







Metal and Hybrid TimePix Detectors Imaging Beams of Particles

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 - at the focal plane of the laser mass-spectrometer
 - at the ion source
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 - Measuring and imaging low energy ion beams at the focal plane of the laser mass-spectrometer
- FUTURE
 - Metal Micro-detectors readout by TimePix for measuring and imaging beams
- Summary and Outlook.

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5 Sections:



- <u>Nuclear Physics</u> (HEP Department including)
- <u>Atomic Energy</u>
- Solid-State Physics
- Plasma Physics
- Radiobiology and Radioecology
- Facilities: Isochronous Cyclotron U-240, Tandem ESG-10K, Cyclotron U-120, Nuclear Reactor WWR-M.

Isochronous cyclotron beams:

- Protons up to 100 MeV
- Deuterons up to 60 MeV
- Alpha 120 MeV
- Heavy ions (Ne, Ar, Xe) 120 Z²/A MeV/nucleon

Introduction

- Recent years significant achievements in miniaturization of mass spectrometers. Many areas of science and technology need such devices providing simultaneous measurement of wide massspectra in real time.
- This progress occurred, in particular, due to microdetectors and readout electronics developments for High Energy Physics experiments.
- Microstrip as well as micropixel detectors could be applied to create the Electronic Focal Plane (EFP) for mass spectrometers.

Introduction (continued)

- EFP Current status: SEM, MCP, Micro-Faraday cup arrays etc.,
- Requirements:
 - Large dynamic range: up to $10^7 10^8$
 - Sensitivity to a single ion
 - Real time data simultaneously over all chemical elements
- These studies:

TimePix evaluation for measuring and imaging low energy ions beams:

- at the focal plane of the laser mass-spectrometer
- at the ion source :
- → Hybrid & Metal response over 256 x 256 pixels.

Future radiation hard Metal Micro-detectors+TimePix for ion and synchrotron beams

Hybrid (Silicon) TimePix measuring and imaging low energy ion beams:

- at the focal plane of the laser mass-spectrometer
- at the ion source

The goal of the studies:

TimePix response as a function of:

- 1. Ion energy (3 40 keV)
- 2. Ion mass (H, He, AI, Cu, Zr, Nb, Sn, Ta, Pb)
- 3. Ion charge (1⁺, 2⁺, 3⁺, 4⁺)
- 4. Ion beam position over 256 x 256 pixels.

Hybrid (Silicon) TimePix at the focal plane of the laser mass-spectrometer





Schematics of the ion path in a laser mass-spectrometer. (Institute of Applied Physics NASU, Sumy, Ukraine.)



1 – Laser, 2 – Target, 3 – Accelerator, 7 – energy analyzer,
9 – Magnet, 10 – TimePix, 11 – Focal plane

The TimePix chip was mounted in a vacuum chamber on a moveable platform at the focal plane of a laser double-focusing mass spectrometer.

TimePix at the focal plane of the Laser Mass Spectrometer.









PIXEL2010. V. Pugatch.

Ужгород, 17-18 травня 2007

TimePix at the focal plane of the laser mass-spectrometer

- lons beam has been generated at the sample-target by the infrared (1064 nm) laser (15 ns, 50 Hz).
- Passing through the magnetic sector ions were focused accordingly to their mass over charge ratio in a focal plane (210 mm long) of the mass-spectrometer.
- For each bunch of ions detected by a pixel a triangular pulse is formed with a height proportional to a number of ions in a bunch. Whenever the new bunch of ions arrives at the pixel its counter content is increased accordingly to the number of ions in the bunch.
- TimePix chip was readout by the PIXELMAN hardware/software (IEAP, Prague) via USB-connection to PC.
- Real-time digital information, high speed communication and data transfer are essential features of TimePix chips for a massspectrometry.



TimePix and its TOT mode



Counter in each pixel can be used as

- Timer to measure detection time => TOF experiments, TPC detectors, ...
- Wilkinson type ADC to measure energy of each particle detected.



If the pulse shape is triangular then Time over Threshold is proportional to collected charge i.e. to energy.

- Due to limited bandwidth the pulse can be NEVER perfectly triangular.
- Linear up to 200ke⁻ (measured 40e⁻)
- Non-linear TOT to energy dependence @ low energies

L. Tlustos, CERN

TimePix at the focal plane of the Laser Mass Spectrometer.



TOT mode calibration

Meaning of parameters:

 $f(x) = ax + b - \frac{c}{(x-t)^d}$

a,b – linear regression in high energy range c,d – curvature (extent and symmetry)

- threshold



ESF Workshop, Sept. 2008

L. Tlustos, CERN

The effect of the non-linearity at the TOT value lower than 6.5 µs has to be taken into account for obtaining correct mass-spectrum



TOT mode - For each bunch of ions detected by a pixel a triangular pulse is formed with a height proportional to a number of ions in a bunch.

Whenever the new bunch of ions arrives at the pixel its counter content is increased accordingly to the number of ions in the bunch.

These studies: THL = 390 - 395, Integration - (0.1 - 5) s

Studies performed (July 2008 – August 2010)

TimePix (Hybrid and Metal) – 2 & 2 samples. Uniformity of response over :

- ion energy (3 40 keV)
- ion charge (1⁺ 4⁺) and mass (H- Pb)
- position of an ion beam at the detector surface

Hybrid (Silicon) TimePix at the focal plane of the laser mass-spectrometer

2D mass spectrum.

Position of the TimePix, Accelerating voltage, Magnetic field adjusted ¹⁵⁰ – to observe 12 keV 2⁺ ions of Pb isotopes



X – axis – along the focal plane (mass-spectrum)

Y – axis – along the image of the laser beam spot at the target

Z – axis – intensity of the analyzed ions

- Two dimensional data on-line 'electronic photo-plate' –
 for alignment, focusing, verifying stability of electric and magnetic fields etc.,)
- A powerful tool in a feedback system for fine tuning of a massspectrometer and similar devices.

Hybrid (Silicon) TimePix at the focal plane of the laser mass-spectrometer



Mass-spectra obtained by projection of the 2-D distribution onto the mass axis. Resolution is good enough to separate single mass unit different lead isotopes.

TimePix (Hybrid-1) - response over 256 x 256 pixels.

Review of the results measured by two samples of the TimePix (Hybrid)





Copper isotope peaks observed at three pixel regions (0.0, 2.8 and 5.6 mm along the focal plane) by increasing the magnetic field.

The ratio of ⁶³Cu/⁶⁵Cu varies by the order of magnitude (Sample 1)

TimePix (Hybrid-1). Position dependence of the pixels response: ^{63,65}Cu and Ta single-charged ions.

Dependence of detector's response on ion beam position



Dependence of detector's response on ion beam position



Dependence of detector's response on ion beam position



Order of magnitude non-uniformity over different regions of the TimePix chip (Hybrid) – Sample 1.

TimePix (Hybrid-1) response uniformity Al-ions, 1⁺, E = 12.1 keV (Sample 1).



9 areas - (85 x 85) pixels each: TOP, MIDDLE and BOTTOM part of the TimePix surface

Uniformity of the TimePix (Hybrid-1) response.

Zr/Nb – isotopes mass-distribution for 1+ - 4+ ions.



Non-uniform response (Sample 1) dependent on the ion charge and position. PIXEL2010. V. Pugatch.

Uniformity of the TimePix (Hybrid-1) response.

Zr/Nb – isotopes mass-distribution for 1⁺ - 4⁺ ions.



Acceleration voltage = 12.1 kV

Uniformity of response is a crucial feature for a sensor imaging mass distribution. Results obtained for the TimePix (Sample1) show irregularity in response by different pixels.

Irregularities in TimePix (Hybrid-1)response to ¹⁴C – beta-particles



Response of MEDIPIX-2 (Hybrid-1) to low energy ions.

• Aperture: 3 holes, 1mm diameter separated by 4 mm



Energy of ions – 30 keV

Factor of 3 difference in the response of MEDIPIX-2 (Hybrid) to He and H_2 ions of the same energy. Ion source at the KINR isochronous cyclotron U-240.

The response variation over the surface of the detector (Sample 1) exceeds order of magnitude.

The most probable reason – varying thickness of the Si-sensor dead layer (0.1 µm - range).

Medipix-2 (Hybrid-1) response to a sunlight



affected by the irradiation
of ions at U-240 –
thin layers of Al –
were deposited (~ 50 nm).

Preliminary conclusion: non-uniformity of the response is determined by non-uniformity of the dead-layer thickness over the Medipix-2 (hybrid) PIXEL2010. V. Pugatch.

TimePix (Hybrid-2) response uniformity



TimePix (Hybrid) – Sample 2. Zr - ions, 2⁺, E = 19 keV Perfect (+/- 1 %) uniformity of the response !

Table:

TimePix (Hybrid-2) response uniformity

DEPENDENCE ON ION POSITION(HYBRID,Zr),(Sumy,Aug10)



TimePix (Hybrid) – Sample 2. Zr - ions, 2+, E = 25.2 keV +/- 1 % uniformity of the response !

TimePix (Hybrid-2)



Response dependence on energy and beam position (Top, Middle, Bottom area of the chip) for $Zr - 2^+$ ions.

TimePix (Hybrid-2)



'Charge quantum' dependence on the ion energy. Zr (2 +).

TimePix – Metal Detector

Test of the TimePix readout chip as a metal detector at the focal plane of the laser mass-spectrometer



Photo of the individual pixels of the TimePIx chip (55 x 55 μ m², 256 x 256 pixels) CERN, MEDIPIX Collaboration. Diameter of the area for bonding ~15 μ m.



A positive voltage has been applied to a mesh over the chip area – to collect Secondary electrons emitted by metal surface of the chip under the impinging low energy ions at the focal plane.

Metal Detectors. Physics principle.



- Incident particles on the strips initiate secondary electron emission as they pass through the nearly transparent medium. When this happens, a positive charge appears at the integrator end and is measured.
- To improve the extraction of secondary electrons an accelerating electric field is applied around the strip.
- This technology works with x-rays, proton and other ion beams. Additionally, the strips are nearly transparent to beams, significantly reducing radiation degradation that is experienced by absorbing detectors.

MMD has been developed at KINR (Kiev) in close collaboration with Institute of Micro-devices (Kiev), Max-Planck Institute of Nuclear Physics (Heidelberg) and DESY (Hamburg) PIXEL2010. V. Pugatch.



Metal Detector. Technical realization.



Metal Foil Detector technology allows for Building any size beam monitoring systems: HERA-B Luminosity monitoring, LHCb Radiation Monitoring system BPM for 21 MeV proton beam (tandem MPIfK) BPM for the LHCb (ST) test beam studies 19 keV Synchrotron BPM at HASYLAB 5 MeV Electron beam BPM - KINR



Metal Detectors at LHCb

Radiation Monitoring System Silicon Tracker, LHCb.

200

\$2

85

55

- 87

Cine

SmDeta

ExpDete
 39.27/(x - 14.14)

0.4297e^(0.00060)

Tep





00:00

Cryo

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00:00

Time

00:05

00.06

TimePix – Metal Detector in a focal plane of the laser mass-spectrometer.



TimePix (METAL-1) in a focal plane of the laser mass-spectrometer.



2D mass spectra of sample with Zr²⁺ – isotopes .

Energy of ions 12,3 keV

X – axis – along the focal plane (mass-spectrum)

Y – axis – along the image of the laser beam spot at the target

Z – axis – intensity of the analyzed ions Two dimensional data on-line – 'electronic photo-plate' – for alignment, focusing, testing stability of electric and magnetic fields etc.,) A powerful tool in a feedback system for fine tuning of a mass-spectrometer and similar devices.

TimePix (METAL-1) in a focal plane of the laser mass-spectrometer.

TimePix response dependence on ion position Isotopes of zirconium (IAP Sumy,Nov09)



1 % response variation of TimePix (Sample1) different pixels

Response of the TimePix (Metal-1) to Cu isotopes as a function of ion (2⁺) energy



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Comparison of the TimePix Hybrid/Metal sensitivity to low energy ions

- The number of Zr (2⁺) ions per 1 count of the TimePix (Hybrid-2) at 25.2 keV is ~ 6
- The number of Zr (2⁺) ions per 1 count of the TimePix (Metal-2) at 25.2 keV is ~ 6 000
- Geometry factor (ratio of active sensor surface) ~ 30
- Thus, Hybrid/Metal factor of sensitivity is ~ 33. Very thin surface layer of the silicon sensor contributes.

TimePix (METAL-2) in the focal plane of the laser mass-spectrometer



Mapping isotope population over the sample area by scanning it with laser or charged particle micro-beam might be useful for applications in material technology, microbiology, medical diagnostics etc.

TimePix (Metal-2) Response at different positions of 2⁺ ion beams (Superimposed data of three measurements)

TimePix (METAL-2) in the focal plane of the laser mass-spectrometer



TimePix (METAL-2) response at different positions of ion (Charge 2⁺ and 3 ⁺) beams and operating voltage (0 and 70 V)



TimePix(METAL-2) in a focal plane of the laser mass-spectrometer

DEPENDENCE ON ION POSITION(METAL,Zr),(Sumy,Aug10)



TimePix (METAL-2) in the focal plane of the laser mass-spectrometer

Image of the grid wires



Wires diameter – 50 μm

Future work

- Test a prototype of the Electronic focal plane:
 - 5 TpX in collaboration with C. Ponchut (ESRF)
 - **+ MCP**.



Fig. 1. PRIAM board block diagram.

Single ion detection sensitivity at few keV energy ²⁷Al (1 ⁺) –ions has been demonstrated for MCP + CMOS active pixel sensors

Sakamoto N., Yurimoto H. // Surface and Interface Analysis. - 2006. - Vol. 38. – P. 1760 - 1762. Nagashima K., Krot A., Huss G. et al. // 40th Lunar and Planetary Science Conference. - 2009. - Abstract #2066.

Future: Electronic Focal Plane.

-Metal Strip & **Pixel Detectors –** – for Beam Profile Monitoring at the submicron level. - Currently available -– 1024 strips metal detector, -60 µm pitch.





ZONE-1 - 256 pixels will be bonded to 256 strips of the MMD by two flexible microcables (128 + 128) lines, pitch 110 mu, width 40 mu, 5 cm long - to the 1st and 3d raw of the TPX Bonding pads - (40 x 40) mu^2

ZONE-2 - (256 x 128) pixels will be bump bonded to the METAL Pixels on Poliimide Poliimide - 40 mu thick, Metal pixels - 20 mu thick (50 x 50) mu^2 ZONE-3 - (256 x 100) pixels - virgin TPX.

Future: Metal Micro Detectors for BPM



MMD-16 sector pixels

Advantages of the MMD:

- High Radiation tolerance (10-100 MGy)
- Nearly transparent sensor 1 μm thickness
- Low operation voltage (20 V)
- Spatial resolution (5 25 μm)
- Well advanced production technology
- Commercially available readout hardware and software.



MMD-64.

MMD could be helpful in Particle Therapy

DETECTORS Selected new topics



Metal microdetectors for measuring and imaging beams of particles Abstract ID: 17 Valery Pugatch, Institute for Nuclear Research



Thin (1micron) metal strips spacing 40 microns (1000 strips)

A Proton Range Telescope for Quality Assurance in Hadrontherapy Abstract ID: 37 David Watts, TERA Foundation 30 x 3mm scintillator telescope for QA and proton radiography



From : Ken Peach (UK) Summary talk. " Physics for Health in Europe". CERN, 2010 MMD – an ideal monitoring device:

- present in the beam, permanently
- does not disturb a beam
- measures X-Y dose distribution
- provides self-control of functionality
- operates reliable over high doses

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SUMMARY and OUTLOOK

- The TimePix (Hybrid and Metal) response to low (3 40 keV) energy ions has been studied as a function of ion mass, charge, energy and beam position.
- The TimePix (Hybrid) chips have demonstrated sample dependence of the pixels response. The pixels response is more uniform (+/- 1 %) for the TimePix (Metal) mode operation.
- The possibility of building electronic focal plane of the massspectrometer based on the TimePix detector operated in a metal mode has been demonstrated.
- The TimePix (Metal & Hybrid) (5 chips systems) will be evaluated soon as a demonstrator of the 'Electronic Focal Plane'.
- Metal micro-detectors are on the way to become super-thin (transparent) radiation hard detectors for measurements of intensity distribution of the particles beams.

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Thank you for your attention !

