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Timepix detector operation at CERN accelerator facilities

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on behalf of the UA9 Collaboration**

Abstract We describe the main performances for the Timepix silicon detector operation at the SPS and H8 extracted beam line at CERN. The main calibration results of the detector and an improved cluster analysis algorithm are presented as well. In the present work we are introducing the main functionality of the device and its limitation for the measurement of the high-energy particles flux.

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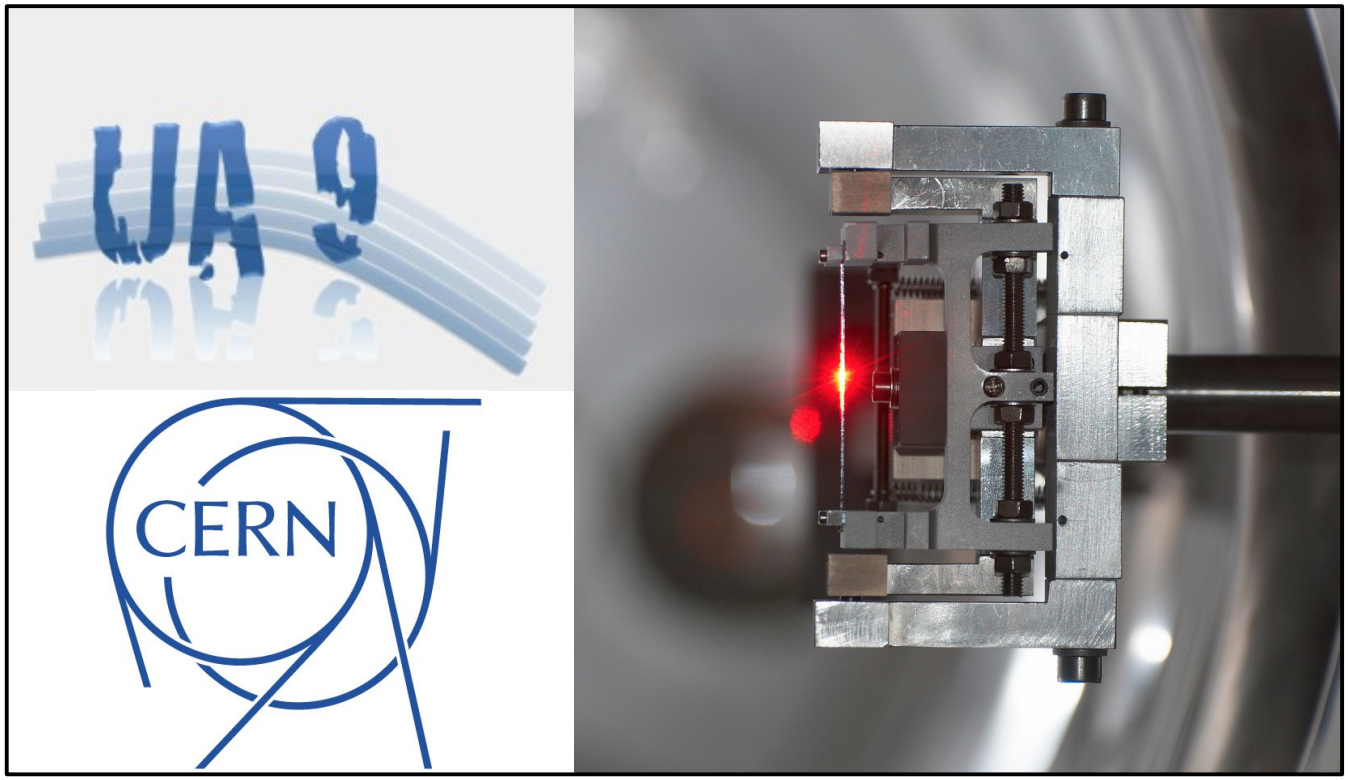
** *https://ua9.web.cern.ch/sites/ua9.web.cern.ch/files/UA9_Experiment_author_list.pdf*

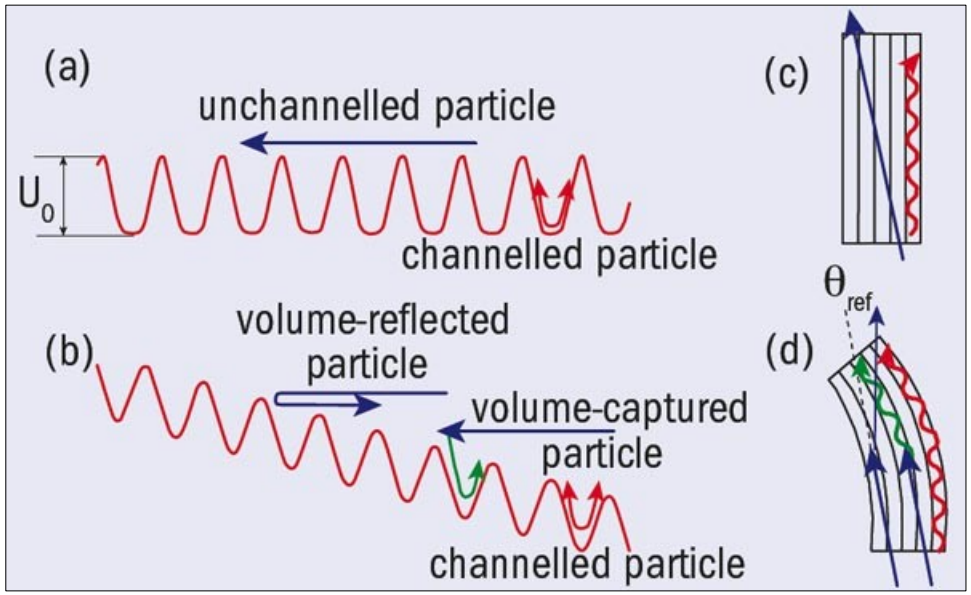
UA9 collaboration



UA9 collaboration. Bent crystal physics

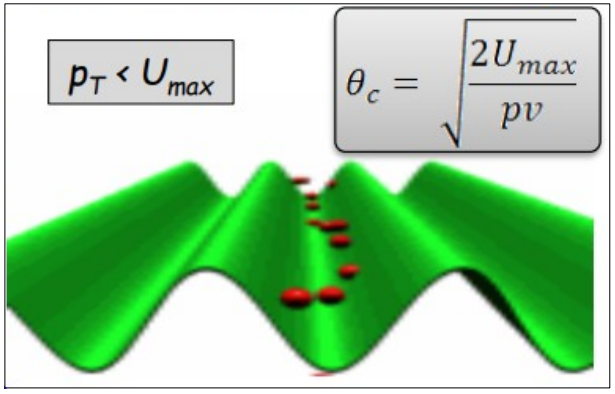
Channeling is the retention between crystalline planes:

→ Charged particles
→ Momentum is nearly parallel to the atomic planes of the crystal
→ Transverse kinetic energy not exceeding the depth U_0 of the crystal potential.

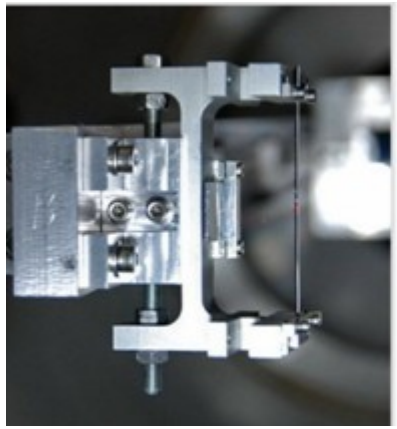


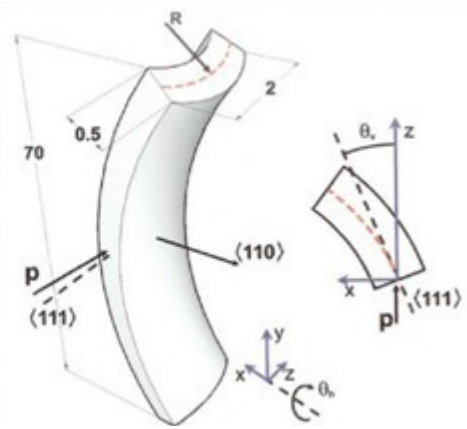
Typical values for a Si-crystal:

Case	Energy [GeV]	θ_c [μrad]	λ [μm]
SPS coast	120	18.3	33.0
SPS coast	270	12.2	49.6
H8	400	10.0	60.3
LHC inj.	450	9.4	64.0
LHC top	6500	2.5	243.2
LHC top	7000	2.4	252.3

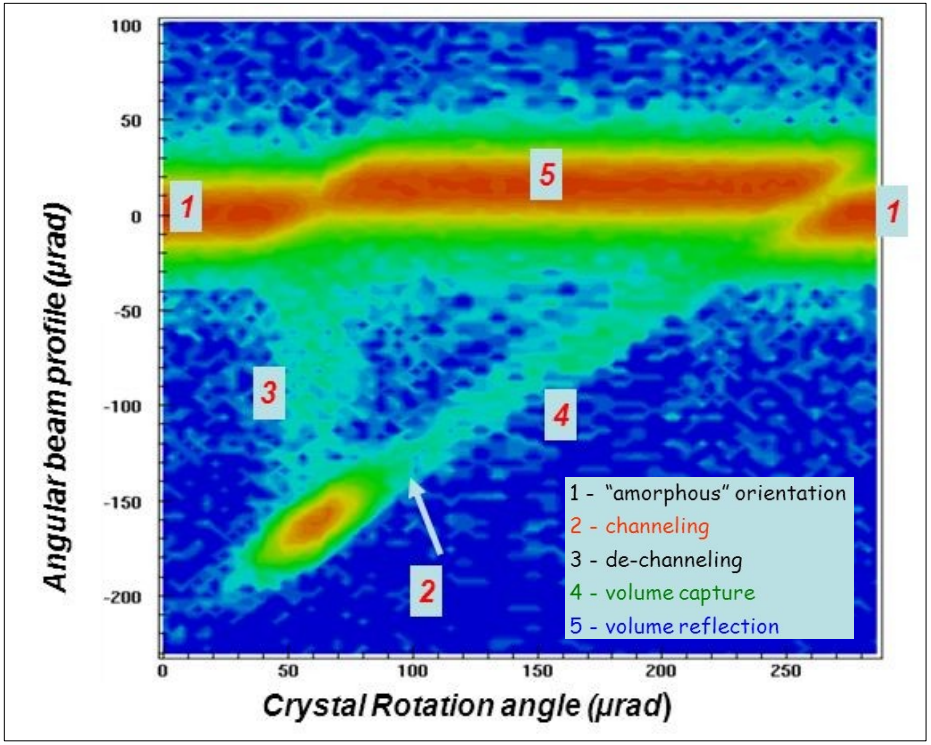


Using of the secondary curvature of the crystal to guide the particles





Mechanically bent crystal

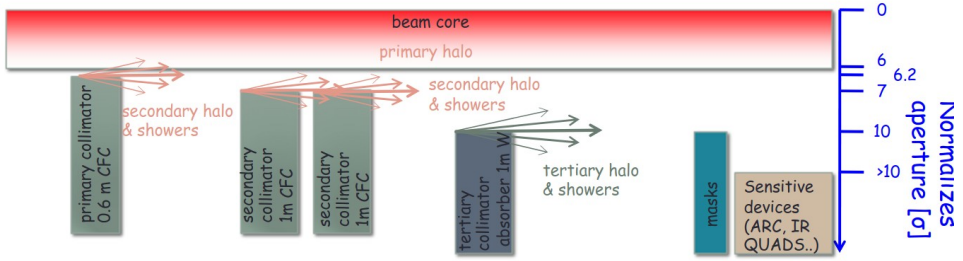


Deflecting Angle of Protons after passing the crystal vs Crystal Rotation Angle

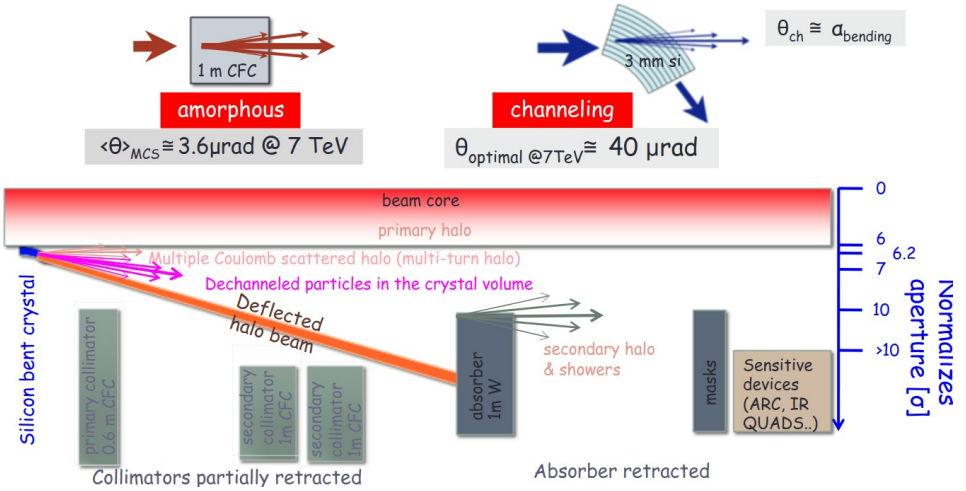
UA9 collaboration. Applications

Beam collimation

- The halo particles are removed by a cascade of amorphous targets:
  1. Primary and secondary collimators intercept the diffusive primary halo.
  2. Particles are repeatedly deflected by Multiple Coulomb Scattering also producing hadronic showers that is the secondary halo
  3. Particles are finally stopped in the absorber
  4. Masks protect the sensitive devices from tertiary halo

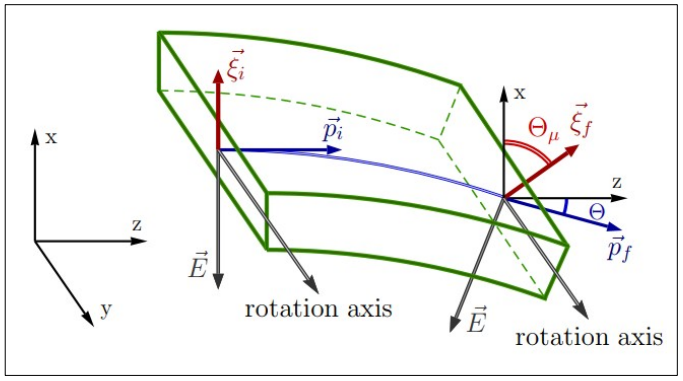


- Bent crystals work as a "smart deflectors" on primary halo particles
- Coherent particle-crystal interactions impart large deflection angle that minimize the escaping particle rate and improve the collimation efficiency



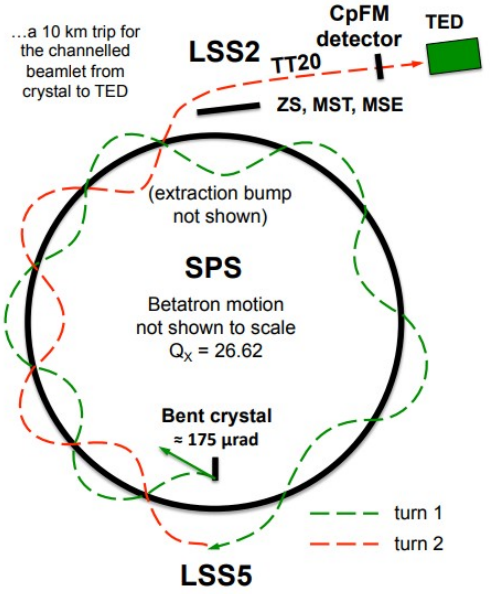
Measuring of short living baryons MDM (e.g. Λc^+[*udc*])

$$\Theta_\mu = \gamma\left(\frac{g}{2} - 1 - \frac{g}{2\gamma^2} + \frac{1}{\gamma}\right)\Theta \approx \gamma\left(\frac{g}{2} - 1\right)\Theta$$



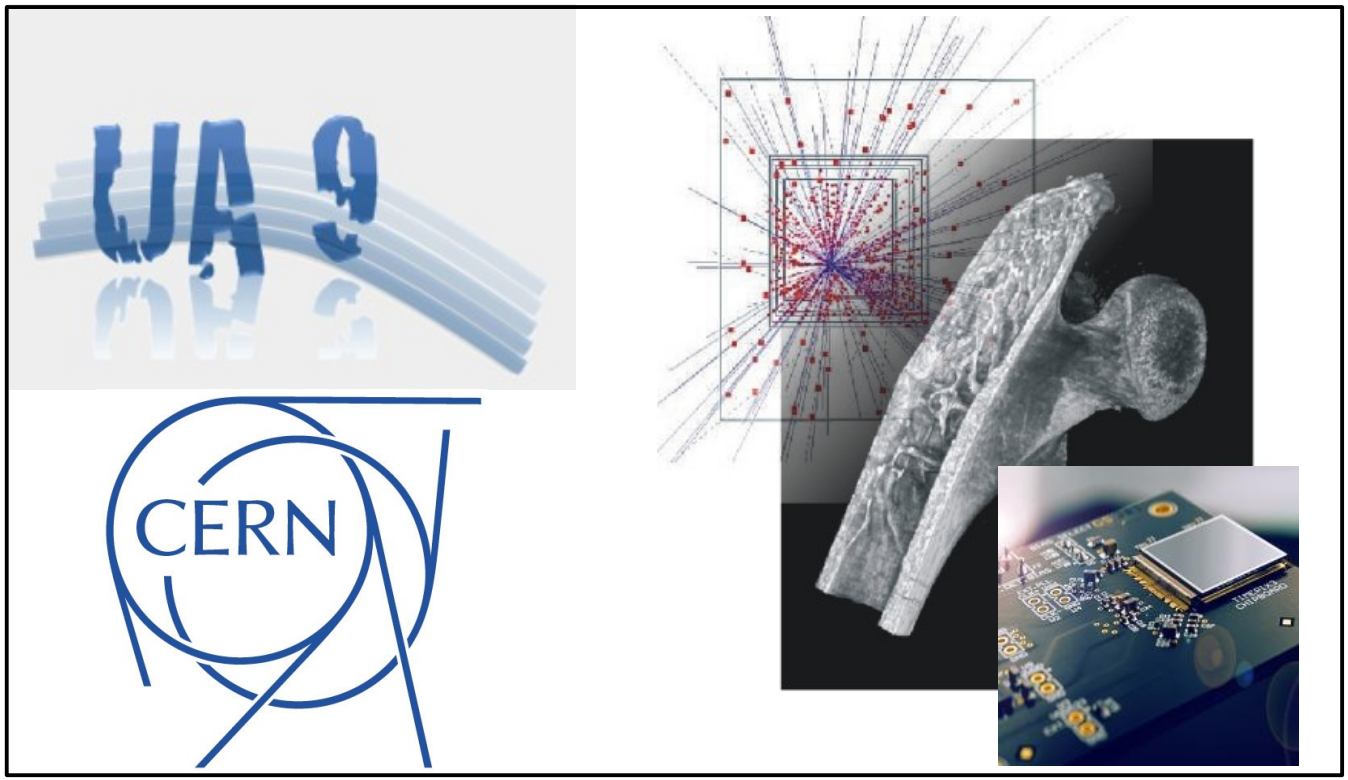
DOI: 10.1007/JHEP08(2017)120

Slow extraction at SPS



https://arxiv.org/pdf/1707.05151.pdf

Timepix & Timepix3



Timepix. Hardware description

Timepix:

→ a **hybrid** pixel detector;
→ **300 μm** thick Silicon layer;
→ **14×14 mm²** bump bonded read-out chip;
→ a matrix formed by **256×256 pixels;**
→ each pixel is **55×55 μm²**;
→ maximum digital counter is **11810** (**13.5 bit**);
→ Clock 96 MHz (~10.4 ns).

Modes of the detector operation:

- **Medipix mode**
- **Time of Arrival (ToA) mode**
- **Time over Threshold (ToT) mode**

Readout: USB2.0 via FITPix, with a frame rate up to 90 frames/s

Timepix3:

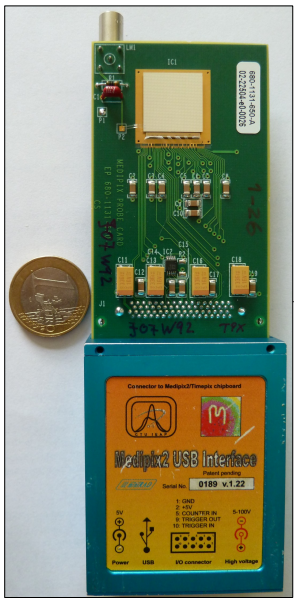
→ a **hybrid** pixel detector;
→ Silicon/Carbon layer;
→ **14×14 mm²** bump bonded read-out chip;
→ a matrix formed by **256×256 pixels;**
→ each pixel is **55×55 μm²**;
→ Clock 40 MHz (**25.0 ns**) + 640 MHz fast Clock (**1.56 ns**)

Each Timepix pixel can work in one of three modes:

- **ToA+ToT mode** (*ToA 18 bit & ToT 10 bit*)
- **ToA mode** (*ToA 18 bit)*
- ***Event count & Integral ToT*** *(iToT 18 bit & eCount 10 bit)*

Readout: Katherine, Ethernet embedded readout interface, 15 Mhits/s

Timepix



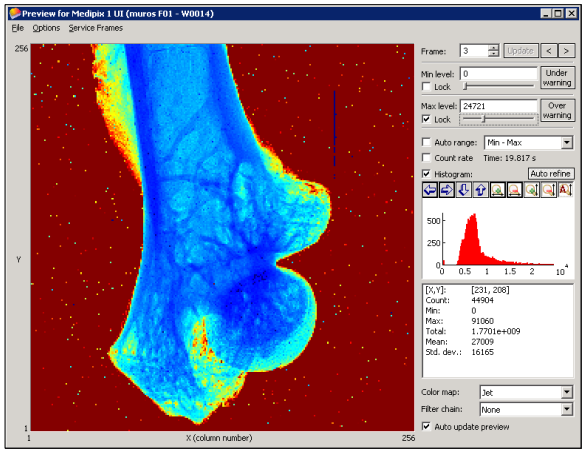
Quadpix (4 Timepix chips)

Timepix3

P. Burian [a,b], P. Broulim [a], V. Georgiev [a], M. Jara [a] and B. Bergmann [b]

[a] Faculty of Electrical Engineering, University of West Bohemia, Univeritni 26, Pilsen, Czech Republic
[b] Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, Prague, Czech Republic

Pixelman:
Timepix + FITPix

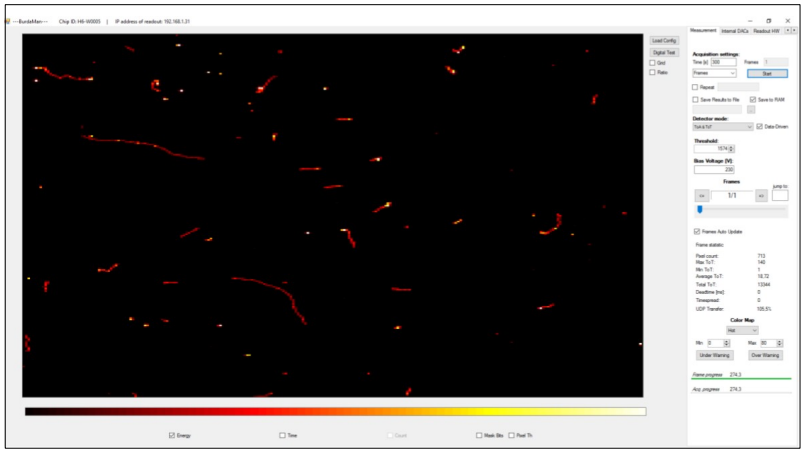


(1) **Pixelman Graphical User Interface** (GUI) (allows to visualize the acquired frames and to write data into the text files);

(2) **Python scripting plugin** (gives a possibility to integrate Pixelman libraries inside other data acquisition (DAQ) systems; multiple device synchronization).

http://aladdin.utef.cvut.cz/ofat/others/Pixelman/Pixelman.html

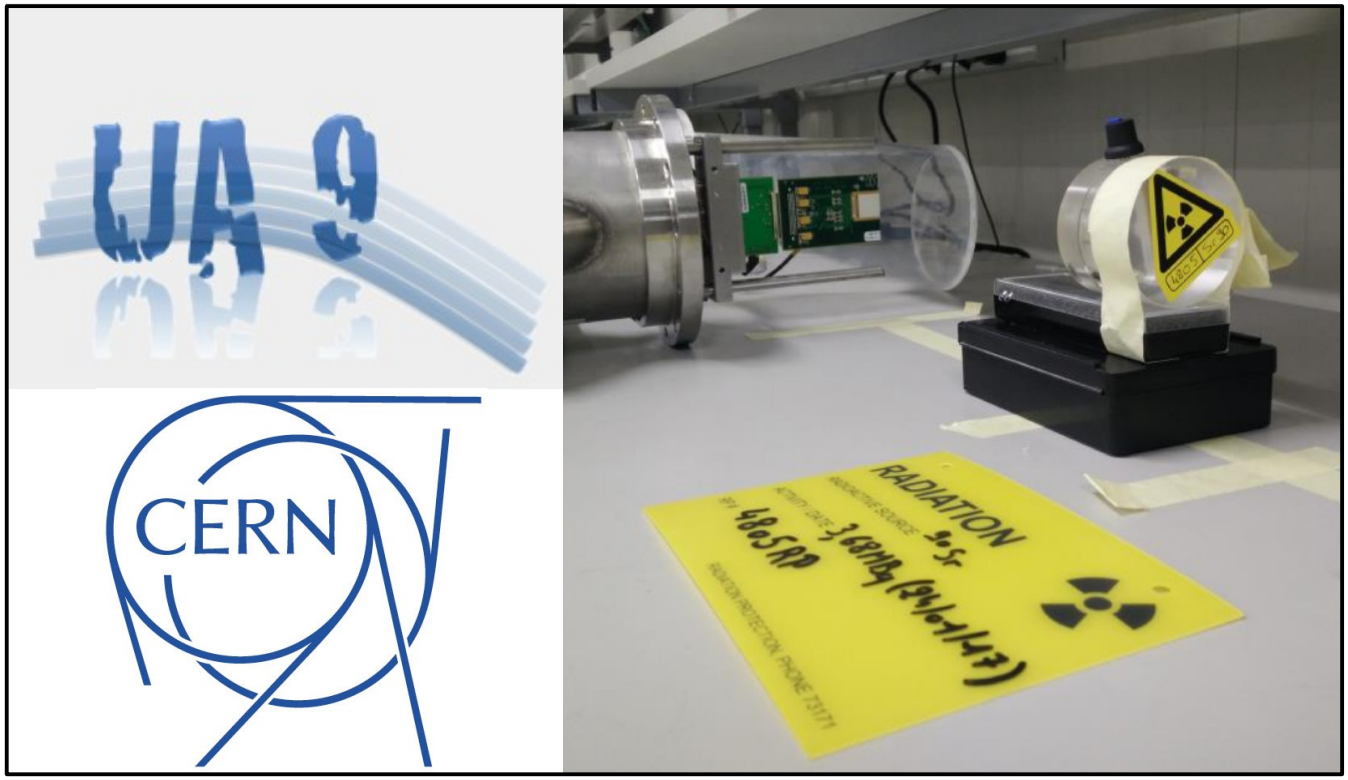
Burdaman:
Timepix3 + Katherine



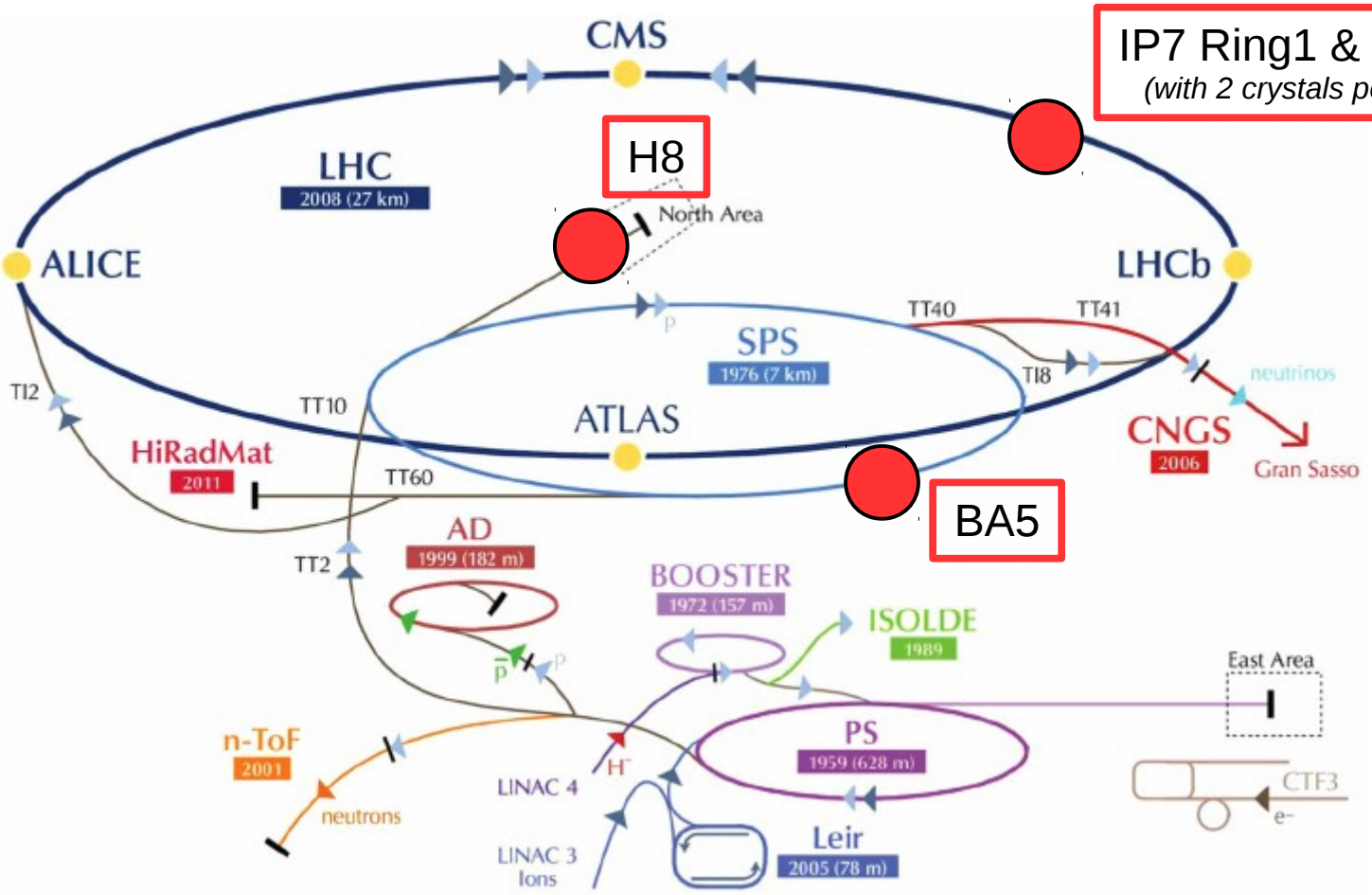
Allows detector control and data acquisition. Supports more readout devices connected to the Ethernet network.

https://doi.org/10.1088/1748-0221/12/11/C11001

Timepix applications in UA9

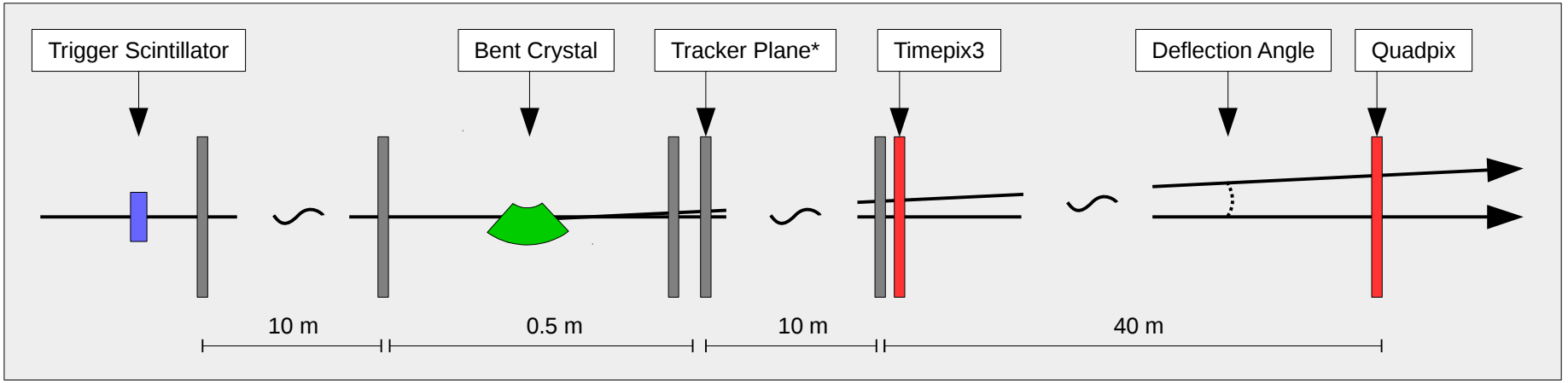


Timepix applications. Experimental areas



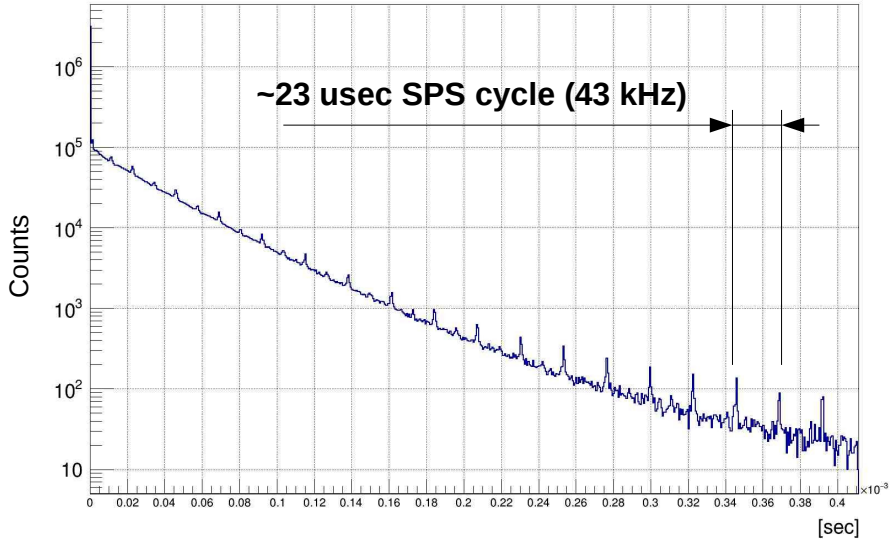
H8 (UA9 test-beam): Xe & Ar ions 70 & 150 GeV/u, protons 400 GeV/c and pions 180 GeV/c – up to 10^6 particles/s
SPS (UA9 MD): protons 270 GeV/c – single bunch ~10^{11} p, beam on COAST, extracted by the crystal ~10^5 particles/s

Timepix applications. H8 test-beam

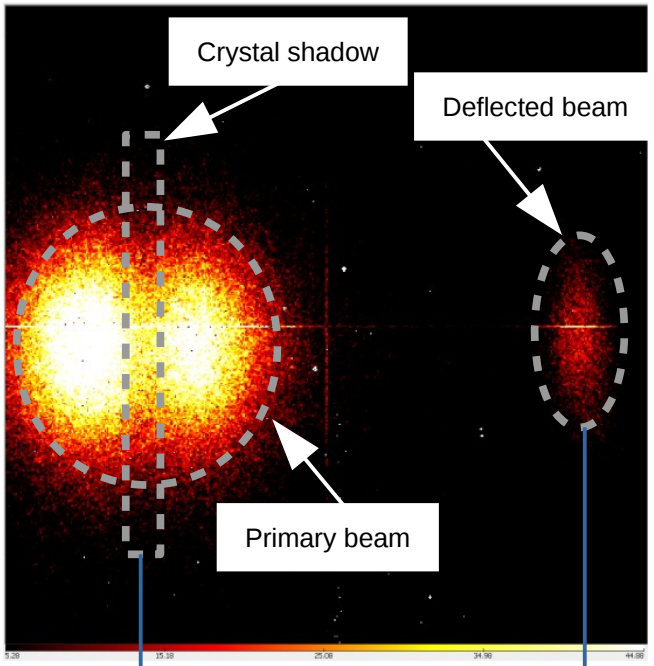


*http://iopscience.iop.org/article/10.1088/1748-0221/6/04/P04006/meta

Timepix3 (Diamondpix)
Placed **~10 m** from the crystal
400 GeV/c protons

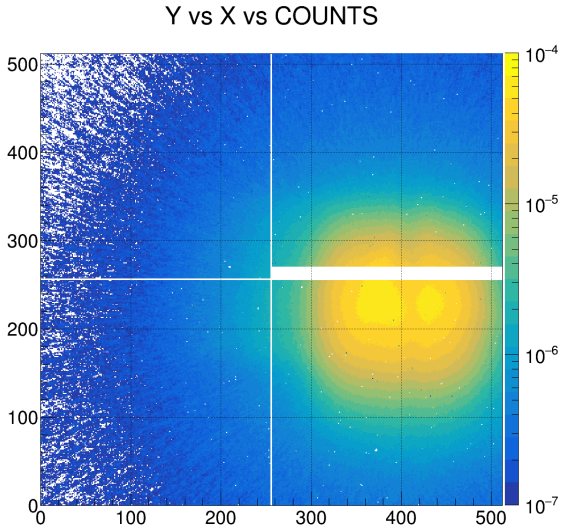


Quadpix (4 Timepix chips)
Placed **~50 m** from the crystal
400 GeV/c protons

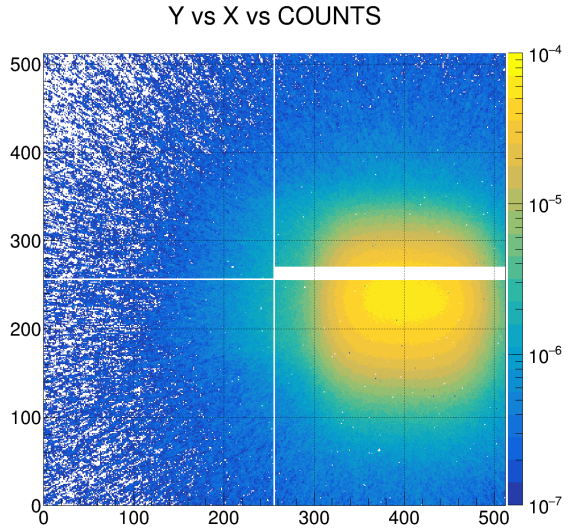


Crystal with **~420 urad** deflection angle

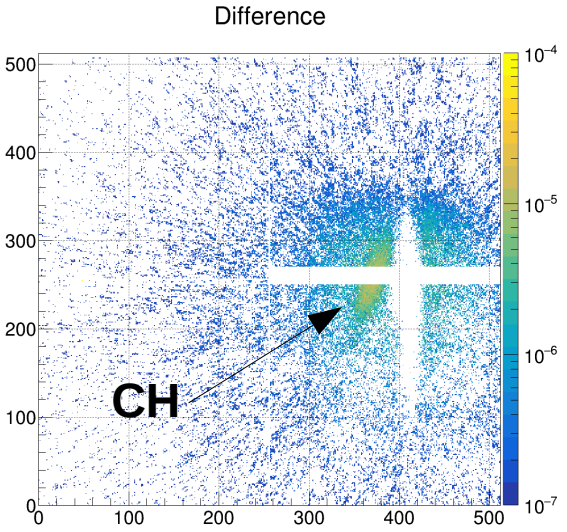
Integrated 500 frames (1 sec each) in MPX mode



Crystal in CH

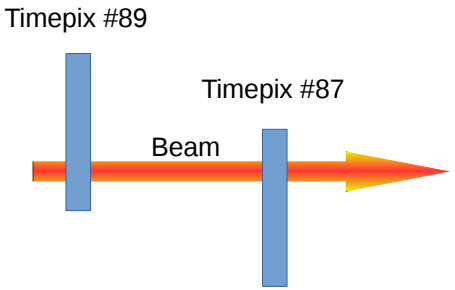


Without any object on the beam

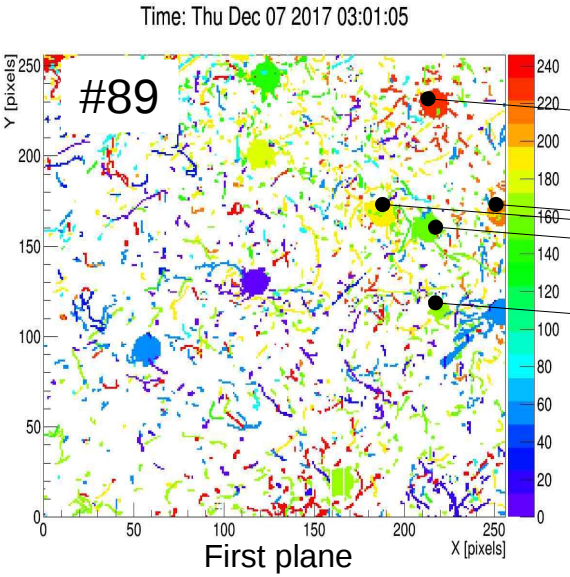


Small (~50 urad) angle crystal

Xe ion beam
Clock 48 MHz (20.8 nsec)
Time acquisition window 0.246 msec



Misaligned detectors,
due to the handmade holder =)

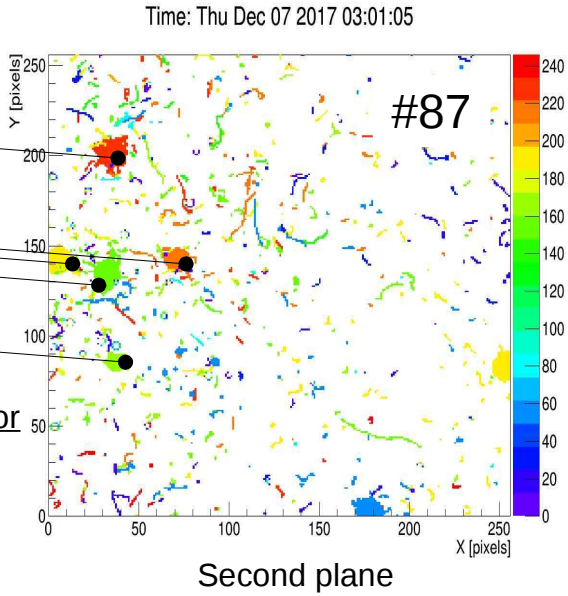


First plane

Beam direction

X

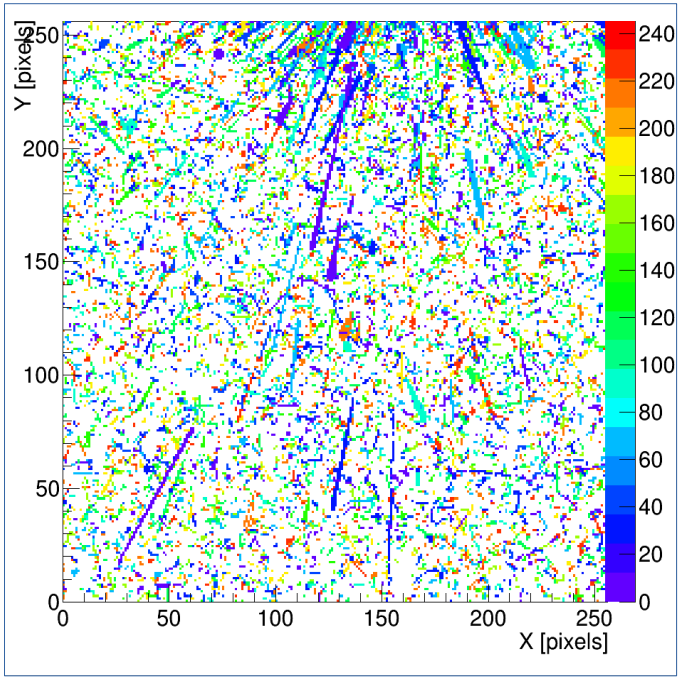
ToA [usec] in color



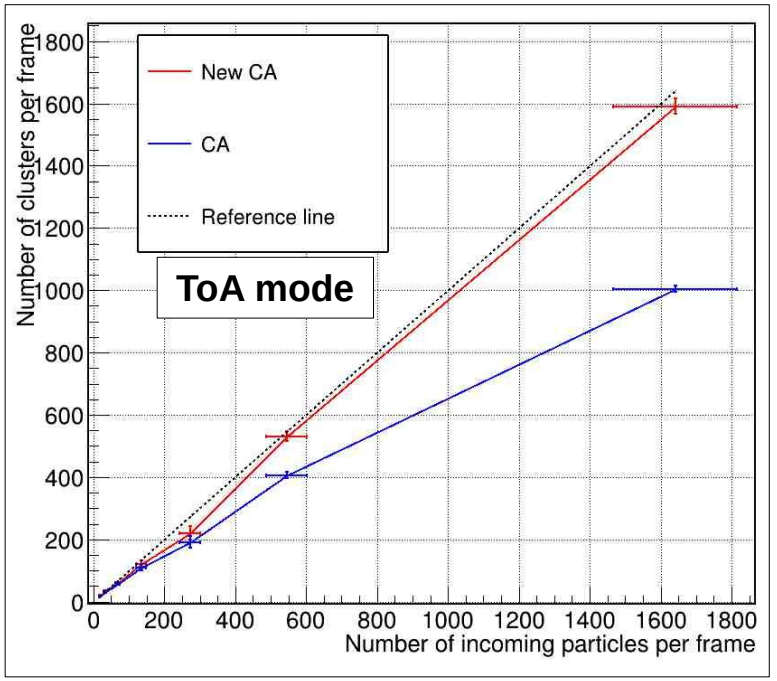
Second plane

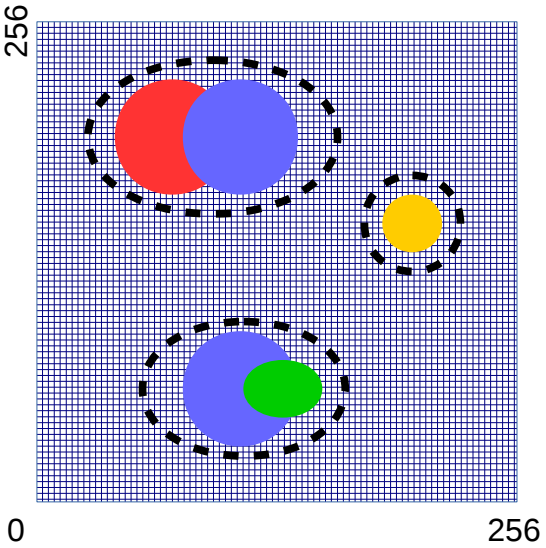
Timepix applications. Cluster analysis

Primaries and secondaries from the particle beam



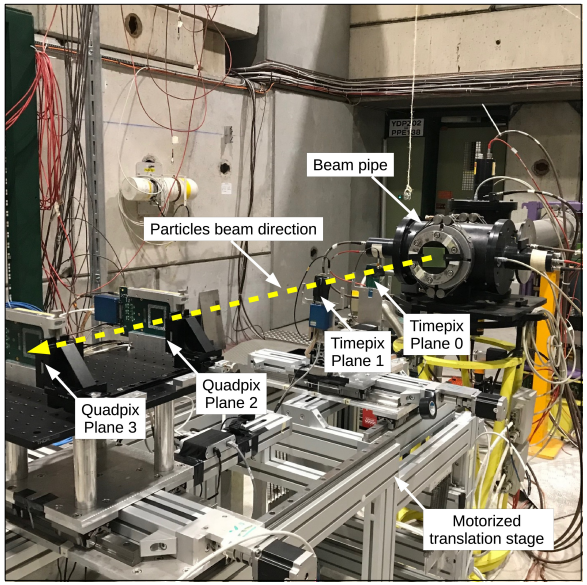
→ In ToA mode we take only the first hit of the pixel
→ Overlapping of the clusters



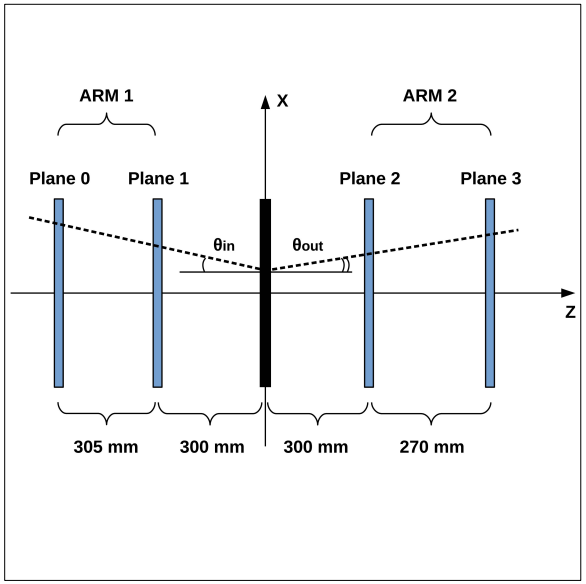


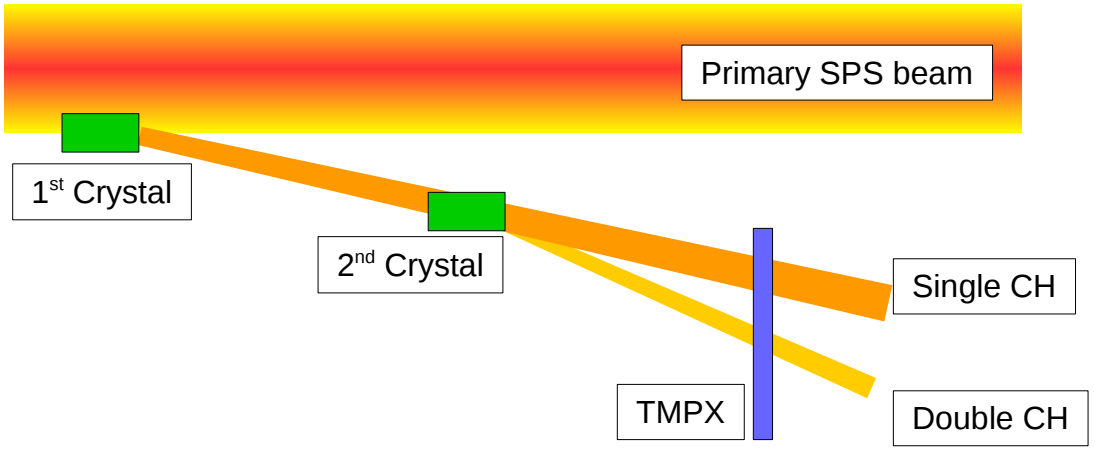
Comparison between the standard Cluster Analysis (CA) and improved one

Timepix applications. Telescope and Double channeling



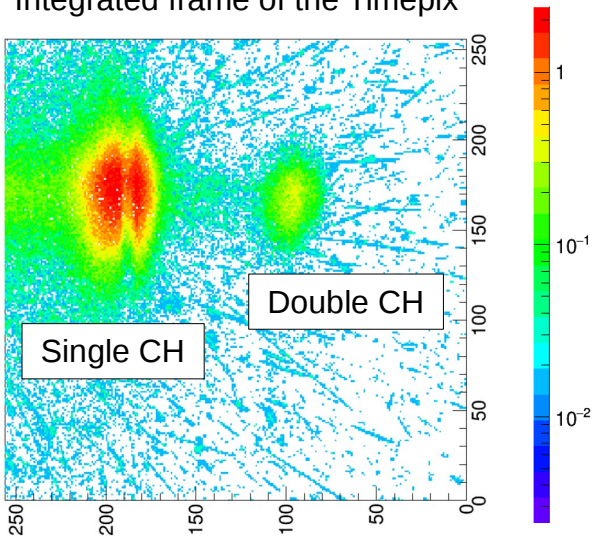
The telescope provides very good **70 µrad** angular resolution for reconstructed particle tracks with a flight base of **1.2 m** and track reconstruction efficiency of about **10 %**.



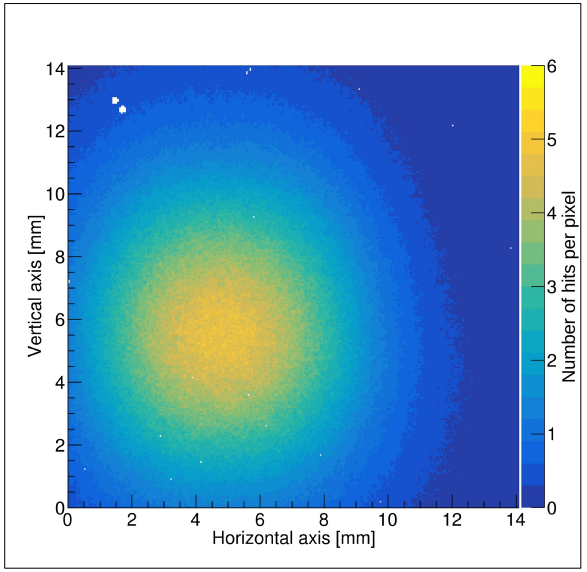


The setup is located inside SPS beampipe.

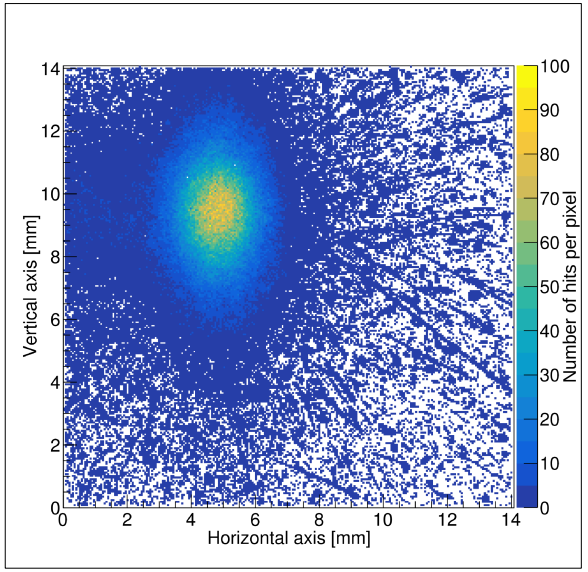
Integrated frame of the Timepix



The measured flux of the particles for H8 is about **$0.6 \cdot 10^5$ pions/s** 180 GeV/c (276 pions/(s·mm^2) in the beam core) and for SPS is about **$1.2 \cdot 10^5$ protons/s** 270 GeV/c (2606 protons/(s·mm^2) in the beam core), done with the Timepix detector (the active area is 196 mm^2).



The image of the pion 180 GeV/c beam at H8 SPS extracted beam line.



The image of the proton 270 GeV/c beam at SPS, deflected by the crystal.

The Timepix is a very user friendly device that seems to be robust enough to be used also in quantified beam monitoring also in secondary vacuum inside beam pipes (three years of operation, up to 0.4 kGy/year at SPS LSS5) of the accelerator machine like SPS at CERN.

Backup slide. Timepix Technical specifications

Features:

Pixel size 55μm x 55μm
256 x 256 pixels
Single energy threshold (adjustable per pixel with 4 bits)
Three modes of operation: (1) single particle counting (2) Time over Threshold (TOT) and (3) Time of Arrival (TOA)
Electron or hole collection -> compatible with various sensor materials
Can be combined with Gas Gain Grid to readout electron deposition in a gas detector
3-side buttable

Applications:

Adaptive optics and other visible or near visible light applications
Astrophysics
Background radiation monitoring
Digital Autoradiography
Dosimetry
Education
Electron microscopy
Life Sciences
Neutron imaging
Various X-ray and gamma-ray imaging applications
X-ray polarimetry measurements

https://medipix.web.cern.ch/collaboration/medipix2-collaboration

General	
Parameter	**Value**
CMOS technology	0.25 um
Pixel matrix	256 x 256
Pixel size	55 um x 55 um
Design	CERN
Features	• Single energy threshold (adjustable per pixel with 4 bits) • Three modes of operation: (1) single particle counting (2) Time over Threshold (TOT) and (3) Time of Arrival (TOA) • Can be combined with Gas Gain Grid to readout electron deposition in a gas detector • Hit rate 100 KHz • 3-side buttable
Power supply	Two independent 2.2V power supplies for the analog and digital part
Number of transistors	~36 million
Analog front end (pixel cell)	
Parameter	**Value**
Baseline shift preamplifier output	112 e- rms
Signal polarity	Positive and negative
Detector capacitance	
Leakage current	-10 to 20 nA
TOT monotonicity	Up to 200Ke-
Time to peak	110 ns
Noise	75 e-
Analog static power comsumption	6 uW
Analog power comsumption	440mW
Digital part (pixel cell + periphery)	
1 counter/shift register	14 bits (11810 counts)
periphery	• 13 8-bit DACs to set voltages in the chip • 1 256-bit Fast Shift Register to write in or readout the sensitive area • 127 I/O pads • LVDS drivers and receivers (configuration of the chip in serial mode) • Parallel 32-bit CMOS bus (chip readout can be serial or parallel)
Readout time in serial mode (100 MHz clock)	9 ms (102 Mbps)
Readout time in parallel mode (100 MHz clock)	266 us (3.5 Gbps)
Digital power comsumption	450mW

Backup slide. Timepix3 Technical specifications

Features:

Pixel size 55µm x 55µm
256 x 256 pixels
Timepix3 is suitable for readout of both semiconductor detectors and gas-filled detectors
Single thresholds per pixel each with 4 bits of local adjustment
Two main measurement modes: (1) simultaneous 10 bit ToT and 18 bit TOA and (2) 10 bit event counting and 14 bit integral TOT
TOT monotonic for large positive charges
Fast TOA for time stamping with a precision of 1.56 ns
Data driven readout: dead time free, for a maximum hit rate of 40 Mhits/s/cm^2
Shutdown/wake-up features for power pulsing tests on a full system
3-side buttable (with a single 1.2mm dead edge)
TSV ready

Applications:

X-rays imaging
Particle track reconstruction.
Timepix3 is suitable for readout of both semiconductor detectors and gas-filled detectors.

General Features	
Parameter	**Value**
CMOS technology	0.13 um
Pixel matrix	256 x 256
Pixel size	55 um x 55 um
Design	CERN, NIKHEF, Bonn University
Features	• Two main measurement modes: (1) simultaneous 10 bit ToT and 18 bit TOA and (2) 10 bit event counting and 14 bit integral TOT • TOT monotonic for large positive charges • Fast TOA for time stamping with a precision of 1.56 ns • Data driven readout: dead time free, for a maximum hit rate of 40 Mhits/s/cm^2 • Shutdown/wake-up features for power pulsing tests on a full system
Power supply	
Number of transistors	
Analog Front end	
Parameter	**Value**
Baseline Preamplifier output	
Signal polarity	Positive and negative
Detector capacitance	25 to 100 fF
Leakage current	-5 to 20 nA
TOT monotonicity	Up to 300Kh+
TOA jitter and mismatch	Compatible with 1.56ns resolution (gas detector applications)
Time to peak	25 ns (in view of VELOpix)
Noise + threshold mismatch	90e-
Equalization DACs	4 bit (compensate pixel to pixel threshold mismatch)
Analog static power consumption	12 uW/pixel

https://medipix.web.cern.ch/collaboration/medipix3-collaboration