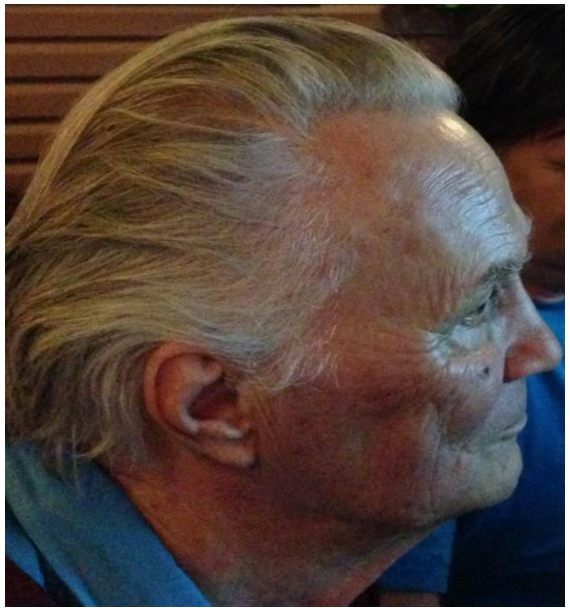
Memorial talk for

Professor Dr. Evgeny Denisovich Donets

O. Kester

19th International Conference on Ion Sources – ICIS’21

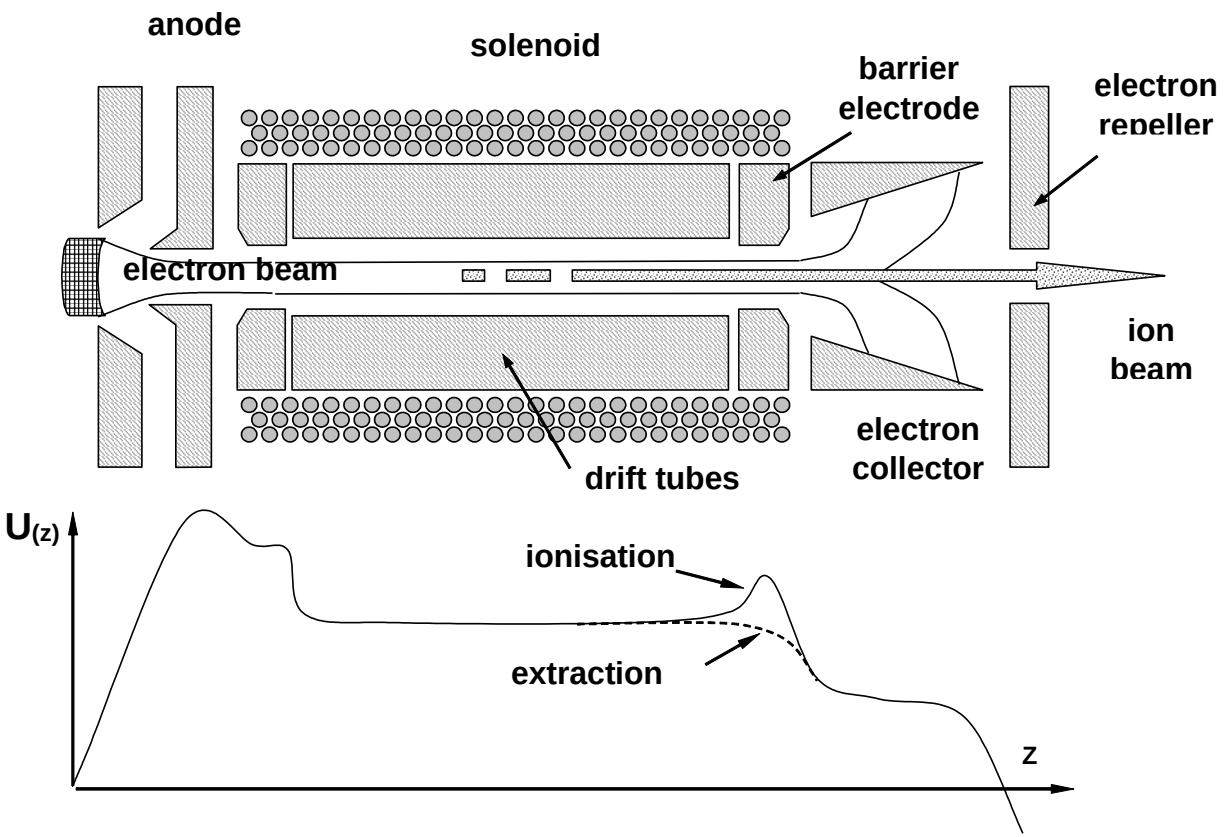


In memoriam

- With great sadness we learned that our friend and colleague Evgeny D. Donets, the father of the Electron Beam Ion source (EBIS) and the Electron String Ion Sources (ESIS), passed away on June 17, 2021.
- The first EBIS has been proposed in 1967 by Evgeny in Dubna, Russia. A demonstrator was operational in 1968.

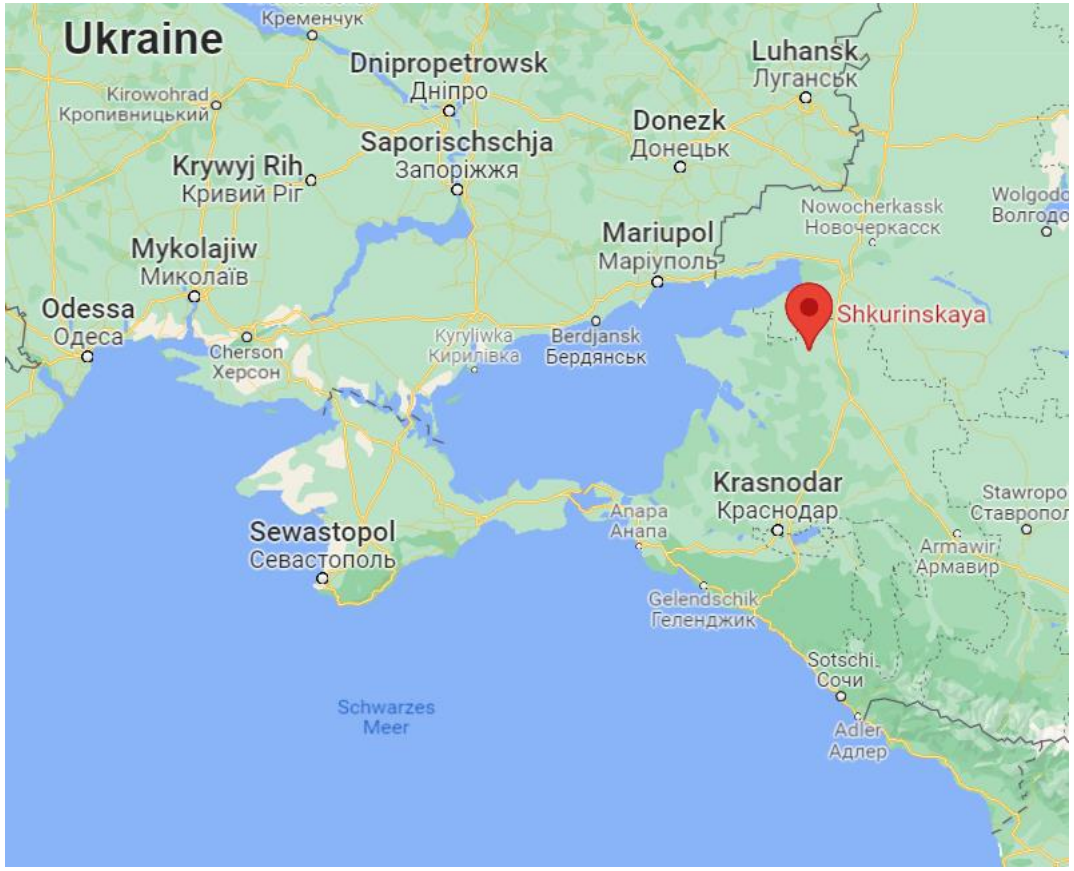
What was the new principle:

- The electrons are produced by an electron gun and not as in case of plasma ion sources from a plasma discharge.
- Confinement of the ions in axial direction
  → potential established by ring electrodes in radial direction
  → space charge potential of the e-beam
- The extraction of ions can be done by switching the collector barrier or the electrodes surrounding the ionization region.



Who was this scientist and what is the story of his life?

- Evgeny Denisovich Donets was born on October 15, 1935 in the village of Shkurinskaya in the Krasnodar Territory, Russia as the youngest of five children in the family.
- His father, Denis Yemelyanovich, was a teacher of Russian language and literature at high school, his mother, Lydia Andreevna, was a housewife.
- In WWII his father was fighting in the army and the mother with five children managed to survive the famine and occupation. They lost their home, but the father survived the war and became director of a high school.
- Evgeny graduated from high school 1953 and entered the Leningrad Polytechnic Institute, where all his siblings studied.
- Evgeny graduated with honors from the Faculty of Physics and Mechanics in 1959 and was hired at the Institute of Atomic Energy (Moscow) in the group of Georgy Flerov, where he did his doctoral thesis.



The early years 1959-1966

- In the same year, 1959, Evgeny moved to Dubna and began working at the Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research (JINR).
- He performed experimental studies of the production of transuranium elements with Z ≥ 100 in nuclear reactions with multicharged ions, which led to the discovery of elements 102 and 103.
- For the next twenty years, there were disputes about the first discovery of element 102 between the group from Dubna, the Swedish group (Nobel institute) and the group of G. Seaborg (Berkeley, USA).
However, in 1992, the IUPAC-IUPAP Transfermium Working Group (TWG) reassessed the claims of discovery and concluded that only the Dubna work from 1966 correctly detected and assigned decays to nuclei with atomic number 102 at the time.

Front row left to right: **Sergey Polikanov, Glenn Seaborg, Georgy Flerov**, **Evgeny Donets, Albert Ghiorso** in the hall of the U-300 cyclotron, Laboratory of Nuclear Reactions, JINR, Dubna; May 1963.

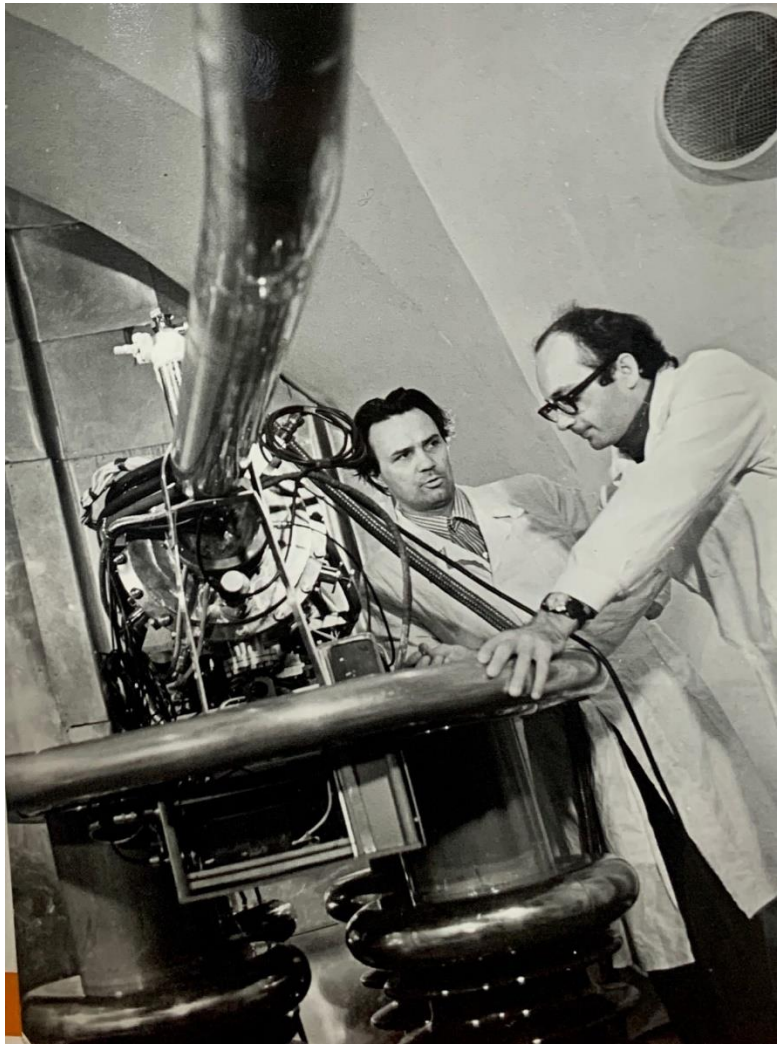
The early years 1959-1966

- The Dubna team (E.D. Donets, V.A. Schegolev, V.A. Ermakov) are therefore officially recognized as the discoverers of Nobelium.
- However, in 1964, Evgeny got married; his wife Vera was with him all the following years until the very end.
- In 1966, Evgeny, defended his PhD thesis "Synthesis and study of the regularities of the formation of isotopes of transuranic elements with Z ≥ 100 in nuclear reactions with multicharged ions".

Left to right: **Evegny D. Donets, Victor A. Ermakov, Vyacheslav A. Schegolev** after discovery of the isotope of element 102 (Nobelium) with the Mass=256 and half-life ~8 s in nuclear reaction 22Ne + 238U; Dubna, JINR. April 1966.

Towards the EBIS

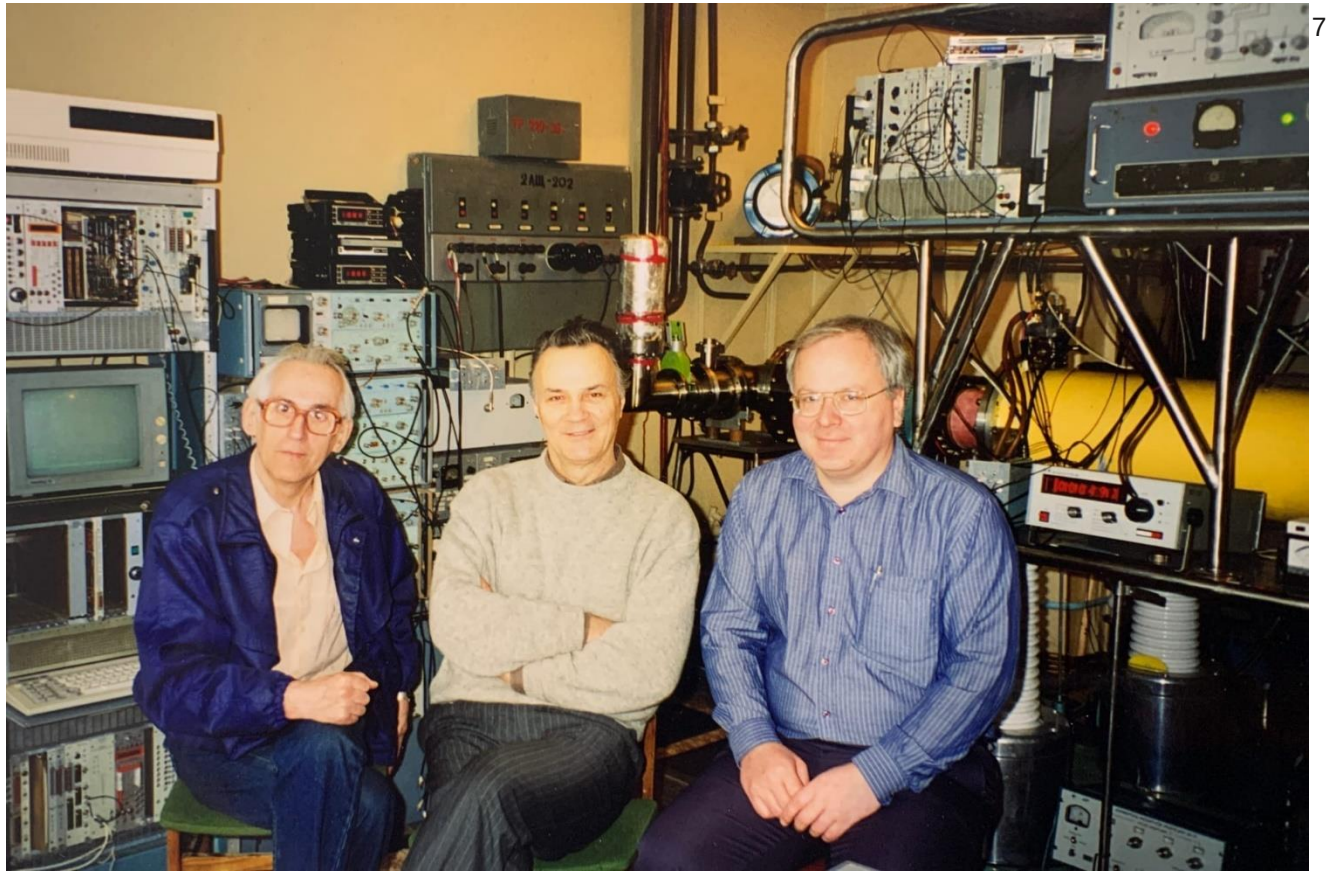
- After 1966, Evgeny became interested in creating sources of highly charged ions, which was initially motivated by the need to accelerate heavier ions for the synthesis of new transuranic elements.
- In 1967, Evgeny D. Donets has proposed an electron-beam ionization method and created a prototype in 1968 based on the proposed principles. However, after moving to the JINR High-Energy Laboratory in 1971, he created the first real EBIS, KRION-1, which was ready for tests in 1972.
- KRION-1 was the world's first complex device that used superconductivity as an applied technology.
- Until that time only Penning-type sources could produce multi-charged ions. But compared to the Penning-type source and EBIS reaches much higher charge state, even bare heavy ions.



E. Donets and A. Pikin at KRION-1

KRION-2

- KRION-2 was completed in 1974 for the production and investigation of the physics of highly charged ions, after obtaining record charge states for that time with KRION-1.
- With KRION-1 and later KRION-2 he created the first EBIS devices using cryogenics systems for the JINR LHE accelerator complex (Synchrophasotron).
- Visitors used KRION-2 for test measurements like Leif Liljeby in 1984.



Vadim G. Dudnikov, Evgeny D. Donets (JINR) and Leif Liljeby (MSL, Stockholm) at Krion-2 EBIS, Dubna, 1984.

Electron impact ionisation cross-section measurements

- In 1983 the Dubna team around Evgeny Donets used the electron beam ionization method an EBIS provides to measure ionization cross sections.
- A well-defined quantity of low charged ions has been injected and then the charge state evolution has been recorded.
- The well-known linear rate equations have been used to extract ionization cross section (note that the current density just scaling the time to reach the charge state)

$$\frac{dn_{q+1}}{dt} = n_e \cdot n_q \cdot v_e \sigma_{q \to q+1} - n_e \cdot n_{q+1} \cdot v_e \sigma^{RR}_{q+1 \to q}$$

- You need to determine the current density well.

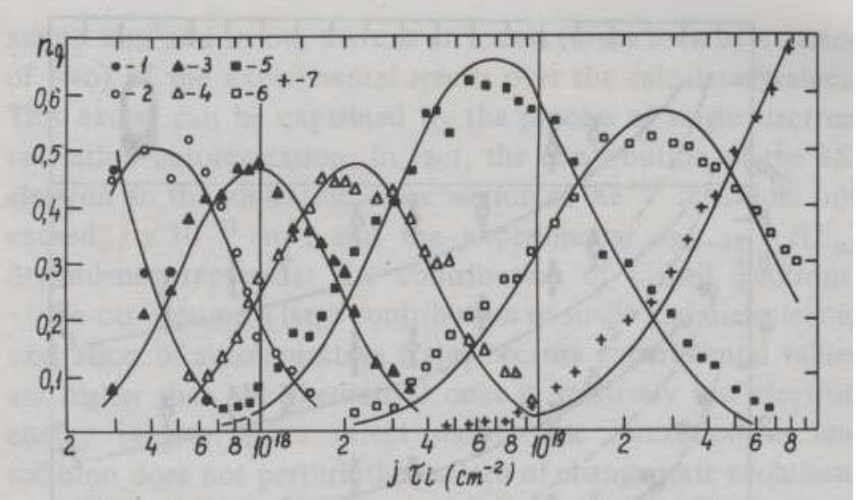


Fig. 5. Charge state distribution evolution of nitrogen ions.

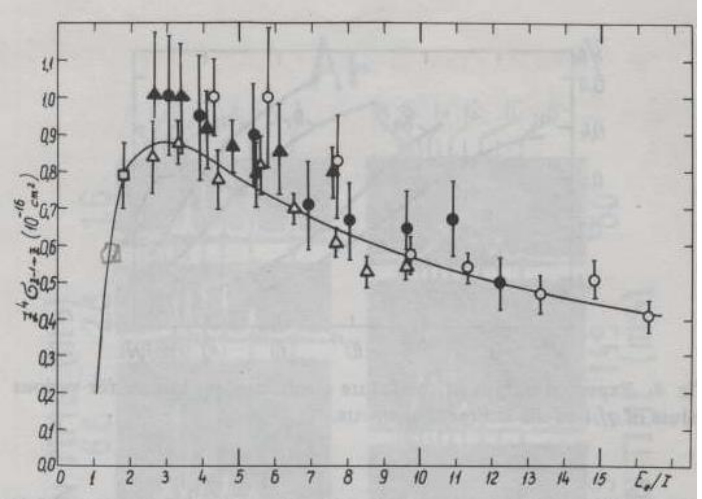


Fig. 7. Dependence of the reduced ionization cross-sections of hydrogen-like ions on electron energy (C^{5+}, N^{6+}, O^{7+}, Ne^{9+}, Ar^{17+}, solid line – calculation [14] for $Z = 128$).

Super-exited states of atoms

- Identifications of bare or hydrogen like ions (Ar^{17+}, $Kr^{35,36+}$,Xe^{53+}) produced with KRION-2 were made by means of detection of K-line x-rays, emitted by the ion recombination at a metallic surface.
- Shift of K-lines of Kr^{35+} (and other species) with respect to neutral Kr is due to absence of electrons in the L-shell which produce partial screening of nuclear charge in neutral Kr.
- Relative intensities of the obtained K-series (alpha, beta and higher) surface show, that electrons fill first very high levels (near Auger-con and then successive step-by-step and relatively slow (in atomic scal cascade down to low level states.
- Theses were called “super-excited” states of “hollow” atoms
  → quasi-stable Rydberg states
- Interesting idea from Evgeny:
  If we have two or more super-excited atoms closed enough to each other, the electrons on their higher levels could be common for few or an assembly of super-excited ions
  Hence, cluster of super-exited ions could exists in metastable state with many common electrons on high excited levels only
  → it could be possible scenario for ball lightning formation in atmosphere...

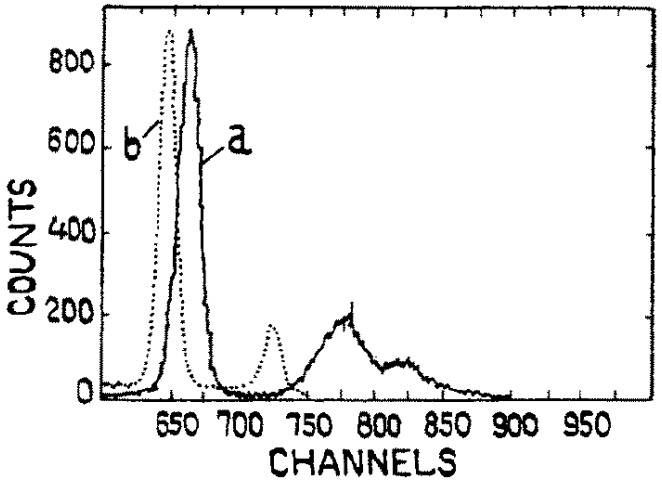
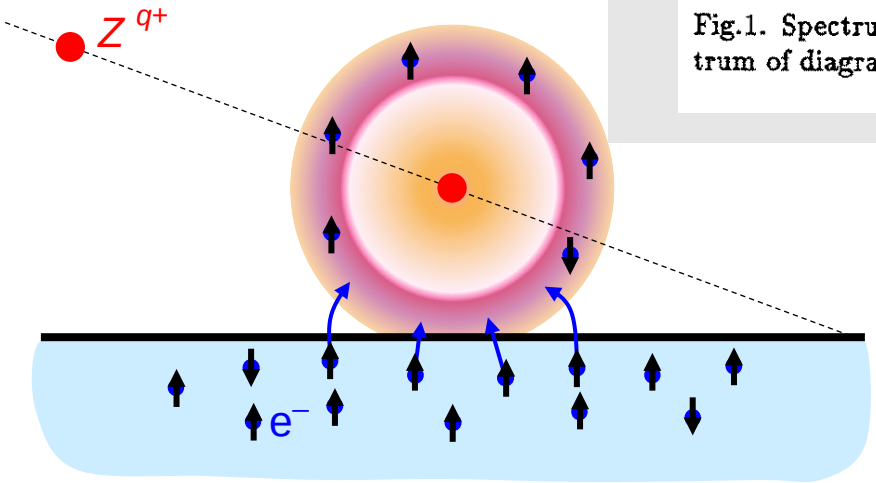


Fig.1. Spectrum of KX-rays of Kr^{35+}-at-surface (a) and spectrum of diagram KX-rays of neutral krypton (b).

Supplement to Z. Phys. D - Atoms, Molecules and Clusters 21, S 337-339 (1991)

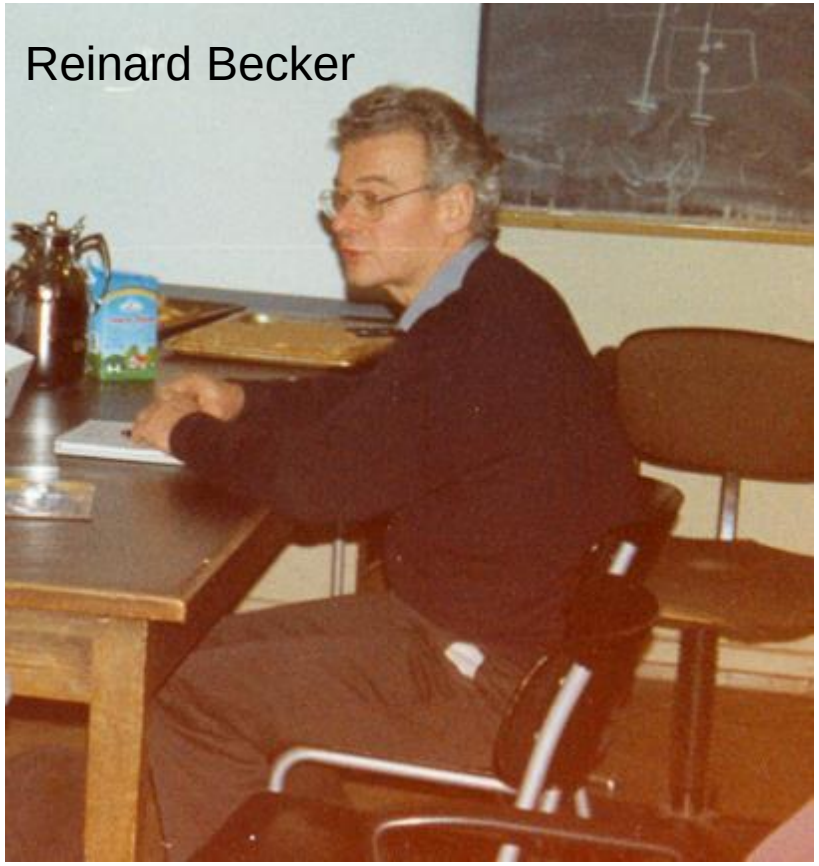


Ion-ion cooling – collaboration with Goethe Universität Frankfurt

- In 1981 Reinard Becker attracted the attention of the EBIS community to the phenomenon of the heating of highly charged ions due to elastic collisions with the beam electrons.
- Calculations showed the production of ions with q > 50 can hardly be reached because of rapid ion losses in a radial direction caused by the heating!

R. Becker, in EBIS Workshop, Saclay-Orsay, May 12–15, 1981, p. 185.

- At the first moment this ionization limit of EBIS looked insufferable, but soon the technique of ion-ion cooling was proposed by Donets and Shirkov.



Ion-ion cooling II

- The proposed cooling technique includes a constant or periodic injection of ‘‘cold’’ low charged ions into the trap that cool highly charges ions via ion-ion collisions.
- This led to the paper “The ion cooling in EBIS”, G. Shirkov, E. Donets, R. Becker, and M. Kleinod, RSI 63 (1992) 2819
- and explained why much higher charge states could be produces up to bare uranium in the LLNL Super-EBIT in 1994.

D. E. Donets, E. D. Donets, E. E. Donets, V. V. Salnikov, V. B. Shutov et al., Rev. Sci. Instrum. 80 (2009) 063304

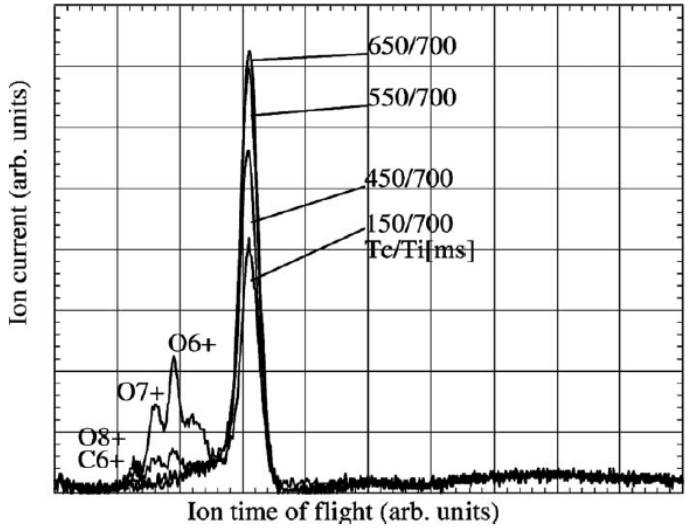
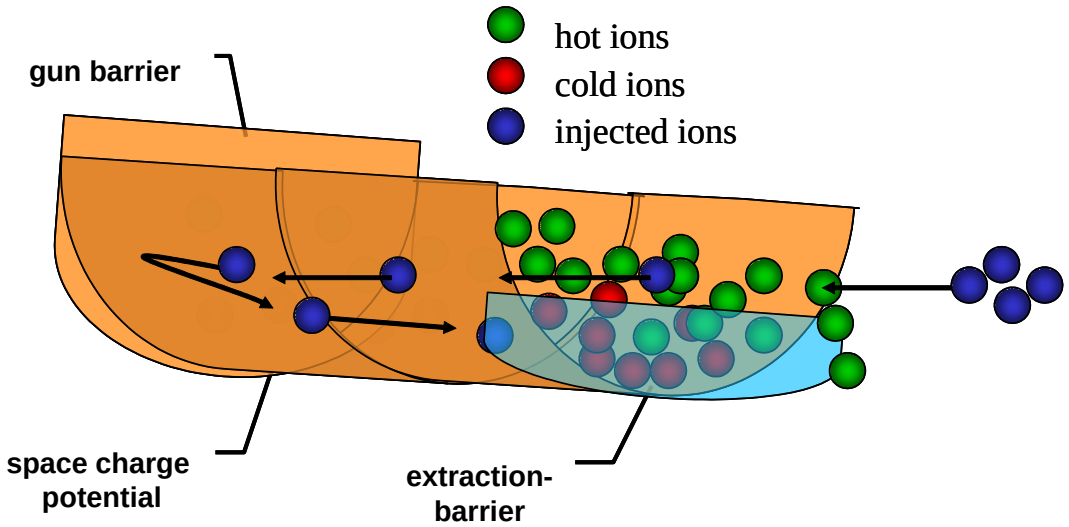
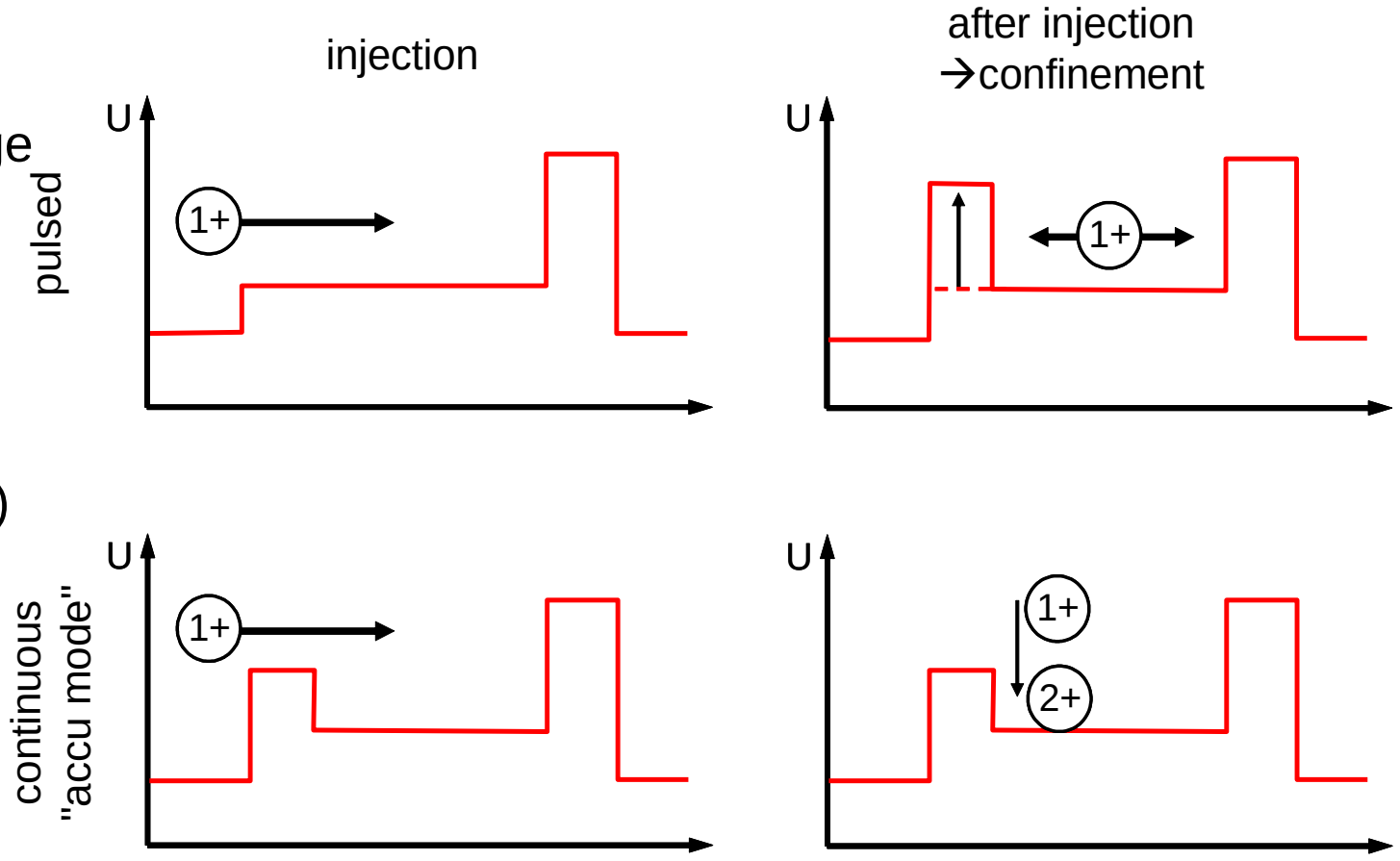


FIG. 5. Au ion yield and TOF spectra (mean $q_{Au}=50.2$) for various injection time of the cooling (CO) gas. $E_{inj}=4.4$ keV. Total ionization time is $T_i=700$ ms. The injection time for cooling gas, as shown on corresponding curves, $T_c=150$ ms, $T_c=450$ ms, $T_c=550$ ms, and $T_c=650$ ms.

Ion-ion cooling III

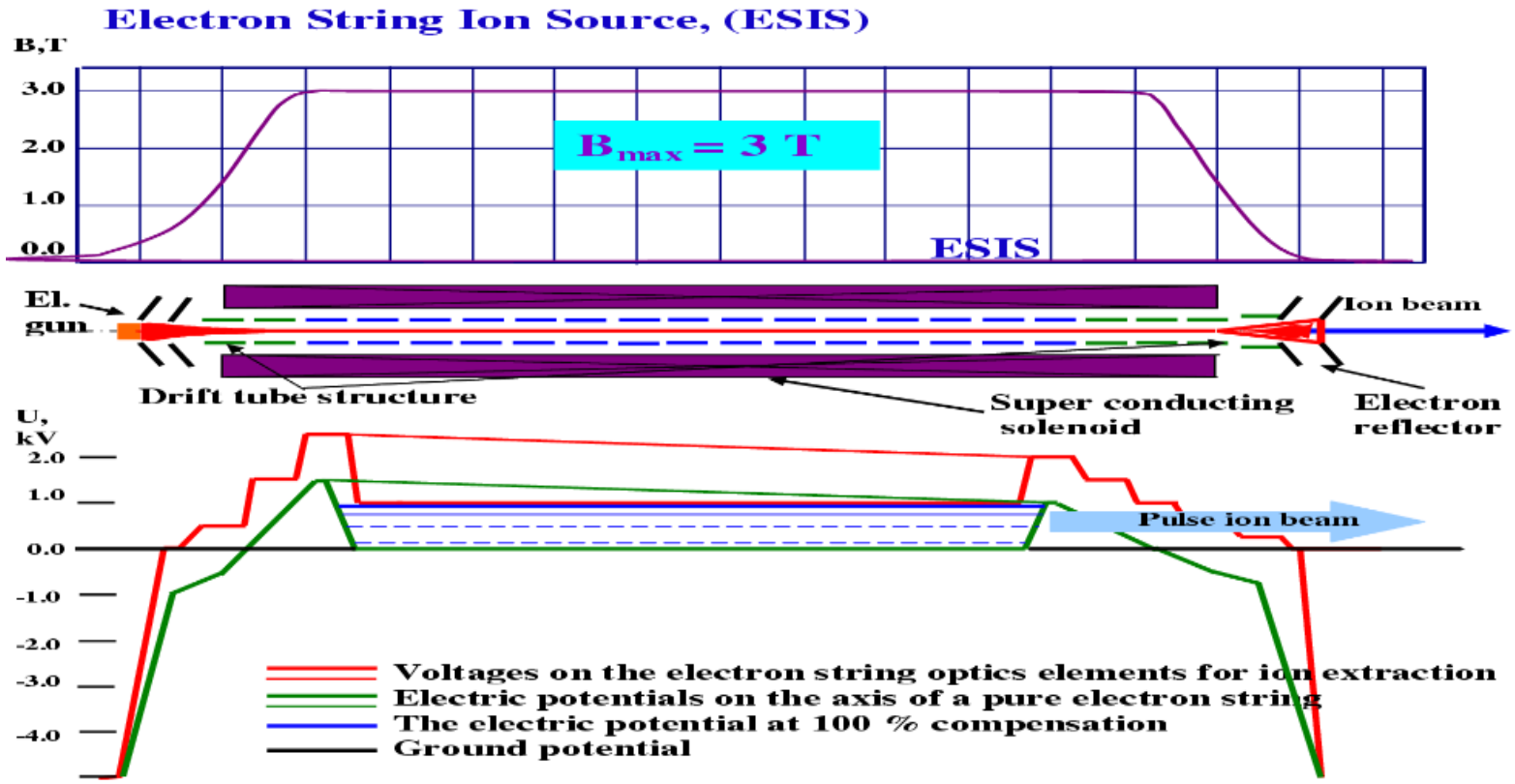
- And informed the proposal of the over-barrier injection into and EBIS as charge breeding mode (Accu-EBIS)
  R. Becker et al., proc. of EPAC92, Edition Frontieres, 1992, 981
- Ion in the confinement region act as “Coulombtarget” and slow down the injected ions (Becker and Kester, 2004)





Father of the Electron String Ion Source - ESIS

- In 1989 Evgeny got the title Professor Evgeny D. Donets in the field of experimental physics.
- Soon after in 1990 he discovered the linear electron string phenomenon - high-temperature single-component electron plasma in a reflex mode EBIS operation!
  Until the very end he did experimental research of the electron string physics.
- Electron string is formed in nonlinear process via strong instability of trapped electrons and exists as a dynamic equilibrium of injected and lost electrons.
  Electrons are collected at the anode → no collector



ESIS II

- The transition into the stable string operation can be determined via current in the extraction pulses.
- The electron energy distribution is modified due to collisions of the electrons, so electrons can reach higher energies than provided by the gun potential.
- The high energy tail of the e-string electrons → higher charge states Au54+ with KRION-2!
- Key parameter: Cathode Heating, e-beam current density, B-field

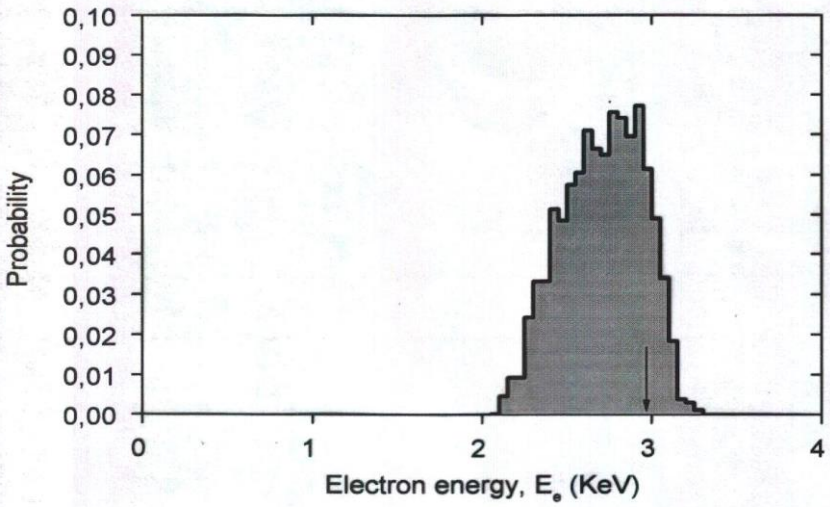
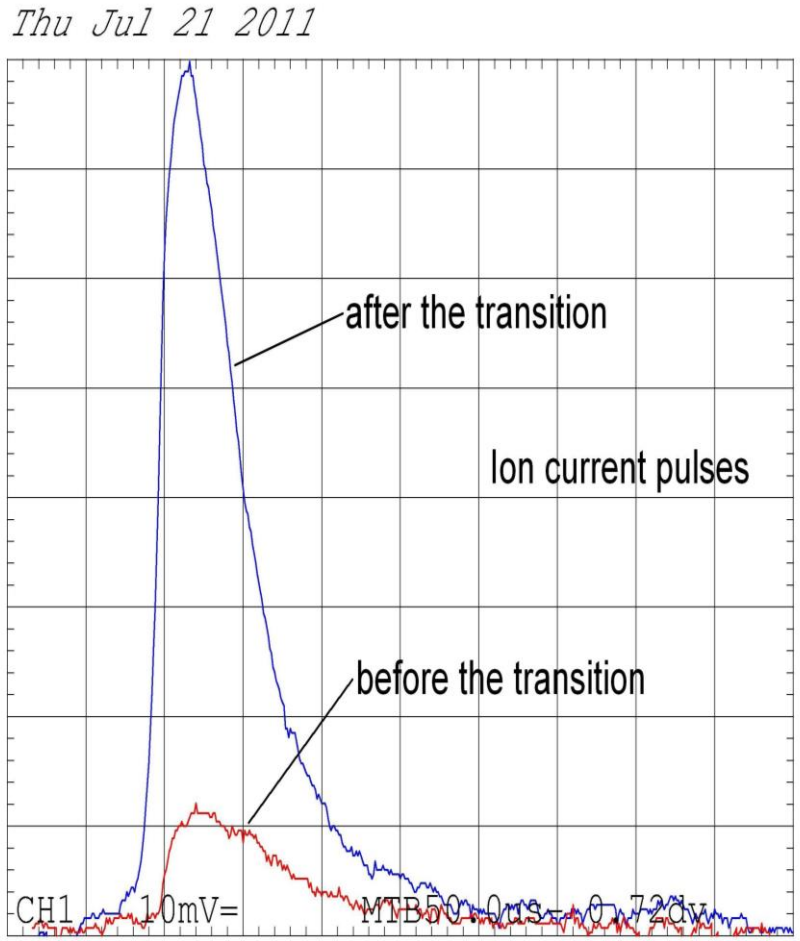
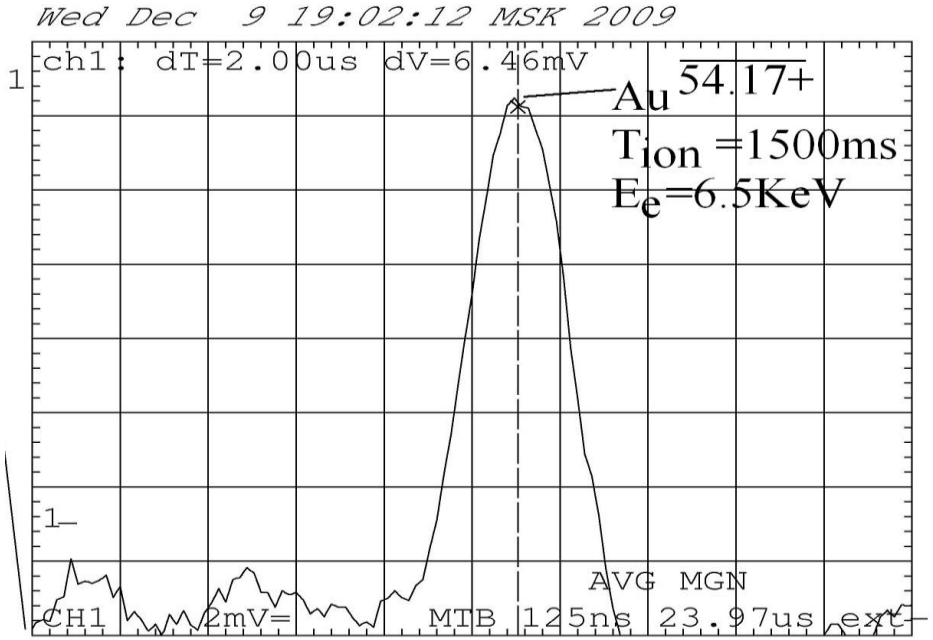


Fig. 8. Electron energy distribution in the string with a feeding electron energy equal to 2.99 KeV.



ESIS III

- KRION-2 had been modified to operate as ESIS (KRION-2M) and was used as injector into the NUCLOTRON at JINR in Dubna.



Evgeny and ESIS

- For the NUCLOTRON the Krion-6T has been developed to increase the injection intensity of highly charged ions, as the stronger magnetic field is beneficial for the string formation.
- Due to the ESIS topic → Visiting Professorships:
  1995 - Institute of Applied Physics, Frankfurt University, Germany
  2001 - Research Center for Nuclear Physics, Osaka University, Japan.
- In 2005 at the ICIS in Caen, E.D. Donets with colleagues got the ICIS conference international "Brightness Award", for the "Electron String source of Highly Charged Ions".

Krion-6T

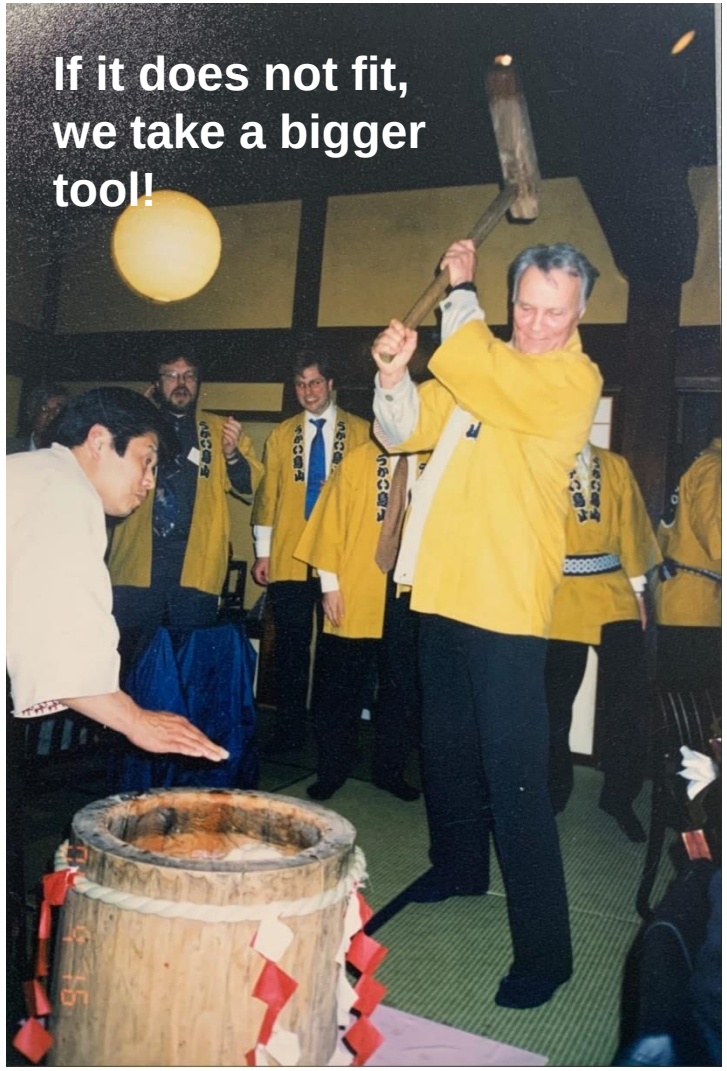
- For ultimate intensities a new concept of a “tubular electron beam/string ion sources (TEBIS/TESIS) has been proposed
  → see Alexey Boytsov’s talk after this presentation

Visiting professor in 2001 - Research Center for Nuclear Physics, Osaka University, Japan

Development of an ion trap for nuclear astrophysics research
→ measurements of excitation functions of d (d,p) t and
3He (d,p) 4He reactions with bare ion beams and target at energies below the Coulomb barrier.

EBIS/T symposium 2004, Tokyo Metropolitan University

Many good discussions and fun at the symposium dinner



My last meeting with a great scientist and teacher

Dubna 2014 – discussion about the planned NICA injector and FAIR

Evgeny D. Donets,

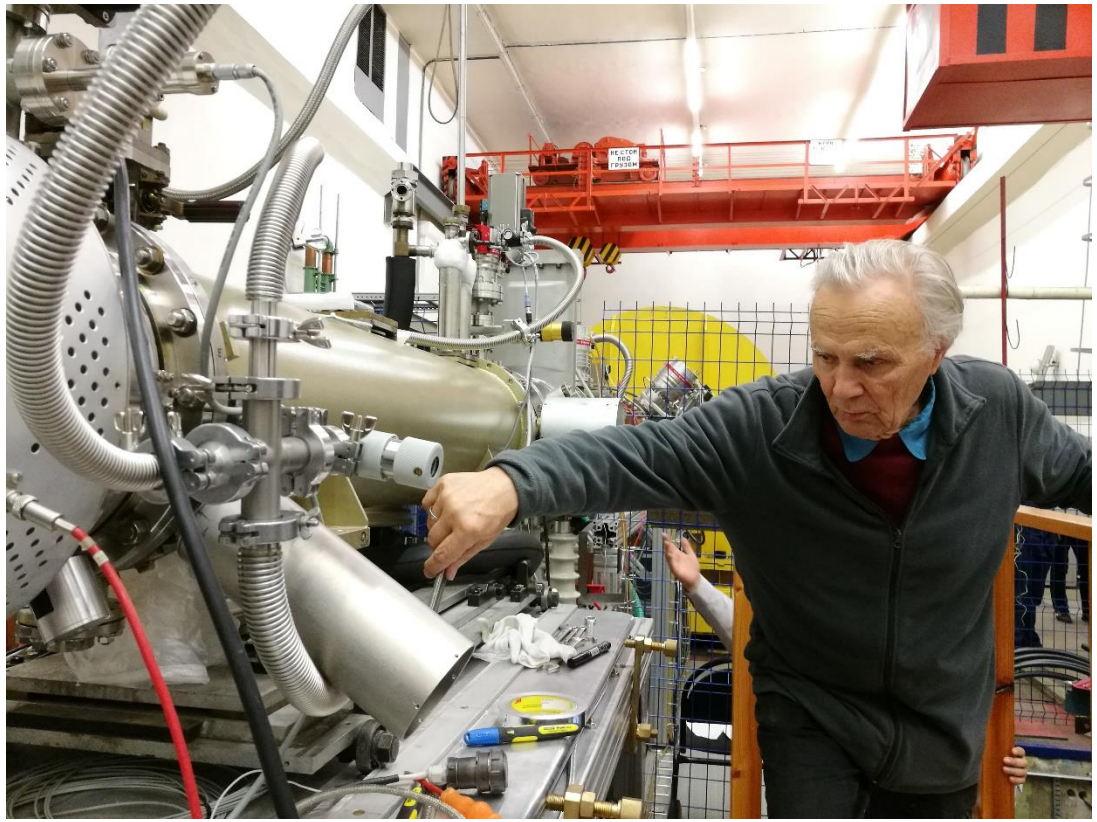
Evgeny E. Donets (Donets junior)

and

Grigory Trubnikov (now director JINR)

Known in the community

- E.D.Donets has about 220 scientific publications, including 1 monography, 10 inventions and two discoveries.
- He was a member of the International Advisory Committee of the ICIS conference and the international symposium on EBIS/T/ for many years
- As you can see, he was still active, cheerful and full of new plans and ideas up to the very end.
- **Evgeny D. Donets is dearly missed and his absence at the ICIS and EBIS/T conferences will not go without notice.**



Evgeny at Krion-6T

† E.D.Donets was buried on June 19, 2021 at the old Dubna cemetery together with his parents.