Первые прямые измерения масс сверхтяжёлых ядер

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ОФВЭ ПИЯФ РАН

Ученый совет ПИЯФ
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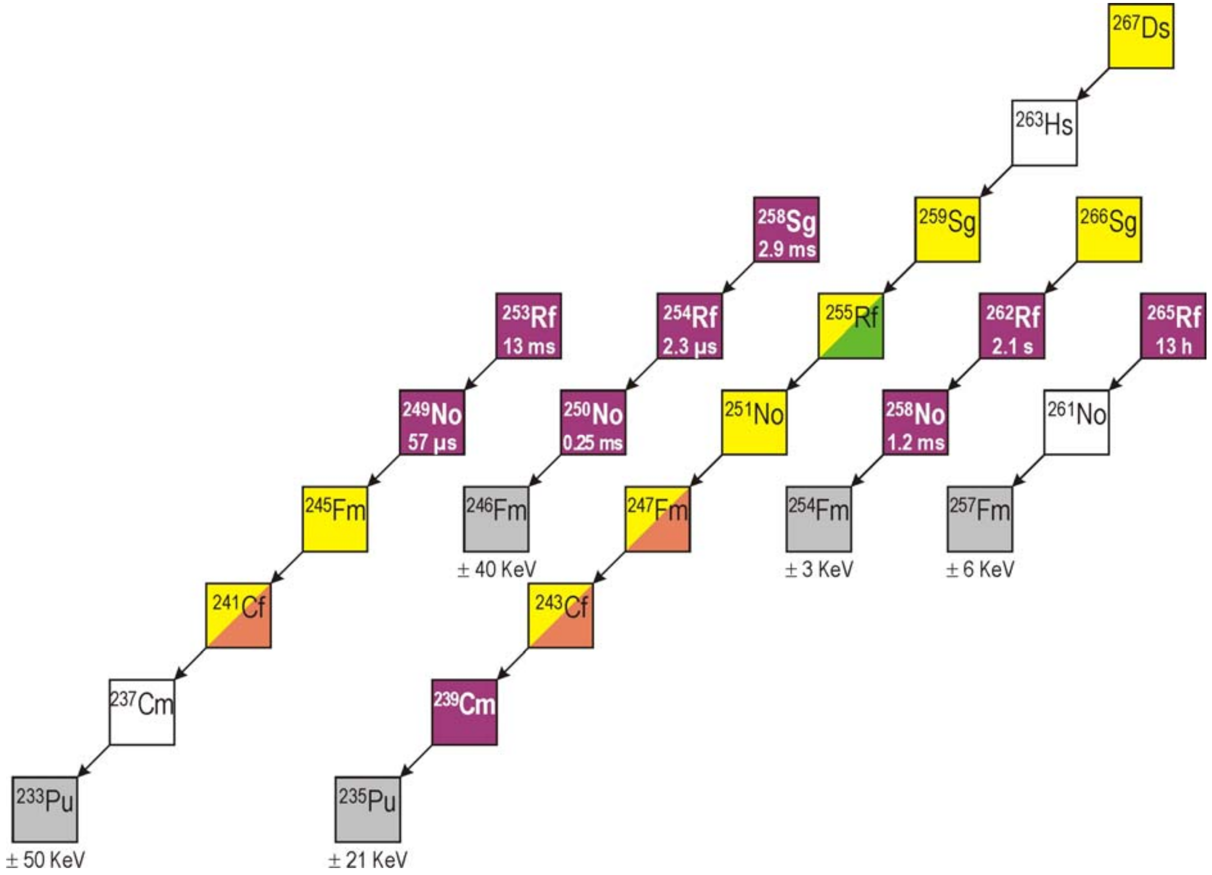
Массовая поверхность Сверхтяжёлых

α-цепочки для чётных Z с разомкнутыми звеньями (*в фиолетовом цвете*)



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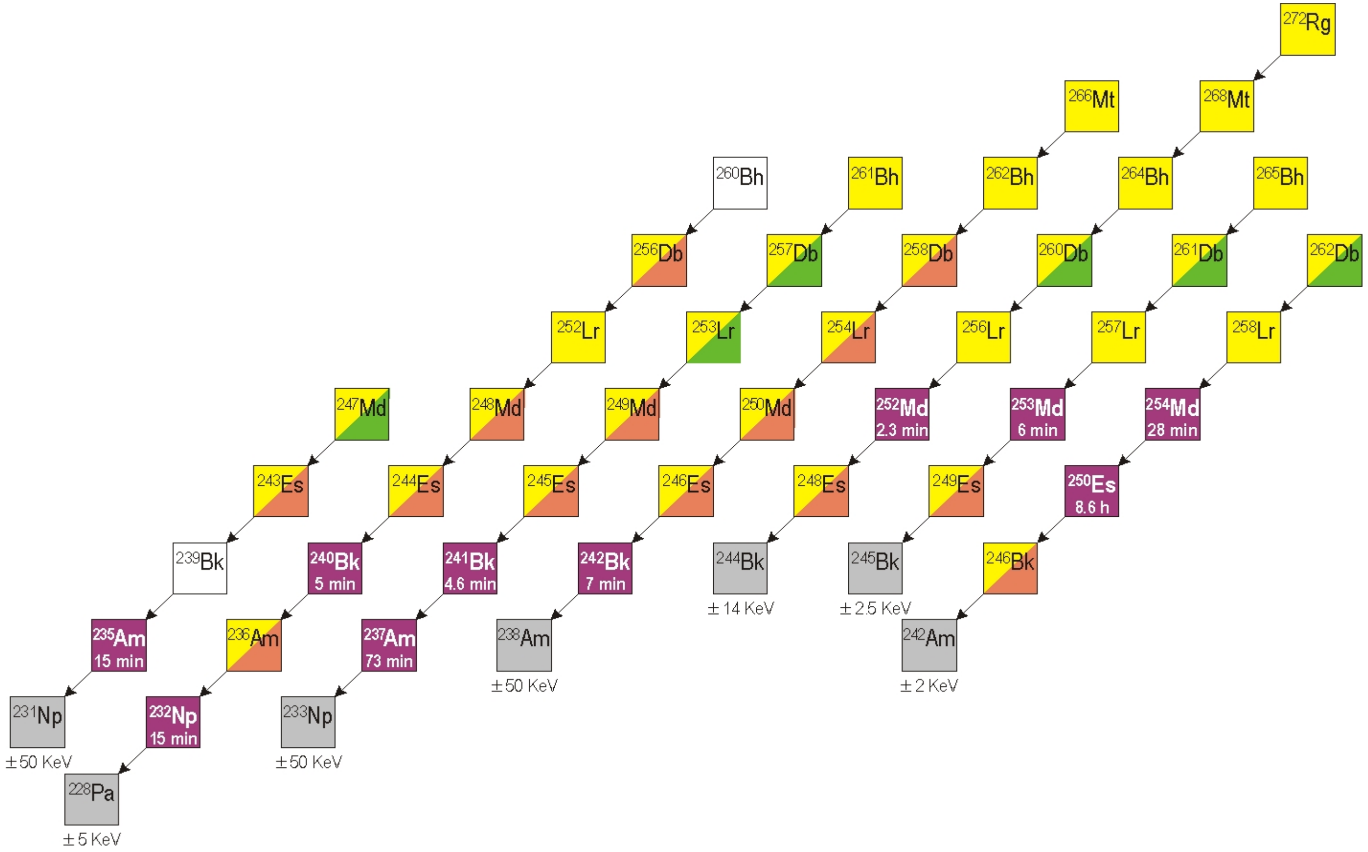
α-цепочки для нечётных Z с разомкнутыми звеньями (*в фиолетовом цвете*)



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Поиск «недостающих» α-излучателей для замыкания цепочек распадов

Лаб.	***Spokes-person***	**Год**	**Реакция**	**Нукл**	**α-ветвь**
JYFL (*Finl.*)	***Novikov***	**1997 - 1998**	^{232}Th+^{14}N	^{239}Bk ^{241}Bk	$<10^{-2,-3}$
JAERI (*Japan*)	***Shino-hara***	**2000 - 2002**	^{232}Th+^{12}C	^{239}Cm	$\approx 6 \cdot 10^{-5}$
GSI (*Germ.*)	***Novikov***	**2004 - 2005**	^{232}Th+^{12}C	^{239}Cm	$< 10^{-5}$

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Прямые измерения масс в ионной ловушке SHIPTRAP

Схема установки SHIP (GSI)

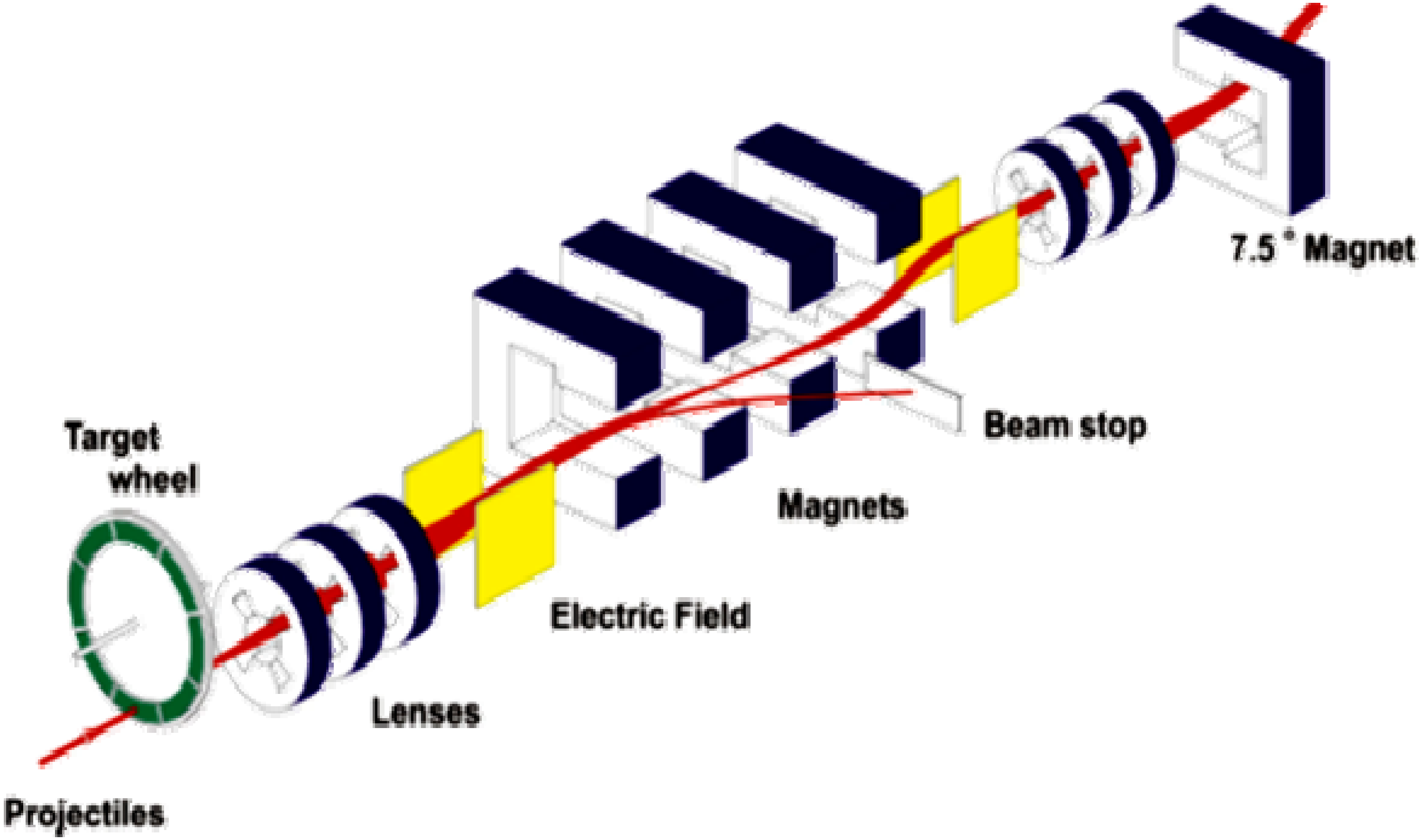
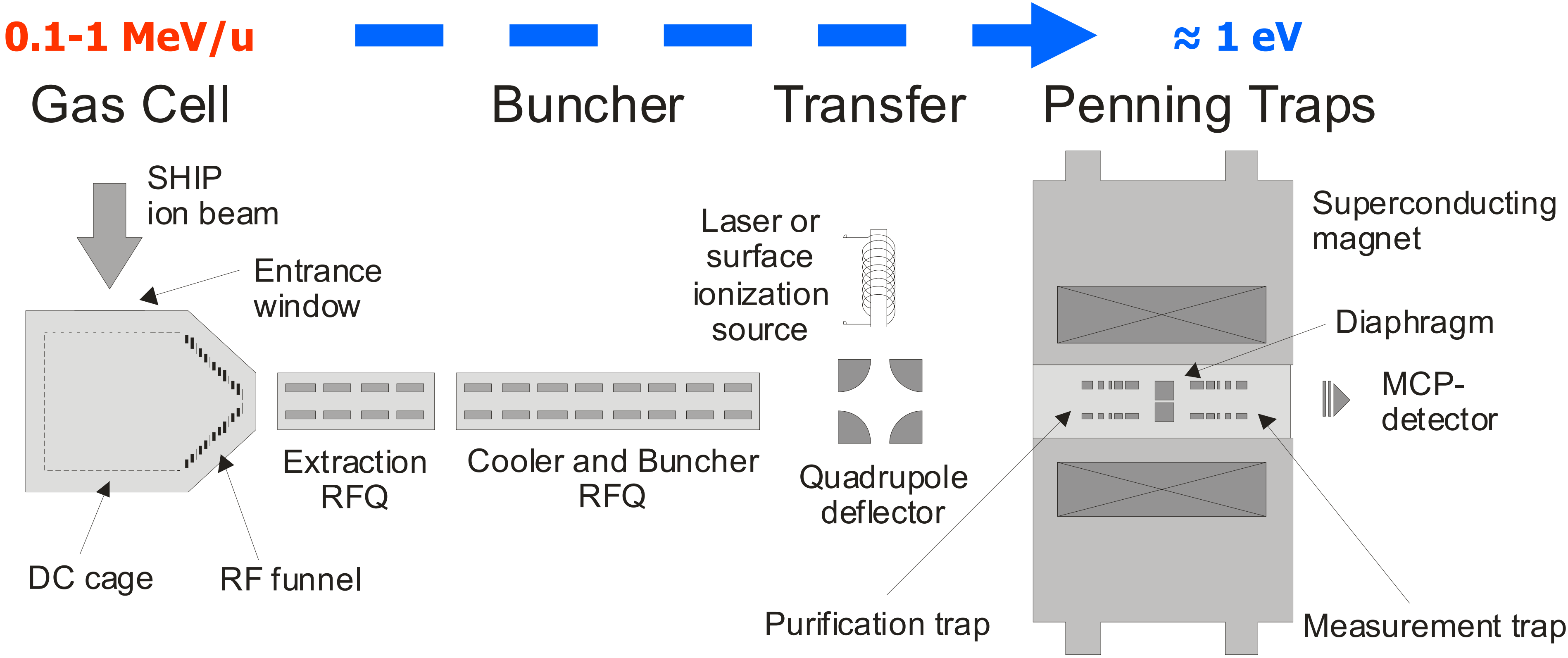


Схема установки SHIPTRAP

(courtesy of M. Block)



0.1-1 MeV/u → **≈ 1 eV**

Gas Cell

Buncher

Transfer

Penning Traps

SHIP
ion beam

Entrance
window

DC cage

RF funnel

Extraction
RFQ

Cooler and Buncher
RFQ

Laser or
surface
ionization
source

Quadrupole
deflector

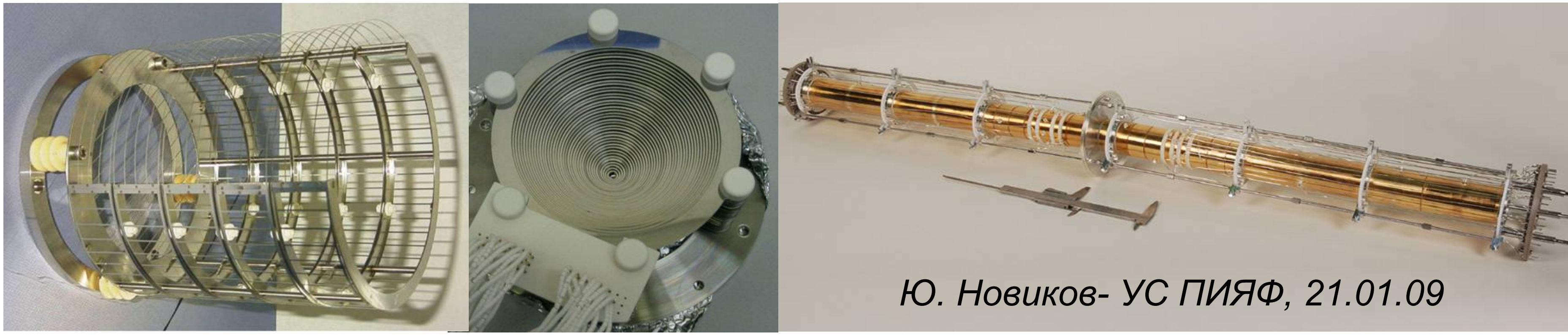
Superconducting
magnet

Diaphragm

MCP-
detector

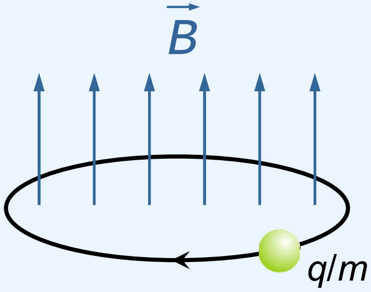
Purification trap

Measurement trap



Принцип действия ионных ловушек Пеннинга

(Нобелевская премия – 1989 г.)

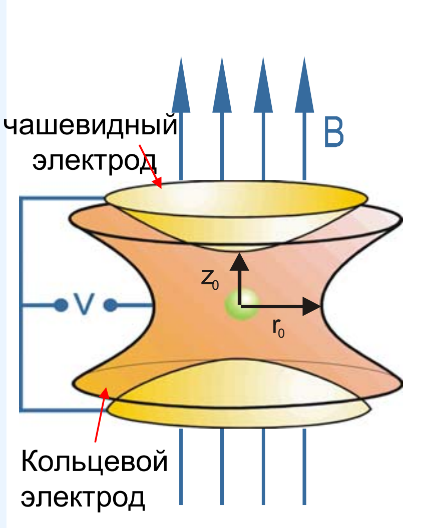


Циклотронная частота:

$$f_c = \frac{1}{2\pi}\cdot\frac{q}{m}\cdot B$$

PENNING trap

- Сильное однородное магнитное поле
- Слабое электро-3D квадрупольное поле

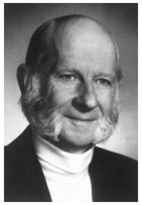


www.quantum.physik.uni-mainz.de/mats/

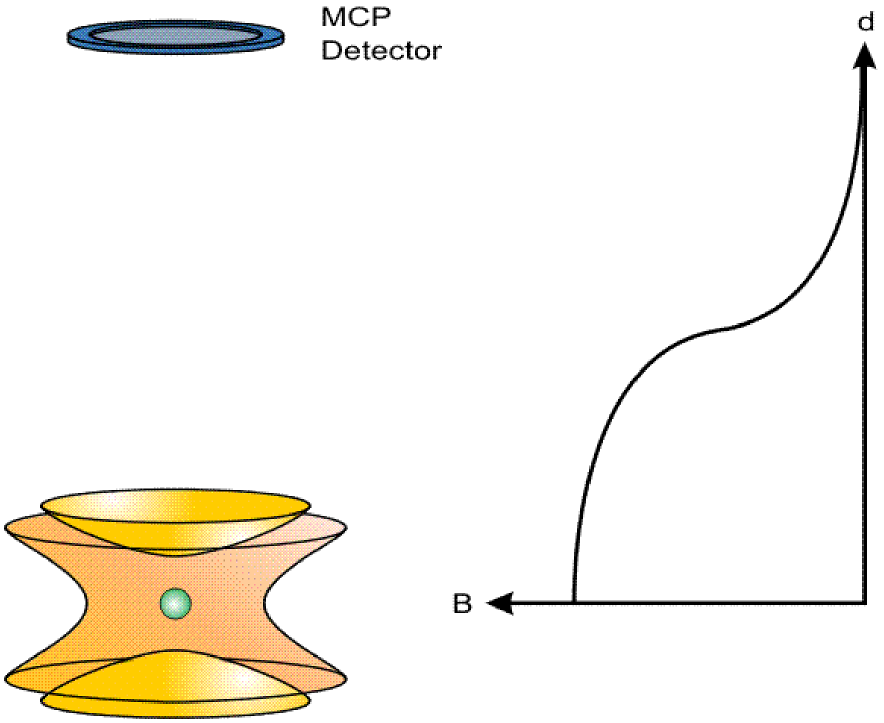
Типичные частоты
q = e, m = 100 u,
B = 6 T
$\Rightarrow$ f_- ≈ 1 kHz
f_+ ≈ 1 MHz

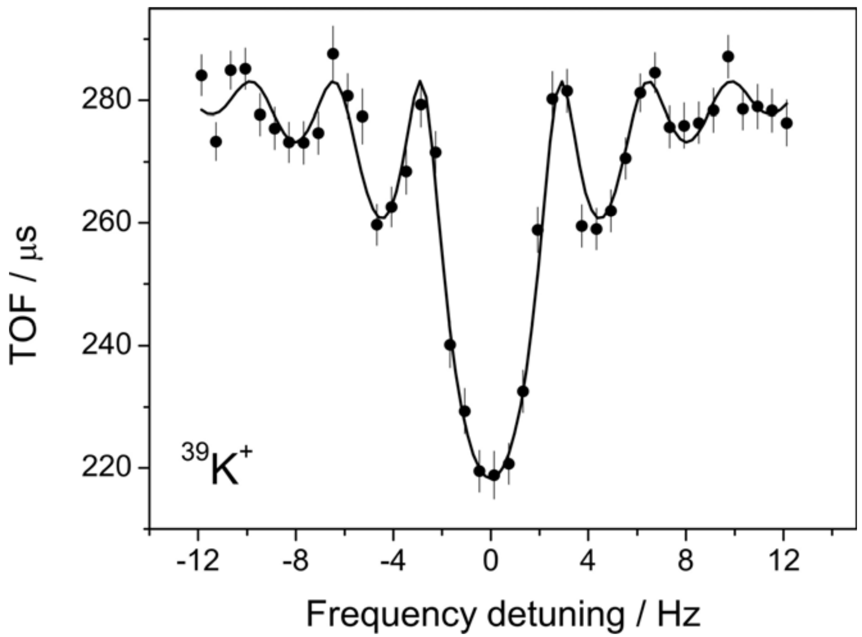
Frans Michel Penning

Hans G. Dehmelt



Время-пролётные измерения





- магнитный момент иона
- градиент магнитного поля

courtesy of K. Blaum

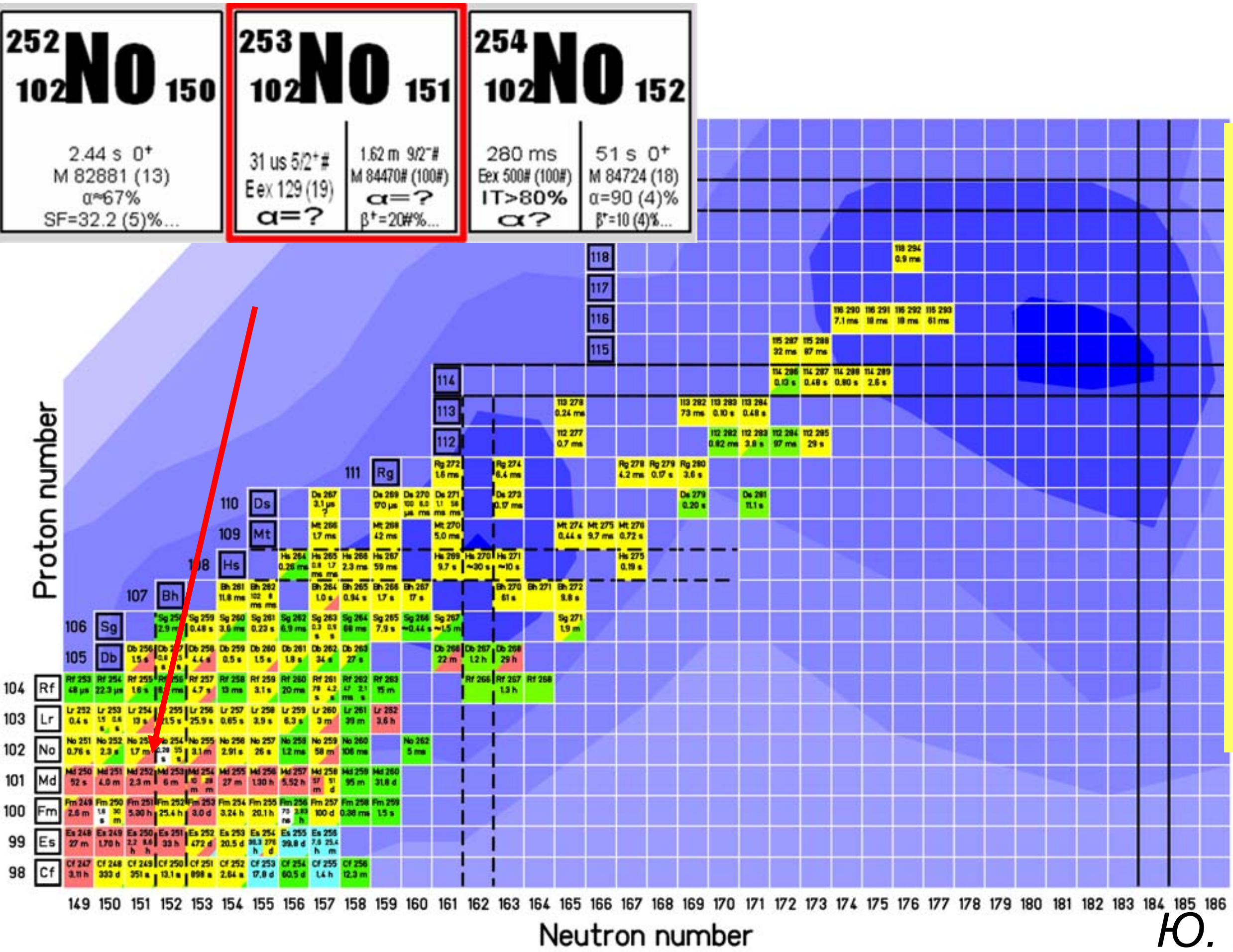
→ превращение радиальной энергии в аксиальную

Параметры SHIPTRAP

Рабочая интенсивность первичного пучка (^{48}Ca)	микроАмпер
Трансмиссия SHIP	10 -50 %
Трансмиссия SHIPTRAP	1 – 10 %
Минимально достижимое для измерений (на 2008 г.) сечение образования продуктов реакций	500 нбарн
Минимально достижимый для измерений (на 2008 г.) период полураспада продукта	100 мс
Типичная прецизионность ($\delta M/M$)	$(2\text{-}4)\cdot 10^{-8}$

Измерения масс нобелия на установке SHIPTRAP

Нобелий на нуклидной карте и способы получения его ядер в реакции «слияние-испарение»



- $^{208}Pb(^{48}Ca,2n)^{254}No$ cross section about 2 μb
- $^{207}Pb(^{48}Ca,2n)^{253}No$ cross section about 1 μb
- $^{206}Pb(^{48}Ca,2n)^{252}No$ cross section about 400 nb

Rate of incoming particles for ^{252}No about 0.6 ions/s

(courtesy of M. Block)

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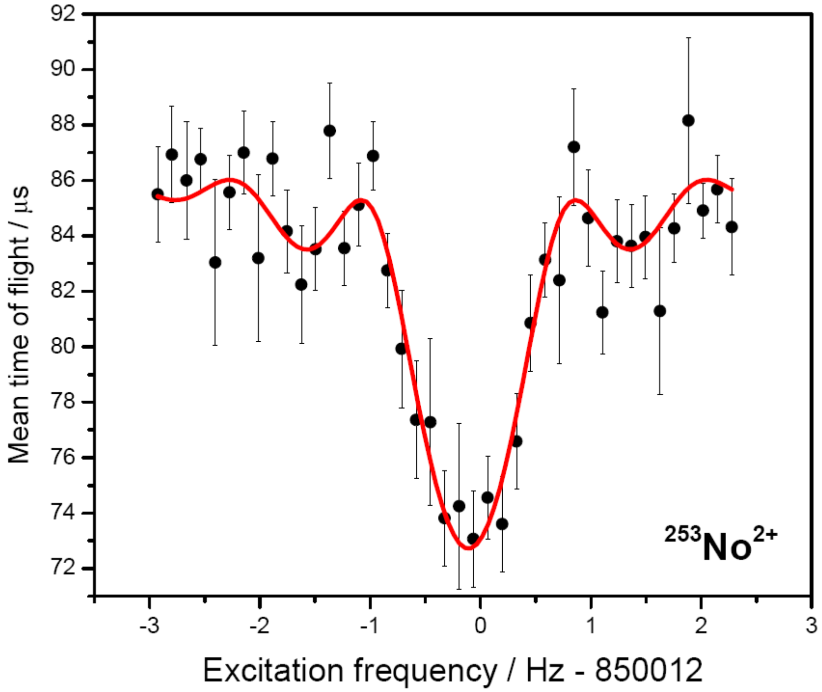
Резонансная кривая времени пролёта ионов нобелия из ловушки

Впервые полученное значение массы ^{253}No составляет

M =253090573 ± 10 μU   (σ_m=4*10^{-8})

(Preliminary data)



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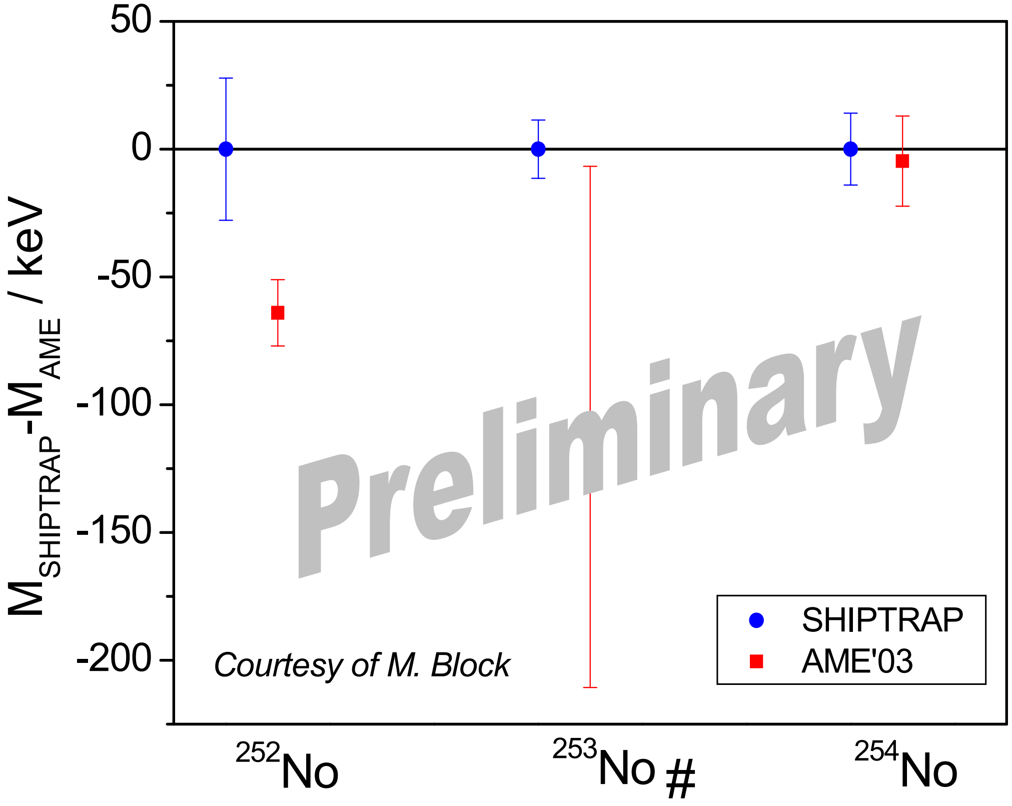
Измеренные значения масс $^{252-254}$No



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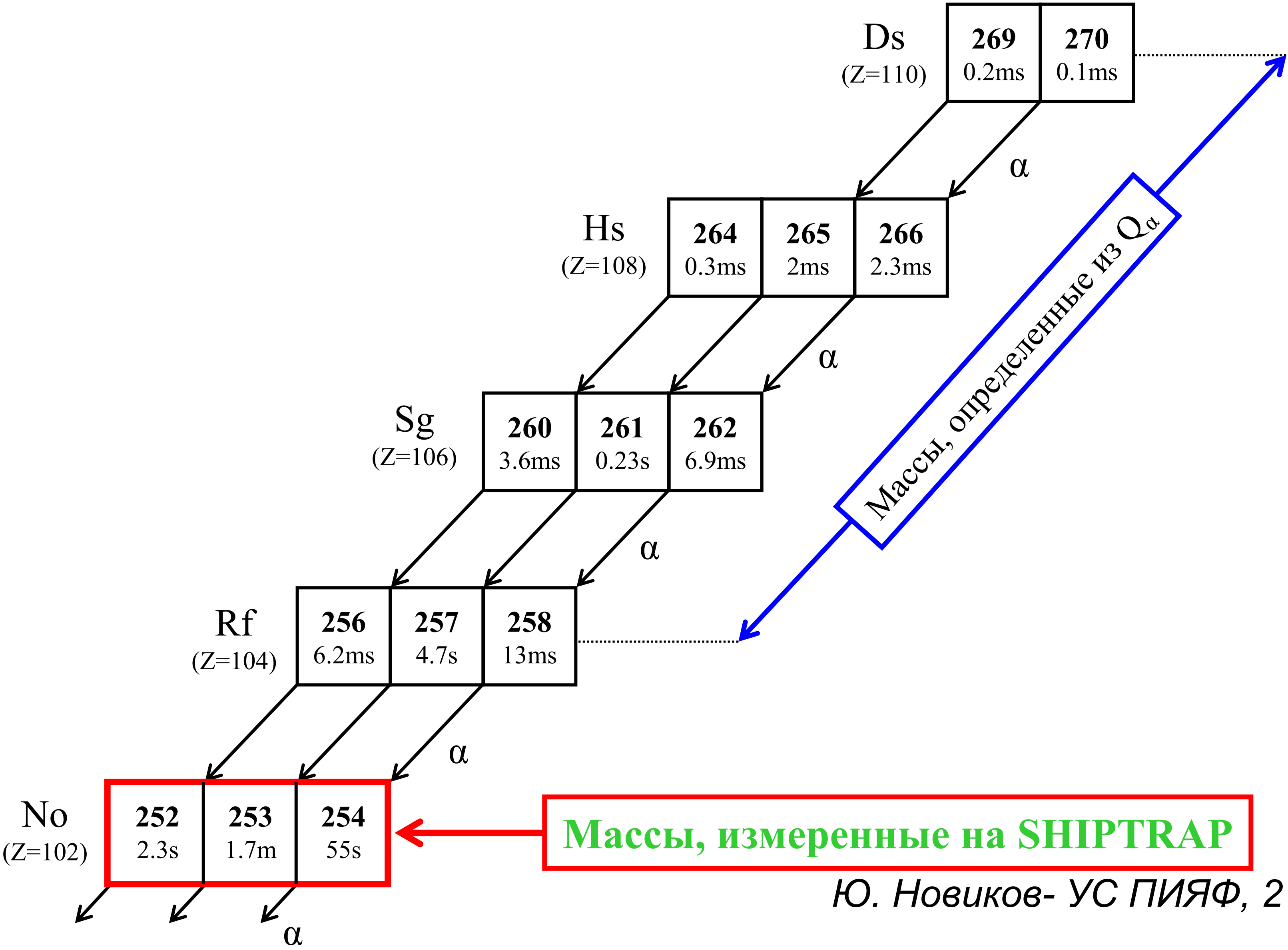
Фрагмент карты сверхтяжёлых нуклидов, массовая поверхность которых получена с использованием прямых измерений масс изотопов нобелия и данных α-спектрометрии



Ds (Z=110)		**269** 0.2ms	**270** 0.1ms
Hs (Z=108)	**264** 0.3ms	**265** 2ms	**266** 2.3ms
Sg (Z=106)	**260** 3.6ms	**261** 0.23s	**262** 6.9ms
Rf (Z=104)	**256** 6.2ms	**257** 4.7s	**258** 13ms
No (Z=102)	**252** 2.3s	**253** 1.7m	**254** 55s

Массы, определенные из Q_α

Массы, измеренные на SHIPTRAP

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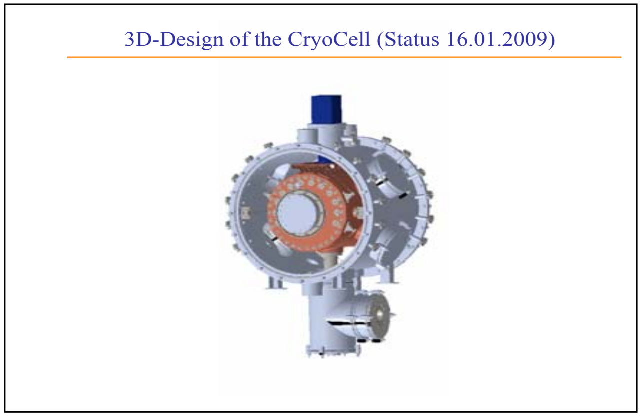
Перспективы

- ✓ Создание криогенного газового стоппера
- Использование недеструктивного детектирования

Преимущества криогенной газовой камеры

(*С. Елисеев*)



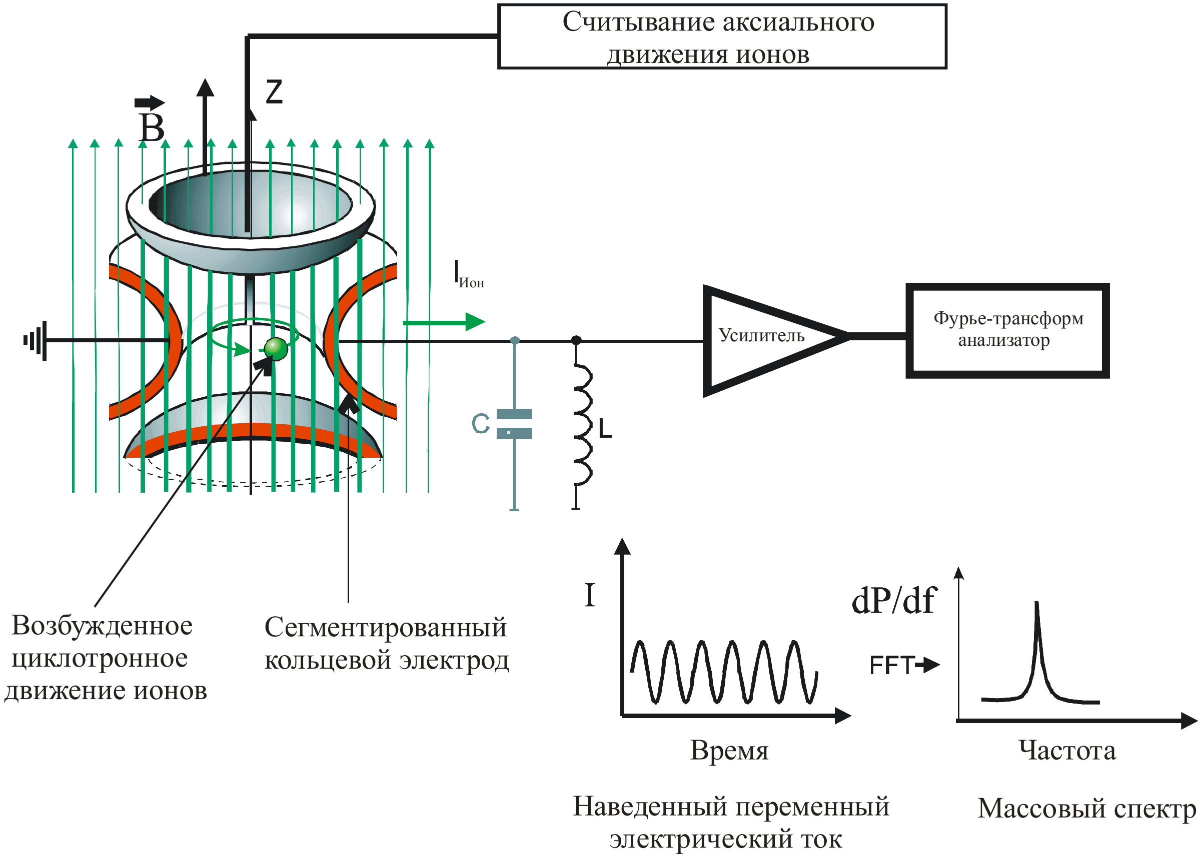
3D-Design of the CryoCell (Status 16.01.2009)

- вымораживание большинства примесей,
- возможность использования легких и тонких органических окон,
- меньшие плотности газа,
- увеличение эффективности экстракции за счёт уменьшения диффузии и использования больших вытягивающих потенциалов.

Ожидаемые параметры

Эффективность торможения	20 – 90 %
Эффективность экстракции	20 – 50 %
Полная эффективность	**4 – 45 %**

Фурье-преобразование циклотронного резонанса



Считывание аксиального движения ионов

Возбужденное циклотронное движение ионов

Сегментированный кольцевой электрод

Наведенный переменный электрический ток

Массовый спектр

Courtesy of K. Blaum

Основные участники коллаборации SHIPTRAP

GSI

HELMHOLTZ GEMEINSCHAFT

ПИЯФ

D. Ackermann, K. Blaum, M. Block, C. Droese, M. Dworschak, S. Eliseev, E. Haettner, F. Herfurth, F. P. Heßberger, S. Hofmann, J. Ketter, J. Ketelaer, H.-J. Kluge, G. Marx, M. Mazzocco, Yu. Novikov, W. R. Plaß, D. Rodríguez, C. Scheidenberger, L. Schweikhard, P. Thirolf, G. Vorobjev, C. Weber

Max-Planck-Institut für Kernphysik

LMU

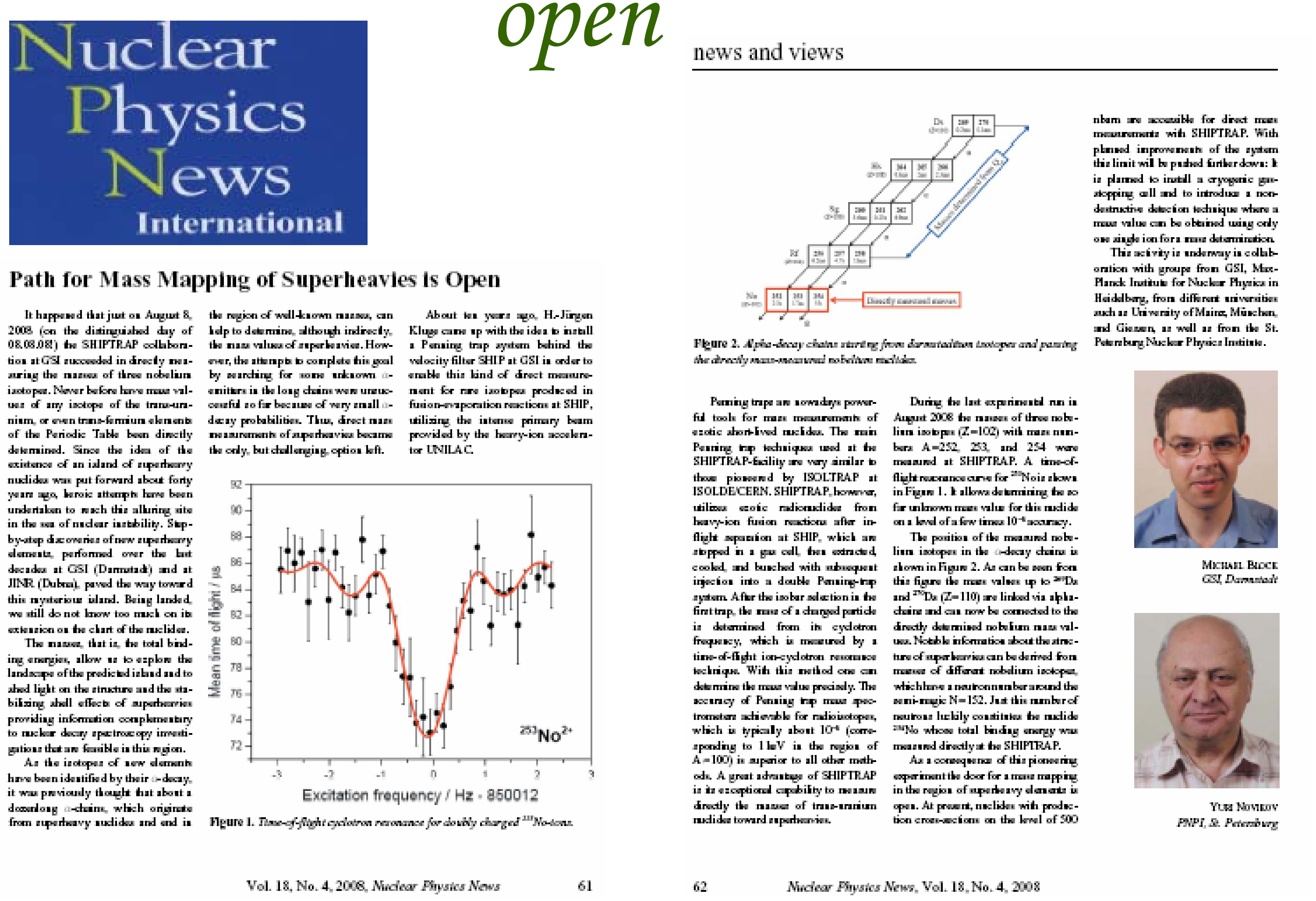
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Участники программы СТЭ от ПИЯФ (Группа физики экзотических ядер):
Л. Батист, Г. Воробьёв, Ю. Гусев, С. Елисеев, Ю. Новиков, А. Попов, Д. Селиверстов

Послесловие:

“Path for mass mapping of Superheavies is open”



Nuclear Physics News International

Path for Mass Mapping of Superheavies Is Open

It happened that just on August 8, 2008 (on the distinguished day of 08.08.08!) the SHIPTRAP collaboration at GSI succeeded in directly measuring the masses of three nobelium isotopes. Never before have mass values of any isotope of the trans-uranium, or even trans-fermium elements of the Periodic Table been directly determined. Since the idea of the existence of an island of superheavy nuclides was put forward about forty years ago, heroic attempts have been undertaken to reach this alluring site in the sea of nuclear instability. Step-by-step discoveries of new superheavy elements, performed over the last decades at GSI (Darmstadt) and at JINR (Dubna), paved the way toward this mysterious island. Being landed, we still do not know too much on its extension on the chart of the nuclides.

The masses, that is, the total binding energies, allow us to explore the landscape of the predicted island and to shed light on the structure and the stabilizing shell effects of superheavies providing information complementary to nuclear decay spectroscopy investigations that are feasible in this region.

As the isotopes of new elements have been identified by their α-decay, it was previously thought that about a dozen long α-chains, which originate from superheavy nuclides and end in the region of well-known masses, can help to determine, although indirectly, the mass values of superheavies. However, the attempts to complete this goal by searching for some unknown α-emitters in the long chains were unsuccessful so far because of very small α-decay probabilities. Thus, direct mass measurements of superheavies became the only, but challenging, option left.

About ten years ago, H.-Jürgen Kluge came up with the idea to install a Penning trap system behind the velocity filter SHIP at GSI in order to enable this kind of direct measurement for rare isotopes produced in fusion-evaporation reactions at SHIP, utilizing the intense primary beam provided by the heavy-ion accelerator UNILAC.

Figure 1. *Time-of-flight cyclotron resonance for doubly charged ^{253}No-ions.*

Figure 2. *Alpha-decay chains starting from darmstadtium isotopes and passing the directly mass-measured nobelium nuclides.*

Penning traps are nowadays powerful tools for mass measurements of exotic short-lived nuclides. The main Penning trap techniques used at the SHIPTRAP-facility are very similar to those pioneered by ISOLTRAP at ISOLDE/CERN. SHIPTRAP, however, utilizes exotic radionuclides from heavy-ion fusion reactions after in-flight separation at SHIP, which are stopped in a gas cell, then extracted, cooled, and bunched with subsequent injection into a double Penning-trap system. After the isobar selection in the first trap, the mass of a charged particle is determined from its cyclotron frequency, which is measured by a time-of-flight ion-cyclotron resonance technique. With this method one can determine the mass value precisely. The accuracy of Penning trap mass spectrometers achievable for radioisotopes, which is typically about 10^{-8} (corresponding to 1 keV in the region of A = 100) is superior to all other methods. A great advantage of SHIPTRAP is its exceptional capability to measure directly the masses of trans-uranium nuclides toward superheavies.

During the last experimental run in August 2008 the masses of three nobelium isotopes (Z = 102) with mass numbers A = 252, 253, and 254 were measured at SHIPTRAP. A time-of-flight resonance curve for ^{253}No is shown in Figure 1. It allows determining the so far unknown mass value for this nuclide on a level of a few times 10^{-8} accuracy.

The position of the measured nobelium isotopes in the α-decay chains is shown in Figure 2. As can be seen from this figure the mass values up to ^{269}Ds and ^{270}Ds (Z = 110) are linked via alpha-chains and can now be connected to the directly determined nobelium mass values. Notable information about the structure of superheavies can be derived from masses of different nobelium isotopes, which have a neutron number around the semi-magic N = 152. Just this number of neutrons luckily constitutes the nuclide ^{254}No whose total binding energy was measured directly at the SHIPTRAP.

As a consequence of this pioneering experiment the door for a mass mapping in the region of superheavy elements is open. At present, nuclides with production cross-sections on the level of 500 nbarn are accessible for direct mass measurements with SHIPTRAP. With planned improvements of the system this limit will be pushed further down: It is planned to install a cryogenic gas-stopping cell and to introduce a non-destructive detection technique where a mass value can be obtained using only one single ion for a mass determination.

This activity is underway in collaboration with groups from GSI, Max-Planck Institute for Nuclear Physics in Heidelberg, from different universities such as University of Mainz, München, and Giessen, as well as from the St. Petersburg Nuclear Physics Institute.

Michael Block
GSI, Darmstadt

Yuri Novikov
PNPI, St. Petersburg

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