MAGiC
Scope Setting Meeting

1 Introduction

This document presents three possible and efficient MAGiC configurations as a function of budget. The request from NSS was to provide budget estimate including a 10% contingency. In this document, all budgets are presented in this framework.

Three versions of the instrument will be described. The first one, fits into the Cost Category B budget of 12 M€ and covers essential parts of the MAGiC's science case. The last one corresponds to the configuration described in the proposal accepted by the SAC. The second one is a balanced configuration covering the full science case and corresponding to the minimum configuration recommended by the diffraction STAP (see June 2016 diffraction STAP report).

These recommendations are summarized below:

1) "Polarization of both cold and thermal beams, and with full XYZ analysis of scattered cold neutrons is essential to the science programme ".
2) "The full scope version of the instrument will be able to carry out the whole science case and like the SAC we are convinced that it will open up many new opportunities, attract a large user community, and be a highlight in the instrument suite of the ESS".
3) "The [Cost Category B configuration] version to some extent would compromise the general performance and sample environment".
4) "The ability to study very small samples is world-beating and should be available from Day 1."
5) "Having 60 out of 160 deg. of large detector coverage for the thermal beam is acceptable for initial performance"
6) "Provision of SE's including magnetic fields up to at least 10 T and dilution fridges is important."
7) "Options for cost reductions for the shielding and sample cave (but without compromising safety) could be explored"

2 Instrument summary

MAGiC is a versatile polarized single crystal diffractometer dedicated to the study of magnetic correlations with "*focus on magnetism and correlated electrons, addressing current questions in areas of:*

1) *Unconventional superconductivity*
2) *Spintronics*
3) *Nano and molecular magnetism*
4) *Spin liquids and ices*
5) *Emergent spin-orbit coupled and topological states*
6) *Multifunctional materials*

and maintaining flexibility to address future questions emerging in the field". (Diffraction STAP report)

Each of these scientific questions is associated to a set of functional requirements (wavelength, polarization, resolution, …) defining the key drivers of the instrument.

2.1 High level scientific requirements

The high level scientific requirements for MAGIC are:

1. The instrument shall provide a polarized incident beam over the $0.6<\lambda<6$Å wavelength range.
2. The instrument shall provide XYZ polarization analysis over a wide angle of 120°x6°.
3. The instrument shall allow data collection from crystals with a magnetic unit cell repeats of 100 Å.
4. The instrument shall allow data to be collected to a d_{min} of 0.35 Å.
5. The instrument shall match the size of the neutron beam to the size of the sample.
6. The instrument shall match the divergence of the neutron beam to the mosaicity of the sample.
7. The instrument shall allow data collection from crystals with volume lower than 0.001 mm^3
8. The instrument shall provide cryogenic capabilities in the 30 mK - 300K range and magnetic field capabilities in the 0-10 T range.
9. The instrument should maximise the signal-to-background (S/B) ratio of the Bragg reflections.
10. The instrument should provide pulsed magnetic fields > 50 T.
11. MAGiC should serve the user, science, and instrumental development program without interruptions during source operation.

2.2 Instrument layout

The MAGiC instrument is subdivided into the following generic main functional blocks:

- ➔ Shielding & Cave
- ➔ Neutron Optics & Polarization
- ➔ Choppers
- ➔ Sample Environment
- ➔ Detectors & Beam Monitors
- ➔ Data Acquisition & Analysis
- ➔ Motion Control & Automation
- ➔ Instrument Specific Technical Equipment
- ➔ Instrument Infrastructure
- ➔ Vacuum
- ➔ Personal Safety System

3 Configurations

In the following, three configurations will be described:

1. A “**Cost Category B**” configuration fitting into the 12.0 M€ envelope.
2. A “**Balanced**” configuration that meets all recommendation from the STAP and covers the full science case.
3. A “**Full Scope**” configuration serving the full science case and offering optimal performance.

The three configurations derive from the Cost Category B one. They differ by detector coverage, beam shaping capabilities and sample environment. The detector is highly modular by design allowing stepwise upgrades of detector coverage from configuration 1 to 2 and 3.

The expected timeline for construction of MAGiC is presented in Figure 1. The current plan is to start procurement as soon as possible to start installation and cold commissioning when the guide hall and experimental hall will be available. Hot commissioning will start in 2022 for a switch to user operations at the end of 2023.

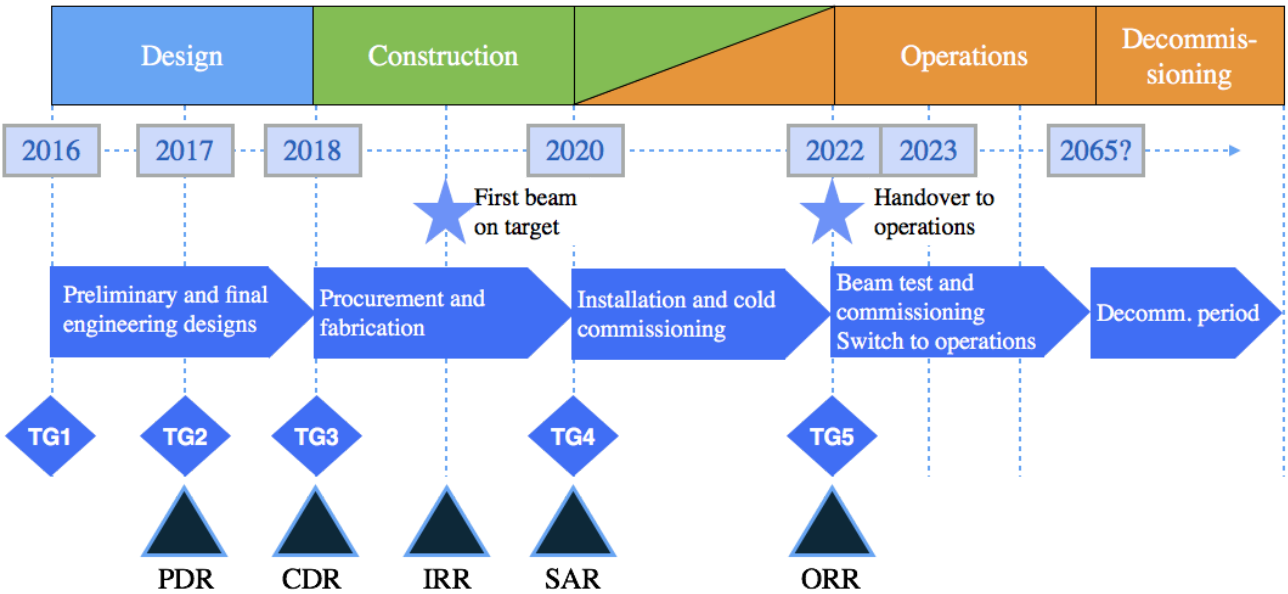

Figure 1: *high-level instrument construction timeline*

The high level cost breakdowns for each configurations are presented in Table 1. A specific color is associated to each configuration for clarity.

	01 Phase 1	02 Phase 2	03 Phase 3	04 Phase 4	Total (k€)
Shielding & Cave					
	0	0	1268	141	**1409**
Neutrons Optics & Polarization					
Cost Category B	0	0	4226	470	**4695**
Balanced	0	0	4484	498	**4982**
Full Scope	0	0	4484	498	**4982**
Choppers					
	0	0	675	75	**750**
Sample Environment					
Cost Category B	0	0	81	9	**90**
Balanced	0	0	1292	144	**1435**
Full Scope	0	0	1292	144	**1435**
Detectors & Beam Monitors					
Cost Category B	0	0	750	83	**833**
Balanced	0	0	1224	136	**1360**
Full Scope	0	0	2732	304	**3036**
Data Acquisition and Analysis					
	0	0	0	0	**0**
Motion Control & Automation					
	0	127	152	83	**362**
Instrument Specific Technical Equipment					
	415	419	473	811	**2119**
Instrument Infrastructure					
	0	0	364	40	**405**
Vacuum					
	0	0	0	0	**0**
Personal Safety System					
	0	0	90	10	**100**
Contingency					
Cost Category B	46	61	898	191	**1196**
Balanced	46	61	1114	215	**1436**
Full Scope	46	61	1281	234	**1622**
Total					
Cost Category B	462	607	8977	1914	**11959**
Balanced	462	607	11135	2154	**14357**
Full Scope	462	607	12811	2340	**16219**

Table 1*: high-level cost breakdown of the MAGiC instrument. Colors are associated to different configurations (green: Cost Category B, orange: balanced and red: full scope). Numbers are rounded to the closest integer.*

4 Cost Category B configuration (11.96 M€)

This first configuration is as close as possible to the Cost Category B budget. It is composed of the absolute minimum necessary to run the instrument as described in the proposal. In this configuration, the instrument will not meet most of the STAP recommendations and large part of the science case will not be covered.

4.1 Budget

In this configuration are included:

1) Instrument shielding and experimental cave:
    a) Guide shielding: **733 k€**
    b) Experimental cave: **676 k€**
2) Neutron transportation:
    a) Neutron guide and polarizer: **2753 k€**
    b) Solid State Bender: **62 k€**
    c) Polarization Analyser: **1888 k€**
3) The complete choppers set (PSC, BC and SC): **750 k€**
4) Sample station (table + utilities): **90 k€**
5) Detectors and monitors:
    a) 36°x48° ^{10}B blades detector with 80% of nominal efficiency: **550 k€**
    b) 120°x6° ^{10}B blades detector dedicated to polarization analysis experiment: **243 k€**
    c) Two beam monitors: **40 k€**
6) Motion control: **362 k€** (under discussion)
7) Manpower (198 months): **2119 k€**
8) Infrastructure (control hutch, sample prep. lab, crane, utilities, ...): **405 k€**
9) Personal Safety System: **100 k€** (mean PSS value)

These elements are essential to transport neutrons, operate the instrument and ensure safety. Sample environment and detectors coverage have been reduced to the absolute minimum.

4.2 Impact on performance and science case

To fit the instrument into the Cost Category B envelope, major compromises have been made on both scientific throughput and science case coverage.

The following components are missing or are severely tuned down:

1) **Detectors**: the "large detector" angular coverage is reduced to 0.5 sr (instead of original 2.3 sr) and its efficiency is reduced by 20%. To do so, thicker blades are used limiting the numbers of ^{10}B blades crossed by scattered neutrons.
2) **Sample environment**:
    a) The cryostat (or CCR) is excluded.
    b) The 10T magnet is excluded.
    c) The dilution fridge insert is excluded.

   d) The in-cryogenics sample orientation is excluded.

3) **Beam Shaping:**
   a) The motorized in-guide divergence slits are excluded.
   b) The radial collimator is excluded.
   c) The focusing device is excluded.

In terms of instrumental performance:

- Large detector: the reduced angular aperture implies 5 detector positions for each data collection. The reduced detector efficiency also increase collection time by 20%. The data collecting time in unpolarized/half-polarized experiments will therefore be increased by a factor 6.
- Focusing device: the data collecting time on small crystals will be increased by a factor 6 or will simply be not possible.
- Radial collimator: the Signal/Background ratio will strongly decrease as background from SE will not be filtered. (A potential solution of the problem could come from using the volume, 4D detection capabilities as a numerical collimator.)
- Divergence slits: the maximum size of resolved magnetic structure will be limited to 100 Å.
- Dedicated magnet: MAGiC will use the ESS pool vertical magnet. This has two side effects. The first one is the availability of a pool magnet certainly lower than what MAGiC needs. Based on current single crystal diffractometer schedules, approximately 50% of the beam time will make use of such magnet. The second one is the non optimized geometry which will strongly reduce the Q-space coverage.
- Dilution fridge: a dilution insert will be needed up to 20% of the time on MAGiC. Depending on the NSS strategy, a dilution fridge may be available in the ESS pool.

The scientific scope of the instrument is therefore reduced:

- The study of micrometric samples will be compromised. This corresponds to the hottest scientific topics, for which large samples simply do not exist (skyrmions, low dimensional magnets, unconventional superconductors, ...).
- Quantum and frustrated magnetism which generally develops at sub-K temperatures.
- Weakly correlated systems stabilize a long range magnetic order at low temperatures. Their complete and exhaustive study require sub-K temperatures and magnetic field.
- Long periodicity magnetism: in multifunctional materials such as multiferroics or the novel skyrmion phases, the magnetic peaks are in the close vicinity of the nuclear ones. To distinguish these magnetic satellites, one needs to be able to tune the incident beam divergence.

The proposed instrument design shall be modular and will allow future upgrades to reach full scope. In the meantime, MAGiC will have to rely on the ESS pool for its Sample Environment needs.

One has to note that strong commitment from the ESS pool will be mandatory to cover MAGiC's activities in this configuration.

4.3 Upgrades

Two main paths for upgrade are foreseen for this first configuration, almost reaching full scope:

1) Covering all of the science case:
   a) Sample environment and in particular a dedicated magnet and dilution fridge for a total cost of **1345 k€** excluding contingency.
   b) Beam shaping at sample position for a total cost of **288 k€**.
2) Increasing performance:
   a) Extension of detector coverage is possible by 7.5° sectors (at the same efficiency) or by 6° sectors with increased efficiency. Independently of the selected option, the upgrade cost is of **~100 k€/sector**. The efficiency of the base detector coverage will not be upgradable.

5 Balanced configuration (14.36 M€)

This configuration covers the full science case and offers improved performance.

5.1 Budget

All of the Cost Category B configuration components with the following changes:

1) Detectors: large detector angular coverage will be extended to 0.85 sr (60°x48°) and its efficiency will be increased to the highest standards: **527 k€**
2) Sample environment: **1345 k€**
   a) Dedicated superconducting magnet: 1 000 k€
   b) Dilution fridge: 250 k€
   c) Cryostat: 50 k€
   d) In-cryogenics sample orientation: 45 k€
3) Beam shaping at sample position: **288 k€**
   a) Radial collimator: 114 k€
   b) Divergence tuner: 100 k€
   c) Focusing device: 74 k€

The total budget of this configuration is therefore 11 960 + 2 400 =**14 360 k€**

5.2 Impact on performance and science case

The full science case is covered by the balanced configuration adding to the scope of the instrument:

1) Small sample crystals (microcrystals)
2) Weakly correlated magnets
3) Quantum and frustrated magnets

4) Long magnetic periodicity (skyrmions, helicoidal magnets, multifunctional materials, ...)

This topics are the core of MAGiC's science case and will be available on Day 1 as recommended by the diffraction STAP.

The data collection time in half-polarized mode is also reduced by the detector increased solid angle.

5.3 Upgrades

This configuration is upgradable to the full scope one by extending the large detector coverage to 2.25 sr, adding the 16 missing sectors for **1526 k€**.

6 Full scope configuration (16.22 M€)

This configuration corresponds to the configuration presented in the instrument proposal both in terms of performance and science case.

6.1 Budget

To the previous configuration the following item are added:

1) Extended "large detector" coverage (2.25 sr): +1526 k€
2) An additional bottom detector allowing out of plane data collection: 150 k€

The total budget of this configuration is therefore 14 360 + 1 860 =**16 220 k€**

6.2 Impact on performance and science case

The full science case is covered by this configuration.
The instrument operates at nominal performance.

6.3 Upgrades

Two major upgrades are foreseen extending the initial scope of the instrument:

1) 60T pulsed magnetic field: **1 500 k€**
   As stated by the Diffraction STAP: "*Inclusion of a high field (60 T) magnet should remain a longer term aspiration"*. A conical horizontal pulsed magnet would extend the scope of the instrument toward extreme magnetic field. The upgrade is splitted into the magnet itself (500 k€) and a dedicated 3 MJ capacitor bank (1 000 k€).
2) Thermal neutron polarization analysis using ^{3}He cells: this upgrade strongly depends on the possibility for ESS to manage, maintain and support the ^{3}He cells technology.

7 Risk analysis

This section presents the major risks endangering the delivery or operation of the MAGiC instrument. The main conclusion is that early procurement for critical elements is mandatory (super-mirrors, choppers, detectors).

Technical related risks

Risk	Proba.	Effect	Risk level	Mitigation
CDT detectors may not meet requirements	2	4	8	Close follow up with CDT development, backup solution by ESS.
CDT is out of business	2	5	10	Close follow up with CDT development, backup solution by ESS.
Solid State Bender misaligned	2	3	6	Use radiation hard alignment mechanism.
SSB demagnetization by fast neutrons	5	3	15	Shield magnets. Magnets out of direct line of sight.
Chopper failure	1	5	5	Use established vendor/technology
Heavy Shutter failure	1	5	5	Manual operation of the heavy shutter.
Insufficient shielding	2	5	10	Upgradable shielding design.
Neutron optics not meeting requirements	1	2	2	Accept lower performance.
Settlement of building	2	2	4	Re-align full optics.
Guide field not meeting requirements	1	3	3	Accept lower polarization
Polarization analyzer not meeting requirements	2	4	8	Realize prototype. Explore Backup Solution.
Important ground shine	2	3	6	Expand shielding under floor level. Accept higher background.
Superconducting magnet not meeting requirements.	4	3	12	Accept lower magnetic field. Use SE pool magnet.
Oscillating collimators failure.	1	2	2	Use static collimation.

Budget related risks

Risk	Proba.	Effect	Risk level	Mitigation
Detector cost estimates are exceeded	2	4	8	Use contingency, reduce detectors coverage.
Shielding needs to be increased	2	4	8	Use contingency
General cost increased	3	4	12	Use contingency
Personnel cost increased due to delay	4	3	12	Use contingency
Analyzer cost increased due to delay	2	4	8	Use contingency
Analyzer cost increased due to €/CHF exchange rate	3	2	6	Use contingency

Schedule related risks

Risk	Proba.	Effect	Risk level	Mitigation
Choppers delivery postponed due to high demand	3	3	9	Early procurement.
Neutron optics delivery postponed	3	5	15	Early procurement.
Detailed design delay	3	1	3	Increase manpower
Broken parts during installation and commissioning	2	4	8	Respect safety rules and proper personal training.