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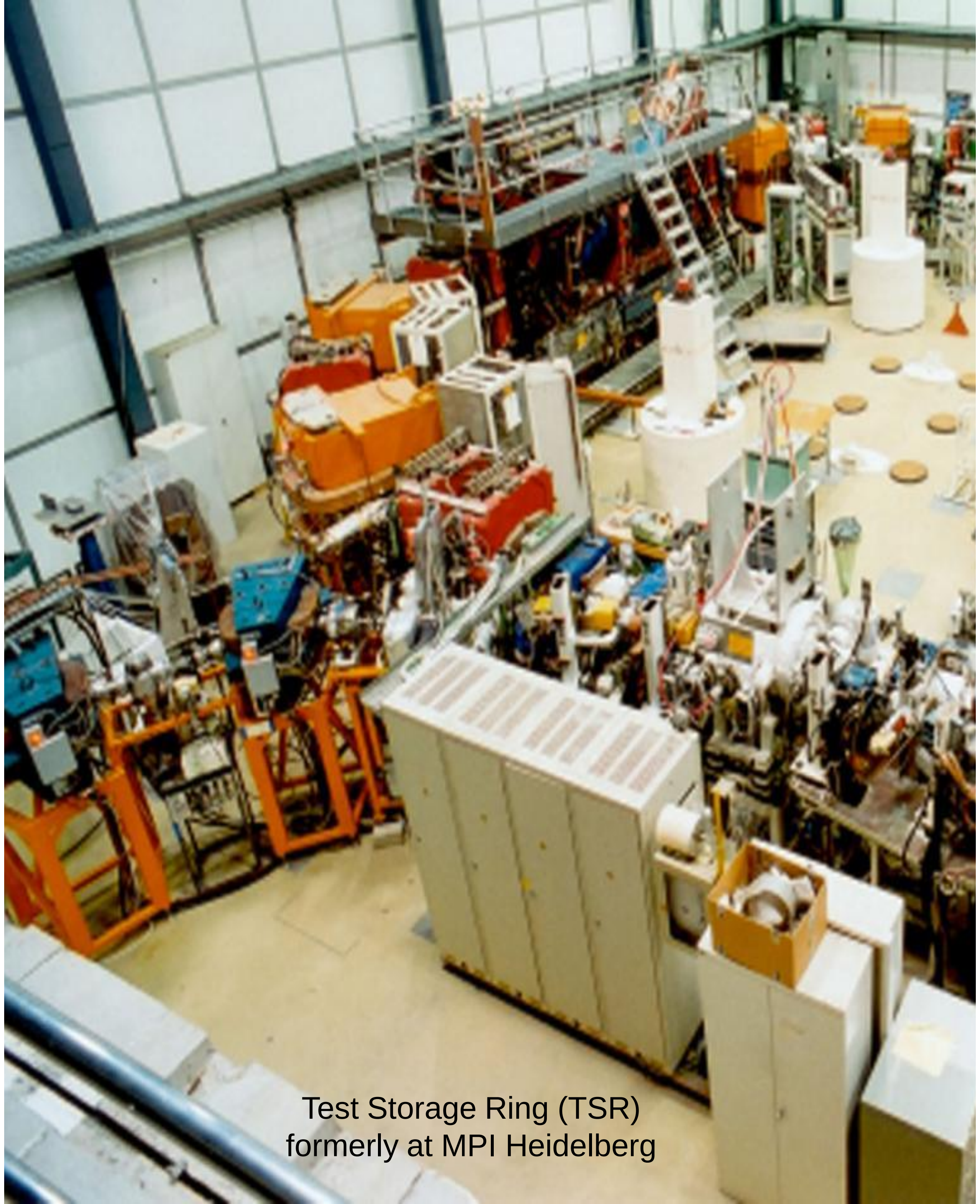
TRISR:

A low energy RIB storage ring for neutron capture (and more?)

Iris Dillmann

Research Scientist (TRIUMF)

Adjunct Professor (University of Victoria)



Test Storage Ring (TSR)
formerly at MPI Heidelberg

Discovery, accelerated

(Modern) Heavy RIB Storage Rings

Fragmentation facility

- Experimental Storage Ring (ESR) at GSI Darmstadt (since 1990)
- Cooler-Storage Ring (CSRe) at Heavy Ion Res. Fac. in Lanzhou (since 2010)
- Rare RI Ring (R3) at RIKEN Nishina Center (since 2012)
- CRYogenic Ring (CRYRING) at GSI Darmstadt (since 2016)
- Collector Ring (CR) and High-Energy Storage Ring (HESR) at FAIR (>2025)
- ~~Test Storage Ring (TSR) at CERN-ISOLDE (2012)~~

⇨ Test Storage Ring (TSR) at Lanzhou (China) ?

ISOL facility

- ISOLDE Storage Ring (ISR, proposed) at CERN-ISOLDE (>2027)
- TRIUMF Storage Ring (TRISR, proposed) at TRIUMF-ISAC (>2030)

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Storage Ring Ideas at TRIUMF

30 GeV “TRISR”

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1983

PROGRESS REPORT
ON THE FEASIBILITY OF USING THE ISR MAGNETS
IN A TRIUMF KAON FACTORY

The following have contributed to various aspects of this study:

E.W. Blackmore
J. Botman
D.V. Bugg
M.K. Craddock (Chairman)
H.G. Hereward
W. Joho
R. Laxdal
G.H. Mackenzie
P.A. Reeve
K. Reiniger
J.R. Richardson
L.C. Teng

TRIUMF is considering the construction of a "kaon factory" post-accelerator to take the present 100 μA proton beam (6×10^{14} p/s) from 500 MeV to energies in the tens of GeV. This would provide beams of kaons, antiprotons, neutrinos, etc., 100-1000 times more intense - or alternatively cleaner - than those available at present. Such beams would open up new fields in both nuclear and particle physics in the same way that the pion factories LAMPF, SIN and TRIUMF have done at lower energies; in particular the enhanced ability to study rare processes could throw light on mass regions far beyond those accessible with any presently conceivable super-high energy accelerator.

Out of various options the one selected as most suitable in terms of its physics capability, site requirements and cost would use one ring of magnets for a 30 GeV 50 μA synchrotron and the other for a 30 GeV dc stretcher ring. The

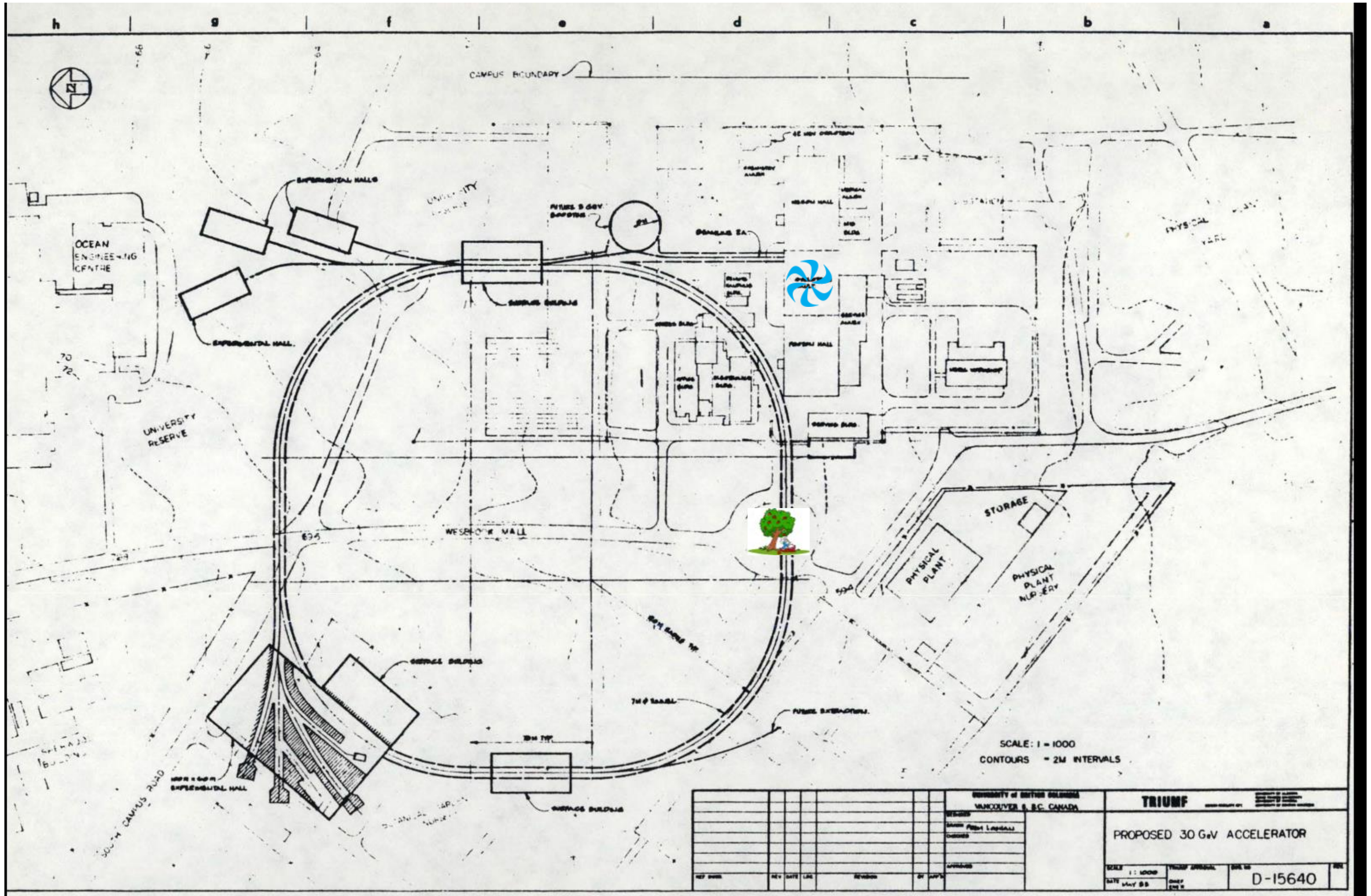

Fig. 2. Possible site layout for 3 GeV booster and 30 GeV main ring synchrotrons.

Storage Ring Ideas at TRIUMF

2003

Proceedings of the 2003 Particle Accelerator Conference

FEASIBILITY STUDIES FOR A RADIOACTIVE-ION STORAGE RING

M.K. Craddock, University of British Columbia and TRIUMF,
and D. Kaltchev, TRIUMF, Vancouver, B.C., Canada

Abstract

The low intensities of beams of unstable isotopes make it vital to use them efficiently. Their collection in a storage ring would open up a number of possibilities: higher beam intensities, enabling better suppression of background and more accurate measurement of isotopic and ionic properties; higher luminosities, by the use of beam cooling and internal targets; acceleration to higher energies; quasi-simultaneous operation with fixed-target experiments; and colliding- or merging-beam experiments with protons, electrons, muons, etc. The most crucial design

Possible ring scenarios

Three general scenarios might be considered, in order of increasing complexity and cost:

Mini: An accumulator ring, with no provision for cooling or further acceleration (similar in purpose to the 5 MeV/u "Recycler" proposed for the Munich Accelerator for Fission Fragments at the high-flux reactor FRM-II).

Midi: A storage ring with cooling and modest acceleration - say to four times greater energies - 35 MeV/u for the heaviest ions and 80 MeV/u for the lightest.

Maxi: A cooler storage ring capable of handling (say) 100 MeV/u beams delivered by a further ISAC accelerator (linac or cyclotron).

Why couple a storage ring to an ISOL facility?

- High intensity, short-lived beams
- ARIEL photofission + CANREB EBIS: cleaner neutron-rich beams
- More beamtime available than at fragmentation facilities
- Beam orbiting in storage rings (~MHz) gives higher luminosity than one-pass experiments (e.g. for neutron capture experiments)

→ **unique physics program enabled**

TRISR: Discussions and consultation with community

1. Low-energy storage ring (E~0.1 -10 MeV/u)
2. Integrate in ISAC-1 hall
3. Integrate **neutron generator target**

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Storage Ring + “Neutron target”

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 014701 (2014

Measurements of neutron-induced reactions in inverse kinematics

René Reifarth[1] and Yuri A. Litvinov[2,3]

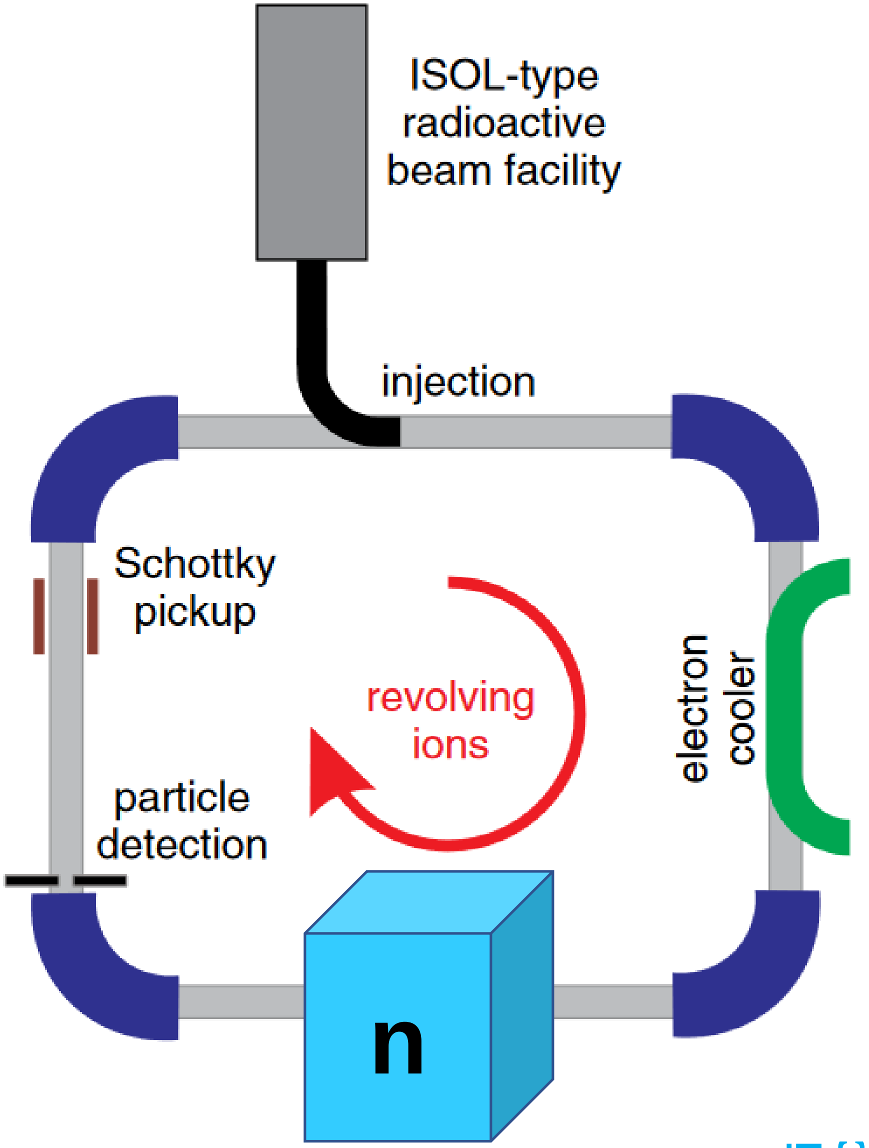
[1]*Goethe-Universität Frankfurt am Main, Max-von-Laue-Str.1, 60438 Frankfurt am Main, Germany*
[2]*GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany*
[3]*Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany*

(Received 17 September 2013; published 10 January 2014)

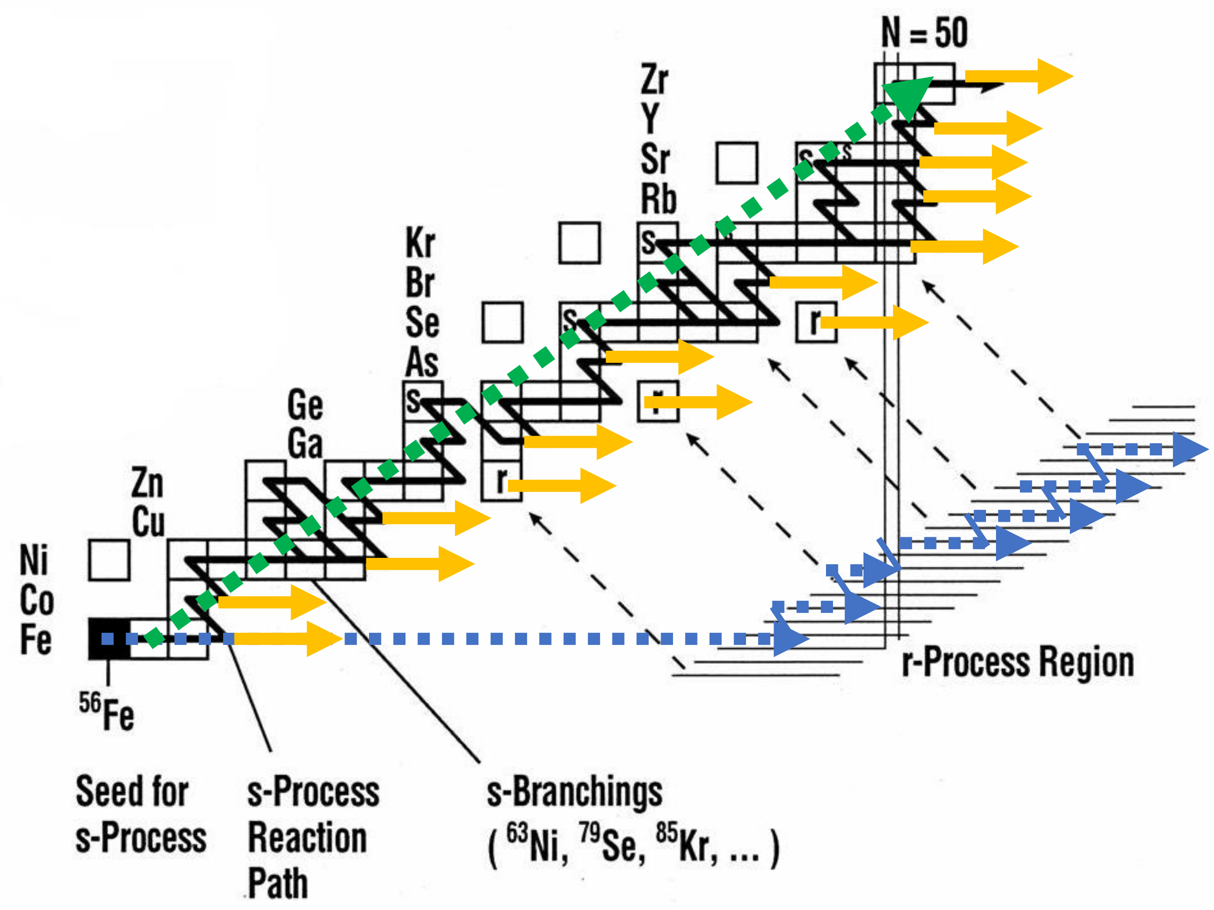
Neutron capture cross sections of unstable isotopes are important for neutron induced nucleosynthesis as well as for technological applications. A combination of a radioactive beam facility, an ion storage ring and a high flux reactor would allow a direct measurement of neutron induced reactions over a wide energy range on isotopes with half lives down to minutes.

DOI: 10.1103/PhysRevSTAB.17.014701 PACS numbers: 25.40.Lw, 29.38.-c, 28.41.-i

~~Reactor~~ ⇨ Neutron Generator



Motivation: Neutron capture cross sections

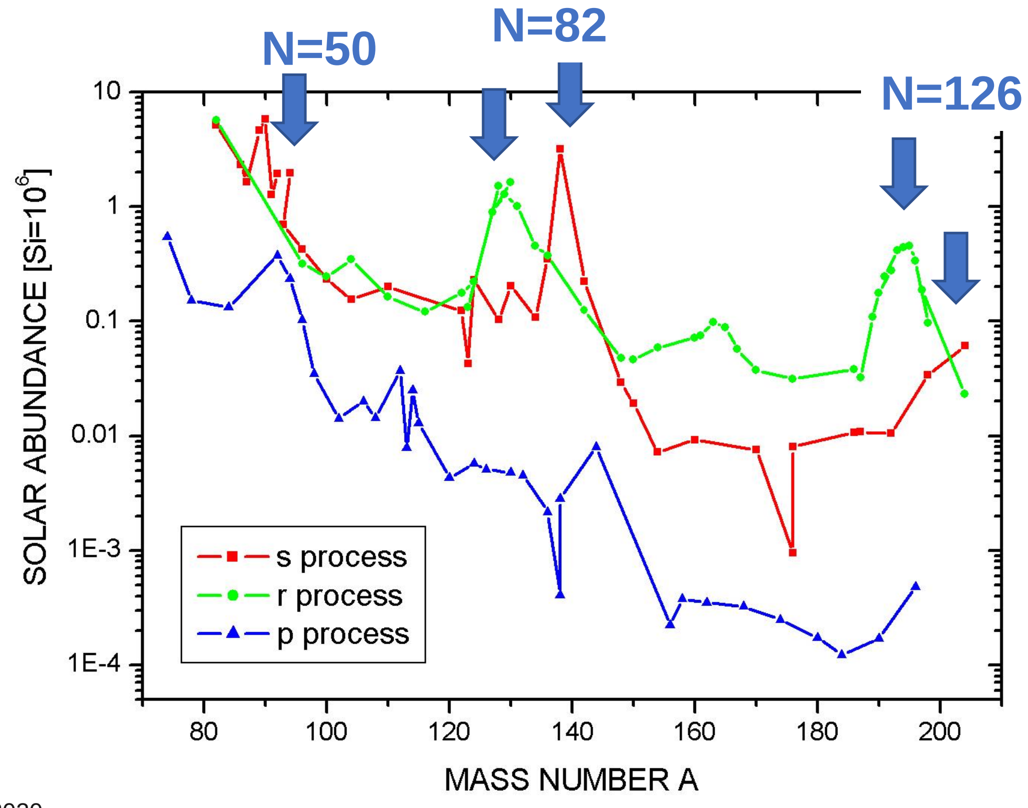


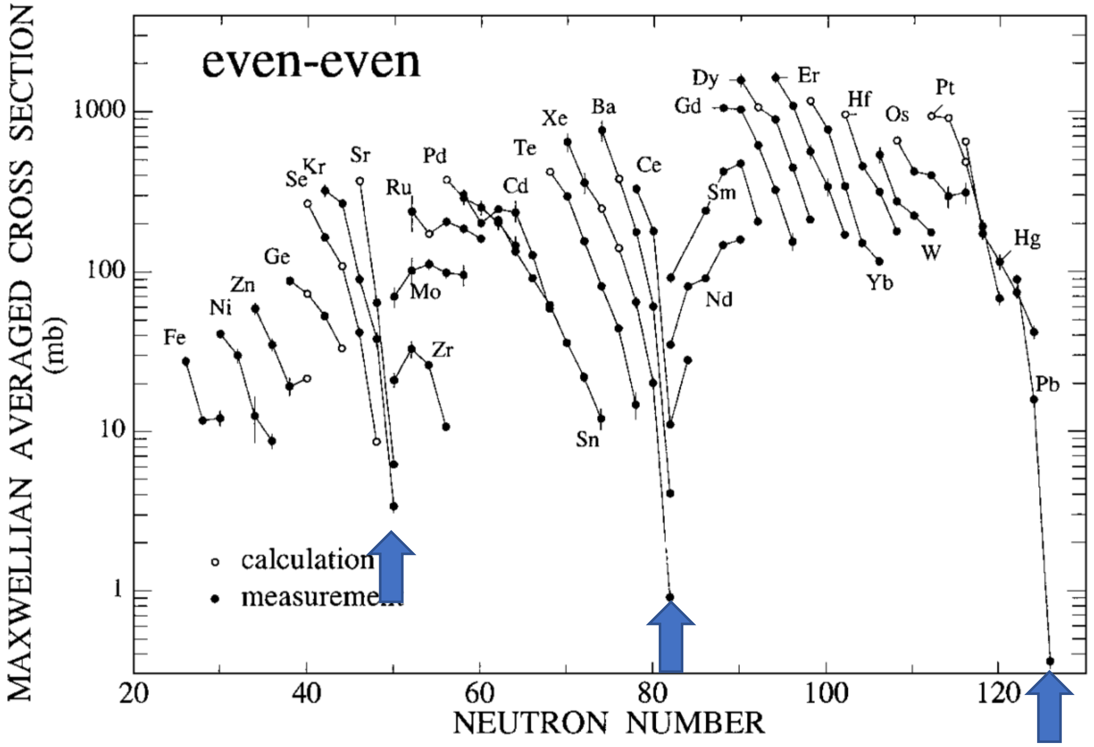
Nuclear astrophysics

- Creation of elements heavier than iron: **slow** and **rapid** neutron capture process
- s-process: along stability (stable nuclei), E_n~ eV – 200 keV, **well investigated**
- r-process: very neutron-rich, E_n~ keV-MeV, not measured yet directly
- i-process: "intermediate" region, E_n~ eV- 200 keV, not measured yet directly

Neutron capture cross sections

- **Hauser-Feshbach theory**: good agreement with exp (~factor 2-3) at stability with exception of area around neutron shell closure (low level density)
  ⇨ abundance peaks



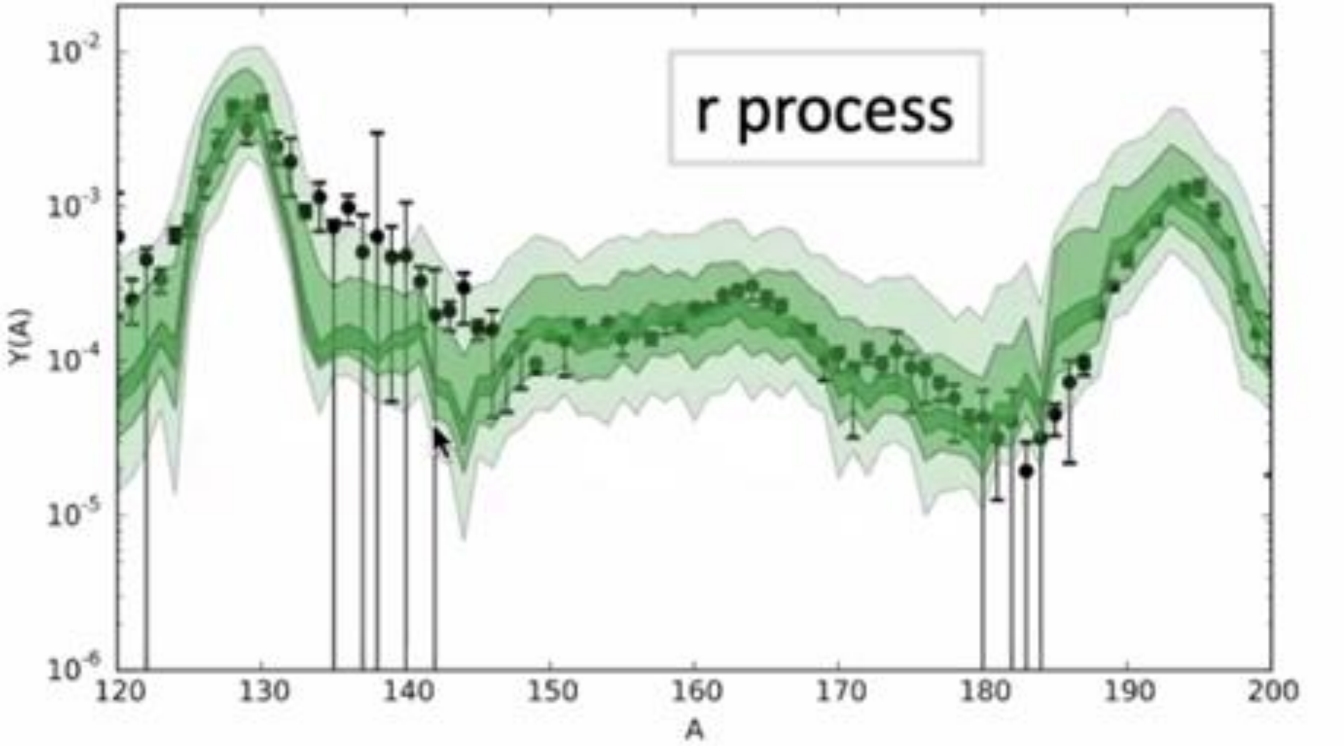


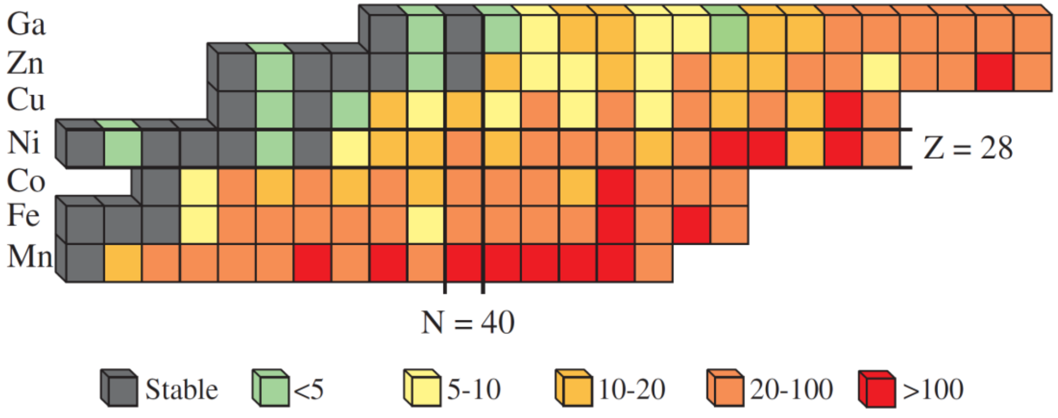
Z.Y. Bao et al., At. Data Nucl. Data Tables 76, 70 (2000)

Neutron capture cross sections

- **Hauser-Feshbach theory**: large deviation (orders of magnitude) away from stability

Ratio of calculated n cross sections at 1.5 GK
Model: TALYS, varying level density and γ-strength function





Monte-Carlo variations of (n,γ) rates within a factor
100 – 10 – 2
light – darker – dark bands

Liddick, Spyrou, et. al. PRL 2016

SW2020 Talk by Artemis Spyrou (Thu morning)

How to measure direct n cross sections?

Beam

Target

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

Neutrons → **Short-lived nuclei**

"inverse kinematics"
Short-lived nuclei → **Neutrons** *Indirect measurements* **Deuterium** *(d,p) reactions* ➡ **Measure reaction products**

Short-lived nuclei → **Storage Ring** **Neutrons** ➡ **Measure heavy reaction product**

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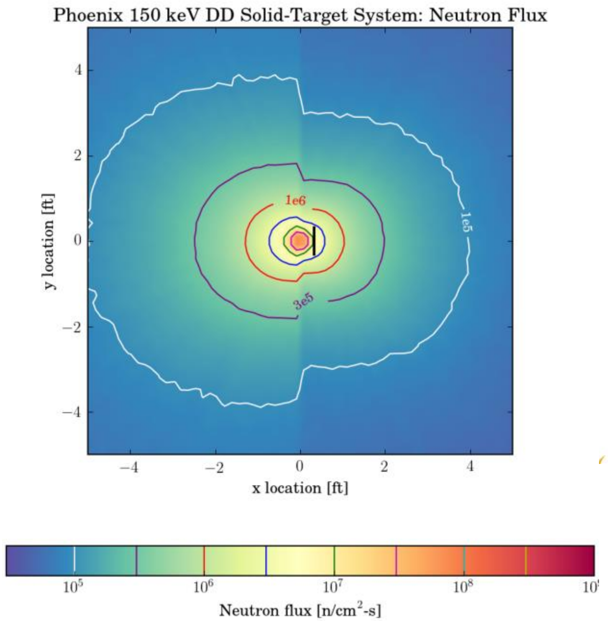
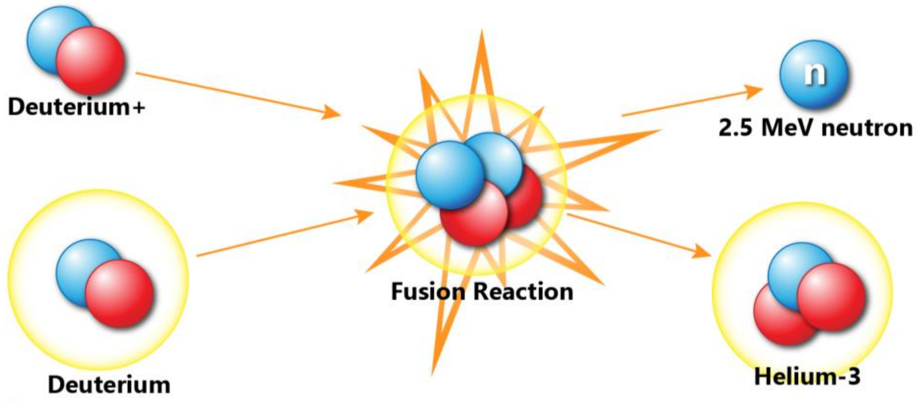
D-D Neutron generator

PHOENIX

- Example: “Thunderbird” compact neutron generator from PHOENIX LLC
- Solid-target DD generator, E_n(DD)= 2.45 MeV
- Neutron fluxes up to $5*10^{10}$ n/s
- Size: 2.1m (W) x 2.7m (H), length 1.6 - 3 m



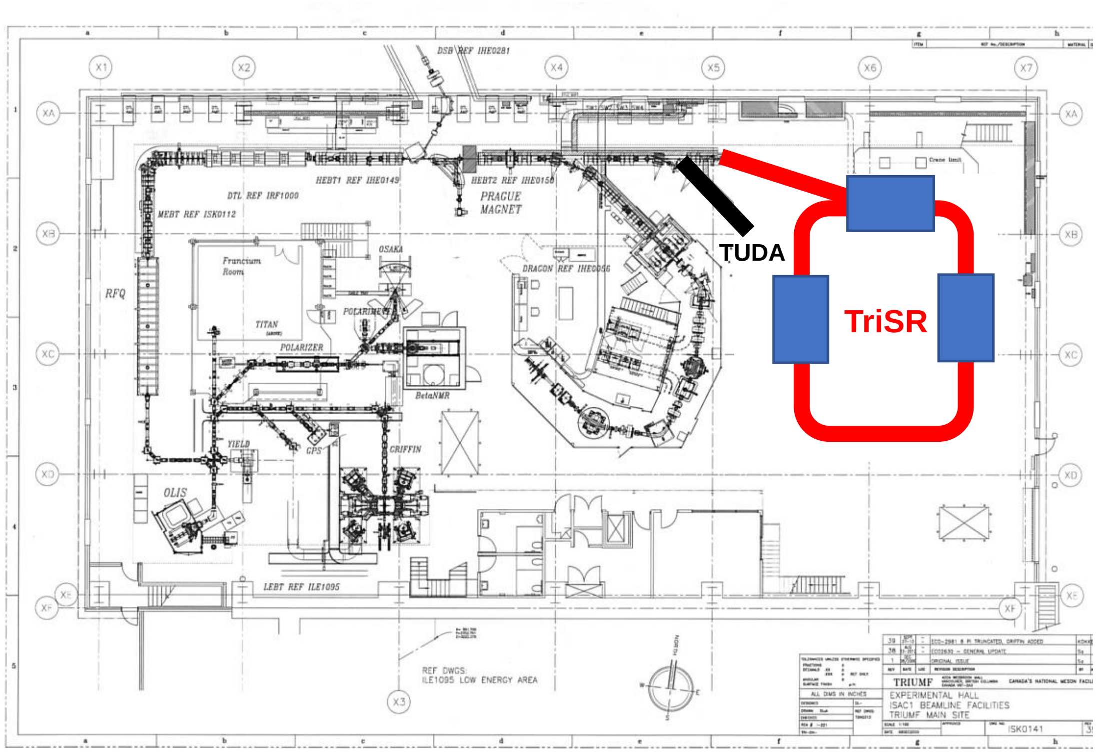


“Thunderbird” DD neutron generators

https://phoenixwi.com/neutron-generators/dd-deuterium-deuterium-neutron-generators/

Discovery, accelerated

A low-energy storage ring (E=0.1-10 MeV/u) for rare isotope research (TRISR@ISAC)



Proponents:
Iris Dillmann, Oliver Kester (TRIUMF, U Victoria)

- Planning “from scratch” allows highest flexibility to user requests
- Injection of clean, highly-charged ions from new CANREB-EBIS
- Neutron generator, Electron cooler, internal gas target (?), Schottky pickups, …

⇨ Direct (n,γ) reactions with RIB **(unique!)**

Main Users: Nuclear physics + nuclear astrophysics
Potential users: Material science, atomic physics?
Physics program will be completely community-driven!

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Timeline

	NSERC Project Grant		CFI	CFI
2021	submission			
2022				
2023				
2024	resubmission		Preselection/LOI	Preselection/LOI
2025			submission	submission
2026			**n generator**	**TriSR**
2027	resubmission		*install.+ comm.*	*construction*
2028			Day-0 exp	*construction*
2029				commissioning
2030	resubmission			Day-0 exp
2031			Day-1 exp	Day-1 exp
2032				
2033	resubmission			
2034				
2035				
2036	resubmission			
2037				

2017: TRIUMF PPAC proposal (**Gate 0**)

2021: Submit **NSERC project grant** (2022-25)
- Neutron generator design & experiments

- TRISR: Beam dynamics calculations

2022/23: Define physics program in User Workshop (**Gate 1**)

2023/24 Physics Book

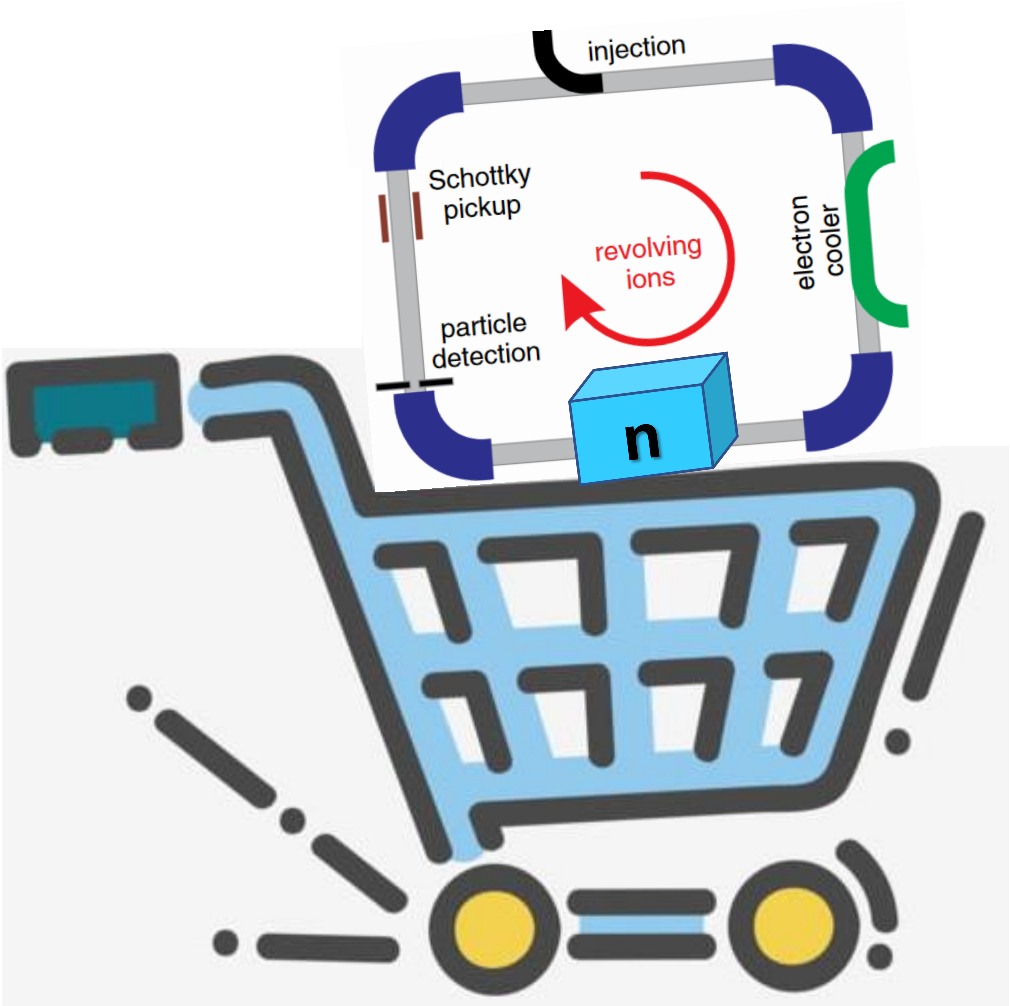
2024/25 Technical Design report (**Gate 2A**)
→ Submit **CFI funding proposal**

2026/27: Start construction

2029: Commissioning experiments

2030/31: Day-0 experiments

Estimated costs



Construction price tag: ~C$ 30-40 million

- Storage Ring ✓
- Neutron generator ✓
- Electron cooler ✓
- Schottky pickups ✓
- Internal gas/jet/droplet target ?
- . . .*(Enter your wish here!)*

Operational costs (incl. salaries) ~C$ 1.5 million/ y

Participants (preliminary expression of interest)

Canada:

- **TRIUMF:** Iris Dillmann (PI), Oliver Kester (co-PI), Rick Baartman, Barry Davids, Dave Hutcheon, Chris Ruiz, (+ others from TRIUMF Accelerator Division)
- **McMaster:** Alan Chen
- **St. Mary's:** Greg Christian

Everyone welcome!

International:

- Storage ring experts from Germany, UK (ring design and technologies, neutron capture experts), Japan

Construction and operation of Storage Ring will require <u>increase</u> of NRC contributions to TRIUMF from 2026 on!

Summary: Storage ring at TRIUMF

- **First-of-its-kind at ISOL facility**
- Fits in existing infrastructure (no new building needed)
- Will highly benefit from new ARIEL infrastructure: CANREB-EBIS, higher beam intensities, cleaner neutron-rich beams
- Storage ring: multi-pass experiments (higher luminosity)
- **Unique access to direct neutron capture cross sections of RIB**
- Diverse research program complementary to existing ISAC program
- **Logical future extension of existing TRIUMF-ISAC program with potential to attract new users (also outside of nuclear physics)**

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Thank you!

Merci!

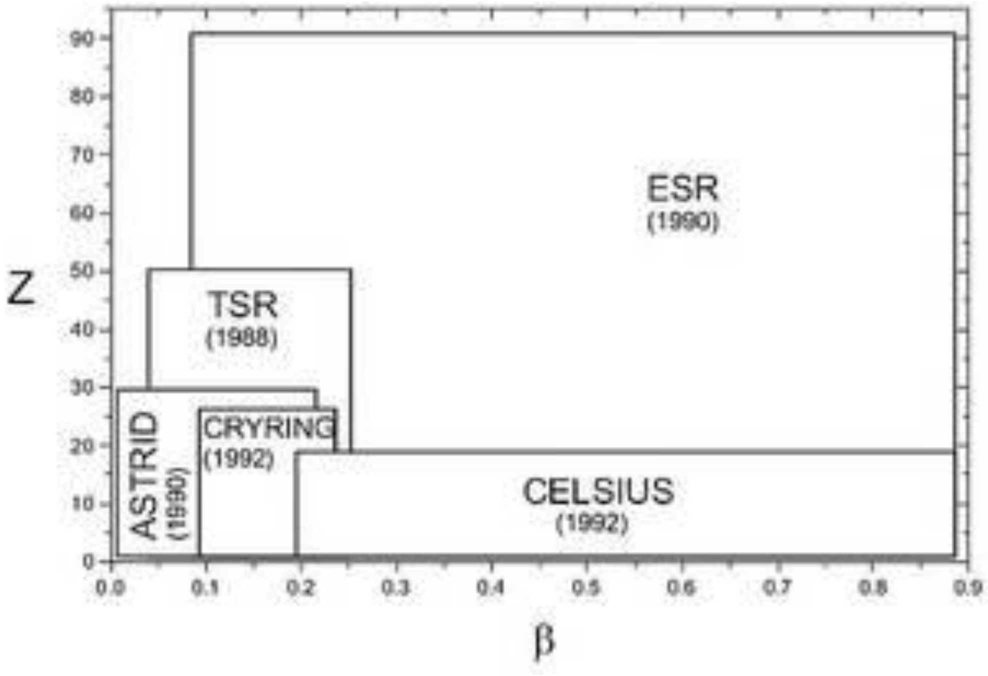
www.triumf.ca

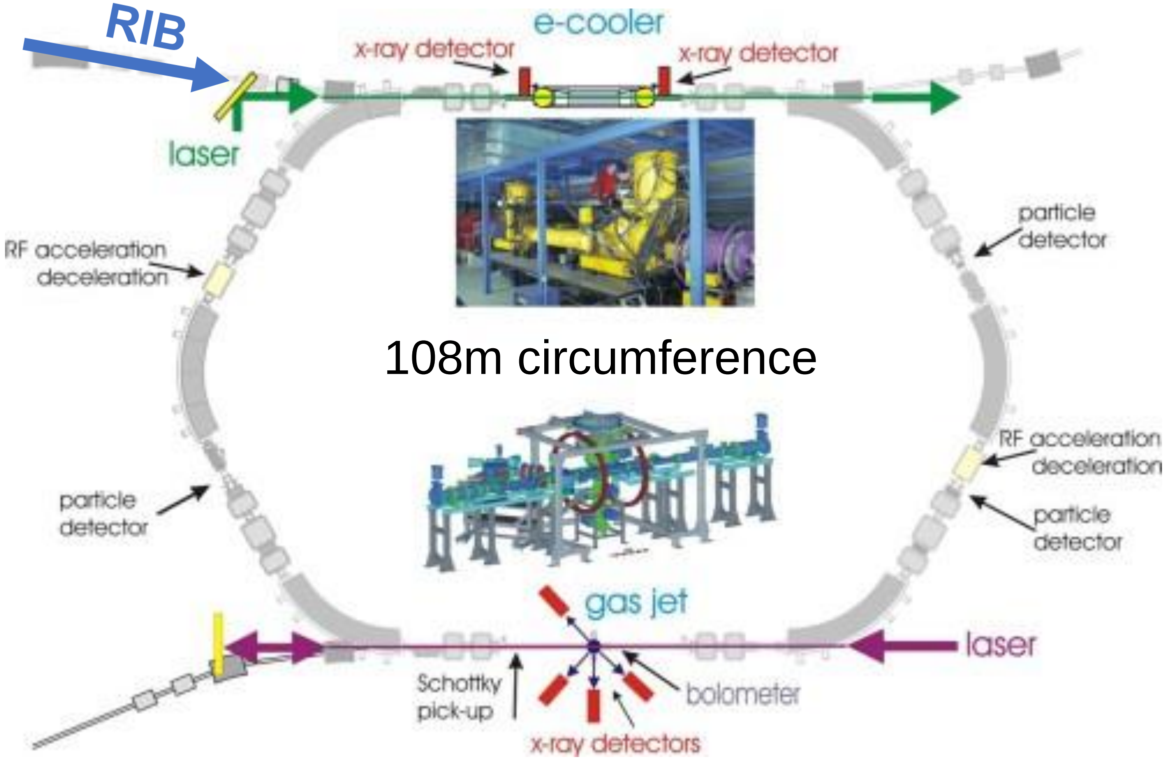
Follow us **@TRIUMFLab**

Discovery, accelerated

Motivation: Heavy Ion Storage Rings

- Experimental Storage Ring (ESR) at GSI Darmstadt (since 1990)
- Test Storage Ring (TSR) at MPI Heidelberg (1988-~2012)
- CRYogening Ring (CRYRING) at U of Stockholm (1992-~2014)





https://www.gsi.de/en/work/research/appamml/atomic_physics/experimental_facilities/esr.htm

Storage Ring + Spallation Neutron Target

PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 044701 (2017)

Spallation-based neutron target for direct studies of neutron-induced reactions in inverse kinematics

René Reifarth,* Kathrin Göbel, Tanja Heftrich, and Mario Weigand
Goethe-Universität Frankfurt, Frankfurt am Main, 60438 Frankfurt, Germany

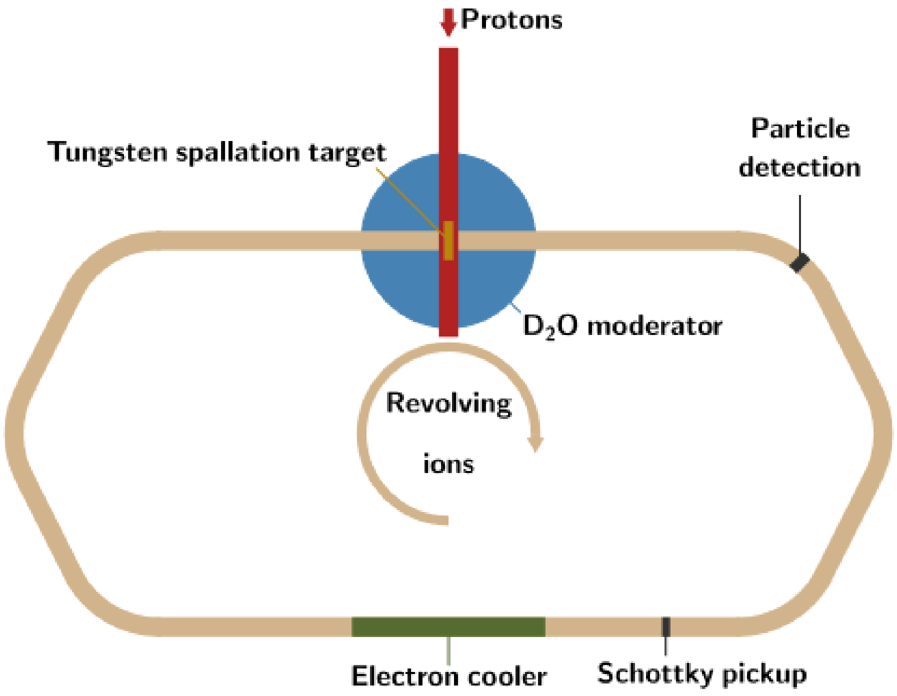
Beatriz Jurado
CENBG, 33175 Gradignan, France

Franz Käppeler
Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Yuri A. Litvinov
GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany
(Received 29 November 2016; published 6 April 2017)

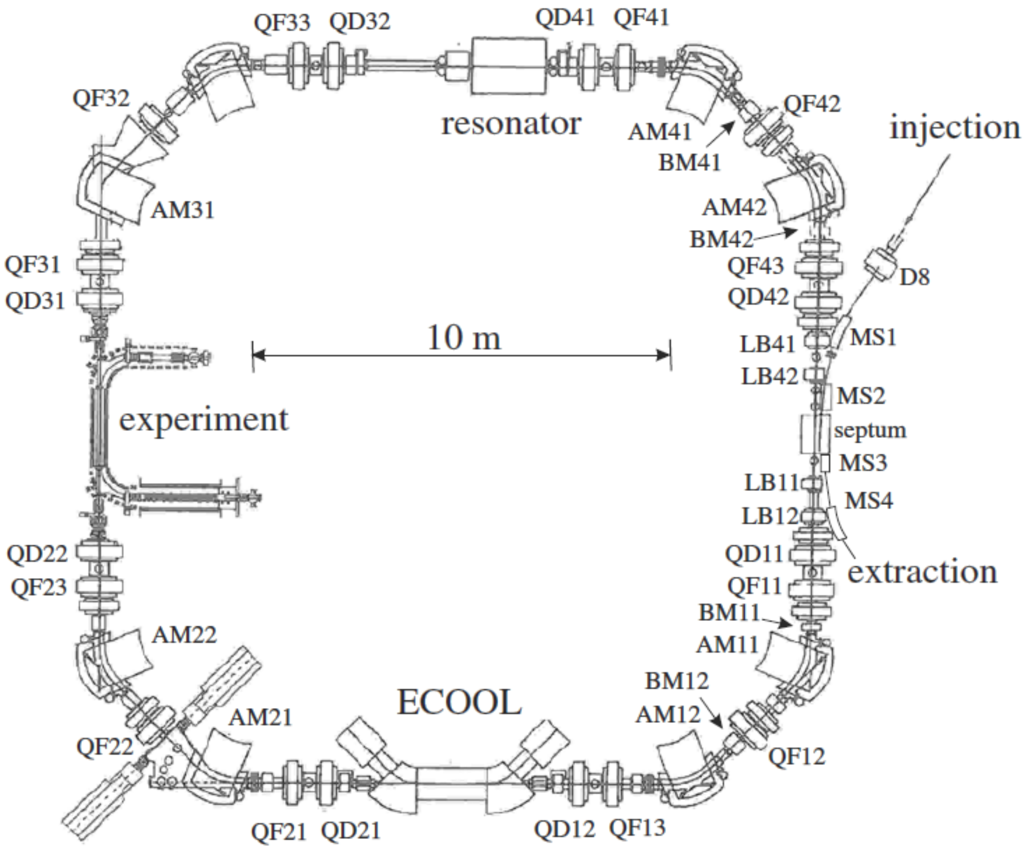
We discuss the possibility to build a neutron target for nuclear reaction studies in inverse kinematics utilizing a storage ring and radioactive ion beams. The proposed neutron target is a specially designed spallation target surrounded by a large moderator of heavy water (D_2O). We present the resulting neutron spectra and their properties as a target. We discuss possible realizations at different experimental facilities.

DOI: 10.1103/PhysRevAccelBeams.20.044701

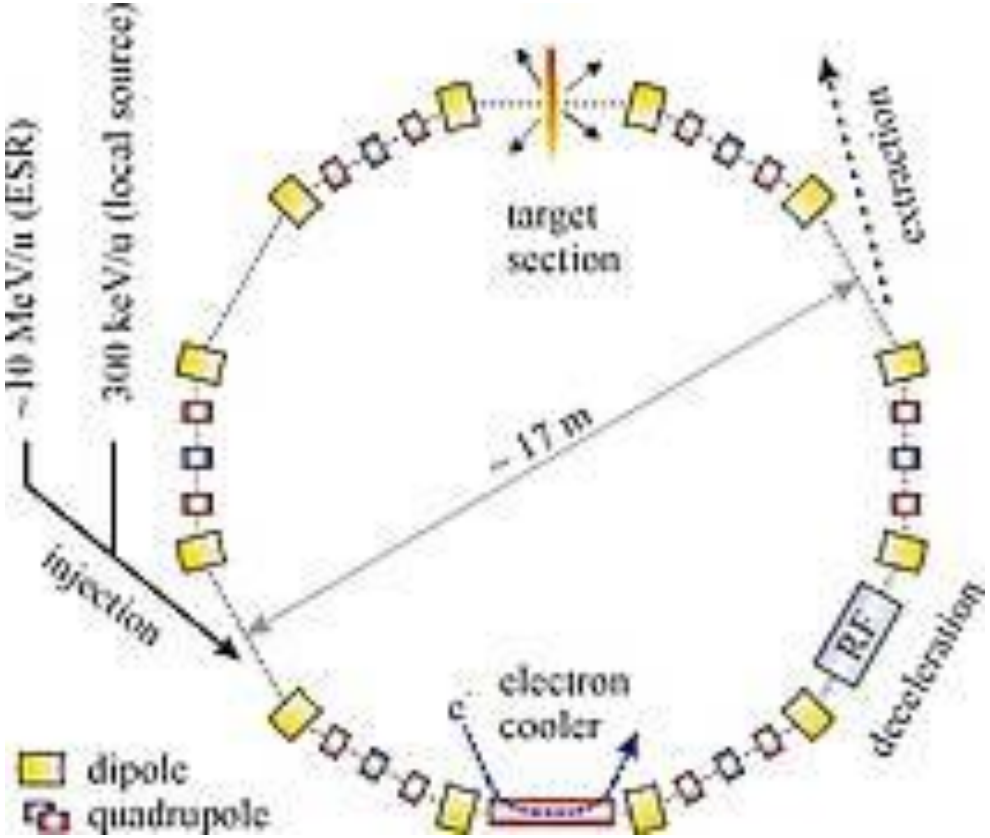


Workshop at Los Alamos (August 2019)

Low-Energy (0.5-10 MeV/u) Heavy Ion Storage Rings



Test Storage Ring (TSR)
in boxes in Heidelberg



Cryostatic Storage Ring (CRYRING)
at GSI Darmstadt

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Example: Test Storage Ring (TSR)

- Was in operation at MPIK Heidelberg since 1988
- Only **stable beams**
- 55 m circumference, Bρ= 1.5 Tm
- Momentum acceptance +/-3%
- Energy **up to 10 MeV/u** (revolution. freq. ≈800 kHz)
- Max. beam current stored: 1 mA
- **Electron and laser cooler**

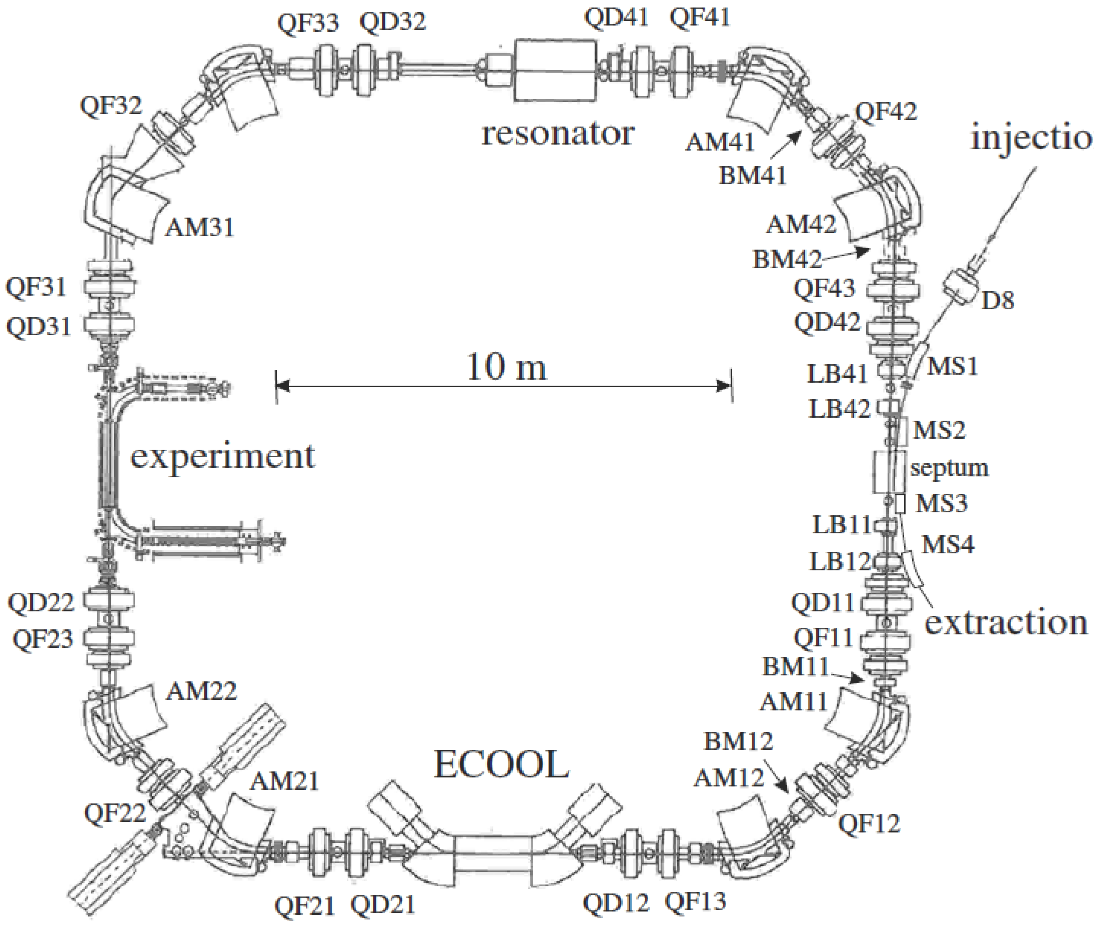

Fig. 33. The lattice of the TSR.

Discovery, accelerated

TSR@ISOLDE TDR (2012)

Eur. Phys. J. Special Topics **207**, 1–117 (2012)

DOI: 10.1140/epjst/e2012-01599-9

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Review

Storage ring at HIE-ISOLDE

Technical design report

M. Grieser[1], Yu.A. Litvinov[2,3,a], R. Raabe[4], K. Blaum[1,2], Y. Blumenfeld[5], P.A. Butler[6], F. Wenander[5], P.J. Woods[7], M. Aliotta[7], A. Andreyev[8], A. Artemyev[2], D. Atanasov[9], T. Aumann[10,3,a], D. Balabanski[11], A. Barzakh[12], L. Batist[12], A.-P. Bernardes[5], D. Bernhardt[13], J. Billowes[14], S. Bishop[15], M. Borge[16], I. Borzov[17], F. Bosch[3,a], A.J. Boston[6], C. Brandau[18,19], W. Catford[20], R. Catherall[5], J. Cederkäll[5,21], D. Cullen[14], T. Davinson[7], I. Dillmann[22,3,a], C. Dimopoulou[3,a], G. Dracoulis[23], Ch.E. Düllmann[24,25,3,a], P. Egelhof[3,a], A. Estrade[3,a], D. Fischer[1],

- TSR@ISOLDE: unique project but deferred until at least 2025
- New storage ring proposed: ISOLDE Storage Ring (ISR)

CRYRING@GSI Darmstadt

- Formerly in operation at University of Stockholm for **Atomic and Molecular Physics**
- Relocated to GSI Darmstadt/ FAIR as Swedish in-kind contribution: CRYRING@ESR: commissioned in summer 2016
- Will later serve as central storage ring in the **FLAIR (Facility for Low-Energy Anti-Proton and Ion Research)** facility
- Ring for testing FAIR technologies and research with slow exotic ion beams for **Atomic and Nuclear Physics**
- Can store, cool and decelerate heavy, highly charged ions down to a few 100 keV/nucleon
- Includes electron cooler and gas-jet target

https://www.gsi.de/work/forschung/appamml/atomphysik/anlagen_und_experimente/cryringesr.htm

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CRYRING@GSI Darmstadt

CRYRING@ESR

Eur. Phys. J. Special Topics **225**, 797–882 (2016)

DOI: 10.1140/epjst/e2016-02643-6

THE EUROPEAN PHYSICAL JOURNAL
SPECIAL TOPICS

Review

Physics book: CRYRING@ESR

M. Lestinsky[1], V. Andrianov[1,2,3], B. Aurand[1], V. Bagnoud[1], D. Bernhardt[3], H. Beyer[1], S. Bishop[4], K. Blaum[5], A. Bleile[1,6], At. Borovik Jr.[7], F. Bosch[1], C.J. Bostock[8], C. Brandau[1,7], A. Bräuning-Demian[1], I. Bray[8], T. Davinson[9], B. Ebinger[7], A. Echler[1,6,3], P. Egelhof[1,6], A. Ehresmann[10], M. Engström[11],