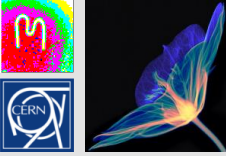


# THE MEDIPIX AND TIMEPIX CHIPS: DESCRIPTION AND POSSIBLE USES FOR BEAM INSTRUMENTATION

**M. Campbell<sup>1</sup>, J. Alozy, R. Ballabriga, E.H.M. Heijne,  
I. Kremastiotis, X. Llopart, T. Poikela, E. Santin, V. Sriskaran,  
L.Tlustos and W.Wong**

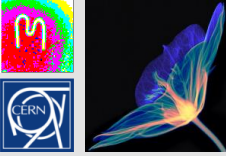
**CERN, PH Department  
1211 Geneva 23  
Switzerland**

**<sup>1</sup> Honorary Professor at Glasgow University**



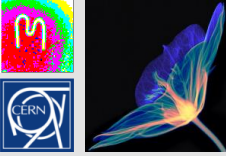
# Medipix2 Collaboration

- University and INFN Cagliari, Italy
- CEA-LIST Saclay, France
- CERN, Geneva, Switzerland
- Friedrich-Alexander-University Erlangen-Nurnberg, Germany
- ESRF, Grenoble, France
- University of Freiburg, Germany
- University of Glasgow, UK
- IFAE Barcelona, Spain
- Mid-Sweden University, Sundsvall, Sweden
- MRC-LMB. Cambridge, UK
- University and INFN Napoli, Italy
- NIKHEF, Amsterdam, The Netherlands
- University and INFN Pisa, Italy
- FZU Czech Academy of Science, Prague, Czech Republic
- IEAP, Czech Technical University in Prague, Czech Republic
- Space Science Laboratory, UC Berkeley, USA

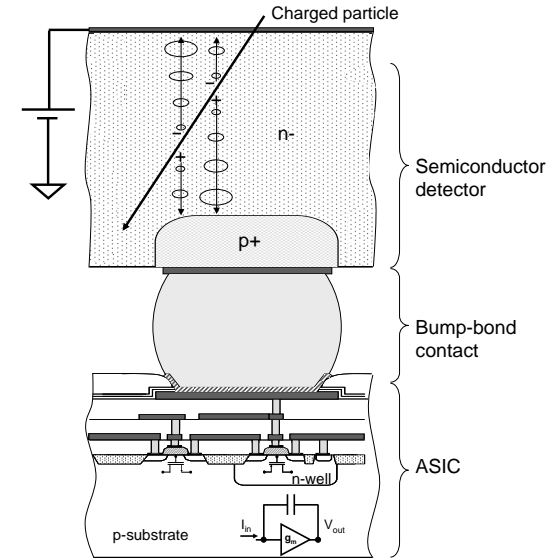
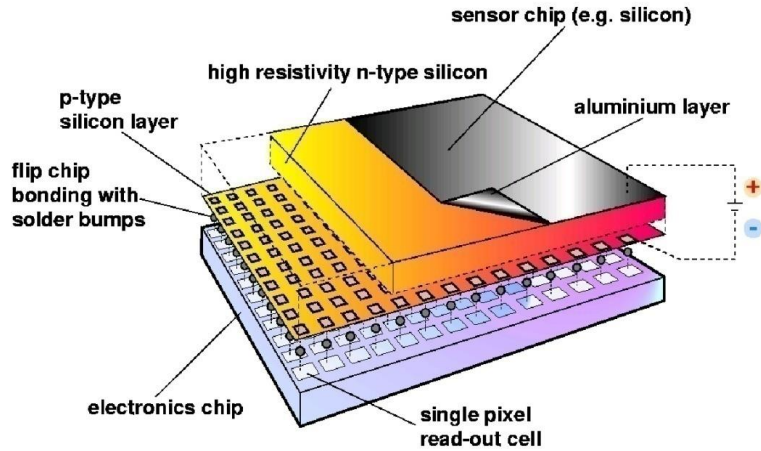


# Medipix3 Collaboration

- University of Canterbury, Christchurch, New Zealand
- CEA, Paris, France
- CERN, Geneva, Switzerland,
- DESY-Hamburg, Germany
- Albert-Ludwigs-Universität Freiburg, Germany
- University of Glasgow, Scotland, UK
- Leiden University, The Netherlands
- NIKHEF, Amsterdam, The Netherlands
- Mid Sweden University, Sundsvall, Sweden
- IEAP, Czech Technical University, Prague, Czech Republic
- ESRF, Grenoble, France
- Universität Erlangen-Nurnberg, Erlangen, Germany
- University of California, Berkeley, USA
- VTT, Information Technology, Espoo, Finland
- KIT/ANKA, Forschungszentrum Karlsruhe, Germany
- University of Houston, USA
- Diamond Light Source, Oxfordshire, England, UK
- Universidad de los Andes, Bogota, Colombia
- University of Bonn, Germany
- AMOLF, Amsterdam, The Netherlands
- Technical University of Munich, Germany
- Brazilian Light Source, Campinas, Brazil

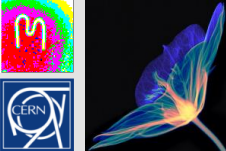


# Hybrid Silicon Pixel Detectors

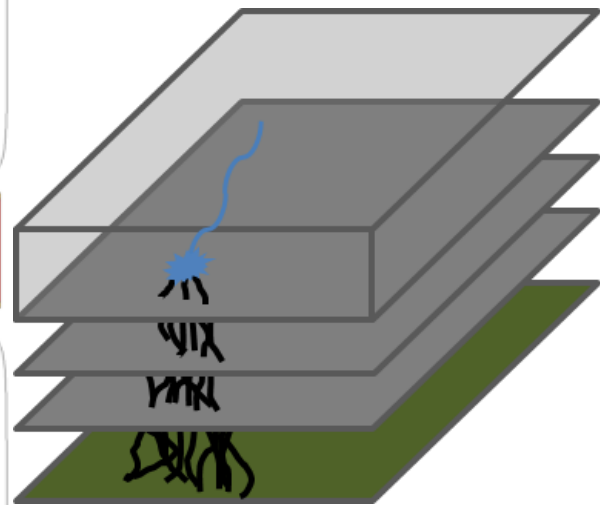
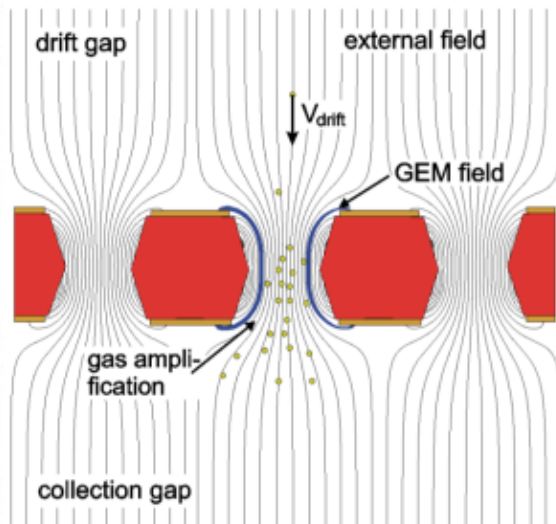
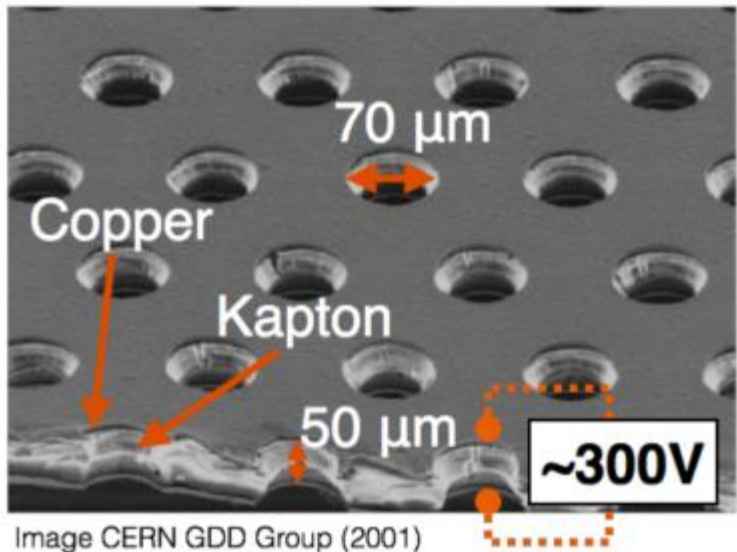


Standard CMOS can be used allowing on-pixel signal processing

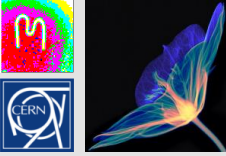
Sensor material can be changed according to the application(Si, GaAs, CdTe..)



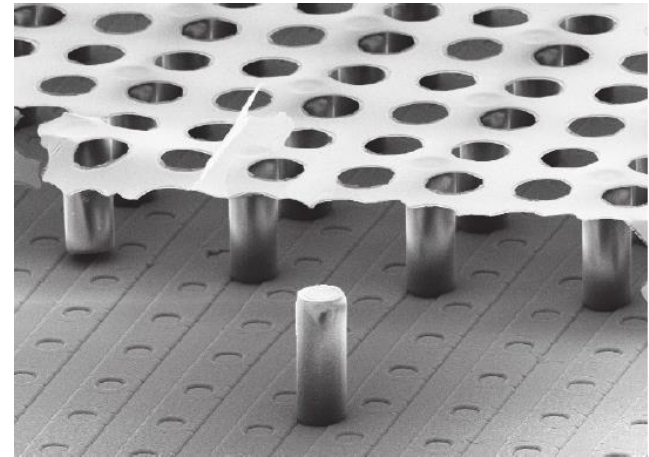
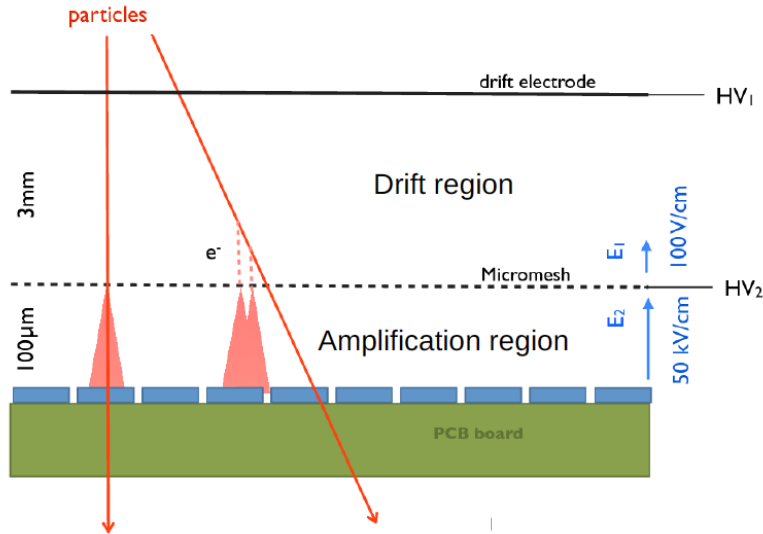
# Gas detector readout - GEM



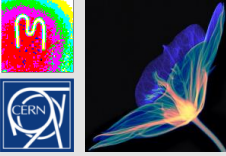
Naked pixel readout chip



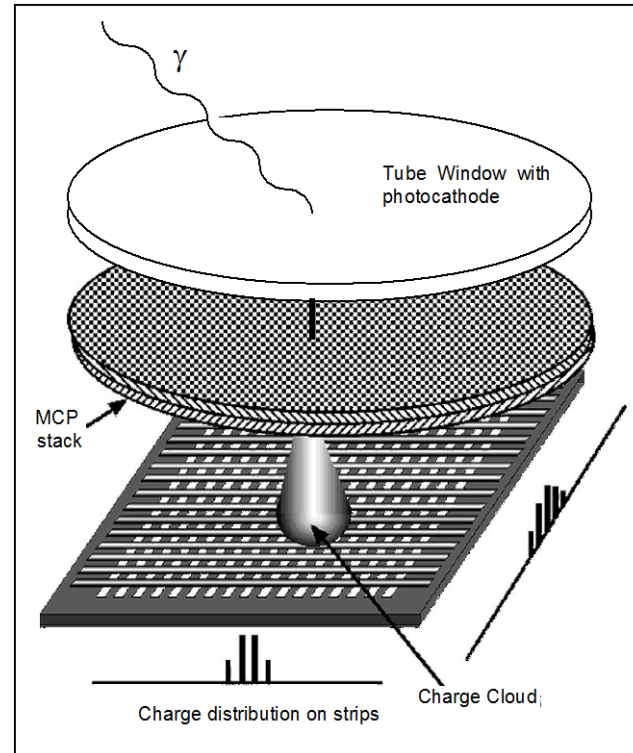
# Gas detector readout - InGrid



Semiconductor detector is replaced with charge amplification grid  
Permits lower energy events to be detected

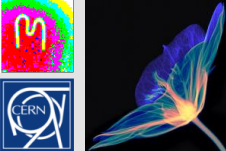


# Micro-channel plate readout

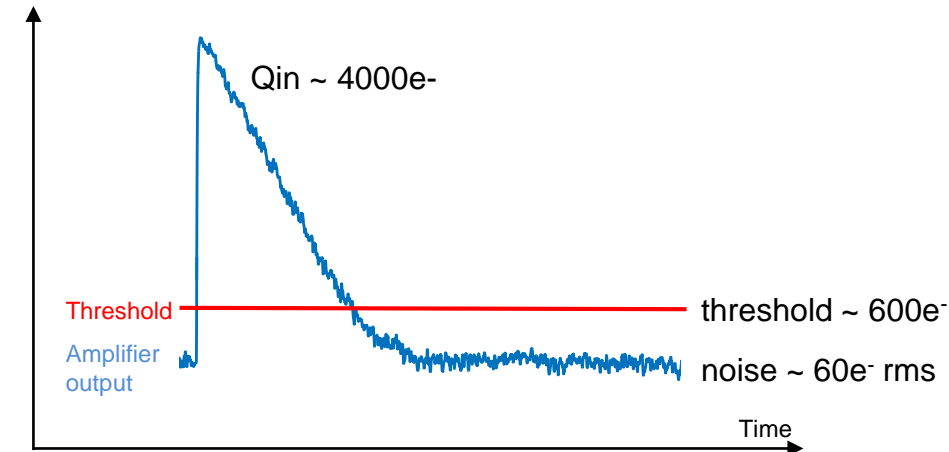
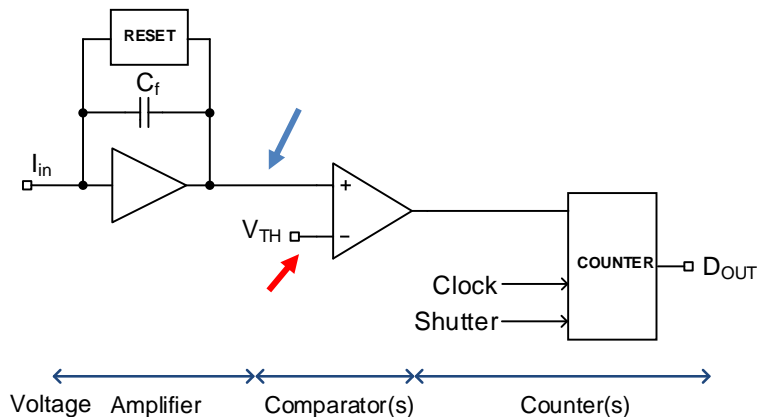


Gain of  $\sim 1000$  to  $10000$  is enough for full sensitivity  
--> improved lifetime

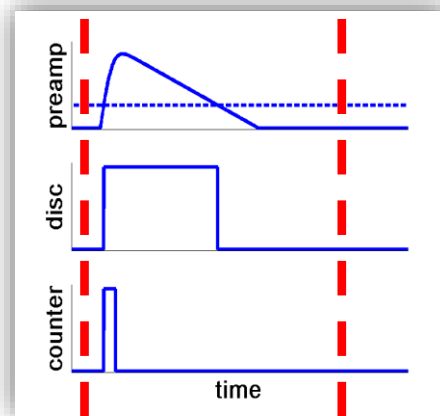
MCP can be used to detector electrons, ions or neutrons (when e.g. B doped)



# Hybrid Pixel Detector – Counting Electronics

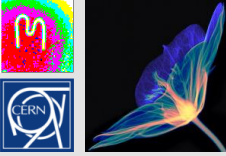


Open shutter      Close shutter



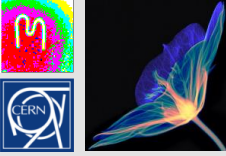
→ Noise hit free imaging





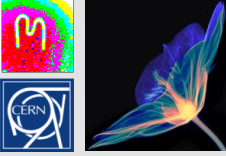
# Hybrid pixel detectors

- Developed initially for LHC
- 3 large scale vertex detector systems (ALICE, ATLAS, CMS) operating smoothly
- One large RICH detector system (based on hybrid pixels in a photodetector tube) contributing to LHCb physics
  
- In the Medipix2 and Medipix3 Collaborations we have taken the technology into many new fields
  
- This talk covers 2 readout chips and describes some applications in beam monitoring



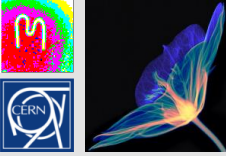
# Medipix chips since 2000

- Medipix2 (2002-2005)
  - First photon counting chip at  $55\mu\text{m}$  pitch
  - Camera logic (shutter driven)
  - Window discriminator/pixel (one 15-bit counter)
  - Frame based readout (sequential read/write)
- Medipix3 (2009-2014)
  - Aimed at spectroscopic X-ray imaging
  - Readout pixel pitch of  $55\mu\text{m}$  but sensor pixel pitch can be  $55\mu\text{m}$  or  $110\mu\text{m}$
  - First photon counting chip with charge summing and allocation scheme
  - 2 counters per  $55\mu\text{m}$  pixel
  - Frame-based readout but possibility of continuous read/write



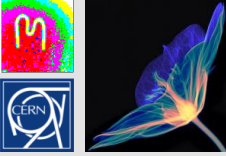
# Timepix chips

- Timepix (2006)
  - Arrival time measurement requested by EuDET Collab.
  - Readout compatible with Medipix2 (frame based)
  - One discriminator, one counter per pixel
  - Possibility to programme pixels in one of three modes:
    - Count hits (like Medipix2)
    - Measure arrival time (ToA)
    - Measure charge (ToT)
- Timepix3 (2014-2015)
  - Fully data driven architecture
  - For each hit pixel coordinates, amplitude (ToT) and arrival time (ToA) are sent off chip
  - Time stamp precision of 1.6ns possible
  - Can handle up to 80Mhits/sec



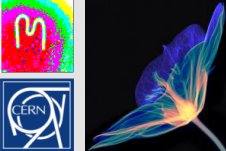
# Outline

- The Timepix chip
  - Educational use
  - Space dosimetry and space weather
  - X-ray histology
  - Use in UA9
  - GEMpix if Hadron therapy Beam
- The Timepix3 chip
  - Silicon TPC
  - BGI system and results
- Medipix4 and Timepix4
- Conclusions



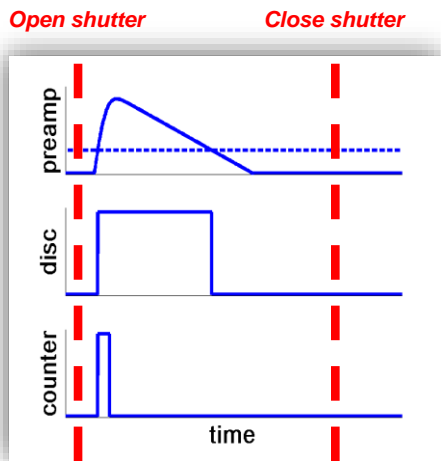
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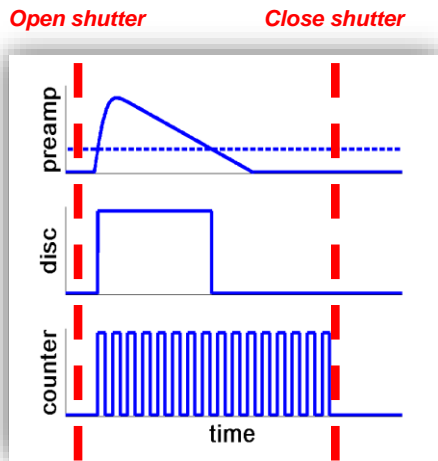


# Timepix Pixel Operation Modes

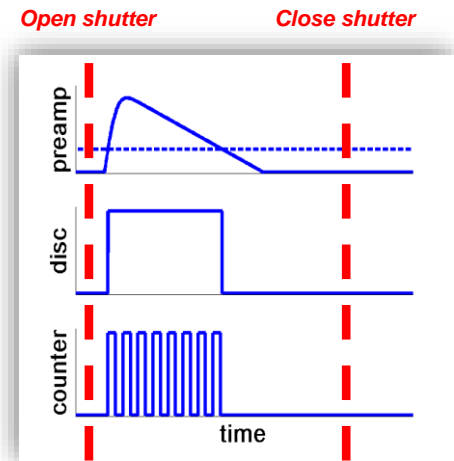
- Particle counting



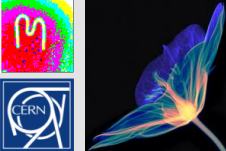
- Arrival Time\*



- Time over threshold

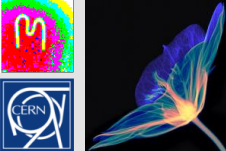


\* Implemented at the request of the EUDet Collaboration



# Timepix Specs

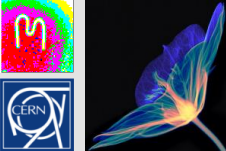
<b>CMOS node</b>	<b>250nm</b>
<b>Pixel Array</b>	256 x 256
<b>Pixel pitch</b>	55 $\mu$ m
<b>Charge collection</b>	e <sup>-</sup> , h <sup>+</sup>
<b>Pixel functionality</b>	PC (Particle Counting), TOT (Energy) or TOA (Arrival time)
<b>Preamp Gain</b>	~16.5mV/ke <sup>-</sup>
<b>ENC</b>	~100e <sup>-</sup>
<b>FE Linearity</b>	Up to 50ke <sup>-</sup>
<b>TOT linearity (resolution)</b>	Up to 200ke <sup>-</sup> (<5%)
<b>TOA resolution</b>	Up to 10ns (@ 100 MHz)
<b>Time-walk</b>	<50ns
<b>Minimum detectable charge</b>	~700e <sup>-</sup> → 2.5 KeV (Si Sensor)
<b>Counter Depth/Overflow</b>	14-bits(11810)/Yes
<b>Max Analog power (2.2V)</b>	6.5 $\mu$ W/pix 190mA/chip
<b>Static Digital Power (2.2V)</b>	~500mW@100MHz/chip
<b>Readout (@ 100 MHz)</b>	Serial readout → 9.17 ms 32-bit Parallel readout → 287 $\mu$ s



# Timepix Specs

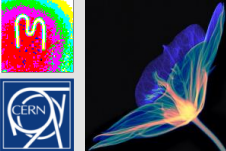
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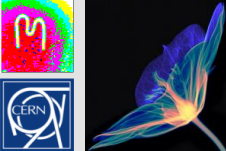
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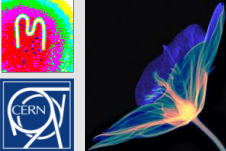
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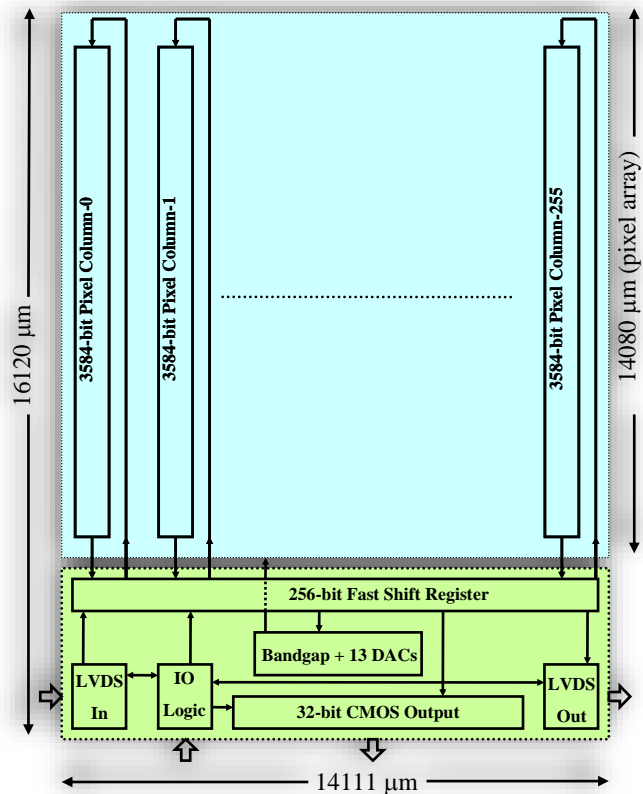


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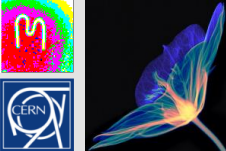
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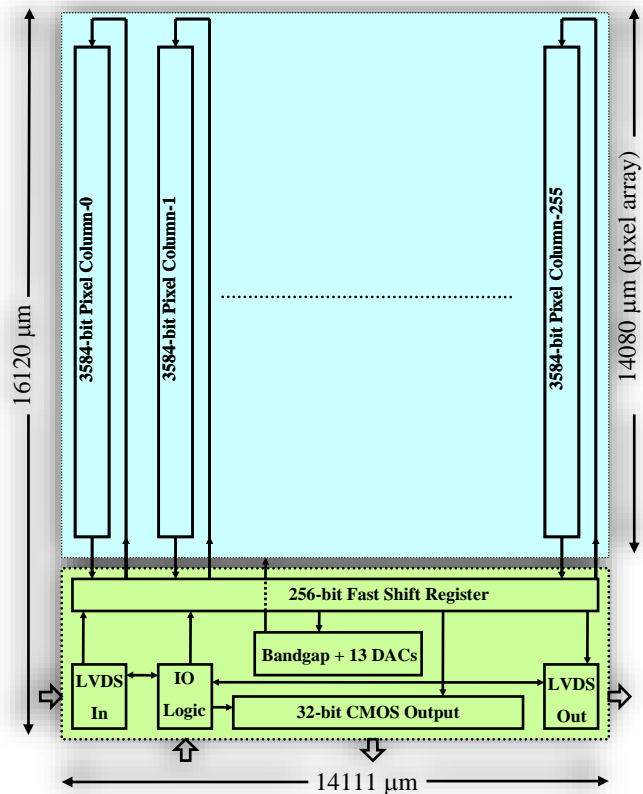
# Timepix chip architecture



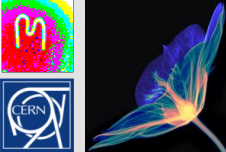
- 3-side Buttable floorplan
- In acquisition mode chip an external clock is used as a time reference (up to 100 MHz)
- 256x256 55μm square pixels
- Analog Power → 440mW
- Digital Power (Ref\_Clk=50MHz) → 220mW
- > 36M Transistors
- System on chip design:
  - On-chip digital global biasing:
    - 14 DACs + Bandgap
  - Simple control logic
  - Serial readout (@100MHz) → 9.17 ms
  - Parallel readout (@100MHz) → 287 μs
  - Daisy-chain (serial only) for simple multiple chip readout



# Timepix chip architecture



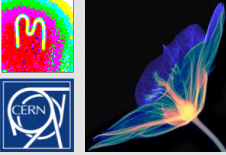
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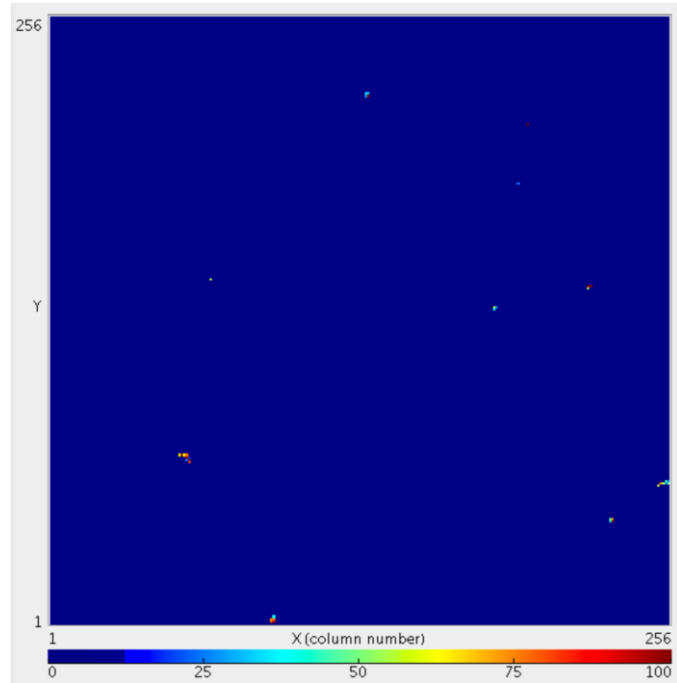
# Timepix miniaturised readout



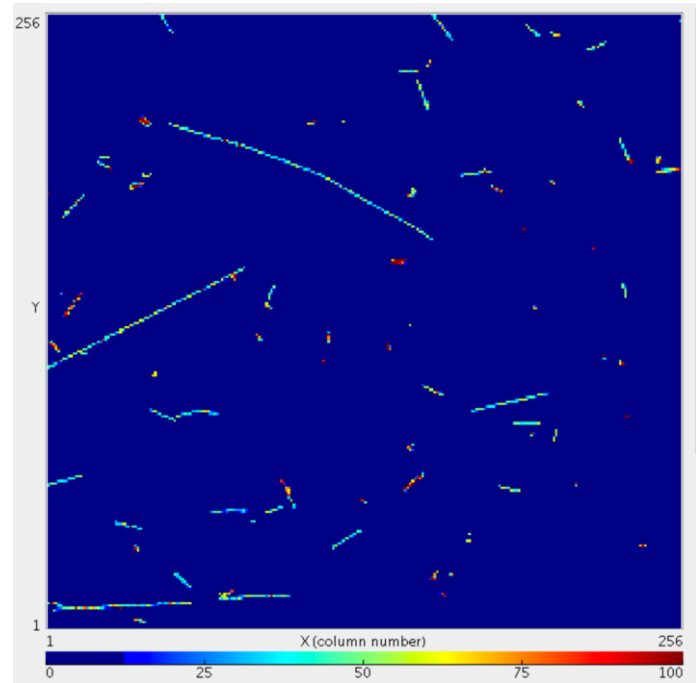
IEAP/CTU, Prague



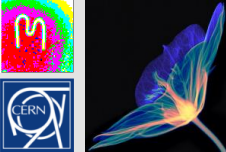
# Timepix chip – 60s exposures



Near sea level



34 000 feet

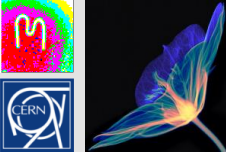


# CERN@school



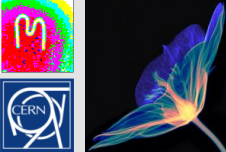
Simon Langton School, Canterbury, England





# LUCID detector





# Institute for Research in Schools

The screenshot shows a web browser displaying the website [www.researchinschools.org](http://www.researchinschools.org). The browser's address bar and navigation tabs are visible at the top. The website header features the logo for 'THE INSTITUTE for RESEARCH in Schools' on the left, which includes a stylized atom symbol. To the right of the logo, it says 'Schools Registered with IRIS' and shows a search bar with the number '00377'. Further right are links for 'JOIN IN', 'CONTACT', and social media icons for Twitter, Facebook, and Twitter. A search icon is also present in a green box on the far right.

Below the header is a horizontal navigation menu with the following items: 'ABOUT US', 'OUR PROJECTS', 'DOCUMENTS', 'HOW TO', 'EVENTS DIARY', 'SCHOOL OFFERS', 'PARTNERS', 'NEWS', 'BLOG', 'VIDEO', and a green 'Newsletter' button on the right.

The main content area features a large background image of an astronaut in a white spacesuit with a British flag patch on the chest. Overlaid on this image is a white text box with a green dot and two grey dots above it. The text inside the box reads: 'Monitor **Tim Peake's** radiation levels using Timepix detector chips from **CERN**'. Above this text box, the text 'Want to know how to write an EPQ, present yo' is partially visible.

At the bottom of the page, there is a grey banner with the text 'Young people, real science' and 'WELCOME TO THE INSTITUTE FOR RESEARCH IN SCHOOLS.' To the right of this banner is a green circular graphic containing the text: ', You're never too young to be a research scientist.'

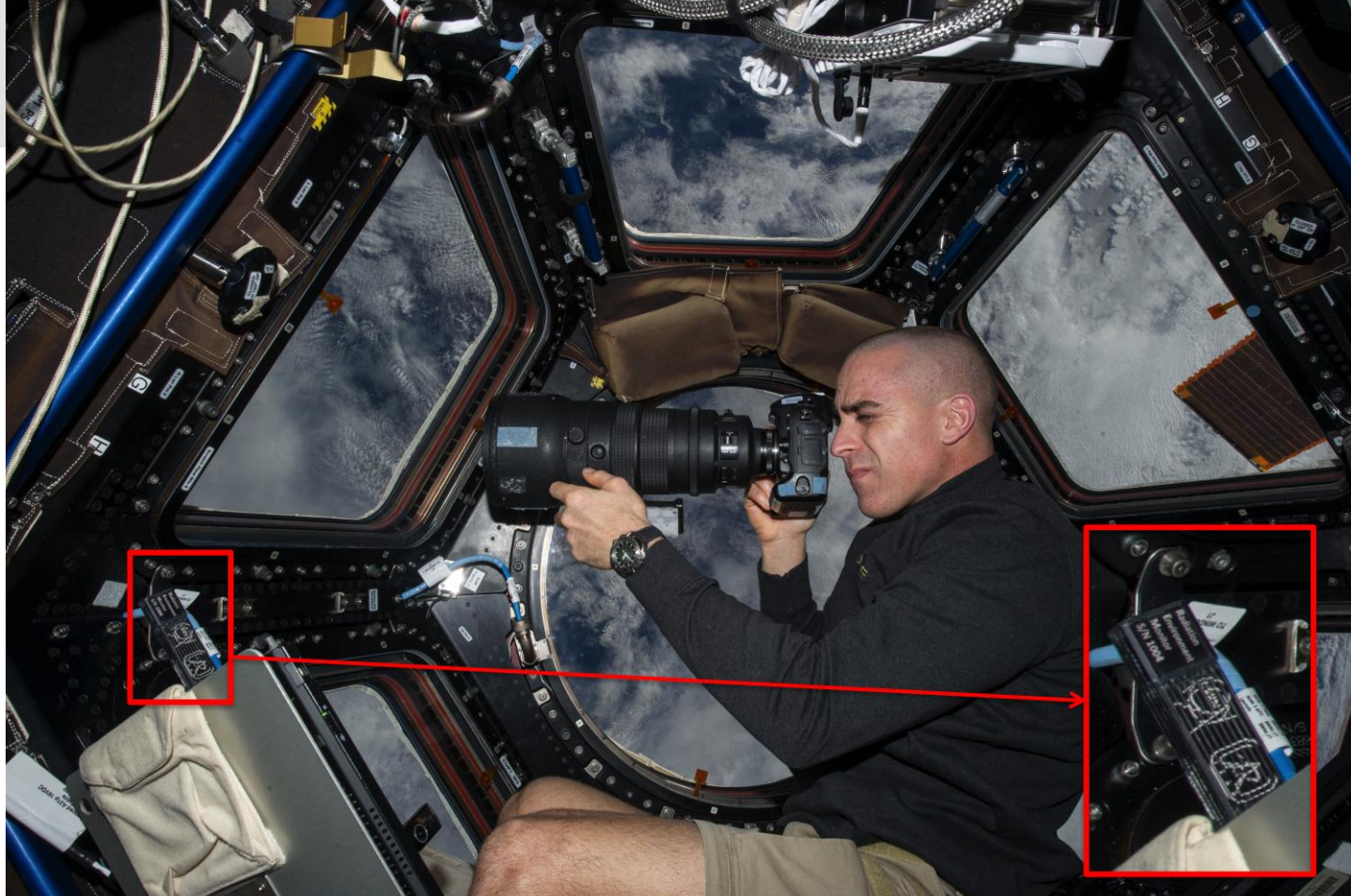
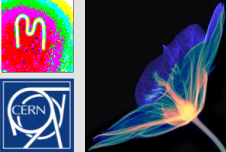
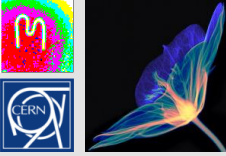
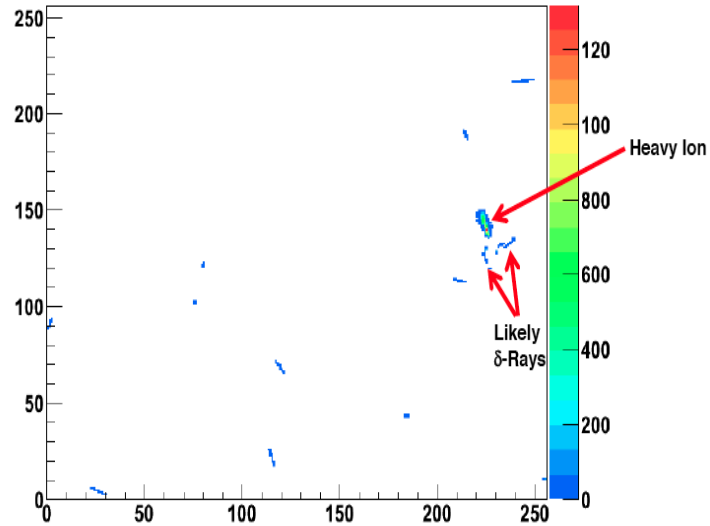


Image of the astronaut Chris Cassidy working near the Timepix USB on the International Space Station (Courtesy of NASA, photo ref. no. iss036e006175)

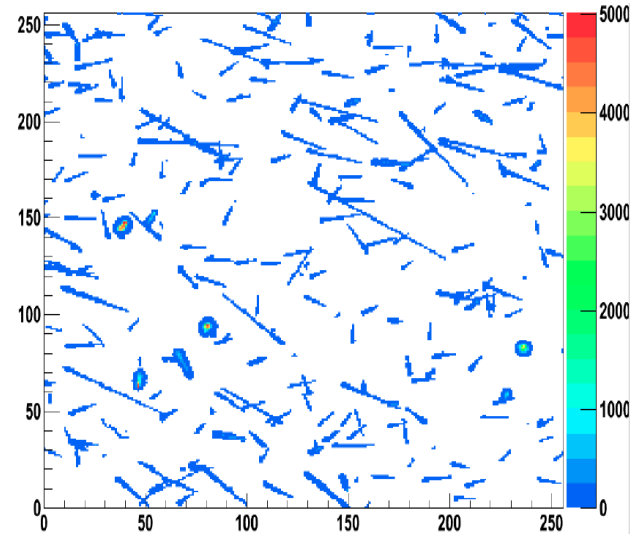




# Timepix - 4s exposures

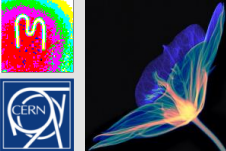


South China Sea

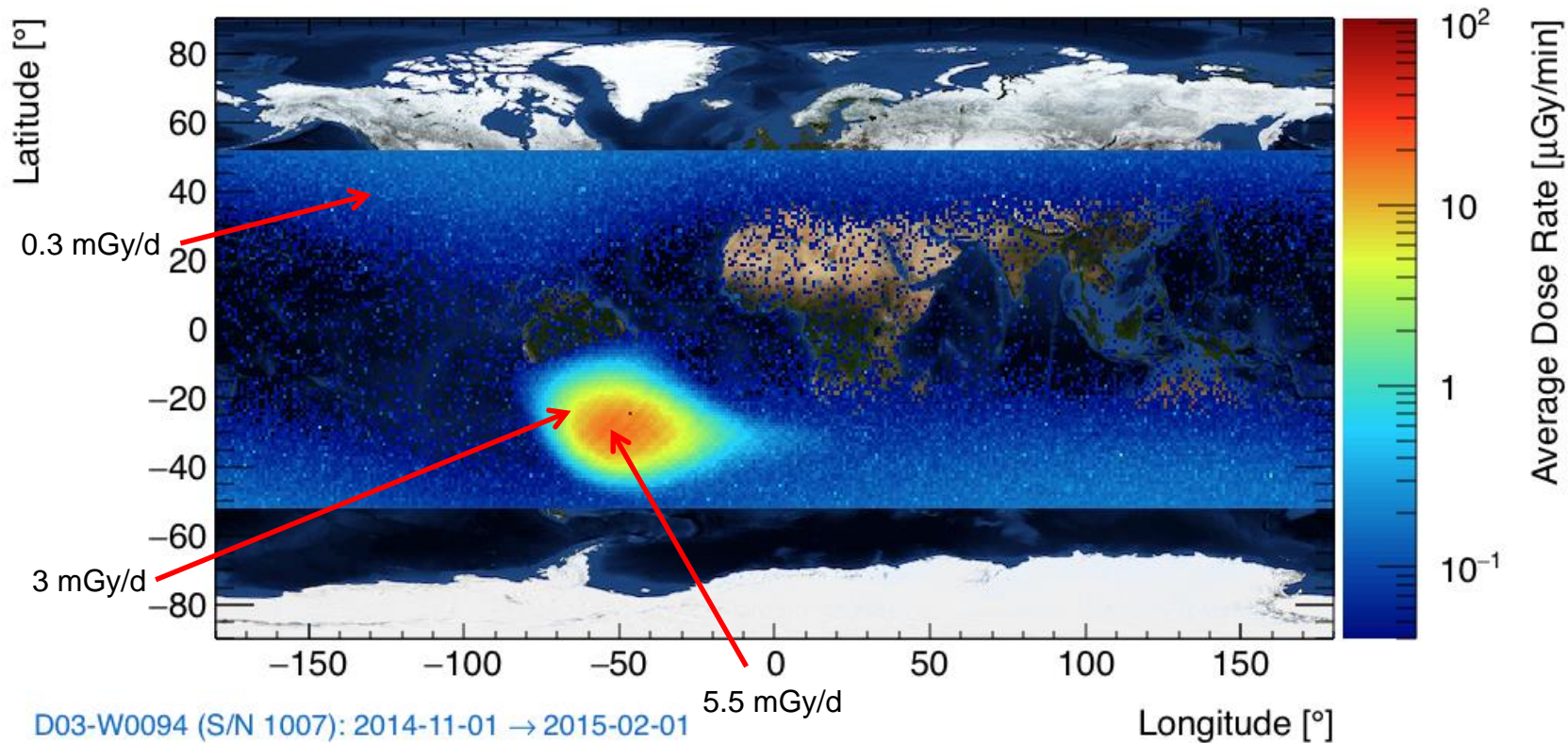


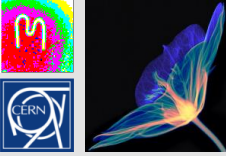
South Atlantic Anomaly

University of Houston, IEAP Prague, NASA



# REM Dose Rate Data ( $\mu\text{G}/\text{min}$ )

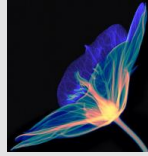
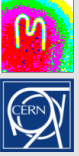




# Large area detectors



WIDEPIX (now Advacam s.r.o.) is a spin-off of IEAP, Czech Technical University

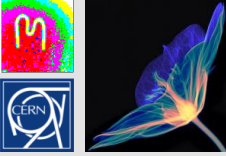


# Micro-Computed Tomography scan of mouse heart



Ethanol-preserved mouse heart scanned using the WidePIX<sub>10x5</sub> detector  
60 kVp tungsten spectrum  
720 projections, 5 seconds per projection (one hours total)  
Spatial resolution ca. 7  $\mu\text{m}$   
Reconstructed using Volex, visualized using CTVox and Amide software

Slide courtesy of J. Dudak, IEAP, Czech Technical University

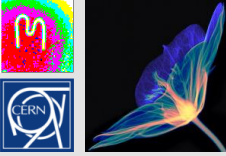


# X-ray Histology



Slide courtesy of J. Dudak, IEAP, Czech Technical University





# The UA9 detectors : Timepix



Based on silicon sensor 500  $\mu\text{m}$  thick

About 20 readouts per seconds

- 200  $\mu\text{s}$  with 20 ns resolution or
- 2 ms with 200 ns resolution

Cluster online reconstruction and data flow reduction

**Synchronized readout with RF**

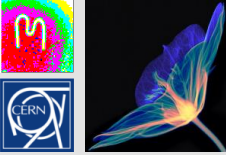
We have three assemblies installed with 14x14 mm<sup>2</sup> active area (2 cm<sup>2</sup>)

- 2 Timepixes on Roman pot #2 (dispersive area for extracted beam image)
- 1 Timepix on Roman pot #1 (image of the channeled beam)

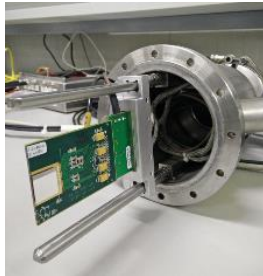
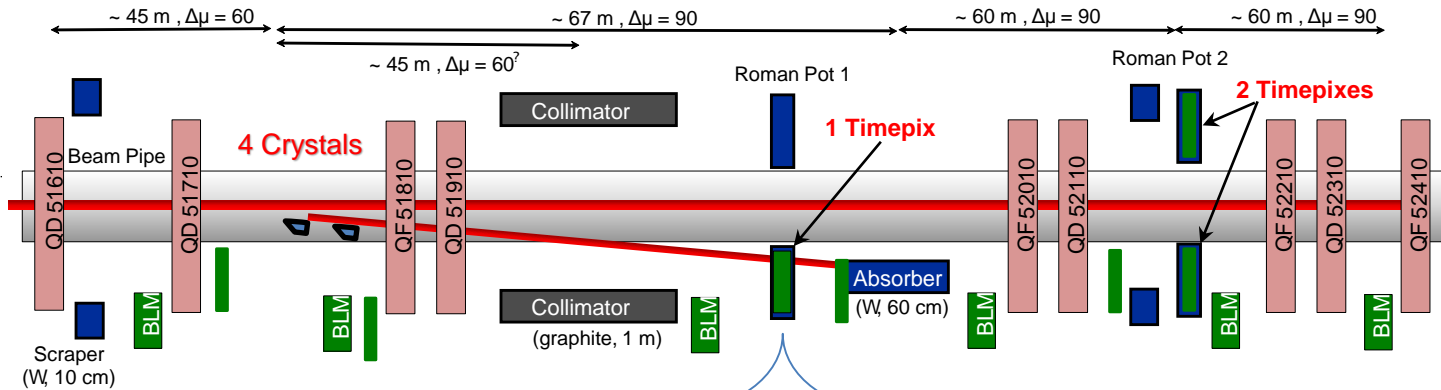
The detector is read in **ToA (Time of Arrival)** to measure the particle flux versus time

This can compromise good flux measurement **if the probability of two hits** in the same pixel is high

F.Murtas, A. Natochi, W.Scandale UA9 Experiment

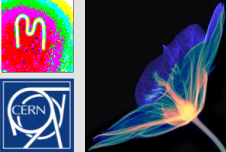


# The UA9 SPS experimental setup



A third Medipix has been installed in the Roman Pot 1 on January 2017

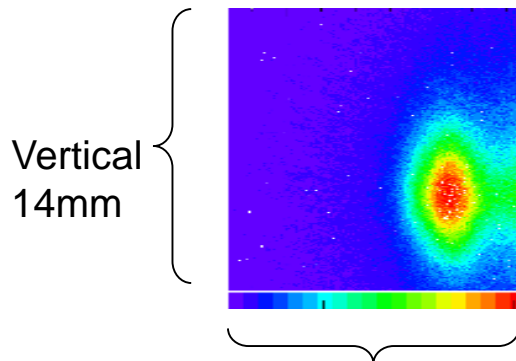
F.Murtas, A. Natochi, W.Scandale UA9 Experiment



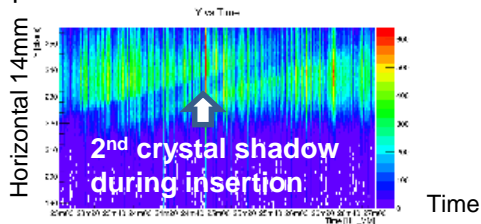
# Channeled beam seen by Timepix

Characteristics of the beam:

- Single bunch
- Nominal intensity:  $1.2 - 1.1 \times 10^{11}$  p/bunch
- $p = 270$  GeV/c
- user LHCMD3:  $Q_h = 20.13$ ,  $Q_v = 20.18$

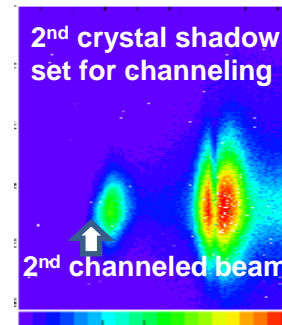
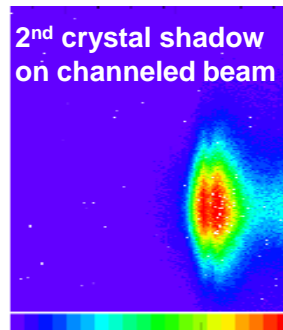


On October 17<sup>th</sup> double crystal experiment was performed

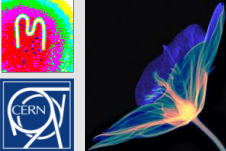


A second crystal was inserted in the channeled beam

Horizontal 14mm

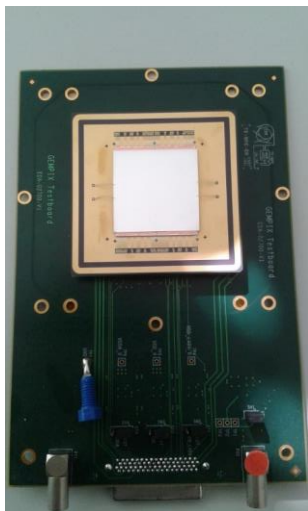


F.Murtas, A. Natochi, W.Scandale UA9 Experiment

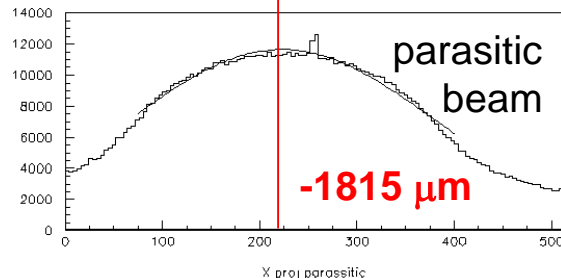
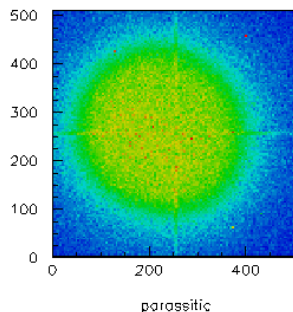
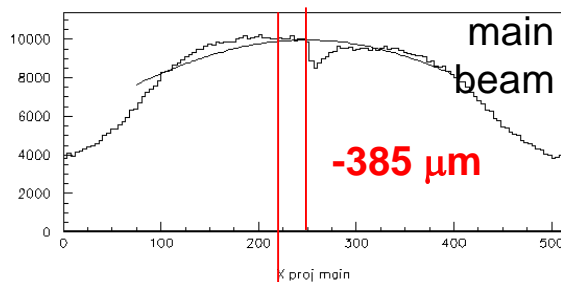
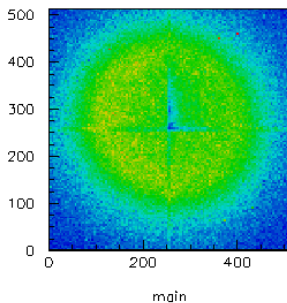


# Timepix-quad @NTOF

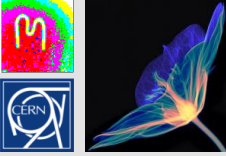
A Timepix-quad has been installed in the dump area of NTOF



Detector active area  
28x28 mm<sup>2</sup>

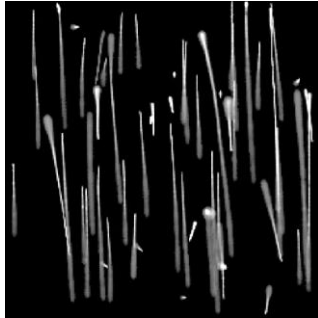


The position of the **main** and the **parasitic** beams differ horizontally by 1.5 mm



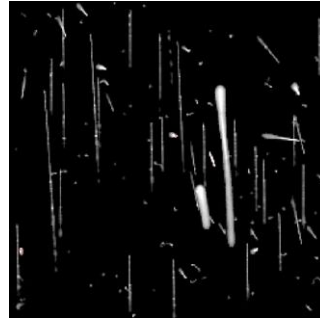
# In-line images of a Hadron Therapy Beam

Protons 48 MeV



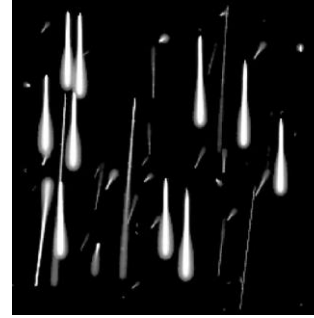
Only protons and their scattering, no secondaries.

Protons 221 MeV



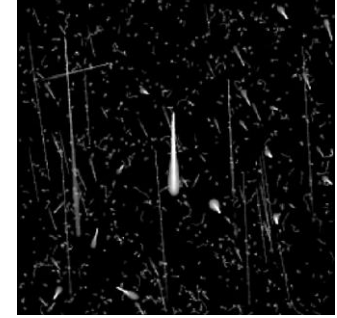
Many secondaries, (delta electrons fragments).

Carbons 89 MeV/u



Carbons and protons and their scattering, no secondaries.

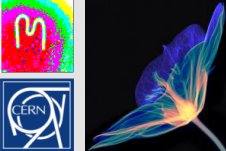
Carbons 430 MeV/u



Carbons and many secondaries.

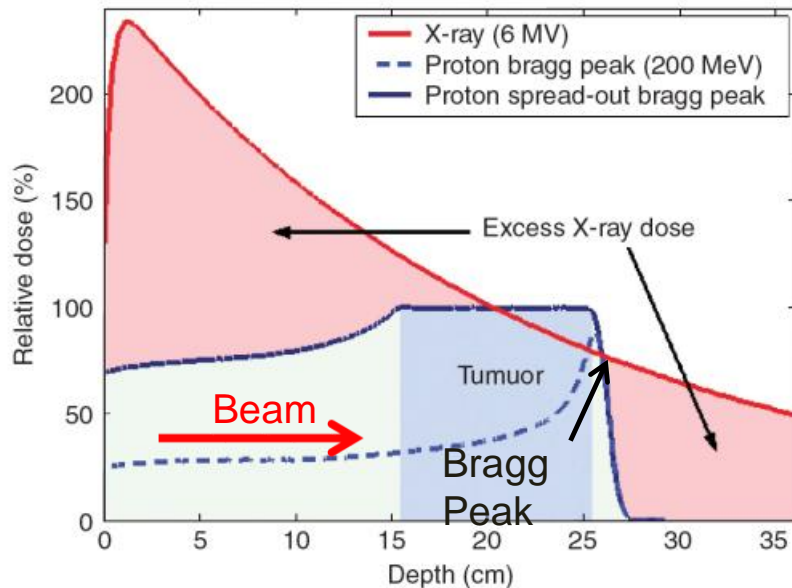
Timepix chip combined with Si detector

Jan Jakůbek  
IEAP, Prague



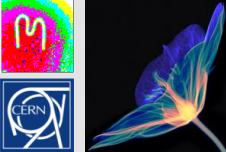
# Introduction: Radiation Therapy

- Cancer therapy:
  - Surgery
  - Chemotherapy
  - Radiation therapy
    - ☐ X-rays
    - ☐ **Proton- / Hadrontherapy**
- Need for quality assurance tools, beam monitors, ...
- Typical system: water phantom + ion chamber
- New detectors needed for Proton- / Hadrontherapy!



→ GEMPix in water phantom

J. Leidner, F.Murtas, M. Silari



# GEMPix: GEMs + Timepix

## 3 GEMs:

- Kapton foil with thin copper layers
- Gas amplification in holes (large field)
- Total gain of max  $10^5$

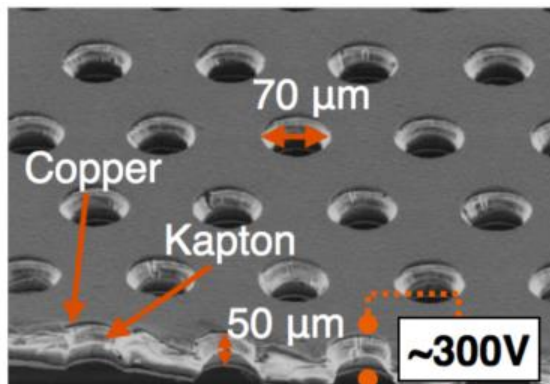
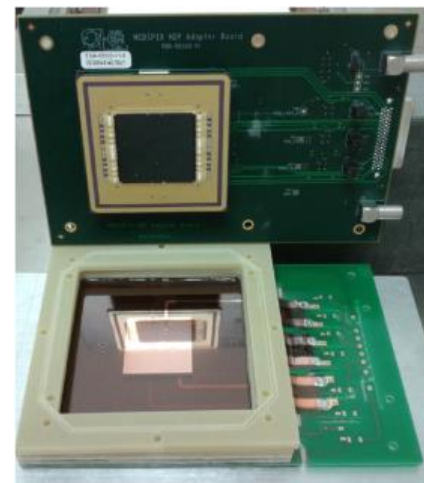
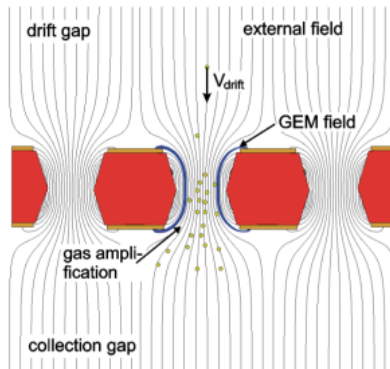


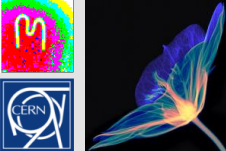
Image CERN GDD Group (2001)

## 4 Timepix chips:

- 512 x 512 pixels
- each  $55\mu\text{m} \times 55\mu\text{m}$
- detection threshold per pixel of 1000 electrons



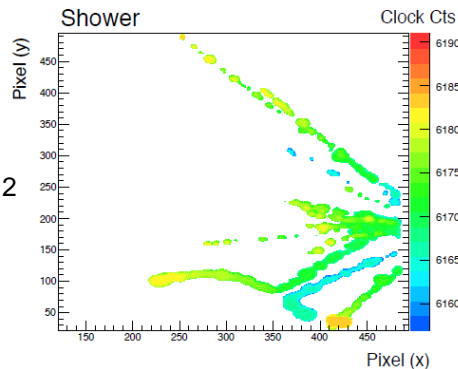
J. Leidner, F.Murtas, M. Silari



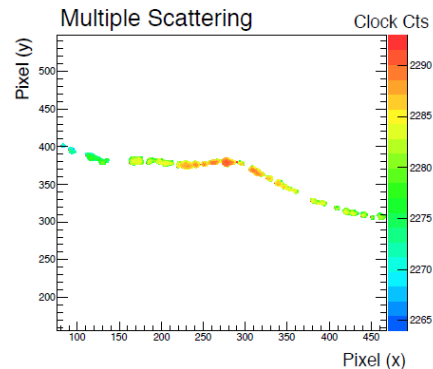
# 3D Track Reconstruction (TOA)

3x3 cm<sup>2</sup>

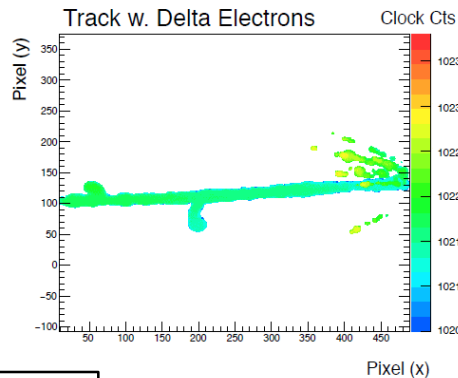
Possibility to study  
single particles  
→ lateral  
measurements  
→ secondaries



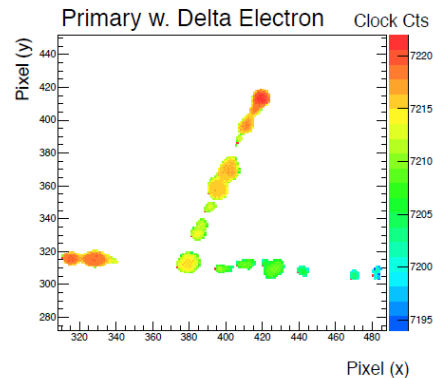
(a)



(b)



(c)



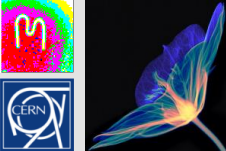
(d)

↑  
Z coordinate (1 cm)

↑  
Z coordinate (1 cm)

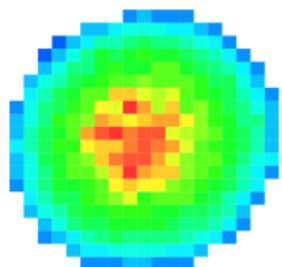
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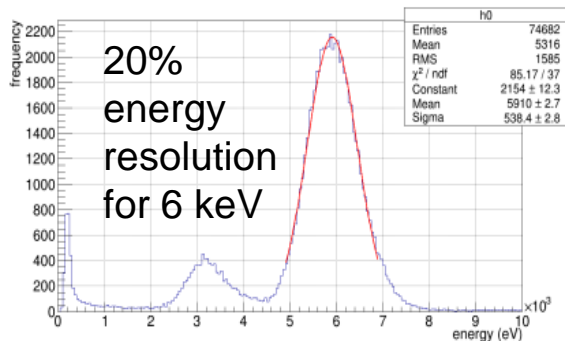


# Charge Measurement (TOT)

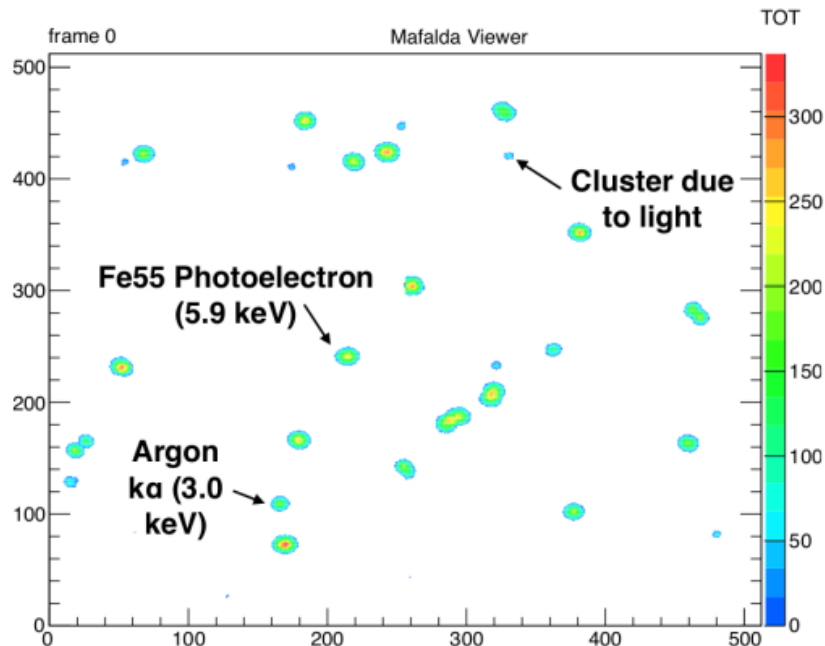
X-ray detection: 6 keV from  $^{55}\text{Fe}$  (1s frame)



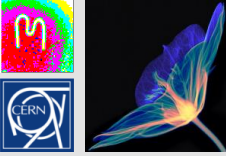
Single 6 keV X-Ray



20% energy resolution



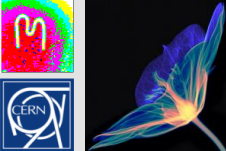
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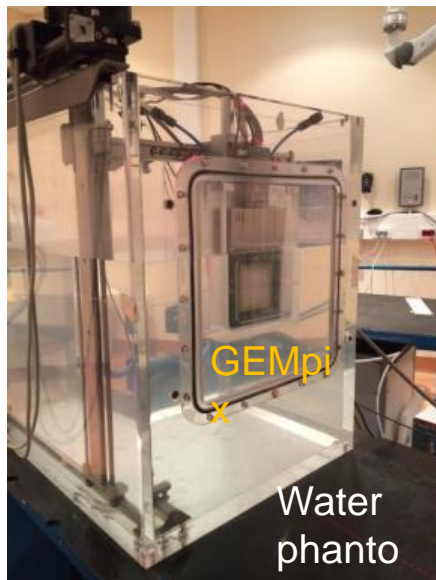
# Measurements at CNAO

- Carbon ions
- Energy: 280 or 332 MeV/n
- Scan along beam axis, ~30 positions
- Frames (pictures) of 20 ms taken, 5-10 frames per position
- TOT mode
- Total: 20 min per scan
  - Frames provide beam monitoring
  - Integrated TOT counts per position provide Bragg Curve
  - 3D reconstruction of energy deposition

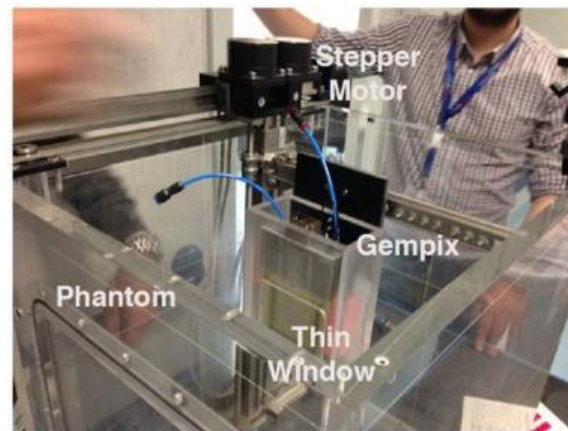
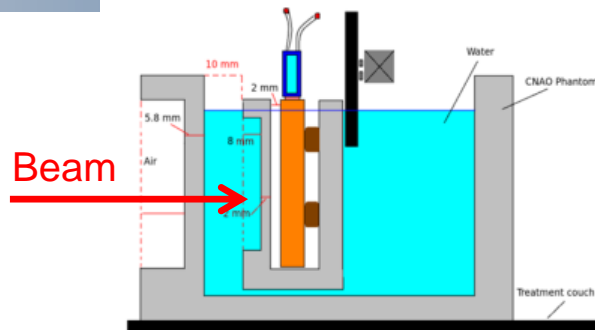
J. Leidner, F.Murtas, M. Silari



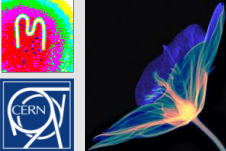
# Setup at CNAO



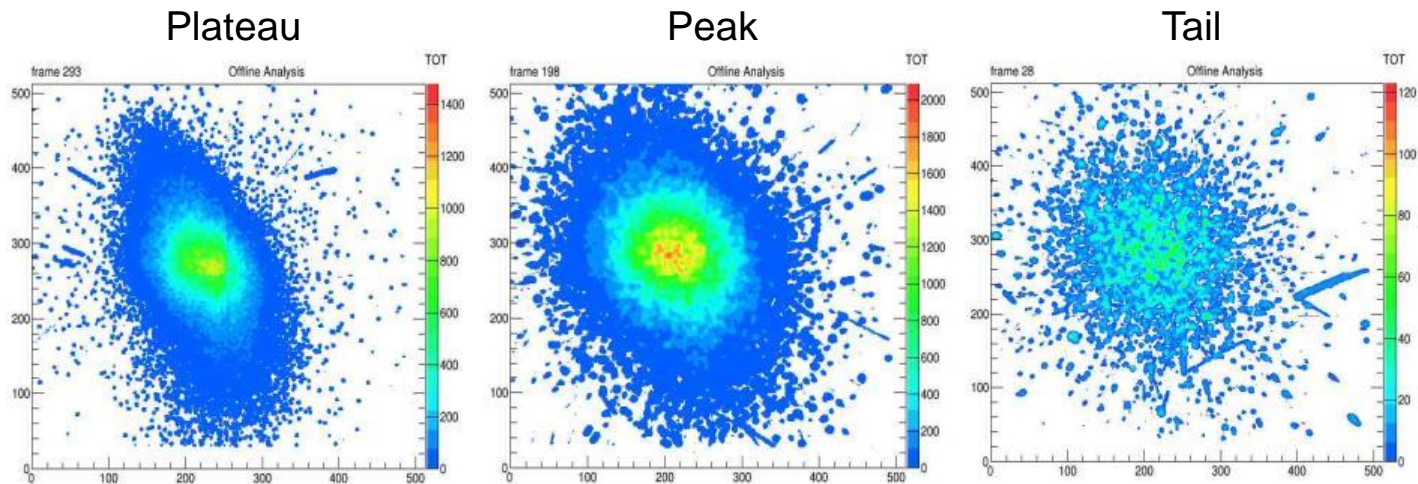
GEMPix inserted in a water phantom



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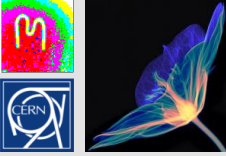


# Beam Monitor

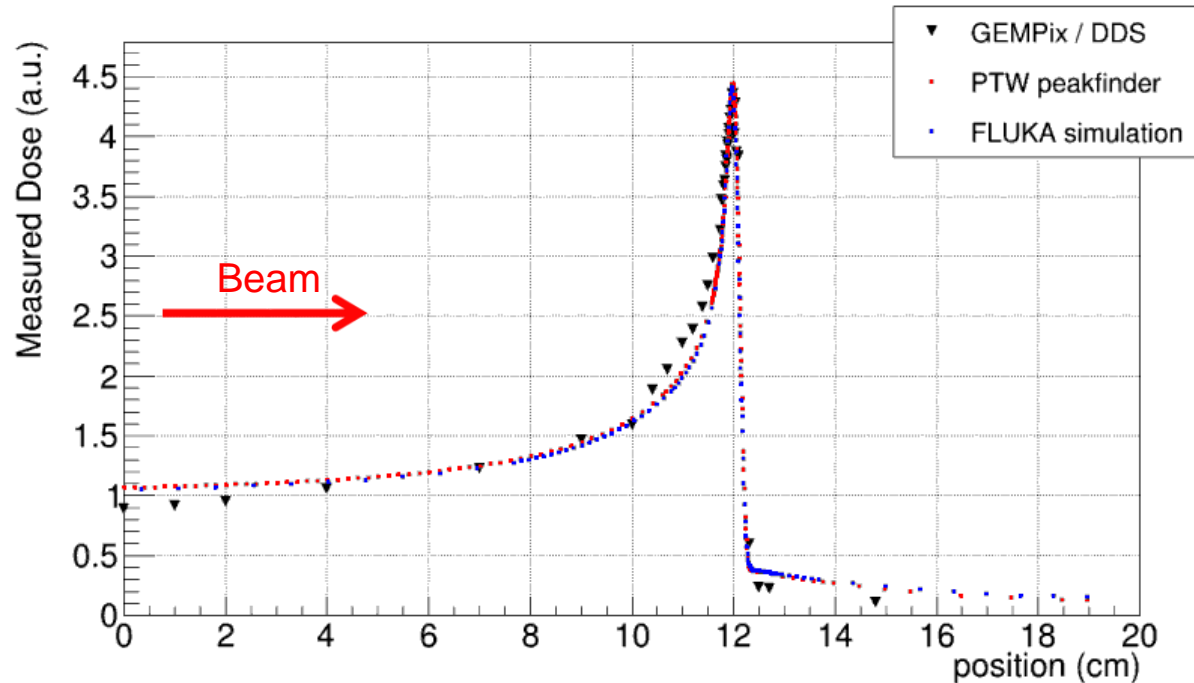


Beam spot taken on Plateau, Bragg Peak and Tail  
Frame length: 20 ms / 100 ms (before / after the Bragg Peak)  
Beam halo: single particle reconstruction

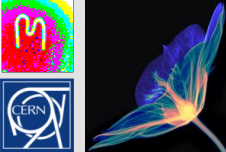
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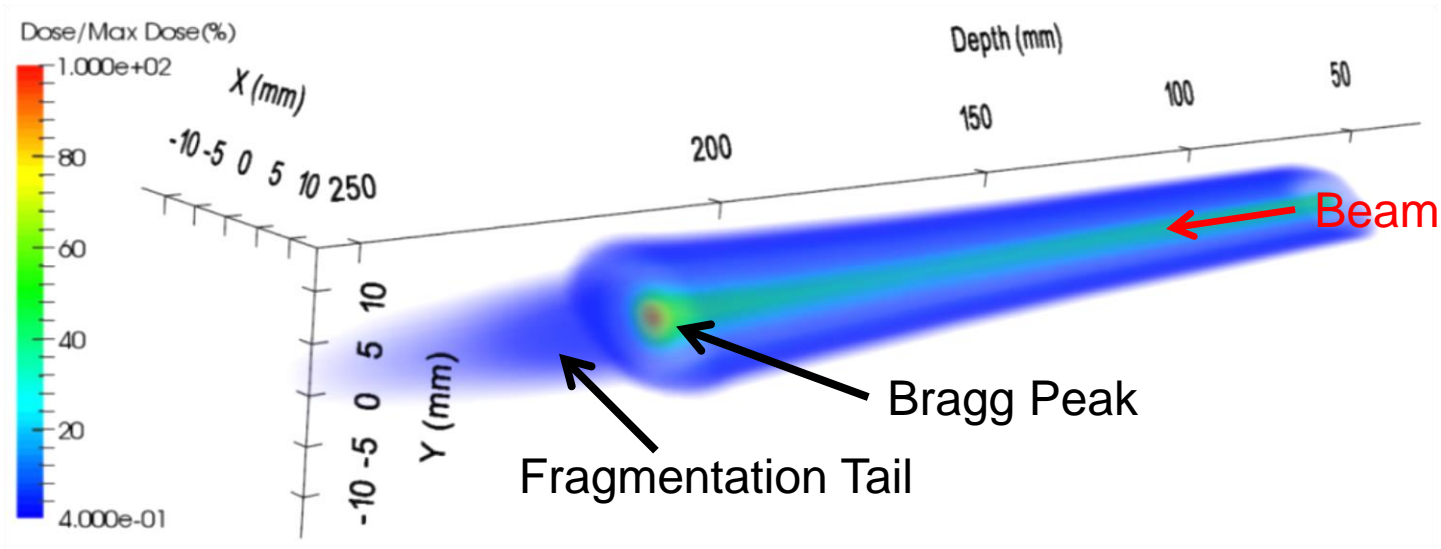
# Depth Scan: Bragg Curve



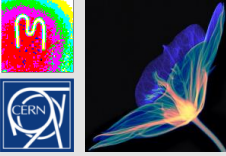
In general: good agreement between reference measurements / simulation and GEMPix



# 3D Reconstruction

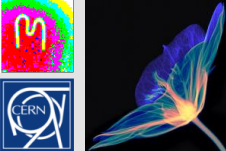


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# Outline

- The Timepix chip
  - Educational use
  - Space dosimetry and space weather
  - X-ray histology
  - Use in UA9 and NTOF
  - GEMpix if Hadron therapy Beam
- The Timepix3 chip
  - Silicon TPC
  - BGI system and results
- Medipix4 and Timepix4
- Conclusions

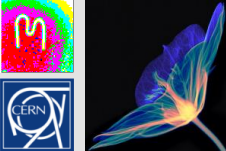


# Timepix3 Specs

<b>CMOS node</b>	<b>130nm</b>
<b>Pixel Array</b>	256 x 256
<b>Pixel pitch</b>	55 $\mu$ m
<b>Charge collection</b>	e <sup>-</sup> , h <sup>+</sup>
<b>Pixel functionality</b>	TOT (Energy) and TOA (Arrival time)
<b>Preamp Gain</b>	~47mV/ke <sup>-</sup>
<b>ENC</b>	~60e <sup>-</sup>
<b>FE Linearity</b>	Up to 12ke <sup>-</sup>
<b>TOT linearity (resolution)</b>	Up to 200ke <sup>-</sup> (<5%)
<b>TOA resolution*</b>	Up to 1.6ns
<b>Time-walk</b>	<20ns
<b>Minimum detectable charge</b>	~500e <sup>-</sup> → 2 KeV (Si Sensor)
<b>Max Analog power (1.5V)</b>	500 mA/chip
<b>Digital Power (1.5V)</b>	~400mA data driven
<b>Maximum hit rate</b>	80Mhits/sec (in data driven)
<b>Readout</b>	Data driven (44-bits/hit @ 5Gbps)

\* Thanks to V. Gromov, et al. Nikhef, C. Brezina et al., Bonn

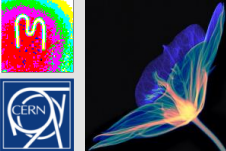




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<b>Charge collection</b>	<b>e<sup>-</sup>, h<sup>+</sup></b>
<b>Pixel functionality</b>	<b>TOT (Energy) and TOA (Arrival time)</b>
<b>Preamp Gain</b>	<b>~47mV/ke<sup>-</sup></b>
<b>ENC</b>	<b>~60e<sup>-</sup></b>
<b>FE Linearity</b>	<b>Up to 12ke<sup>-</sup></b>
<b>TOT linearity (resolution)</b>	<b>Up to 200ke<sup>-</sup> (&lt;5%)</b>
<b>TOA resolution*</b>	<b>Up to 1.6ns</b>
<b>Time-walk</b>	<b>&lt;20ns</b>
<b>Minimum detectable charge</b>	<b>~500e<sup>-</sup> → 2 KeV (Si Sensor)</b>
<b>Max Analog power (1.5V)</b>	<b>500 mA/chip</b>
<b>Digital Power (1.5V)</b>	<b>~400mA data driven</b>
<b>Maximum hit rate</b>	<b>80Mhits/sec (in data driven)</b>
<b>Readout</b>	<b>Data driven (44-bits/hit @ 5Gbps)</b>

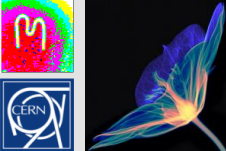
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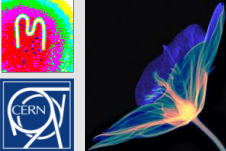
\* Thanks to V. Gromov, et al. Nikhef, C. Brezina et al., Bonn



# Timepix3 Specs

<b>CMOS node</b>	<b>130nm</b>
<b>Pixel Array</b>	<b>256 x 256</b>
<b>Pixel pitch</b>	<b>55<math>\mu</math>m</b>
<b>Charge collection</b>	<b>e<sup>-</sup>, h<sup>+</sup></b>
<b>Pixel functionality</b>	<b>TOT (Energy) and TOA (Arrival time)</b>
<b>Preamp Gain</b>	<b>~47mV/ke<sup>-</sup></b>
<b>ENC</b>	<b>~60e<sup>-</sup></b>
<b>FE Linearity</b>	<b>Up to 12ke<sup>-</sup></b>
<b>TOT linearity (resolution)</b>	<b>Up to 200ke<sup>-</sup> (&lt;5%)</b>
<b>TOA resolution*</b>	<b>Up to 1.6ns</b>
<b>Time-walk</b>	<b>&lt;20ns</b>
<b>Minimum detectable charge</b>	<b>~500e<sup>-</sup> → 2 KeV (Si Sensor)</b>
<b>Max Analog power (1.5V)</b>	<b>500 mA/chip</b>
<b>Digital Power (1.5V)</b>	<b>~400mA data driven</b>
<b>Maximum hit rate</b>	<b>80Mhits/sec (in data driven)</b>
<b>Readout</b>	<b><u>Data driven</u> (44-bits/hit @ 5Gbps)</b>

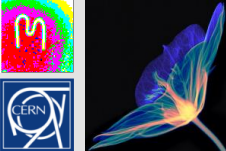
\* Thanks to V. Gromov, et al. Nikhef, C. Brezina et al., Bonn



# Timepix3 Specs

<b>CMOS node</b>	130nm
<b>Pixel Array</b>	256 x 256
<b>Pixel pitch</b>	55 $\mu$ m
<b>Charge collection</b>	e <sup>-</sup> , h <sup>+</sup>
<b>Pixel functionality</b>	<b>TOT (Energy) and TOA (Arrival time)</b>
<b>Preamp Gain</b>	~47mV/ke <sup>-</sup>
<b>ENC</b>	~60e <sup>-</sup>
<b>FE Linearity</b>	Up to 12ke <sup>-</sup>
<b>TOT linearity (resolution)</b>	Up to 200ke <sup>-</sup> (<5%)
<b>TOA resolution*</b>	Up to 1.6ns
<b>Time-walk</b>	<20ns
<b>Minimum detectable charge</b>	~500e <sup>-</sup> → 2 KeV (Si Sensor)
<b>Max Analog power (1.5V)</b>	500 mA/chip
<b>Digital Power (1.5V)</b>	~400mA data driven
<b>Maximum hit rate</b>	80Mhits/sec (in data driven)
<b>Readout</b>	Data driven (44-bits/hit @ 5Gbps)

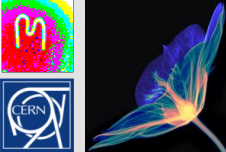
\* Thanks to V. Gromov, et al. Nikhef, C. Brezina et al., Bonn



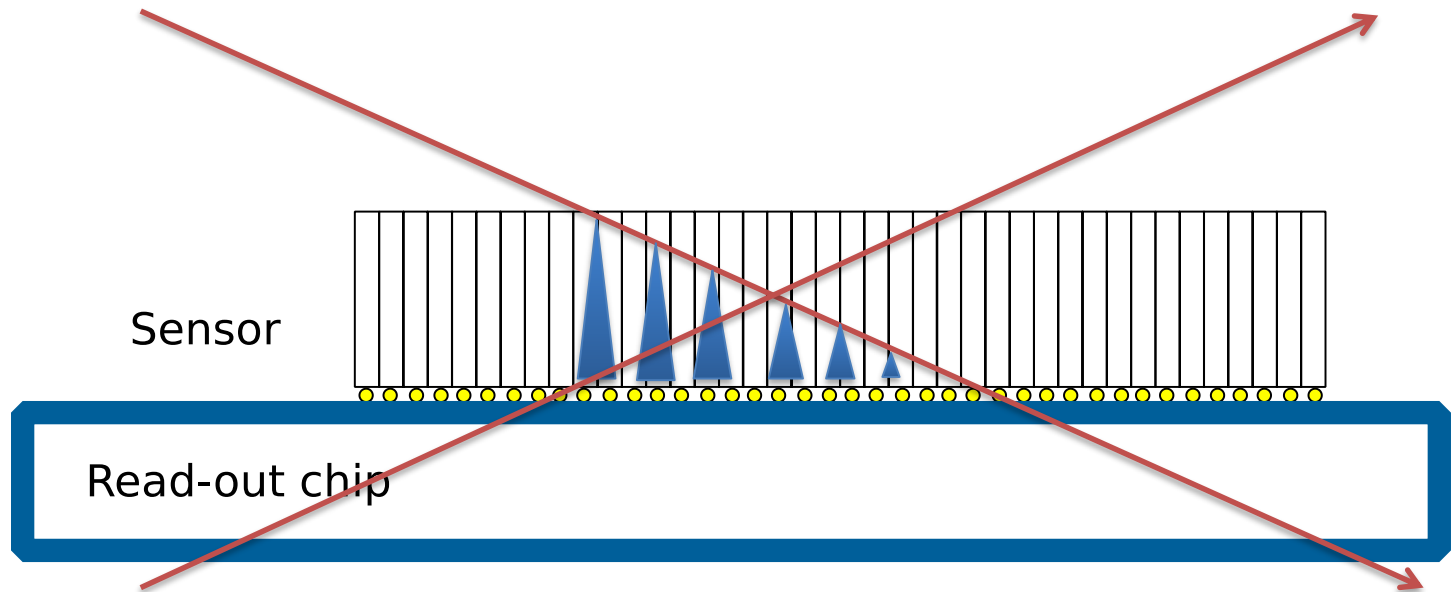
# Timepix3 Specs

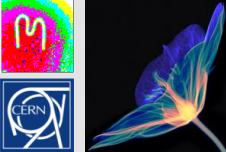
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\* Thanks to V. Gromov, et al. Nikhef, C. Brezina et al., Bonn

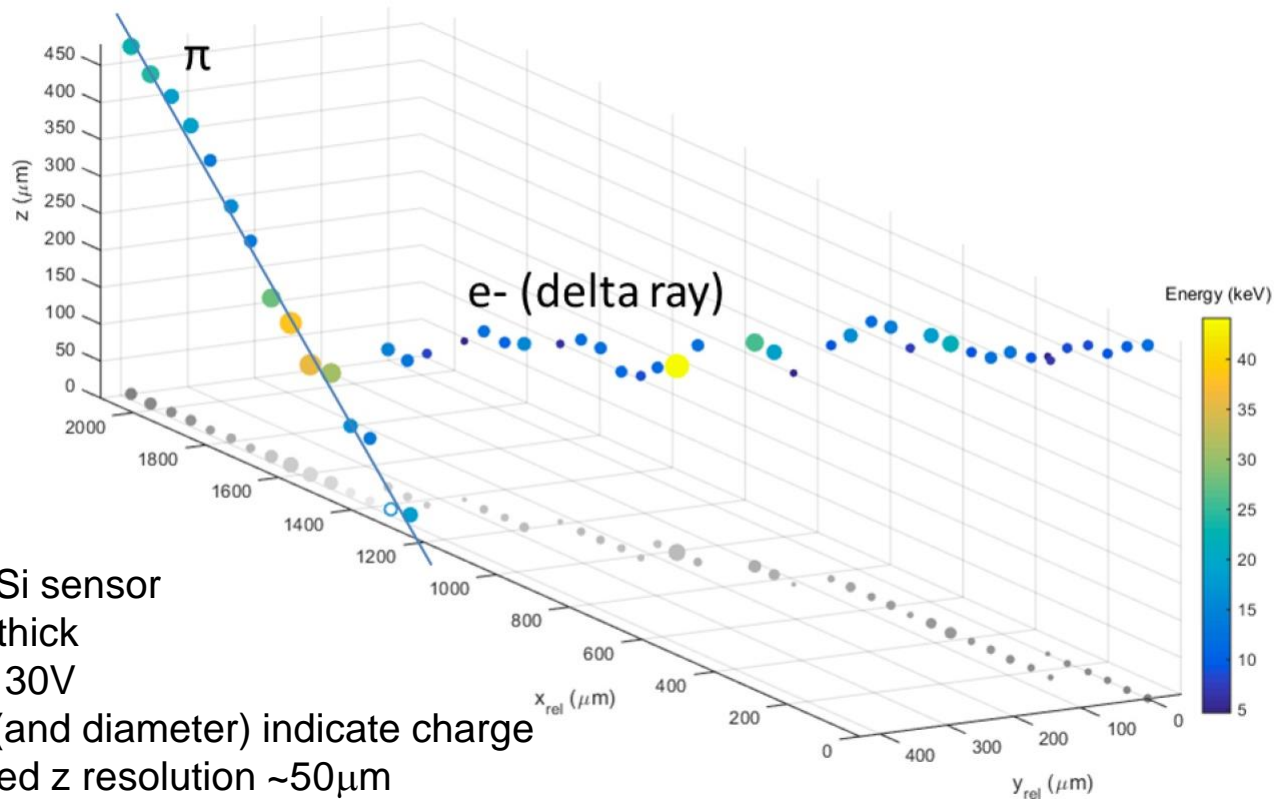


# Tracking in a single Si layer



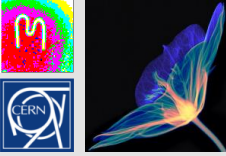


# Test with 120GeV/c Pion Track



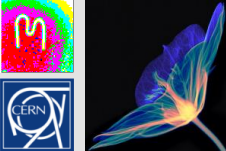
60 deg  
p+ in n Si sensor  
500 $\mu$ m thick  
 $V_{bias} = 130V$   
Colour (and diameter) indicate charge  
Measured  $z$  resolution  $\sim 50\mu$ m

Slide courtesy of B. Bergmann, S. Pospisil, IEAP, CTU, Prague

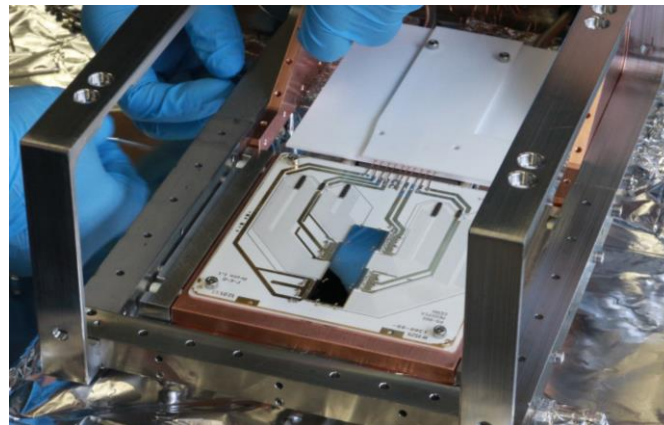
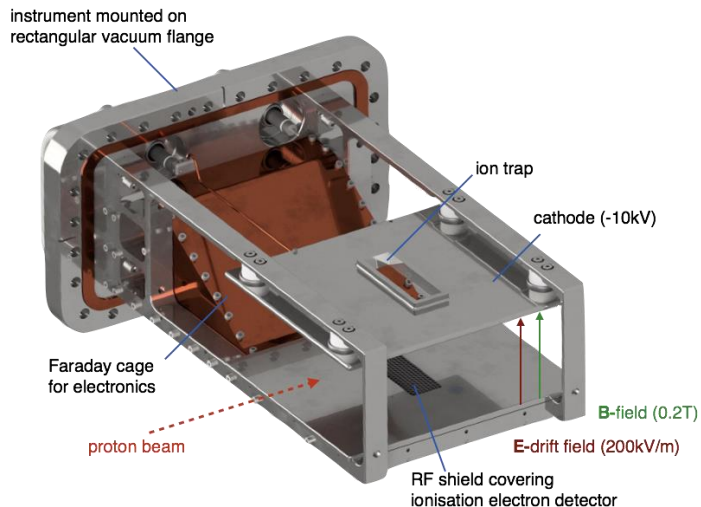


# Timepix3 miniaturised readout

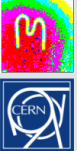




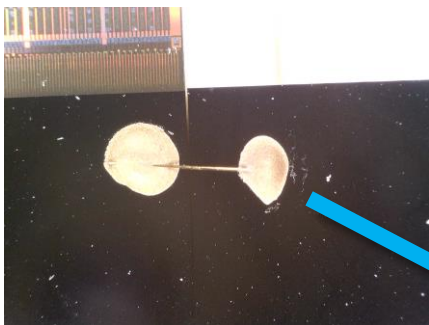
# PS-BGI Instrument



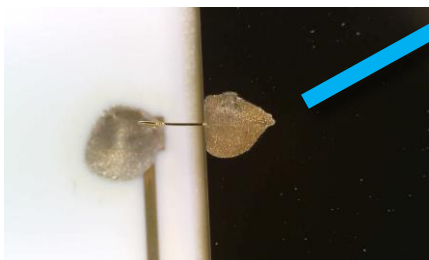
- Simplified explanation:
  - The beam ionize the rest gas, generating electron<sup>-</sup>/ion<sup>+</sup> pairs
  - An electric drift field accelerates the electrons down onto the pixel detectors
- Electronics for operation directly inside the ultra-high vacuum environment of the beam pipe
  - 4x Timepix3 with edgeless, p-on-n, non-metallized sensor mounted on a ceramic board
  - 3 out of 4 Timepix3 working



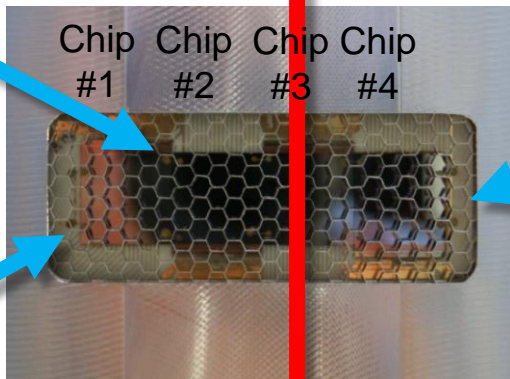
# PS-BGI Instrument - Bias and honeycomb



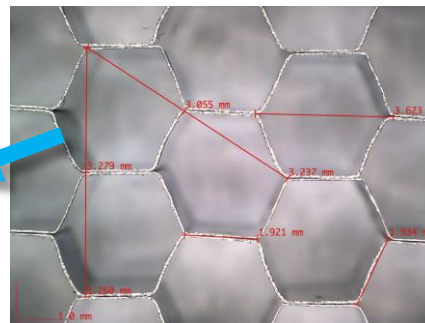
Bias wire between chips  
(conductive glue)



Bias wire from ceramic board to  
sensor (conductive glue)

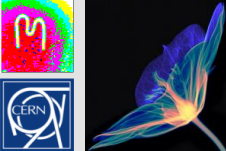


Chip #3 is the non-functional chip



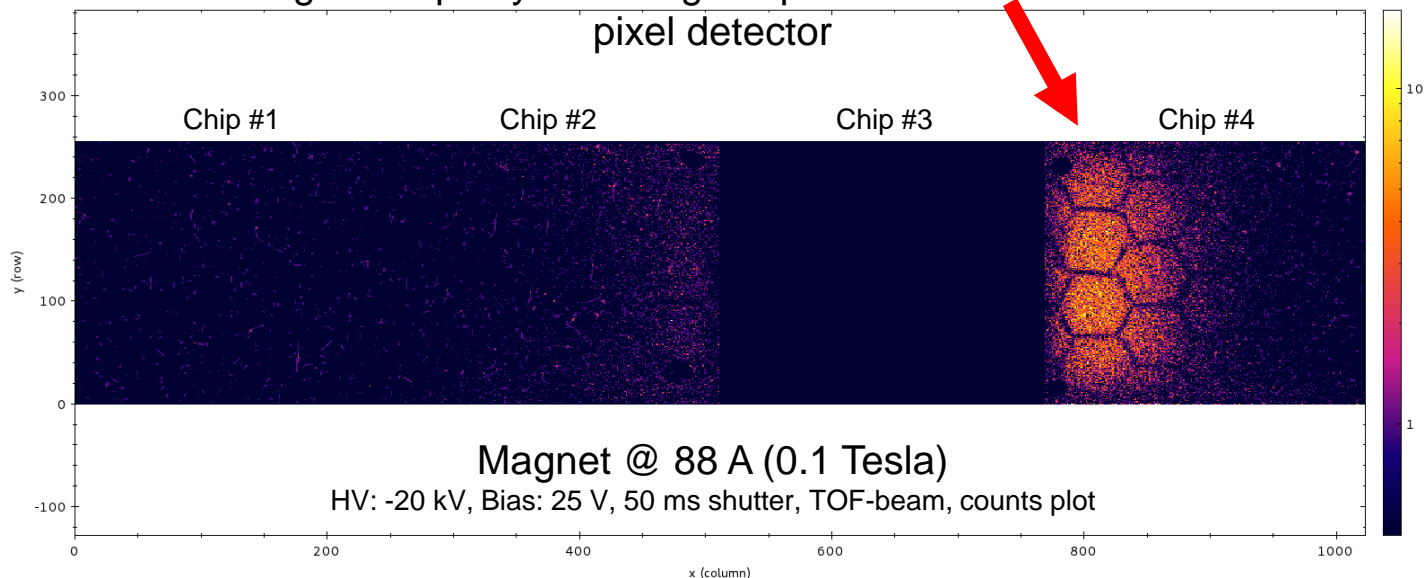
Honeycomb  
structured RF shield

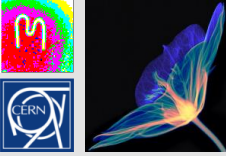
Beam  
passing  
over



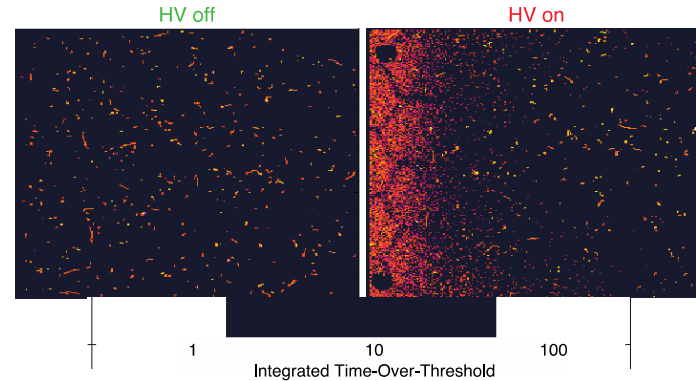
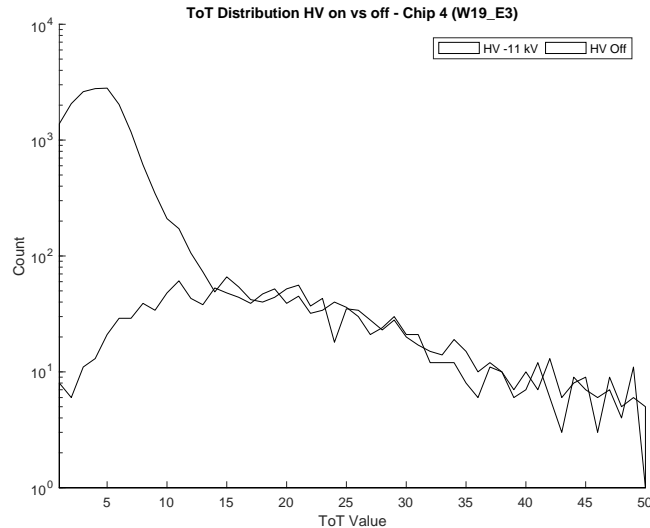
# Turning on the magnet

**The electrons we have been looking for!**  
The magnet helps by confining the path for the electrons to the  
pixel detector

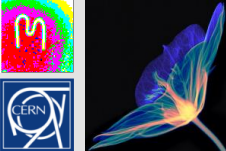




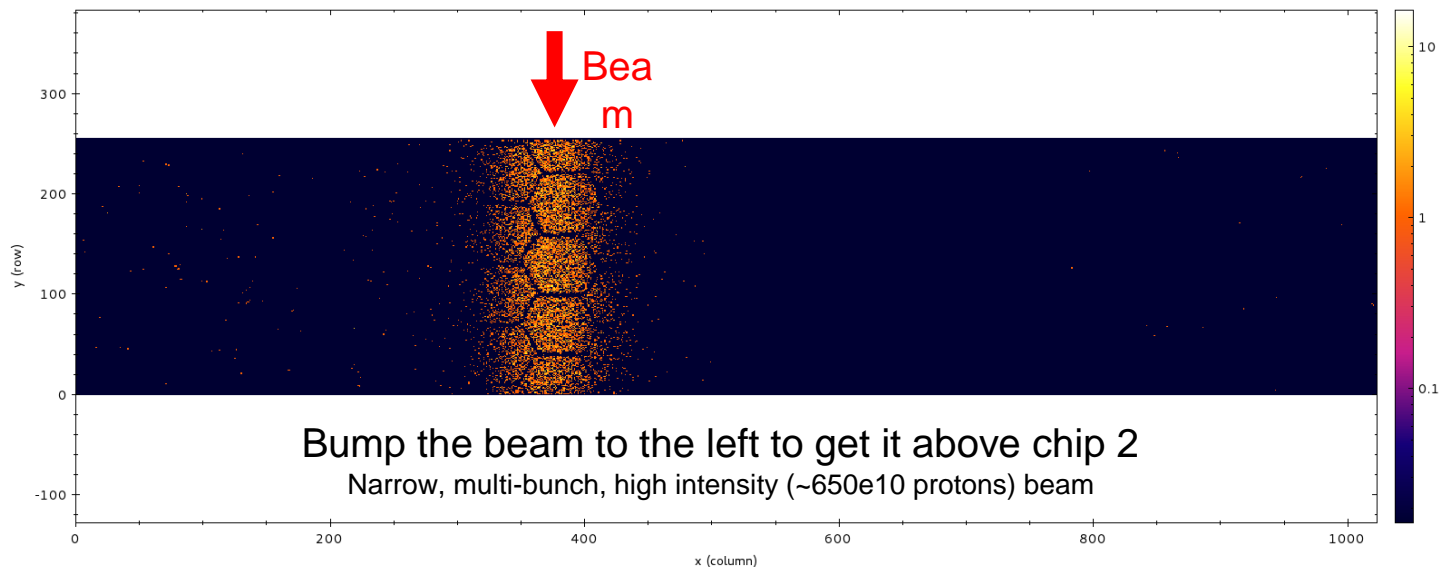
# Detection of ionization electrons



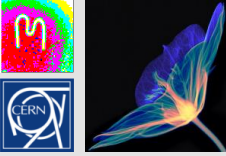
- A clear peak is visible with the HV on located at low ToT values
  - -> Ionization electrons
- For higher ToT values the distribution looks similar for HV on and off
  - Indicates a common background signal
- This enables us to apply a simple filter based on ToT to get a cleaner signal



# Beam profile measurement

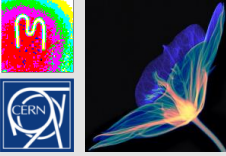


Magnet: 176 A (0.2 Tesla), HV: -13 kV, Bias: 30 V, 10 ms shutter, LHC 25ns 48-bunch beam, counts plot



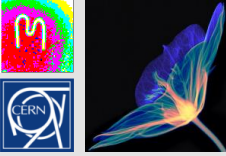
## Other applications

- X-ray materials analysis
  - X-ray non-destructive testing
  - Large area synchrotron detectors
  - X-ray imaging of cultural heritage items
  - Dosepix chip development
  - Gamma camera
  - Compton camera
  - Low Energy Electron Microscopy
  - Transmission electron microscopy
  - Dose deposition tracking in hadron therapy
  - High resolution neutron imaging
  - Single (visible) photon imaging
  - Time-of-Flight mass spectrometry
- } combined with MCP



# Applications for CERN/Physics

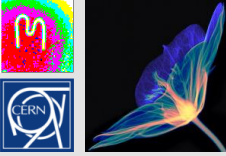
- LHCb VELOpix chip is directly derived from Timepix3
- LHCb Timepix3 telescope – 80 Mhits/sec
- Sensor studies for CLIC/LHCb
- Background radiation monitoring at ATLAS and CMS
- **Beam monitoring in UA9**
- **Beam Gas Interaction monitor is operating at CERN PS**
- ASACUSA experiment
- Beta particle channeling in ISOLDE
- Forward physics using Timepix3?
- Axion search at CAST (with InGrid)
- Large area TPC (with InGrid)
- Transition radiation measurements for ATLAS
- **GEMPIX development for radiation therapy beam monitoring**
- GEMPIX for  $^{55}\text{Fe}$  waste management
- Developments for CLIC: CLICpix, CLICpix2, C3PD



# Industrial licensing of Medipix/Timepix chips

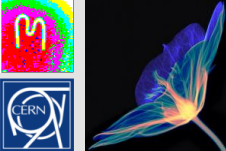
- 2 Medium Sized Enterprises
  - PANalytical (The Netherlands)
  - Kromek (UK)
- 6 start-ups from Collaboration members:
  - Advacam s.r.o. (from IEAP, Czech Republic)
  - Amsterdam Scientific Instruments (from NIKHEF, The Netherlands)
  - MARS Bio-imaging (from University of Canterbury, New Zealand)
  - Quantum Detectors (from Diamond, UK)
  - X-ray Imaging Europe (from FMF, Germany)
  - X-Spectrum (from DESY, Germany)



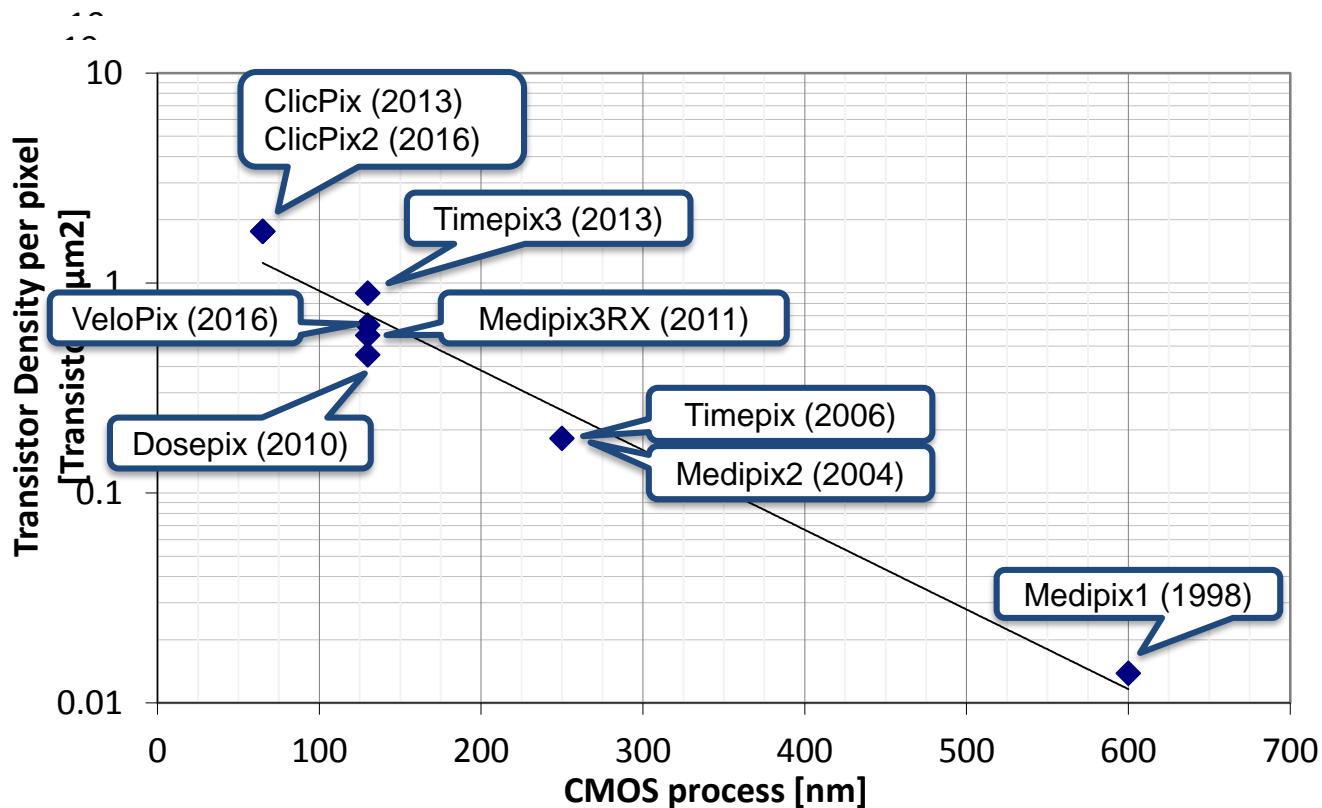


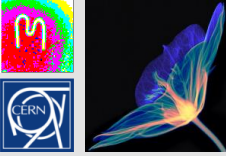
# Outline

- The Timepix chip
  - Educational use
  - Space dosimetry and space weather
  - X-ray histology
  - Use in UA9
  - GEMpix if Hadron therapy Beam
- The Timepix3 chip
  - Silicon TPC
  - BGI system and results
- **Medipix4 and Timepix4**
- Conclusions



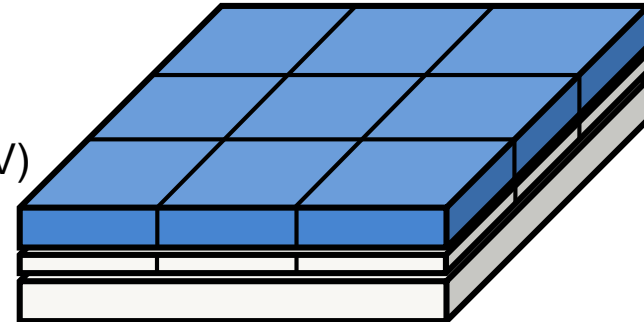
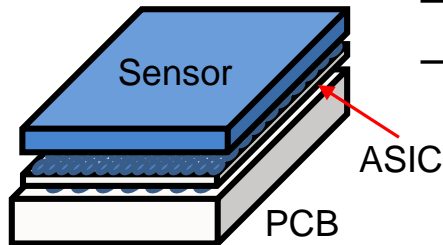
# “Moore’s Law” of Medipix Family

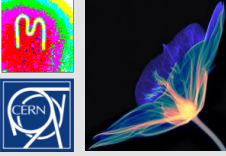




# What's next?

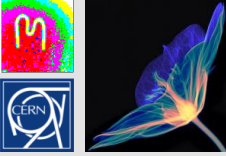
- The Medipix4 Collaboration was started in March 2016
- Chips to be fully tile-able on 4-sides – use of Through Silicon Vias (TSV) for I/O
- Medipix4 Photon counting spectrometric chip
  - Will use charge summing and allocation scheme
  - Multiple thresholds
  - Pixel pitch varied to match sensor material
  - Better high count rate performance (aimed at human CT)
- Timepix4
  - Smaller pixel pitch?
  - Better timing resolution (~200ps)
  - Better high count rate performance (TSV)





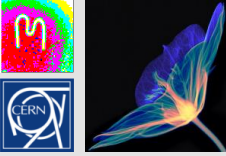
# The Medipix4 Collaboration

- CEA, Paris, France
- CERN, Geneva, Switzerland,
- DESY-Hamburg, Germany
- Diamond Light Source, Oxfordshire, England, UK
- IEAP, Czech Technical University, Prague, Czech Republic
- IFAE, Barcelona, Spain
- JINR, Dubna, Russian Federation
- NIKHEF, Amsterdam, The Netherlands
- University of California, Berkeley, USA
- University of Houston, USA
- University of Maastricht, The Netherlands
- University of Canterbury, New Zealand
- University of Oxford, England, UK
- University of Geneva, Switzerland



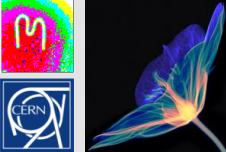
# Conclusions

- Hybrid pixel detectors were developed as tracking detectors of LHC
- The Medipix2 and Medipix3 Collaborations have taken the technology into many other fields
- Timepix chips are actively detecting background radiation in school classrooms and in space
- Timepix has been used extensively in particle beam monitoring applications (in spite of some obvious limitations)
- Timepix3 is opening new possibilities with single layer tracking
- The next generation of readout chips will use Through Silicon Via technology permitting seamless tiling of large areas

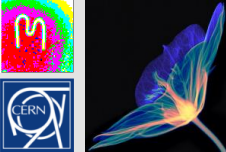


# Thank you for your attention!



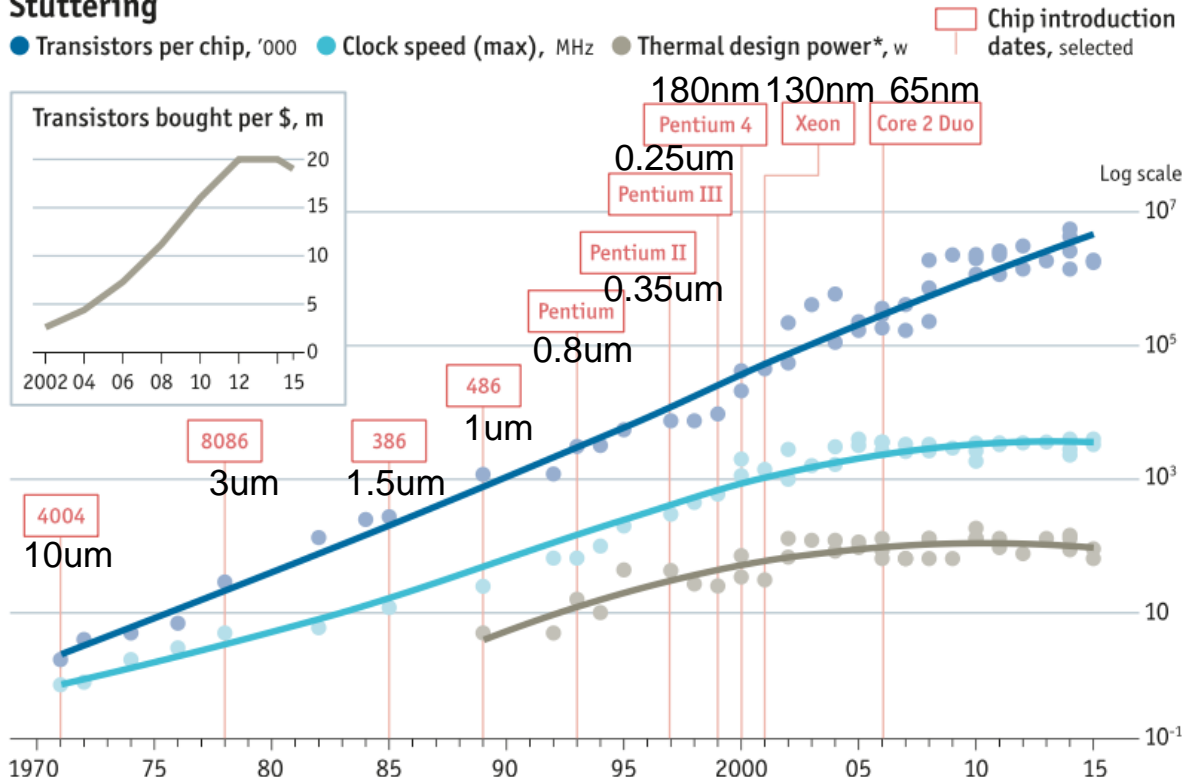


# Backup slide



# Moore's uncertain future

## Stuttering



Sources: Intel; press reports; Bob Colwell; Linley Group; IB Consulting; *The Economist*

\*Maximum safe power consumption