NEWS-G: Search for Light Dark Matter with a Spherical Proportional Counter

P. Knights
University of Birmingham, UK

NEWS-G

New **E**xperiments **W**ith **S**pheres - **G**as

Light DM searches with a novel gaseous detector, the spherical proportional counter

Queen's University

cea
DE LA RECHERCHE À L'INDUSTRIE

SNOLAB

UKRI Science and Technology Facilities Council
Boulby Underground Laboratory

University of Birmingham

RMC CMR

TRIUMF

Subatech

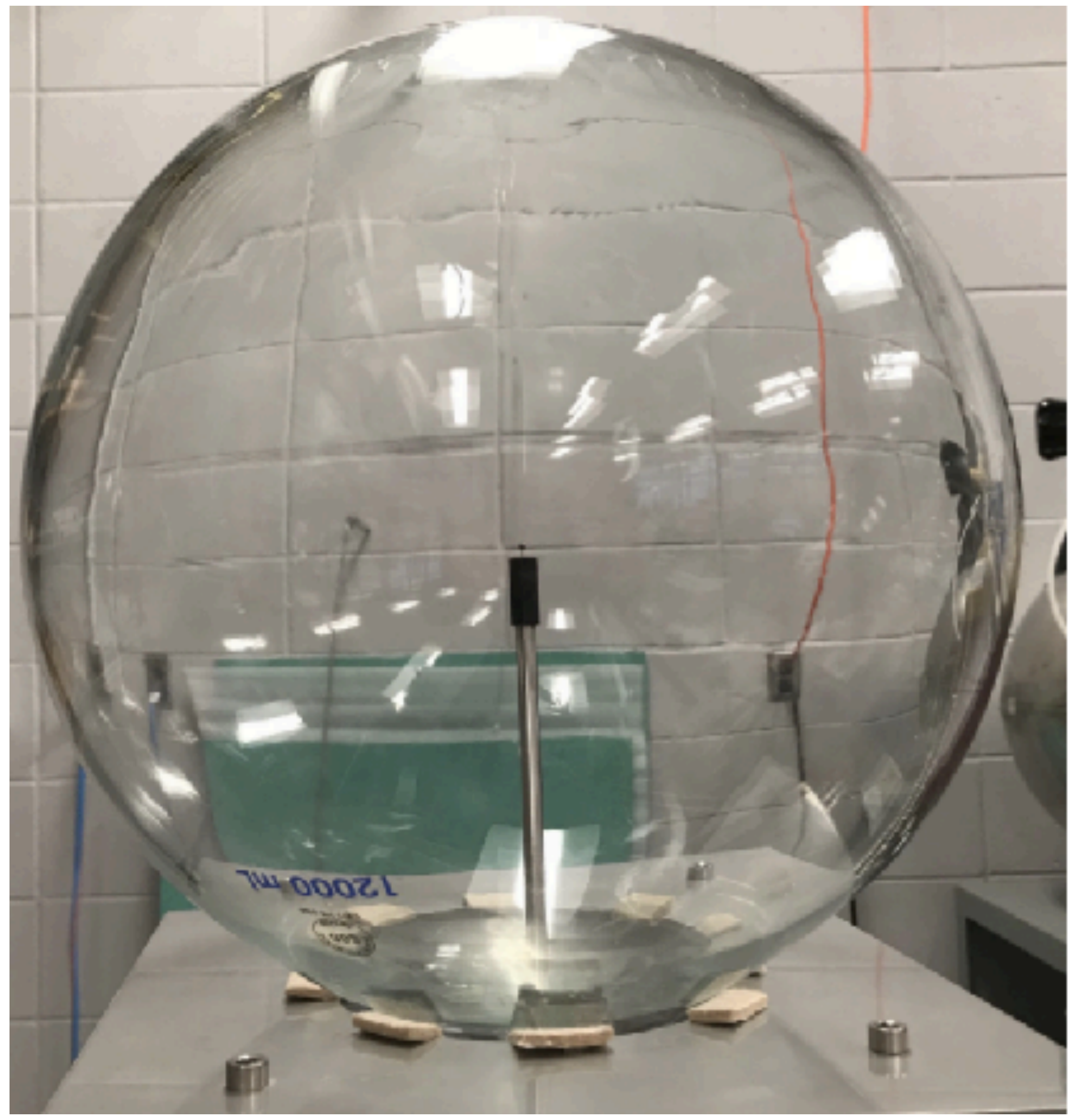
LPSC Grenoble

Pacific Northwest National Laboratory

University of Alberta

Aristotle University of Thessaloniki

SPCs *In the Wild*



Glass Sphere (Queen's U., Canada)

NEWS-G: SNOGLOBE (SNOLAB, Canada)

NEWS-G: SEDINE (LSM, France)

G. Charpak and I. Giomataris in CEA Saclay, France
(sphere was previously a LEP RF cavity)

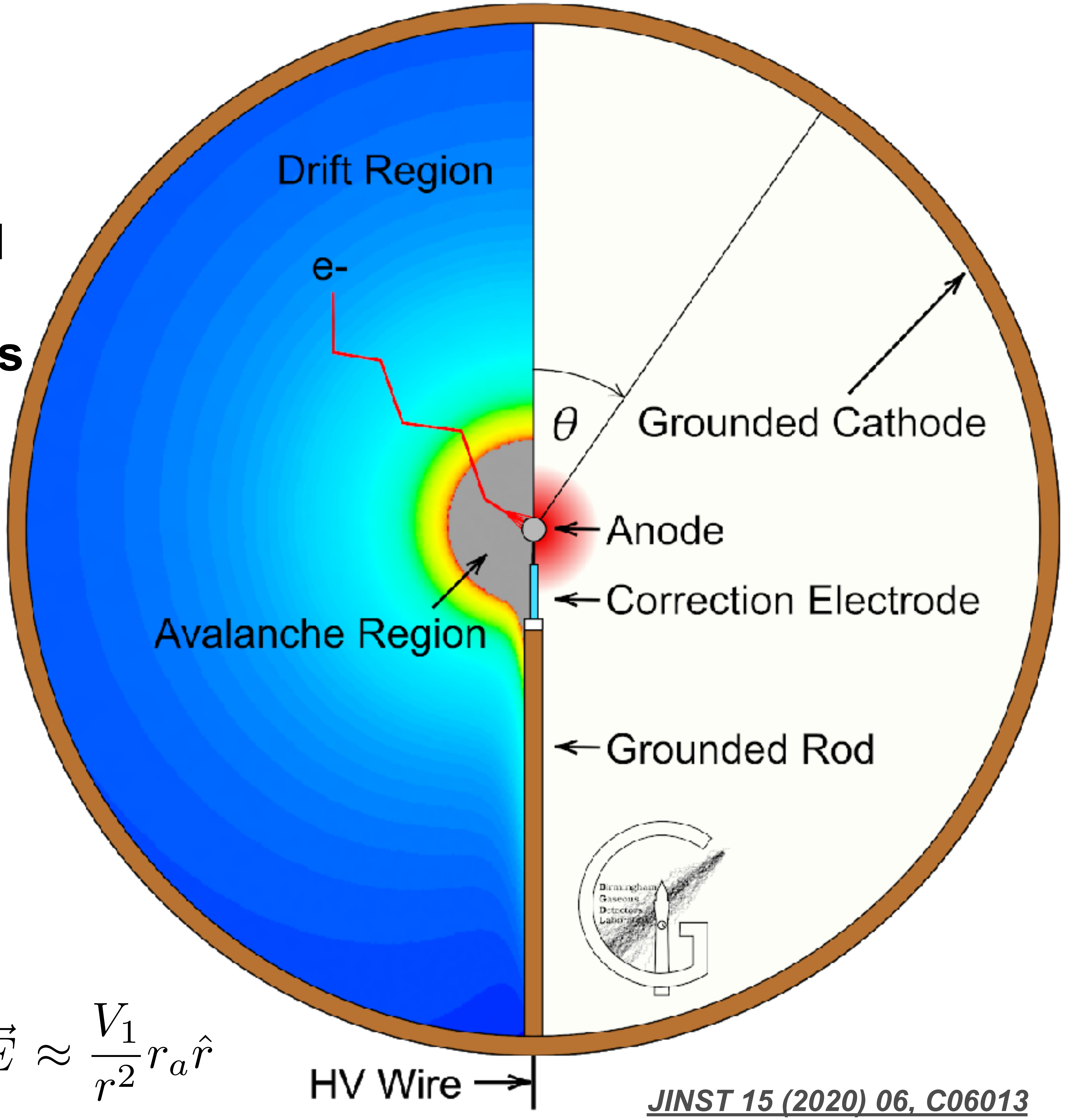
Gaseous Detector Laboratory (University of Birmingham)

Boulby Underground Laboratory

Principle of Operation

- Simplest form: **~ mm ball** in a **~0.1-1 m spherical shell**
- Ideal electric field varies as $1/r^2$
  - **Naturally divides** detector: **drift** and **avalanche regions**

- **Low capacitance**, independent of detector size
  - Single-electron detection
- **Lowest surface area to volume ratio**
- Fiducialisation and PID from radial E-field
- **Choice of gas** targets (H, He, Ne) and pressures
  - Kinematic match to light-DM



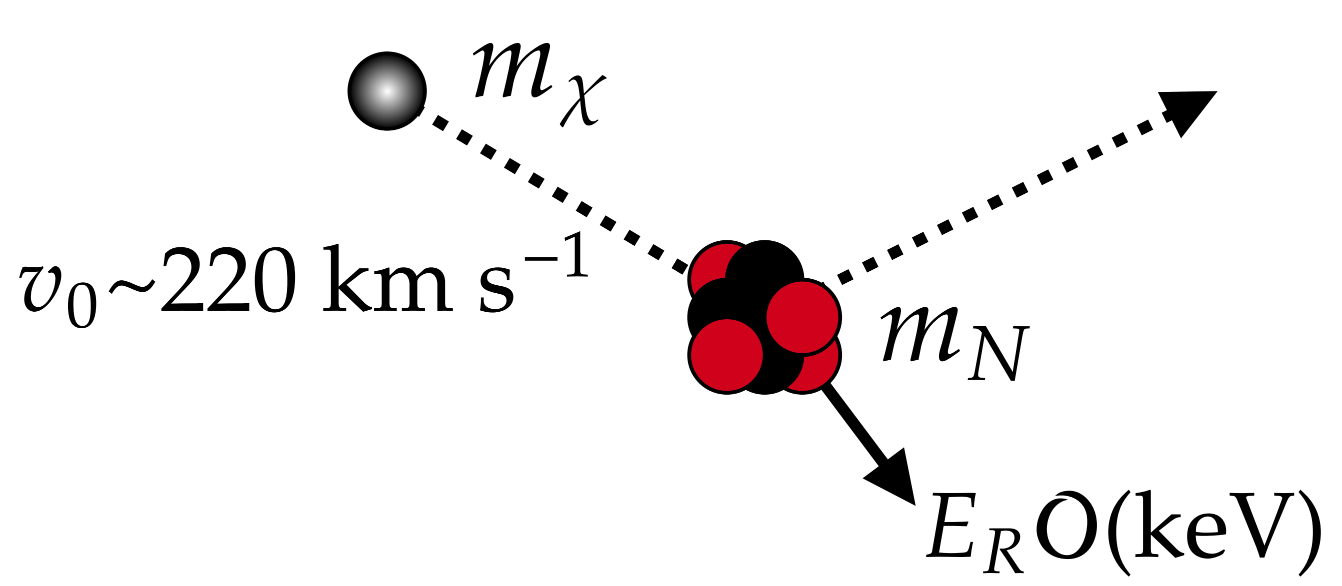
$$\vec{E} \approx \frac{V_1}{r^2} r_a \hat{r}$$

JINST 15 (2020) 06, C06013

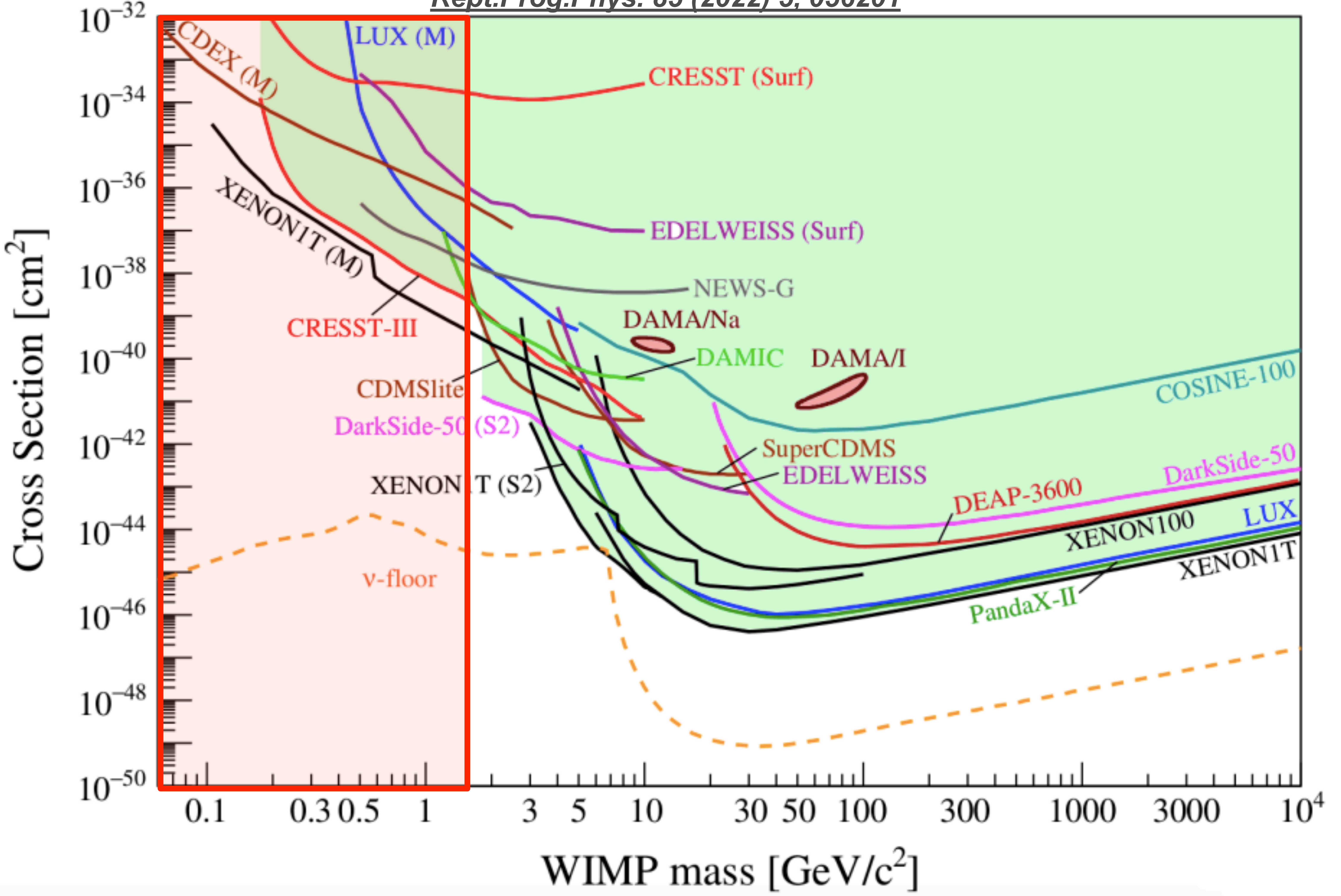
The Search for Light Dark Matter

- Light DM region has **attracted theoretical** interest

- **Exploring light DM** with nuclear recoils requires:
  - **Low energy threshold**
  - **Low-mass target nuclei**



Rept.Prog.Phys. 85 (2022) 5, 056201



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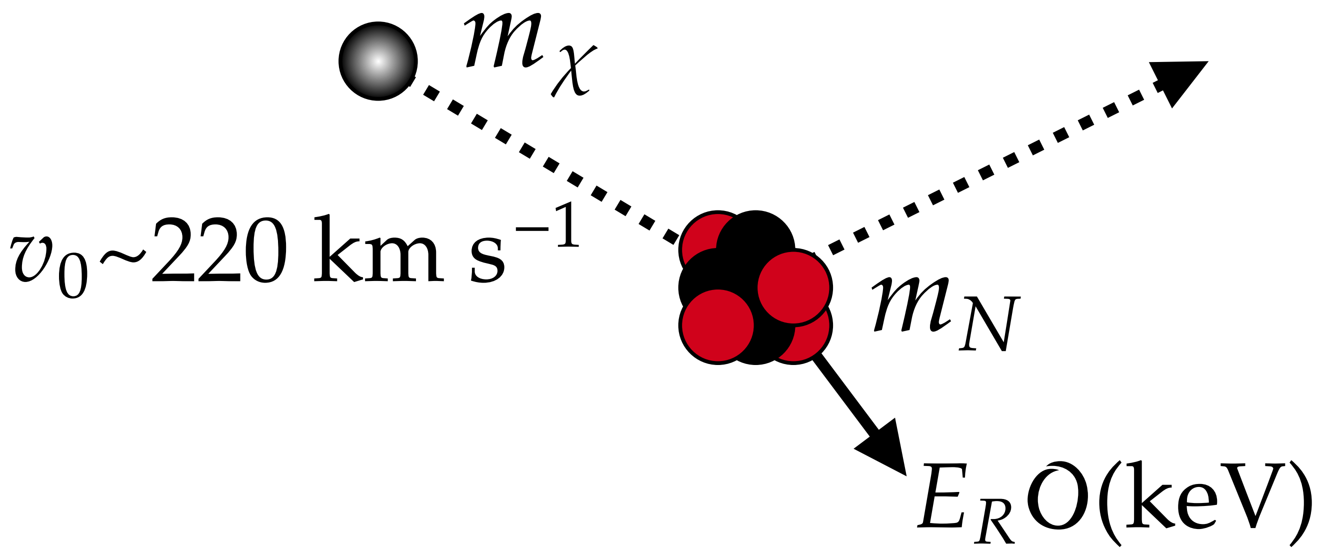
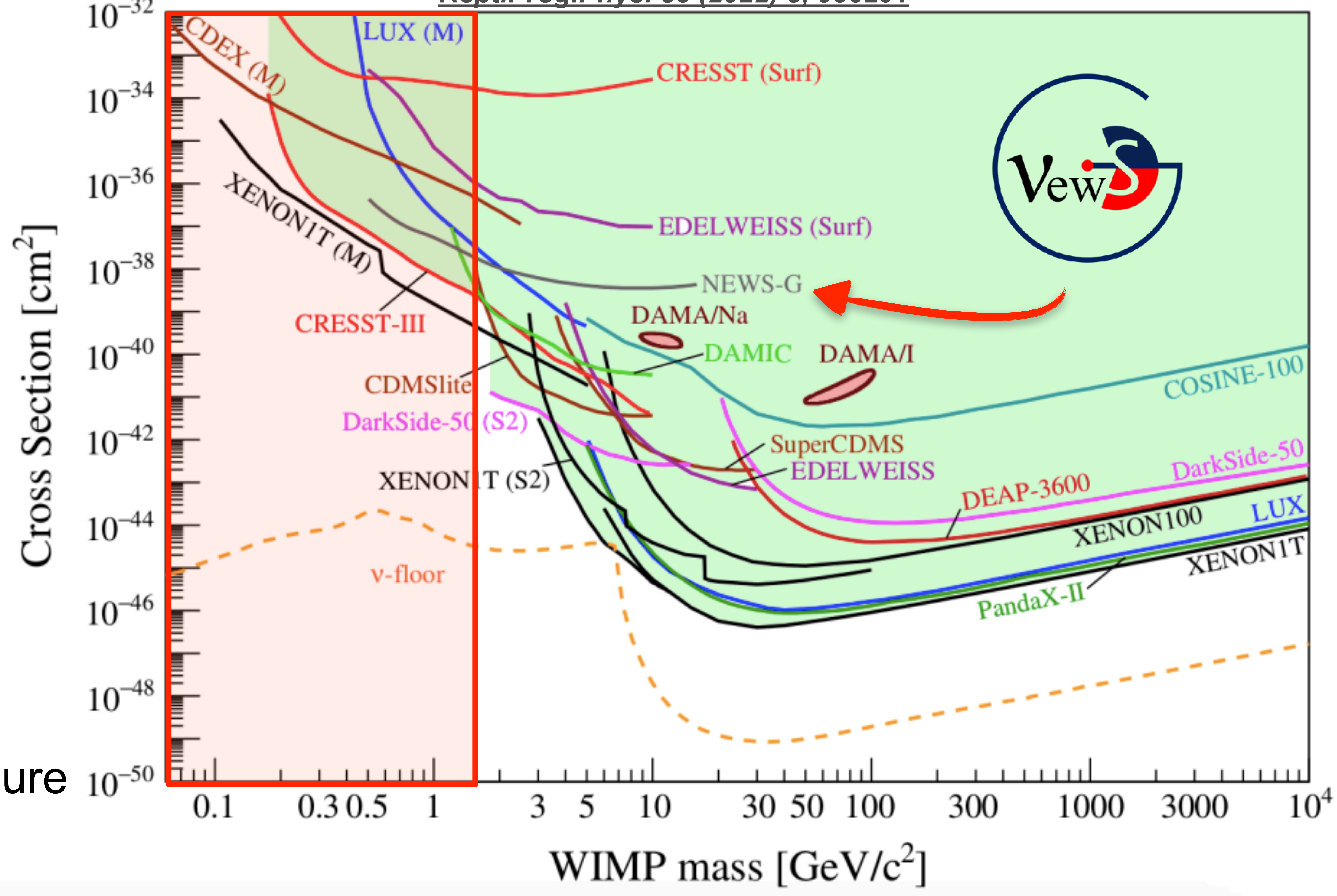


- **NEWS-G:** First results in 2018
  - ⌀60 cm prototype in LSM
  - Ne:CH_4 (99.3%:0.7%) 9.6 kg day exposure
  - **Strongest SI limit at time on 0.5 GeV**

Astropart.Phys. 97 (2018) 54-62

  - **More with this data?**

Rept.Prog.Phys. 85 (2022) 5, 056201

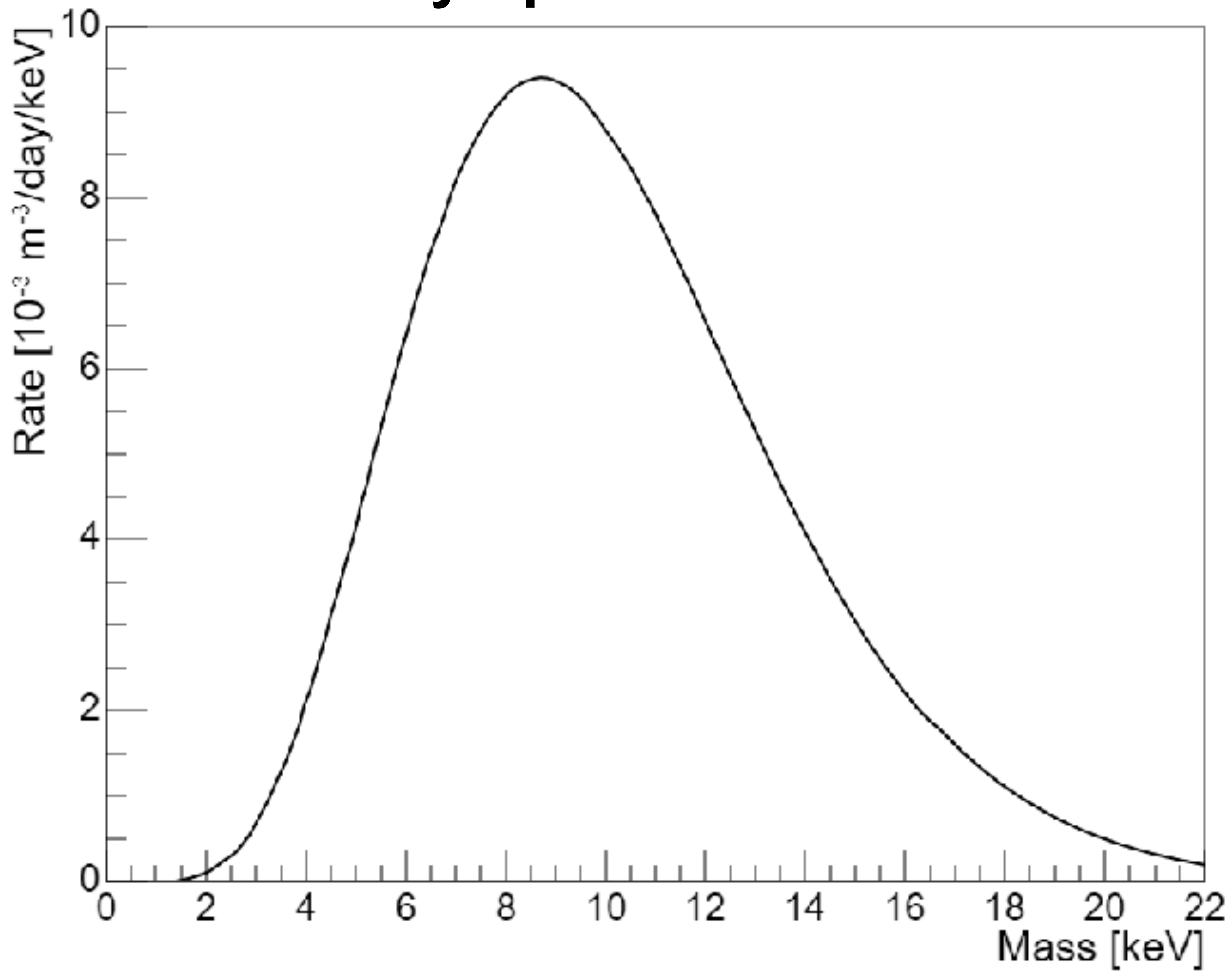


Phys.Rev.D 105 (2022) 1, 012002

Kaluza-Klein Axion Search

- KK axions produced in the sun Phys.Rev.D 62 (2000) 125011
  - Gravitationally bound to solar system
  - Could explain corona heating problem
- Signal: **Decay to 2 photons**
  - Look for 2, point-like events with similar energy

Decay Spectrum on Earth



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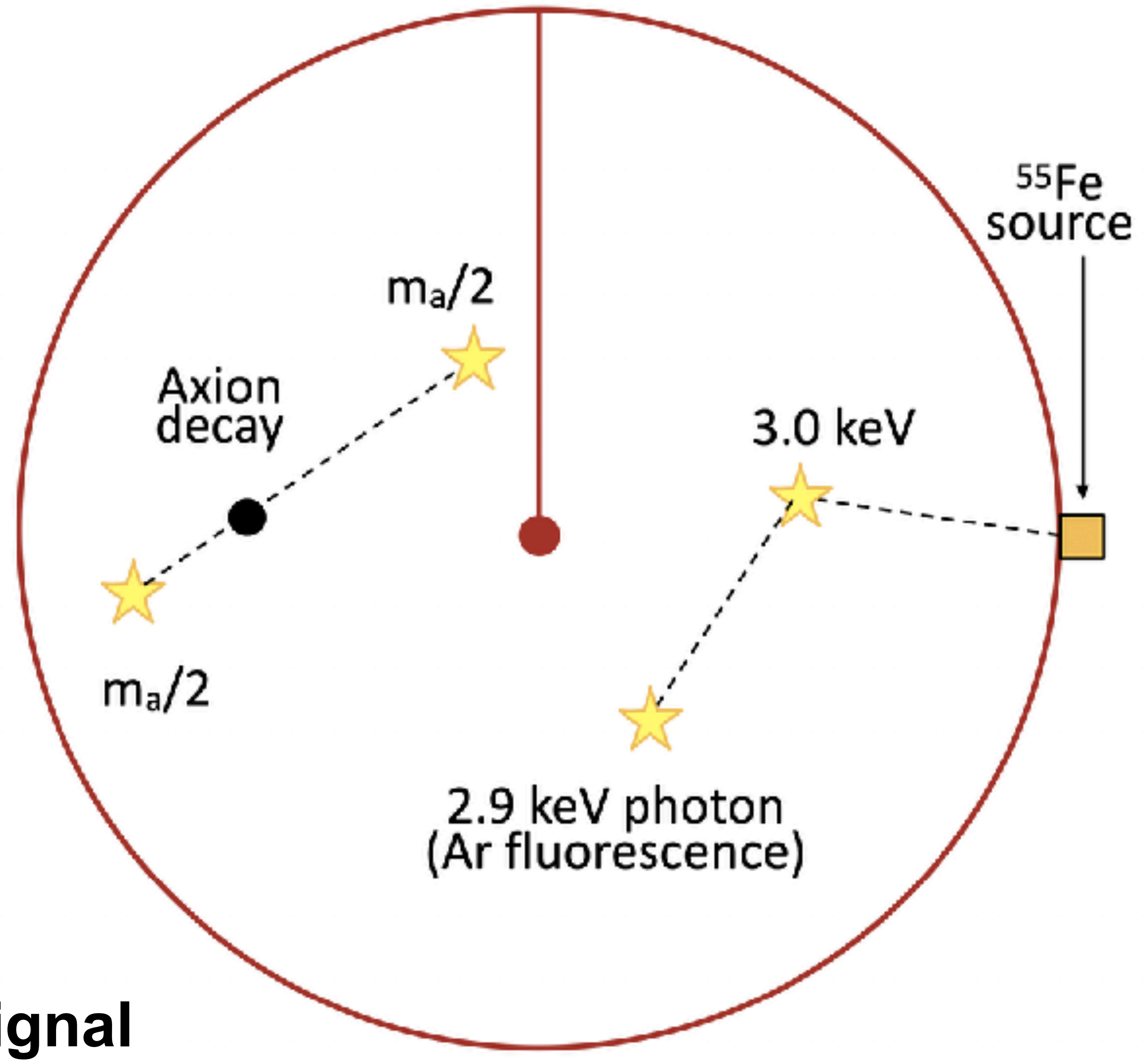

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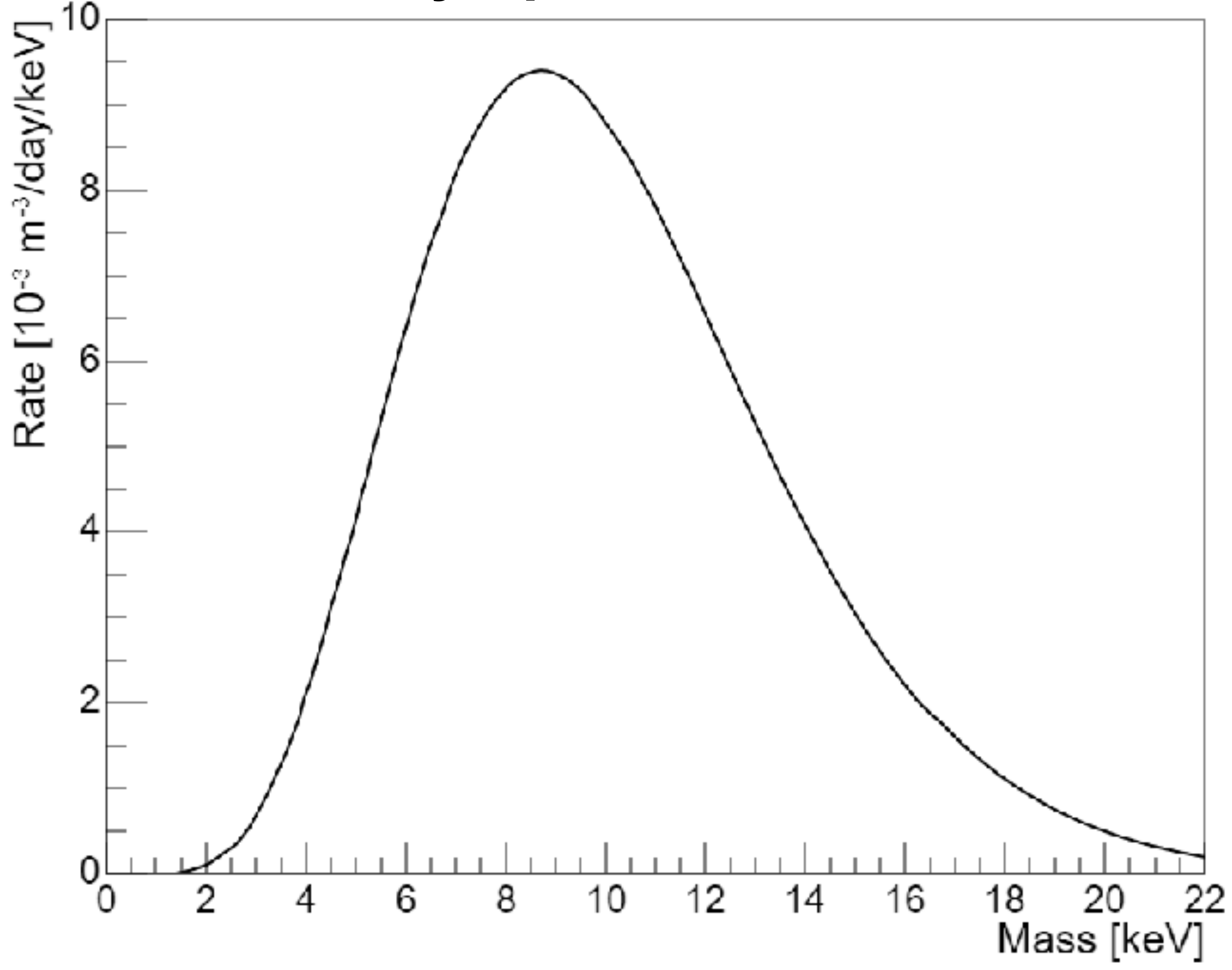
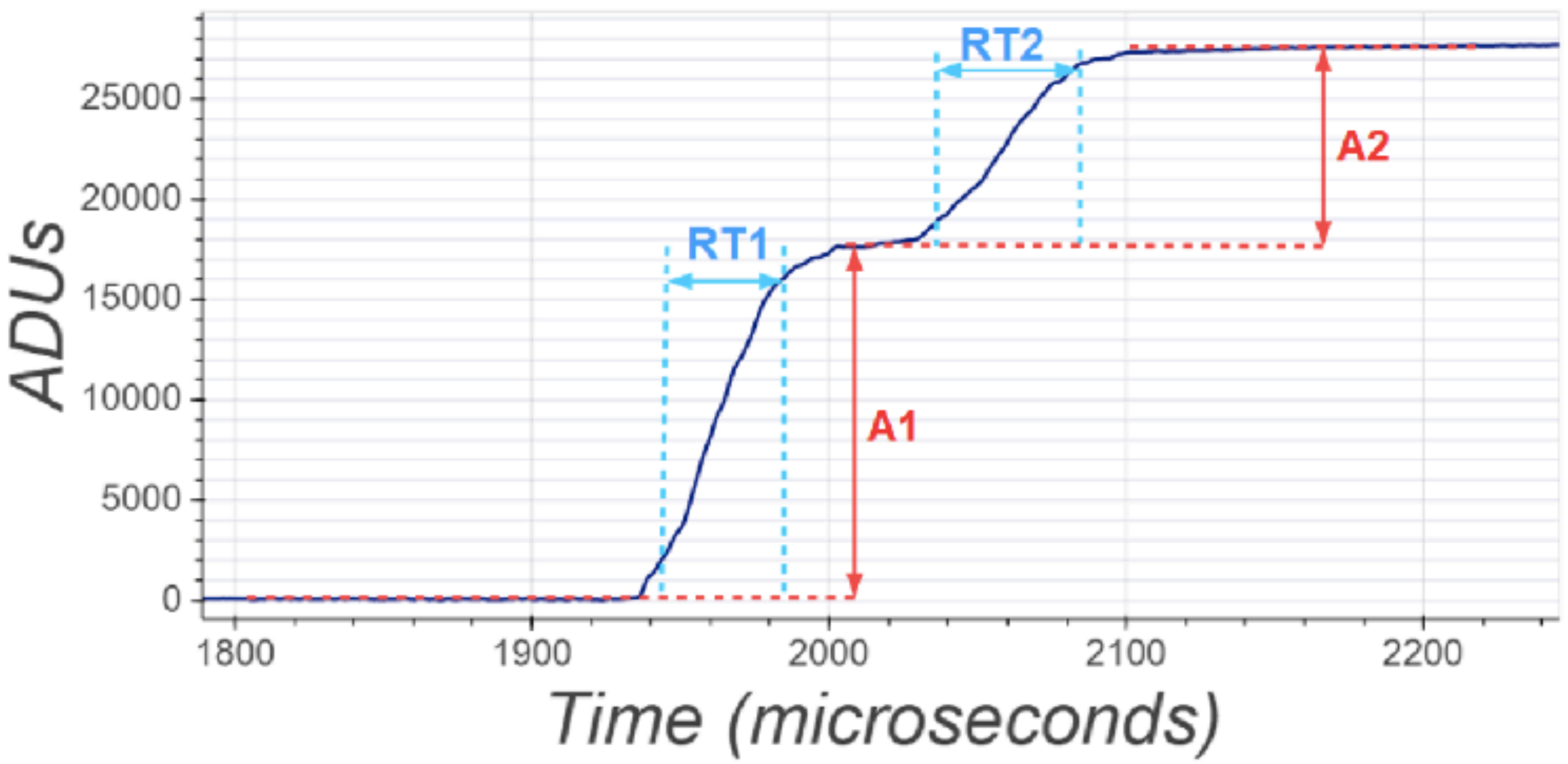
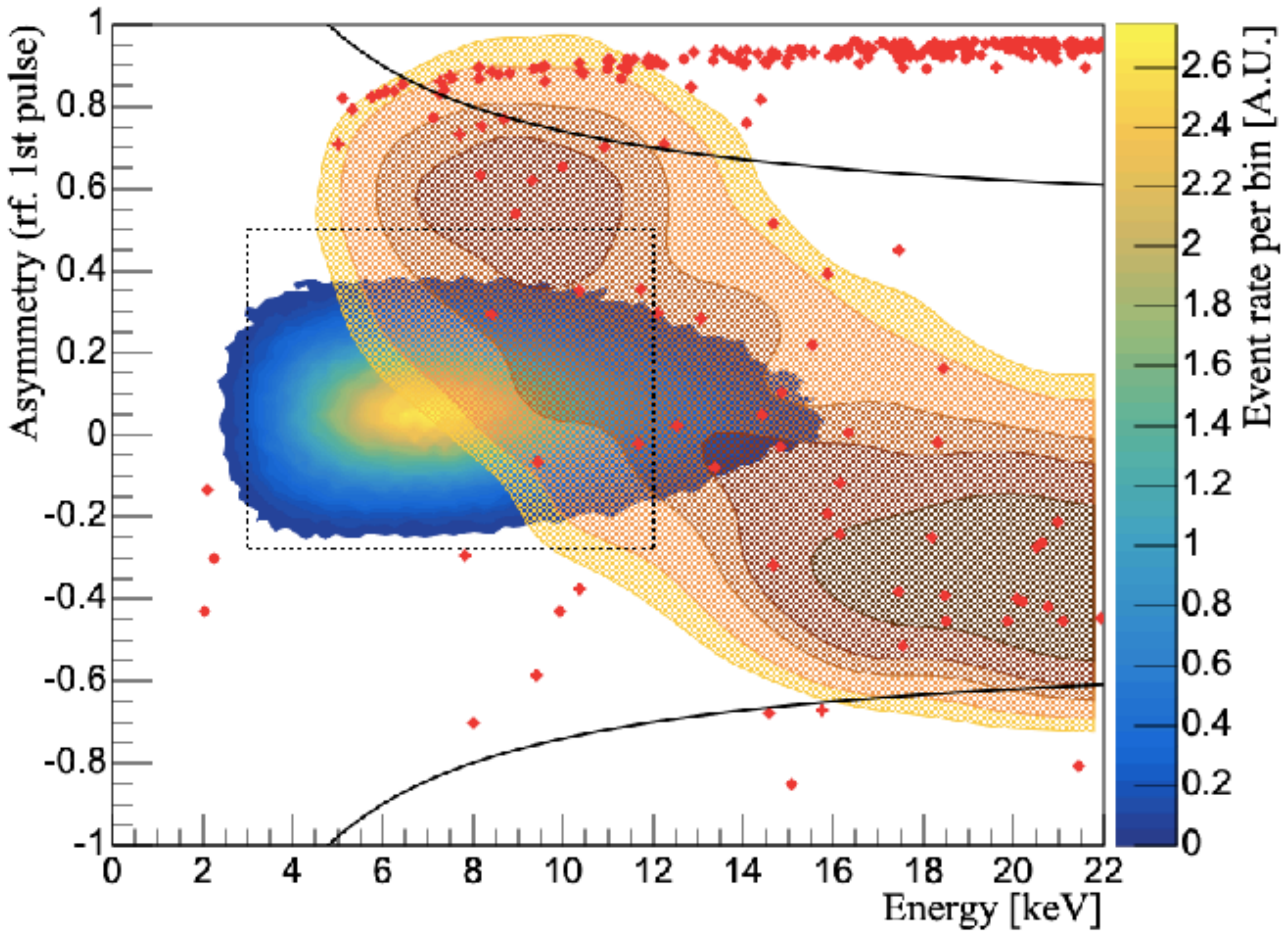


Example Signal



Kaluza-Klein Axion Search

- Search performed with SEDINE data (⌀60 cm) More info on SEDINE: Astropart.Phys. 97 (2018) 54-62
  - 48 days data → 4.3 day·m^3 exposure
  - Ne:CH4 (98.3:0.7%) 3.1 bar



*assuming n_a = 4.07x10^{-13} m^{-3}, 2 extra dimensions of R = 1 eV^{-1}

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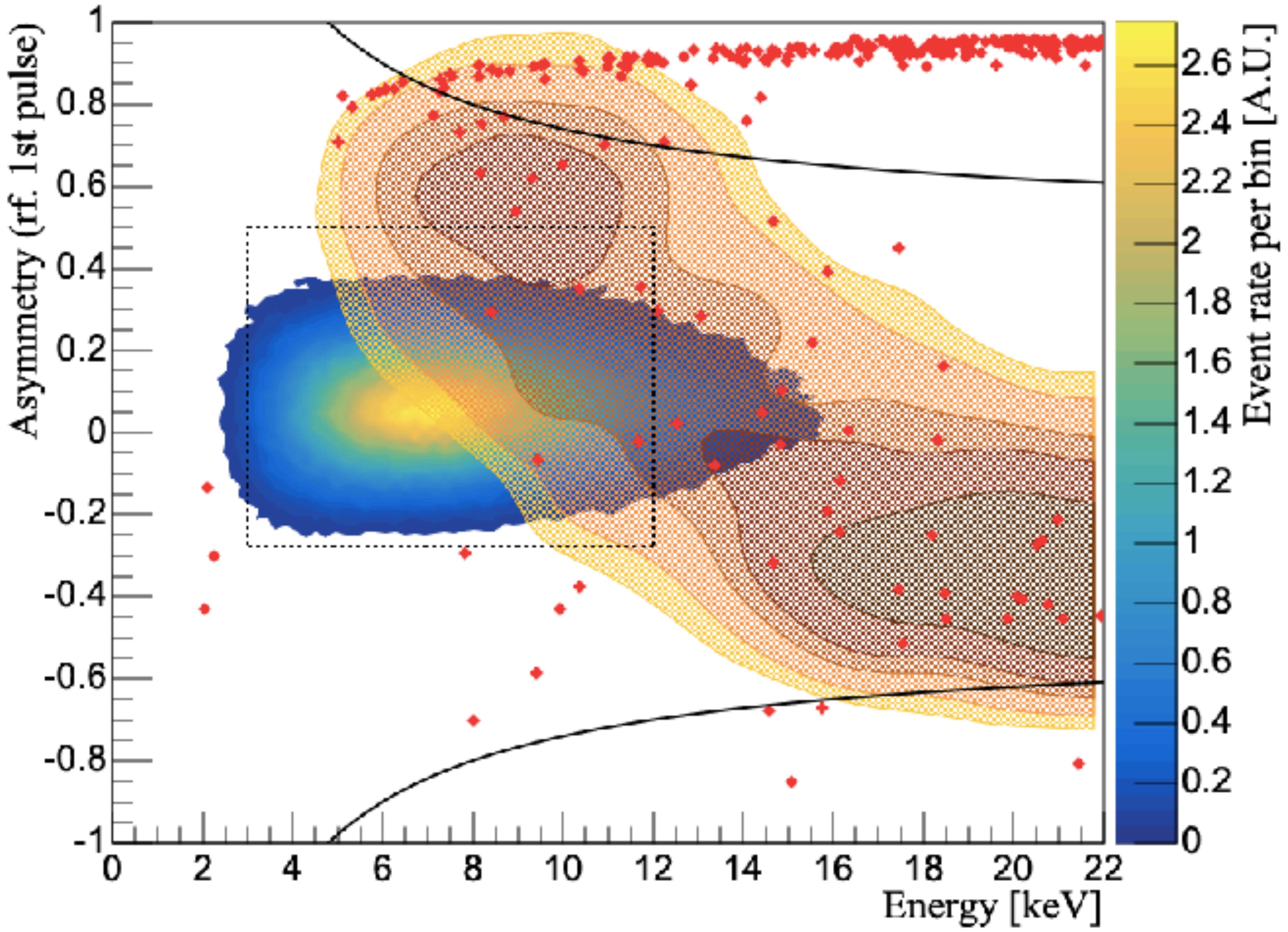

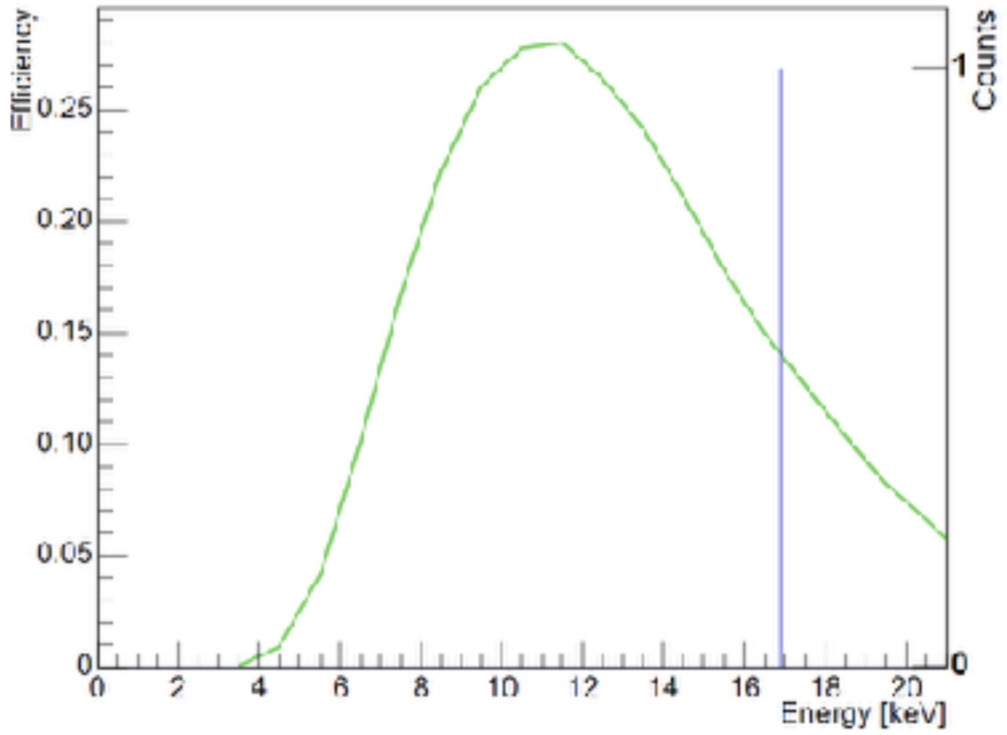

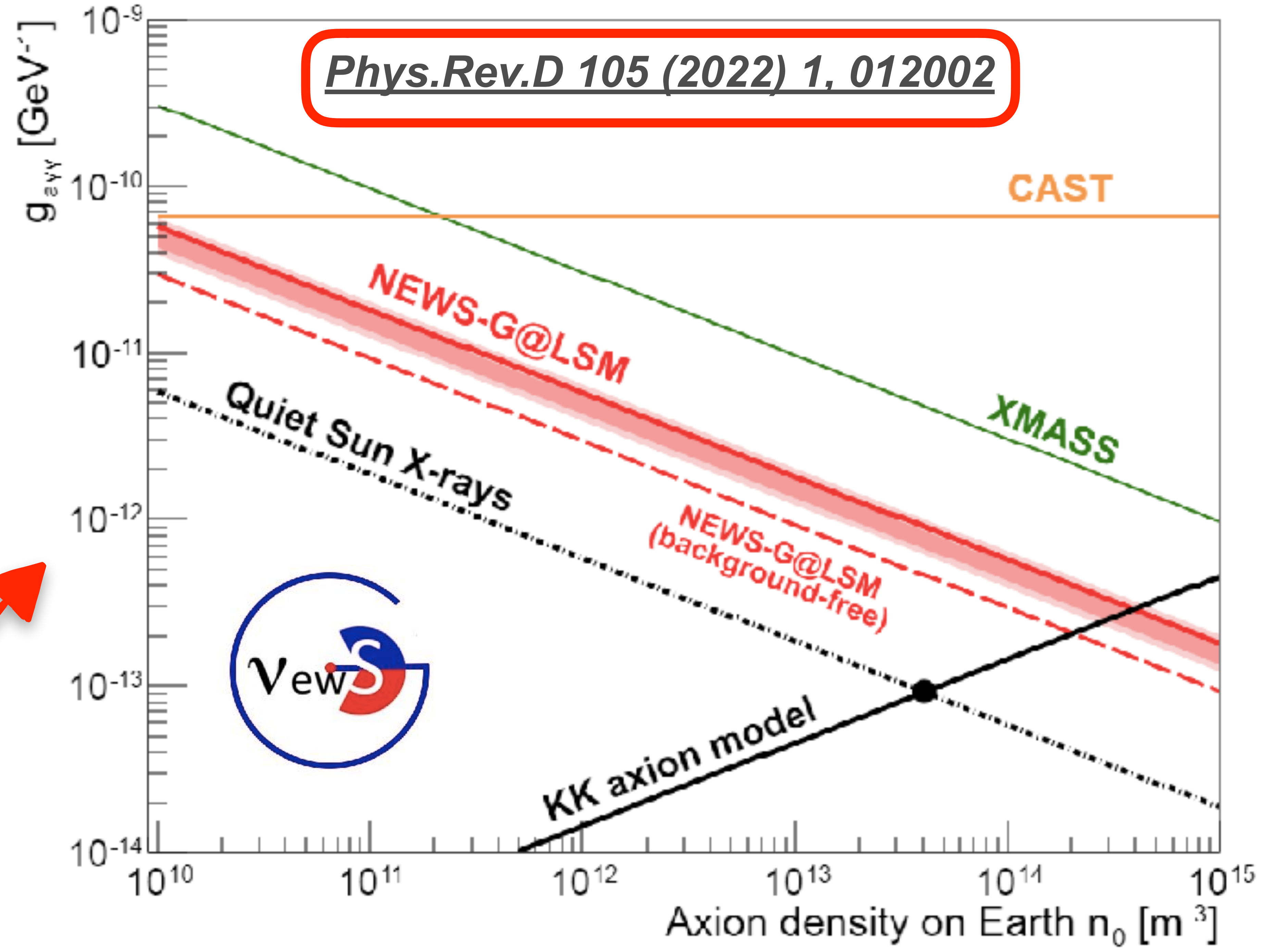

New Result!

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PHYSICAL REVIEW D **105**, 012002 (2022)

Solar Kaluza-Klein axion search with NEWS-G

Q. Arnaud,[1] L. Balogh,[2] C. Beaufort,[4] A. Brossard,[3] J.-F. Caron,[2] M. Chapellier,[3] J.-M. Coquillat,[3] E. C. Corcoran,[5] S. Crawford,[3] A. Dastgheibi-Fard,[4] Y. Deng,[5] K. Dering,[3] D. Durnford,[6] C. Garrah,[6] G. Gerbier,[3] I. Giomataris,[7] G. Giroux,[3] P. Gorel,[8,9,10] M. Gros,[7] P. Gros,[3] O. Guillaudin,[4] E. W. Hoppe,[12] I. Katsioulas,[13] F. Kelly,[5] P. Knights,[13] S. Langrock,[8,9,10] P. Lautridou,[11] R. D. Martin,[3] J.-P. Mols,[7] J.-F. Muraz,[4] T. Neep,[13] K. Nikolopoulos,[13] P. O'Brien,[5] M.-C. Piro,[6] D. Santos,[4] G. Savvidis,[3] I. Savvidis,[14] F. A. Vazquez de Sola Fernandez,[11,*] M. Vidal,[3] R. Ward,[13] and M. Zampaolo[4]

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[5]Chemistry and Chemical Engineering Department, Royal Military College of Canada, Kingston, Ontario K7K 7B4, Canada
[6]Department of Physics, University of Alberta, Edmonton, Alberta T6G 2R3, Canada
[7]IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
[8]Department of Physics and Astronomy, Laurentian University, Sudbury, Ontario P3E 2C6, Canada
[9]SNOLAB, Lively, Ontario P3Y 1N2, Canada
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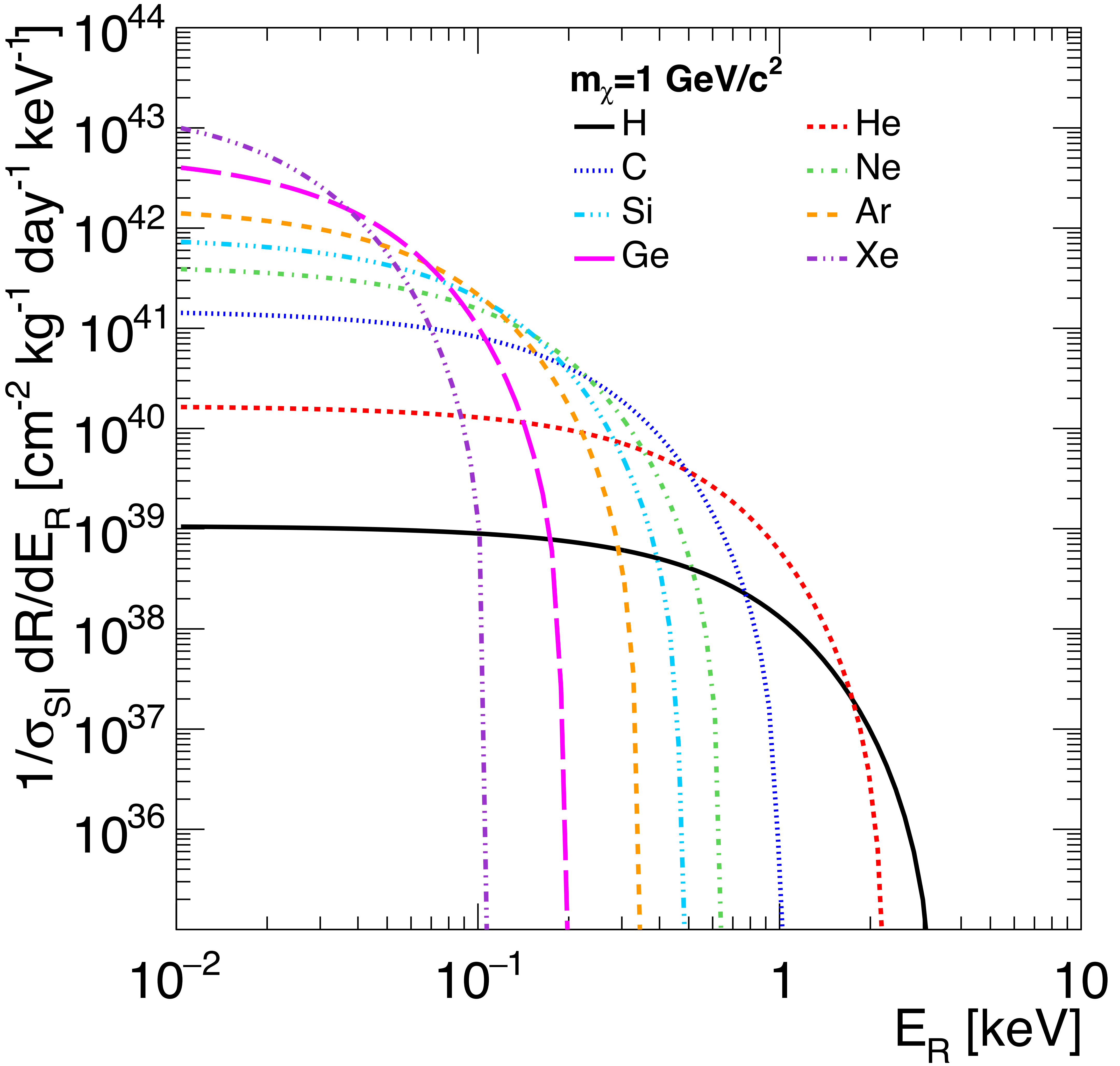
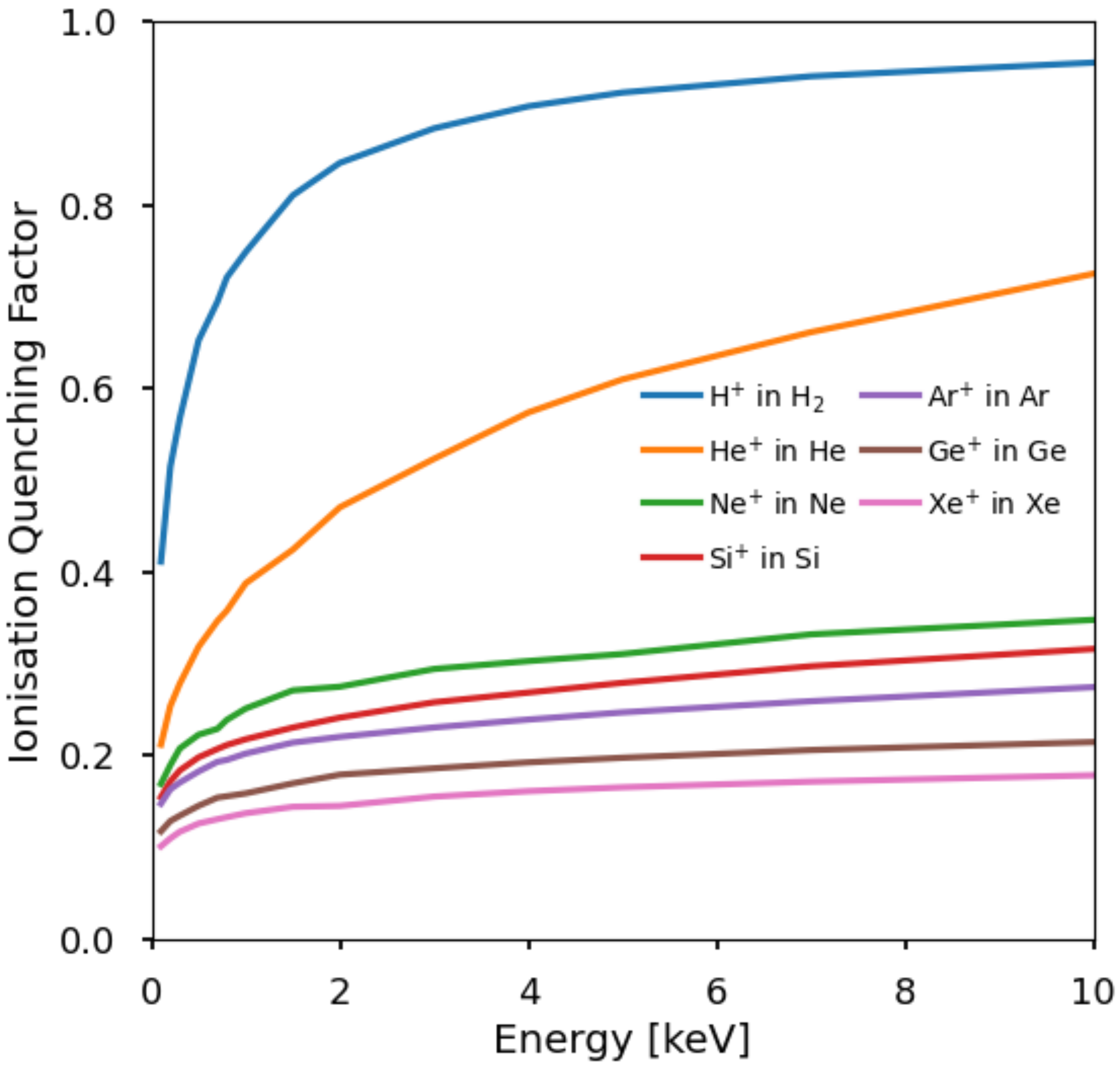
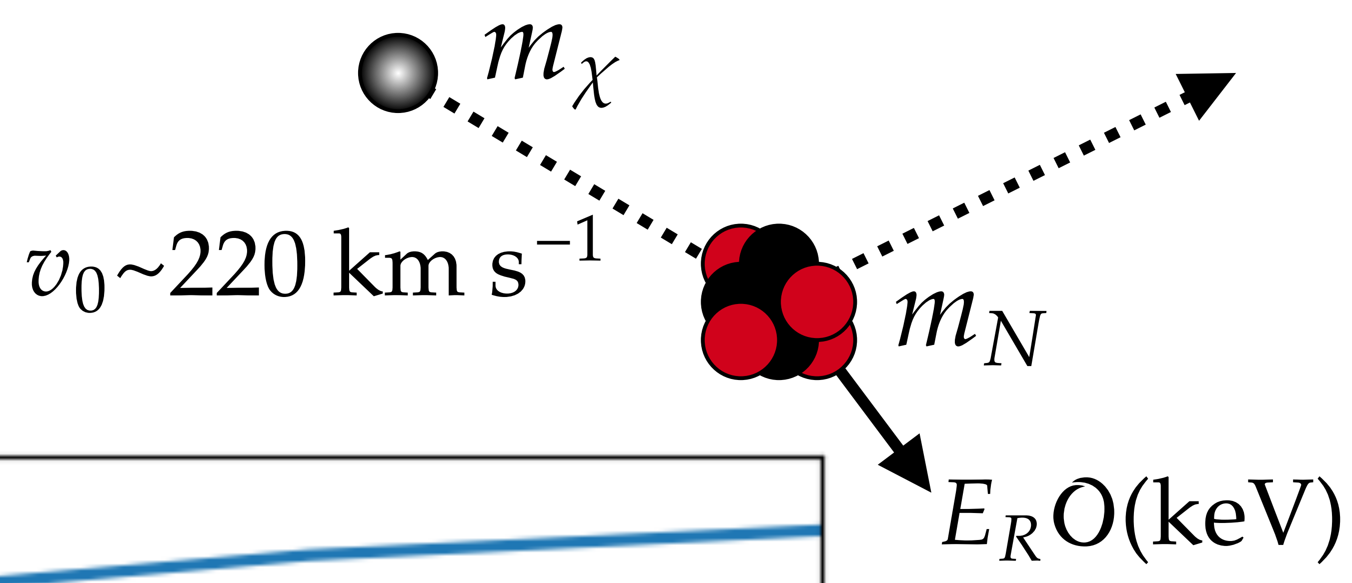
Kaluza-Klein axions appear in theories with extra dimensions as higher mass, significantly shorter lifetime, excitations of the Peccei-Quinn axion. When produced in the Sun, they would remain gravitationally trapped in the solar system, and their decay to a pair of photons could provide an explanation of the solar corona heating problem. A low-density detector would discriminate such a signal from the background, by identifying the separation of the interaction point of the two photons. The NEWS-G collaboration uses large volume spherical proportional counters, gas-filled metallic spheres with a spherical anode in their centre. After observation of a single axionlike event in a 42 day long run with the SEDINE detector, a 90% C.L. upper limit of $g_{a\gamma\gamma} < 8.99 \times 10^{-13}$ GeV^{-1} is set on the axion-photon coupling for the benchmark of a Kaluza-Klein axion density on Earth of $n_a = 4.07 \times 10^{13}$ m^{-3} and two extra dimensions of size $R = 1$ eV^{-1}.

DOI: 10.1103/PhysRevD.105.012002

Light DM Kinematics







- **Kinematic matching**: **low-mass targets** are **favourable for light-DM** detection by nuclear recoils
- **Light targets** have **favourable quenching factors**

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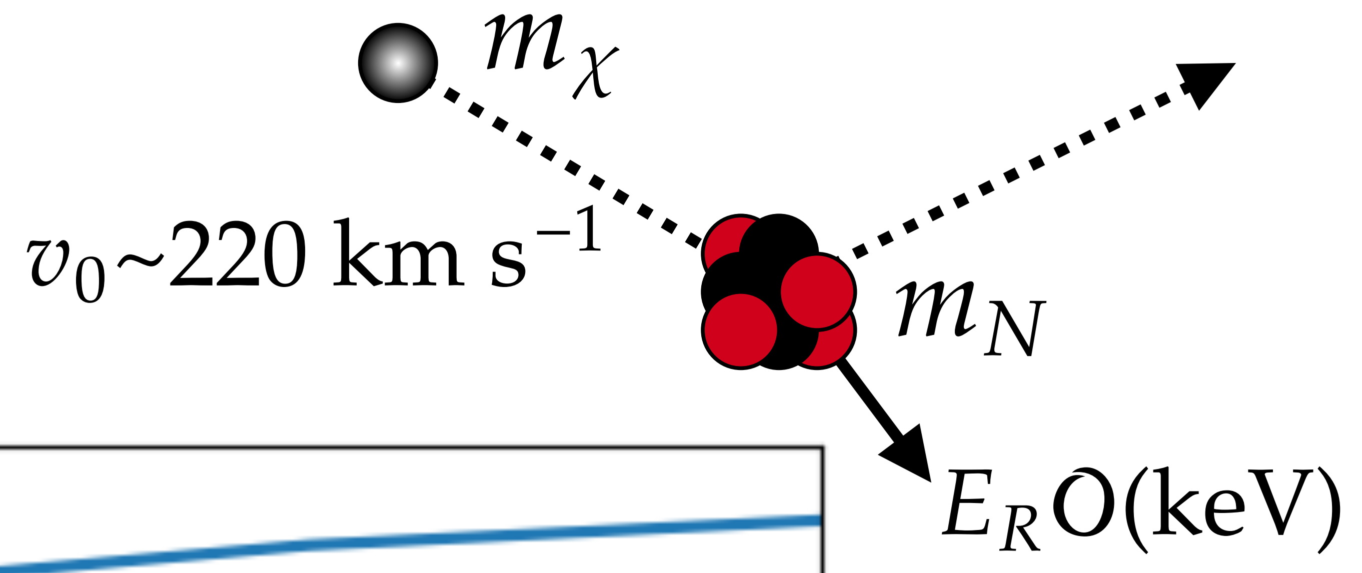
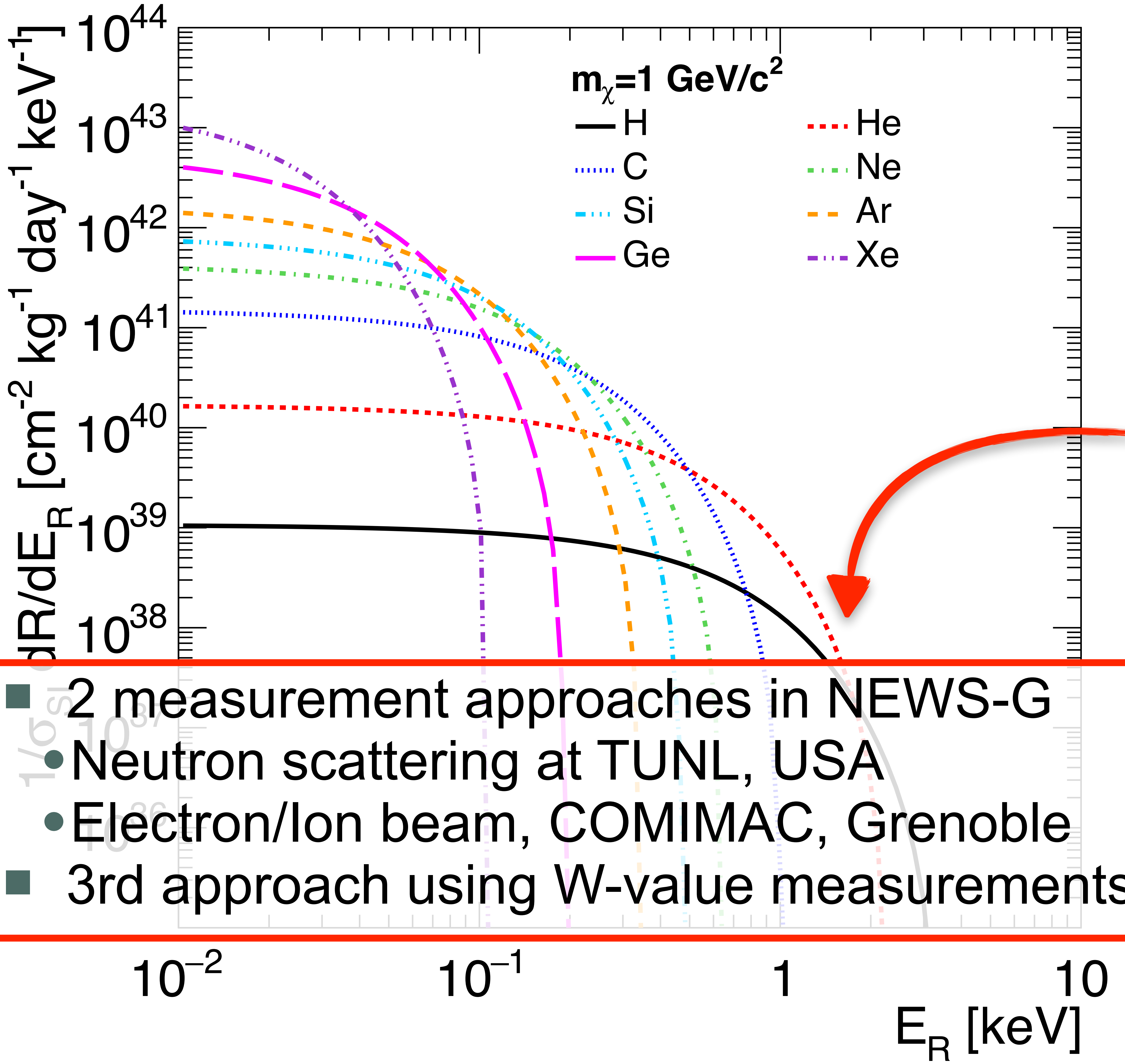
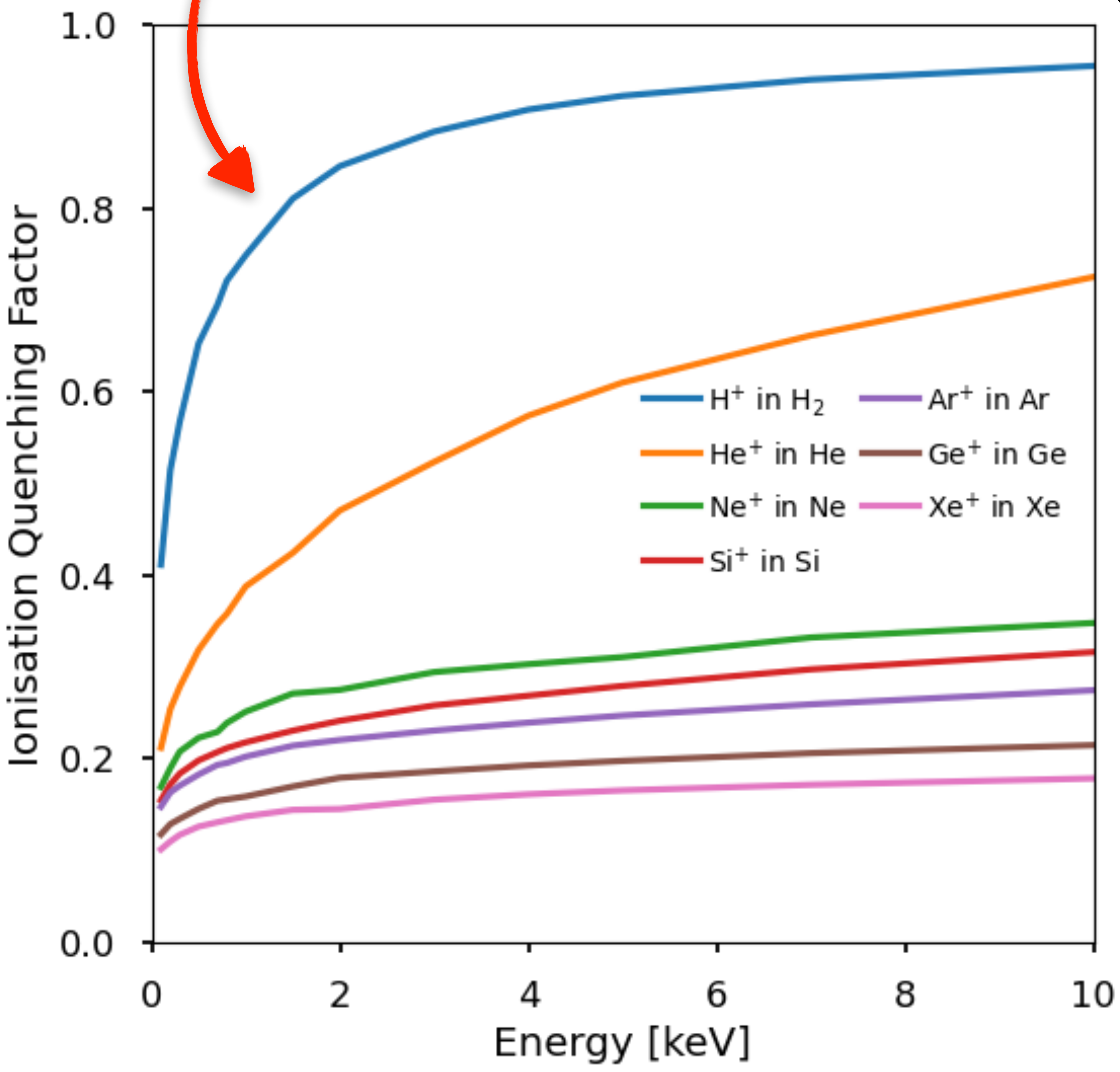


Stopping and Range of Ions in Matter (SRIM) simulation



- 2 measurement approaches in NEWS-G
  - Neutron scattering at TUNL, USA
  - Electron/Ion beam, COMIMAC, Grenoble
- 3rd approach using W-value measurements



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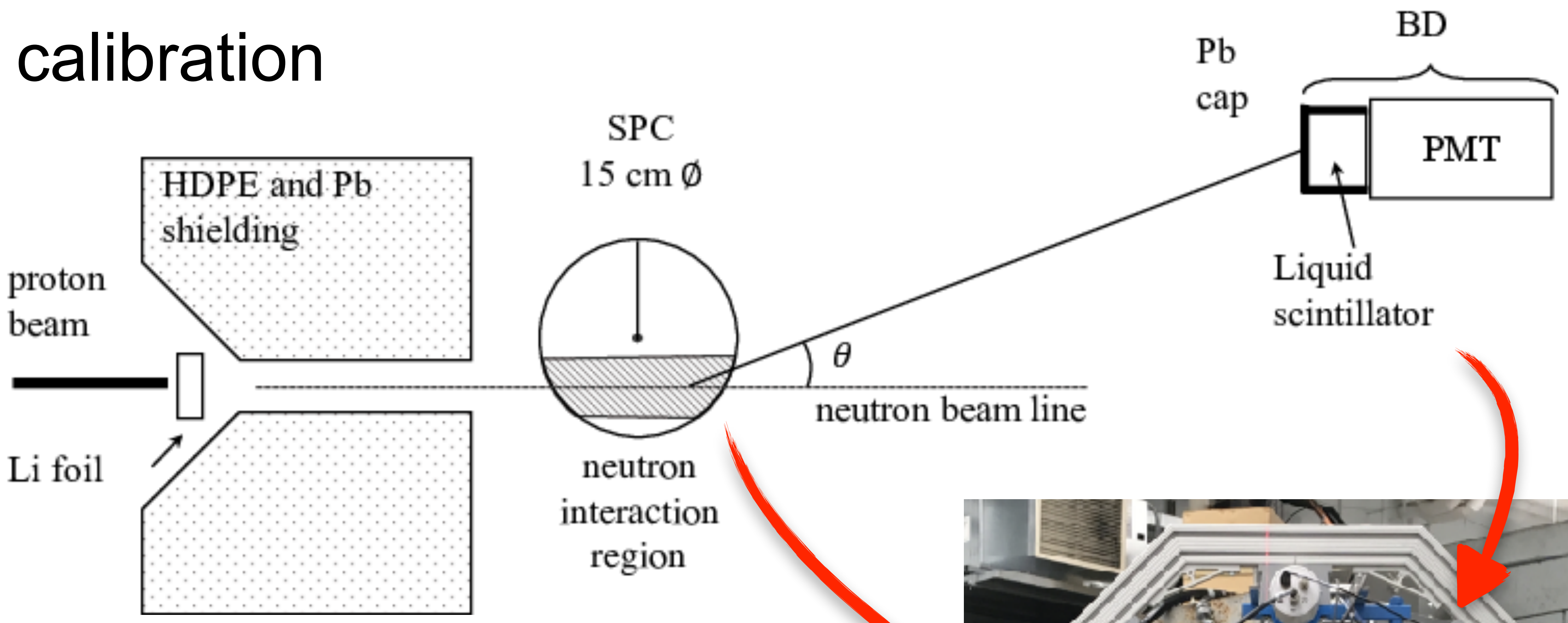
Quenching Factor Measurements: TUNL

Neutron scattering-induced nuclear recoils in SPC → compare to calibration



Run	E_{nr} [keV_{nr}]	$\sigma_{E_{nr}}$ [keV_{nr}]	θ [°]	σ_θ [°]
8	6.80	1.15	29.02 ± 0.4	2.45
7	2.93	0.46	18.84 ± 0.1	1.47
14	2.02	0.29	15.63 ± 0.3	1.12
9	1.70	0.26	14.33 ± 0.06	1.1
10	1.30	0.2	12.48 ± 0.05	0.94
14	1.03	0.2	11.13 ± 0.3	1.1
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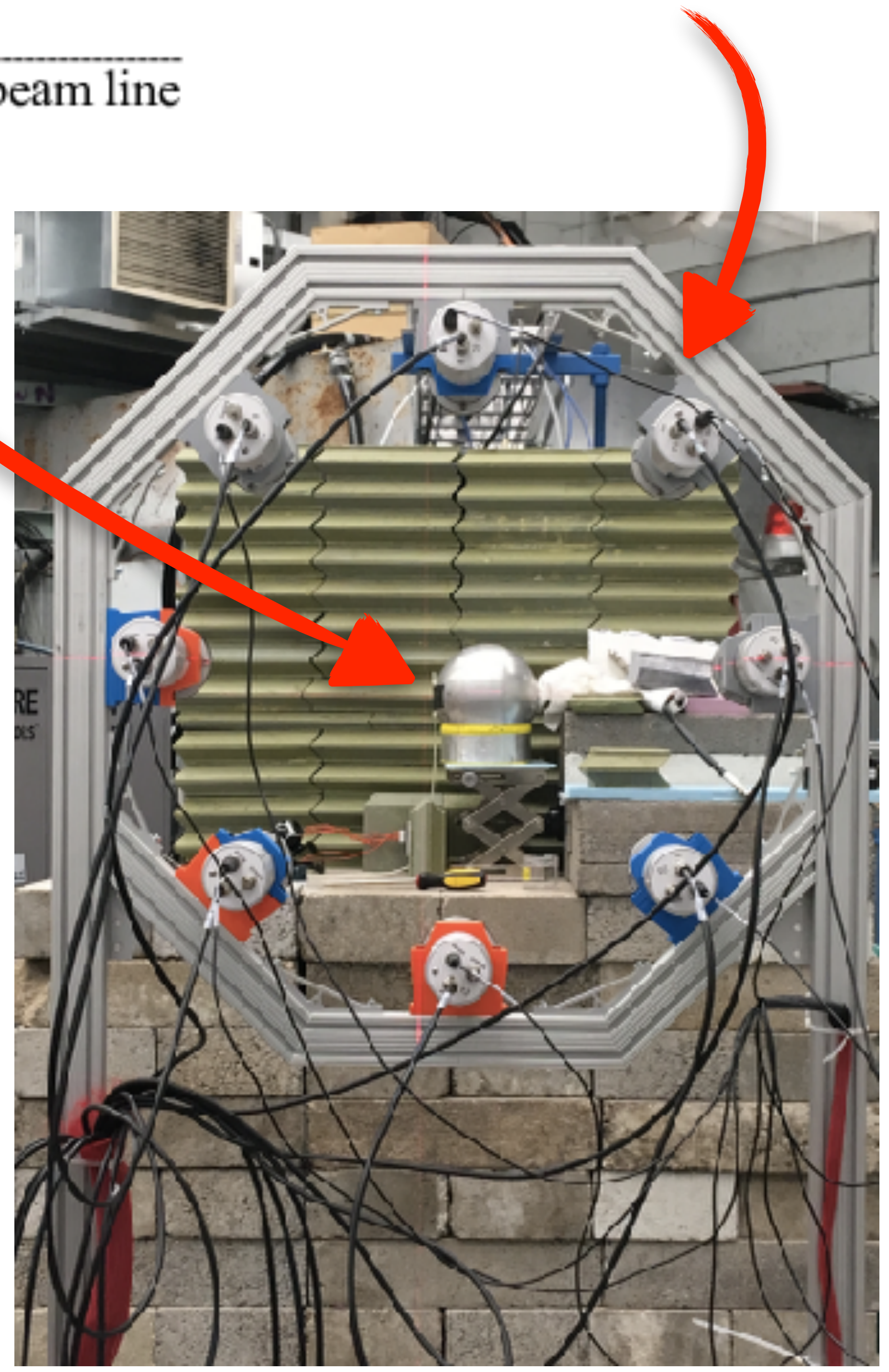

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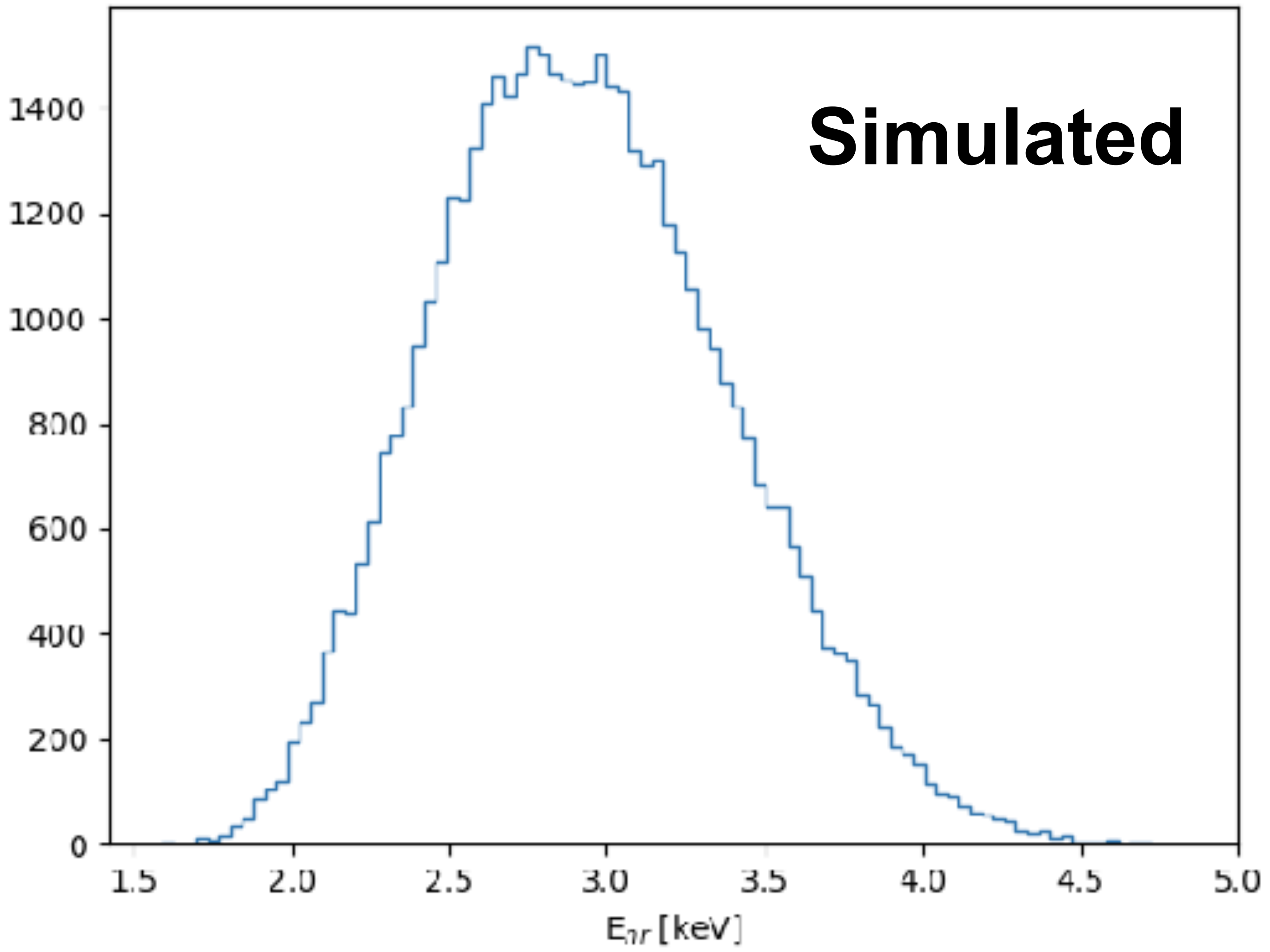

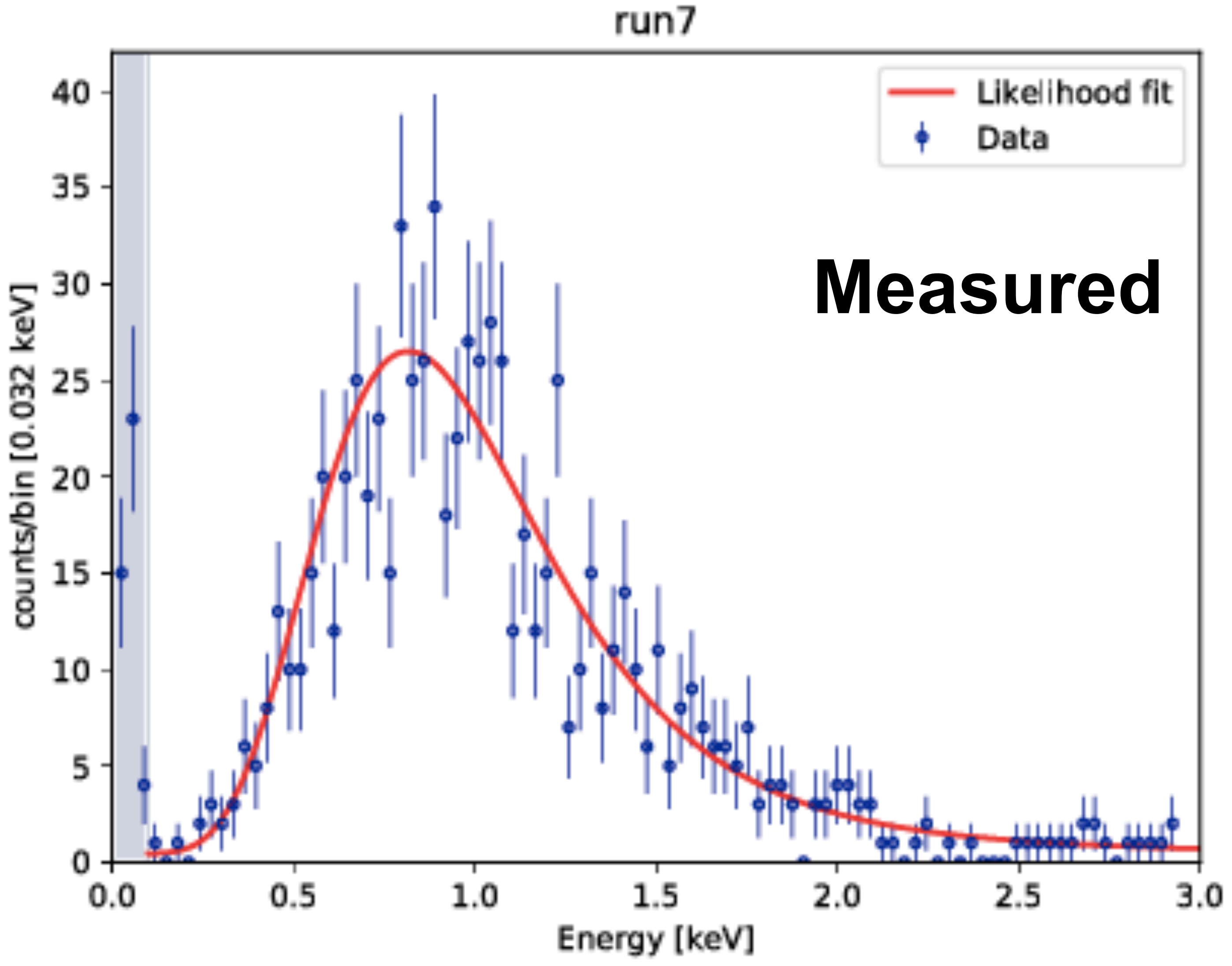

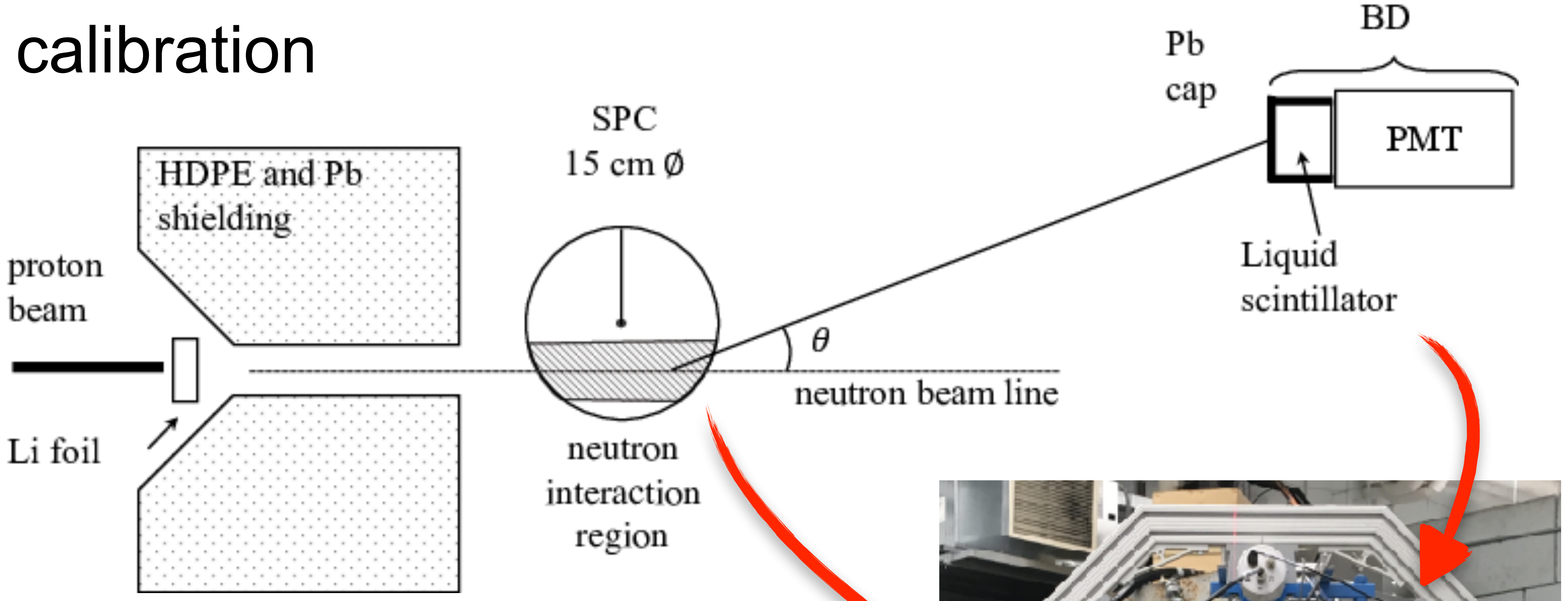

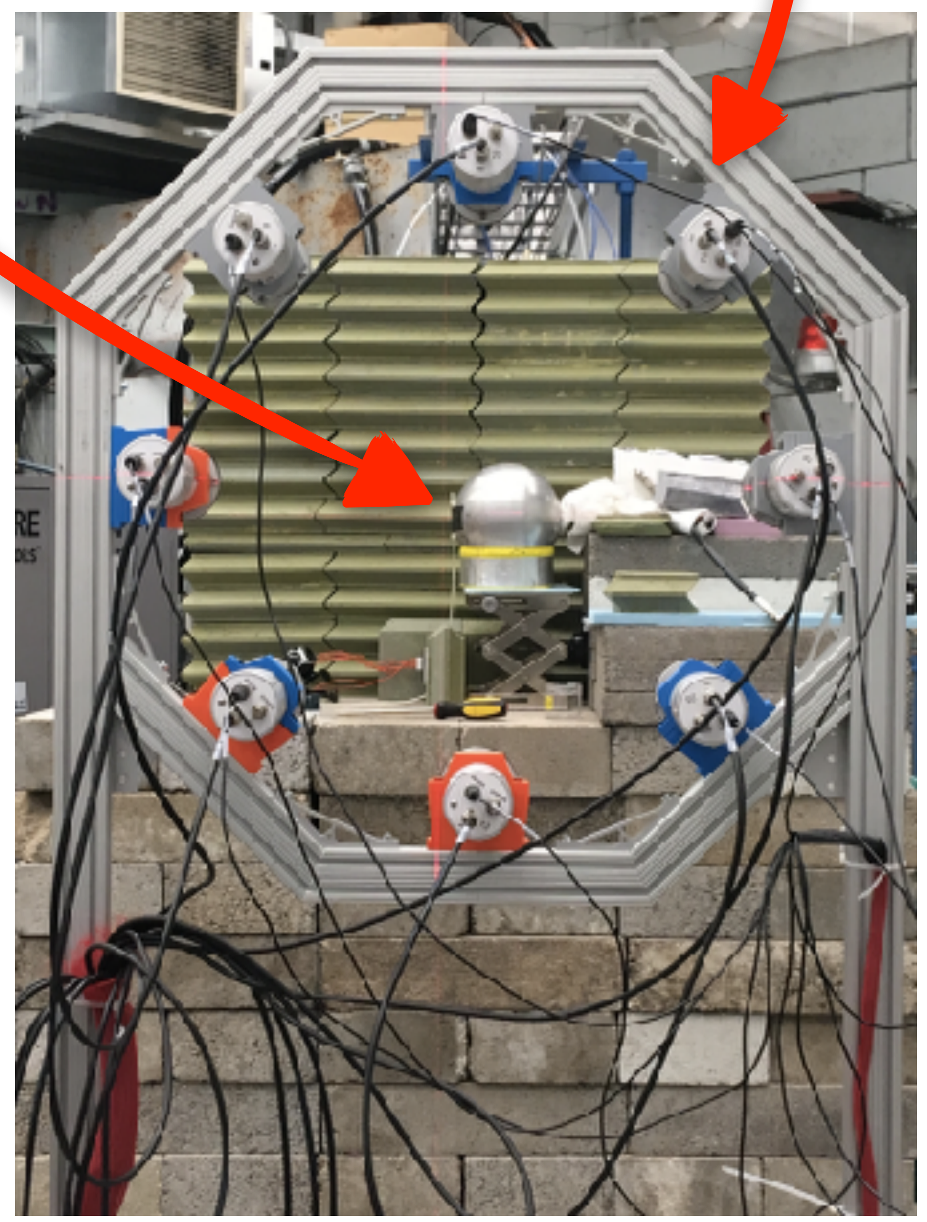

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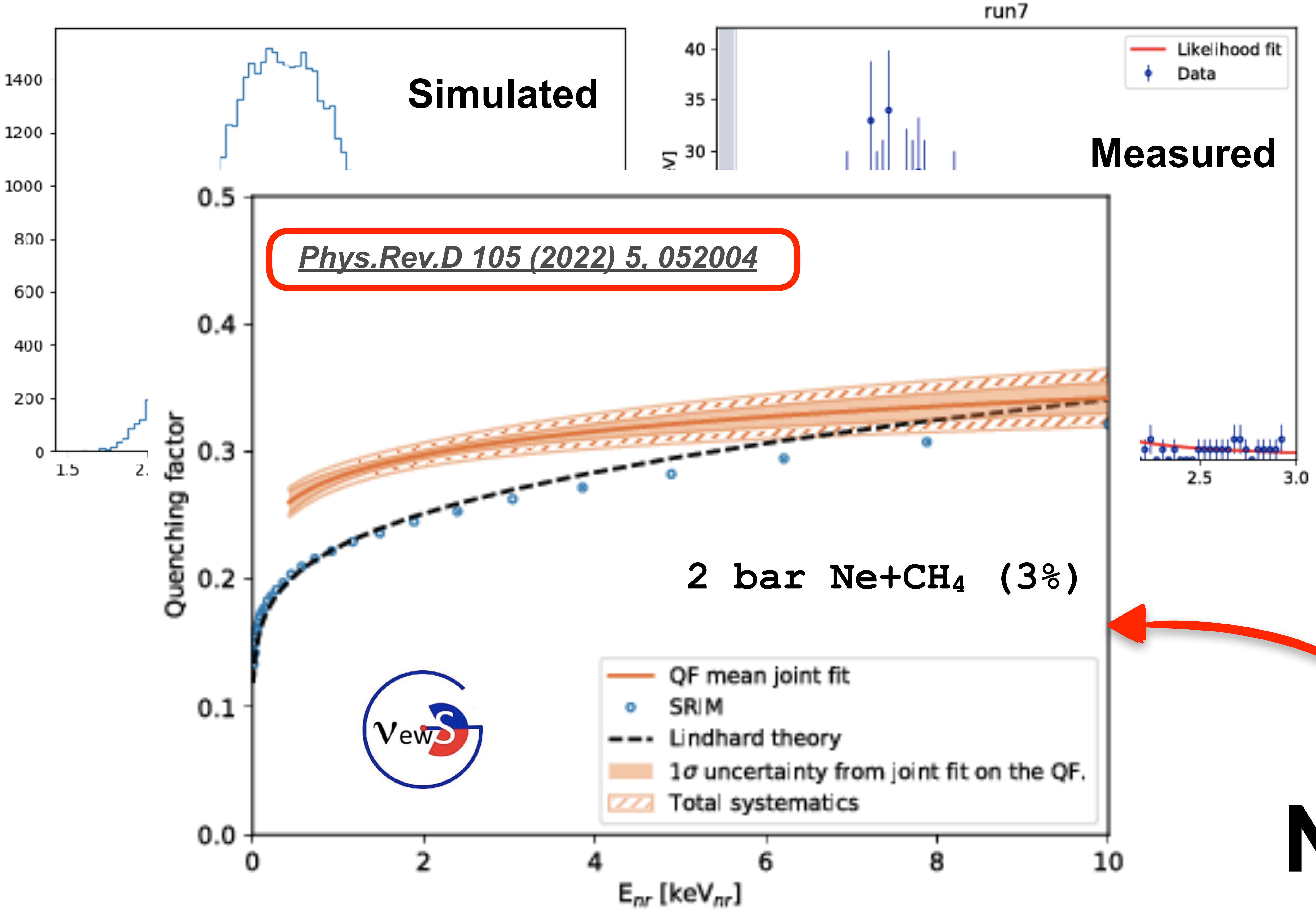

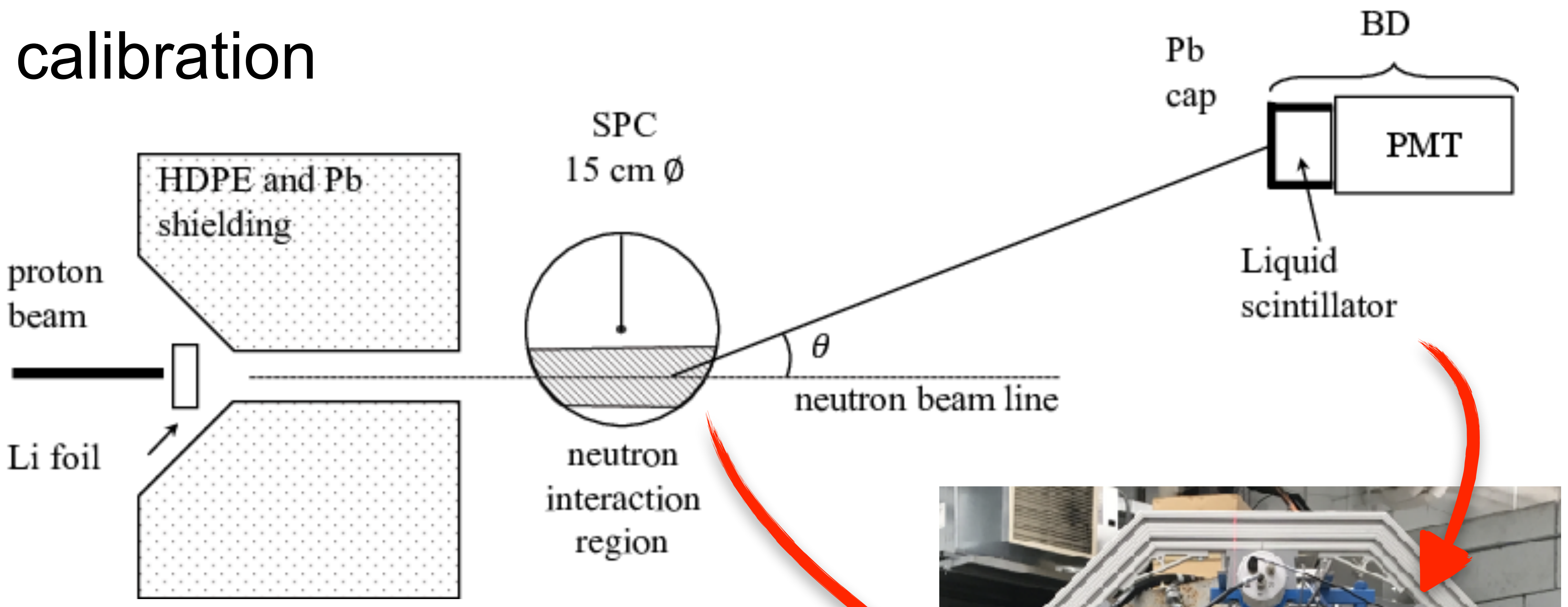

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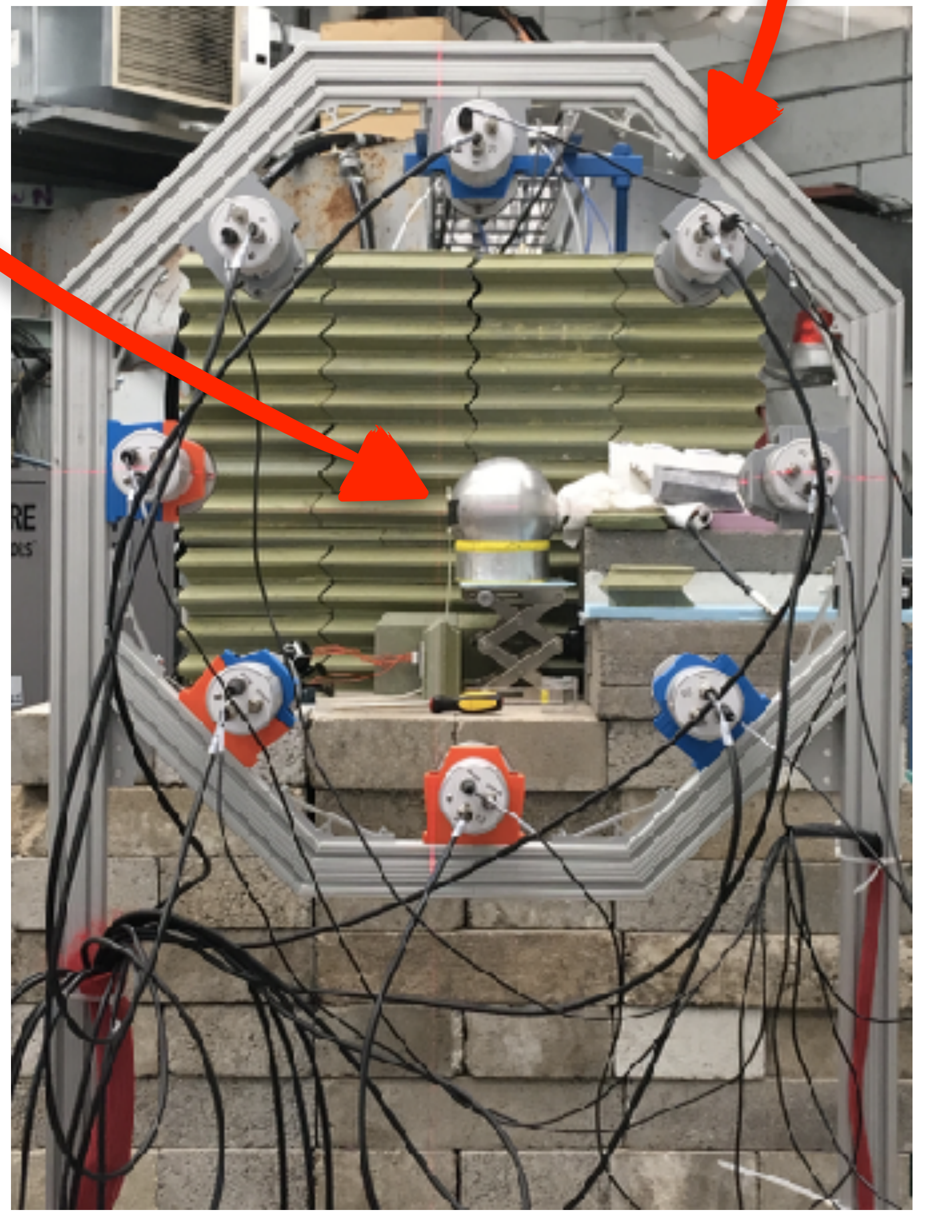
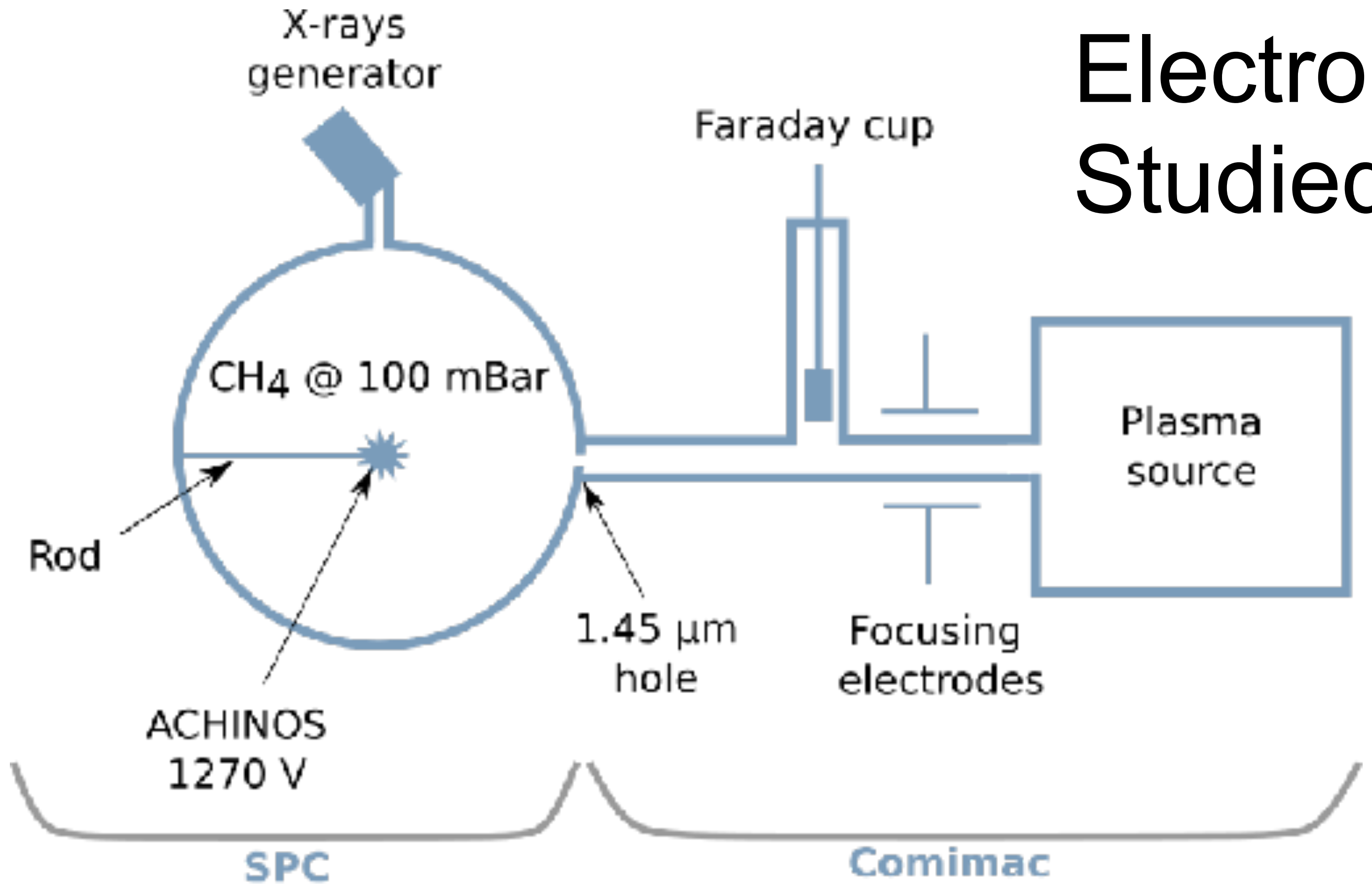


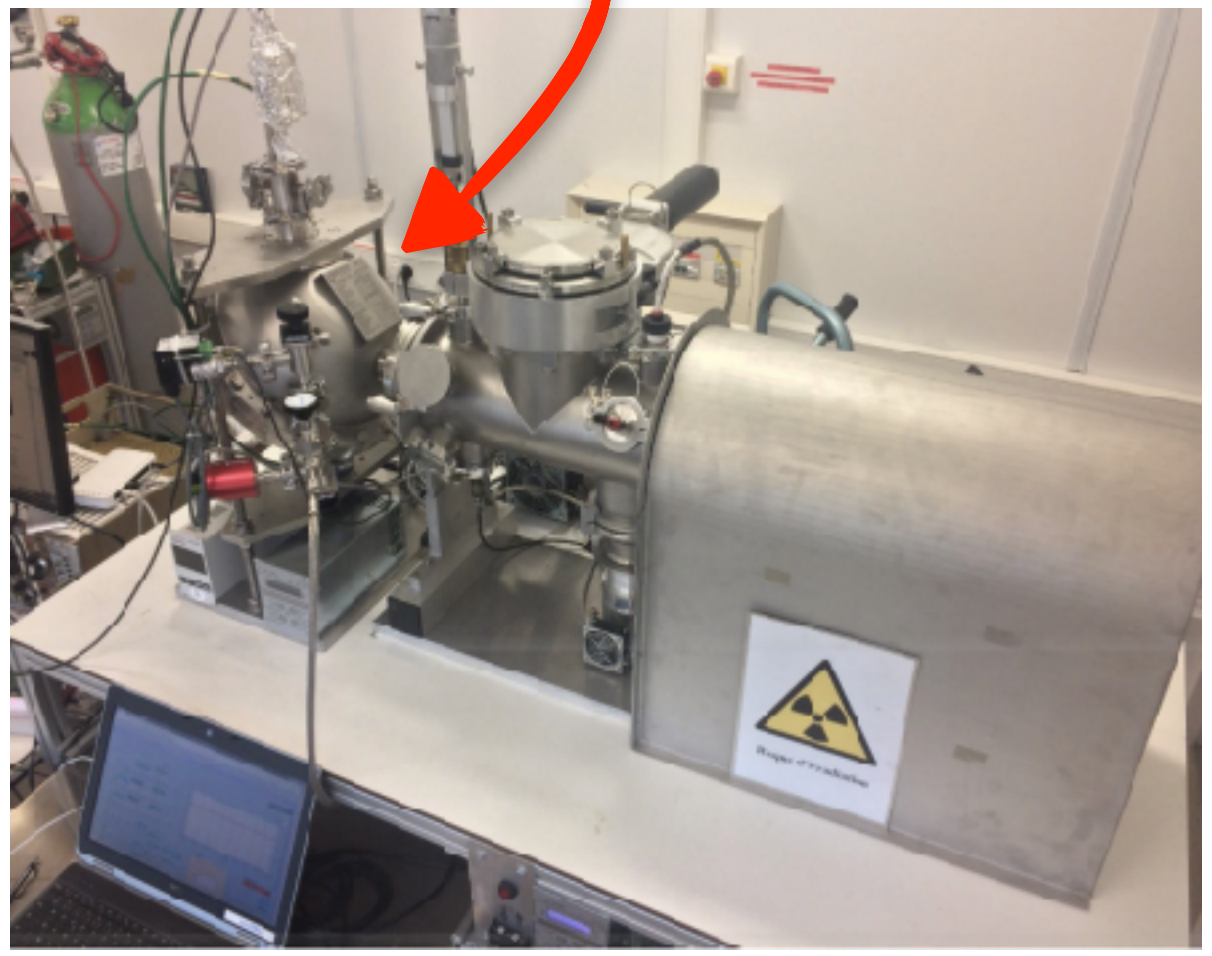
New Result!

Quenching Factor Measurements: COMIMAC



Electrons and ions directed into SPC → compare response
Studied ions 2 - 13 keV, calibrated with e⁻ 1.5 - 13 keV

⌀30 cm SPC



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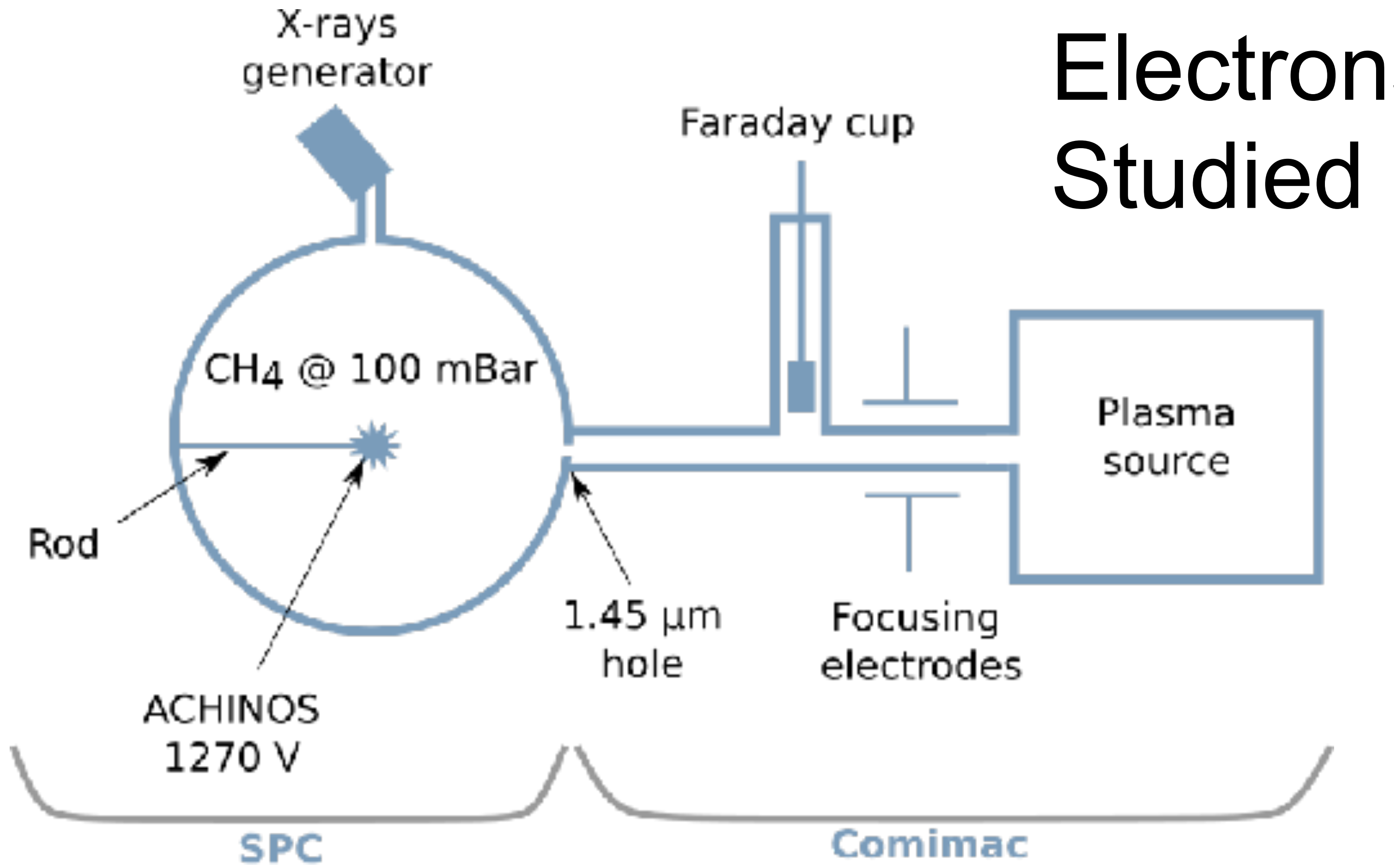

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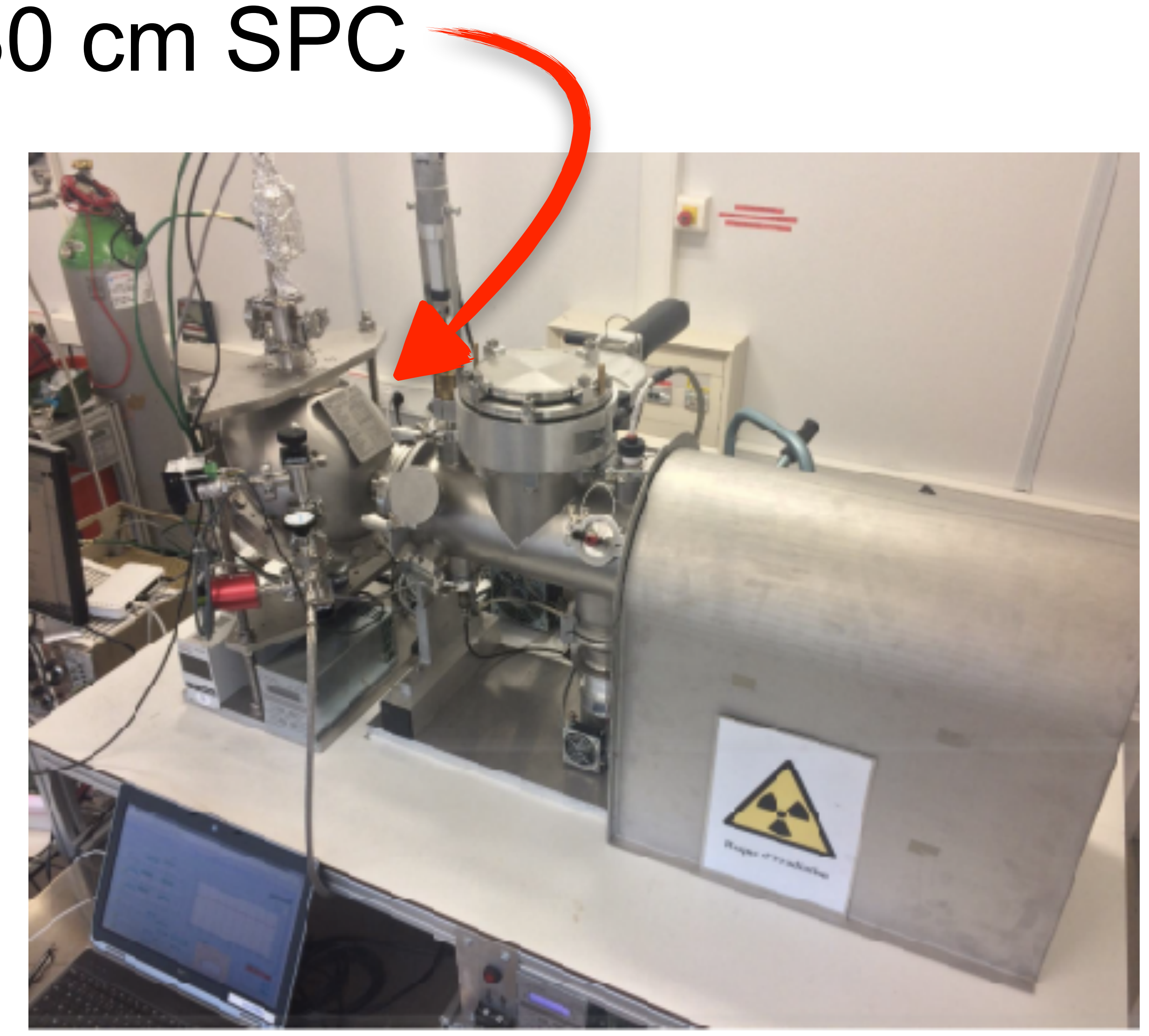

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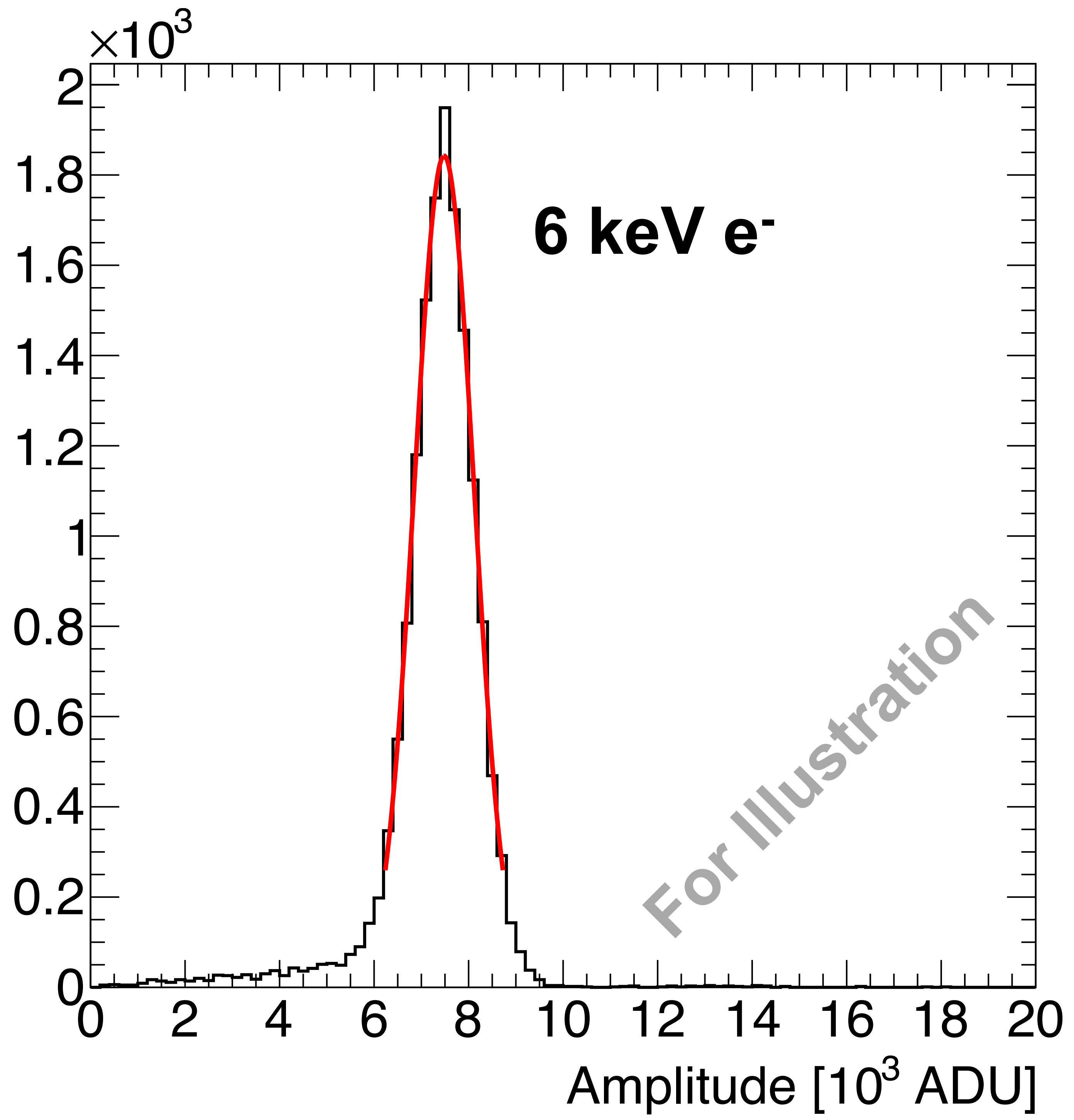

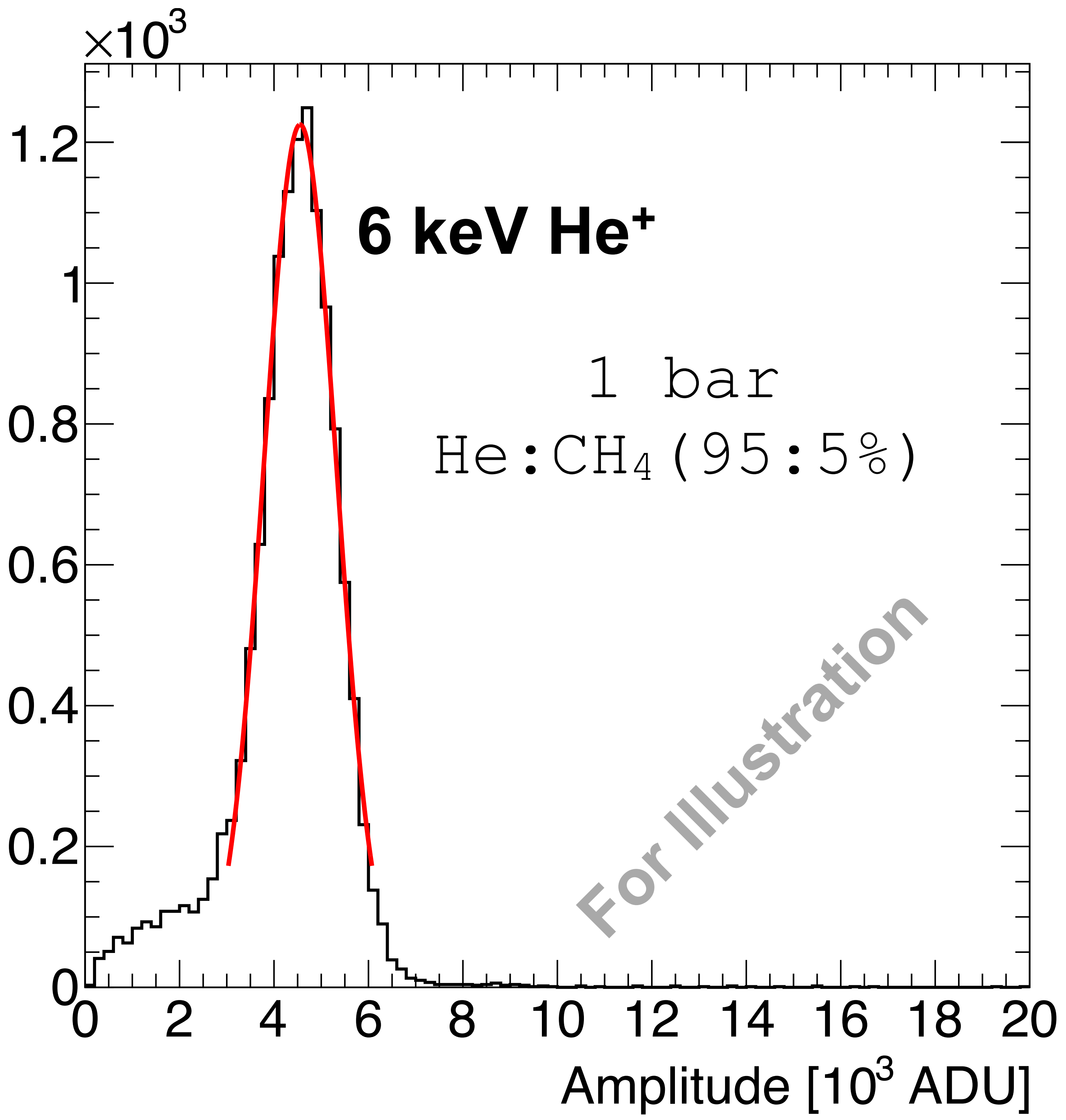

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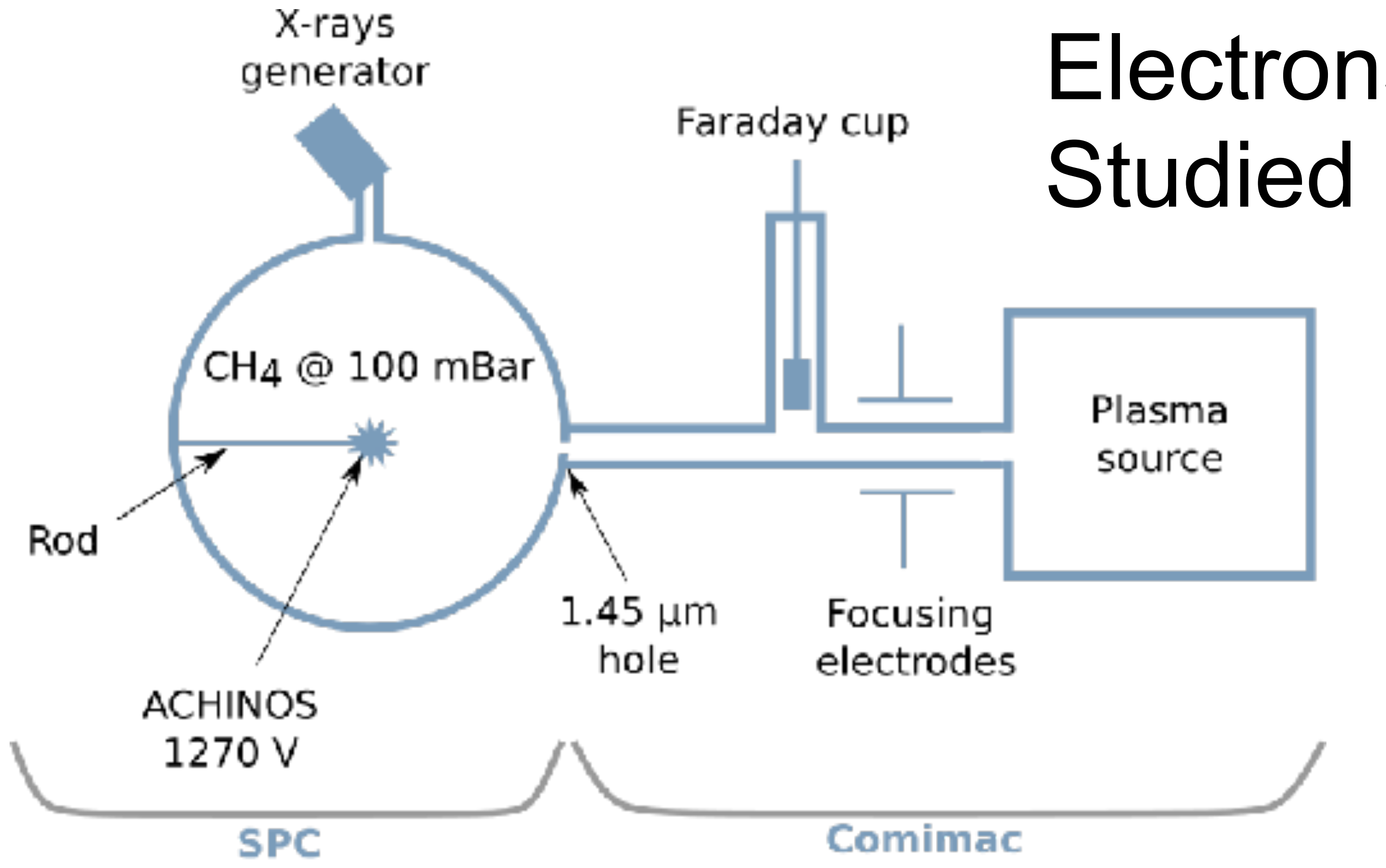

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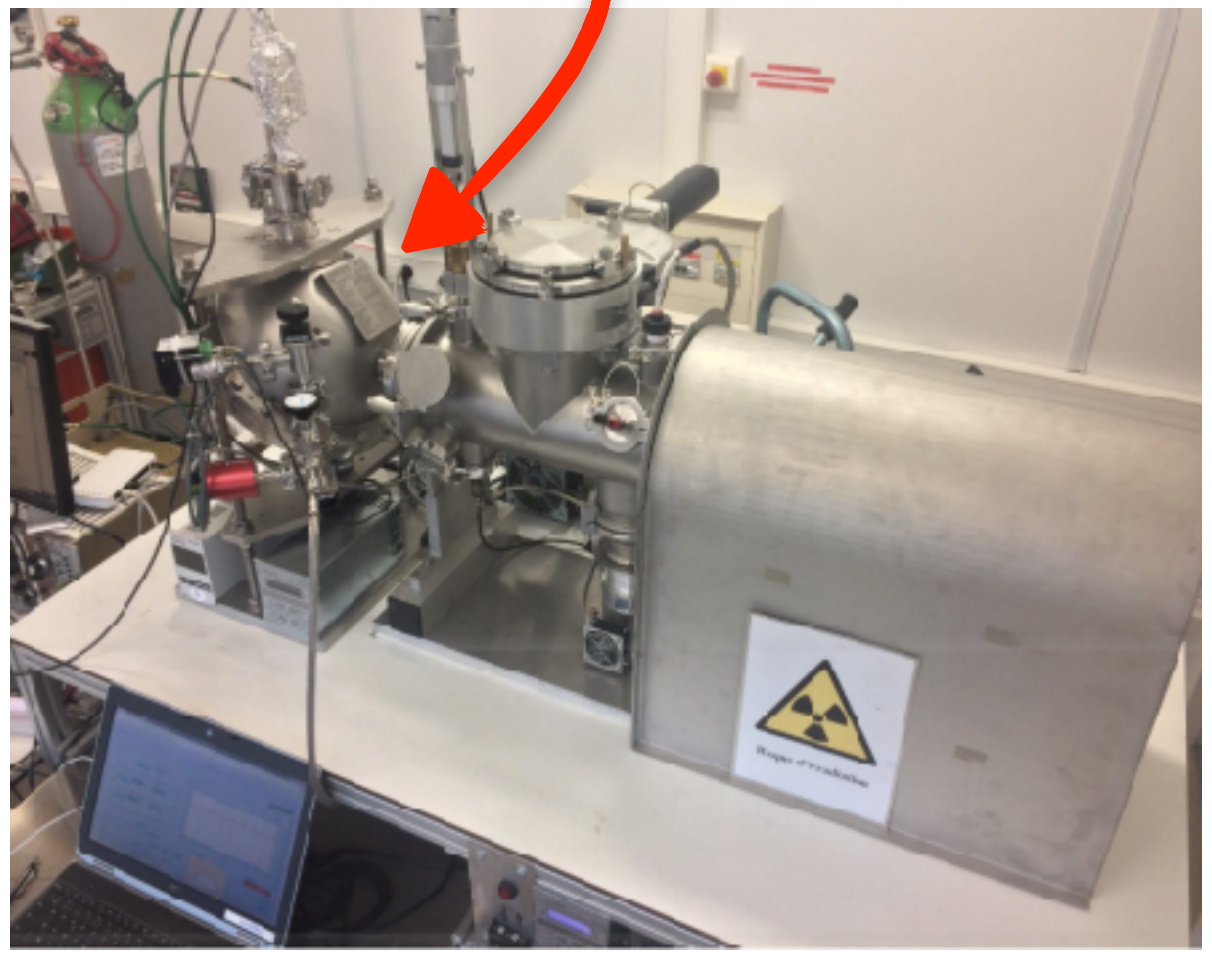
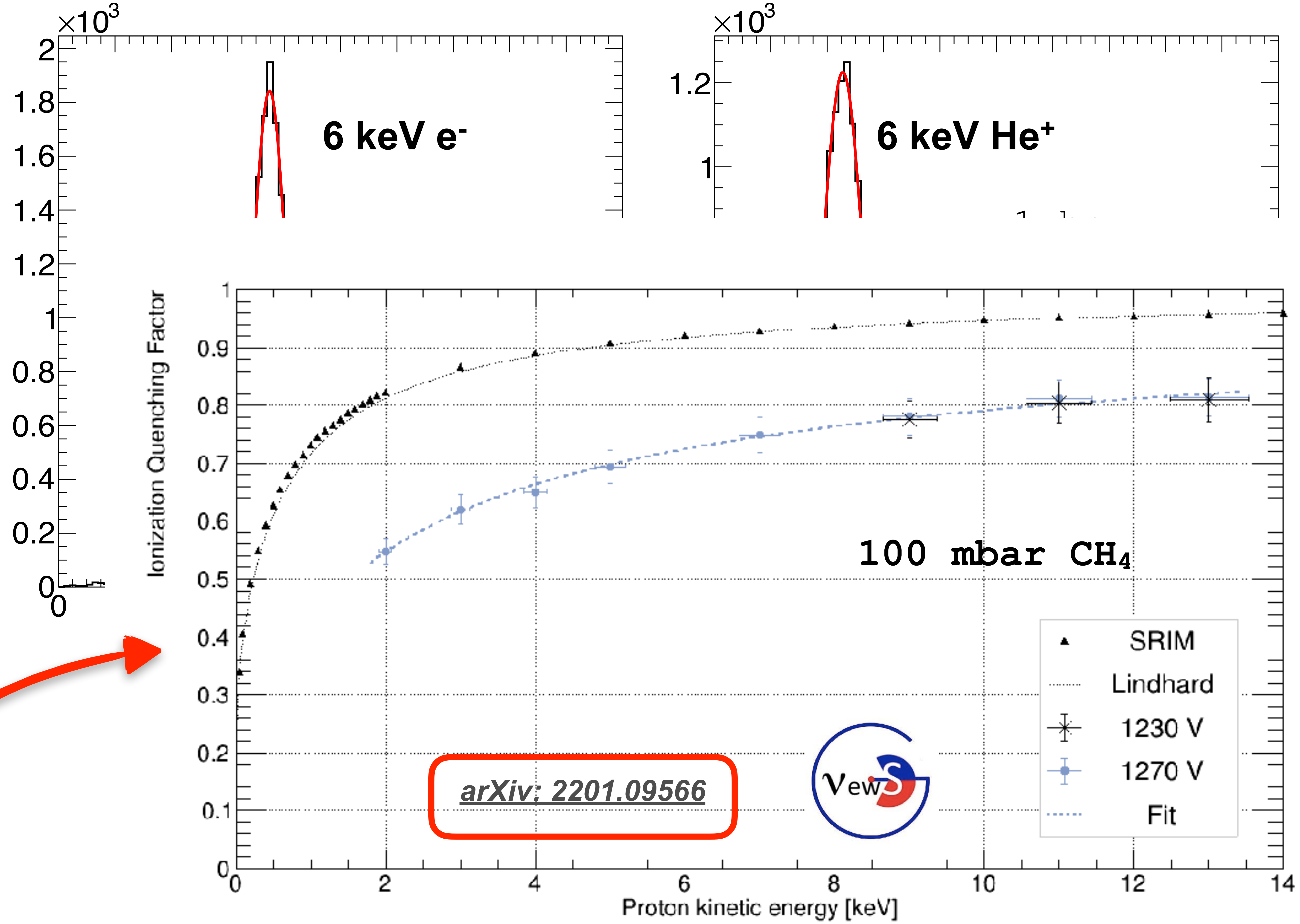


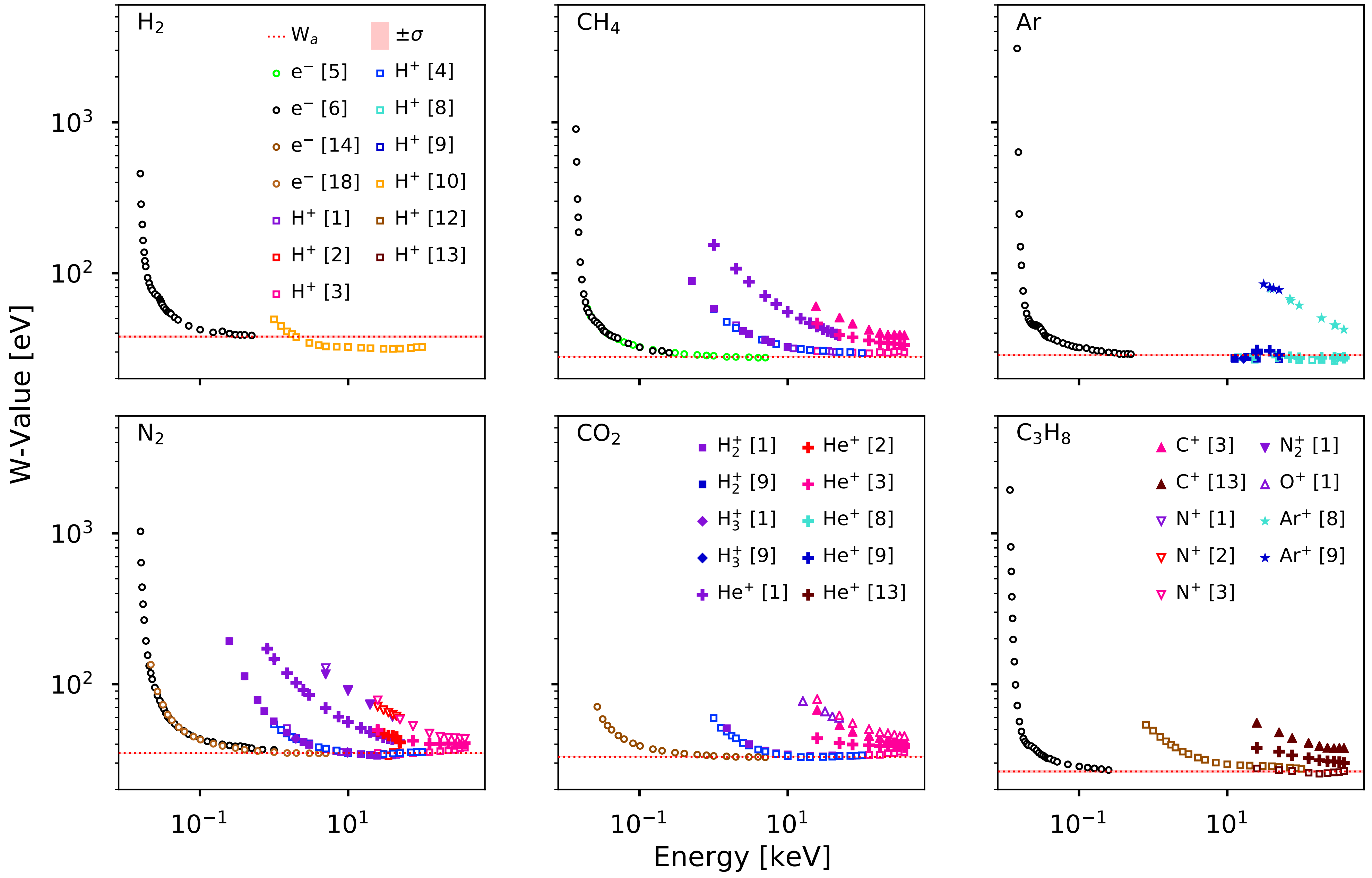


New Result!

Quenching Factor Estimates: W-Values

- W-value: **Average energy** required to produce **electron-ion pair**
- W different for electrons and ions, and varies with energy
  - Difference is quantified by QF
- W of electrons and ions in gases prev. studied for dosimetry
  - Comparing asymptotic electron W-value and W(E) for ions, get QF

Astropart.Phys. 141 (2022) 102707



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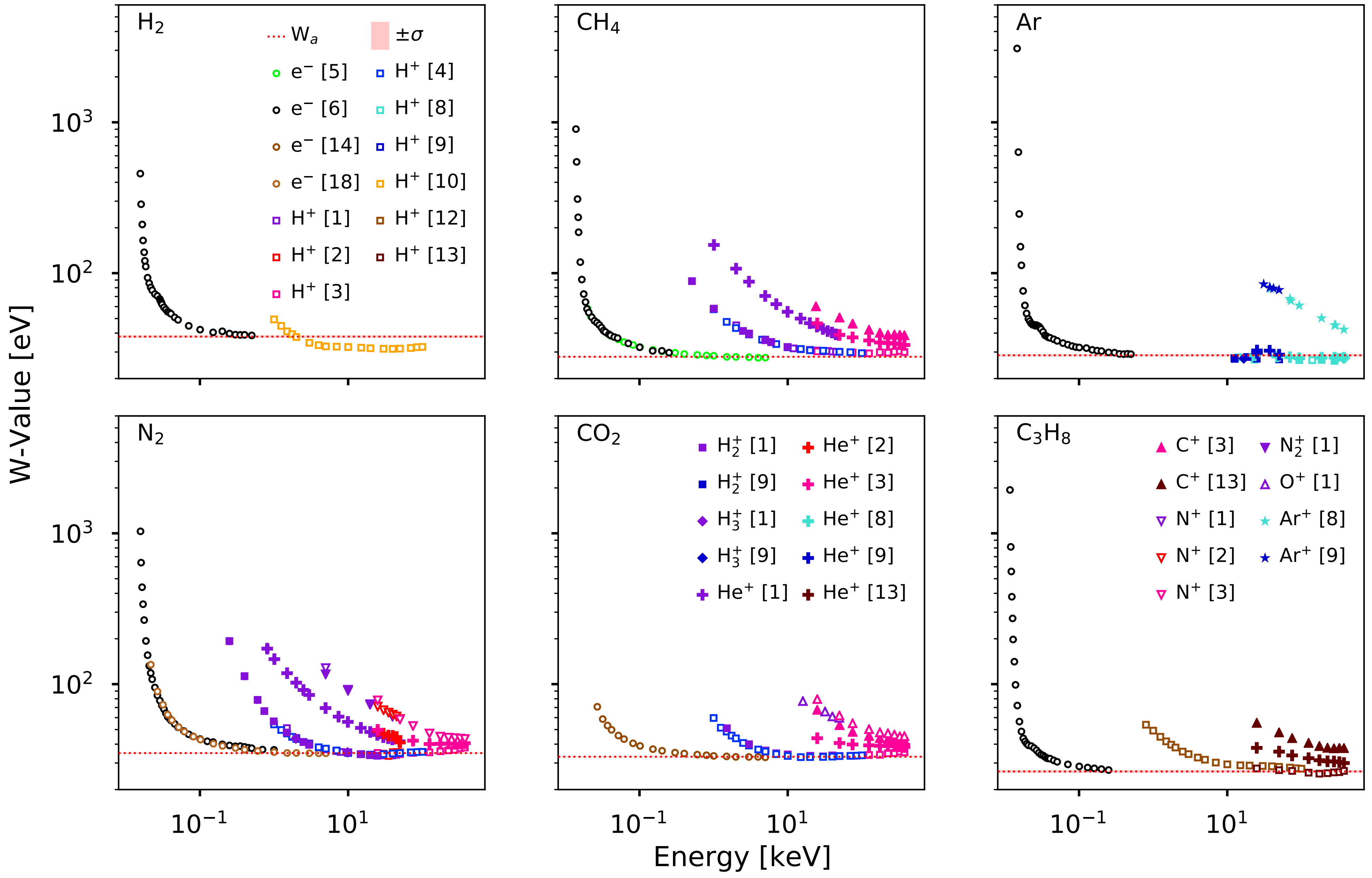
Astropart.Phys. 141 (2022) 102707

Gas	W [eV]	
	ICRU	Asymptotic
H_2	36.5±0.7	38.0±0.8
CH_4	27.3±0.6	27.90± 0.01
N_2	34.8±0.7	34.91±0.17
Ar	26.4±0.5	28.5±0.6
CO_2	33.0±0.7	33.02±0.12
C_3H_8	24.0±0.5	26.4±0.5



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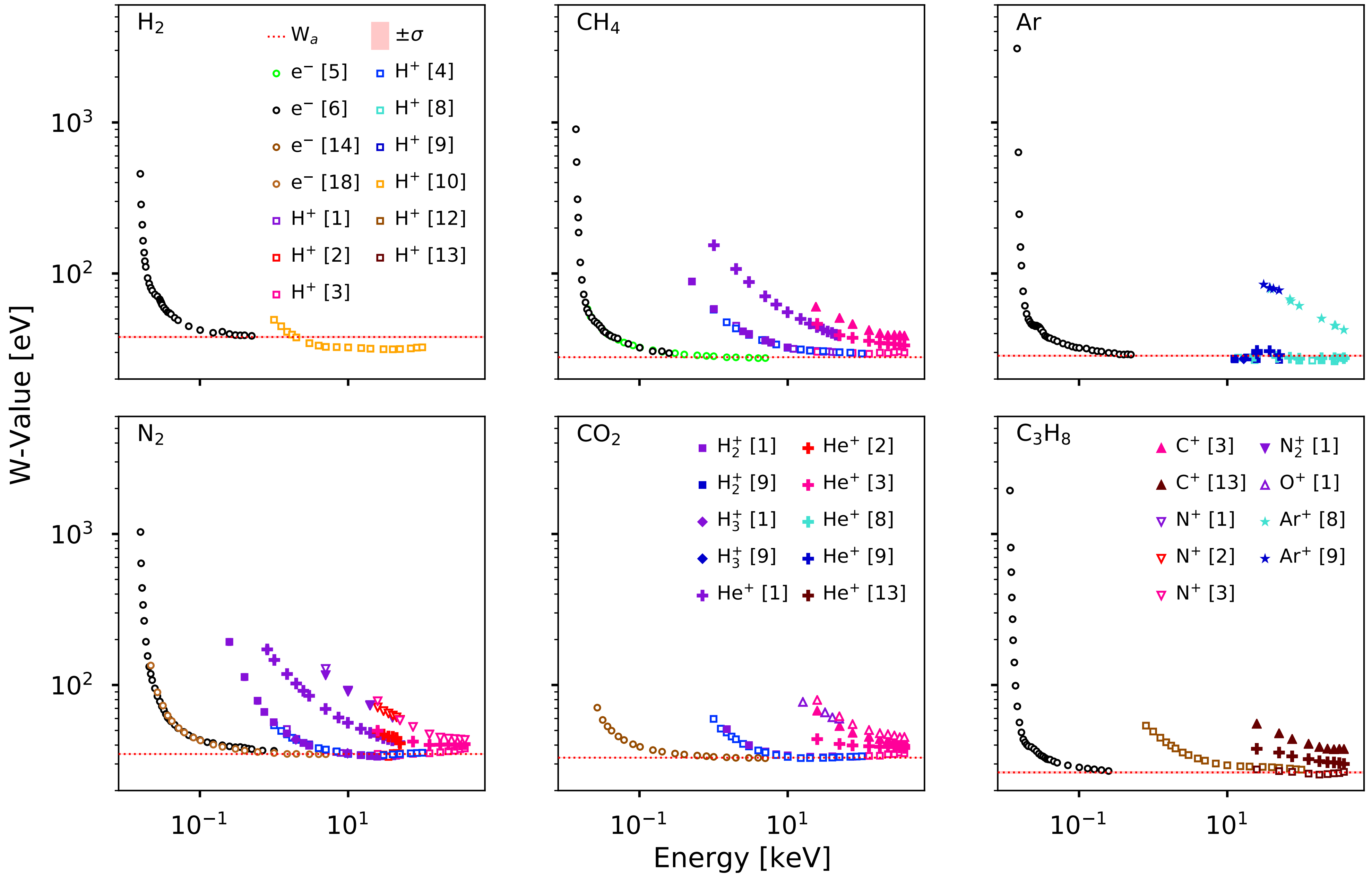
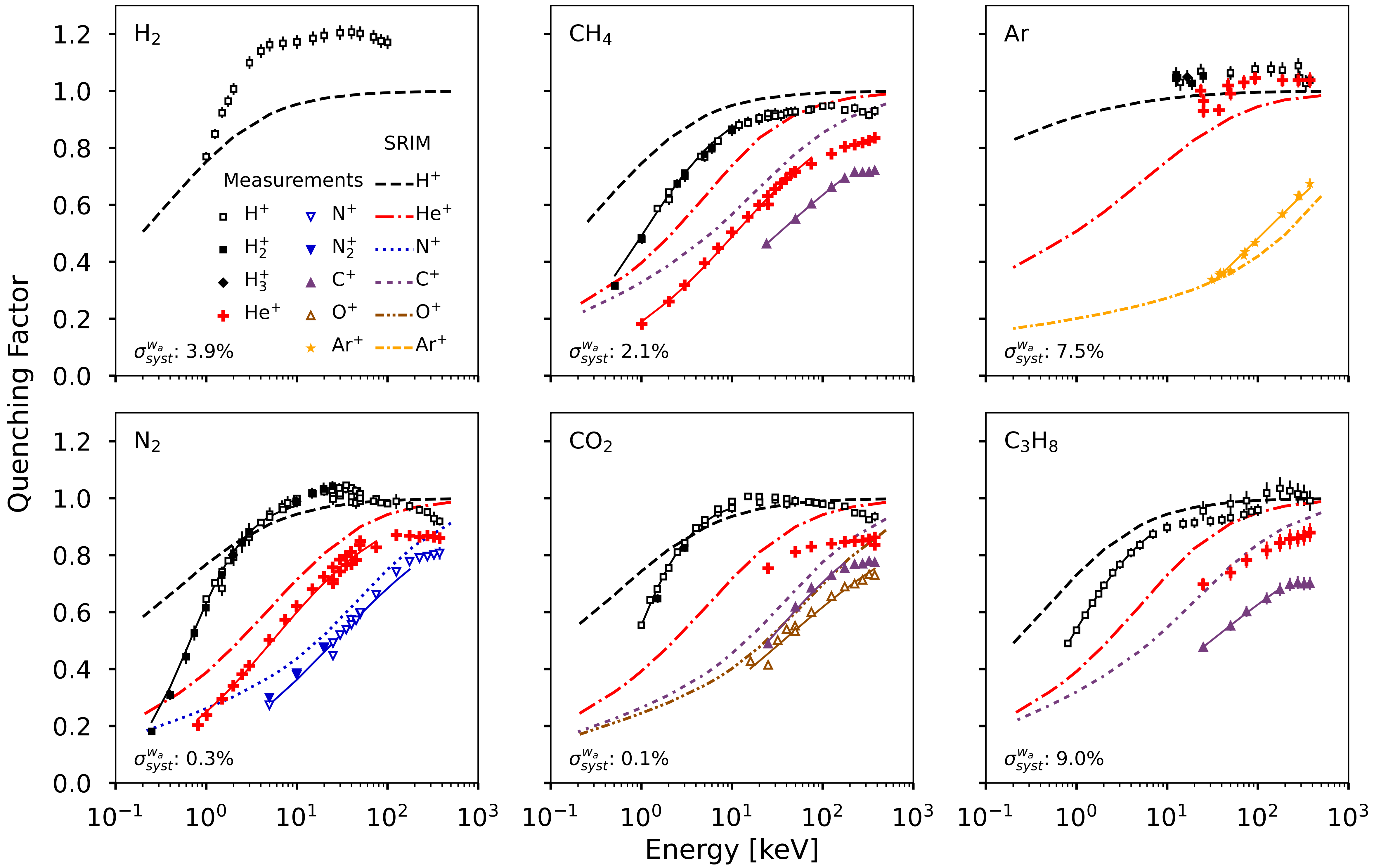
Astropart.Phys. 141 (2022) 102707



New Result!

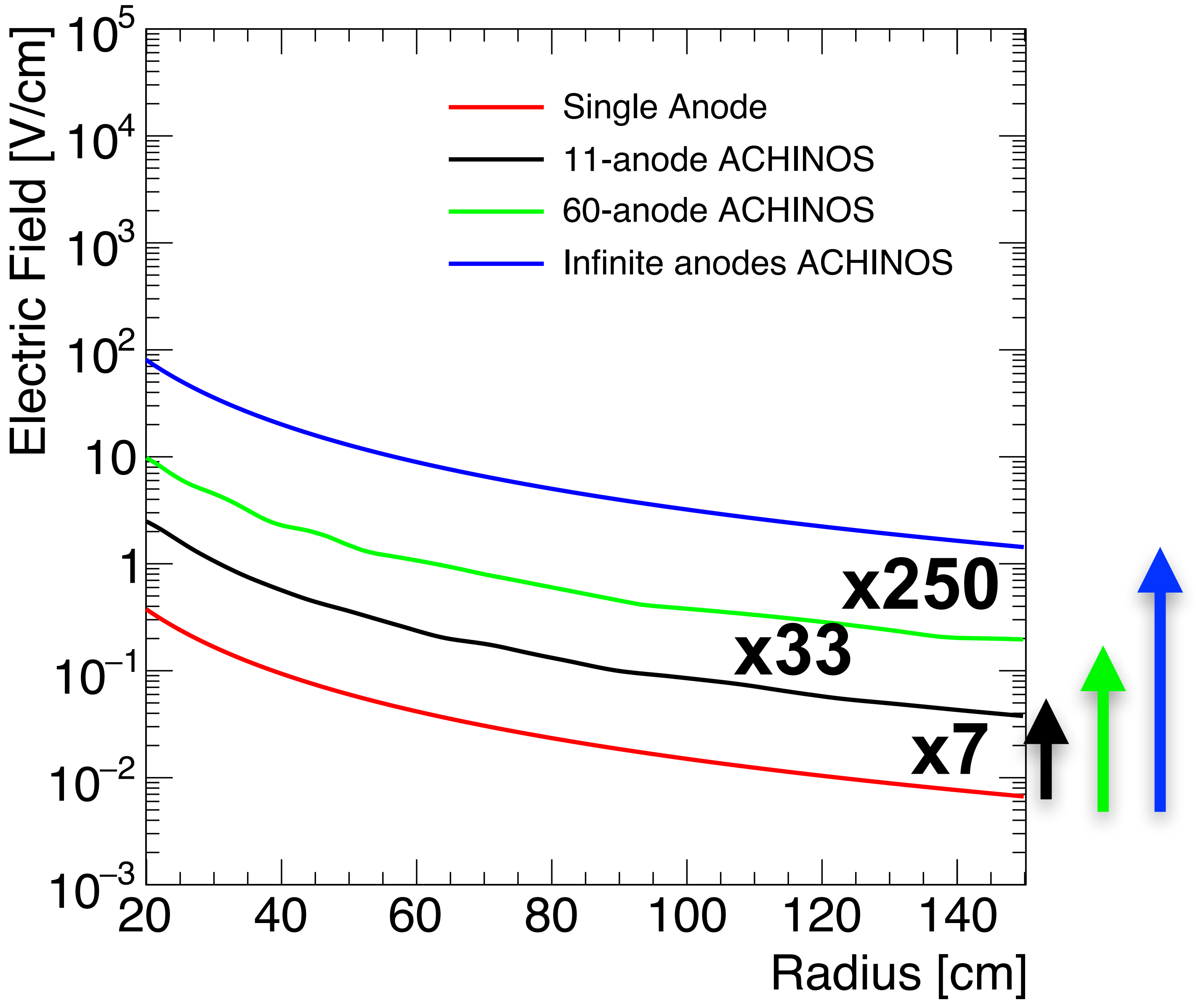


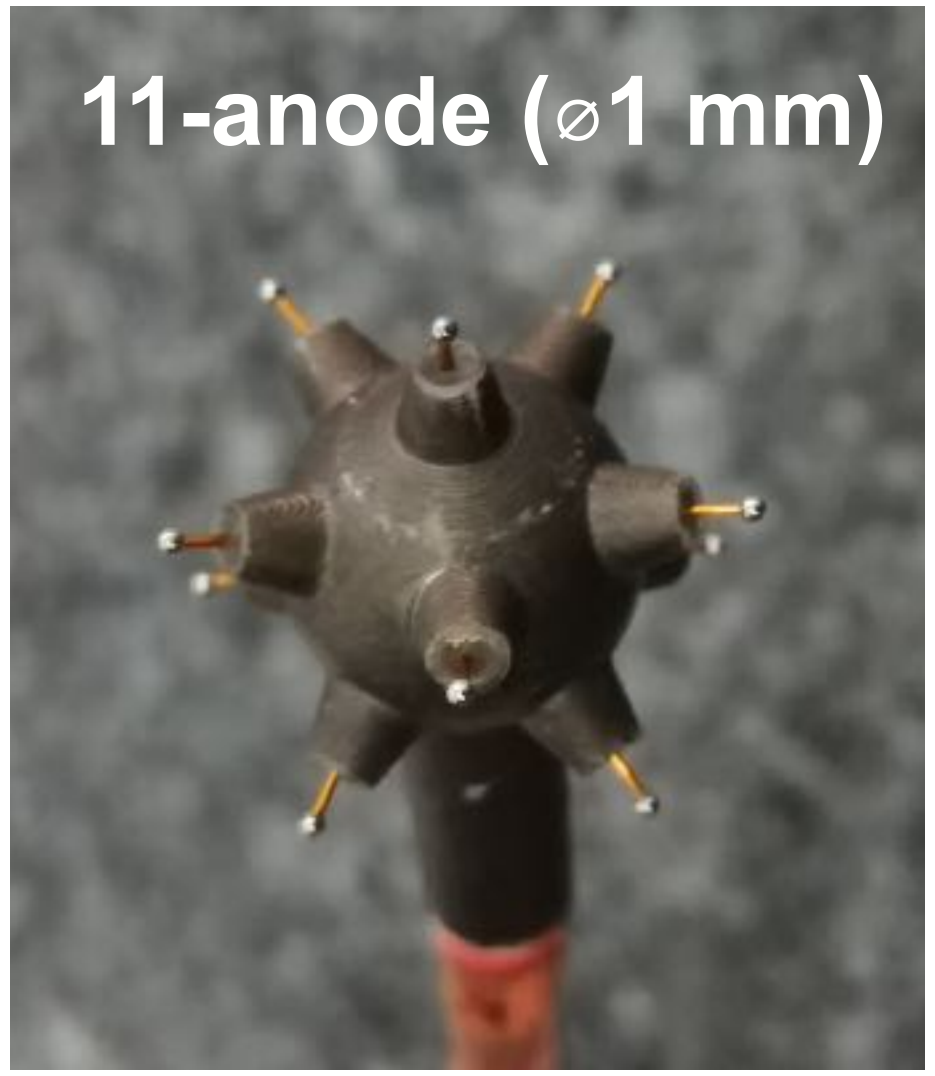
JINST 12 (2017) 12, P12031

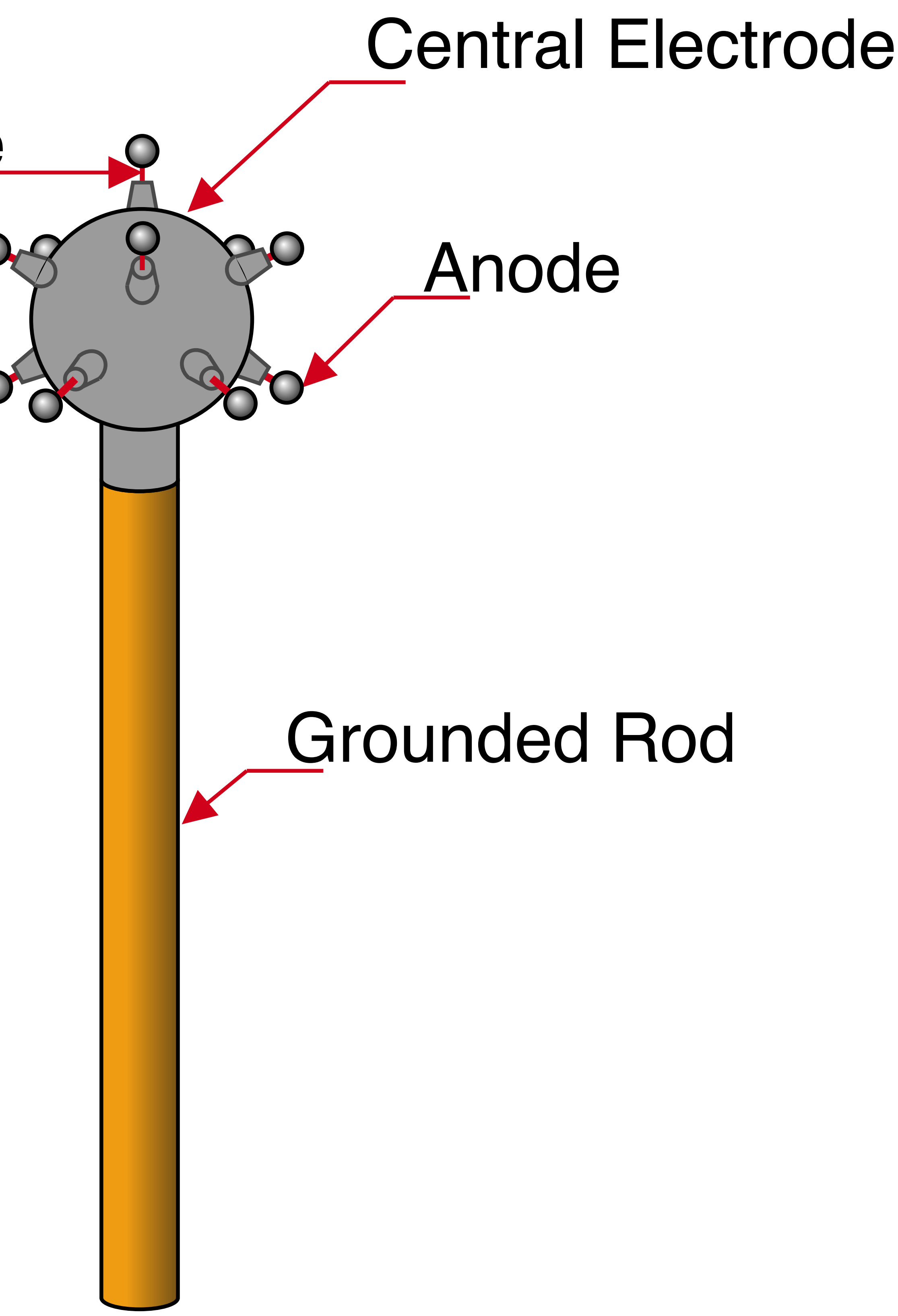
JINST 15 (2020) 11, 11

SPC Readout: ACHINOS

- Single anode: **gain and drift fields coupled**
- Idea: **Multiple anodes** located at same distance from centre of detector
- **Gain and drift decoupled**
  - **Drift field** determined by **collective field of all anodes**
  - **Gain** determined by **individual anode**
- Anodes arranged to sit on surface of sphere with radius r_s
- Future: Individual anode readout

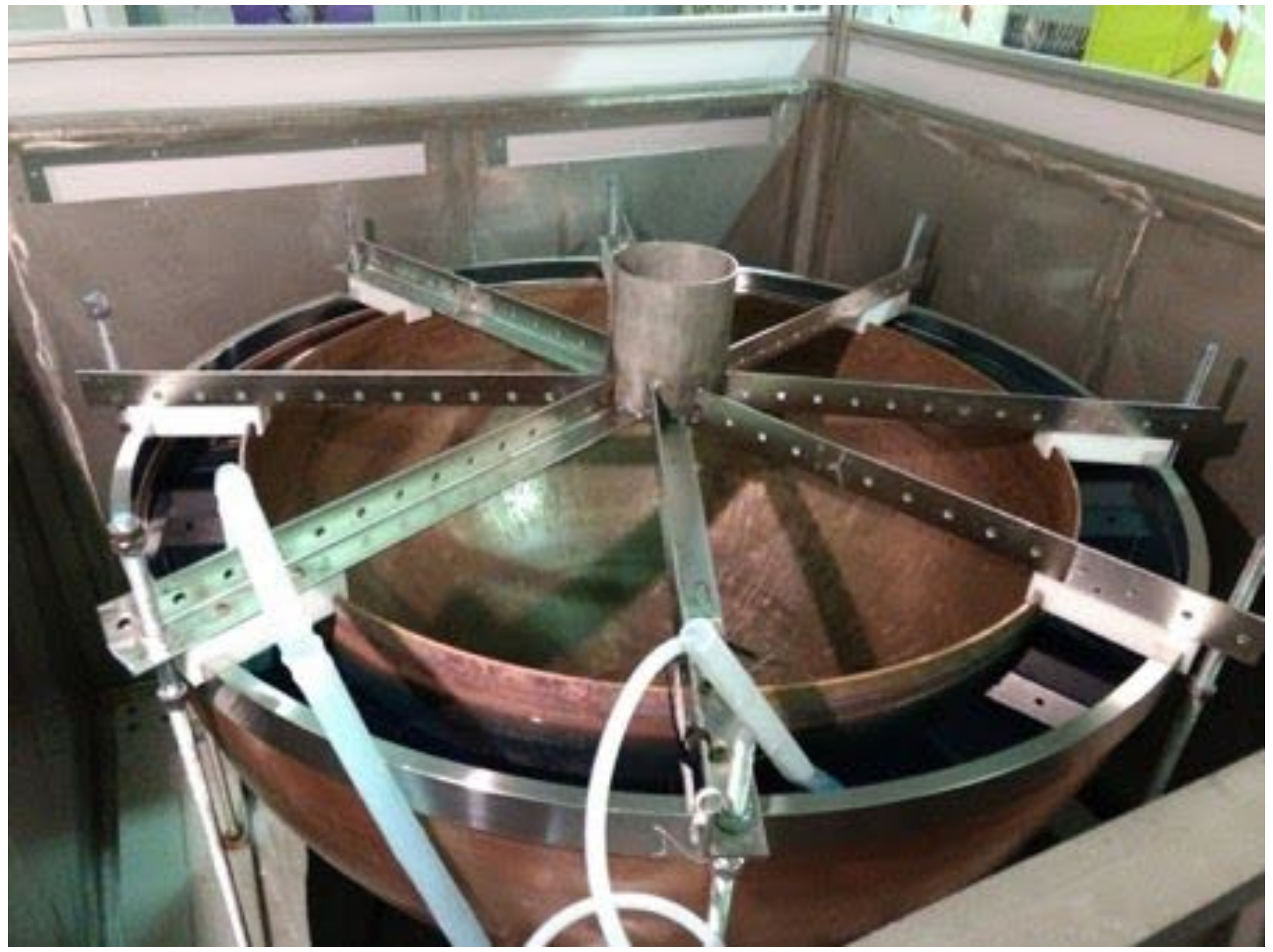






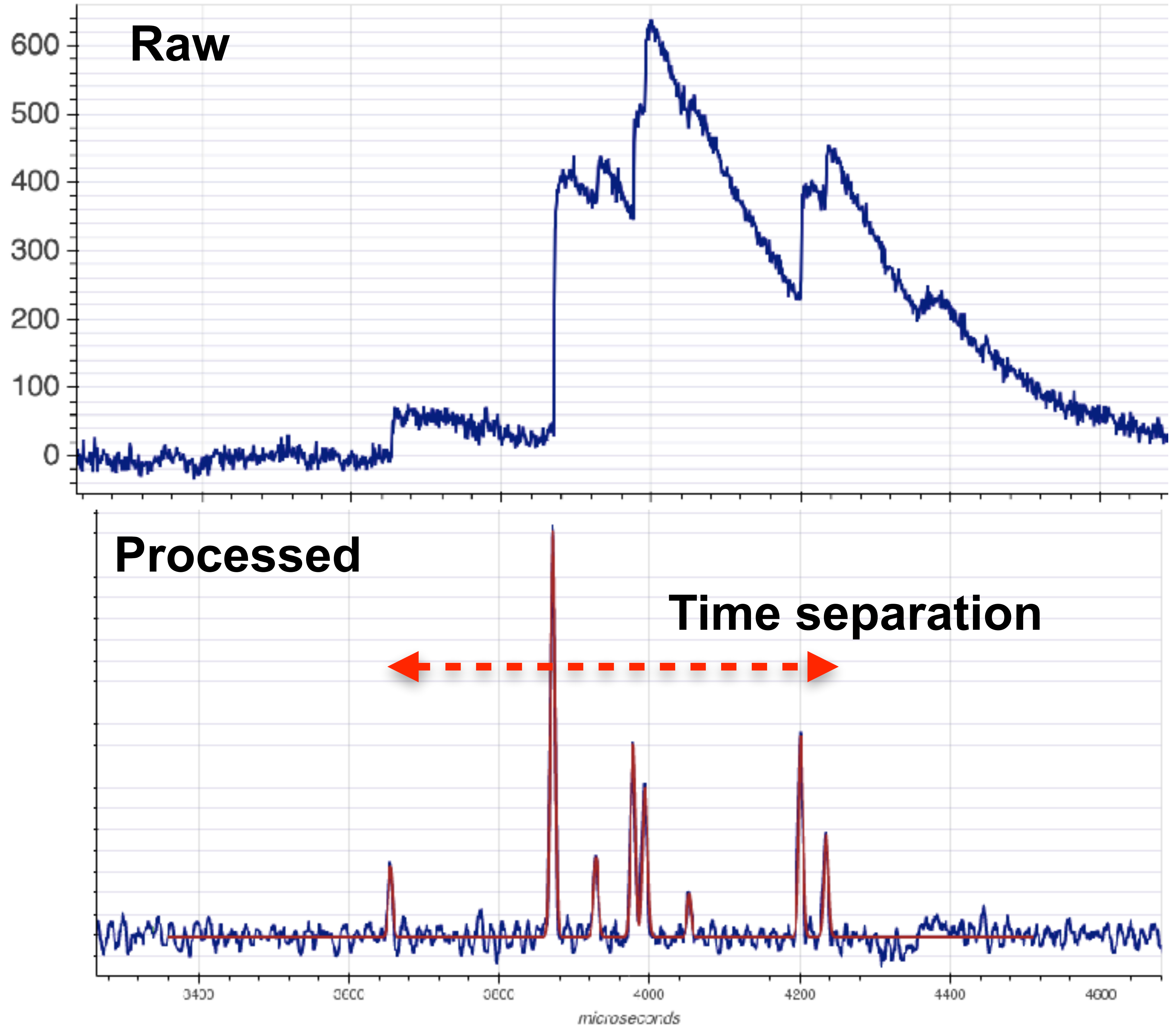
SNOGLOBE in LSM

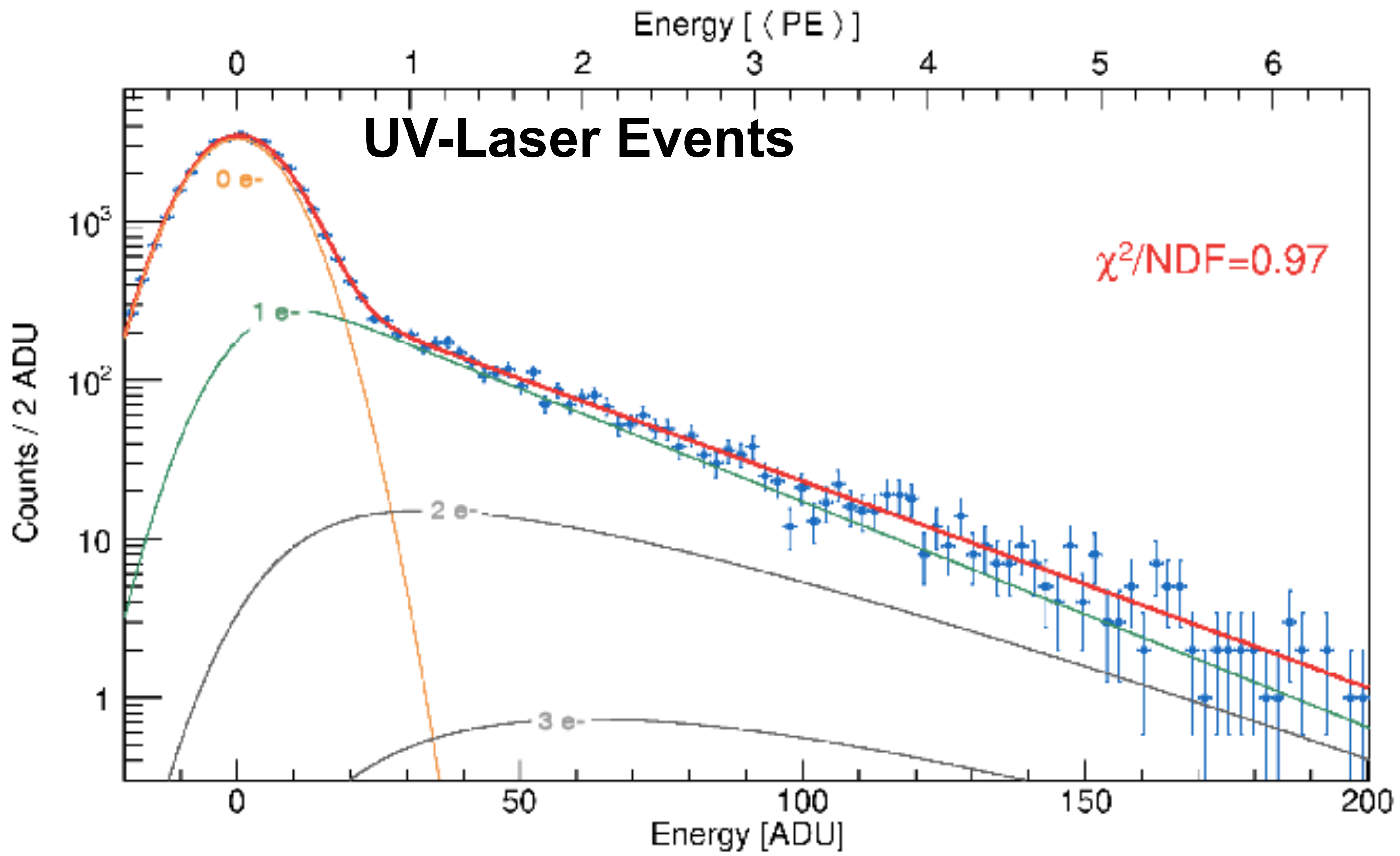
- 140 cm detector
  - 99.99% pure copper
  - Ultra-pure electroplated inner layer *NIMA 988 (2021) 164844*
- Initial commissioning data taking in LSM
  - **UV Laser and ^{37}Ar calibration systems**
  - Multi-anode sensor - ACHINOS
- Lead and water shielding installed end 2019
- **156 hrs of commissioning data taken**
  - **135 mbar of CH_4 (~100g)**



Electron Counting

- After pulse treatment, resolve primary electrons
  - Diffusion $\mathcal{O}(100\ \mu s)$ in commissioning data
  - If >1e, **time separation** surface/volume discrimination

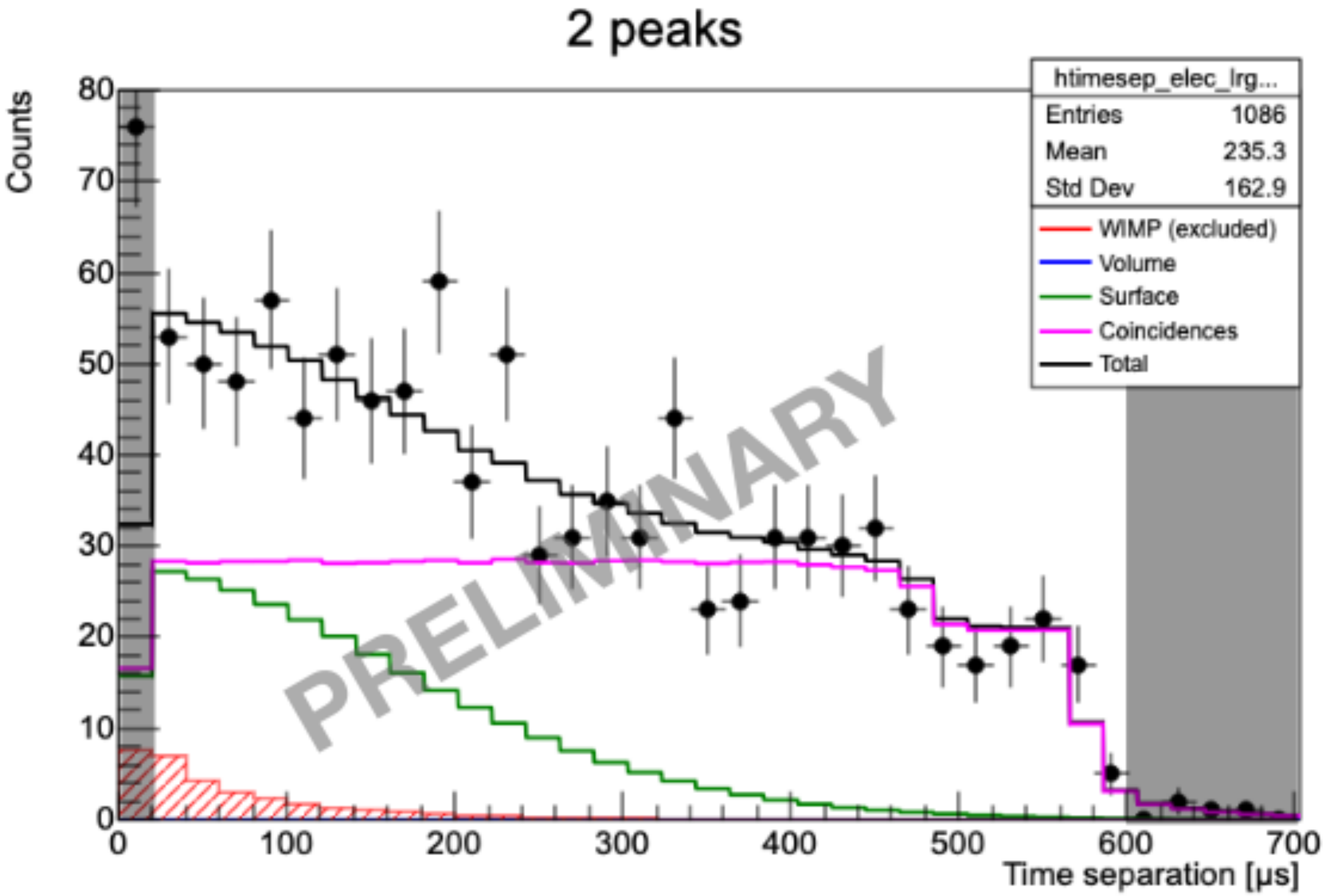


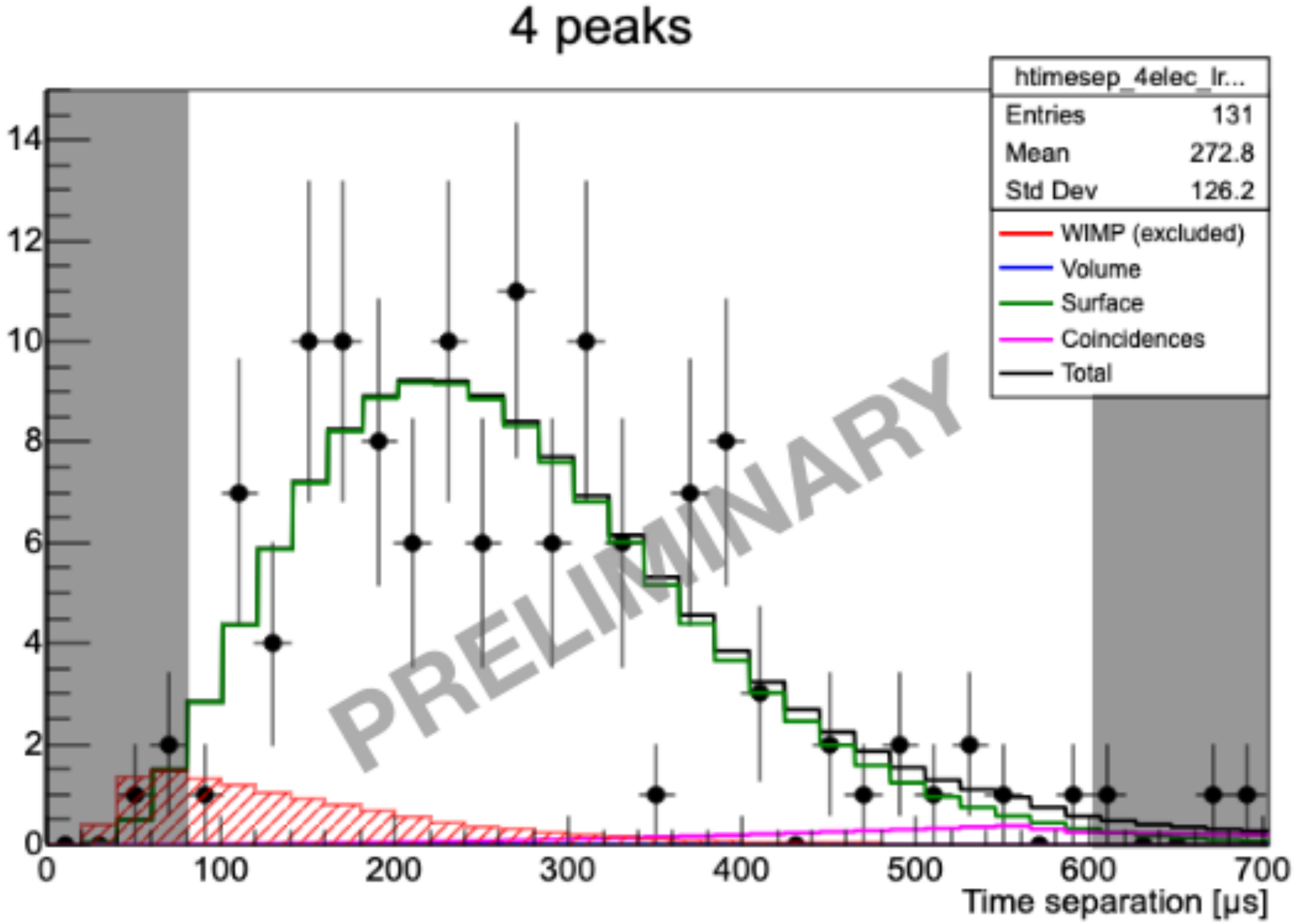


- **UV 231 nm laser** used for continuous detector monitoring
  - Drift time, gain, efficiencies etc.
- ^{37}**Ar** at end of data taking
  - Gain measurements
  - W-value and Fano
  - Electron attachment

Commissioning Data in LSM

- Data divided into 2/3/4 peak
- Principle discriminating variable: time separation
  - Surface/volume and coincidence discrimination
- Only test data analysed so far: ~30% data
  - Remaining data is blind
- No significant DM signal observed

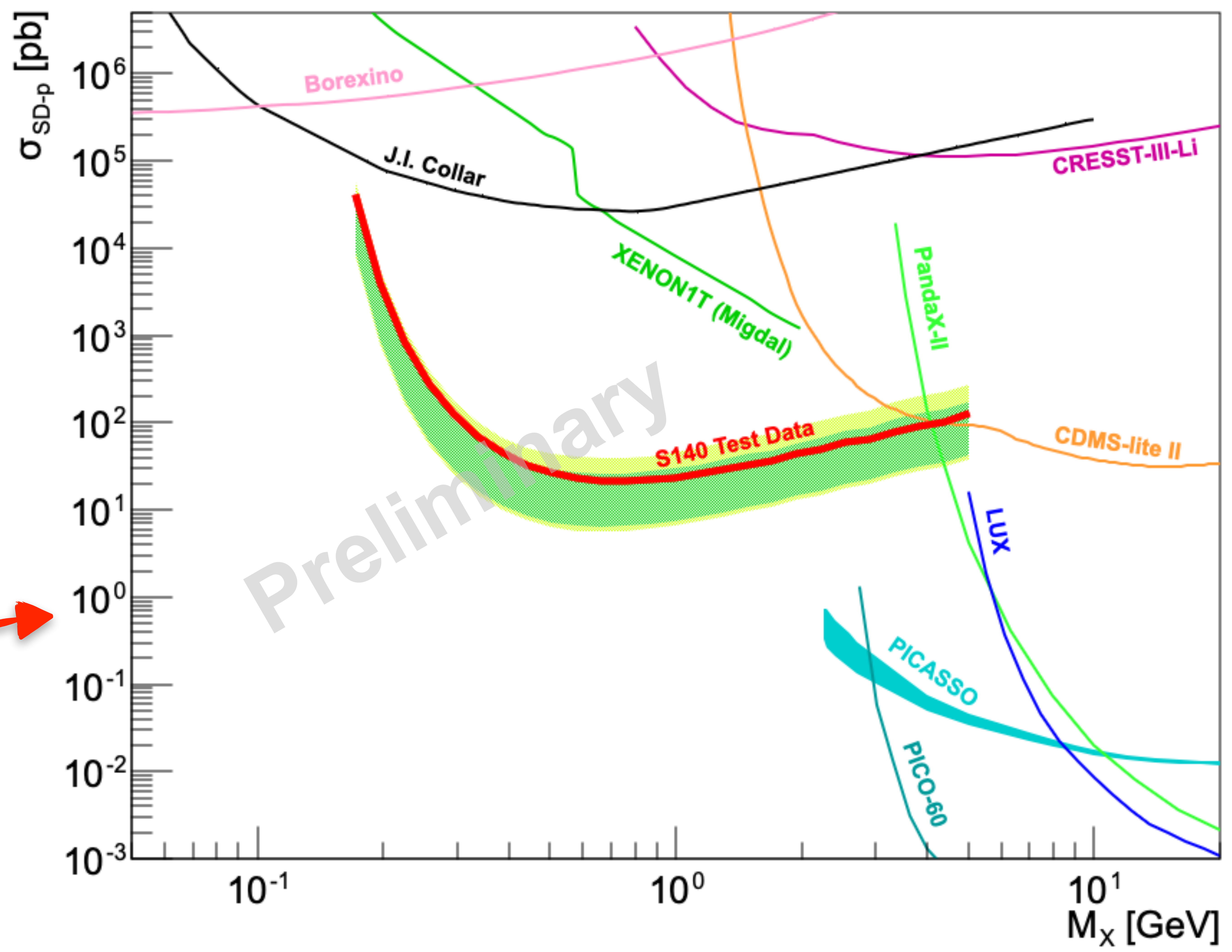




LSM Physics Results

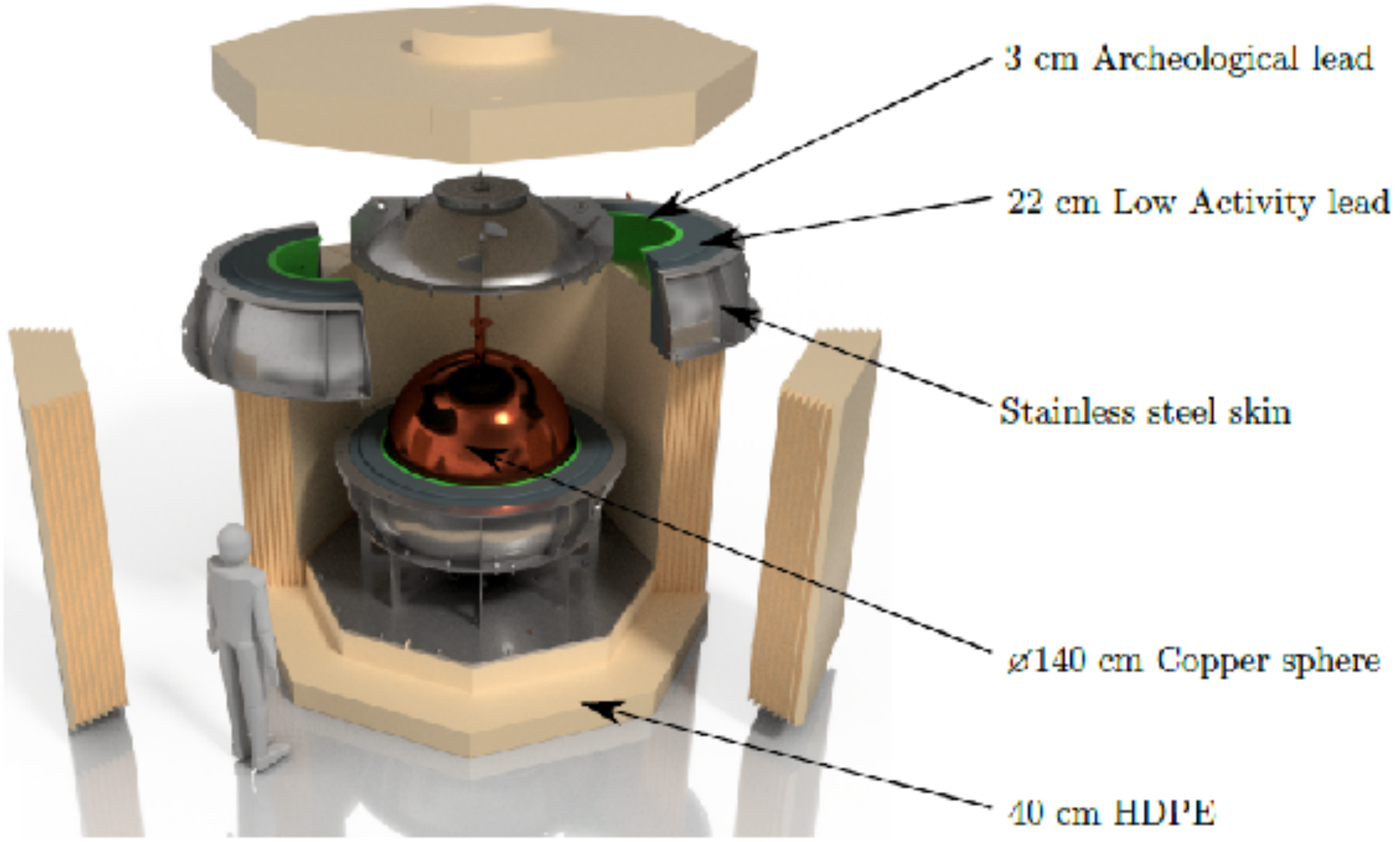
- Results with 0.12 kg·days test data
- Combination of W-value and Comimac QF used
  - Conservative logarithmic extrapolation
- Profile likelihood ratio method used to calculate 90% exclusion limit
- Full results with blind data expected within weeks - **potential for best constraints on SD-p DM interactions below 1 GeV!**

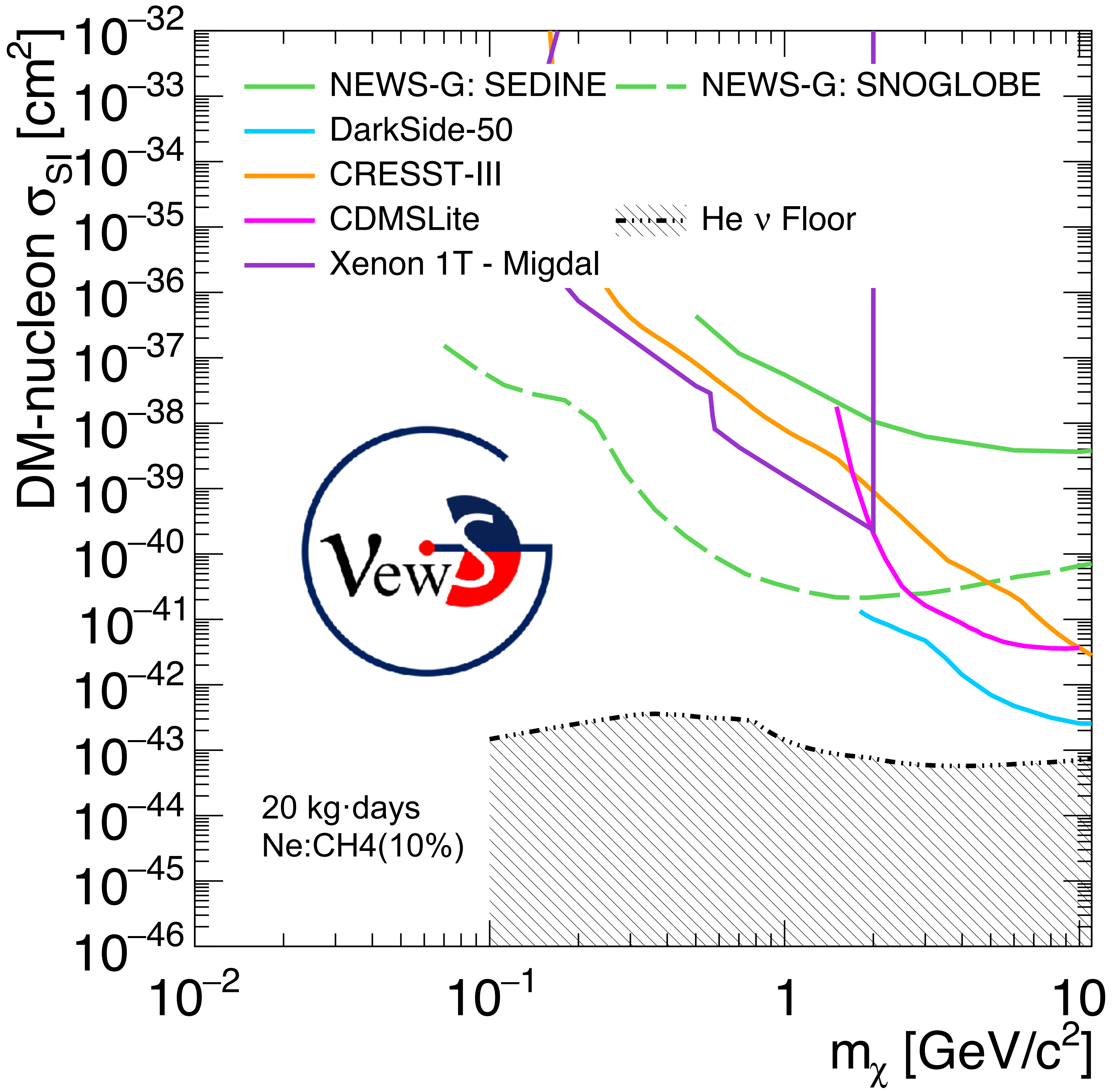
New Result!



SNOGLOBE: Prospects

- Now in commissioning in SNOLAB





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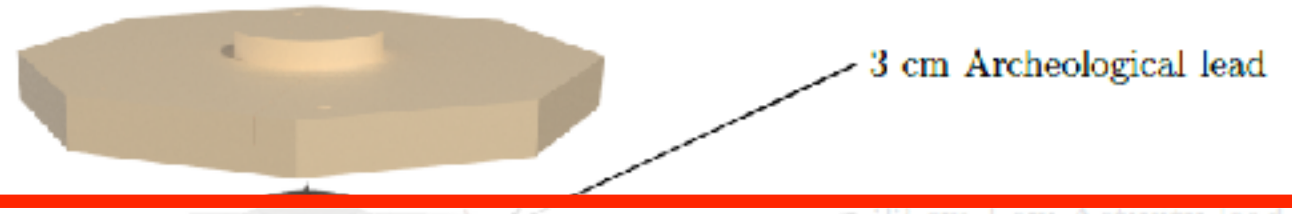
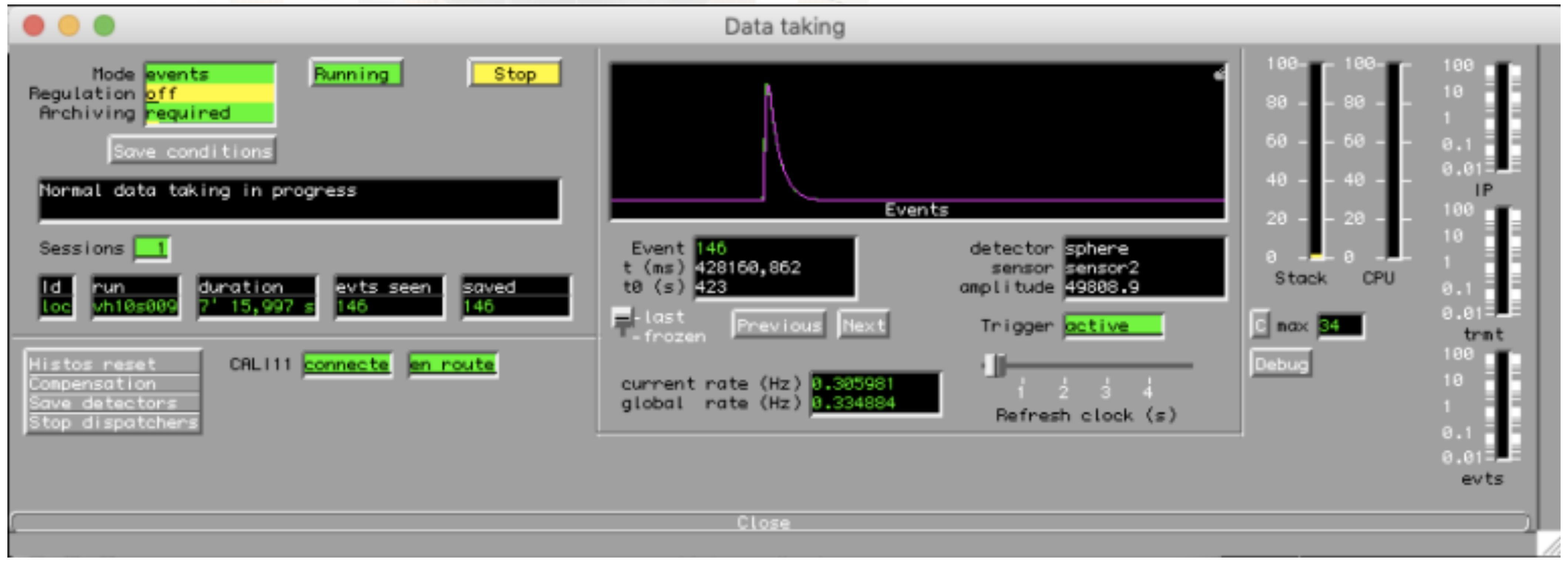
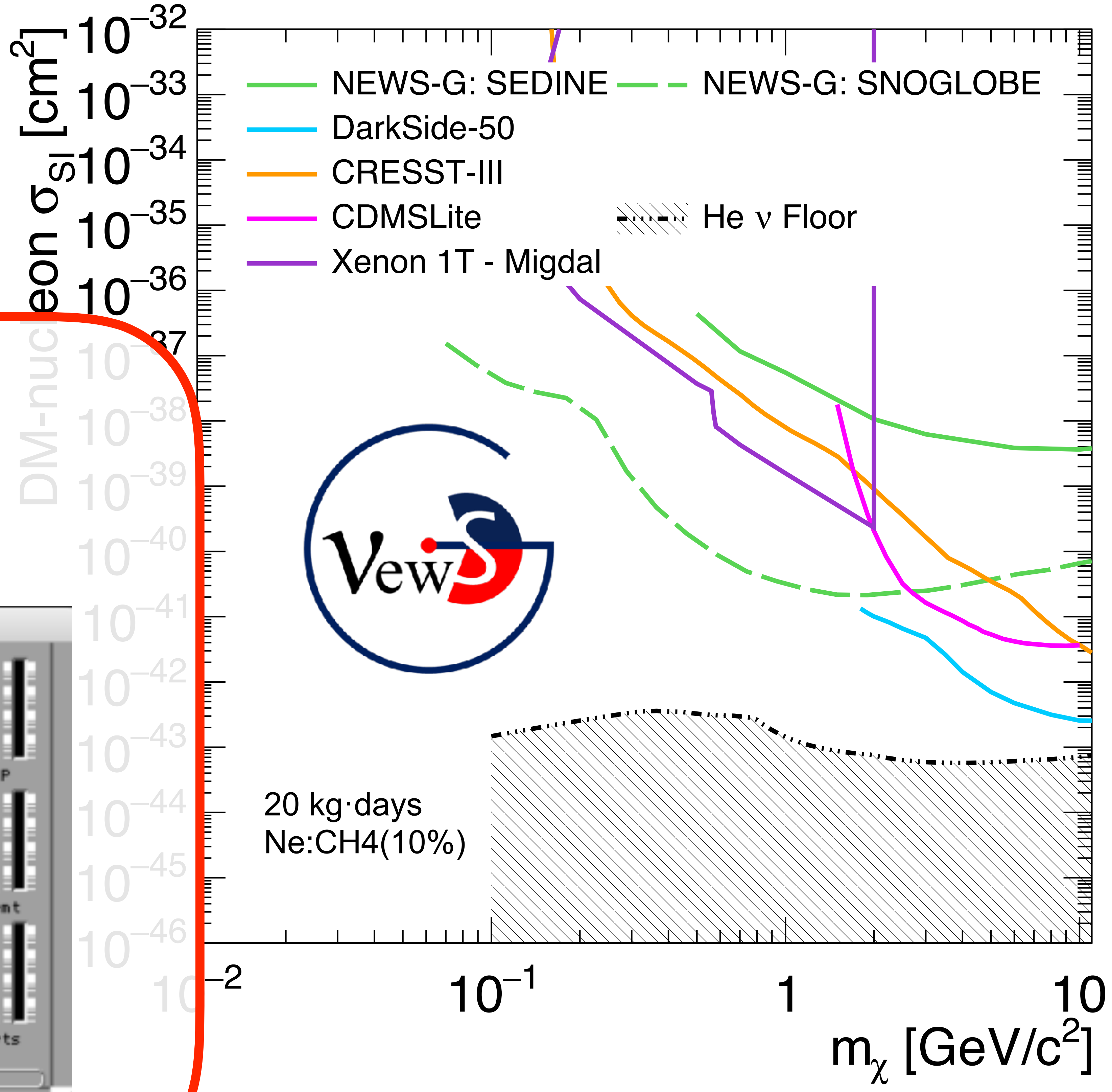


First signal in SNOLAB, summer 2021!

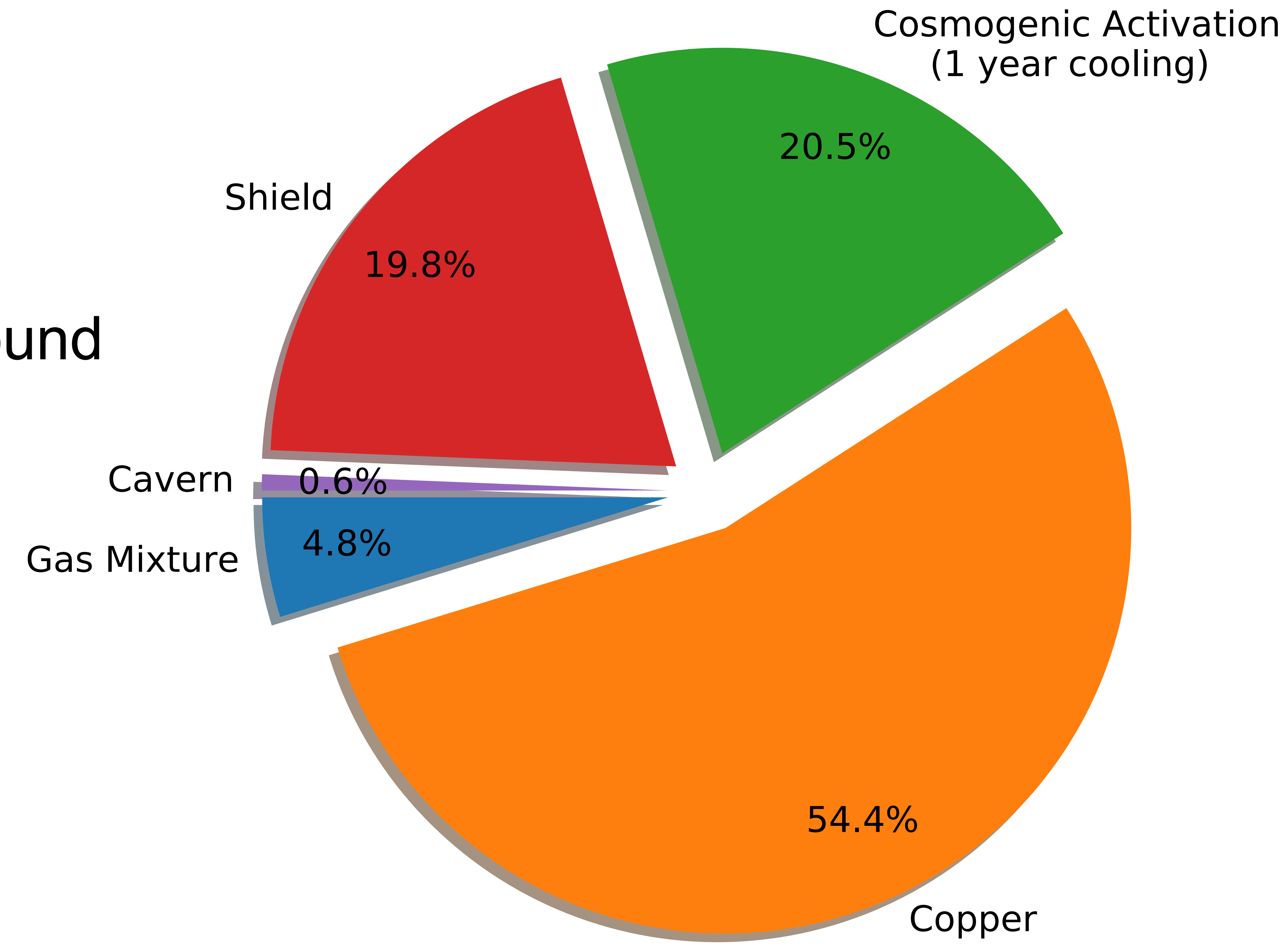




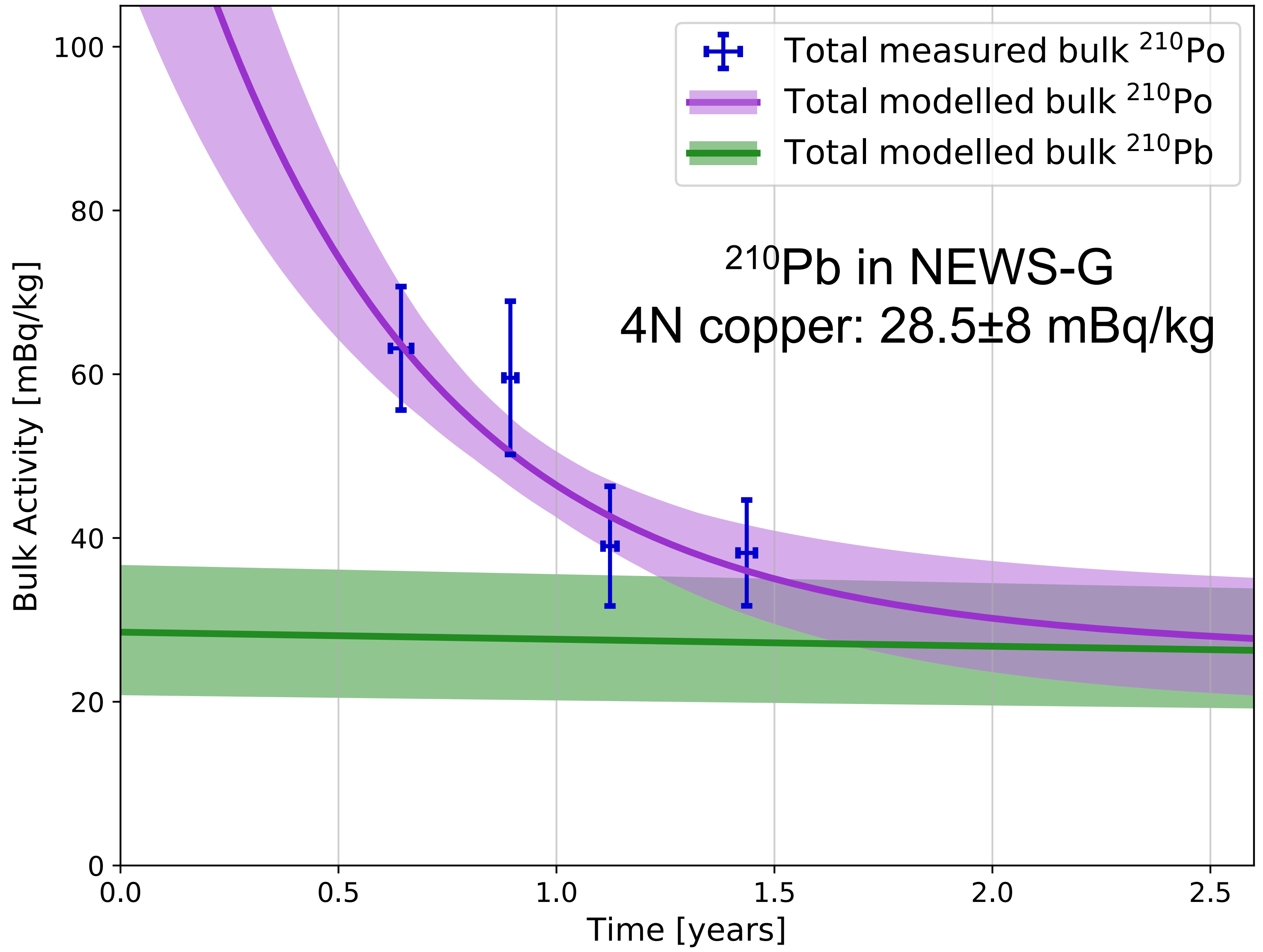
Future Detectors

- Dominant background in current detector: Copper
- **Ultra-pure EF Cu, underground, intact**

Expected
SNOGLOBE Background



XIA Measurement



ICP-MS Assay

Sample	Weight [g]	^{232}Th [μBq kg^{-1}]	^{238}U [μBq kg^{-1}]
C10100 Cu (Machined)	-	8.7 ± 1.6	27.9 ± 1.9
Cu Electroformed	-	<0.119	<0.099
Hemisphere 1	0.256	<0.58	<0.26
Hemisphere 2	0.614	<0.24	<0.11

NIMA 988 (2021) 164844

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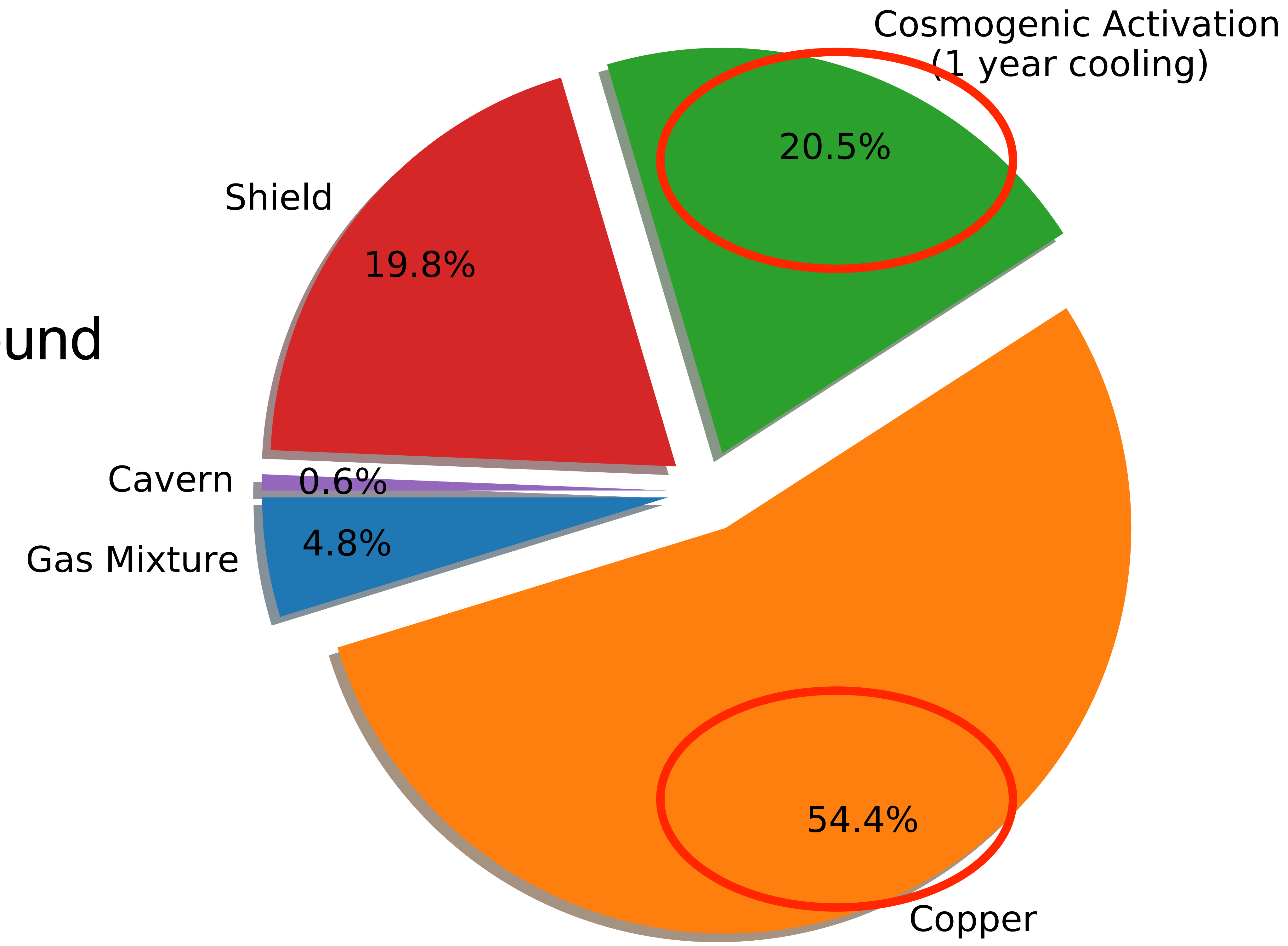
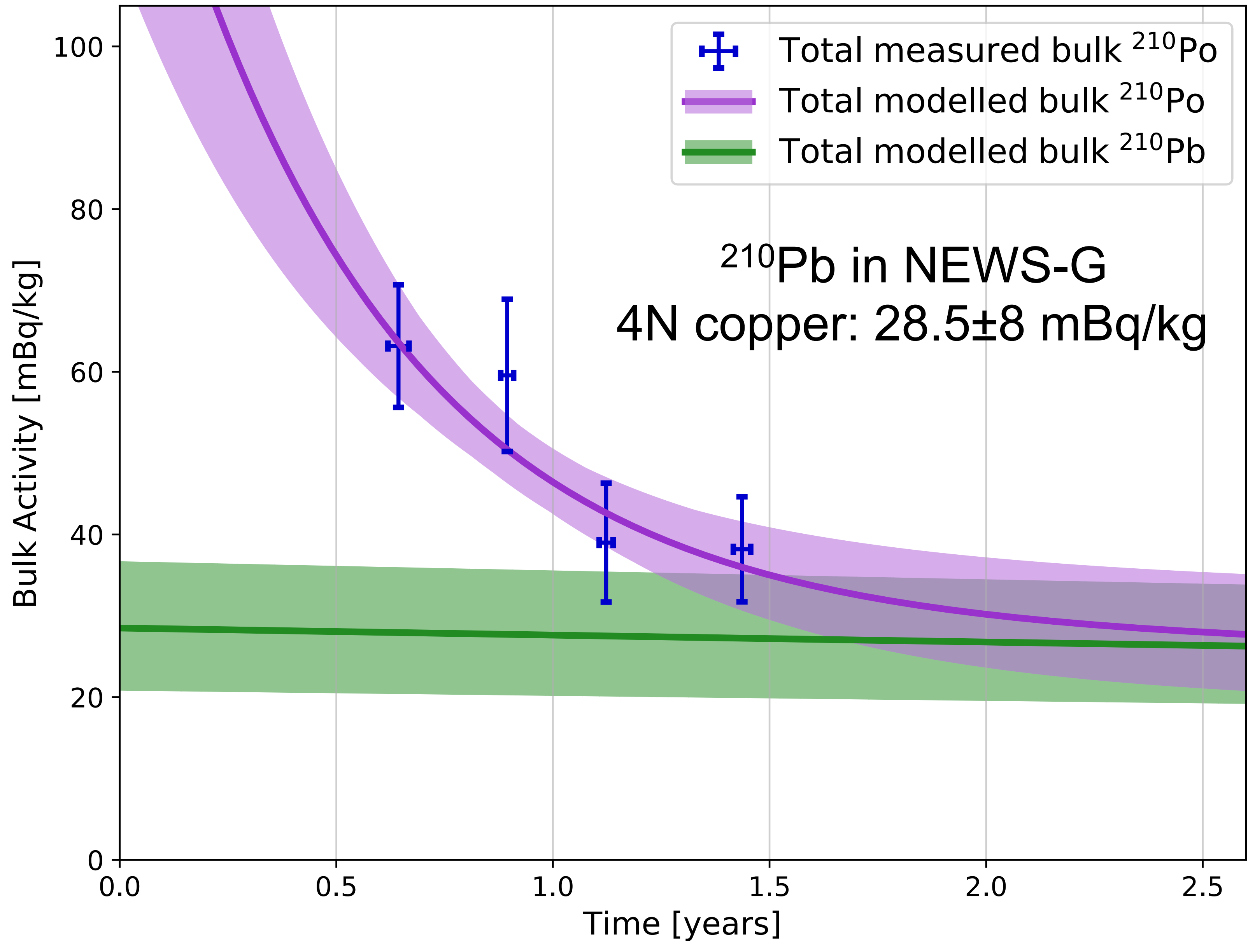


XIA Measurement



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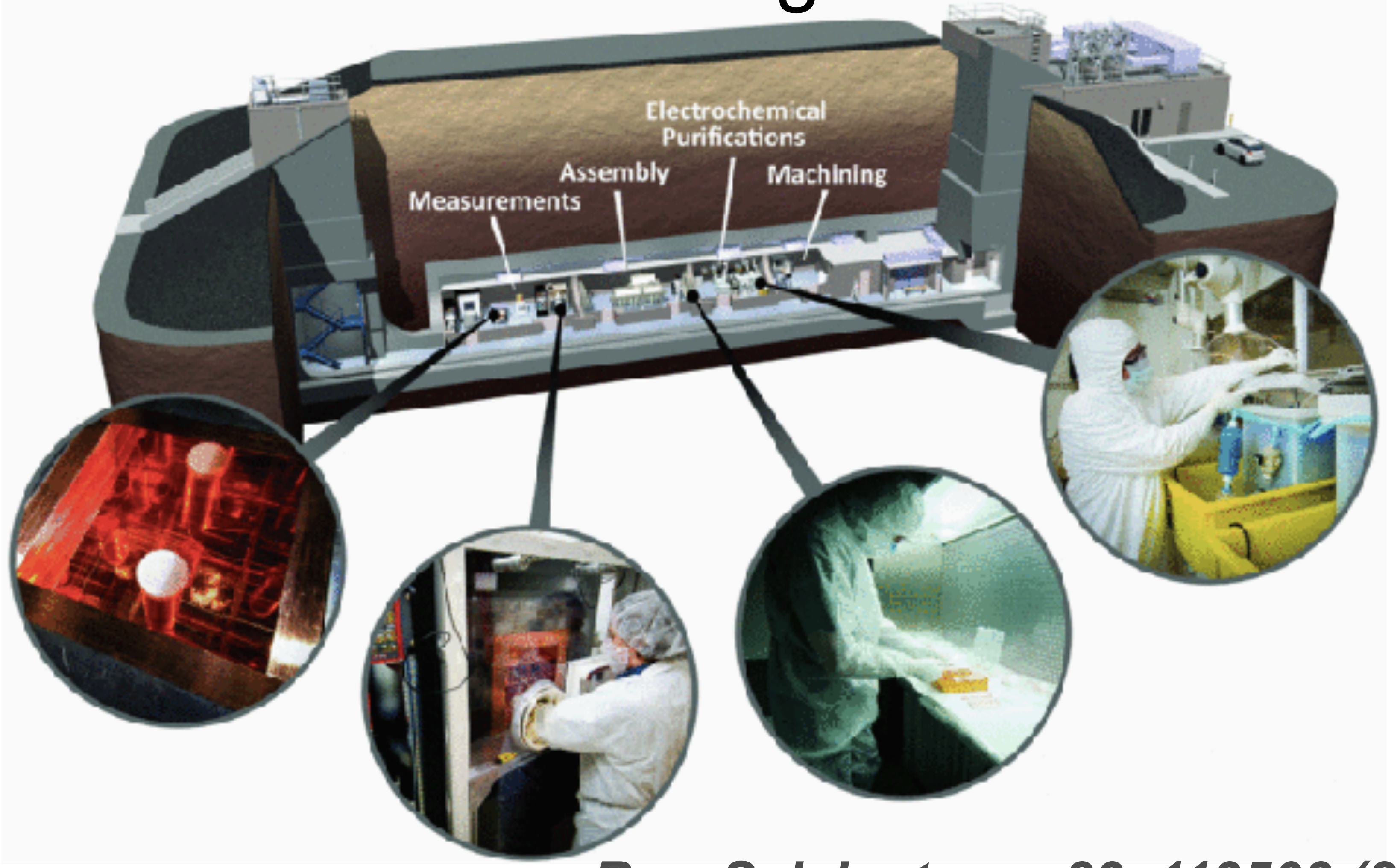
NIMA 988 (2021) 164844

Electroformed Cuprum Manufacturing Experiment

- **ECuME:** An EFCu facility in SNOLAB
- Will make a ⌀140 cm, fully electroformed SPC
  - Use SNOGLOBE'S shielding
- Work ongoing for ⌀30 cm prototype **miniECuME**

ECuME

PNNL Shallow Underground Laboratory



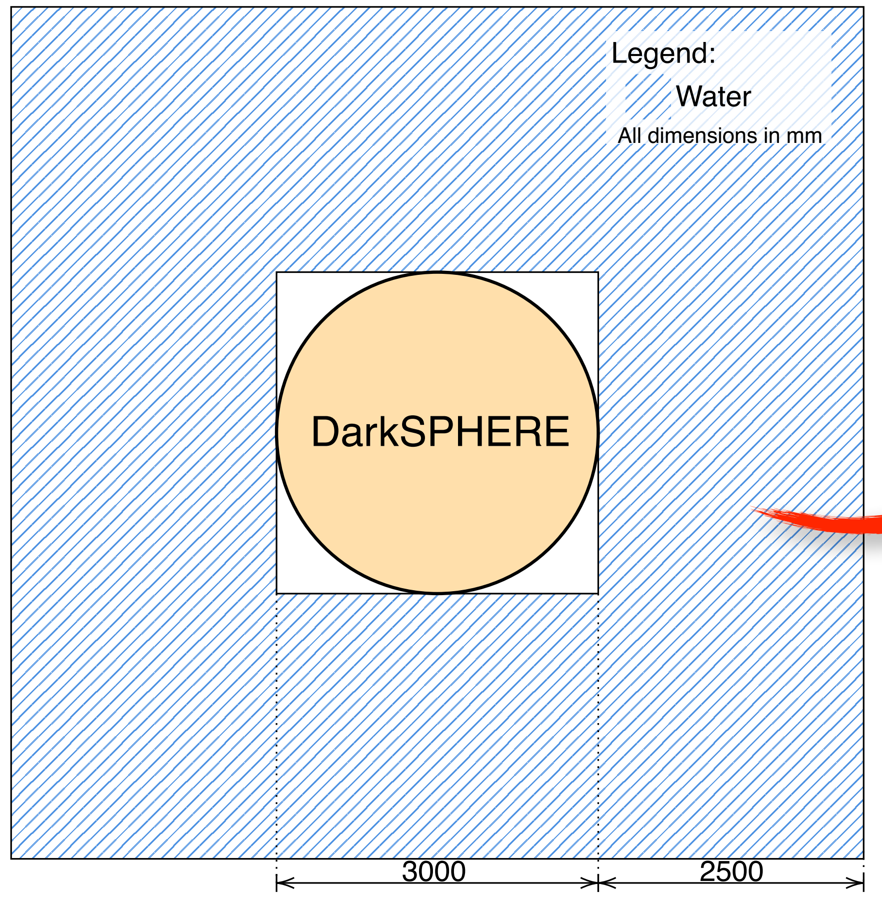
[Rev. Sci. Instrum. 83, 113503 (2012)]

[https://tour.pnnl.gov/shallow-lab.html#Assembly]

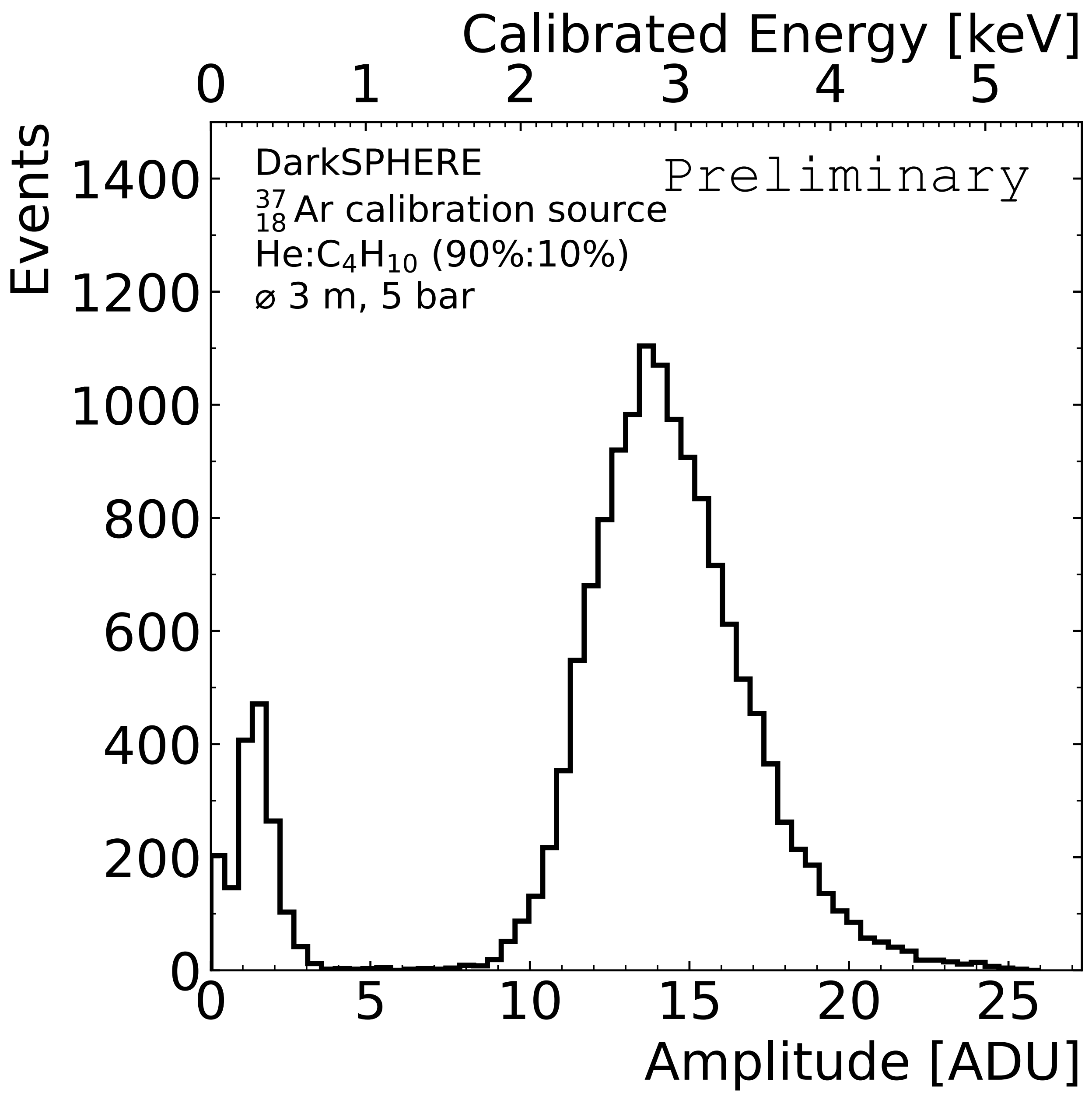
- PNNL will produce prototype in shallow underground laboratory
  - Used to define conditions required for ECuME
- **Following these tests, we still have a (mini) detector…**
  - Potentially exciting physics to be done there!

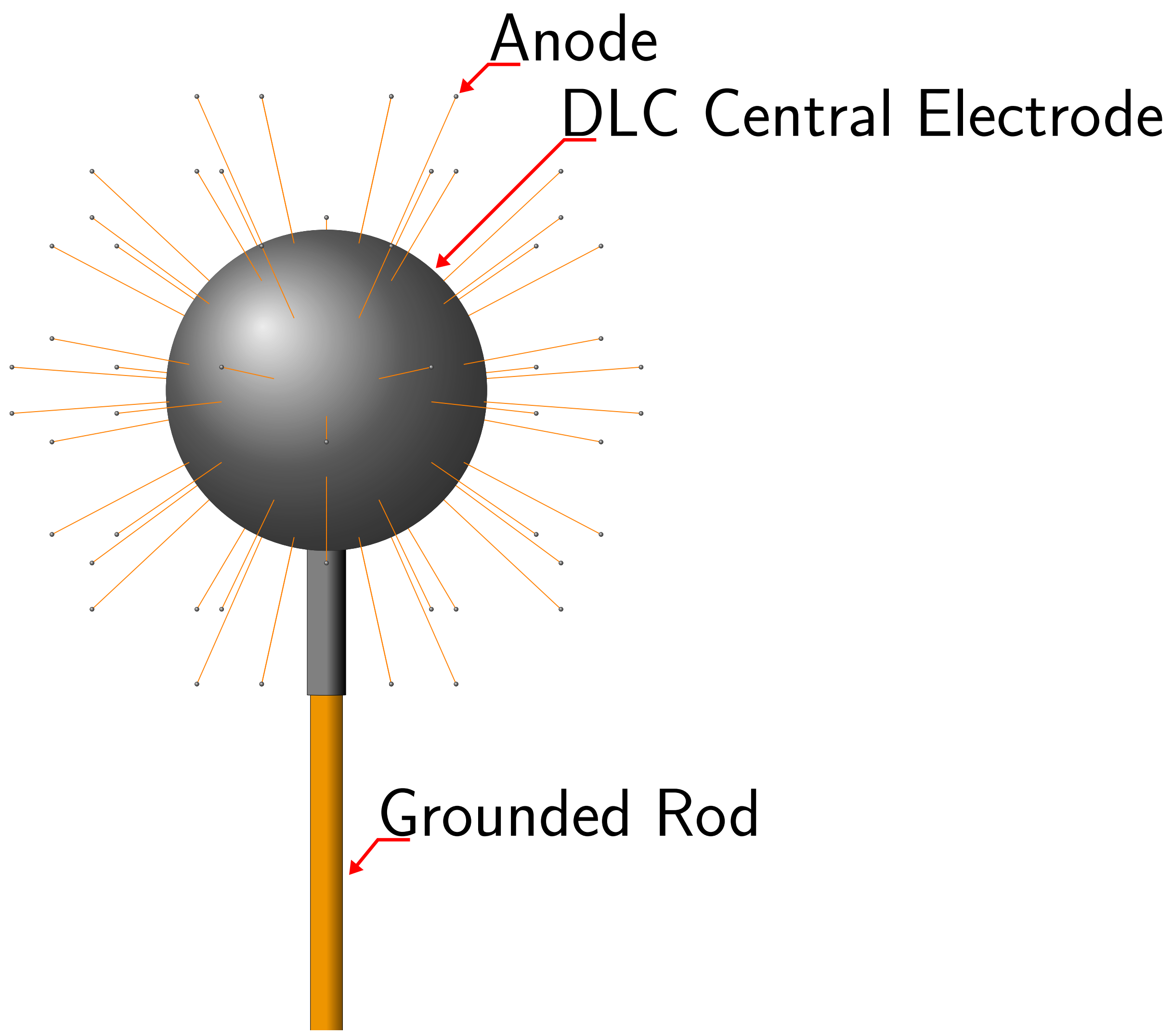
DarkSPHERE

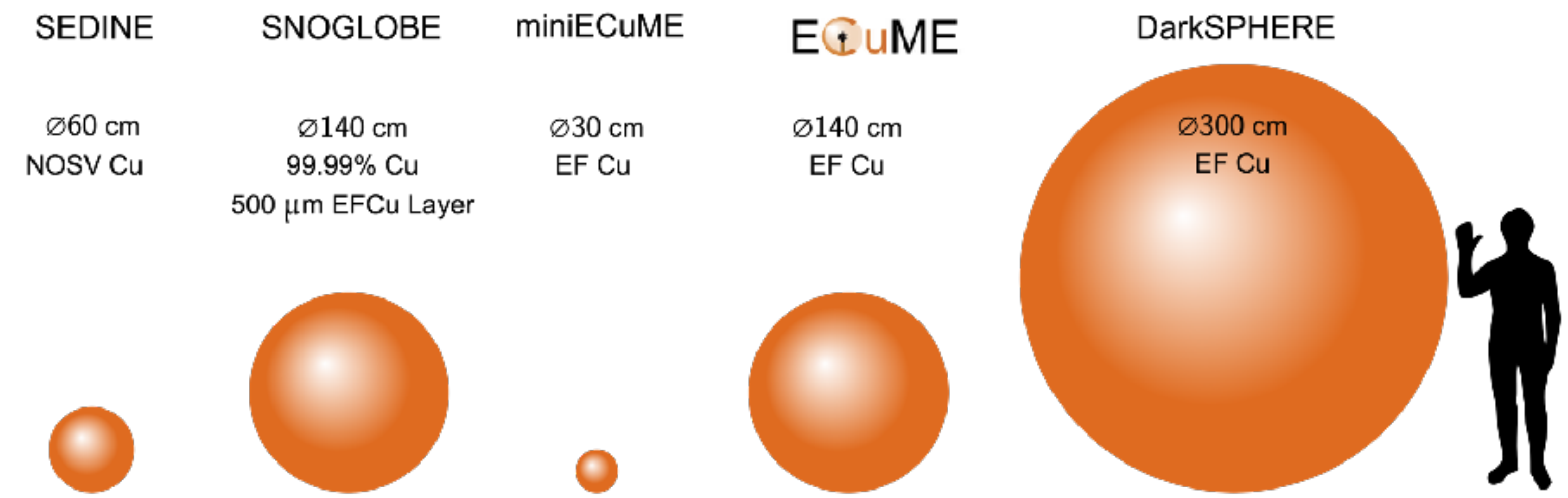
- After copper, next leading BG: shield
- **DarkSPHERE**: ⌀300 cm SPC with low-background water shield
- 2.5m thick water is sufficient for <0.01 dru BG
  - Dominant BG: photons in cavern
- Additional R&D ongoing for required ACHINOS
- Physics potential and design paper coming v. soon!



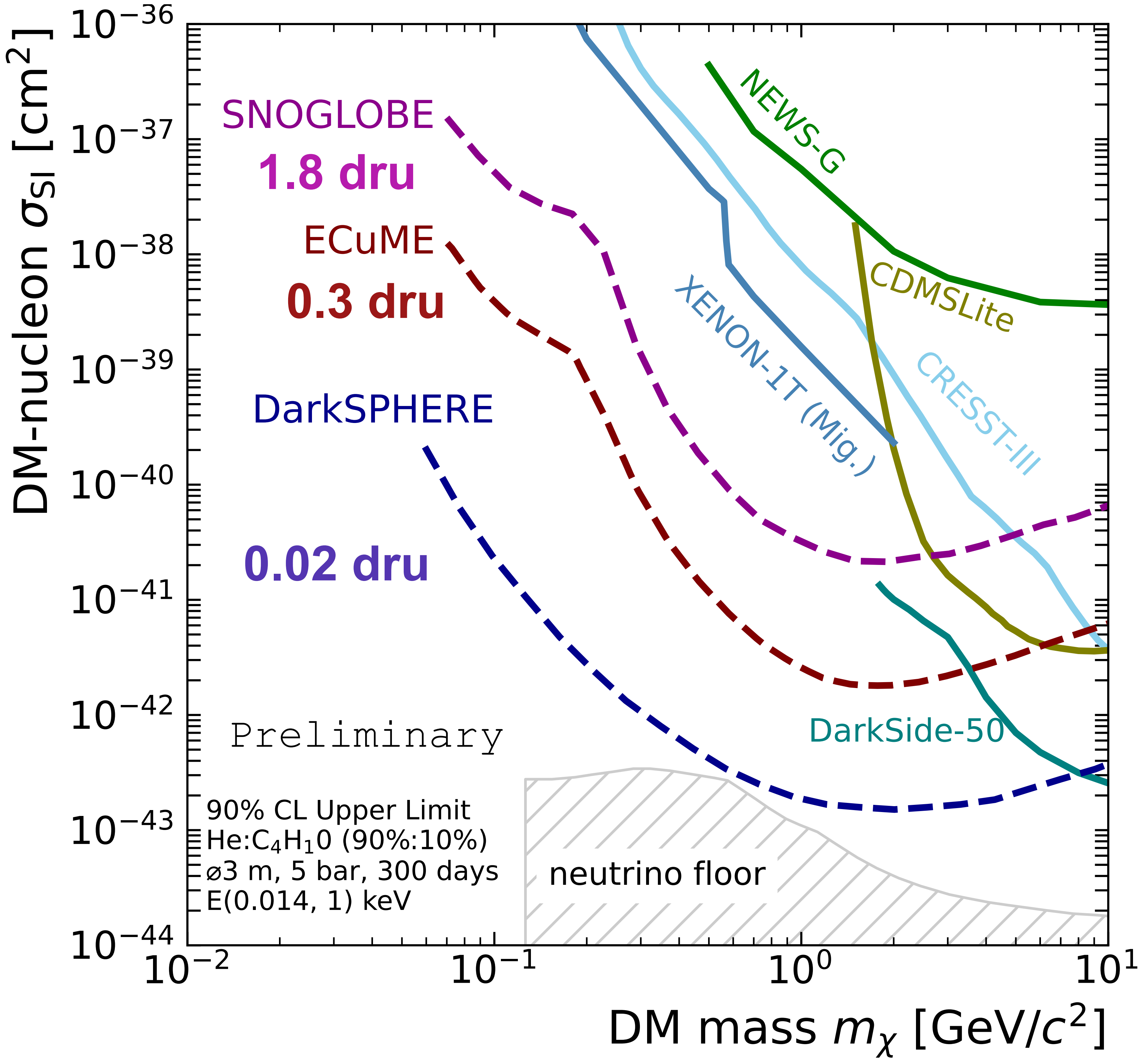
Simulation with 60-anode ACHINOS in DarkSPHERE







DarkSPHERE



SNOGLOBE
1.8 dru
ECuME
0.3 dru
DarkSPHERE
0.02 dru
NEWS-G
CDMSLite
XENON-1T (Mig.)
CRESST-III
DarkSide-50
Preliminary
90% CL Upper Limit
He:C4H10 (90%:10%)
ø3 m, 5 bar, 300 days
E(0.014, 1) keV
neutrino floor
DM-nucleon σ_{SI} [cm^2]
DM mass m_χ [GeV/c^2]

DarkSPHERE

DM-nucleon σSI [cm²]
SNOGLOBE
1.8 dru
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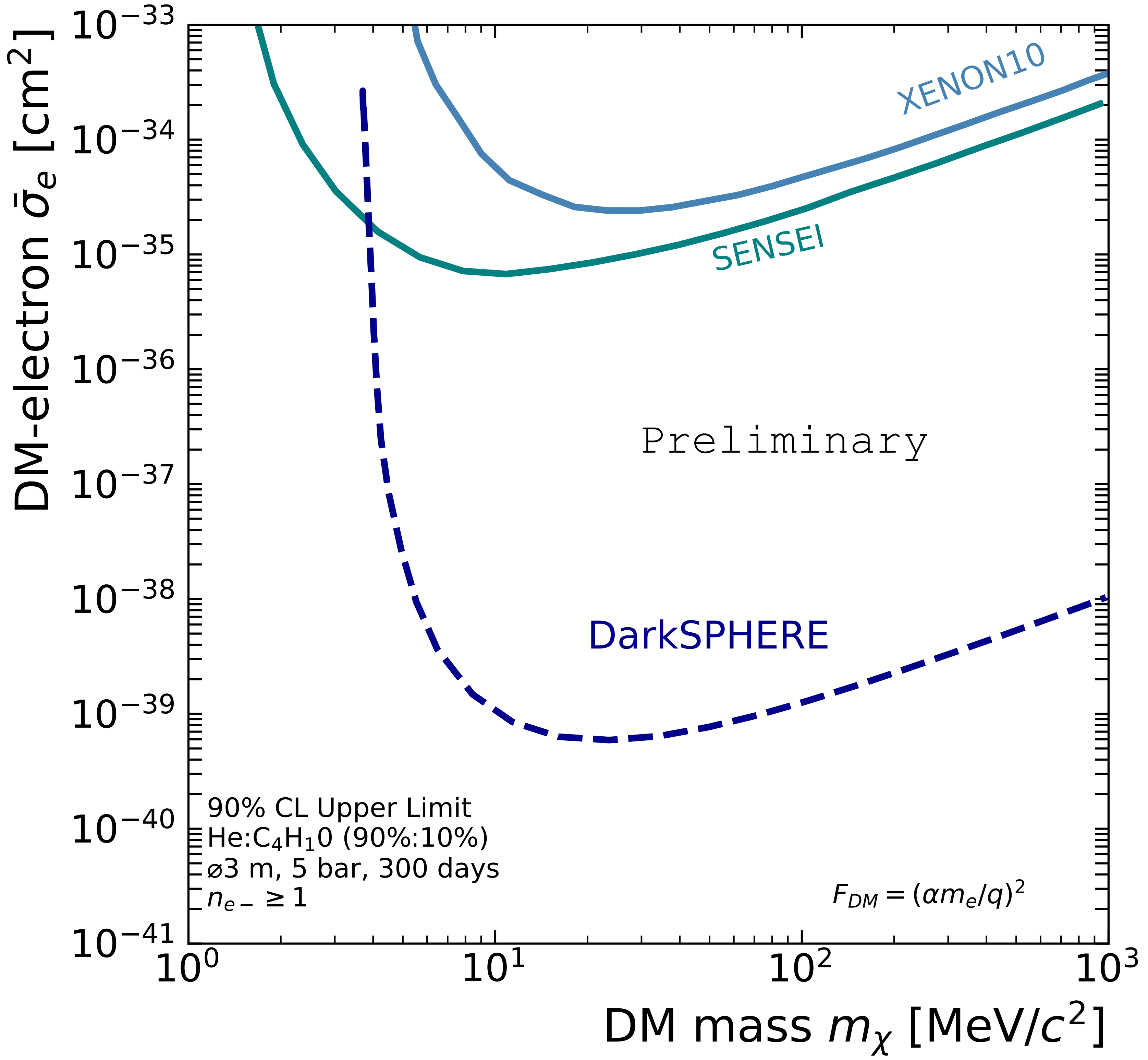
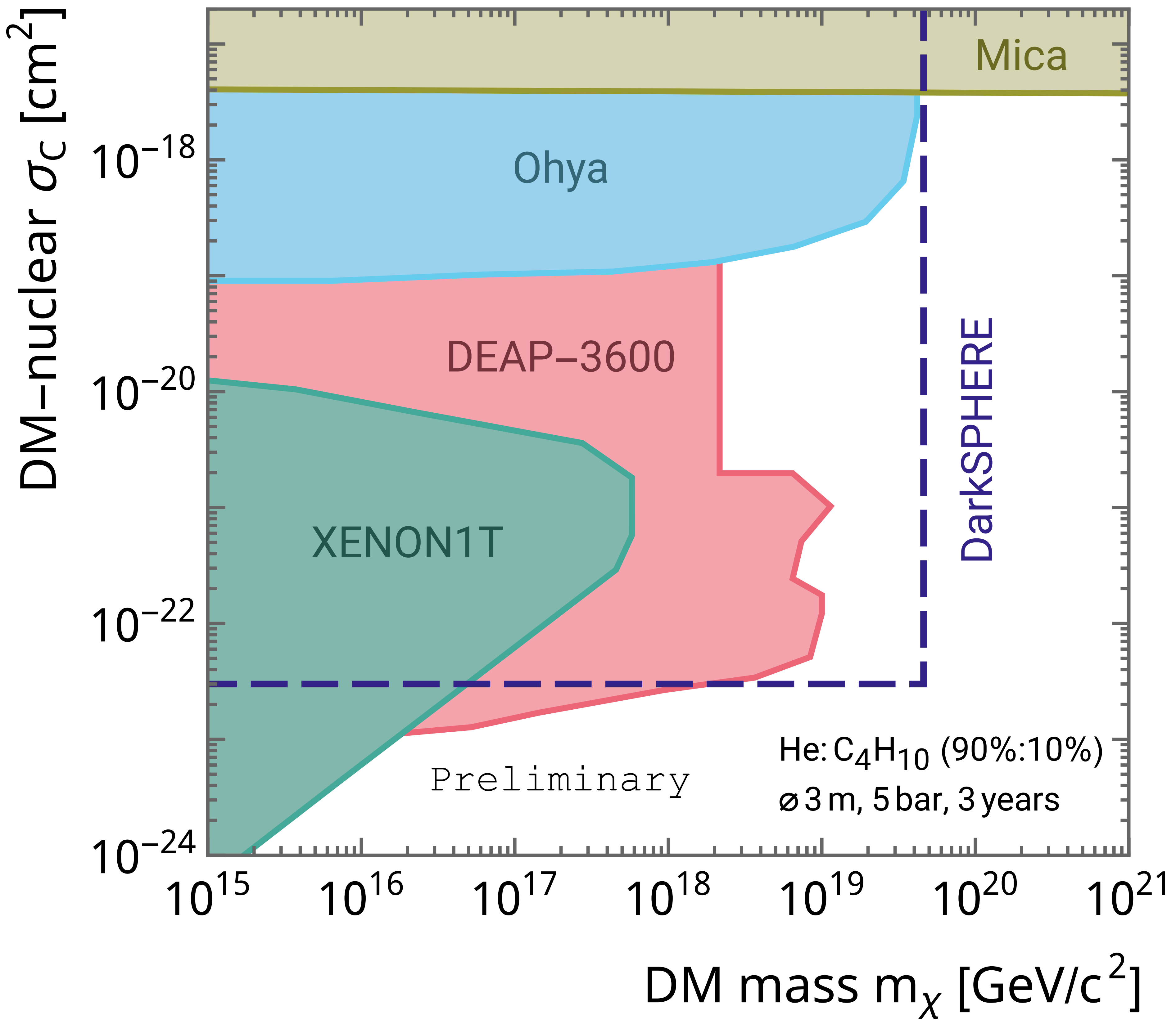
90% CL Upper Limit
He:C4H10 (90%:10%)
ø3 m, 5 bar, 300 days
E(0.014, 1) keV
neutrino floor
DM mass mχ [GeV/c²]
DM-proton σSD [cm²]
Collar (2018)
XENON-1T (Mig.)
CDMSLite
Preliminary
90% CL Upper Limit
He:C4H10 (90%:10%)
ø3 m, 5 bar, 300 days
E(0.014, 1) keV
PICASSO
Pico-60
DarkSPHERE
DM mass mχ [GeV/c²]
DM-neutron σSD [cm²]
XENON-1T (Mig.)
CDMSLite
DarkSPHERE
XENON-1T
XENON-1T
Preliminary
90% CL Upper Limit
He:C4H10 (90%:10%)
ø3 m, 5 bar, 300 days
E(0.014, 1) keV
DM mass mχ [GeV/c²]

DM-e Scattering and Heavy DM

Fuelling the search for light dark matter-electron scattering, L. Hamaide and C. McCabe



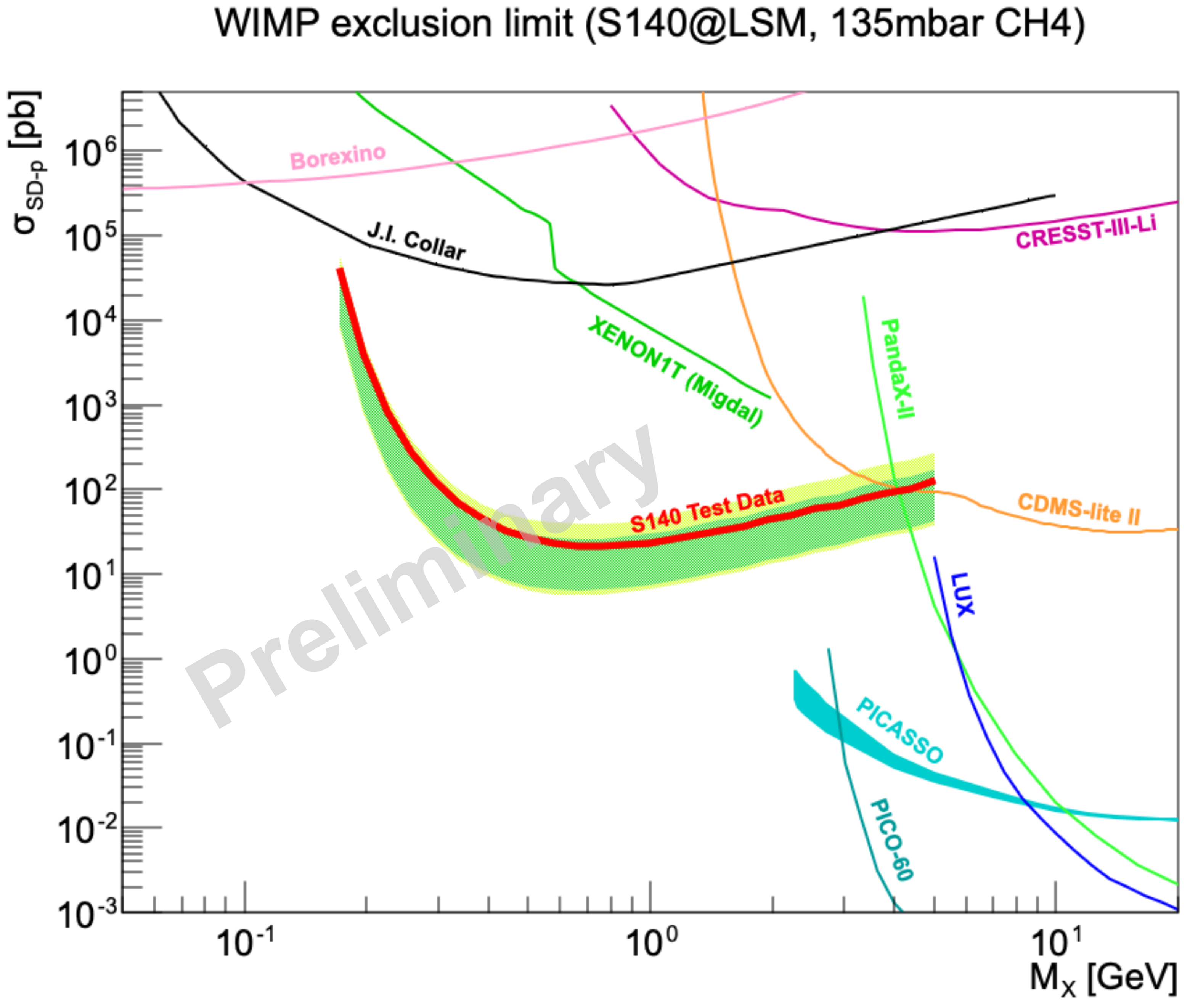


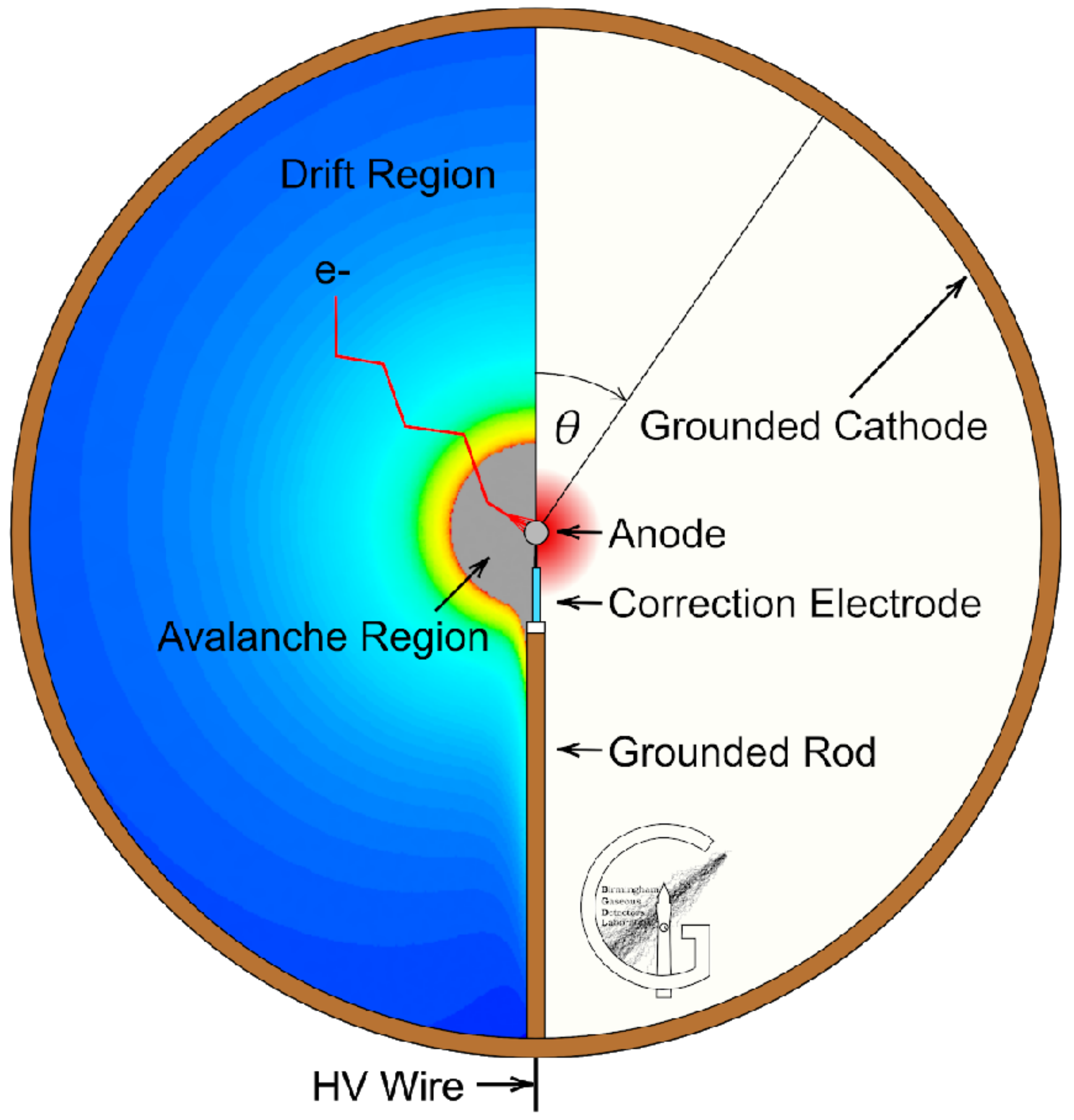
Plots from C. McCabe and L. Hamaide

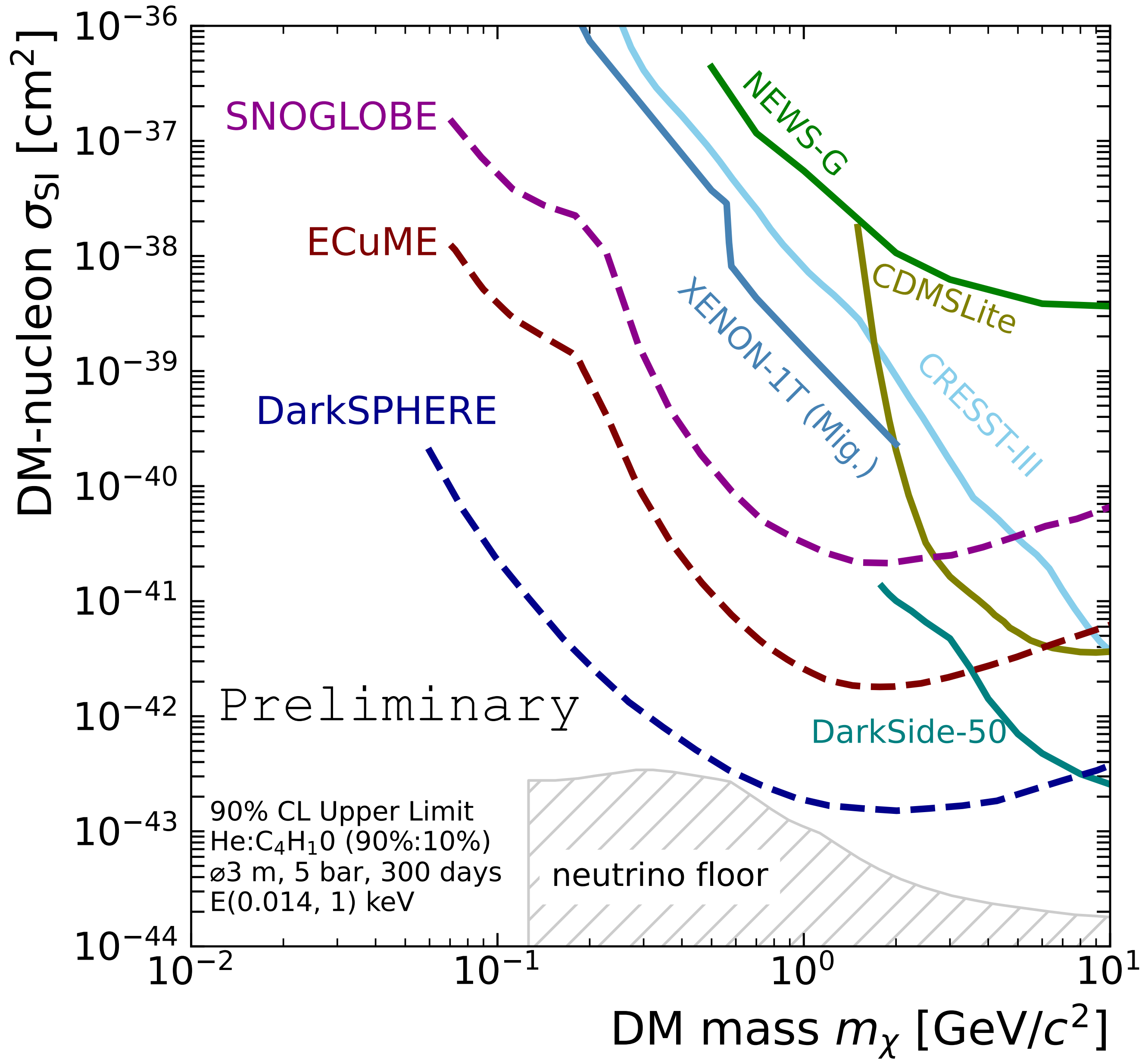
- Attracted interest of theorists
  - Applying work to DarkSPHERE for searches beyond 'standard' methods and candidates

Summary

- SPC is versatile detector used for DM searches
- Quenching factor result in two experiments
  - Third method using W-value measurements
- Analysis commissioning data in LSM concluding
  - Expect strongest SD-proton limit on 1 GeV DM!
- SNOGLOBE installed and commissioning in SNOLAB
  - Will begin physics data taking soon!
- Future SPCs using underground EFCu: ECuME, DarkSPHERE, …

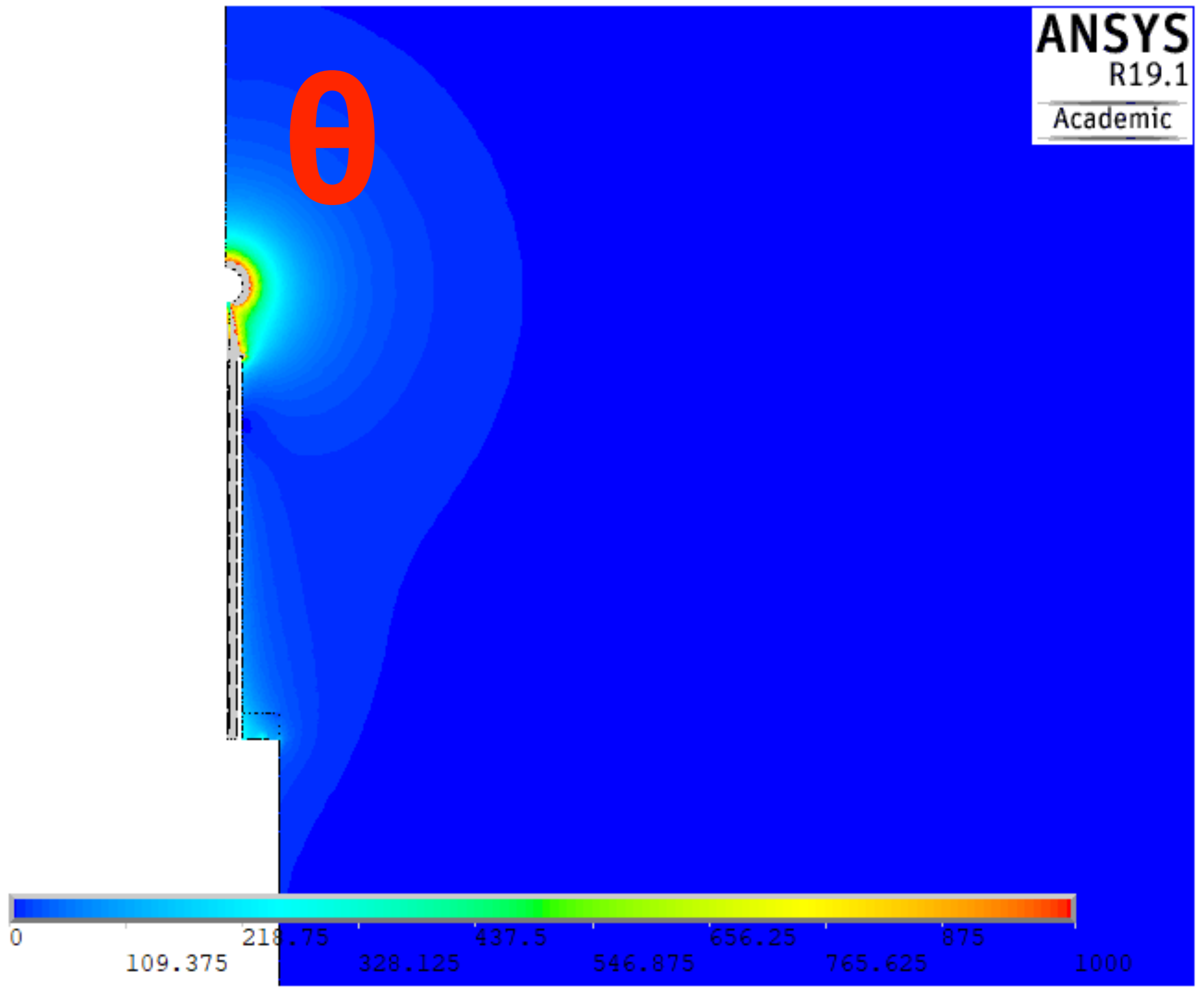


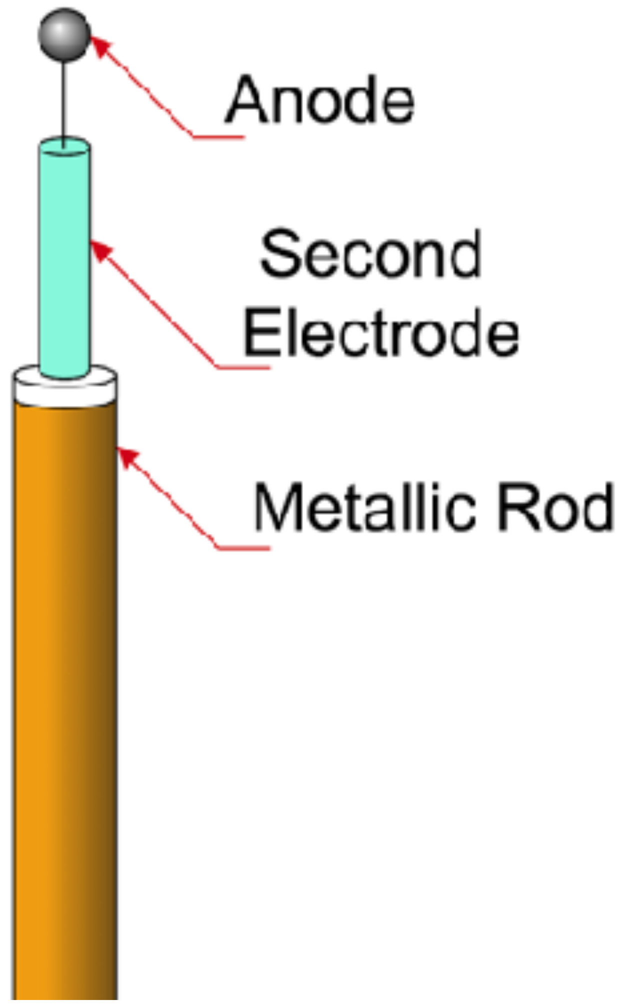


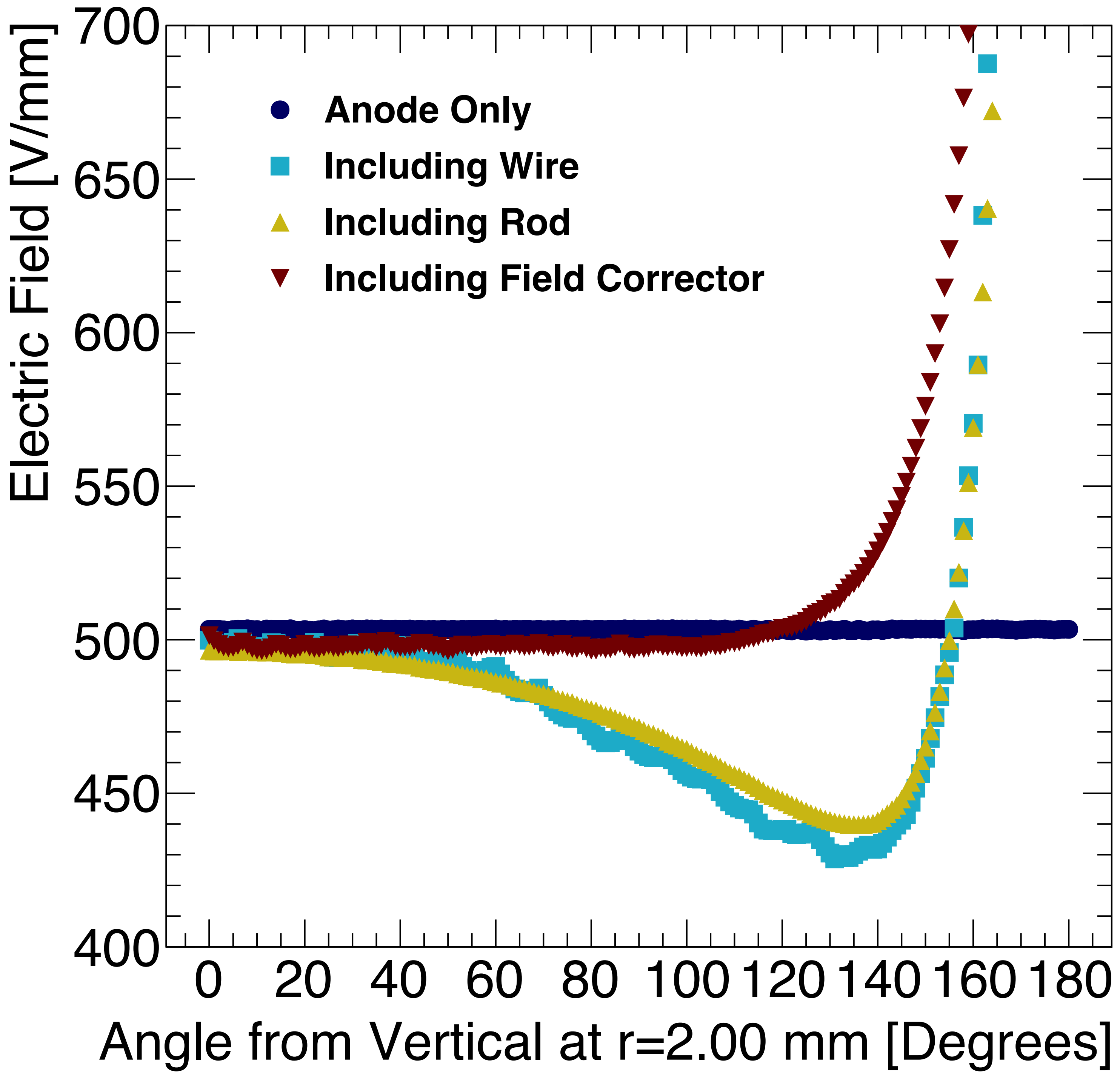


Additional Material

Correction Electrode







- Idea: incorporate **correction electrode** at top of support rod
- Voltage on correction electrode used to adjust electric field
- **Shapes electric field near anode**
- Geometry and voltages studied using ANSYS Finite Element Method (FEM) software
  - **Figure of merit**: electric field homogeneity near the anode

A sparkless resistive glass correction electrode for the spherical proportional counter

JINST 13 (2018) 11, P11006

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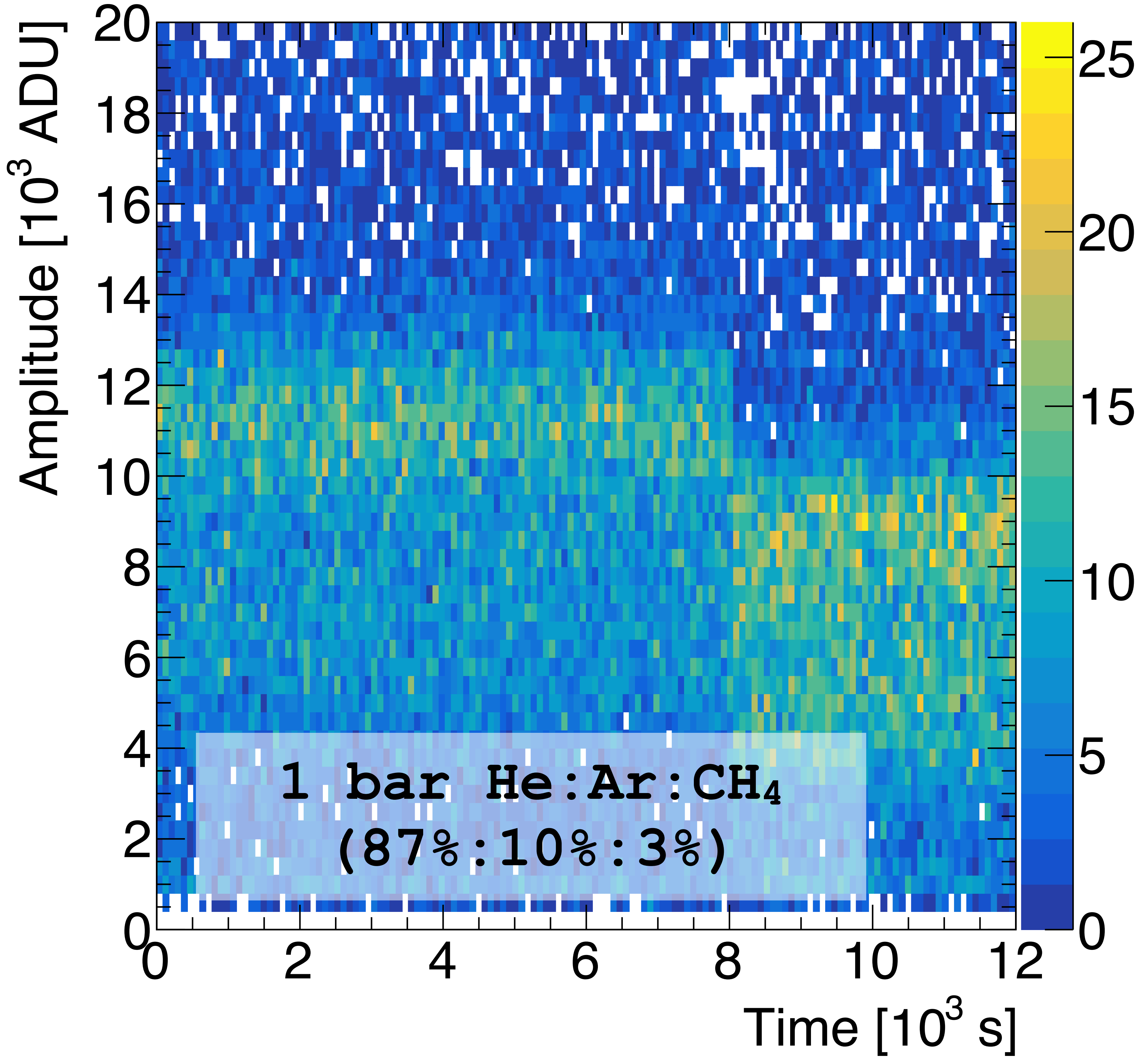
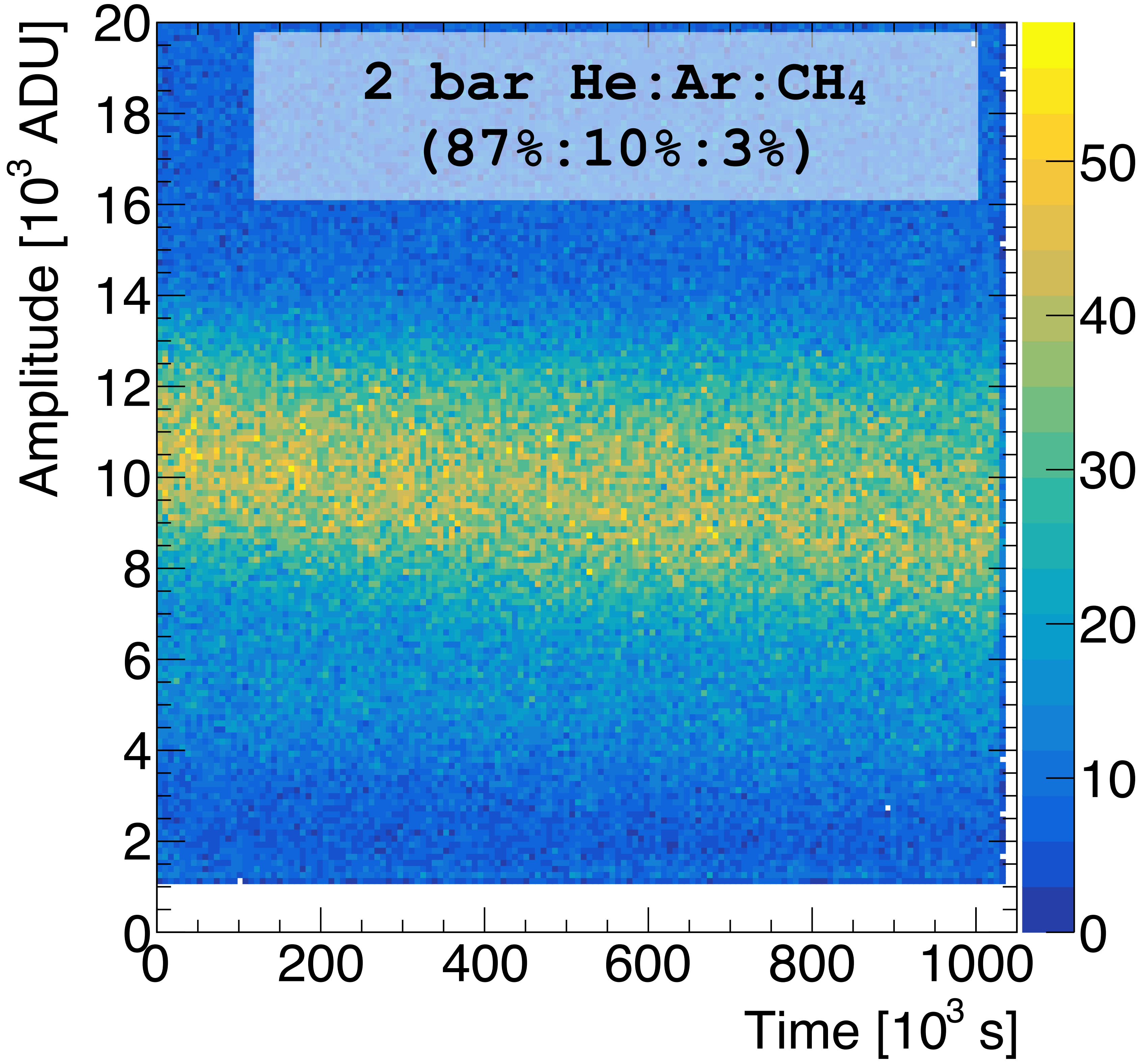
[a]IRFU, CEA, Universite Paris-Saclay, F-91191 Gif-sur-Yvette, France
[b]School of Physics and Astronomy, University of Birmingham, B15 2TT, United Kingdom
[c]Aristotle University of Thessaloniki, Greece

E-mail: ioannis.katsioulas@cea.fr

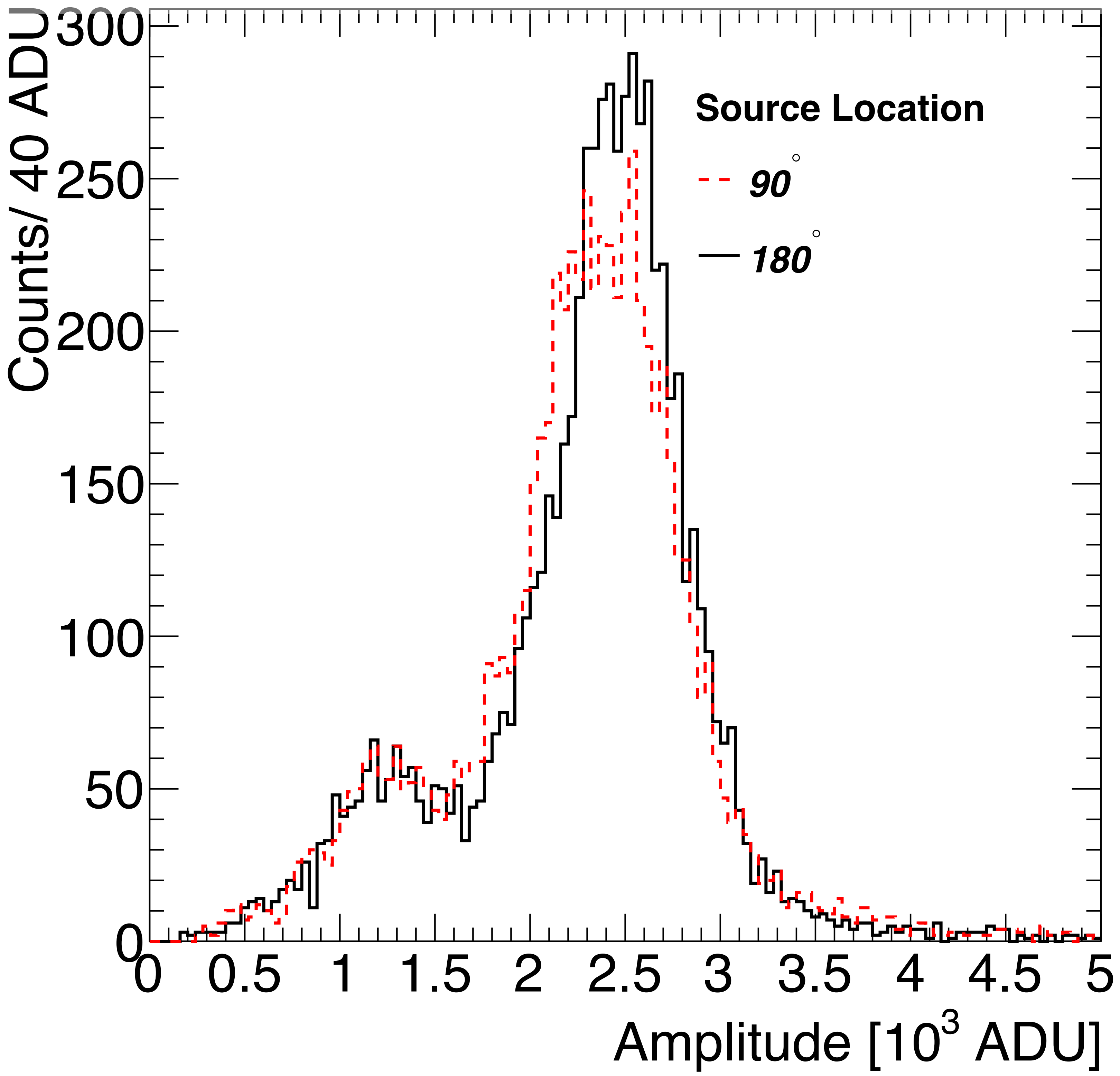
Abstract: A new anode support structure for the spherical proportional counter is presented that incorporates a resistive correction electrode made of glass. This electrode improves the electric field homogeneity versus angle, while suppressing the probability and intensity of sparks compared to non-resistive alternatives. The configuration of the correction electrode was optimised with simulations. Such support structures have been constructed and measurements have demonstrated homogeneous response of the detector and operational stability. A measurement of the resistivity of the glass used is also presented.

Single-Anode Sensor Testing





1 bar He:Ar:CH4
(92%:5%:3%)



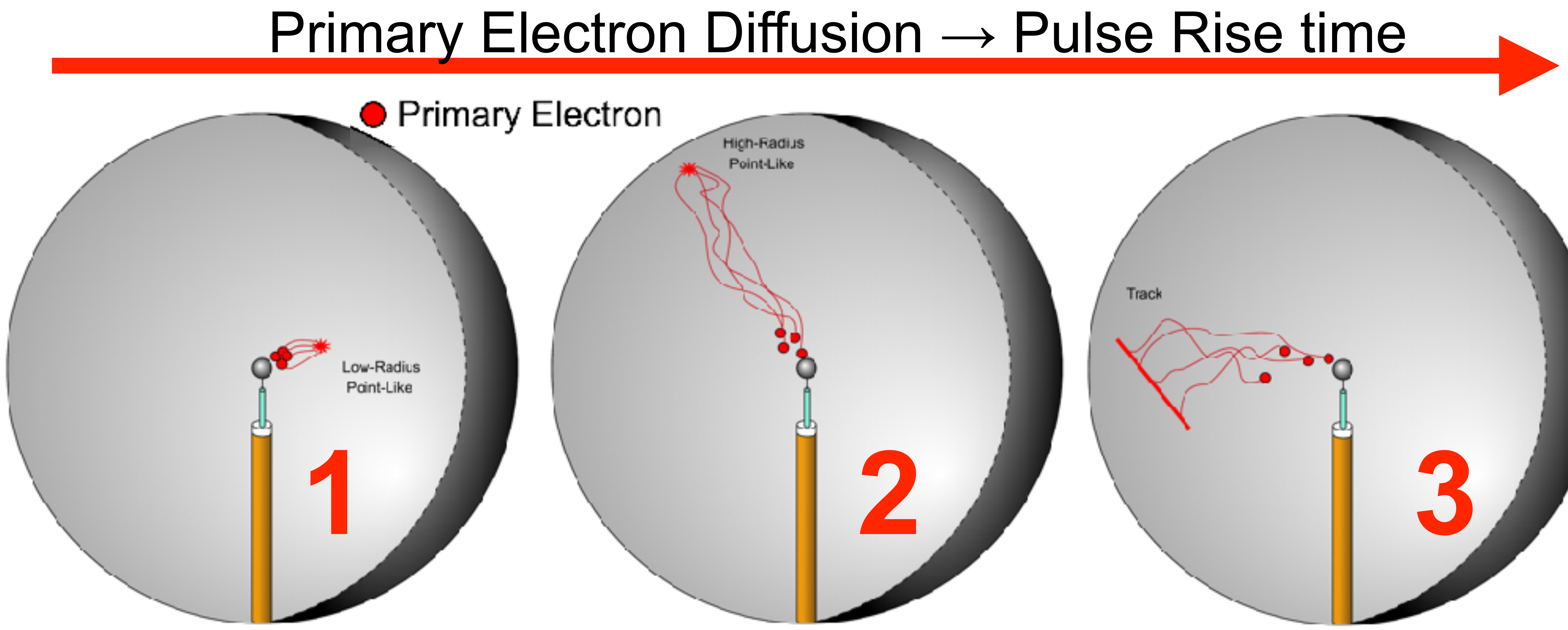
- ^{55}**Fe** source placed inside detector
  - Source of 5.9 keV X-rays
- At 8000 s, **correction electrode voltage changed** from 100 V to 200 V
  - **Immediate response** in amplitude

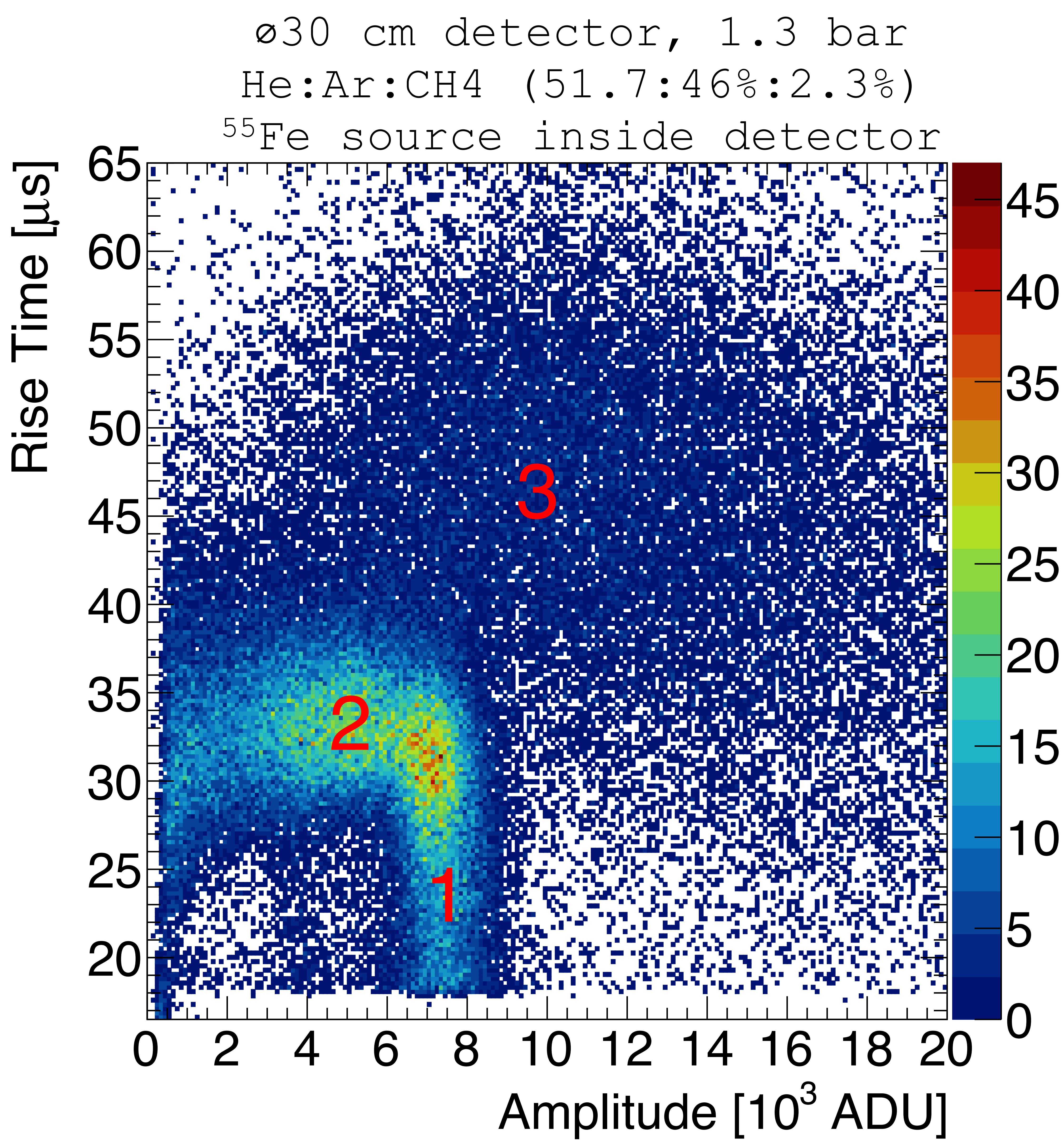
- Over **~12 days**, **stable gain, no sparks**
- Small decrease in gain over time due to contaminant gases (e.g. O_2) leaking into the detector/out gassing

- Source moved between two positions
  - **Uniform detector response**

Pulse-Shape Discrimination

- Lots of information in a pulse. e.g. in rise time
- Electron from **larger radii diffuse more**
  - Larger spread in arrival → higher pulse rise time/width
- Spatially extended primary ionisation results in higher rise time/width
- **Particle ID by pulse-shape discrimination** possible





(1) X-rays in volume, (2) X-rays near shell, (3) Cosmic muons

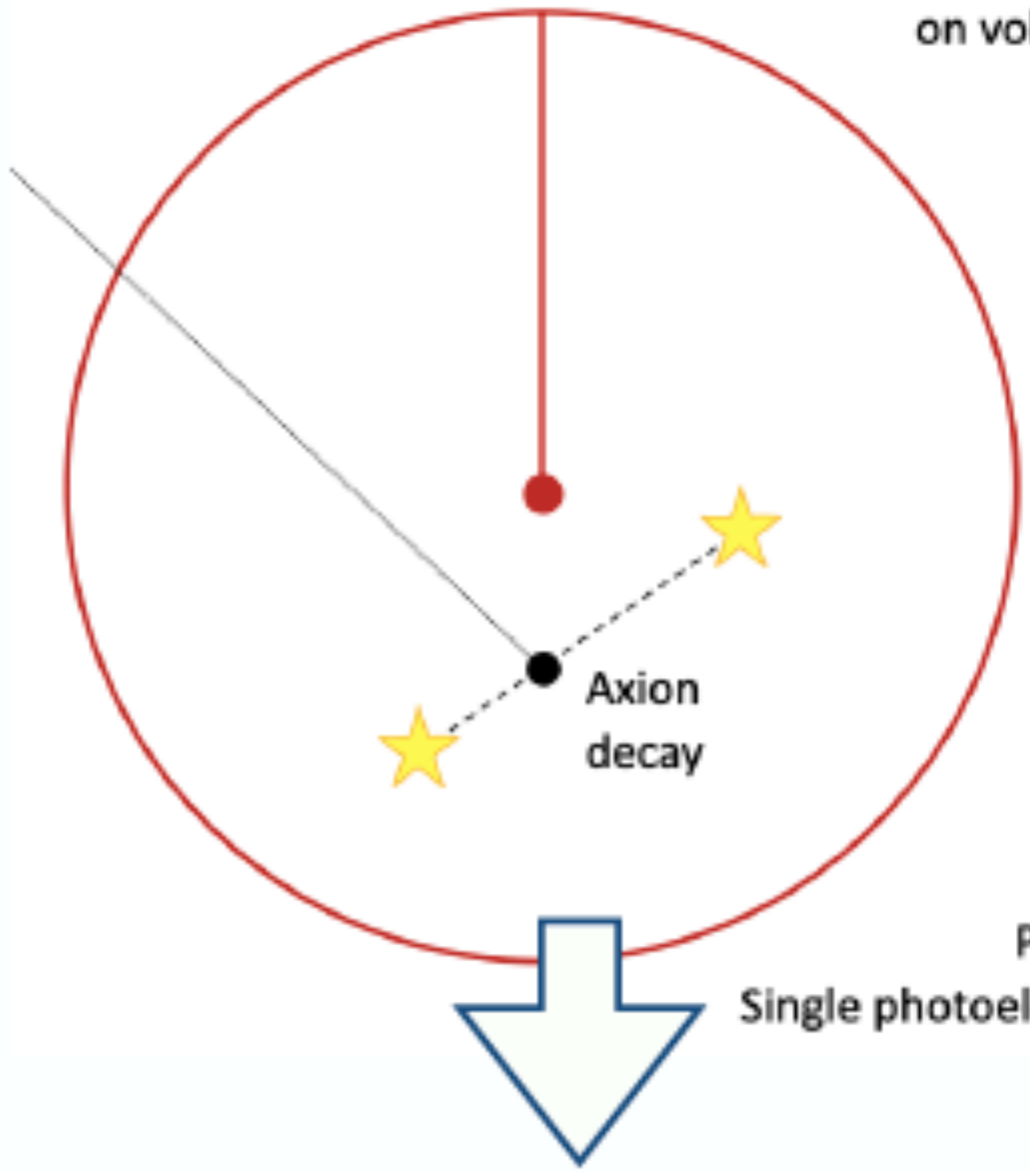
Other projects

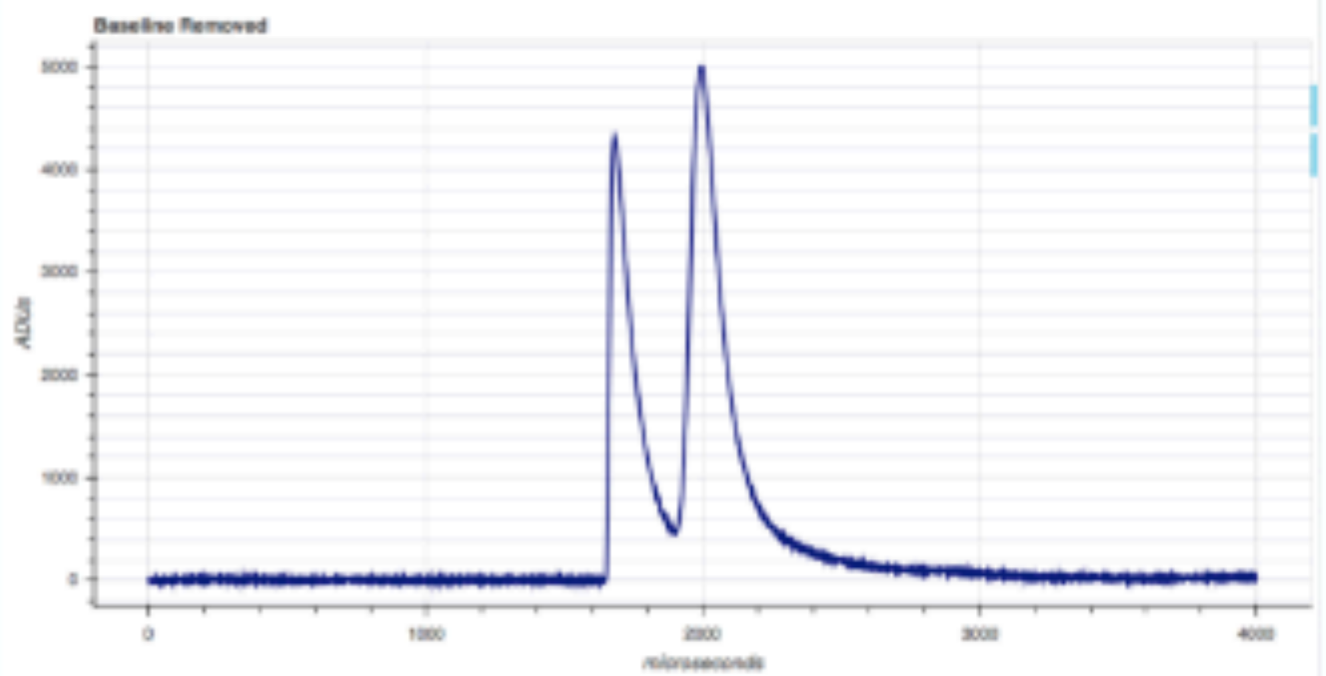
Solar KK axions

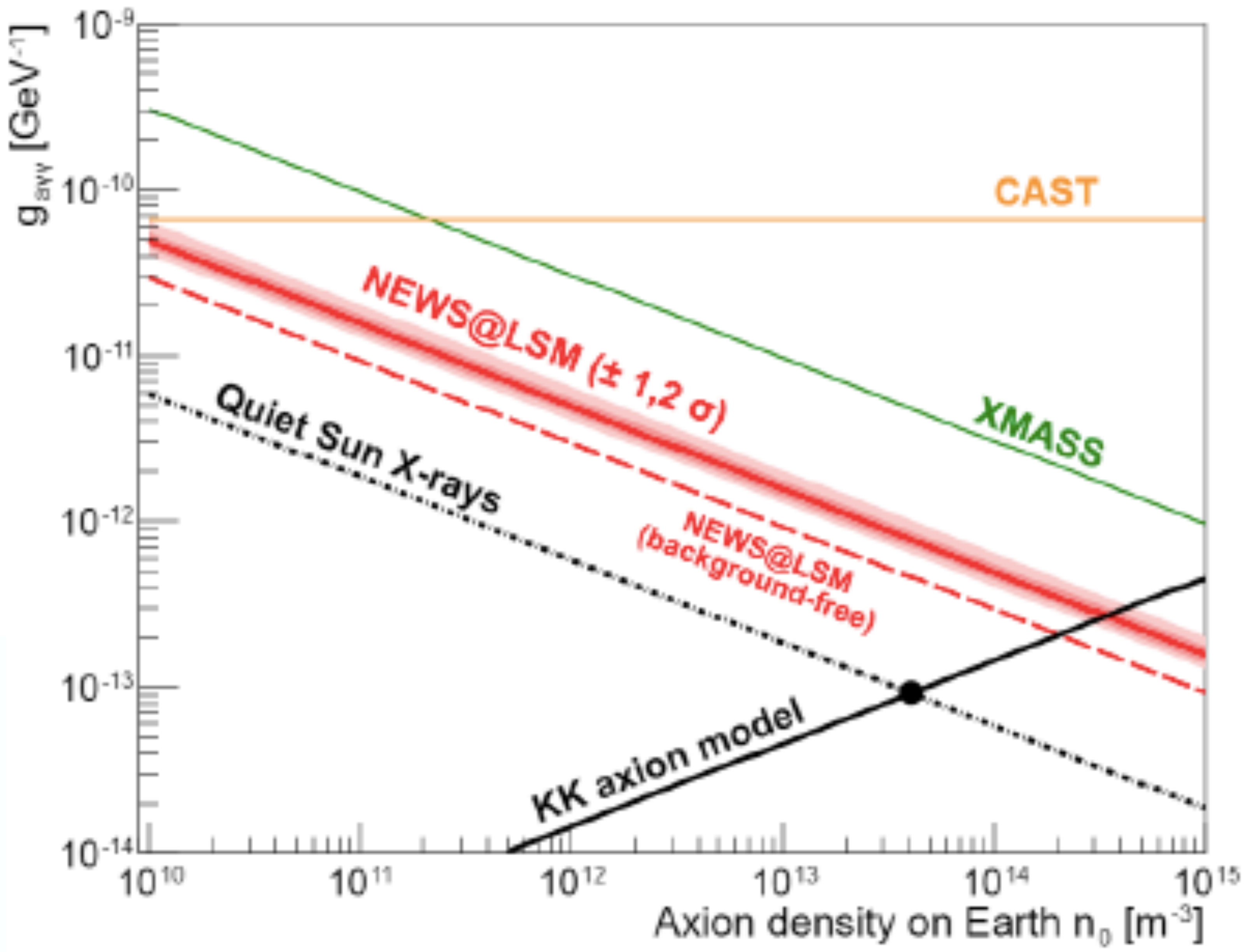
Solar KK axion model predicts accumulation of heavy (~10 keV) axions in the Solar System. These axions decay into two photons of equal energy, absorbed at different locations in an SPC.

Can reject background at 99.99% in 2-22 keV range by keeping only events with two pulses of similar amplitude arriving shortly after each other.

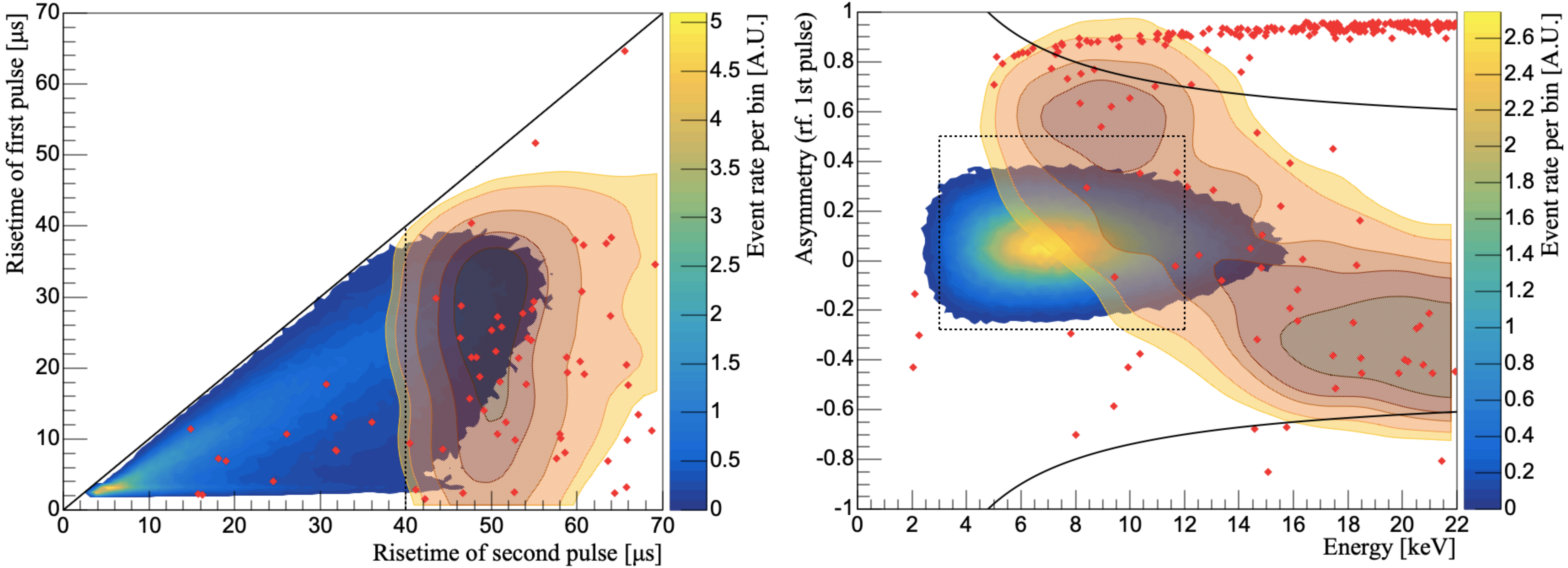
With 42 day exposure of SEDINE detector, and an integrated sensitivity to solar KK axion decays of 16%, still improve over previous XMASS limit by factor ~6.





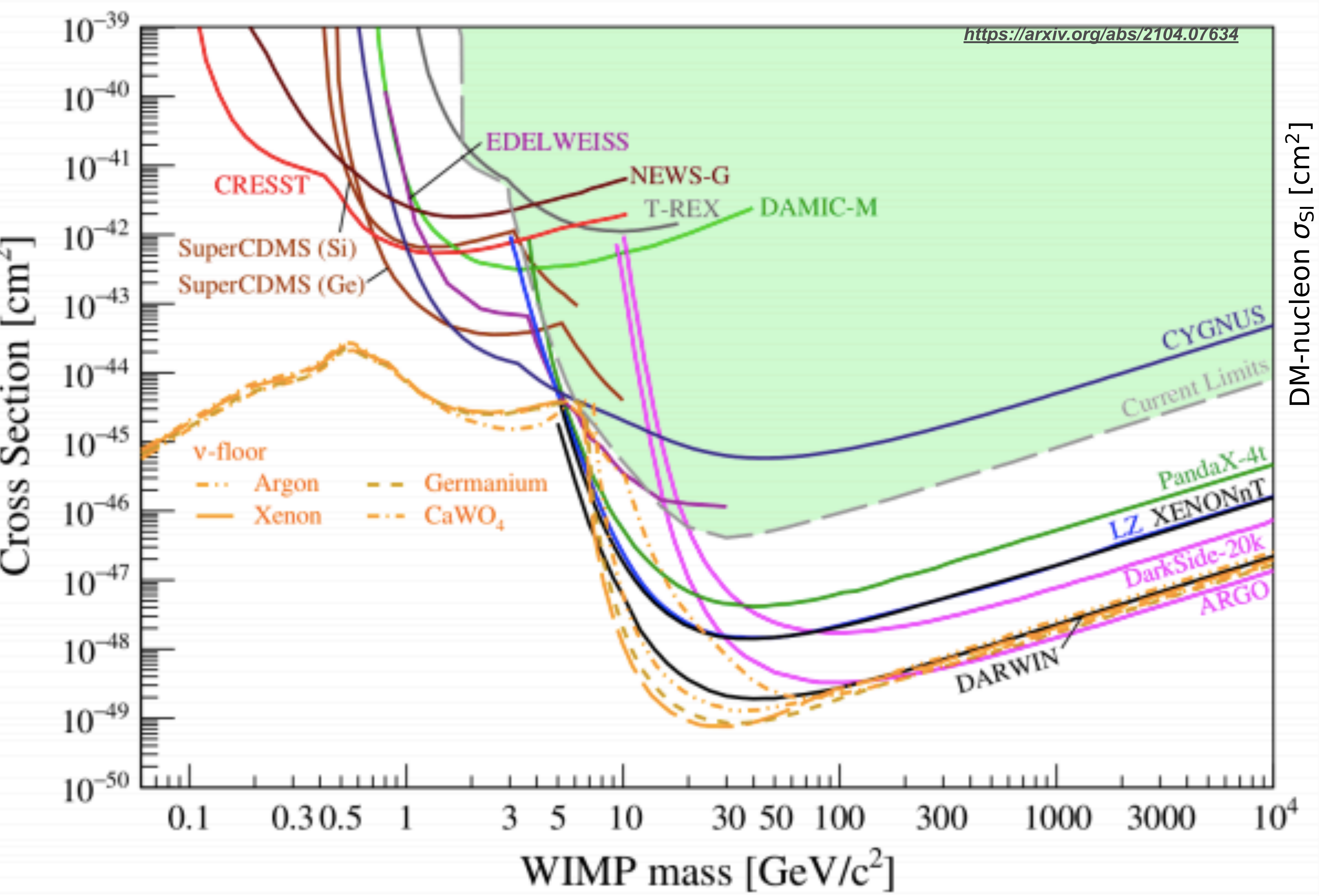


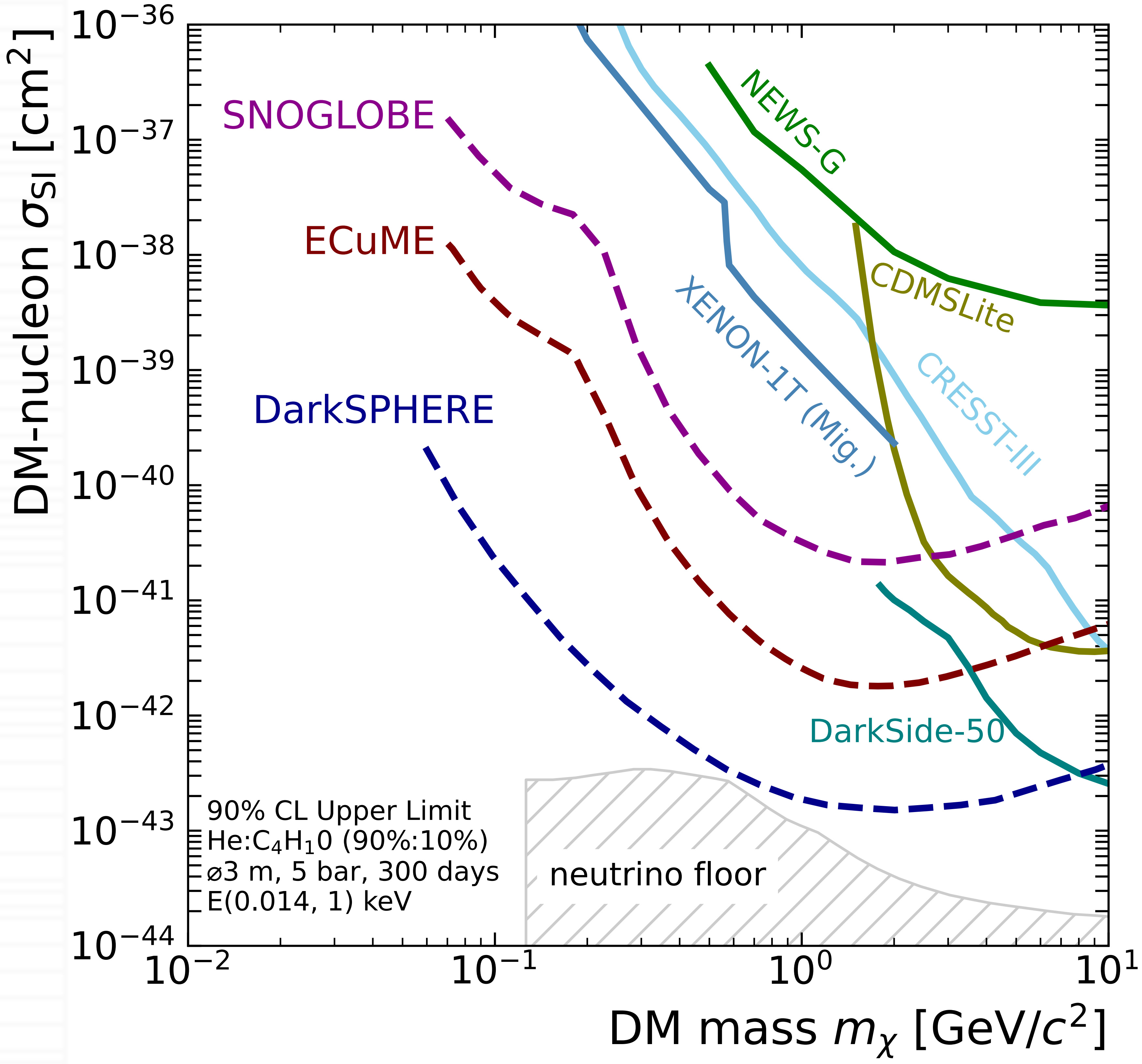
NEWS-G collab., PHYSICAL REVIEW D 105, 012002 (2022)



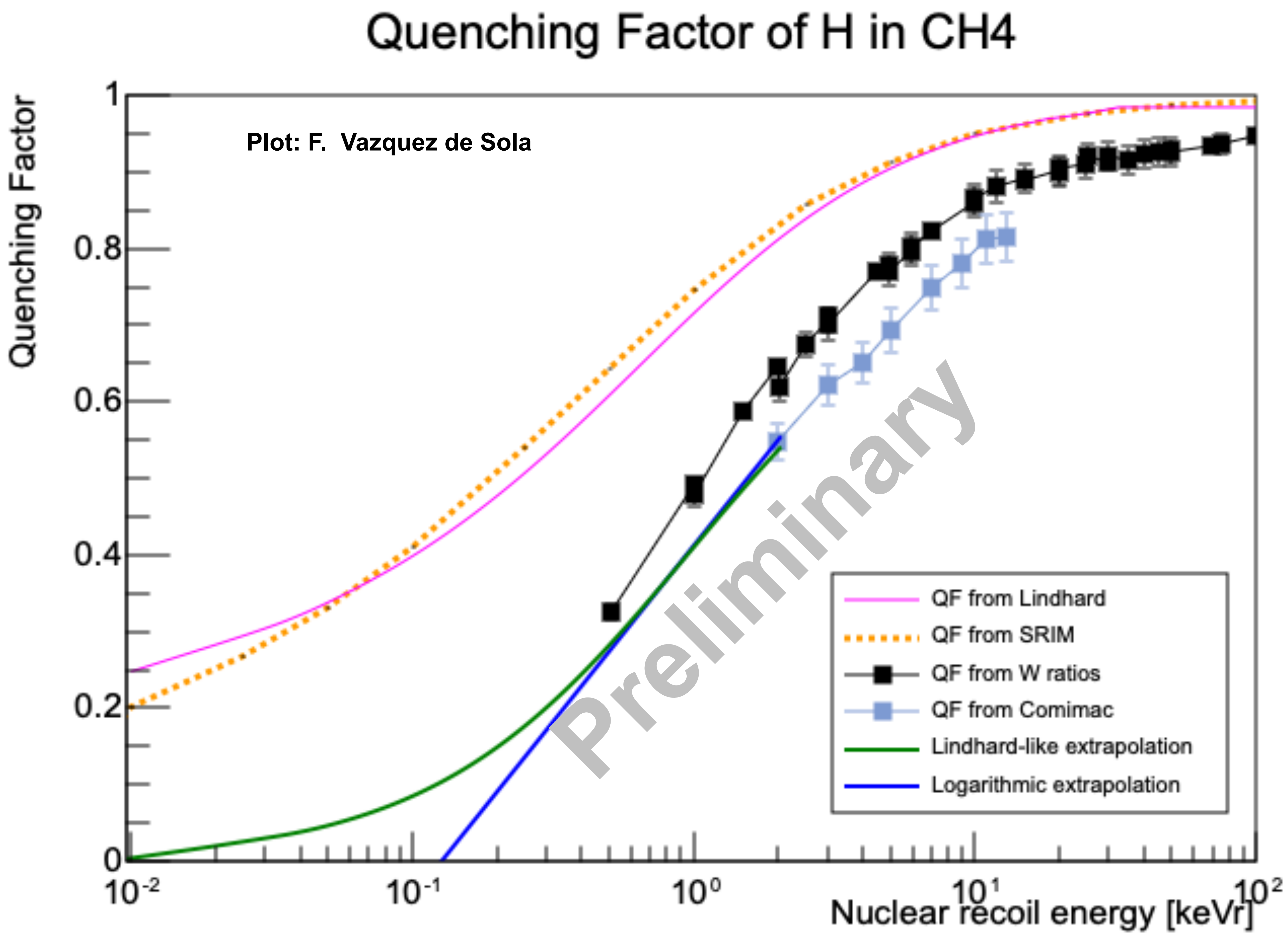
Cut	Physics data	Axion simulation	Background simulation	^{210}Pb (Cu surface)	^{210}Bi (Cu bulk)	^{210}Bi (Pb shield)
Quality cuts	13078	95.5%	9050	3540	2000	1890
Prel. axion cuts	44	25.5%	111	83.7	14.2	3.96
+ adv. risetime cut	6	19.2%	5.06	1.78	1.00	1.50
+ adv. asym. cut	2	19.2%	4.07	1.42	0.795	1.16
+ adv. energy cut	1	17.9%	2.23	0.769	0.476	0.476

Table 1: Effect of the preliminary and advanced cuts on data and simulations in the 2 – 22 keV range. The numbers for the data column (resp. background simulation and specific contributions) are the number of observed (resp. expected) events for the 38.0 days SEDINE run. Background simulations are taken from Ref. [35]. The numbers for the axion simulation column is the proportion of simulated axion decays under 22 keV that pass the cuts.


https://arxiv.org/abs/2104.07634
Cross Section [cm^2]
WIMP mass [GeV/c^2]
EDELWEISS
NEWS-G
T-REX
DAMIC-M
CRESST
SuperCDMS (Si)
SuperCDMS (Ge)
CYGNUS
Current Limits
PandaX-4t
LZ XENONnT
DarkSide-20k
ARGO
DARWIN
ν-floor
Argon
Xenon
Germanium
CaWO$_4$


DM-nucleon σ_{SI} [cm^2]
DM mass m_χ [GeV/c^2]
SNOGLOBE
ECuME
DarkSPHERE
NEWS-G
CDMSLite
XENON-1T (Mig.)
CRESST-III
DarkSide-50
90% CL Upper Limit
He:C$_4$H$_1$0 (90%:10%)
ø3 m, 5 bar, 300 days
E(0.014, 1) keV
neutrino floor

Quenching Factor



- Combination of W-value and Comimac QF used
  - Use conservative logarithmic extrapolation

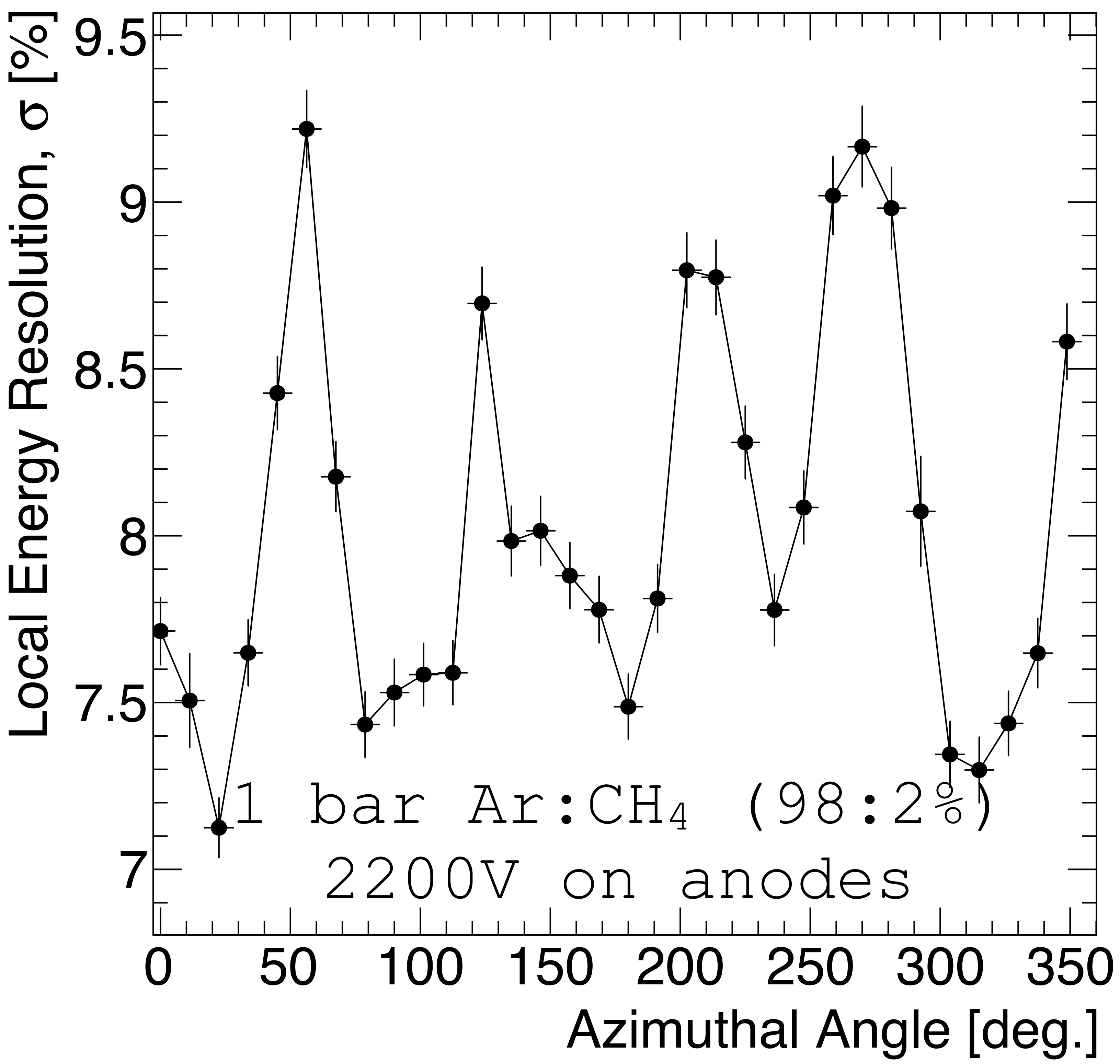
Background Contributions to SNOGLOBE

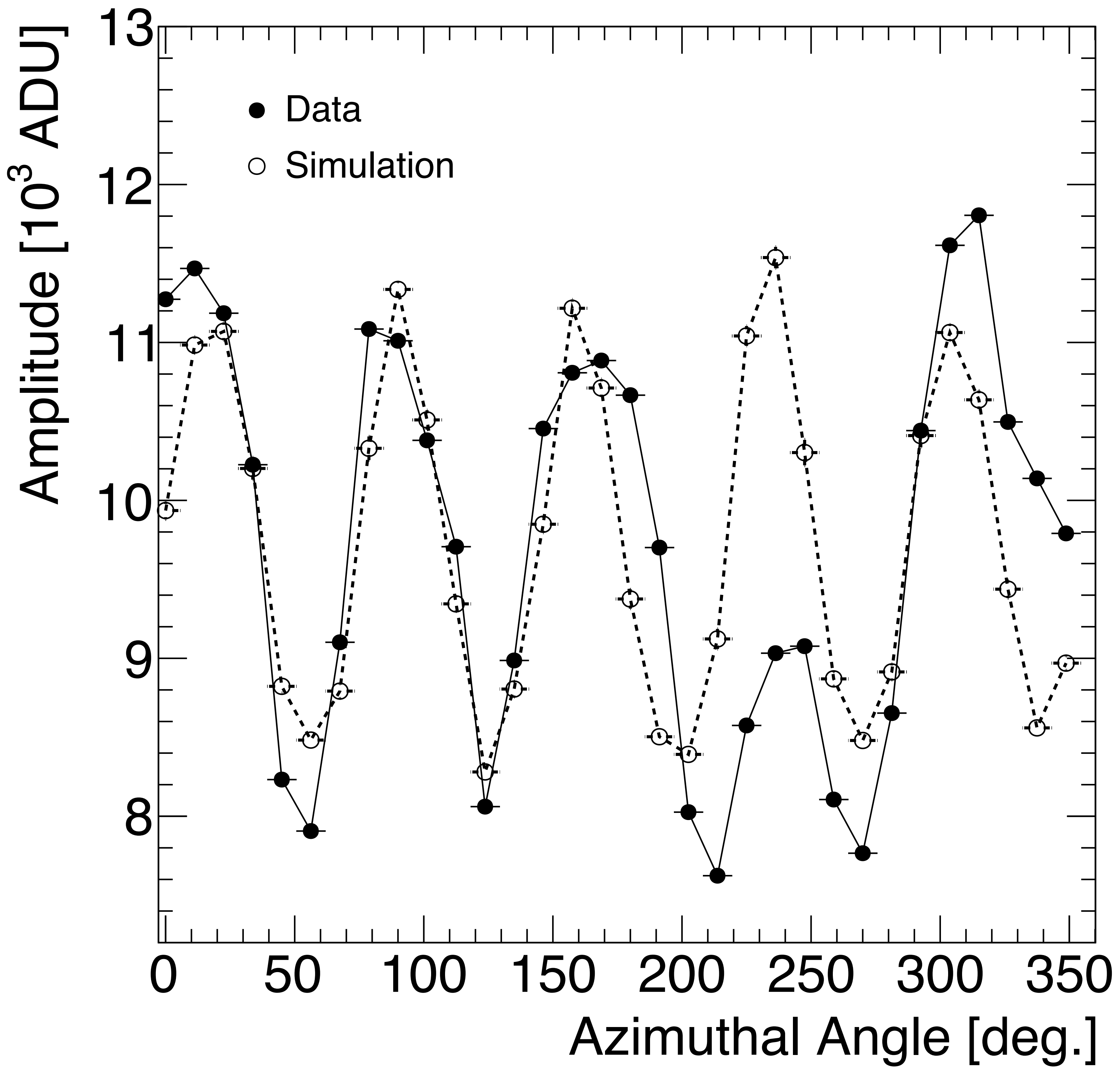
	Source	Contamination / flux	Unit	Events rate <1 keV [dru]	Events rate in [1;5] keV [dru]	Total rate [mHz]
Gas mixture	^{3}H	13	μBq/kg	0.05	0.06	0.005
	^{222}Rn	111	μBq/kg	0.05	0.04	0.2
Copper sphere 500 μm electrolyte	^{210}Pb	28.5	mBq/kg	1.04	1.01	0.86
	^{238}U	3	μBq/kg	0.0117	0.115	0.028
	^{232}Th	13	μBq/kg	0.0754	0.0692	0.163
	^{40}K	0.1	mBq/kg	0.0157	0.0186	0.0622
Roman lead	^{210}Pb	<25	mBq/kg	<0.14	<0.12	0.057
	^{238}U	44.5	μBq/kg	0.142	0.094	0.277
	^{232}Th	9.1	μBq/kg	0.0256	0.0161	0.0577
	^{40}K	<1.3	mBq/kg	<0.28	0.23	0.65
Low activity lead	^{210}Pb	4.6	Bq/kg	0.053	0.055	0.17
	^{238}U	79	μBq/kg	0.17	0.132	0.5
	^{232}Th	9	μBq/kg	0.0251	0.0201	0.075
	^{40}K	<1.46	mBq/kg	<0.35	0.26	0.67
Cavern	Gamma	4.87×10^{-8}	γ/cm^2/s	0.0084	0.0095	0.00464
	Neutron	4000	neutron/m^2/day	0.0044	0.0004	3.54×10^{-11}
	Muon	0.27	muon/m^2/day	0.00062	0.00044	5.04×10^{-8}
Total				1.67	1.54	2.4
Total + cosmogenic activation of the copper sphere				5.20	5.20	5.4
Total + cosmogenic activation of the copper sphere and 6 months of cooling				2.8	2.5	3.4
Total + cosmogenic activation of the copper sphere and 1 years of cooling				2.1	1.9	3.0
Total + cosmogenic activation of the copper sphere and 2 years of cooling				1.9	1.7	2.9

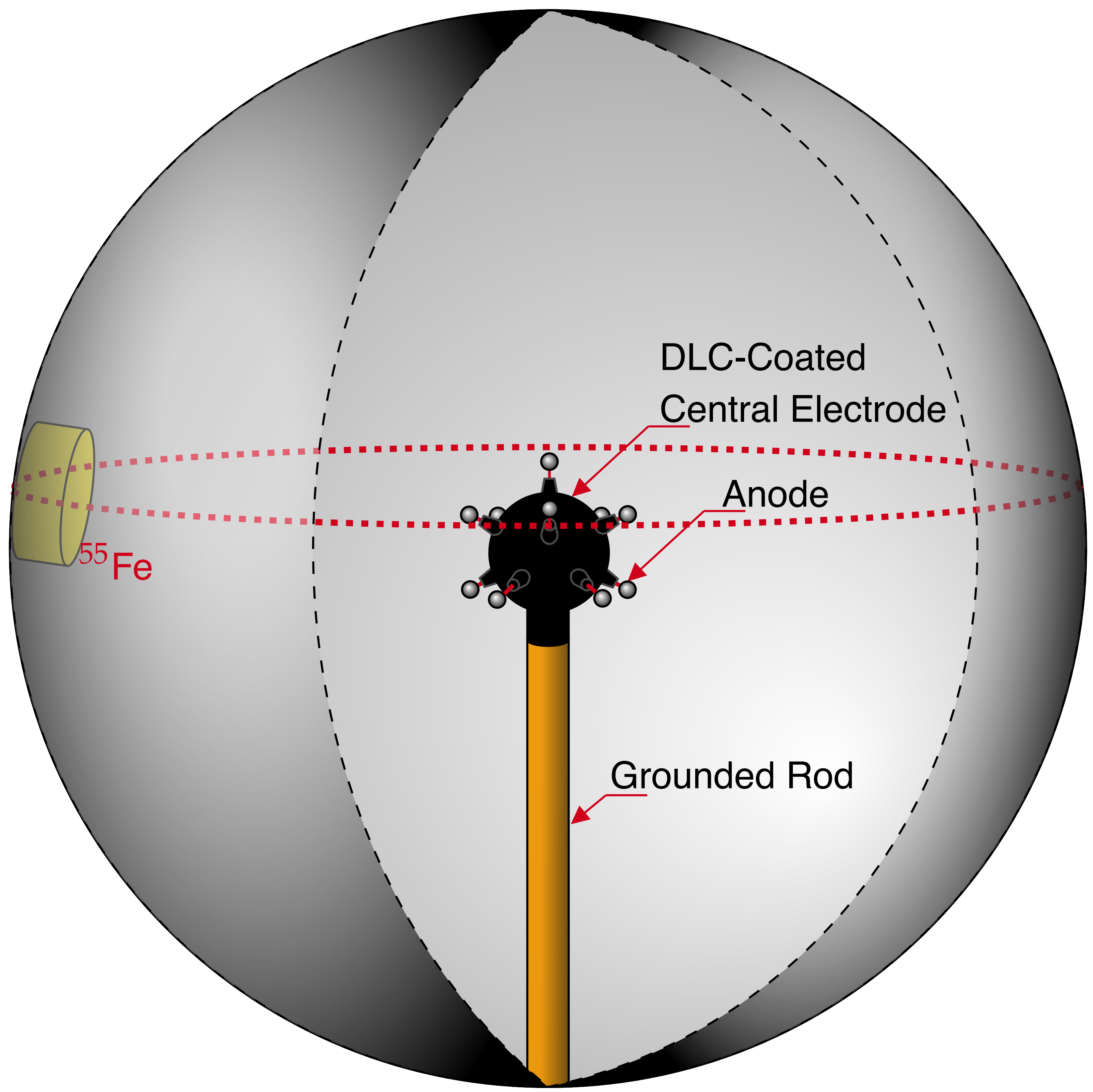
Table 5.6: Summary of the main background of NEWS-G at SNOLAB, without rise time selection. The upper limits of activities in the lead are not taking into account in the total.

From A. Brossard, Ph. D. Thesis

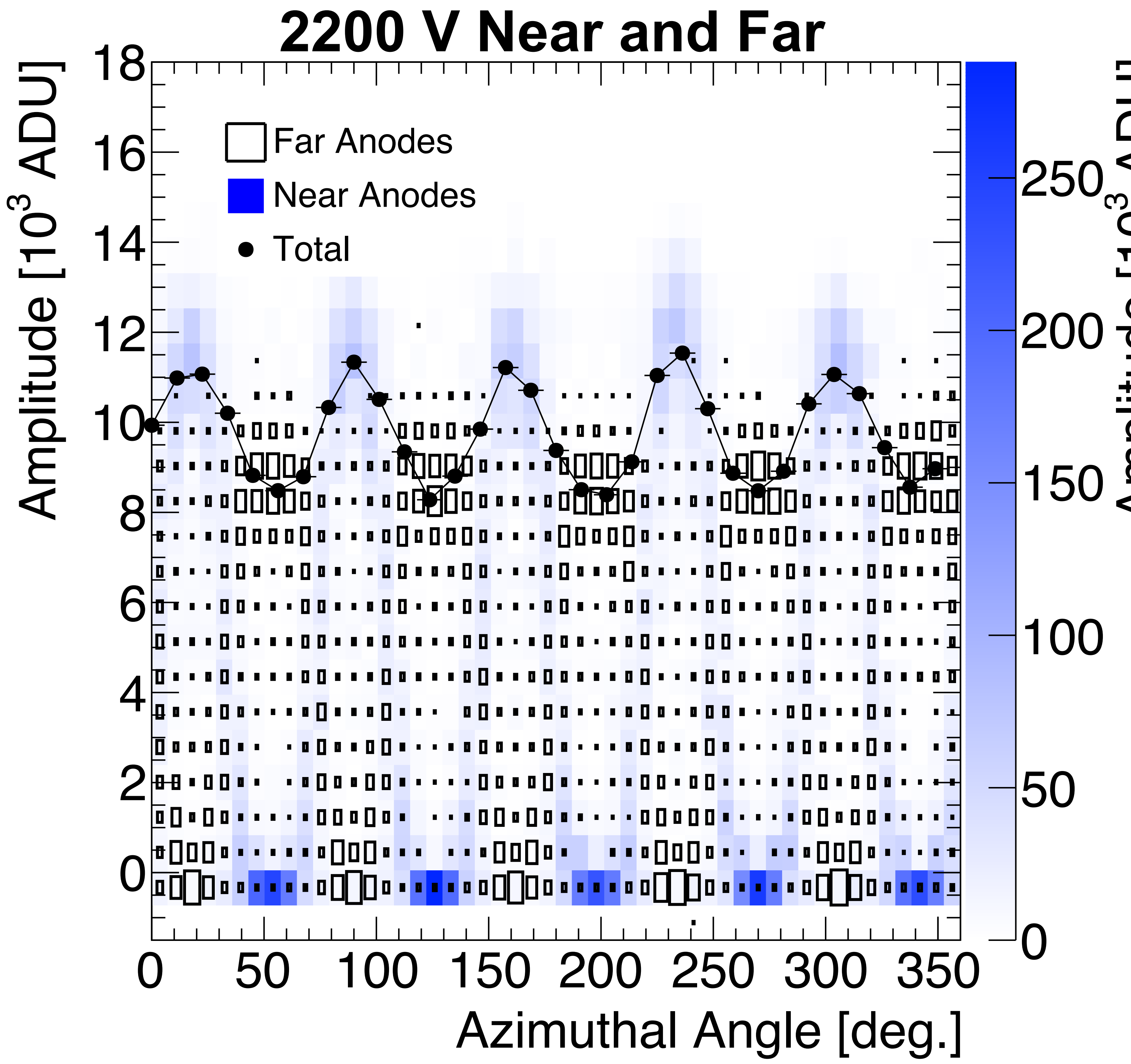
Uniformity of Anode Response

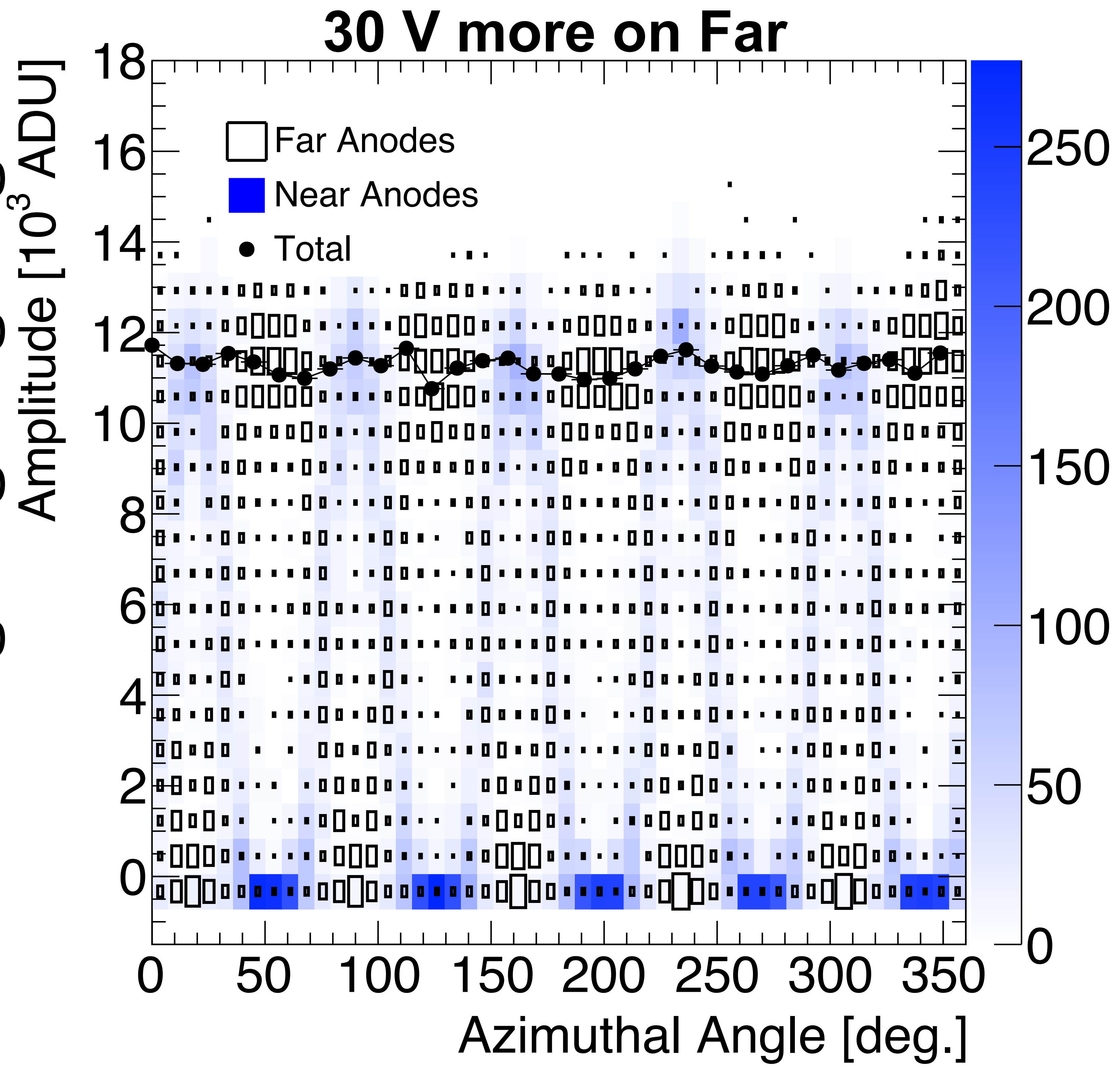


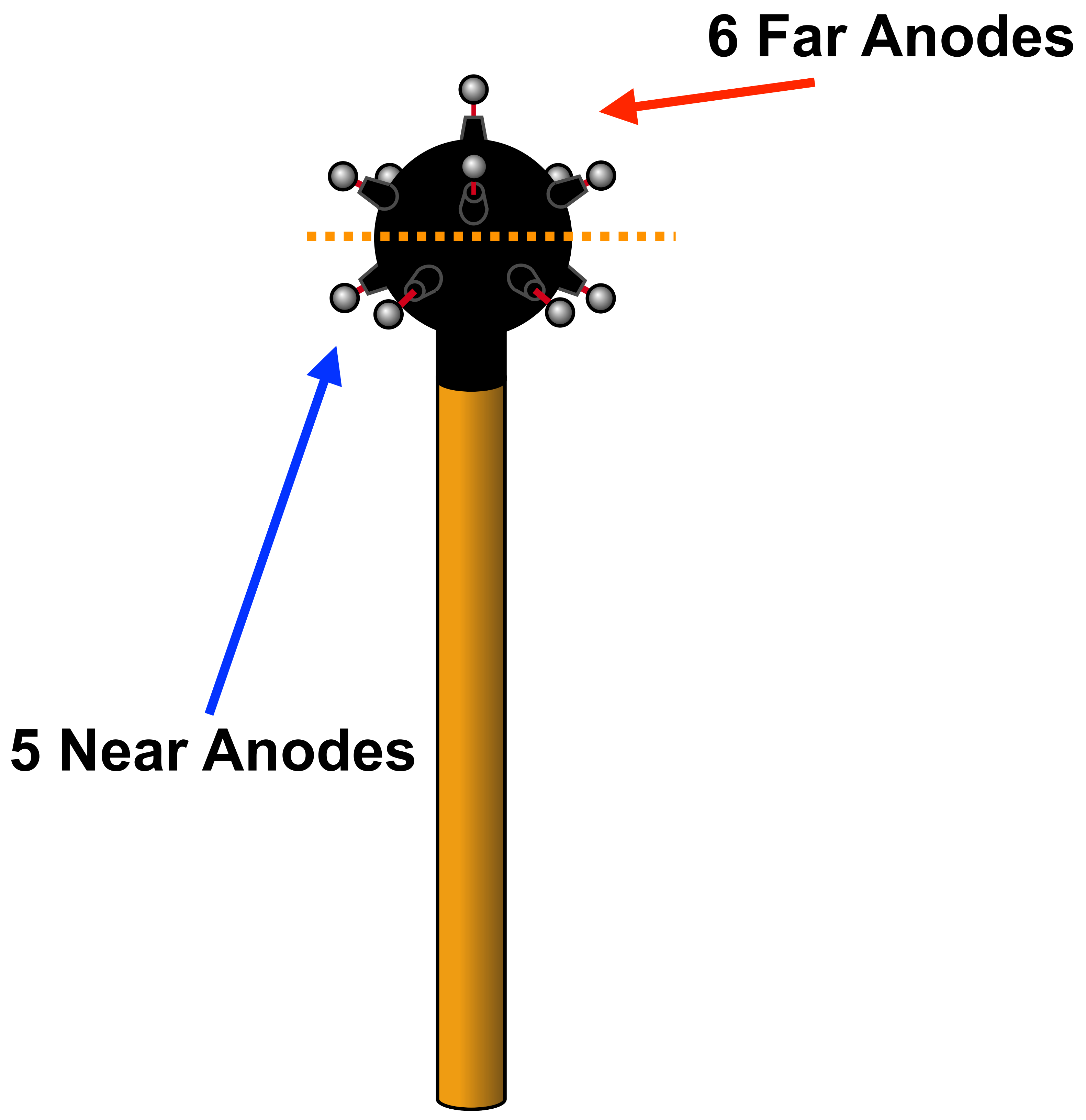




ACHINOS Simulation Study







- Simulate experiment sending 5.9 keV photons from different φ at fixed θ
- Looking at signal generated on **Near and Far anodes separately** found higher amplitudes on Near
  - **Electric field higher on Near side** due to grounded rod
- **Increasing voltage** applied to **Far anodes corrects for effect**

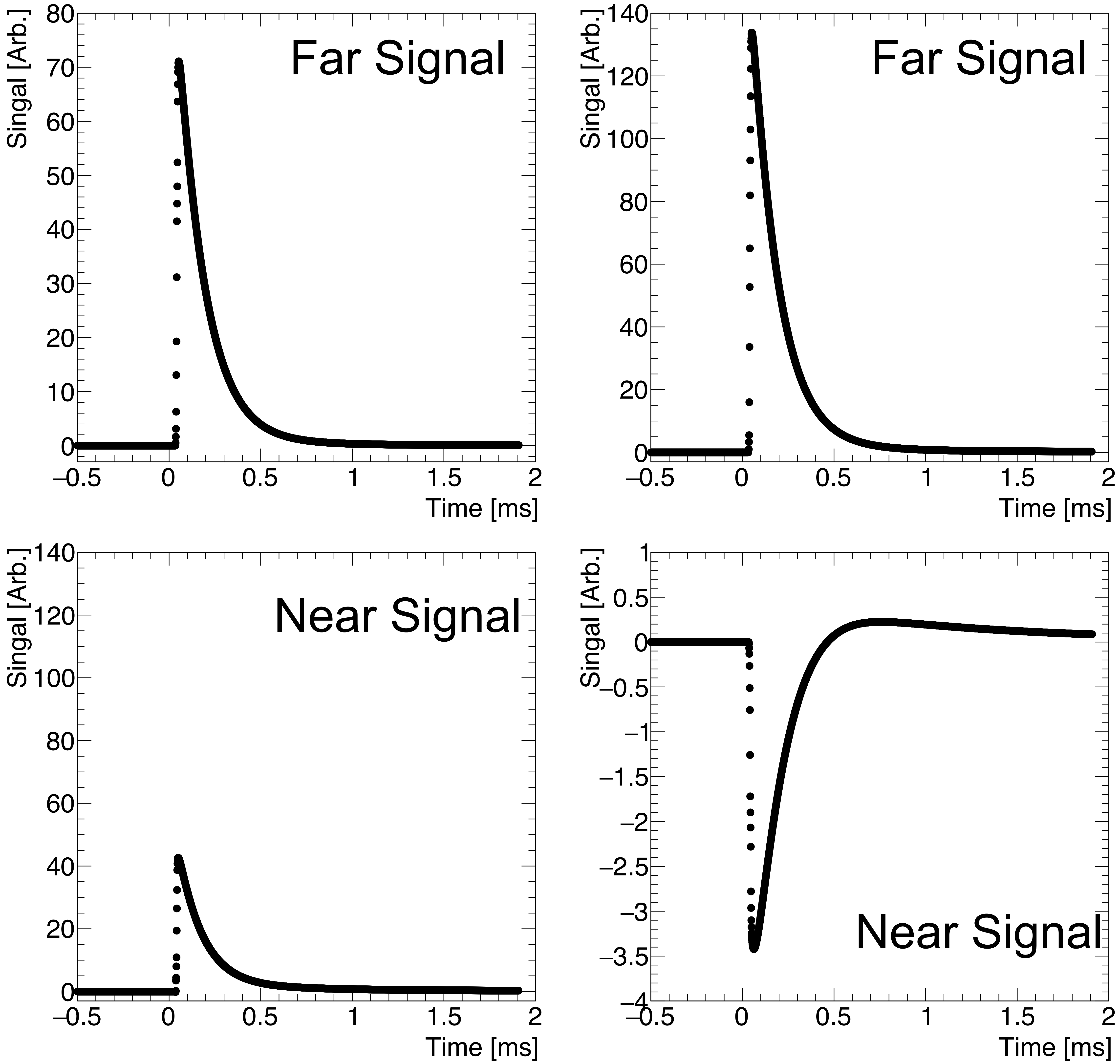
Near vs Far Signals

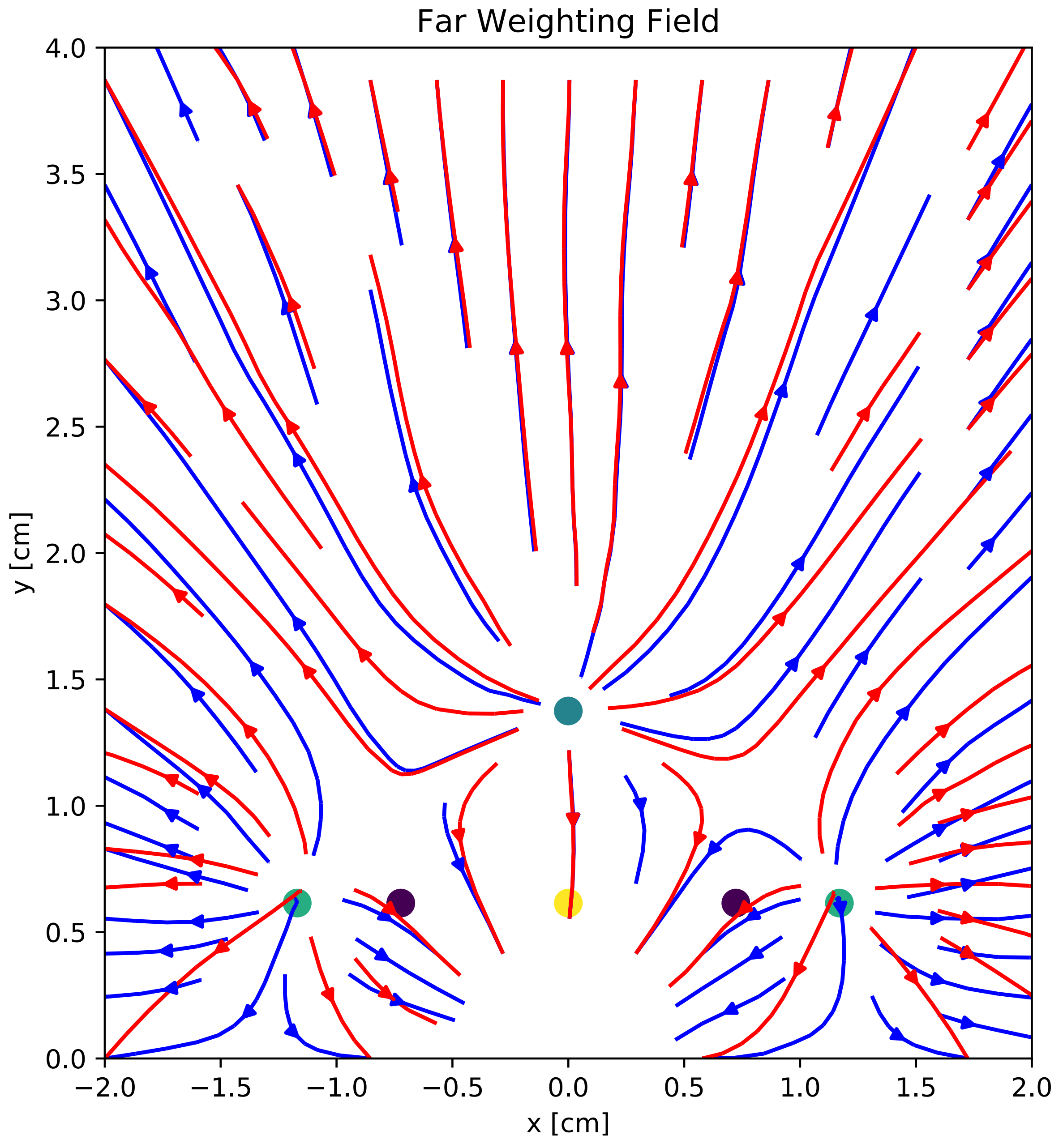
- Experimentally observe:
  - **Both positive signals**
  - **One positive, one negative**
- **'++'** explained by ionisation electrons arriving to both
- **'+-'** explained by **Shockley-Ramo theorem** and field lines of **weighting fields**

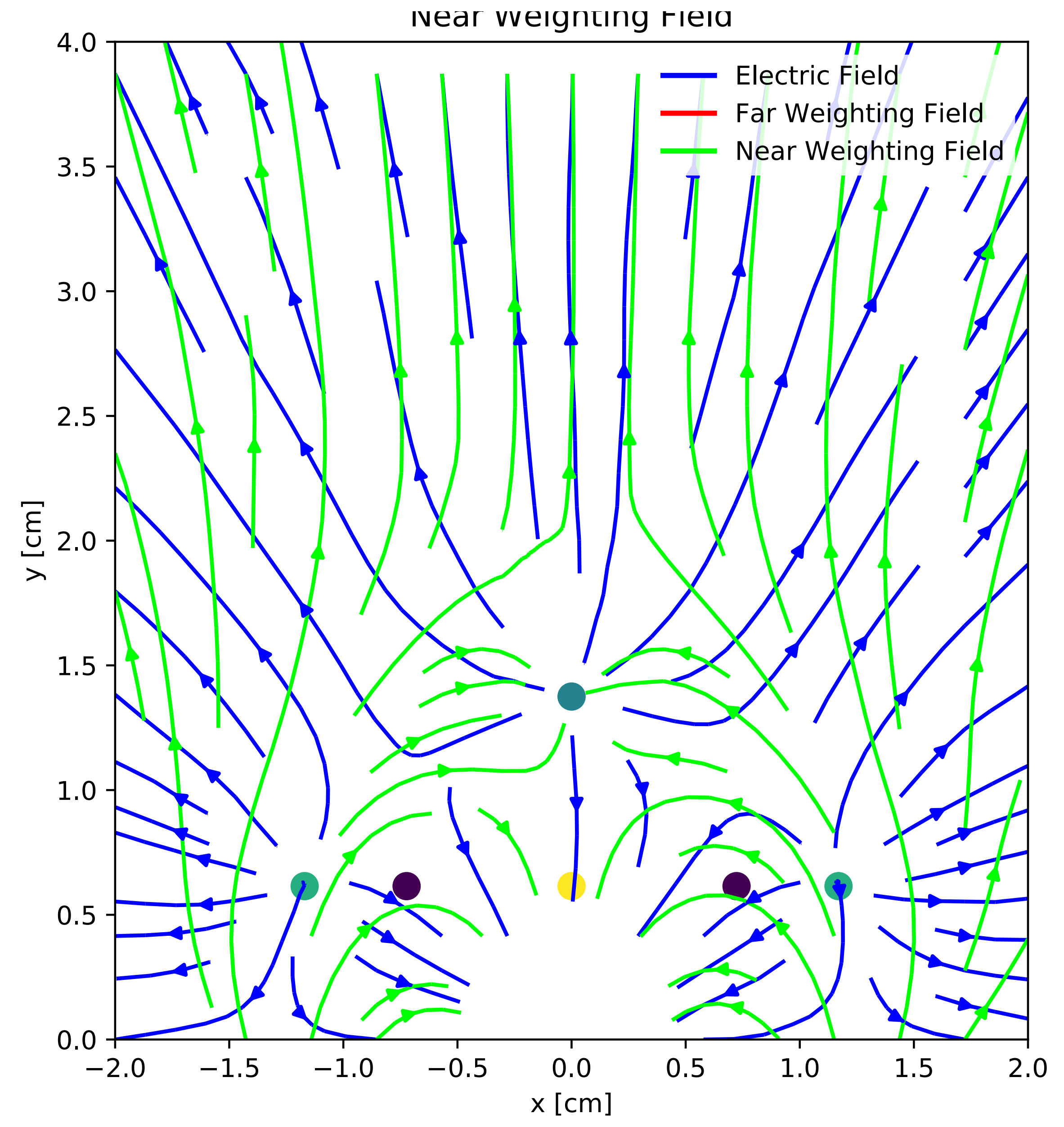
$$i = -q\frac{\boldsymbol{E}_w \cdot \boldsymbol{v}}{V_w}$$

Simulation

Electrons arrive Near and Far	Electrons arrive only Far

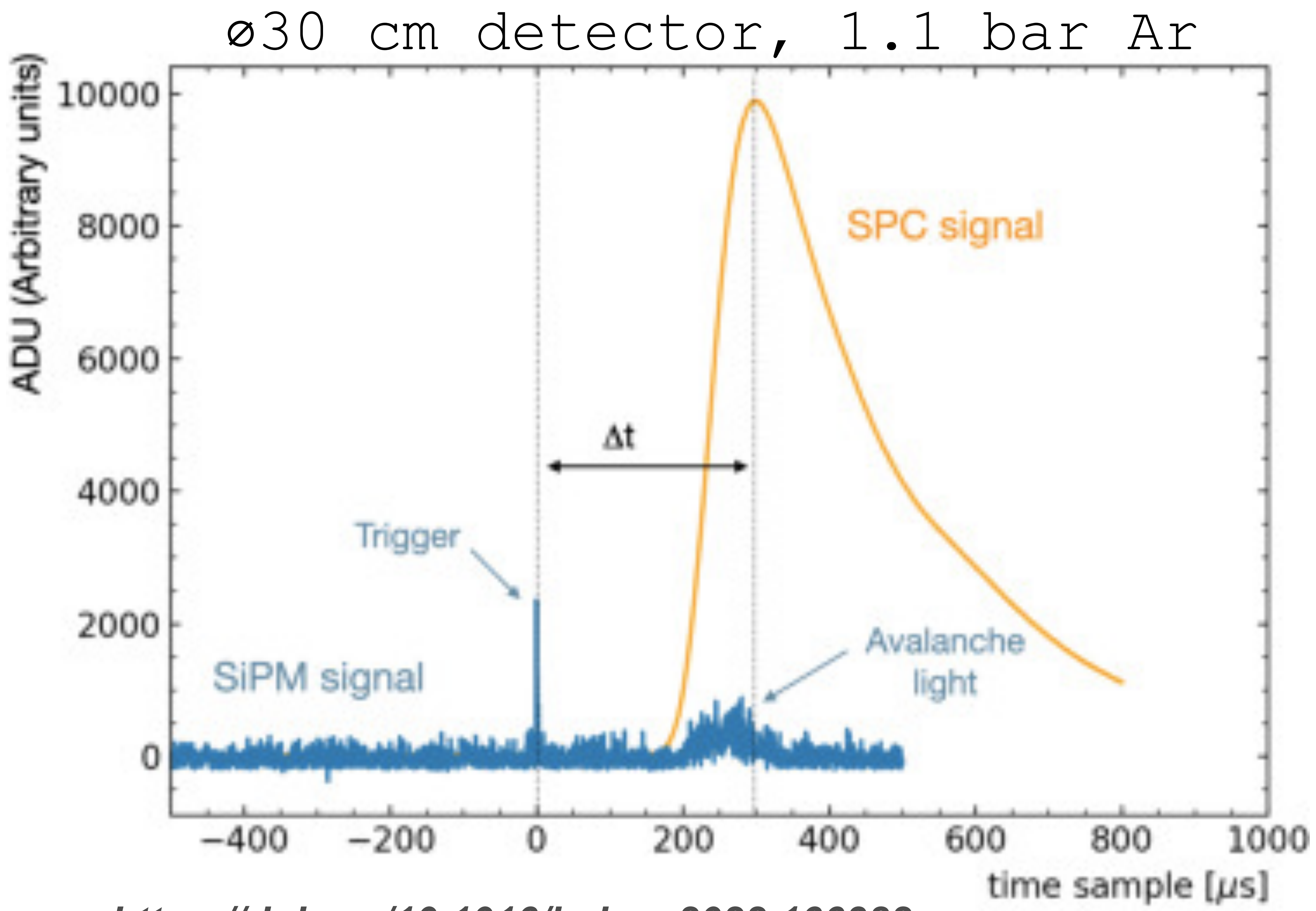




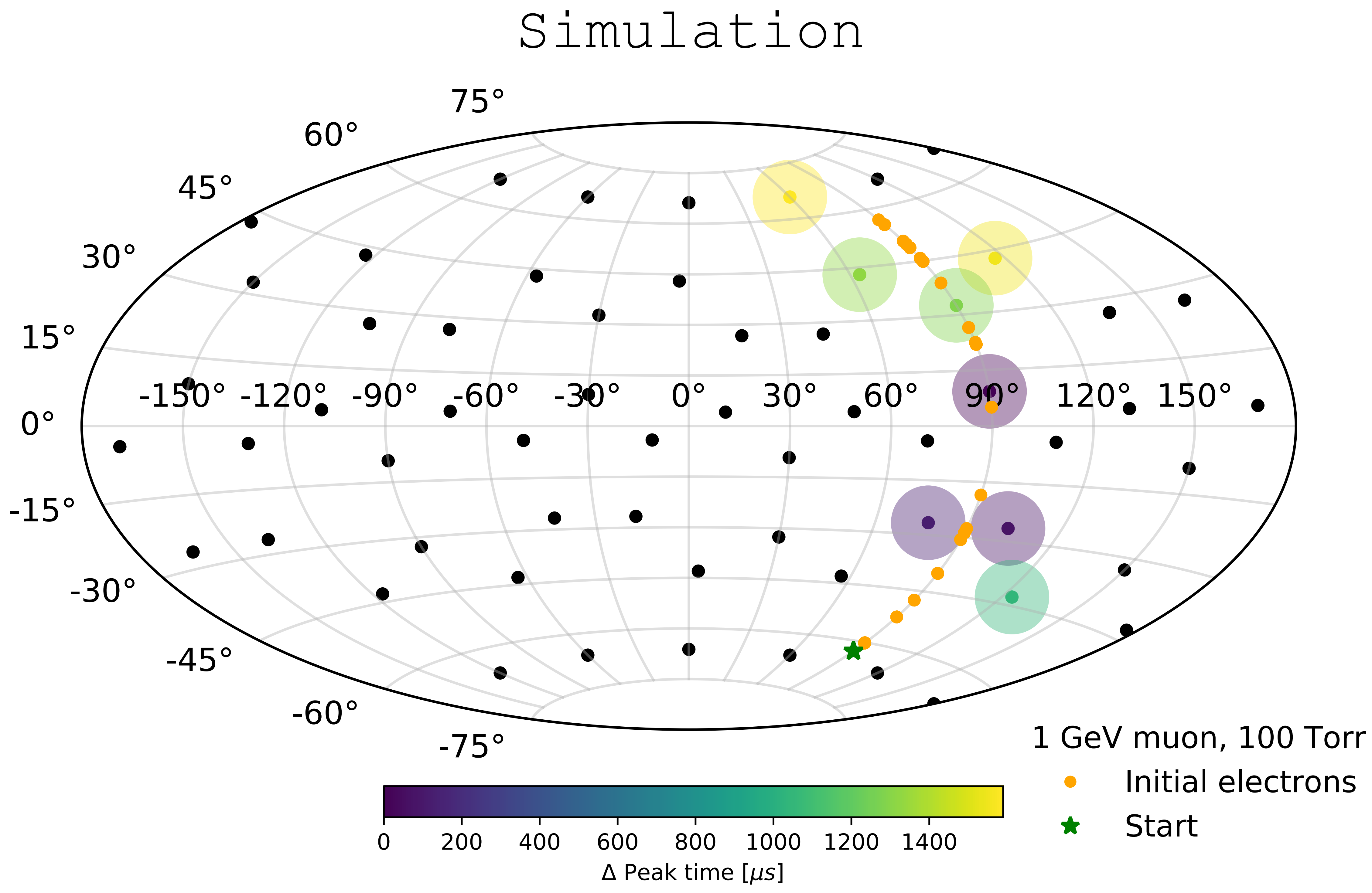


Towards TPC Mode Operation

- Increased number of anodes → **spatial information**
- For TPC operation need a **t_0**
  - **P**rimary interaction and avalanche **scintillation**
  - Additional **light-readout** could be used
- Demonstrated by R2D2 collaboration using SiPM



https://doi.org/10.1016/j.nima.2022.166382.

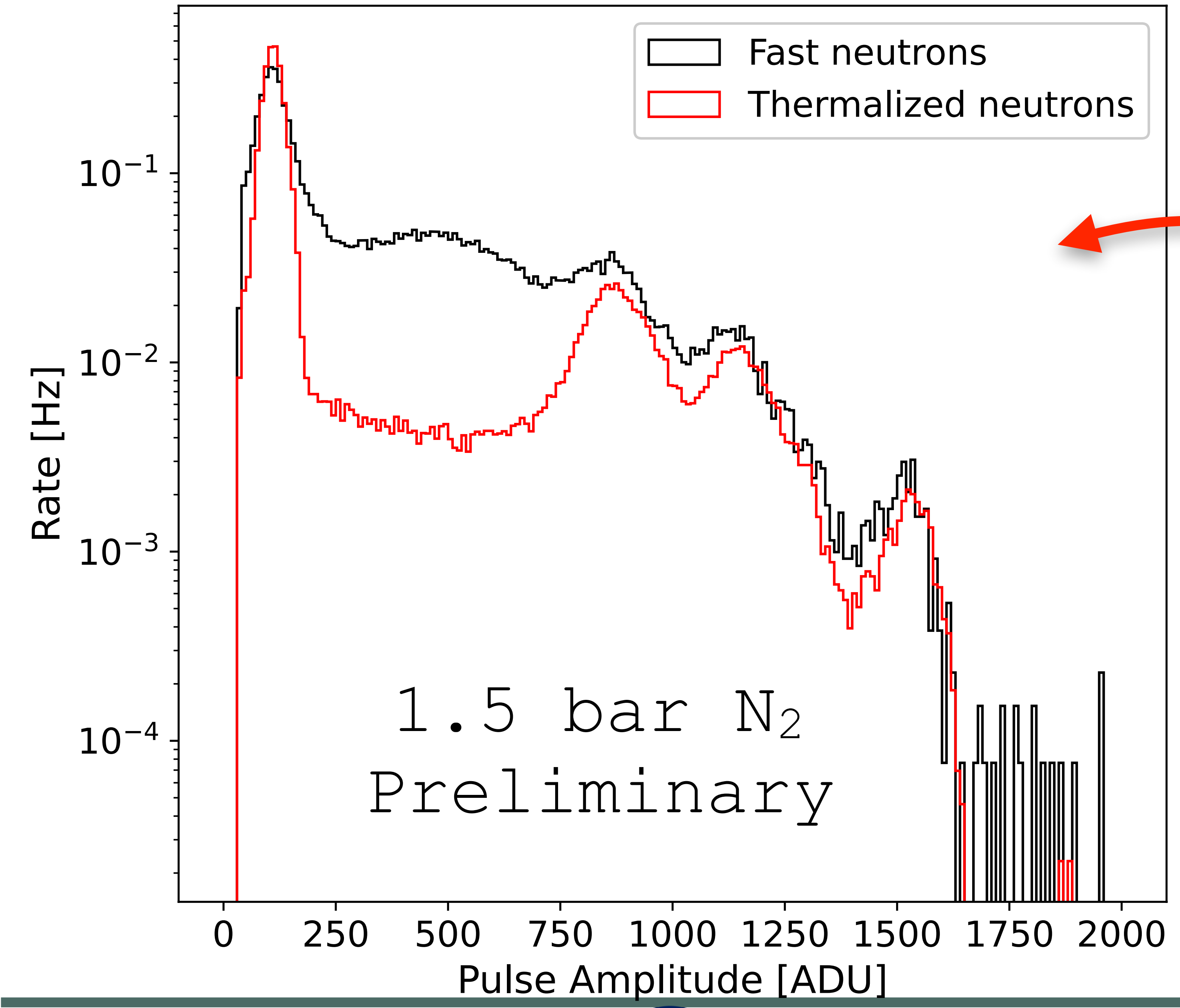


Simulation framework: *JINST 15 (2020) 06, C06013*

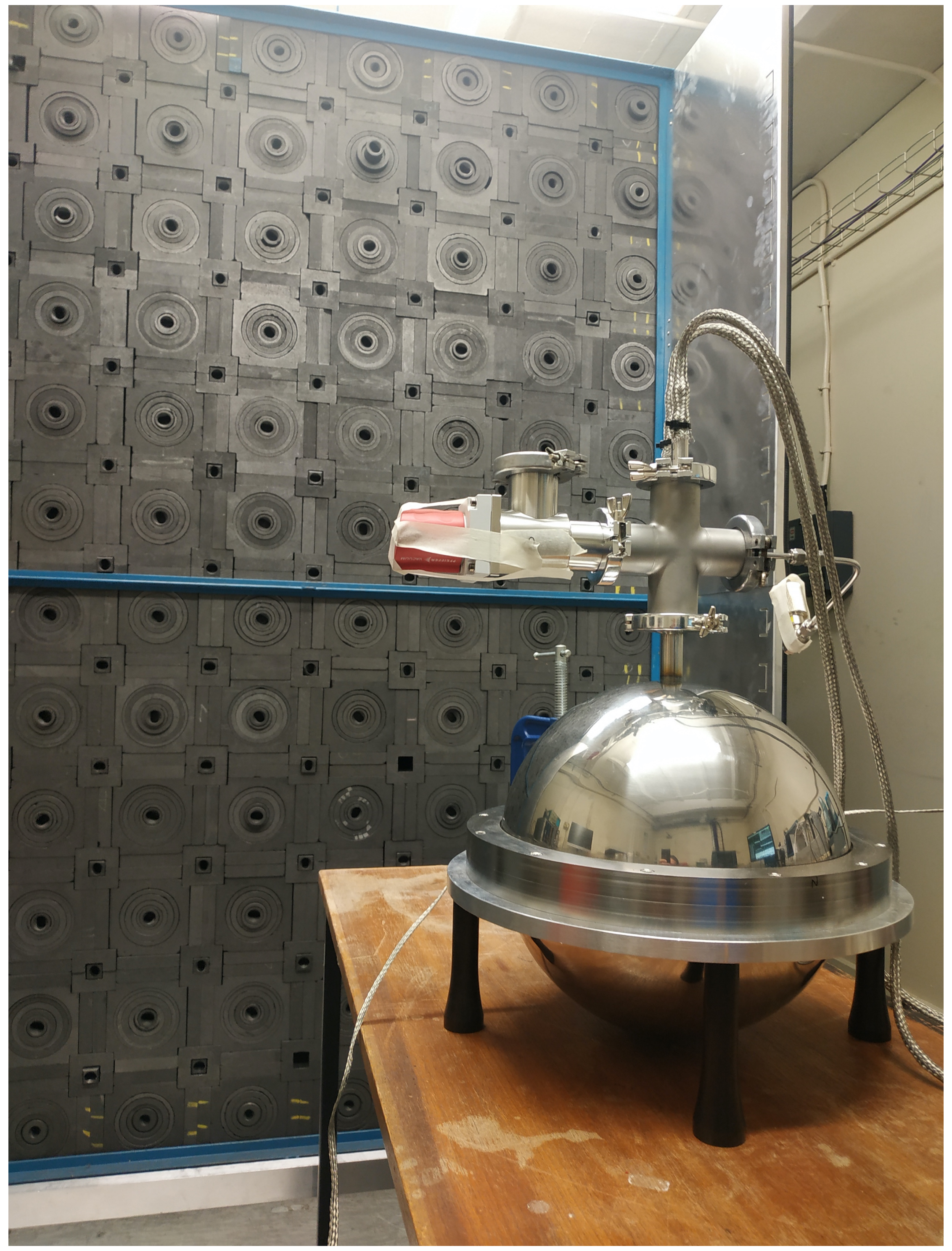
Neutron Detection

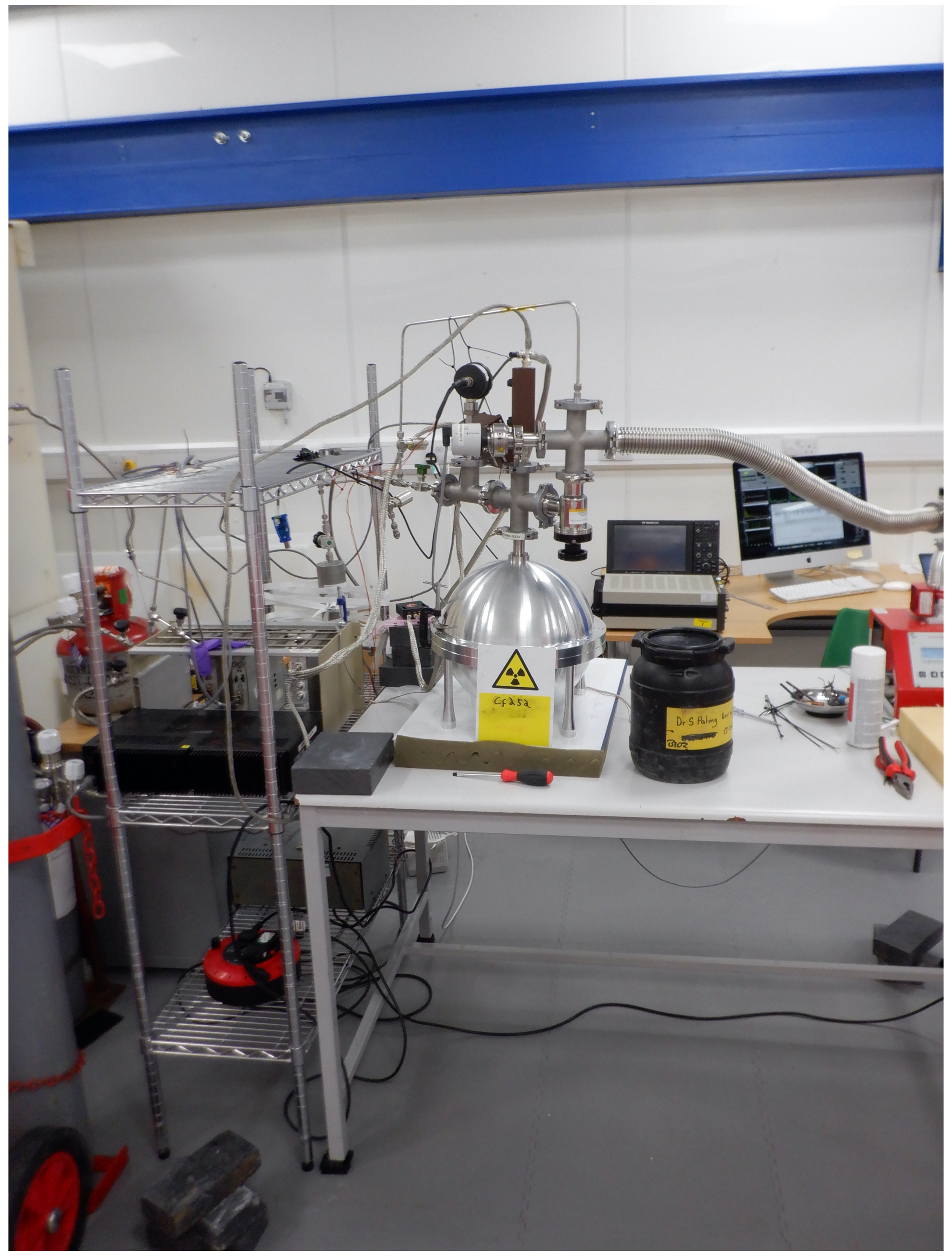
- Exploring SPC as a fast and thermal neutron detector with N_2 gas
  - Non-toxic, non-flammable
  - Simple and robust set-up
  - Easy deployment and operation
  - Cost efficient
  - Low γ-ray efficiency
  - Direct spectroscopic measurement of fast neutrons

Birmingham Gaseous Detectors Laboratory



^{222}Rn + progeny α-particles





$^{14}N + n \rightarrow {}^{14}C + p$ **+ 625 keV**

$^{14}N + n \rightarrow {}^{11}B + \alpha$ **- 159 keV**

- Measurements conducted at UoB and Boulby Underground Laboratory
  - Including Birmingham MC40 cyclotron
- Studied using dedicated simulation framework for SPCs
  - Unfolding is next step

Simulation Framework

- Many packages available for detector simulation:
- **Geant4**: for simulation particle interactions with matter
- **ANSYS**: finite-element methods software for electric field calculations
- **Garfield++**: For simulating electron-ion drift and signal calculations
  - Interfaces with Magboltz, SRIM and HEED
- **Simulation framework combines these** with custom calculations to form complete simulation
- Used by NEWS-G, but also R2D2 and for detector R&D

Development of a simulation framework for spherical proportional counters

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Abstract: The spherical proportional counter is a novel gaseous detector with numerous applications, including direct dark matter searches and neutron spectroscopy. The strengths of the Geant4 and Garfield++ toolkits are combined to create a simulation framework for spherical proportional counters. The interface is implemented by introducing Garfield++ classes within a Geant4 application. Simulated muon, electron, and photon signals are presented, and the effects of gas mixture composition and anode support structure on detector response are discussed.

Keywords: Detector modelling and simulations I (interaction of radiation with matter, interaction of photons with matter, interaction of hadrons with matter, etc); Detector modelling and simulations II (electric fields, charge transport, multiplication and induction, pulse formation, electron emission, etc); Gaseous detectors; Simulation methods and programs

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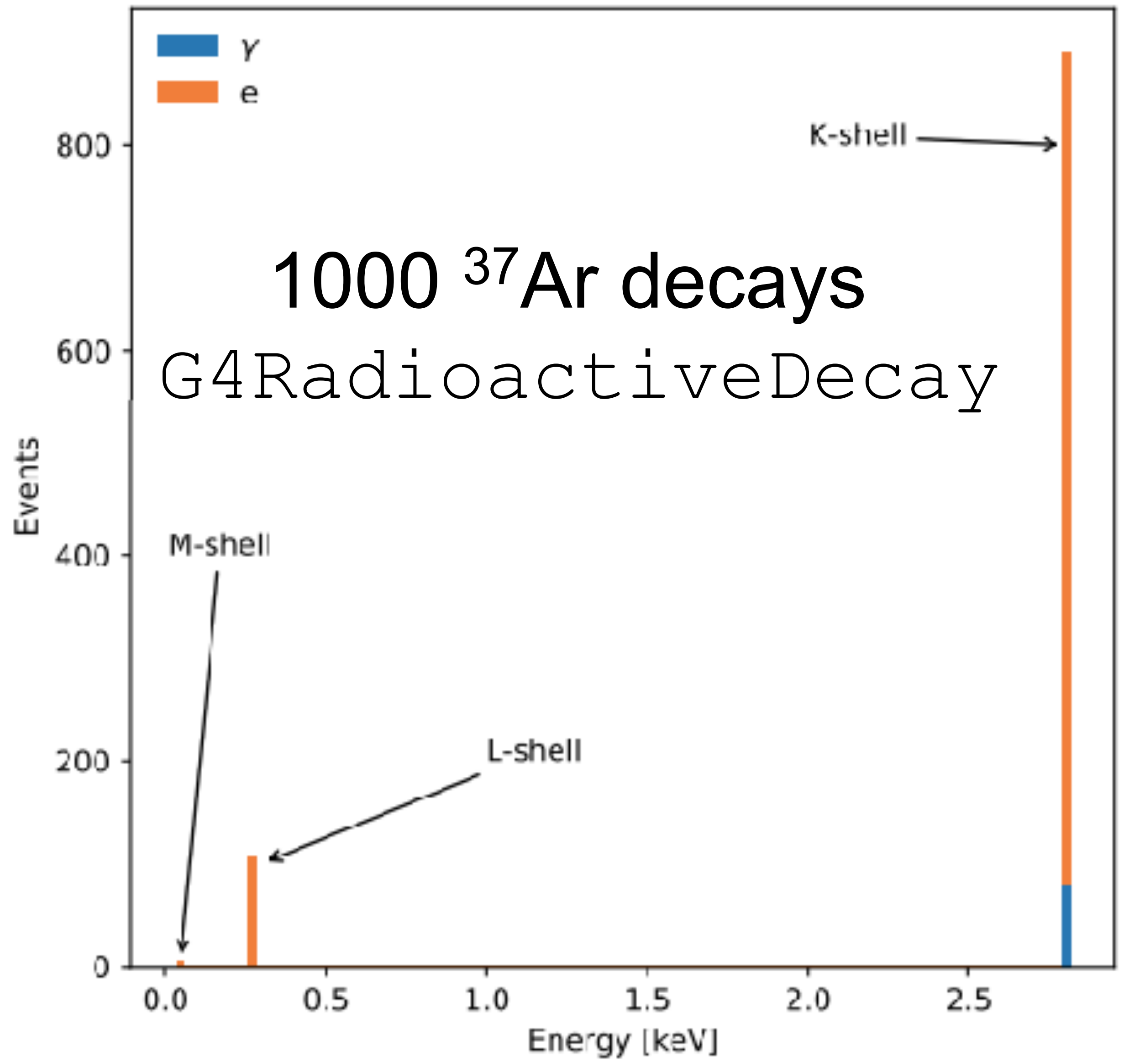
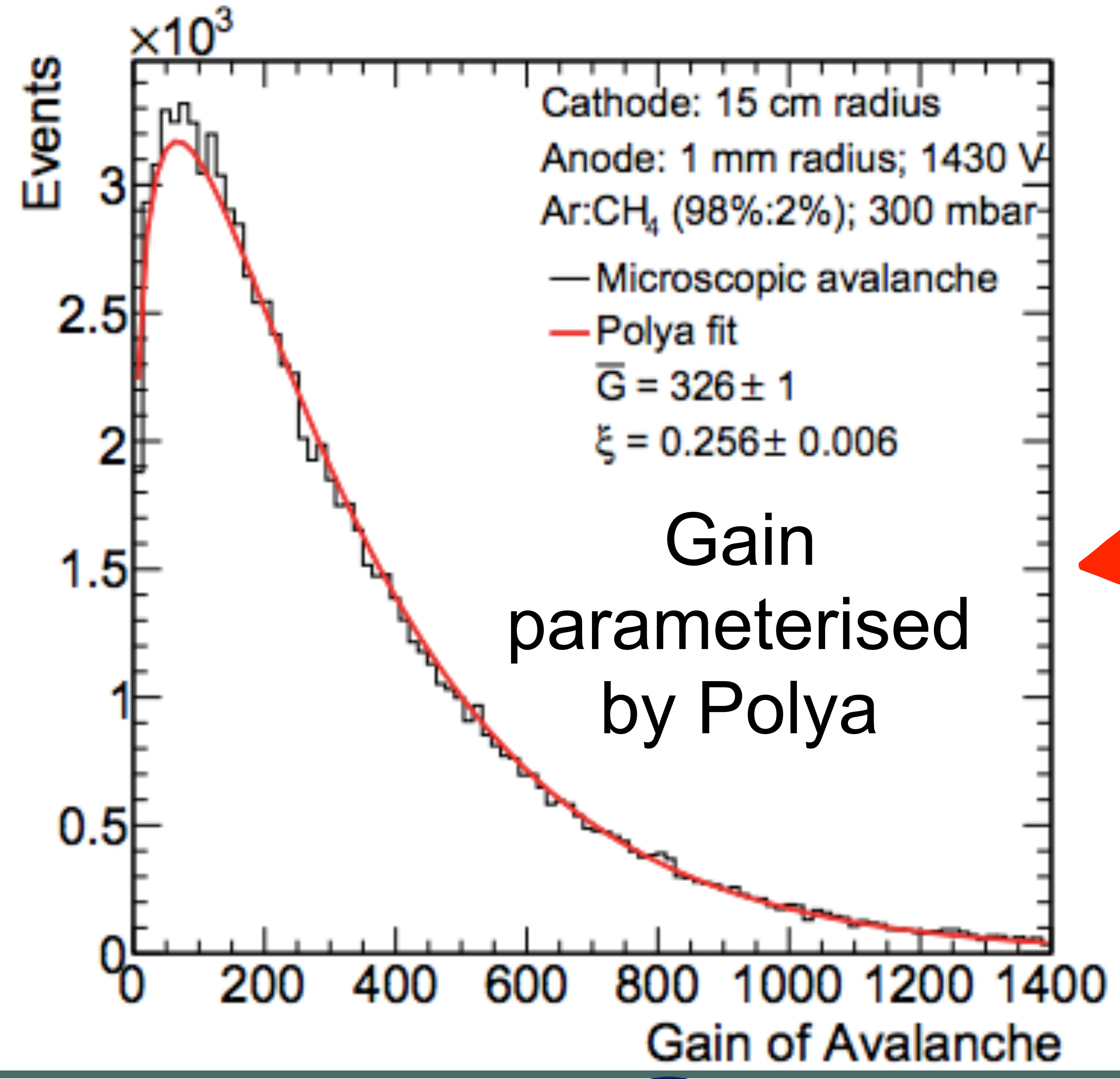
Simulation Chain





Detector is initialised and initial particle is generated in Geant4

↓

Geant4 tracks particles and interactions

↓

Electrons with kinetic energy <2 keV are passed to Garfield++

↓

Heed calculates further ionisation

↓

Using the electron transport parameters, ionisation electrons are transported up to the avalanche region

↓

Electron multiplication is simulated

↓

Ions and electrons produced in avalanche drift in electric field, and induced electric current is calculated

↓

Signal is processed through electronics module to form pulse

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