Characterization of superheated fluids in the PICO-0.1 bubble chamber for the search of Dark Matter

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Université de Montréal

PICO

Winter Nuclear & Particle Physics Conference

WNPPC 2018

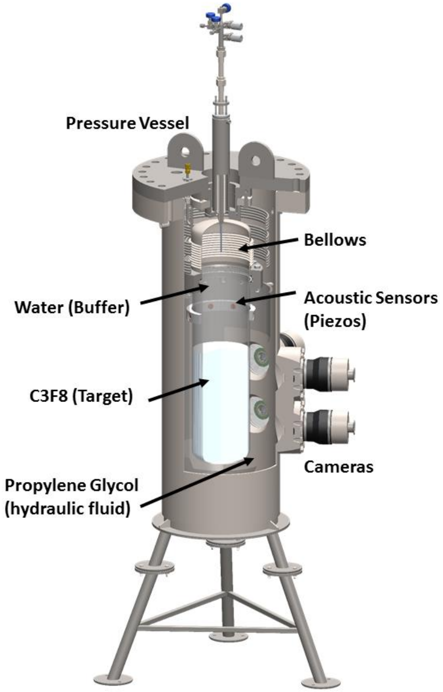
Outline

- The PICO Experiment
  - PICO-0.1
- PICO-0.1 with C_2ClF_5 : ^{35}Cl (n_{th},p) ^{35}S
  - 17 keV monoenergetic ^{35}S recoil
    - Threshold characterization
  - 600 keV monoenergetic proton recoil
    - Proton detection with a bubble chamber
- PICO-0.1 with $C_2H_2F_4$
  - Proton detection

PICO Experiment : Superheated liquid detectors

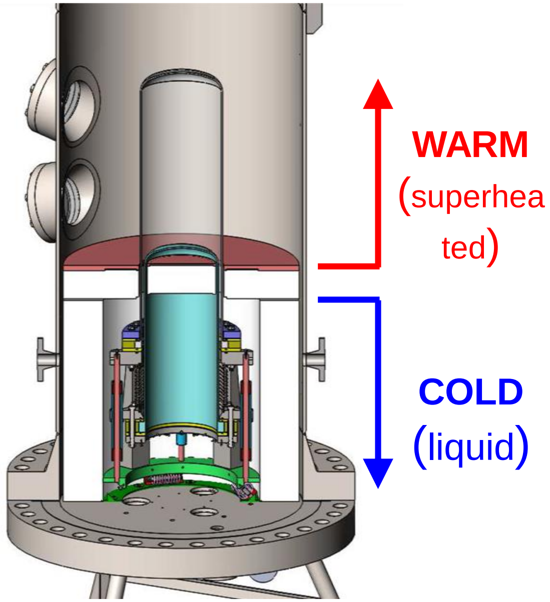
Latest results :

PICO-60

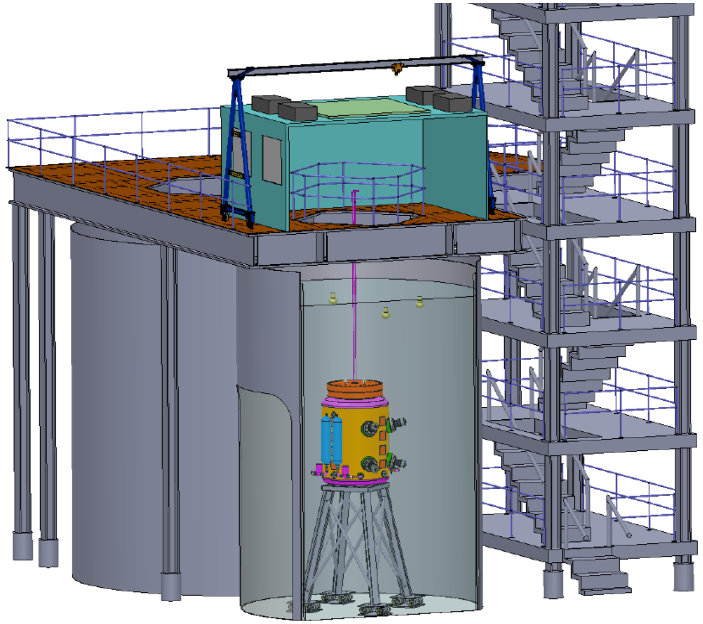


Future detectors :

PICO-40L

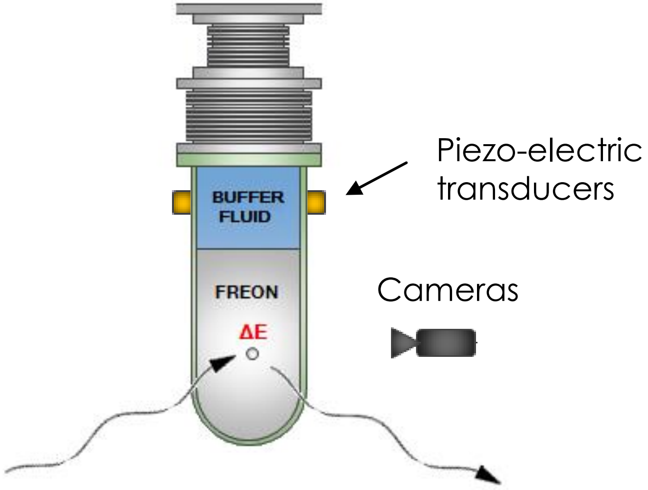


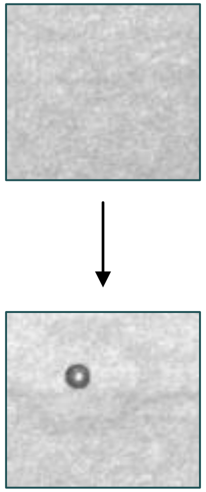
PICO-500

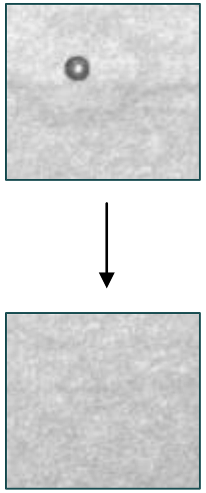


PICO Experiment : Superheated liquid detectors

- Bubble chamber event :







Incoming particle + Superheated fluid + Energy deposition > Threshold energy → Phase transition, bubble event → Recompression, end of event

PICO-0.1 Calibration Chamber

- Same principle as all other PICO bubble chambers

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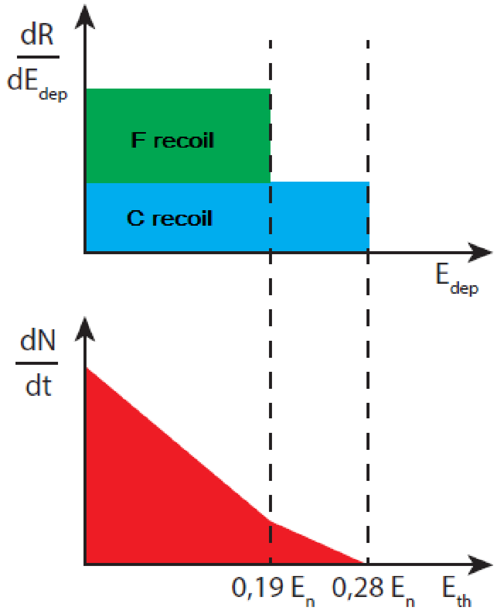
- Purpose : calibration, tests, active mass fluids characterization, etc

PICO-0.1 filled with C_2ClF_5

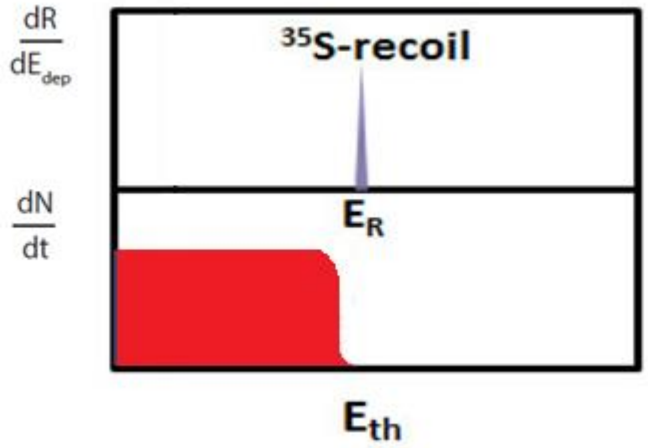
- ^{35}Cl (n_{th},p) ^{35}S : monoenergetic recoils
  - 17 keV ^{35}S recoil
  - 600 keV proton recoil
- Monoenergetic recoils : Unique opportunity to precisely characterize thresholds in superheated fluids bubble chambers
- Can we detect proton recoils in bubble chambers?

Previously : PICO-0.1 with C_3F_8

- Threshold detector : integration of energy spectrum

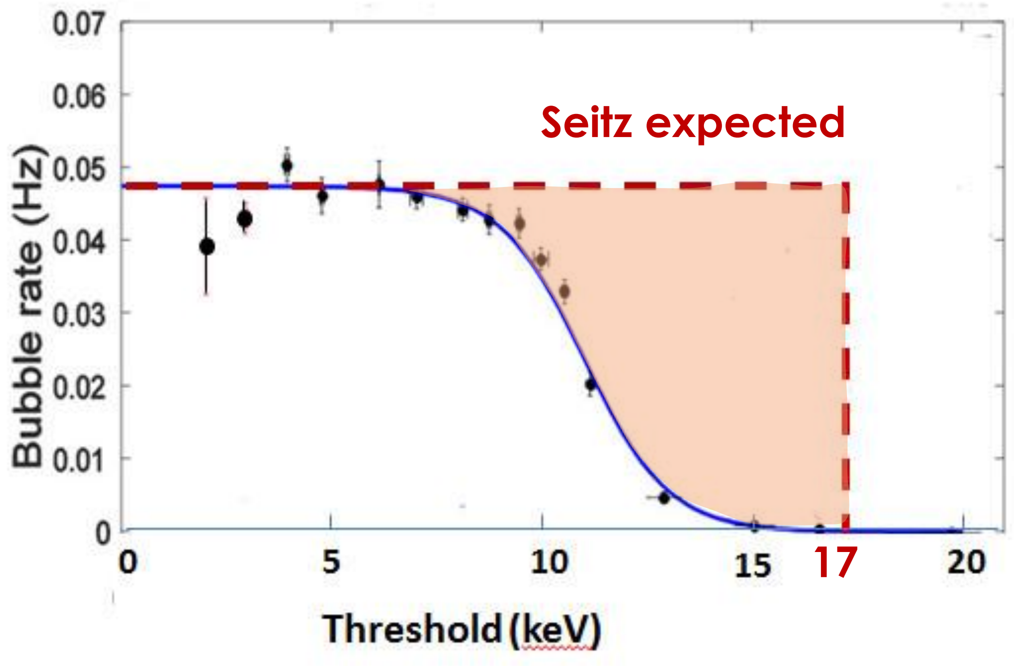


- Monoenergetic ^{35}S recoil : Step function



17 keV ^{35}S monoenergetic recoil results

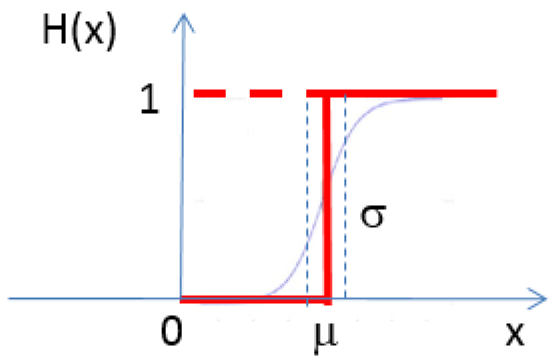
PICO-0.1 Response to 17 keV ^{35}S - Recoils in C_2ClF_5



17 keV ^{35}S monoenergetic recoil analysis: Revisited 'Seitz' Threshold

- Hypothesis : Seitz threshold (from the Seitz Model for superheated liquids) is the Heaviside limit of a Gaussian Blurred Step (GBS) of mean μ and width σ:

$$H(x) = \frac{1}{2}\lim_{\sigma\to 0} \operatorname{erf}\left(\frac{\mu - x}{\sigma}\right)$$

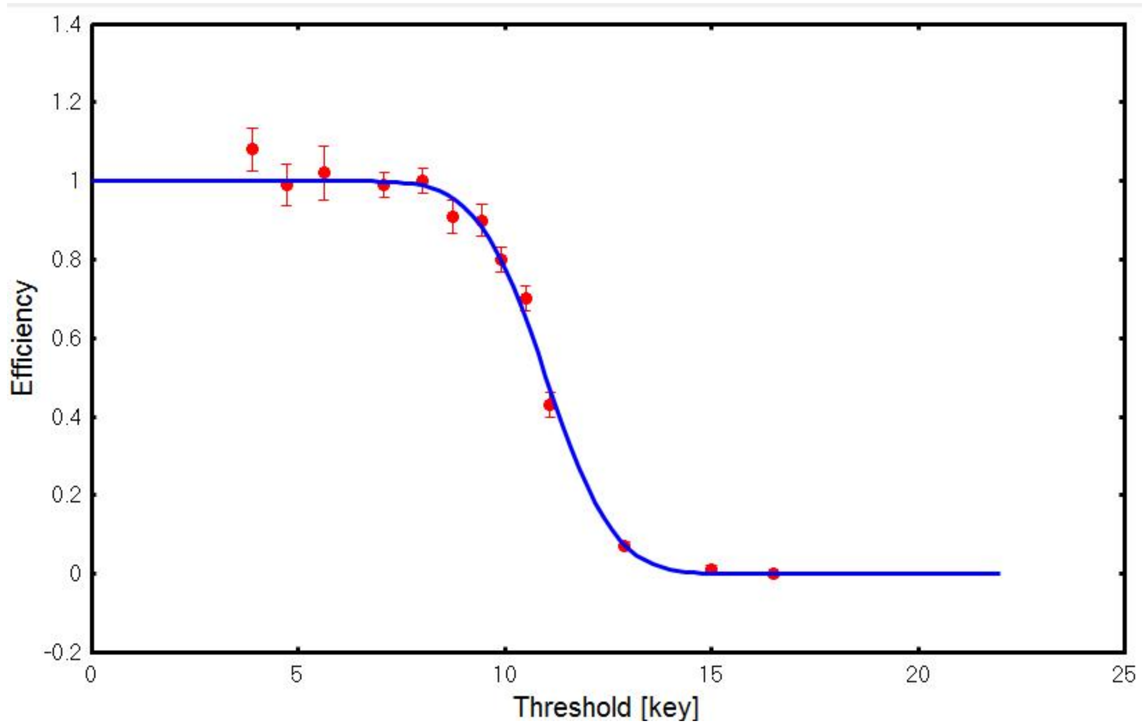


- Revisited threshold (event probability) :

$$P(E, E_{th}) = \frac{1}{2}\left[\operatorname{erf}\left(\frac{E - E_{th}}{\sqrt{2}\sigma}\right) - \operatorname{erf}\left(\frac{0 - E_{th}}{\sqrt{2}\sigma}\right)\right]$$

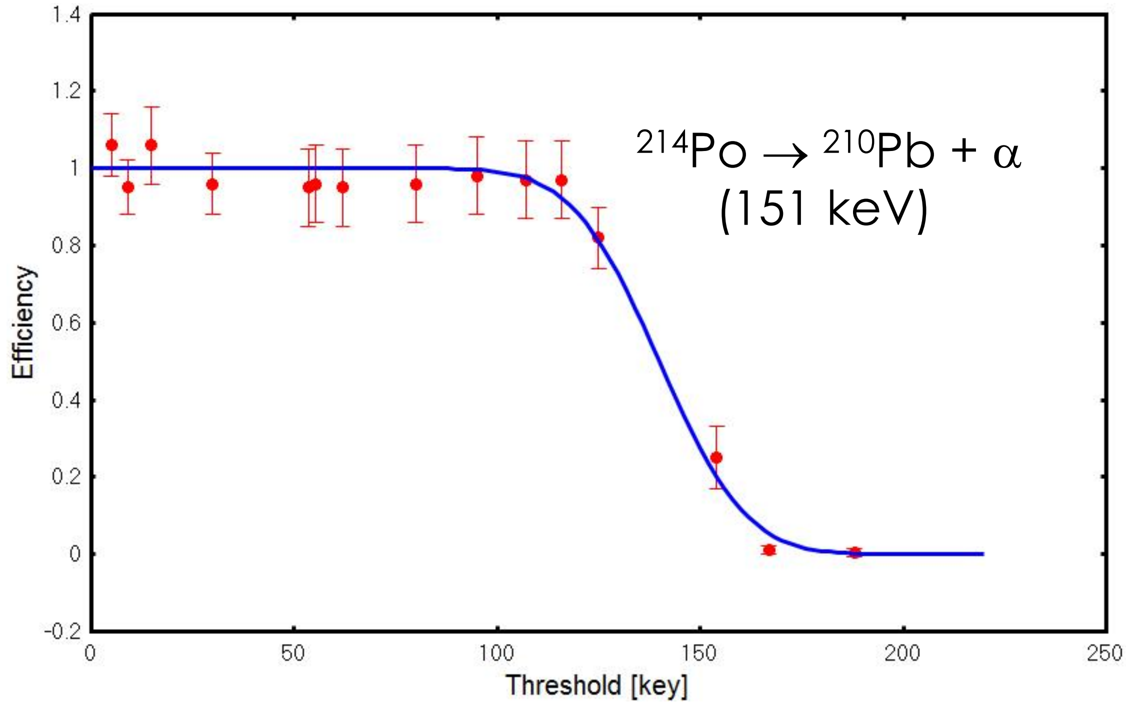
17 keV ^{35}S monoenergetic recoil analysis: Revisited 'Seitz' Threshold

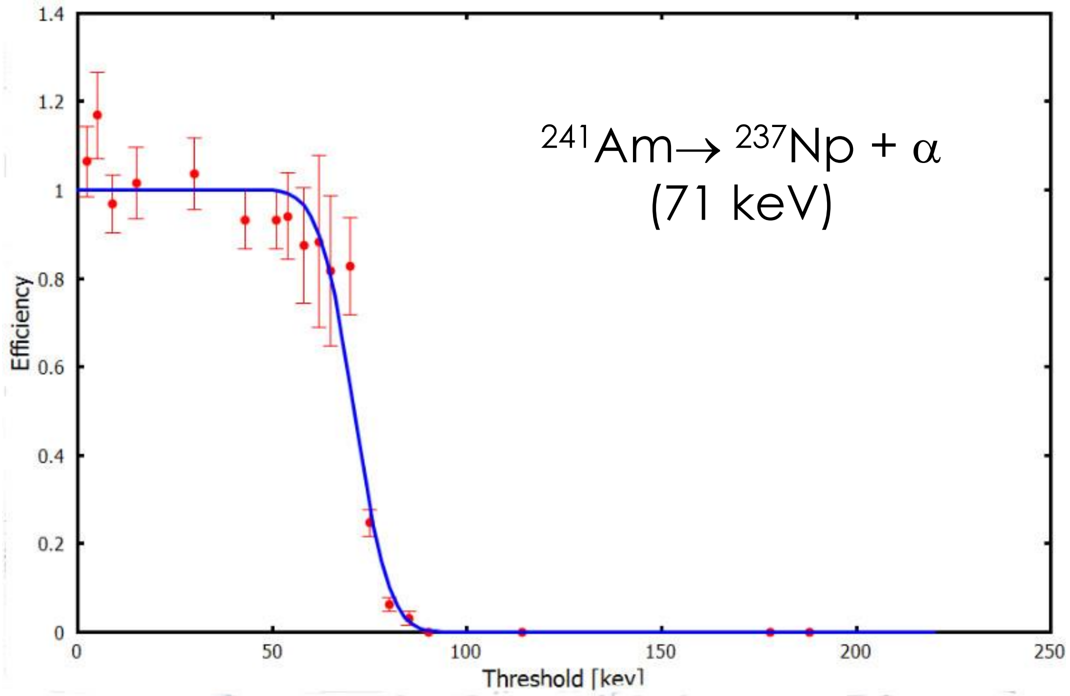
- Revisited threshold : Fits with data



17 keV ^{35}S monoenergetic recoil analysis: Revisited 'Seitz' Threshold

- Also with previous monoenergetic data (PICASSO) :





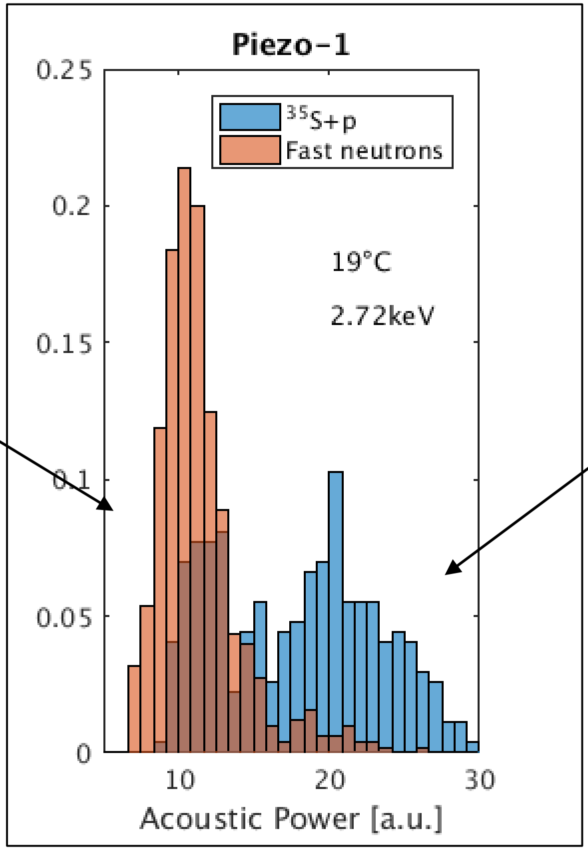
600 keV proton recoils

- ^{35}Cl (n_{th},p) ^{35}S : 17 keV ^{35}S recoil and 600 keV proton recoils
  - Can't isolate only proton recoils in detector
  - Can compare to data without proton recoils
- ^{35}S+p recoils vs. Fast neutrons elastic scattering
  - ^{35}S alone and fast neutrons recoils have same acoustics (depends only on threshold energy)
  - Protons could create their own bubble (too close to ^{35}S bubble to been seen on camera)
- ^{35}S+p should have a more powerful acoustic signal when proton creates its own bubble

600 keV proton recoil results

- Acoustic power normalized distribution
- Clearly, excess at high acoustic power : proton events

Nuclear recoils only



Nuclear + proton recoils

PICO-0.1 filled with $C_2H_2F_4$

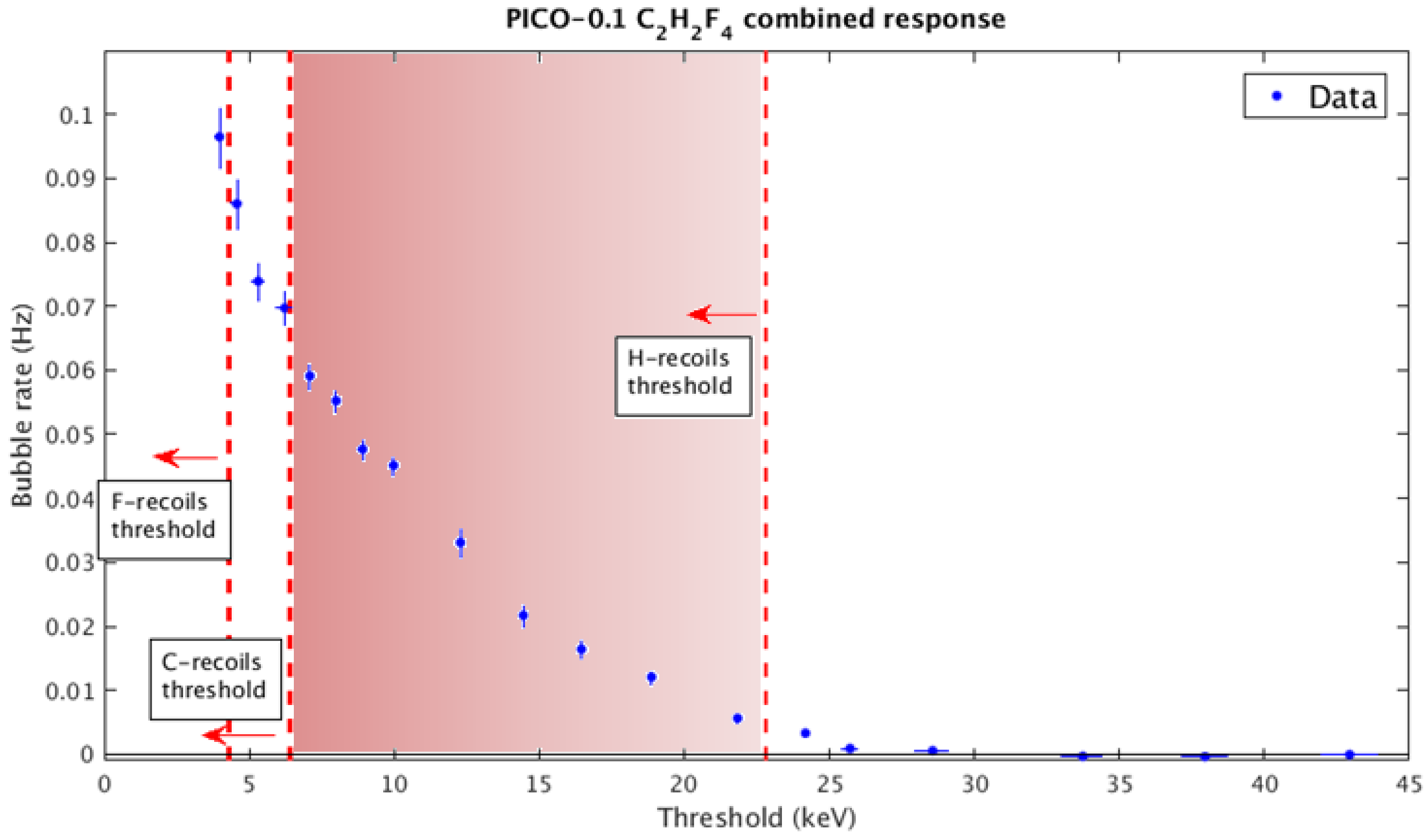
- Hydrogenated freon : proton recoils
- From kinematics :
  - Fluorine : $E_{R\,max} \approx 0.19\ E_n$
  - Carbon : $E_{R\,max} \approx 0.28\ E_n$
  - Hydrogen : $E_{R\,max} = E_n$

$$E_R = \frac{2A}{[A+1]^2}(1 - cos\theta)E_n$$

PICO-0.1 filled with $C_2H_2F_4$: Results

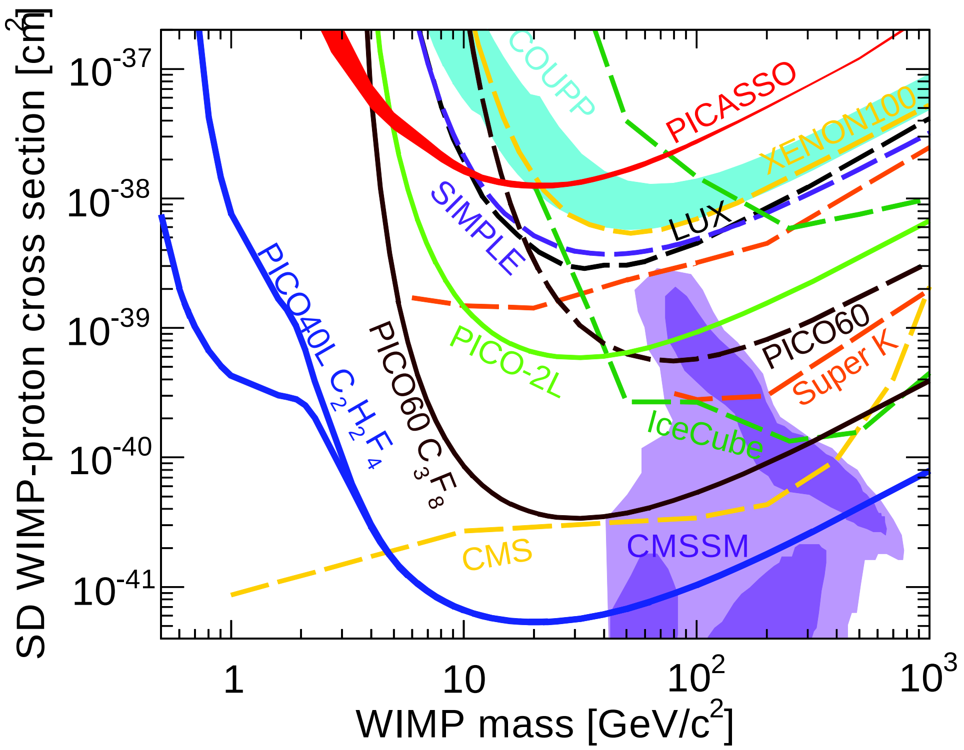
- For 22 keV neutrons :

- Conclusion : We see proton recoils in the region [6,22] keV



Proton recoils : Why is it important?

- Allows to search for WIMPs at much lower mass
- Limits plot could look like :
  - Unexplored region in parameter space



Conclusion

- Monoenergetic 17 keV ^{35}S recoil : provides insight on thresholds for superheated fluids bubble chambers
- 600 keV proton recoils and $C_2H_2F_4$: show evidences for proton recoils detection in bubble chambers
  - Allows to search for WIMPS at low masses

Thank you!

QUESTIONS?

Backup slides

Seitz Threshold for bubble formation in superheated fluids

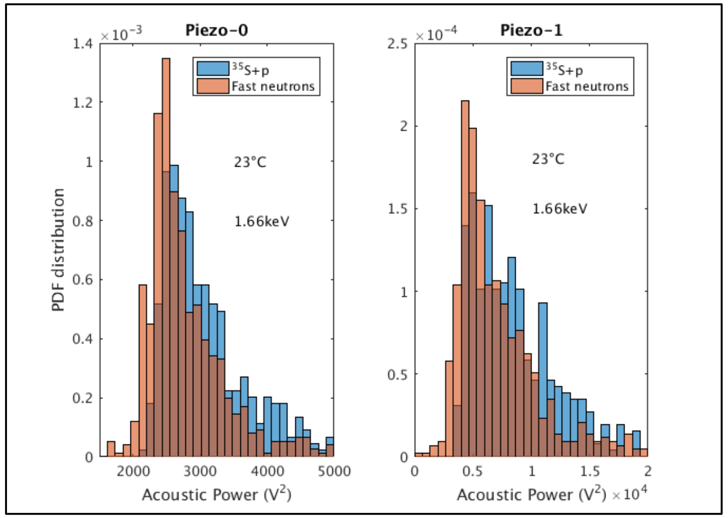
- Critical Radius : Minimum radius the bubble needs to have not to collapse on itself.
- Critical Energy : Energy needed to create a bubble in a superheated fluid, deposited inside the critical radius.
- Given by the « Seitz Model » :

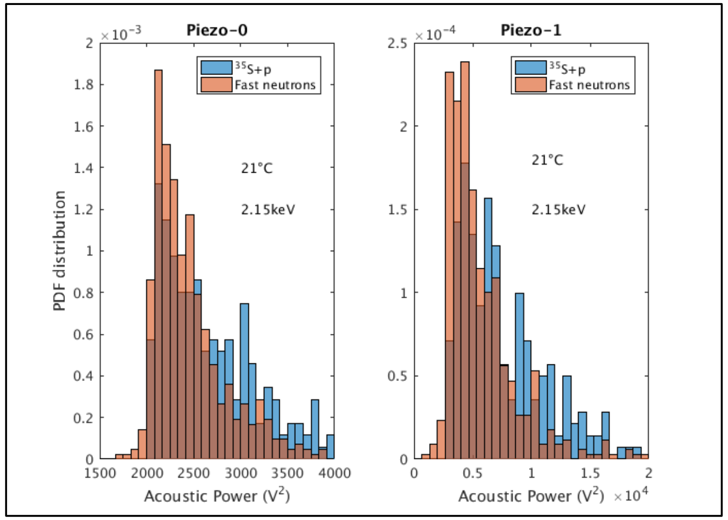
$$Q = \frac{4}{3}\pi {r_c}^3 \rho_b (h_b - h_l) + 4\pi {r_c}^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)$$

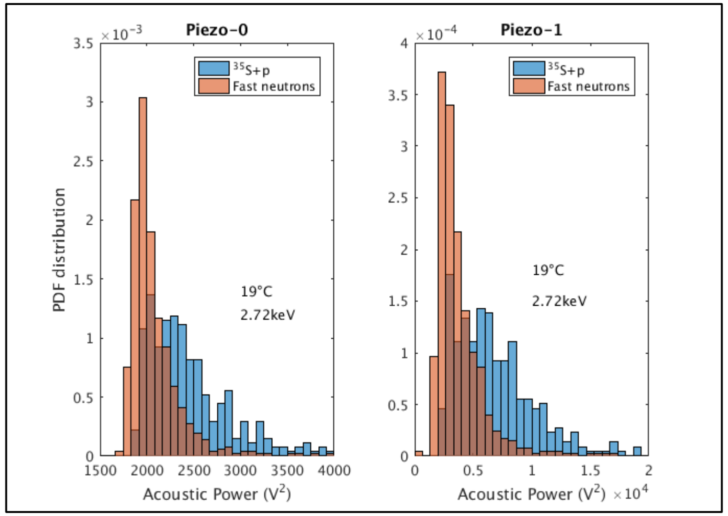
  - Seitz Threshold

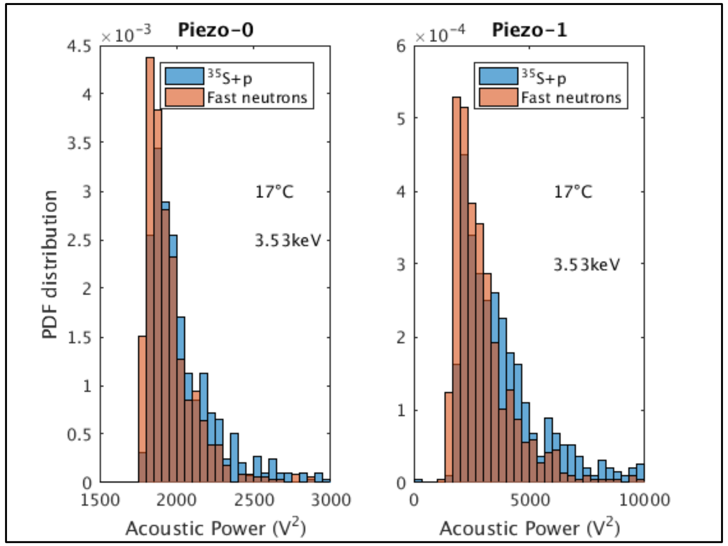
Proton bubble efficiency in PICO-0.1

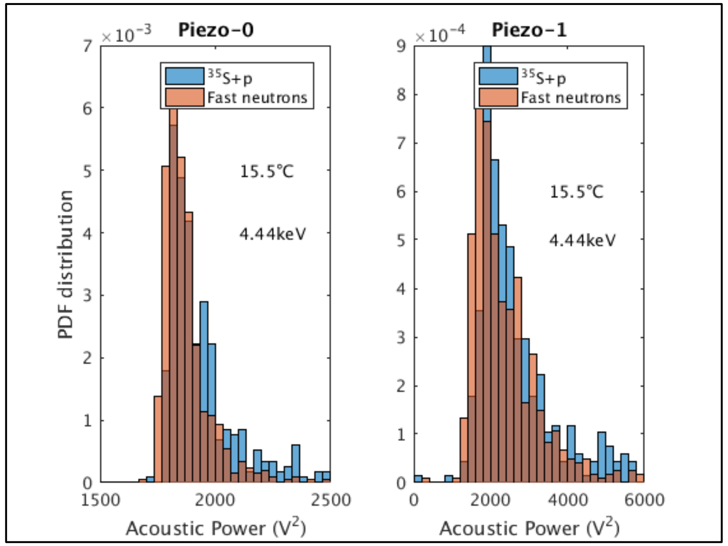
Acoustics analysis : Acoustic Power (all at 35 PSI)

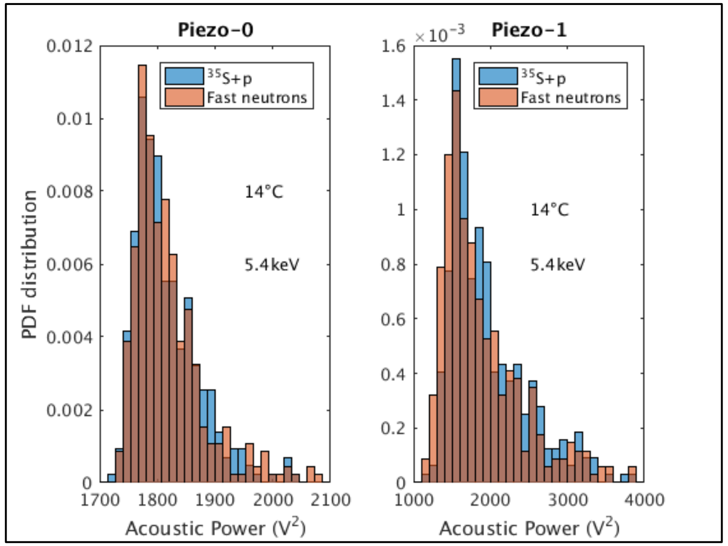






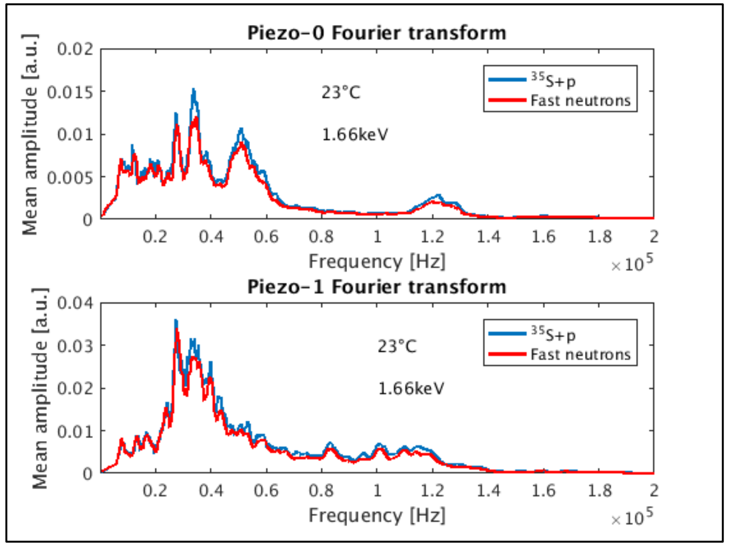


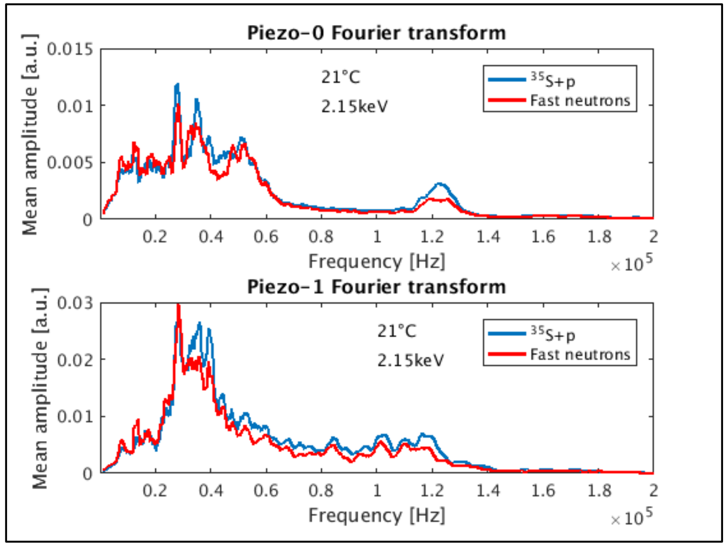


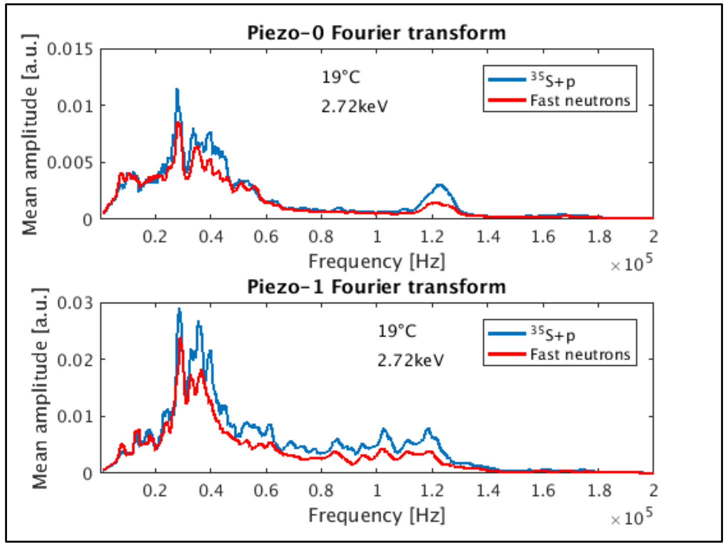


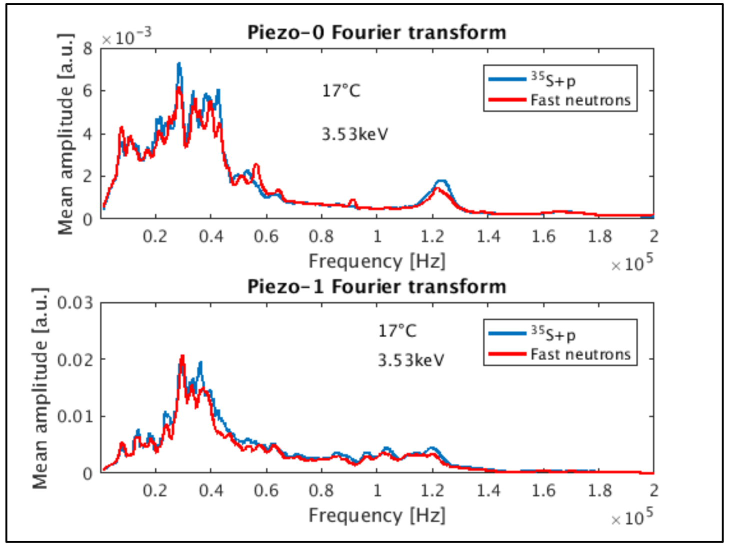
Proton bubble efficiency in PICO-0.1

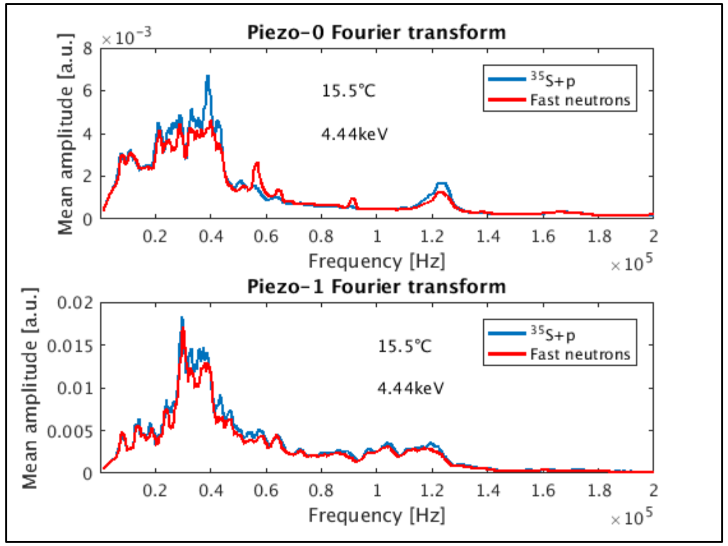
Acoustics analysis : FFT

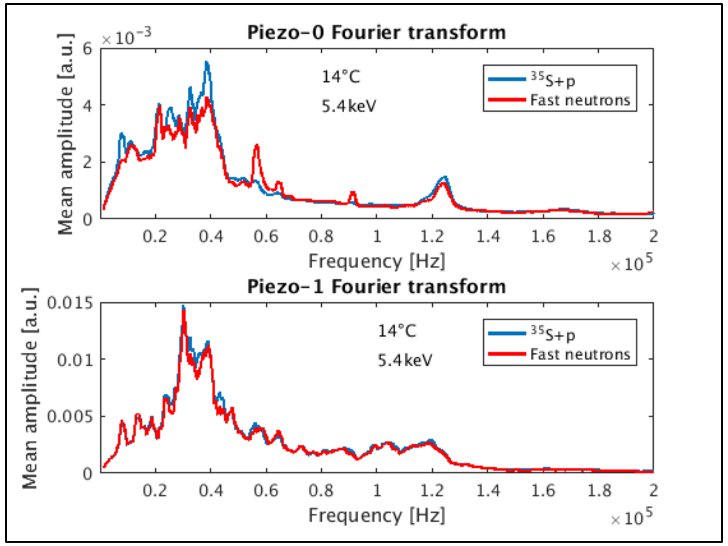












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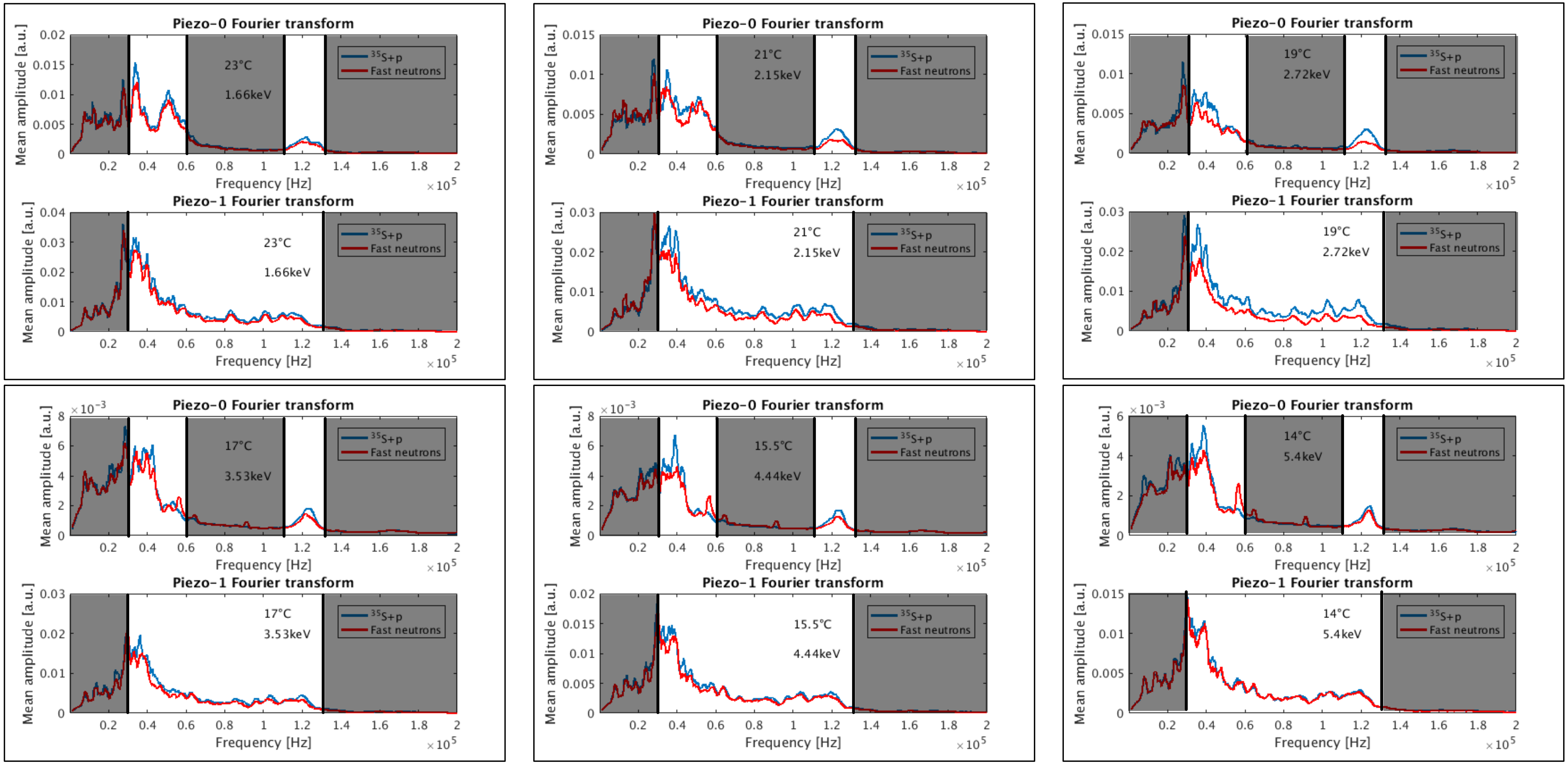

Proton bubble efficiency in PICO-0.1

Acoustics analysis : Acoustic Power (all at 35 PSI)