution	Passive detecting and recording media
III	Wire chamber	gas	Fast & electronic read-out	
IV	Multi-wire proportional chamber		(III) + Measures also the energy	
V	Drift chamber		(IV) + Improved positioning accuracy (by timing the signals in ind. wires)	
VI	Time projection chamber		(V) + 3D information	
VII	Strip detectors	semiconductor (Si)	High density Fast & electronic read-out	
VIII	Drift detectors		(same as VII) + 3D information	
IX	Pixel hybrid detectors (Medipix2)		(VII) + compact size, small pixel dimension, energy– and position–sensitive spectroscopy, no noise, room temperature operation	

1.6 MEDIPIX2/USB RADIATION CAMERA

In order to increase the functionality and ease of operation of the Medipix2 detector, a novel, fully integrated USB–based readout interface [18],[19] was developed at IEAP CTU Prague. All power supply including the high voltage (5–100 V) for the Medipix2 detector bias is derived from the USB connector. As a result, a significant reduction in interface electronics dimensions is achieved and external power supplies are not needed. This USB–based interface thus provides both communication and power supplying lines. Also a tailored made fully integrated and user friendly Pixelman software package[8] was developed [20] which controls and operates the Medipix2/USB system and handles data acquisition and storage. This software, and the detector, can be used on any Windows running PC or laptop.

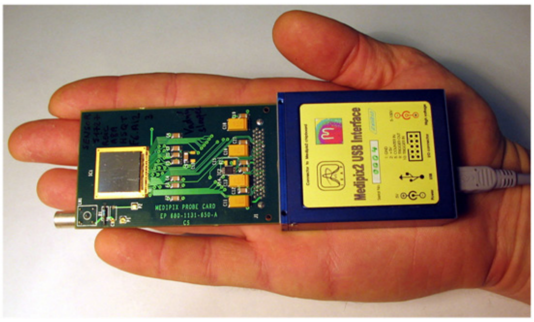

Figure 2, Compact portable Medipix2/USB radiation camera. The Medipix2 chipboard (left) is attached to the USB–readout (right).

[8] http://www.utef.cvut.cz/medipix

The Medipix2/USB system (see Figure 2) operates in real–time as a versatile portable radiation camera (for imaging) and as an active nuclear emulsion for single–quantum and on–line particle tracking (for spectroscopy) [21]. In addition to the intrinsic features and advantages of the Medipix2 detector, the assembled Medipix2/USB system together with the Pixelman software package presents advantages listed in Table 5. In combination with suitable methods of data processing and image reconstruction [11], the Medipix2/USB camera operates successfully in radiation imaging using various types of radiation (X–rays, electrons, alpha particles and neutrons [9],[13],[14],[15]) and is being exploited into new applications of experimental physics [2],[3],[4],[5],[7],[8] which this Thesis aims to show.

Table 5: Advantages of Medipix2/USB camera

On–line operation
continuous data taking and storage
real–time imaging/spectroscopy
room temperature operation
vacuum operation
portability
battery operated (power and electronics independent)
plug and play on running PC/laptop
windows compatible
ease of operation

2 POSITION SENSITIVE SPECTROSCOPY OF FISSION FRAGMENTS

Study of nuclear fission demands fast response and precise position and energy sensitive spectroscopy. Investigations include systematic and variations in fragment–mass and kinetic–energy distributions of spontaneous fission [22],[23] as well as measurements of rare fission processes such as ternary and quaternary fission [24],[25] which require precise coincidence spectroscopy in terms of energy resolution and angular correlation.

2.1 POSITION–SENSITIVE SPECTROSCOPY

The response of Medipix2 to spontaneous fission products of ^{252}Cf was investigated [7] with the Medipix2/USB camera which serves as a position– and energy–sensitive active emulsion for event–by–event and tracking spectroscopy. The heavy–mass products of spontaneous fission of ^{252}Cf were measured using a thin source containing low activity of ^{252}Cf. The fission products were detected with a Medipix2 detector having a 700 μm thick silicon sensor. The Medipix2/USB camera operated in vacuum at room temperature in real–time, position-sensitive, noiseless, single-quanta *tracking* mode. For these experiments were used two detectors which operated independently or in coincidence each placed facing the source.

Data readout was done with the portable USB–based interface [14] with average counting rate of about 5 frames per second. The integrated readout software package Pixelman [20] was used which evaluates and displays in real time the spectrometric data and parameters of measurement. A total of about 10^5 frames were acquired each of mean time exposure 1 s. In the measurements the frame shutter was set to close upon hit of a heavy fragment (driven by threshold setting of the back–side pulse). The detection of fission fragments (accompanied by the numerous alpha particles from α decay) of ^{252}Cf by Medipix2 is presented in Figure 3 which shows four random frames with varying shutter frame time[9]. The fission products of ^{252}Cf (one heavy fragment in each frame), accompanied by the more numerous alpha particles from α decay, are seen.

Long measurements were done with shutter time set to fully collect the whole charge generated and register all the pixels involved. Random examples of frames collected for the two Medipix2 detectors used are presented in Figure 4.

[9] The frame shutter of the detector can be set to open, or close, upon hit of a heavy fragment (driven by threshold setting of the back–side pulse). One can also tune the delay from trigger detection till the shutter signal closes.

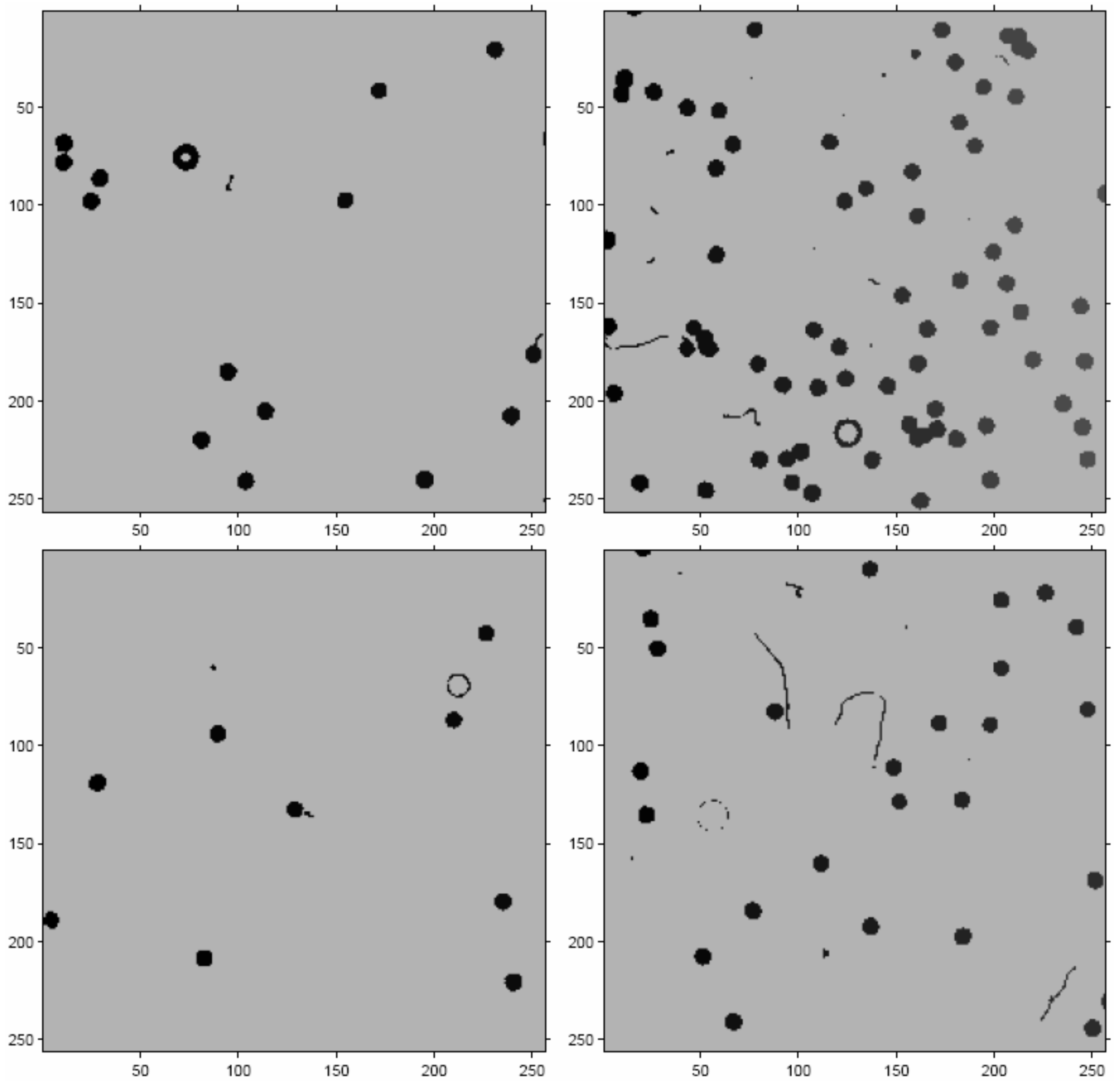

Figure 3, Fission fragments (empty large rings) and alpha particles (small compact clusters) of ^{252}Cf as seen by the 256×256 pixel array matrix of Medipix2. The frames shown were collected by one Medipix2 detector with *varying* shutter close time which result in the heavy fission fragments being registered as rings with varying contour thickness. Electrons (long tracks) and X–rays (small dots) are observed too.

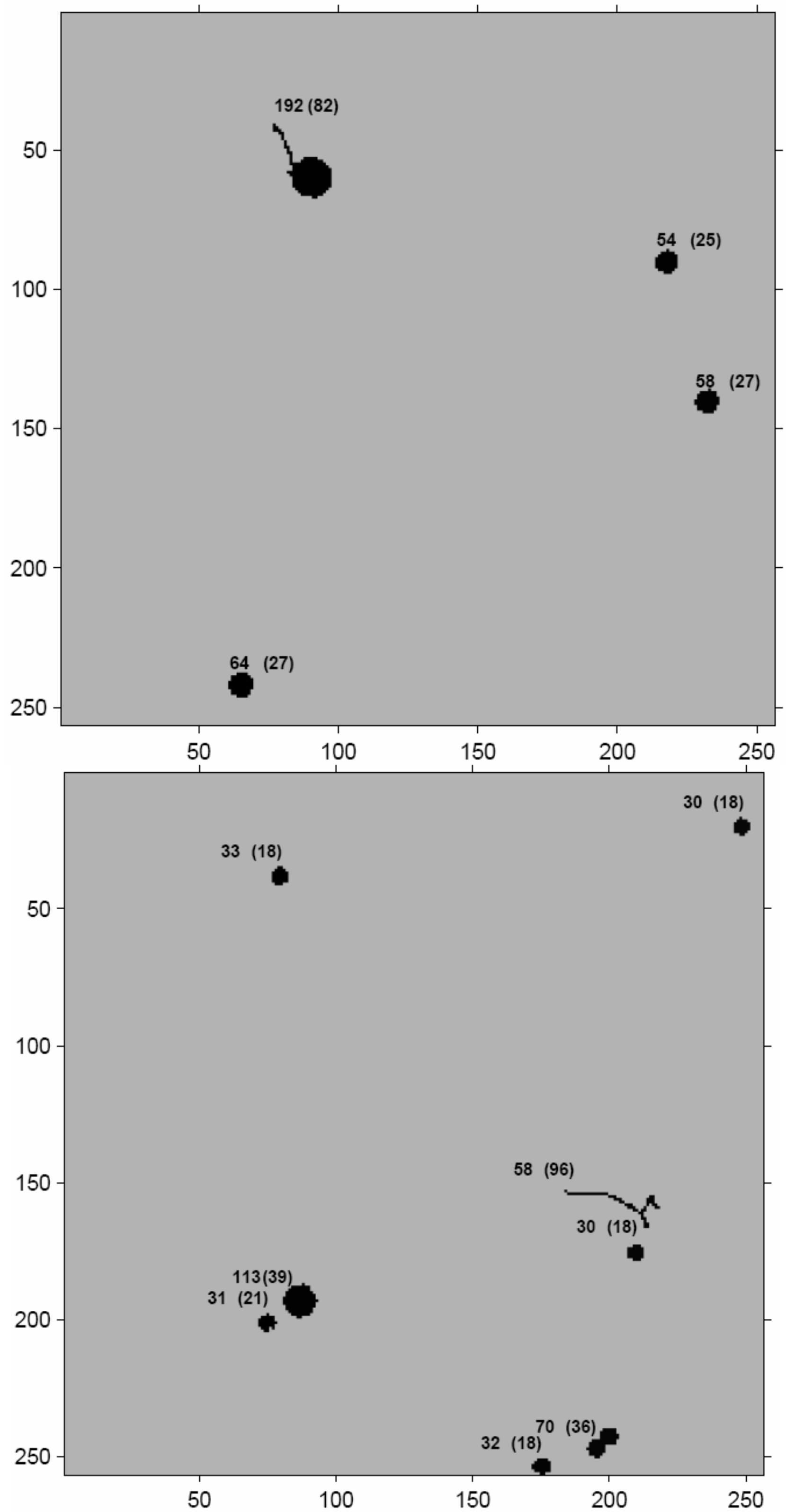

Figure 4, Fission fragments (large clusters) and alpha particles (smaller clusters) of ^{252}Cf registered by Medipix2 with long shutter close time. The number of pixels of the area (and perimeter) of single events is included.

2.2 CLUSTER PATTERN RECOGNITION

Heavy charged particles deposit their energy close to the sensor surface[10] producing massive ionization. Ionization charge has to be collected to pixelated electrode through the full sensor thickness (700 μm). Due to charge diffusion the charge cloud expands and can spread even over many adjacent pixels (pixel size 55 μm). Each pixel compares the collected charge with the threshold level and counts if the charge is large enough. The single heavy charged particle is in such cases counted by several adjacent pixels forming a collection of pixels with signal. Thus, particles produce upon impact a collection of signals (see Figure 3) so–called *clusters* of several pixels. The area (i.e., number of pixels) of a cluster is determined by the kinetic energy and ionizing power of the hitting particle. The cluster area (number of pixels) and perimeter (sum of pixel side contour) were determined for every event as included in Figure 4.

Values of cluster size (for the wide range of energy and mass of heavy fission fragments) range between 100–200 pixels. Alpha particles from α decay, which in the case of ^{252}Cf are 32–times more abundant than fission, have an energy of 6.1 MeV and generate clusters which are about 3 times smaller than clusters of heavy fission fragments. Additional events are also observed, such as tracks of electrons from X–ray photons interacting in the sensor chip or from beta decay.

Fission fragments were identified by evaluation of cluster pattern characteristics which was done by automatic recognition processing. A number of filters were successively applied according to cluster (i) area, (ii) perimeter, (iii) shape (roundness, elongation), and (iv) ratio between two of the above quantities.

Careful evaluation of values and range for these quantities were set for each measurement due to particular detector and preamplifier settings. Alpha particles were thus removed namely by filter (i) and (ii). Superposed alpha particles are removed by (iii). Electron and other particle tracks are removed namely by (i) and (iv). Fragments partially collected (i.e., hitting the border of the sensor matrix) and also those whose clusters are perturbed by other events (e.g., alpha particle, electron track – see Figure 3) were removed namely by (iii) and (iv).

2.3 DISTRIBUTION OF FRAGMENT KINETIC ENERGY

The distribution of cluster area provides the distribution of kinetic energy of the fission fragments. This result is confirmed by the information from back–side pulse (Figure 5). The histogram of fragment cluster area (Figure 6) gives the distribution of fragment kinetic energy. This Figure includes also the result separately for summed data for the two detectors used. A linear calibration, assumed to be approximately valid for this region, used as reference the known energy values of the maxima of the lower– and higher–energy peaks (80.8 and 106.1 MeV, respectively [23]).

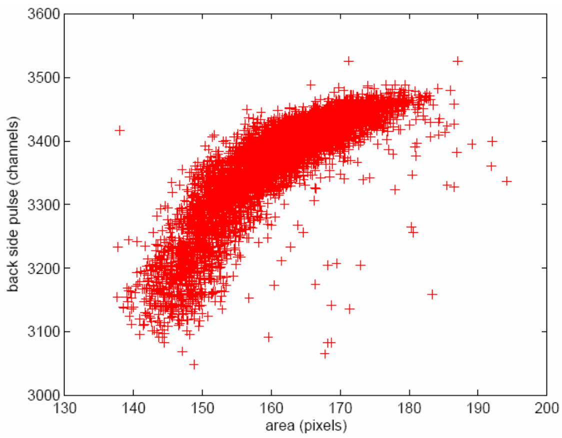

Figure 5, Correlation of back–side pulse height with cluster area (number of pixels) for fission fragments. The data shown amounts to about for 2×10^4 events and is shown after equalization and normalization.

[10] The range of heavy–mass charged particles in silicon is of order of tens of microns. The range of A ~ 110 at E=10^5 MeV and A ~ 143 at E=80 MeV nuclei (the most probable fragment mass and energy of spontaneous fission of ^{252}Cf) in silicon is 17 μm and 14 μm, respectively.

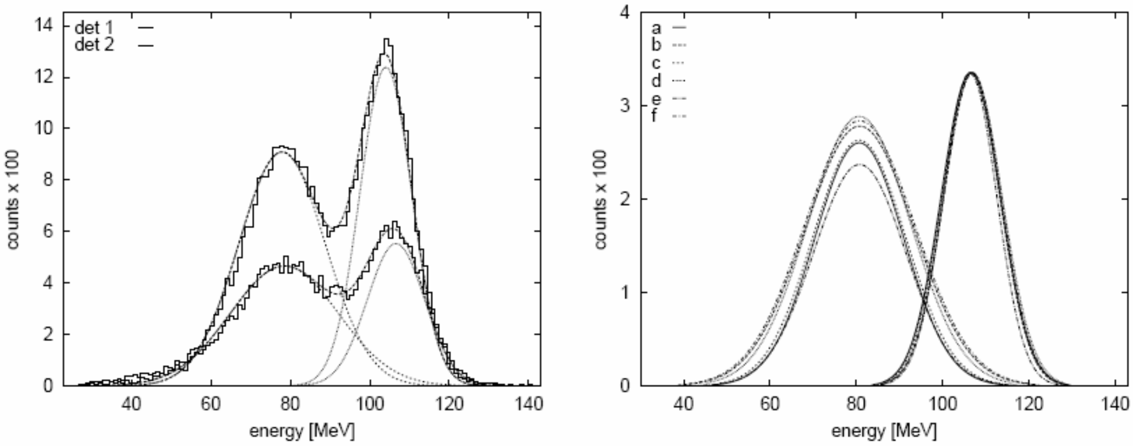

Figure 6, Histogram of fragment cluster area giving the distribution of fragment kinetic energy from spontaneous fission of ^{252}Cf. The result and corresponding fit of the sum of all measurements (for each detector separately) are shown (on left). The fits of several measurements of are compared (on right) where the curves are normalized to the maximum of the lighter-mass fragment peak of measurement.

The resulting FWHM obtained is 25.7 MeV and 15.4 MeV, respectively[11]. The agreement between different measurements and different detectors is included too.

[11] Full width at half maximum derived as 2.35 × σ, where σ is the dispersion of the fit for the sum of all measurements by one of the detectors. The corresponding value from previous work [23] is 20.2 MeV and 15.7 MeV, respectively.

3 COSMIC RAY TRACKING WITH PIXEL DETECTORS

The application of pixel detectors is suitable also for detection and imaging of tracks of cosmic rays [8]. In this work, it is demonstrated the operation and potential of the Medipix2/USB camera for detection and on–line visualization of atmospheric cosmic rays.

The compact Medipix2/USB radiation camera can operate as a portable active nuclear emulsion [20] in single–quantum counting and on-line tracking mode. The device can provide additional information for spectroscopic studies by use of back–side–pulse spectrometry. This compact and flexible system allows performing simple and quick measurements and can operate in vacuum and at room or low temperature.

Measurements were made at room temperature at 10 km above sea level (on aircraft) and at ground level (200 m above sea level). For airborne measurements two Medipix2 detectors with a 700 µm thick silicon sensor were used. A number of measurements were done with fixed frame

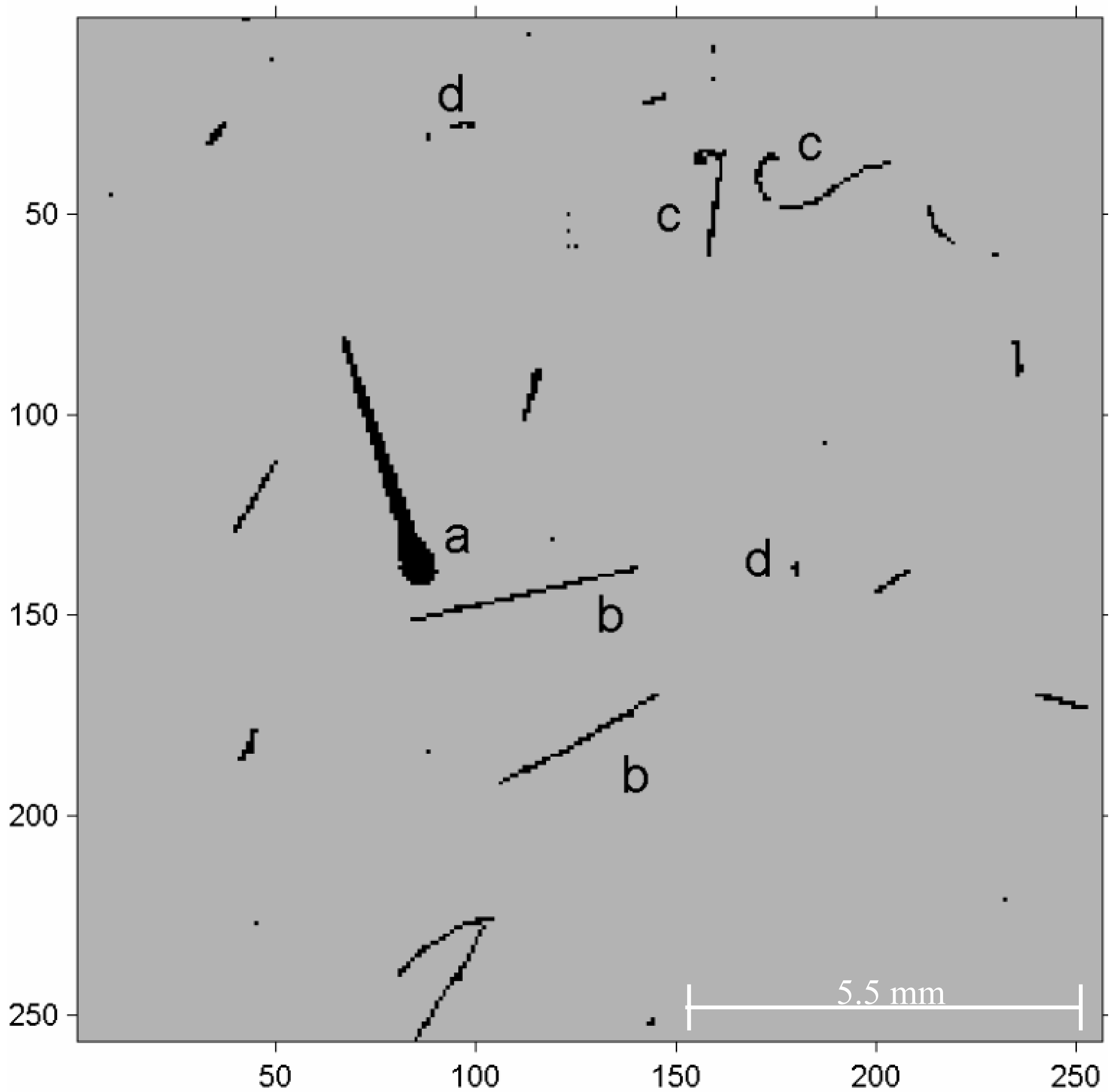

Figure 7, Cosmic rays as seen by the 256x256 pixel matrix of Medipix2. This frame was collected at height 10 km with 5 s shutter time. Various types of particles can be identified according to their characteristic track/cluster patterns: Heavy charged particles (a), fast light charged particles (b), slow light charged particles (c), X-rays and low-energy gamma rays (d).

time (shutter driven by software) and with shutter triggered by the back-side pulse[12]. Frame shutter times were typically 5s, 10s, 30s, and 60s. A sample frame of cosmic rays observed at 10 km above sea level is shown in detail in Figure 7. The average dose rate[13] was about 4 μSv/h and 0.1 μSv/h at 10 km and 200 m above sea level, respectively.

3.1 PARTICLE DETECTION AND TRACK IDENTIFICATION

The various components of cosmic rays which can be distinguished (see Sec. 3.2) leave characteristic patterns and tracks as shown in Figure 7. Characteristic tracks and/or clusters of pixels are generated on the Medipix2 pixel matrix upon impact of individual minimum ionizing particles (MIP's). These patterns are 2D projections of the charge deposited in the chip sensor volume as illustrated in Figure 8. By track and cluster pattern analysis, imaging and spectrometric information can be obtained about the particle position and energy .

Four types of events generated by MIP's can be noticed (see Figure 7): (a) Large (many pixel) clusters generated by heavy charged particles (protons, alpha particles and any heavier nuclei); (b) Thin straight tracks generated namely by high energy medium mass charged particles (muons, pions, kaons and highly relativistic electrons); (c) Thin curled tracks generated namely by electrons; (d) Small (few-pixel) cluster tracks and dots generated namely by transverse (i.e., incident perpendicular on the pixel array plane) light charged particles (electrons, muons) and X– and low–energy γ rays, respectively.

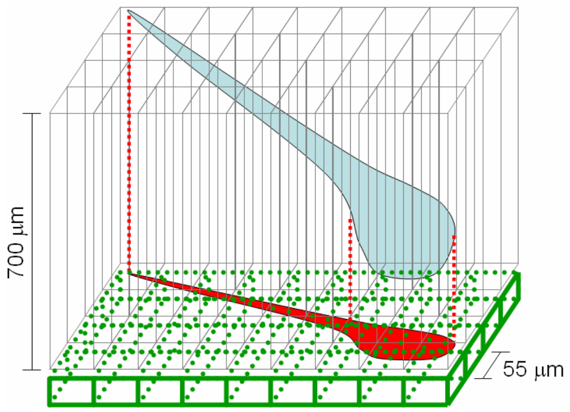

Figure 8, Detection of a heavy charged particle (e.g., a proton) in the Medipix2 sensor chip (gray grid volume). The deposited charge (blue) is collected onto the readout chip (green) as a 2D projection (red).

3.2 COSMIC RAYS

Several components (processes) of atmospheric cosmic ray are observed (see Figure 7): (***i***) Relativistic light charged particles (electrons, muons): long thin straight tracks in Figure 9 (***ii***) Non–relativistic light charged particles (electrons): Figure 10; (***iii***) Pair (e^+e^-) production and generation of secondary light charged particles (muons, fast electrons): Figure 13; (***iv***) Generation of secondary light charged particles (delta electrons) by light charged particles (muons, relativistic electrons: Figure 14) or by heavy charged particles (protons: Figure 12); (***v***) Heavy charged particles: Figure 11 – see also large clusters and wide patterns in Figure 7 and Figure 12).

For illustration of a given type of process, Figure 10 to Figure 14 show a collection of similar events together (which were however recorded in *different* frames).

Identification of electrons was verified with a ^{90}Sr source which gives patterns such as those in Figure 1. Alpha particles were tested with ^{241}Am, ^{239}Pu and ^{252}Cf sources. For a more adequate description namely of heavy charged particles, a detailed calibration with ions (of varying energy and mass) from an accelerator (cyclotron) is planned.

[12] The back-side contact of the sensor chip collects the charge generated which is proportional to the kinetic energy of the impacting particle. This signal can be used for energy amplitude measurement of the signals above pressed level and also for trigger generation. The frame shutter can be set to open, or close, upon hit of a particle (driven by threshold setting of the back–side pulse of the Medipix2 sensor chip). The delay from trigger detection can be also tuned till the shutter signal closes.

[13] Measured with a portable Dosimeter Canberra UltraRadiac MRAD101 (operational for X- and γ-rays at 58 keV–1.25 MeV).

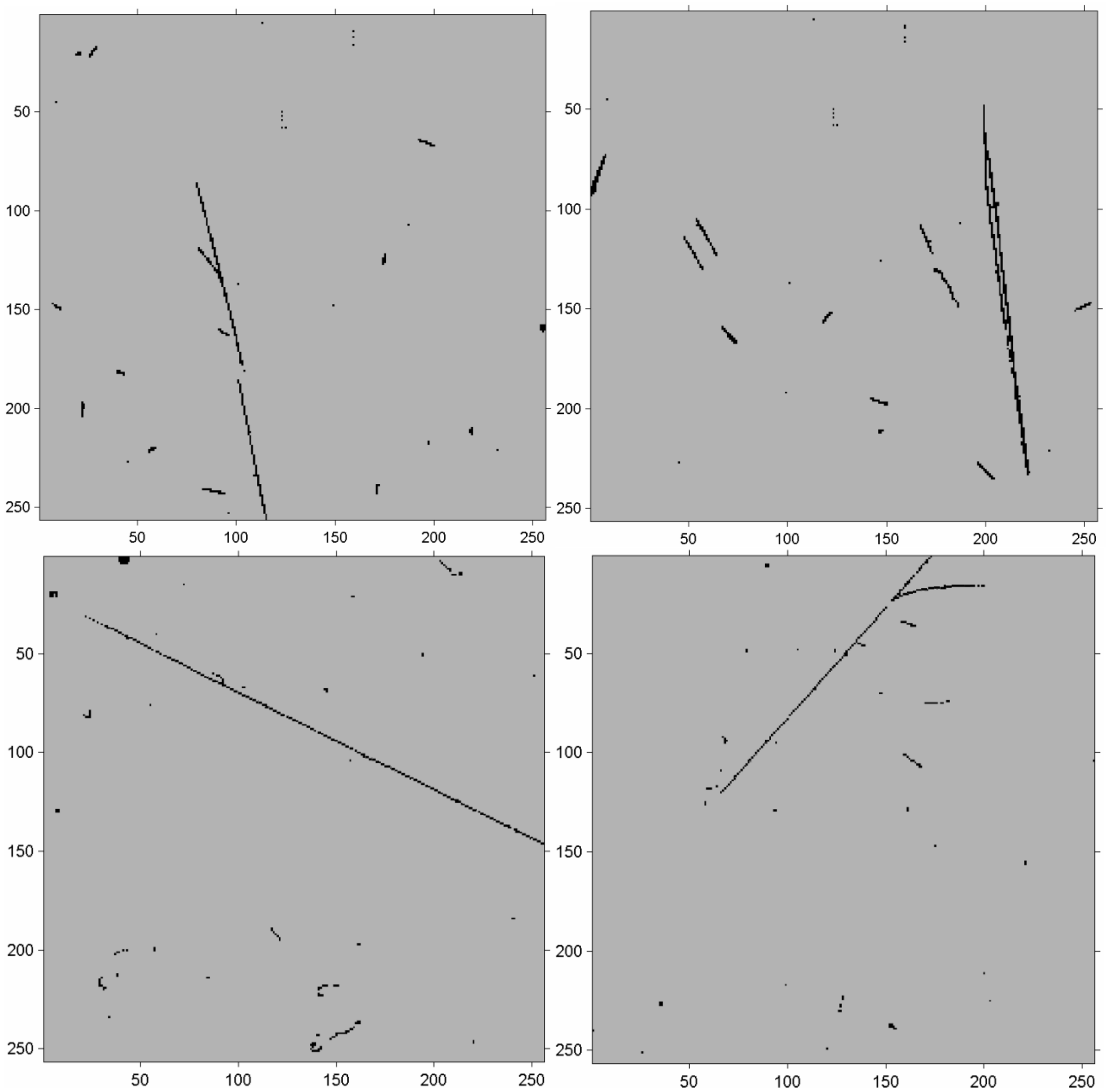

Figure 9, Cosmic ray tracks as observed by Medipix2. Illustraiton of frames collected at 10 km (top) and ground level (bottom).

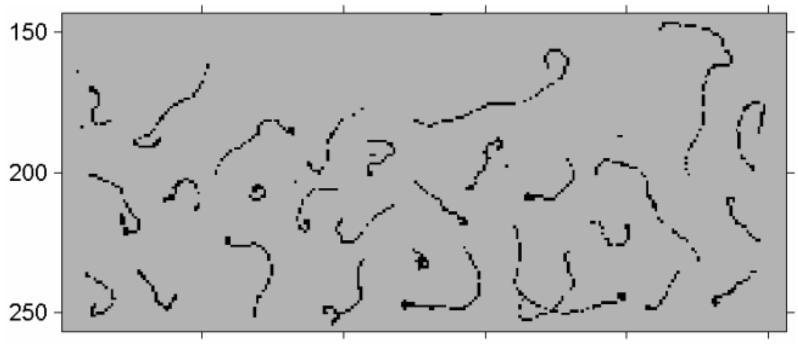

Figure 10, Low energy light charged particles (electrons) recorded at ground level by Medipix2. Events are shown together into one frame for illustration.

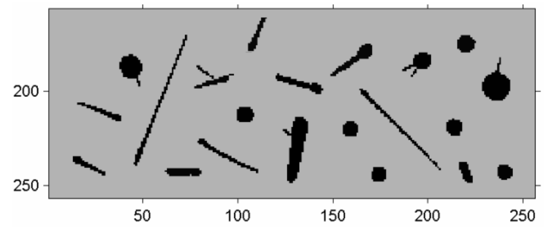

Figure 11, Heavy charged particles. Patterns are given by direction and energy of indicdent particle. Events recorded at 10 km above sea level.

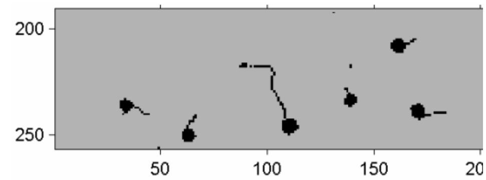

Figure 12, Knock out of secondary light charged particles (delta electrons) by heavy charged particles (protons). Events recorded at ground level.

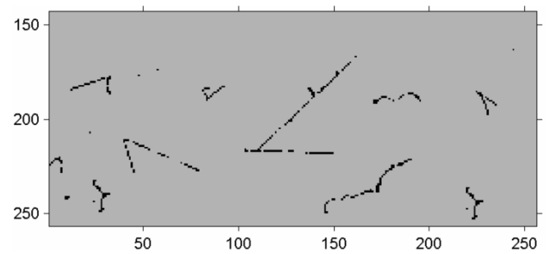

Figure 13, Pair creation of light charged particles (electrons) and generation of secondary light charged particles. Events recorded with the 700 µm thick sensor at 10 km above sea level.

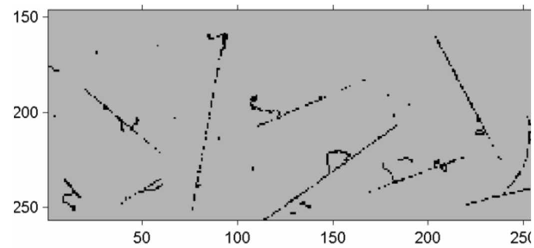

Figure 14, Generation of light charged particles by fast light charged particles. Events recorded at 10 km above sea level.

CONCLUSIONS

Operation and the application of pixel detectors (with the state–of–the–art Medipix2/USB radiation camera) have been demonstrated by novel experiments carried out on dental micro–roentgenography and spectroscopy of fission fragments of ^{252}Cf and cosmic ray tracking. The results obtained demonstrate the capability of single–quantum position–sensitive detection and spectroscopy of the Medipix2 device for both fundamental and applied experimental physics. This device has a number of features suitable for both radiation imaging and particle spectroscopy in the laboratory at the table–top scale. Future applications include non–destructive material analysis and testing. Together with a novel USB readout interface, the Medipix2/USB radiation camera operates as a single–photon counting imager (for radiography) and as an "active nuclear emulsion" in event–by–event and on–line tracking mode (for spectroscopy). As a tracking detector this device serves for real–time particle detection and visualization. The camera can operate in vacuum and at room temperature which enable to carry out remote measurements in a simple and flexible way. In combination with spectroscopy (e.g., coincidence) techniques, precise calibration, track and cluster pattern recognition (e.g., subpixel spatial resolution can be reached by computation of the event cluster centroid) the system stands promising for wide application in physics experiments, material research and non–destructive testing.

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ABSTRACT

This work summarizes the Habilitation Thesis of the author on the application of novel pixel radiation detectors in experimental physics. This subject is based on the research papers published by the Author representing in particular the methodological results of work carried out in novel projects on fundamental subatomic physics (spectroscopy of fission fragments, cosmic ray tracking and nuclear excitation by laser–produced plasma) as well as applied physics (dental micro–roentgenography). This work summarizes two of these projects (spectroscopy of fission fragments and cosmic ray tracking) including an outline of hybrid pixel detectors and the characteristics of the state–of–the–art Medipix2/USB radiation camera developed at IEAP CTU Prague and the CERN Medipix Collaboration.

ABSTRAKT (ČESKY)

Tato teze je shrnutím habilitační práce autora věnované aplikaci pixelových detektorů v experimentální fyzice. Toto téma je podkladem vědeckých publikací autora, které prezentují zejména metodické výsledky originální práce jak ve fundamentální subatomové fyzice (spektroskopie štěpných fragmentů, detekce a vizualizace kosmických paprsků a jaderná excitace pomocí laserově generovaného plazmatu) tak i v aplikované fyzice (dentální mikro–roentgenografie). Teze se věnuje dvěma tématům z uvedených oblastí (spektroskopie štěpných fragmentů, detekce kosmických paprsků) a zahrnuje krátký úvod pixelových detektorů a přehled vlastností nového detektoru Medipix2/USB.

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