The ILIMA@ESR Project at GSI/FAIR

Present and Future

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ILIMA Spokesperson

TRIUMF & U of Victoria

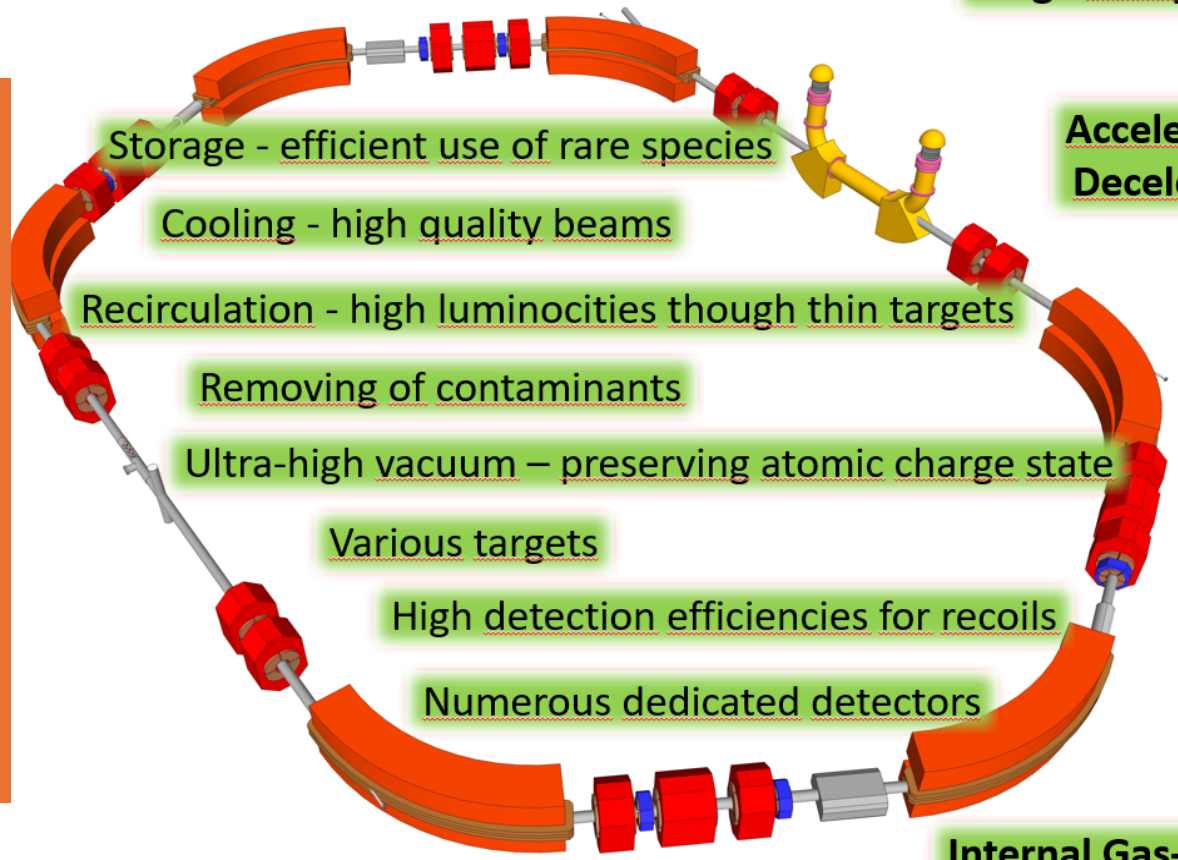
Discovery, accelerated

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

(Modern) Heavy RIB Storage Rings

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

Fragmentation facility

- **Experimental Storage Ring (ESR) at GSI Darmstadt (since 1990)**
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- Spectrometer Ring at HIAF in Huizhou (2025)

ISOL facility

- ~~Test Storage Ring (TSR) at CERN-ISOLDE (2012)~~ (1988-2013)
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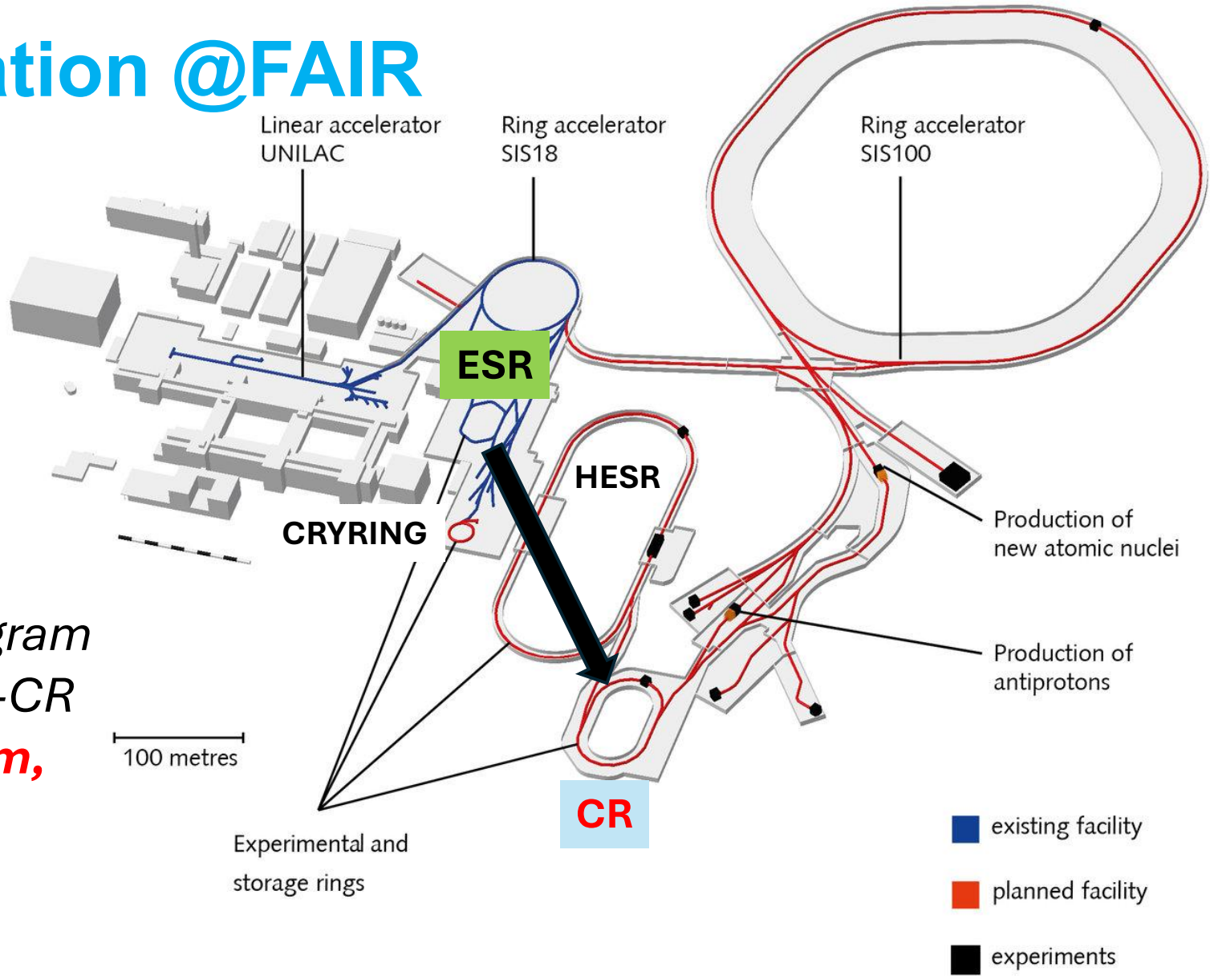
Discovery, accelerated

ILIMA Collaboration @FAIR

Isomers
LIfetimes
MAsses

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

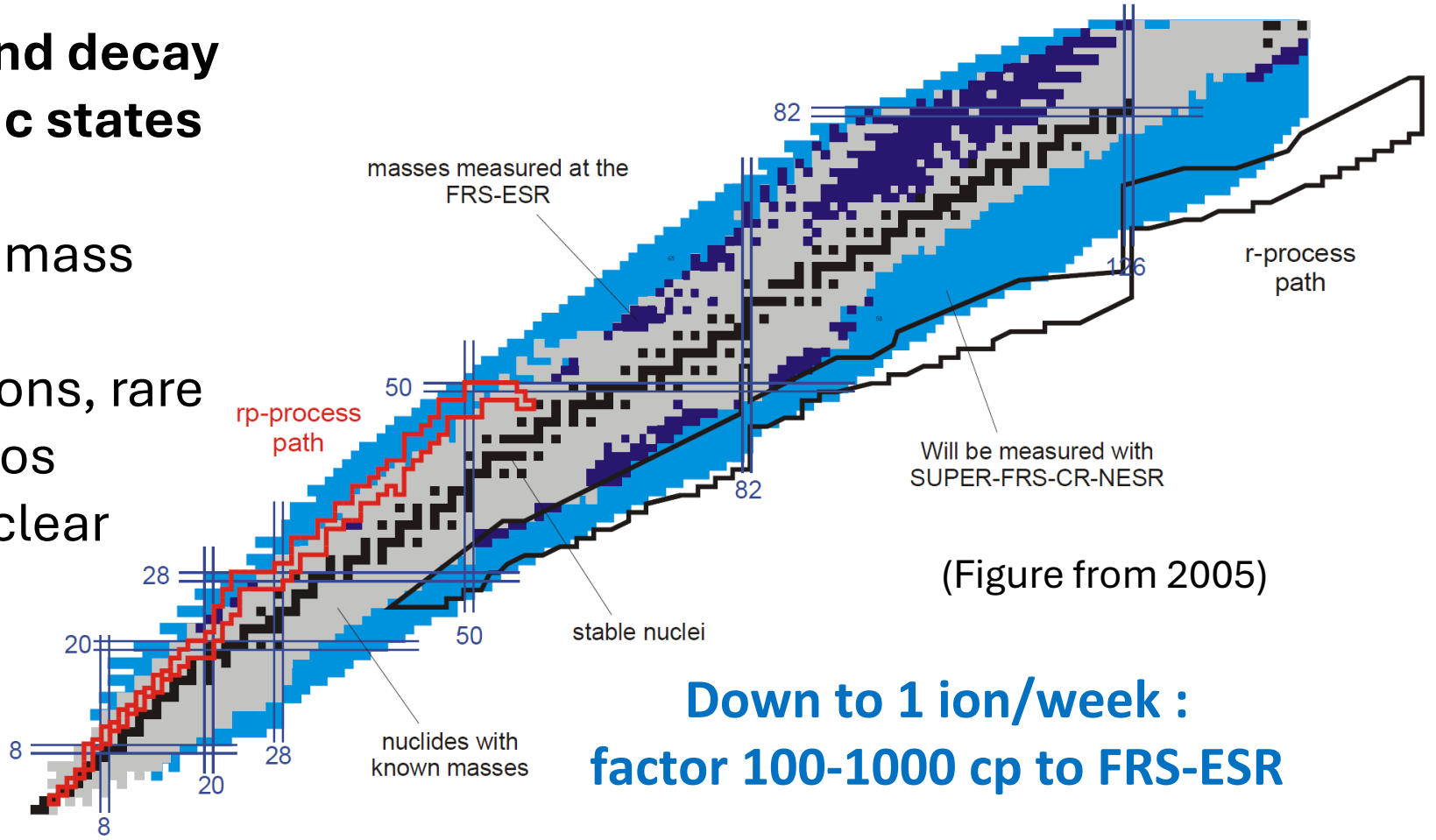
- ***Measure masses < 1ppm,***
- ***$t_{1/2}$ > 10 μs,***
- ***Yields <1 ion per week***



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

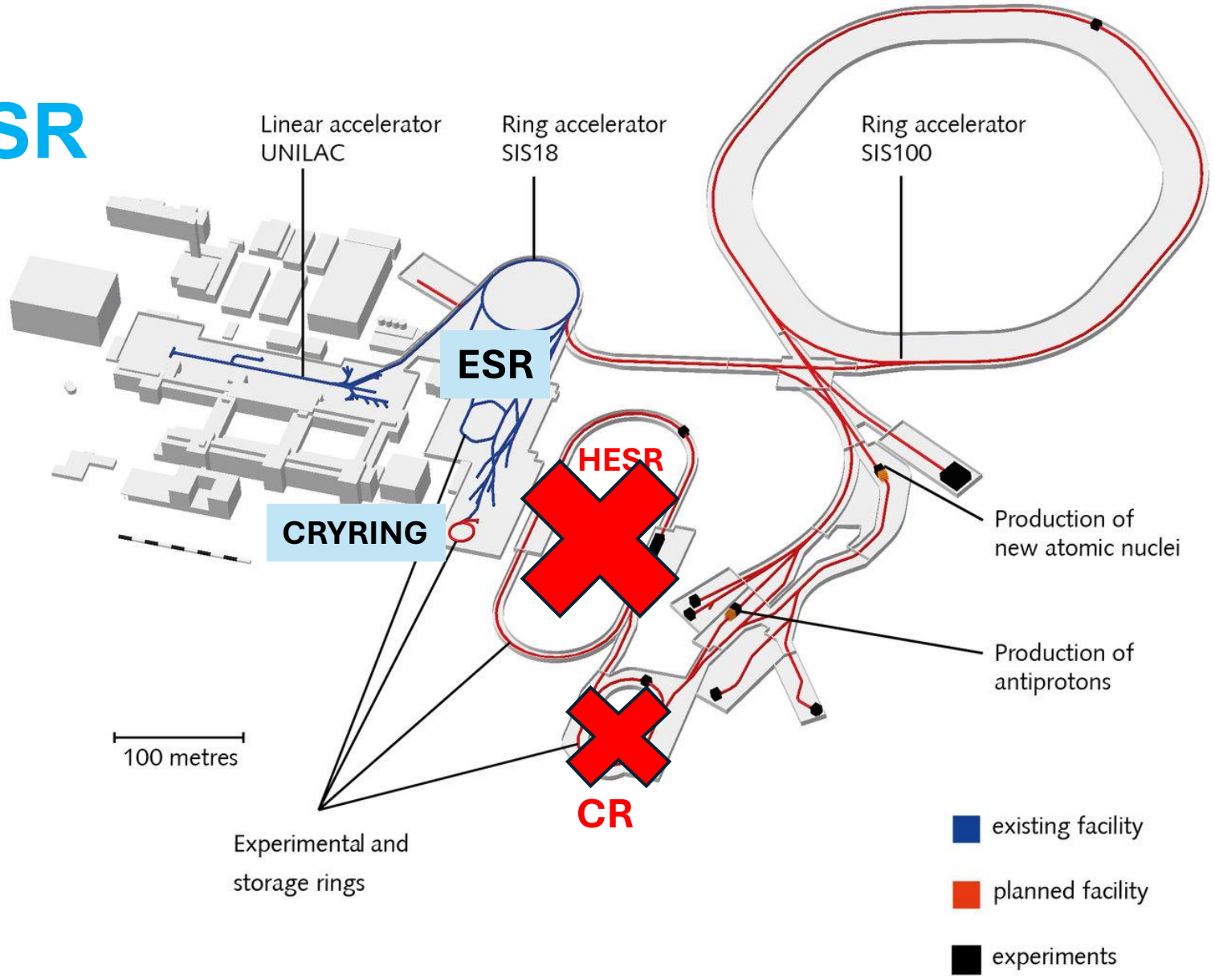


(Figure from 2005)

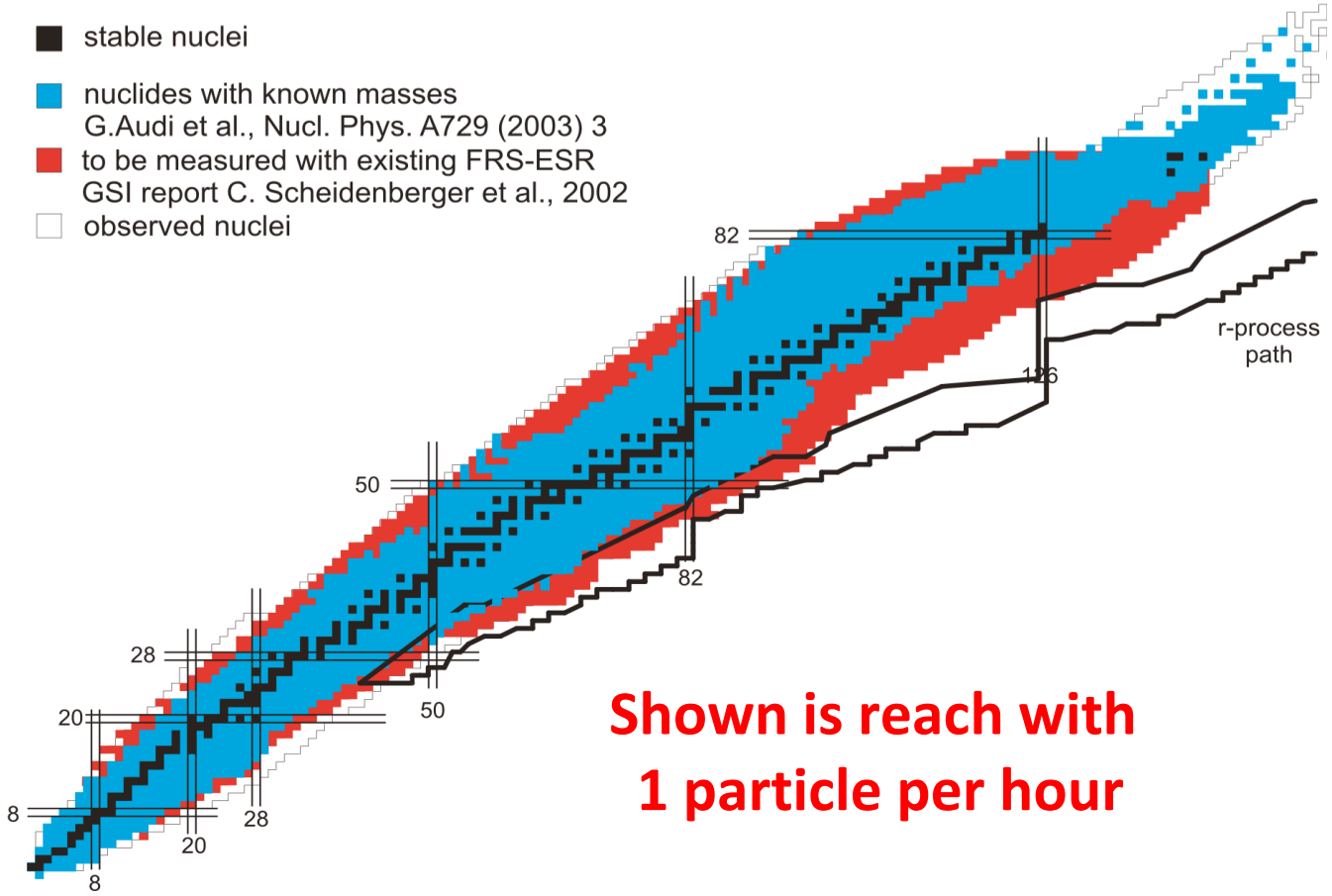
Down to 1 ion/week : factor 100-1000 cp to FRS-ESR

2025: ILIMA@ESR

Only ESR and CRYRING for now…
Let's do the best with this situation!



ILIMA@ESR Physics Program



Shown is reach with 1 particle per hour

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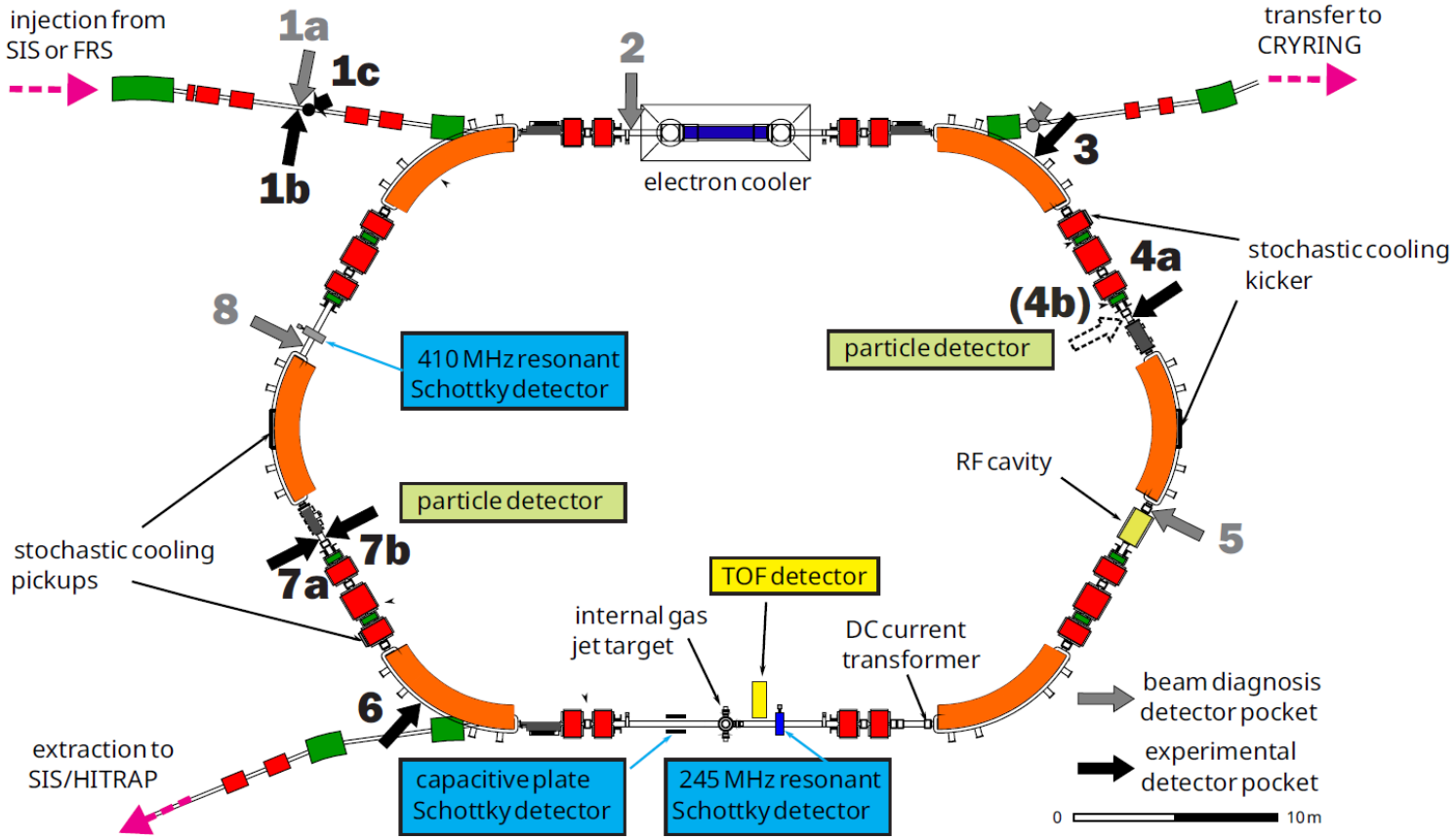
New developments (existing and upcoming)

- Time-resolved Schottky + Isochronous Mass Spectroscopy (S+IMS)
- Position-sensitive TOF detectors
- Reaction studies at ESR and CRYRING (joint effort btw EXL, ILIMA and SPARC)
- Nuclear Excitation by EC (NEEC) (joint effort btw SPARC and ILIMA)
- …

Discovery, accelerated

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

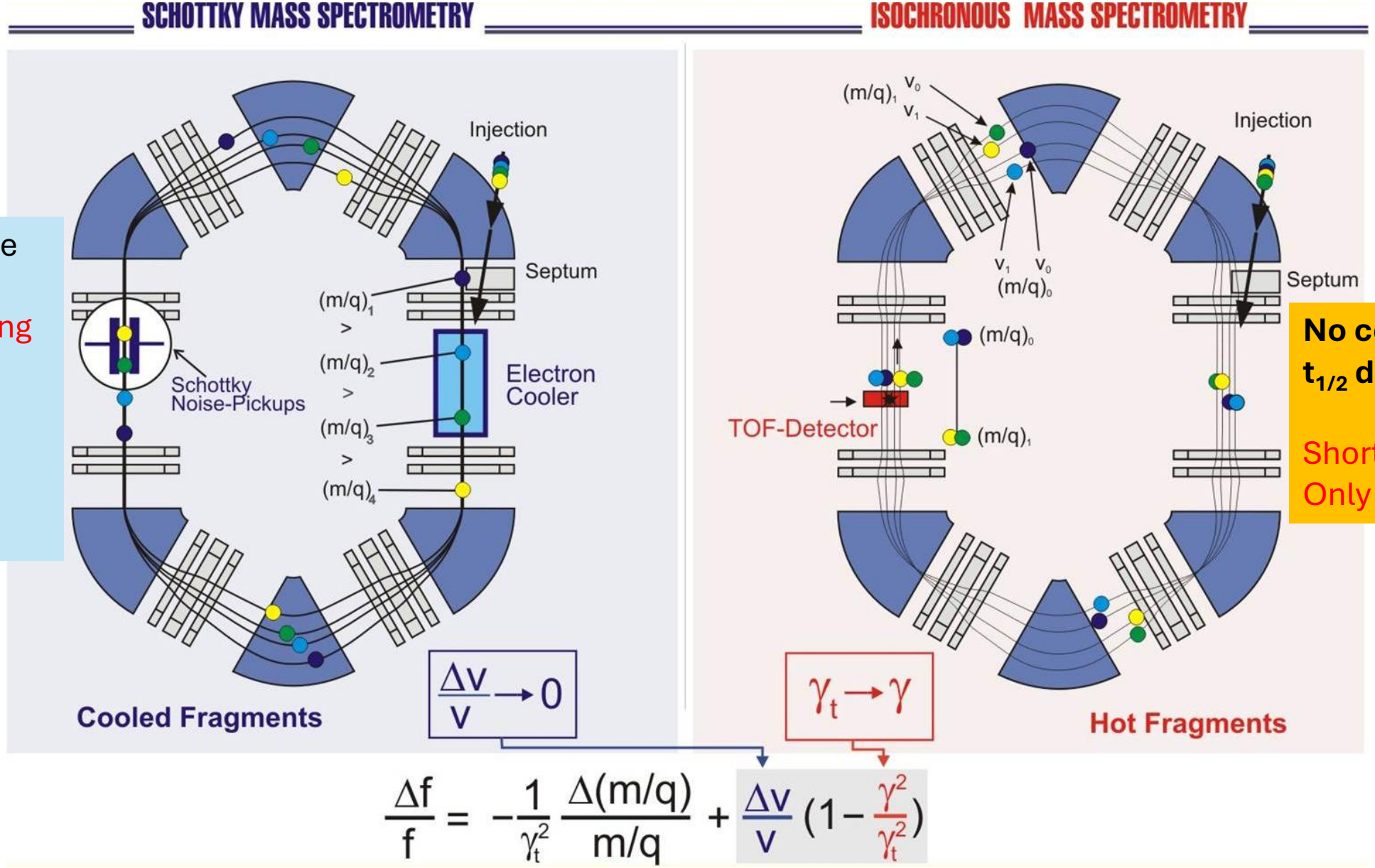


Schottky detector

TOF detector

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

High precision



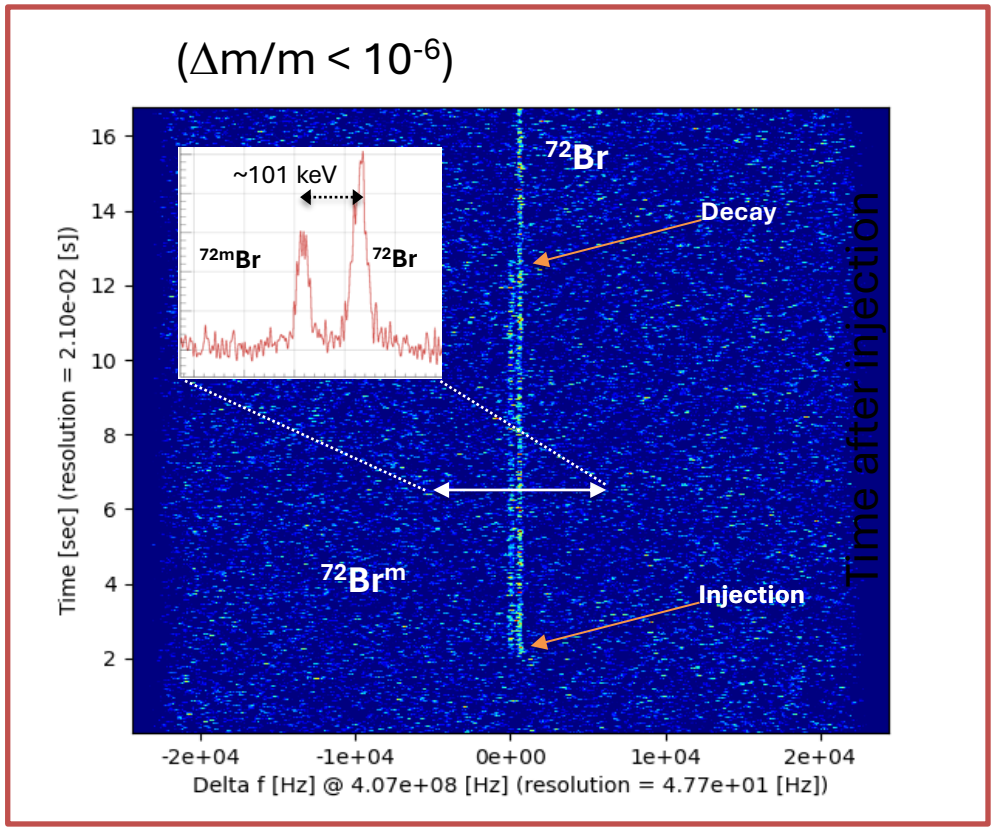
No cooling
$t_{1/2}$ down to 10 µs

Short storage times:
Only ~100 orbits

Combined Isochronous + Schottky Mass Spec

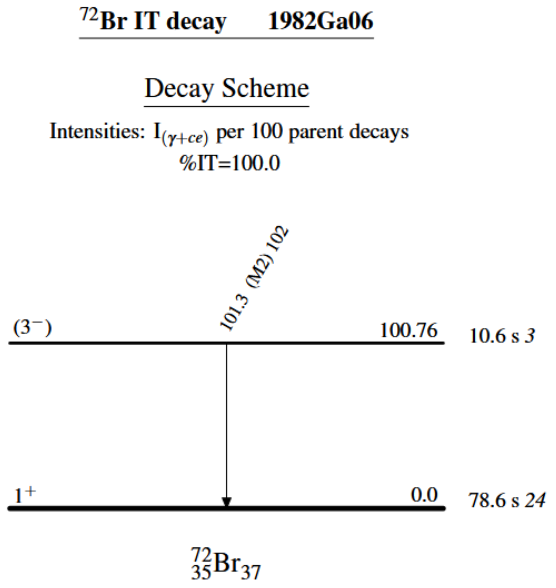
Time-resolved Schottky + Isochronous Mass Spectroscopy (S+IMS)

- 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



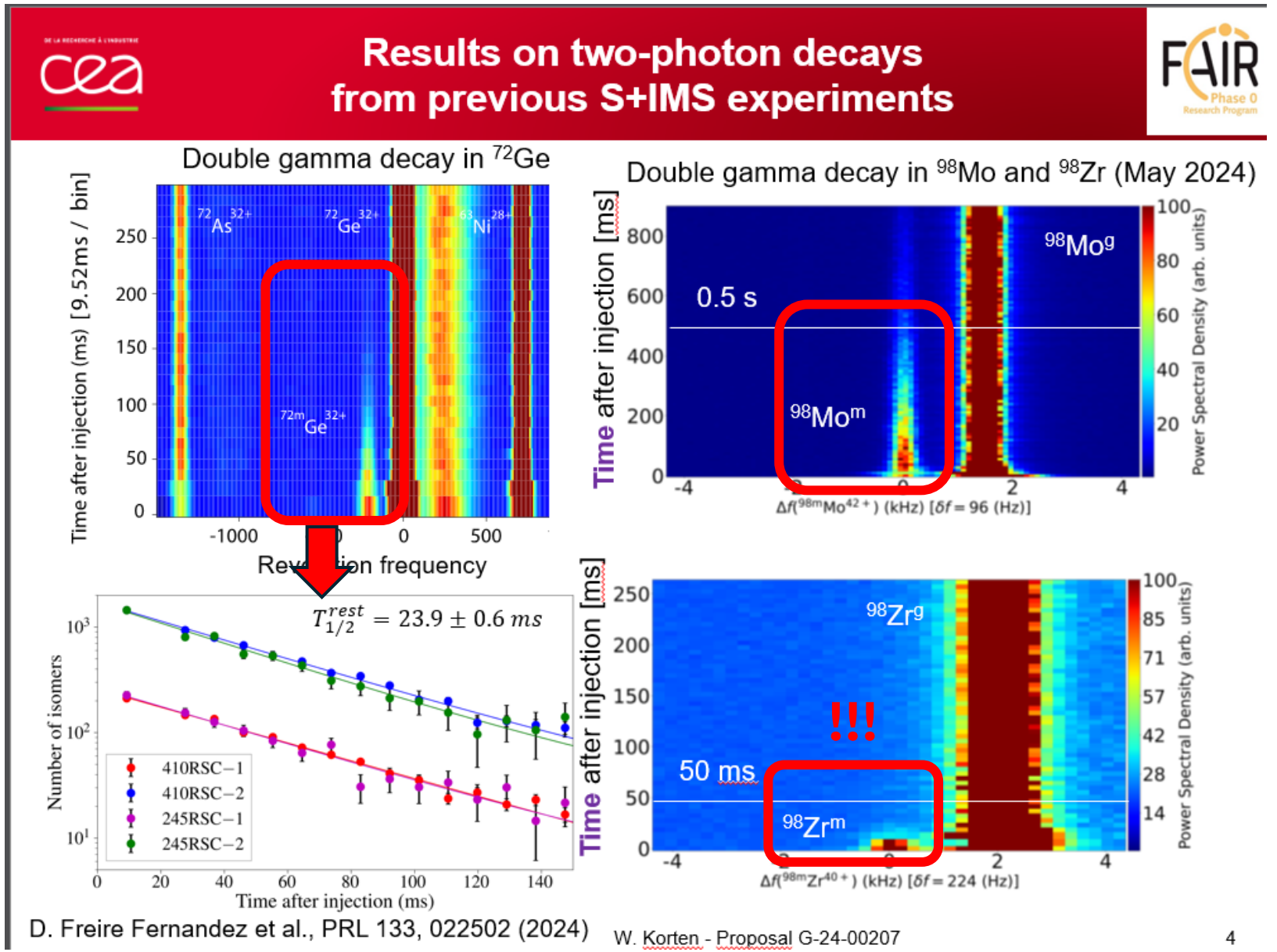
(from ENSDF)

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

Recent Highlight

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

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



D. Freire Fernandez et al., PRL 133, 022502 (2024)

W. Korten - Proposal G-24-00207

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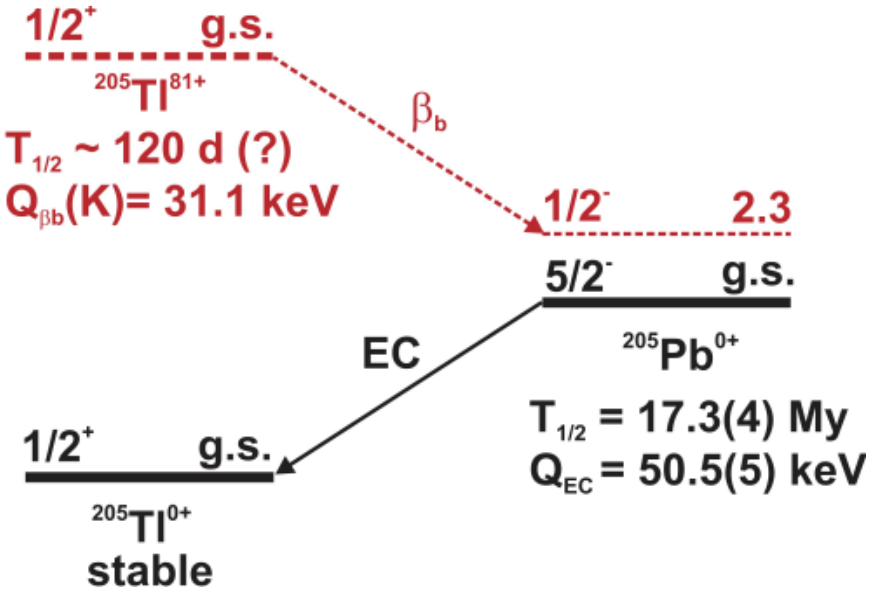
Slide from W. Korten

Discovery, accelerated

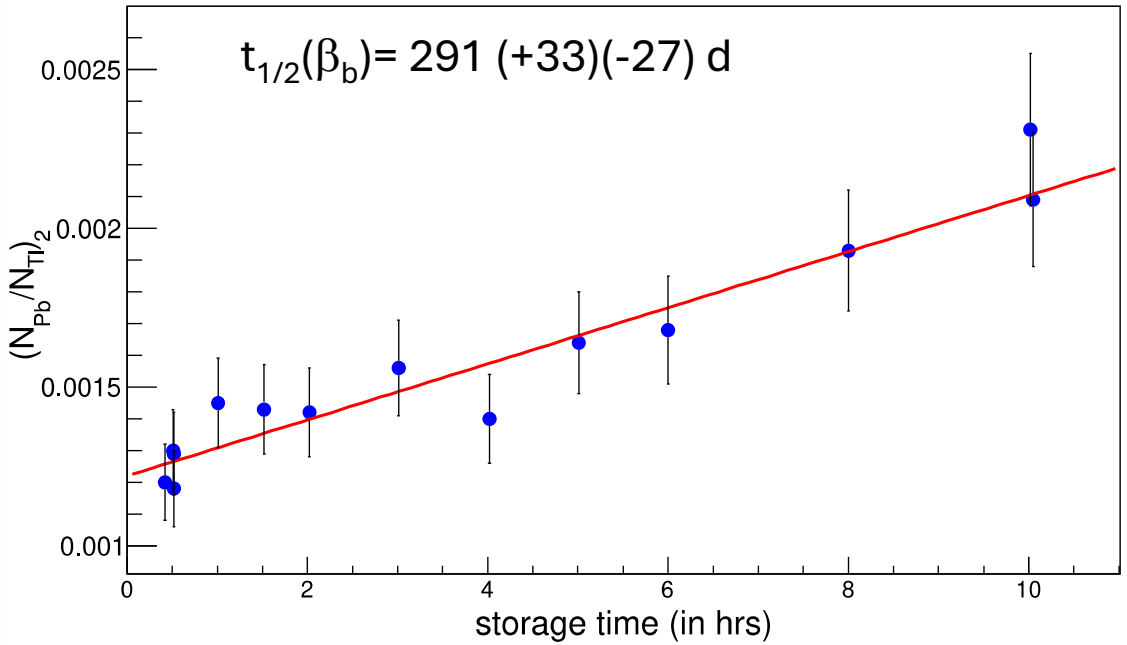
Bound-state β-decay

^{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!
- Measured β_b-half-life longer than expected!
- ^{205}Pb is cosmochronometer in s-process
- Lorandite Experiment (LOREX): Solar neutrino detector - 15(4) ^{205}Pb atoms produced by neutrino capture per gram lorandite ($TlAsS_2$) - 30% less than predicted ☹

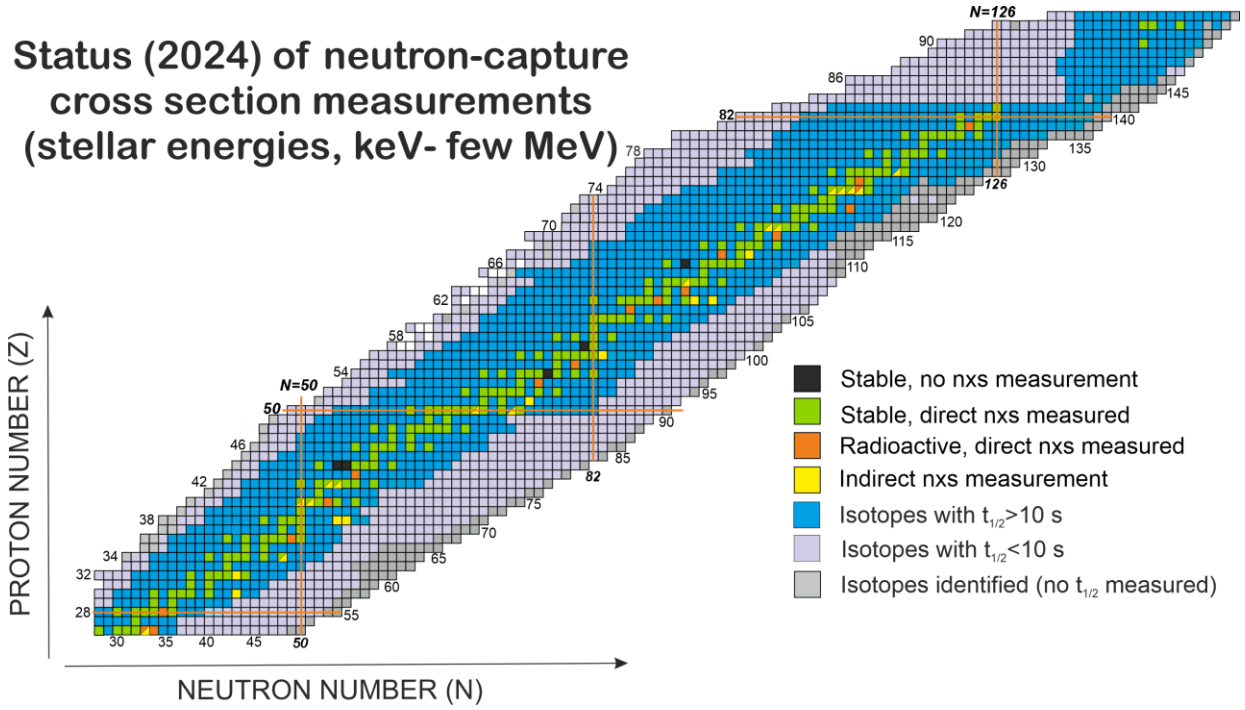


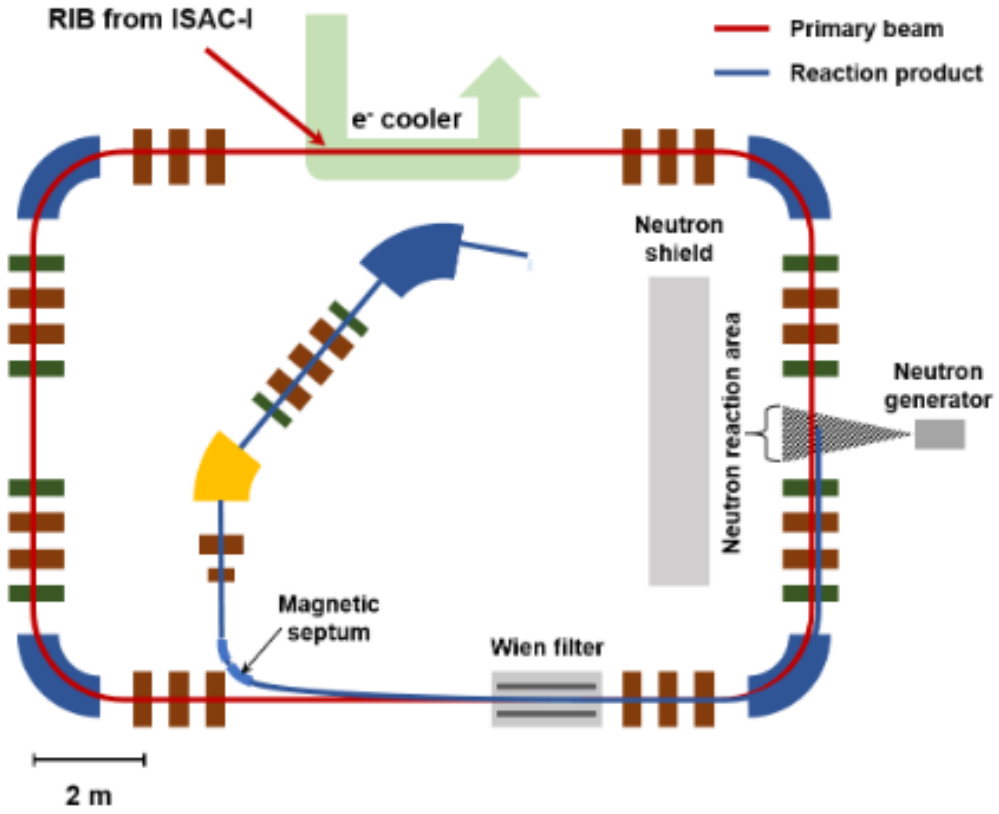
G. Leckenby et al., Nature 634, 321 (2024)
R. S. Sidhu et al., PRL 133, 232701 (2024)

Discovery, accelerated

What is the next big thing?

Direct neutron capture reactions on **radioactive** nuclei!





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)

NSTARS project at CRYRING
TRIUMF Storage Ring project

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+ Neutron Target

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- *TRIUMF Storage Ring (TRISR, proposed) at TRIUMF-ISAC (>203x)*
- *Los Alamos Storage Ring (proposed) at LANSCE (>203x)*

Discovery, accelerated

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!

Stay tuned!

TRIUMF

Thank You!
Merci!
hay č xʷ q̓ə!

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