Леонид Григоренко

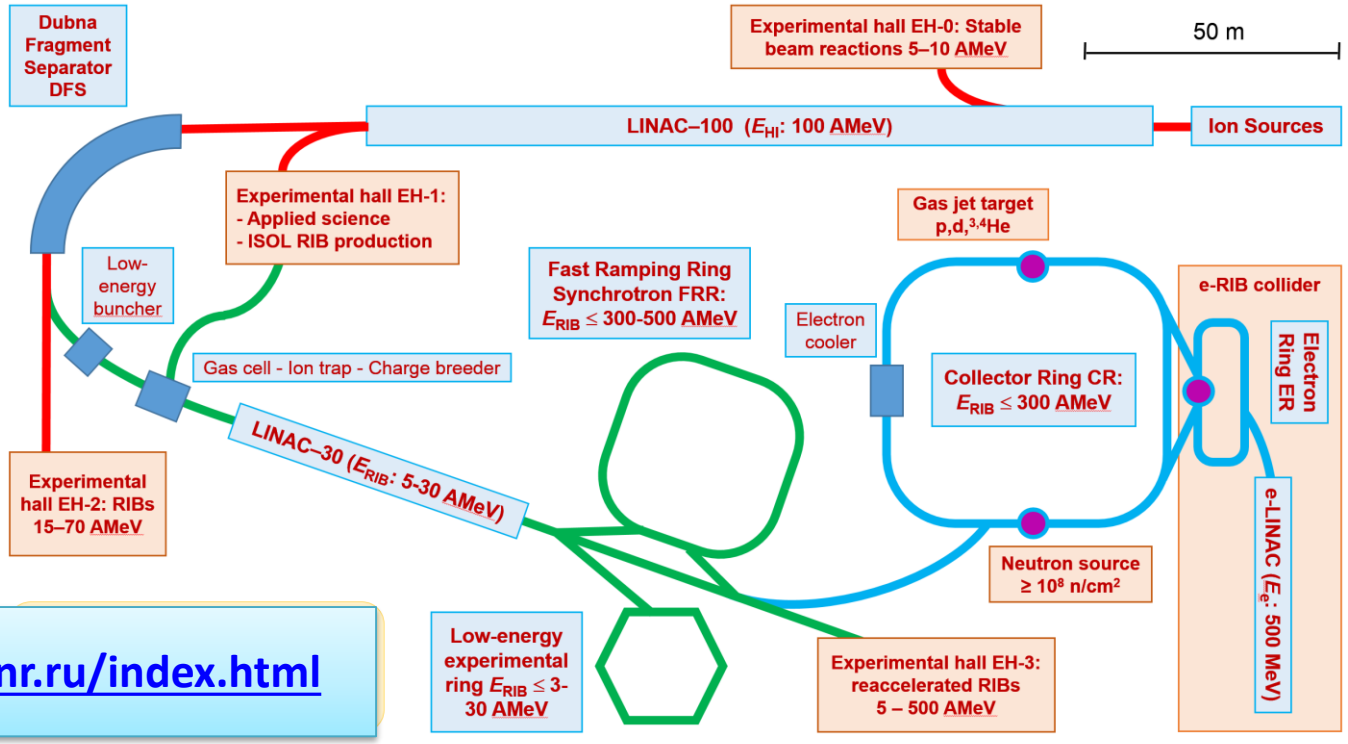
ОИЯИ, Дубна

Joint Institute for Nuclear Research

SCIENCE BRINGING NATIONS TOGETHER

DERICA

Проект DERICA



http://derica.jinr.ru/index.html

Does DERICA project exist in any sense?

Officially what is happening are “feasibility studies of DERICA project”

Developments of number of key technologies to be started NOW

Public visibility of the project

★Совета РАН по физике Тяжелых Ионов, Дубна, 1 декабря 2017

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

★ 41 European Cyclotron Progress Meeting, Dubna, Russia, September 3 – 5, 2018

★ EXON 2018, Petrozavodsk, September 10 – 14, 2018

★ General meeting of the Physical Section of RAS November 12, 2018

★ Technical Meeting on Novel Multidisciplinary Applications with Unstable Ion Beams and Complementary Techniques , IAEA Headquarters, Vienna, Austria, December 10–14, 2018

★ Nuclear Physics section of RAS meeting, JINR, Dubna, March 14 – 15, 2019

★ NUPECC meeting, Dubna, Russia, June 20 – 21, 2019

★ COOL 2019 workshop, Budker INP, Novosibirsk, Russia, 23-27 September 2019

April 26, 2018. The is project is submitted to Russian Ministry of Education and Science on the call for «Proposals to build “megascience”-class facilities on the territory of Russian Federation» as joint JINR-BINP venture

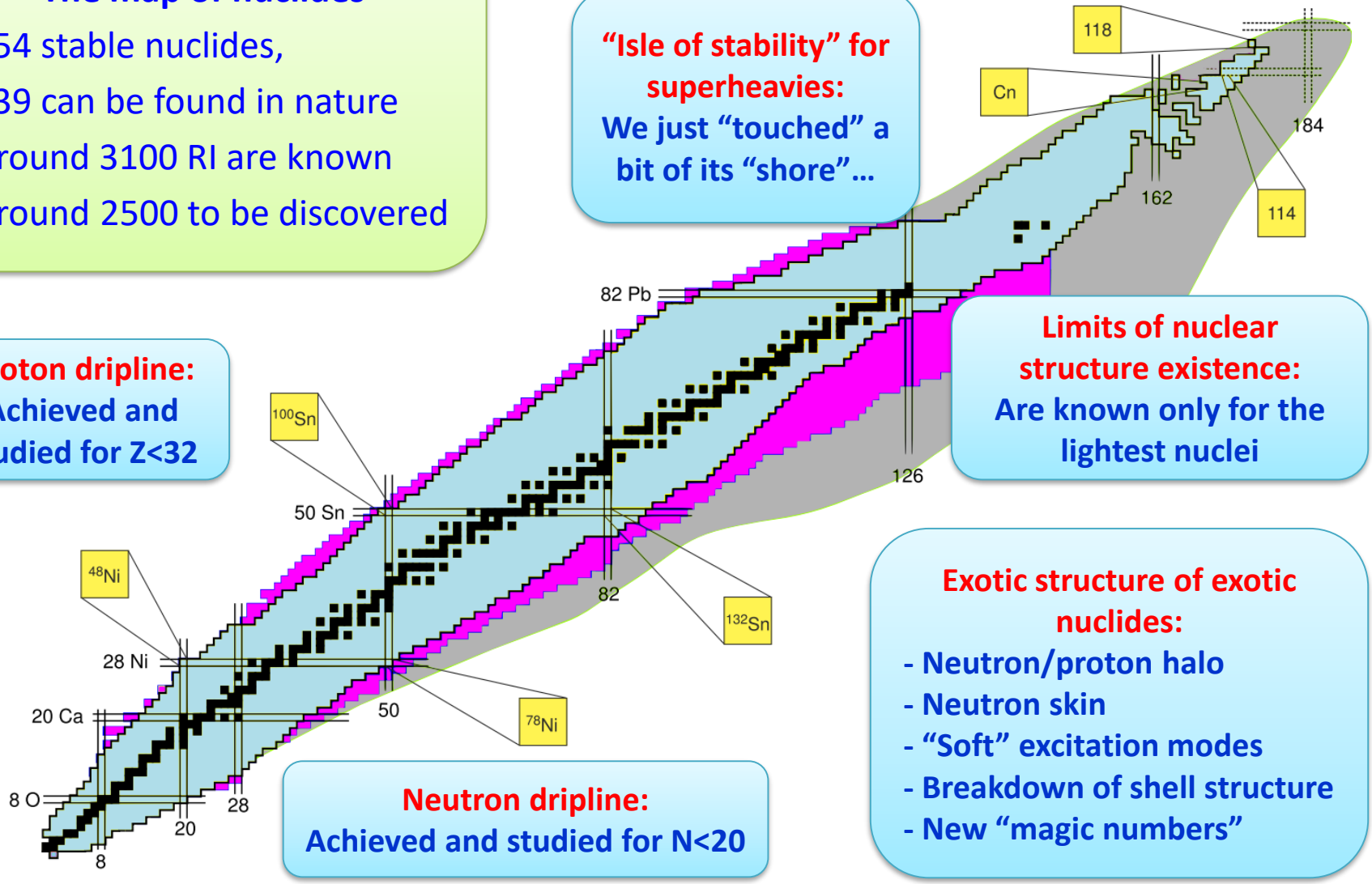
In September 2018 evaluation by Russian Academy of Sciences positioned DERICA in the top of the proposals list.

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"

“Discovery potential” of Radioactive Ion Beam

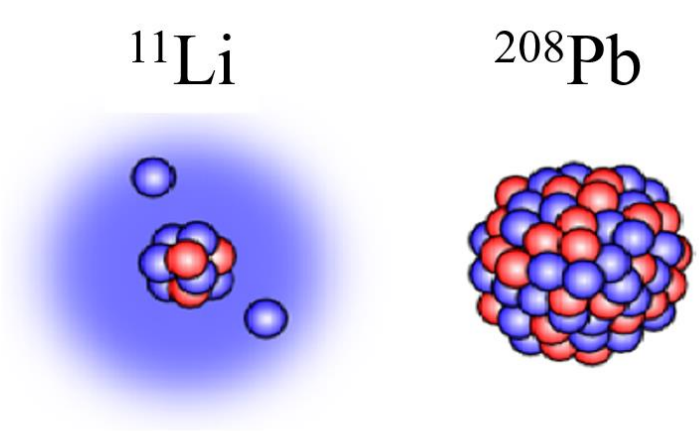
Перевод с «новояза»: Дохода от вас все равно никакого, так хоть когда вы привезете нобелевскую премию?

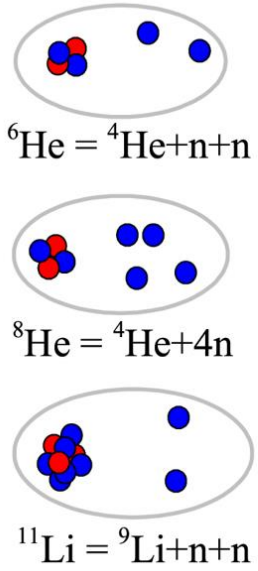
Замечание. Прежде чем речь пойдет о нобелевских премиях неплохо бы в стране создать просто современную исследовательскую инфраструктуру

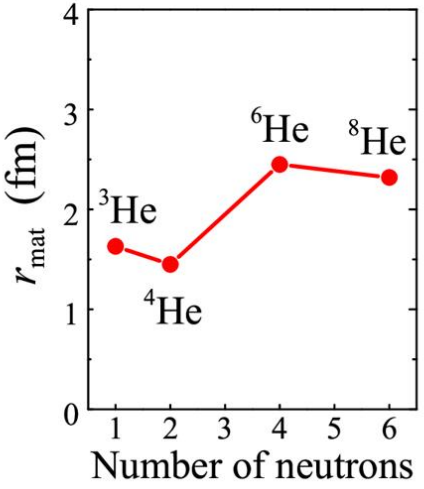
1991, диплом в Курчатовском институте.

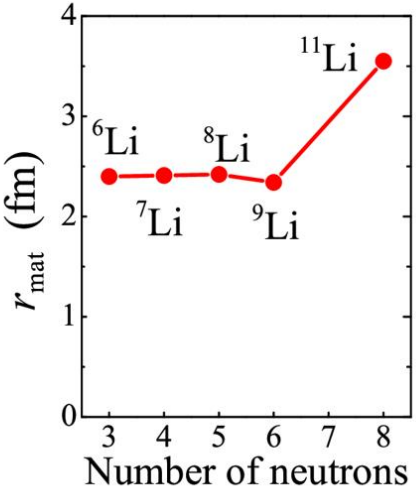
«Гуру»: Ядерная физика низких энергий это архаическая и бесперспективная наука в которой уже 40 лет ничего существенного не происходит.

Nuclear halo

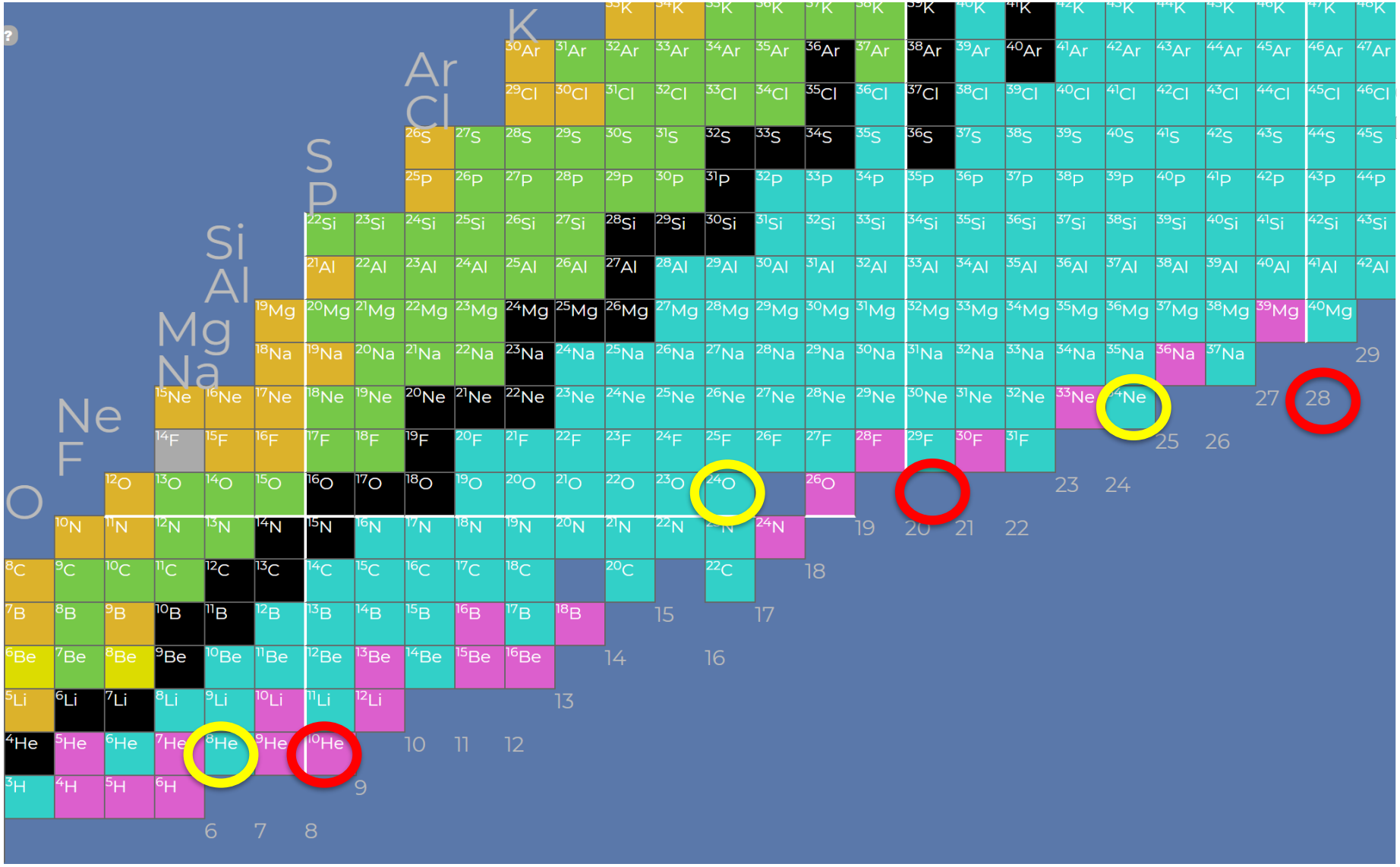








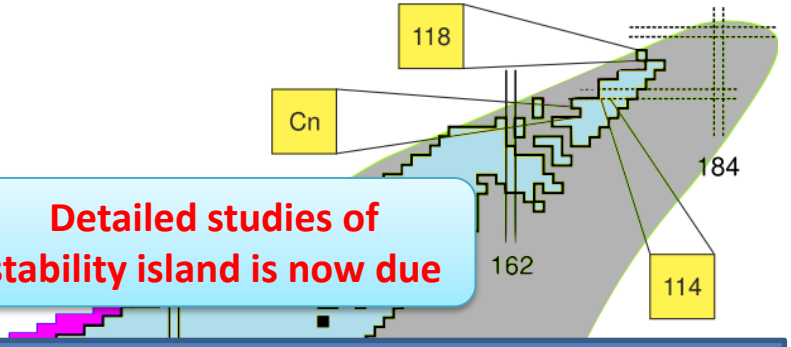
New shells far from stability



Superheavy “island of stability”

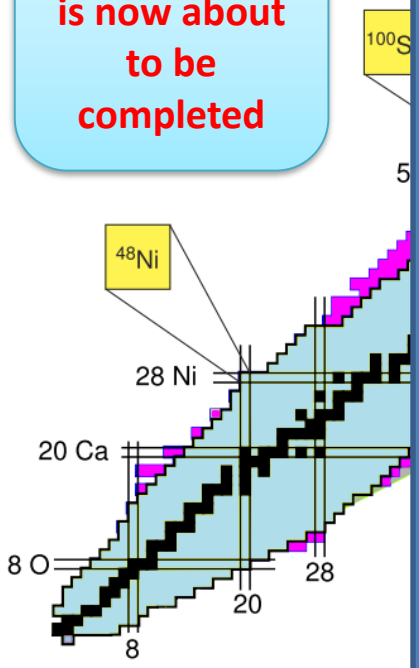
Elements 113 - 118 discovered at Flerov lab.

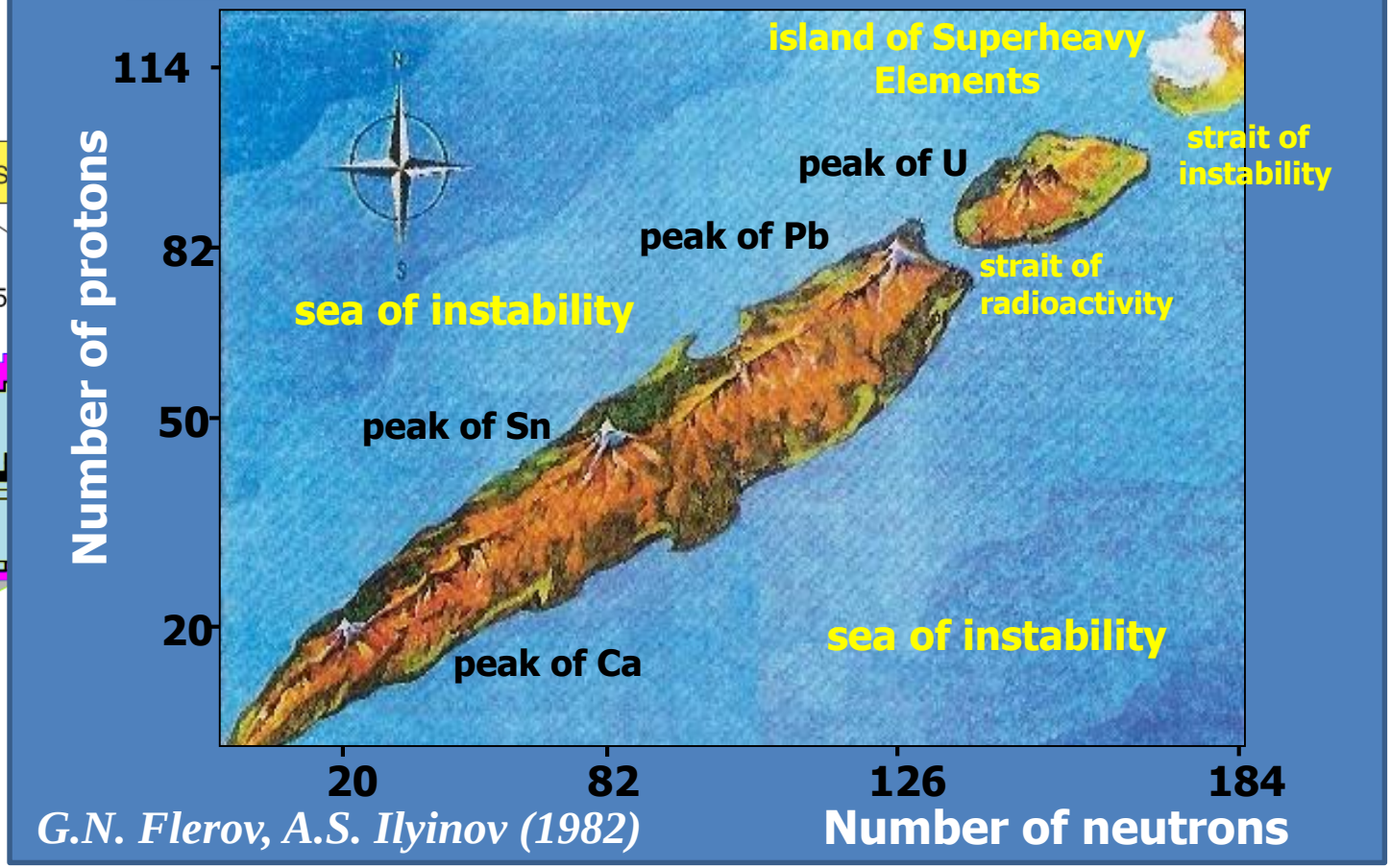
^{114}Fl Flerovium
^{116}Lv Livermorium
^{113}Nh Nihonium
^{115}Mc Moscovium
^{117}Ts Tennessine
^{118}Og Oganesson



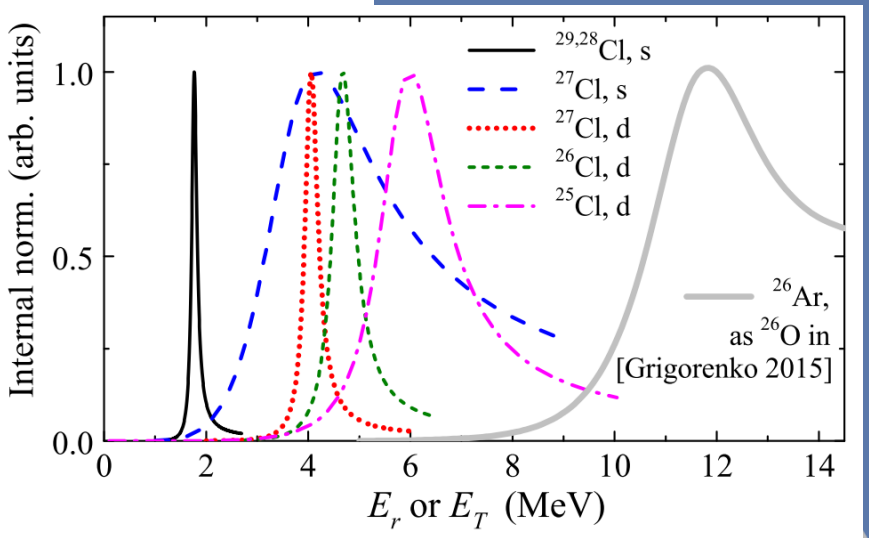
Detailed studies of stability island is now due

Chemical periodic table is now about to be completed

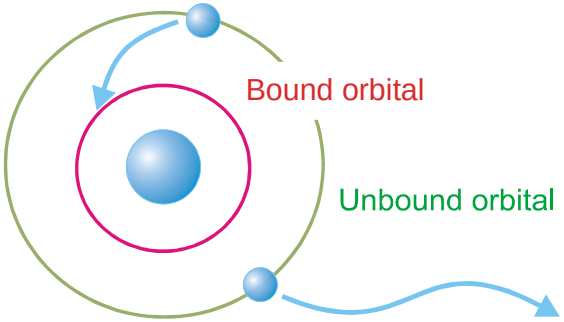




Towards the limits of nuclear structure existance

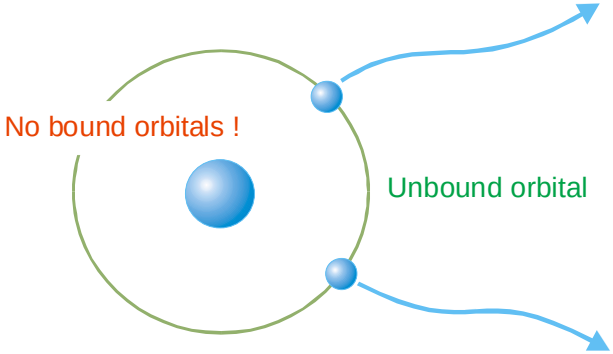


Exotic types of radioactive decays



Classical case:
one particle emission is always possible

Quantum mechanical case:
it could be that both particles should be emitted simultaneously



Goldansky and Zeldovich, 1960
p, 2p radiaoctivity

S. Hofmann, 1984
p radioactivity

M. Pfutzner, 2002
2p radioactivity

?

???
2n radioactivity

?

???
4n radioactivity

What we already have at Flerov lab

JINR
114 Flerovium
FLNR
Dubna

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

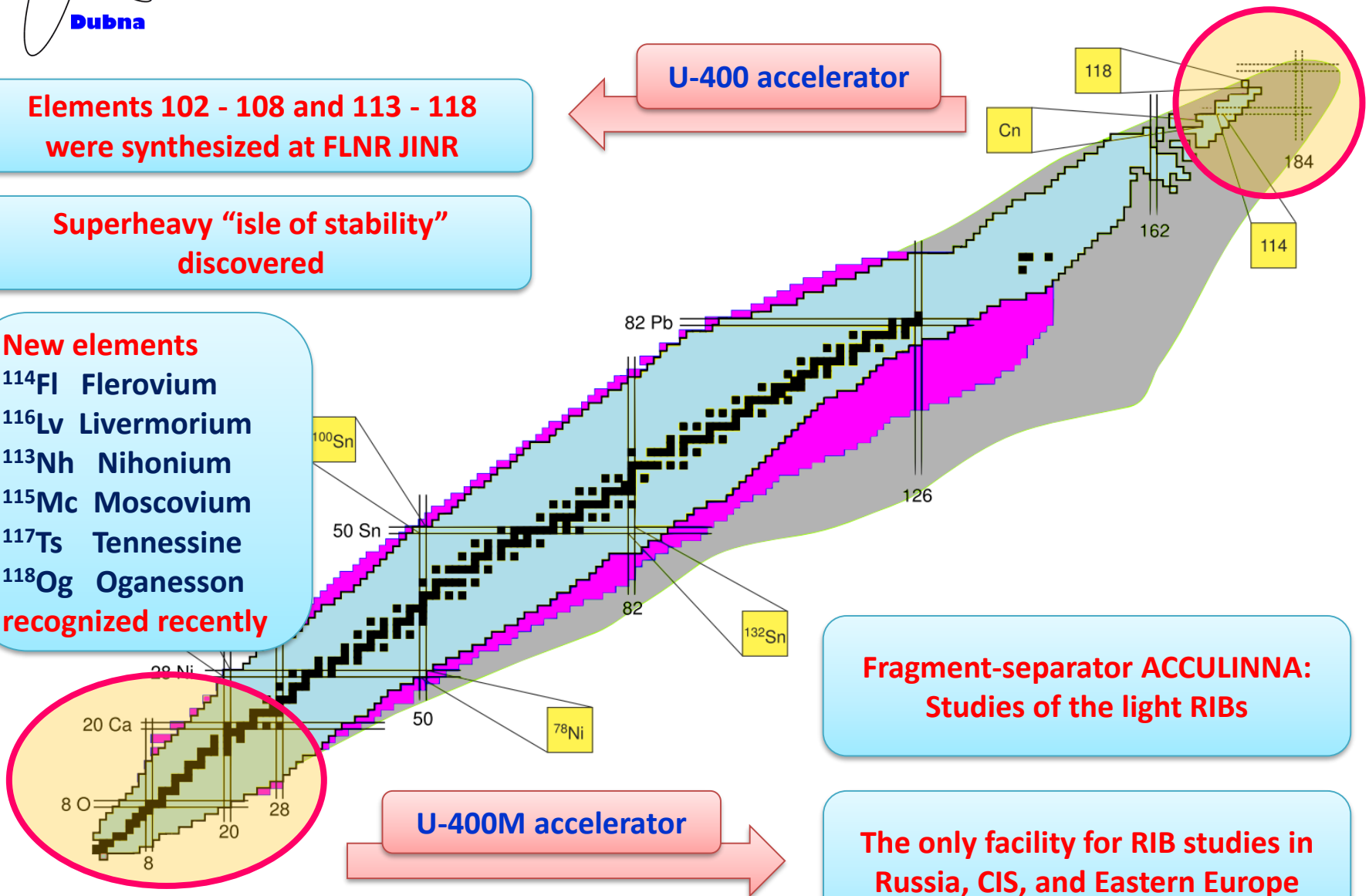
Superheavy "isle of stability" discovered

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



Fragment-separator ACCULINNA: Studies of the light RIBs

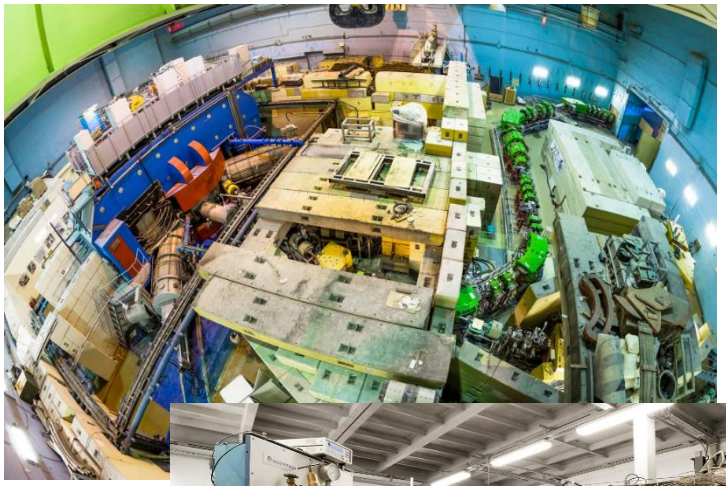
U-400M accelerator

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

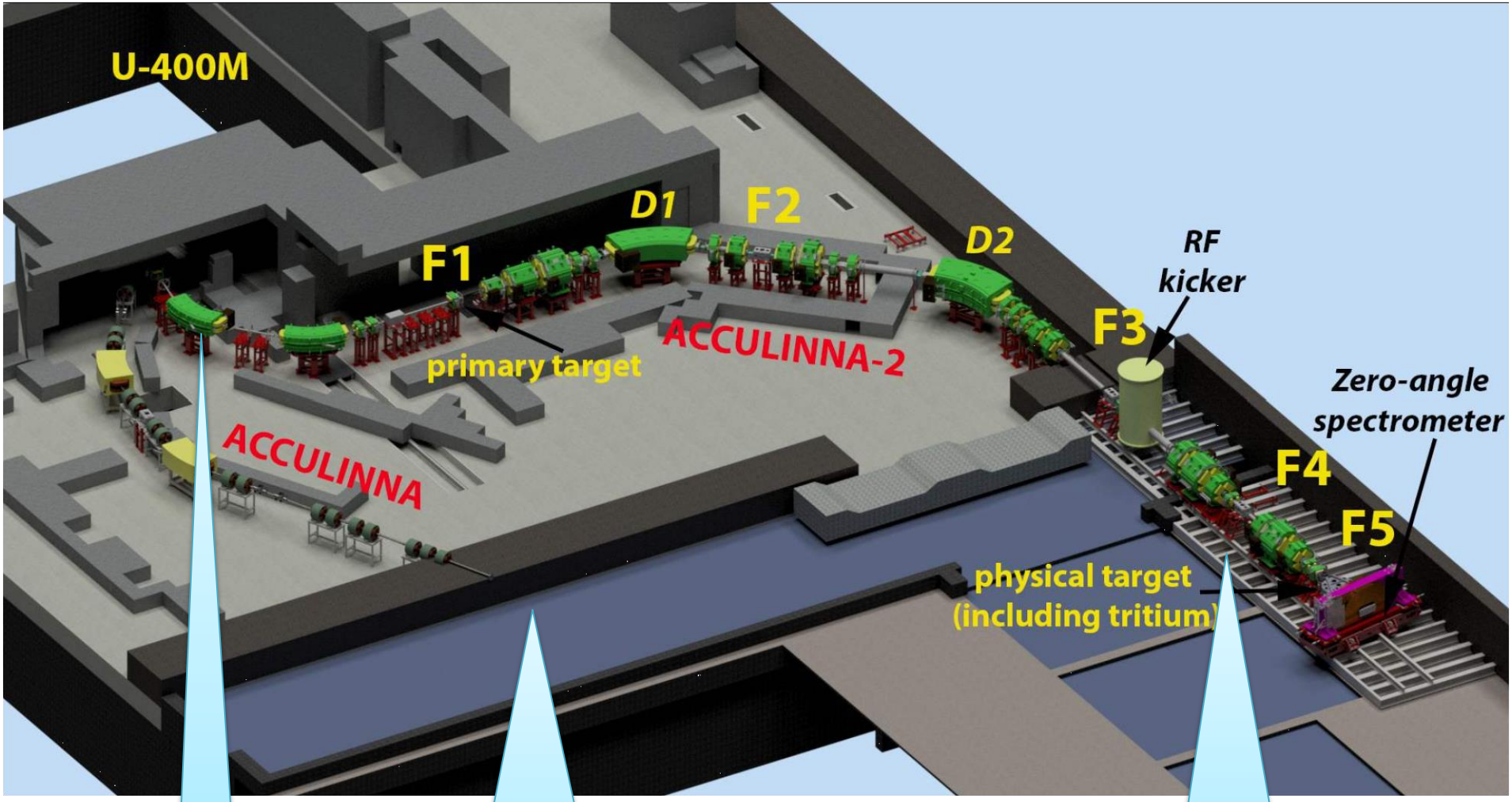
New facilities at FLNR

“Factory of superheavy elements”

ACCULINNA-2 fragment-separator



2014-2018: from ACCULINNA to ACCULINNA-2

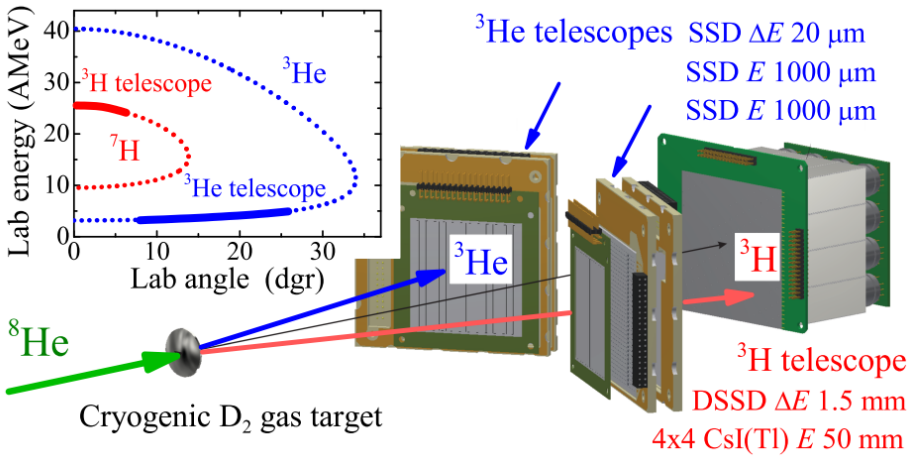


U-400M hall

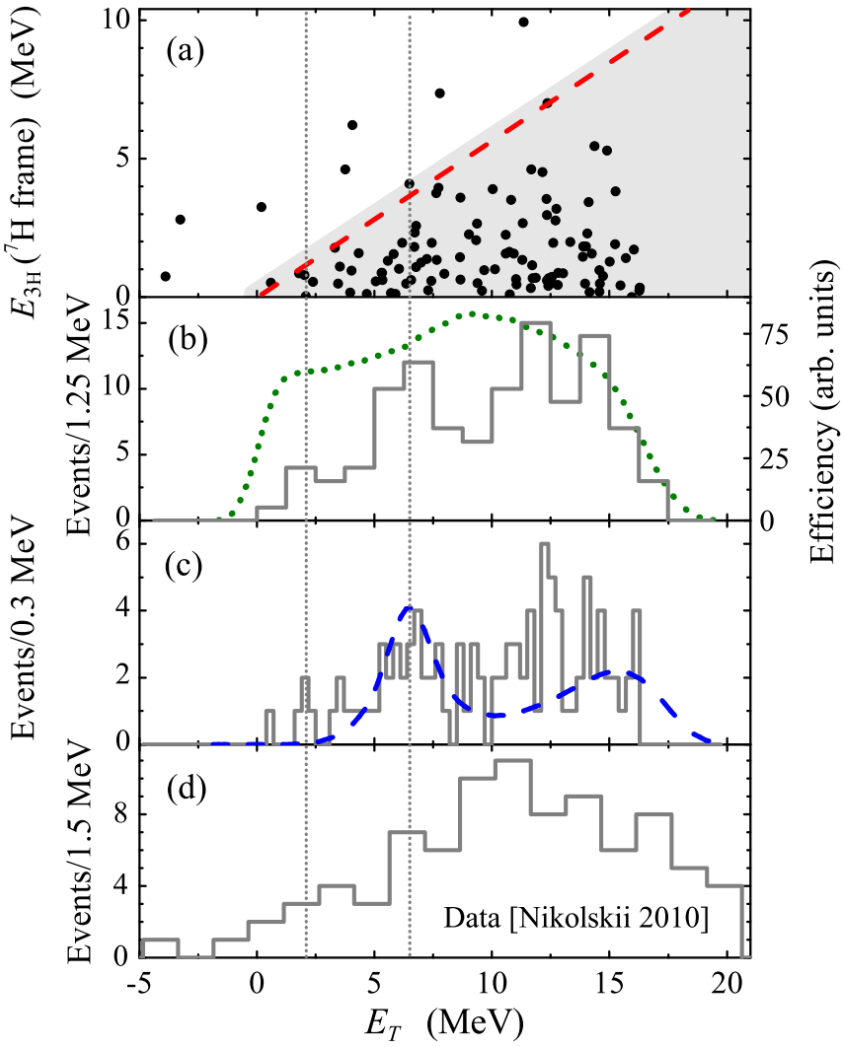
ACCULINNA experimental hall

ACCULINNA-2 experimental hall

^{7}H studied in the ^{2}H(^{8}He, ^{3}He)^{7}H -> t+4n reaction



^{8}He beam 26 AMeV, >10^{5} pps



A.A. Korsheninnikov, 2003, ^{8}He(p,2p)^{7}H
There is something E<2

M.S. Golovkov, 2004,
No long living g.s.

Caamano, 2007,
^{7}H g.s. at 0.57 MeV

Nikolskii, 2010,
There is something E<3

- Excited state at 6.5 MeV
- Indication of ground state at 2.1 MeV
- May be something at 12 MeV

A. A. Bezbakh, PRL **124**, 022502 (2020)

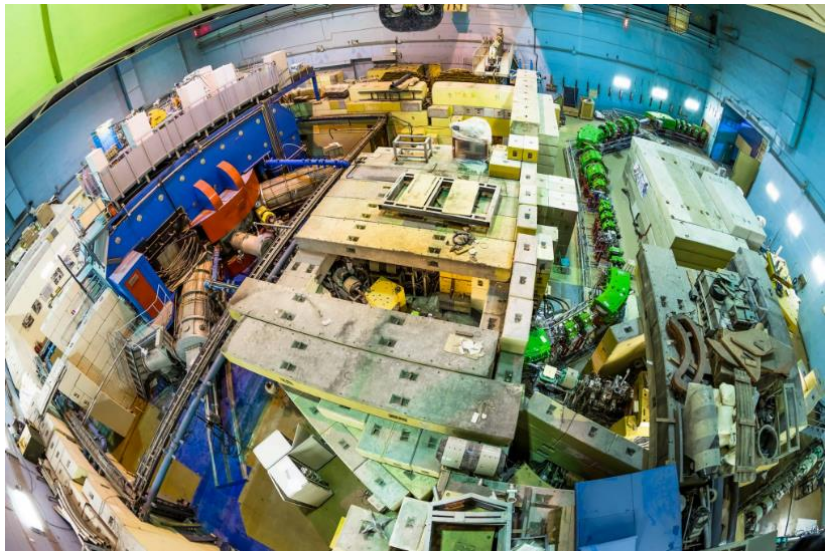
New facilities at FLNR

DC-280

U-400 1976

U-400M 1989

ACCULINNA-2 fragment-separator



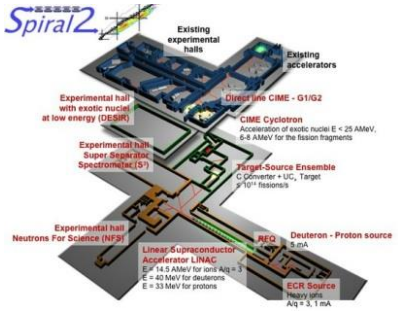
LISE (GANIL) 1984

RIPS (RIKEN) 1989

RIB facilities in the world

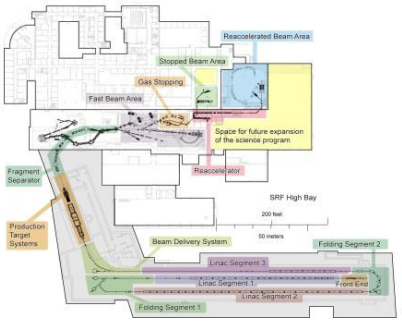
What to be added?

RIB factories: Big, bigger, the biggest…

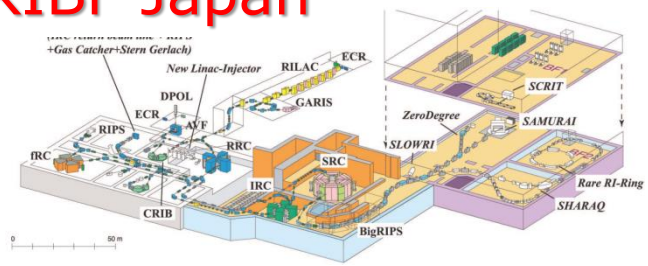


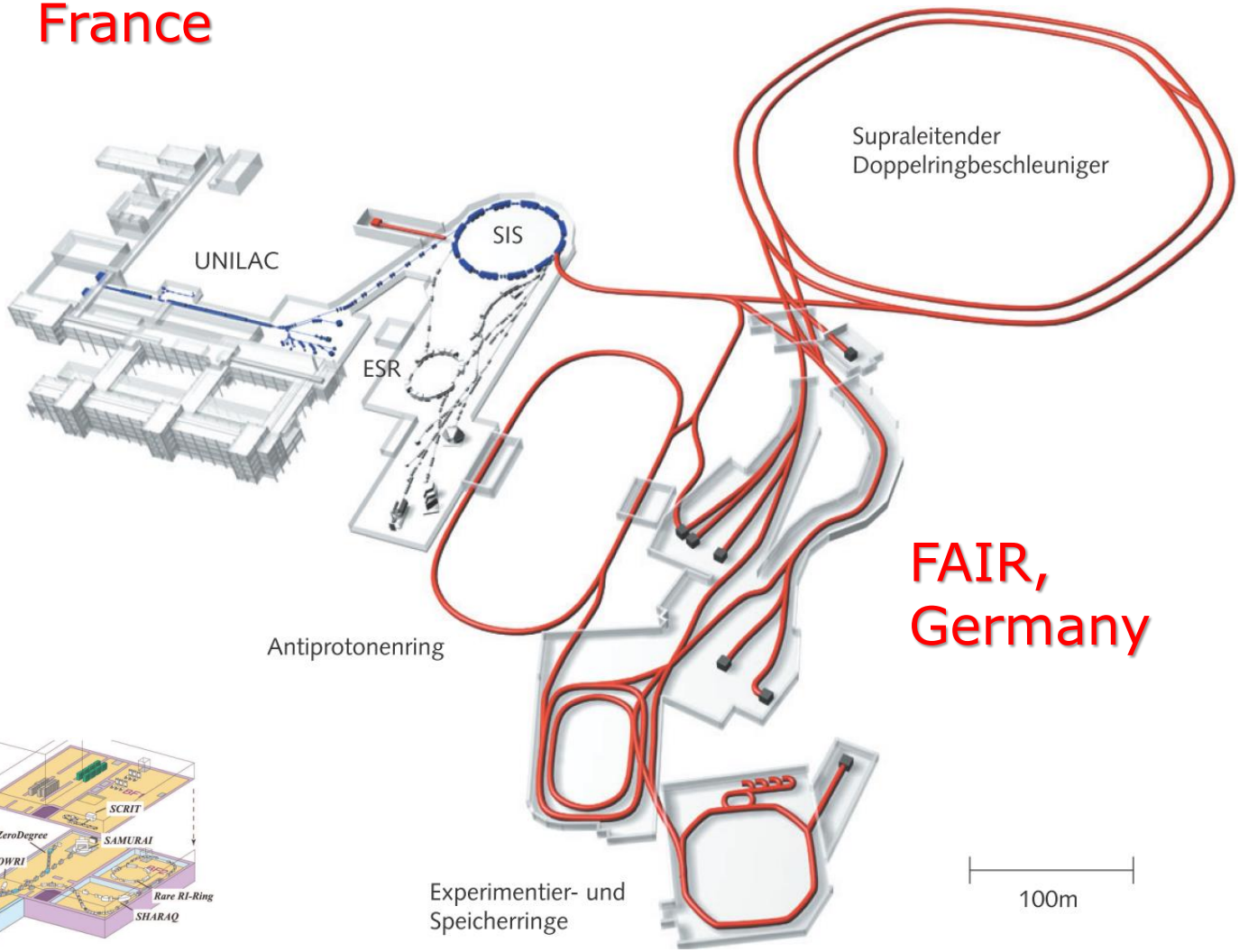
SPIRAL2
France

FRIB USA



RIBF Japan

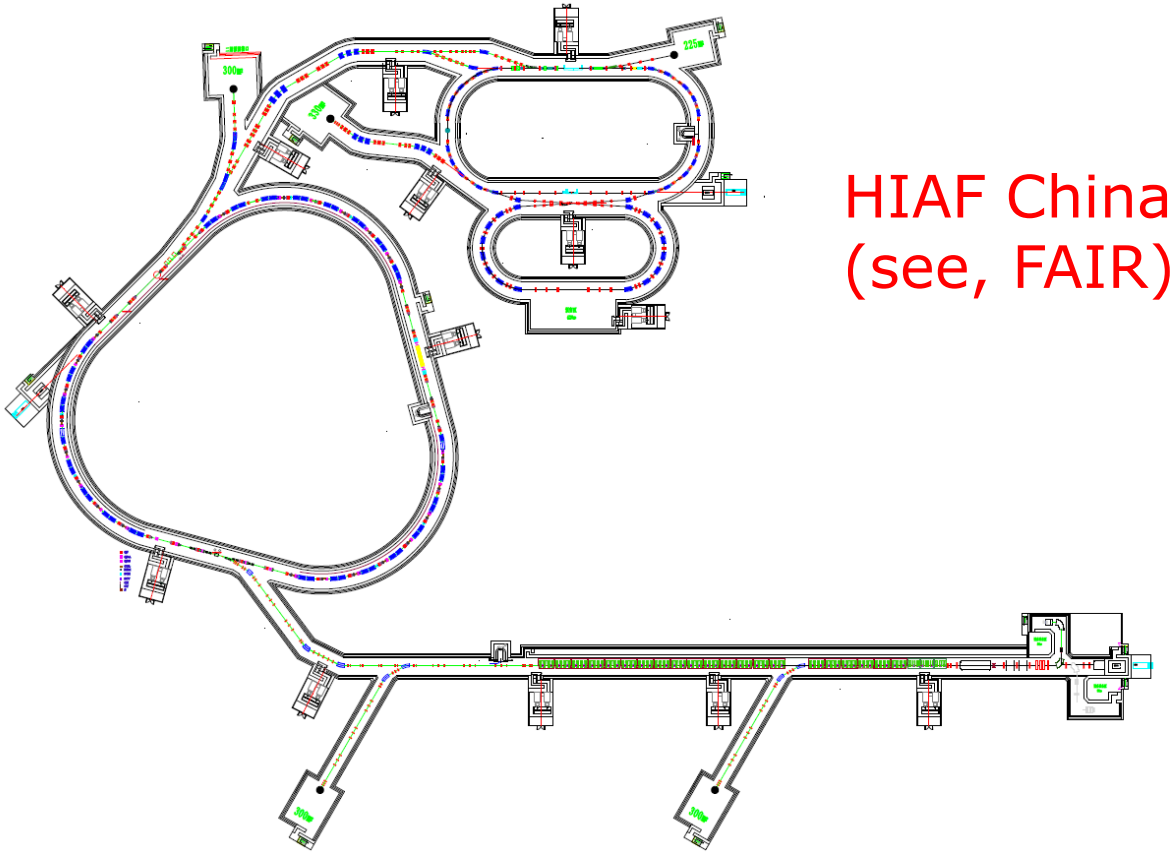




FAIR,
Germany

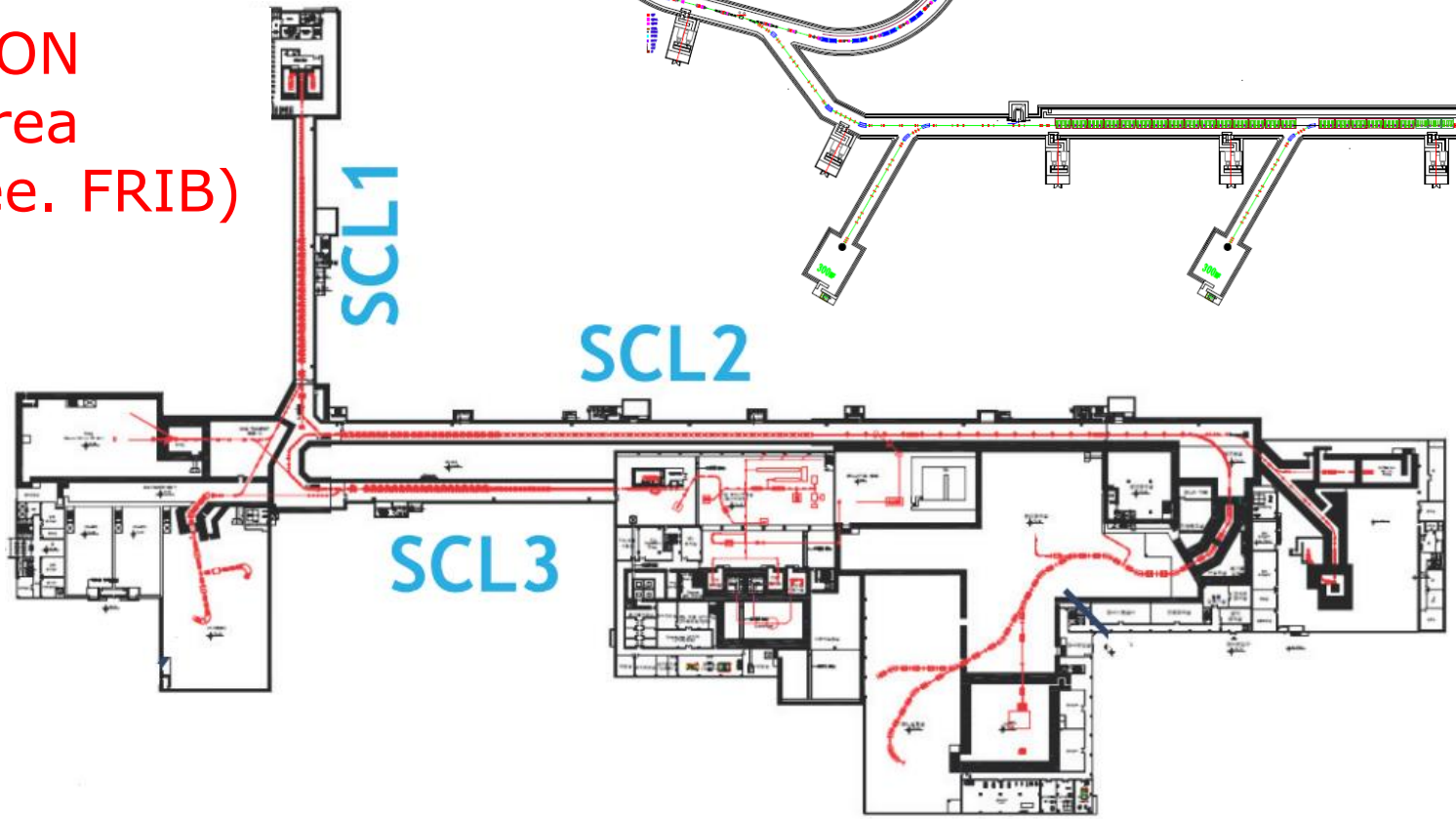
However,
even bigger…

Horizontal size of the slide ~1 km



HIAF China
(see, FAIR)

RAON
Korea
(see. FRIB)



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

Scale increase – (i) RIB production increase via primary beam energy increase and (ii) universality of RIB facility

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

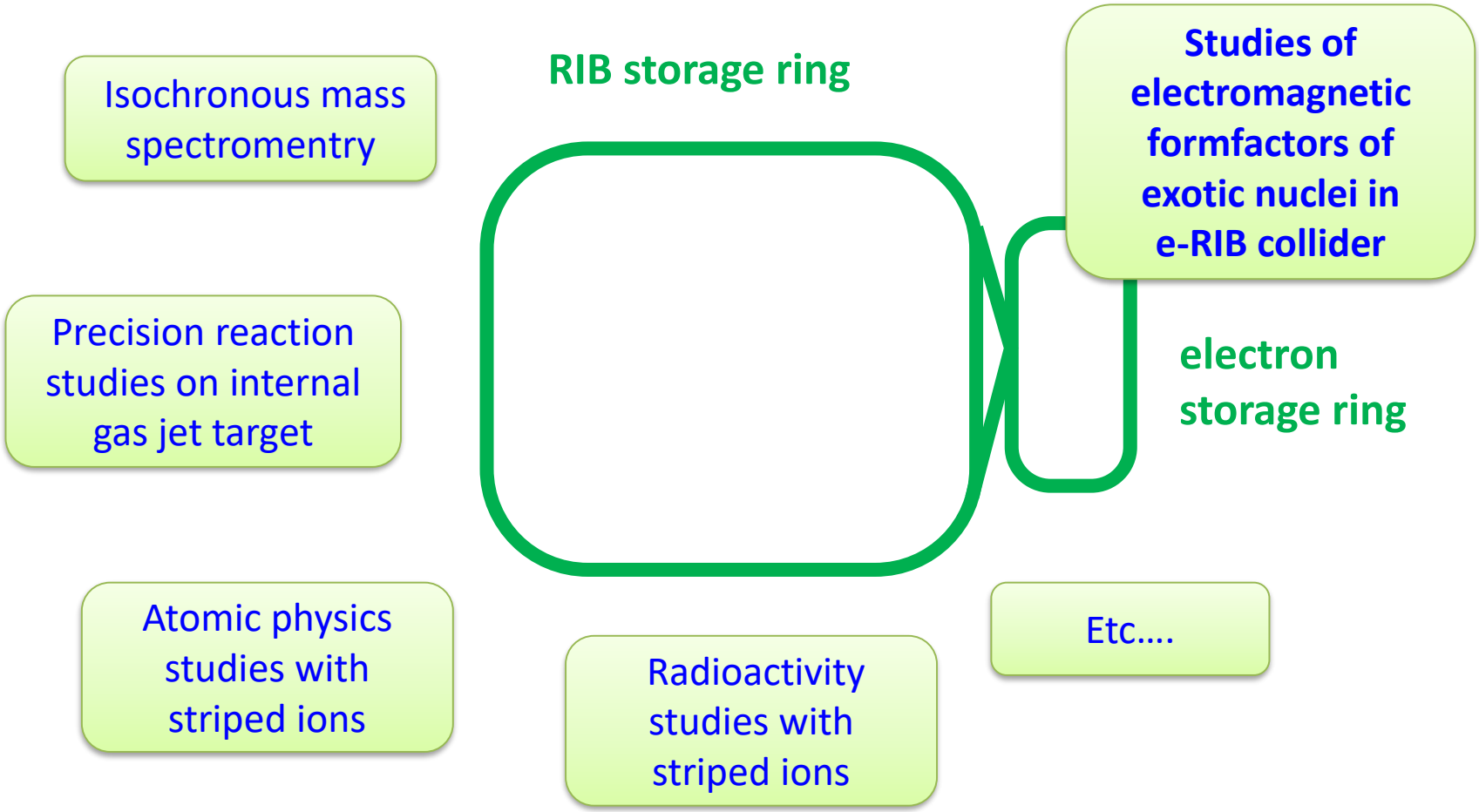
To limit universality

To go to “underdeveloped” fields

Empty “ecological niche”

Underdeveloped field: storage ring physics with RIBs

Empty field: studies of RIBs in electron-RIB collider



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

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

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

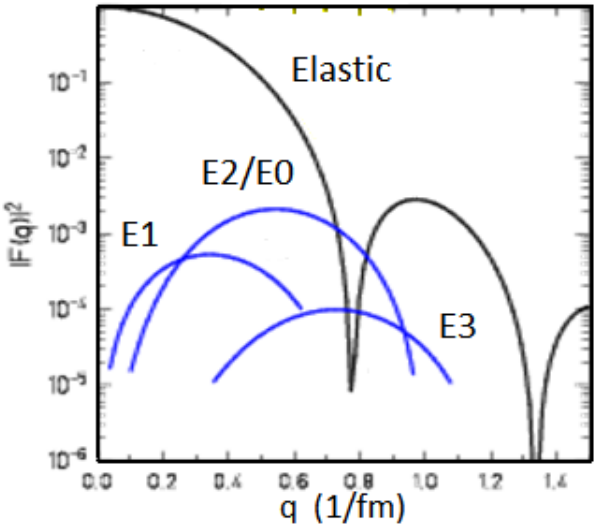
$$q = 2k\sin(\theta/2)$$

- Charge formfactor, charge radius

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

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

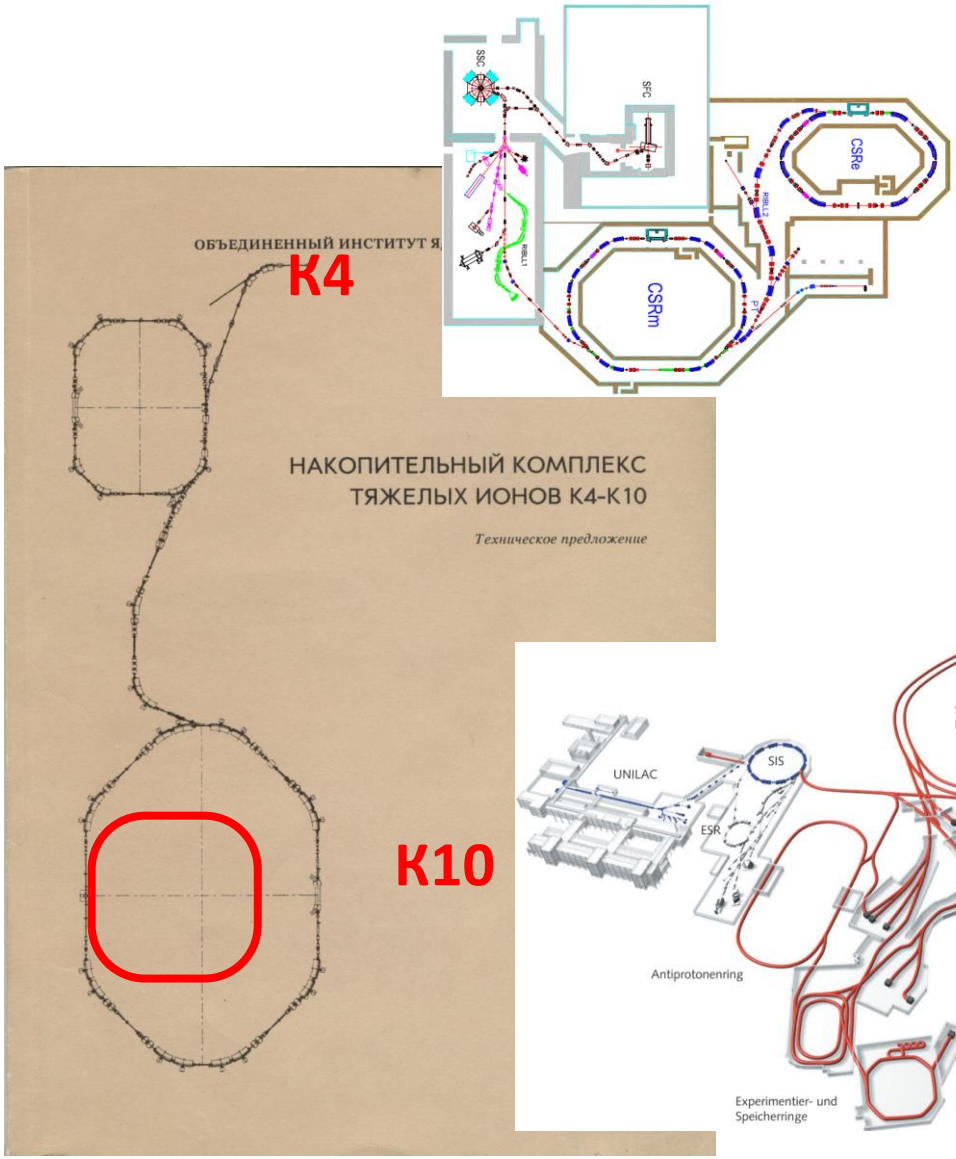
Electromagnetic probe is the most reliably studied
- Electron scattering

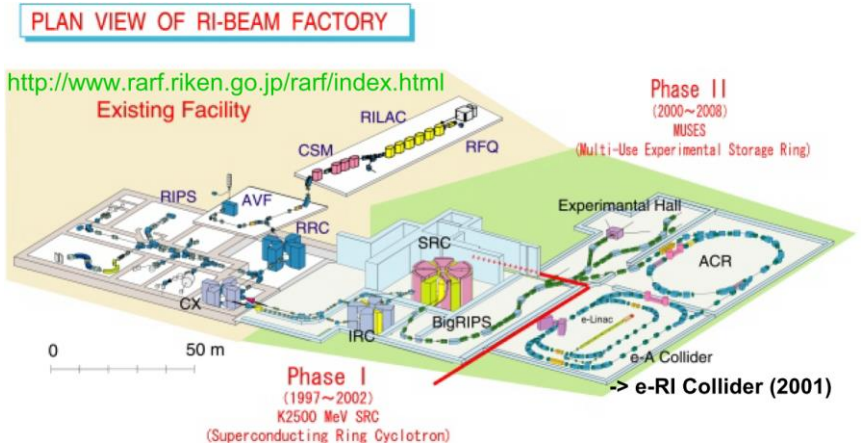


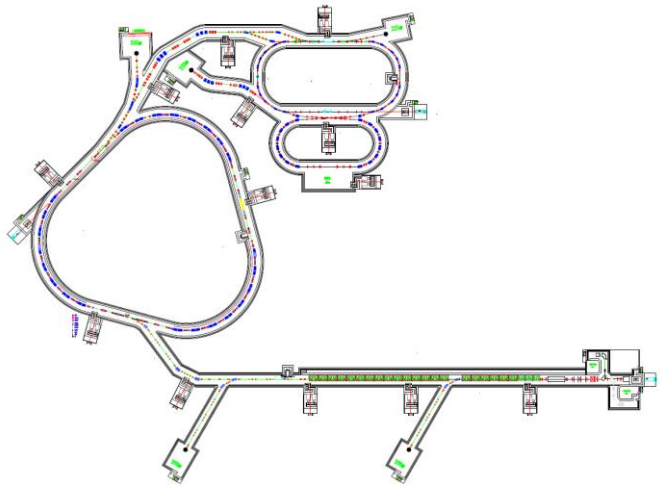
- Experiments in traps – "static" EM characteristics -> derivation of r_{ch}

- Electron scattering – differenttial characteristics

Continuous interest to low-energy nuclear physics in storage rings and e-RIB collision topic

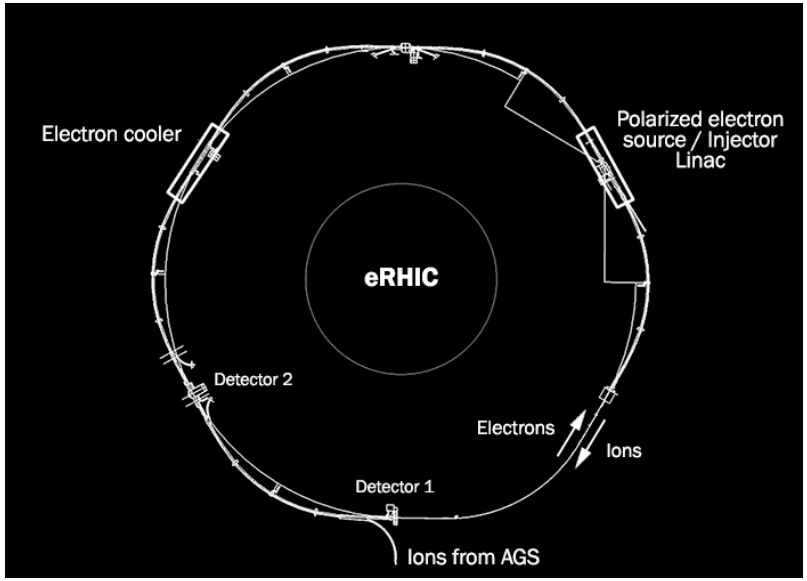




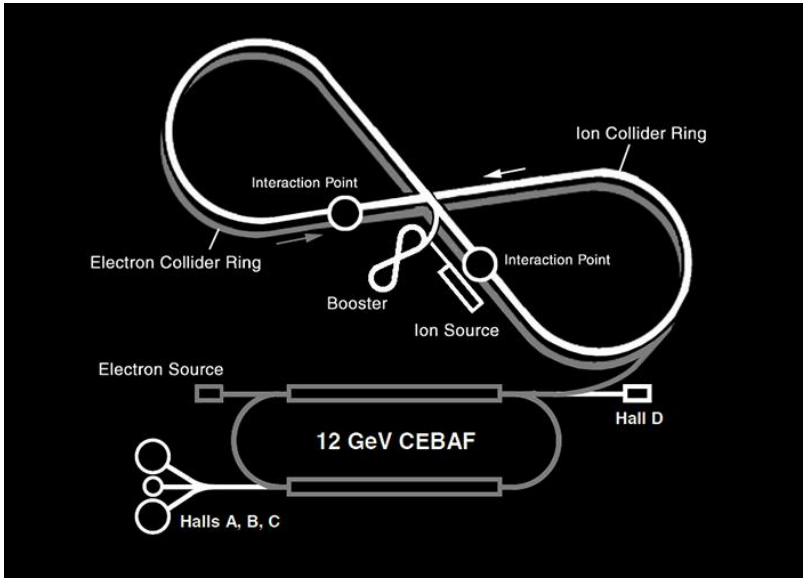


Electron-ion colliders in high-energy physics …

eRHIC – RHIC upgrade, Brookhaven National Laboratory



JLEIC – JLab Electron-Ion Collider, Thomas Jefferson National Accelerator Laboratory



Need for e-ion colliders:

– RIB physics: difficult to create an ion target in lab system

– High-energy physics: opportunity to flexibly choose the kinematical conditions and opportunity of polarized beam studies

DERICA concept

(1) Meaningful world unique program. e-RIB collider is selected

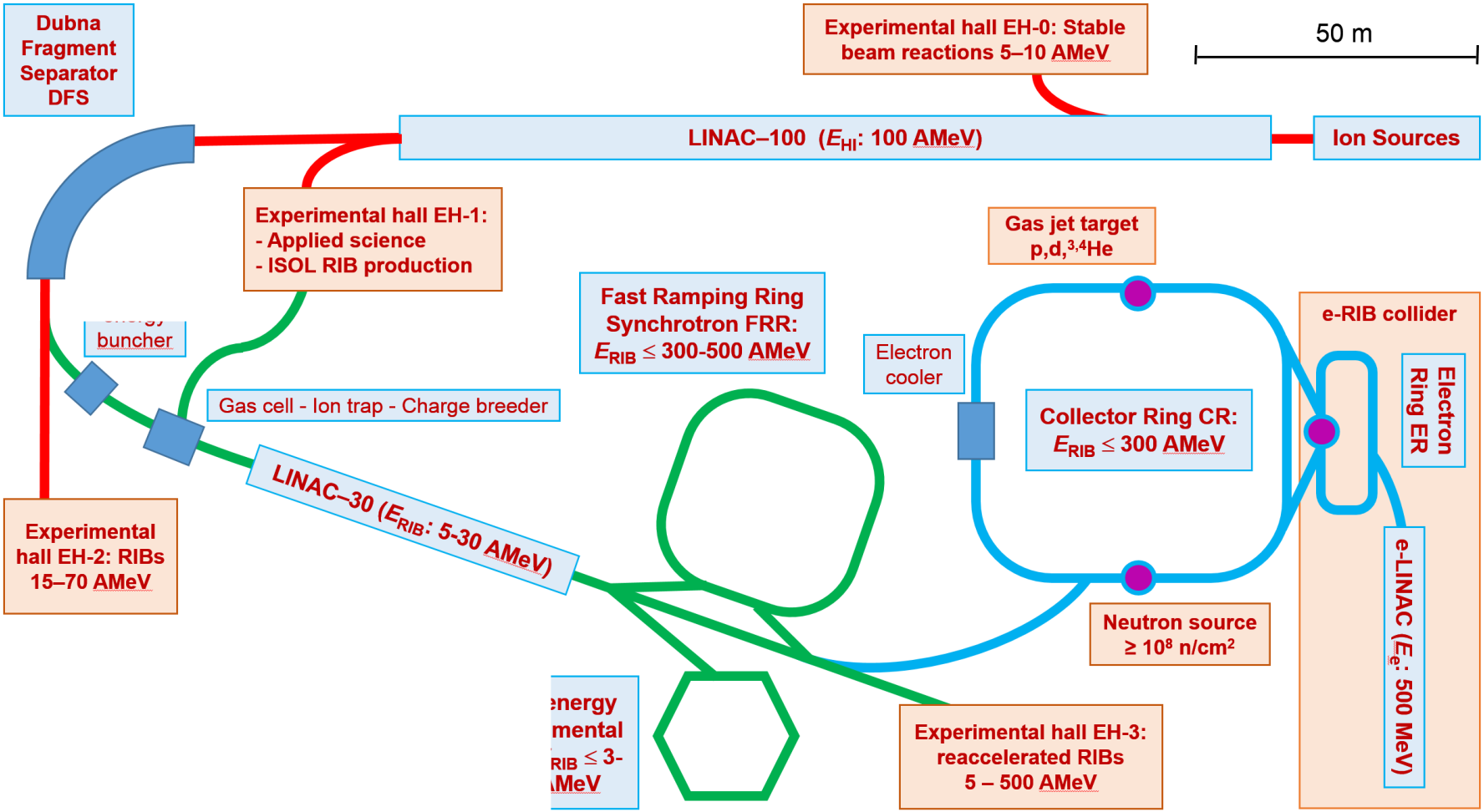
(2) Realistic (Russian realities) amount of financing. 300 M$ limit.

(3) “Safe” program of development with scientifically motivated stages

(4) Highly upgradable facility layout

Important compromises and motivation for proposed facility layout

DERICA – Dubna Electron-Radioactive Isotope Collider fAcility



Primary beams at modern and prospective RIB factories

RIBF (RIKEN)	370 AMeV
FAIR (Darmstadt)	1500 AMeV
FRIB (MSU)	240 AMeV
RAON (S.Korea)	200 AMeV
HIAF (China)	800 AMeV

No way to compete in primary beam energies

DERICA strategy for RIB production

Focus efforts on HIGH INTENSITY of primary beams with relatively MODEST ENERGIES ~100-160 AMeV

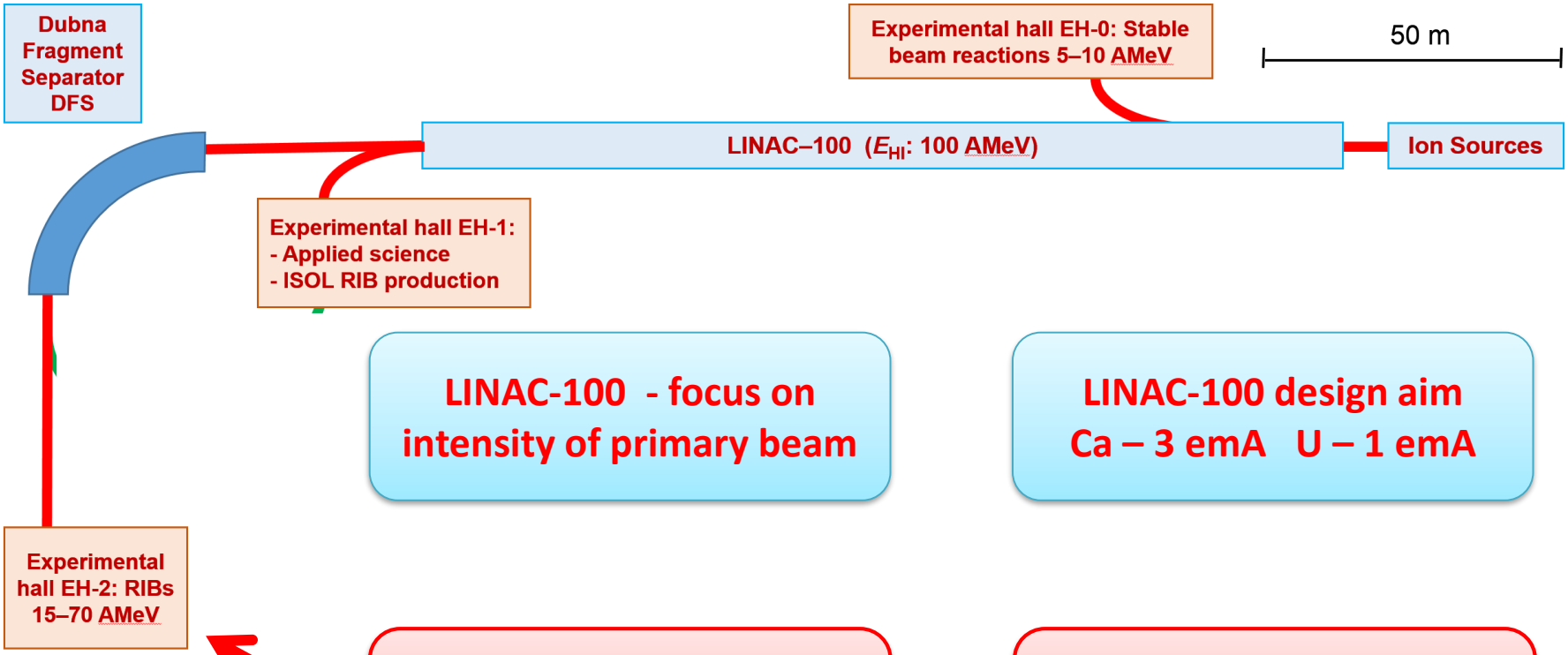
Advantages of relatively low-energy RIBs:

- **Easier to study direct reactions at 20-70 AMeV**
- **Easier to work with stopped beams**

The first challenge of the project – to construct record high-current (e.g. Ca beam ~3 emA, U beam ~1 emA) heavy-ion superconducting cw-LINAC

DERICA stage 2

New scientific opportunities emerging on each stage



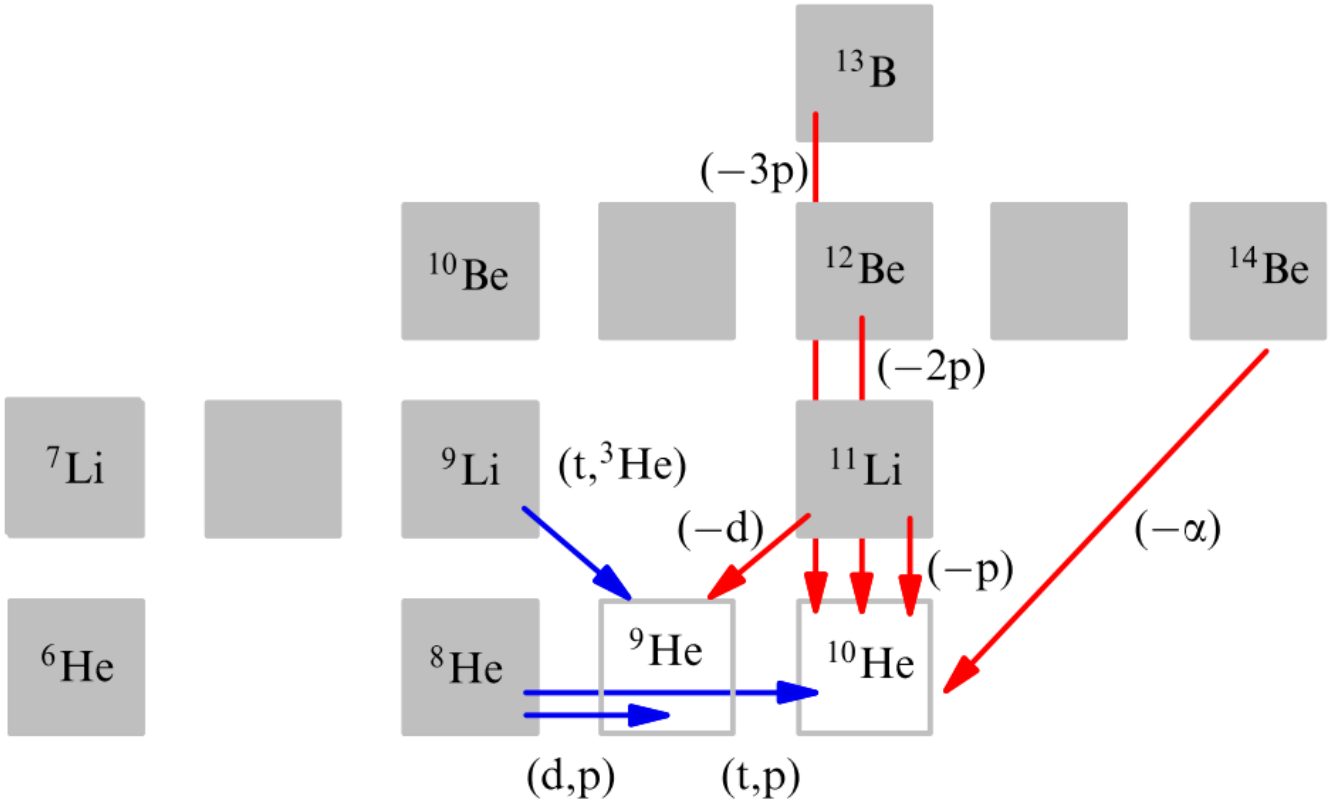
LINAC-100 - focus on intensity of primary beam

LINAC-100 design aim
Ca – 3 emA U – 1 emA

Direct reactions with RIBs at intermediate energies (15-80 AMeV)

Aim to get record intensities of 30-80 AMeV RIBs

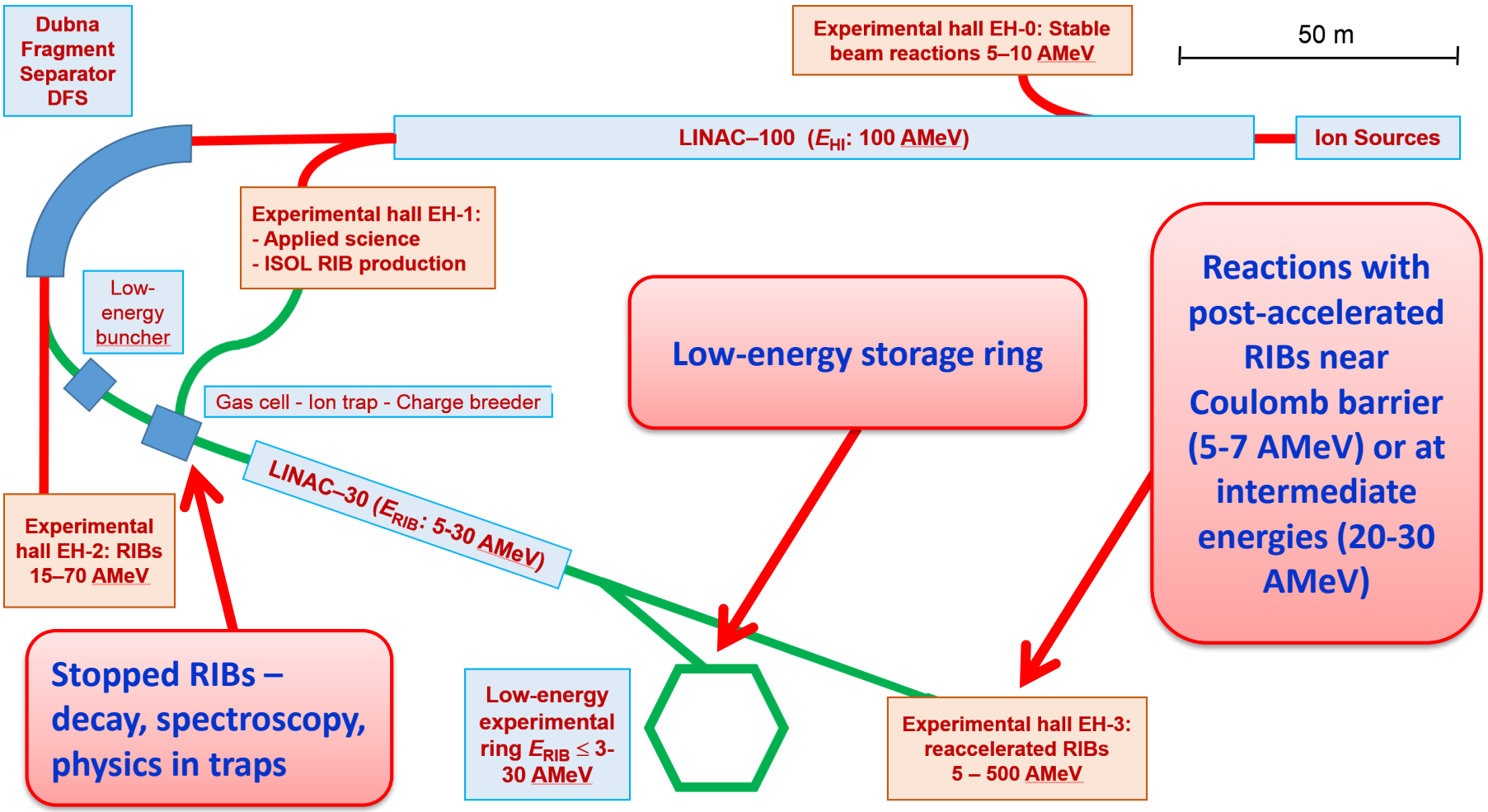
Why direct reactions at intermediate energies?



Only knock-out is possible at high energies and thus in all the other prospective RIB facilities

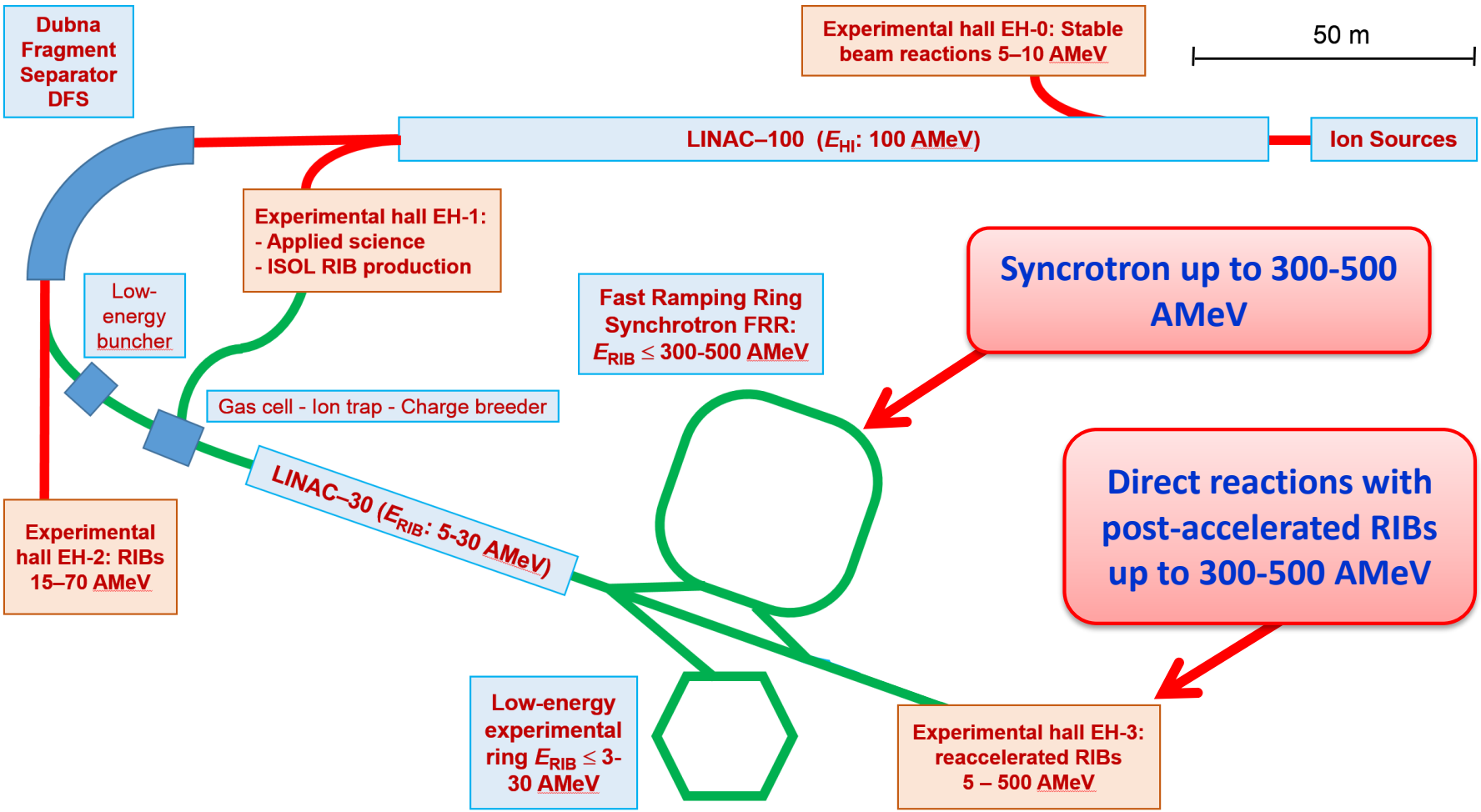
DERICA stage 3.1

New scientific opportunities emerging on each stage



DERICA stage 3.2

New scientific opportunities emerging on each stage



Pro et contra for reaccelerated beams

Contra

- Lifetime limit $T_{1/2}$ > 10-100 ms (compared to $T_{1/2}$ > 100 ns for I-F)

- Factor 5-20 intensity loss at {gas cell-ion source} system

- Around $5x10^8$ pps intensity limit of existing gas cells

- Bunched operation 1-20 Hz - specific DAC requirements

Pro

- Choice of secondary beam energy in a broad range

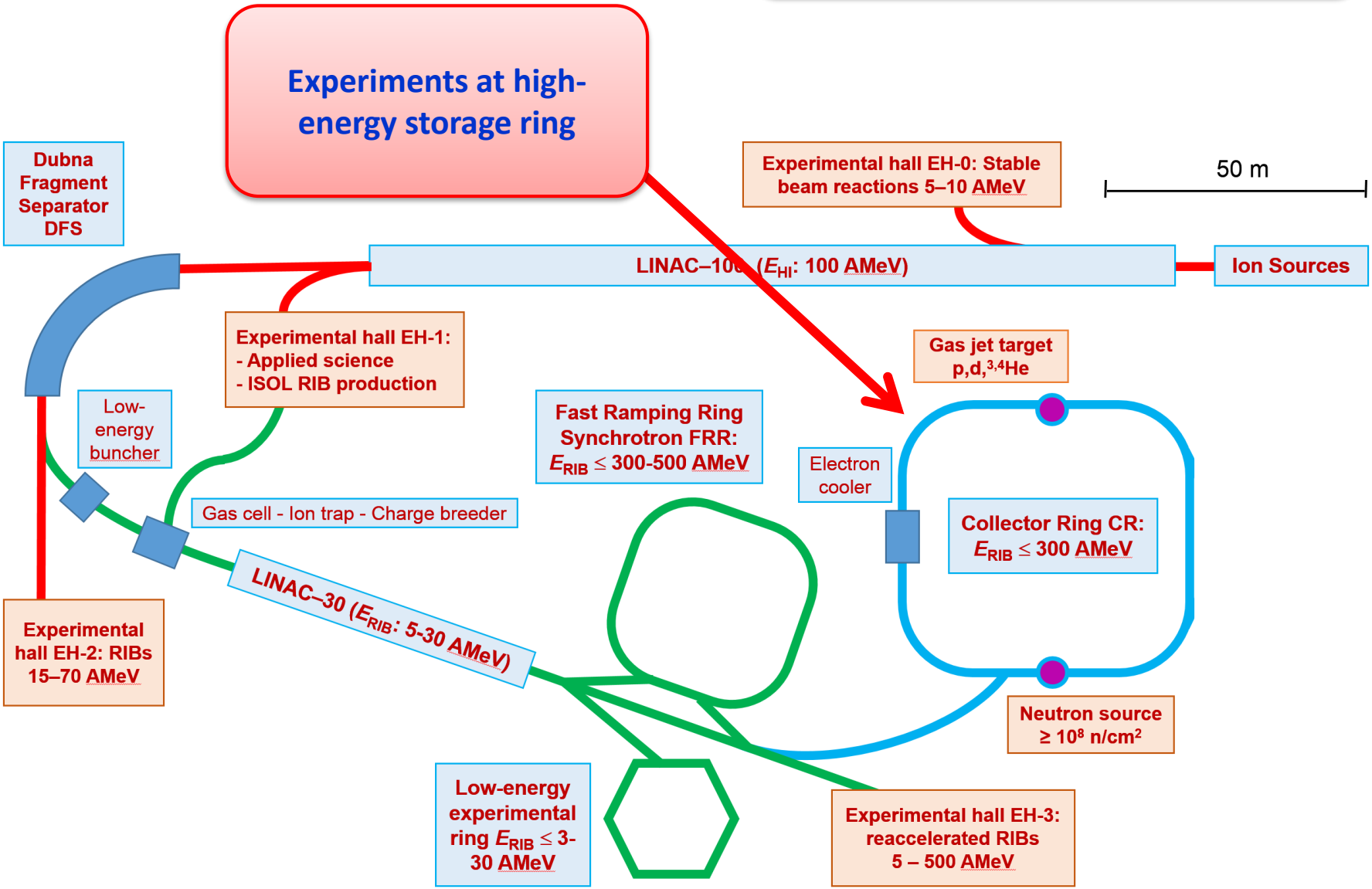
- High quality secondary beams: monochromatic, “zero emittance”

- For intense secondary beams overcome 10^5 pps limitation of event-by-event operation at in-fight facilities

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

DERICA stage 4.1

New scientific opportunities emerging on each stage



Why direct reactions at intermediate energies?

Contra

Pro

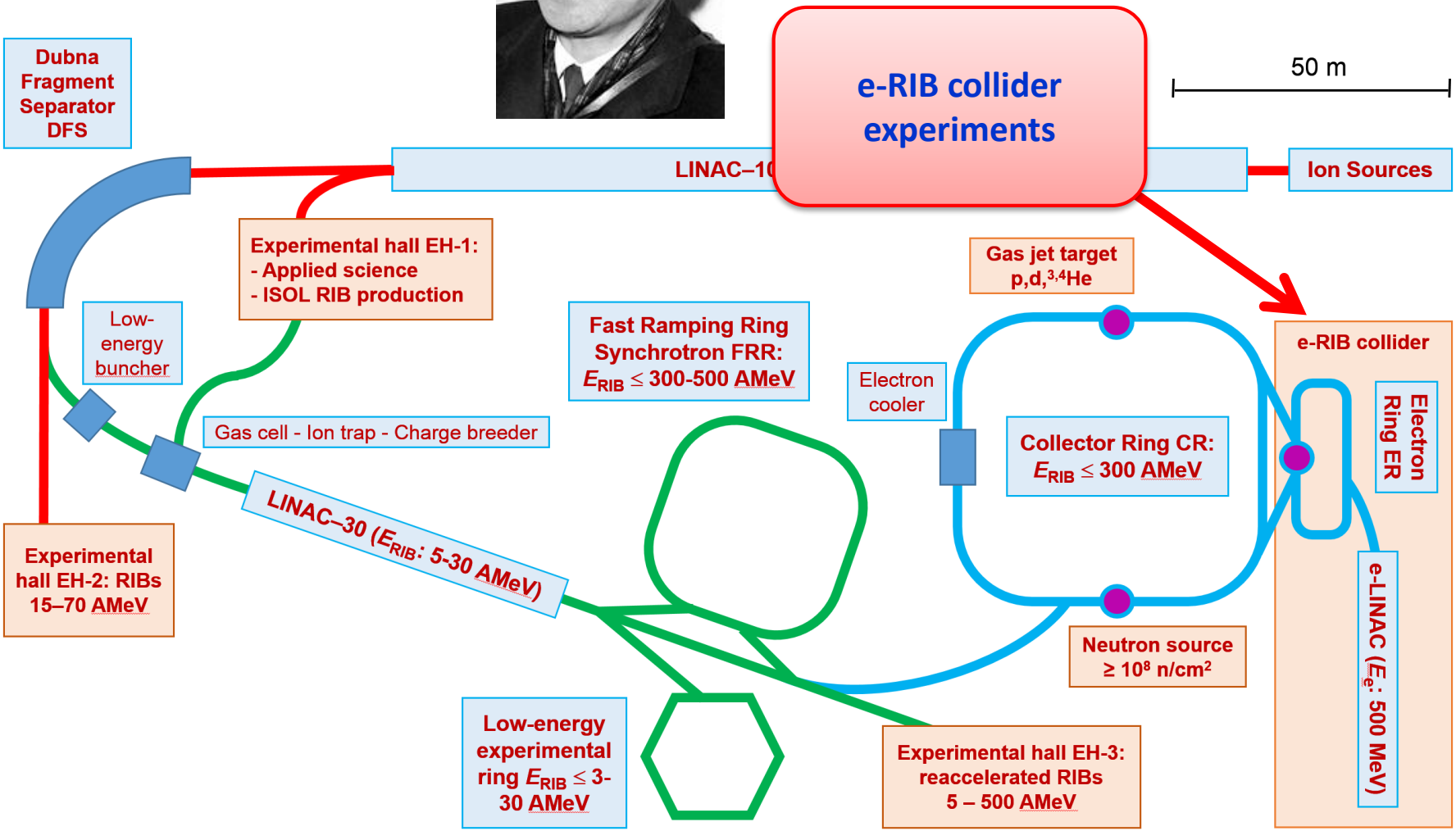
High-tech

- **Ions in high charge state (fully striped, H-like, etc)**
- **Precision studies with windowless gas jet targets**
- **RIB experiments with neutron target**
- **RIB experiments with neutron target**

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

DERICA stage 4.2

New scientific opportunities emerging on each stage



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 500 AMeV

Staged development

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

Unique opportunities

- World most intense RIBs for direct reaction studies at intermediate (20-70 AMeV) energies
- Reaccelerated RIBs up to 500 AMeV
- e-RIB collider experiment

Developments of DERICA

Letter of Intent:
Russian review journal Physics-Uspekhi (2019)

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://derica.jinr.ru/publications.html

Joke about construction business

Build fast

Build cheap

High quality standard

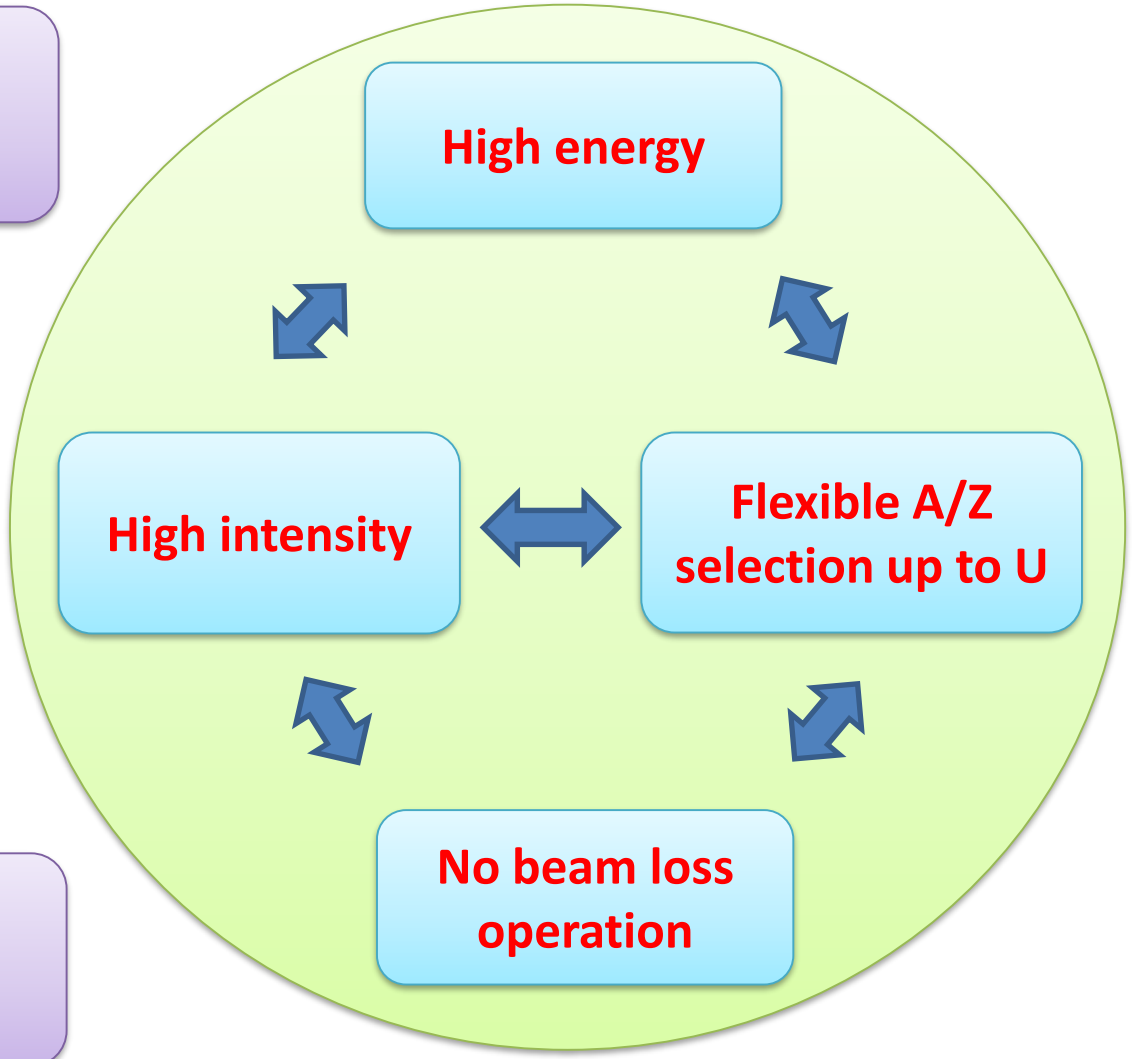
Just select any two of three options!

Problem of heavy-ion acceleration for RIB physics

4 conditions to be fulfilled simultaneously

Compromise search as any three are strongly controversial

Complicated acceleration "tactics"



LINAC-100 workshop February 7-8, JINR

Declaration of most urgent task

To start development of the "front end" for LINAC-100 immediately

Workshop consequence: support by JINR directorate for 2019

- Resources allocated: 600 k$

JINR PAC, June 24-25

Recommended to start new research project at JINR for 2020-2021

- Resources allocated 2020: 1400 k$ - 2021: 1450 k$

Project: **"Construction of a prototype of the initial section of the high-current heavy-ion linear accelerator for the production of intense radioactive ion beams for basic research"**

Supplement for the physical program of the project **"Development of the FLNR accelerator complex and experimental setups (DRIBs-III)"** on the years 2020/2021.

Theme: 03-0-1129-2017/21

Project leaders: L.V. Grigorenko (FLNR JINR)
T.V. Kulevoy (NRC "KI" - ITEP)

Deputy project leaders:
A.S. Fomichev (FLNR JINR)
A.A. Efremov (FLNR JINR)
S.M. Polozov (NRNU MEPhI)

Expected output by the end 2021

- TDR + prototypes for LINAC-100

- CDR for DERICA

Two modalities of the project development

(1) LINAC-100 + DFS

can be build within JINR

(2) “Full DERICA”

national scale megaproject, can be built only with high-level political approval

The full DERICA layout is to be defined now

DERICA preliminary layout

http://derica.jinr.ru

Important possible "bottlenecks" of the project

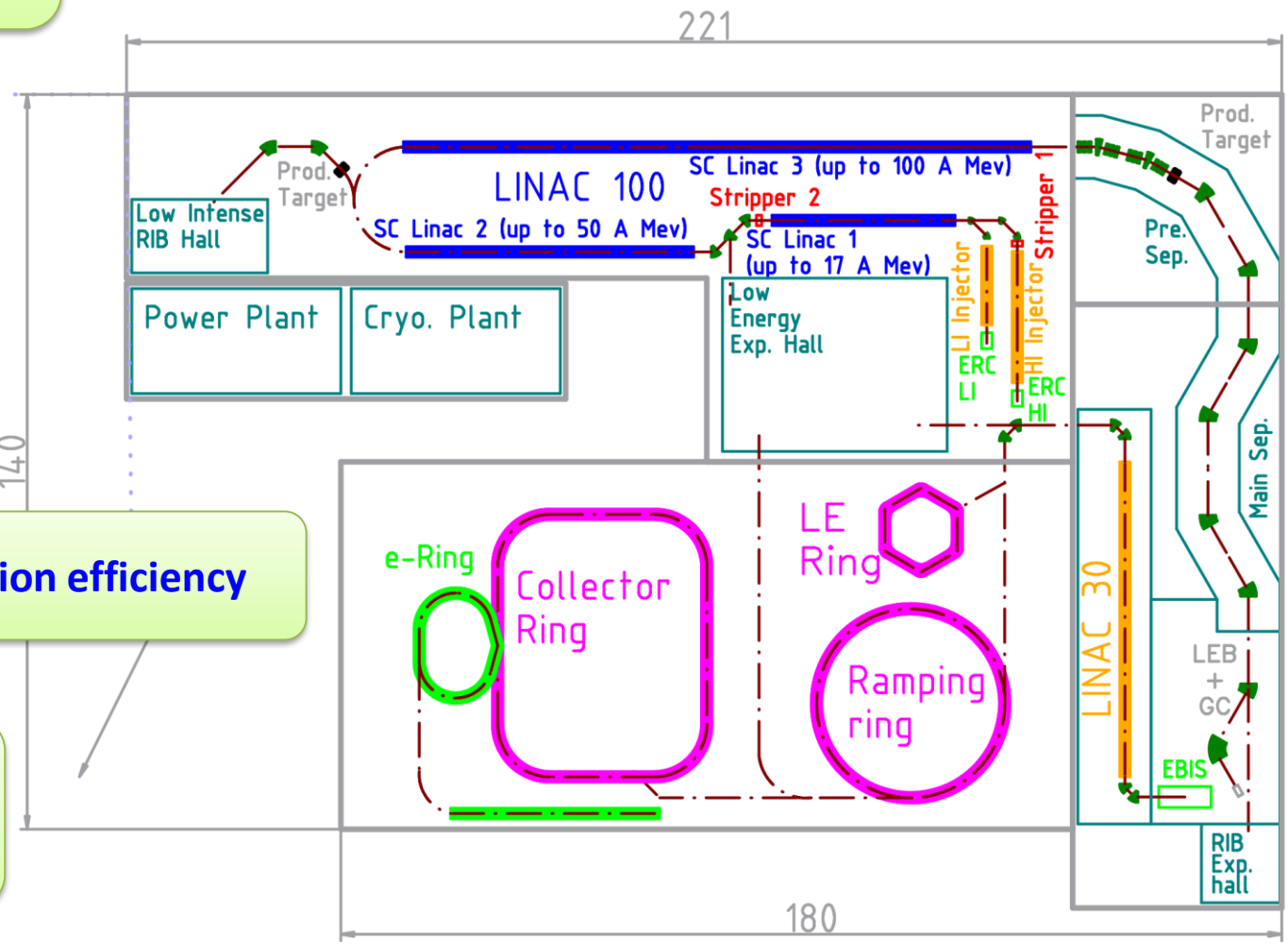
LINAC-100 front end performance

Fragment separator design (target area)

Gas cell perform ance

Reacceleration efficiency

e-RIB collider performance



LINAC-100 working plans

LINAC-100 concept

– Front-end: 1 (universal A/Z~3-8) or 2 (A/Z~3 + A/Z~6-8)
– Ratio of warm/cryogenic parts to be decided
– “Acceleration tactics” – A/Z, strippers, etc. MEPhI + ITEPh + GSI

Prospective ECR ion source 28 GHz

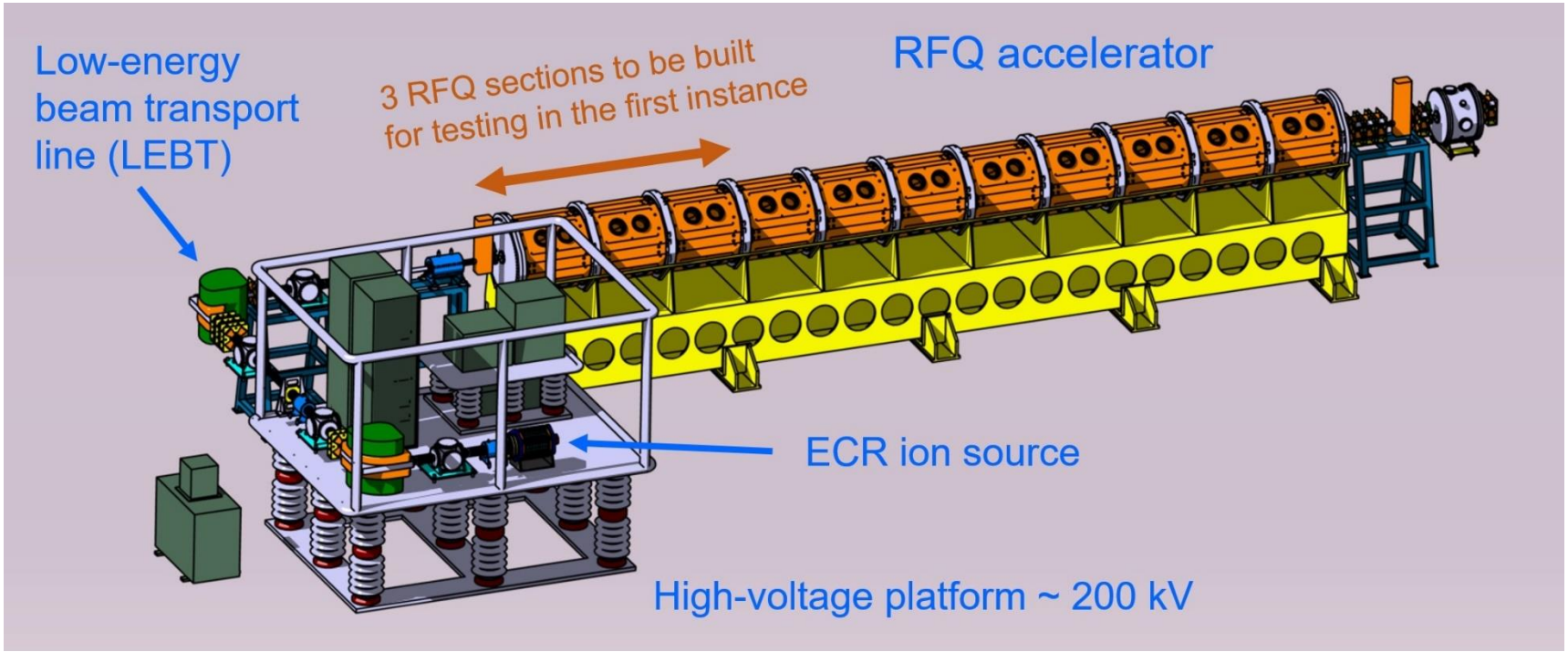
– Design FLNR – Magnet system NIIFA – RF system IAP Nizniy Novgorod

Prototyping front-end for LINAC-100

– Test ECR на for current ~ 3-5 mA	FLNR + NIIFA
– Up to 3 sections of RFQ	VNIITPh
– Test assembly ECR + LEBT + RFQ	FLNR + ITEPh + NRI Troitsk

By the end 2021: TDR for LINAC-100, front-end prototype, prototype parts for ECR-28

LINAC-100 front end project 2019-2021



Urgent question of location

Contract for test ECR 14 GHz

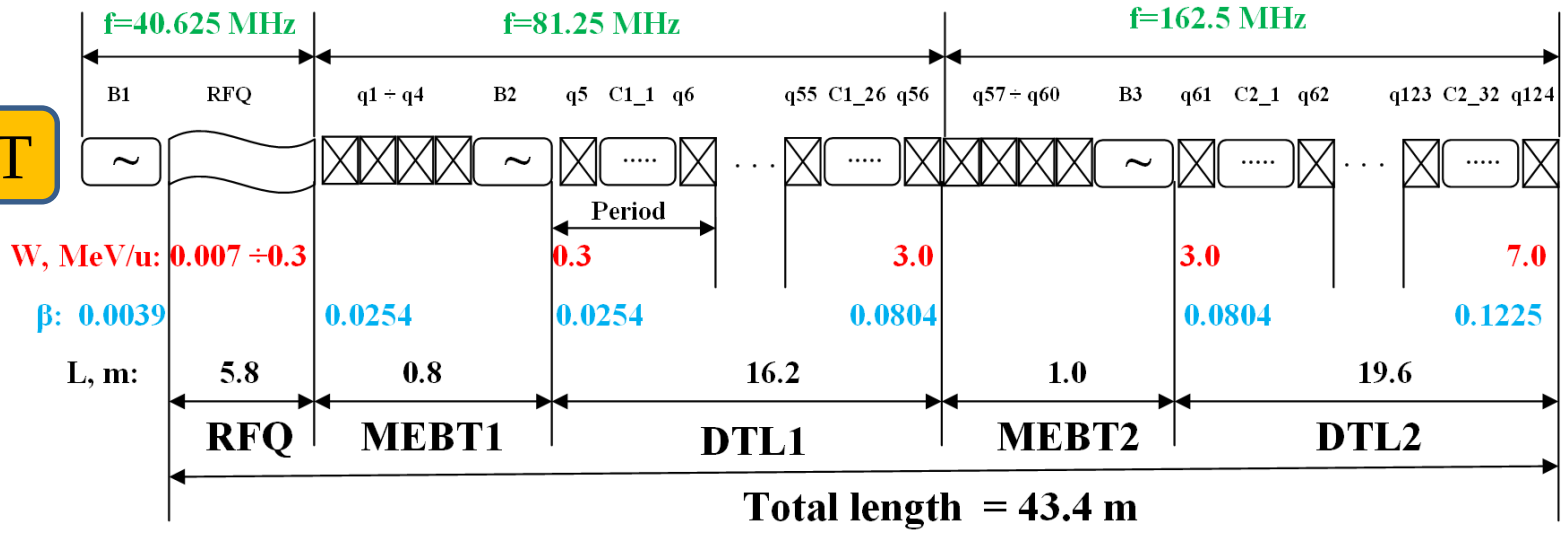
Contract for RFQ fabrication

Contract for high-voltage platform

Possible LINAC-100 normal conducting part

By T. Kulevoy

IS+LEBT

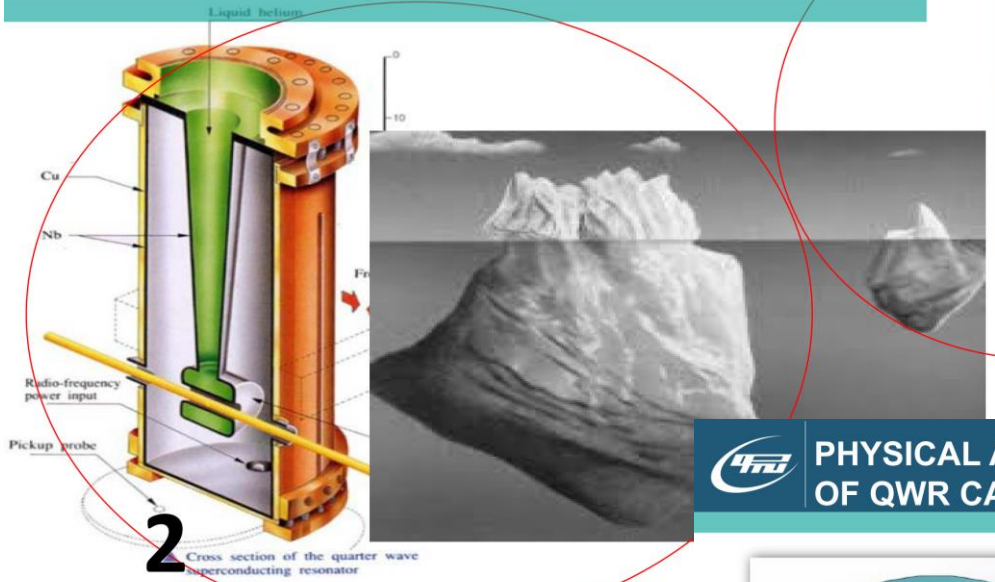


- **A/Z ≤ 7**
- **CW *Input current=1 mA***
- ***Input transverse emittance ε=1 π·mm·mrad***
- ***E_{smax}=1.5 Kp***
- ***V_k / ε ≥ 6***
- ***R_b /R_a ≤ 0.75, R_b – beam radius; R_a – aperture radius***
- ***Transport (N_{out} /N_{inj}) = 100%***
- ***Transmission (N_{out} (accel)/N_{inj}) = 100%***

LINAC-100 superconducting part

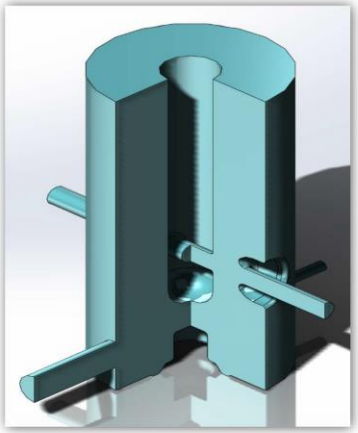
By S. Polozov

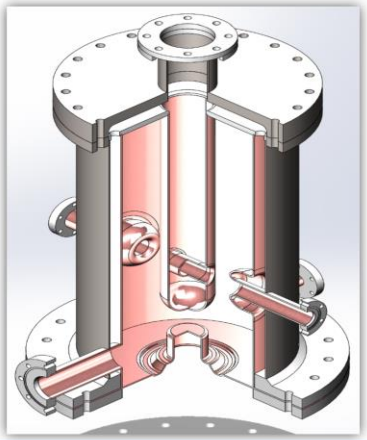
COMPARISON OF TECHNICAL AND FINANCIAL COSTS FOR THE FIRST AND SECOND PROJECT



1

PHYSICAL ANALOGUE AND DESIGN OF QWR CAVITY





By V. Zaleski

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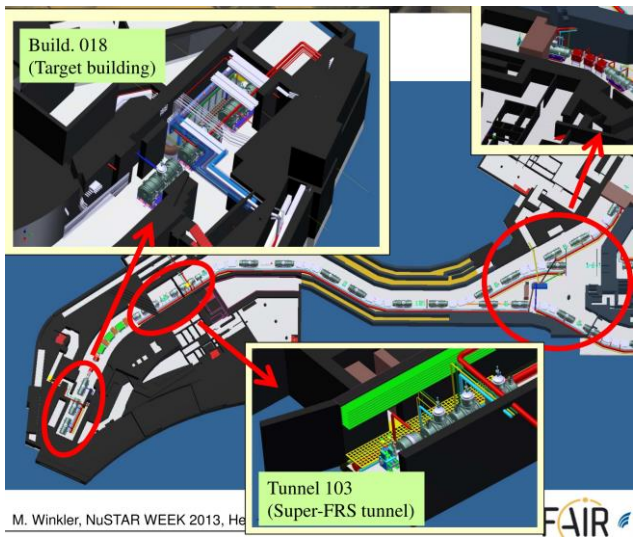
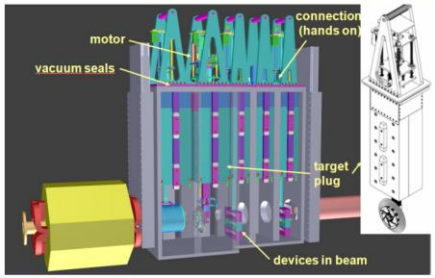
Challenge of DFS – DERICA Fragment separator

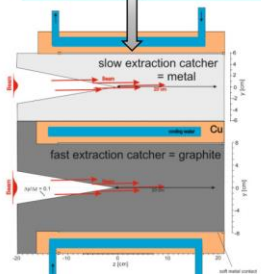


target chamber including plug inserts



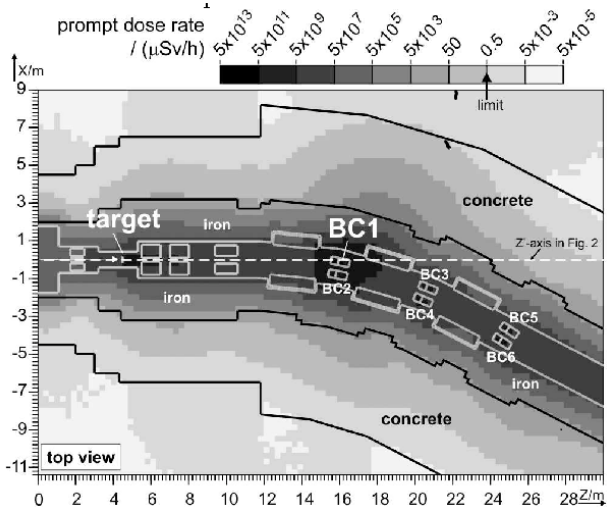
prototype target wheel

two-halves catcher



FAIR, SuperFRS

U beam ~1500 AMeV ~1 pμA



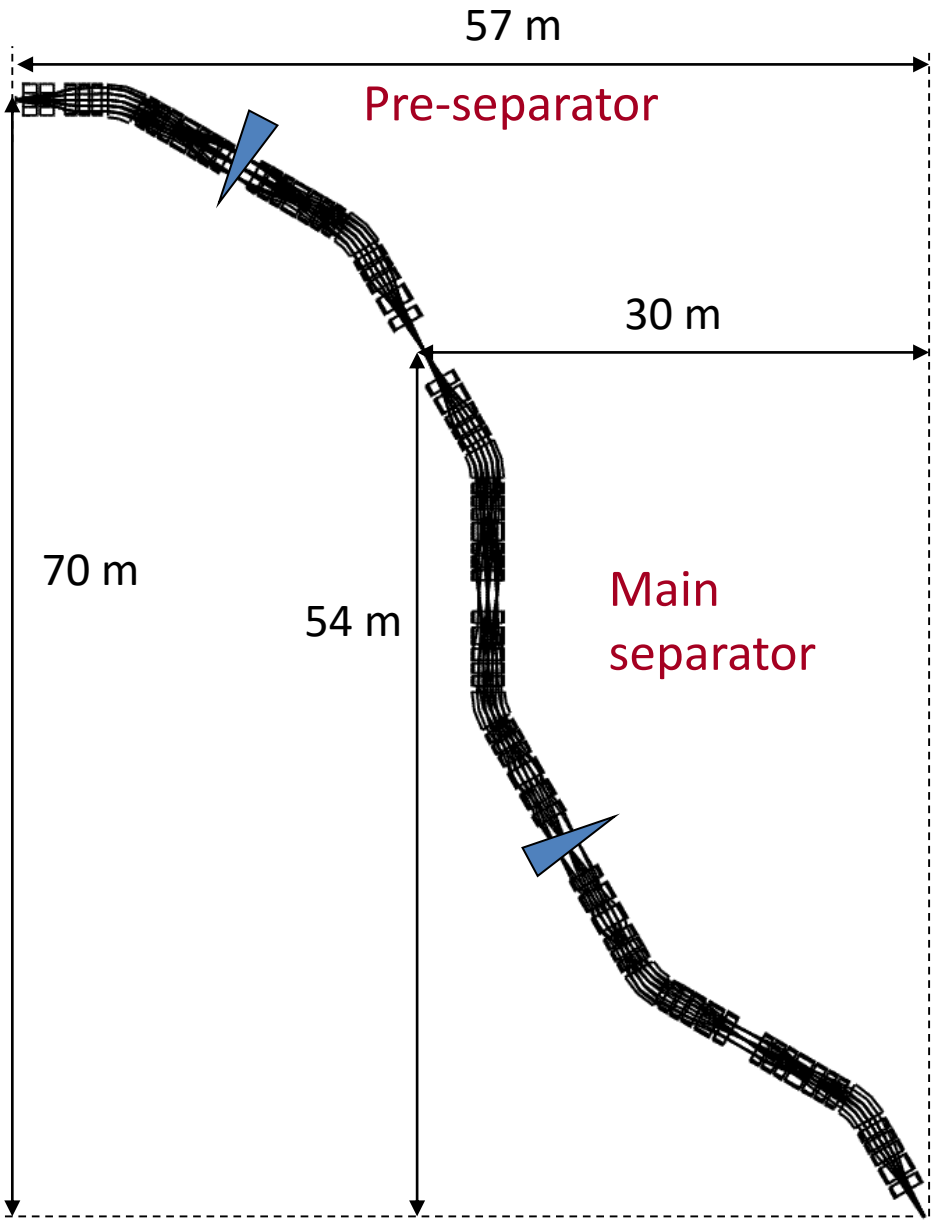
DERICA, DFS

- Ca beam 160 AMeV ~3 emA ~250 pμA 1500 kW beam
- U beam 100 AMeV ~1 emA ~30 pμA 600 kW beam

By the end of 2021 concept (can not call it CDR) for production target, radiation shielding and DFS are ready

By M. Yavor

Layout: S-shaped main separator



6 dipoles:
R = 4.375 m
air gap = 10 cm
B = 1.6 T

Quadrupoles (B < 0.87 T):
36 quadrupoles R = 17.5 cm
13 pcs 0.7 m long
23 pcs 1.05 m long
1 quadrupole R = 5 cm
0.6 m long
1 quadrupole R = 9.5 cm
1 m long

24 hexapoles (B < 0.3 T):
R = 17.5 cm
0.6 m long

12 octopoles (B < 0.16 T):
R = 17.5 cm
0.6 m long

- Pre-separator (P/ΔP = 1500) + main separator (P/ΔP = 3000) (at 1 mm diameter initial spot)
- Warm type:
  - Dipoles B ≤ 1.6 T
  - Quadrupoles B ≤ 0.87 T,
  - Hexapoles B ≤ 0.3 T,
  - Octopoles B ≤ 0.16 T
  - Hexapoles and octopoles separate from quadrupoles
- Bρ: 7 Tm
- Momentum acceptance ±3%
- Angular acceptances:
  - Dispersion plane (X-direction) ±50 mrad
  - Y-direction ±30 mrad

Challenge of ring branch

Low-energy storage ring

– Energies 3-30 AMeV – Shape – probably «hexagon» (???)

Fast ramping synchrotron FRR

– Injection ~30 AMeV, extraction 100-500 AMeV (???)

High-energy storage ring

– Energies 100-500 AMeV (???) – Shape – probably «square» (???)

e-RIB collider facility

– e-LINAC – electron storage ring

– collision point (???) – electron spectrometer (???)

Expected that by the end of 2021 BINP Novosibirsk produce important part of CDR for the ring branch

DERICA preliminary layout

http://derica.jinr.ru

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Gas cell perform ance

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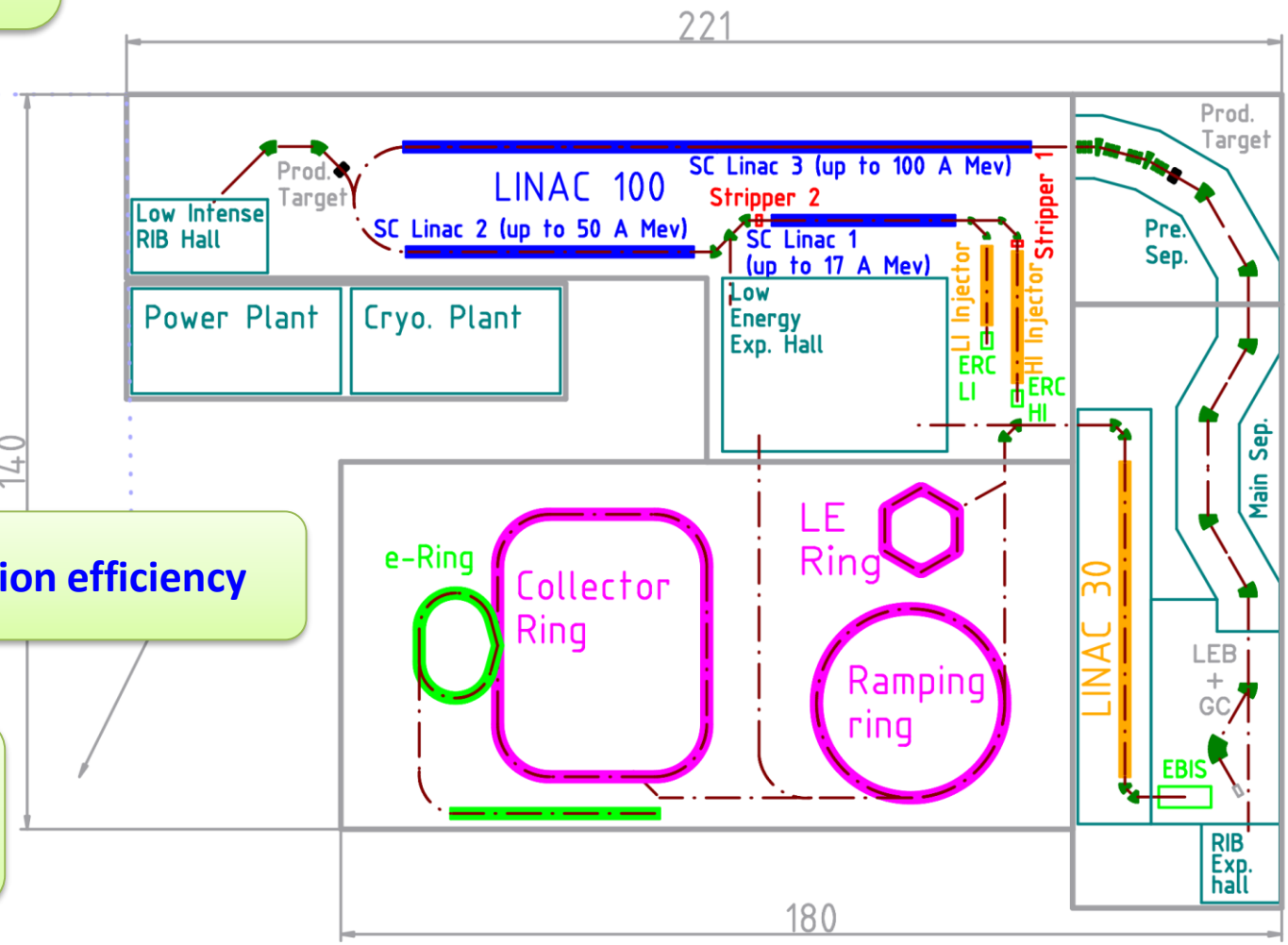

Experts

LINAC-100 + DFS

A realistic option to replace aging U-400M cyclotron and give bright future to existing RIB program at FLNR (aim – at least factor 100 in beam intensities)

DERICA

In certain sense it is not a project with well defined end point, but a strategy for the low-energy nuclear physics development in Russia for 15-30 years