Resolving Power of Pixel Detector Timepix for Wide-Range Electron, Proton and Ion Detection

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German Cancer Research Center DKFZ, HIT, Heidelberg, Germany

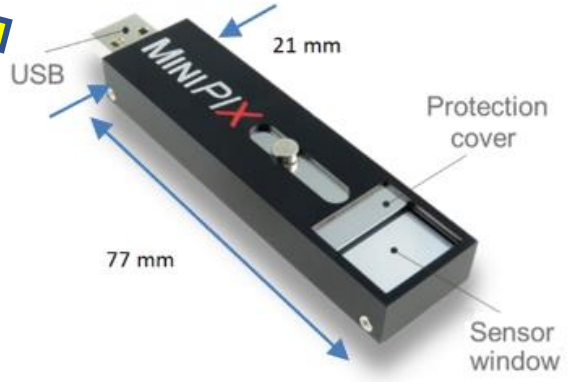
Resolving Power of Pixel Detector Timepix for Wide-Range Electron, Proton and Ion Detection

Motivation + Goals + Challenges + Status

- Timepix family of detectors increasingly used to detect and characterize **mixed radiation fields** such as those found in **outer space, near Earth, deep space**, upper atmosphere, ion beam radiotherapy.
- Of particular value is the detector **resolving power** in terms of **particle-type**, **spectral- (energy loss)** and **direction/tracking**.
- The challenge is to provide resolving power with high sensitivity and wide dynamic range in terms of particle types, stopping power and direction with a single compact device
- Experimental study, tests and calibration of a **single Timepix** (300 µm Silicon): evaluation of detection response in **defined fields** of various radiations (electrons, protons, ions) in wide range of fluxes, energies and incident directions

Use of Timepix in space

- Applications:
  - Radiation dosimetry (quantum imaging dosimetry, LET spectra, on line response)
  - Radiation monitoring (miniaturization, integration)
  - Characterization of radiation fields (photon counting, per-px spectrometry, wide range)
- Science/research
  - Space weather
  - Focal plane X-ray imager
  - Micro-tracker/directional camera
  - Gamma-ray Compton camera
  - Neutron detection



Deployments of Timepix in space/orbit

- Applications:
  - NASA - ISS-REM-TPX 2012
  - ESA - Proba-V/SATRAM-TPX spacecraft payload 2013
  - NASA – BIRD-TPX Orion EFT-1 2014
  - NASA – ISS HERA-TPX 2016
  - NASA – ISS EPT TPX telescope 2017
- Science/research
  - CZ - X-ray focal plane detector/X-ray telescope on board Czech VZLUSAT-1 cubesat 2016
- Educational
  - GB – TechDemoSat1

https://crreat.eu

CRREAT

RESEARCH CENTRE OF COSMIC RAYS
AND RADIATION EVENTS IN THE ATMOSPHERE

Prof. G. Reitz, O. Ploc, C. Granja, et al., CRREAT-UJF*

Research area/subjects

- ❑ Atmospheric phenomena & ionizing radiation
- ❑ Sources, variation, characterization of primary & secondary cosmic rays
- ❑ Radiation instrumentation/methodology

Experiments/projects/deployment

- ❑ Atmospheric balloons
- ❑ UAV/drones, remote/terrain vehicles
- ❑ DLR aircraft flights
- ❑ Dosimetry experiments on board ISS
- ❑ Satellite borne payloads/experiments
- ❑ Return satellite capsule
- ❑ High-altitude radiation stations

Biological satellite BION-M1, return capsule
LEO orbit, IBMP RAS Moscow

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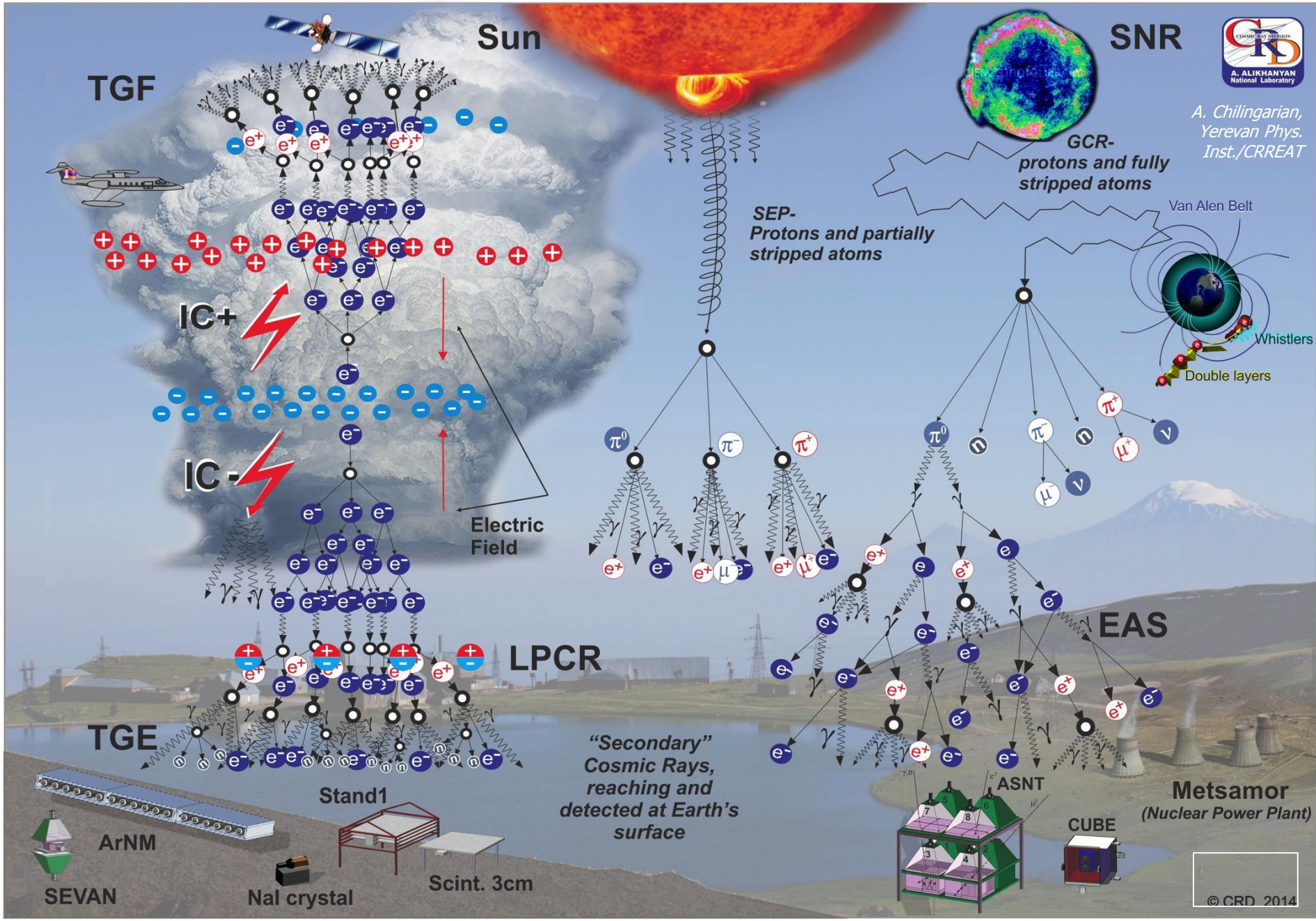
Imaging the Unseen

Origin of Secondary Cosmic Rays



The isochronous cyclotron U-120M

Cyklotron accelerator

Ions		Energy [MeV]	Max. current [μA]
H^+	Internal beam	1 - 37	> 200
H^+	External beam	6 - 25	5
H^-/H^+	External beam	6 - 37	50 - 30
D^+	Internal beam	2 - 20	> 80
D^+	External beam	12 - 20	5
D^-/D^+	External beam	11 - 20	35 - 20
$^3He^{+2}$	Internal beam	3 - 55	20
$^3He^{+2}$	External beam	18 - 52	2
$^4He^{+2}$ (α)	Internal beam	4 - 40	40
$^4He^{+2}$ (α)	External beam	24 - 38	5

Note: Energy range of internal beams is for the probe radii from 20–50 cm.

Electron microtron accelerator

	Before modernization	After modernization
Maximum energy	25 MeV	25 MeV
Energy range	6 - 25 MeV	6 - 25 MeV
Electron current	10 μA	25 μA
High frequency source		
Tunable magnetron	2 790 ± 50 MHz	2 796 ± 5 MHz
Peak power	2 MW	3 MW
Pulse lenght	3 μs	3 μs
Repetition rate	400 s^{-1}	max. 425 s^{-1}
Resonator freq.	2 784 MHz	2 796 MHz
Power supply freq.	400 Hz	50 Hz

NPI-CAS, Rez near Prague
Electron Microtron Accelerator

WIDEPIX®

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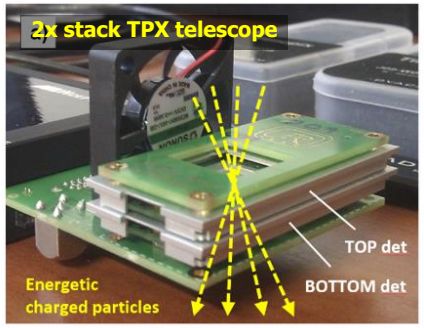
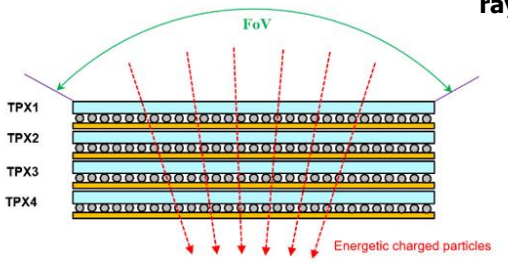
www.advacam.com

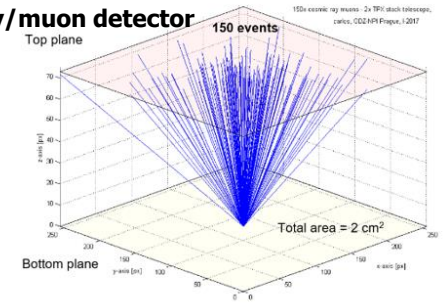
RASPIX

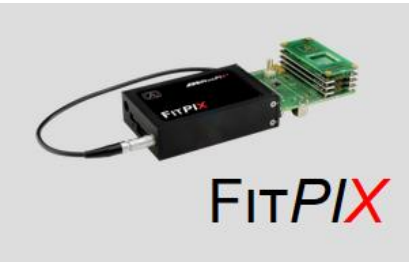
MINIPIX



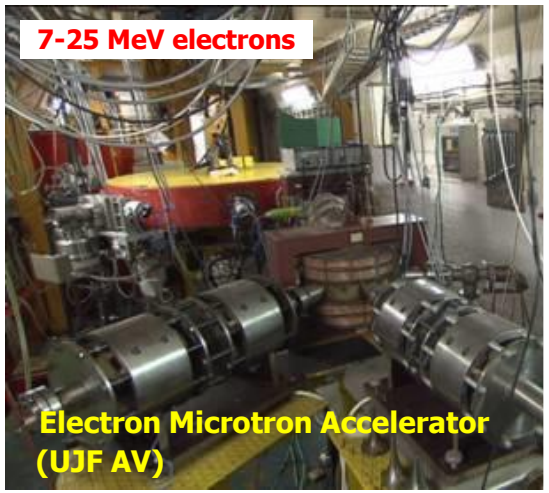


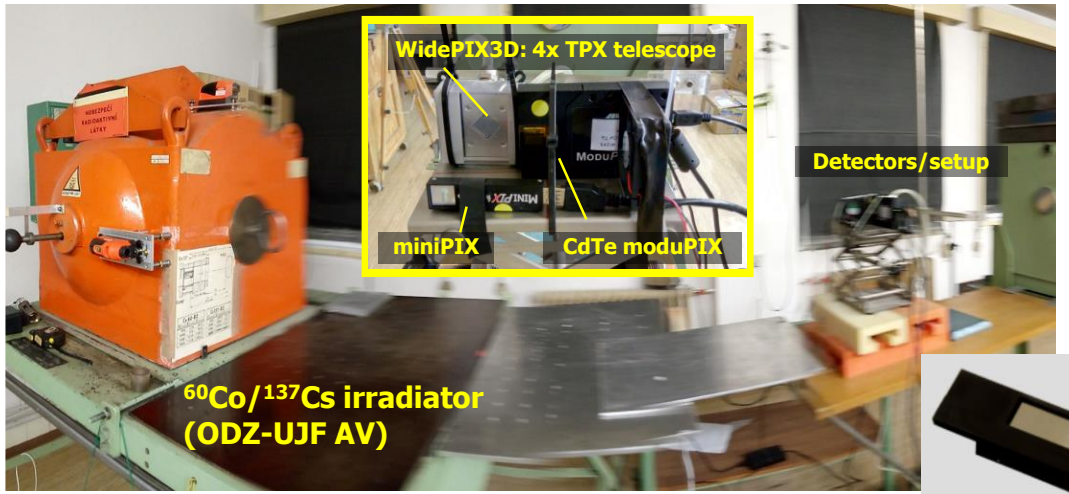
Directional cosmic ray/muon detector





FITPIX





WIDEPIX® 10x10

WIDEPIX® 1x5

WIDEPIX® 4x5

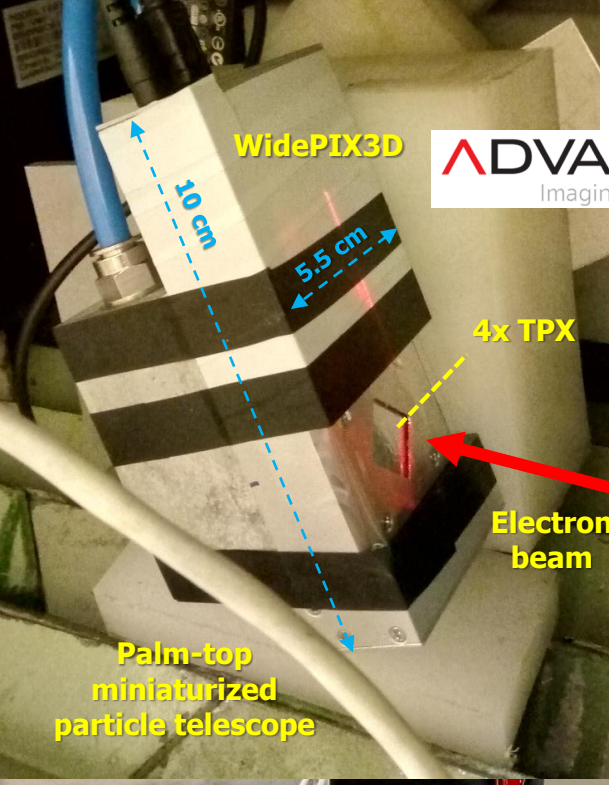
CREAT seen

Physics/radiation research at accelerator research facilities

Highly integrated (contact geometry) WidePIX3D 4xTPX tracker

Electron Microtron accelerator

Nuclear Physics Institute, Prague, Czech Academy of Sciences



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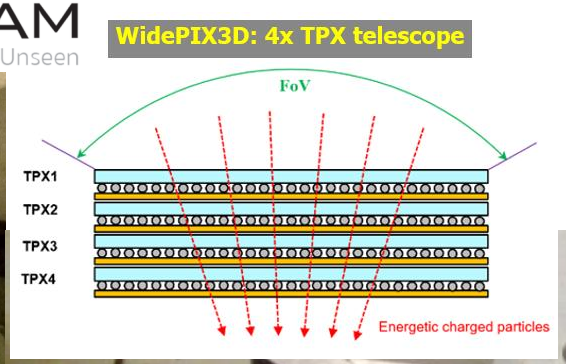
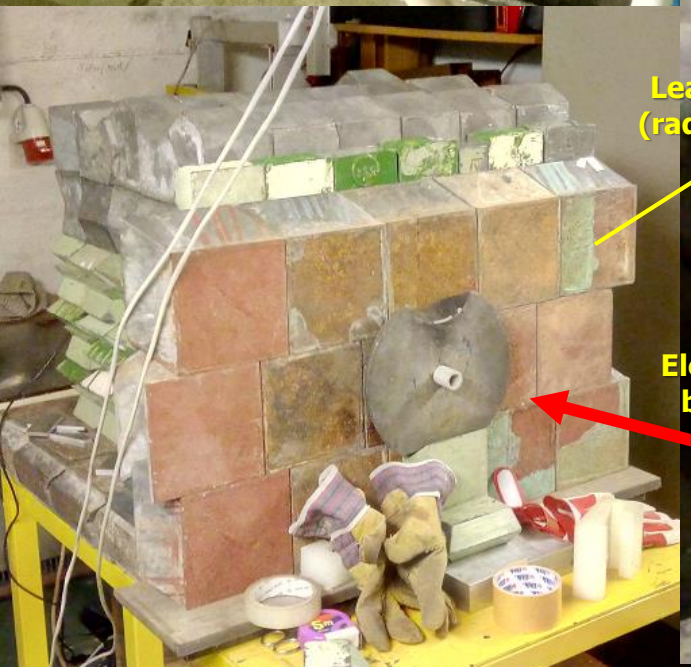
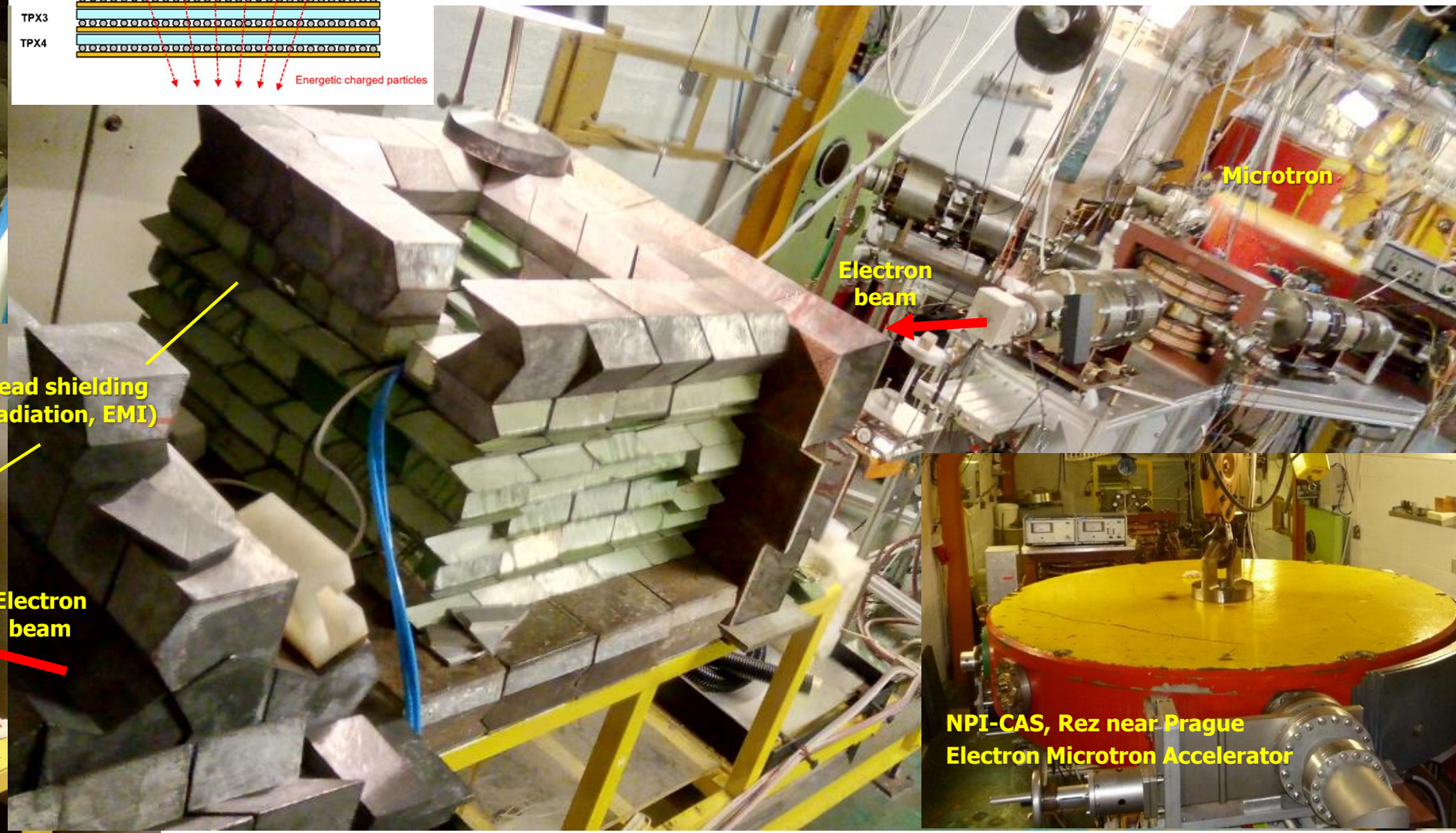
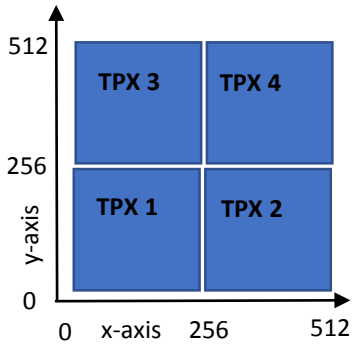


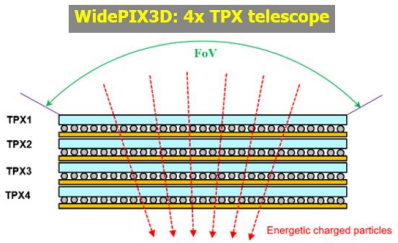




3D charged particle tracking

Widepix3D 4xTimepix miniaturized Tracker





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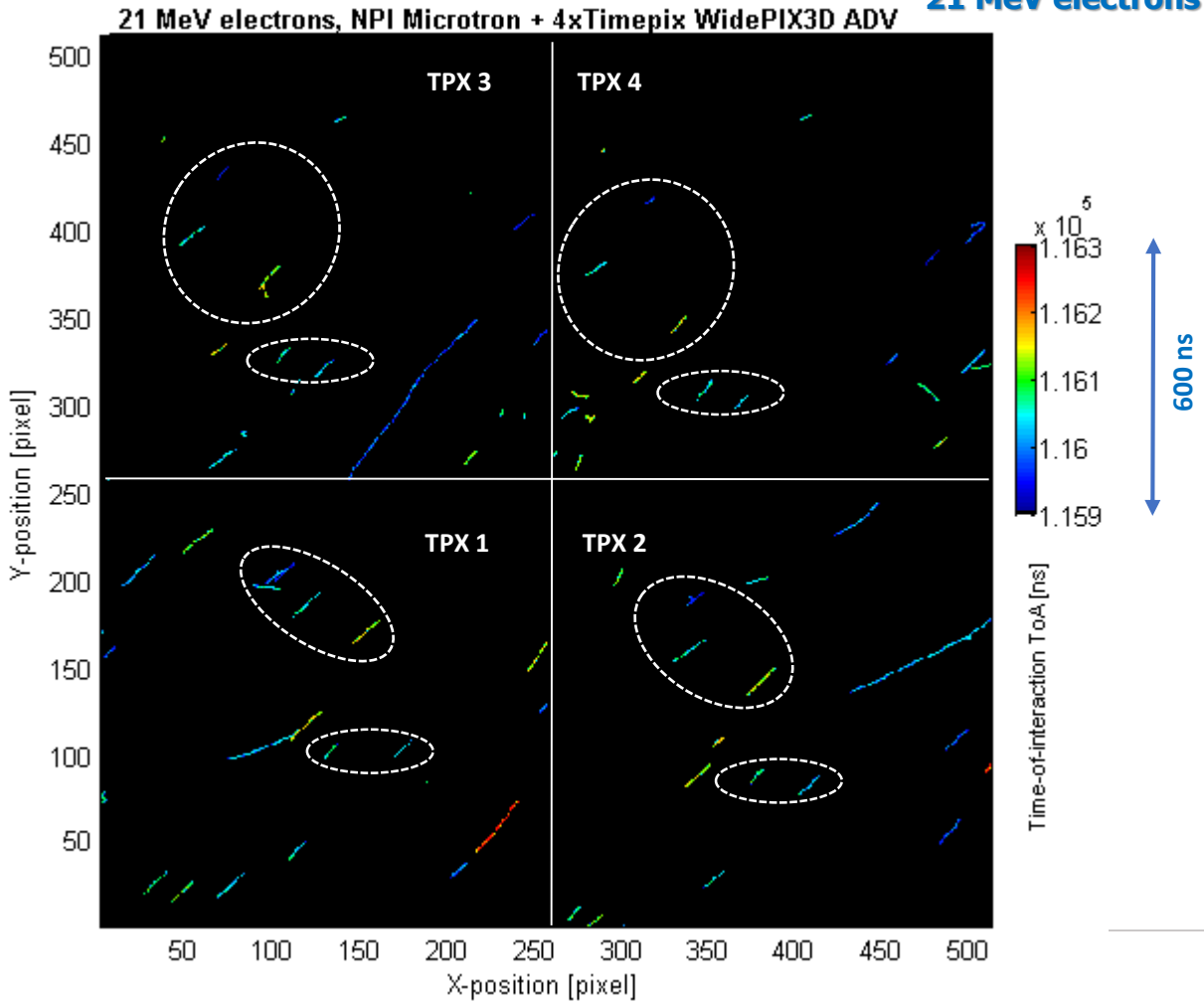
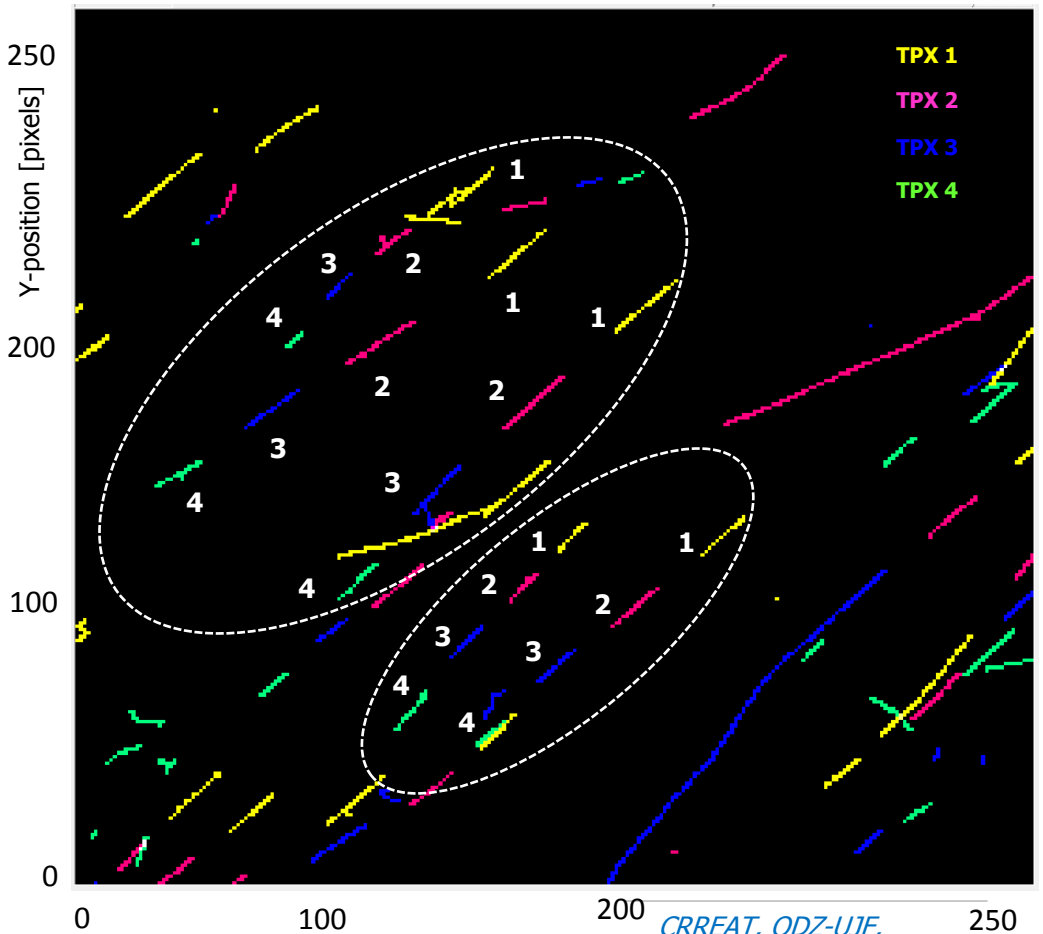
Spatial + Time correlated detection

Color value = Time of interaction



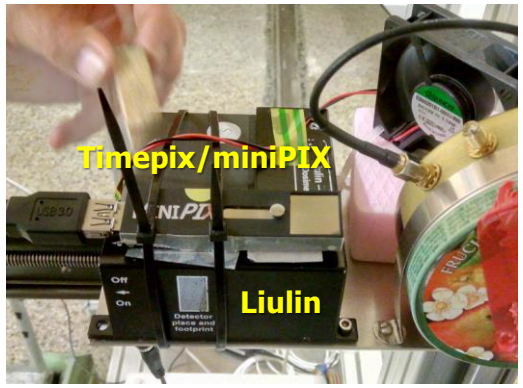
21 MeV electrons (NPI Microtron)

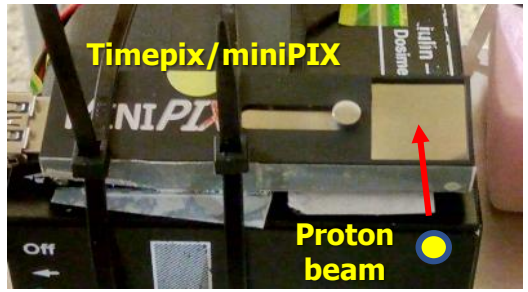
Color value = pixel layer ordering

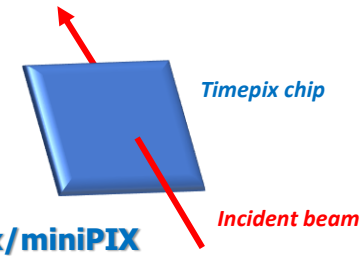


protons: varying E + unfiltered data

Medium-energy protons
Cyclotron accelerator, NPI-CAS, Rez near Prague

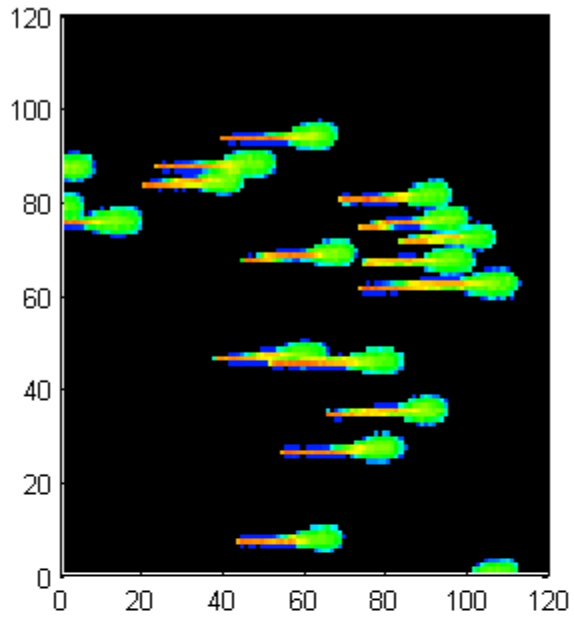


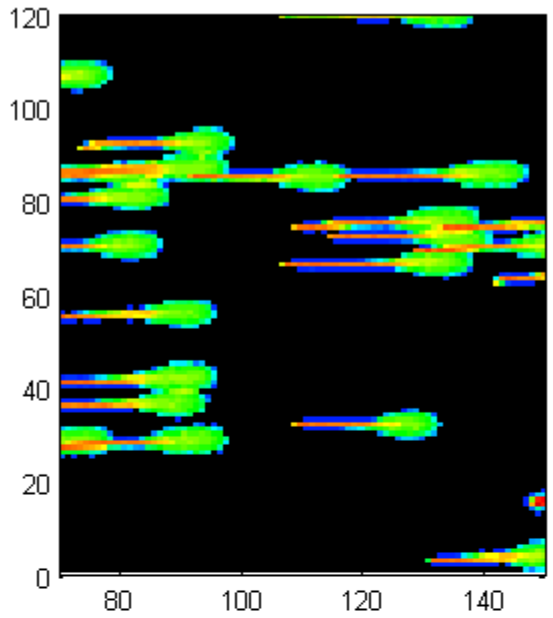


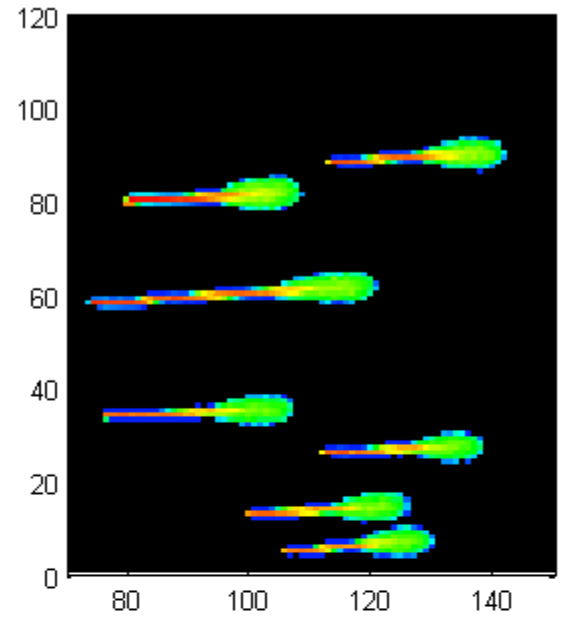


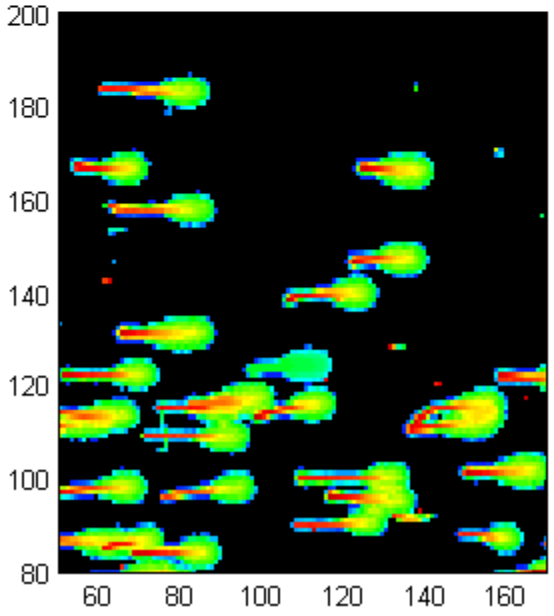
Timepix/miniPIX

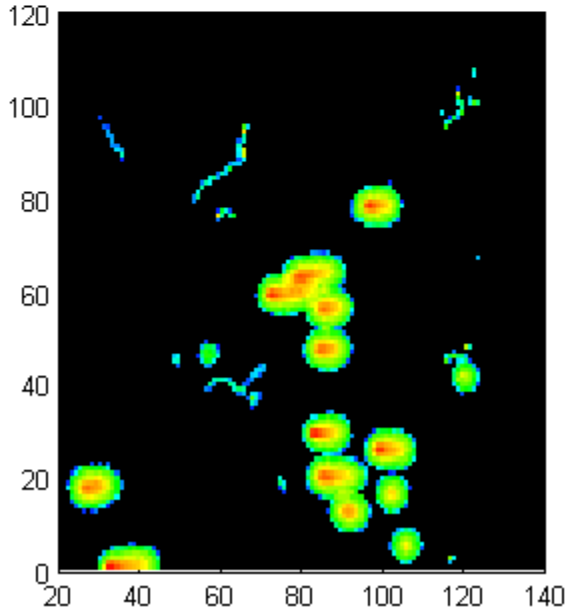
ADVACAM
Imaging the Unseen

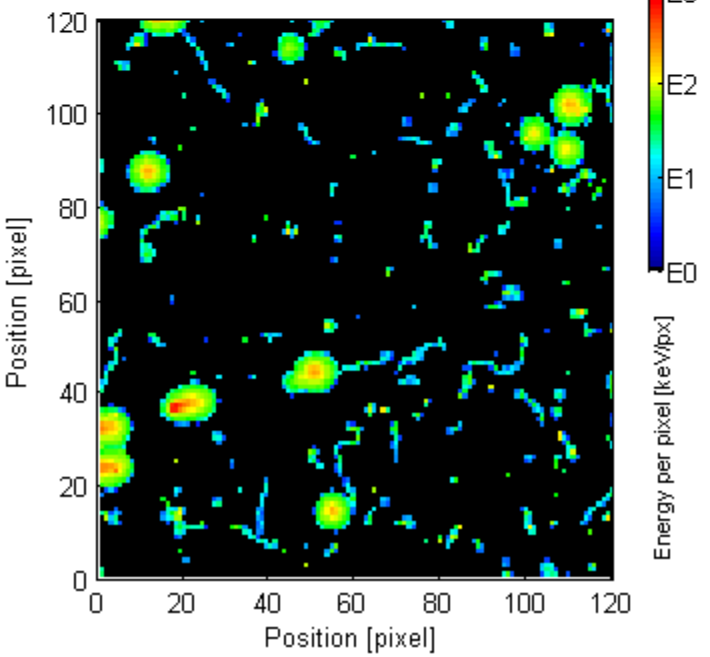












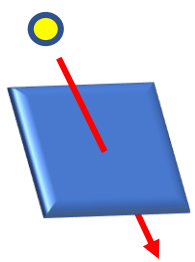
CRREAT

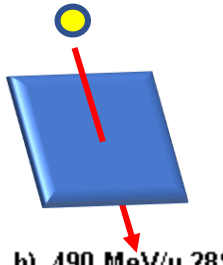
ujf

Quantum imaging detection, spectrometry, tracking

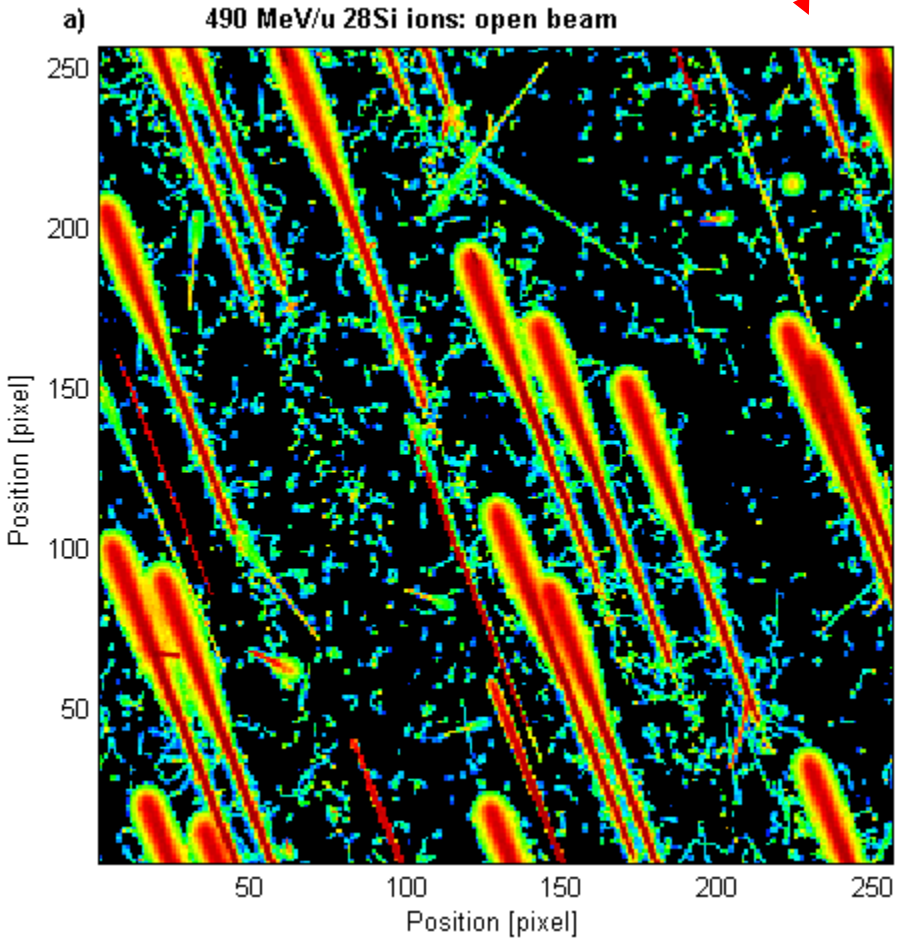
Energetic charged particles: relativistic ions, secondary reaction/fragmentation products

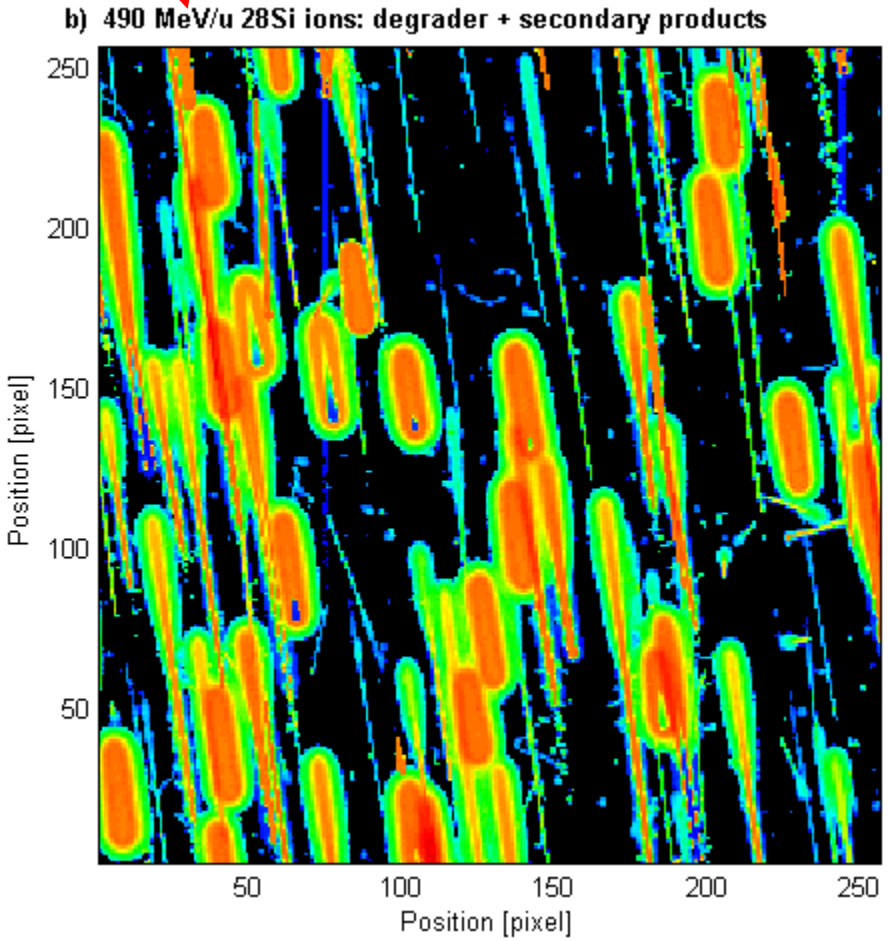
490 MeV/u ^{28}Al ions





85 MeV/u ^{28}Al ions
& secondary reaction products



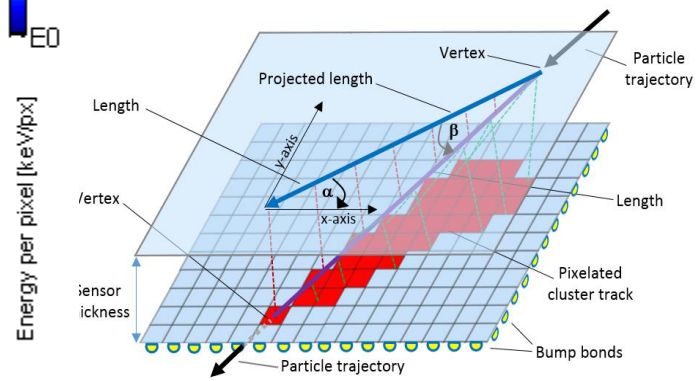


Relativistic ions
HIMAC ion synchrotron accelerator, NIRS, Chiba, Japan

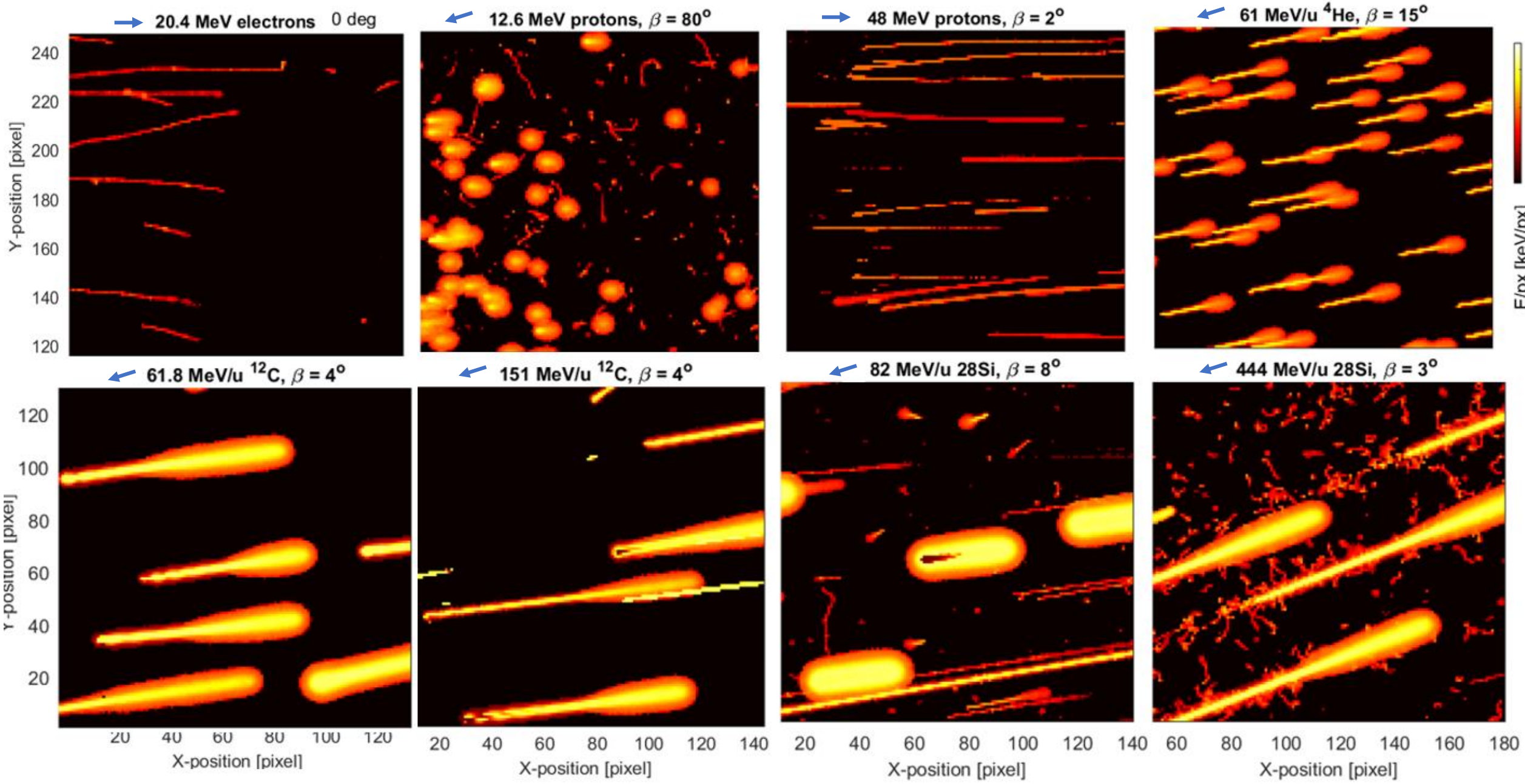
Timepix/miniPIX
Medipix spin-off www.advacam.com

Energetic (penetrating) charged particles:

- Deposited energy
- Position of interaction
- dE/dx → LET, stopping power
- Direction (limited angular resolution)



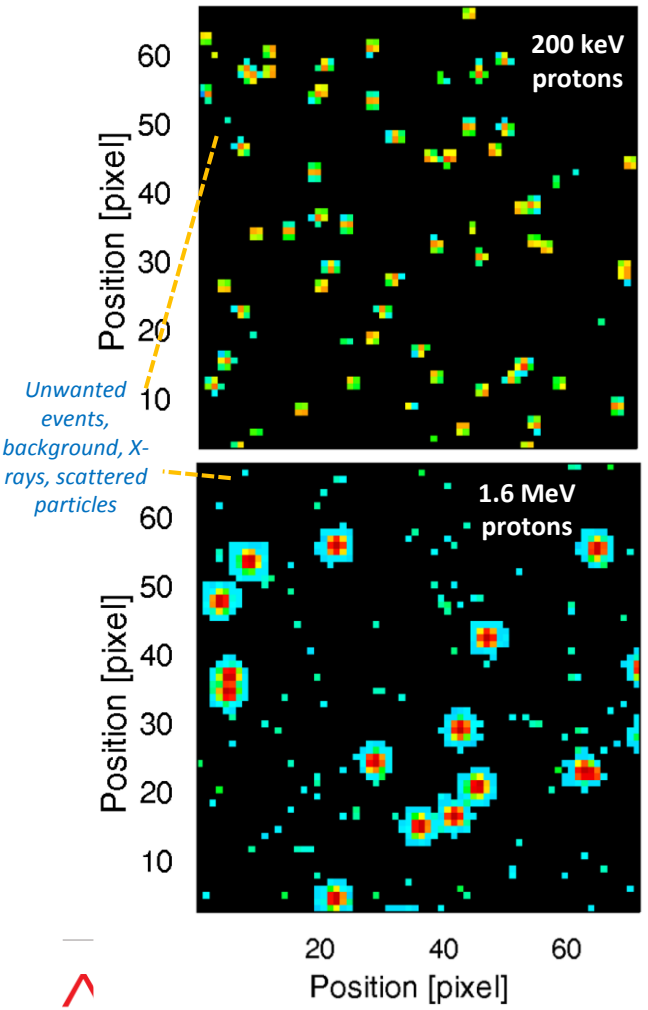
Micro-scale particle tracking + high-resolution pattern recognition of single charged particles


20.4 MeV electrons 0 deg
12.6 MeV protons, β = 80°
48 MeV protons, β = 2°
61 MeV/u 4He, β = 15°
61.8 MeV/u 12C, β = 4°
151 MeV/u 12C, β = 4°
82 MeV/u 28Si, β = 8°
444 MeV/u 28Si, β = 3°
Y-position [pixel]
X-position [pixel]
E/px [keV/px]
E3
E2
E1
E0

Single particle detection and spectrometry

Cluster analysis + Pattern recognition: Heavy charged particles: protons, ions

Low-energy protons
VdG accelerator, IEAP CTU Prague



Charged particles:

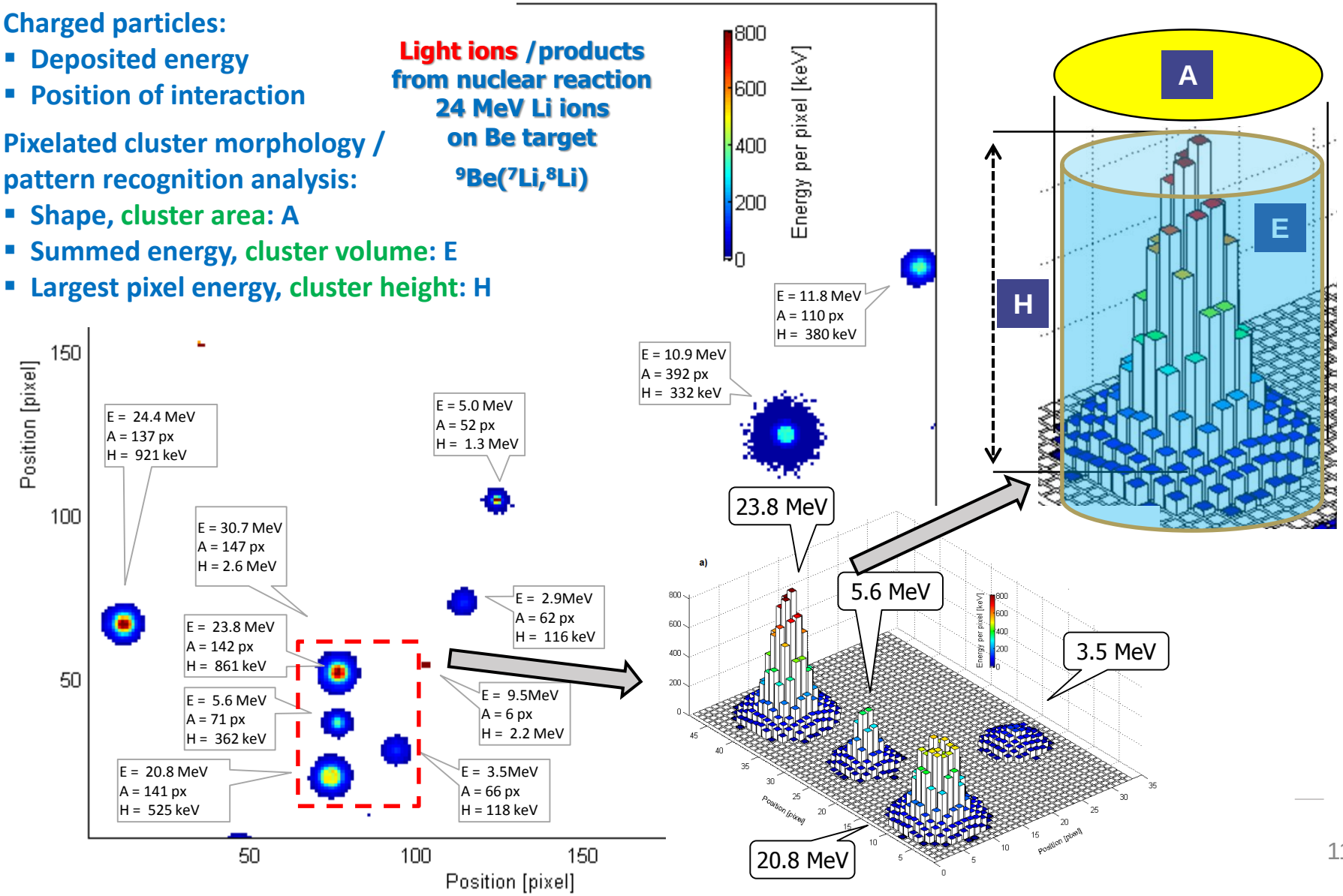
- Deposited energy
- Position of interaction

Pixelated cluster morphology / pattern recognition analysis:

- Shape, cluster area: A
- Summed energy, cluster volume: E
- Largest pixel energy, cluster height: H

Light ions /products from nuclear reaction 24 MeV Li ions on Be target

^{9}Be(^{7}Li,^{8}Li)



Detection Response of Timepix: Micro-scale tracks

Pattern recognition + cluster analysis parameters + (physics) degrees of freedom

Table 1: Morphology, spectrometric and tracking parameters of cluster analysis.

#	Parameter	Value in cluster	Range#	Units
A	Area	# of pixels	1 – few 100's	px
E	Deposited energy	Sum of energies of all pixels	5 – 1_x10^6 $	keV
H	Height	Largest per-pixel energy	5 – 1_x10^3 $@	keV
R	Roundness	Extent of circular shape	0 – 1	a.u.
Lin	Linearity	Extent of track length approaching a straight line	0 – 1	a.u.
Len	Length	Path length of track across sensor	1 – few 100	px
W	Width	Transversal width of pixel distribution along track length		
LET	Linear energy transfer	Ratio of energy to length		
α	Polar angle	Projected angle on the sensor plane	0 - 180°	deg
β	Elevation angle	Elevation angle to the sensor plane	0 - 90°	deg

#: Upper limit approximate level

$: Lower limit given by the detector sensitivity and calibration, typically at the level of few keV/px

@: Upper limit typically up to 1 MeV (linear range of calibration) and 2 MeV (distorted region).

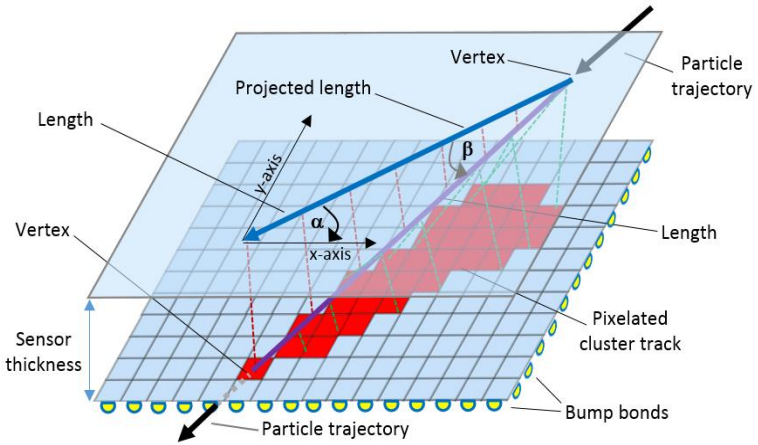
a.u.: arbitrary units

px: pixels

Degrees of freedom:
- **Particle type**
- **Particle energy, stopping power**
- **Particle direction**

Energetic (penetrating) charged particles:
- **Deposited energy**
- **Position of interaction**
- **dE/dx → LET, stopping power**
- **Direction (ang res ≈ 5-10°)**

Pattern recognition and micro-scale tracking of single charged particles



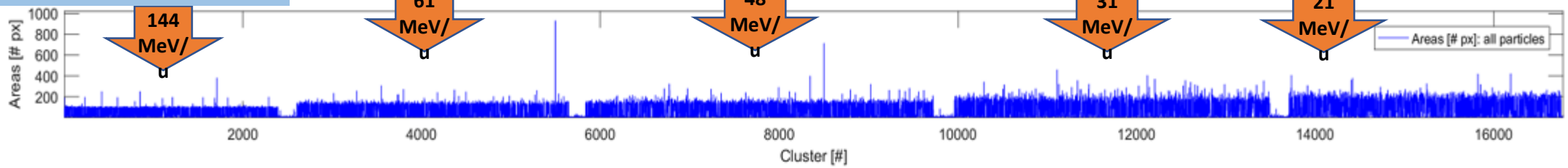
α = Azimuth angle
β = Elevation angle

SINGLE-PARAMETER ANALYSIS

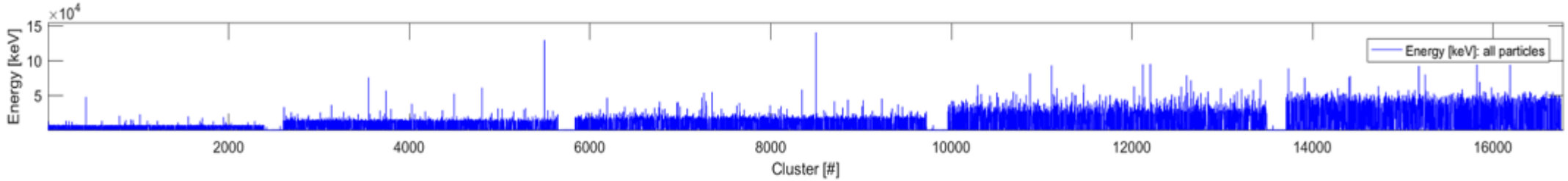
Response of cluster analysis parameters: Varying ion energy

^{4}He beam: 20-150 MeV/u: all particles

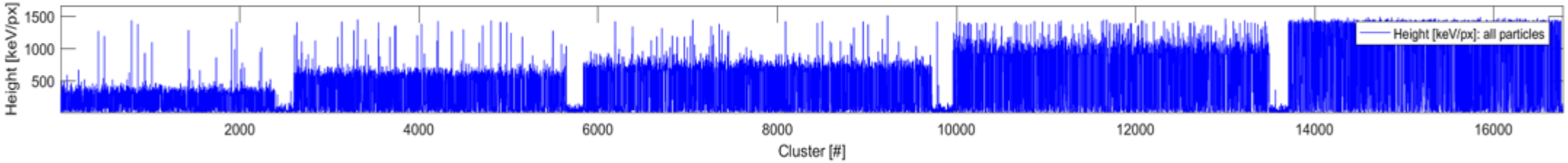
Area [# px]



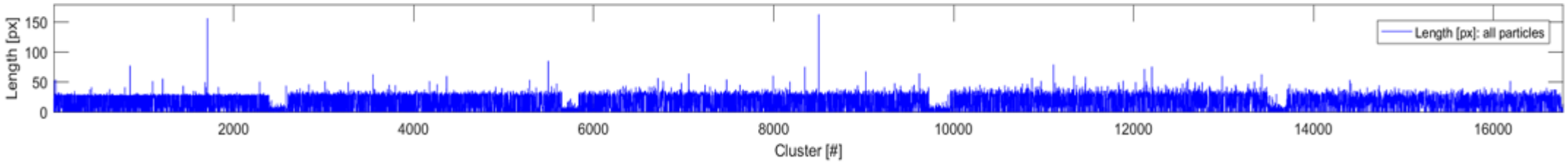
Energy (volume) [keV]



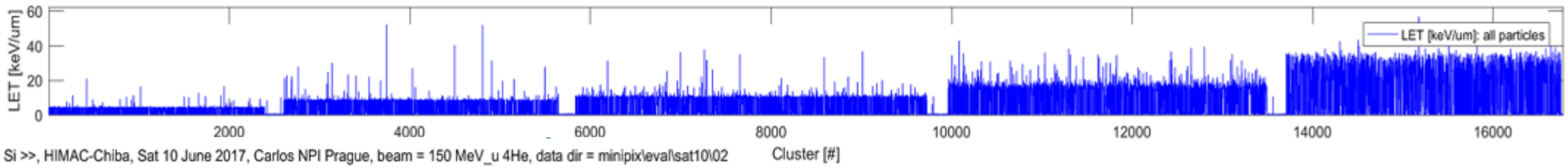
Height [keV]



Track length [um]



LET [keV/um]



<< miniPIX TPX 300 um Si >>, HIMAC-Chiba, Sat 10 June 2017, Carlos NPI Prague, beam = 150 MeV_u 4He, data dir = minipix\eval\sat10\02

Response of cluster analysis parameters: Varying ion energy

^{4}He beam: 20-150 MeV/u: all particles

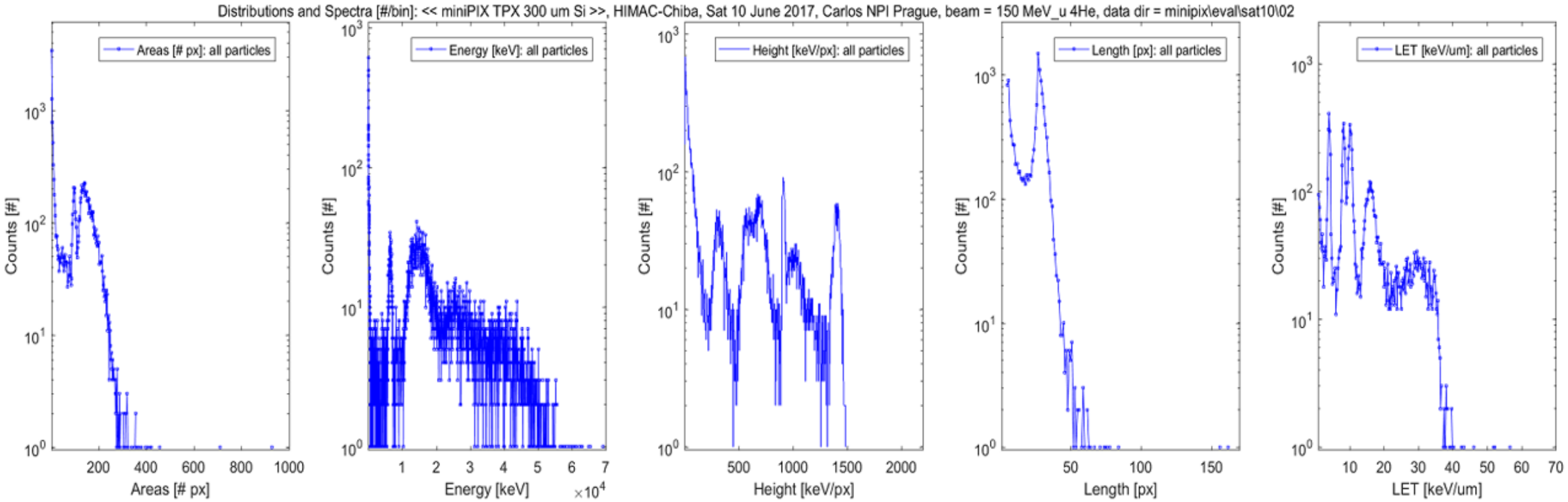
Area [# px]

Energy (volume) [keV]

Height [keV]

Track length [um]

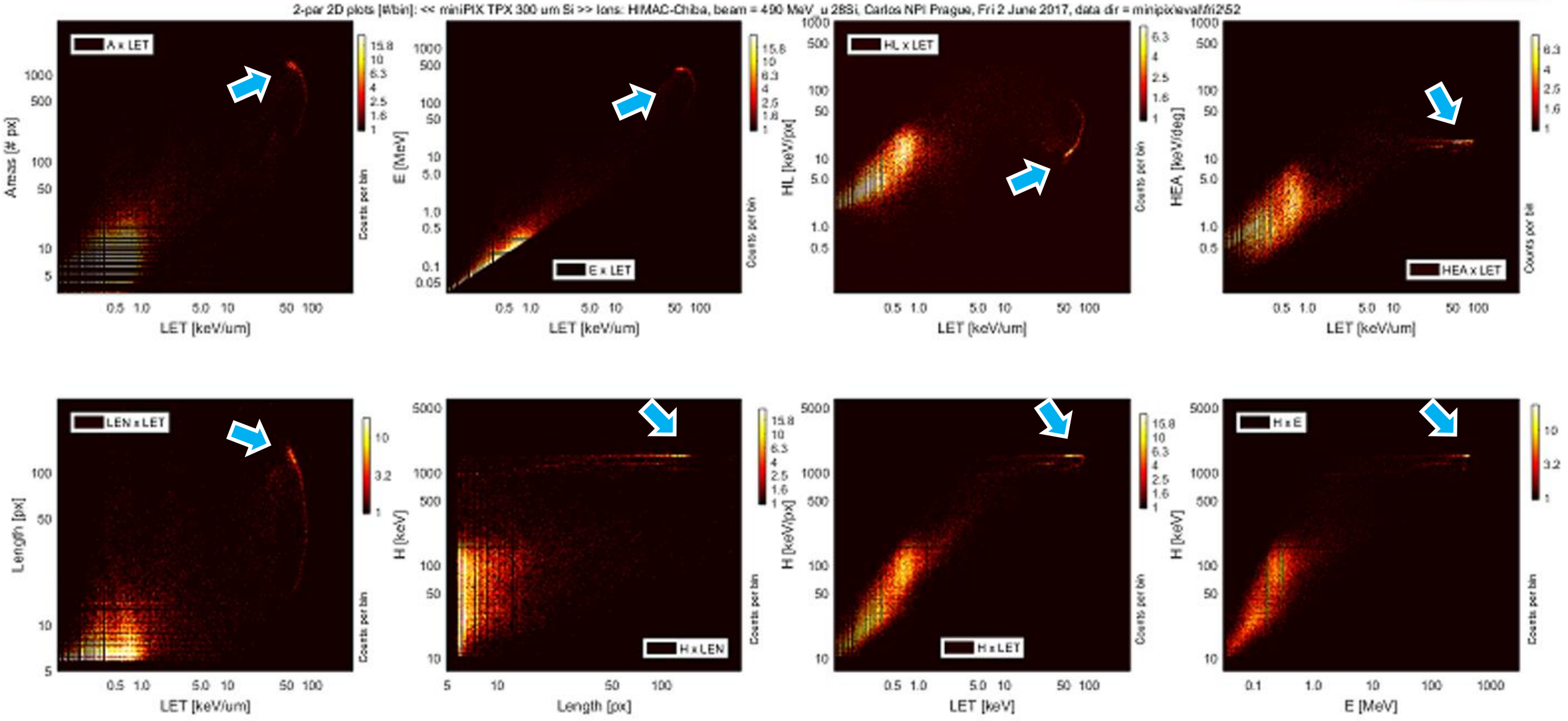
LET [keV/um]



TWO-PARAMETER ANALYSIS

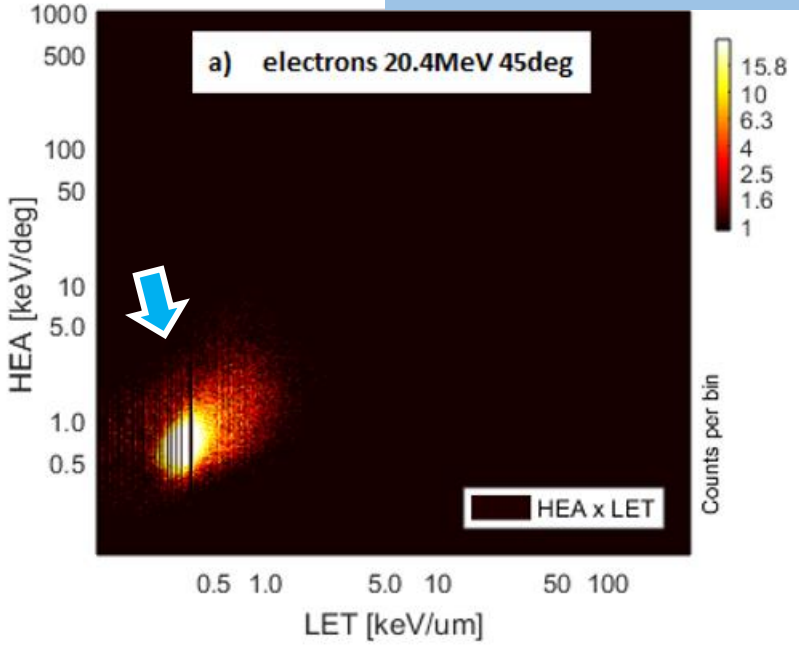
^{28}Si beam: 490 MeV/u: all particles

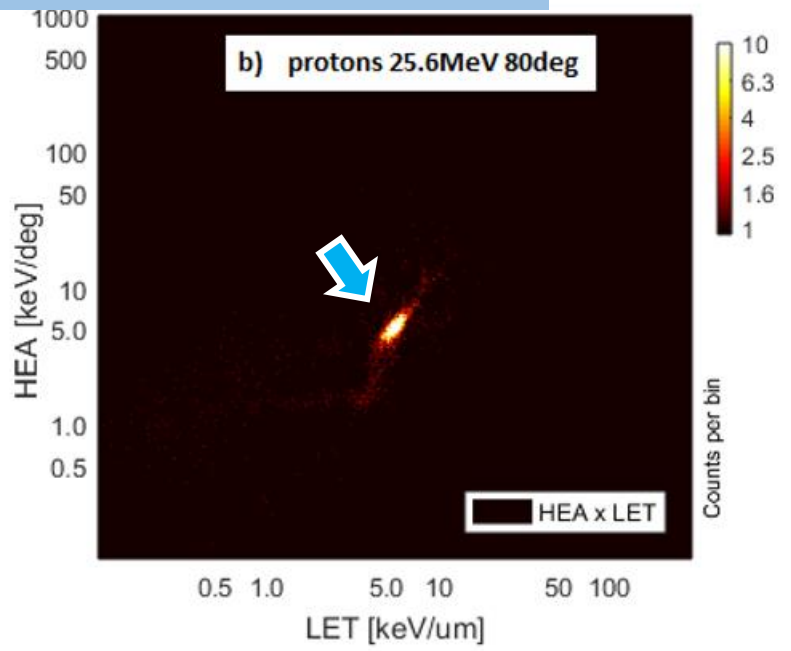
490 MeV/u ^{28}Si

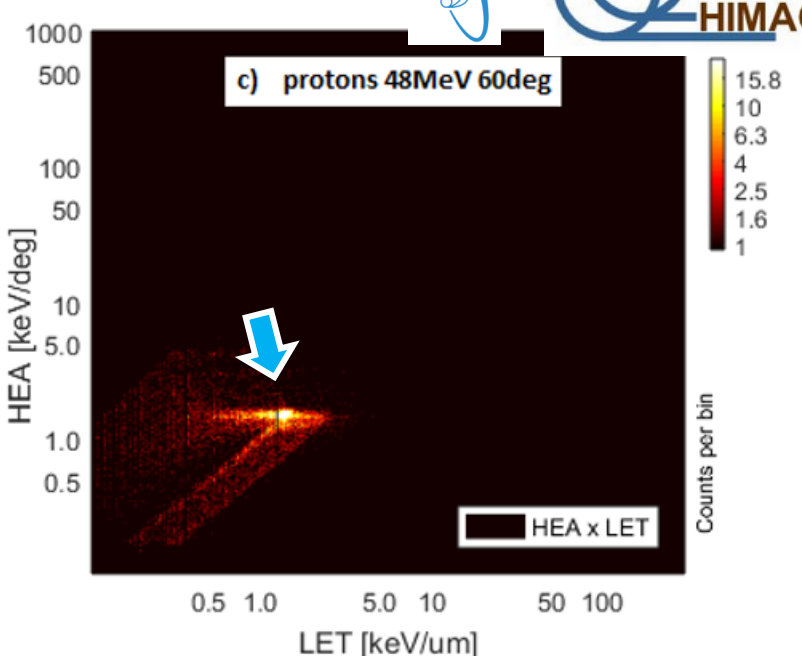


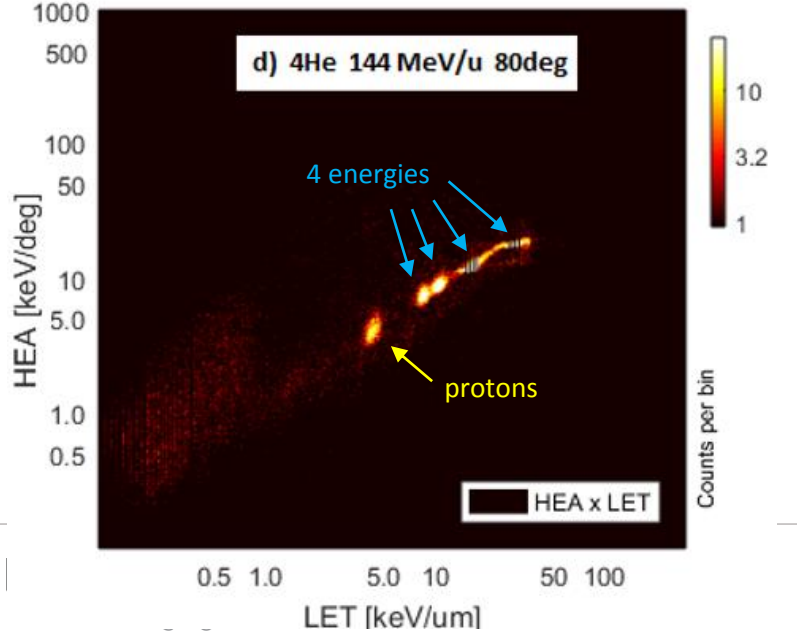
TWO-PARAMETER ANALYSIS

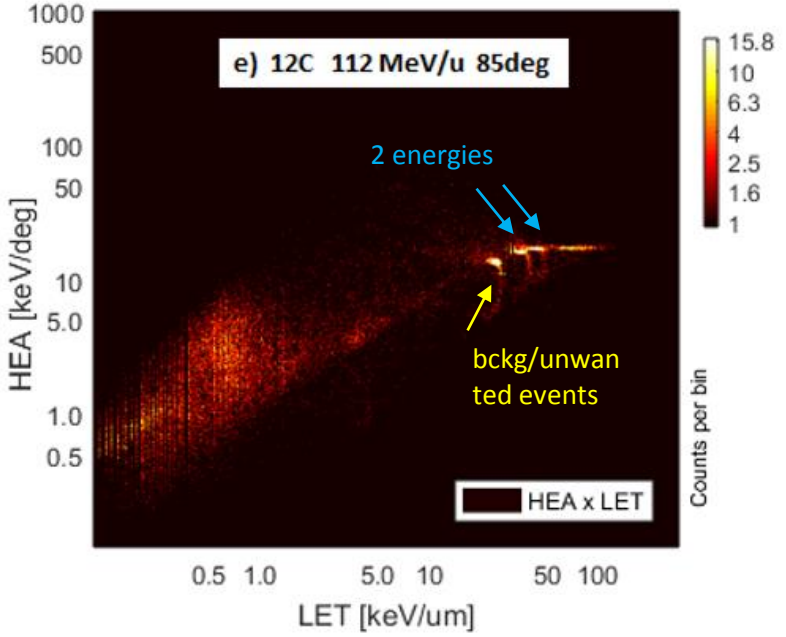
Electrons, protons, ions: all particles

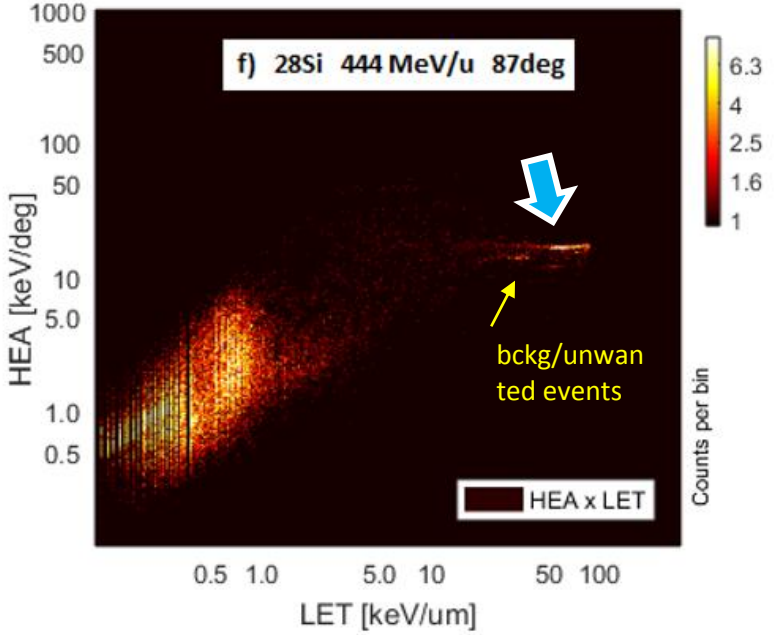


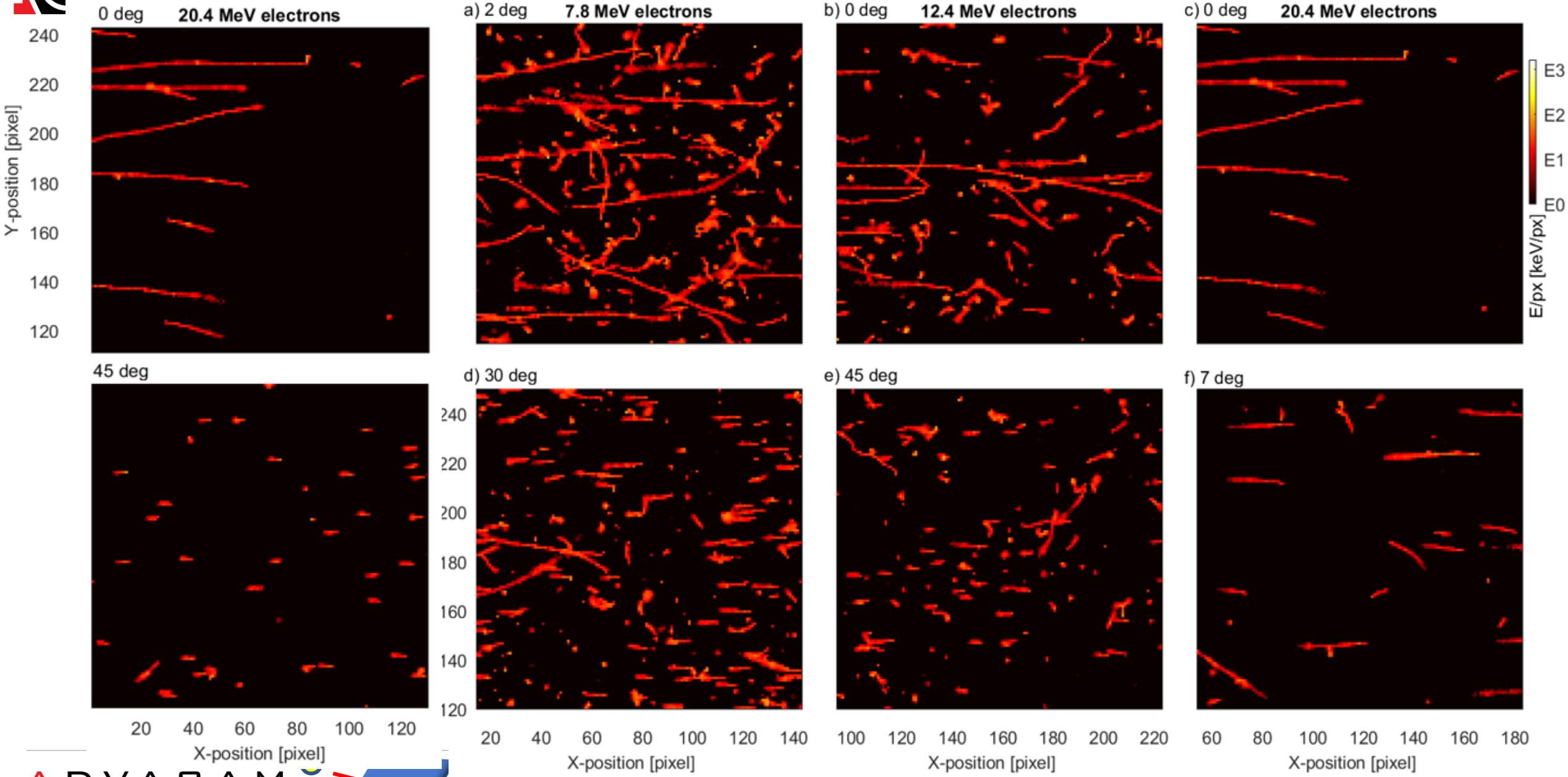


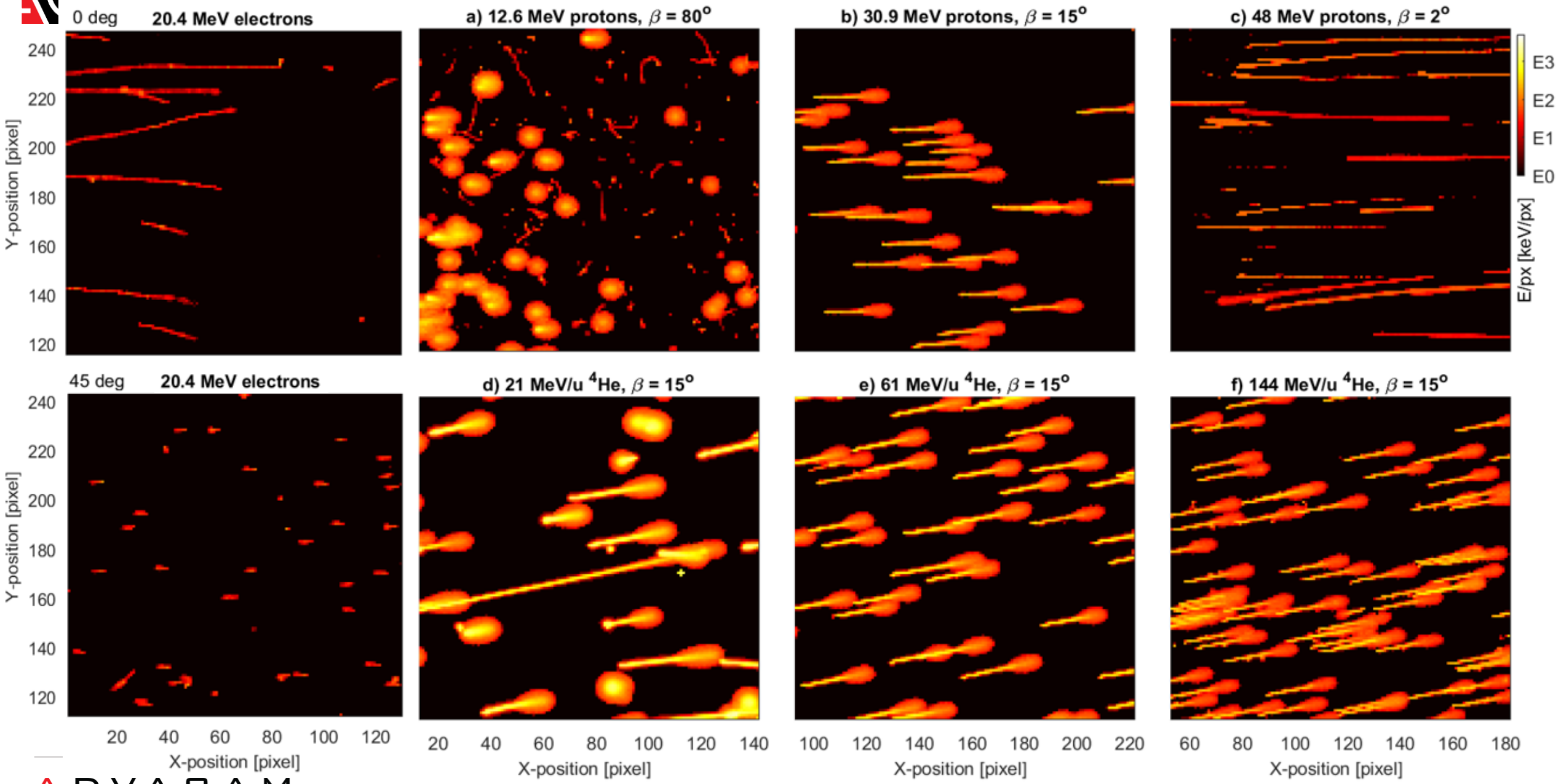









0 deg
20.4 MeV electrons
a) 2 deg
7.8 MeV electrons
b) 0 deg
12.4 MeV electrons
c) 0 deg
20.4 MeV electrons
45 deg
d) 30 deg
e) 45 deg
f) 7 deg
Y-position [pixel]
X-position [pixel]
E/px [keV/px]
E3
E2
E1
E0



ADVACAM
Imaging the Unseen

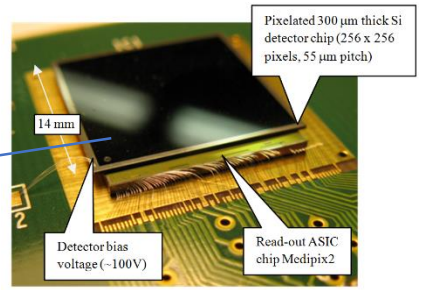
VZLUSAT-1 Czech cubesat in LEO orbit

X-ray 1-D optics telescope + focal plane detector Timepix

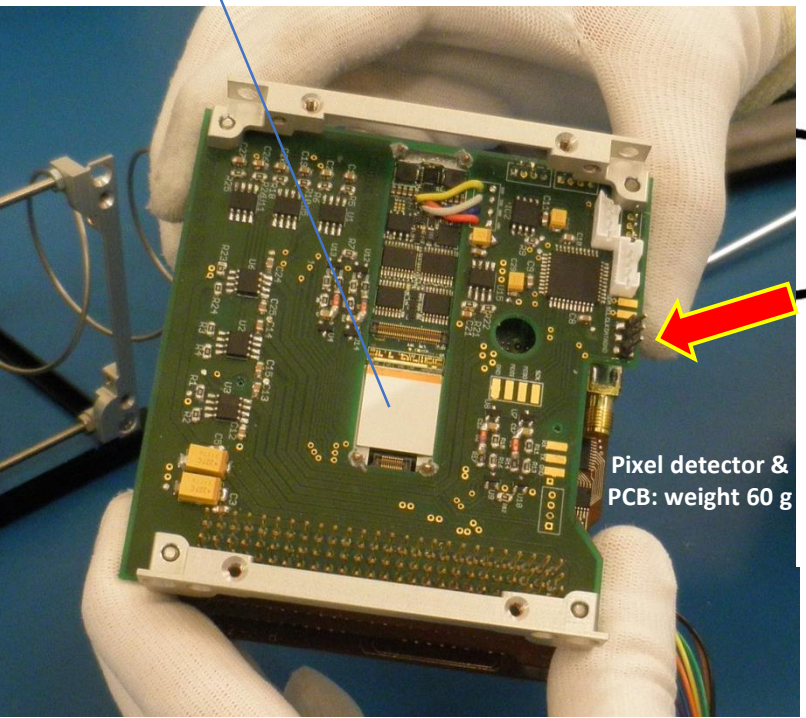
http://vzlusat1.cz

- ❑ **VZLUSAT-1: Technology demonstration**
- ❑ **QB50: Launched 23rd June 2017 in LEO 505 km polar orbit on board India's PSLV-XL rocket**
- ❑ **Successful commissioning, presently taking data**

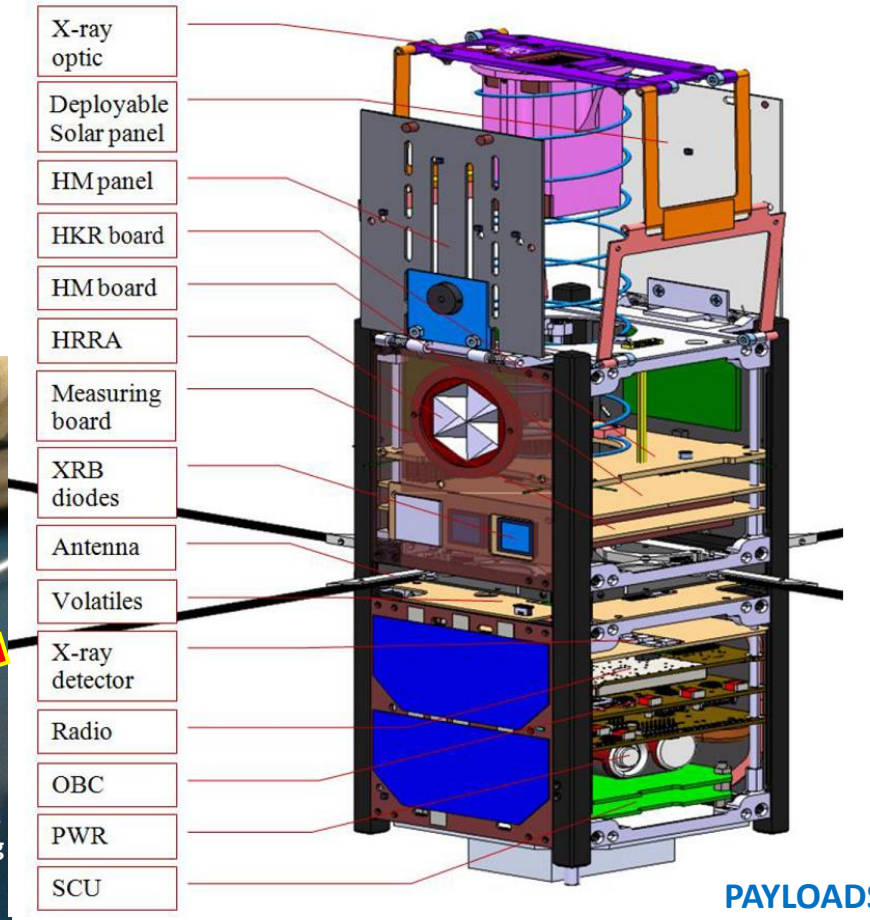
- Vladimir Daniel, et al.,
Czech Aerospace Research Centre (VZLU), Prague
- A. Inneman, et al, Rigaku, Prague
- T. Baca, et al, FEL, Czech TU Prague



Pixel detector: Timepix ASIC chip + 300 µm Si sensor

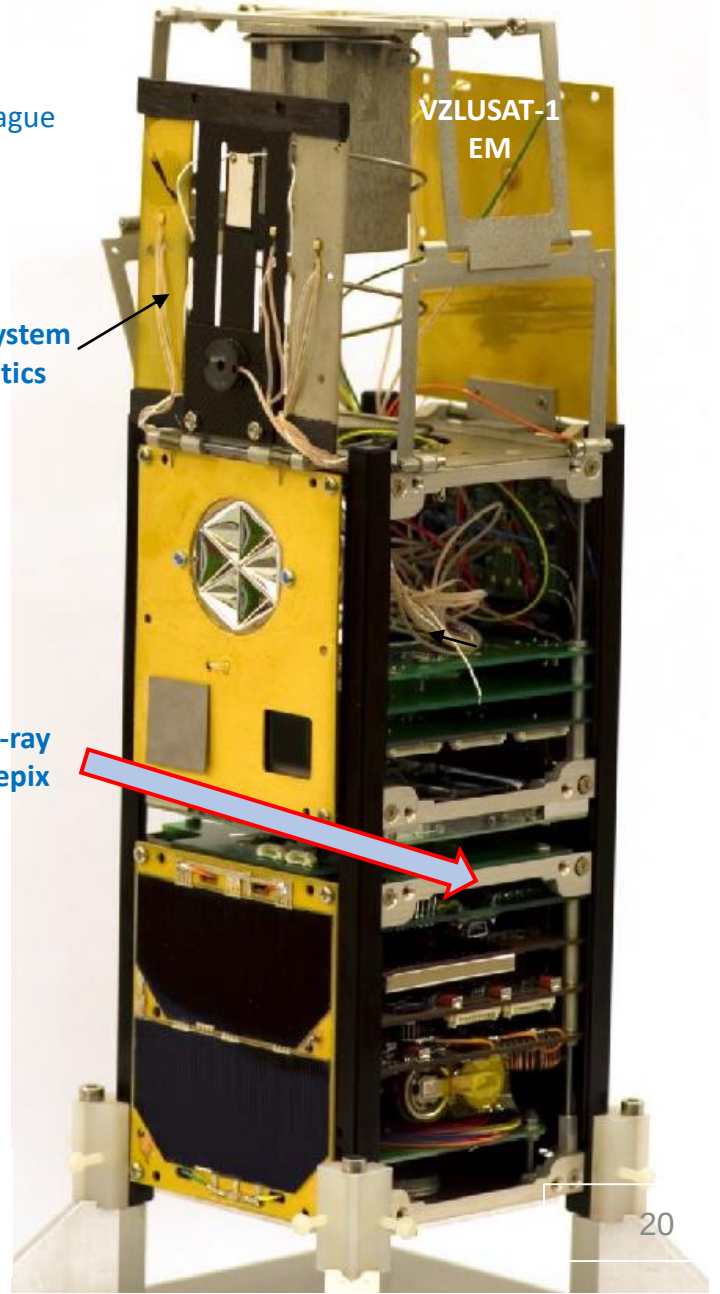


Pixel detector & PCB: weight 60 g



PAYLOADS:

- ❑ **Miniaturized X-ray telescope (1D Lobster optics + Timepix)**
- ❑ **Composite material components → radiation shielding**
- ❑ **Oxygen measuring FIPEX QB50 sensor**

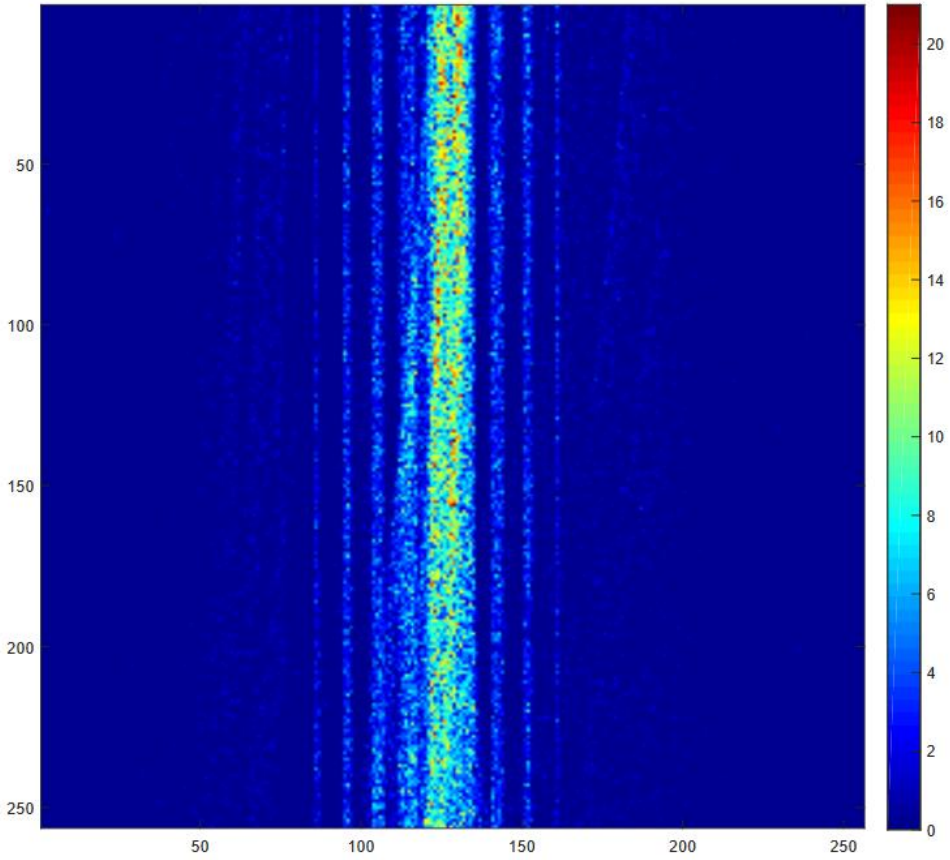


VZLUSAT-1 Czech cubesat in LEO orbit

http://vzlusat1.cz

Miniaturized X-ray telescope + focal plane detector Timepix

Image of X-ray source (3 m apart, Au anode) registered by Timepix and X-ray optics system



1-D Lobster Eye X-ray optics

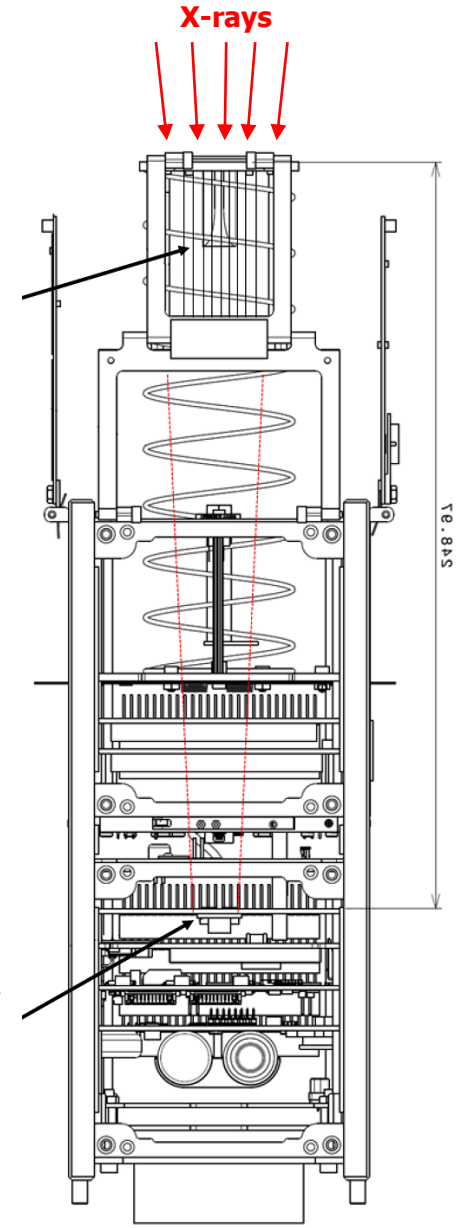
- Intended for imaging of stellar X-ray sources
- 1D Lobster eye optic (LE) system is used for the soft X-ray region (5 –20keV). For hard X-ray region above 35 keV behaves as a collimator (Soller slit).
- 1D system chosen for demonstration
- 2D system can be derived from the 1D system

Parameters

- 1D Lobster eye system
- focal length 250 mm
- 5-20keV
- FOV 3,5°x4,5°
- 1.25W
- 500 grams

Semiconductor pixel detector Timepix

- X-ray image in energy range 3-50 keV
- 256×256 pixels, pixel pitch size 55 microns
- Sensitive area 14×14 mm^2 = 2 cm^2



VZLUSAT-1 Czech cubesat in LEO orbit

http://vzlusat1.cz

Miniaturized X-ray telescope + focal plane detector Timepix

Detection and visualization of radiation field along VZLUSAT-1 orbit (7th Sept 2017 – geomagnetic storm)