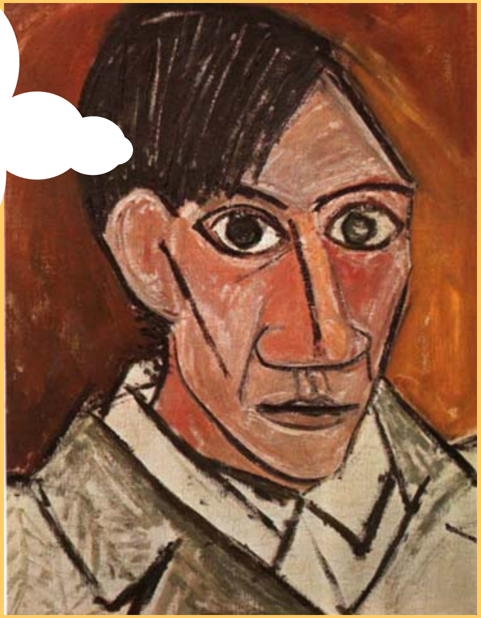

Simulation of PICASSO detectors

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On behalf of the PICASSO Collaboration
(Montréal, Queen’s, Indiana South Bend, Prague)

2006

Simulation of PICASSO detectors

- **PICASSO detectors**
- **Required simulation parameters:**
  - **Detector geometry**
  - **Droplet distribution / active mass**
  - **Physical processes**

  Geant4

  - **Threshold energy**
  - **Probability factor**

  Analysis
- **Results**
- **Future studies**

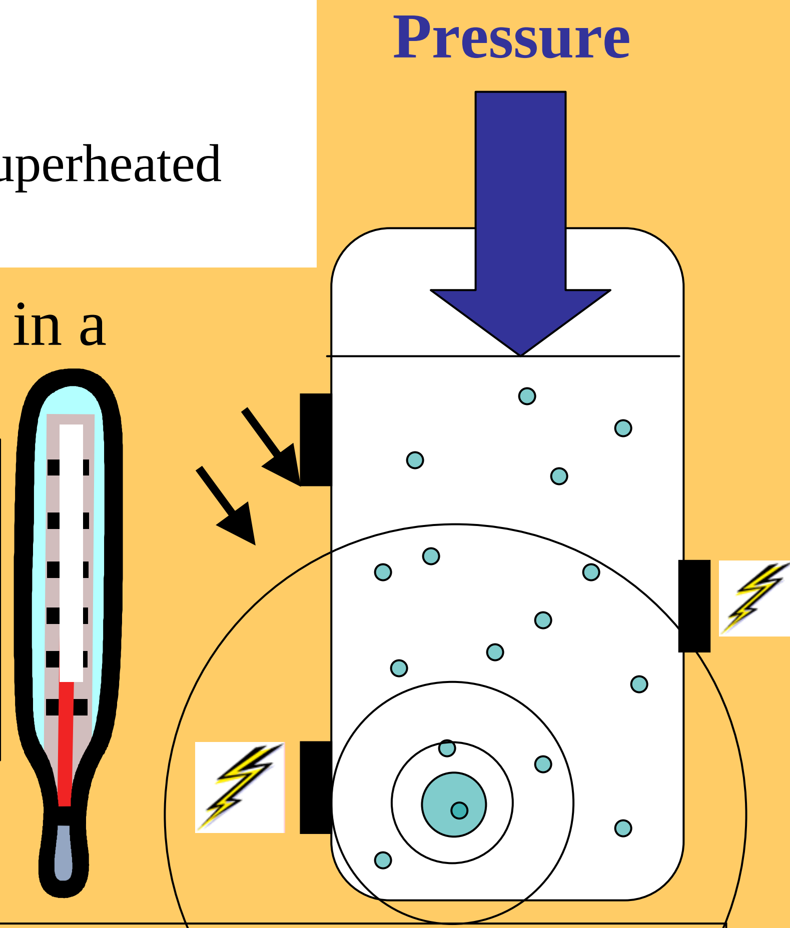
PICASSO detectors

PICASSO: Project In CAnada to Search for Supersymmetric Objects

Cold dark matter search experiment based on superheated droplet technique

Detector: Superheated droplets dispersed in a polymerized gel

Passing through the detector a particle loses energy. If this deposited energy is sufficient, a phase transition occurs.



A droplet bursts, creating an acoustic wave detected by piezo-electric transducers.

Detection principle: Seitz theory

For a phase transition to occur:

$$E_{kin,\,particle} \geq \frac{dE}{dx} \times \left(R_{crit}\right) \geq E_{\min}$$

How much is sufficient energy deposition?

R_{crit} and E_{min} being defined as :

$$R_{crit} \equiv \frac{2\gamma(T)\varepsilon}{\Delta P(T)}$$

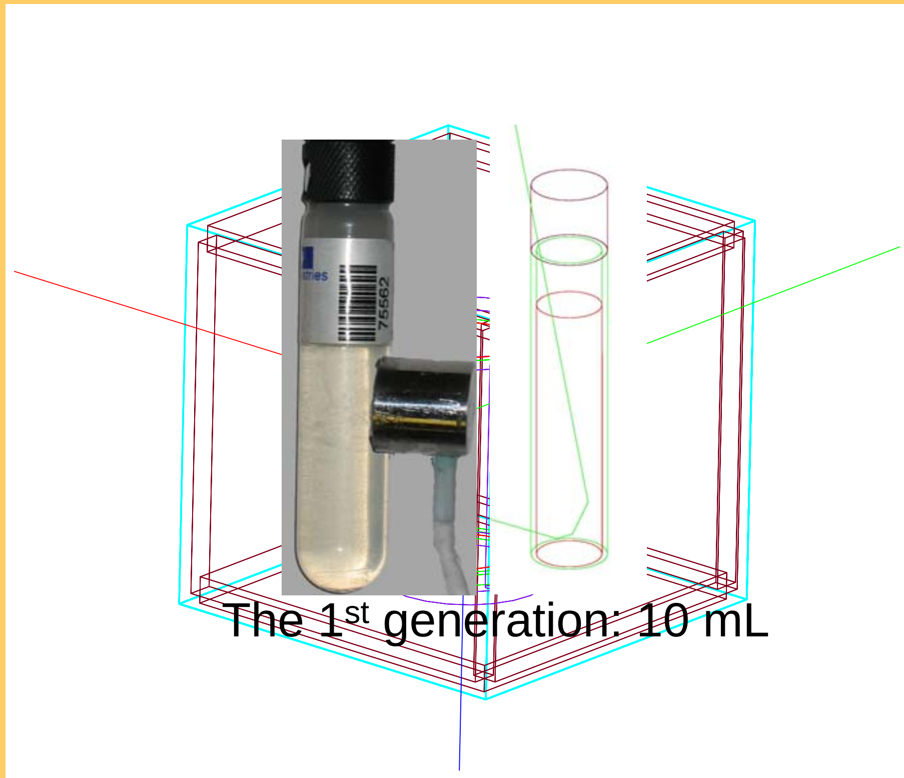
$$E_{\min} \equiv \frac{16\pi}{3\times\eta}\,\frac{\gamma^{3}(T)}{(\Delta P(T))^{2}}$$

$\gamma(T)$ is the droplet's surface tension:

$$\gamma(T) = \frac{2.1(T_C - T)}{\left[M/\rho(T)\right]^{2/3}}$$

T = temperature of operation
T_C= critical temperature
M = molecular mass
ρ= density
ε= critical length factor
$\Delta P(T)$ = difference between the vapour pressure and the applied pressure
η= efficiency

What is needed – Geant 4
1 – Geometry (examples)

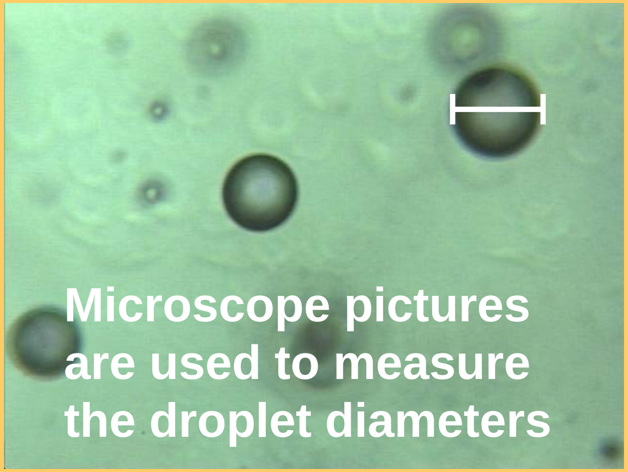


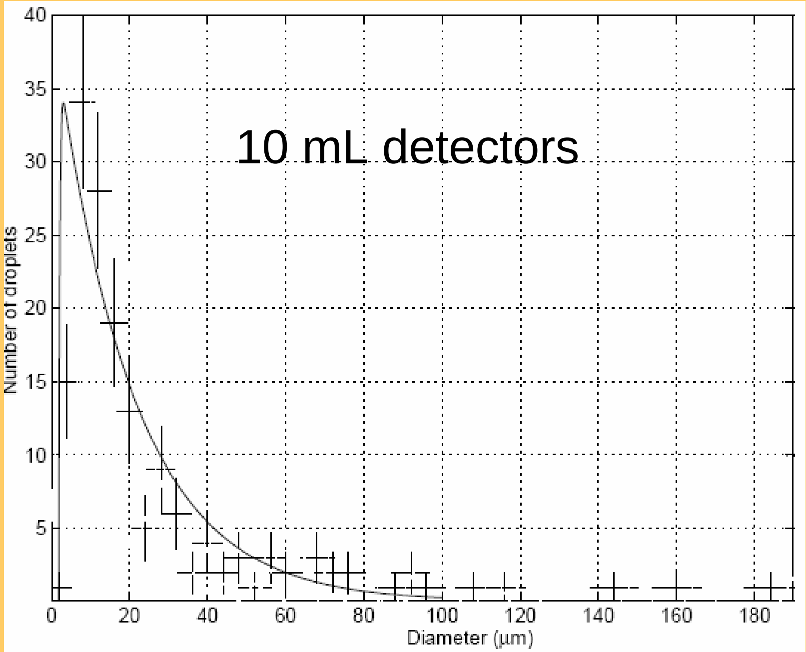
The 1st generation: 10 mL

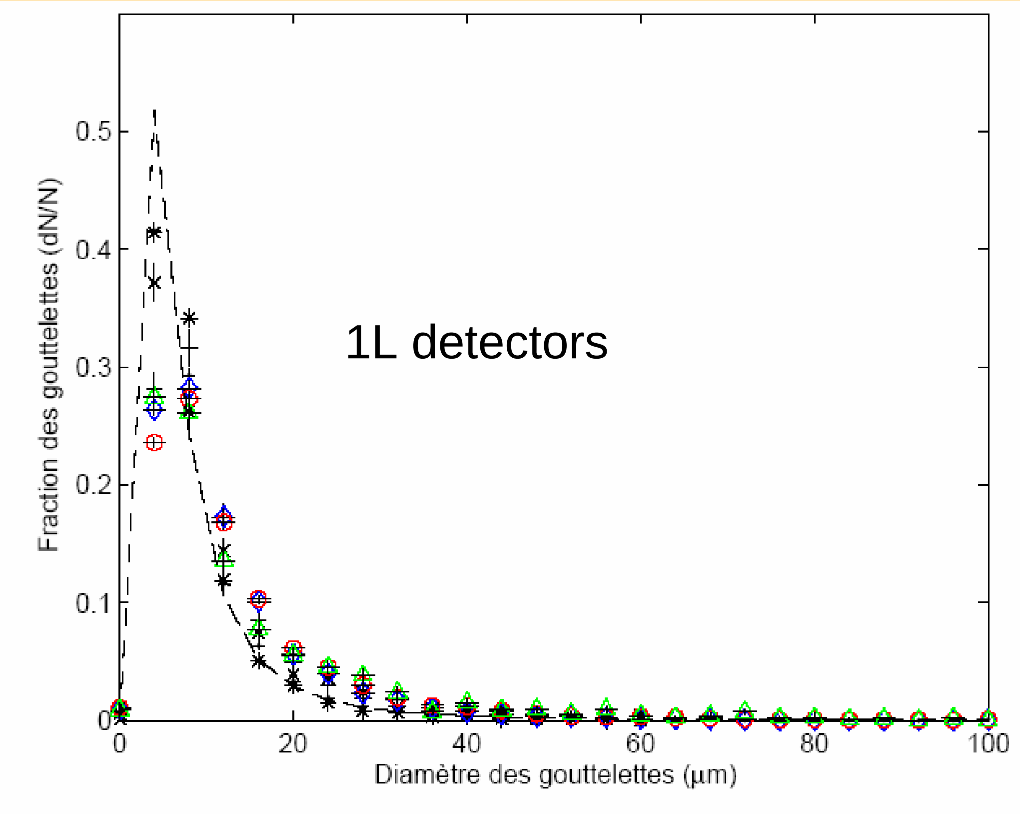
4.5L detector in a temperature and pressure control box

All materials have to be defined in their chemical composition and density.

What is needed – Geant 4
2 – Droplet distribution







Important in the alpha particle response amplitude …

What is needed – Geant 4
3 – Physical processes

- Elastic/inelastic neutron scattering considered for all nuclei in all physical volumes
  - → Cross sections taken from ENDF/B-VI librairies

- Low energy ionization energy loss for nuclei
  - → Nuclear stopping power model : ICRU_R49
  - → Electronic stopping power model: SRIM2000p

Output information → analysis

When a particle enters in a droplet, the output file is updated. This file contains, for all events:

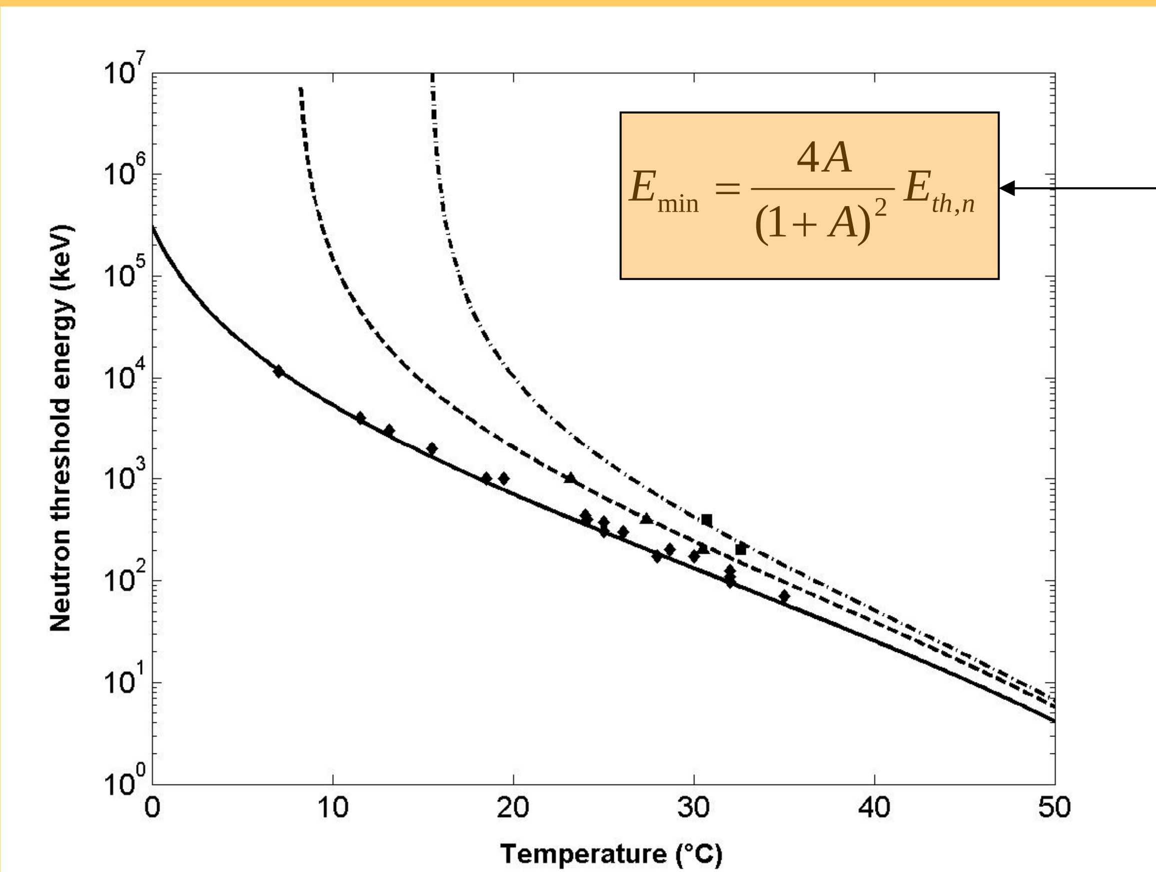
- The event number
- The event position inside the detector
- The particle or nucleus ID (via a code system)
- The particle’s kinetic energy
- The energy deposited within a step along the path
- The step length

This information is used in the analysis code to determine the response according to Seitz theory.

Is the energy deposited within a critical length by each particle going through a droplet enough to form a bubble ?

What is needed - Analysis
4 – Threshold energy

The neutron threshold energy as a function of temperature has been measured with monoenergetic neutron beams



$$E_{\min} = \frac{4A}{(1+A)^2} E_{th,n}$$

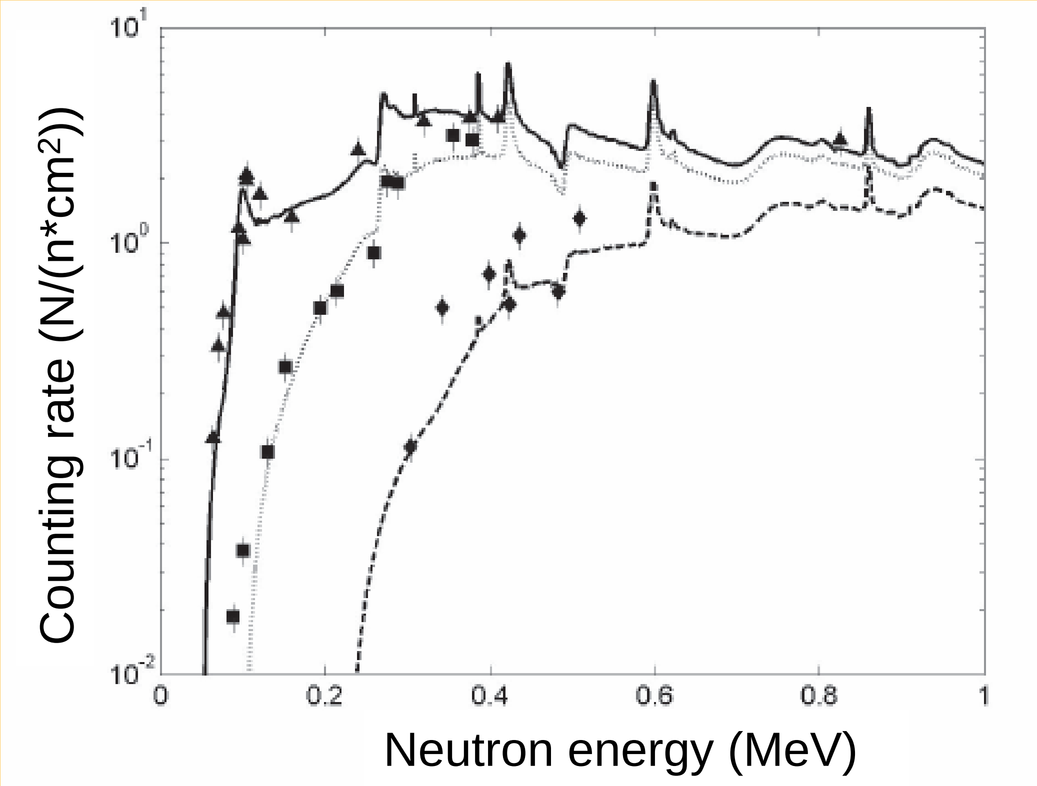
The neutron threshold energy is converted in a minimal energy deposition in the superheated liquid (C_4F_{10}) by considering a maximal nucleus recoil after a neutron-nucleus scattering.

What is needed – Analysis
5 – Probability factor

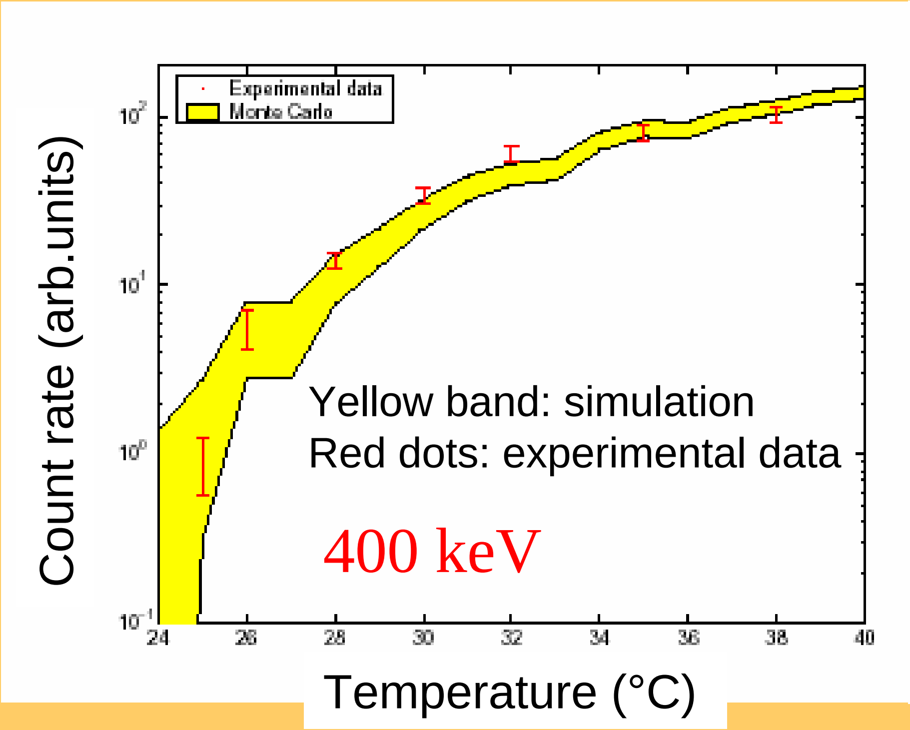
Even above the threshold energy, the deposited energy is not always efficient in triggering a phase transition.

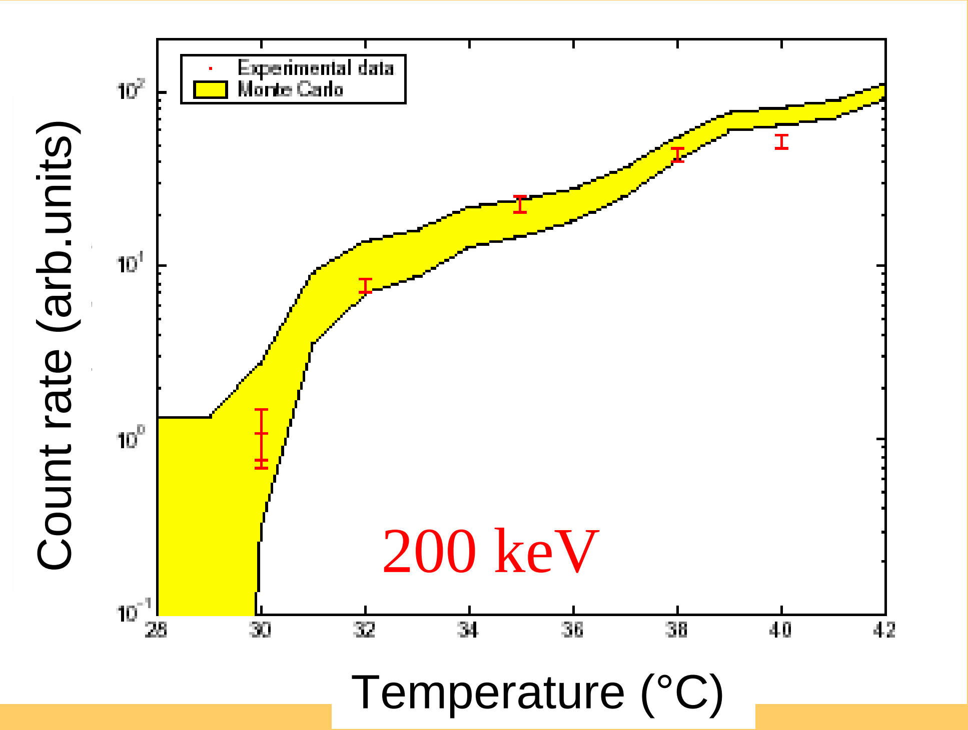
The probability of a droplet bursting as a function of the energy deposition was adjusted to the detector response for three different temperatures (10,15 and 20°C) and is given by:

$$P = 1 - \exp\frac{a(E_{min} - E_{dep})}{E_{min}}$$



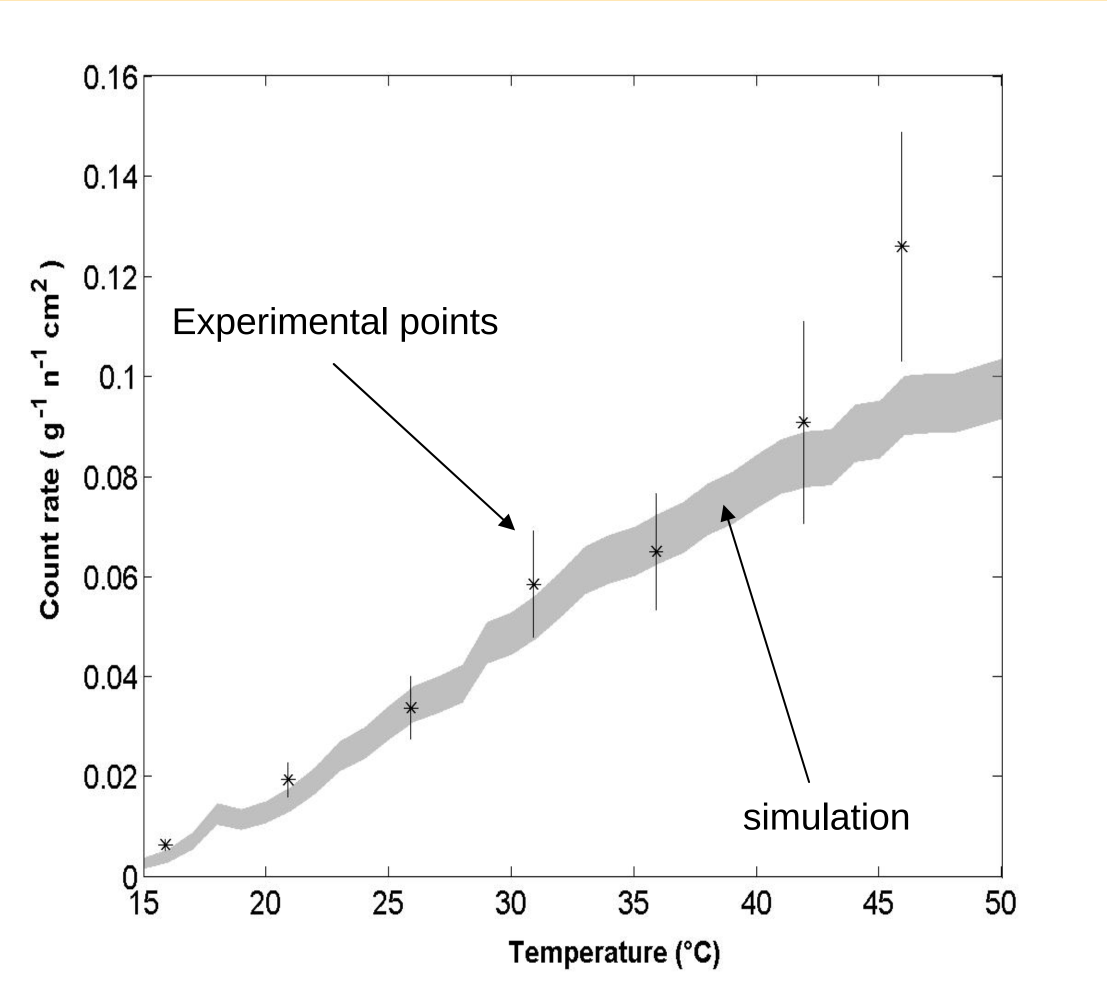
Results: monoenergetic neutrons

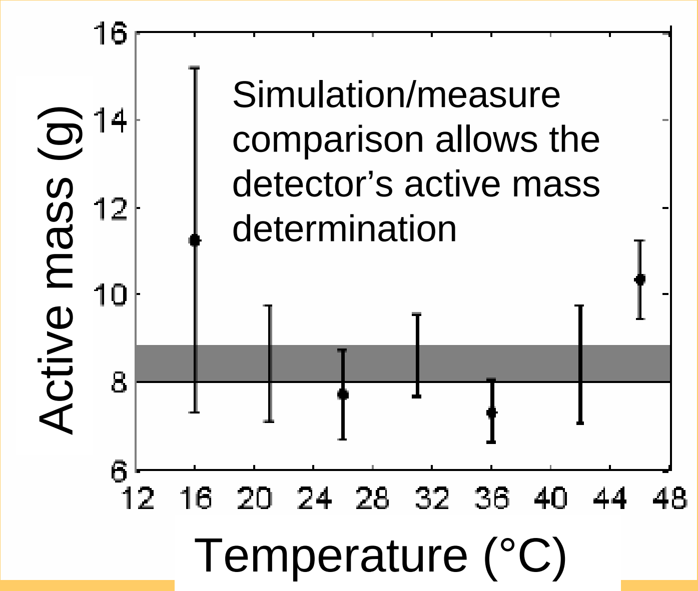




First simulations: 10 mL detectors

Results: AcBe neutron source





AcBe source

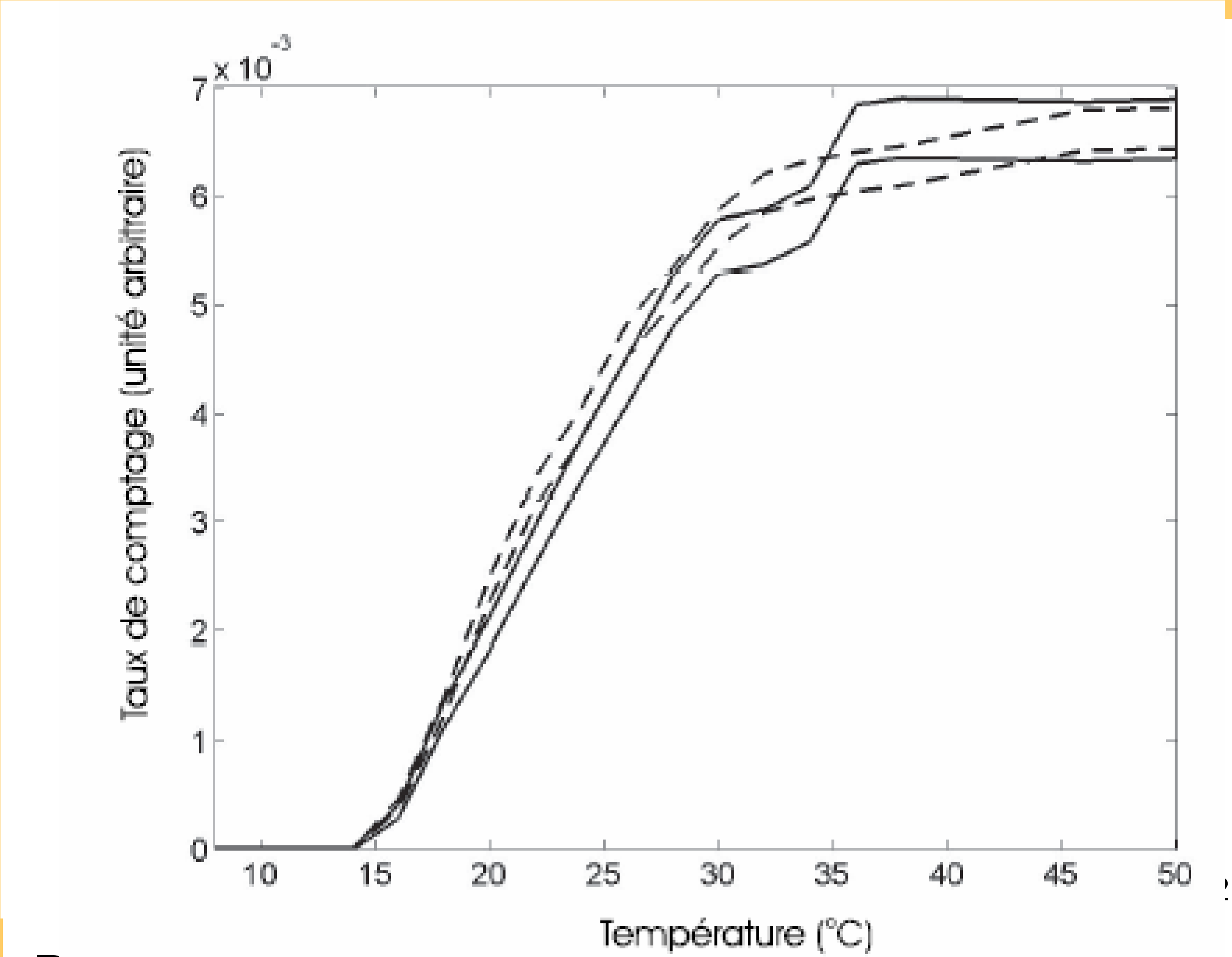
Actinium → α emitter
Beryllium → $^{9}Be(\alpha,n)^{12}C$

E_{prob} = 4.6 MeV

E_{max} = 12 MeV

Activity: 1.4×10^{5} n/s

Results: alpha particle study

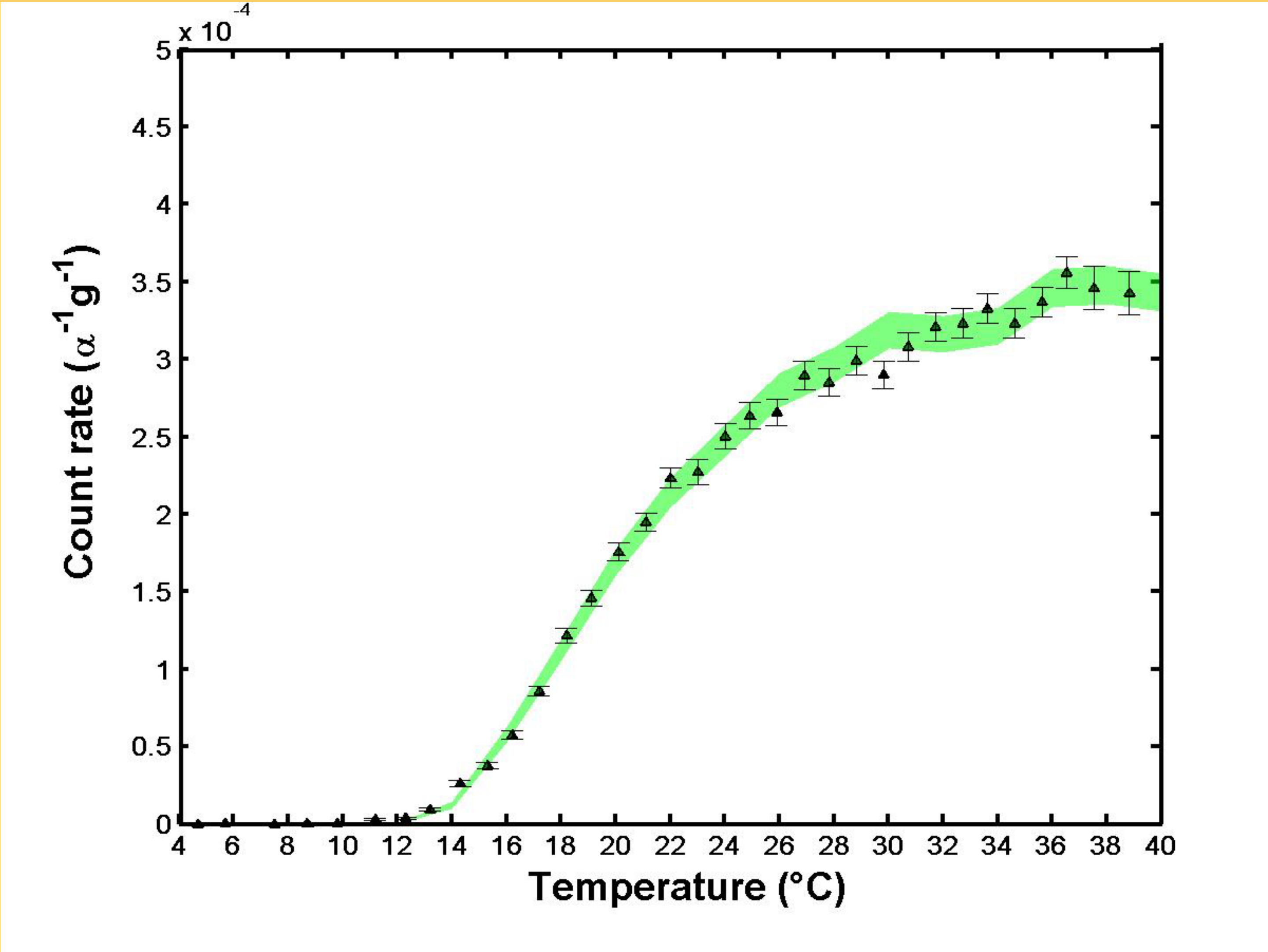


Between 25 and 50°C the alpha response curve shape is unchanged for different droplet distributions.

The greater the droplet's radius, the smaller the alpha response for the same active mass (geometrical purification)

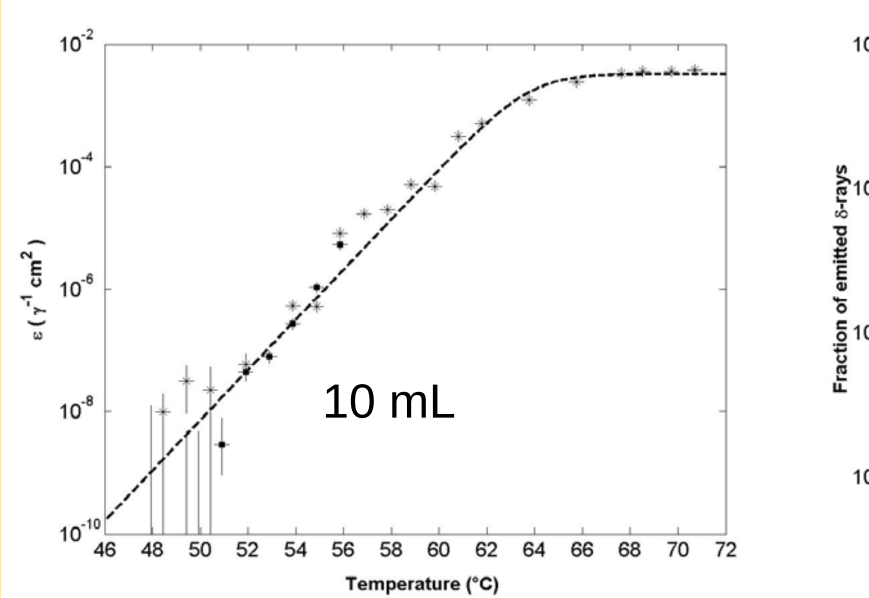
Different contaminants (here, ^{241}Am and the U) – same response shape

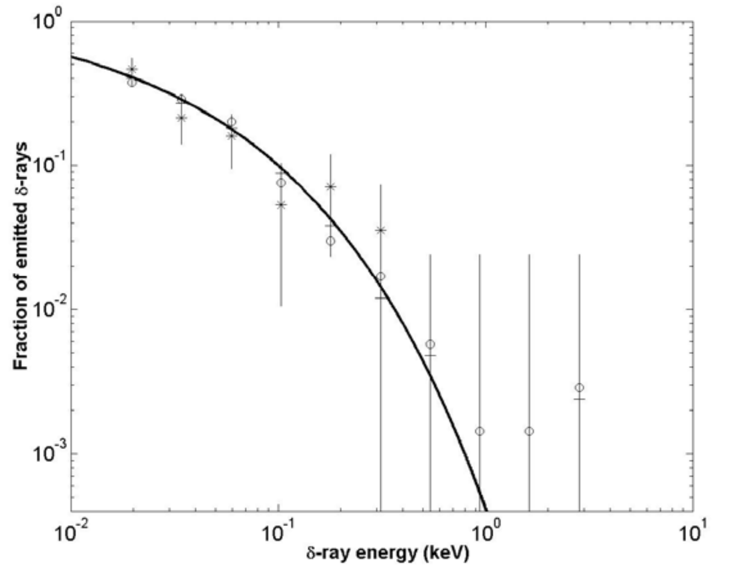
Results: alpha particles



Response curve of ^{238}U-spiked detector

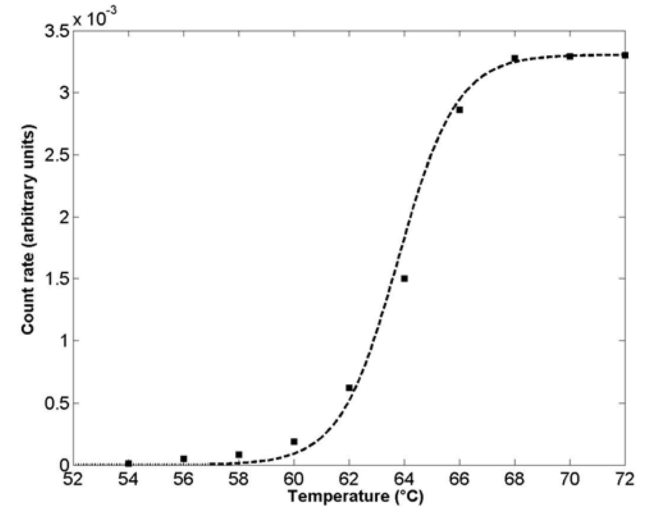
Preliminary results: gamma response



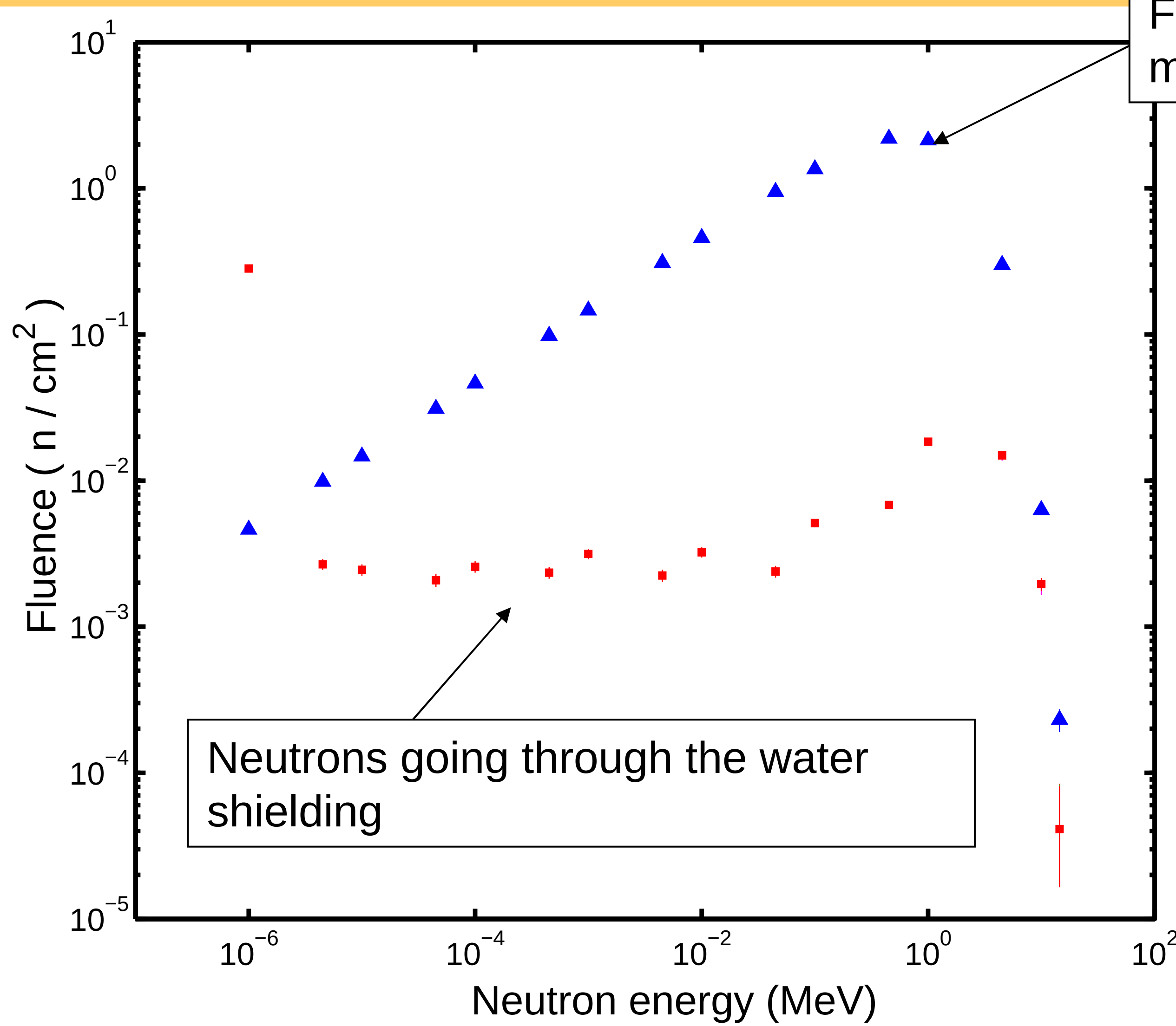


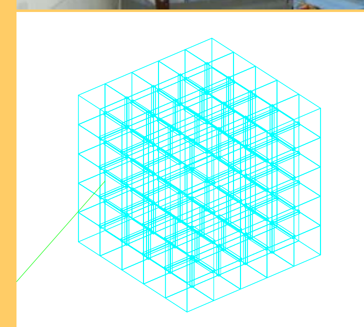
No complete simulation:

The response shape is understood as resulting from the energy spectrum of the delta-ray electrons emitted along the gamma-ray path



Studies for TDR: Neutron shielding

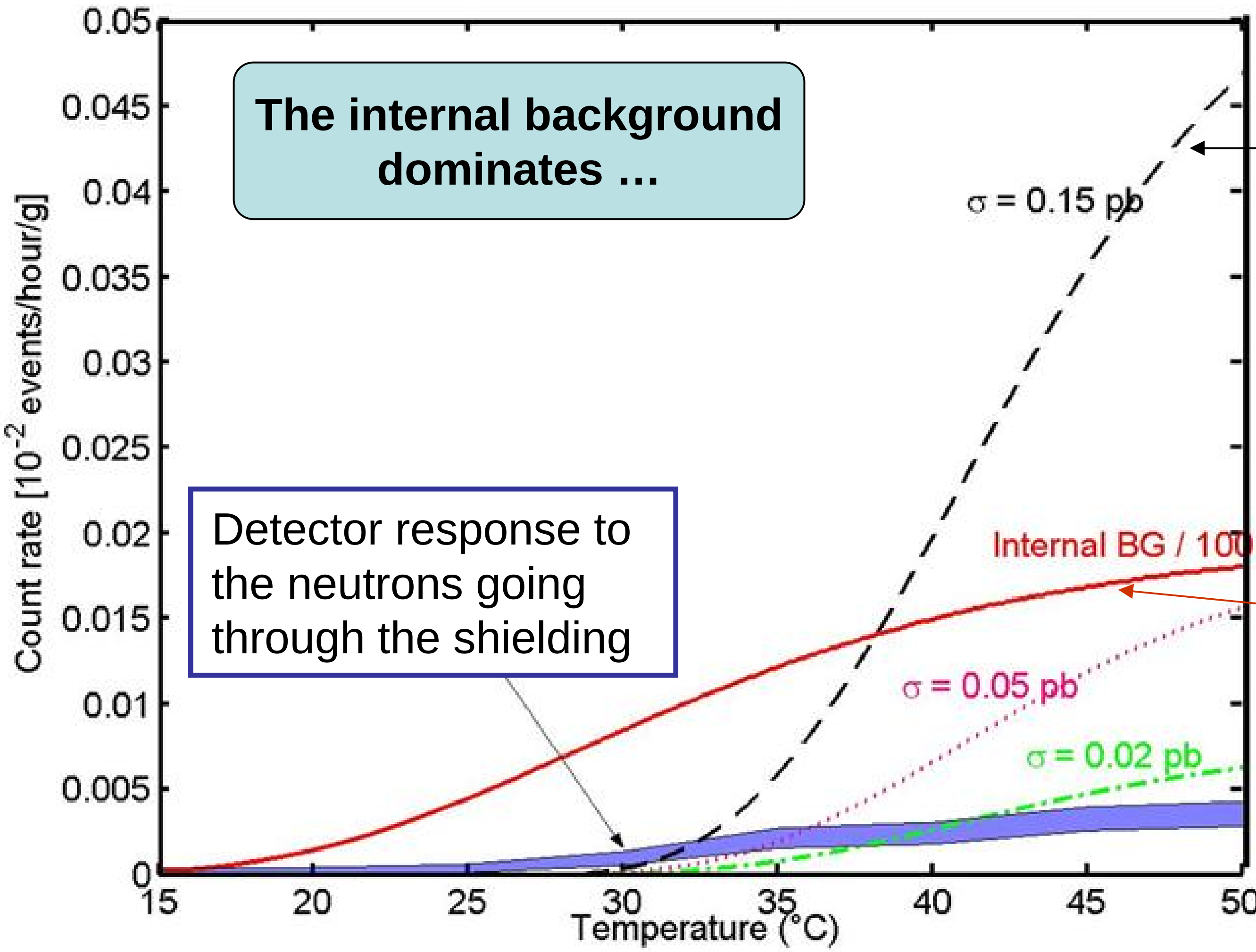




Shielding: 30 cm water cubes placed around the experimental set-up

Studies for TDR: Neutron shielding

The internal background dominates …



neutralino predicted response (for different cross sections and $M_\chi = 50$ GeVc^{-2})

Internal background expected (alpha contamination)

Detector response to the neutrons going through the shielding

Future prospects…

- Low energy monoenergetic neutron beam: measurements and simulation
- 4.5L ^{226}Ra-spiked detector simulation(experimental results coming soon)
- Multiple neutron interactions for a 32-detector set-up (possible discrimination)
- Measurement of the gamma response for 4.5L detectors and complete gamma simulation
- … !

Other PICASSO talks at ACP !

Here, today:

16:45 Razvan Gornea

New Improved Phase of PICASSO Installation at SNOLAB

17:00 Ken Clark

Analysis of PICASSO-II Data

Wednesday:

Instrumentation for Particle Physics

10:00 François Aubin

Event Localisation in PICASSO Detectors

10:15 Patrick Doane

Improved Fabrication Method of PICASSO Detectors

Non-Acclerator Particle Physics

14:45 Ubi Wichoski

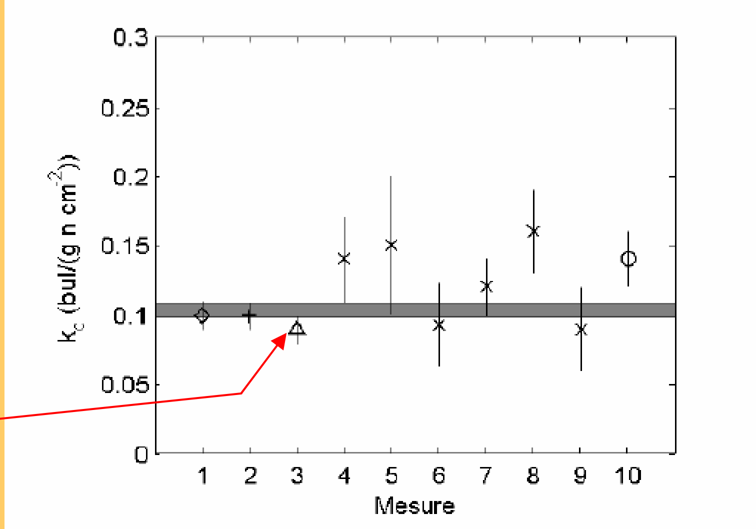
Results and Status of the PICASSO Experiment

Geant4
http://geant4.web.cern.ch/

- Geant4 is a toolbox for the passage of particles through matter
- Geant4 has been developped by RD44, an international collaboration of a hundred scientists working on more than 10 experiments (Europe, Russia, Japan, Canada and United-States).
- Geant4 gives tools for all simulation aspects: geometry, tracking, detector response, visualization, user interface…
- A large number of physical processes describing the different particle-matter interactions for a wide energy range is available. For many processes, different models are available.

Extra !

The detector calibration constant obtained by simulation agrees with the other methods (microscopes, weighting …)



Geant4 – what is needed

Detector :

- Geometry (container, gel, droplets)
- Chemical composition of all parts
- Density of the materials

Particles:

- Physical processes needed
- Particles to generate (particle ID, energy,vertex)

Tracking:

- The tracking is performed step by step for all primaries and secondaries (cuts can be applied)
- The output information for each event has to be defined

The analysis code (detector's response) could be implemented here, but an external code allows the possibility to play with the response parameters without having to re-generate events.

Analysis code: detector's response

The Geant4 output file is analyzed:

- For each temperature, the code calculates:
  - The threshold energy
  - The critical radius within which the minimal energy must be deposited
  - For all particles going through droplets, the maximal energy deposited within the critical radius
- The code then compares, for each particle in the output file, the maximal deposited energy and the threshold energy, using the probability function to determine whether a phase transition occurs or not
- The number of bubbles created is saved and the temperature is incremented