Future Nuclear Physics Facilities around the world

-- How we compete and how we collaborate ---

From the discussions in IUPAP Working Group 9.

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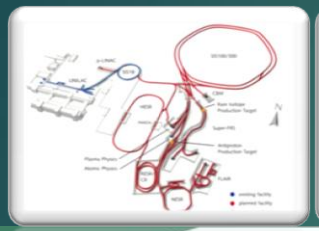
RIKEN NISHINA CENTER FOR ACCELERATOR-BASED SCIENCE

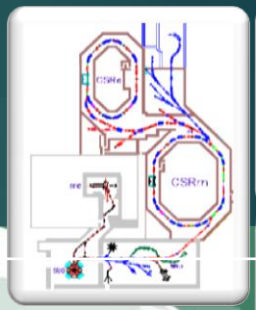
MEMBER OF WG9

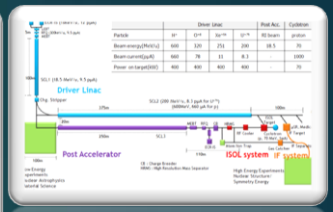
OCT 13TH 2014

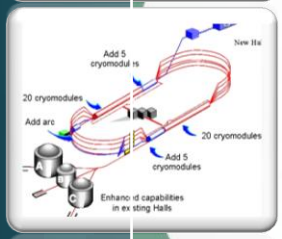
sketch a world-wide framework for the key issues in nuclear science research for the next 10 to 20 years.

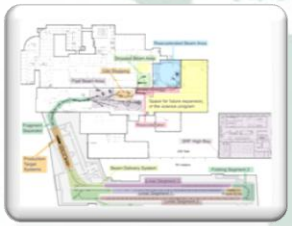
Today I mention….

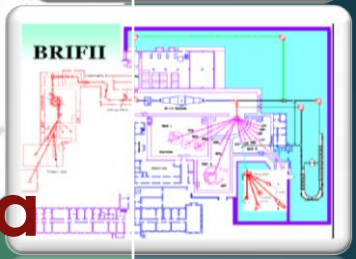








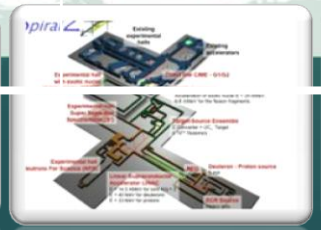


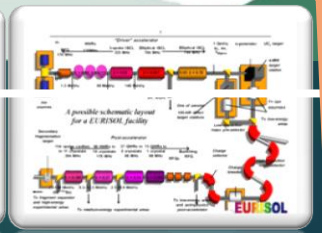


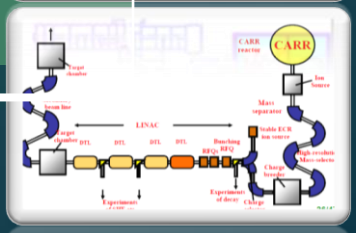
AMERICA
North/South

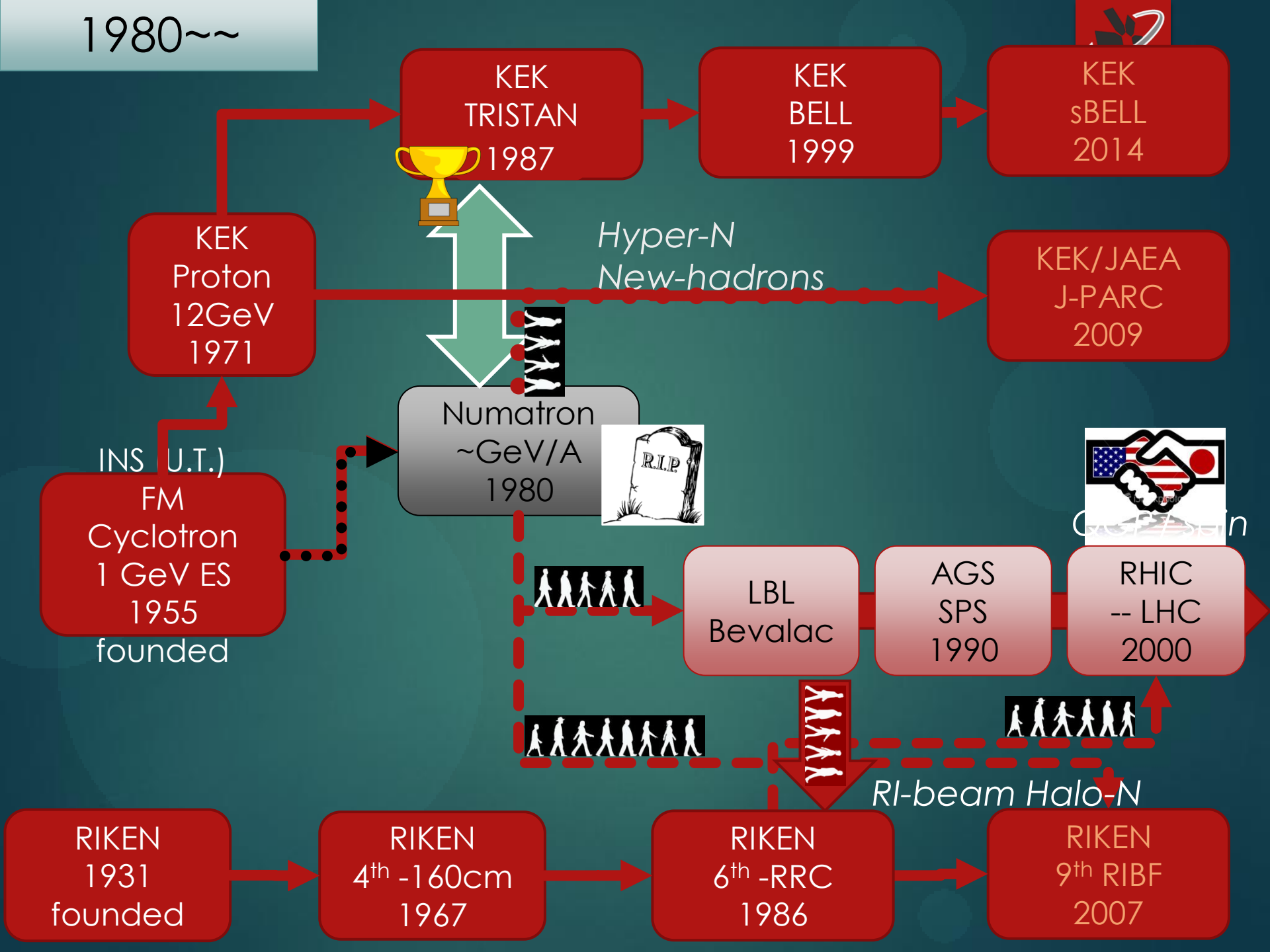
EUROPE
Africa

ASIA
Oceania



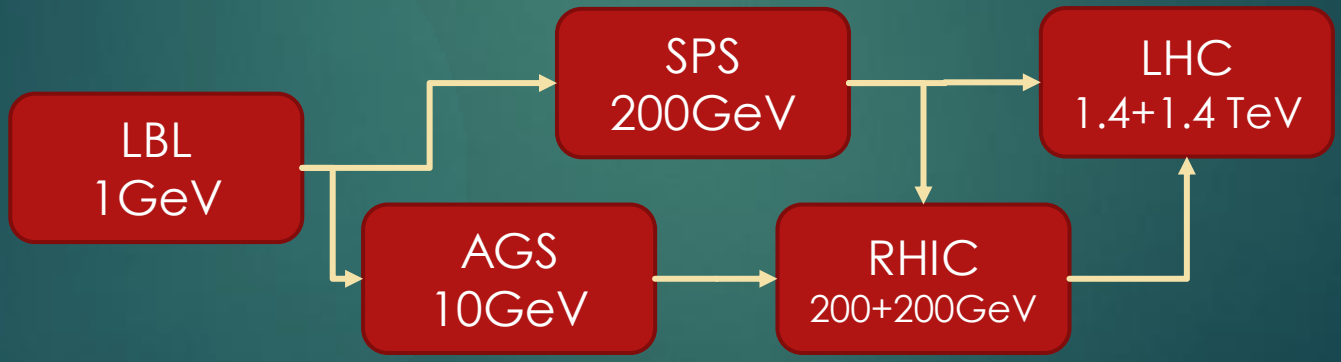





1980~~
KEK
TRISTAN
1987
KEK
BELL
1999
KEK
sBELL
2014
KEK
Proton
12GeV
1971
Hyper-N
New-hadrons
KEK/JAEA
J-PARC
2009
Numatron
~GeV/A
1980
R.I.P
INS U.T.)
FM
Cyclotron
1 GeV ES
1955
founded
LBL
Bevalac
AGS
SPS
1990
RHIC
-- LHC
2000
RI-beam Halo-N
RIKEN
1931
founded
RIKEN
4th -160cm
1967
RIKEN
6th -RRC
1986
RIKEN
9th RIBF
2007

Lessen learned

- *If Japan had NUMATRON in 80th, We would not have JPARC nor RIBF at present.*
- *Two Colliders (e+e, A+A) in a country (at least in Japan) is beyond our nations ability.*
- *We have sold High Energy A+A (Hot QCD) community to the international collaboration.*
  - *Quite successful with 5 accelerators (2+1+2) to reach QGP*



- *But none from scratch.*
- *We have to be practical and wise.*

National, Regional, International

Scale of the project						
10 M$	50 M$	100 M$	500 M$	1,000 M$	5,000 M$	10,000 M$
Institutional		national		regional		International
			RHIC JLAB NICA	eRHIC JPARC FAIR	SSC LHC	ILC
ARIEL HIE-ISOLDE SPES			RIBF FRIB RISP SPIRAL2	FAIR	EURISOL CARIF	

Rule of thumb

- We do region wide collaboration due to Man-Power/Money-Power limitation
  - Not by nature (do it by myself is scientist's nature)
- Good Facility wins the game.
- Researches are international, Educations are often not (distance).
- Good balance required (only one in the world is not a good approach)

and family life

Physics

Quark many body (Hot QCD)

Quark gluon plasma
property of early universe

Quark many body (Cold QCD)

QCD chiral symmetry
nucleon/meson structure

Nucleon many body

Ultimate nuclear picture
nuclear property/structure (Hyper)

Element Genesis
R/P process, Astrophysics

Island of stability
Super heavy element/chem.

Fundamental Physics

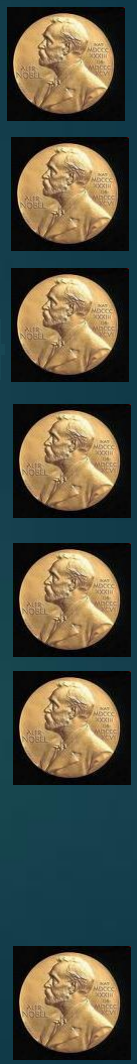
Double beta, nEDM…
Using rare RI/forbiidden decays

Computation

Ab-initio calculation
Nuclear force in lattice, Shell model

Applications

Muon catalyzed fusion
Nuclear transmutation



Physics promoting projects

	America role-shared	Europe role sharing	Asia No-controle
Quark many body (Hot QCD)	RHIC	LHC(ALICE) FAIR(SIS300)	-
Quark many body (Cold QCD)	JLAB-12GeV eRHIC(eIC)	FAIR(SIS100) NICA	JPARC Spring-8 HIRFL
Nucleon many body	FRIB ARIEL/ISAC2	GSI/FAIR SPIRAL2 SPES HIE-ISOLDE Du na	RIBF RISP HIRFL BRIEF

Two body

Mean Field

Three Body

Fundamental Physics / C

Mean Field

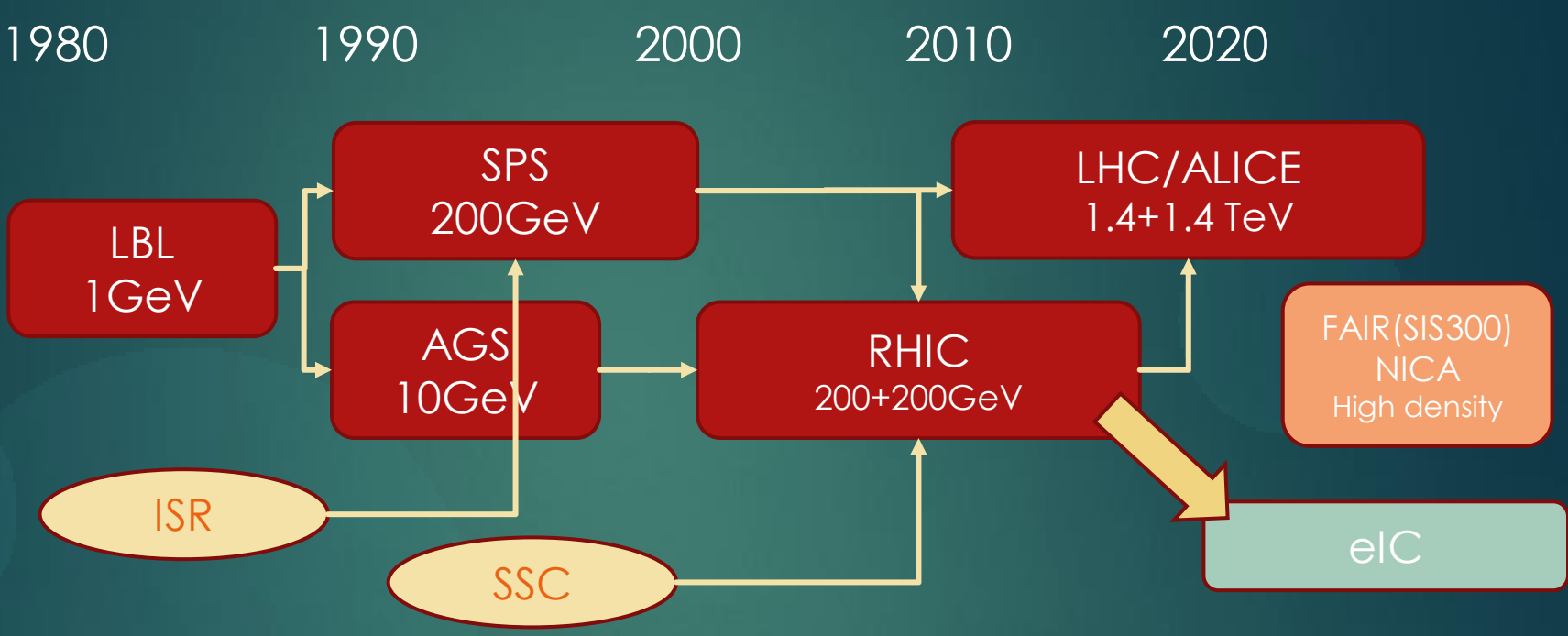
Projects -- time line ---

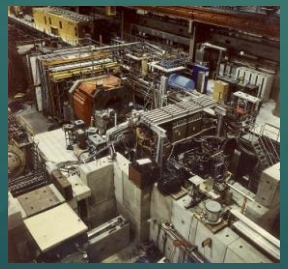
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fair	Const.								Exp		Complt										
Jparc			Exp						1MW												
RHIC																			eIC (eRHIC)		
LHC				Exp												HL-LHC					
JLAB	Operating(old)								12GeV Exp												
NICA																					

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
RIBF	Exp					Complete								RIBF2 ???							
FAIR	Const.								Exp		Complt										
FRIB							Const.							Exp							
ARIEL		Const					Exp		Complt												
GANIL		Const						Exp		RIB Complt											
SPES						Const				Exp											
ISOLDE								2	10 MeV												
EURISOL																					
RISP									Const.					Exp							
HIRFL	Operating								Upgrade?					HIAF ???							
BRIEF	Const						Exp						CARIF?								

HOT QCD

Hot QCD


1980
1990
2000
2010
2020
LBL
1GeV
SPS
200GeV
AGS
10GeV
ISR
SSC
RHIC
200+200GeV
LHC/ALICE
1.4+1.4 TeV
FAIR(SIS300)
NICA
High density
eIC



COLD QCD

J-PARC/Japan

Hadron Physics

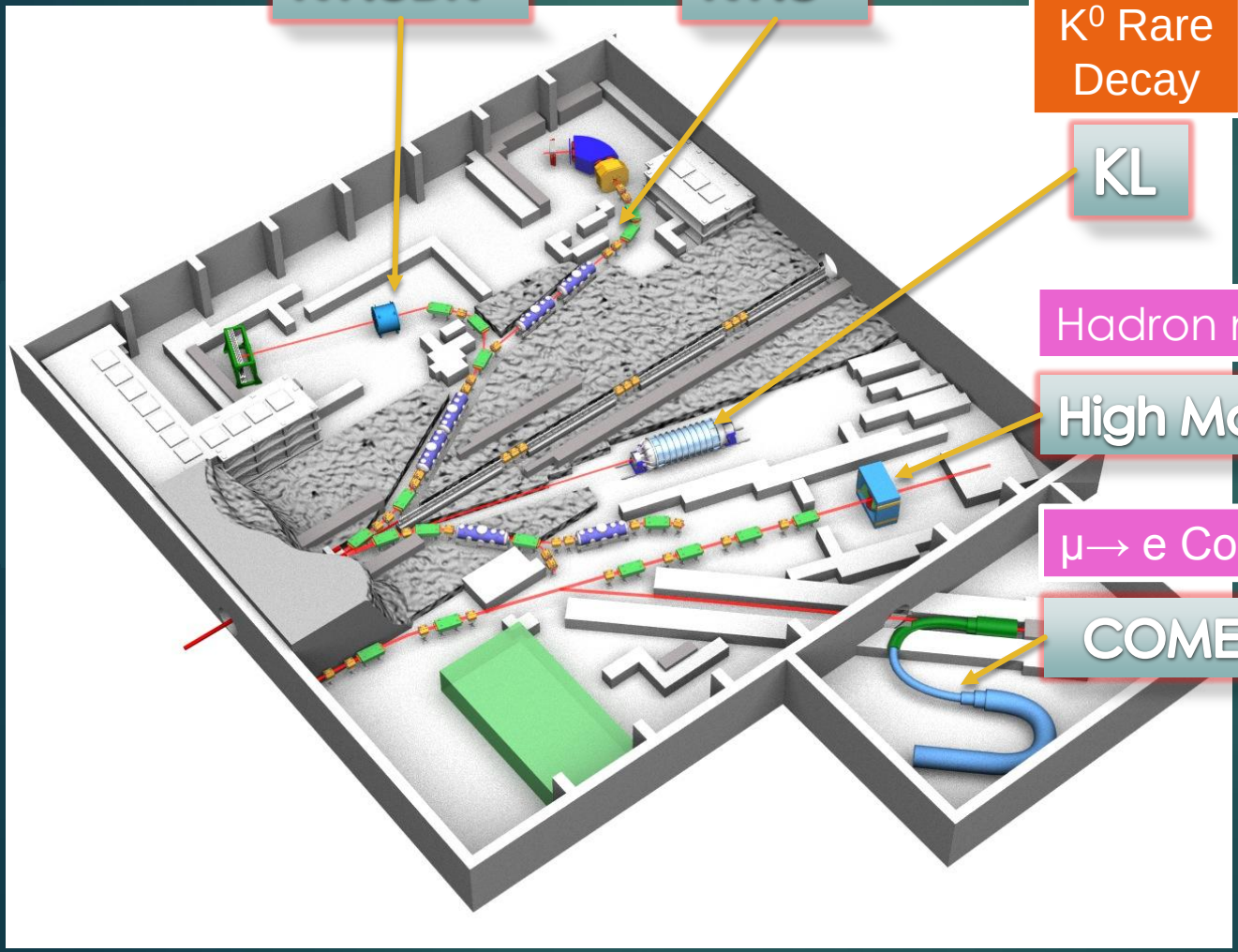
K1.8BR

Strangeness Nuclear Physics

K1.8

K^0 Rare Decay

KL



Hadron mass

High Momentum

μ→ e Conv.

COMET

30GeV Proton Beam

Intensity > 10~20kW

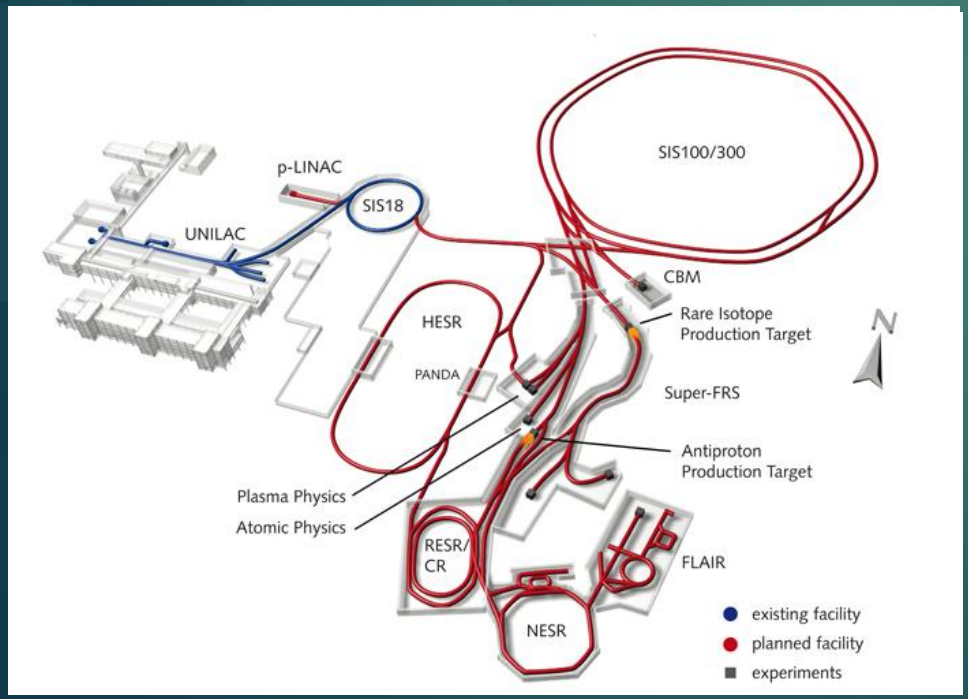
→ Experiments with K beam starts soon

Proton Beam Intensity ~100kW

Hall extension(*2.5) foreseen

FAIR

Facility for Antiprotons and Ins Research

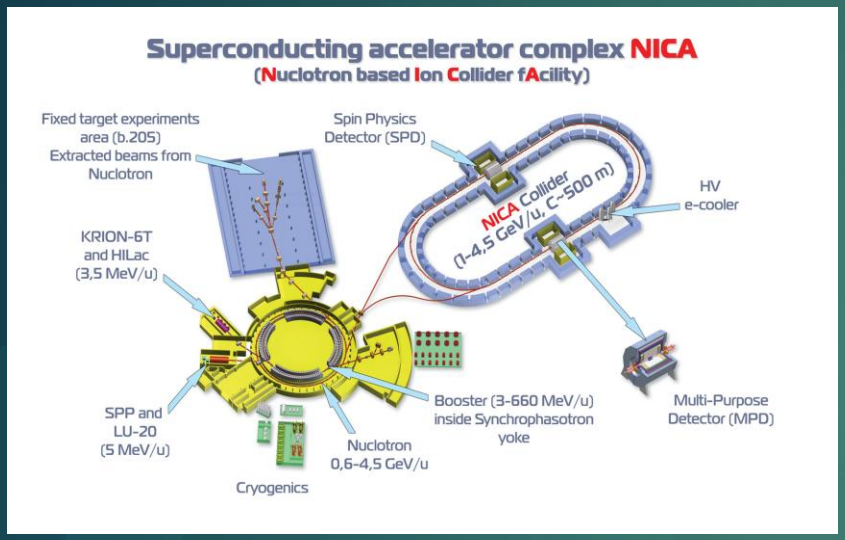


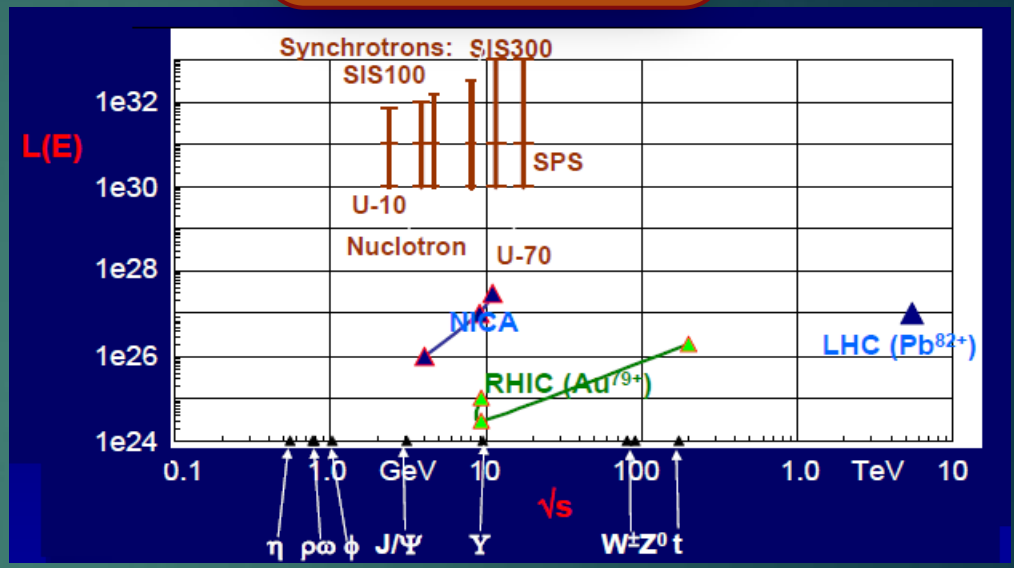
- Very cleaver versatility
- Greedy but Nich
- Dual MR + cooler/storage rings

Field	Energy GeV/u	Average Intensity pps	Time Structure
Hot QCD (SIS300)	U^{92+}: 34	$2x10^{9}$	Slow ext <100s
Cold QCD (SIS100)	p 29	$5x10^{12}$	Fast exit ≈ 25 ns
RIB (SIS100)	U^{28+} 1.5	$\sim 3 \cdot 10^{11}$	Fast ext 60 ns Or CW

NICA at JINR

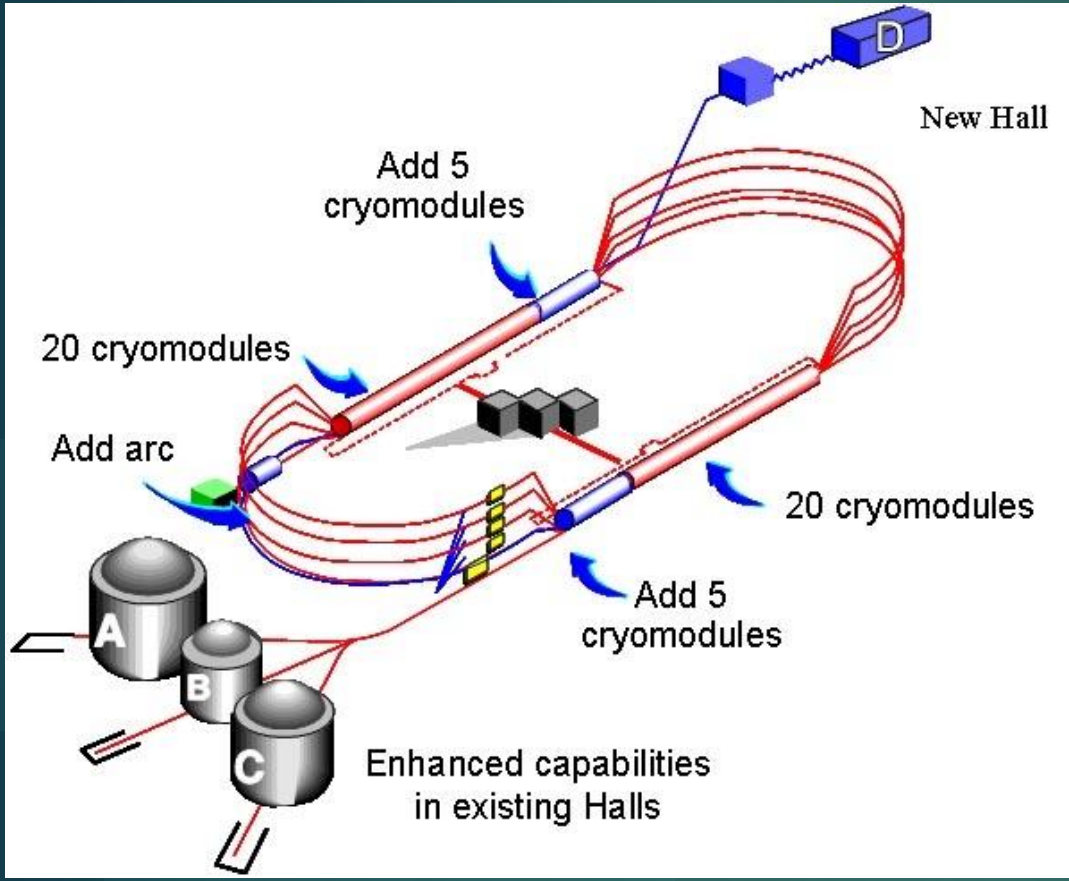
Region once examined at SPS.
Hot QCD
⇩
Dense QCD



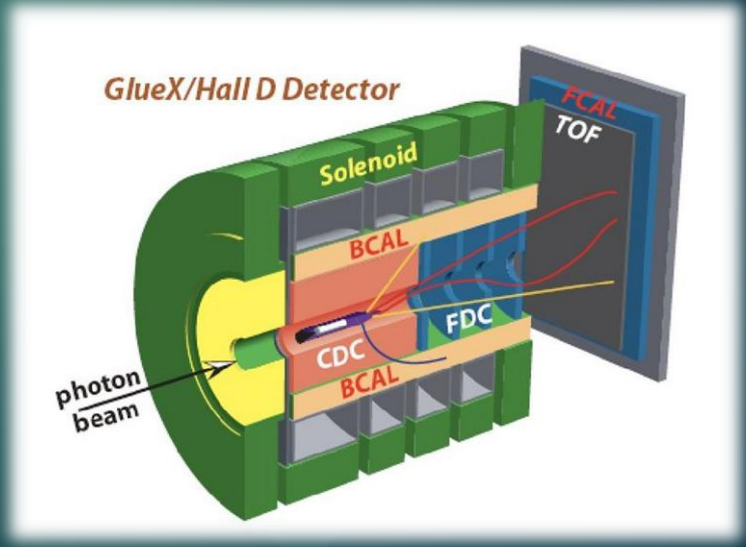


	typical	$\sqrt{s_{NN}}$ (GeV)	$L_{average}$ ($/cm^2/s$)
A+A	$^{197}Au^{79+}$ +$^{197}Au^{79+}$	4 ÷11	10^{27}
p↑+p↑	polarized	12 ÷25	
d↑+d↑	polarized	4 ÷13.8	

J-LAB in USA

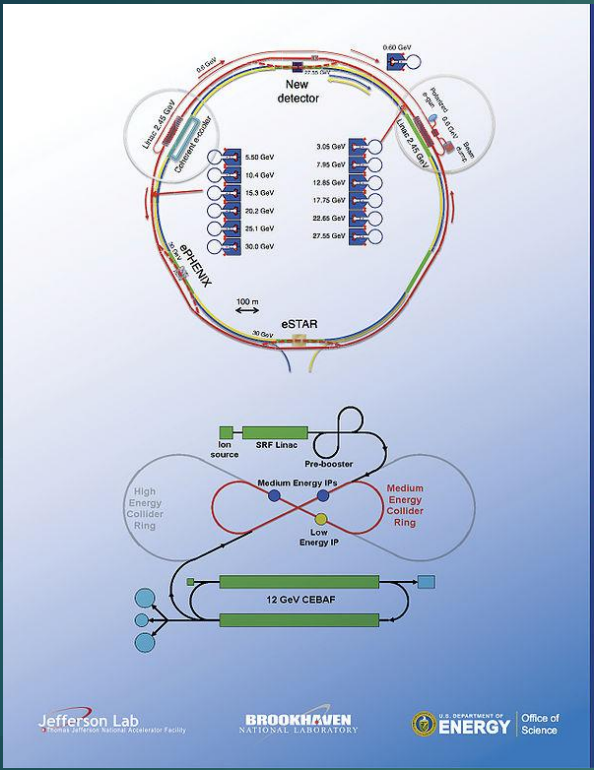


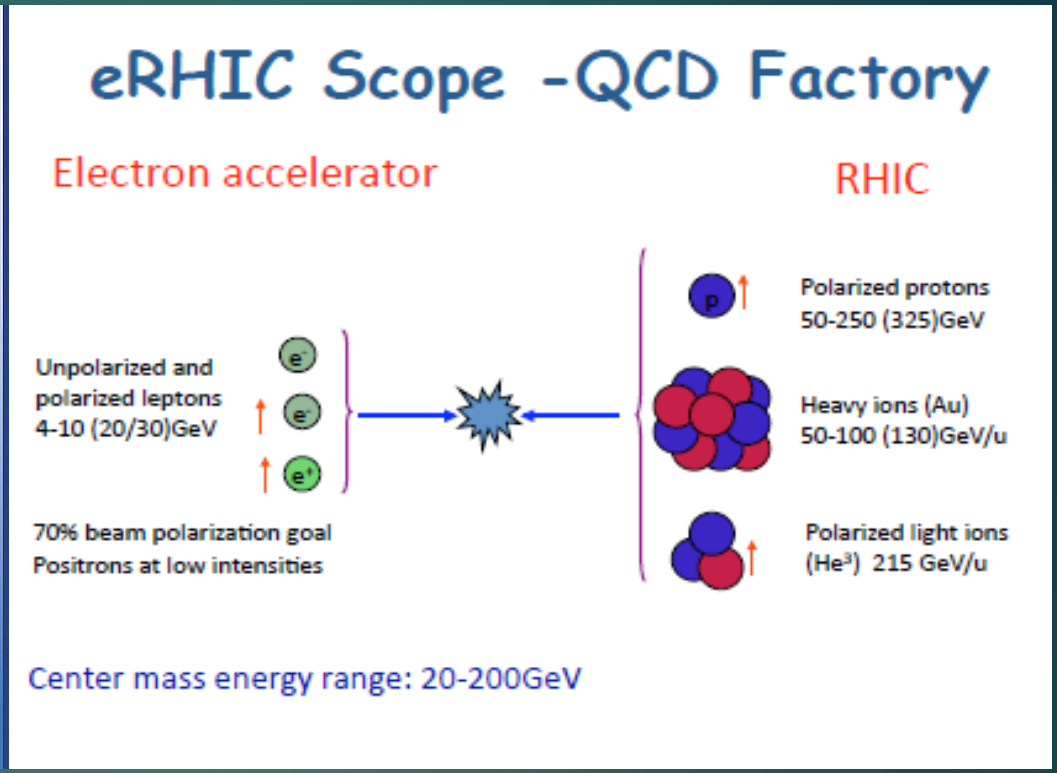
- 12 GeV Upgrade
- highly cost effective due to existing features of CEBAF.
- To 24 GeV in the future.
- New experimental Hall D
  - bremsstrahlung beam
  - New solenoid detector



eRHIC (or eIC)

to be the world's first electron-nucleus collider





- eRHIC = RHIC + (5~10) GeV electron ring
- ultimately to 20 or even 30 GeV in the future
- ep Luminosity 100 times of HERA accelerator at DESY (and polarized).
- Nucleon spin structure, low-x physics, geometrical sccalig…..

Cold QCD laboratories

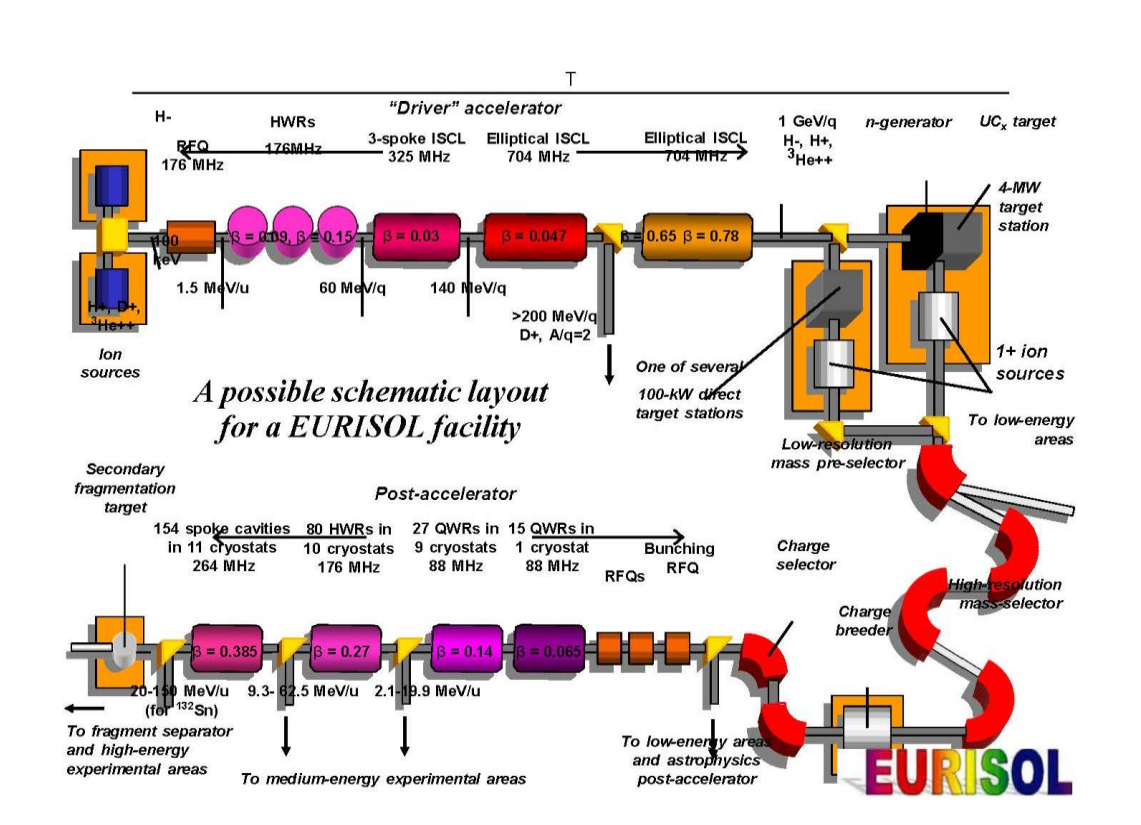
- Less compared to 20 years ago due to the collider projects in CERN and BNL (pain we paid)
- Many scientists moved to Hot QCD
- There are many-but-small electron-beam laboratories around the world.

	America	Europe	Asia
Hadronic beams	- ! -	FAIR (CERN SPS)	JPARC HIRFL
Electro Magnetic beams	JLAB-12GeV	(CERN Muon,Mainz…….)	(Spring-8)
e-A, p-A Collider	eRHIC(eIC)	-	-
A-A/p-p Colliders	-	NICA	-

- Good balance realized
- eIC migt be a key to the future, NICA is an interesting option
- B factory is another important addition !

RIB facilities (ISOL to begin with)

EURISOL
(1500M$ for European future & dream)



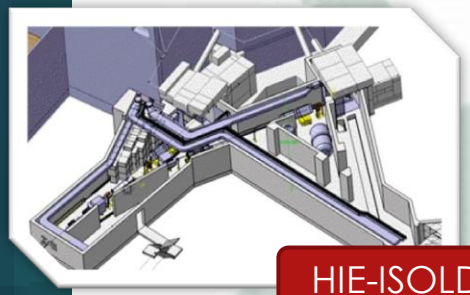
20 institutes and laboratories within Europe as full **Participants**,
20 institutions in Europe, North America and Asia as **Contributors**.

Contributors from non-European Countries
USA: ORNL, ANL, NSCL, FNAL
Canada: TRIUMF Korea: KAERI Japan: JAEA

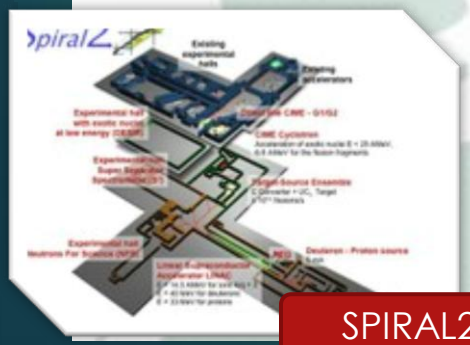
Clever European Strategy

- ISOL projects, such as SPIRAL2 at GANIL, HIE-ISOLDE at CERN and SPES at LNL, Legnaro, are now regarded as "intermediate" .
- "intermediates" are not minors.

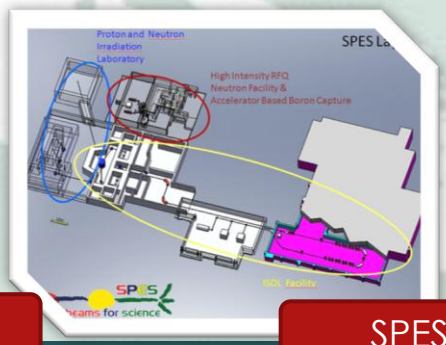
FAIR



HIE-ISOLDE



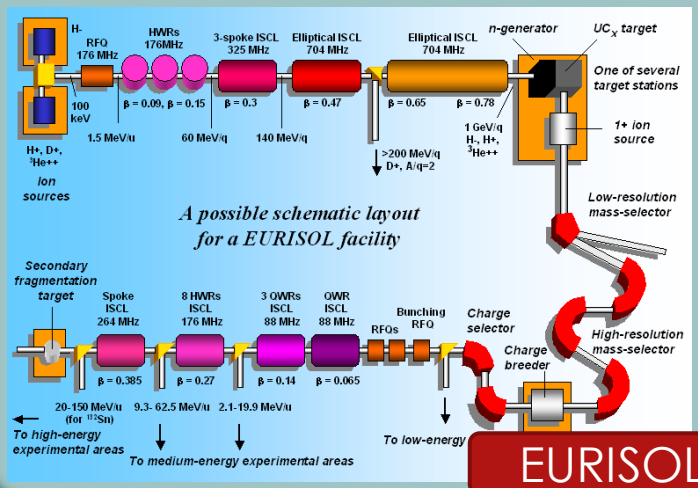
SPIRAL2



SPES

Future Two Goals

FAIR/EURISL complementary



EURISOL

ARIEL @TRIUMF/CANADA
(Advanced Rare Isotope Laboratory)

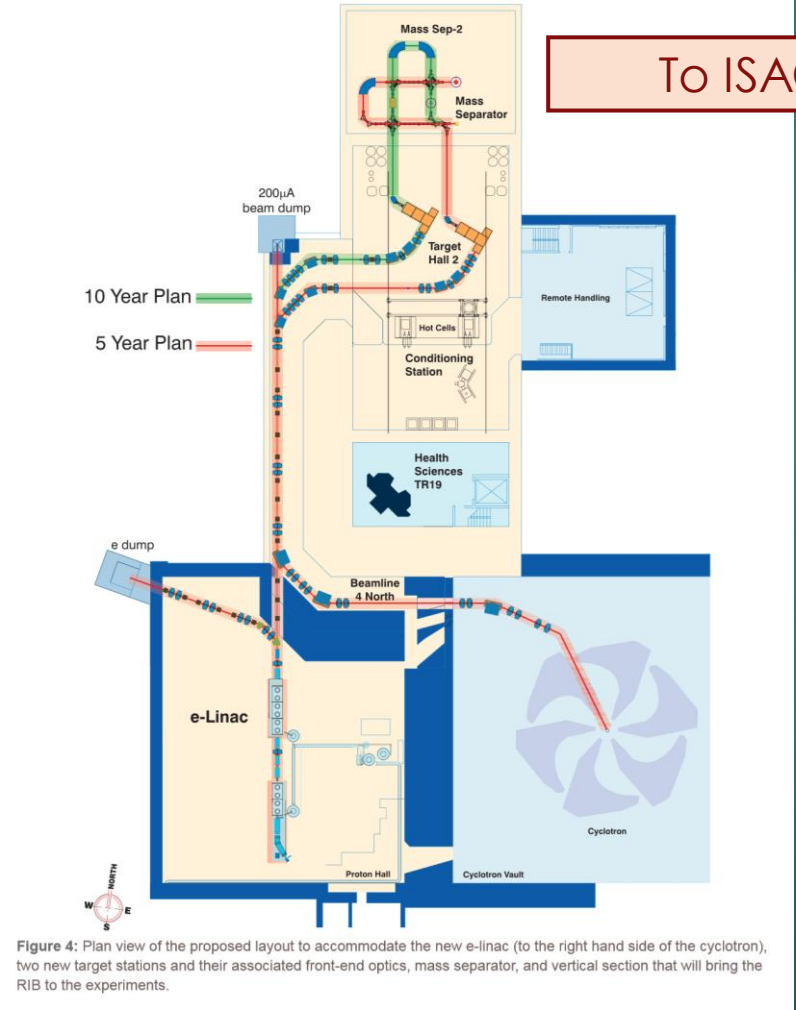


Figure 4: Plan view of the proposed layout to accommodate the new e-linac (to the right hand side of the cyclotron), two new target stations and their associated front-end optics, mass separator, and vertical section that will bring the RIB to the experiments.

To ISAC 1&II

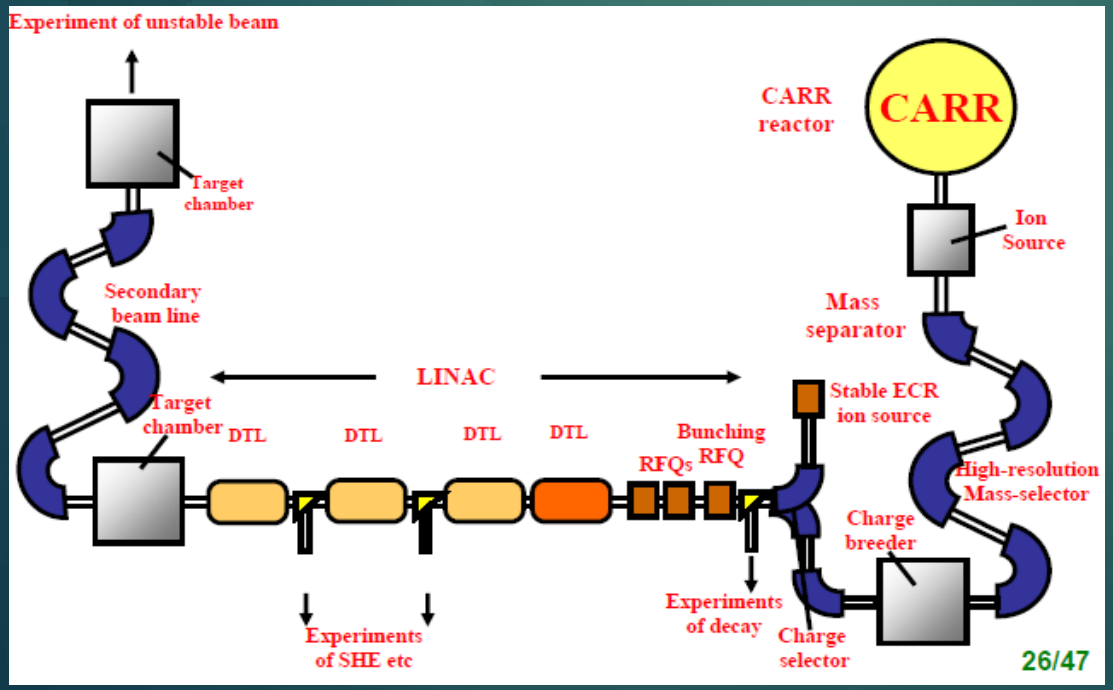
- Sc e- Linac 50 MeV, 10 mA CW
- Proton beamline 500MeV100 μA
- Two new high-power ISOL
- Mass separated transport to ISAC-I /II

Starting with 25MeV(100kW) e-beam
50-75MeV 10mA with ERL in future

Goal **$1*10^{14}$** fissions/s
Comparable to EUROPEAN intermediates.

Clear strategy
for medical RI delivery

CARIF (Beijing ISOL)
China Advanced Rare Ion-beam Facility
Chinese EURISOL (not Asianisol)



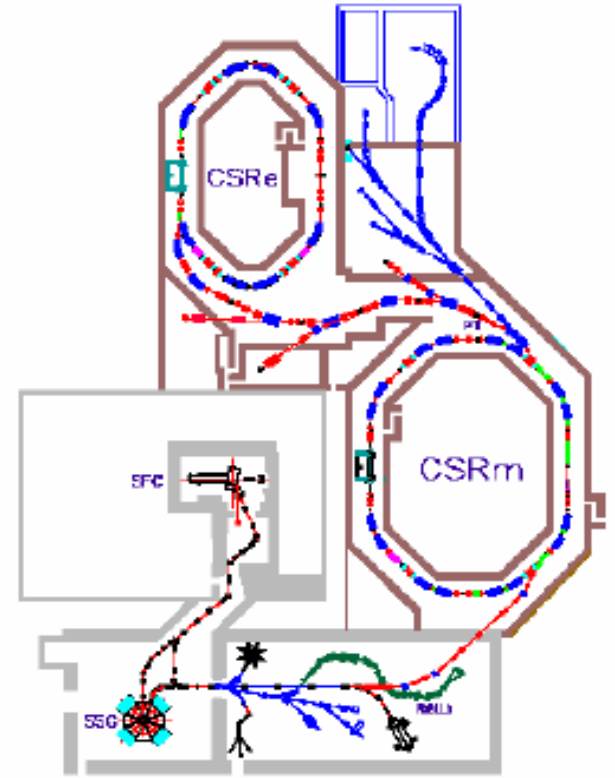
- CARR 60MW

Chinese Advanced Research Reactor

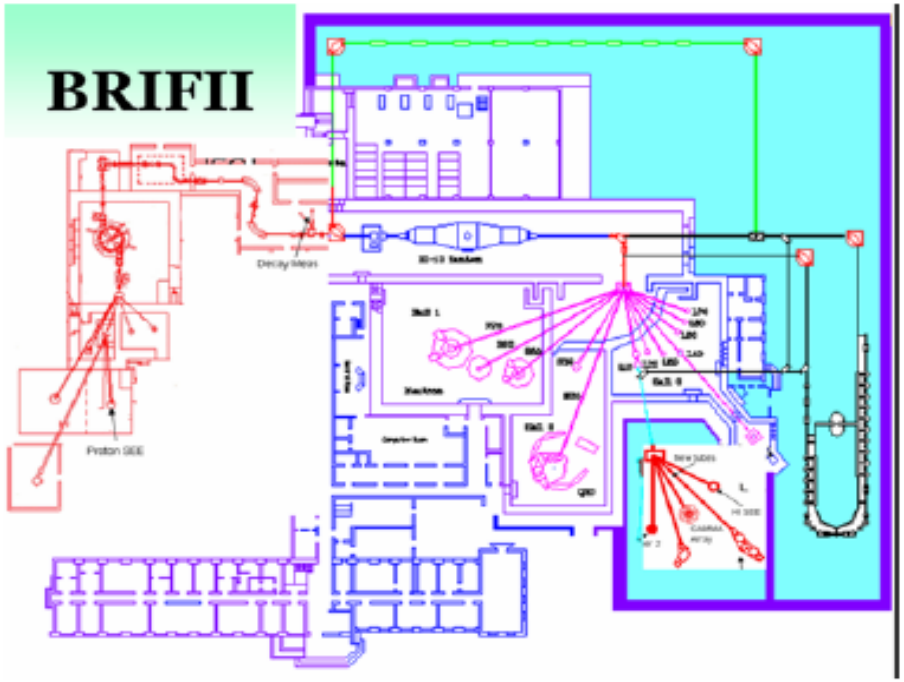
- Post acceleration up to 100MeV/c

China - Before CARIF

Current major facilities of nuclear physics in China



Lanzhou, CSR
Med E HI, RIB, 2008



Beijing
BRIF, BRIF II ,
Low E HI, RIB, 2013

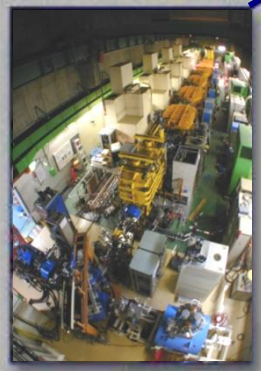
RIB facilities (Projectile Fragmentation)

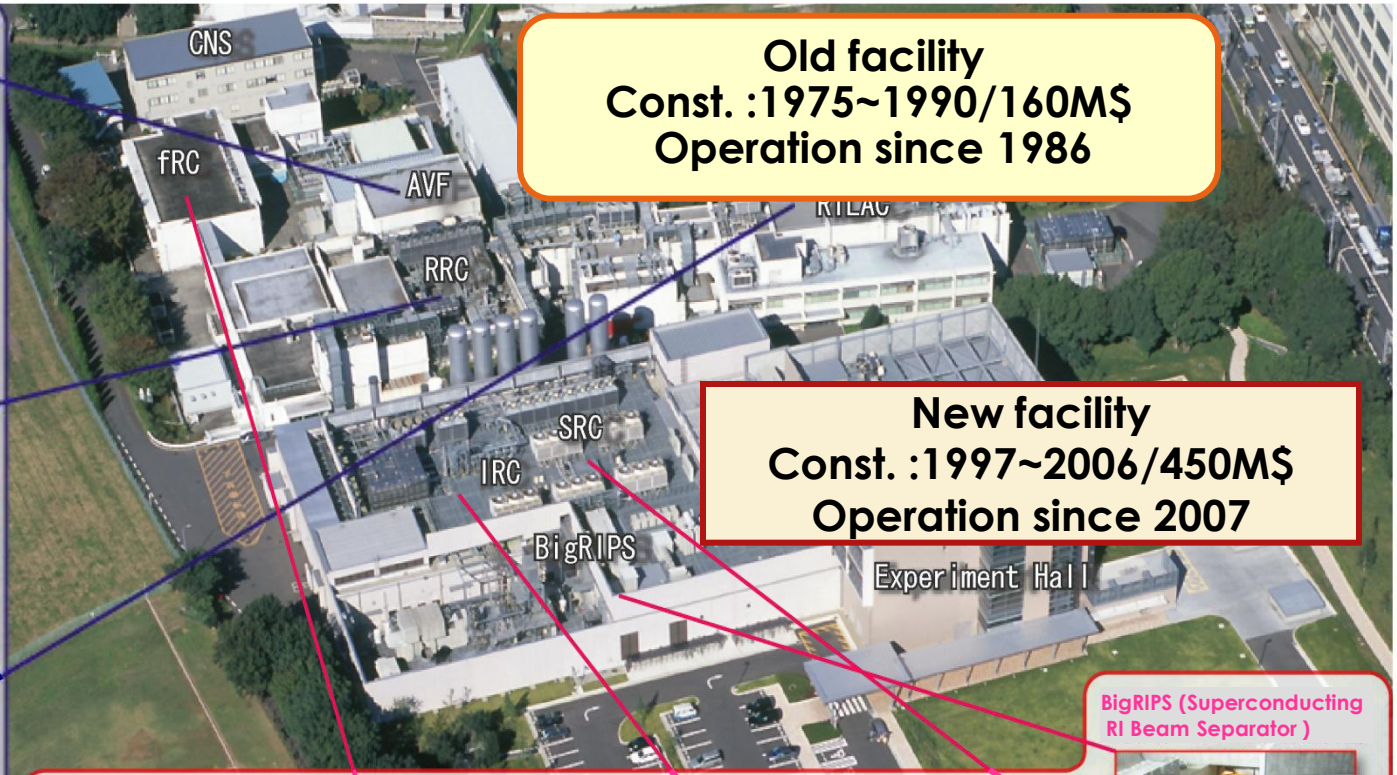
RI Beam Factory (RIBF), RIKEN Nishina Center

AVF Cyclotron

RRC
(Riken Ring Cyclotron)

RILAC
(Riken Heavy Ion LINAC)

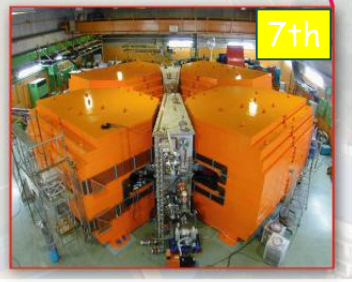




Old facility
Const. :1975~1990/160M$
Operation since 1986

New facility
Const. :1997~2006/450M$
Operation since 2007

fRC (fixed-Frequency Ring Cyclotron)



IRC (Intermediate-Stage Ring Cyclotron)

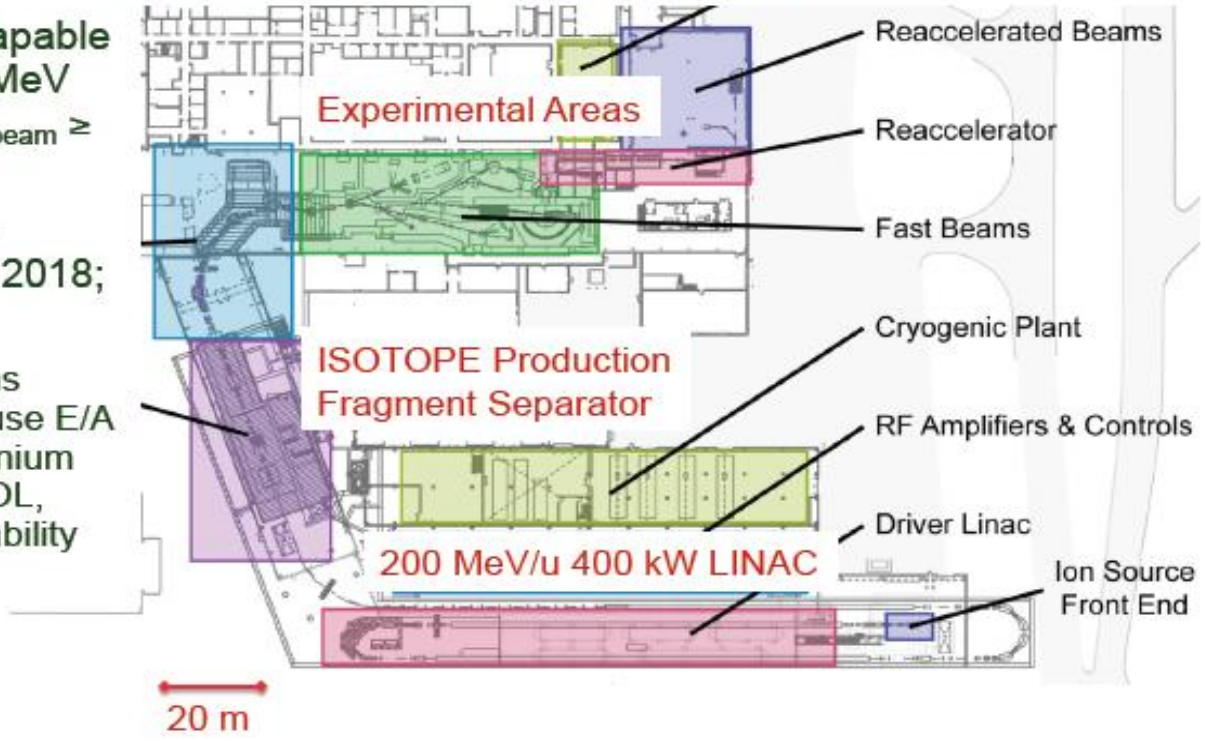
SRC (Superconducting Ring Cyclotron)

BigRIPS (Superconducting RI Beam Separator)

FRIB at MSU

Facility for Rare Isotope Beams, FRIB Broad Overview

- Driver linac capable of E/A ≥ 200 MeV for all ions, P_{beam} ≥ 400 kW
- Early date for completion is 2018; TPC 613M$
- Upgrade options (tunnel can house E/A = 400 MeV uranium driver linac, ISOL, multi-user capability …)



FRIB Facility for Rare Isotope Beams
U.S. Department of Energy Office of Science
Michigan State University

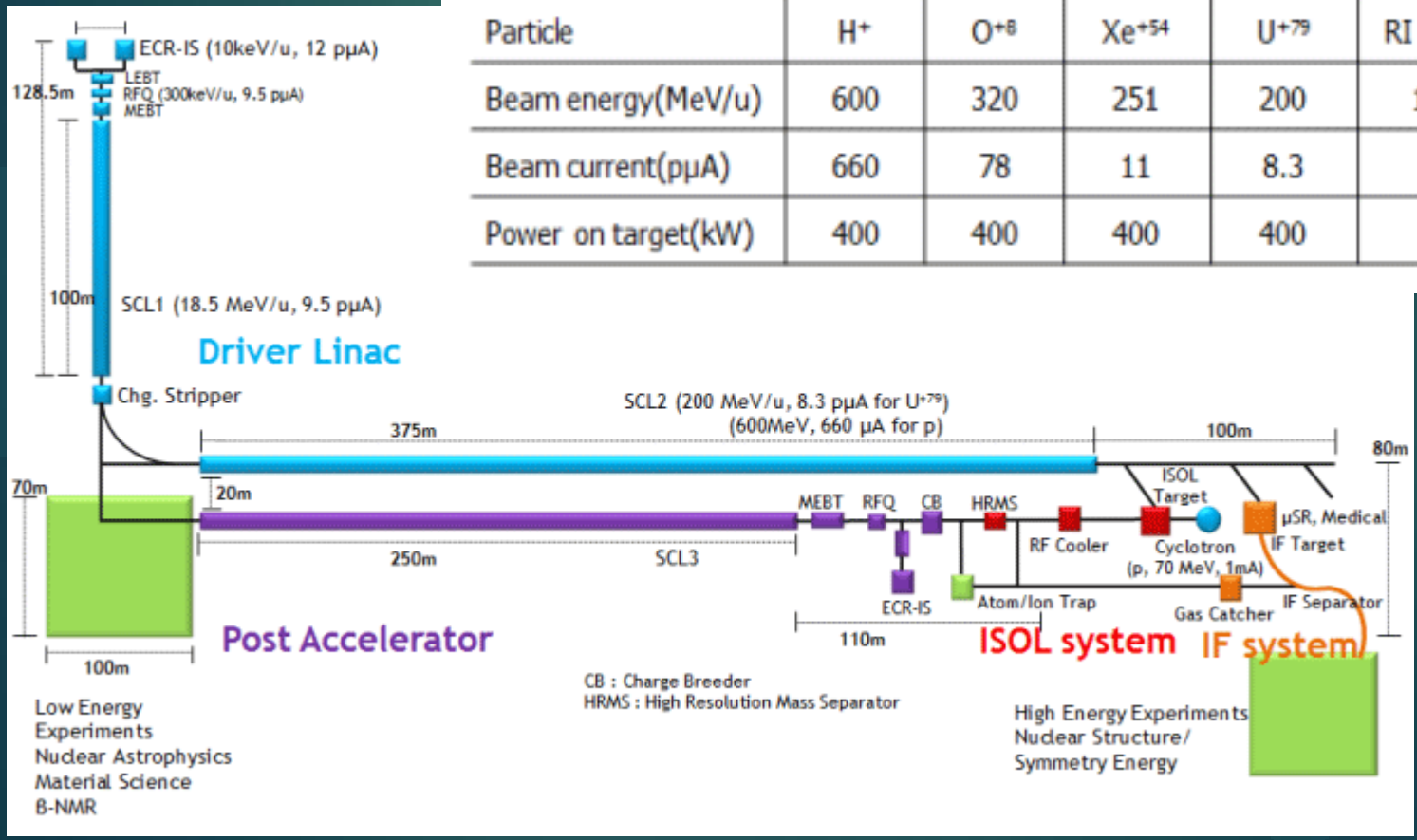
Brad Sherrill, ACS Boston 2010, Slide 10

RISP Rare Isotope Science project promotes machine called

RAON (라온) formerly called KoRIA, at

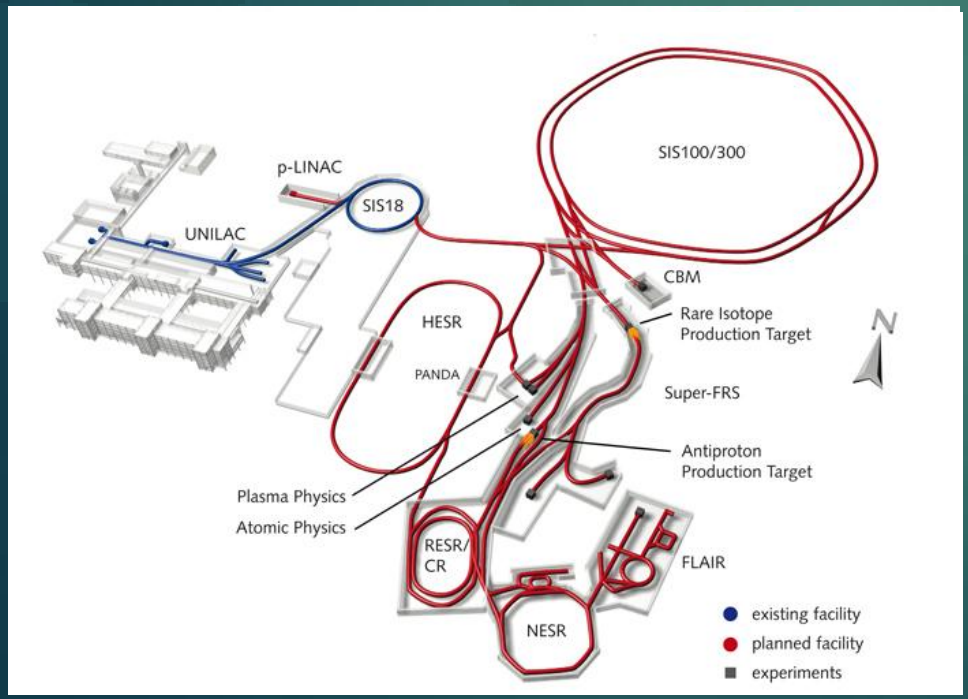
IBS Institute for Basic Science in Korea

	Driver Linac				Post Acc.	Cyclotron
Particle	H^+	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Beam energy(MeV/u)	600	320	251	200	18.5	70
Beam current(pμA)	660	78	11	8.3	-	1000
Power on target(kW)	400	400	400	400	-	70



FAIR

Facility for Antiprotons and Ins Research



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- Dual MR + cooler/storage rings

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Projectile Fragmentation Facilities

ISOL + post acceleration v.s. Projectile Fragmentation

		America	Europe	Asia
Projectile Fragmentation with sub/few GeV Uranium		**MSU/FRIB**	**GSI/FAIR**	**RIKEN/RIBF**
PF + ISOL				**RISP/RAON**
ISOL + 10MeV post AC		ARIEL/ISAC2	SPIRAL2 SPES HIE-ISOLDE	HIRFL BRIEF
ISOL + 100MeV post AC			EURISOL	CARIF

Scores

Nation	Facility	Beam		Target		Post acceleration		
		Beam	Power (kw)	Dirct/ Conv/PF	Fissions/s Beam pnA	Method	MeV/A	132Sn/s
ISOL coming	ARIEL	e 50MeV 10000μA p 500MeV 100μA	~100	Direct	$1*10^{14}$			$2*10^{9}$
	HIE ISOLDE			Both	$4*10^{12}$	SC Lin		$2*10^{8}$
	SPIRAL2	d 40MeV 5000μA	200	Convert	$1*10^{14}$	C ron	3 10	$2*10^{9}$
	SPES	p 40MeV 200μA	8	Direct	$1*10^{13}$	inac	10	$3*10^{8}$
Super ISOL	EURISOL	p 1GeV 5000 μA	4M	D&C	$1*10^{15}$		50	$4*10^{11}$
	CARIF	Reactor	6M	reactor	$2*10^{15}$	ac	0	$5*10^{10}$
PF coming	FRIB	U+33 200MeV	400	PF	8300		-	10^{8}~10^{9}
	RISP	U+79 200MeV	400	PF	8000			10^{8}~10^{9}
	FAIR	U+28 1500MeV	10	PF	50 pr		-	10^{7}~10^{8}
PF running	RIBF2015	U+86 345MeV	4	PF	100 pnA			$3*10^{6}$

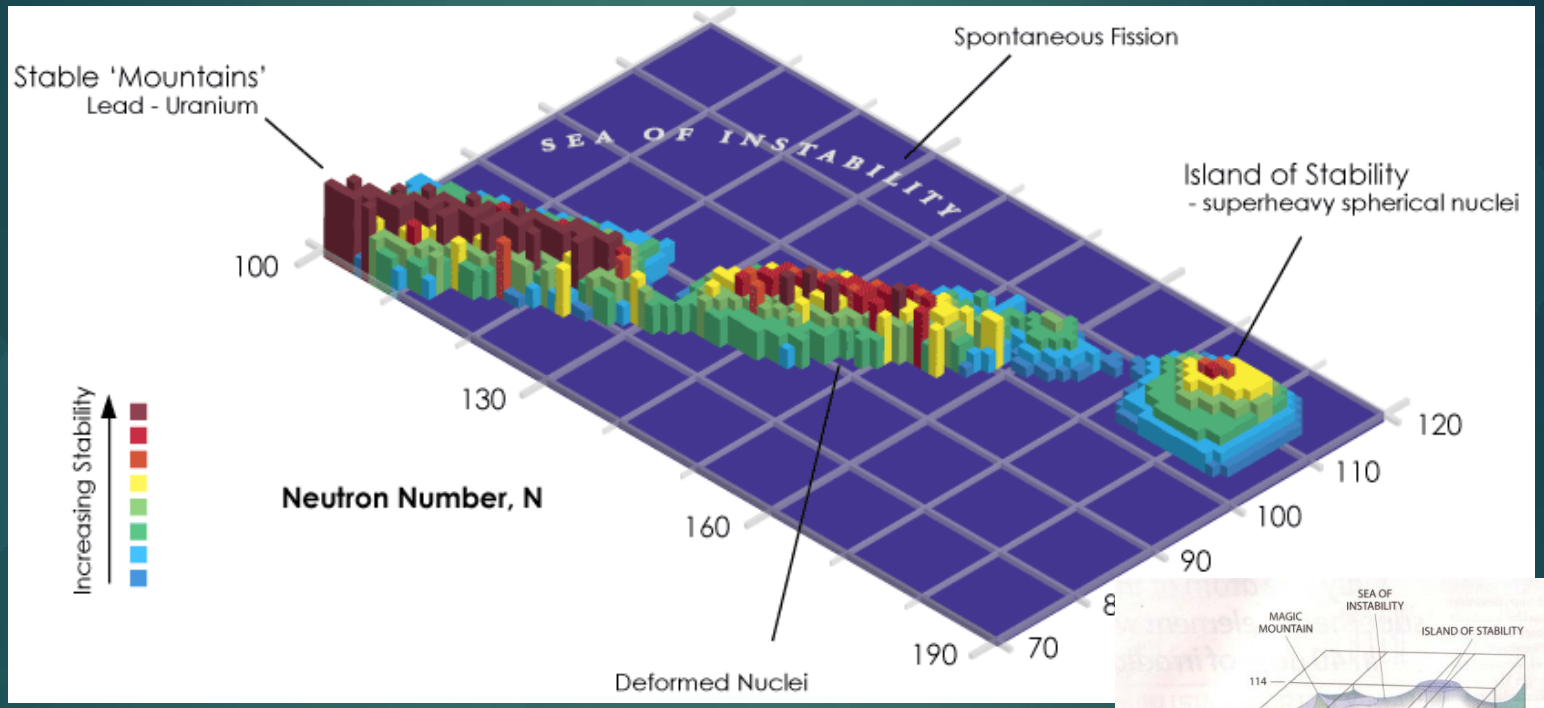
Summary remarks

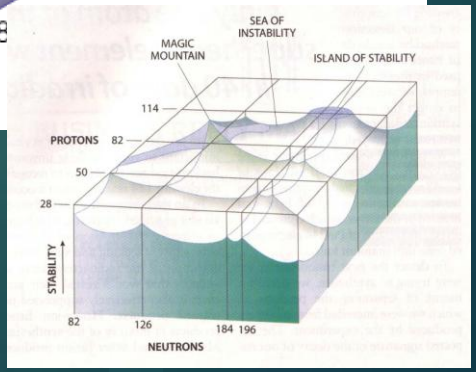
	Beams		America	Europe	Asia	
Hot QCD	A+A	T	RHIC	**LHC(ALICE)**	-	Future determined
		ρ		**FAIR(SIS300)** NICA		Success Story in dense QCD?
Cold QCD	hadron		-	FAIR(SIS100)	JPARC	Missing American
	e-		**JLAB-12GeV**		Spring-8	1+many
	collider		eRHIC(eIC)	NICA		1 in the world
RI Beam	Proj Frag		**FRIB**	**FAIR**	RIBF	Regionally well covered. Asian needs more interaction
	Both				RISP	
	ISOL		**ARIEL**	**SPIRAL2** SPES HIE-ISOLDE	HIRFL BRIEF	
	Super ISOL		--	**EURISOL**	**CARIF**	1 in the world ?

Bon Voyage

Super Heavy Element

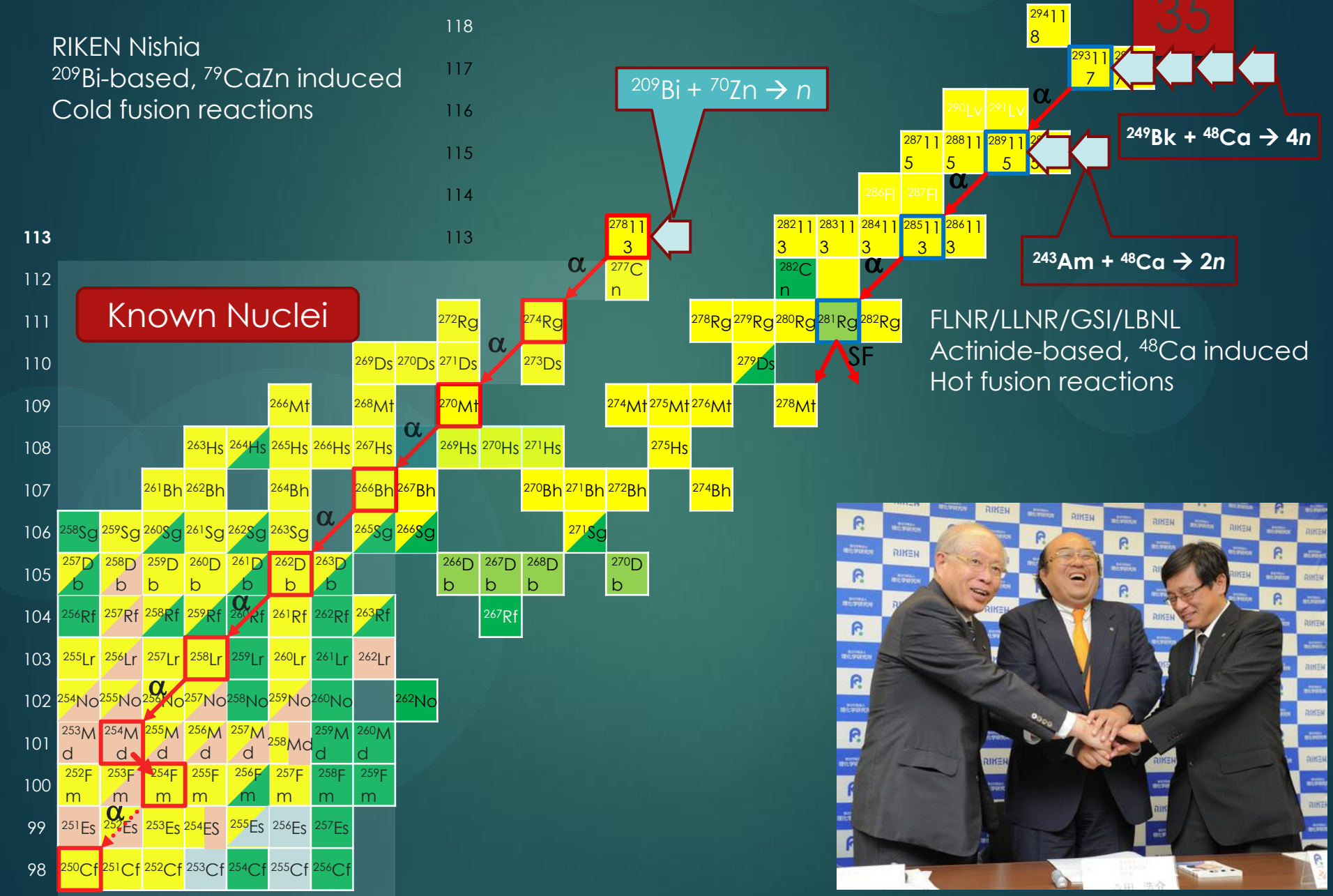
Ultimate goal



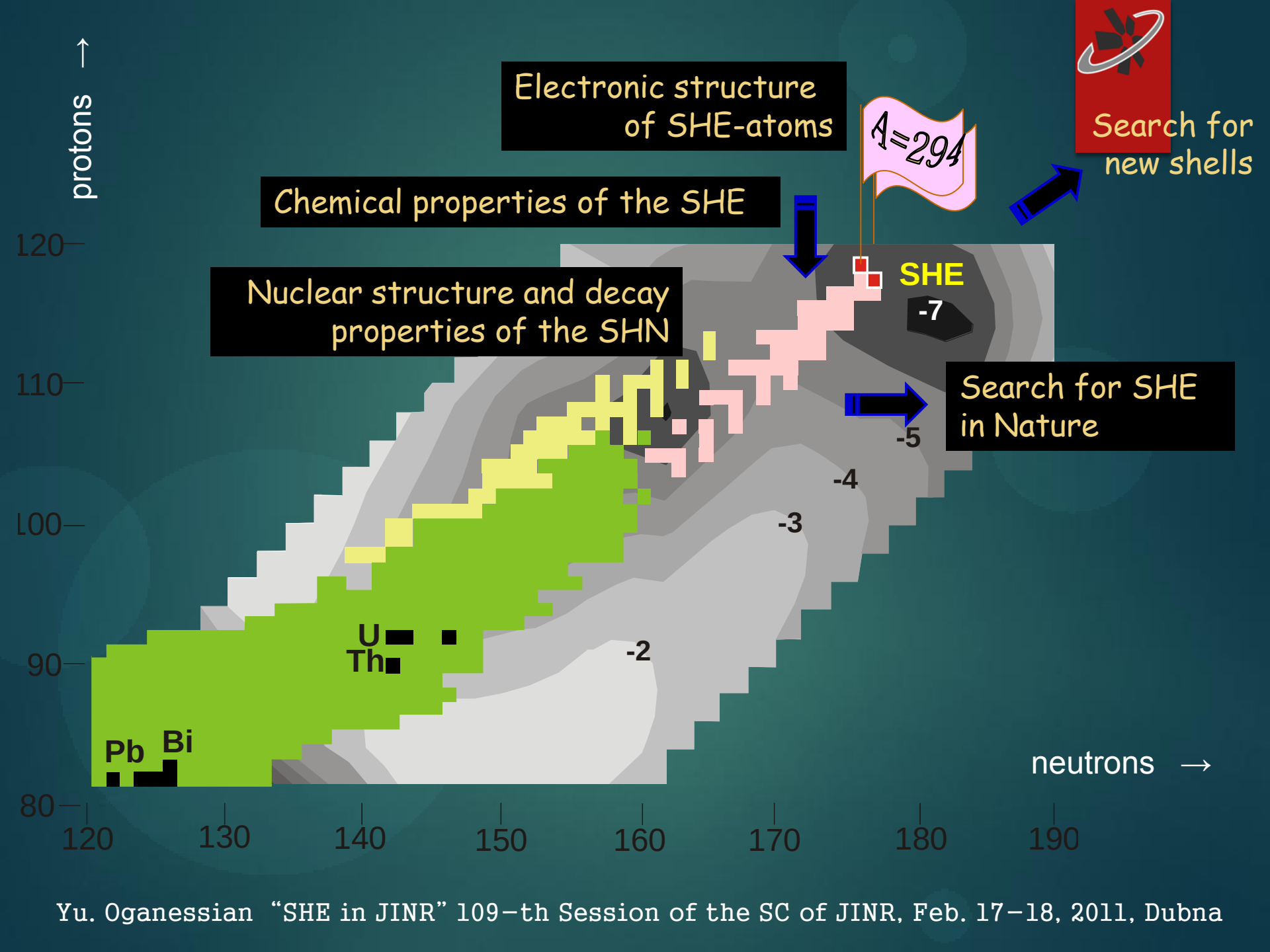


New event; 113th element (3rd of 278113)

RIKEN Nishia
^{209}Bi-based, ^{79}CaZn induced
Cold fusion reactions



FLNR/LLNR/GSI/LBNL
Actinide-based, ^{48}Ca induced
Hot fusion reactions


protons →
Electronic structure of SHE-atoms
A=294
Search for new shells
Chemical properties of the SHE
Nuclear structure and decay properties of the SHN
SHE
-7
Search for SHE in Nature
-5
-4
-3
-2
U
Th
Pb
Bi
neutrons →
120
110
100
90
80
120
130
140
150
160
170
180
190

Road map ?

		2012	2013	2014	2015	2016	2017	2018	2019
Dubna (FLNR)		2.5uA48Ca			3.0				
		New accelerator/setup					20uA		
RIKEN	Cold	**10puA**							
	Hot		preparation		to Z119/120				
	Chem								
GSI	Hot/X						??		

- *Z=119/120 may be reachable, but not beyond*
- *Beam time becomes too long*
- *Target becomes too rare (expensive M$s)*
- *Need to collaborate*
- *New idea wanted (n-rich RI* + Actinoid + *multi nucleon transfer)*

RIB in ASIA

Competitions in far east

	Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
J	RIBF PF	Start Exp					Complete Construction													
															RIBF2 ???					
K	RISP both							Start Cont.				Start Exp								
C	HIRFL ISOL	Operating								Upgrade?										
															HIAF : High Intensity Accelerator Facility ???					
	BRIEF2 ISOL	Construction						Start Exp												
	CARIF ISOL						CARISOL Ready			Construction				Start Exp						

Though, ASIA No Regional Consensus within ASIA. CARIF can be a ASIANI-SOL.
Who can be a "Projectile Fragmentation" leader in 2020 ?

ISOLs: past, present and future

Nation	Facility	Beam		Target		Post acceleration		
		Beam	Power (kw)	Dirct/ Conv	Fissions/s	Method	MeV/A	132Sn/s
CERN	ISOLDE	p 1Gev 2000μA	0.4	both	$4*10^{12}$	Linac	3	$1*10^{7}$
USA	HRIBF	p 40MeV 10μA	0.4	Direct	$4*10^{11}$	Tandem	4	$2*10^{5}$
JAPAN	TRIAC	p 30MeV 3μA	0.9	Direct	$1*10^{11}$	IH Linac	1	$1*10^{5}$
CANADA	ARIEL	e 50MeV 10000μA p 500MeV 100μA	~100	Direct	$1*10^{14}$			
CERN	HIE ISOLDE			Both	$4*10^{12}$	SC Linac	5-10	$2*10^{8}$
FRANCE	SPIRAL2	d 40MeV 5000μA	200	Convert	$1*10^{14}$	Cyclotron	3-10	$2*10^{9}$
ITALY	SPES	p 40MeV 200μA	8	Direct	$1*10^{13}$	SC Linac	10	$3*10^{8}$
EUROPE	EURISOL	p 1GeV 5000 μA	4000	Both	$1*10^{15}$	SC Linac	20-150	$4*10^{11}$

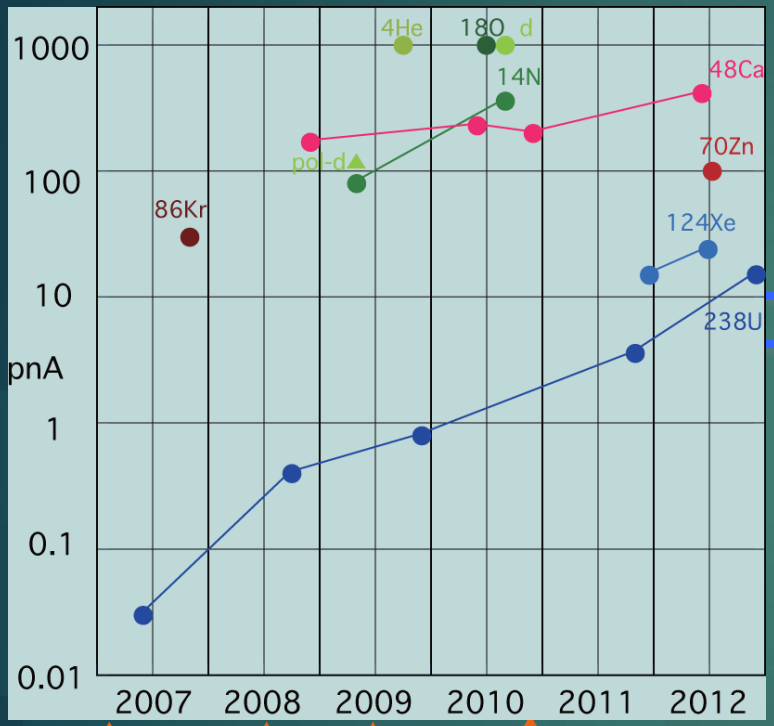
CARIF vs EURISOL

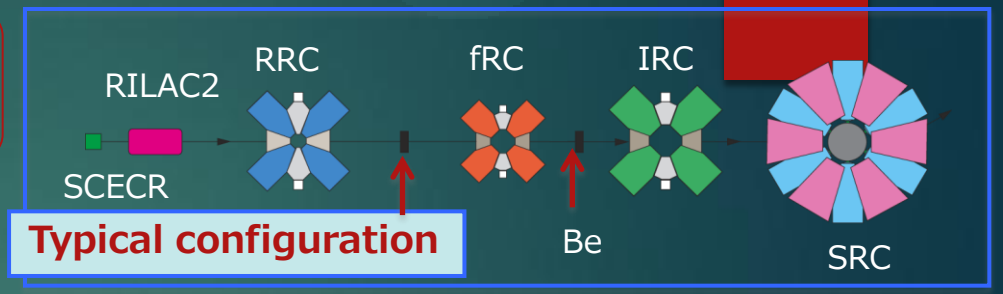
Nation	Facility	Beam		Target		Post acceleration		
		Beam	Power (kw)	Dirct/ Conv	Fissions/s	Method	MeV/A	132Sn/s
CANADA	ARIEL	e 50MeV 10000μA p 500MeV 100μA	~100	Direct	$1*10^{14}$			
CERN	HIE ISOLDE			Both	$4*10^{12}$	SC Linac	5-10	$2*10^{8}$
FRANCE	SPIRAL2	d 40MeV 5000μA	200	Convert	$1*10^{14}$	Cyclotron	3-10	$2*10^{9}$
ITALY	SPES	p 40MeV 200μA	8	Direct	$1*10^{13}$	SC Linac	10	$3*10^{8}$
EUROPE	EURISOL	p 1GeV 5000 μA	4M	Both	$1*10^{15}$	SC Linac	20-150	$4*10^{11}$
CHINA	CARIF	Reactor	6M		$2*10^{15}$	Linac	>100	$5*10^{10}$

- Present RIKEN RIBF can deliver 200MeV 132Sn with $3*10^{5}$/s (regularly)
- Will reach $3*10^{6}$/s by 2015

RIBF beam improvements

Uranium beam intensity reached 1000 times compared to the beginning.

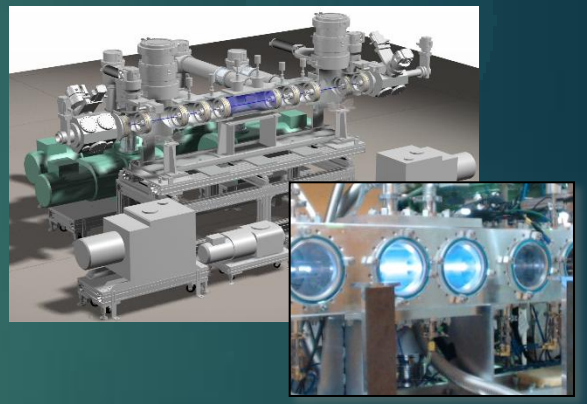




RIBF Goal (U)

RIBF present

GSI present

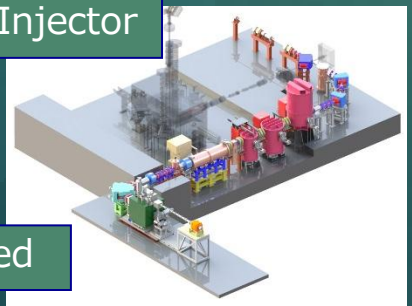


RIBF Start

Improvement on Transmission & Stability

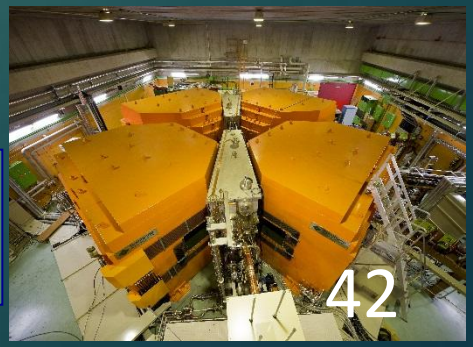
SC-ECR introduced

New Injector



He gas charge Stripper

fRC modification (K570=>K700)

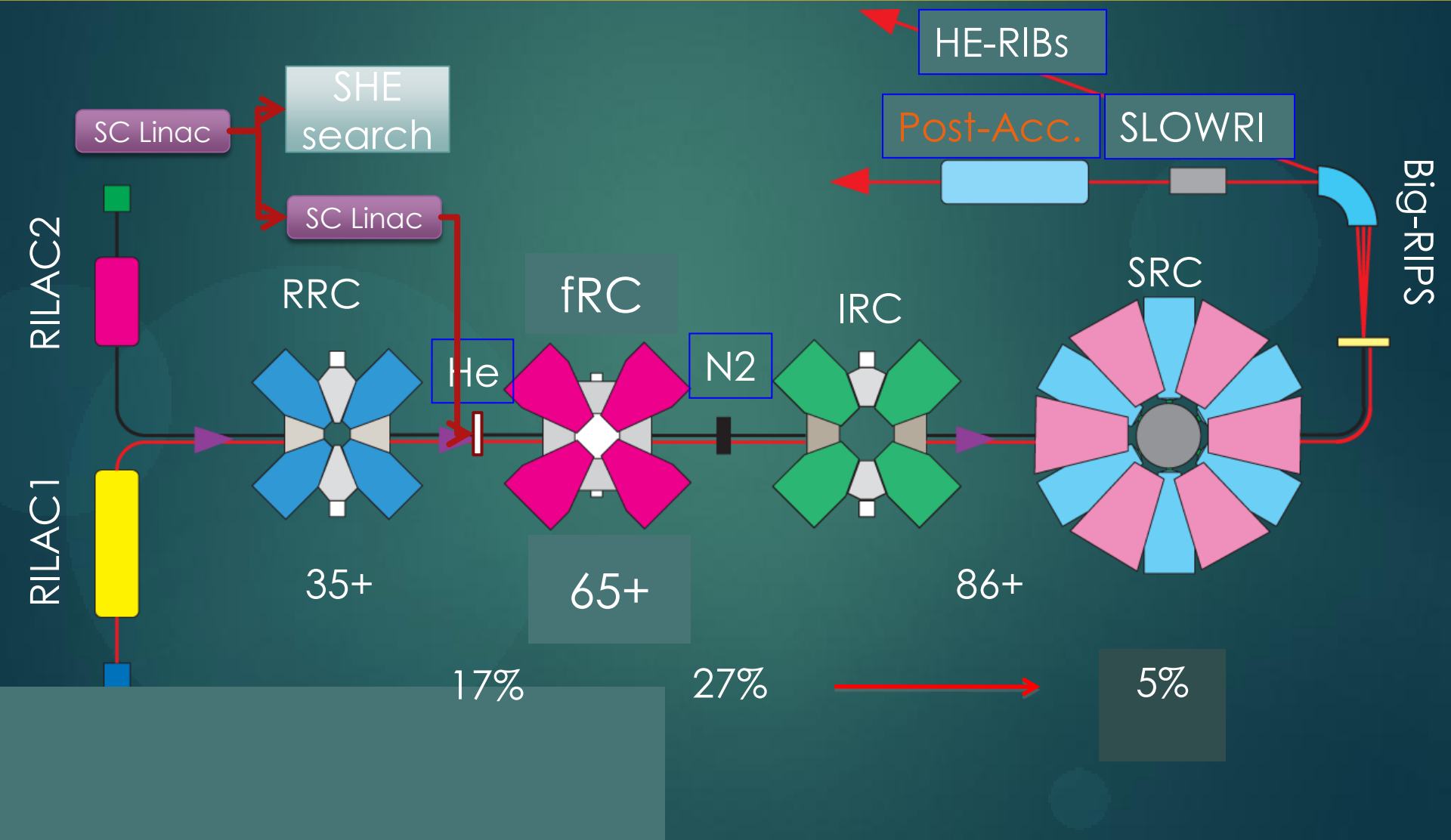


RIBF Upgrade Options – Long-term plan, after 5 years.

Option 0: ISOL or PF+ Post Acceleration (more exotic beams)

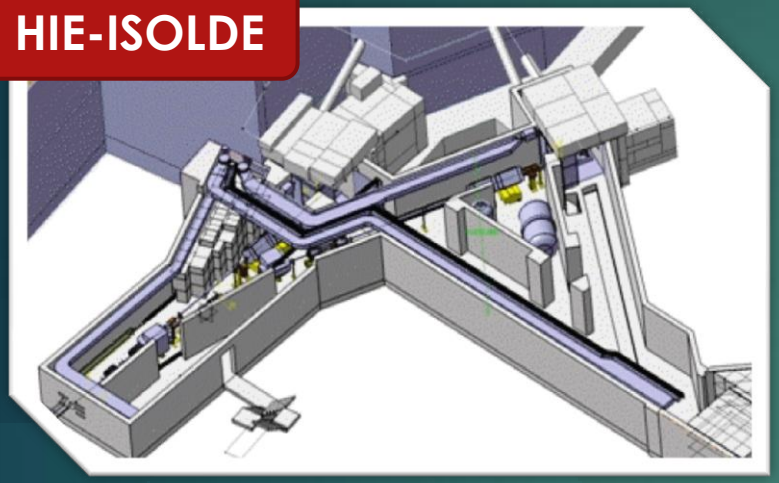
Option 1: Super Conducting fRC(stripper 2->1)

Option 2: SC-Linac (1st section: 5MeV-SHE, 2nd section 11MeV-fRC)

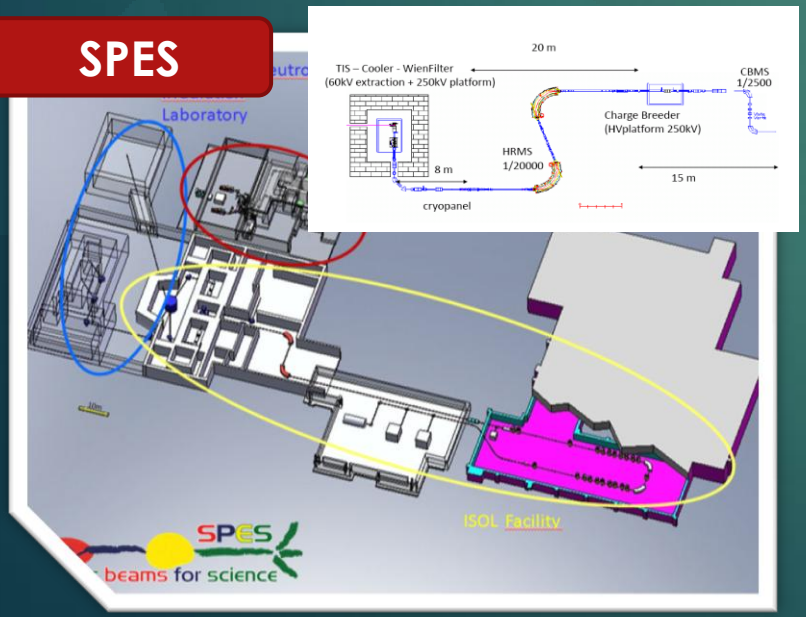


Great "intermediate" Facilities

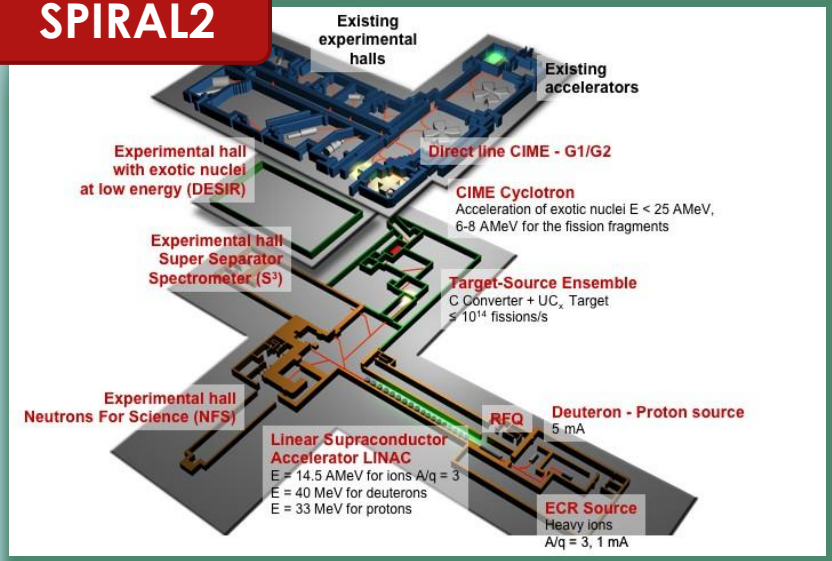
HIE-ISOLDE



SPES



SPIRAL2



- SC linac (d)
- DESIR facility: Disintegration, Excitation and Storage of Radioactive Ions
- NFS: Neutron For Science
- S3: Super Separator Spectrometer
- RI to CHIME: post acc. (Existing cyclotron) in 2016