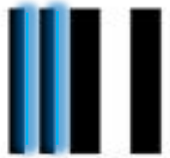


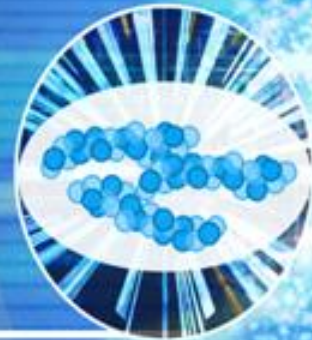
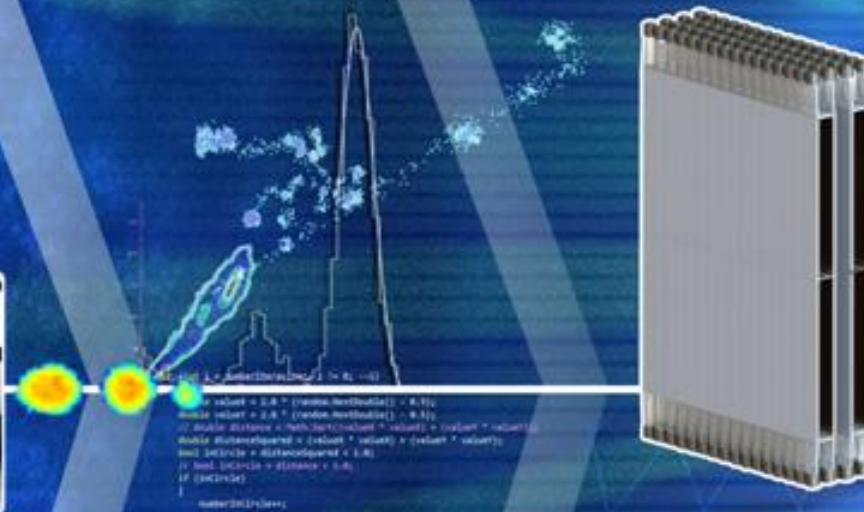
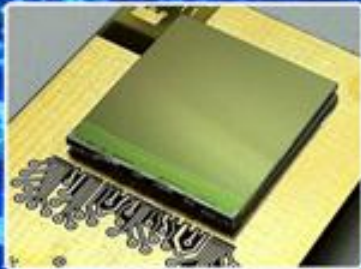
# Novel Neutron Detectors based on the Time Projection Method



ICNS 2017  
13.07.2017

**Markus Köhli**

T. Wagner, F. Schmidt, J. Kaminski, U. Schmidt, K. Desch





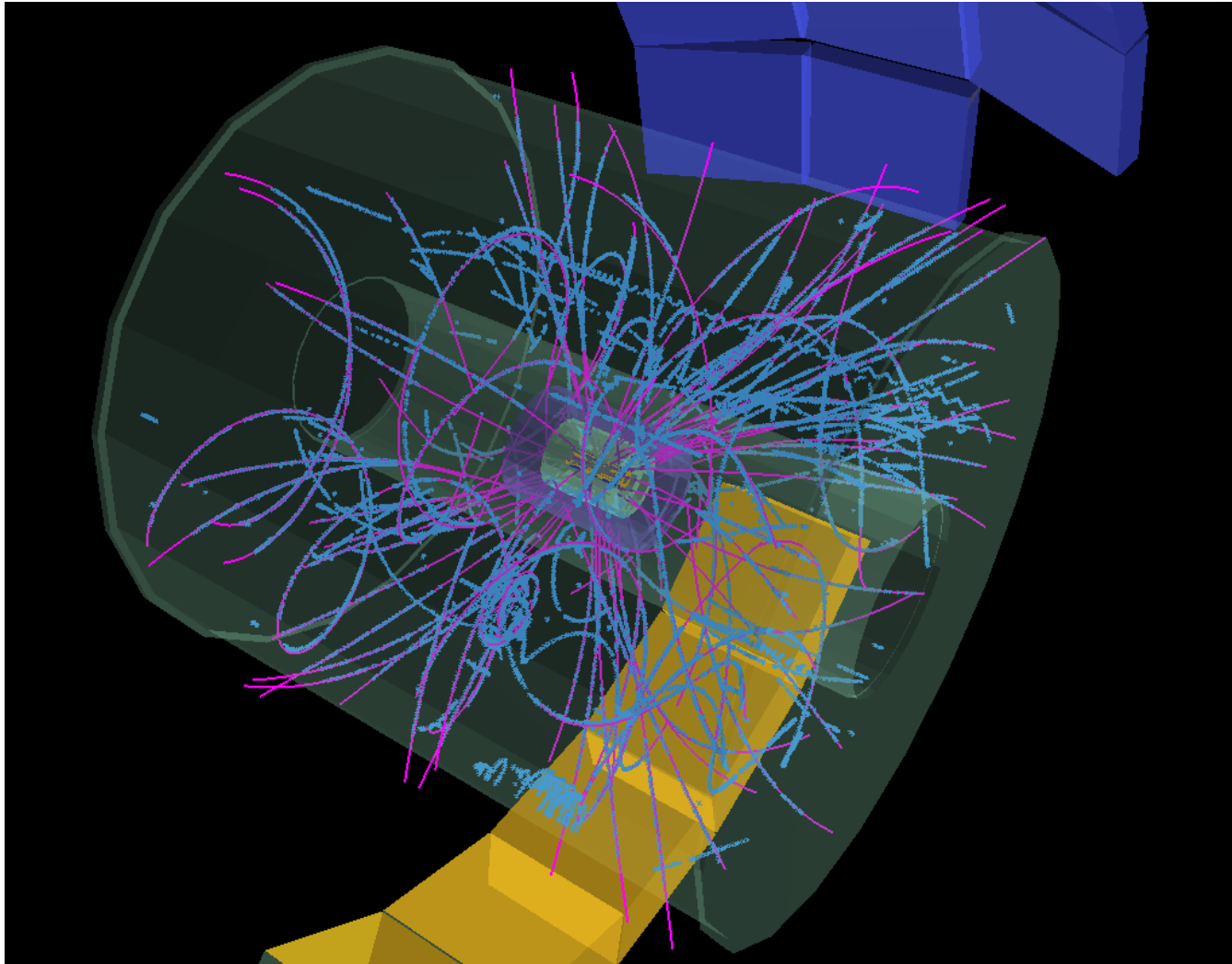
# BASTARD & BODELAIRE

High Rate

High Resolution



# The TPC



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

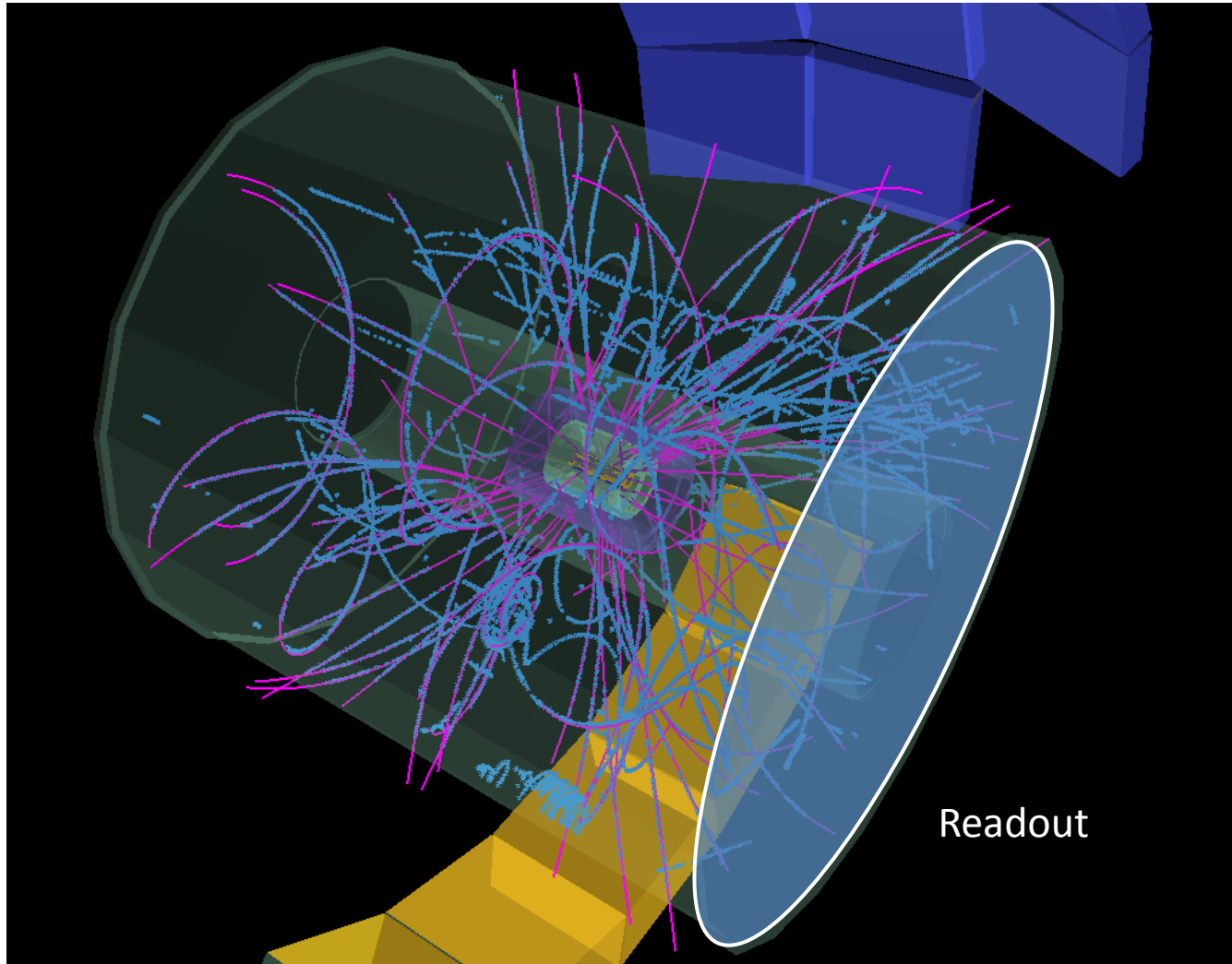
MARKUS KÖHLI

Physikalisches Institut

University of Bonn



# The TPC



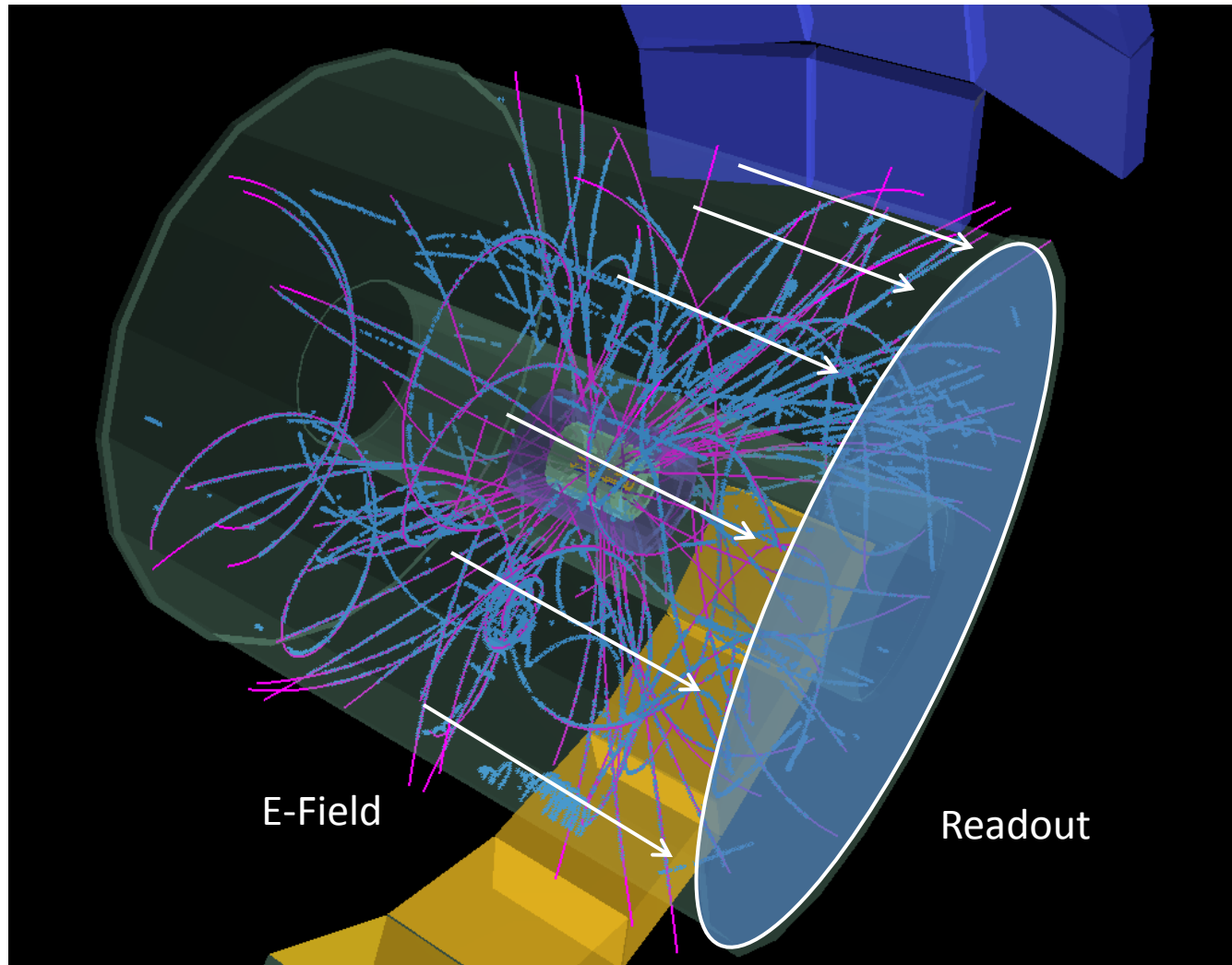
[1] <http://www-alice.gsi.de>

MARKUS KÖHLI

Physikalisches Institut

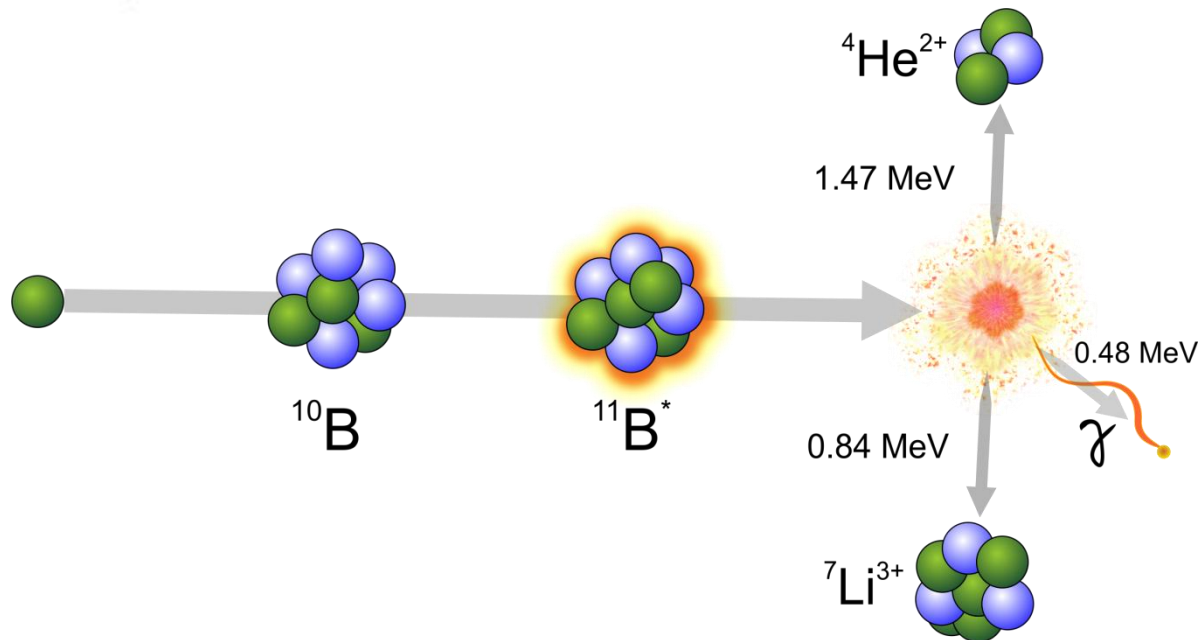
University of Bonn

# The TPC



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

# The Neutron TPC Trigger

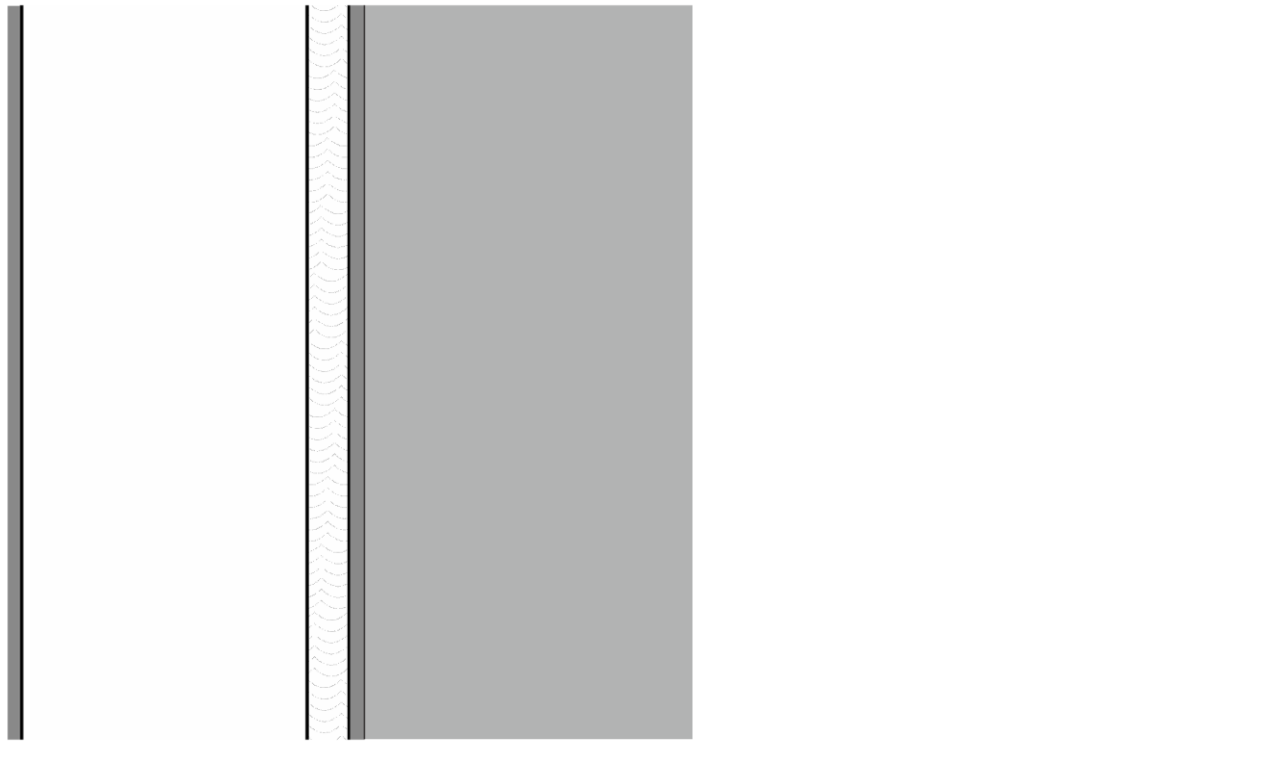


# The Neutron TPC

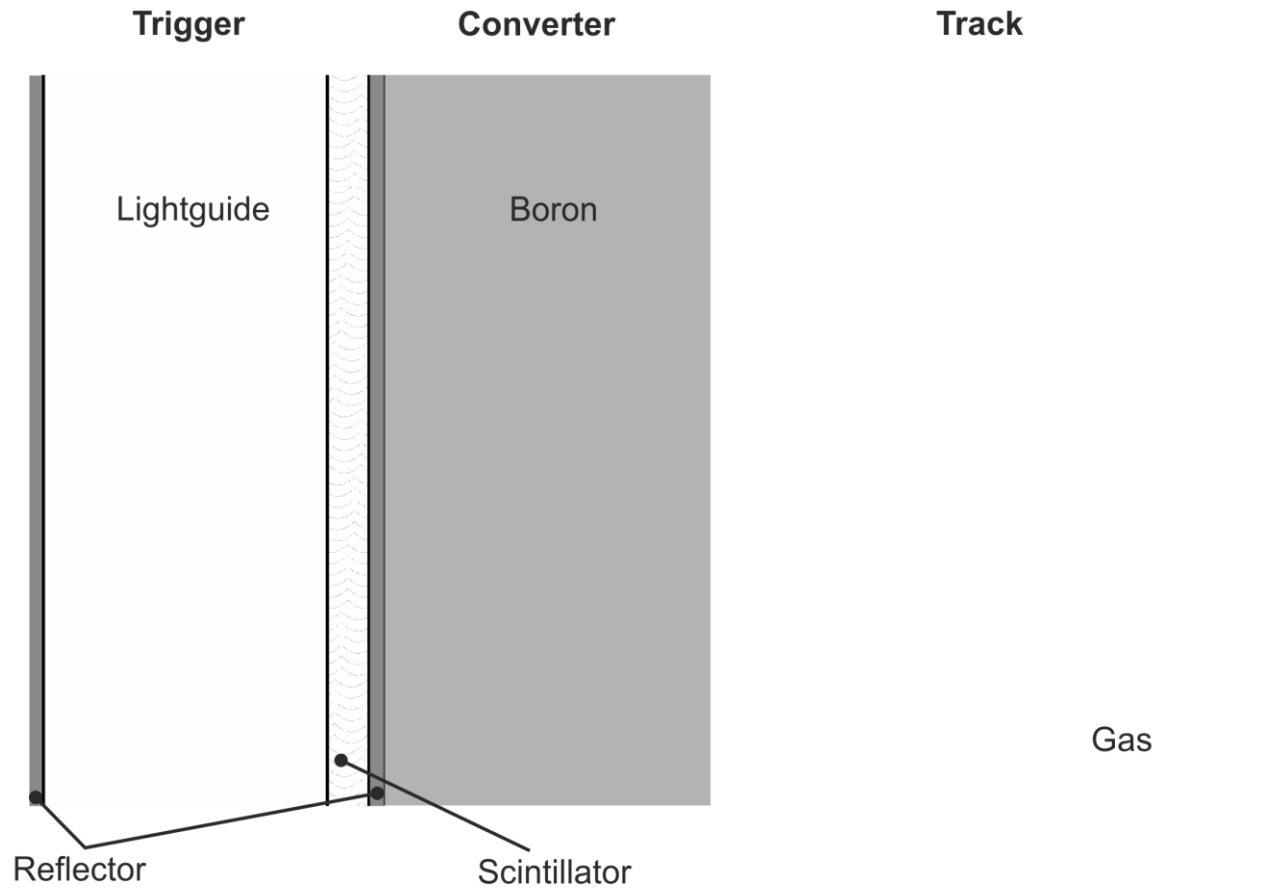
Trigger

Converter

Track

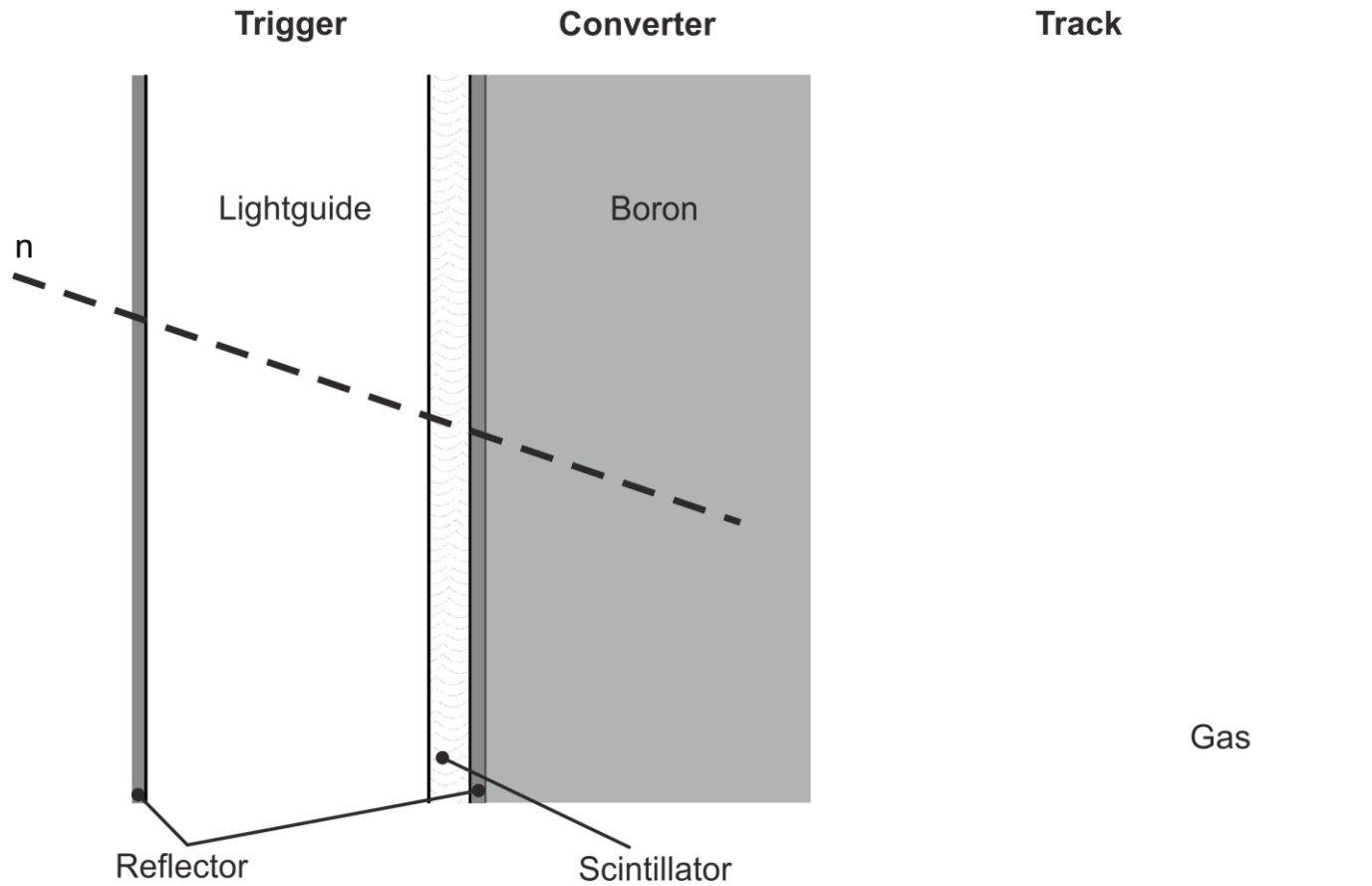


# The Neutron TPC

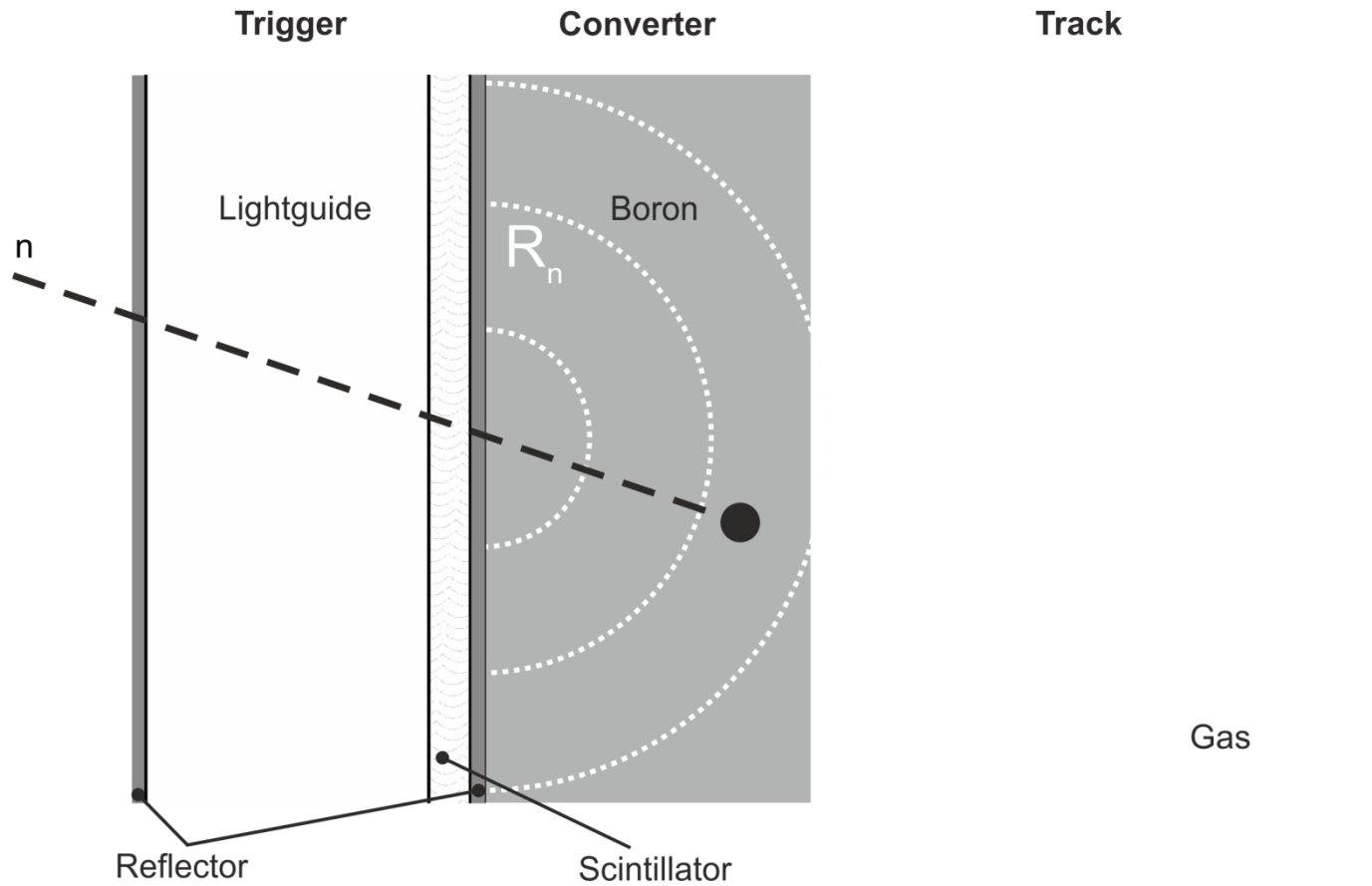




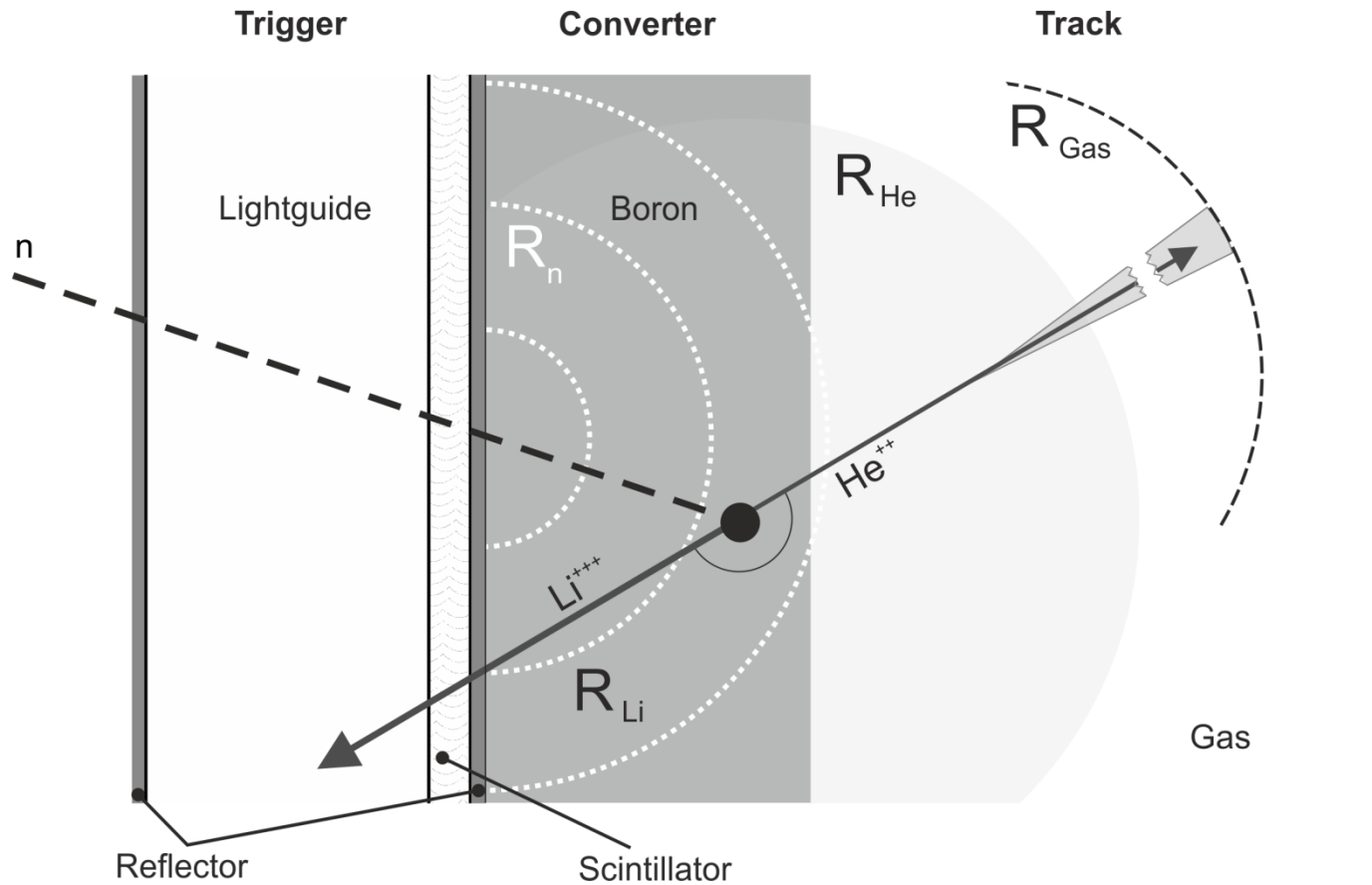
# The Neutron TPC



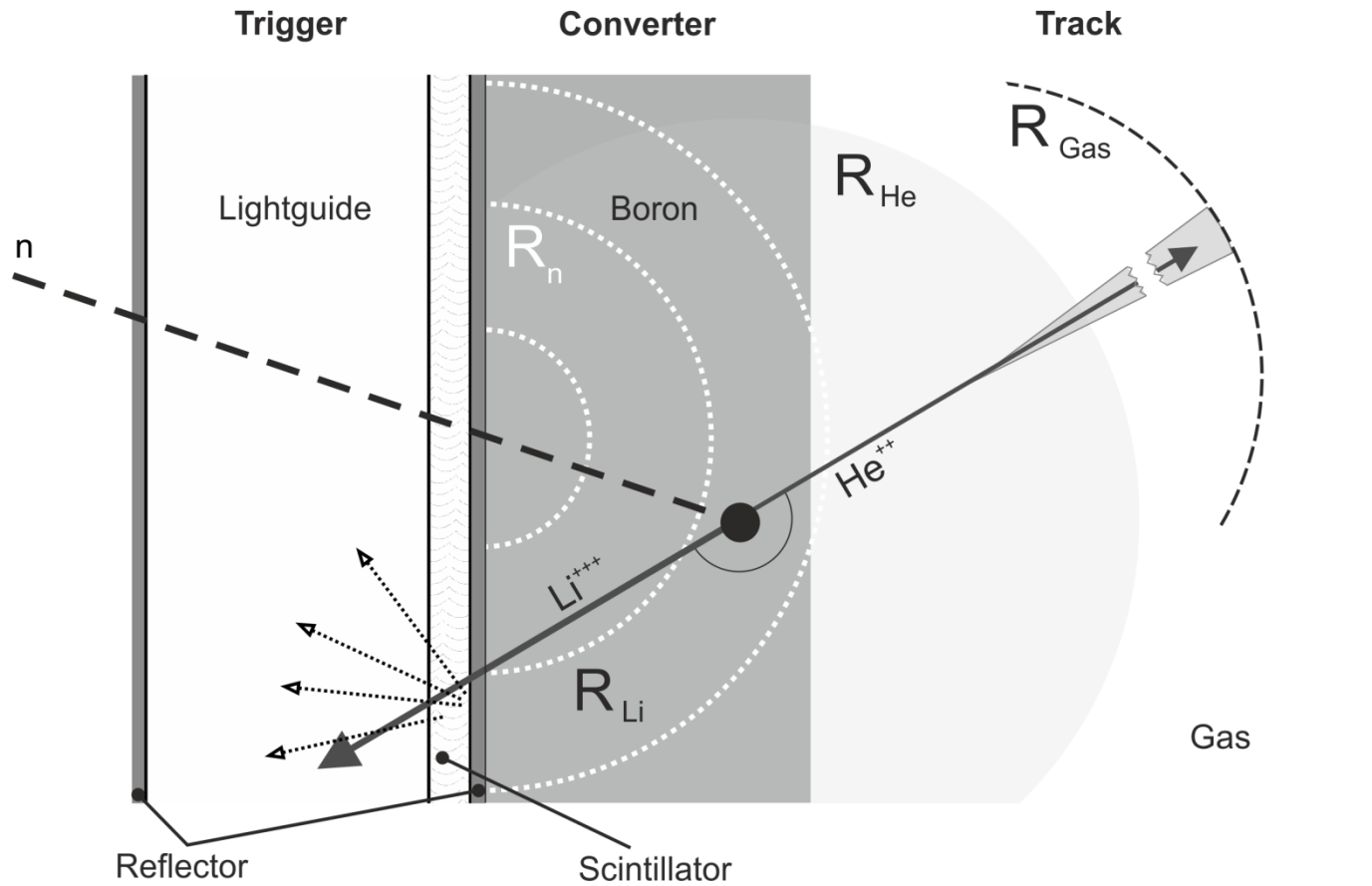
# The Neutron TPC



# The Neutron TPC



# The Neutron TPC

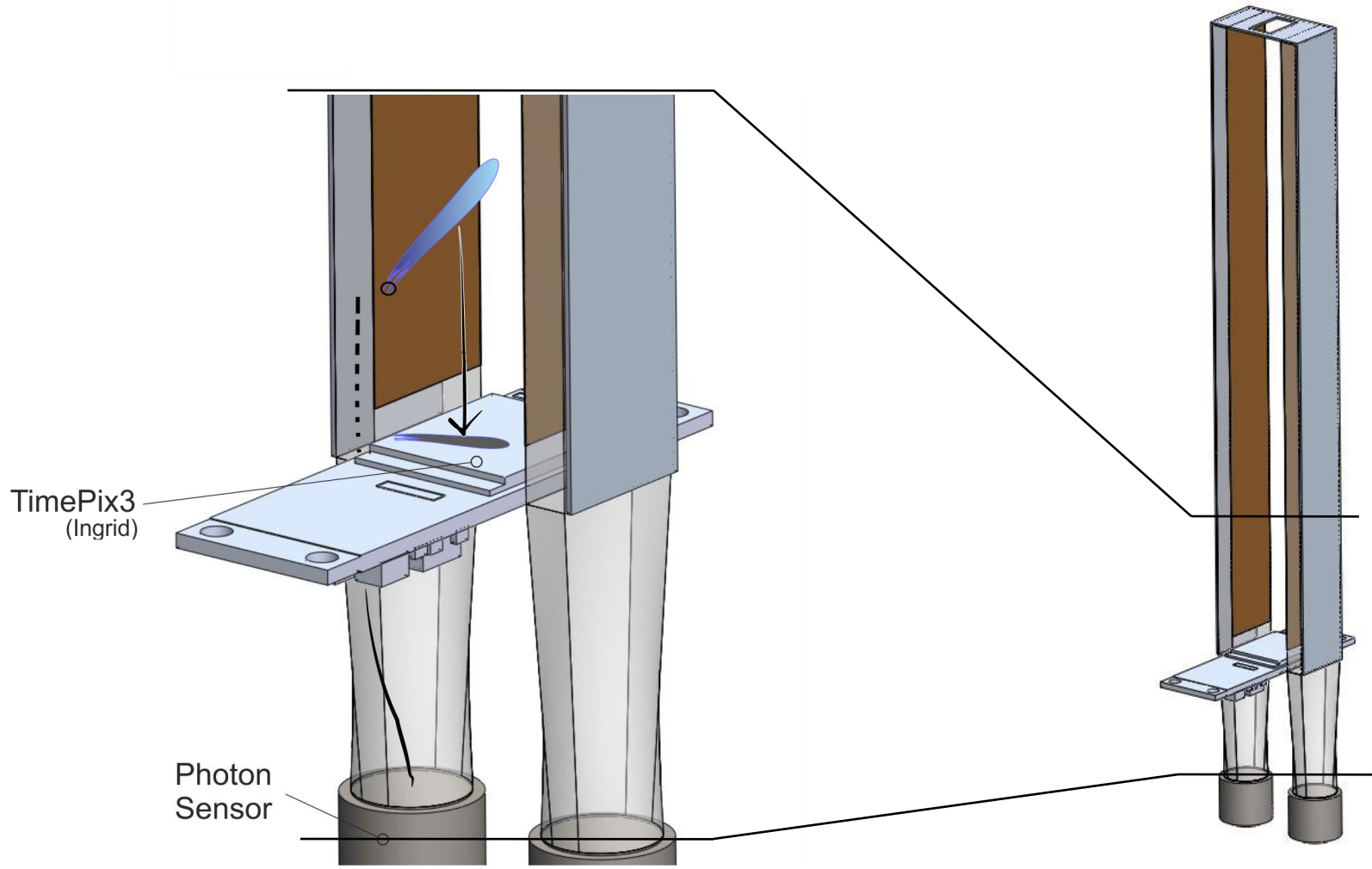




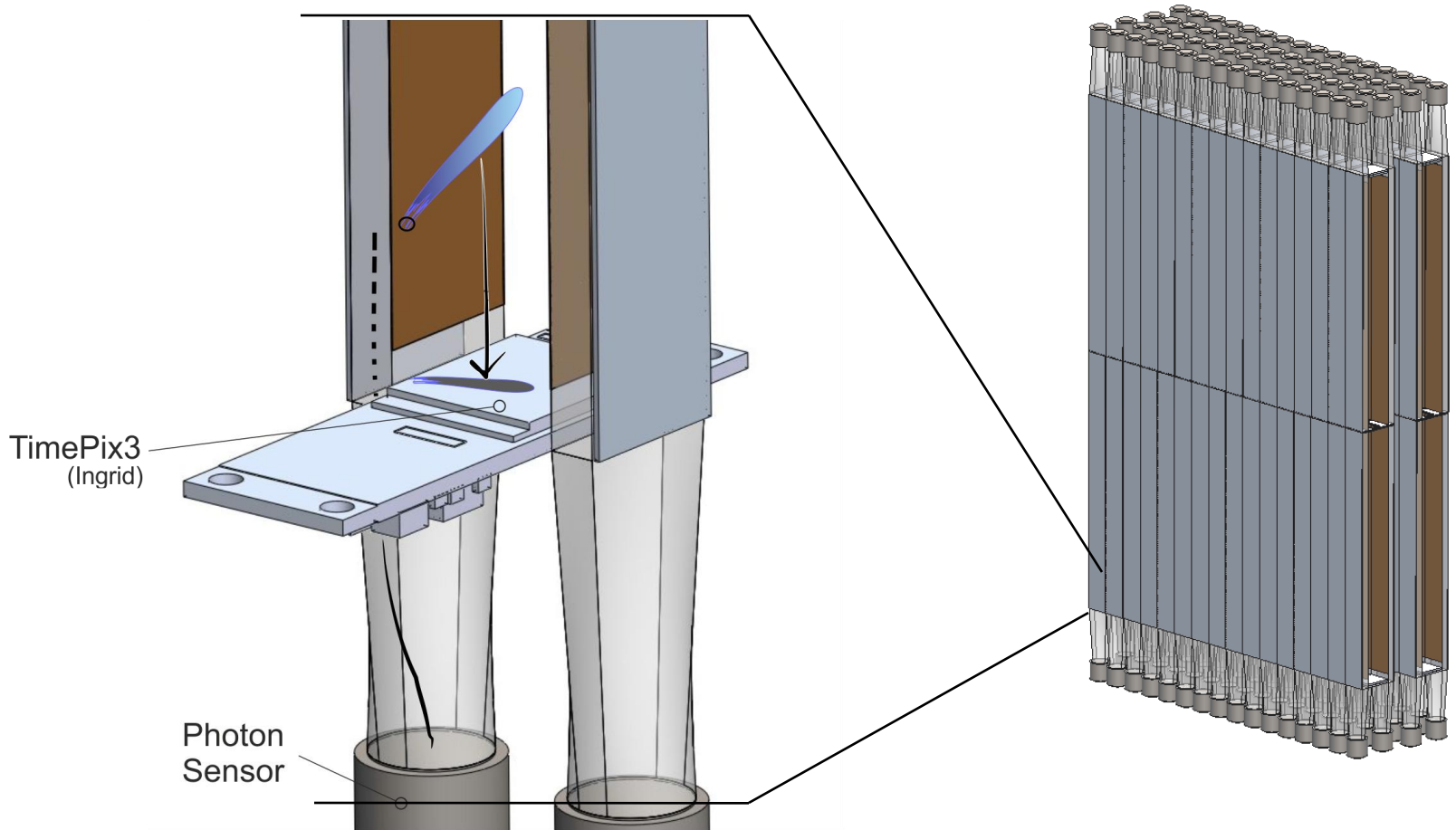
# ||| The Detector



# The Neutron TPC



# The Neutron TPC

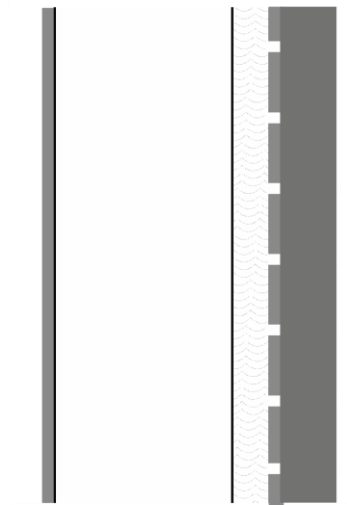
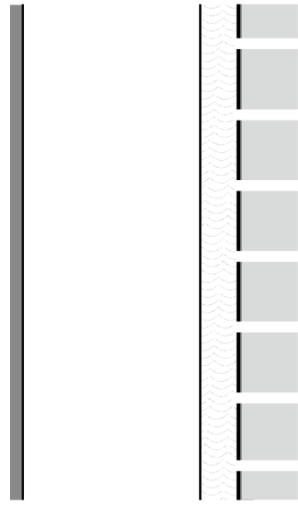
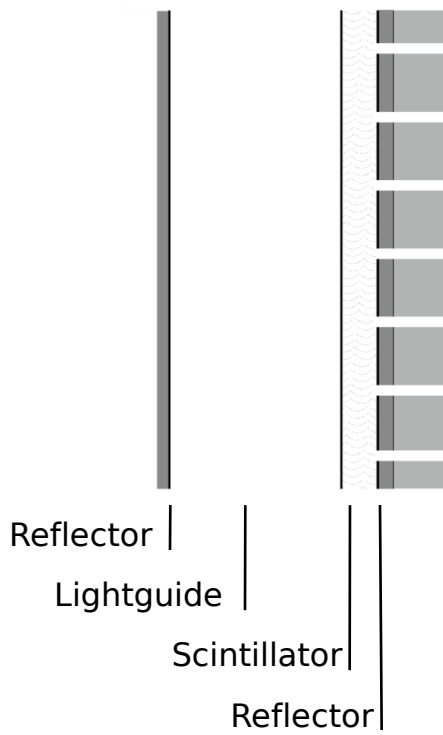


# Field Cage Design

Boron Carbide

Boron Nitride

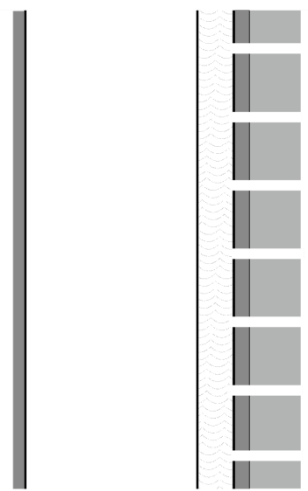
Boron



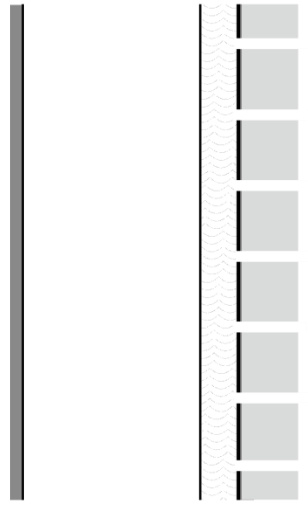


# Field Cage Design

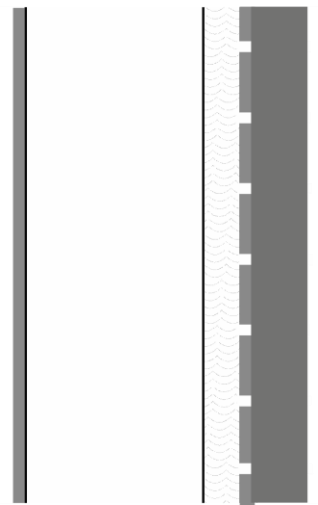
Boron Carbide



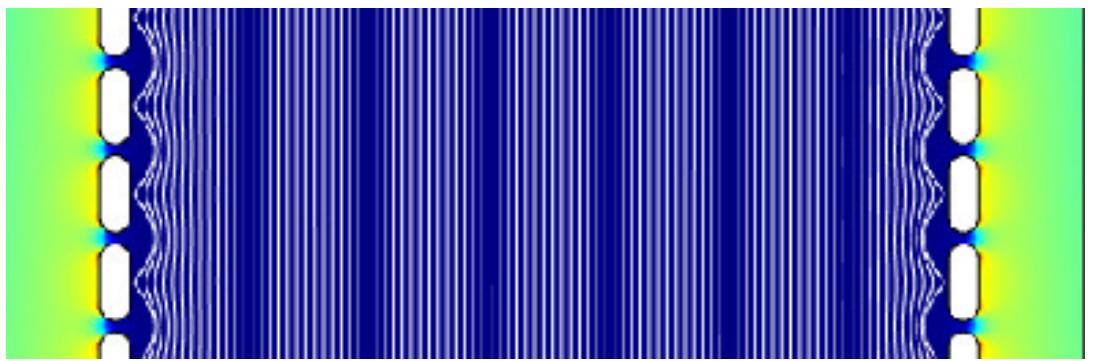
Boron Nitride



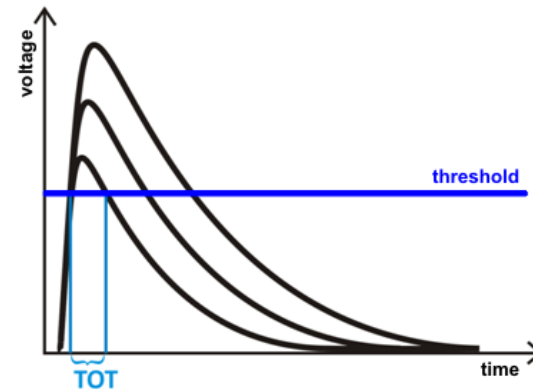
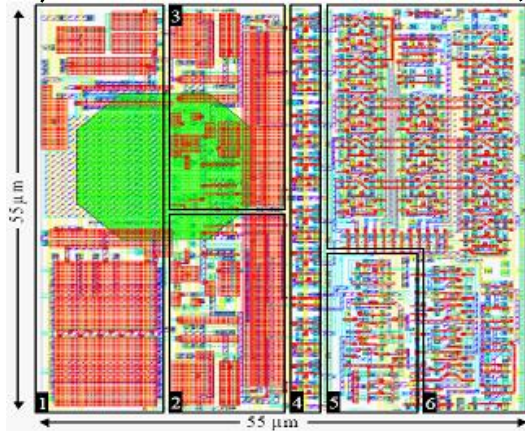
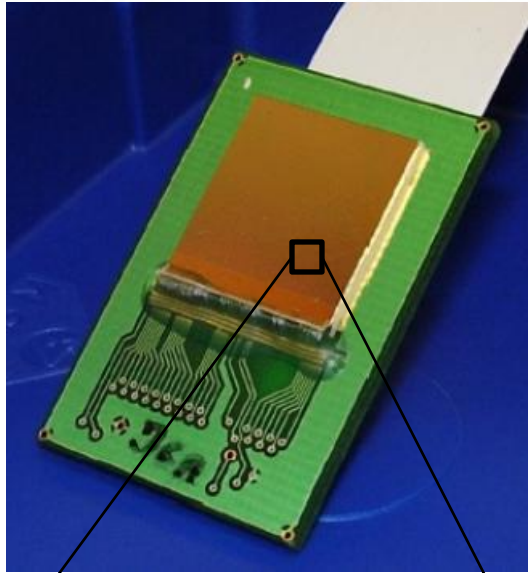
Boron



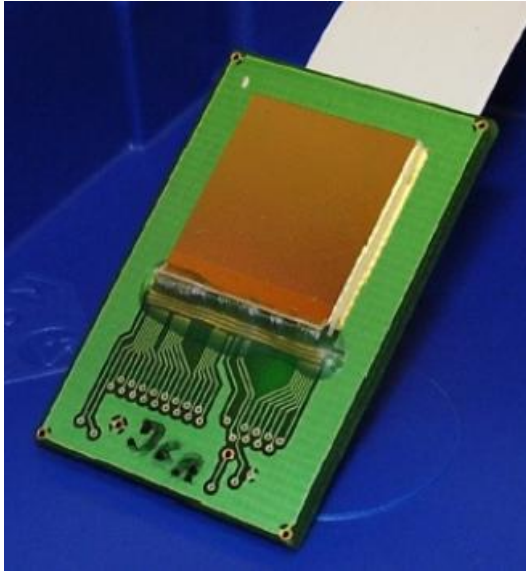
Reflector |  
Lightguide |  
Scintillator |  
Reflector



# The TimePix Chip



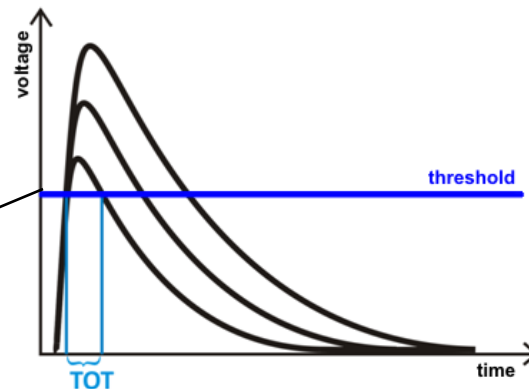
# The TimePix Chip



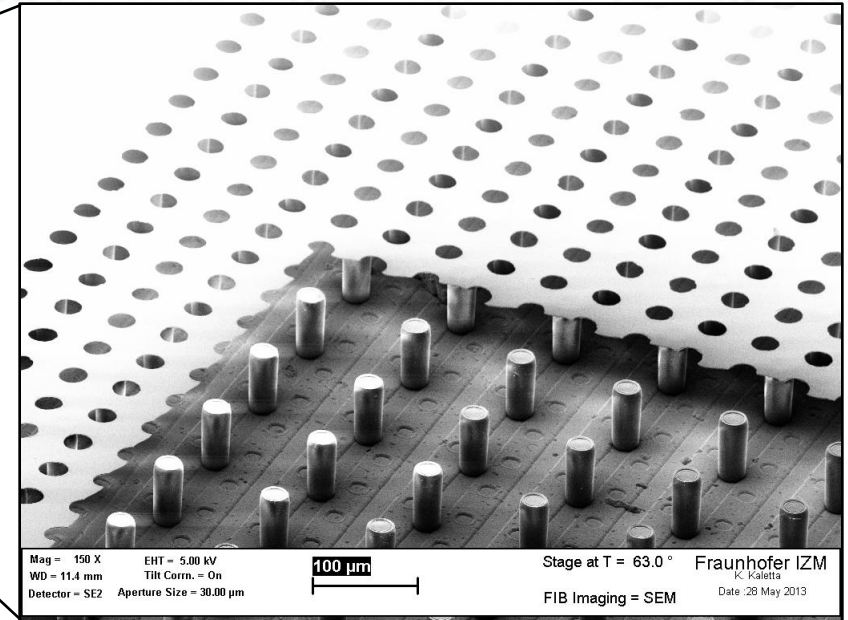
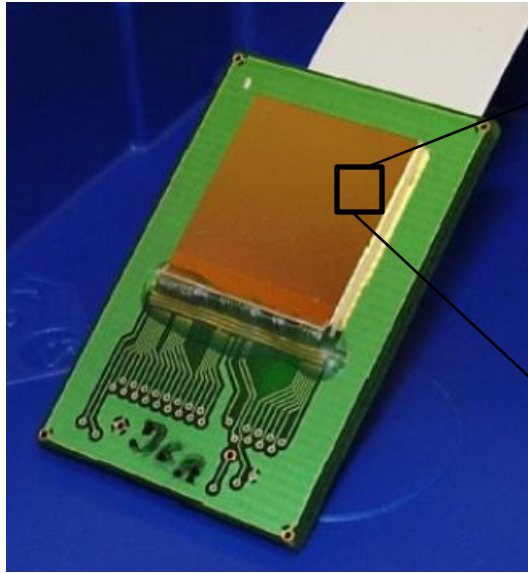
- 256 × 256 pixels @ 55 × 55  $\mu\text{m}^2$
- 1.4 × 1.4  $\text{cm}^2$
- 40 MHz clock
- ENC ca. 90  $e^-$

Modes:

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



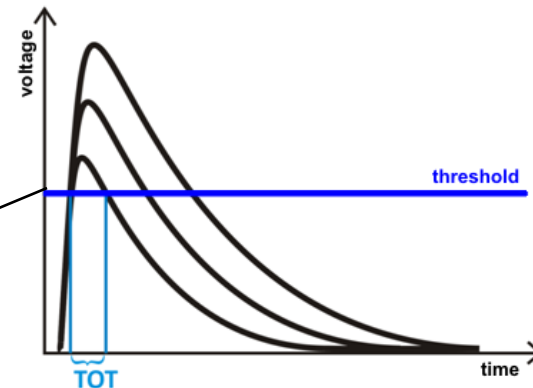
# The TimePix Chip



- 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<sup>-</sup>

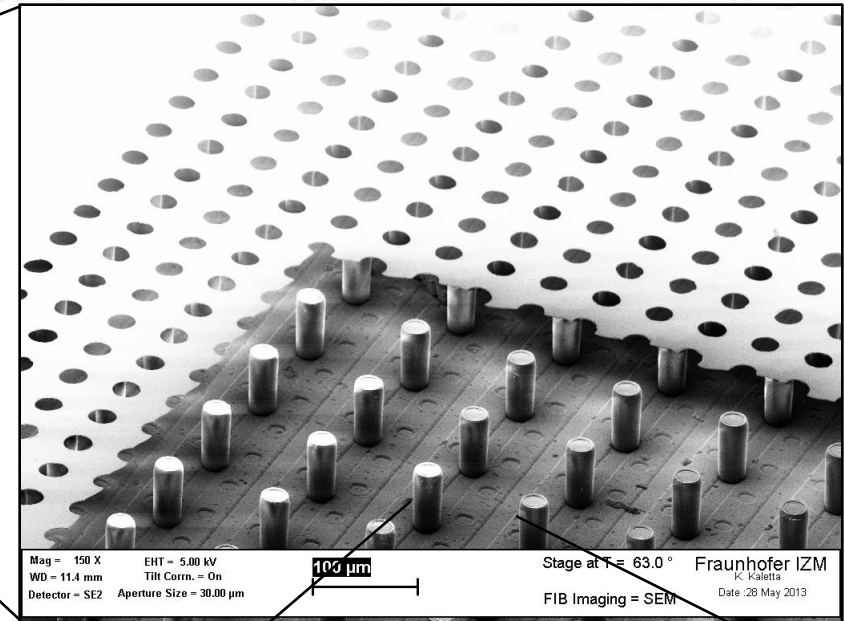
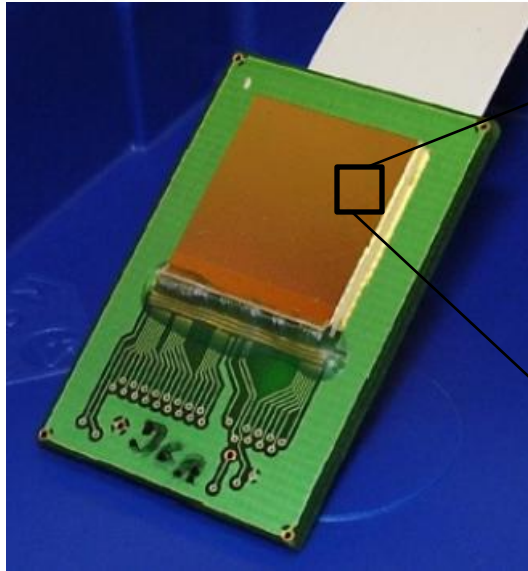
Modes:

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





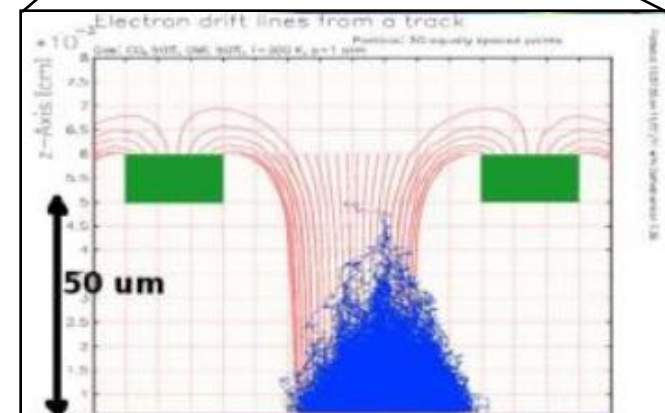
# The TimePix Chip



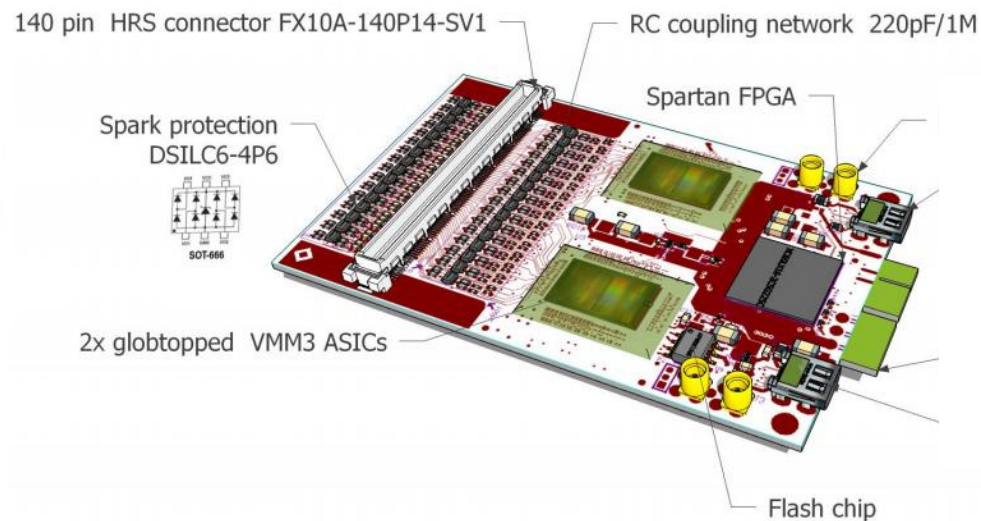
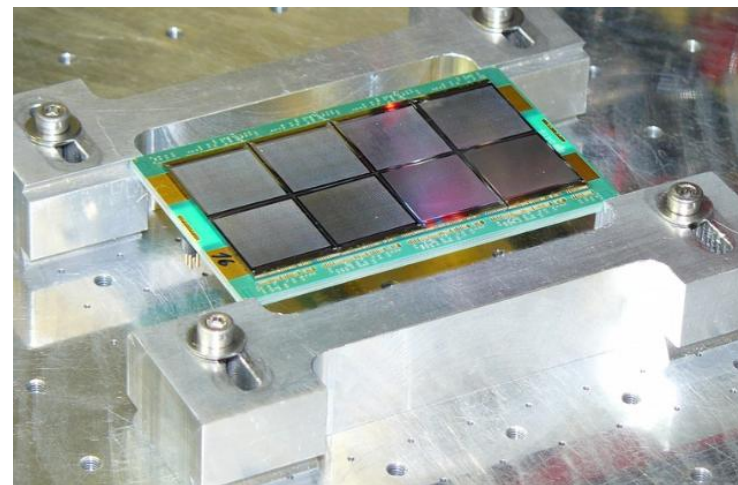
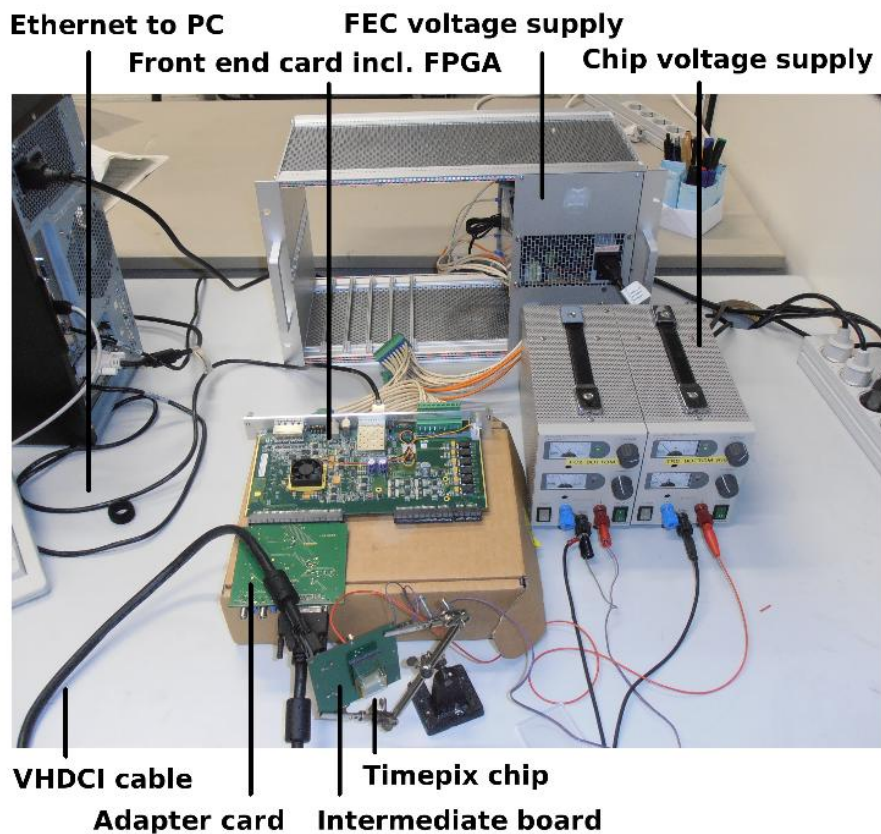
- $256 \times 256$  pixels @  $55 \times 55 \mu\text{m}^2$
- $1.4 \times 1.4 \text{ cm}^2$
- 40 MHz clock
- ENC ca.  $90 e^-$

Modes:

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



# TimePix Readout System



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

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



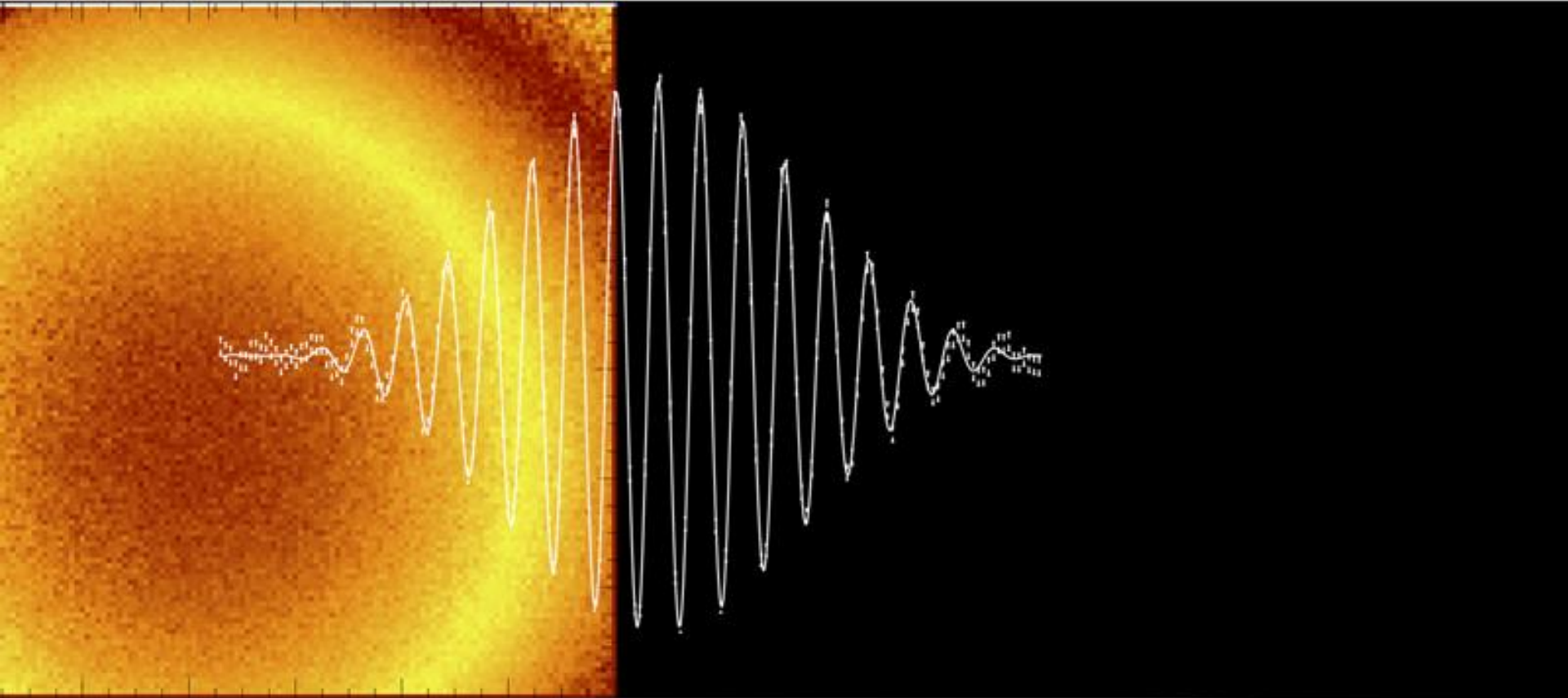
# LCTPC Event Display



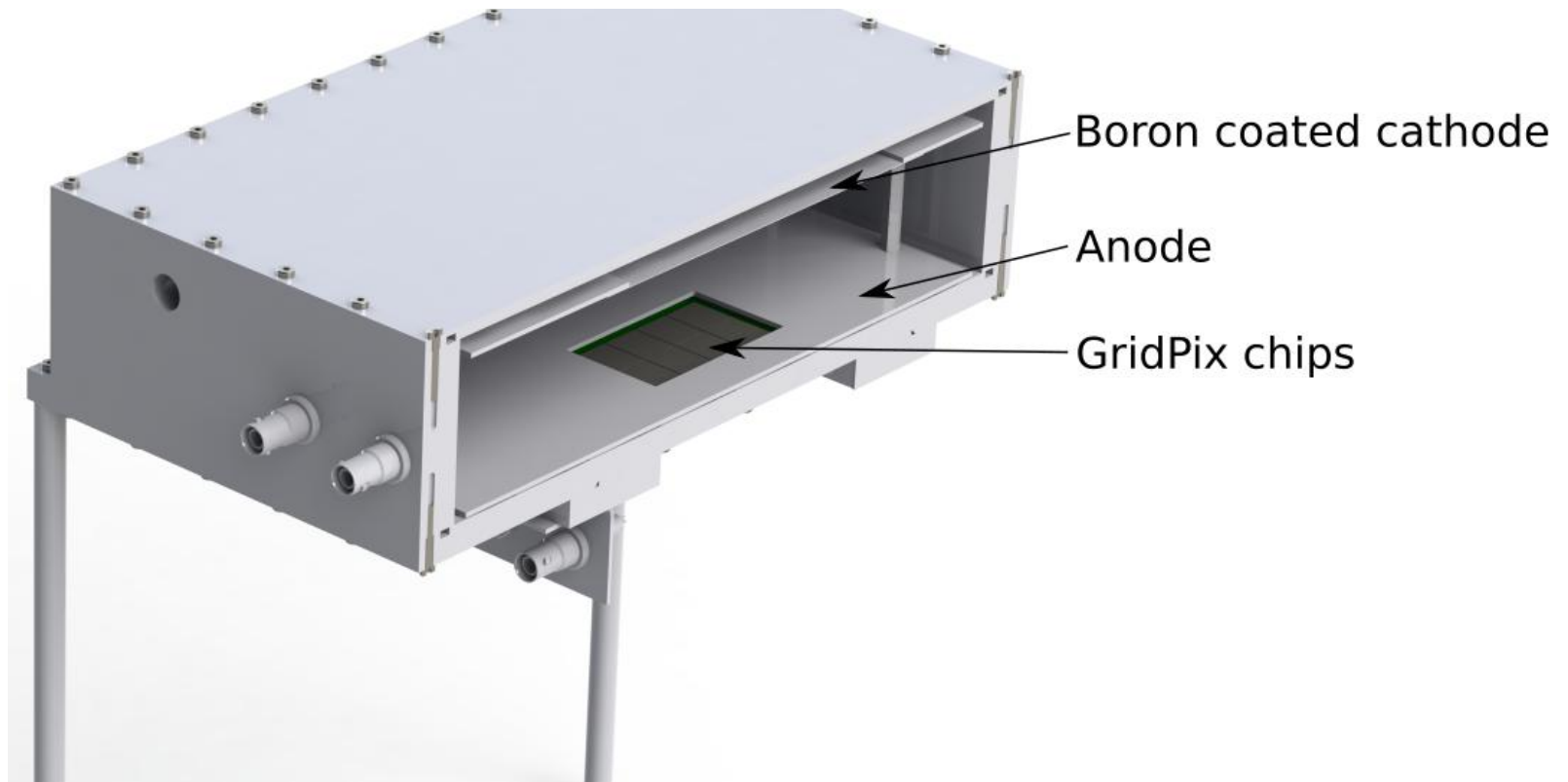
[1]

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

# |||| Neutrons

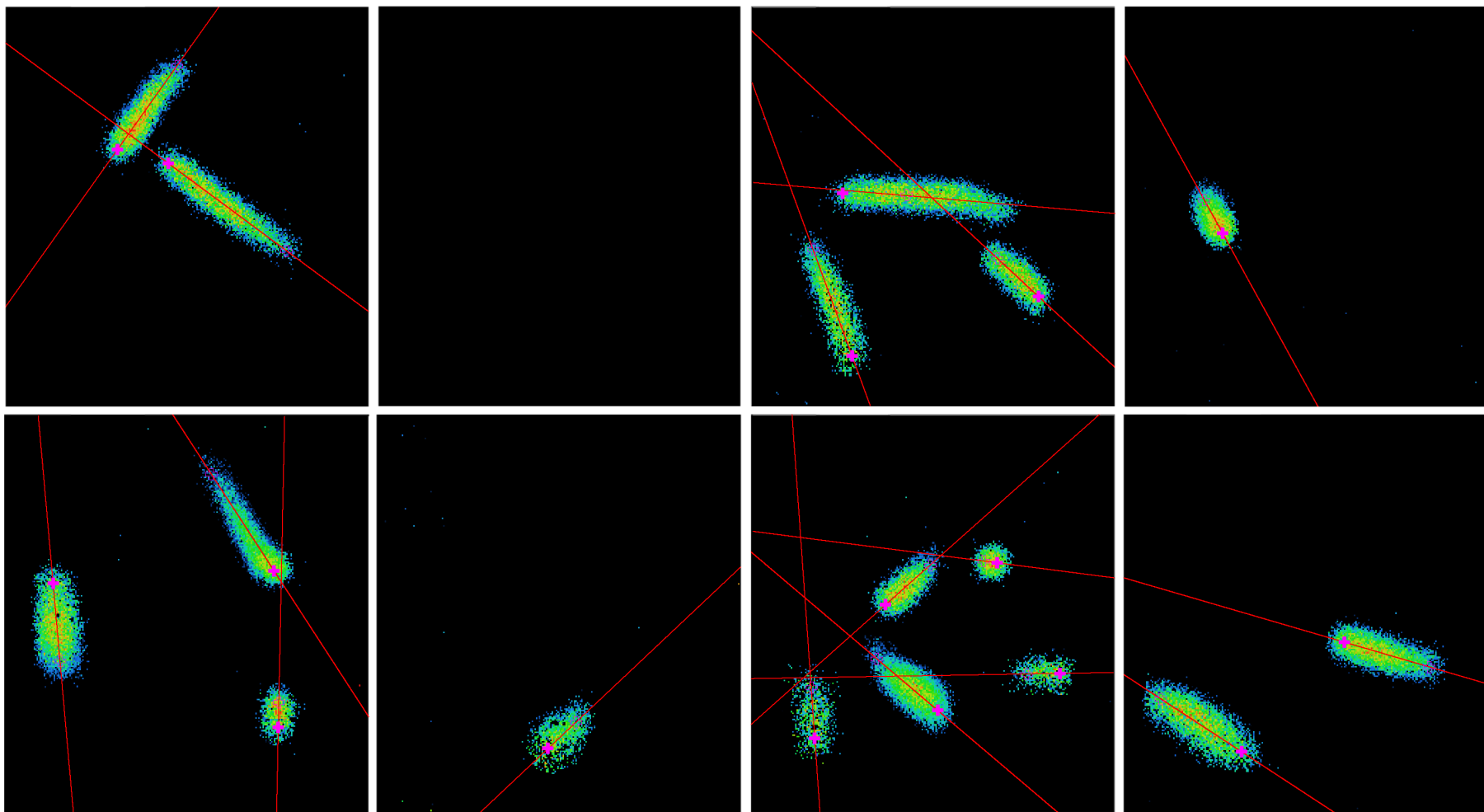


# Test Detector



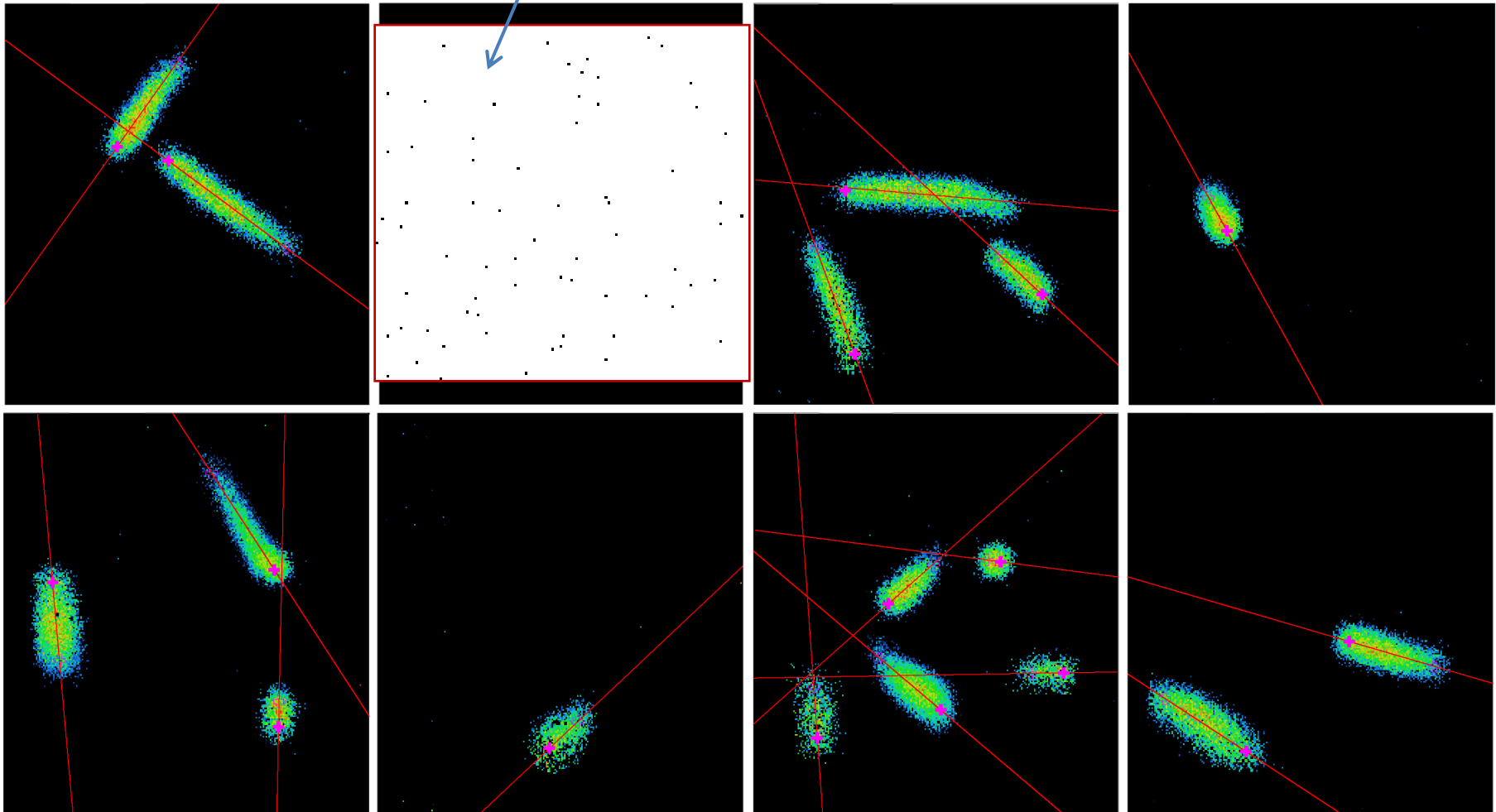


# Neutron Conversion Tracks

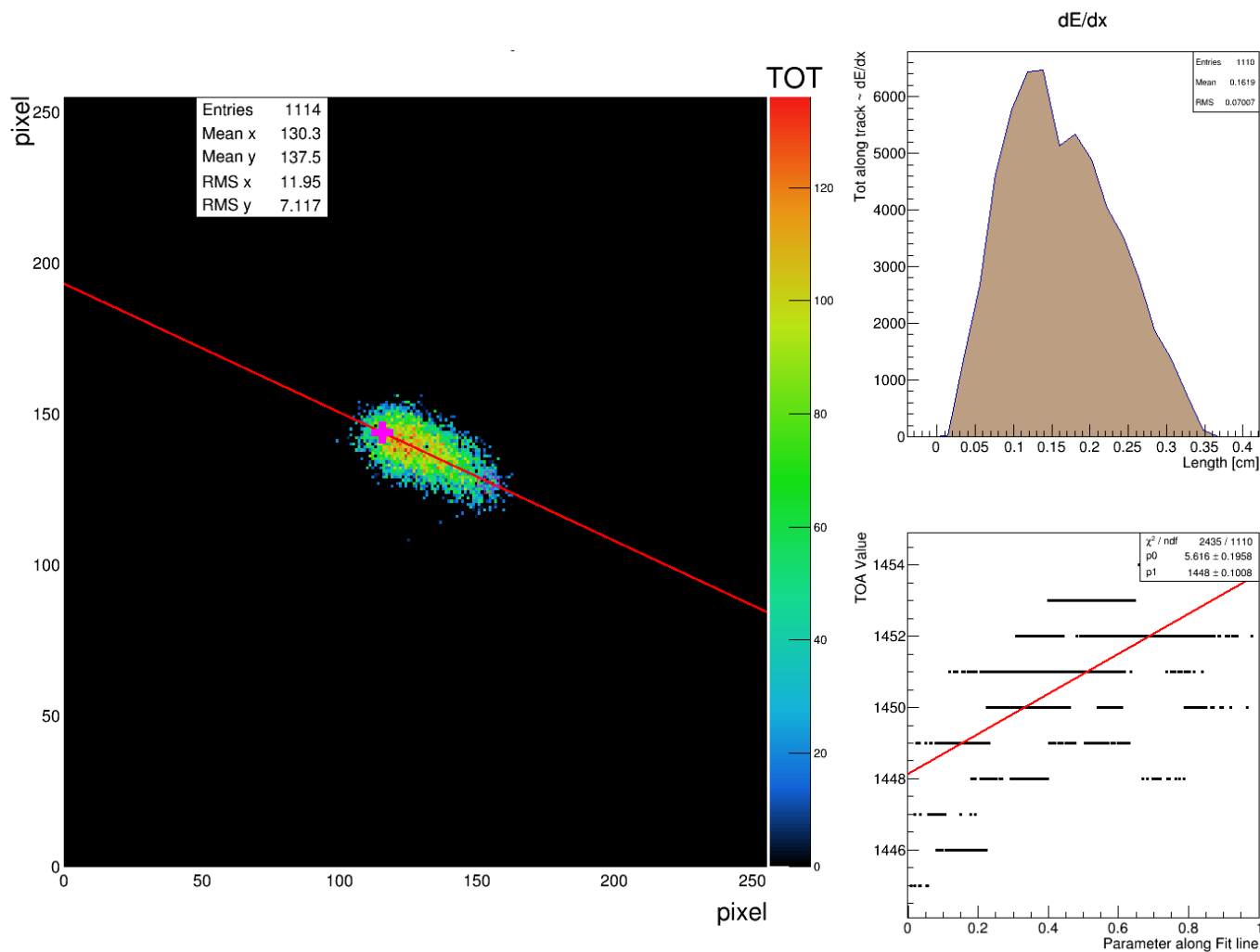


# Neutron Conversion Tracks

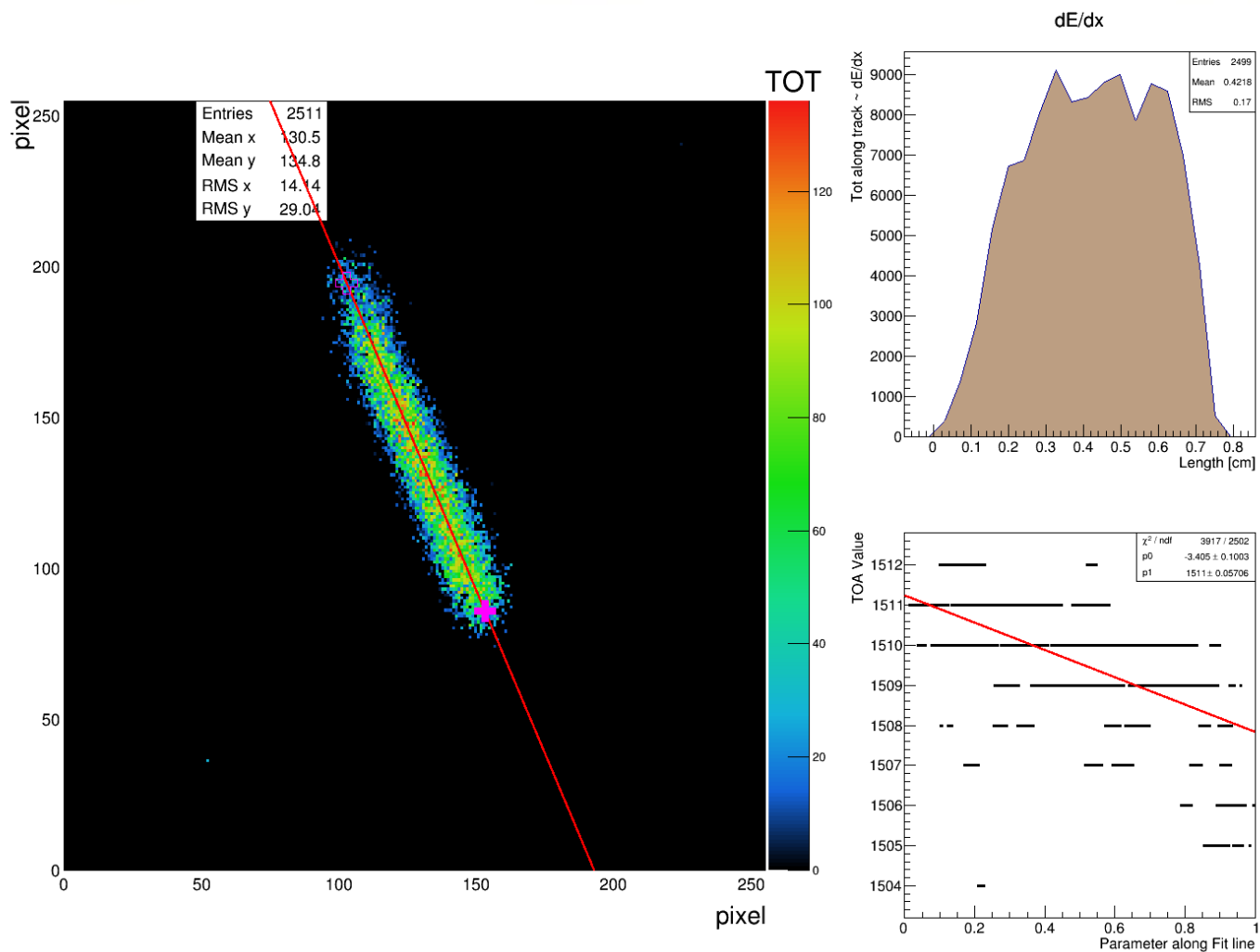
5% Time Pixel (Random Pattern)



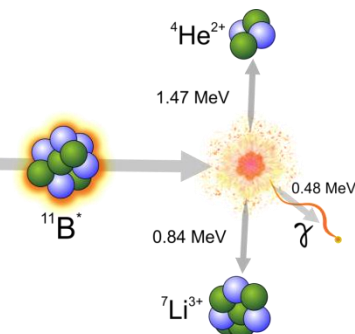
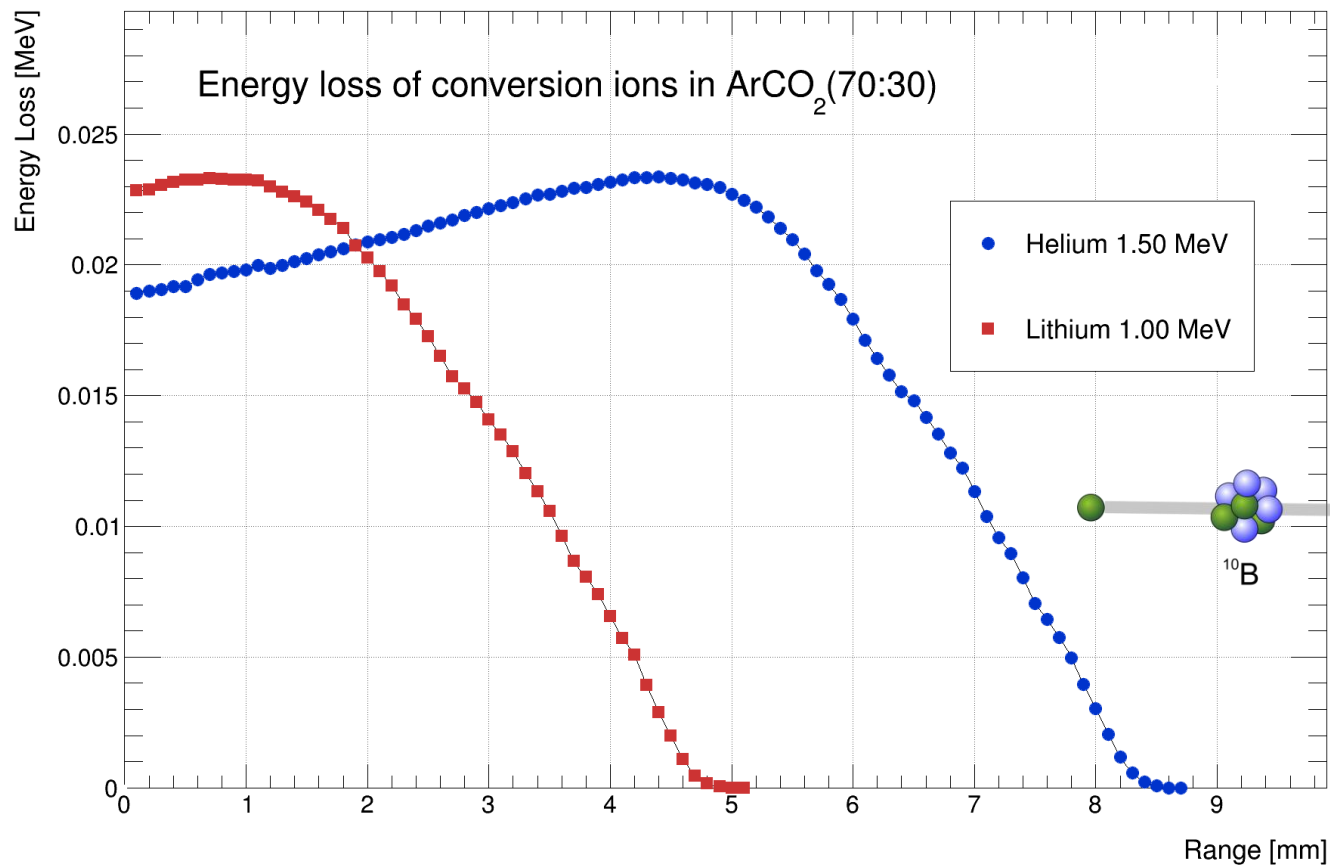
# Event Example: Lithium



# Event Example: Helium



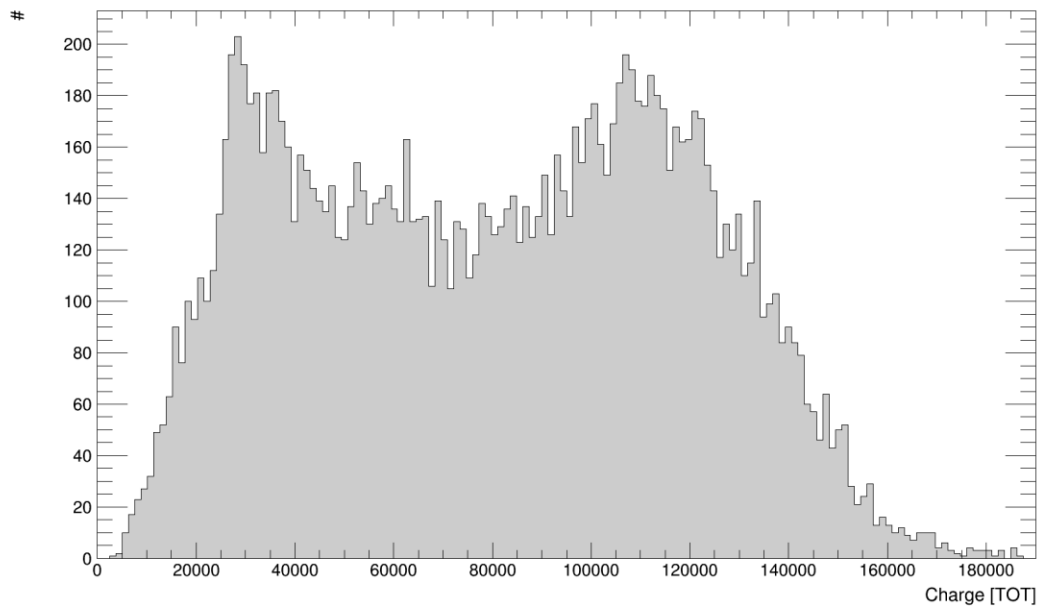
# Energy Loss in Gas



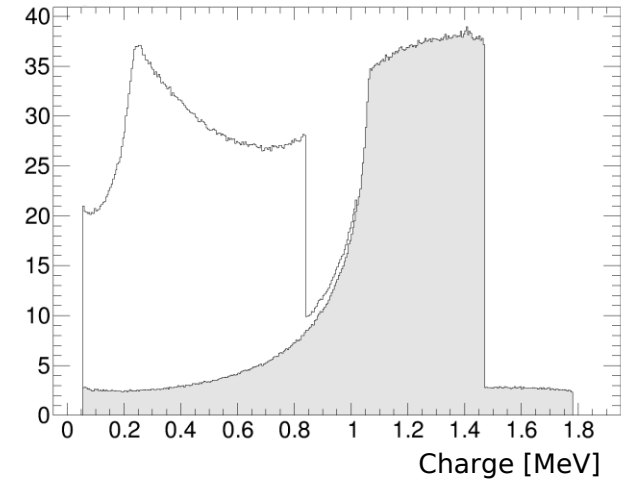


# Energy Spectrum

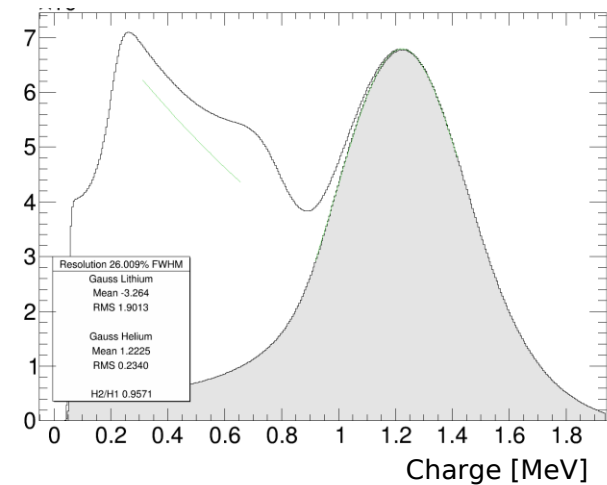
TOT Spectrum (fiducialized)



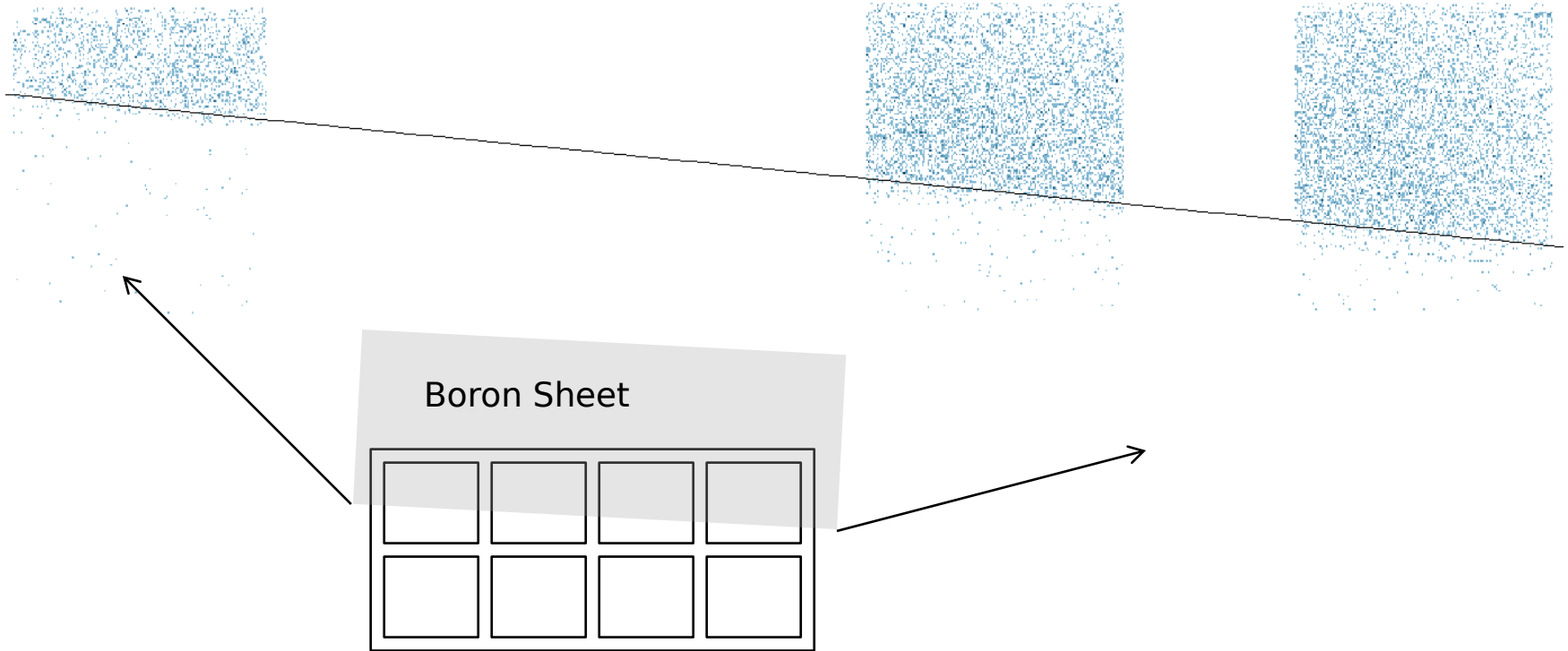
Simulation: 1  $\mu\text{m}$  Layer



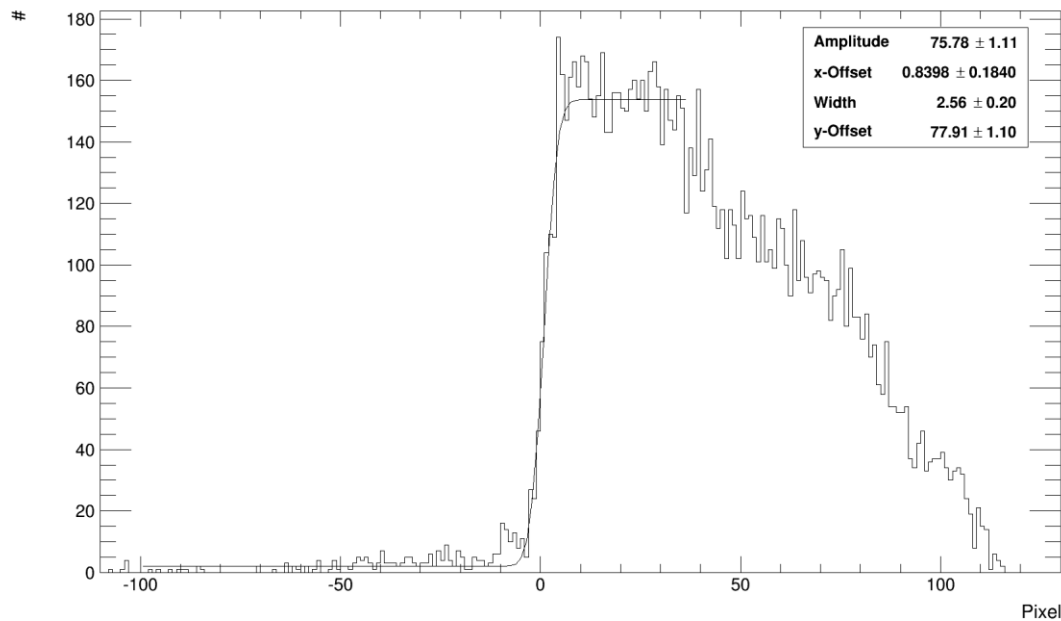
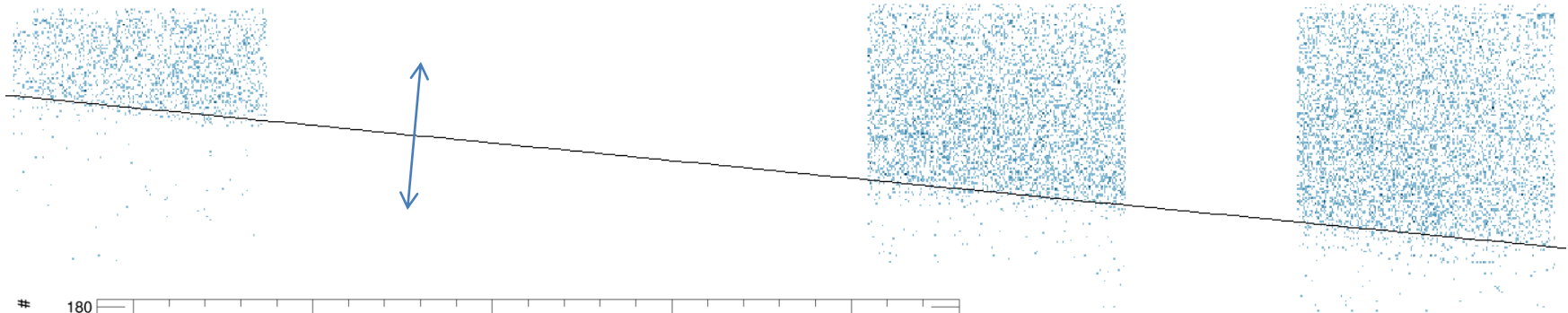
Folded with 25 % FWHM



# Spatial Resolution



# Spatial Resolution



Spatial Resolution  $\sigma$   
(140 +/- 10)  $\mu\text{m}$

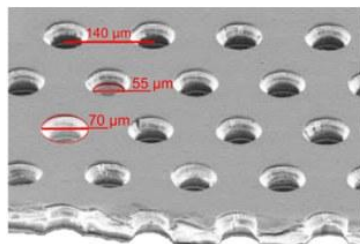
# ▶ To New Shores

## CASCADE

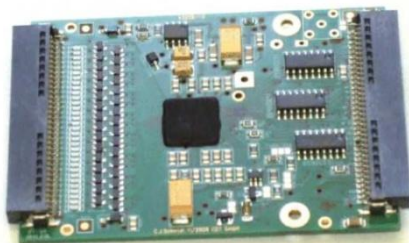
Uni Heidelberg

Technology available in 2000

GEM



CiPix  
Multichannel  
ASIC



# ▶ To New Shores

**CASCADE**  
Uni Heidelberg

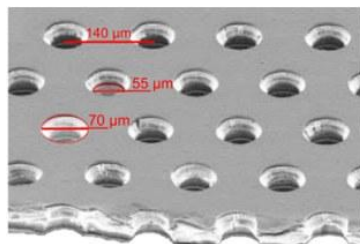


**New Project**  
Uni Bonn

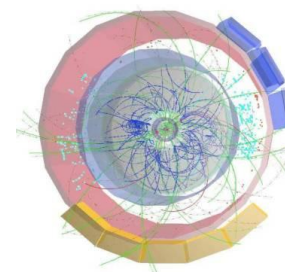
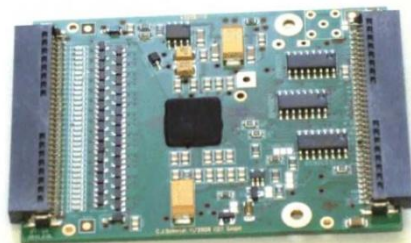
Technology available in 2000

Technology available in 2017

GEM



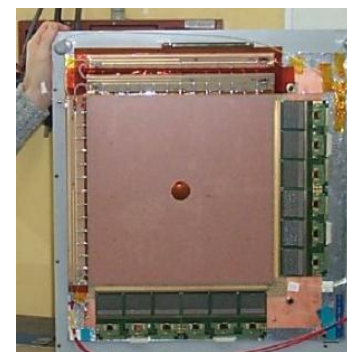
CiPix  
Multichannel  
ASIC



TPC



TimePix



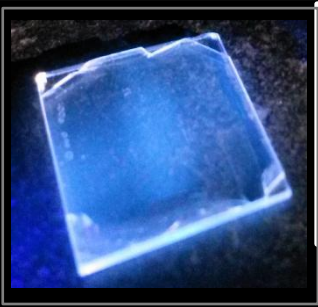
ASICs



**Markus Köhli**

Physikalisches Institut (LCTPC)

Rheinische  
Friedrich-Wilhelms-Universität  
Bonn



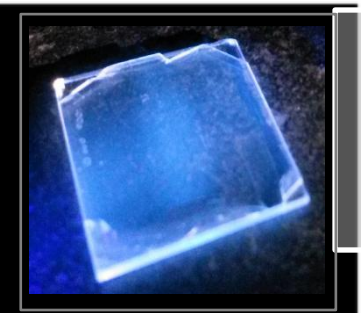
## The Neutron Time Projection Chamber

BODELAIRE

**Markus Köhli**

Physikalisches Institut (LCTPC)

Rheinische  
Friedrich-Wilhelms-Universität  
Bonn



## The Neutron Time Projection Chamber

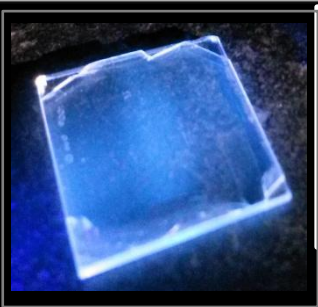
- Trigger & Track Principle

BODELAIRE

**Markus Köhli**

Physikalisches Institut (LCTPC)

Rheinische  
Friedrich-Wilhelms-Universität  
Bonn



## The Neutron Time Projection Chamber

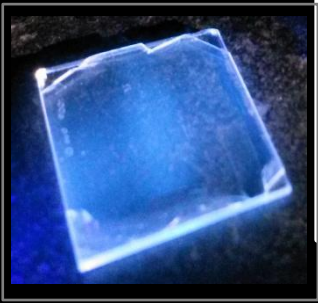
- Trigger & Track Principle
  - Using both conversion products

BODELAIRE

**Markus Köhli**

Physikalisches Institut (LCTPC)

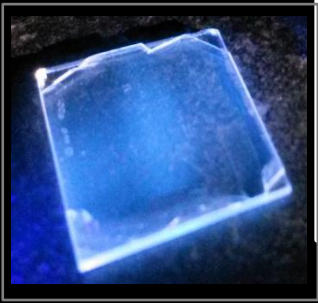
Rheinische  
Friedrich-Wilhelms-Universität  
Bonn



## The Neutron Time Projection Chamber

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

BODELAIRE



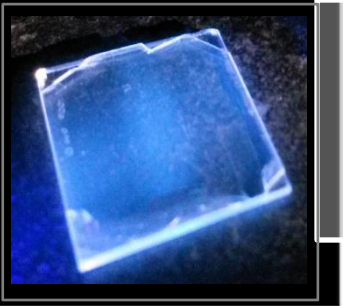
## The Neutron Time Projection Chamber

- Trigger & Track Principle

- Using both conversion products
- Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]
- [ Spatial Resolution  $\sigma$   
(140 +/- 10)  $\mu\text{m}$  ]

BODELAIRE





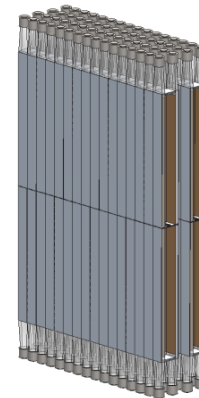
## The Neutron Time Projection Chamber

- Trigger & Track Principle

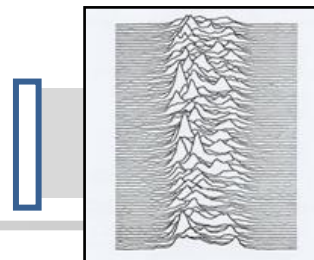
- Using both conversion products
- Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]

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

BODELAIRE



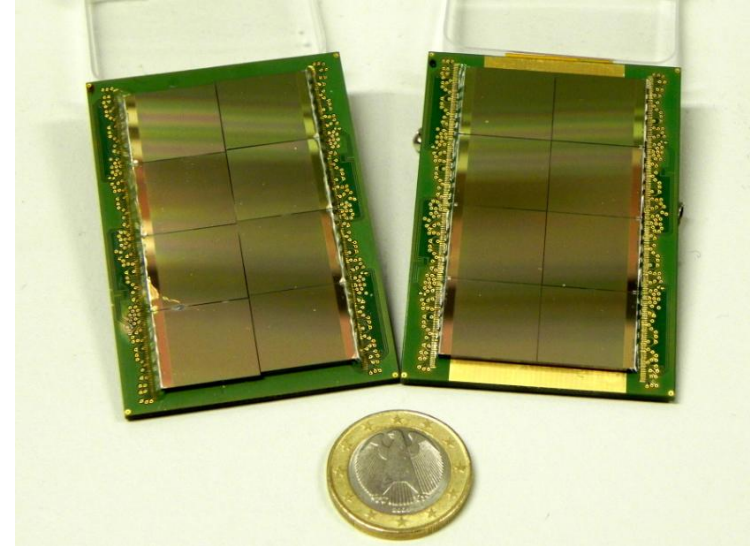
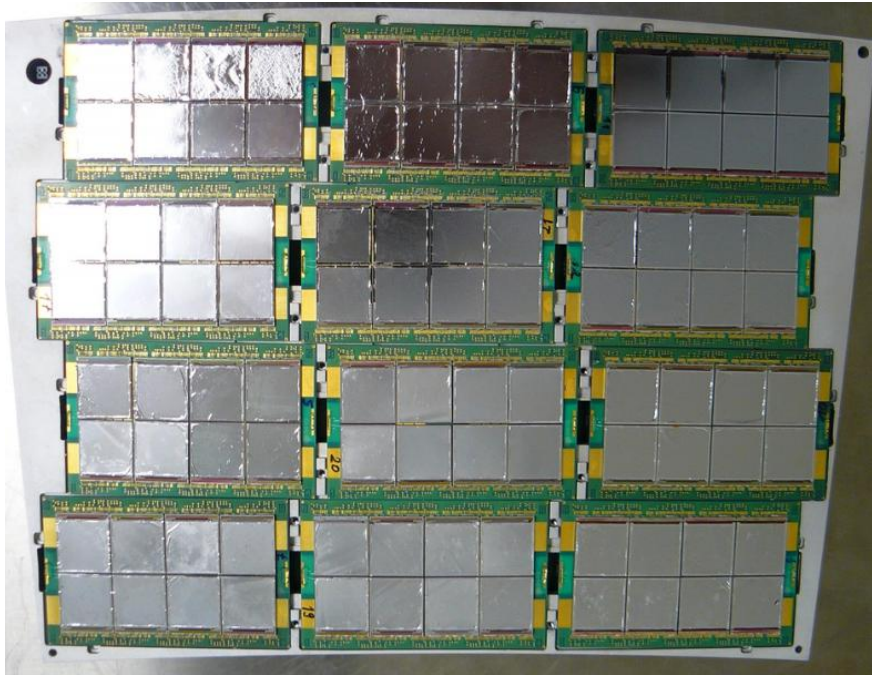
to be continued



# Backup

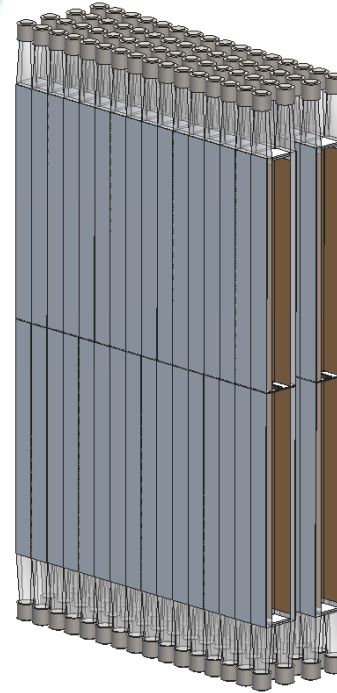


# ▶ Octoboards

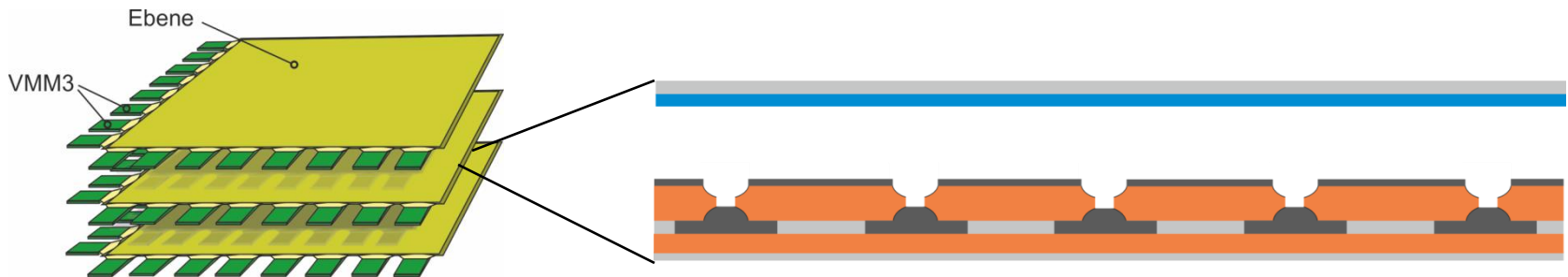


# To New Shores

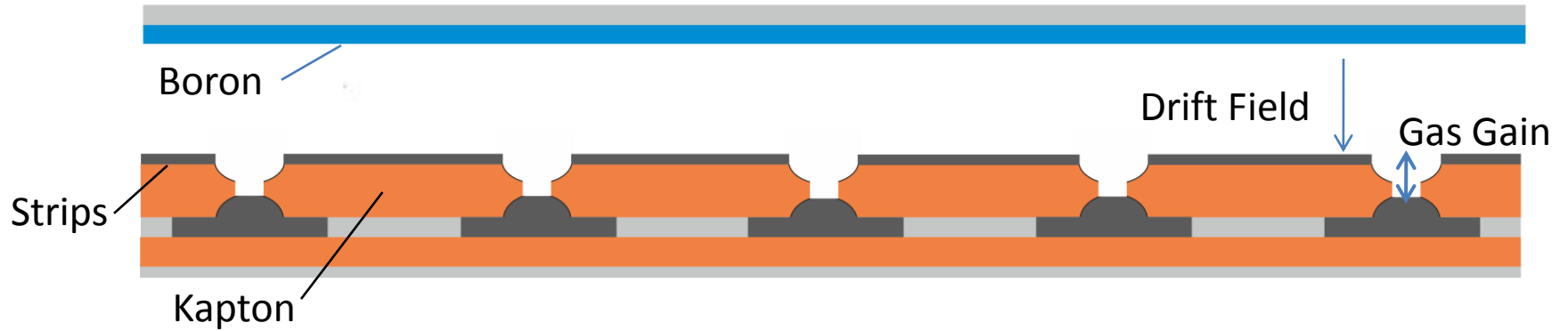
**BODELAIRE**  
High Resolution



**BASTARD**  
High Rate



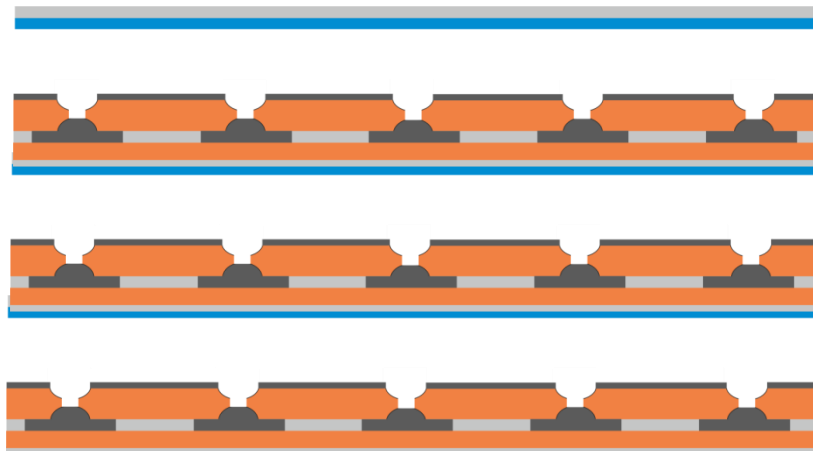
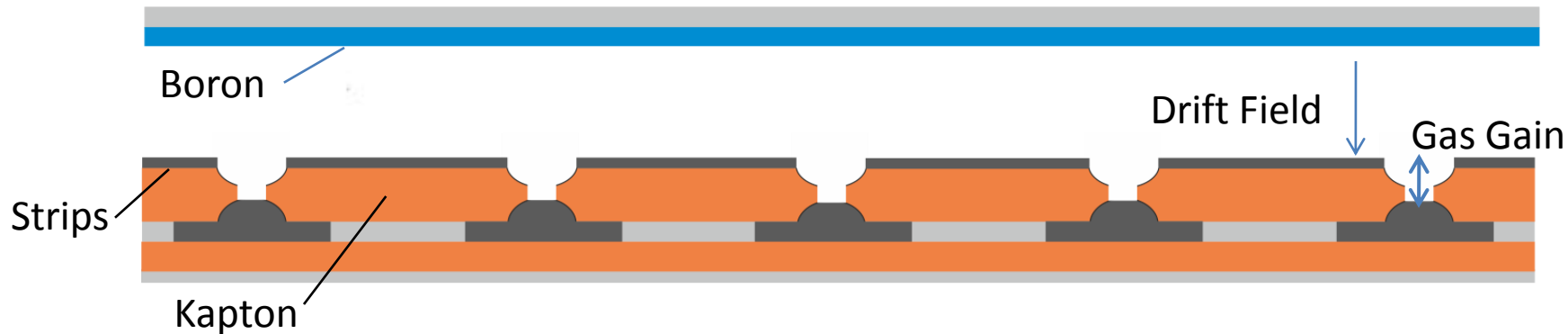
# The BASTARD System



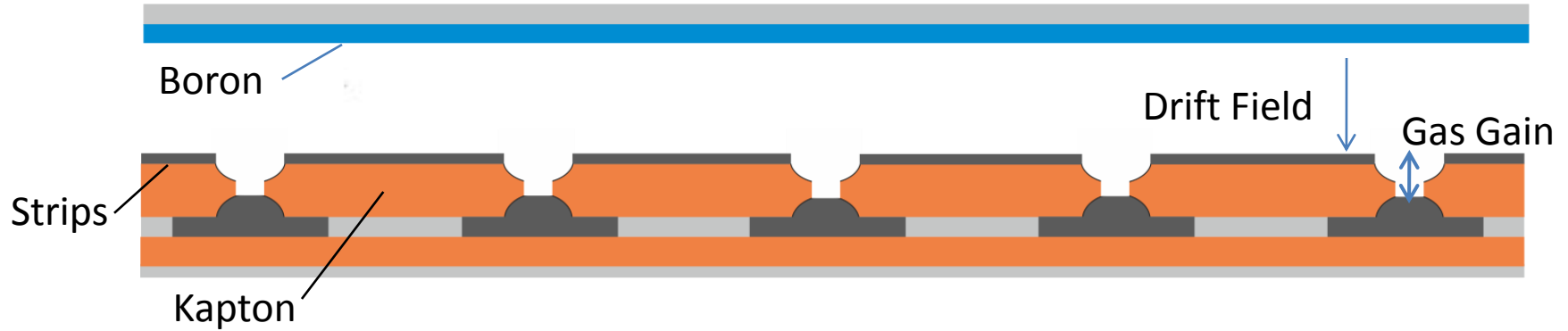




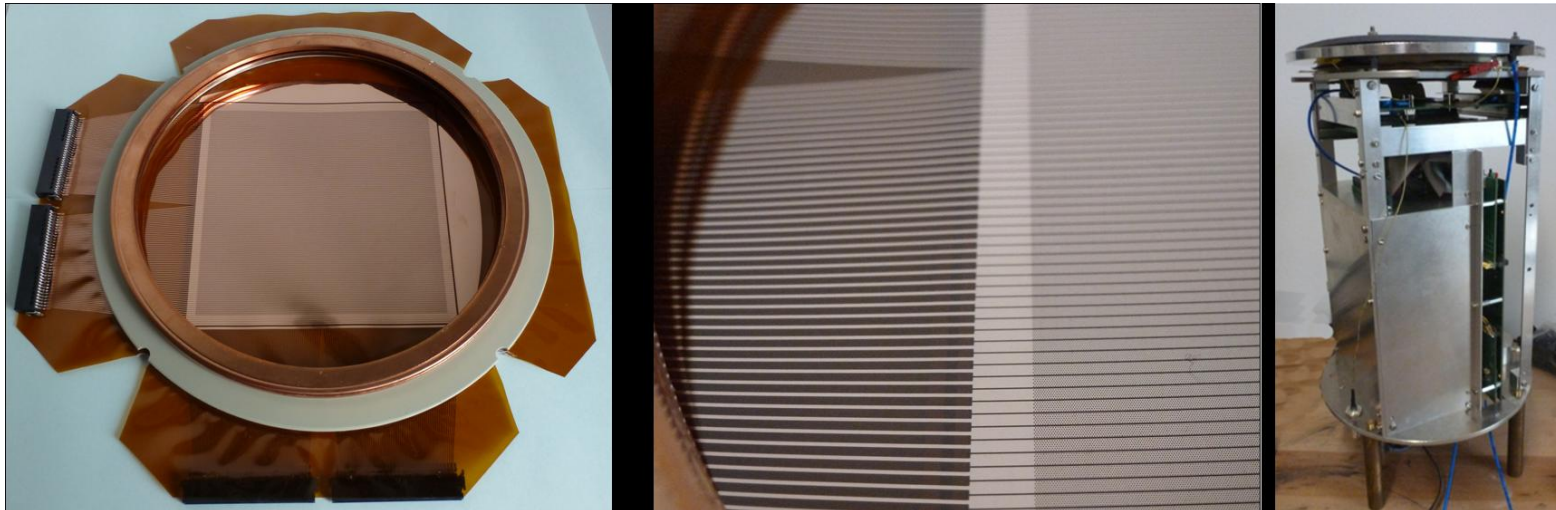
# The BASTARD System



# The BASTARD System

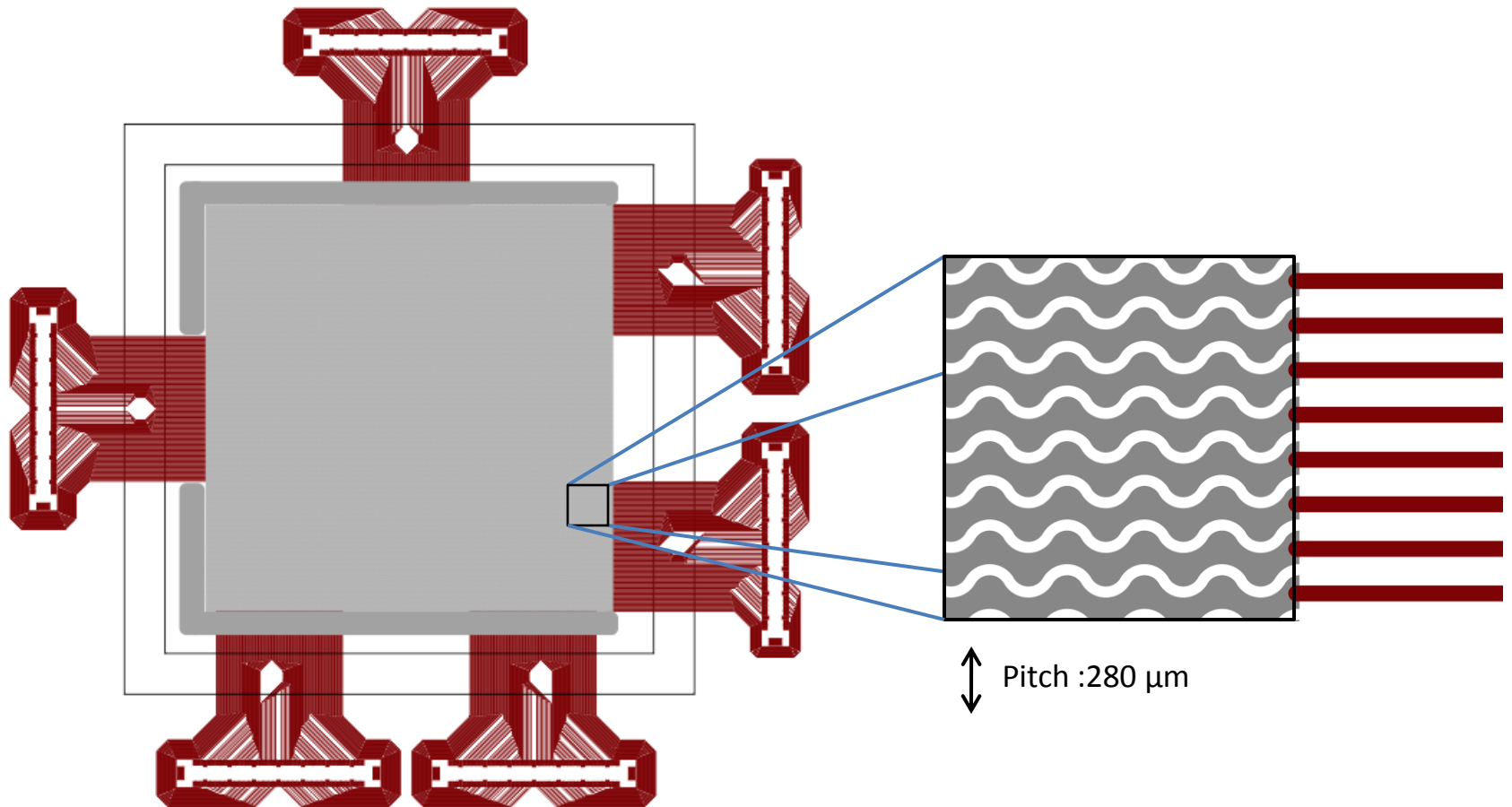


nXYter  
Prototype:



M. Liebig  
Uni HD  
2015

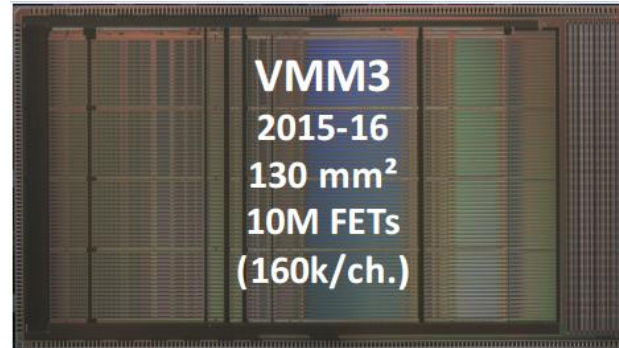
# The BASTARD System



10 cm x 10 cm

# The BASTARD System

VMM1 2011/12 → VMM2 2013/14 →



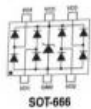
- 4 MHz/ch
- 10bit ADC
- self triggered
- 400 e- noise
- 1 ns time resolution

[1]

140 pin HRS connector FX10A-140P14-SV1

RC coupling network 220pF/1M

Spark protection DSILC6-4P6



Spartan FPGA

MMCX GND and neighborhood connector

Master HDMI

2x globtopped VMM3 ASICs

IPL1 3 pin power connector

Slave HDMI

[2]

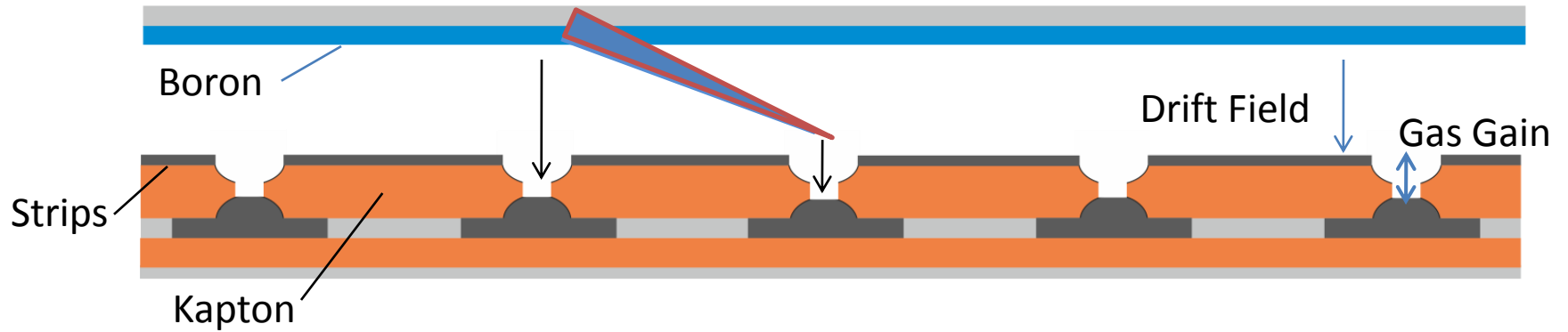
Flash chip

[1] G. Iakovidis, RD51 MiniWeek CERN, Feb. 2017

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

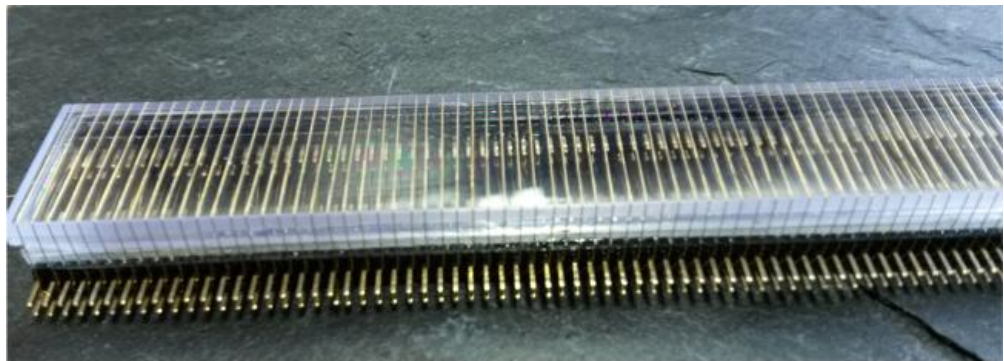


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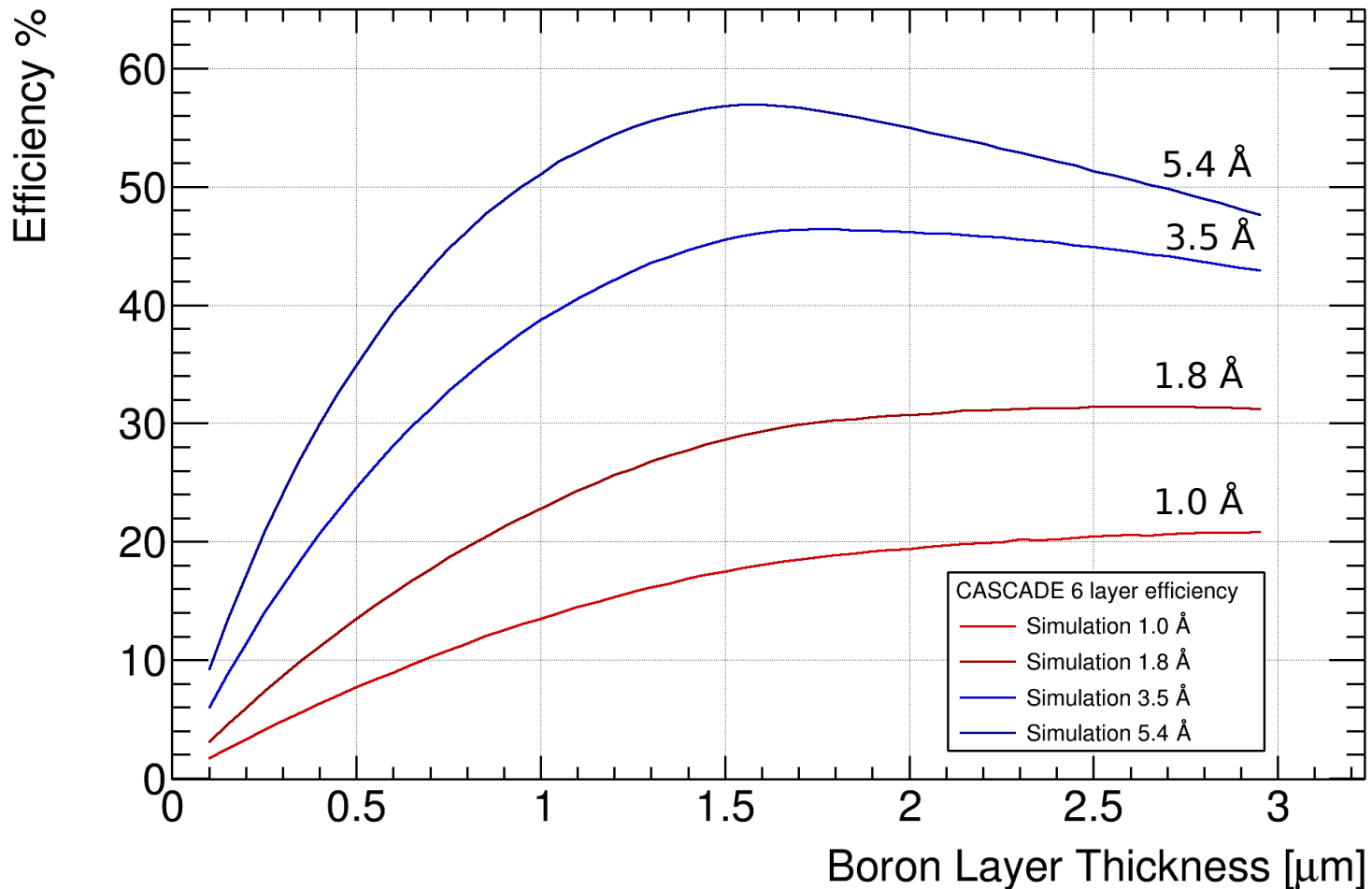


# ▶ Scintillator Slab



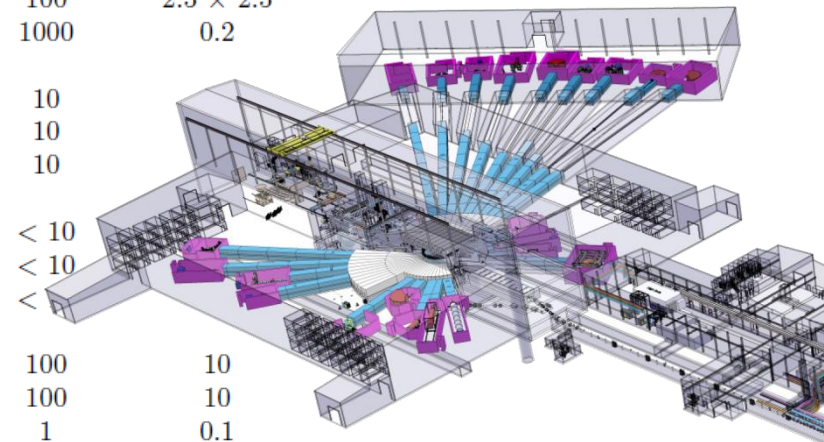
# Detection Efficiency

Simulation of the 2D efficiency with different coating thicknesses



# ESS Instrumentation

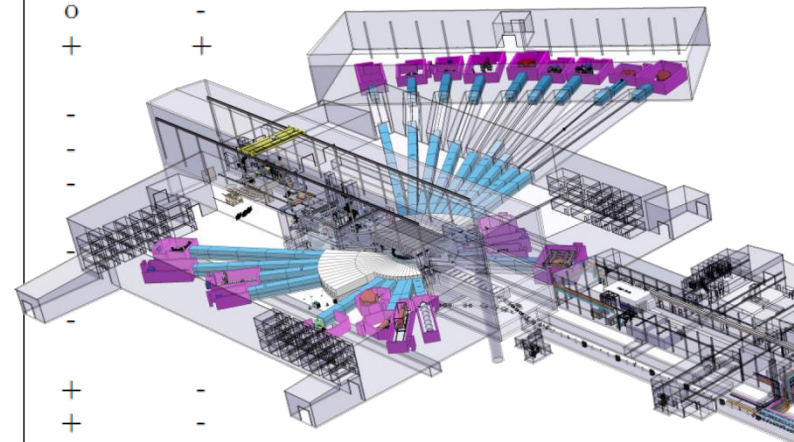
Instrument	Detector area [m <sup>2</sup> ]	Wavelength range [Å]	Time resolution [μs]	Spatial resolution [mm]
Multi-purpose imaging	0.5	1 - 20	1	0.001 - 0.5
General purpose polarised SANS	5	4 - 20	100	10
Broad-band small sample SANS	14	2 - 20	100	1
Surface scattering	5	4 - 20	100	10
Horizontal reflectometer	0.5	5 - 30	100	1
Vertical reflectometer	0.5	5 - 30	100	1
Thermal powder diffractometer	20	0.6 - 6	< 10	2 × 2
Bi-spectral powder diffractometer	20	0.8 - 10	< 10	2.5 × 2.5
Pulsed monochromatic powder diffractom.	4	0.6 - 5	< 100	2 × 5
Material science & engineering diffractom.	10	0.5 - 5	10	2
Extreme conditions instrument	10	1 - 10	< 10	3 × 5
Single crystal magnetism diffractometer	6	0.8 - 10	100	2.5 × 2.5
Macromolecular diffractometer	1	1.5 - 3.3	1000	0.2
Cold chopper spectrometer	80	1 - 20	10	
Bi-spectral chopper spectrometer	50	0.8 - 20	10	
Thermal chopper spectrometer	50	0.6 - 4	10	
Cold crystal-analyser spectrometer	1	2 - 8	< 10	
Vibrational spectroscopy	1	0.4 - 5	< 10	
Backscattering spectrometer	0.3	2 - 8	<	
High-resolution spin echo	0.3	4 - 25	100	10
Wide-angle spin echo	3	2 - 15	100	10
Fundamental & particle physics	0.5	5 - 30	1	0.1
<b>Total</b>	<b>282.6</b>			



ESS TDR 2013

# ESS Instrumentation

Instrument	<sup>10</sup> B thin films		Detector technology			Micropattern	
	⊥	∥	WSF	Anger	<sup>3</sup> He	Rate	Resolution
Multi-purpose imaging	-	-	-	-	-	0	+
General purpose polarised SANS	0	+	-	+	0	+	-
Broad-band small-sample SANS	0	+	-	+	-	+	-
Surface scattering	0	+	-	+	0	+	-
Horizontal reflectometer	-	0	-	+	+	0	-
Vertical reflectometer	-	0	-	+	+	0	-
Thermal powder diffractometer	0	+	+	-	-	0	-
Bi-spectral powder diffractometer	0	+	+	-	-	0	-
P-M powder diffractometer	0	+	+	-	-	0	-
MS engineering diffractometer	0	+	+	-	-	0	-
Extreme conditions diffractometer	0	+	+	-	-	0	-
Single crystal diffractometer	0	+	+	-	-	0	-
Macromolecular diffractometer	-	0	0	0	-	+	+
Cold chopper spectrometer	+	0	0	-	-	-	-
Bi-spectral chopper spectrometer	+	+	0	-	-	-	-
Thermal chopper spectrometer	+	+	+	-	-	-	-
Cold crystal analyser spectrometer	-	0	-	+	+	-	-
Vibrational spectrometer	-	0	-	0	+	-	-
Backscattering spectrometer	-	0	-	+	+	-	-
High-resolution spin echo	-	0	-	0	+	+	-
Wide-angle spin echo	-	0	-	0	+	+	-
Fundamental & particle physics	-	-	-	-	+	+	+



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