EUROPEAN SPALLATION SOURCE

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Scope Setting Report

CSPEC: the cold chopper spectrometer of the ESS

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SUMMARY

The purpose of this document is to describe the possible baseline options for the CSPEC project and how the instrument performance will be upgraded over time after the construction project to get from the day one scope to the full scope as envisaged in the instrument proposal.

Three possible baseline options are presented. Additionally, a discussion of detector opportunities that may lower cost, increase performance and potentially lower risk is presented.

CSPEC has been assigned to cost category C (15M€). **The conclusion from analysing the costs is that it is not possible to deliver CSPEC within cost category C in a manner that delivers adequate day one performance and a reasonable, affordable path to world leading performance.**

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1. OVERVIEW

1.1. Science Case

Many research fields and scientific questions of the future can best be addressed using a High-performance direct geometry time-of-flight spectrometer. The areas of interest include biological and life sciences, soft condensed matter research, magnetic materials and novel quantum critical phenomena, or materials science and materials development. The questions to be addressed are driven by fundamental interest as well as technological relevance. Common to these seemingly diverse areas is the fact that the full understanding of their properties and functionalities requires a detailed understanding of their dynamics. For instance, dynamic properties govern the response of stimuli responsive polymers, hydrogels, or of molecular liquids and the understanding and development of the materials properties will have significant impact on technological applications. In the field of biology, life depends on mobile water and with ceasing mobility of the water molecules all biological activity comes to a halt. Studies of the complex interplay of structural form, dynamic properties and functionality of e.g proteins will improve our understanding of diseases and will assist in the drug development. While current experiments mainly probe the static state of a sample, neutron spectroscopy experiments that probe the dynamic response e.g. of electrolytes in an electric field, or laser excited light harvesting proteins, are still in an exploration stage mainly due to the lack of intensity at the instruments available today. Those questions will be of increasing relevance in the coming years and we intend these questions to be addressed on CSPEC. The requirements for these scientific domains are two fold: greater signal and a much reduced background. An upgrade path that includes polarisation analysis will be necessary to further enhance the scientific output.

In the field of hard condensed matter, measurements of the excitation spectrum of novel magnetic materials are crucial for the understanding of the interaction potentials and to benchmark experiments with theory. We currently probe a small portion of experimentally interesting compounds since only a small number of samples can be synthesized in an adequate size for inelastic neutron scattering. Increasing the flux and focusing onto a smaller sample area will improve the signal to noise substantially. A vast array of new scientific domains can thus be accessed.

In the case of magnetism there is currently a great interest in out of equilibrium phenonema that drive new states of matter. These can be driven by electric, magnetic or laser based pumps. A notable example are spin ice materials, that have received much attention of late thanks to the theoretical proposal and experimental discovery of magnetic monopole excitations. This is a rare experimental instance of fractionalisation in three dimensions and the first context where we can access and manipulate free magnetic charges. The existence of these emergent excitations has been demonstrated to have a direct effect on the thermodynamic properties of these systems [Castelnovo, Fennel]. A large interest in these compounds now lie in the response of such compounds in an excited state. However, to date, the lack of flux at a neutron scattering facility have made this an impossible task. CSPEC will open up these avenues of investigation.

1.2. Basic instrument layout

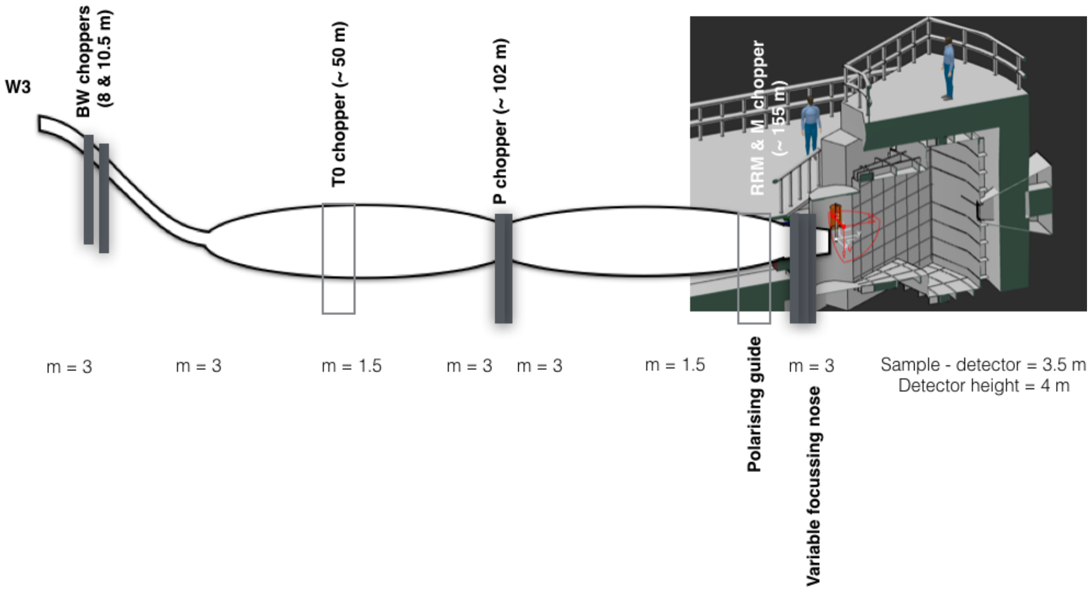


Fig. 1 Basic instrument layout of CSPEC (Vertical cut).

The CSPEC instrument is subdivided into the following main functional blocks:

- Beam extraction
- Neutron guides
- Chopper system
- Shielding
- Detector tank
- Detectors
- Sample environment
- Shutters
- Beam monitoring
- Vacuum monitoring
- Beam stop
- Personnel Safety System, PSS
- Control hutch
- Instrument control

All components have been defined and designed to fulfill the high-level requirements as the basis for the detailed functional and non-functional instrument and component requirements

1.3. Requirements

The top level requirements for CSPEC define the target scope for the instrument construction project. They have been formulated to capture the key aspects of the instrument proposal science case and are :

1. Wavelength range = 2 – 20 Å.
2. CSPEC shall probe excitations up from 0.005 up to 20 meV.
3. CSPEC shall measure in repetition rate multiplication configuration.
4. CSPEC shall be capable of energy resolutions down to ΔE/E = 1% at the highest wavelengths.
5. CSPEC shall access a wavevector transfer Q up to 3 $Å^{-1}$ with ΔE = 100 μeV.
6. CSPEC shall be capable of spatial resolution ΔQ/Q = 2%.
7. CSPEC shall provide at least a signal to noise of 10^4 at 5 Å. Signal to noise is defined as the peak intensity of the elastic line of a vanadium sample versus background obtained far away at a time of flight when the background level has been reached.
8. The chopper cascade shall ensure that each incident wavelength arrives when the scattering from the previous incident wavelength has reached background levels.
9. The neutron beam at the sample position shall illuminate a sample area ranging from 4 x 2 cm^2 to 0.5 x 0.5 cm^2.
10. CSPEC should follow kinetic processes with time steps of one minute.
11. CSPEC should enable the development of pump-probe experiments.
12. The detectors will ensure the Q and E requirements (including ΔE and ΔQ) outlined in the CSPEC proposal.
13. CSPEC shall probe magnetic excitations in magnetic fields up to 12 T.
14. CSPEC shall ensure the possibility to perform polarization analysis in the future.
15. The systems design shall provide the space and flexibility necessary to host and drive future developments.
16. Sample environment for the wide range of scientific cases studied on CSPEC must be consistent with the demands of signal to noise.

1.4. Project timeline

The project timeline is outlined in the CSPEC Work Breakdown Structure (WBS). The project started in May 2016 and is a collaboration between Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II) / Technische Universität München, Germany, and CEA-CNRS via Laboratoire Léon Brillouin. The collaboration aims to deliver the instrument as one of the first eight instruments constructed.

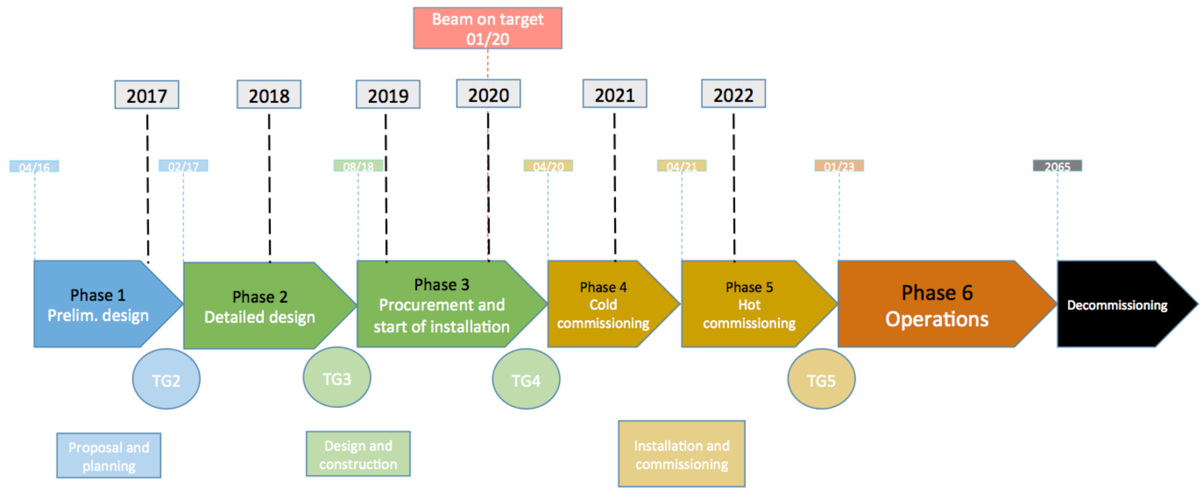


Fig. 2 Timeline derived from the Work Breakdown Structure (WBS) of CSPEC

1.5. Configuration options

Three configuration options are presented:

1. Cost Category: A configuration that is within cost category C (15M€). The aim was to meet the cost category.
2. Preliminary world class: A configuration that manages to meet preliminary scientific requirements at reasonable performance. Cost : 18.550 M€
3. Full scope: A configuration that is the full technical scope. This is a refinement of the scope presented in the proposal, taking into account changes in ESS design during Phase 1 and advice from the Spectroscopy STAP. Cost : 20.937 M€

The three cost categories are provided with the consideration that a 19% VAT is included on any components bought by TUM.

2. OPTION 1 : SCOPE WITHIN COST CATEGORY C (15M€)

2.1. Scope

- Guide that is curved twice out of line of sight, vertically, providing the best signal to noise.
- Unfocussed and focussing nose – exchangeable guide pieces.
- Guide position, and considerations, foreseen for polarising guide.
- Sample position at 157 m.
- Bandwidth choppers
  - Single disk rotating at 14 Hz ~8.5 m (Hybrid ball bearings, Boron coated metallic blades)
  - Single disk rotating at 14 Hz ~10 m (Hybrid ball bearings, Boron coated metallic blades)
- Pulse shaping choppers
  - Counter rotating disks, 3 slits, rotating up to 350 Hz ~101.8 m (Magnetic bearing, Boron coated carbon fibre)
- Pulse removal chopper (RRM chopper), 1 slit, rotating up to 350 Hz ~ 155.4 m (Magnetic bearing, Boron coated carbon fibre)
- Monochromating choppers
  - Counter rotating disks, single slit, rotating up to 350 Hz ~155.5 m (Magnetic bearing, Boron coated carbon fibre)
- Space allocated for T0 chopper.
- Detector tank, sample to detector distance = 3.5 m (detector horizontal coverage : 5-140^{o}, vertical coverage +/- 29^{o}), evacuated to cryogenic pressures no windows between sample and detector window.
- Sample area of detector tank provides side access and a gate valve to perform experiments under ambient and under inert atmosphere.
- Oscillating collimator within sample area.
- B10 detector technology for detectors covering 20 % of detector area.
- Sample environment : Cryofurnace, multiple sample changer for cryofurnace, sample rotation stage and goniometer, He3 insert and access to a 12 T magnet.
- All necessary associated infrastructure (shielding, cabling, cabins etc)

This scope does **not** meet the top level requirements for:

- Kinetic measurements (#10)
- In-situ pump-probe measurements (#11)
- Wide Q range (#12)

CSPEC will provide of an order of magnitude increase in flux on sample across the entire wavelength range accessible, with respect to the current world leading chopper spectrometer. However, taking into account the severely limited detector range (20%) provided by this budget, minimal improvement to current day neutron time of flight spectroscopy is made with ESS at 5 MW, considering only the integrated intensities. If we furthermore consider the wavevector transfer accessible with this limited detector range, then performing an experiment on CSPEC will be futile for 90 % of scientific fields we wish to address, independent of the power of the ESS.

Thus, this scope **does not fulfil** the science case for CSPEC.

2.2. Costing

	01 Management	02 Design	03 Procurement & Start of Installation	04 Installation and Start of Cold Commissioning	Total
01 Shielding	0	0	1 344	0	1 344
02 Neutron Optics	0	0	3 685	99	3 784
03 Choppers	0	0	1 571	0	1 571
04 Sample Environment	0	0	375	0	375
05 Detector (B10)	0	300	2 313	0	2 613
05.1 Detector set (7m²)	0	0	988	0	988
05.2 Detector Tank and Beam Monitors	0	300	1 326	0	1 626
06 Data Acquisition and Analysis	0	0	0	0	0
07 Motion Control and Automation	0	48	33	19	101
08 Instrument Team	484	1 134	628	499	2 745
09 Instrument Infrastructure (Cave and Shielding)	0	0	867	0	867
10 Vacuum	0	0	0	0	0
11 PSS	0	33	33	33	100
12 Contingency	0	0	0	0	1 500
Total	484	1 816	10 849	651	**15 000**

Labour included in 08 (Person-Years)	3,47	8,50	4,92	3,58	20,47

Table 1: Costing for CSPEC in Cost Category C with 19 % VAT on components bought by TUM, prices in k€. The detector coverage is 20%.

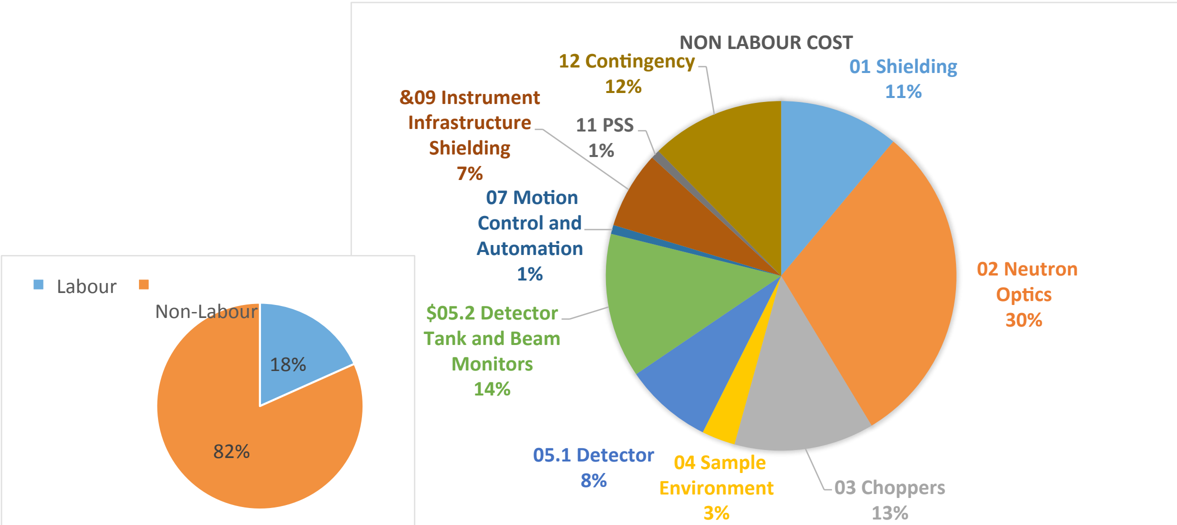


Fig. 3 Relative costs contributing to CSPEC for configuration 1. (left) Labour to non-labour costs (right) non-labour costs.

The costing is based on bottom-up calculation of the procurement costs and manpower required for the tasks needed to deliver the higher level PBS items. Vacuum equipment and data management requirements are not included in the cost as this is expected to be delivered from outside the CSPEC budget. The table below provides an overview of the details behind the costing outlined in the budgets.

01 Shielding	Calculated from the estimate given by the shielding group. Price estimate of the concrete given by Nuvia and the design department of the LLB (see the sheet Guide shielding calculation), costs used are 1k€/m^3 for concrete (ρ = 2300 kg/m^3) and 15.6 k€/m^3 for steel (ρ = 7800 kg/m^3)
02 Neutron Optics	2 estimates: (a) Calculated from the price with respect to the m value given by the LLB (see the sheet Guide calculation) (b) quote from Swiss Neutronics, breakdown = guide ~ 2.7 M€, vacuum housing ~ 0.7 M€, installation ~ 0.11 M€ (plus 19 % VAT) – Currency Risk (Swiss Franc/€) is high.
03 Choppers	Quote received from Airbus Chopper group including the Scope of Work for the cold commissioning (Chopper integration, Drives and power, installation, integration, power system, Chopper cooling, Master and slave rack considered, Vacuum provided by vacuum group)
04 Sample Environment	Calculated from the estimates of the sample environment needed for Day One
05 Detector (B10)	Cumulative cost, 05.1 + 05.2

05.1 Detector set	2 estimates: (a) Quote provided by the ESS Detector group. (b) Quote provided by GE Oil & Gas.
05.2 Detector Tank and Beam Monitors	Calculated from the estimate given by the design department of the LLB (in collaboration with SDMS, Grenoble) after experience with instruments Fa# and PA20 at LLB and ZOOM at ISIS. Radial collimator and cadmium sheets were added to this subsection (see the sheet Detector tank)
06 Data Acquisition and Analysis	Cost outside of scope
07 Motion Control and Automation	Discussions and quote with MCA group
08 Instrument Team	Salary of the team (see the sheet Budget personnel)
09 Instrument Infrastructure (Cave and Shielding)	Calculated from the estimate given by the shielding group. Price estimate of the concrete given by Nuvia and the design department of the LLB (see the sheet Guide shielding calculation). A control hutch and various construction costs has been added to this subsection. Their prices were given by the ESS.
10 Vacuum	Vacuum group
11 PSS	Provided by ESS

Table 2: Overview presenting the origin of the costs for the various budgets.

2.3. Upgrade/Staging plan

The primary staging plan for this option would be (a) to complete the detector array as soon as possible (b) to fully develop the sample environment requirements for this instrument (c) installation of a T0 chopper if required. Polarisation analysis would be delivered at a later stage. There is thus a great risk that polarisation analysis on CSPEC will not occur until many years into operation.

2.4. Risk

The greatest risk with this configuration is the failure to deliver the science case that was presented to the SAC. In this respect there may be two scenarios for this to happen. (a) Incomplete detector array: Experience from LET at ISIS suggests that an incomplete detector array resulted in the disappearance of the soft matter and biological sciences community from their user base due to a weak scattering signal. As a result LET is currently considered as an instrument focussed on magnetism with a strong magnetism base. (b) Poor shielding implementation. At present the shielding requirements for a high signal to noise level remains unclear. Simulations are underway and a greater understanding of the requirements are made on a daily basis. However the CSPEC team must have a good understanding of the noise levels at the sample position within 6 months to ensure a successful signal to noise on the instrument. An inability to (a) obtain a complete detector array and (b) to provide an adequate shielding solution presents a clear reputational risk to ESS. CSPEC must be able to perform new experiments beyond that which is possible now.

Below are top 5 risks rated high using ESS risk measures (impact x likelihood)

Table 3 Top 5 risks for Option 1: 5 high level risks are described below.

Risk level	Risk Event	Risk impact	Treatment	Category	Treatment plan
Catastrophic 5x5	Failure to deliver science case	Instrument will not perform at the frontier of science. Users will not be forthcoming.	Lower expectation or increase budget	Budget, quality and function	Communicate with stakeholders the lowered performance expectations. Begin planning for upgrade and seek funding. Responsible: CSPEC Team, ESS management
Very serious 4 x 4	Shielding design is not adequate	Instrument cannot measure as expected. Signal to noise will be poor. Science case cannot be delivered	Contingency to improve shielding once the instrument is in operation.	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. CSPEC team and Optics group.
Serious 5 x 3	B10 multigrid detectors do not perform as expected	Instrument cannot measure as expected. Signal to noise will be poor. Science case cannot be delivered.	Time is required to optimise the technology or find alternative solutions.	Schedule, budget, Quality and function	Detector technical group is following an action plan and schedule for delivery to CSPEC of B10 detectors Responsible: Detector Groups
Serious 5 x 3	Bandwidth choppers in the bunker fails during operation.	The instrument cannot deliver the signal to noise required.	If problems are continuous then we foresee installing a new set of bandwidth choppers beyond the bunker (associated costs and increase of noise will have to be accepted).	Budget, quality and function	Continuous monitoring of bandwidth chopper parameters is essential. Responsible: CSPEC team and chopper group.
Substantial 5 x 2	Late delivery of components	External areas like labs and workshops	Mitigate	Schedule, budget	External areas will give the opportunity to start pre-installations Responsible: CF

3. OPTION 2 : PRELIMINARY WORLD CLASS MEETING REQUIREMENTS

3.1. Scope

The scope within this cost category is:

- Guide that is curved twice out of line of sight, vertically, providing the best signal to noise.
- Unfocussed and focussing nose – exchangeable guide pieces.
- Guide position, and considerations, foreseen for polarising guide.
- Sample position at 157 m.
- Bandwidth choppers
  - Single disk rotating at 14 Hz ~8.5 m (Hybrid ball bearings, Boron coated metallic blades)
  - Single disk rotating at 14 Hz ~10 m (Hybrid ball bearings, Boron coated metallic blades)
- Pulse shaping choppers
  - Counter rotating disks, 3 slits, rotating up to 350 Hz ~101.8 m (Magnetic bearing, Boron coated carbon fibre)
- Pulse removal chopper (RRM chopper), 1 slit, rotating up to 350 Hz ~ 155.4 m (Magnetic bearing, Boron coated carbon fibre)
- Monochromating shaping choppers
  - Counter rotating disks, single slit, rotating up to 350 Hz ~155.5 m (Magnetic bearing, Boron coated carbon fibre)
- Space allocated for T0 chopper.
- Detector tank, sample to detector distance = 3.5 m (detector horizontal coverage : 5-140^{o}, vertical coverage +/- 29^{o}), evacuated to cryogenic pressures no windows between sample and detector window.
- Sample area of detector tank provides side access and a gate valve to perform experiments under ambient and under inert atmosphere.
- Oscillating collimator within sample area.
- B10 detector technology for detectors covering 100 % of the detector area but electronics only for 5-72^{o}. Of utmost priority is the lack of gaps in the detector array.
- Sample environment : Cryofurnace, multiple sample changer for cryofurnace, sample rotation stage and goniometer, He3 insert and access to a 12 T magnet.
- All necessary associated infrastructure (shielding, cabling, cabins etc)

This scope meets all the high level requirements. The upgrade path will be (a) to complete the electronics for the detector array (b) to fully develop the sample environment requirements for this instrument (c) installation of a T0 chopper.

The science case will mostly be met by this configuration. This configuration will provide a four-fold increase in signal (5 MW) with respect to the world leading chopper spectrometer. In addition we expect the background levels to be improved significantly with respect to current day choppers spectrometers thereby improving the signal to noise further. However current background estimates are too limited to provide quantitative numbers.

The science case for CSPEC is focussed on in-situ kinetic measurements. The most important parameter that determines the feasibility of probing the dynamic response of a system is signal to noise. A recent study of a novel type of (laser-neutron) pump-probe experiment combined in-situ optical activation of the biological function of a membrane protein with a time dependent monitoring of the protein dynamics using inelastic neutron scattering on the cold chopper spectrometer IN5 of the ILL. The data acquired after a single laser flash was followed by 56 neutron pulses [Pieper] while also combining data from several samples. Several samples were required since they deteriorated as a function of time. The dependence on wavevector transfer, Q, was neglected in favour of intensity of the energy transfer by integrating the complete detector area in Q. Information obtained from the Q-dependence is vital to understand the spatial behaviour of the relevant dynamics and is not available for many measurments on current chopper spectrometers.

This configuration provides the best opportunity to complete detector coverage as soon as possible to enable an optimised signal to noise. This will ensure a strong multi-disciplinary scientific user base. The lack of sample environment dedicated to in-situ measurements and kinetic phenomena will be mitigated by collaborations with in-kind partners such as J. Pieper of Tartu University. J. Pieper will shortly be testing an in-situ device on TOF-TOF, TUM, our partner instrument, with the aim to further develop the device for CSPEC.

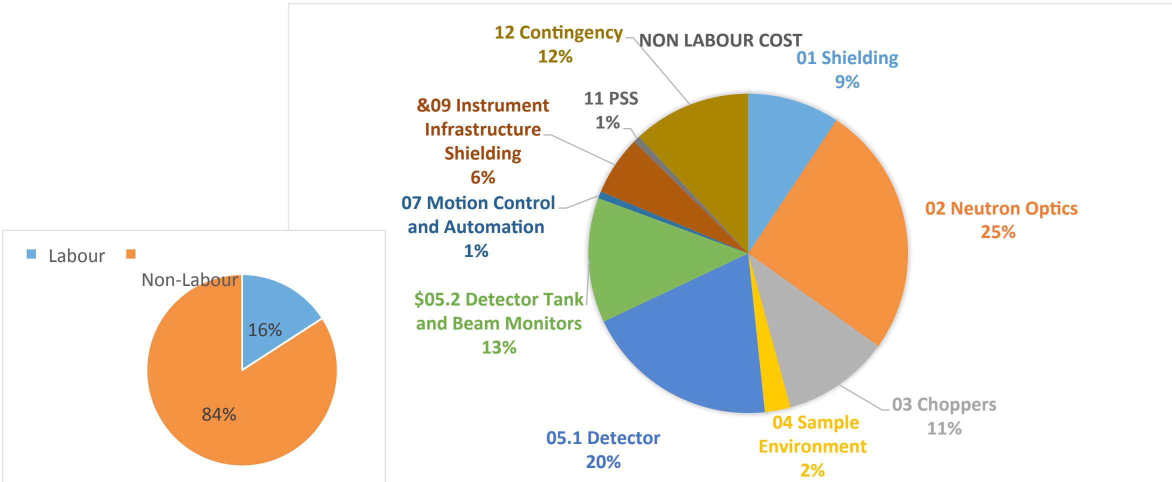
3.2. Costing

	01 Management	02 Design	03 Procurement & Start of Installation	04 Installation and Start of Cold Commissioning	Total
01 Shielding	0	0	1 344	0	1 344
02 Neutron Optics	0	0	3 685	99	3 784
03 Choppers	0	0	1 571	0	1 571
04 Sample Environment	0	0	375	0	375
05 Detector (B10)	0	300	5 509	0	5 809
05.1 Detector set (33m²)	0	0	4 183	0	4 183
05.2 Detector Tank and Beam Monitors	0	300	1 326	0	1 626
06 Data Acquisition and Analysis	0	0	0	0	0
07 Motion Control and Automation	0	48	33	19	101
08 Instrument Team	484	1 134	628	499	2 745
09 Instrument Infrastructure (Cave and Shielding)	0	0	867	0	867
10 Vacuum	0	0	0	0	0
11 PSS	0	33	33	33	100
12 Contingency	0	0	0	0	1 855
Total	484	1 816	14 045	651	**18 550**

Labour included in 08 (Person-Years)	3,47	8,50	4,92	3,58	20,47

Table 4 Costing for CSPEC Preliminary world class configuration with 19 % VAT on components bought by TUM, prices in k€. The functioning detector coverage on day 1 is 50%.

The costing is based on bottom-up calculation of the procurement costs and manpower required for the tasks needed to deliver the higher level PBS items. Vacuum equipment and data management requirements are not included in the cost as this is expected to be delivered from outside the CSPEC budget.



3.3. Upgrade/Staging plan

The upgrade path will be (a) finalise the detector bank (1 M€) (b) to fully develop the sample

Fig. 4 Relative costs contributing to CSPEC for configuration 2. (left) Labour to non-labour costs (right) non-labour costs.

environment required (c) installation of a T0 chopper if required and (d) polarisation analysis.

3.4. Risk

Below are top 5 risks rated high using ESS risk measures (impact x likelihood).

In this scenario the highest risk is the shielding design as outlined previously in section 2.4. Furthermore the detector technology remains a risk. Tests using CNCS (SNS) and TOFTOF (TUM) will enable us to further understand the possibilities and difficulties associated with B10 multigrid detectors. It must also be noted that if the technology poses no risk then, nevertheless, this option has a high detector coverage and thus the likelihood of a delay in detector delivery is rather great.

Table 5 : Top 5 risks for Option 2

Risk level	Risk Event	Risk impact	Treatment	Category	Treatment plan
Very serious 4 x 4	Shielding design is not adequate	Instrument cannot measure as expected. Signal to noise will be poor. Science case cannot be delivered	Contingency to improve shielding once the instrument is in operation.	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. CSPEC team and Optics group.
Serious 5x3	B10 multigrid detectors do not perform as expected	Instrument cannot measure as expected. Signal to noise will be poor. Science case cannot be delivered.	Time is required to optimise the technology or find alternative solutions.	Schedule, budget, Quality and function	Detector technical group is following an action plan and schedule for delivery to CSPEC of B10 detectors Responsible: Detector Groups
Serious 5 x 3	Bandwidth choppers in the bunker fails during operation.	The instrument cannot deliver the signal to noise required.	If problems are continuous then we foresee installing a new set of bandwidth choppers beyond the bunker (associated costs and increase of noise will have to be accepted).	Budget, quality and function	Continuous monitoring of bandwidth chopper parameters is essential. Responsible: CSPEC team and chopper group.
Substantial 5 x 2	Late delivery of components	CSPEC schedule	Properly assess the delivery time and transportation, also the time that is required for installation and arriving at site.	Schedule, budget	Define the critical path for every component. Responsible: CSPEC Team
Substantial 5x2	Weak integration process	Integration plan , Checklist of activities, work package documentation, interface control document	Assess the integration plan.	Schedule, budget, quality and function	Integration plan is consider in work package documentation, detail description of interfaces, schedule and a detail list of activities Responsible: CSPEC team

4. OPTION 3 : FULL SCOPE

4.1. Scope

The full instrument scope consists of:

The scope within this cost category is:

- Guide that is curved out of line of sight, vertically, providing the best signal to noise.
- Unfocussed and focussing nose – exchangeable guide pieces.
- Guide position, and considerations, foreseen for polarising guide.
- Sample position at 157 m.
- Bandwidth choppers
  - Single disk rotating at 14 Hz ~30 m (Hybrid ball bearings, Boron coated Steel)
  - Single disk rotating at 14 Hz ~35 m (Hybrid ball bearings, Boron coated Steel)
  - Single disk rotating at 14 Hz ~40 m (Hybrid ball bearings, Boron coated Steel)
- Pulse shaping choppers
  - Counter rotating disks, 3 slits, rotating up to 350 Hz ~51.8 m (Magnetic bearing, Boron coated carbon fibre)
- Monochromating shaping choppers
  - Counter rotating disks, single slit, rotating up to 350 Hz ~155.5 m (Magnetic bearing, Boron coated carbon fibre)
- T0 chopper.
- Detector tank, sample to detector = 3.5 m (Detector array horizontal: 5-140^{o}, vertical +/- 29^{o}), evacuated to cryogenic pressures no windows between sample and detector window.
- Sample area of detector tank provides side access and a gate valve to perform experiments under ambient and pressurised conditions.
- Oscillating collimator within sample area.
- B10 detector technology for detectors covering 100 % of the detector area.
- Sample environment (full):
  - Cryofurnace
  - Cryostat
  - High temperature furnace,
  - Multiple sample changer,
  - Dilution and access to a 12 T magnet,
  - Huber goniometer: Rotating 2 axis table +/- 10 degrees,
  - Internal goniometer for single crystals (attocube style),
  - Levitation furnace,
  - Gas handling panels for catalysis,
  - Humidity chamber for life science research,
  - Secondary sample characterization: NMR sample cells, coupled impedance spectrometer.
- All necessary associated infrastructure (shielding, cabling, cabins etc)

This scope meets all the high level requirements and almost completely fulfils the science case. Polarisation analysis remains on the upgrade path since there are no resources within the ESS allocated towards the development of polarisation analysis. As such a day 1 option would be unrealistic.

4.2. Costing

	01 Management	02 Design	03 Procurement & Start of Installation	04 Installation and Start of Cold Commissioning	Total
01 Shielding	0	0	1 344	0	1 344
02 Neutron Optics	0	0	3 685	99	3 784
03 Choppers	0	0	2 136	0	2 136
04 Sample Environment	0	0	910	0	910
05 Detector (B10)	0	300	6 456	0	6 756
05.1 Detector set (33m²)	0	0	5 130	0	5 130
05.2 Detector Tank and Beam Monitors	0	300	1 326	0	1 626
06 Data Acquisition and Analysis	0	0	0	0	0
07 Motion Control and Automation	0	97	66	39	202
08 Instrument Team	484	1 134	628	499	2 745
09 Instrument Infrastructure (Cave and Shielding)	0	0	867	0	867
10 Vacuum	0	0	0	0	0
11 PSS	0	33	33	33	100
12 Contingency	0	0	0	0	2 094
Total	484	1 864	16 125	670	**20 937**
Labour included in 08 (Person-Years)	3,47	8,50	4,92	3,58	20,47

Table 6 Costing for CSPEC full scope configuration with 19 % VAT on components bought by TUM, prices in k€. B10 multigrid detector with 100 % functioning detector coverage on day 1.

The costing is based on bottom-up calculation of the procurement costs and manpower required for the tasks needed to deliver the higher level PBS items. Vacuum equipment and data management requirements are not included in the cost as this is expected to be delivered from outside the CSPEC budget.

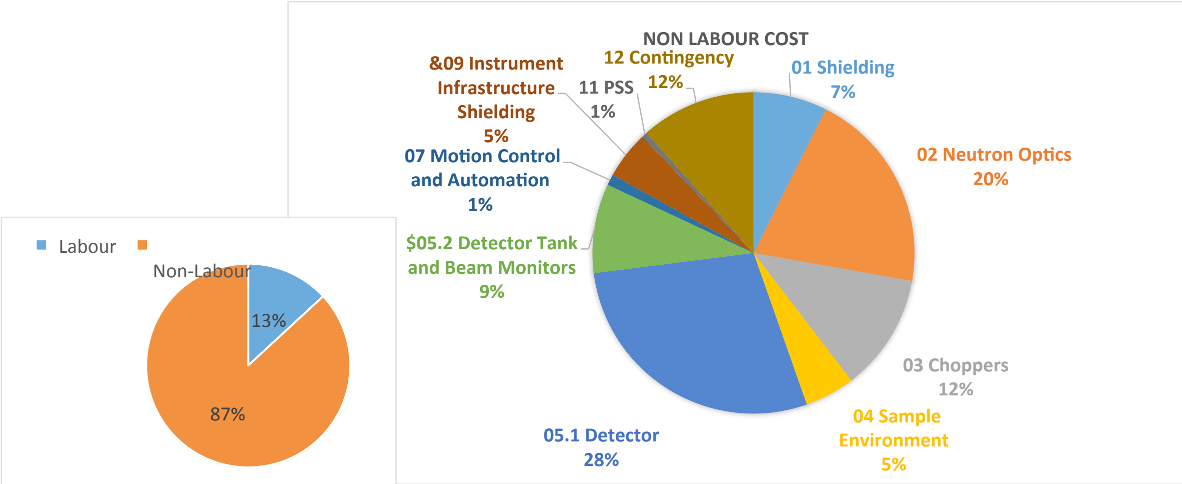


Fig. 5 Relative costs contributing to CSPEC for configuration 3. (left) Labour to non-labour costs (right) non-labour costs.

4.3. Risk

As in section 3.4 the main risks for this configuration remains the shielding solution and the detector technology. Further risks include delays in delivery of various ESS systems and CSPEC components.

Below are top 5 risks rated high using ESS risk measures (impact x likelihood).

Table 3 : Risks for Option 3

Risk level	Risk Event	Risk impact	Treatment	Category	Treatment plan
Very serious 4 x 4	Shielding design is not adequate	Instrument cannot measure as expected. Signal to noise will be poor. Science case cannot be delivered	Contingency to improve shielding once the instrument is in operation.	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. CSPEC team and Optics group.
Serious 5 x 3	B10 multigrid detectors do not perform as expected	Instrument cannot measure as expected. Signal to noise will be poor. Science case cannot be delivered.	Time is required to optimise the technology or find alternative solutions.	Schedule, budget, Quality and function	Detector technical group is following an action plan and schedule for delivery to CSPEC of B10 detectors Responsible: Detector Groups
Substantial	Late delivery of components	CSPEC schedule	Properly assess the delivery	Schedule, budget	Define the critical path for every component. Responsible: CSPEC

5 x 2			time and transportation, also the time that is required for installation and arriving at site.		Team
Substantial 5x2	Weak integration process	Integration plan, Checklist of activities, work package documentation, interface control document	Assess the integration plan.	Schedule, budget, quality and function	Integration plan is consider in work package documentation, detail description of interfaces, schedule and a detail list of activities Responsible: CSPEC team
High 3 x 5	Proper design according to instrument requirements and delay in monolith insert design	Schedule for external milestone TARGET LEVEL ESS-0019533	Observe	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. CSPEC Team Responsible: target Focus on Safety, feasibility and requirements Responsible: target

5. MITIGATION OF RISK WITH RESPECT TO DETECTOR TECHNOLOGY.

The B10 multigrid detector tests are very promising, however it remains possible that a solution involving B10 multigrid detectors are not possible due to technical issues that we cannot currently foresee. We therefore provide a budget that contains a He3 detector solution. Quotes have been provided by GE Oil & Gas for He3 detectors at various pressures, 2, 3 and 5 bars. In order to satisfy the science case of CSPEC it is imperative that we employ 5 bar He3 which provides adequate efficiency at low wavelengths (up to 2 Å) while maintaining a good penetration length at long wavelengths. This is not the case for lower pressures of He3.

We provide a budget for the costs of the preliminary world class configuration with He3 detectors (45%). A quick preliminary comparison of budgets coverage provided by B10 and 5 bar He3 detectors would lead one to determine that there are minimal differences. However the budget for the preliminary world class configuration with B10 multigrid detectors requires a further 1 M€ euros to achieve full detector coverage, from the initial scope of full detector coverage and 50 % electronics. In contrast the budget comprising 5 bar He3 detectors would require 6.4M€ to upgrade to full detector coverage.

	01 Management	02 Design	03 Procurement & Start of Installation	04 Installation and Start of Cold Commissioning	Total
01 Shielding	0	0	1 344	0	1 344
02 Neutron Optics	0	0	3 685	99	3 784
03 Choppers	0	0	1 571	0	1 571
04 Sample Environment	0	0	375	0	375
05 Detector (He3 5bars)	0	300	5 464	0	5 764
05.1 Detector set ($14.85m^2$)	0	0	4 138	0	4 138
05.2 Detector Tank and Beam Monitors	0	300	1 326 €	0	1 626
06 Data Acquisition and Analysis	0	0	0 €	0	0
07 Motion Control and Automation	0	48	33 €	19	101
08 Instrument Team	484	1 134	628 €	499	2 745
09 Instrument Infrastructure (Cave and Shielding)	0	0	867 €	0	867
10 Vacuum	0	0	0 €	0	0
11 PSS	0	33	33 €	33	100
12 Contingency	0	0	0 €	0	1 850
Total	484	1 816	14 000 €	651€	**18 500**

Labour included in 08 (Person-Years)	3,47	8,50	4,92	3,58	20,47

Table 7 Costing for CSPEC configuration with 19 % VAT on components bought by TUM, all prices in k€. He3 detectors with 5 bar He3 pressure. The functioning detector coverage on day 1 is 45%.

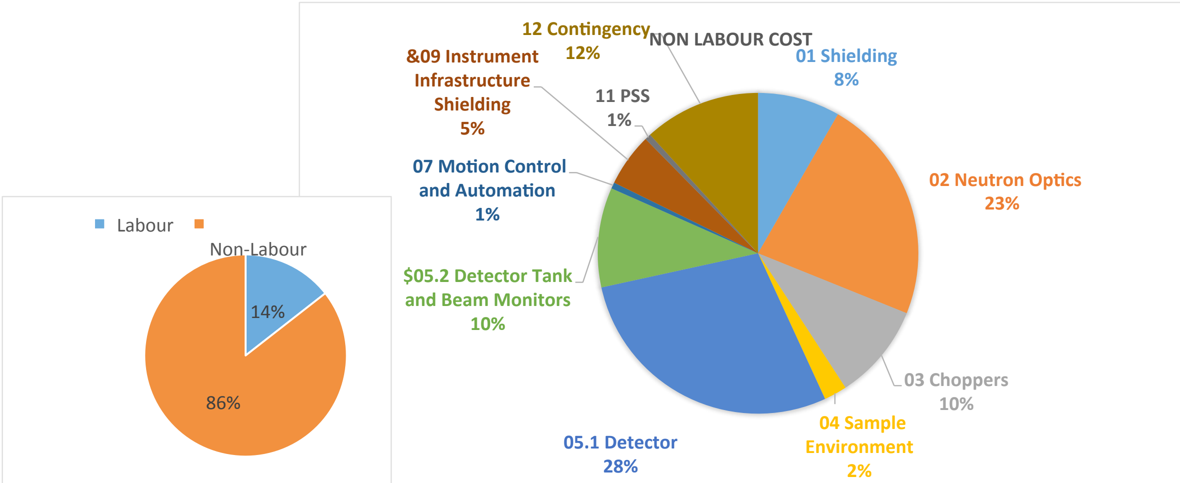


Fig. 5 Relative costs contributing to CSPEC for configuration 2 with He3 detectors (5 bar)) (45 % detectors, 45 % electronics). (left) Labour to non-labour costs (right) non-labour costs.

6. REFERENCES

1. Concept of operations CSPEC September 2016.
2. System_Requirements CSPEC September 2016.
3. CSPEC STAP report May 2014.