ILIMA@ESR
Group Report

Iris Dillmann

ILIMA Spokesperson

TRIUMF & U of Victoria

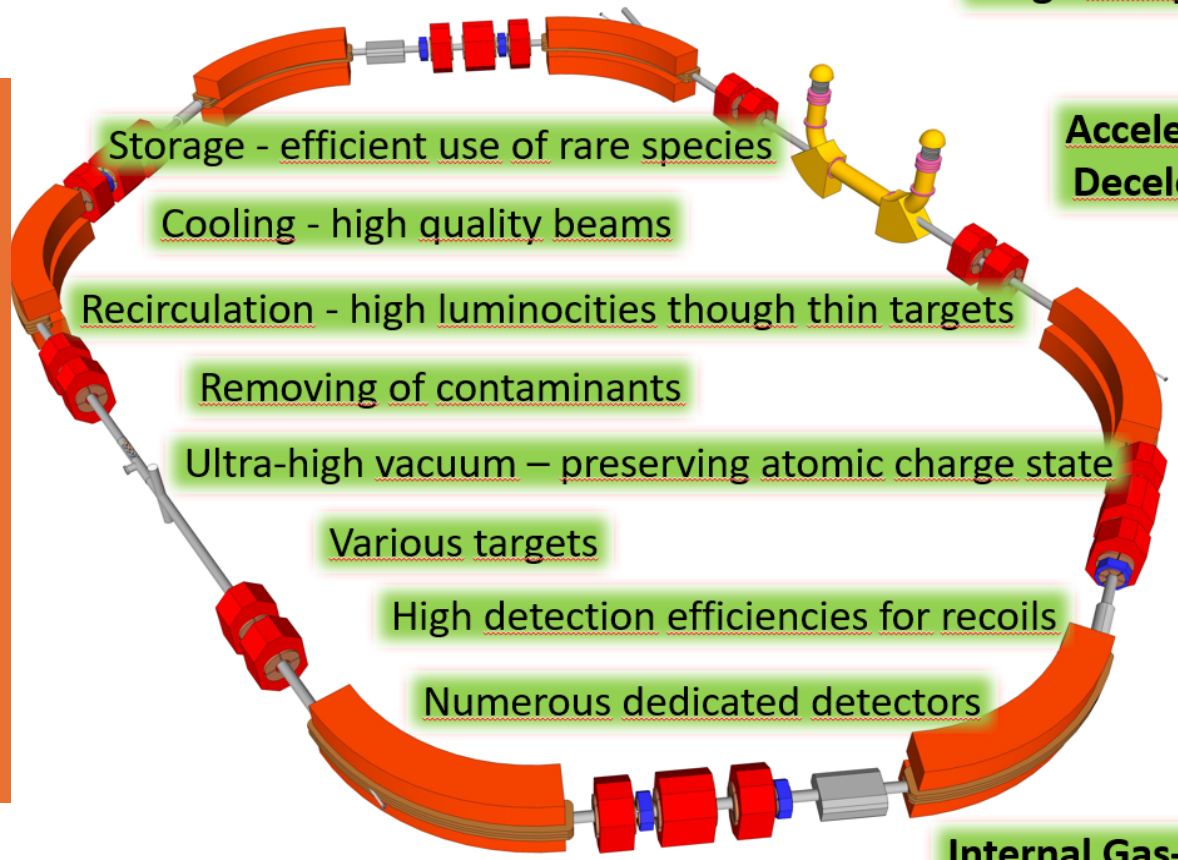
Discovery, accelerated

Why storage rings? - Versatile Capabilities

Unique environment!

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

→ **Unique experiments!**



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

Slide from Yuri Litvinov

TRIUMF

(Modern) Heavy RIB Storage Rings

Operational
Under construction
Postponed
Proposed
~~Cancelled/closed~~

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)**
- **Collector Ring (CR) and High-Energy Storage Ring (HESR) at FAIR (>203x)**
- Spectrometer Ring at HIAF in Huizhou (2025)

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)*

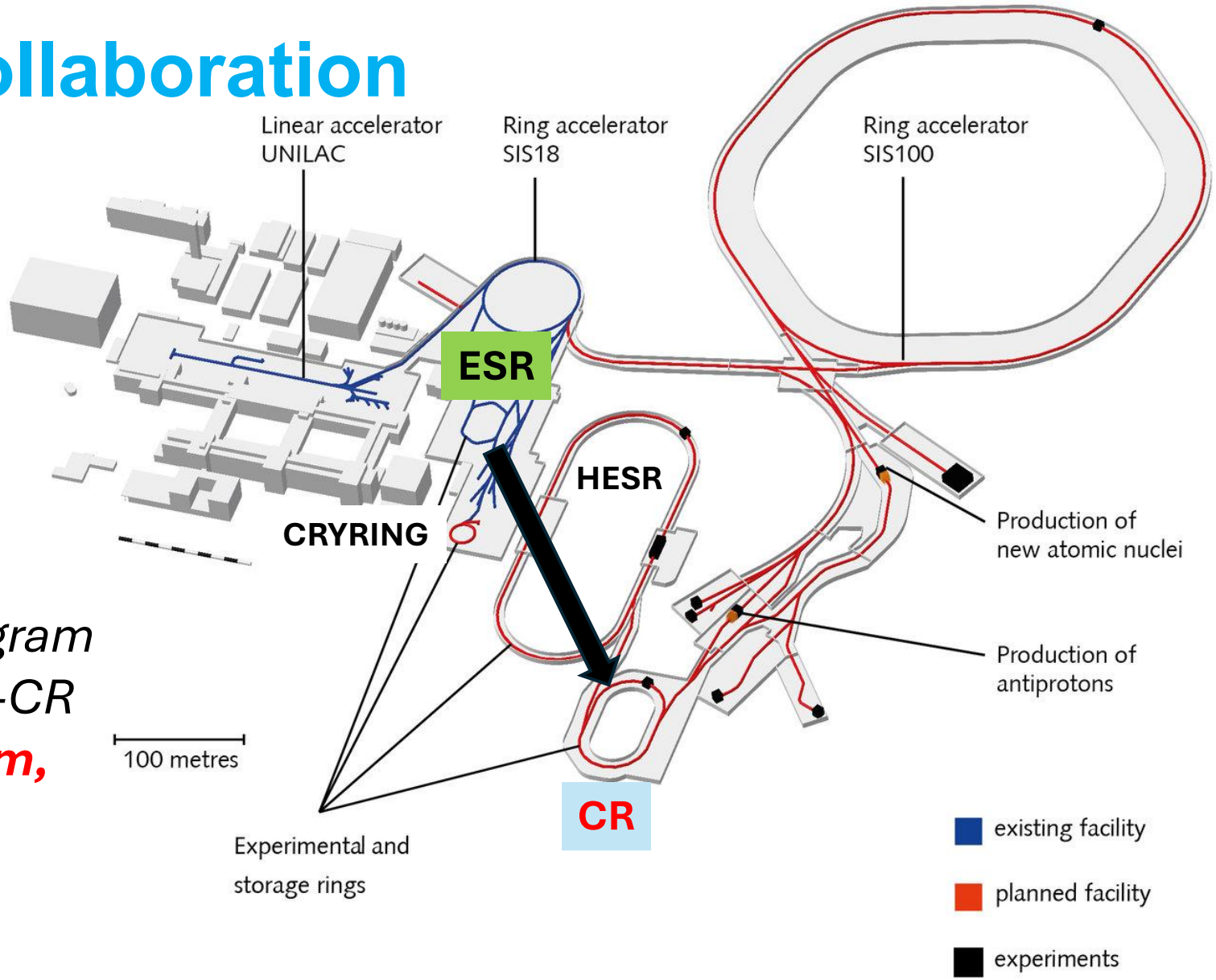
Discovery, accelerated

ILIMA@FAIR Collaboration

Isomers
LIfetimes
MAsses

Original idea: Move highly successful 30-year old program from FRS-ESR to SuperFRS-CR

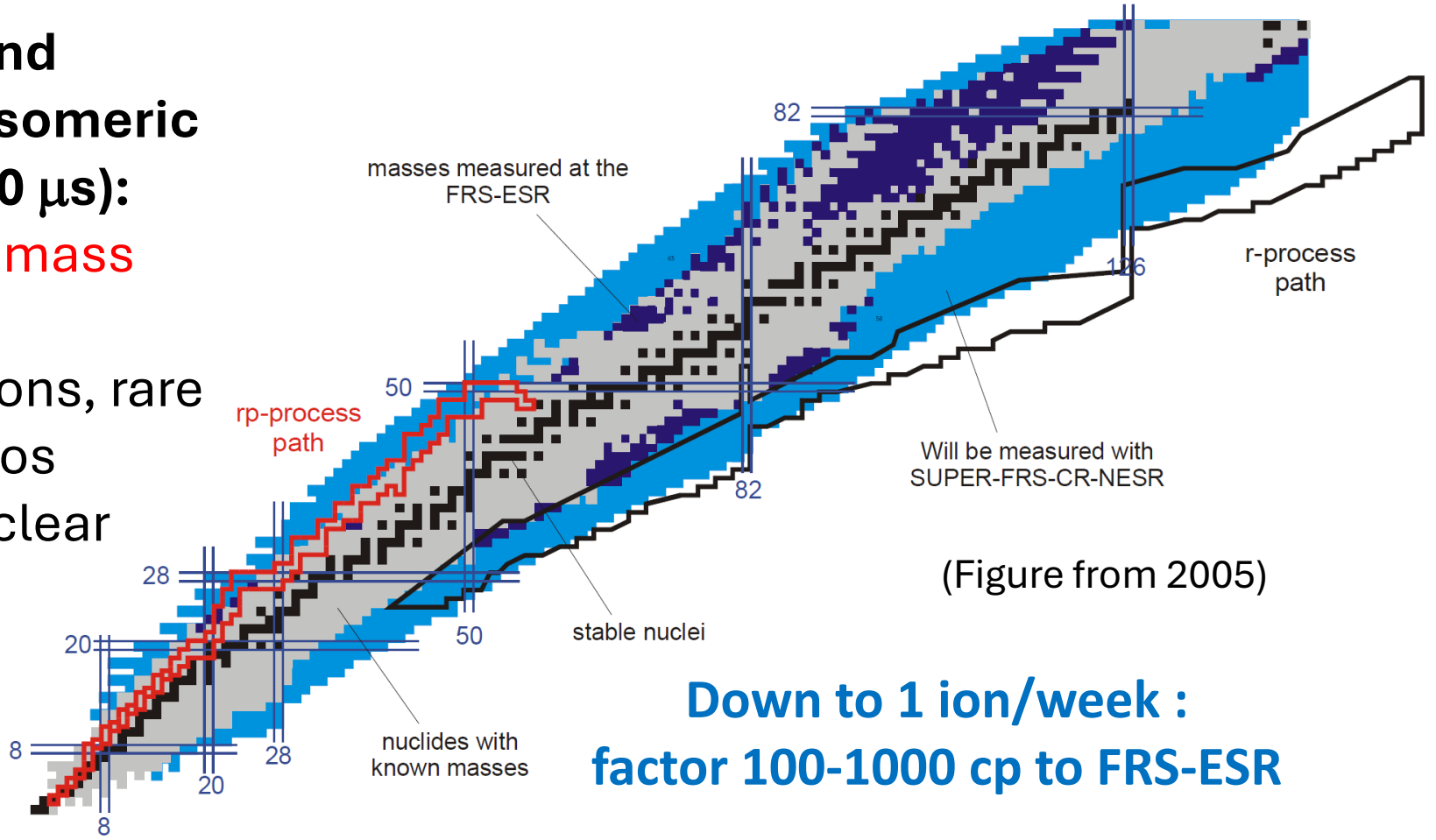
- ***Measure masses < 1ppm,***
- ***$t_{1/2}$ > 10 μs,***
- ***Yields <1 ion per week***



ILIMA@FAIR Physics Program

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
- Investigations with pure isomeric beams

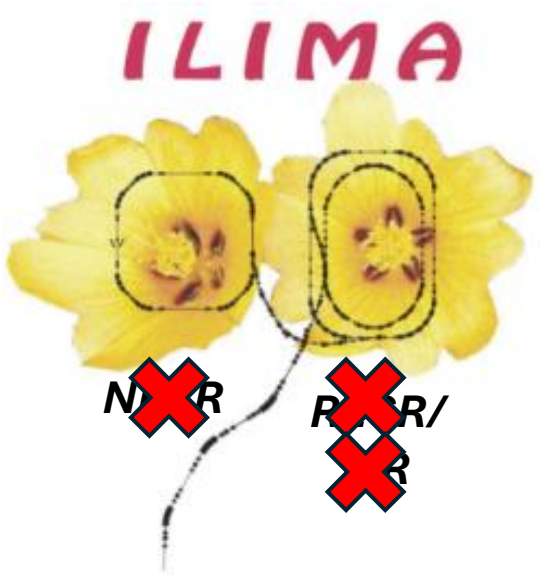


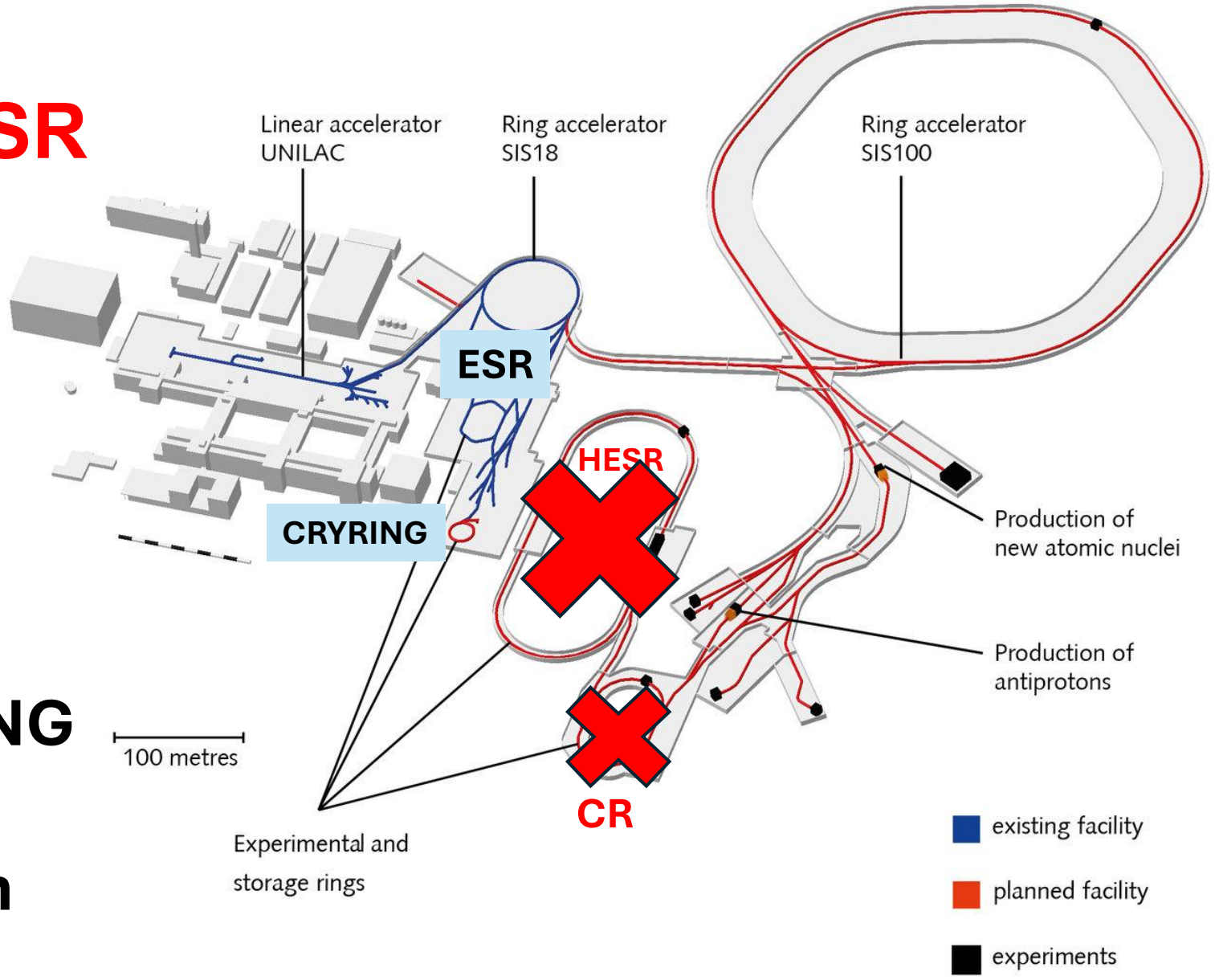
(Figure from 2005)

Down to 1 ion/week : factor 100-1000 cp to FRS-ESR

Disc
accel

2025: ILIMA@ESR

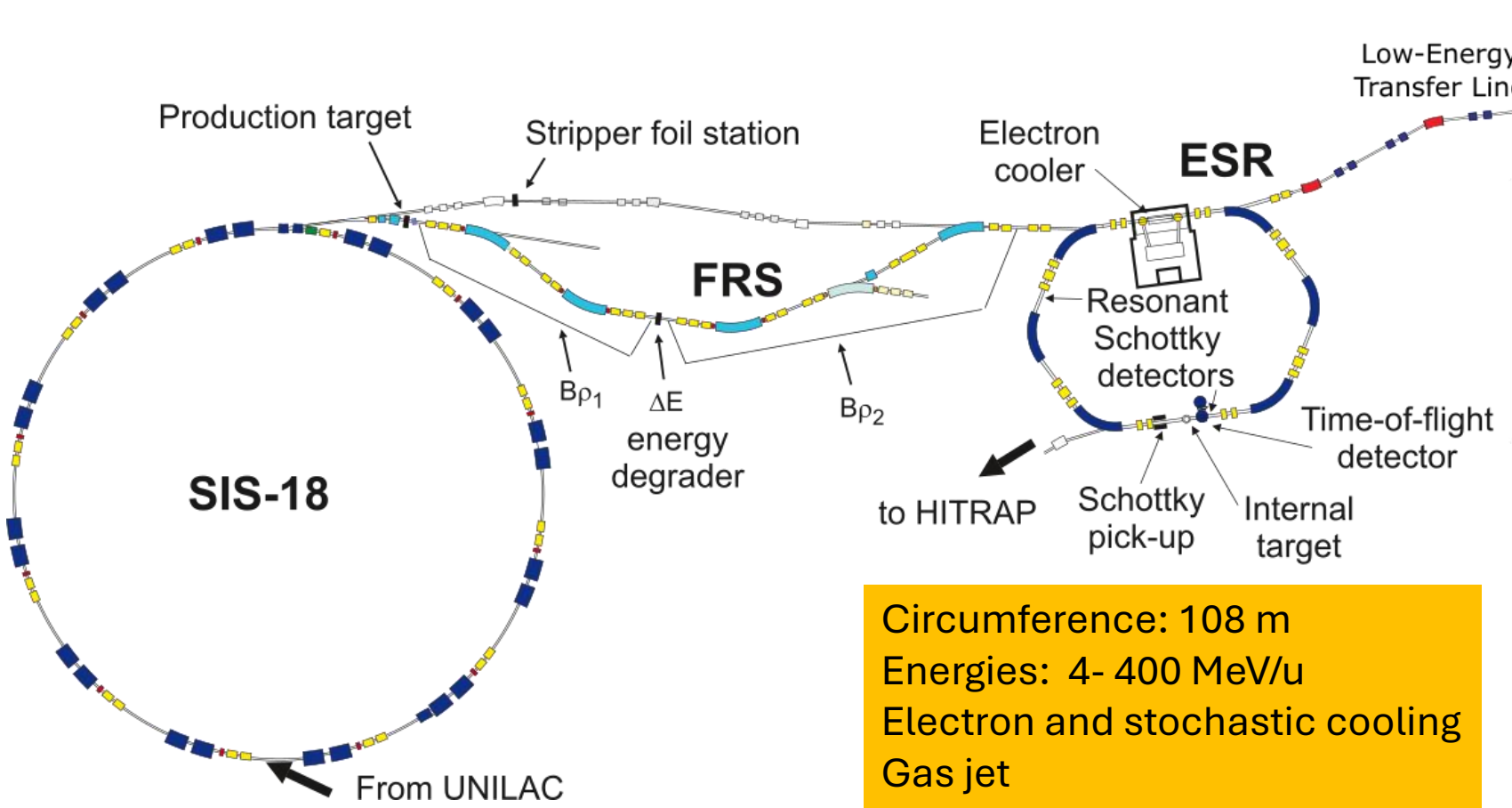




Only ESR and CRYRING left for now…

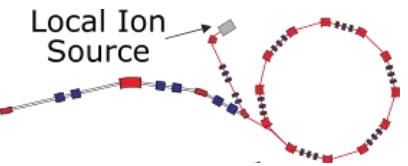
Let's do the best with this situation!

ESR and CRYRING



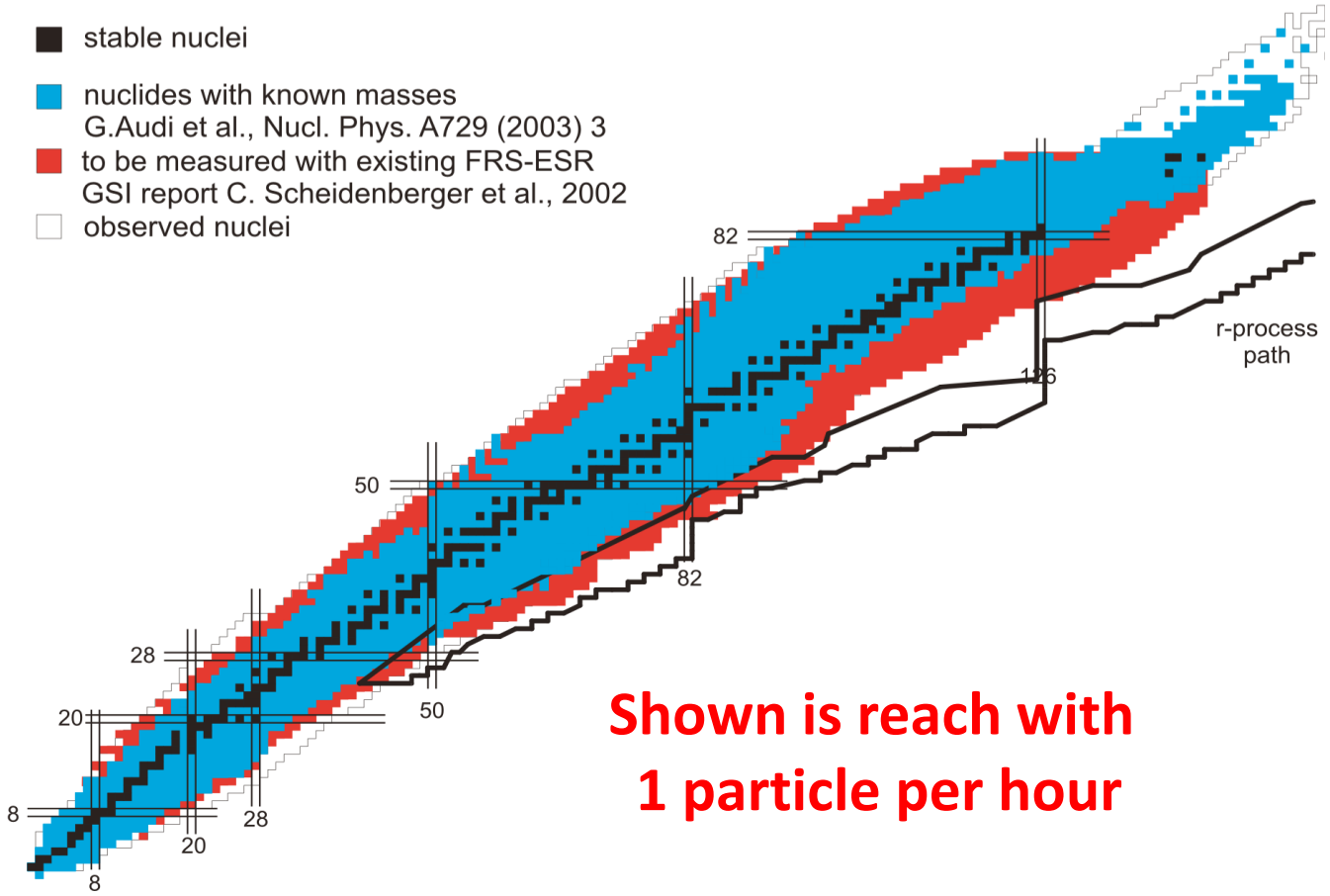
Circumference: 108 m
Energies: 4- 400 MeV/u
Electron and stochastic cooling
Gas jet
Since 1990

CRYRING



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

ILIMA@ESR Physics Program



Shown is reach with 1 particle per hour

New developments (existing and upcoming)

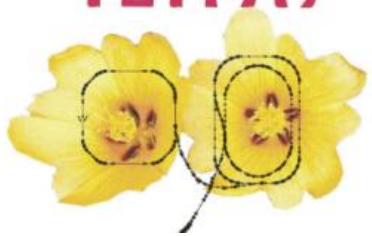
- Time-resolved Schottky + Isochronous Mass Spectroscopy (S+IMS)
- Position-sensitive TOF detectors

Joint efforts ILIMA + SPARC

- Reaction studies at ESR and CRYRING
- Nuclear Excitation by EC (NEEC)

Nuclear Physics at the ESR and CRYRING

ILIMA



Isomers, LIfetimes, and MAsses

Mass measurements

Rare and Exotic Decay Modes of highly-charged ions

Historical division due to FAIR- does not make sense anymore.
Lots of overlap in people and science; shared equipment.

sparc

Stored Particles Atomic Physics Research Collaboration

Stored Particles Atomic physics Research Collaboration

Low-energy capture reactions (for astrophysics)

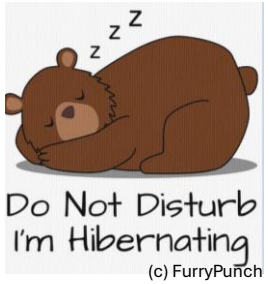
Surrogate reactions

EXL

EXotic nuclei with electromagnetic and Light hadronic probes

Nuclear structure studies of unstable exotic nuclei in light-ion scattering experiments at intermediate energies (NESR)

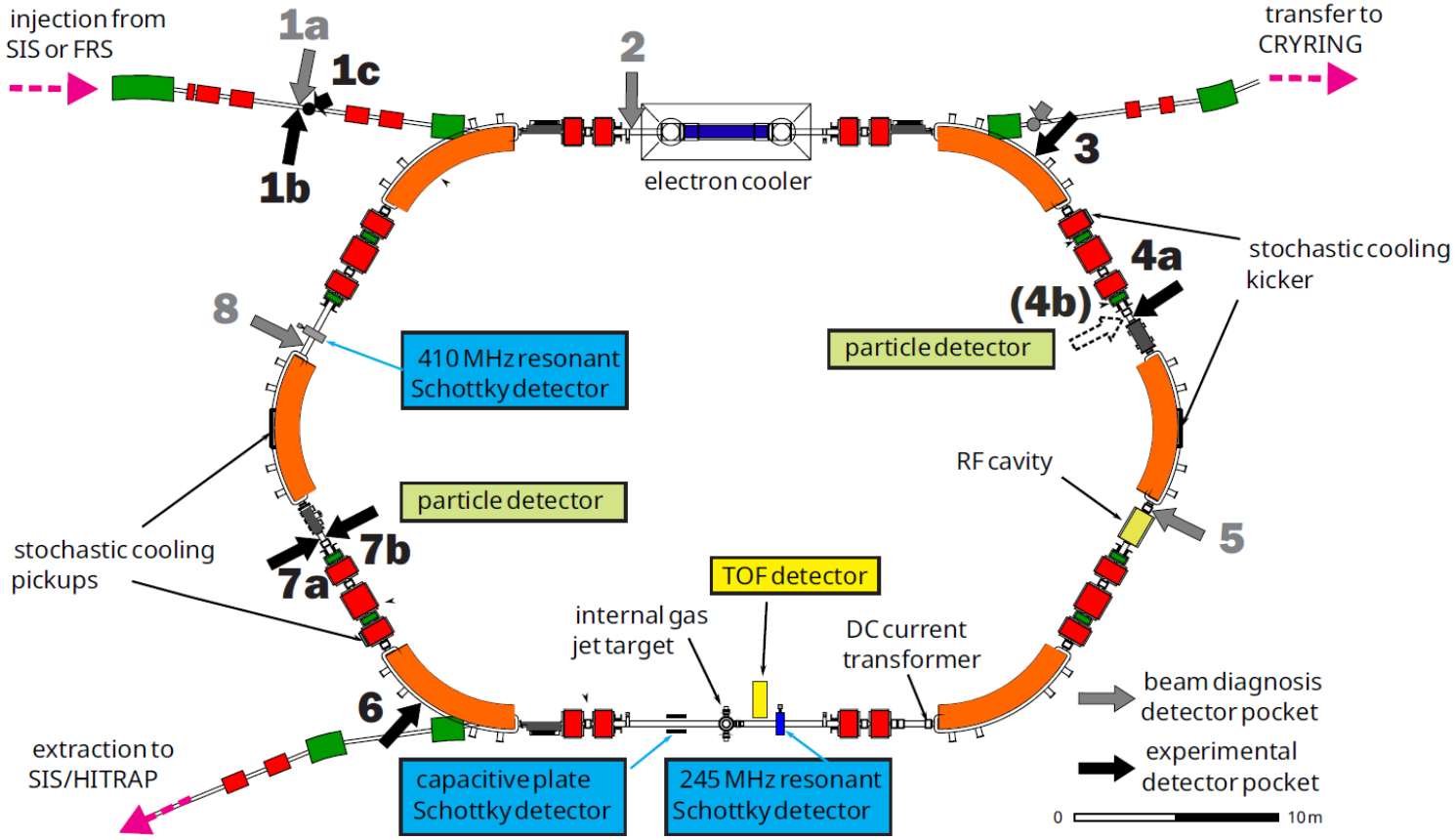
ILIMA and EXL



- EXL collaboration is in “dormant” state
- **ILIMA created new WG “Nuclear Reactions”,** EXL members were encouraged to join ILIMA collaboration
- EXL-type experiments: None scheduled for near future
- Need more human-power to run also EXL within collaboration
- **Details to be worked out in upcoming ILIMA collaboration meetings**

ILIMA@ESR (existing setups)

- TOF detector: Isochronous Mass Spectrometry
- Schottky pickups: Time-resolved mass spectrometry, destruction-free ion detection
- Particle detectors (pocket): Particle detection outside of acceptance



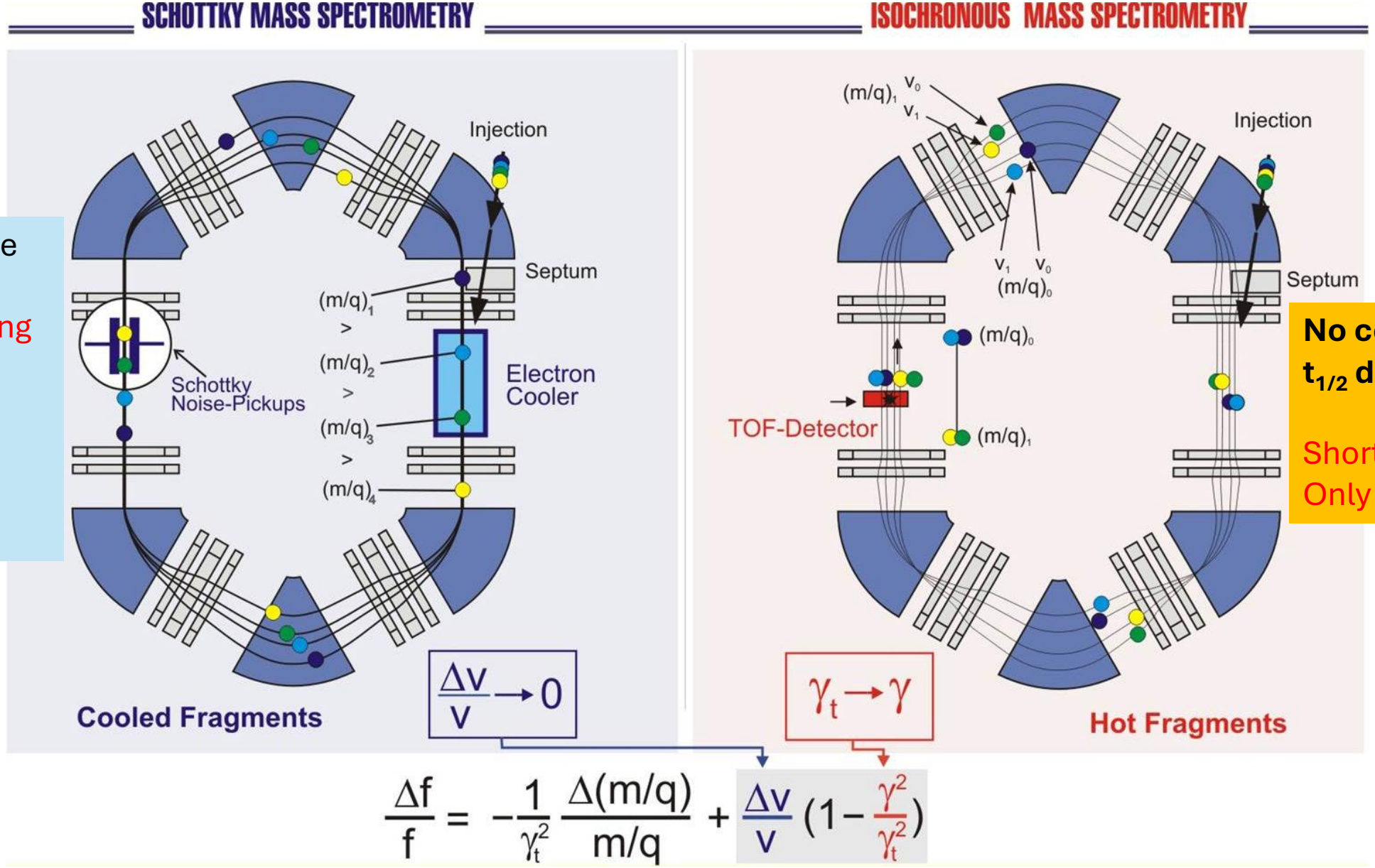
Short-term: Build and install CR-type equipment, test and develop
Long-term: Move equipment to CR and "re-use" it

Schottky detector

TOF detector

Long storage times
Beam cooling needed:
$t_{1/2}$> 1s

High precision



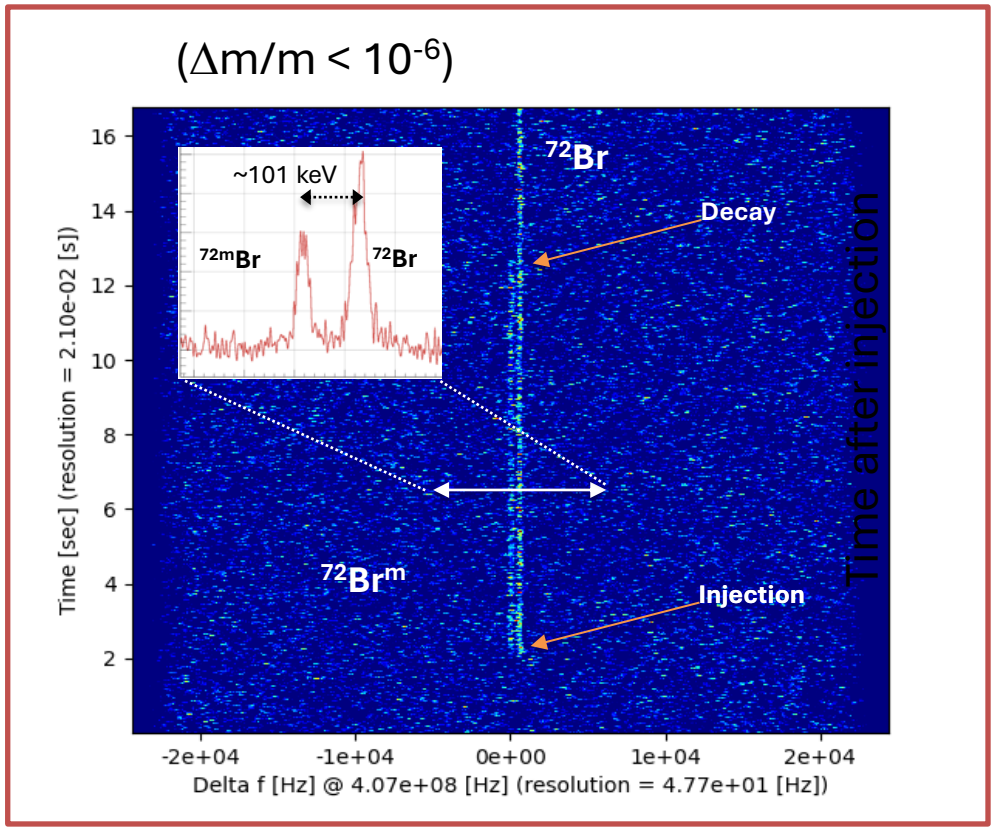
No cooling
$t_{1/2}$ down to 10 µs

Short storage times:
Only ~100 orbits

Combined Isochronous + Schottky Mass Spec

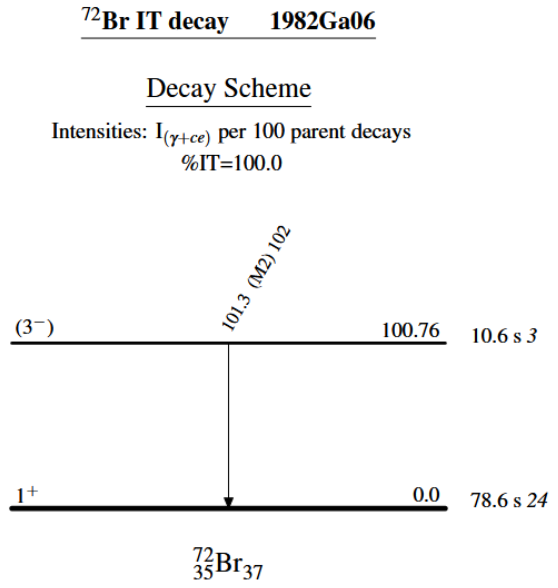
Time-resolved Schottky + Isochronous Mass Spectroscopy (S+IMS)

- Fast method (<u>without</u> beam cooling)
- Single-ion sensitivity
- Non-destructive → Lifetime measurements
- Very good mass resolution (~10^{-6})



Revolution frequency

IT decay of a <u>single</u> ion



(from ENSDF)

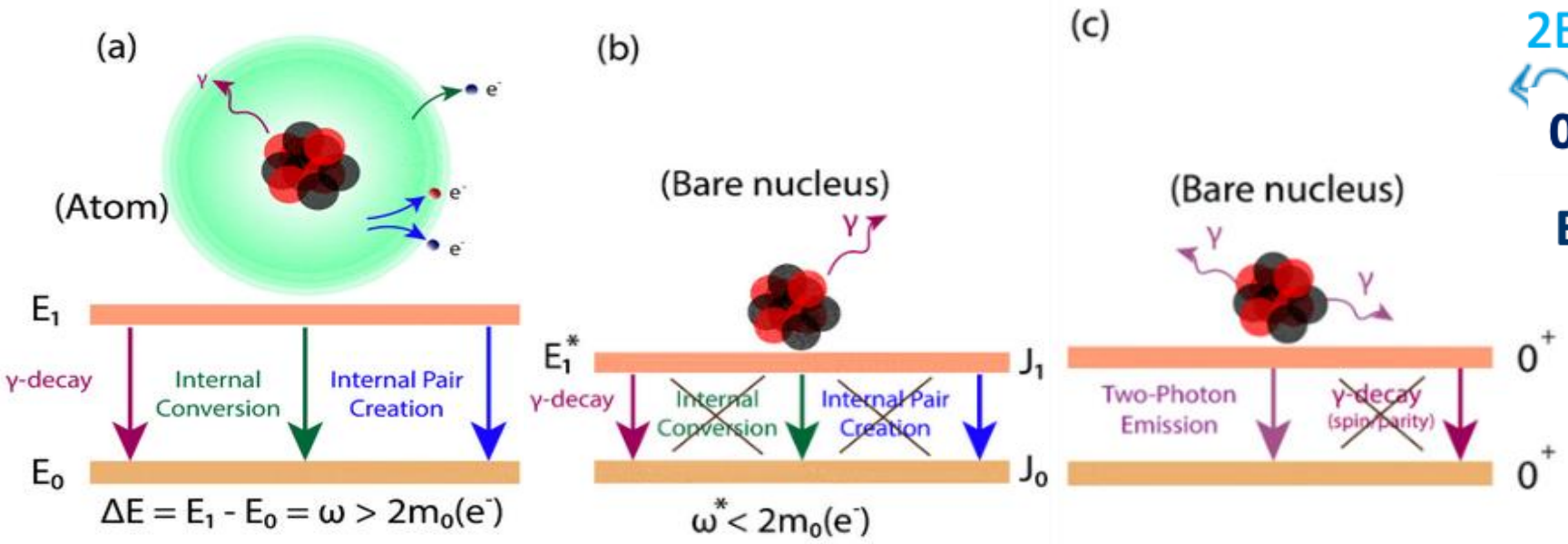
X.L. Tu et al., PRC014321 (2018)
D. Freire-Fernandez, PRL 133, 022502 (2024)

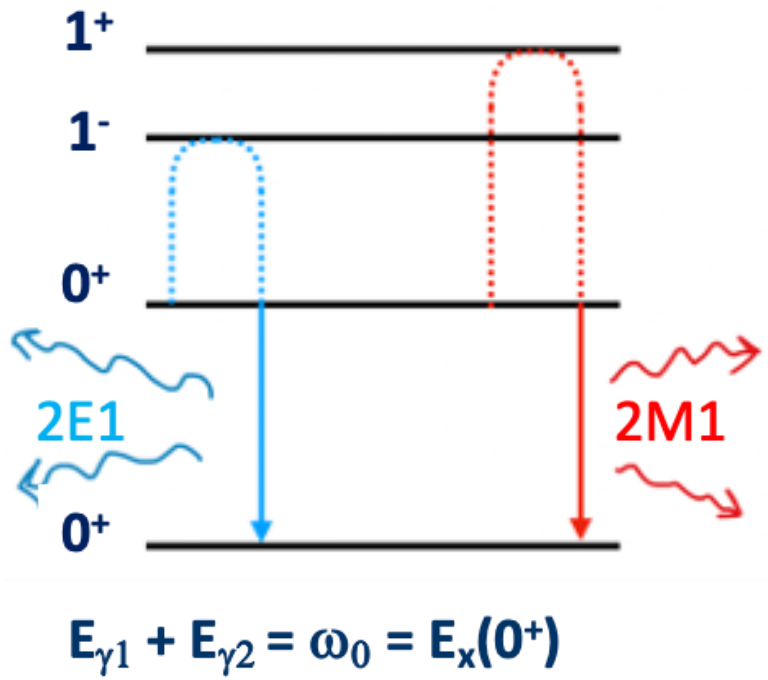
Discovery, accelerated

PI: Wolfram Korten
Carlo Forconi (PhD student)
David Freire (former PhD)

Nuclear Two-Photon Decay of Isomers

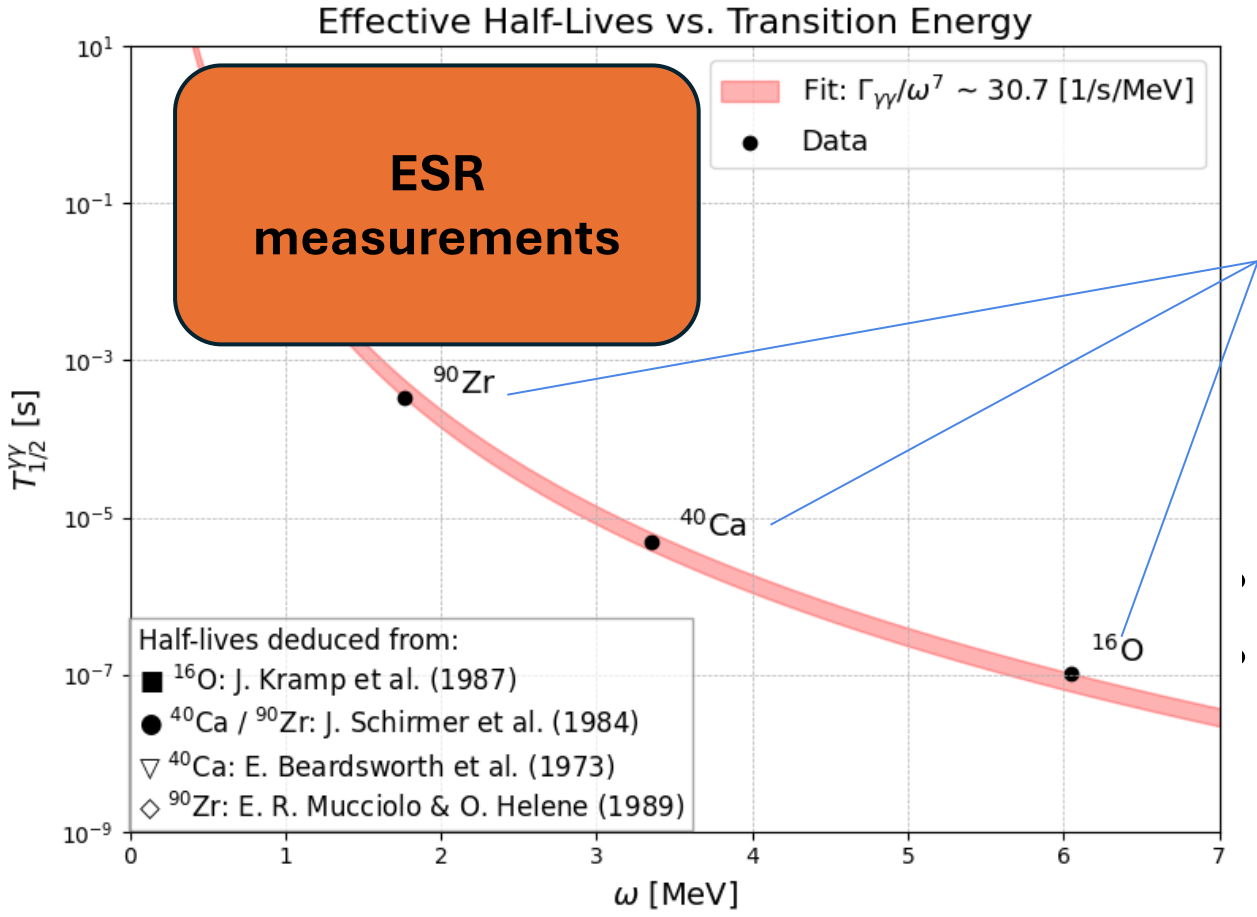
- Study of shape isomers
- Selective blocking of decay modes in highly-charged ions
- $0^+ \rightarrow 0^+$ transitions < 1022 keV: ^{72}Ge, ^{98}Mo, and ^{98}Zr
- Use of time-resolved Schottky + Isochronous MS

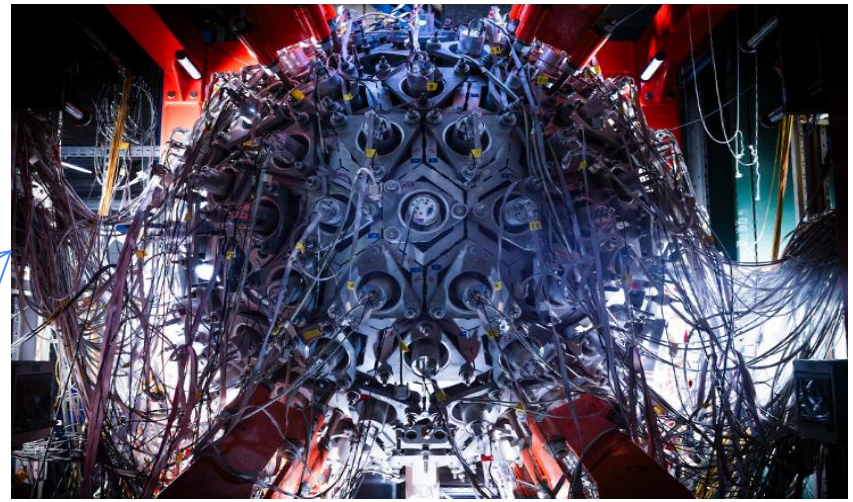




Discovery, accelerated

Nuclear Two-Photon Decay of Isomers





- So far only measured with large γ-arrays
- Only “magic” nuclei

$$\Gamma_{\gamma\gamma} = \frac{\omega_0^7}{105\pi}\left(\alpha_{E1}^2 + \chi_{M1}^2 + \frac{\omega_0^4}{4752}\alpha_{E2}^2\right)$$

Electric dipole transition polarizability

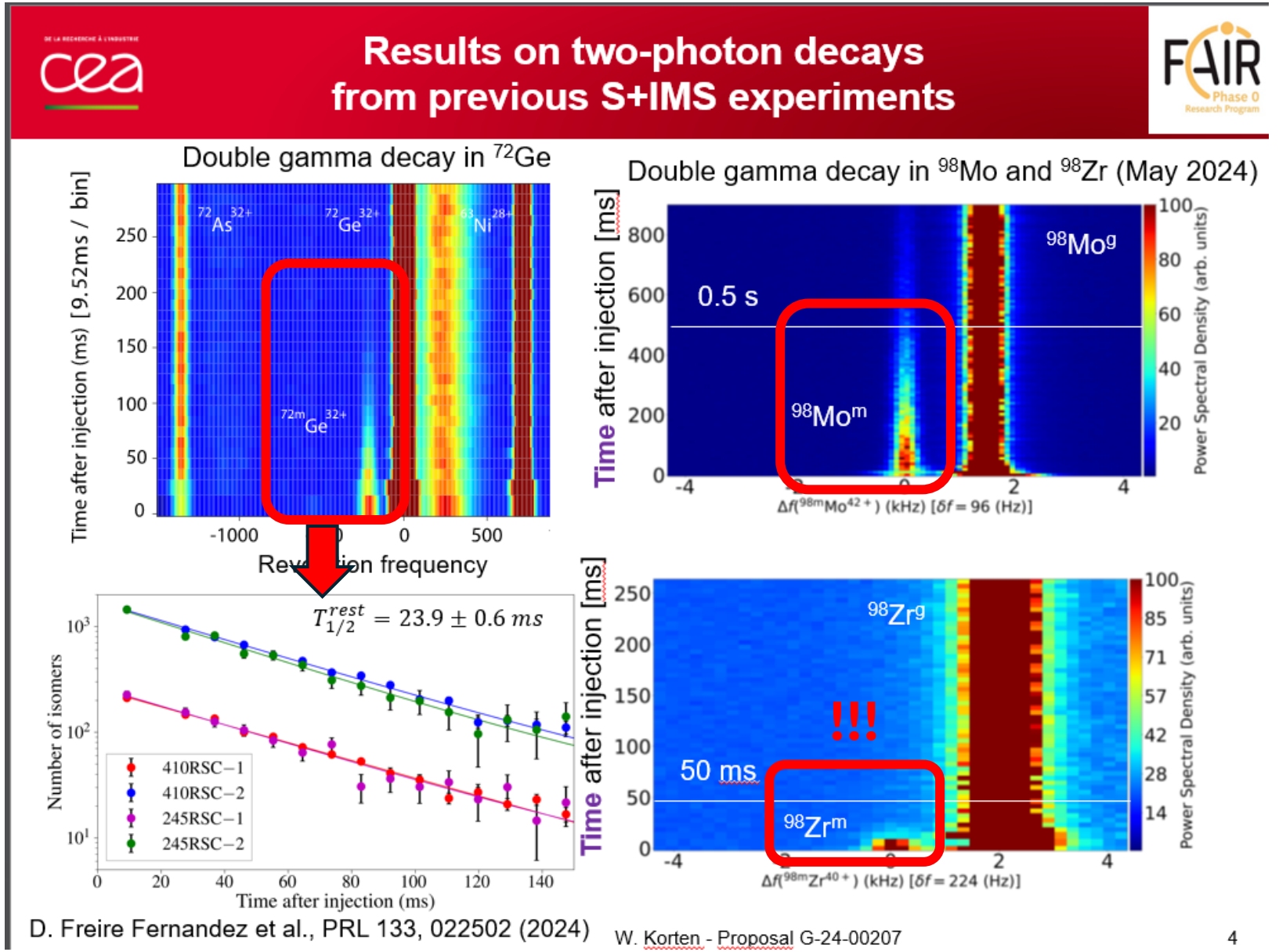
Magnetic dipole transition susceptability

Electric quadrupole transition polarizability

Two-Photon Decays

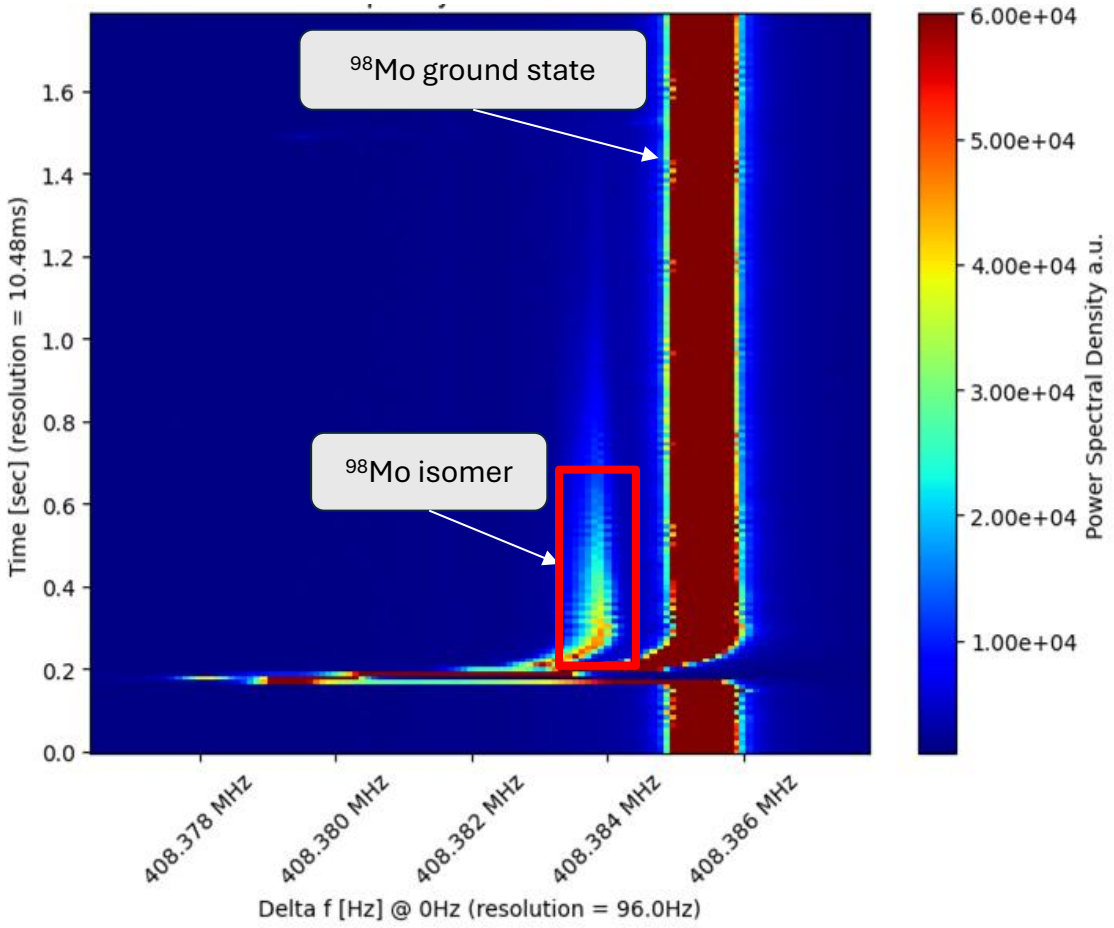
Time-resolved Schottky + Isochronous Mass Spectroscopy (S+IMS)

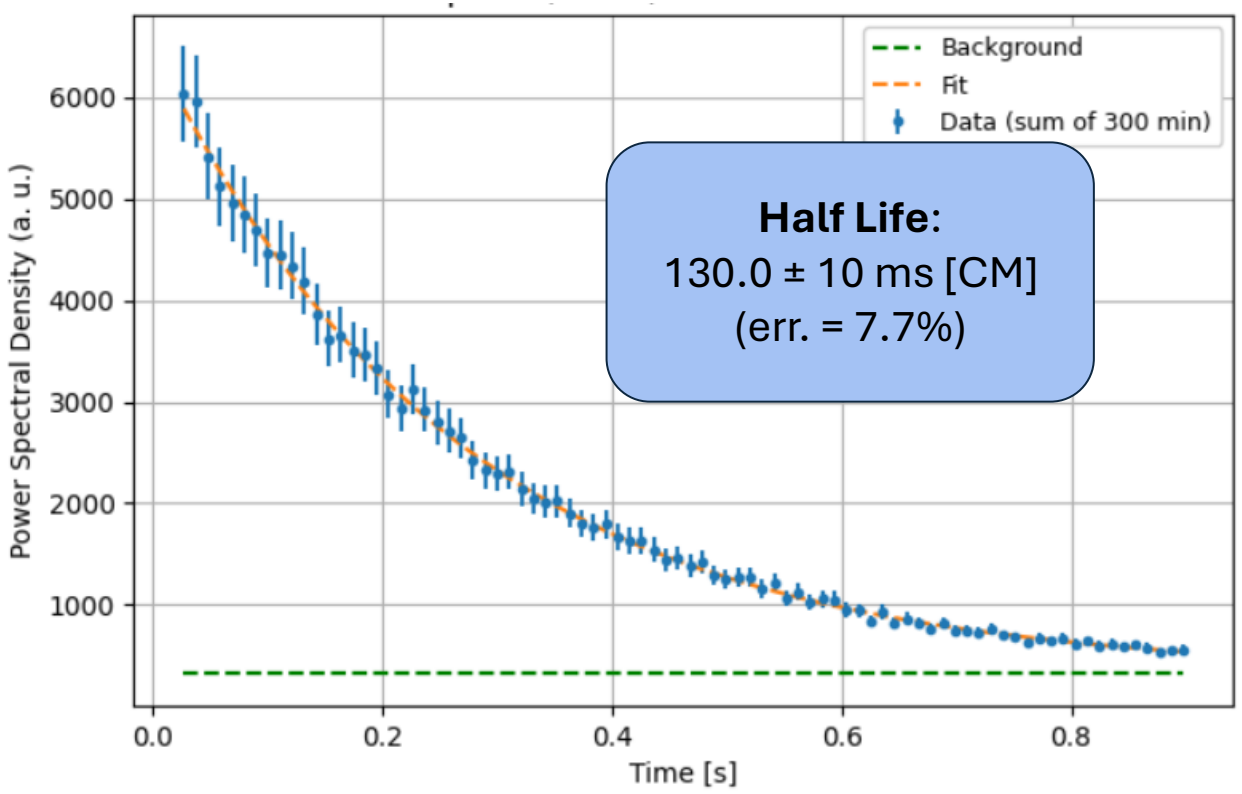
- **Down to half-lives of few ms!!!**



Slide from W. Korten

Nuclear Two-Photon Decay: ^{98}Mo Results



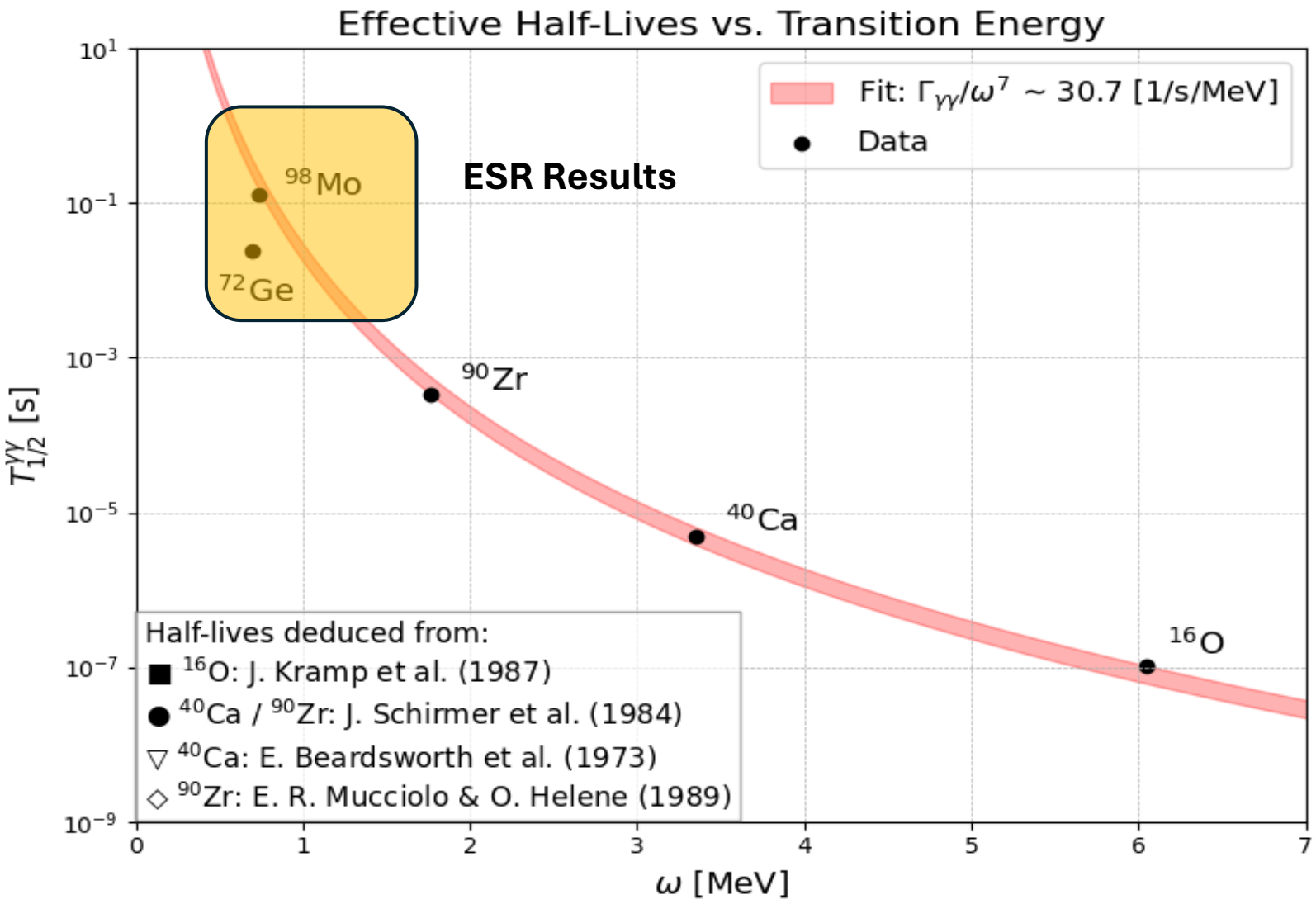


Half Life:
130.0 ± 10 ms [CM]
(err. = 7.7%)

PhD thesis Carlo Forconi

Discovery, accelerated

Nuclear Two-Photon Decay of Isomers

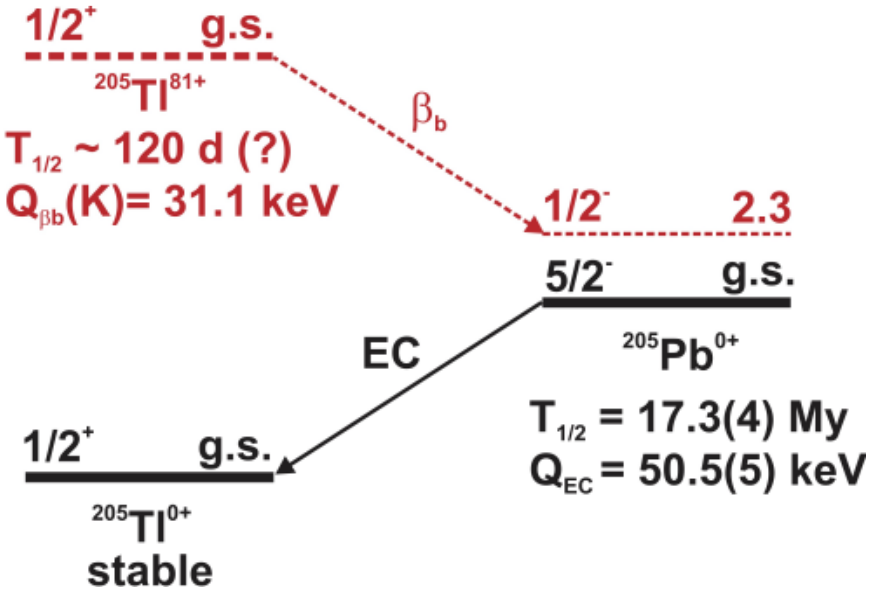


- Next: Analyze ^{98}Zr data (2024)
- Analyze ^{192,194}Pb test (2025)

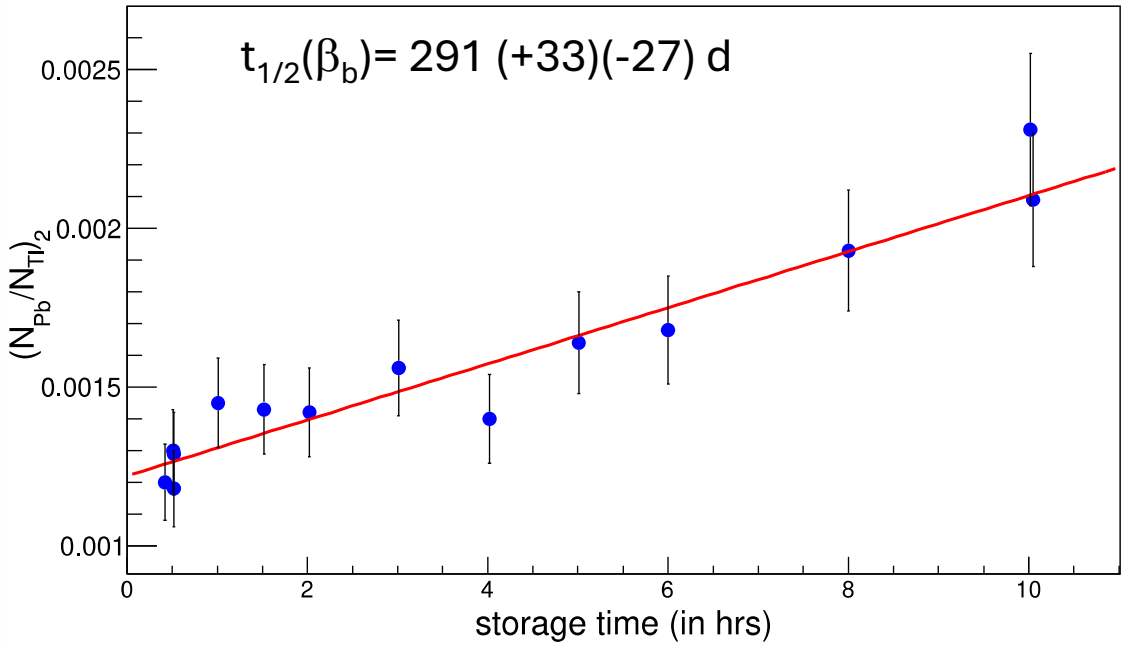
Bound-state β-decay

^{205}Tl: Stable in neutral atoms (0+)
Radioactive in bare ions (81+)

Lifetime of highly-charged ions



- Storage of millions of $^{205}Tl^{81+}$ ions → only possible in ESR!
- ^{205}Pb is cosmochronometer in s-process
- Measured β_b-half-life **longer** than expected!
- Lorandite Experiment (LOREX): Solar neutrino detector - 15(4) ^{205}Pb atoms produced by neutrino capture per gram lorandite ($TlAsS_2$) - **30% less than predicted** ☹



G. Leckenby et al., Nature 634, 321 (2024)
R. S. Sidhu et al., PRL 133, 232701 (2024)

Discovery, accelerated

ILIMA@ESR: The next 5+x years

GPAC2025: **Renewed interest in unique physics capabilities: 7 proposals (*5 new)!**

1. *Search for bound-state pair conversion in bare atomic nuclei (Wolfram Korten)
2. *Exploration of shape isomers in Kr and Se via Schottky isochronous mass spectrometry (Ruijiu Chen)
3. *Harvesting Isomers, LIfetime & MAsses (ILIMA) south-west of ^{208}Pb (Shahab Sanjari)
4. *Isomer beam technique and its first reaction studies with ESR (Taka Yamaguchi)
5. Symbiotic measurement of masses, half-lives, and neutron branching ratios of ^{137,138}I at the ESR (Chris Griffin)
6. *Measurement of the bound-state and continuum β decay of $^{134}Cs^{55+}$ ions (David Mascali)
7. Influence of Hyperfine Interaction on Nuclear Electron Capture in ^{111}Sn (Ragandeep Singh Sidhu)

What is the next big thing?

Direct neutron capture reactions on **radioactive** nuclei!
NSTARS project at CRYRING (**under funding review*)

Submitted to Physical Review Accelerators and Beams

Direct Neutron Reactions in Storage Rings Utilizing a Supercompact Cyclotron Neutron Target

Ariel Tarifeño-Saldivia* and César Domingo-Pardo
Instituto de Física Corpuscular (CSIC-Universitat de València), Valencia, Spain

Iris Dillmann
TRIUMF, Vancouver BC, Canada and
Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada

Yuri A. Litvinov
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany and
Institut für Kernphysik, Universität zu Köln, Köln, Germany
(Dated: August 22, 2025)

https://arxiv.org/pdf/2508.15465

WP1: NSTAR at CRYRING (Y. Litvinov, GSI)

WP2: Neutron Target (A. Tarifeno, IFIC)

WP3: Ion Detection (I. Dillmann, TRIUMF)

WP4: Experiments (C. Domingo, IFIC)

WP5: Design of Future Facility (all)

(Modern) Heavy RIB Storage Rings

Operational
Under construction
Postponed
Proposed
~~Cancelled/closed~~

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)
- Collector Ring (CR) and High-Energy Storage Ring (HESR) at FAIR (>203x)
- Spectrometer Ring at HIAF in Huizhou (2025)

+ Neutron Target

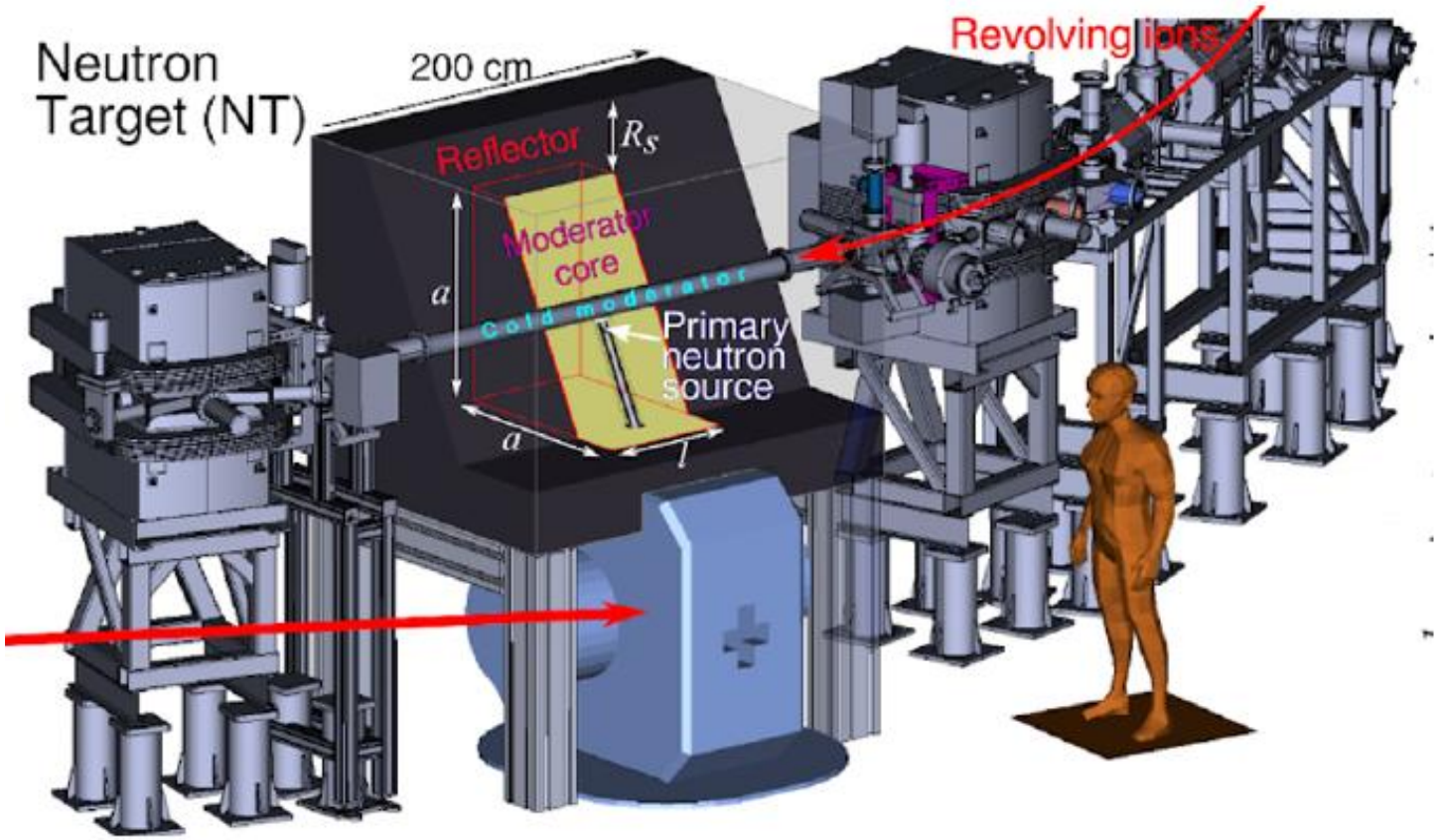
ISOL facility

- ~~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)*

Future facilities

Discovery, accelerated

Assembly at CRYRING (2026-2032 if funded)



Cyclotron

https://arxiv.org/pdf/2508.15465

Summary

- Nuclear Physics program at ESR: Unique experiments since >30 years!
- ILIMA@ESR program will continue until CR is built
- Many new ideas (S+IMS, nuclear 2-photon decay, NEEC, isomeric beams…)
- Upgrade/ construction of FAIR detectors - can be transferred to CR later
- Expansion of experimental program: Reactions in storage rings (ESR and CRYRING)
  - protons and α's ✓
  - neutrons are the future!

In Memoriam: Markus Steck

1958-2025

We mourn the loss of our long-time colleague Markus Steck, who passed away suddenly and unexpectedly on August 1, 2025, at the age of 66.

Markus began his work at GSI in July 1990.

In 1999, he became head of the ESR group, a role he held with great dedication until his retirement in October 2024.

Markus was considered the “head and heart of the ESR”, combining deep understanding of beam dynamics with technical expertise and system-wide insight.

His legacy will continue to impact storage ring physics research for years to come.

TRIUMF

Thank You!
Merci!
hay č xʷ q̓ə!

www.triumf.ca
@TRIUMFLab