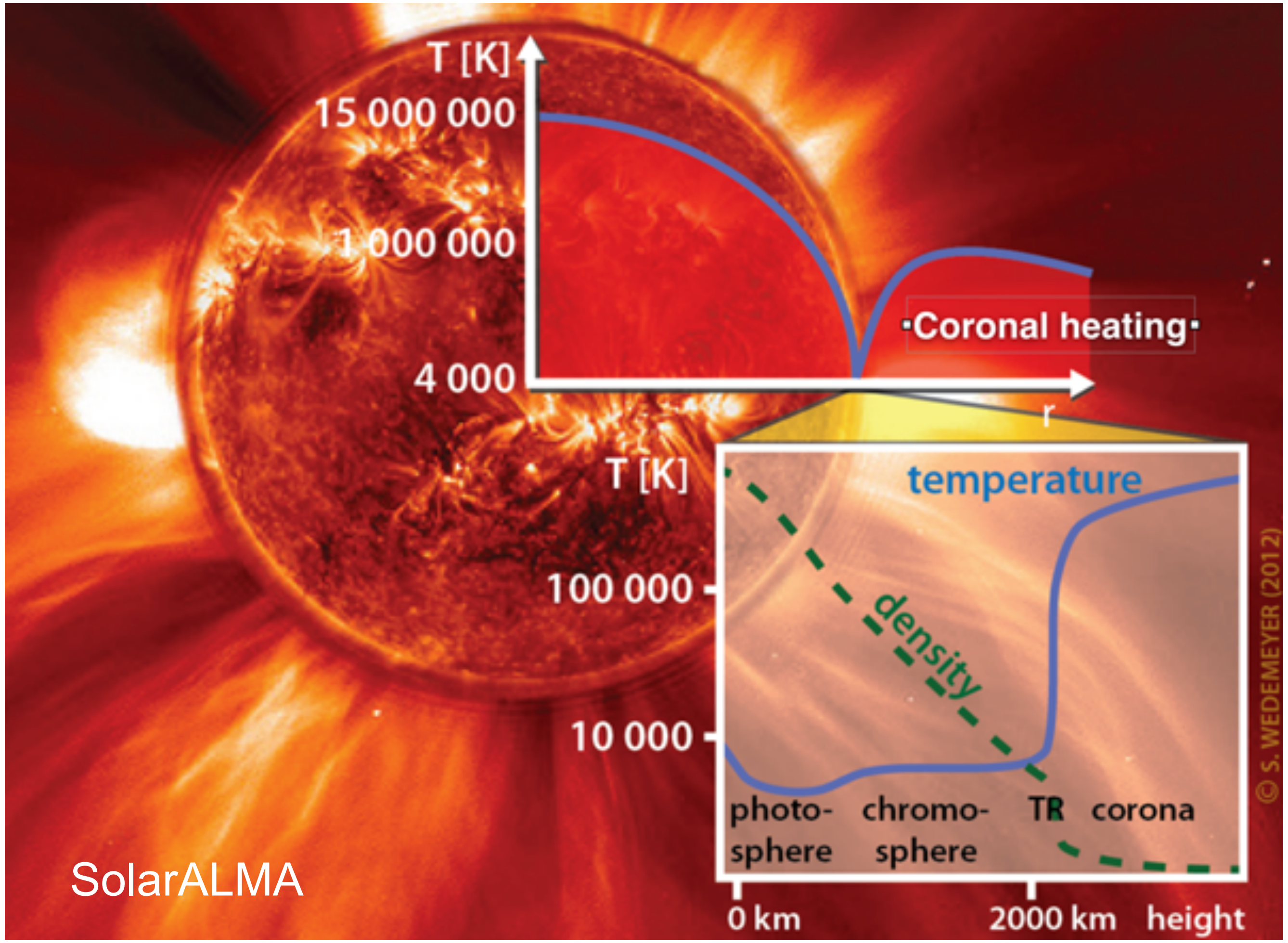
Solar KK Axions search with NEWS-G

FRANCISCO VAZQUEZ DE SOLA FERNANDEZ

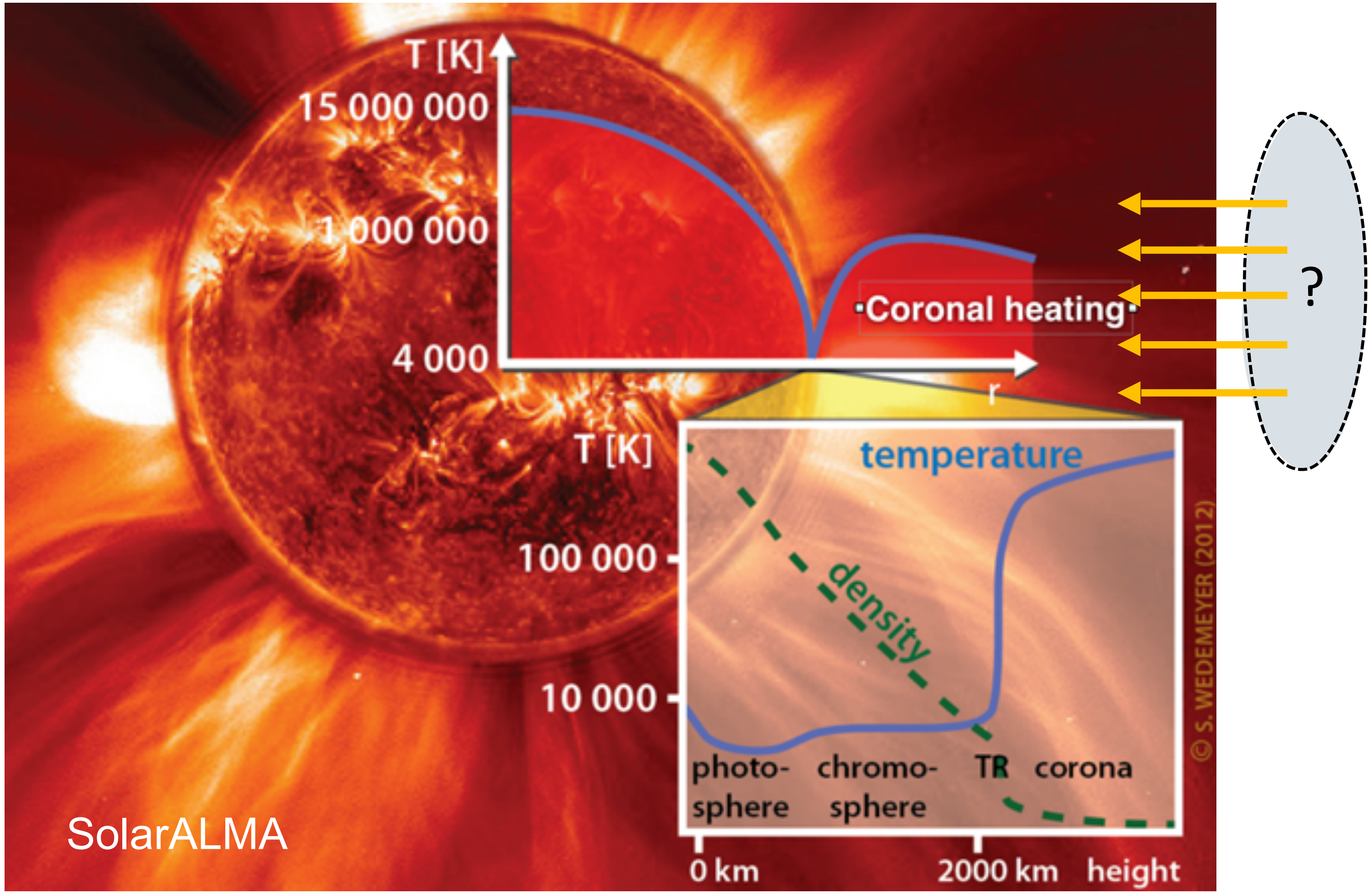
CAP CONGRESS, JUNE 2021



Problem

Atmosphere of the Sun is hotter than its surface, in defiance of thermodynamics. Possible explanation through wave or microflare mechanisms remain unproven.

C. E. Parnell, I. D. Moortel, A contemporary view of coronal heating (2012). doi:10.1098/rsta.2012.0113.



Problem

Atmosphere of the Sun is hotter than its surface, in defiance of thermodynamics. Possible explanation through wave or microflare mechanisms remain unproven.

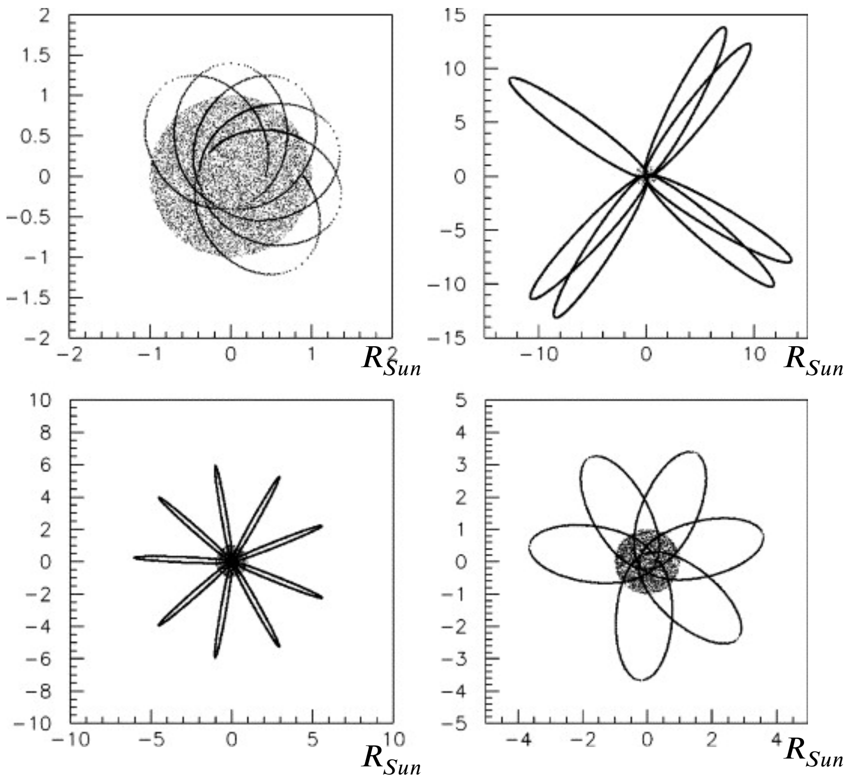
C. E. Parnell, I. D. Moortel, A contemporary view of coronal heating (2012). doi:10.1098/rsta.2012.0113.

New hypothesis

External irradiation from cloud of particles surrounding the Sun?

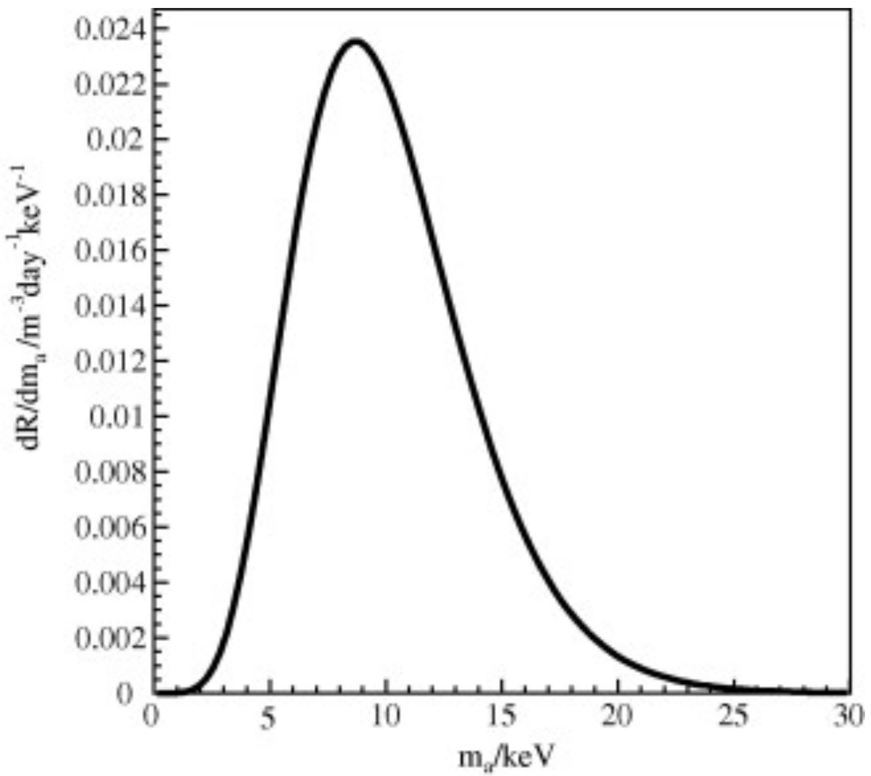
Heavy axion model developed by DiLella & Zioutas:

- Produced in the Sun
- Too heavy to escape its gravitational pull, accumulate around the Sun over its lifetime
- Source of external irradiation from their decays into two photons



Solar KK axion orbit examples

L. DiLella and K. Zioutas. Observational evidence for gravitationally trapped massive axion(-like) particles. Astropart. Phys., 19(1):145{170, 2003.

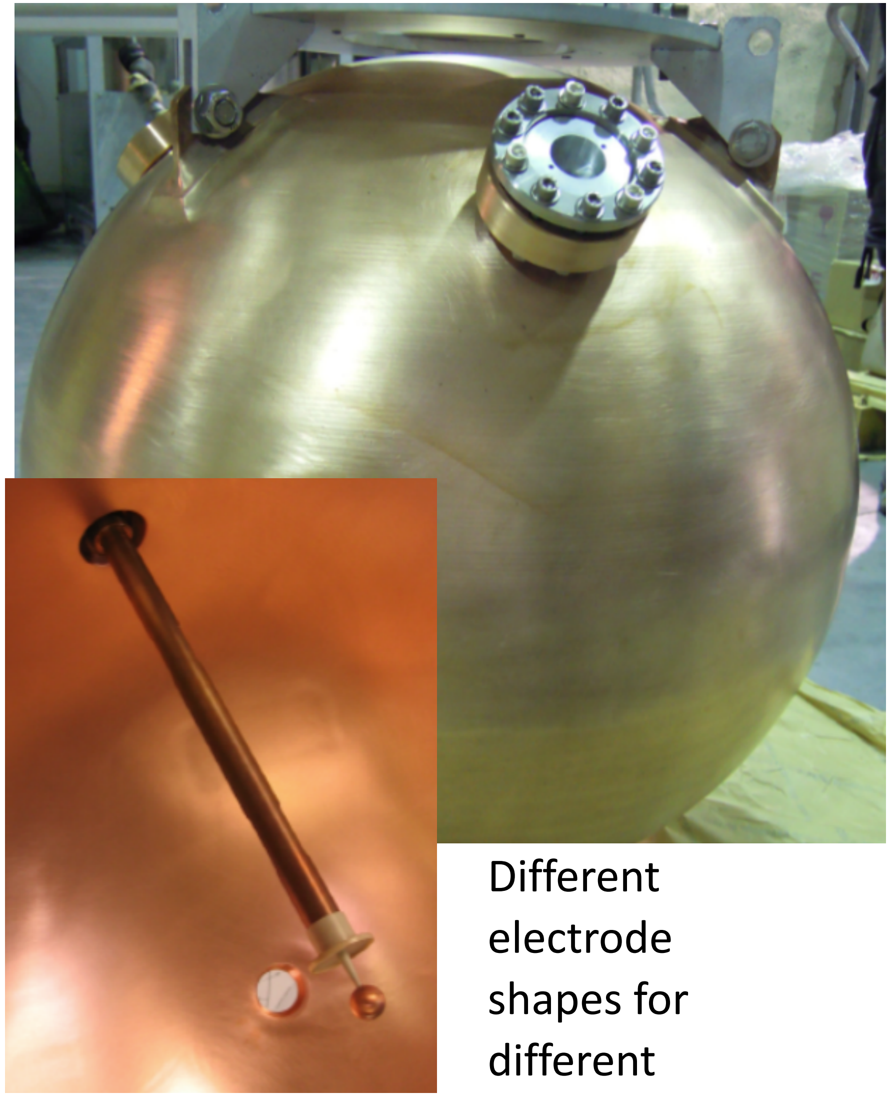


Solar KK axion decay rate on Earth

B. Morgan et al. Searches for solar Kaluza-Klein axions with gas TPCs. Astropart. Phys., 23:28{302, 2005.

Heavy Axion solution

Decays detectable on Earth with current technology!

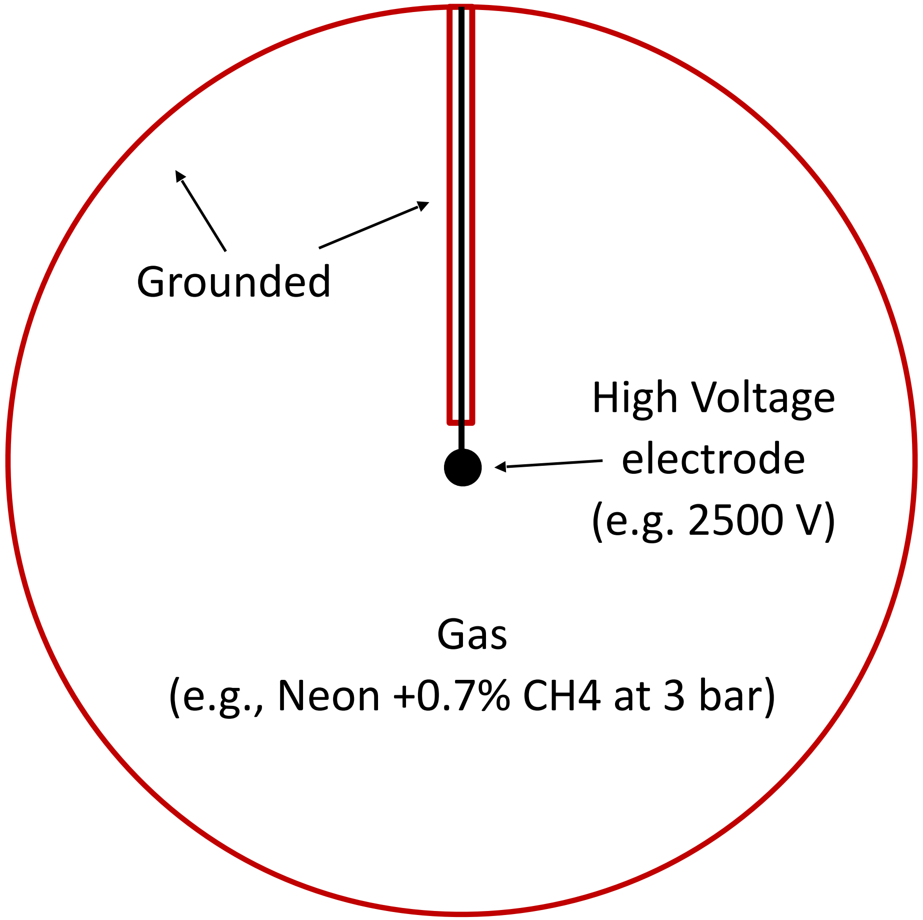


Different electrode shapes for different setups

Metallic sphere holding target gas

High voltage electrode collects ionization signal from incident particles

Choice of gas, pressure and voltage for different campaigns

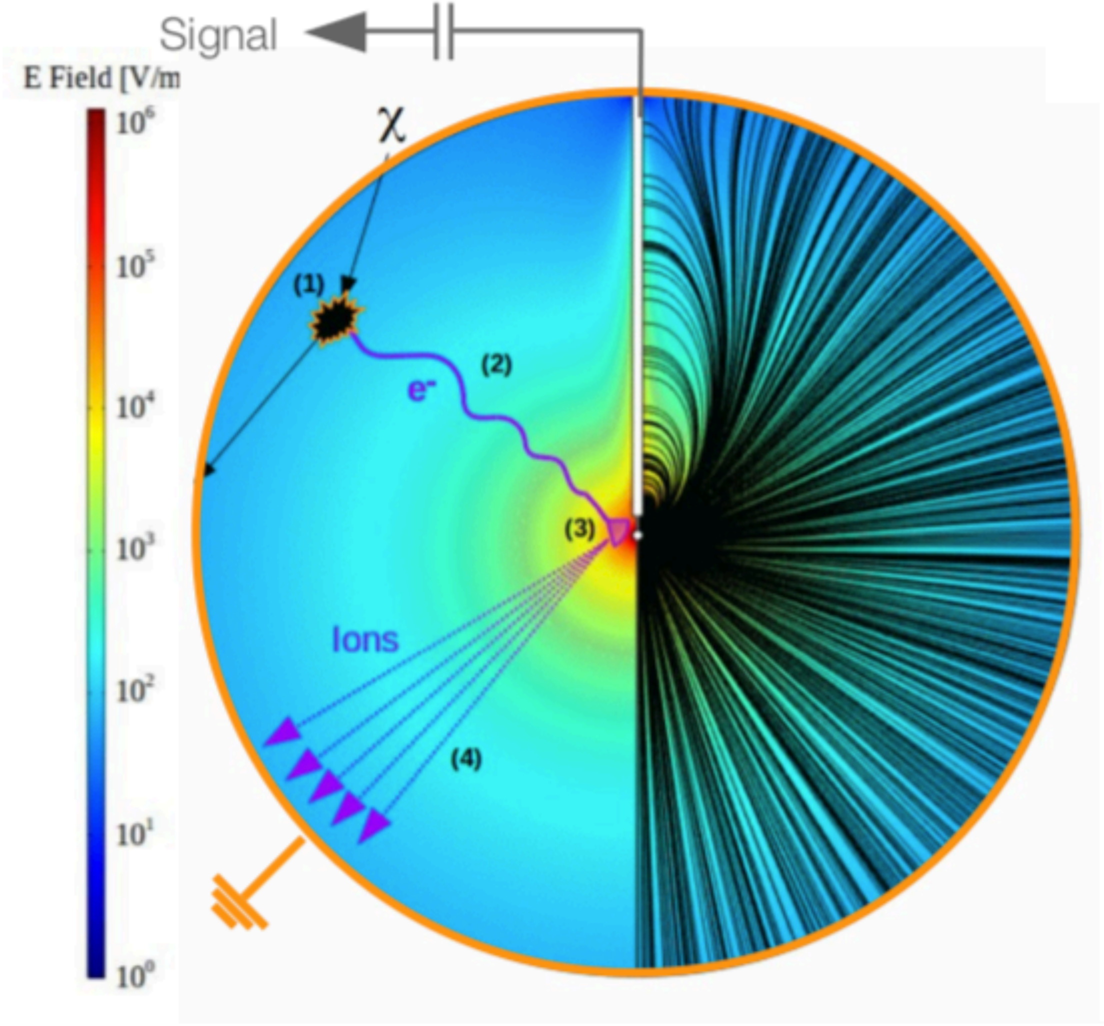


1) **Primary ionization**
   Particle interaction ionizes gas
   (1 electron per 36 eV on average in neon)

2) **Primary electron drift**
   Drift time and diffusion (“spread”) depends on radial position
   (400 μs, 40 μs resp., for 60 cm SPC)

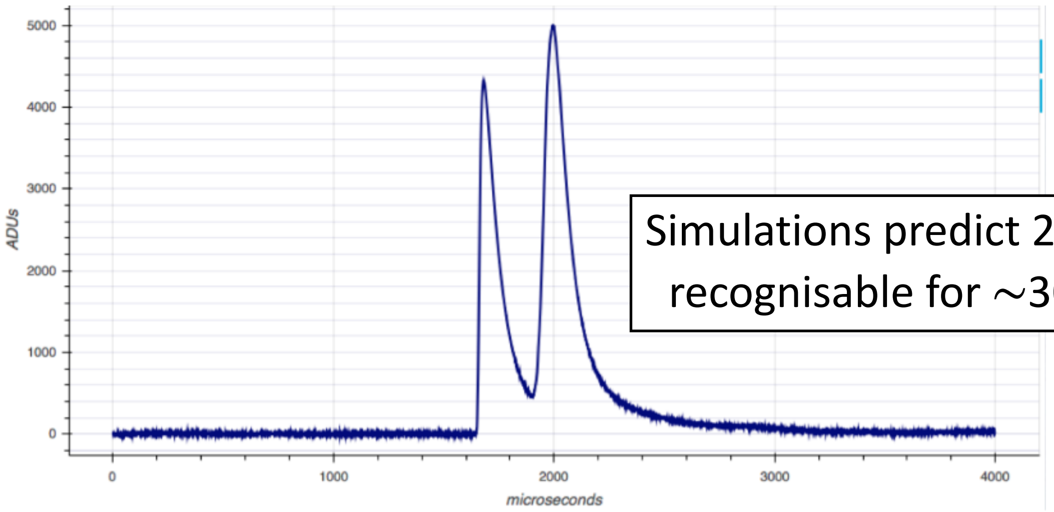
3) **Avalanche**
   Charge multiplication due to high electric field close to anode
   (typical gain of 10^3-10^4)

4) **Ion drift signal**
   Drift of ions in electric field induces current on readout electronics



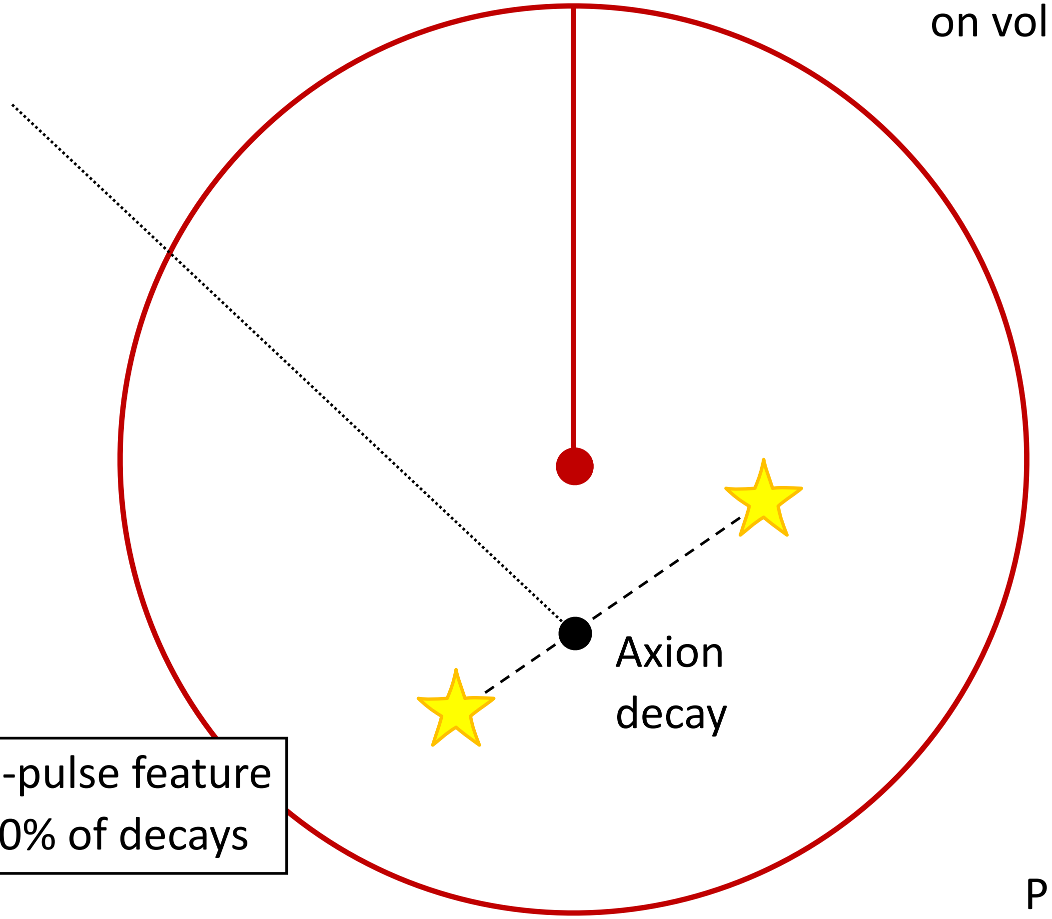
Q. Arnaud et al. First results from the NEWS-G direct dark matter search experiment at the LSM. Astropart. Phys. J. C, 97:54{62, 2018.

Axion decay into two back-to-back photons, captured at different sites. Recognizable as two different pulses of same amplitude within one event window. Allows for improved background rejection

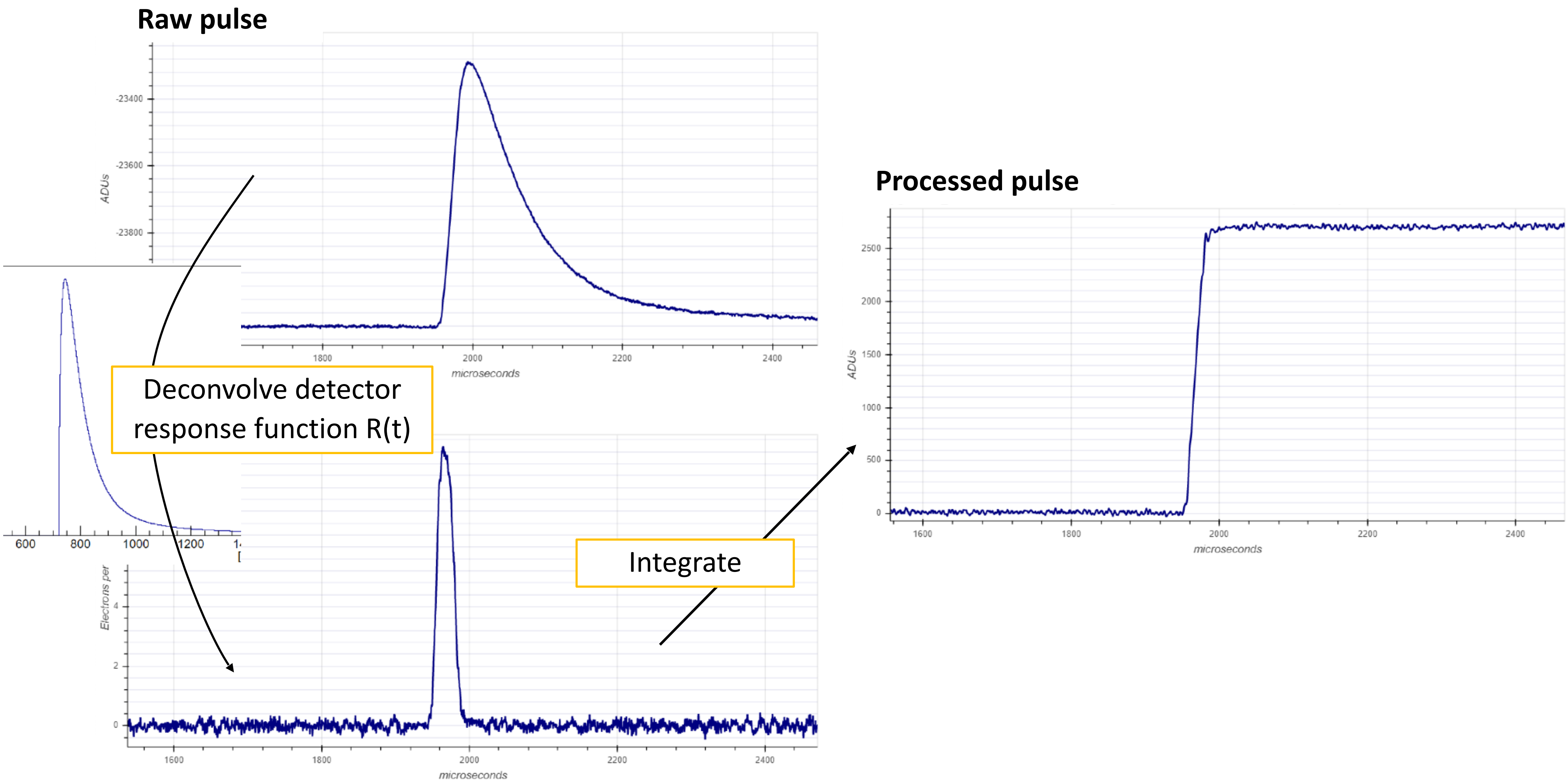


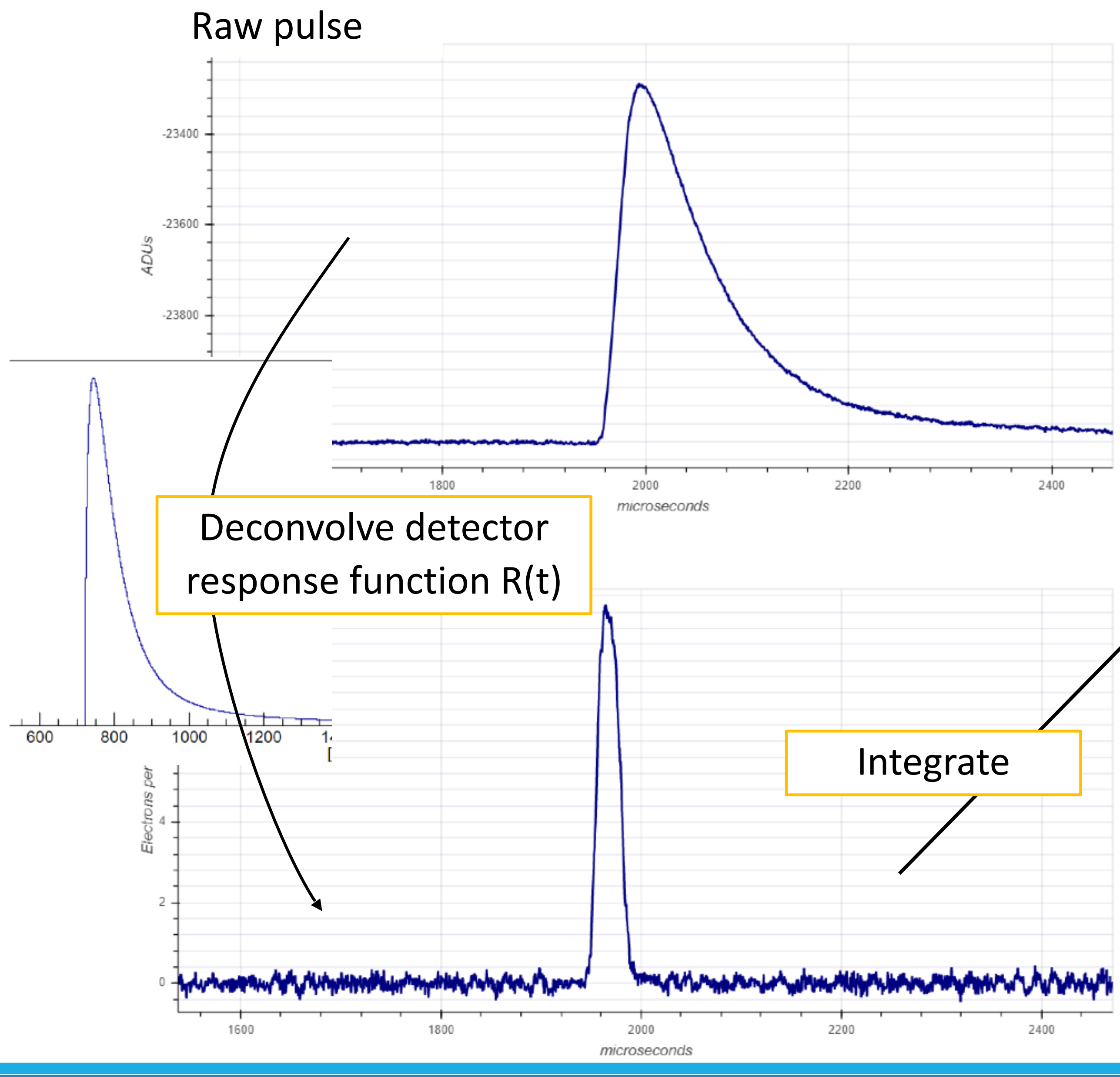
Simulations predict 2-pulse feature recognisable for ∼30% of decays

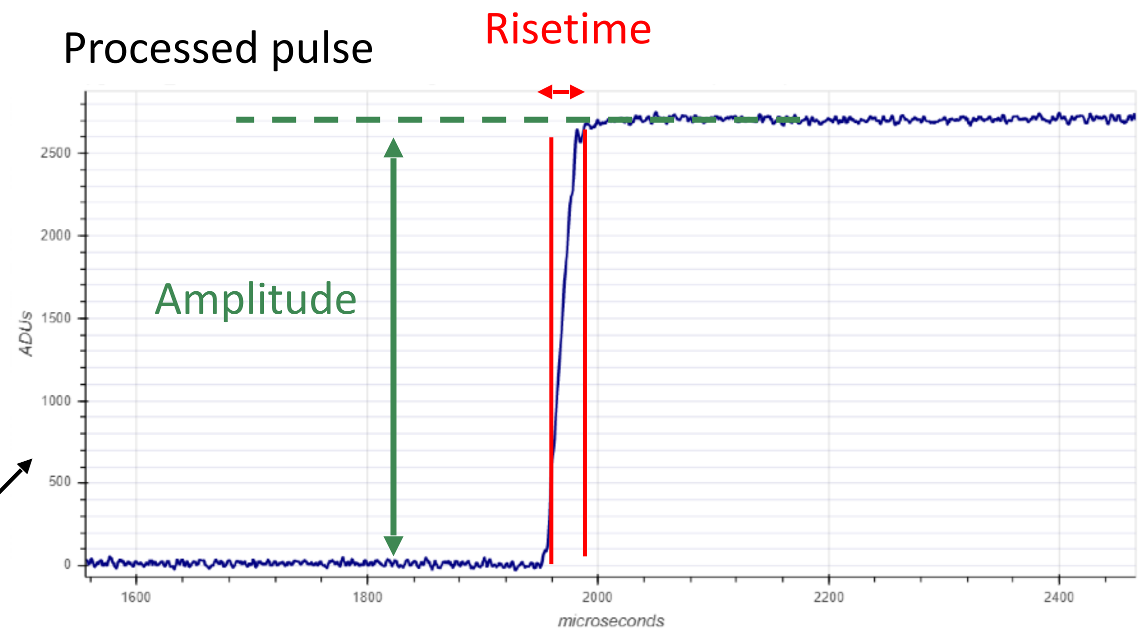
Axion decay rate depends only on volume of detector, not its mass!



Photons < 10 keV:
Single photoelectric interaction

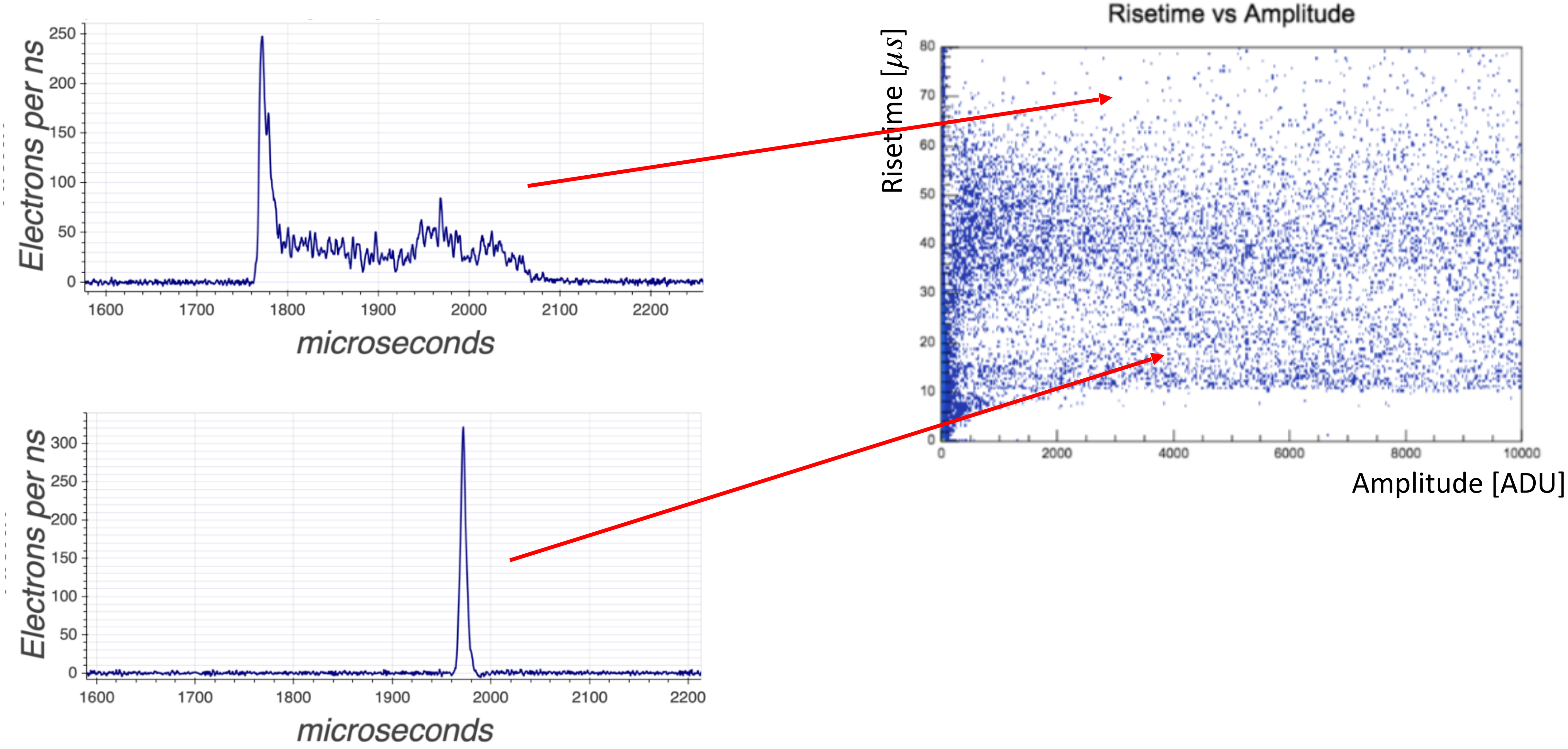

Raw pulse
-23400
-23600
-23800
ADUs
1800
2000
2200
2400
microseconds
600
800
1000
1200
Deconvolve detector response function R(t)
Electrons per
0
2
4
1600
1800
2000
2200
2400
microseconds
Integrate
Processed pulse
2500
2000
1500
1000
500
0
ADUs
1600
1800
2000
2200
2400
microseconds

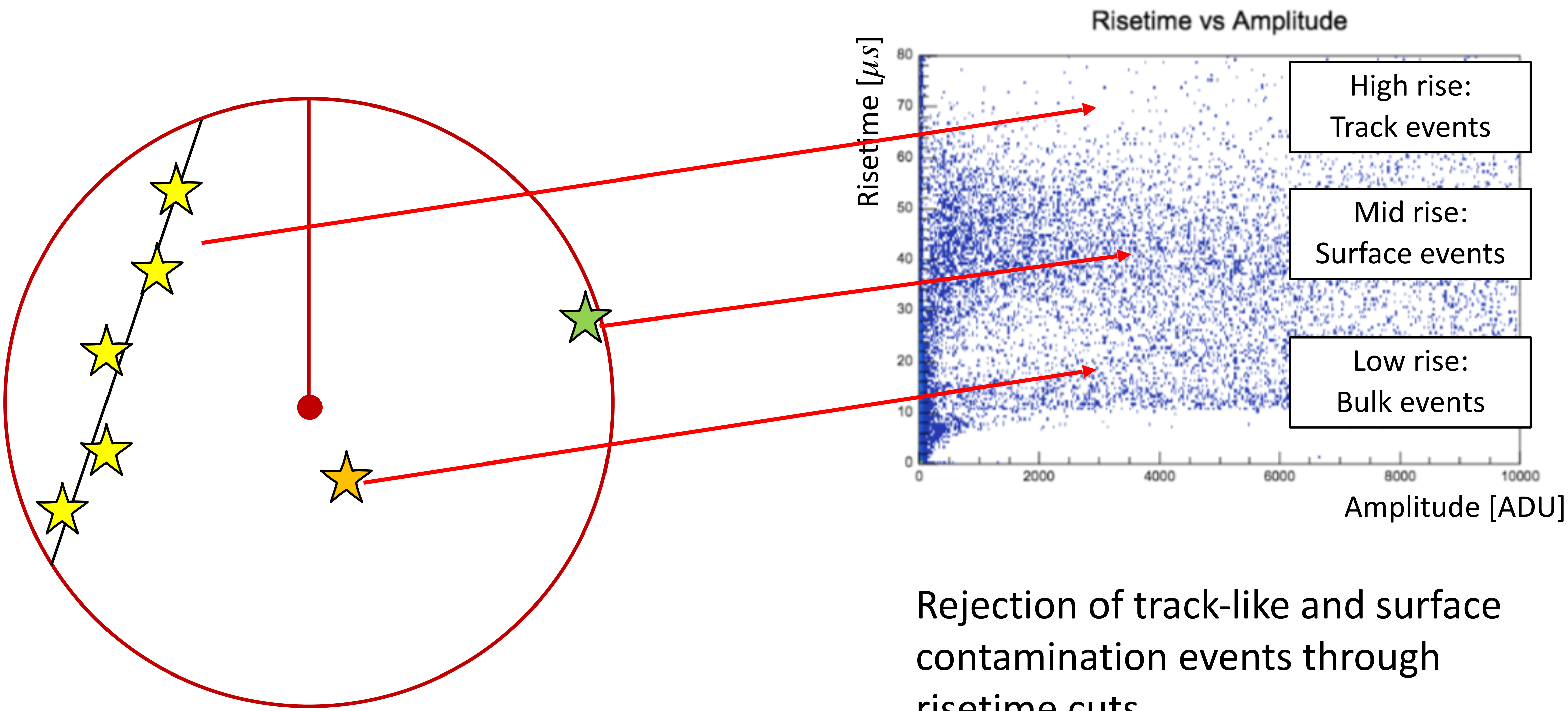




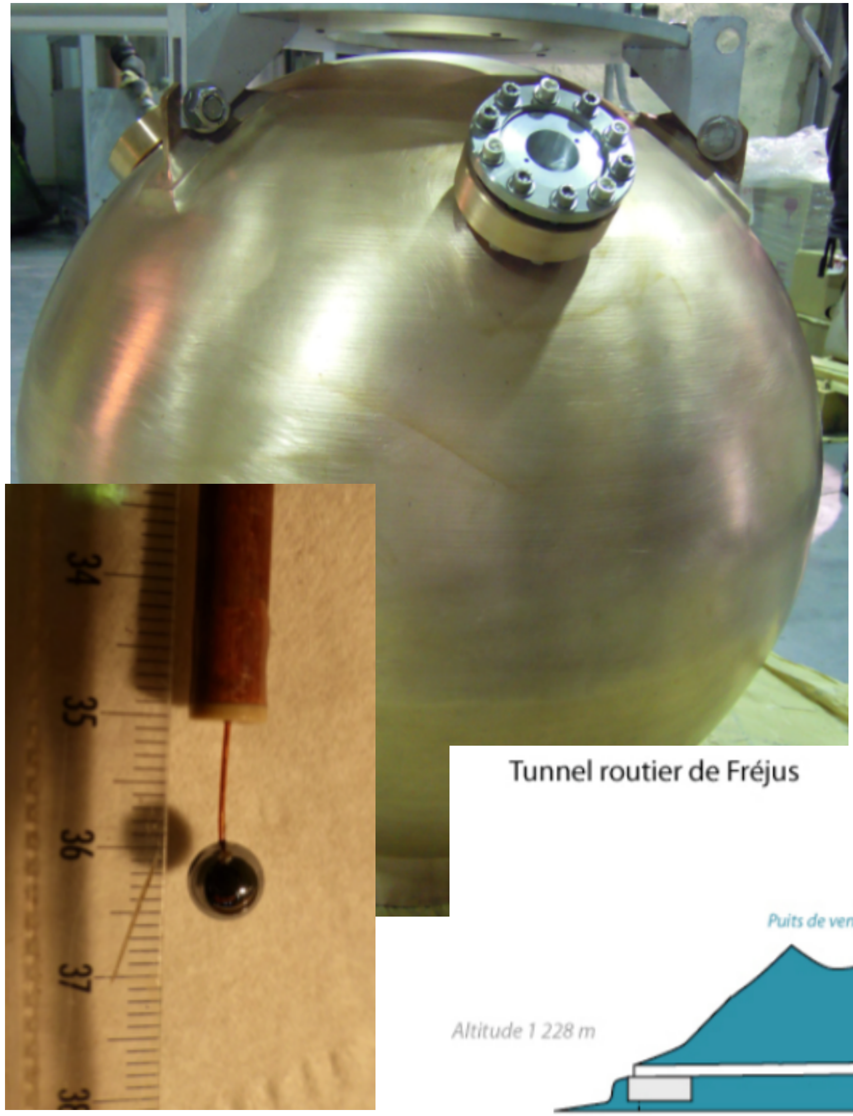
Amplitude : Energy of event

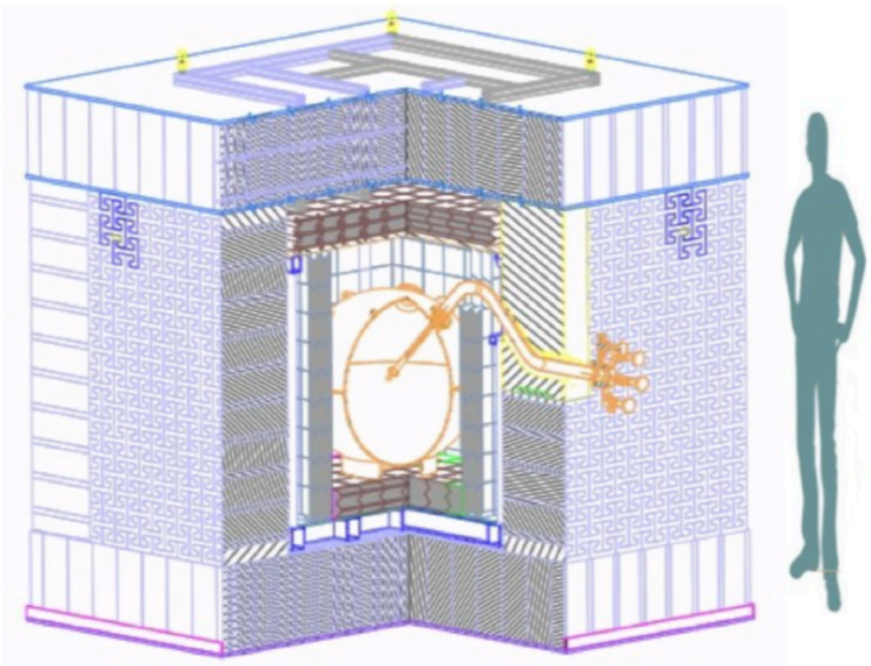
Risetime : Primary electrons arrival spread

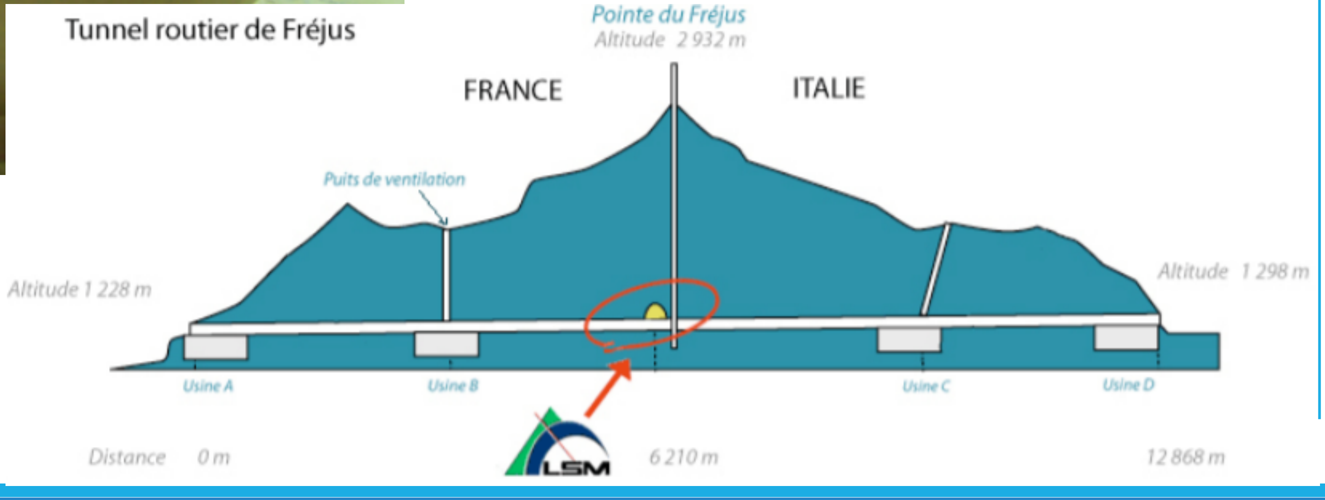

Electrons per ns
250
200
150
100
50
0
1600
1700
1800
1900
2000
2100
2200
microseconds
Electrons per ns
300
250
200
150
100
50
0
1600
1700
1800
1900
2000
2100
2200
microseconds
Risetime vs Amplitude
Risetime [μs]
80
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
Amplitude [ADU]



Rejection of track-like and surface contamination events through risetime cuts



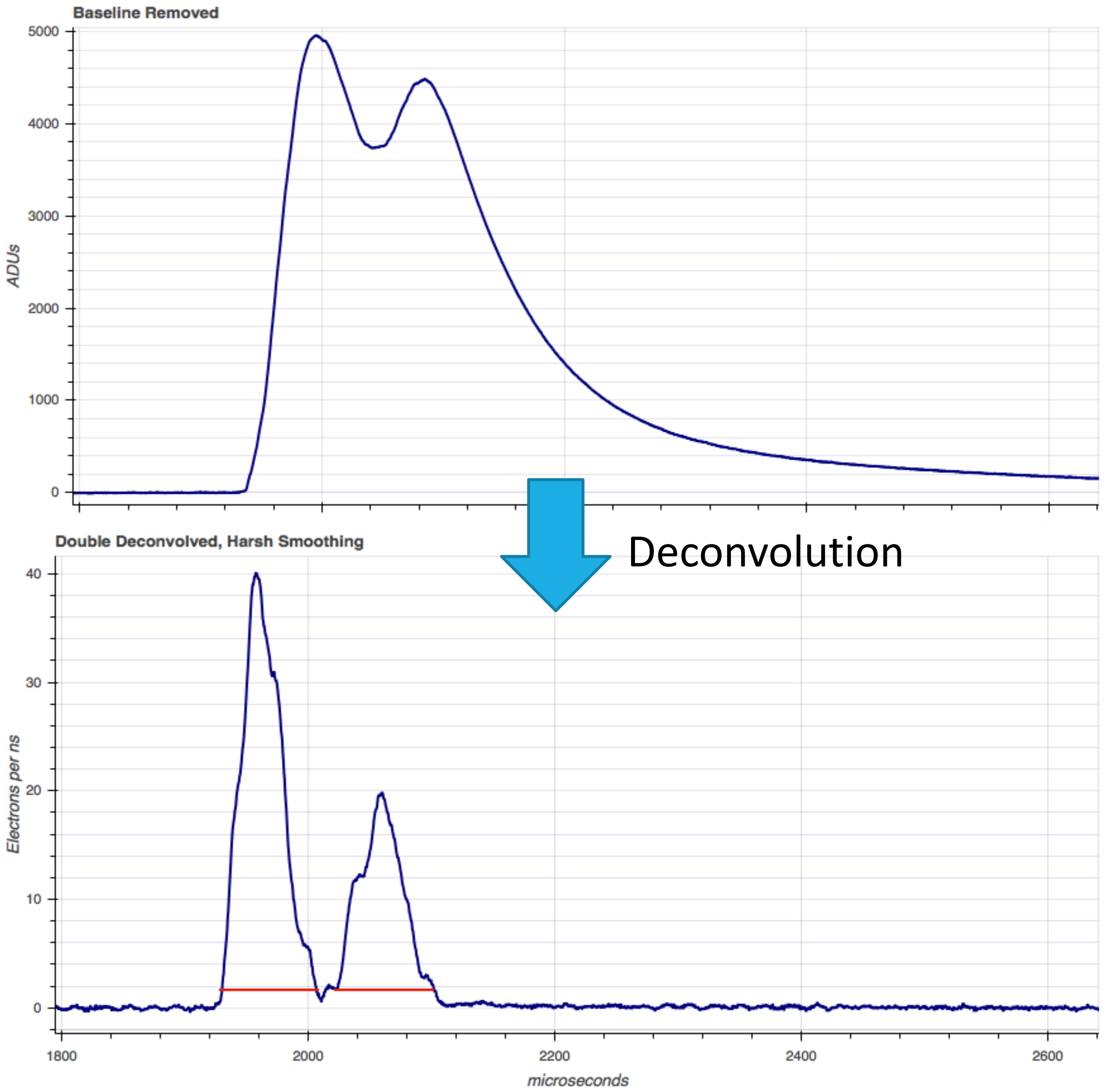




60 cm sphere
In Laboratoire Souterrain de Modane

3.1 bar of neon +0.7% CH_4
42 days of exposure

Background dominated by ^{210}PB contamination on inner surface of SPC



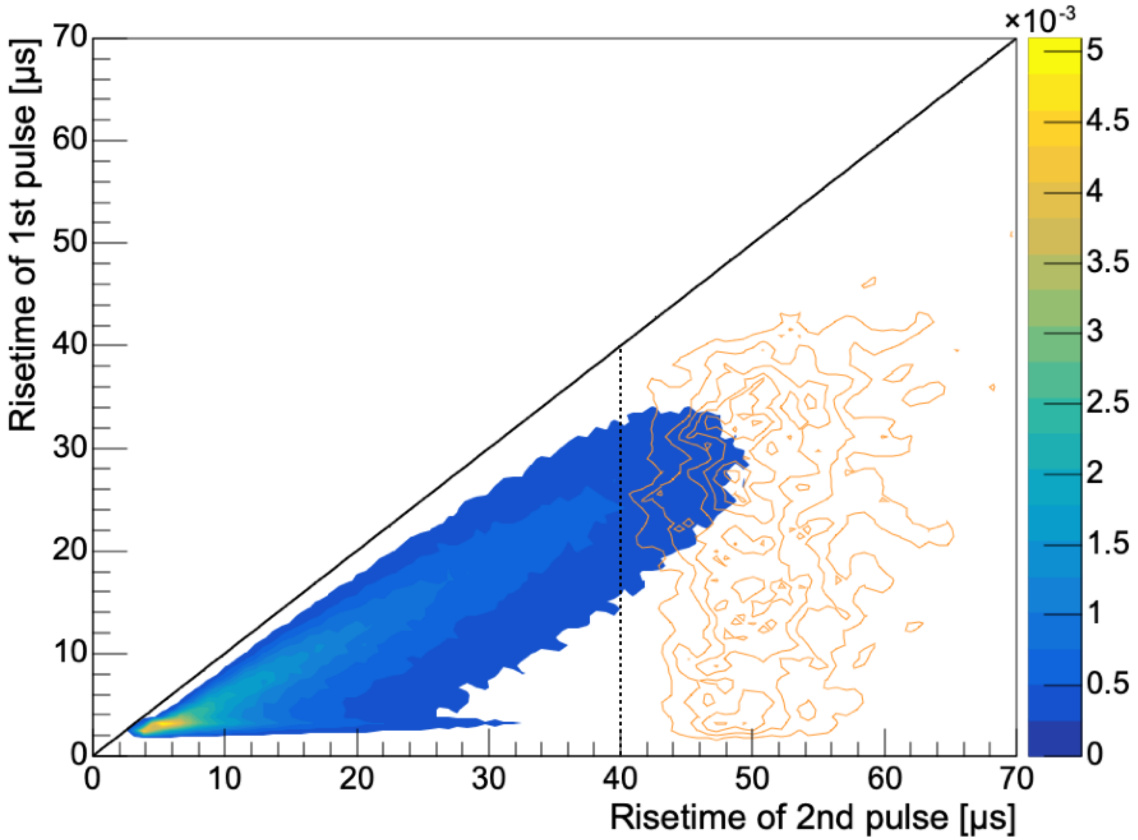
Detector response deconvolution provides improved pulse separation

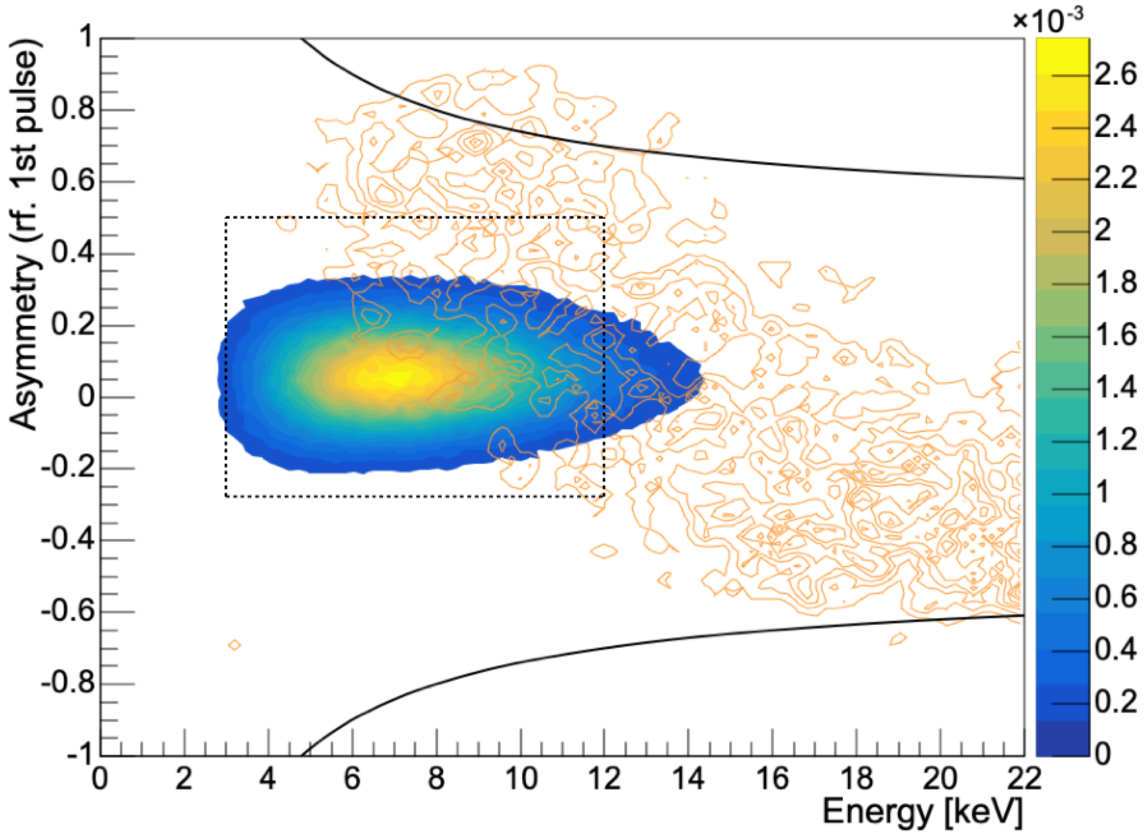
Event split into pulses based on deconvolved signal. Amplitude and risetime computed for each pulse independently

For 2-pulse axion decays, risetimes should be consistent with pointlike events, first shorter than second, and the « asymmetry » should be close to zero:

$$A = \frac{E1 - E2}{E1 + E2}$$

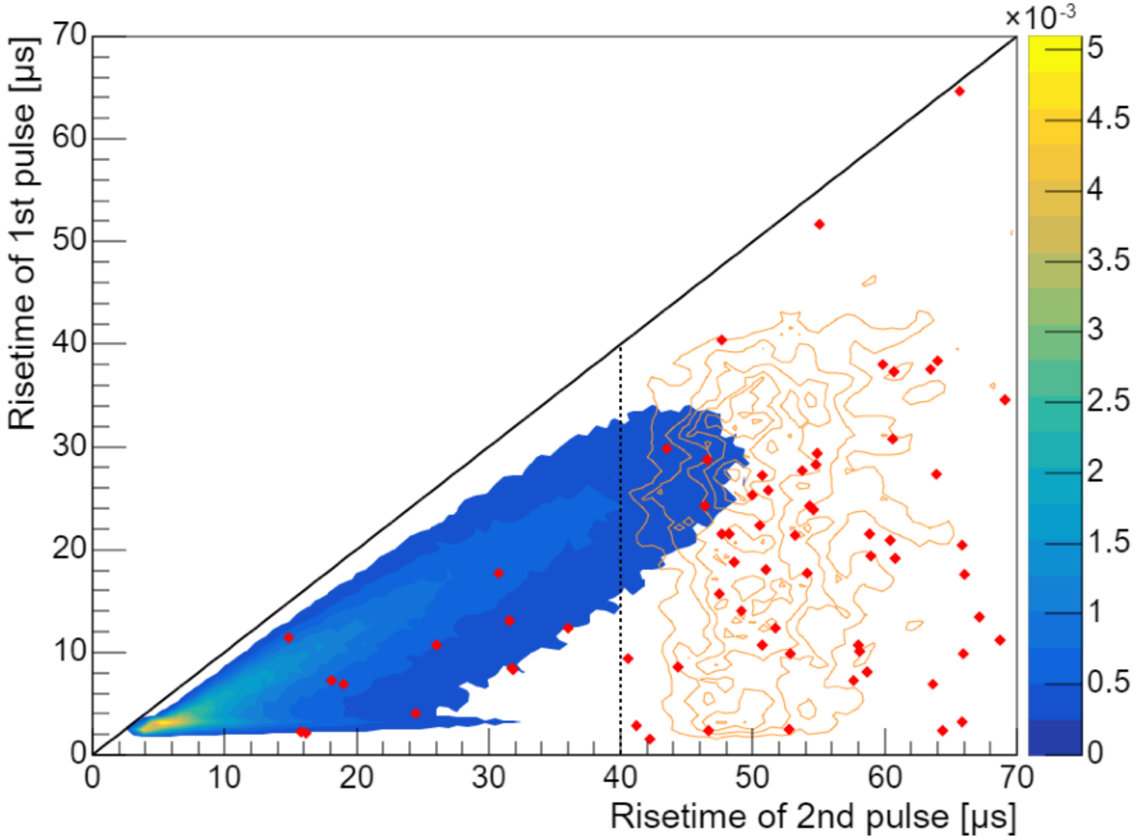
Amplitude of first and second pulse

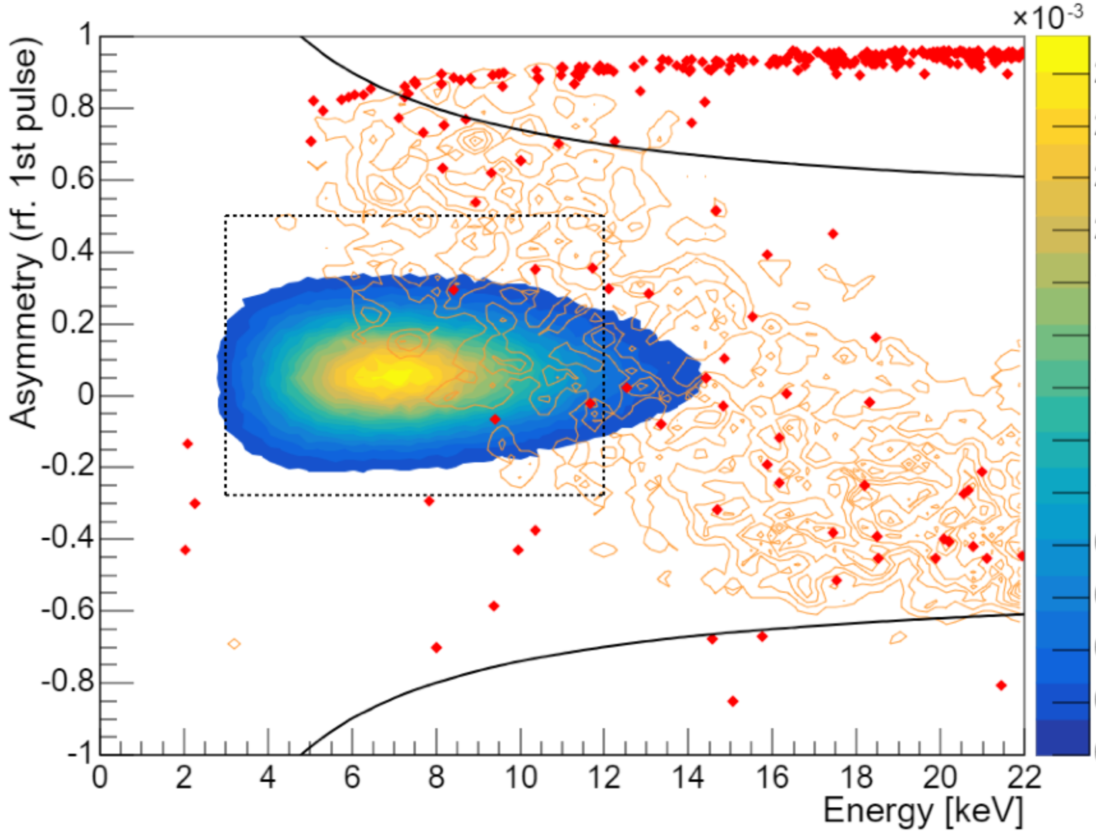




B/Y: **Axion simulations**
Orange: **Background simulations**

Solid lines: **Preliminary axion cuts**
Dashed lines: **Advanced cuts**





B/Y: **Axion simulations**
Orange: **Background simulations**
Red: **SEDINE data**

Effect of combined cuts:

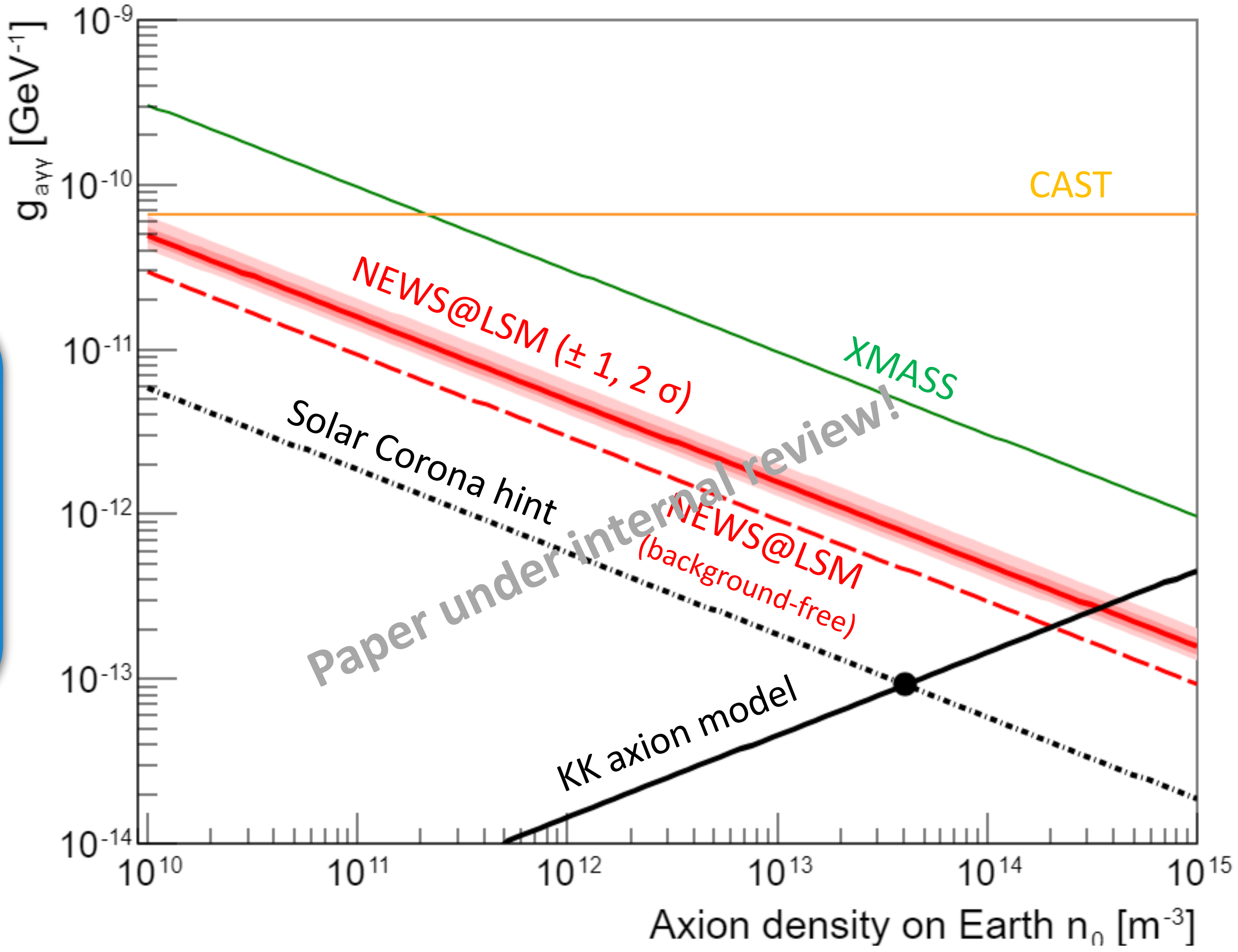
- Background rejection in 2-22 keV range of 99.99%
- KK Axion sensitivity of 16.3%

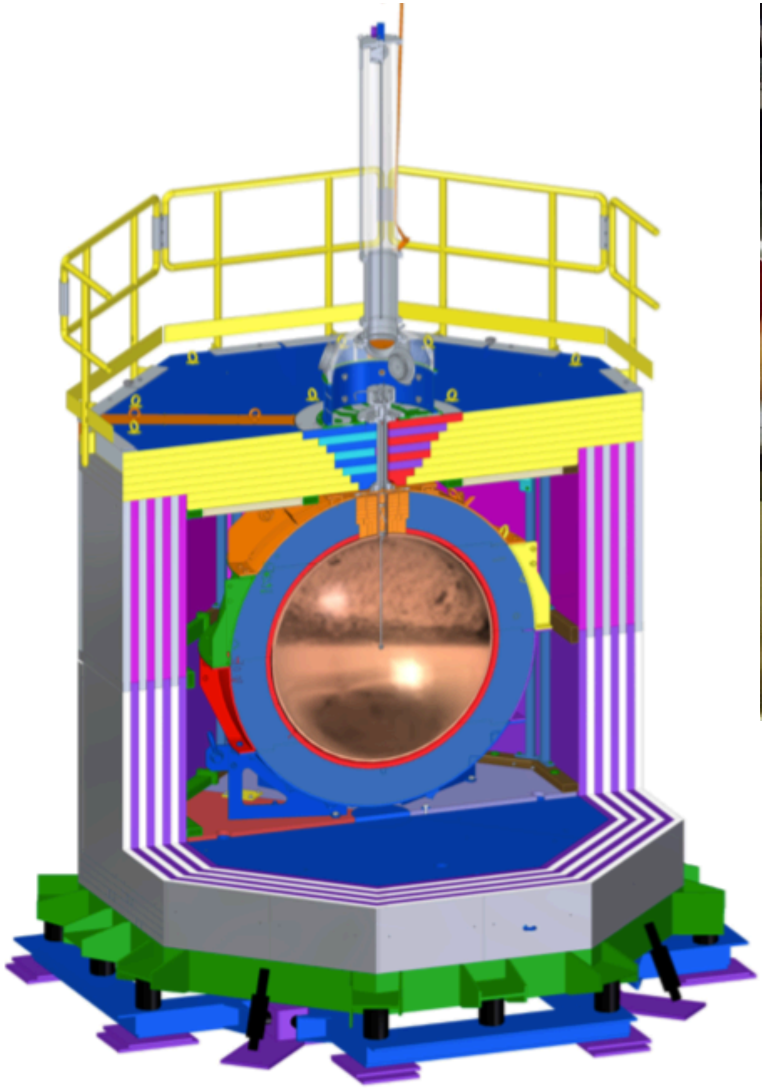
Solid lines: **Preliminary axion cuts**
Dashed lines: **Advanced cuts**

Exposure
Time = 42 days
Volume = 0.113 m^3
Detector efficiency: 16.3%

Expected axion events:
0.0589
Expected background events:
2.52
Observed events:
1

Systematic uncertainty on result dominated by limited calibrations on drift and diffusion time



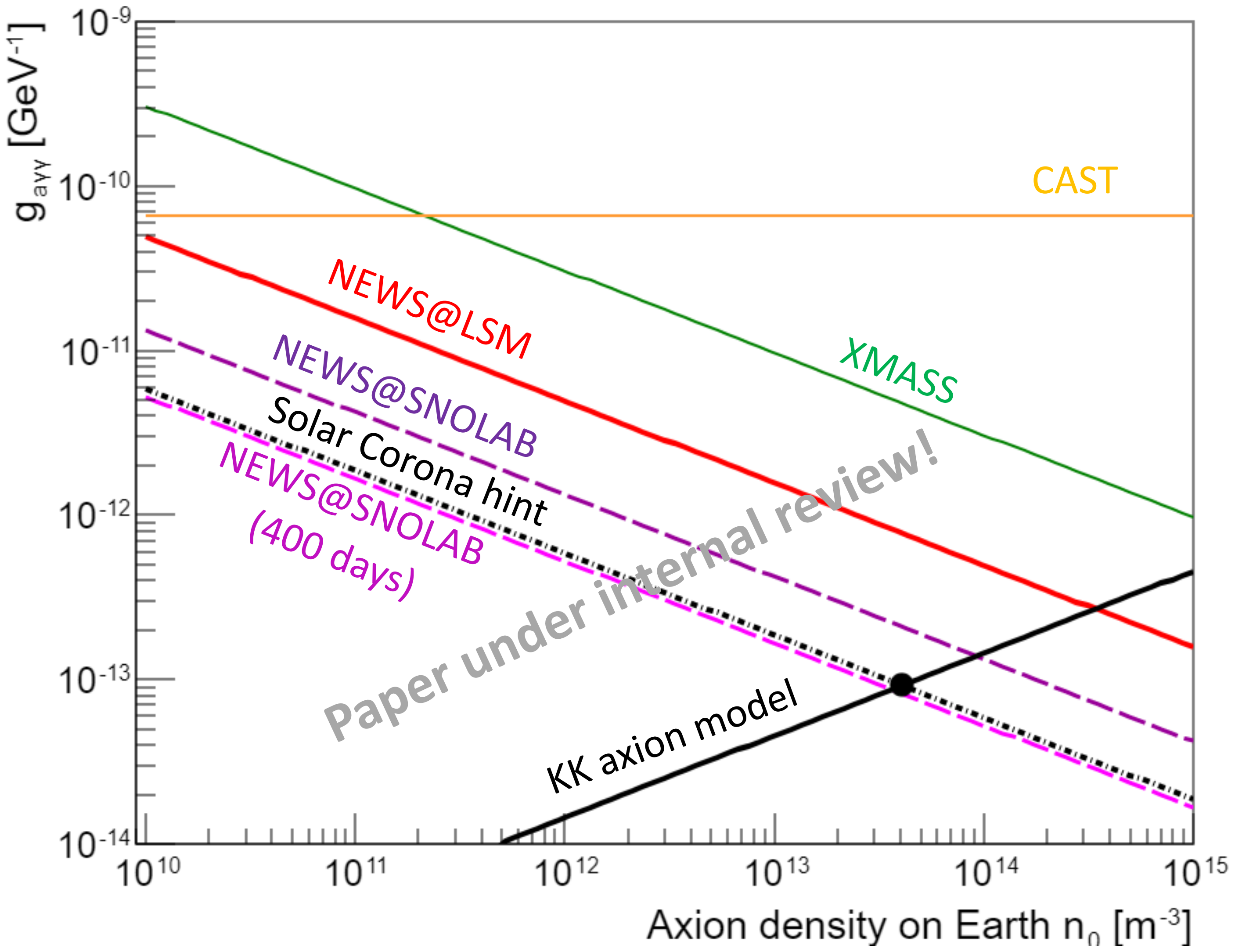


140 cm wide SPC

Improved radiopurity of components

New kind of electrode (ACHINOS) to accommodate for larger size

Installed at SNOLAB, with commissioning about to start



Running conditions:
600 mbar of neon,
2000V achinos

- **30 days of exposure:** Improvement on SEDINE limit by factor 3.7

- **400 days of exposure:** Either reject Solar Corona hint, or discovery of Solar KK axions

KK axions potentially produced by the Sun, and trapped in its gravity well. Their decays are observable due to their high mass (>keV).

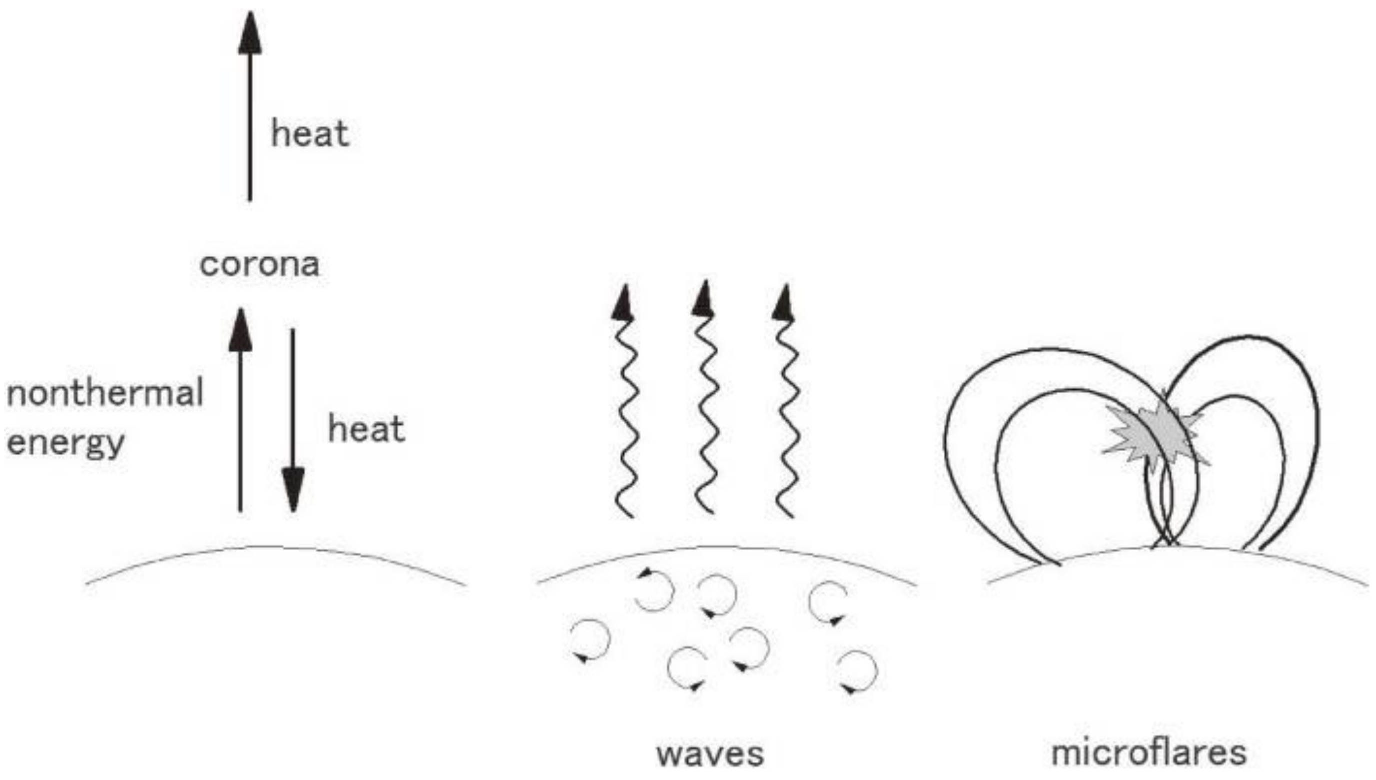
Use of target gas in SPCs makes axion decay appear as simultaneous interactions at separate locations, allowing for background rejection of 99.99% at energies considered. Proof-of-concept demonstrated with ^{55}Fe-induced argon fluorescence calibration.

42-day run with SEDINE observed single axion-like event, setting limit at $g_{a\gamma\gamma} = 7.76\times10^{-13}\ GeV^{-1}$ for predicted KK axion density, 6 times lower than previous XMASS limit. S140 at SNOLAB projected to set limit at $g_{a\gamma\gamma} = 2.1\times10^{-13}\ GeV^{-1}$ with a 30 day run.

Thank you for your attention!

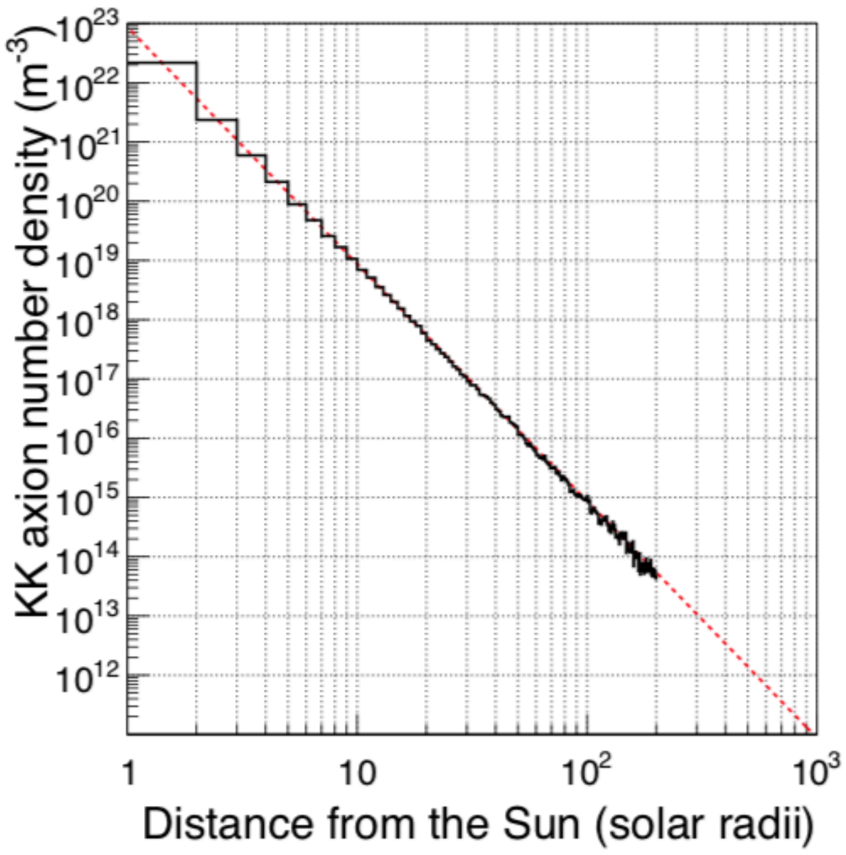
NEWS-G : Science in the Time of COVID (December 2020 collaboration meeting)

Extra slides



T. SAKURAI. Heating mechanisms of the solar corona. Proceedings of the Japan Academy, Series B, 93:87–97, 02 2017

Leading categories of Solar Corona Heating problem solutions
Current observational capabilities cannot detect either heating mechanism at work



Solar KK axion density

XMASS Collaboration. Search for solar Kaluza-Klein axion by annual modulation with the XMASS-I detector. PTEP, 2017(10):103C01, 2017

Axion type

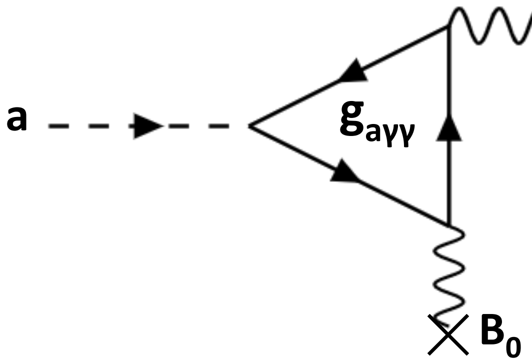
QCD axion

- Solves Strong CP problem
- Dark Matter candidate
- Postulated by Peccei and Quinn in 1977

KK axions

- *Excitations of QCD axion with much higher masses* (keV instead of meV)
- Arise in quantum gravity theories with additional dimensions

Axion-Photon coupling



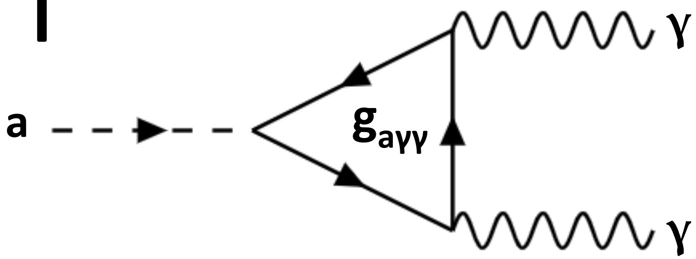
"Primakoff"

QCD axion conversion to photon requires presence of (strong) magnetic field

Search for axion is active field in particle physics, with direct detection experiments such as ADMX, CAST, OSQAR…

Not detected yet

\+



Decay

KK axions decay into two photons of equal energy due to their higher mass, providing additional detection channels

KK axion detection could prove existence of QCD axion and of additional dimensions

Calibration etup : Queen's S130

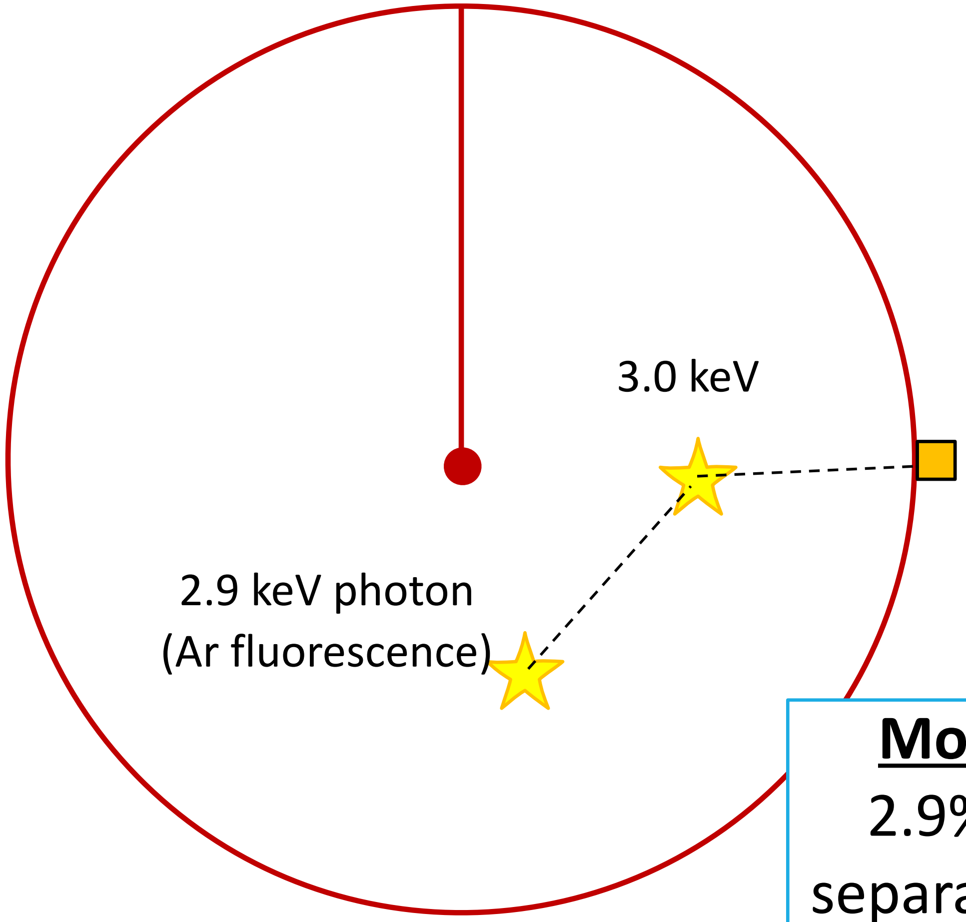
130cm SPC at Queen's, with 200 mbar of argon

^{55}Fe source inside detector window:
5.9 keV gamma source

130cm SPC at Queen's, with 200 mbar of argon

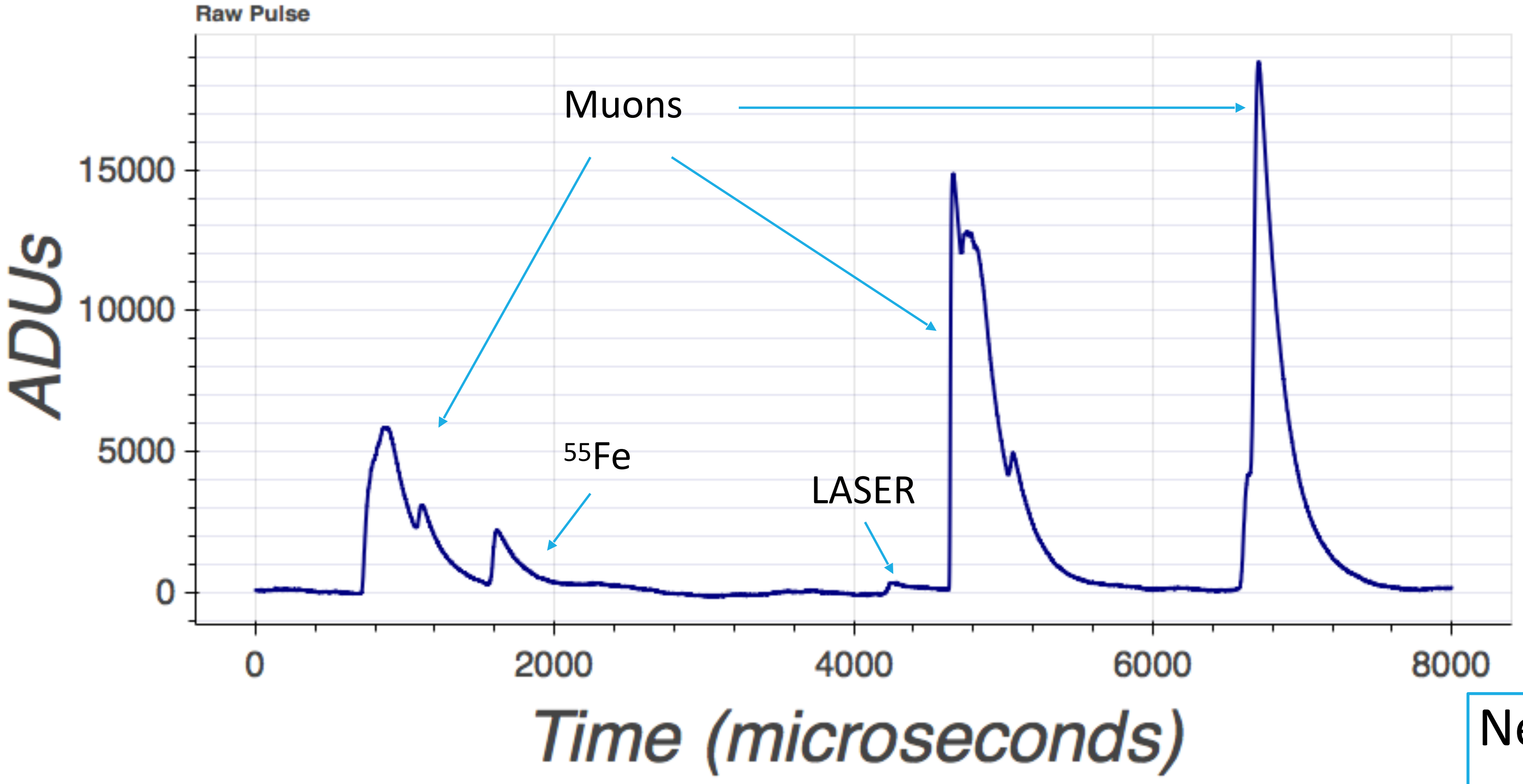
^{55}Fe source inside detector window:
5.9 keV gamma source
12% of the time:
Argon fluorescence (2.9 keV)

2 interactions at distinct locations of same energy!



Pressure selected to minimize non-separable fluorescence events or escape events

Monte-Carlo simulation:
2.9% of all ^{55}Fe events are separable fluorescence events

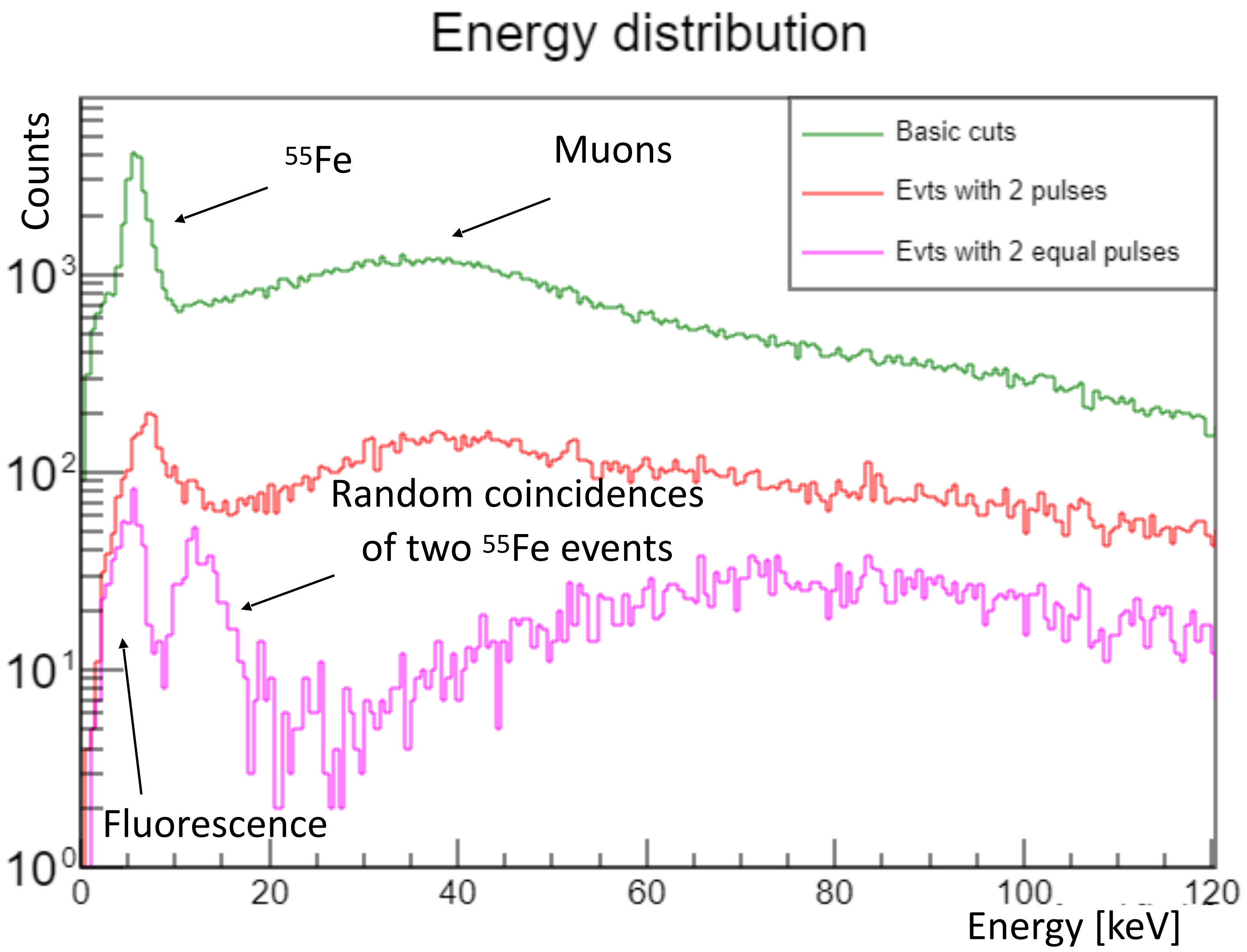


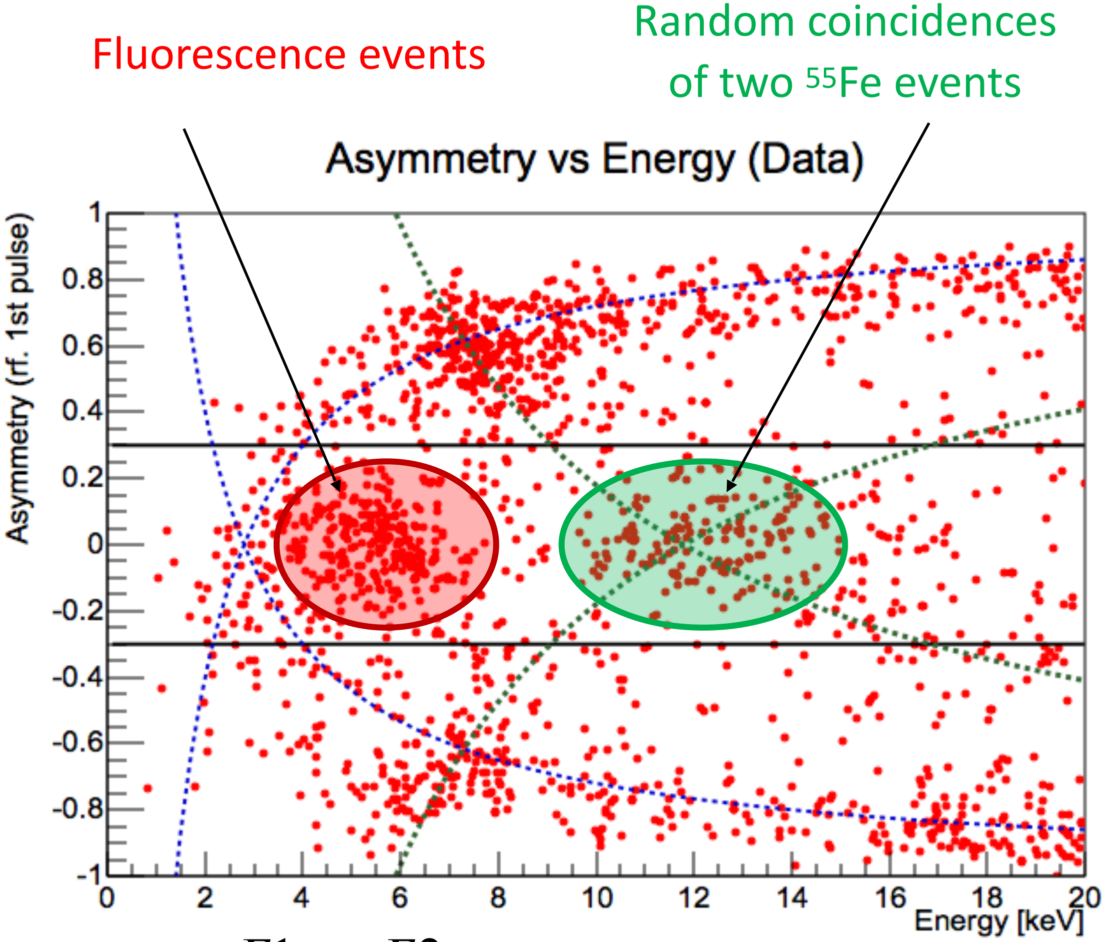
- Surface detector:
400 Hz of cosmic ray muons

- Continuous calibration:
10 Hz of LASER events

- ^{55}Fe source:
30 Hz, of which 3.5 Hz with argon fluorescence

Need to distinguish random coincidences from argon fluorescence events!



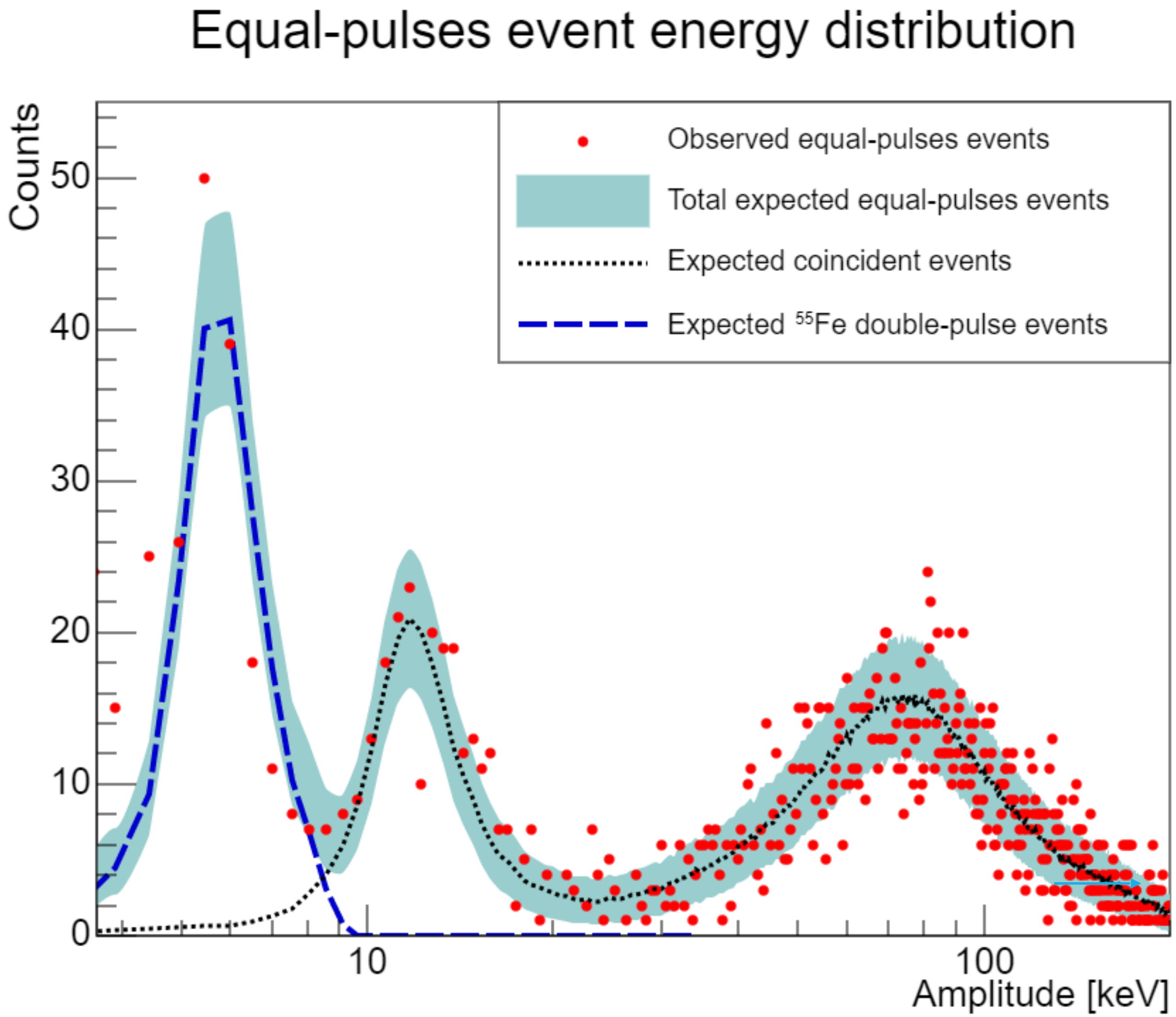


$$A = \frac{E1 - E2}{E1 + E2}$$

Asymmetry between both pulses in an event

Green lines: Events with at least one ^{55}Fe pulse

Blue lines: Events with at least one "noise" pulse



3 fit parameters

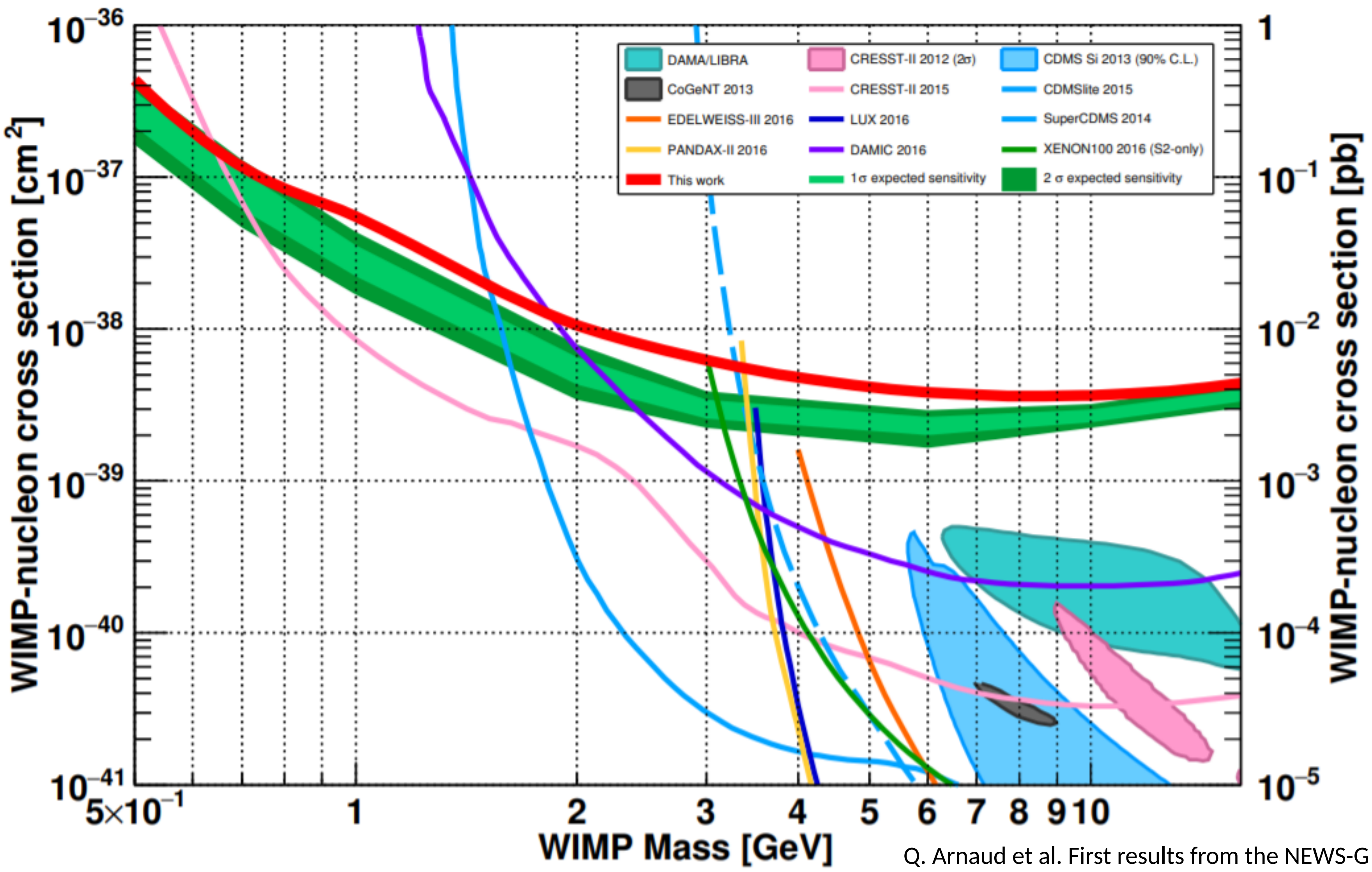
- Proportion of separable fluorescence events
- Total random coincidence rate
- False positive rate (set to zero by fit)

Expected from simulations:
2.93 +/- 0.29 %

Fit result on data:
2.99 +/- 0.28 %

Agreement!

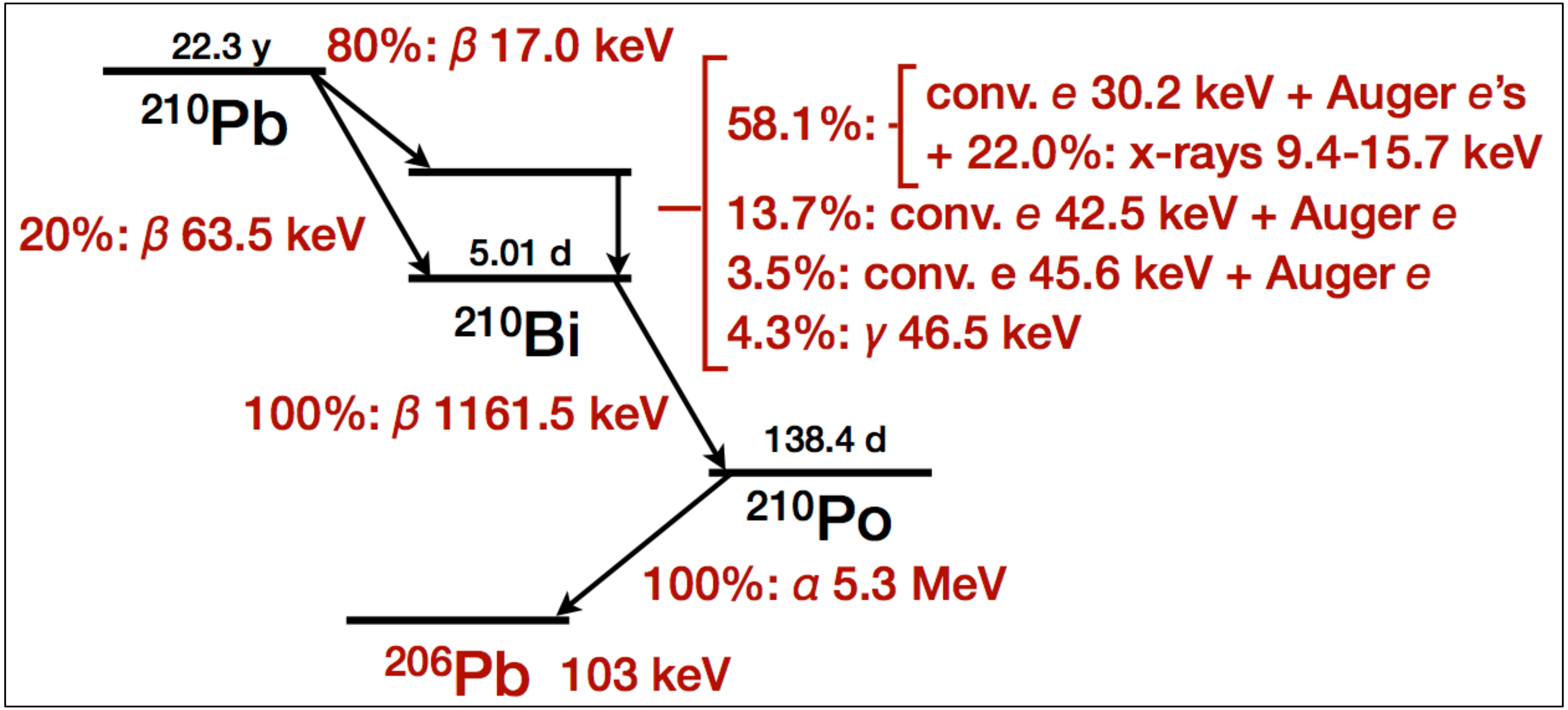
SEDINE data : WIMP searches



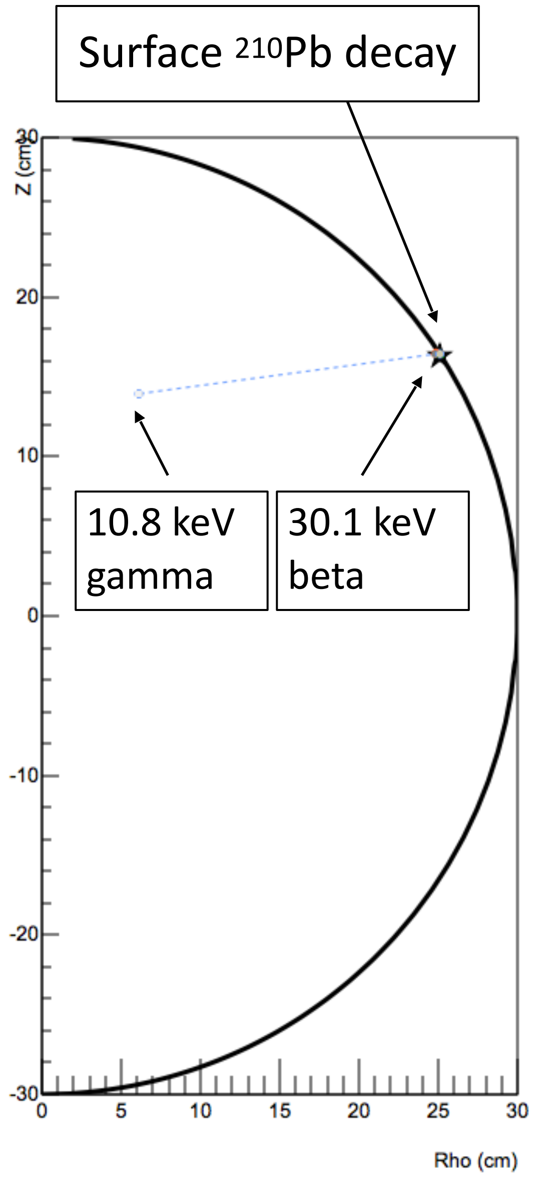
Q. Arnaud et al. First results from the NEWS-G direct dark matter search experiment at the LSM. Astropart. Phys. J. C, 97:54{62, 2018.

^{210}Pb contamination in Copper (detector shell) and Lead (shield)

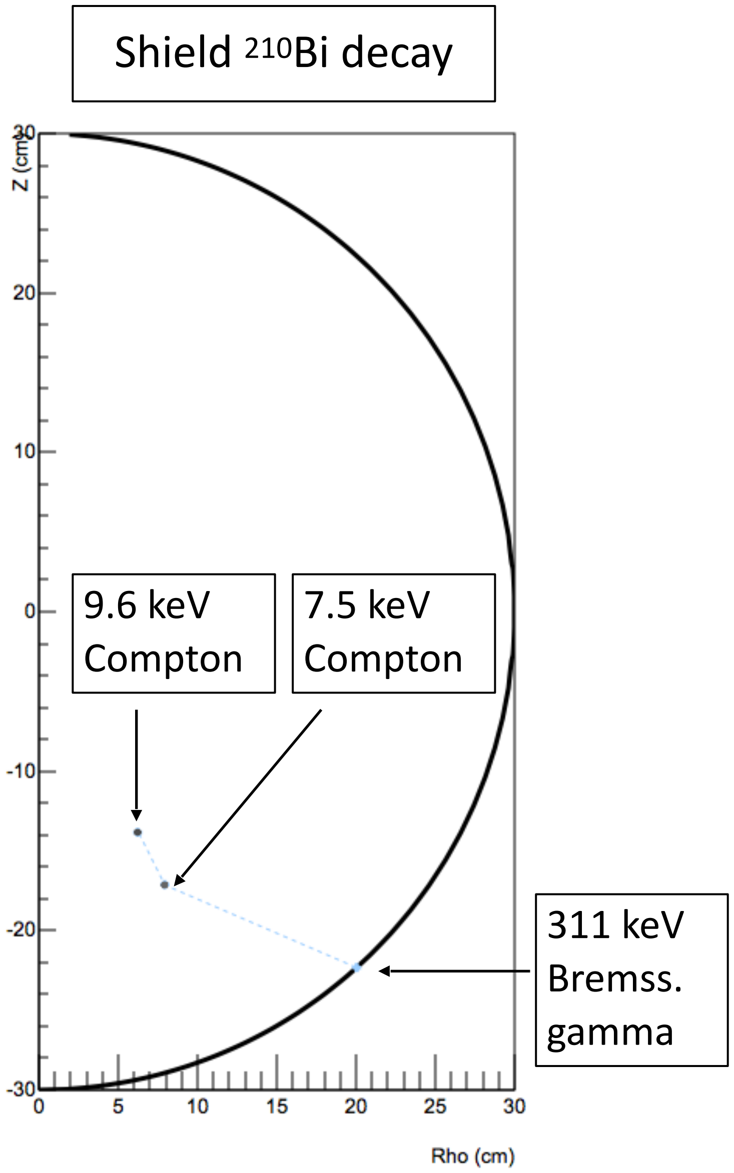
^{210}Pb deposition on inner surface of detector shell from ^{222}Rn decays (in air)



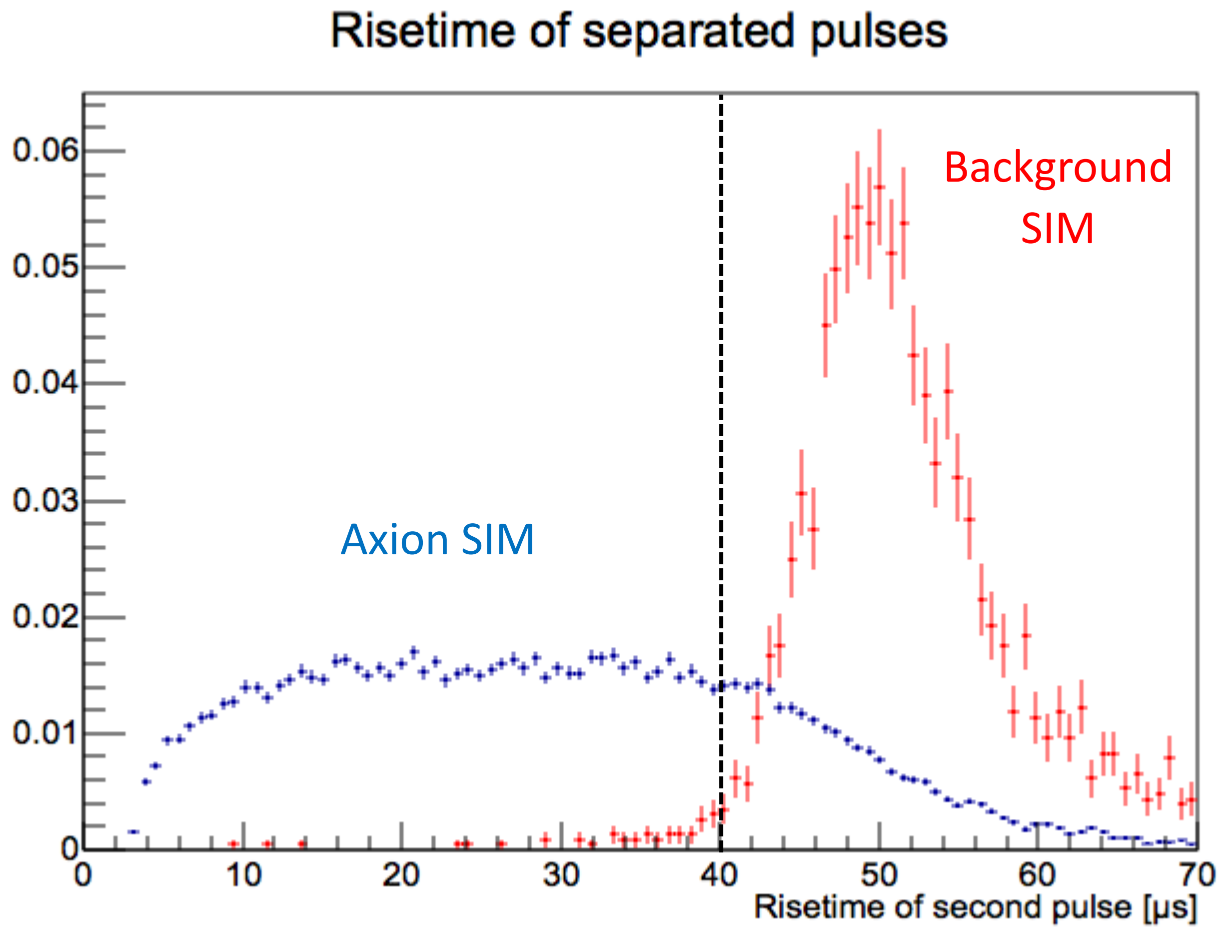
Axion-like Background : Geant4 Examples



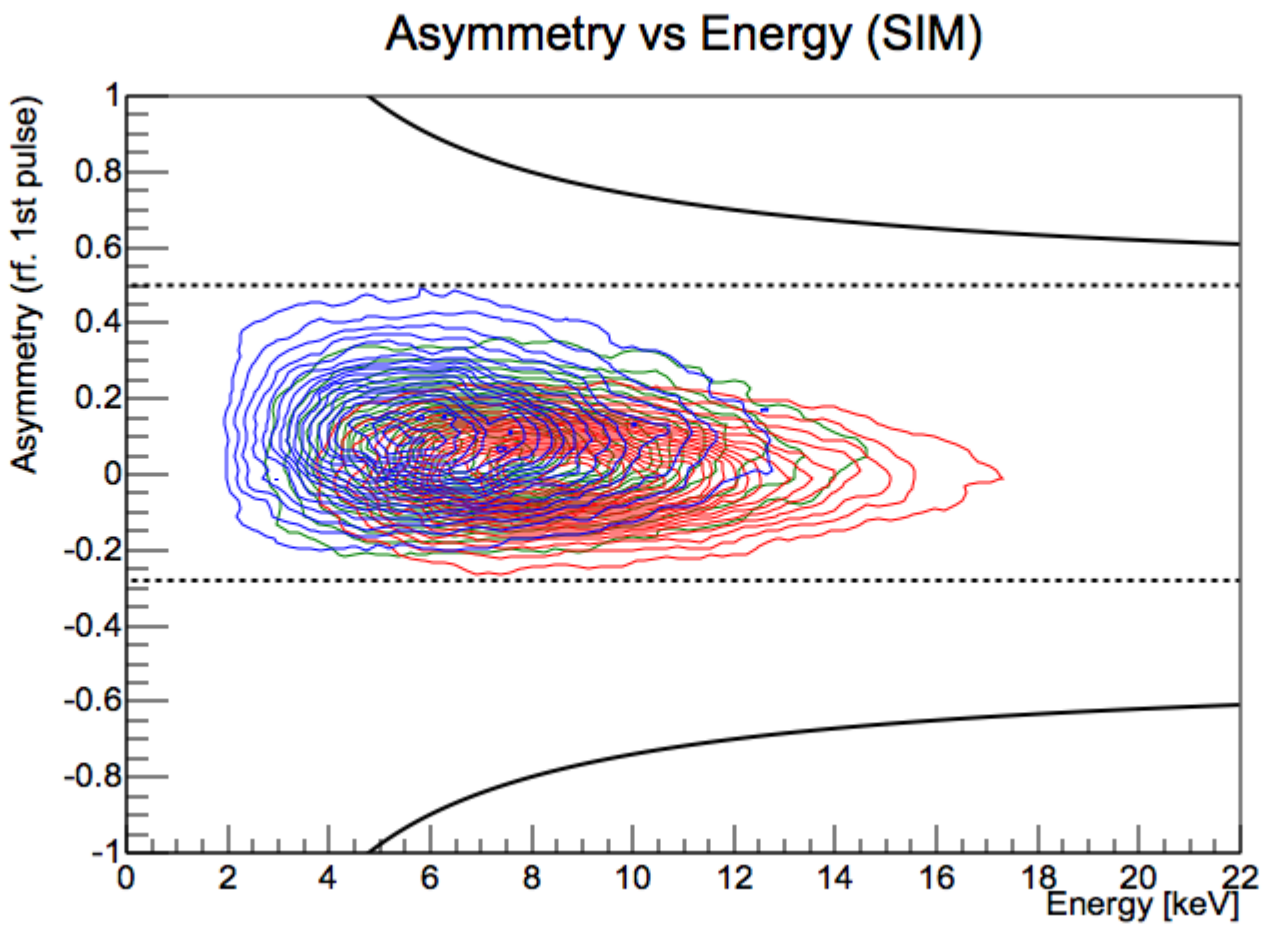
Dominant background



2nd dominant background

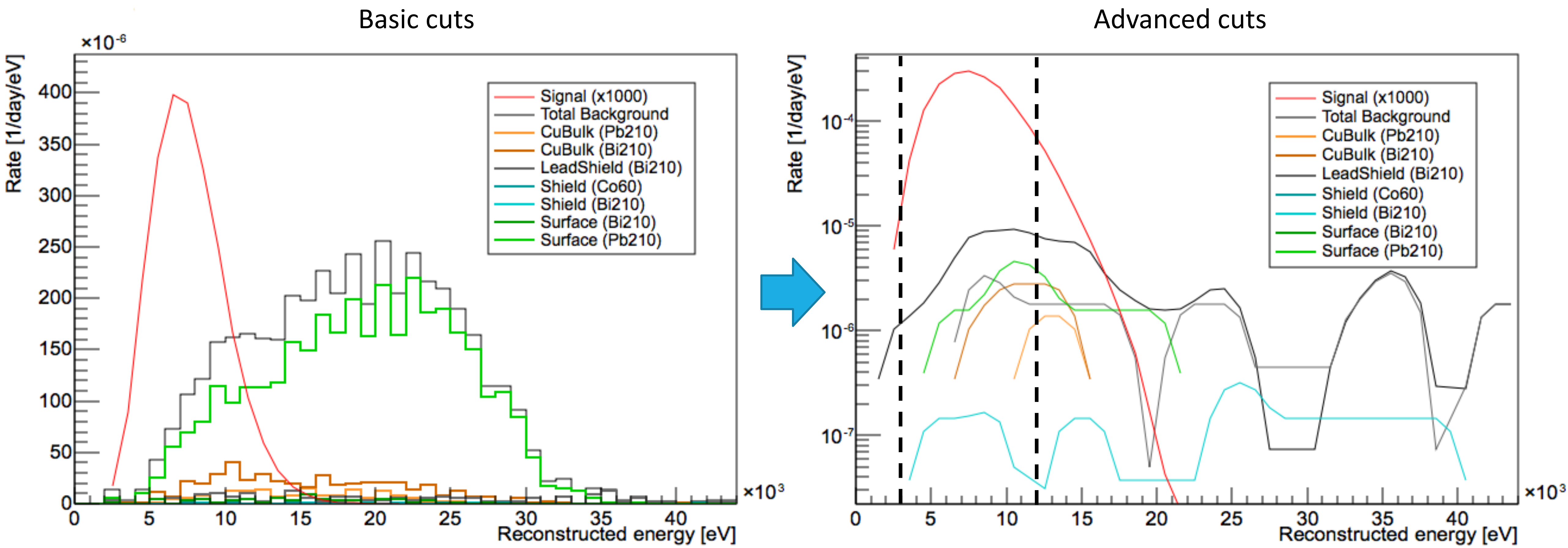


Max 2nd Risetime cut to reject background



Systematics: Low / Mid / High electron attachment

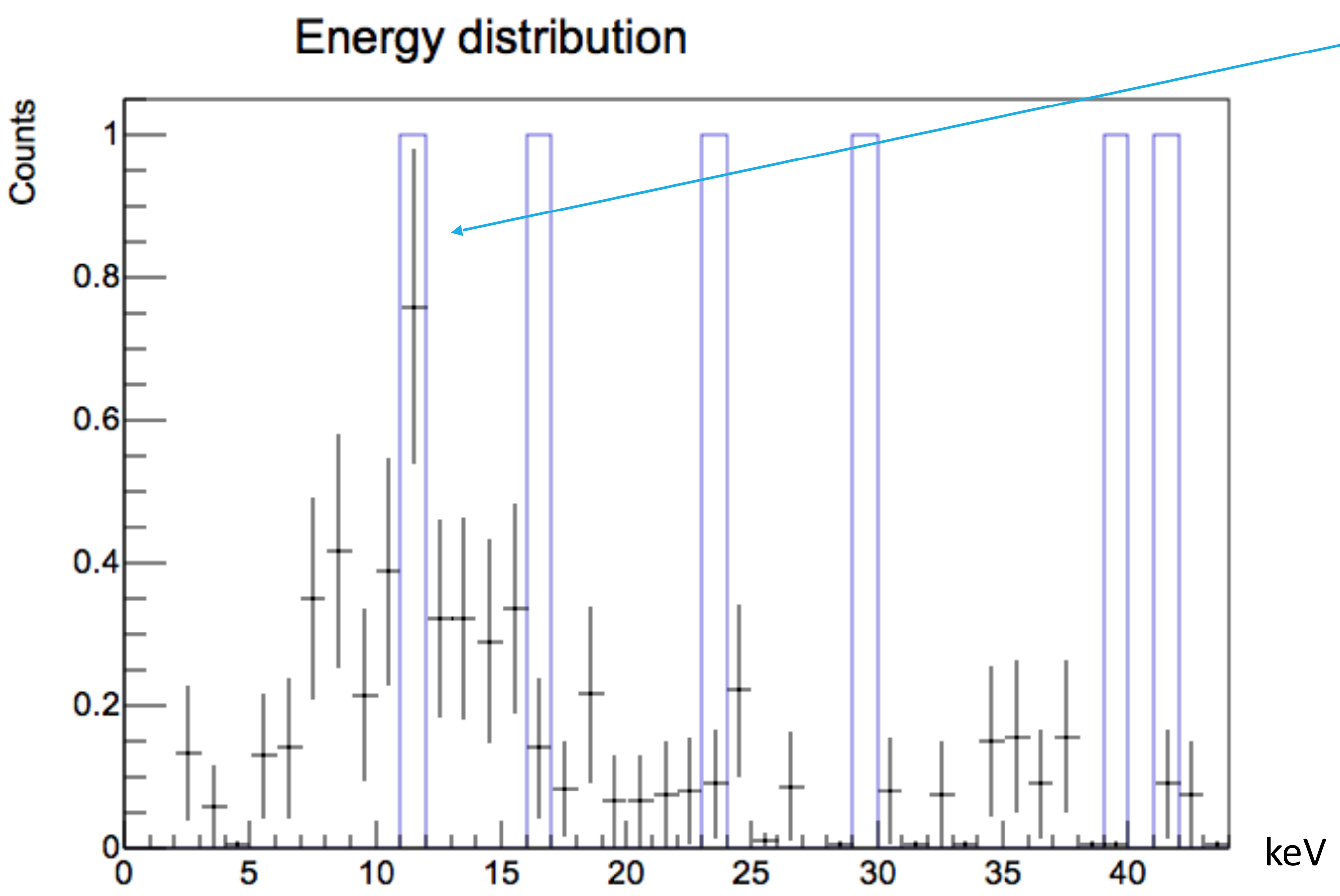
Min/Max asymmetry cut accounting for attachment uncertainties



Advanced cuts lead to severe reduction in expected background

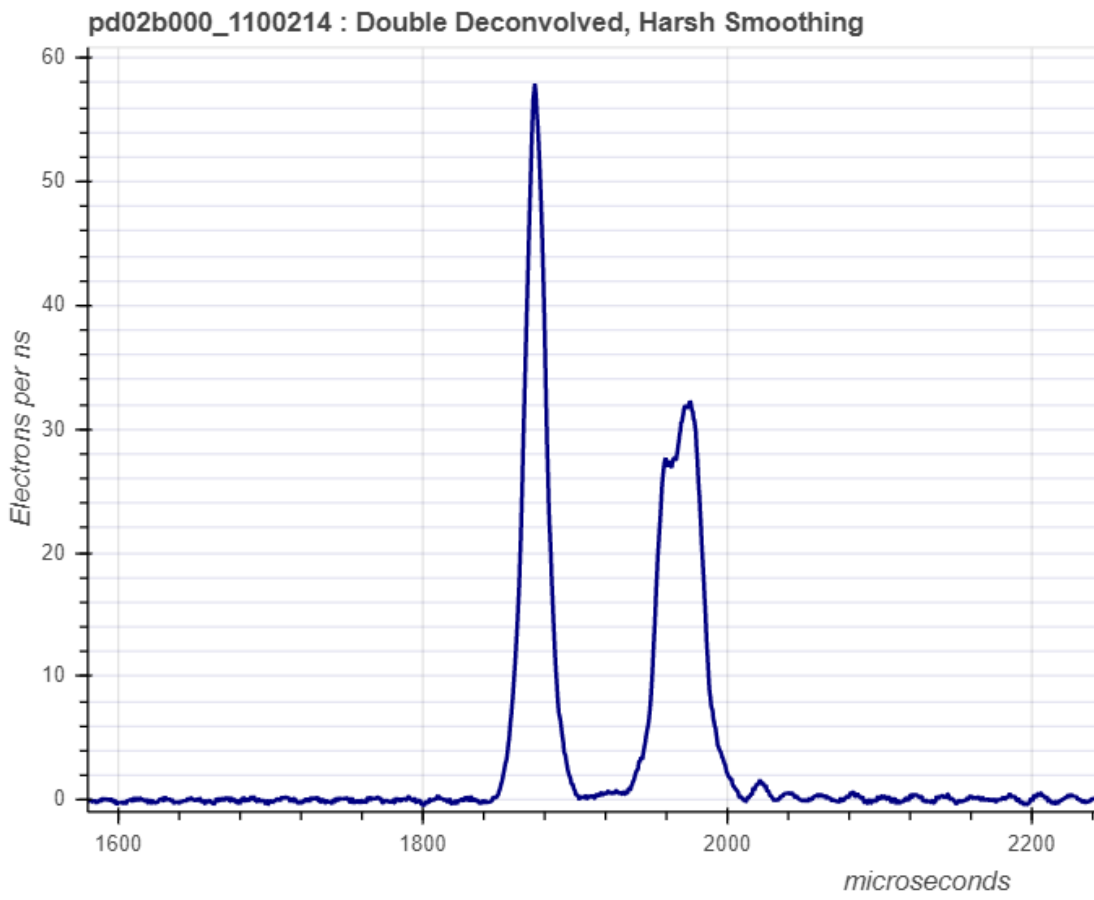
Energy range restricted to optimal axion-to-background ratio: 3-12 keV

SEDINE data

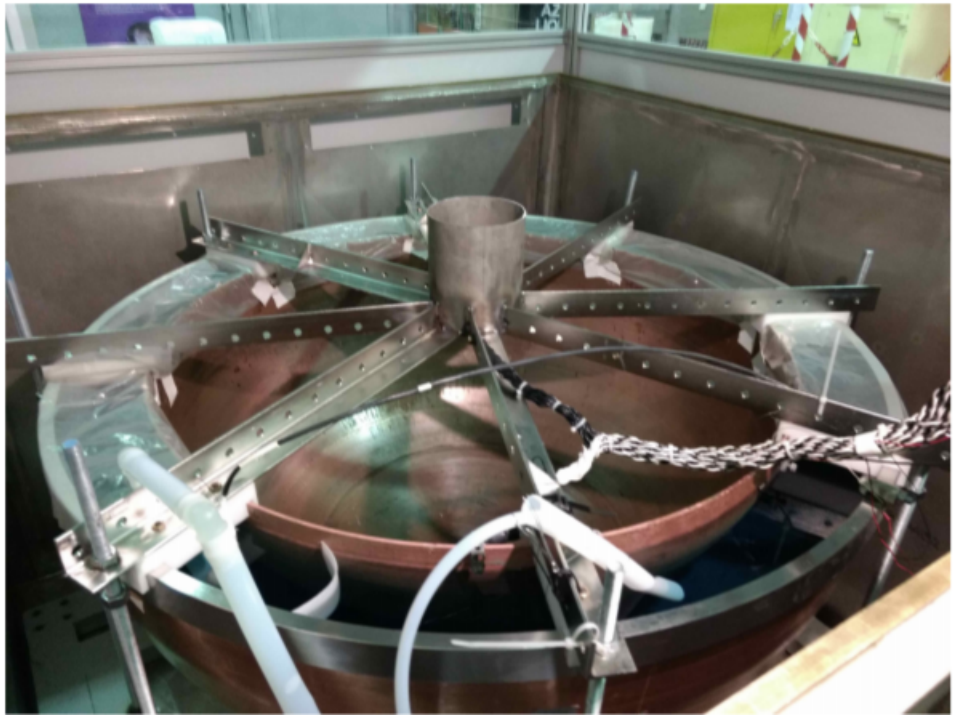


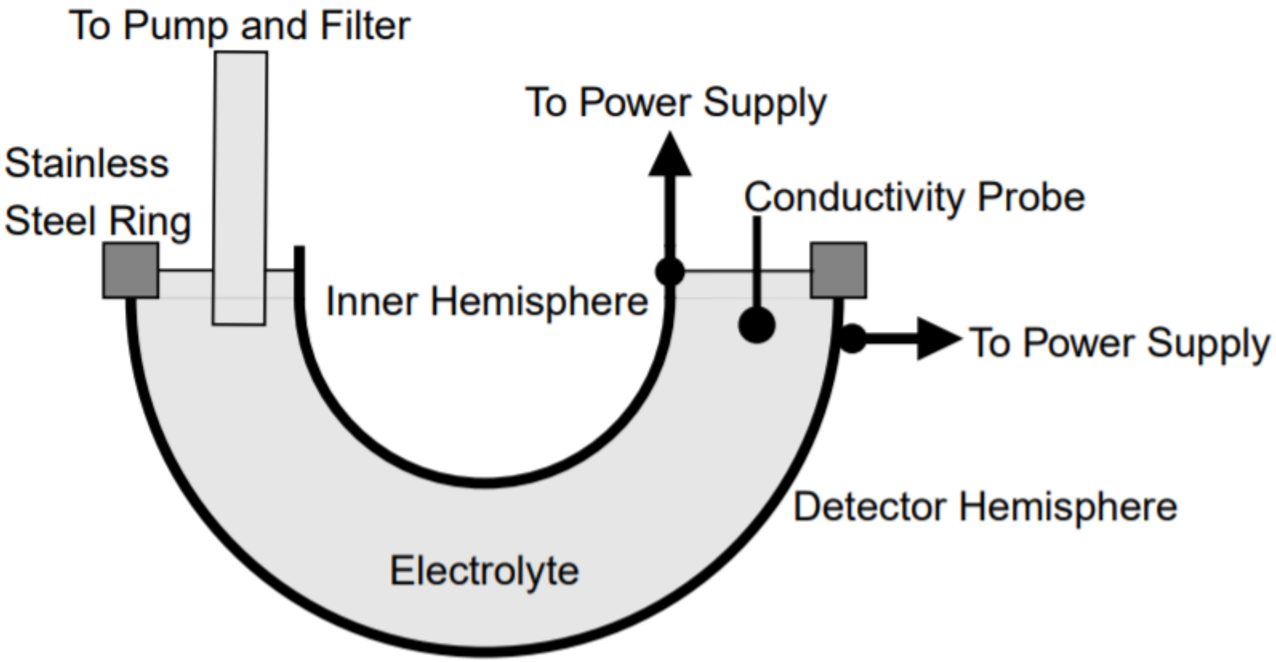
Black: Background simulation

Blue: SEDINE data



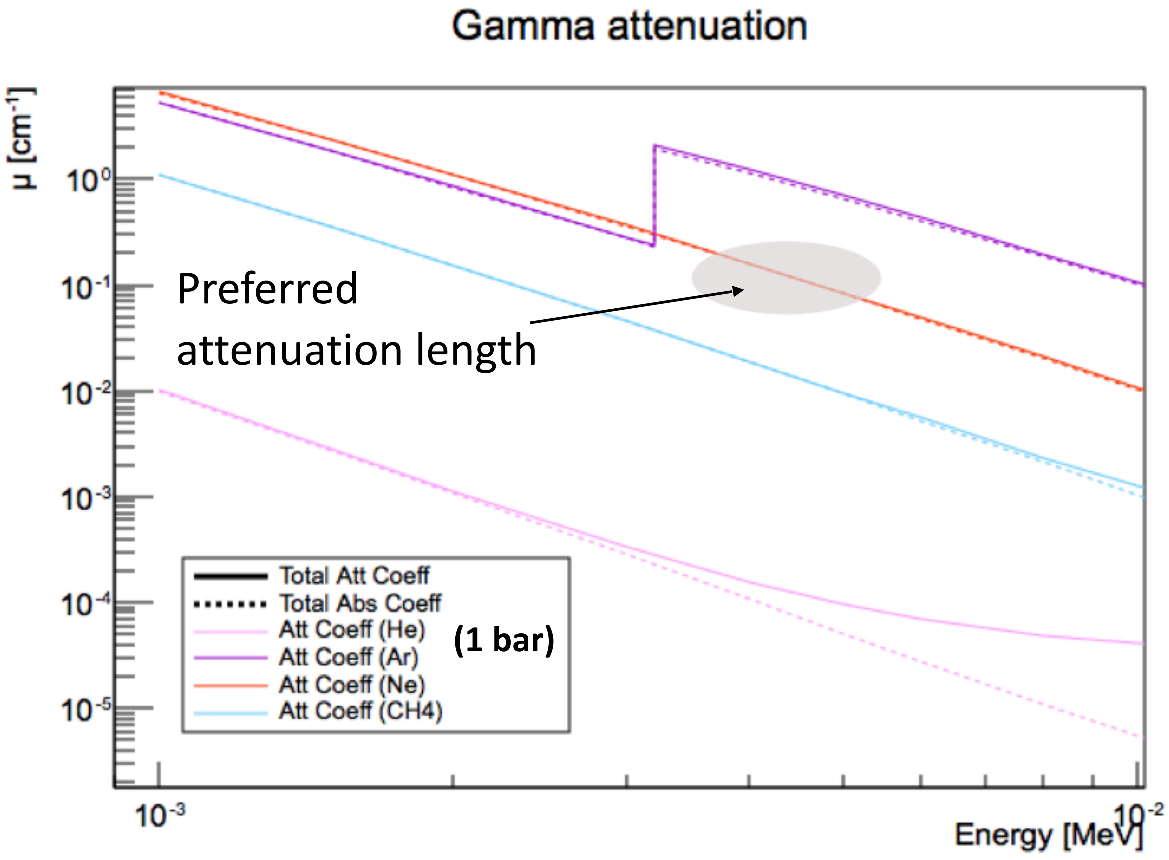
Background rejection in 2-22 keV range of 99.99%





L. Balogh et al, Copper electroplating for background suppression in the NEWS-G experiment, Nucl.Instrum.Meth.A 988 (2021)

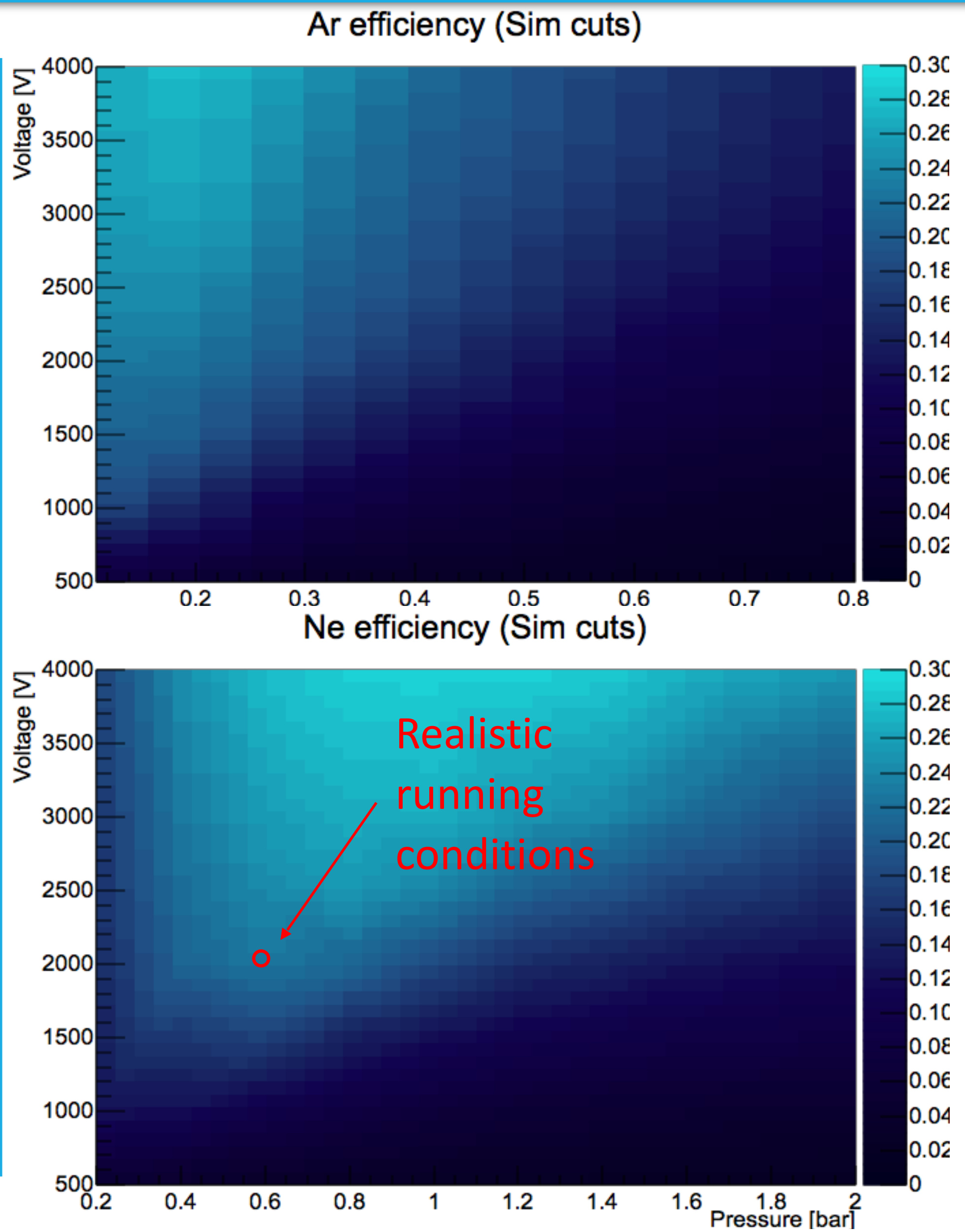
Planned electroplating of ~0.5 mm of ultrapure copper on inner surface of S140 detector, drastically reducing surface contamination backgrounds.



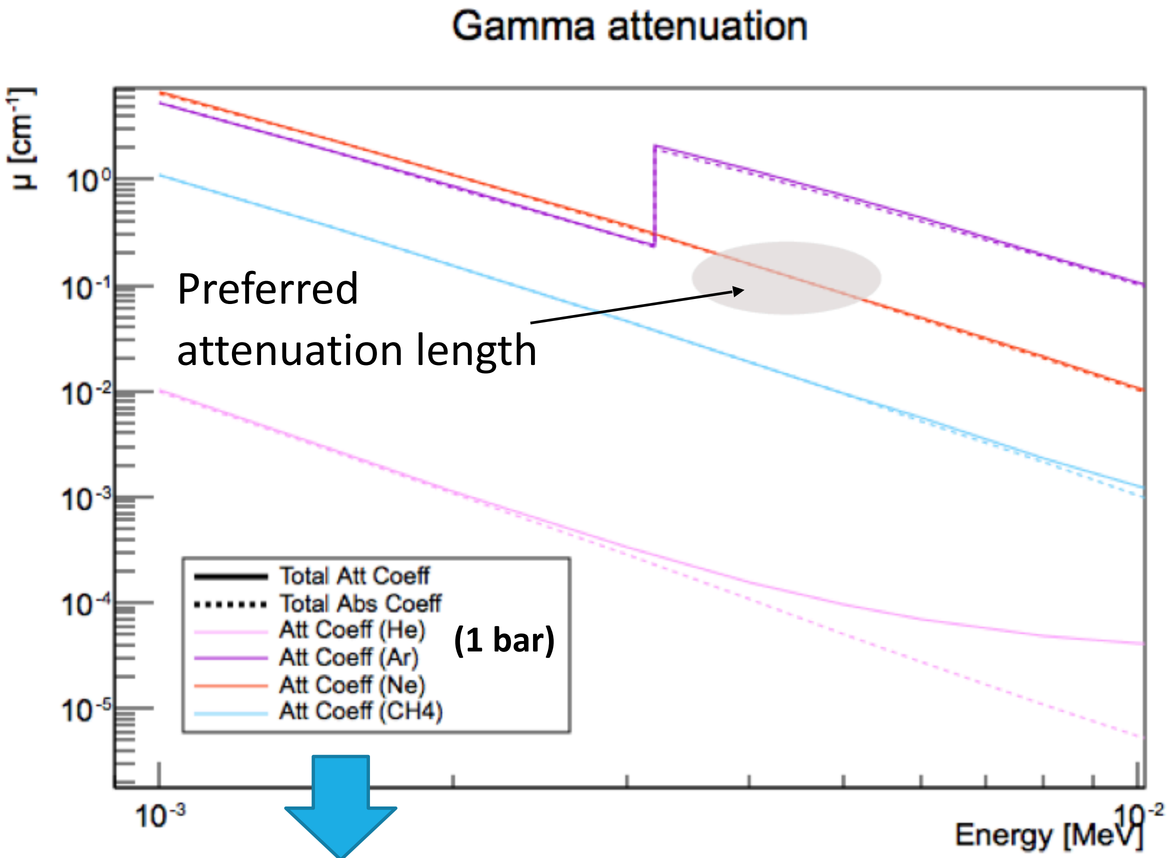
Optimal running conditions:

- Attenuation length short enough to contain both photons
- Attenuation length long enough to distinguish both interactions

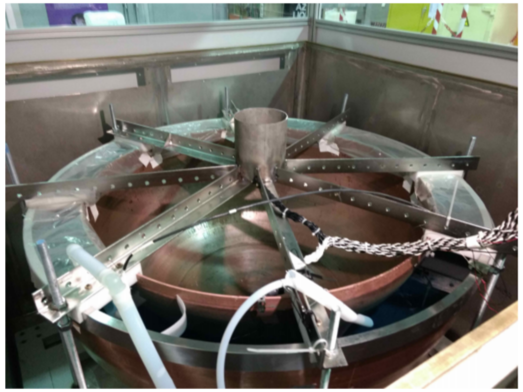
Choice of gas, pressure, voltage



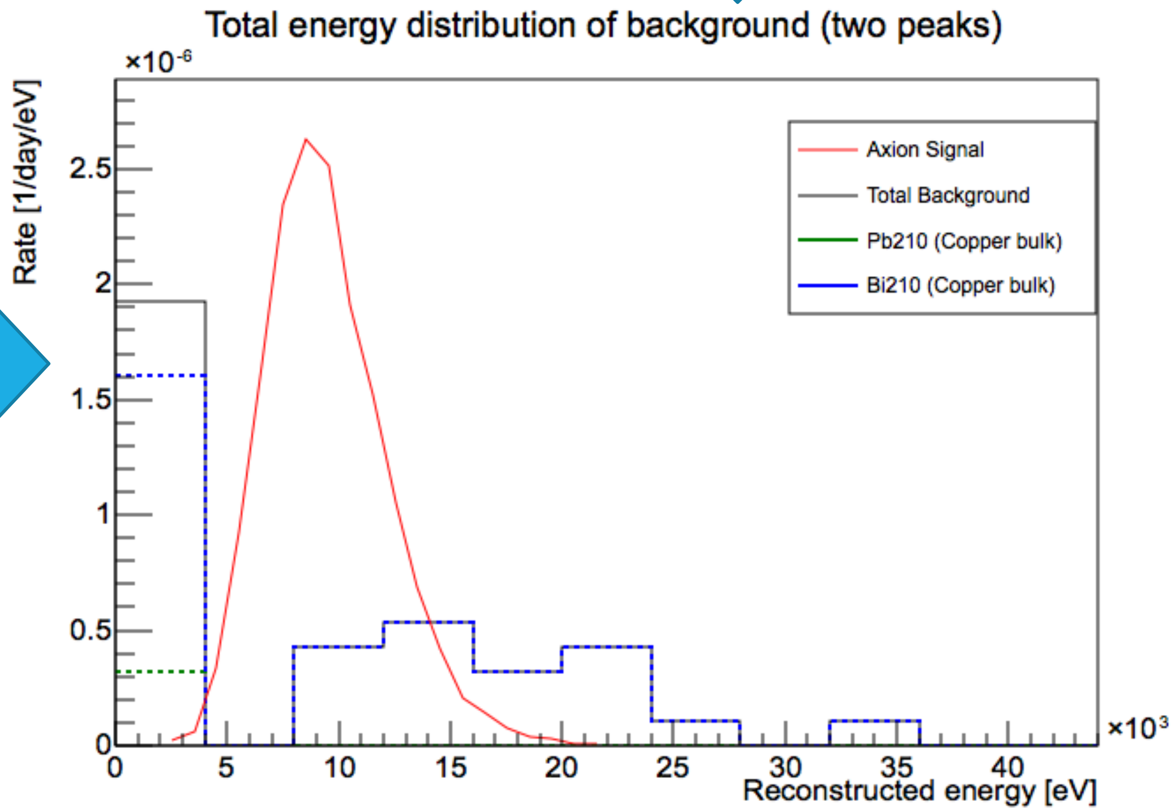
S140 : Background improvements



Sims suggest optimal running conditions:
600 mbar of neon, 2000 V on electrode



Electroplating of inner detector surface: drastic reduction of all surface contamination. **Background dominated by ^{210}Bi in copper bulk**



Expect only 20% background-to-axion ratio in 5-15 keV energy range for S140!