AION-10 Work Package

Chris Foot, Oxford Physics

AION Workshop

March 25th 2019

AOIN-10 Work Package

Objective:

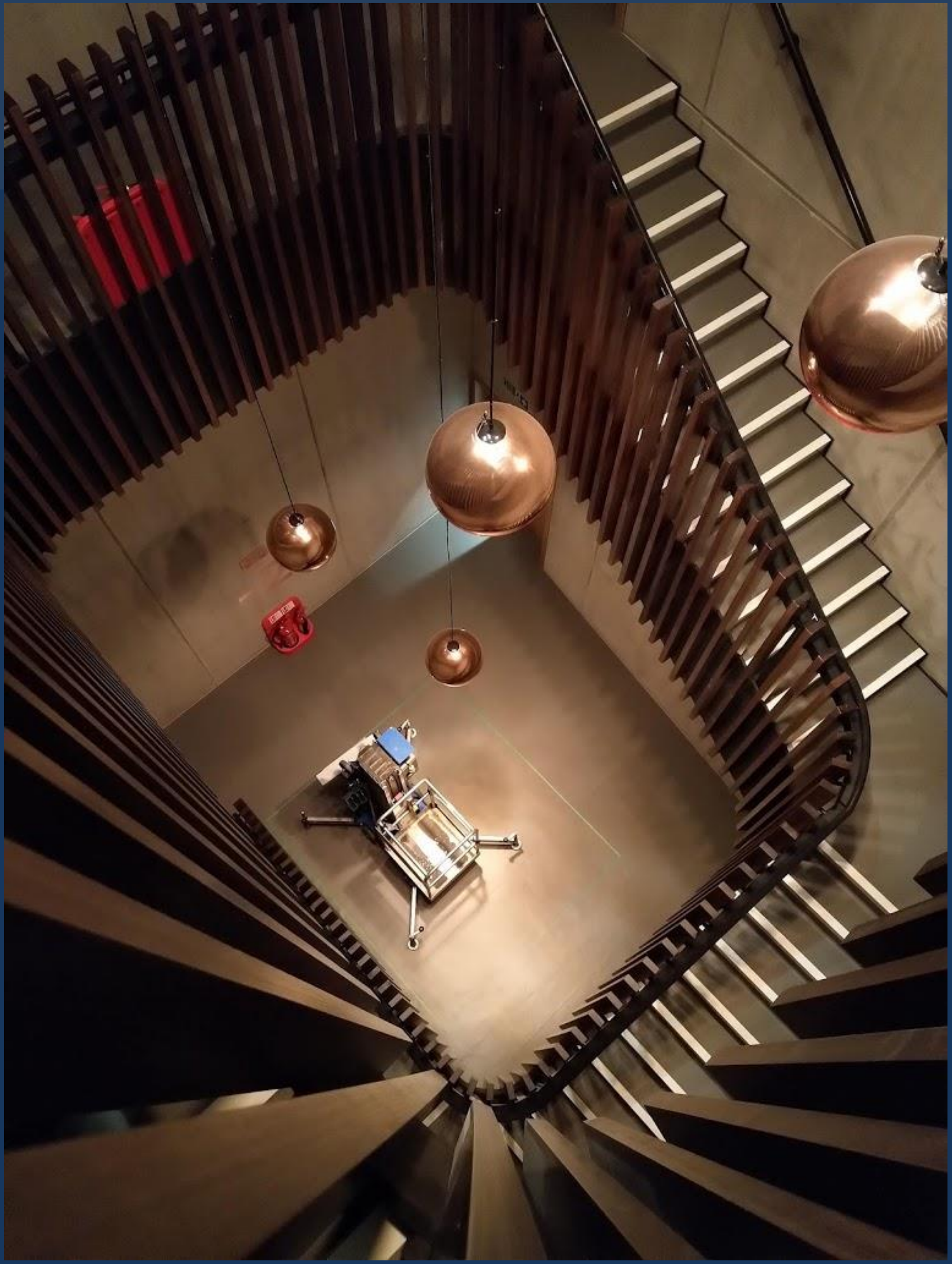
- Build two atom interferometers in a 10m high apparatus

Motivation:

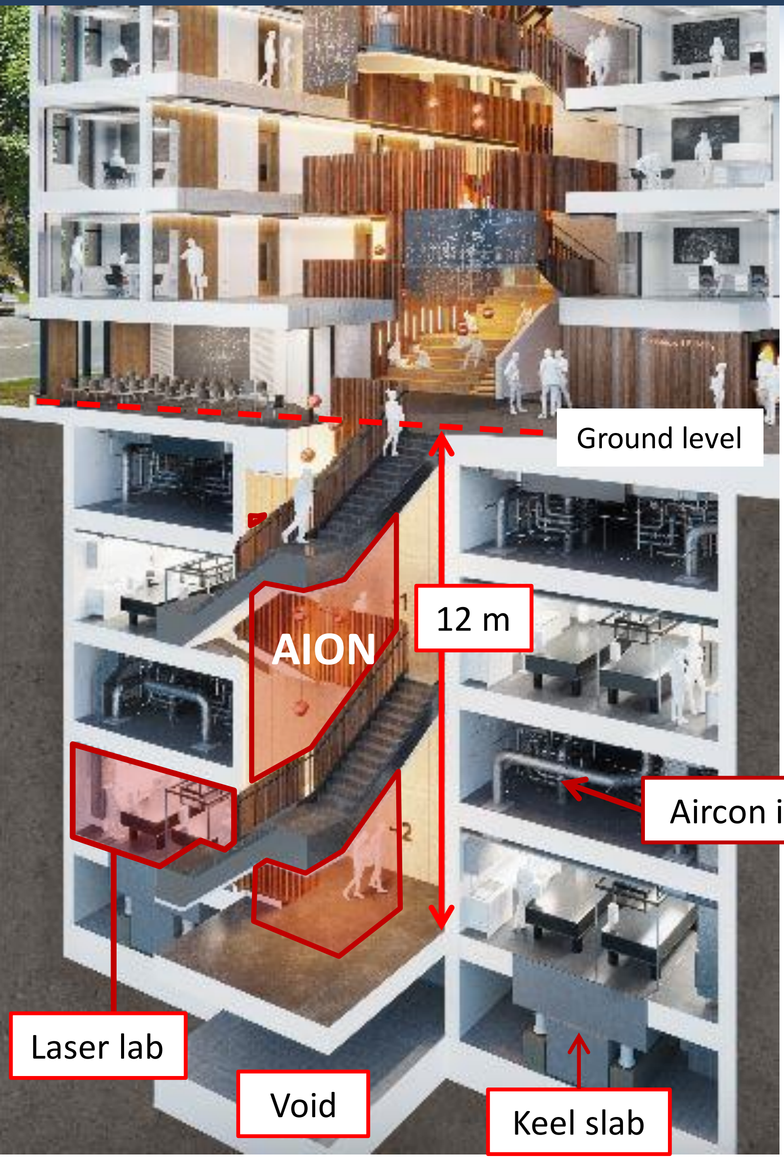
- Prototype for larger scale apparatus
- Tests of fundamental physics

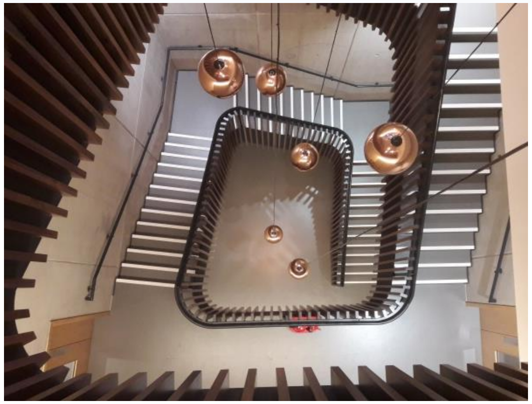
Beecroft building, Oxford Physics

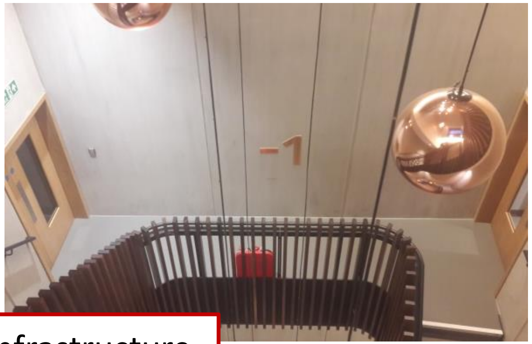
The Beecroft in Oxford is the proposed site, with a backup at RAL (MICE Hall) in case show-stoppers are encountered.

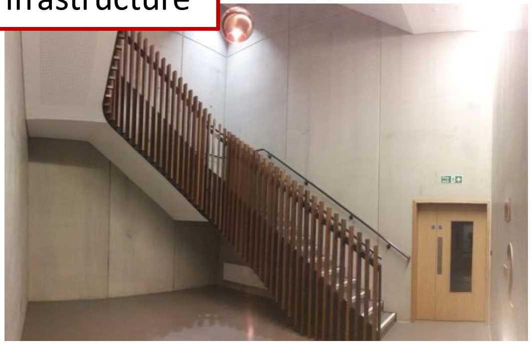


Beecroft building, Oxford Physics









Ultralow vibration
- All plant isolated
- Thick concrete walls

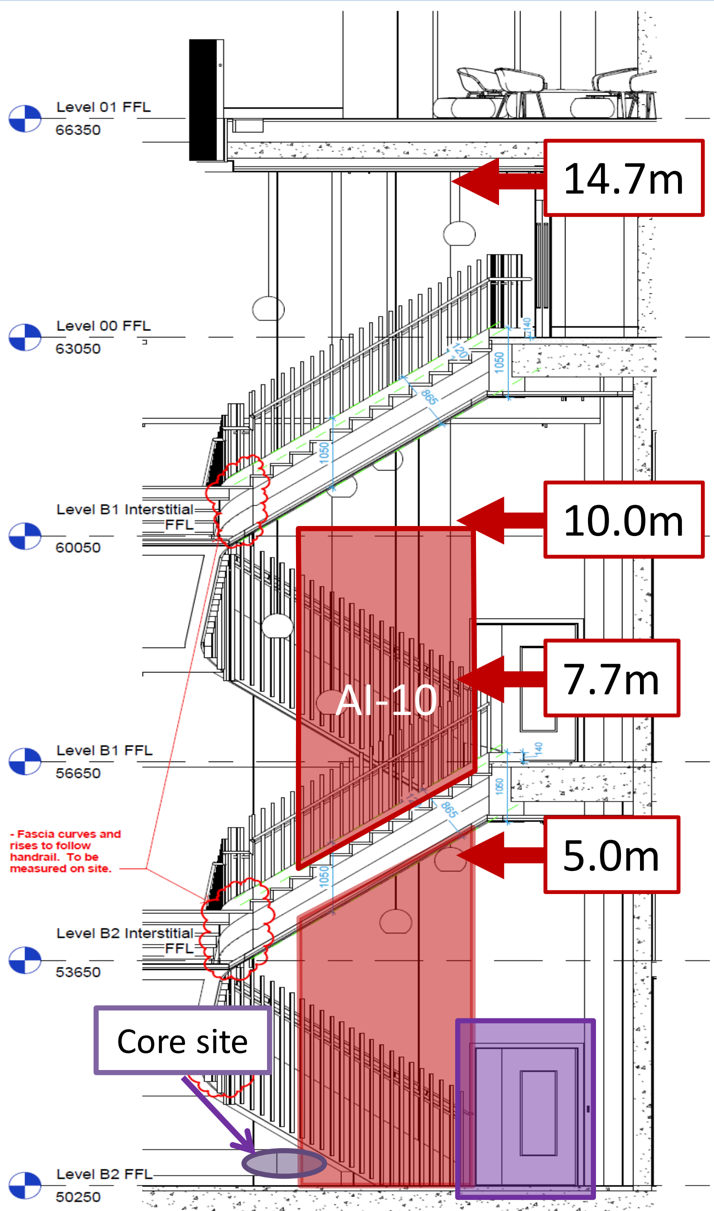
Adjacent laser lab reserved for AION use
- keel slabs
- ±0.1°C stability
- Isolated mains

Vertical space
- 12m basement to ground floor
- 14.7m floor to ceiling

Stairwell is **not** a fire escape route.

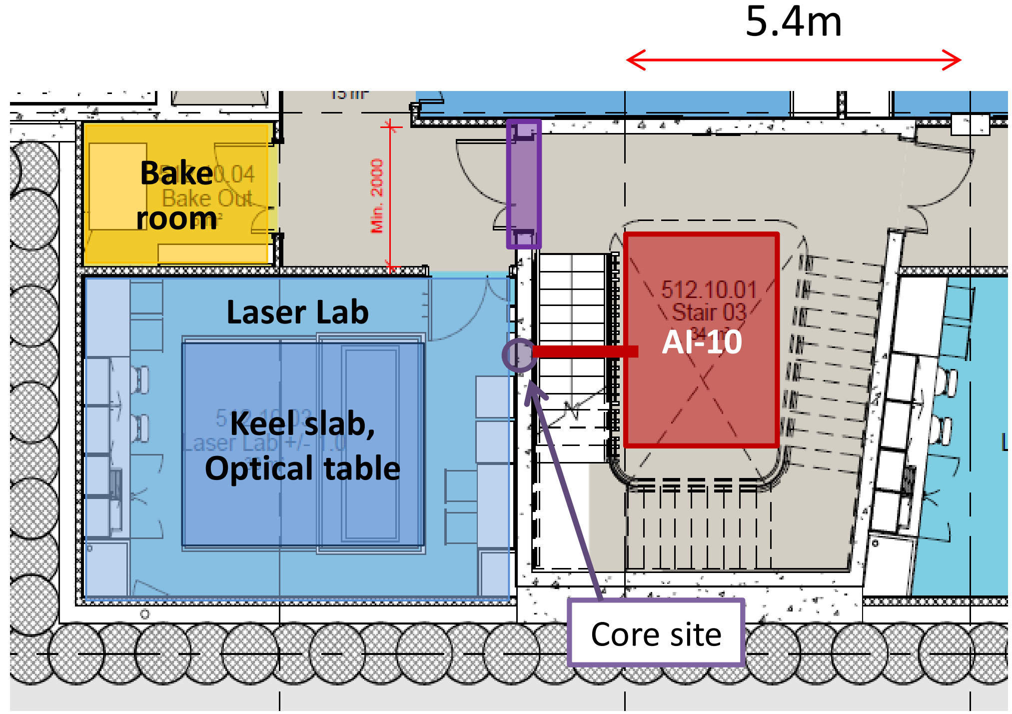
Bakeout room and cleanroom nearby

Beecroft building, Oxford Physics



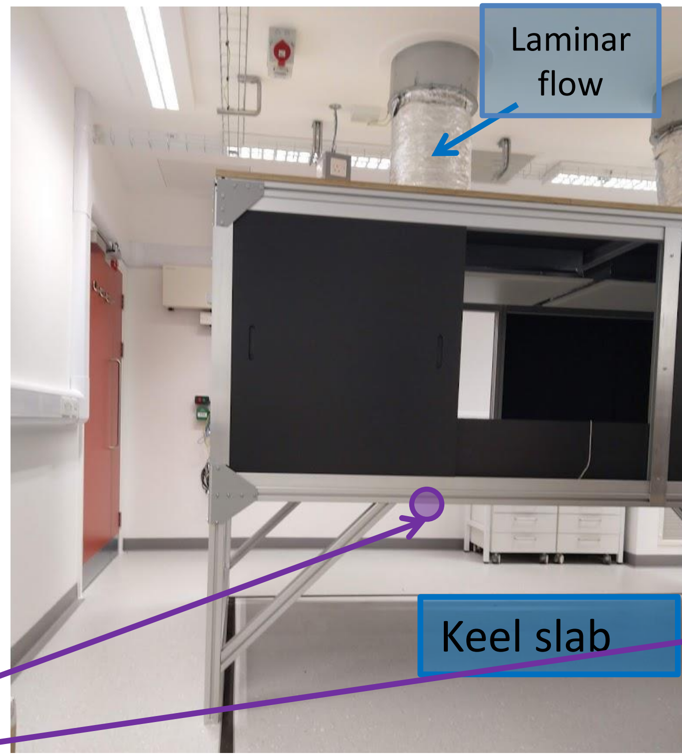
← Side view

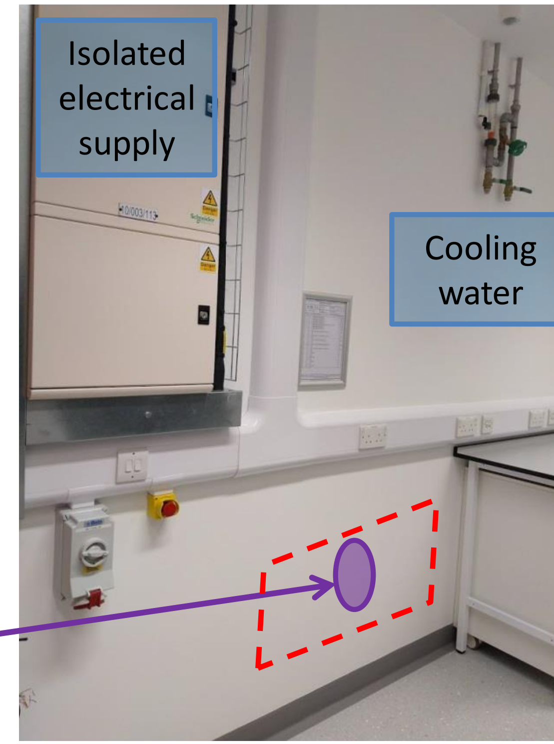
↓ Plan view



Beecroft building laser lab

Beecroft stairwell: lowest level





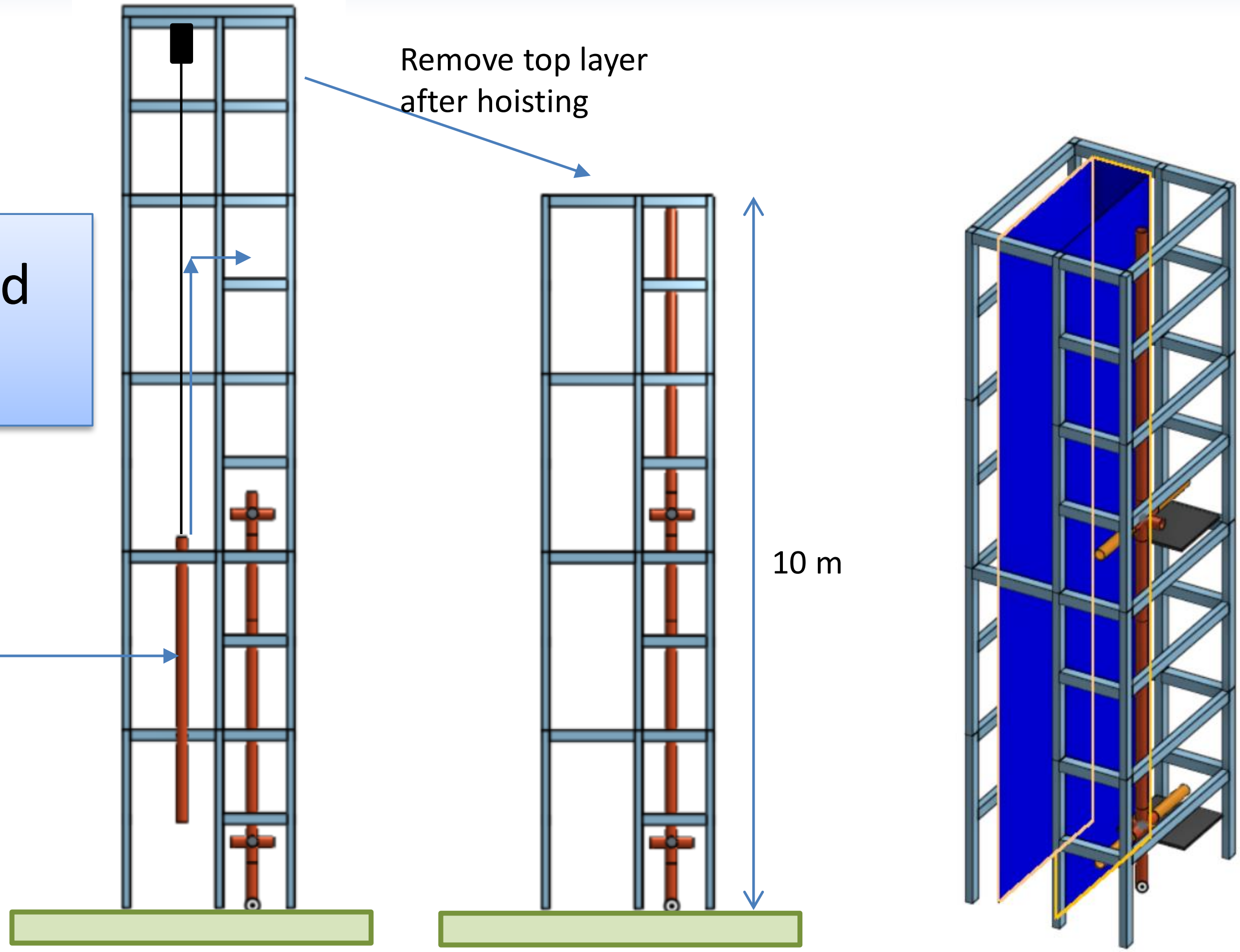
Core site: feed through fibre and cables

laser lab (interior): optical table enclosure with laminar air flow and temperature-control installed.

Bake-out room next door

Assembly: extruded aluminium support structure

Scaffolding erected from ground up.

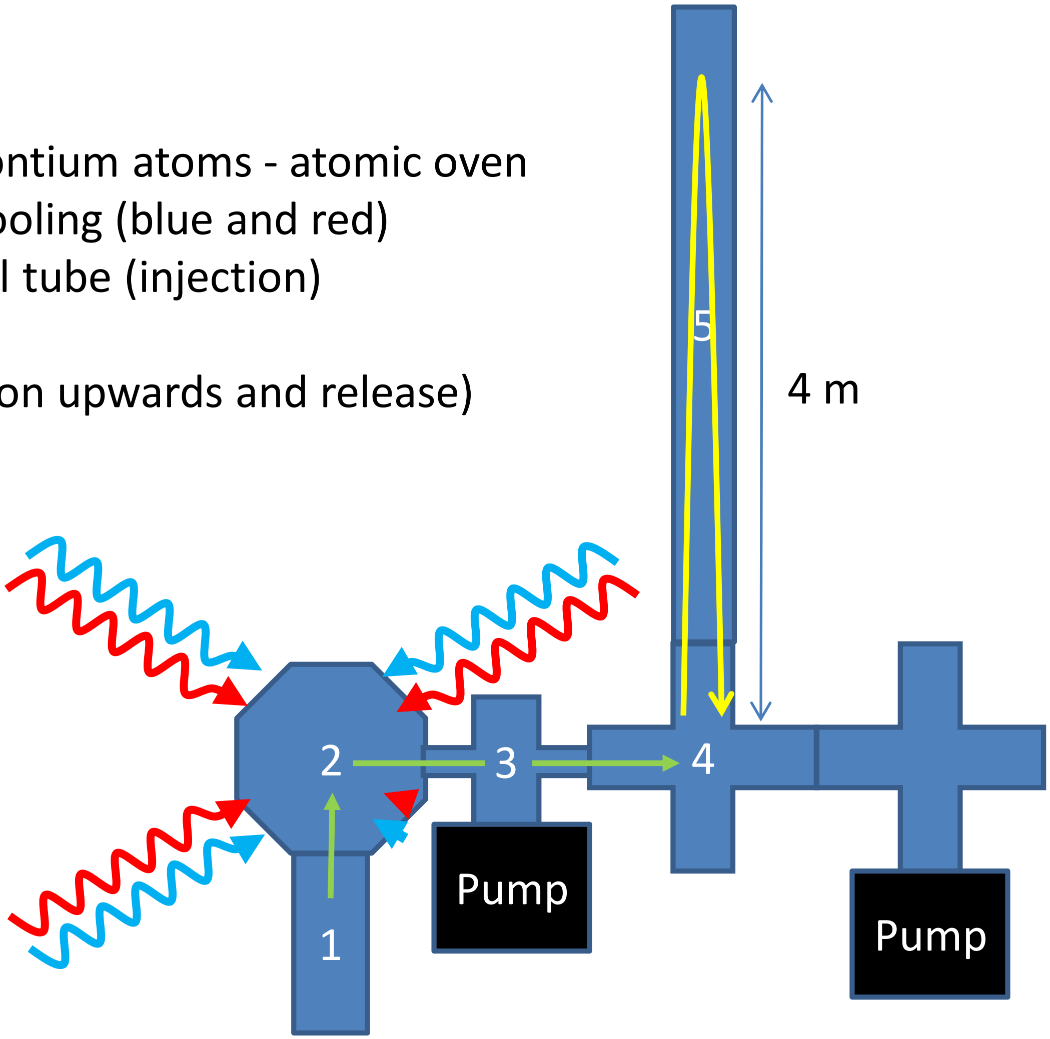


Visit to Stanford, Jan 2019

(Existing Rb fountain, not Sr)

AOIN-10: Breakdown into sub-assemblies

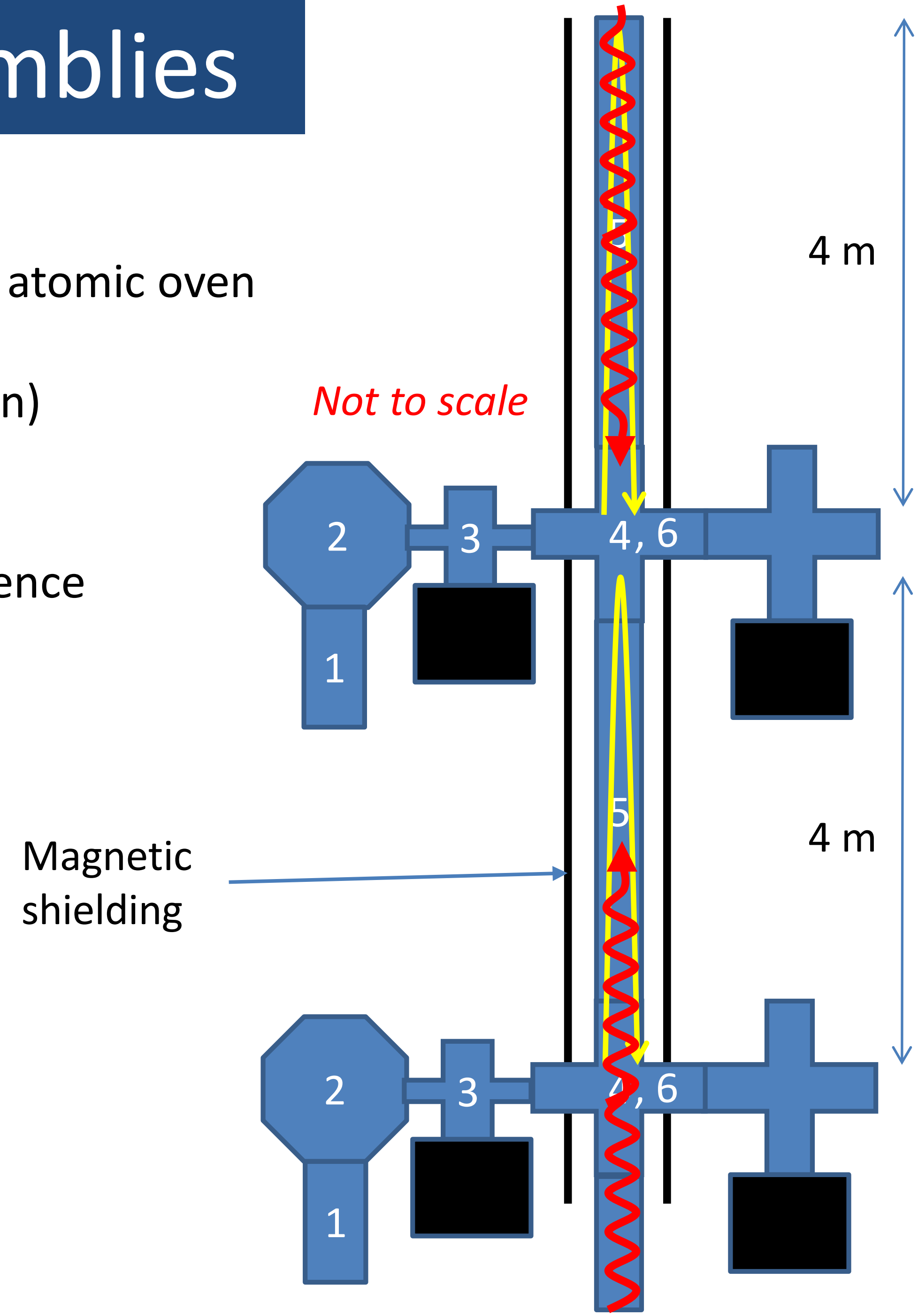
Key stages:
1. Source of neutral strontium atoms - atomic oven
2. Two stages of laser cooling (blue and red)
3. Transport into vertical tube (injection)
    - further cooling
4. Launching (acceleration upwards and release)
5. Time of flight



AOIN-10: sub-assemblies

Key stages:

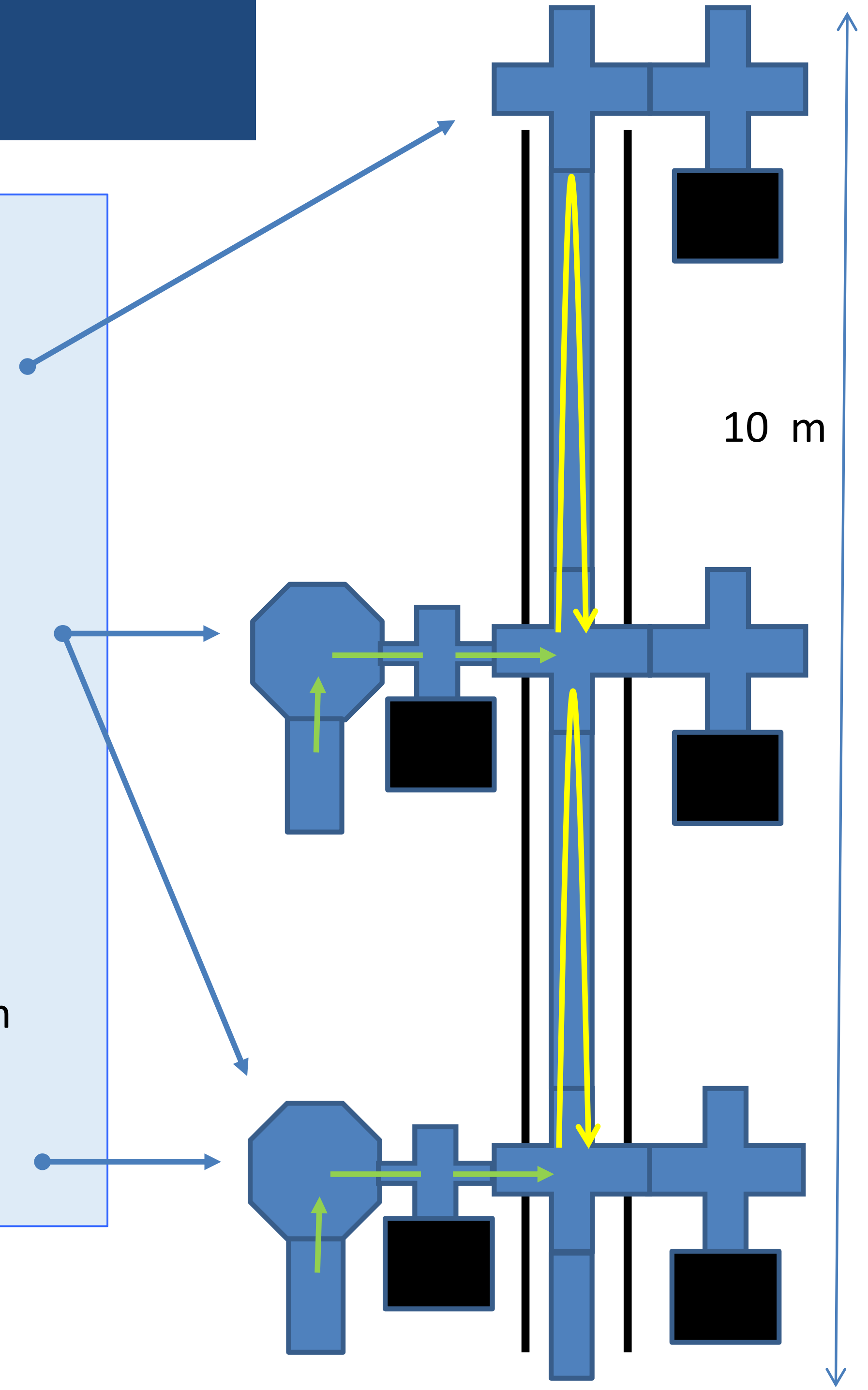
1. Source of neutral strontium atoms - atomic oven
2. Two stages of laser cooling
3. Transport into vertical tube (injection)
   - Further cooling
4. Launching (acceleration)
5. Time of flight - interferometer sequence
6. Detection – CCD camera



AOIN-10: operation

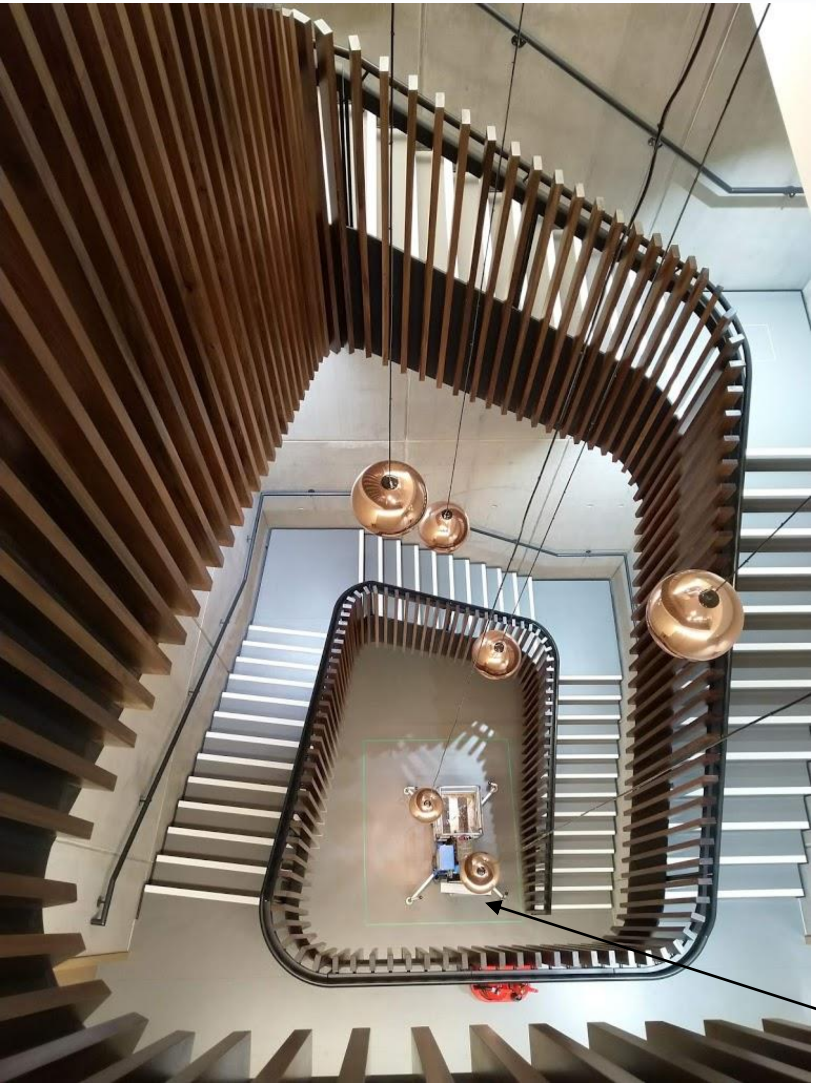
Design requirements (TBC with Stanford):

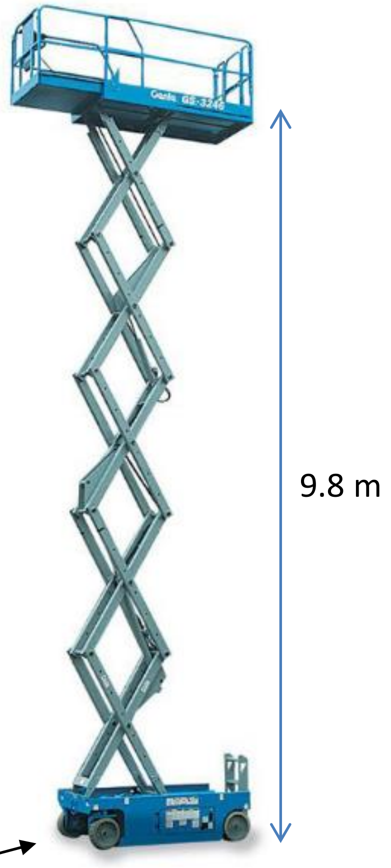
- Infrequent access to top for maintenance. (pumps + piezo adjustable mirrors)
- Easy access to atom sources (halfway and bottom) for laser beam alignment etc.
- Optical fibres, electrical power supplies from bottom (current to four bias coils, vacuum pumps, AOMs, shutters etc), from laser lab

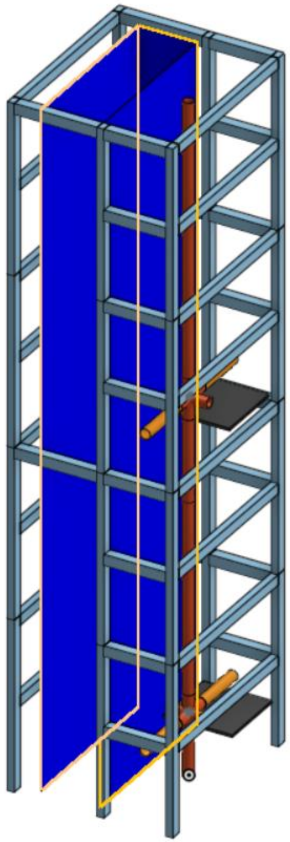


AOIN-10: operation

Scissors lift for access to all heights







Not the same model

Construction of AION-10: Mechanical Engineering budget

1. Support structure, temperature-control and dust-free environment (provided by host site)
2. Vacuum (150 k£)
   - manufacture of long time-of-flight tubes (about 4 m).
   - Other vacuum components: ion pumps and viewports (AR-coated for required wavelengths)
   - assemble and bake out the vacuum system (UHV)
3. Strontium source(s) mounted on a sidearm (not costed – see talk later)
4. Breadboards and enclosures for optics (one mounted halfway up the interferometer) (low cost)
5. Transport rail, or other method, for moving cold atoms horizontally into the vertical tube. (15 k£)
6. Magnetic shielding and bias magnetic field (160 k£)
   - Similar to MAGIS design (to be decided). Demagnetisation after positioning.
7. Laser lab (available in the recently built Beecroft building, Oxford Physics) (*approx. 1000 k£ contribution*)
   - Optical table(s), Clean air system, Laser safety – responsibility of host site.
8. In-vacuum optics (40 k£ estimated)
   - Retro-reflecting mirror fixed to ground at base (cf. the Coriolis compensator in the Rb fountain at Stanford).
   - Steering mirror(s) at the top of the apparatus. Propagation in vacuum ‘cleans’ the laser beam mode (diffract out the higher spatial frequency components).

Total cost = 365 k£ estimated

AION-10: Lasers & optics budget

Abbreviations: Ti:Sa – Titanium-doped sapphire laser e.g. M Squared Lasers
diode – semiconductor diode lasers, e.g. AO Sense Inc., Toptica

1. blue cooling (1st stage) – Ti:Sa or amplified diode laser
2. red cooling (2nd stage) - diode or Ti:Sa
3. clock (narrow bandwidth) – power critical for one-photon interferometry
4. two repumping lasers – diodes for low power
5. dipole trapping lasers – high power at a frequency far off resonance
   - transport by optical tweezers from sidearm into vertical tube
   - optical lattice for launching without heating
   - (Launching squeezed states in future upgrades)
6. Optics: mirrors, polarisers, AOMs, EOMs, shutters, optical fibres etc. (modular system for ease of transport to different locations)
7. Laser frequency stabilisation – reference cavity provided by National Physical Laboratory (NPL), or a frequency comb (not included in budget)

Total cost = 1 380 k£ - not including all contributions in kind

AION-10: Detectors and Electronics

1. Electronics: servo-control for multiple systems for frequency and intensity stabilisation. (NPL/Oxford design)
2. Control system: light pulse timing and shaping, laser cooling and transport sequences. (to be decided)
3. CCD cameras for detection, e.g. Andor in the UK
4. Test & Measurement equipment (mostly contributed)

Total cost = 110 k£ estimated

AION-10: Total Budget (k£)

Mechanical Engineering	365
Lasers and Optics	1380
Electronics	110
Staff: 2 PDRAs (72 months FTE)	600
Staff: 1 Engineer (36 months FTE)	300
TOTAL =	2755

Preliminary: not including all contributions such as lasers

Beecroft site – specifications*

- **Services** installed in the laser lab., to be feed through the wall to the interferometer (distance of 2 m to base).
  - Electrical power, inc. 3-phase if necessary (each lab has isolation transformer).
  - Processed water, e.g. for cooling coils.
  - Temperature controlled, clean air. (This can be feed to improve temp stability of interferometer.)
  - Compressed air e.g. for driving gate valves.
- **Bake-out room** next to laser lab (shared with other UHV users, mainly the ion-trapping group). Computer-controlled bake-out oven suitable for most components of the atom source and chambers (not 4 m lengths).
- Large **goods access lift** nearby, large enough for optical tables, 3.8m tubes and scissors lift.
- Shared access on the stairwell
  - It is **not** a fire escape (although the landings must permit access between E and W corridors)
  - Two other internal staircases are the designated fire escapes. It's likely that users at the N end of the Beecroft building will use the nearby stairs rather than walking to the stairwell which is at the S end. **This makes it straightforward to restrict access (close the staircase) for certain periods**, e.g. during construction. Data taking carried out remotely.
  - The staircase is only for users of the Beecroft labs. No undergraduate teaching in the building.
  - Vibration is negligible in the building by construction. Solid concrete walls. A vibration survey has been carried out by external consultants (world-class facility for STM).
- **Laser safety**: all laser systems to be totally enclosed.
- **Outer cover/casing** over the whole interferometer has multiple purposes:
    - Second layer of laser shielding
    - Dust cover/clean air circulation (assits temperature control)
    - Aesthetics – cables and optical fibres should run up conduits inside the enclosure (no trailing cables).

Contributions in kind from Oxford Physics*

- Beecroft stairwell and adjacent fully-equipped **£1m laser lab**
  - Ultralow vibration environment, temperature control
  - £1m value based on construction cost of Beecroft (£50m for 20 labs).
  - Vacant and reserved for AION use.
- Site **preparation & refurbishment**
  - Beecroft: coring holes through concrete to link laser lab and stairwell. Complete works will take of order weeks.
  - Supporting infrastructure eg. laser safety interlocks.
- Oxford Physics will pay for Mechanical workshop to produce **support structure/frame and an outer covering** of the enclosure (copper, or other material).
- **Equipment:** Optical table, M^2 Ti:Saph laser and 18W Verdi pump laser (purchased through the department equipment fund, cost > 110 k£. Computer control system (to be decided).
- **Studentship** for graduate student to work on project (70 k£)

Oxford Physics*

- A range of technical workshops are available, see eg https://www2.physics.ox.ac.uk/enterprise/services-and-specialist-equipment.
  - Class 100 and 1000 cleanrooms
  - Mechanical workshops.
  - Electrical workshops used for fabrication of CERN LHCb detectors.
- Full-time laser safety officer, who has been consulted, and in-house equipment (interlocks etc.) installed by maintenance team as required.
- A **frequency comb** for measuring and stabilising laser frequencies, purchased by the NQIT quantum hub, will be located in the Beecroft (lower basement). The use of such a comb is under consideration by Jason Hogan at Stanford.
- Large number of academics in the QSFP program, both theorists and experimentalists. Mutually supportive local community. Expect to hire several academics in the QSFP program in the next 3 years.
- Strong possibility of additional private funding. For example, the Beecroft received £13.8m in private funding.
- Host to many visiting scientists (offices).
- Many meeting rooms/discussion spaces in Beecroft.
- Good transport links and accommodation
- Working on the site out-of-hours is straightforward and lone-working is permitted for certain tasks.