

CMOS SPAD sensor chip for the readout of scintillating fibre mats



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Benedict Maisano

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Robert Zimmermann

University Heidelberg

FEE 2023

Intro



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CMOS SPADs

Intro



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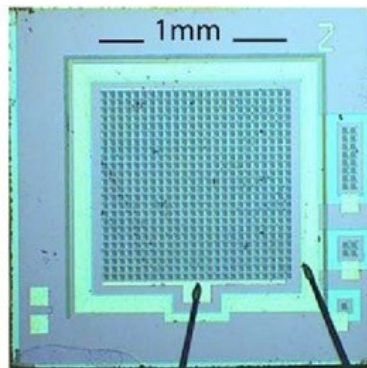
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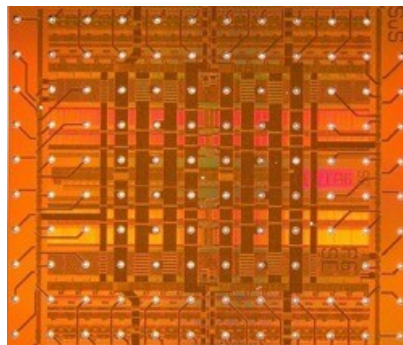
Page 2

CMOS SPADs

SiPM + ASIC



+



Intro

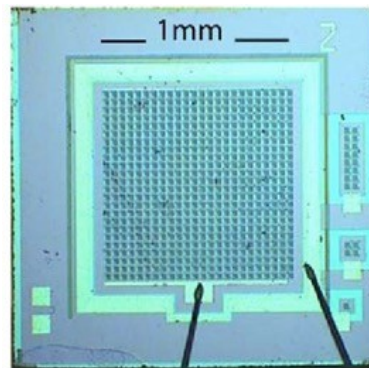


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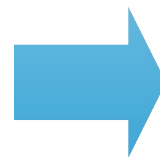
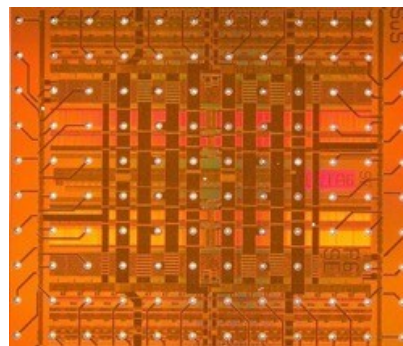
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CMOS SPADs

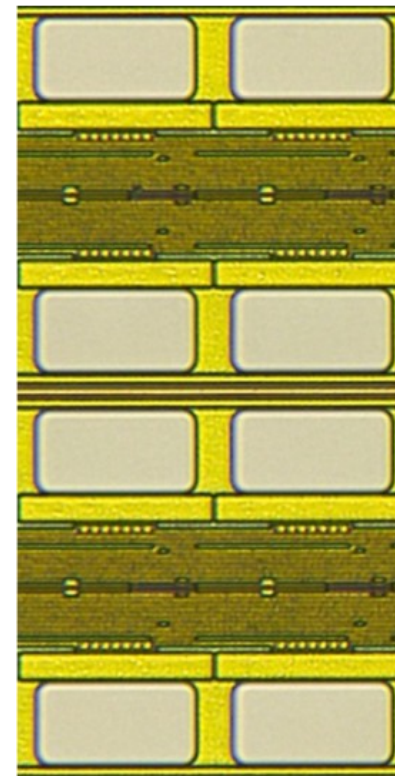
SiPM + ASIC



+



Digital SiPM



Intro

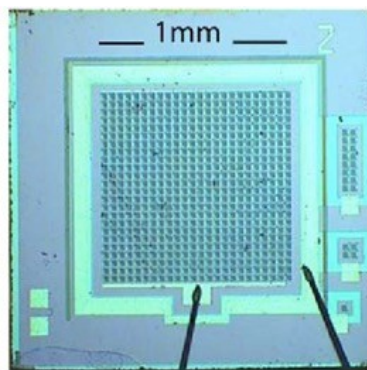


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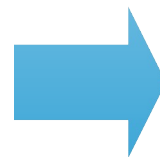
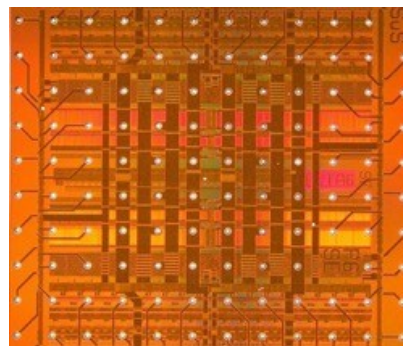
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CMOS SPADs

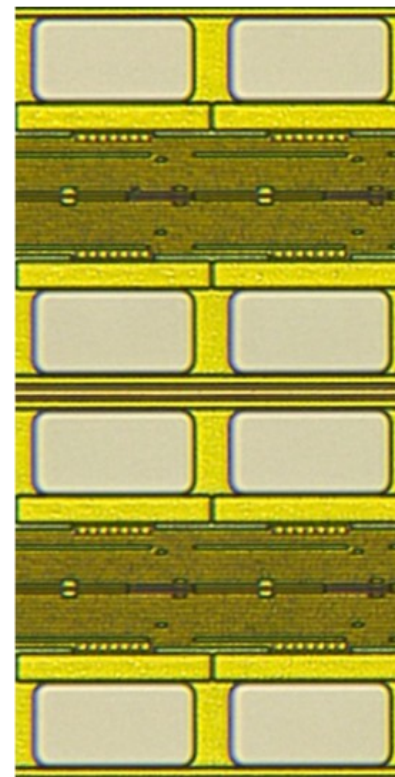
SiPM + ASIC



+



Digital SiPM



SPAD and readout circuitry on same substrate

Structure

Motivation

Concept

Chip Design

Setups

Results

Outlook

Motivation

Motivation



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Motivation



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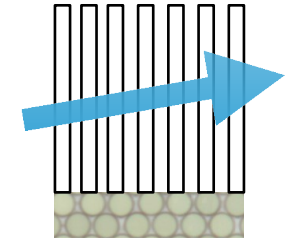
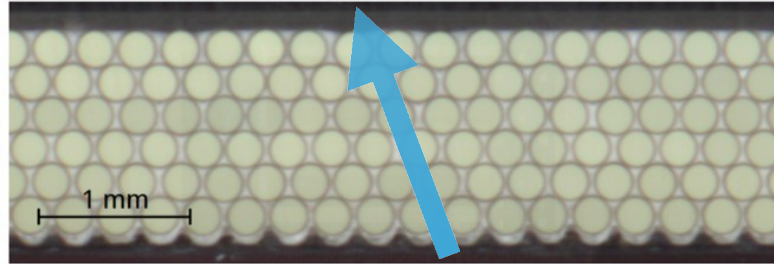
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Scintillating fibre mat readout

Motivation

Scintillating fibre mat readout



Charged particles cause fibres to emit light



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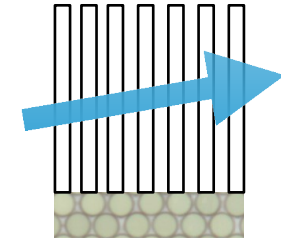
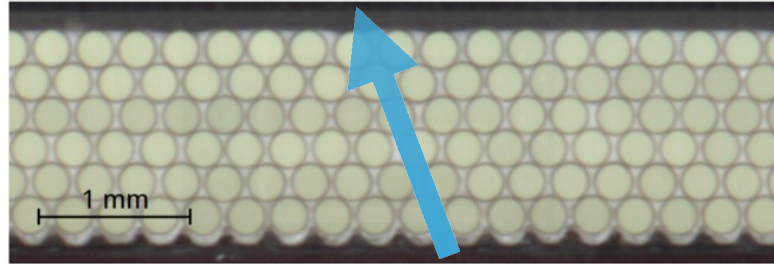
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Motivation

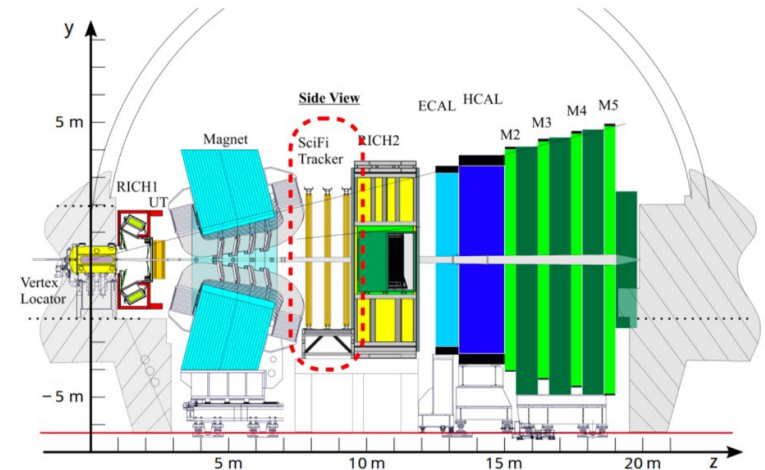
Scintillating fibre mat readout



Charged particles cause fibres to emit light

Application:

- Particle physics
- Hadron therapy
- Calorimeters



LHCb @ CERN



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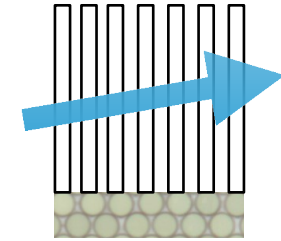
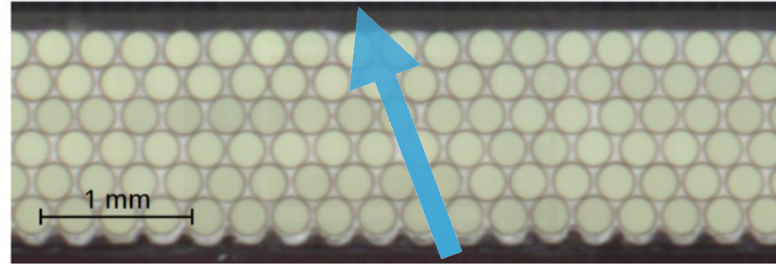
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Motivation

Scintillating fibre mat readout

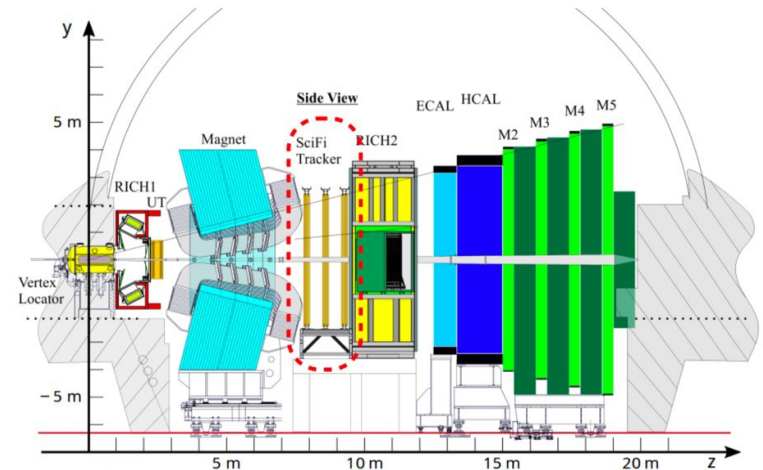


Charged particles cause fibres to emit light

Application:

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- Hadron therapy
- Calorimeters

Versatile Particle Tracker



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Motivation



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Scintillating fibre mat readout

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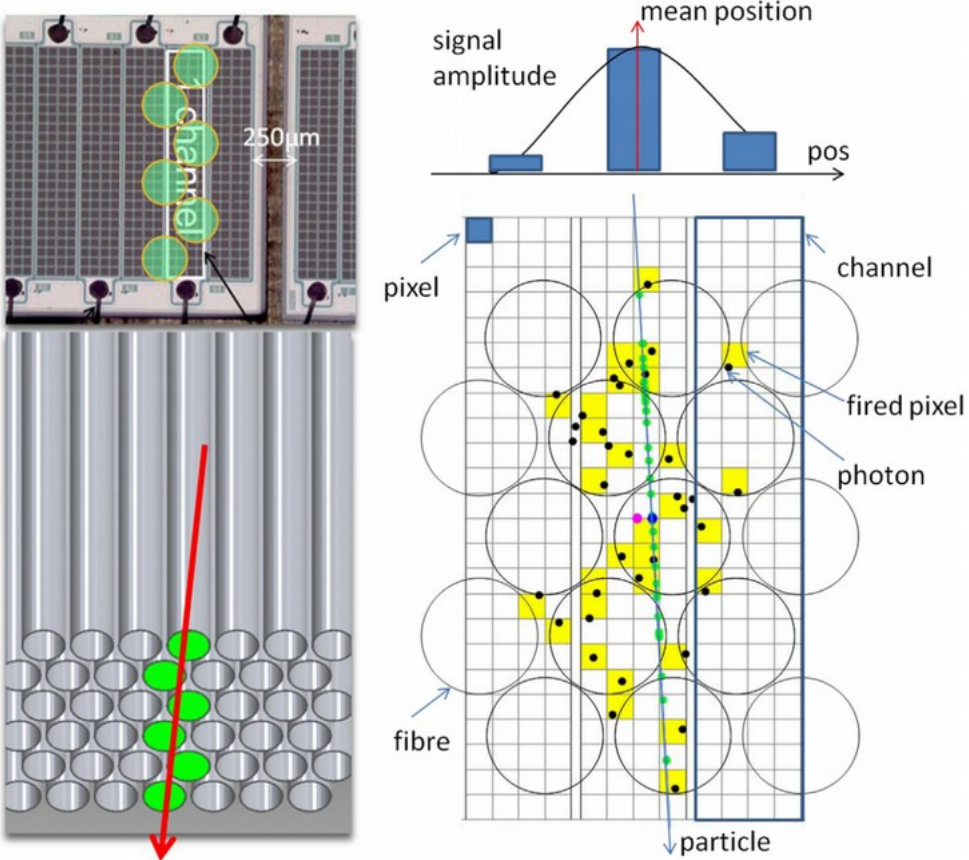
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Motivation



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Scintillating fibre mat readout



Motivation

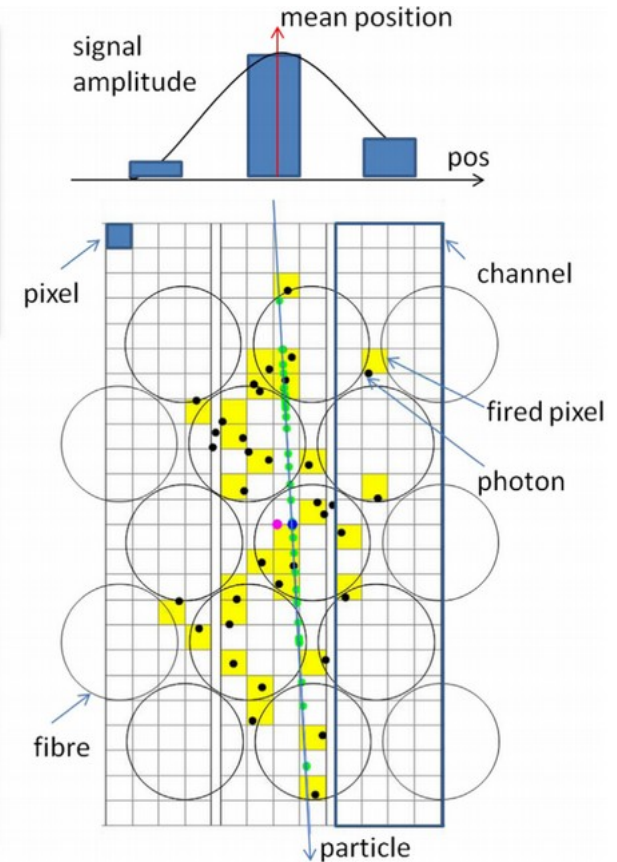
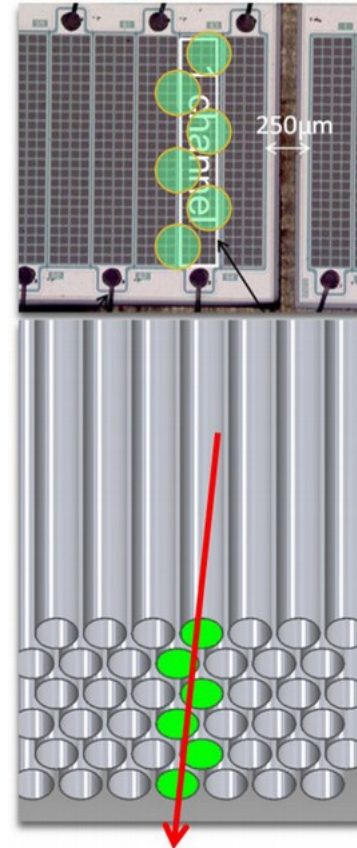


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Scintillating fibre mat readout

State of the Art

- Alignment is critical
- Complex data
- Modest timing
- Many parts



Concept

Concept

Scintillating fibre mat readout



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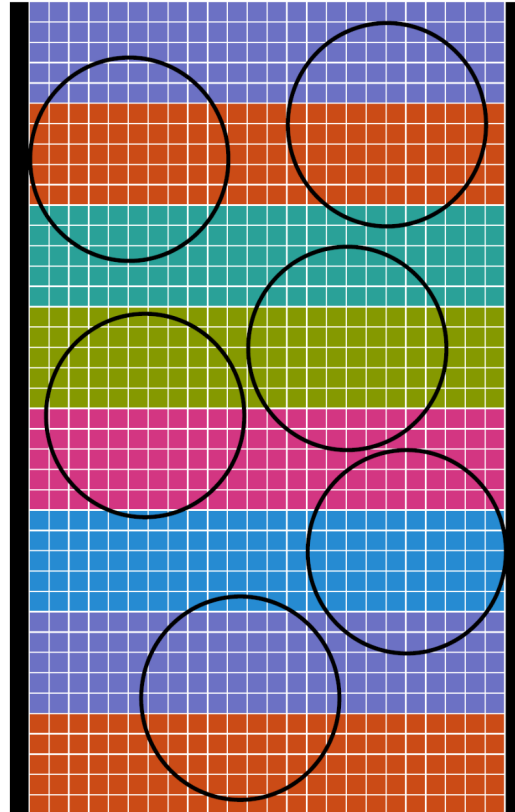
Concept



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Scintillating fibre mat readout



Concept

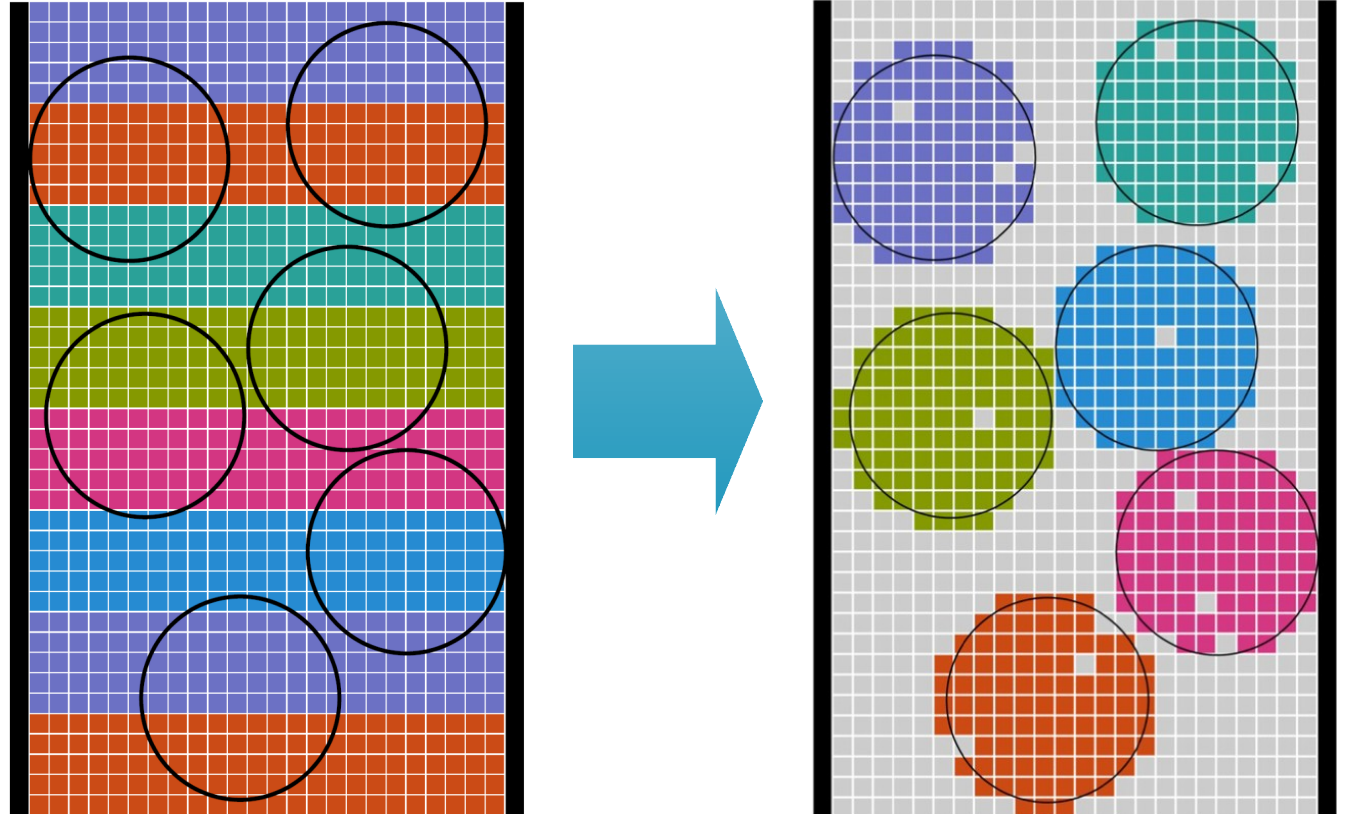


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Scintillating fibre mat readout

Single fibre readout by grouping individual SPADs

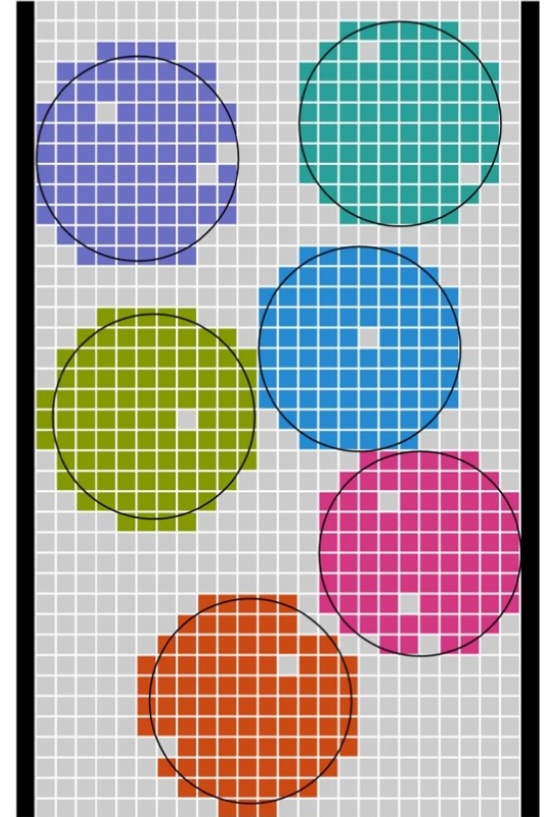


Concept

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 ($\sim 500\text{ps}$ so far)



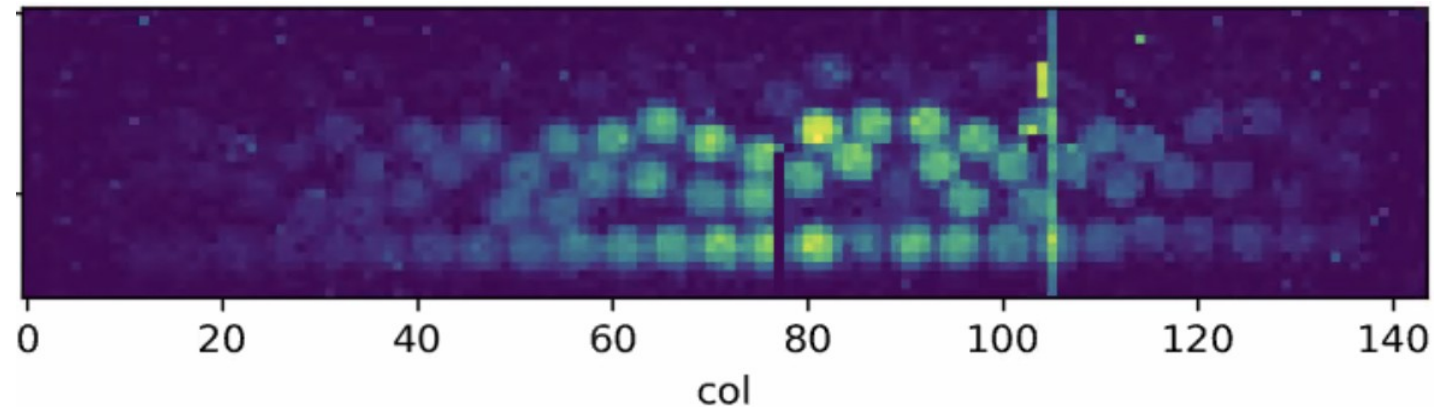
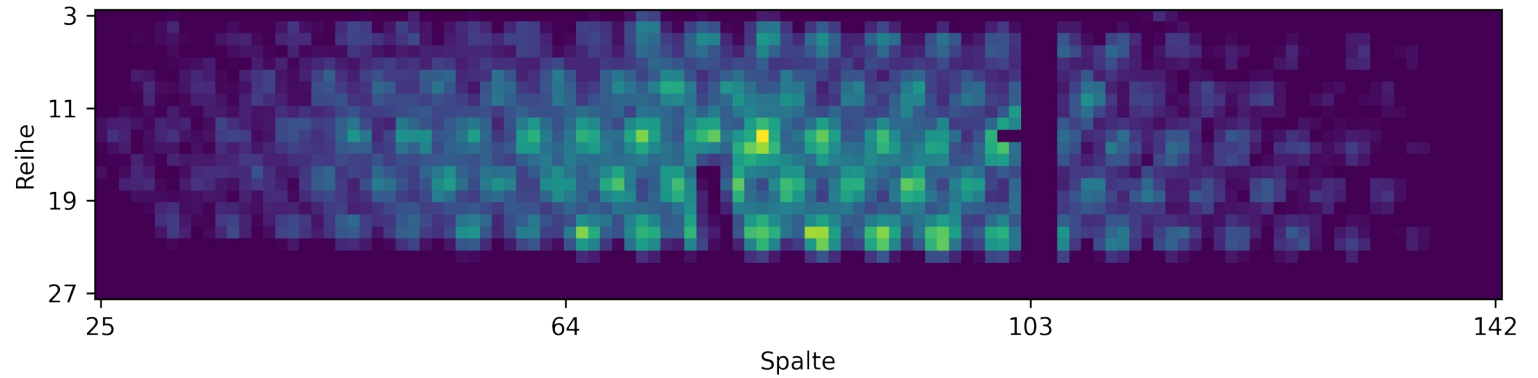
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Concept



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Scintillating fibre mat readout



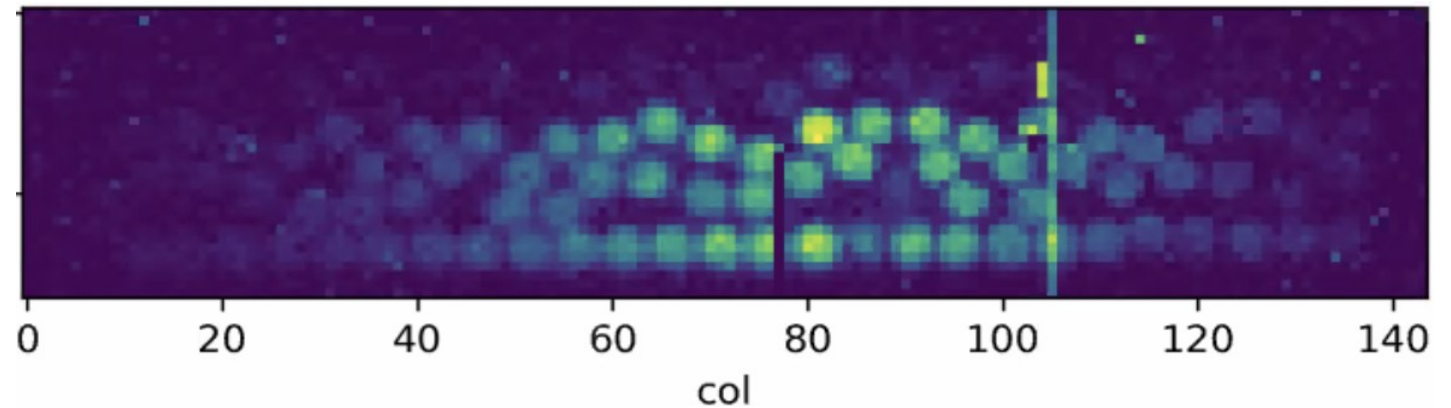
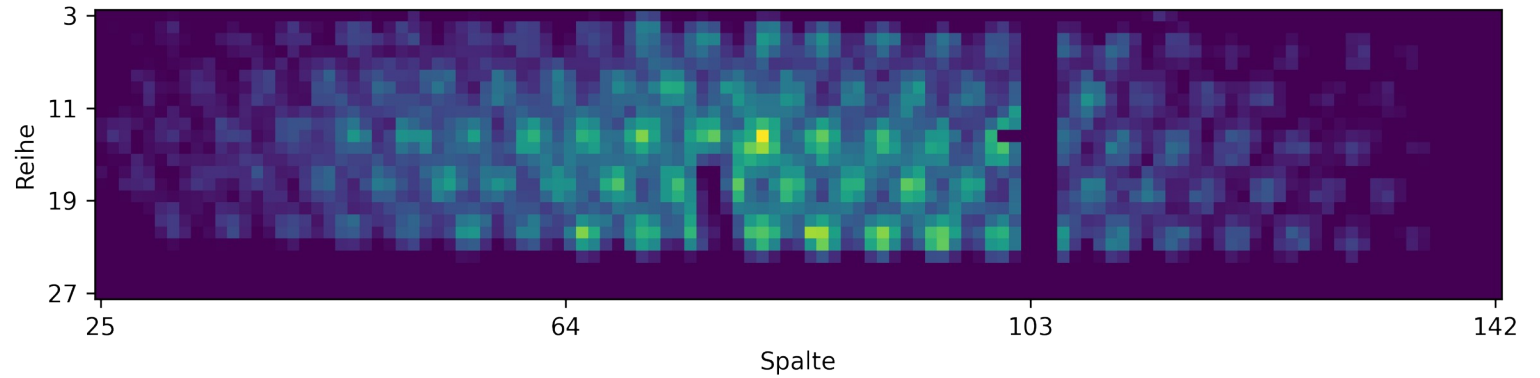
Concept



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Scintillating fibre mat readout

It works brilliantly!



Concept



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Defining a group:

SPAD

SPAD

SPAD

Concept



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Defining a group:

SPAD

SPAD

SPAD

SPAD

SPAD

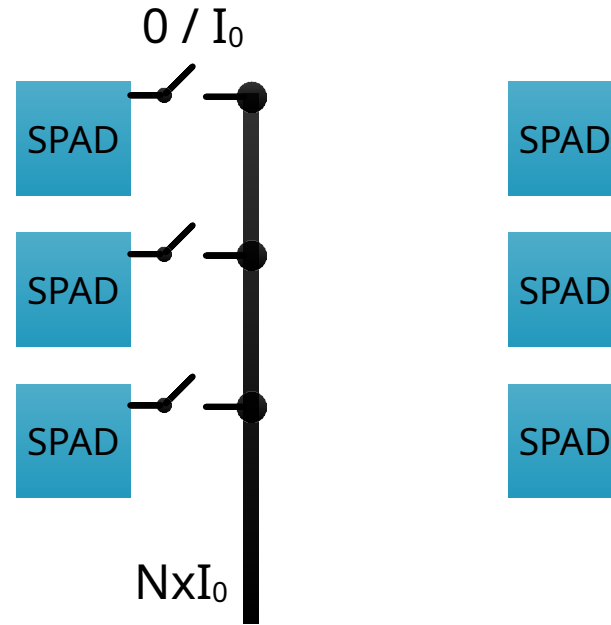
SPAD

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Defining a group:

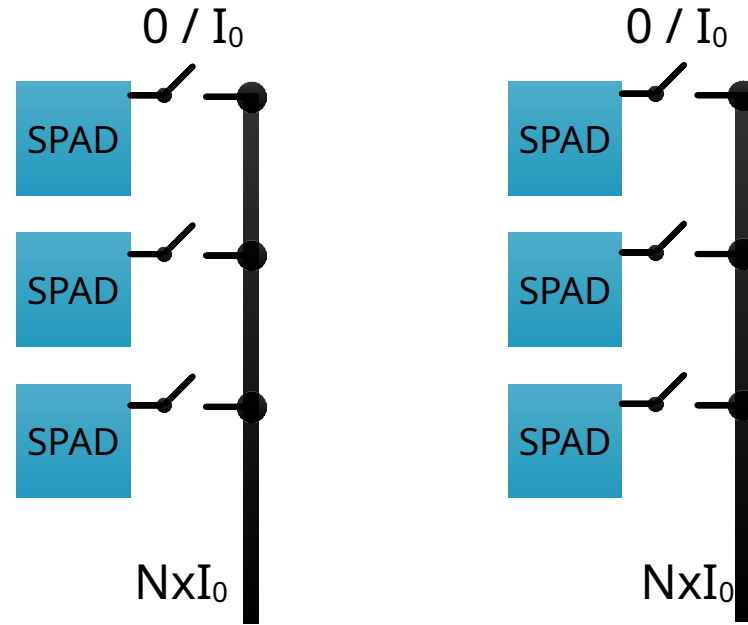


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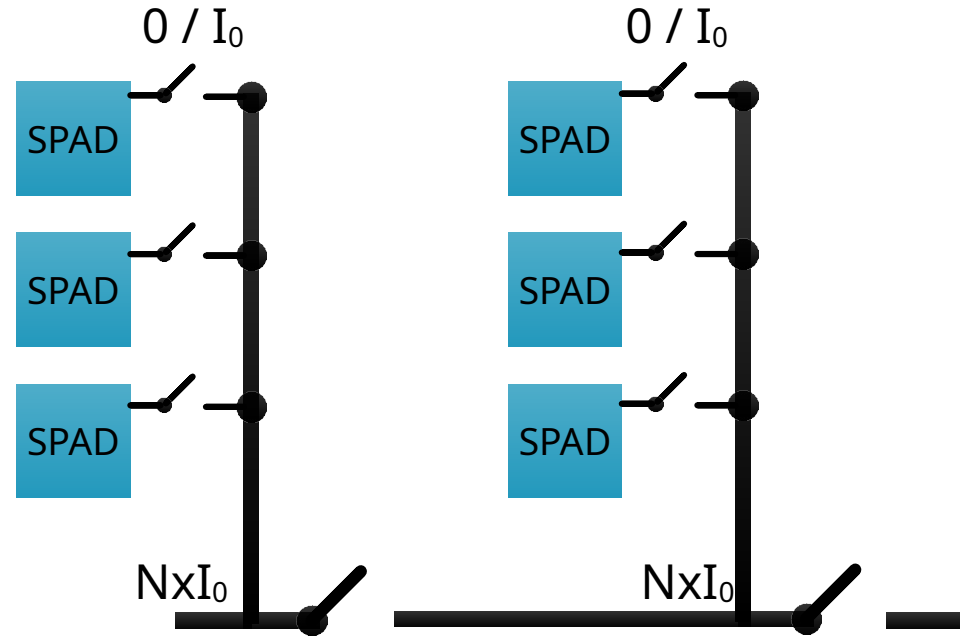


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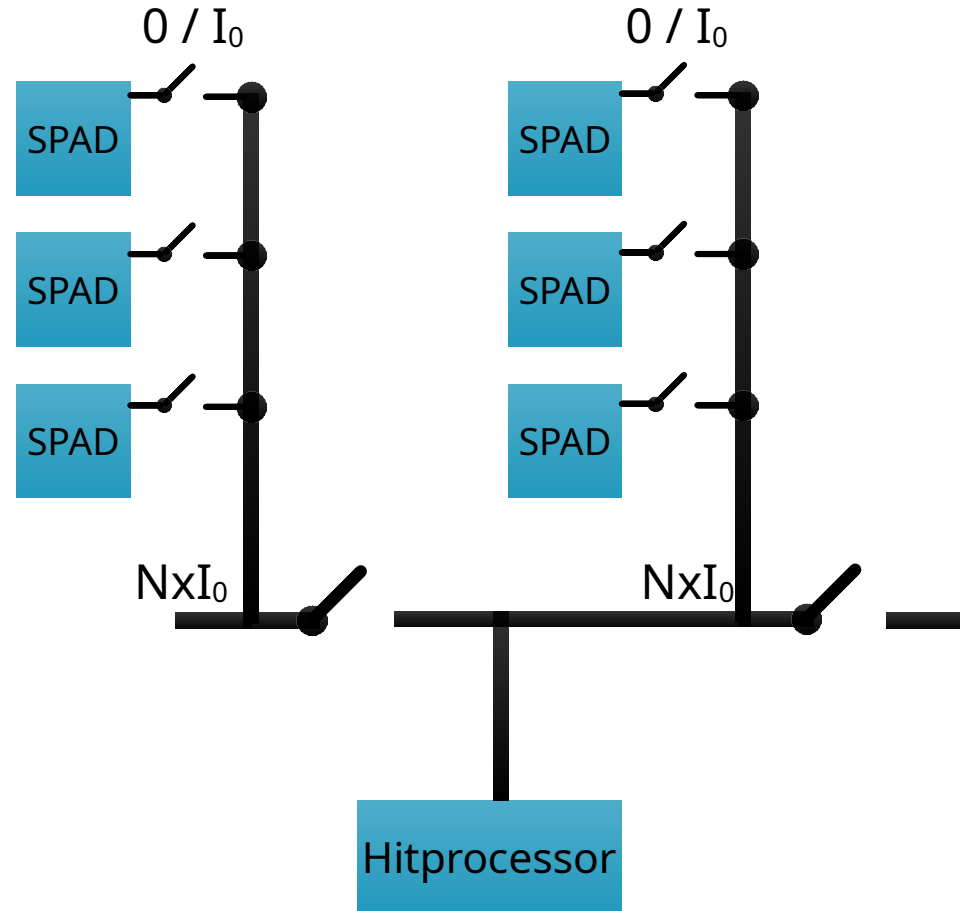


Concept



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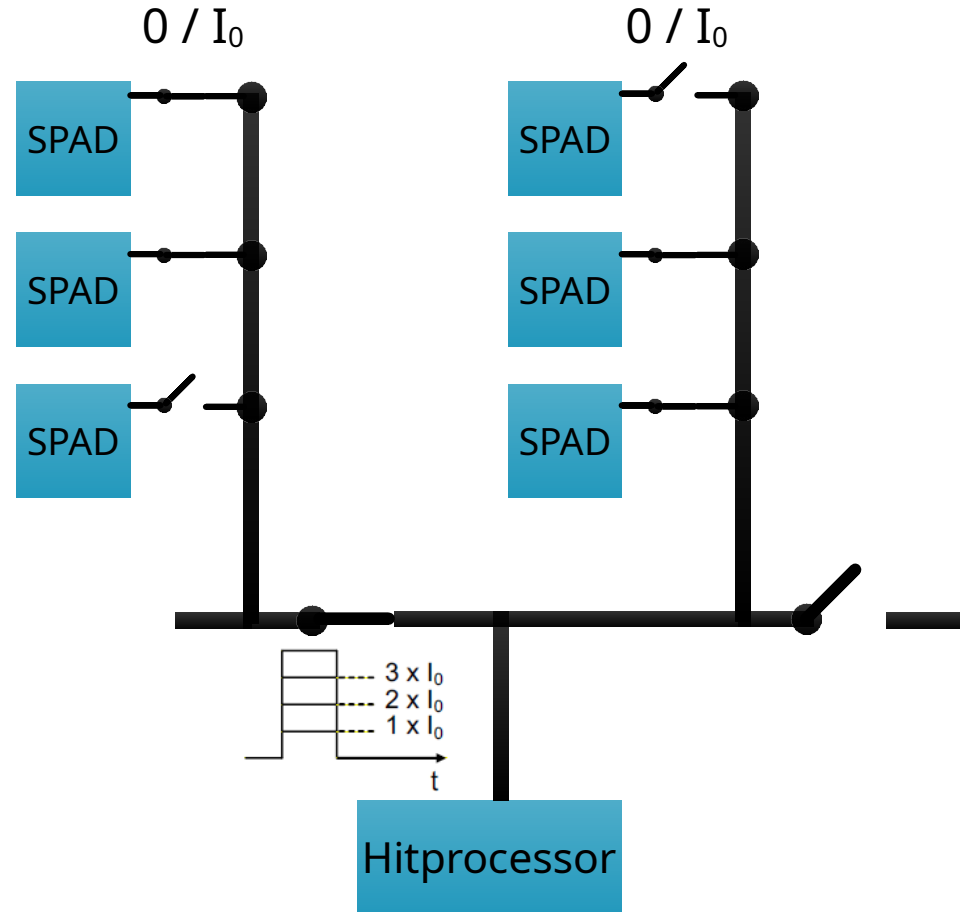
Concept



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Defining a group:



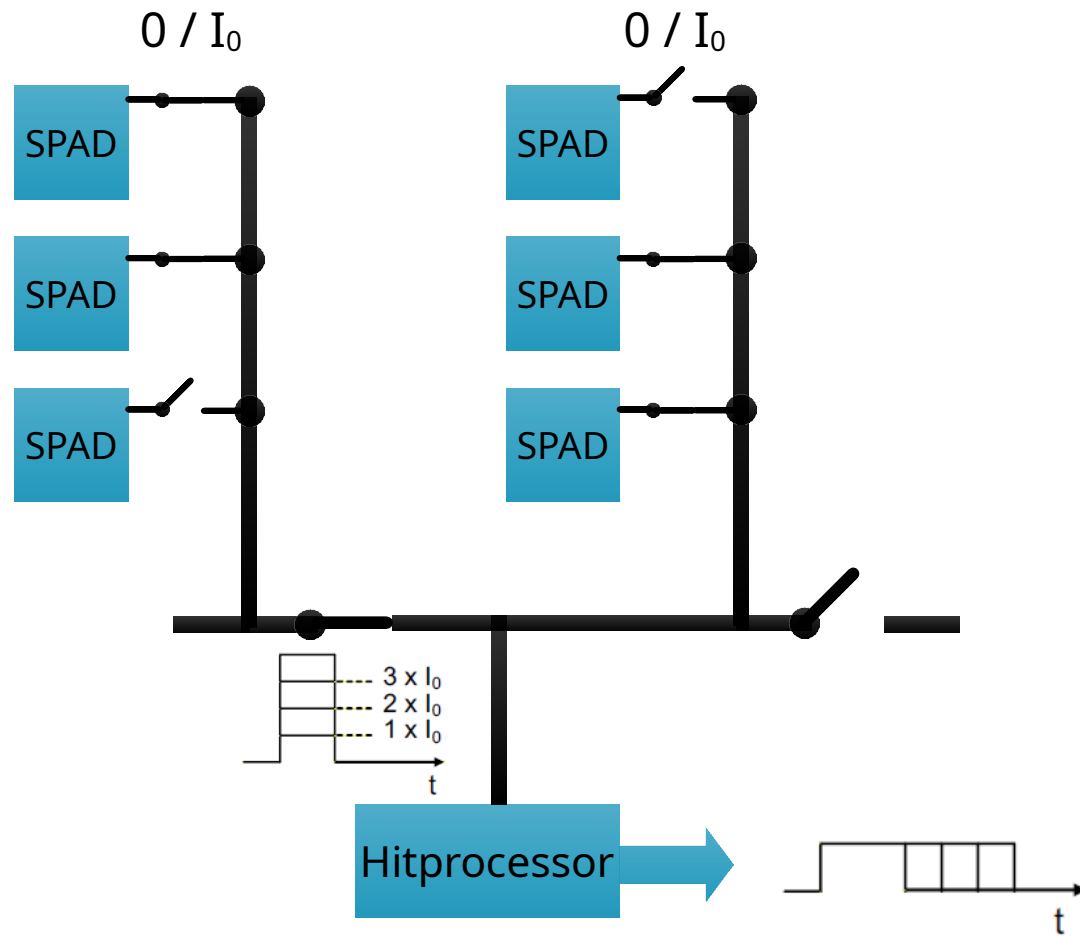
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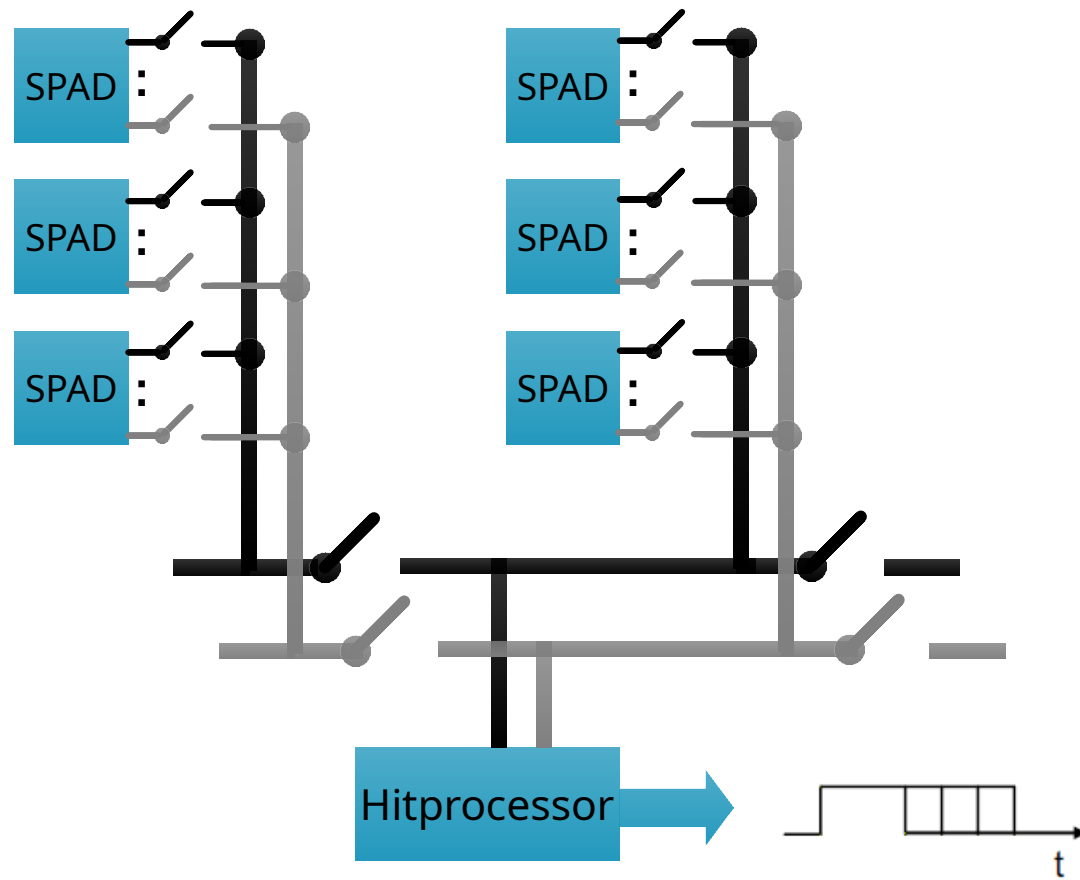
Concept



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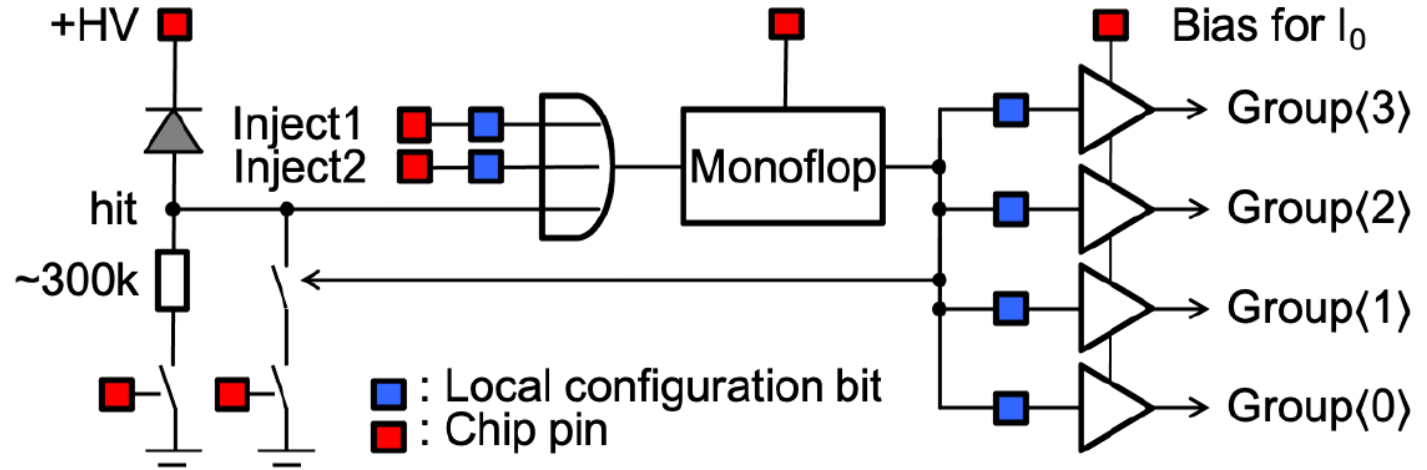
Chip Design

Chip Design



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SPAD to Group

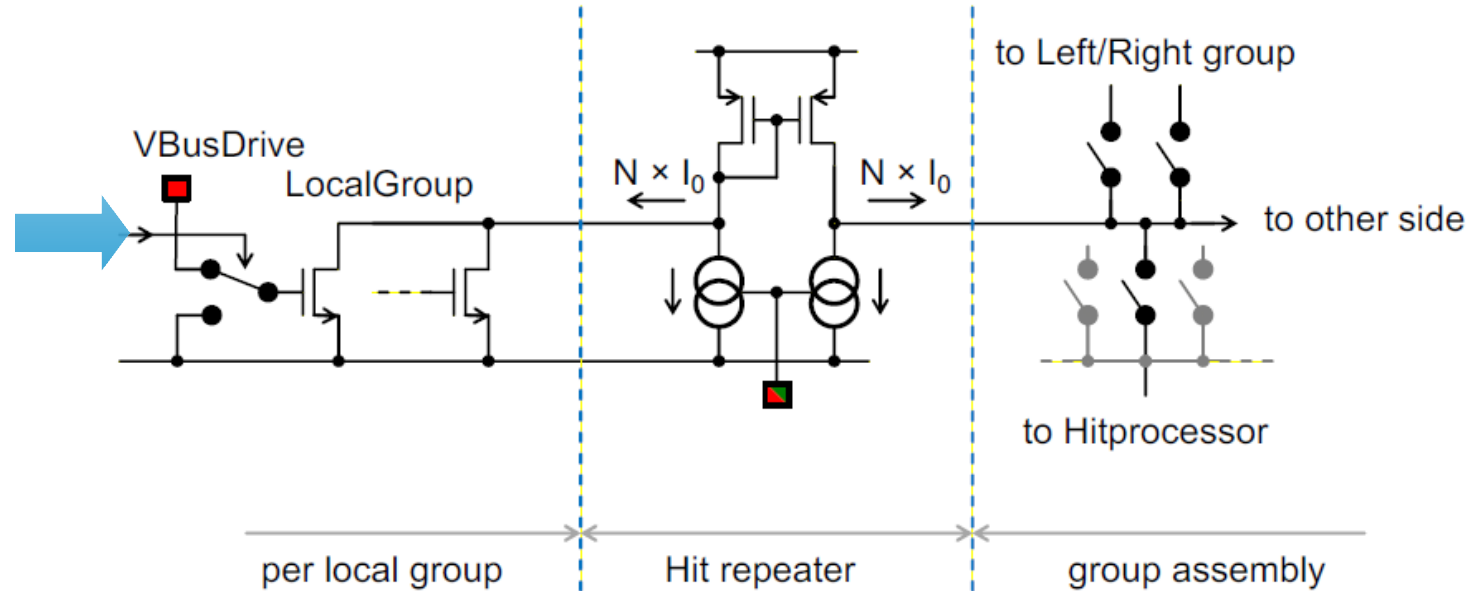


Chip Design



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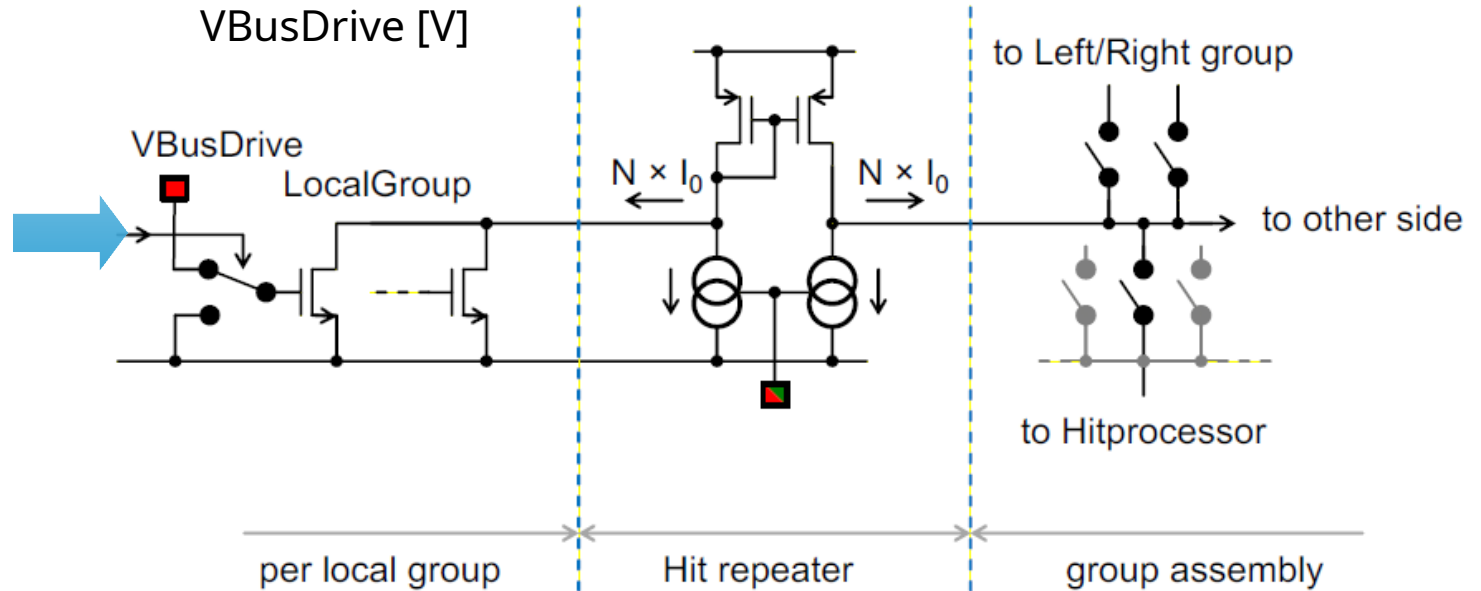
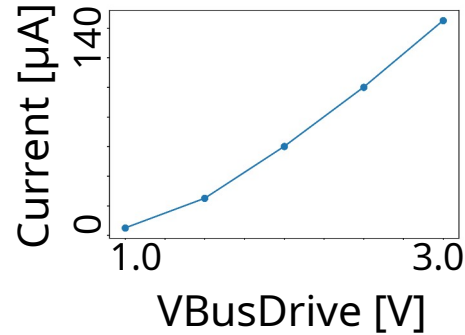


Chip Design



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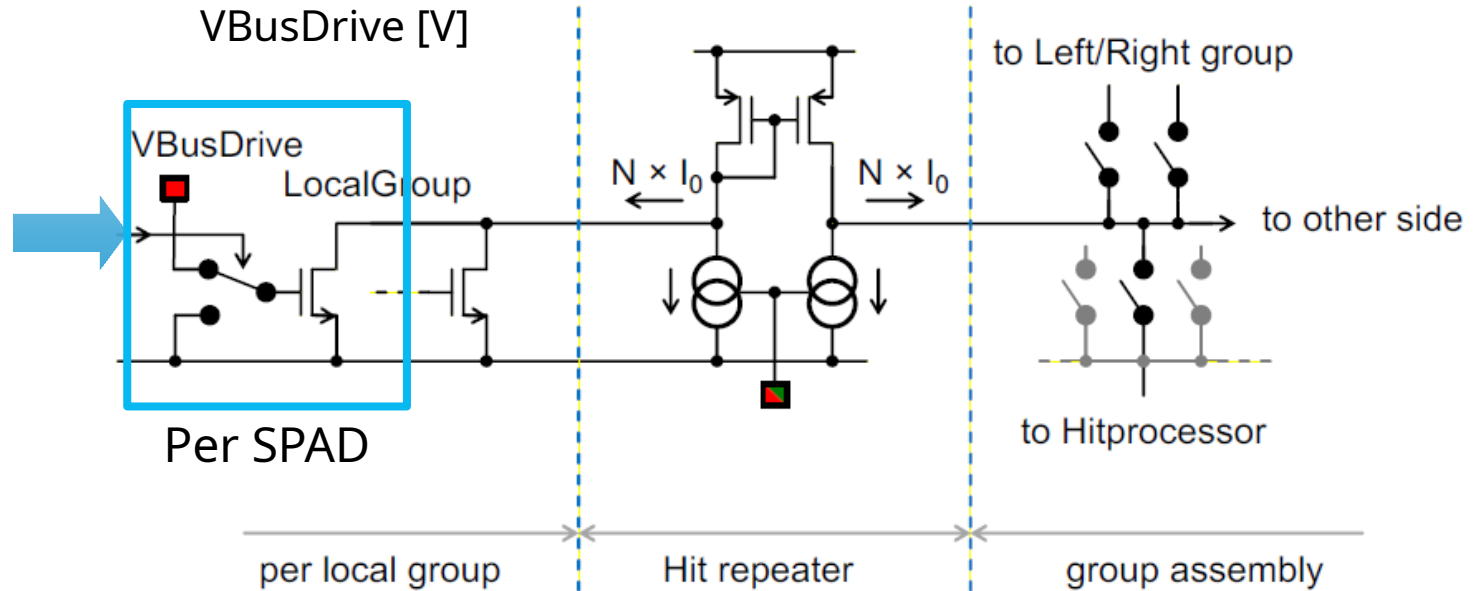
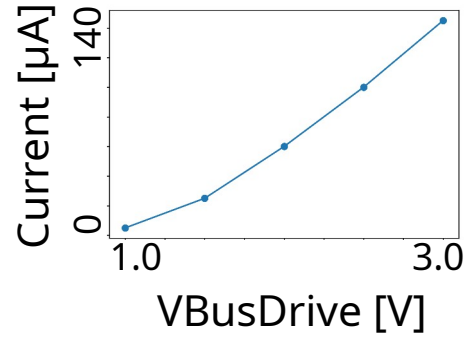


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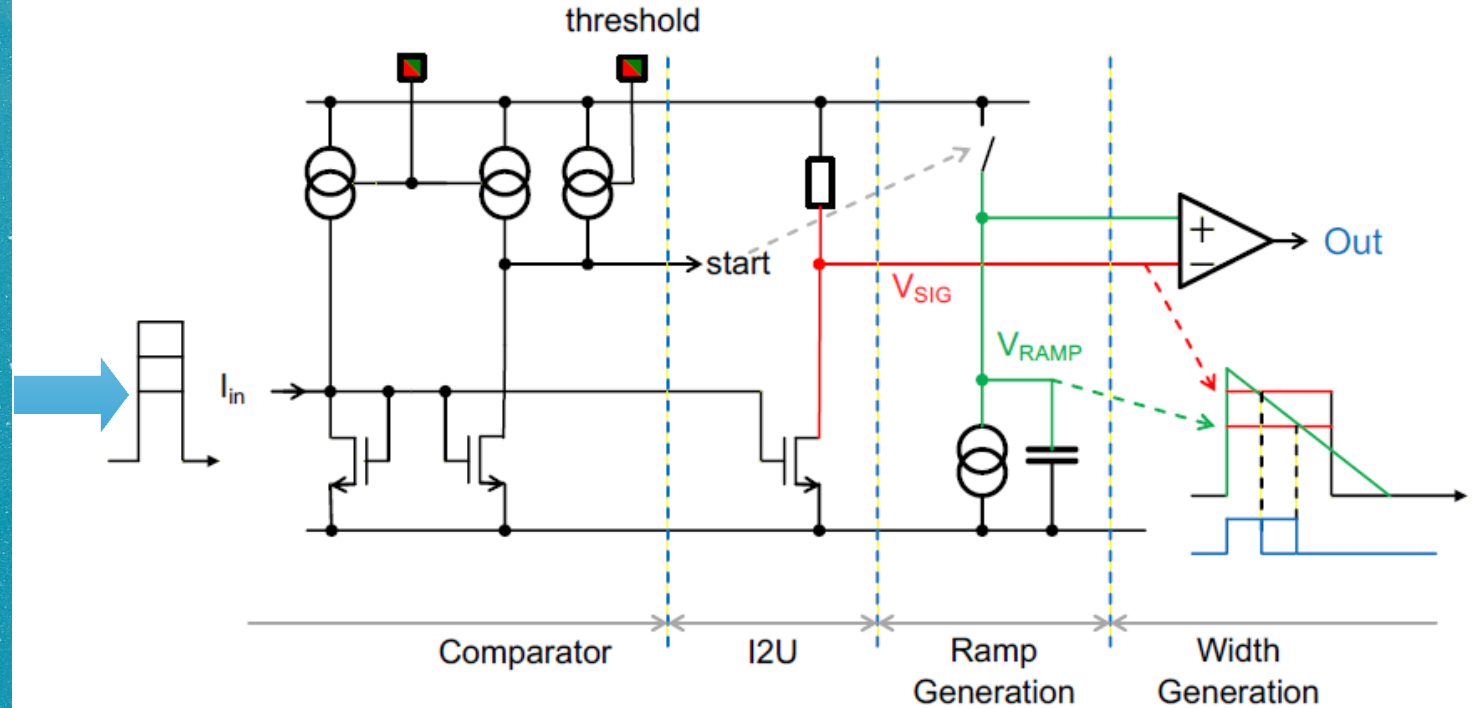
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Group to Hitprocessor



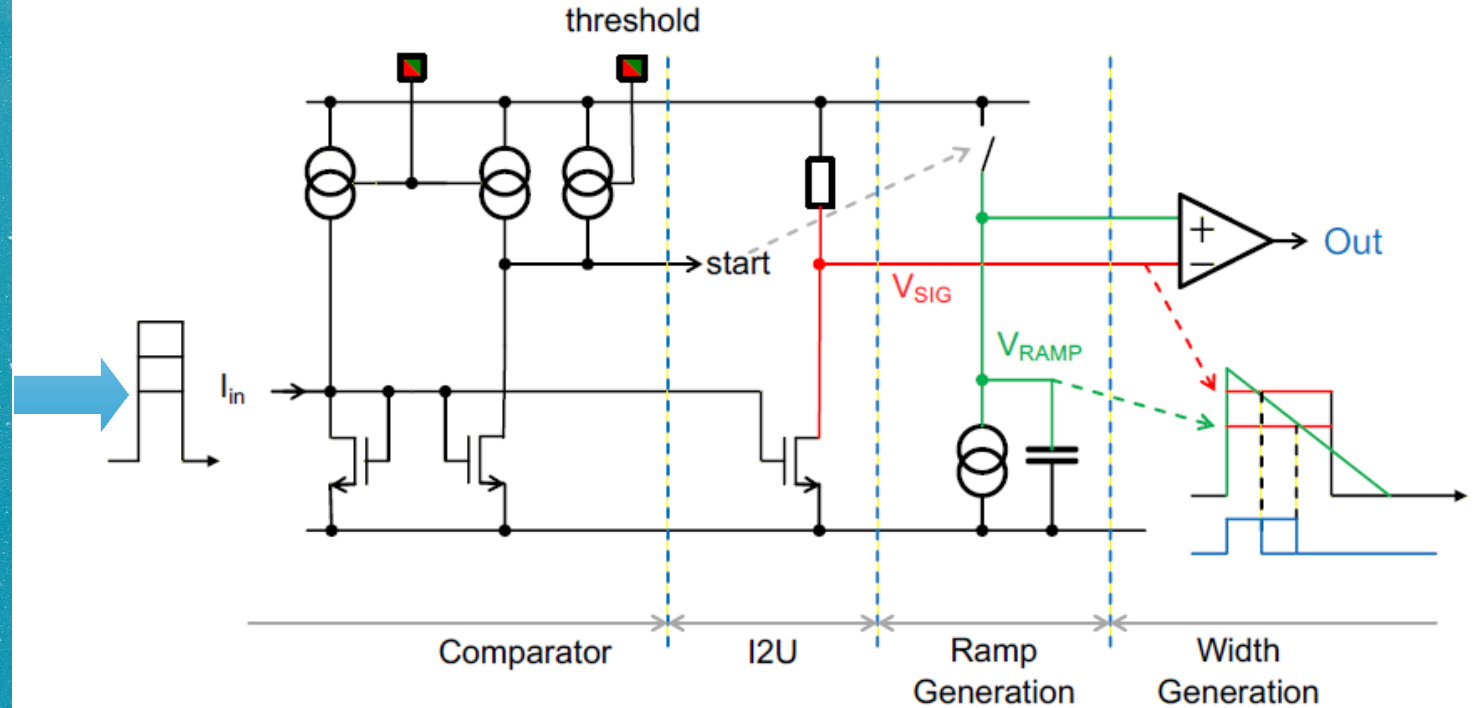


The Hitprocessor





The Hitprocessor



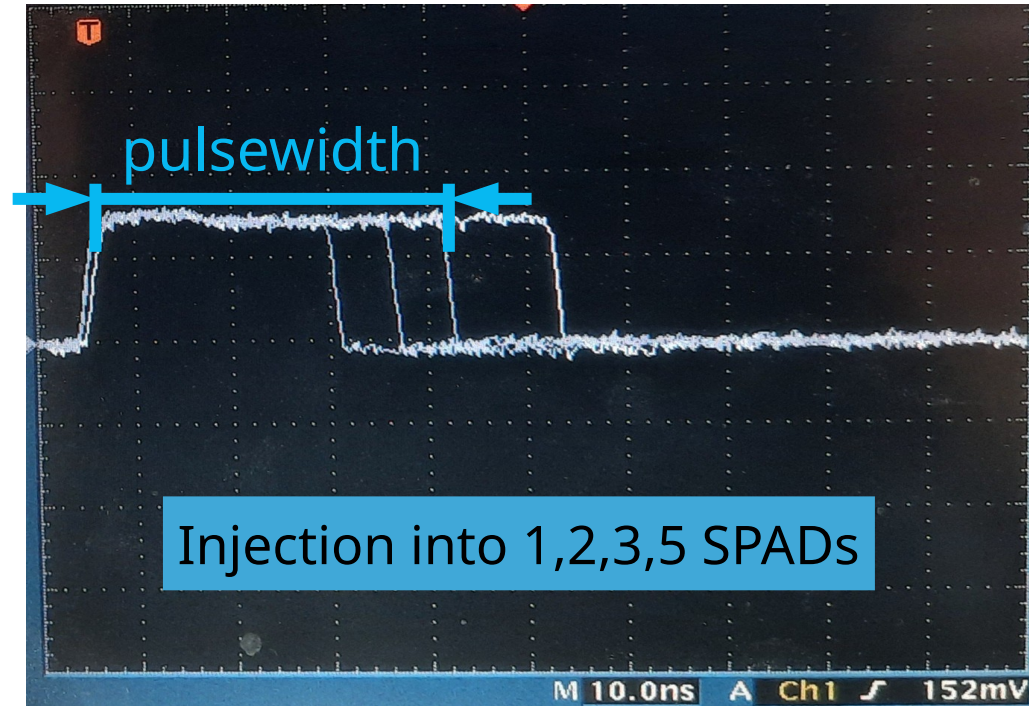
$$T_{out} \sim I_{in}$$

Chip Design



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Measured Hitprocessor Output

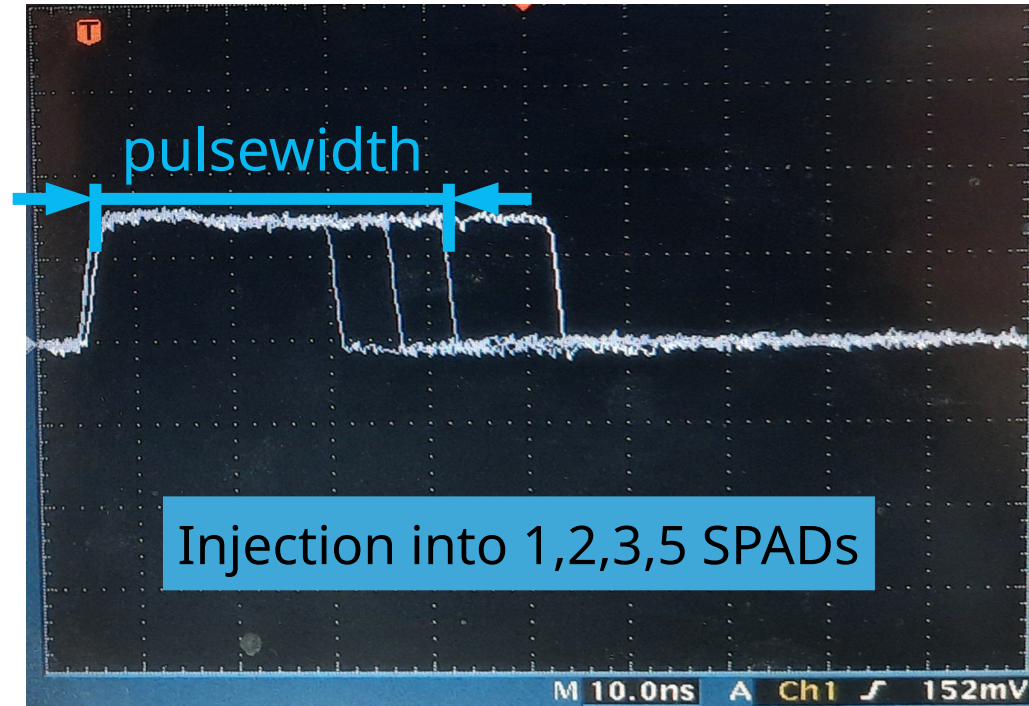


Chip Design



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Measured Hitprocessor Output



Easy to separate number of firing SPADs

Setup & first Results

Setup



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The Sensor

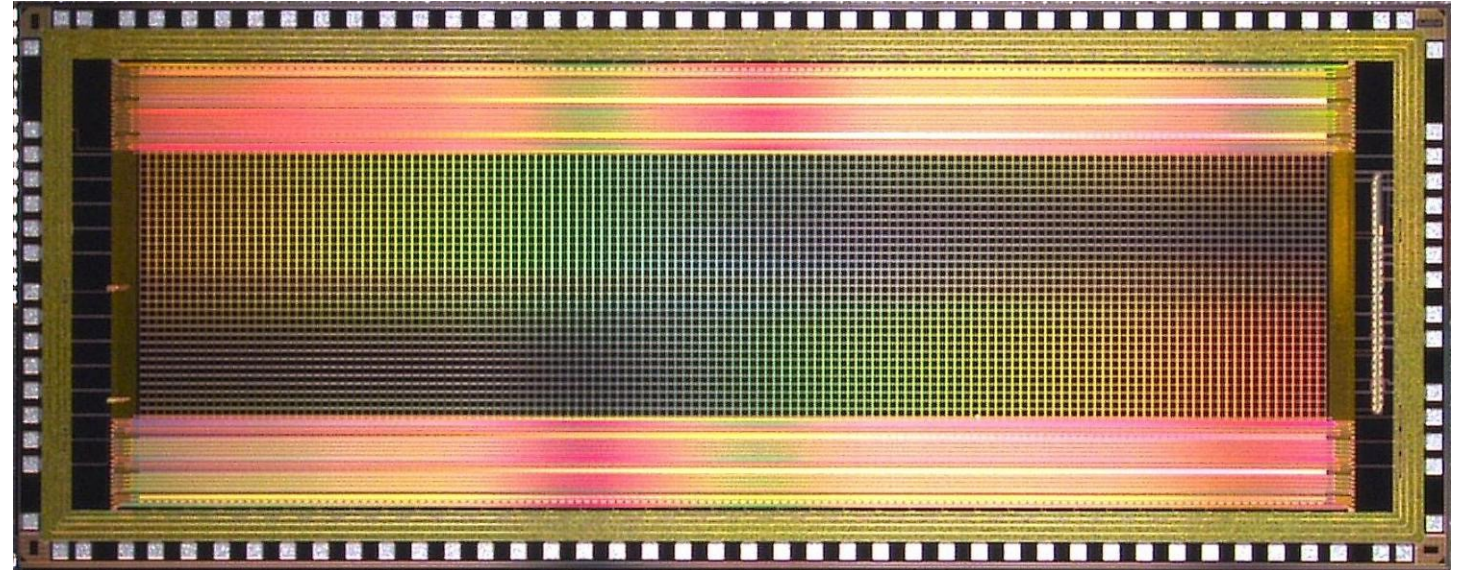
Setup



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The Sensor



Setup



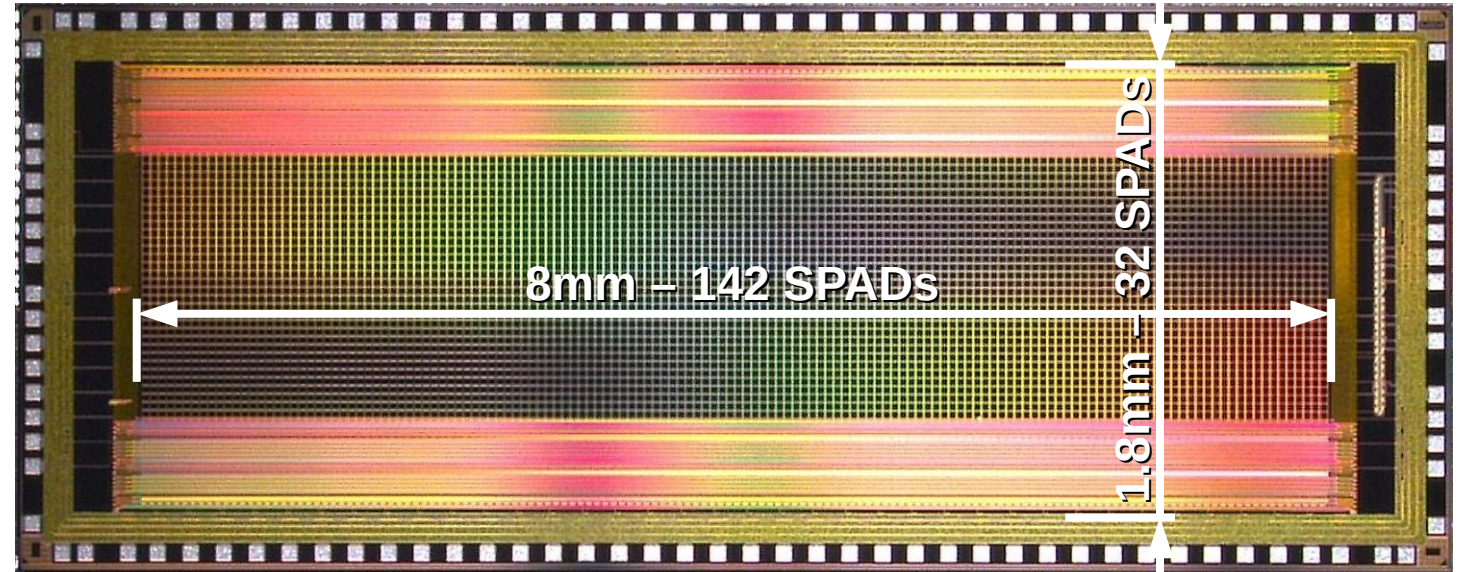
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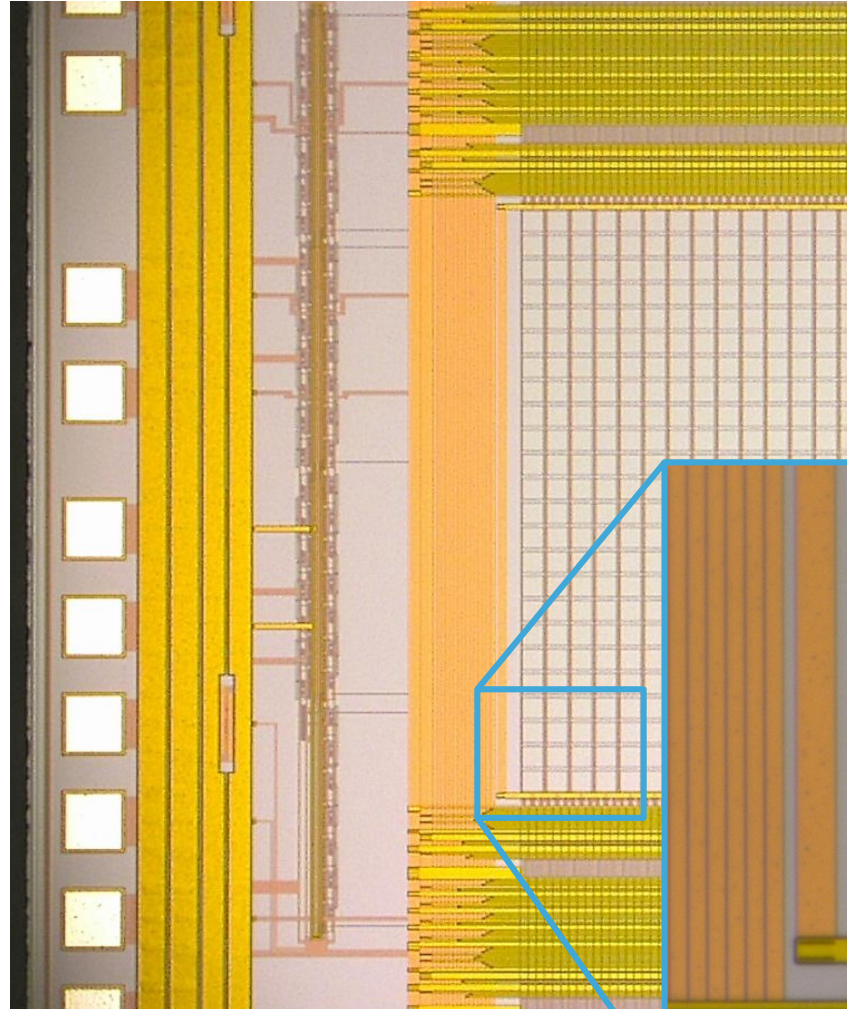
The Sensor



Setup



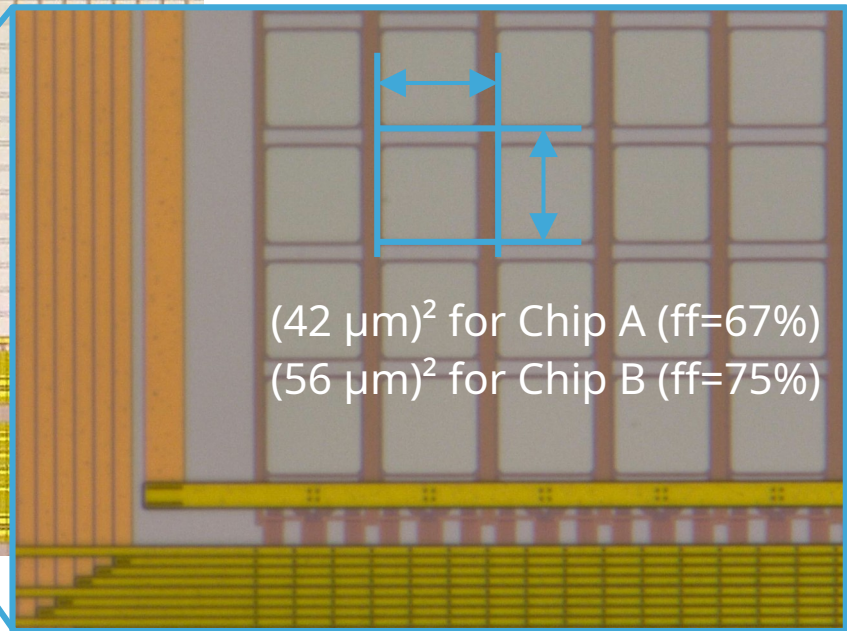
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Two prototypes (mostly B)

No circuitry in SPAD Matrix
→ max fill factor

Signals are routed to logic
above/below



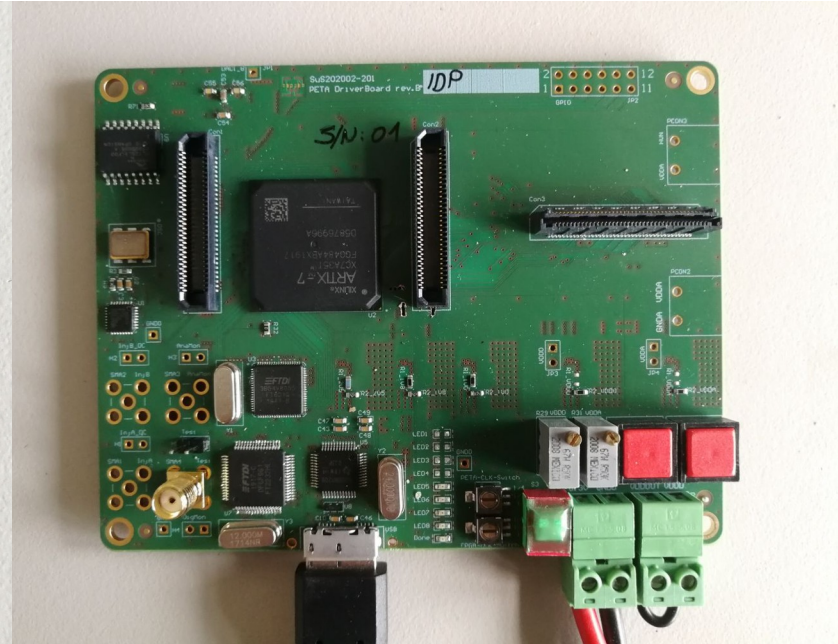
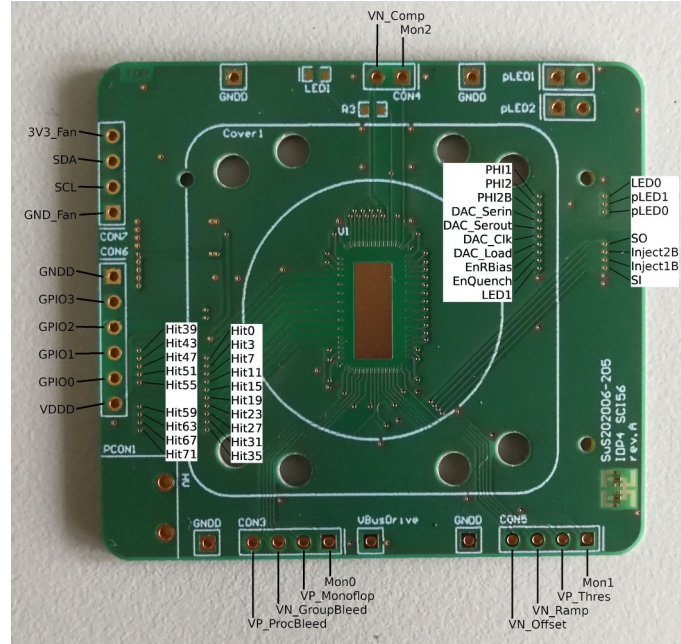
$(42 \mu\text{m})^2$ for Chip A (ff=67%)
 $(56 \mu\text{m})^2$ for Chip B (ff=75%)

Setup



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Sensor board and FPGA



Setup



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Setup



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Controlling software:

C++-library:

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

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Setup

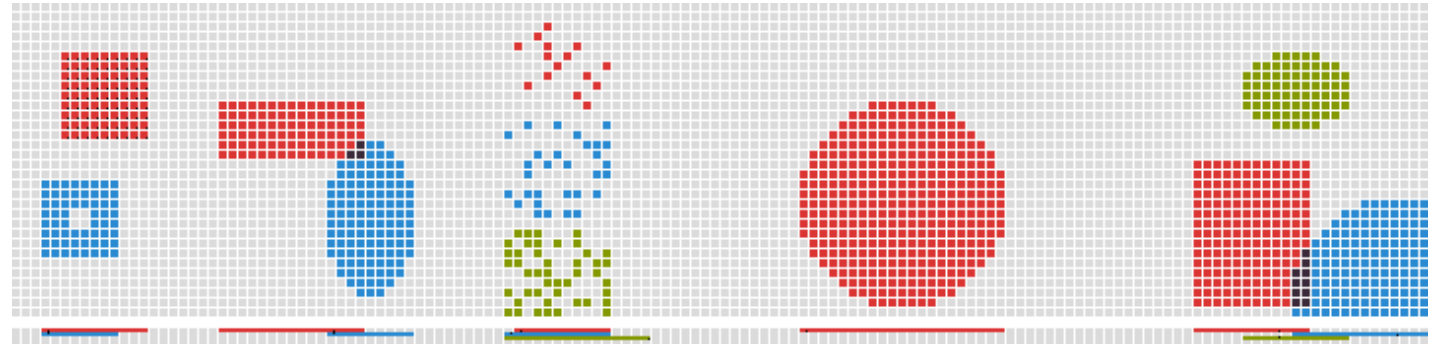


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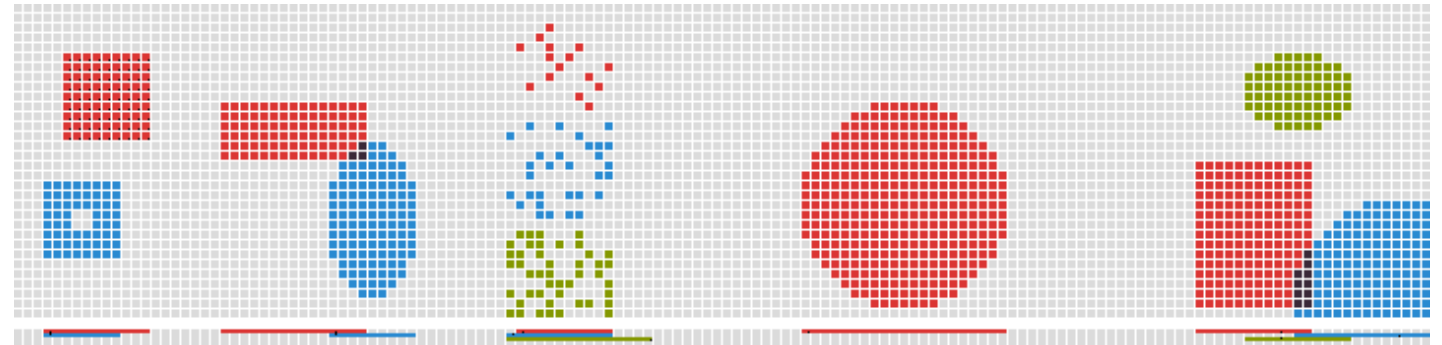
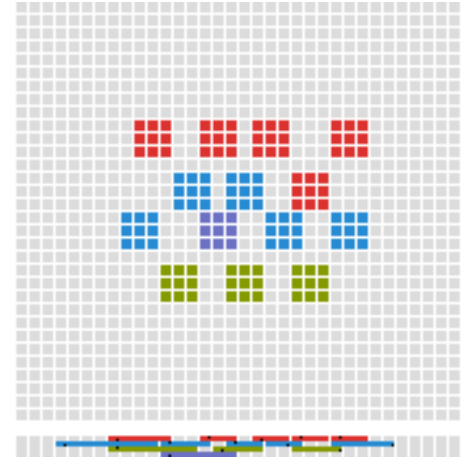


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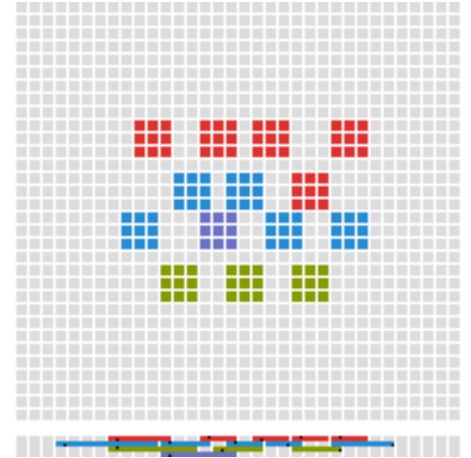


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Controlling software:

C++-library:

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FPGA Code:

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

Setup

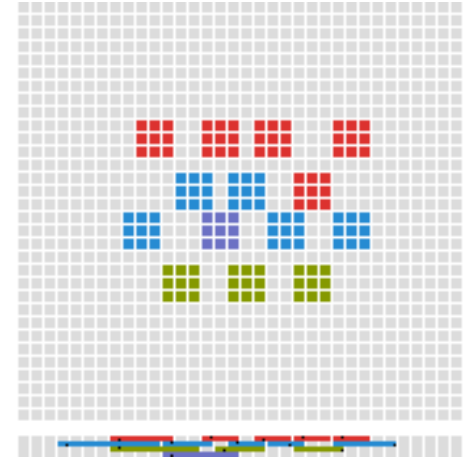


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FPGA Code:

- Data transfer to PC
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Where, When, how many?

Complete controlling software

Results



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Results



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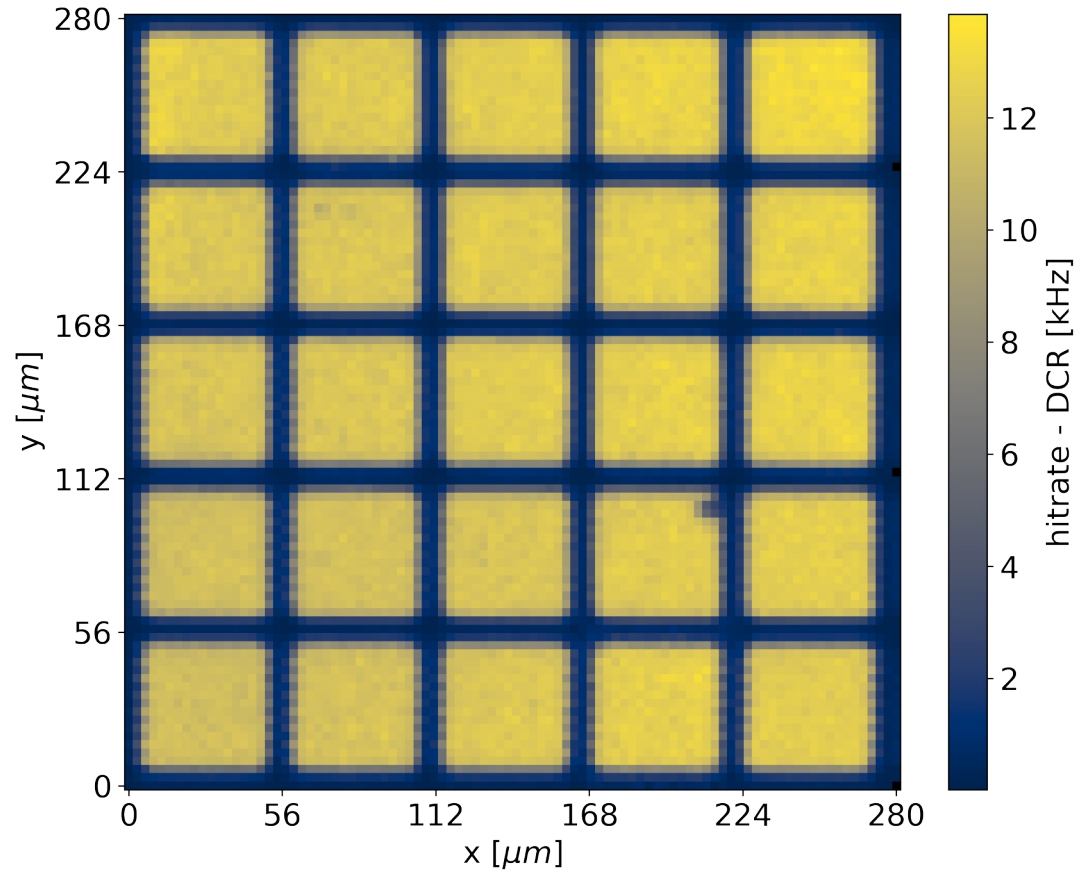
SPAD signal for a fine laser

Results



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SPAD signal for a fine laser



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Results



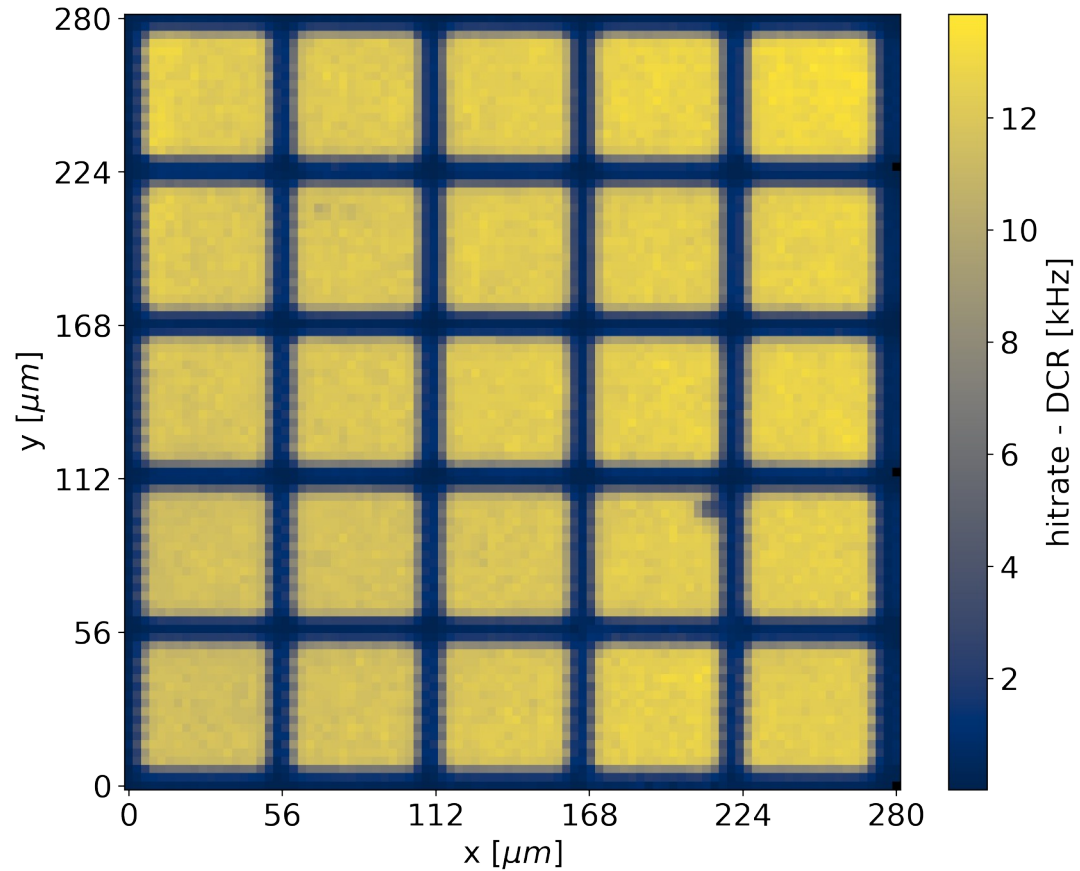
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SPAD signal for a fine laser



Measured fillfactor $77.5 \pm 1.6\%$

Results

Measured group signals for a LED Source



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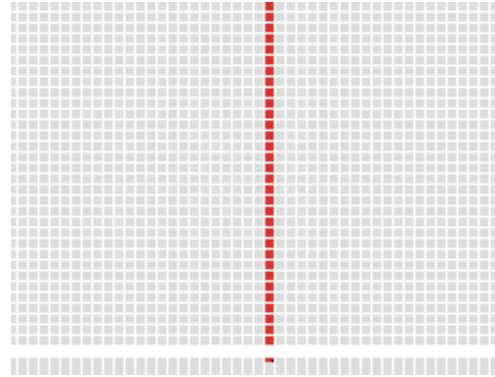
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Results

Measured group signals for a LED Source



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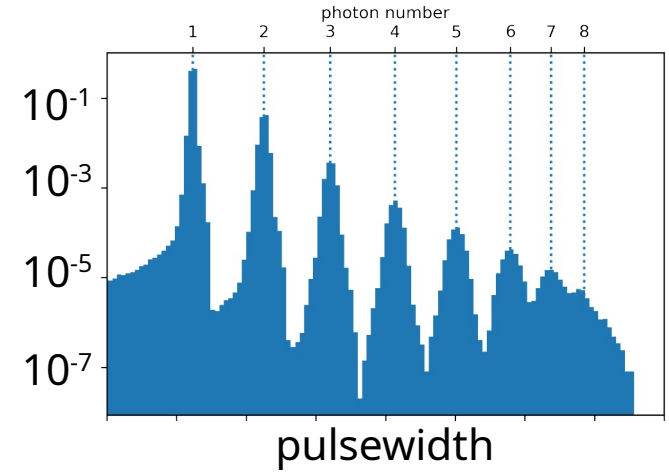
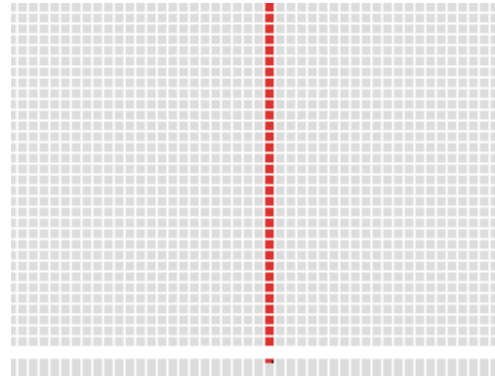
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Page 26

Results

Measured group signals for a LED Source



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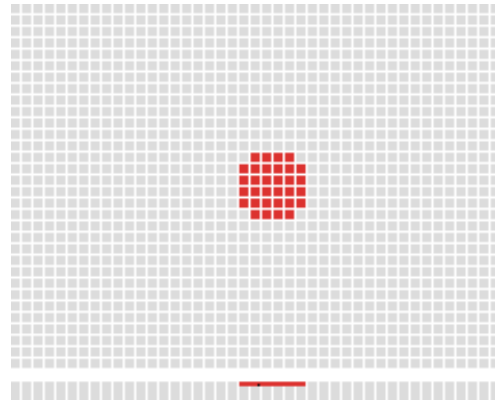
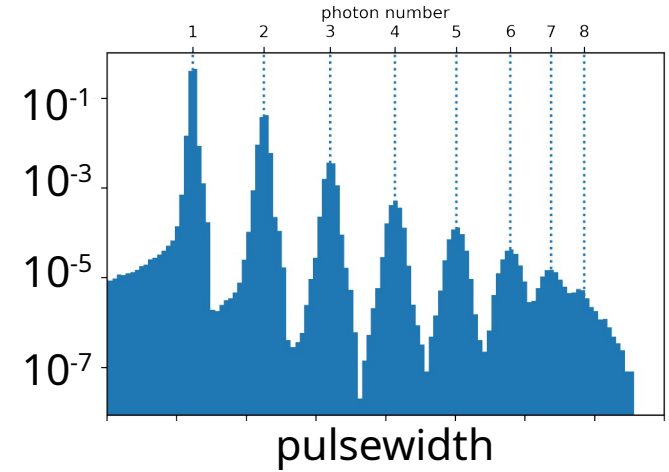
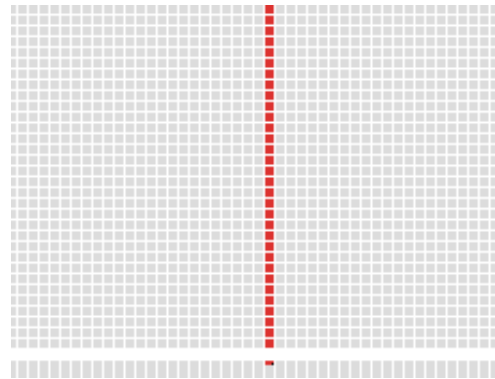
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Results

Measured group signals for a LED Source



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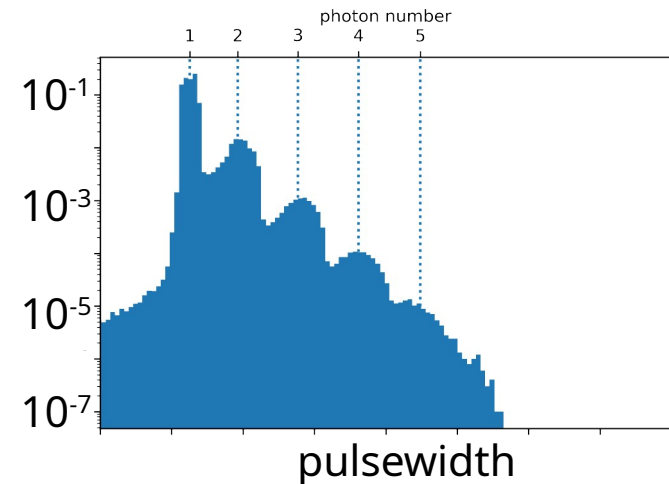
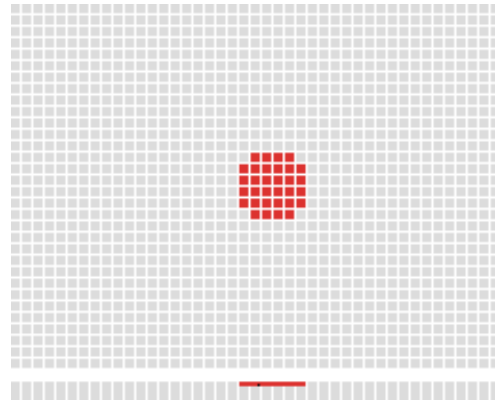
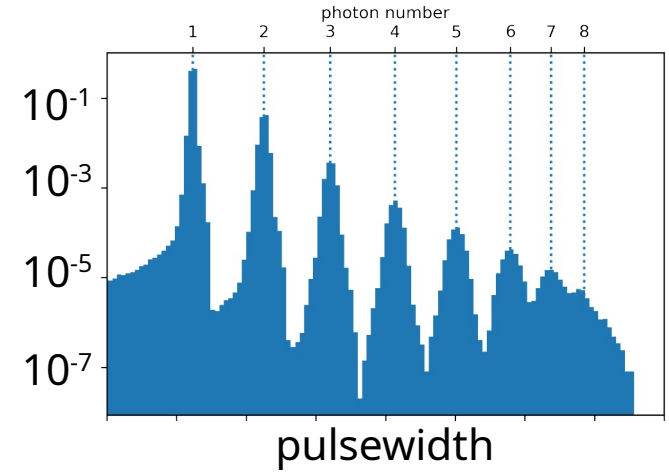
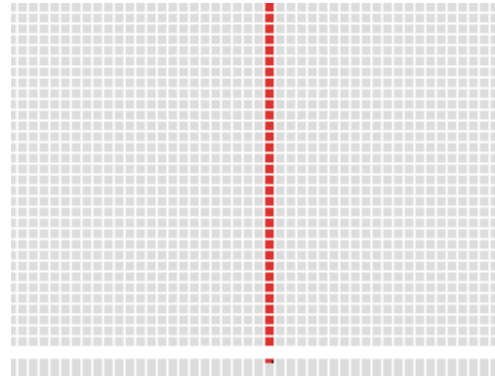
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Results

Measured group signals for a LED Source



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Fibre Setup & Results

Setup



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Fibre mat readout setup

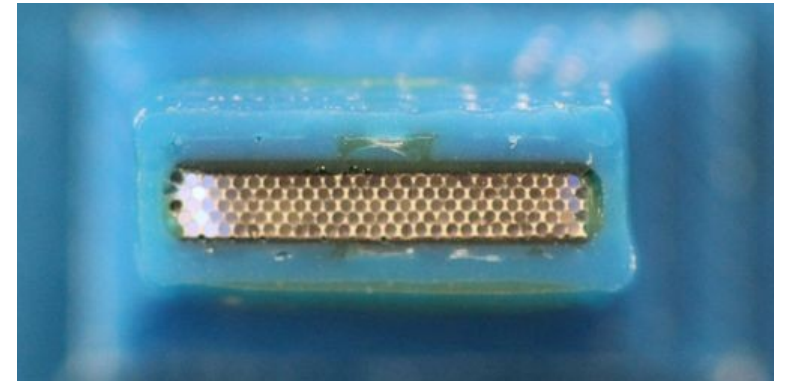
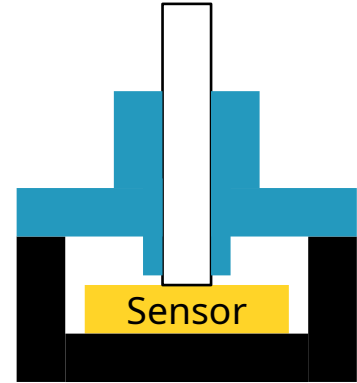
Setup



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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



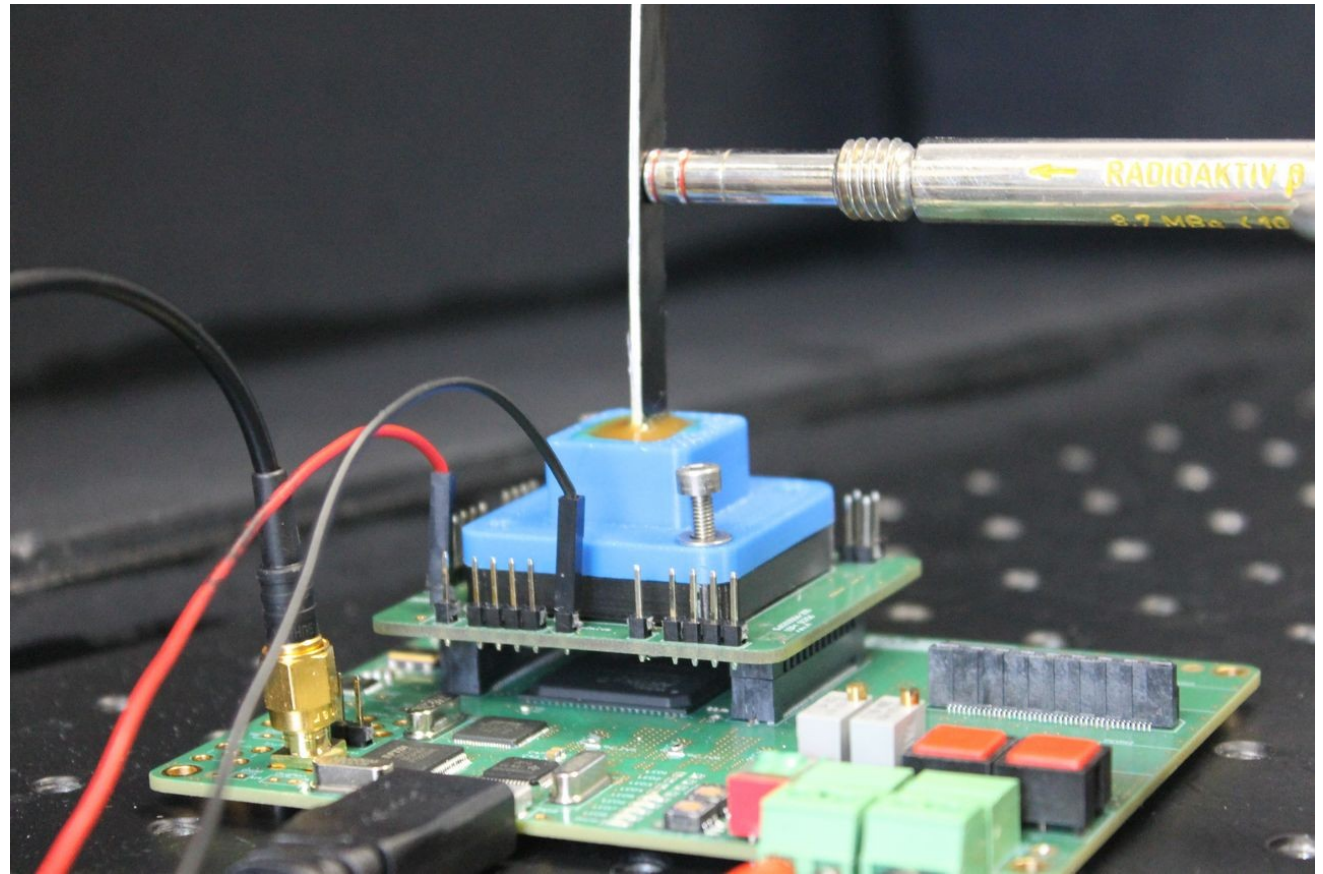
Setup



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Fibre mat readout setup



Results



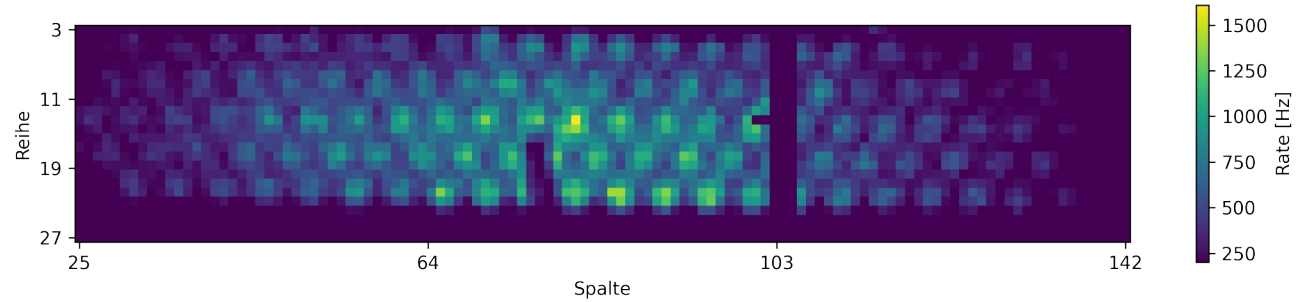
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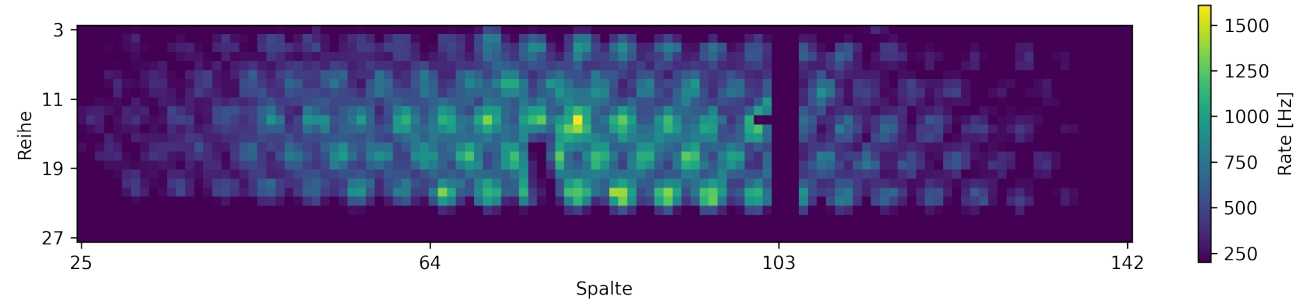
Results



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Results

First Step: Find single fibres and read them out



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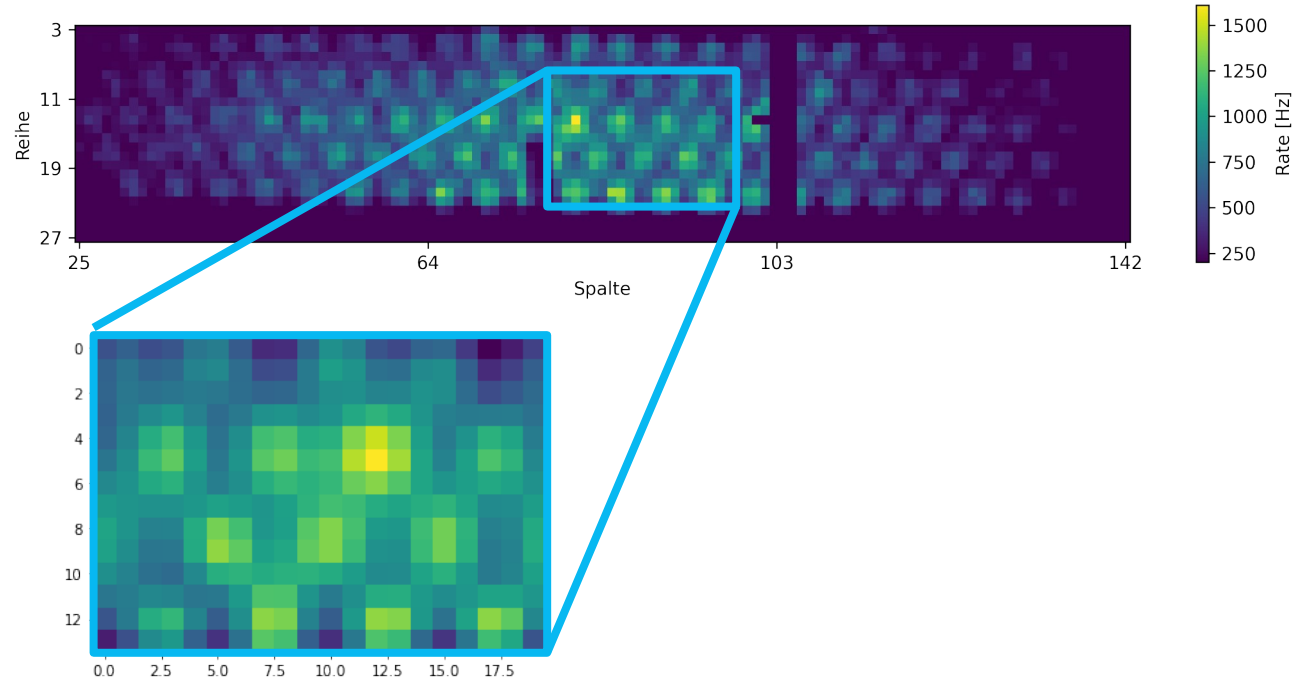
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Results

First Step: Find single fibres and read them out



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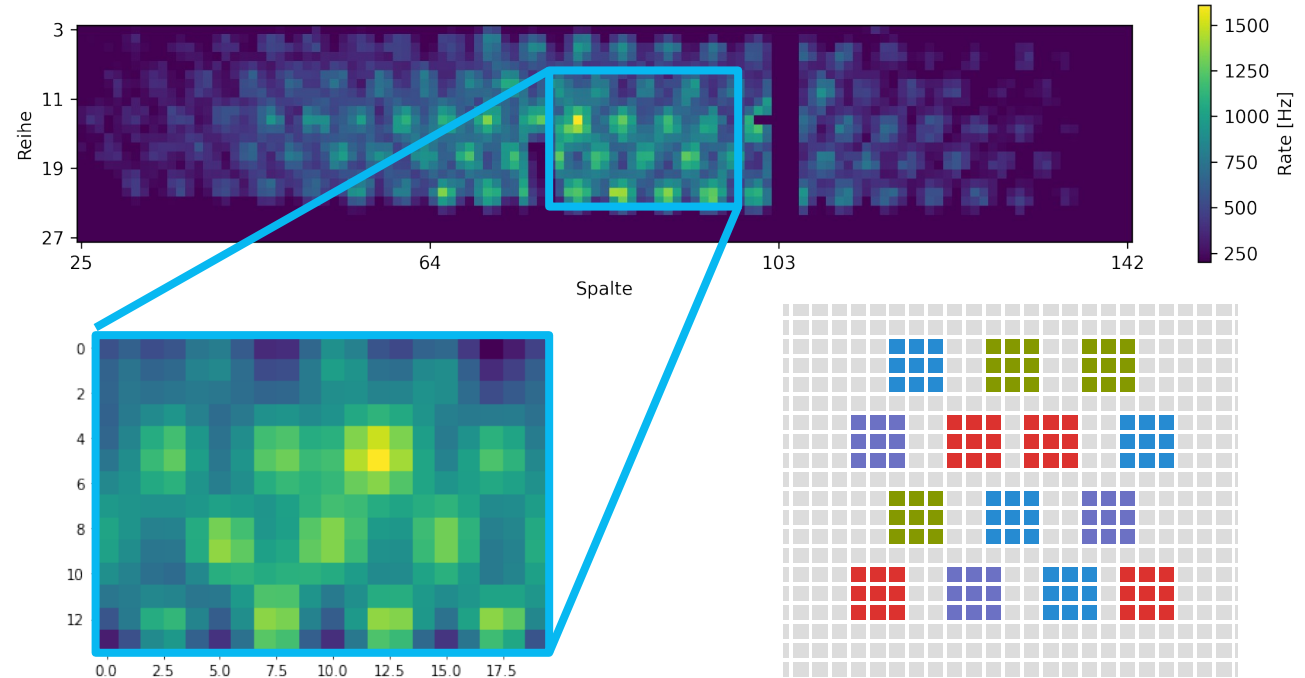
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Results

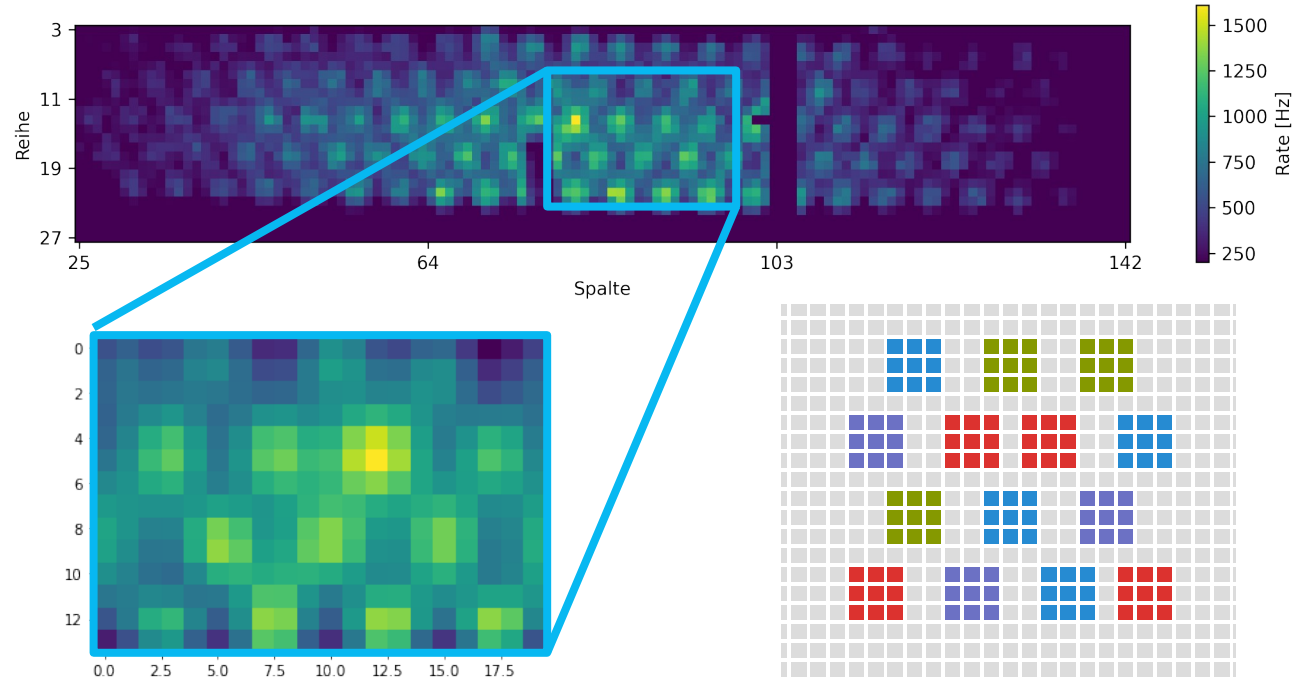
First Step: Find single fibres and read them out



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Results

First Step: Find single fibres and read them out



Automatically finds fibres and assigns groups!



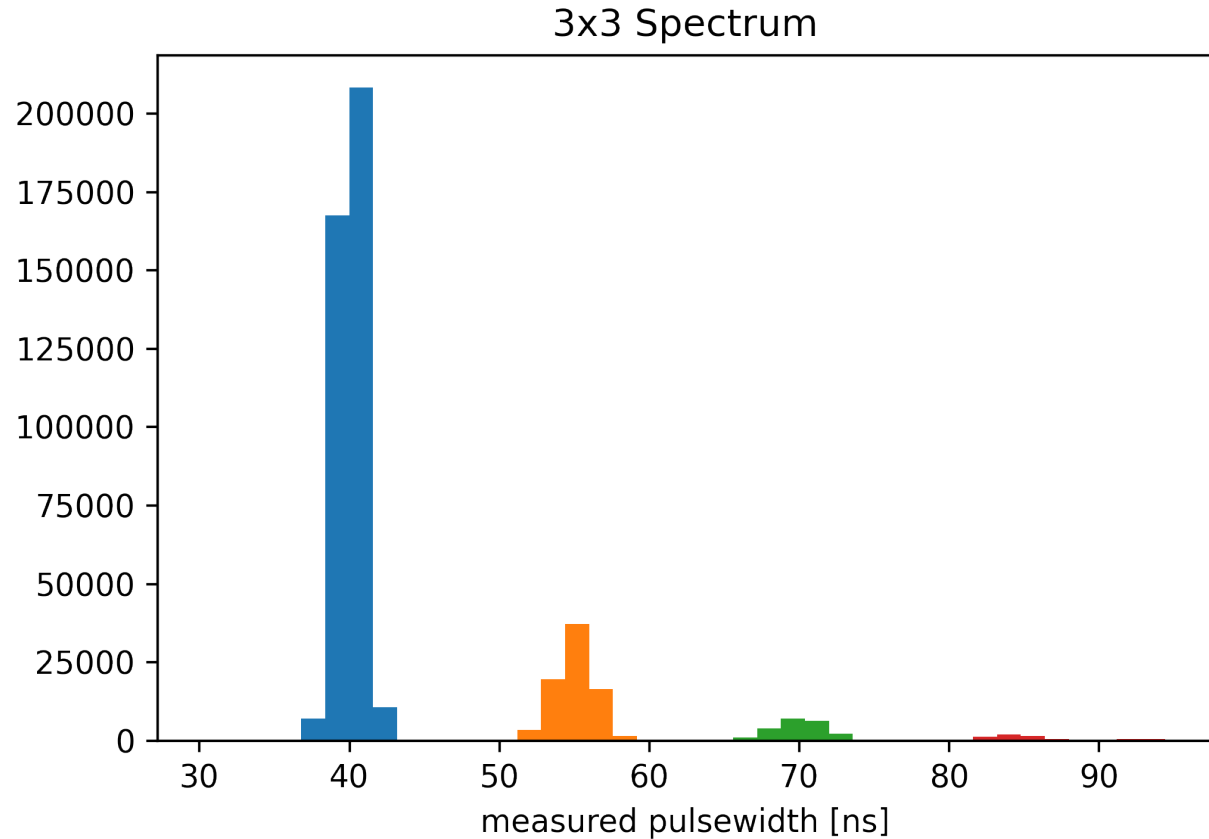
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Results



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Single fibre photon yield



Results



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First particle tracks

Results



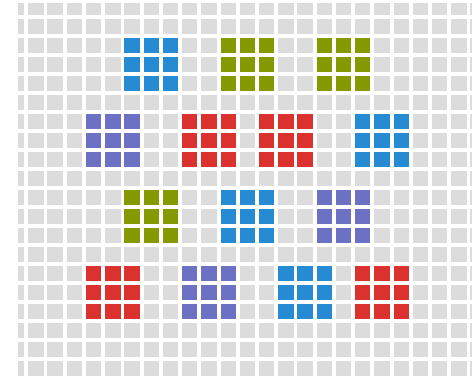
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First particle tracks

Read 14 fibres simultaneously

Defined events:

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



Results



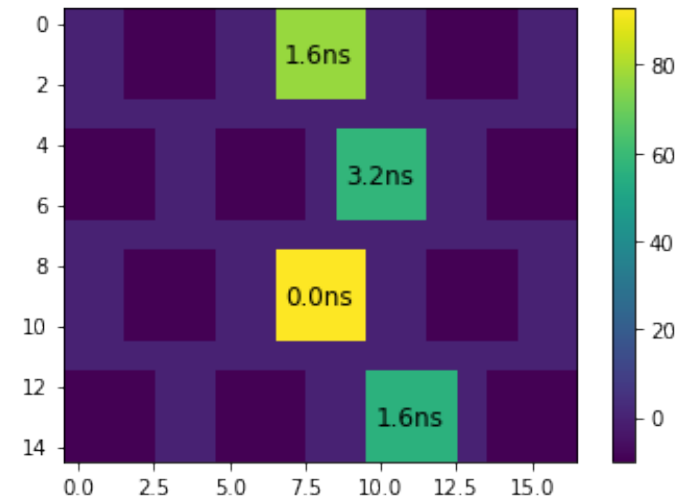
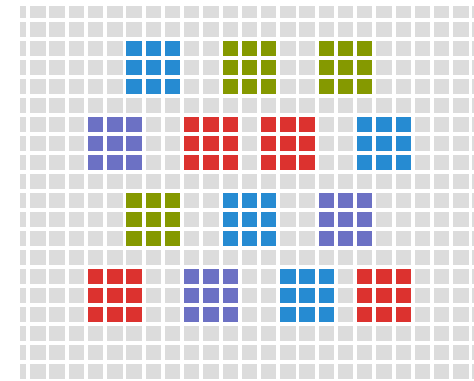
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Results



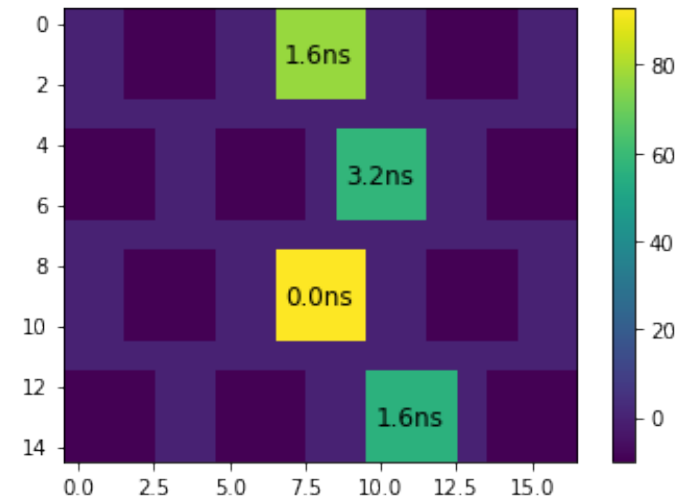
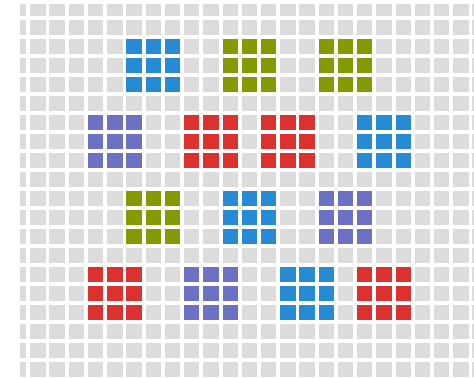
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First particle tracks

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- Coincidence with external detector



Proof of Principle!

Results



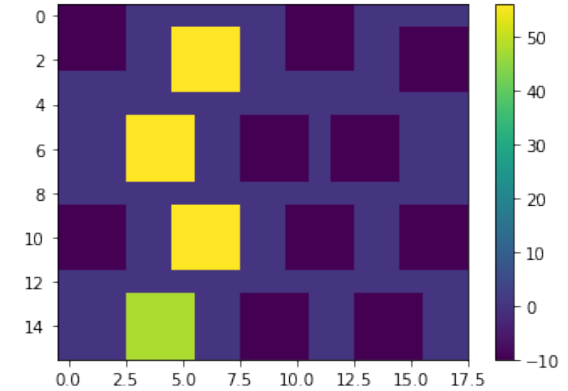
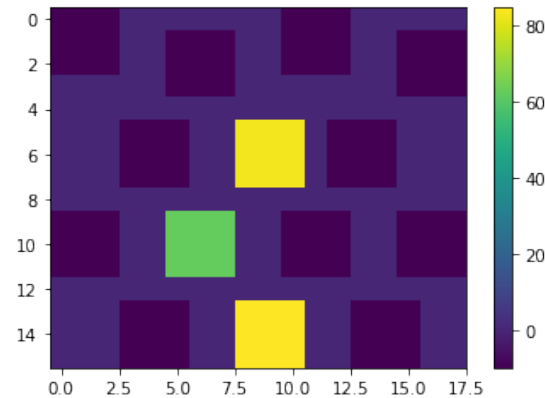
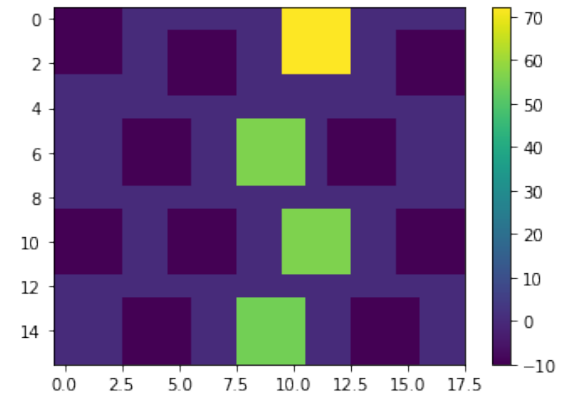
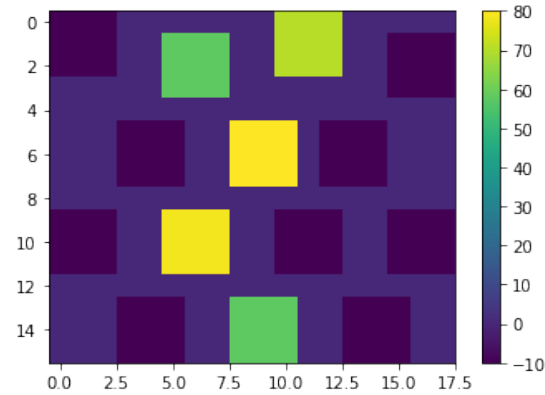
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First particle tracks and more!



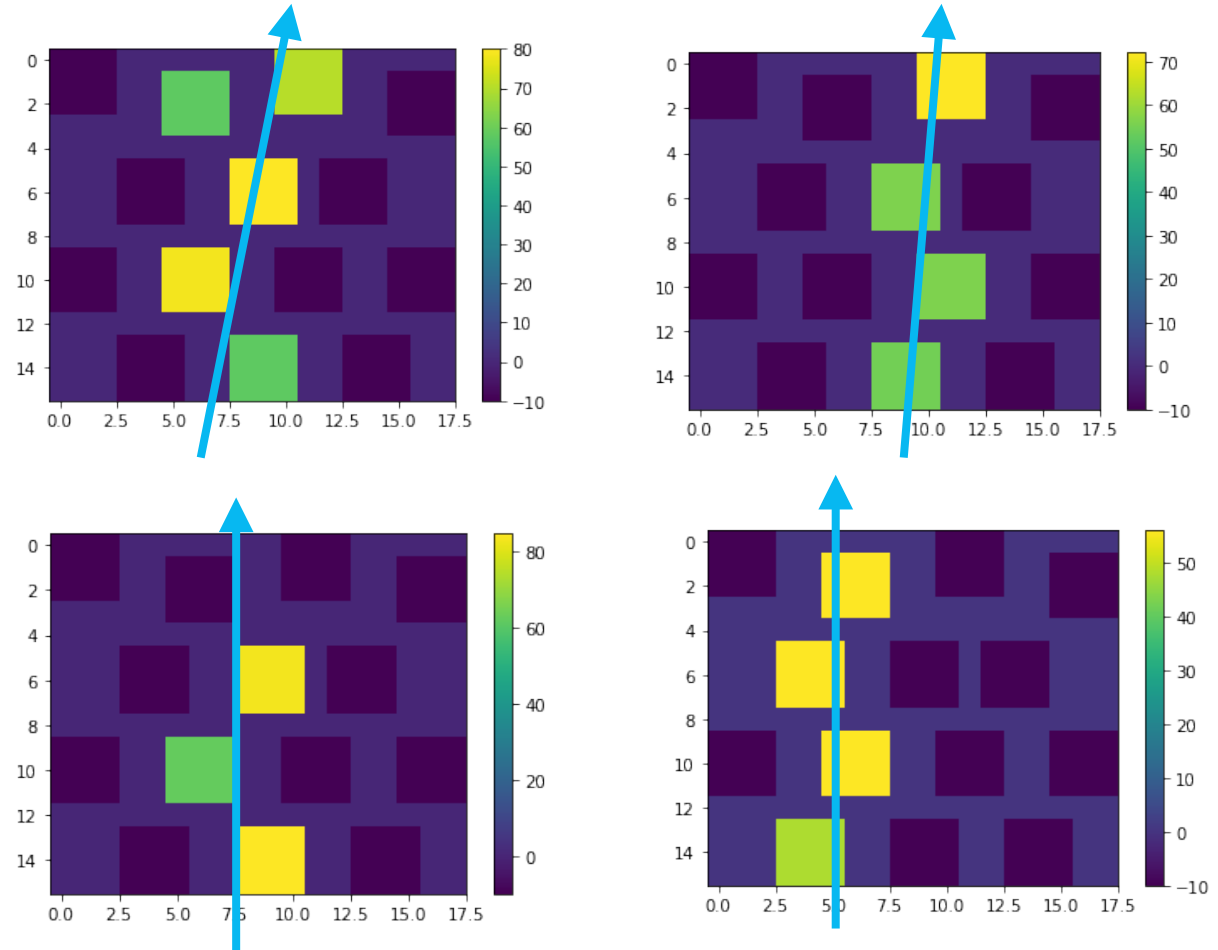
Results



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First particle tracks and more!



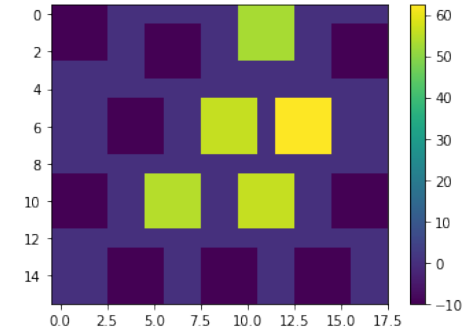
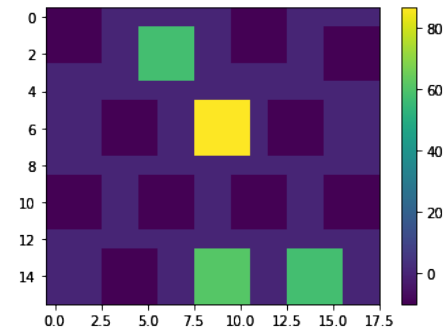
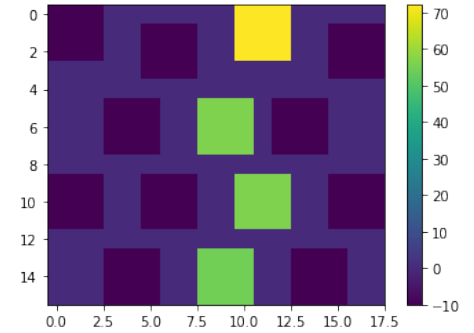
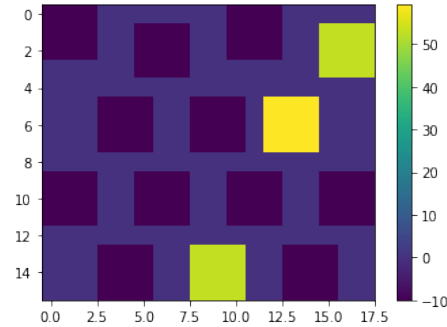
Results



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First particle tracks and more!

less constraints:



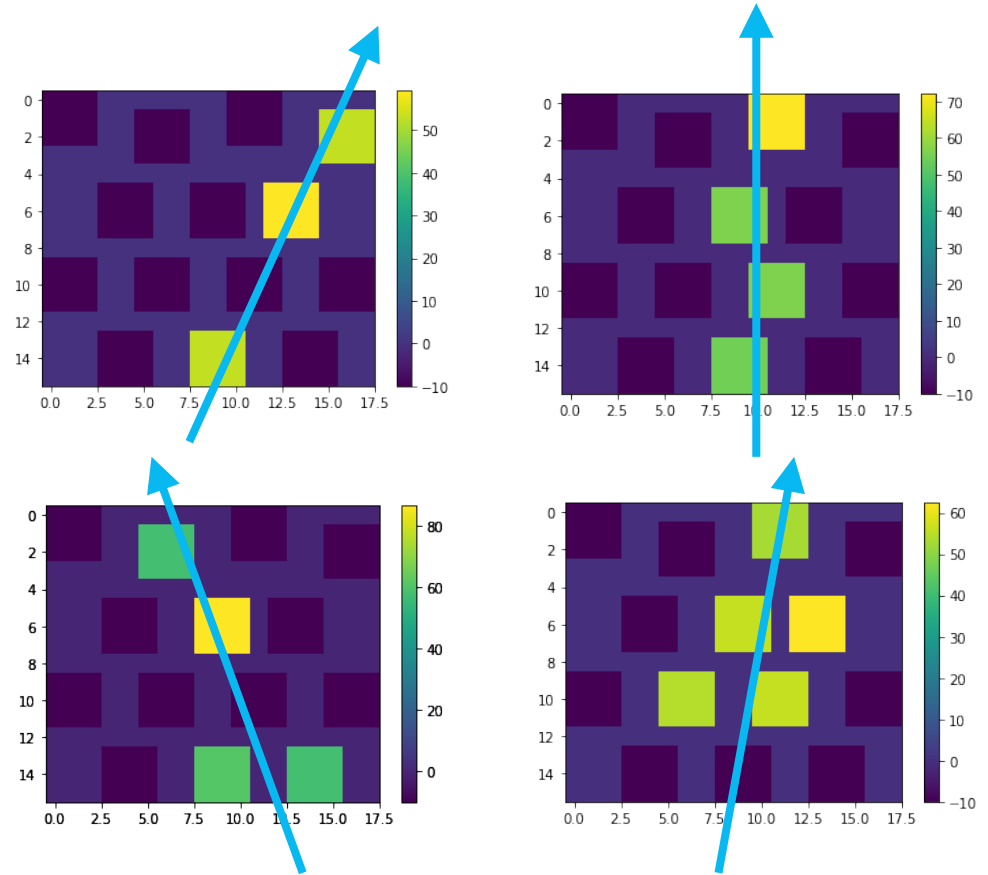
Results



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First particle tracks and more!

less constraints:



Results

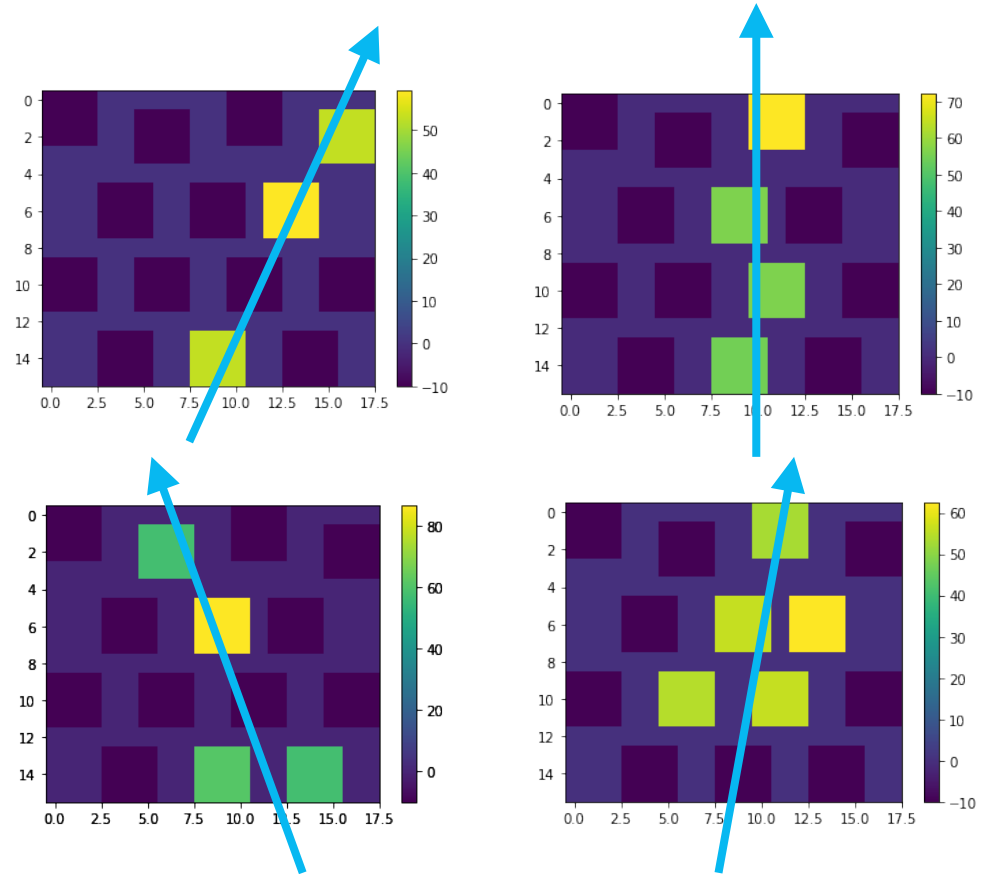


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First particle tracks and more!

less constraints:

Micro Tracking

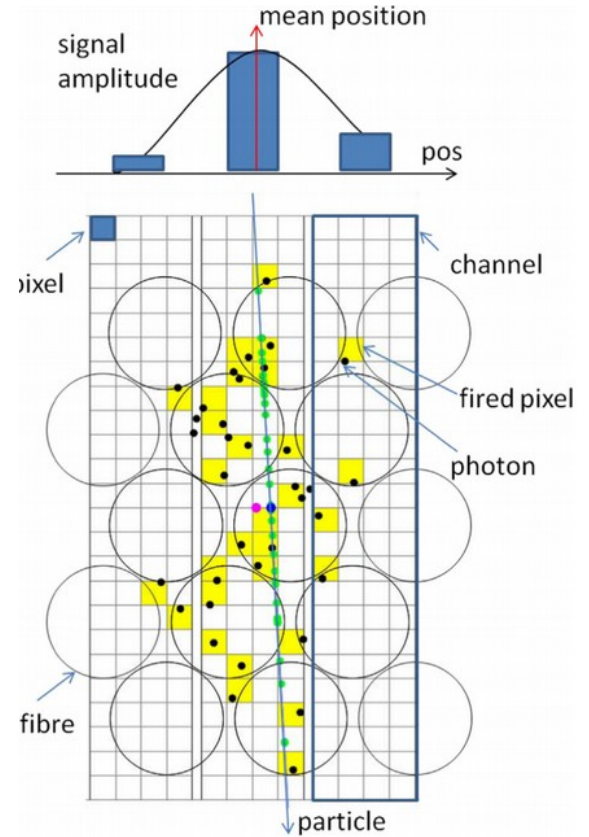
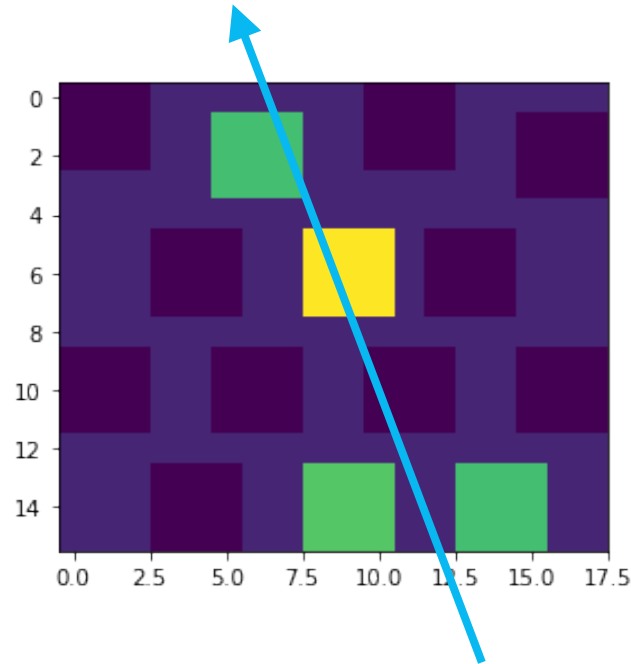


Results



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First particle tracks and more!



Results



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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

Outlook

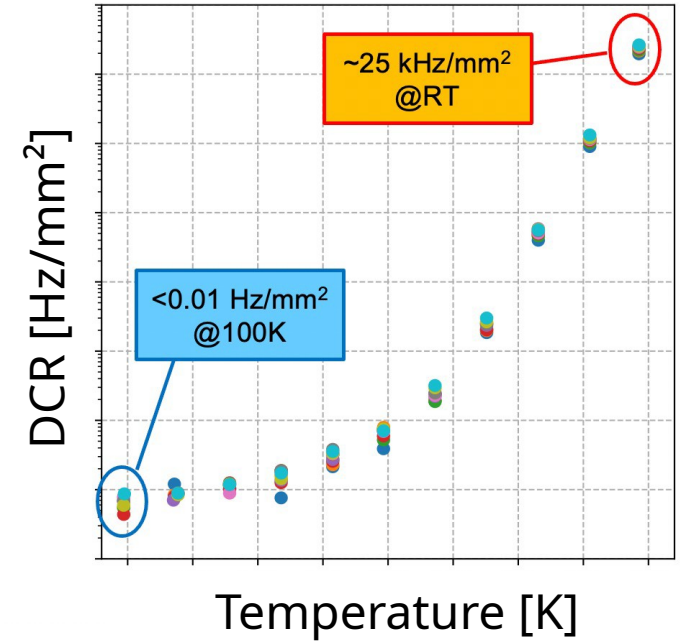
Improvements

Test cooled setup

- Reduce dark counts



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Outlook



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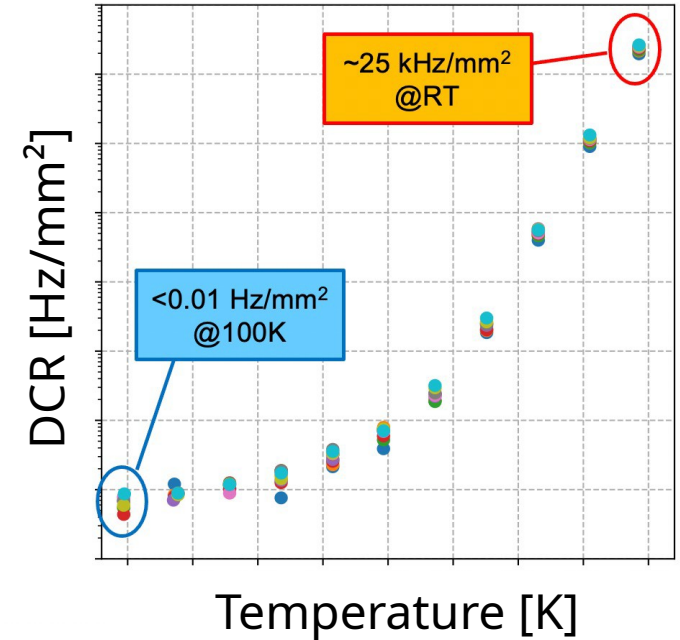
Improvements

Test cooled setup

- Reduce dark counts

Prepare new chip submission

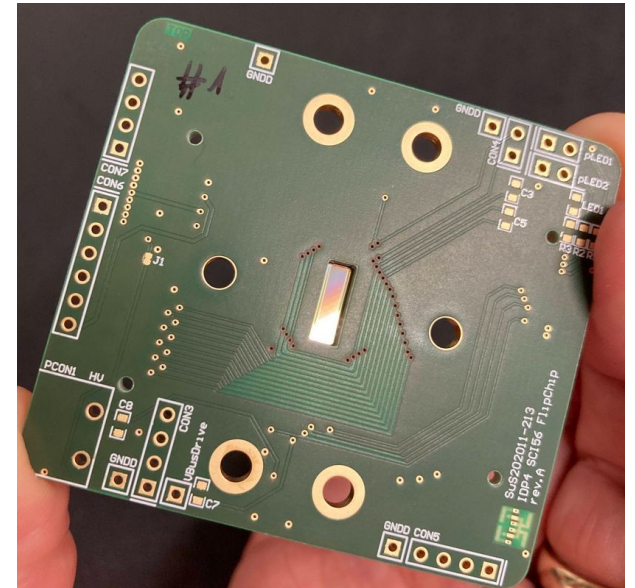
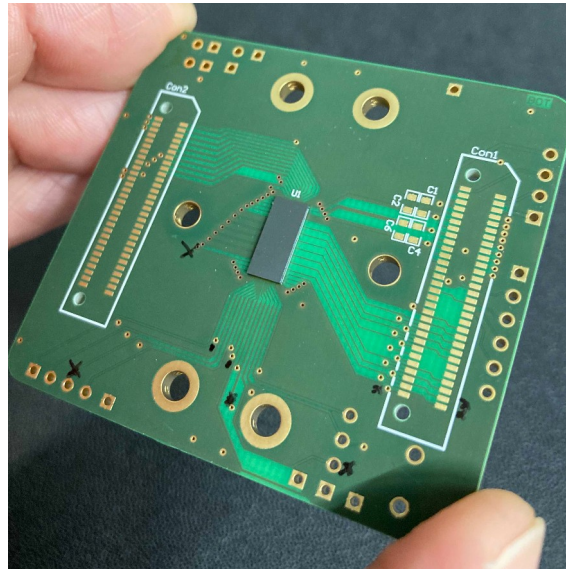
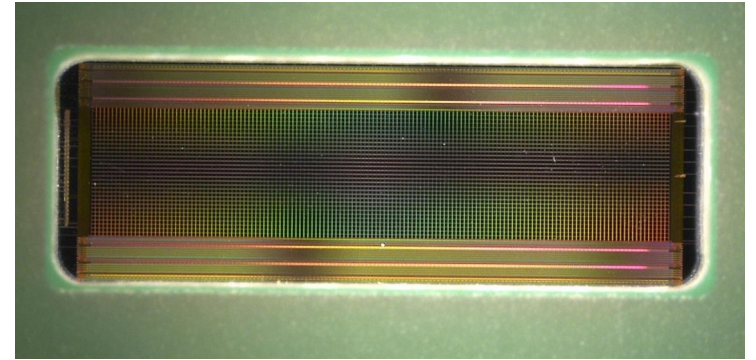
- Bug fixes & faster bus signal
- On chip pulsewidth measurement and buffered readout



Outlook

Improvements

Improve fibre coupling
- Flip chip mounting



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Thank you

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

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

Chip Design



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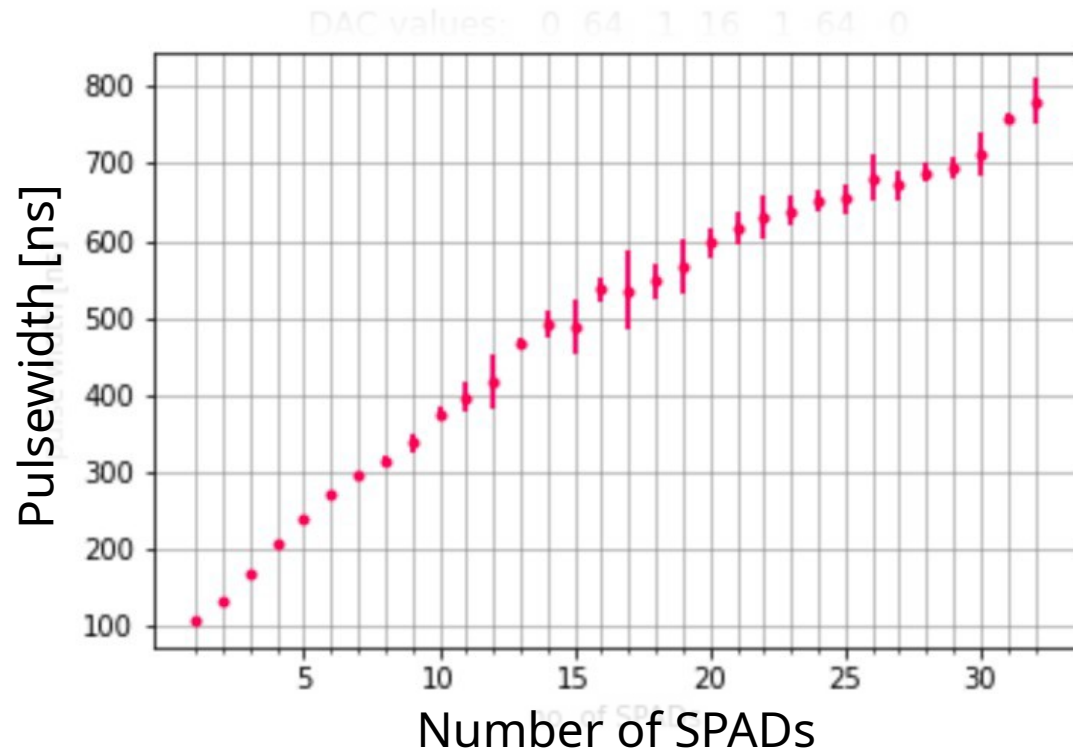
Measured Hitprocessor Output

Chip Design



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Measured Hitprocessor Output



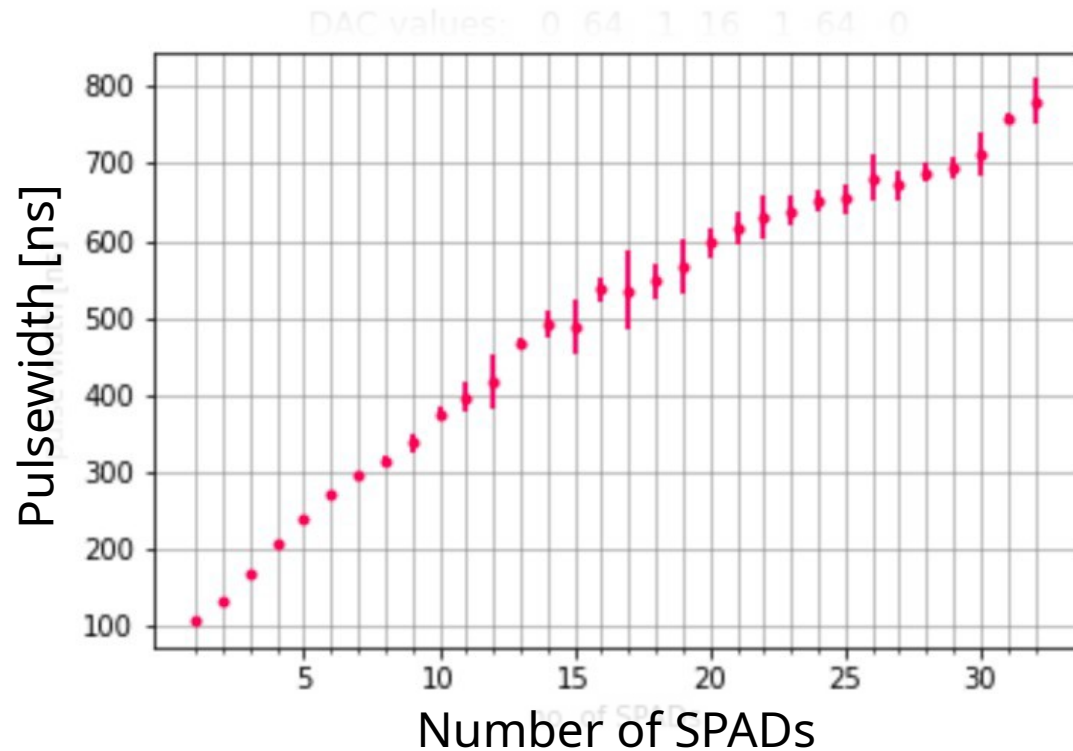
Chip Design



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Measured Hitprocessor Output



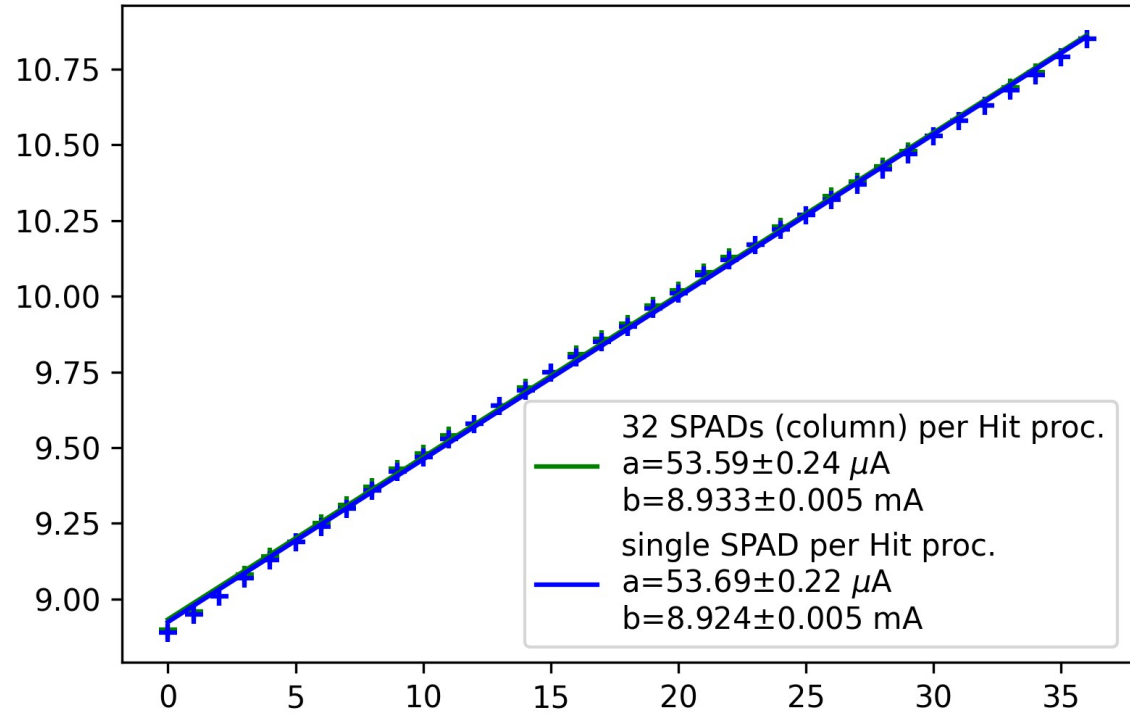
Dynamic photon detection range

Results



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Currents of Hitprocessors



Results



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New Chip Design

