# Particle tracking in wide field-of-view with miniaturized pixel detector arrays



# for space weather and space radiation research

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**Ix TPX WidePIX-3D** 

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HIT

### **Motivation & Aims**

- Timepix's [1] granularity + per-pixel spectrometric + tracking response  $\rightarrow$  directional sensitive tracking of charged particles  $\Box$  Highly integrated architectures  $\rightarrow$  miniaturized, low-power, deployable particle micro-trackers, wide FoV, no collimators needed
- $\Box$  Stack architecture + synchronized detection/readout  $\rightarrow$  enhanced event discrimination + high angular resolution
- Evaluate the acceptance range, field-of-view, solid angle, effective area, geometric factor, binning and angular resolution
- Tests and calibration of angular resolution performed with charged particle beams
- beam radiotherapy environments



**Online Active Nuclear Emulsion** 

(a) Illustration of the hybrid semiconductor pixel detector Timepix consisting of a semiconductor radiation-sensitive sensor (300 Technique applied in angular measurements of cosmic rays and ion μm silicon, full size 14 mm x 14 mm – shown in yellow) bump-bonded to the ASIC Timepix readout chip (shown in green) consisting of an array of 256 x 256 pixels (total 65536 independent channels). (b) The highly integrated radiation camera miniPIX-Timepix. (c) Illustration of micro-scale particle tracking. Vector of direction expressed by the elevation  $\beta$  and polar  $\alpha$  angles.

### **Miniaturized Particle Telescopes Timepix Resolving Power**

## **Quantum Imaging & Particle Tracking**

Detection and track visualization [4] of monoenergetic protons of 22 MeV (white labels – left half) and 31 MeV (yellow labels – right half) by a single-layer MiniPIX-Timepix camera (300 µm silicon sensor, +30 V bias) at the light ion cyclotron, NPI-CAS, Rez near Prague. Events shown for varying incident angle 6 from 0° to 88° (see labels) entering the sensor from left to right. The data was recorded separately. The per-pixel energy response is shown in color by the color bar in log scale. A portion (205 x 160 pixels = approximately 1 cm<sup>2</sup> or half of the whole sensor area) of the pixel matrix is shown.



Charged particle detection [2-3] by a single layer MiniPIX-Timepix camera. Two-dimensional correlated plots of cluster analysis parameter HL (Height × Track Length, in units keV×µm) vs LET (Linear Energy Transfer, in units keV/ $\mu$ m). Particles and energies shown in legend. Data measured at the NPI-CAS Rez cyklotron and the ion synchrotrons at HIT Heidelberg and HIMAC Chiba.

**1x TPX MiniPIX** 5.0 1 LET [keV/μm] 5.0 LET [keV/μm]

Detection and track visualization of 12 MeV electrons at  $\beta$  = 60° by a single layer MiniPIX-Timepix camera at the NPI-CAS Microtron accelerator. Per-pixel energy shown by color bar in log scale.



GF  $[cm^2 sr] = \Omega [sr] \times A_{eff} [cm^2]$ Effective Area A<sub>eff</sub>

Stacked Timepix arrays of two (bottom) and four (right) layer architectures. The Timepix chips are operated and readout in sync in time window 100's ns.

2x TPX stack

1<sup>st</sup> layer

x-axis 256

### **High angular resolution & Wide Field-of-View**

The 2x stack Timepix tracker with spacing 3.6 mm geometry for enhanced event from which the directional vector in 3D is reconstructed (bottom left).

The highly integrated WidePIX-3D telescope with 4x Timepix



300 μm silicon). The 3D sky view (c) displays the event intensity by the color bar in log scale.

Same as above [3] for (a-b) 13, 31 MeV protons (cyclotron, NPI-CAS Rez) and (c-e) 48, 140, 220 MeV protons (synchrotron, HIT Heidelberg), (f-h) 31, 61, 144 MeV/u 4He ions (synchrotron, HIMAC, Chiba), (i-k) 88, 270, 430 MeV/u 12C ions (synchrotron, HIT Heidelberg) and (I-n) 82, 118, 444 MeV/u 28Si ions (synchrotron at HIMAC, Chiba). The particles entered the detector from right to left. The data was recorded separately. Accompanying background and secondary particles are included. Only a portion of the pixel matrix is shown (220×190 pixels or 1.28 cm<sup>2</sup>, about 2/3 of the sensor area). Timepix sensor at +30 V except c (+100 V). Background and associated secondary particles are registered including energetic delta electrons – event n).





#### **IN-BEAM GEOMETRY**

Angular distribution of a 12 MeV electrons beam incident at  $\beta$  = 60° and  $\alpha$  = 45°. By single layer MiniPIX-Timepix camera. Displayed in 3D sky view, event intensity by color bar in log scale.

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Proton beam 31 MeV – proton beam **Cyklotron NPI-CAS Prague Rez** Electron beam 12 MeV – **Microtron NPI-CAS Prague** 1x TPX MiniPI **1x TPX MiniPIX** Elevation angle 40 Elevation angle  $\beta$  [deg] Polar angle  $\alpha$ β = 80° <sup>45</sup>Angular flux [cnt × cm<sup>-2</sup> × min<sup>-1</sup> × sr<sup>-1</sup>] <sup>45</sup> Angular flux [cnt  $\times$  cm<sup>-2</sup>  $\times$  min<sup>-1</sup>  $\times$  sr<sup>-1</sup>] Polar angle  $\alpha$  [deg] Angular distributions of charged particle beams registered by the 4xlayer WidePIX-3D Timepix telescope (4x 300 µm silicon) at selected energies and directions. 3D sky maps displayed. **IN-BEAM GEOMETRY** Electron beam 21 MeV – Microtron NPI-CAS Prague Proton beam 31 MeV – Cyklotron NPI-CAS Prague Rez <sup>4</sup>He ion beam 150 MeV/u – HIMAC-NIRS Chiba 4x TPX WidePIX-3D 4x TPX WidePIX-3D 4x TPX WidePIX-3D

#### **COSMIC RAYS**

Histograms of (a) particle flux of cosmic rays at Milesovka mountain (800 m) for all particles (blues), X rays and low-energy Angular distribution of a 31 MeV proton beam along the (a) elevation and (b) polar angles for particles/electrons (red), energetic charged charged four incident geometries (collected separately) by a single layer MiniPIX-Timepix camera (sensor particles/muons (black) and background radioactive/Rn products (green). The (b) total dose rate is included. Measured in 12 days. The angular distribution along the elevation angle  $\beta$  of the energetic charged particle component by a (c) single-layer MiniPIX-Timepix camera (300 µm silicon) in 12 bins and by a 2x stack in 45 bins showing the (d) measured and (e) normalized angular flux. The corresponding 3D sky view for (f) Milesovka and (g) Prague by 2x stack and the 4x WidePIX-3D telescopes, respectively.



4x TPX WidePIX-3D



4x TPX WidePIX-3D

inshielded

telescope

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Angular distributions of energetic secondary charged particles from in-beam targets by 2x stack Timepix telescope. 3D sky maps displayed <sup>12</sup>C ion beam 250 MeV/u + PMMA block – HIT-Heidelberg

NORT

210

225

240

### **Conclusions & Future work**

### References

Prague

Asymmetric field

shielde

North

**4**-----

Cosmic rays (muons) – Milesovka mountain (800 m)

0.0 0.1

• Instrumentation of Timepix micro-tracker arrays developed and tested as particle telescopes

• WidePIX-3D telescope best provides enhanced event discrimination, wide FoV (nearly  $2\pi$ ) and angular resolution Methodology developed for directional detection of energetic charged particles, solid angle, FoV, geometric factor derived, binning, angular resolution (see Table) • Comprehensive wide-range detection, characterization and directional mapping of energetic charged particle field • Application of the technique in detection/angular distributions of cosmic rays and ion beam RT environments • Future work: directional data evaluation of existing Timepix space radiation in LEO orbit on board satellites (Proba-V, VZLUSAT-1, LUCID-TechDemoSat-1) and the International Space Station ISS

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