Direct Mass Measurements of Stored Exotic Nuclei

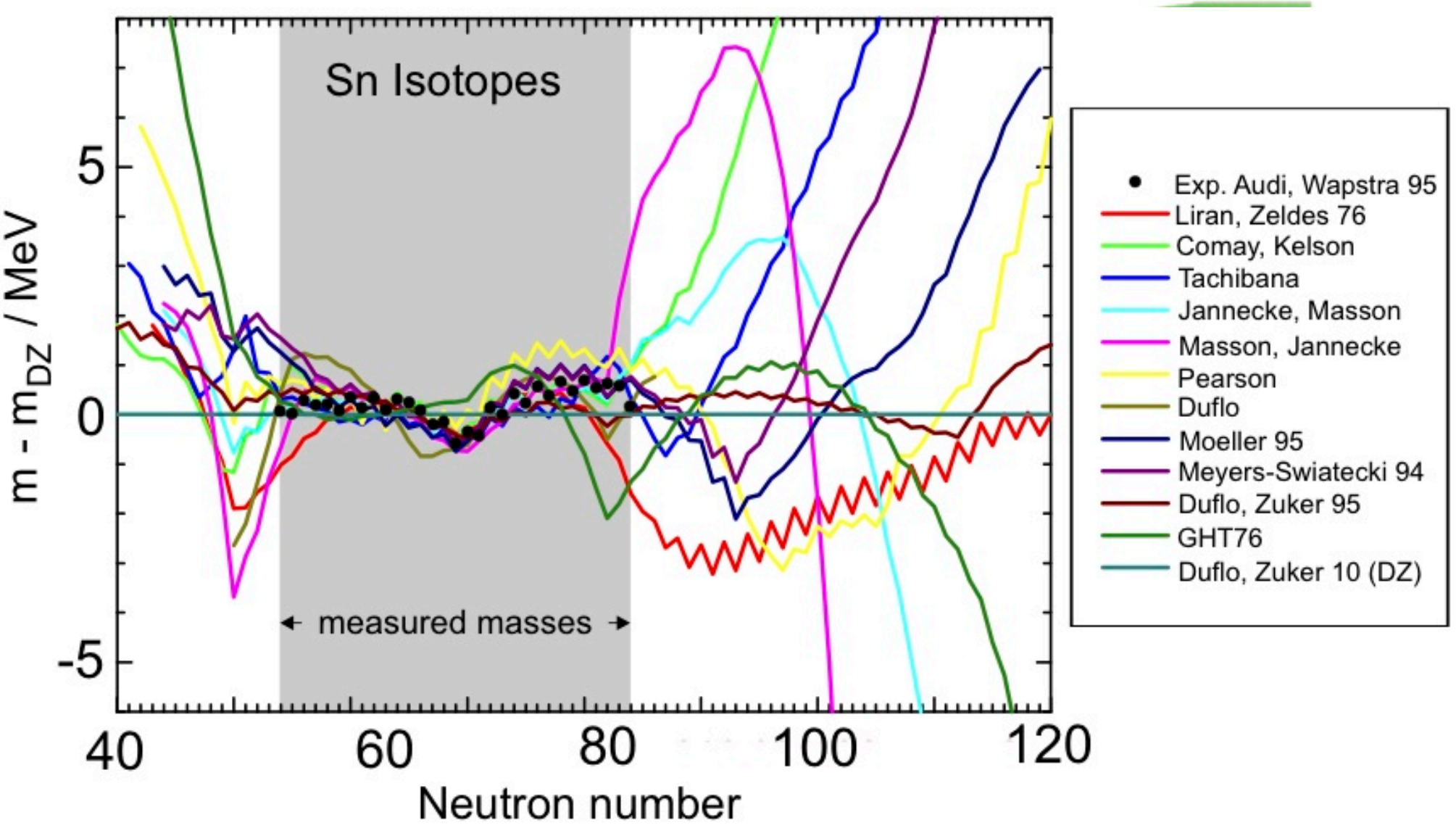
Yuri A. Litvinov

NIC XII – Satellite Workshop on R-Process Nucleosynthesis
4-5 August 2012, The Sebel Hotel, Cairns, Australia

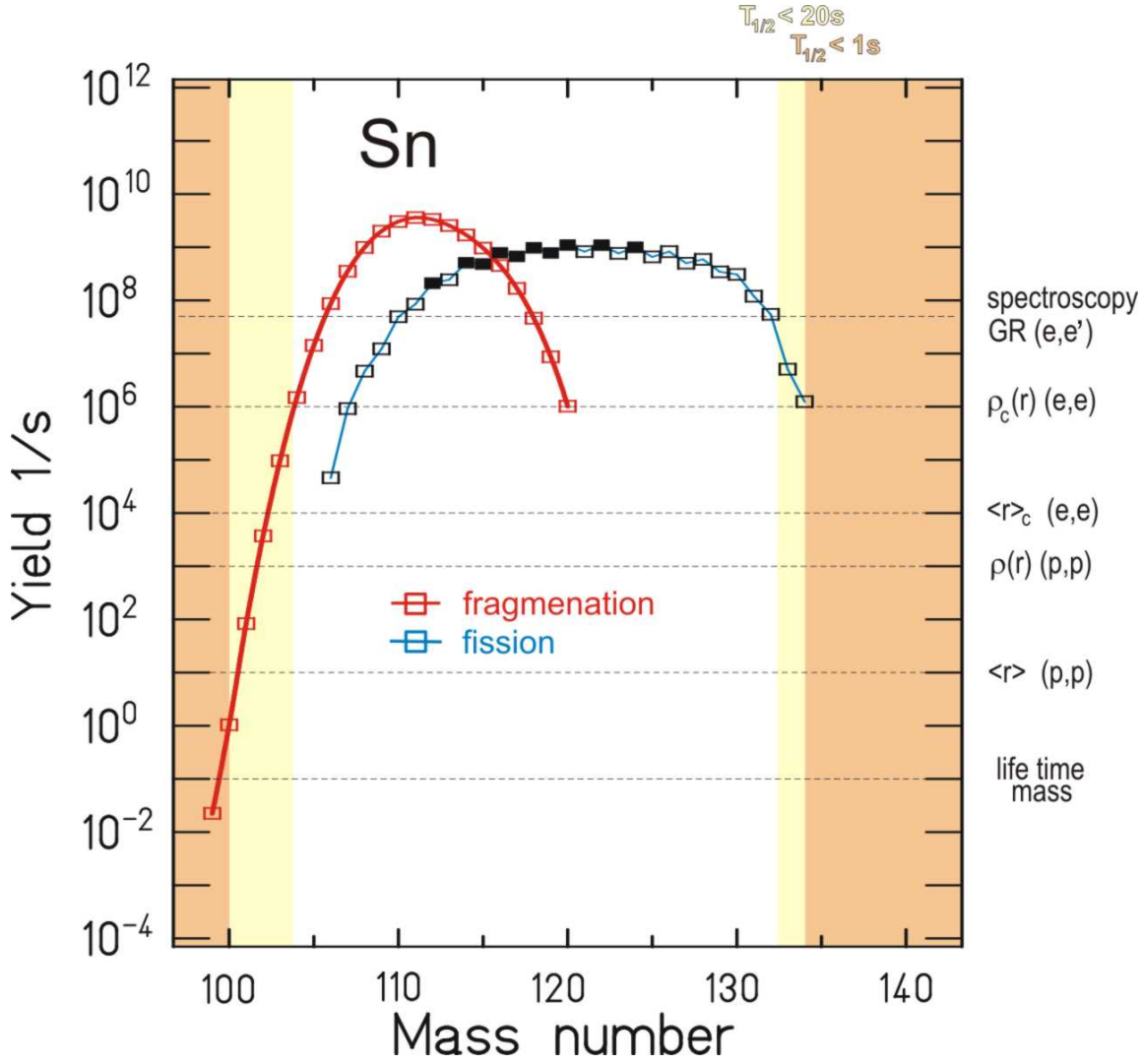
HELMHOLTZ GEMEINSCHAFT

GSI

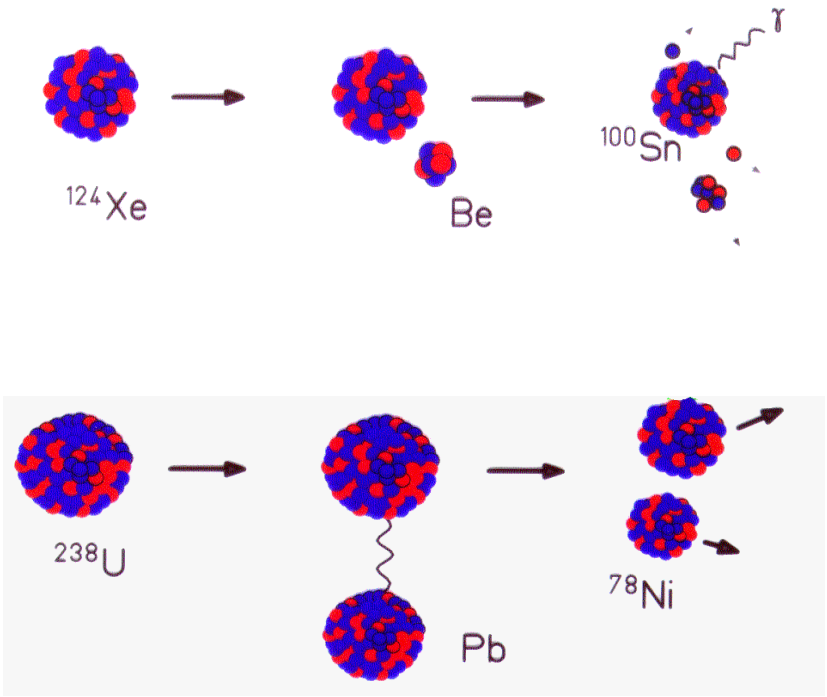
Nucleosynthesis on the Chart of the Nuclides



Production of Exotic Nuclei



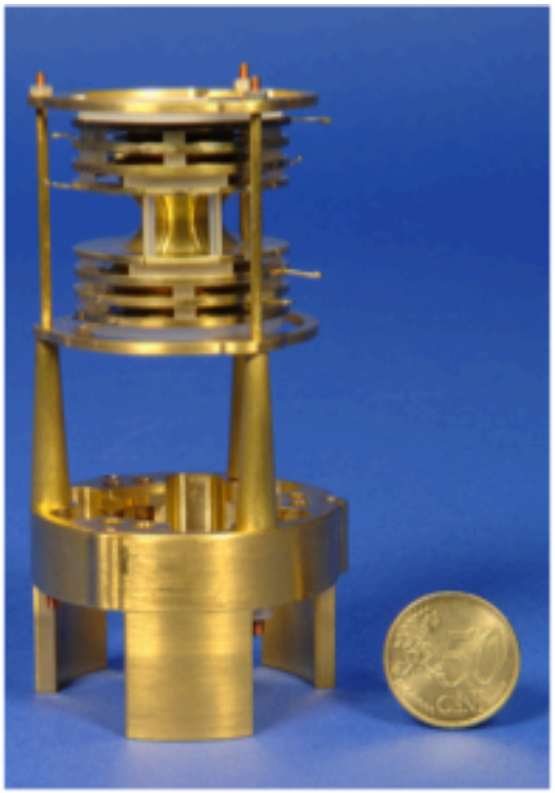
Fragmentation



Coulomb fission

Devices for precise mass measurements

Penning trap



Storage ring

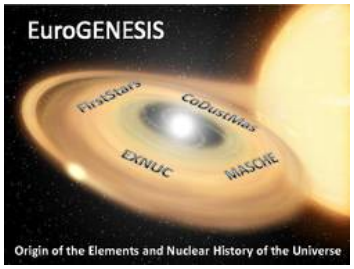
particles at nearly rest in space

relativistic particles

* ion cooling
* long storage times
* single-ion sensitivity
* high accuracy

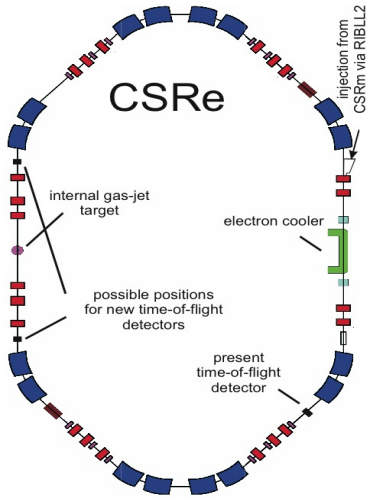
Direct Mass Measurements on the Chart of the Nuclides

Status: 2011



Individual Project
High-Precision Measurements of Nuclear Ground State Properties

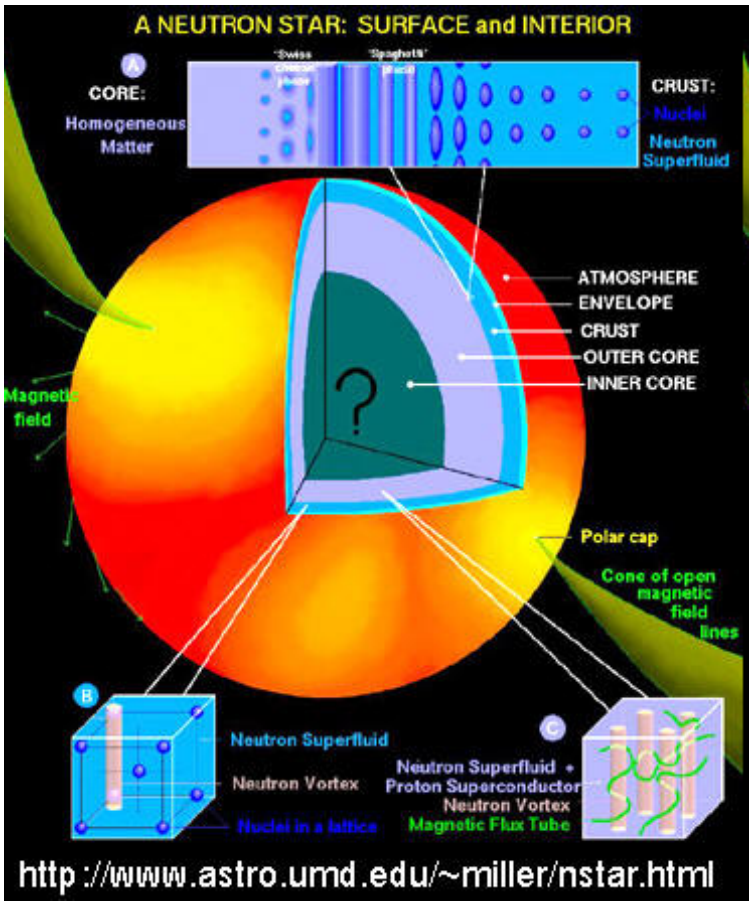
Penning Traps

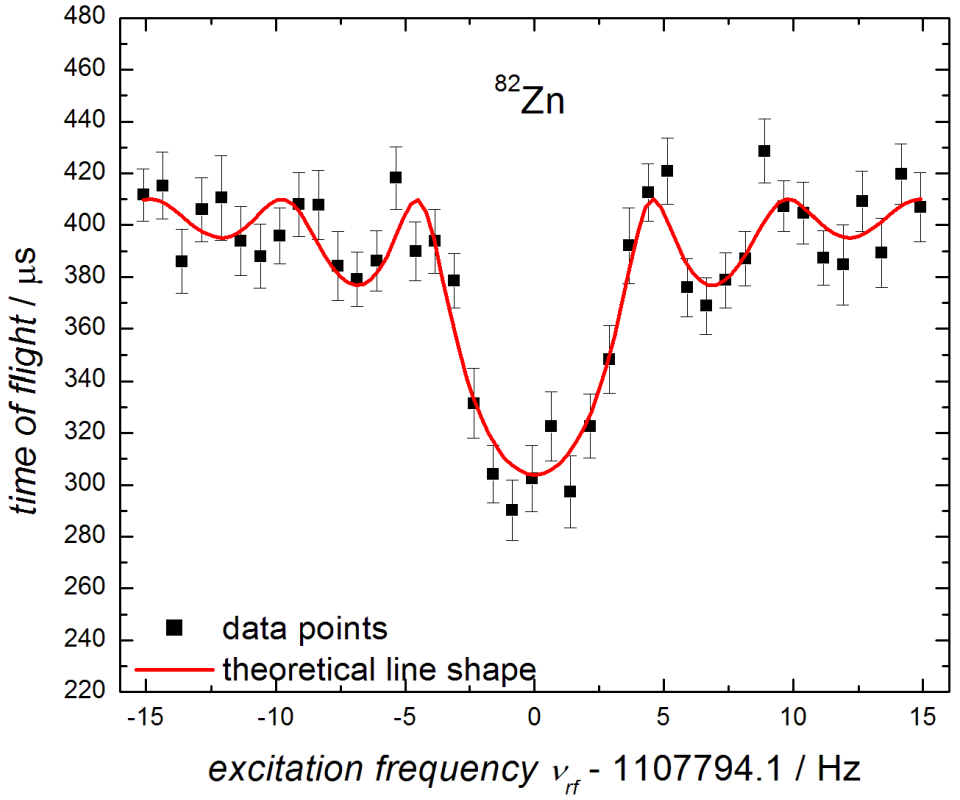


Storage Rings

The mass of ^{82}Zn

Composition of the outer crust of a neutron star





$\delta m/m \sim 10^{-8}$ (< 1 keV)
$T_{1/2} \sim 80(20)$ ms

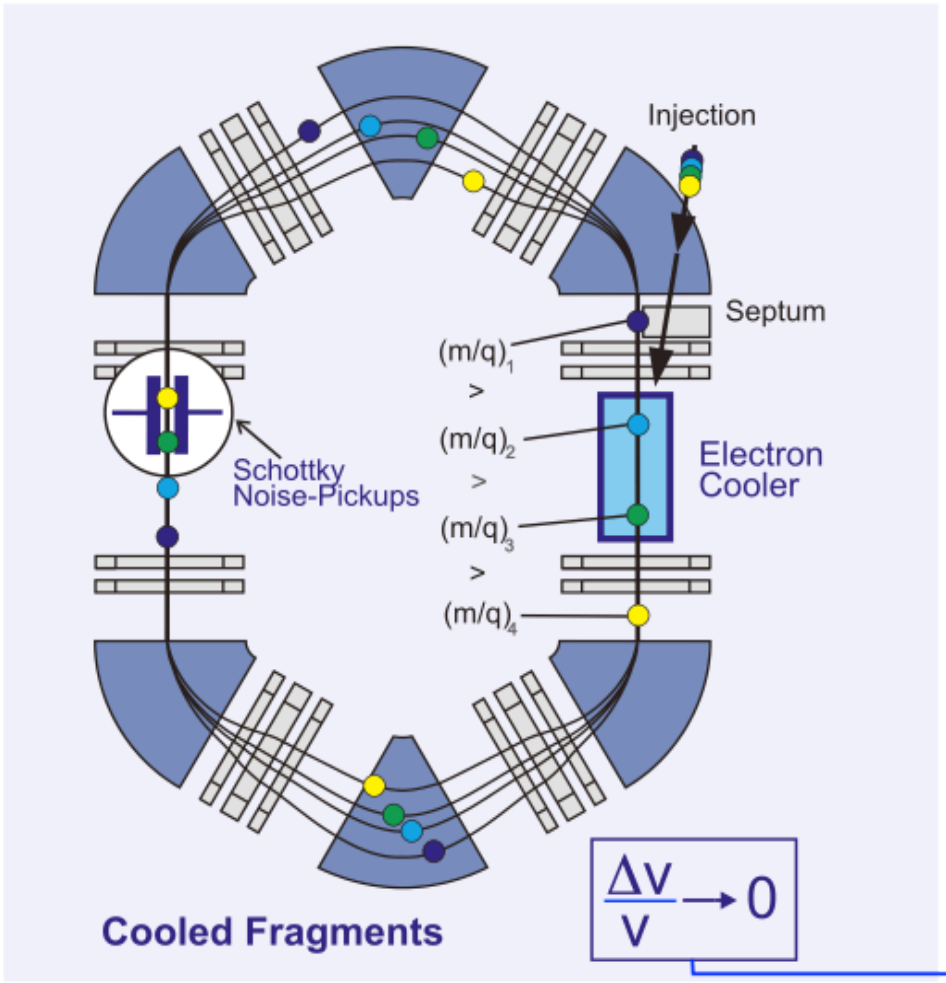
ISOLTRAP (ISOLDE)

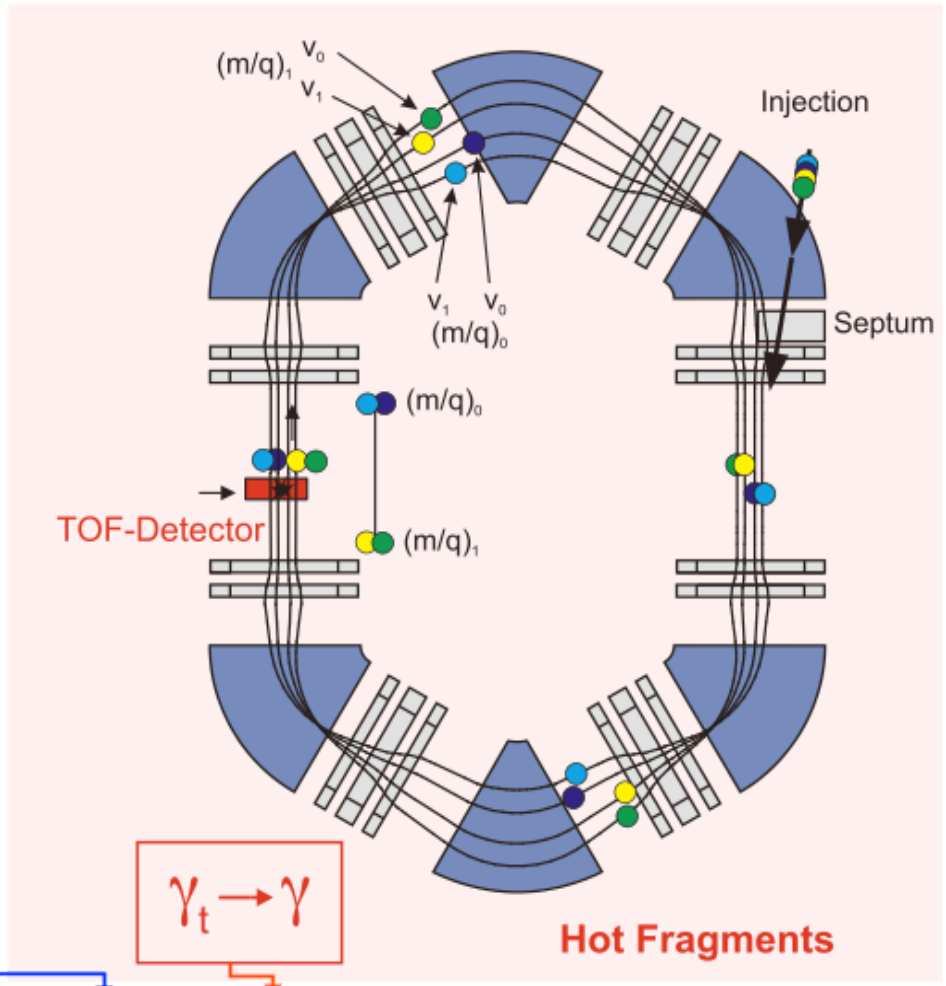
S. Kreim and the ISOLTRAP Coll. (2011)

MAX PLANCK INSTITUTE FOR NUCLEAR PHYSICS

MAX-PLANCK-GESELLSCHAFT

Schottky and Isochronous Mass Spectrometry





N=126

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

N=50, 82

B. Franzke, H. Geissel & G. Münzenberg, Mass Spectr. Rev. 27 (2008) 428

Schottky Mass Spectrometry

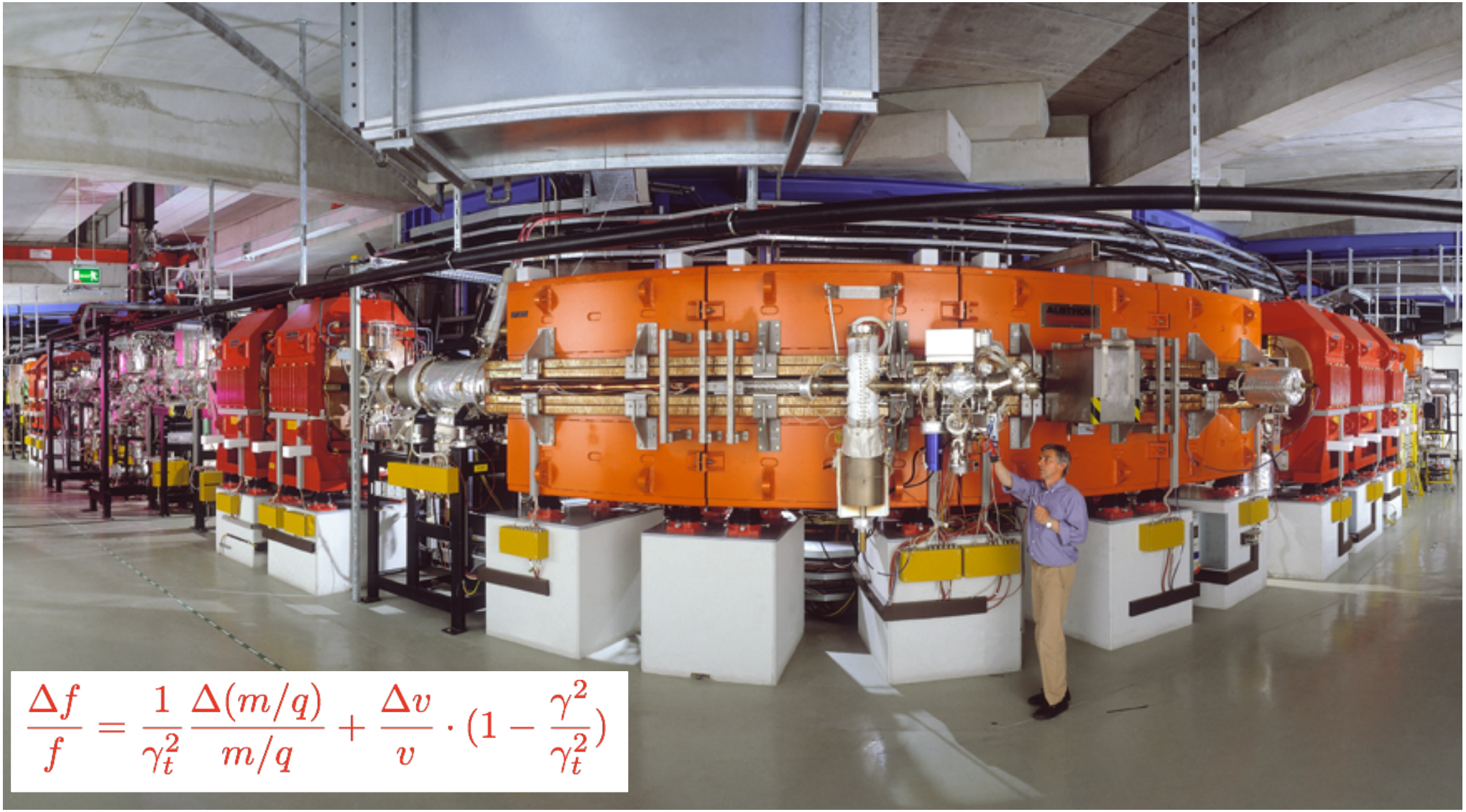
1987 - B. Franzke, H. Geissel, G. Münzenberg

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

$$\frac{\Delta v}{v} \rightarrow 0$$

N=126

Experimental Storage Ring ESR

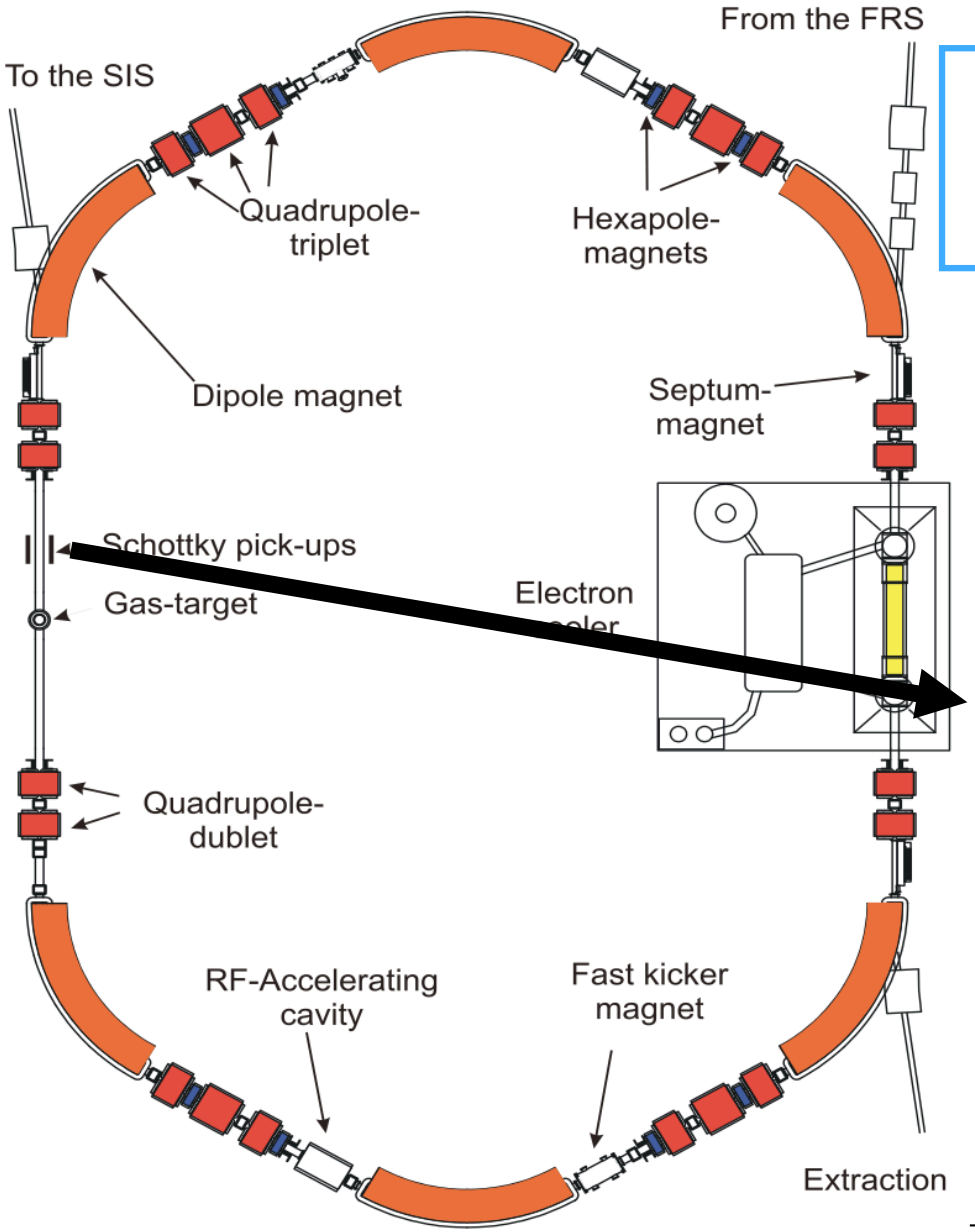


$$\frac{\Delta f}{f} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\cdot\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

ESR: B. Franzke, NIM B 24/25 (1987) 18

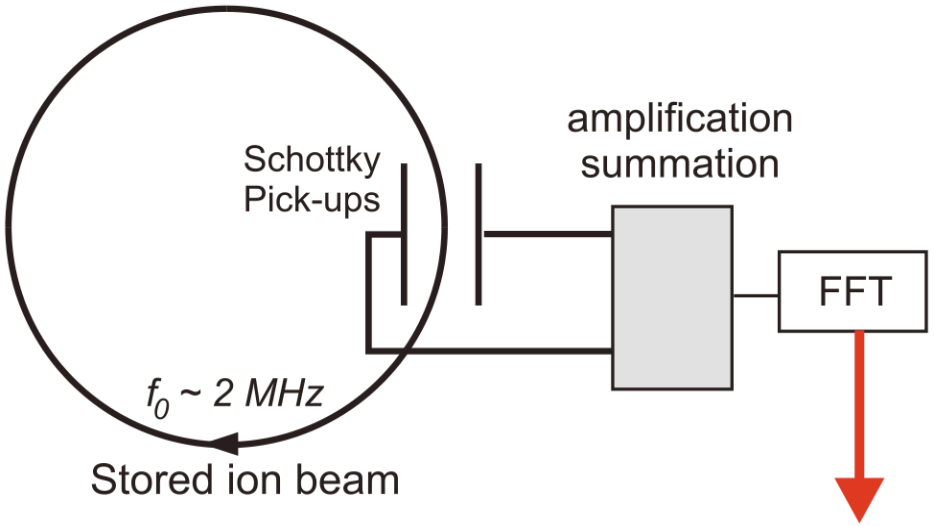
Stochastic cooling: F. Nolden et al., NIM B 532 (2004) 329
Electron cooling: M. Steck et al., NIM B 532 (2004) 357

Schottky Mass Spectrometry (SMS)



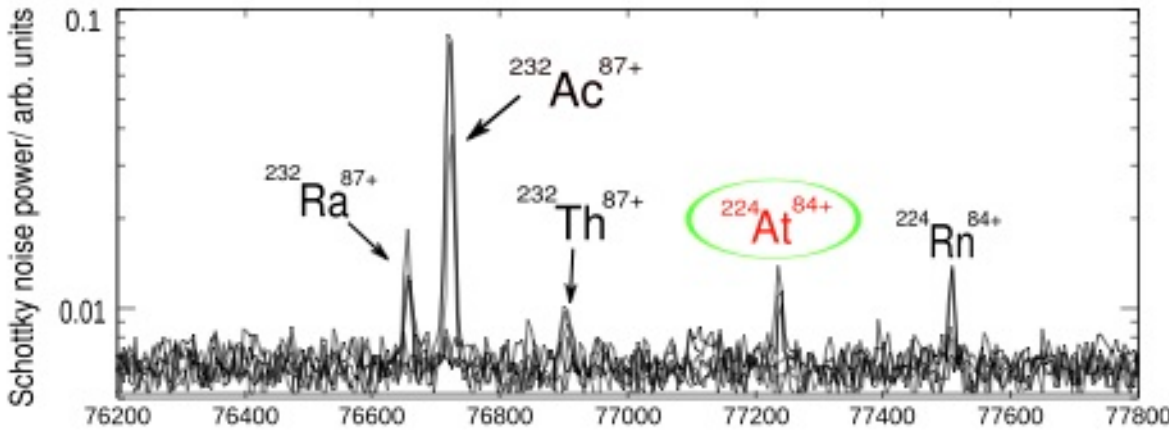
$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

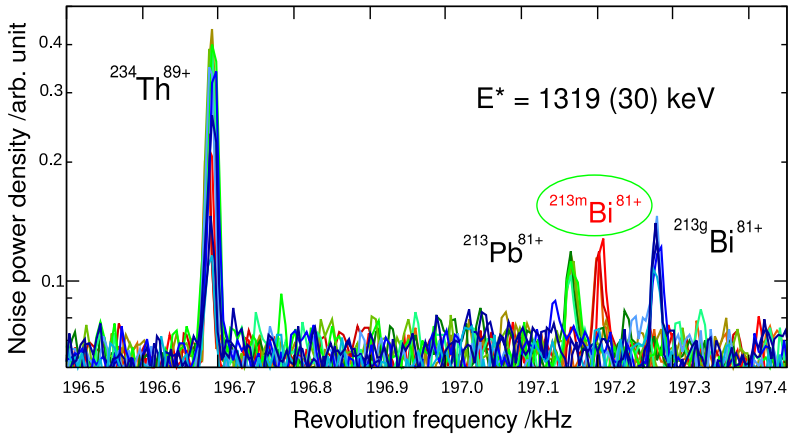
$$\frac{\Delta v}{v} \rightarrow 0$$

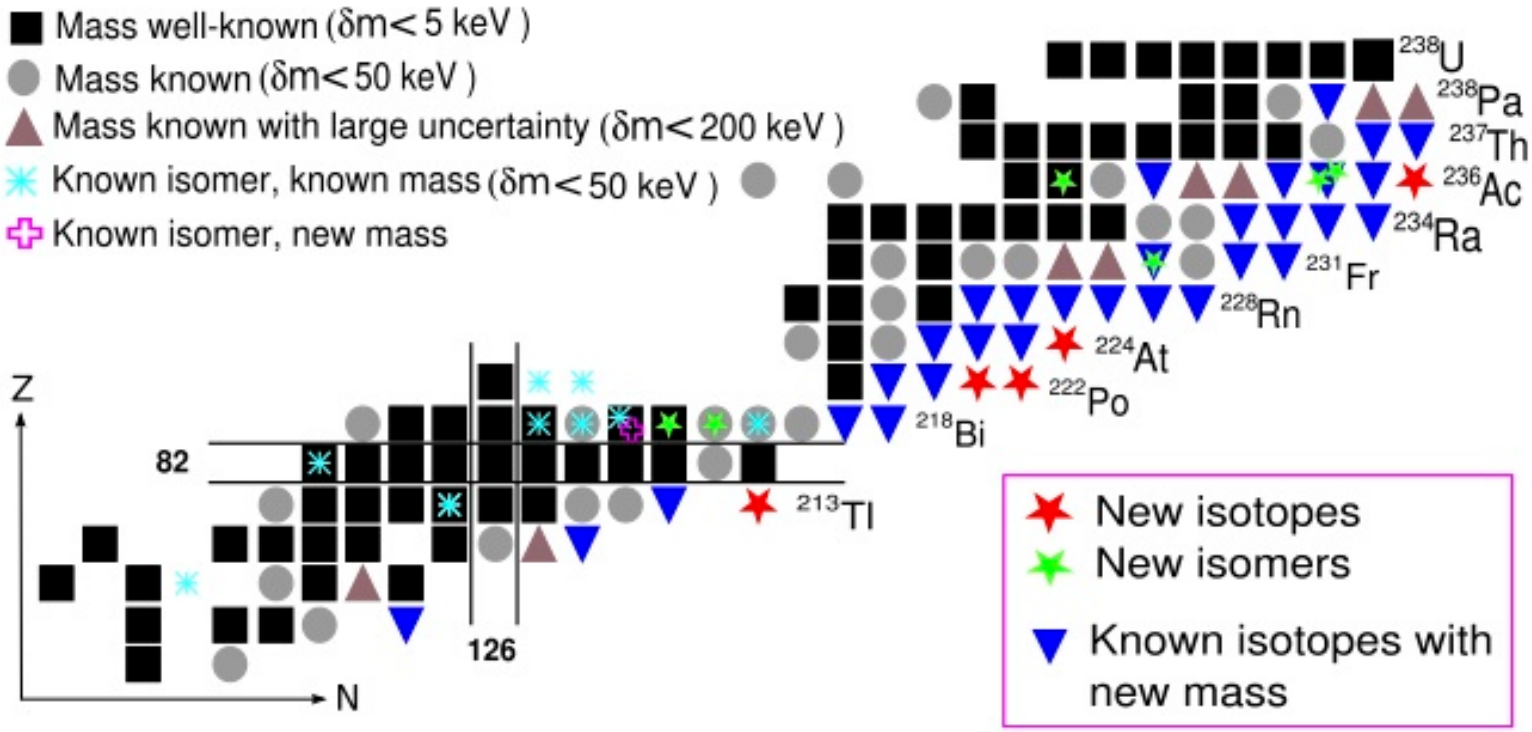


Continuous digitizing and storage of raw data

Discovery of New Isotopes and Isomers



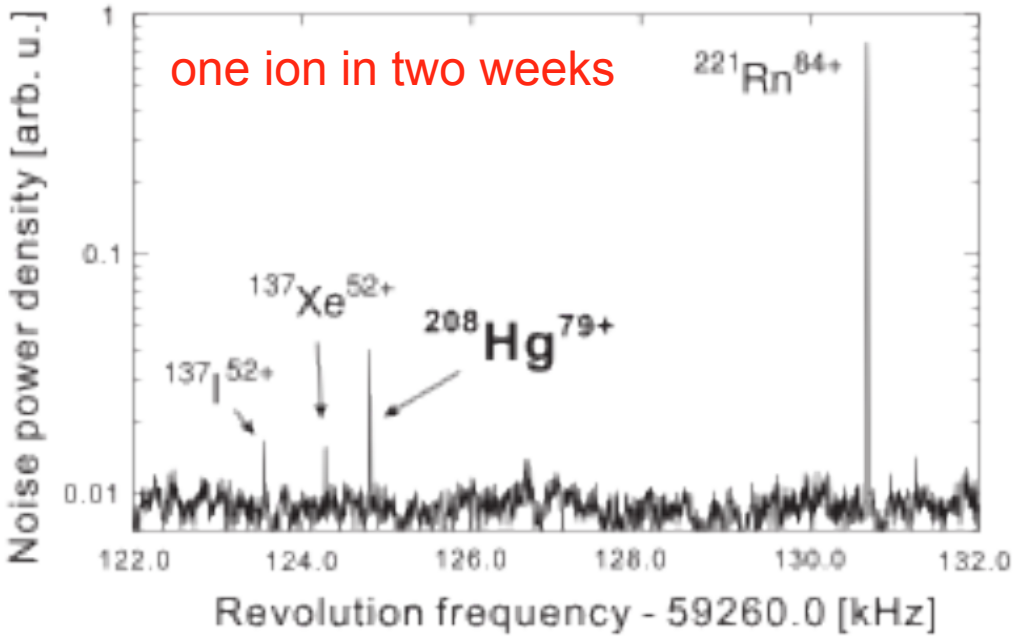




L. Chen et al., Phys. Lett. B691 (2010) 234

L. Chen et al., in preparation (2012)

Direct Mass Measurement of ^{208}Hg Nuclide

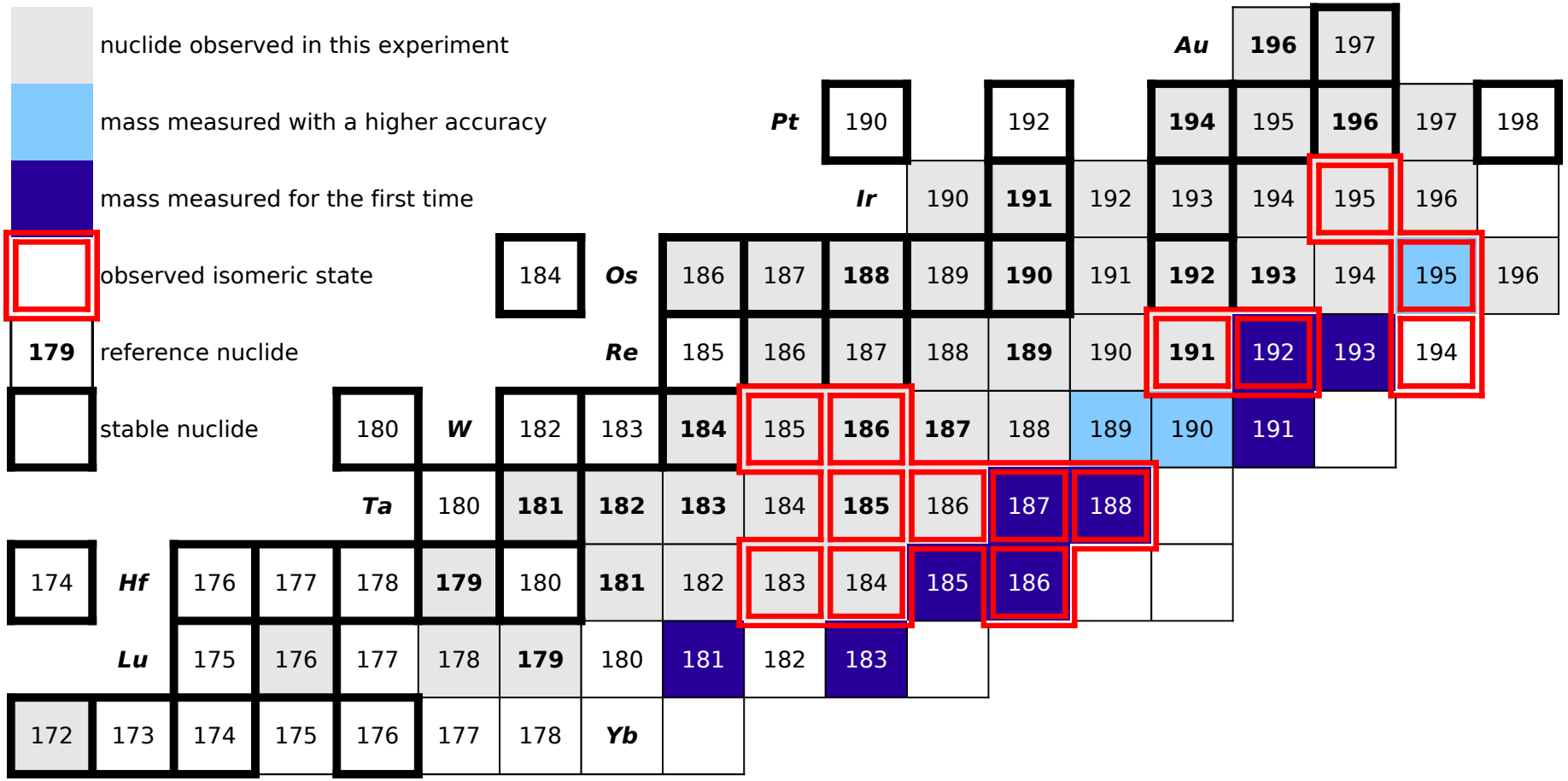


$$\delta V_{pn}(Z,N) = \frac{1}{4}\Big[B(Z,N) - B(Z,N-2) - B(Z-2,N) + B(Z-2,N-2)\Big]$$

p-n interactions are sensitive to the spatial overlaps of the proton and neutron wave functions

L. Chen et al., PRL 102 (2009) 122503

Direct Mass Measurement of ^{197}Au Projectile Fragments



D. Shubina et al., In preparation (2012)

Isochronous Mass Spectrometry

1985 - H. Wollnik, Y. Fujita, H. Geissel, G. Münzenberg, et al.

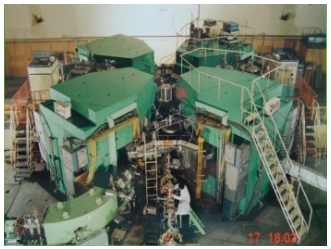
$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \cancel{\frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)}$$

$$\gamma_t \rightarrow \gamma$$

N=50, 82

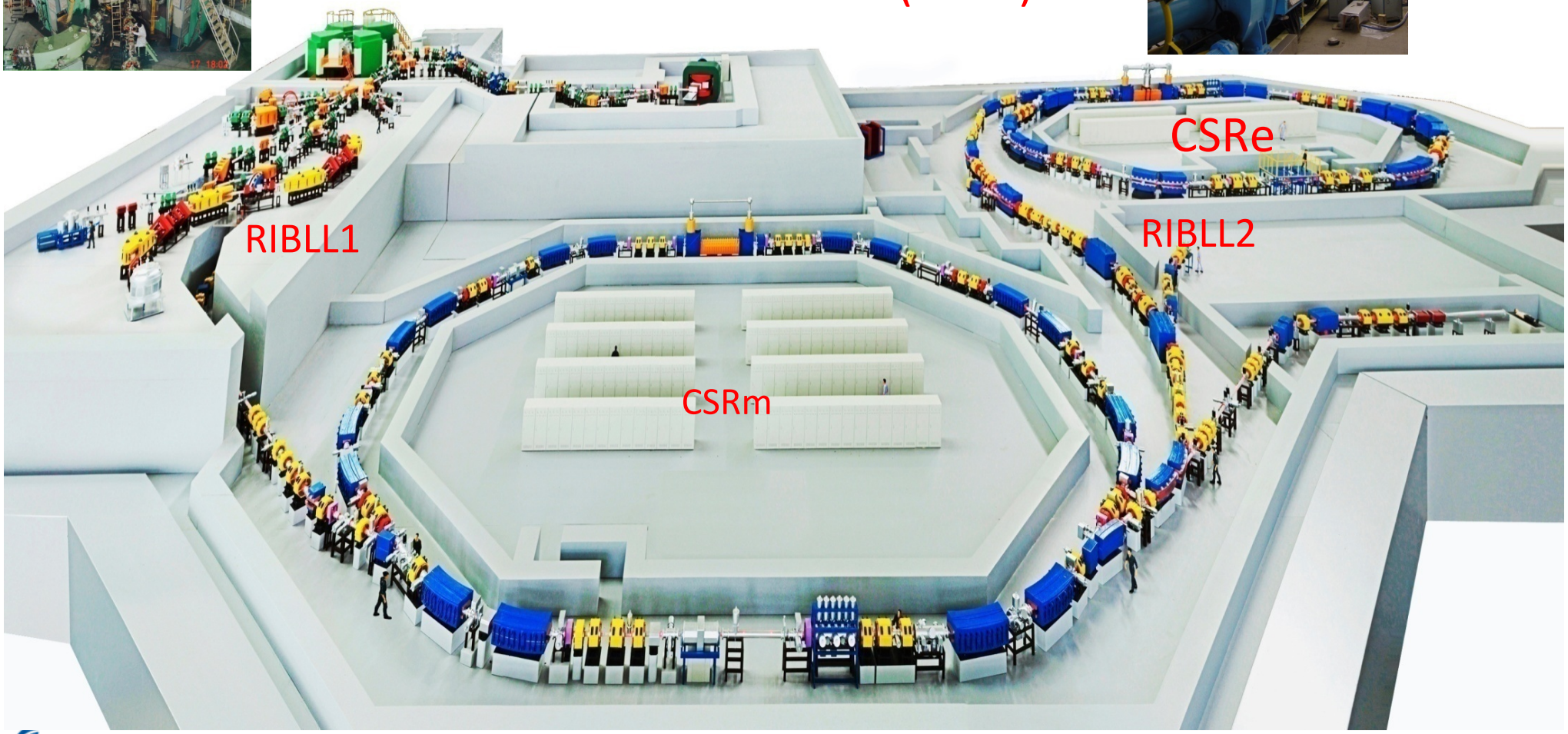
ims_basic2.swf

Heavy Ion Research Facility in Lanzhou (HIRFL)

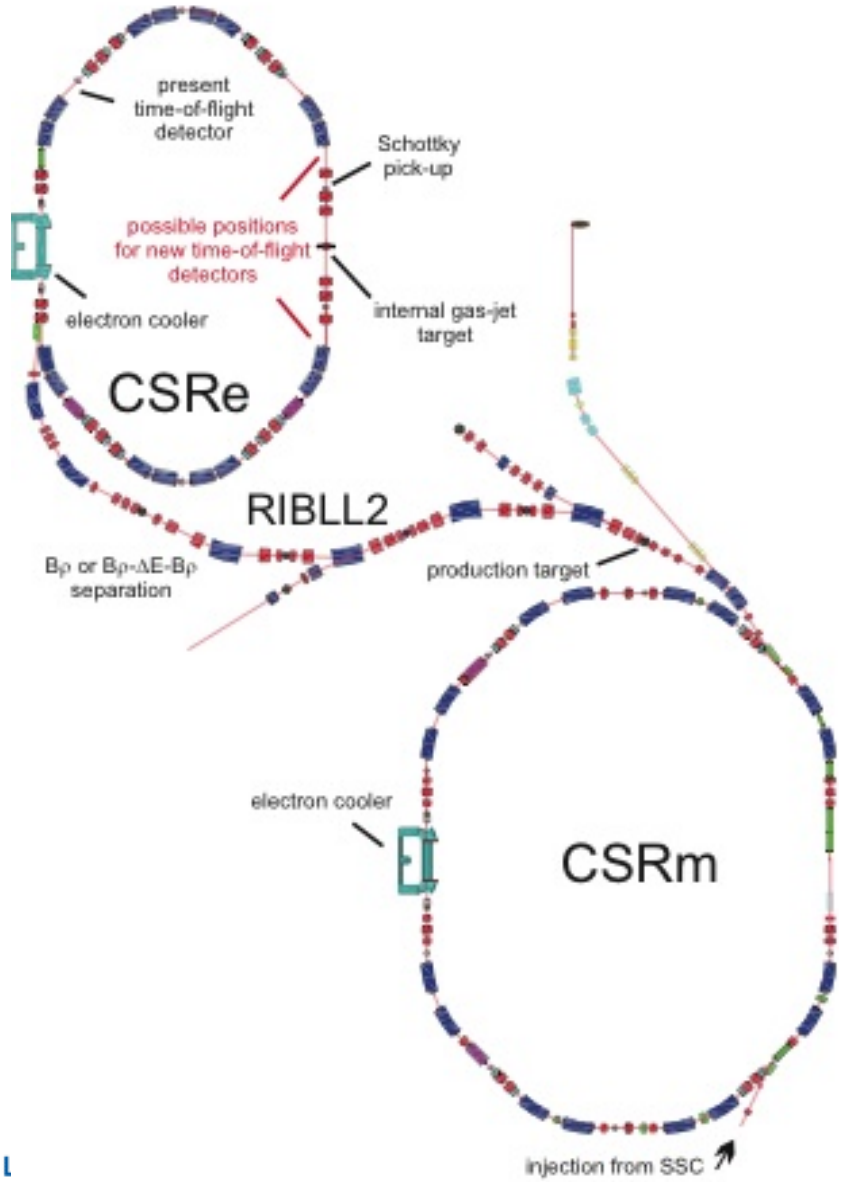


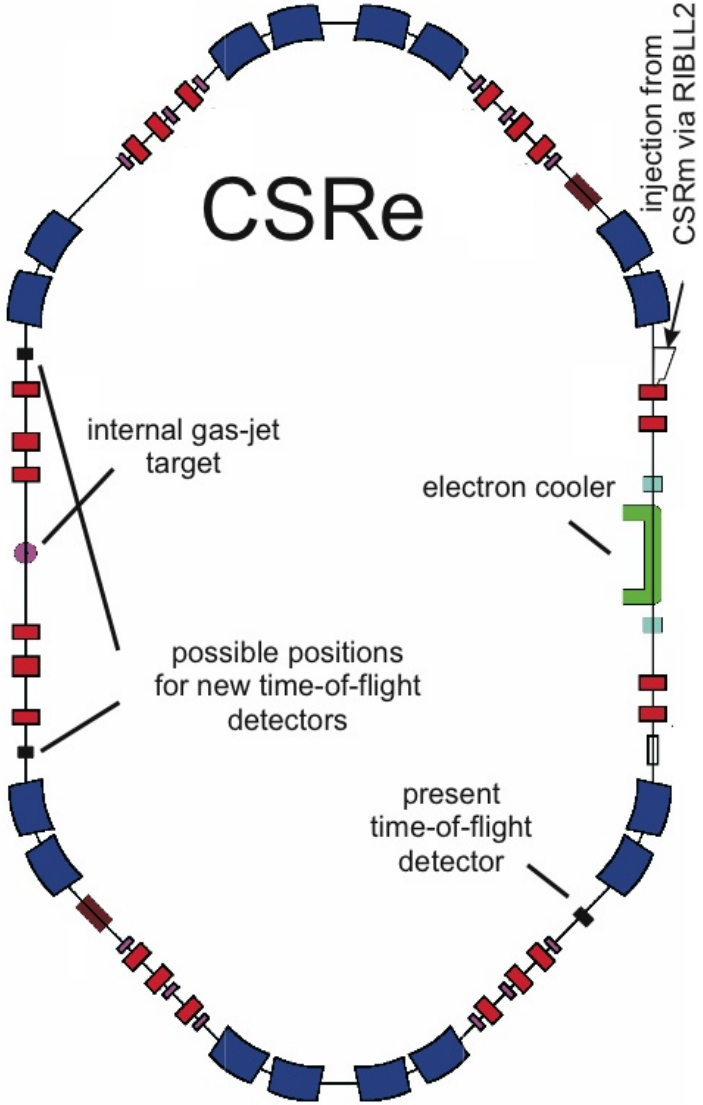
SSC(K=450)

SFC (K=69)



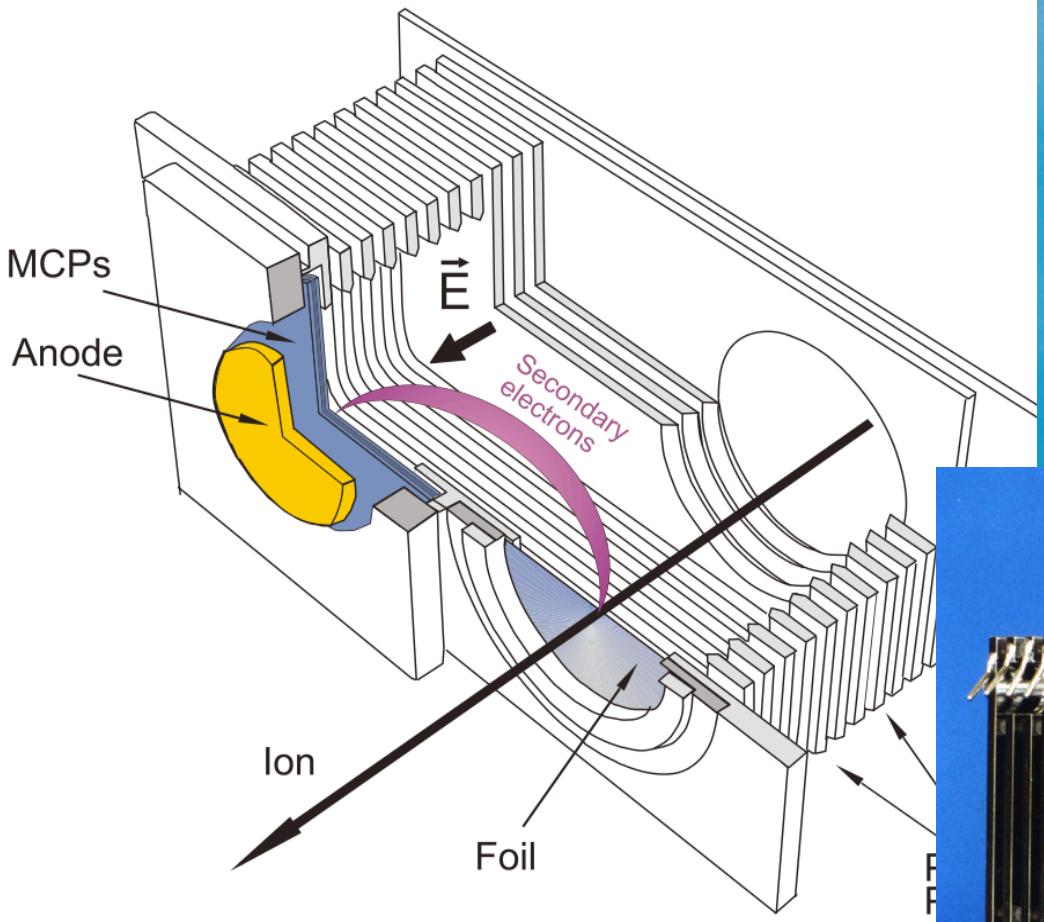
CSRm-CSRe Complex at IMP in Lanzhou

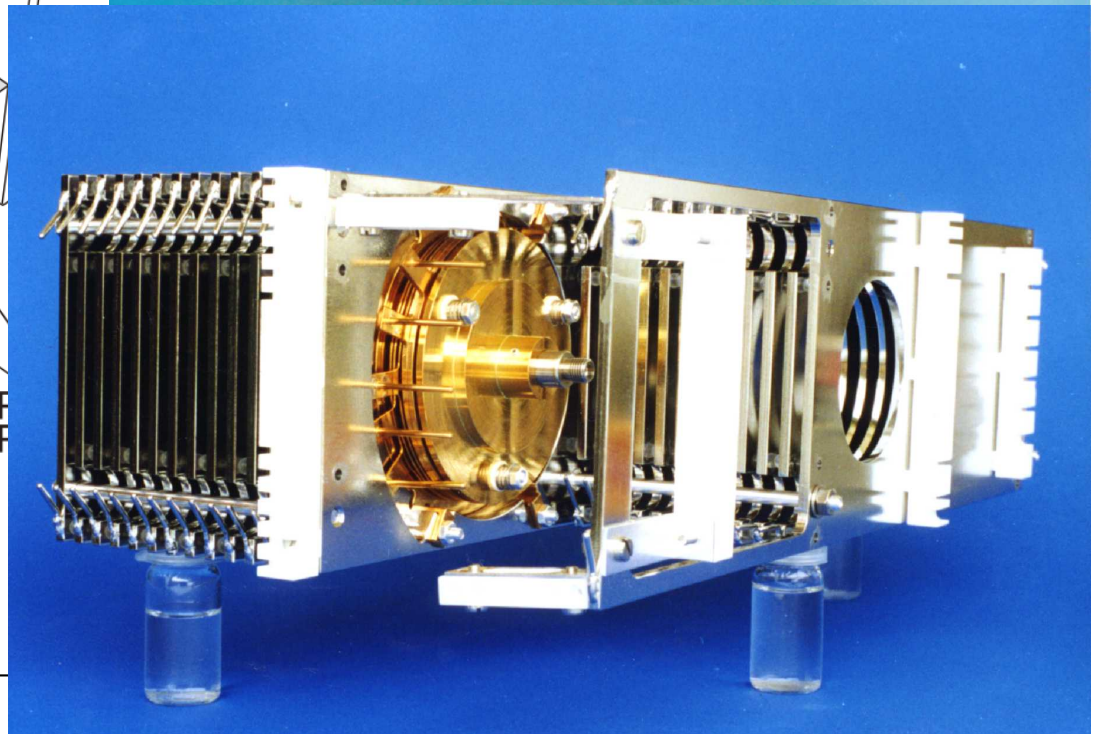




W.L. Zhan et al., Nucl. Phys. A834 (2006) 694c

Time-of-Flight detector for the IMS

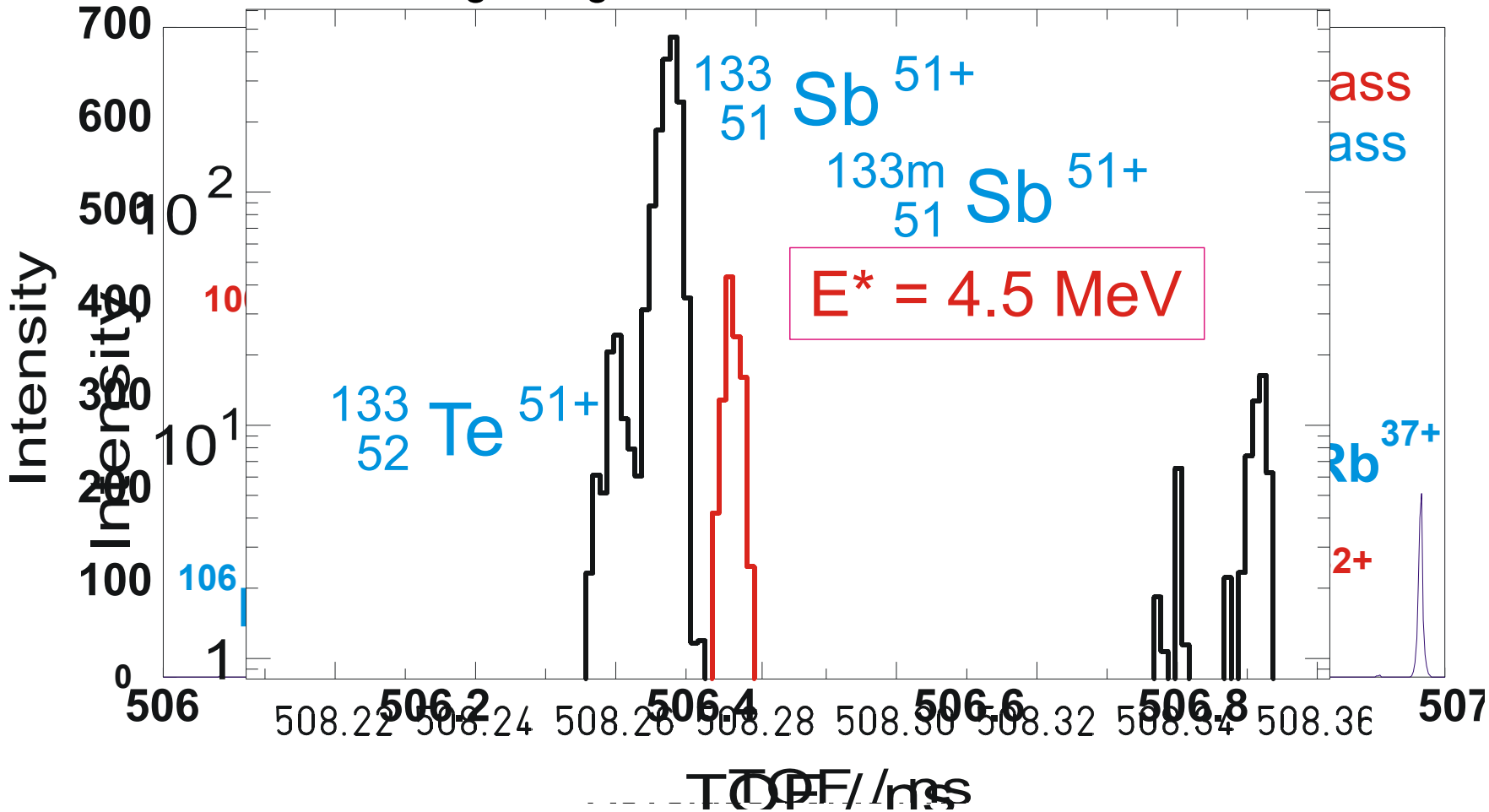




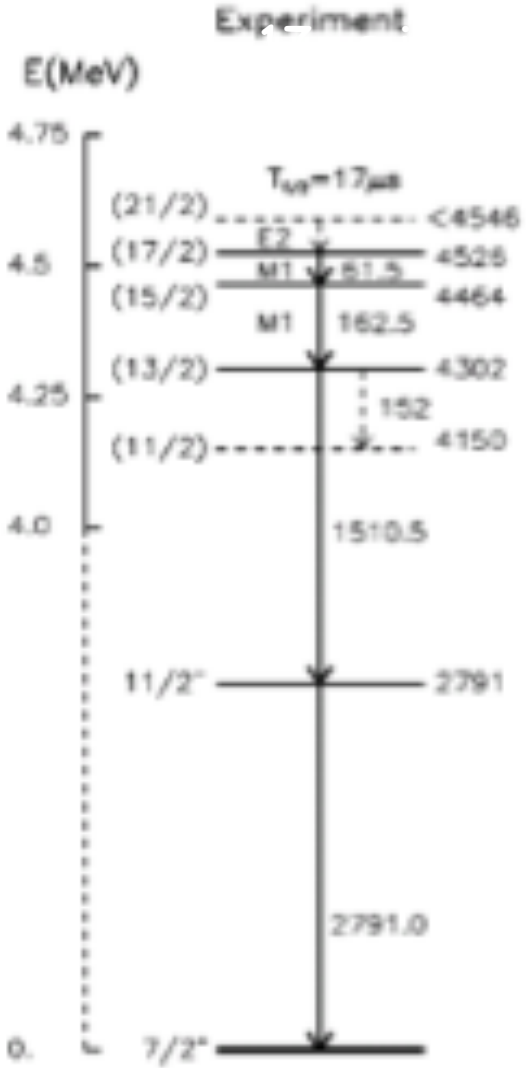
IMS: Time-of-Flight Spectra

Nuclei with half-lives as short as 20 μs

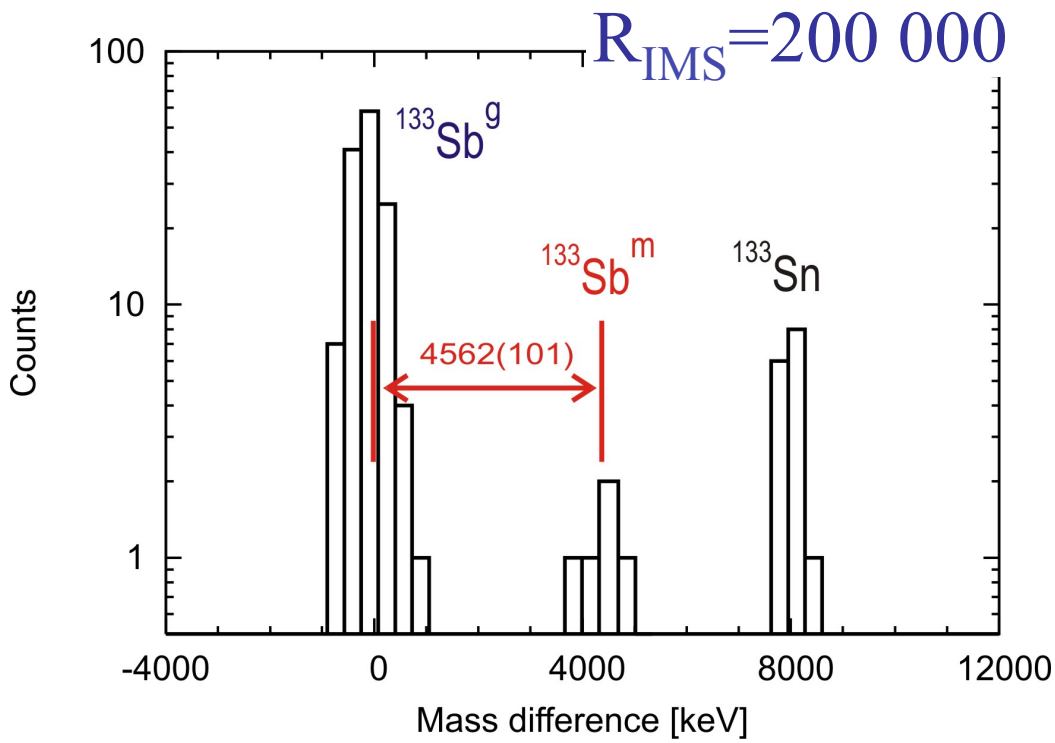
About 13% in mass-over-charge range



New half-live domain for storage-ring experiments



Genevey et al., EPJA 7, 463 (2000)



Expected half-live of bare isomer: ~ 17 ms, α_t~991

A new half-live domain for storage-ring experiments

B. Sun, et al., Phys. Lett. B 688 (2010) 294

Mass Measurements Relevant for Nucleosynthesis in Stars

NUCLEAR ASTROPHYSICS

Star bursts pinned down

One of the main uncertainties in the burn-up of X-ray bursts from neutron stars has been removed with the weighing of a key nucleus, ^{65}As, at a new ion storage ring.

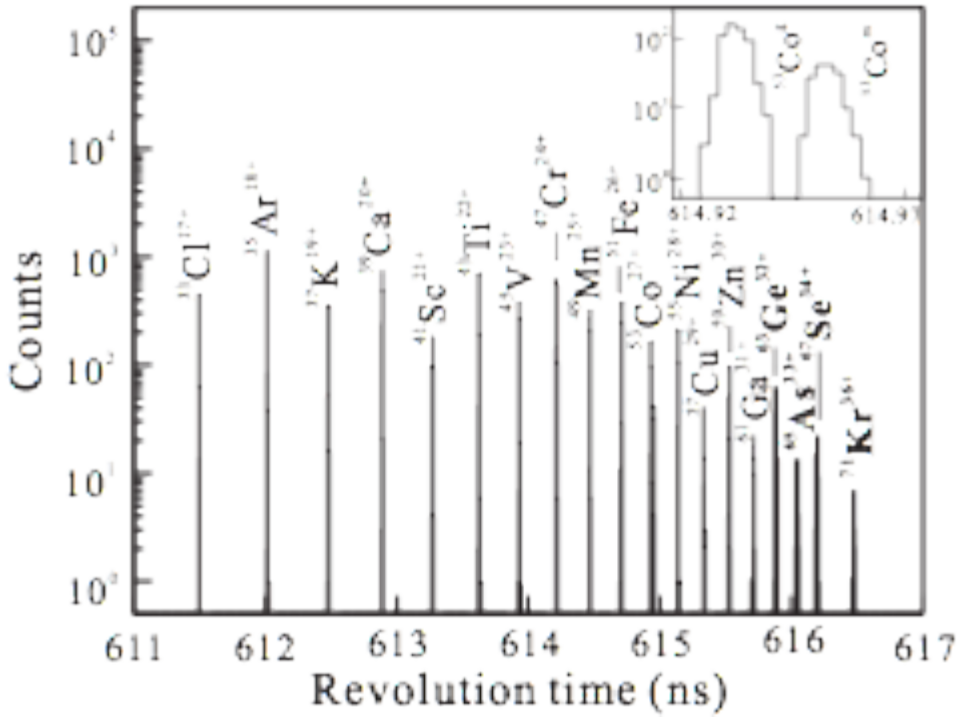
NATURE PHYSICS | VOL 7 | APRIL 2011 | www.nature.com/naturephysics

BRENNPUNKT

Kein Halten am Wartepunkt

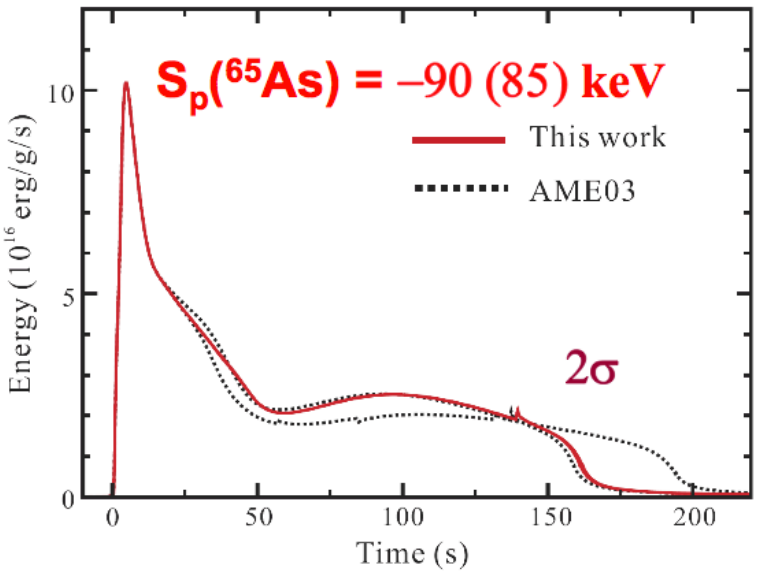
Hochpräzise Massenmessungen erklären die Kernreaktionen bei Ausbrüchen von Röntgenstrahlung.

Physik Journal 10 (2011) Nr. 6



Rate of ^{71}Kr was just 2 ions/day

Light curve shape of Type I x-ray burst



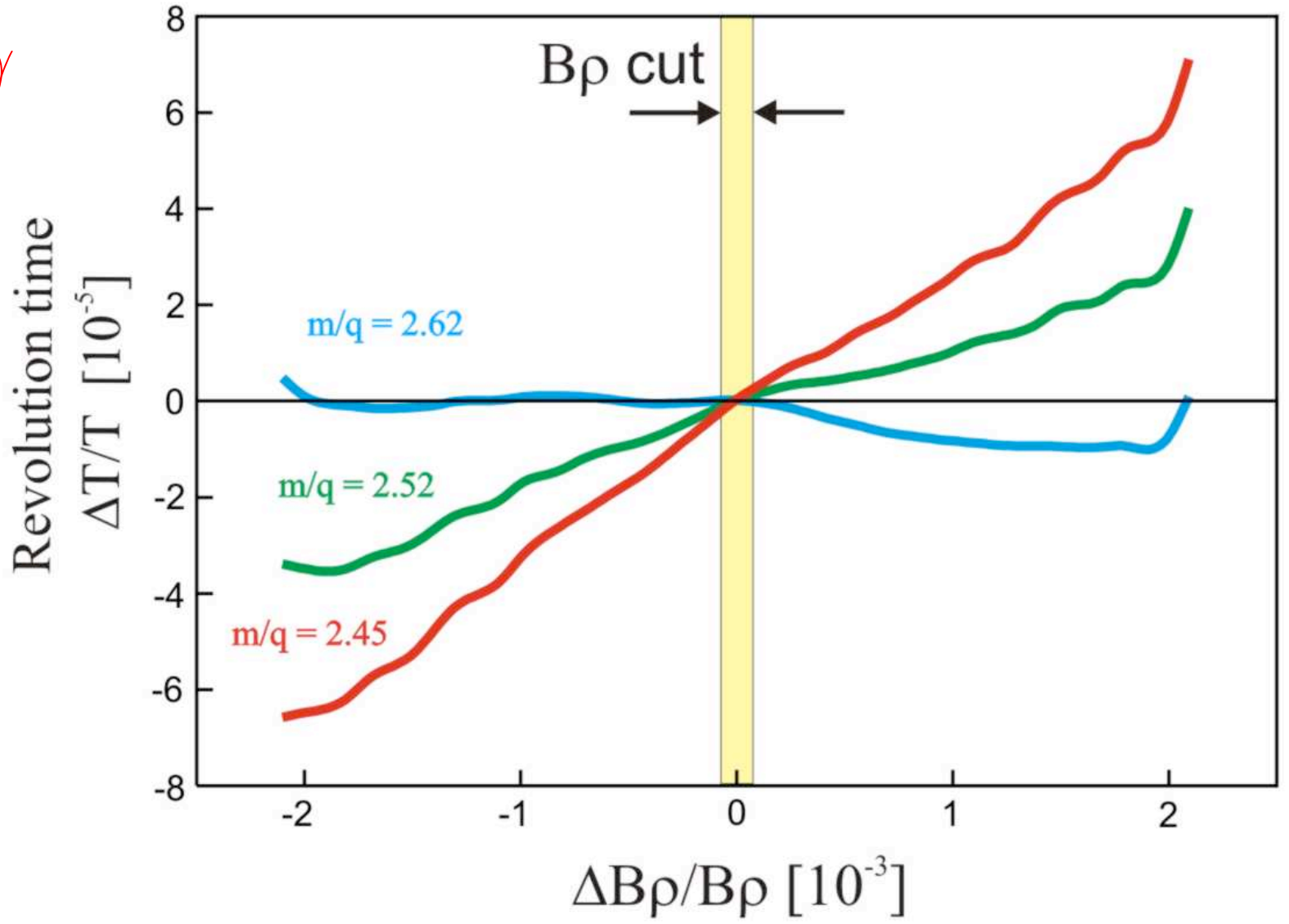
X.Tu, et al., PRL 106 (2011) 112501

Limitation of the Isochronicity

Magnetic rigidity

$$B\rho = \frac{m}{q} v\gamma$$

Good isochronous conditions are fulfilled only in a small range



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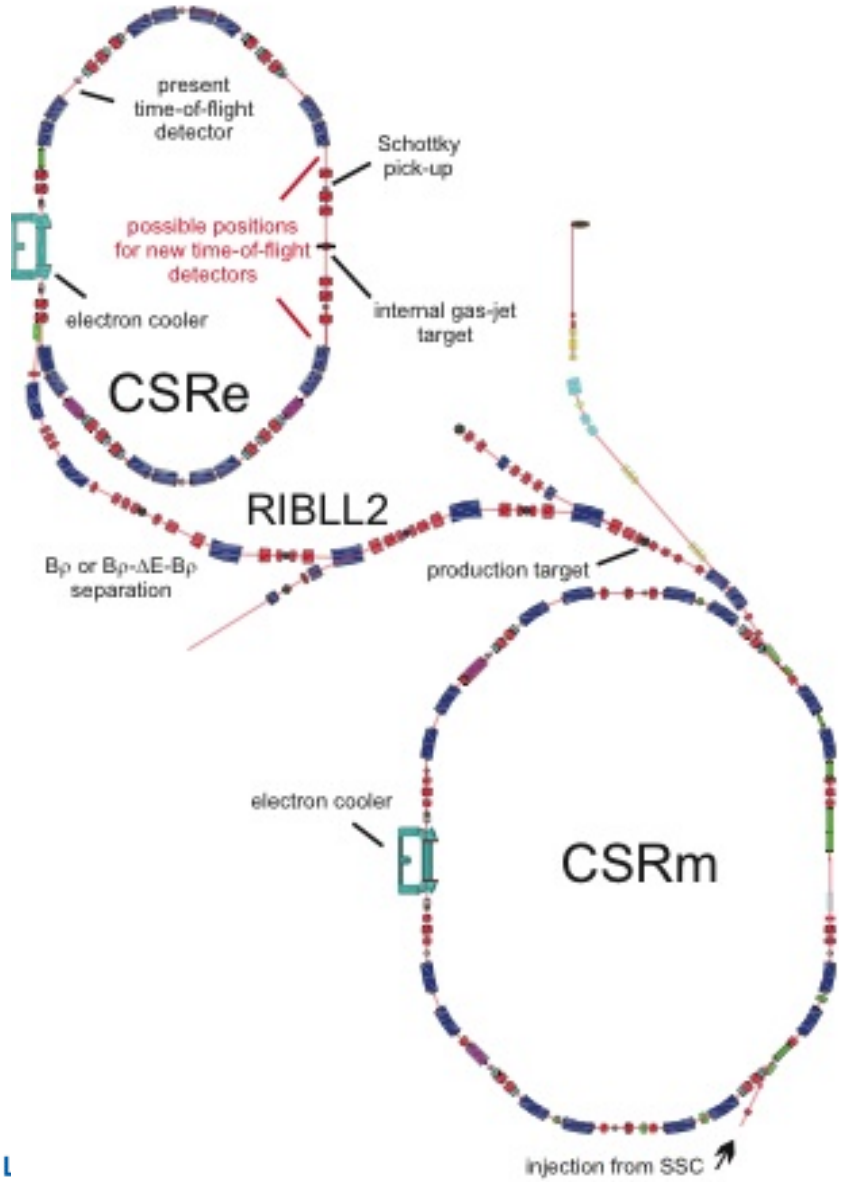
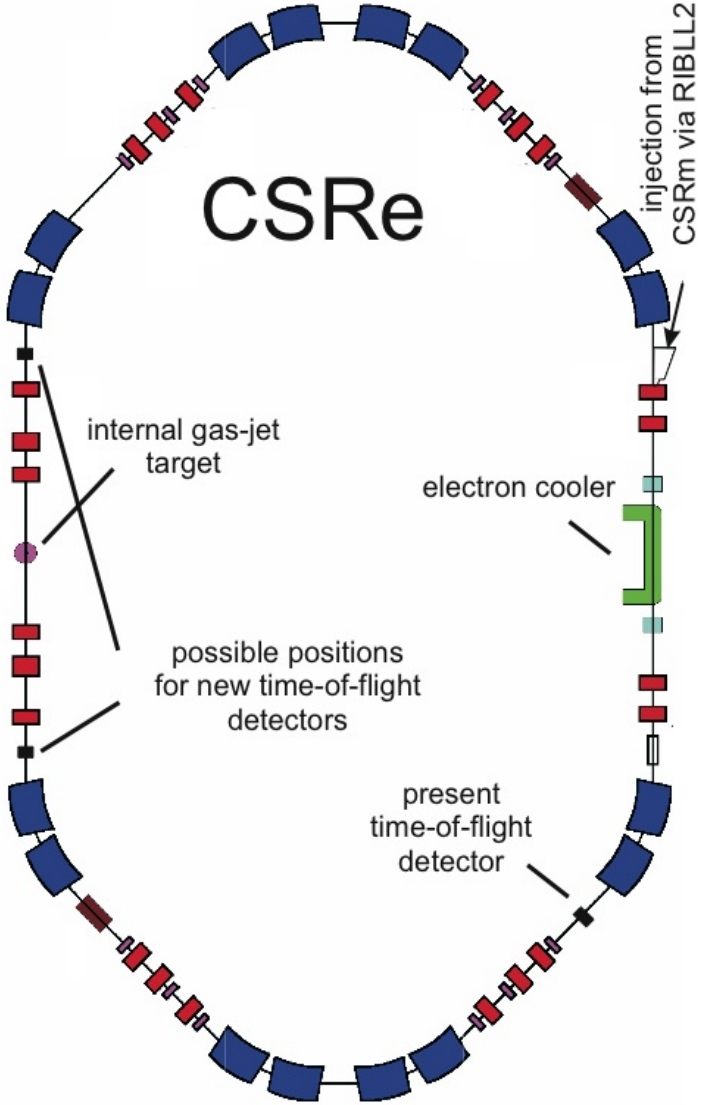
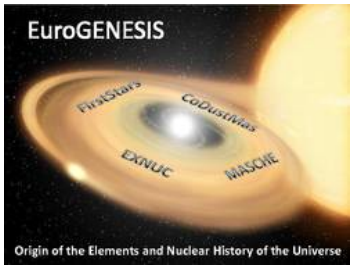




W.L. Zhan et al., Nucl. Phys. A834 (2006) 694c

Direct Mass Measurements on the Chart of the Nuclides

Status: 2011



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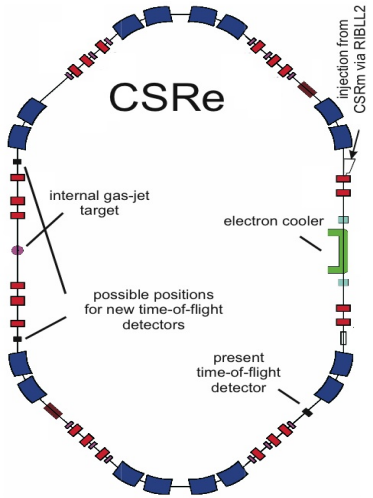
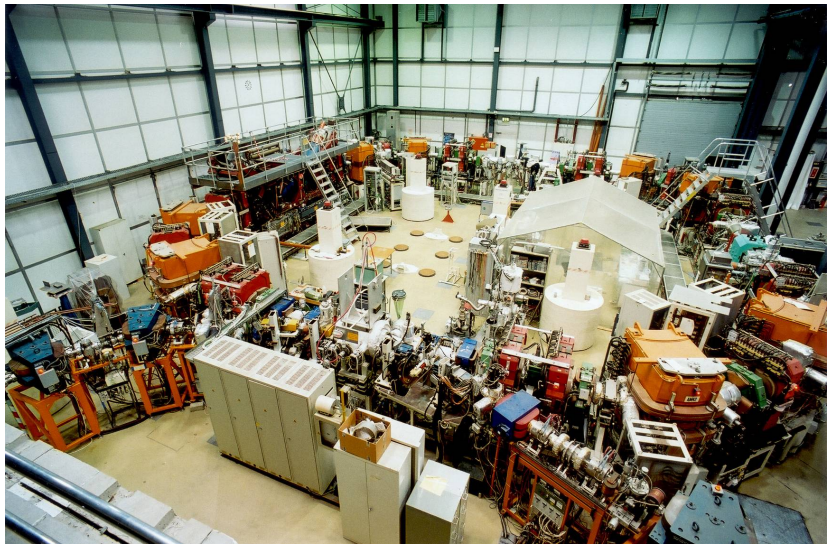


Storage Rings

TSR @ ISOLDE



Eur. Phys. J. Special Topics **207**, 1–117 (2012)
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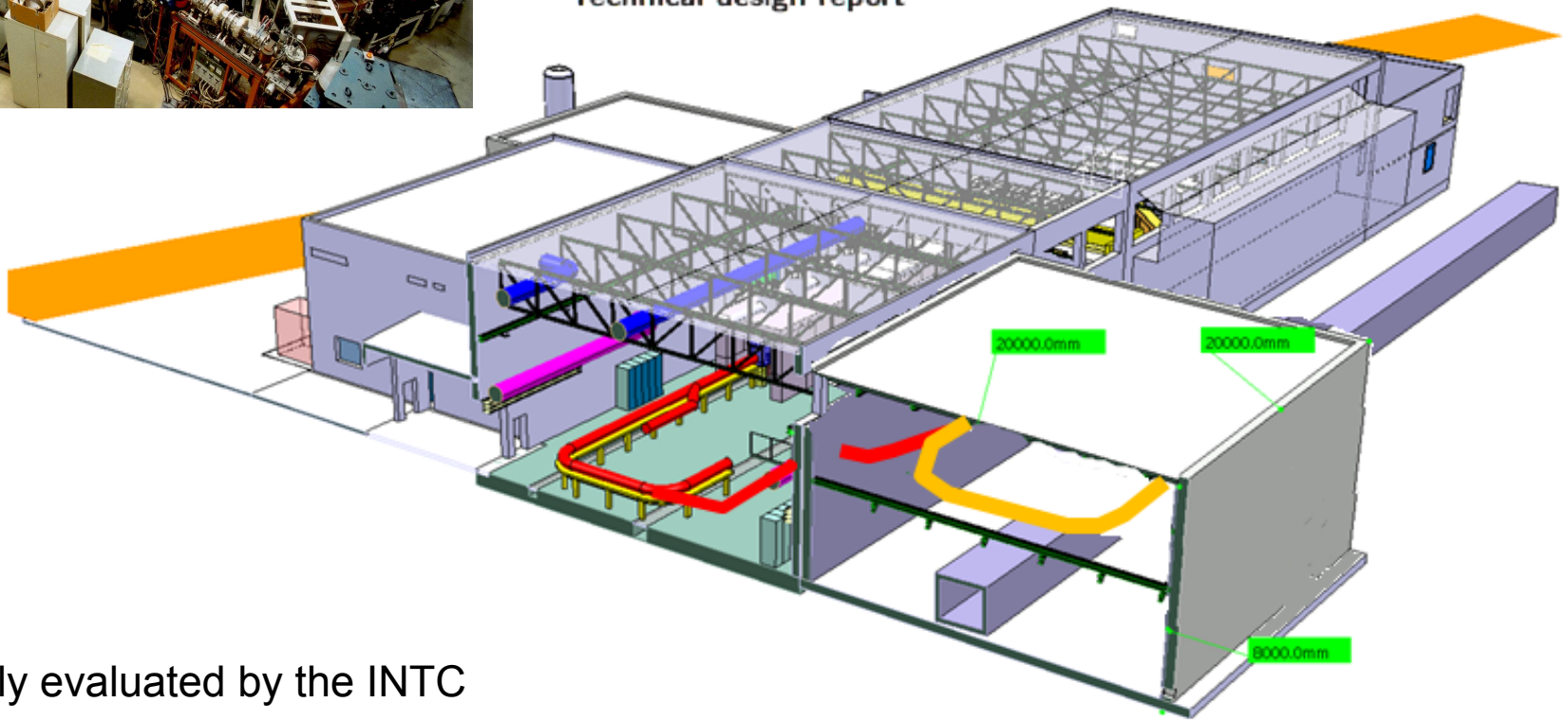
DOI: 10.1140/epjst/e2012-01599-9

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Review

Storage ring at HIE-ISOLDE

Technical design report

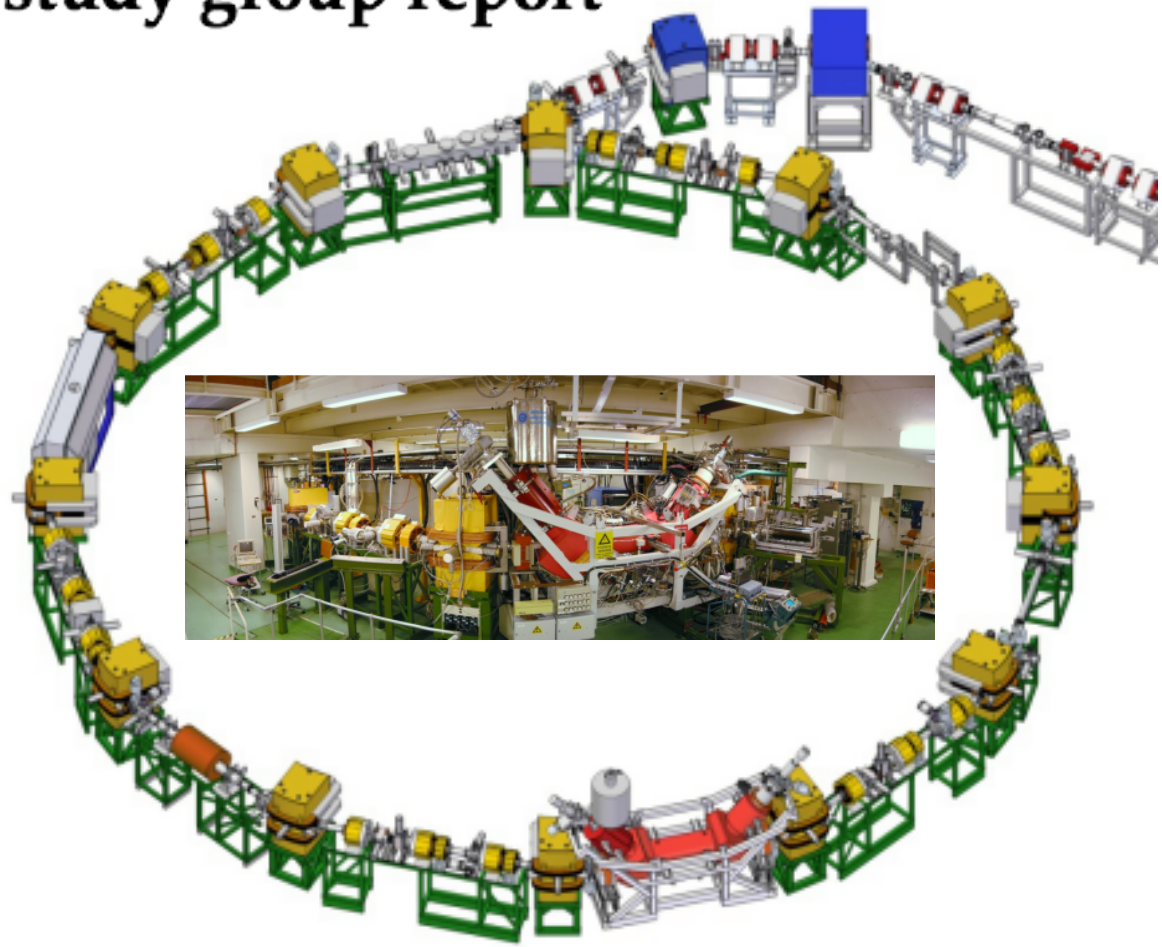


TDR positively evaluated by the INTC

CRYRING@ESR

CRYRING@ESR:

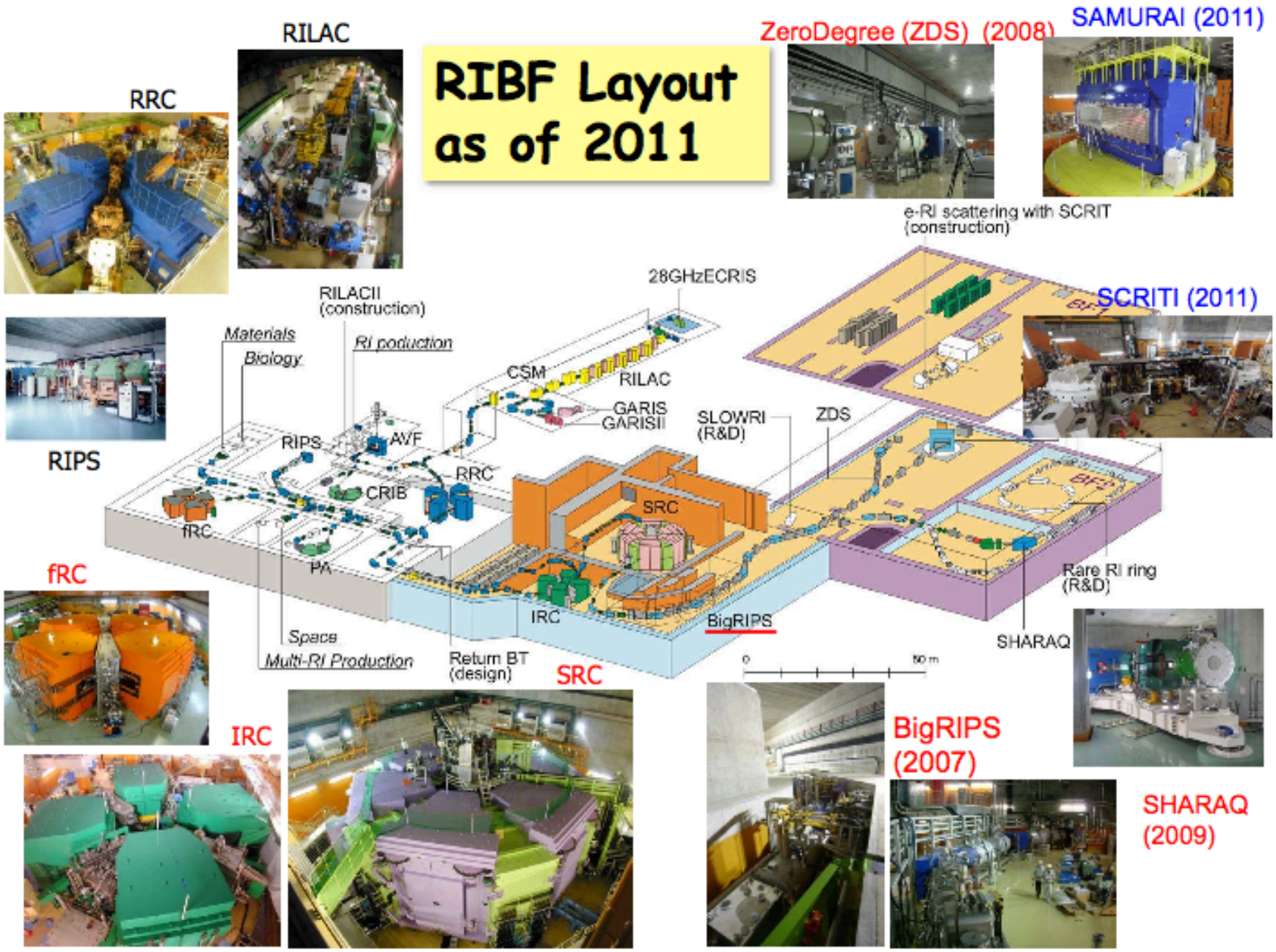
A study group report



Study Group

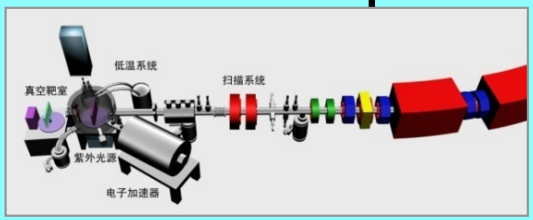
Norbert Angert
Angela Bräuning-Demian
Hakan Danared
Wolfgang Enders
Mats Engström
Bernhard Franzke
Anders Källberg
Oliver Kester
Michael Lestinsky
Yuri Litvinov
Markus Steck
Thomas Stöhlker

RIKEN Radioactive Ion Beam Facility

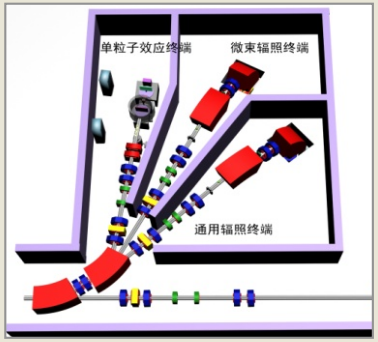


Next-Generation Heavy-Ion Beam Facility HIAF

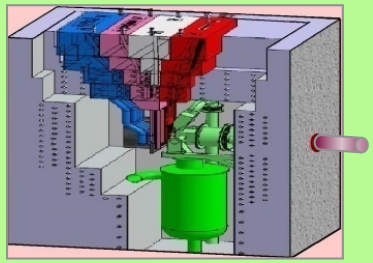
•Irradiation Setup



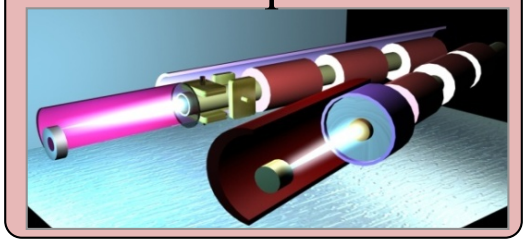
•Multi-Function Setup



•Material Setup



•HEP Setup 10s kJ



4 Beam Line 5 Exp. Setups

Cooler-Synchrotron
ECS-45
(High Pulse Power)

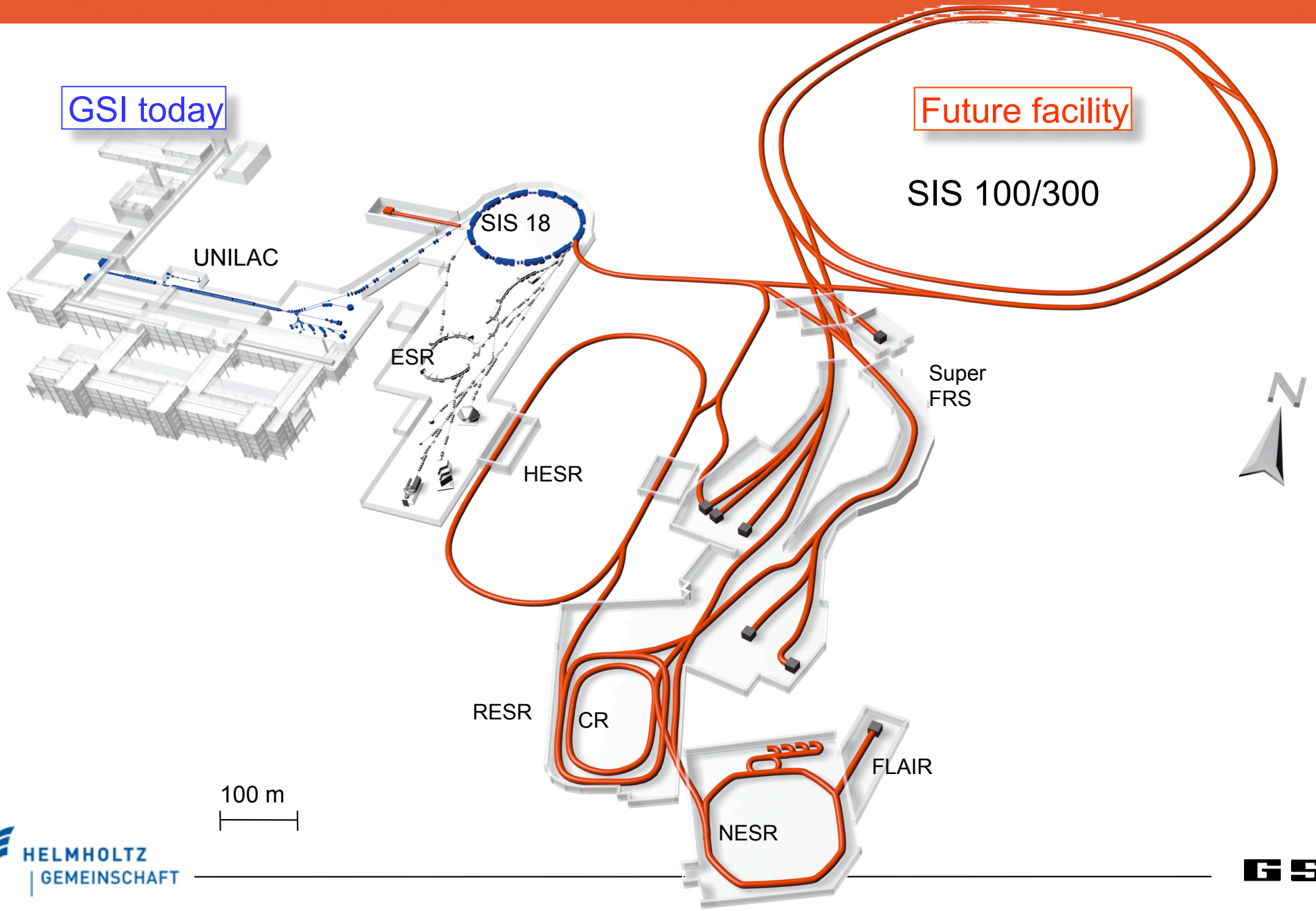
Isochronisms'
Mass Measurement
(High Accuracy)

ECR LIS

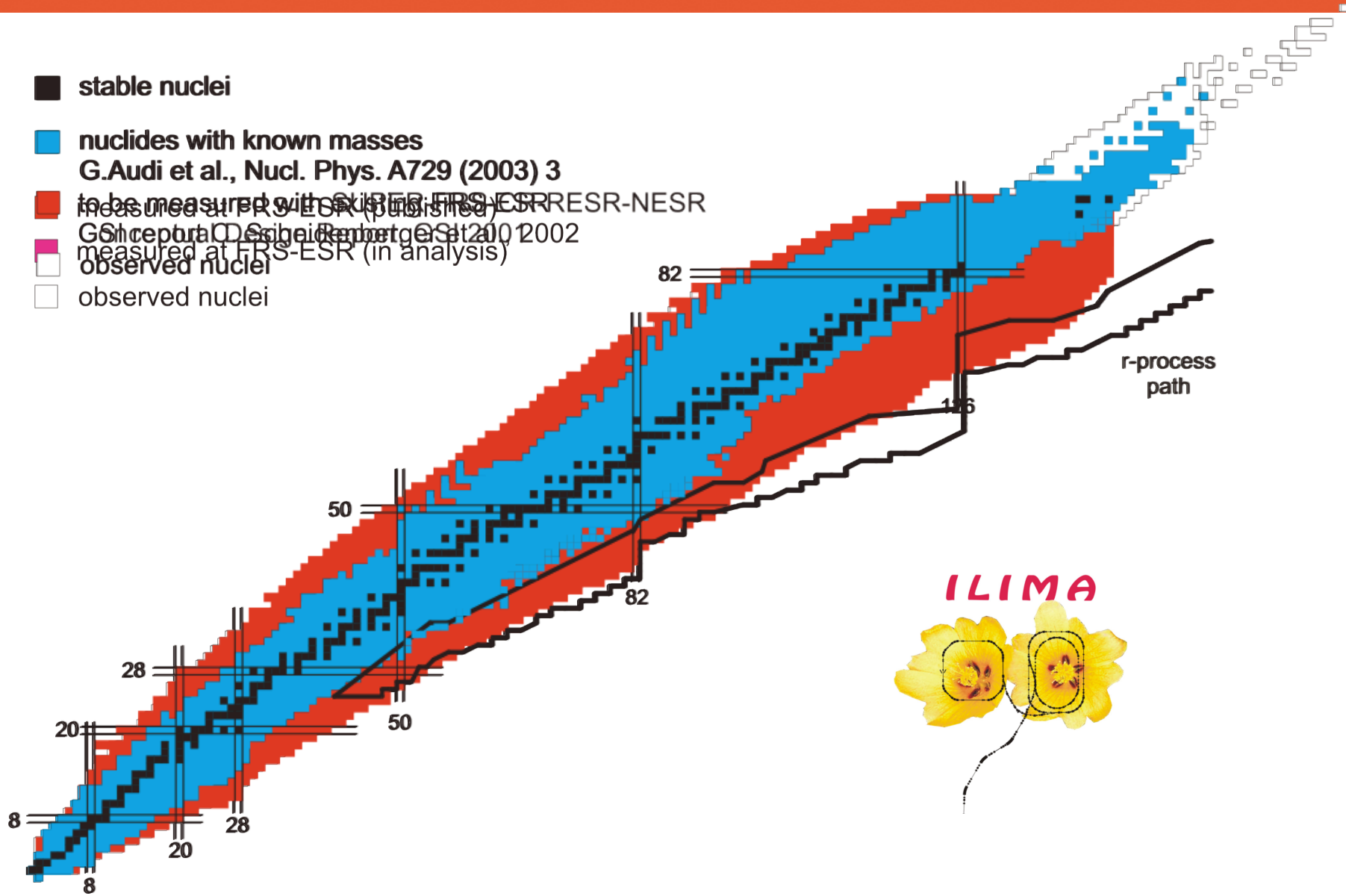
i-LINAC
(Multi-Charge State)

U-RIBLL
(Large Acceptance)

FAIR - Facility for Antiproton and Ion Research



ILIMA: Masses and Halflives



1913 - J. J. Thompson, Entdeckung der Isotope (Nobelpreis 1906)

Sir Joseph John Thomson (1856-1940)

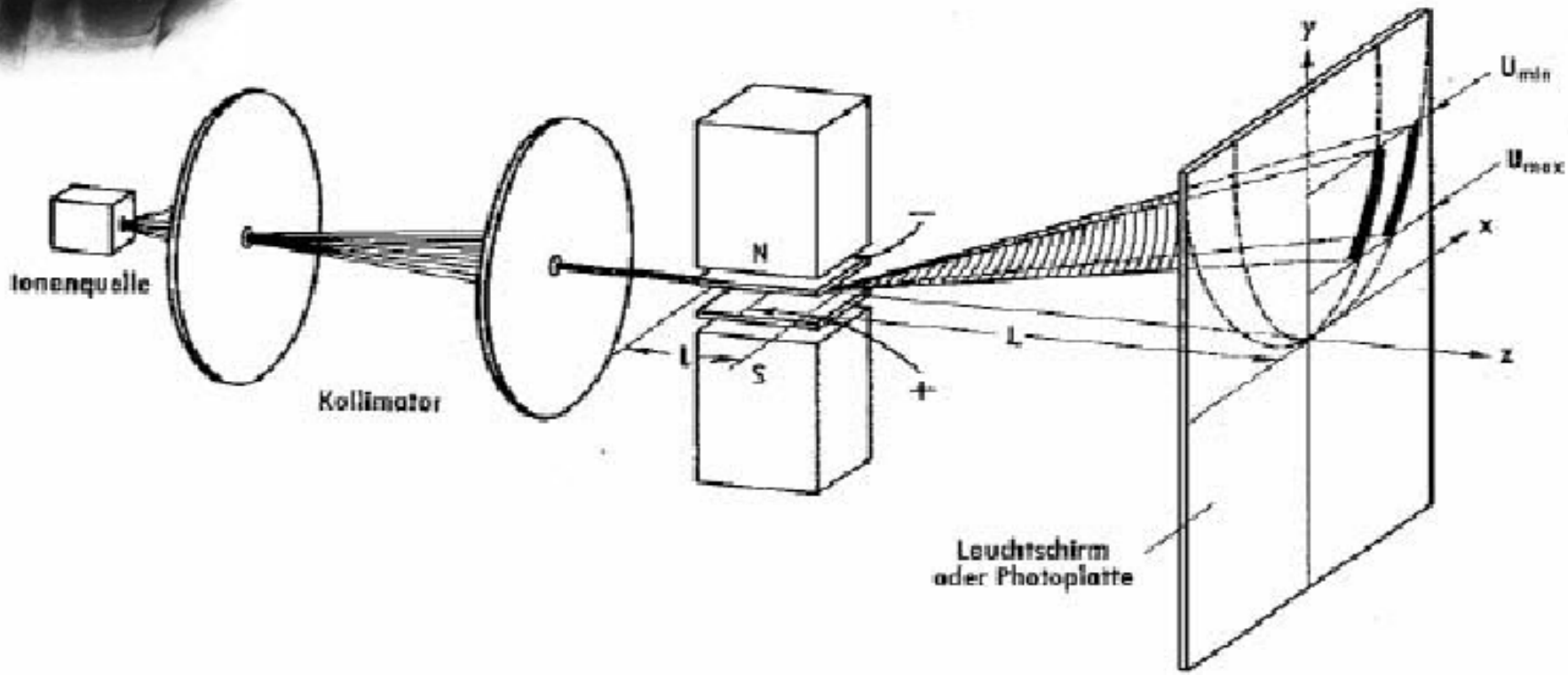


Abb. 1.6: Prinzipskizze des Thompson'schen Parabelspektrographen

- Special Issue of International Journal of Mass Spectrometry "Birth of Mass Spectrometry"
(Klaus Blaum, Yuri Litvinov (Eds.))

- Dedicated Symposium "100 Years of Mass Spectrometry", DPG-Meeting, Hanover, 2013
(Klaus Blaum, Yuri Litvinov (Org.))

- 513. WE-Heraeus Seminar on "Astrophysics with Ion-Storage Rings"
(Yuri Litvinov, Rene Reifarth and Kerstin Sonnabend (Org.))

- 530. WE-Heraeus Seminar on "Nuclear Masses and Nucleosynthesis"
(Almudena Arcones, George Bertsch and Klaus Blaum (Org.))

AMDC
Atomic Mass Data Center

IMP
中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

New Atomic Mass Evaluation (AME2012) is to appear in 2012/2013

Many Thanks to

ISOLTRAP Collaboration
FRS-ESR Collaboration
MATS Collaboration
ILIMA Collaboration
RI-RING Collaboration
CSRe Collaboration
TSR@ISOLDE Collaboration
CRYRING@ESR Collaboration
SPARC@HESR Collaboration