R&D for neutrinoless double beta decay with Borexino

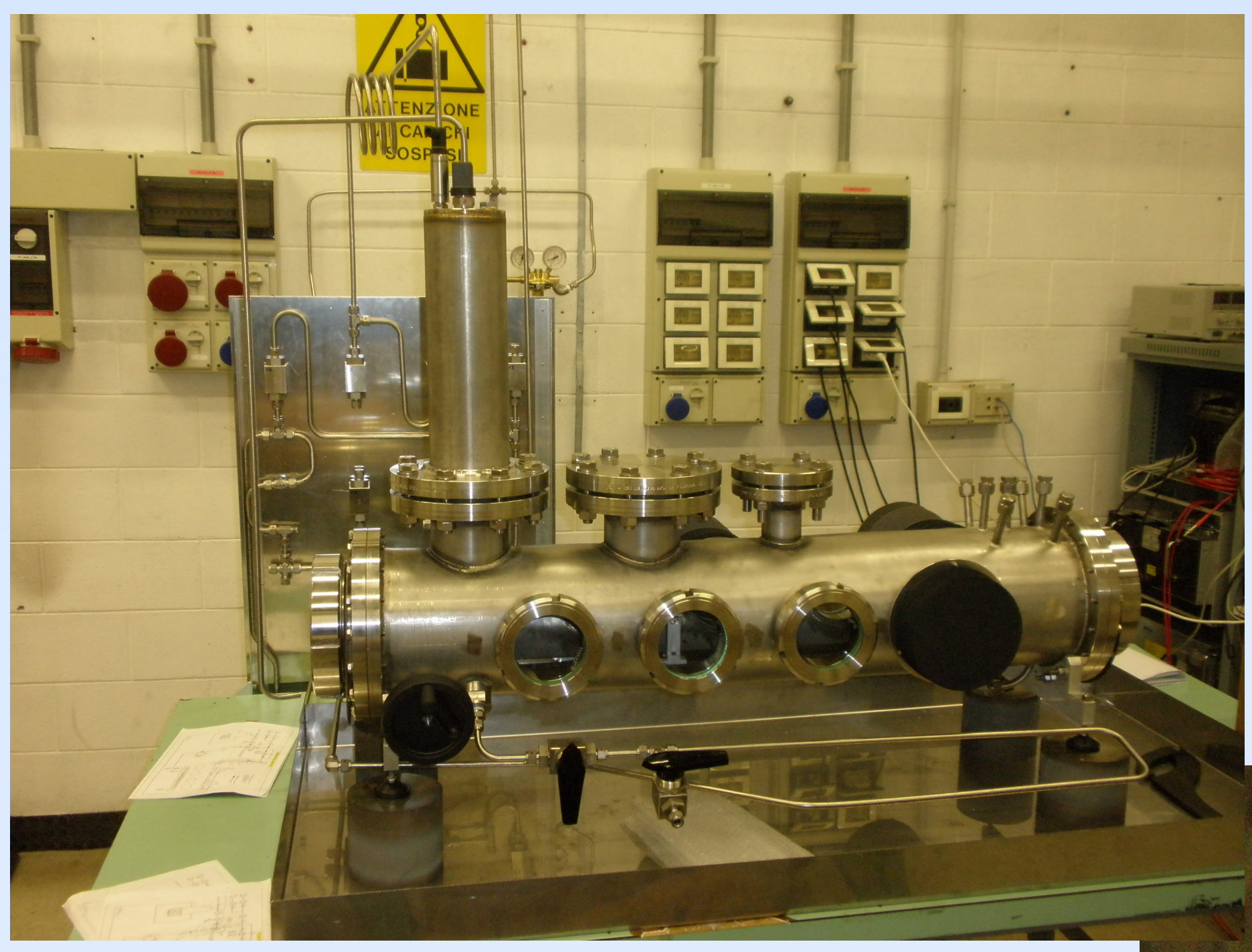
A. Caminata[a], S. Marcocci[b, a] and M. Pallavicini[a]
on behalf of the Borexino Collaboration*

[a] Dipartimento di Fisica, Università degli Studi e INFN, Genova, Italy
[b] Gran Sasso Science Institute (INFN), L'Aquila, Italy

Abstract

Since the beginning of the Borexino project in the early nineties, the idea to perform a neutrinoless double beta decay experiment with ^{136}Xe dissolved in the scintillator was considered [1, 2]. The beautiful results obtained by the Borexino experiment [3, 4], which achieved a purity far exceeding design goals, and a new concept for dissolving large quantities of xenon in the scintillator make this possibility even more interesting for a third generation experiment in the next decade. Since the solubility of a gas in a liquid grows with the pressure (Henry's law), it is possible to reach an active xenon mass of 10-15 tons, and possibly even more. We present the ongoing R&D studies to look for neutrinoless double beta decay using liquid scintillators, discussing the optical properties of the Borexino scintillator when xenon is dissolved in large quantity and with high pressure.

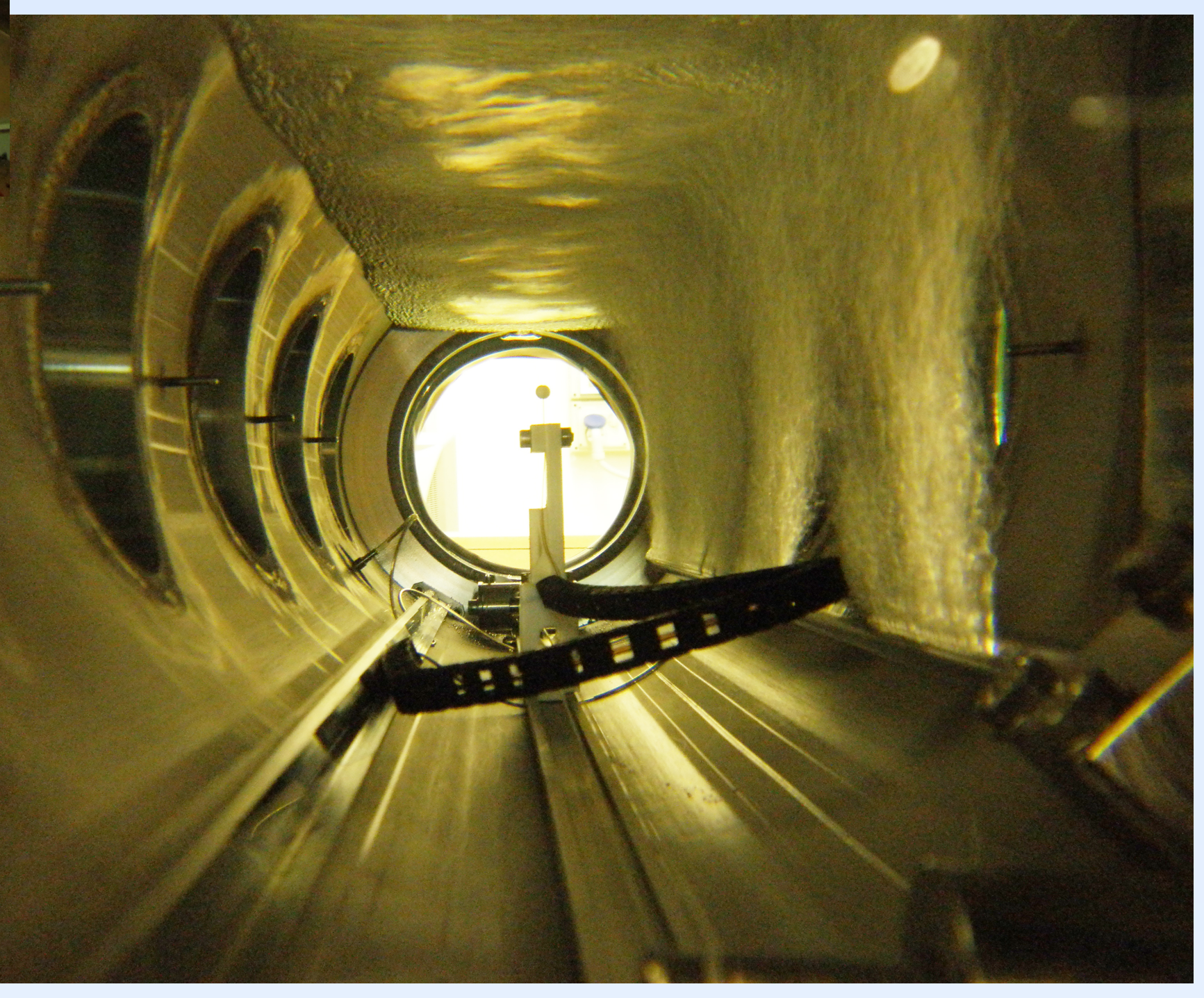
Setup



The chamber at the INFN laboratories in Genoa.

The chamber used for this R&D

- is a cylindrical tank (diameter ~20 cm, height ~1 m);
- contains ~40 L of Borexino's liquid scintillator (pseudocumene doped with PPO in a concentration of 1.5 g/L);
- withstands a pressure of 5 bar.



Internal view of the system while the gas is bubbling in the scintillator.

- Two 5'' PMTs are placed in front of 2 quartz windows at the bases;
- 9 lateral windows can house 3'' PMTs;
- a little movable carriage, with a tiny teflon sphere on the top, is used to spread light in the scintillator;
- a small perforated pipe at the bottom introduces the gas in the chamber.

Methods

We aim to measure the light yeld variation as a function of the amount of Xe dissolved in the scintillator, with respect to the pure Borexino scintillator case.

Xe Dissolution Control: while inserting gas, the system mass increases as follows:

$$M_{tot} = m_{PC}\,(k_{Xe}\,p_{Xe} + k_{N2}\,p_{N2}) + A_{Xe}\,n_{Xe} + A_{N2}\,n_{N2} + M_0 + m_{PC}$$

- M_{tot} = total mass of the system;
- m_{PC} = mass of the scintillator;
- $k_{Xe}(k_{N2})$ = Xe(N_2) solubility in PC;
- $p_{Xe}(p_{N2})$ = Xe(N_2) partial pressure;
- $A_{Xe}(A_{N2})$ = Xe(N_2) molecular mass;
- $n_{Xe}(n_{N2})$ = number of moles of Xe(N_2);
- M_0 = mass of the empty chamber.

If we:

- ✓ assume Henry's and ideal gases laws;
- ✓ consider that Borexino's scintillator is saturated with N_2;
- ✓ measure temperature, pressure, mass of the system and gaseous flux;

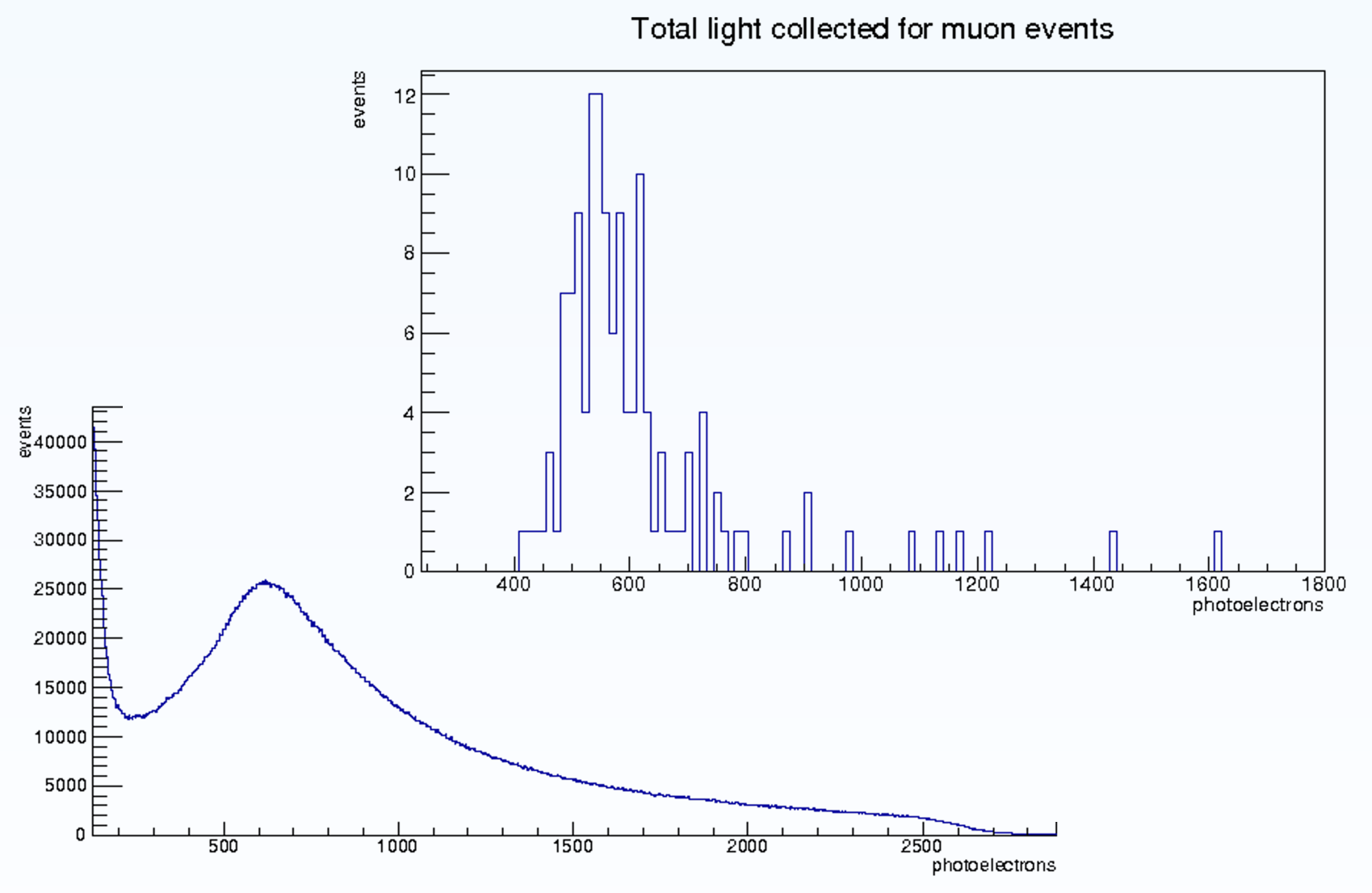
⇨

we can infer:

- ✓ the amount of PC inside the chamber;
- ✓ p_{Xe};
- ✓ the amount of Xe dissolved in the scintillator.

Light Measurement: we exploit the scintillation light produced by cosmic muons in the scintillator.

- Two inorganic scintillator detectors, located above and below the chamber, tag muons crossing the scintillator;
- the position of the peak in the spectrum correspondent to the vertical crossing of the chamber is our estimator of the light yield.

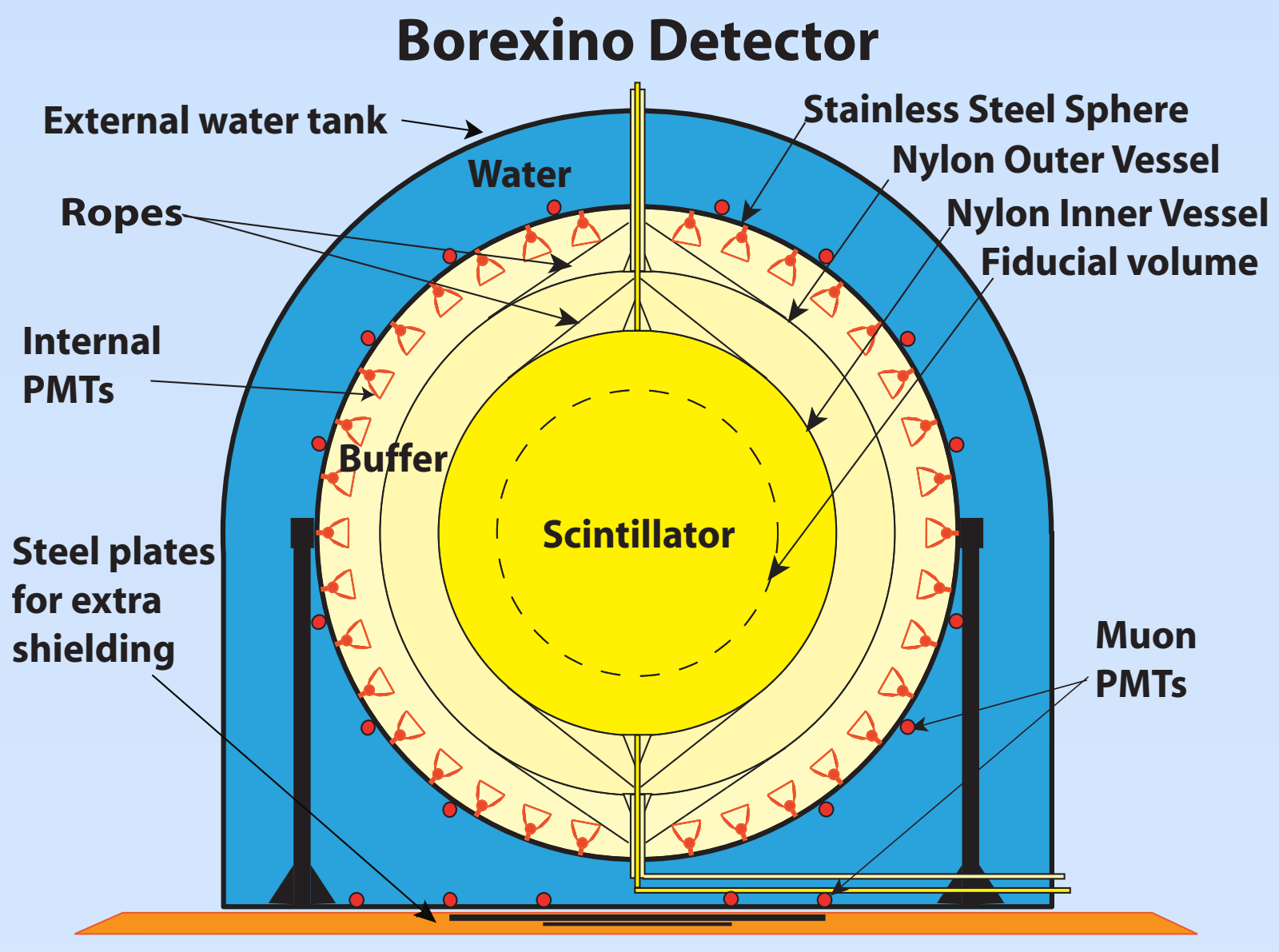


Energy spectrum of the signal induced by muons in the scintillator with (up) and without (down) the external tagging.

References
[1] Phys. Rev. Lett. 112, 068103 (1994)
[2] Borexino Proposal edited by G. Bellini and R. Raghavan (1991)
[3] arXiv:1308.0443 [hep-ex] (2013)
[4] Phys. Rev. Lett. 108, 051302 (2012)
[5] Nuclear Instruments and Methods in Physics Research 600, p 568-593 (2009)

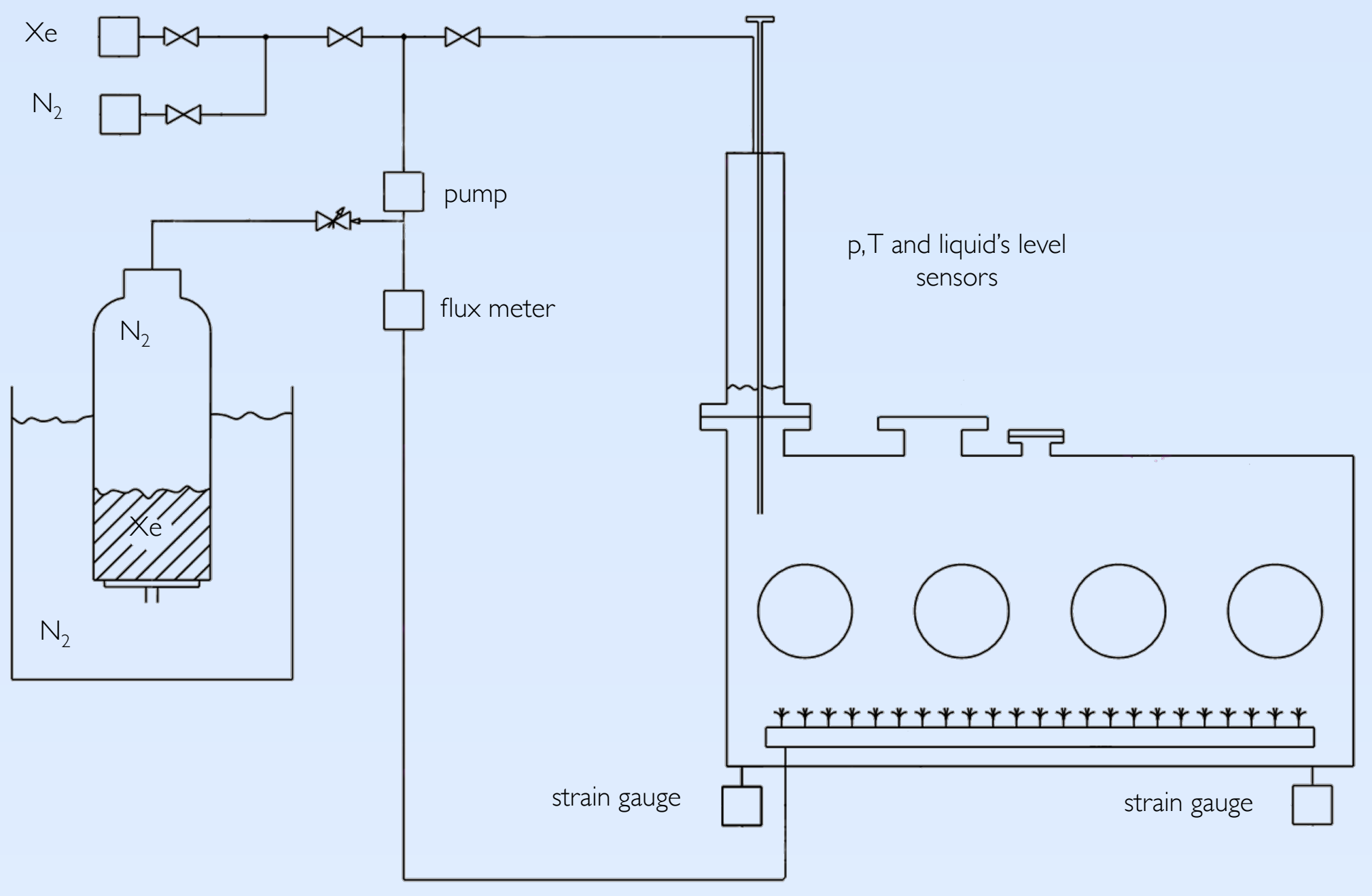
The Borexino detector

Borexino is a large volume liquid scintillator detector whose primary purpose is the real-time measurement of low energy solar neutrinos. It is located deep underground at the Laboratori Nazionali del Gran Sasso (Italy) [5]. The developed purification techniques allowed to reach an exceptional radio-purity (e.g. ^{238}U<6x10^{-18} g/g and ^{232}Th<5x10^{-18} g/g [4]). This feature could allow for almost zero background coming from impurities in the region of interest for a new generation double beta decay experiment.



Schematic drawing of the Borexino detector.

System handling

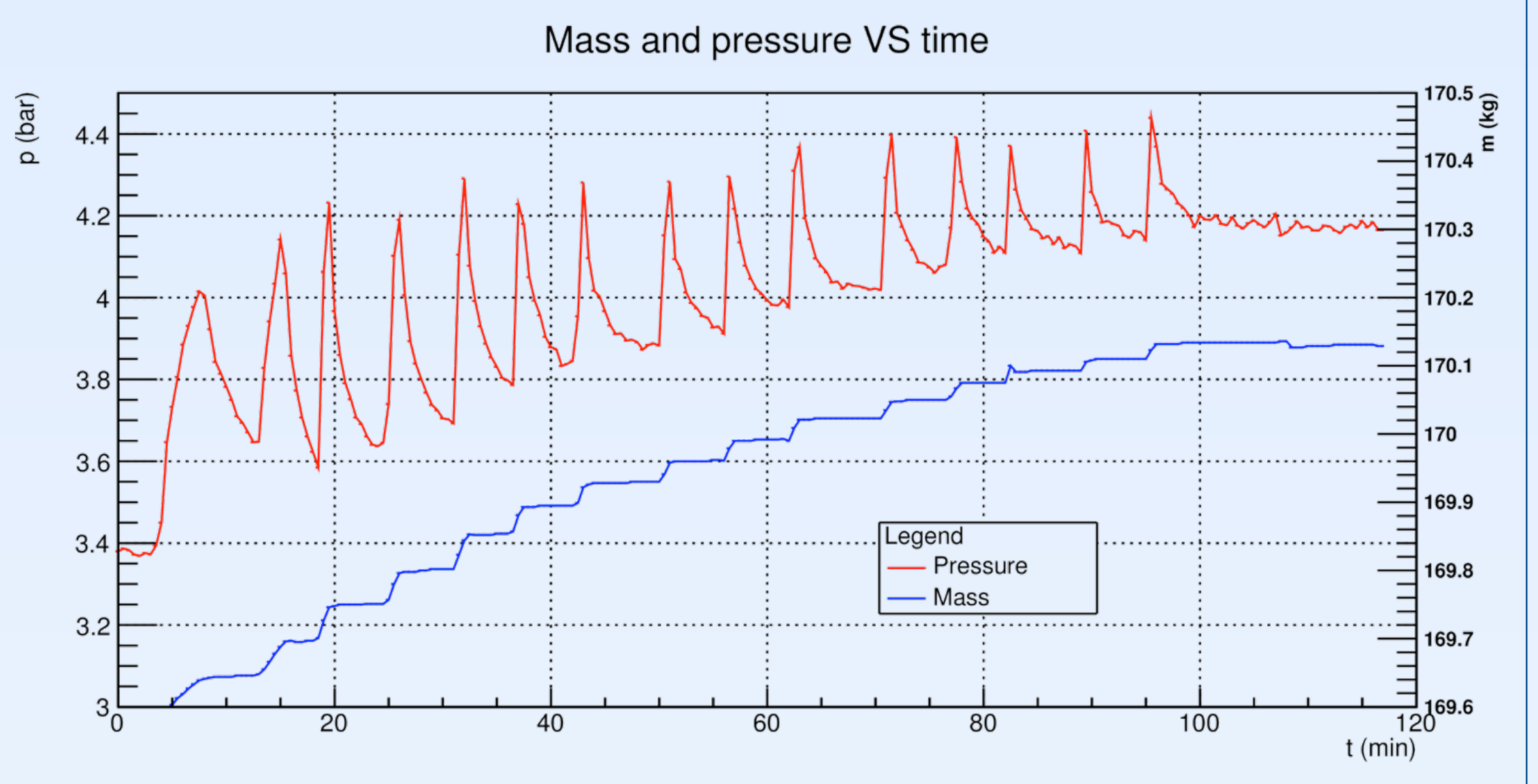


Conceptual hydraulics scheme of the apparatus.

- The plant allows to insert, extract and recirculate gas inside the chamber;
- Xe and N_2 come from two different input bottles;
- a pump can recirculate the gas inside the system;
- temperature and pressure are constantly monitored;
- 4 high sensitivity strain gauges measure the system mass;
- Xe is recovered in a dedicated condenser.

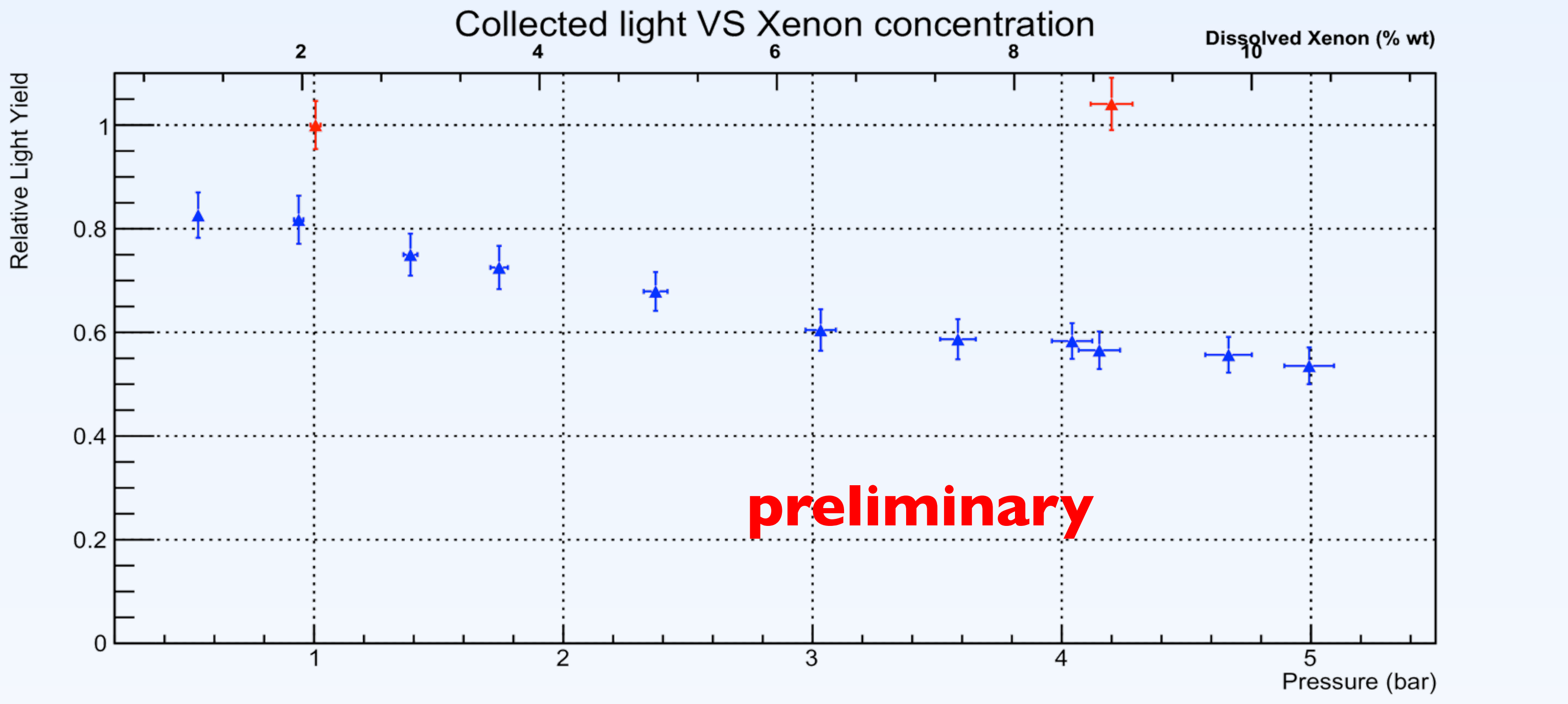
The thermodynamic equilibrium of the system is crucial. The plot shows in red (blue) the pressure (mass) as a function of time during a filling with Xe:

- **addition** corresponds to spikes in p and steps in m;
- **dissolution** corresponds to decreasing p and flat m.



Typical mass and pressure behavior during a filling with Xe.

Results



The plot shows the light yield measurements as a function of the N_2/Xe partial pressure. Red dots indicate the measurements done with N_2 dissolved in the scintillator (Borexino condition), while blue ones refer to Xe. Light yield values are normalized to the Borexino one.

We measured the light yield of the compound Xe-scintillator with respect to the pure Borexino scintillator case at different pressures and we found that:

- **at the pressure of 1 bar the light yield is ~15% lower;**
- **at 5 bar the light yield decreases of ~45%.**

Outlook

- Full characterization of the Xe+scintillator compound, measuring the attenuation length and testing pulse shape discrimination capabilities;
- study of the light yield loss as a function of the fluor concentration;
- investigation of the behavior of other liquid scintillators and wavelength shifters.

Contacts
M. Pallavicini, marco.pallavicini@ge.infn.it
S. Marcocci, simone.marcocci@ge.infn.it
A. Caminata, alessio.caminata@ge.infn.it

---

* The Borexino Collaboration: G. Bellini, J. Benziger, D. Bick, G. Bonfini, D. Bravo, B. Caccianiga, F. Calaprice, A. Caminata, P. Cavalcante, A. Chavarria, A. Chepurnov, D. D'Angelo, S. Davini, A. Derbin, A. Empl, A. Etenko, K. Fomenko, D. Franco, G. Fiorentini, C. Galbiati, S. Gazzana, C. Ghiano, M. Giammarchi, M. Göger-Neff, A. Goretti, C. Hagner, E. Hungerford, Aldo Ianni, Andrea Ianni, V. Kobychev, D. Korablev, G. Korga, D. Kryn, M. Laubenstein, B. Lehnert, T. Lewke, E. Litvinovich, F. Lombardi, P. Lombardi, L. Ludhova, G. Lukyanchenko, I. Machulin, S. Manecki, W. Maneschg, F. Mantovani, S. Marcocci, Q. Meindl, E. Meroni, M. Meyer, L. Miramonti, M. Misiaszek, P. Mosteiro, V. Muratova, L. Oberauer, M. Obolensky, F. Ortica, K. Otis, M. Pallavicini, L. Papp, L. Perasso, A. Pocar, G. Ranucci, A. Razeto, A. Re, B. Ricci, A. Romani, N. Rossi, R. Saldanha, C. Salvo, S. Schönert, H. Simgen, M. Skorokhvatov, O. Smirnov, A. Sotnikov, S. Sukhotin, Y. Suvorov, R. Tartaglia, G. Testera, D. Vignaud, R.B. Vogelaar, F. von Feilitzsch, H. Wang, J. Winter, M. Wojcik, A. Wright, M. Wurm, O. Zaimidoroga, S. Zavatarelli, K. Zuber and G. Zuzel.