Search for light Dark Matter with NEWS-G: Status and Recent Developments

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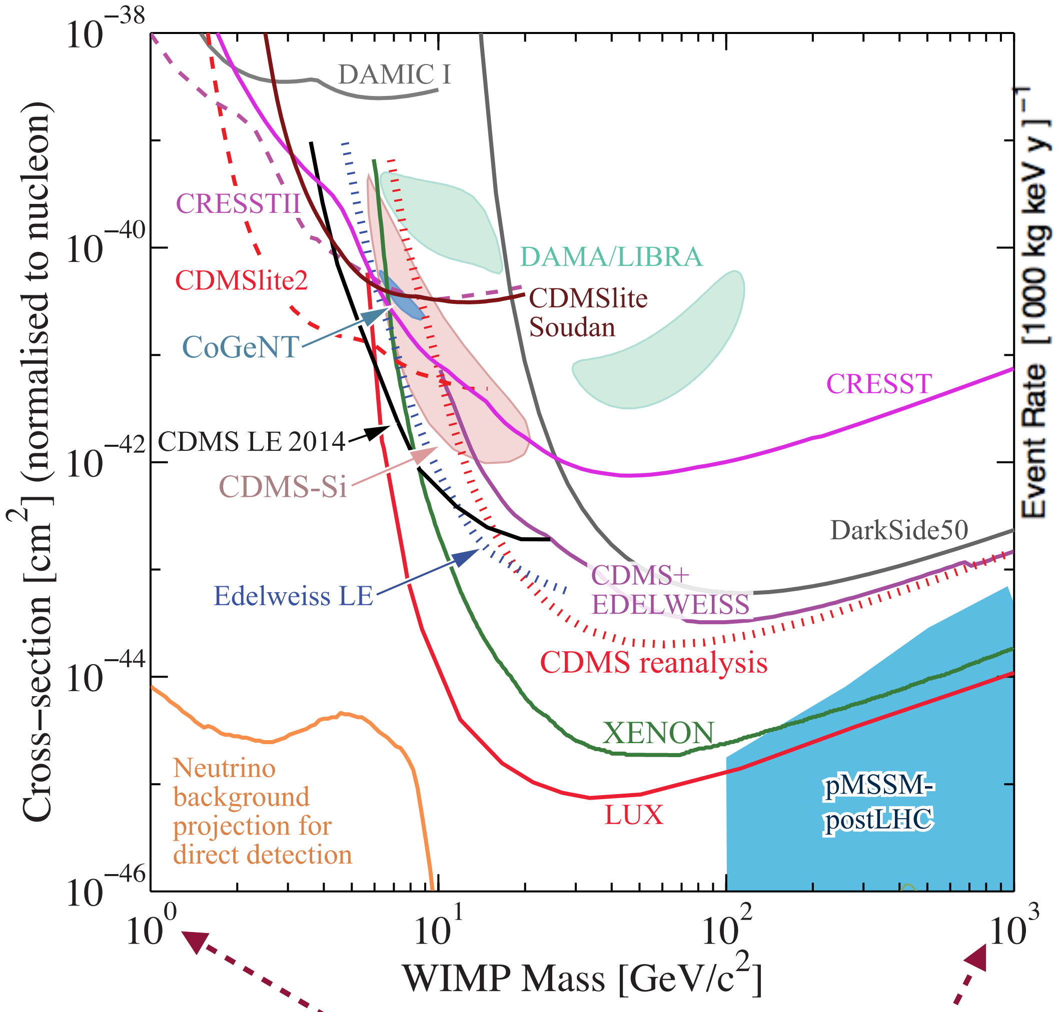
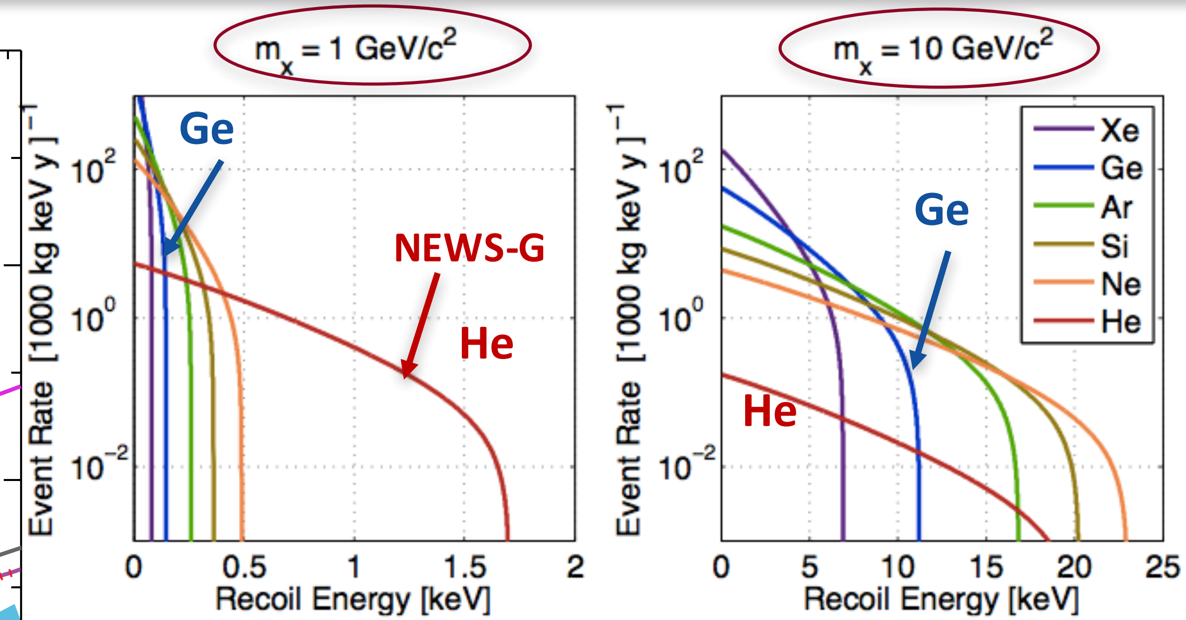
SNOglobe prototype at LSM

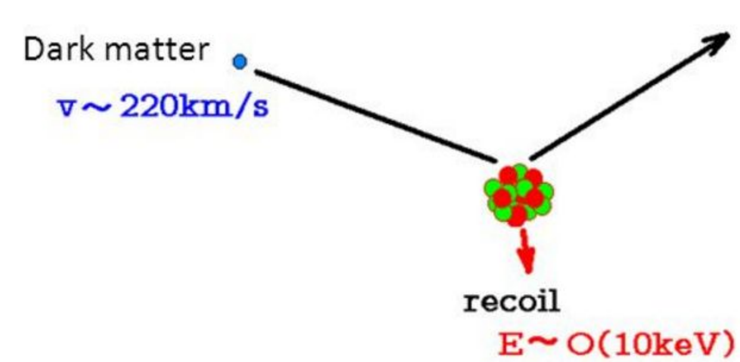
15th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD19)
15th October 2019, Siena, Italy

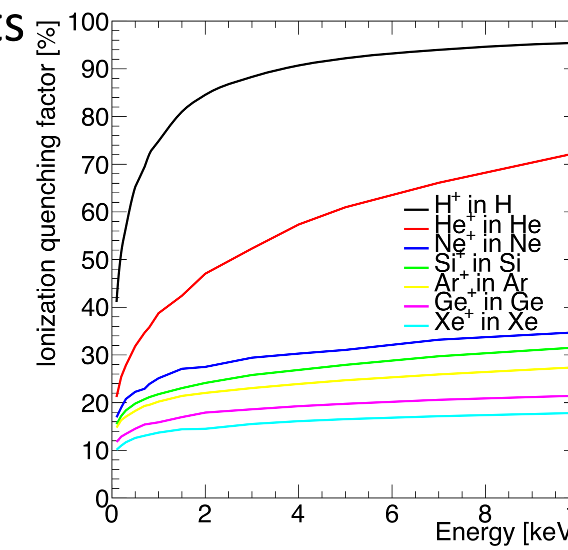
New Experiments With Spheres - Gas

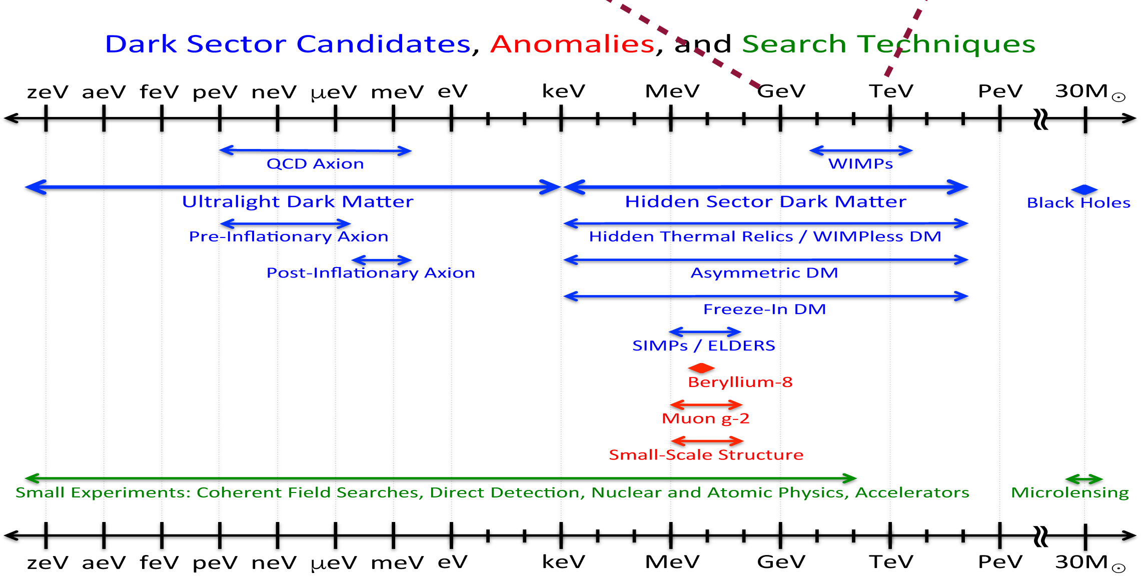




Recoil distributions with various targets





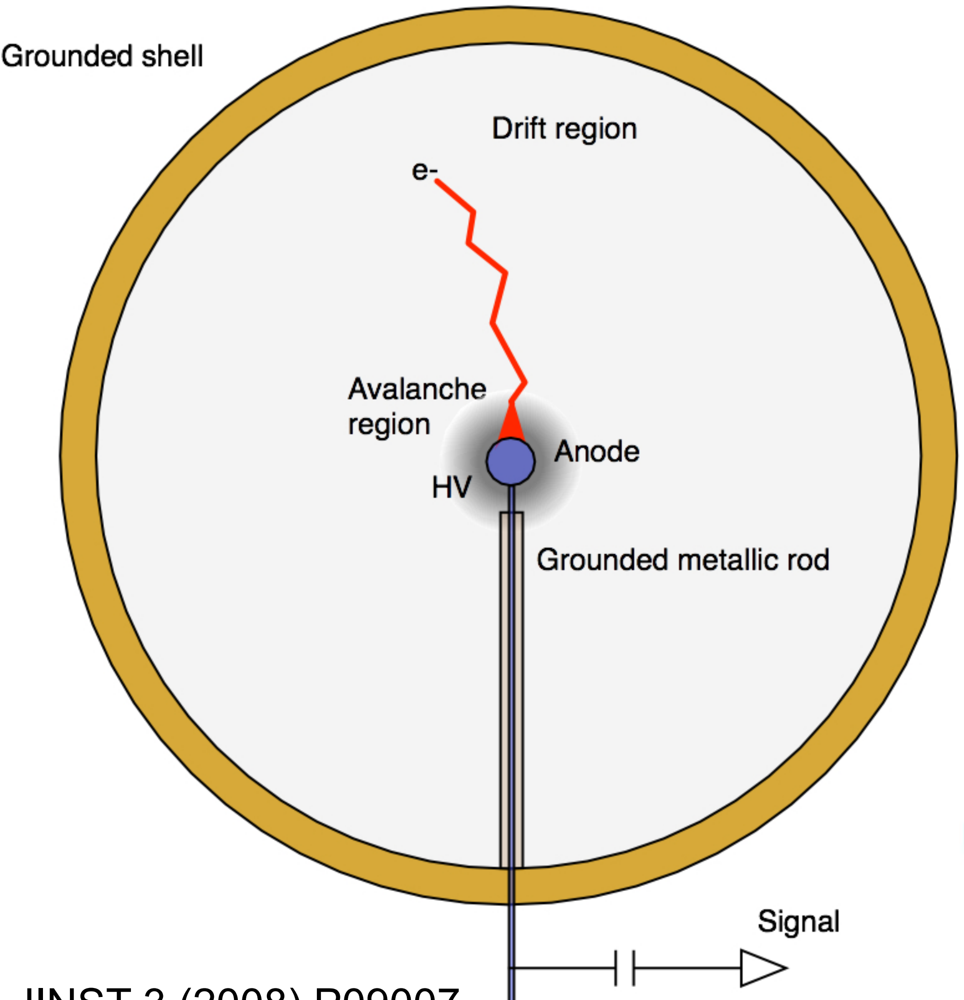


- Search for DM candidates in 0.1 - 10 GeV range
- Direct Detection experiment
  - Novel Spherical Gaseous Proportional Chamber
  - Light Gases as target (H, He, Ne)
    - Better projectile - target kinematic match
  - Low energy threshold
  - Favourable quenching factor

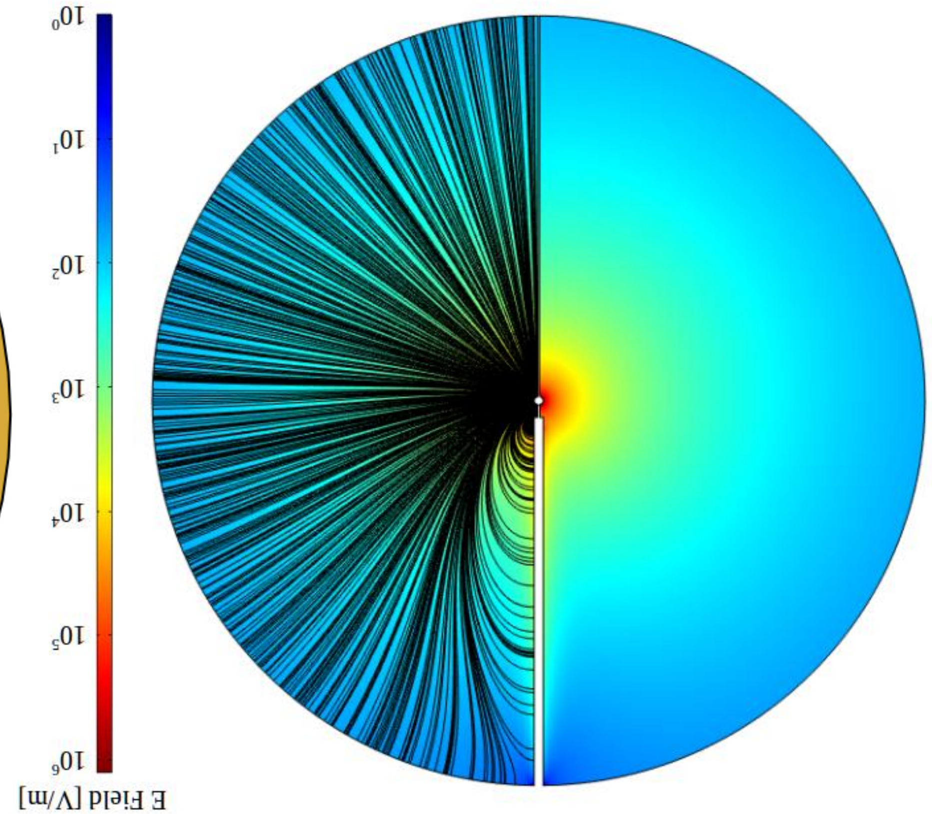
The NEWS-G Collaboration

6[th] collaboration meeting, LPSC, Grenoble, June 2019

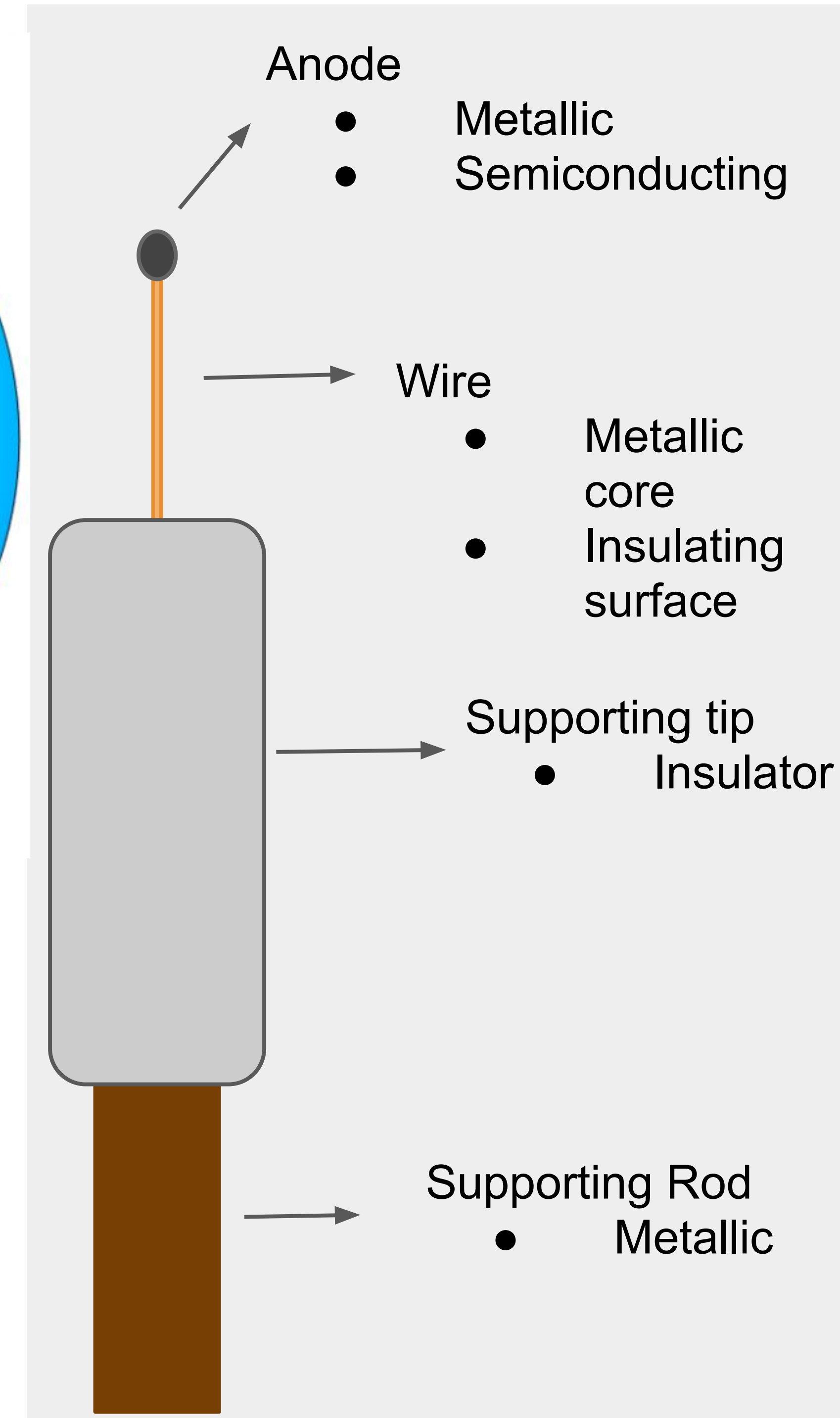
Spherical Proportional Counter



JINST 3 (2008) P09007



Realistic Electric Field



$$E = \frac{V_0}{r^2}\frac{r_1 r_2}{r_2 - r_1} \approx \frac{V_0 r_1}{r^2}$$

$$C = \frac{4\pi\epsilon}{r_2 - r_1} r_1 r_2 \approx 4\pi\epsilon r_1$$

$$r_1 = \text{anode radius}$$

$$r_2 = \text{cathode radius}$$

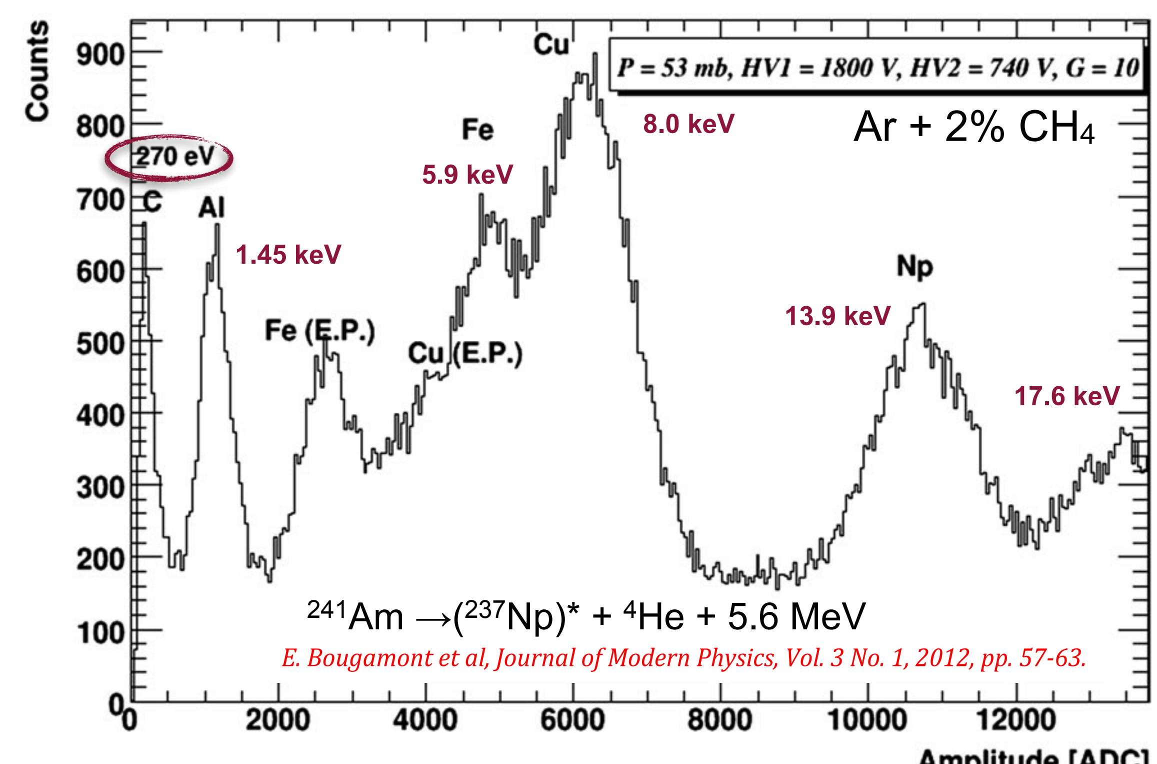
Detector volume naturally divided in a “drift” and an “amplification” volume.

Spherical Proportional Counter

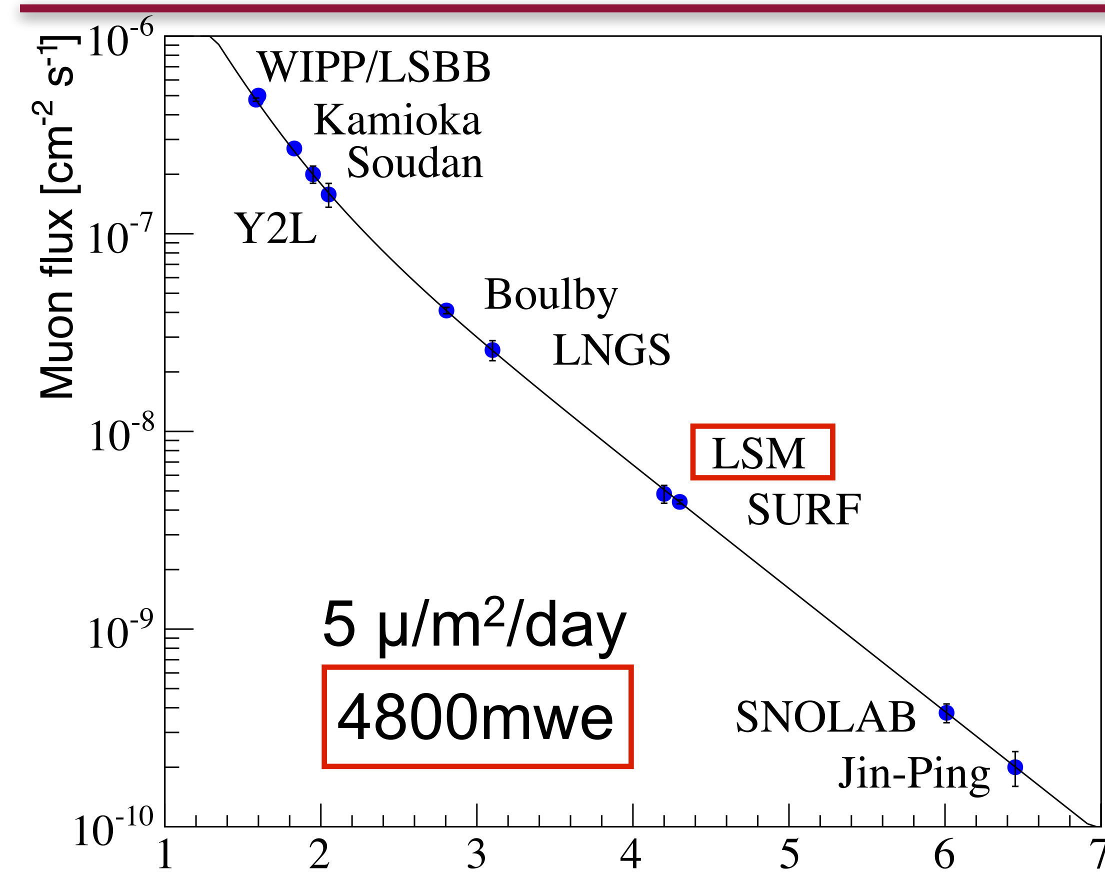
First Spherical Proportional Chamber made out of LEP RF Cavities

I. Giomataris and G. Charpak

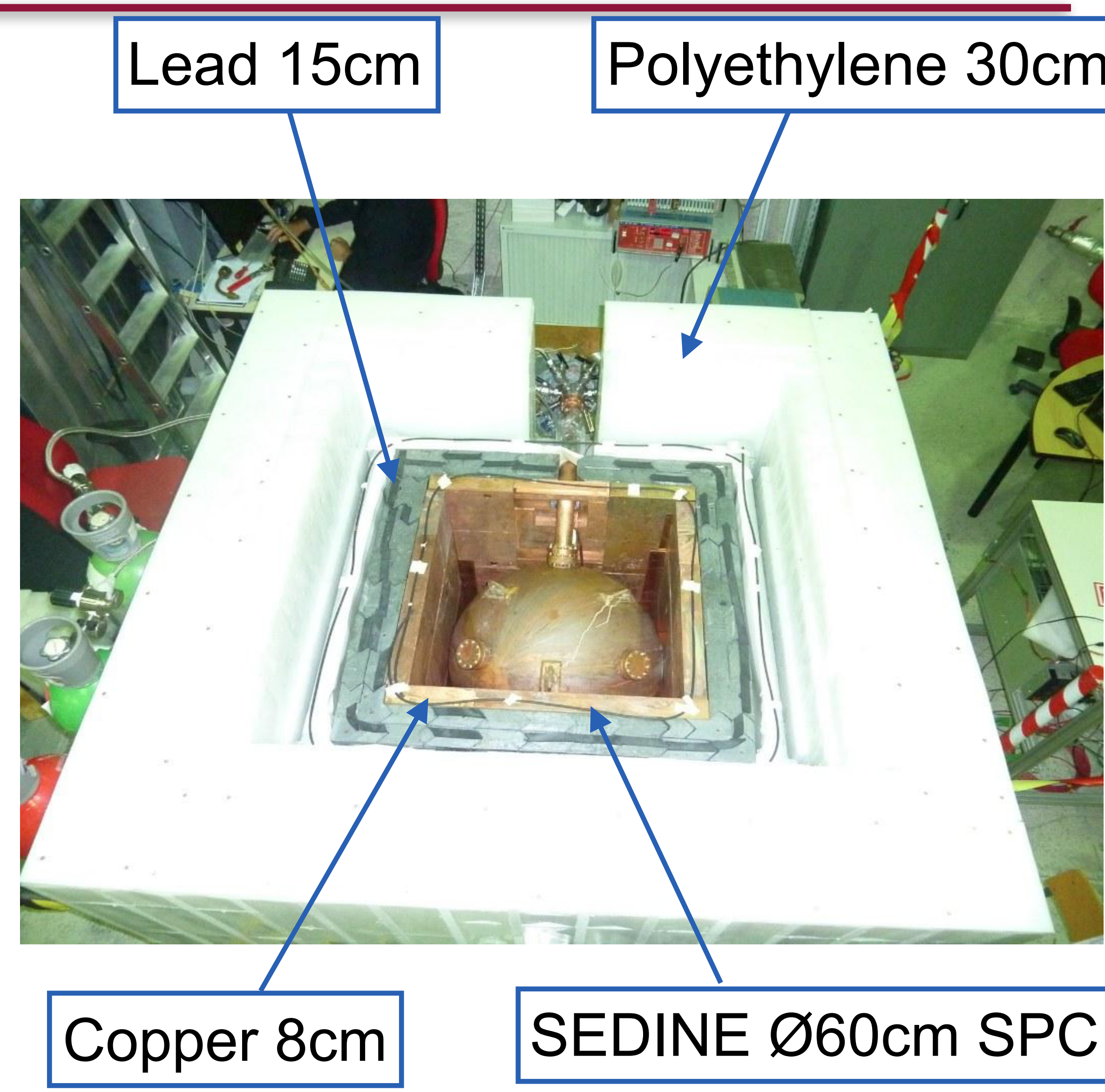
- Large Volume
  - Small number of electronic channels
- Low Energy Threshold
  - Low Capacitance
  - High Gain
- Lowest surface to volume ratio
- Fiducial volume selection
  - Through pulse shape analysis
- Flexible (pressure, gas)
- Simple sealed mode



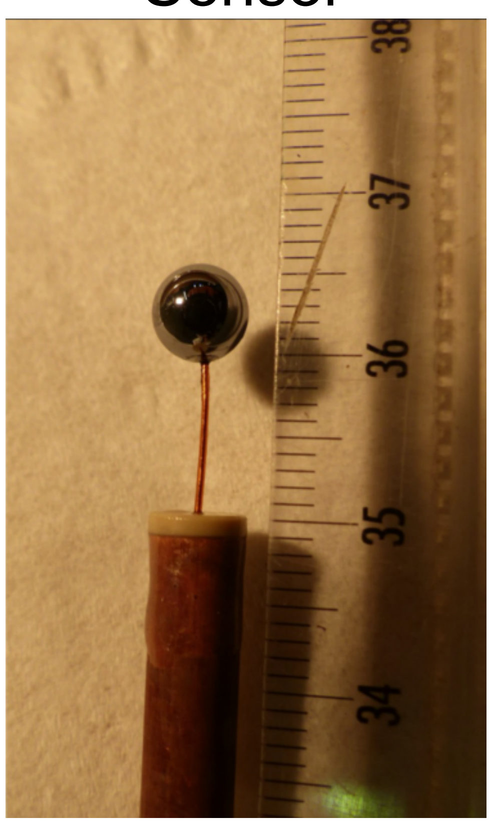
SEDINE: NEWS-G Prototype at LSM



J.Phys. G43 (2016) 013001



Sensor

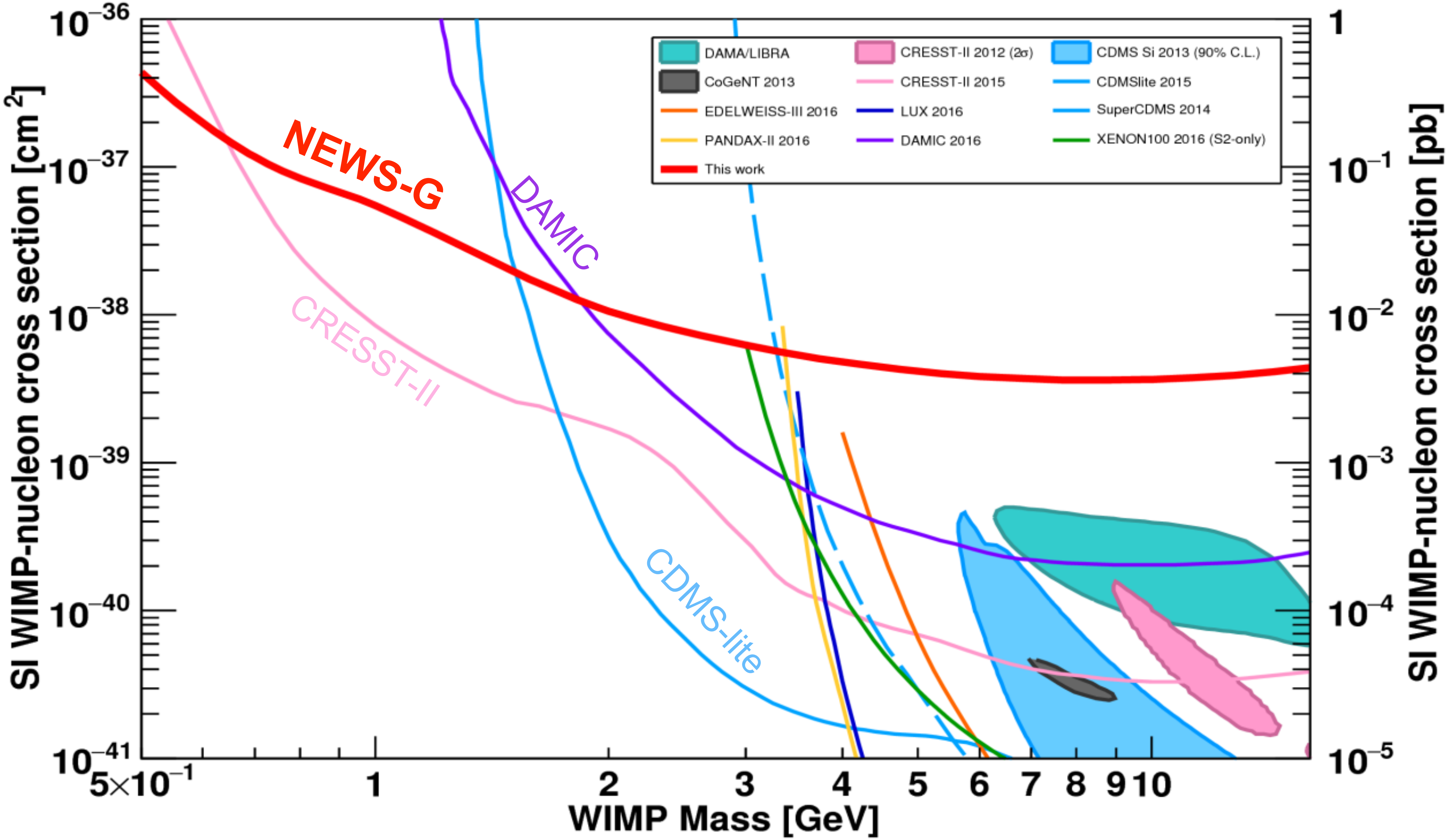


Vessel

- NOSV Copper vessel (Ø60 cm)
- Equipped with a Ø6.3 mm sensor
- Chemically cleaned several times for Radon deposit removal

First results of NEWS-G with SEDINE at LSM

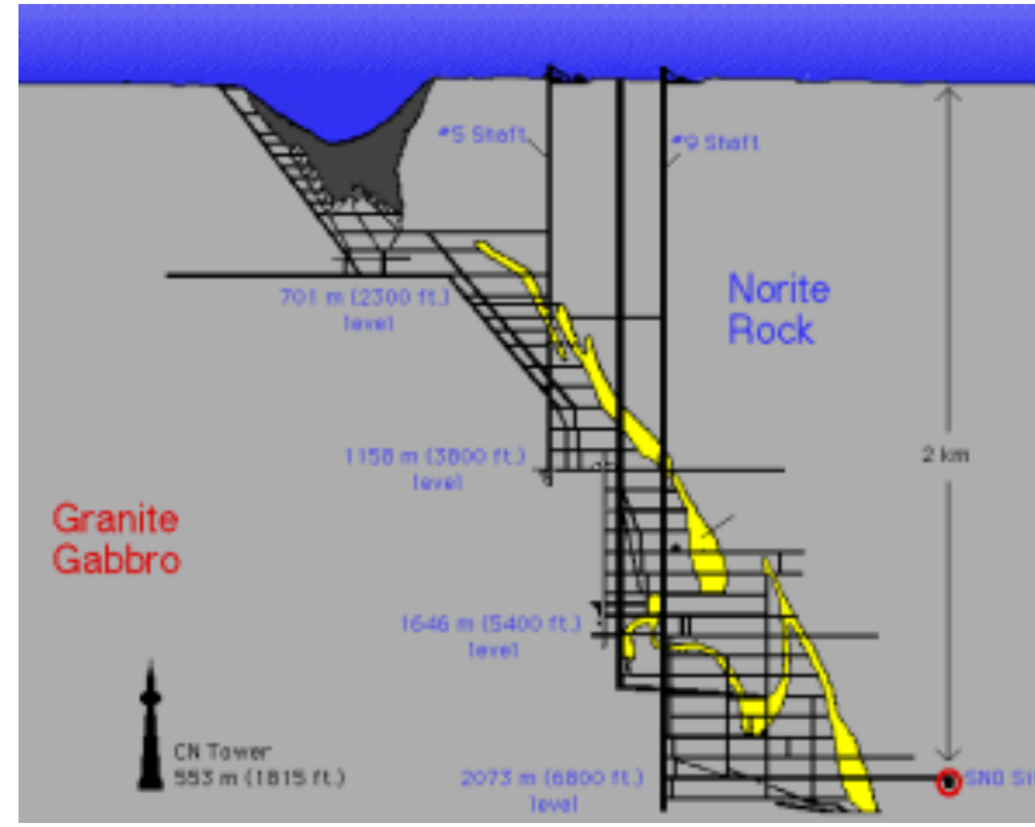
NEWS-G collaboration, Astropart. Phys. 97, 54 (2018)

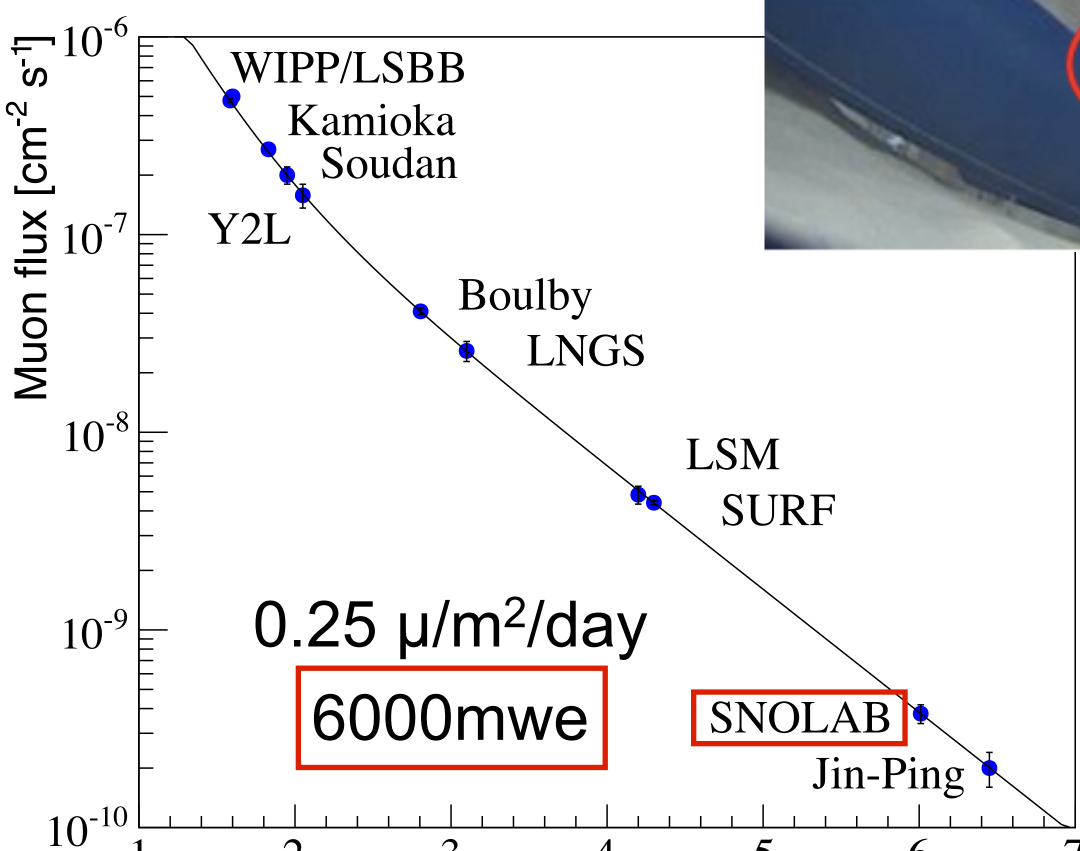


- **Gas Mixture:** Ne+0.7%CH4 at 3.1 bar
- **Exposure:** 9.6 kg×days (34.1 live-days x 0.28 kg)

NEWS-G at SNOLAB

- Main experiment to take place at SNOLAB
  - NEWS-G to be installed in Cube Hall





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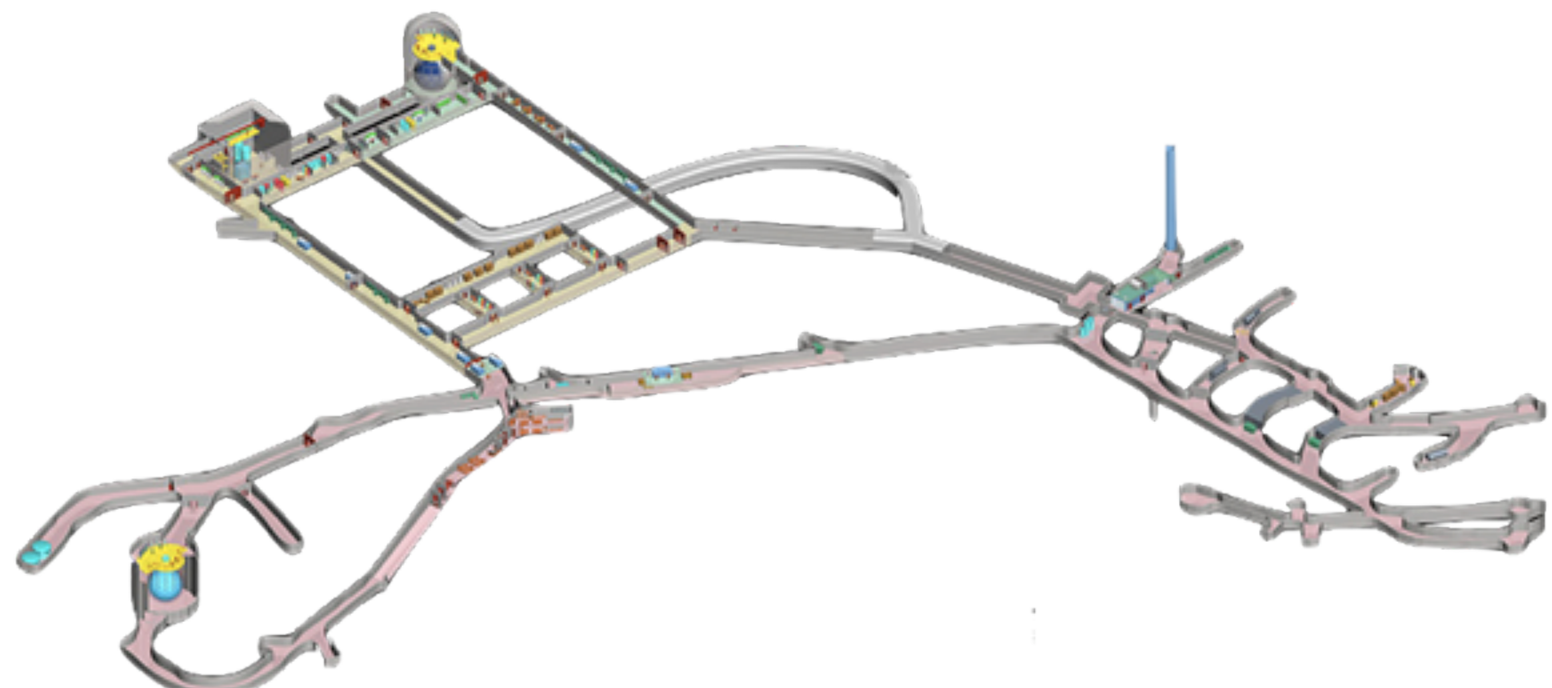

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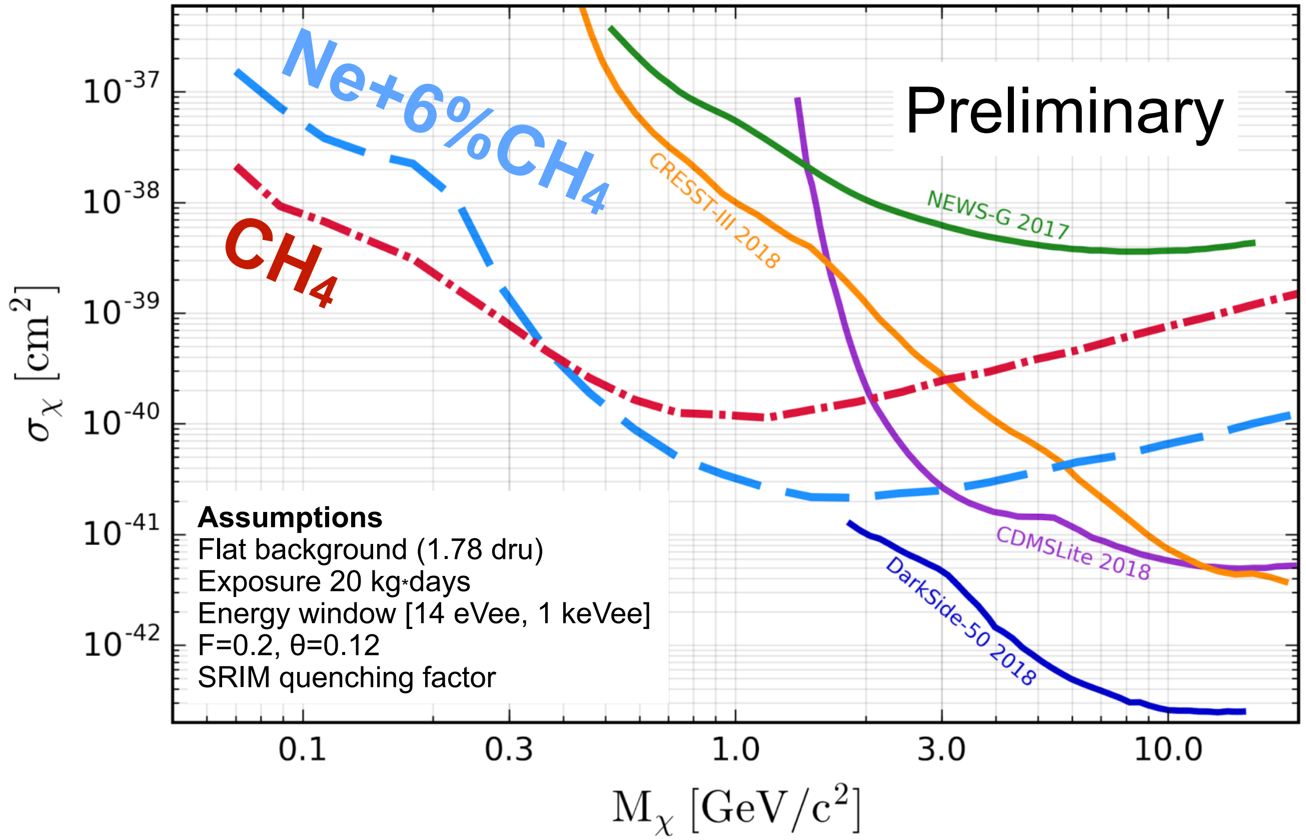
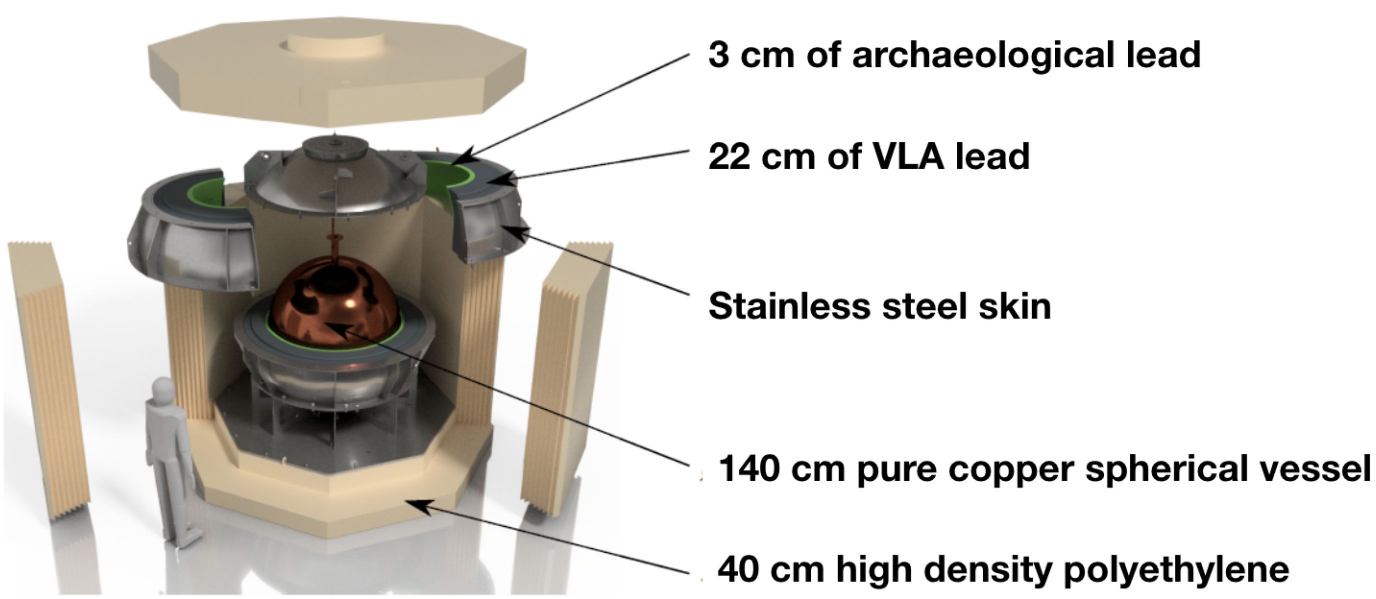
NEWS-G at SNOLAB

- NEWS-G is preparing SNOglobe
  - Ø140 cm
  - assembled and commissioned at LSM
  - currently being transferred to SNOLAB
- H-rich mixtures
- Expected to be sensitive to WIMP masses ~100 MeV
- Detector already operating at LSM (commissioning run)

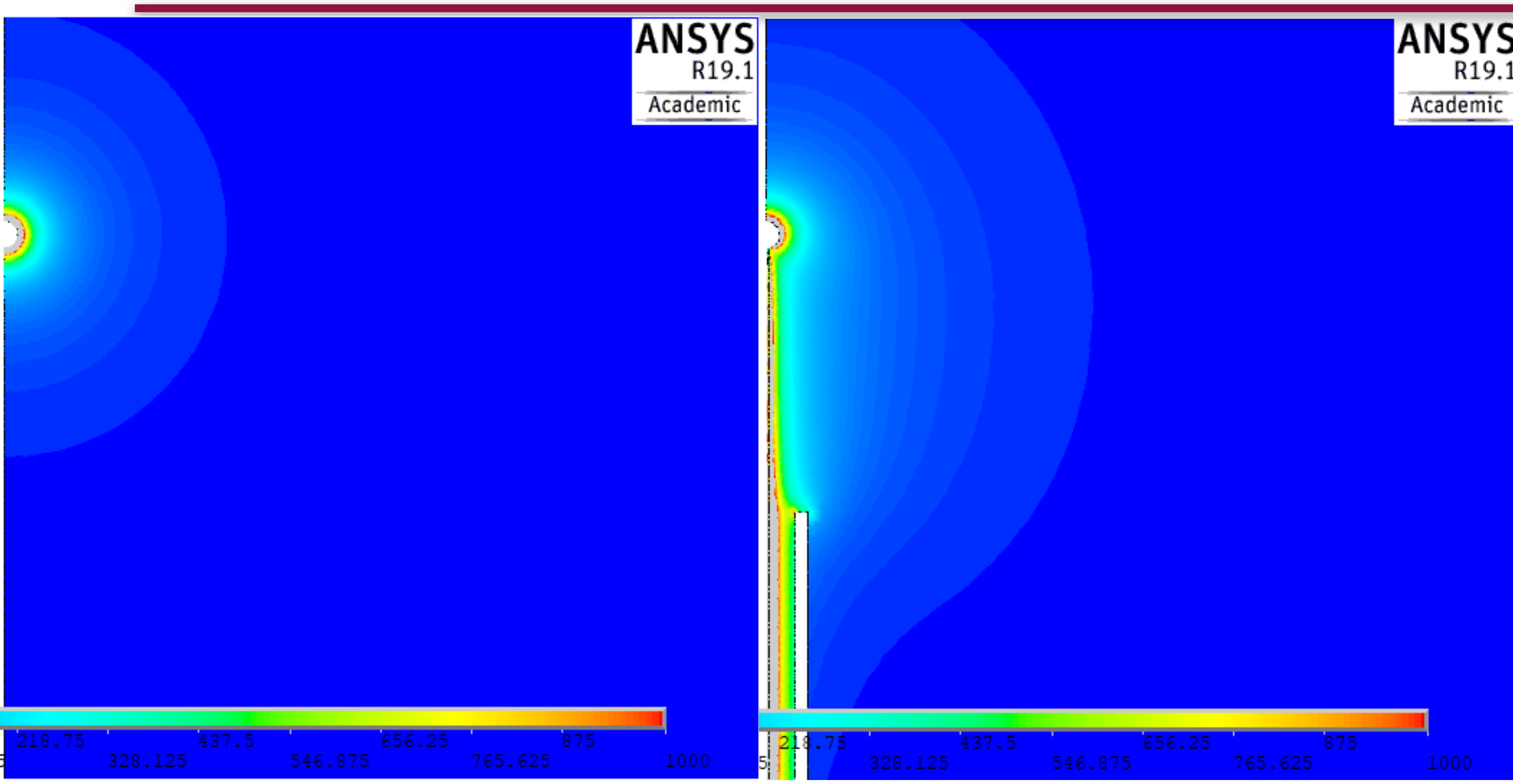
SNOglobe at LSM

NEWS-G at SNOLab



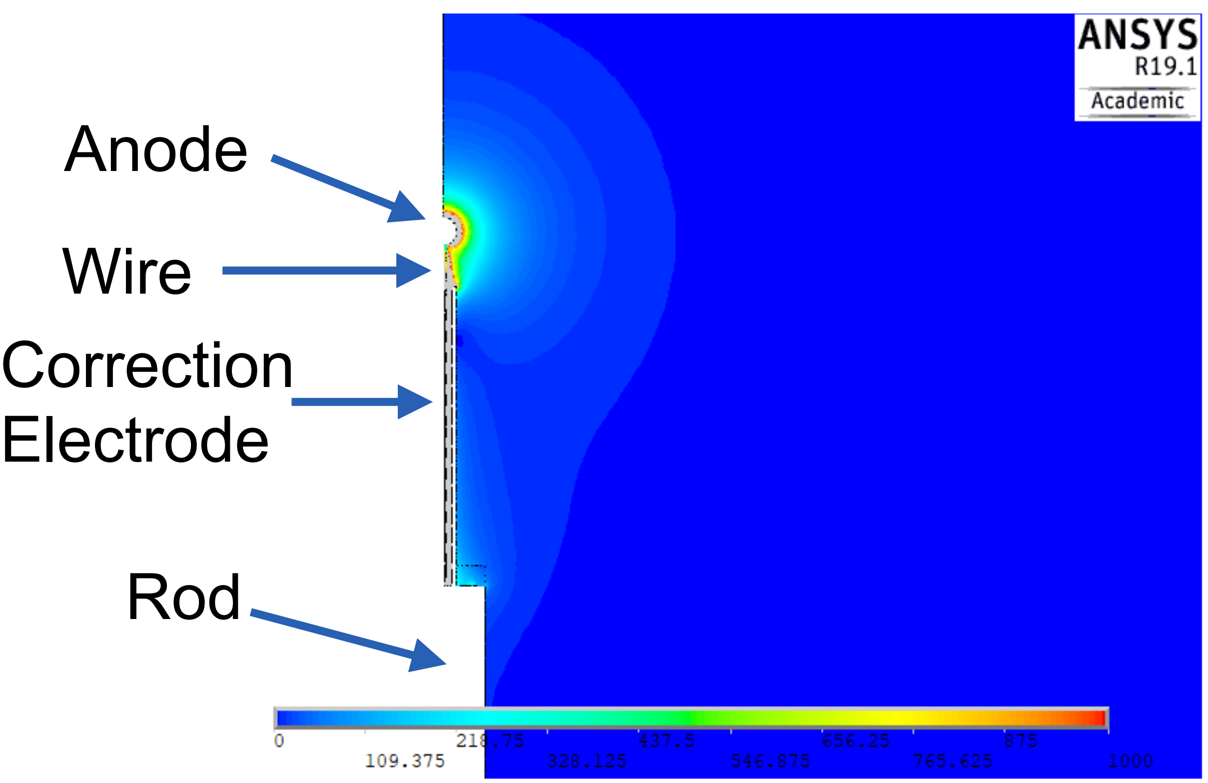


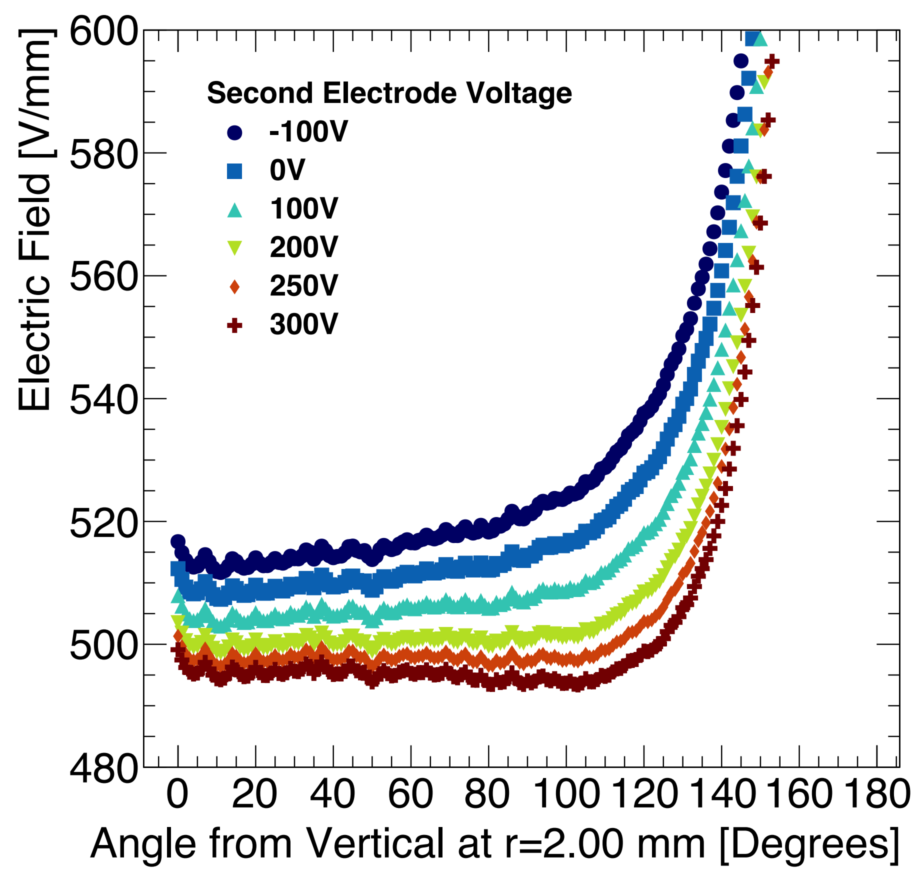
Electric field homogeneity



- Ideally, electric field:
  - purely radial
  - strength $1/r^2$
- Reality more complex, as support structure needed for sensor
  - $E=E(r,\theta)$
  - Non-uniform detector response
- Improved field uniformity by adding correction electrode

I. Katsioulas et al, JINST, 13, 11, P11006, 2018 10.1088/1748-0221/13/11/P11006

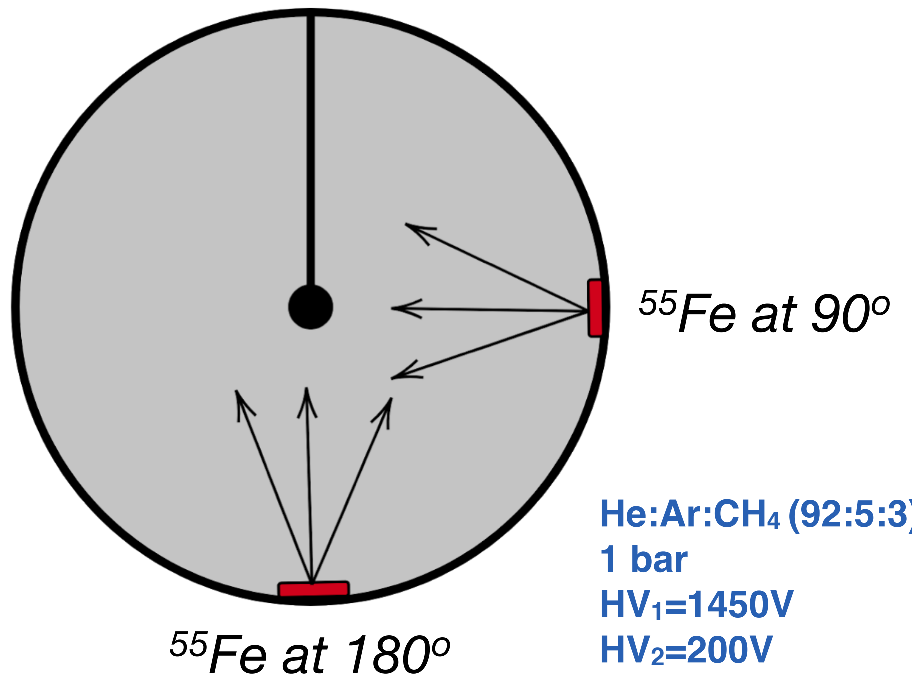




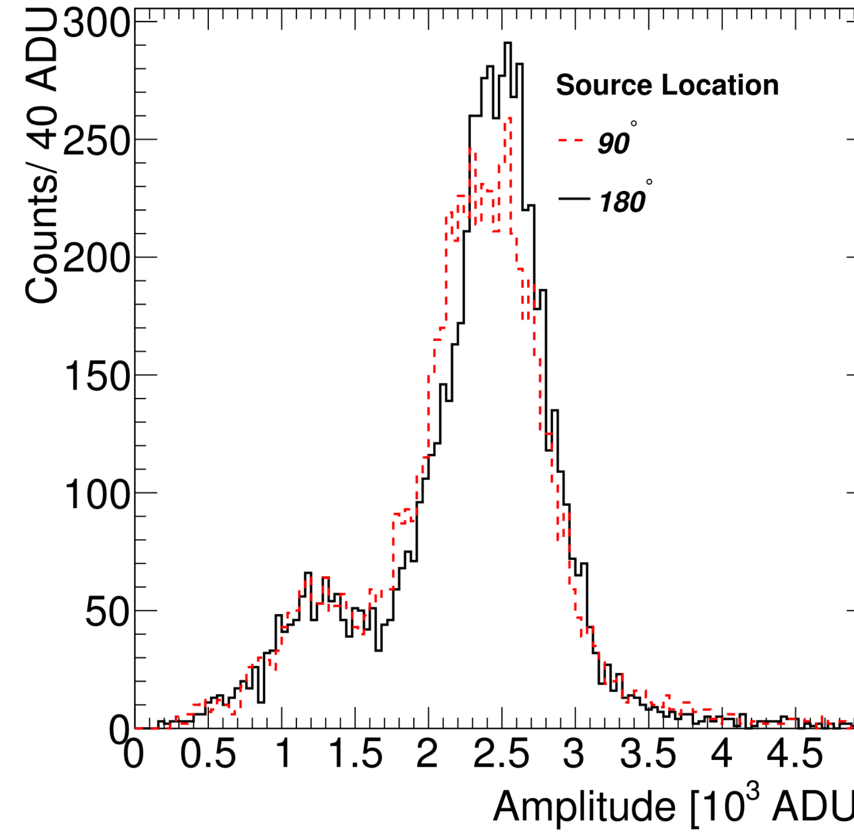
Resistive Glass Electrode

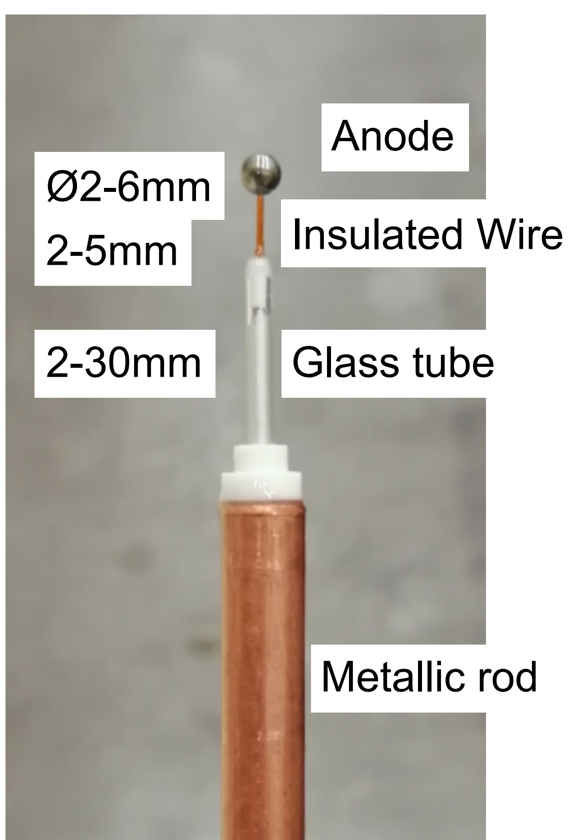
- Spark quenching
- Charge evacuation
- Advantages
  - Simple/Robust
  - Symmetric
  - Low material budget
- Material properties
  - Soda-lime glass
  - $\rho = 5\times10^{10}\ \Omega\text{cm}$
  - $d = 2.1\text{-}2.25\ \text{g/cm}^3$
  - A = 14.5 mBq/g

Irradiation with 5.9 keV X-rays

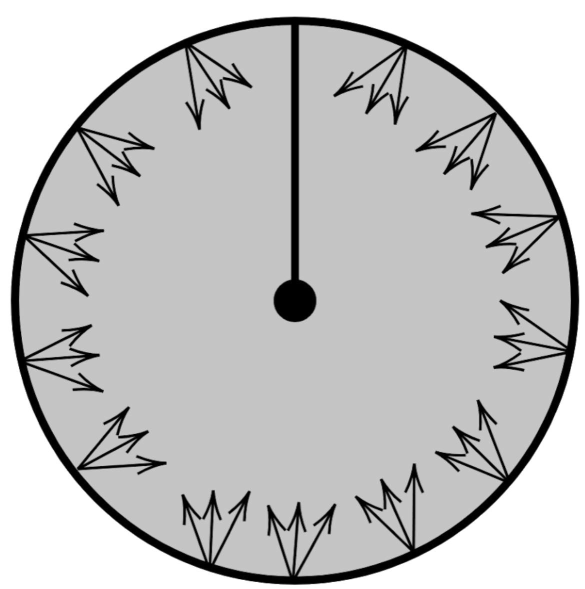


He:Ar:CH_4 (92:5:3)
1 bar
HV_1=1450V
HV_2=200V
2 mm Ø anode

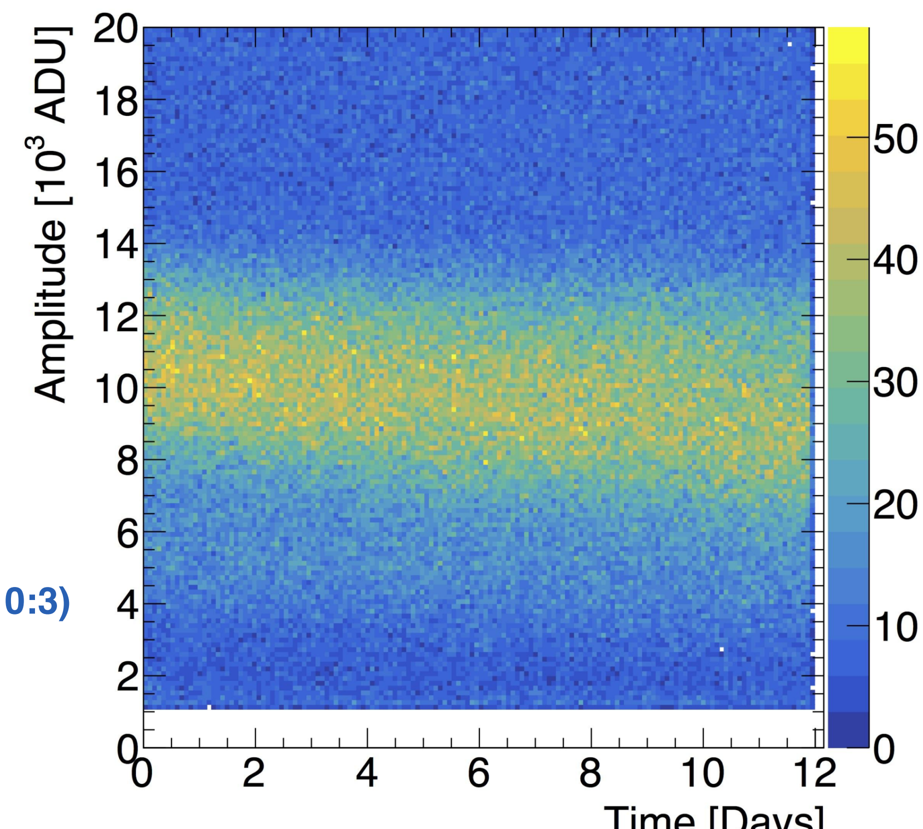




6.4 keV iron fluorescence induced by environmental radiation



He:Ar:CH_4 (87:10:3)
2 bar
HV_1 = 2350V
HV_2 = 0V
2 mm anode



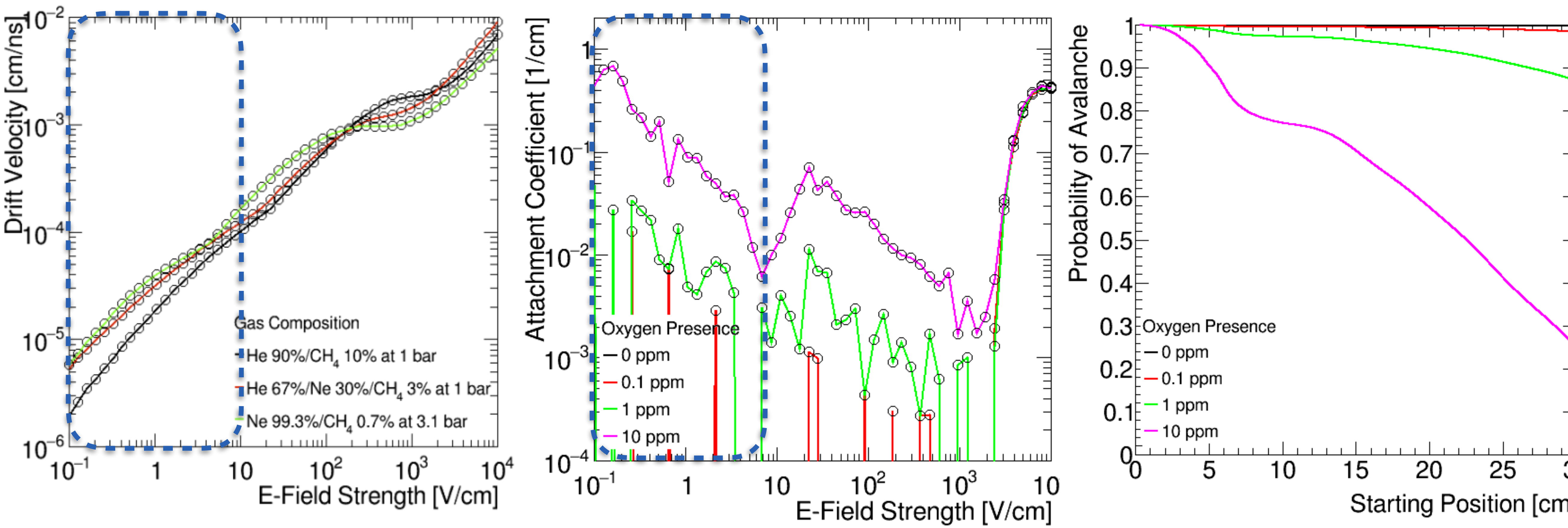
Charge Collection in low electric field

- Gain and drift velocity both depend on E/P
- At large radii
  - Low drift velocity
  - Susceptibility to attachment
- Crucial aspects
  - Electric field magnitude
    - depends on anode voltage and radius
  - Gas quality

$$\ln(G) = \int_{E(r_1)}^{E(r_2)} \alpha\,(E/P)\,\frac{dr}{dE}dE$$

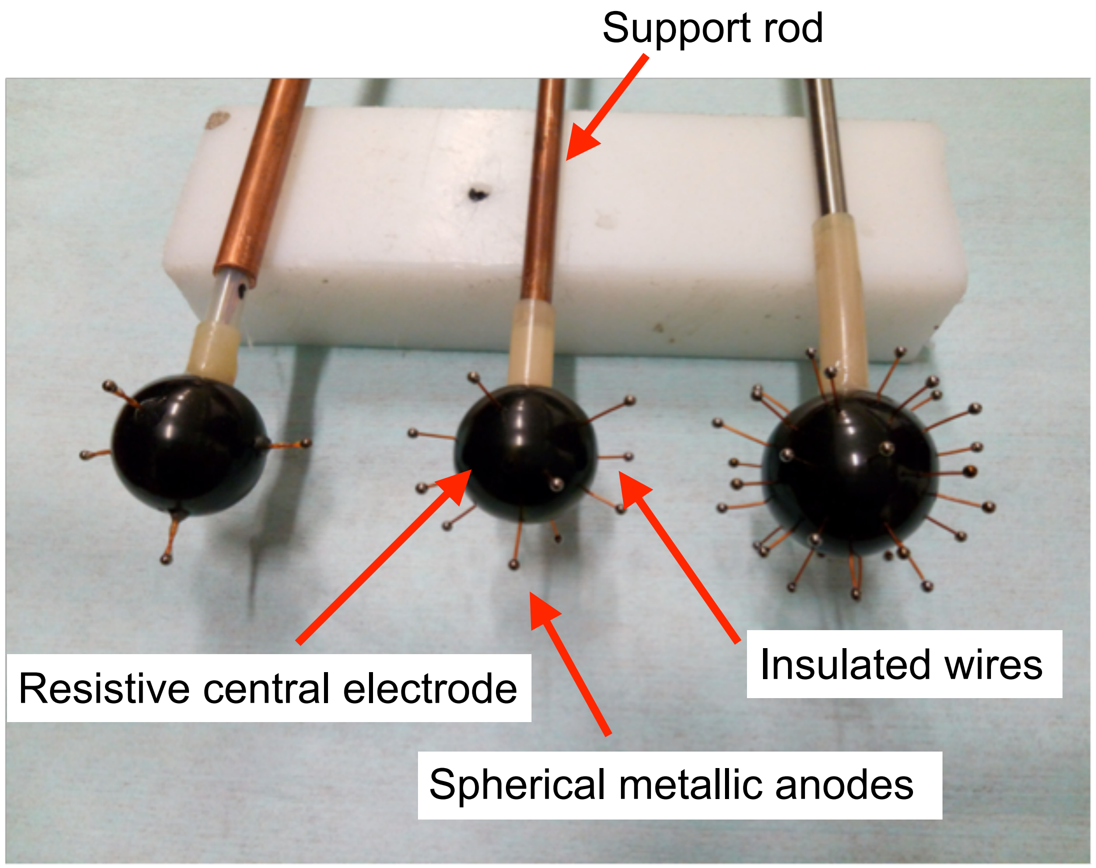
$$v_{drift} = \mu\frac{E}{P}$$

$$E(r) \approx \frac{V_0}{r^2}r_1$$



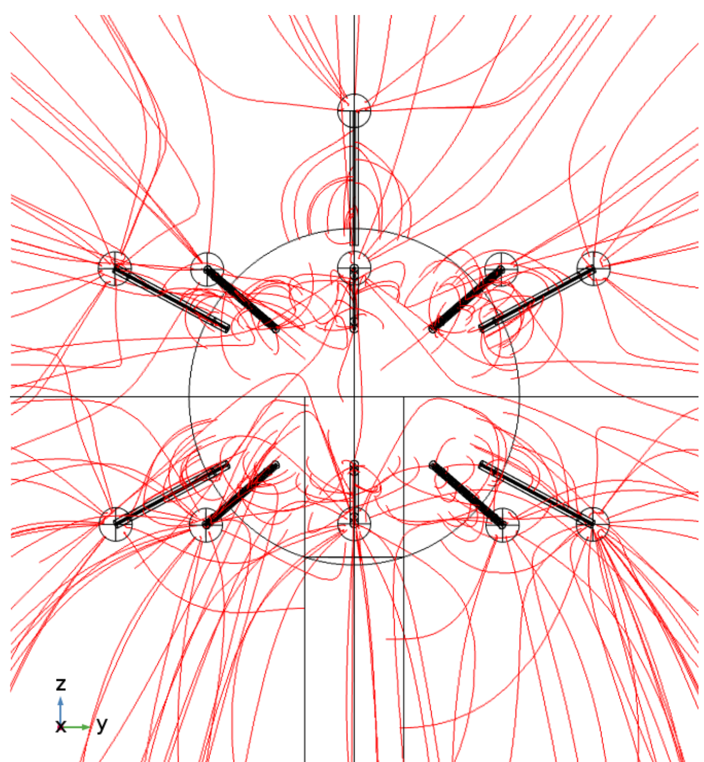
Magboltz study on gas properties and sensitivity to contaminants

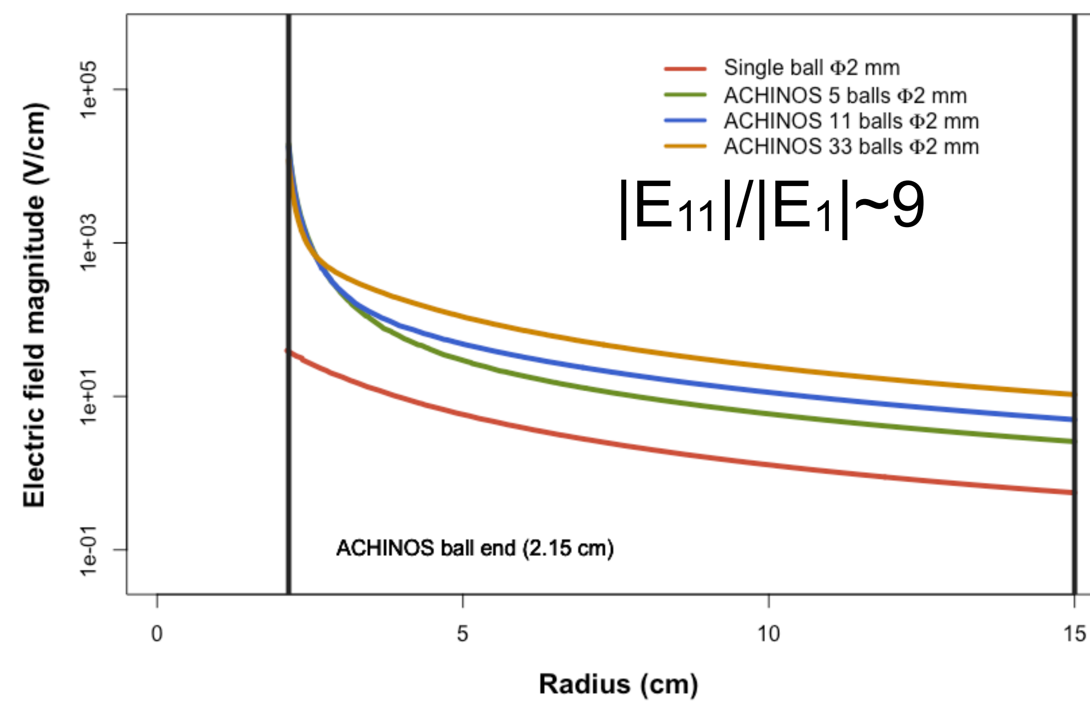
Multi-anode sensors: Achinos



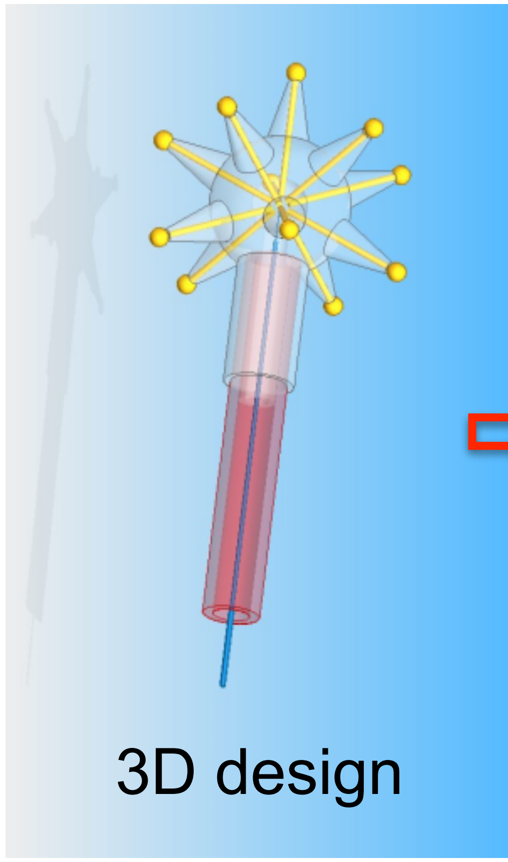
- Achinos: Multiple anode balls place at equal distances on a sphere
  - Same gain but increased field at large radii
  - Decoupling Gain and Drift
    - Amplification tuned by anode radius
    - Volume electric field tuned by structure size and number of anodes
  - Anodes can be read out individually
  - TPC-like capabilities
- Prototypes: 5, 11, 33 metal balls ∅2mm successfully operated
- 3D printed Achinos sensors built and operated

JINST 12 (2017) P12031

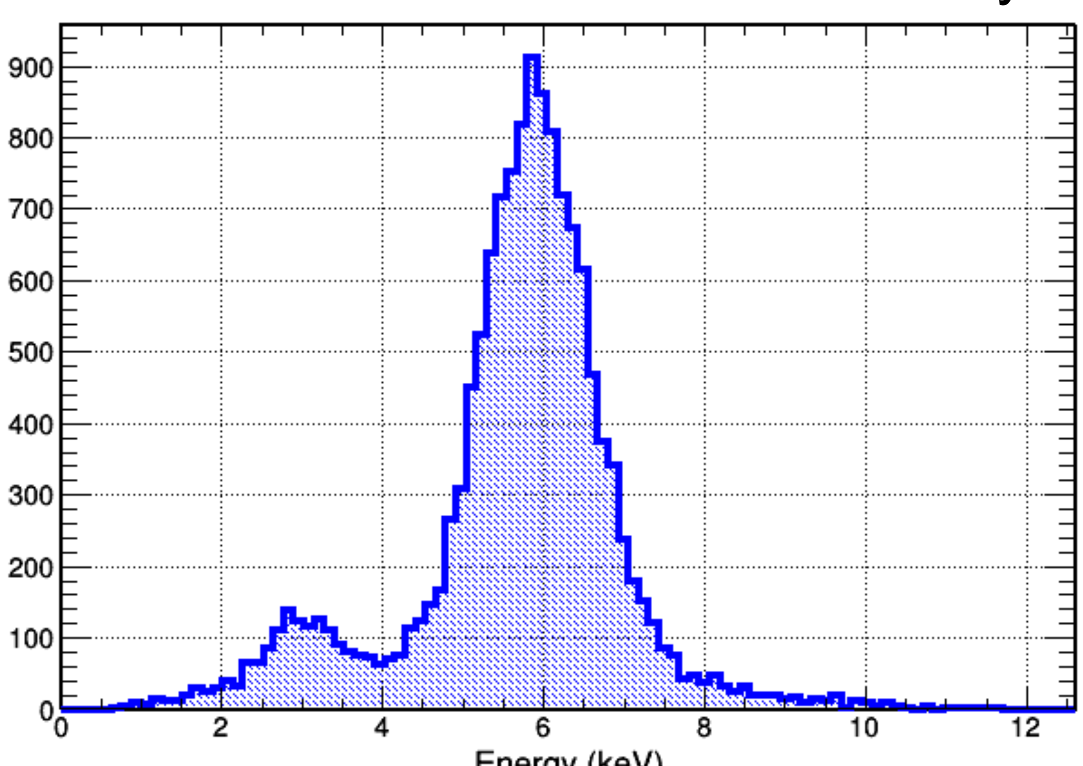




Achinos second generation modules



Measurement of the 5.9 keV ^{55}Fe X-ray line

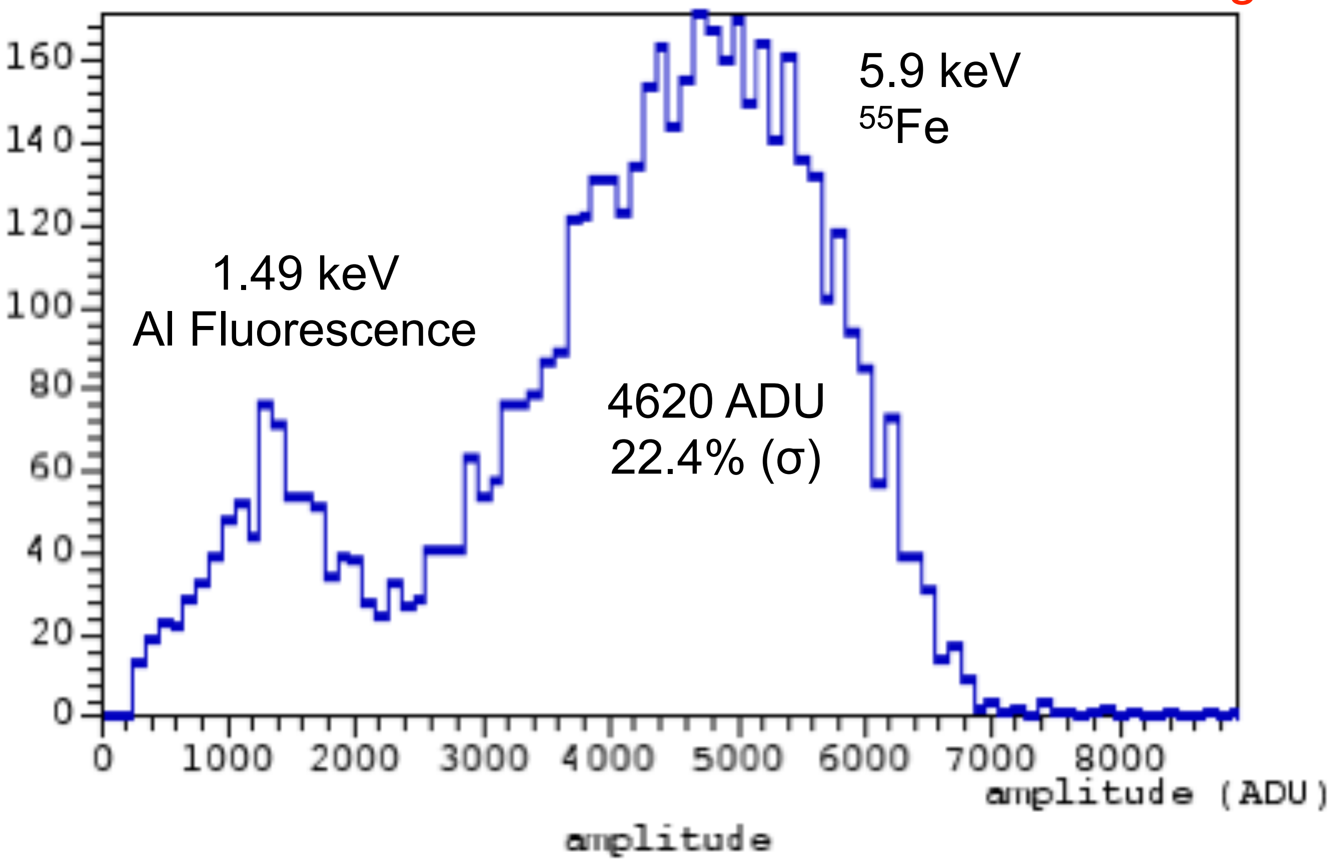


He:Ar:CH4 (56:37:7)
455 mbar
HV1 = 1100 V, HV2 = -100 V
2 mm Ø anodes

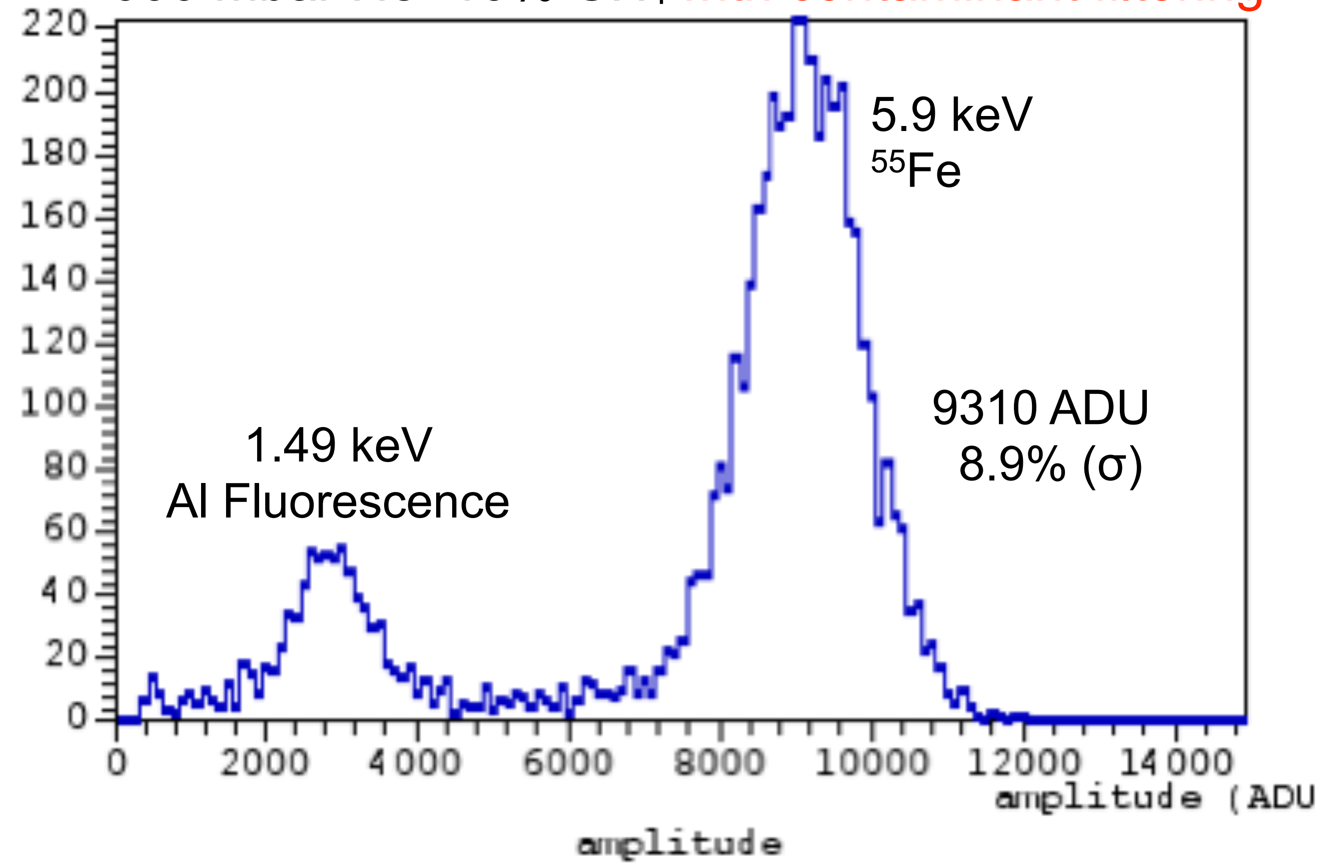
- Good energy resolution
- High pressure operation (~2 bar)
- Resistive layer materials tested:
  - Araldite/Graphite, Araldite/Cu
  - Polymer resistive paste
  - DLC (Diamond Like Carbon)

Gas Purification

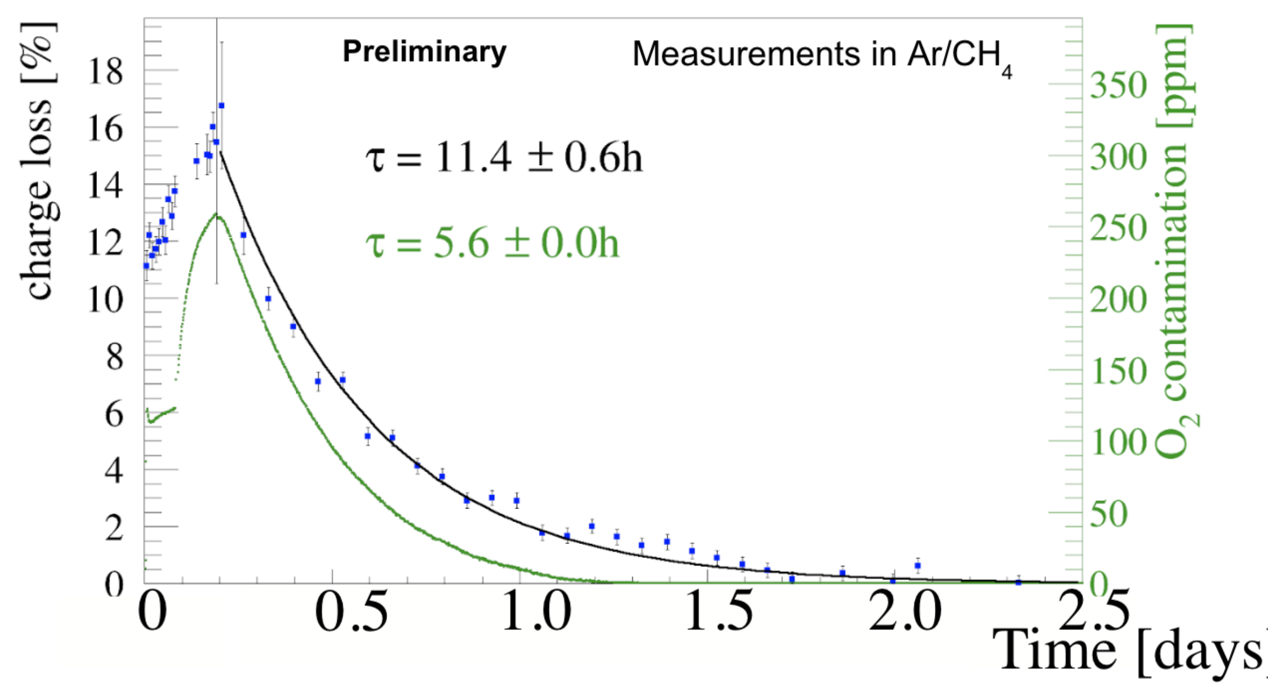
600 mbar He+10% CH_4 without contaminant filtering



600 mbar He+10% CH_4 with contaminant filtering



- Contaminants: O_2, H_2O, electronegative gases
- Filtering with: Getter, Oxysorb
- Filtering in a gas re-circulation system
  - SAES MicroTorr Purifier (MC700 902-F)
  - Incorporated with Residual Gas Analyser
- Improved filtering efficiency in large sphere



Laser Calibrations

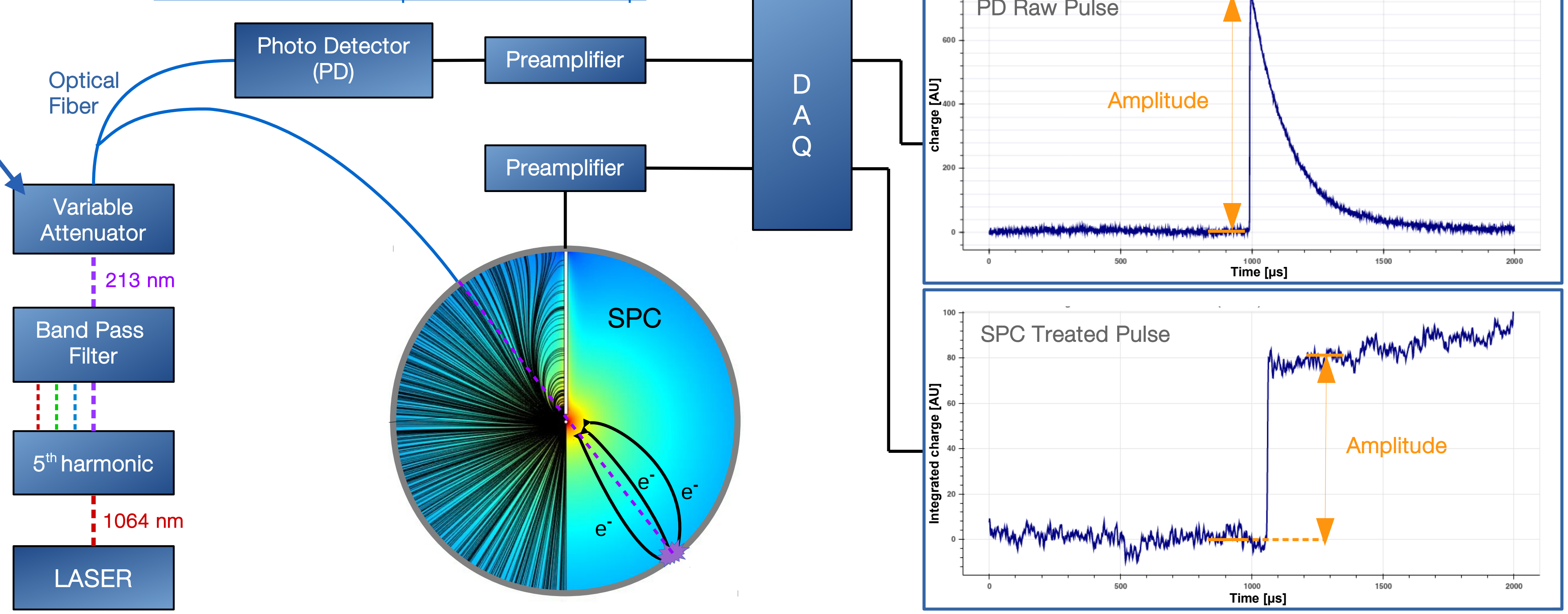
Q. Arnaud et al. (NEWS-G Collaboration), Phys. Rev. D 99, 102003 (2019)

Parallel photo-detector to tag laser events

Tunable transmission to control the mean number of electrons

Common DAQ for timing analysis between two channel

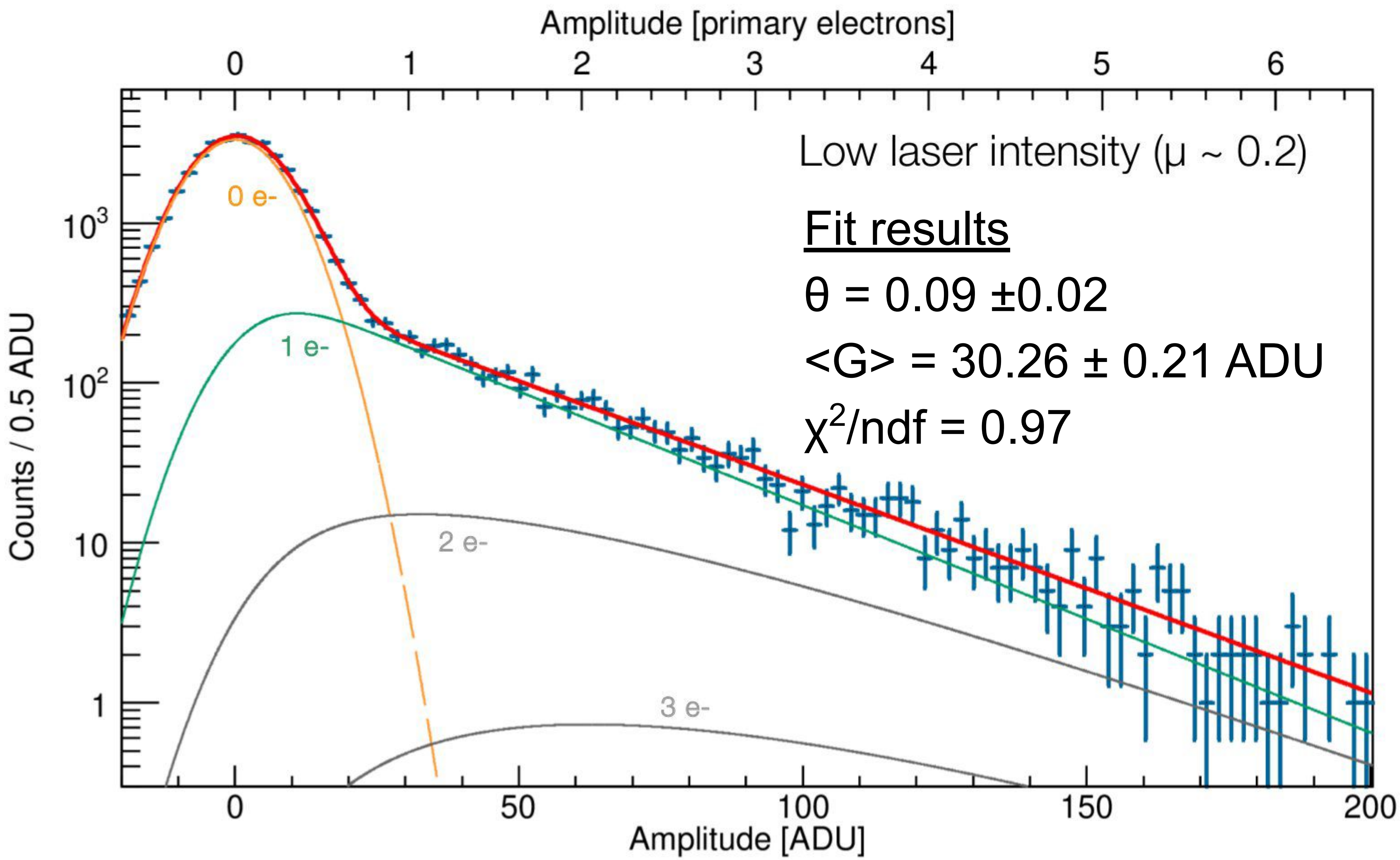
Scheme of the experimental set-up



A powerful UV laser capable of extracting 100s of electrons

- 213 nm laser used to extract primary electrons from wall of SPC
- Photo detector in parallel tags events and monitors laser power
- Laser intensity can be tuned to extract 1 to 100 photo electrons

Modelling Single Electron Response



- N photo-electrons are extracted from the surface of the sphere: Poisson
- Each photo-electron creates S avalanche electrons
- Sum the contributions of all N photo-electrons: N^{th} convolution of Polya
- The overall response is convolved with a Gaussian to model baseline noise

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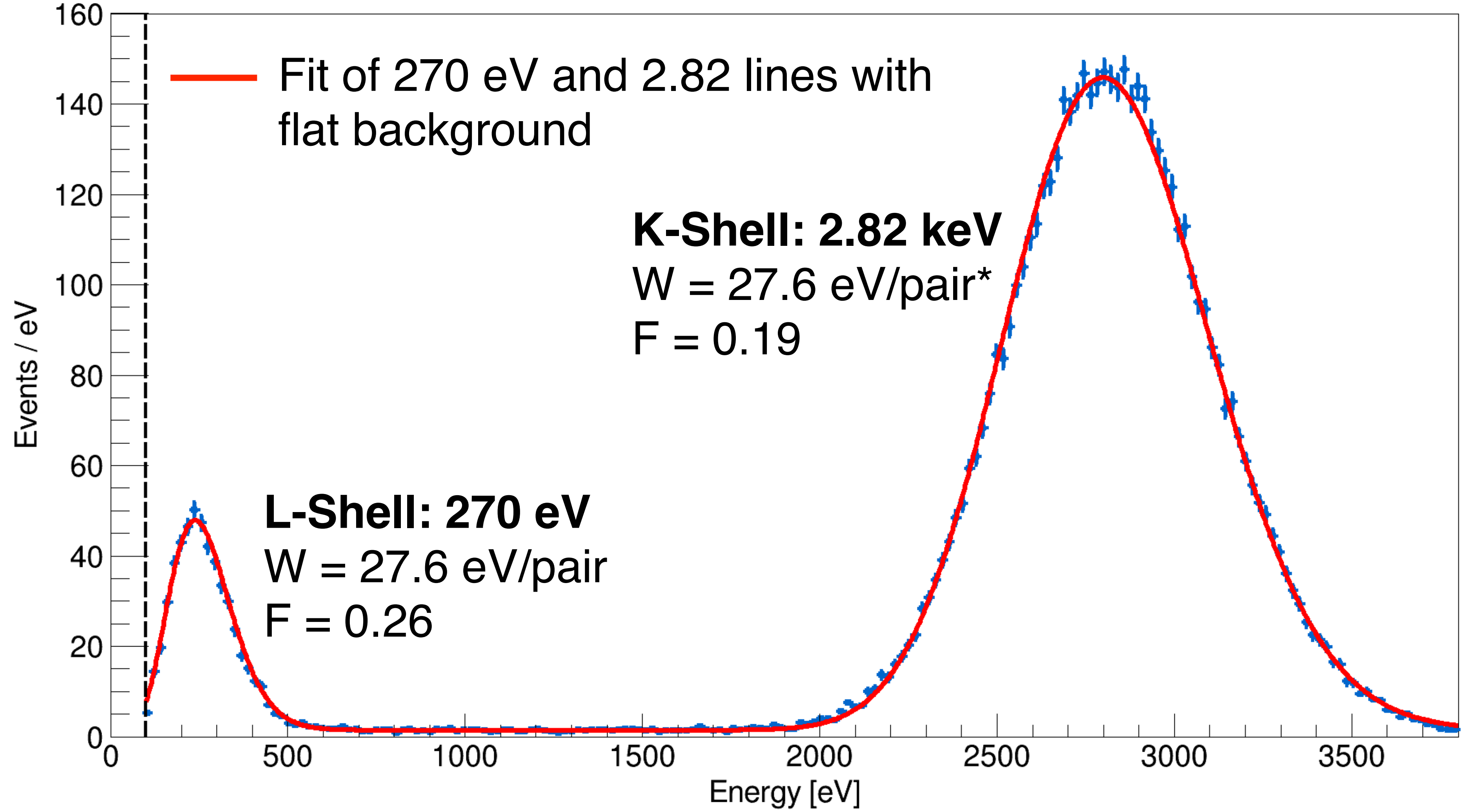
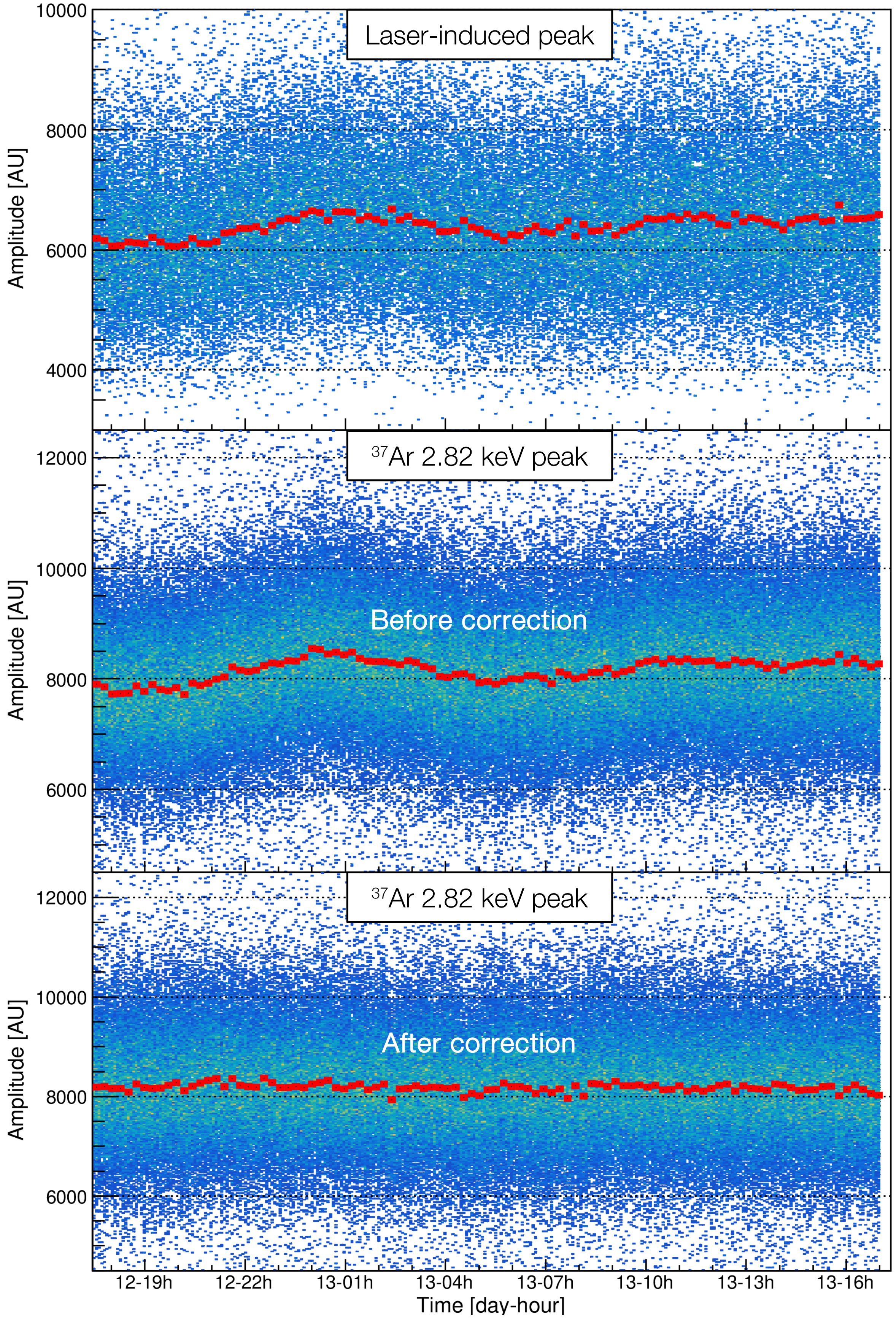
Measurements of gas properties



- ^{37}Ar produced by irradiating Ca power with a high flux of fast neutrons
- Together with laser calibrations, can find W (mean Ionization energy) with 1% precision for target gas, and set upper limits on F (Fano factor)
- Detector response modelled:
  - Primary ionisation (COM-Poisson) D. Durnford et al, Phys. Rev. D 98, 103013 (2018)
  - Avalanche (Polya)

*The W-value at 2.82 keV was calculated directly from <G> and fixed for this fit

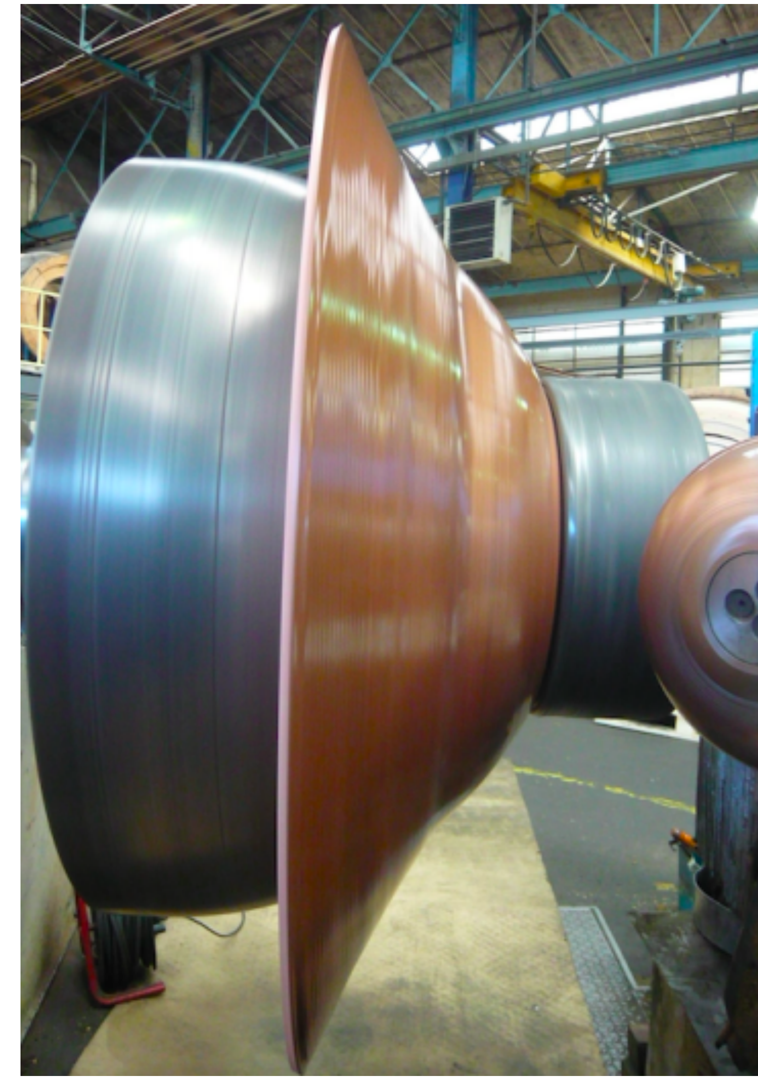
Detector Monitoring

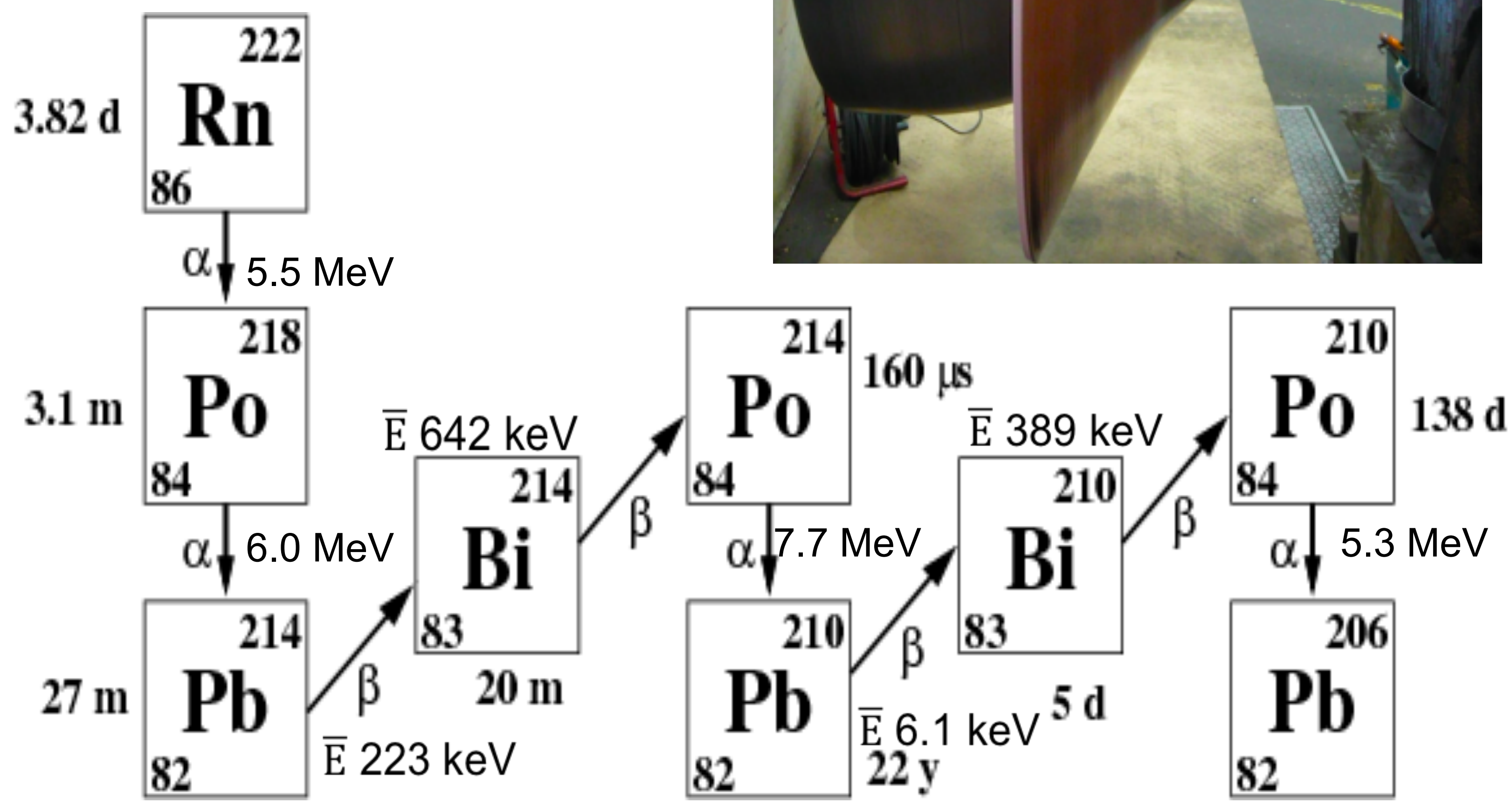


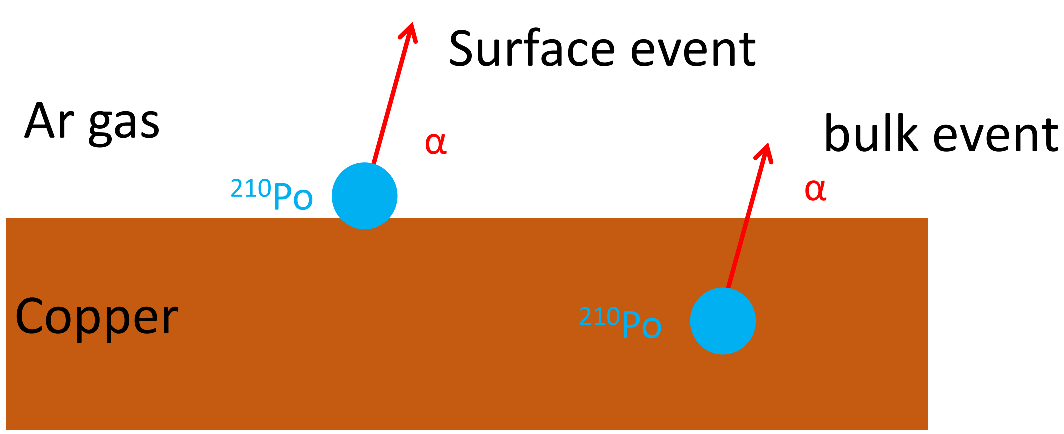
- ^{37}Ar calibrations provide crucial information, but can only be used at the end of a run
- Within a run, gain fluctuations can be induced by temperature/pressure changes, O_2 contamination, sensor damage...
- Laser calibrations provide crucial detector response monitoring during physics runs

Background in NEWS-G copper

- 4N Aurubis copper (99.99% pure)
  - Spun into two hemispheres
- Copper has no long-lived isotopes
- $^{63}Cu(n,\alpha)^{60}Co$ from fast neutrons
  - mostly cosmic muon spallation
- Contaminants: U and Th decay chain traces
  - Measured for NEWS-G ~10 μBq/kg (ICP-MS)
  - ^{210}Pb out of equilibrium - 28.5 mBq/kg (XIA UltraLo)

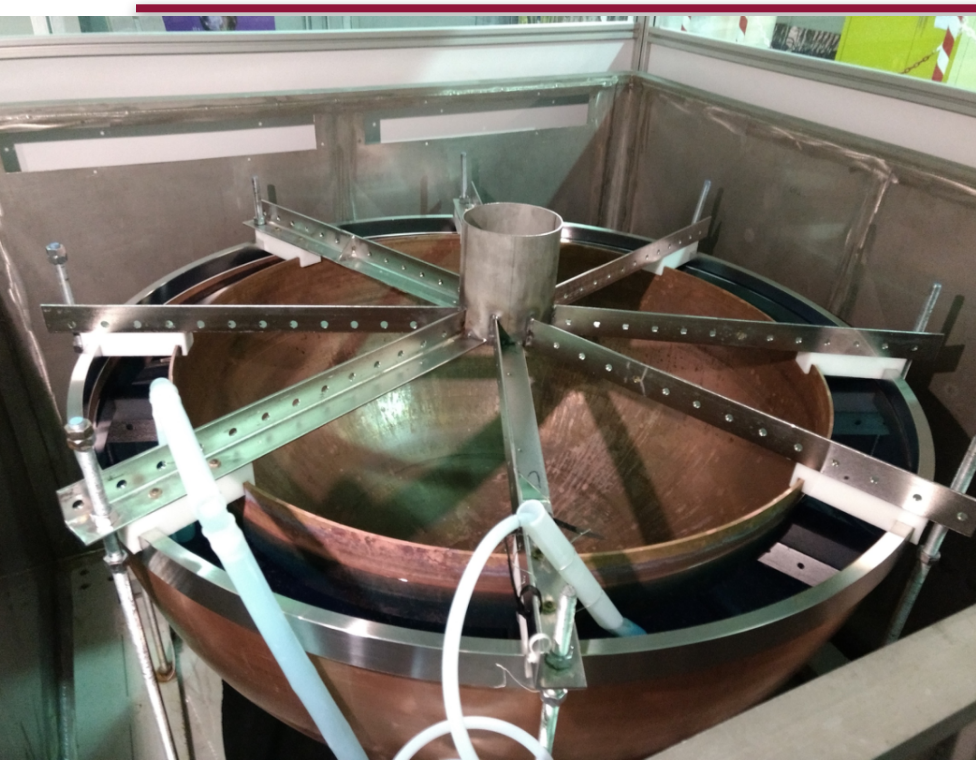






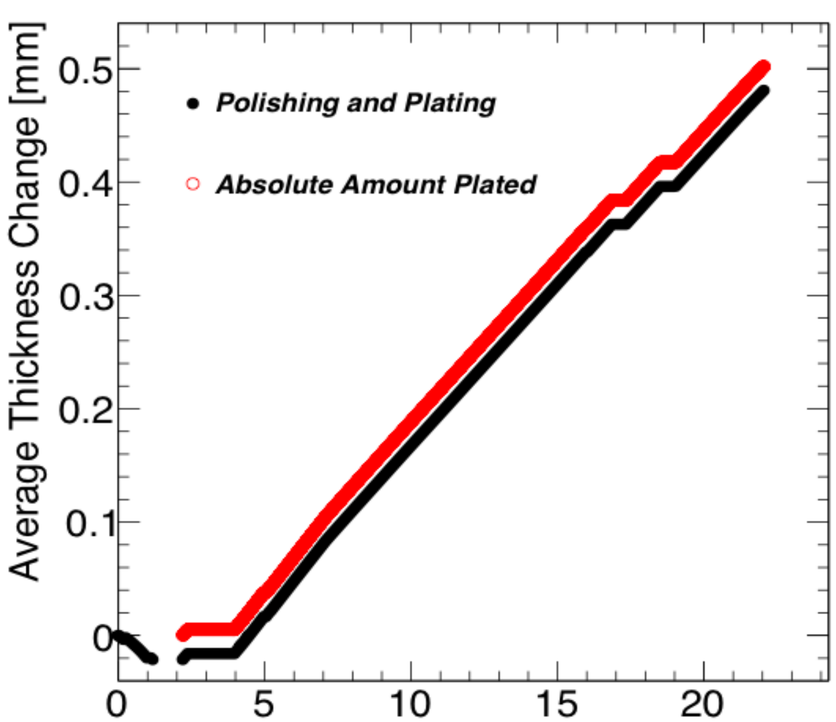
Kobayashi LRT2017

Copper Electroplating



Electroplating setup at LSM

- PNNL expertise in Cu electroforming crucial
- Detector inner surface electroplated
  - 0.5 mm pure copper plated
  - Good surface quality achieved
- Hemispheres electron-beam welded together
- Suppress backgrounds from:
  - Bremsstrahlung X-rays from ^{210}Pb
  - ^{210}Bi β-decays in copper
  - For <1 keV reduced from 4.58 to 1.96 dru
- Copper deposition rate ~36 μm/day
  - Promising: fully underground electroformed detector



Summary

- NEWS-G searches for DM candidates with mass 0.1 – 10 GeV
  - First competitive results with gas detector
- Improved sensitivity to light Dark Matter
  - Lighter targets
  - Improved shield /materials/procedure
  - Lower energy threshold
- Sensor Development
  - Better Electric field uniformity
  - Higher Electric field in large detectors
- Improved gas quality and monitoring
  - Getter, Recirculation, RGA
- Improved calibration and monitoring
  - Laser
  - ^{37}Ar
- Many physics opportunities!

Astropart.Phys. 97 (2018) 54-62

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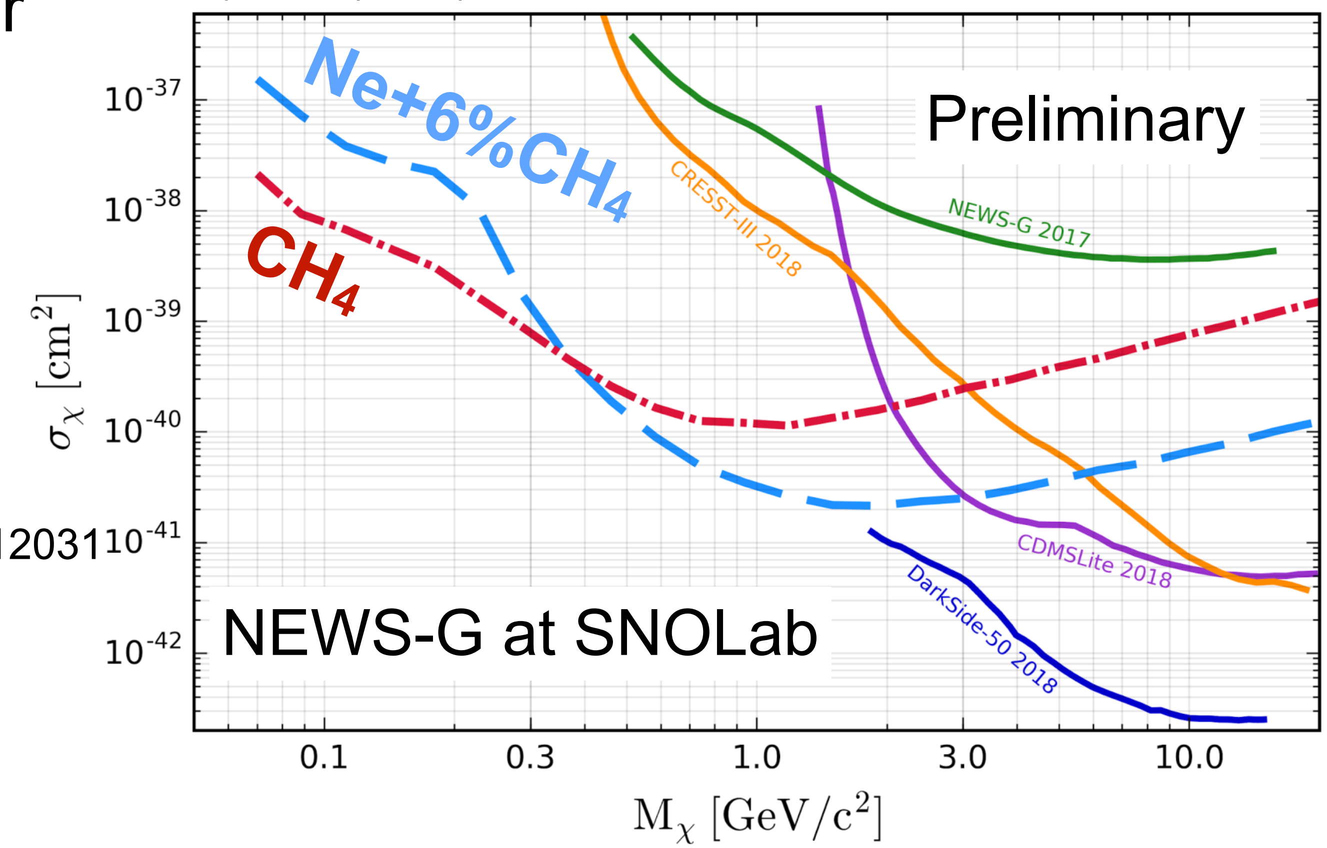
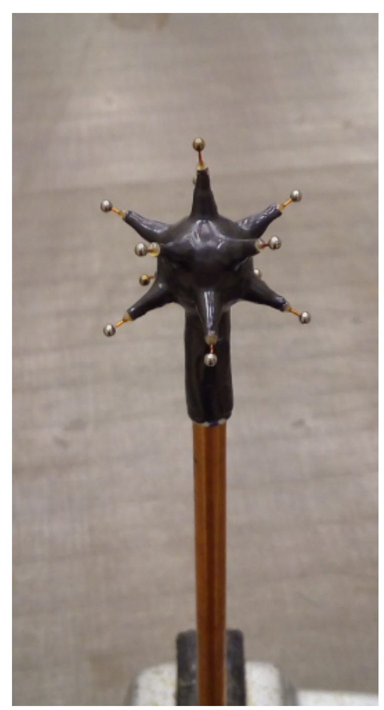
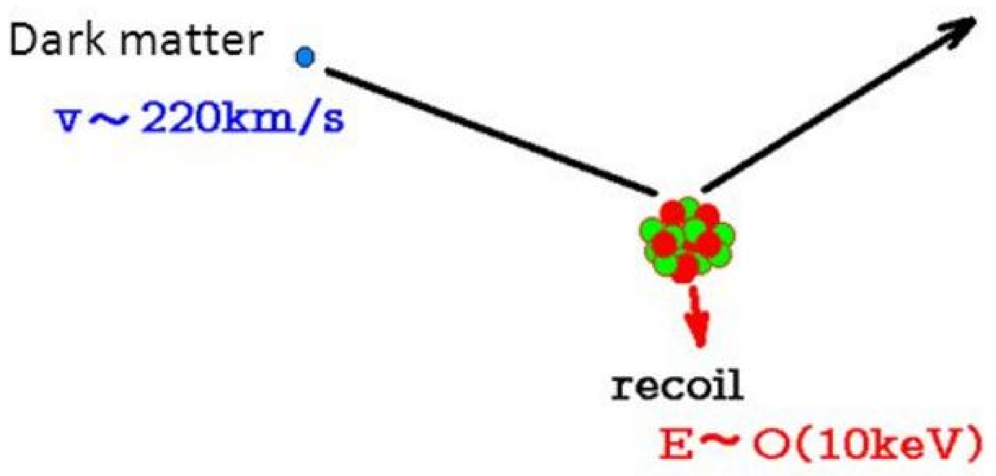




Additional Slides

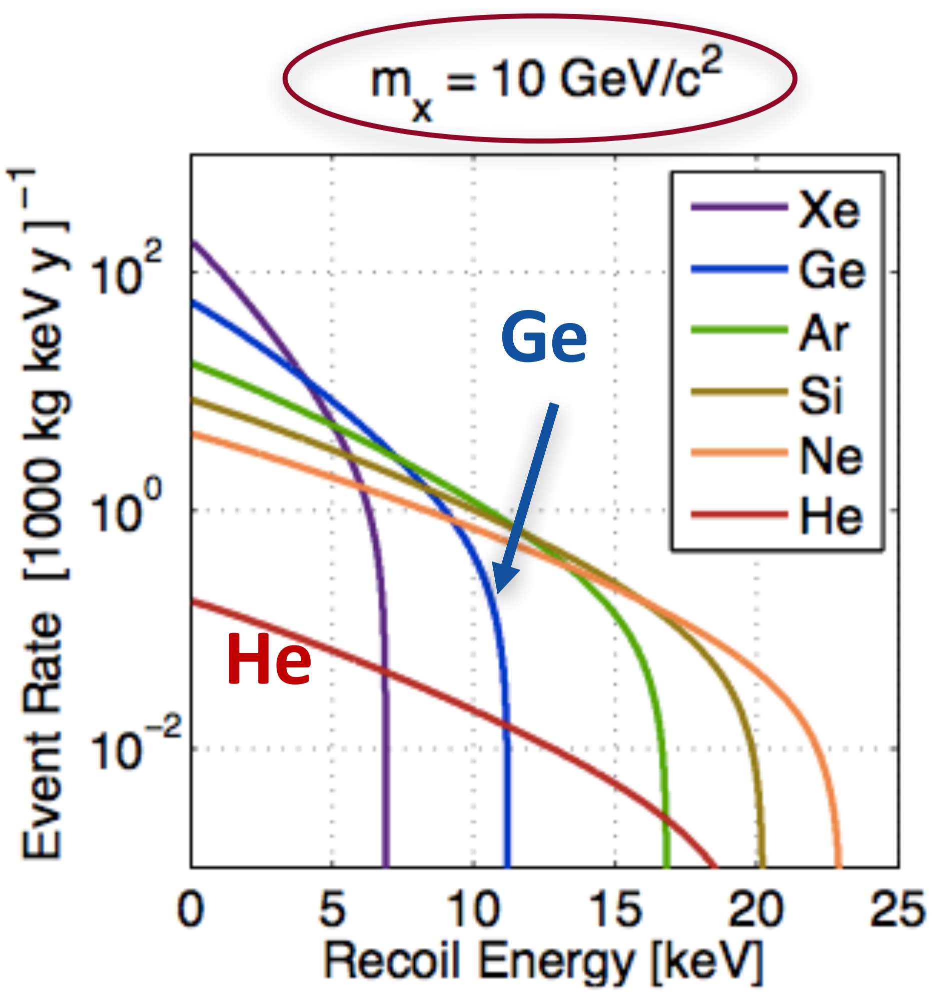
Searching for light DM: Recoil Energy

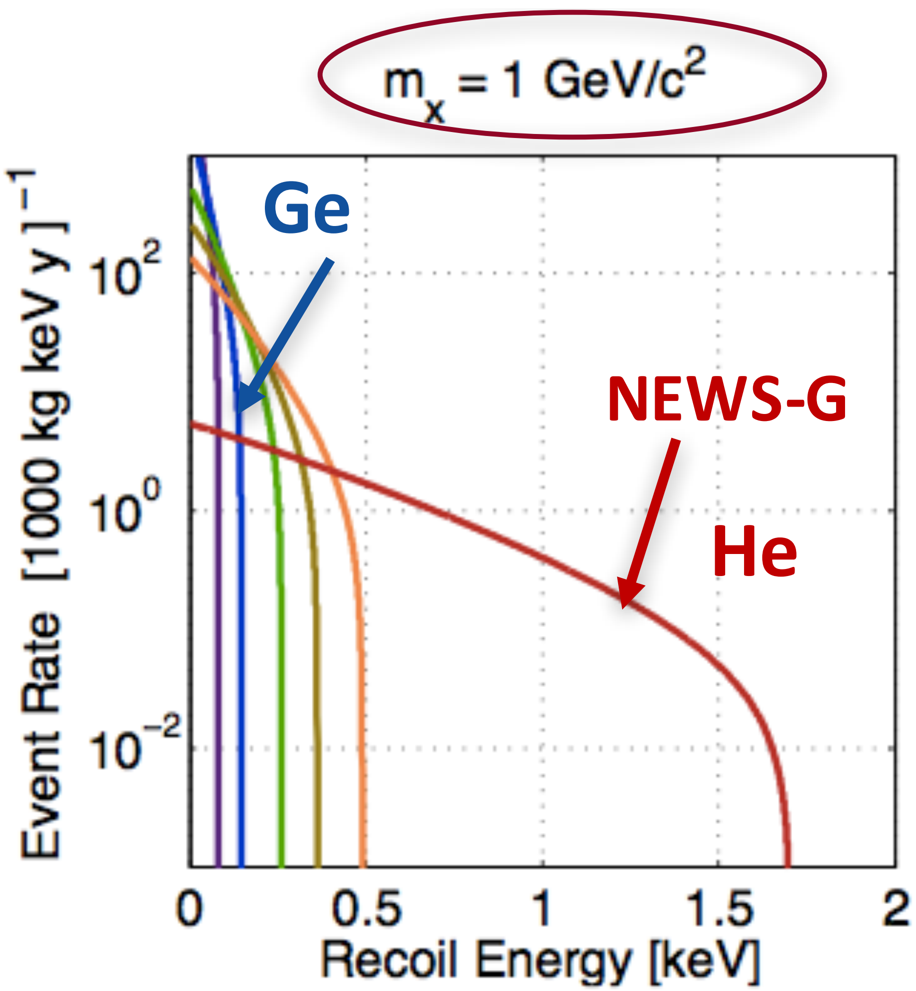


Recoil energy during DM scattering, E_R:

$$E_R = \frac{1}{2} m_\chi u^2 \frac{4 m_\chi m_N}{(m_\chi + m_N)^2} \frac{1+\cos\theta}{2}$$

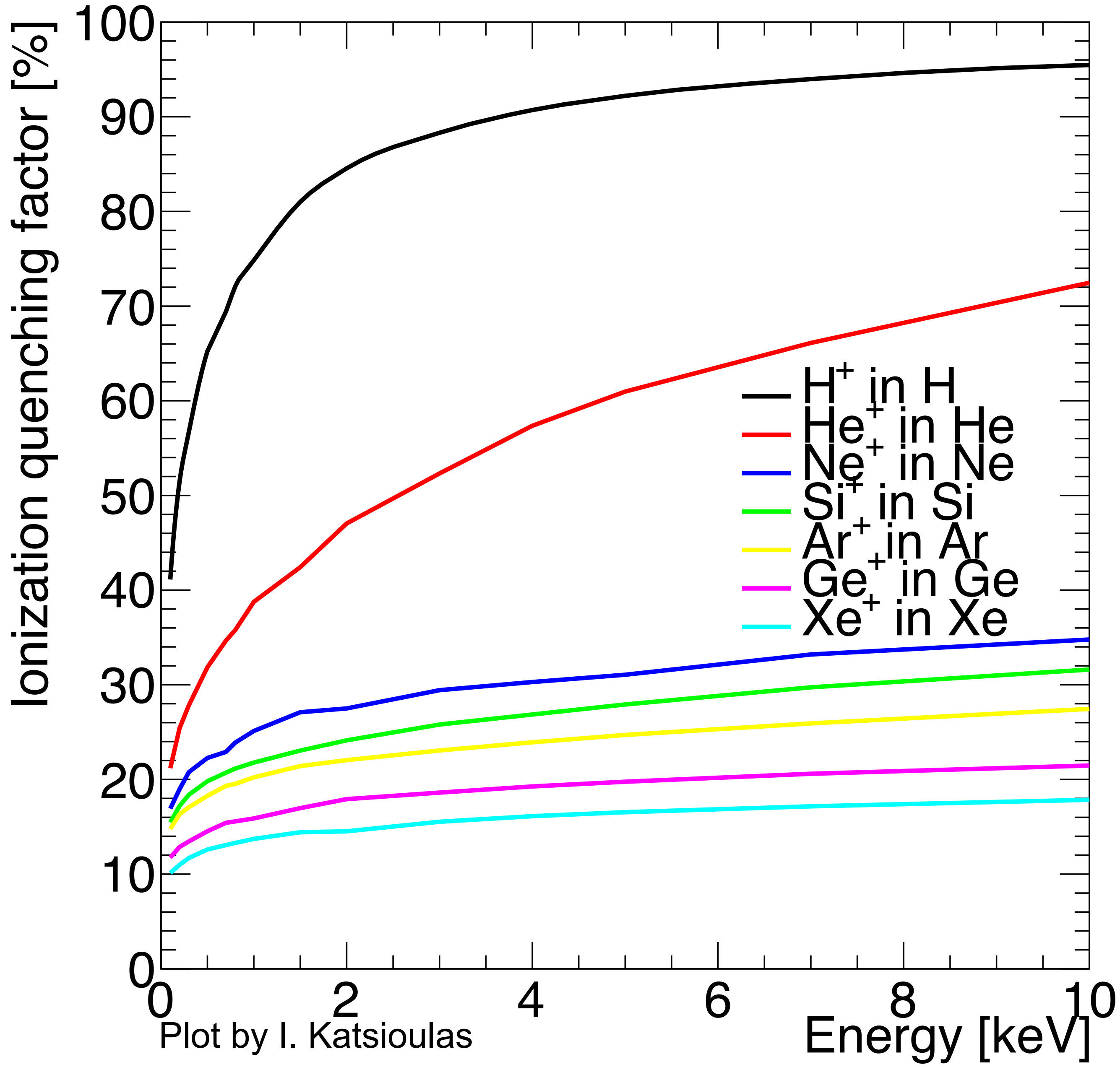
max E_R: head-on-collision and $m_\chi = m_N$





Searching for light DM: Quenching Factor

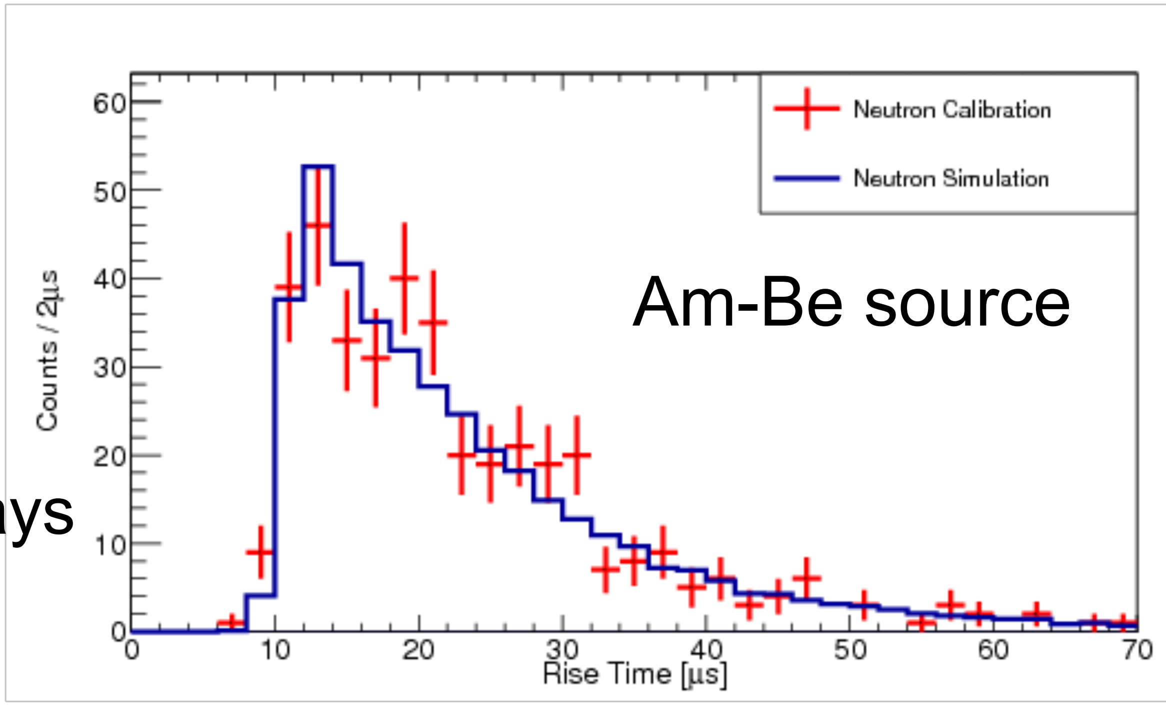
- Quenching factor: fraction of ion kinetic energy dissipated in a medium in the form of ionization electrons and excitation of the atomic and quasi-molecular states.

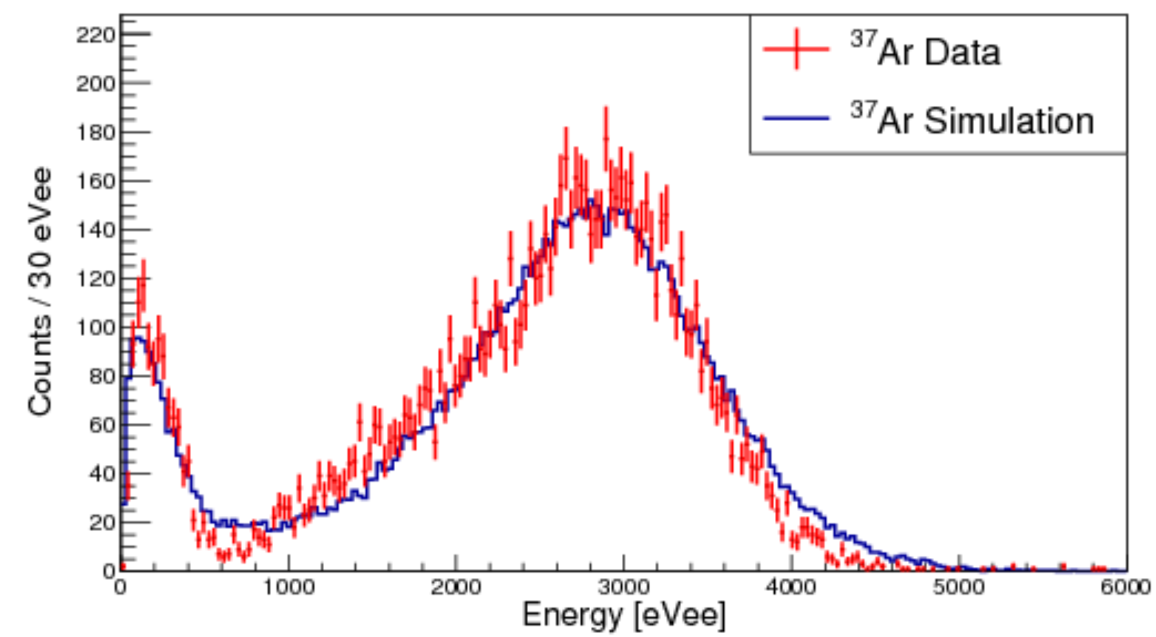


- Direct detection experiment using light gases as target (H, He, Ne)
  - Better projectile-target kinematic match
  - Favourable quenching factor

SEDINE: Data taking conditions

- **Target:** Neon + 0.7% CH_4 at 3.1 bar (282 gr)
- **Run time:** Continuous data taking for 42.7 days
  - **Exposure:** 34.1 live-days x 0.282 kg =9.6 kg.days
- Anode high voltage 2520 V, no sparks
  - Absolute Gain ~3000.
  - Loss of gain 4% throughout the period
- Sealed mode, no recirculation.
- **Read-out:** Canberra charge sensitive preamplifier (τ_{RC}=50 μs)
- **Calibration:** ^{37}Ar gaseous source,8 keV Cu fluorescence line, AmBe neutron source





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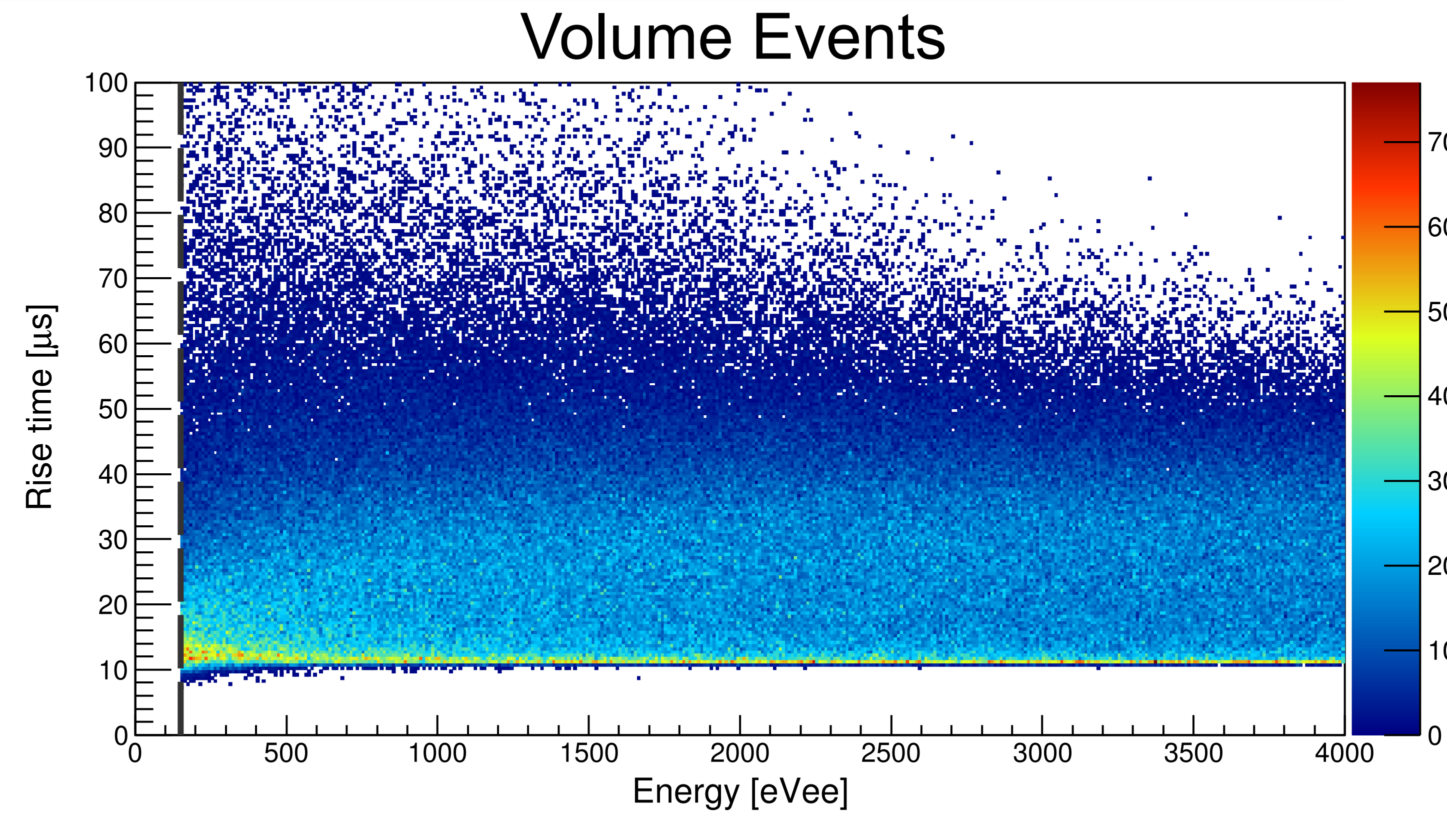
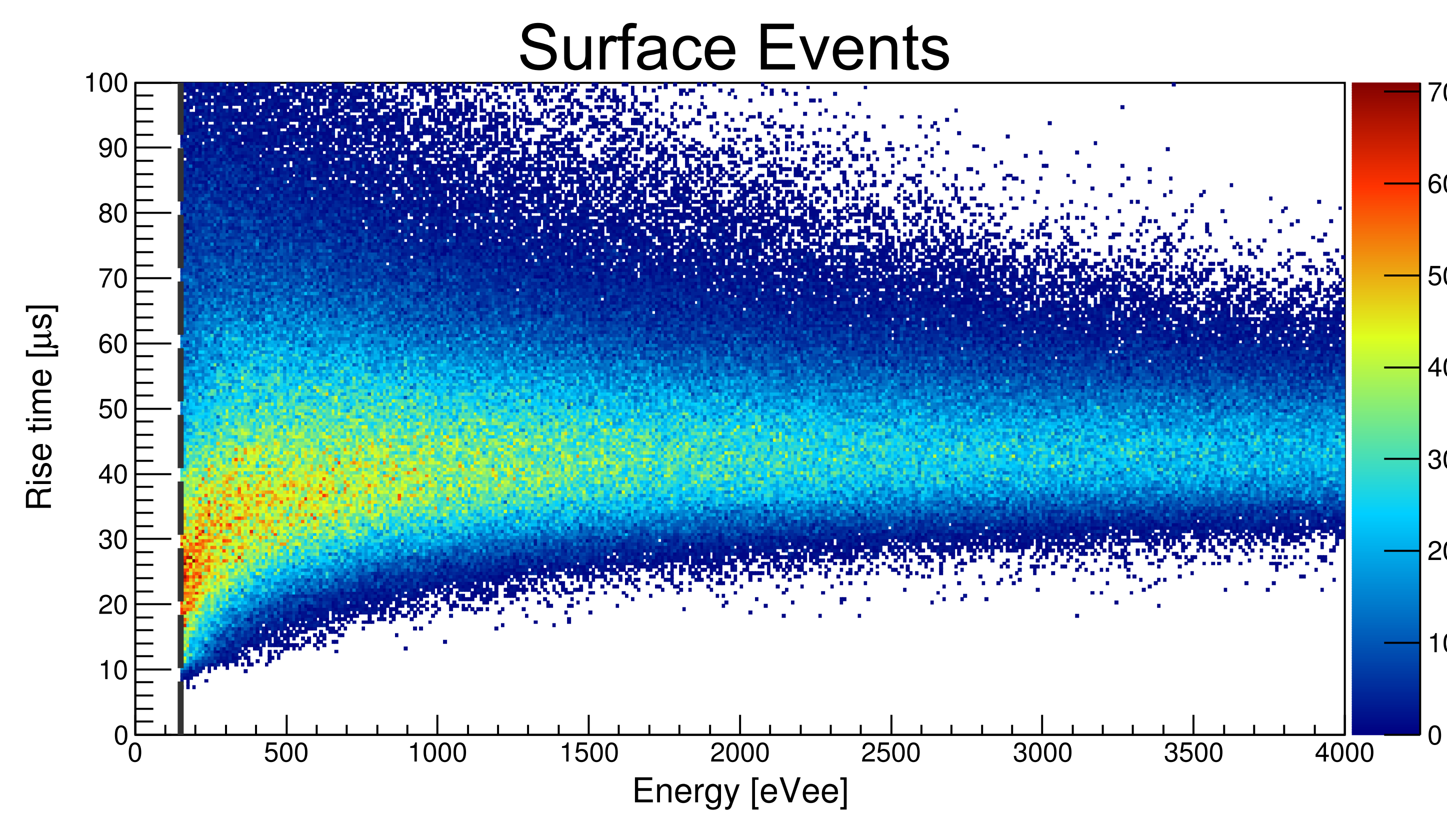
SEDINE: Background simulation

- Anticipated main backgrounds:
  - Volume: Compton electrons
    - ^{208}Tl and ^{40}K in the rock
    - ^{238}U, ^{232}Th, and ^{60}Co copper shell/shielding
  - Surface: Radon decay products
  - Chemical Cleaning (nitric acid)
    - >200eV: 180 mHz → ~2mHz
    - <200eV: 400 mHz → ~20mHz
- Pulse simulations include:
  - Electric field (FEM)
  - Diffusion (Magboltz)
  - Avalanche process
  - Signal induction
  - Preamplifier response





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SEDINE: Event Selection

- Analysis threshold: 150 eVee (~720 eVnr)
- 100% trigger efficiency (threshold @ ~35 eVee)
- Optimised Signal Region determined with Boosted Decision Tree (8 candidate masses)
- 1620 events selected in preliminary ROI
  - Failed BDT
  - Pass 0.5 GeV BDT: 15 events
  - Pass 16 GeV BDT: 123 events
  - Pass BDT for other masses