Low Radioactivity Techniques 2013

The COUPP detector and the acoustic alpha background discrimination technique.

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For the COUPP collaboration

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MultiDark
Multimessenger Approach for Dark Matter Detection

Coupp Collaboration

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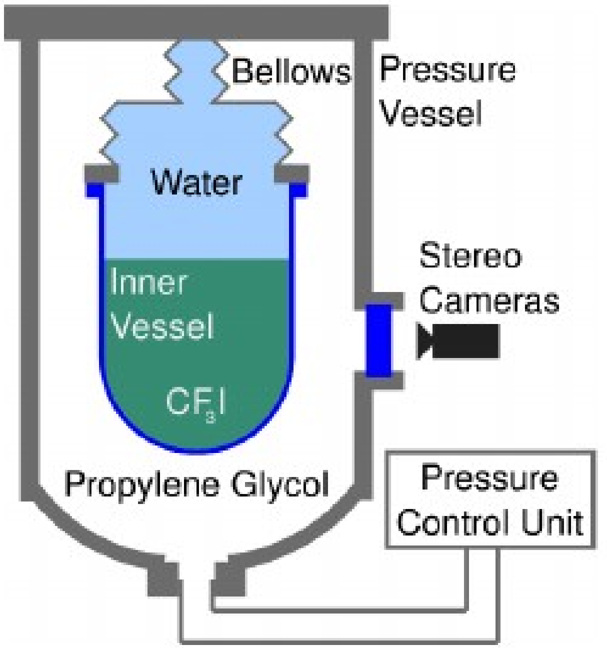
With support from:

Coupp: ***Bubble Chamber***



- Target material:

  Superheated CF3I

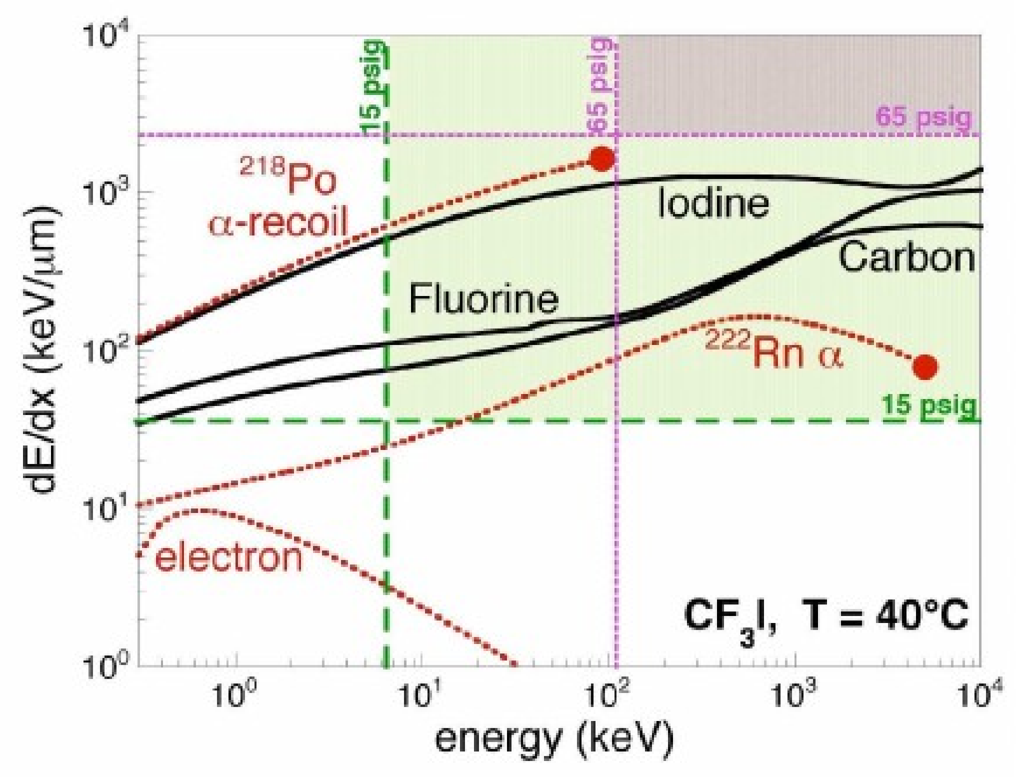
  Spin dependent / independent

  interaction
- Particle interaction ➡ Bubble

  nucleation
- After expansion target liquid is superheated able to detect (if no event BC is compressed after ~ 500s).
- VGA cameras record bubble growth (~100 frames/s)
- Piezo sensors glued to the quartz vessel record the acoustic signal emitted by bubble growth, pressure sensor gives the P inside of the jar.

Coupp: Bubble nucleation

- Bubble nucleation depends; deposited energy & $\frac{dE}{dx}$
- Pressure and Temperature of the target material fix threshold for bubble nucleation.
- Outer $\alpha - decay, n^0$ shielded by low Z – water, polyethylene material.
- Inner $\alpha - decay$ discriminated by acoustic technique.
- Signal processes of I, F, C nuclear recoils

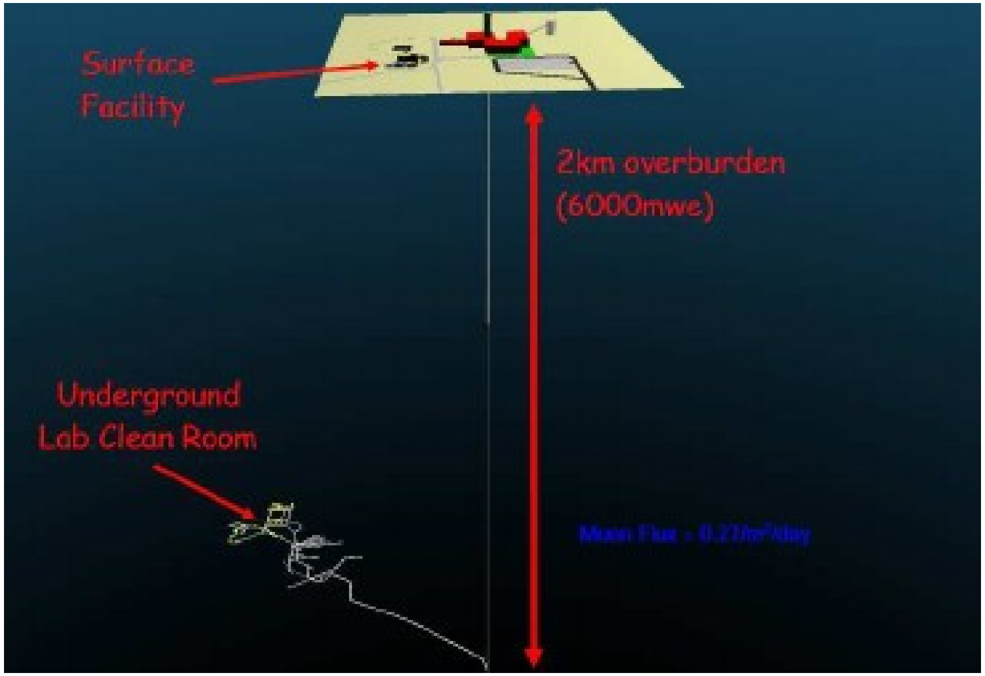


No sensitive to

e^- , γ

Proper values for P & T.

Coupp: At Snolab



- SNOLAB deepest and cleanest large-space international facility in the world.
- 2 km underground near Sudbury, Ontario.
- Ultra-low radioactivity background environment.
- Physics programme focused on neutrino physics and direct dark matter searches

Coupp: *At Snolab*

- Installation in summer 2010
- First Physics run begins Nov. 3, 2010

  (second Physics run in 2012)
- Run settings (P=30.5 psia):

  17.4 days at 8 keV (39 ºC)

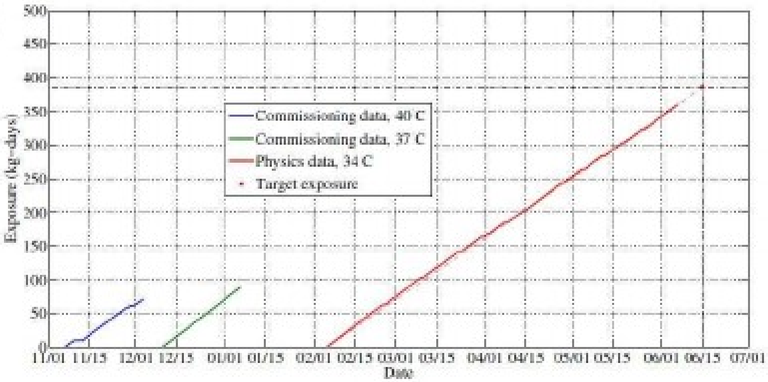
  21.9 days at 10 keV (36 ºC)

  97.3 days at 15 keV (33.5 ºC)
- 4.048 kg of CF3 I
- Calibrations:

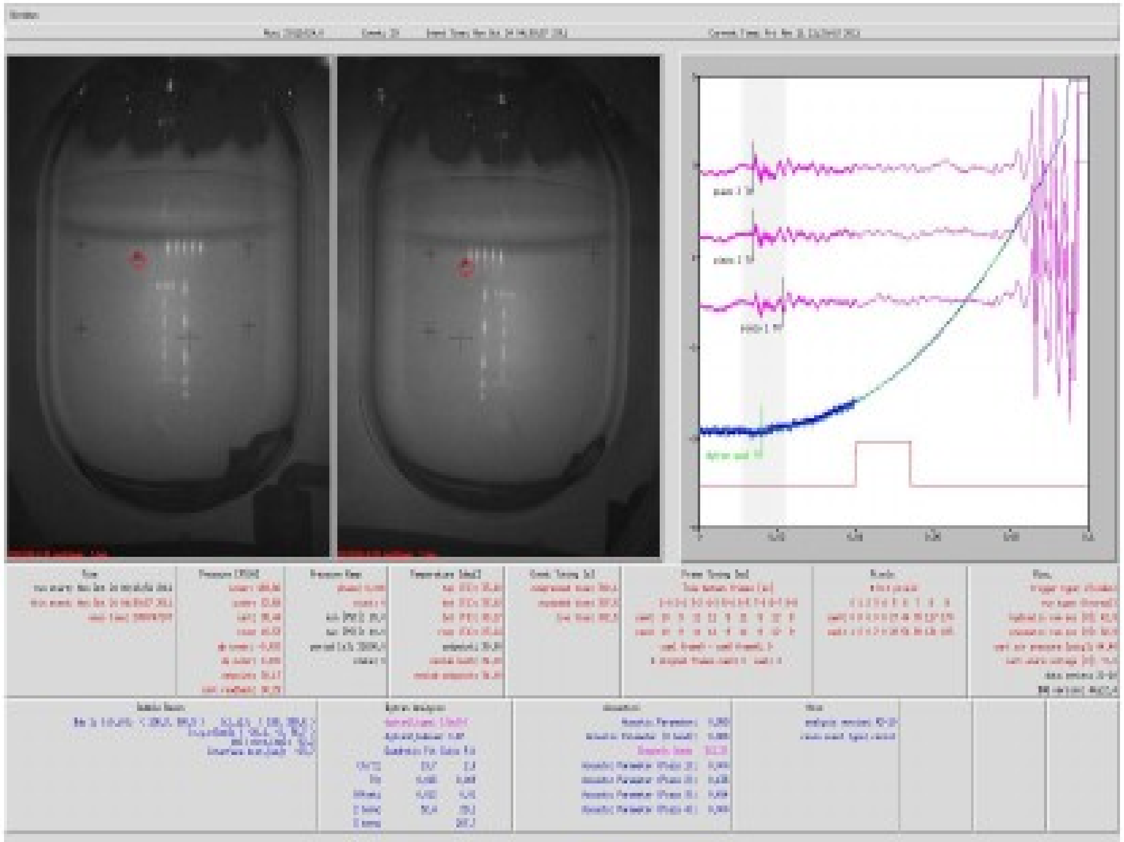
  Neutron calibration runs:

  AmBe and ^{252}Cf

  Continuous source of ^{222}Rn



Coupp: *Data analysis*



Basic analysis chain involves:

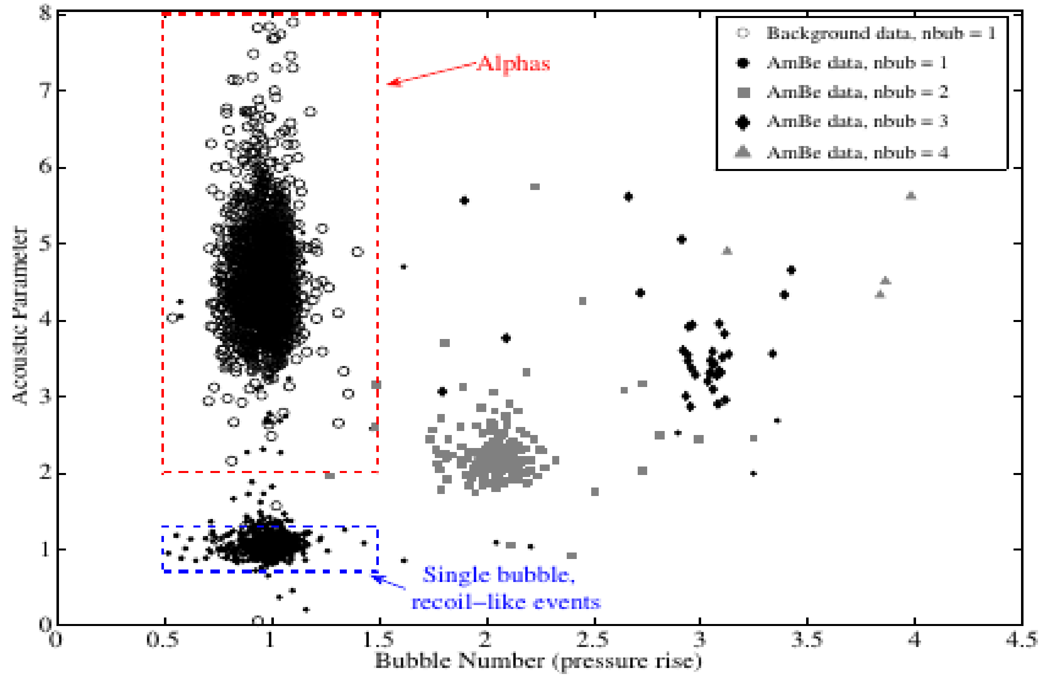
- Examination of images: algorithm searching for clusters among pixels that changed between consecutive frames (trigger based on comparison of consecutive images).
- Examination of pressure rise: fit to the rate of pressure rise by a quadratic time dependence for bubbles in the bulk.
- Examination of acoustic signal received by piezo-electric transducers.

Coupp: Data analysis (Acoustic)

Acoustic transducer signals digitized with a 2.5 Mhz sampling rate and recorded for 40 ms for each event.

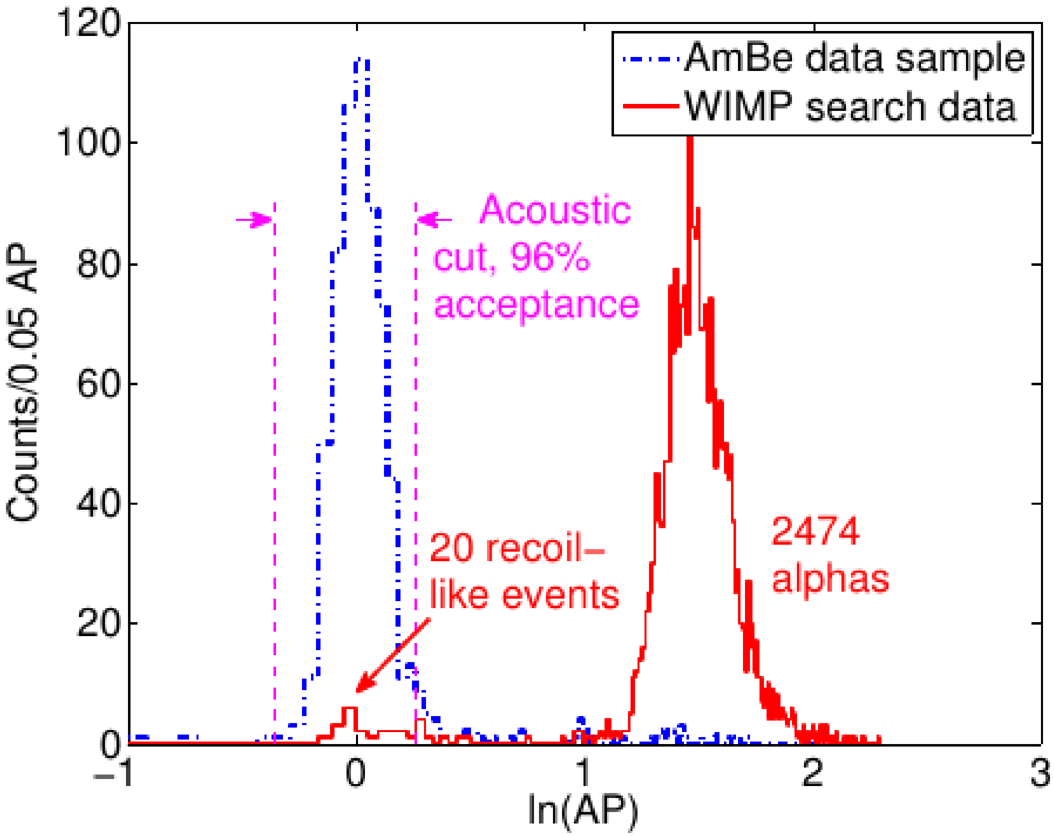
- AP can be defined as frequency weighted acoustic power density integral (corrected by sensor gain and bubble position).

The nuclear recoil acceptance of the AP cut 95.8 ± 0.5%



$$AP = A(T) \cdot \sum_j G_j \cdot \sum_n C_n(\vec{x}) \cdot \sum_{f_{min}}^{f_{max}} f \cdot psd_f^{\,j}$$

Coupp: Results (I)



456 kg-days, 2474 alphas
1733 alphas (15 keV data)

5.3 alpha decays/ kg-day
95% from radon
> 98.9% α rejection
> 99.3% (15 keV data)

- 6 events at 8 keV
- 6 events at 10 keV
- 8 events at 15 keV

Coupp: Results

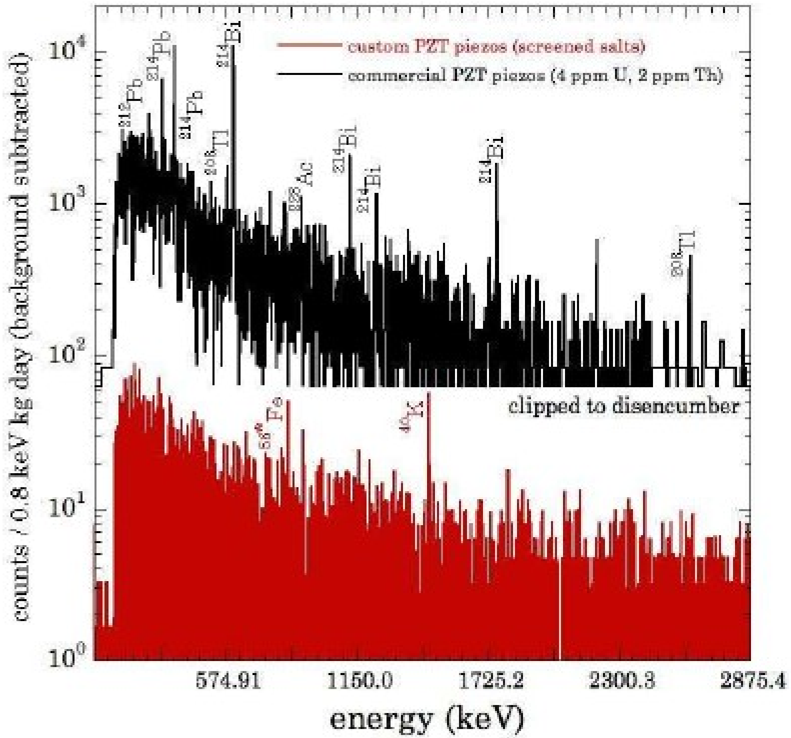
- Found Internal neutron sources of background
- View-ports:

  0.5 ppm ^{238}U and 0.8 ppm ^{232}Th (~ 5 events)
- Piezos:

  4.0 ppm ^{238}U, 1.9 ppm ^{232}Th , (~ 2 events)

- New piezos built (low background salts)

- New view-ports (synthetic silica)

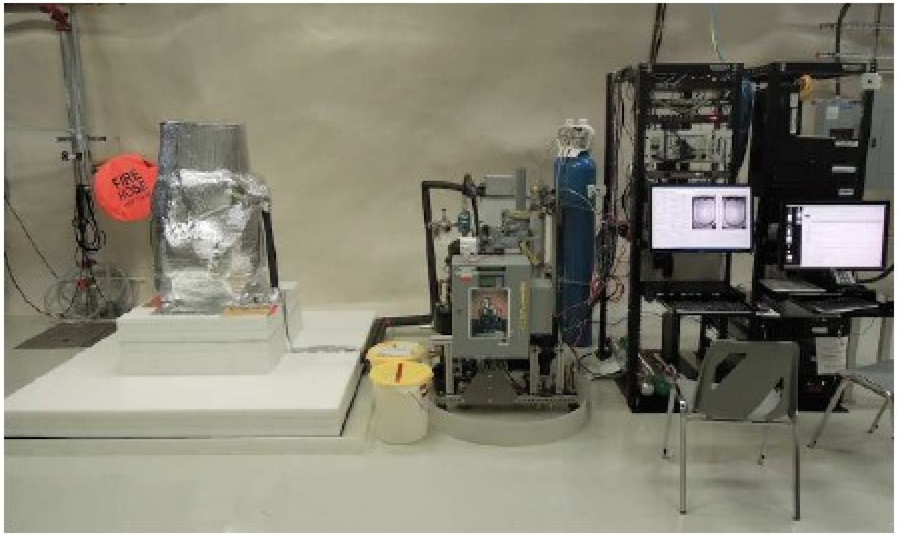


***Coupp:* Results**

New physics run in 2012

- 8 singles,
- 1 double
- 1 triple

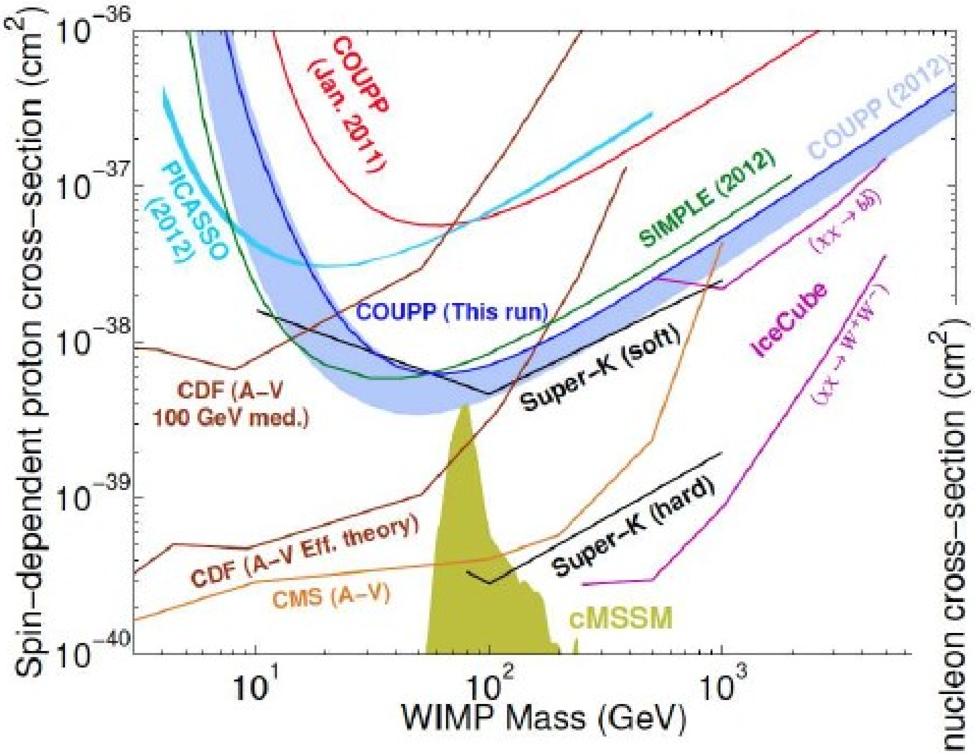
Replace more components



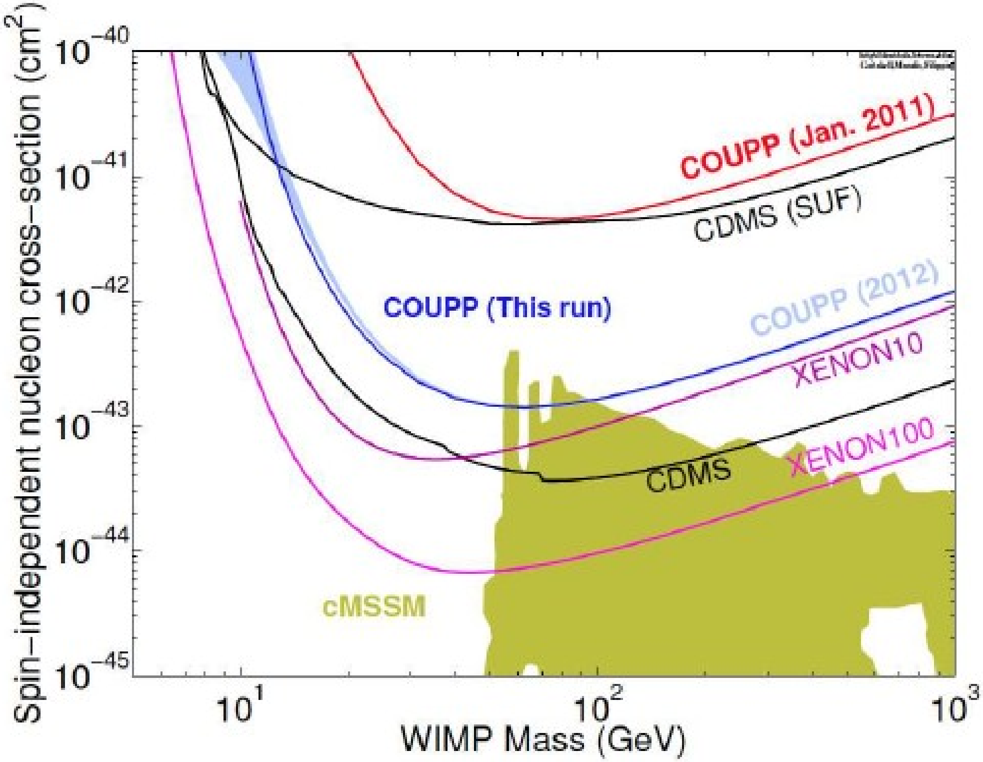
Hydraulics failed

Piezos detached from IV

Coupp: Results

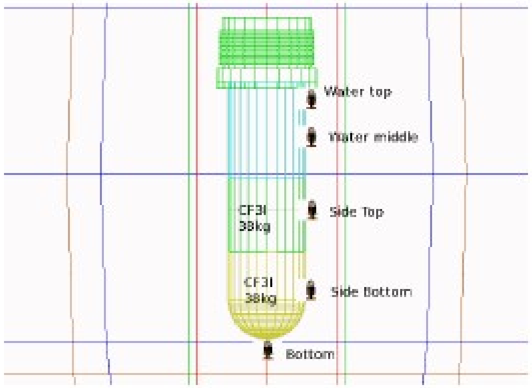


Estimation of cross sections for Spin-dependent and Spin independent interactions

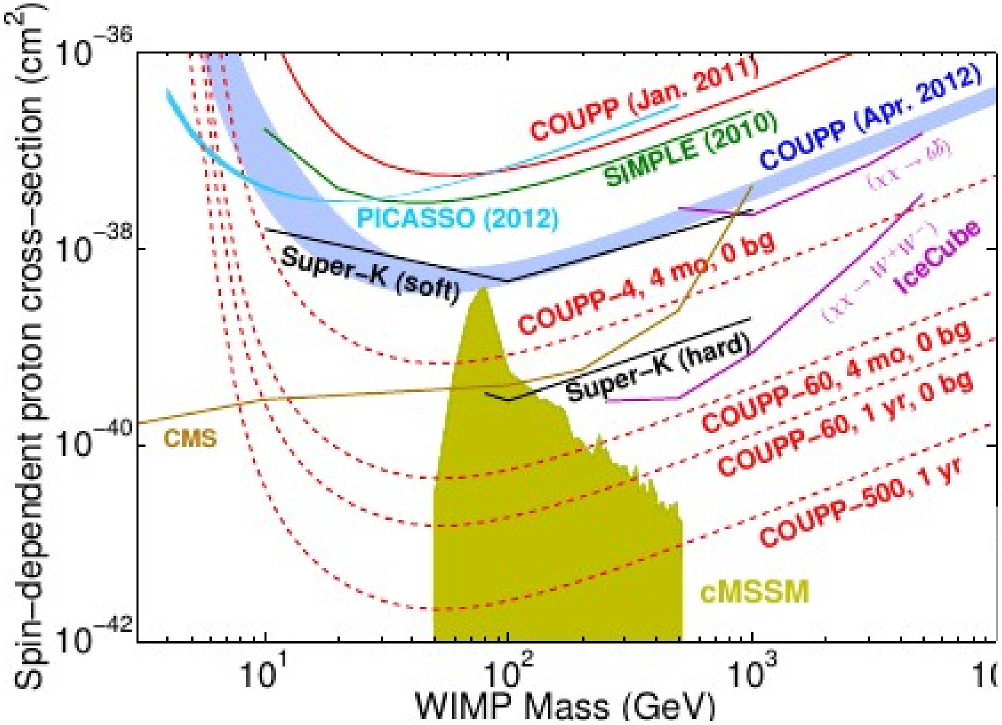


Coupp: 60Kg bubble chamber

- Engineering run at Fermilab: successful commissioning
- COUPP60 moved to SNOLAB
- Ready for physics run in a few weeks



Coupp: 60Kg bubble chamber



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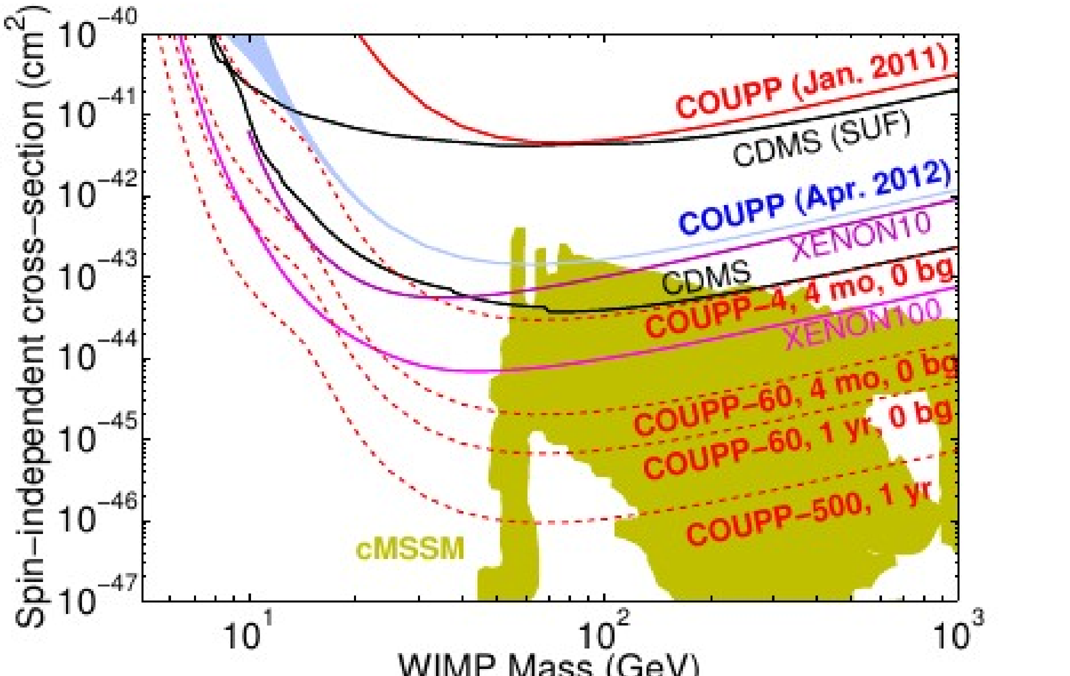
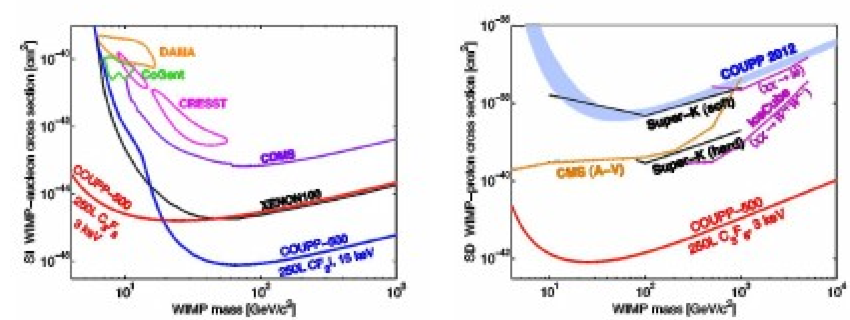


Coupp: 500Kg bubble chamber

- > 10^{10} γ/β insensitivity
- > 99.3% acoustic α discriminatior
- Multi-target capability
- SD- and SI-coupling
- High- and low-mass WIMPs
- Easily scalable, inexpensive to replicate
- Growing collaboration
  Newly merged with PICASSO



- R&D phase (I)

Coupp: ***(R&D) on acoustics***

- Acoustics system is essential for a good alpha background rejection.
- R&D Studies to improve the technique:

  Piezoelectric Transducers.

  Acoustic transmission Fluid- Fluid, Fluid – Solid.

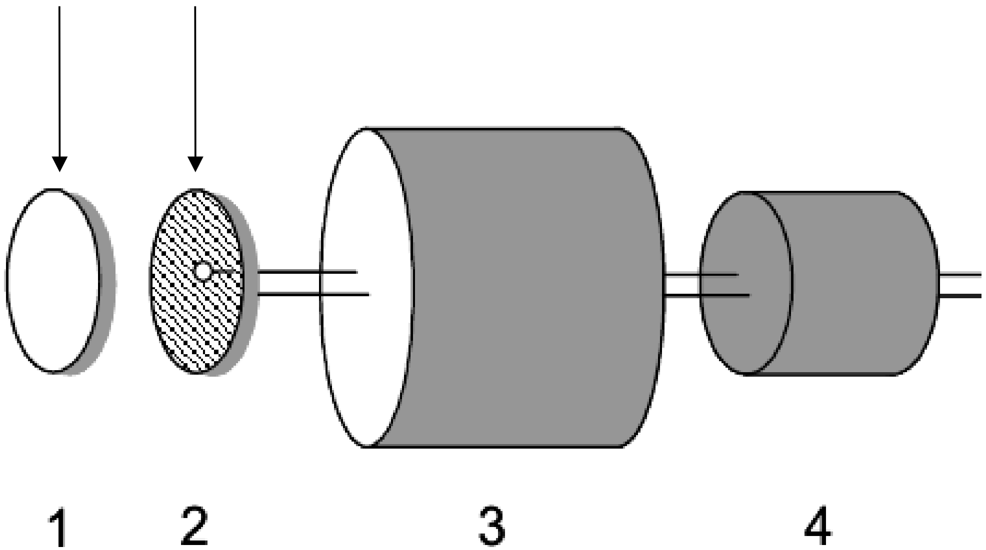
  Acoustic signature of bubble growth.

Coupp: (R&D) Transducer

Improving the sensitivity of piezo sensors by using a convenient head that increases the acoustic transfer function between the load medium and the piezo ceramic.

Optimum acoustic impedance for the head → $\sqrt{(Z_c \cdot Z_m)}$

$\frac{\lambda_h}{4}$ $\frac{\lambda_c}{2}$



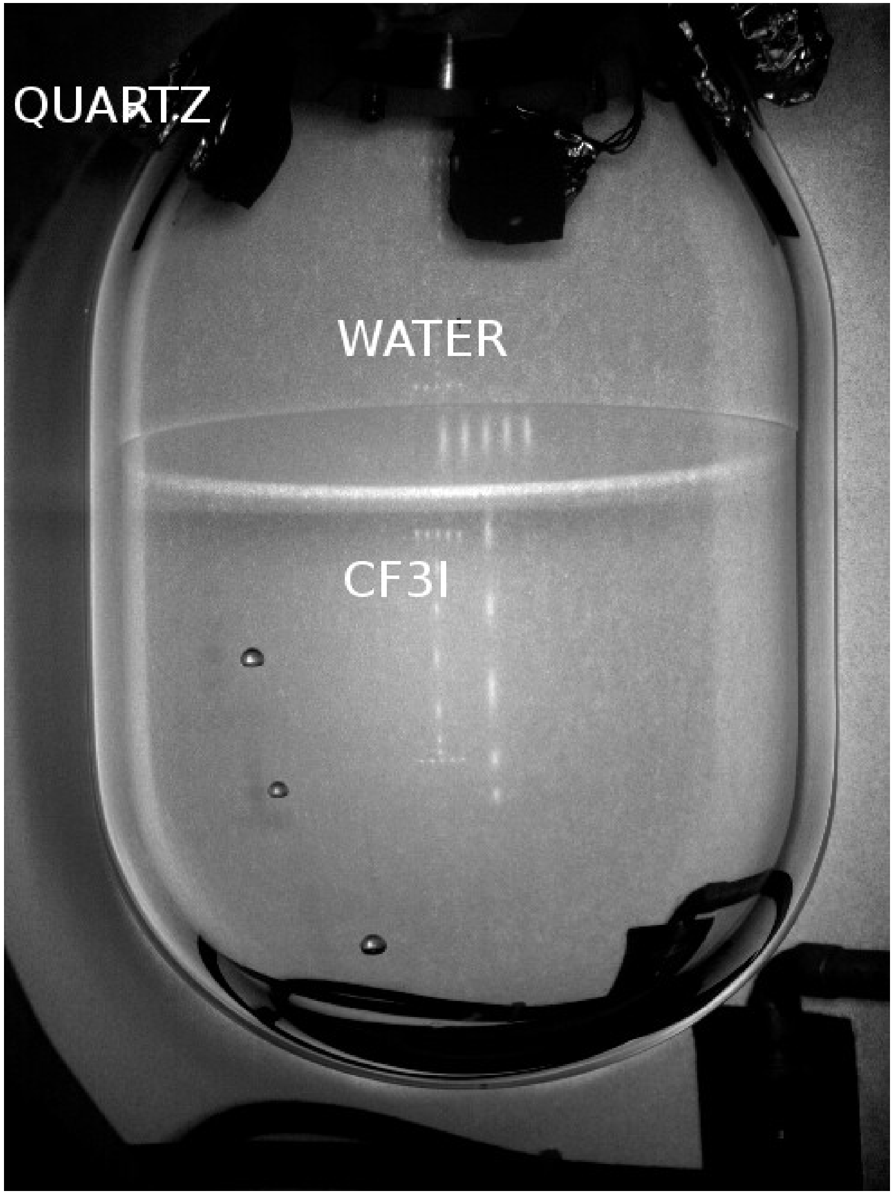
Thickness of the optimum head:

$$\lambda_h = \frac{C_h}{frequency}$$

Desired Frequency

$$thickness_h = \frac{\lambda_h}{4}$$

Coupp: (R&D) Transmission

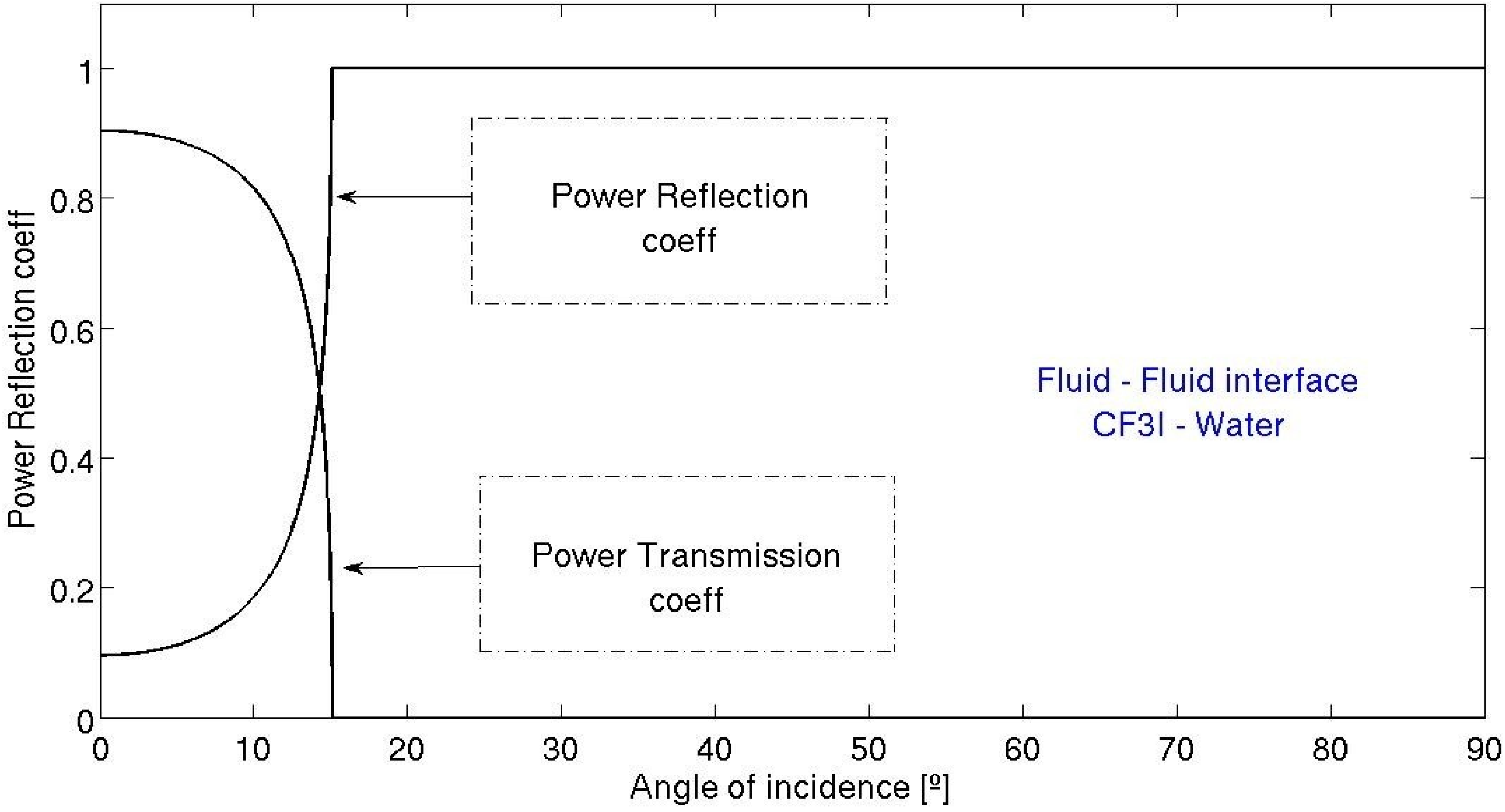


- Acoustic transmission between different
  layers have been studied:
  - CF3I - Water
  - CF3I - Quartz
  - Water- Quartz
- There are only longitudinal waves in fluids but in interfaces fluid – solid it appears longitudinal and shear waves at the solid.
- In order to know in which way the acoustic signal generated by the growth of the bubble is better transmitted, the transmission line model for acoustic waves has been applied .

Coupp: (R&D) Transmission

CF3I – Water Interface.

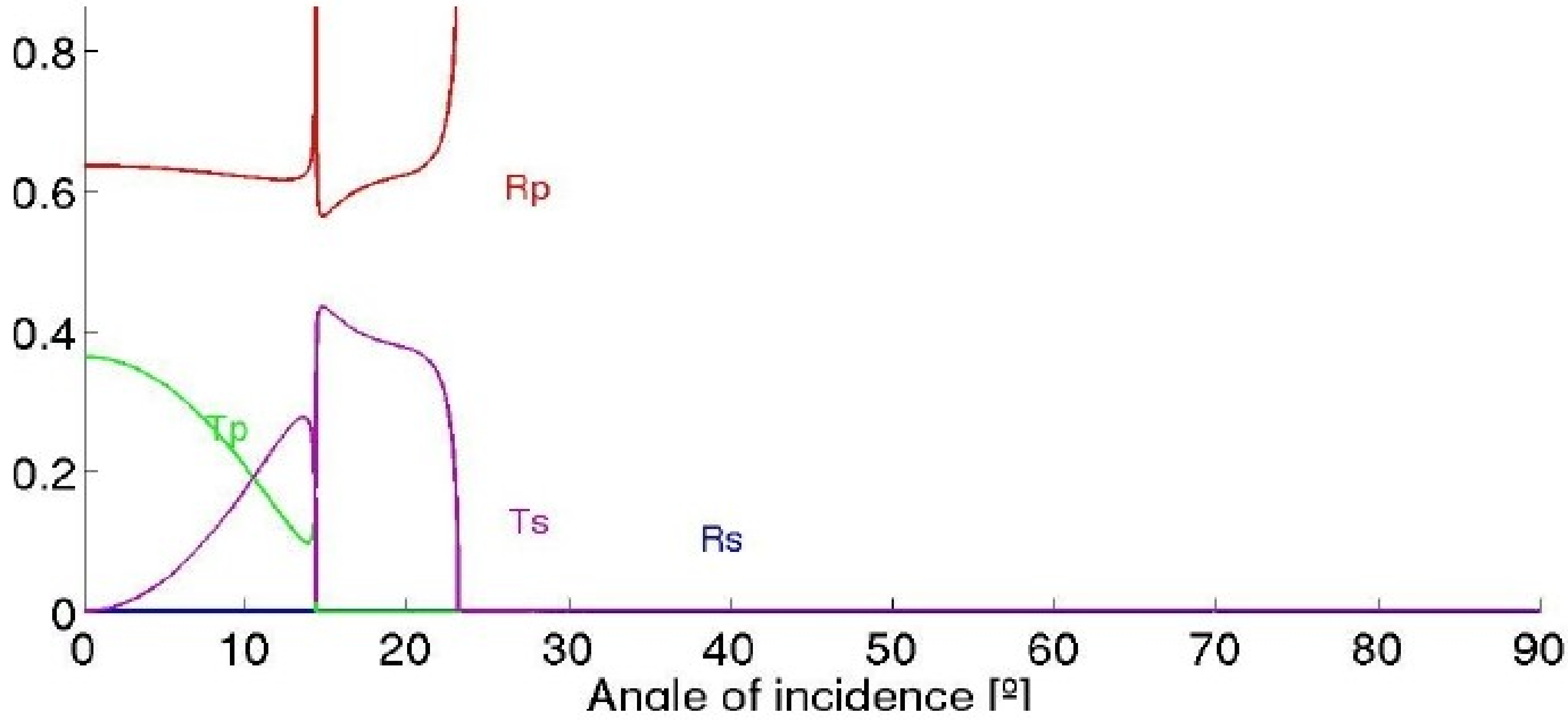
- For this case the speed of sound in CF3I is smaller than the speed of sound in water, by this reason there is a critical angle between the two fluids $\sigma_c = 14.6$.



Coupp: *(R&D) Transmission*

Water – Quartz Interface.

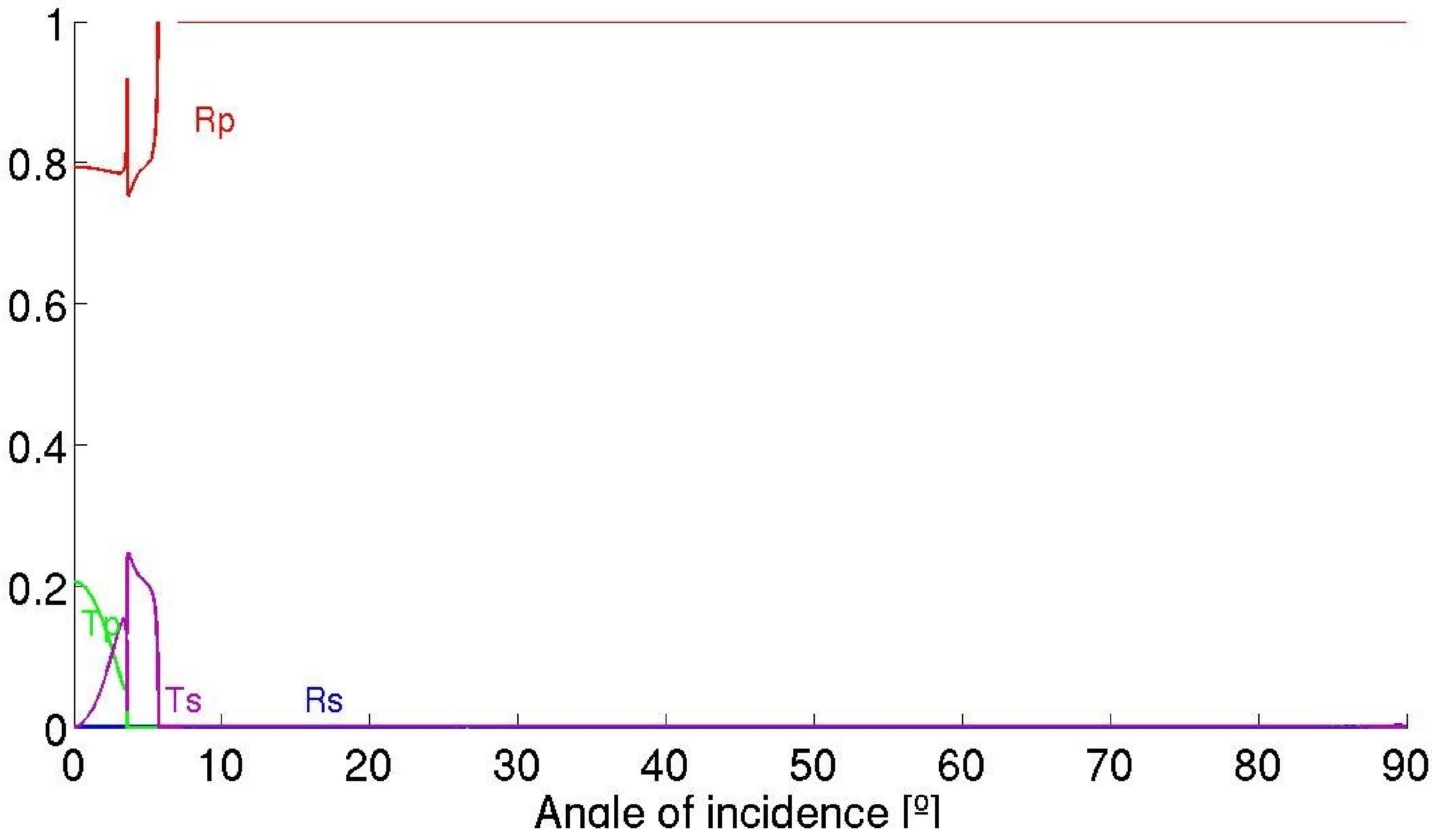
- Also in this case, the velocity of sound is larger in the wall of the chamber than in the water so there is a critical angle from which all acoustic signal is reflected.In this case the critical angle for the transmission of longitudinal waves and shear waves are, respectively σ_c=14.3 σ_c=23.2



Coupp: *(R&D) Transmission*

CF3I – Quartz Interface.

- With respect to the CF3I-QUARTZ interface, the results for the critical angles for longitudinal and shear waves are, σ_c=3.6 and σ_c=5.6 respectively.



Coupp: ***(R&D) Generation***

The growth of a bubble in superheated liquid presents three phases:

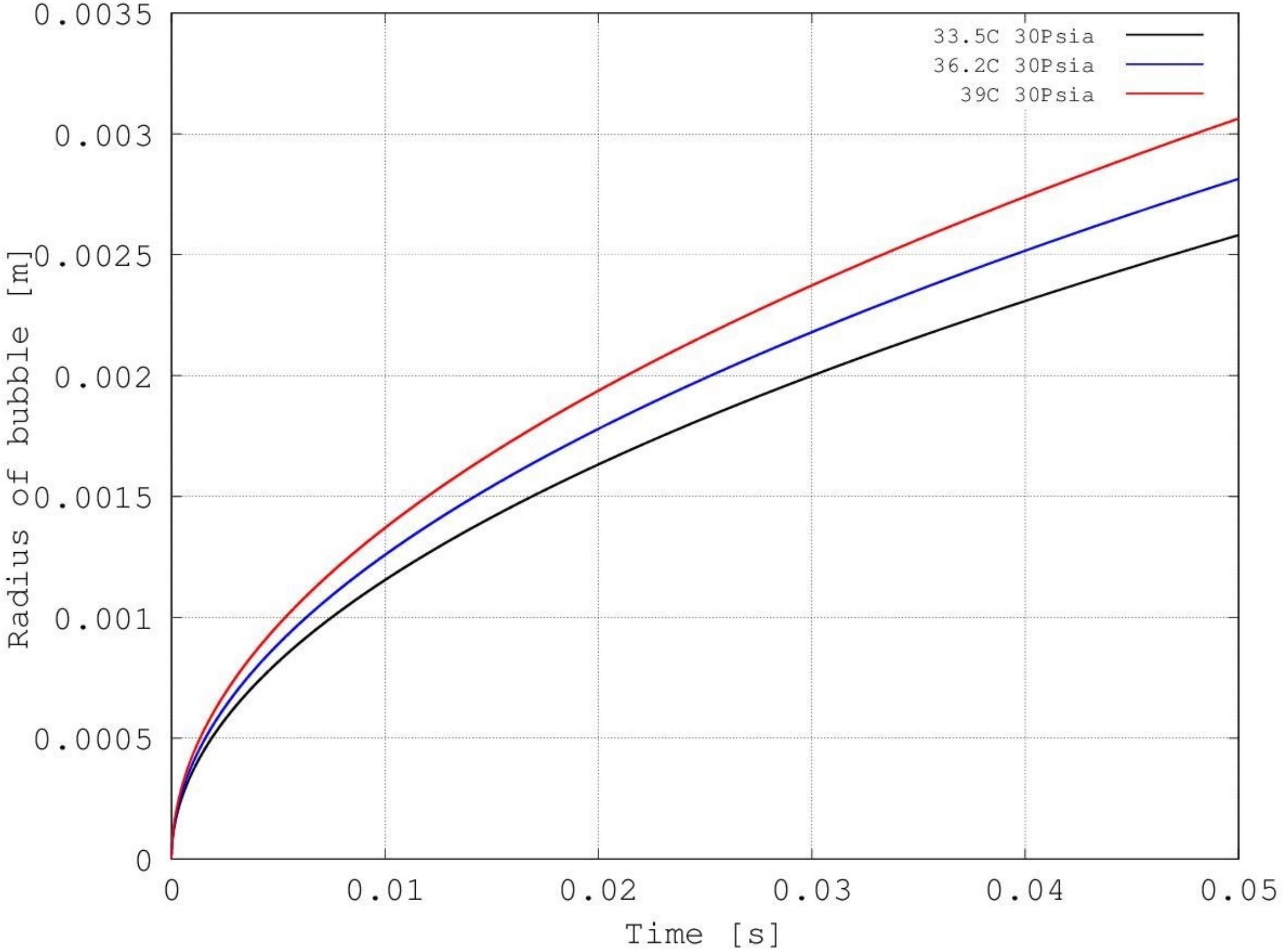
- Nucleation.
- Regime dominated by inertia.
- Regime dominated by heat diffusion.

The growth of the bubble has been simulated using FEM techniques according to the Mikic model of bubble growing.

$$R^{+}=\frac{2}{3}\cdot\left[\left(t^{+}+1\right)^{(3/2)}-\left(t^{+}\right)^{(3/2)}-1\right]$$

Coupp: (R&D) Generation

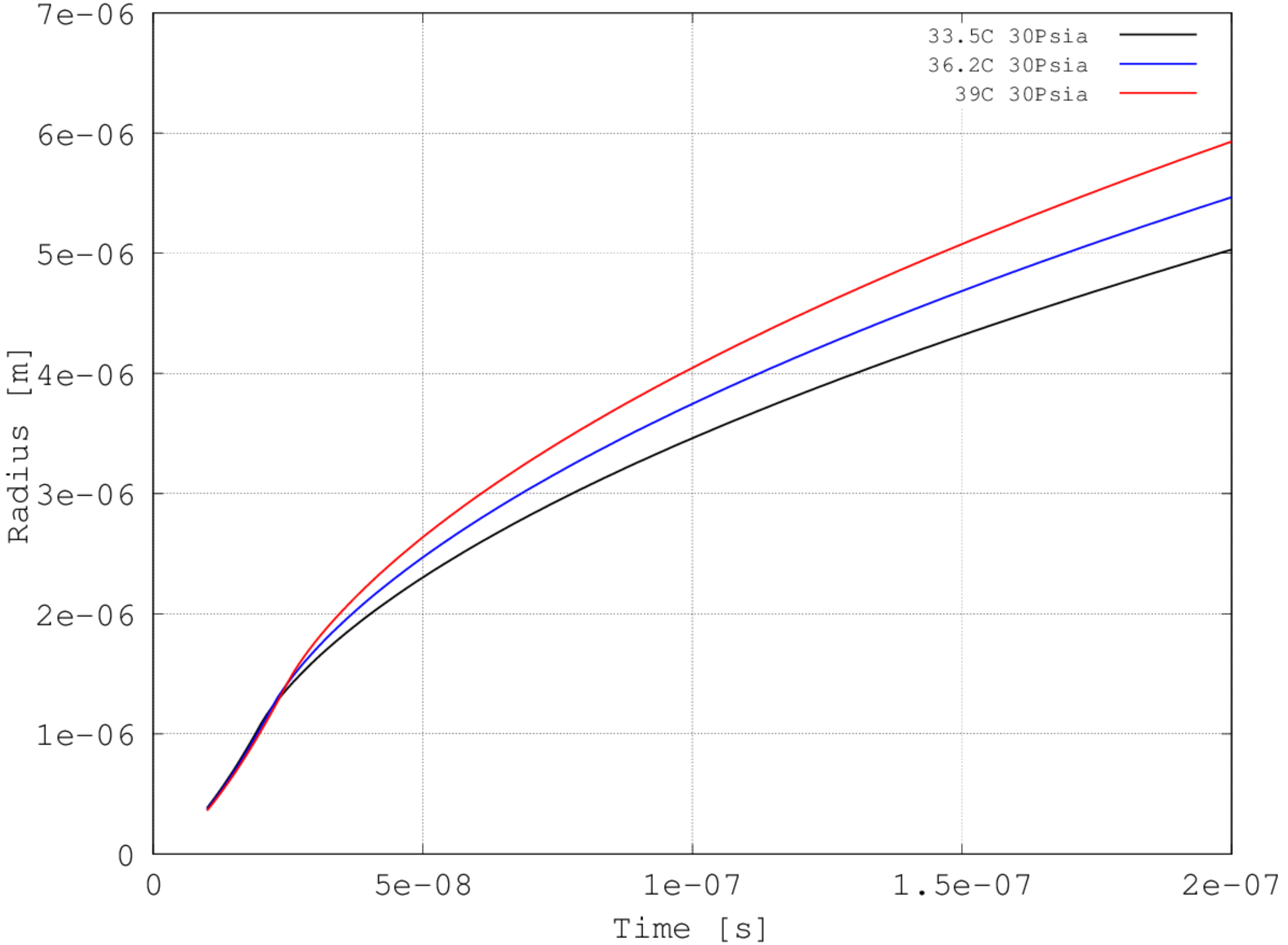
Bubble growing with the conditions of the three thresholds of the 4kg bubble chamber in COUPP has been simulated



Results obtained are in agreement with experimental data R ~ 3mm , in addition Mikic model reproduce the dependence of radius with temperature and time.

Coupp: ***(R&D) Generation***

Performing a more accurate simulation for early times of bubble growth it is possible to observe the transition between inertial and heat diffusion phases.



This transition phase is the main effect to understand the deposition of energy in the medium.

***Coupp:* Conclussions**

- ***Physics run at SNOLAB completed for COUPP4***

  Results published in 2012

  Spin-dependent competitive limit achieved

  Excellent acoustic alpha rejection: > 98.9%

  COUPP family of detectors making huge improvements

- ***COUPP60 at SNOLAB:***

  Physics run in a few weeks (with 38kg)

  Calibrations, calibrations and calibrations going on:

- ***COUPP500*** s coming soon, it is currently under R&D phase to improve and adapt the systems.

  Acoustics have an important role, some studies for improvements have been presented

  (see as well the poster '***Acoustic studies for alpha background rejection in dark matter bubble chamber detectors***')

That's all

Thanks for your attention!