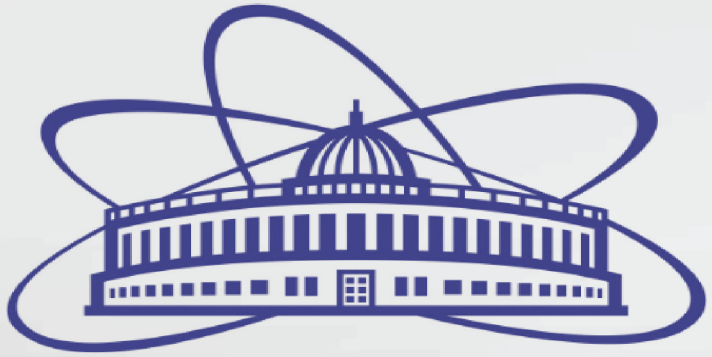

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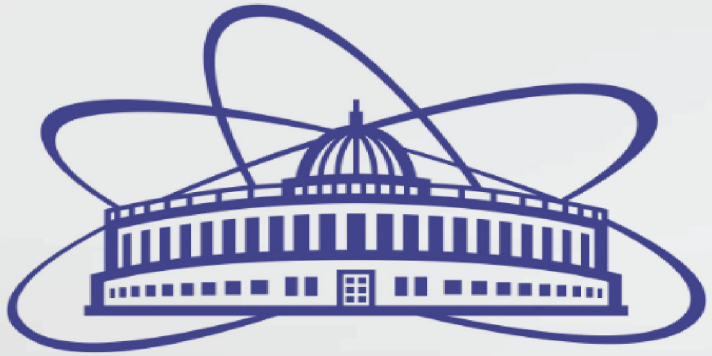
МЕЖДУНАРОДНАЯ МЕЖПРАВИТЕЛЬСТВЕННАЯ ОРГАНИЗАЦИЯ

JOINT INSTITUTE FOR NUCLEAR RESEARCH
ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

Accelerator and Storage Ring Facility for Radioactive Ion Beam Physics - DERICA Project



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Accelerator and Storage Ring Facility for Radioactive Ion Beam Physics - DERICA Project

Boris Sharkov

on behalf of DERICA collaboration

Substantial increase in the scale of modern and prospective RIB facilities:
Price tag >1 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 terra incognita

Empty “ecological niche”

Storage ring physics with RIBs

Non-explored field: studies of RIBs in electron-RIB collider

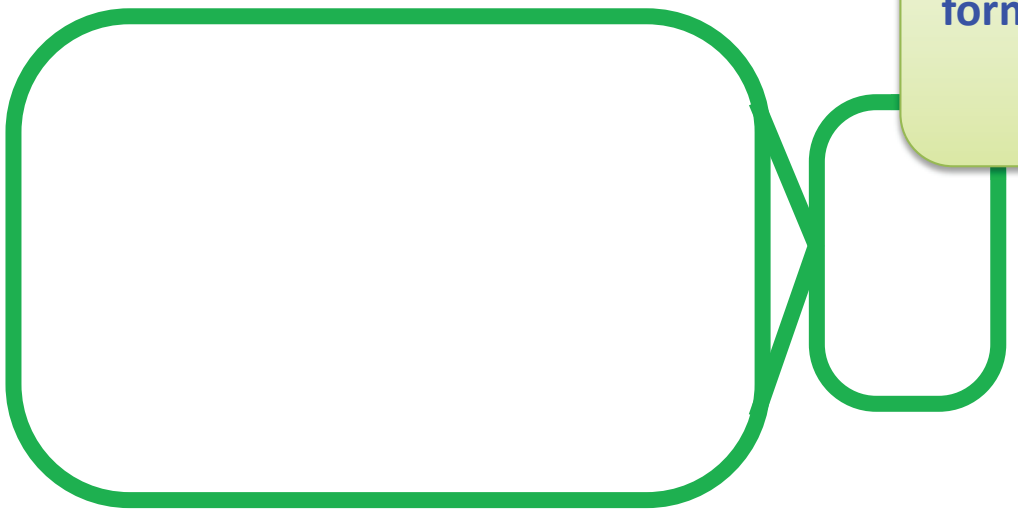
Isochronous mass spectromentry

RIB storage ring

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

Precision reaction studies on internal gas jet target

electron storage ring



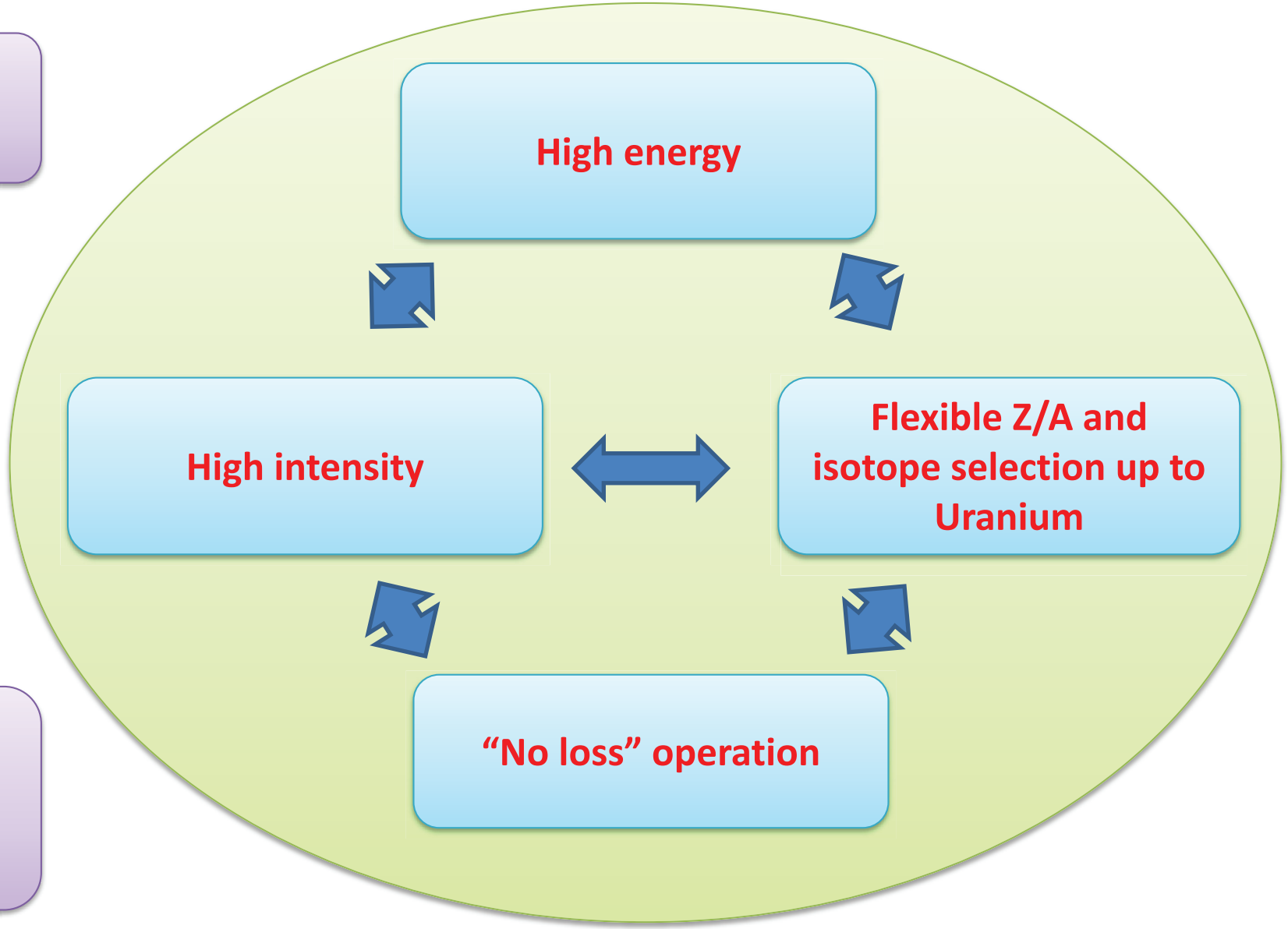
Atomic physics studies with striped ions

Radioactivity studies with striped ions

Etc….

Problem of heavy-ion acceleration for RIB research

4 requirements to be suited simultaneously



Compromises required: any 3 of them are contradictory

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**

  электроны, достаточно легкие ядра

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

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

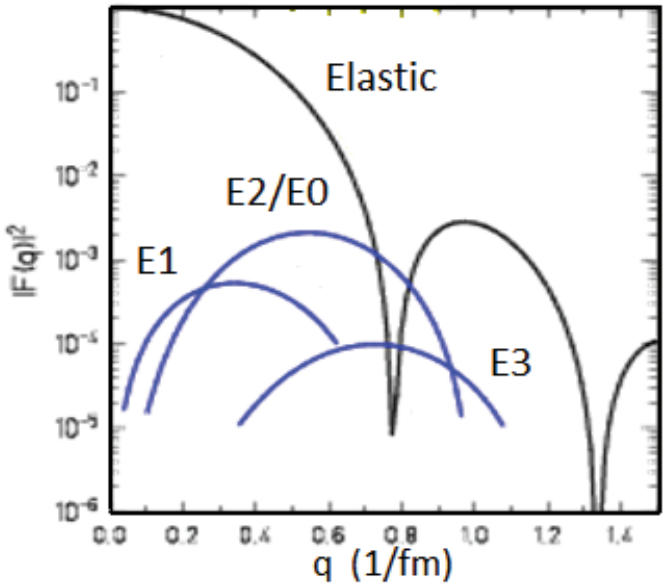
$$q = 2k\sin(\theta/2)$$

Electromagnetic probe is the most reliably studied
- Electron scattering as extremely reliable tool for research

- **Charge formfactor, charge radius**

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

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



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

- Electron scattering – differential characteristics

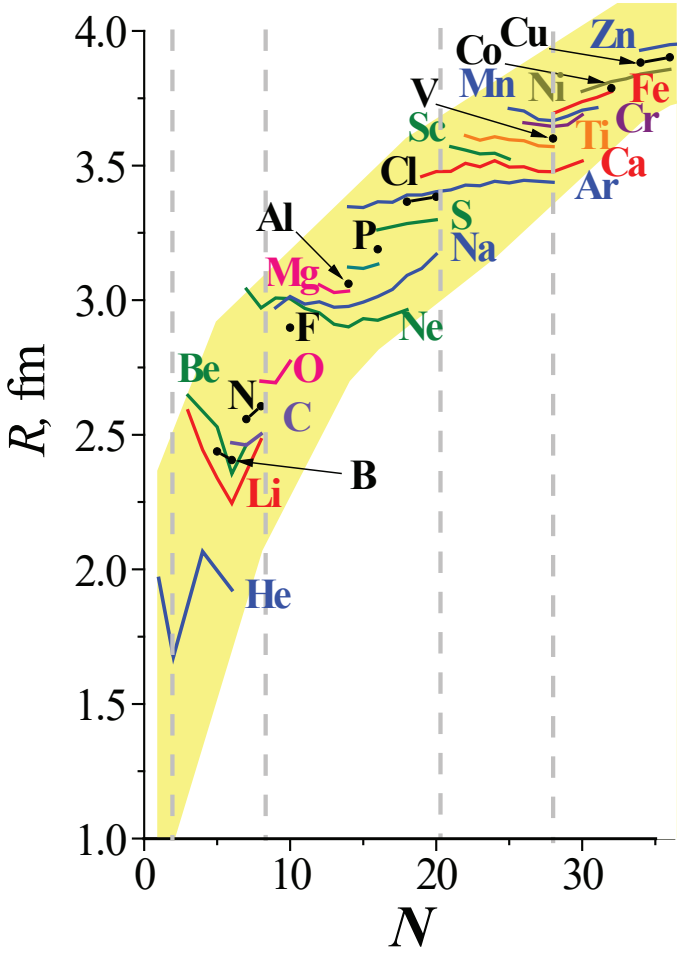
Status of charge radii studies – broad field for exploration

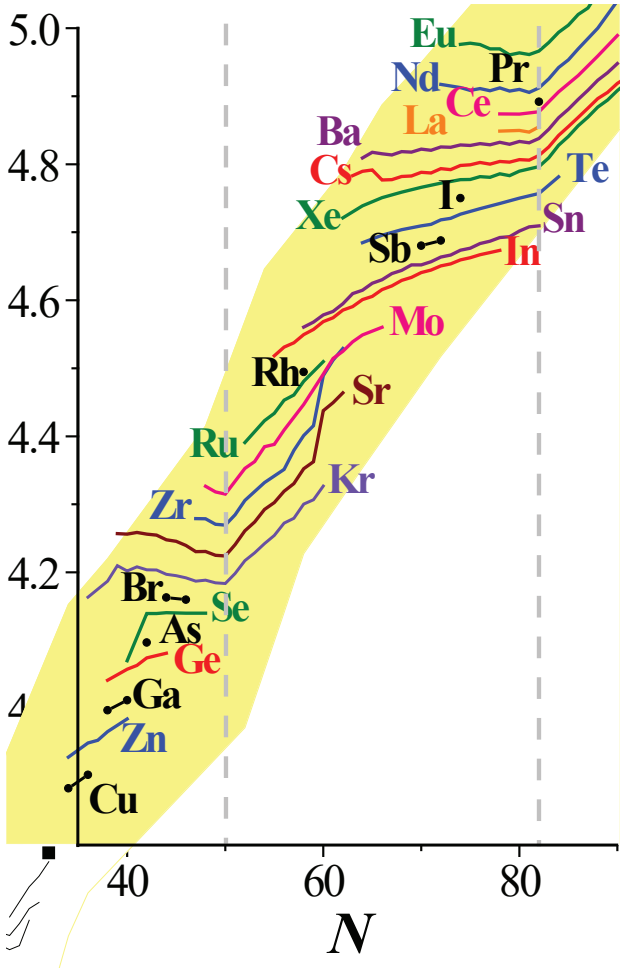
900 measured for 3100 known nuclear-stable isotopes

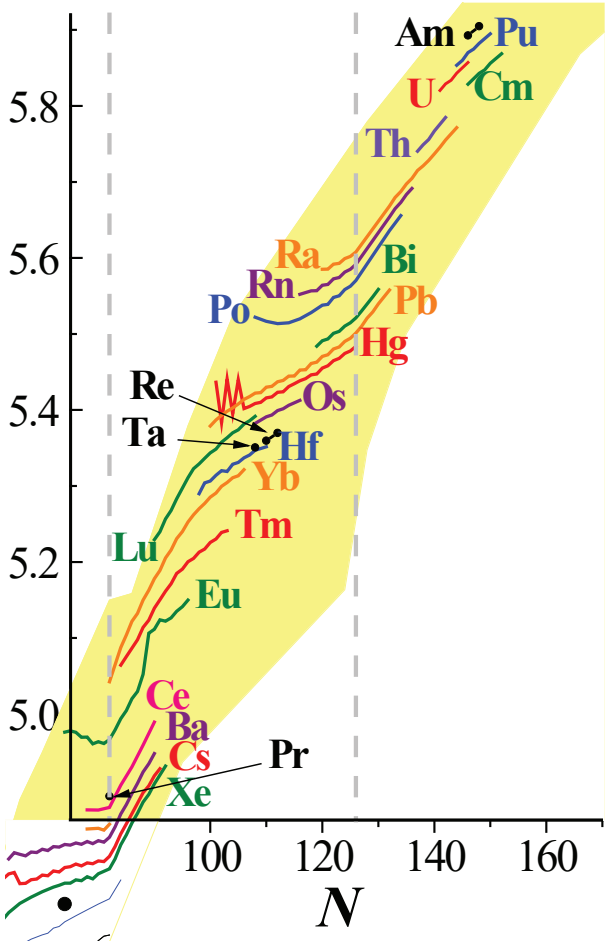
Some isotopic chains are well studied – some not at all

Somewhere driplines are nearly achieved – somewhere very far

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

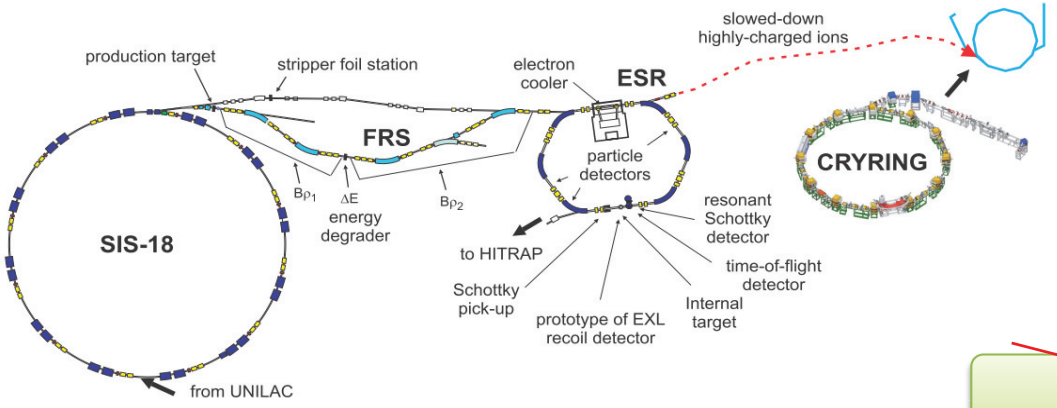




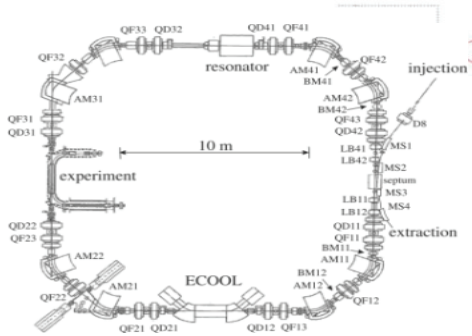


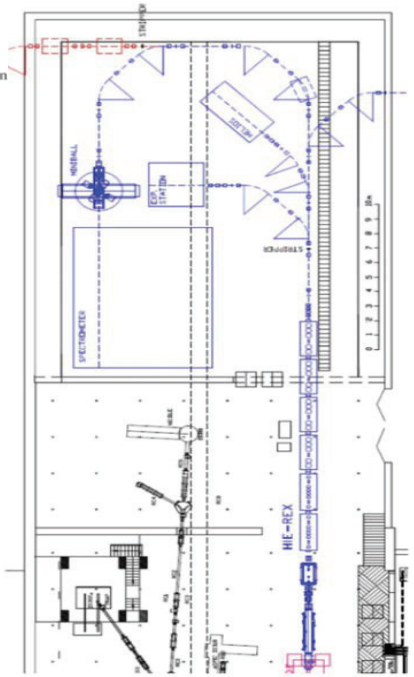
Ring projects in the world

~~ELISe/NESR@FAIR~~ → ESR/CRYRING@GSI

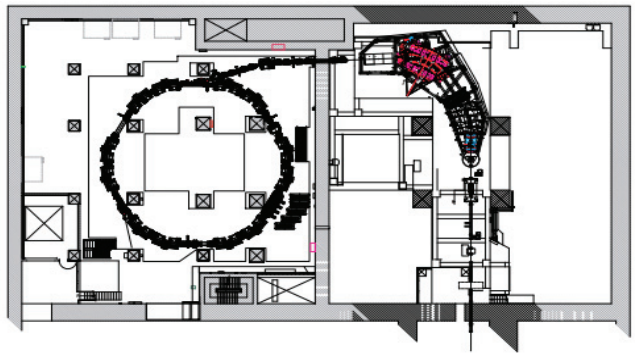


~~TSR/ISOLDE@CERN~~

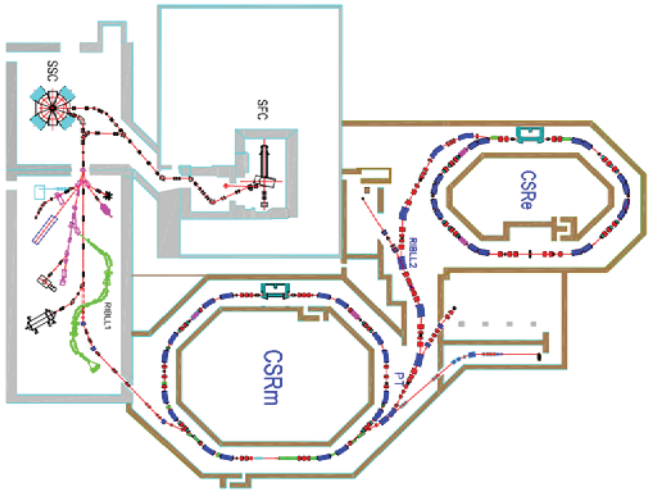




~~MUSES@RIKEN~~ → RI-Ring@RIKEN



~~HIRFL-CSR@Lanzhou~~ → HIAF



Not in scale

– Number of ring projects – essential interest to the topic

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

- Attack this problem requires record intensities of RIBs with T1/2>100 ms

DERICA

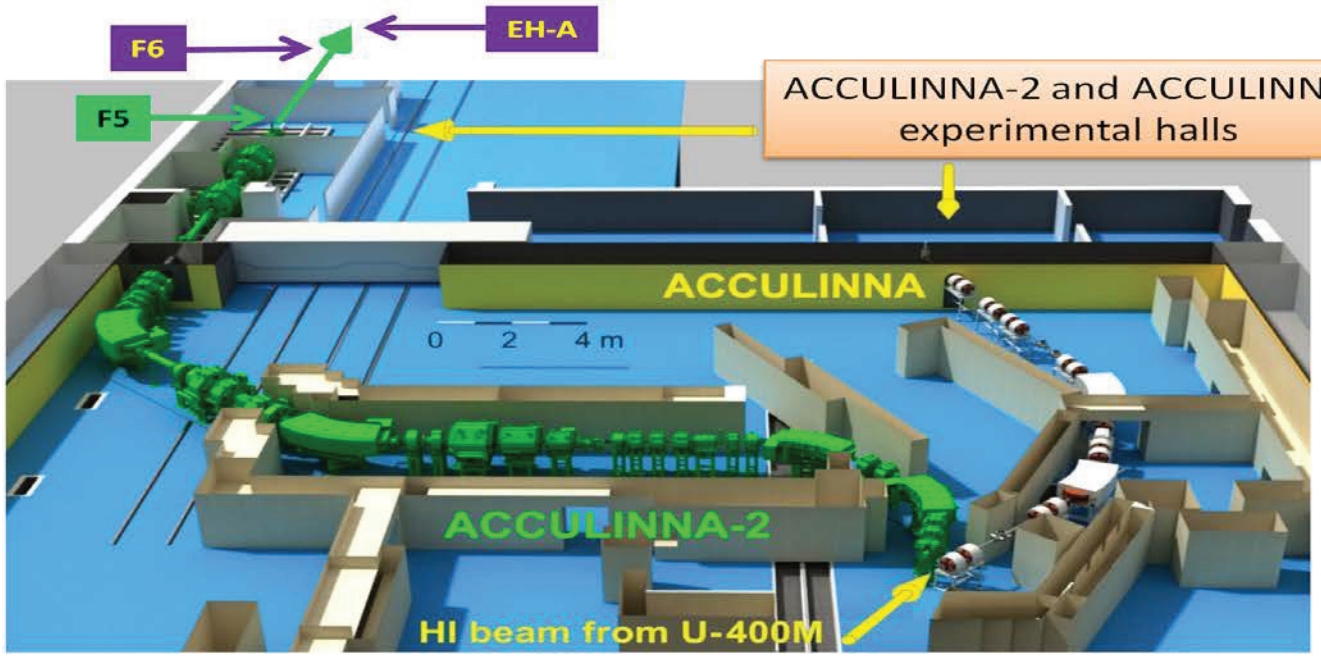
Dubna Electron-Radioactive Isotope Collider fAcility

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



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

DERICA stages 0 -1

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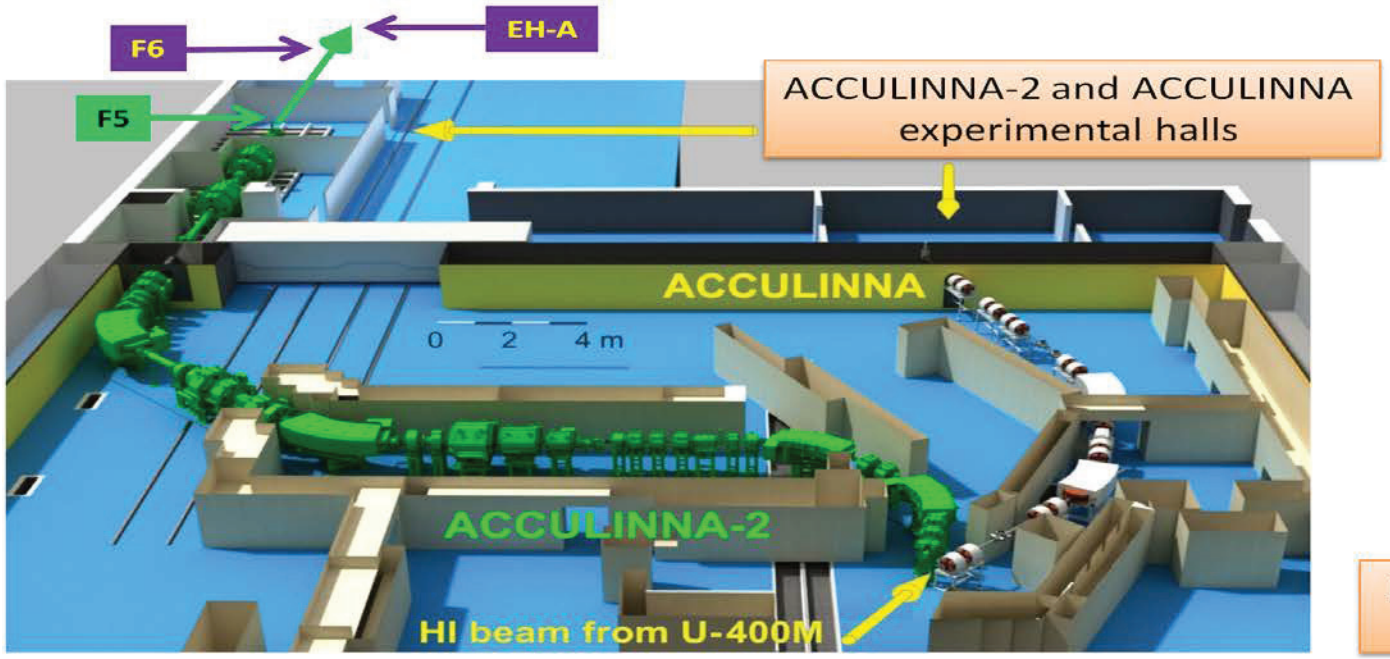
Minimization of technological risks



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DERICA stages 0 -1

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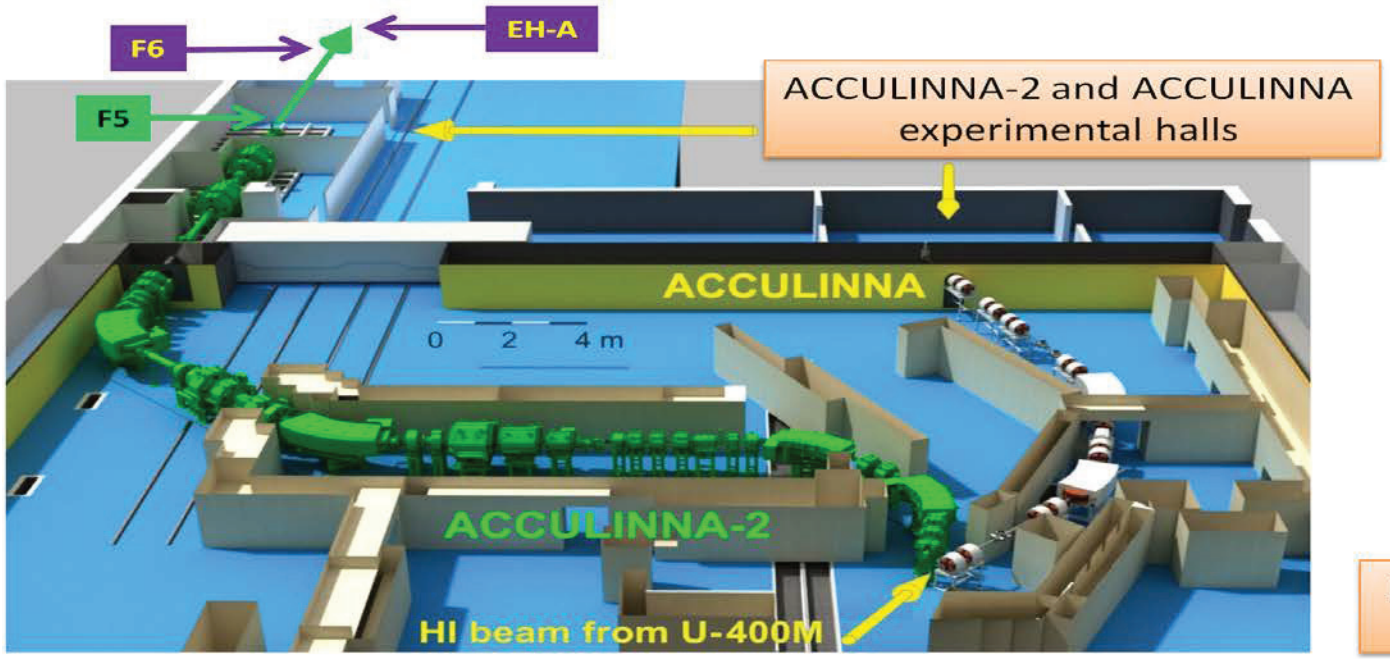

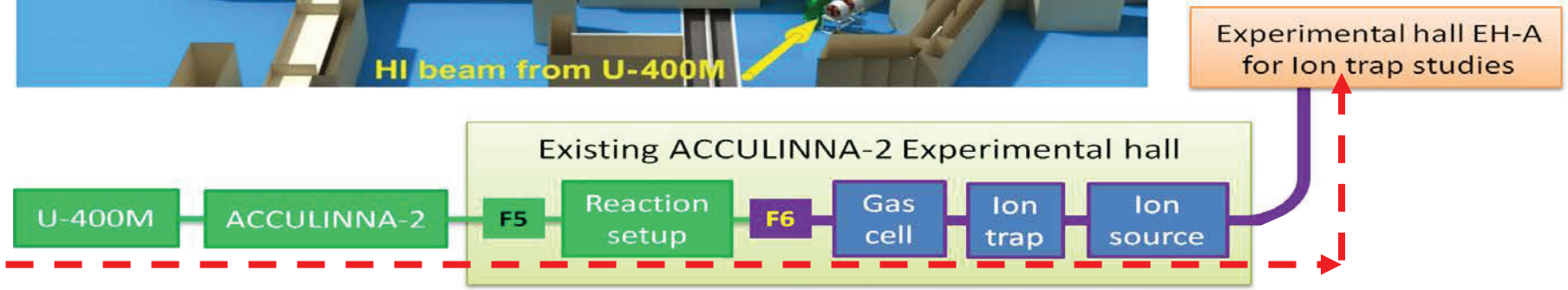

DERICA stages 0 -1

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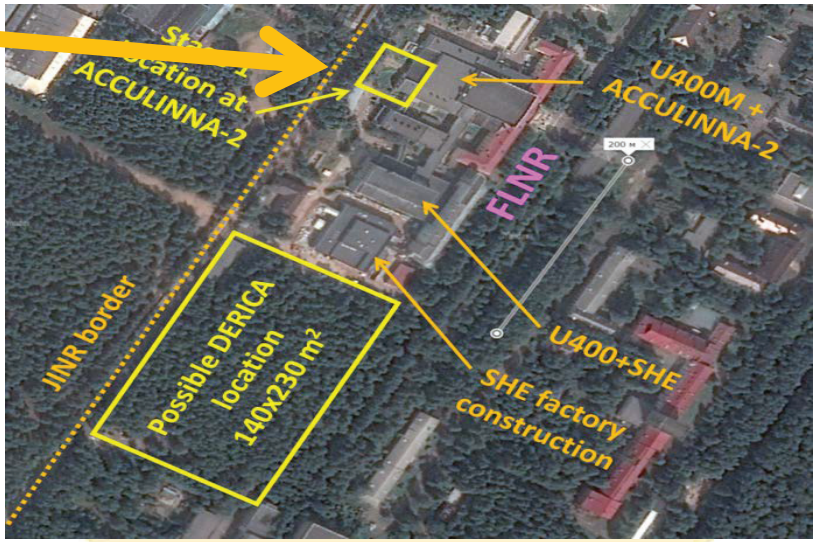

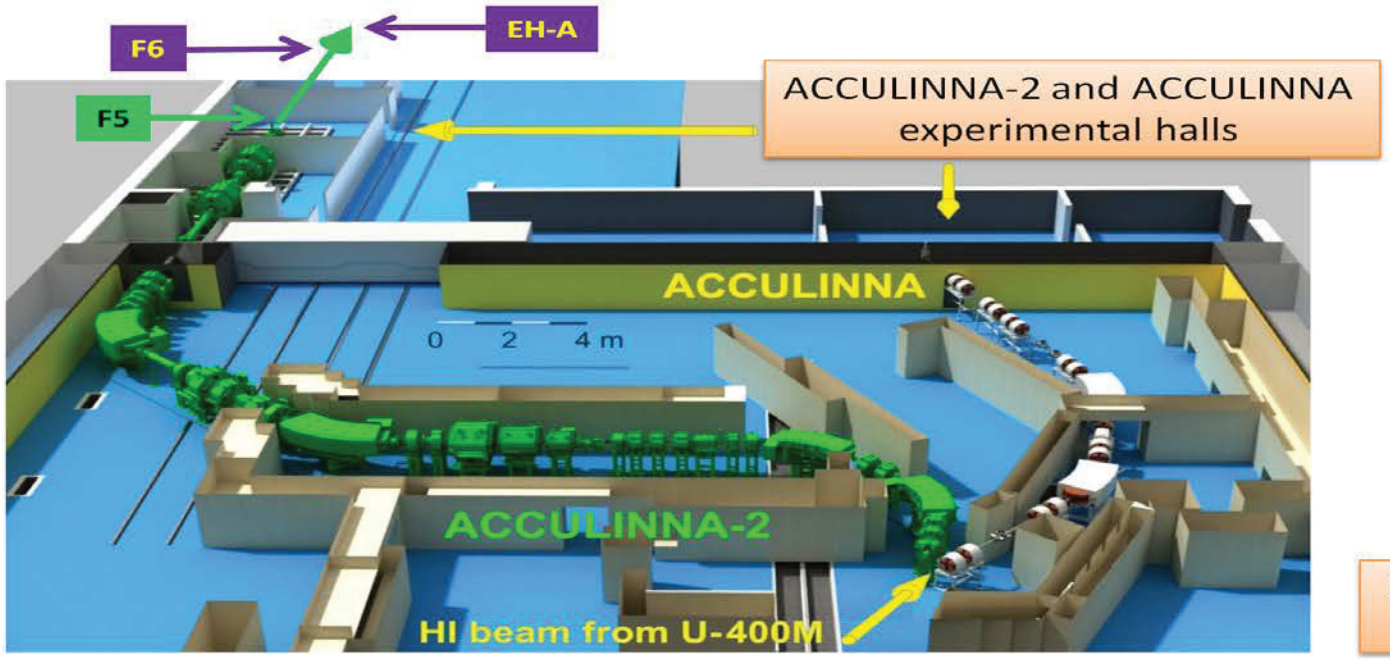

Stopped RIB – decay spectroscopy and studies in traps

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U-400M → ACCULINNA-2 → F5 → Reaction setup → F6 → Gas cell → Ion trap → Ion source

DERICA stages 0 -1

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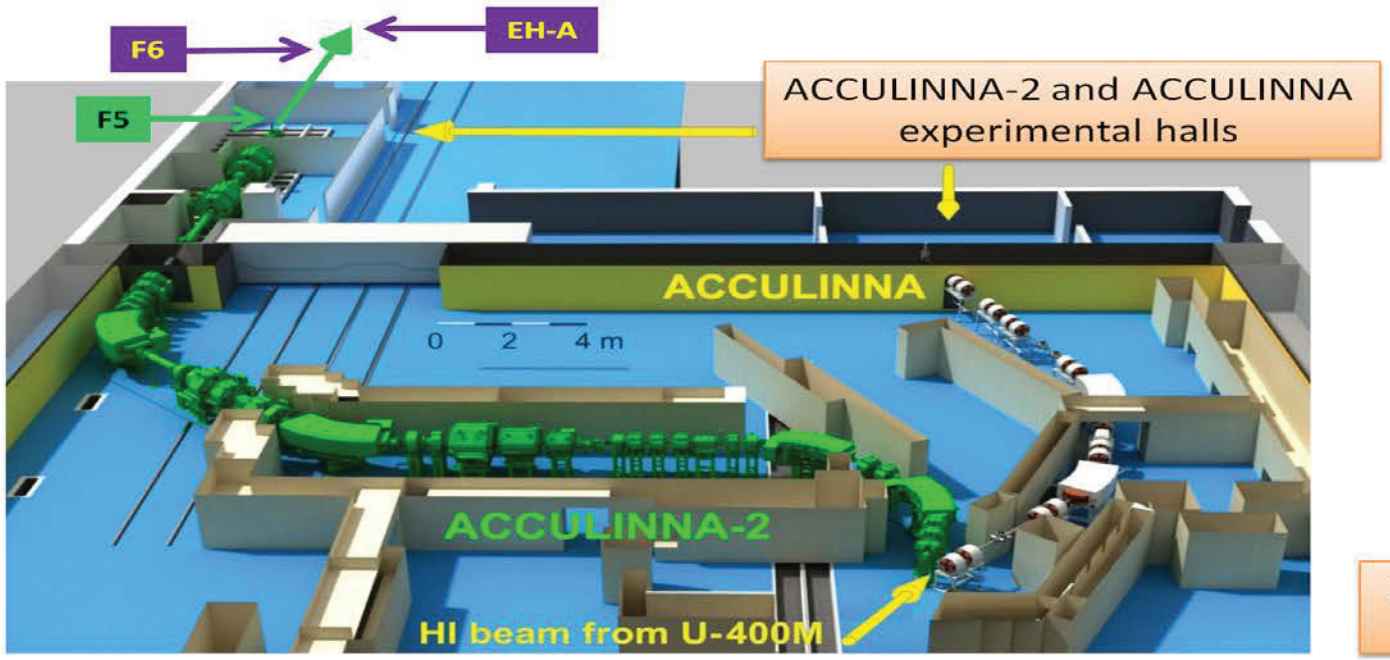
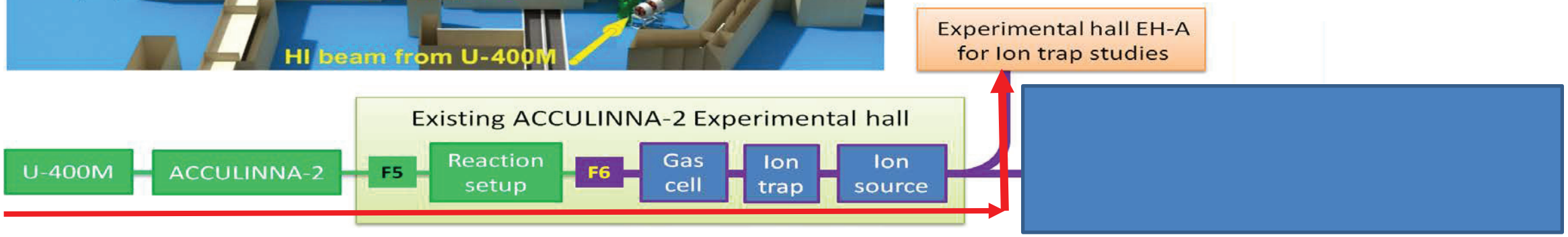
Minimization of technological risks





DERICA stages 0 -1

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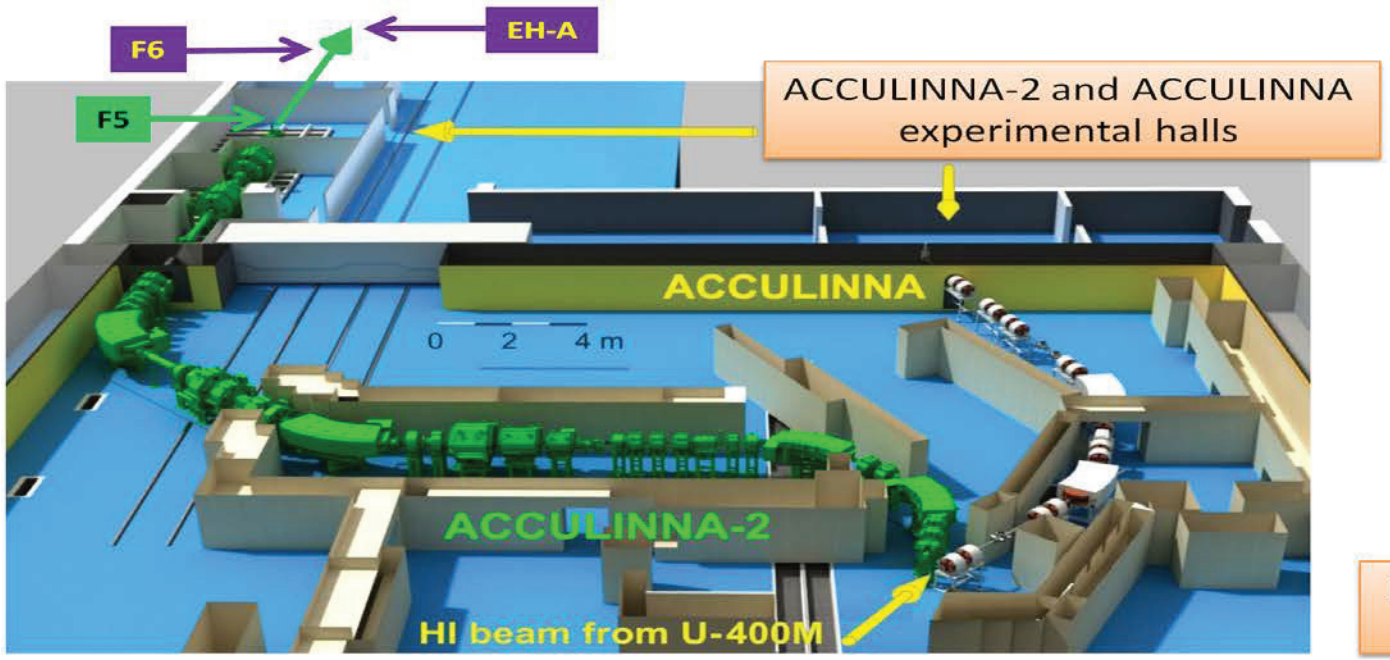

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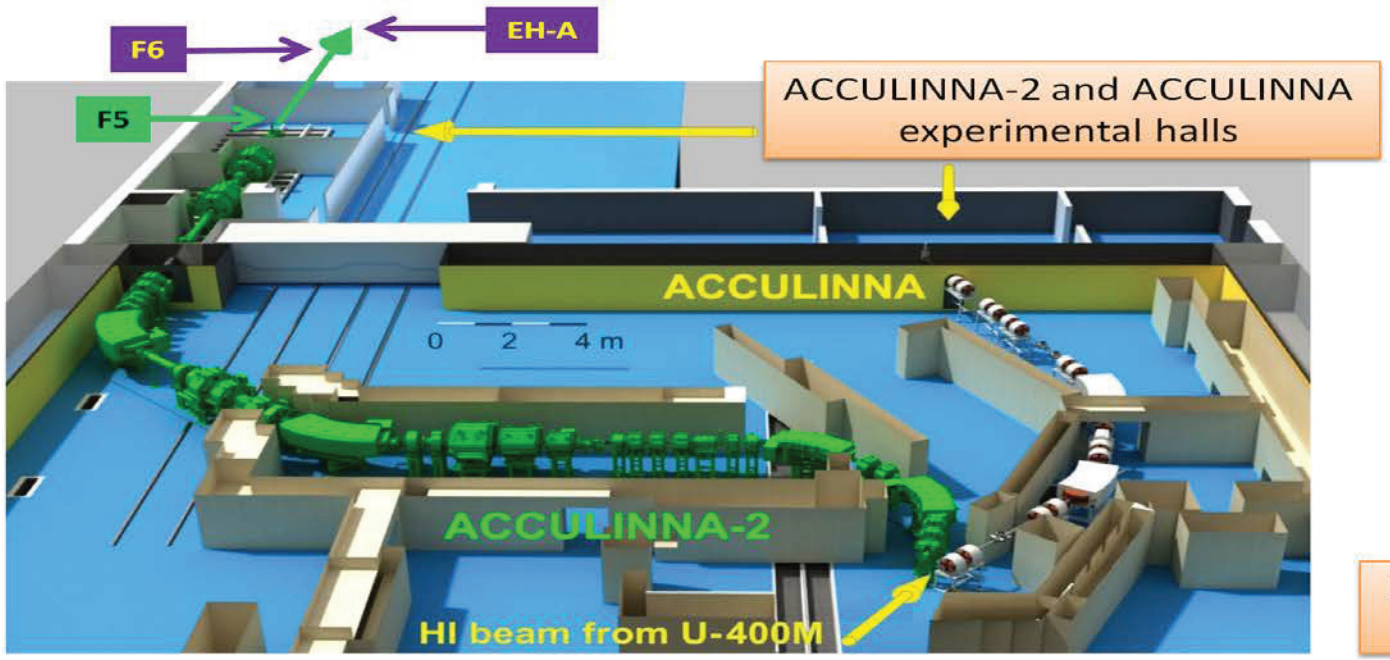
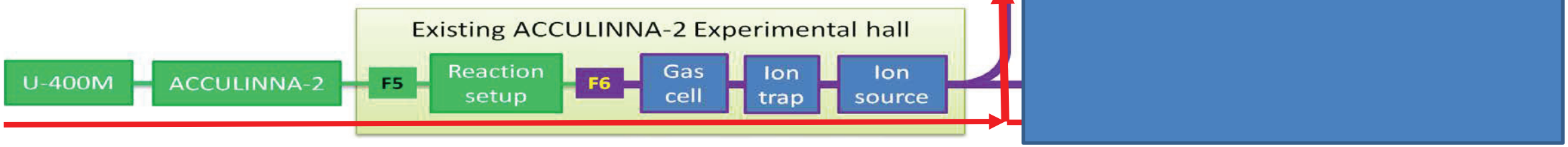


Reactions with reaccelerated RIBs around Coulomb barrier energy (5-7 AMeV)

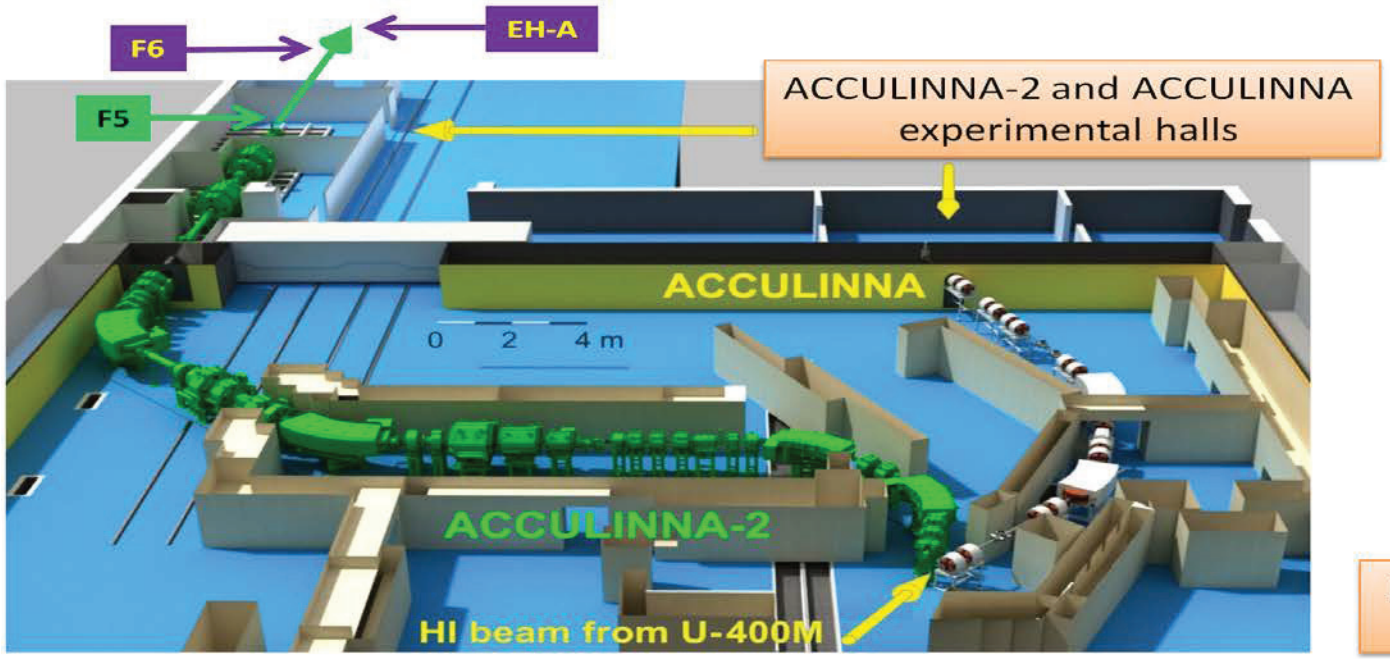
Experimental hall EH-A for Ion trap studies



DERICA stages 0 -1

Continuity of scientific program

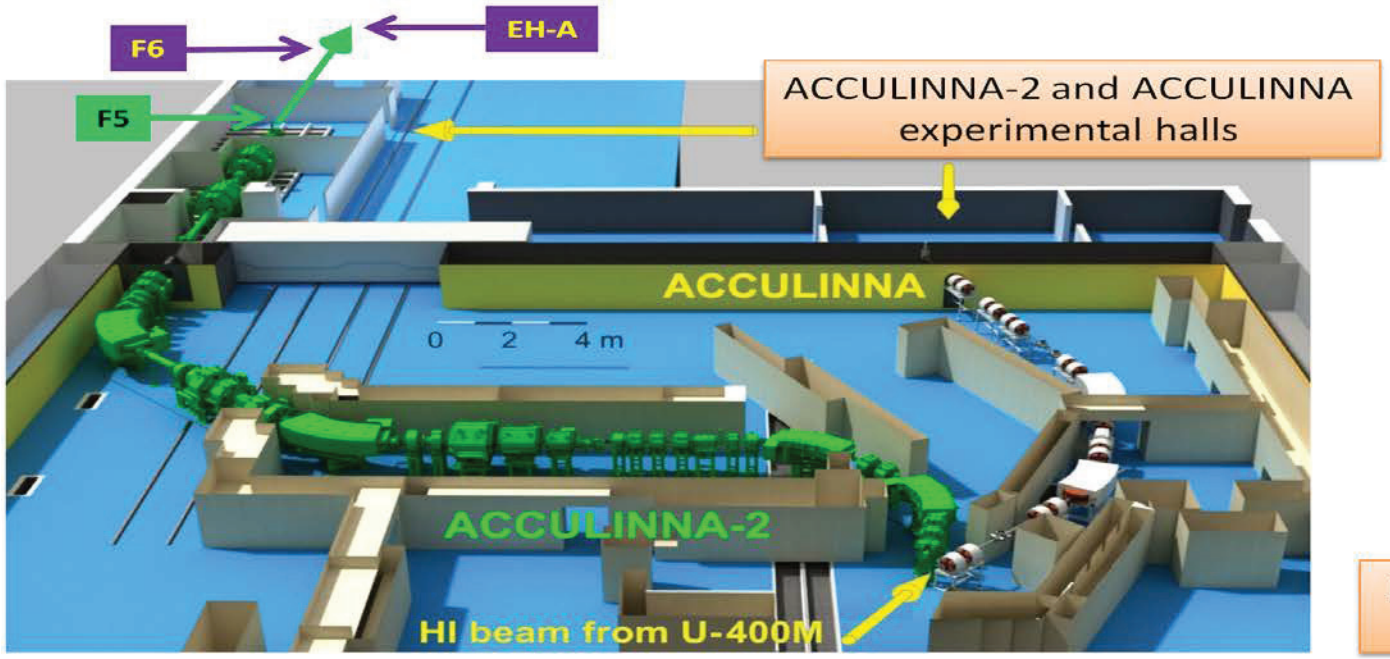
Minimization of technological risks



DERICA stages 0 -1

Continuity of scientific program

Minimization of technological risks



DERICA stages 0 -1

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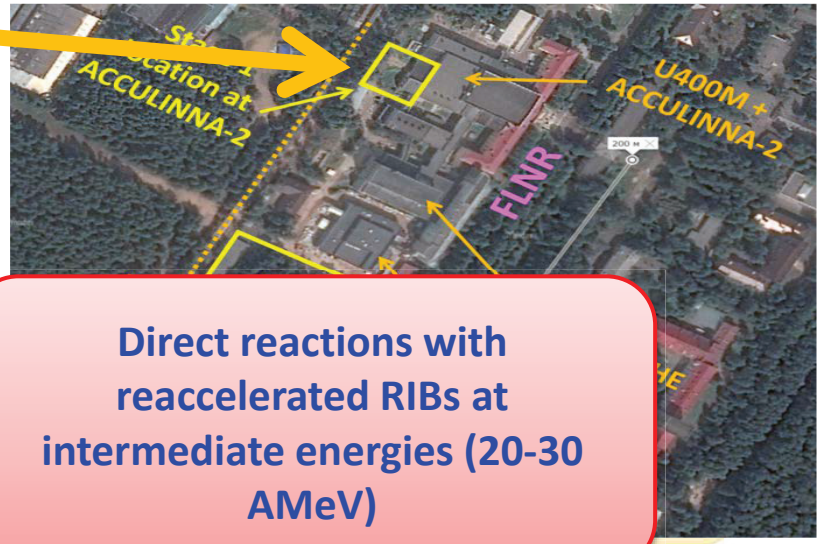
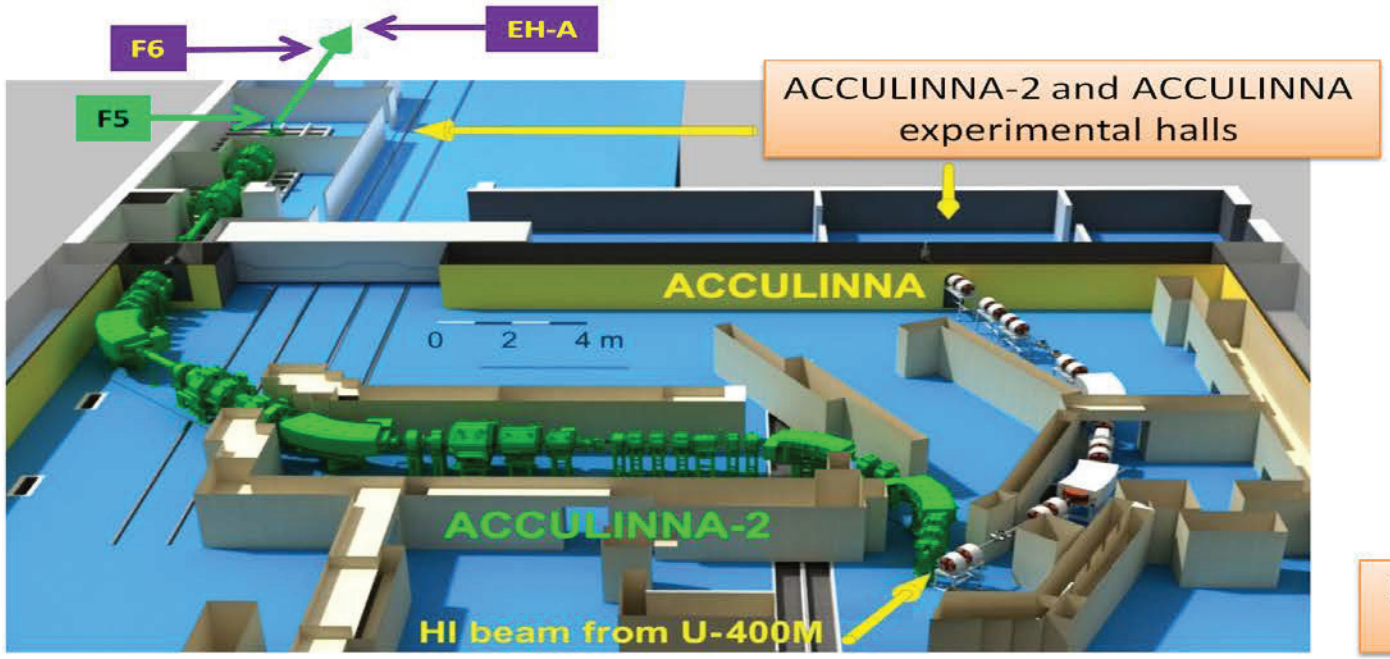


Direct reactions with reaccelerated RIBs at intermediate energies (20-30 AMeV)

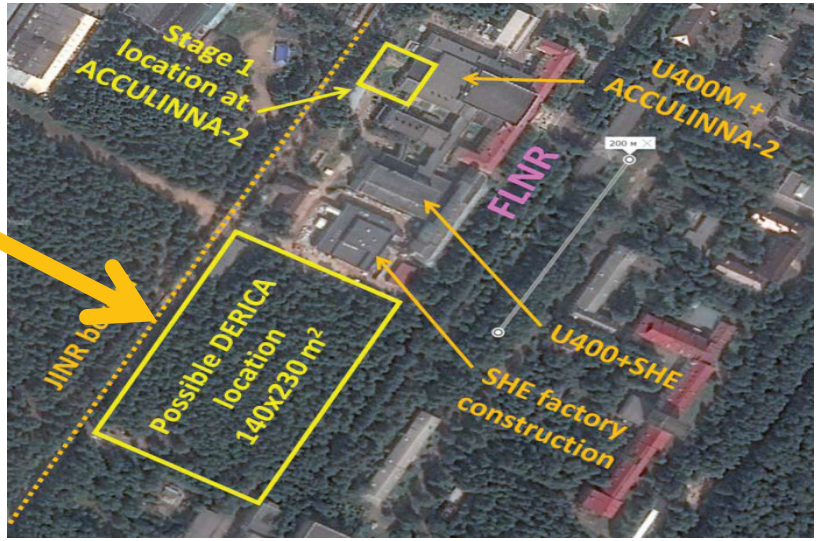


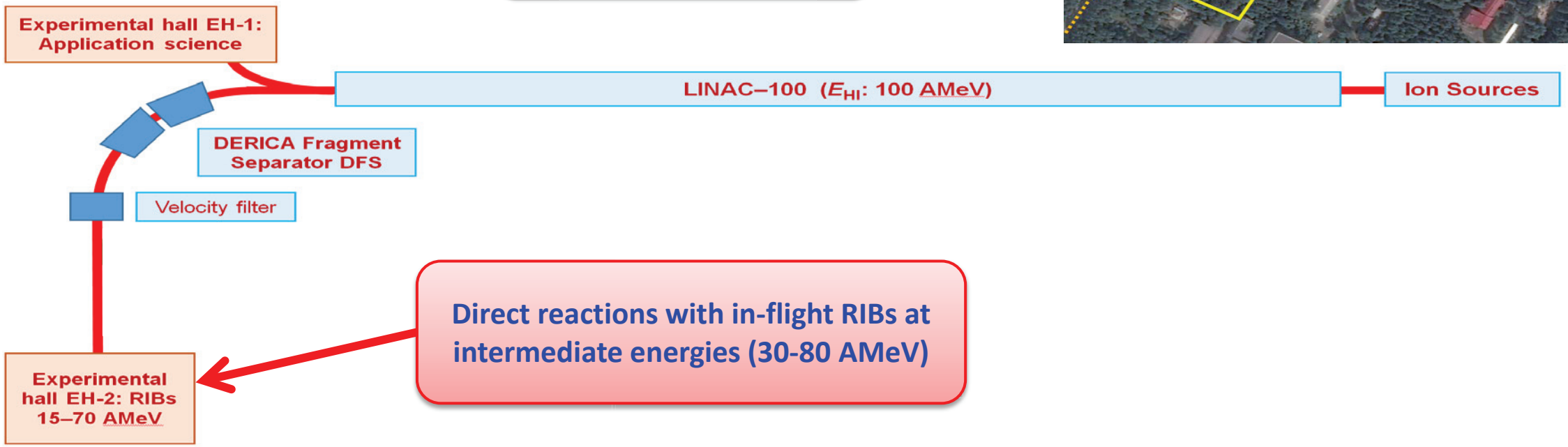
DERICA stages 2 - 4

New experimental opportunities for each stage

Spacious cite for development

Good upgrade capability





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

World-leading intensities are expected for this energy range

DERICA stages 2 - 4

New experimental opportunities for each stage

Spacious cite for development

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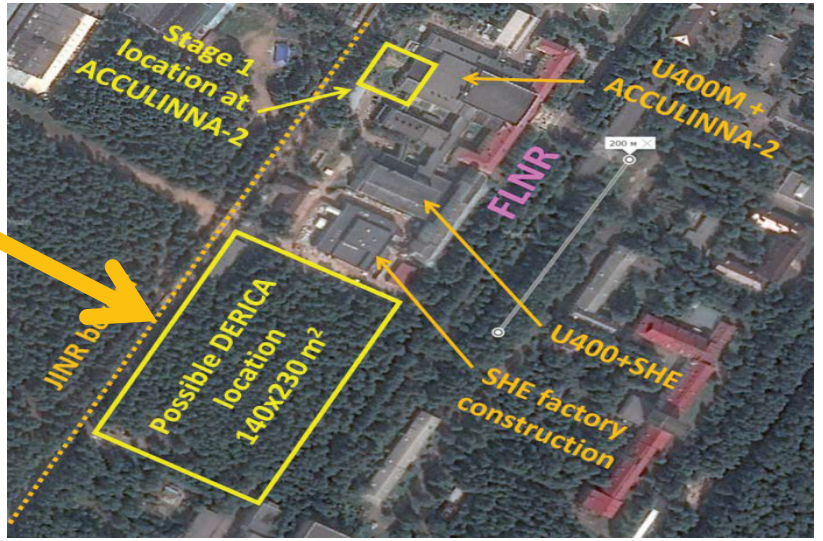

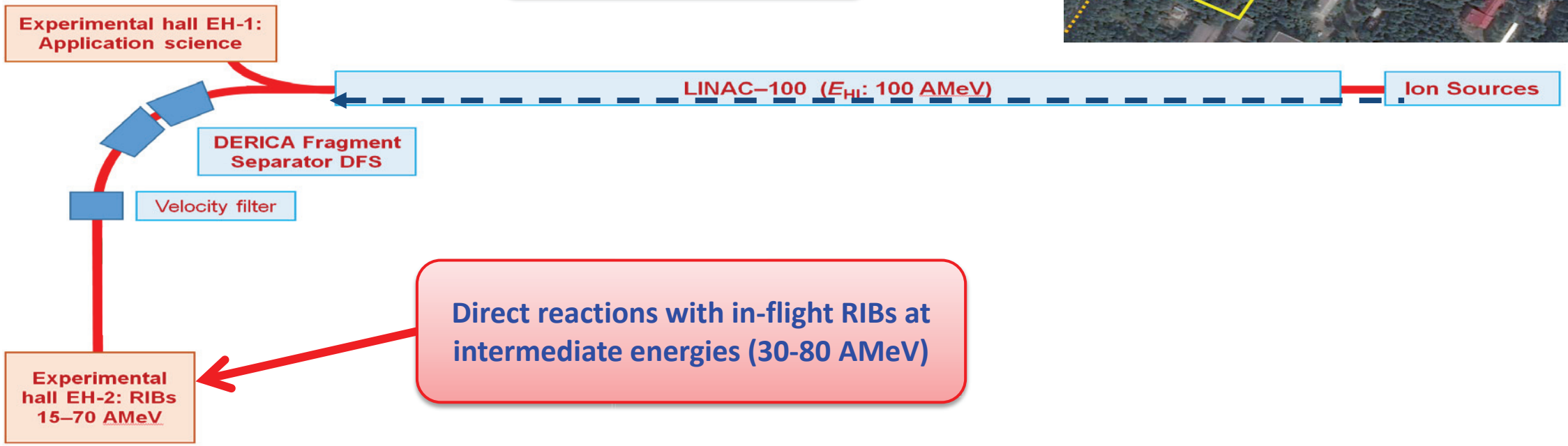

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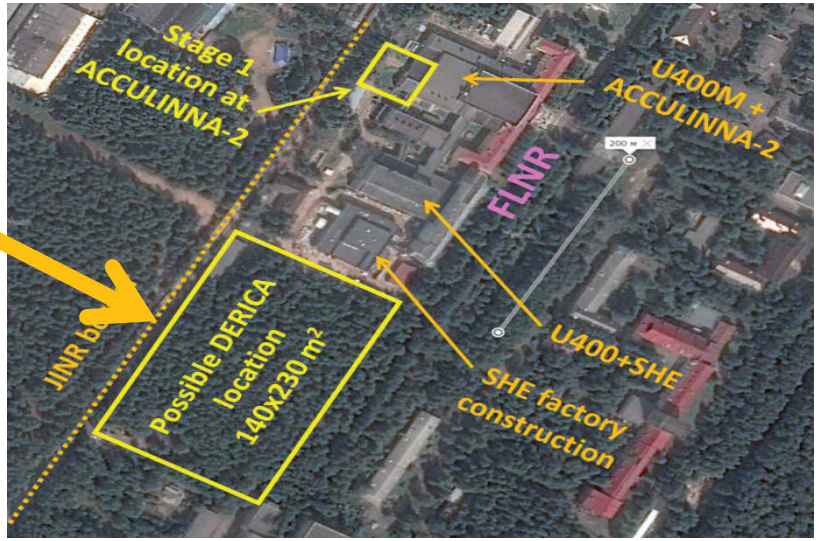
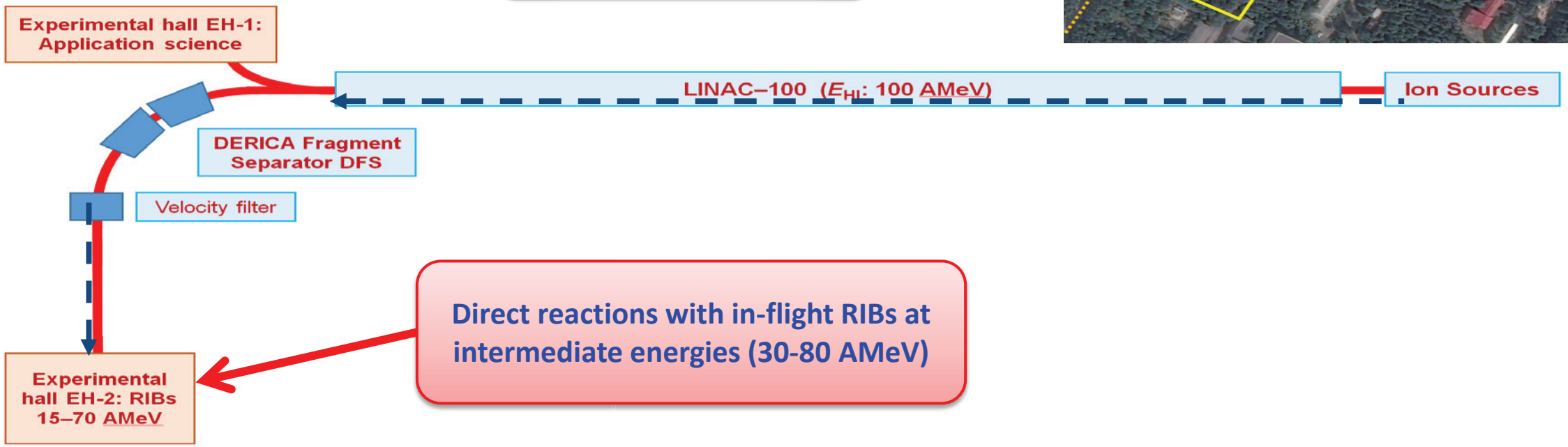




Direct reactions with in-flight RIBs at intermediate energies (30-80 AMeV)

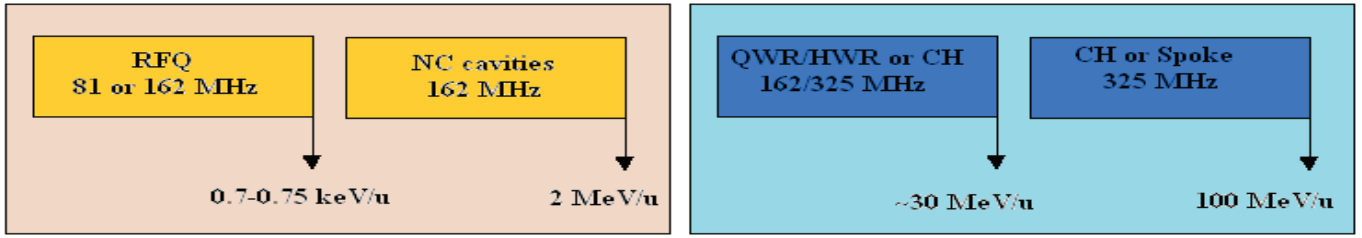
World-leading intensities are expected for this energy range

Driver LINAC-100 concept under development by ITEP (*T.Kulevoy*) and MEPhI (*S.Polozov*) team

Primary beams

Ion	*A*/*Z*	*I*, pμA
$^{11}B^{2+}$	5.5	10 and more
$^{18}O^{3+}$	6.0	10 and more
$^{20,22}Ne^{4+}$	5.5	8 and more
$^{32,36}S^{6+}$	6.0	5 and more
$^{36}Ar^{6+}$	6.0	5 and more
$^{40,48}Ca^{7+}$	6.0	5 and more
$^{56,64}Ni^{11+}$	5.8	5 and more
$^{86}Kr^{15+}$	5.7	5
$^{132}Xe^{22+}$	6.0	5
$^{160}Gd^{27+}$	5.9	5
$^{209}Bi^{37+}$	5.65	4
$^{238}U^{40+}$	5.95	~ 0.8*

Normal conducting + SC parts



Normal conducting = RFQ + DTL

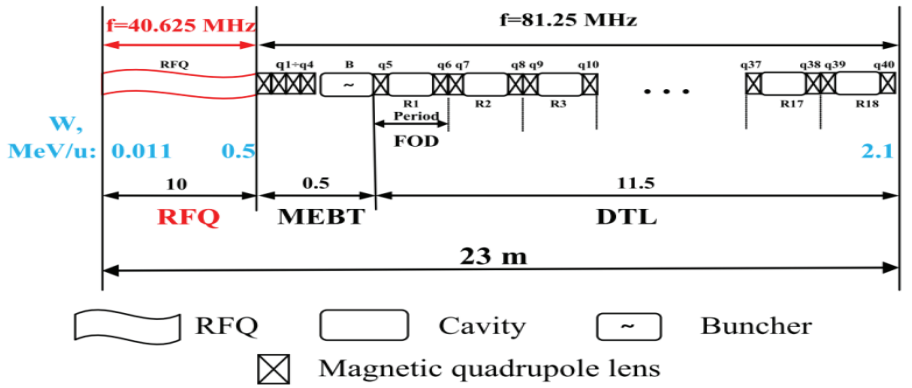
DERICA

A/Z ≤ 6.5
Input current=1 mA
Input transverse emittance ε=1 π·mm·mrad
E_{smax}=1.5 Kp
V_k / ε =10

RFQ & MEBT& DTL (L=22 m)

RFQ : **f=40.625 MHz**; W=0.011 ÷ 0.5 MeV/u; L=10 m
MEBT: **f=81.25 MHz**; W=0.5 ÷ 0.5 MeV/u; L=0.5 m
DTL : **f=81.25 MHz**; W=0.5 ÷ 2.1 MeV/u; L=11.5 m

Layout of NC (normal conduction) linac

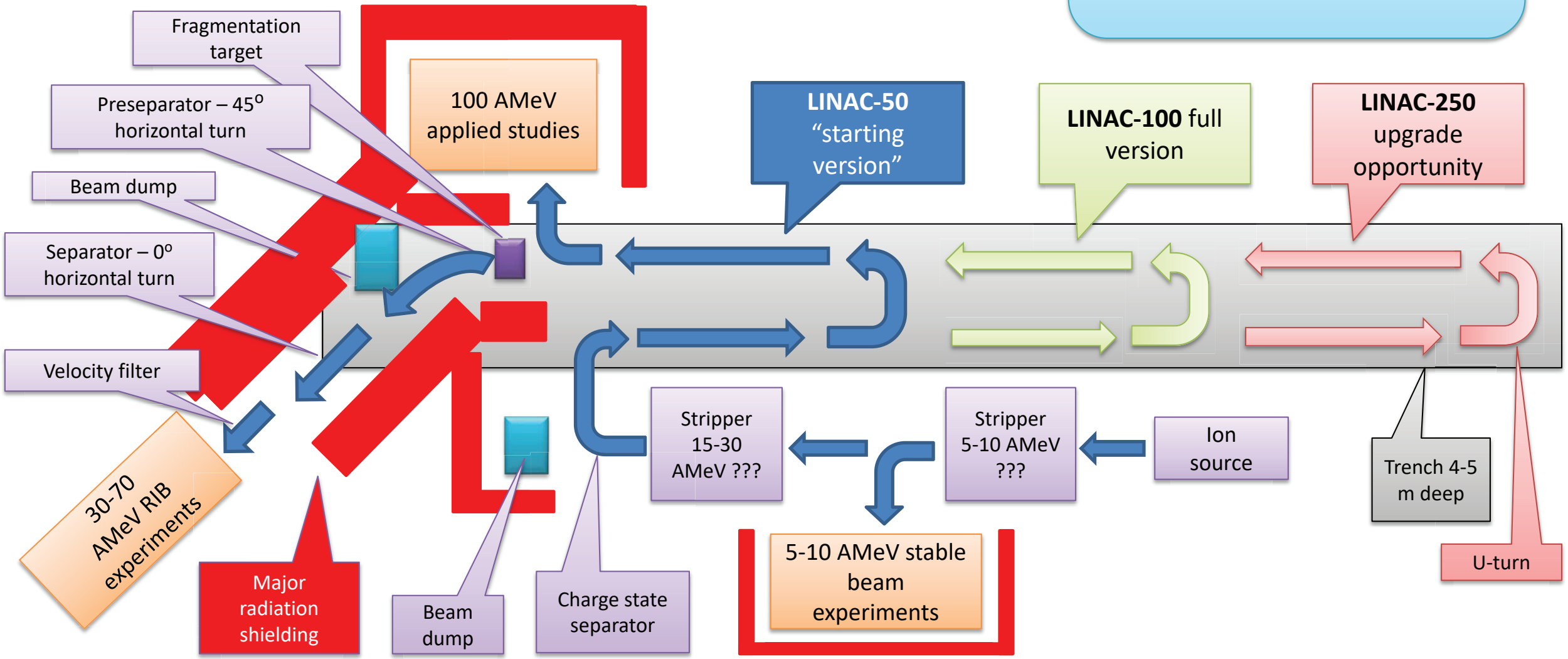


LINAC-100 + DFS layouts

(DERICA Fragment separator)

Flexible acceleration strategy – effective both for light and heavy primary beams

Low cost start version, but powerful upgrade option – continuity of research program

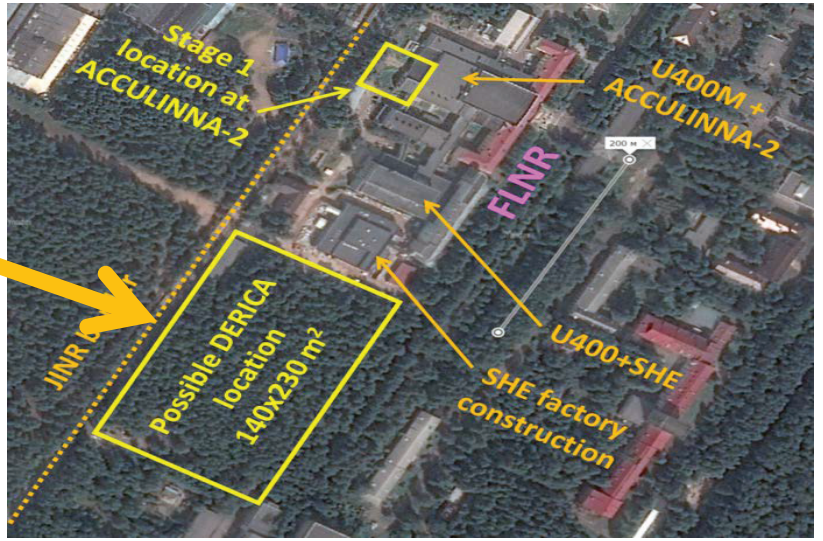


DERICA stages 2 - 4

New experimental opportunities for each stage

Spacious cite for development

Good upgrade prospects



Experimental hall EH-1: Application science

LINAC–100 (E_{HI}: 100 AMeV)

Ion Sources

DERICA Fragment Separator DFS

Velocity filter

- Gas cell - Ion trap
- Charge breeder

Stopped RIB – decay spectroscopy and studies in traps

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

LINAC–30 (E_{RIB}: 30 AMeV)

Experimental hall EH-2: RIBs 15–70 AMeV

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

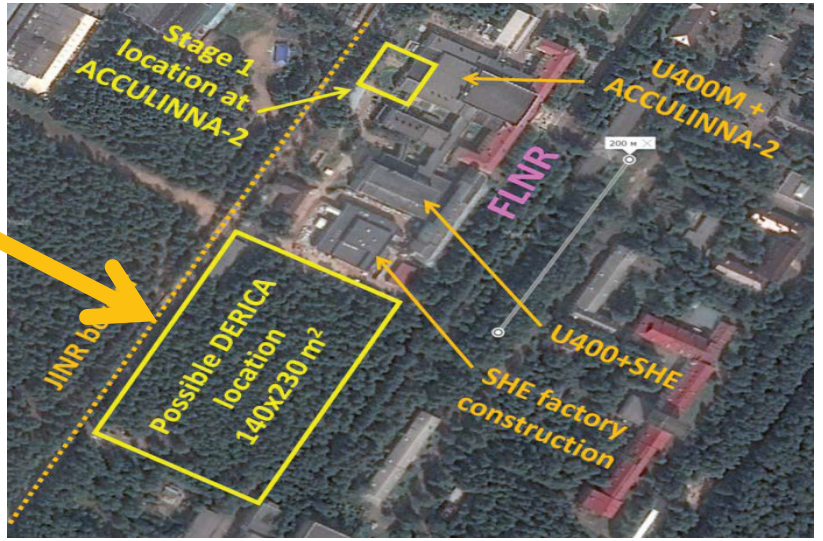
Experimental hall EH-3: reaccelerated RIBs 5 – 300 AMeV

DERICA stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects



Experimental hall EH-1: Application science

LINAC–100 (E_{HI}: 1

Ion Sources

DERICA Fragment Separator DFS

Velocity filter

- Gas cell - Ion trap
- Charge breeder

Fast Ramping Ring Synchrotron FRR: $E_{RIB} \leq 300$ AMeV

Low-energy storage ring experiments

LINAC–30 (E_{RIB}: 30 AMeV)

Experimental hall EH-2: RIBs 15–70 AMeV

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

Experimental hall EH-3: reaccelerated RIBs 5 – 300 AMeV

DERICA stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects

Storage ring experiments

Experimental hall EH-1: Application science

LINAC–100 (E_{HI}: 100 AMeV)

DERICA Fragment Separator DFS

Velocity filter

- Gas cell - Ion trap
- Charge breeder

Experimental hall EH-2: RIBs 15–70 AMeV

LINAC–30 (E_{RIB}: 30 AMeV)

Fast Ramping Ring Synchrotron FRR: $E_{RIB} \leq$ 300 AMeV

Gas jet target p,d,^{3,4}He

Electron cooler

Collector Ring CR: $E_{RIB} \leq$ 300 AMeV

Neutron source $\geq 10^8$ n/cm²

Experimental hall EH-3: reaccelerated RIBs 5 – 300 AMeV

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 stages 2 - 4

New experimental opportunities on each stage

Spacious cite for development

Good upgrade prospects

e-RIB collider experiments

Experimental hall EH-1: Application science

LINAC–100 (E_{HI}: 100 AMeV)

DERICA Fragment Separator DFS

Velocity filter

- Gas cell - Ion trap
- Charge breeder

Experimental hall EH-2: RIBs 15–70 AMeV

LINAC–30 (E_{RIB}: 30 AMeV)

Fast Ramping Ring Synchrotron FRR: $E_{RIB} \leq$ 300 AMeV

Gas jet target p,d,^{3,4}He

Electron cooler

Collector Ring CR: $E_{RIB} \leq$ 300 AMeV

Neutron source ≥ 10^8 n/cm²

Experimental hall EH-3: reaccelerated RIBs 5 – 300 AMeV

e-RIB collider

Electron Ring ER

e-LINAC (E_e: 500 MeV)

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

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

http://arxiv.org/abs/1806.08983

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.*

April 26, 2018. This 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»

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I. Meshkov, Electron-Ion Collider with Quasi-Ordered Ion Beam Submitted to NIM A, http://arxiv.org/abs/1806.08983

Thank you for your patience and attention!

Спасибо за ваше терпеливое внимание!

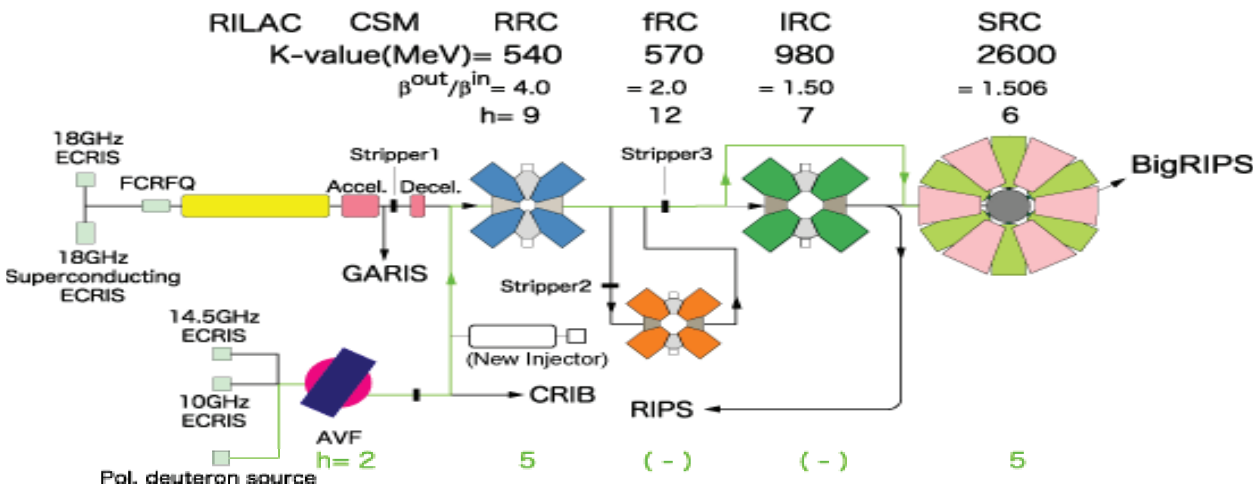
back up slides

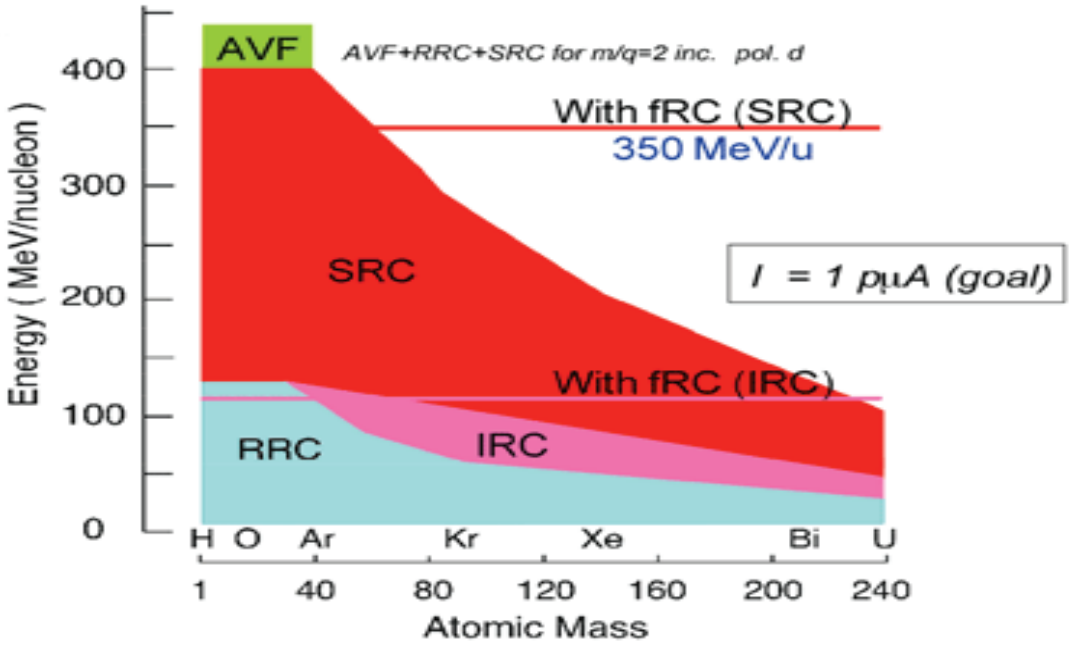
Common solution – cascades of accelerators

Operates	In construction	Upgrade plans
RIKEN: LINAC+4xCyc/ LINAC+3xCyc/3xCyc		RIBF+: +Cyc
GSI: LINAC+Sync	FAIR: LINAC+Sync+Sync	FAIR+: LINAC+Sync
	HIAF: LINAC+Sync	
GANIL: Cyc+Cyc	SPIRAL2: LINAC	
MSU: Cyc+Cyc	FRIB: LINAC	FRIB+: LINAC
	RISP: LINAC	
K4/K10: Cyc+Sync		
Lanzhou: Cyc+Sync		Lanzhou: LINAC+Sync

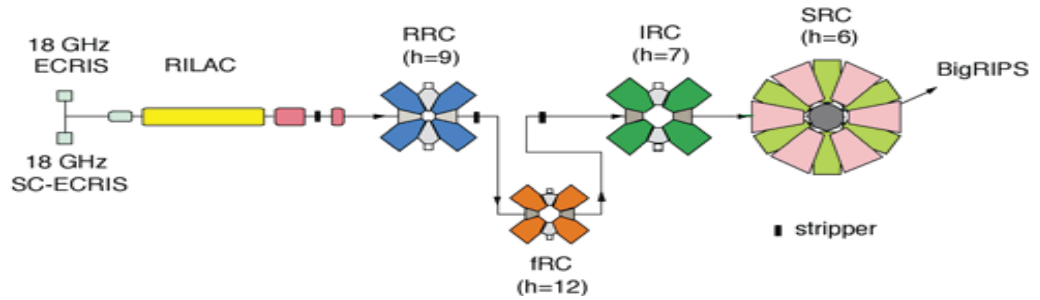
RIKEN RIBF cyclotron layout and operation

Schematic diagram of the RIBF heavy-ion accelerator system

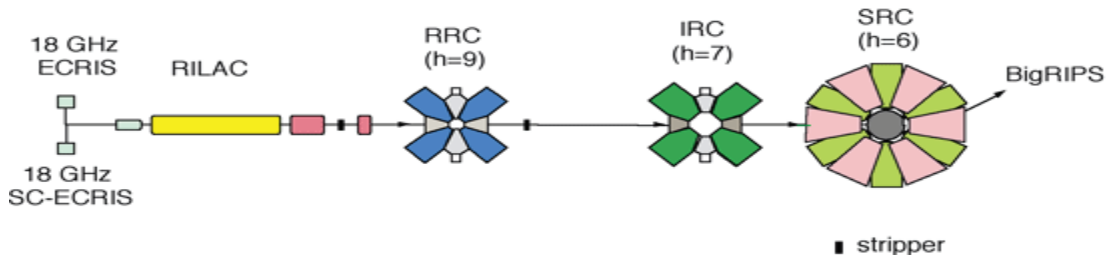




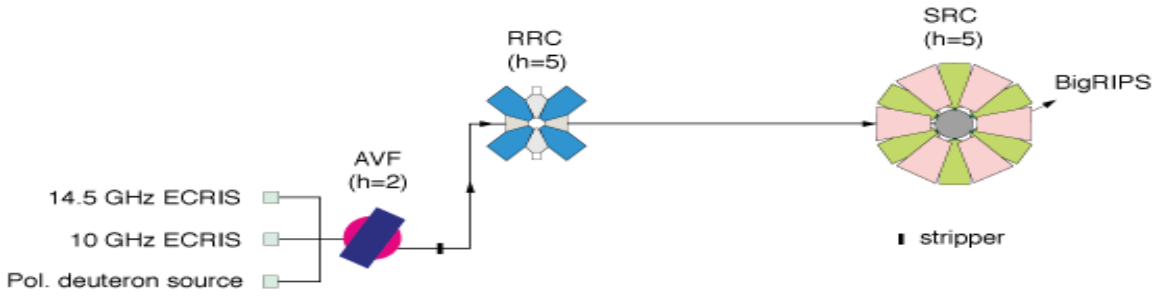
Mode (1): RILAC + RRC + (stripper2) + fRC + (stripper3) + IRC + SRC



Mode (2): RILAC + (stripper1) + RRC + (stripper3) + IRC + SRC



Mode (3): AVF + RRC + SRC



Cyclotron vs. LINAC – pro et contra

	Cyclotron	LINAC
Basic	Injection <50% transmission Acceleration of 1 charge state	RFQ ~99% transmission Acceleration of 3 to 5 charge states
Plus	Compact Easy to operate	"No loss" operation Flexible acceleration strategy Upgradable Easy to repair Variable energy
Minus	Could be hard to repair HI Injection/extraction problems Superconductivity for U > 50 AMeV	Length Cost per AMeV Superconductivity for CW

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Factor 6 - 10

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

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.