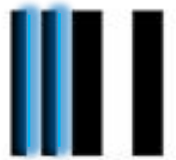




Bundesministerium  
für Bildung  
und Forschung

# High Resolution Neutron Detection by the (y)TPC method



*International Workshop on Position Sensitive Neutron Detectors 2018*  
17.05.2018

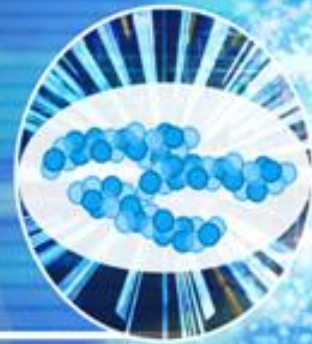
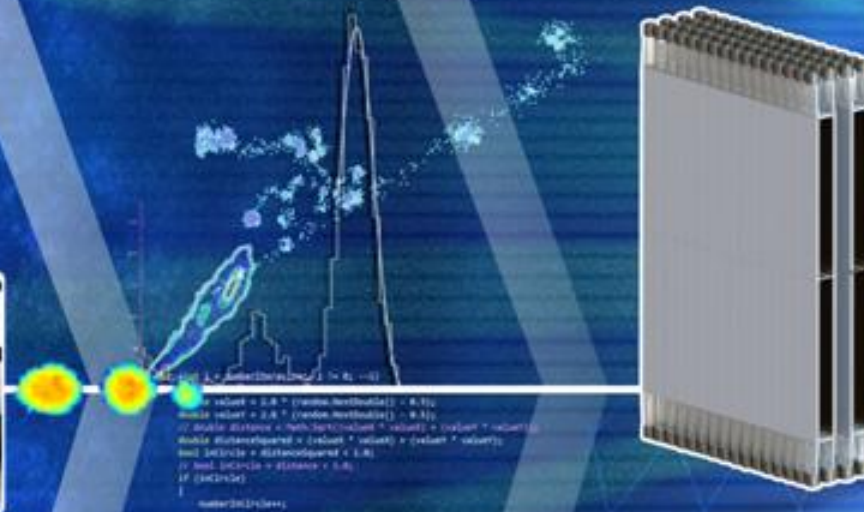
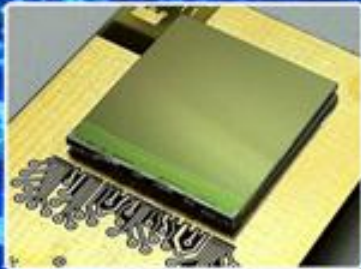


universität**bonn**

Physikalisches Institut (LCTPC)  
Rheinische  
Friedrich-Wilhelms-Universität  
Bonn

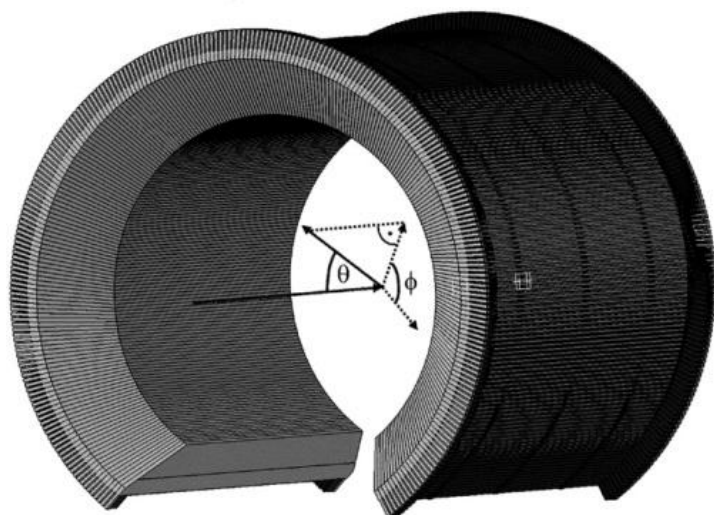
**Markus Köhli**

F. P. Schmidt, M. Gruber, J. Kaminski, K. Desch



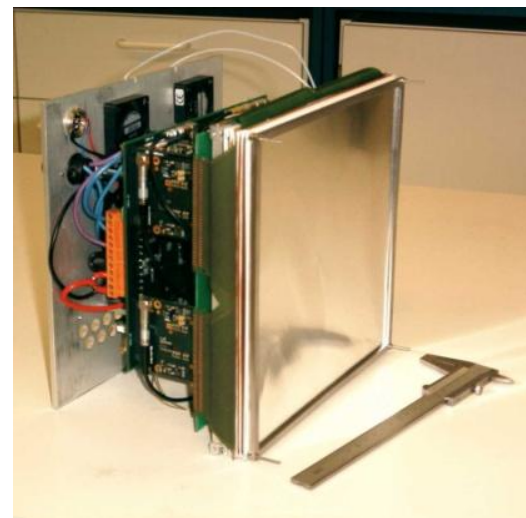


Physikalisches Institut  
Ruprecht-Karls-Universität  
Heidelberg



Jalousie (Powtex)

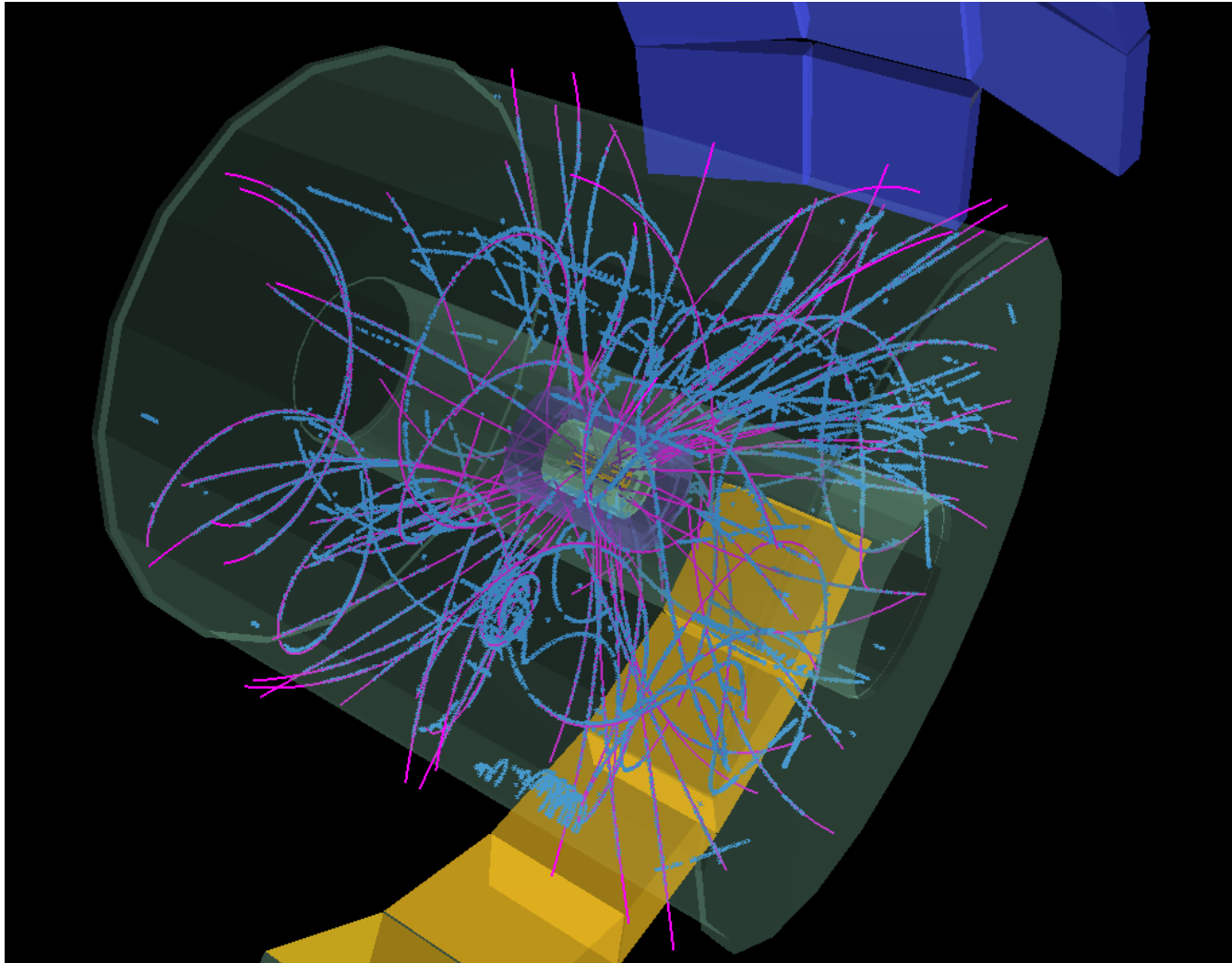
- ToF Diffractometer -



CASCADE (Reseda/Mira)

- Spin Echo-

# ▶ The Time Projection Chamber



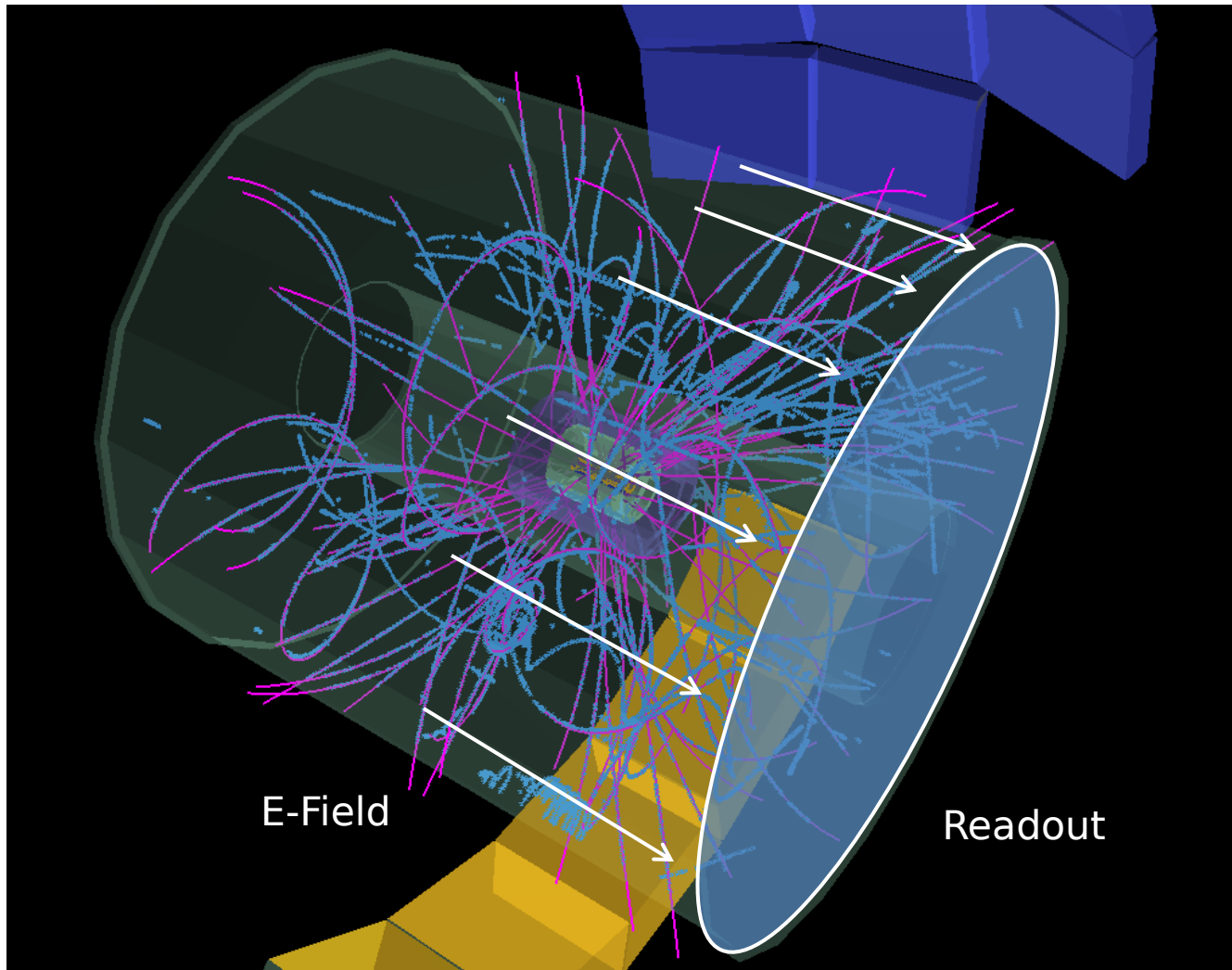
[1] <http://www-alice.gsi.de>

MARKUS KÖHLI

Physikalisches Institut

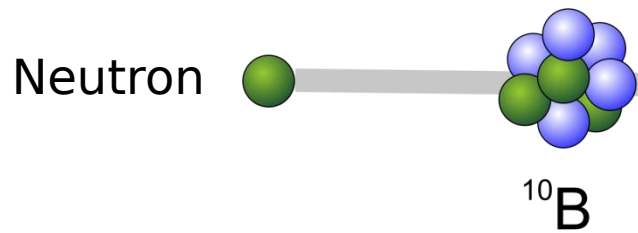
University of Bonn

# The Time Projection Chamber

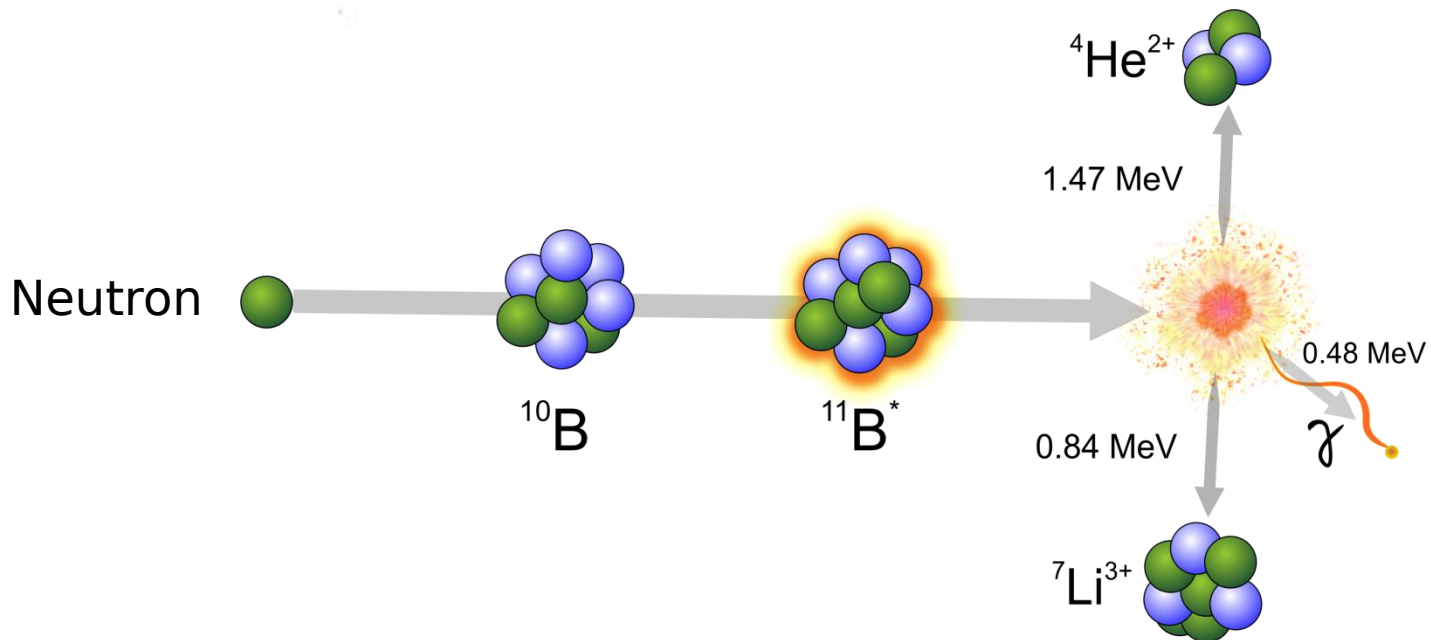


[1] <http://www-alice.gsi.de>

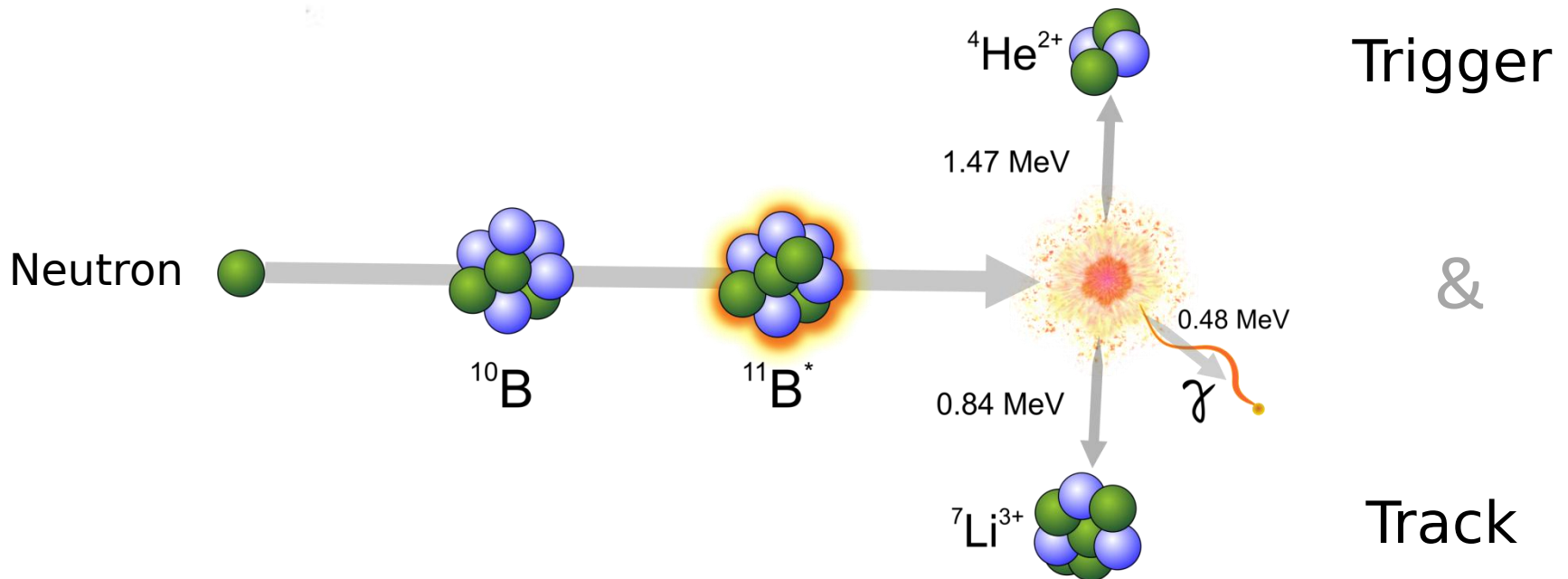
# The Neutron TPC Trigger



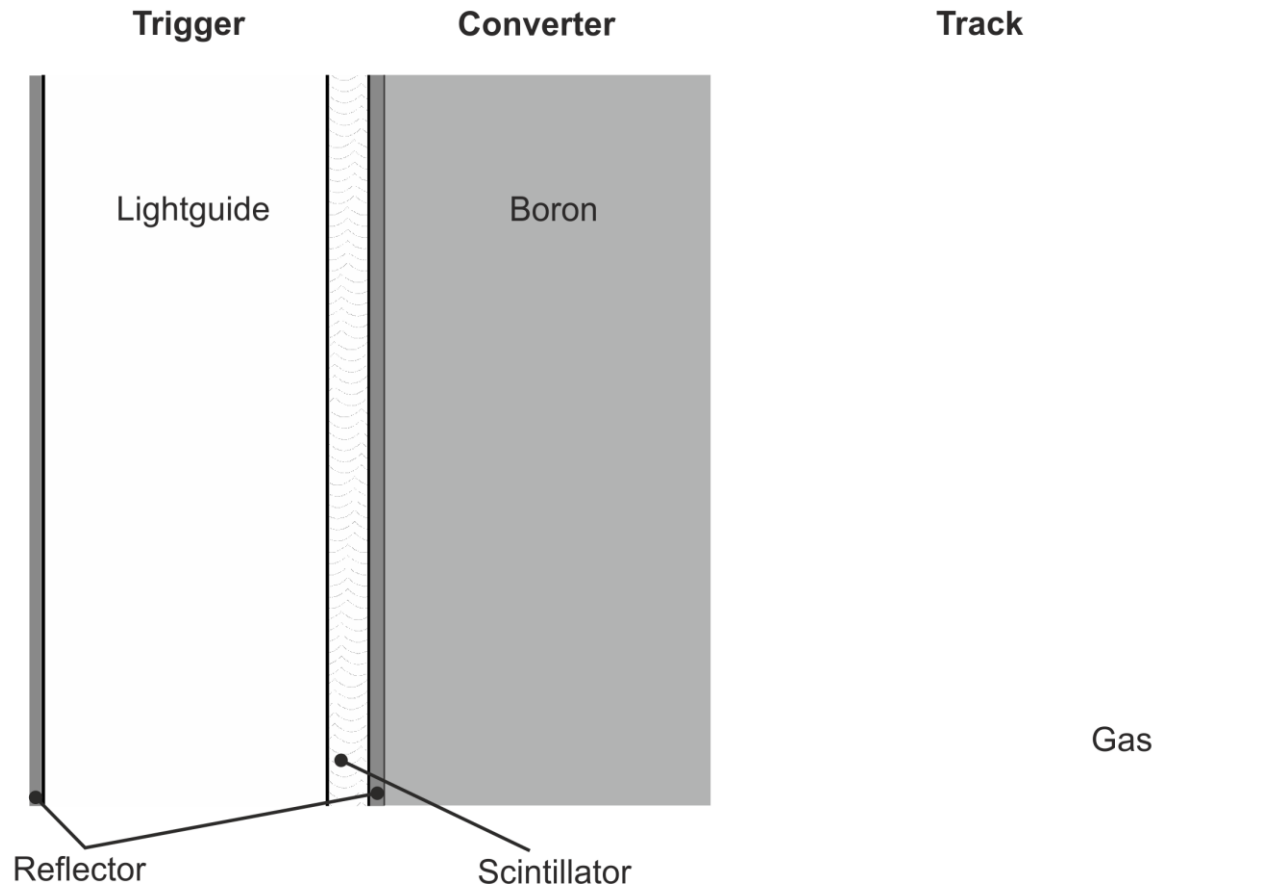
# The Neutron TPC Trigger



# The Neutron TPC Trigger



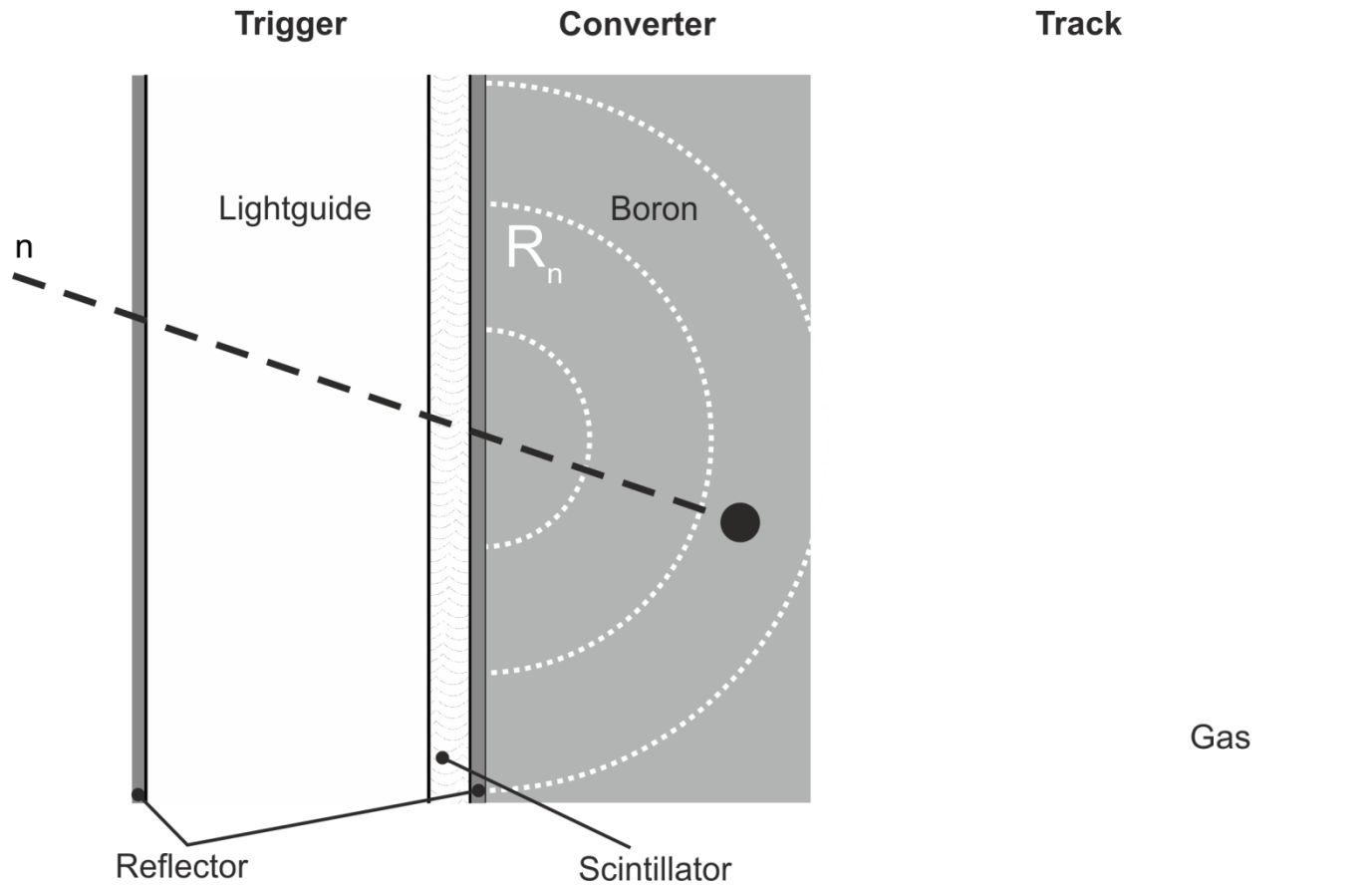
# The Neutron TPC



(not to scale)

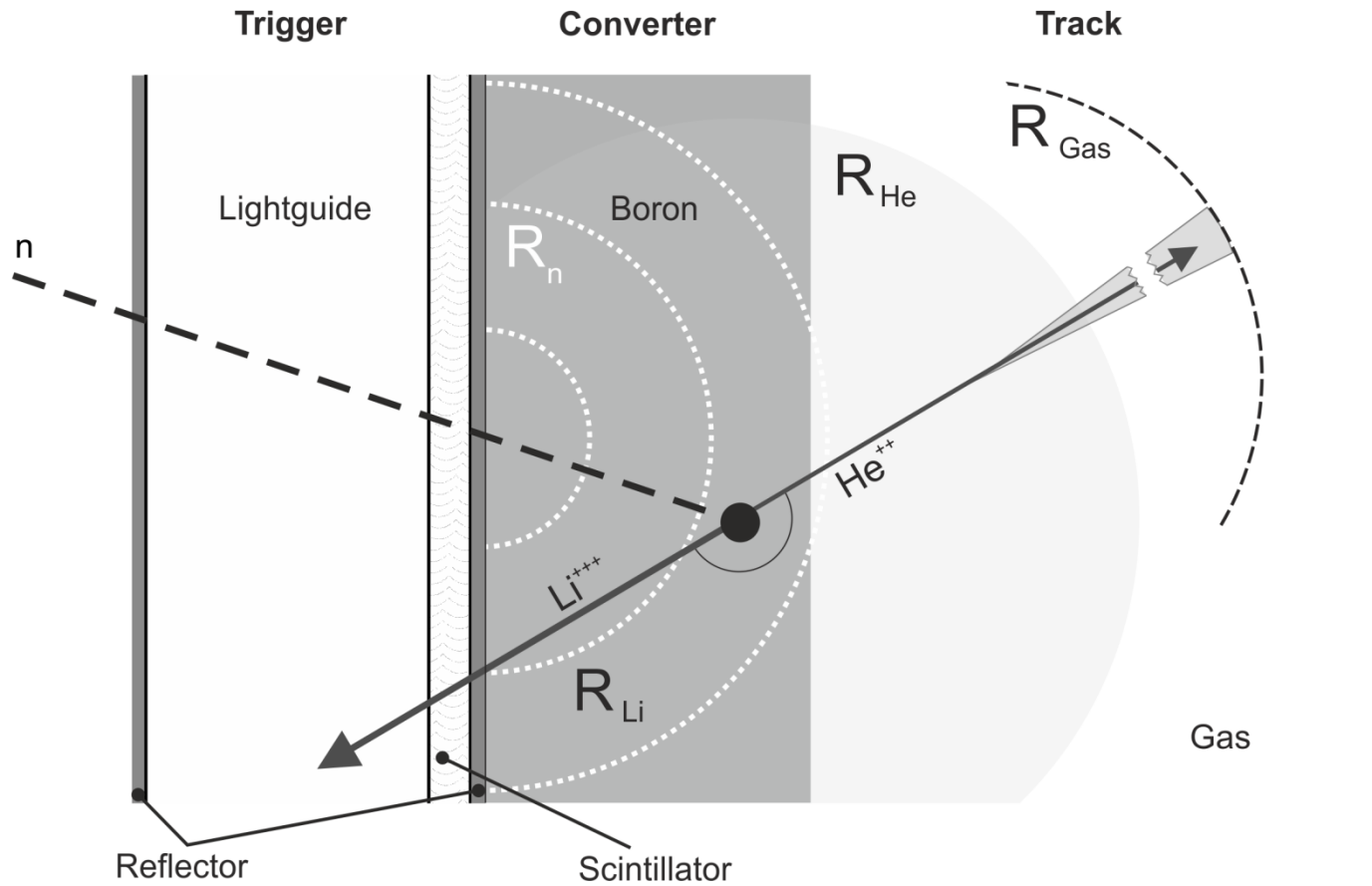


# The Neutron TPC



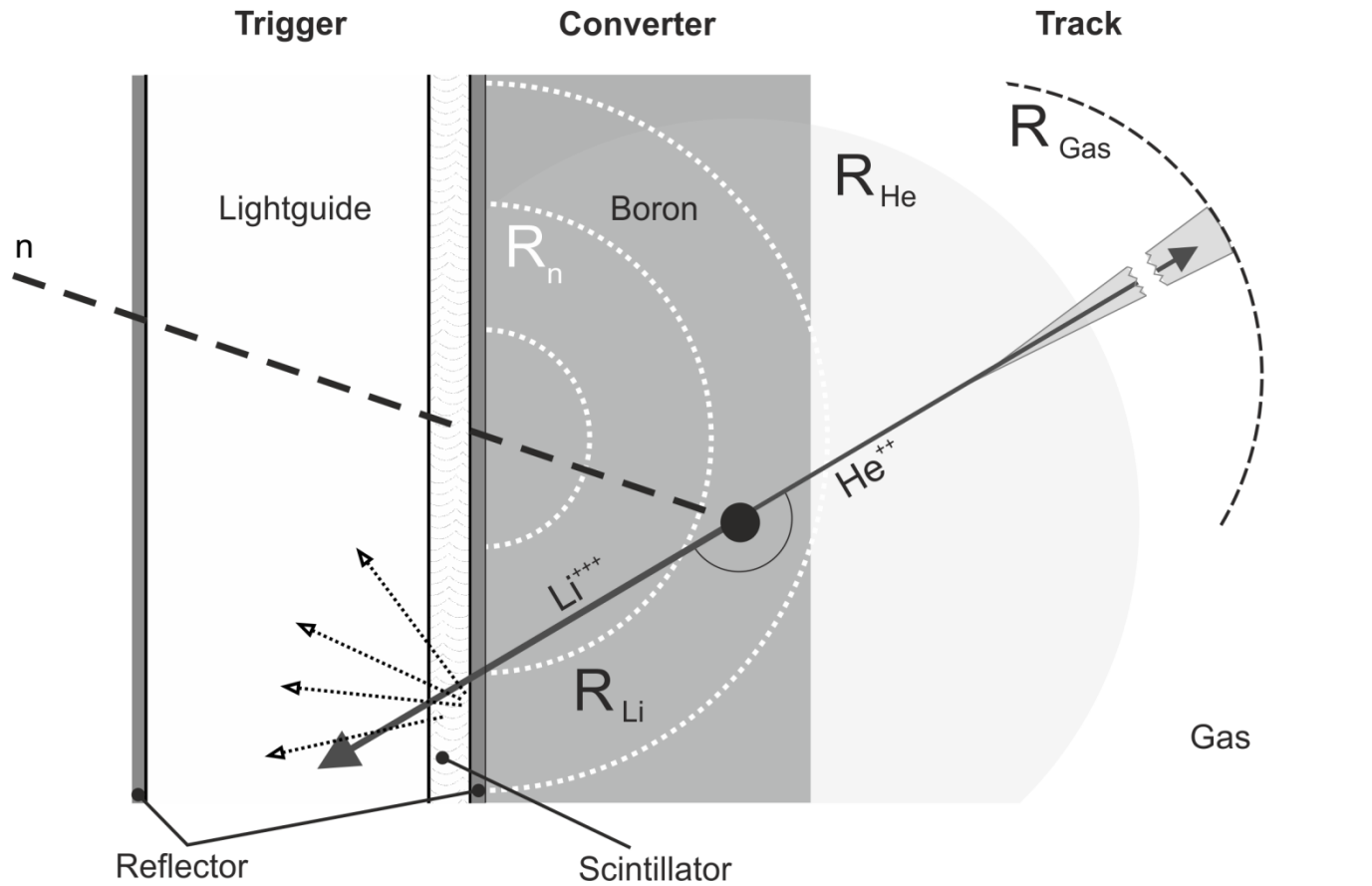
(not to scale)

# The Neutron TPC



(not to scale)

# The Neutron TPC

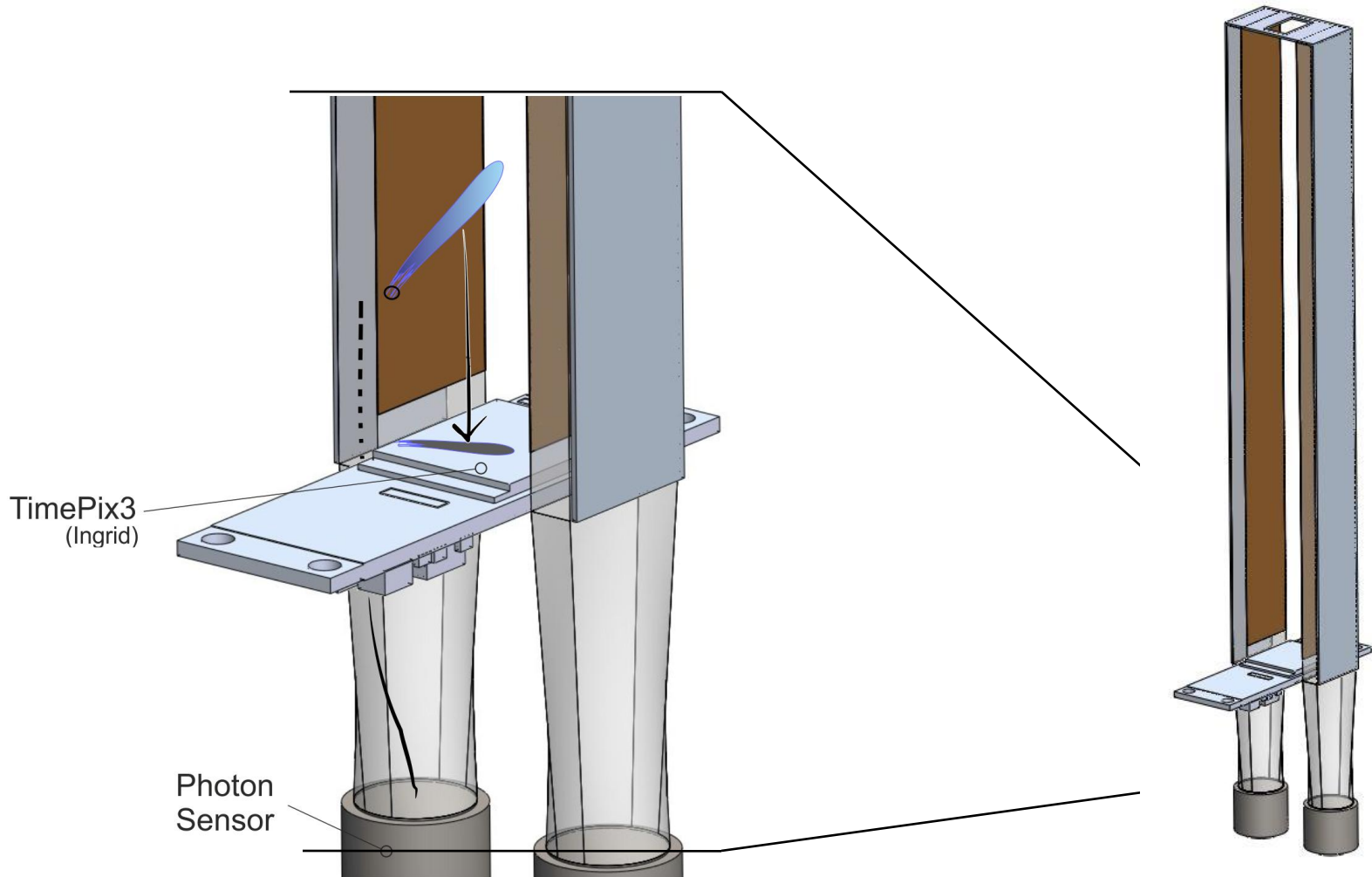


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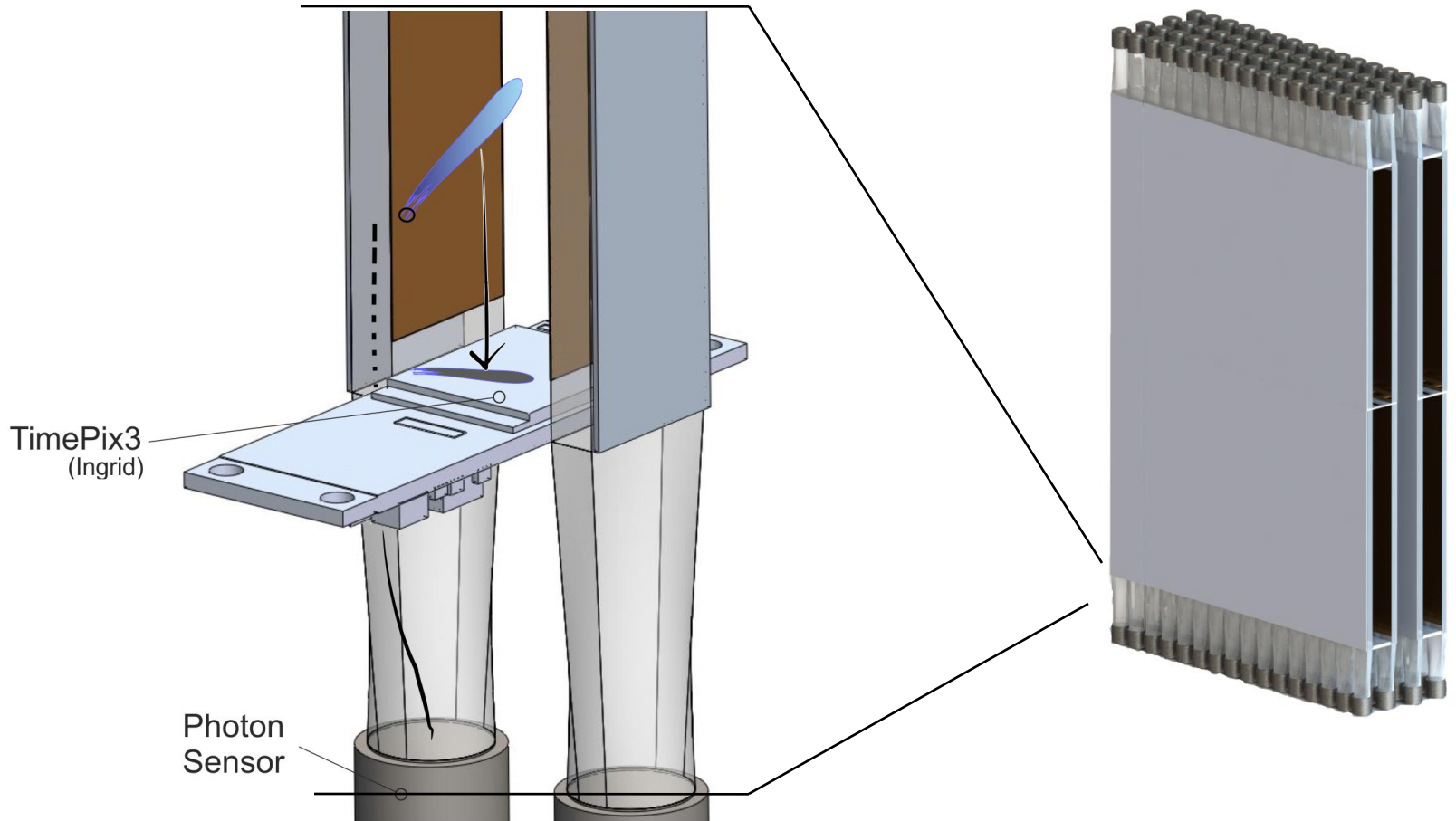
# ||| The Detector



# The Neutron TPC



# The Neutron TPC: BODELAIRE

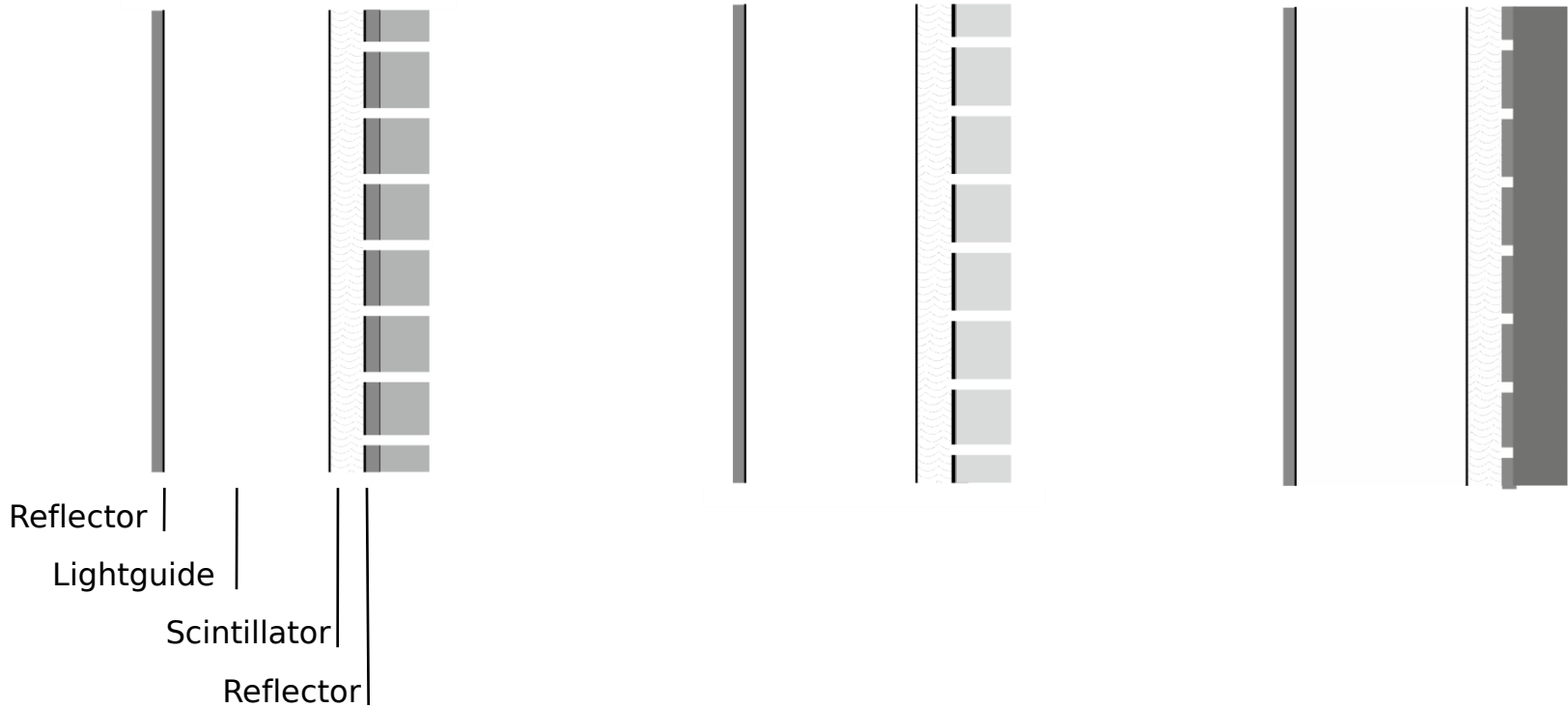


# Field Cage Design

Boron Carbide

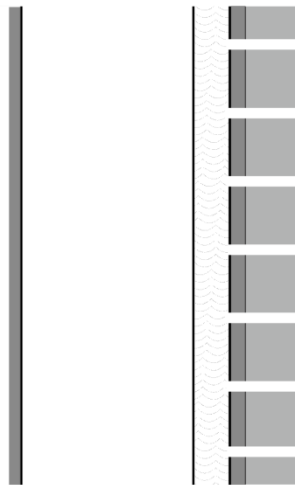
Boron Nitride

Boron

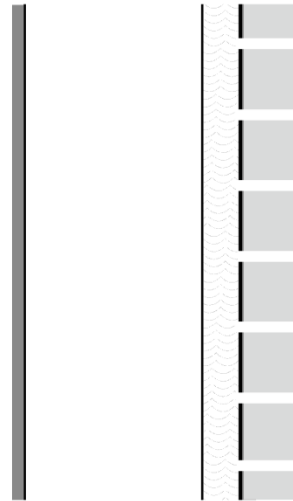


# Field Cage Design

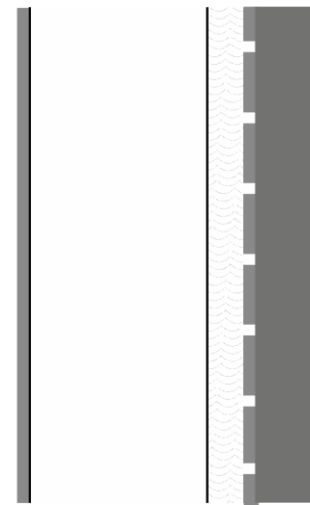
Boron Carbide



Boron Nitride

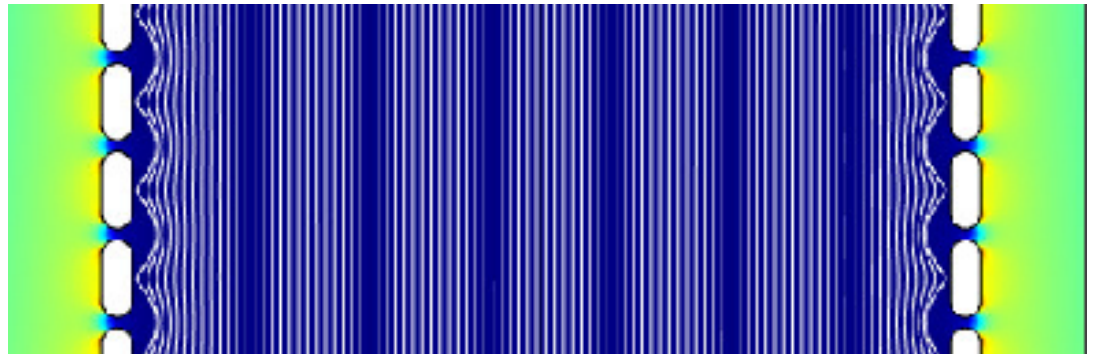


Boron



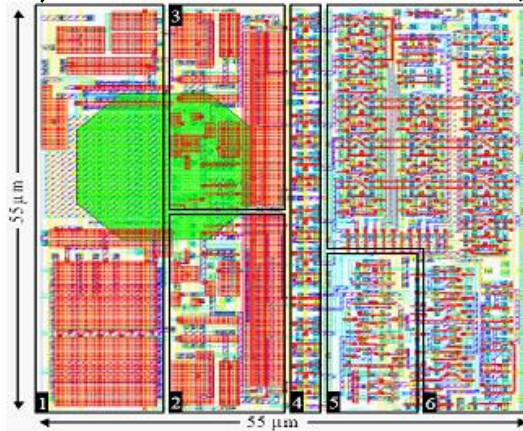
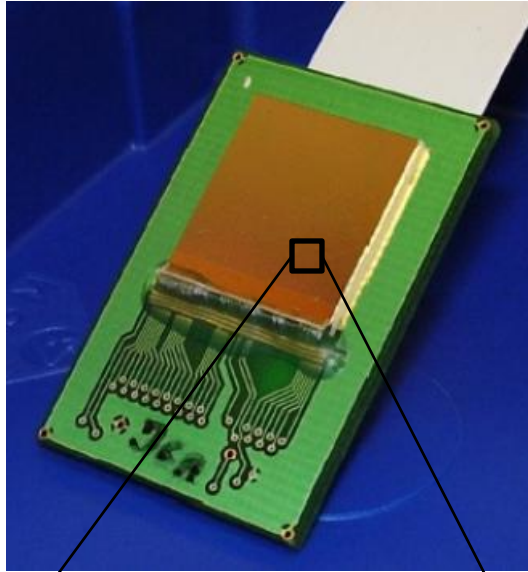
Reflector |  
Lightguide |  
Scintillator |  
Reflector

Simulation: Electric Field Homogeneity

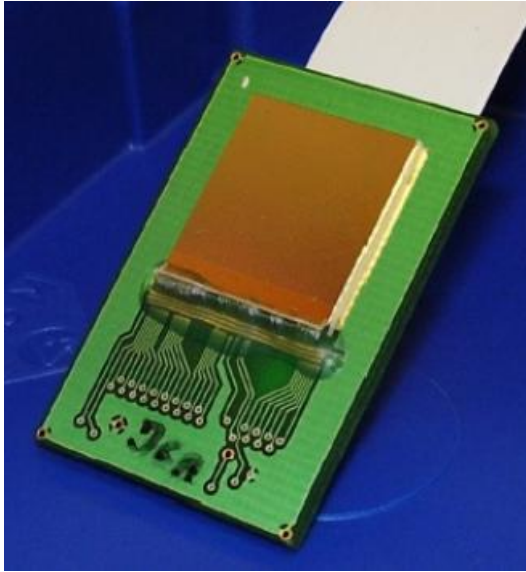




# The TimePix Chip

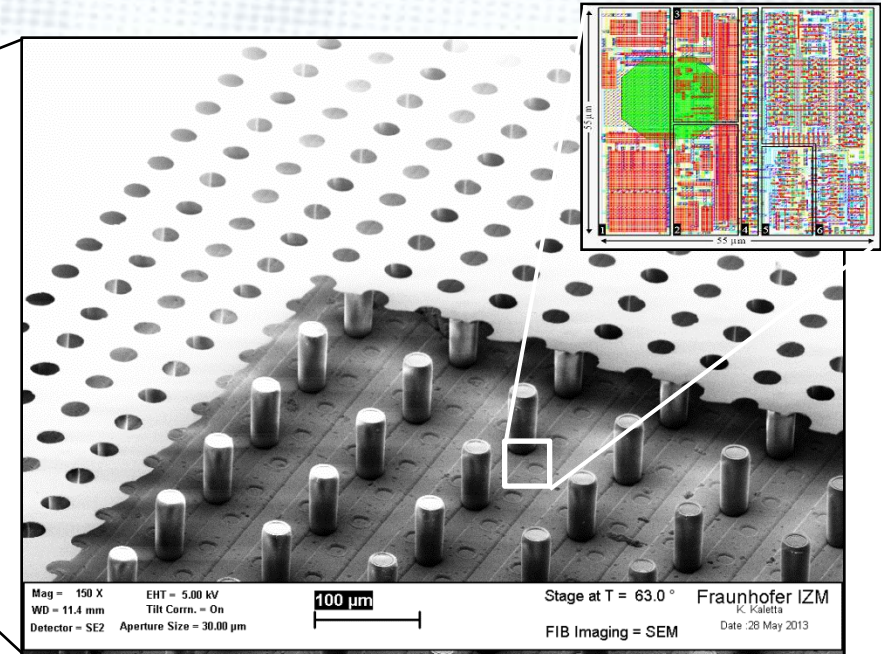
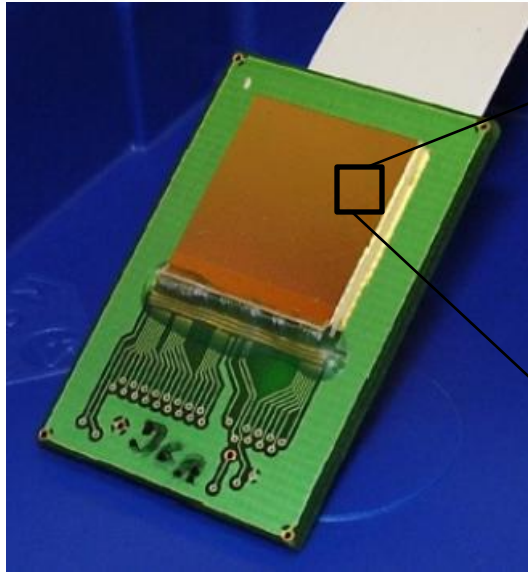


# The TimePix Chip



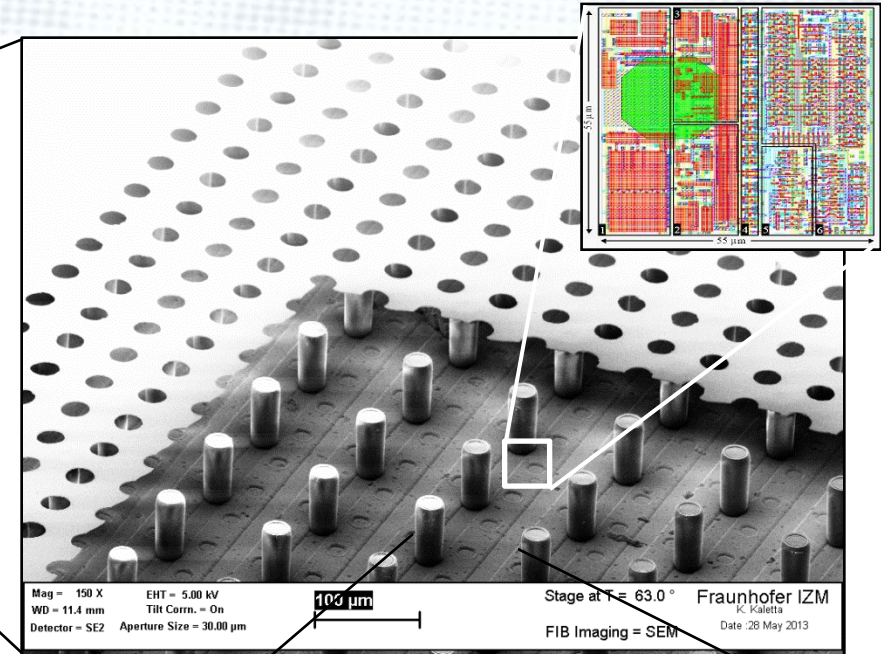
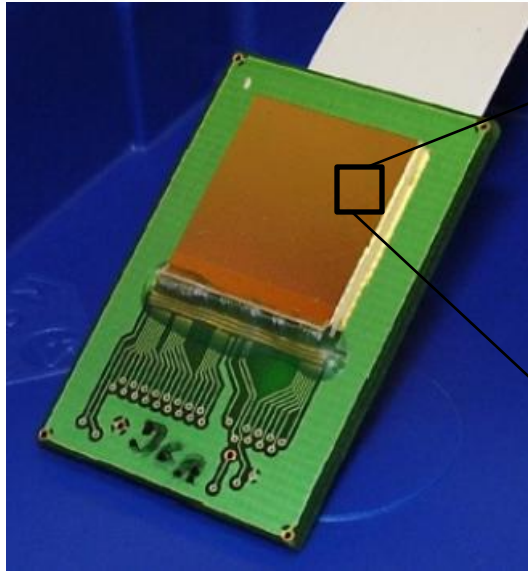
- $256 \times 256$  pixels @  $55 \times 55 \mu\text{m}^2$
- $1.4 \times 1.4 \text{ cm}^2$
- 40 MHz clock
- ENC ca.  $90 e^-$

# The TimePix Chip

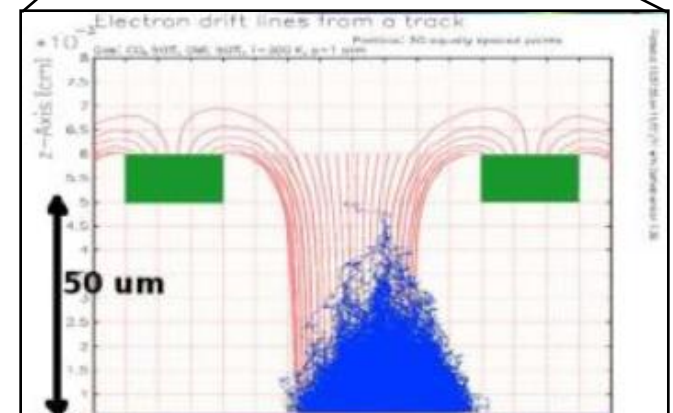


- 256  $\times$  256 pixels @ 55  $\times$  55  $\mu\text{m}^2$
- 1.4  $\times$  1.4  $\text{cm}^2$
- 40 MHz clock
- ENC ca. 90 e<sup>-</sup>

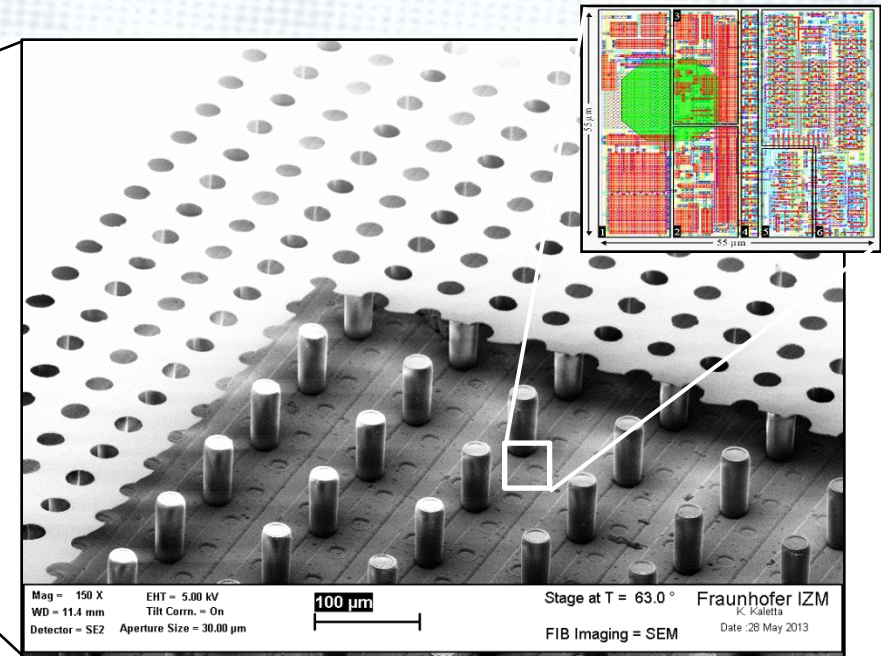
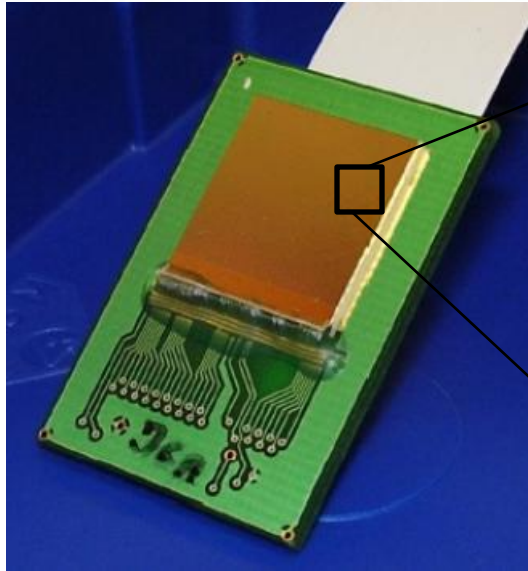
# The TimePix Chip



- 256 × 256 pixels @ 55 × 55 μm<sup>2</sup>
- 1.4 × 1.4 cm<sup>2</sup>
- 40 MHz clock
- ENC ca. 90 e<sup>-</sup>



# The TimePix Chip

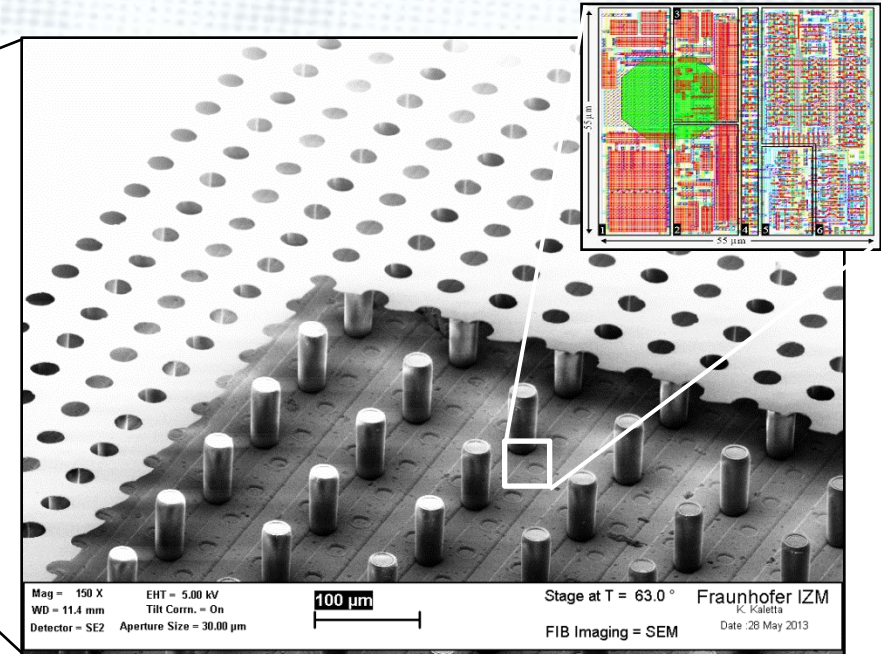
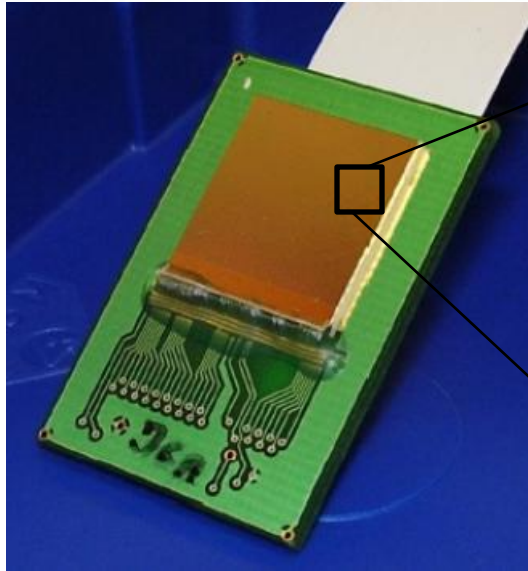


- $256 \times 256$  pixels @  $55 \times 55 \mu\text{m}^2$
- $1.4 \times 1.4 \text{ cm}^2$
- 40 MHz clock
- ENC ca.  $90 \text{ e}^-$

Modes:

- Time Over Threshold (TOT)
- Time of Arrival (ToA)
- Geiger Counter

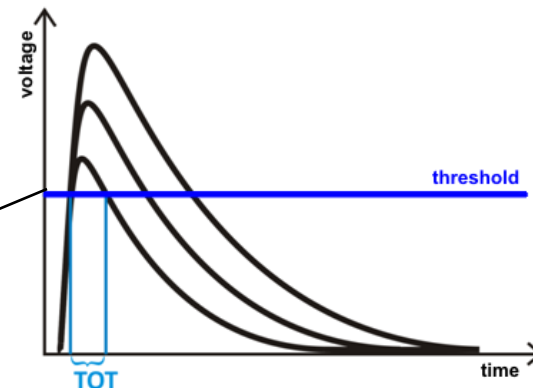
# The TimePix Chip



- 256  $\times$  256 pixels @ 55  $\times$  55  $\mu\text{m}^2$
- 1.4  $\times$  1.4  $\text{cm}^2$
- 40 MHz clock
- ENC ca. 90  $e^-$

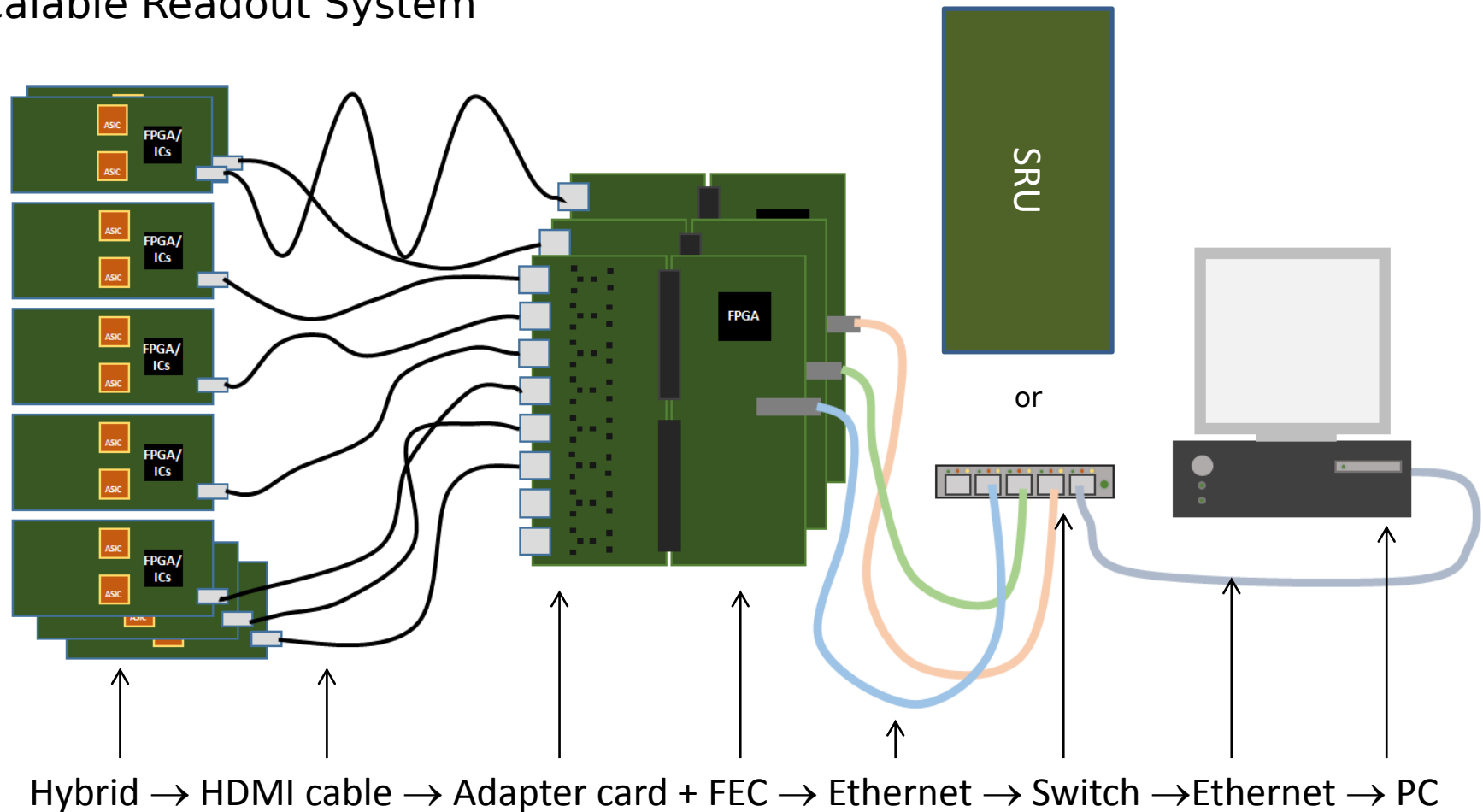
Modes:

- Time Over Threshold (TOT)
- Time of Arrival (ToA)
- Geiger Counter



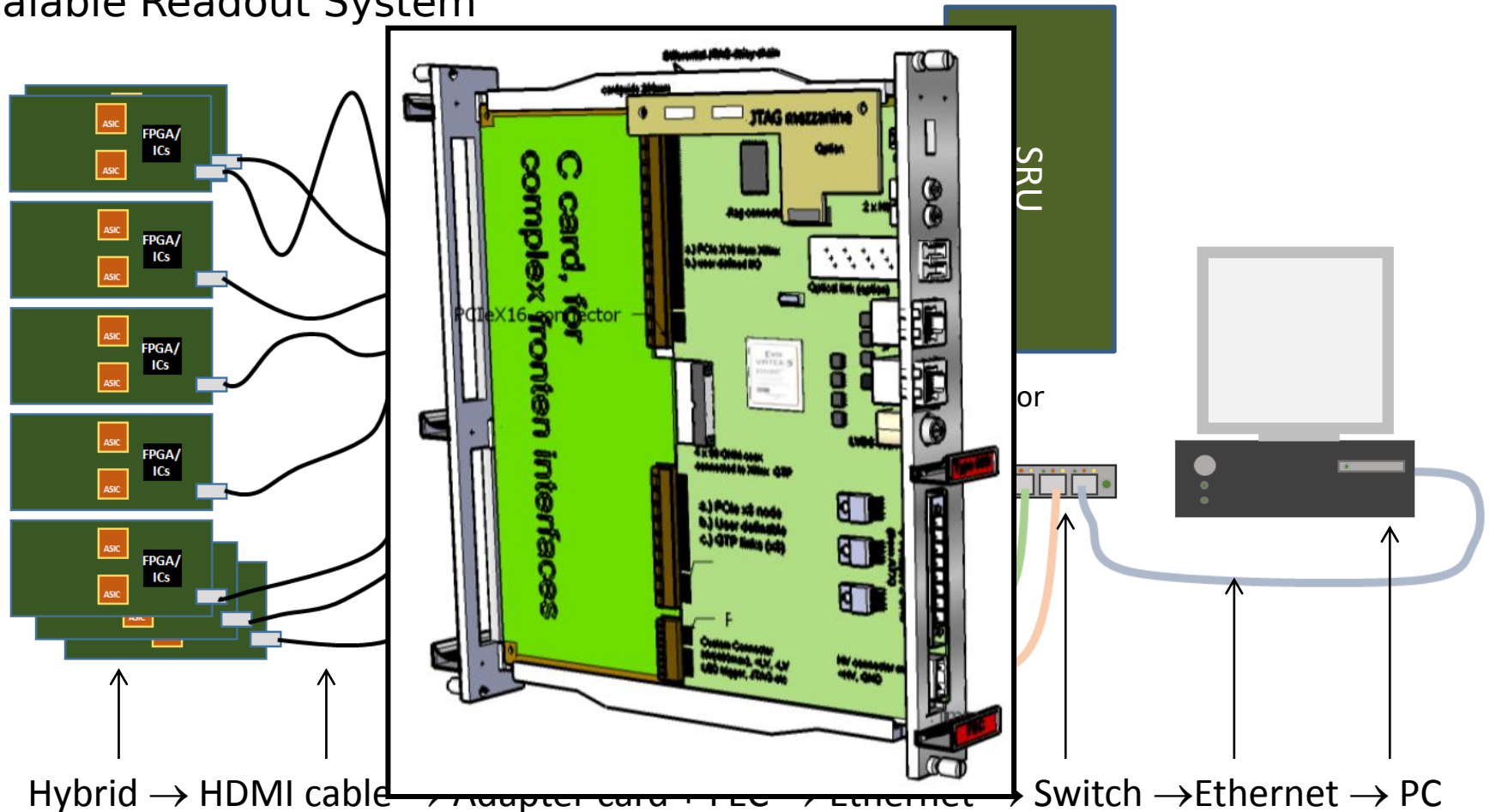
# TimePix Readout System

## Scalable Readout System



# TimePix Readout System

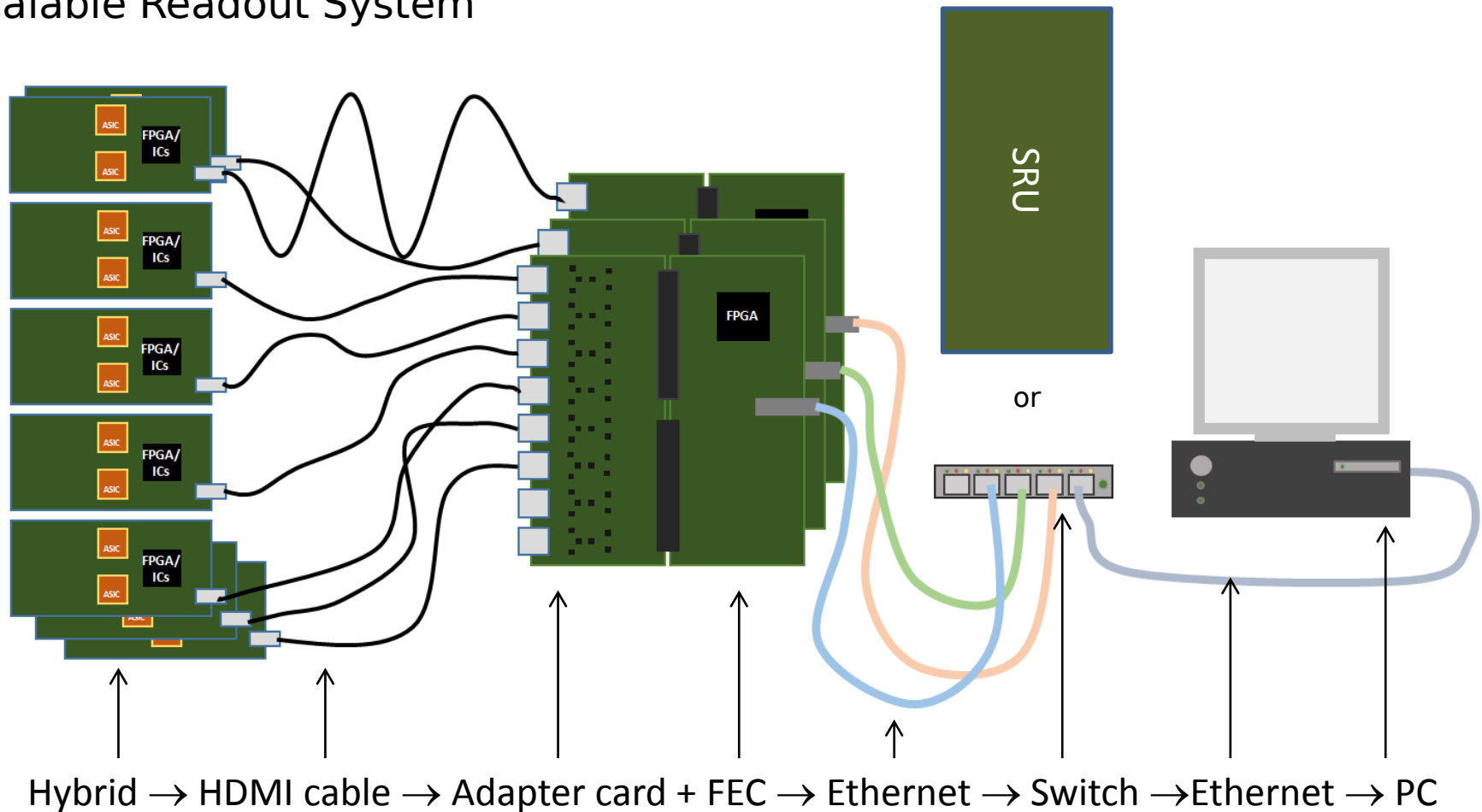
## Scalable Readout System





# TimePix Readout System

## Scalable Readout System



# TimePix Readout System



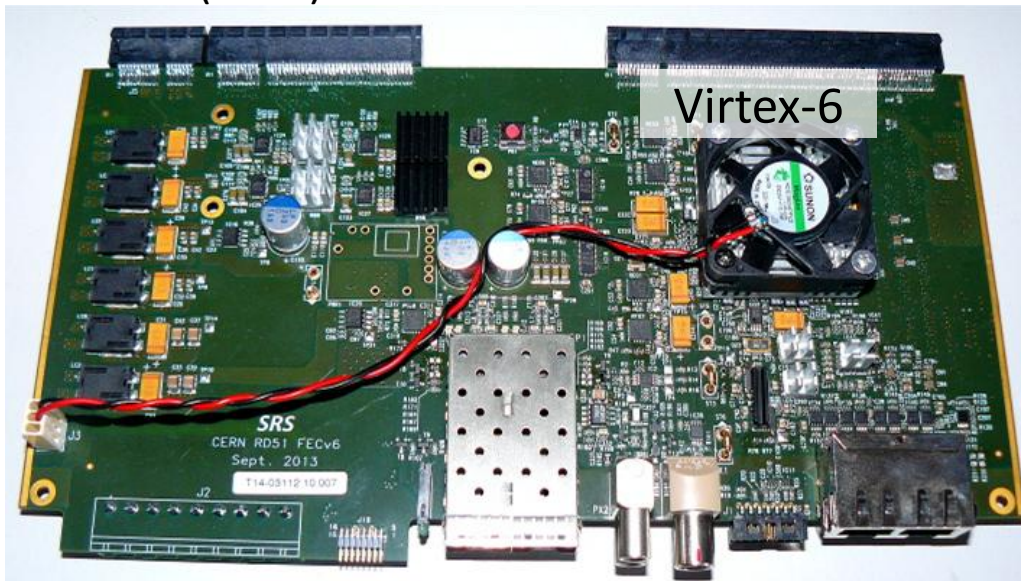
10 GbE SFP+

Virtex-6

40x DDTC from FECs

Scalable Readout Unit

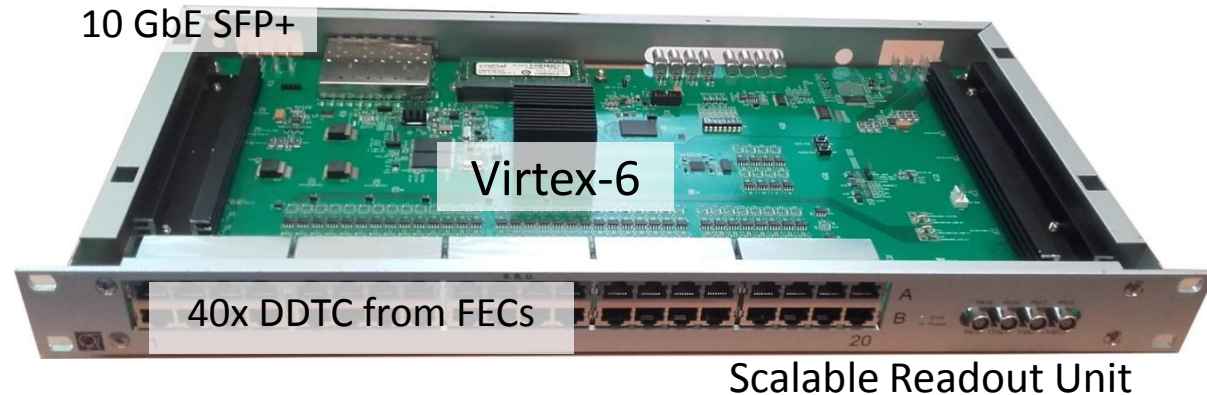
FECv6 (2013)



Virtex-6

1 GbE or DDTC to SRU

# TimePix Readout System



FECv6 (2013)



1 GbE or DDTC to SRU

Front-end ASICS implemented in SRS:

- APV25,
- VFAT,
- Timepix,
- Beetle,
- [Timepix3],
- [VMM3]

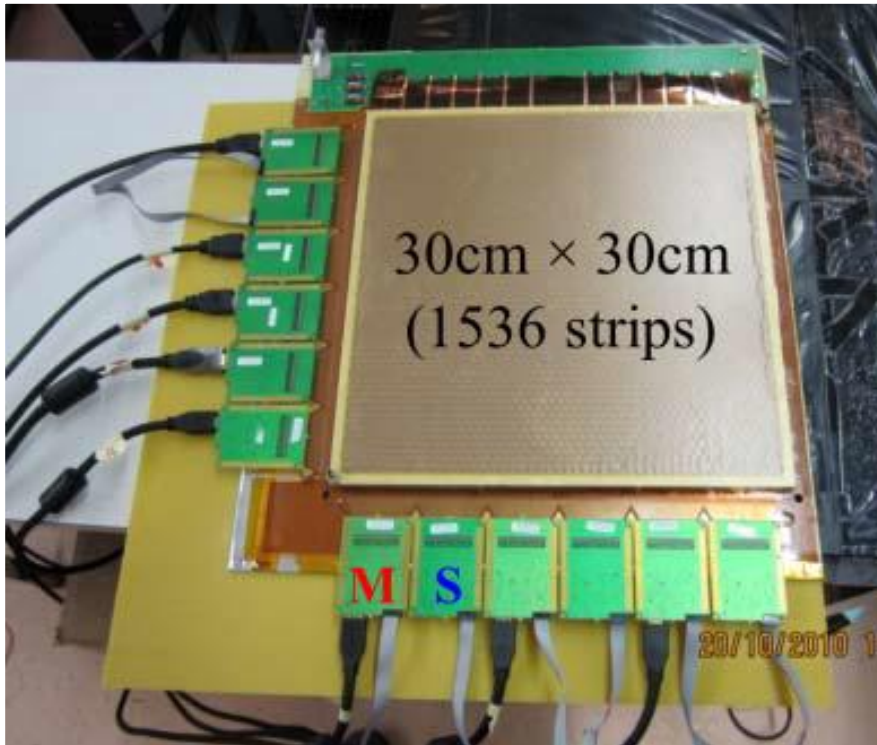
# TimePix Readout System

10 GbE SFP+

Virtex-6



FECv6 (



Scalable Readout Unit



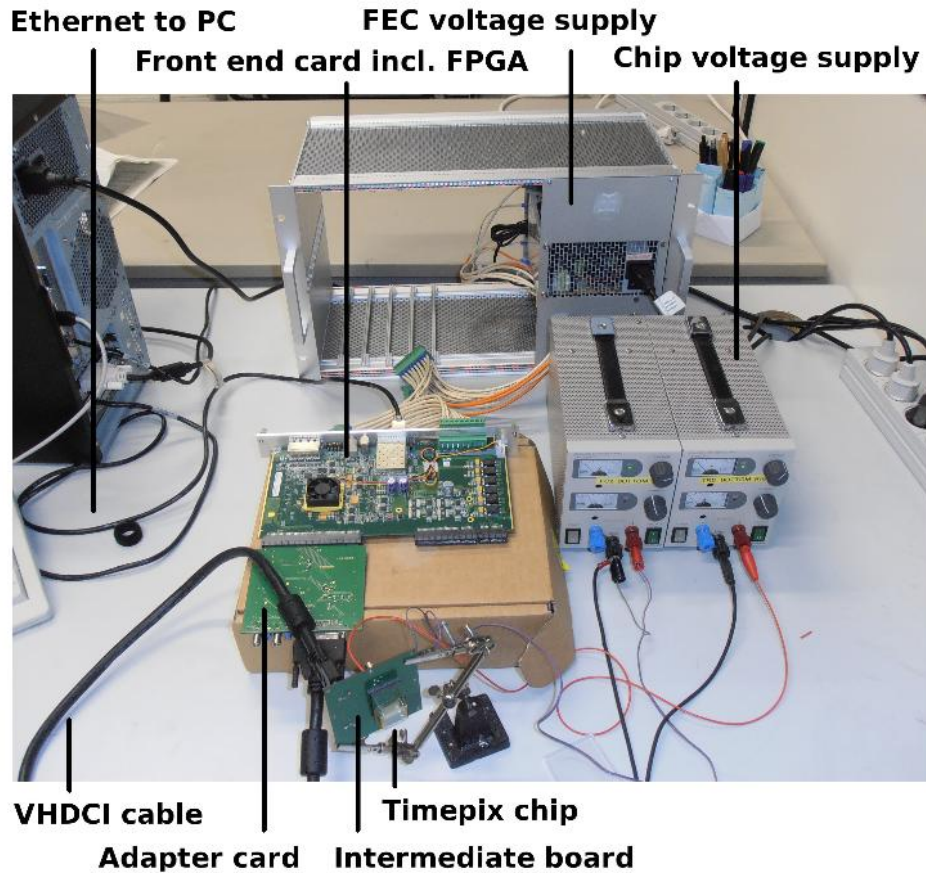
Front-end ASICs implemented in SRS:

- APV25,
- VFAT,
- Timepix,
- Beetle,
- [Timepix3],
- [VMM3]

[1]

[1] Detection and imaging of high-Z materials with a muon tomography station using GEM detectors  
Gnanvo, K., et al. *Nuclear Science Symposium Conference Record (NSS/MIC)*, 2010 IEEE. IEEE, 2010.

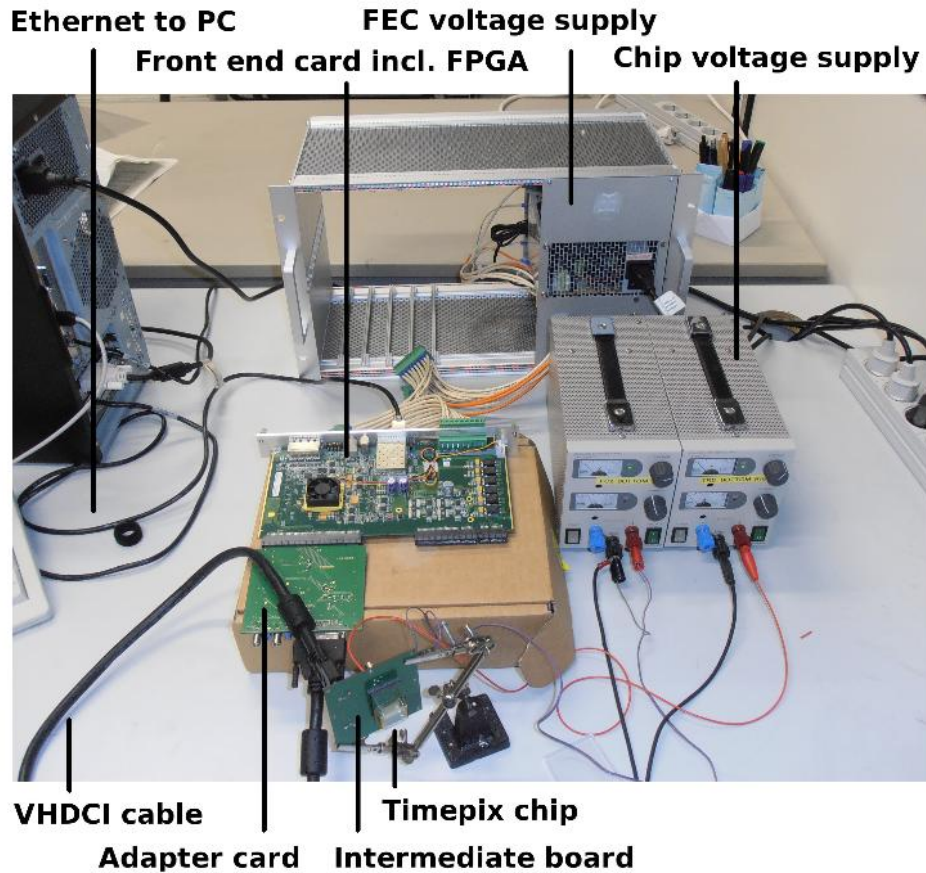
# TimePix Readout System



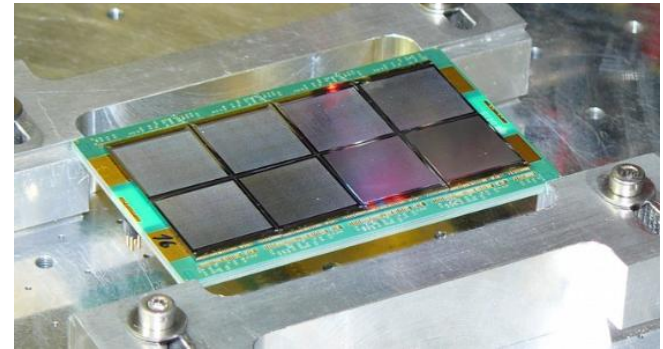
[1] M. Lupberger, The Pixel-TPC - A feasibility study, Thesis 2016

[2] H. Muller, RD51 SRS Status December 2016, CERN

# TimePix Readout System



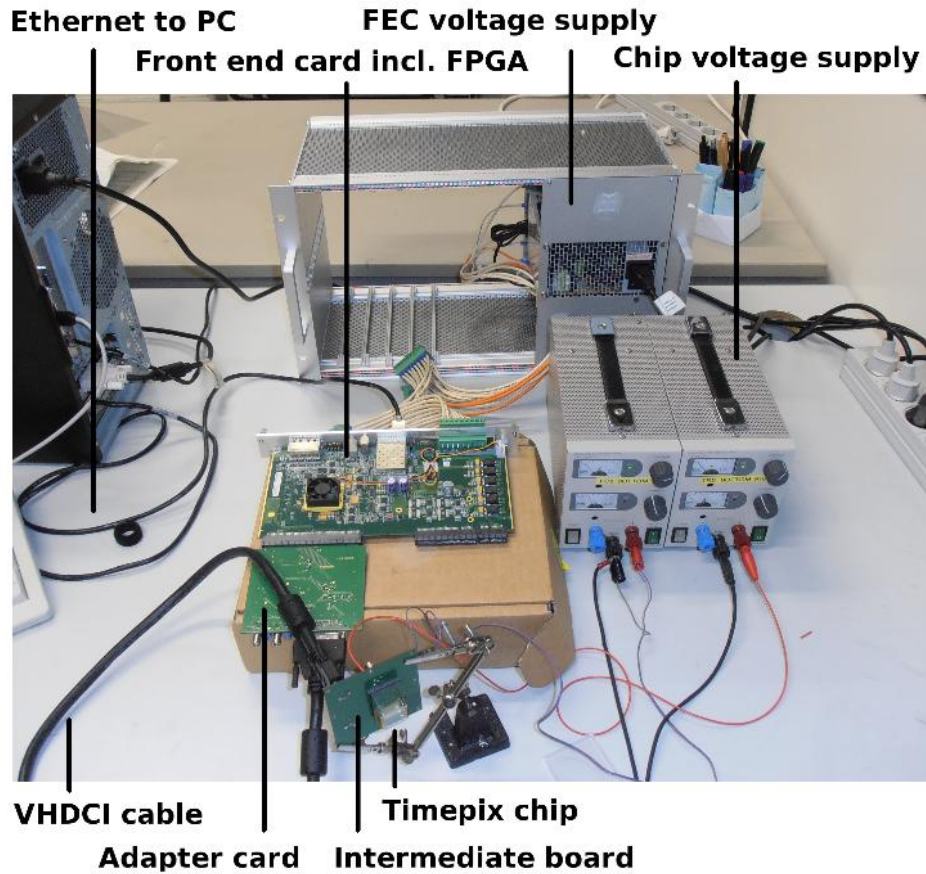
Octoboard:



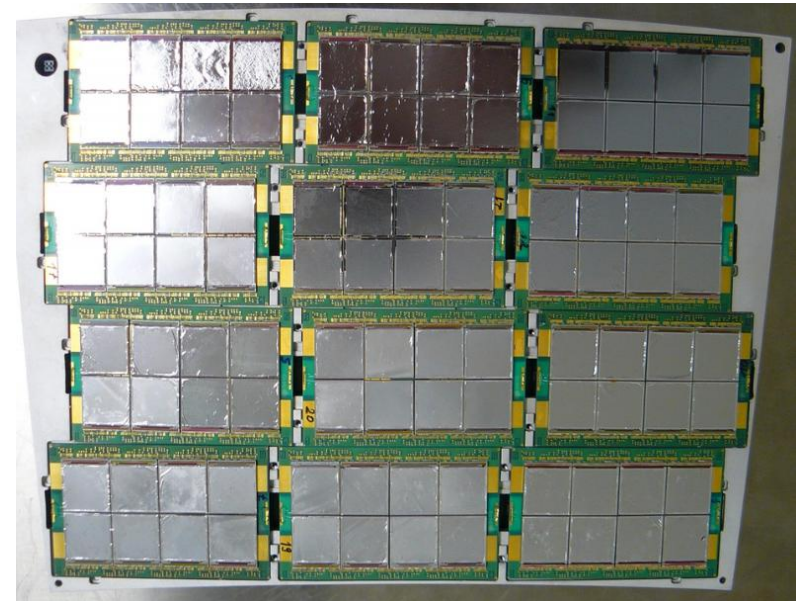
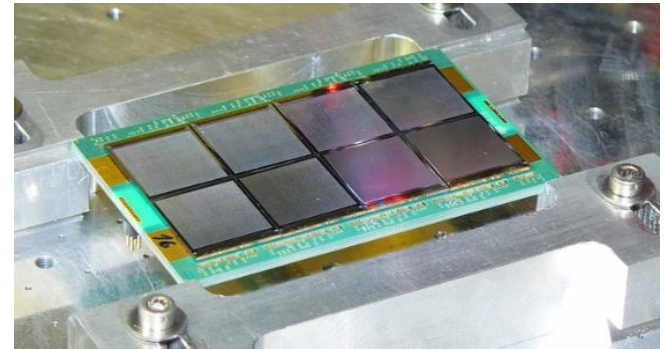
[1] M. Lupberger, The Pixel-TPC - A feasibility study, Thesis 2016

[2] H. Muller, RD51 SRS Status December 2016, CERN

# TimePix Readout System

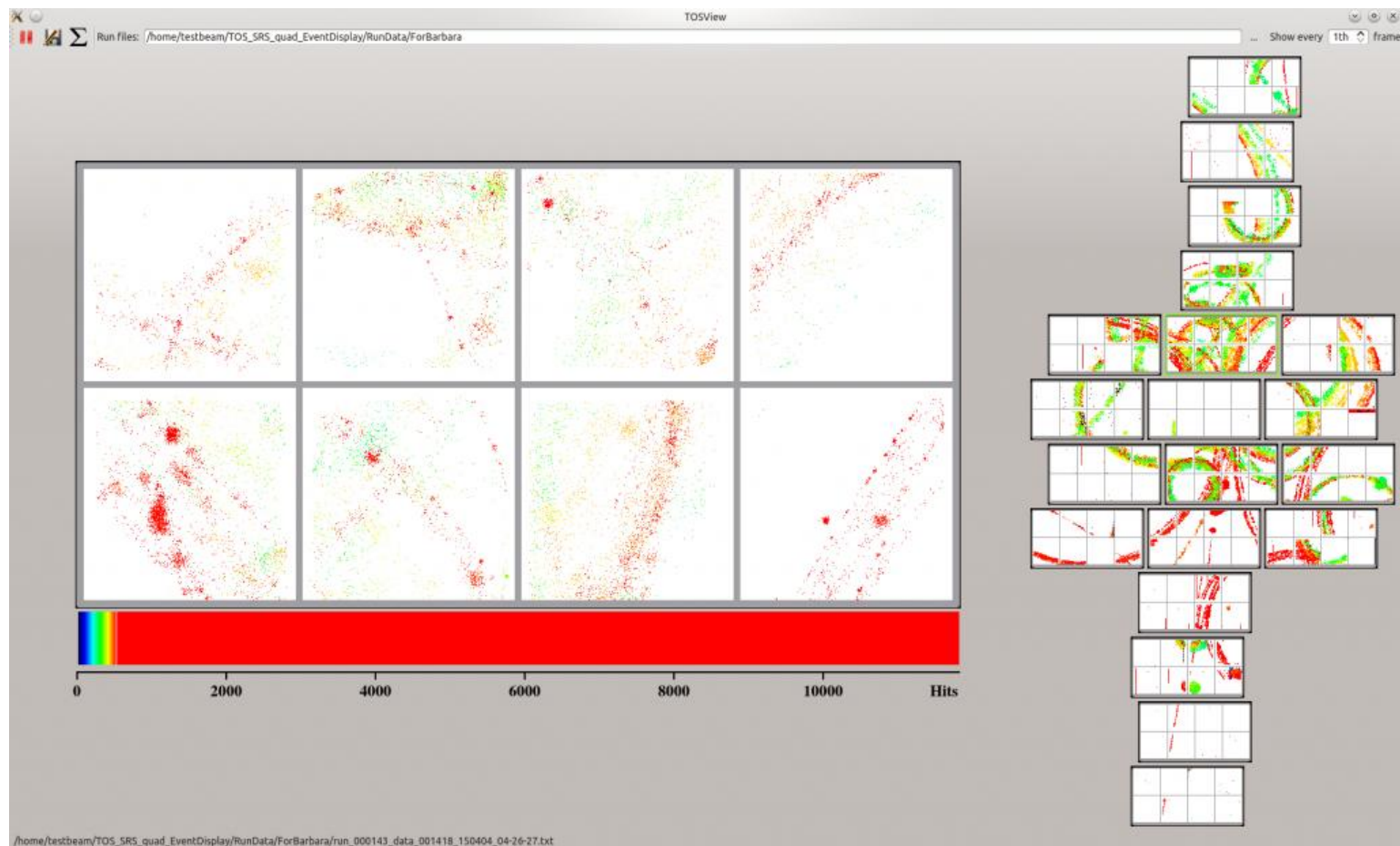


Octoboard:



- [1] M. Lupberger, The Pixel-TPC - A feasibility study, Thesis 2016  
 [2] H. Muller, RD51 SRS Status December 2016, CERN

# LCTPC Event Display



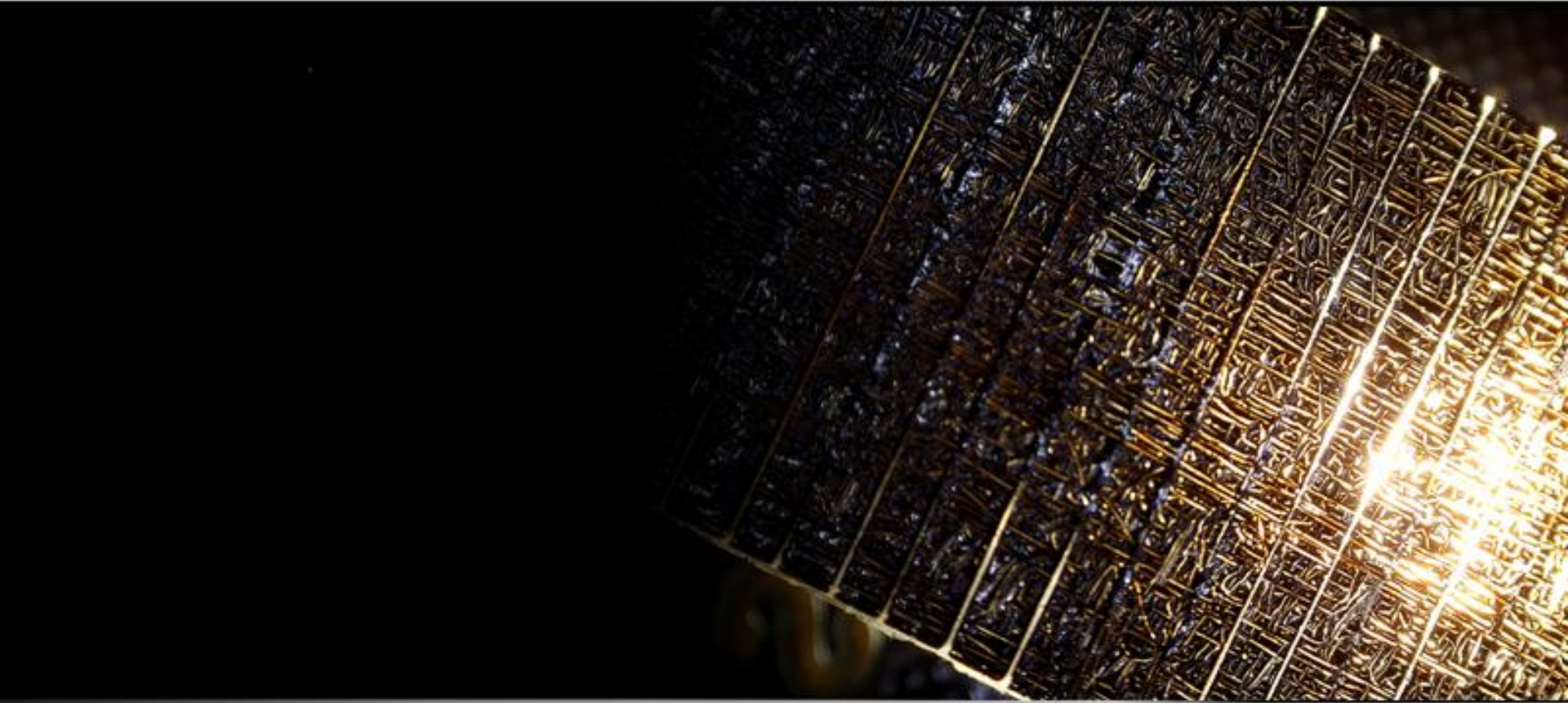
[1]

[1] <http://newslines.linearcollider.org>

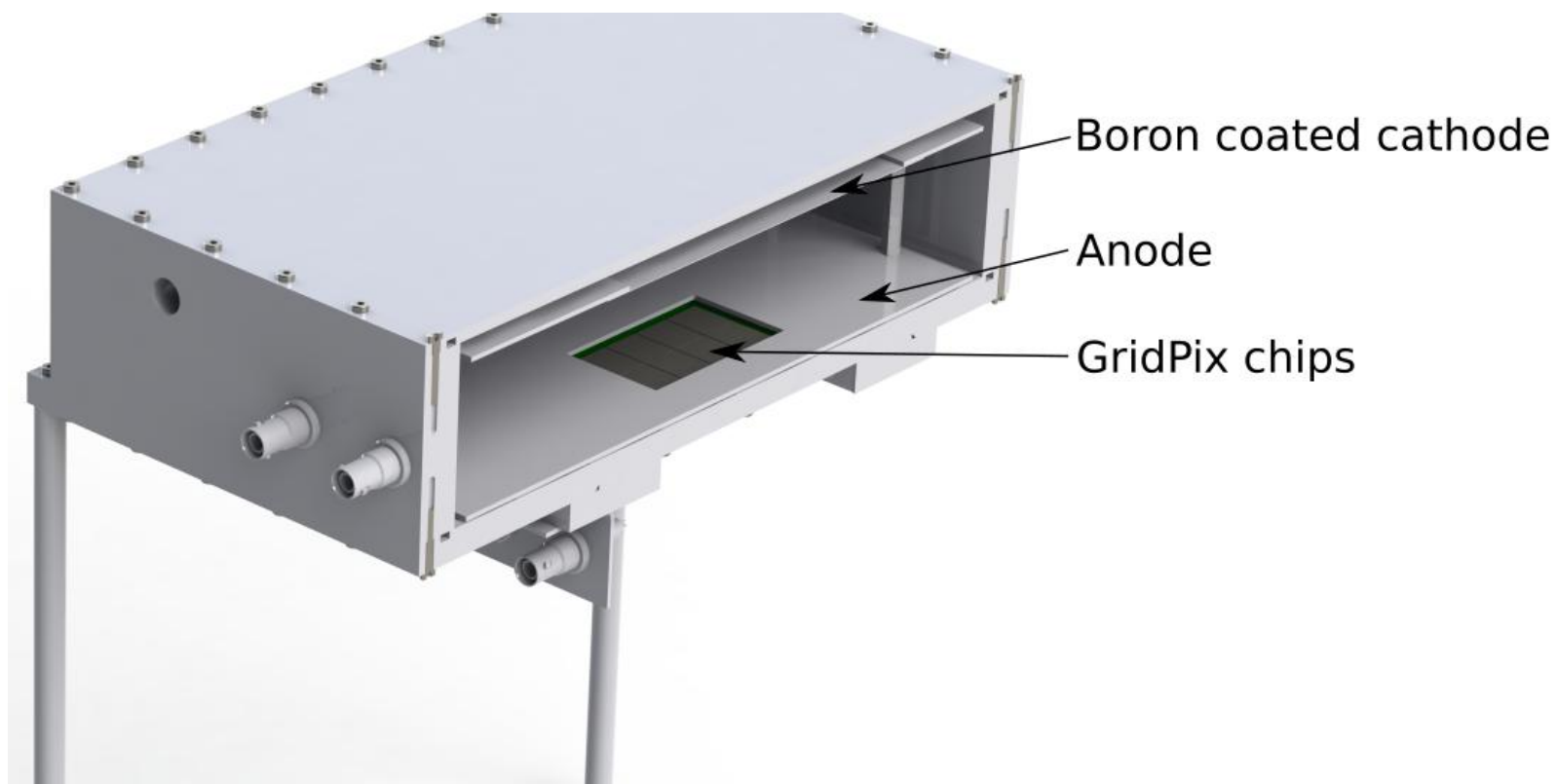




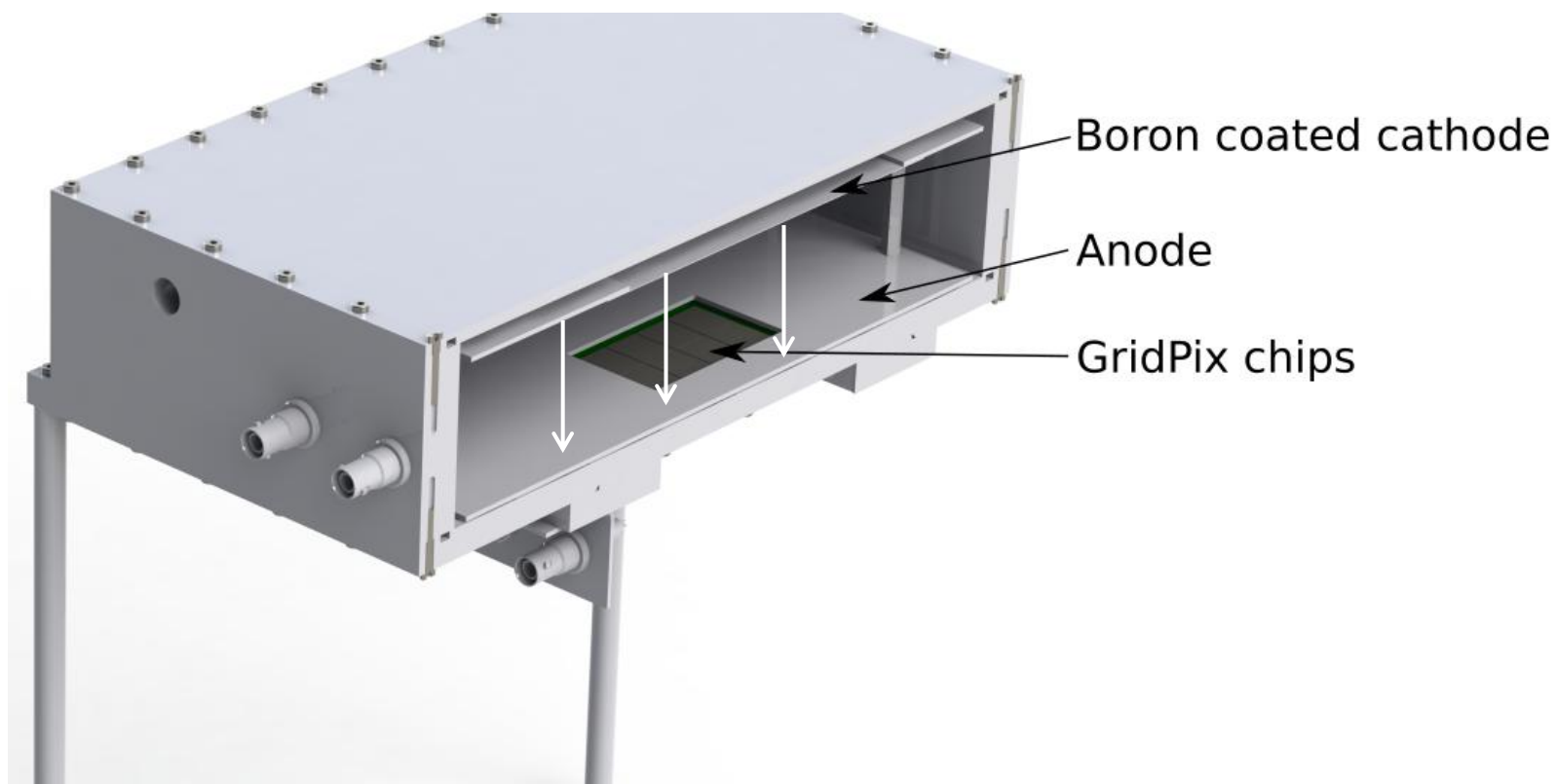
# Detecting Neutrons



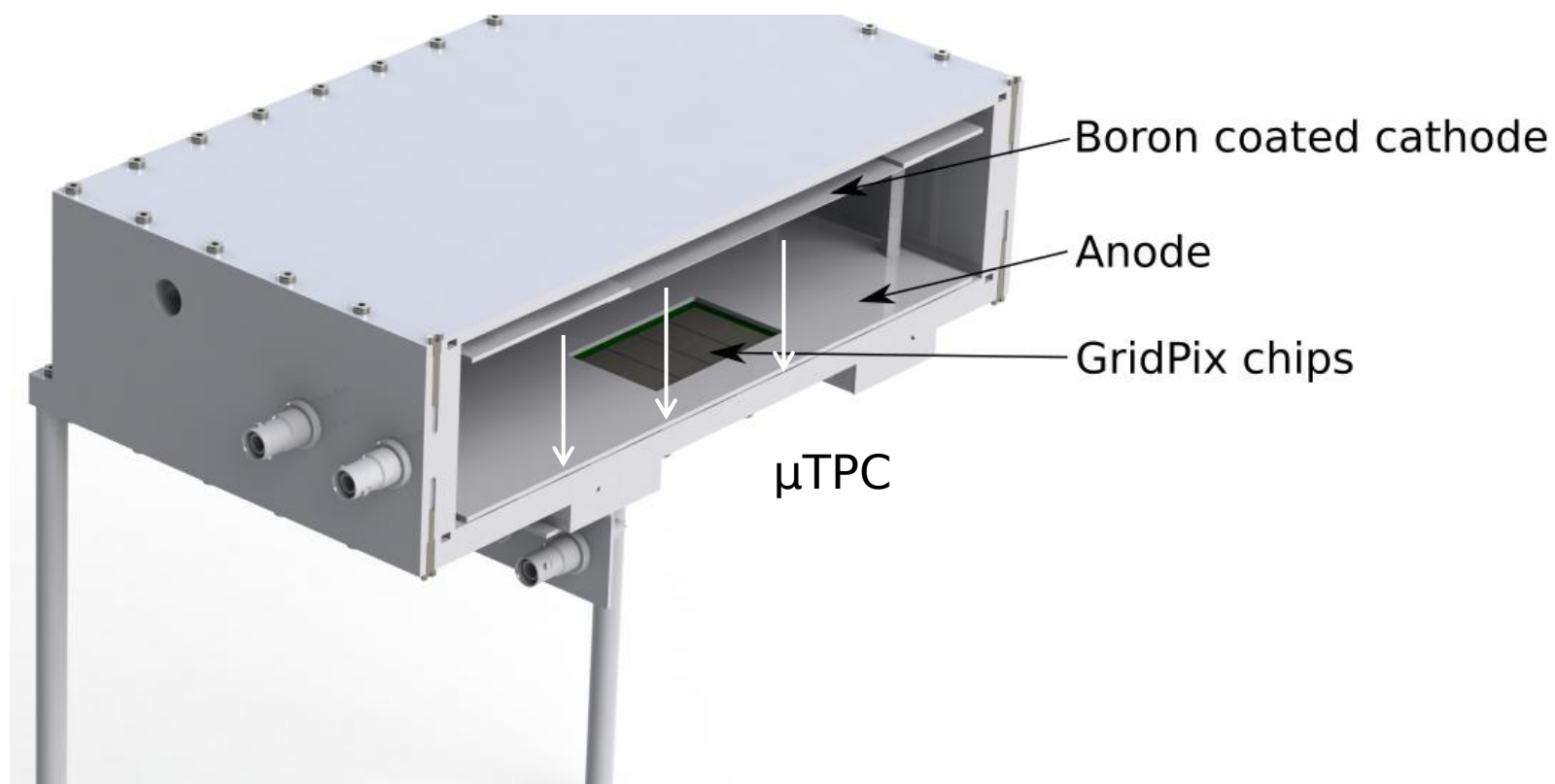
# Test Detector



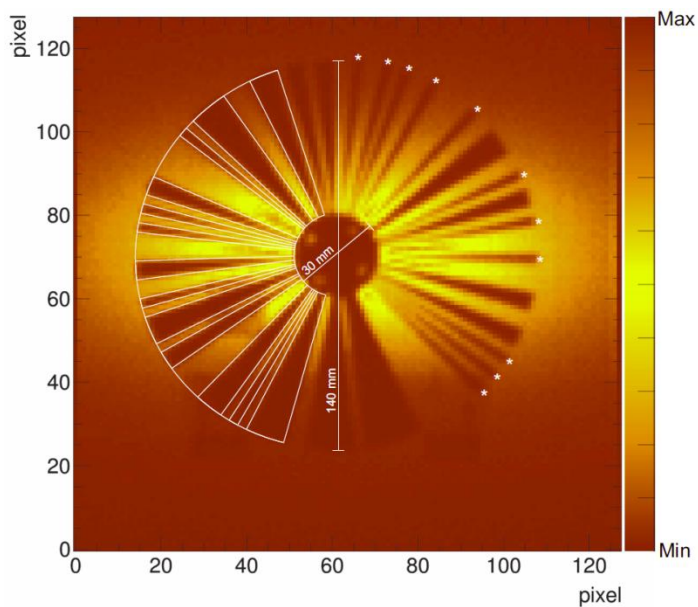
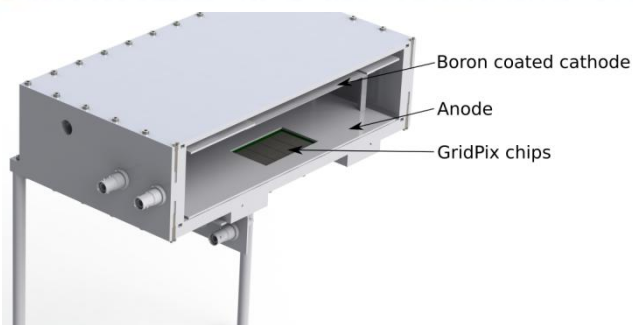
# Test Detector



# Test Detector



# Track Topology

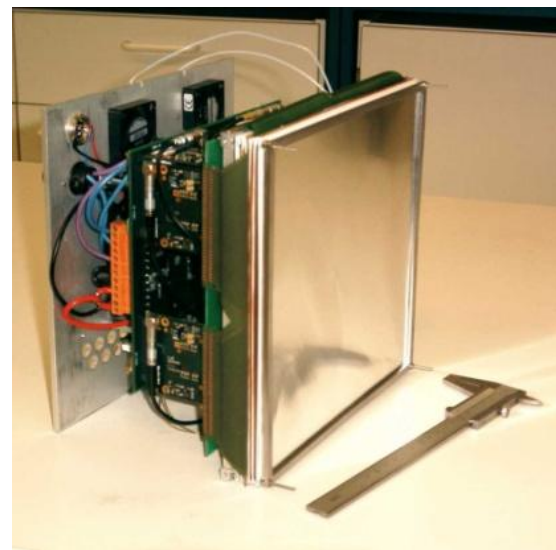
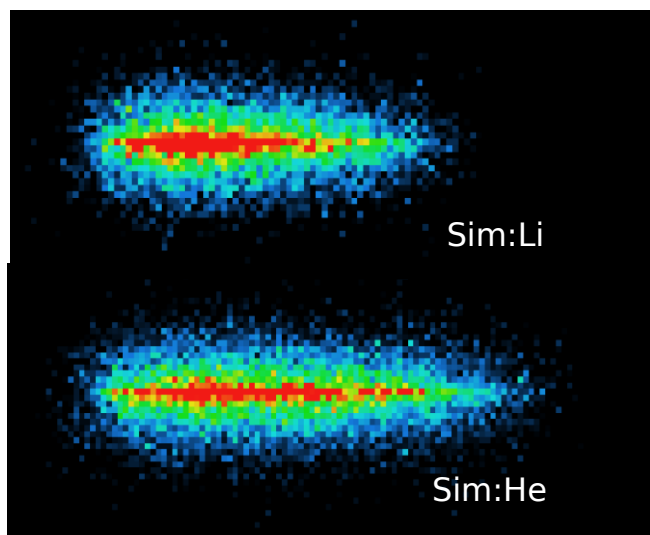
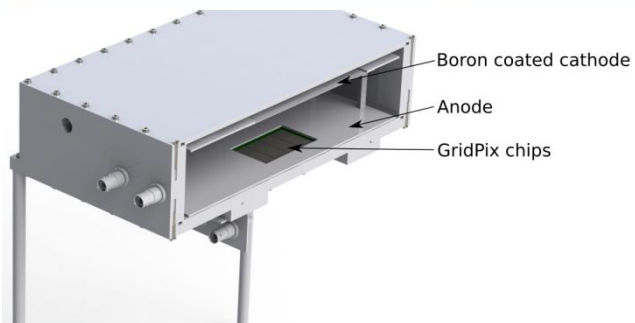


Siemens Star Resolution: 1.4 mm

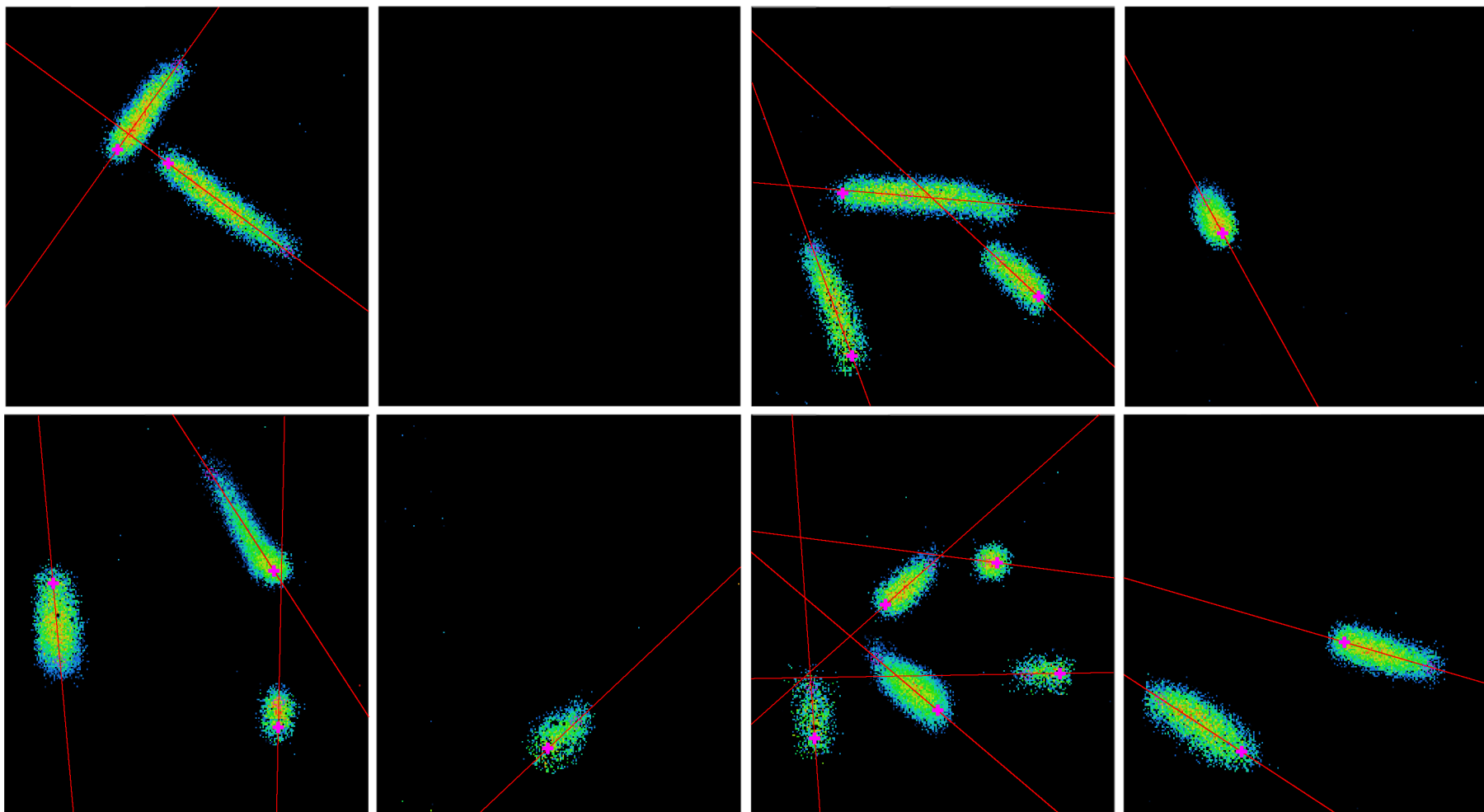


Pitch: 1.56 mm

# Track Topology

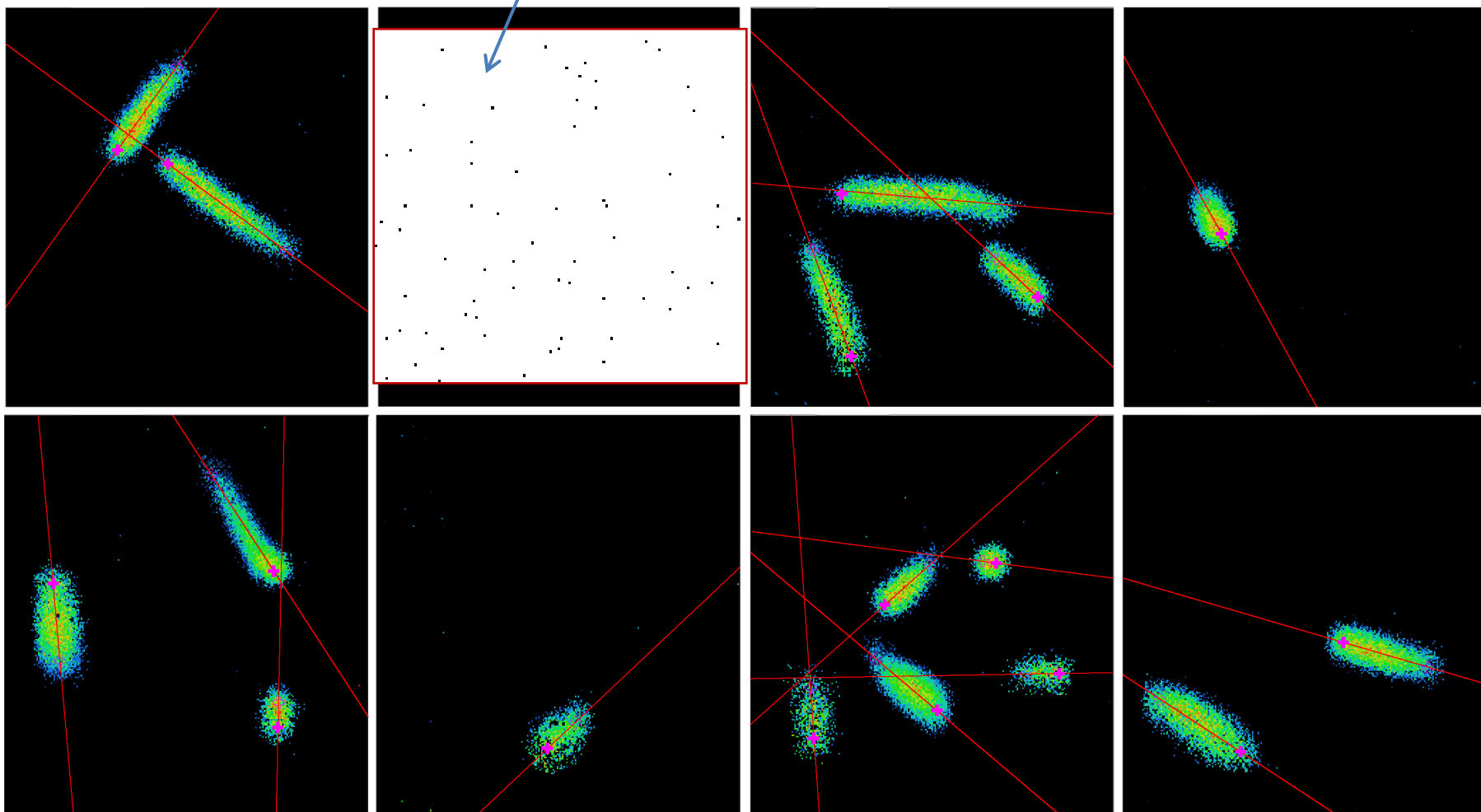


# Neutron Conversion Tracks



# Neutron Conversion Tracks

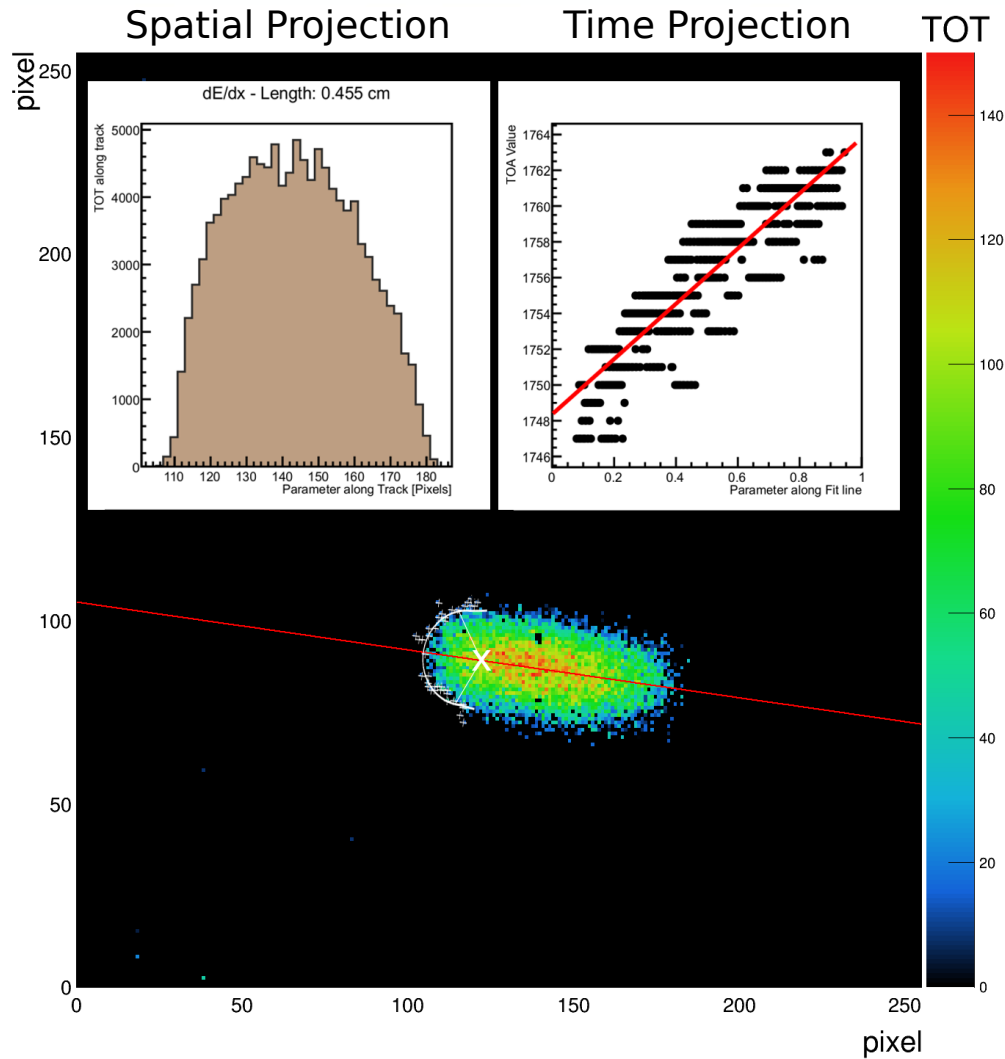
5-23 % Time Pixel (Random Pattern)





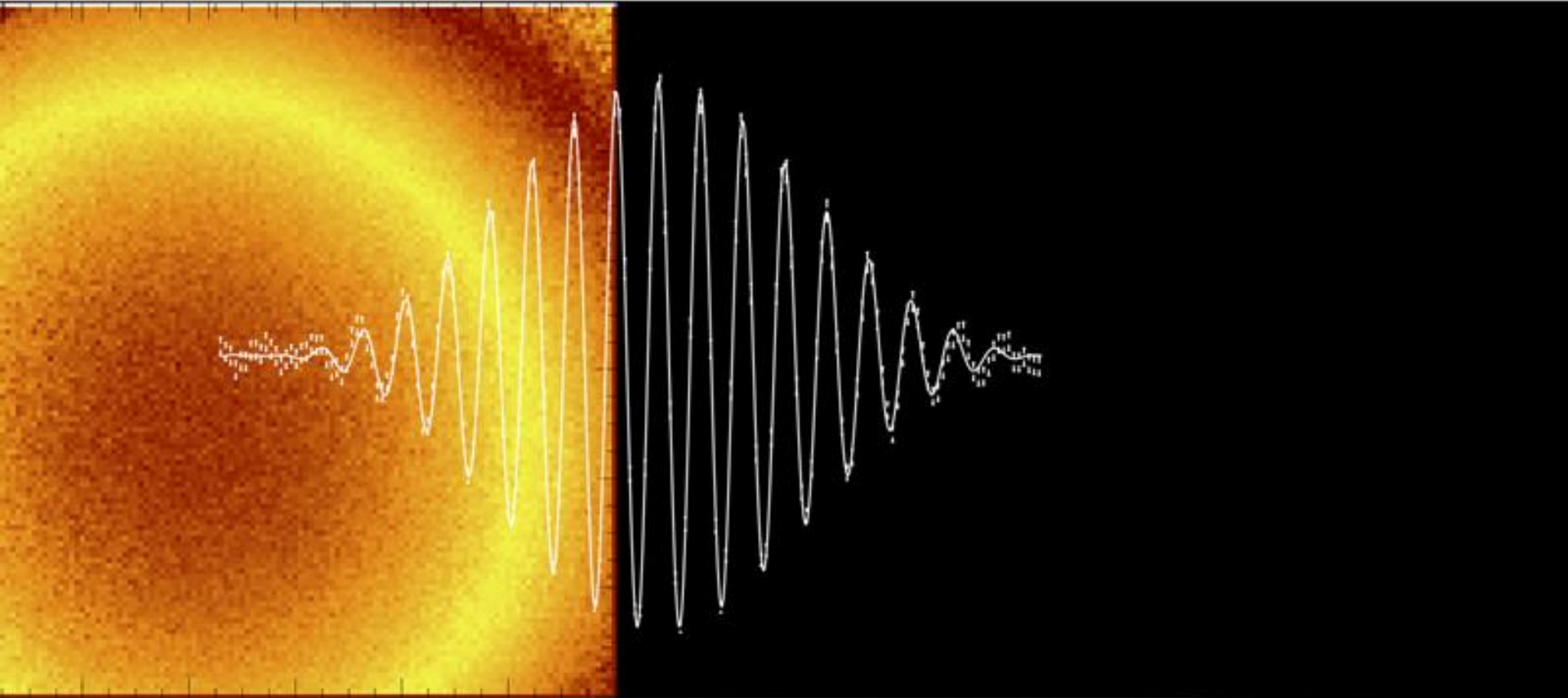


# Event Example: Helium

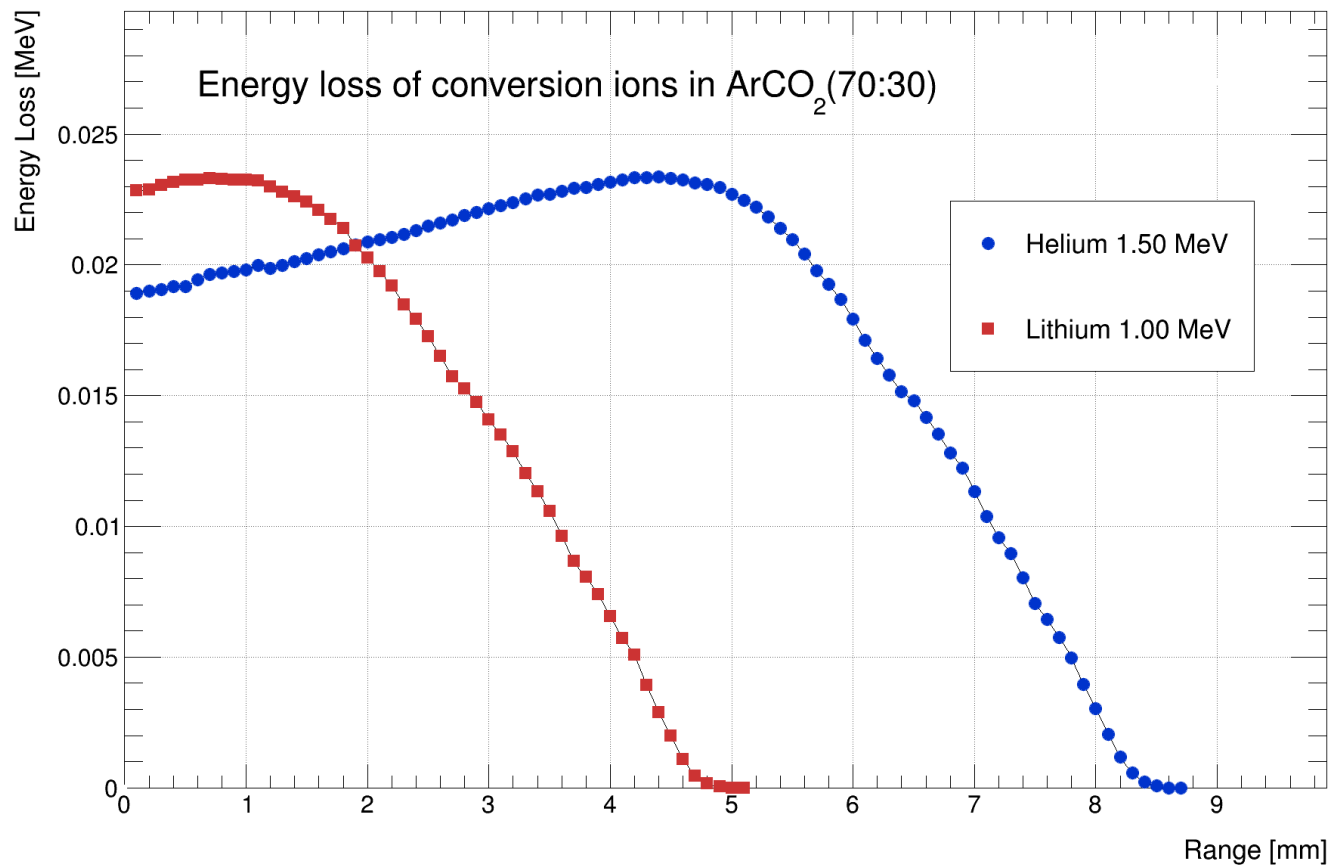




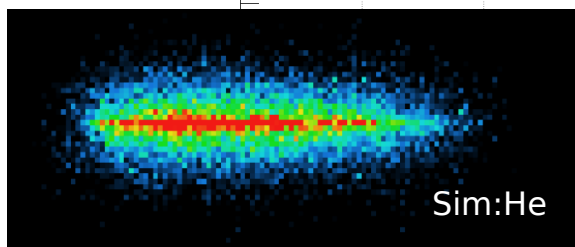
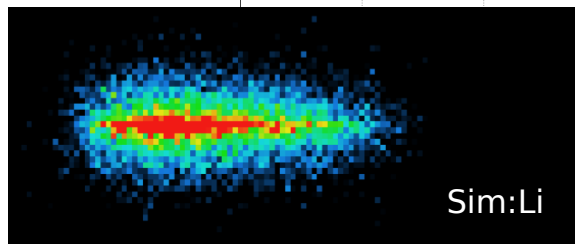
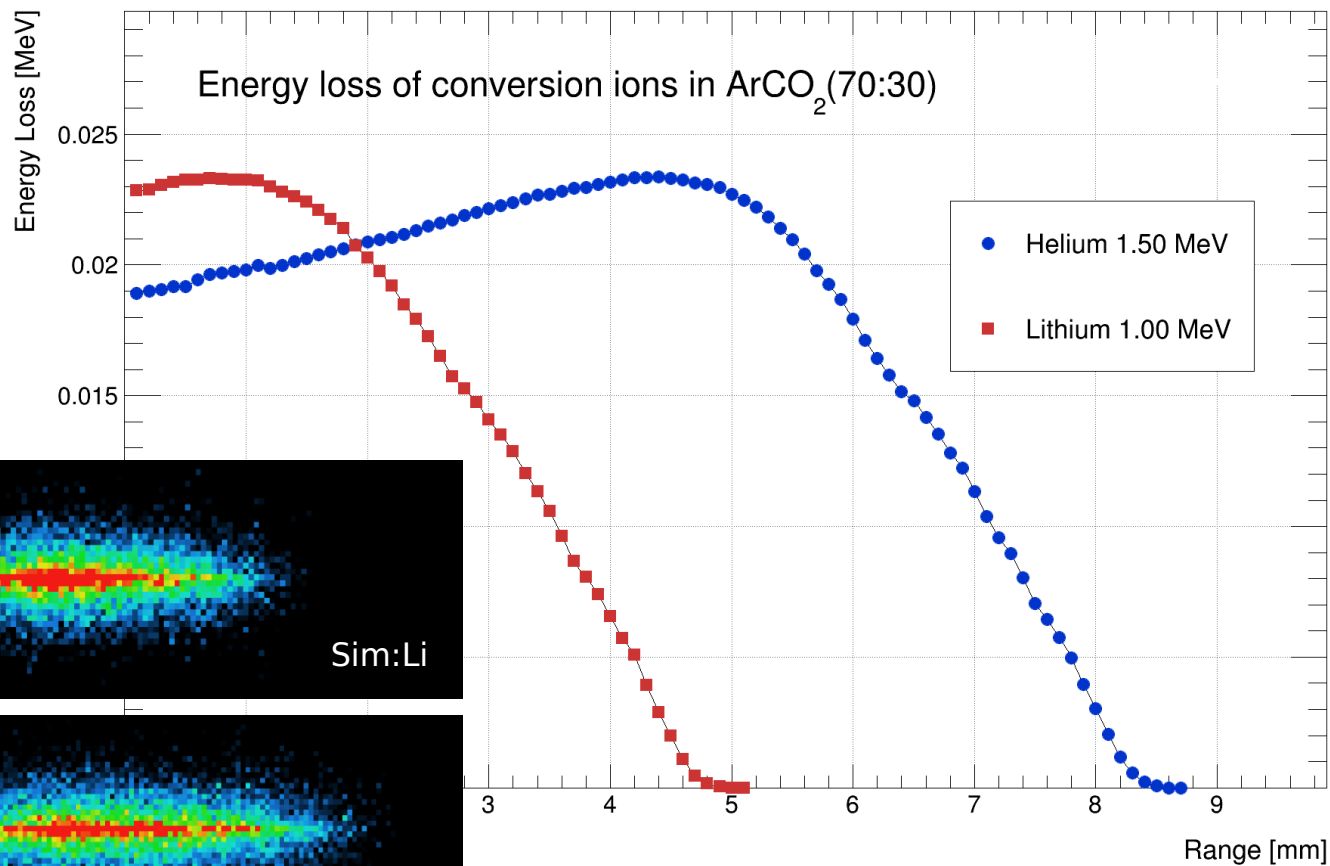
# Analysis and Results



# Energy Loss in Gas

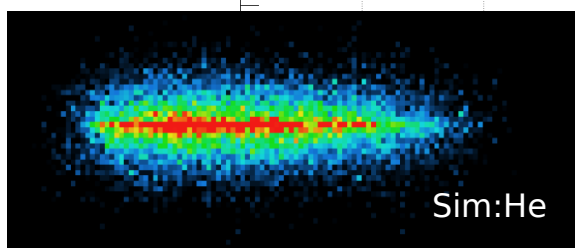
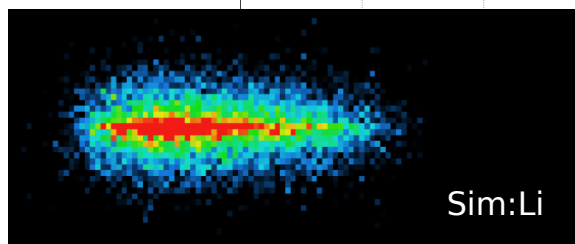
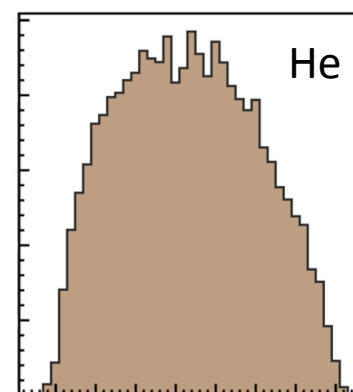
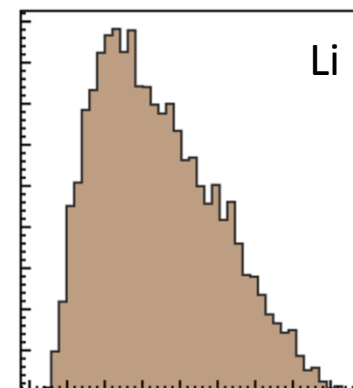
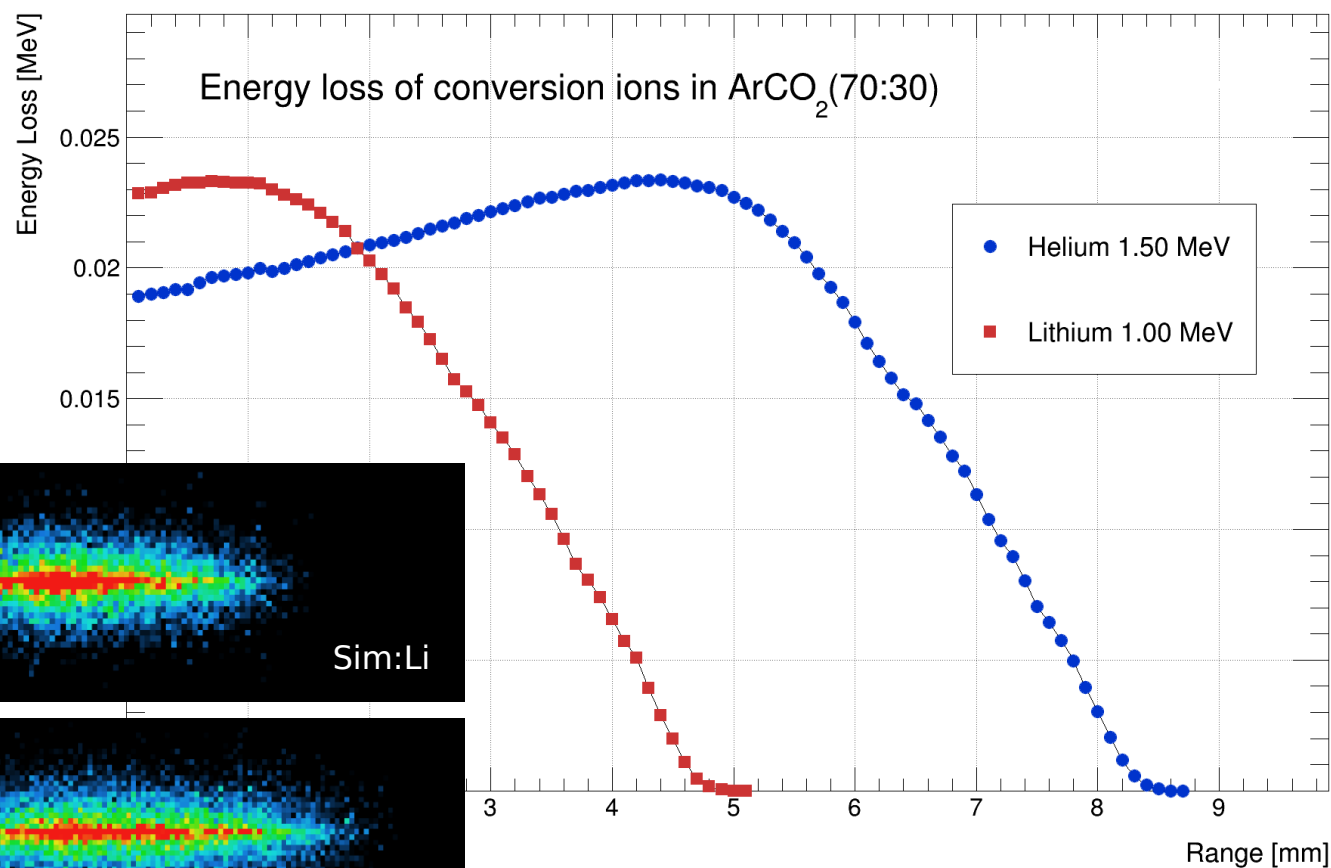


# Energy Loss in Gas



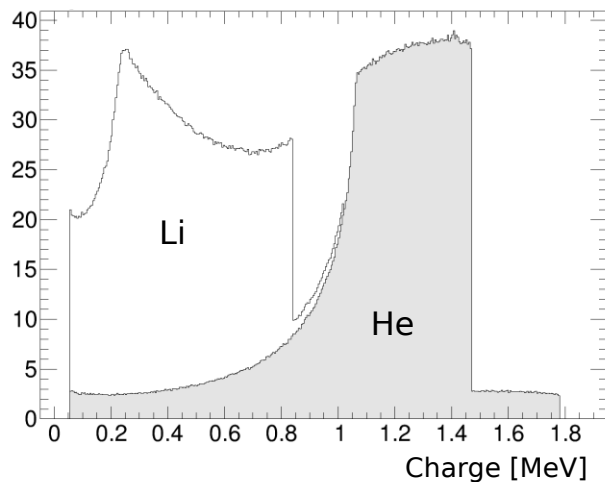
# Energy Loss in Gas

## Spatial Projection

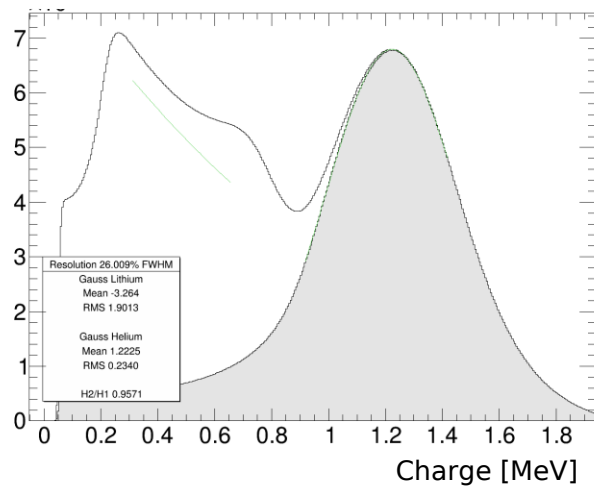


# Energy Spectrum

Simulation: 1  $\mu\text{m}$  Layer of Boron

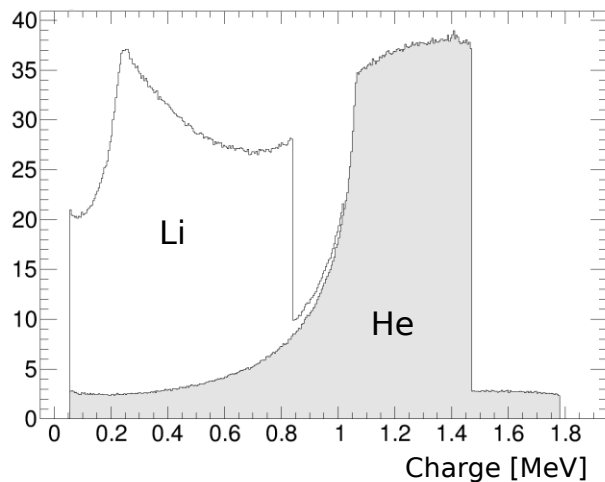


Folded with 25 % FWHM

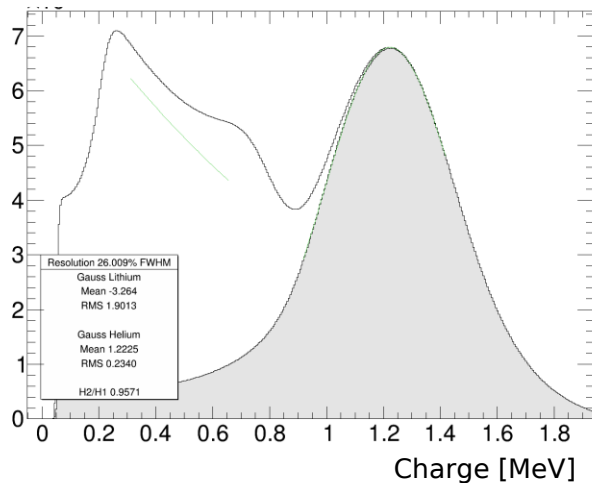


# Energy Spectrum

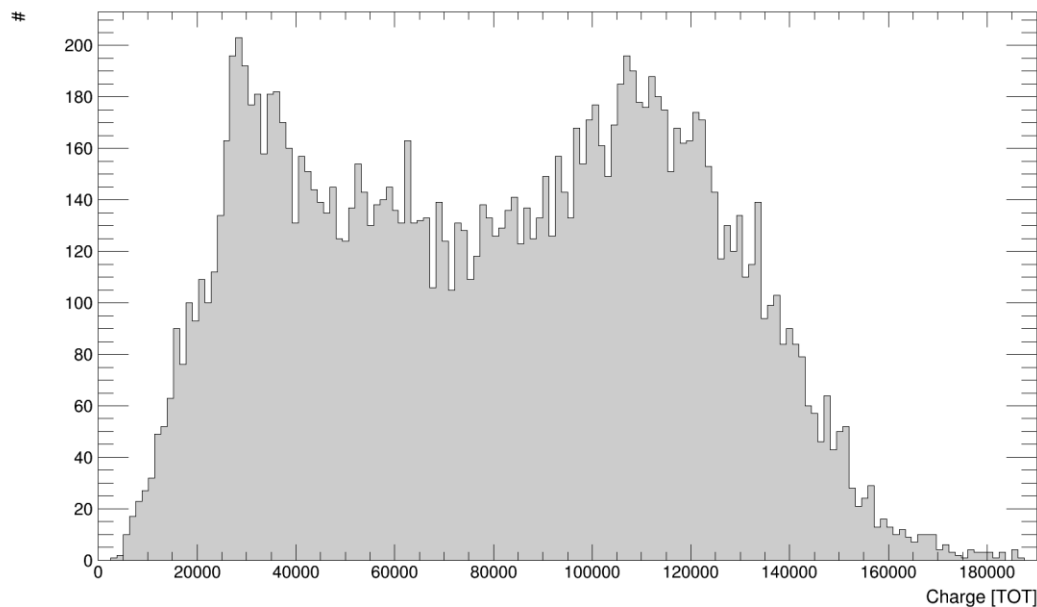
Simulation: 1  $\mu\text{m}$  Layer of Boron



Folded with 25 % FWHM

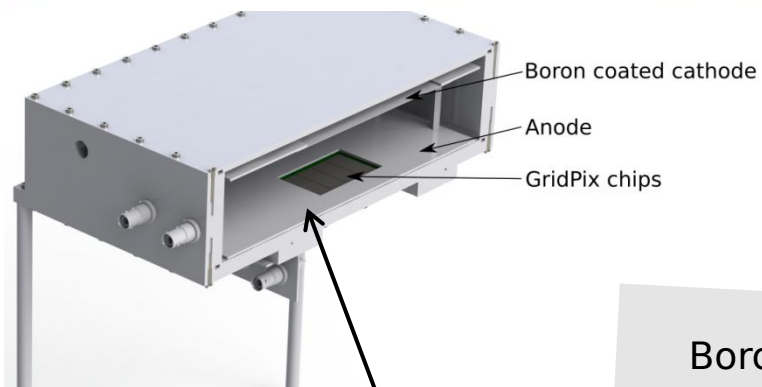


TOT Spectrum (fiducialized)

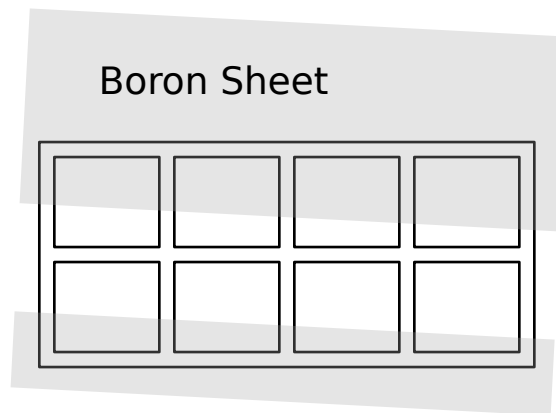




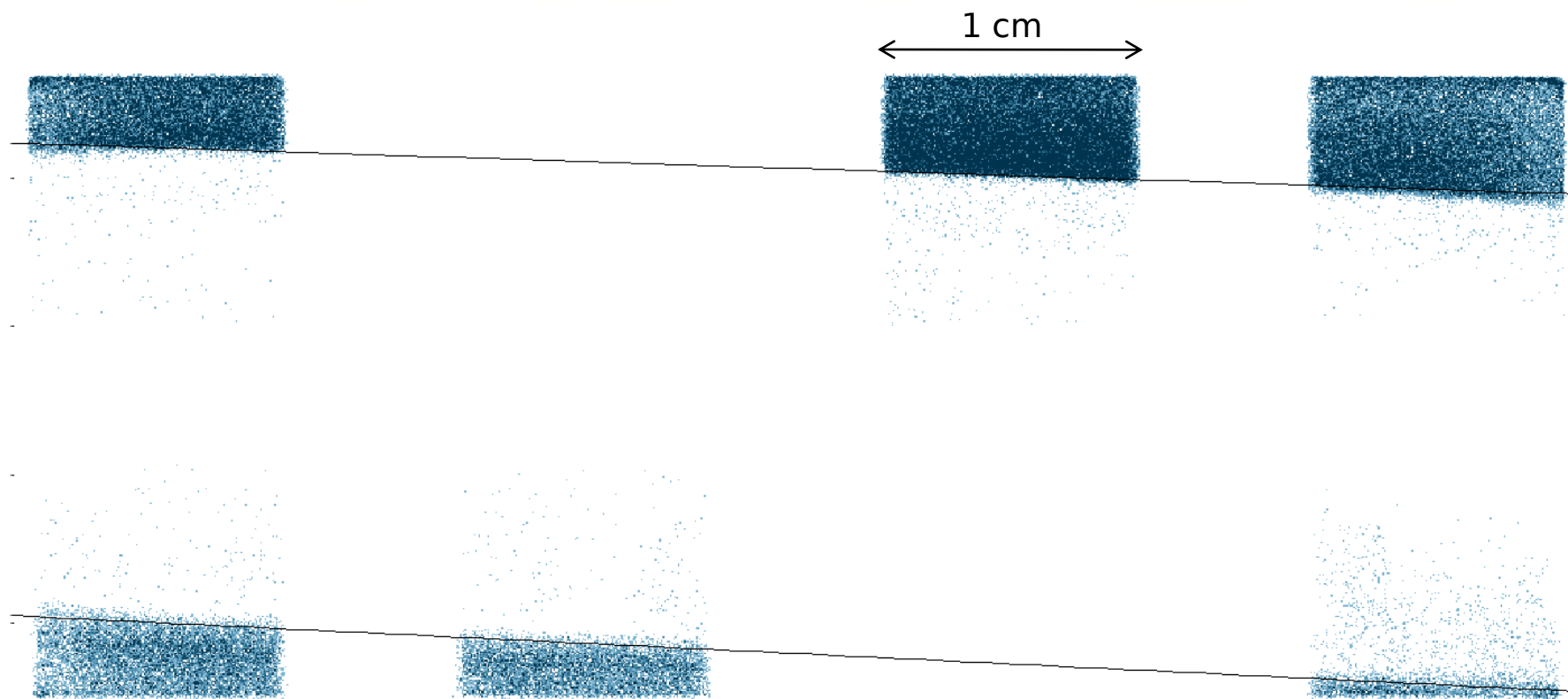
# Spatial Resolution



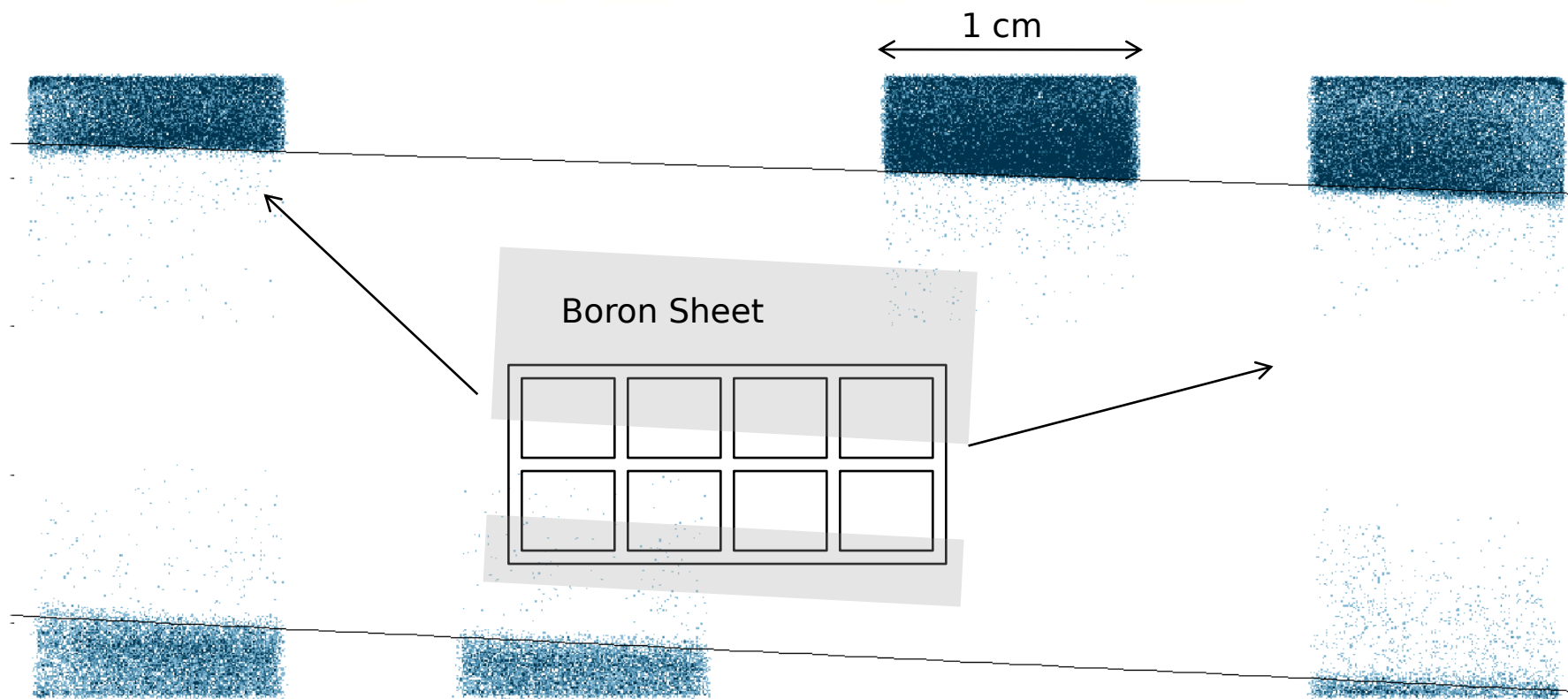
Drift Gap:  
3.8 cm



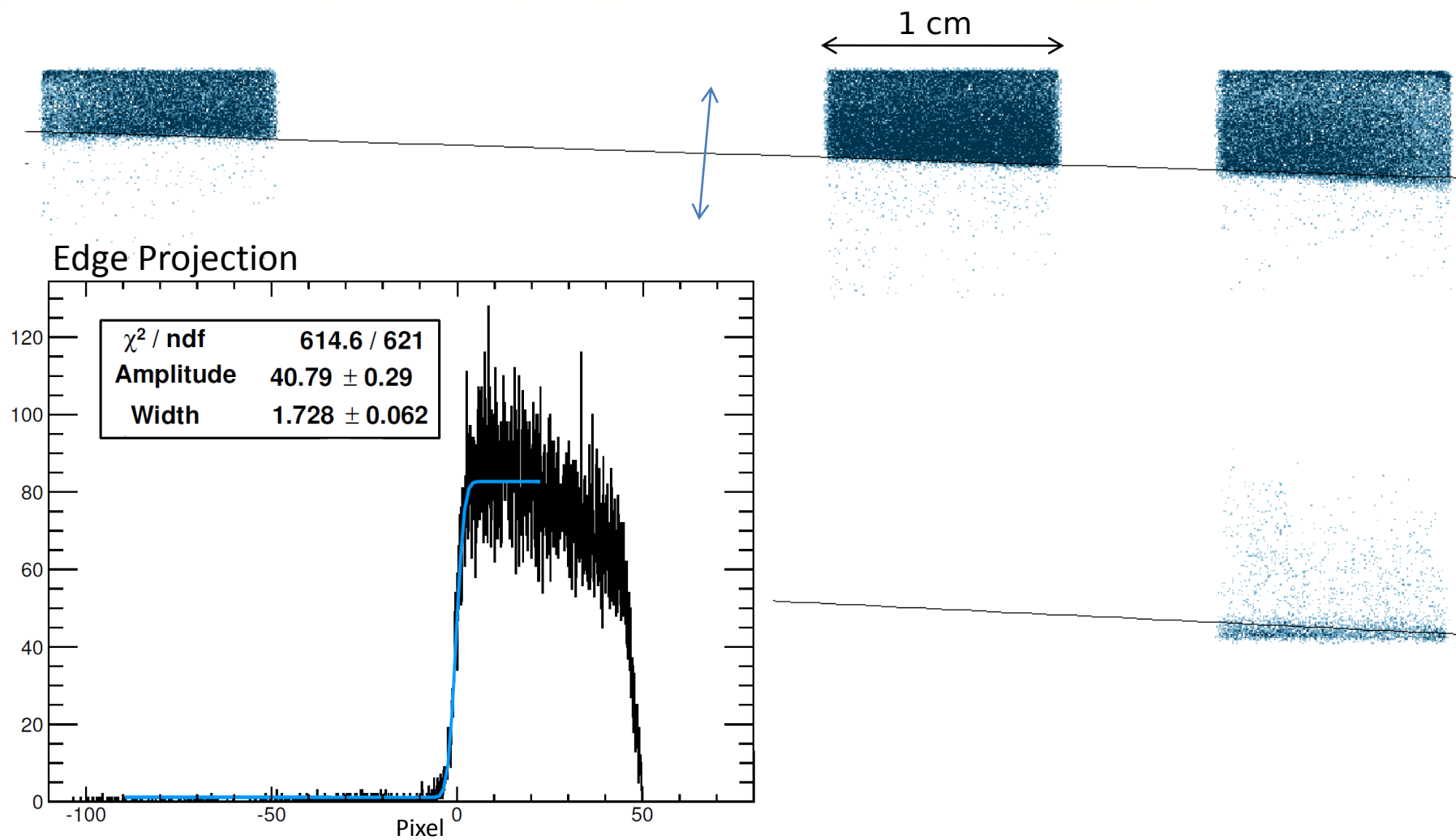
# Spatial Resolution



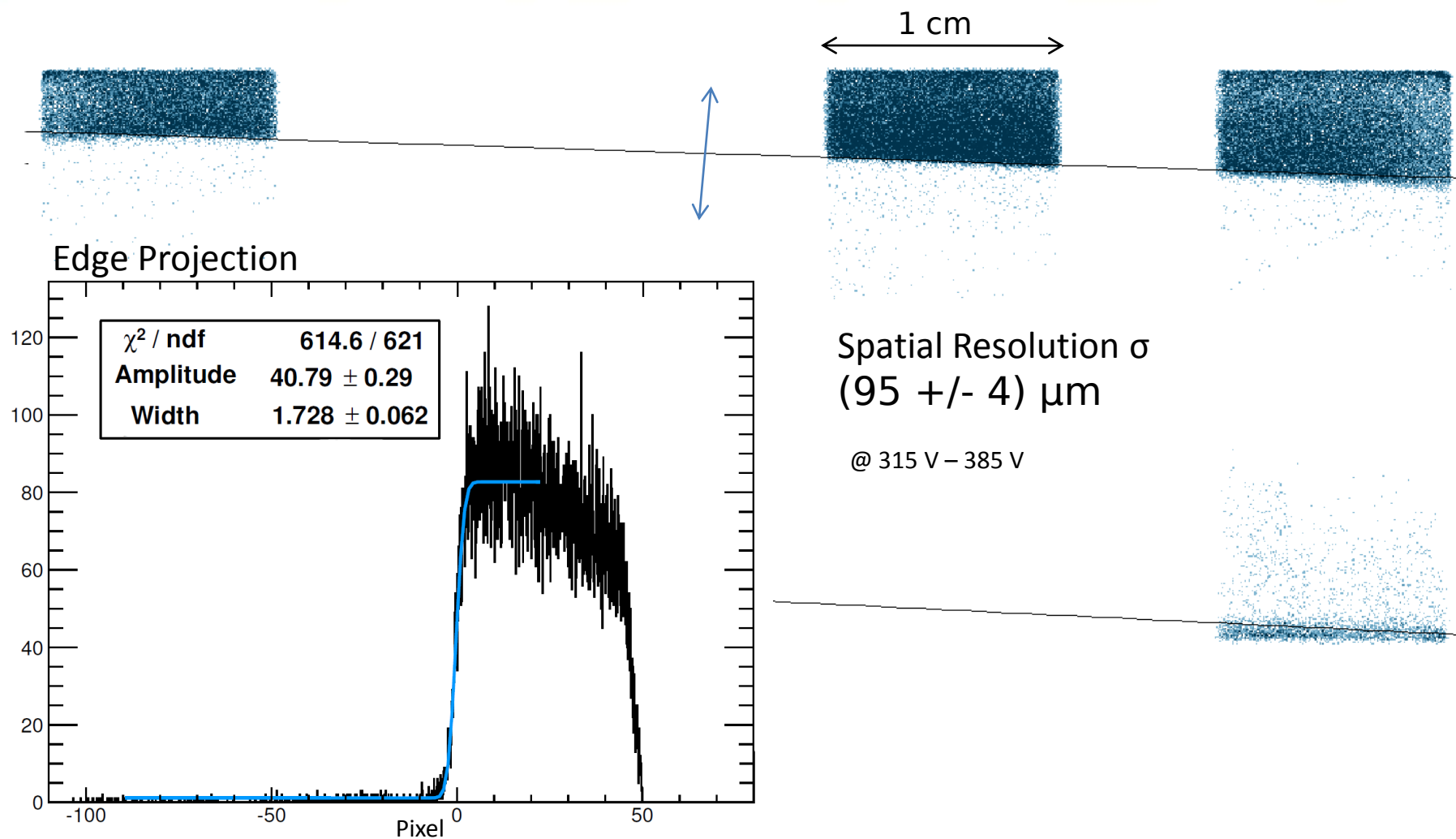
# Spatial Resolution



# Spatial Resolution



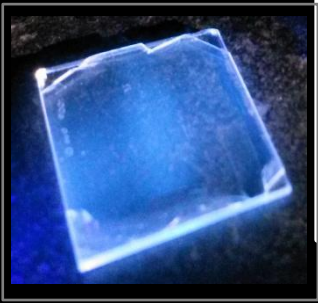
# Spatial Resolution



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Bonn



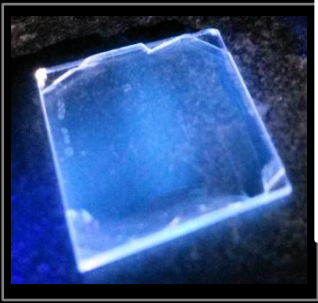
## High Resolution Neutron Detection The Neutron Time Projection Chamber

BODELAIRE

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Bonn



## High Resolution Neutron Detection The Neutron Time Projection Chamber

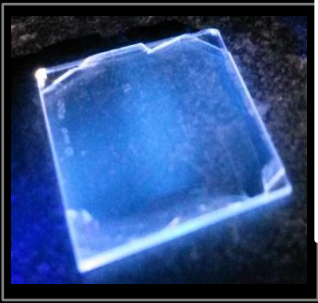
- Trigger & Track Principle

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## High Resolution Neutron Detection The Neutron Time Projection Chamber

- Trigger & Track Principle
  - Using both conversion products

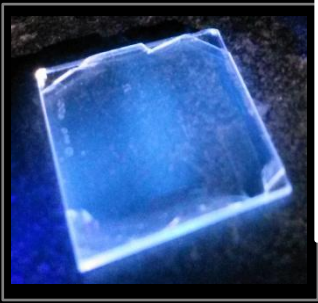
BODELAIRE



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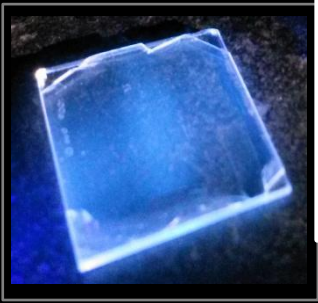


## High Resolution Neutron Detection The Neutron Time Projection Chamber

- Trigger & Track Principle

- Using both conversion products
- Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]

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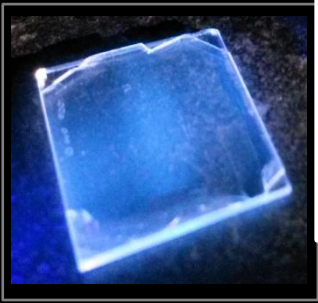
## High Resolution Neutron Detection The Neutron Time Projection Chamber

- Trigger & Track Principle

- Using both conversion products
- Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]

- [ Spatial Resolution  $\sigma$   
(95 +/- 4)  $\mu\text{m}$  ]

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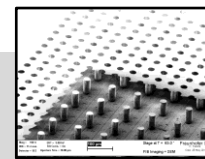
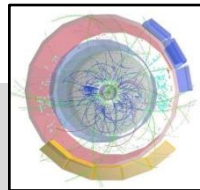
## High Resolution Neutron Detection The Neutron Time Projection Chamber

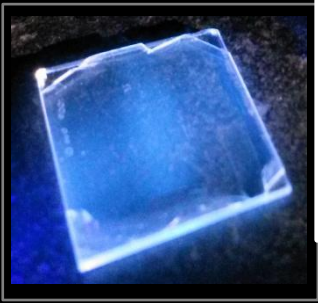
- Trigger & Track Principle

- Using both conversion products
- Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]

- [ Spatial Resolution  $\sigma$  ]  
[  $(95 \pm 4) \mu\text{m}$  ]

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## High Resolution Neutron Detection The Neutron Time Projection Chamber

- Trigger & Track Principle

- Using both conversion products
- Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]

- [ Spatial Resolution  $\sigma$   
(95 +/- 4)  $\mu\text{m}$  ]

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