Science and Technology Facilities Council

Imperial College London

Site requirements for long-baseline atom interferometry

Richard Hobson, Imperial College London

Terrestrial very-long-baseline atom interferometry workshop, 14/03/2023

Detector layout

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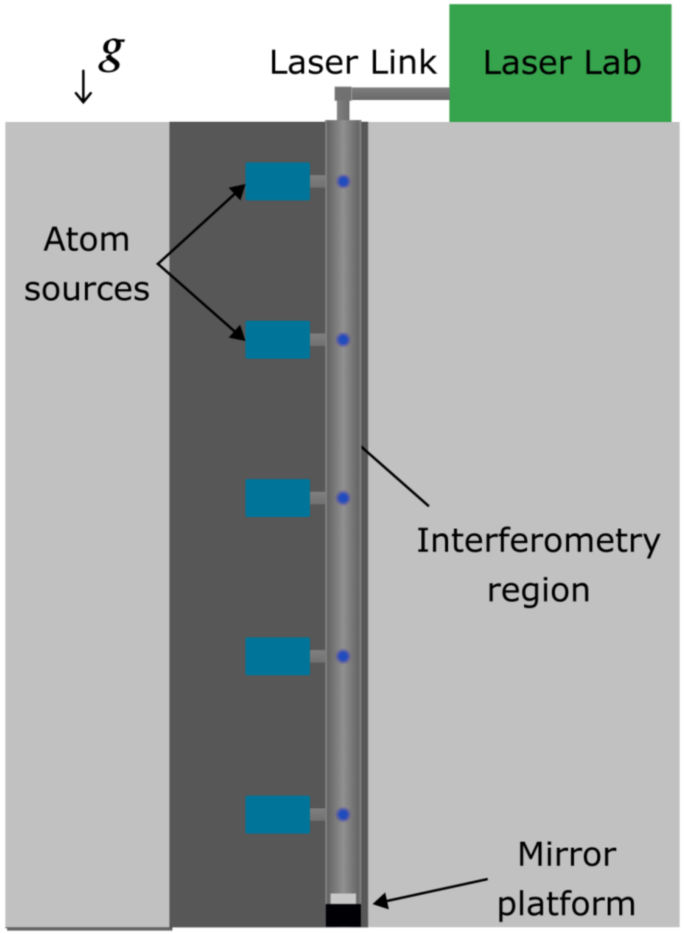
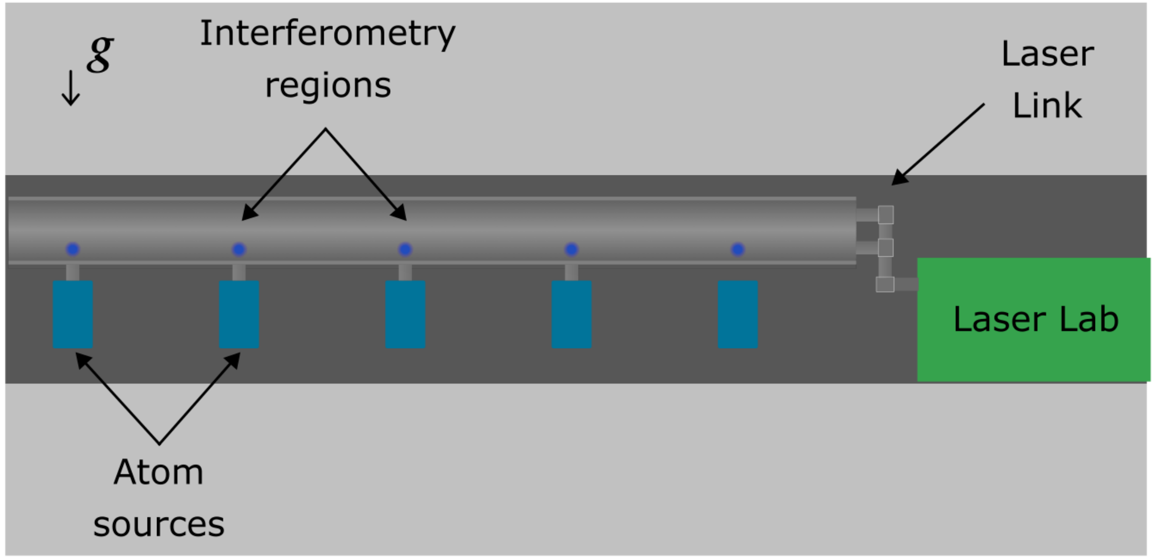
Vertical baseline



Horizontal baseline



Both options are highly configurable:

- Length of baseline(s)
- Number/location of atom sources and laser lab(s)
- Atom species; state prep/launch; AI sequence; Cavity…

CERN-PBC feasibility study

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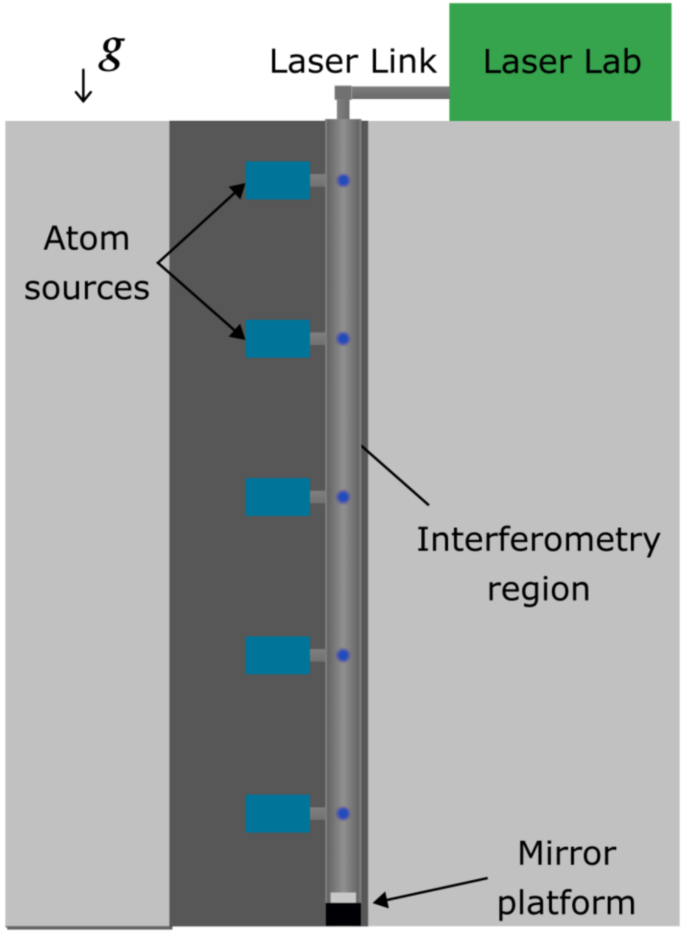
Vertical baseline



CERN-PBC 2023 → Estimated requirements for vertical baseline

CERN Physics Beyond Colliders

CERN-PBC Report-2023-002

A Long-Baseline Atom Interferometer at CERN: Conceptual Feasibility Study

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[1] CERN, [2] King's College London, [3] Imperial College London, [4] University of Cambridge

[*] Editors

Abstract

We present results from exploratory studies, supported by the Physics Beyond Colliders (PBC) Study Group, of the suitability of a CERN site and its infrastructure for hosting a vertical atom interferometer (AI) with a baseline of ∼ 100 m. We first review the science motivations for such an experiment to search for ultralight dark matter and measure gravitational waves, and then outline the general technical requirements for such an atom interferometer, using the AION-100 project as an example. We present a possible CERN site in the PX46 access shaft to the Large Hadron Collider (LHC), including the motivations for this choice and a description of its infrastructure. We then assess its compliance with the technical requirements of such an experiment and what upgrades may be needed. We analyse issues related to the proximity of the LHC machine and its ancillary hardware and present a preliminary safety analysis and the required mitigation measures infrastructure modification. In conclusion, we identify primary cost drivers and describe constraints on the experimental installation and operation schedules arising from LHC operation. We find no technical obstacles: the CERN site is a very promising location for an AI experiment with a vertical baseline of ∼ 100 m.

Laser lab: requirements

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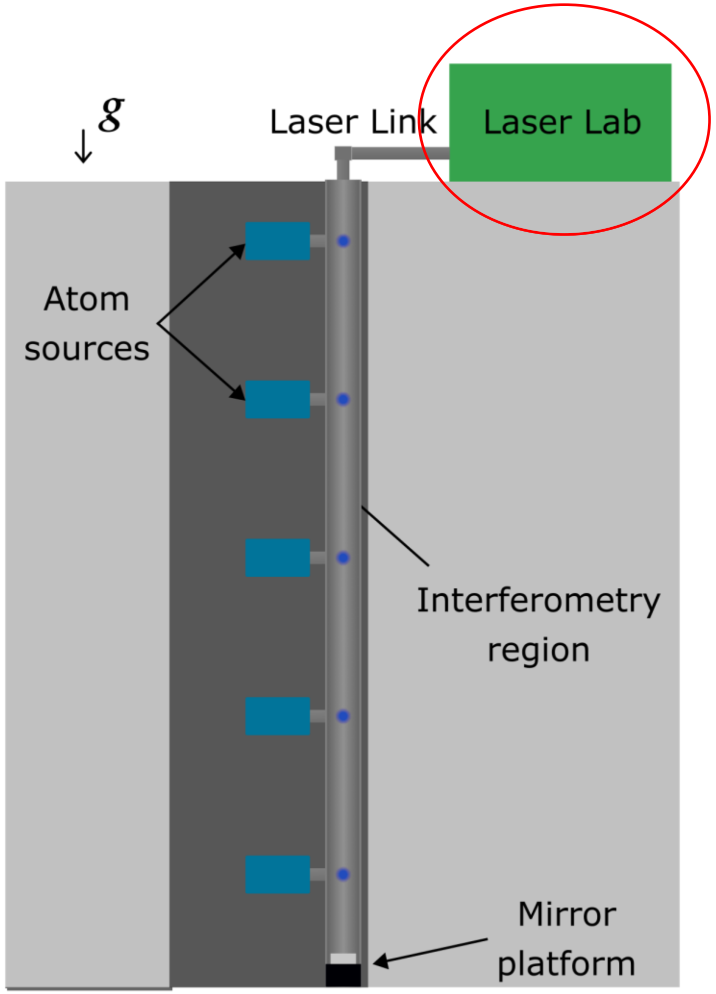

Physical volume	Light-tight room ≳ 50 m^2 floor area x 3 m height
Services	Electrical power ~ 35 kW Cooling water ~ 30kW, 5 barg, above dew point, < 20 °C Gases: Compressed dry air; Helium; Argon Ethernet, optical fibres, coaxial cables
Environmental controls	Temperature stability +/- 1 °C pk-pk (~ 20-23 °C; spatial variation ok, time variation bad) Ventilation to remove up to 30 kW heat; dust filtered; low acoustic noise
Access and safety	Access year-round ≳ 12 hours/day Laser safety controls – engineering (enclosures), admin (training) and PPE (glasses) Smoke detector; Oxygen depletion monitor

Laser lab: example

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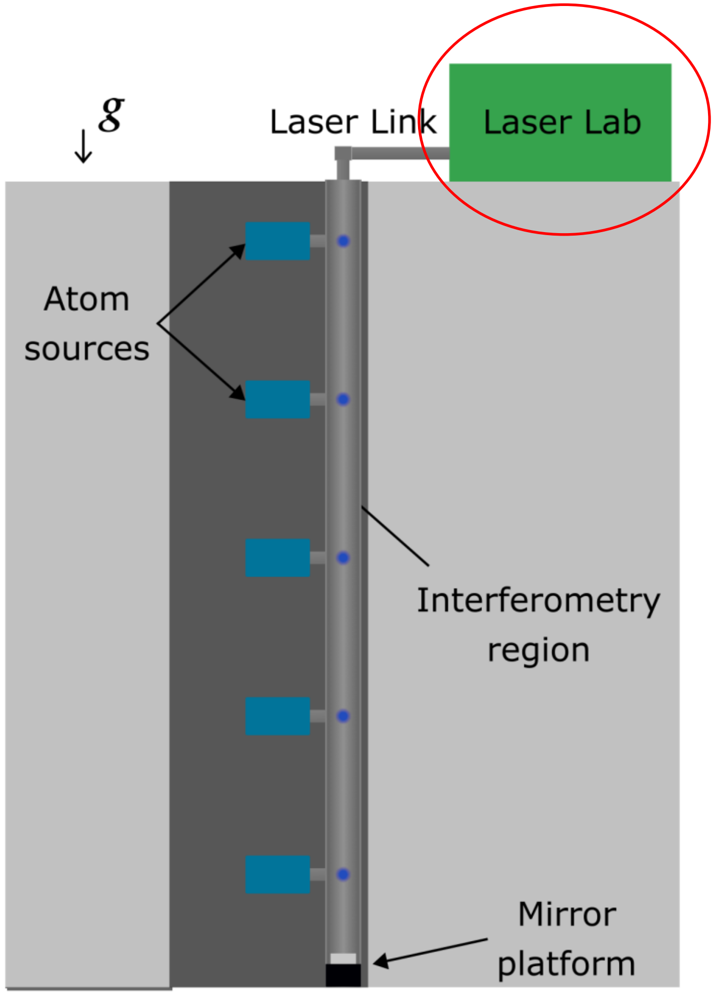


HVAC

Optical tables (x4)

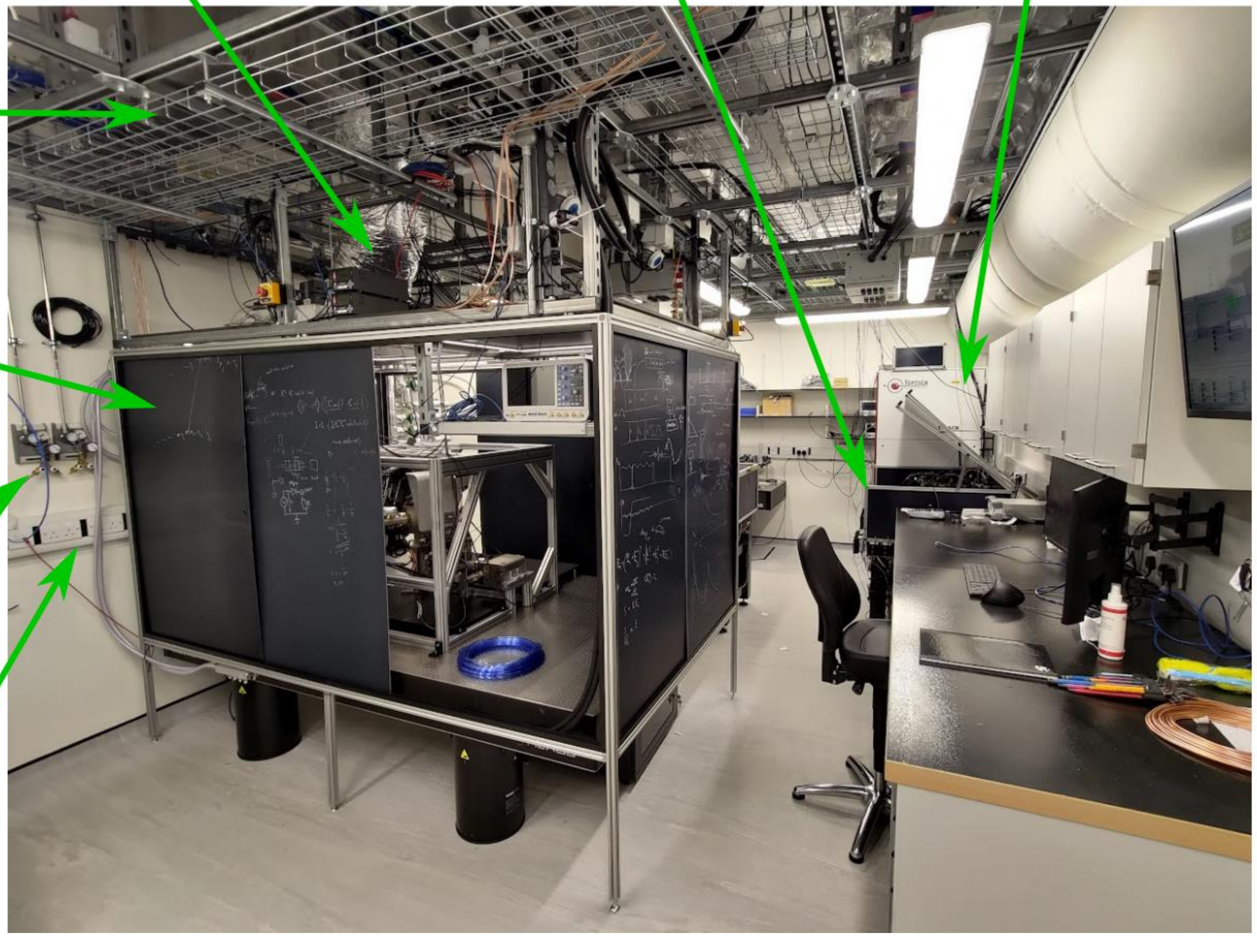
Benching and racks

Gantry & trays
~ 2 - 3 m height

Laser enclosure
~ 2 m height

Compressed He,
Ar & dry air

Electrical power
& data



Atom sources - requirements

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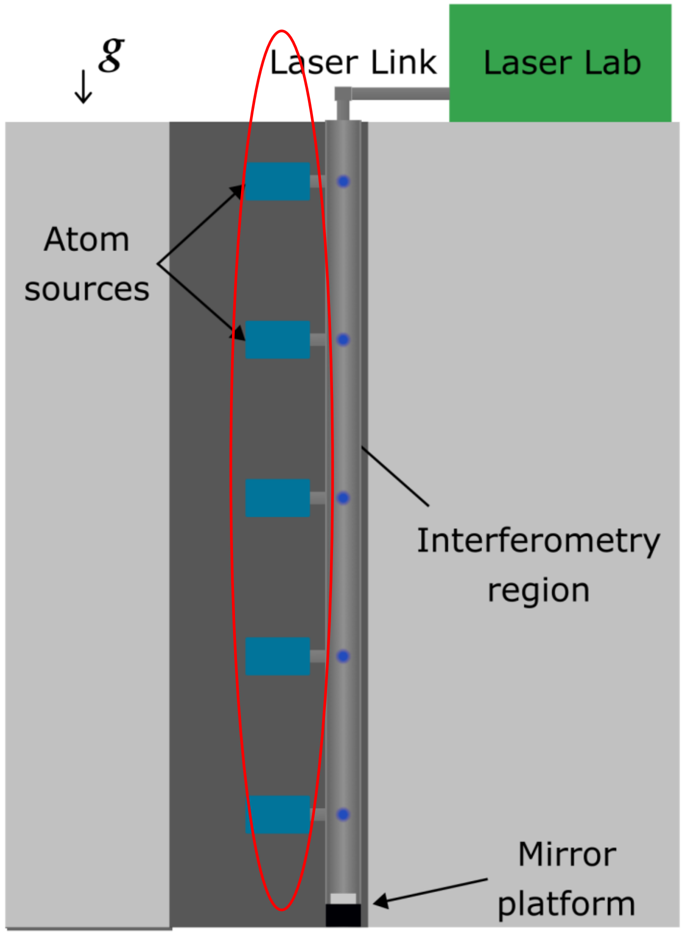
Specifications per atom source:



Physical volume	Enclosure ~ 1 x 1 x 2 m
Services	Electrical power ~ 10 kW Cooling water ~ 5 kW, 5 barg, above dew point, stable to 1 °C pk-pk Helium (for commissioning only – UHV check) Ethernet, optical fibres, coaxial cables
Environmental controls	NEMA-rated enclosure; Temperature stability +/- 1 °C pk-pk Air flow to remove up to 5 kW heat (Low acoustic noise) Magnetic field: no fast fluctuations > 50 nT
Access and safety	Access via moving platform, year-round $\gtrsim$ 12 hours/day Laser safety controls – engineering (enclosures), admin (training) and PPE (glasses) External risks: Radiation, fire, ventilation (e.g. LHC He leak)

Atom sources: examples (Sr)

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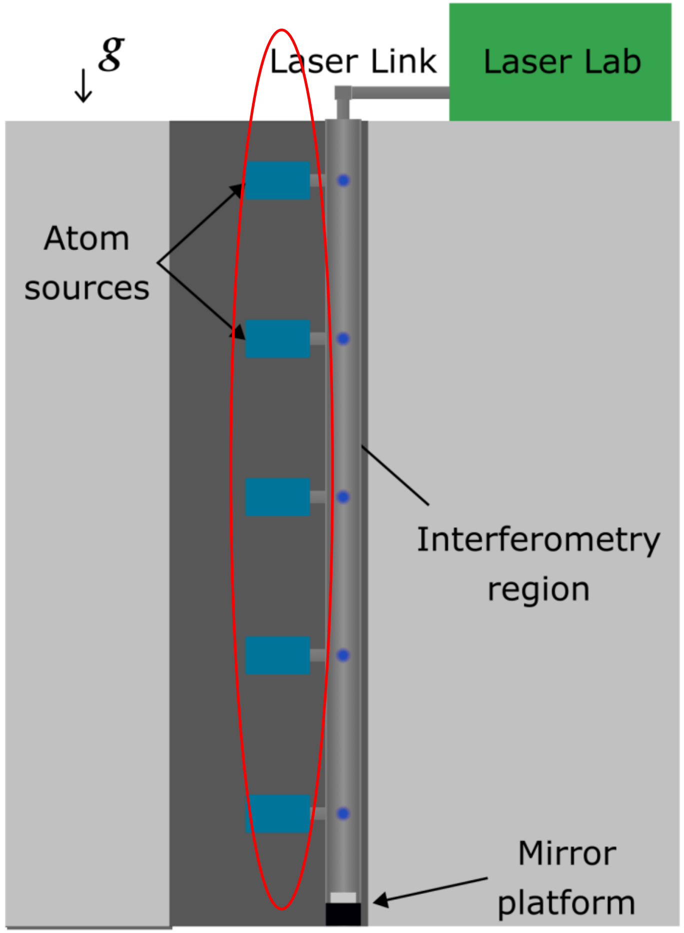
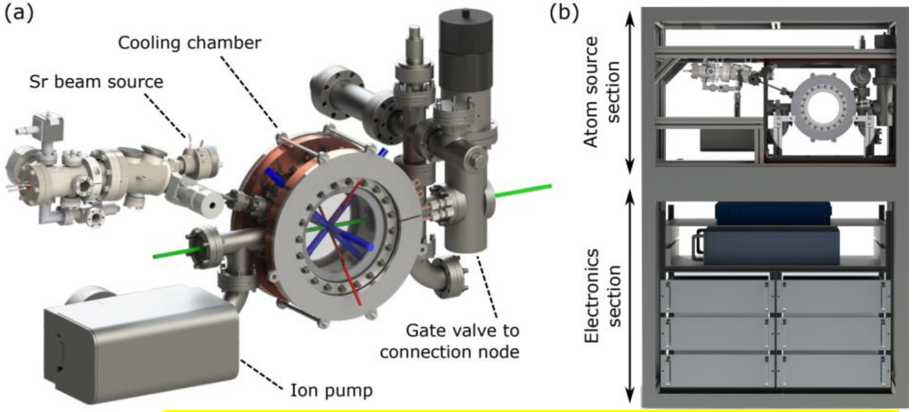
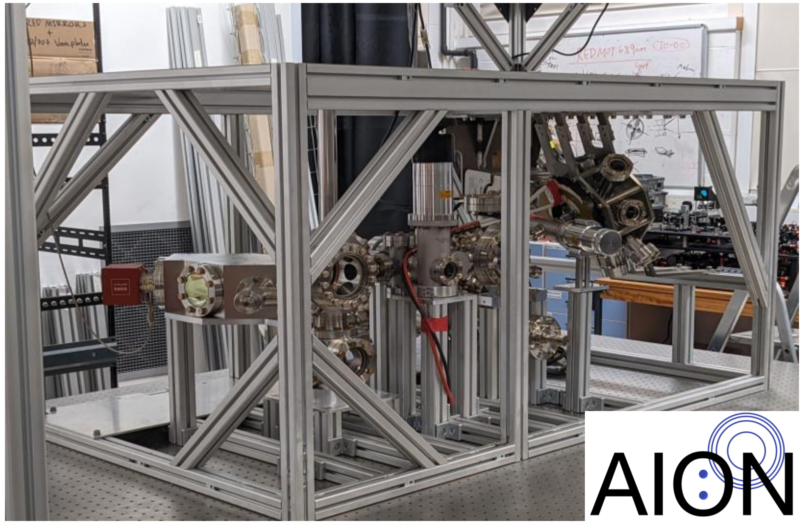


S. Origlia et al.
Proc. SPIE 9900, 990003 (2016)



MAGIS - Quantum Sci. Technol. 6, 044003 (2021)



Atom sources: examples (Rb)

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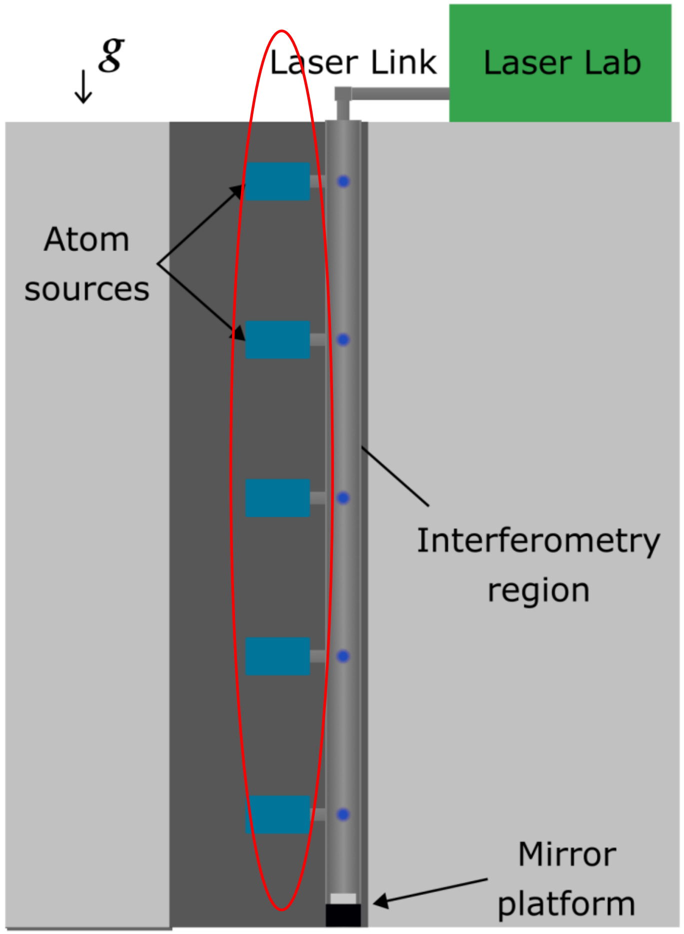
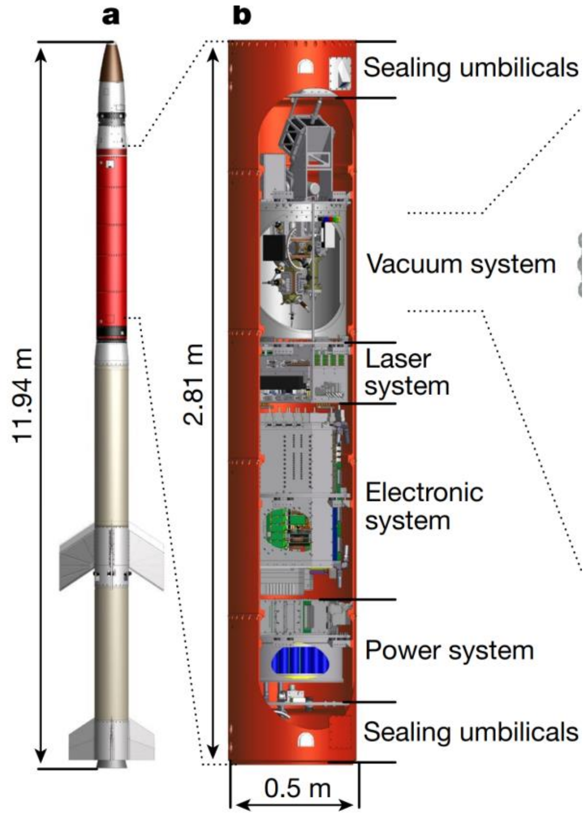
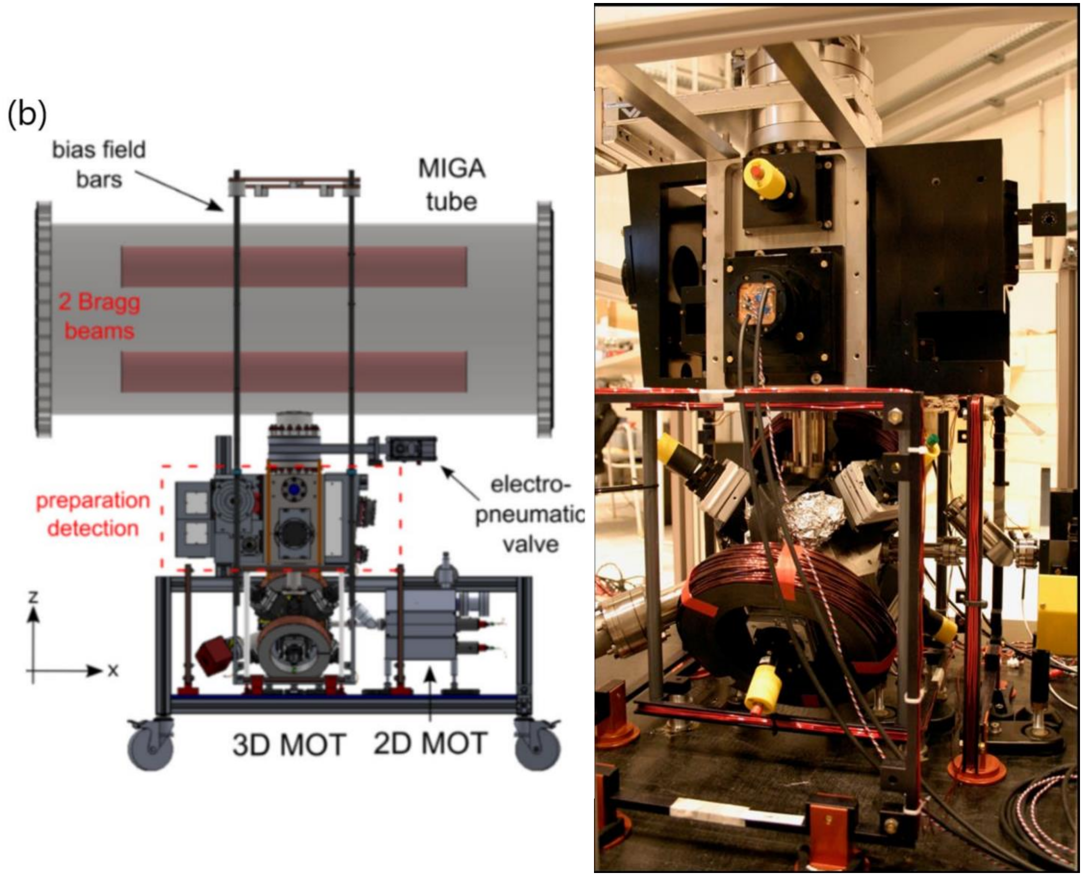




MAIUS - Nature **562**, 391–395 (2018)



MIGA – Beaufils et al., Nature Sci. Rep. 12, 19000 (2022)

Interferometry region

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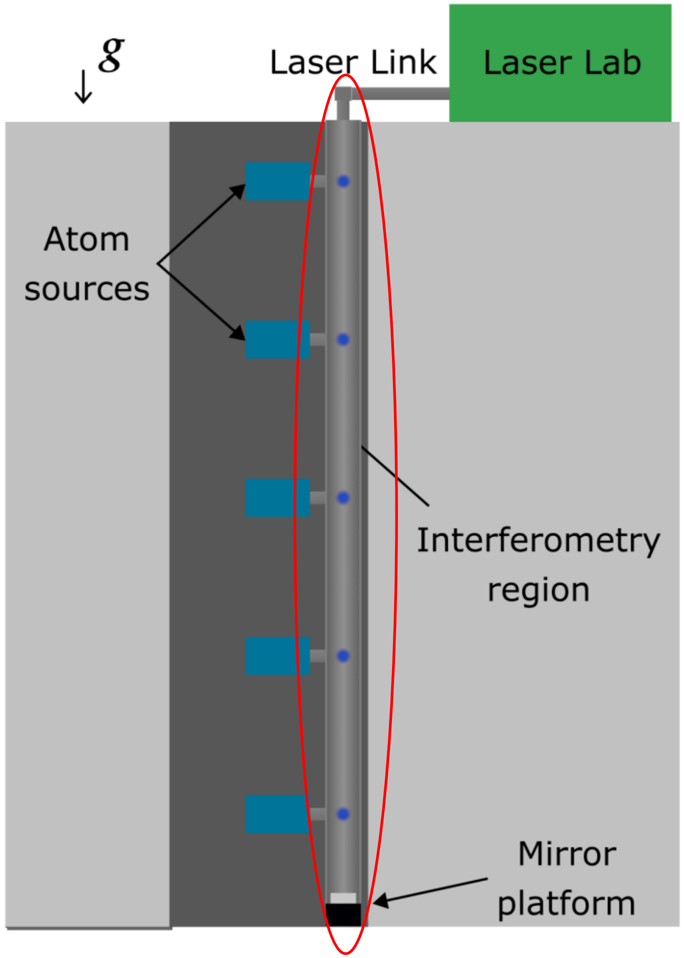

Physical volume	~ 1 m x 1 m cross-section, ~ 100 m to 2 km long
Services	Electrical power ~ 100 W Helium (for commissioning only – UHV check) Environmental monitoring cables; Magnet wires Hoisting equipment for installation, up to ~ 907 kg modules
Environmental controls	Temperature drift < 1 °C/hour Air flow to maintain temperature specification Magnetic field: $\lesssim 100\ \mathrm{pT}/\sqrt{\mathrm{Hz}}$ in 0.05-10 Hz band for Sr, Yb (Potentially more stringent field requirements for Rb)
Access and safety	Regular access via moving platform during commissioning Rare access after commissioning for servicing/maintenance

Interferometry region: examples

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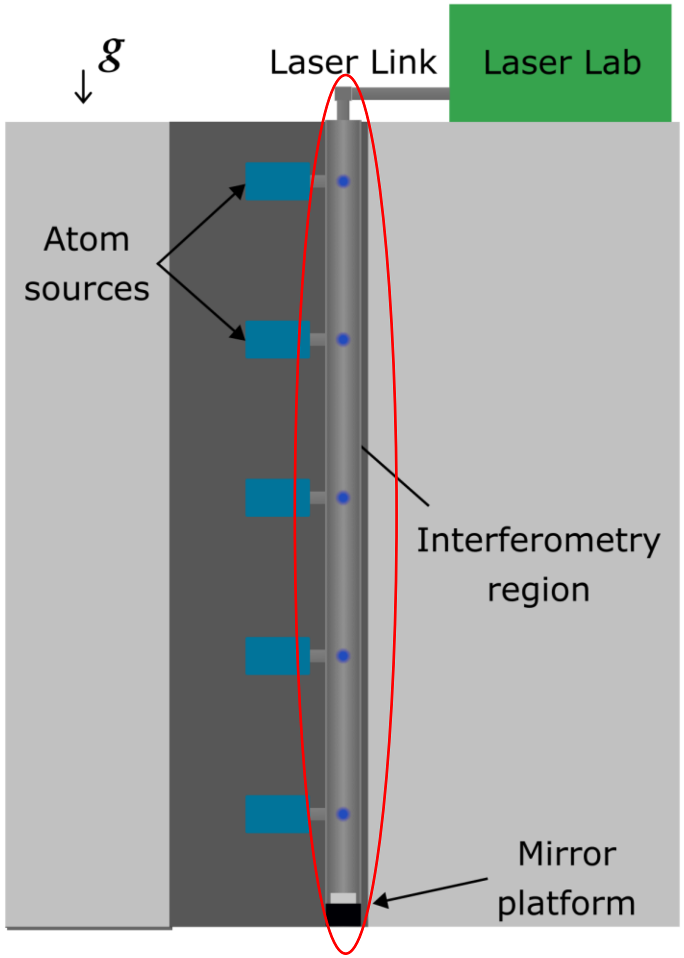

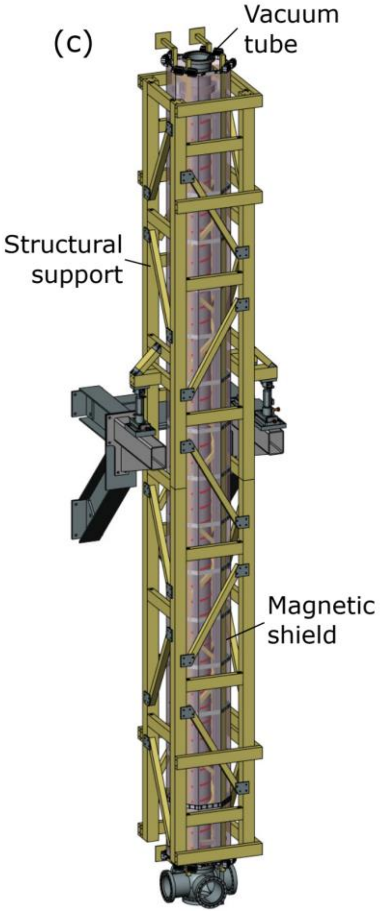

MAGIS-100, Fermilab
Quantum Sci. Technol. 6, 044003 (2021)

VLBAI, Leibniz Universität Hannover
June 2019: Twitter @VLBAI_Hannover

Laser link

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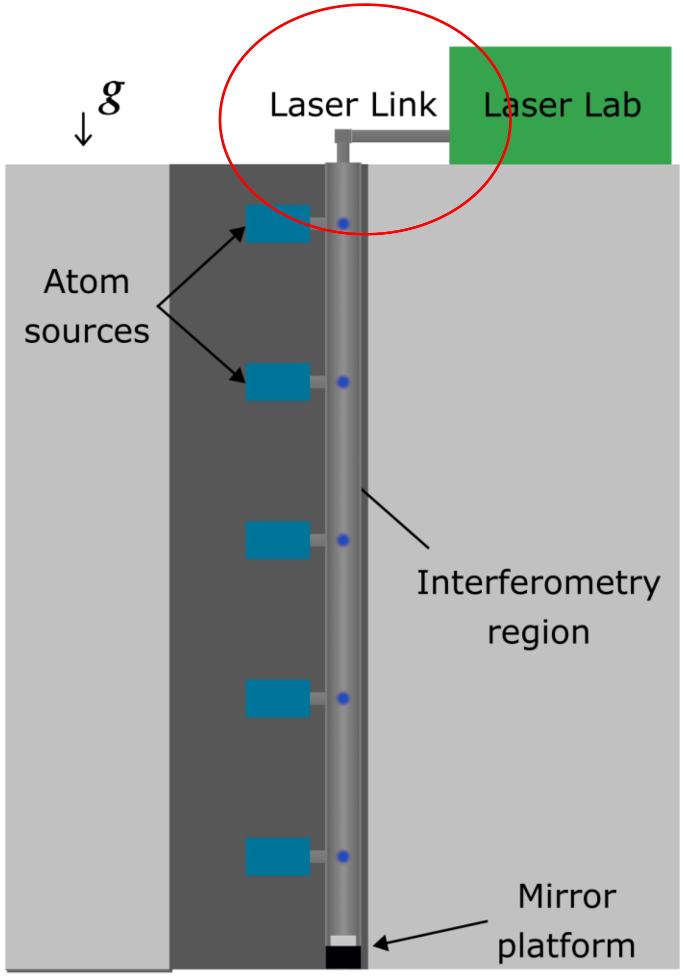
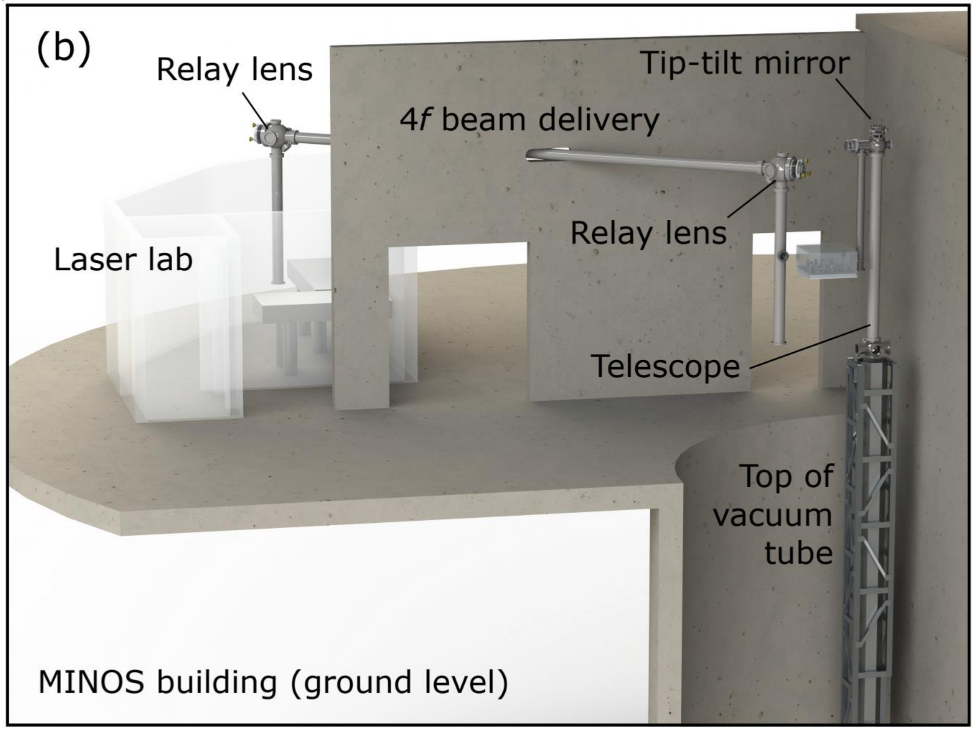


Most lasers can be delivered from laser lab to atoms by optical fibre

But the high-power interferometry beam should be delivered in (shielded) free space



MAGIS-100 interferometry beam, Fermilab - Quantum Sci. Technol. 6, 044003 (2021)

Flexibility in site requirements

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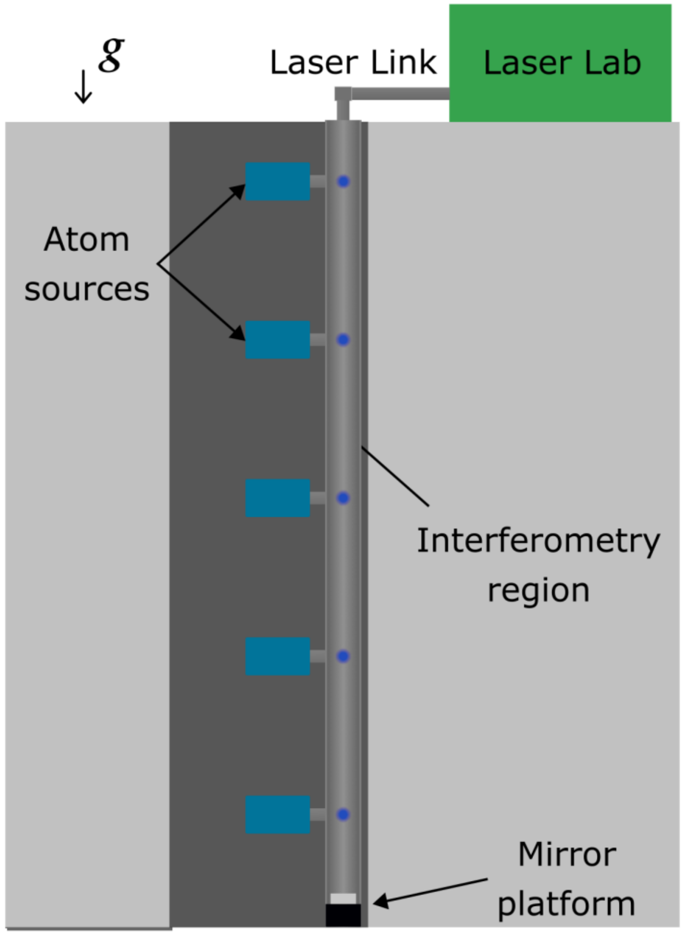

Some site requirements can be relaxed at the cost of extra effort/delays to detector build (e.g. fancy enclosures; highly-engineered optics, electronics etc.)

Some things we can't be flexible about:

- Deeply-buried baseline, with low vibrations
  → GGN (J Mitchell) and beam pointing stability
- Extreme temperature/magnetic field fluctuations

Thank you

More details soon available in CERN PBC report

Many thanks to:

Jeremiah Mitchell (Cambridge)

Charles Baynham (Imperial College)

Funders, CERN PBC group, and AION collaborators (see logos)