Secondary Beams

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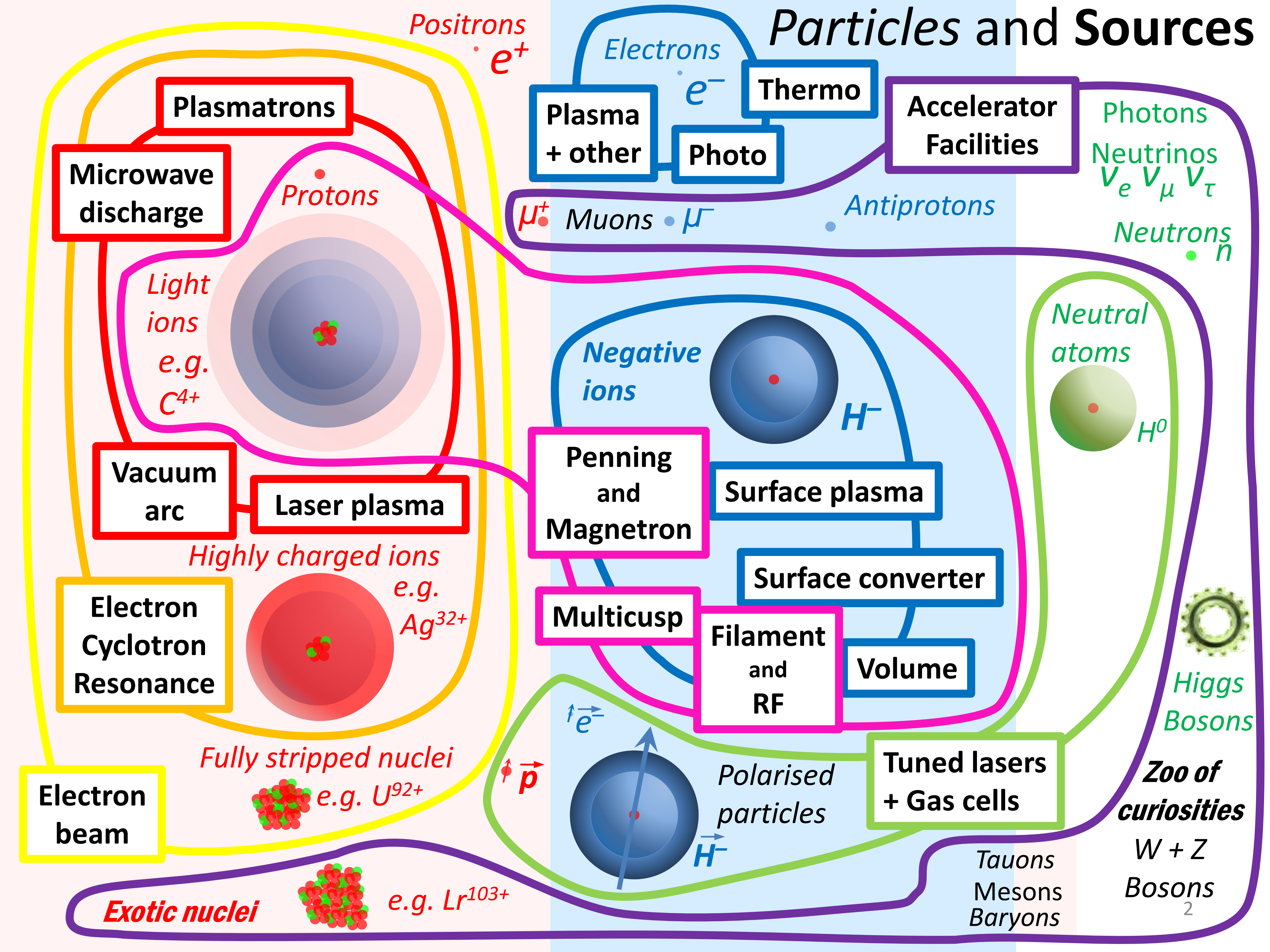
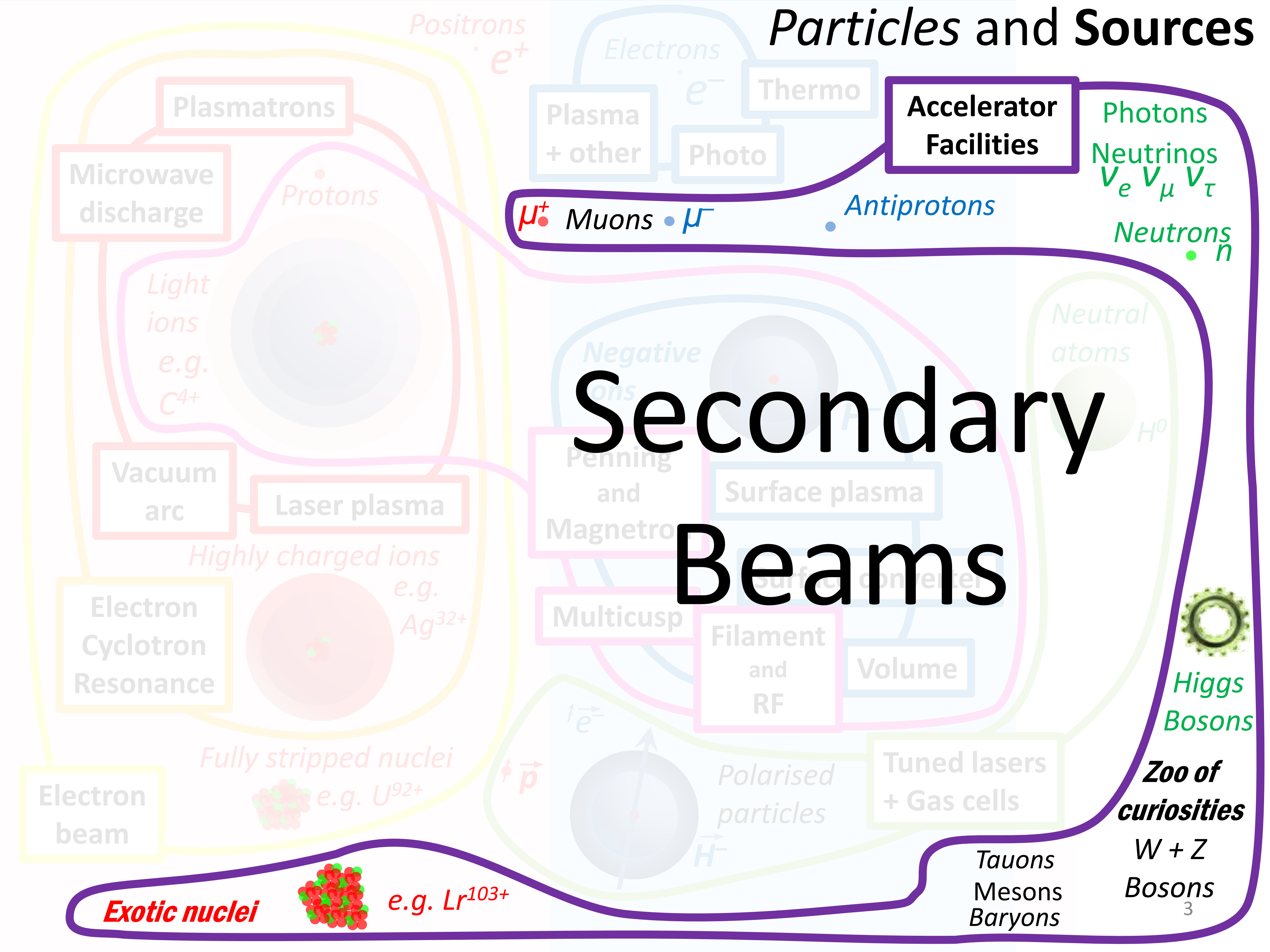
Rutherford Appleton Laboratory

CERN Accelerator School, Introduction to Accelerator Physics
Vysoke-Tatry, Slovakia
Saturday 14th September 2019

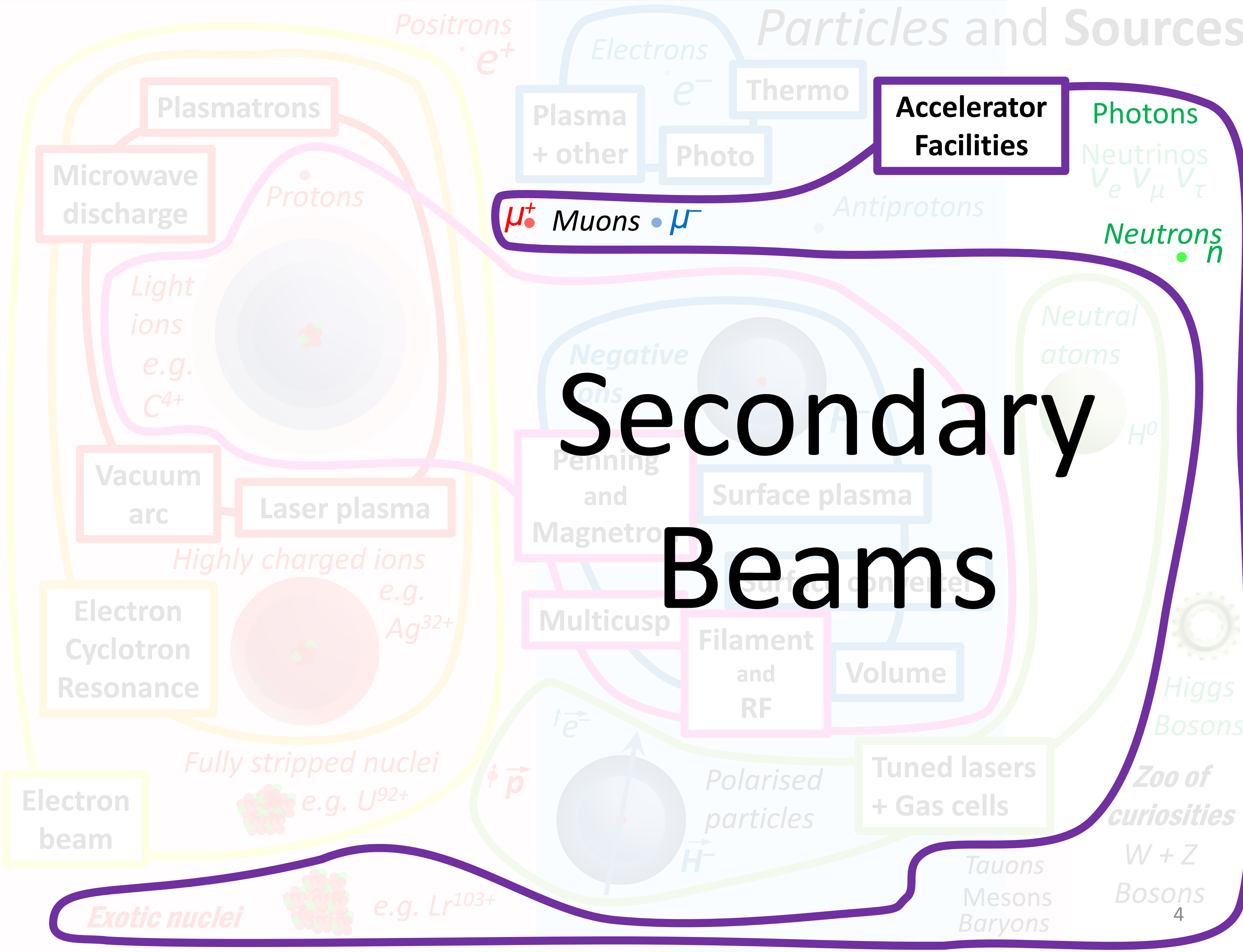
Particles and **Sources**





Particles and Sources
Secondary Beams
Accelerator Facilities
Photons
Neutrinos
ν_e ν_μ ν_τ
Neutrons
n
μ^+ Muons μ^-
Antiprotons
Higgs Bosons
Zoo of curiosities
W + Z Bosons
Tauons
Mesons
Baryons
Exotic nuclei
e.g. Lr^{103+}
Positrons
e^+
Electrons
e^-
Thermo
Plasma + other
Photo
Plasmatrons
Microwave discharge
Protons
Light ions e.g. C^{4+}
Vacuum arc
Laser plasma
Highly charged ions
e.g. Ag^{32+}
Electron Cyclotron Resonance
Fully stripped nuclei
e.g. U^{92+}
Electron beam
Negative ions
Penning and Magnetron
Surface plasma
Multicusp
Filament and RF
Volume
Neutral atoms
H^0
Polarised particles
Tuned lasers + Gas cells

Particles and Sources



Rutherford Appleton Laboratory
Oxfordshire, UK

Harwell Campus

Diamond Light Source-

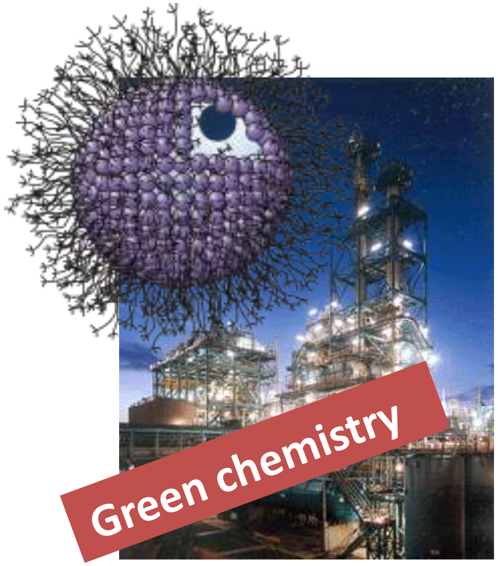
Secondary Beams?

ISIS Neutron and Muon Source

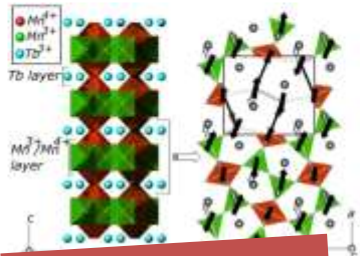
A world leading centre for condensed matter physics-

Neutrons are used to see where atoms are and what atoms do

ISIS is used to study everything!

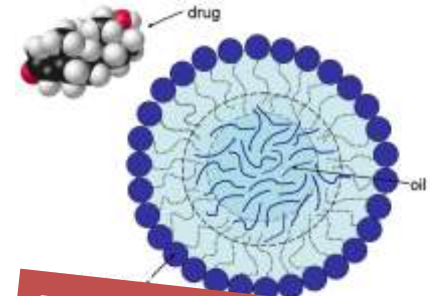


Green chemistry



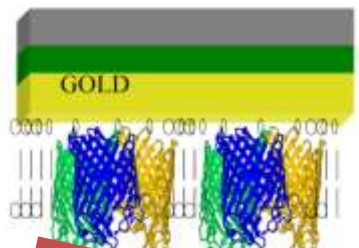
Fundamental magnetism

Superconductors

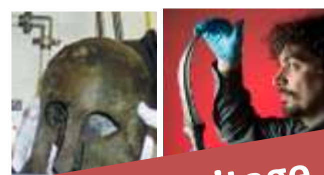


Medical applications

Biological structures



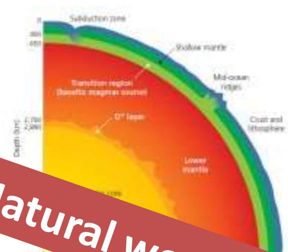
Bio-sensors



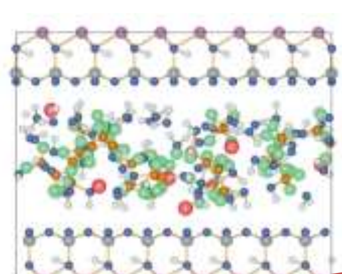
Cultural heritage

Materials for clean energy

Mechanical Engineering

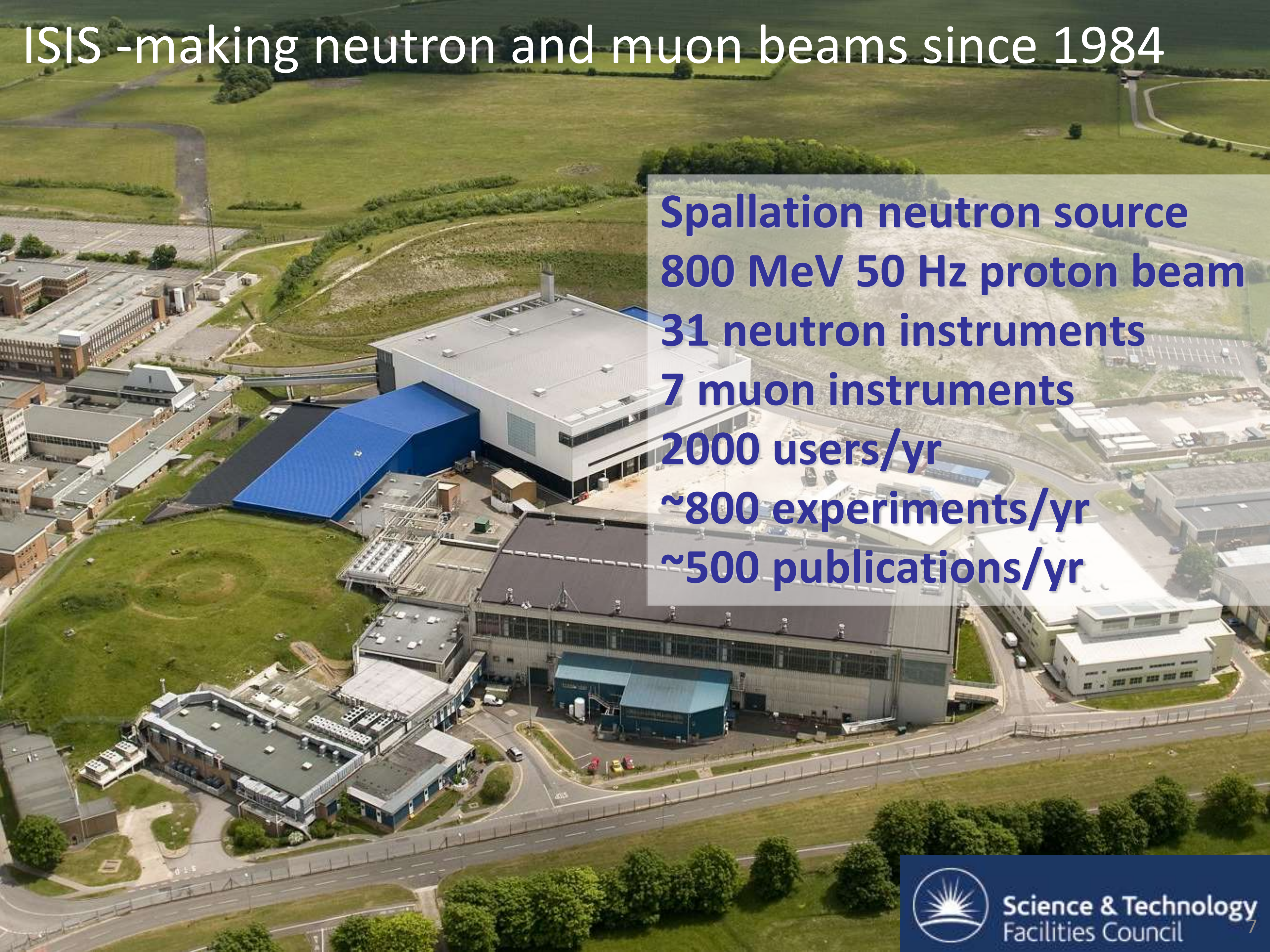


Natural world



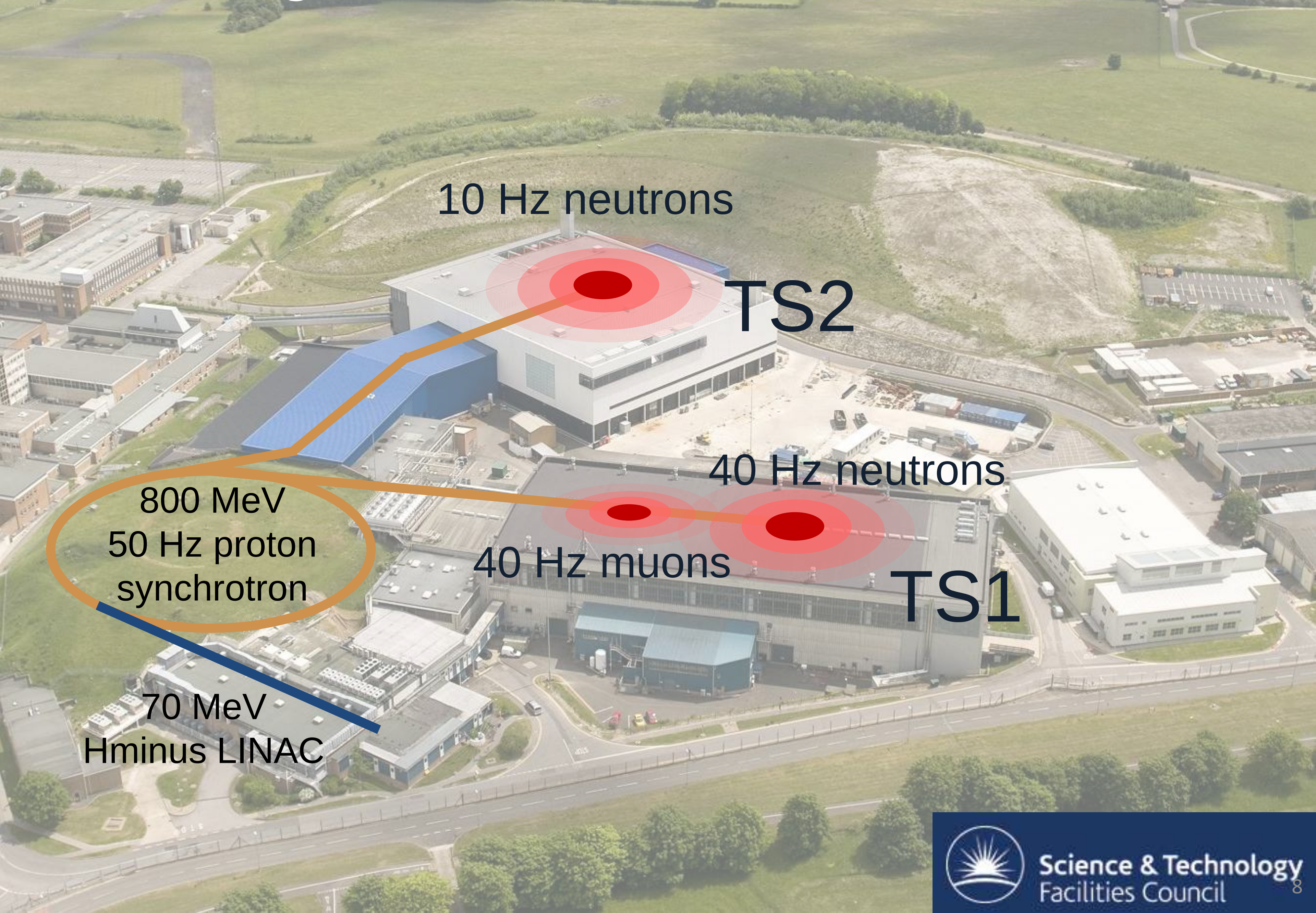
Pollution, energy and the environment

ISIS -making neutron and muon beams since 1984



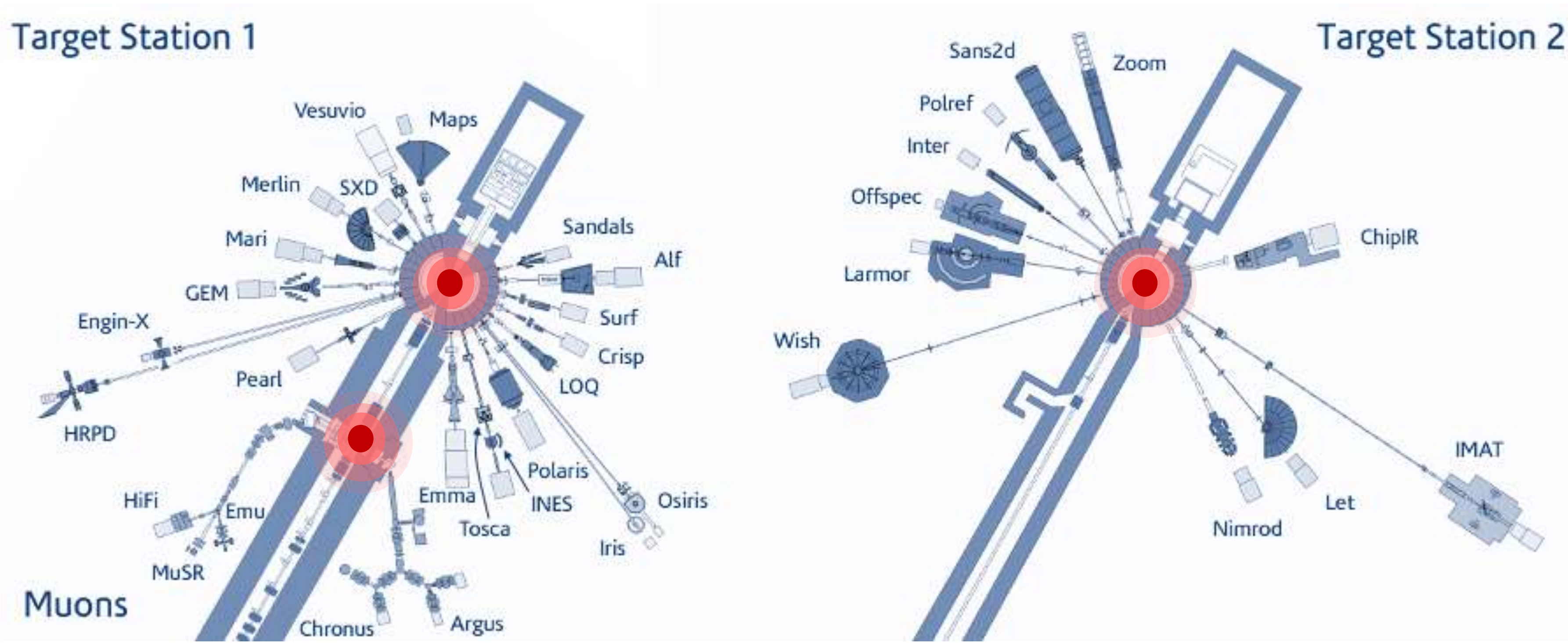
Spallation neutron source
800 MeV 50 Hz proton beam
31 neutron instruments
7 muon instruments
2000 users/yr
~800 experiments/yr
~500 publications/yr

ISIS -making neutron and muon beams since 1984



Science & Technology Facilities Council

ISIS has many different types of neutron and muon instruments:



20 neutron instruments
7 muon instruments

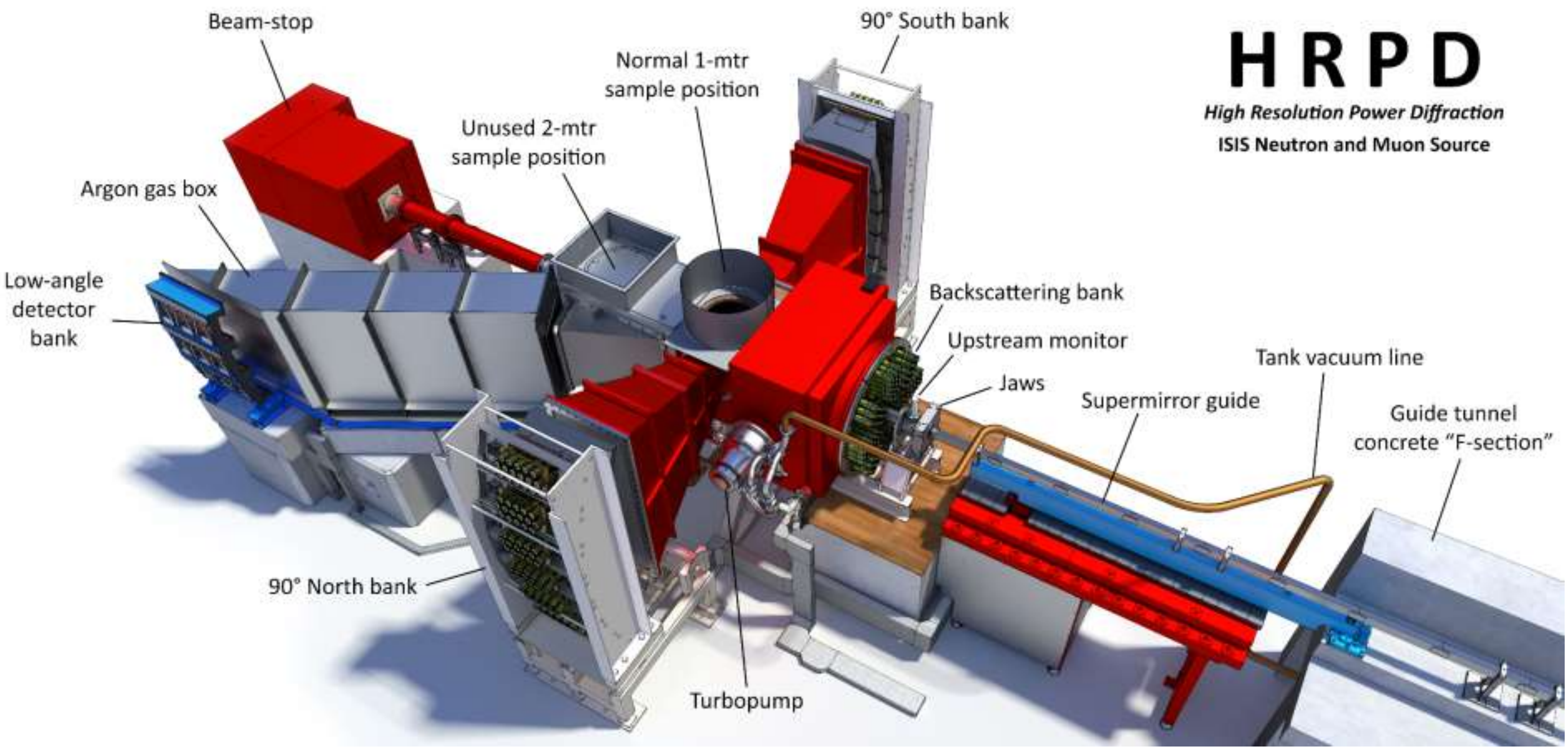
11 neutron instruments
(room for more)

LET Spectrometer

… some are very big

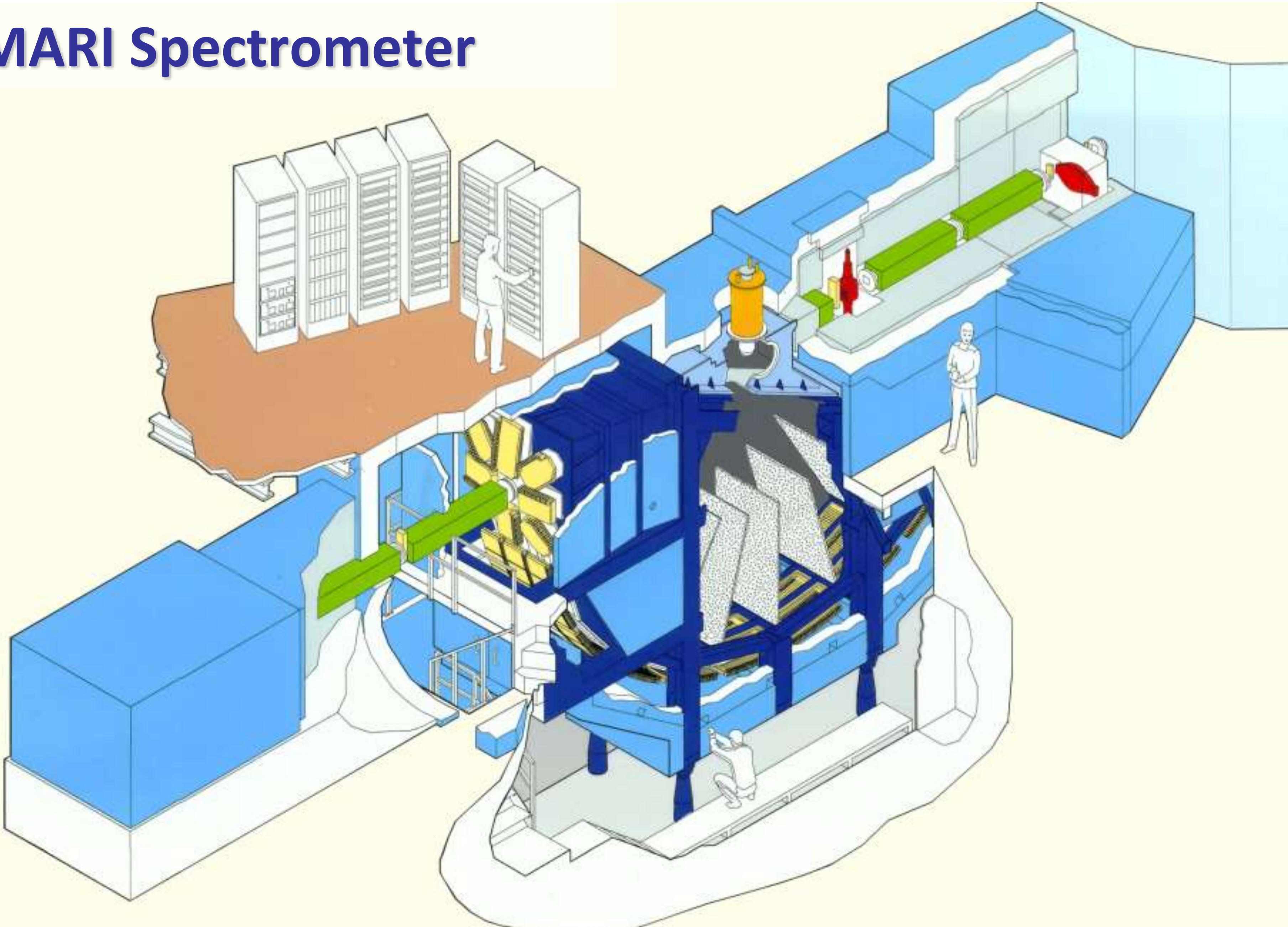
…some are smaller and movable

Each instrument is unique and complex…

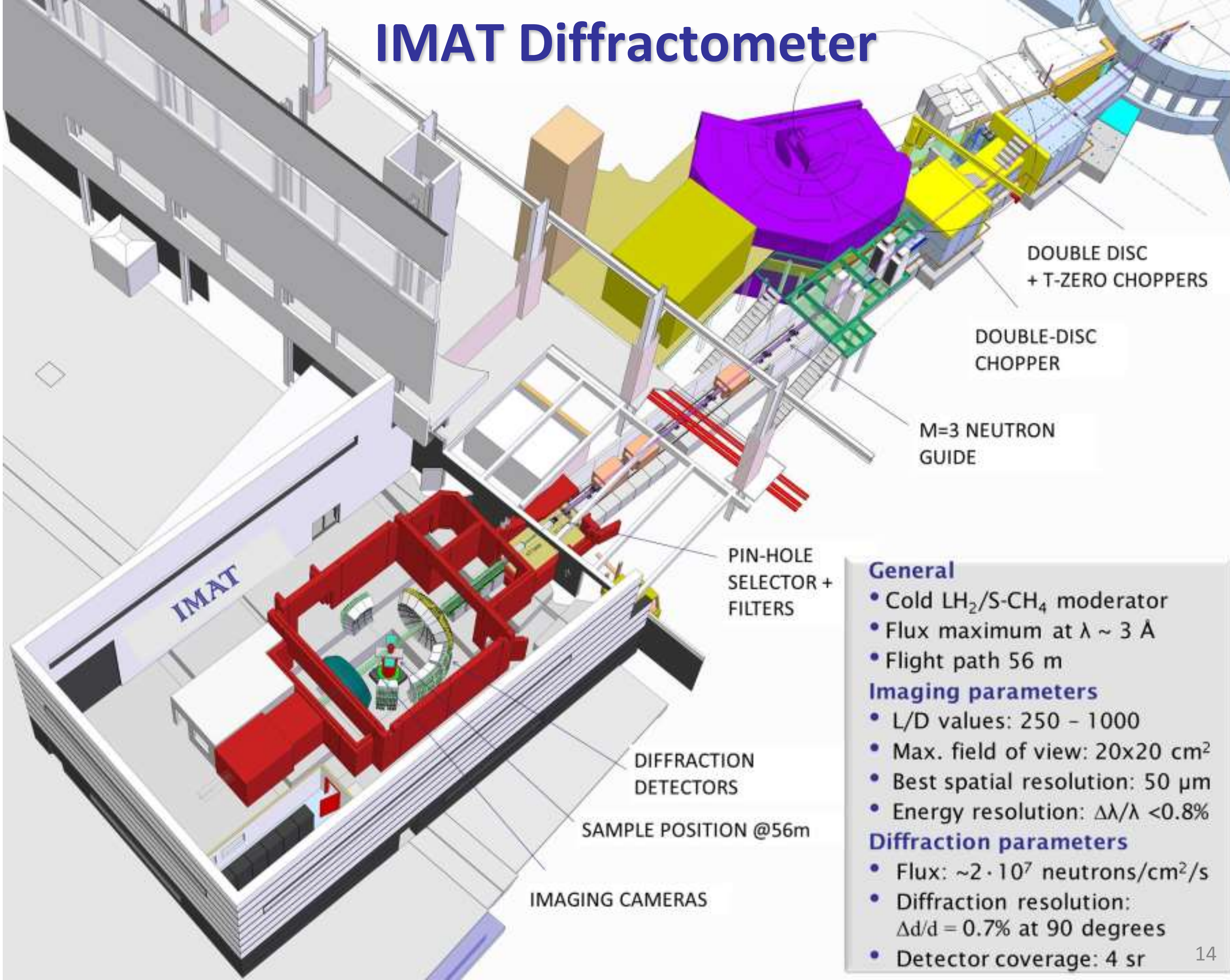


HRPD Diffractometer

MARI Spectrometer



IMAT Diffractometer



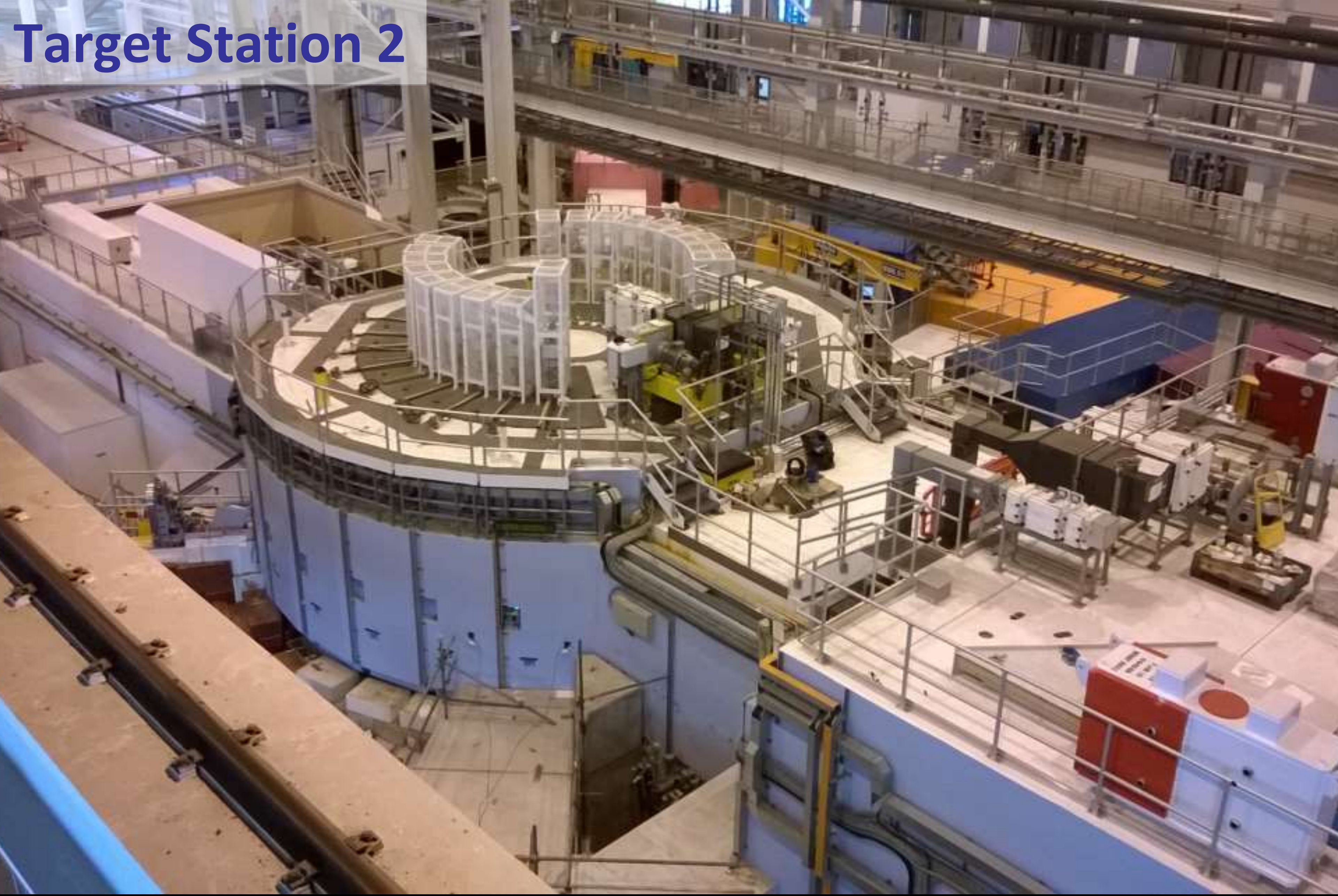
General
- Cold LH_2/S-CH_4 moderator
- Flux maximum at λ ~ 3 Å
- Flight path 56 m

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%

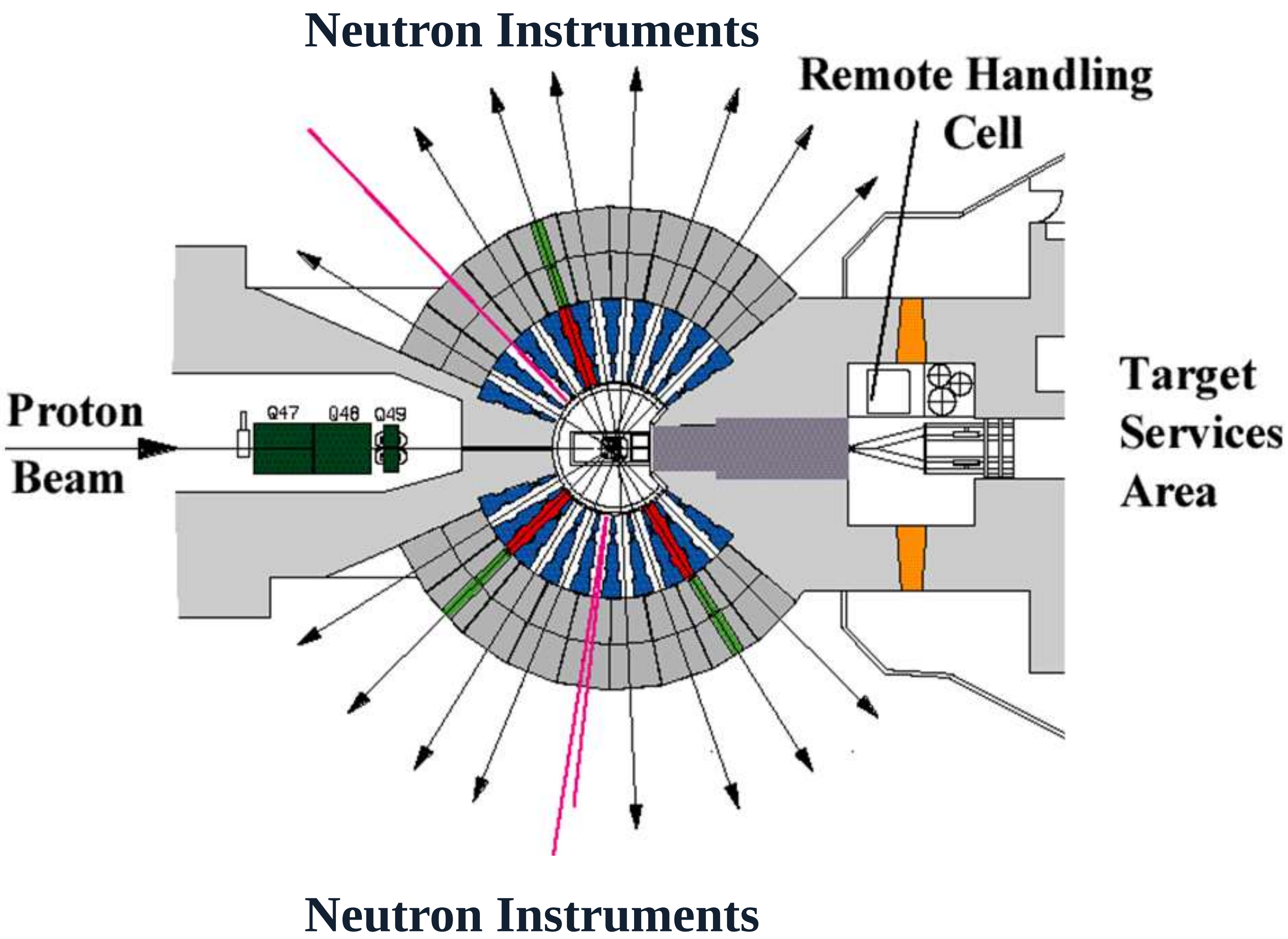
Diffraction parameters
- Flux: ~$2 \cdot 10^7$ neutrons/cm^2/s
- Diffraction resolution: $\Delta d/d$ = 0.7% at 90 degrees
- Detector coverage: 4 sr

Target Station 1

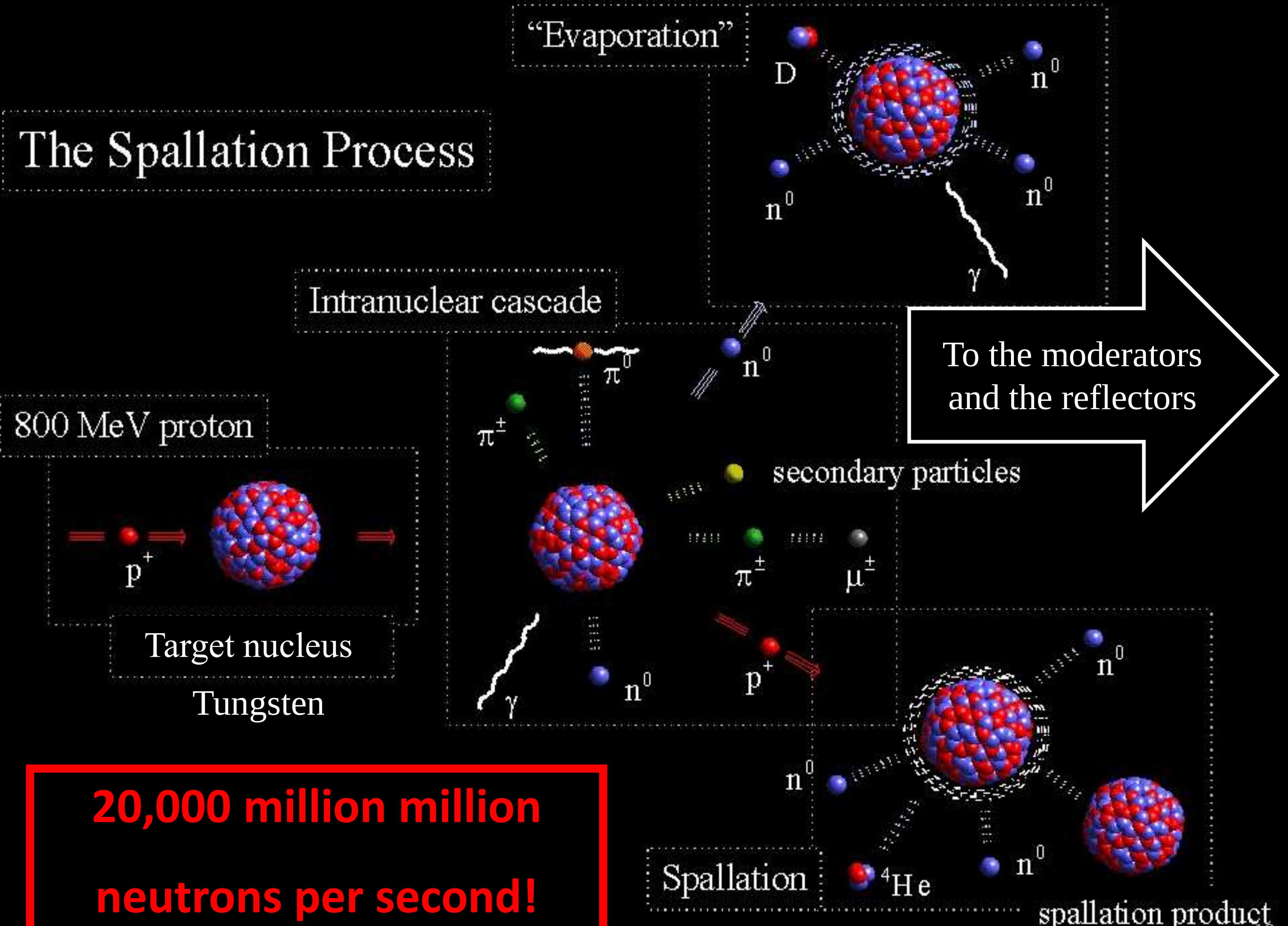
Target Station 2



Basic Layout of ISIS Target Stations

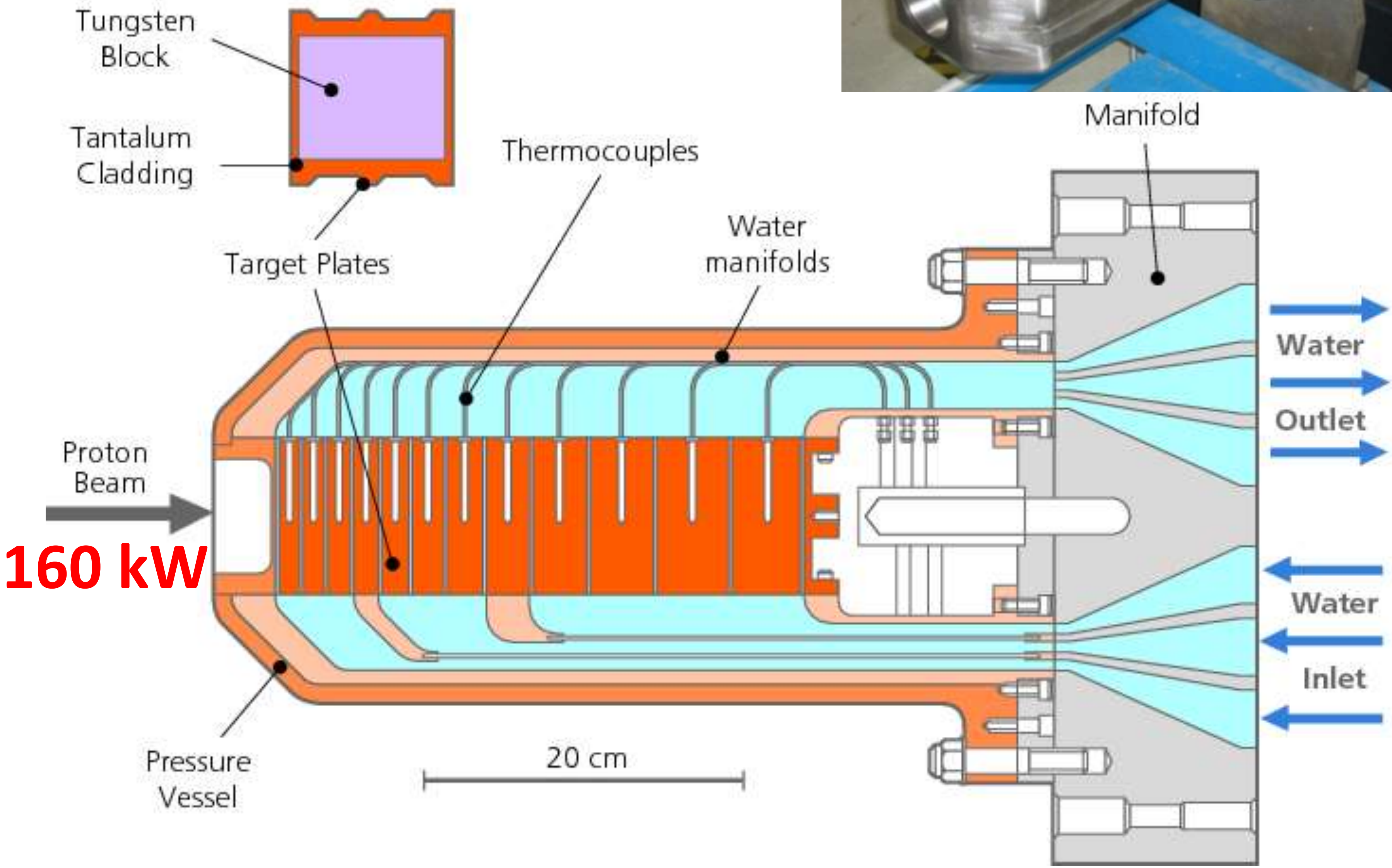


The Spallation Process

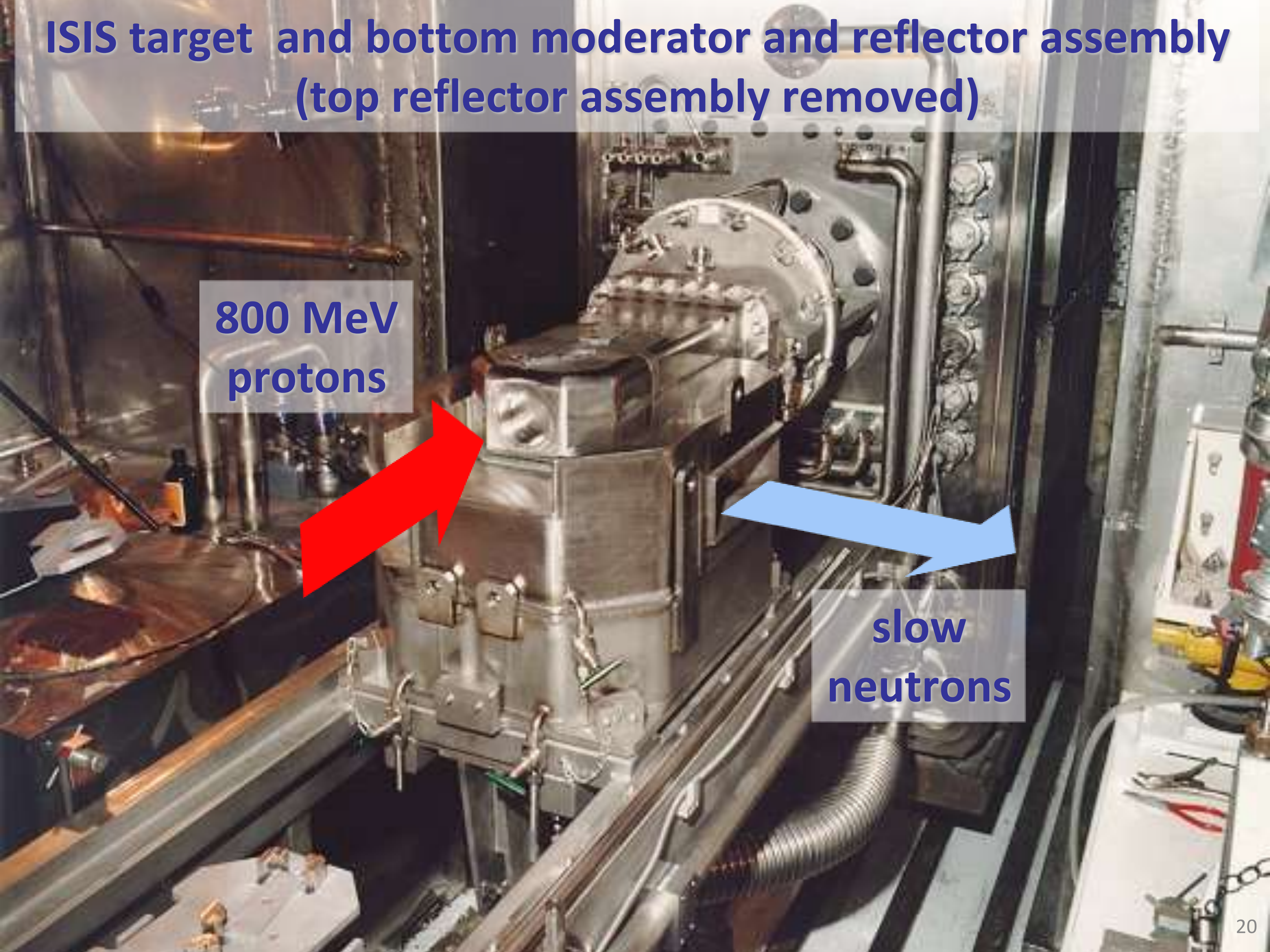


20,000 million million neutrons per second!

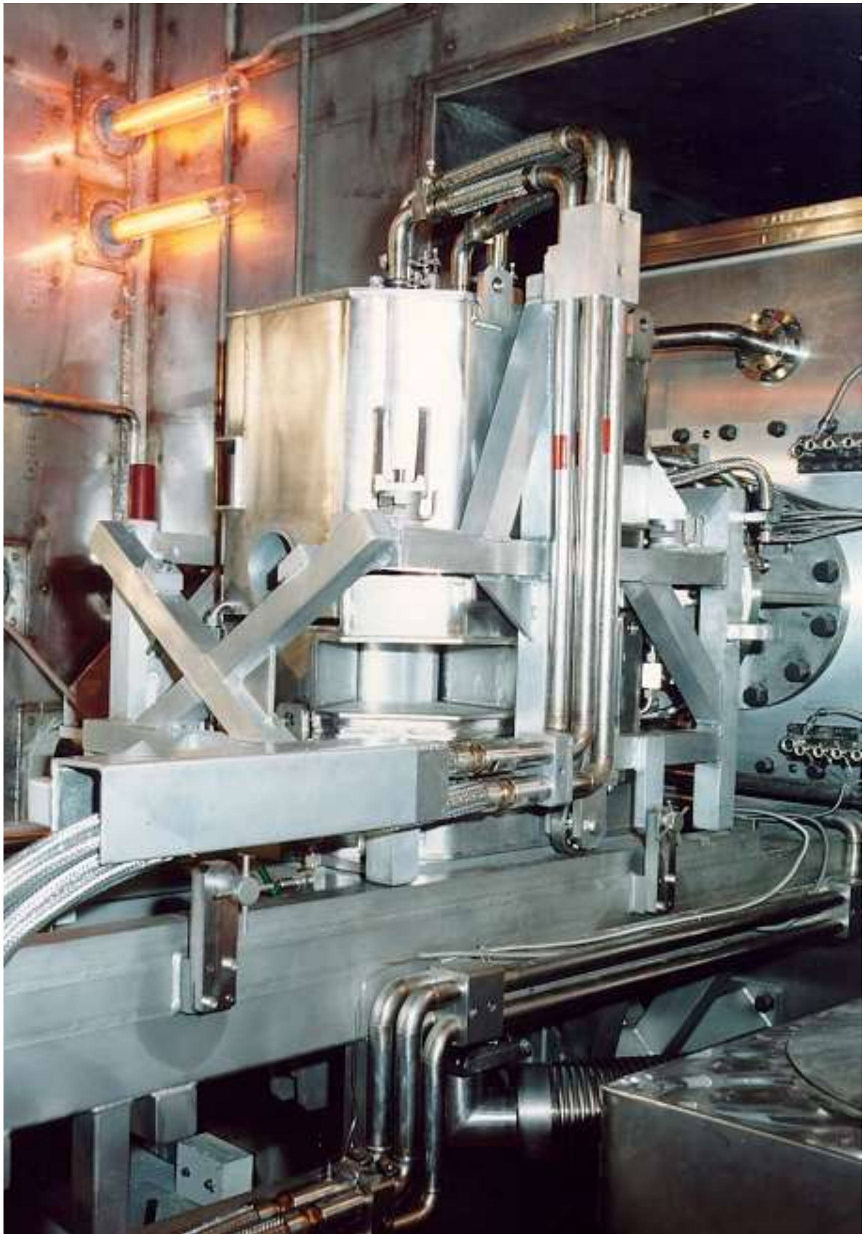
Section view of ISIS TS1 target

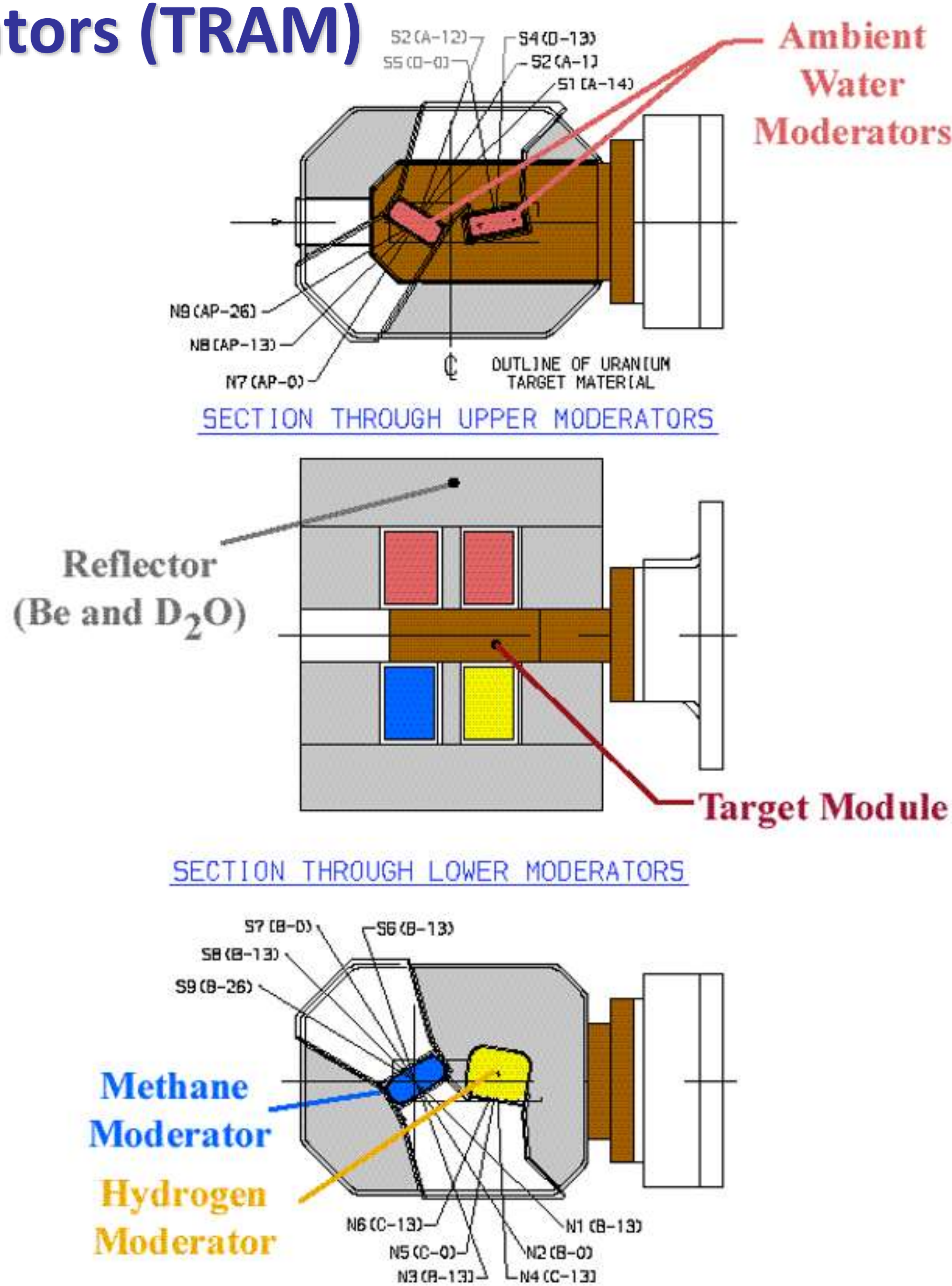


ISIS target and bottom moderator and reflector assembly (top reflector assembly removed)



Target Reflector And Moderators (TRAM)





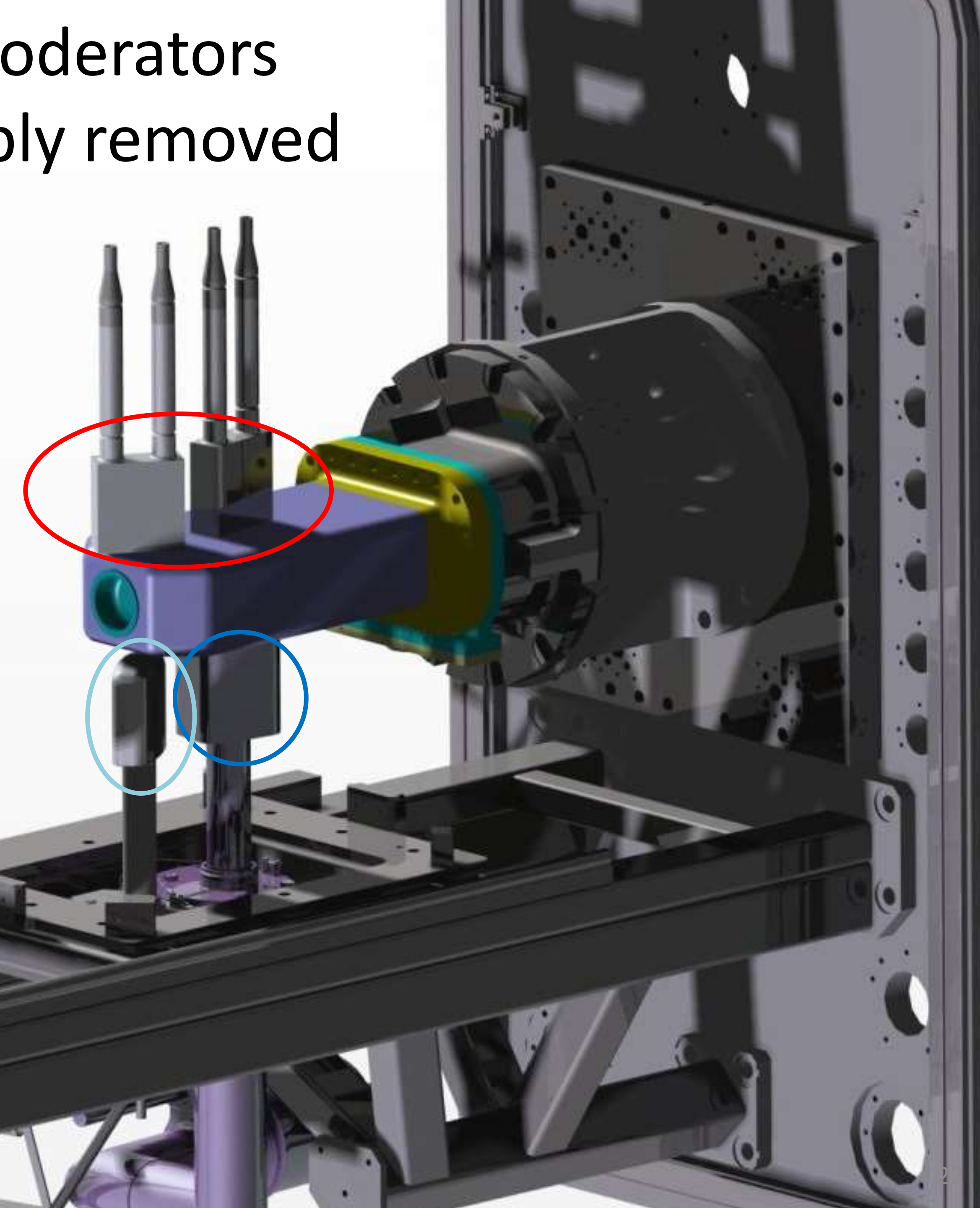
ISIS TS1 target and moderators with reflector assembly removed

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

Cryogenic moderators

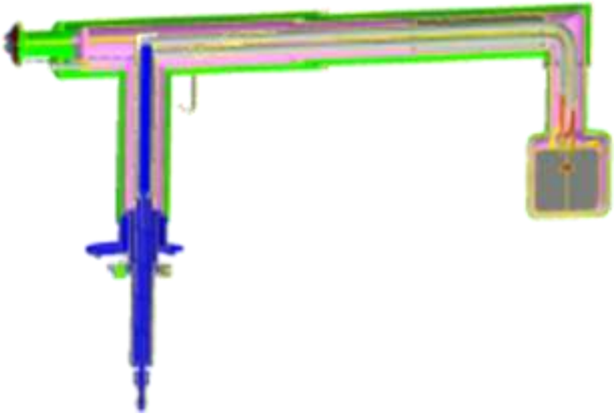
decoupled liquid CH_4 moderator
110 K methane @ 3 Bar
heat load 200 W

Coupled liquid H_2 moderator
heat load 200 W
20 K hydrogen @ 8 Bar



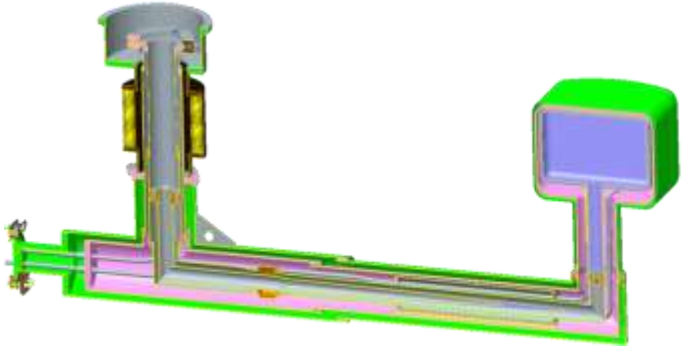
ISIS Target Station 2 TRAM with the edge cooled beryllium reflector open in maintenance mode

TS2 Cryogenic Moderators



decoupled moderator: solid CH_4 @ 45 K

coupled moderator: liquid H_2 @ 20 K 4 Bar



Choppers- spinning shielding

precise timing

magnetically levitating bearings

slotted shielding

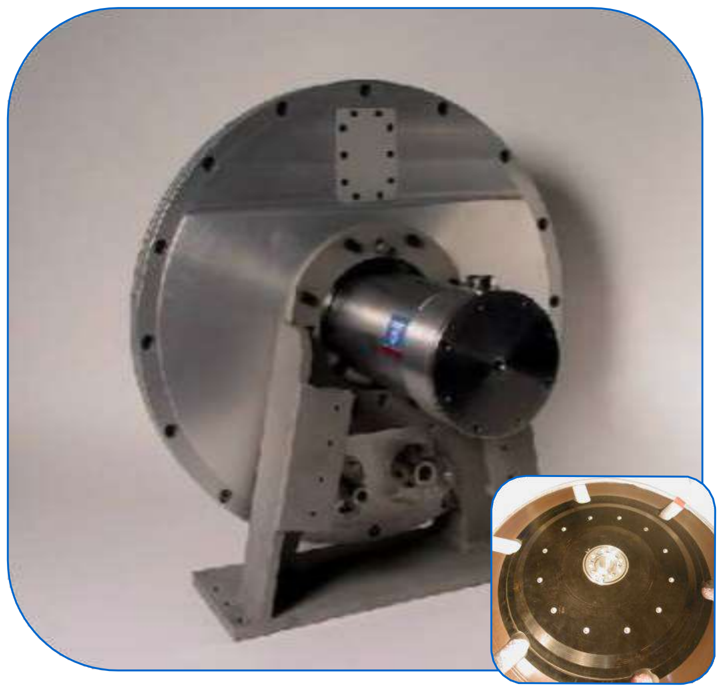
Choppers- spinning shielding

Fermi (17)

7.3 kg Payload
36,000 rpm
±0.05° Phase Control

Disk (56)

30 kg Payload
20,000 rpm
±0.05° Phase Control

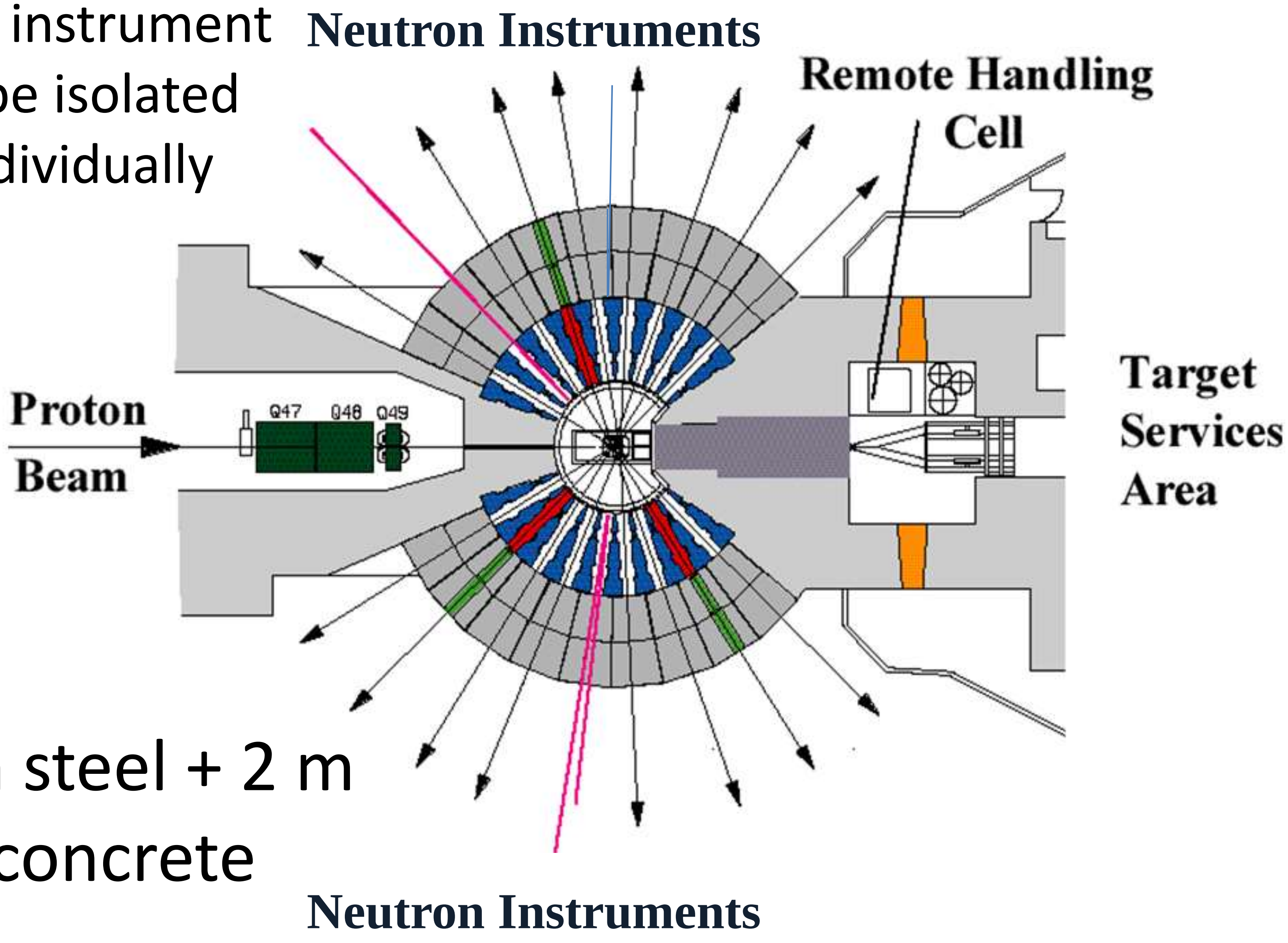


T-Zero (4)

68 kg Payload
10,800 rpm
±0.43° Phase Control

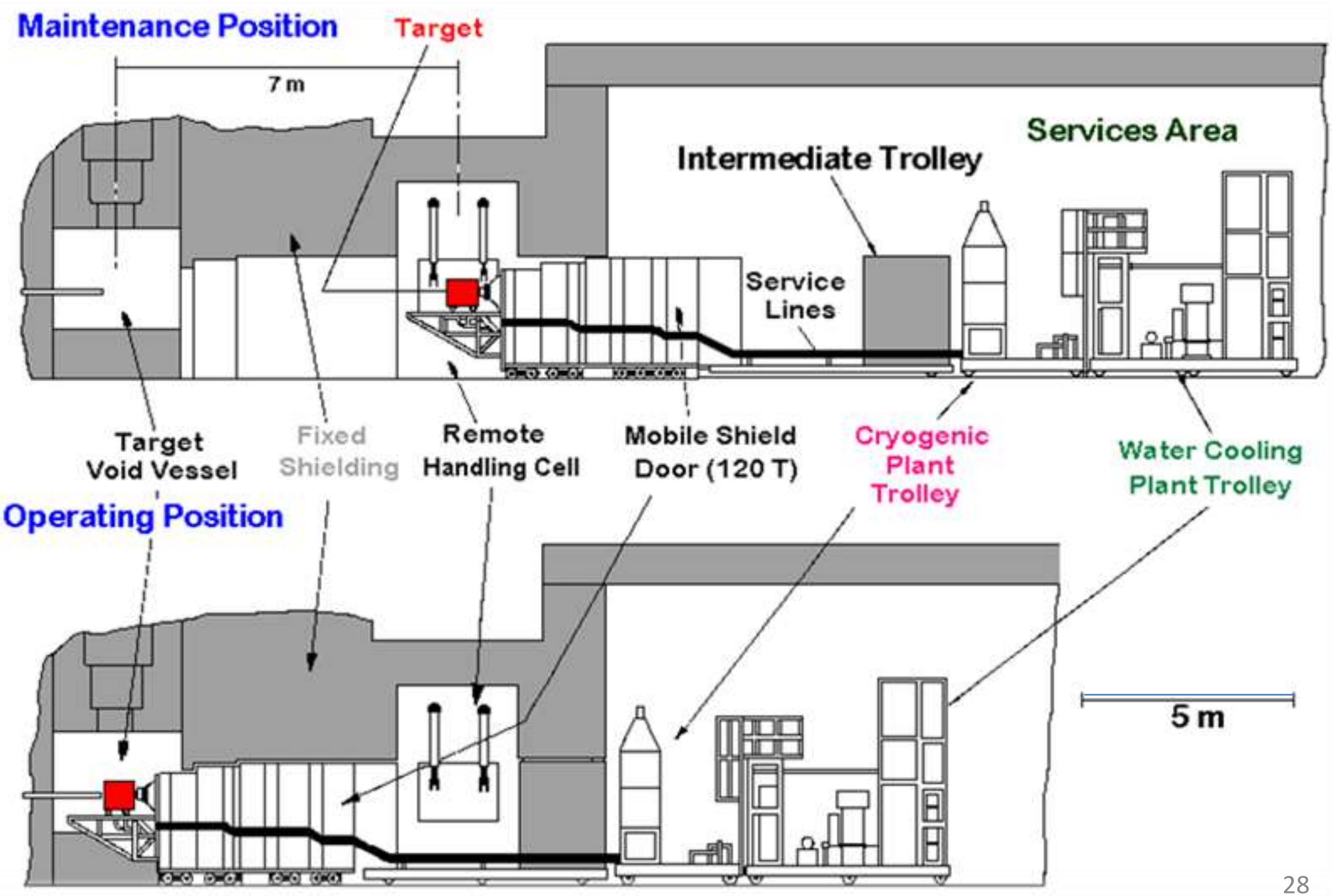
Shielding

Shutters allow each instrument to be isolated individually



2 m steel + 2 m concrete

The services trolley moves to position the TRAM for operation or maintenance



Target void vessel filled with helium

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

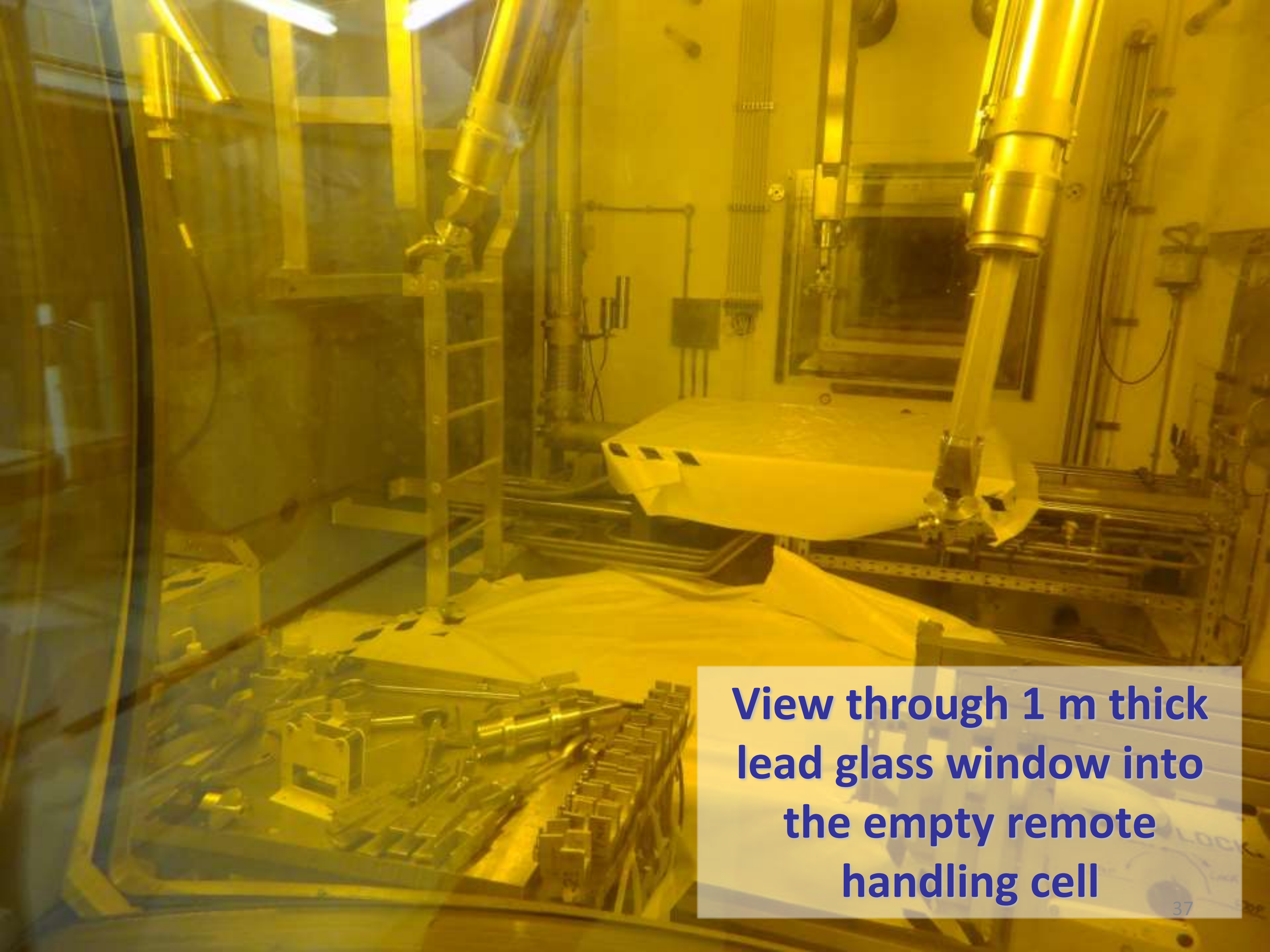
TS1 Tungsten
Target #4 on flow
test rig

remote manipulator set in TS1

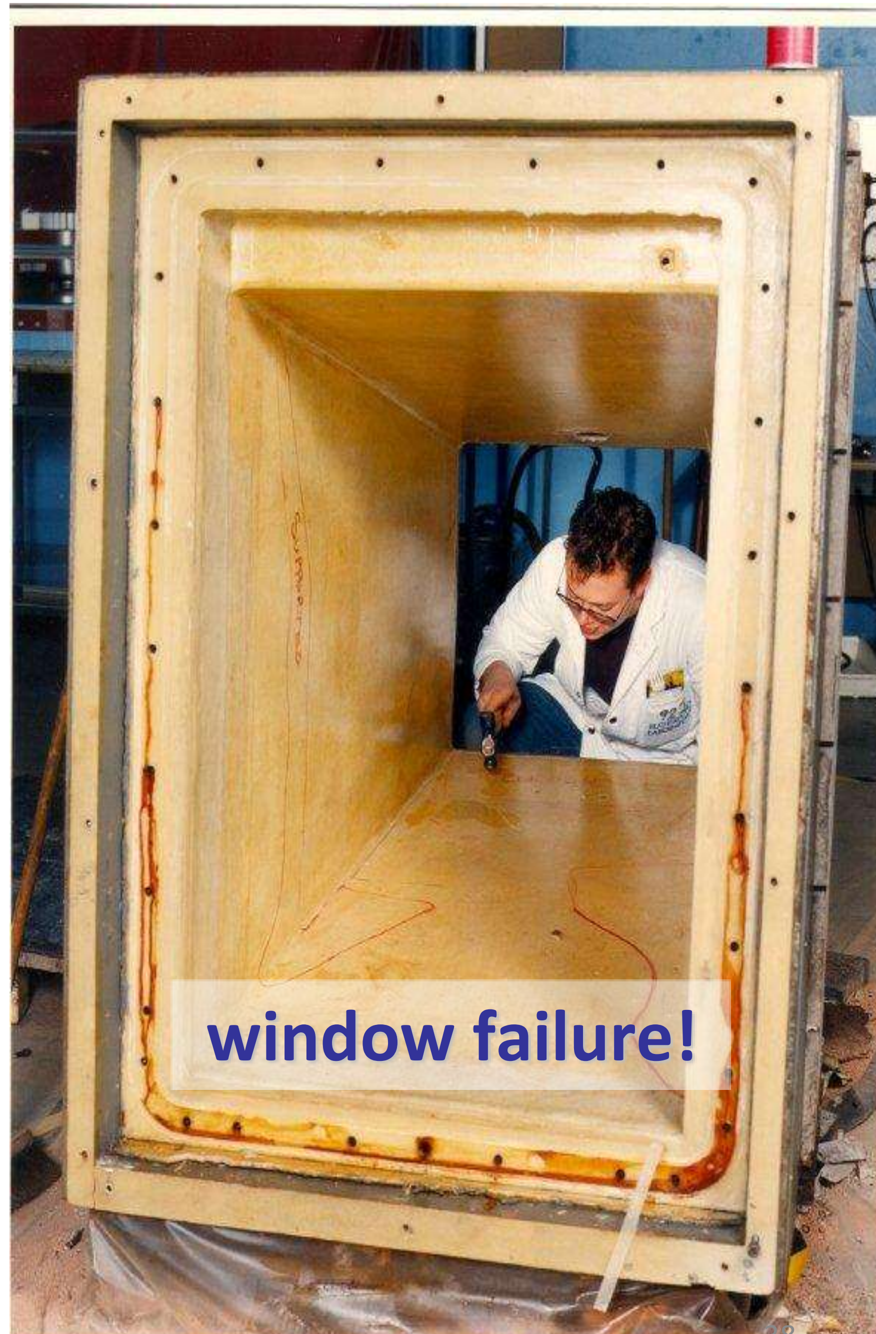
remote manipulator set in TS2

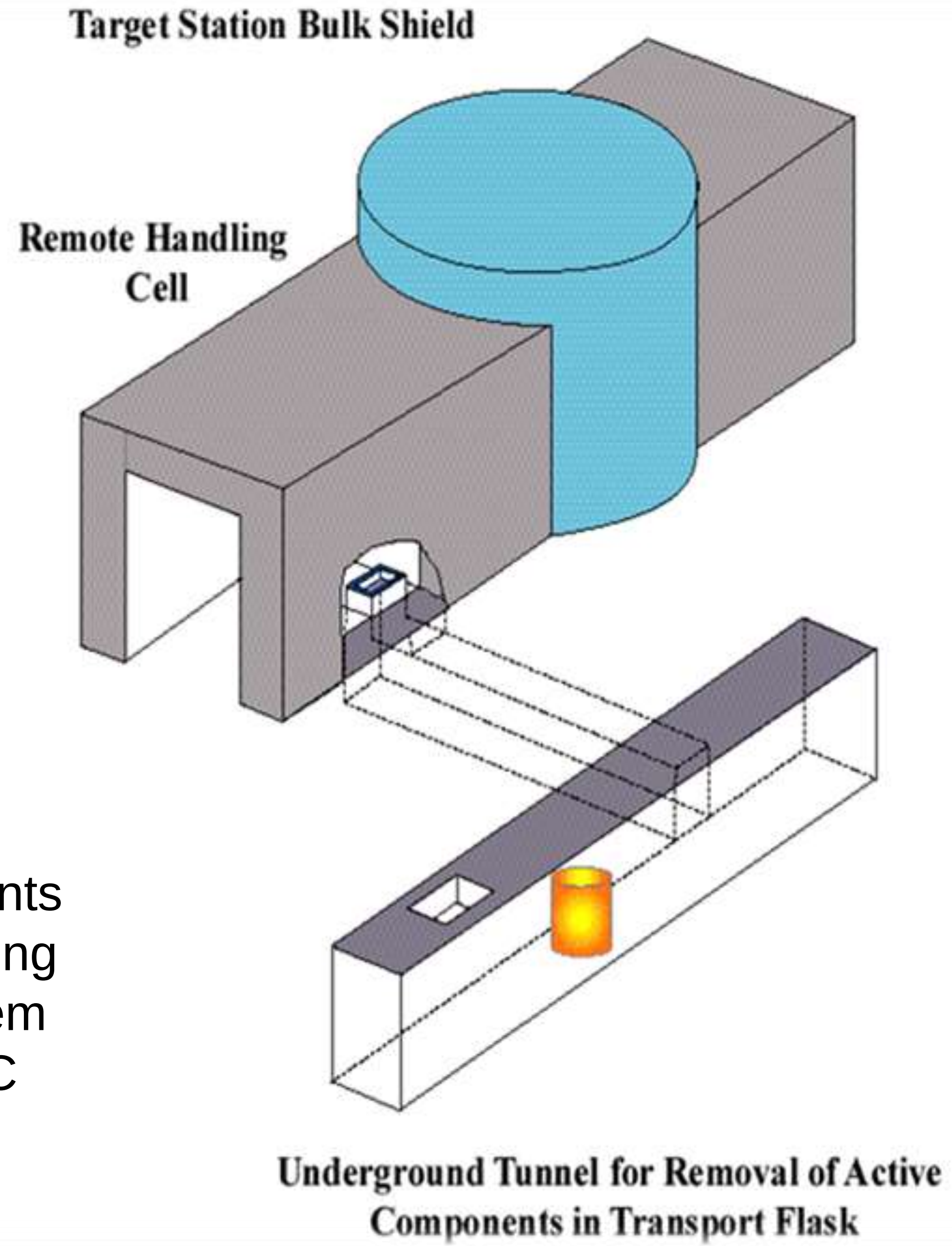
remote manipulator sets on both sides of the remote handling cell

Crews in contact with other areas by headset

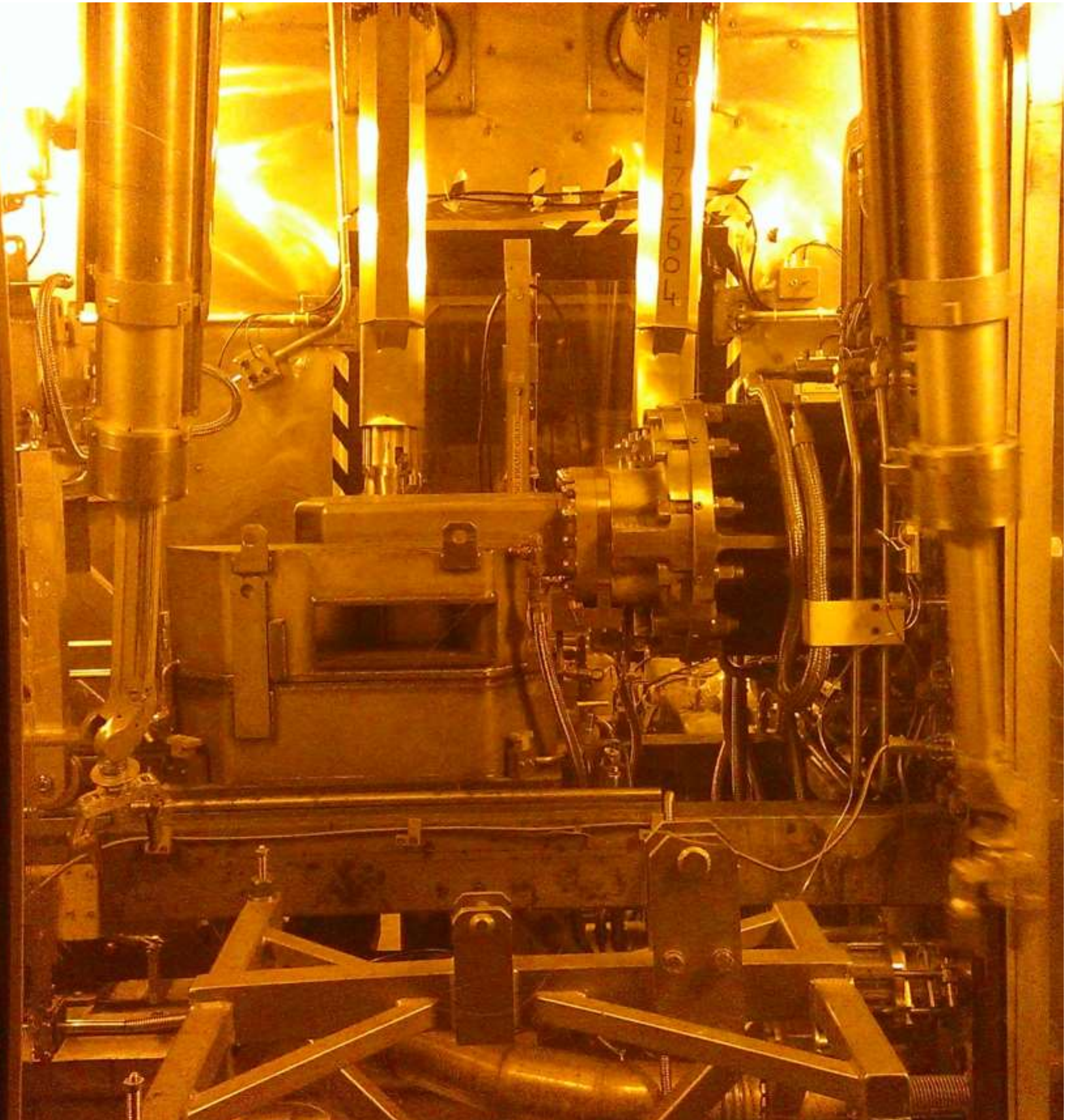


View through 1 m thick lead glass window into the empty remote handling cell


window failure!



Active components are removed using the tunnel system under the RHC

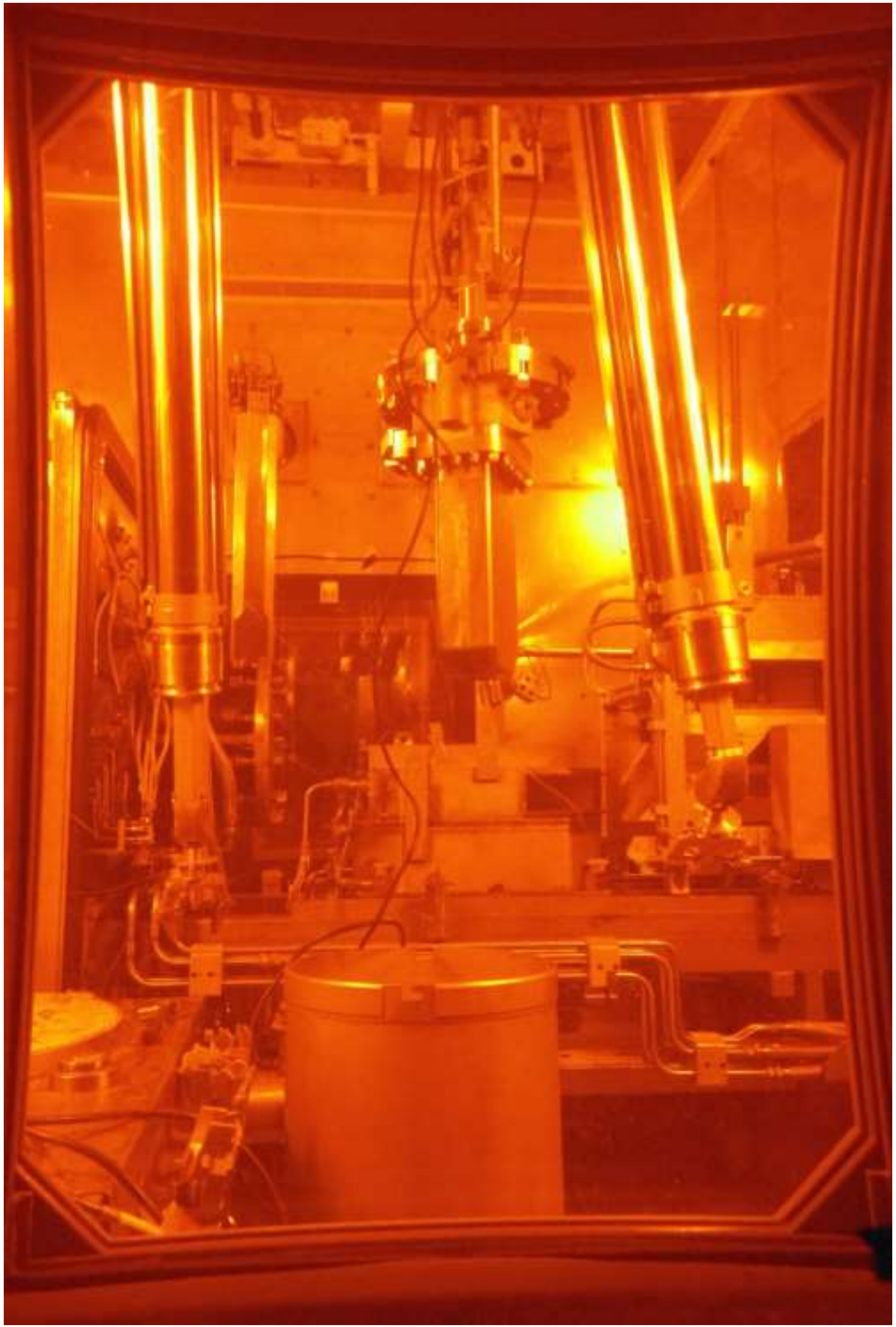


View of the TS1 TRAM withdrawn into the RHC

This view is from the north side of the RHC

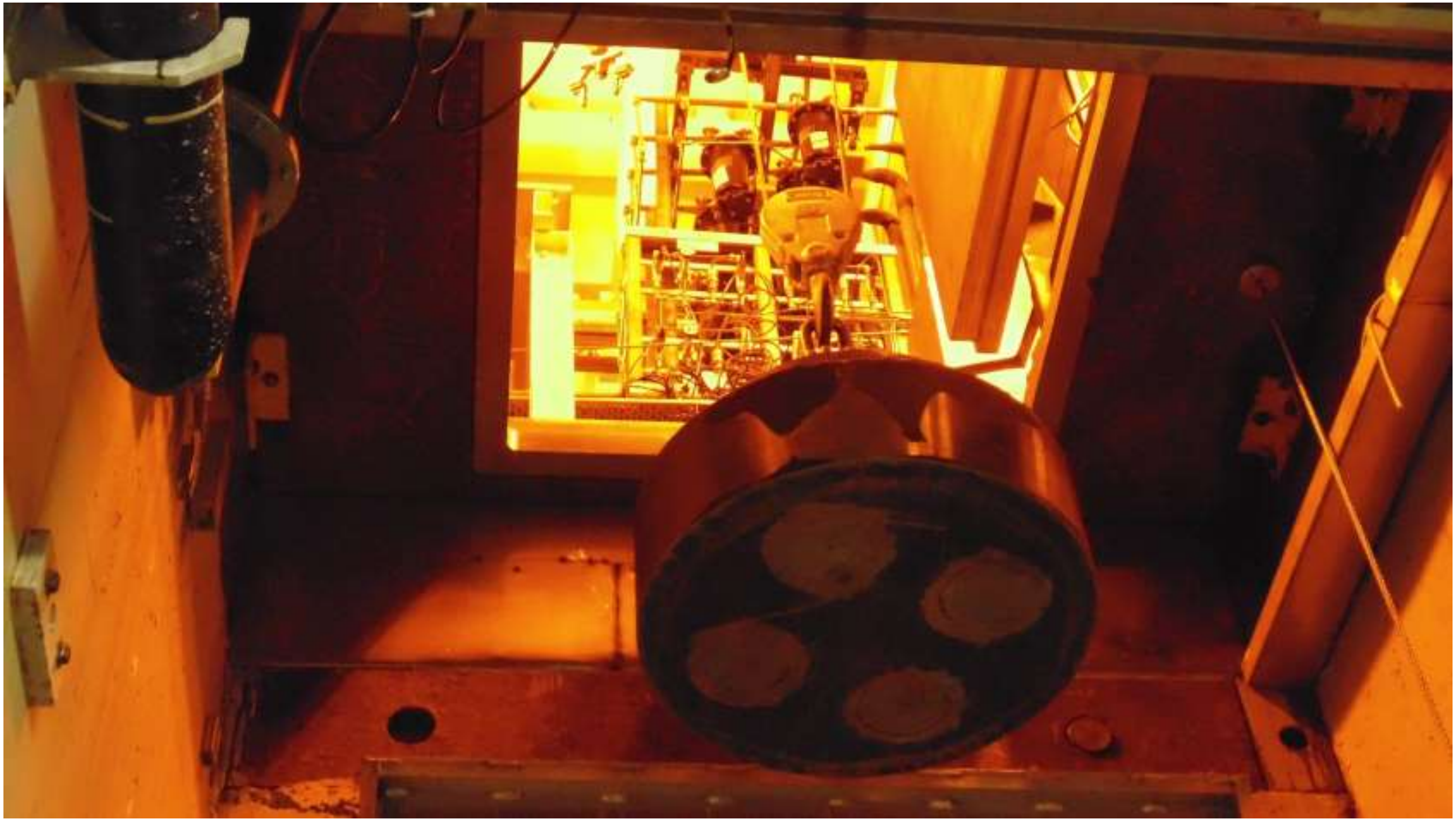
The reflector top section is rolled forward to expose the Tungsten Target

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

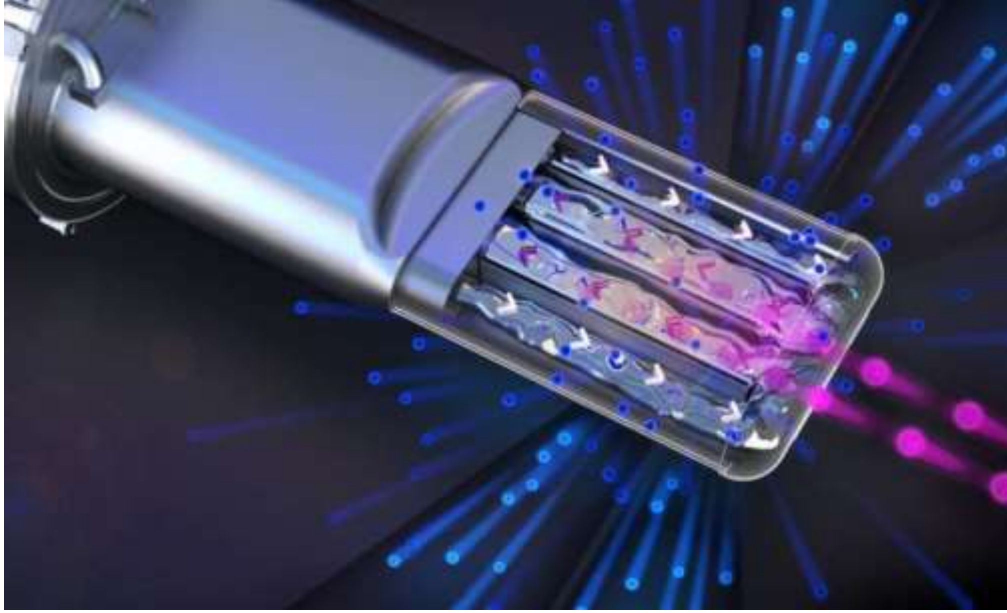
Full suit, gloves, overshoes and respirator are required for this work

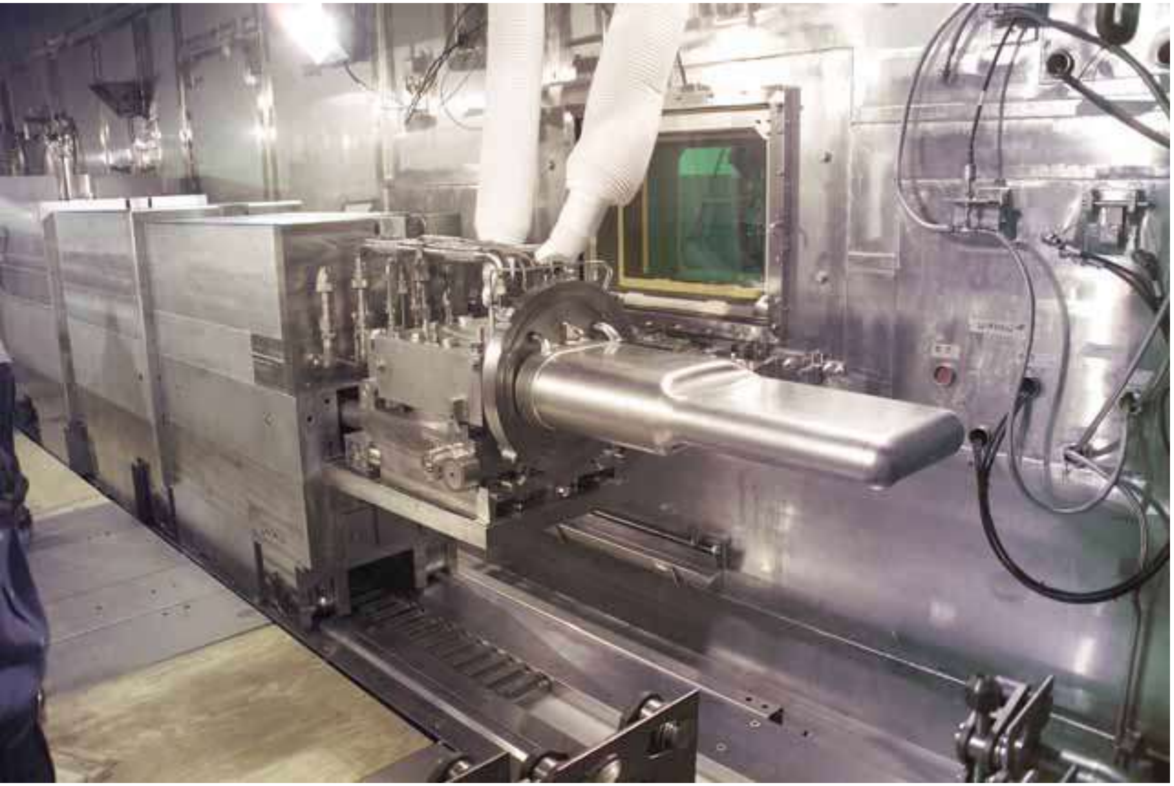
For final disposal the target is transferred to a registered and licenced Type B package and transported to Sellafield the UK's nuclear waste storage facility

More power!

- ISIS 160 kW on target
- More power = more neutrons
- The power must be removed somehow
- SNS Oakridge USA = 1.4 MW

SPALLATION NEUTRON SOURCE

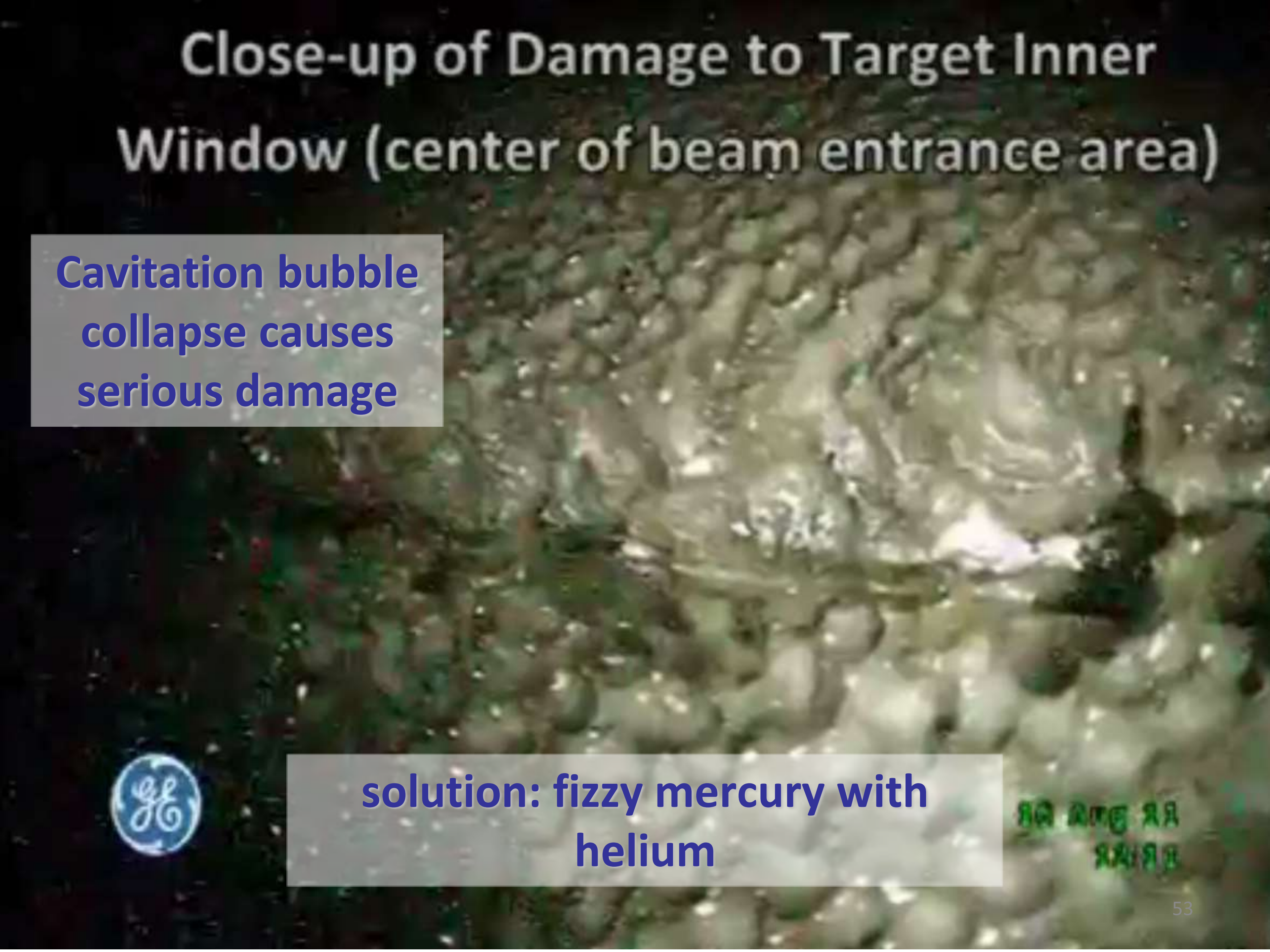




1.4 MW liquid mercury target

SNS
SPALLATION NEUTRON SOURCE

Close-up of Damage to Target Inner Window (center of beam entrance area)



Cavitation bubble collapse causes serious damage

solution: fizzy mercury with helium

EUROPEAN
SPALLATION
SOURCE

ESS currently under constructio
3 MW on target!

A rotating wheel of ISIS targets!

EUROPEAN SPALLATION SOURCE

2.6 m diameter stainless steel disk containing tungsten bricks

5000 kg

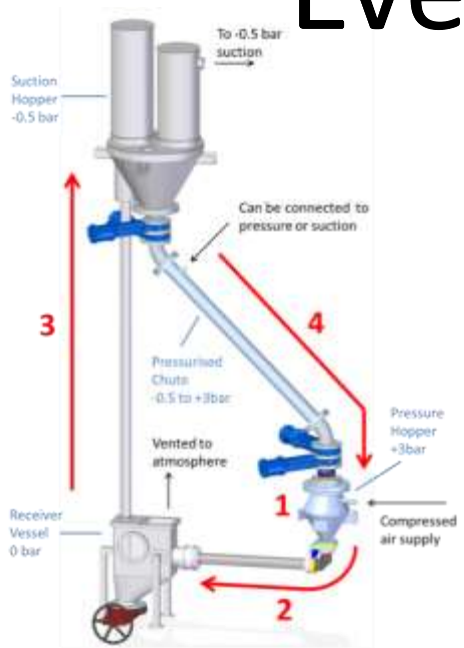
helium cooled

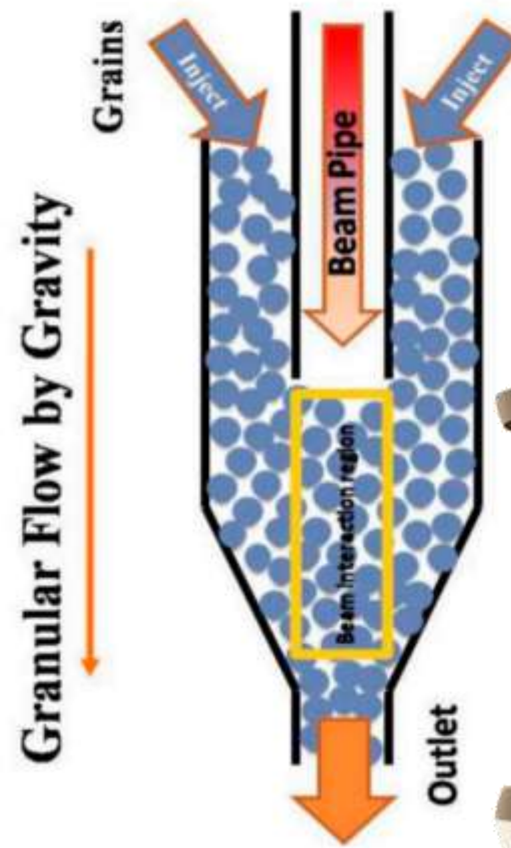
23.3 rpm

A solution for SNS TS2

protons

Even more power!

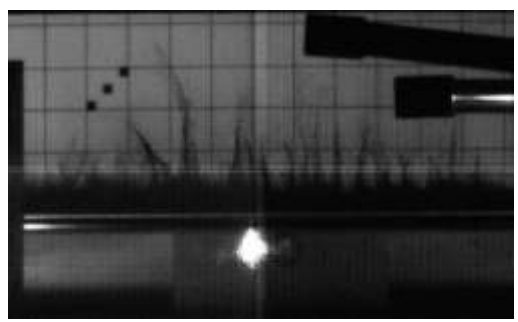




ADS

Tungsten powder handling system developed at RAL

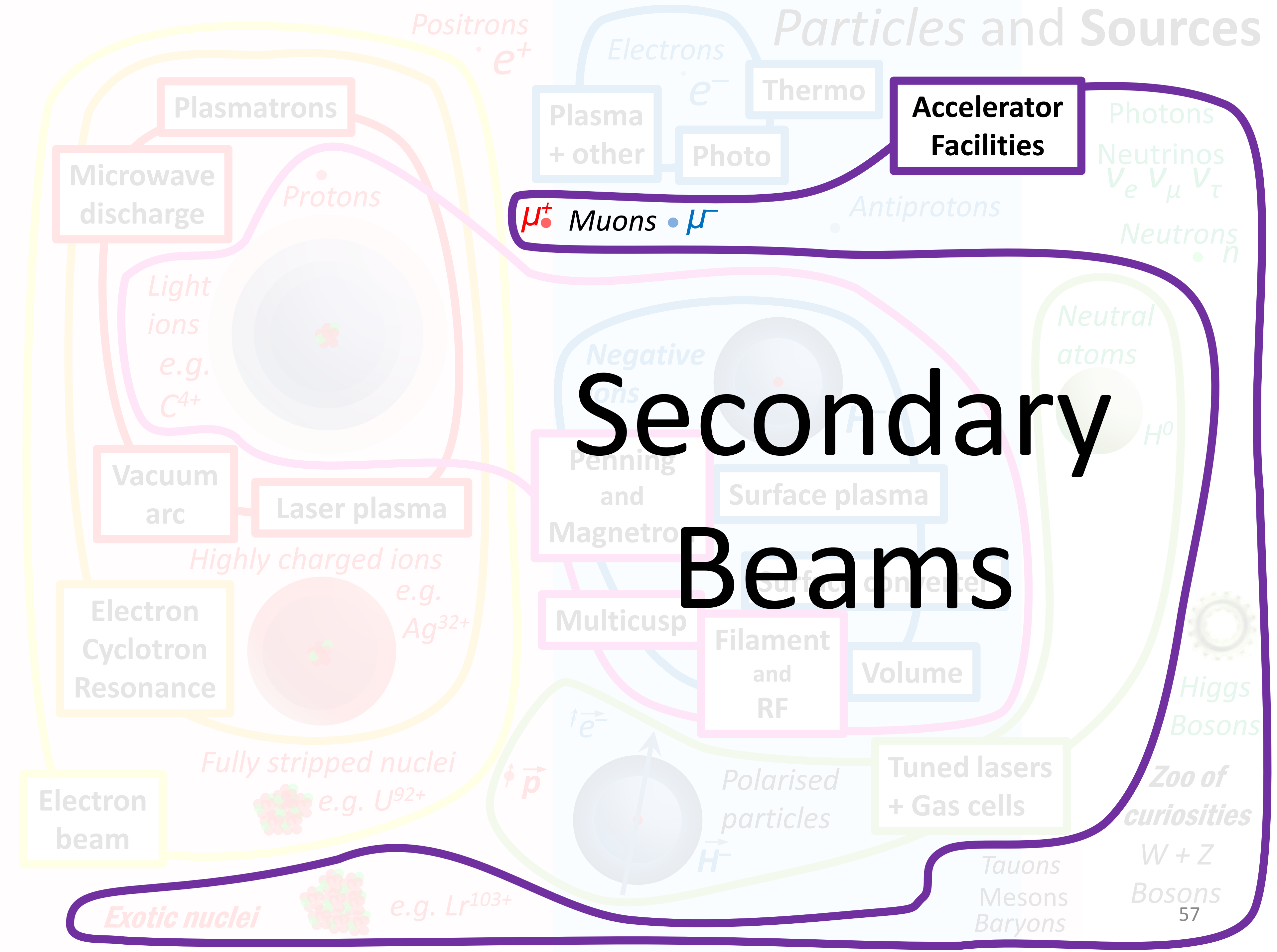
Science & Technology Facilities Council



Tests at CERN

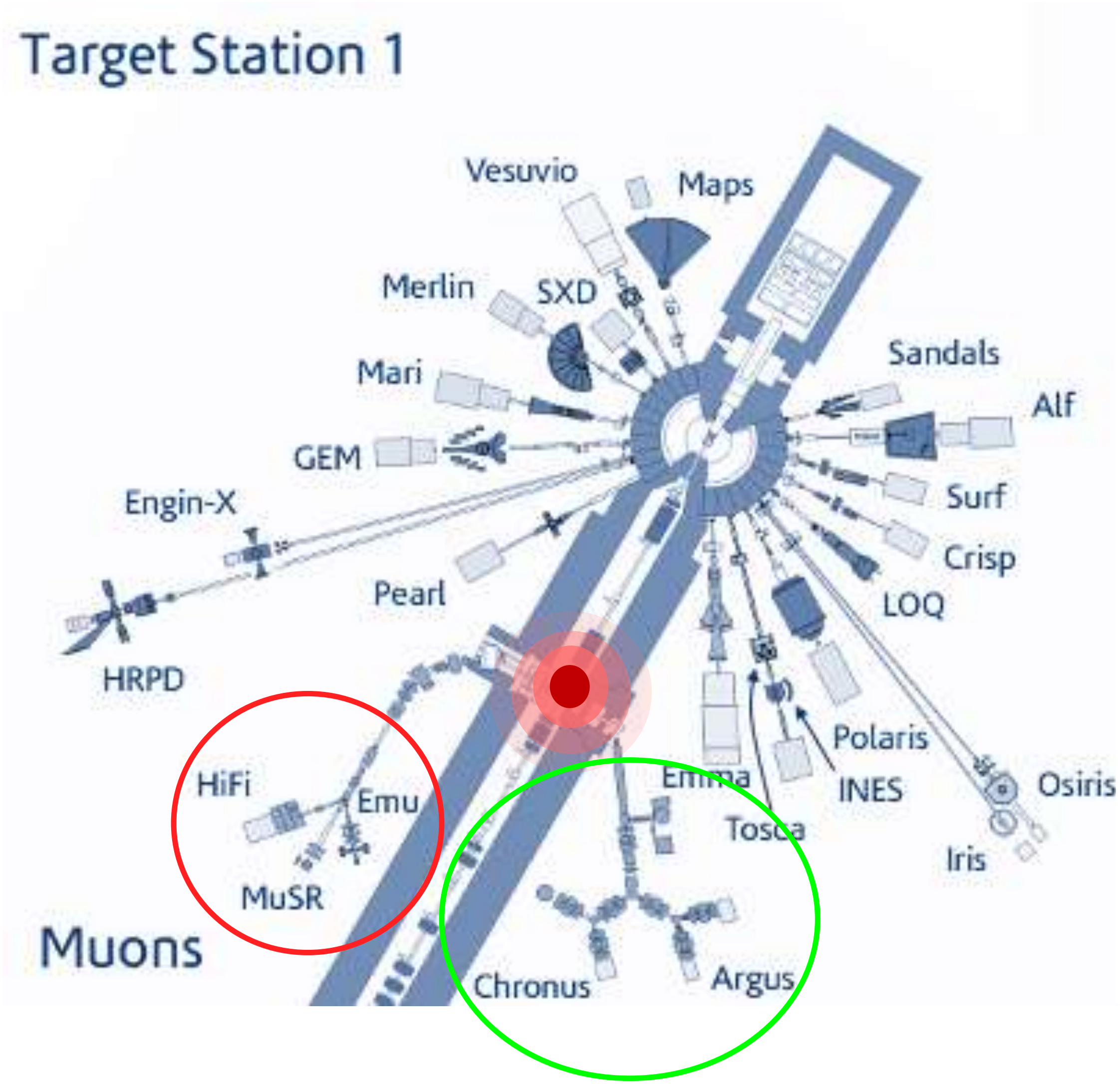
中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

10-100 MW!



Particles and Sources
Secondary Beams
Accelerator Facilities
Muons
Positrons
Electrons
Thermo
Plasmatrons
Plasma + other
Photo
Microwave discharge
Protons
Antiprotons
Photons
Neutrinos
Neutrons
Light ions e.g. C4+
Negative ions
Neutral atoms
Penning and Magnetron
Surface plasma
Vacuum arc
Laser plasma
Highly charged ions e.g. Ag32+
Surface converter
Electron Cyclotron Resonance
Multicusp
Filament and RF
Volume
Higgs Bosons
Fully stripped nuclei e.g. U92+
Polarised particles
Tuned lasers + Gas cells
Zoo of curiosities
W + Z Bosons
Electron beam
Tauons
Mesons
Baryons
Exotic nuclei e.g. Lr103+

Muons at ISIS



7 muon instruments

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

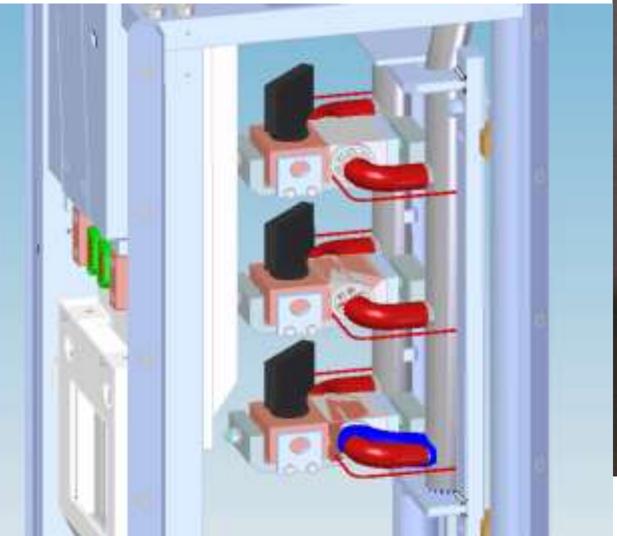
ISIS Muon Target

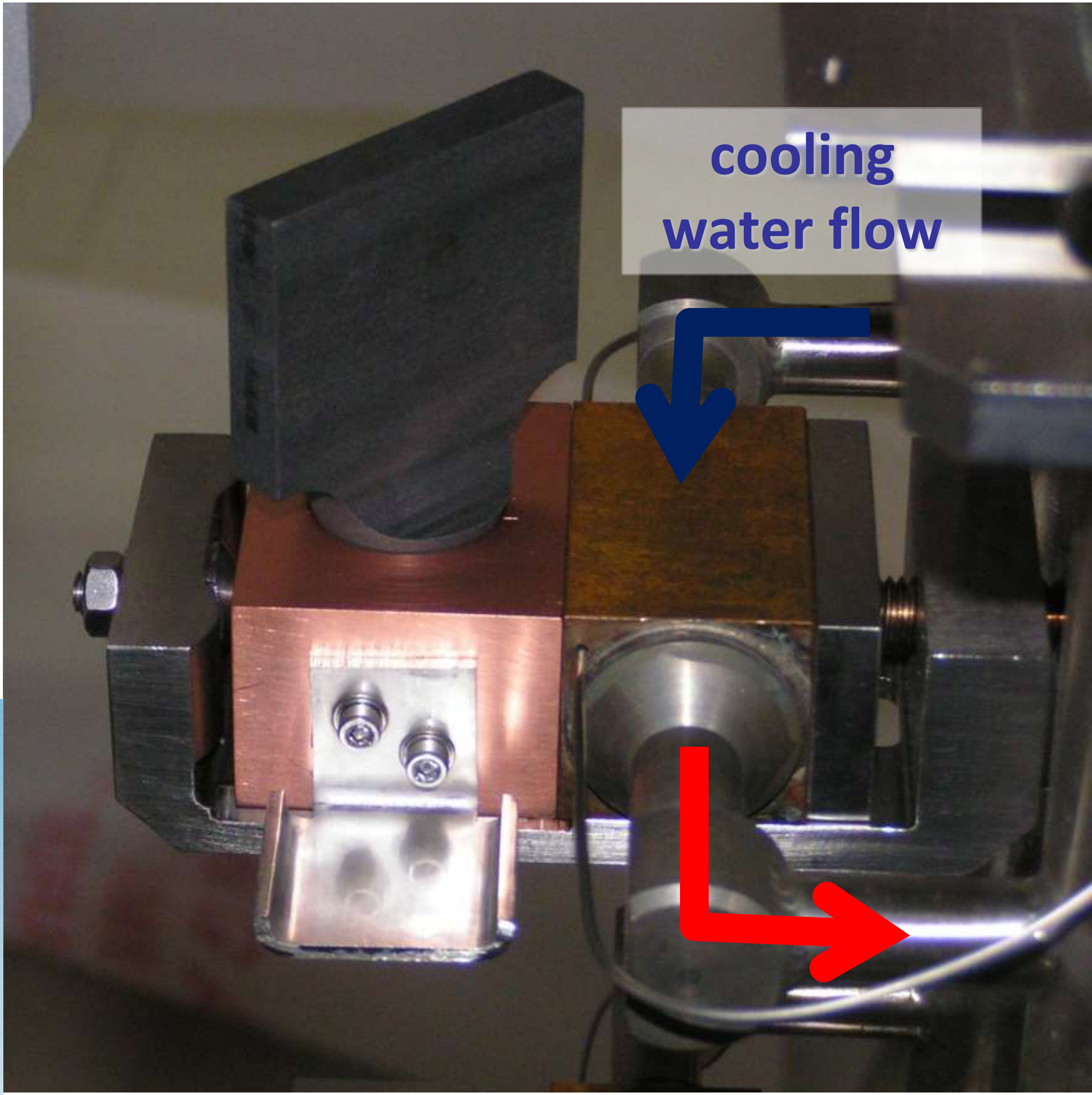
10 mm thick graphite target at 45° to the 800 MeV proton beam

About 5% beam lost.

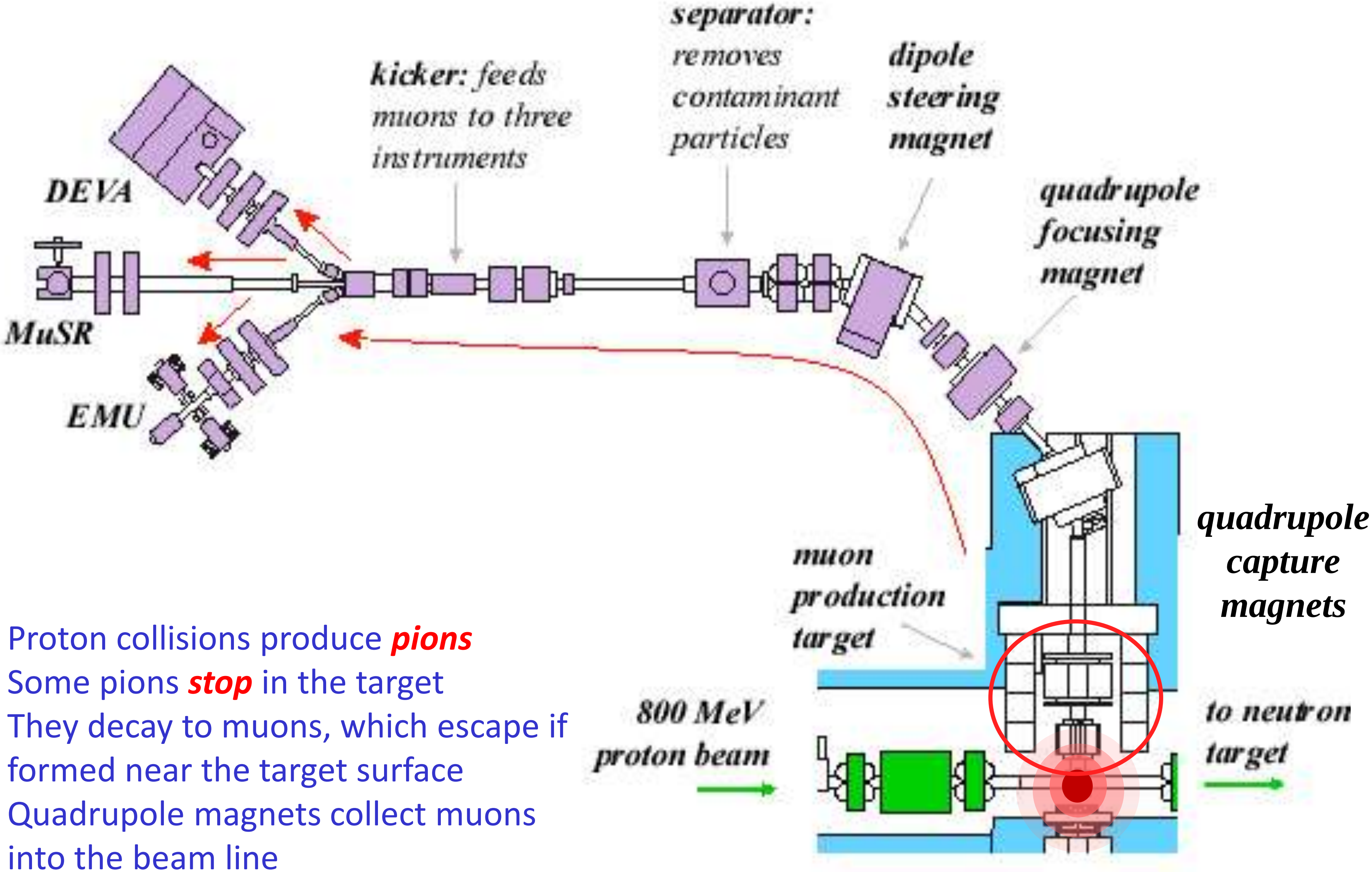
Diffusion bonded to copper to maximise thermal contact

10 kW maximum heat load

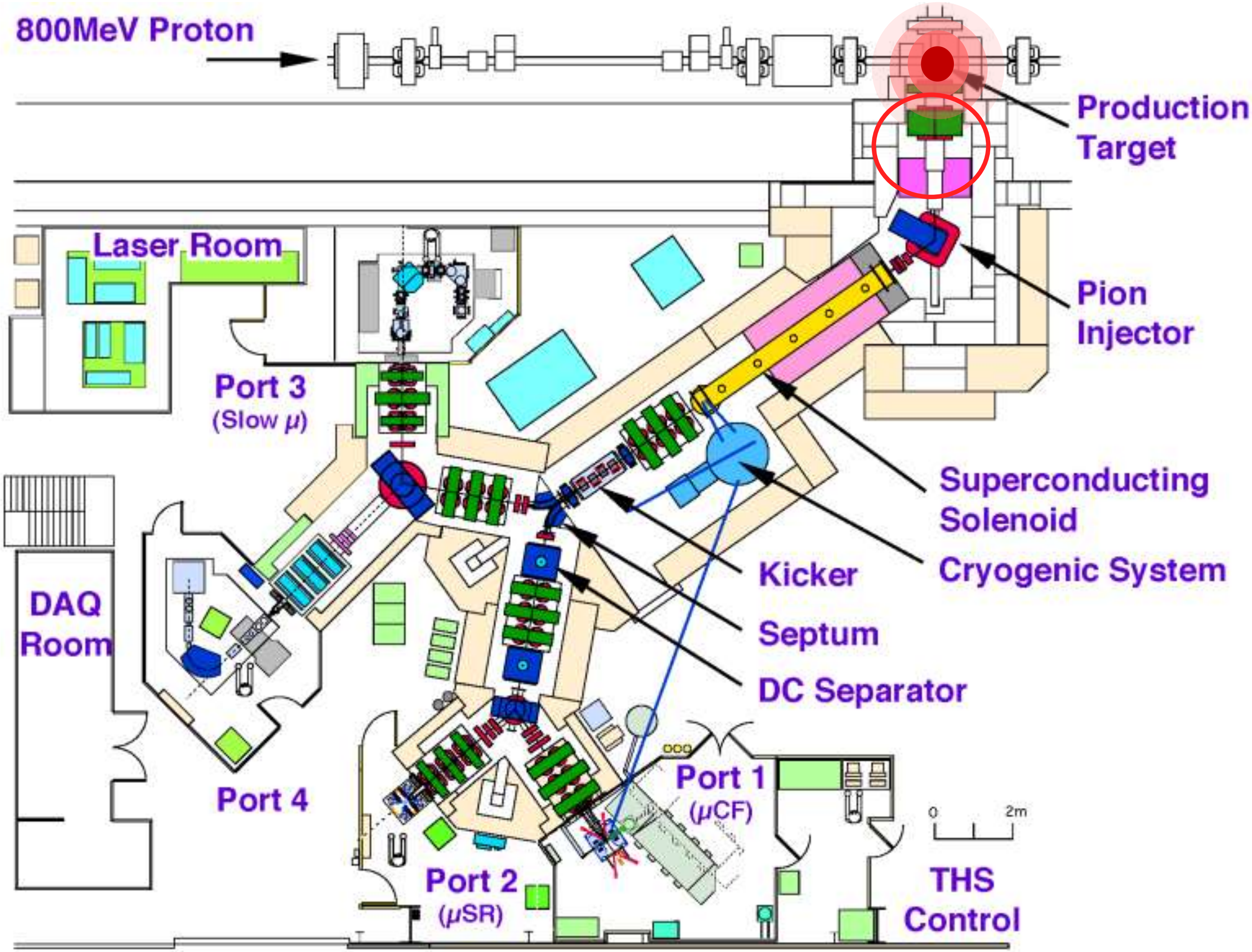




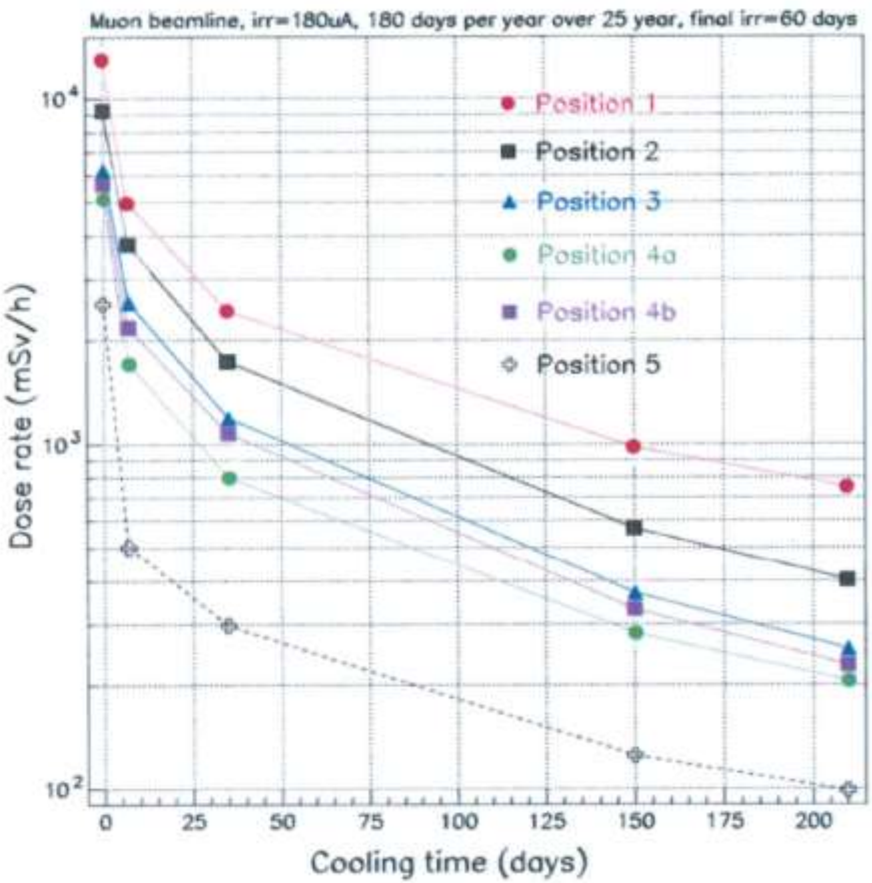
The EC Muon Facility

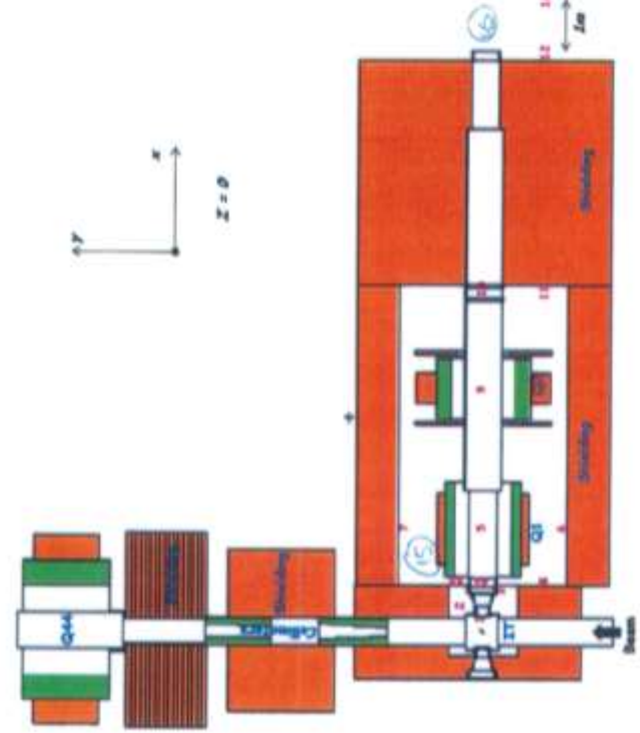


- Proton collisions produce ***pions***
- Some pions ***stop*** in the target
- They decay to muons, which escape if formed near the target surface
- Quadrupole magnets collect muons into the beam line


800MeV Proton
Production Target
Pion Injector
Laser Room
Port 3
(Slow μ)
Superconducting Solenoid
Kicker
Cryogenic System
Septum
DC Separator
DAQ Room
Port 4
Port 1
(μCF)
Port 2
(μSR)
0
2m
THS Control

Radiation Levels

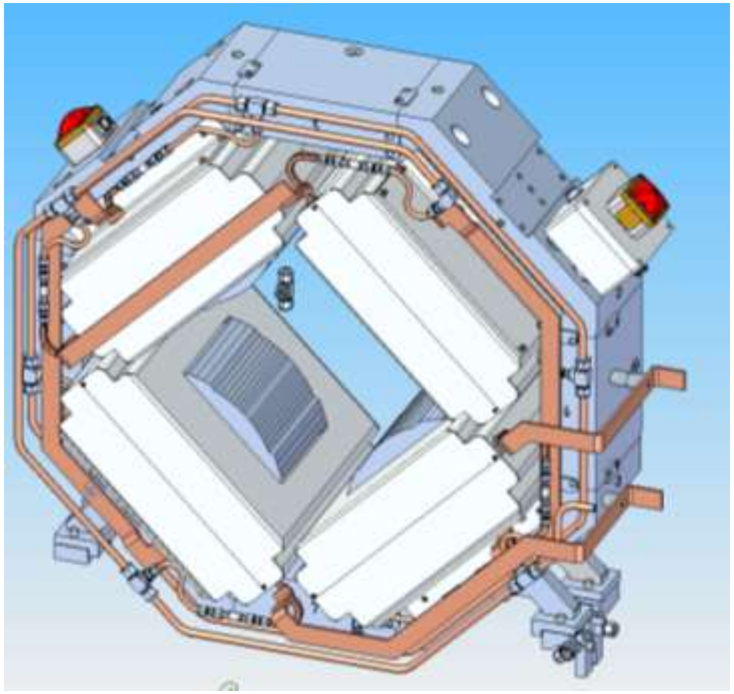


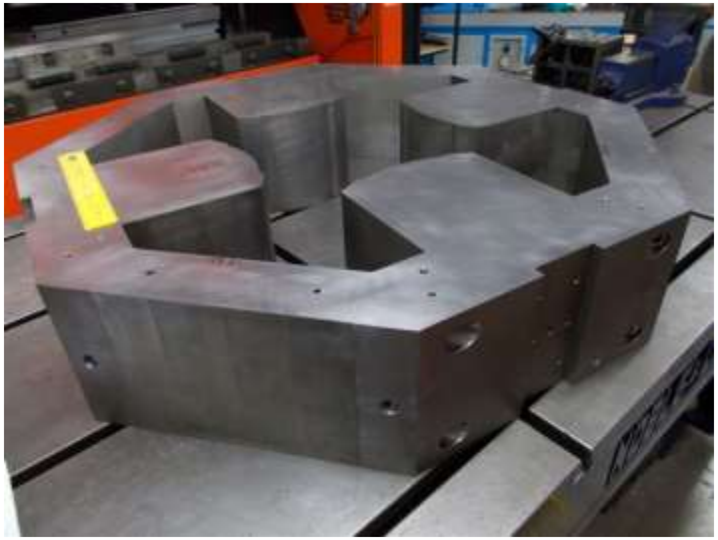


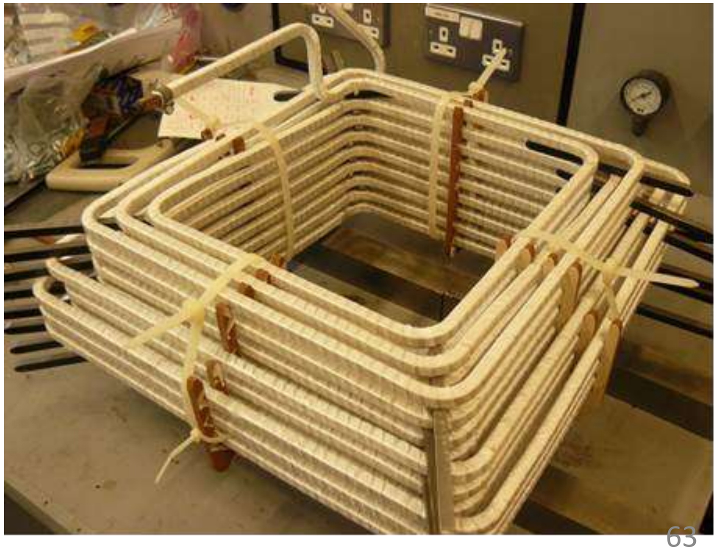
Radiation Hard Magnets

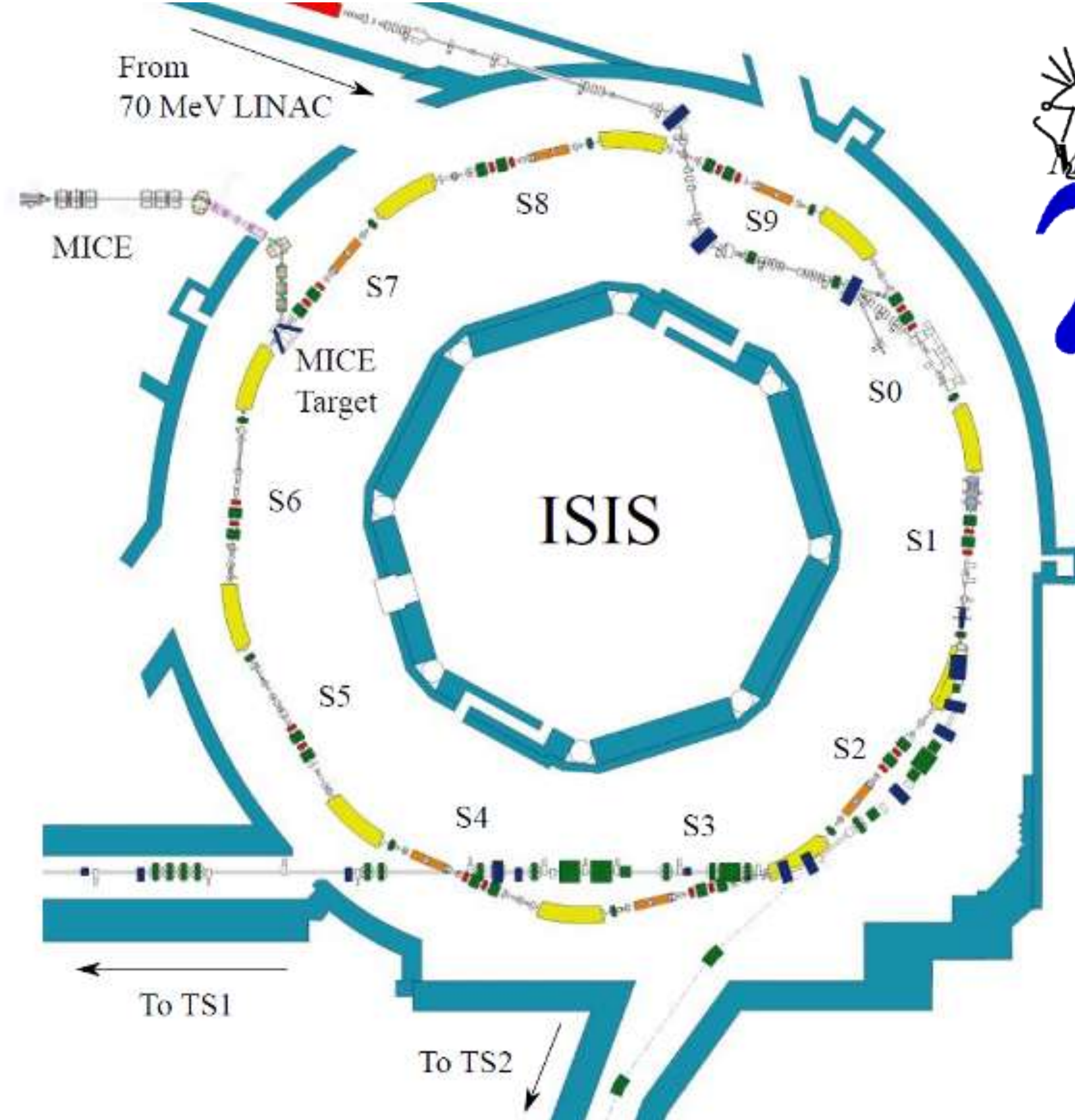
Radiation Hard Magnet Design

- In house concrete magnet design
- Coils Potted in concrete
- Water Cooled



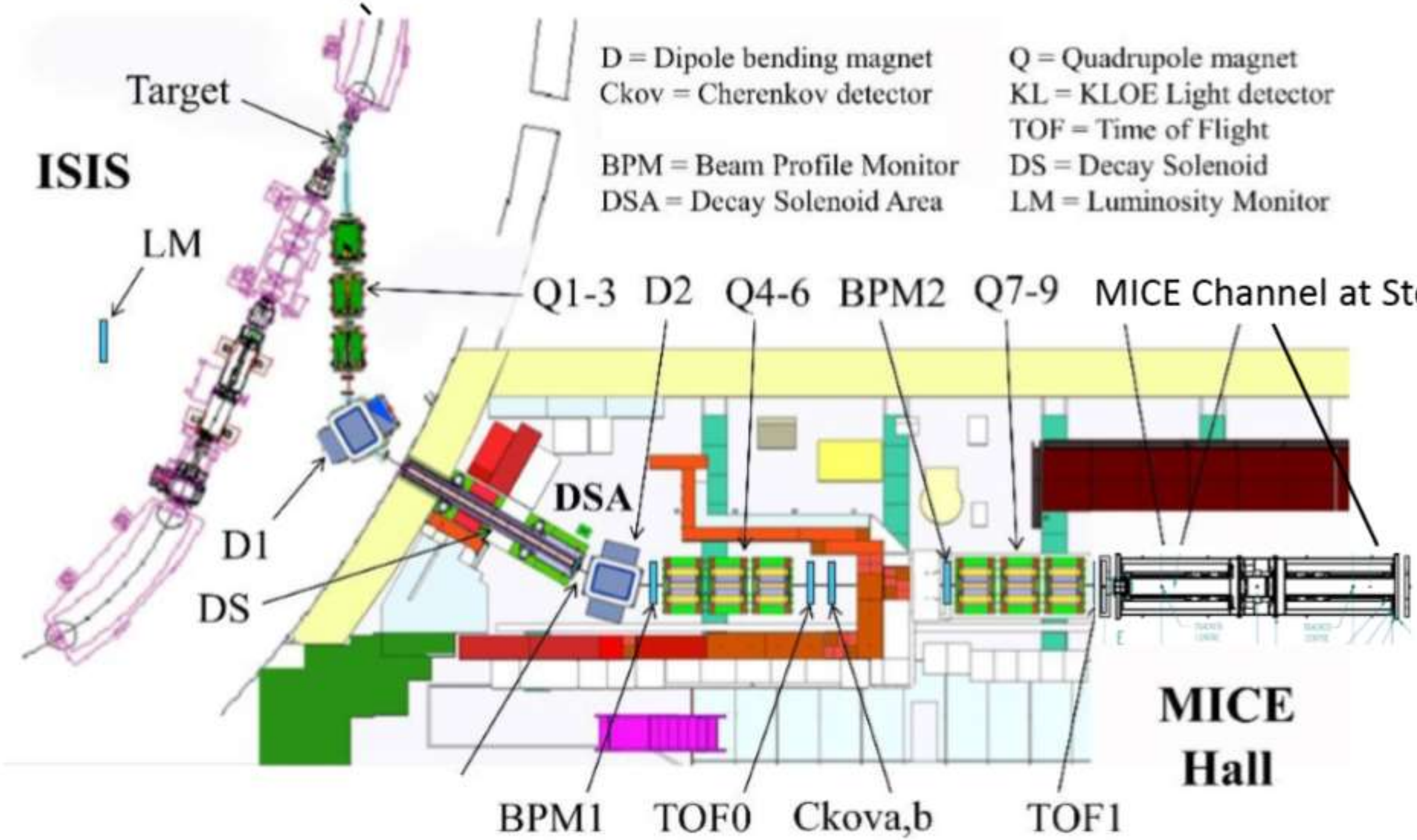






Muon
Ionisation
Cooling
Experiment

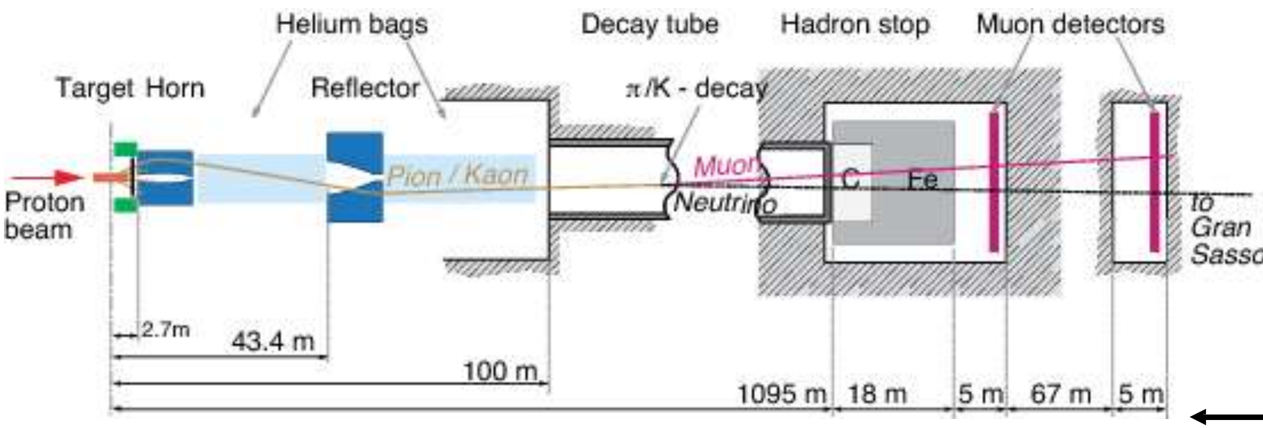
MICE Beamline



MICE Beamline
Conceptual Layout

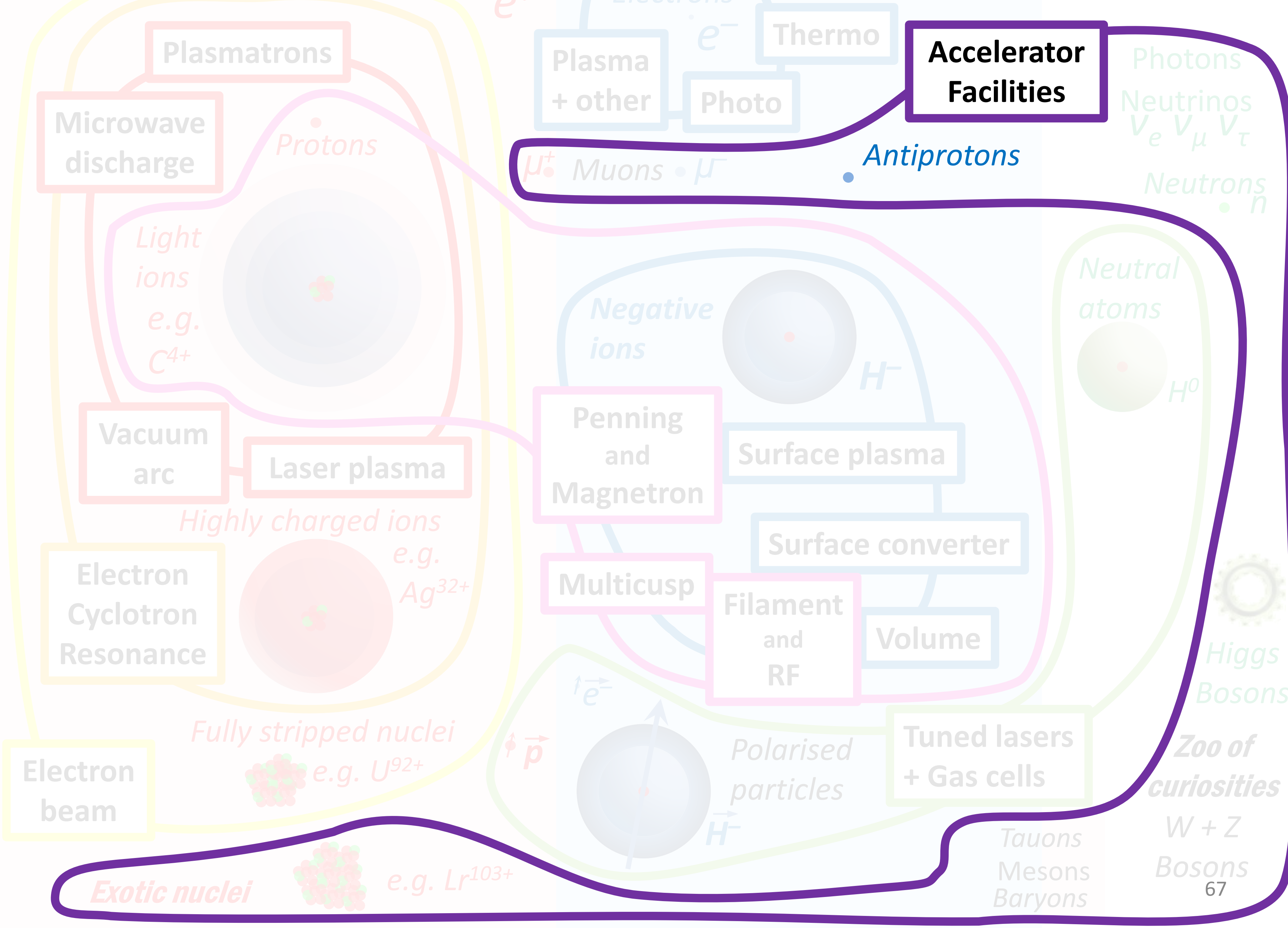
Mice demonstrated muon cooling in 1D

CERN Neutrinos to Gran Sasso (**CNGS**)



732 km

Particles and **Sources**



Magnetic Horn

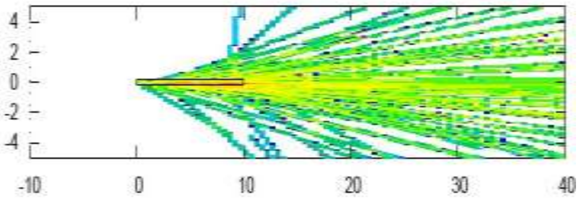
Simon van der Meer

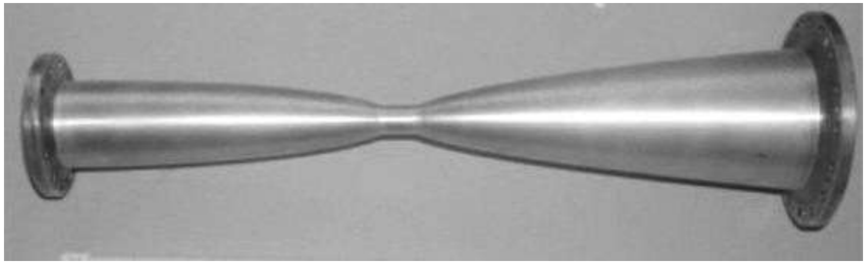
1960s "current sheet lens"
originally for neutrino beams
then for antiprotons

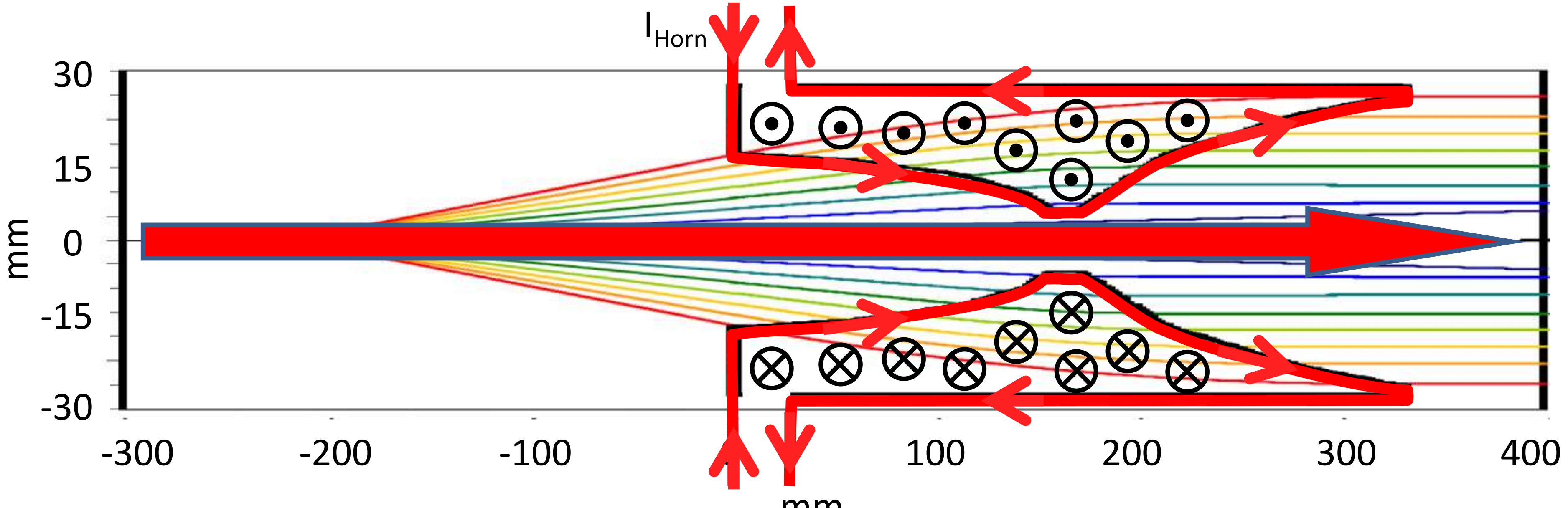
1.4 mm Al 400 kA 15 µs

(half-sine)

Magnetic Horn



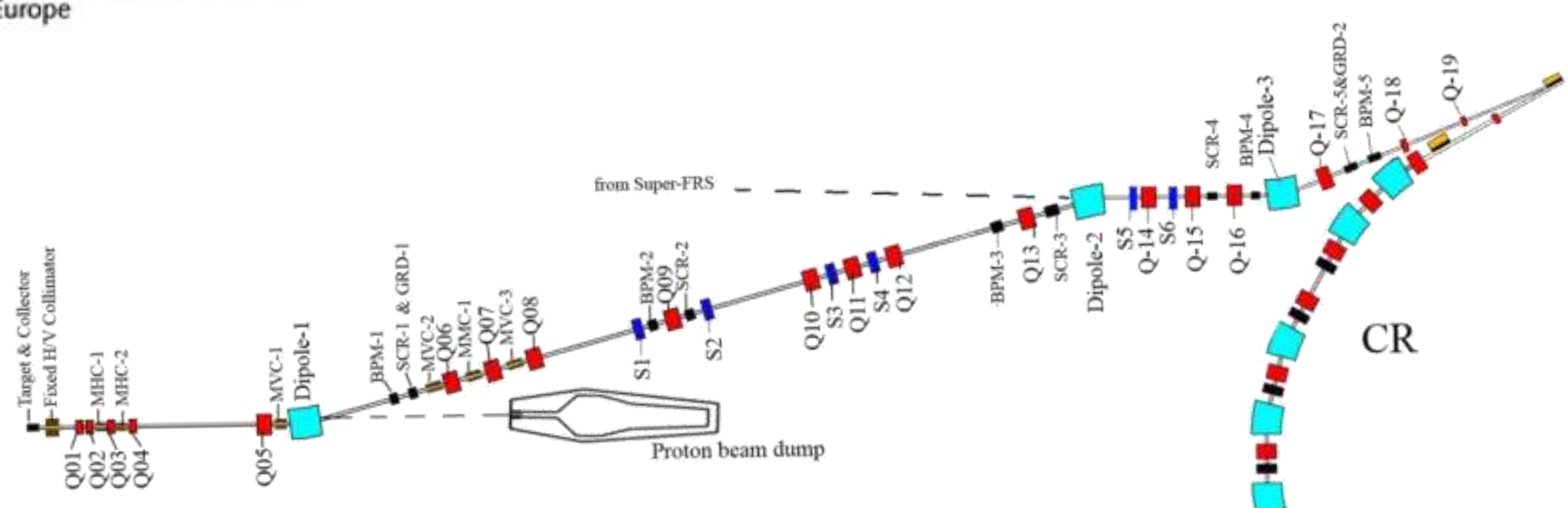




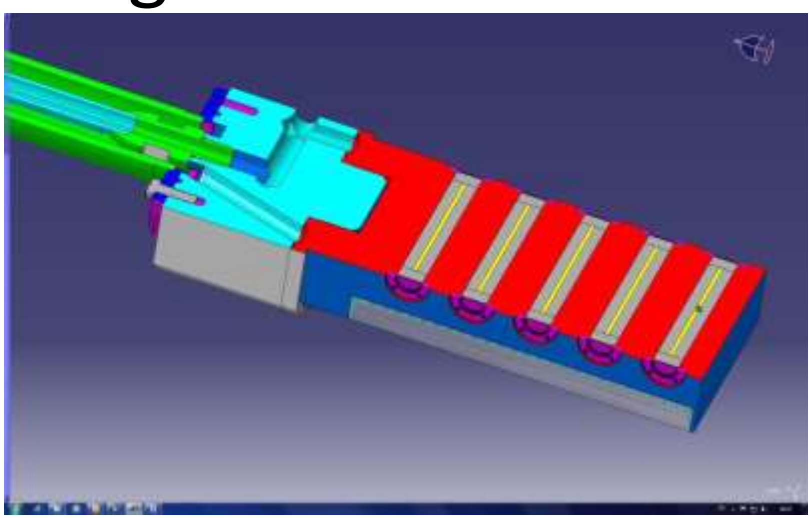
FAIR

FAIR — Facility for Antiproton and Ion Research in Europe

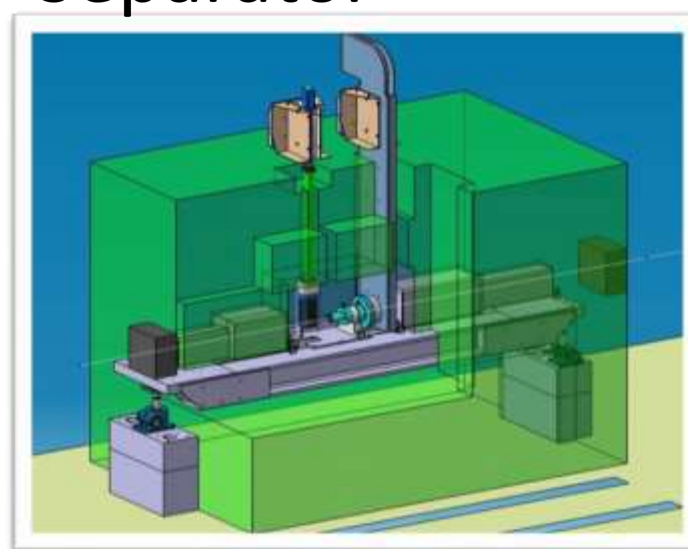
Beam Separation



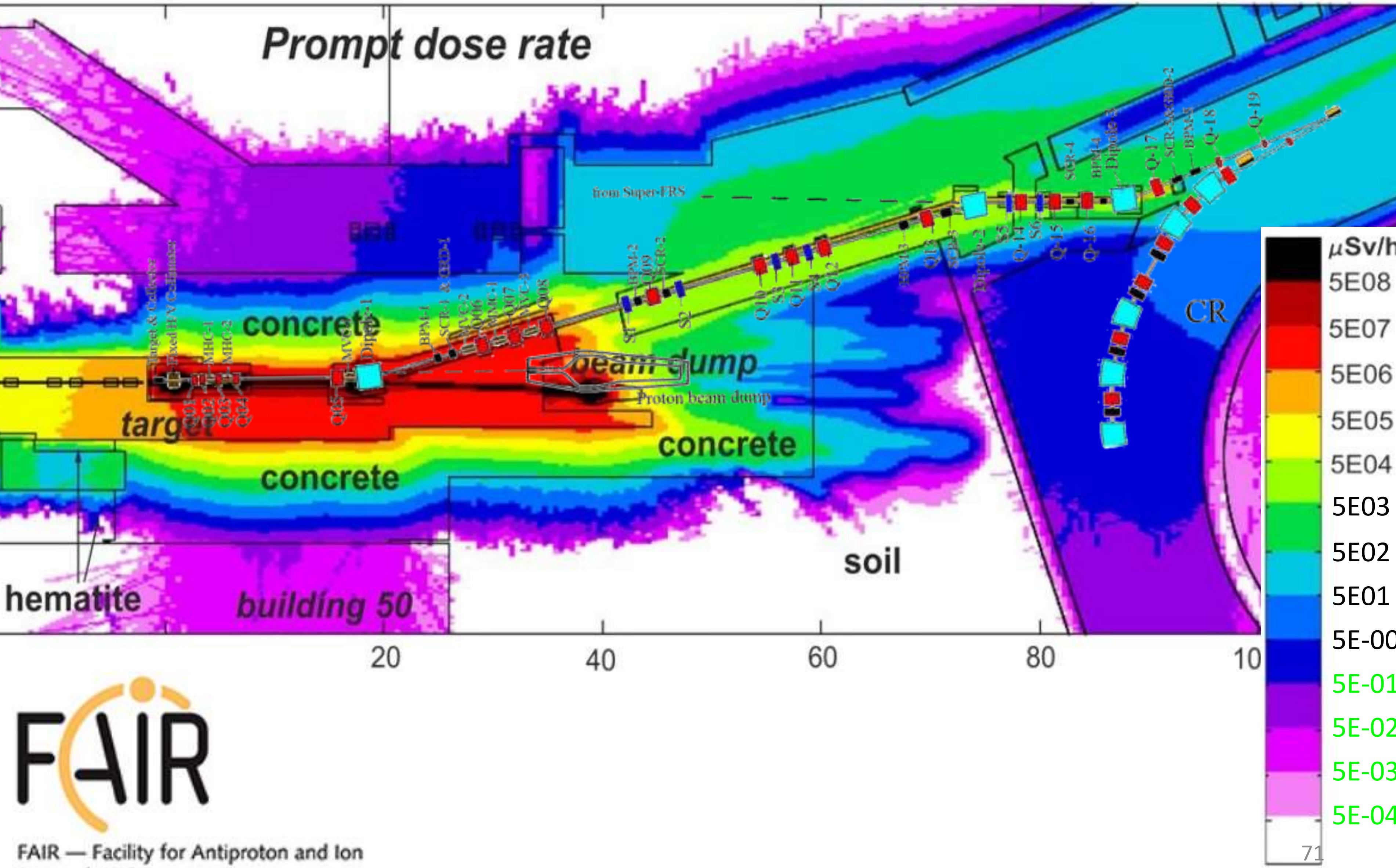
Target



Separator



Beam Separation



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Shielding Required

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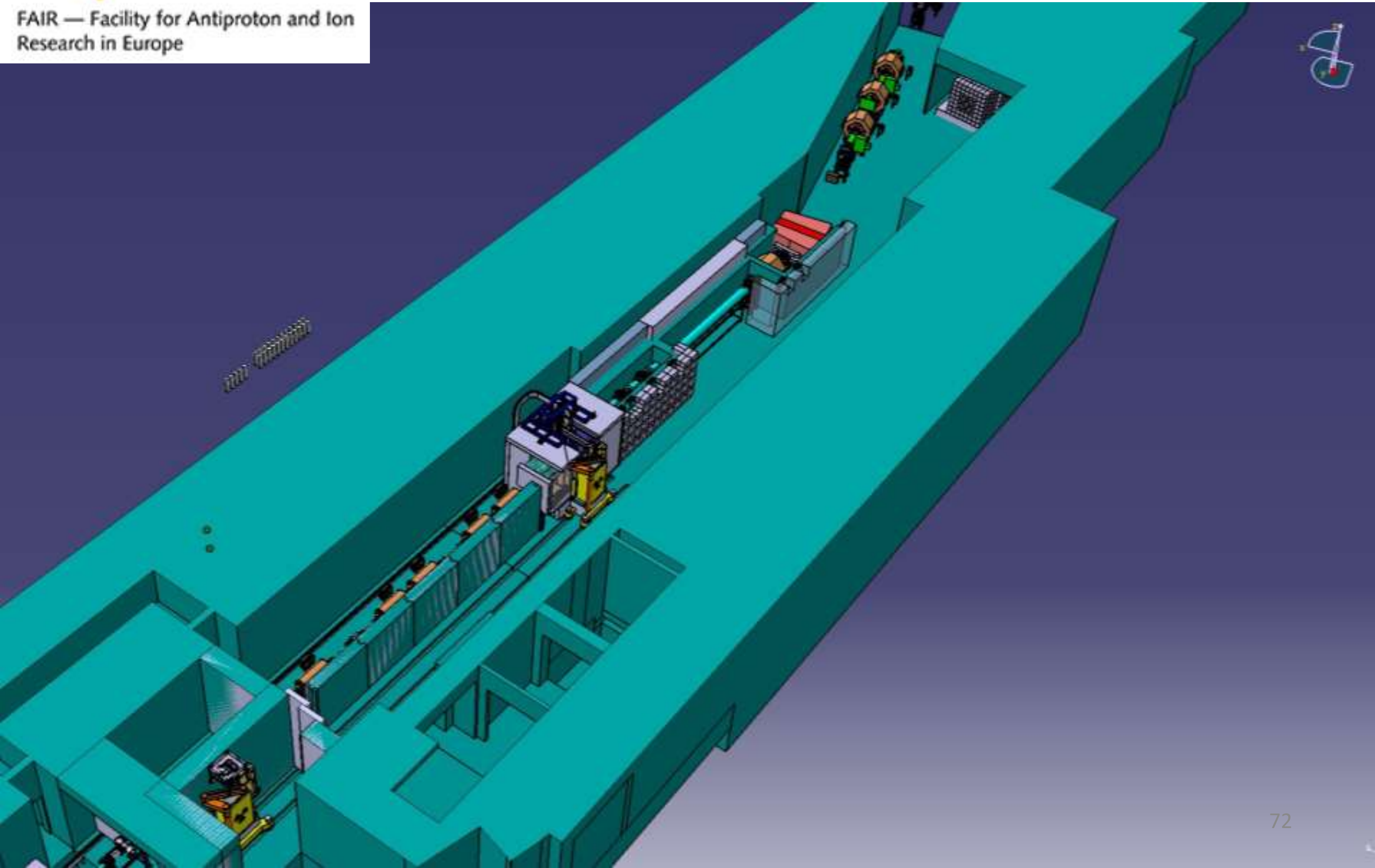
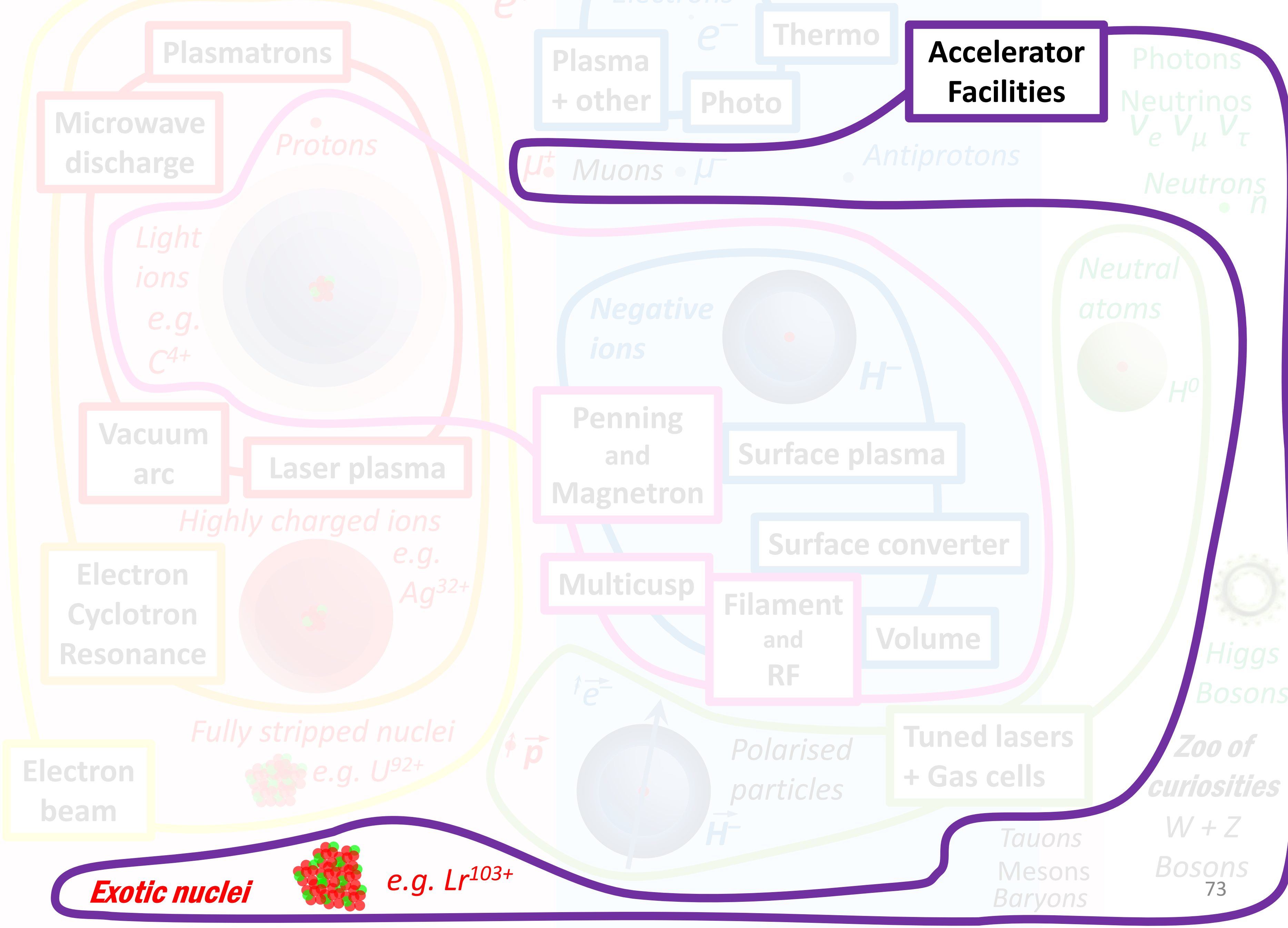
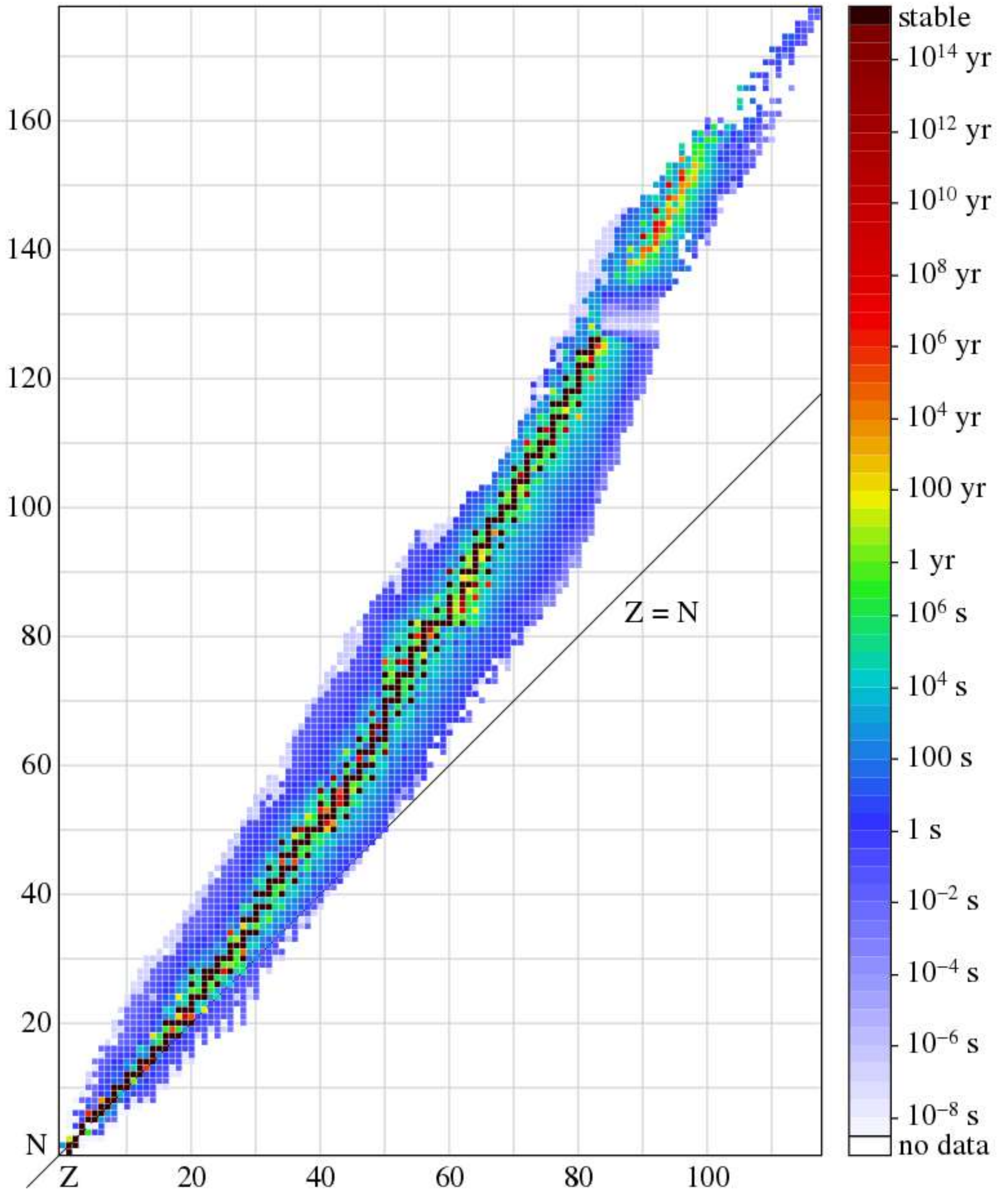


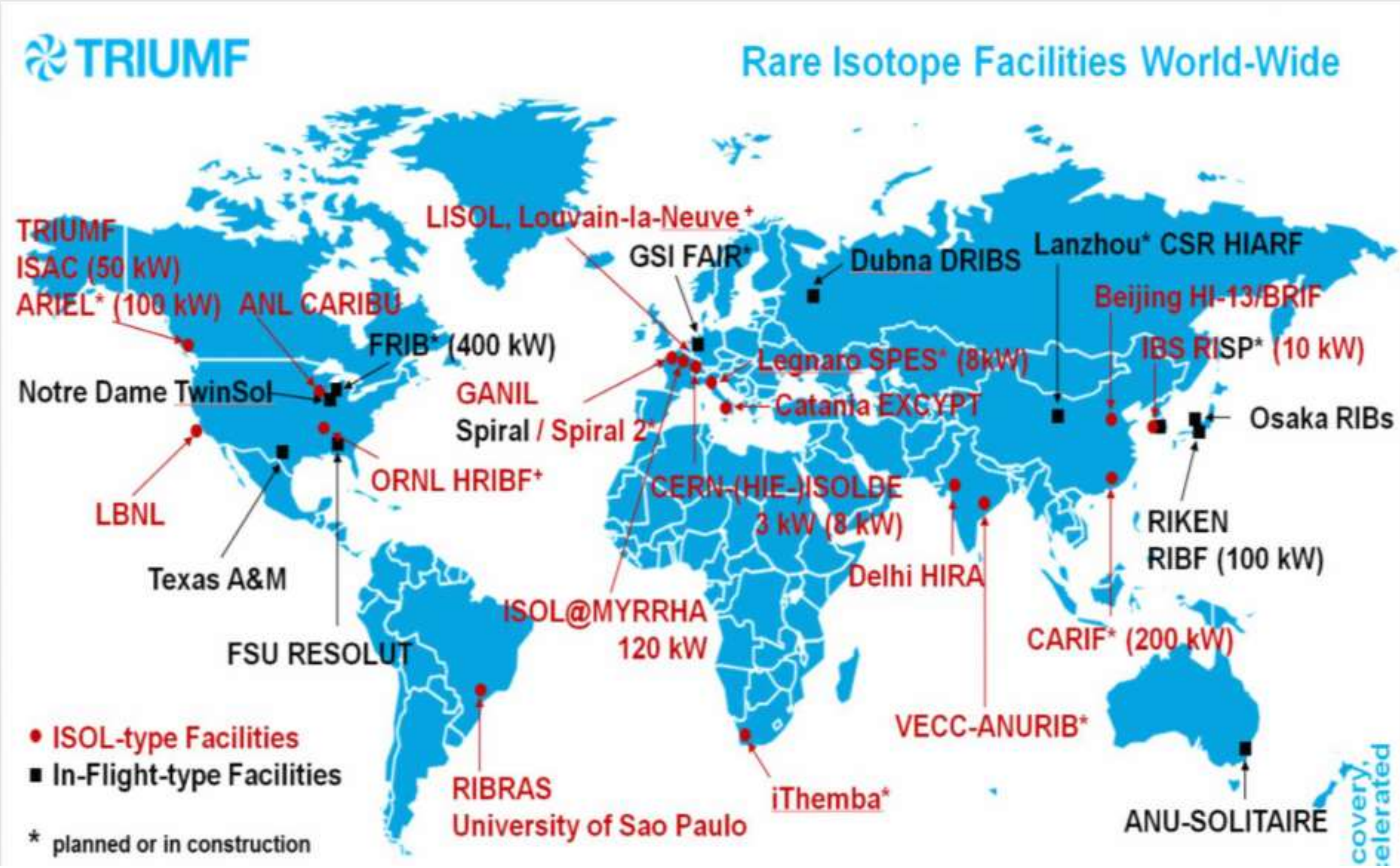
Particles and **Sources**





Radioactive Ion Beams

A powerful way of studying the atomic nucleus


TRIUMF
Rare Isotope Facilities World-Wide
TRIUMF
ISAC (50 kW)
ARIEL* (100 kW)
ANL CARIBU
FRIB* (400 kW)
Notre Dame TwinSol
LBNL
Texas A&M
FSU RESOLUT
ORNL HRIBF+
LISOL, Louvain-la-Neuve+
GSI FAIR*
GANIL
Spiral / Spiral 2*
Legnaro SPES* (8kW)
Catania EXCYPT
CERN-(HIE-)ISOLDE
3 kW (8 kW)
ISOL@MYRRHA
120 kW
Dubna DRIBS
Lanzhou* CSR HIARF
Beijing HI-13/BRIF
IBS RISP* (10 kW)
Osaka RIBs
RIKEN
RIBF (100 kW)
Delhi HIRA
CARIF* (200 kW)
VECC-ANURIB*
iThemba*
RIBRAS
University of Sao Paulo
ANU-SOLITAIRE
• ISOL-type Facilities
■ In-Flight-type Facilities
* planned or in construction

ISOL vs In Flight Fragmentation

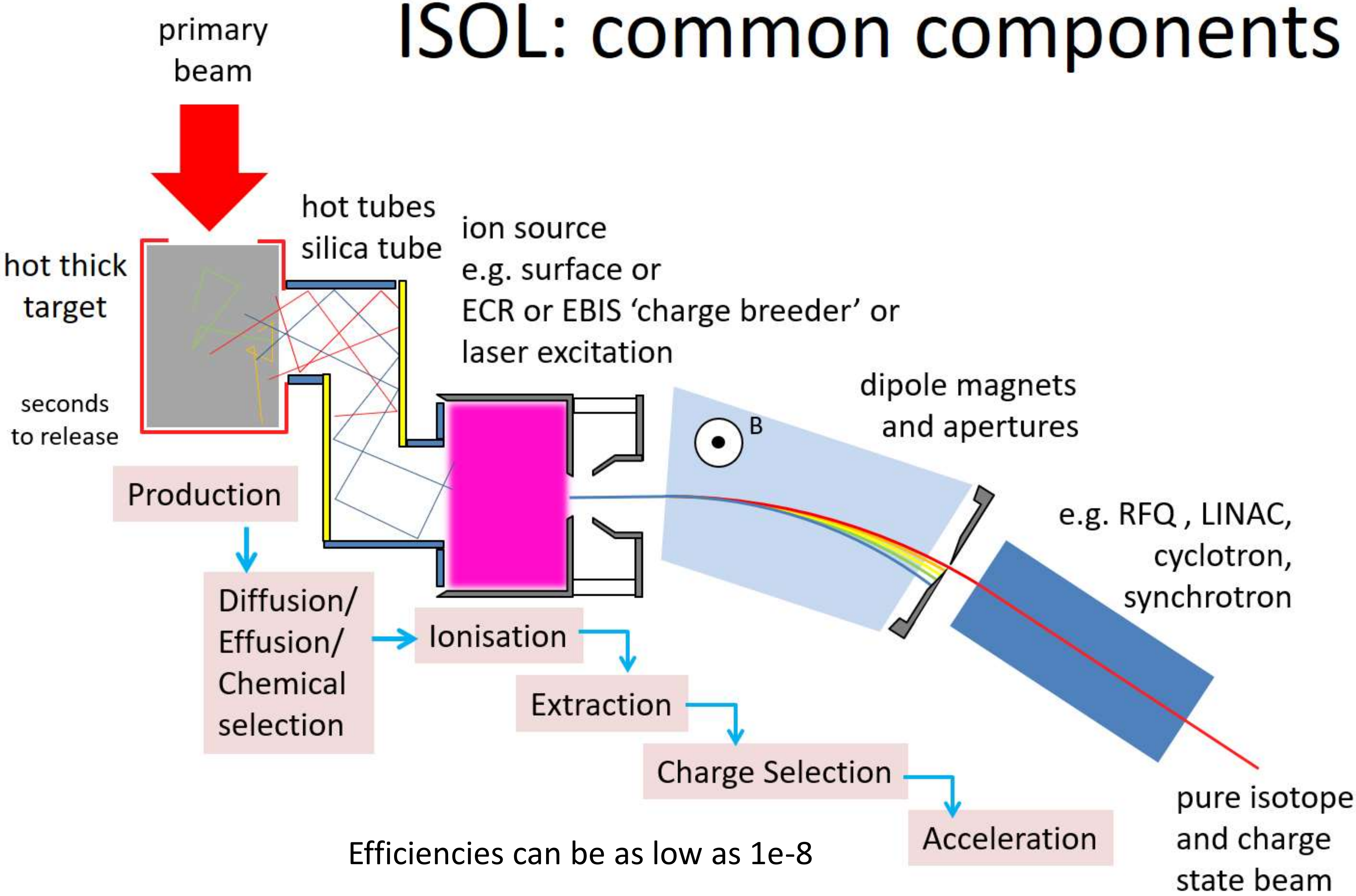
Isotope Separation On Line (ISOL): A production line

A → B → C → D → E → F

Very complicated chains of acceleration and separation have been created

In Flight Fragmentation:
Filtering an explosion

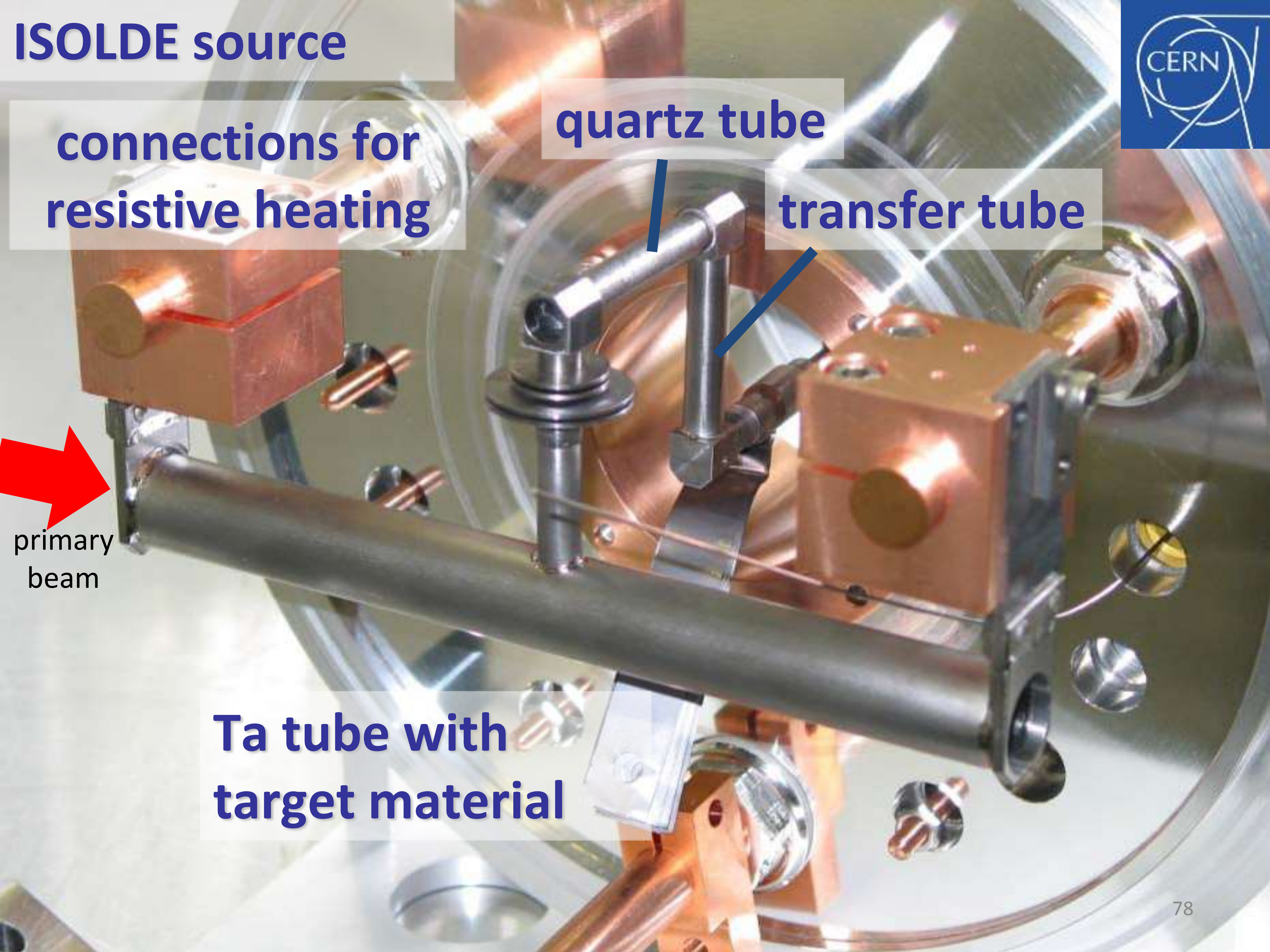
ISOL: common components

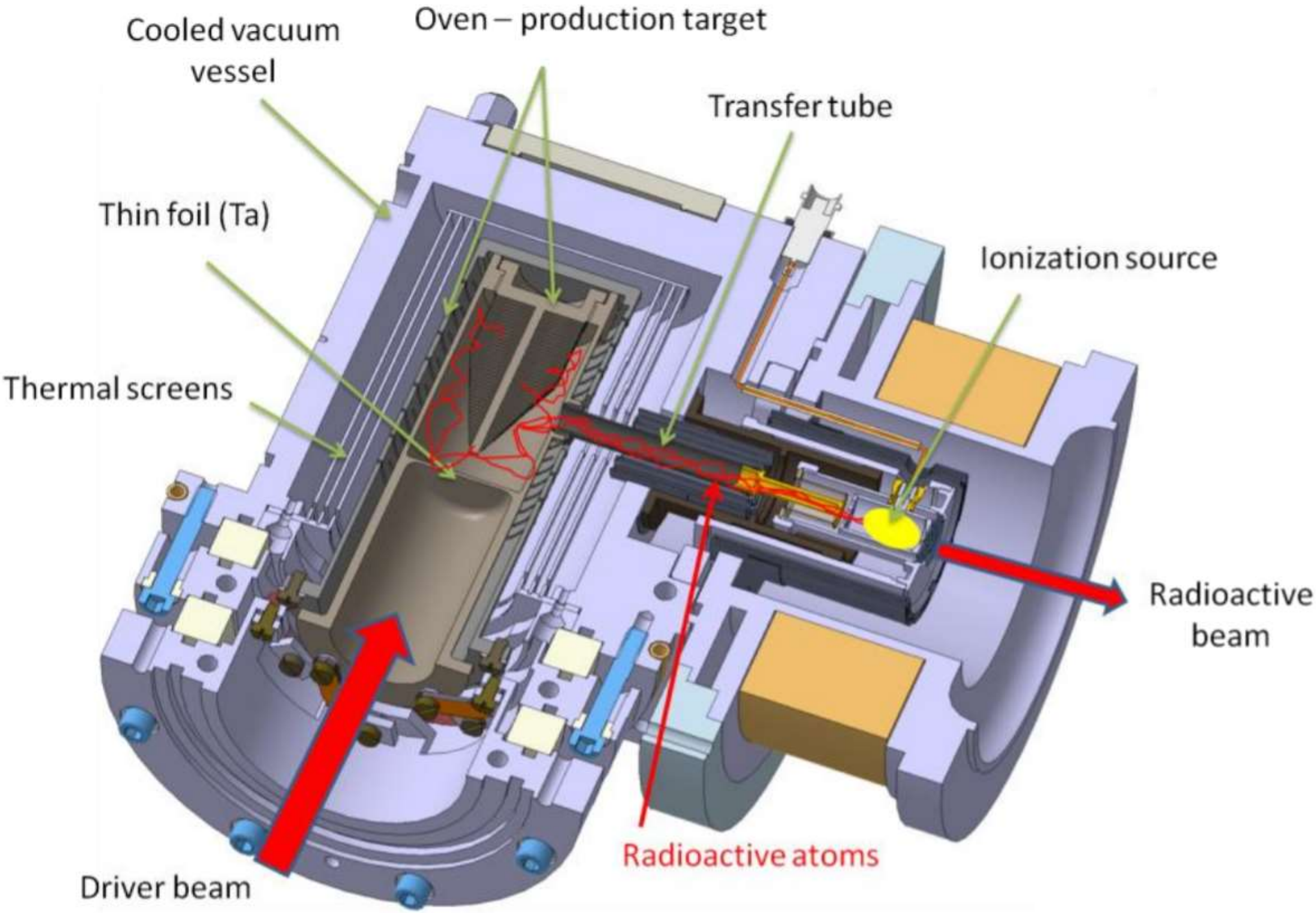


Efficiencies can be as low as 1e-8

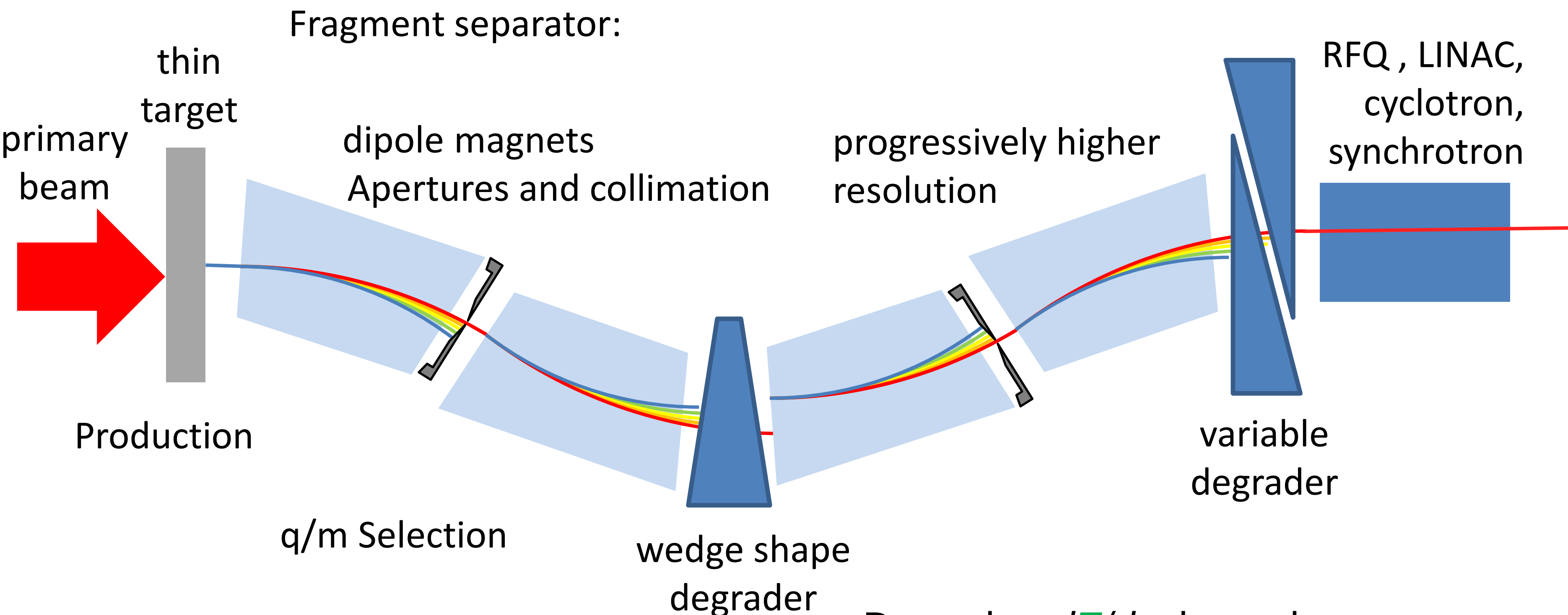
ISOL produces very pure beams with "long" half life

ISOLDE source



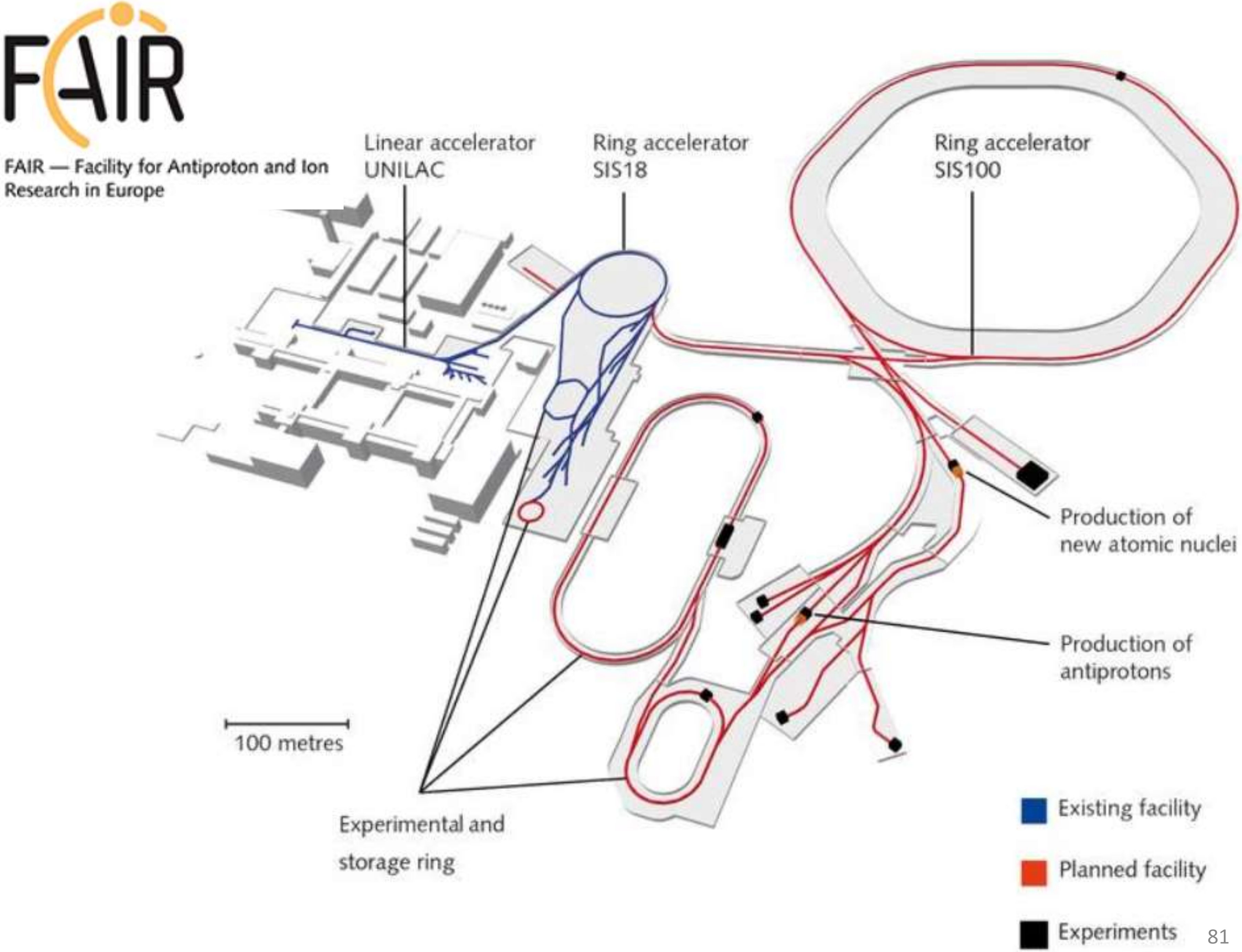

Cooled vacuum vessel
Oven – production target
Transfer tube
Thin foil (Ta)
Ionization source
Thermal screens
Radioactive beam
Radioactive atoms
Driver beam

In Flight Fragmentation: common components

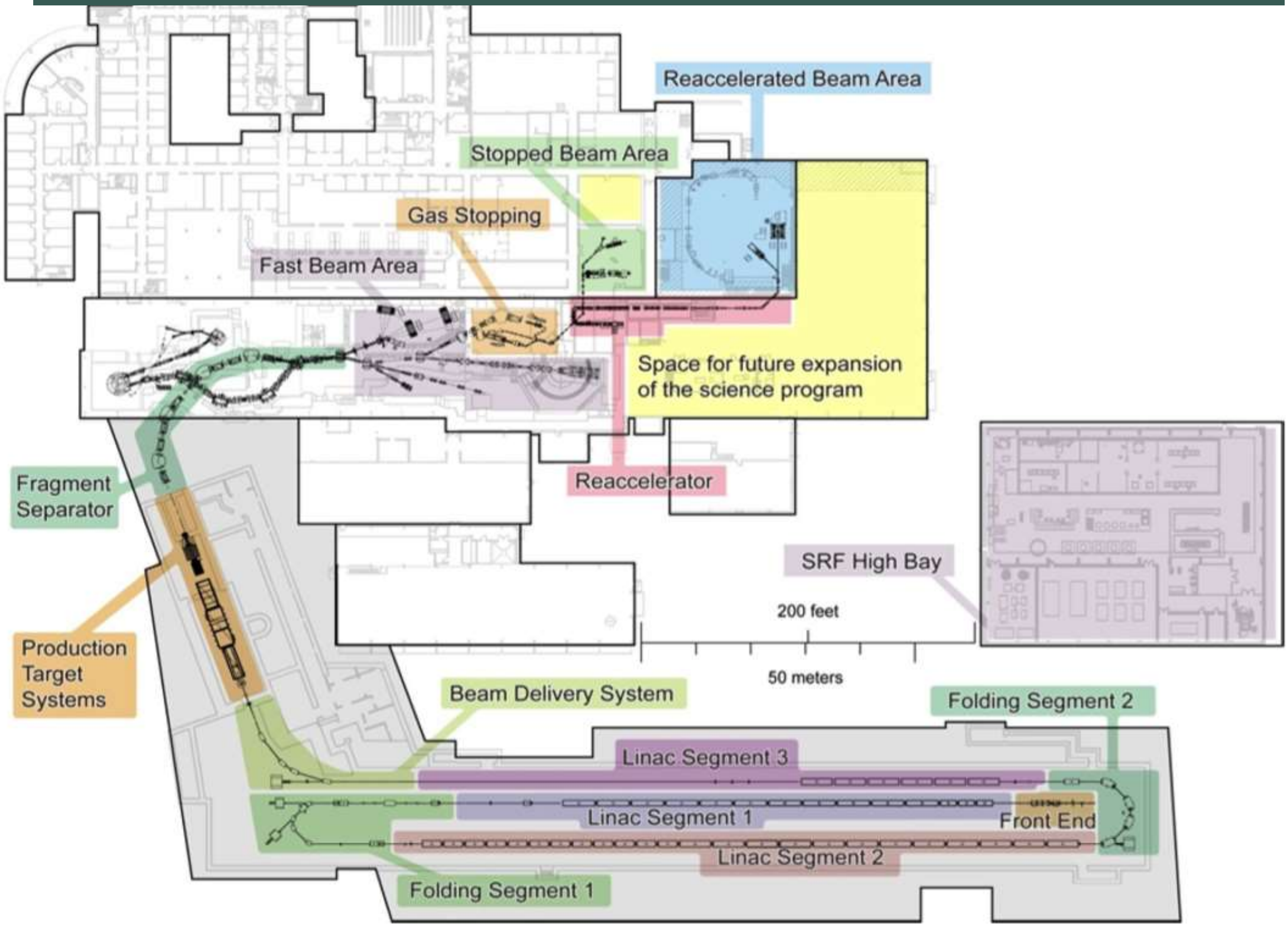


Degrader: *dE/dx* depends on projectile's ***Z***.

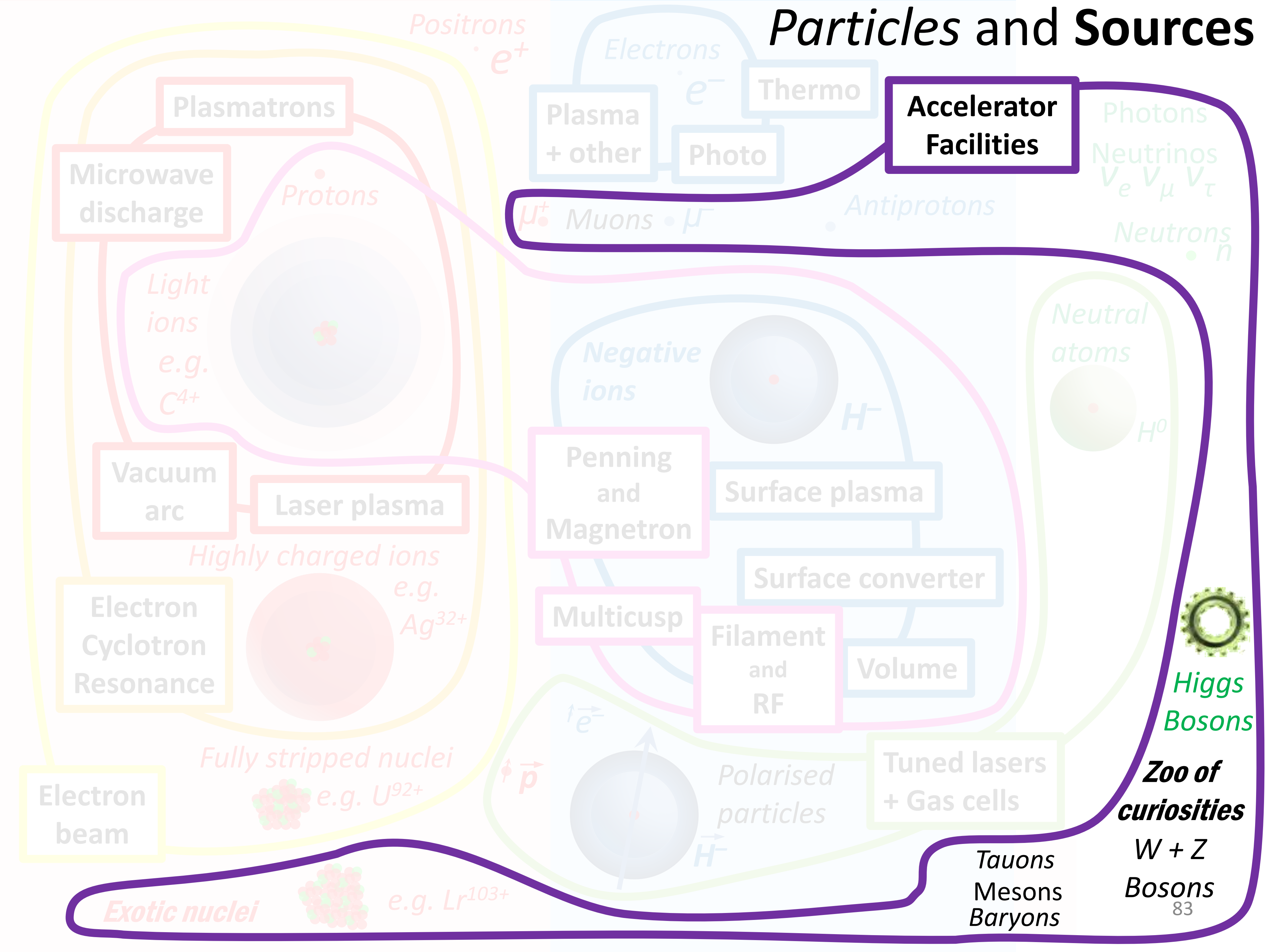
In flight fragmentation suitable for very short half life beams


FAIR
FAIR — Facility for Antiproton and Ion Research in Europe
Linear accelerator UNILAC
Ring accelerator SIS18
Ring accelerator SIS100
Production of new atomic nuclei
Production of antiprotons
100 metres
Experimental and storage ring
Existing facility
Planned facility
Experiments

Facility for Rare Isotope Beams
at Michigan State University



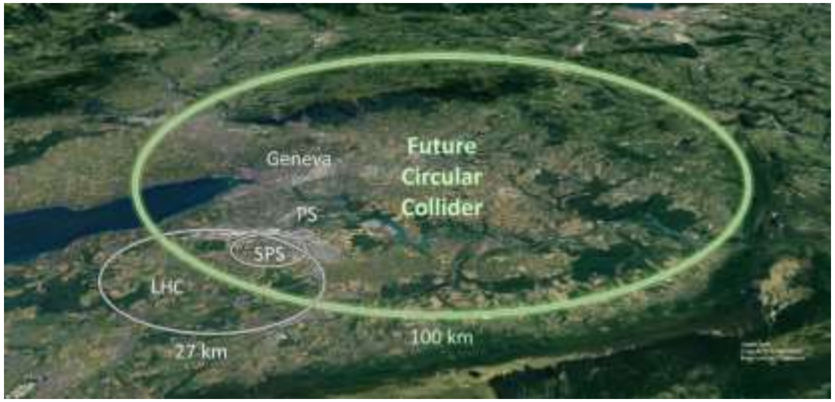
Particles and **Sources**



Future Colliders

CLIC Compact Linear Collider

NLC The Next Linear 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?