Time-of-flight mass measurements for astrophysics

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Darmstadt, Oct 12th 2011

Outline

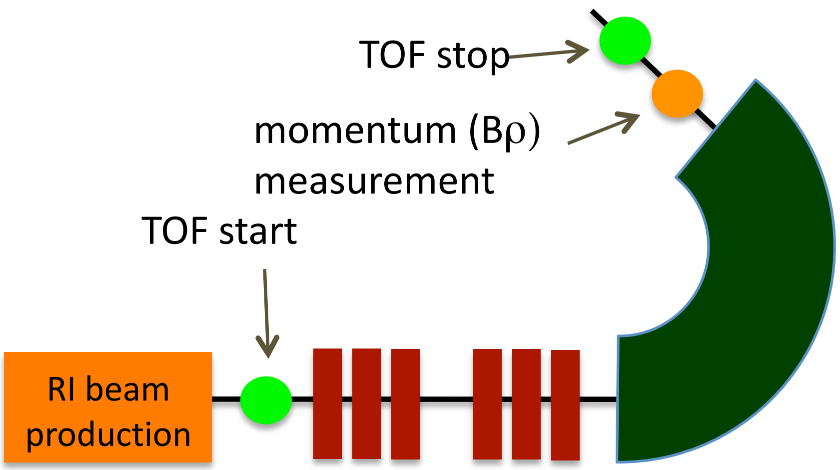
- Basic principles of Time-of-flight (TOF) mass measurements.

- Recent results.

- Perspectives.

Principles of time-of-flight (TOF) measurements

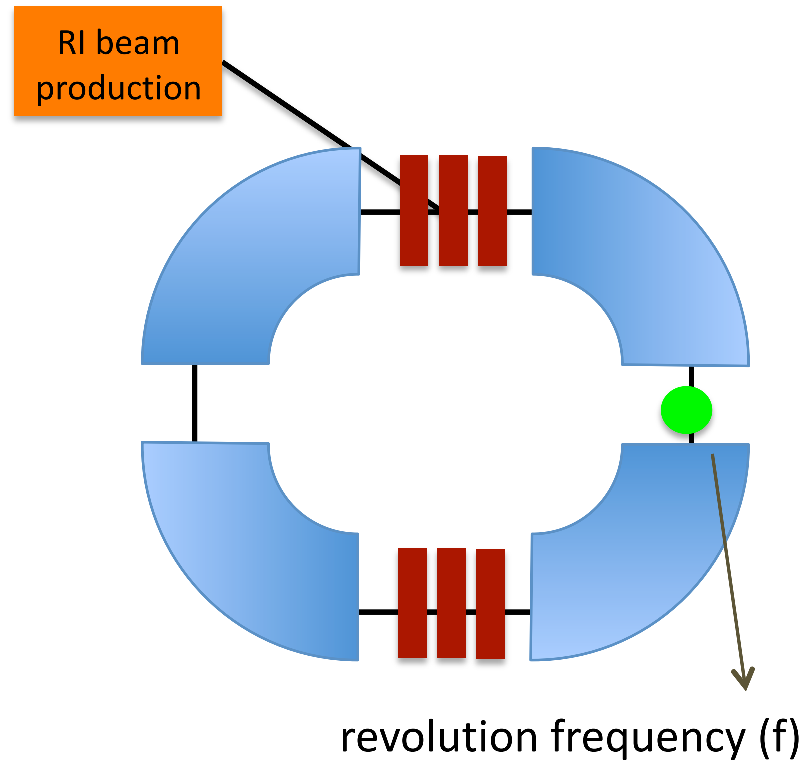
TOF + momentum measurement



$$B\rho = \frac{\gamma p}{q} = \frac{\gamma m_0}{q}\left(\frac{L}{TOF}\right)$$

Measure mass relative to isotopes in the beam with well known masses (calibration masses).

Multi-turn measurements at storage rings



$$\frac{\Delta f}{f} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\cdot\left(1 - \frac{\gamma^2}{\gamma_t^2}\right)$$

Beam cooling (Schottky)

Isochronous optics

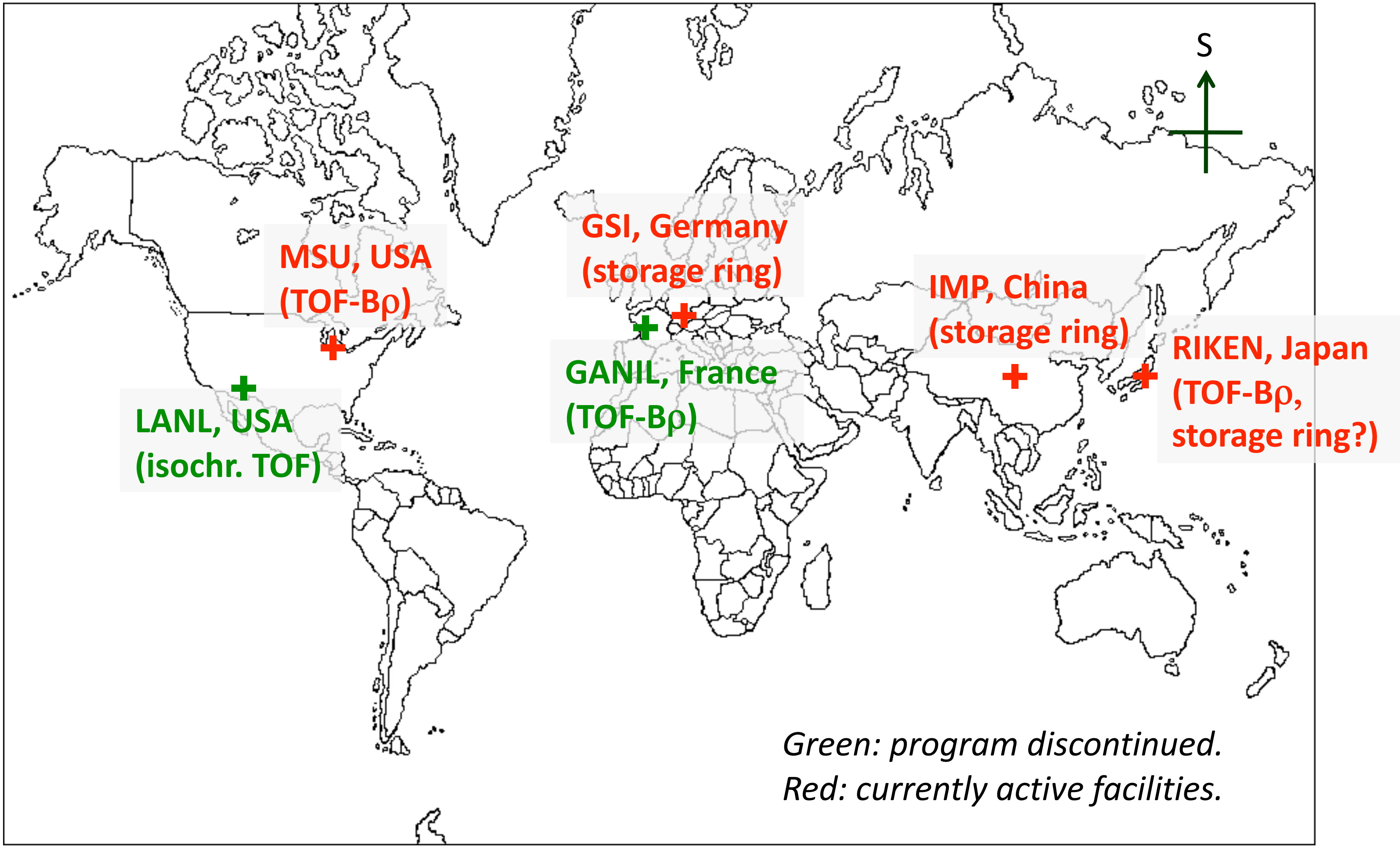
Main features of TOF mass measurements

• Sensitive technique can reach masses of very unstable nuclei (few 100s to few 1000s ions required).
• Well suited to fast beams, as in new generation radioctive ioen beam facilities (RIBF, FAIR, FRIB).
• Allows to map large regions of the nuclear chart by measuring several masses simultaneously.

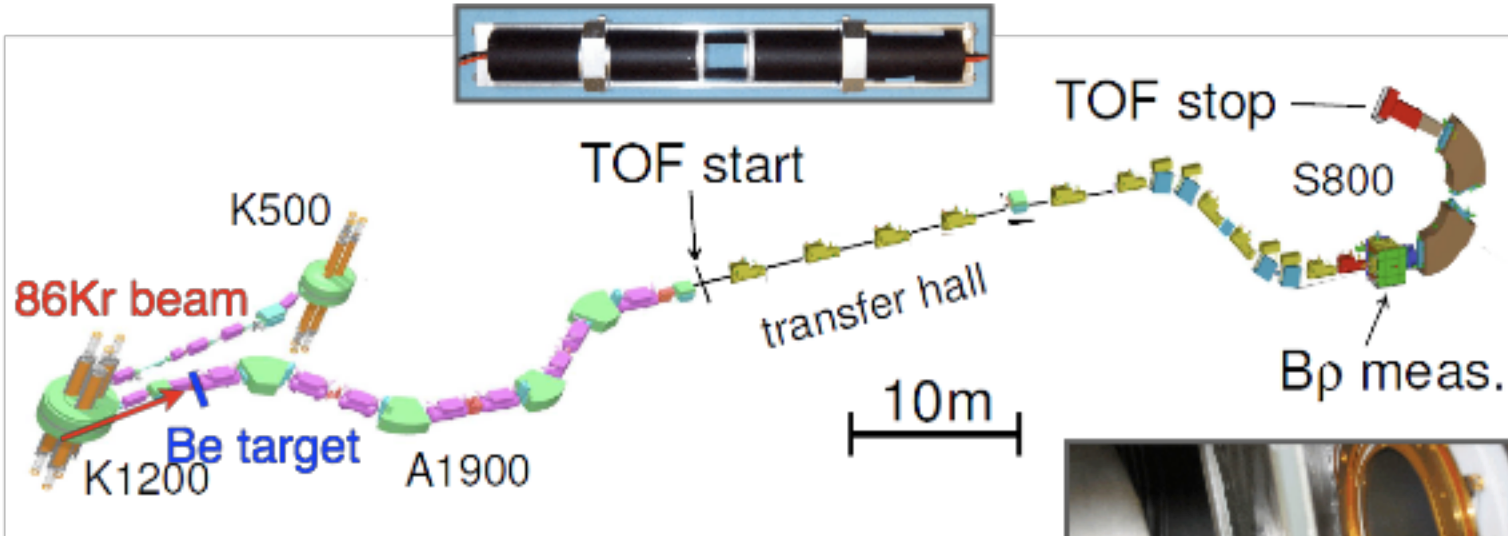
Some typical parameters:

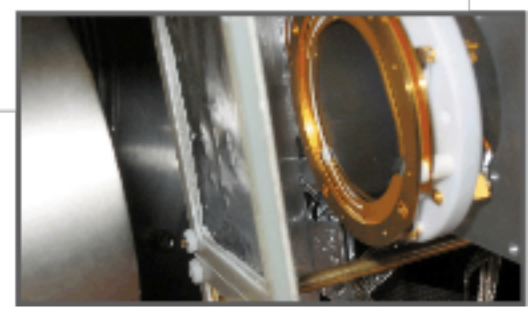
Technique	**TOF-Br**	**Storage ring - Isochronous**	**Storage ring - cooled beam**
Resolving power ($\Delta m/m$)	1.e-4	5.e-6	1.e-7
Mass uncertainty	200 keV	100 keV	10 keV
Measuring time	µsec	µsec	sec

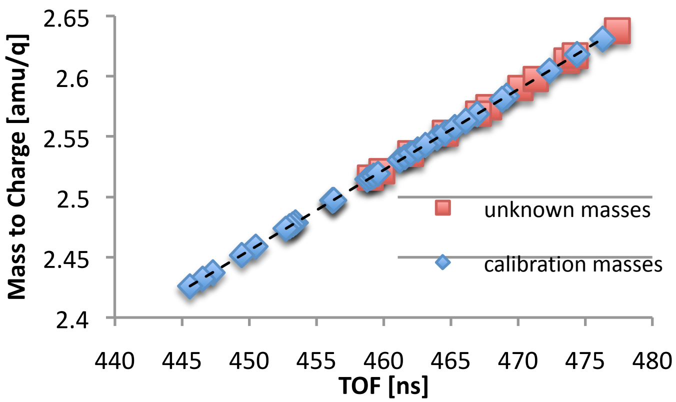
Recent and current programs of TOF measurements



Experimental setup at NSCL

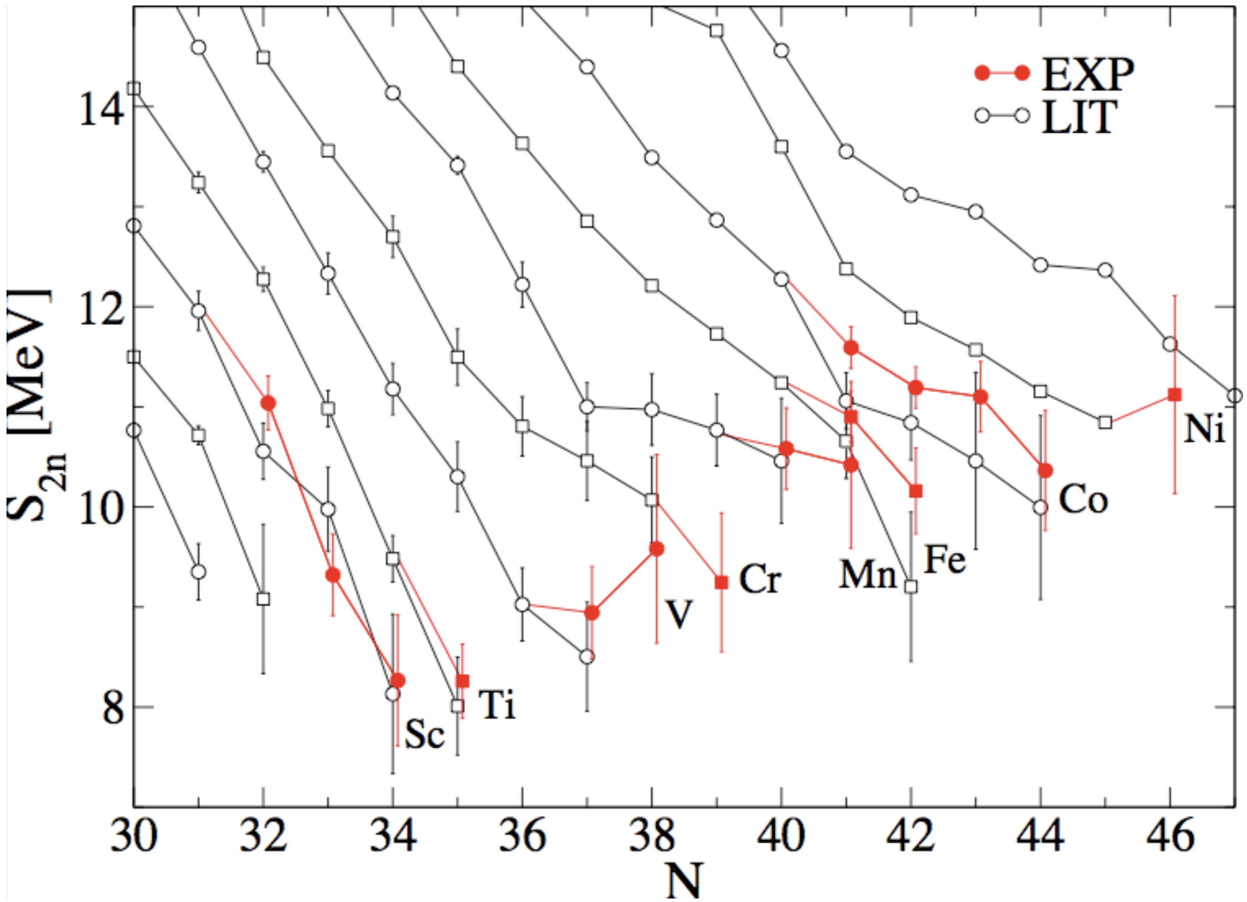






- 58 m path length, TOF ≈ 450 ns.
- fast plastic scintillators for timing (TOF resolution 80 ps; dTOF/TOF ≈ 2e-4)
- microchannel plate -detectors for position (momentum).

First results from TOF experiments at NSCL



Two neutron separation energy measures binding energy of last two neutrons:

S2n = M(A-2,Z) - M(A,Z) + 2 M(n).

Slope change indicates onset of deformation.

A. Estrade et al, to be published in PRL (arXiv:1109.5200) ➡ impact on nuclear processes in accreting NS.

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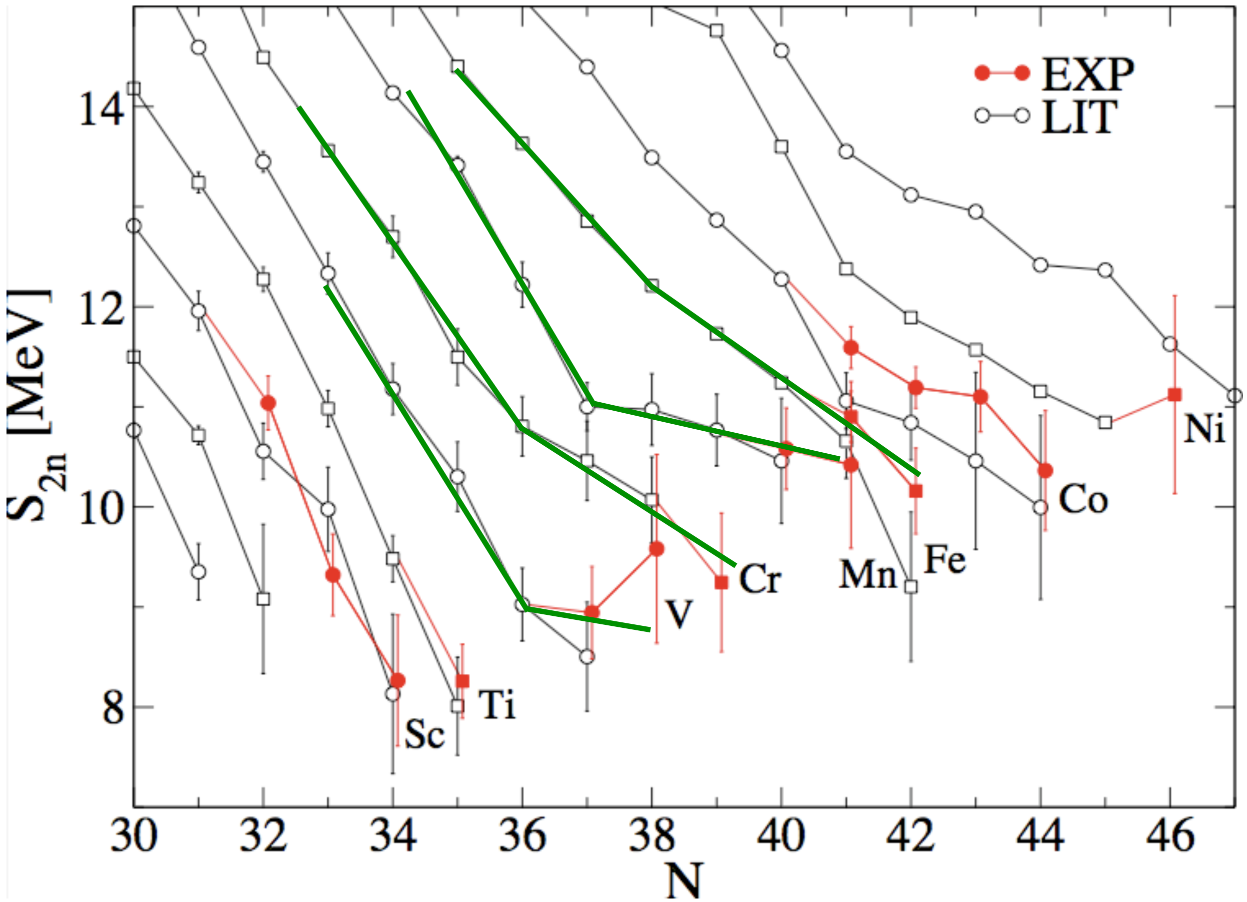

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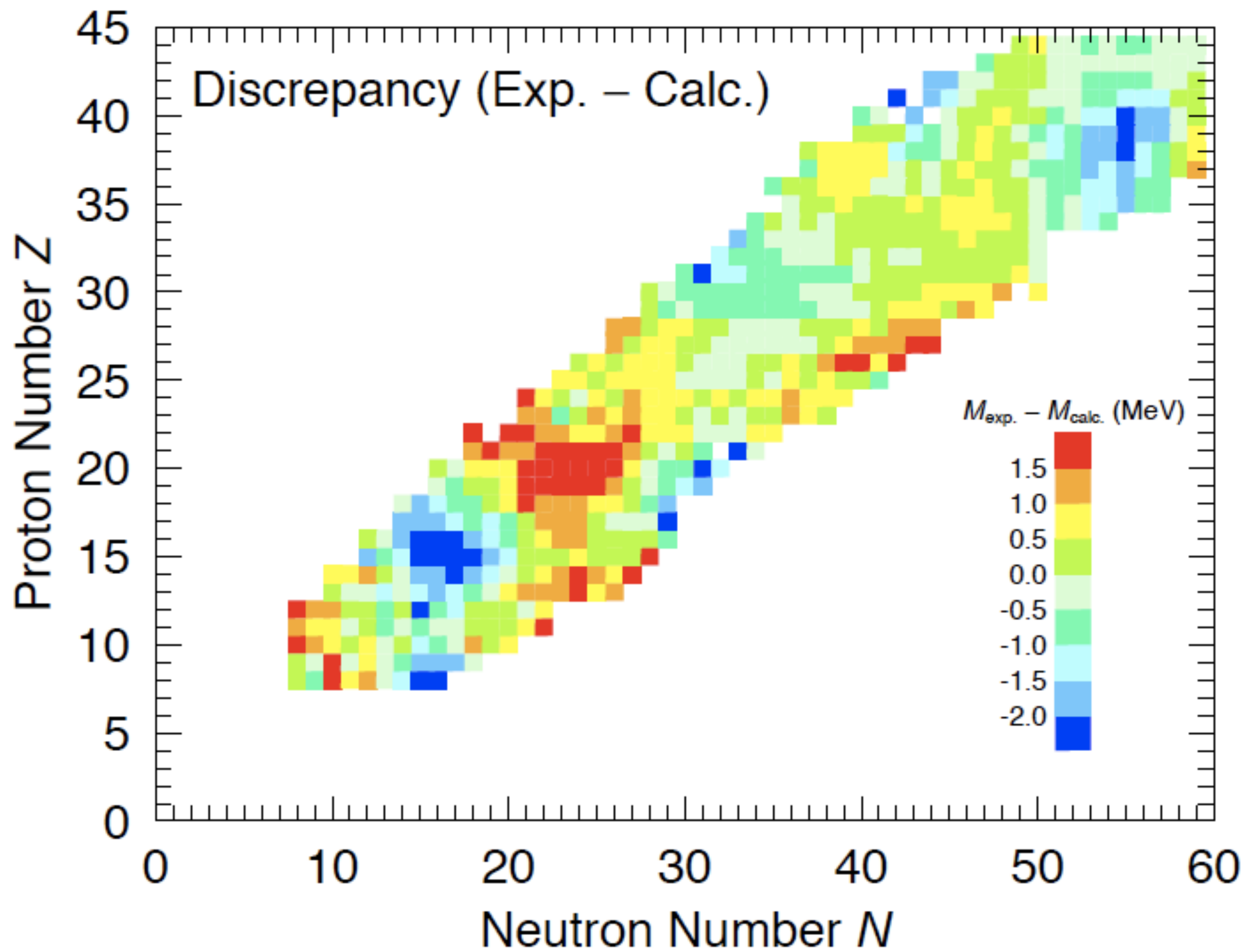
Constraints for nuclear mass models

'Calc.'= Finite Range Droplet Model



Constraints for nuclear mass models

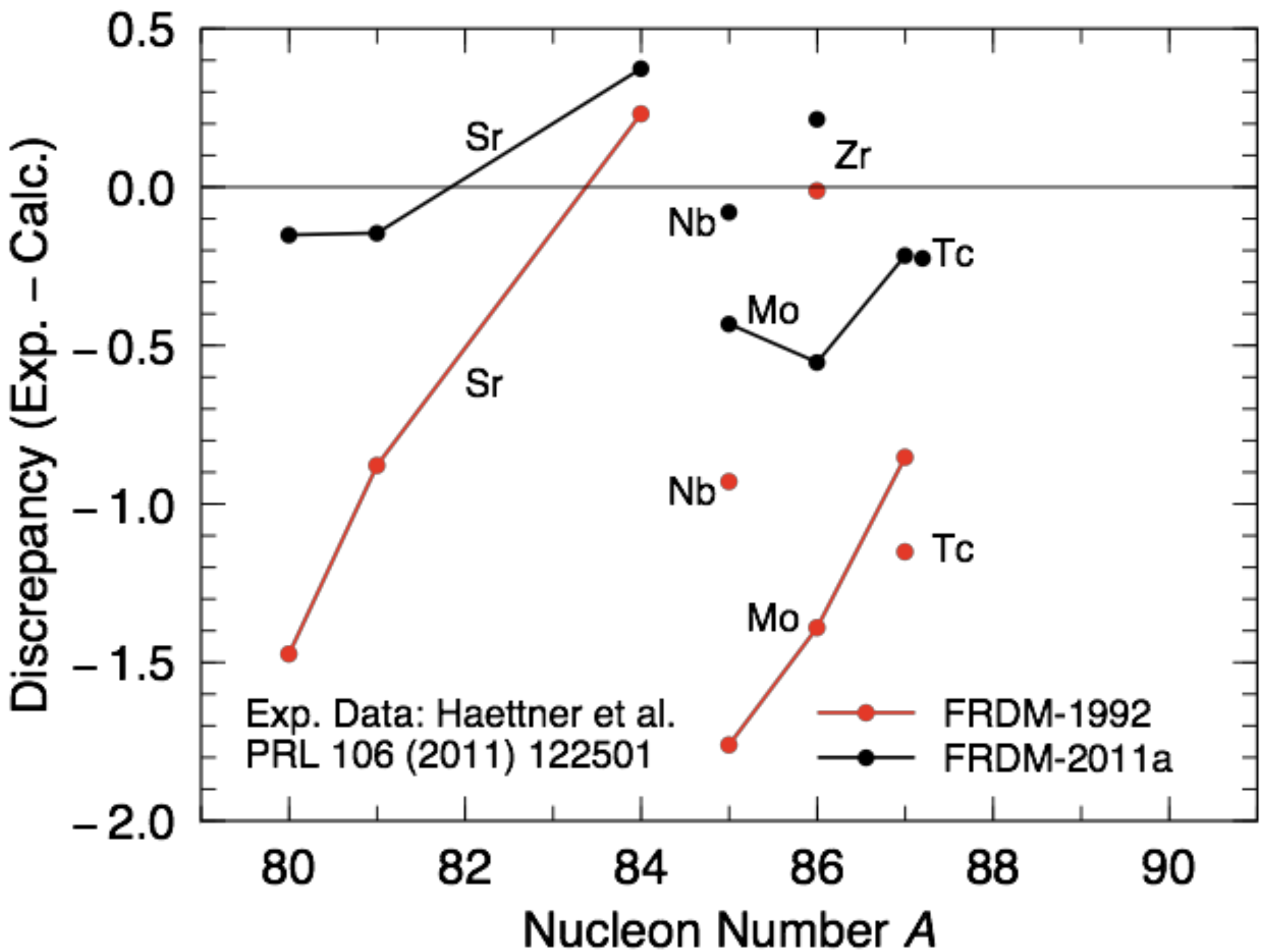
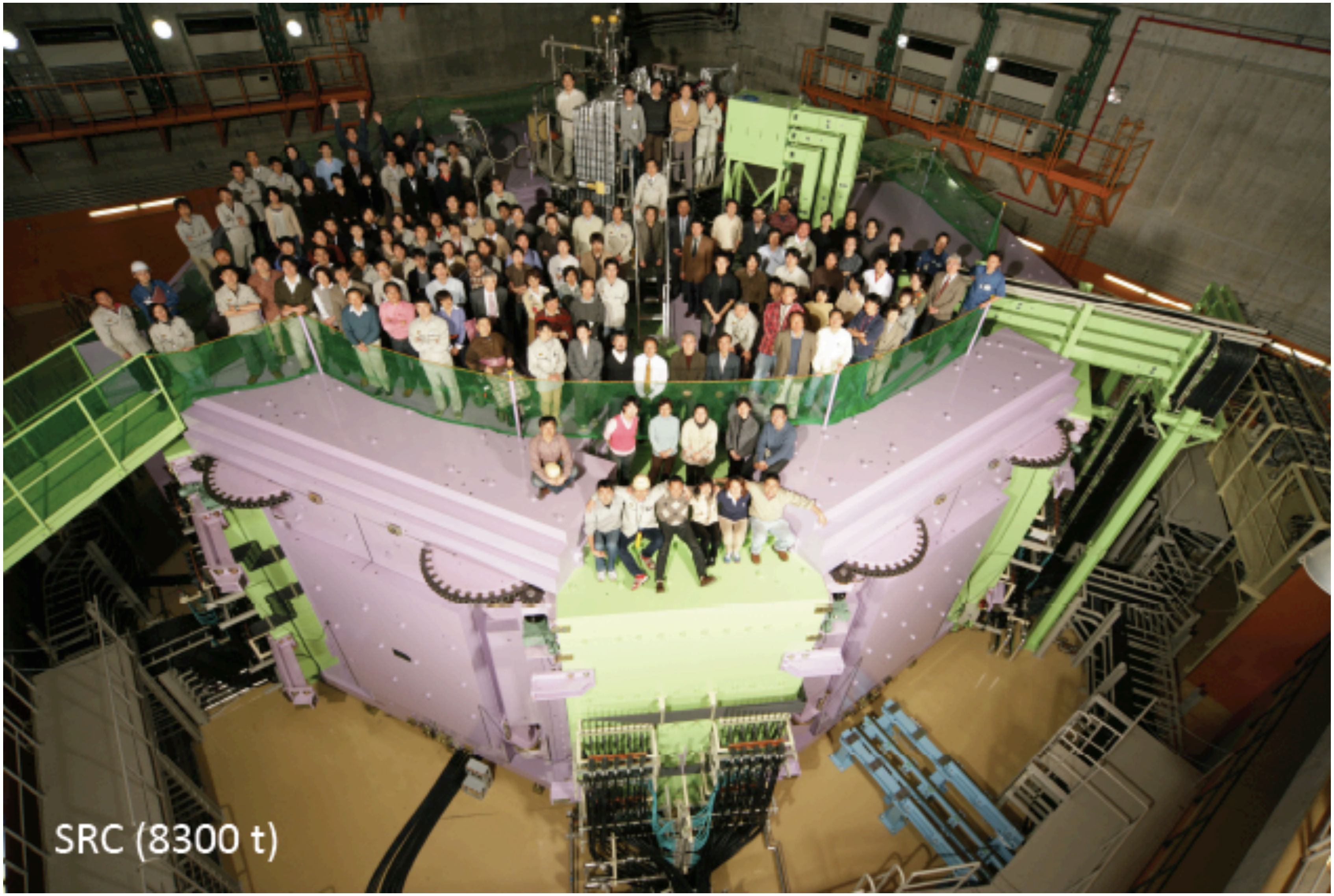


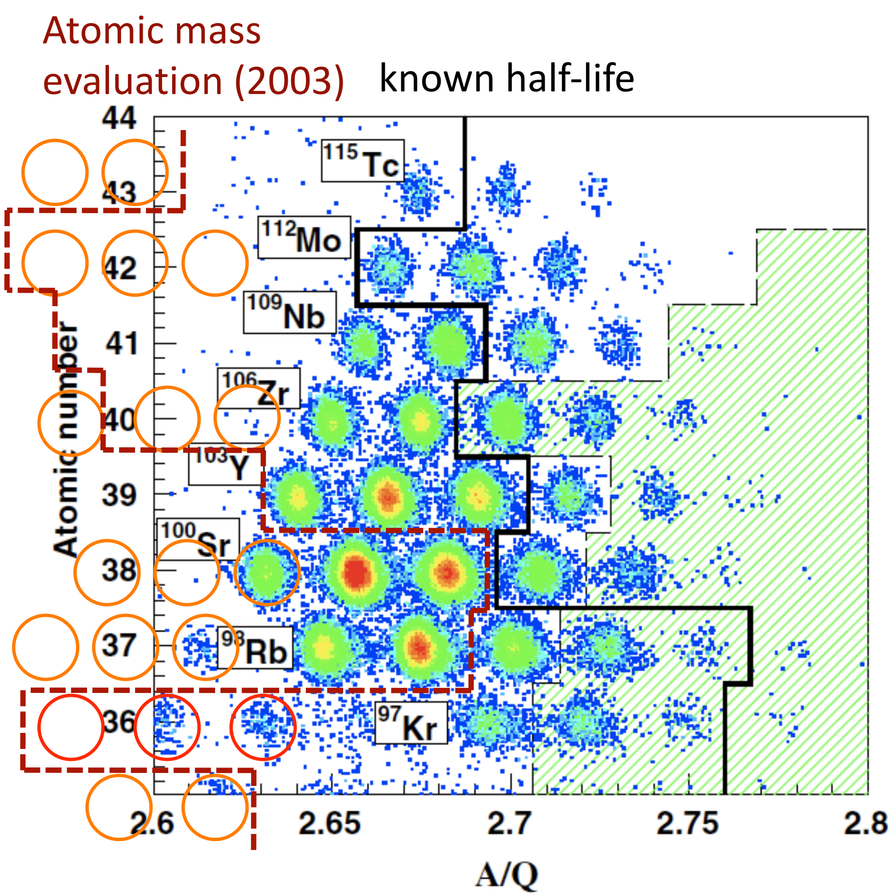
Figure courtesy of P. Moeller.

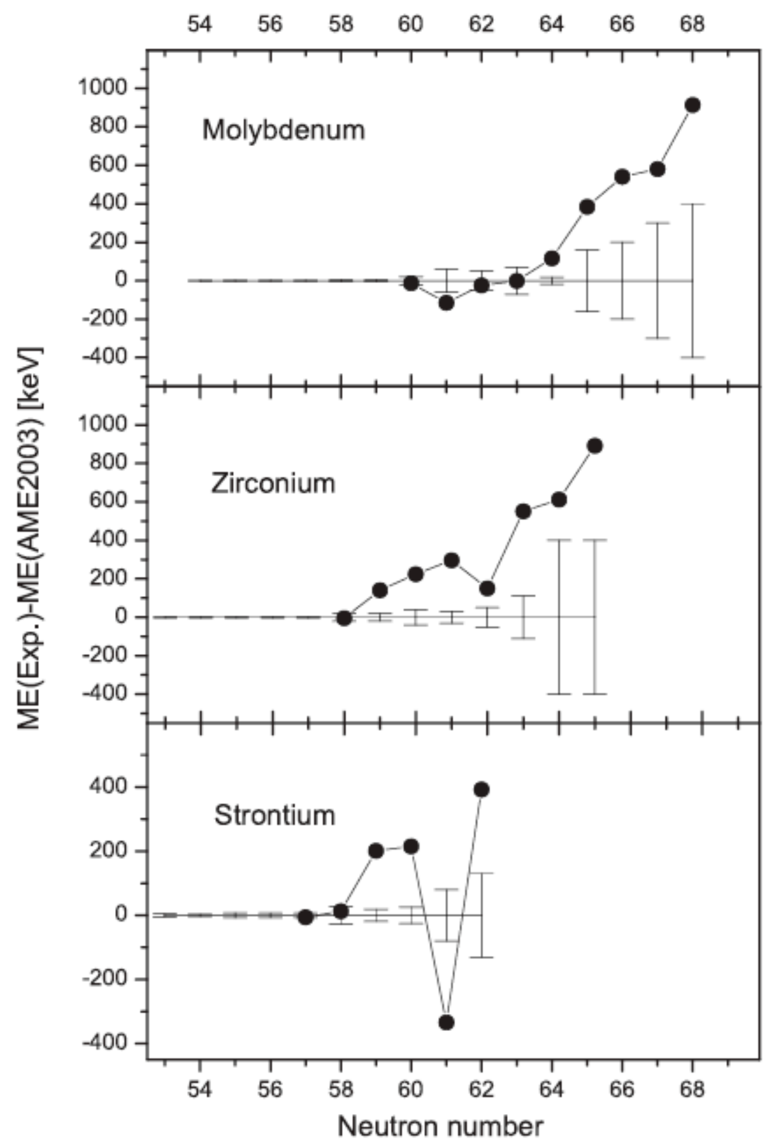
Radioactive Ion Beam Factory at RIKEN



r-process experiments at RIKEN

S. Nishimura et al, PRL 106, 052502 (2011)

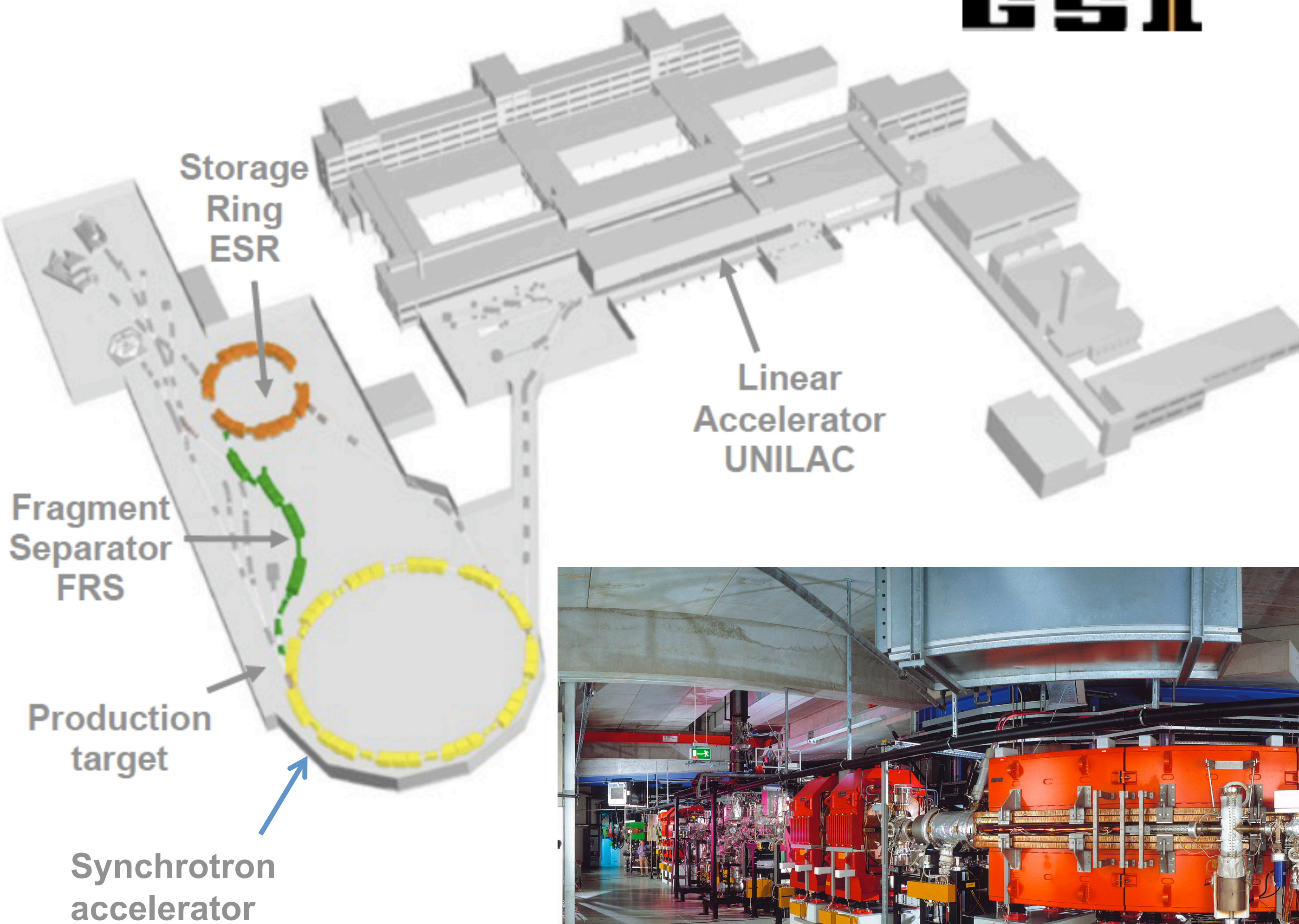


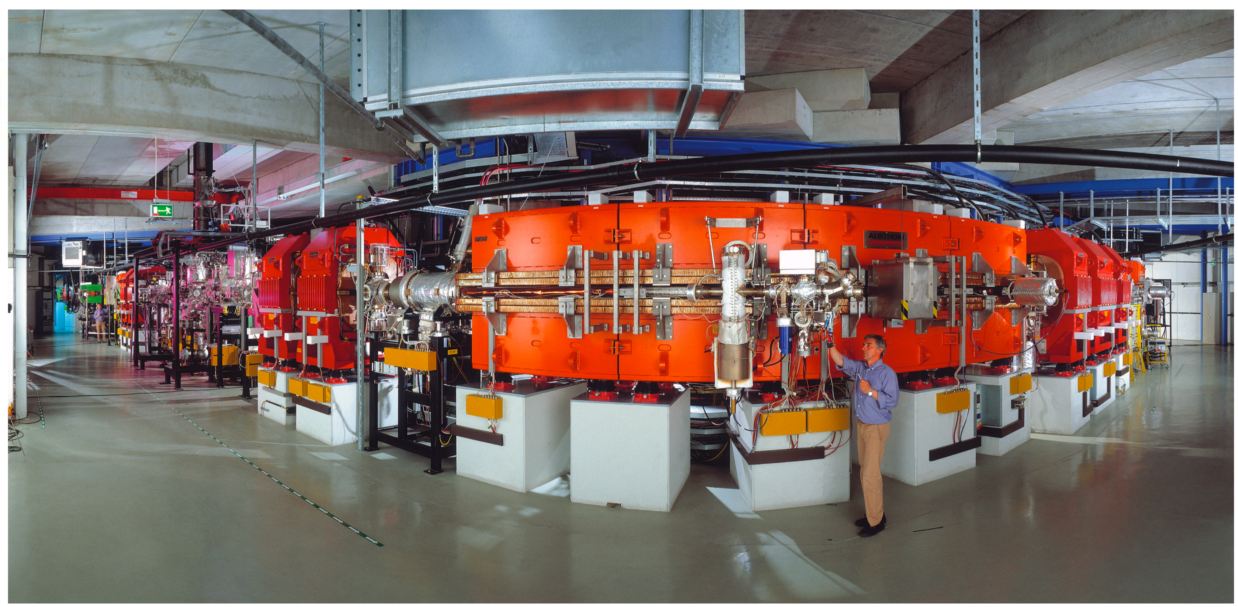


Recent Penning trap measurements near N=60

- U. Hager et al, PRL 96, 042504 (2006)
- U. Hager et al, PHYSICAL REVIEW C 75, 064302 (2007)
- S. Rahaman et al, Eur. Phys. J. A 32, 87–96 (2007)
- P. Delahaye, PHYSICAL REVIEW C 74, 034331 (2006)

Experimental Storage Ring (ESR) at GSI

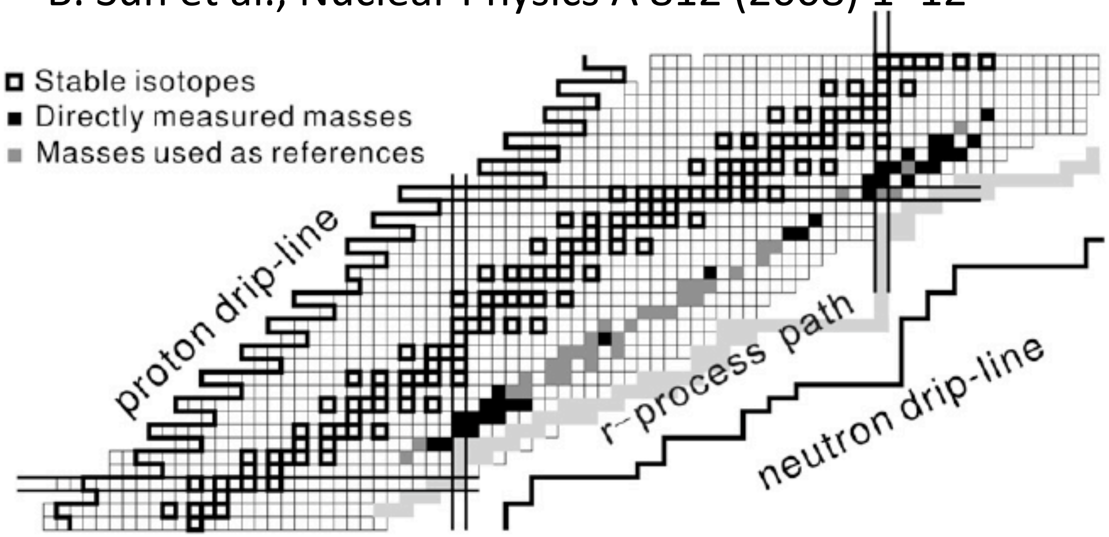




Recent storage ring results

Mass measurements towards r-process path at GSI

B. Sun et al., Nuclear Physics A 812 (2008) 1–12

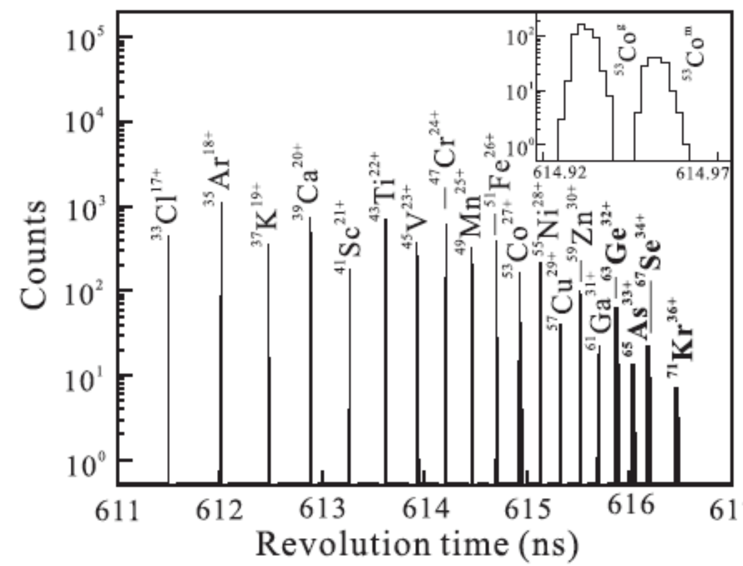


see also (U fragments):

L. Chen, et al, Phys. Lett. B 691 (2010) 234.

First mass measurement at IMP

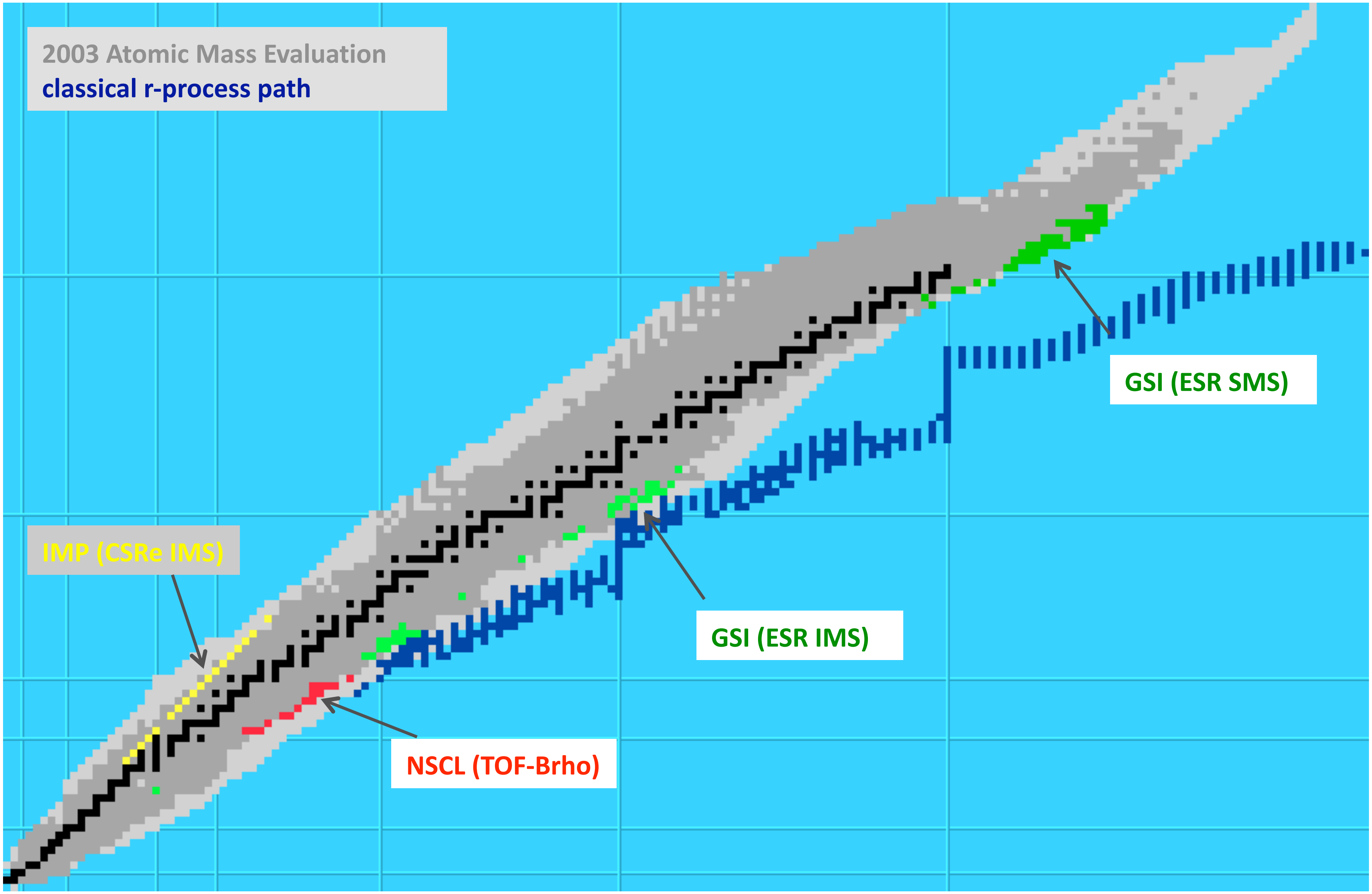
(proton-rich A=2Z-1 nuclei)



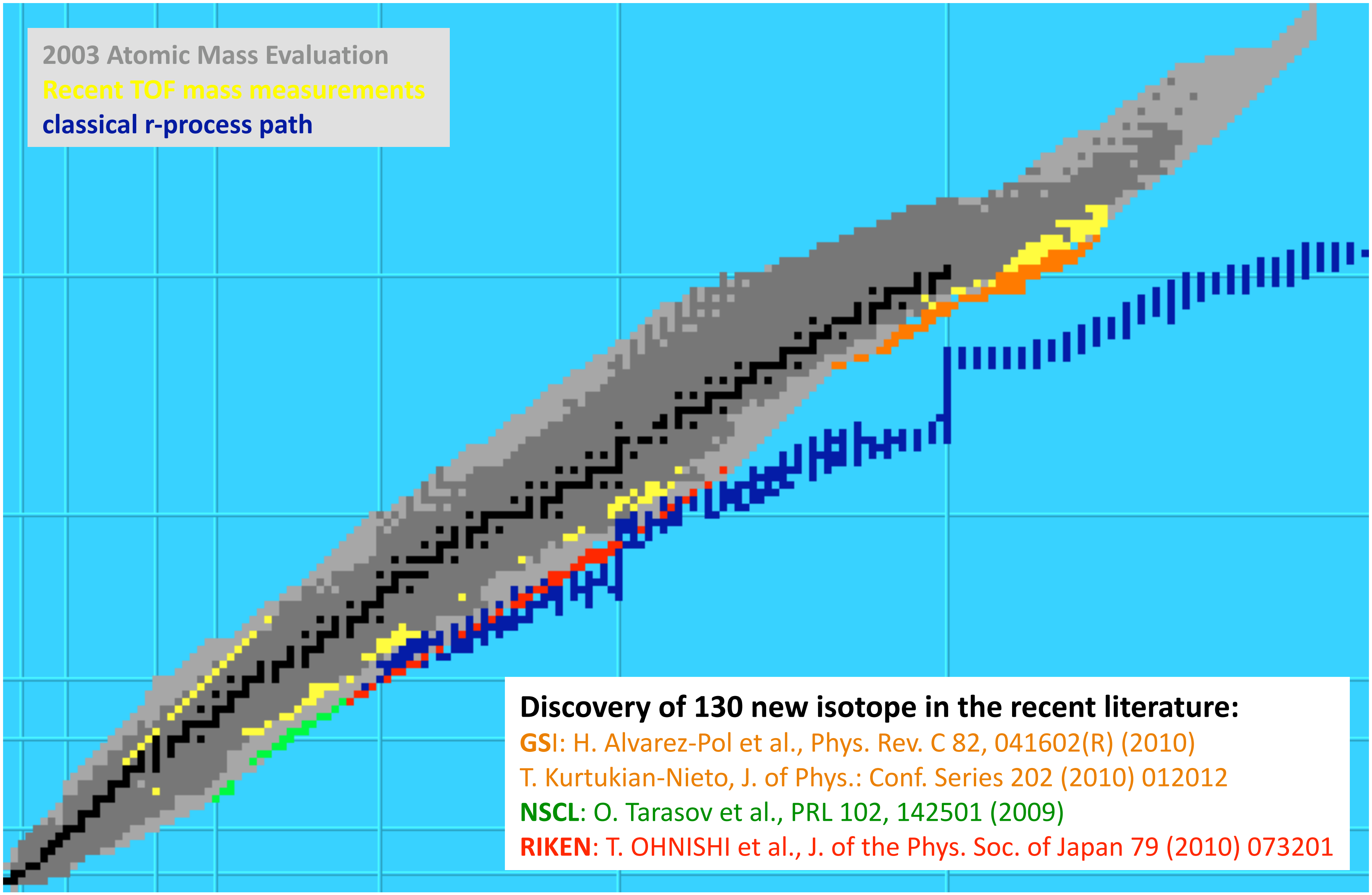
X. L. Tu et al, PRL 106, 112501 (2011)

Physics result: 64Ge not significant rp-process waiting point.

Summary of recent TOF mass measurements relevant to nuclear astrophysics



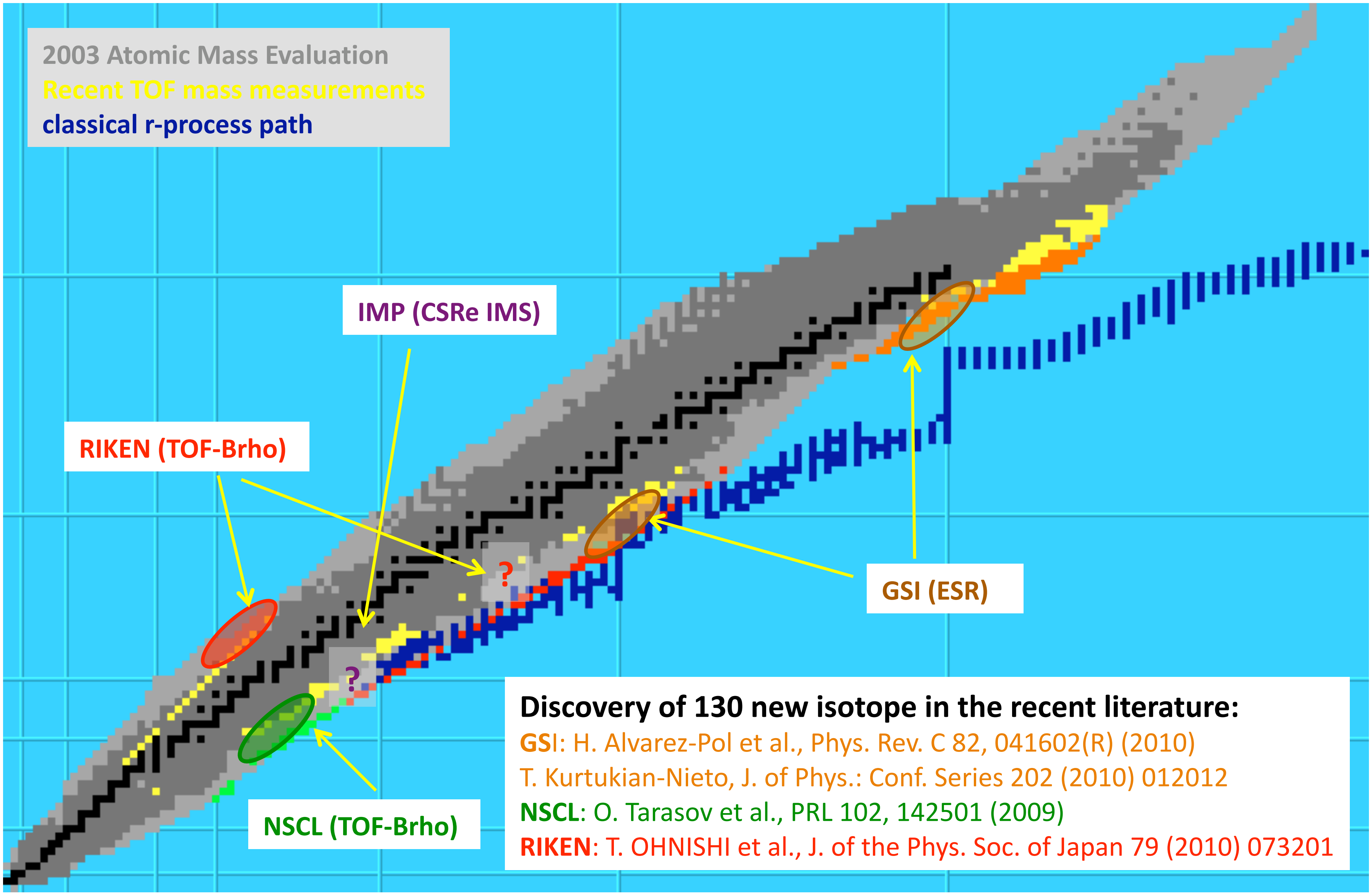
Production of new isotopes



Discovery of 130 new isotope in the recent literature:

GSI: H. Alvarez-Pol et al., Phys. Rev. C 82, 041602(R) (2010)
T. Kurtukian-Nieto, J. of Phys.: Conf. Series 202 (2010) 012012
NSCL: O. Tarasov et al., PRL 102, 142501 (2009)
RIKEN: T. OHNISHI et al., J. of the Phys. Soc. of Japan 79 (2010) 073201

Production of new isotopes

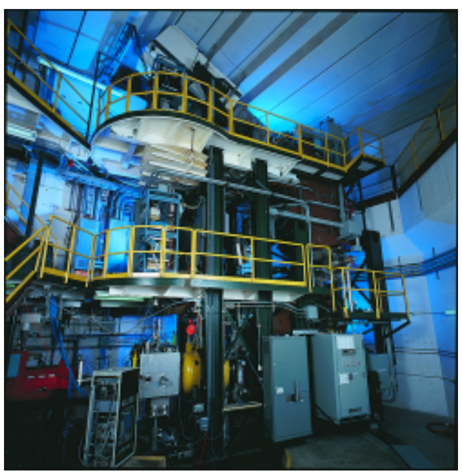


Conclusions

-Time-of-flight mass measurements well suited to measure masses of very unstable nuclei for astrophysics applications.

- Offer a complementary approach to other mass measurement techniques (traps).

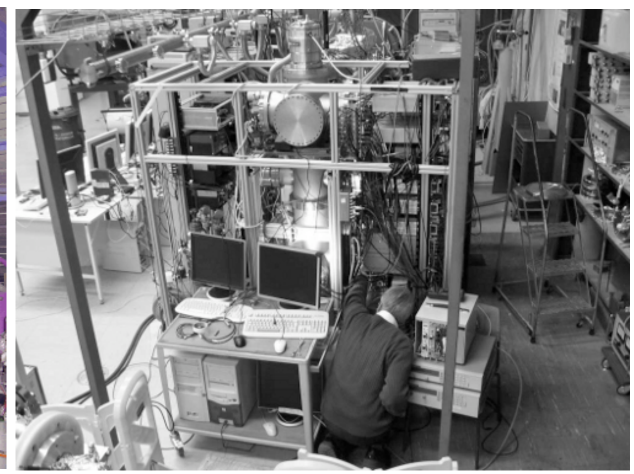
- Measurement programs currently active at several facilities around the world (GSI, NSCL, IMP, RIKEN).



S800 spectrometer ,NSCL

Penning Trap

ESR Electron cooler, GSI



MR-TOF spectrometer, U. Giessen