EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee
(Following HIE-ISOLDE Letters of Intent I-107 and I-110)

# Probing intruder configurations in $^{186,188}$Pb using Coulomb excitation

29.5.2013

ANU Canberra (G. Dracoulis, T. Kibedi, G. Lane)
CERN-ISOLDE (J. Kurcewicz, E. Rapisarda, T. Stora, D. Voulot, F. Wenander)
STFC Daresbury Laboratory (M. Labiche, J. Simpson)
TU Darmstadt (C. Bauer, S. Bönig, S. Ileva, Th. Kröll, M. Scheck, R. Stegmann, M. Thuerauf)
University of Edinburgh (T. Davinson)
GANIL (B. Bastin, E. Clement, G. de France)
University of Jyväskylä and Helsinki Institute of Physics (T. Grahn, P.T. Greenlees, R. Julin, J. Konki, J. Pakarinen, P. Papadakis, P. Rahkila)
Universität zu Köln (A. Blazhev, C. Fransen, P. Reiter, N. Warr)
KU Leuven (L.P. Gaffney, M. Huyse, N. Kesteloot, P. Van Duppen, K. Wrzosek-Lipska)
University of Liverpool (P.A. Butler, R.-D. Herzberg, D.T. Joss, G. O'Neill, R.D. Page)
University of Lund (J. Cederkäll, C. Fahlander)
TU München (D. Mücher, R. Gernhäuser)
University of Oslo (A. Görgen, M. Guttormsen, A.C. Larsen, S. Siem)
CEA-Saclay (W. Korten, A. Obertelli, M.-D. Salsac, Ch. Theisen, M. Zielinska)
Georgia Institute of Technology (J. Wood)
HIL University of Warsaw (K. Hadynska-Klek, P. Napiorkowski, J. Srebrny)
University of York (A.N. Andreyev, P. Davies, D.G. Jenkins, R. Wadsworth)

Spokesperson: Janne Pakarinen (janne.pakarinen@jyu.fi)

Local contact: Elisa Rapisarda (elisa.rapisarda@cern.ch)

## Abstract

Coulomb excitation measurements to study the shape coexistence, mixing and quadrupole collectivity of the low-lying levels in neutron-deficient $^{188}$Pb nuclei are proposed with a view to extending similar studies to the $^{186}$Pb midshell nucleus. The HIE-ISOLDE beam of $^{186,188}$Pb nuclei will be delivered to MINIBALL+SPEDE set-up for simultaneous in-beam $\gamma$-ray and conversion electron spectroscopy. The proposed experiment will allow the sign of the quadrupole deformation parameter to be extracted for the two lowest $2^+$ states in $^{188}$Pb. Moreover, the advent of SPEDE will allow probing of the bandhead $0^+$ states via direct measurements of E0 transitions. Beam development is requested to provide pure and intense $^{186}$Pb beam.

**Requested shifts**: 12 shifts, (split into 1 run over 1 year), beam development for $^{186}$Pb
**Beamline:** MINIBALL + SPEDE + CD

# 1 Introduction

The interplay between single-particle motion, collectivity, and pairing in light Pb nuclei is manifested as a rich gamut of coexisting nuclear shapes and exotic excitations [1 and references therein]. One of the goals of modern nuclear physics research is to understand the origin of these structures and their relation to the fundamental interactions between the nuclear constituents. These subjects can be investigated particularly well in the Pb isotopes close to neutron mid-shell, where a relatively small proton shell gap, together with a large valence neutron space, provides fertile ground for studies of shape transitions within a small energy range. In $\alpha$-decay studies, the first two excited states of the mid-shell nucleus $^{186}$Pb were observed to be $0^+$ states [2]. On the basis of $\alpha$-decay hindrance factors, the $0^+_2$ state was associated with mainly $\pi(2p-2h)$ configuration, whereas the $0^+_3$ state was associated with a $\pi(4p-4h)$ configuration. Consequently, together with the spherical ground state [3], the three $0^+$ states with largely different structures establish a unique shape-triplet in $^{186}$Pb. Similarly, the three different structures have been manifested in the form of isomeric states associated with different shapes in $^{188,190}$Pb [4-7]. Recently, rotational bands built on these states in $^{186,188}$Pb were observed by in-beam $\gamma$-ray measurement [5,8] and their collectivity confirmed in lifetime measurements [9,10].

A complementary view of these $0^+$ states is provided by mean-field methods in which each local minimum of the potential energy surface is associated with a different collective shape. The first calculations of quadrupole potential energy surfaces were performed within the Strutinsky approach [11-13]. The existence of a spherical ground state with low-lying oblate and prolate minima has been found in self-consistent mean-field approaches based on effective Skyrme [14-16] and Gogny [17] interactions. In a truncated shell-model approach, these oblate and prolate mean-field configurations can be associated with $\pi(2p-2h)$ and $\pi(4p-4h)$ excitations, respectively, forming a unique system of the three different shapes. Although much experimental effort has been put into investigating light Pb nuclei, the information obtained is still rather scarce. It remains a challenge for both theoretical and experimental studies to obtain a consistent and detailed description of the observed phenomena.

We propose to carry out the investigations of nuclear collectivity and mixing of the low-lying states in the neutron-deficient Pb nuclei, namely the isotopes $^{186,188}$Pb, employing the Coulomb excitation (Coulex) technique at the HIE-ISOLDE facility. In Fig. 1, the level energy systematics of even-mass Pb isotopes is shown. The $0^+$ states of the $\pi(2p-2h)$ configuration, associated with the oblate shape, intrude down in energy close to the spherical ground state when approaching the neutron mid-shell at N = 104 and becomes the first excited state already at A = 194. The onset of prolate deformation, mainly associated with the $\pi(4p-4h)$ configuration, can be seen around A = 190 for states with $I^\pi \leq 4^+$. The prolate states with $I^\pi \geq 4^+$ form the yrast band at A = 188. Thus, light Pb isotopes provide a unique laboratory to study the three competing structures of different shapes around 1 MeV.

In order to establish a complete picture of shape coexistence in this region, knowledge of transition probabilities from nuclear states assigned with different shapes is essential. Transition probabilities are very sensitive to the details of a nuclear wave function and, consequently, information about nuclear shape and configuration mixing can be inferred. Furthermore, the knowledge of the nuclear wave functions renders it possible to extract an effective nucleon-nucleon interaction to produce a realistic nuclear potential. So far, collectivity of $\gamma$-ray transitions originating from prolate states in $^{186,188}$Pb has been established by in-beam lifetime measurements [9,10]. While in-beam lifetime experiments probe mainly yrast states, with Coulex the population of low-lying non-yrast states becomes feasible and, enables a comprehensive study of collectivity, coexisting shapes and their mixing in these nuclei. In our recent IS494 MINIBALL experiment at REX-ISOLDE, the $2^+_1$ states were populated in even-mass $^{188\text{-}198}$Pb via Coulex. Preliminary analysis suggests that the systematic trend of B(E2) values in these isotopes and the quadrupole moments for $^{188\text{-}192}$Pb can be extracted from that data. It is worth noting that a detailed understanding of the competing structures in Pb isotopes will be of direct relevance to developing a fuller picture of the evolution of these phenomena in the neighbouring nuclei such as isotopes of Hg.

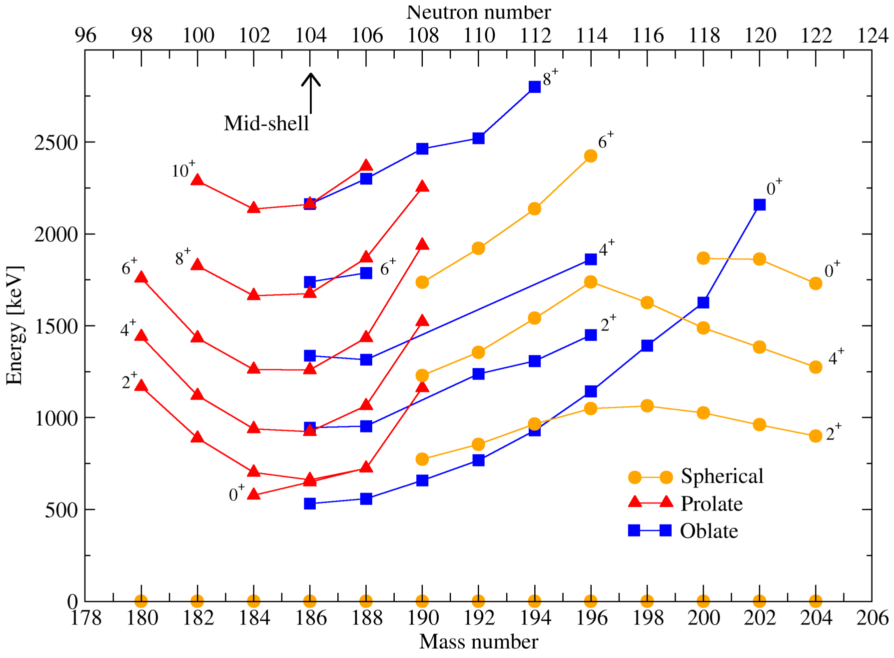

**Figure 1.** Level energy systematics of the even-mass Pb isotopes.

## 2 Proposed experiment and data analysis

The isotopes of interest in the present proposal are of particular importance as they lie at the heart of triple shape coexistence; these are the only Pb isotopes where both (predominantly) prolate and oblate rotational bands have been observed. The measurement of the sign of the quadrupole deformation parameter allows unambiguous confirmation of these shapes. SPEDE will not only allow probing of the $0^+$ bandhead states, but also to directly measure the enhanced E0 strengths arising from mixing between states with same spin and parity, but different deformation.

The ISOLDE facility is currently only laboratory where these experiments can be carried out. In the following, the proposed $^{188}$Pb experiment is described. The proposed $^{186}$Pb experiment employs a similar technique, but needs beam development that will be briefly described later. In the IS494 experiment, radioactive beams of neutron-deficient Pb isotopes were produced using the UCx primary target and laser ionization (RILIS) [18]. Despite the use of RILIS, isobaric Tl contamination originating from surface ionization was present. In the case of $^{188}$Pb, the Pb/Tl ratio was about 50/50. This impurity issue was overcome by means of a laser on/off technique, that enabled us to extract the amount of target excitation arising from Tl contaminants; that information in turn is needed for cross normalization between projectile (Pb) and target excitations. Consequently, we propose to use a similar scenario for beam production as in IS494. The required charge state to accelerate $^{188}$Pb beams up to 4.2 MeV/u will be obtained with the REX-TRAP/EBIS charge breeder. Accelerated HIE-ISOLDE Pb beams will be delivered to the MINIBALL+SPEDE target position where Pb nuclei will be Coulomb excited in inverse kinematics using various secondary targets. The MINIBALL and SPEDE detector arrays will be exploited for simultaneous detection of both $\gamma$ rays and conversion electrons, respectively, that de-excite the levels under investigation. Both scattered projectiles and target recoils will be detected using an annular double-sided silicon strip detector (CD) downstream from the secondary target. We propose to use two different beam energies ("low" and "high") and two different targets. This allows us to probe:

1) different angular ranges,
2) different population of states.

It should be noted, that the low-lying states in the proposed nuclei have been probed using $\alpha$- and $\beta$-decay and in-beam spectroscopic techniques, that all have rather selective population of low-lying states. In comparison, multistep Coulex is more a powerful technique for the population of non-yrast states. A “low” beam energy can be used to limit the number of multistep Coulomb-excited states. These data can be used to fix the diagonal and transitional matrix elements associated with the low-lying states. The use of “high” beam energies maximizes the Coulex yields, and has been chosen so that the bombarding energy still remains below the so-called “safe” energy. Excitation patterns obtained in "low" and "high" energy measurements will be different and thus combination of both data sets will help constraining the multi-dimensional fit aiming at extraction of the matrix elements from measured $\gamma$-ray yields. In addition, each data set will be divided into a few angular ranges to assure sensitivity for diagonal matrix elements. The essential parameters concerning the yield calculations are given in Table 1.

**Table 1.** Parameters used in the yield calculations.

| **General parameters** | **Value** | **Note** |
|---|---|---|
| HIE-ISOLDE transmission | 3% | Assumed same as REX-ISOLDE |
| $^{188}$Pb HIE-ISOLDE yield | $1\times10^{6}$pps | Limited by instantaneous rate |
| $^{120}$Sn target thickness | 2 mg/cm$^{2}$ | |
| $^{48}$Ti target thickness | 1 mg/cm$^{2}$ | |
| **Number of shifts** | | |
| $^{188}$Pb on $^{120}$Sn @ 4.2MeV/u | 2 | Lasers off runs 30% of beam time |
| $^{188}$Pb on $^{120}$Sn @ 3.5MeV/u | 3 | --- “ --- |
| $^{188}$Pb on $^{48}$Ti @ 4.0MeV/u | 2 | --- “ --- |
| $^{188}$Pb on $^{48}$Ti @ 3.5MeV/u | 3 | --- “ --- |

A sample $\gamma$-ray energy spectrum of $^{188}$Pb from experiment IS494 is shown in Fig 2. Most of the $\gamma$-ray transitions in $^{188}$Tl (black labels) can be distinguished from the ones associated with $^{188}$Pb (blue labels). As can be seen, the 953 keV $2_2^+ \rightarrow 0_1^+$ transition was populated as well, although statistics are not sufficient to extract the B(E2) value. Further purification of the energy spectra can be obtained via $\gamma$-$\gamma$ or $\gamma$-$e^-$ coincidence analysis. The transitions of interest are shown in a partial level scheme of $^{188}$Pb in Fig. 2.

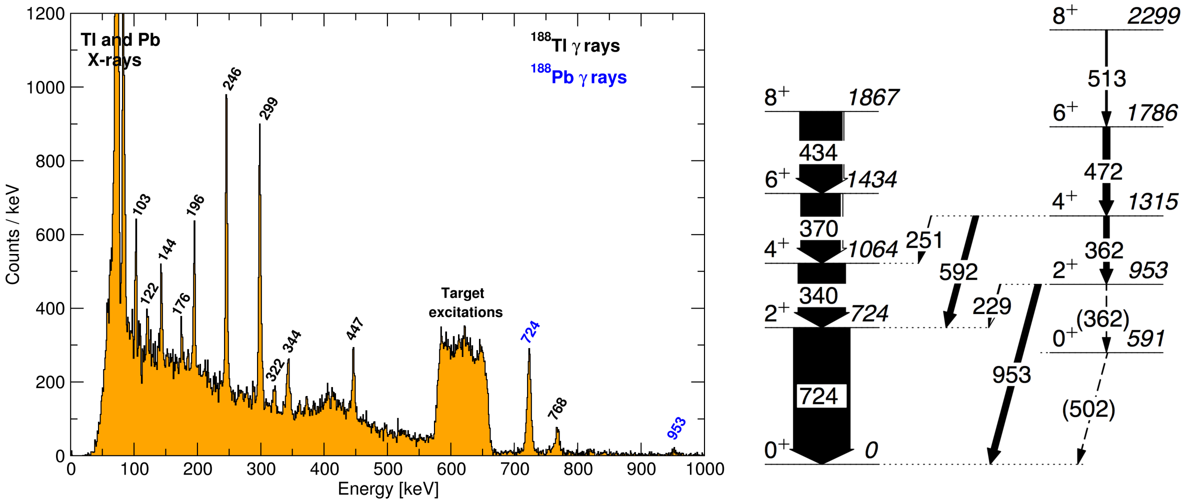

**Figure 2**. Left: Doppler corrected, background subtracted $\gamma$-ray energy spectra obtained in the IS494 experiment. Transitions associated with $^{188}$Tl (black) and $^{188}$Pb (blue) are labeled. Data include both laser on and off runs. Right: Partial level scheme of $^{188}$Pb showing transitions of interest [5]. The $0_2^+ \rightarrow 0_1^+$ transition energy is shown as the K-conversion electron energy.

## 3 Count rate estimate and beam time request

It has been shown in several experiments that heavy radioactive beams can be exploited in Coulex studies at REX-ISOLDE. In those experiments, the MINIBALL DAQ and REX-ISOLDE beam time structure allowed yields up to ~$5\times10^6$pps impinging on a target without running into electronics dead-time issues. This figure is not expected to change remarkably for the HIE-ISOLDE beams; nevertheless, in the present proposal we have used the conservative estimate of $1\times10^6$pps of $^{188}$Pb beam on target (in IS494, the average yield at MINIBALL was $1.6\times10^6$pps). In Table 2, the $\gamma$-ray yield estimates for the proposed $^{188}$Pb experiment calculated using the GOSIA code are shown [19]. The matrix elements used in the GOSIA calculation for the yrast band transitions have been extracted from lifetimes measured in Ref. [9], whereas for the non-yrast transitions values extracted from IBM calculations in Ref. [20] are used. Table 2 also lists the MINIBALL $\gamma$-ray detection efficiency at the energies of interest together with conversion electron efficiency. In order to obtain sufficient statistics for coincidence analysis, 100000 counts for the $2_1^+ \rightarrow 0_1^+$ transition is estimated to be enough. It should be noted, that figures given in Table 2 are for the whole CD; it is foreseen that CD will be divided in a few angular ranges in the final analysis.

**Table 2.** Counts obtained for projectile and target excitations in four different beam-target combinations as listed in Table 1 for $^{188}$Pb. Beam energies for different reactions are given on top of each column. γ-ray transitions from yrast and non-yrast bands are shown on light brown and white backgrounds, respectively. Conversion electron decays are shown on a light blue background.

| $I_i^\pi \rightarrow I_f^\pi$ Projectile | $E_{transition}$ [keV] | Det. Eff. [%] | 4.3MeV/u $^{188}$Pb+ $^{120}$Sn | 3.5MeV/u $^{188}$Pb+$^{120}$Sn | 4.0MeV/u $^{188}$Pb+$^{48}$Ti | 3.5MeV/u $^{188}$Pb+$^{48}$Ti |
|---|---|---|---|---|---|---|
| $2_1^+ \rightarrow 0_1^+$ | 723.5 | 8.8 | 126375 | 107093 | 3695 | 4749 |
| $4_1^+ \rightarrow 2_1^+$ | 340.2 | 14.1 | 61877 | 36737 | 1890 | 1607 |
| $6_1^+ \rightarrow 4_1^+$ | 369.7 | 13.3 | 28827 | 10907 | 666 | 359 |
| $8_1^+ \rightarrow 6_1^+$ | 433.8 | 12.0 | 8725 | 1752 | 115 | 35 |
| $2_1^+ \rightarrow 0_2^+$ | 133.9 | 7.0 | 170 | 455 | 16 | 20 |
| $2_2^+ \rightarrow 0_1^+$ | 952.5 | 7.5 | 37970 | 24846 | 1341 | 1380 |
| $4_2^+ \rightarrow 2_2^+$ | 362.5 | 13.5 | 19402 | 7680 | 533 | 345 |
| $6_2^+ \rightarrow 4_2^+$ | 471.5 | 11.4 | 4570 | 890 | 70 | 26 |
| $8_2^+ \rightarrow 6_2^+$ | 513.0 | 10.8 | 812 | 73 | 6 | 1 |
| $2_2^+ \rightarrow 0_2^+$ | 361.5 | 13.5 | 3542 | 2317 | 125 | 129 |
| $2_2^+ \rightarrow 2_1^+$ | 228.7 | 18.0 | 1352 | 879 | 47 | 48 |
| $2_2^+ \rightarrow 2_1^+$ | 140.2$^{a)}$ | 8.0 | 1202 | 782 | 42 | 29 |
| $0_2^+ \rightarrow 0_1^+$ | 502.5$^{a)}$ | 8.0 | 2294 | 1538 | 80 | 83 |
| **Target** | | | | | | |
| $2_1^+ \rightarrow 0_1^+$ | $^{120}$Sn: 1171<br>$^{48}$Ti: 984 | 6.6<br>7.3 | 53153 | 26619 | 17241 | 17875 |
| $4_1^+ \rightarrow 2_1^+$ | $^{120}$Sn: 1023<br>$^{48}$Ti: 1312 | 7.2<br>6.1 | 10795 | 1640 | 63 | 16 |
| $2_2^+ \rightarrow 0_1^+$ | $^{120}$Sn: 2097<br>$^{48}$Ti: 2421 | 4.2<br>3.5 | 71 | 12 | 1 | 0 |

$^{a)}$ K-conversion electron energy

### Request for beam development

During IS494, an attempt was made to study $^{186}$Pb, but no transitions associated with $^{186}$Pb were observed. This could be because of an ageing of primary target that caused a drop of the $^{186}$Pb yield, but of more concern is the amount of isobaric Tl contamination. The ISOLDE database value for $^{186}$Pb yield reads $4.6\times10^4$ ions/uC, whereas for $^{186}$Tl the corresponding figure is $3.3\times10^7$ ions/uC. Thus, isobaric Tl contamination originating from surface ionization is present in the laser ionized Pb beam. Nevertheless, a few different methods can be tried to purify the Pb beam [21]:

1) Molecular extraction: the PbO molecule can be stabilized vs atomic Pb and a similar approach in other molecular beams have led to 10% molecular sideband formation efficiency.
2) The nanoUCx target (tested recently at ISOLDE), in conjunction with the $GdB_6$ low-work-function cavity could reduce non-specific ionization and improve the Pb/Tl ratio.
3) There are ongoing activities to reduce signal/unspecific ions by improving the time structure (bunching) of the produced RILIS ions, and therefore also improving the Pb/Tl ratio.

However, for all the above methods, developments and tests are required to obtain pure $^{186}$Pb beam with sufficient yield for Coulomb excitation study. It is worth mentioning that $^{188}$Pb experiment would also benefit from beam development as background conditions would be cleaner in the case of a pure Pb beam.

### Further notes

The SPEDE spectrometer is under construction. It is a combined effort mainly between University of Jyväskylä and University of Liverpool. SPEDE will be commissioned in the Accelerator Laboratory of Jyväskylä in 2014 (beam time for development and commissioning has been accepted by the JYFL PAC). SPEDE will be mounted in a new target chamber within the MINIBALL Ge-detector array.

## Summary of requested shifts

10 shifts of beam time are required for the $\gamma$-ray yield measurement of $^{188}$Pb (includes laser off runs). A further 2 shifts are required for setting up of HIE-ISOLDE. Thus, **in total we request 12 shifts for $^{188}$Pb and beam development for $^{186}$Pb**. An addendum for $^{186}$Pb will be submitted later in case of successful beam development.

## References:

[1] K. Heyde and J.L. Wood, Rev. Mod. Phys. **83**, 1467 (2011).
[2] A.N. Andreyev *et al.*, Nature (London) **405**, 430 (2000).
[3] H. De Witte *et al.*, Phys. Rev. Lett. **98**, 112502 (2007).
[4] G.D. Dracoulis *et al.*, Phys Rev C **60**, 014303 (1999).
[5] G.D. Dracoulis *et al.*, Phys Rev C **67**, 0151301(R) (2003).
[6] G.D. Dracoulis *et al.*, Phys. Rev. C **69**, 054318 (2004).
[7] G.D. Dracoulis *et al.*, Phys Lett B **432**, 37 (1998).
[8] J. Pakarinen *et al.*, Phys. Rev. C **75**, 014302 (2007).
[9] A. Dewald *et al.*, Phys. Rev. C **68**, 034314 (2003).
[10] T. Grahn *et al.*, Phys. Rev. Lett. **97**, 062501 (2006).
[11] F.R. May *et al.*, Phys. Lett. B **68**, 113 (1977).
[12] R. Bengtson and W. Nazarewicz, Z. Phys. A **334**, 269 (1989).
[13] W. Nazarewicz, Phys. Lett. B **305**, 195 (1993).
[14] N. Tajima *et al.*, Nucl. Phys. A **551**, 409 (1993).
[15] T. Duguet *et al.*, Phys. Lett. B **559**, 201 (2003).
[16] M. Bender *et al.*, Phys. Rev. C **69**, 064303 (2004).
[17] R.R. Rodrıguez-Guzman *et al.*, Phys. Rev. C **69**, 054319 (2004).
[18] U. Köster *et al.*, Nucl. Instr. Methods Phys. Res. B **204**, 347 (2003).
[19] T. Czosnyka *et al.*, Bull. Amer. Phys. Soc. **28**, 745 (1983).
[20] V. Hellemans, S. De Baerdemacker and K. Heyde, Phys. Rev. C **77**, 064324 (2008).
[21] T. Stora, private communication (2013).

# Appendix

## DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: MINIBALL+SPEDE+CD

| Part of the Choose an item. | Availability | Design and manufacturing |
|---|---|---|
| MINIBALL + only CD | ☒ Existing | ☒ To be used without any modification |
| | | |
| MINIBALL | ☒ Existing | ☒ To be used without any modification<br>☐ To be modified |
| SPEDE | ☒ New | ☐ Standard equipment supplied by a manufacturer<br>☒ CERN/collaboration responsible for the design and/or manufacturing |
| CD | ☒ Existing | ☐ To be used without any modification<br>☒ To be modified |
| | ☐ New | ☐ Standard equipment supplied by a manufacturer<br>☐ CERN/collaboration responsible for the design and/or manufacturing |
| SPEDE development is going on and will be reported later for INTC | | |

## HAZARDS GENERATED BY THE EXPERIMENT

*(if using fixed installation)* Hazards named in the document relevant for the fixed MINIBALL + only CD installation.

Additional hazards:

| ***Hazards*** | *SPEDE* | *[Part 2 of the experiment/equipment]* | *[Part 3 of the experiment/equipment]* |
|---|---|---|---|
| **Thermodynamic and fluidic** | | | |
| Pressure | [pressure][Bar], [volume][l] | | |
| Vacuum | | | |
| Temperature | [temperature] [K] | | |
| Heat transfer | | | |
| Thermal properties of materials | | | |
| Cryogenic fluid | [fluid], [pressure][Bar], [volume][l] | | |
| **Electrical and electromagnetic** | | | |
| Electricity | 4000 V, neglible A | | |
| Static electricity | | | |
| Magnetic field | [magnetic field] [T] | | |
| Batteries | ☐ | | |
| Capacitors | ☐ | | |
| **Ionizing radiation** | | | |
| Target material | [material] | | |
| Beam particle type (e, p, ions, etc) | $^{188}$Pb ions | | |
| Beam intensity | $10^6$ pps | | |

| | | | |
|---|---|---|---|
| Beam energy | <4.2MeV/u | | |
| Cooling liquids | [liquid] | | |
| Gases | [gas] | | |
| Calibration sources: | ☐ | | |
| • Open source | ☐ | | |
| • Sealed source | ☐ [ISO standard] | | |
| • Isotope | | | |
| • Activity | | | |
| Use of activated material: | | | |
| • Description | ☐ | | |
| • Dose rate on contact and in 10 cm distance | [dose][mSV] | | |
| • Isotope | | | |
| • Activity | | | |
| **Non-ionizing radiation** | | | |
| Laser | RILIS, scheme for Pb | | |
| UV light | | | |
| Microwaves (300MHz-30 GHz) | | | |
| Radiofrequency (1-300MHz) | | | |
| **Chemical** | | | |
| Toxic | [chemical agent], [quantity] | | |
| Harmful | [chemical agent], [quantity] | | |
| CMR (carcinogens, mutagens and substances toxic to reproduction) | [chemical agent], [quantity] | | |
| Corrosive | [chemical agent], [quantity] | | |
| Irritant | [chemical agent], [quantity] | | |
| Flammable | [chemical agent], [quantity] | | |
| Oxidizing | [chemical agent], [quantity] | | |
| Explosiveness | [chemical agent], [quantity] | | |
| Asphyxiant | [chemical agent], [quantity] | | |
| Dangerous for the environment | [chemical agent], [quantity] | | |
| **Mechanical** | | | |
| Physical impact or mechanical energy (moving parts) | [location] | | |
| Mechanical properties (Sharp, rough, slippery) | [location] | | |
| Vibration | [location] | | |
| Vehicles and Means of Transport | [location] | | |
| **Noise** | | | |
| Frequency | [frequency],[Hz] | | |
| Intensity | | | |
| **Physical** | | | |
| Confined spaces | [location] | | |
| High workplaces | [location] | | |
| Access to high workplaces | [location] | | |
| Obstructions in passageways | [location] | | |
| Manual handling | [location] | | |
| Poor ergonomics | [location] | | |

## 0.1 Hazard identification

The secondary target will be applied in high tension (<4000V) for reduction of delta-electrons.

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

*… kW*