Pixel detectors with GaAs sensor and Timepix chip for radiation background measurements in the ATLAS cavern

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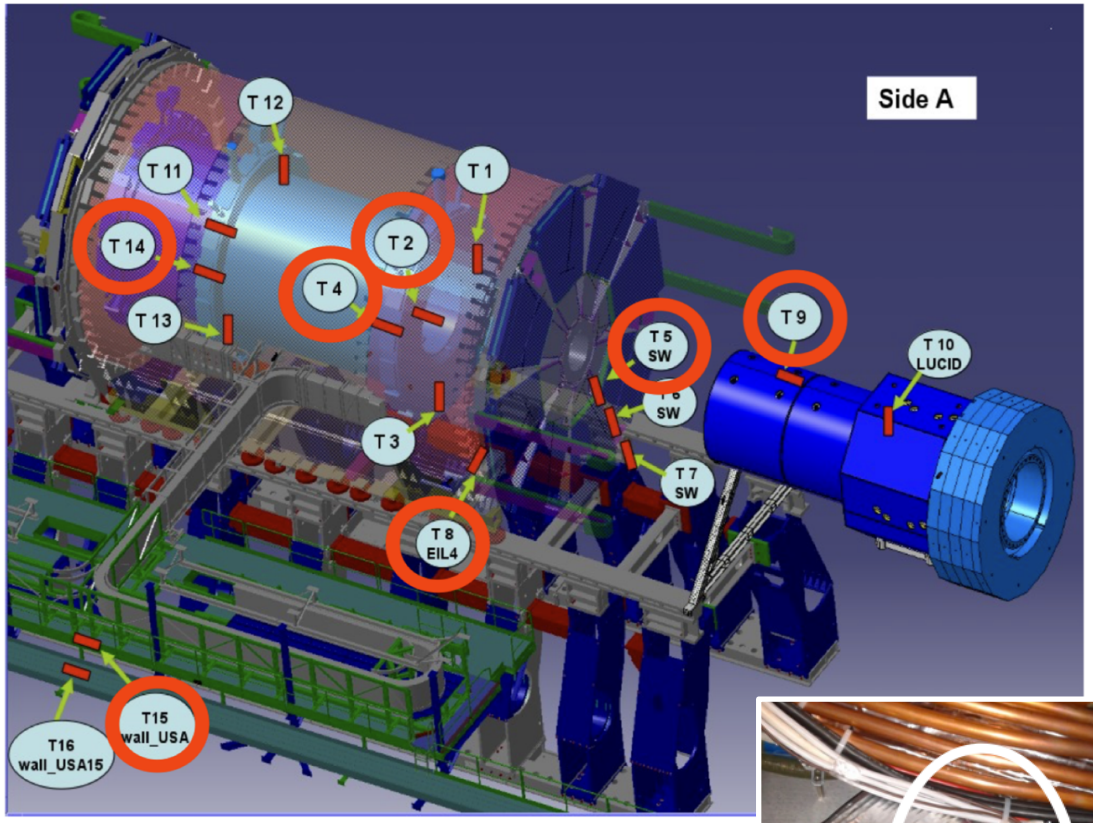
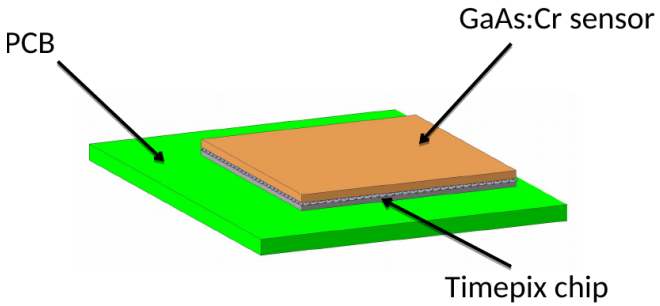
ATLAS-GaAsPix Network

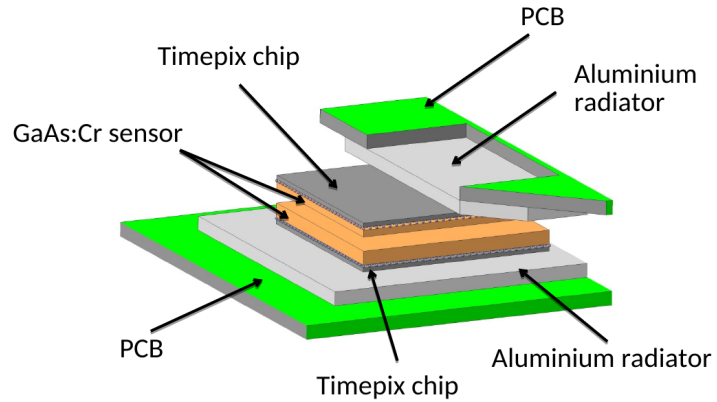


Detectors location around the ATLAS detector

Single detector

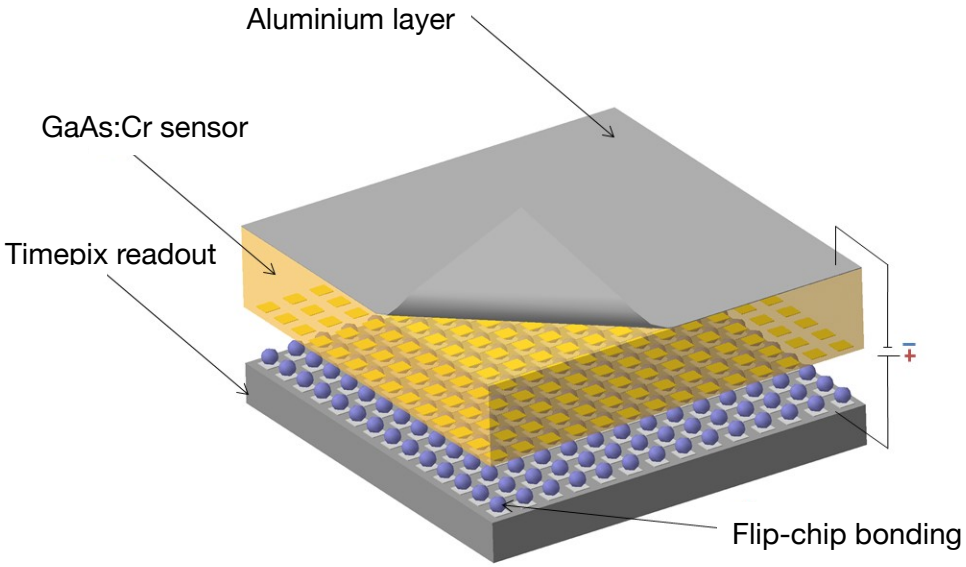


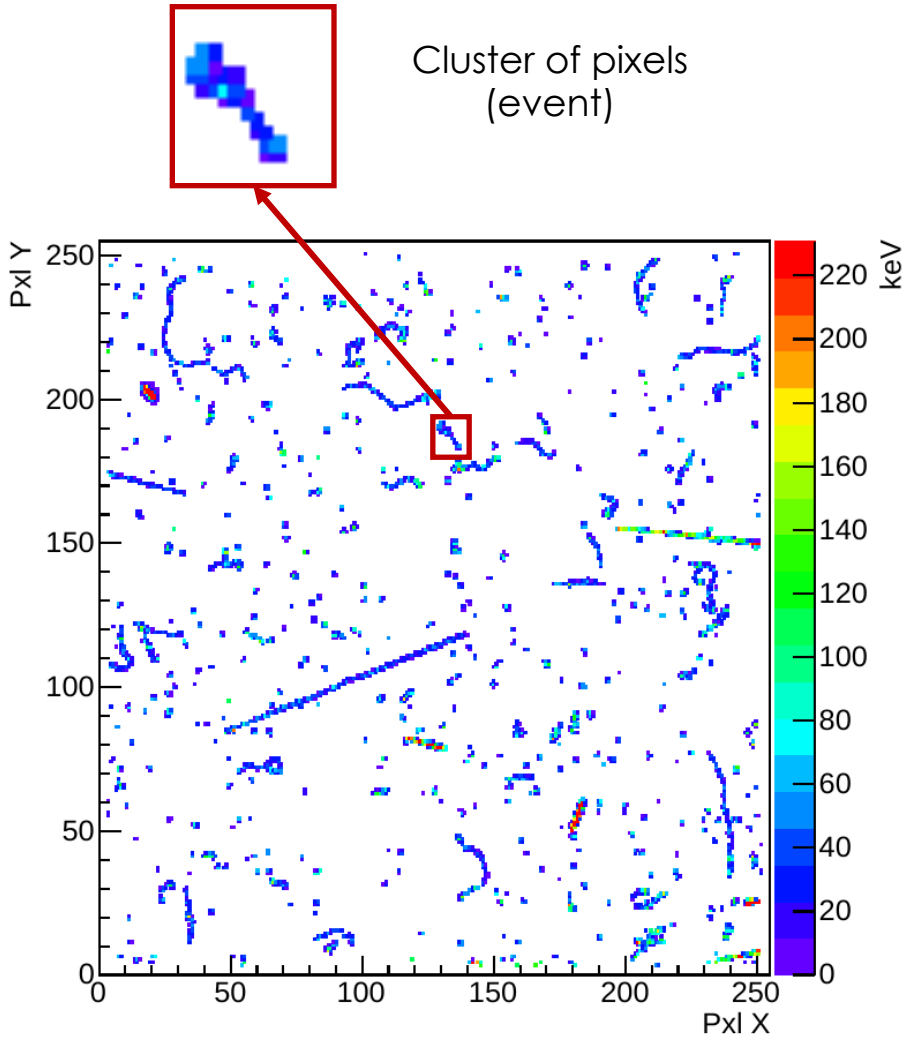
Twin detector



- 10 pixel detectors with Timepix chip and GaAs:Cr sensor were mounted in 2016
- Purpose: to extent the existing ATLAS-TPX detector system with Si sensor in background radiation studies
- Operated during 2017-2018

Timepix detector



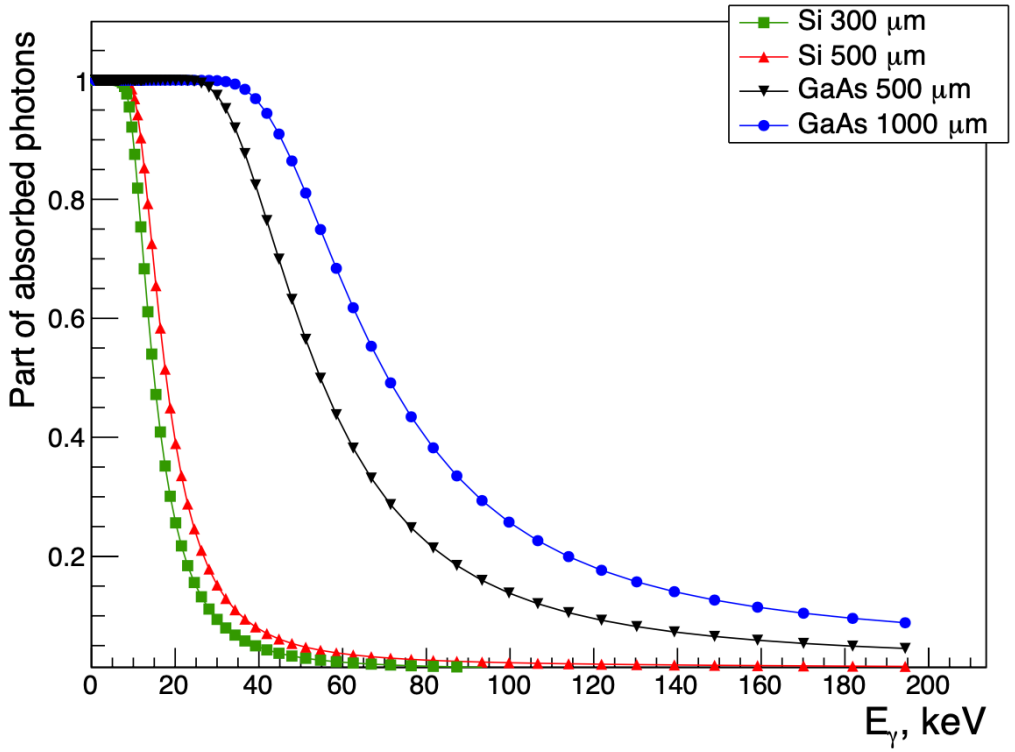


One frame

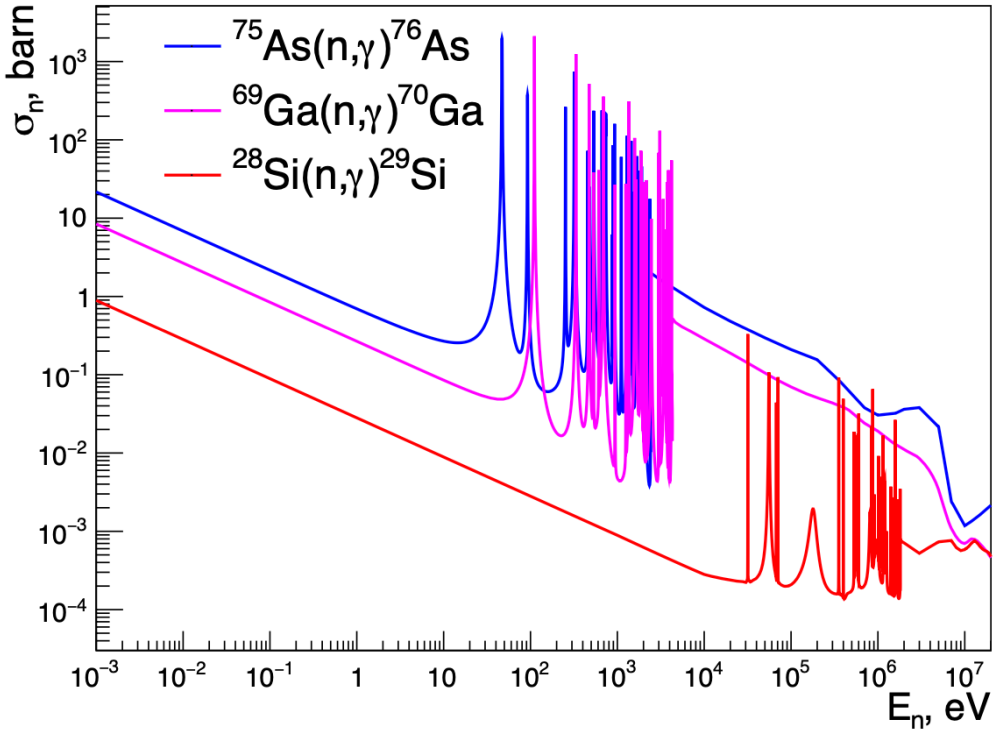
- 256x256 pixels
- 65536 independent channels
- Pixel size: (55x55) μm^2
- Sensor size: (14.1x14.1) mm^2
- Sensor thickness: 500μm and 1000 μm
- Mode of operation: timepix (energy) mode

GaAs:Cr sensor

X-ray and gamma absorption efficiency of GaAs and Si sensors



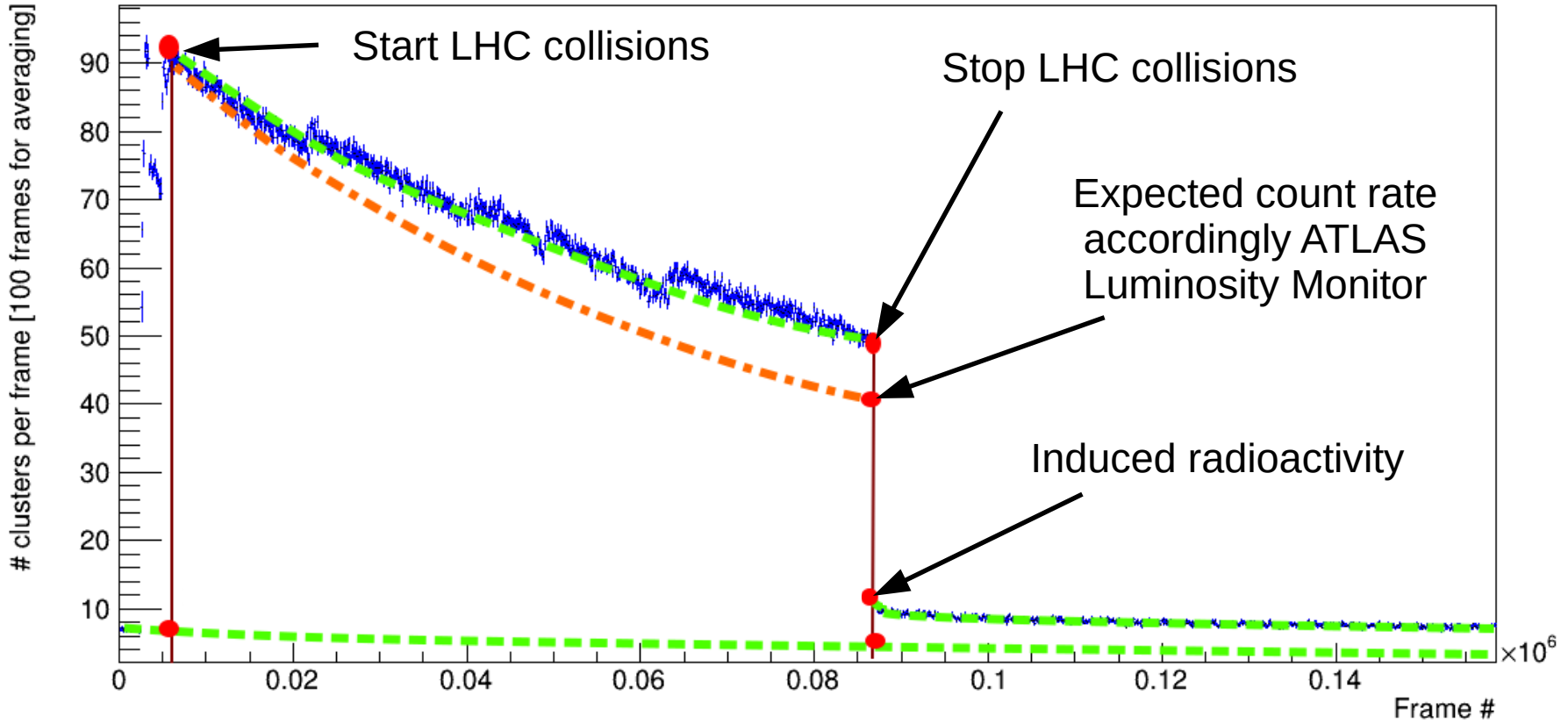
The cross sections for neutron capture of ^{28}Si, ^{69}Ga and ^{75}As



- Higher registration efficiency of gamma and X-ray radiation with energies above 20-30 keV
- Stronger radiation hardness
- Easier activated by neutrons

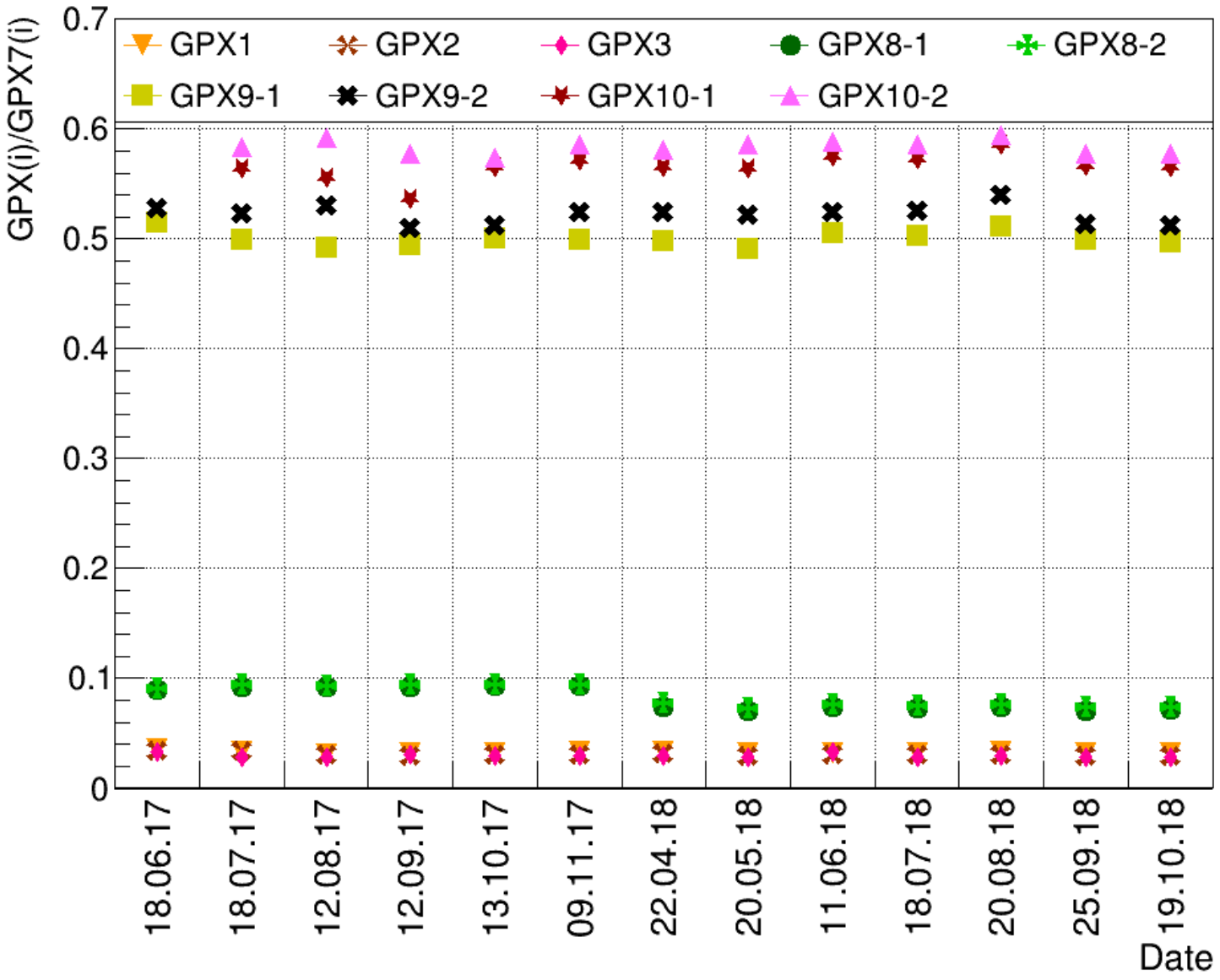
Data collection

The cluster (event) rate of the GPX1 detector (blue point) in collisions-on and collisions-off periods



- Data collected in 2017-2018
- LHC beam-on data used for normalised radiation levels measurement and charged and neutral radiation components calculations
- LHC beam-off data used for the estimation of neutron fluence by GaAs induced radioactivity

Normalised radiation levels in the period 2017–2018

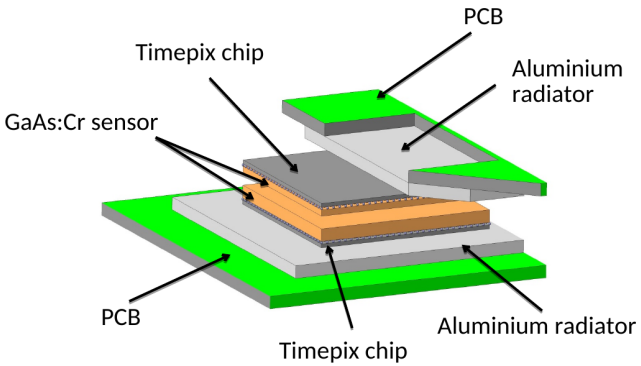


Cluster counts in each detector normalized on cluster counts of GPX7-1 ($1000\mu m$) and GPX7-2 ($500\mu m$) in accordance with the thickness of the sensor.

- The data demonstrate reasonable stability with time permitting averaging over the entire running period 2017— 2018

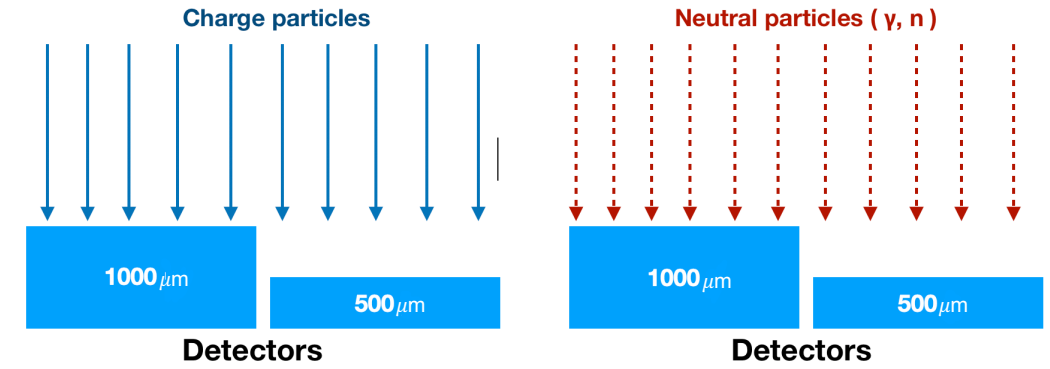
Charged and neutral radiation components

Twin detector



Assumptions:

- Neutral components is dominated by γs with energies above 60 keV
- Registration efficiency of charged particles is 100%
- Registration efficiency of neutral particles linearly depends on the sensor thickness



ε (Charge) ~ 100% and does not depend on the thickness of the detector

ε (500 μmCharge) = ε (1000 μmCharge)

ε (Neutral) ~ strongly depends on the thickness of the detector

ε (500 μmNeutral) = 0,5 ε (1000 μmNeutral)

Estimation of the charged and neutral radiation components

Detector #	N_{tot} (1000 μm) / N_{tot} (500μm)	$N_{charged}$	$N_{neutral}$
1 2	1.62 ± 0.04	0.24 ± 0.03	0.76 ± 0.03
7-1 7-2	1.7 ± 0.1	0.17 ± 0.09	0.83 ± 0.09
9-1 9-2	1.7 ± 0.1	0.18 ± 0.08	0.82 ± 0.08
10-1 10-2	1.676 ± 0.008	0.194 ± 0.006	0.806 ± 0.006
8-1 *8-2*	*0.96 ± 0.08*	-	-

$$N_{Total}(1000um) = N_{Charged} + N_{Neutral}$$
$$N_{Total}(500um) = N_{Charged} + 0.5N_{Neutral}$$
$$N_{Charged} + N_{Neutral} = 1$$

$$N_{neutral}(1000) = 2\,\frac{1 - N_{total}(500)}{N_{total}(1000)}$$

$$N_{charged}(1000) = \frac{2N_{total}(500)}{N_{total}(1000)} - 1$$

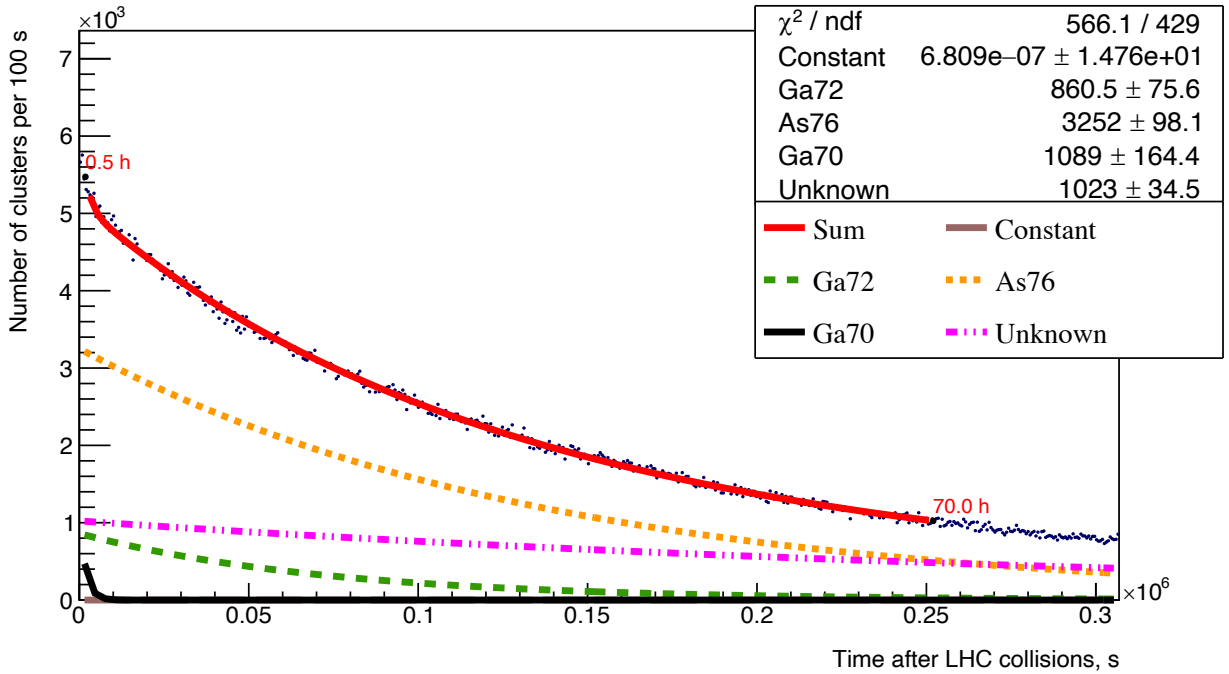
Average estimated ratio of neutral/charged particles is 80% / 20%

GaAs activation

$$^{71}\mathrm{Ga} + \mathrm{n} \rightarrow {}^{72}\mathrm{Ga} \rightarrow \mathrm{e}^{-}\ (3{,}997\ \mathrm{MeV}) + {}^{72}\mathrm{Ge}\ (T_{1/2} = 14, 11\ \mathrm{h}),$$
$$^{75}\mathrm{As} + \mathrm{n} \rightarrow {}^{76}\mathrm{As} \rightarrow \mathrm{e}^{-}\ (2{,}962\ \mathrm{MeV}) + {}^{76}\mathrm{Se}\ (T_{1/2} = 26, 26\ \mathrm{h}),$$
$$^{69}\mathrm{Ga} + \mathrm{n} \rightarrow {}^{70}\mathrm{Ga} \rightarrow \mathrm{e}^{-}\ (1{,}65\ \mathrm{MeV}) + {}^{70}\mathrm{Ge}\ (T_{1/2} = 21, 13\ \mathrm{m}).$$

Data taking periods:
- 30.06.2017 – 03.07.2017
- 20.08.2018 – 23.08.2018
- 26.09.2018 – 29.09.2018

$$f(t) = P_0 + P_1 \exp(-\lambda_{\mathrm{Ga72}} t) + P_2 \exp(-\lambda_{\mathrm{As76}} t) + P_3 \exp(-\lambda_{\mathrm{Ga70}} t) + P_4 \exp(-\lambda_4 t) \quad (1)$$



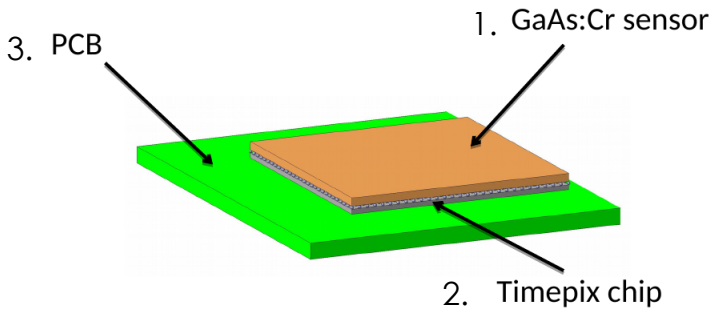
Fit of the time dependence of the response of GPX8-1 in the period 20.08.2018– 23.08.2018 with the function (1)

Fit results for the 1st period:

Run	GPX	Const (p0)	^{72}Ga(p1)	^{76}As(p3)	^{70}Ga(p5)	Long (p7)	p1+p3+ p5+p7	Error
	1	5.8%	21.3%	0.0%	37.4%	35.5%	94.2%	2.9%
LHC	2	0.0%	38.2%	6.9%	43.3%	11.6%	100.0%	1.8%
30.06.17	7-1	0.0%	31.5%	19.0%	39.6%	9.9%	100.0%	1.1%
until	7-2	0.0%	30.4%	21.1%	39.6%	9.0%	100.0%	1.4%
03.07.17	8-1	0.0%	25.8%	33.6%	32.3%	8.4%	100.0%	0.4%
	8-2	0.0%	25.8%	31.2%	34.9%	8.1%	100.0%	1.8%
	9-1	0.0%	35.5%	20.2%	35.8%	8.5%	100.0%	1.6%
	9-2	0.0%	32.6%	24.7%	35.2%	7.5%	100.0%	2.1%

The half-life time of the 4th component is determined as 65 h.

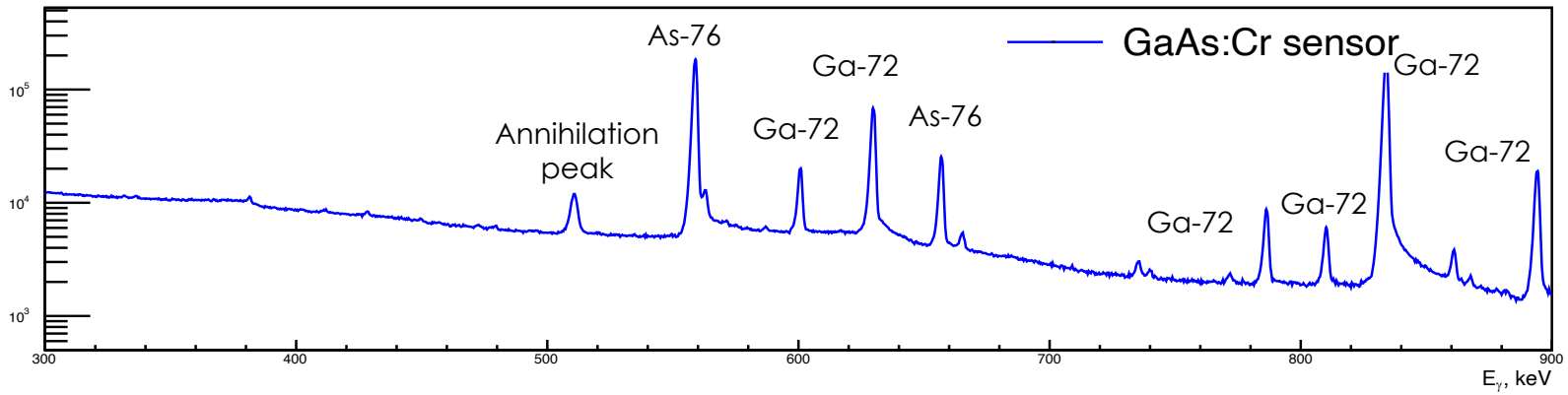
Neutron activation analysis

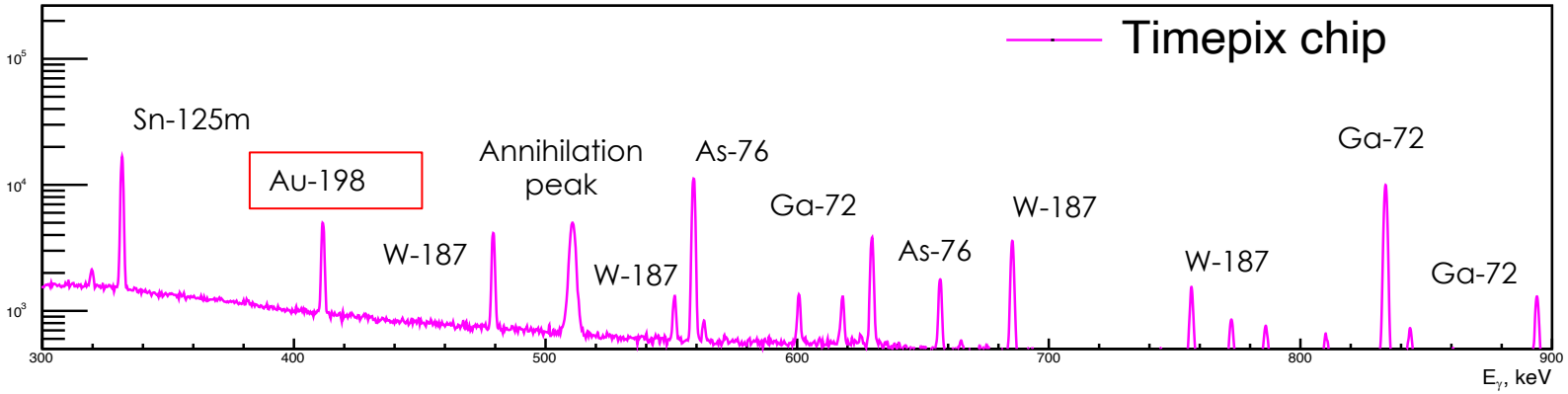


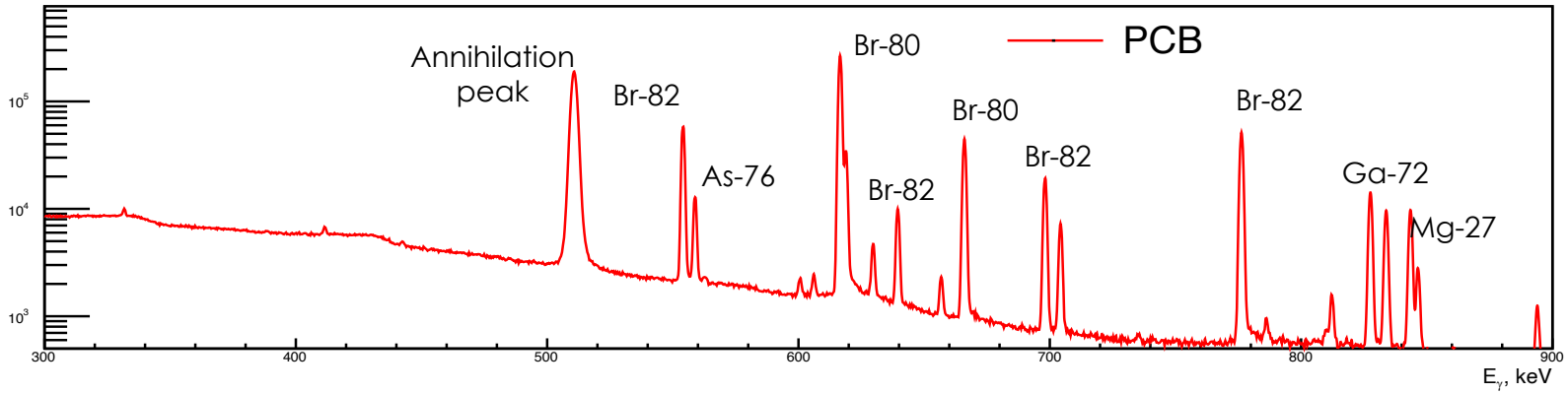
Additional analysis

An other similar detector was broken into three parts: GaAs:Cr sensor layer, Timepix chip, and PCB

The decay process of ^{198}Au ($T_{1/2}$ = 65.5 h) was found in the sample with the Timepix chip. This isotope was produced in the $^{197}Au(n, \gamma)^{198}Au$ reaction with huge cross section (~100 barn !)







Summary

- The ATLAS-GaAsPix Network proved stable and reliable operation in 2017-2018.
- The network of GaAsPix detectors could permit measuring and monitoring the radiation environment at different locations around the ATLAS detector.
- The comparison of the responses from detectors with different sensor layer thicknesses allows estimating the charged and neutral radiation components (20% and 80%, within the error limits).
- The activation of the sensor material permits an estimate of the neutron fluence during beam collisions.

Thank you for attention!