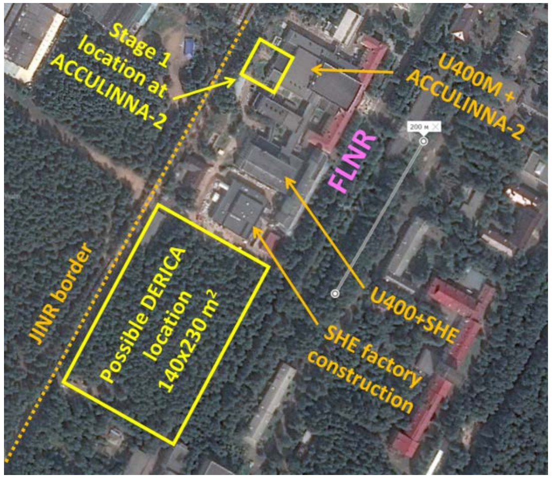
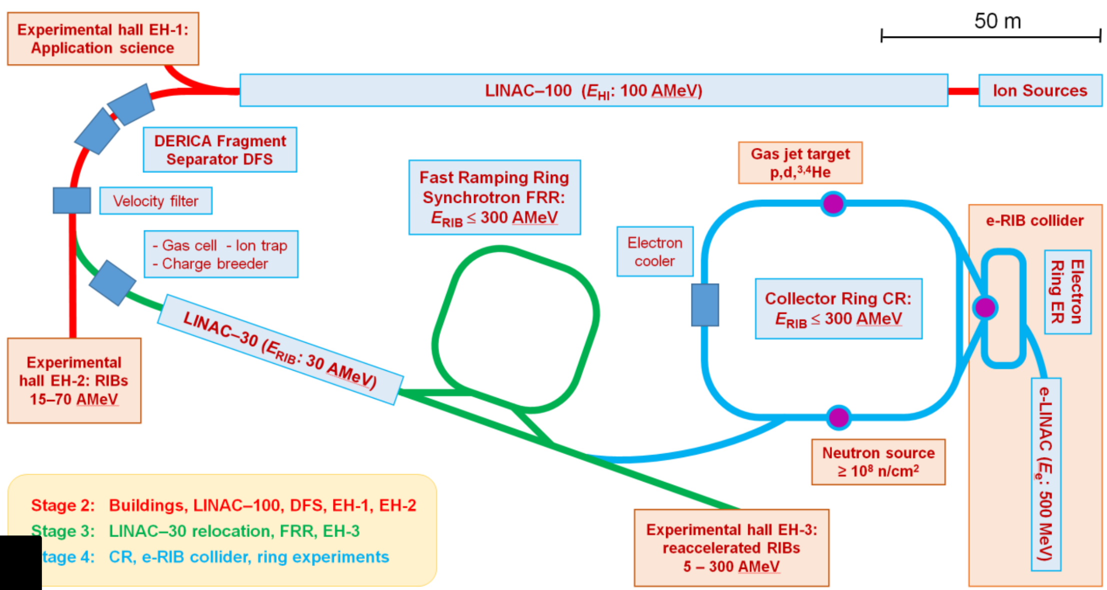
Leonid Grigorenko

Flerov Laboratory of Nuclear Reactions, JINR, Dubna

“DERICA – prospective accelerator and storage ring facility for radioactive ion beam research





http://aculina.jinr.ru/derica.php

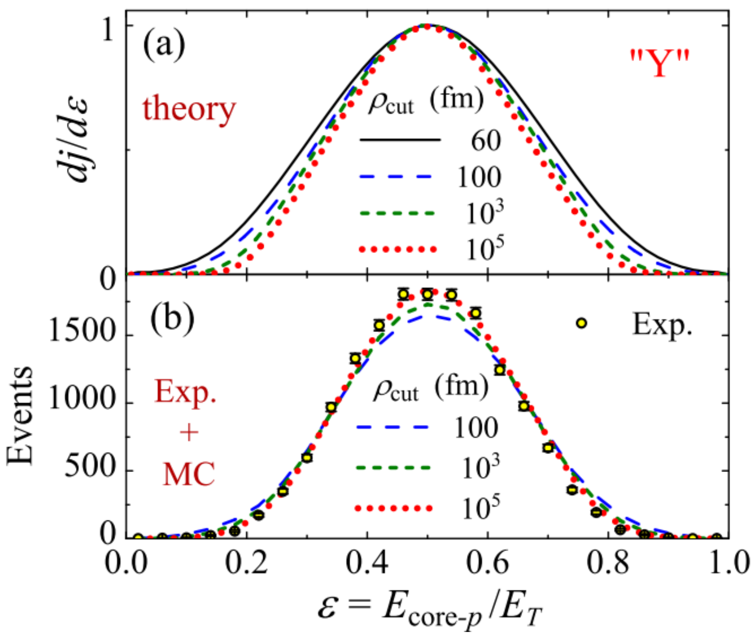
ECT* workshop on “Probing exotic structure of short-lived nuclei by electron scattering”, July 16-20, 2018

Few-body dynamics in continuum of clusterized exotic (dripline) nuclei

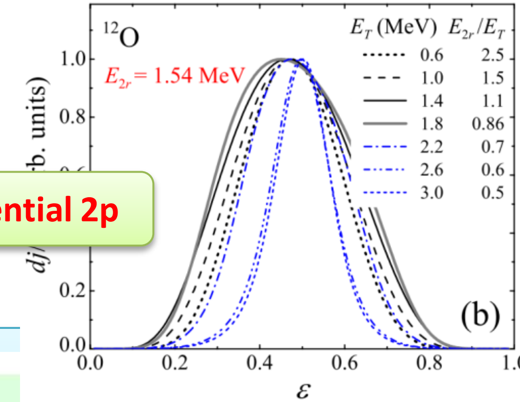
Transitional (phase-transition-like) dynamics in three-body decays

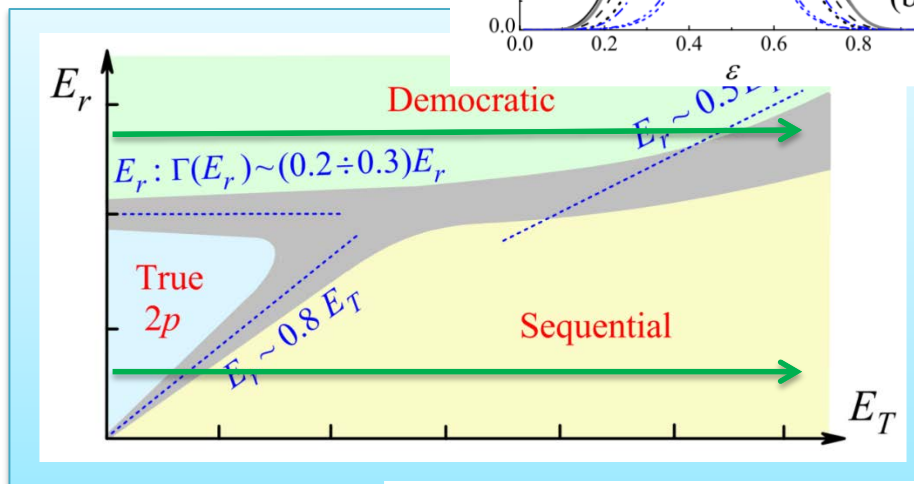
Long-range character of three-body Coulomb continuum problem by example of ^{16}Ne

K. Brown et al., PRL **113** (2014) 232501



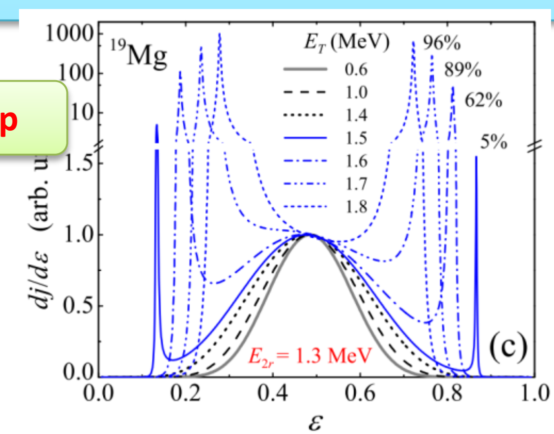
Democratic 2p <-> Sequential 2p





True 2p <-> Sequential 2p

T.A. Golubkova *et al.*, PLB **762** (2016) 263



LoI: Russian physics review journal Physics-Uspekhi (2018) in print

Scientific program of DERICA – prospective accelerator and storage ring facility for radioactive ion beam research

L.V. Grigorenko, B.Yu. Sharkov, A.S. Fomichev, A.L. Barabanov, W. Barth, A.A. Bezbakh, S.L. Bogomolov, V. Chudoba, S.N. Dmitriev, V.K. Eremin, S.N. Ershov, M.S. Golovkov, A.V. Gorshkov, I.V. Kalagin, A.V. Karpov, T. Katayama, O.A. Kiselev, A.A. Korsheninnikov, S.A. Krupko, T.V. Kulevoy, Yu.A. Litvinov, E.V. Lychagin, I.P. Maksimkin, I.N. Meshkov, I.G. Mukha, E.Yu. Nikolskii, Yu.L. Parfenova, V.V. Parhomchuk, M. Pfutzner, S.M. Polozov, C. Scheidenberger, S.I. Sidorchuk, P.G. Sharov, P.Yu. Shatunov, Yu.M. Shatunov, V.N. Shvetsov, N.B. Shulgina, H. Simon, R.S. Slepnev, G.M. Ter-Akopyan, G.V. Trubnikov, A.A. Yukhimchuk, S. Yaramyshev, M.V. Zhukov

Abstract. *Studies of radioactive ions (RI) is the most intensively developing field of the low-energy nuclear physics. In this paper the concept and the scientific agenda of prospective accelerator and storage ring facility for the RI beam (RIB) research are proposed for the large-scale international project based at the Flerov Laboratory of Nuclear Reactions of the Joint Institute for Nuclear Research. The motivation for the new facility is discussed and its characteristics are briefly presented, showing to be comparable to those of the advanced world centers, the so-called "RIB factories". In the project the emphasis is made on the studies with the short-lived RIBs in storage rings. A unique feature of the project is the possibility to study the electron-RI interactions in the collider experiment for determination of fundamental properties of the nuclear matter, in particular, electromagnetic form-factors of exotic nuclei.*

http://aculina.jinr.ru/derica.php

April 26, 2018. The is project is submitted to Russian Ministery of Education and Science on the call for «Proposals to build "megascience"-class facilities on the territory of Russian Federation»

Radioactive Ion Beam (RIB) physics – "highway" of modern low-energy nuclear science

The map of nuclides

- 254 stable nuclides,
- 339 can be found in nature
- Around 3100 RI are known
- Around 2500 to be discovered

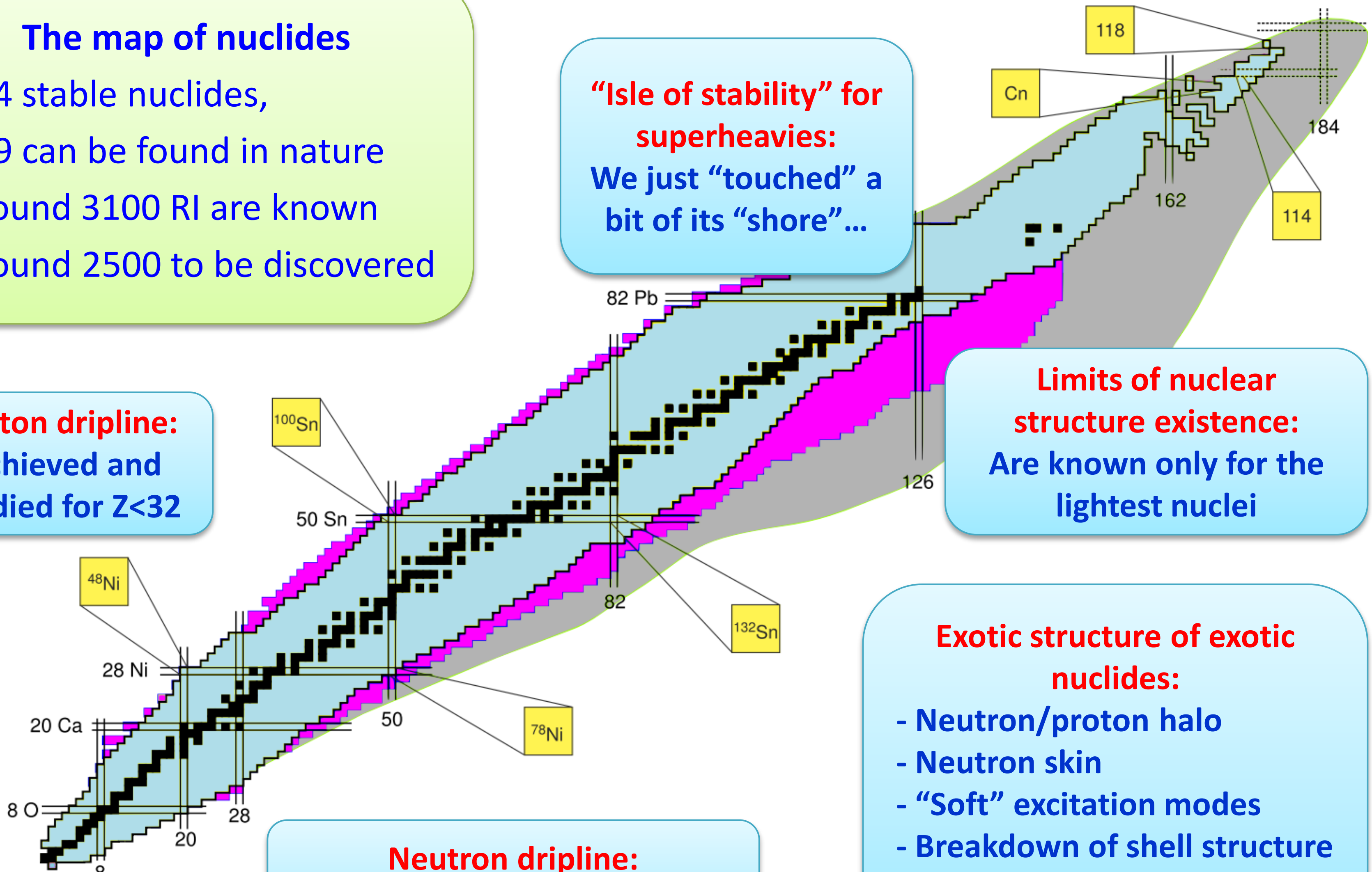
"Isle of stability" for superheavies:
We just "touched" a bit of its "shore"…

Proton dripline:
Achieved and studied for Z<32

Limits of nuclear structure existence:
Are known only for the lightest nuclei

Neutron dripline:
Achieved and studied for N<20

Exotic structure of exotic nuclides:
- **Neutron/proton halo**
- **Neutron skin**
- **"Soft" excitation modes**
- **Breakdown of shell structure**
- **New "magic numbers"**



What we already have at Flerov lab

JINR
114 Flerovium
FLNR
Dubna

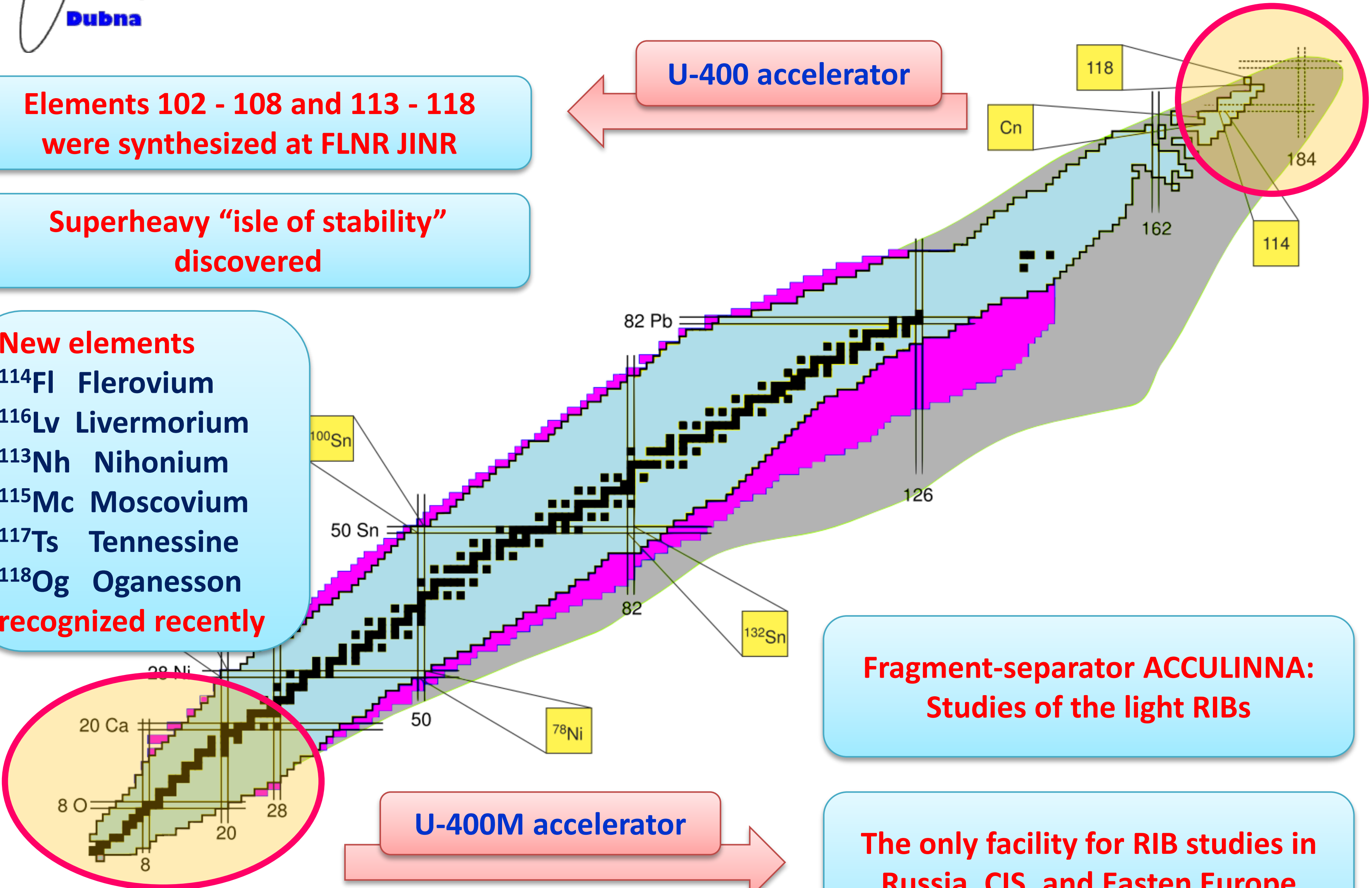
Elements 102 - 108 and 113 - 118 were synthesized at FLNR JINR

Superheavy "isle of stability" discovered

New elements
- ^{114}Fl Flerovium
- ^{116}Lv Livermorium
- ^{113}Nh Nihonium
- ^{115}Mc Moscovium
- ^{117}Ts Tennessine
- ^{118}Og Oganesson

recognized recently

U-400 accelerator



U-400M accelerator

Fragment-separator ACCULINNA: Studies of the light RIBs

The only facility for RIB studies in Russia, CIS, and Easten Europe

March 30 2018 – The Lomonosov great gold medal is awarded to Yuri Oganessian and Bjorn Jonson

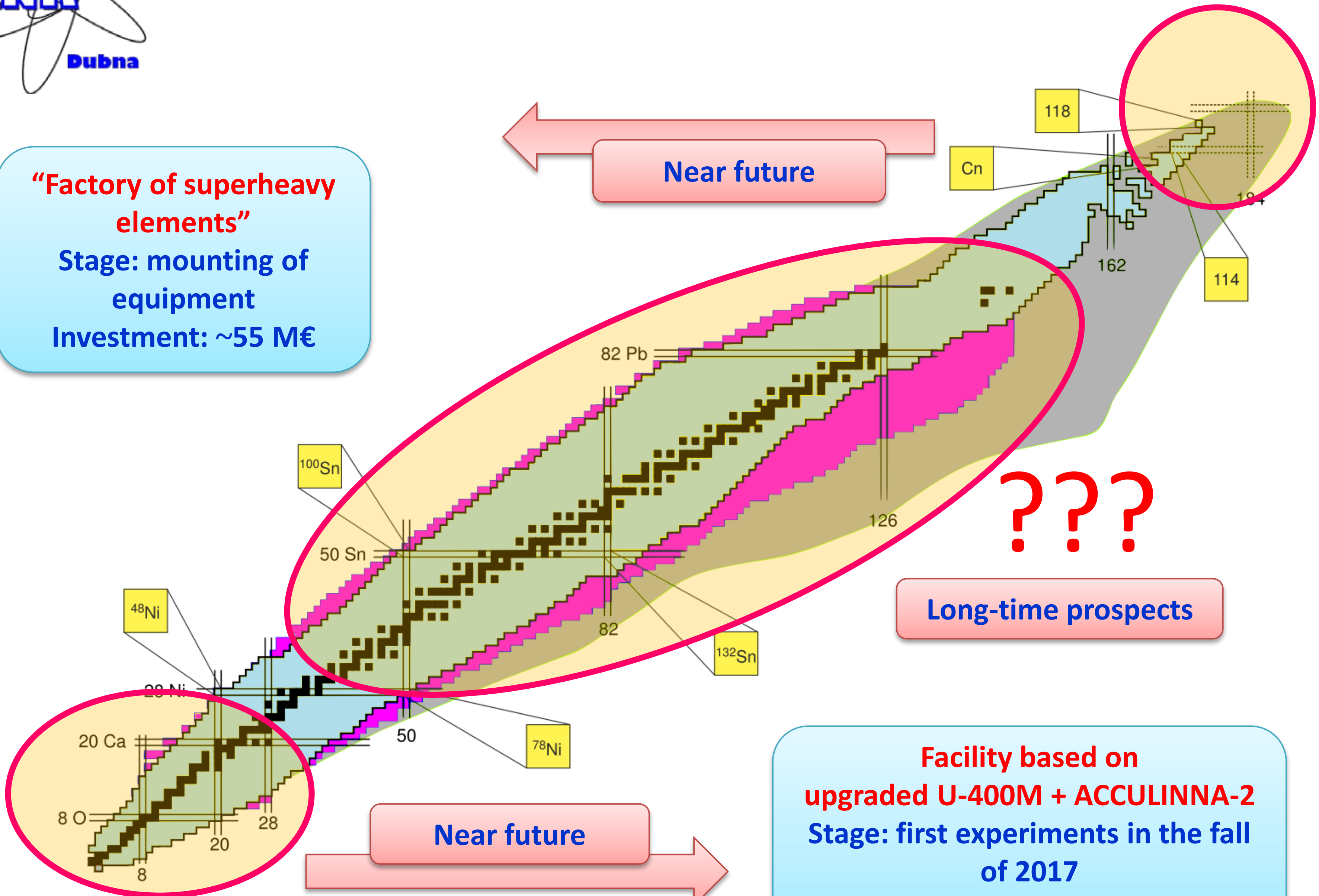
Yu.Ts. Oganessian – synthesis of superheavy elements

B. Jonson – contribution of studies of exotic nuclei (ISOL method and nucleon halo)

JINR FLNR 114 Flerovium Dubna

7-year planning prospects

“Factory of superheavy elements”
Stage: mounting of equipment
Investment: ~55 M€

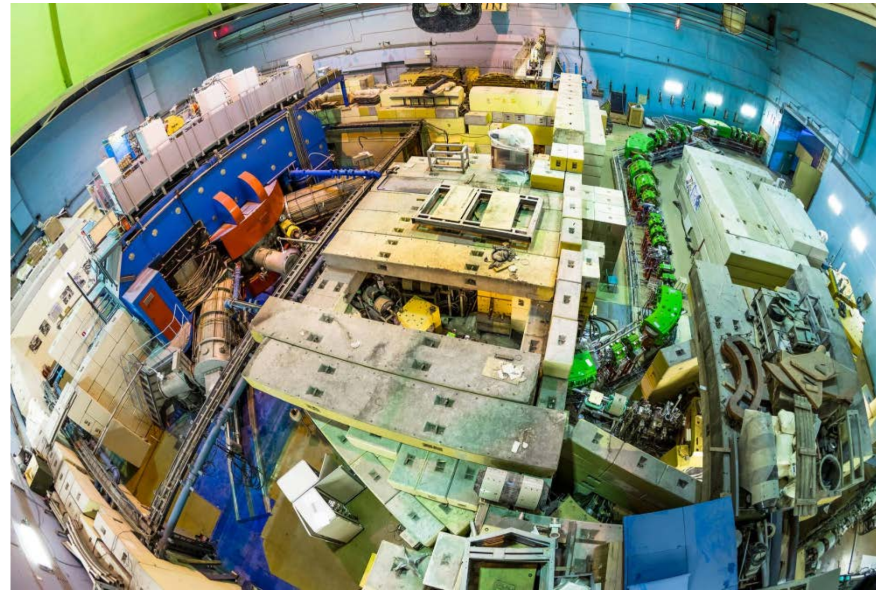


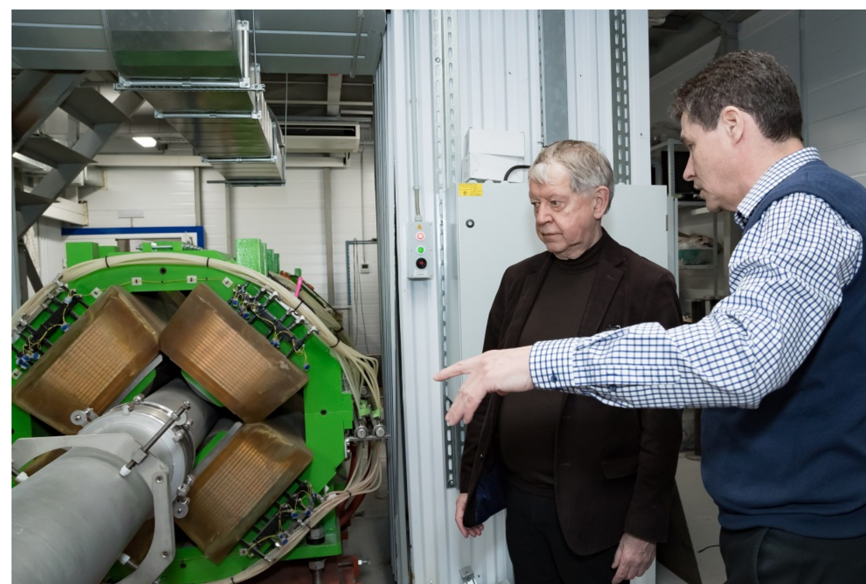
Facility based on upgraded U-400M + ACCULINNA-2
Stage: first experiments in the fall of 2017
Investment: ~10 M€

New facilities at FLNR

"Factory of superheavy elements"

ACCULINNA-2 fragment-separator





Huge increase in the scale of modern and prospective RIB facilities:
Price tag 1-2 G€

Scale increase – (i) RIB production increase and (ii) universality of RIB facility

Is it possible to have world competitive RIB program with modest investment scale?

To limit universality

To go to underdeveloped fields

Empty “ecological niche”

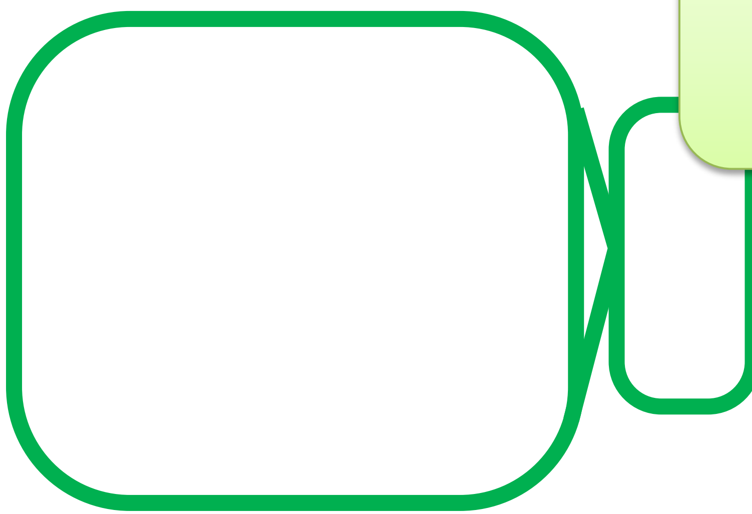
Underdeveloped field: storage ring physics with RIBs

Empty field: studies of RIBs in electron-RIB collider

Isochronous mass spectromentry

Precision reaction studies on internal gas jet target

Atomic physics studies with striped ions



Studies of electromagnetic formfactors of exotic nuclei in e-RIB collider

Radioactivity studies with striped ions

Etc….

Electron scattering

After masses, the radial properties are the most important characteristics of nuclei

Robert Hofstadter 1915-1990, 1961 Nobel Prize "for his pioneering studies of electron scattering in atomic nuclei and for his consequent discoveries concerning the structure of nucleons.."

- First Born approximation, fast electrons, relatively light nuclei

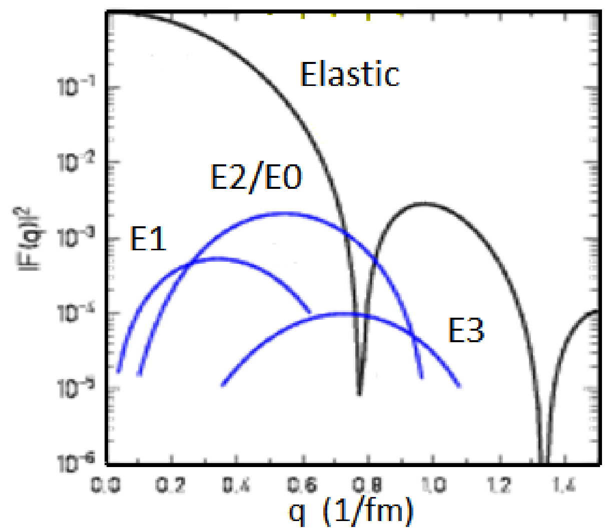
$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{PWBA}} = \frac{\sigma_M}{1+(2E/M_A)\sin^2(\theta/2)}|F_{\text{ch}}(q)|^2$$

$$\sigma_M = (e^4/4E^2)\cos^2(\theta/2)\sin^{-4}(\theta/2)$$

$$q = 2k\sin(\theta/2)$$

Electromagnetic probe is the most reliably studied

- Electron scattering



- Charge formfactor, charge radius

$$F_{\text{ch}}(q) = 4\pi\int_0^\infty dr\, r^2 j_0(qr)\rho_{\text{ch}}(r)$$

$$F_{\text{ch}}(q)/Z = 1 - \frac{q^2}{6}\langle r^2_{\text{ch}}\rangle + \cdots$$

- Experiments in traps – “static” EM characteristics -> derivation of r_{ch}

- Electron scattering – differenttial characteristics

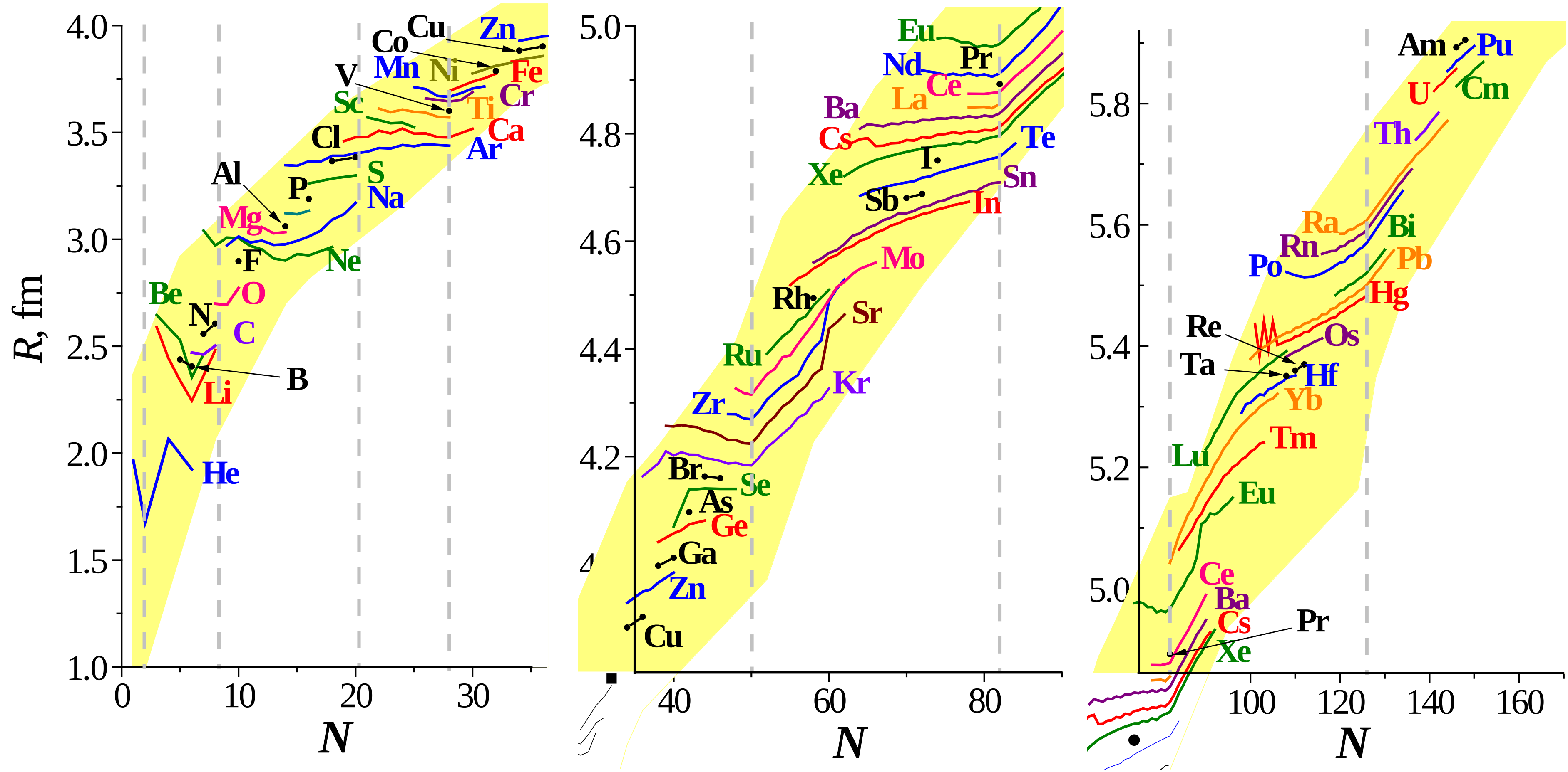
Status of charge radii studies – broad field for exploration

900 measured for 3100 known nuclear-stable isotopes

Some isotopic chains are well studied – some not at all

Somewhere driplines is nearly achieved – somewhere very far

Systematics demonstrate complicated dynamical effects in the isotopic chains, especially near the driplines

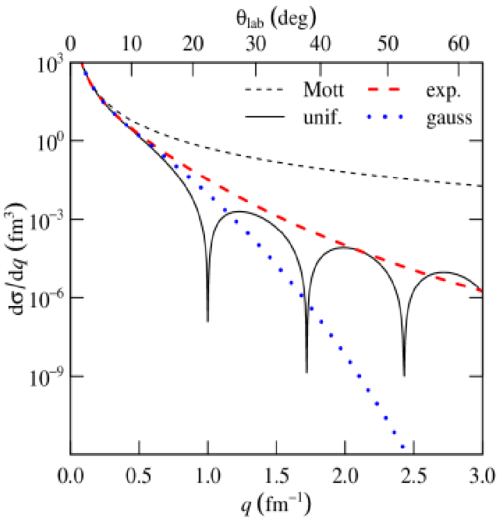


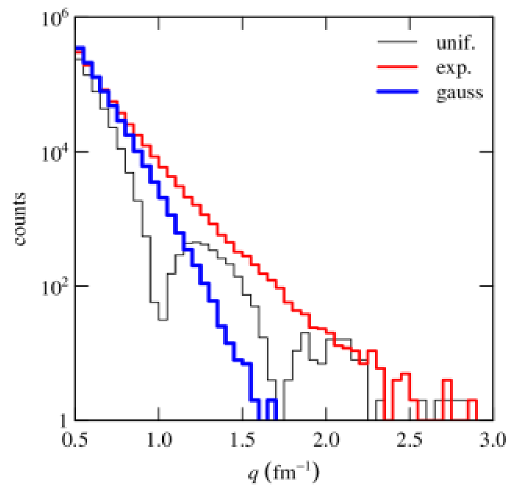
Luminosity requirements for e-RIB collider studies

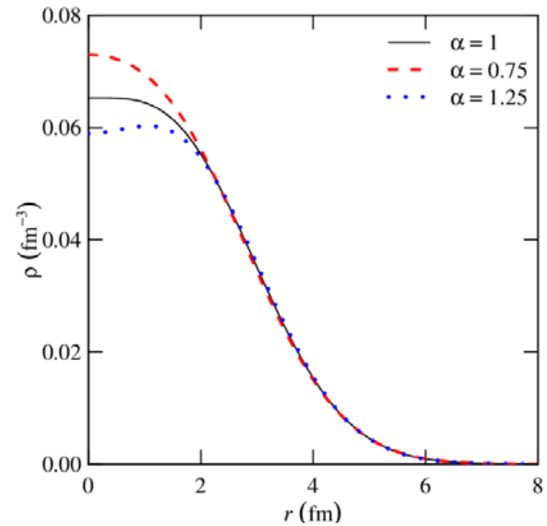
Realistic setup 10 days of measurements

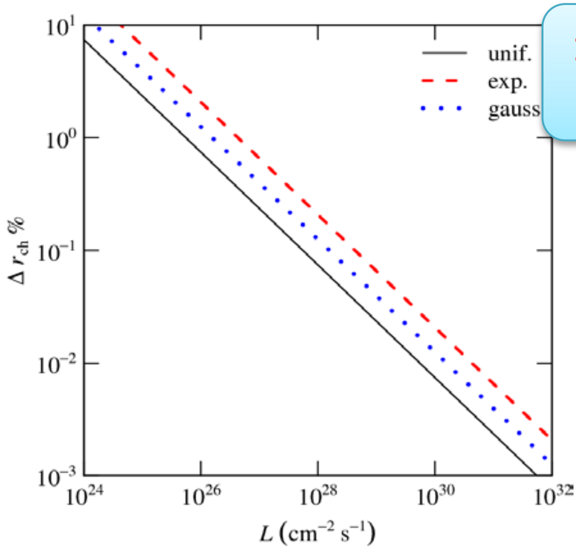
Limiting cases of charge distributions

^{40}Ca and ^{48}Ca realistic 2 parameter density



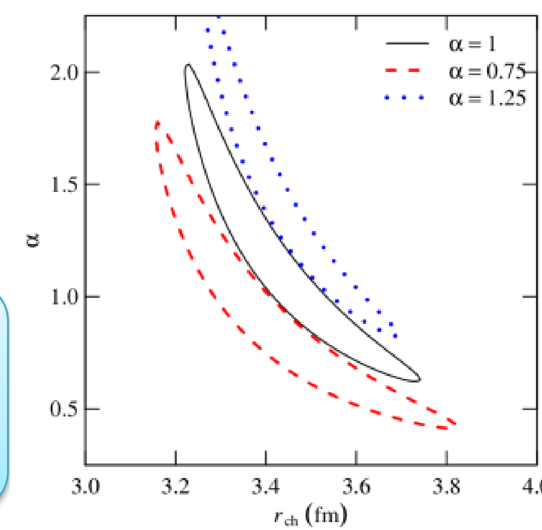






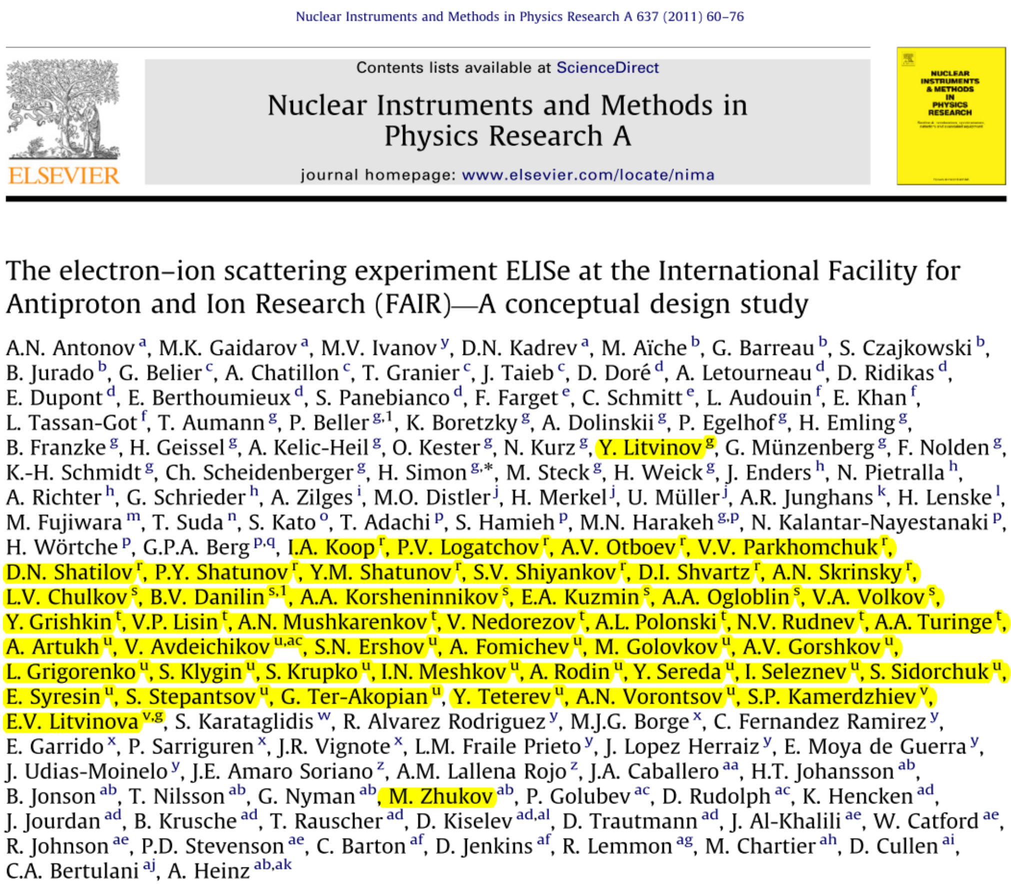
1% precision charge radius
L = 10^{26}-10^{27} cm^{-2} s^{-1}

T = 10 days
L = 7x10^{27} cm^{-2} s^{-1}
2σ (95% confidence)



Storage ring and e-RIB collider topic in Russia

Expertize in the field especially at Dubna and Novosibirsk



Nuclear Instruments and Methods in Physics Research A 637 (2011) 60–76

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

The electron–ion scattering experiment ELISe at the International Facility for Antiproton and Ion Research (FAIR)—A conceptual design study

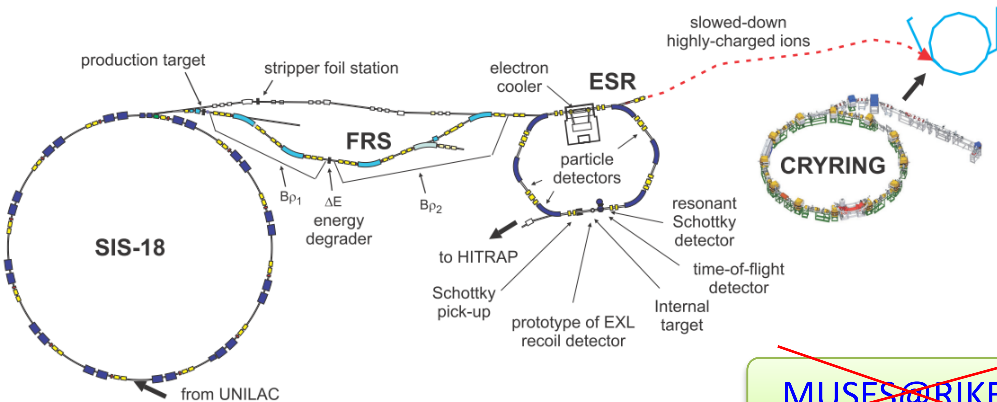
A.N. Antonov[a], M.K. Gaidarov[a], M.V. Ivanov[y], D.N. Kadrev[a], M. Aïche[b], G. Barreau[b], S. Czajkowski[b], B. Jurado[b], G. Belier[c], A. Chatillon[c], T. Granier[c], J. Taieb[c], D. Doré[d], A. Letourneau[d], D. Ridikas[d], E. Dupont[d], E. Berthoumieux[d], S. Panebianco[d], F. Farget[e], C. Schmitt[e], L. Audouin[f], E. Khan[f], L. Tassan-Got[f], T. Aumann[g], P. Beller[g,1], K. Boretzky[g], A. Dolinskii[g], P. Egelhof[g], H. Emling[g], B. Franzke[g], H. Geissel[g], A. Kelic-Heil[g], O. Kester[g], N. Kurz[g], Y. Litvinov[g], G. Münzenberg[g], F. Nolden[g], K.-H. Schmidt[g], Ch. Scheidenberger[g], H. Simon[g,*], M. Steck[g], H. Weick[g], J. Enders[h], N. Pietralla[h], A. Richter[h], G. Schrieder[h], A. Zilges[i], M.O. Distler[j], H. Merkel[j], U. Müller[j], A.R. Junghans[k], H. Lenske[l], M. Fujiwara[m], T. Suda[n], S. Kato[o], T. Adachi[p], S. Hamieh[p], M.N. Harakeh[g,p], N. Kalantar-Nayestanaki[p], H. Wörtche[p], G.P.A. Berg[p,q], I.A. Koop[r], P.V. Logatchov[r], A.V. Otboev[r], V.V. Parkhomchuk[r], D.N. Shatilov[r], P.Y. Shatunov[r], Y.M. Shatunov[r], S.V. Shiyankov[r], D.I. Shvartz[r], A.N. Skrinsky[r], L.V. Chulkov[s], B.V. Danilin[s,1], A.A. Korsheninnikov[s], E.A. Kuzmin[s], A.A. Ogloblin[s], V.A. Volkov[s], Y. Grishkin[t], V.P. Lisin[t], A.N. Mushkarenkov[t], V. Nedorezov[t], A.L. Polonski[t], N.V. Rudnev[t], A.A. Turinge[t], A. Artukh[u], V. Avdeichikov[u,ac], S.N. Ershov[u], A. Fomichev[u], M. Golovkov[u], A.V. Gorshkov[u], L. Grigorenko[u], S. Klygin[u], S. Krupko[u], I.N. Meshkov[u], A. Rodin[u], Y. Sereda[u], I. Seleznev[u], S. Sidorchuk[u], E. Syresin[u], S. Stepantsov[u], G. Ter-Akopian[u], Y. Teterev[u], A.N. Vorontsov[u], S.P. Kamerdzhiev[v], E.V. Litvinova[v,g], S. Karataglidis[w], R. Alvarez Rodriguez[y], M.J.G. Borge[x], C. Fernandez Ramirez[y], E. Garrido[x], P. Sarriguren[x], J.R. Vignote[x], L.M. Fraile Prieto[y], J. Lopez Herraiz[y], E. Moya de Guerra[y], J. Udias-Moinelo[y], J.E. Amaro Soriano[z], A.M. Lallena Rojo[z], J.A. Caballero[aa], H.T. Johansson[ab], B. Jonson[ab], T. Nilsson[ab], G. Nyman[ab], M. Zhukov[ab], P. Golubev[ac], D. Rudolph[ac], K. Hencken[ad], J. Jourdan[ad], B. Krusche[ad], T. Rauscher[ad], D. Kiselev[ad,al], D. Trautmann[ad], J. Al-Khalili[ae], W. Catford[ae], R. Johnson[ae], P.D. Stevenson[ae], C. Barton[af], D. Jenkins[af], R. Lemmon[ag], M. Chartier[ah], D. Cullen[ai], C.A. Bertulani[aj], A. Heinz[ab,ak]

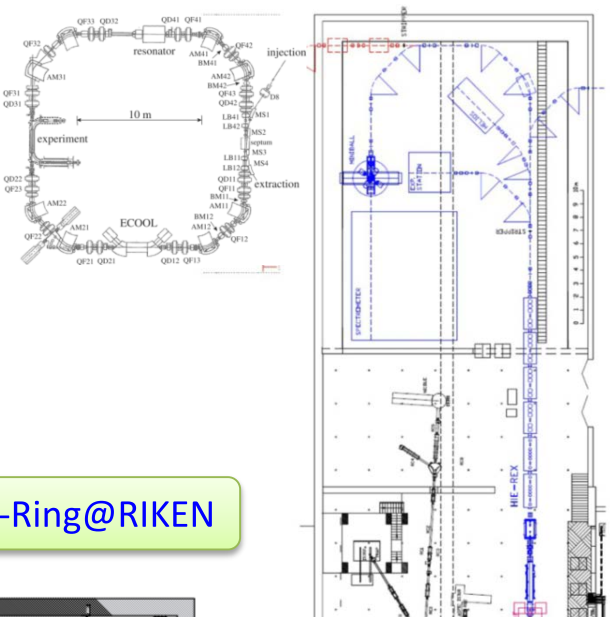
Yu.Ts. Oganessian *et. al.*, Z. Phys. A341 (1992) 217

Status of ring projects in the world

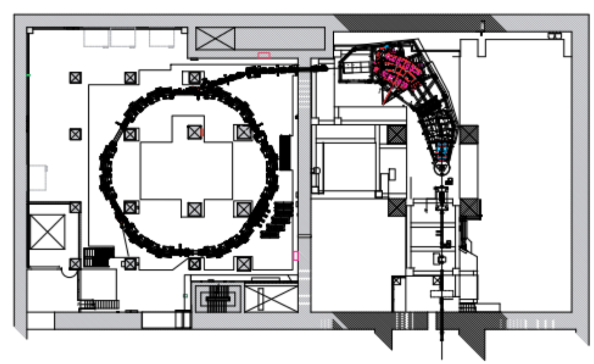
~~TSR/ISOLDE@CERN~~

~~ELISe/NESR@FAIR~~ → ESR/CRYRING@GSI

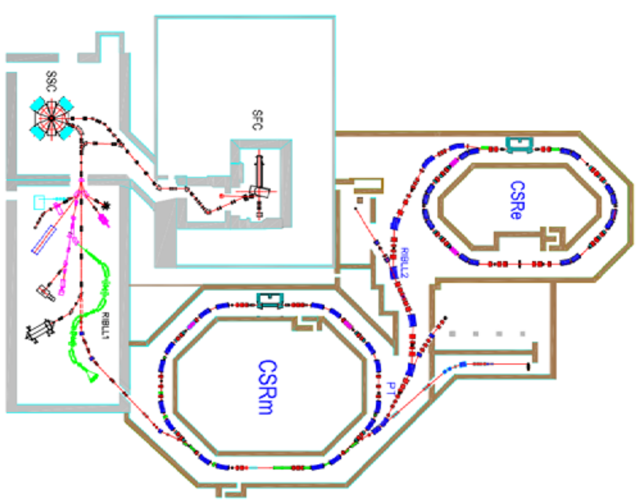




~~MUSES@RIKEN~~ → RI-Ring@RIKEN



~~HIRFL-CSR@Lanzhou~~ → HIAF



Not in scale

– A lot of ring projects – serious interest to the topic

– All the ring projects with e-collider abilities were cancelled or indefinitely postponed

A lot of ring projects – serious interest to the topic

All the ring projects with e-RIB-collider abilities were cancelled or indefinitely postponed

Attack at this problem requires record intensities of RIBs with $T_{1/2}$>100 ms

DERICA

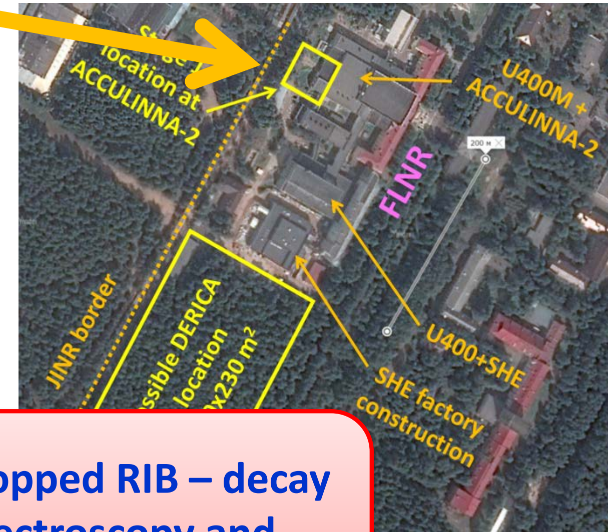
Dubna Electron-Radioactive Isotope Collider fAcility

According to different sources "Derica" is female name of German origin with meaning "beloved leader, ruler of the people"

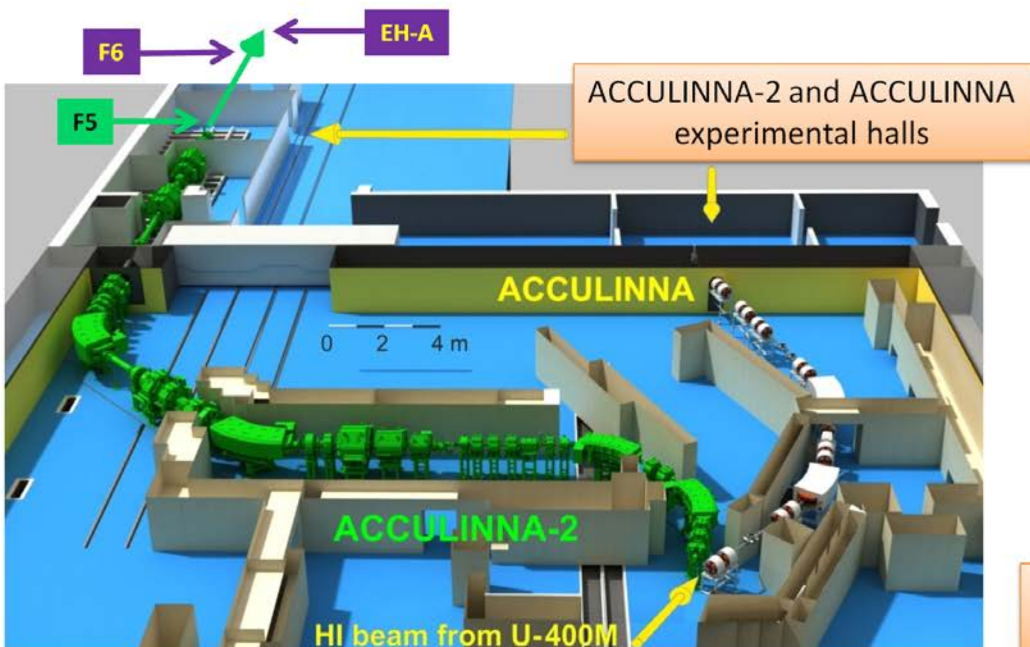
DERICA stages 0 -1

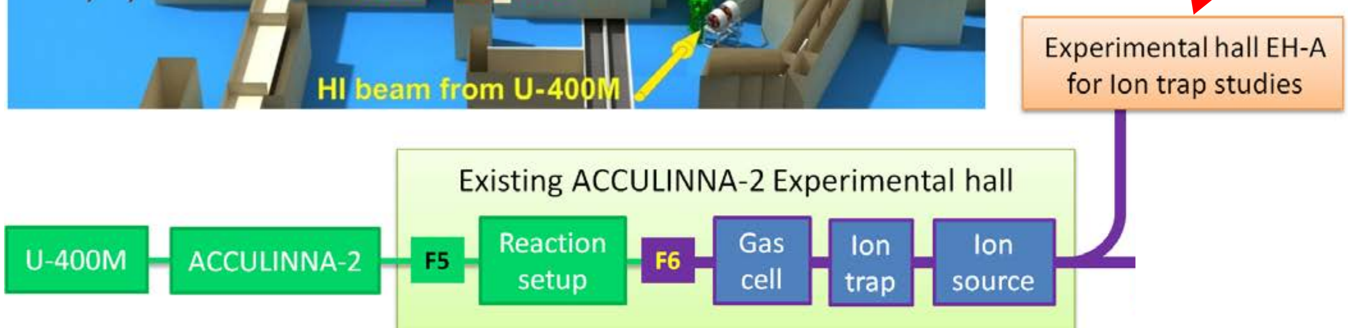
Continuity of scientific program

Minimization of technological risks



Stopped RIB – decay spectroscopy and studies in traps

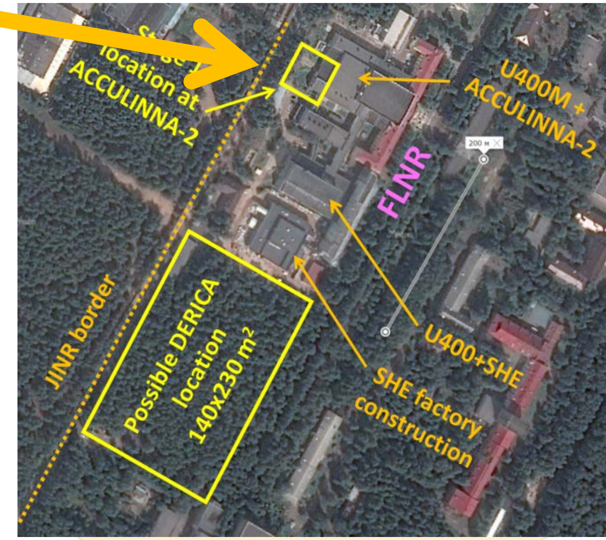




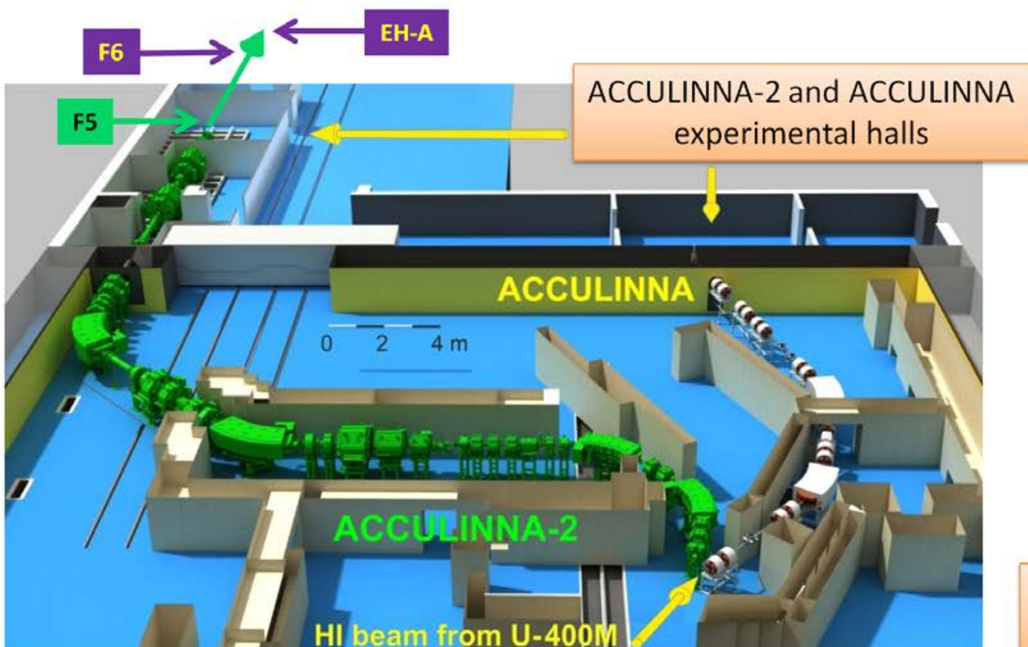
DERICA stages 0 -1

Continuity of scientific program

Minimization of technological risks



Reactions with reaccelerated RIBs around Coulomb barrier energy (5-7 AMeV)



Experimental hall EH-A for Ion trap studies

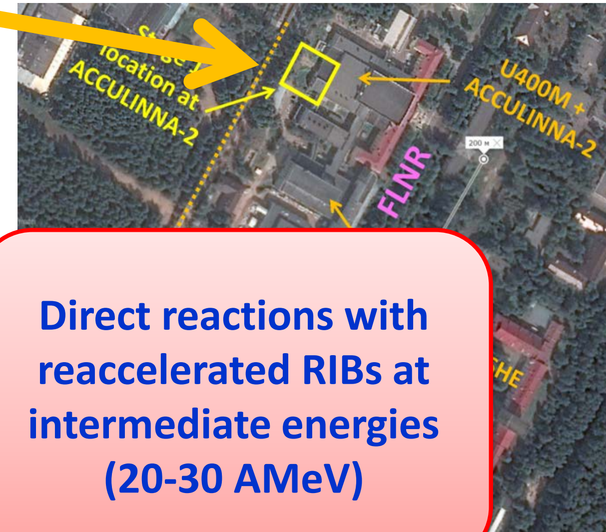
Existing ACCULINNA-2 Experimental hall

U-400M — ACCULINNA-2 — F5 — Reaction setup — F6 — Gas cell — Ion trap — Ion source — LINAC-30 5-10 AMeV — Experimental hall EH-B for Coulomb barrier reaction studies 5-10 AMeV

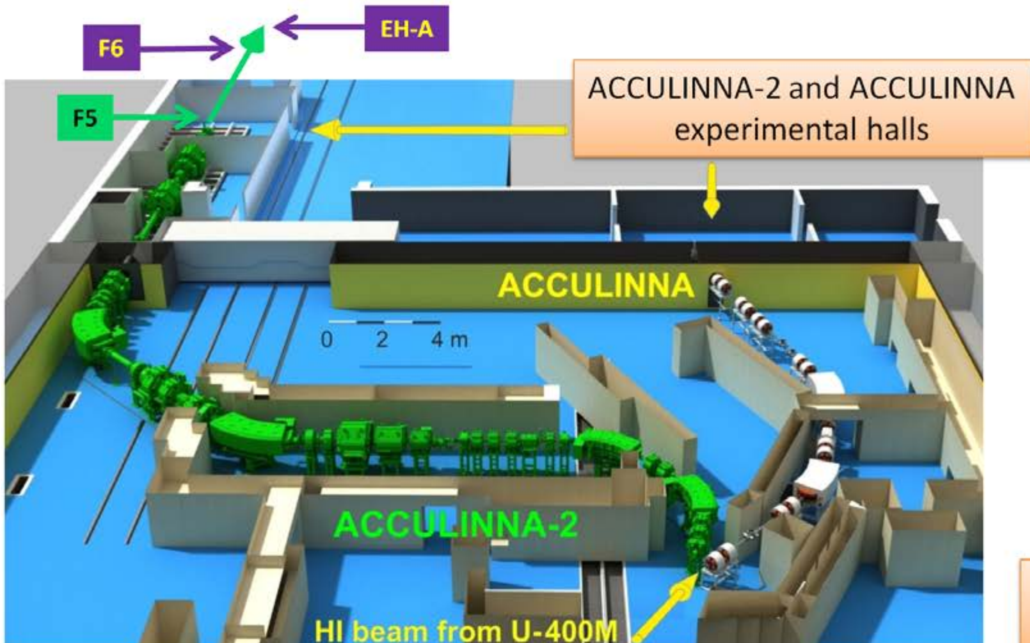
DERICA stages 0 -1

Continuity of scientific program

Minimization of technological risks



Direct reactions with reaccelerated RIBs at intermediate energies (20-30 AMeV)

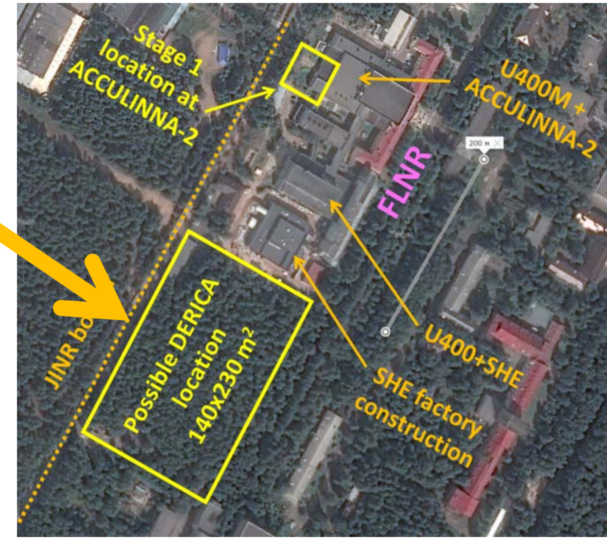


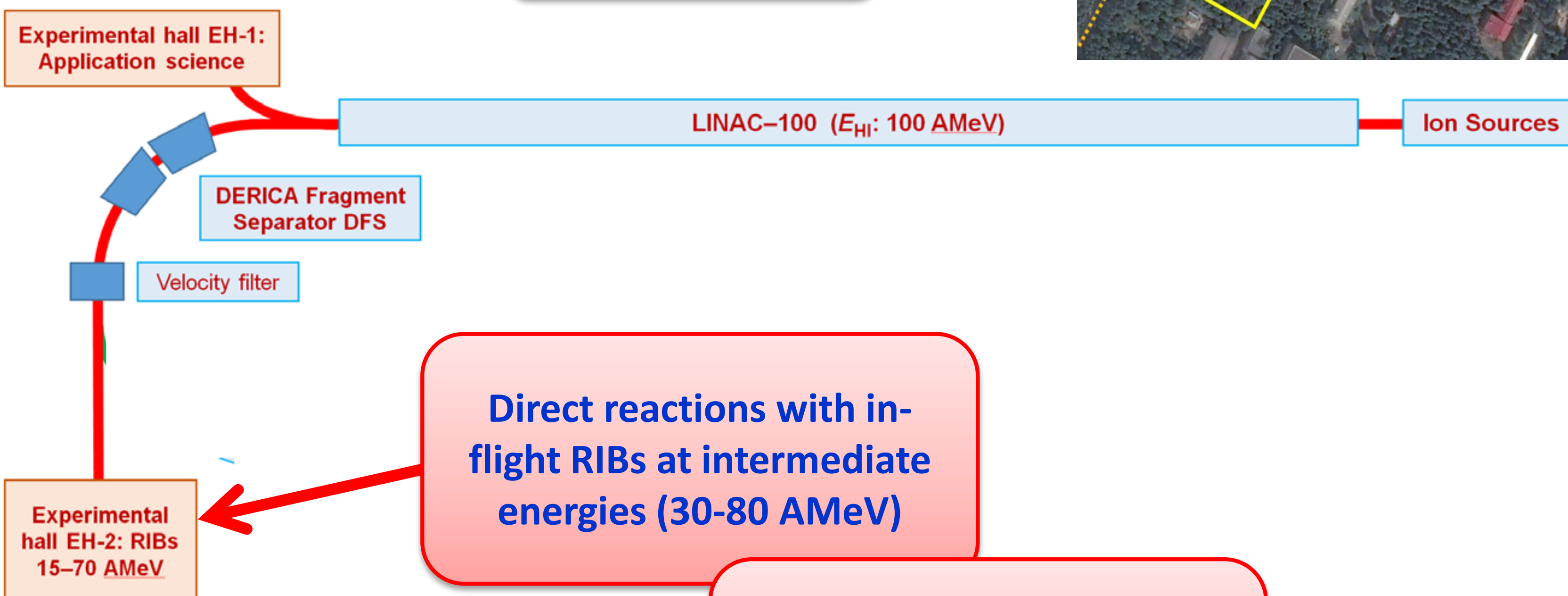
DERICA stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects





Direct reactions with in-flight RIBs at intermediate energies (30-80 AMeV)

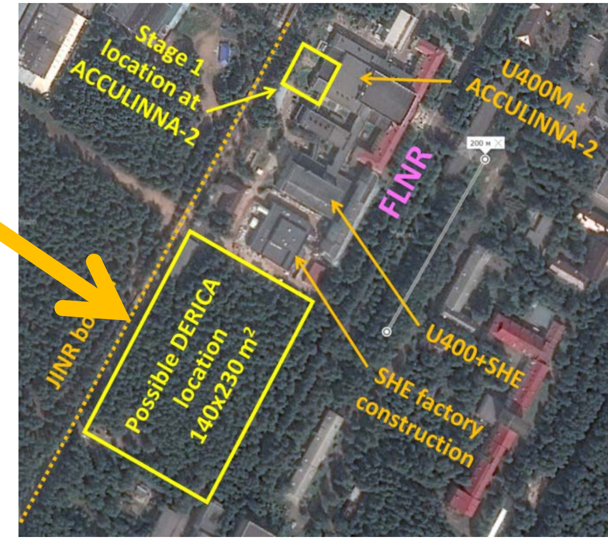
World-leading intencities are expected for this energy range

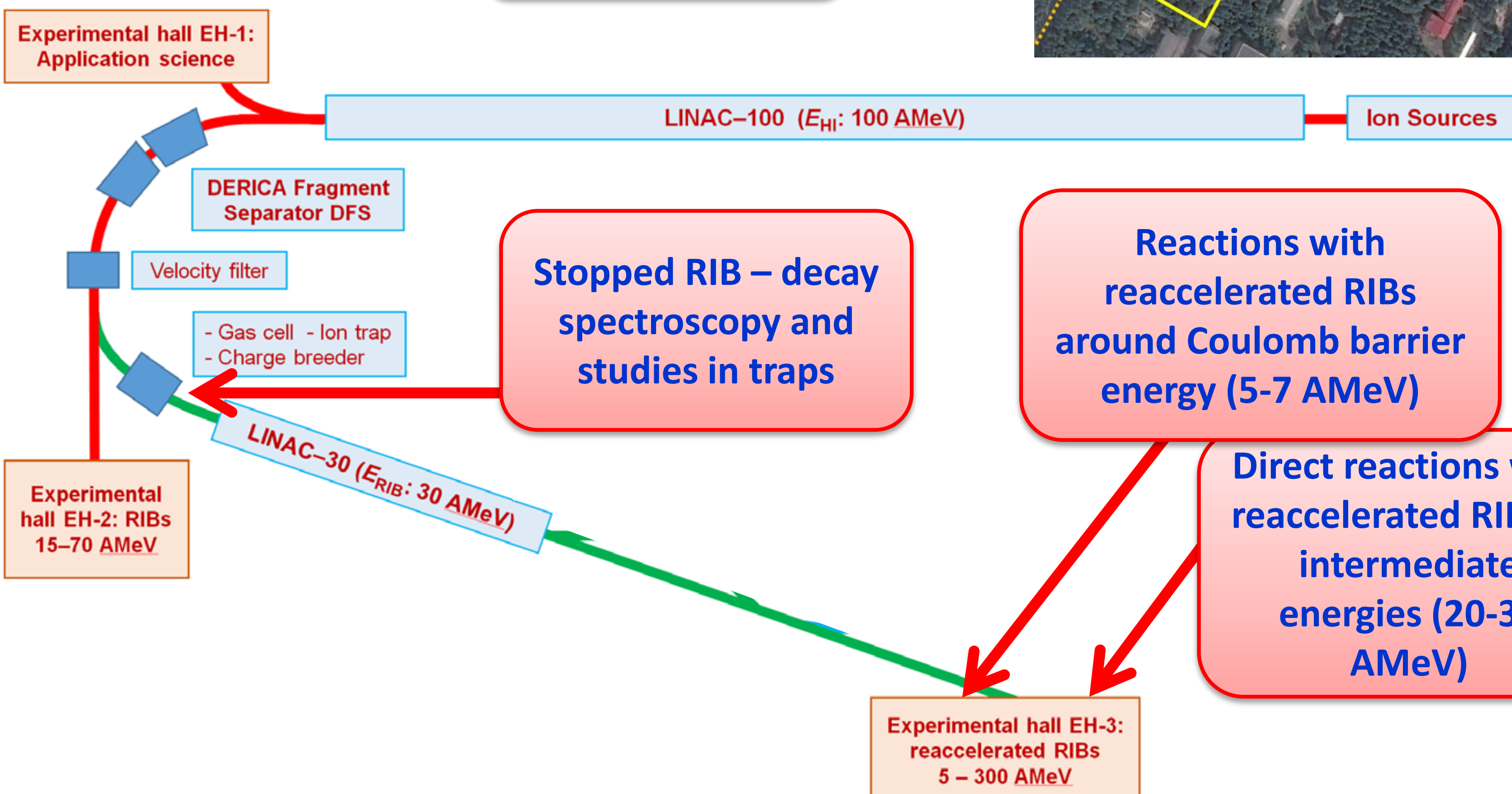
DERICA stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects





Stopped RIB – decay spectroscopy and studies in traps

Reactions with reaccelerated RIBs around Coulomb barrier energy (5-7 AMeV)

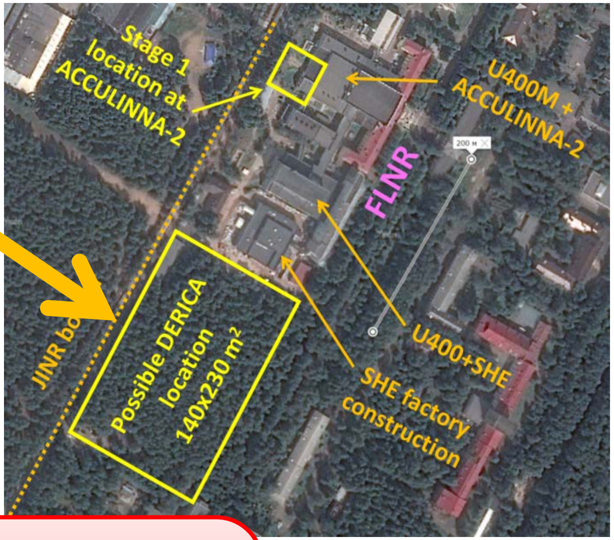
Direct reactions with reaccelerated RIBs at intermediate energies (20-30 AMeV)

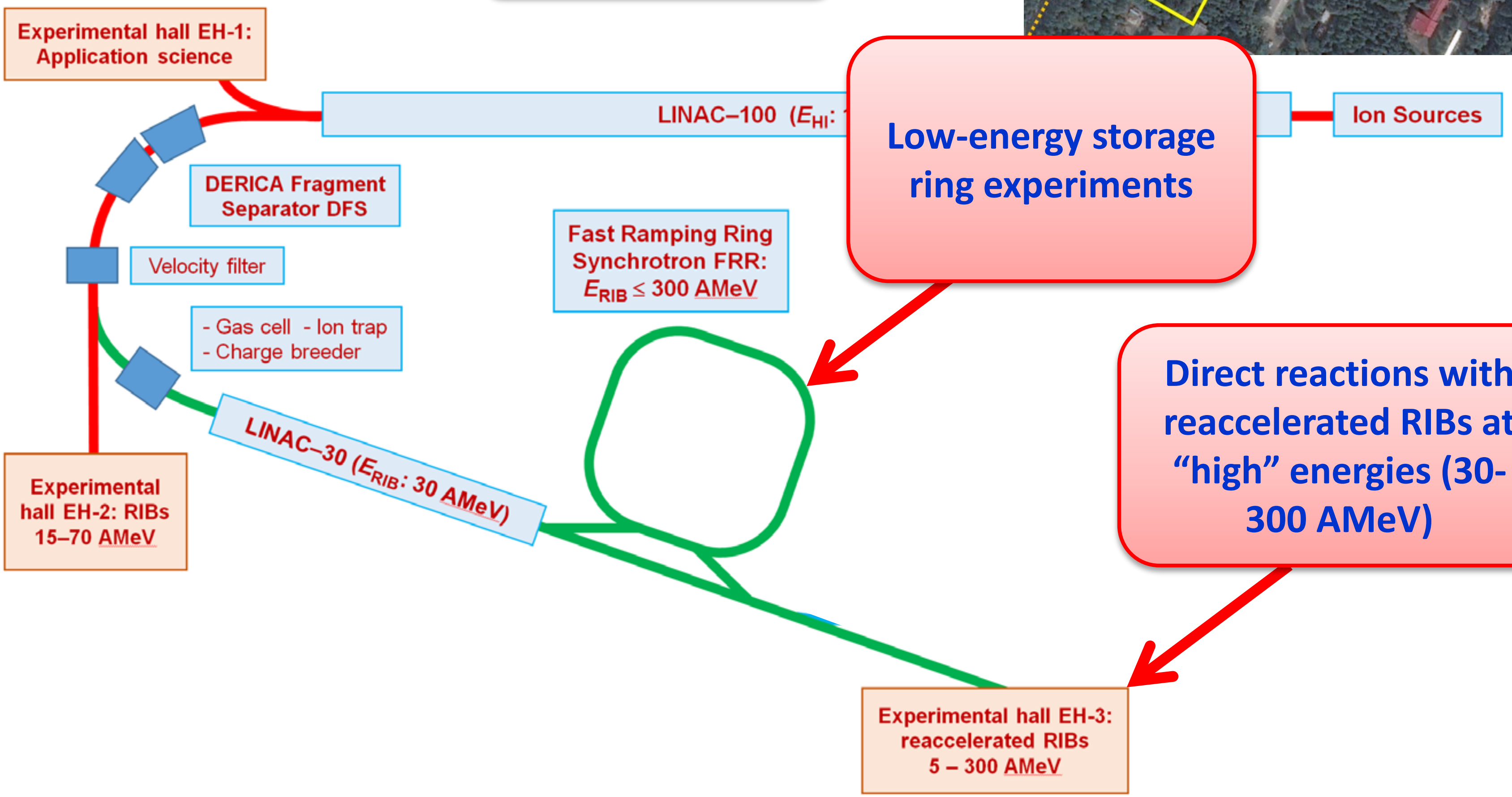
DERICA stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects





Low-energy storage ring experiments

Direct reactions with reaccelerated RIBs at “high” energies (30-300 AMeV)

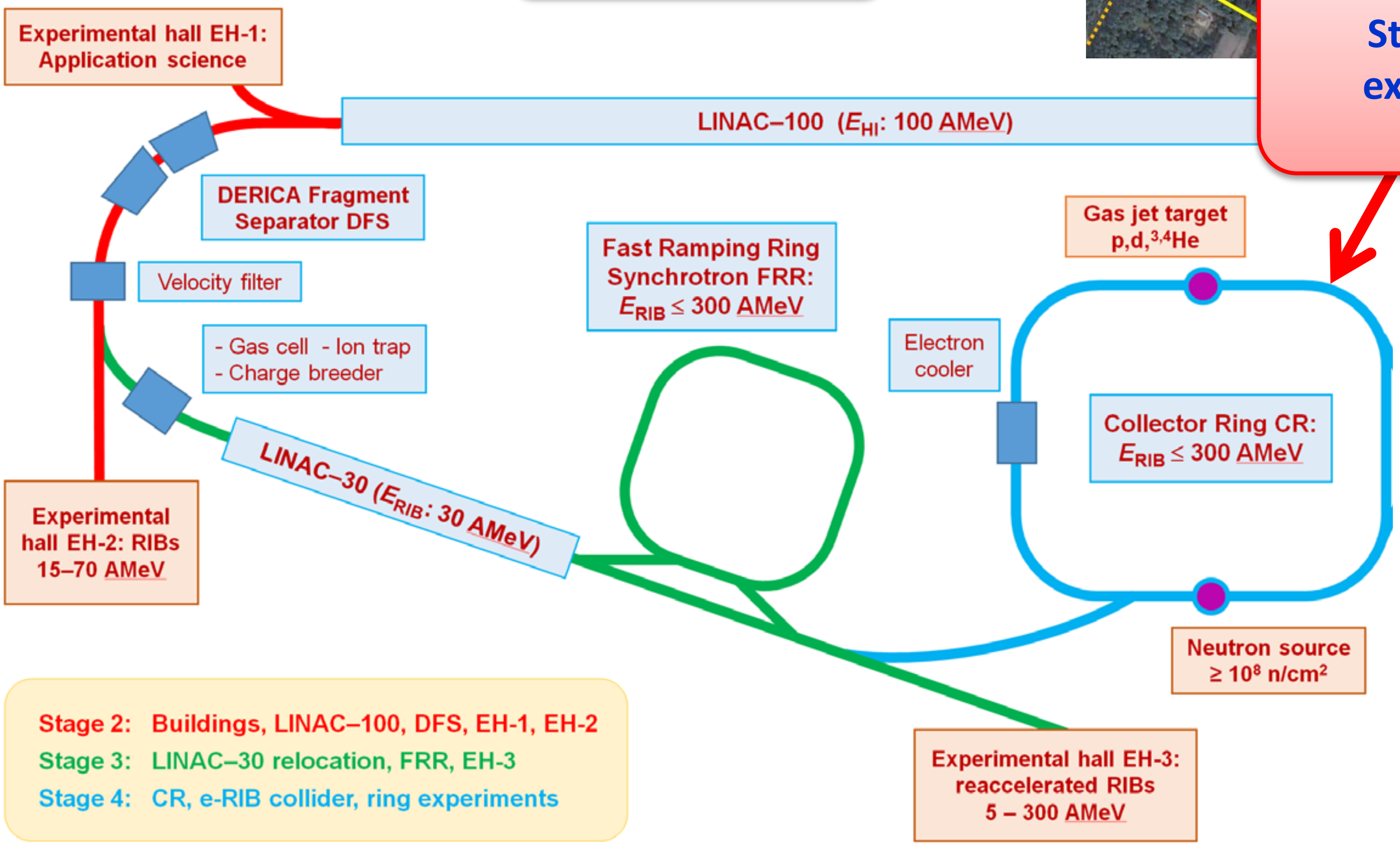
DERICA stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects

Storage ring experiments

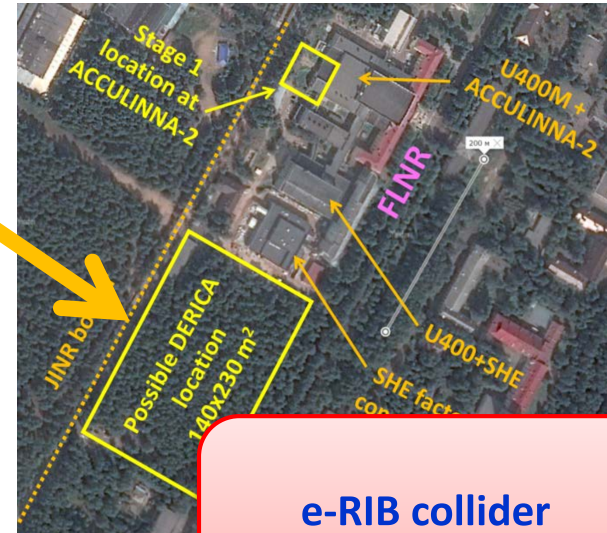


DERICA stages 2 - 4

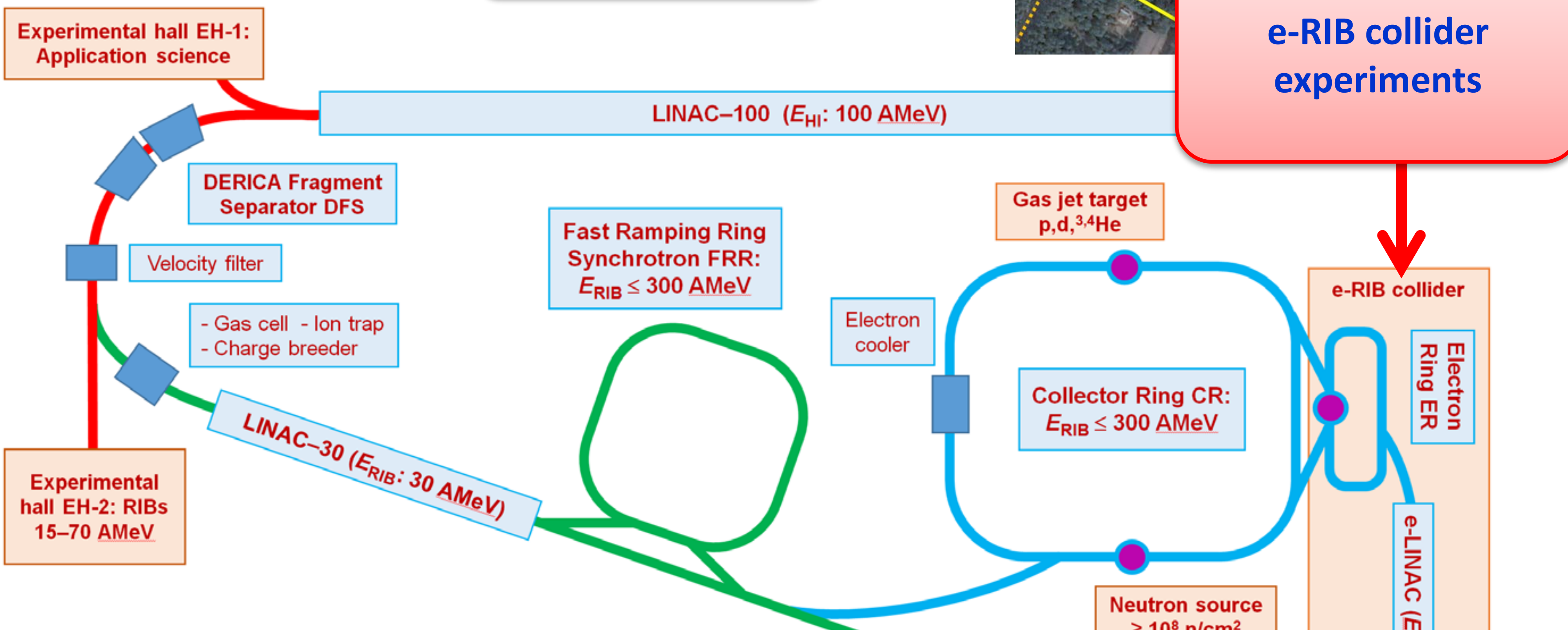
New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects



e-RIB collider experiments



Stage 2: Buildings, LINAC–100, DFS, EH-1, EH-2
Stage 3: LINAC–30 relocation, FRR, EH-3
Stage 4: CR, e-RIB collider, ring experiments

DERICA timeline and opportunities for modern research

Stopped RIB – decay spectroscopy and studies in traps	beginning stage 1 stages 3-4
Reactions with reaccelerated RIBs around Coulomb barrier energy (5-7 AMeV)	stage 1 stages 3-4
Direct reactions with reaccelerated RIBs at intermediate energies (20-30 AMeV)	end stage 1 stages 3-4
Direct reactions with reaccelerated RIBs at “high” energies (30-300 AMeV)	stages 3-4
Direct reactions with in-flight RIBs at intermediate energies (30-80 AMeV)	stages 2-4
Storage ring experiments	end stage 3 stage 4
e-RIB collider experiments	end stage 4

Most (many?) important fields of modern RIB research are covered

No wait to construction completion. New research opportunities arise each 3-6 years

Advantages of the proposed facility

Unusual facility layout

Ordinary approach 1:
ISOL RIB production ->
problem to reaccelerate RIBs

Ordinary approach 2:
In-flight RIB production ->
Problem to stop/cool RIBs

DERICA approach:
In-flight RIB production + RIB “cooling” in gas cell + reaccelerated RIBs up to 300 AMeV

Staged development
- Continuity and flexibility of the research program
- Low technological risks
- Highly upgradable facility design

Unique opportunities
- World most intense RIBs with intermediate energy (20-70 AMeV) for reaction studies
- Reaccelerated RIBs up to 300 AMeV
- e-RIB collider experiment

Pro et contra for reaccelerated beams

Contra	Pro
- Lifetime limit $T_{1/2}$ > 10-100 ms (compared to $T_{1/2}$ > 100 ns for I-F)	- Choice of secondary beam energy in a broad range
- Factor 5-20 intensity loss at {gas cell-ion source} system	- High quality secondary beams: monochromatic, "zero emittance"
- Around 5×10^8 pps intensity limit of existing gas cells	- For intense secondary beams overcome 10^5 pps limitation of event-by-event operation at in-fight facilities
- Bunched operation 1-20 Hz - specific DAC requirements	

Re-accelerated beams become *acceptable* for reaction studies RIB production I>10^4 pps, and become *preferable* for I>10^6 pps

Luminosity estimates

Table 4. Estimates of luminosity in various experimental scenarios in units of ($cm^{-2}sec^{-1}$). J - the flux of RI produced in the fragment separator, $\overline{N_{stor}}(1)$ and $\overline{N_{stor}}(2)$ numbers of RI accumulated CR after acceleration in LINAC-30 and FRR, respectively. L_1 is the luminosity of the experiment in the experimental hall EH-3 for the fixed gas target $5x10^{20}$ cm^{-2} thickness. L_2 is the luminosity in the CR ring in the jet gas target 10^{13} cm^{-2} thick at the energy 7 MeV/nucleon. L_3 and L_4 are the luminosities in the CR ring in the jet gas target $5x10^{15}$ cm^{-2} thick at the energies 30 and 300 MeV/nucleon. L_5 is the luminosity of the collider experiment in the CR ring at the energy 300 MeV/nucleon. Primary beams for the Be, C, Ar and S isotopes are ^{15}N, ^{22}Ne, ^{40}Ca and ^{48}Ca, respectively.

Ion	$T_{1/2}$ (s)	J (s^{-1})	L_1	$\overline{N_{stor}}(1)$	L_2	L_3	$\overline{N_{stor}}(2)$	L_4	L_5
^{11}Be	13.7	5.0E9*	3.7E29	1.5E10	2.4E28	2.5E31	1.5E10	6.5E31	1.4E29**
^{12}Be	0.02	1.0E9*	1.1E28	6.2E5	1.0E24	1.1E27	2.5E5	1.1E27	
^{16}C	0.7	1.5E9*	1.0E29	2.1E8	3.4E26	3.5E29	1.8E8	8.0E29	
^{17}C	0.19	2.5E8	1.3E28	7.3E6	1.2E25	1.2E28	4.7E6	2.1E28	
^{18}C	0.09	3.0E7	1.1E27	3.0E5	4.9E23	5.0E26	1.5E5	6.6E26	
^{19}C	0.05	3.8E6	9.6E25	1.4E4	2.3E22	2.3E25	6.0E3	2.6E25	
^{32}Ar	0.098	2.0E6	8.0E25	2.3E4	3.8E22	3.8E25	1.2E4	5.2E25	
^{33}Ar	0.17	4.0E7	2.1E27	1.0E6	1.7E24	1.7E27	6.3E5	2.8E27	
^{34}Ar	0.84	2.0E9*	1.4E29	3.4E8	5.5E26	5.6E29	3.0E8	1.3E30	
^{35}Ar	1.77	1.0E10*	7.2E29	3.7E9	6.1E27	6.2E30	3.5E9	1.5E31	2.8E28**
^{40}S	8.8	2.0E9*	1.5E29	3.8E9	6.3E27	6.4E30	3.7E9	1.7E31	
^{41}S	2.0	7.0E8*	5.1E28	2.9E8	4.8E26	4.9E29	2.8E8	1.2E30	
^{42}S	1.0	2.0E8	1.4E28	4.0E7	6.7E25	6.8E28	3.7E7	1.6E29	
^{43}S	0.265	6.0E7	3.5E27	2.7E6	4.4E24	4.5E27	1.9E6	8.5E27	
Limit of luminosity			1E23		1E23	1E23		1E25	1E25

* *Productivity of modern gas cells (the stage of the RI stop in gas) is limited by the value ~ $5x10^8$ ions/sec.*

** Corresponding *luminosities for* ^{11}Be *and* ^{35}Ar *in the ELISe project [3] are* $2.4x10^{29}$ *and* $1.7x10^{27}$ $cm^{-2}sec^{-1}$.

Major bottlenecks

LINAC-100

Gas cell

Ring branch layout and measurement strategy

LINAC-100

4 new high-current HI LINACs are in construction

To recover high-frequency superconductivity technology in Russia and built most intense HI LINAC 100 AMeV (with possibility of upgrade) based on the gained experience in the world

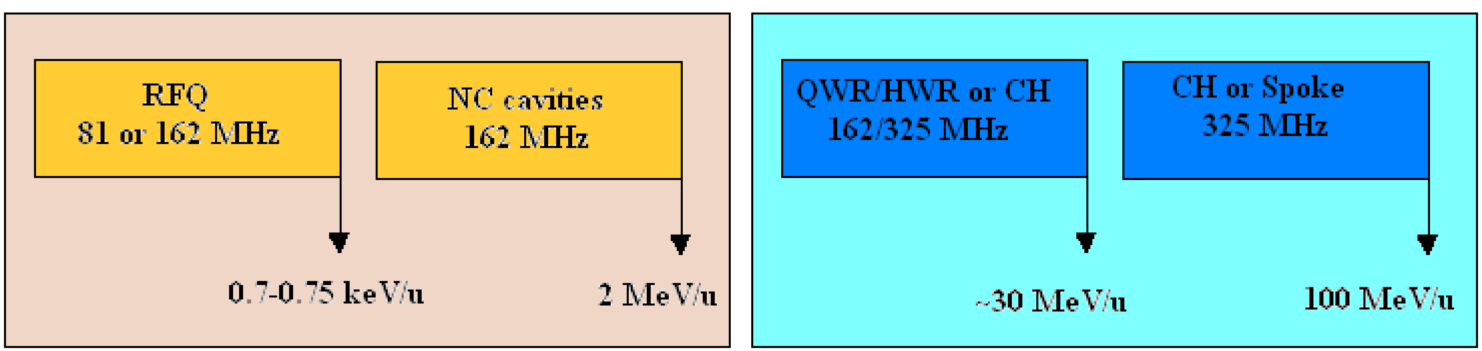
SPIRAL-2 CW-LINAC ~7 AMeV

GSI/FAIR UNILAC replacement, pulsed ~17 AMeV

MSU/FRIB CW-LINAC ~240 AMeV

HIAF pulsed LINAC ~17 AMeV

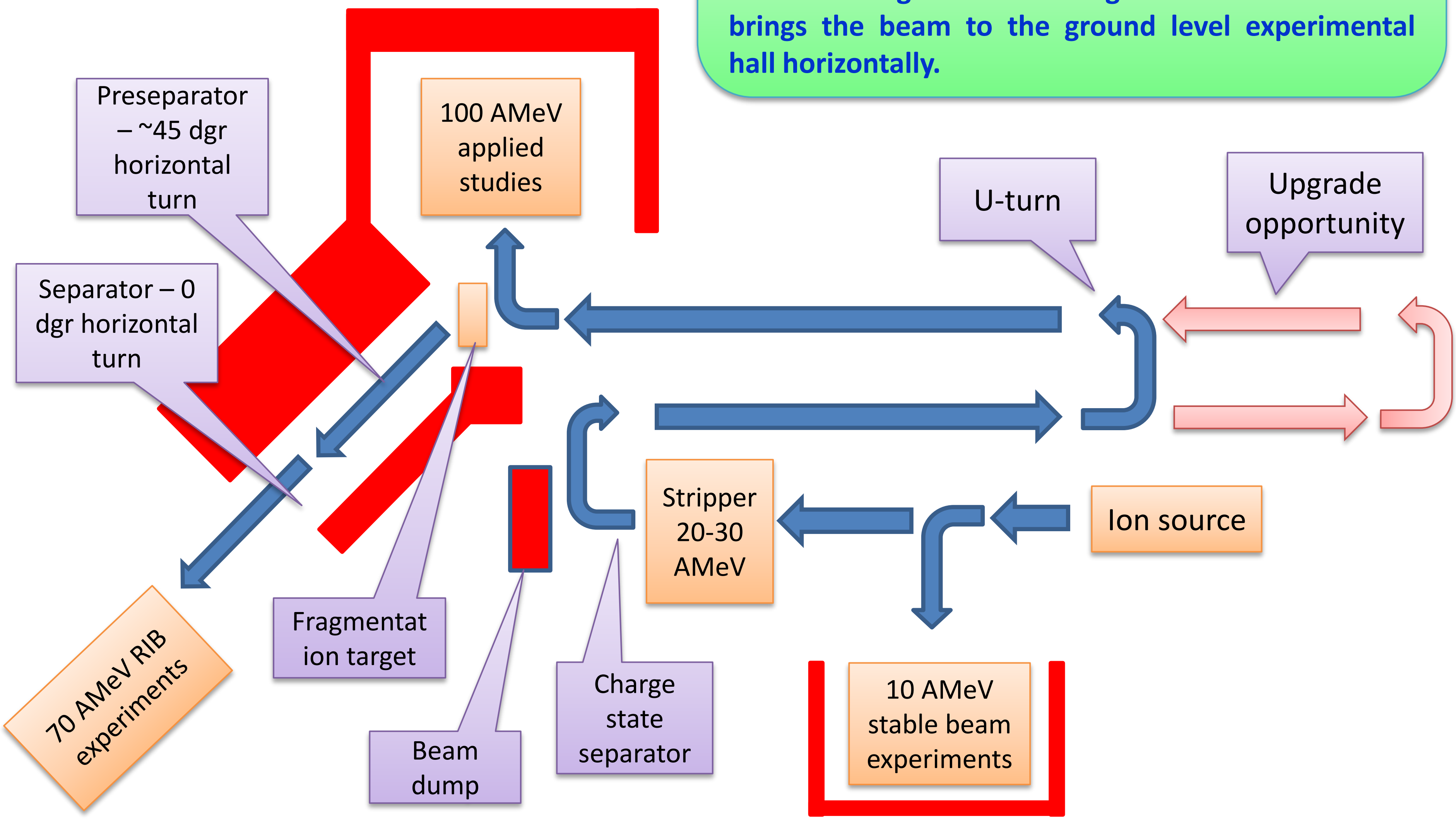
Korea - ???



First version of DERICA's driver LINAC-100 general layout

LINAC-100 + DFS layouts

Basic considerations: LINAC-100 in trench several meters underground. U-turn for opportunity of linac main section upgrade. Beam dump for charge state separator after striper. Two experimental halls. First DFS acromat (few meters underground), horizontal total turn angle around 45 dgr. Second DFS acromat brings the beam to the ground level experimental hall horizontally.



Major bottlenecks

Gas cell

Ring branch layout and measurement strategy

Major bottlenecks

Ring branch layout and measurement strategy

Outlook

Development of the large-scale accelerator and storage ring RIB facility based at FLNR JINR is proposed. The project is focused on the storage-ring studies of RIBs. World unique feature of the project is proposed studies of the electromagnetic formfactors of RI electron-RIB collider experiment.

– Important expertize in RF

but

– Never build without world expertize involved

– Comparatively cheap (~ 300 M€)

but

– World unique research opportunities

– Relatively small weight of concrete shielding

but

– Relatively large weight of hi-tech devices

– Long list of challenges for Russian scientific and engineering community

but

– Seem to be no crucial technological bottlenecks

Россия – щедрая душа

К концу декабря 2015 г. Прохоров стал единоличным владельцем команды "Бруклин Нетс", поскольку купил долю, которая принадлежала девелоперу Брюсу Ратнеру. В общей сложности российский бизнесмен потратил на команду $825 млн, включая долговые обязательства.

Вклад России в ценах 2005 года – 178.05 М€, что соответствует 17.4% от стоимости проекта ФАИР. Ожидается что ежегодный вклад на эксплуатацию составит порядка 30 М€.

Оценка стоимости проекта DERICA – около 270 М€ - сущие копейки…

http://aculina.jinr.ru/derica.php

Reserve

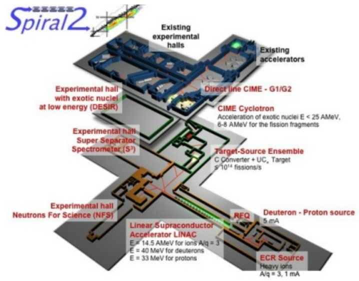
Reserve

Big, bigger, the biggest

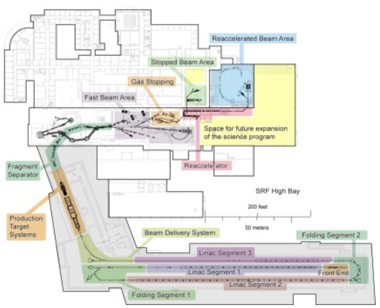
Huge increase in the scale of modern and prospective RIB facilities: Price tag 1-2 G€

Scale increase – (i) RIB production increase and (ii) universality of RIB facility

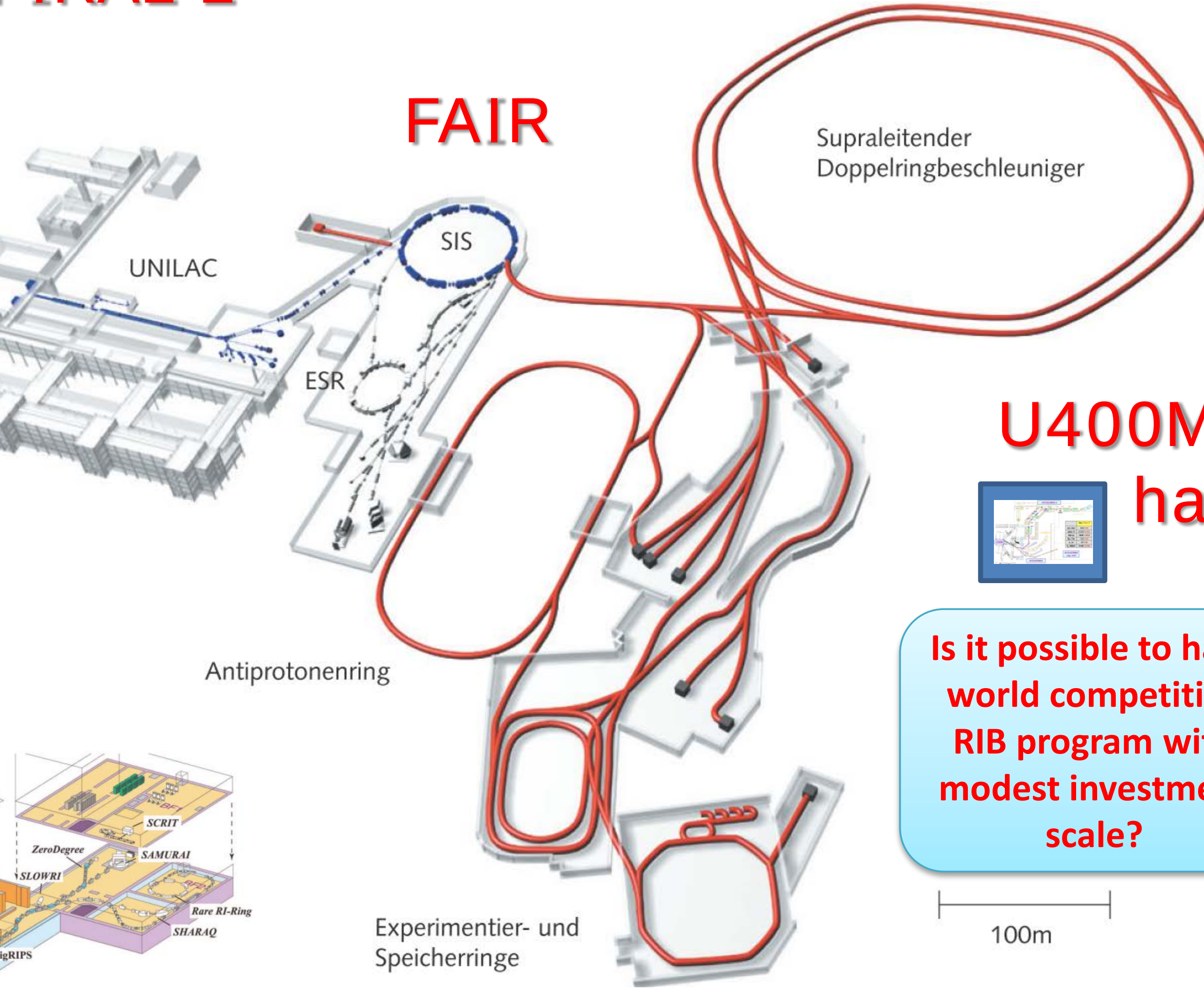
SPIRAL 2



FRIB



FAIR

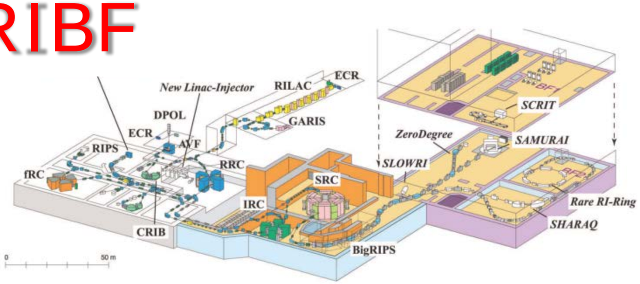


U400M hall

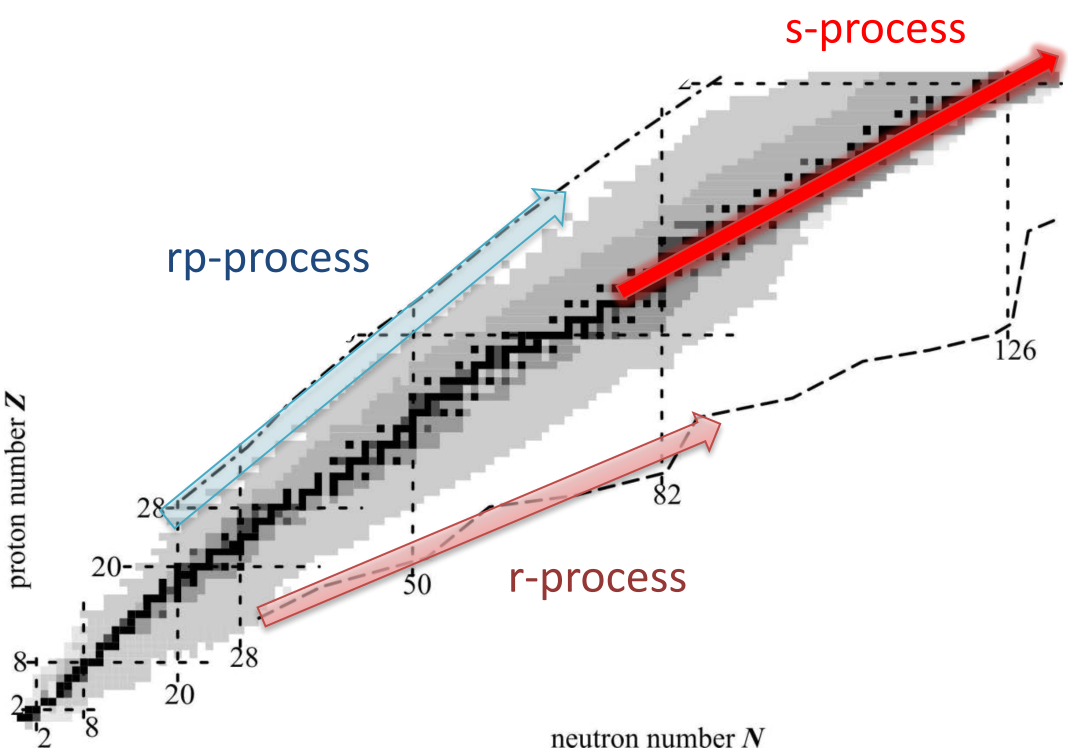
Is it possible to have world competitive RIB program with modest investment scale?

100m

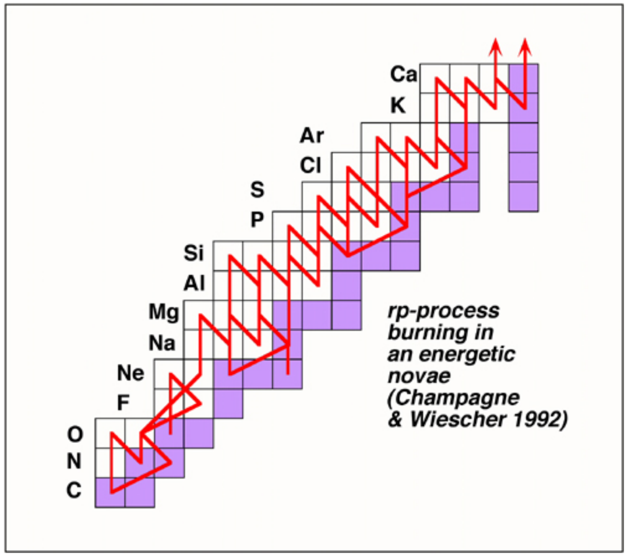
RIBF



Motivation – Applications to astrophysics (nucleosynthesys)



rp-process fragment



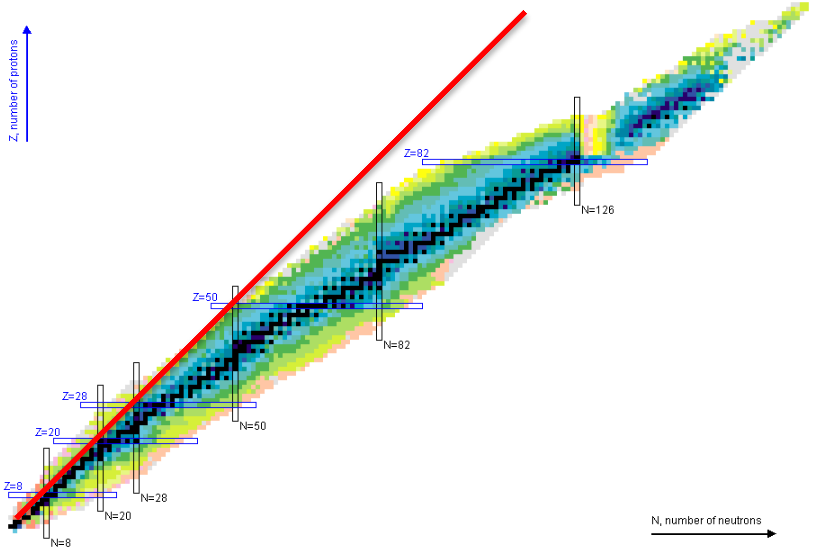
- Hydrostatic burning – slow process
- Explosive burning – rapid processes
- Where does it take place?
- Every day observed violent events in space are produced by rp-processes
- Element abundance in space is connected with r-processes
- No quantitative understanding until the driplines are studied in details

Motivation – Applications to neutron stars

PV = (m/μ) RT

Equation of state for ideal gas. What about nuclear matter?

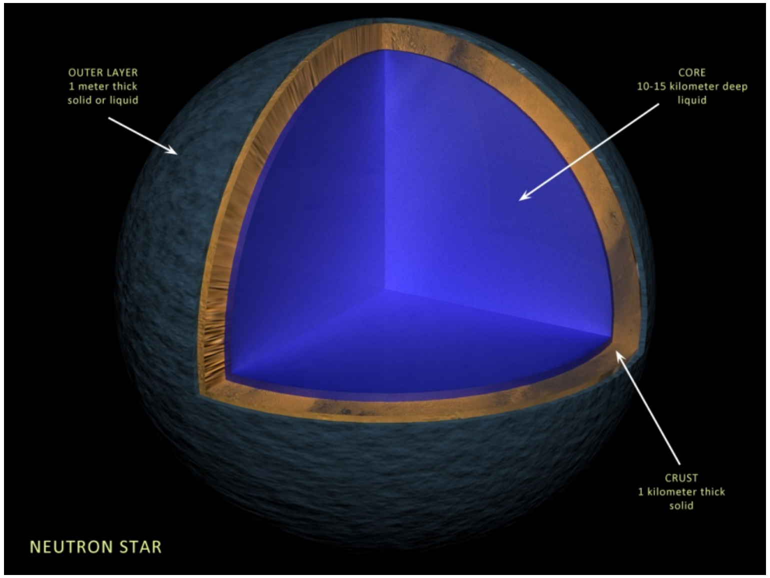
Known nuclei: practically symmetric nuclear matter



All the heavy elements in the Universe are produced in explosive nucleosynthesys

Supernovae explosions. How we get from neutron star to Supernova?

Neutron star: very large nucleus with absolutely asymmetric nuclear matter



Moving towards the driplines we get experimental knowledge about more and more asymmetric nuclear matter

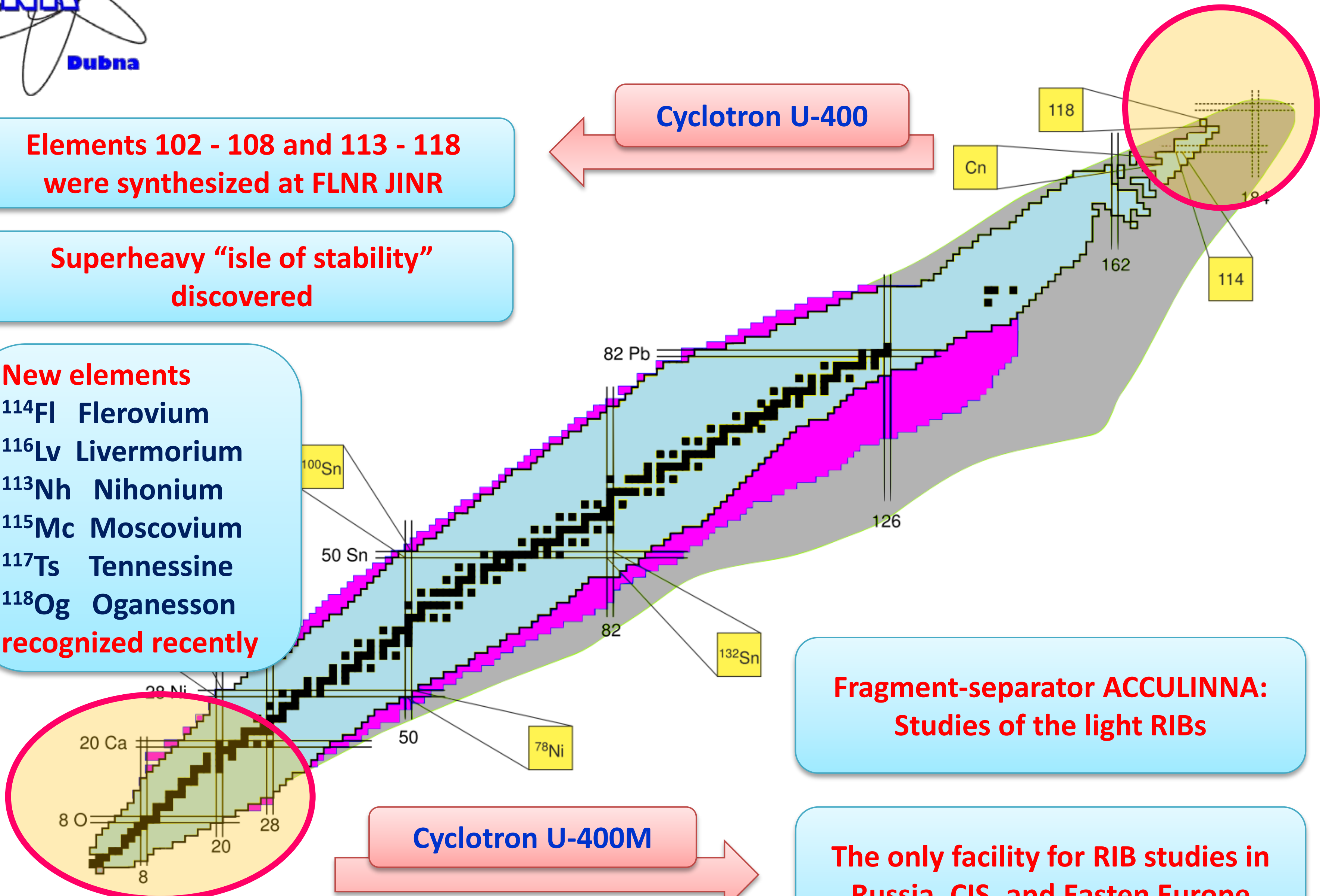
What we already have at Flerov lab

Cyclotron U-400

Elements 102 - 108 and 113 - 118
were synthesized at FLNR JINR

Superheavy “isle of stability”
discovered

New elements
^{114}Fl Flerovium
^{116}Lv Livermorium
^{113}Nh Nihonium
^{115}Mc Moscovium
^{117}Ts Tennessine
^{118}Og Oganesson
recognized recently



Fragment-separator ACCULINNA:
Studies of the light RIBs

Cyclotron U-400M

The only facility for RIB studies in
Russia, CIS, and Easten Europe

Challenges: rings

FRR Fast Ramping Ring Synchrotron

- $\Delta E \sim 30 - 300$ AMeV
- Fastest possible operation time (< 0.5 s - ?) to enhance research opportunities with short- lived nuclides

CR Collector Ring

- Versatile design with 3 major experimental areas

CE Electron Ring

- E ~ 500 MeV
- Highest possible bunched beam intensity for collider operation

Challenges: LINACs

Luminosity is our absolute aim

LINAC-100

- Universal heavy-ion accelerator
- Good for RI production nuclides from B to U
- Up to 100 AMeV for B, 60 AMeV for U
- Up to 10 pμA for light ions DC operation

LINAC-30

- Universal heavy-ion accelerator
- ALL CHART OF NUCLIDES
- Up to 30 AMeV, 10^{10} pps
- Pulses < 50 ms, < 20 Hz

e-LINAC

- 500 MeV electrons
- Pulses of highest possible intensity

Challenges: other important devices

DFS fragment-separator
- Unusual design with very large aperture for gas cell mode operation
- Double achromatic or velocity filter?

Ion sources
- ECR for LINAC-100 with highest charges/intensities
- EBIS for LINAC-30 with highest charges /shortest operation time

Gas jet target at CR
- Operation modes for maximum luminosity (~5x10^{15} thickness) and precision experiments (~5x10^{13} thickness)

Gas Cell
- For high intensity RIBs from DFS this is a bottleneck technology
- Modern limitation 10^{8} pps – what about 10^{10} ?

Neutron "target" at CR
- Neutron-RI collision can be studied only on "neutron target" in ring

Electron cooler at CR
- Sufficient performance for "crystallized beam" CR mode for low-intensity RIBs

Предыстория. К4-К10.

Yu.Ts. Oganessian *et. al.*,
Z. Phys. A341 (1992) 217

Инжекция от циклотрона U-400M

Кольцо К4 (Магнитное поле 4 Tm)
- Накопление
- Охлаждение
- Формирование банчей
- Ускорение

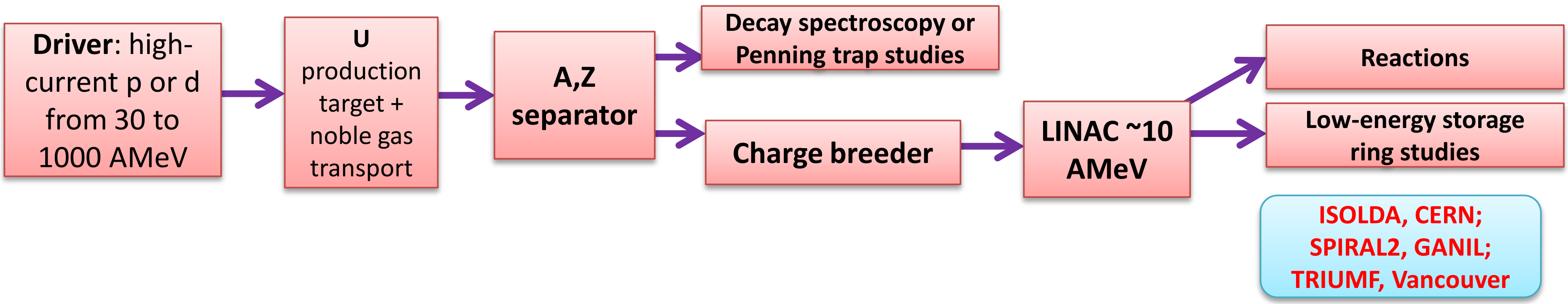
Канал сепарации
(фрагмент-сепаратор)

Кольцо К10 (Магнитное поле 10 Tm)
- Спектрометр сверхвысокого разрешения
- Реакции на внутренней мишени

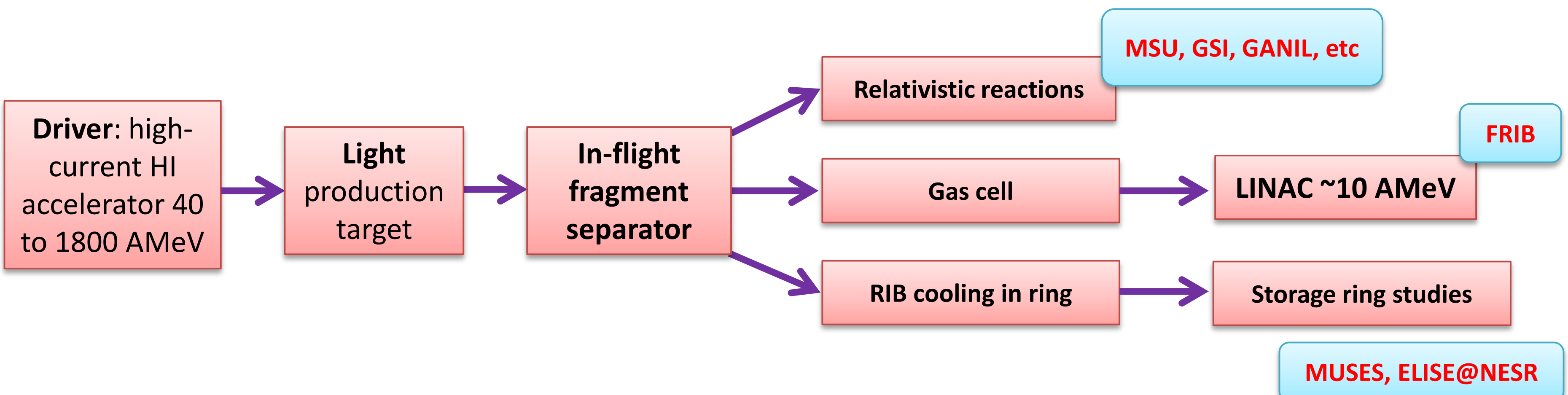
Электрон-ионный коллайдер

Currently realized RIB studies strategies

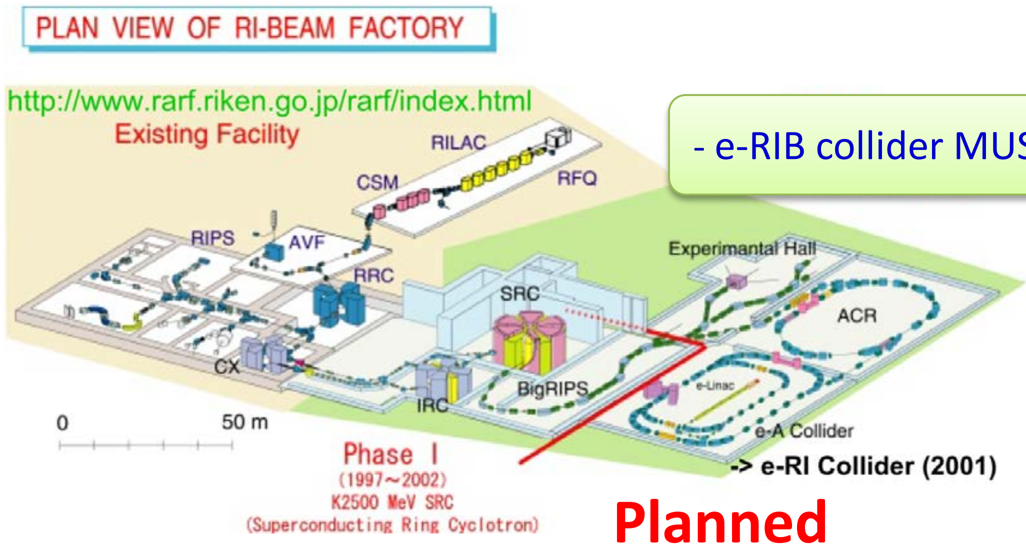
Ordinary approach 1: ISOL RIB production + reaccelerated RIBs up to 10 AMeV



Ordinary approach 2: In-flight RIB production

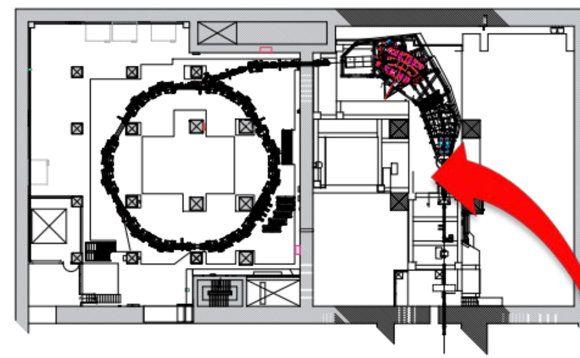


e-RIB colliders: Evolution of RIKEN



- e-RIB collider MUSES

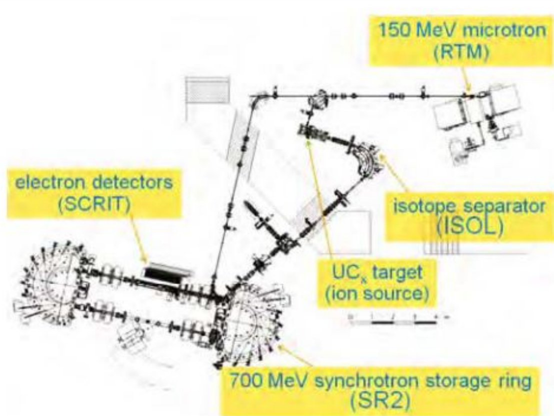
RI-Ring: isochronous mass spectroscopy for very rare events

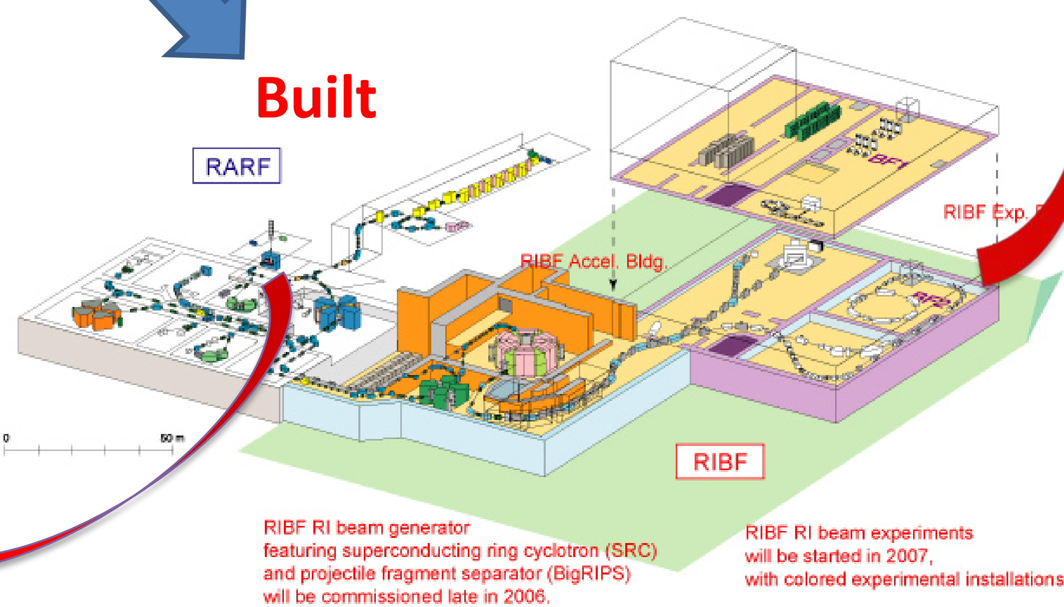


Planned

Built

SCRIT: separate-standing ISOL facility for e-RIB collision studies in trap



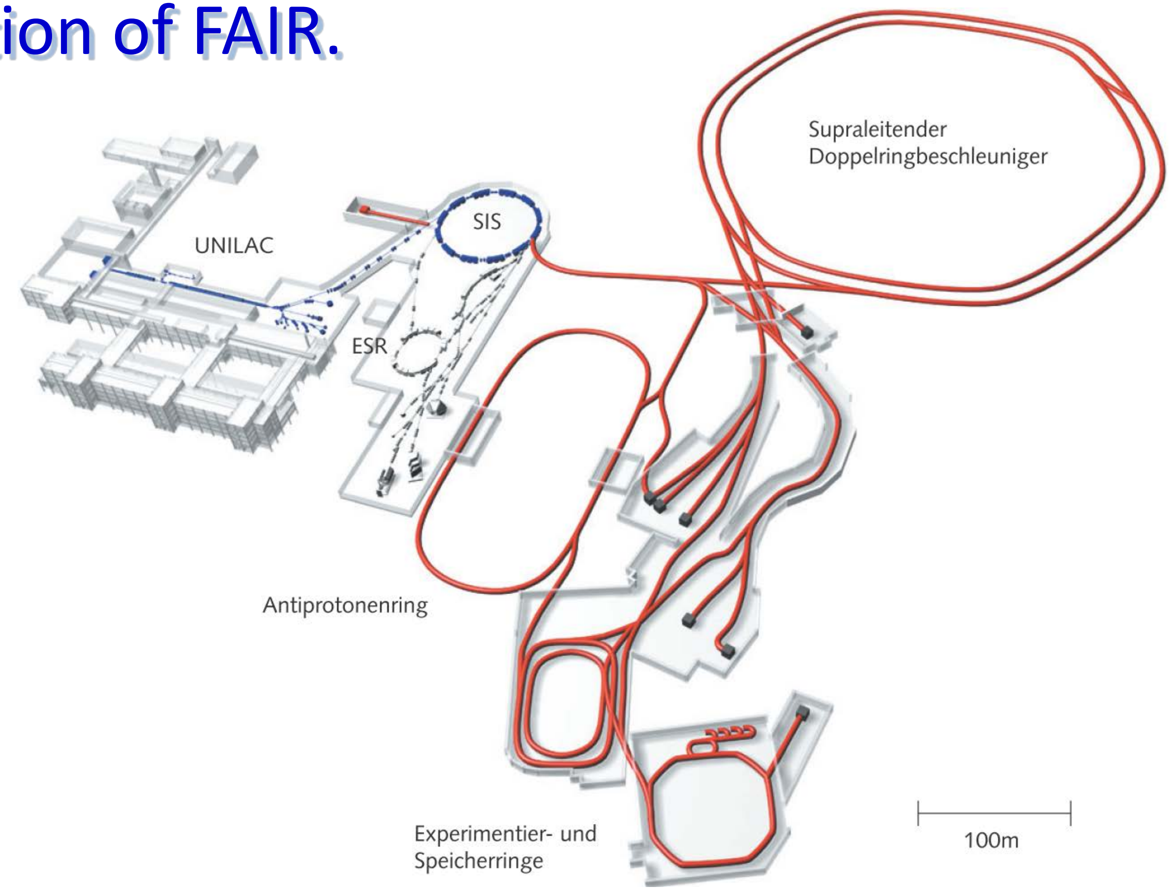


e-RIB colliders: Evolution of FAIR.

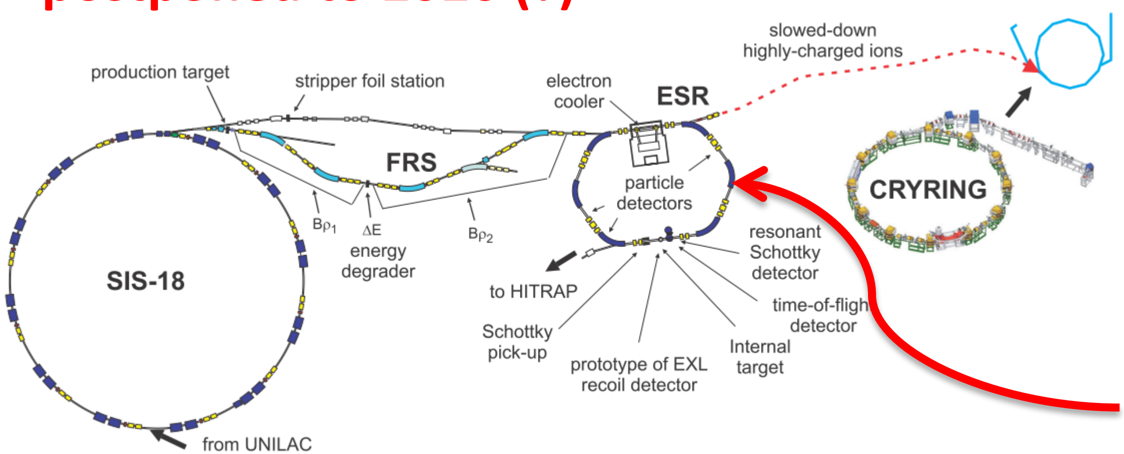
Planned

FAIR "Ring Branch":
- Storage ring CR
- Experimental ring NESR

NESR@FAIR:
- e-RIB collider ELISE
- experiments on the internal gas target EXL



Decision postponed to 2026 (?)



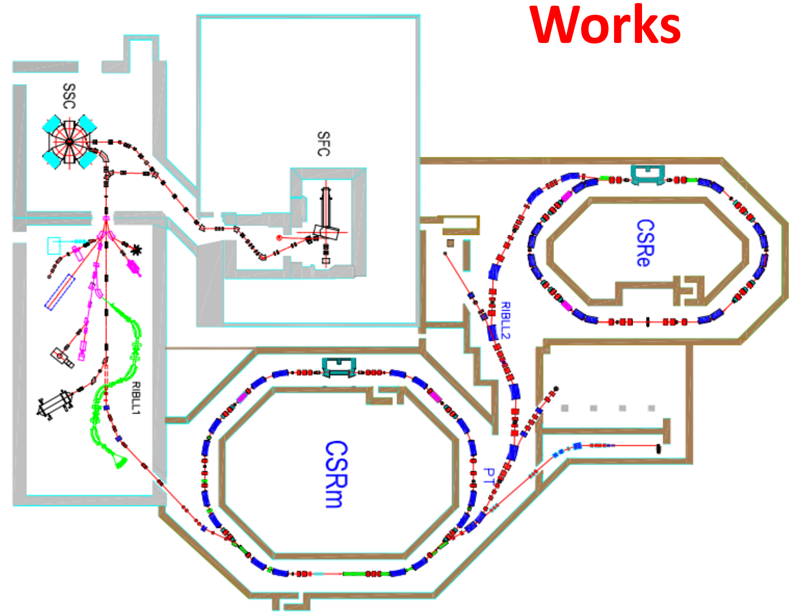
Низкоэнергетическая программа: переезд CRYRING из Швеции

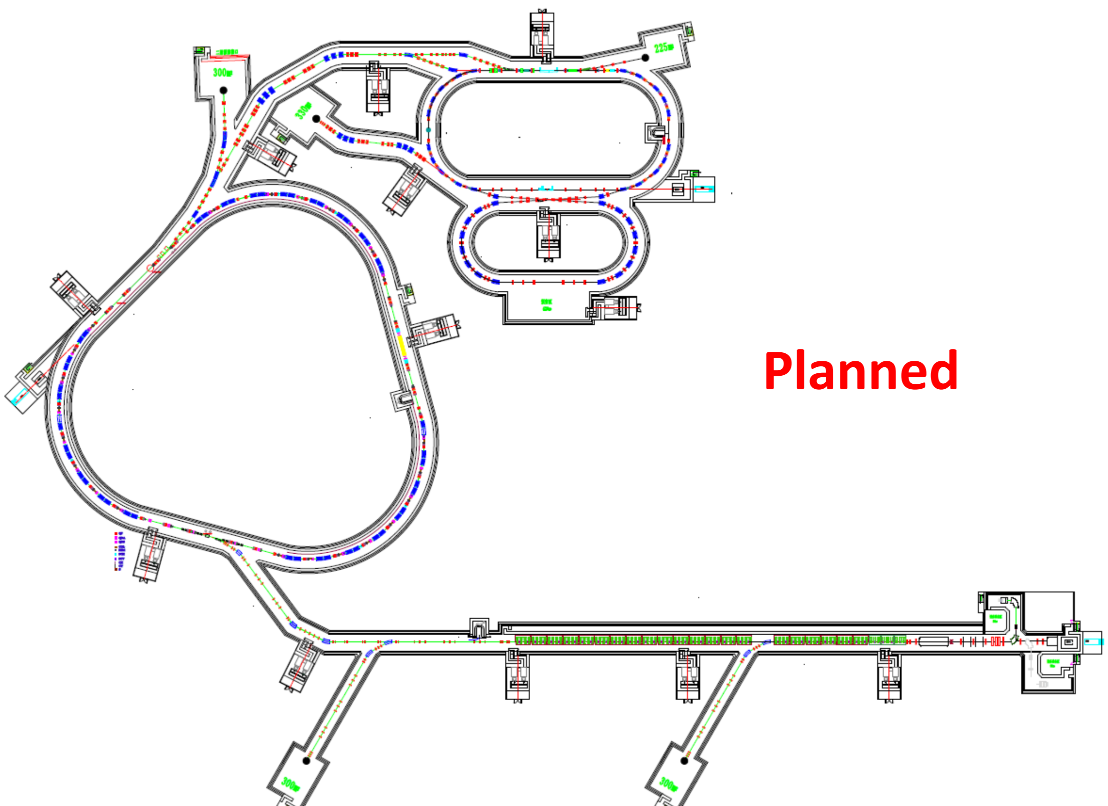
Возможность включить ESR в FAIR: Пучковая линия от SuperFRS ??? L ~ 200 m !!!

Storage rings. China

HIRFL-CSR@Lanzhou
- Weak “driver”
- Not much space for driver upgrade

Works





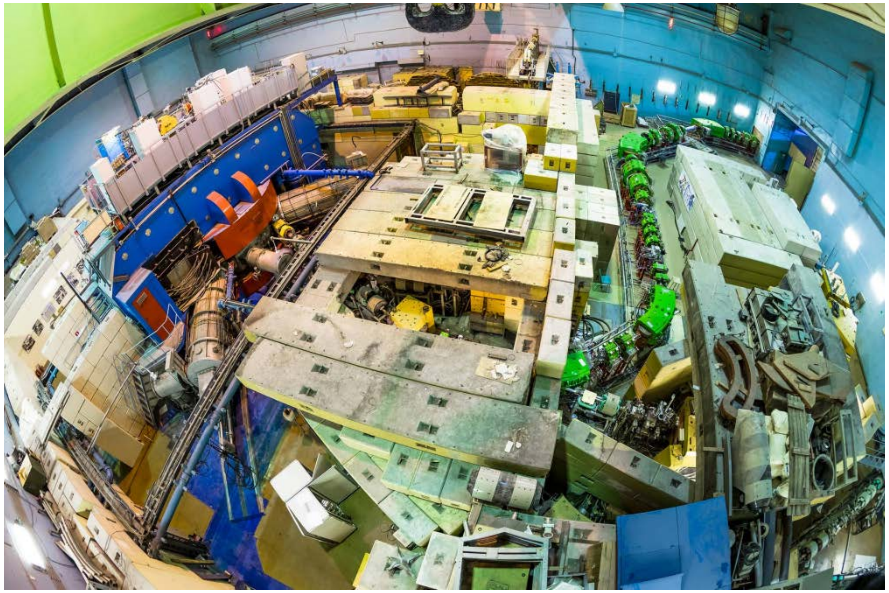
Planned

HIAF:
- 2 storage rings
- 1-st – main function spectrometer
- 2-nd – reactions with “merging beams”

New facilities at FLNR

“Factory of superheavy elements”

ACCULINNA-2 fragment-separator



History of U-150 vs U-400M

Underdeveloped field: storage ring physics with RIBs

Empty field: studies of RIBs in electron-RIB collider

Isochronous mass spectromentry

RIB stor

СОВРЕМЕННАЯ ИССЛЕДОВАТЕЛЬСКАЯ ИНФРАСТРУКТУРА РОССИЙСКОЙ ФЕДЕРАЦИИ
УНИКАЛЬНЫЕ НАУЧНЫЕ УСТАНОВКИ

СВЕДЕНИЯ О РЕЗУЛЬТАТИВНОСТИ ЗА 2016 ГОД (ДАННЫЕ МОНИТОРИНГА)

УЧАСТИЕ В МОНИТОРИНГЕ нет

ЧИСЛО ОРГАНИЗАЦИЙ-ПОЛЬЗОВАТЕЛЕЙ, ЕД. 0

ЧИСЛО ПУБЛИКАЦИЙ, ЕД. 0

ЗАГРУЗКА В ИНТЕРЕСАХ ВНЕШНИХ ОРГАНИЗАЦИЙ-ПОЛЬЗОВАТЕЛЕЙ, % 0.00

Precision reaction studies on internal gas jet target

Atomic physics studies with striped ions

Radioactivity studies with striped ions

Etc….