CMOS SPAD sensor chip for the readout of scintillating fibre mats

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

Benedict Maisano
Prof. Dr. Peter Fischer
Robert Zimmermann
University Heidelberg

FEE 2023

Intro

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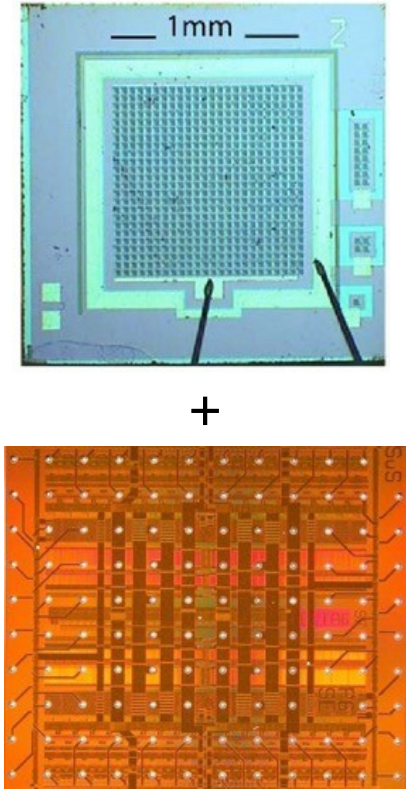
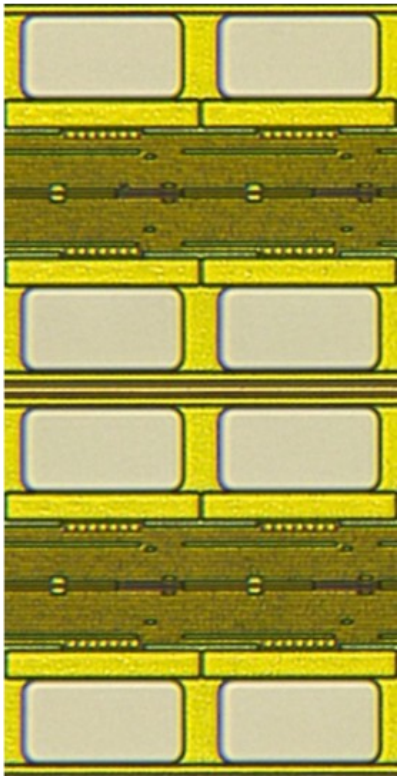
CMOS SPADs

SiPM + ASIC



Digital SiPM



SPAD and readout circuitry on same substrate

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Structure

Motivation

Concept

Chip Design

Setups

Results

Outlook

Motivation

Motivation

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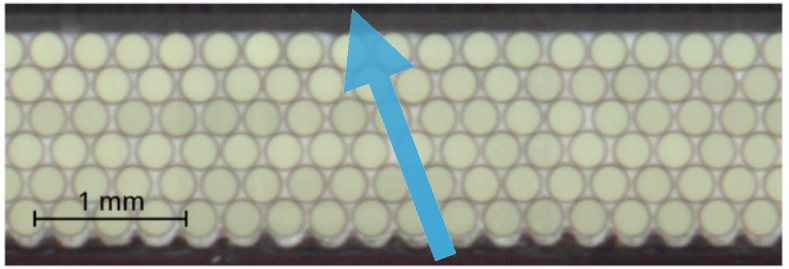
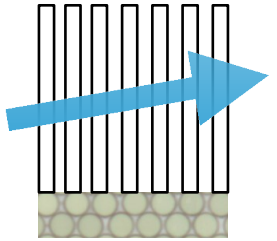
Scintillating fibre mat readout



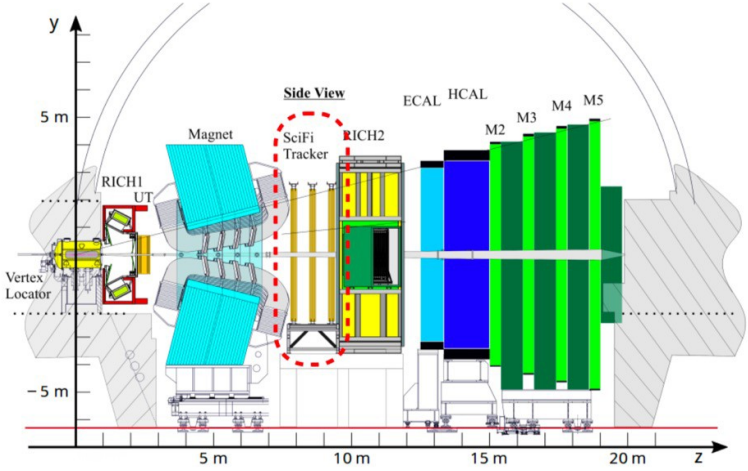


Charged particles cause fibres to emit light

Application:

- Particle physics
- Hadron therapy
- Calorimeters

Versatile Particle Tracker



LHCb @ CERN

Motivation

Scintillating fibre mat readout

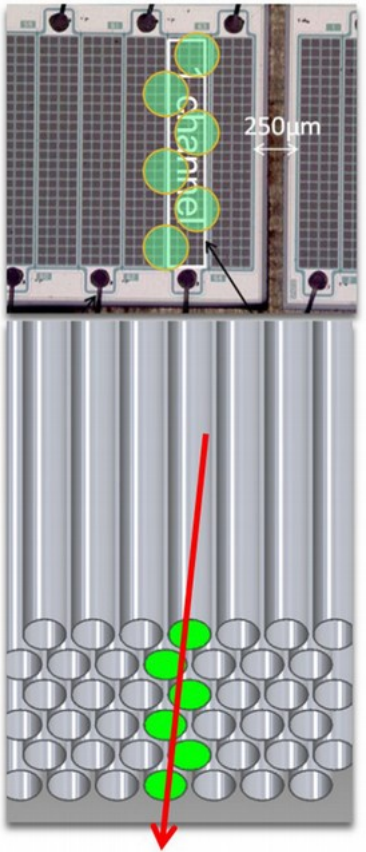
State of the Art

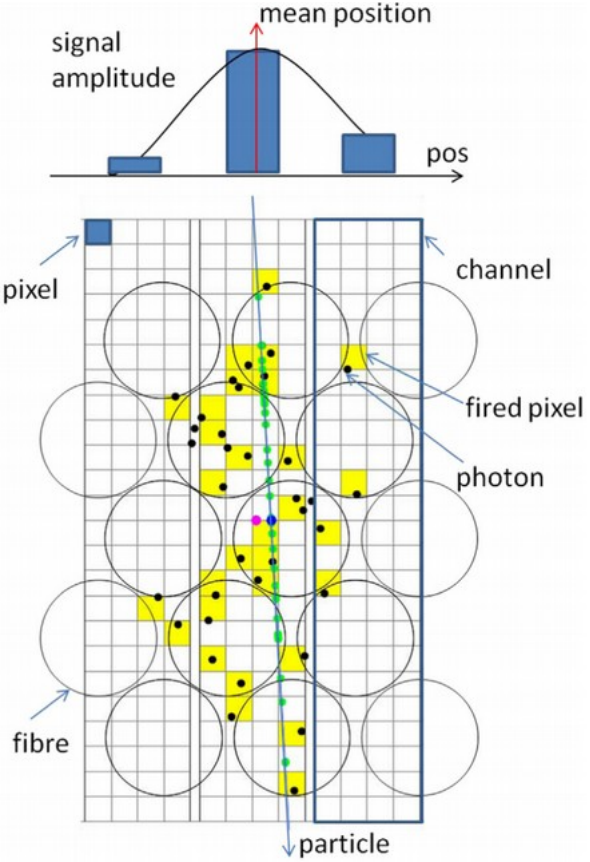
- Alignment is critical

- Complex data

- Modest timing

- Many parts





Concept

Concept

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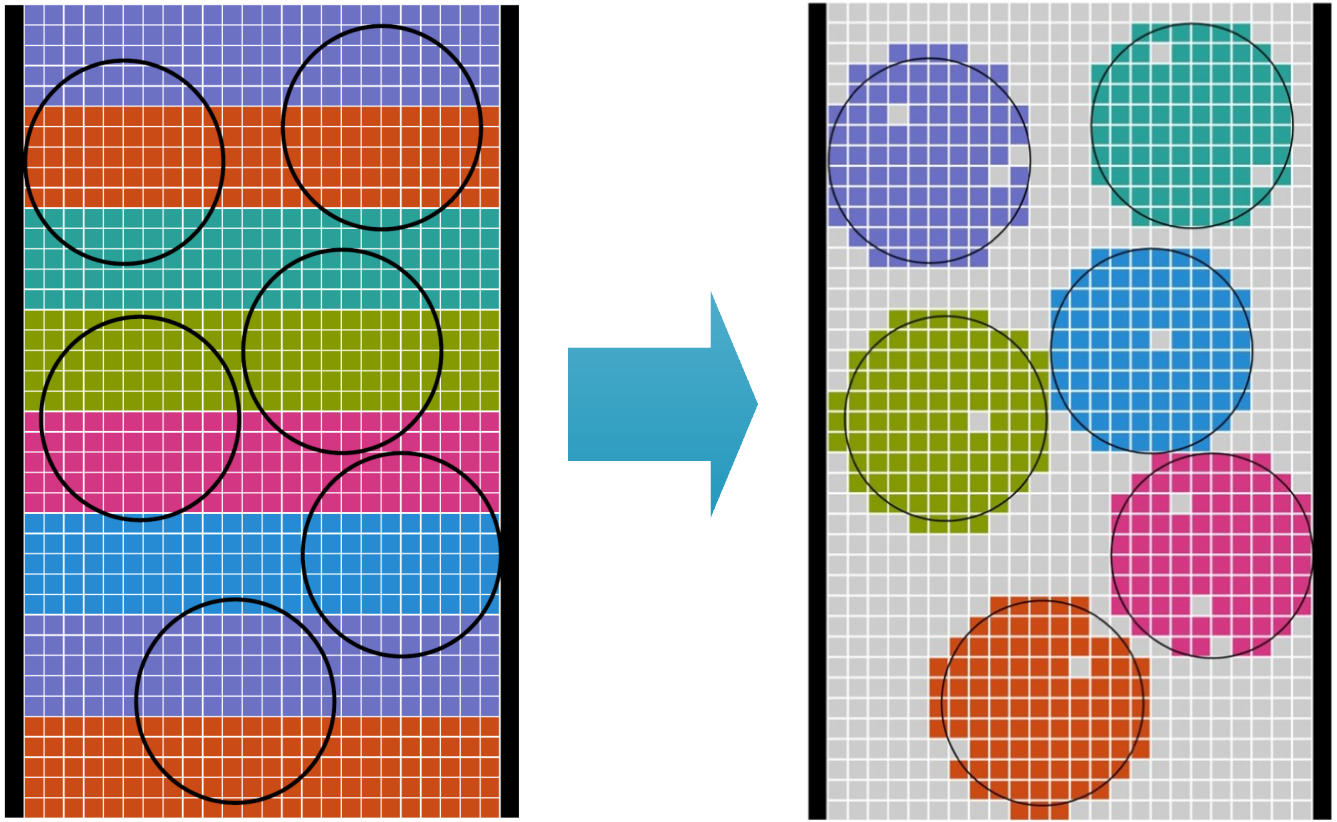
Scintillating fibre mat readout

Single fibre readout by grouping individual SPADs



Concept

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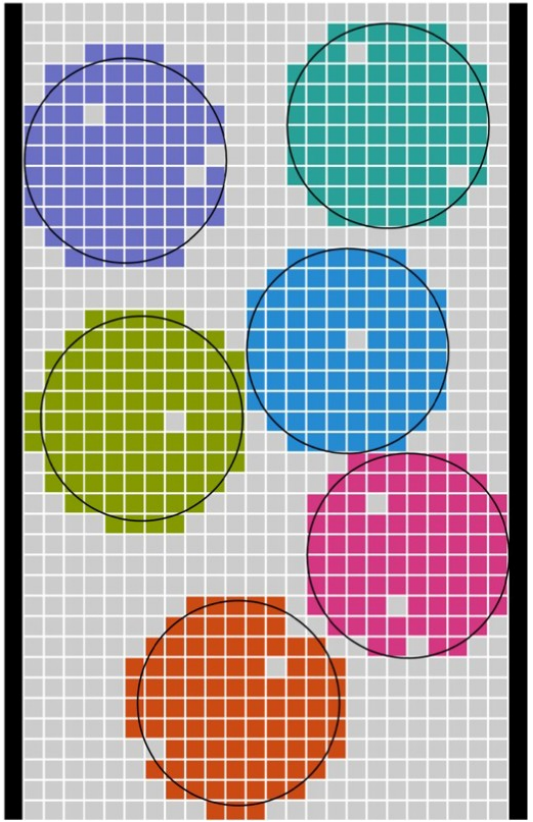
Scintillating fibre mat readout

Single fibre readout by grouping individual SPADs

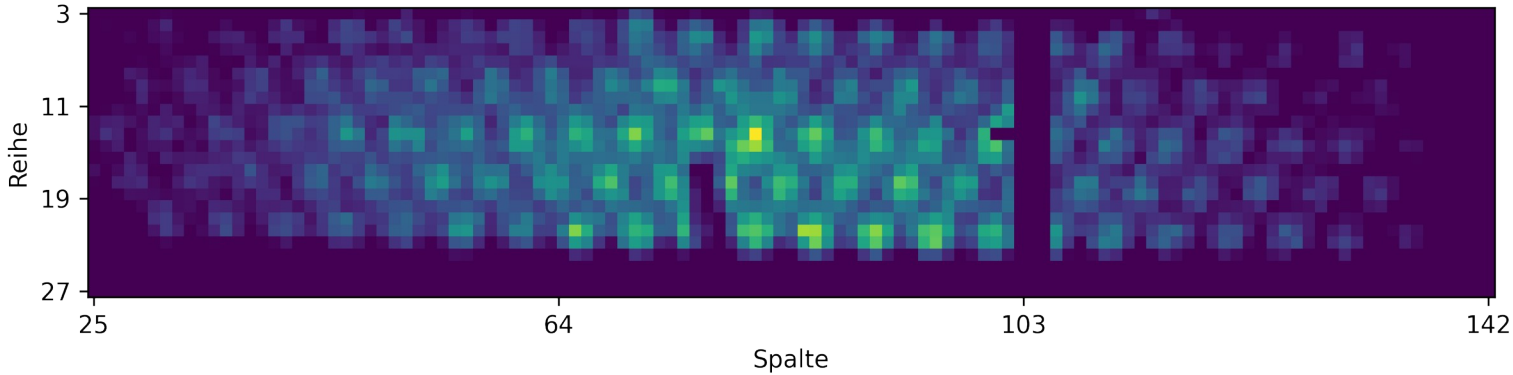
- Maximal spacial resolution
- Alignment is fully uncritical
- No DCR from unused SPADs
- Simpler system
- Fair timing (~500ps so far)

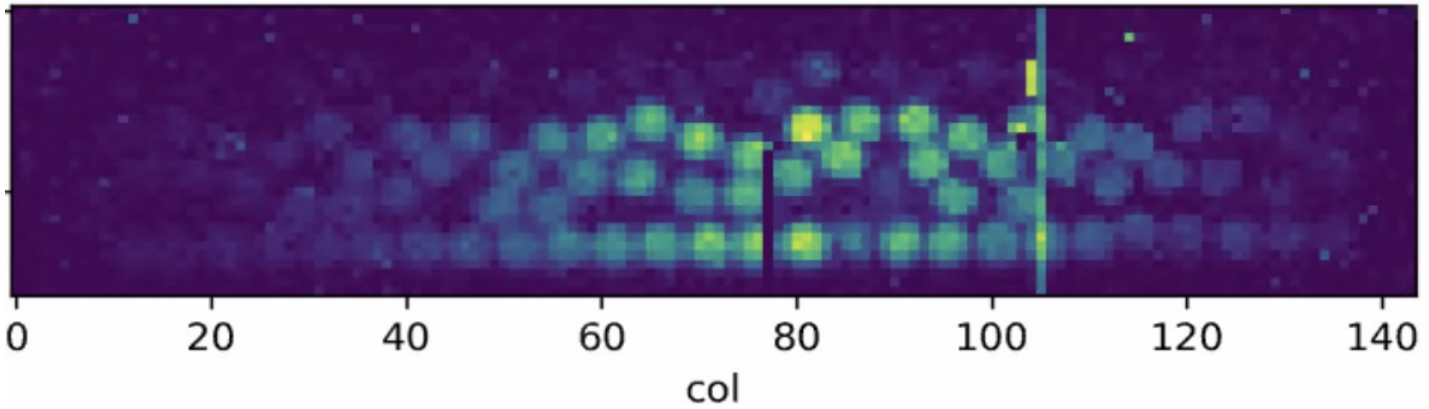


Concept

Scintillating fibre mat readout

It works brilliantly!





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Concept

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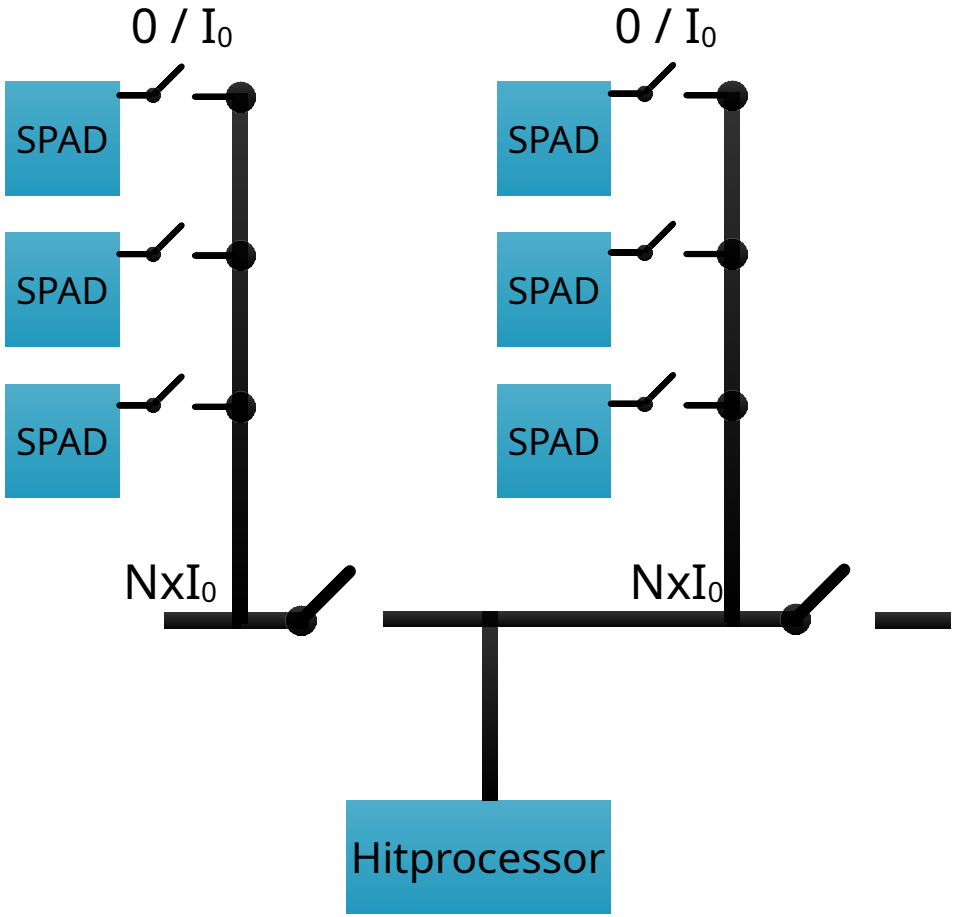
Defining a group:



Concept

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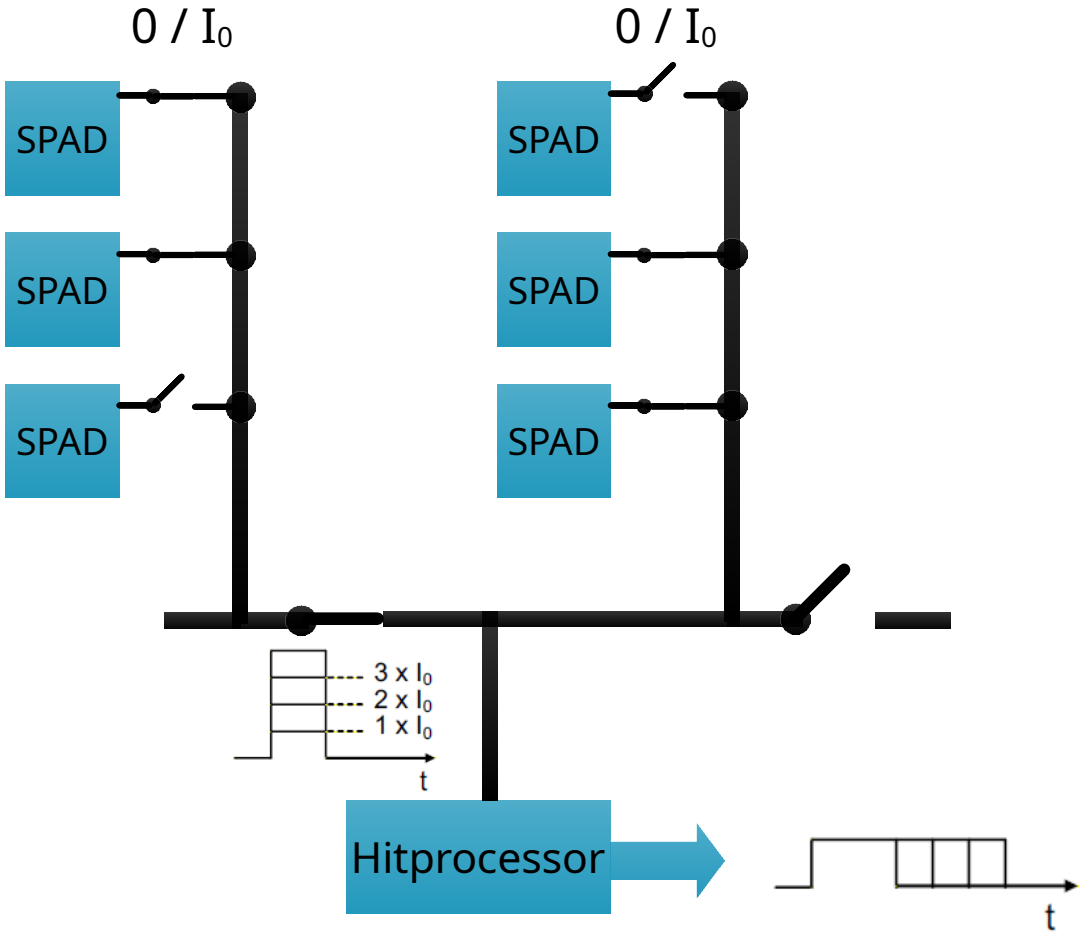

Concept

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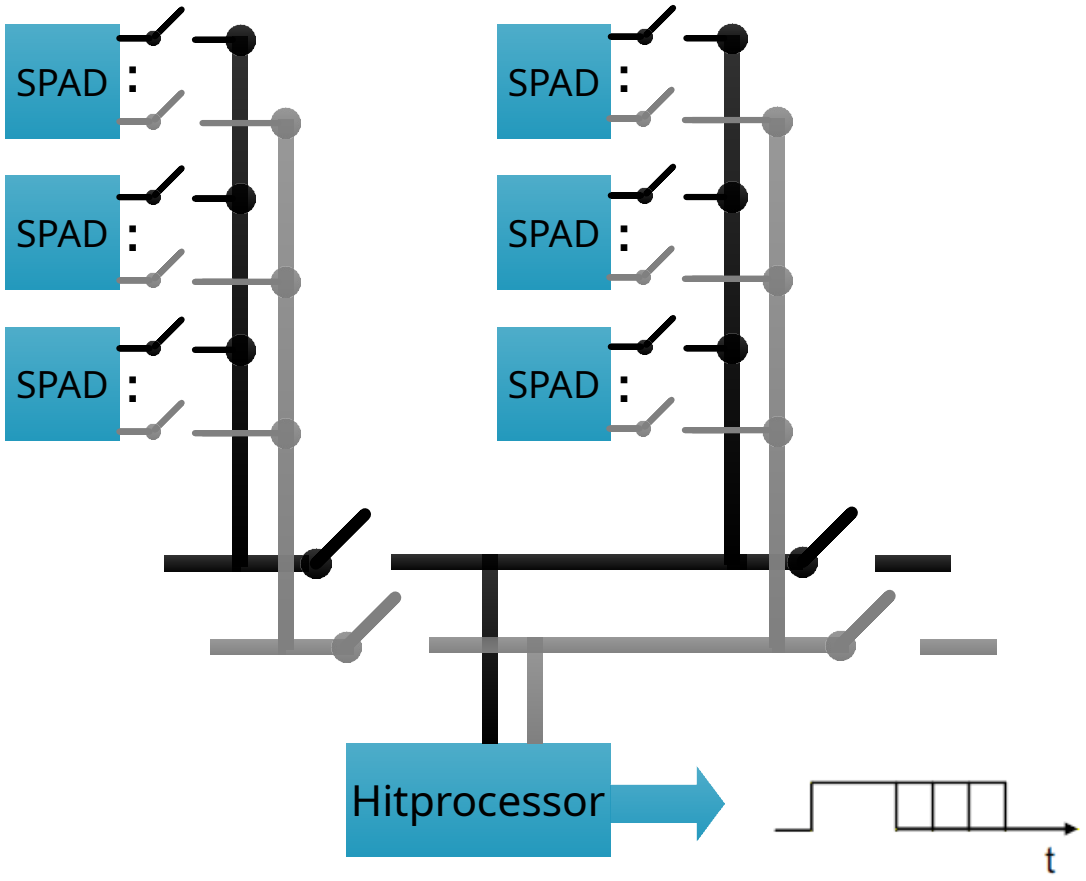
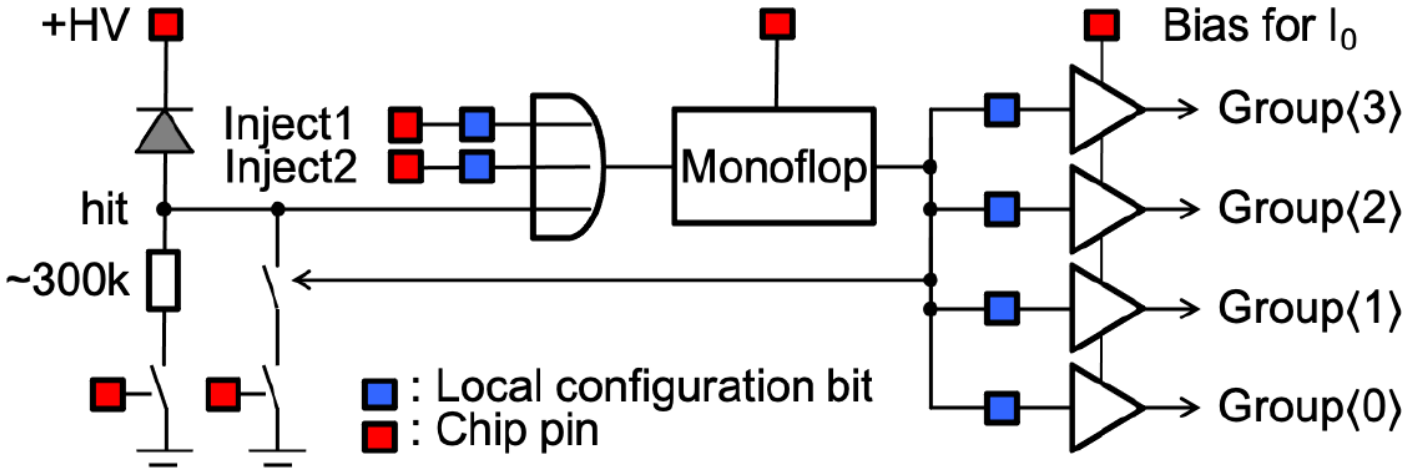
Defining a group:



Chip Design

SPAD to Group



Chip Design

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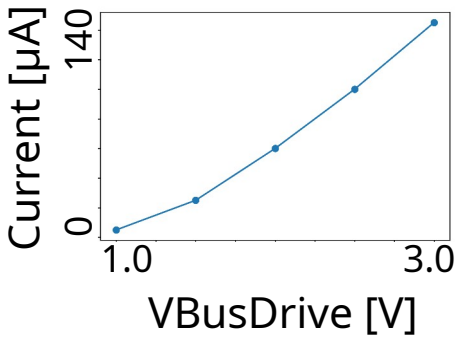
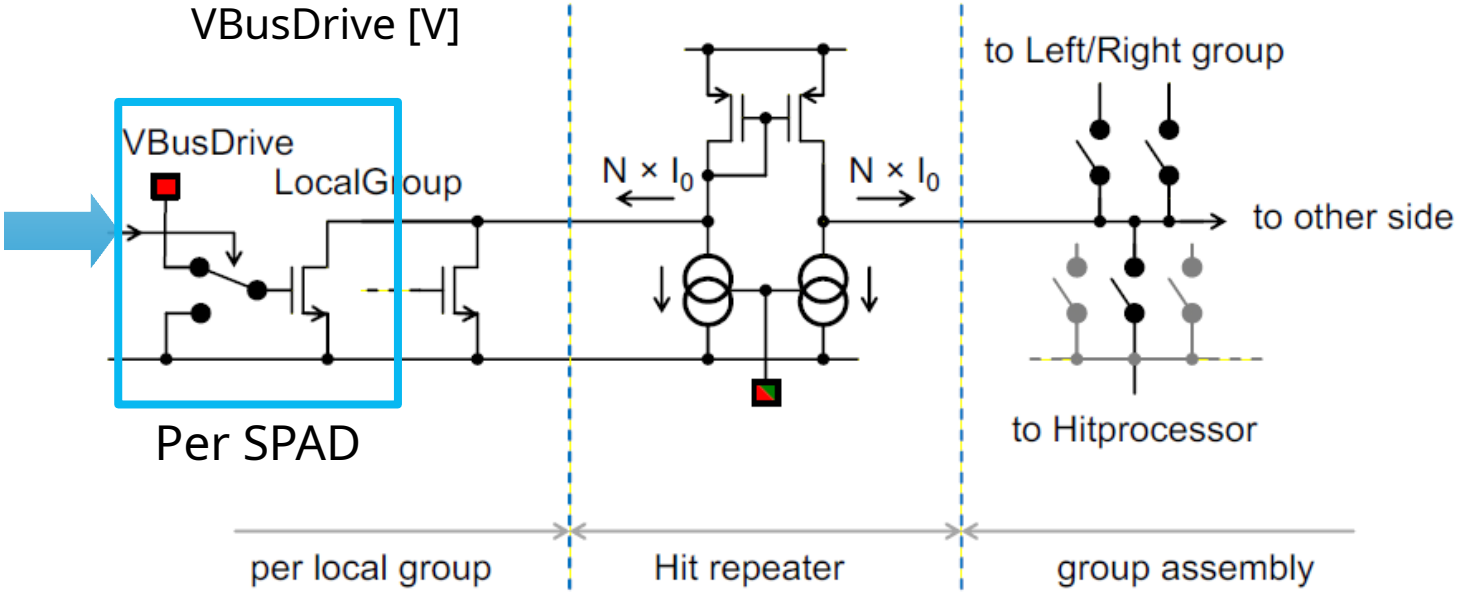
Group to Hitprocessor





Chip Design

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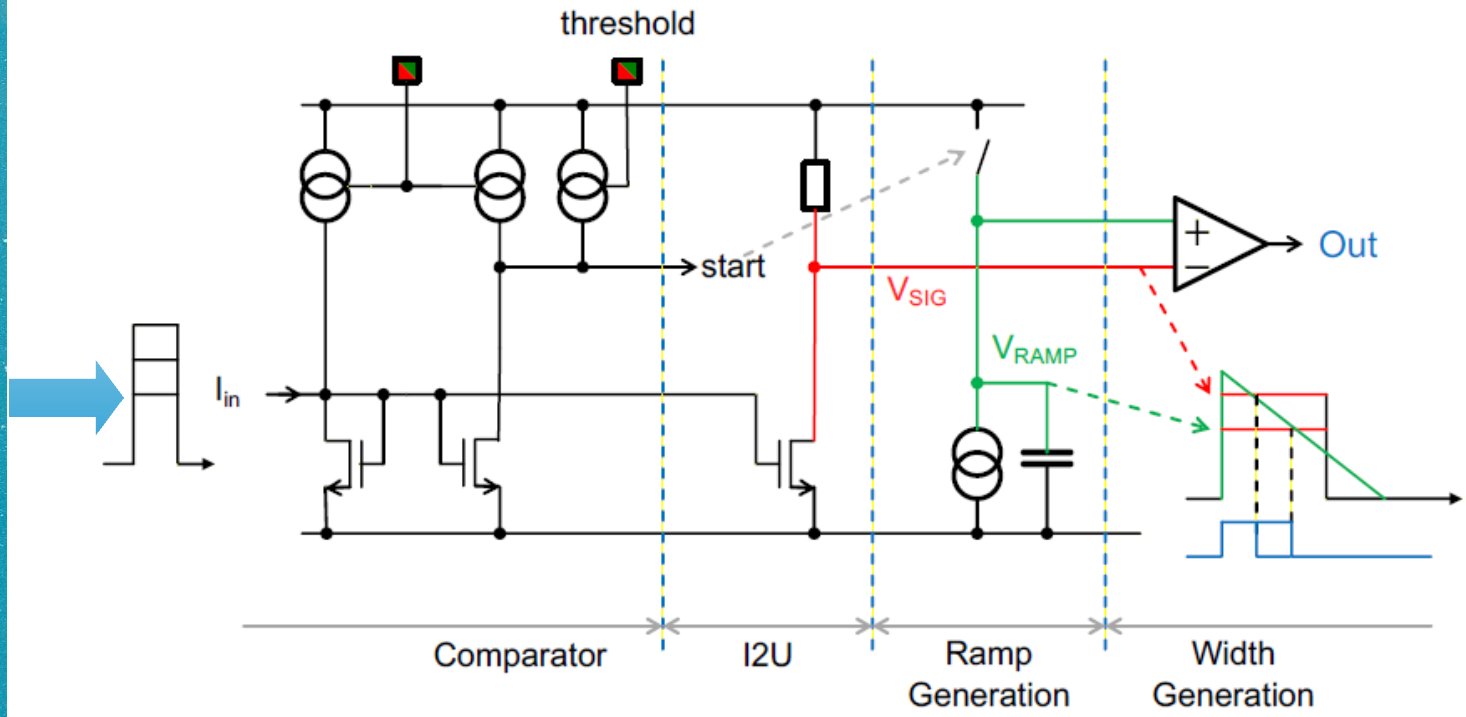
The Hitprocessor



$T_{out} \sim I_{in}$

Chip Design

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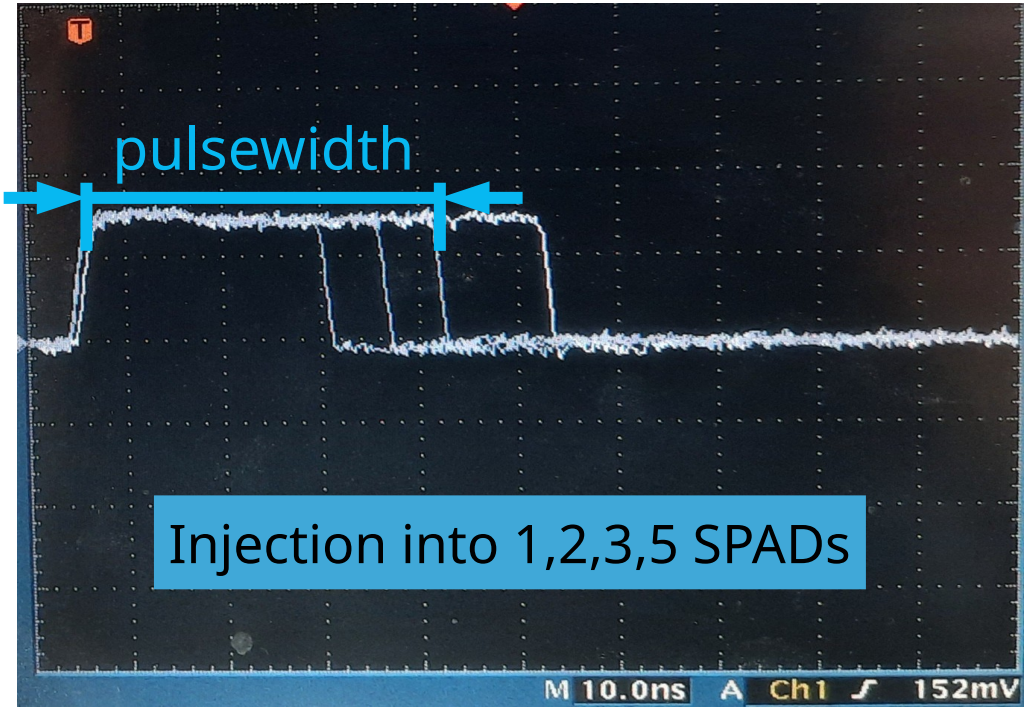
Measured Hitprocessor Output



Easy to seperate number of firing SPADs

Setup & first Results

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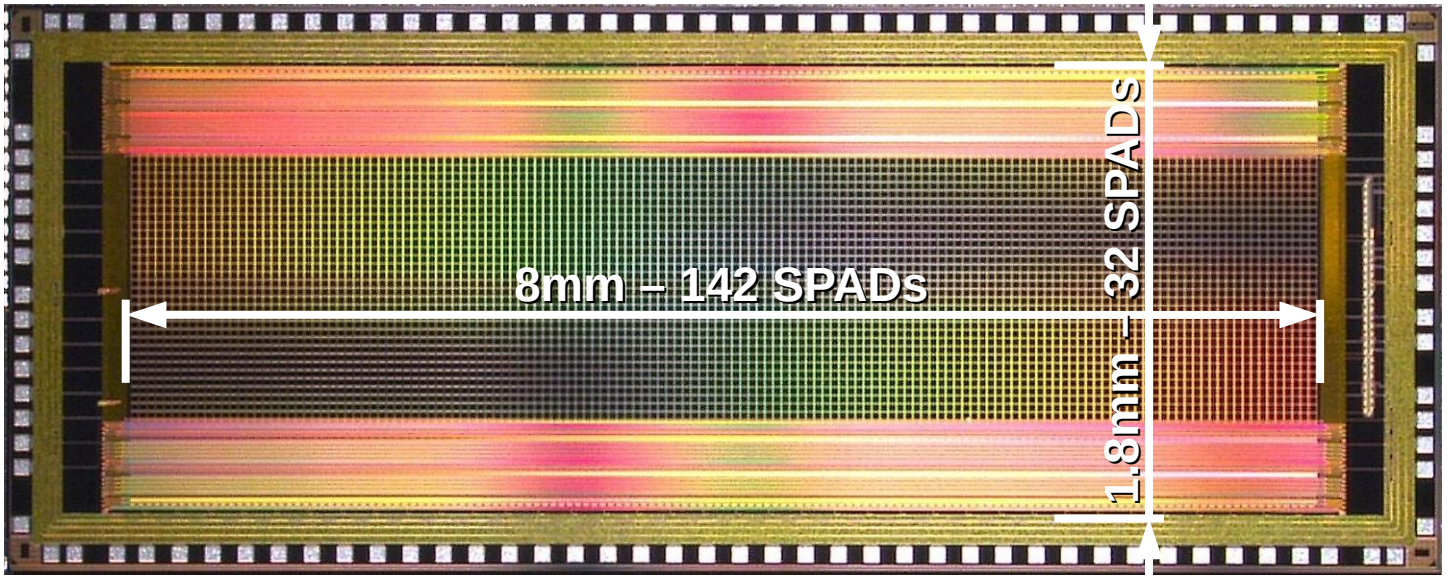
The Sensor



Setup

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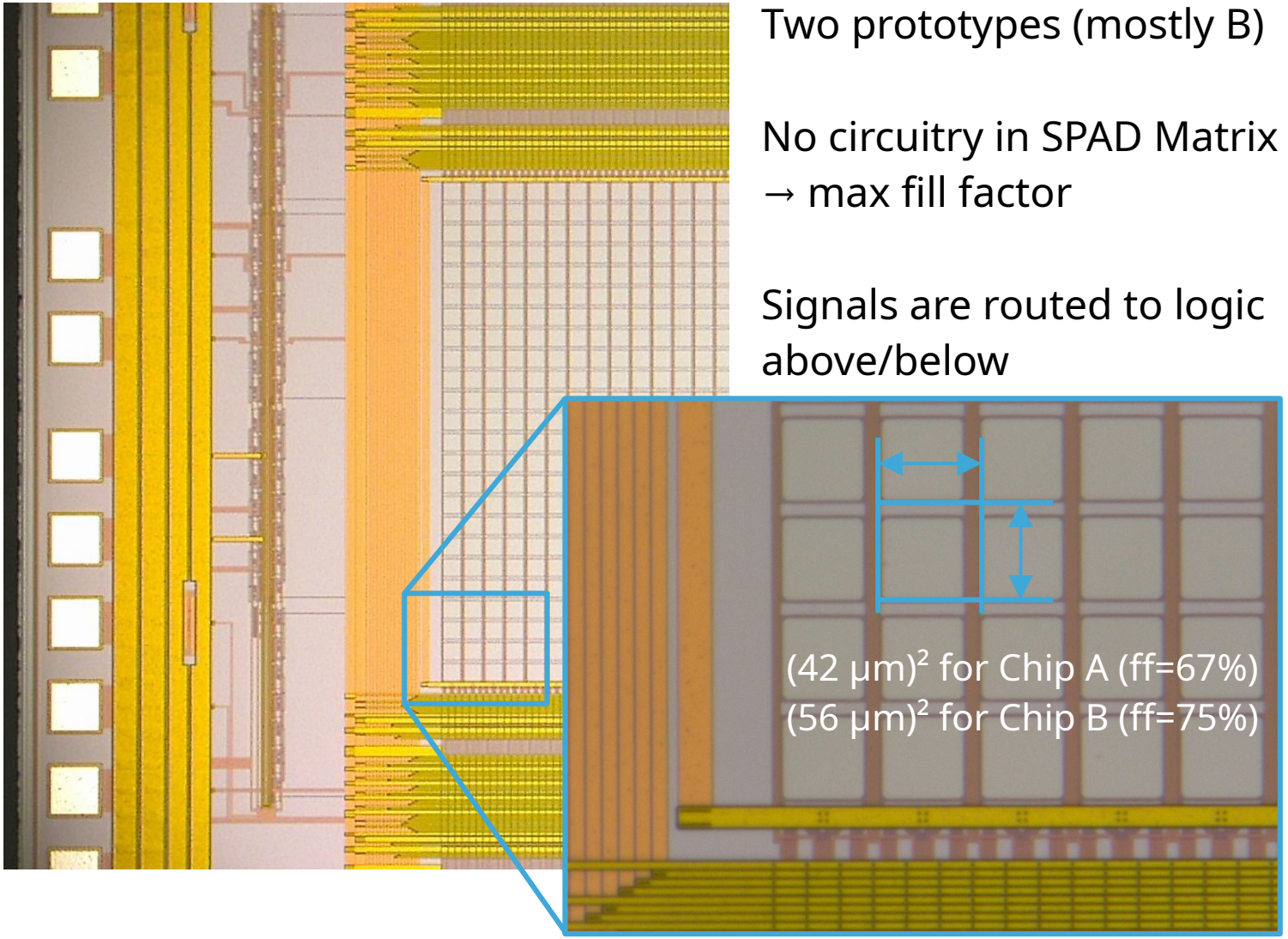
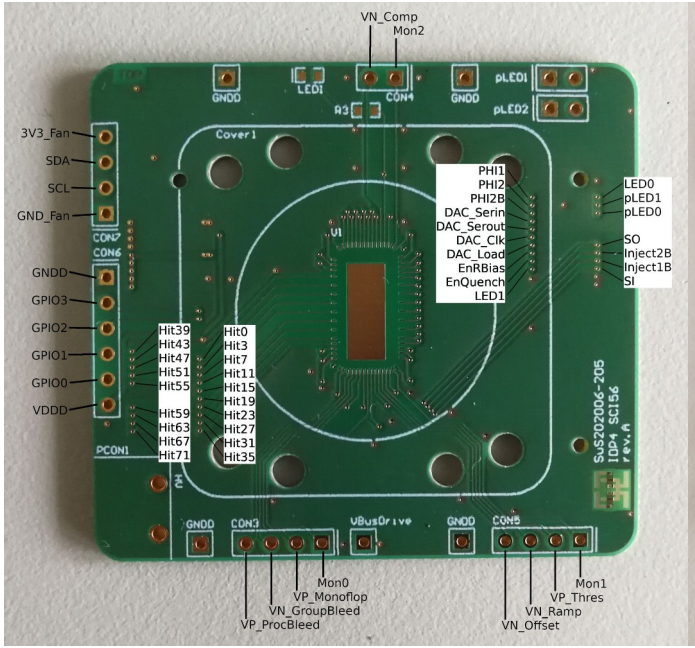


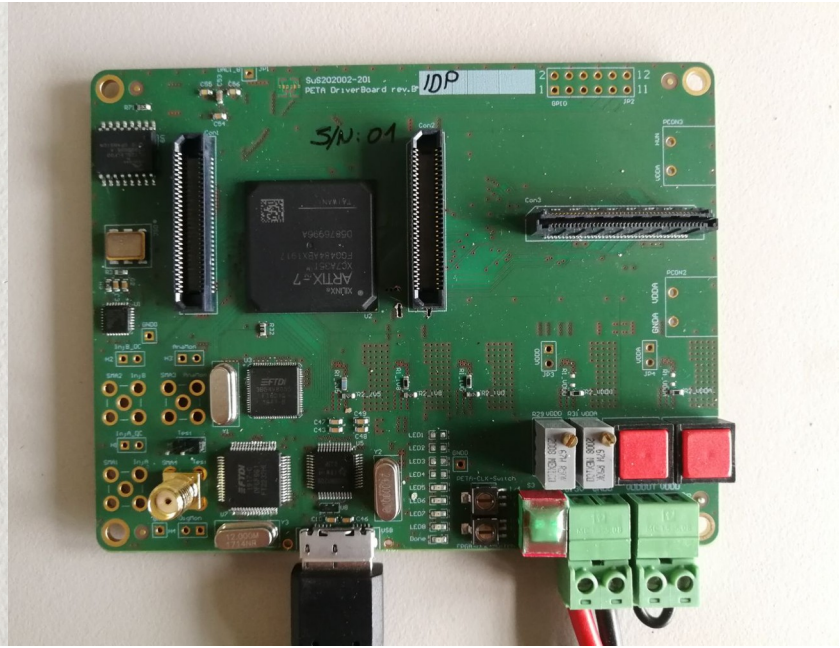
Two prototypes (mostly B)

No circuitry in SPAD Matrix
→ max fill factor

Signals are routed to logic above/below

Sensor board and FPGA





Setup

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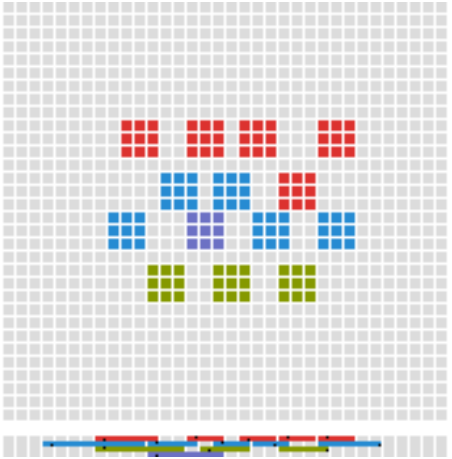
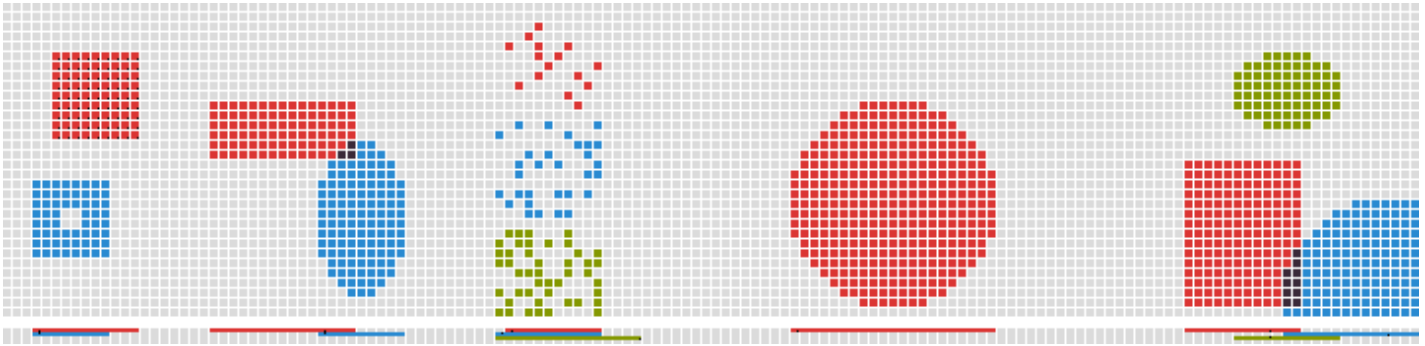
Controlling software:

C++-library:

- Defining groups
- Setting pins and voltages
- Common use templates





Setup

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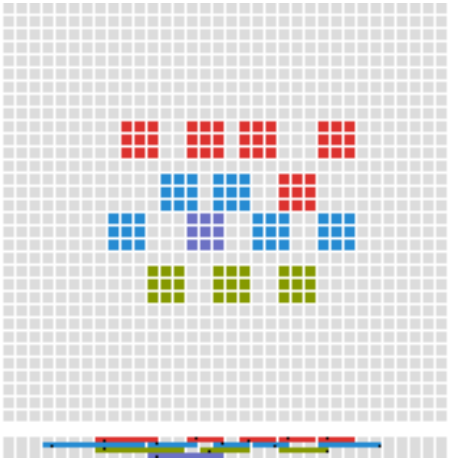
Controlling software:



C++-library:

- Defining groups
- Setting pins and voltages
- Common use templates

FPGA Code:

- Data transfer to PC
- First data analysis (hit time, pulsewidth)
  Where, When, how many?

Complete controlling software

Results

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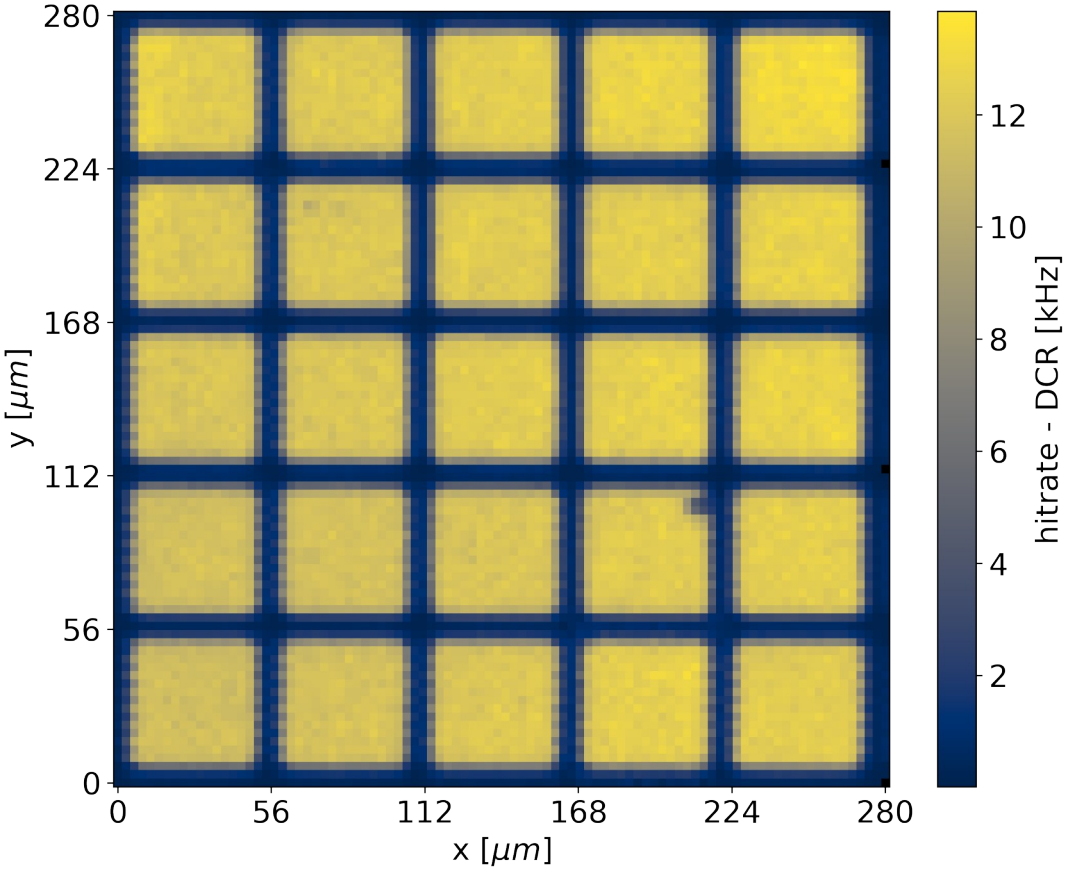
SPAD signal for a fine laser



Measured fillfactor 77.5 ± 1.6%

Results

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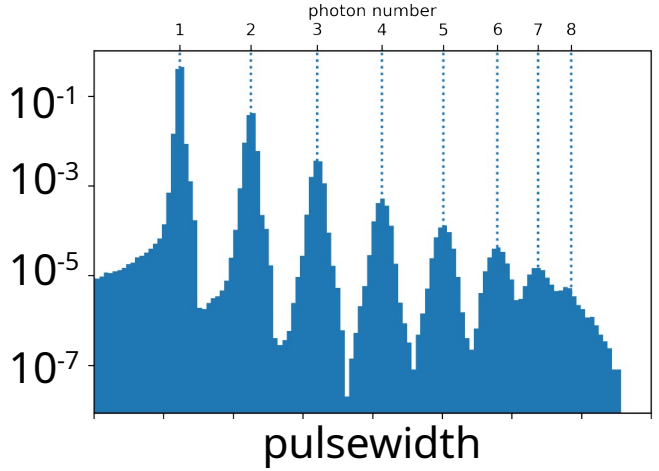
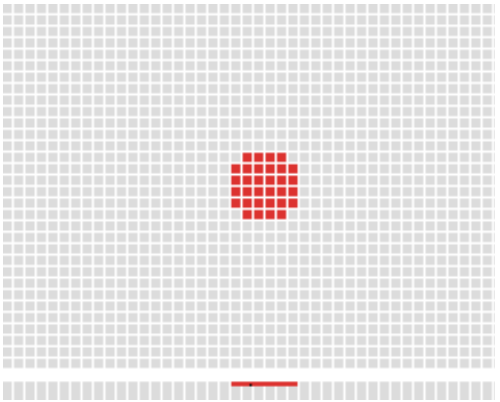
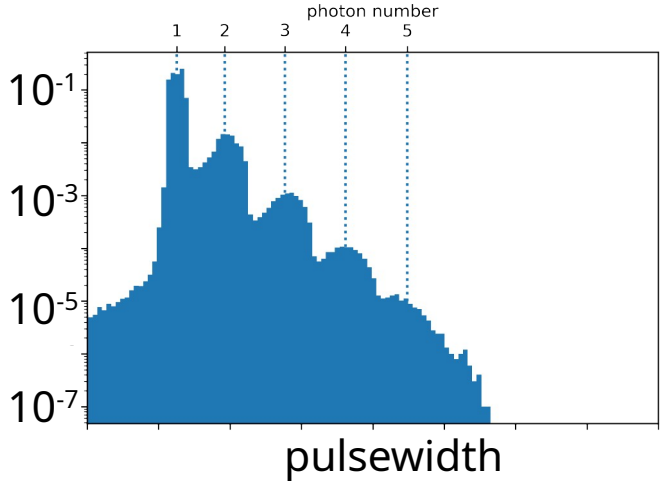
Measured group signals for a LED Source







Results

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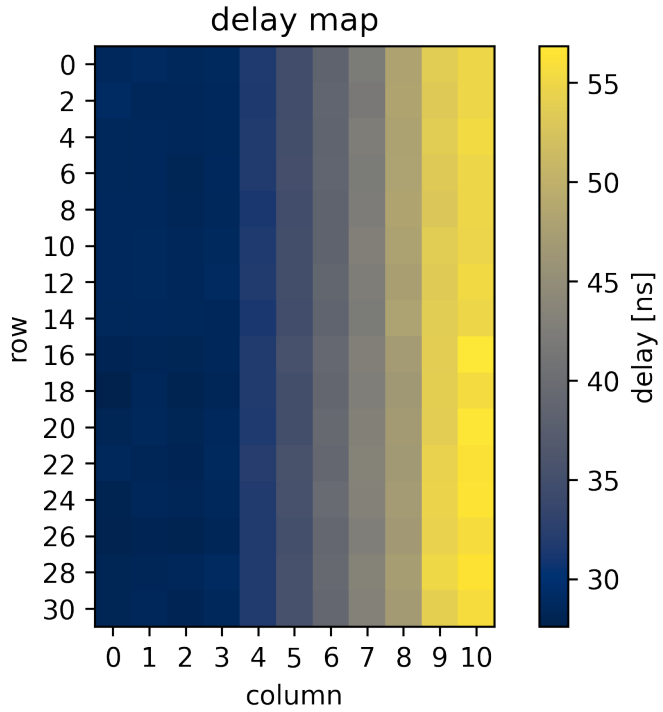
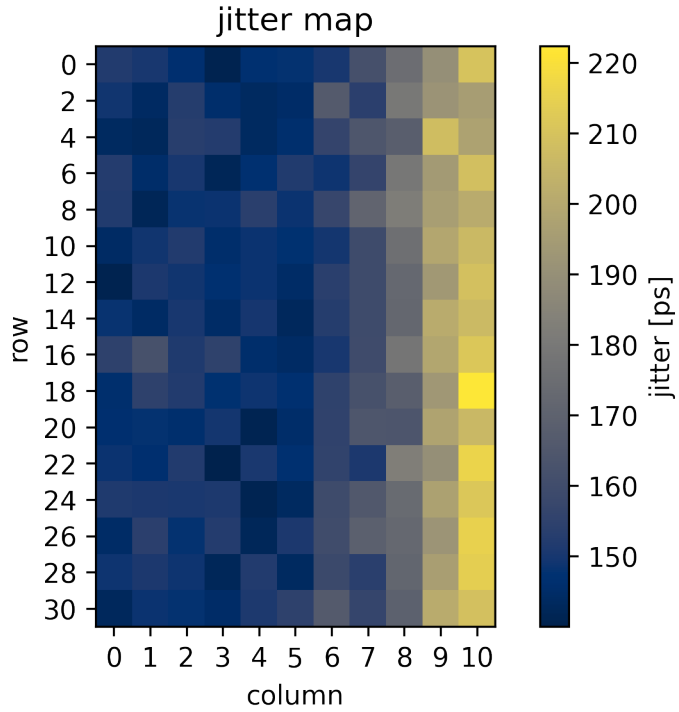
Delay & Jitter





Fibre Setup & Results

Setup

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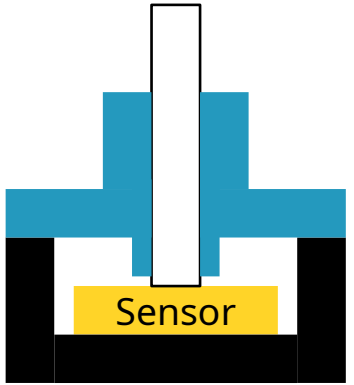
Fibre mat readout setup

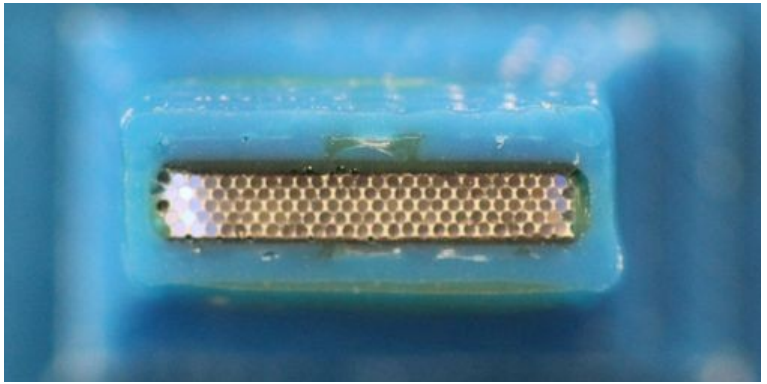
- Chip connected to FPGA

- LHCb fibre mat connected via 3D printed cap

- Testing beta source

- Coincidence setup





Setup

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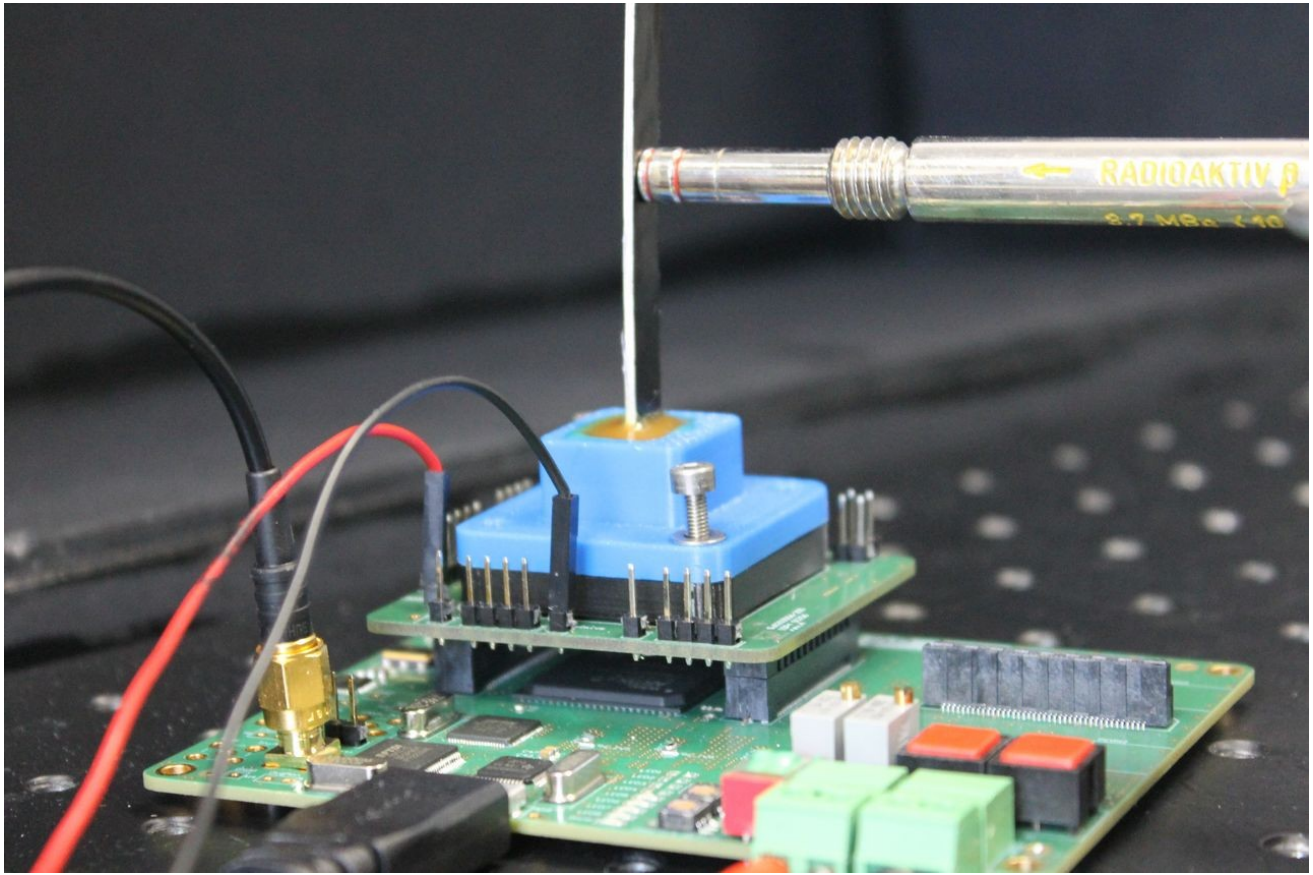
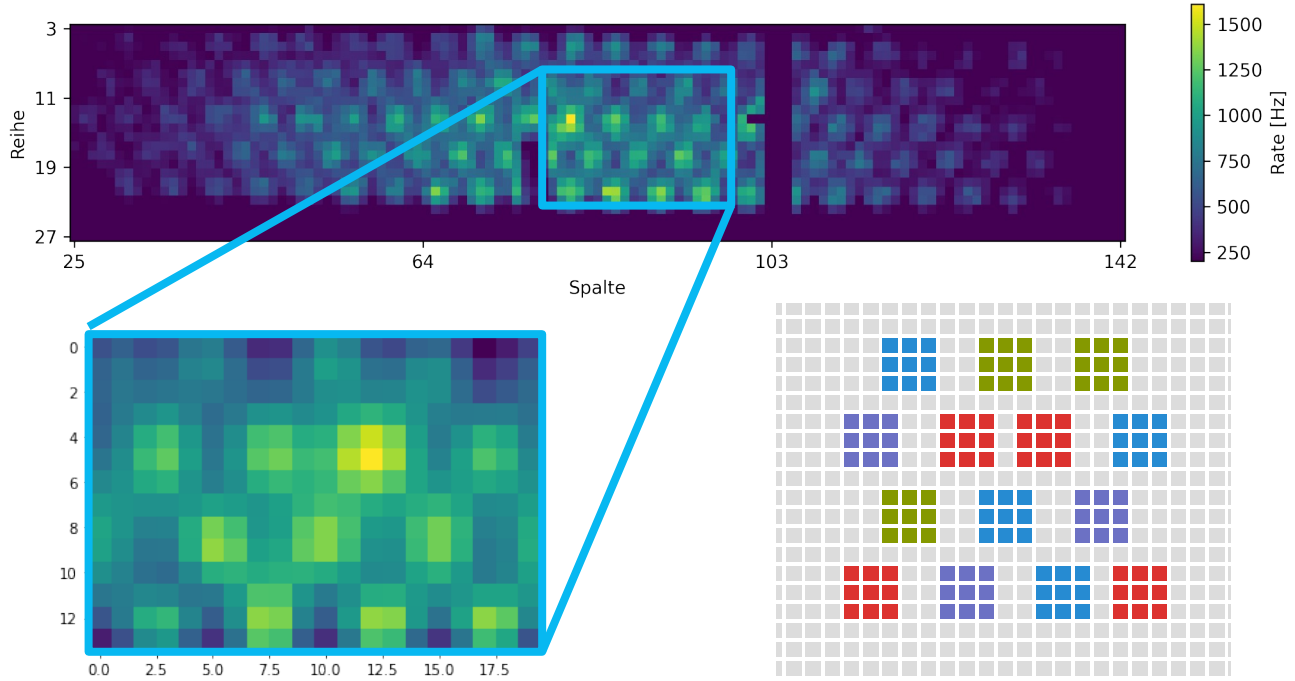
Fibre mat readout setup



Results

First Step: Find single fibres and read them out



Automatically finds fibres and assigns groups!

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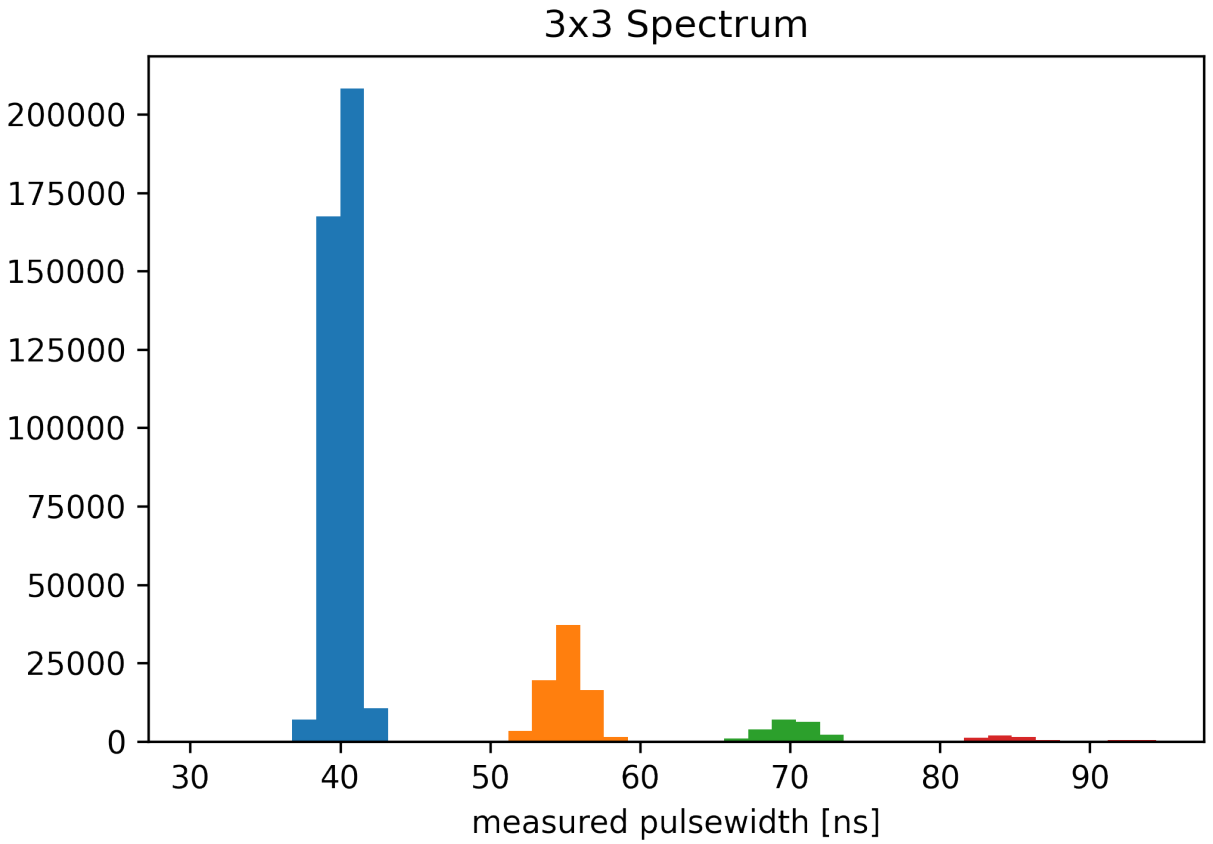
Results

Single fibre photon yield



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Results

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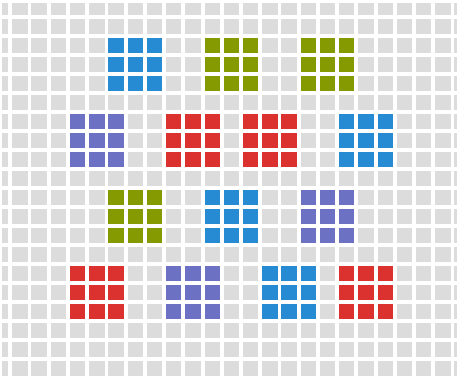
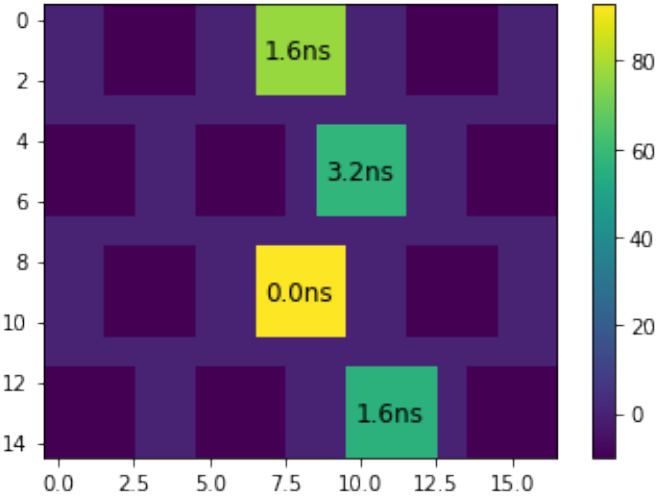
First particle tracks

Read 14 fibres simultaneously



Defined events:

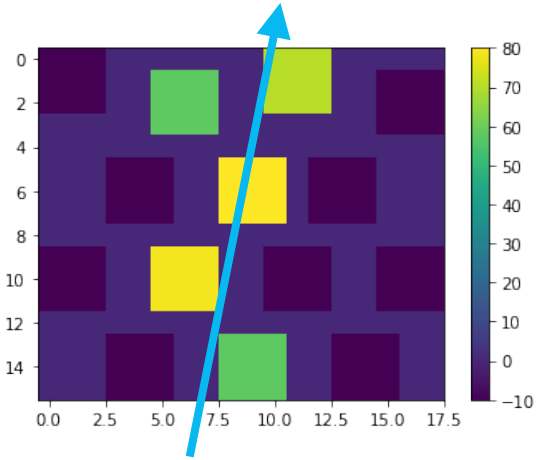
- 3.2ns coincidence window
- Require at least 3 layers
- Isolated track
- Coincidence with external detector

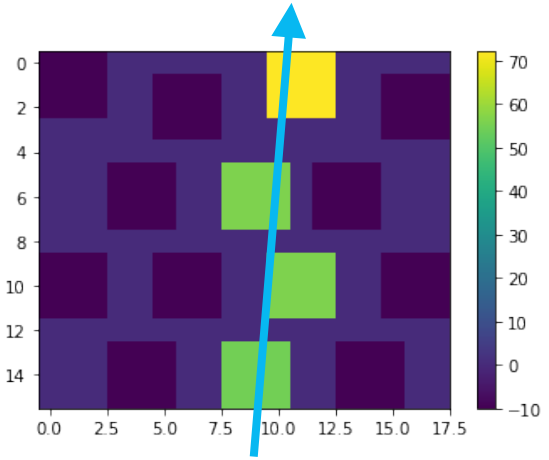


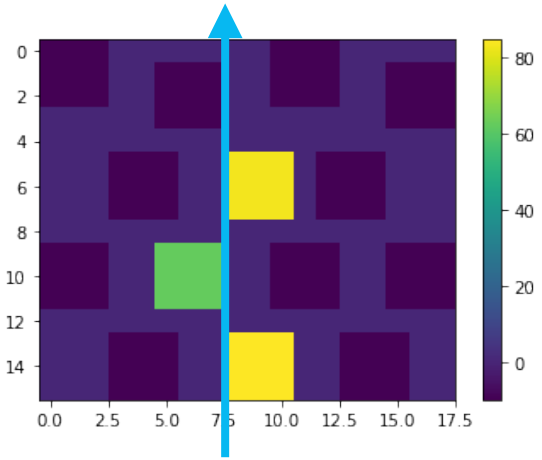
Proof of Principle!

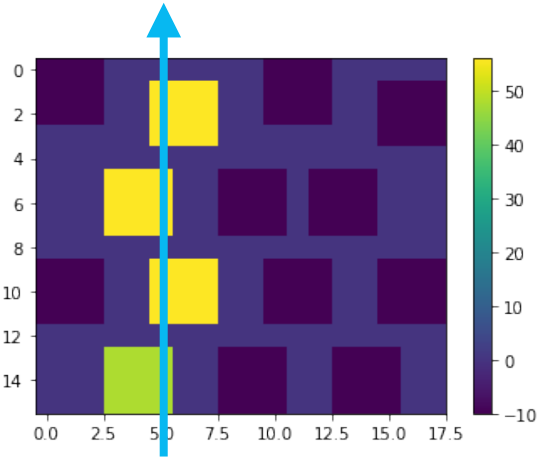
Results

First particle tracks and more!









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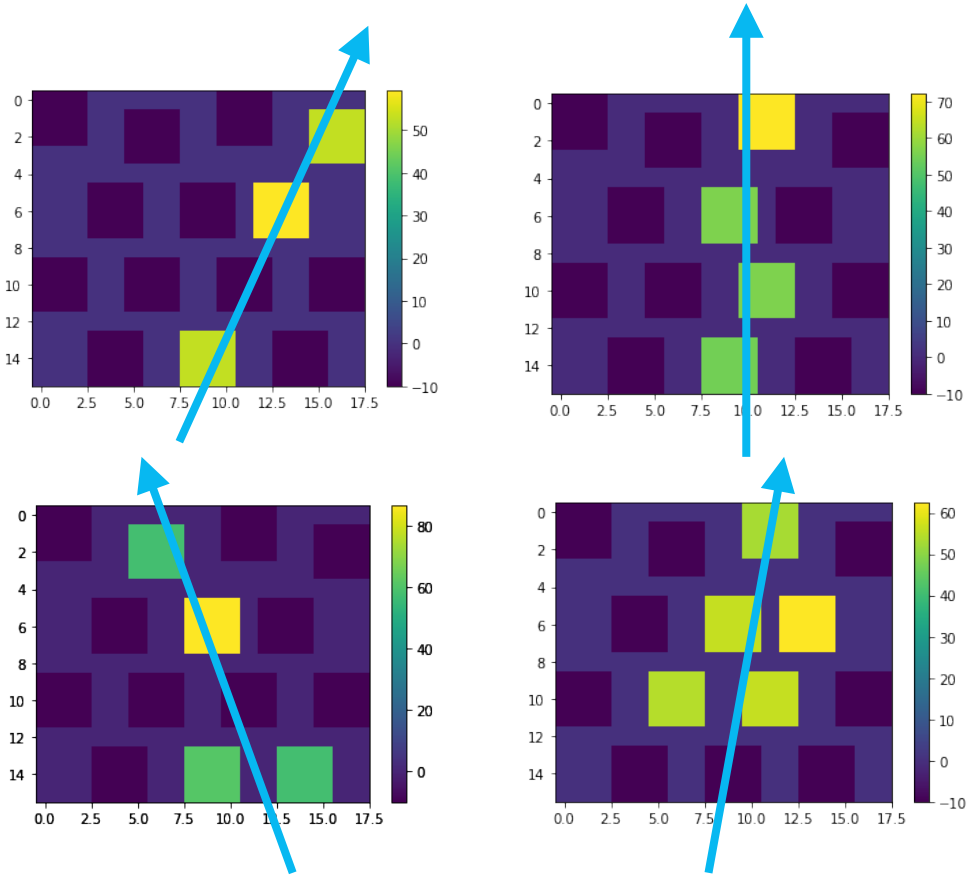
Results

First particle tracks and more!

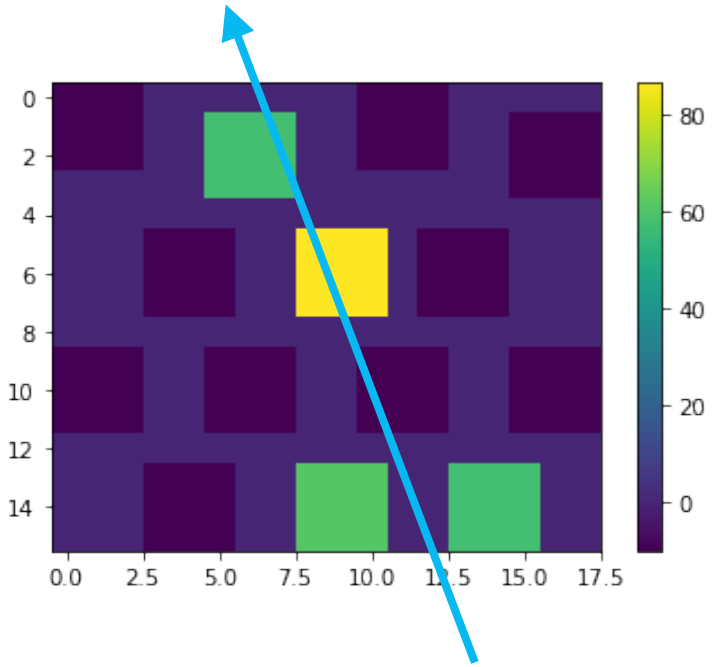
less constraints:

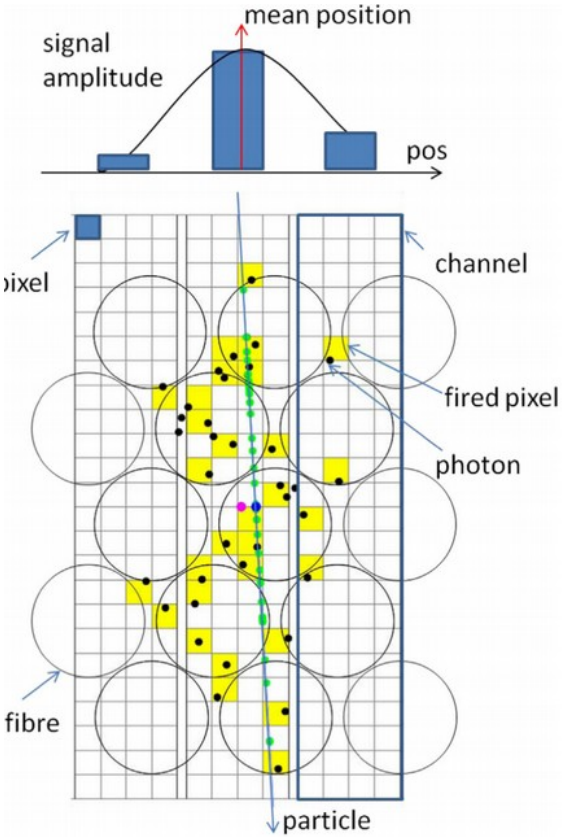


Micro Tracking

Results

First particle tracks and more!





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Conclusion

Chip concept is working nicely

Single fibre readout of a fibre mat is possible

Particle tracks can be detected

Micro Tracking for angular information

Setup is compact, low power, cost efficient and compatible with large fibre systems

Outlook

Outlook

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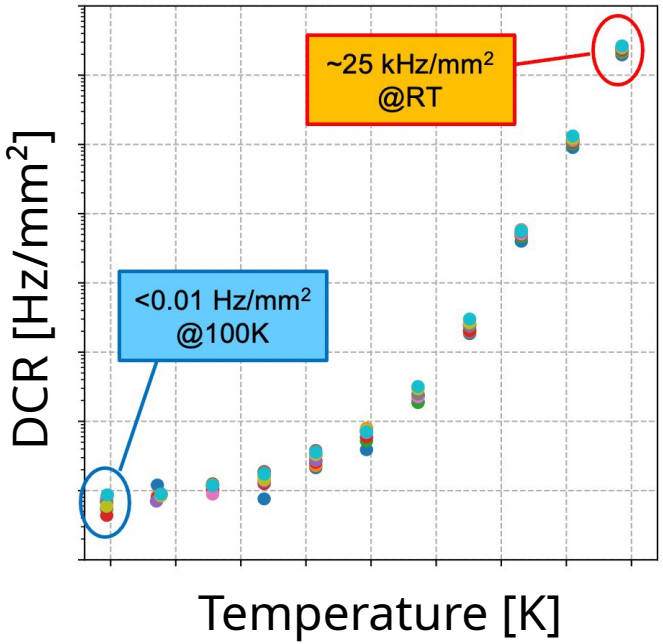
Improvements

Test cooled setup

- Reduce dark counts



Prepare new chip submission

- Bug fixes & faster bus signal
- On chip pulsewidth measurement and buffered readout

Outlook

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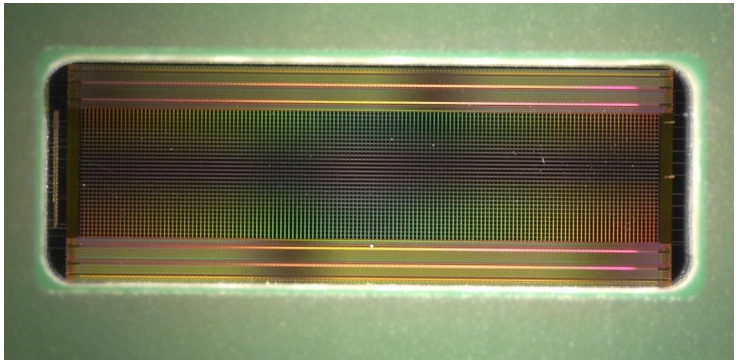
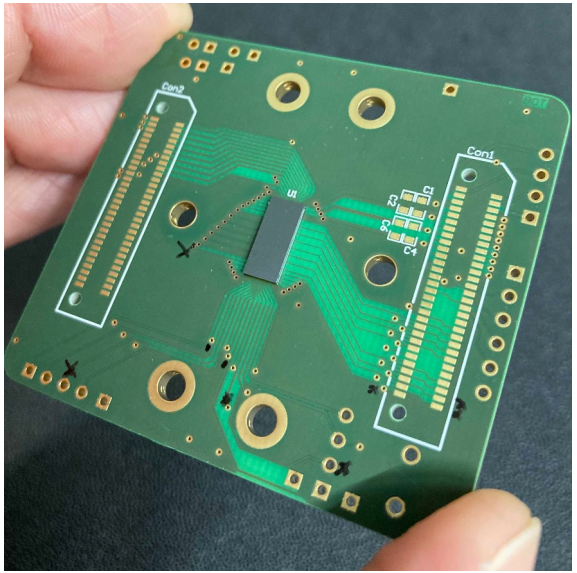
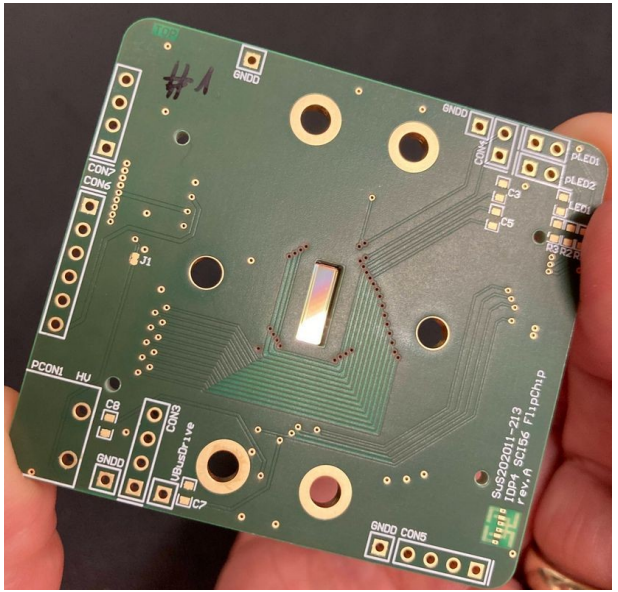
Improvements

Improve fibre coupling
- Flip chip mounting







Thank you

Benedict Maisano: maisano@physi.uni-heidelberg.de

Prof Peter Fischer: peter.fischer@ziti.uni-heidelberg.de

Robert Zimmermann: robert.zimmermann@stud.uni-heidelberg.de

Chip Design

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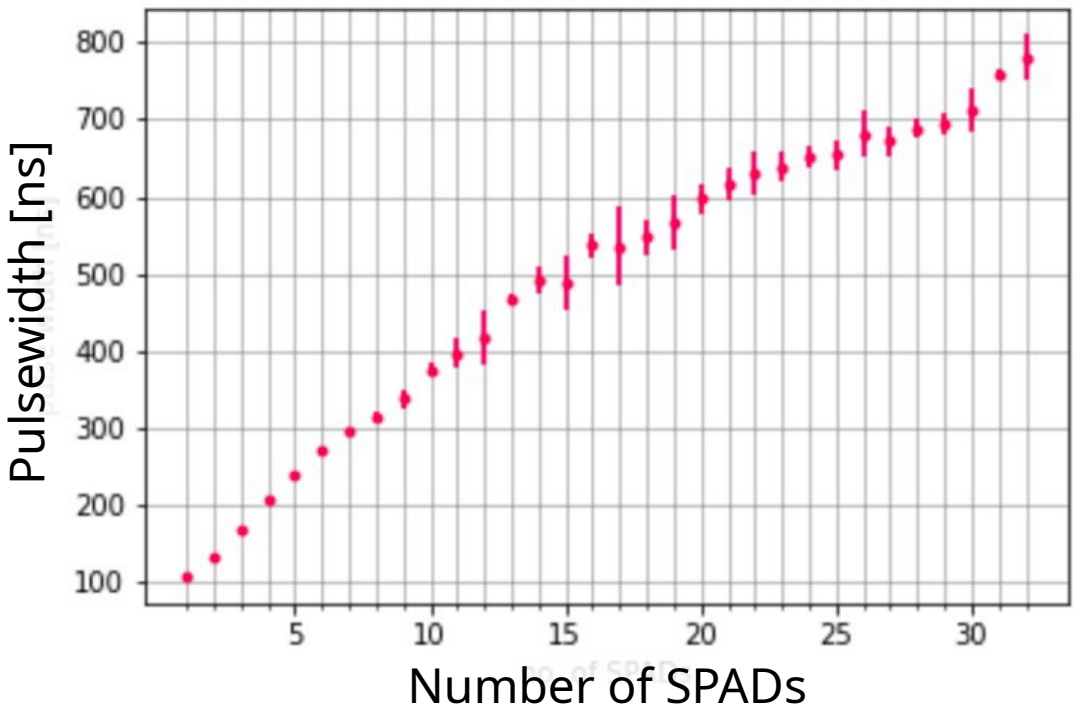
Measured Hitprocessor Output



Dynamic photon detection range

Results

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ZUKUNFT
SEIT 1386

Benedict Maisano
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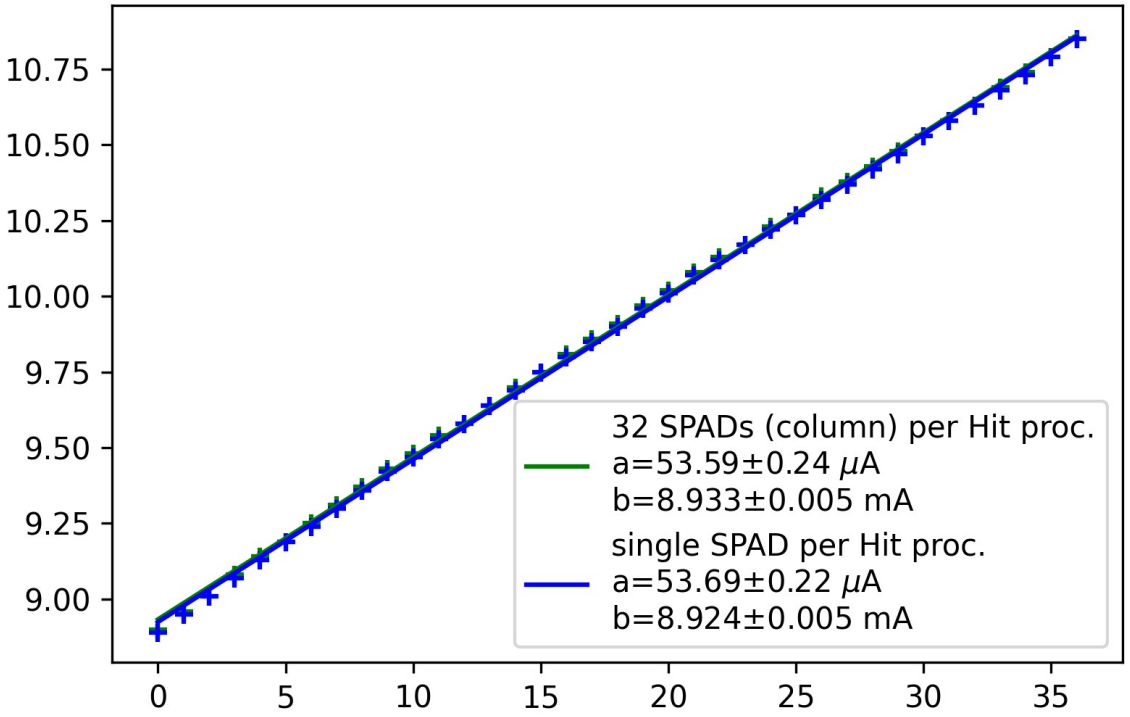
Currents of Hitprocessors



Results

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New Chip Design