ARTIE (near)-final results

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on the behalf of the ARTIE Collaborations

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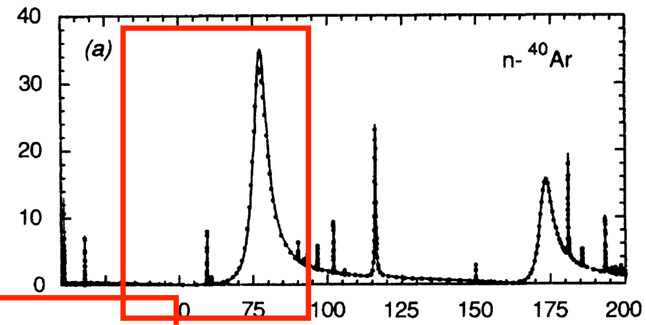
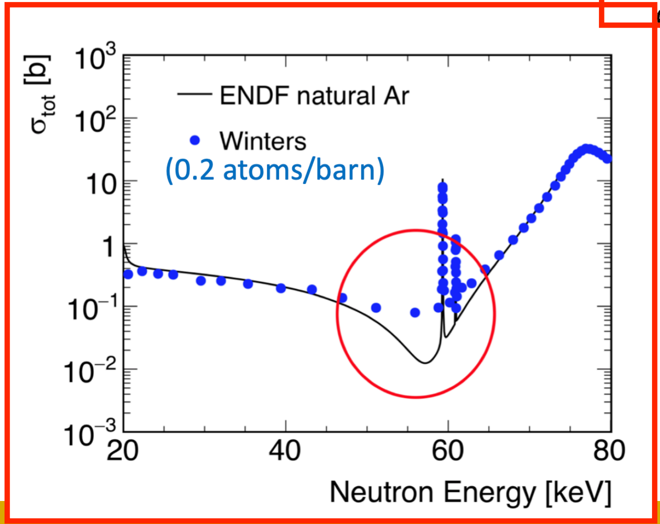
Reminder: why and what's ARTIE?

- ARTIE @ LANL (Flight path 13): 10-20th October 2019
- ARTIE's goal is to measure the 57 keV neutron anti-resonance using a liquid argon target (previous experiment did not see the anti-resonance at 57 keV, but may not have been sensitive enough) and TOF technique





Reminder: how to calculate cross section

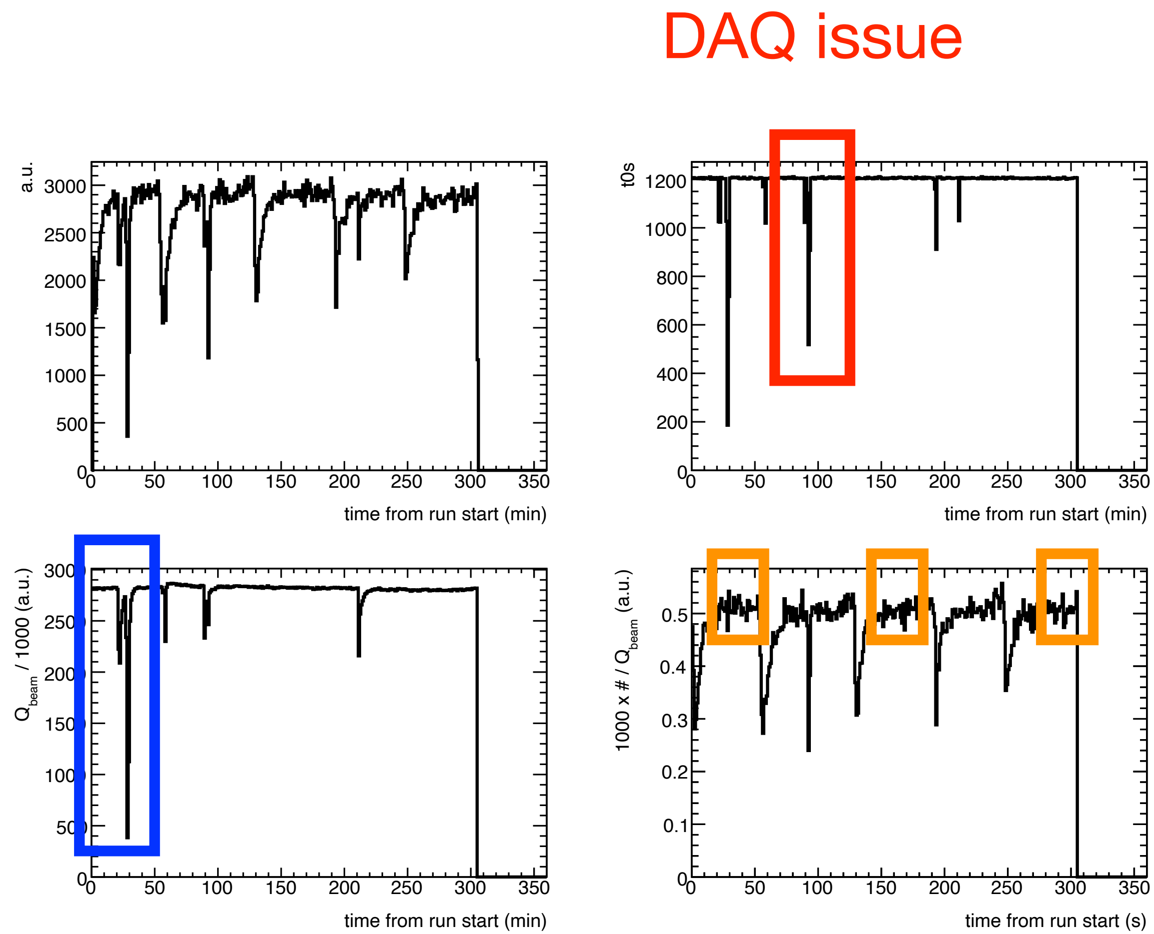
- Consider data taken with target in (i) and target out (o)
- Transmission coefficient can be determined via
  $\mathbf{T = (C_i - B_i) / (C_o - B_o) * Q_o / Q_i}$
  where:
  - $C_i(o)$ are the counts recorded with target in(out)
  - $B_i(o)$ are the background counts determined with target in(out)
  - $Q_i(o)$ is the total # of neutrons during the run with target in(out)
- Given T, the cross section can be calculated as
  $\boldsymbol{\sigma = - \ln T / n}$ where
  - n is the “density” of the target in atoms/b
  - $n = L\,[\text{cm}] * N_A\,[\text{atoms/mol}] * \rho\,[\text{g/cm}^3] / m_A\,[\text{g/mol}] * 10^{-24}\,\text{cm}^2 / \text{b}$

Possible source of systematics

- Major:
  - Beam-Target alignment
  - Background subtraction
  - Effective target density
  - Ice build up
- Minor:
  - External temperature bias
  - Afterpulses and dead-time
  - Liquid argon contamination
  - Other experiment background
  - Others?

Run quality cut and beam-target alignment

- Consider rune where target was filled with LAr
- 2 main plots to determine run quality:
  - **t0s:** help identify possible DAQ issues
  - **# / Q_{beam}:** where to look for stable data period
- Keep only stable periods

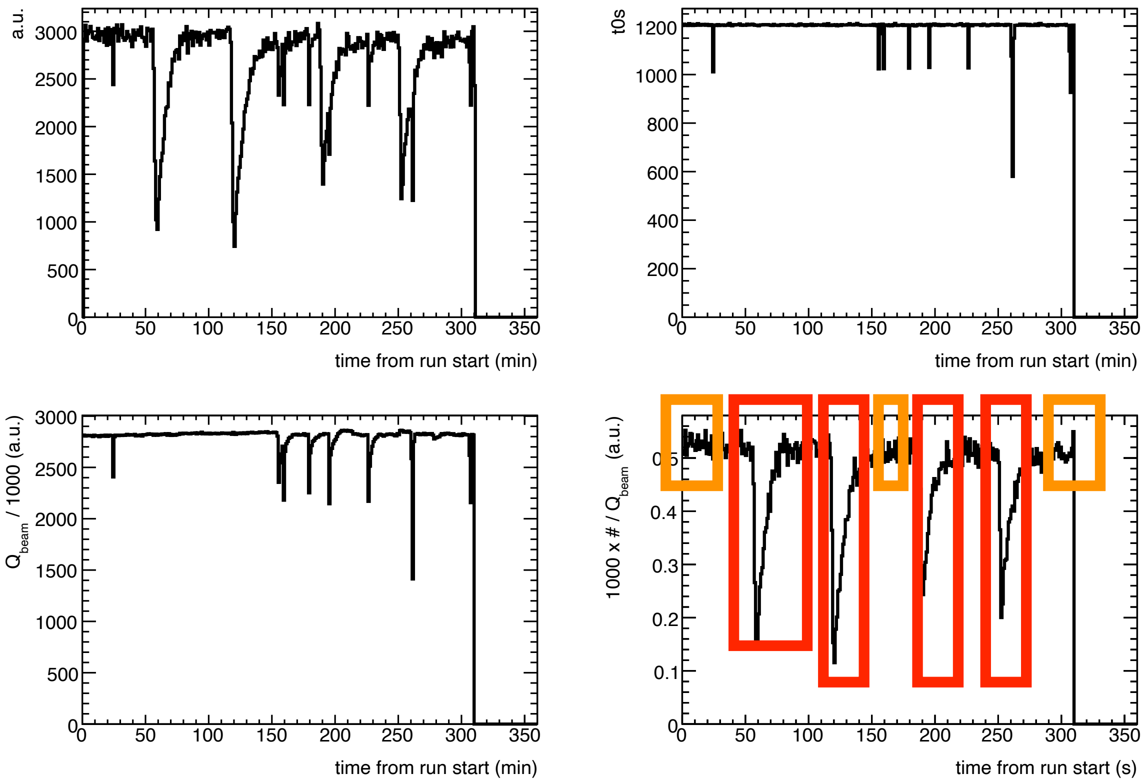


Beam fluctuations

Work done by J. Huang and L. Pagani

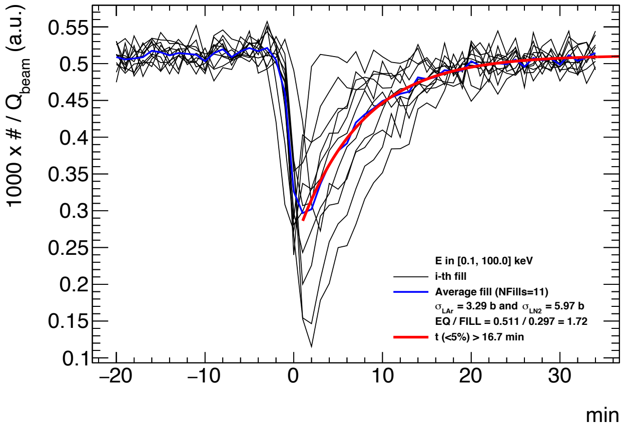
Run quality cut and beam-target alignment

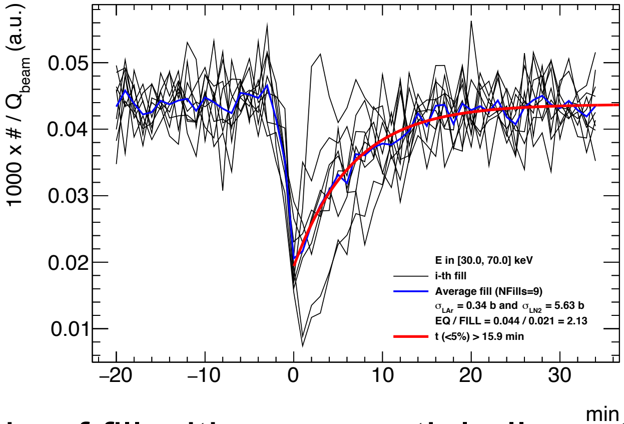
- Dips in event rate are due to LAr refills (correspondence with logbook)
- But … drop between equilibrium (**EQ**) and fill (**FILL**) is to big to be explained by only difference in gas content in the target
- What is causing it?

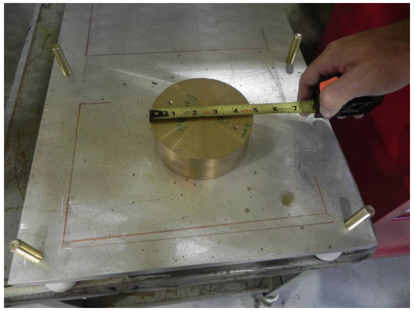


Run quality cut and beam-target alignment

- Change in rate is **energy independent**: most probable cause is misalignment
- During filling brass collimator downstream the target get expose to cold vapor and splashes
- Δt~200K causes ~0.5mm shrinkage cutting a good portion of neutron bunch
- **Alignment is very sensitive**: it took 3 days and very careful not to move/ touch the target



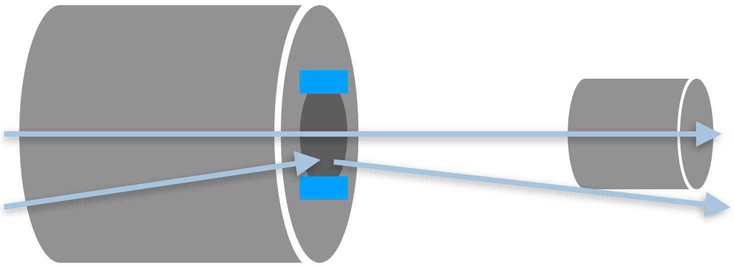




- Run quality cut: fit right end side of fill with exponential allows to determine after how much time misalignment becomes negligible: ~16 min (+9 min safety period) for total 25 min
- Quality cut results: out of 176 h of data taking, ~21 h are discarded by this cut
- Next: (TODO) play with the cut and see how this affect final determination of cross section

Background subtraction

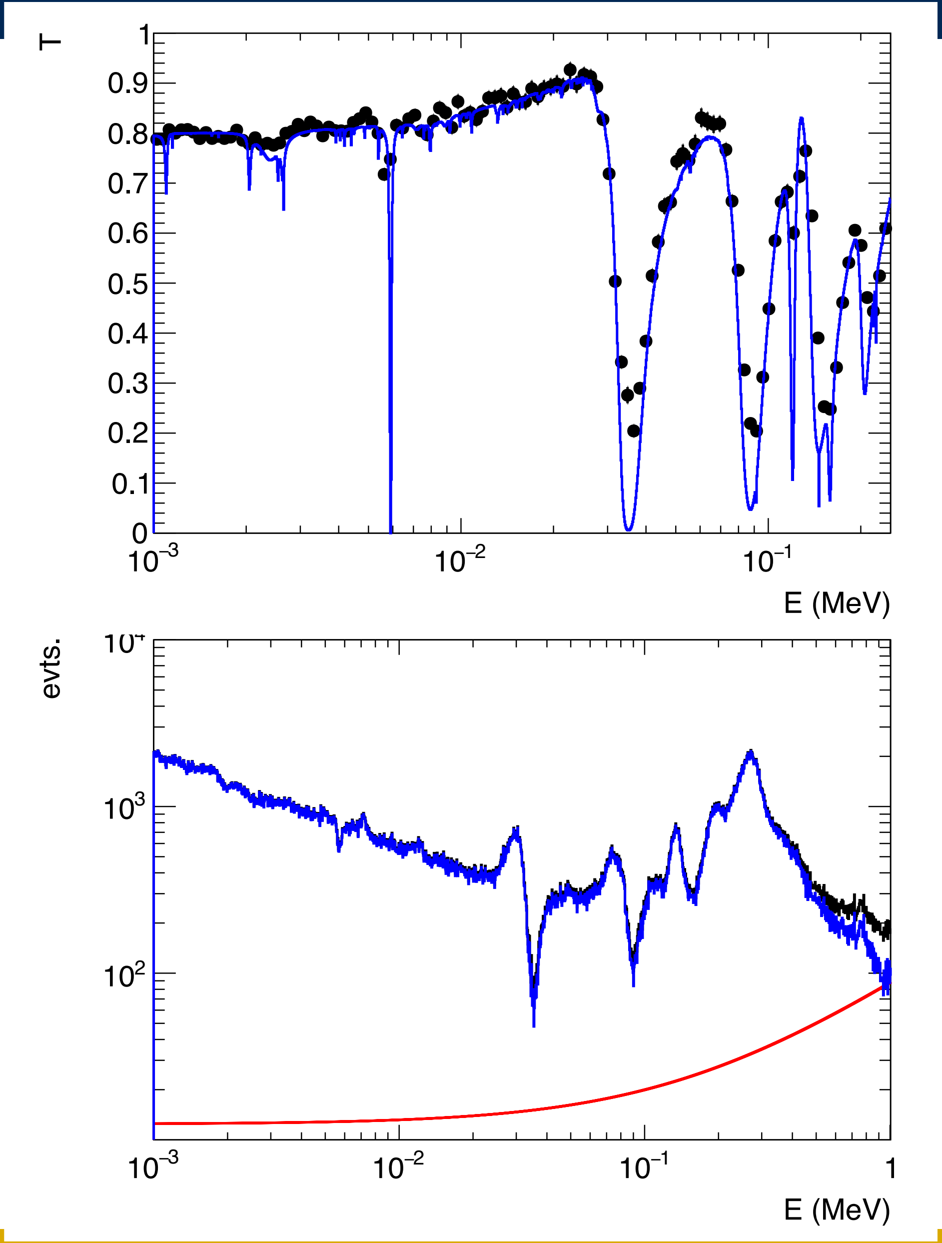
- Background estimated using "black-resonance" technique by looking at places where transmission coefficient is T=0
- Look aluminium and argon run
- Background estimation:
  - Measured: $T_M = C_i / C_o * Q_o / Q_i$
  - Real:
    $T_R = (C_i-B_i) / (C_o-B_o) * Q_o / Q_i =$
    $= T_M (1-B_i/C_i) / (1-B_o/C_o)$
  - If $B_i \geq B_o$ then $B_o \leq C_o*(T_M-T_R) / (1-T_R)$



Work done by L. Pagani and J. Wang

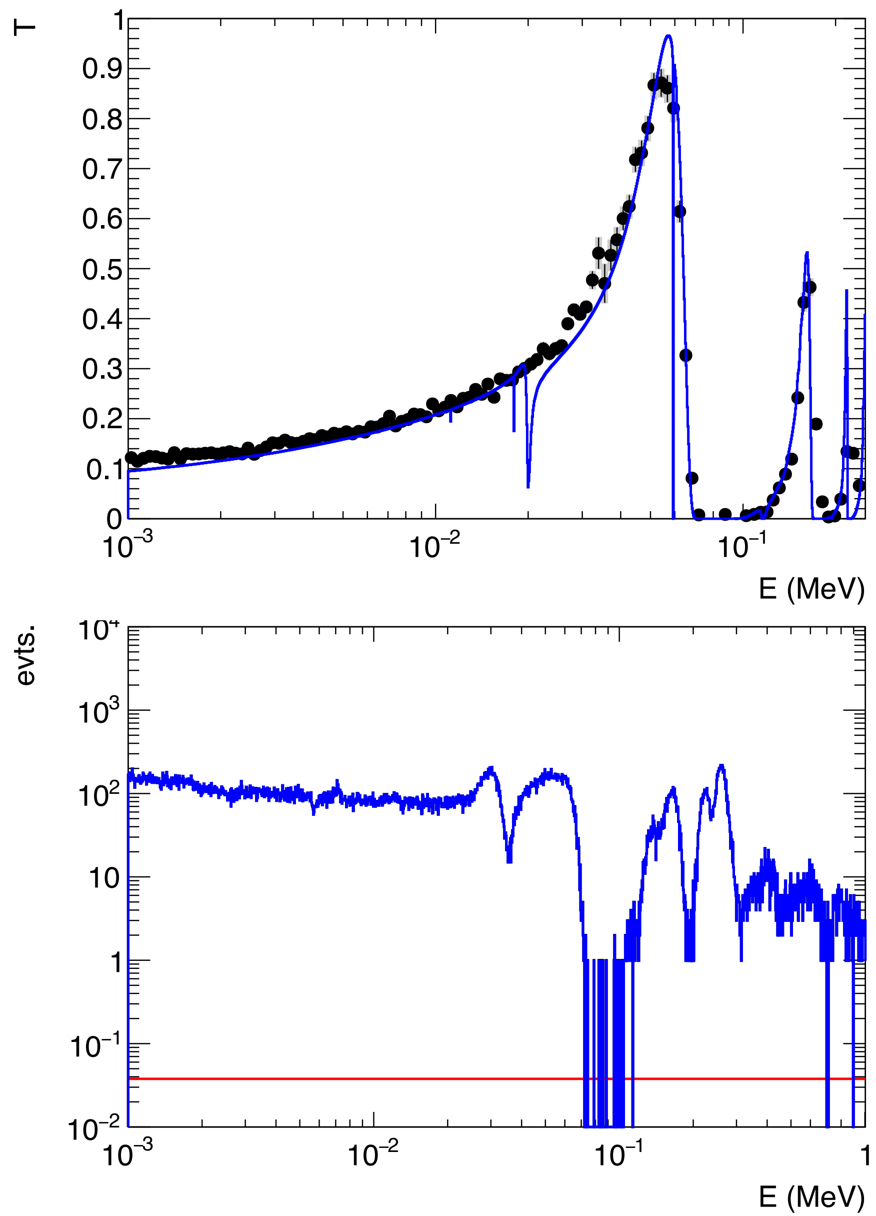
Target out background: aluminium

- ENDF cross section converted to transmission coefficient via n
- T from data obtained by comparing run with Al disks vs. runs where ARTIE target was flushed with gases argon
- At 35 and 88keV expected T=0.006 and 0.05 but 0.19 and 0.18 measured
- Event excess due to background: assumed linear background in [35,88]keV
- Background contribution small (consistent with other experiment) - only stat error: ~0.5%



Target out background: aluminium

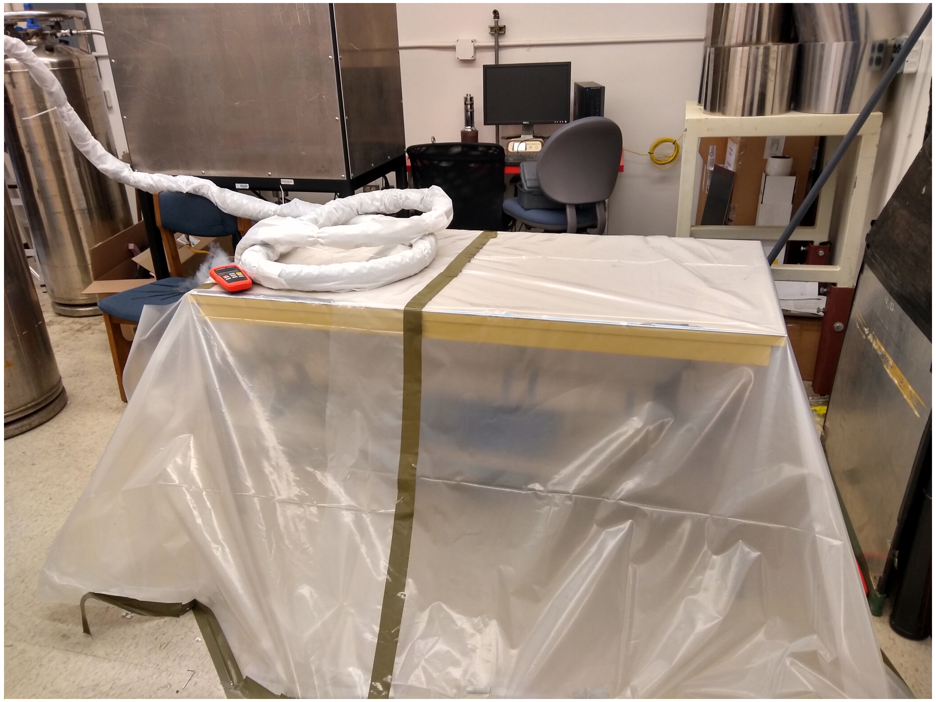
- ENDF cross section converted to transmission coefficient via n
- T from data obtained by comparing run with LAr vs. runs where ARTIE target was flushed with gases argon
- At 76keV expected T=9E-49 but 6E-3 measured
- Event excess due to background: assumed linear background around 76keV
- Background contribution small (≪1) - only stat error: ~0.5%



Bubbles in argon

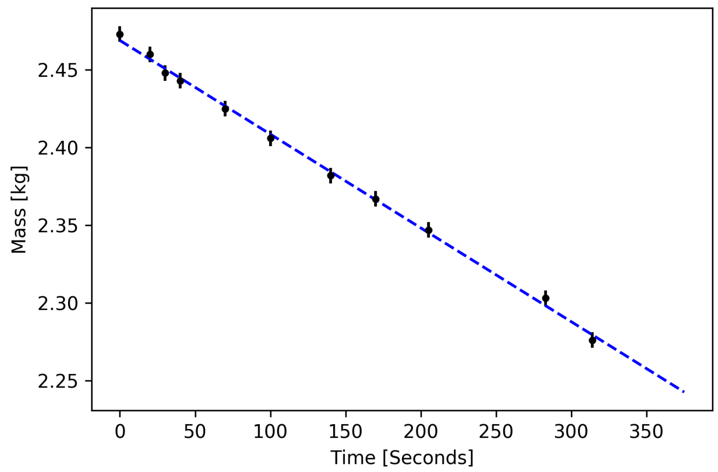
- Due to the ARTIE target not being pressurized nor vacuum insulated, LAr boil off must taken into account when determining effective density
- Effective density measurements: 3 parameters are needed (see later eq.):
    1. mass of the empty target
    2. mass of the filled target (m) and
    3. volume of LAr inside the target (V_{tot}-V_{GAr})
- Experiment: fill the target with LAr and then allow it to boil off naturally, all the while taking mass and liquid level measurements. Measure mass of the target (via precise scale ±1g) and total volume inside the target (calibrated liquid level reference) as function of time
- Given $m = \rho_{LAr} V_{LAr} + \rho_{GAr} V_{GAr}$ and $V_{tot} = V_{LAr} + V_{GAr}$
- Volume of gas:
  $V_{GAr} = (V_{tot}\ \rho_{GAr} - m) / (\rho_{LAr} - \rho_{GAr})$
- Effective density: $\boldsymbol{\rho_{eff} = \rho_{LAr} (V_{tot} - V_{GAr}) / V_{tot}}$

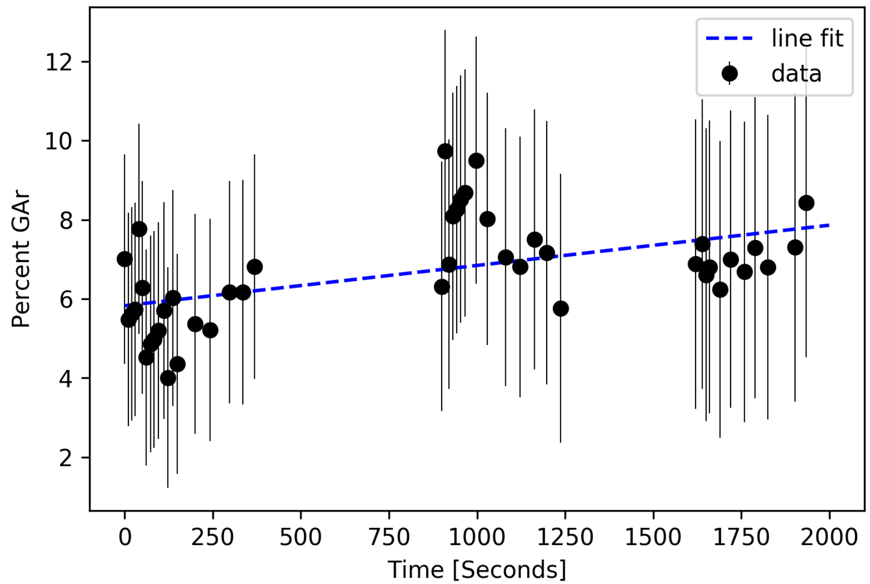
Work done by T. Erjavec and Y. Bezawada



Bubbles in argon

- Simultaneous measurement of mass and liquid level as function of time allows to calculate boiling off rate: ~1.6 L/h compatible with theoretical prediction and what experienced at LANL. Able to reproduce ARTIE data tacking conditions
- Boiling off rate → estimate fraction of GAr present in the target used to determine effective density
- On average, GAr fraction is ~7% yielding:
  ρ_{eff} =1.308±0.016$_{(stat)}$±0.012$_{(sys)}$ kg/cm^3
- Note: stematic error accounts for scale sensitivity, volume calibration, and estimated ice build up





Work done by T. Erjavec and Y. Bezawada

Ice build up

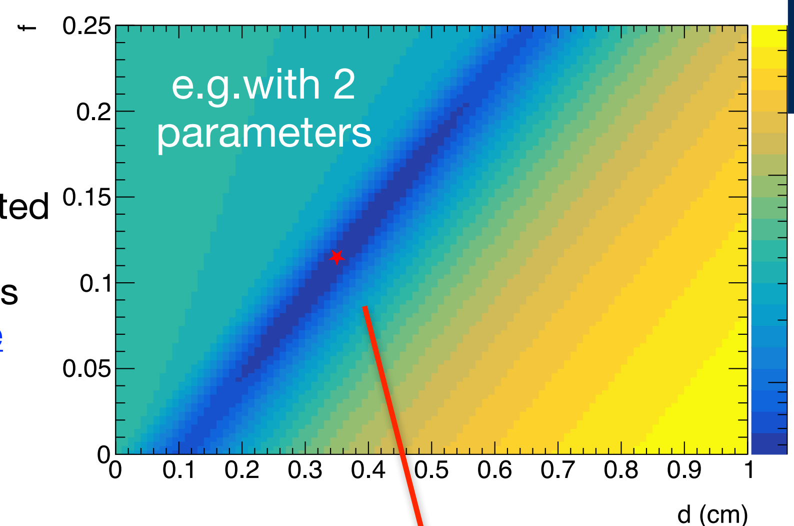
- Despite efforts to flush the target's end-cap Kapton windows with gaseous nitrogen, a thin layer of ice formed on the collars
- Ice layer thickness assessed by considering data before (ice layer at its thickest) and after (windows free of ice) warming up
- À la Ar cross section, transmission coefficient can be calculated as **T = Ci / Co * Qo / Qi** and $\mathbf{T = e^{-n\sigma}}$ where n depends on ice layer thickness d

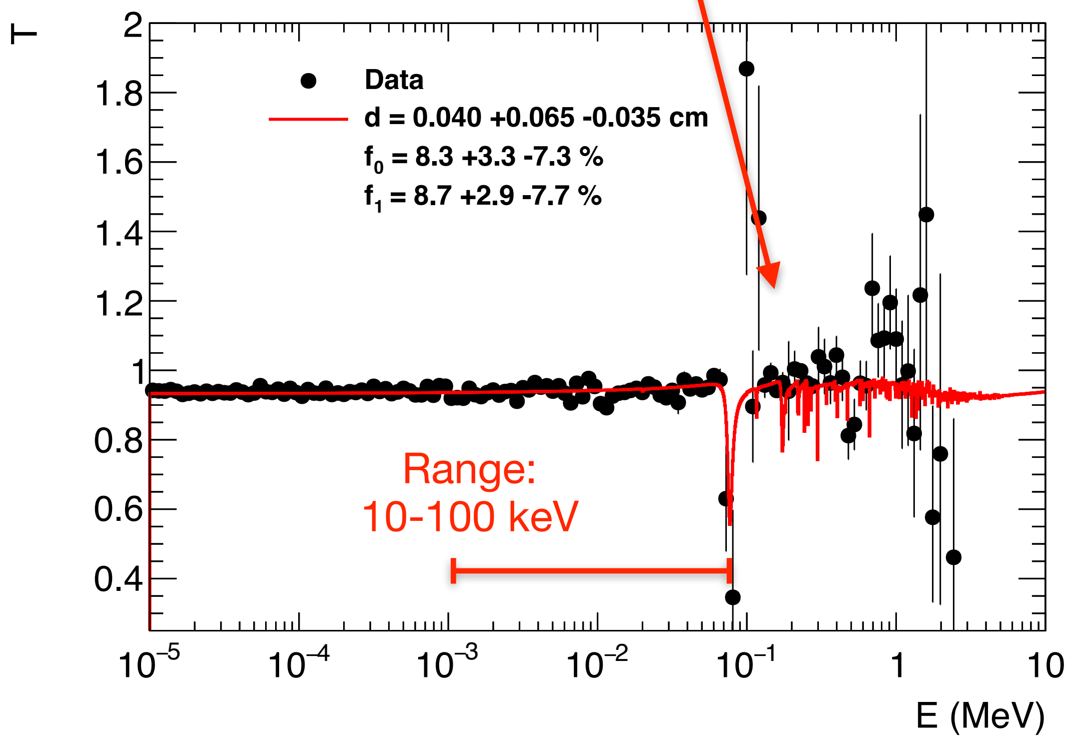
Work done by L. Pagani

Estimate ice layer

- Since target conditions could vary between before and after ice melting, use toy Monte Carlo to determine T
- Being f_0 and f_1 respectively the gas fractions, knowing dimension of the target parameters (assumed Ar cross section, density at liquid and gas known) construct T for various combinations of d, f_0, and f_1 and fit the data
- Best fit yields d = 0.040±0.035 cm with f_0, f_1 compatible with the measured bubble rate (~7% gas in the target)
- 0.4 mm of ice produces a reduction in the number of neutrons of $3.8^{+3.3}_{-3.2}$%

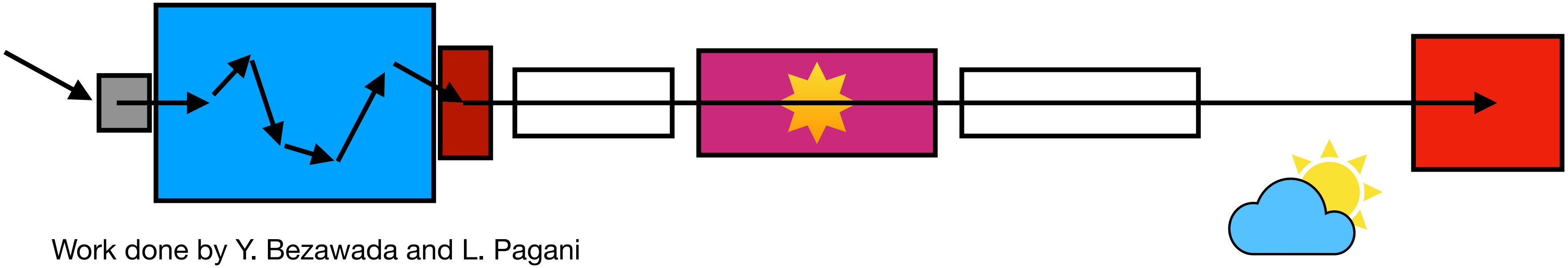
Errors are calculated as contours of $X^2 < X^2_{min}+3.53$ as described here





Effects of exposure to the elements

- Part of the flight path (~2 m) is not under vacuum and expose to ambient condition: specifically from the end of the vacuum pipe to the 6Li-glass detector
- Day-to-day and day-night temperature/pressure variation could bias surviving neutrons count and needs to be considered as systematic
- Study effect by simulating how air density variation impact survival neutron counts. Assumed 2 m of air



Work done by Y. Bezawada and L. Pagani

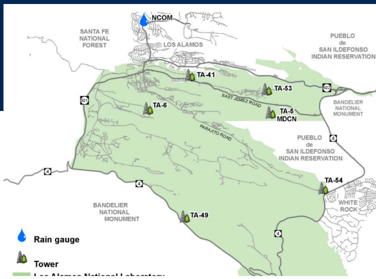
Temperature variation

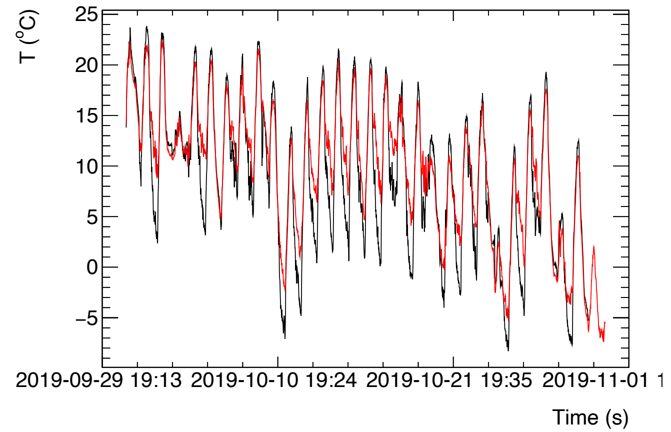
- LANL has different meteorological stations from which data can be retrieve. For LANSCE is TA-53 but does not have pressure info which is needed for determine air density
- Moist air density: $\boldsymbol{\rho_{moist}=p/R_aT\ (1+x)/(1+xR_a/R_w)}$ where p is pressure (Pa), R_a and R_w are respectively the gas constant for air (286.9 J/kg K) and water (461.5 J/kg K), T is the temperature (K), and x is the humidity ratio (%)
- Use TA-54 (red) which shows same temperature trend
- $<\rho>=0.00085$ g/cm3 and $\rho_{min}=0.00075(-11.1\%)$ and $\rho_{max}=0.00095(+12.0\%)$
- ~10% density variation results in a ~0.4% difference in the # of surviving neutrons

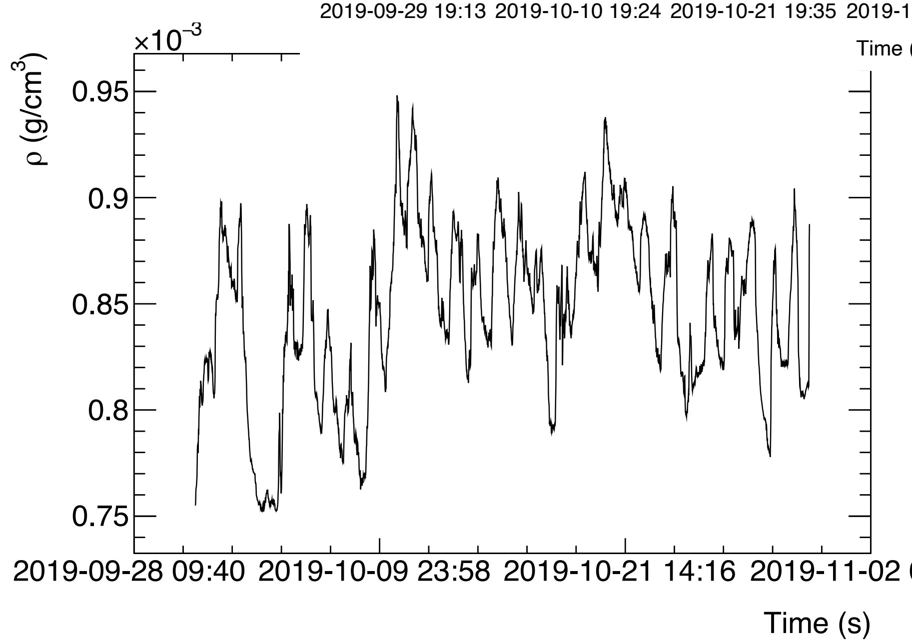
Table 3-1: Meteorological Monitoring Stations and Summary of Meteorological Measurements at Each Location

Station Name	Alternate Name(s)	LANL Structure Number	Latitude/Longitude Coordinates (°)		Elevation (feet)	Surface Measurements (at 1.5 meters)	Tower Levels of Measurements (meters)	Tower Measurements	Record of Observations
			Latitude	Longitude					
TA-6	Los Alamos	TA-06-0078	35.8615	106.3195	7424	Temperature, pressure, humidity, shortwave radiation, longwave radiation, precipitation	12, 23, 46, 92	Wind speed, wind direction, temperature	Feb 1990–present
TA-6 SODAR[a]	SODAR	TA-06-0100	35.8615	106.3187	7417	N/A[b]	100–1000[c]	Wind speed, wind direction, temperature	Dec 2014–present
TA-49	Bandelier	TA-49-0123	35.8133	106.2993	7045	Temperature, humidity, shortwave radiation, precipitation	12, 23, 46	Wind speed, wind direction, temperature	Jun 1987–present
TA-53	LANSCE[d]	TA-53-1020	35.8701	106.2543	6990	Temperature, humidity, shortwave radiation, precipitation	12, 23, 46	Wind speed, wind direction,	Feb 1992–present
TA-54	White Rock	TA-54-0088	35.8259	106.2232	6548	Temperature, pressure, humid shortwave radiation, longwave radiation, precipitation			
TA-5 MDCN	Mortandad Canyon	TA-05-0061	35.8597	106.2522	6750	Temperature, solar radiation			
NCOM	North Community	N/A	35.9009	106.3216	7420	Precipitation			
TA-41[f]	Los Alamos Canyon	N/A	35.8764	106.2964	6914	Temperature, solar radiation			
PJMT[f]	Pajarito Mountain	N/A	35.8864	106.3948	10,360	Temperature, precipitation			

[a] SODAR = Sound detection and ranging.
[b] N/A = not applicable.
[c] Measurements every 20 meters depending upon current weather conditions.
[d] LANSCE = Los Alamos Neutron Science Center
[e] Located on the rooftop.
[f] Station no longer in operation.

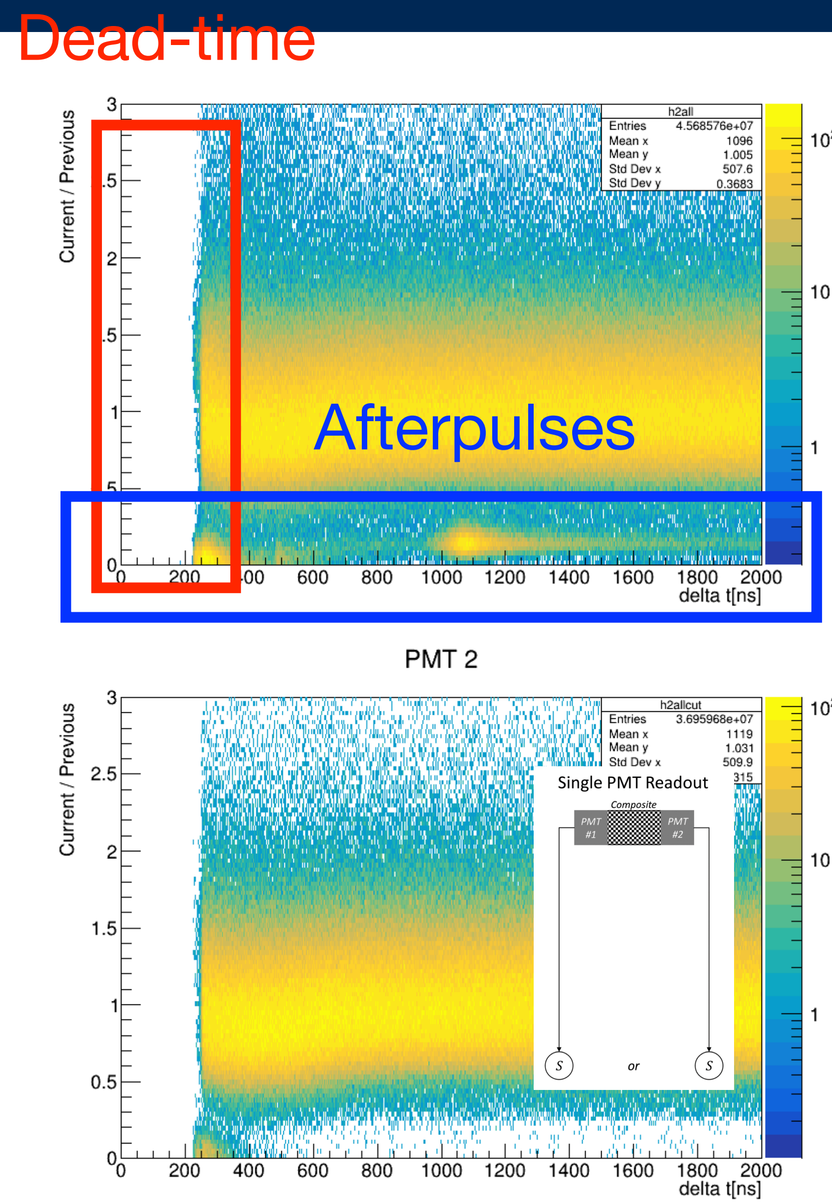






Afterpulses and dead-time

- Afterpulses are important to consider in. TOF experiment since they manifest by shifting neutron spectrum to higher energy
  - In ^{6}Li-glass detector (neutron detector downstream the target) coincidence of 2 PMTs effectively removes after pulses (≪1)
- Dead-time arises on how digitizer and DAQ are configured (~200ns integration window after each identified pulse) and can lead to loose neutrons which come close (in time) to each other
  - Current (ongoing) methods to correct for dead time include use if analytical Bowman correction and a toy Monte Carlo



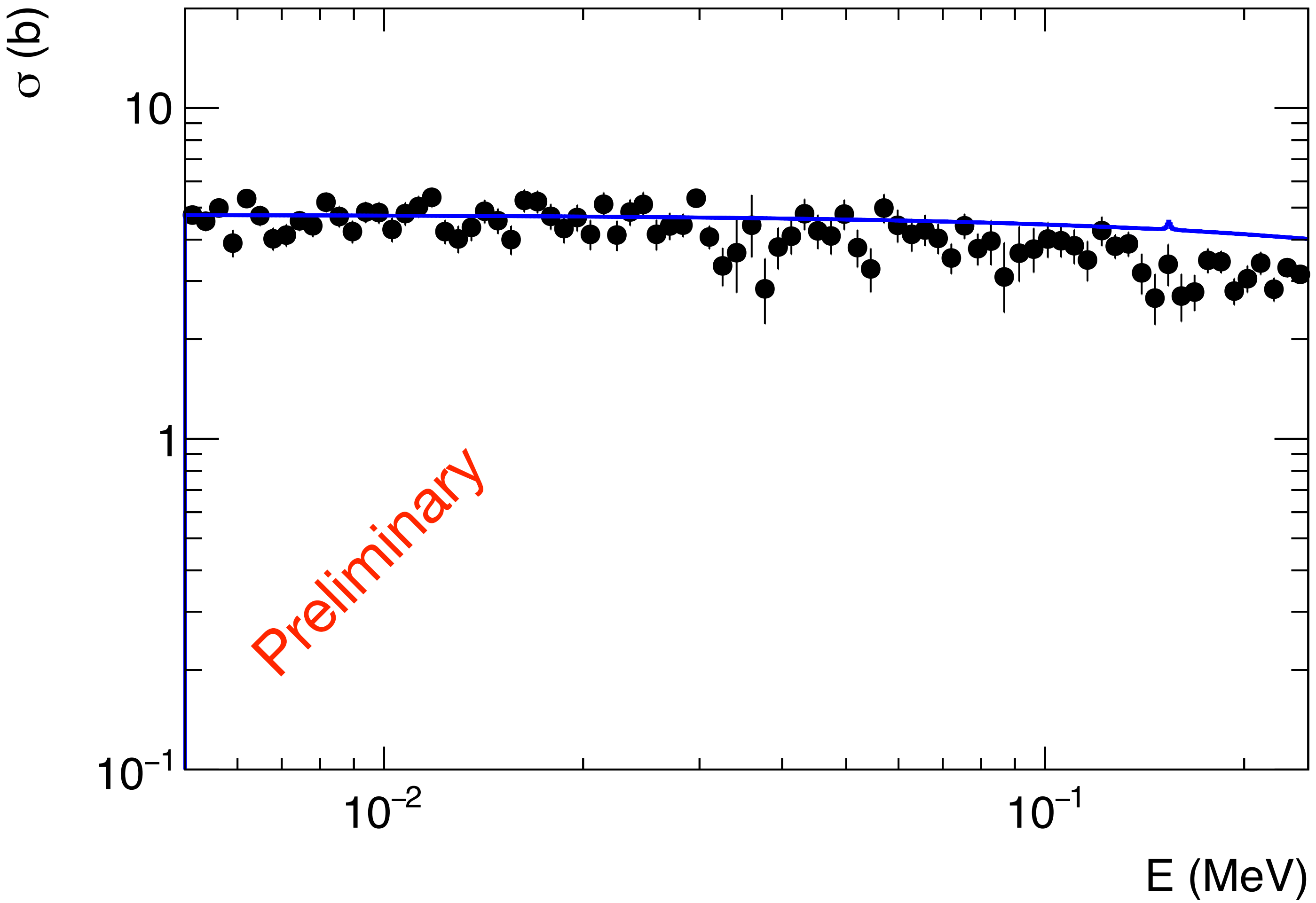
Work done by T. Erjavec

Summary systematics

- Summary of the various errors (stat and systematic)
- Others:
  - Nitrogen contamination of the LAr. Measured by RGA (ppm level)
  - Background due to other experiment. Found that activities nearby ARTIE produces variation on background

ERROR	STATISTICAL (%)	SySTEMATIC (%)
Background subtraction	±1	
Effective density	±1.2	±0.9
External temperature		±0.4
Ice build up		-3.8
Afterpulses and dead time		≪1 + ?
Others	≪1	≪1

Carbon results



Preliminary results