PAUL SCHERRER INSTITUT

Michael Eichin:: Centre for Proton Therapy :: Paul Scherrer Institut

Pixel Detector System for Pencil Beam Scanning Proton Therapy

21st IEEE Real Time Conference 2018 – Colonial Williamsburg – June 14th

Outline

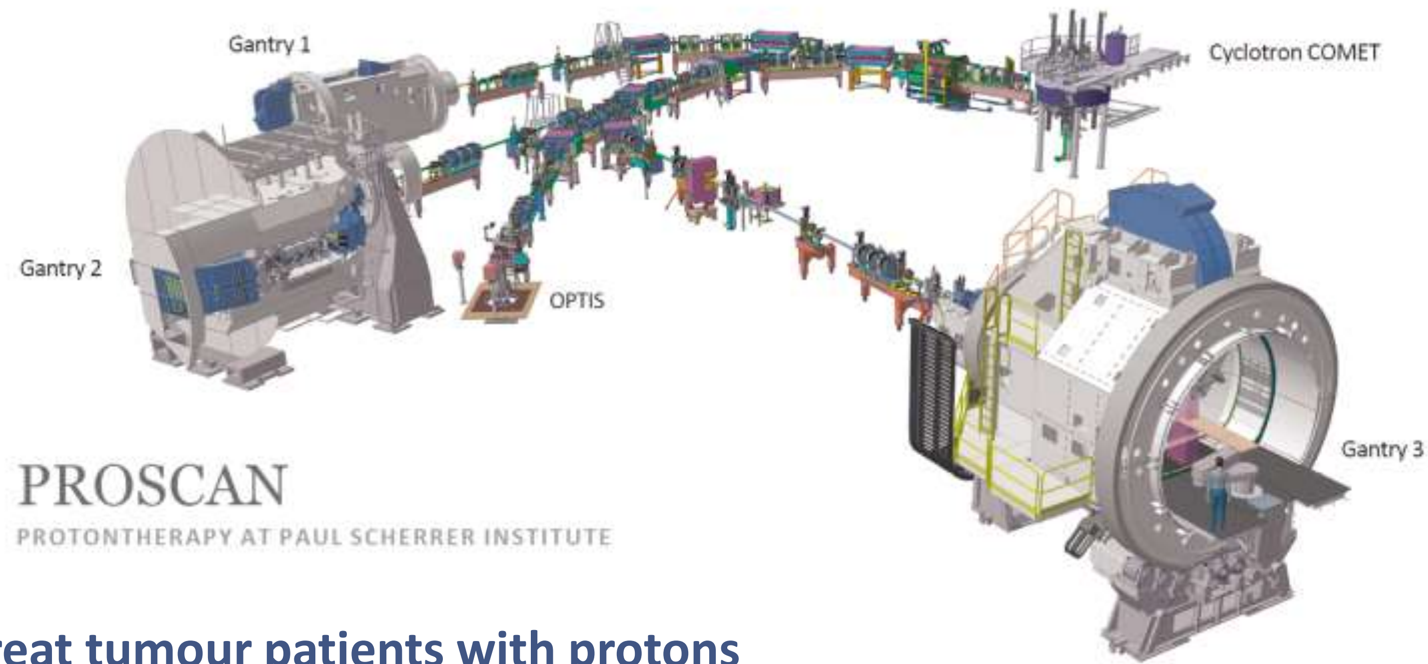
Proton Therapy at PSI

Pixel Detector 1 – Technology & Results

Pixel Detector 2 – Technology & Results

Outlook & Summary

Proton Therapy at PSI



PSI facility to treat tumour patients with protons

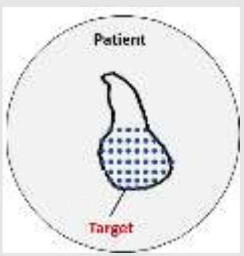
- COMET — Superconducting accelerator. One accelerator for all treatment areas
- Gantry1 — PSI development. In operation since 1996. Worldwide 1st gantry with spot scanning pencil beam technology.
- Gantry2 — PSI development. Performance optimized Gantry design for continuous scanning technologies.
- OPTIS2 — PSI development. Horizontal fixed beamline based on scattering technology
- Gantry3 — Commercial gantry from VARIAN Medical Systems. Based on raster scanning technology

Gantry 2 – Advanced Pencil Beam Scanning Technologies

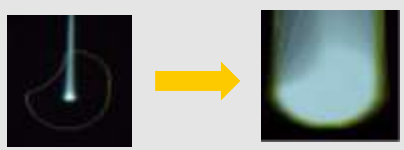
Gantry design

- ⇨ Further development of Gantry 1
- ⇨ Optimized for fast beam energy changes < 100 ms
- ⇨ Fast continous scanning in two directions
- ⇨ Scanning area 12 cm x 20 cm

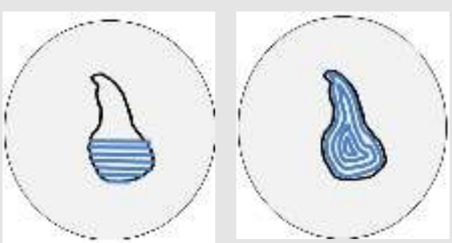
Spot Scanning



- ⇨ The tumor target of the patient is treated spot by spot
- ⇨ Patient treatment mode



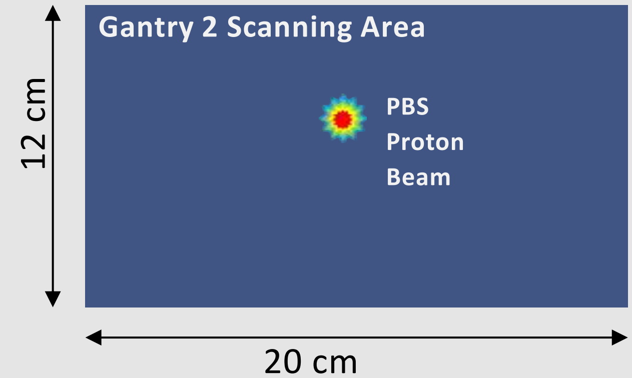
Continuous Scanning

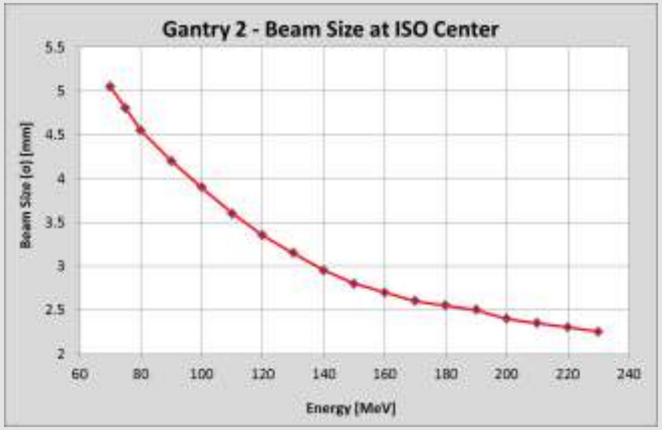


- ⇨ Line Scanning — Fast scanning in one direction
- ⇨ Contour Scanning — 2-dimensional scanning

Gantry 2 – Beam Characterization

- Scanning area size 20 cm x 12 cm
- Beam size is energy dependent
  - $\sigma_{beam\ size}$ 2 mm - 5 mm
- Delivery of a thin and round proton beam
  - Beam diameter < 3 cm
  - Proton beam covers only 3 % of scanning area
- Strip monitor for beam profile verification
  - 2 separate 1- D beam profiles
  - Calculation of beam position
  - **No direct beam shape measurement**





Conclusion

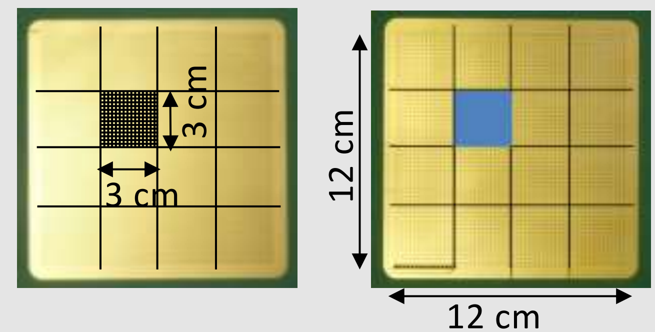
1. Only a small part of the scanning area will be used once.
2. True 2-D beam shape measurement requires a pixel detector.

Pixel Detector 1 – Technology

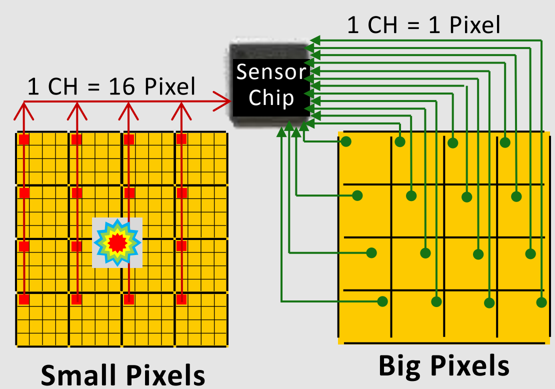
Pixel Detector – Prototype Design 1 – Proof of Principle

Detector material	Standard FR4 PCB
PCB Design	Multilayer – 100 µm structures
Active Area	12 cm x 12 cm
PCB Top Layer	3600 small copper pixels devided into 16 segments. Each segment has 15 x 15 pixels **(Pixel size 2x 2 mm)**
PCB Bottom Layer	Structure with 16 big pixels. Each big pixel covers one 15 x 15 small pixel field.
Pixel Layout	**Channel recycling** From each segment the same small pixels are connected to one PCB signal
Number of Readout channels	225 + 16 = **241**

TOP – Small Pixels **BOTTOM – Big Pixels**



Basic principle of Channel Multiplexing



Pixel Detector 1 – Technology

Pixel Detector – Prototype Design 1

Detector principle

- Ionization Chamber
- Gas medium ⇨ Air

Final detector design

- PCB Detector
- 2x HV electrode over TOP and BOTTOM side
- 2x Readout electronic boards.
  With total 256 readout channels
- **Compact design**
  Everything integrated in one mechanical case, including high voltage supply

Detector Ionization Chamber

Pixel Detector Prototype 1 with Case

Pixel Detector 1 – Technology

Readout Electronics – Multi Channel Current Sensor Board (MCCS)

Board Design Multi-Layer PCB design with µVia technology

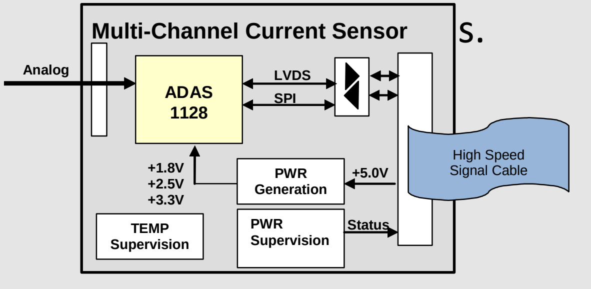
Core component **ADAS1128** Commercial readout chip

ADAS1128 Features
- ⇨Current to Digital converter
- ⇨128 analog readout channels
- ⇨Sensitivity range (configurable) 2.5×10^{-18} C to 40.3×10^{-18} C
- ⇨Readout cycle time (configurable) 50 µs to 900 µs

Other Features
- ⇨ OnBoard power generation
- ⇨ OnBoard power supervision
- ⇨ OnBoard temperature supervision

Detector interface side

Digital interface side



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Pixel Detector 1 – Technology

Readout Electronics – Control System Integration

Detector

Frontend electronics

2x MCCS boards (256 Channels)

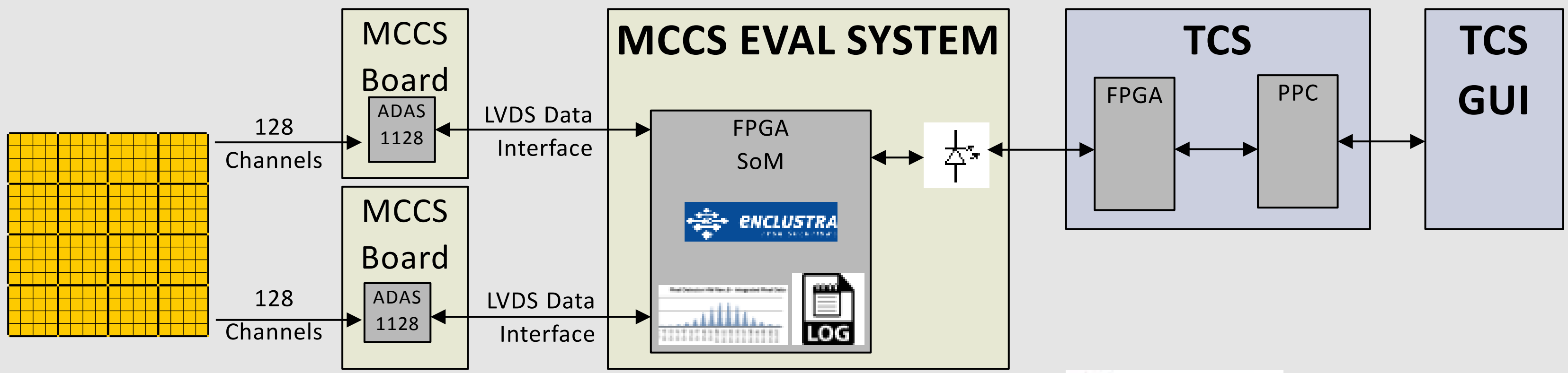
FPGA SoM from eNCLUSTRA

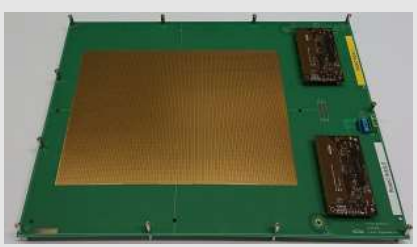
Therapy Control System

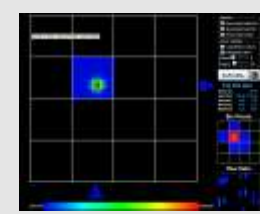
VME Plattform with FPGA

VxWorks OS running on PPC

JAVA GUI application



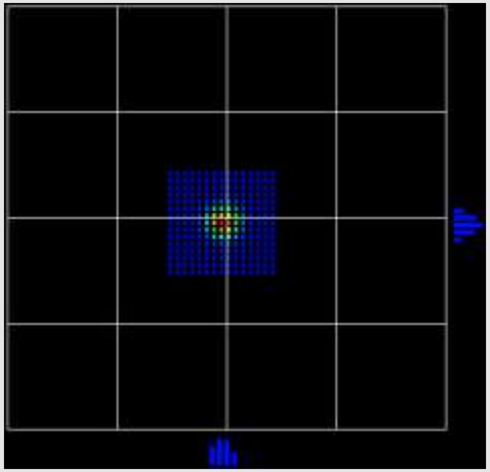




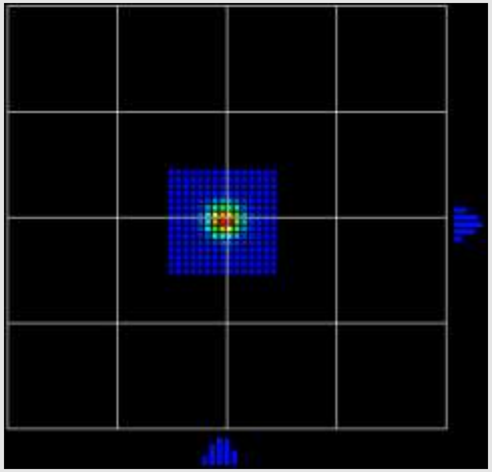
Pixel Detector 1 – Measurement Results

Pixel Detector – Prototype 1 – Spot Scanning Measurements

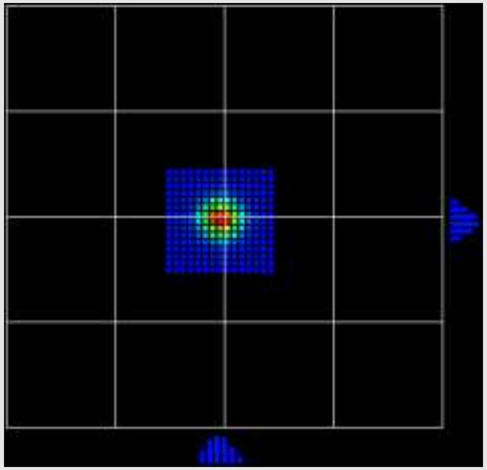
230 MeV



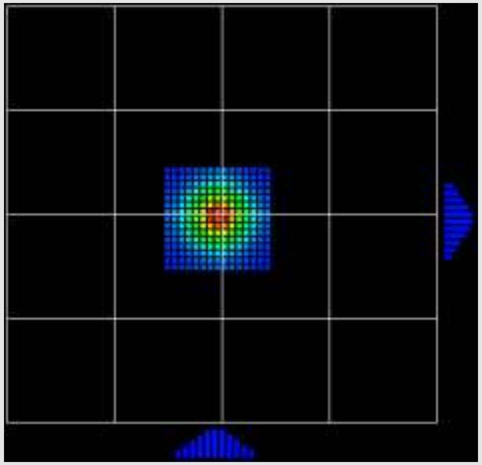
190 MeV



150 MeV



70 MeV



Pixel Detector 2 – Technology

Pixel Detector – Prototype Design 2

<u>Main changes from Detector 1 to Prototype 2</u>

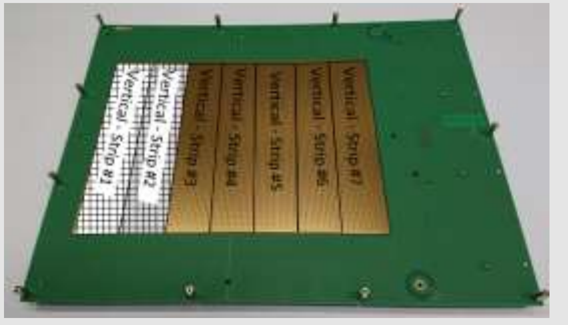
Active Area 26.25 cm x 18.75 cm
(Gantry 2 scanning area 20 cm x 12 cm)

Small Pixels 7875 – 35 segments with 15 x 15 Pixels on TOP and BOTTOM side.
(**Pixel Size 2.5 x 2.5 mm**)

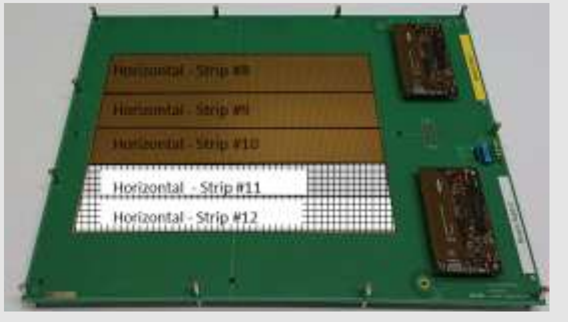
Strips Big pixels replaced by horizontal and vertical strips. This reduces the number of signals.

Number of Readout channels 225 + 12 = **237**

BOTTOM side – Pixels and vertical strips



TOP side – Pixels and horizontal strips

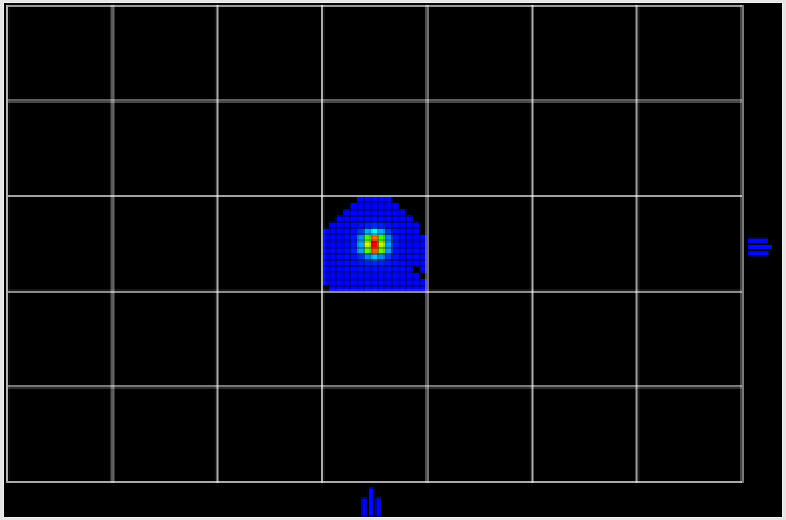


Detector with HV foils end electronic boards

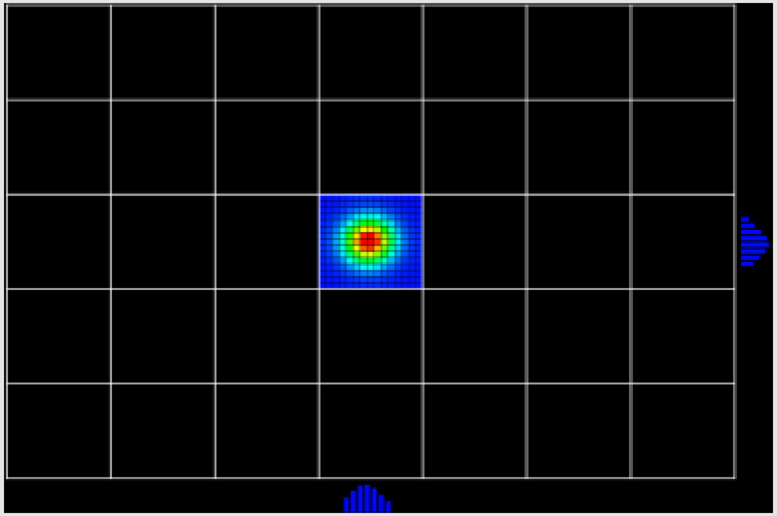
Pixel Detector 2 – Measurement Results

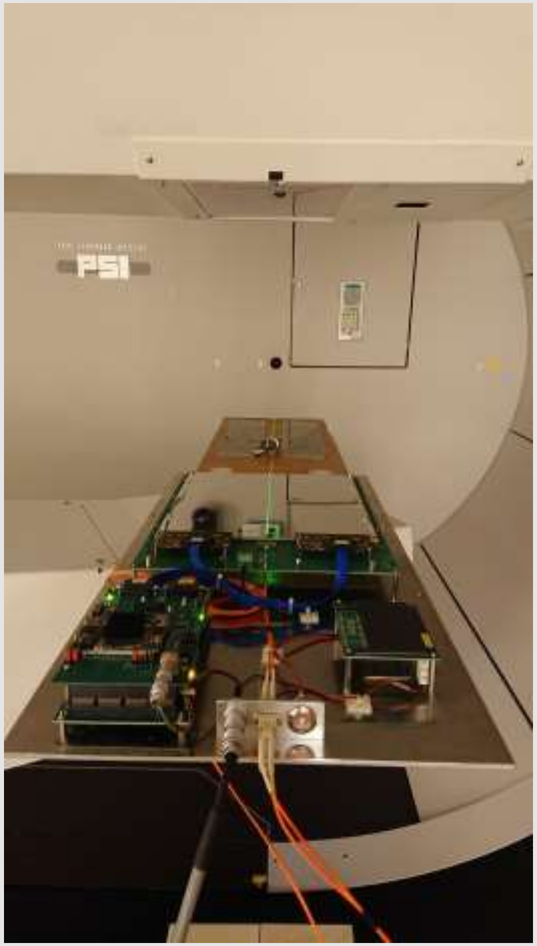
Pixel Detector – Prototype 2 – Spot Scanning Measurements

230 MeV



70 MeV

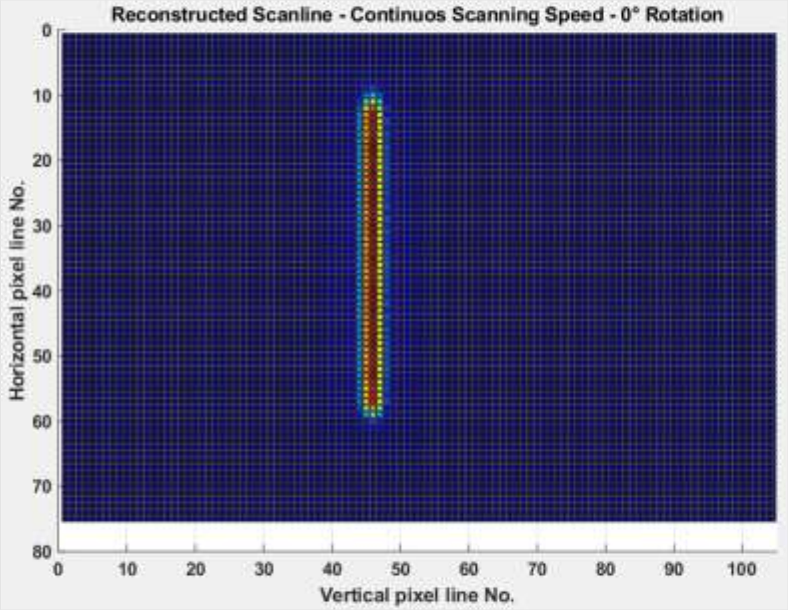


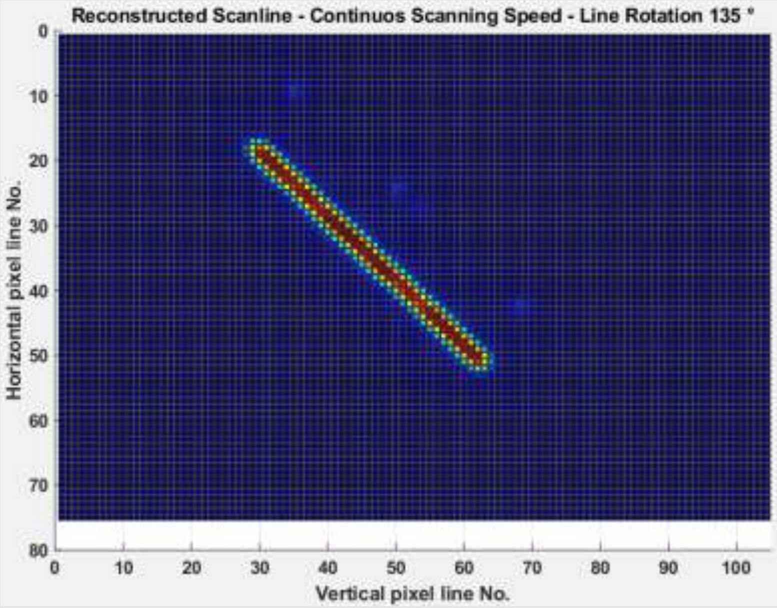


Pixel Detector 2 – Measurement Results

Pixel Detector – Prototype 2 – Continuous Scanning

Scan line length	12 cm
Scanning speed	0.2 cm/ms ⇨ 60 ms
Proton beam current	~3 nA
Logging cycle time	200 µs

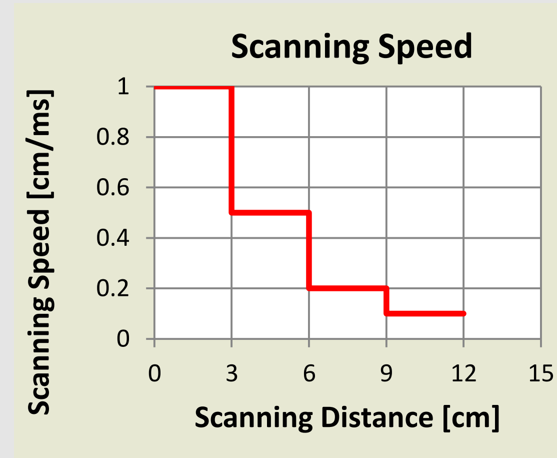


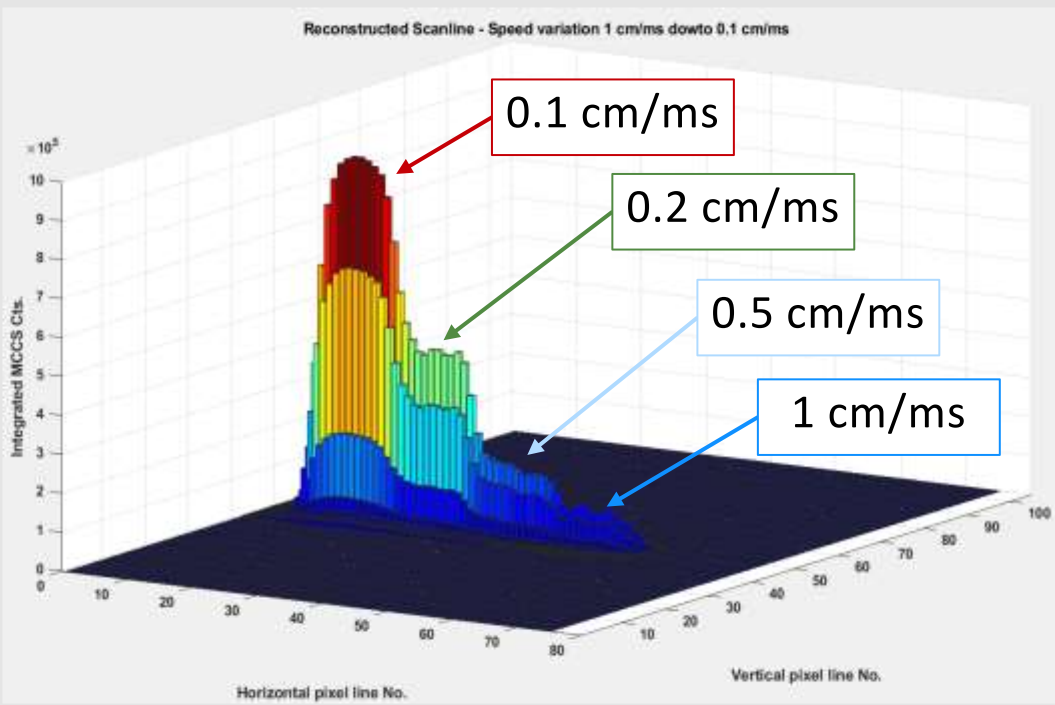


Pixel Detector 2 – Measurement Results

Pixel Detector – Prototype 2 – Line Scanning Speed Variation

Scan line length	12 cm
Scanning speed	Changed every 3 cm
Proton beam current	~3 nA
Logging cycle time	200 µs

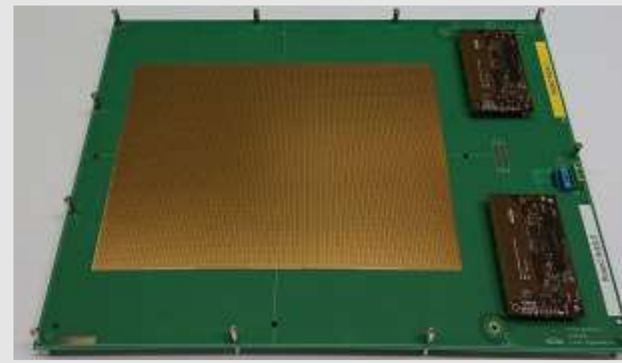




Summary

✓ ⇨ **Standard technology**

- Standard PCB technology for detector design
- Commercial readout chip from industry



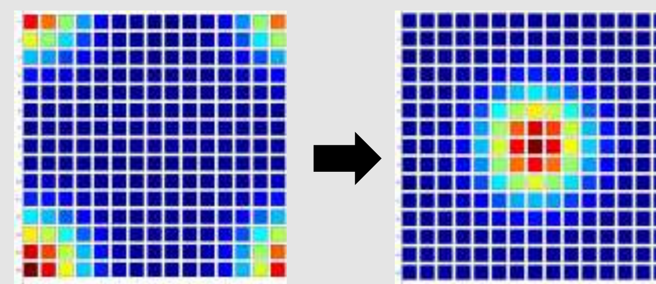
✓ ⇨ **Scalable detector design**

✓ ⇨ **Ressource optimized design**

- Minimum number of readout channels

✓ ⇨ **Readout electronics synchronized to beam delivery**

✓ ⇨ **Full 2-D beam shape reconstruction (Spots & Lines)**



Raw Detector Data → **Reconstructed Spot Profile**