CINP Briefs:

Nuclear Astrophysics with Storage Rings

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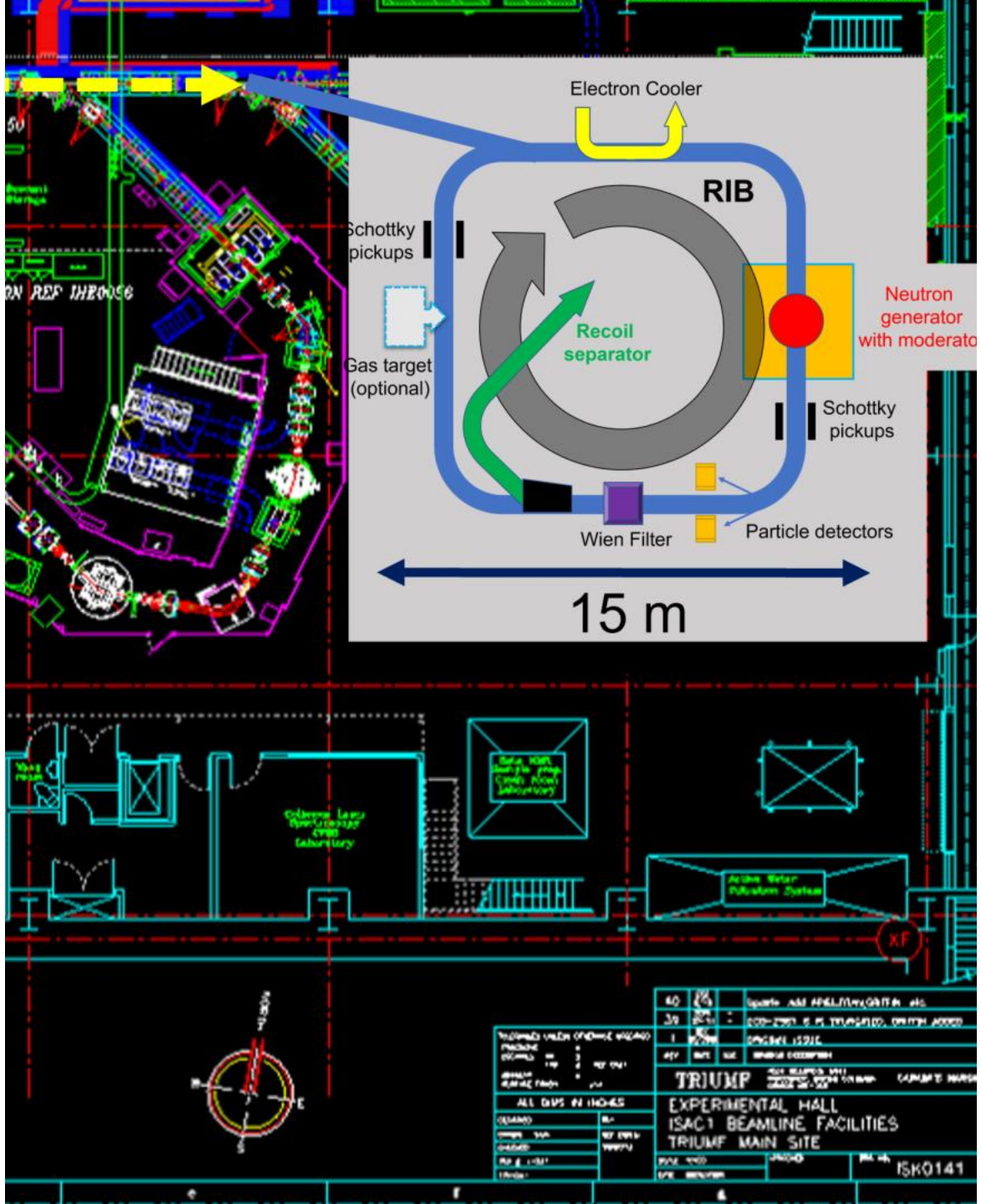


Two Briefs about Storage Rings

1. Decay Spectroscopy of Exotic Nuclei at GSI (ongoing)
2. TRISR - A dedicated storage ring for neutron captures on radioactive nuclei (future)

What is the role of radioactive nuclei in shaping the visible matter in the universe?

One of the 5 key questions in Nuclear Physics from the Report of the Canadian Institute of Nuclear Physics
"The 2022 – 2036 Horizon for Nuclear Physics in Canada - From the Core of Matter to the Fuel of Stars"

Where do our building blocks come from?

How can we measure them in the laboratory?

LEGO CUUSO Research Institute

"The 2022-2036 Horizon for Nuclear Physics in Canada" Report,
Canadian Institute of Nuclear Physics (CINP)
Input for Canadian Subatomic Physics Long Range Plan

TRIUMF

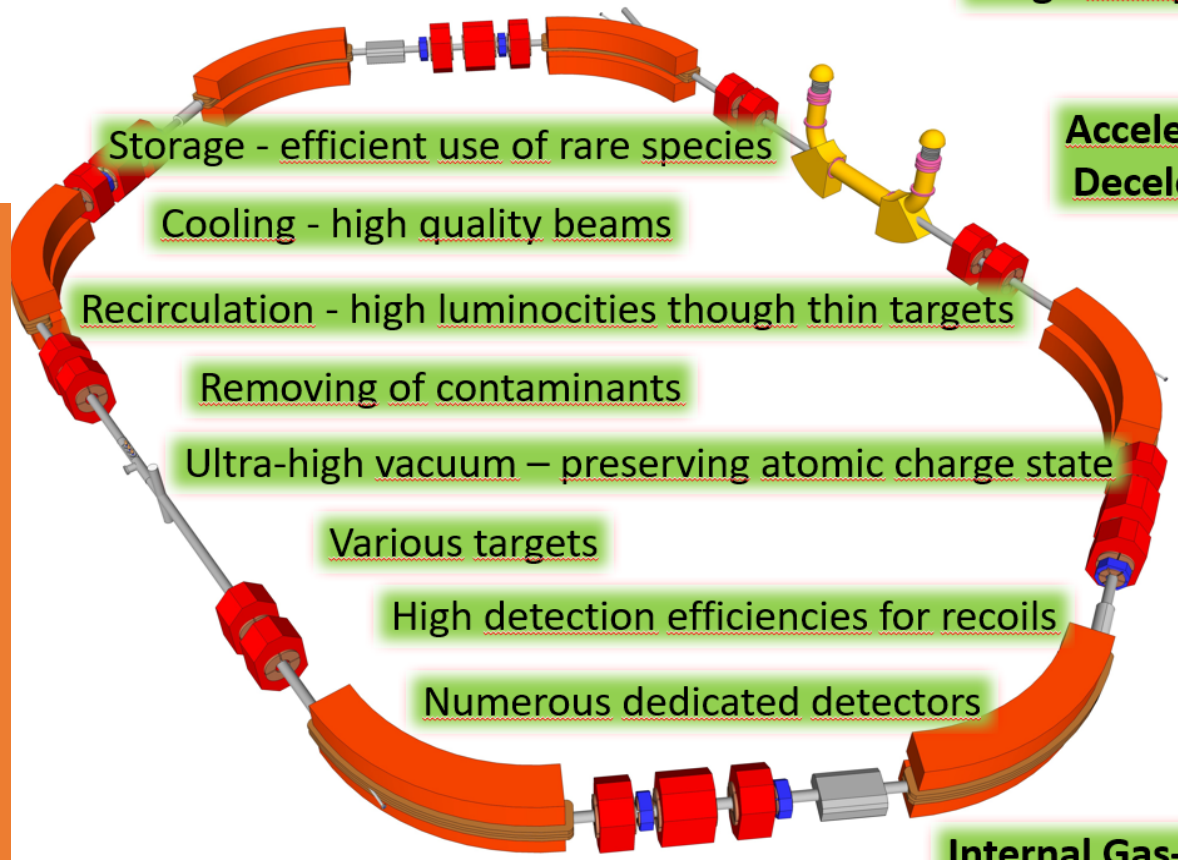
Unique environment!

- Beam cooling, manipulation, accumulation, …
- Long storage times (hours!)
- High charge states
- **Multi-pass experiments (reactions)**

→ Unique experiments!

Slide from Yuri Litvinov

Why storage rings? - Versatile Capabilities



Storage - efficient use of rare species

Cooling - high quality beams

Recirculation - high luminocities though thin targets

Removing of contaminants

Ultra-high vacuum – preserving atomic charge state

Various targets

High detection efficiencies for recoils

Numerous dedicated detectors

Large Acceptance

Beam Accumulation

Acceleration/ Deceleration

Beam Cooling:
- Stochastic
- Electron
- (Laser)

UHV

Beam Bunching

Various targets:
- Electrons
- Photons
- Atoms
- (Ions)
- (Neutrons)

Detection:
- Electrons
- Photons
- Recoils

Internal Gas-Jet Target

Non-destructive particle detection

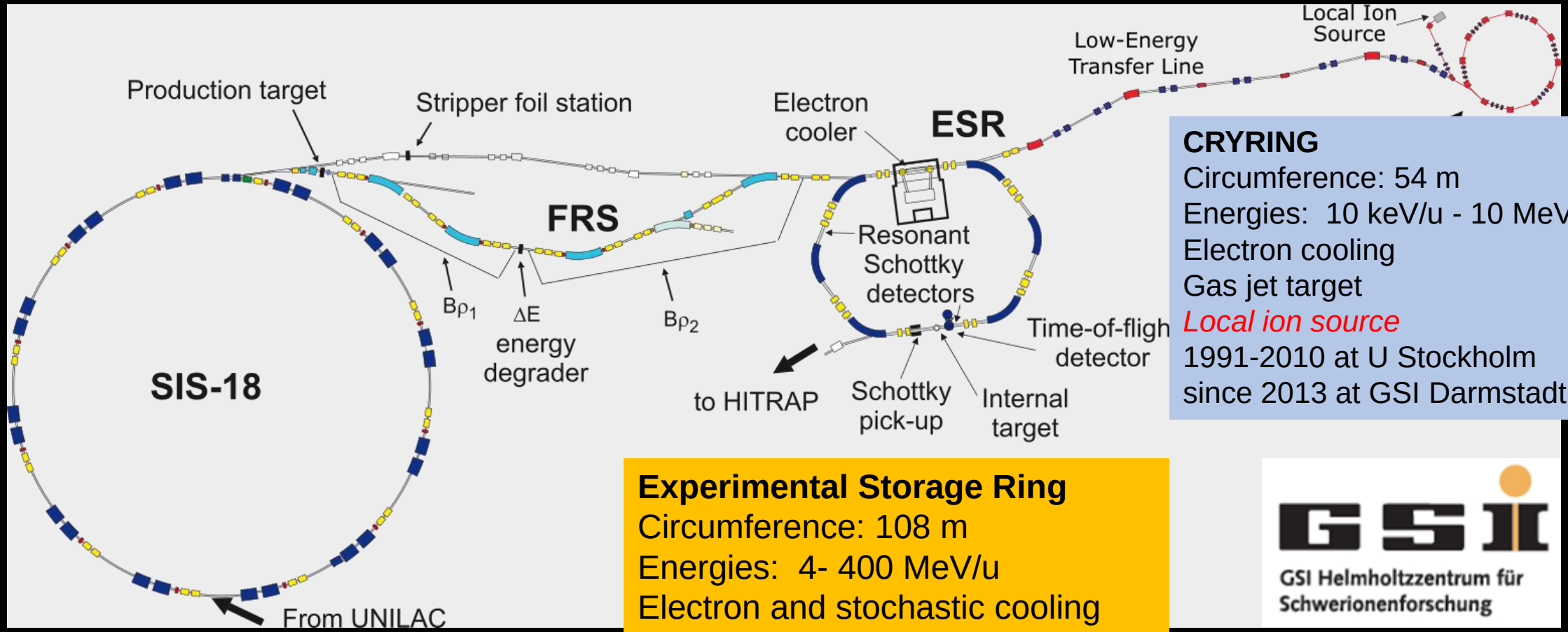
erc ASTRUm

HELMHOLTZ GSI

Discovery, accelerated

ESR and CRYRING at GSI Darmstadt

CRYRING



CRYRING
Circumference: 54 m
Energies: 10 keV/u - 10 MeV/u
Electron cooling
Gas jet target
Local ion source
1991-2010 at U Stockholm
since 2013 at GSI Darmstadt

Experimental Storage Ring
Circumference: 108 m
Energies: 4- 400 MeV/u
Electron and stochastic cooling
Gas jet target
Since 1990

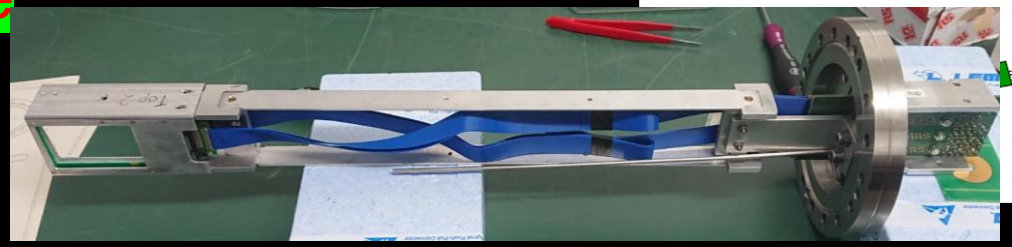
GSI Helmholtzzentrum für Schwerionenforschung

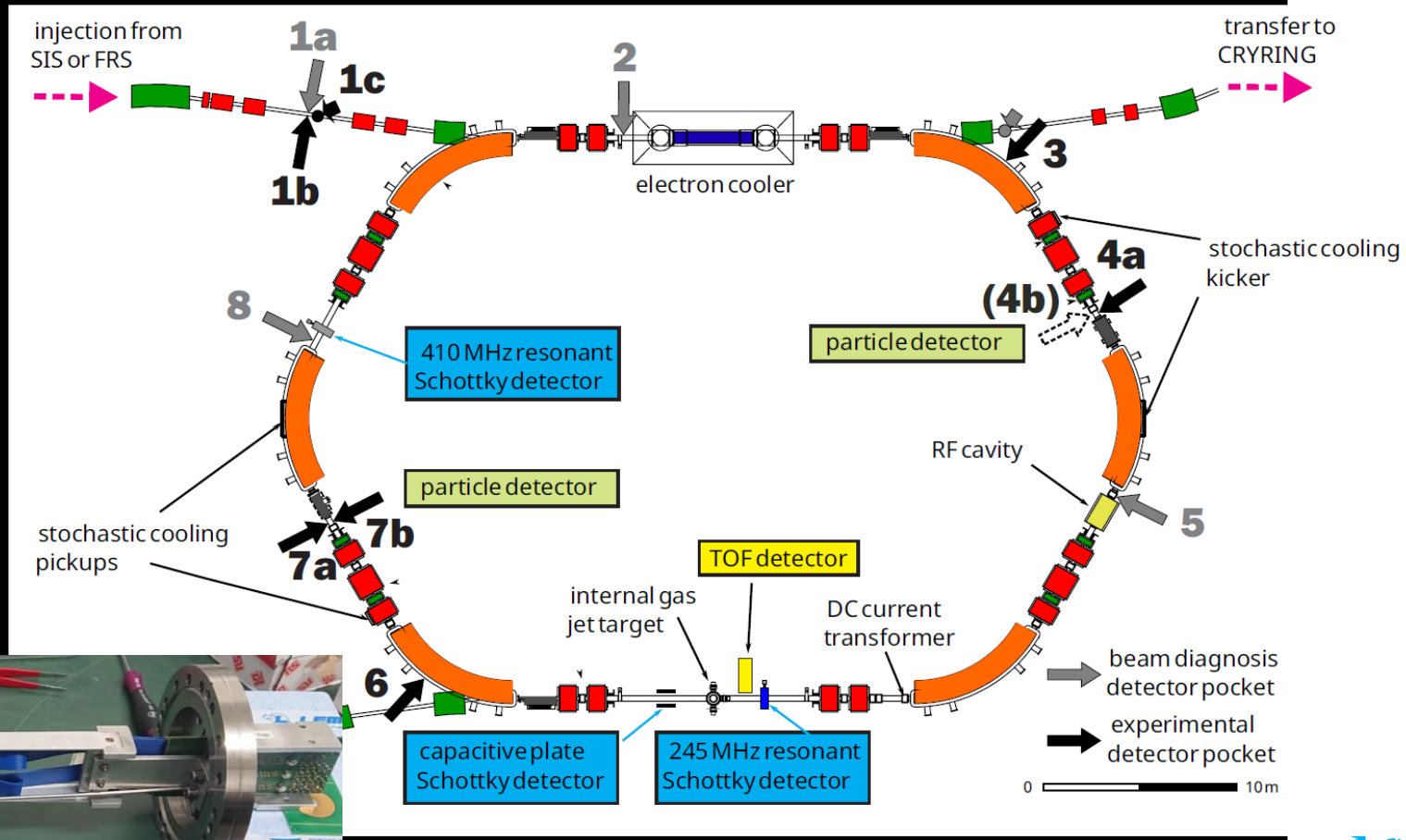
ILIMA@ESR (existing setups)

TOF detector: Isochronous Mass Spectrometry

Schottky pickups: Time-resolved mass spectrometry, destruction-free ion detection

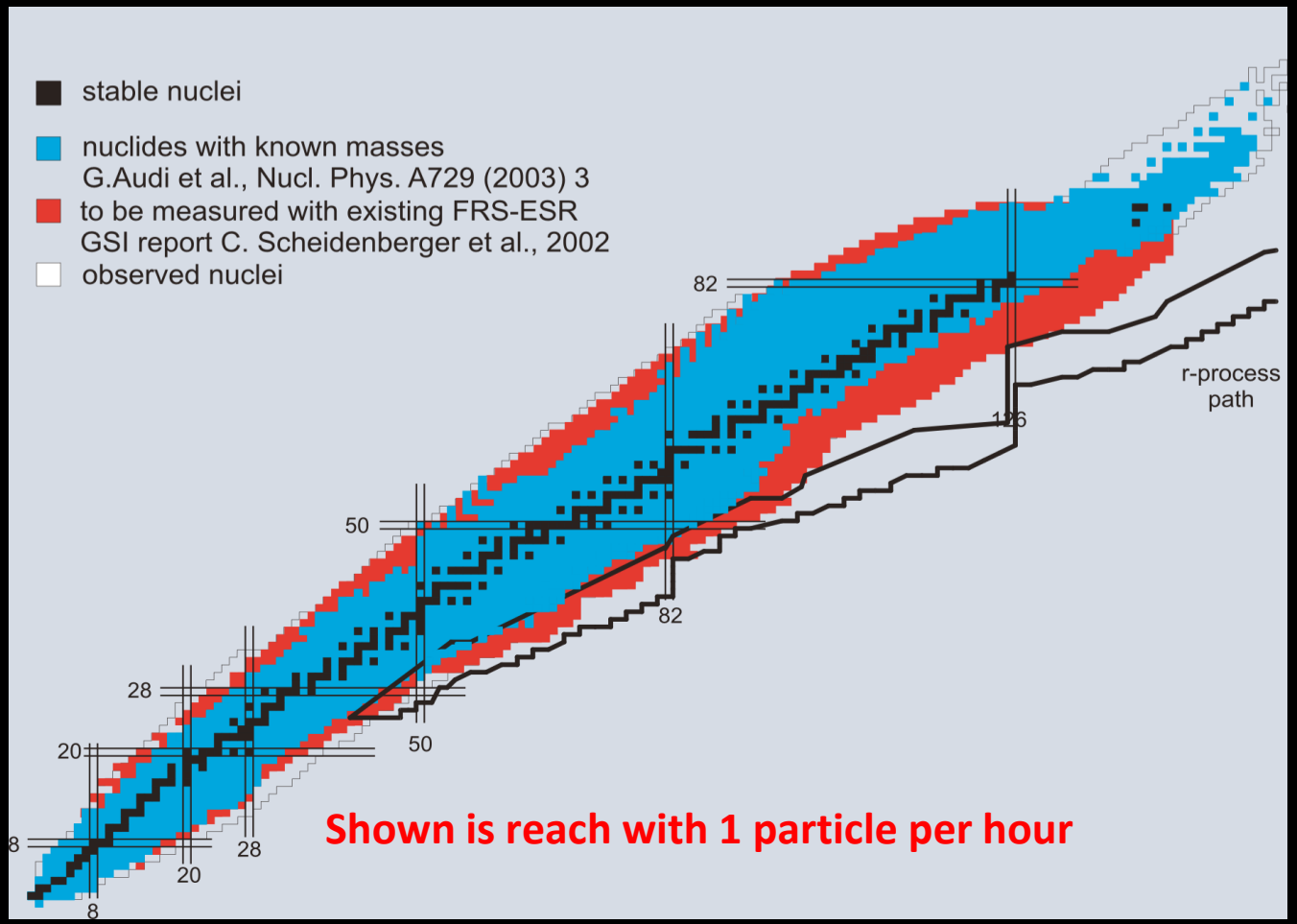
Two particle detectors (pocket): Particle detection outside of acceptance





NSERC RTI-funded

ILIMA@ESR Physics Program (>2025)



Measure masses, lifetimes and decay modes of ground and isomeric states of exotic nuclei ($t_{1/2}$> 10 μs):

- Map large areas of unknown mass surface
- Lifetimes of highly-charged ions, rare decay modes, branching ratios
- Isomeric states and their nuclear properties

New developments (existing and upcoming)

- Time-resolved Schottky + Isochronous Mass Spectroscopy (S+IMS)
- Position-sensitive TOF detectors
- **Reaction studies at ESR and CRYRING**
- **Investigations with pure isomeric beams**
- Nuclear Excitation by EC (NEEC)

"One-pass experiments"

How to measure cross sections?

Beam

Target

p/ α/ n → **Stable/ long-lived nuclei** → **Measure decay or reaction products**

down to ~10^{15} atoms

p/ α/ n → ~~**Short-lived nuclei**~~

"Inverse kinematics"

Short-lived nuclei

>10^5 pps

→ **Hydrogen**
Helium → **Measure decay and/or reaction products**

~~**Neutrons**~~

$t_{1/2}$ ~ 10 m

Indirect measurements

Deuterium

(d,p) reactions → **Measure decay and/or reaction products**

How to measure direct neutron cross sections?

Beam

Target

Neutrons → **Stable/ long-lived nuclei** → **Measure decay or reaction products**

down to ~10^{15} atoms

Neutrons → ~~**Short-lived nuclei**~~

"Inverse kinematics"

Short-lived nuclei → ~~**Neutrons**~~

>10^5 pps

$t_{1/2}$ = 10 m

Indirect measurements

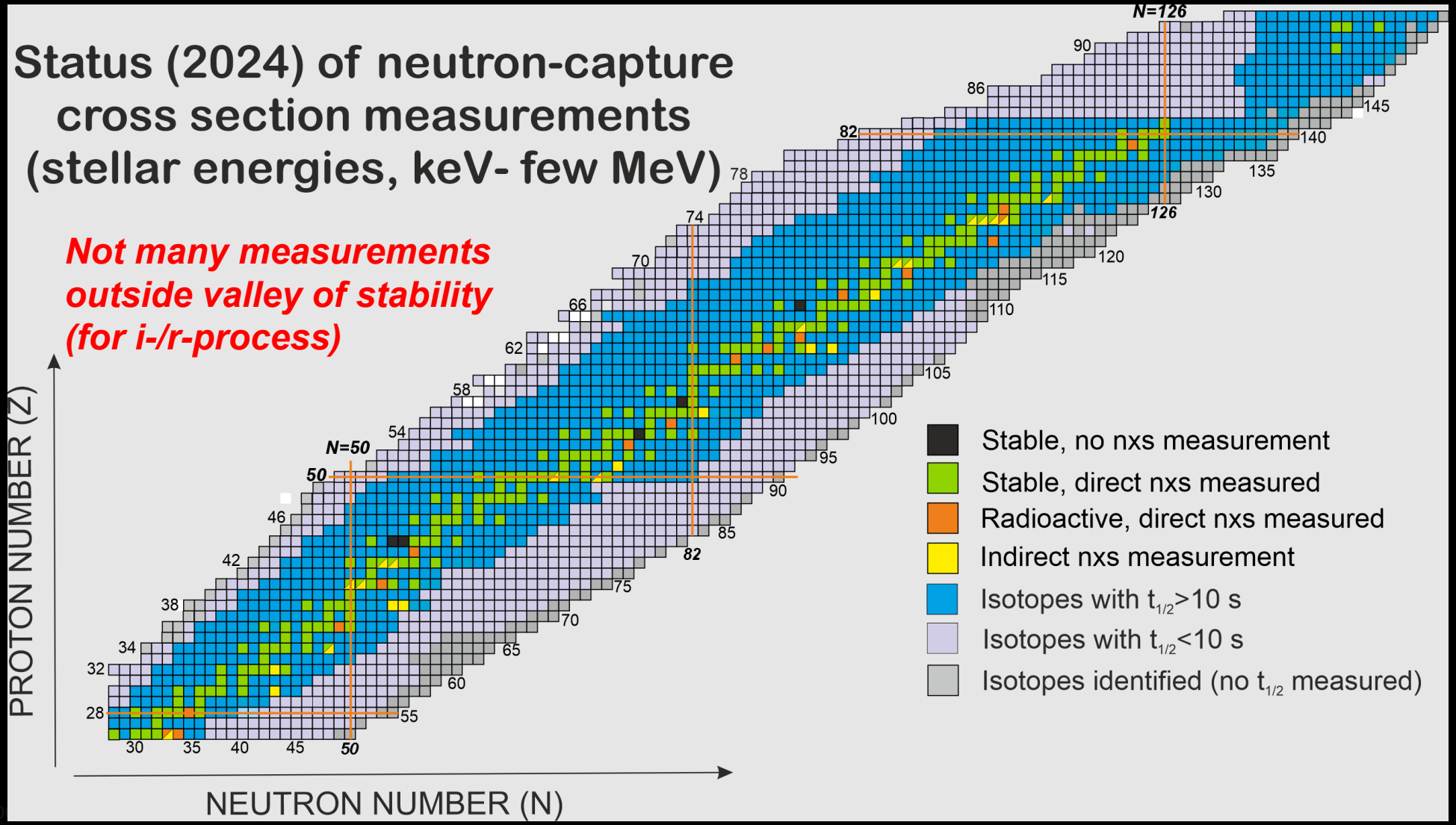
Deuterium → **Measure decay and/or reaction products**

(d,p) reactions

Short-lived nuclei → **Storage Ring** → **Neutrons** → **Measure reaction products**

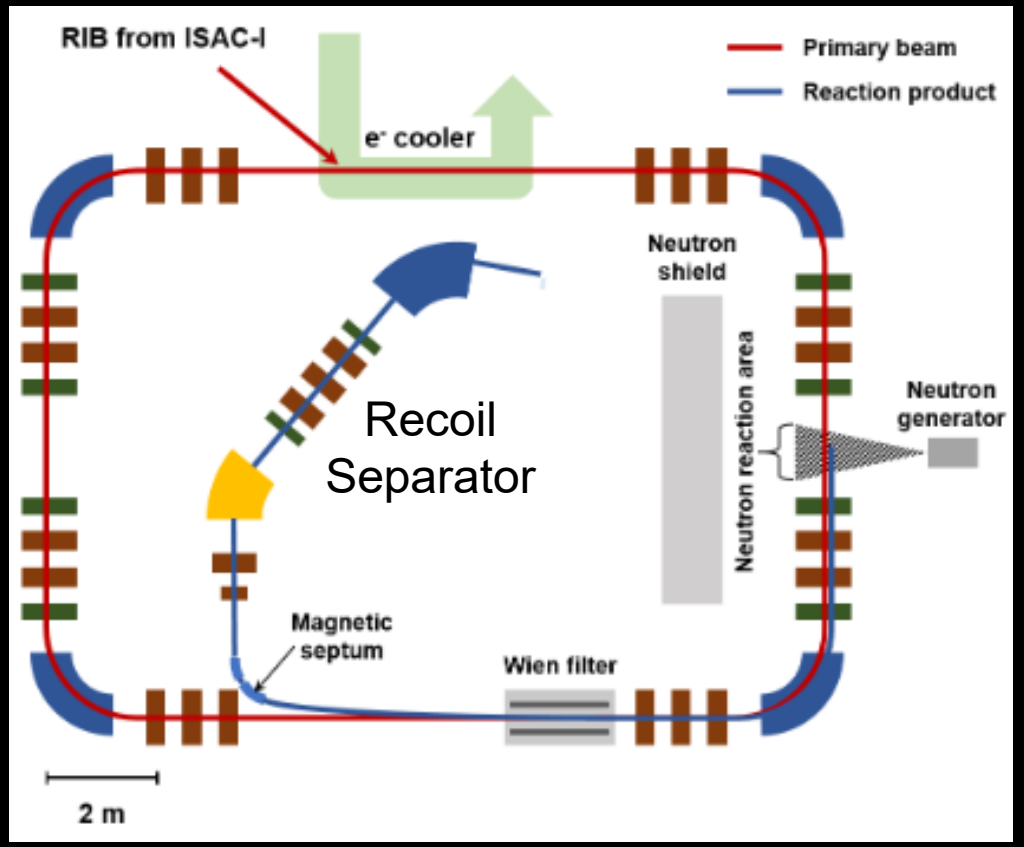
"Multi-pass experiments" (~MHz)

Astrophysical Neutron Capture XS



What is the next big thing?

Direct neutron capture reactions on **radioactive** nuclei ($t_{1/2}$>10s)!!!



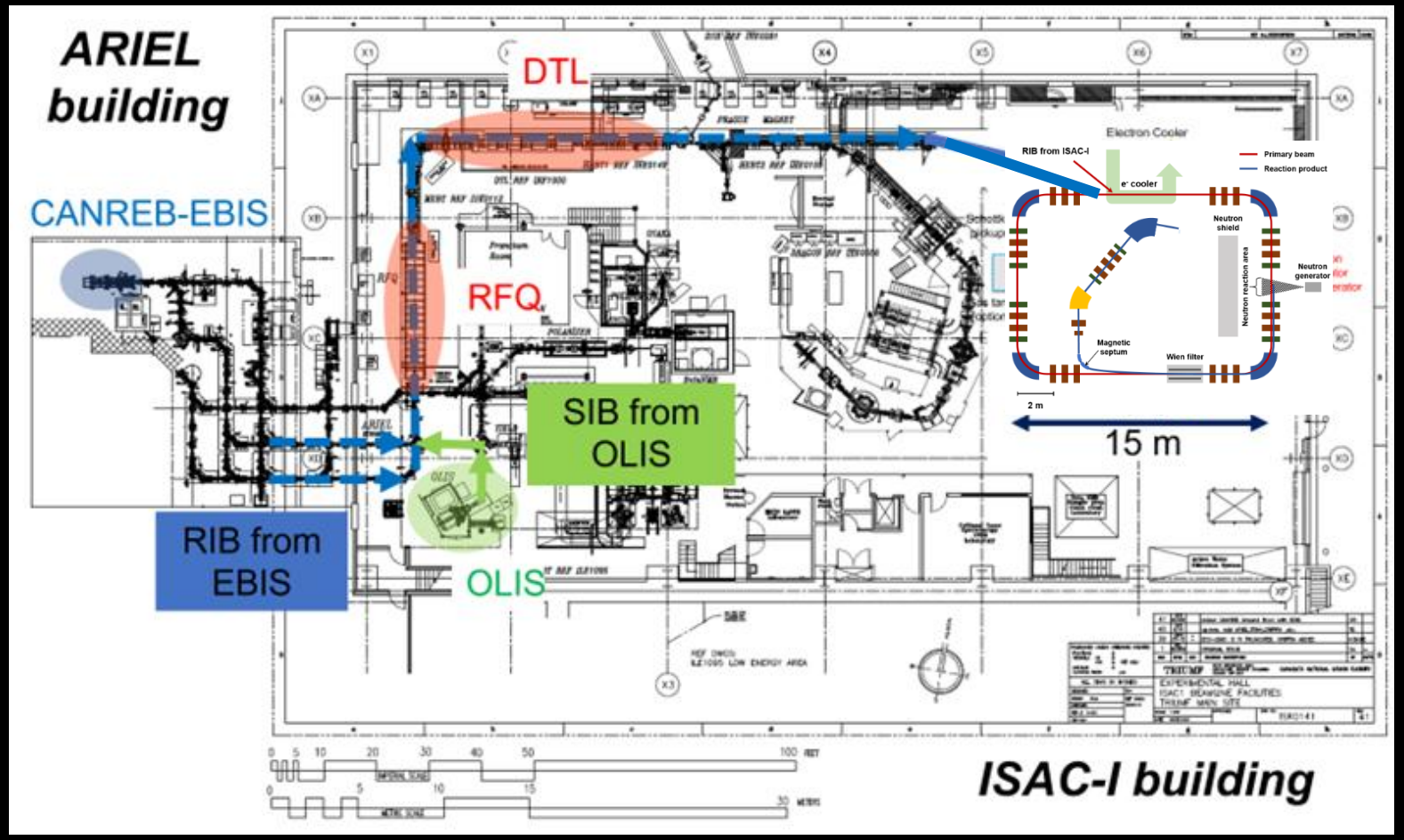
Step 1- ERC project NSTARS at CRYRING (under funding review):

- Develop neutron target and detection methods at existing low-energy storage ring (CRYRING at GSI)
- Make proof-of-principle neutron capture measurements
- Develop plan for “ideal” storage ring facility at ISOL facility “from scratch”

R. Reifarth and Y. Litvinov, PRST-Acc and Beams 17, 014701 (2014)
R. Reifarth et al., PR Acc and Beams 20, 044701 (2017)
I. Dillmann et al., EPJA 59, 105 (2023)

Step 2: The TRIUMF Storage Ring (TRISR) Project

Existing ISOL facility + Storage Ring + Recoil Separator + Neutron Generator



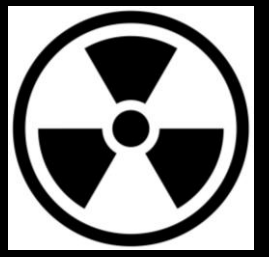
Focus on neutron capture cross sections for heavy nuclei with A>50 (r- and i-process) at astrophysical energies (150-2000 keV)

Needs NSERC funding for design study!

Discovery, accelerated

TRIUMF

(Modern) Heavy RIB Storage Rings



Operational
Under construction
Postponed
Proposed
~~Cancelled~~

Fragmentation facility

- Experimental Storage Ring (ESR) at GSI Darmstadt (since 1990)
- Cooler-Storage Ring (CSRe) at HIRF in Lanzhou (since 2010)
- Rare RI Ring (R3) at RIKEN Nishina Center (since 2012)
- **CRYRING at GSI Darmstadt (1992-2014, since 2016)**
- Spectrometer Ring at HIAF in Huizhou (2025)
- Collector Ring (CR) and High-Energy Storage Ring (HESR) at FAIR (>203x)

NSTARS project

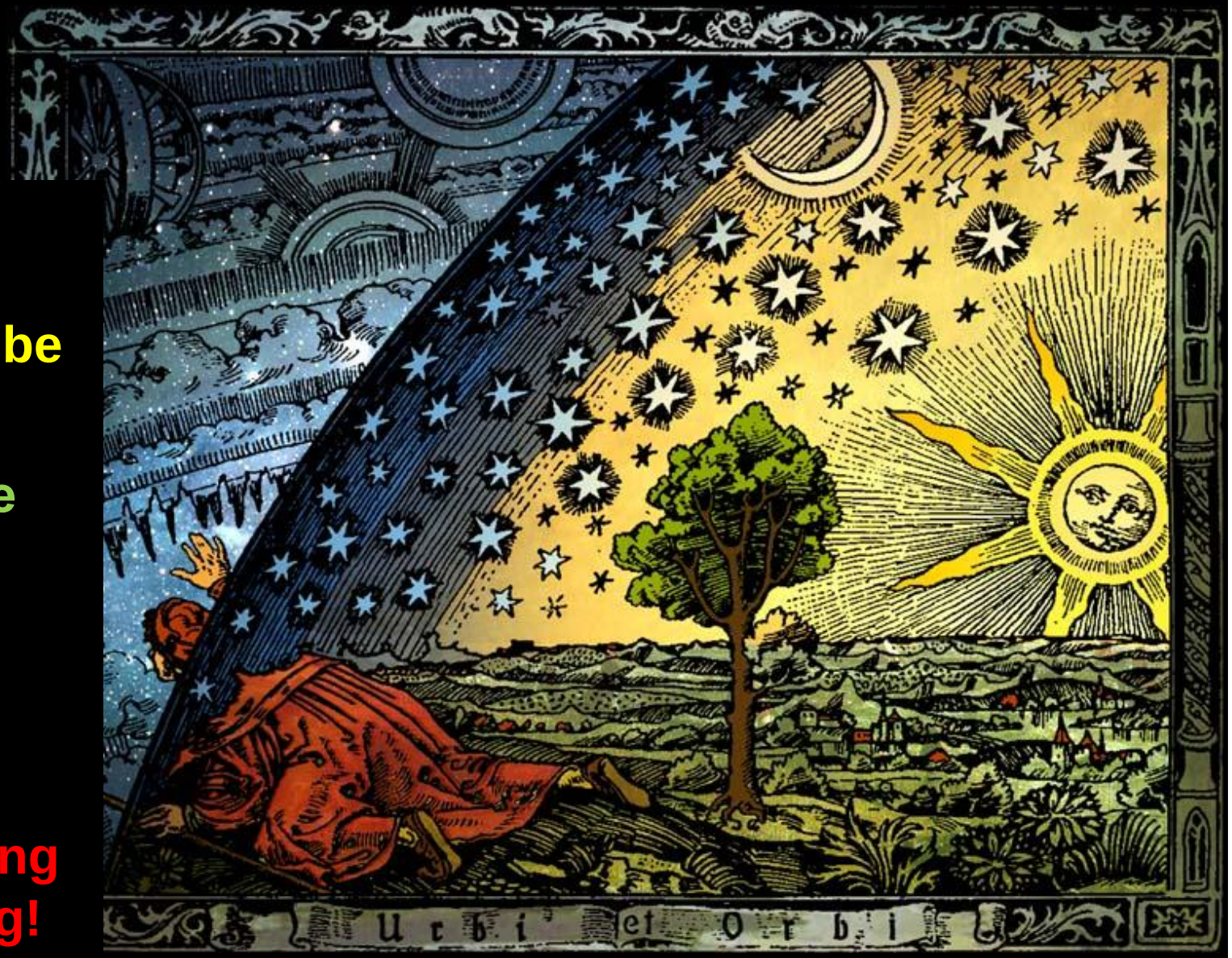
+ Neutron Target

ISOL facility

- ~~Test Storage Ring (TSR) at CERN-ISOLDE (2012)~~ (1988-2013)
- ISOLDE Storage Ring (ISR, proposed) at CERN-ISOLDE (>203x)
- ***TRIUMF Storage Ring (TRISR, proposed) at TRIUMF-ISAC (>203x)***
- *Los Alamos Storage Ring (proposed) at LANSCE (>203x)*

Summary

- **Storage rings are unique facilities for unique experiments that cannot be done otherwise**
- **“Neutron capture storage rings” are the future!**
- **Canada could host and build such a world-wide unique facility**
- **This needs NSERC funding now and later CFI funding!**



Engraving from Camille Flammarion: L'Atmosphere - Météorologie Populaire. Paris 1888.
Color: Heikenwaelder Hugo, Wien 1998.

TRIUMF

Funding requests

TRISR co-PI: R. Baartman (TRIUMF, ret.), A. Chen (McMaster), B. Davids (TRIUMF), F. Herwig (UVic), T. Junginger (Uvic), A. Lennarz (TRIUMF), C. Ruiz (TRIUMF), N. Vassh (TRIUMF)

NSERC CRSNG

NSERC (Project Grant): Facility-specific Design Study (now!!!)

	Y1	Y2	Y3
Total funding requested:	$270k	$330k	$290k
Student/ postdoc salaries:	70%	72%	70%

(1 UG, 2 Masters, 2 Doctoral, 0.7 PD)

ERC Synergy Grant Request (under review, 2026-31):
14MEuro (IFIC Valencia, GSI Darmstadt, TRIUMF)

erc European Research Council Established by the European Commission

Estimated construction price tag (TRISR, >2030): $35-40M
(via CFI funding *and potential international partners*)

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TRIUMF

Thank You!
Merci!
hay č xʷ q̓ə!

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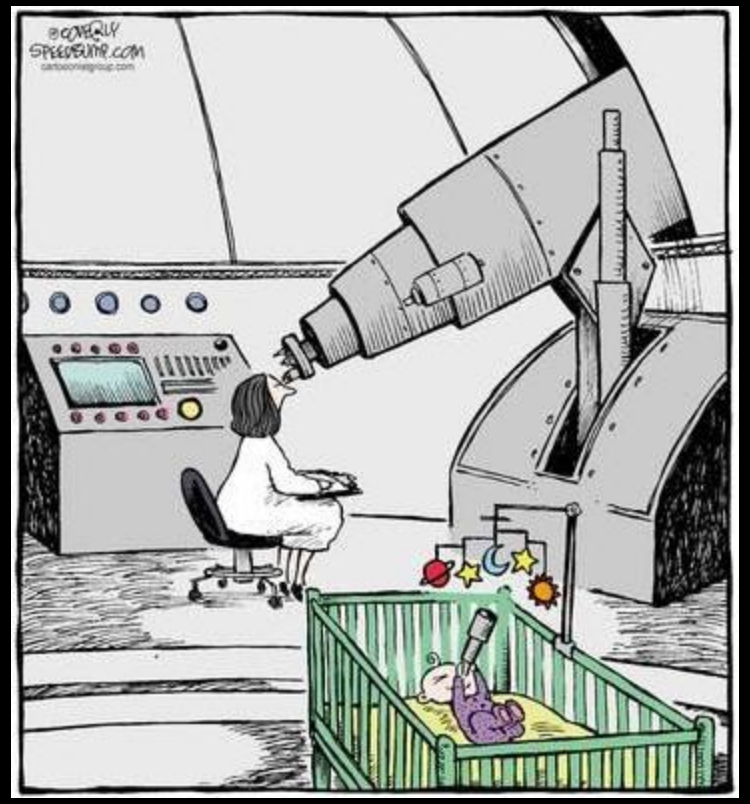
The TRIUMF Storage Ring Project



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Regular Article - Experimental Physics

Measuring neutron capture cross sections of radioactive nuclei

From activations at the FZK Van de Graaff to direct neutron captures in inverse kinematics with a storage ring at TRIUMF

Iris Dillmann[1,2,a], Oliver Kester[1,2], Richard Baartman[1,2], Alan Chen[3], Tobias Junginger[1,2], Falk Herwig[2], Dobrin Kaltchev[1], Annika Lennarz[1,3], Thomas Planche[1,2], Chris Ruiz[1,2], Nicole Vassh[1]

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