Bundesministerium
für Bildung
und Forschung

High Resolution Neutron Detection

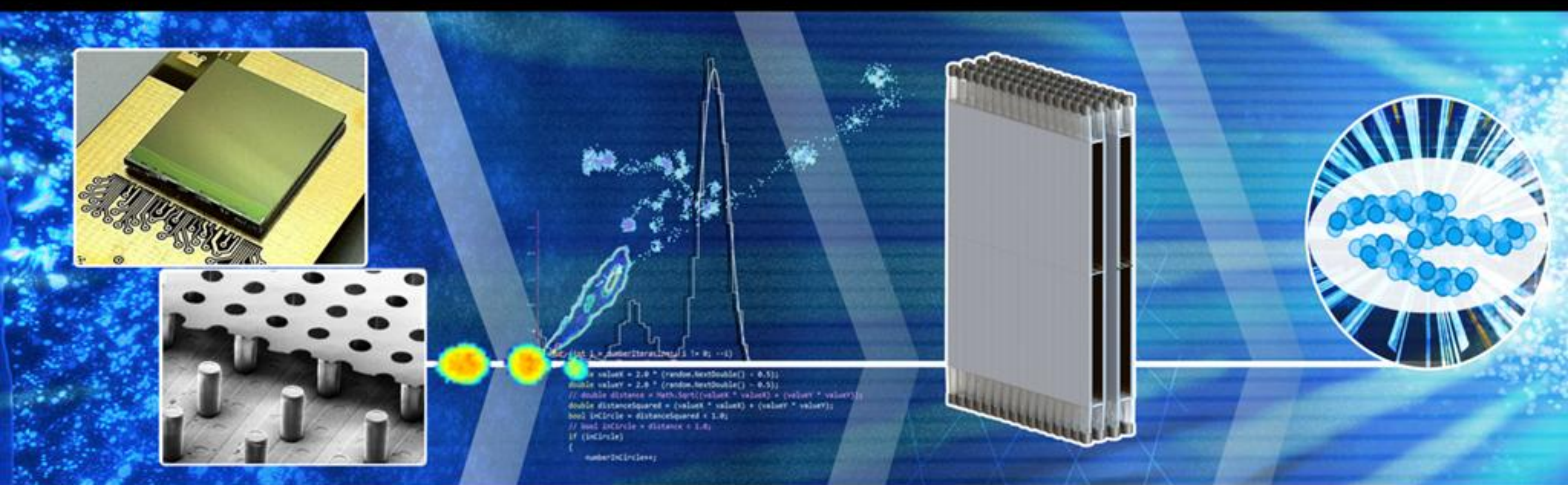
DPG Würzburg 2018
19.03.2018

universitätbonn

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

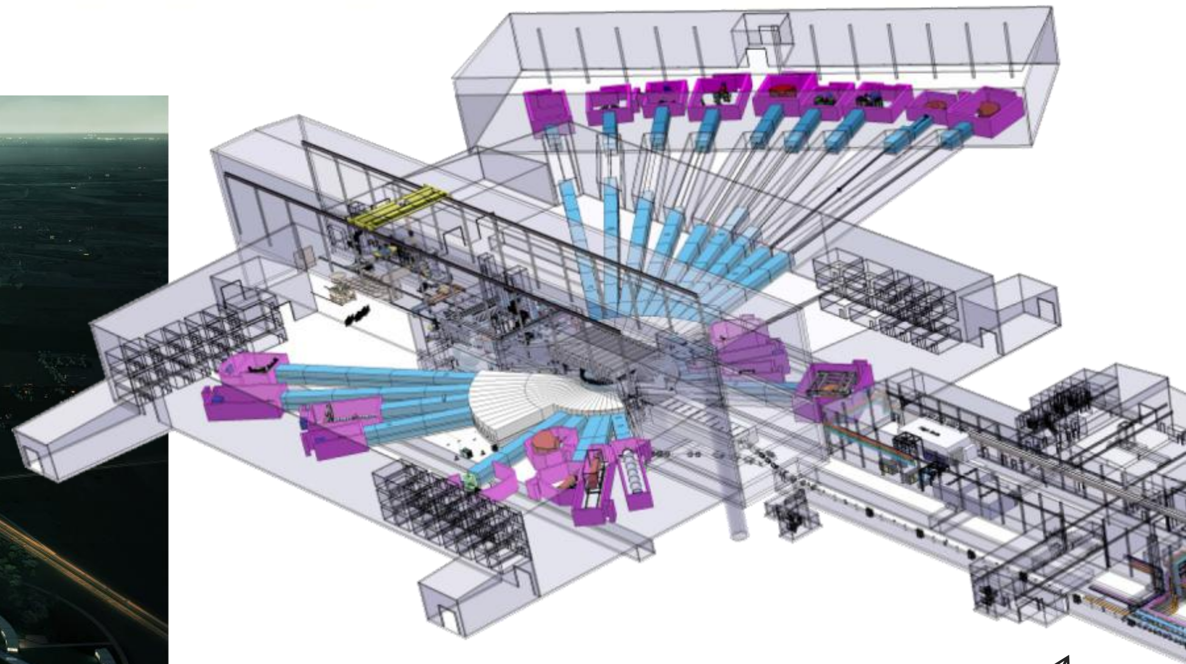
Markus Köhli

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



ESS Neutron Scattering Facility

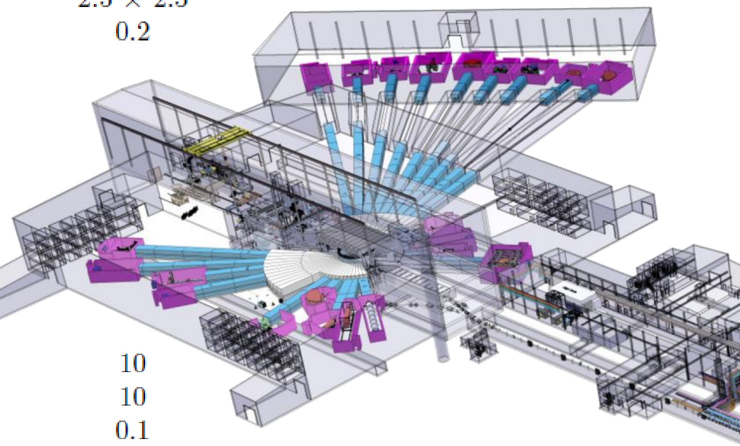
ESS TDR 2013
Lund, Sweden



Linear Accelerator
2 GeV
3 ms Pulse
62.5 mA

ESS Instrumentation

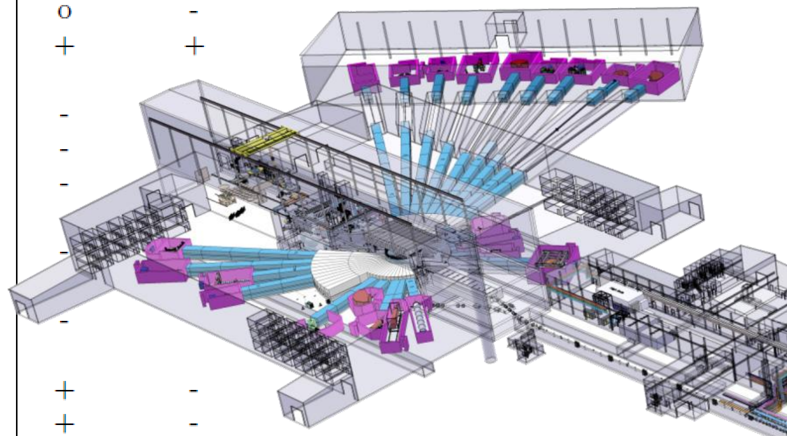
Instrument	Detector area [m^2]	Wavelength range [Å]	Time resolution [μs]	Spatial resolution [mm]
Multi-purpose imaging	0.5	1 - 20	1	0.001 - 0.5
General purpose polarised SANS	5	4 - 20	100	10
Broad-band small sample SANS	14	2 - 20	100	1
Surface scattering	5	4 - 20	100	10
Horizontal reflectometer	0.5	5 - 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
Total	**282.6**			



ESS TDR 2013

ESS Instrumentation

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



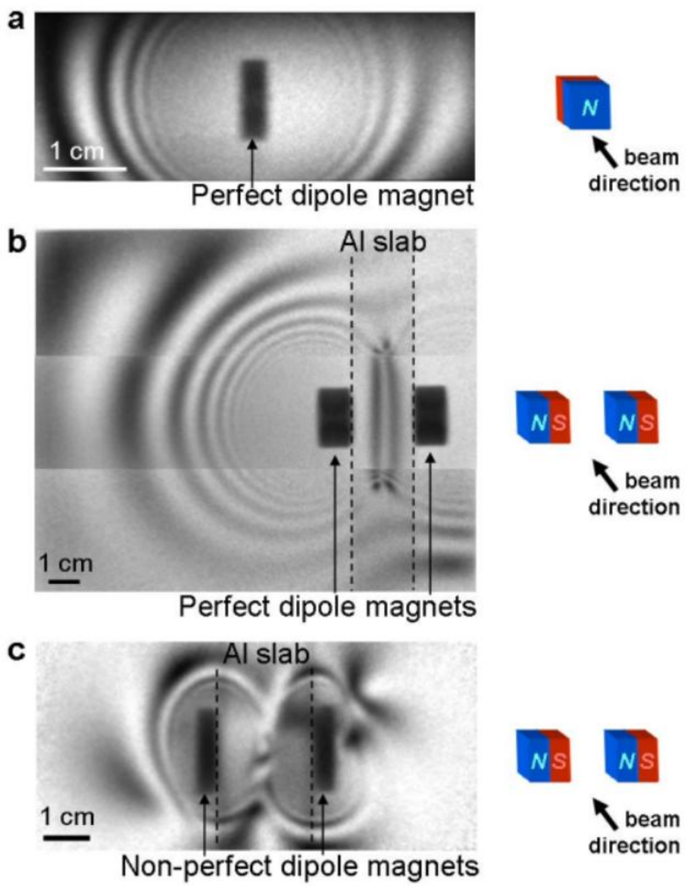
ESS TDR 2013

Neutron Examples

[2]

[1] Nikolay Kardjilov et al., Three-dimensional imaging of magnetic fields with polarised neutrons , Nature Physics 4(5), 399–403 (2008)
[2] https://www.psi.ch/media/the-characteristics-and-capabilities-of-neutrons
[3] Z. Ibrahim et al. **Time-resolved neutron scattering provides new insight into protein substrate processing by a AAA+ unfoldase,** Sci Rep. 2017; 7: 40948.

Neutron Examples



[1]

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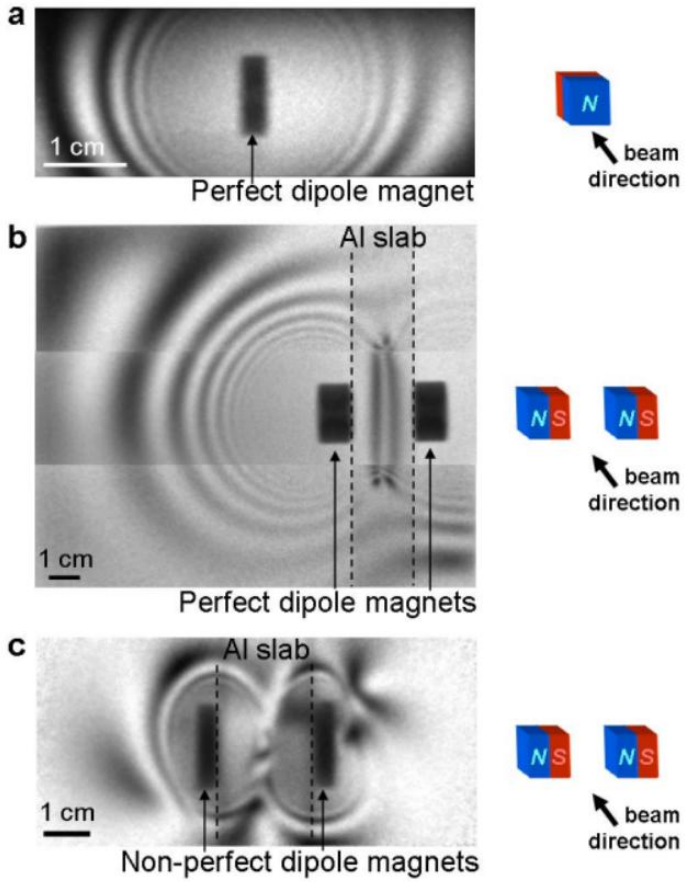
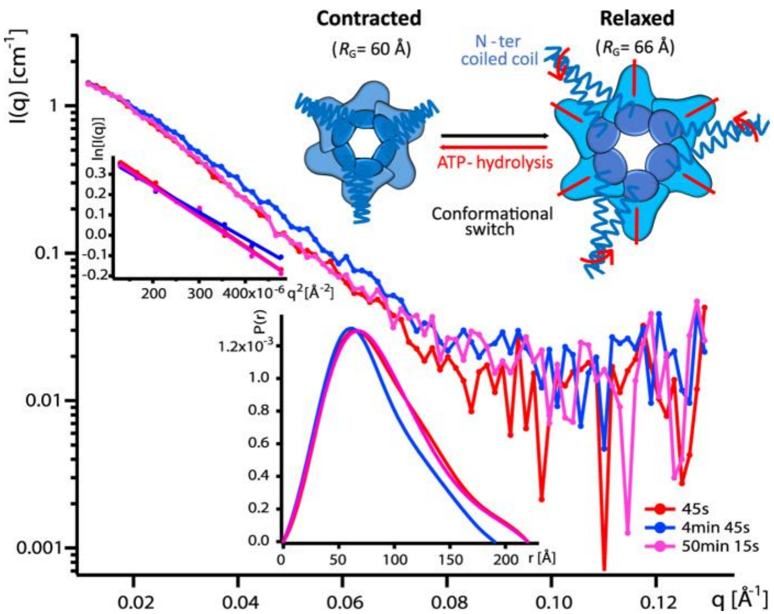
Neutron Examples



[1]

[2]



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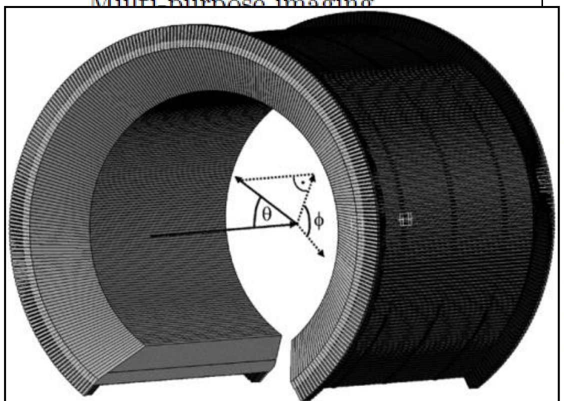
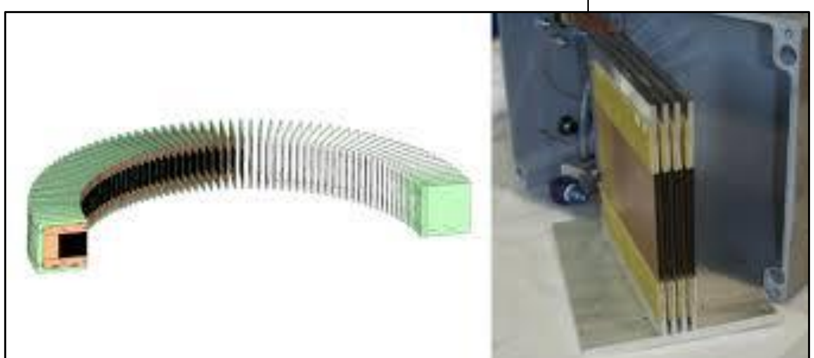
ESS Instrumentation

Instrument	^{10}B thin films ⊥	^{10}B thin films ∥	Scintillators WSF	Scintillators Anger	^{3}He	Micropattern Rate	Micropattern Resolution
Multi-purpose imaging	-	-	-	-	-	o	+
	o	+	-	+	o	+	-
	o	+	-	+	-	+	-
	o	+	-	+	o	+	-
	-	o	-	+	+	o	-
	-	o	-	+	+	o	-
	o	+	+	-	-	o	-
	o	+	+	-	-	o	-
	o	+	+	-	-	o	-
	o	+	+	-	-	o	-
Extreme conditions diffractometer	o	+	+	-	-	o	-
Single crystal diffractometer	o	+	+	-	-	o	-
Macromolecular diffractometer	-	o	o	o	-	+	+
			o	-	-	-	-
			o	-	-	-	-
			+	-	-	-	-
			-	+	+	-	-
			-	o	+	-	-
			-	+	+	-	-
			-	o	+	+	-
			-	o	+	+	-
Fundamental & particle physics	-	-	-	-	+	+	+





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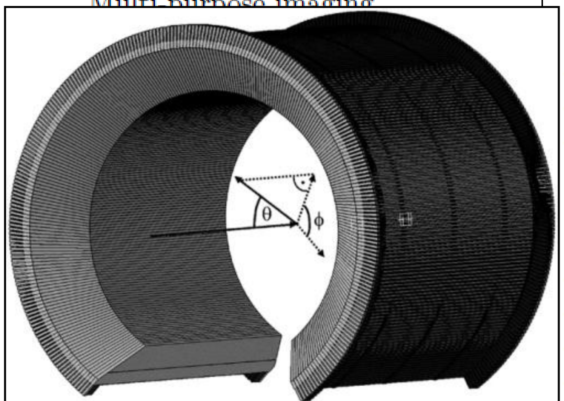
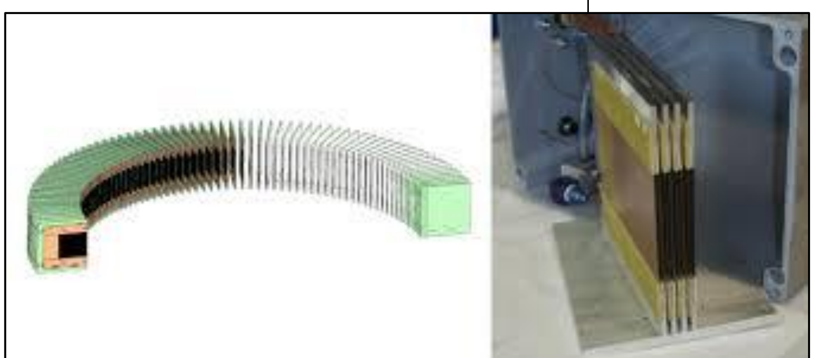
ESS Instrumentation

Instrument	Detector technology: ^{10}B thin films ⊥	^{10}B thin films ∥	Scintillators WSF	Scintillators Anger	^{3}He	Micropattern Rate	Micropattern Resolution
Multi-purpose imaging	-	-	-	-	-	o	+
	o	+	-	+	o	+	-
	o	+	-	+	-	+	-
	o	+	-	+	o	+	-
	-	o	-	+	+	o	-
	-	o	-	+	+	o	-
	o	+	+	-	-	o	-
	o	+	+	-	-	o	-
	o	+	+	-	-	o	-
	o	+	+	-	-	o	-
Extreme conditions diffractometer	o	+	+	-	-	o	-
Single crystal diffractometer	o	+	+	-	-	o	-
Macromolecular diffractometer	-	o	o	o	-	+	+
			o	-	-	-	-
			o	-	-	-	-
			+	-	-	-	-
			-	+	+	-	-
			-	o	+	-	-
			-	+	+	-	-
			-	o	+	+	-
			-	o	+	+	-
Fundamental & particle physics	-	-	-	-	+	+	+





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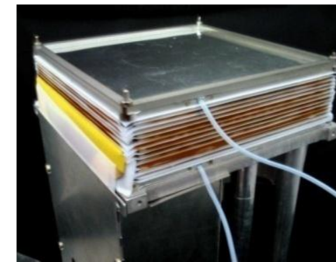

[2]

[1] The Multi-Blade Detector, ILL Grenoble
[2] (MCP) www.neutrondetector.com
[3] PSI, neutron radiography

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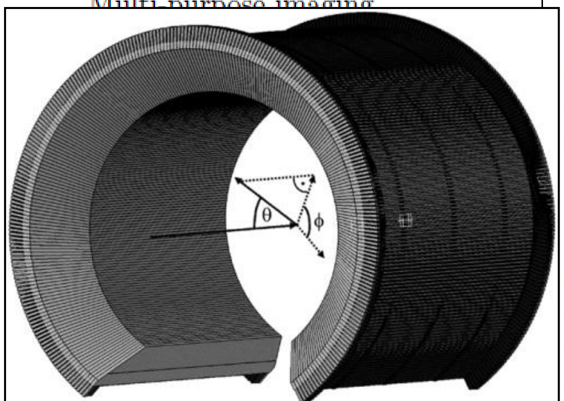
Instrument	Detector technology: ^{10}B thin films ⊥	^{10}B thin films ∥	Scintillators WSF	Scintillators Anger	^{3}He	Micropattern Rate	Micropattern Resolution
Multi-purpose imaging	-	-	-	-	-	o	+
	o	+					
	o	+					
	o	+					
	-	o					
	-	o					
	o	+					
	o	+					
	o	+					
	o	+					
Extreme conditions diffractometer	o	+					
Single crystal diffractometer	o	+	+	-	-	o	-
Macromolecular diffractometer	-	o	o	o	-	+	+
			o	-	-	-	-
			o	-	-	-	-
			+	-	-	-	-
			-	+	+	-	-
			-	o	+	-	-
			-	+	+	-	-
			-	o	+	+	-
			-	o	+	+	-
Fundamental & particle physics	-	-	-	-	+	+	+



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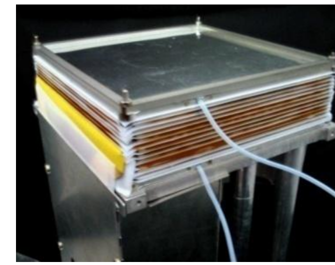

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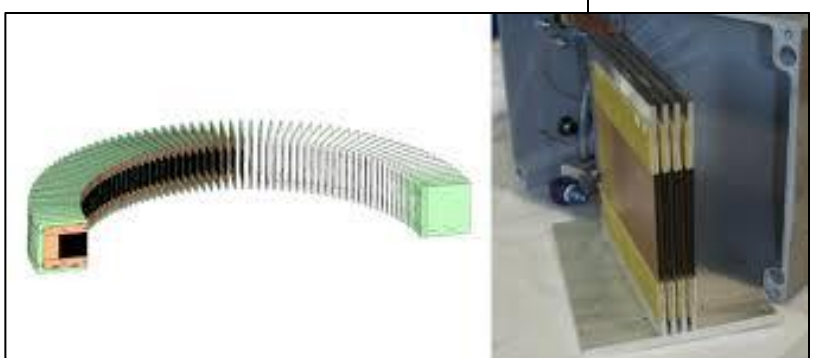

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[3] PSI, neutron radiography

The MediPix Family

Hybrid-Detector Concept:

readout electronics and sensor separated

MediPix 1

1997 [1]

- active area 1,2 cm²
- matrix of **64 x 64 pixels**
- 1,6 M transistors/chip
- **170 x 170 μm² per pixel**

- 1 discriminator per pixel
- 15-bit counter
- threshold (whole chip): ≈ 1500 e^-

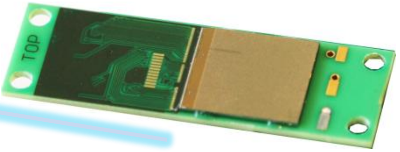
- 1,4 x 1,4 cm²
- matrix of **256 x 256 pixels**
- 0.25 μm CMOS technology (33M transistors/chip)
- **55 x 55 μm² per pixel**

- serial or parallel I/O (min. readout time of full matrix 266 μs)
- preamplifier/shaper (t_{rise} ≈ 150 ns)
- 2 discriminators (lower and upper threshold)
- 14-bit counter
- threshold (whole chip): ≈ 1000 e^-

MediPix 2

2001

TimePix

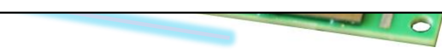


2006

[1] http://medipix.web.cern.ch/medipix/pages/images.php

The MediPix Family

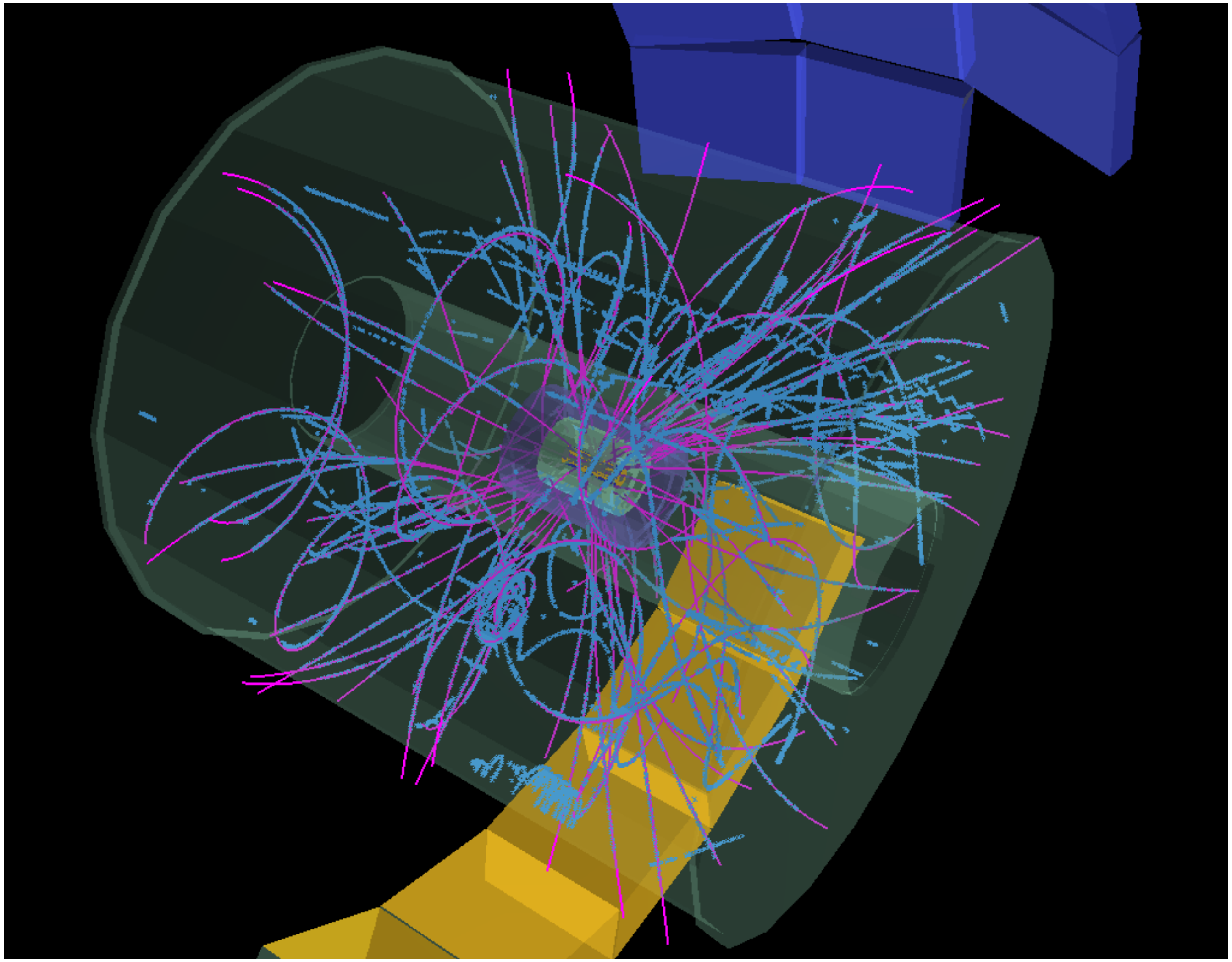
2003	Single neutron pixel detector based on Medipix-1 device	(IEEE)
2005	Spatial resolution of Medipix-2 device as neutron pixel detector	(NIMA)
2004	Properties of the single neutron pixel detector based on the Medipix-1	(NIMA)
2005	Properties of neutron pixel detector based on Medipix-2 device	(IEEE)
2006	Neutron imaging with Medipix-2 chip and a coated sensor	(NIMA)
2008	Detection of fast neutrons with the Medipix-2 pixel detector	(IEEE)
2008	High-resolution UV, alpha and neutron imaging with the Timepix CMOS readout	(NIMA)
2009	Neutron Detector Based on Timepix Pixel Device with Micrometer Spatial Resolution	(SPIE)
2009	A coated pixel device TimePix with micron spatial resolution for UCN detection	(NIMA)
2009	High-resolution neutron radiography with microchannel plates: Proof-of-principle experiments at PSI	(NIMA)
2010	Fast neutron detector based on TimePix pixel device with micrometer spatial resolution	(IEEE)
2010	Monte-Carlo simulation of fast neutron detection using double-scatter events in plastic scintillator and Timepix	(IEEE)
2011	Design, Implementation and First Measurements with the Medipix Neutron Camera in CMS	(arxiv)
2011	Detection of fast neutrons with particle tracking detector Timepix combined with plastic scintillator	(Rad. Meas.)
2011	High-resolution strain mapping through time-of-flight neutron transmission diffraction with a microchannel plate neutron counting detector	(Strain)
2011	A high resolution neutron counting sensors in strain mapping through a transmission bragg edge diffraction	(IEEE)
2012	A highly miniaturized and sensitive thermal neutron detector for space applications	(AIP)
2012	High resolution neutron counting detectors with microchannel plates and their applications in neutron radiography, diffraction and resonance absorption imaging	(Neutron News)
2012	Neutron radiography with sub-15 µm resolution through event centroiding	(NIMA)
2013	Directional detection of fast neutrons by the Timepix pixel detector coupled to plastic scintillator with silicon photomultiplier array	(IOP)
2014	Fast Neutron Dosimeter using the pixelated detector TimePix	(Rad. Prot. Dos.)
2014	Position sensitive detection of neutrons in high radiation background field	(Rev. Sci. Instrum.)
2014	Characterization of Timepix Detector Coated with 10B4C Film for High Resolution Neutron Imaging	(Proc. ICATPP)
2014	Dosimetry measurements using Timepix in mixed radiation fields induced by heavy ions; comparison with standard dosimetry methods	(J. Radiat. Res.)
2014	Time-of-flight measurement of fast neutrons with Timepix detectors	(JInst)
2014	Fast Sensors for Time-of-Flight Imaging Applications	(Phys. Chem.)
2015	Time-resolved neutron imaging at ANTARES cold neutron beamline	(JInst)
2016	Development and characterization of high-resolution neutron pixel detectors based on Timepix read-out chips	(JInst)
2016	Improved fast neutron detector based on timepix and plastic scintillating converter	(IEEE)
2017	Real-time Crystal Growth Visualization and Quantification by Energy-Resolved Neutron Imaging	(Sci. Rep.)
2017	Evaluation of Wavelength-Dependent Detection Efficiency of Neutron-Sensitive Microchannel Plate Detector	(Sensors and Mat.)
2018	Neutron Imaging with Timepix Coupled Lithium Indium Diselenide	(J. Imaging)
2018	Energy-Resolved Neutron Imaging for Reconstruction of Strain Introduced by Cold Working	(J. Imaging)
2018	Towards high-resolution neutron imaging on IMAT	(IOP)



2006

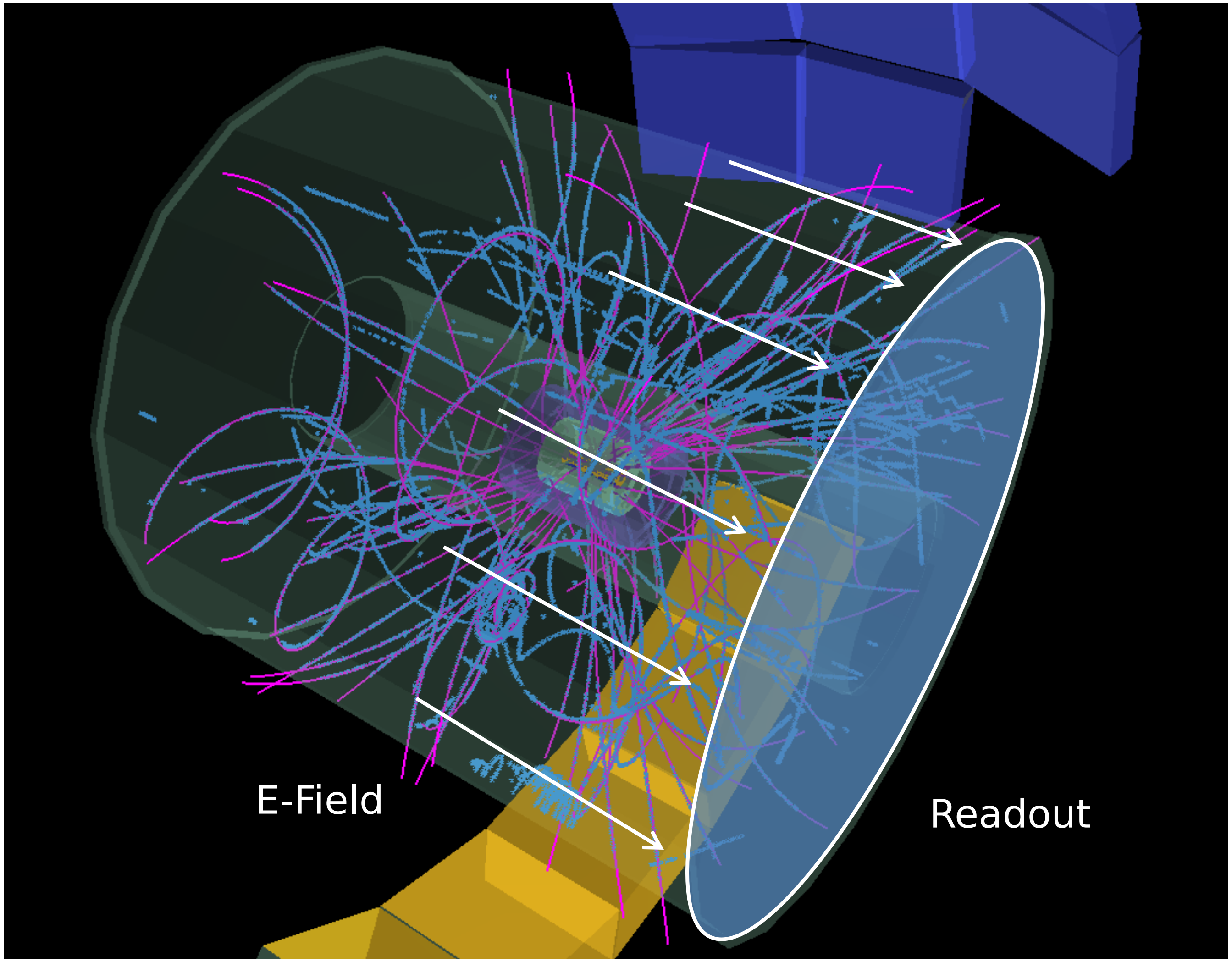
[1] http://medipix.web.cern.ch/medipix/pages/images.php

The Time Projection Chamber



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

The Time Projection Chamber



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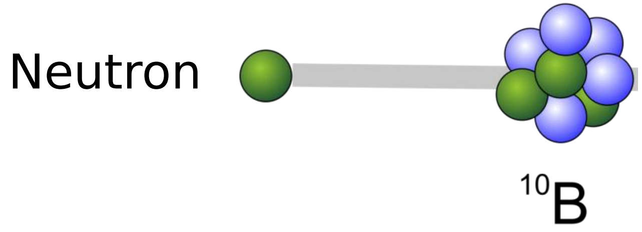
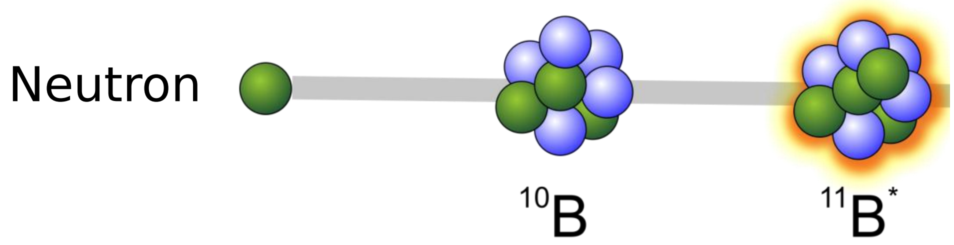
The Neutron TPC Trigger



The Neutron TPC Trigger



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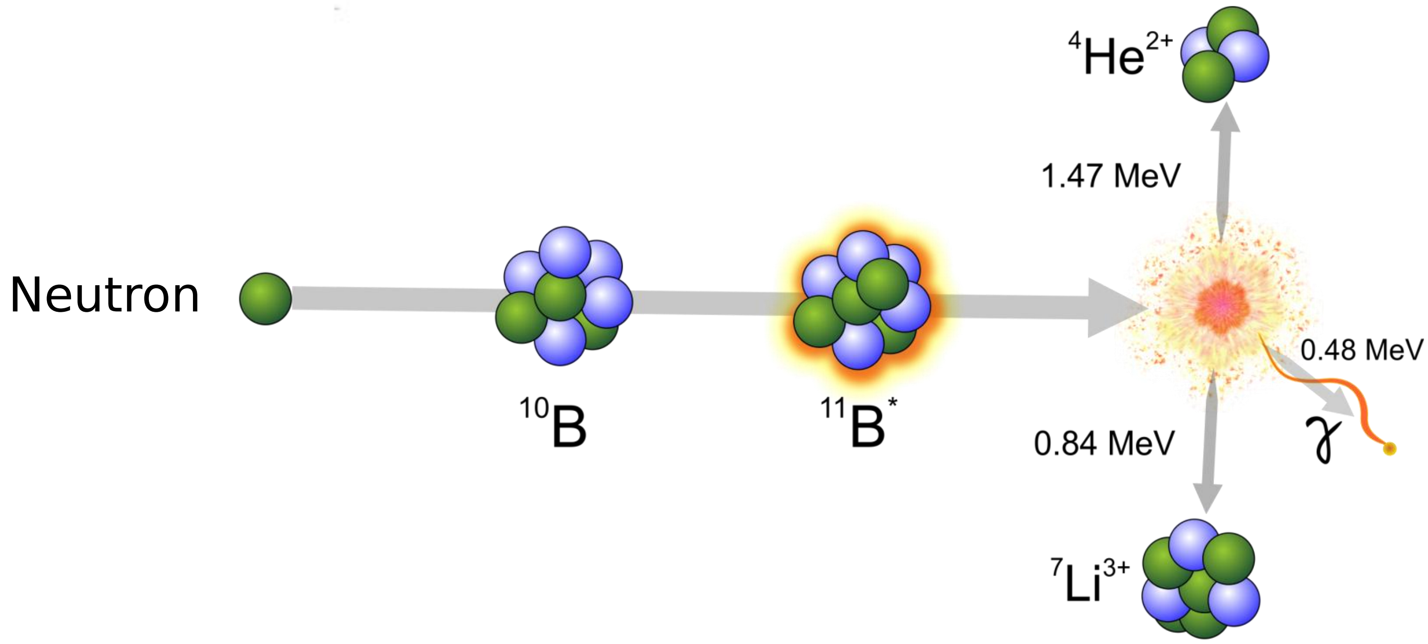
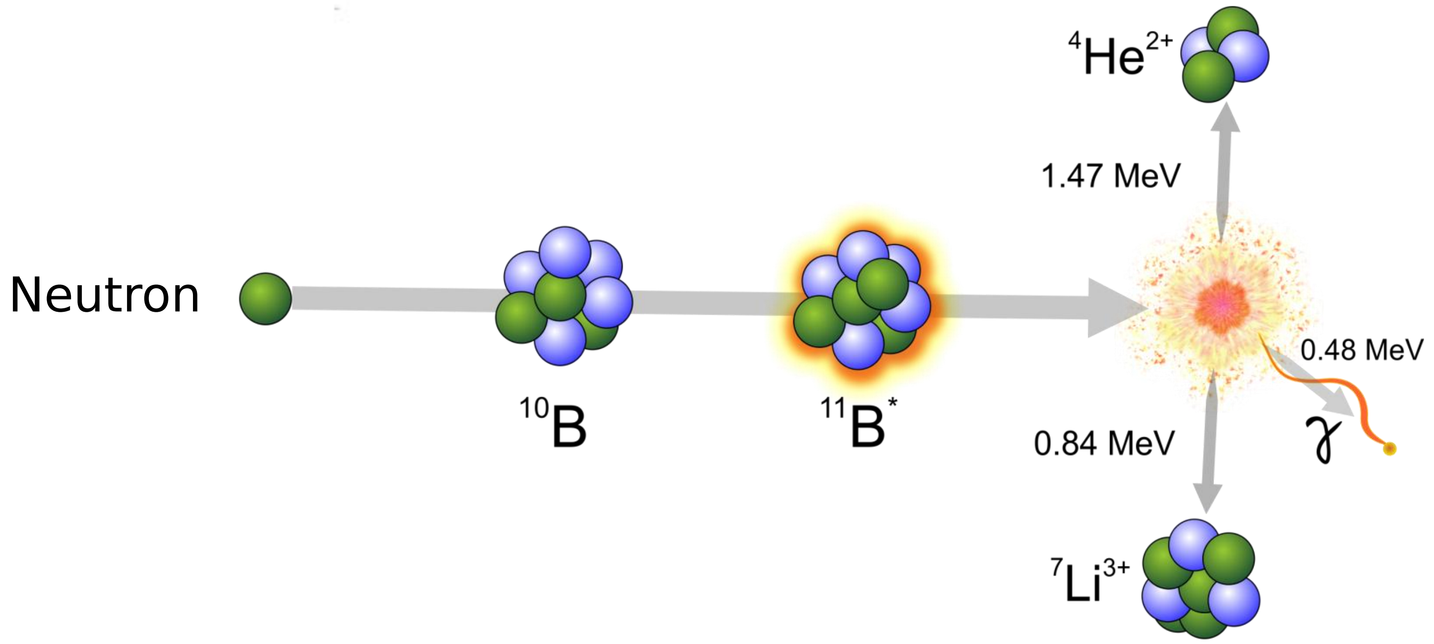


The Neutron TPC Trigger

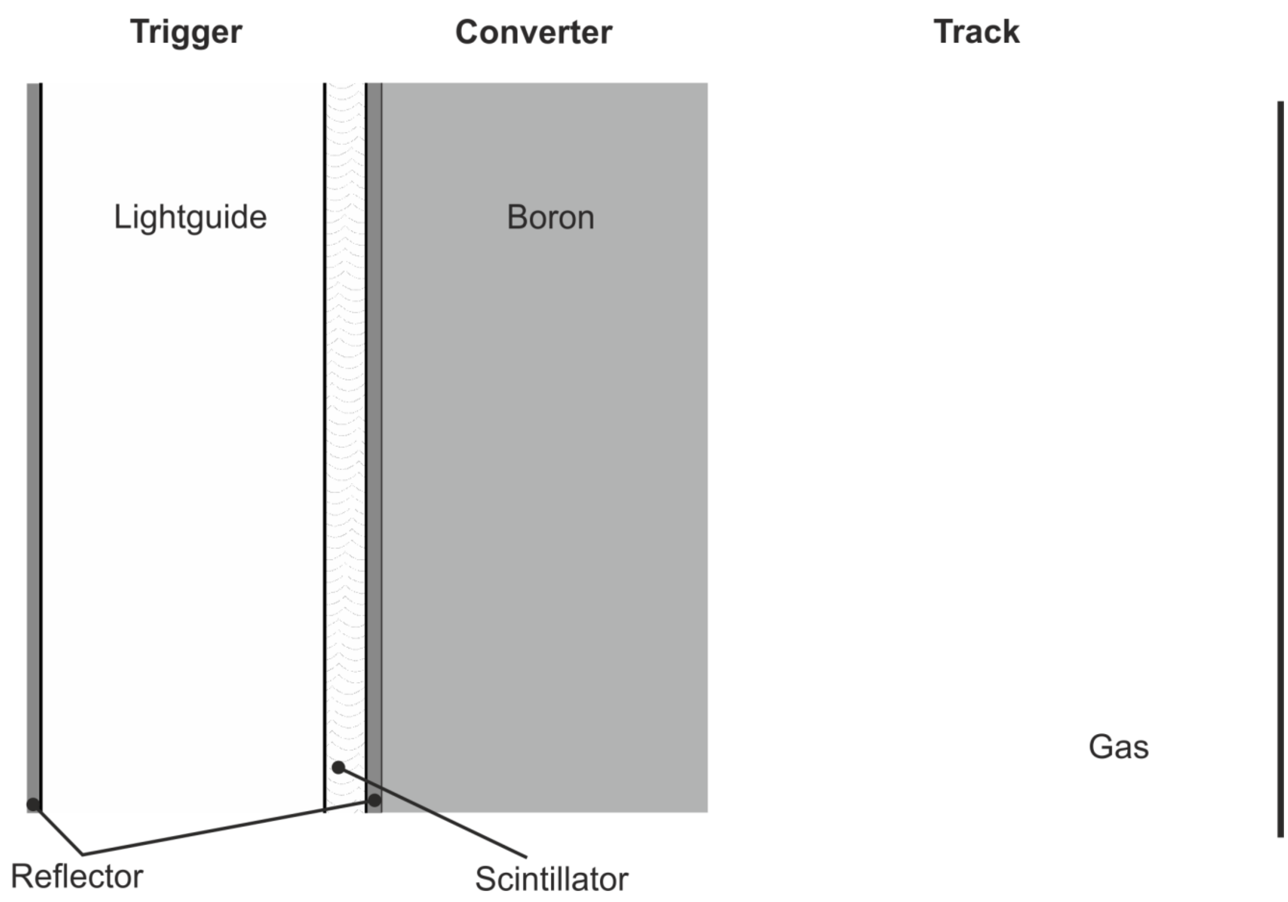


Trigger

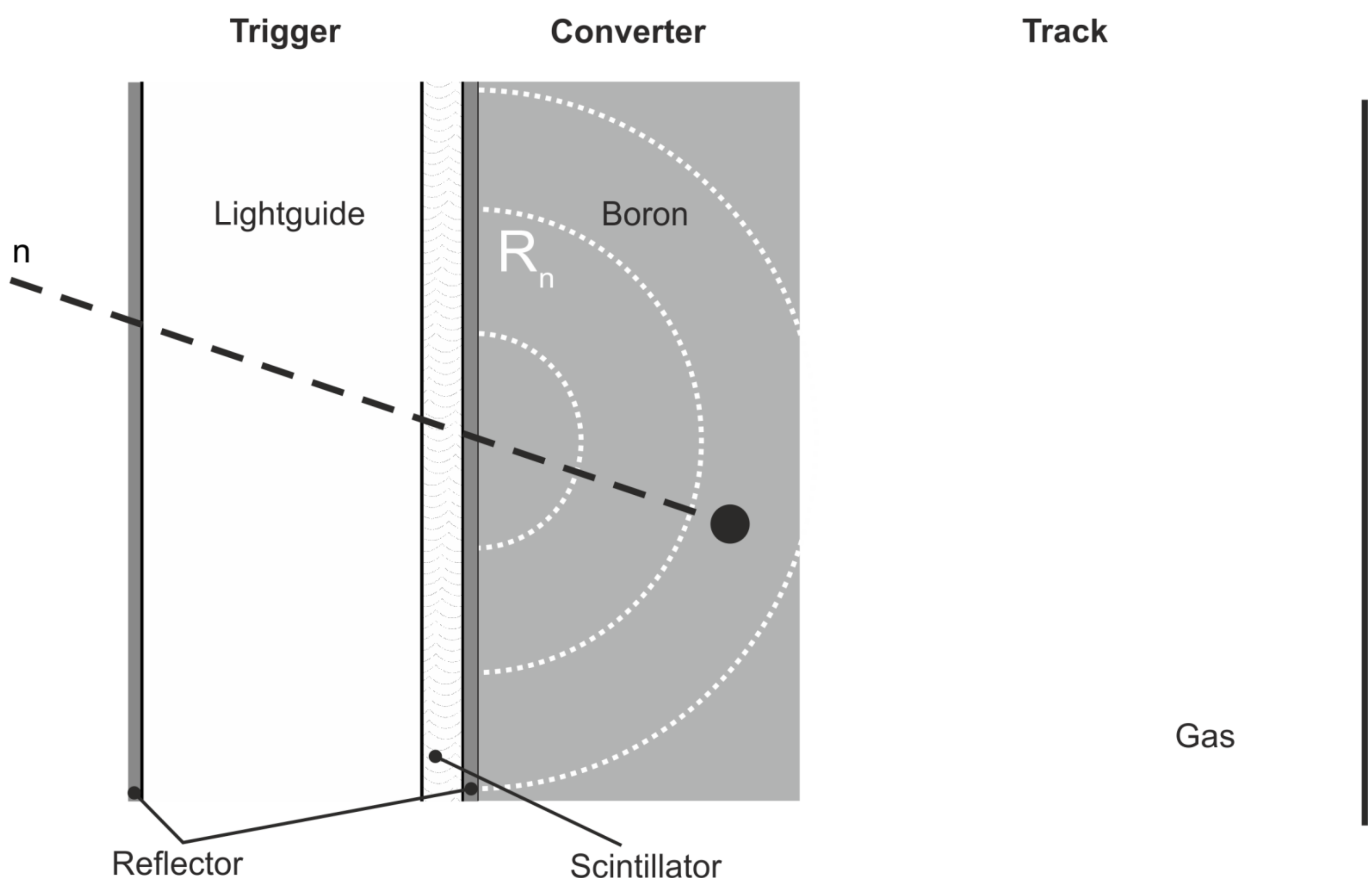
&

Track

The Neutron TPC



The Neutron TPC



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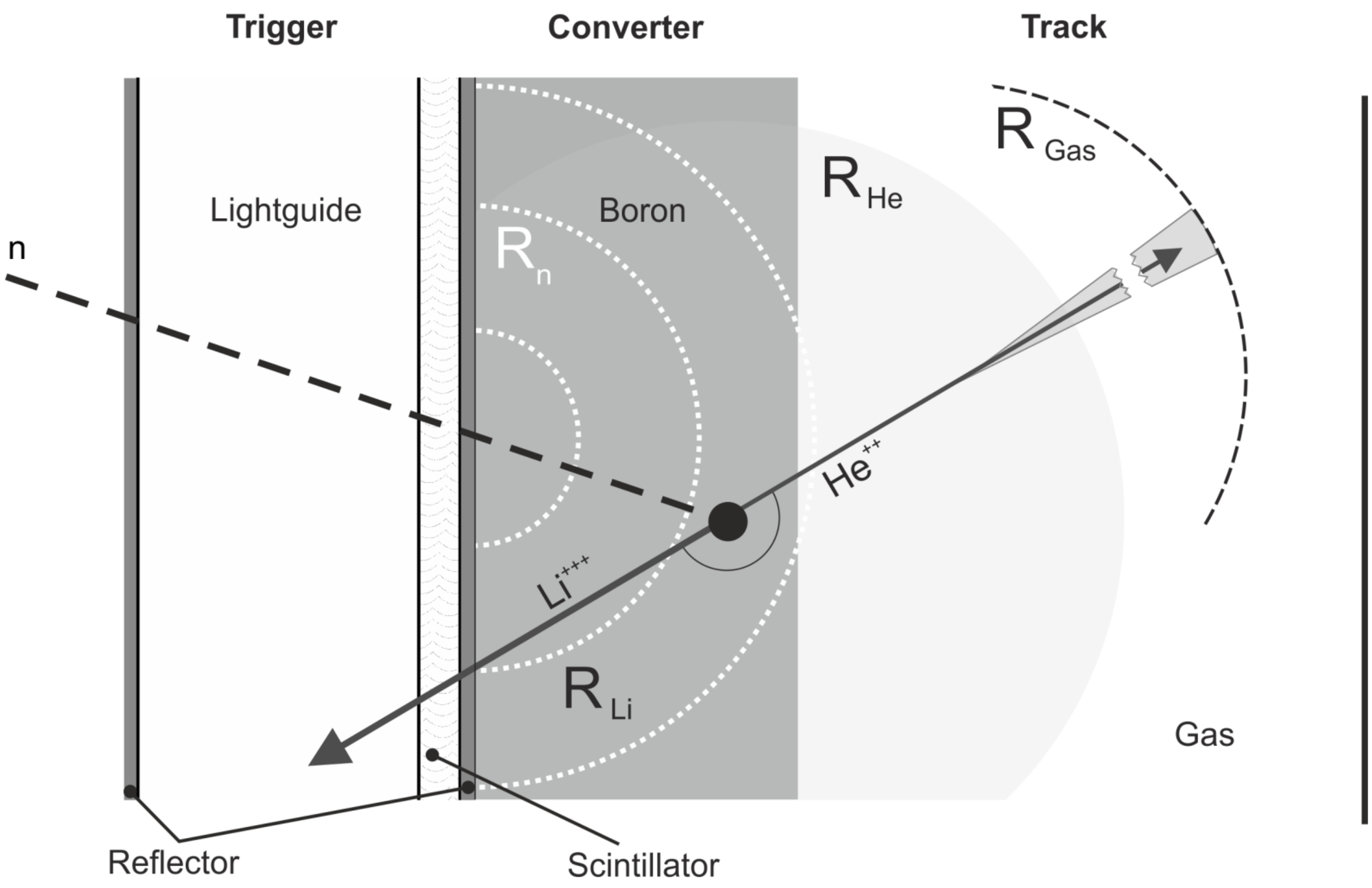
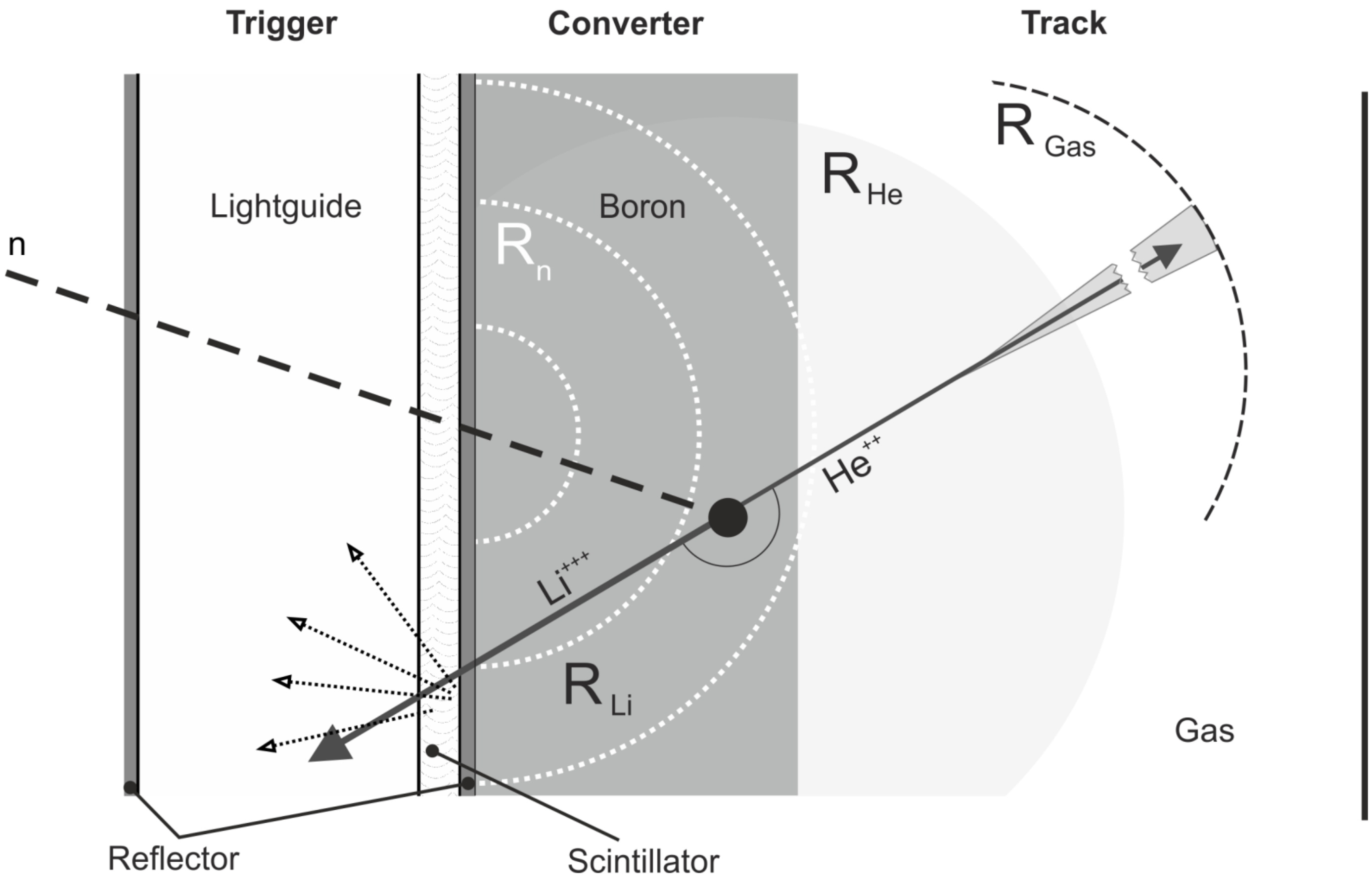
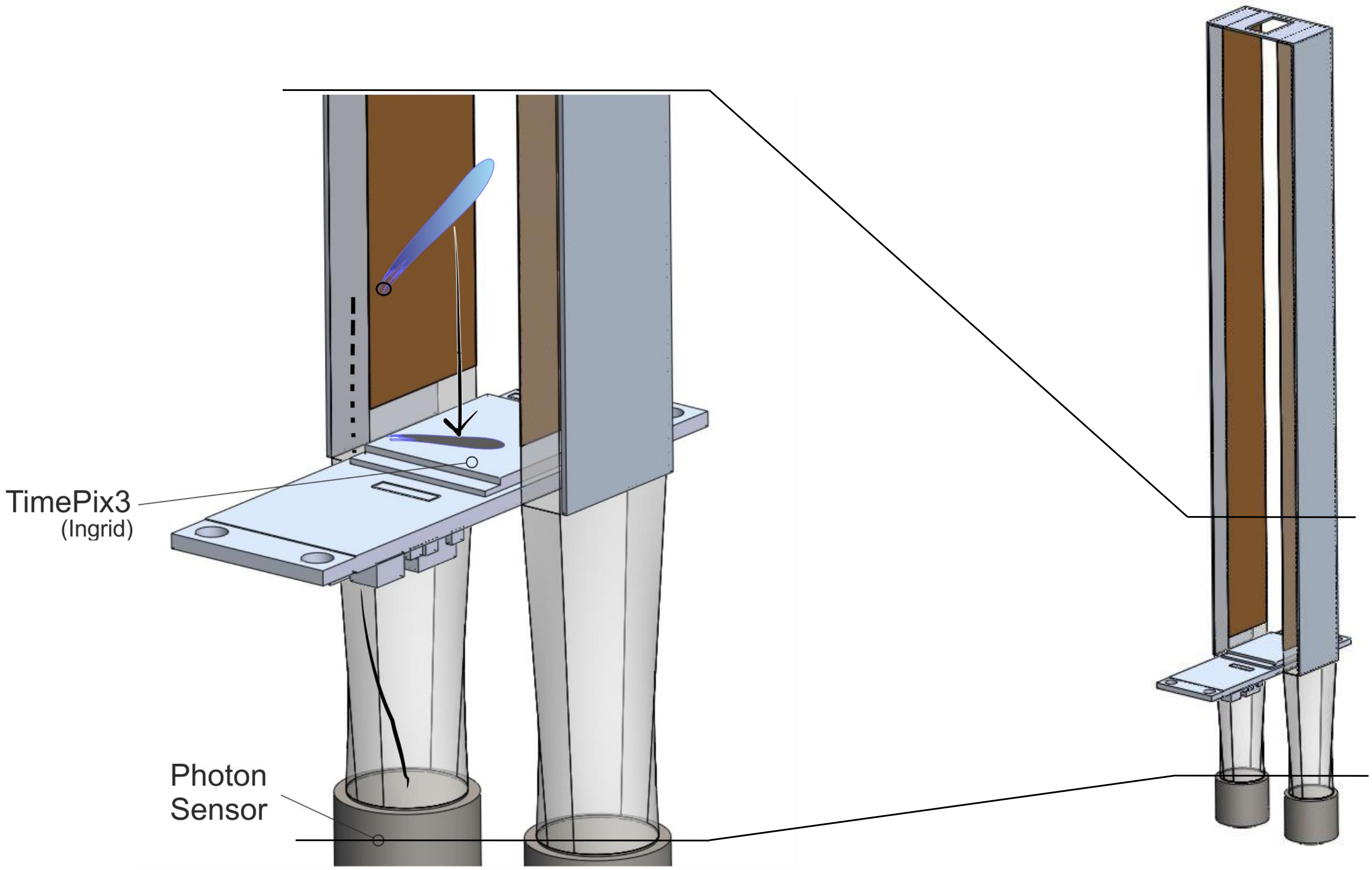


The Neutron TPC

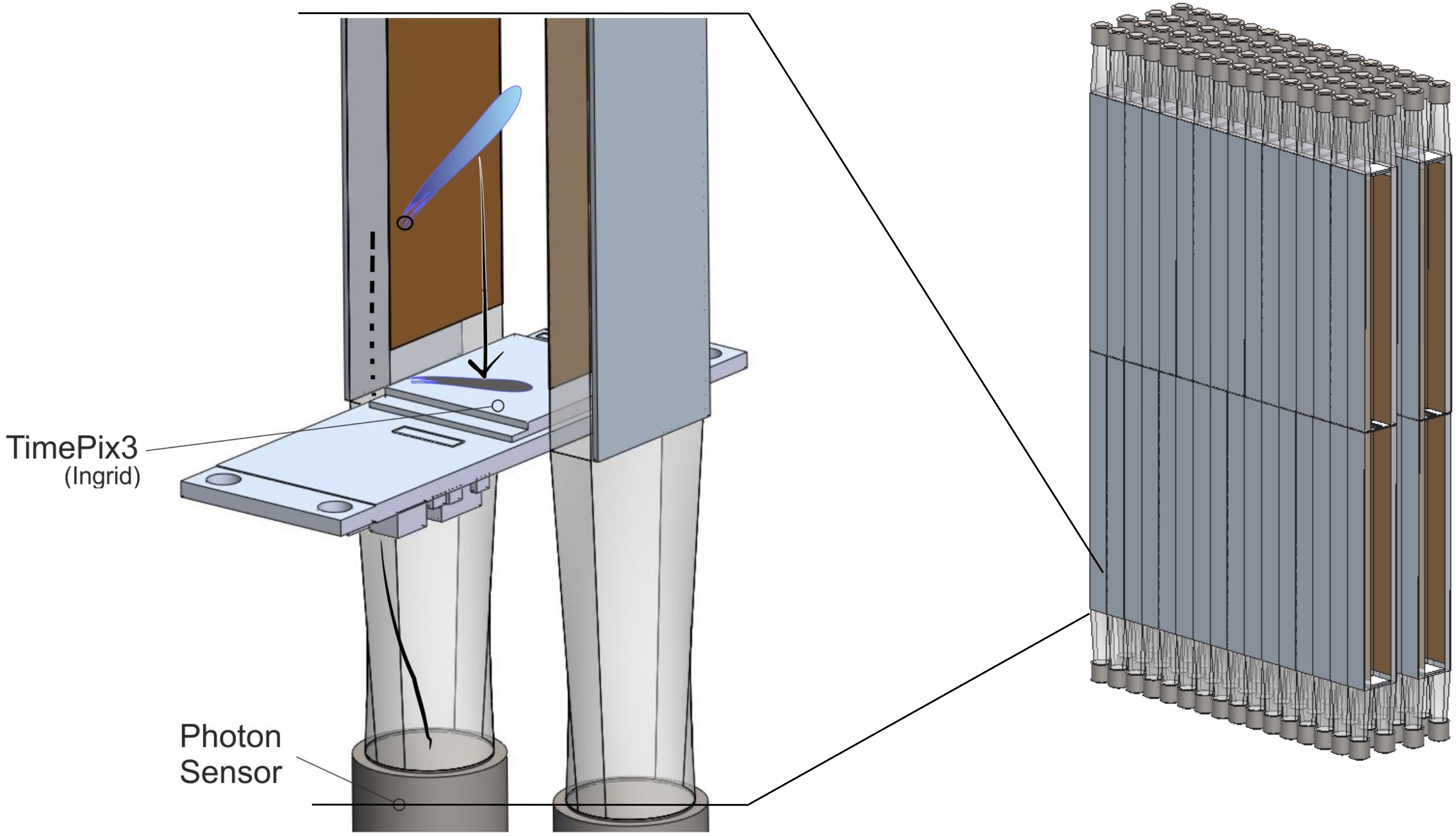


The Detector

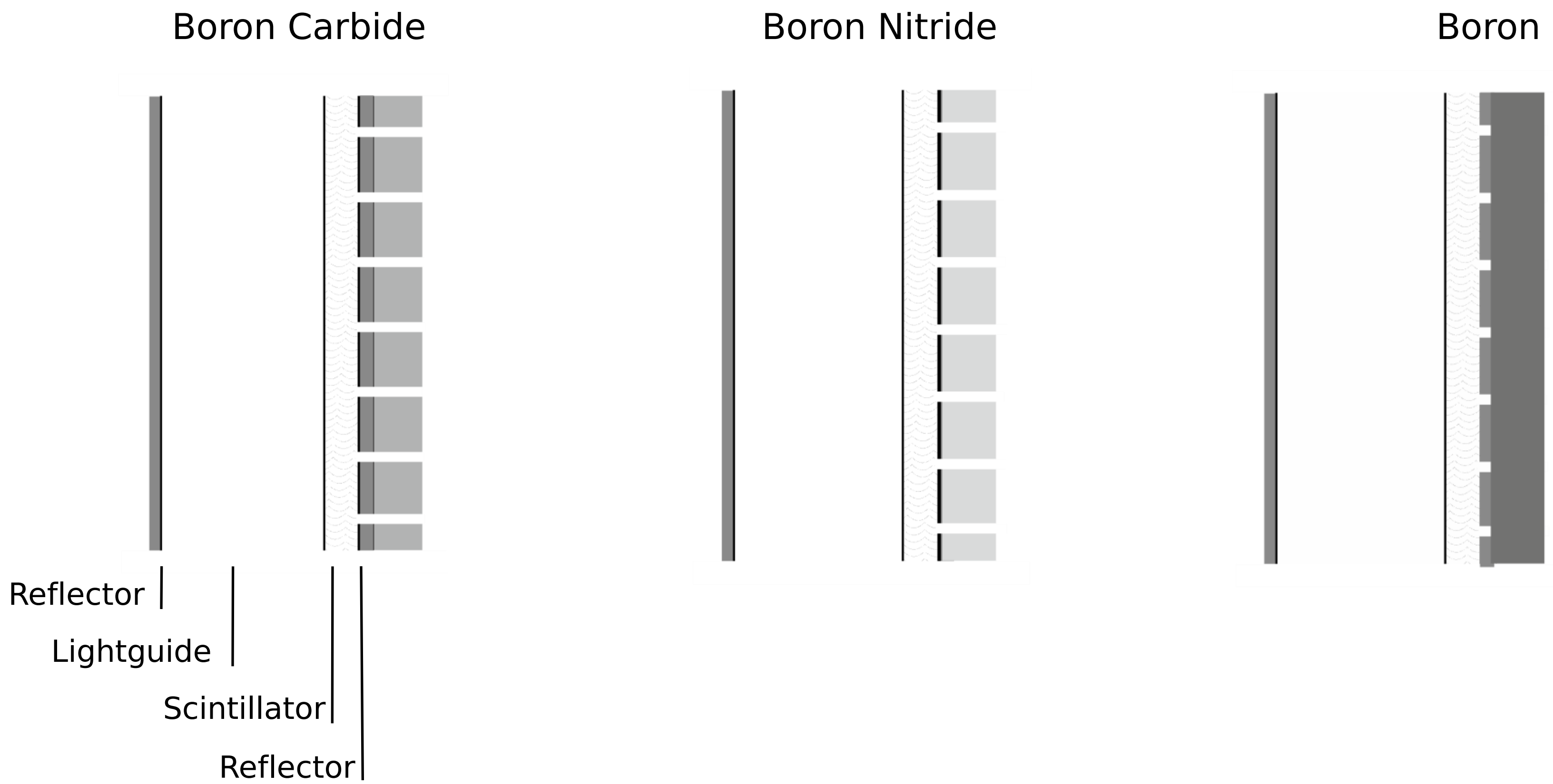
The Neutron TPC



The Neutron TPC: BODELAIRE

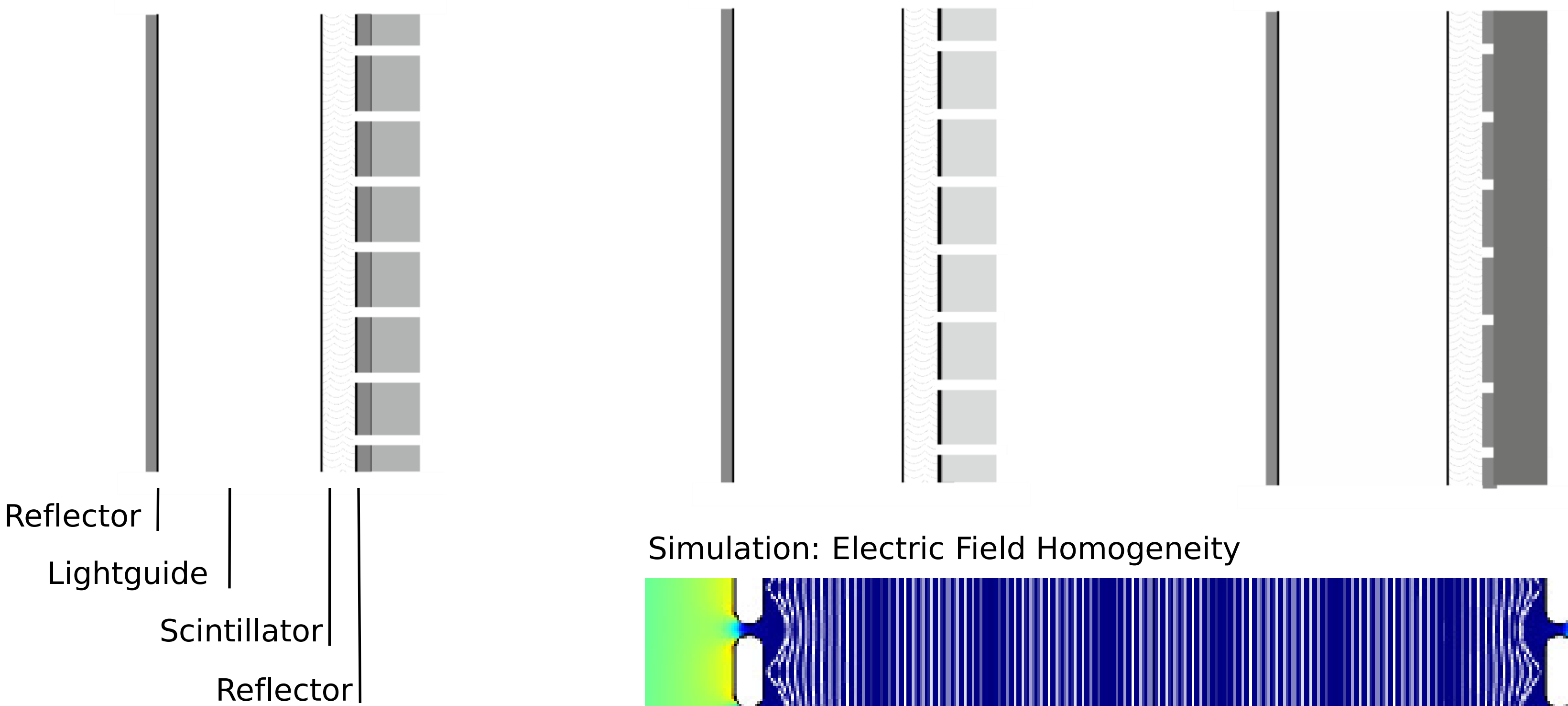


Field Cage Design

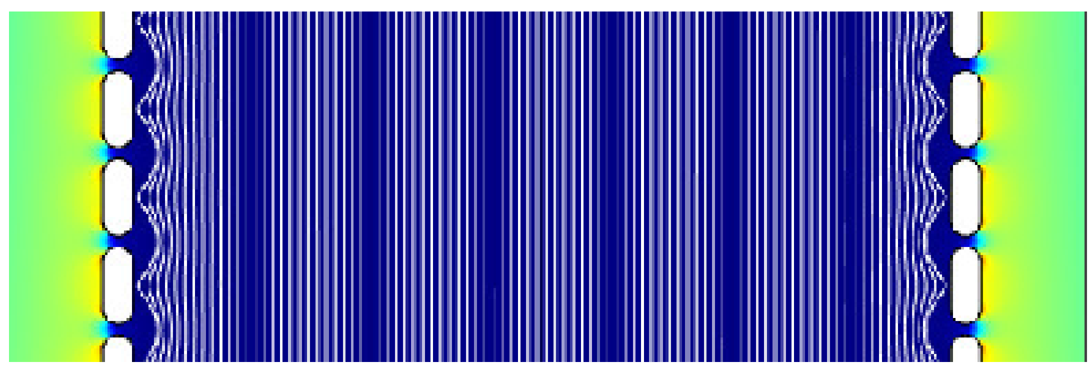


Field Cage Design

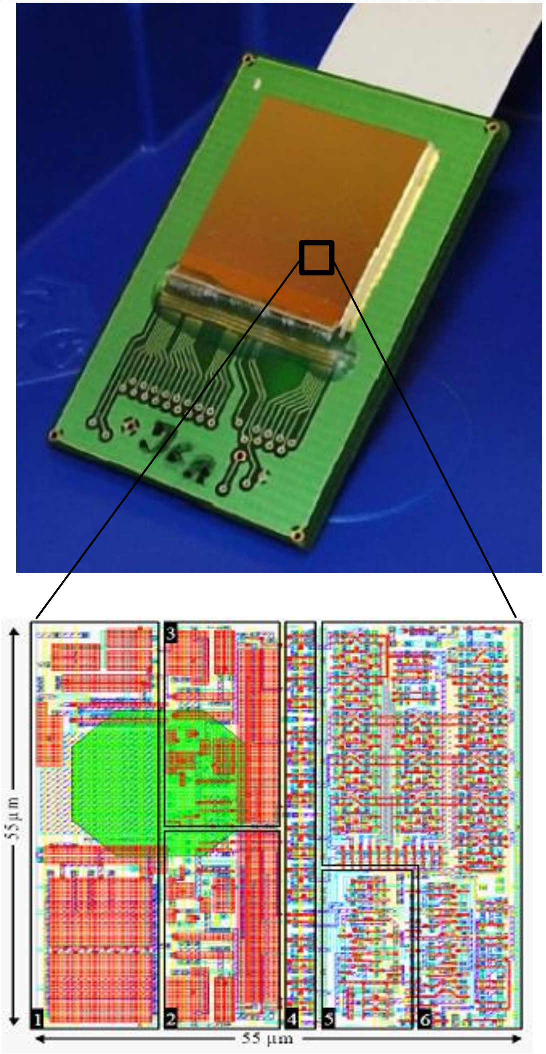
Boron Carbide | Boron Nitride | Boron



Simulation: Electric Field Homogeneity



The TimePix Chip



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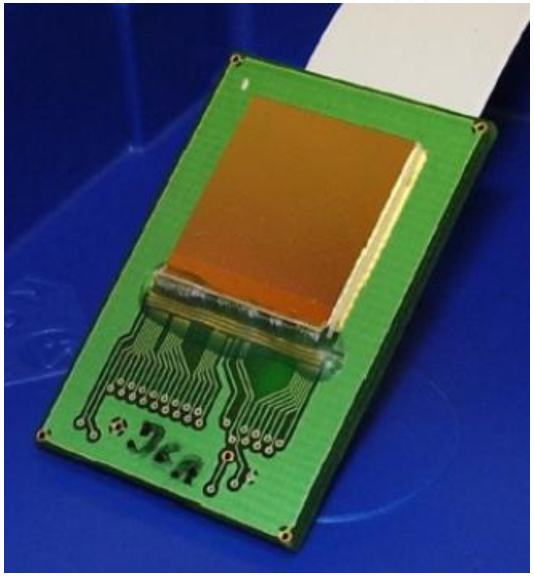
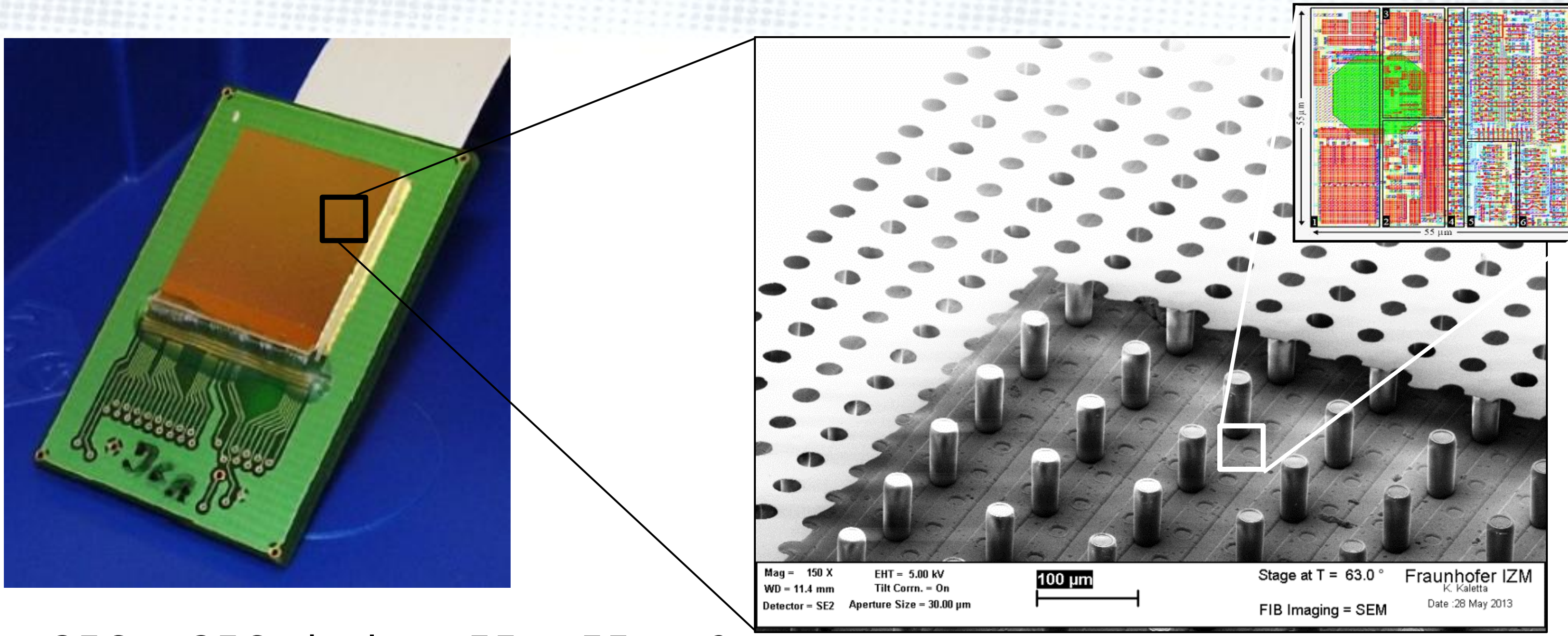


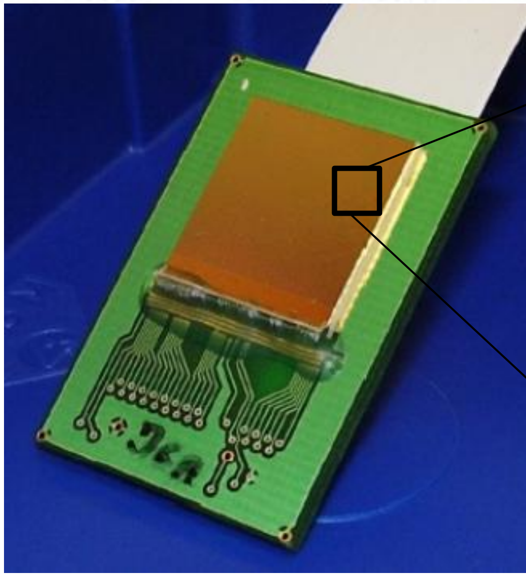
- 256 × 256 pixels @ 55 × 55 µm²
- 1.4 × 1.4 cm²
- 40 MHz clock
- ENC ca. 90 e^-

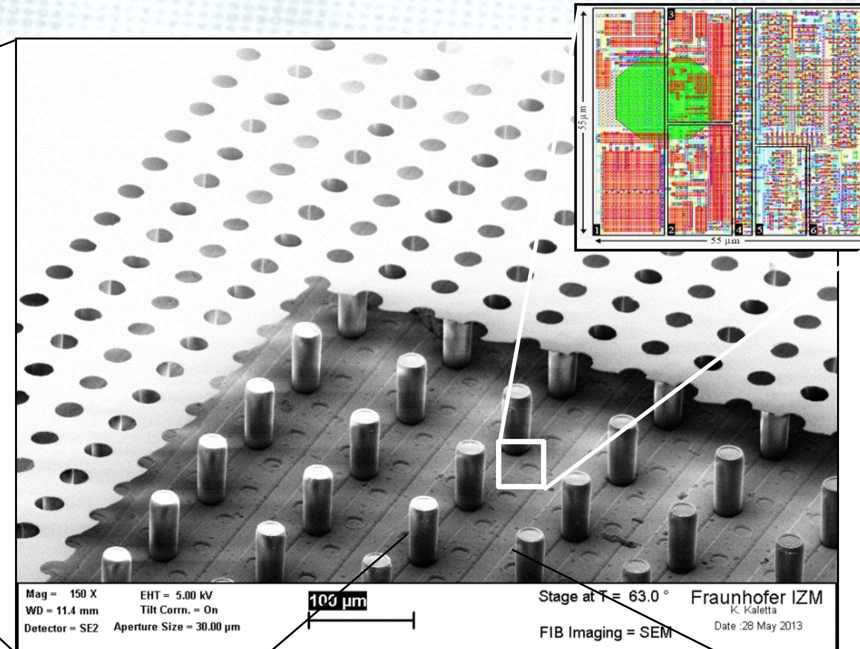
The TimePix Chip



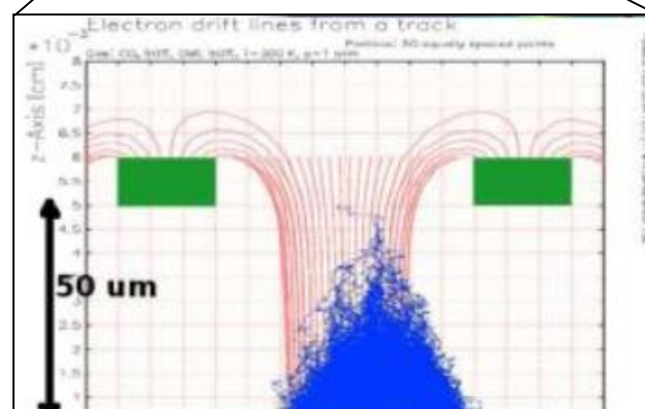
- 256 × 256 pixels @ 55 × 55 µm²
- 1.4 × 1.4 cm²
- 40 MHz clock
- ENC ca. 90 e⁻

The TimePix Chip

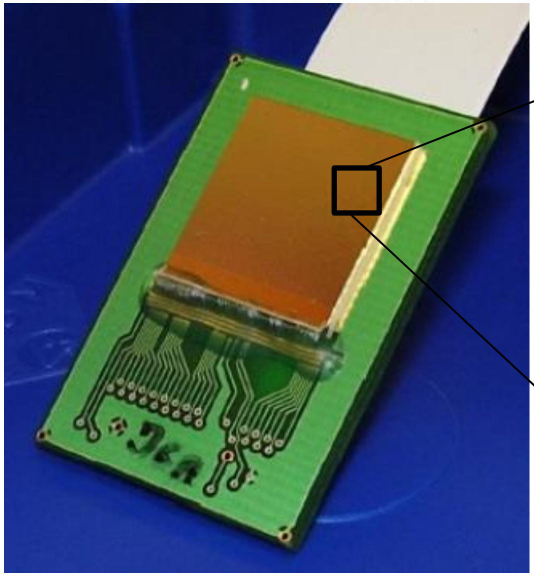


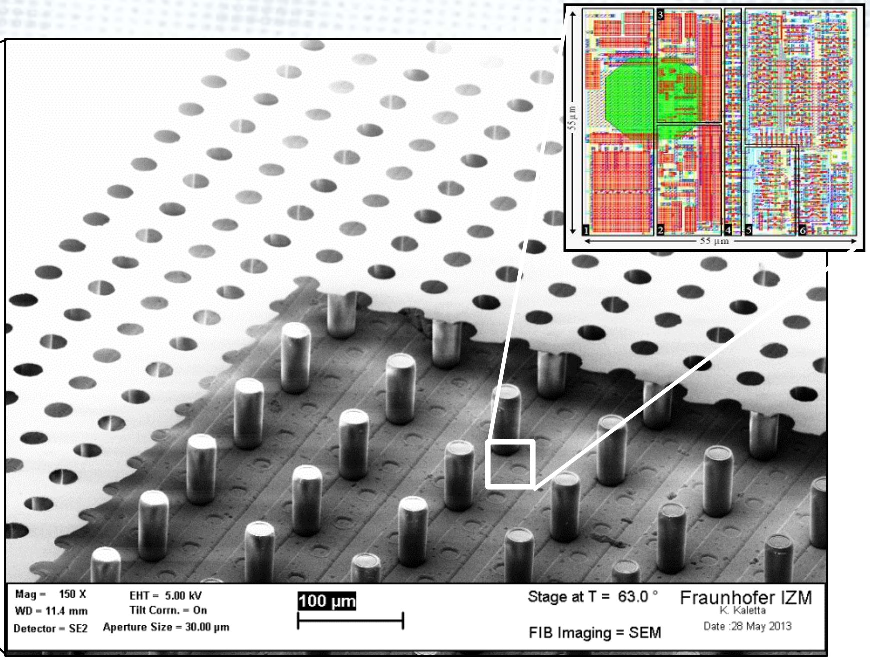


- 256 × 256 pixels @ 55 × 55 µm²
- 1.4 × 1.4 cm²
- 40 MHz clock
- ENC ca. 90 e⁻



The TimePix Chip





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Modes:
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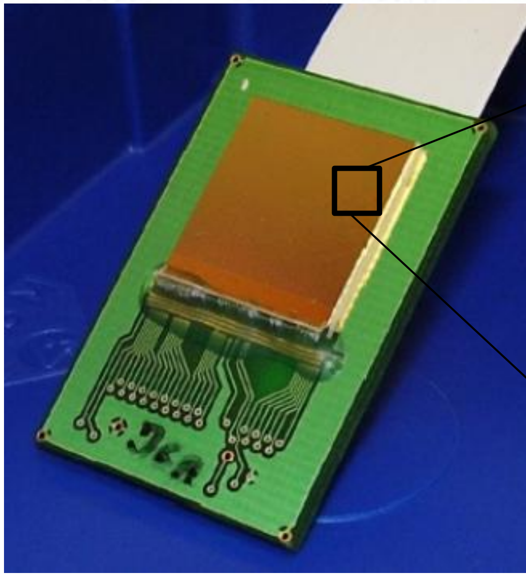
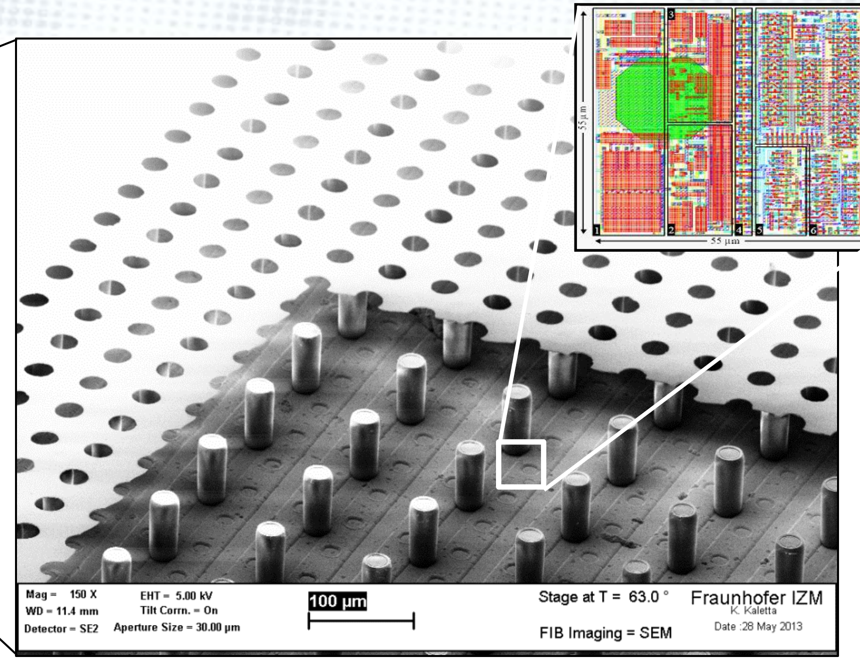
- Time of Arrival (ToA)
- Geiger Counter

The TimePix Chip





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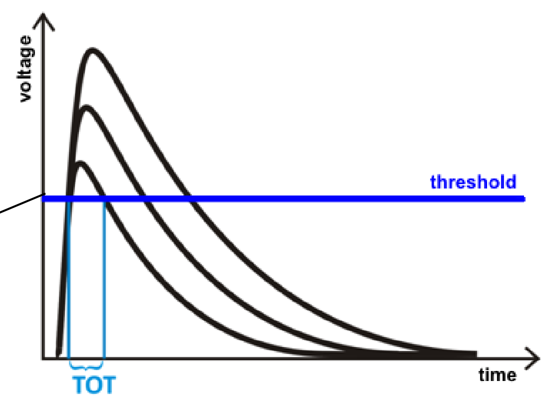
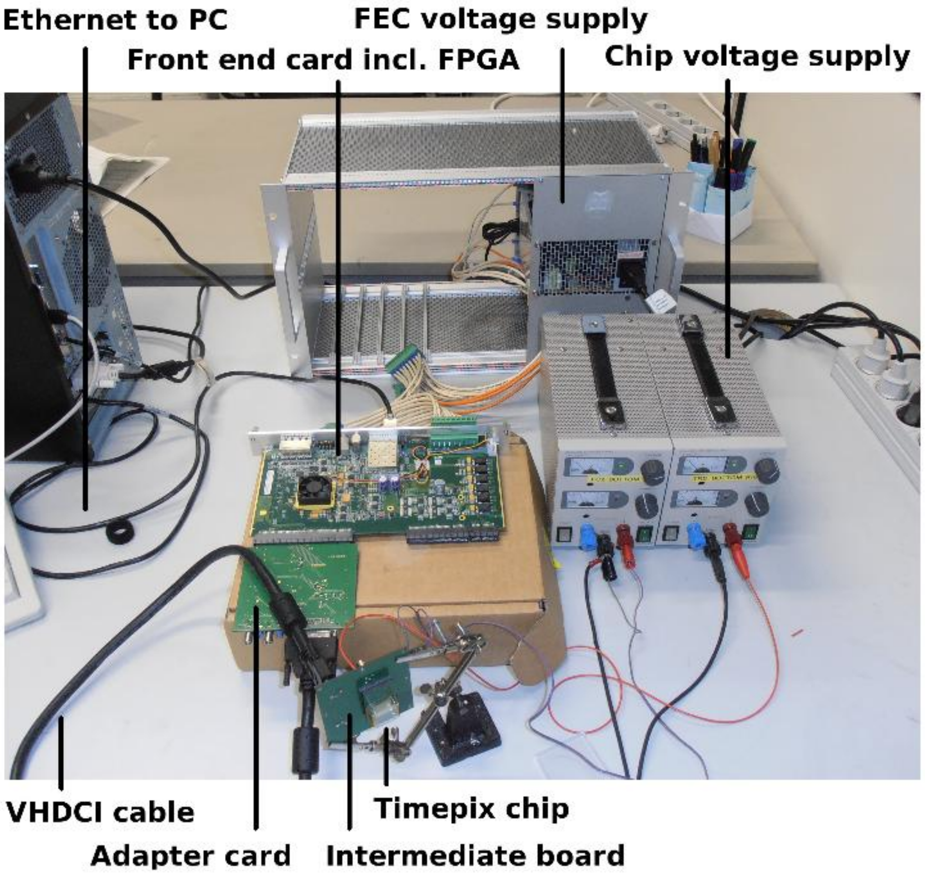
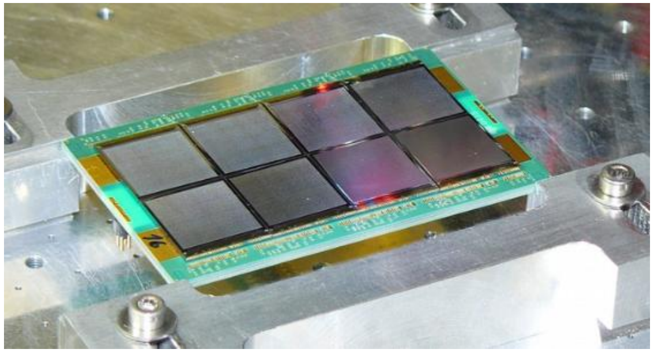


TimePix Readout System

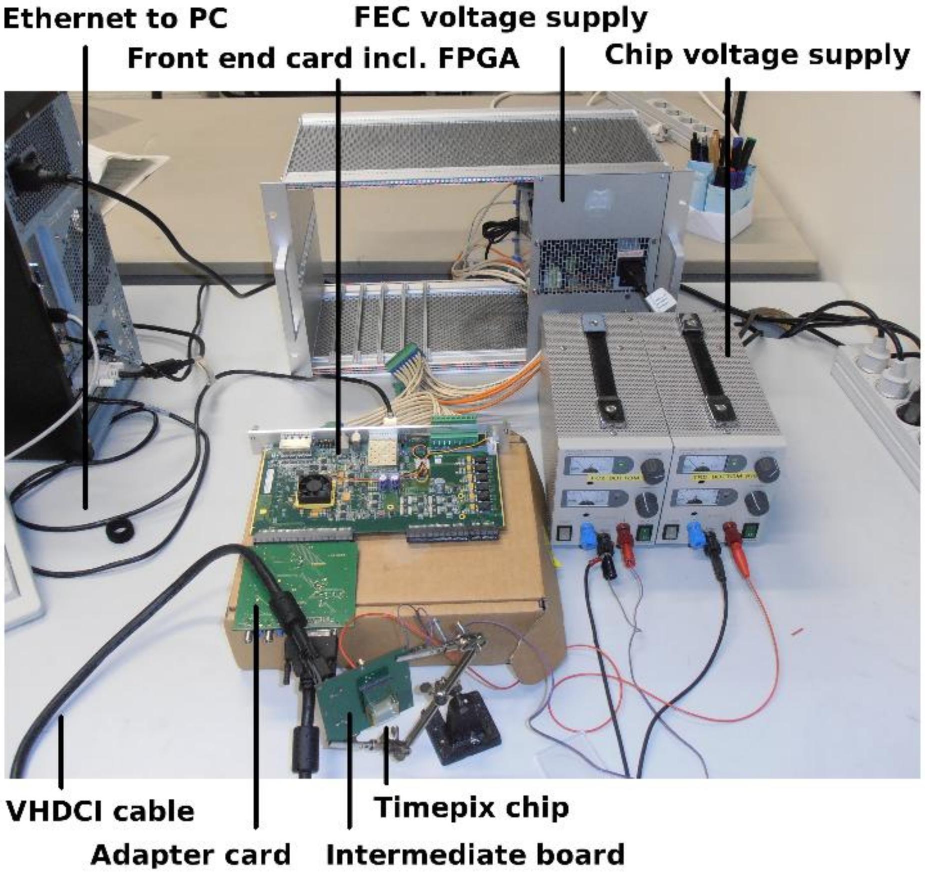


Octoboard:



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

TimePix Readout System



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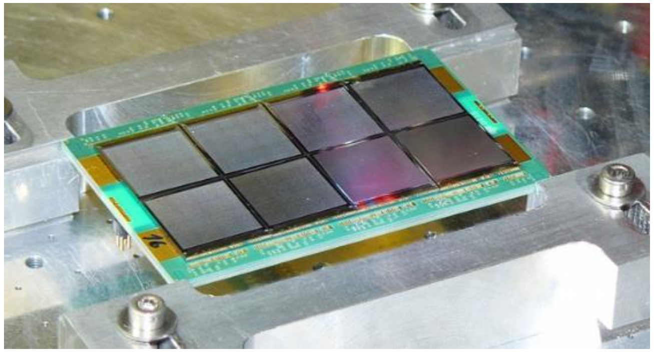

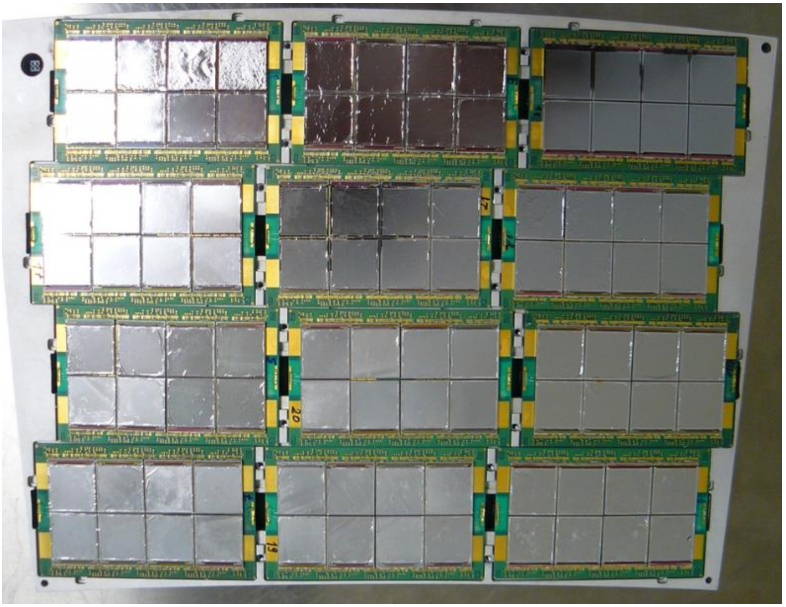

[1] M. Lupberger, The Pixel-TPC – A feasibility study, Thesis 2016
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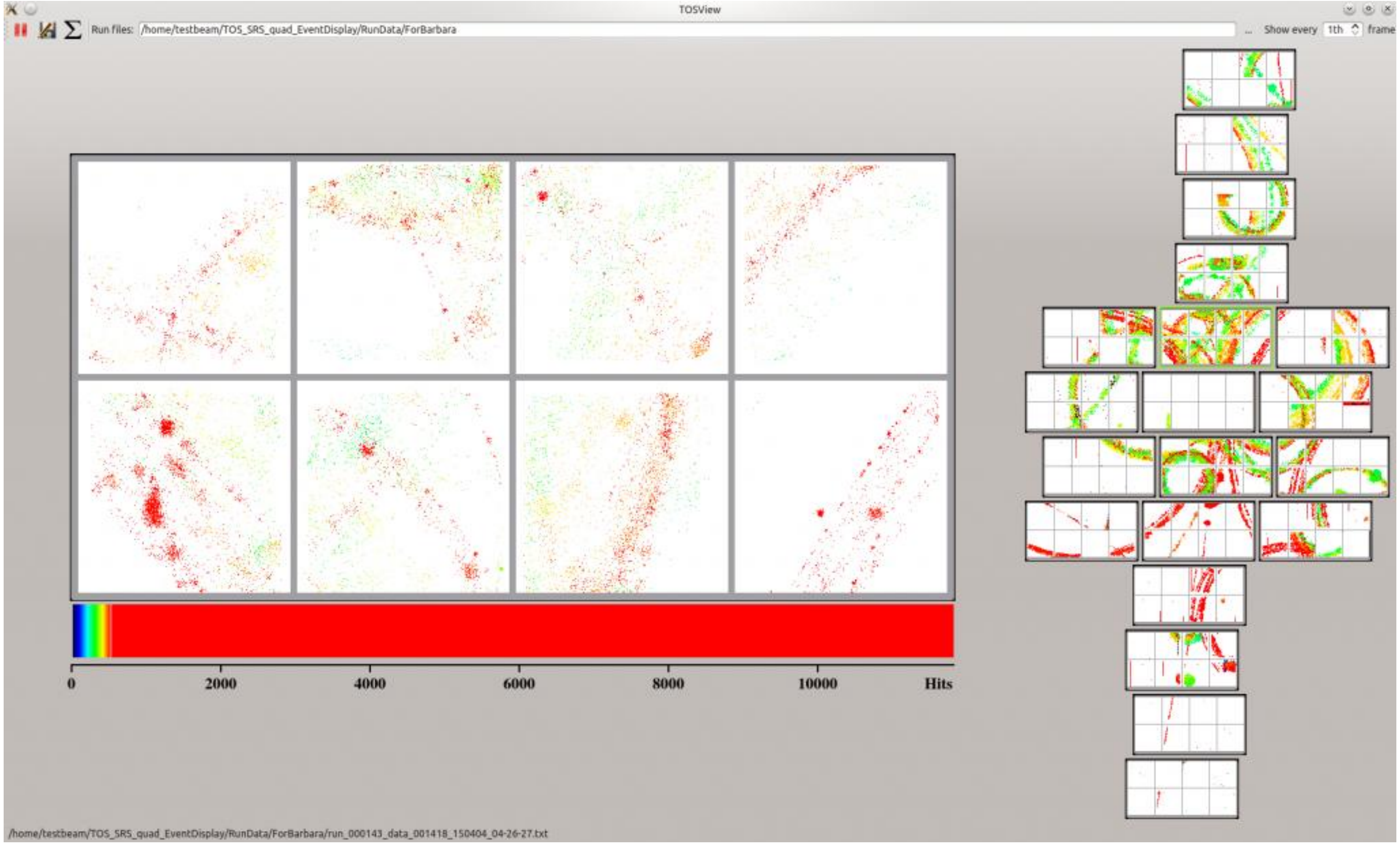
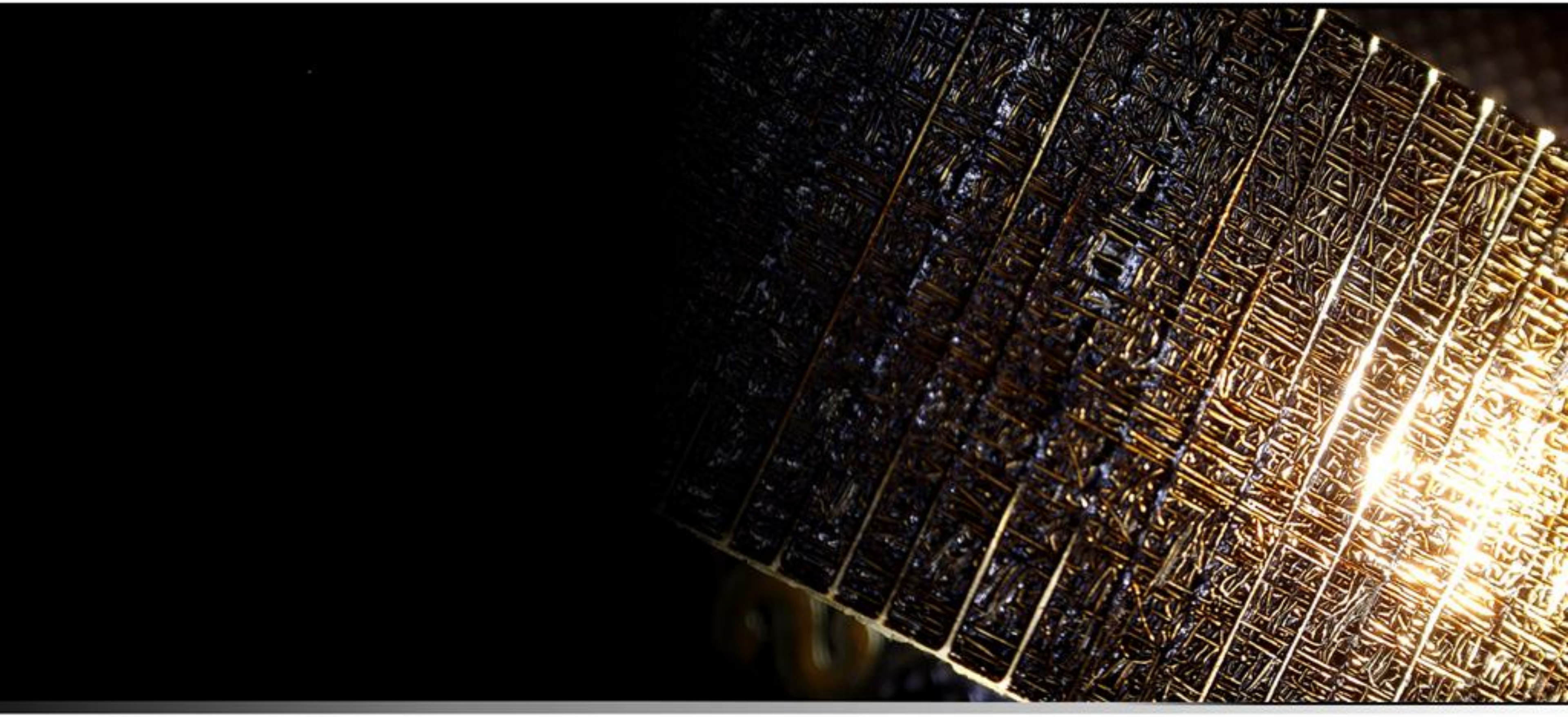
LCTPC Event Display



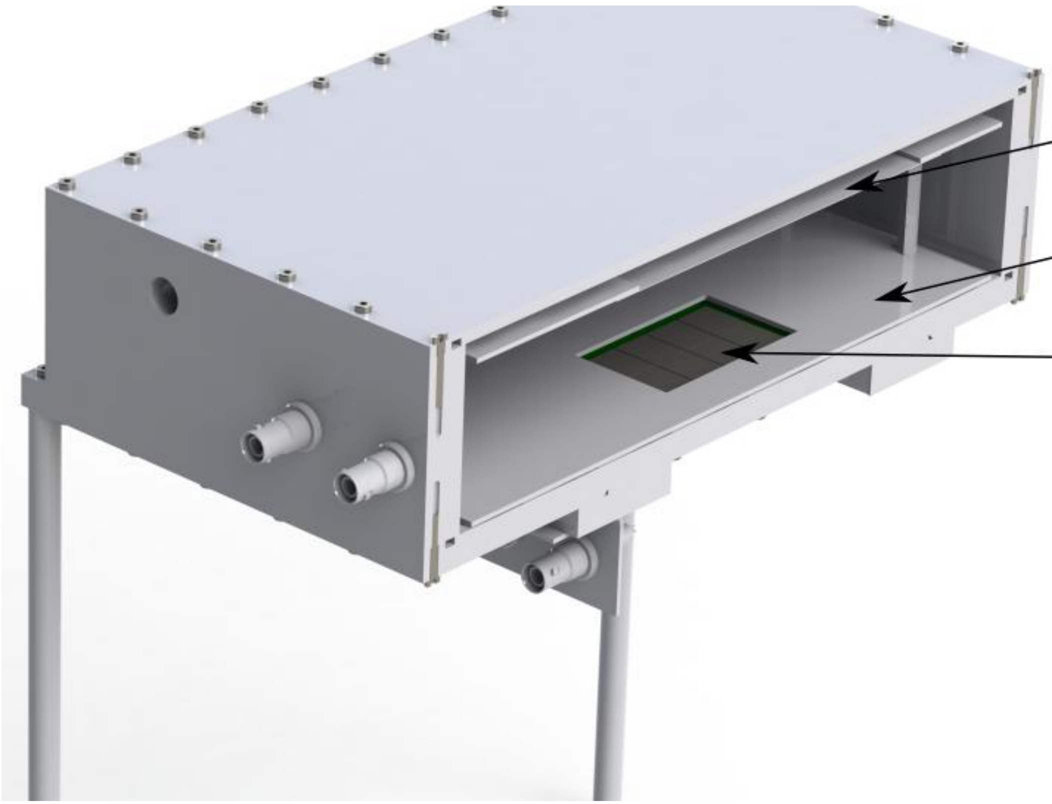
[1]

[1] http://newsline.linearcollider.org

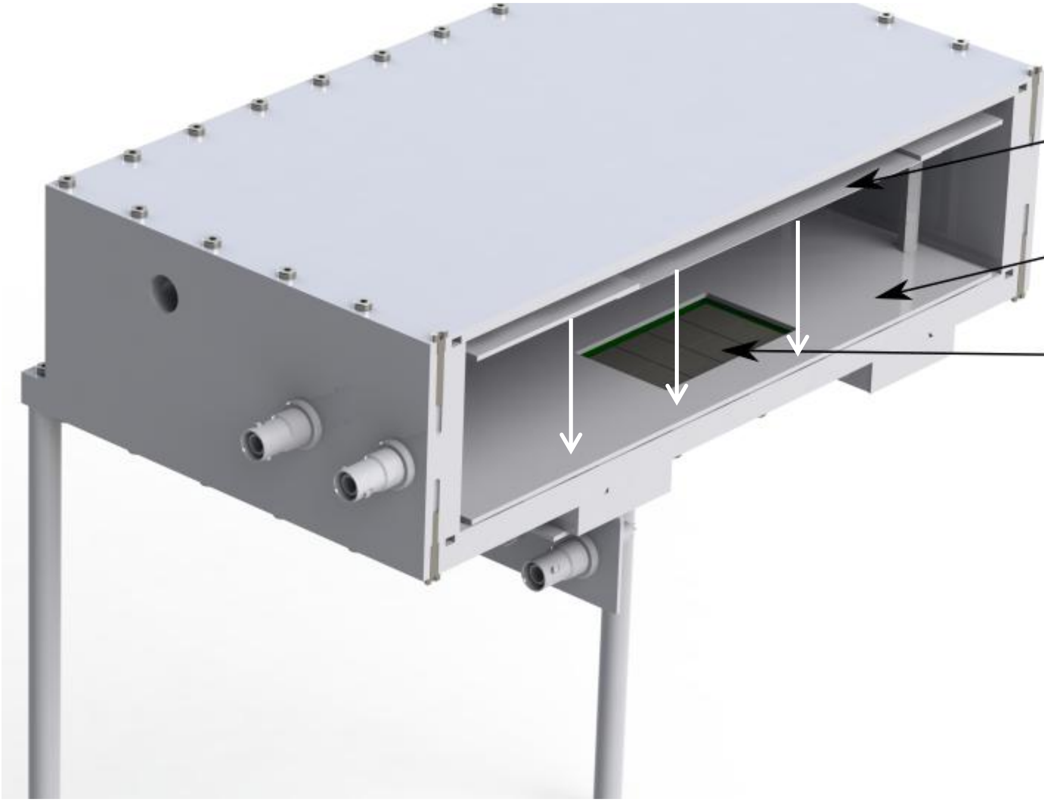
Detecting Neutrons



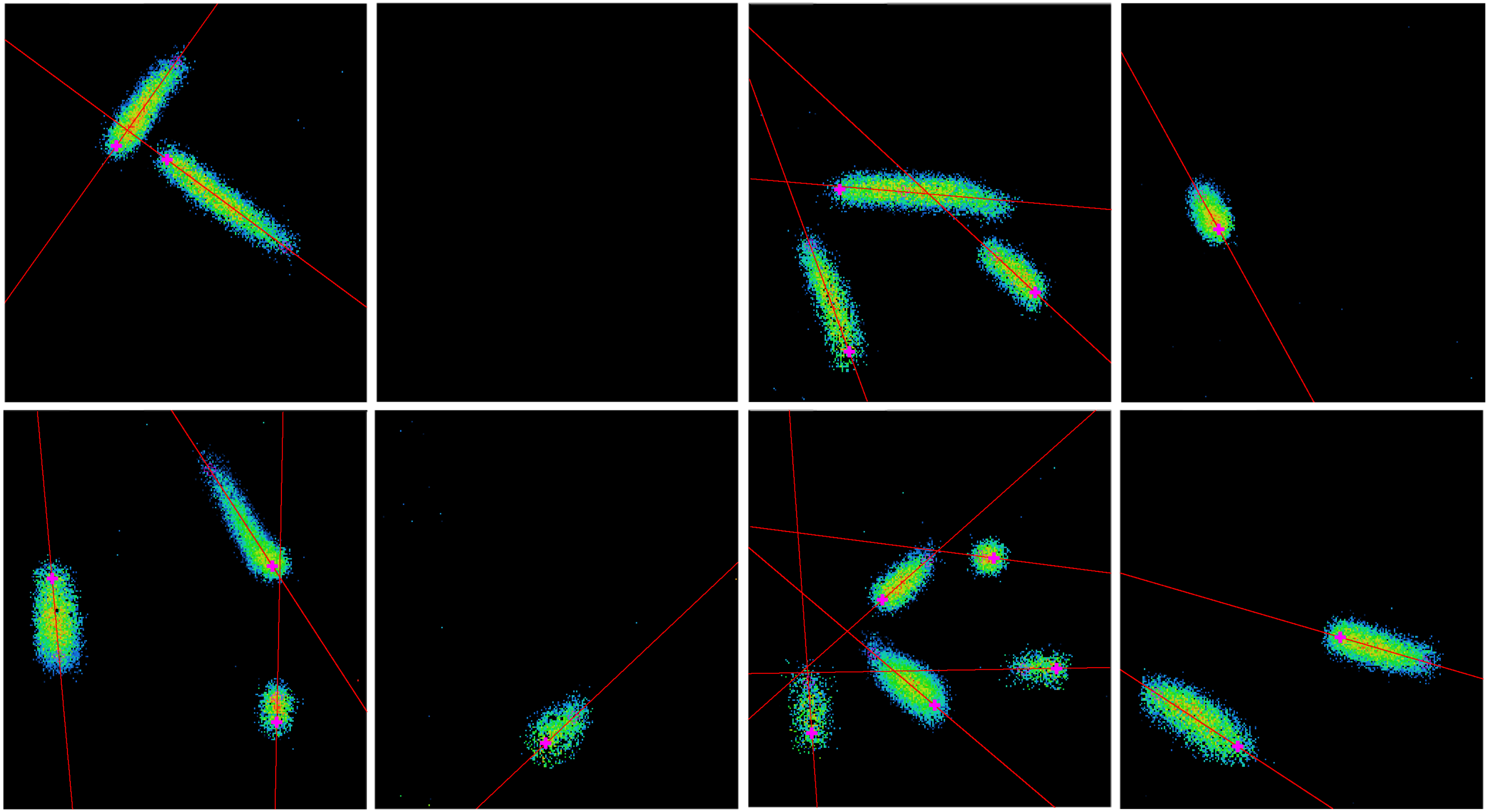
Test Detector



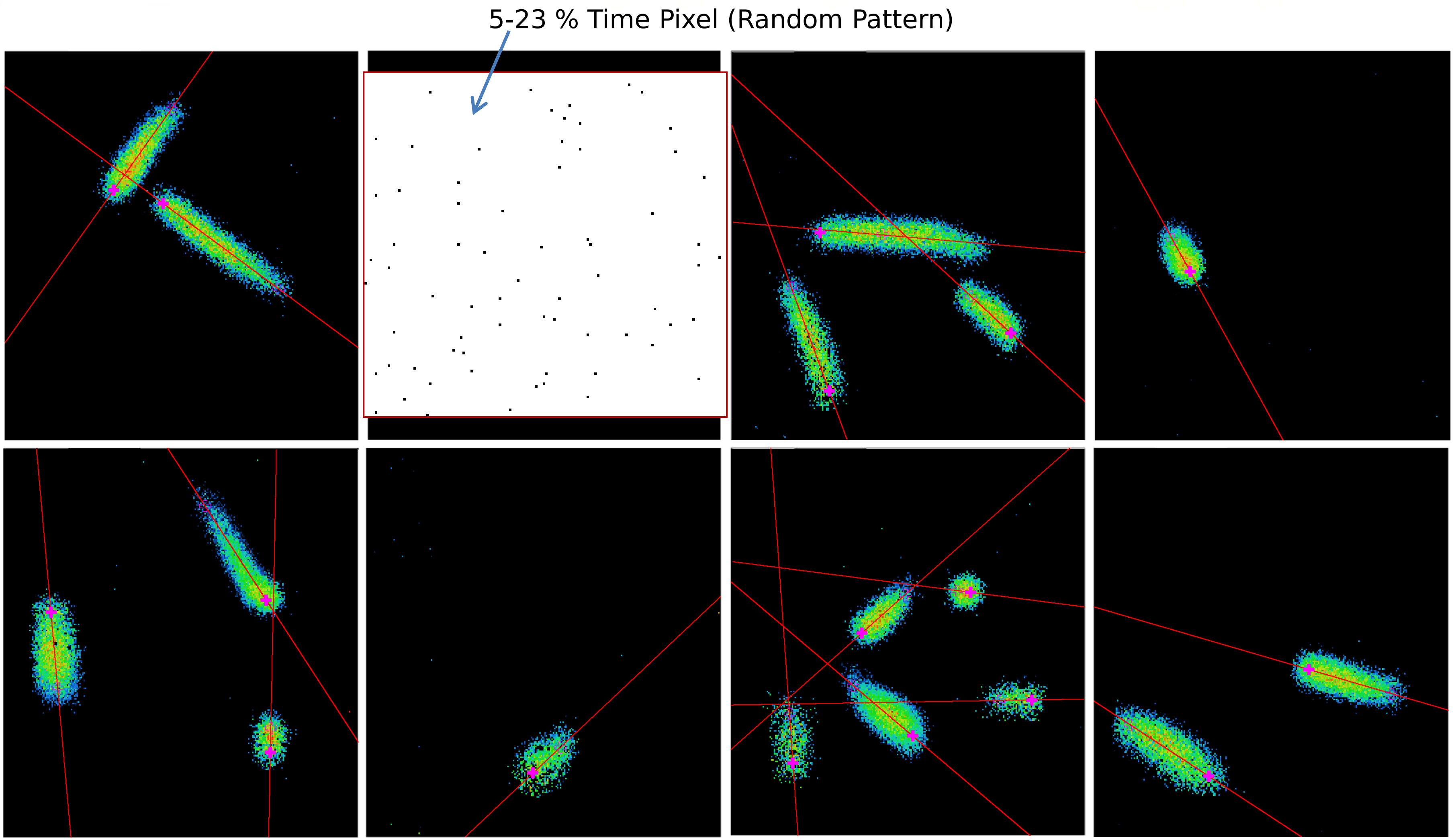
Test Detector



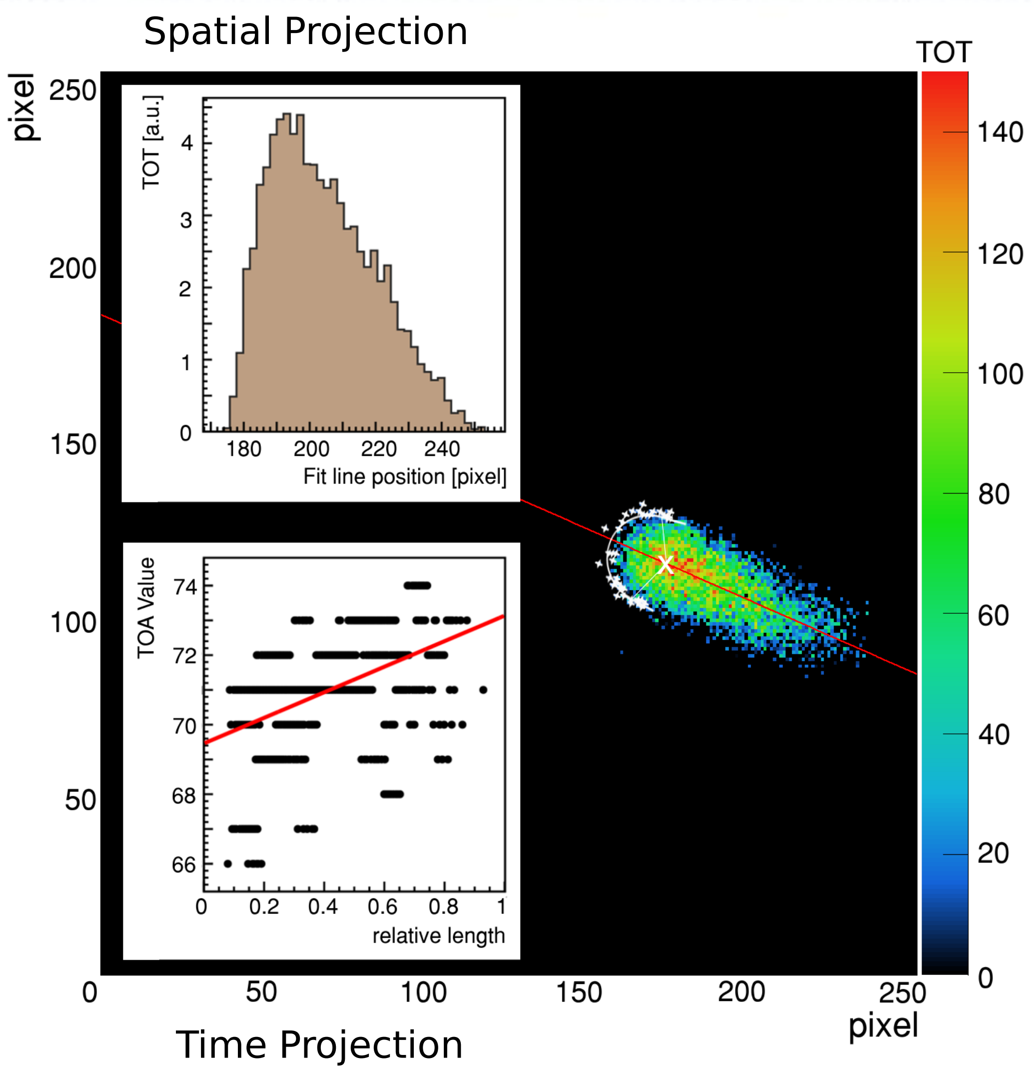
Neutron Conversion Tracks



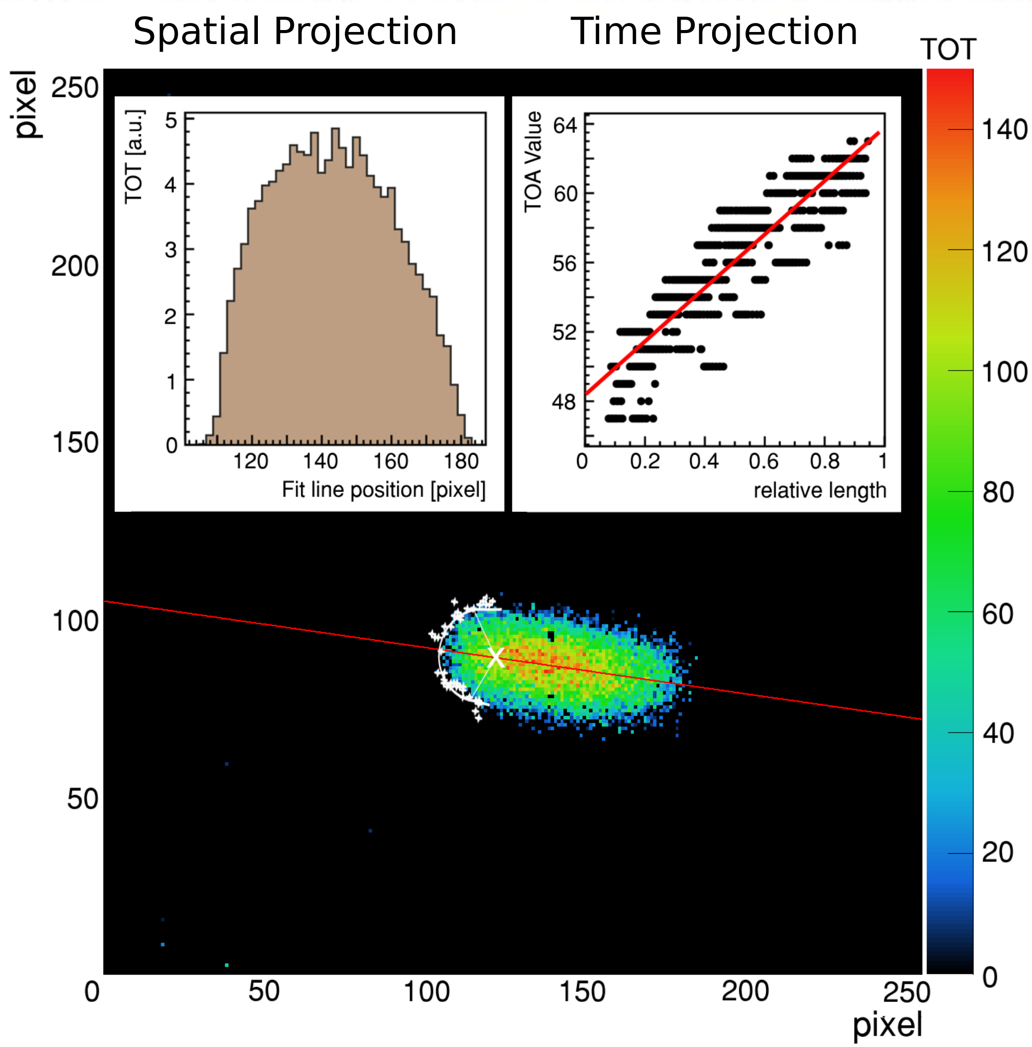
Neutron Conversion Tracks



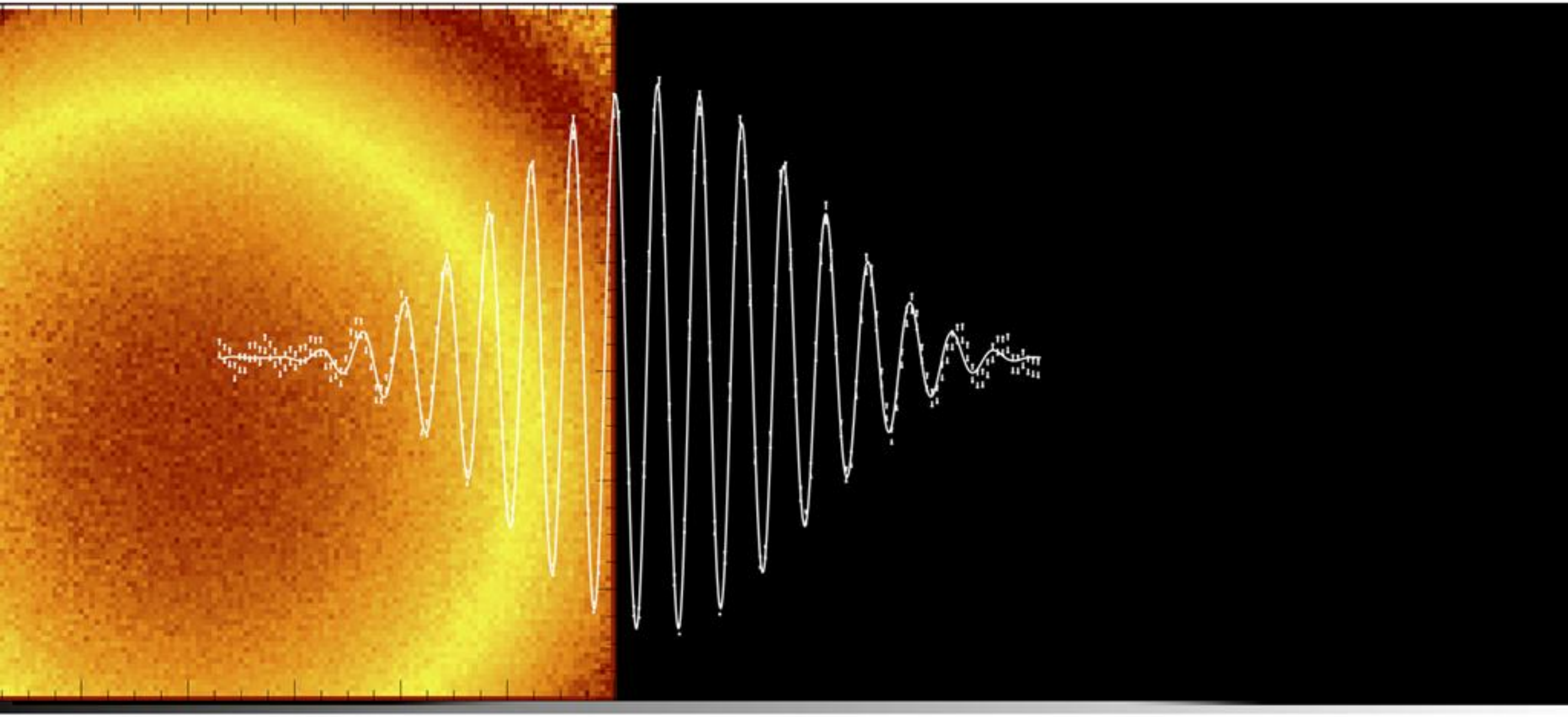
Event Example: Lithium



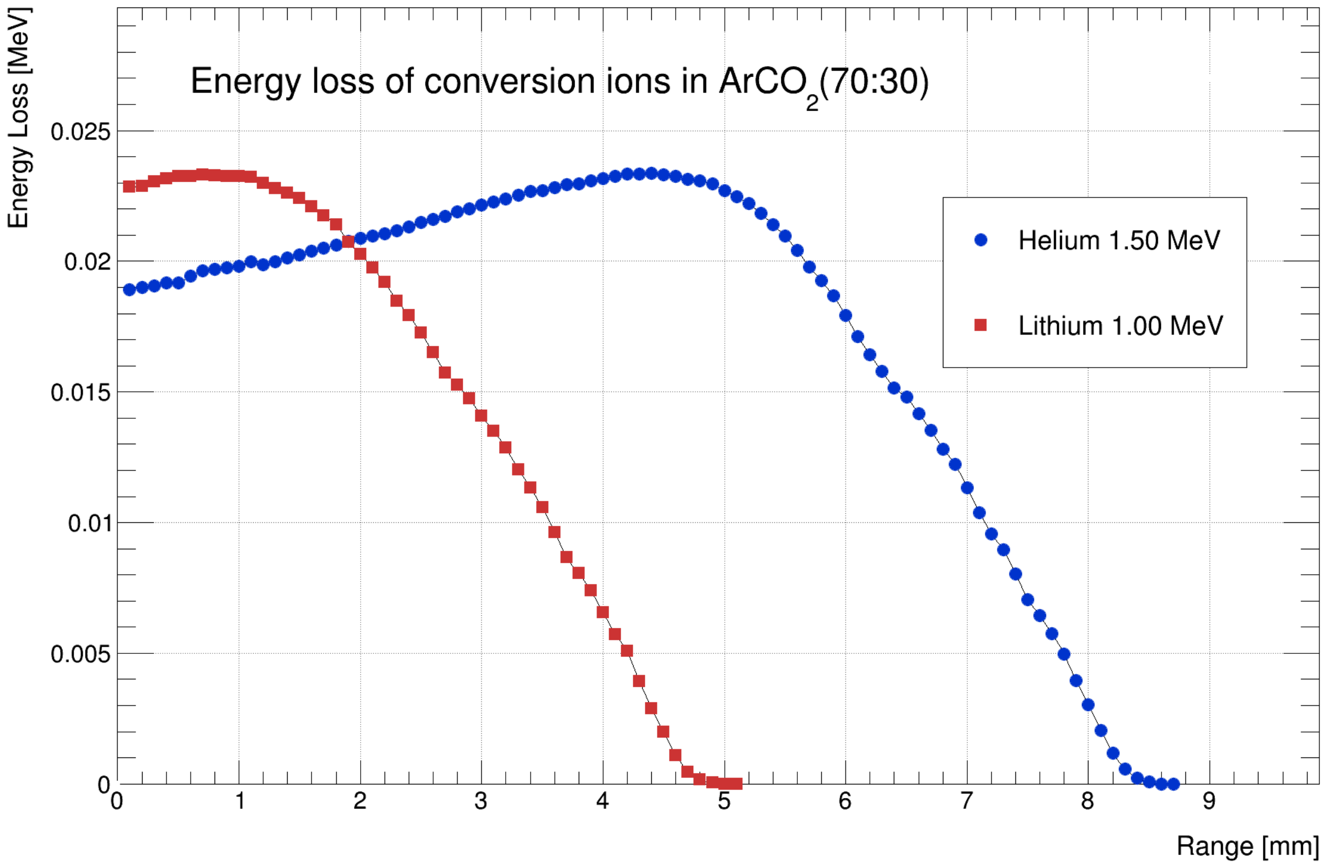
Event Example: Helium



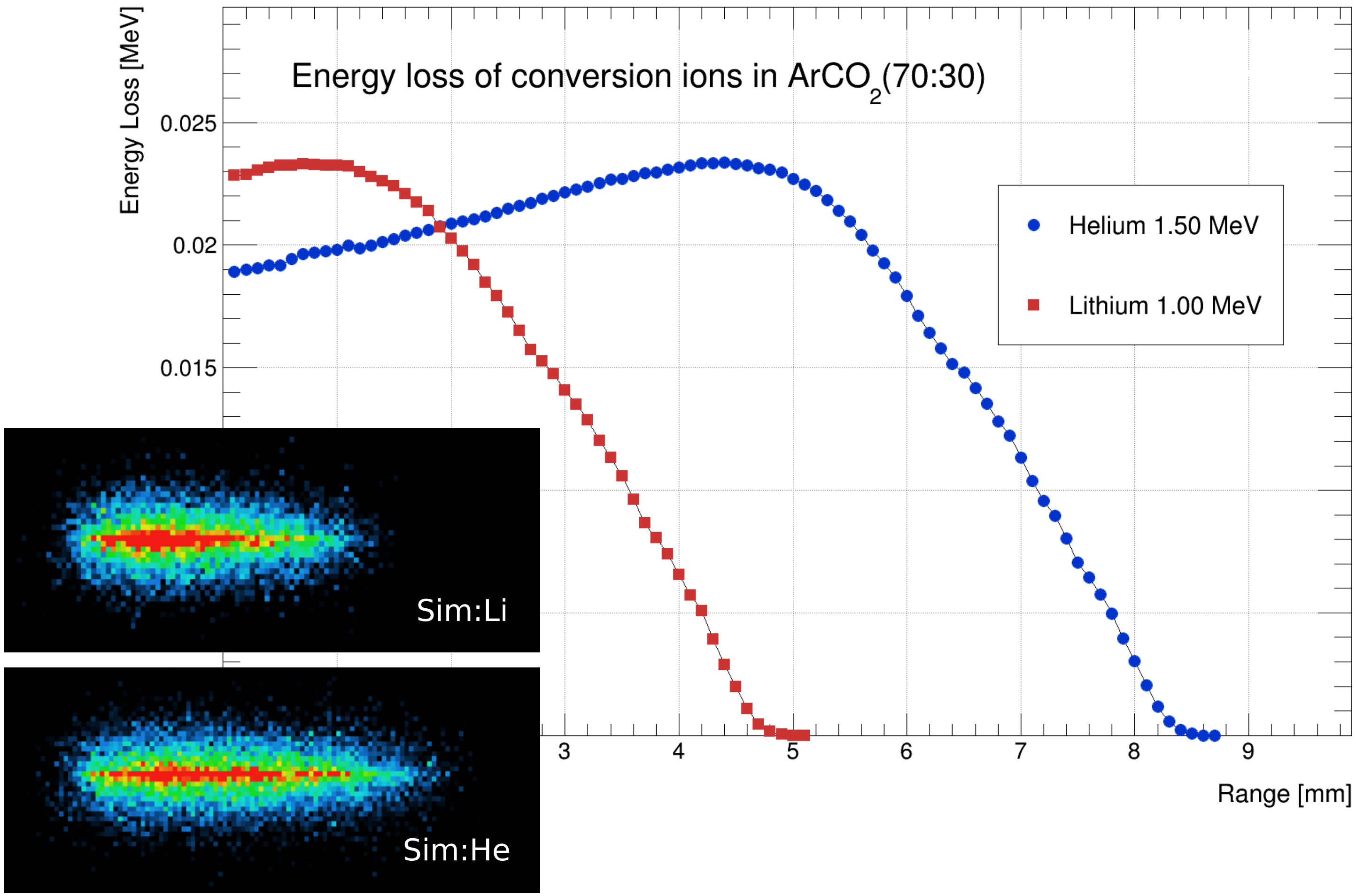
Analysis and Results



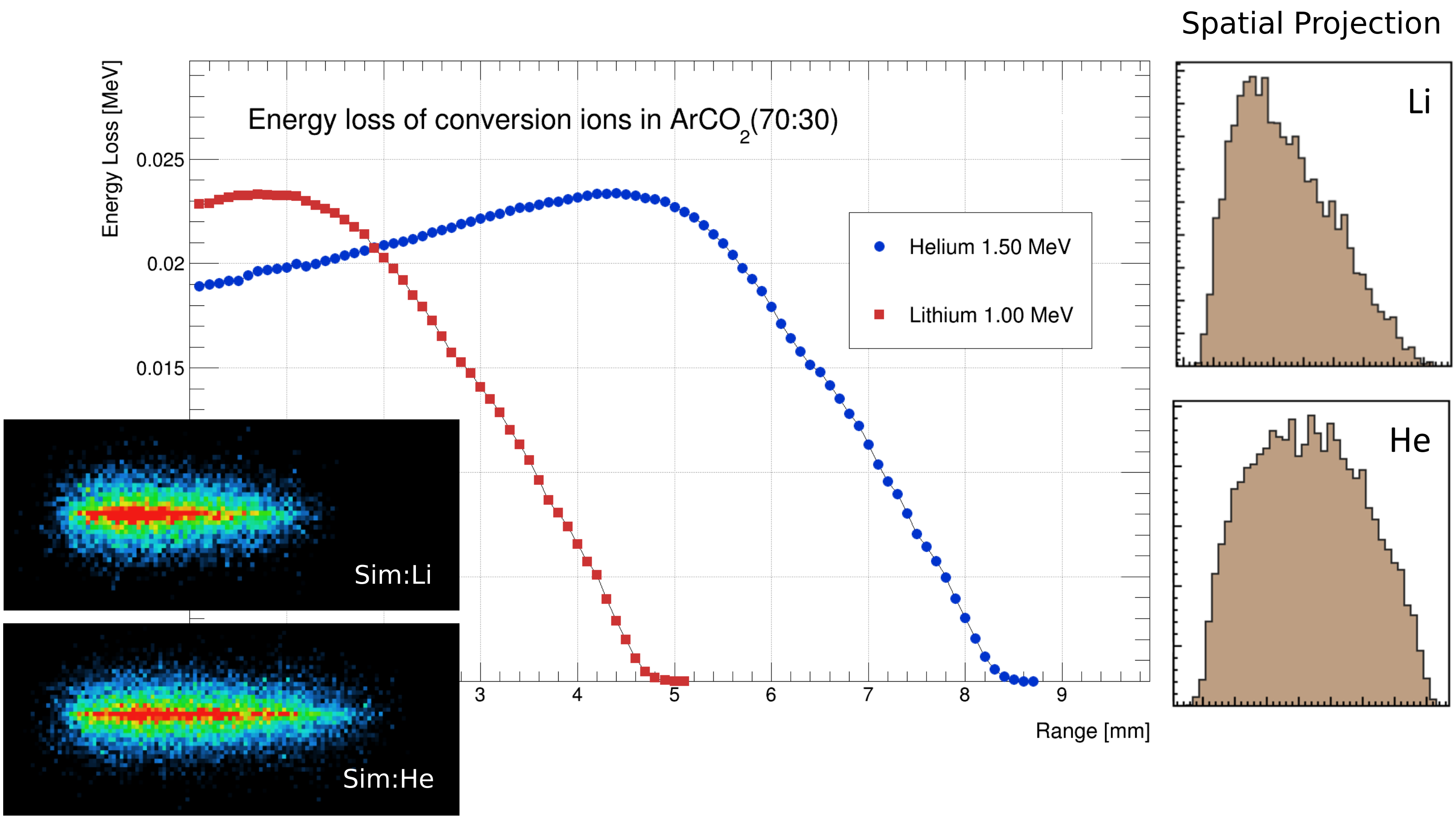
Energy Loss in Gas



Energy Loss in Gas

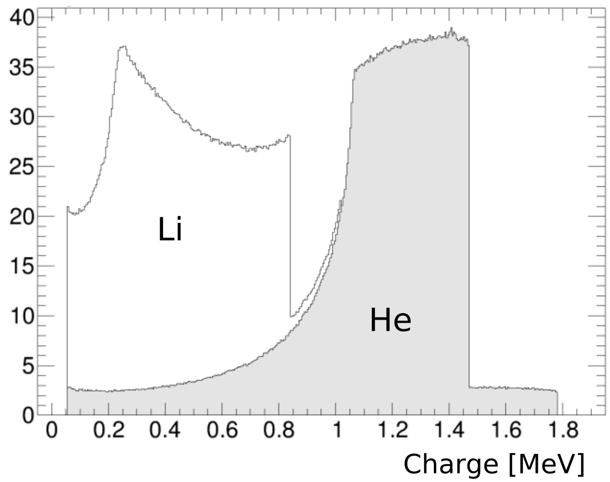


Energy Loss in Gas

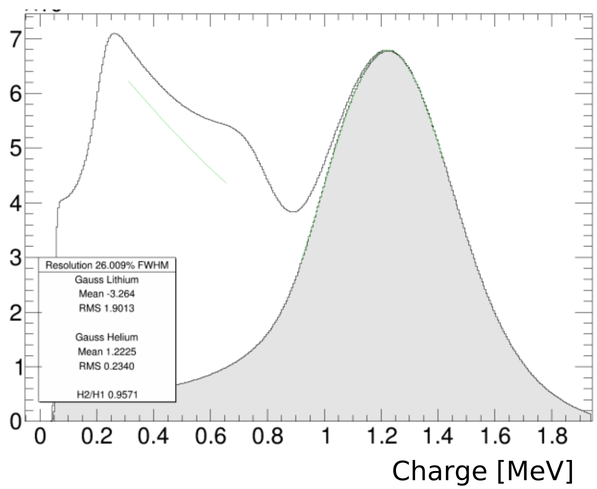


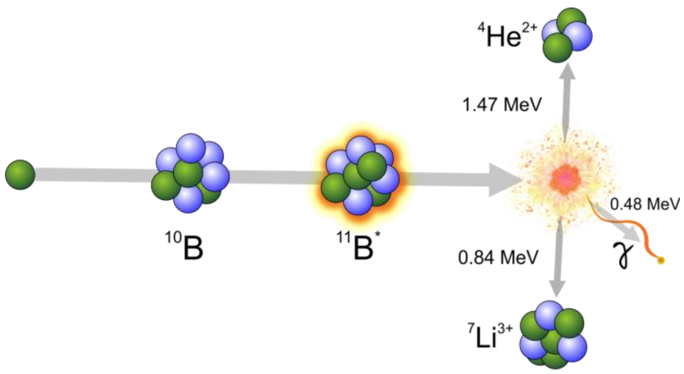
Energy Spectrum

Simulation: 1 µm Layer of Boron



Folded with 25 % FWHM





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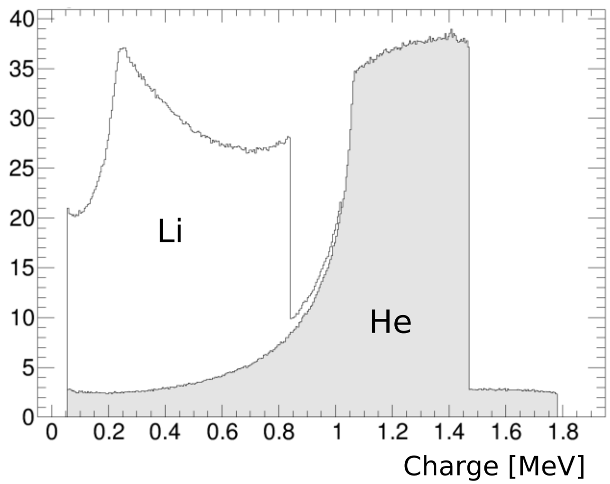
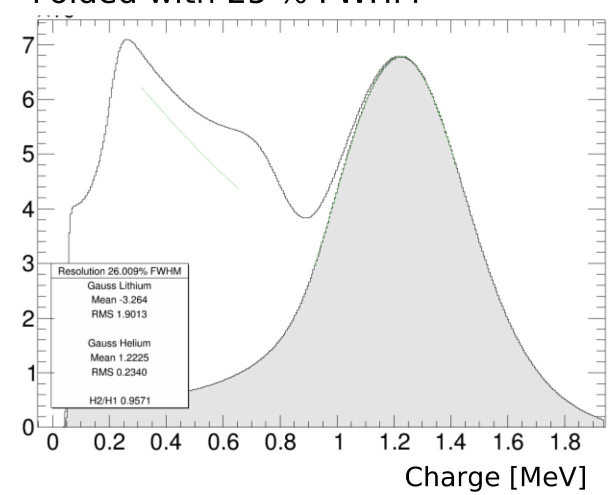
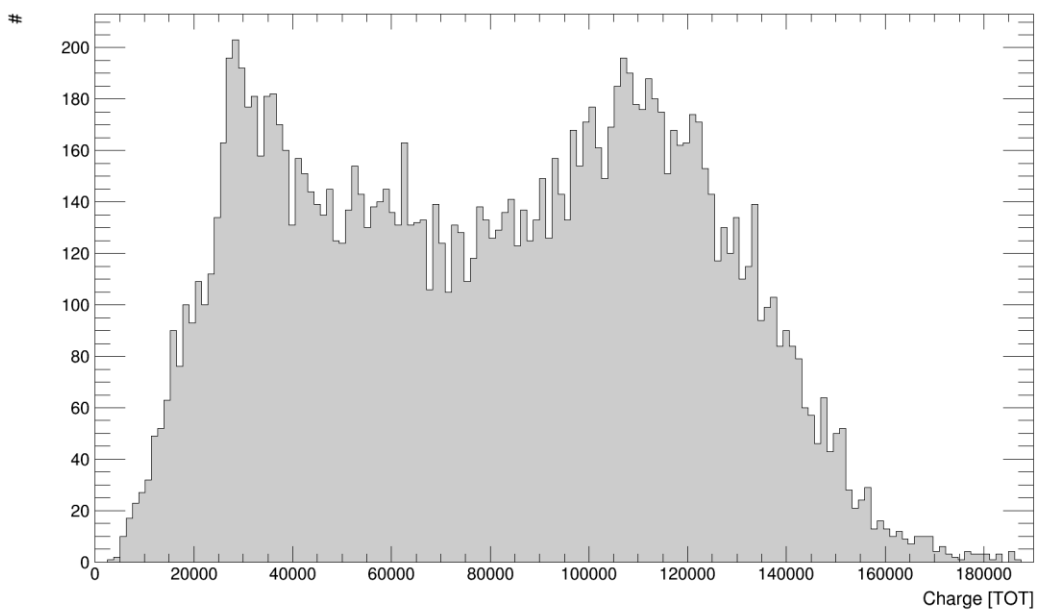


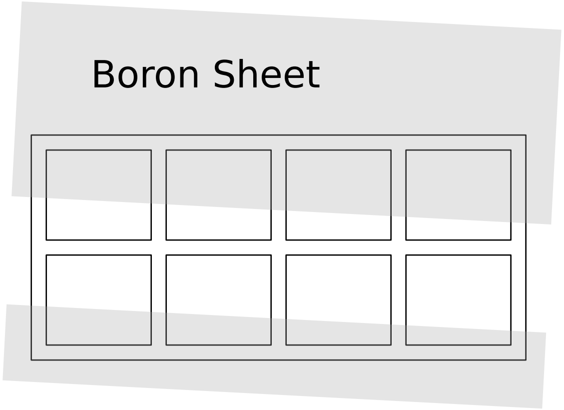
Folded with 25 % FWHM



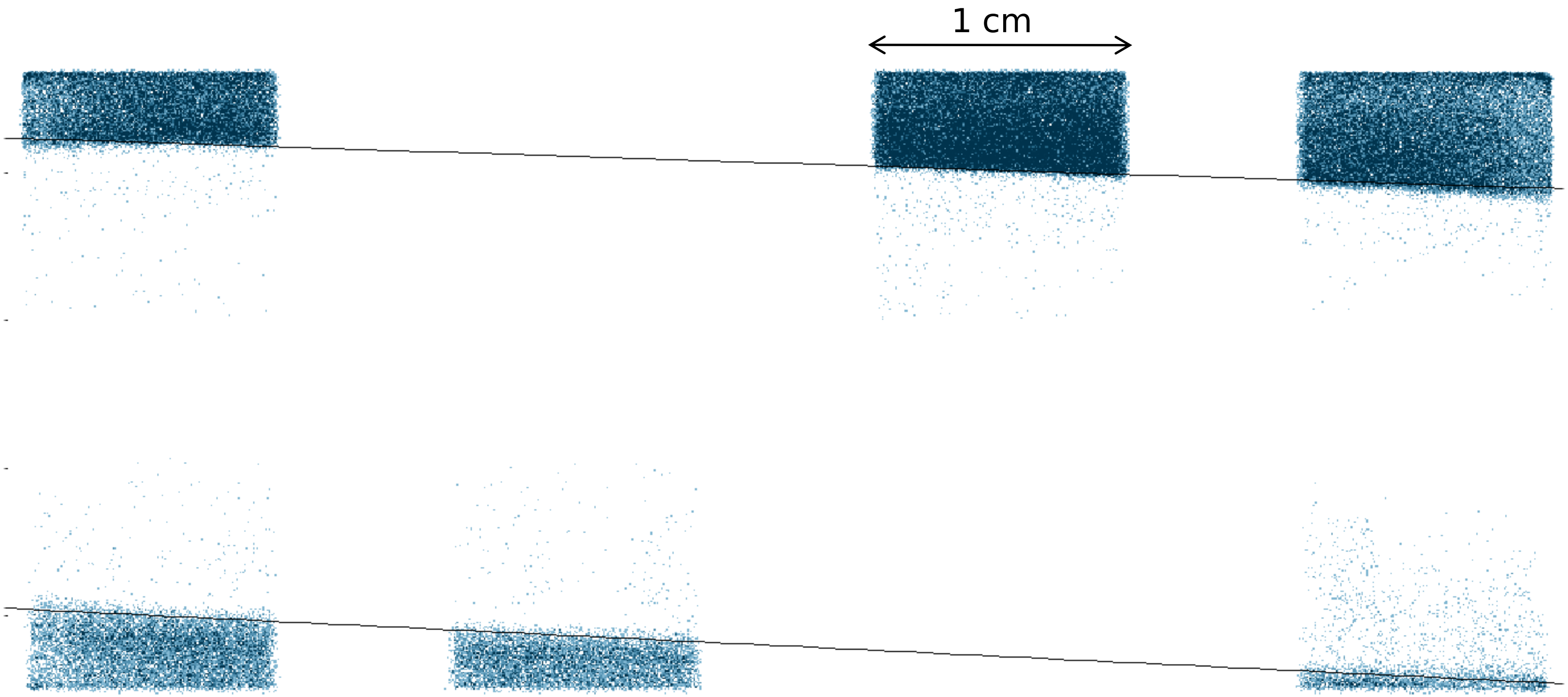
TOT Spectrum (fiducialized)



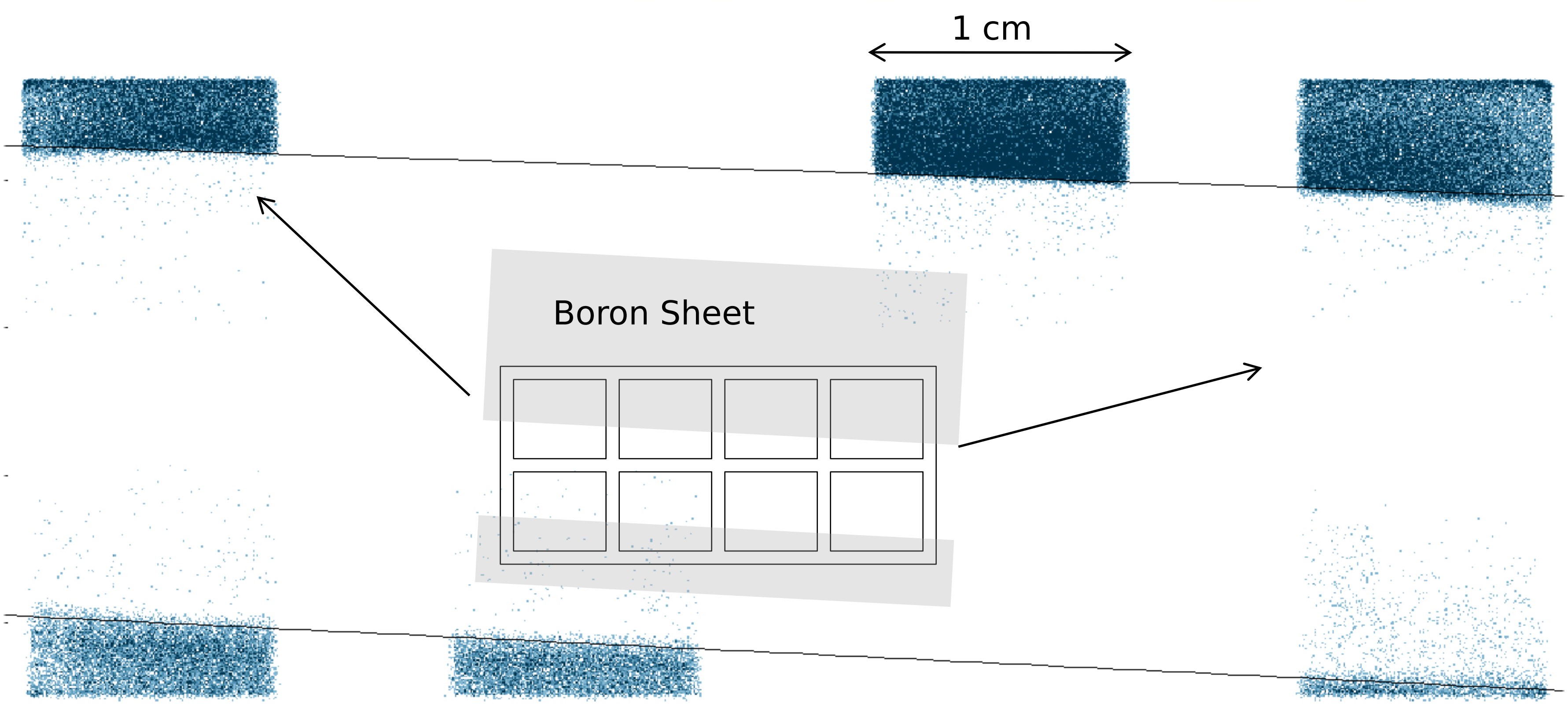
Spatial Resolution



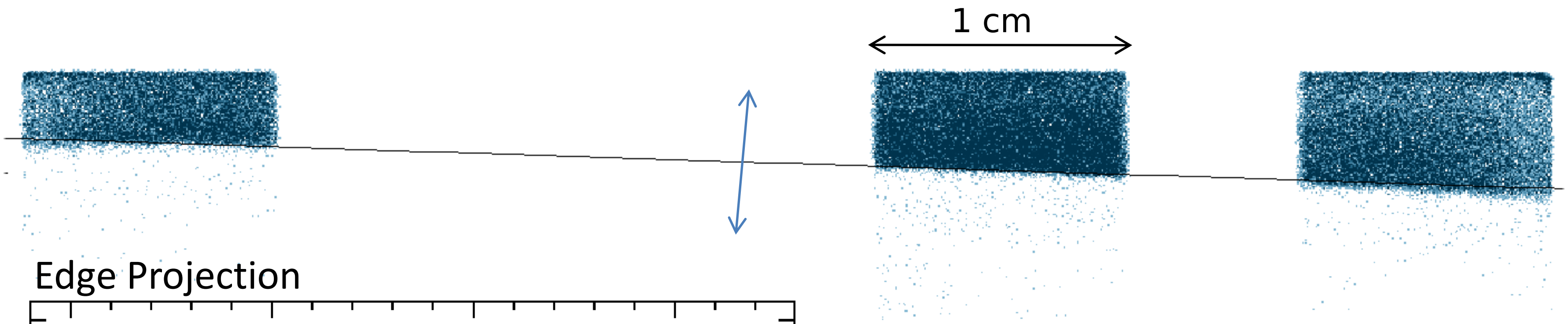
Spatial Resolution



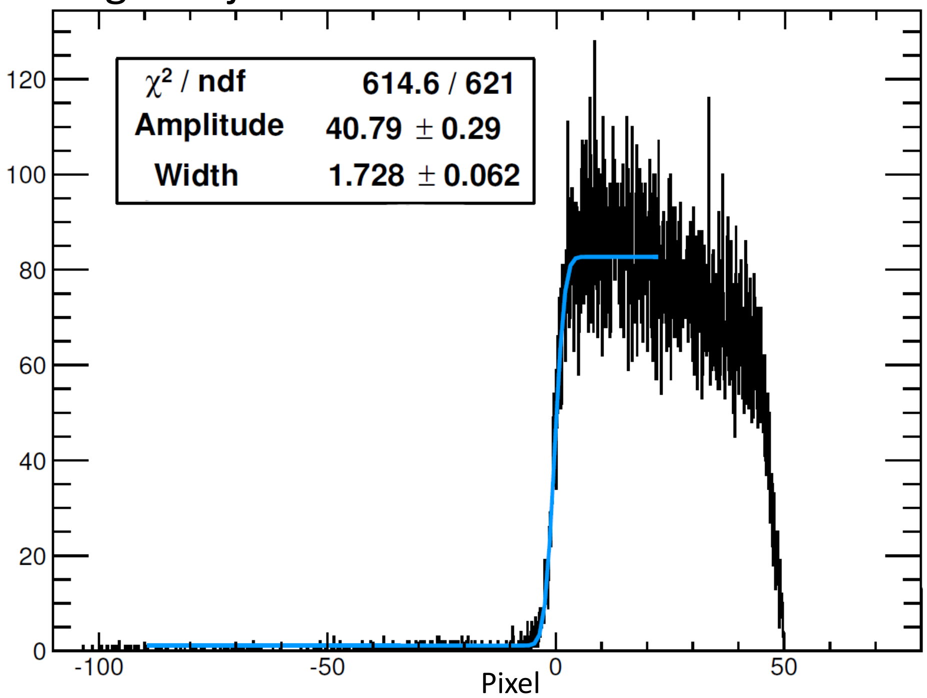
Spatial Resolution



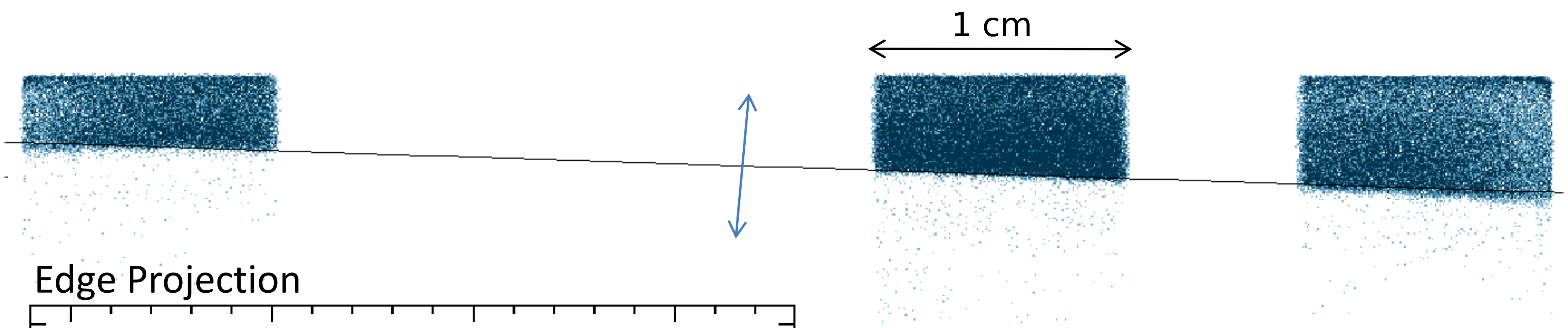
Spatial Resolution



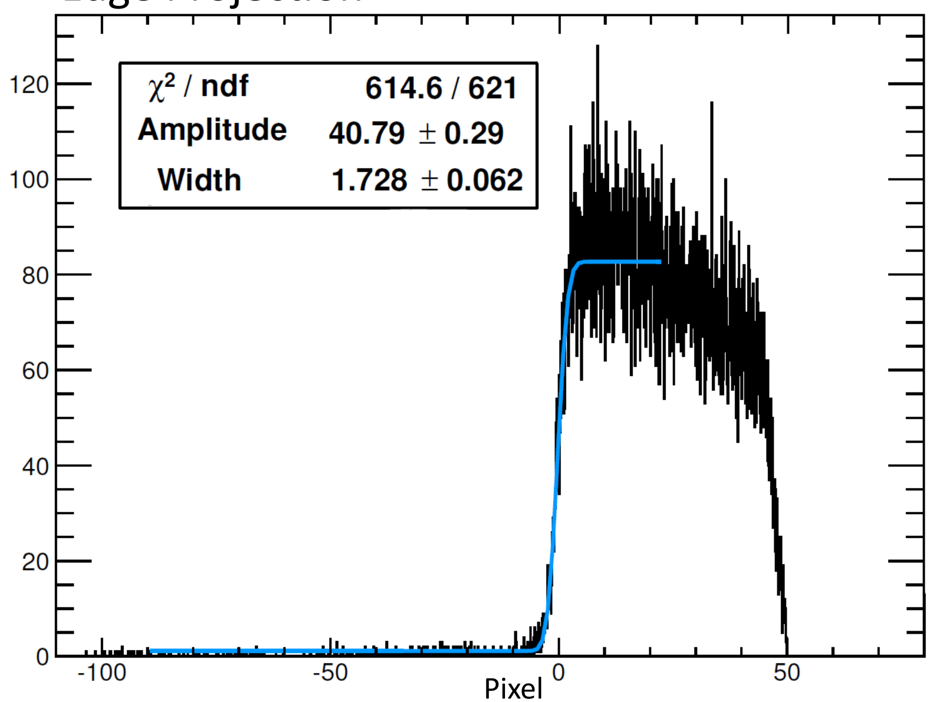
Edge Projection



Spatial Resolution



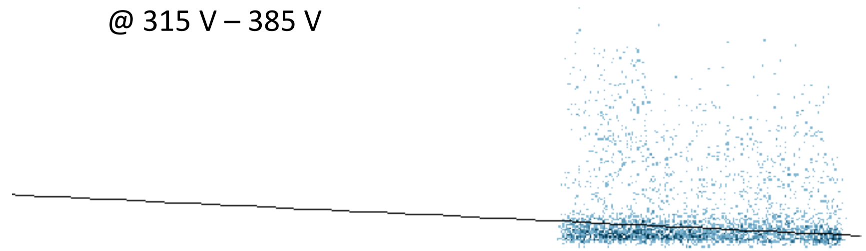
Edge Projection



Spatial Resolution σ

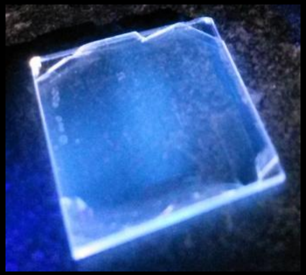
(95 +/- 4) µm

@ 315 V – 385 V



Summary

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



High Resolution Neutron Detection
The Neutron Time Projection Chamber

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Summary

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Markus Köhli

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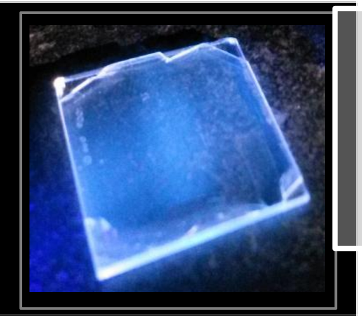
**Rheinische
Friedrich-Wilhelms-Universität
Bonn**



High Resolution Neutron Detection
The Neutron Time Projection Chamber

- Trigger & Track Principle

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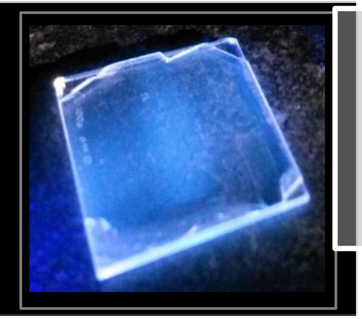

- Trigger & Track Principle
  - Using both conversion products

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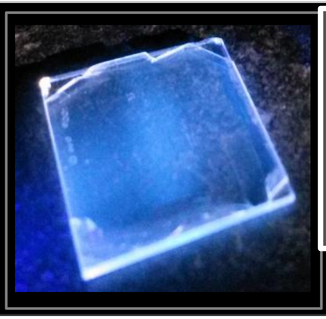

High Resolution Neutron Detection
The Neutron Time Projection Chamber

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

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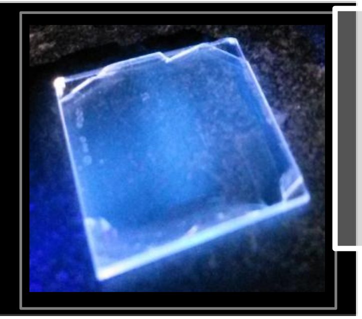

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  - Using both conversion products
  - Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]
  - [Spatial Resolution σ (95 +/- 4) µm]

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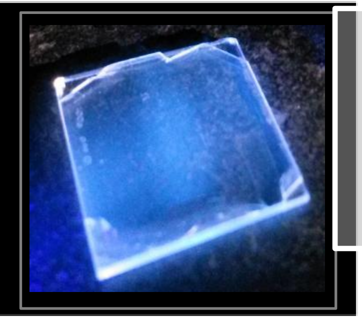

High Resolution Neutron Detection
The Neutron Time Projection Chamber

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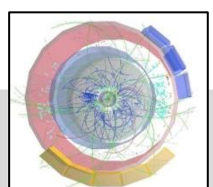

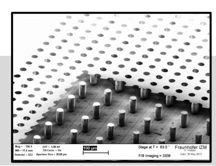

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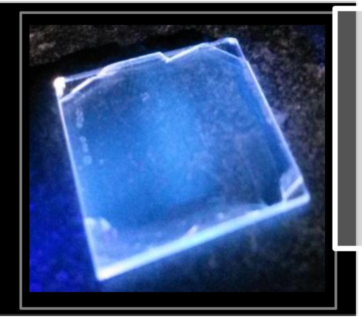

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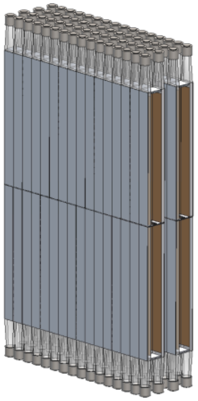
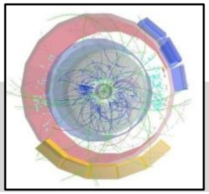
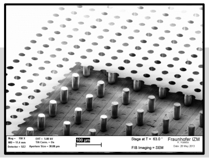
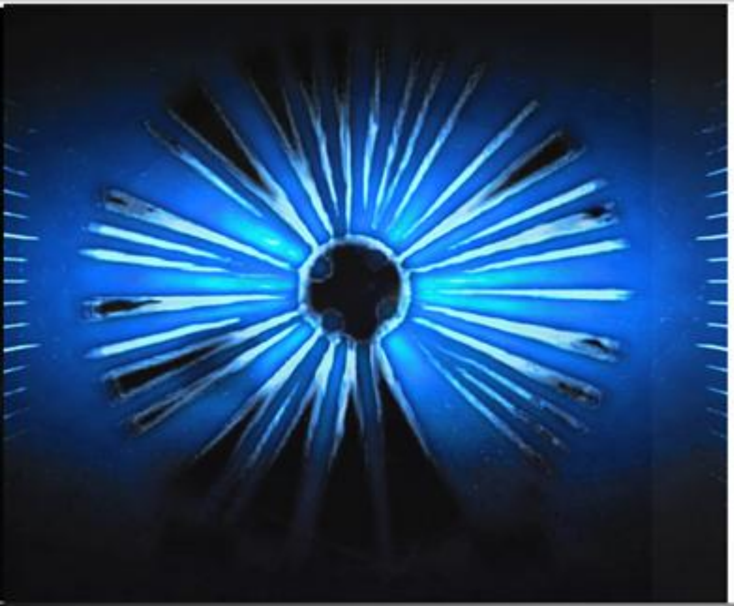






Backup



Detection Efficiency

Simulation of the 2D efficiency with different coating thicknesses