Secondary Beams

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Rutherford Appleton Laboratory
Secondary Beams

- Electron beam
- Vacuum arc
- Microwave discharge
- Laser plasma
- Electron Cyclotron Resonance
- Fully stripped nuclei (e.g. U^{92+})
- Light ions (e.g. C^{4+})
- Exotic nuclei (e.g. Lr^{103+})
- Neutrons ($n$)
- Antiprotons
- Antineutrinos ($\bar{\nu}$)
- Positrons ($e^+$)
- Electrons ($e^-$)
- Protons ($H^+$)
- Neutral atoms ($H^0$)
- Positrons ($e^+$)
- Electrons ($e^-$)
- Penning and Magnetron
- Multicusp
- Surface plasma
- Volume
- Tuned lasers + Gas cells
- Photons
- Neutrons
- Higgs Bosons
- Tauons
- Mesons
- Baryons
- Microwave discharge
- Electron Cyclotron Resonance
- Exotic nuclei
- Plasma + other
- Thermo
- Surface plasma
- Volume
- Electron
- Cyclotron
- Resonance
- Electron beam
- Tuned lasers + Gas cells
- Polarised particles
- Penning and RF
- Multicusp
- Surface plasma
- Volume
- Tuned lasers + Gas cells
- Photons
- Neutrons
- Higgs Bosons
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A world leading centre for condensed matter physics-

Neutrons are used to see where atoms are and what atoms do
ISIS is used to study everything!

- Green chemistry
- Fundamental magnetism
- Medical applications
- Superconductors
- Cultural heritage
- Bio-sensors
- Materials for clean energy
- Biological structures
- Mechanical Engineering
- Natural world
- Pollution, energy and the environment
ISIS - making neutron and muon beams since 1984

Spallation neutron source
800 MeV 50 Hz proton beam
31 neutron instruments
7 muon instruments
2000 users/yr
~800 experiments/yr
~500 publications/yr
ISIS - making neutron and muon beams since 1984

- 800 MeV 50 Hz proton synchrotron
- 70 MeV Hminus LINAC
- 10 Hz neutrons
- 40 Hz neutrons
- 40 Hz muons
- TS1
- TS2
ISIS has many different types of neutron and muon instruments:

- 20 neutron instruments
- 7 muon instruments
- 11 neutron instruments (room for more)
... some are very big
...some are smaller and movable

OFFSPEC Reflectometer
Each instrument is unique and complex...

HRPD Diffractometer
MARI Spectrometer
**General**
- Cold LH$_2$/S-CH$_4$ moderator
- Flux maximum at $\lambda \sim 3$ Å
- Flight path 56 m

**Imaging parameters**
- L/D values: 250 – 1000
- Max. field of view: 20x20 cm$^2$
- Best spatial resolution: 50 μm
- Energy resolution: $\Delta\lambda/\lambda < 0.8$

**Diffraction parameters**
- Flux: $\sim 2 \cdot 10^7$ neutrons/cm$^2$/s
- Diffraction resolution: $\Delta d/d = 0.7\%$ at 90 degrees
- Detector coverage: 4 sr
Target Station 1
Basic Layout of ISIS Target Stations

Neutron Instruments

Remote Handling Cell

Target Services Area

Neutron Instruments

Proton Beam
The Spallation Process

Intranuclear cascade

800 MeV proton

Target nucleus
Tungsten

“Evaporation”

To the moderators and the reflectors

20,000 million million neutrons per second!
Section view of ISIS TS1 target

Tungsten Block
Tantalum Cladding
Target Plates
Thermocouples
Water manifolds
Proton Beam
Pressure Vessel
Manifold

160 kW
ISIS target and bottom moderator and reflector assembly (top reflector assembly removed)

800 MeV protons

slow neutrons
Target Reflector And Moderators (TRAM)
ISIS TS1 target and moderators with reflector assembly removed

**Water moderators**
heat load 380 W
25 litres/min 30°C demin water
Moderator depth defined by Al clad Gadolinium poisoning layer

**Cryogenic moderators**
- **Decoupled liquid CH\(_4\) moderator**
  110 K methane @ 3 Bar
  heat load 200 W
- **Coupled liquid H\(_2\) moderator**
  heat load 200 W
  20 K hydrogen @ 8 Bar
ISIS Target Station 2 TRAM with the edge cooled beryllium reflector open in maintenance mode
TS2 Cryogenic Moderators

coupled moderator: liquid H$_2$ @ 20 K 4 Bar

decoupled moderator: solid CH$_4$ @ 45 K
Choppers - spinning shielding

Precise timing

Magnetically levitating bearings

Slotted shielding
## Choppers - spinning shielding

<table>
<thead>
<tr>
<th></th>
<th>Disk (56)</th>
<th>T-Zero (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fermi (17)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Payload</td>
<td>30 kg</td>
<td>68 kg</td>
</tr>
<tr>
<td>RPM</td>
<td>20,000</td>
<td>10,800</td>
</tr>
<tr>
<td>Phase Control</td>
<td>±0.05°</td>
<td>±0.43°</td>
</tr>
</tbody>
</table>
Shielding

Shutters allow each instrument to be isolated individually.

2 m steel + 2 m concrete

Neutron Instruments

Remote Handling Cell

Target Services Area
The services trolley moves to position the TRAM for operation or maintenance.
TS1 Services Trolley Cooling Plant
TS2 Services Trolley Cooling Plant
The main remote handling task carried out is CH4 moderator replacement
Every 3-4 cycles
Targets also need to be replaced every 4-5 years

TS1 Tungsten
Target #4 on flow test rig
remote manipulator set in TS1
remote manipulator set in TS2
remote manipulator sets on both sides of the remote handling cell
Crews in contact with other areas by headset
View through 1 m thick lead glass window into the empty remote handling cell
window failure!
Active components are removed using the tunnel system under the RHC
View of the TS1 TRAM withdrawn into the RHC

This view is from the north side of the RHC

The reflector top section is rolled forward to expose the Tungsten Target
The target has been disconnected and is being lifted away from its working position.
The target being lifted over to the disposal can on the south side of the RHC
Target and can being lowered into the transport flask
Shield plug is lowered onto flask. After the plug is fitted personnel can approach the loaded flask.
The loaded flask is checked by ISIS Health Physics for external radiation and contamination.
Storage flask total weight is 9 Tonnes

Flask is moved on ‘MasterMover’ powered pallet truck
The loaded flask is lifted out of the tunnel
The loaded flask is transported back to R40 for storage
After work in the RHC is complete the area must be cleared and checked

Personnel can enter the RHC when the TRAM is in the forward position

Full suit, gloves, overshoes and respirator are required for this work
For final disposal the target is transferred to a registered and licenced Type B package and transported to Sellafield the UK’s nuclear waste storage facility
More power!

- ISIS 160 kW on target
- More power = more neutrons
- The power must be removed somehow
- SNS Oakridge USA = 1.4 MW
1.4 MW liquid mercury target
Cavitation bubble collapse causes serious damage.

solution: fizzy mercury with helium
ESS currently under construction!

3 MW on target!
A rotating wheel of ISIS targets!

2.6 m diameter stainless steel disk containing tungsten bricks 5000 kg helium cooled 23.3 rpm

A solution for SNS TS2

protons
Even more power!

Tungsten powder handling system developed at RAL

Tests at CERN

10-100 MW!
Muons at ISIS

EC muon facility:
- +ve muons
- Three spectrometers for materials studies

RIKEN-RAL muon facility:
- +ve or –ve muons
- Variable momentum
- Two spectrometers for materials studies
- Low energy muon development
- Other fundamental muon physics experiments

7 muon instruments
ISIS Muon Target

10 mm thick graphite target at 45° to the 800 MeV proton beam

About 5% beam lost.

Diffusion bonded to copper to maximise thermal contact

10 kW maximum heat load
The EC Muon Facility

- Proton collisions produce pions
- Some pions stop in the target
- They decay to muons, which escape if formed near the target surface
- Quadrupole magnets collect muons into the beam line
Radiation Levels

Radiation Hard Magnets
Radiation Hard Magnet Design

- In house concrete magnet design
- Coils Potted in concrete
- Water Cooled
Muon Ionisation Cooling Experiment
Mice demonstrated muon cooling in 1D.
CERN Neutrinos to Gran Sasso (CNGS)

732 km
Magnetic Horn

Simon van der Meer

1960s "current sheet lens" originally for neutrino beams then for antiprotons

1.4 mm Al 400 kA 15 µs (half-sine)
Magnetic Horn

![Diagram of Magnetic Horn with measurements and labels.]

- Magnetic Horn
- Measurements: 30 - 30 - 300 - 0 - 200 - 100
- Vector lHorn
- Axes: mm (horizontal) and mm (vertical)
Beam Separation

Target

Separator
Beam Separation

Prompt dose rate

concrete

beam dump

concrete

hematite

building 50

soil

FAIR — Facility for Antiproton and Ion Research in Europe
Shielding Required
Particles and Sources

- **Light ions**: e.g. C⁴⁺
- **Fully stripped nuclei**: e.g. U⁹²⁺
- **Highly charged ions**: e.g. Ag³²⁺
- **Negative ions**: H⁻
- **Neutral atoms**: H⁰
- **Electrons**: e⁻
- **Positrons**: e⁺
- **Protons**: H⁺
- **Neutral atoms**: H⁰
- **Electrons**: e⁻
- **Positrons**: e⁺
- **Polarised particles**: μ⁻, μ⁺
- **Antiprotons**: p⁻
- **Neutrons**: n
- **Muons**: μ⁻, μ⁺
- **Photons**: γ
- **Zoo of curiosities**: τ⁻, τ⁺, νₑ, ν_μ, ν_τ
- **Higgs Bosons**: H
- **Baryons**: ν
- **Thermo Plasma**: + other
- **Surface plasma**: Surface converter
- **Volume**: Volume
- **Microwave discharge**: Microwave discharge
- **Laser plasma**: Laser plasma
- **Vacuum arc**: Vacuum arc
- **Plasmatrons**: Plasmatrons
- **Microwave discharge**: Microwave discharge
- **Vacuum arc**: Vacuum arc
- **Laser plasma**: Laser plasma
- **Electron Cyclotron Resonance**: Electron Cyclotron Resonance
- **Penning and Magnetron**: Penning and Magnetron
- **Multicusp**: Multicusp
- **Filament and RF**: Filament and RF
- **Surface plasma**: Surface plasma
- **Surface converter**: Surface converter
- **Volume**: Volume
- **Tuned lasers + Gas cells**: Tuned lasers + Gas cells
- **Polarised particles**: Polarised particles
- **Exotic nuclei**: e.g. Lr¹⁰³⁺
- **Tuned lasers + Gas cells**: Tuned lasers + Gas cells
- **Accelerator Facilities**: Accelerator Facilities
Radioactive Ion Beams
A powerful way of studying the atomic nucleus
ISOL vs In Flight Fragmentation

Isotope Separation On Line (ISOL): A production line

\[ A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow F \]

Very complicated chains of acceleration and separation have been created.

In Flight Fragmentation:
Filtering an explosion
ISOL: common components

ISOL produces very pure beams with "long" half life
ISOLDE source

connections for resistive heating

quartz tube

transfer tube

Ta tube with target material

primary beam
In Flight Fragmentation: common components

- **Primary beam**
- **Thin target**
- **Production**
- **q/m Selection**
- **Dipole magnets**
- **Apertures and collimation**
- **Wedge shape degrader**
- **Progressively higher resolution**
- **Fragment separator:**
  - RFQ, LINAC, cyclotron, synchrotron
- **Variable degrader**

Degrader: $dE/dx$ depends on projectile’s $Z$.

In flight fragmentation suitable for very short half life beams
Facility for Rare Isotope Beams
at Michigan State University
Particles and Sources

- Positrons \( e^+ \)
- Electrons \( e^- \)
- Plasma + other
- Antiprotons
- Photons
- Neutrinos: \( \nu_e \), \( \nu_\mu \), \( \nu_\tau \)
- Neutrons \( n \)
- Protons \( H^+ \)
- Neutral atoms \( H^0 \)
- Neutrinos \( \bar{\nu}_e \), \( \bar{\nu}_\mu \), \( \bar{\nu}_\tau \)
- Light ions e.g. \( C^{4+} \)
- Fully stripped nuclei e.g. \( U^{92+} \)
- Highly charged ions e.g. \( Ag^{32+} \)
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  - Mesons
  - Baryons
Future Colliders

Compact Linear Collider

The Next Linear Collider

International Linear Collider

Future Circular Collider
Higgs Factory

- China Electron Positron Collider (CEPC)
- 100 km underground circular tunnel
- 240 GeV
- $6bn
- More than million Higgs bosons in 7 years
- $6000 per Higgs and one Higgs every 3 mins!
Summary

• Secondary beams are incredibly fascinating
• The work they do moves forward our understanding of the universe
• They are at the extreme limit of our:
  Knowledge of physics
  Engineering capability
  Financial and Political ability

• We have only scratched the surface
Thank you for listening
Questions?