ECOS NA

Task D1 High power thin-target technology
Task D2 SHE using high-intensity ion beams

FLRN, Dubna – activities (short summary)
– courtesy of Yu. Ts. Oganessian

- *achievements*
- *SHE factory*

ECOS NA report on task 1 and 2

- *instrumentation*
    - *accelerators*
    - *separators*
- *outline*
- *ECOS goals*
- *ENSAR ECOS NA*
    - *tasks*
    - *deliverables*
    - *activities*

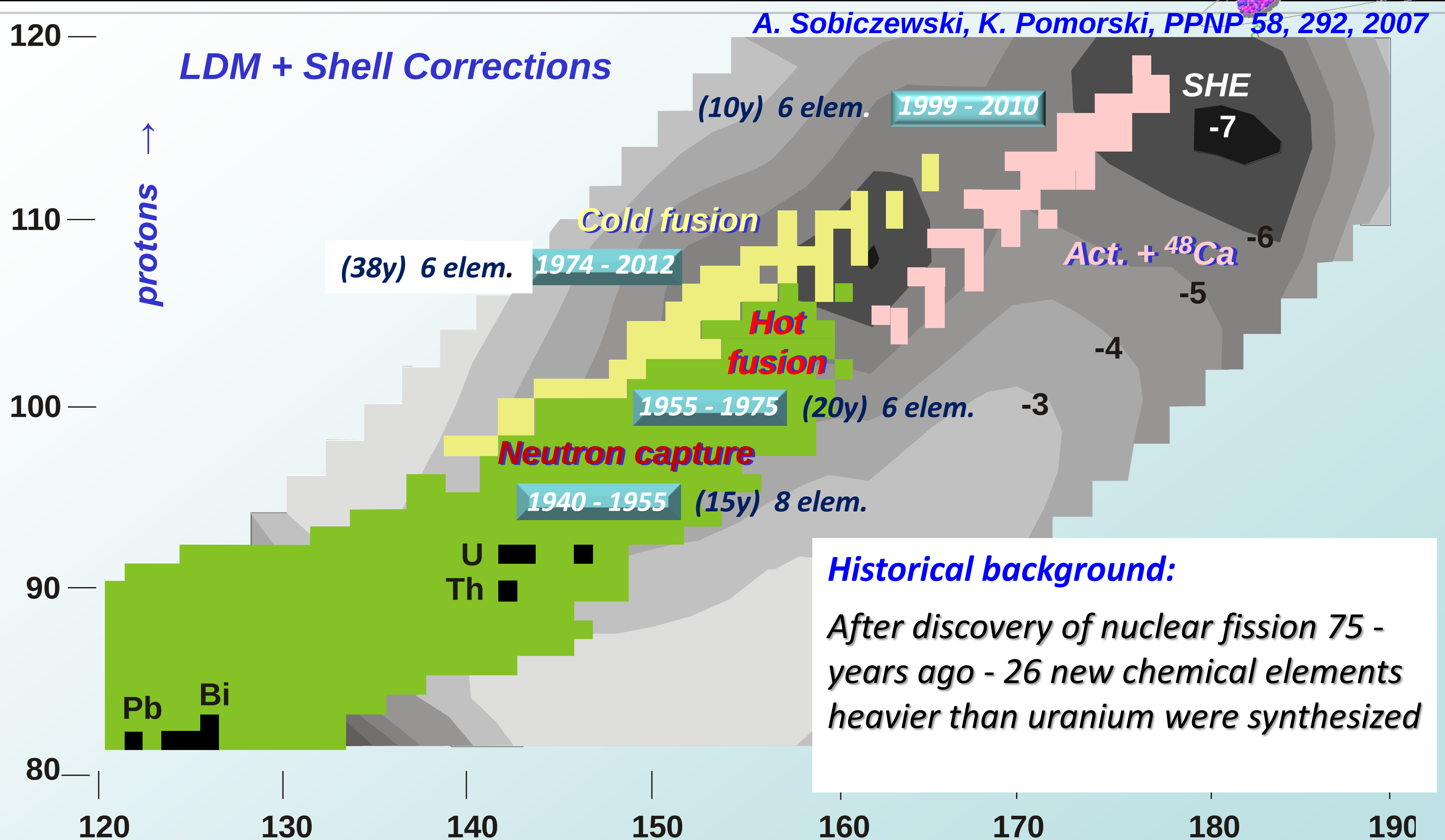
Discussion issues

Dieter Ackermann

GSI
Helmholtzzentrum für Schwerionenforschung GmbH

Reactions of Synthesis

courtesy of Yu. Ts. Oganessian



Historical background:

After discovery of nuclear fission 75 - years ago - 26 new chemical elements heavier than uranium were synthesized

Yu/ Oganessian. XXII International Baldin Seminar, September 15-20, 2014, JINR, Dubna

Cold/hot fusion systematics

courtesy of Yu. Ts. Oganessian

hot fusion

^{48}*Ca-induced reactions*

E_x = 35 - 45 MeV

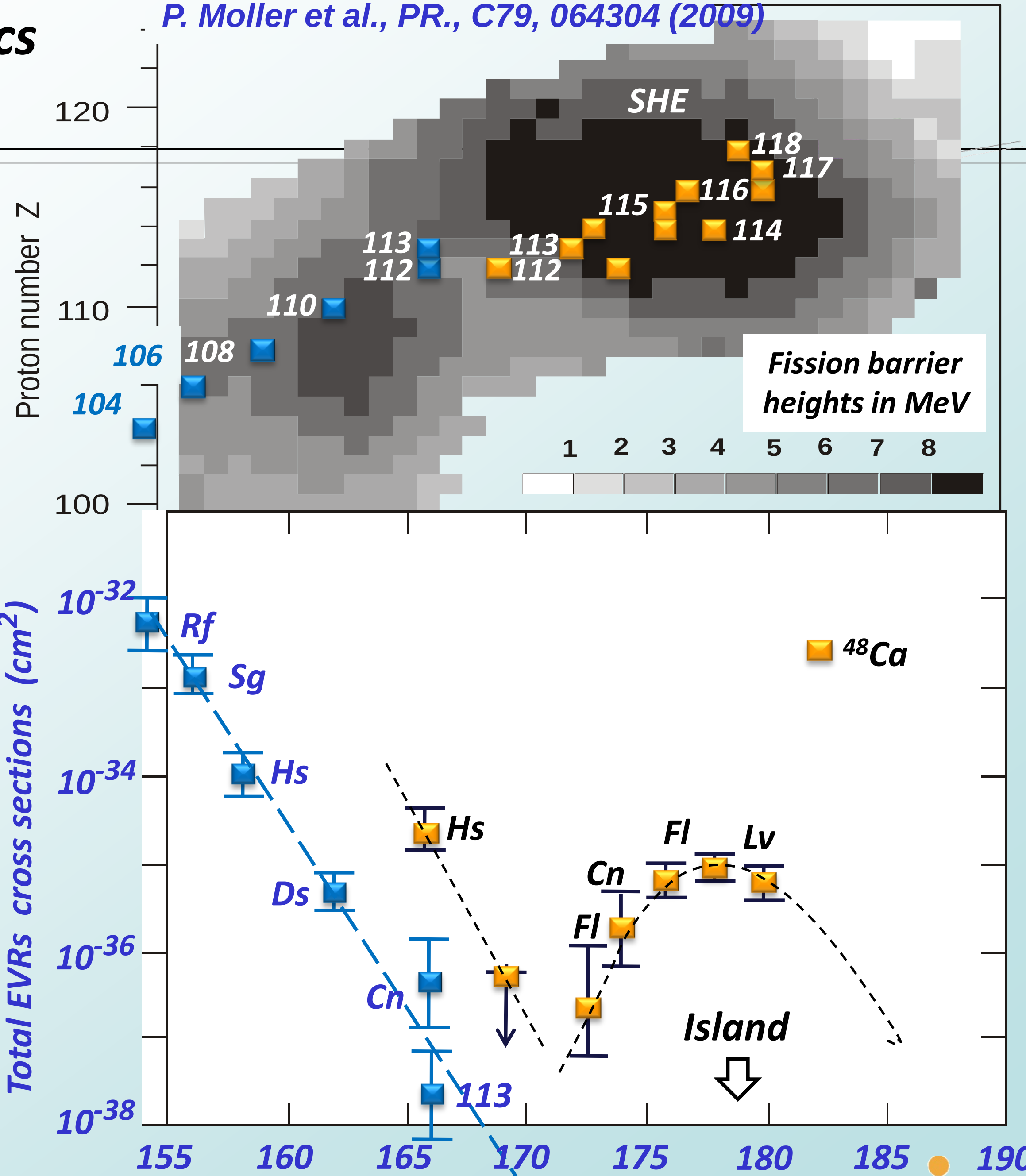
x = 3 – 4

cold fusion

^{208}Pb, ^{209}Bi + ^{50}Ti,……^{70}Zn

E_x = 12 - 15 MeV

x = 1

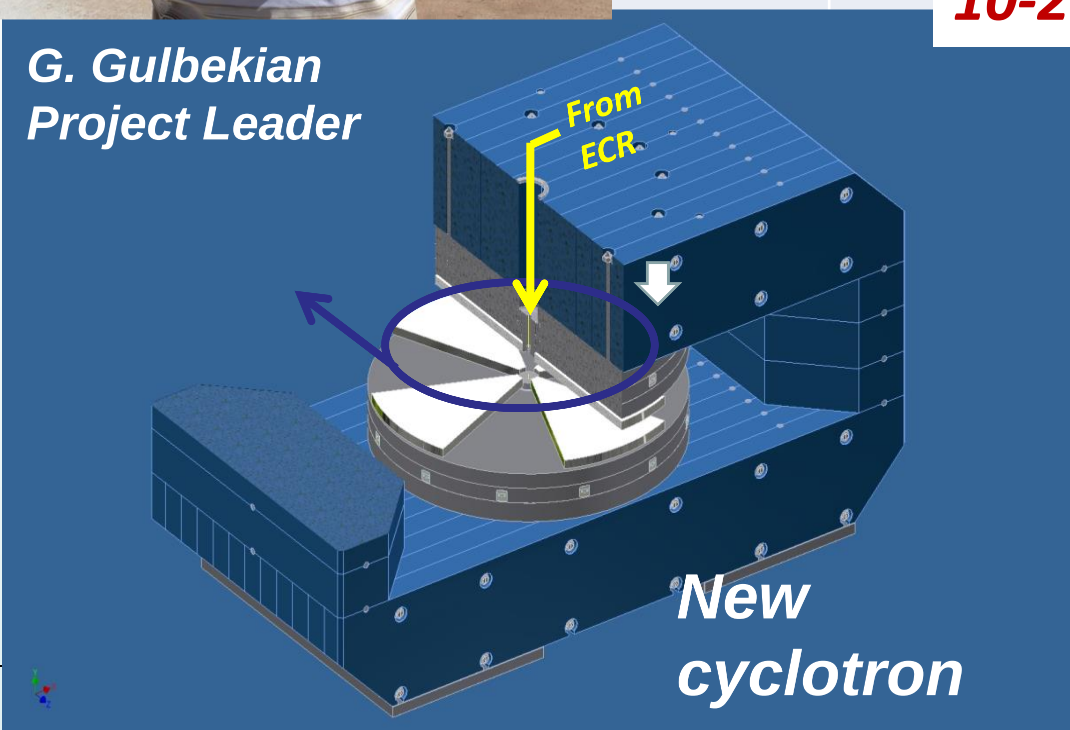


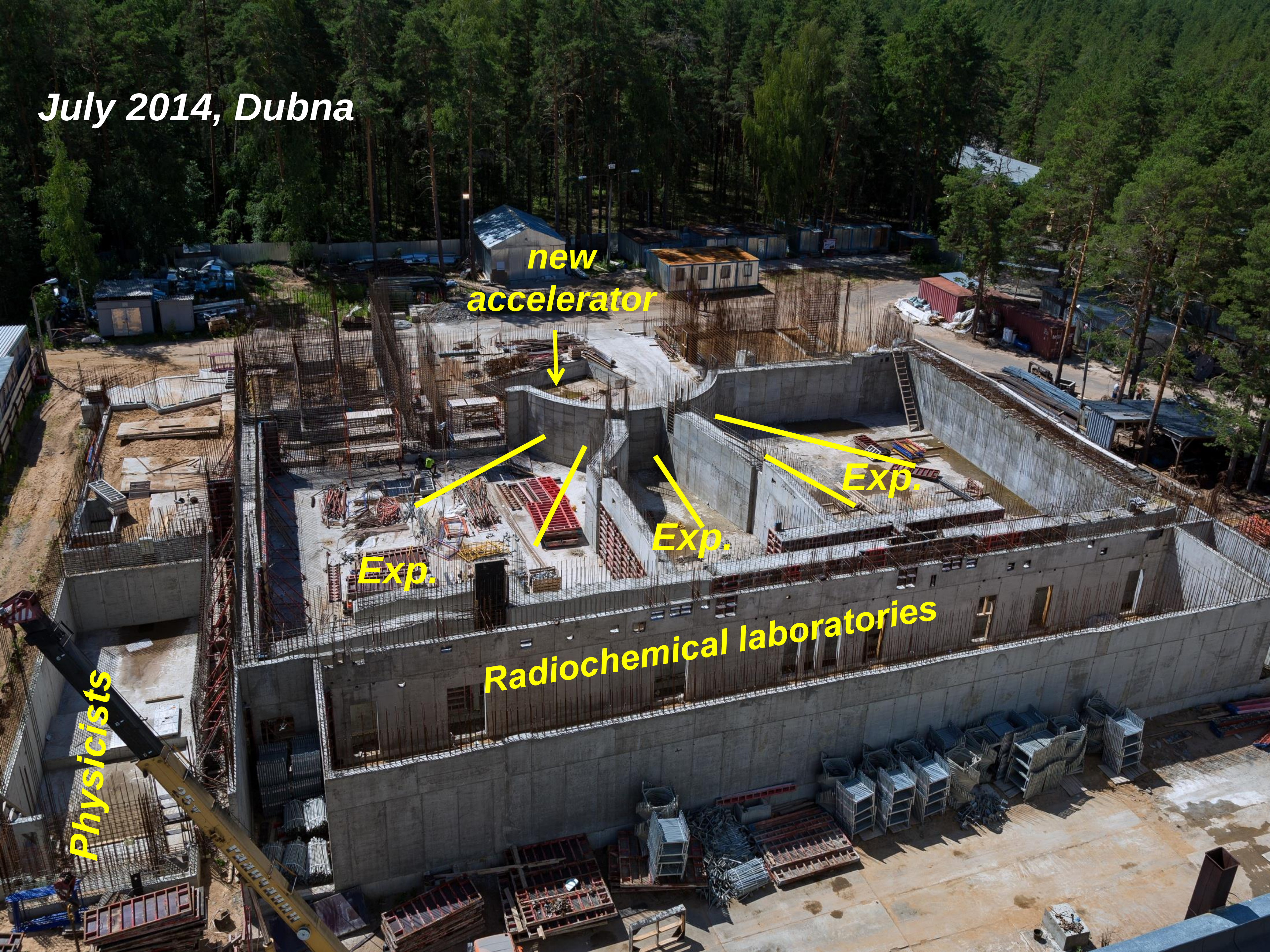
New accelerator and new Lab. in Dubna

courtesy of Yu. Ts. Oganessian

today: ~ $5 \cdot 10^{19}$/y with Factory: $1.0 \cdot 10^{21}$/y

beam dose		factor: ~ 20
Beam intensity	&	Beam time
10-20 pμA		↓
		Factory
		↓ ~ 7000 h/year

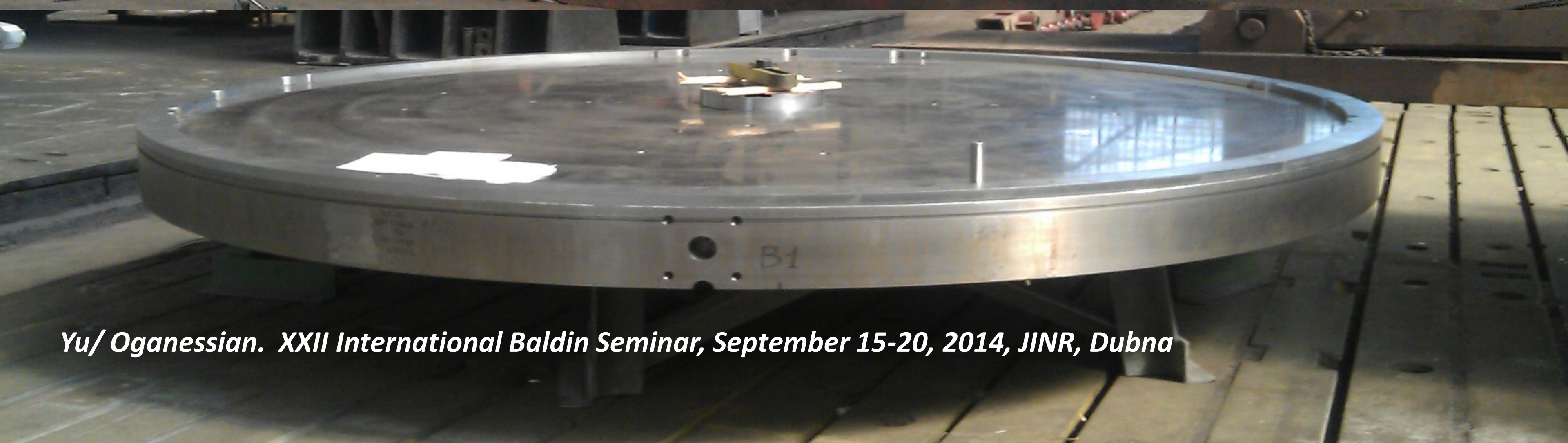




July 2014, Dubna
new
accelerator
Exp.
Exp.
Exp.
Radiochemical laboratories
Physicists


August 2014, Dubna

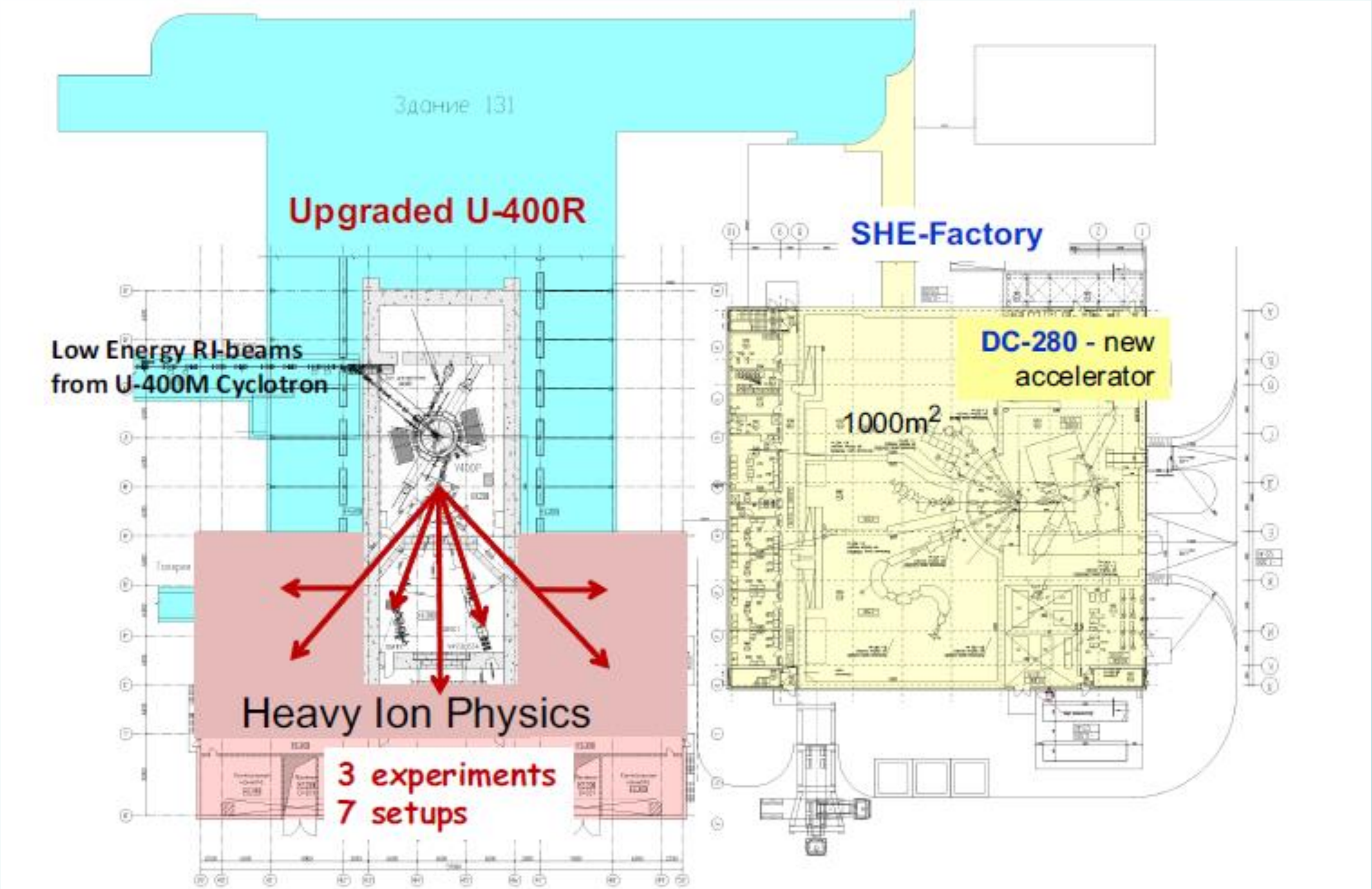

Novokramatorks
Ukraine
June 2014


B1
Yu/ Oganessian. XXII International Baldin Seminar, September 15-20, 2014, JINR, Dubna


Novokramatorks
Ukraine
August 2014
UpRight AB38
UpRight

SHE-factory at Dubna

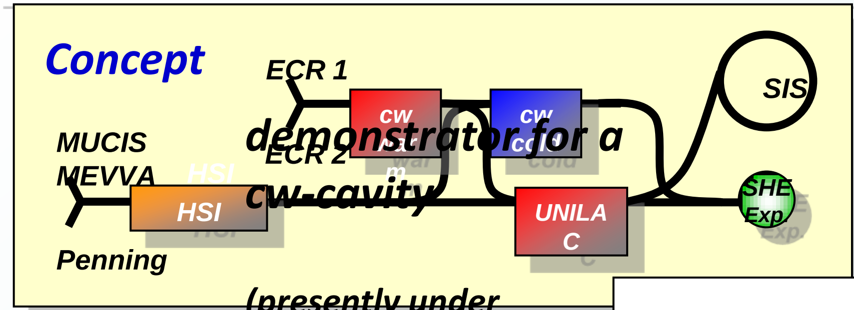
- integration in FLNR facility



Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012,Weilrod, Germany

cw-accelerator project at GSI

- concept and “step-wise” realization



demonstrator for a cw-cavity

(presently under constrcution)

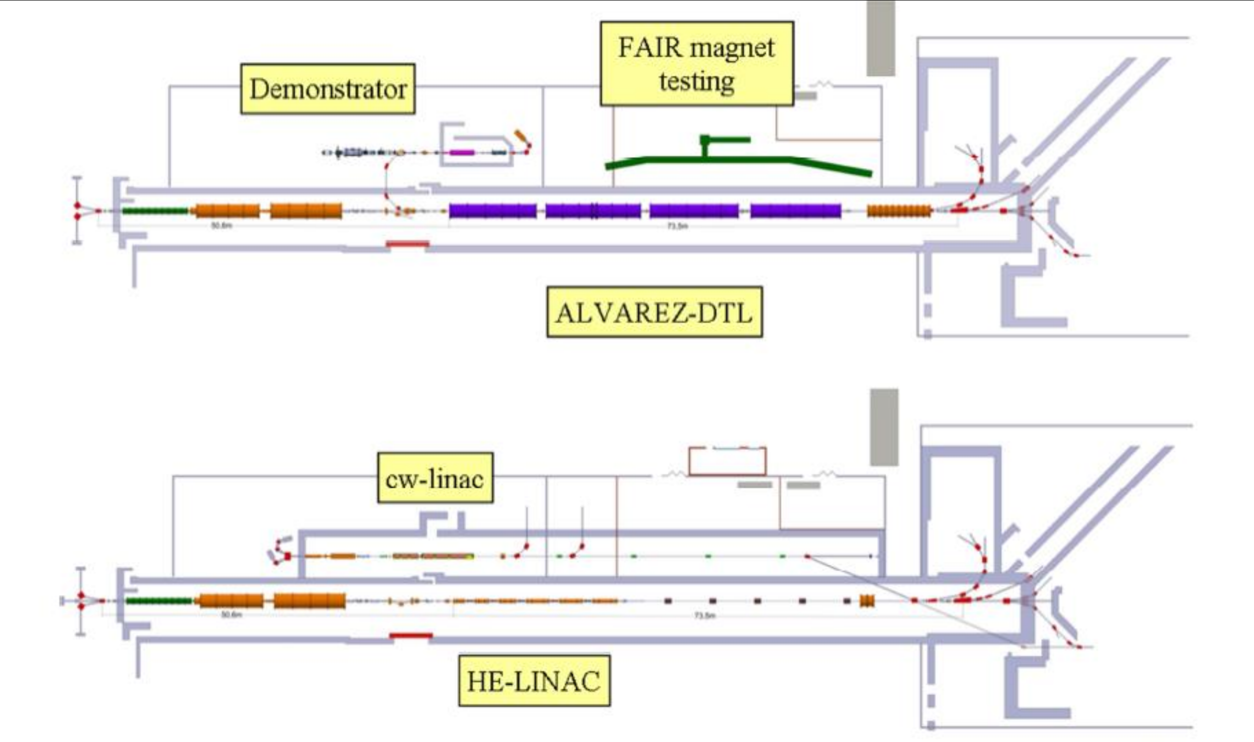


Figure 4: Complete GSI-injector environment; with demonstrator in place as scheduled for 2014 (top), after completion with HE-linac and cw-LINAC in place (bottom).

cw-accelerator project at GSI

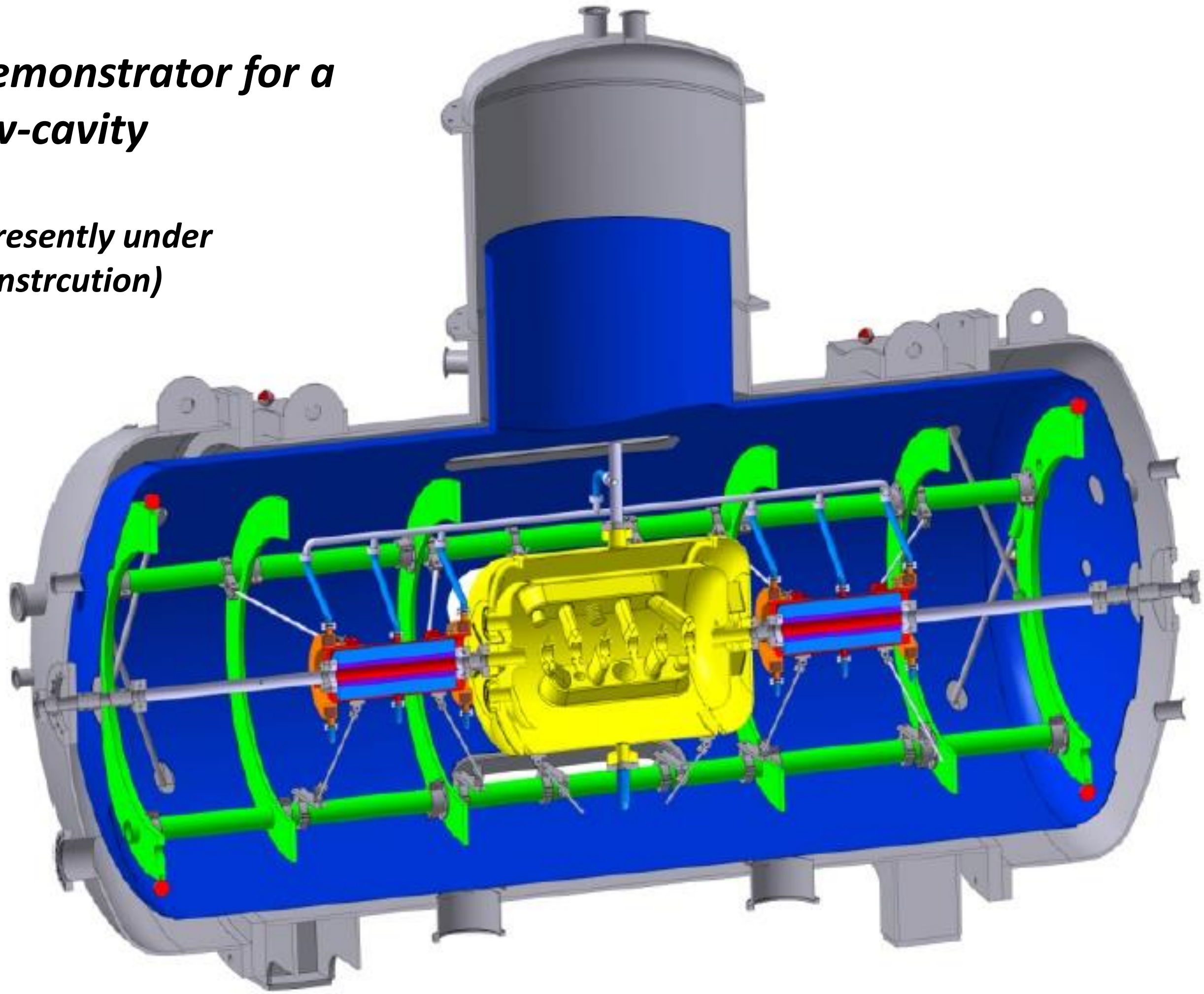
- concept and "step-wise" realization

Concept

MUCIS
MEVVA
HS
Penning

demonstrator for a cw-cavity

(presently under constrcution)

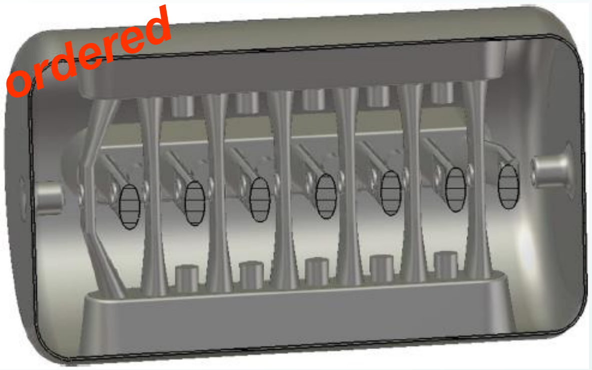


heduled for

sc-216 MHz-CH-Protype

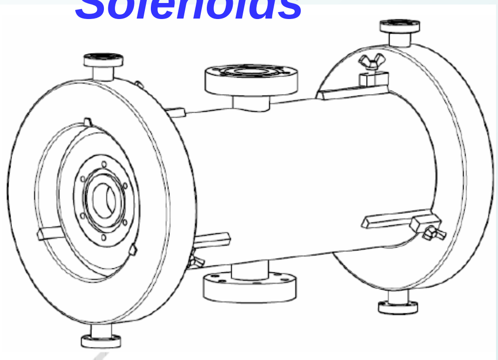
- W. Barth at FUSHE 2012

216 MHz-CH-cavity
(Goethe Univ. Frankfurt)



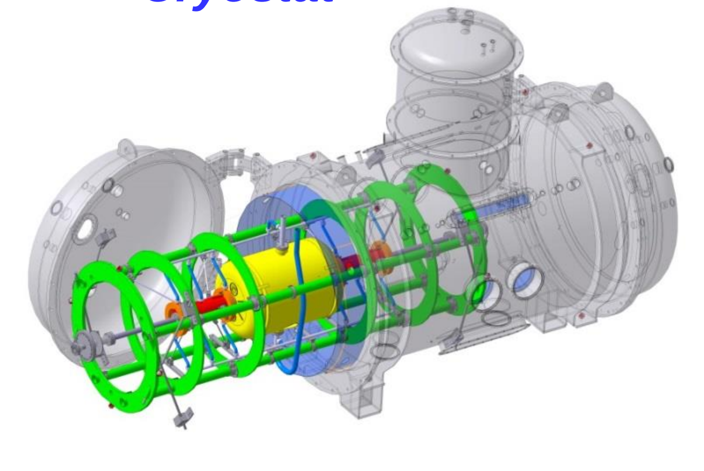
Parameter	Unit	CH-1
Beta		0.059
Frequency	MHz	217
Gap number		15
Total length	mm	690
Cavity diameter	mm	420
Cell length	mm	40.82
Aperture	mm	20
Effective gap voltage	kV	225
Voltage gain	MV	3.13
Accelerating gradient	MV/ m	5.1
E_p/ E_a		6.5
B_p/ E_a	mT/ (MV/m)	5.9
R/ Q	Ω	3540
Static tuner		9
Dynamic bellow tuner		3

Solenoids

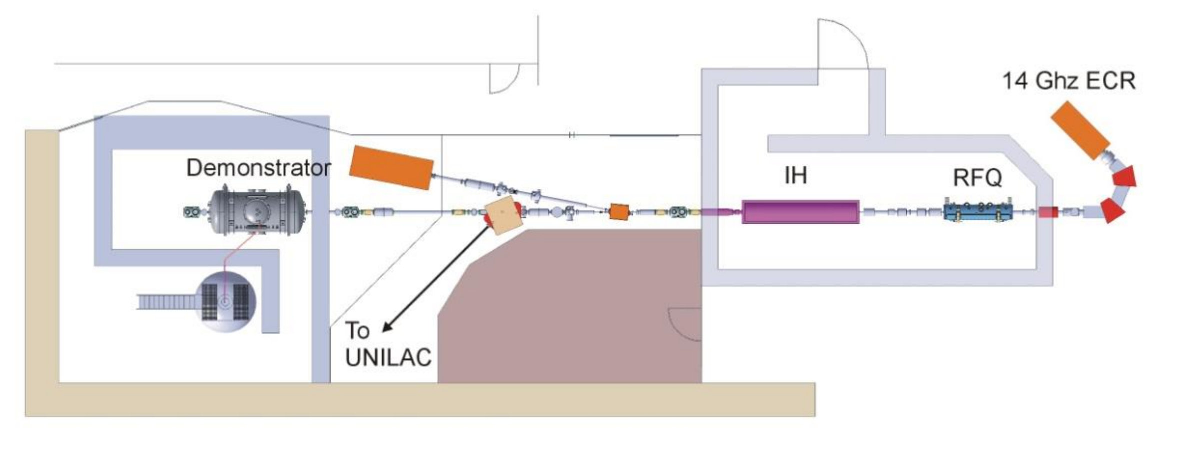


Bmax	9,323T
B*L	2,635 Tm
L	0,28 m
Aperture	30 mm

Cryostat



Demonstrator Project (HIM, GSI)

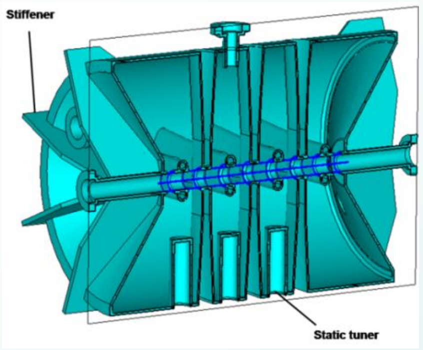


cw-accelerator project at GSI

- short CH-cavity and the advanced demonstrator

short CH-cavity

geometry

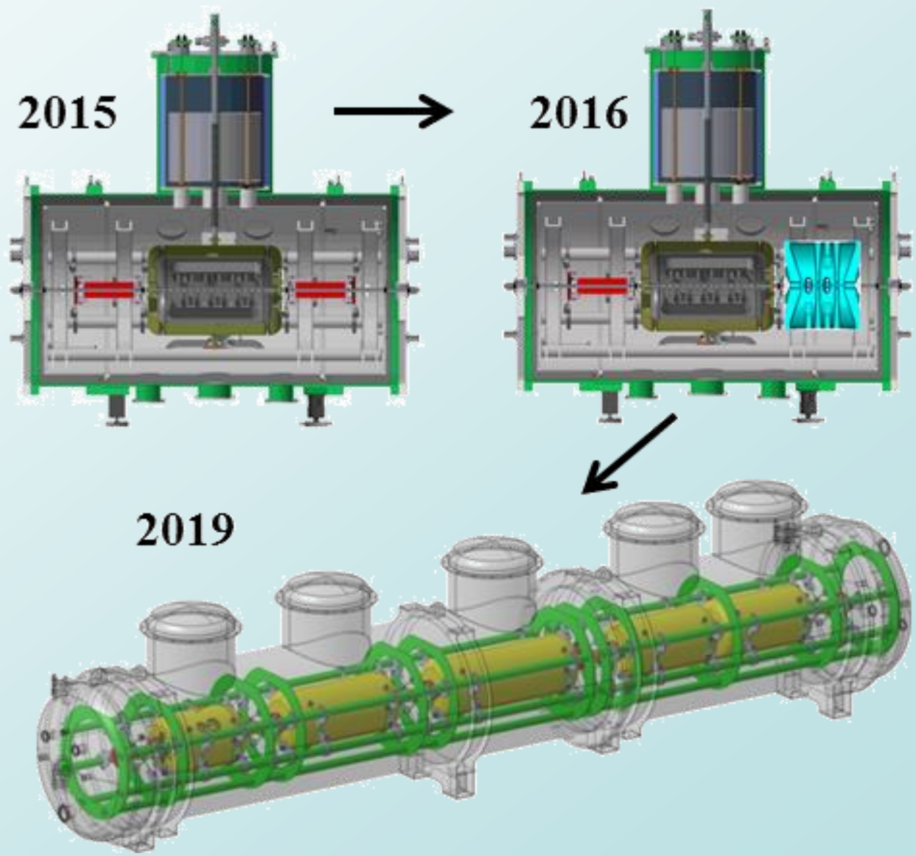


properties

Frequency	217	MHz
β	0.069	
Length (8βλ/2)	381.6	mm
Number gaps	8	
Inner tank diameter	438	mm
Aperture diameter	30	mm
Maximum inner length	560	mm
Wall thickness	≈3.5-4	mm
E_p/E_a	5.3	
B_p/E_a	6.5	mT/(MV/m)
E_a	>5	MV/m

advanced demonstrator

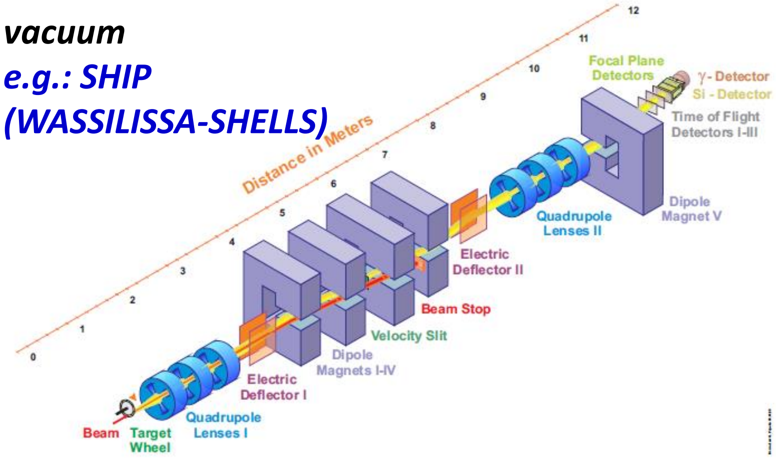
implementation time line



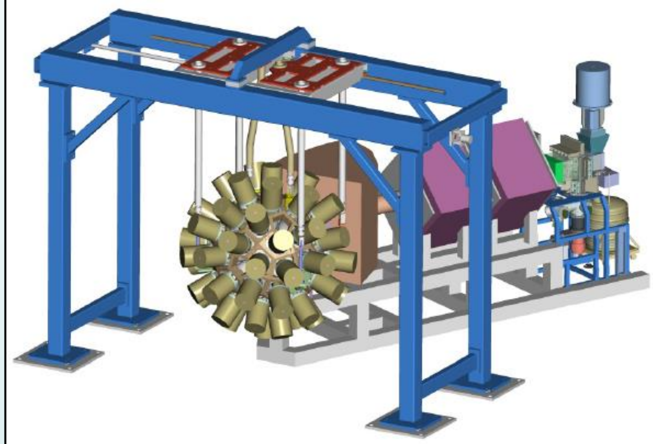
Separators

- present and (near) future devices

vacuum
e.g.: SHIP (WASSILISSA-SHELLS)



gas-filled
e.g.:RITU (DGFS, GARIS, BGS...)

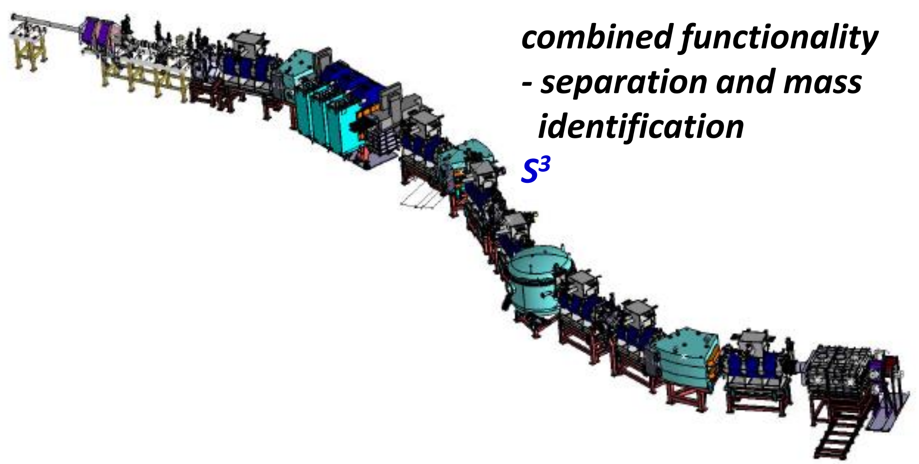


complementary configurations

- ***vacuum separators***
  - ***velocity filters (SHIP, LISE)***
  - ***mass spectrometers (FMA,RMS,..., EMMA, MARA)***
- ***gas-filled separators***
  - ***DGFRS, GARIS, TASCA, BGS, RITU, ...***

instrumental/detection features

- ***comprehensive detection systems***
  - ***decay spectroscopy (GREAT, TASISPEC, SHIP or FMA focal plane set-ups***
  - ***inbeam (JUROGAM, AGATA, GAMMASPERE, ...)***
  - ***inbeam electrons (SAGE)***
  - ***X-rays ...***



combined functionality
- separation and mass identification
S^3

ENSAR ECOS NA Report

- excerpt from the FUSHE 2012 paper (to be published)

ECOS (European Collaboration On Stable ion beams)

ENSAR NA Report

Task 1 - High power thin-target technology

Task 2 - Synergies in Super Heavy Element Research

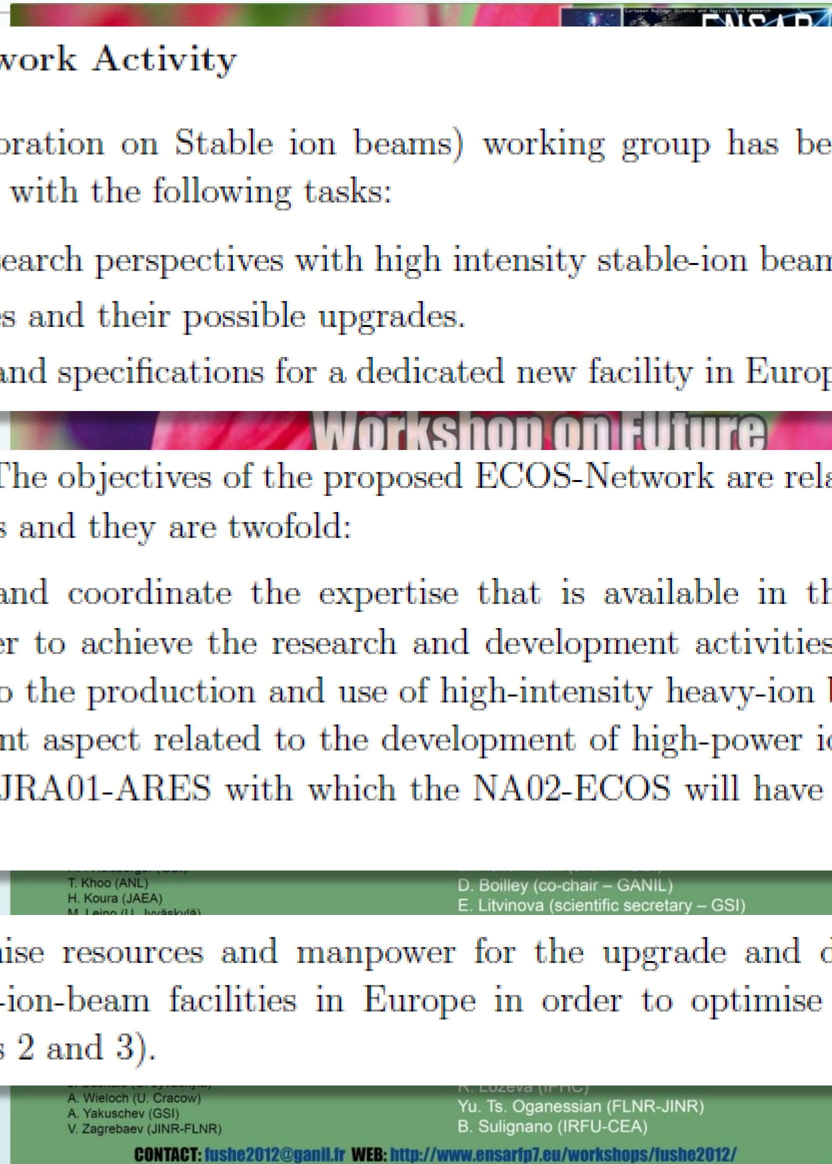
D. Ackermann[1]‡, E. Litvinova[2], D. Boilley[3], Ch. Stodel3, B. Avez[4], W. Barth[1], M. Block[1,5], Ch. Düllmann[5],6, S. Fritzsche[6], P. Greenlees[7], R.-D. Herzberg[8], F.P. Heßberger[1,5], W. Loveland[9], W. Nazarewicz[10], V. Pershina [1], G. Pollarolo[11], J. Roberto[12], P. Schwerdtfeger[13], A. Türler[14,15], J. Uusitalo[7], D. Vretenar[16]

[1] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[2] Western Michigan University, Kalamazoo, U.S.A.
[3] GANIL, Caen, France
[4] N.N., N.N., N.N.
[5] HIM, Mainz, Germany
[6] University of Mainz, Mainz, Germany
[6] University of Jena, Jena, Germany
[7] University of Jyväskylä, Jyväskylä, Finland
[8] University of Liverpool, Liverpool, U.K.
[9] Oregon State University, Corvallis, U.S.A.
[10] Michigan State University, East-Lansing, U.S.A.
[11] Universit di Torino and INFN, Torino, Italy
[12] ORNL, Oakridge, U.S.A.
[13] CTCP Massey University, Auckland, New Zealand
[14] University of Bern, Bern, Switzerland
[15] PSI, Villigen, Switzerland
[16] University of Zagreb, Zagreb, Croatia

Contents

CONTACT: fushe2012@ganil.fr WEB: http://www.ensarfp7.eu/workshops/fushe2012/

- excerpt from the FUSHE 2012 paper (to be published)



1. The ENSAR ECOS Network Activity

The ECOS (European COllaboration on Stable ion beams) working group has been appointed by NuPECC in 2004 with the following tasks:

- Describe and access the research perspectives with high intensity stable-ion beams.
- Categorise existing facilities and their possible upgrades.
- Identify the opportunities and specifications for a dedicated new facility in Europe.

The objectives of the proposed ECOS-Network are related to these two recommendations and they are twofold:

(i) Bring together and coordinate the expertise that is available in the European countries in order to achieve the research and development activities in essential aspects related to the production and use of high-intensity heavy-ion beams (Task 1). The important aspect related to the development of high-power ion sources is the objective of JRA01-ARES with which the NA02-ECOS will have a significant synergy.

(ii) Optimise resources and manpower for the upgrade and development of various stable-ion-beam facilities in Europe in order to optimise their scientific output (Tasks 2 and 3).

ENSAR ECOS NA Report

- deliverables and actions

deliverables

D-NA02-1: Report on the development of high power thin-target technology with special emphasis on new techniques and methods that will allow increasing the primary beam intensity usable with such targets. (month 40)

D-NA02-2: Report on the research activities related to SHE s ,and on the achievement made in this research field (month 40)

D-NA02-3: Report on the collaborations and synergies between facilities providing stable Ions beam facilities in Europe initiated and driven by ECOS network (month 40)

actions

The report on task 1 and two is mainly based on the strategy discussion and in its results performed during the FUSHE 2012 workshop and follow up activities initiated by it. The FUSHE 2012 workshop was held in Weilrod, Germany, from May 13^{th} 16^{th} 2012 covered in with comprehensive program all subjects related to superheavy element research including experimental, instrumental and theoretical questions (http://www.ensarfp7.eu/ projects/ecos/workshops-meetings/fushe2012). The workshop was attended by about 90 participants from all institutions involved in SHE research worldwide. It was organized in 7 sessions with a strong emphasis on discussions including Theory, Experiment and Instrumentation in an integrated fashion in order to foster a constructive dialogue between theory and experiment. The sessions were organized as a combination of invited talks followed by a topical discussion for the subjects:

subjects discussed at FUSHE 2012

- SHE Synthesis
- Nuclear Structure of SHE
- Chemistry
- Atomic Physics and Alternative Approaches

Strategy and open questions

- visions and challenges (FUSHE 2012 paper)

ENSAR

- How many protons and neutrons can a nucleus hold together? What is the heaviest element that we can synthesize today and in the future? Where is the end of the periodic table in atomic number and mass?
- Can we develop a comprehensive theory of nuclei from the lightest to the heaviest? Are superheavy nuclei fundamentally different, and do they represent a new state of nuclear matter?
- What are the properties and boundaries of the predicted "island of stability" for superheavy elements? Does the stabilization emerge without large energy gaps?
- How can we produce superheavy nuclei that are more neutron rich?
- What is the physical and chemical behavior of elements with extreme numbers of neutrons, protons, and electrons?
- Can we understand the details of the fission process and competing decay modes?
- Can we understand and optimize the production mechanisms for superheavy nuclei: hot and cold fusion, multi-nucleon transfer, etc? Can we produce measurable quantities of superheavy elements?
- Do superheavy elements exist in the universe, and how are they produced? Are there remnants of long-lived superheavy elements on earth?

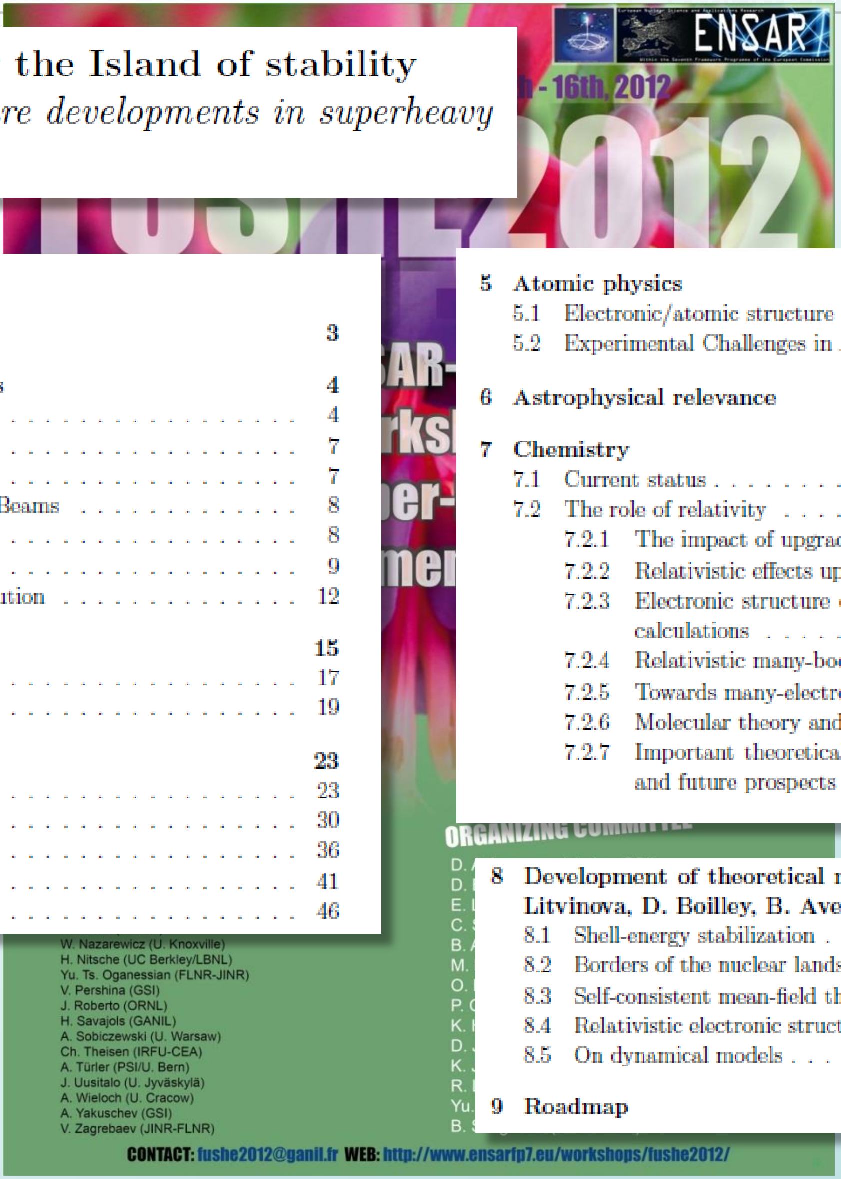
V. Pershina (GSI)
J. Roberto (ORNL)
H. Savajols (GANIL)
A. Sobiczewski (U. Warsaw)
Ch. Theisen (IRFU-CEA)
A. Türler (PSI/U. Bern)
J. Uusitalo (U. Jyväskylä)
A. Wieloch (U. Cracow)
A. Yakuschev (GSI)
V. Zagrebaev (JINR-FLNR)

O. Dorvaux (IPHC)
P. Greenlees (JYFL)
K. Hauschild (CSNSM)
D. Jacquet (IPNO)
K. Jadambaa (GSI)
R. Lozeva (IPHC)
Yu. Ts. Oganessian (FLNR-JINR)
B. Sulignano (IRFU-CEA)

CONTACT: fushe2012@ganil.fr WEB: http://www.ensarfp7.eu/workshops/fushe2012/

FUSHE 2012 paper on SHE strategy

- outline



Exploring and Harvesting the Island of stability

Strategy for near and far future developments in superheavy element research

Contents

Discussion issues

- contributions to this session and beyond ...

models

- *self-consistent – macro-micro*
- *dynamic*
- *beyond mean field ...*

stable beams

- *high intensity accelerators – ECOS*
  - *cw-linac project GSI*
  - *LINAG at SPIRAL2*
  - *LINCE at Huelva ...*

RIB facilities

- *reaction mechanism studies*
  - *multi nucleon transfer*
  - *spin distribution*
- *nuclear structure of n-rich heavy species*
  - *isotonic/isotopic trends of single particle states*
  - *deformation, K-isomers*

instrumentation

- *accelerators, separators, detectors, ...*

targets

- *stable (Pb, Bi, ...), actinides (^{243}Am, ^{A}U, ^{242,244}Pu, ^{248}Cm, ^{249}Cf, ^{249}Bk, ...)*

alternative approaches

- *traps*
- *lasers, ...*

continuation in ENSAR2

- *cw-accelerator – first beams(?)*
  - *GSI/HIM*
  - *LINAG at SPIRAL2*
  - *FLNR SHE-factory*
  - *LINCE (?)*
  - *...*
- *possible synergies with RIB*
  - *ReA12 at FRIB*
  - *SPIRAL2, FAIR, EURISOL...?*
- *...*

additional material on:

- RIB
- alternative methods
  - multinucleon transfer
  - spindistrbution

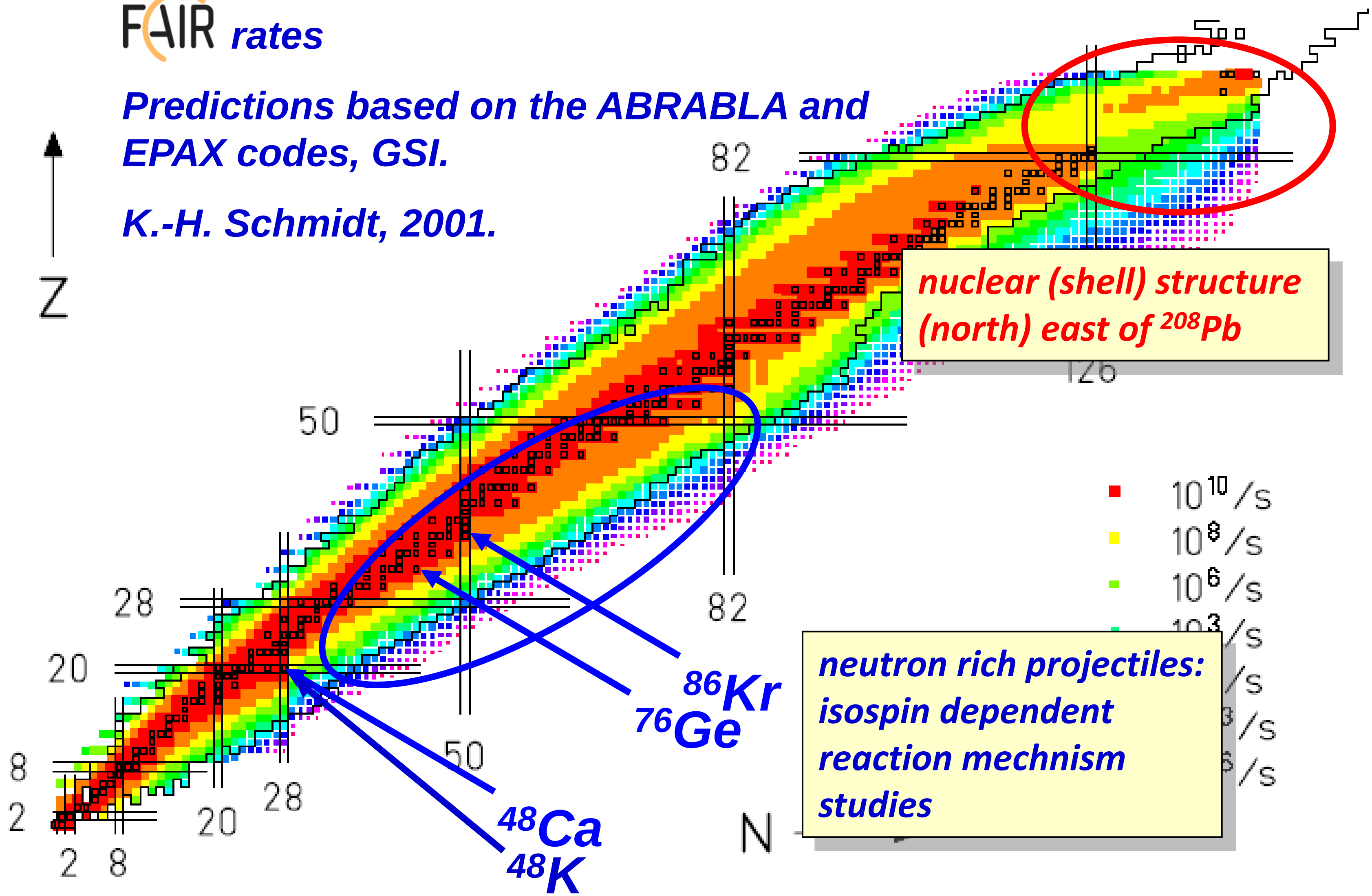
RIB reaction rates

- optimum rates from projectile fission and fragmentation

FAIR *rates*

Predictions based on the ABRABLA and EPAX codes, GSI.

K.-H. Schmidt, 2001.

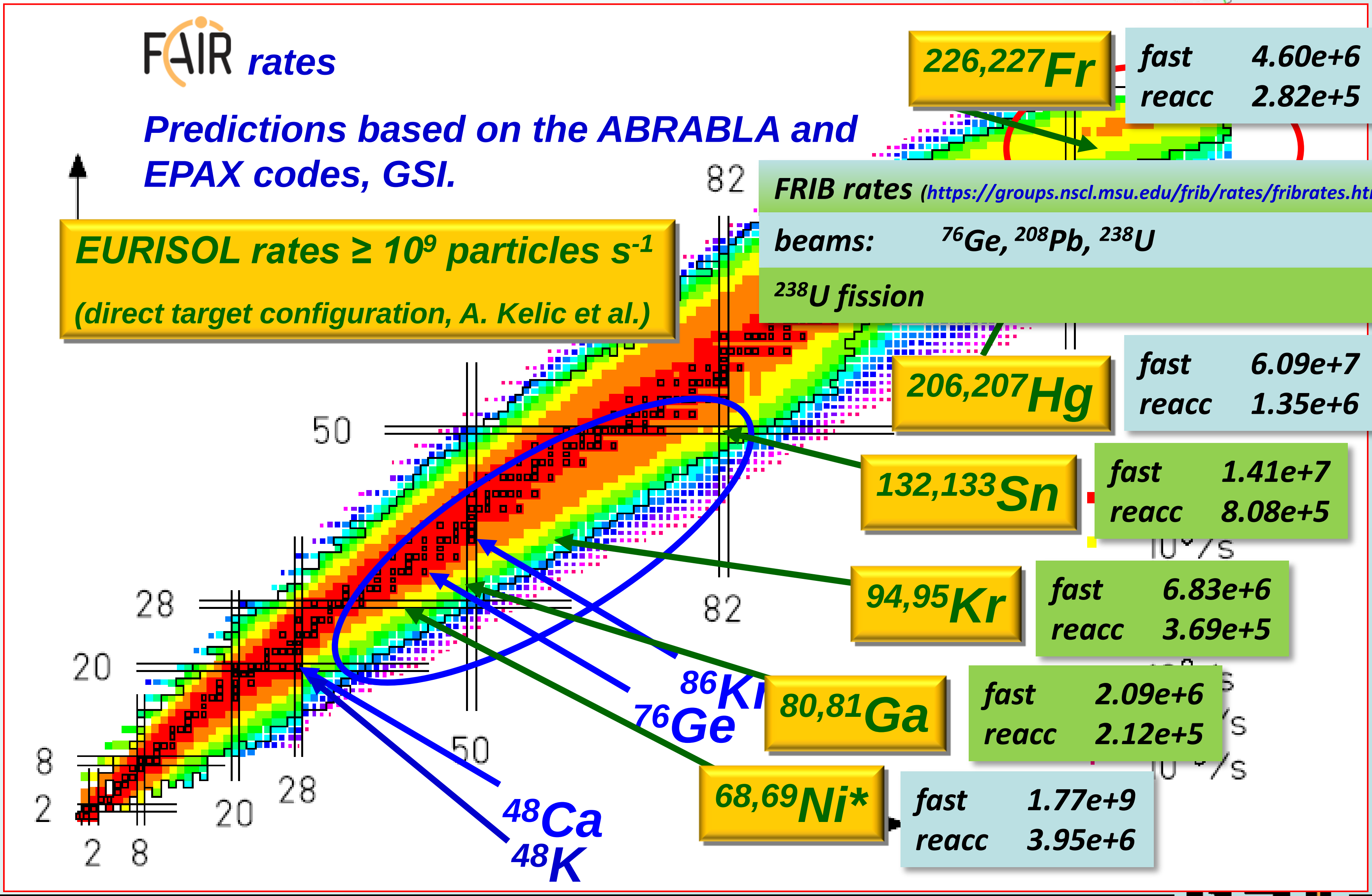


nuclear (shell) structure (north) east of ^{208}Pb

neutron rich projectiles: isospin dependent reaction mechnism studies

RIB reaction rates

- optimum rates from projectile fission and fragmentation, and ISOL



Perspectives for SHE research @ RIB facilities

- approaching and understanding SHE

- extension of nuclear structure studies towards n-rich (n-rich K,Ca-Zn projectiles)

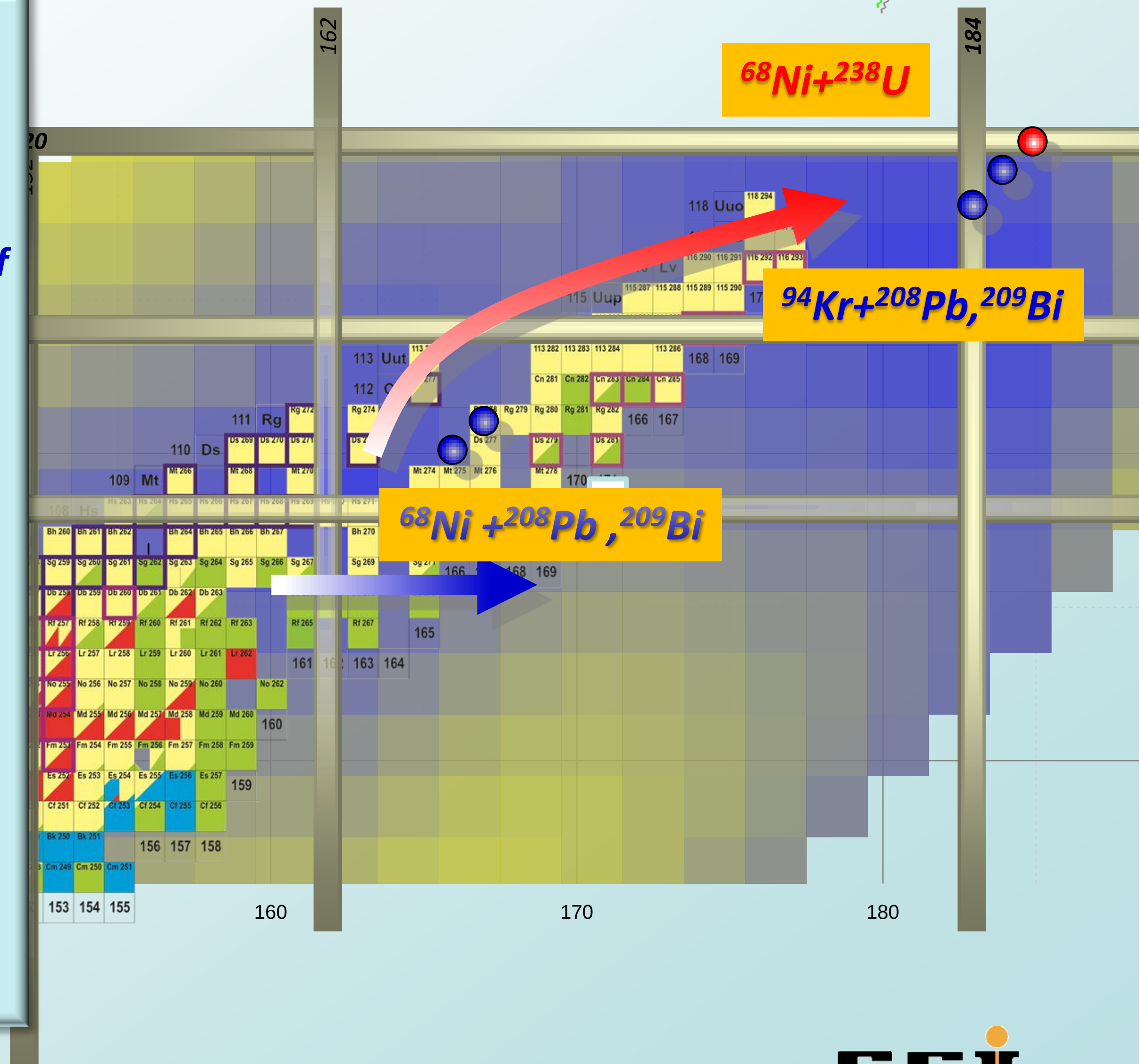
  → mapping of the borders of deformed region (?)

- heavier n-rich projectile-target combinations

  → approaching the “island of stability” ??? (x-section dependance curcial)

- prerequisites:

  →reaction mechanism (isospin dependent) & nuclear structure studies @ FAIR, FRIB, ...



Multi nucleon transfer as a tool to study n-rich species

- Reaction dynamics

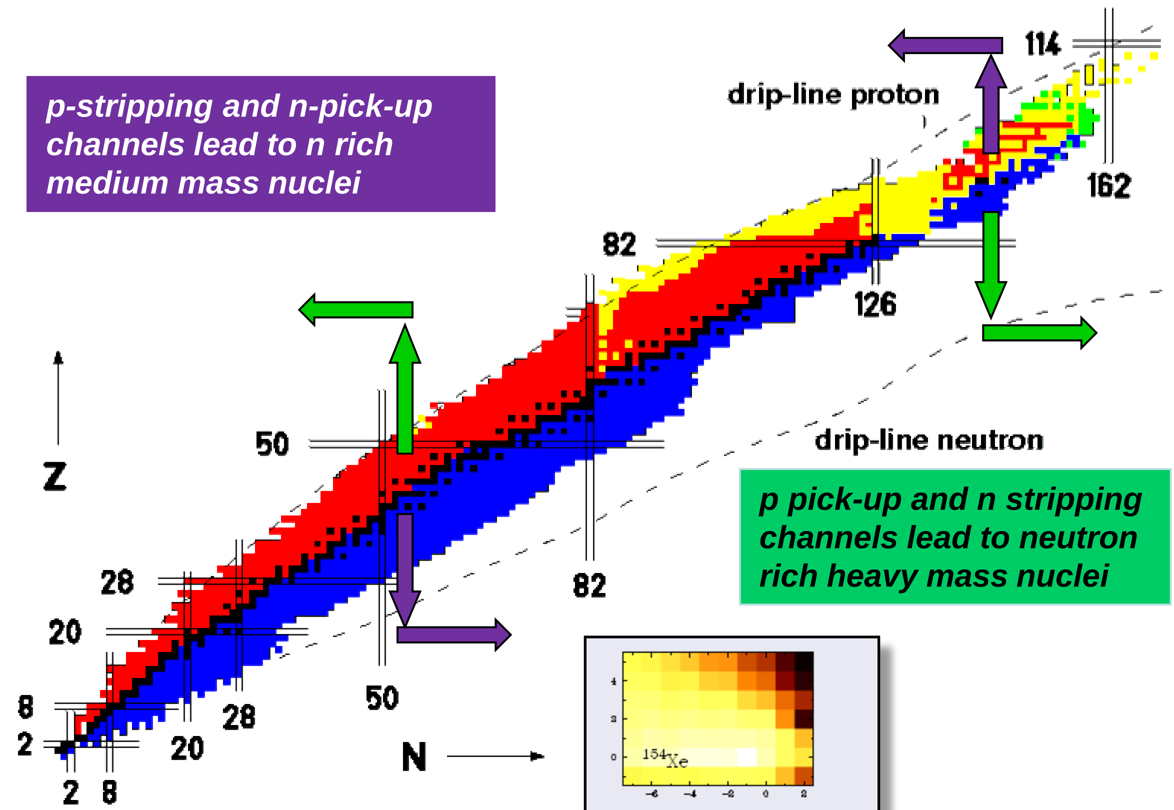
D. Ackermann, L. Corradi, E. Fioretto, D. Montanari, G. Montagnoli,
G. Pllatolo, F. Scarlassara, A.M. Stefanini, S. Szilner

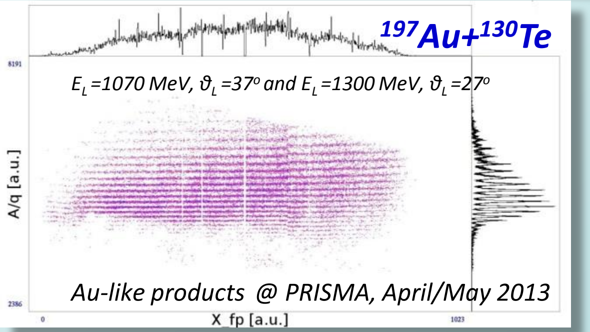
investigation of transfer reaction dynamics

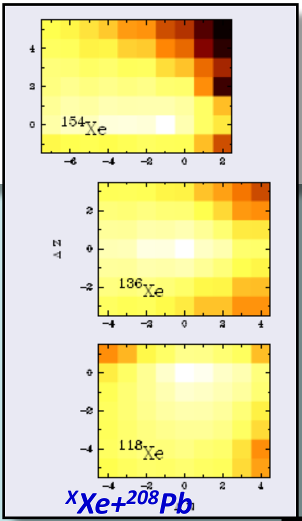
- *n rich projectiles favor p pick-up/n stripping (light partner)*
  - *caution: n evaporation and (transfer induced) fission shifts towards stability*

instrumental requirements:

- *large acceptance magnetic (tracking) spectrometer (PRISMA/VAMOS type)*
  - *also in coincidence with particle and γ detector arrays*
- *detection of the heavy partner $\rightarrow$ high spatial and energy resolution (PRISMA:*
  - *$\Delta x, \Delta y$ ≈ 1mm*
  - *$\Delta\theta_{in}$ ≈ 1°*
  - *ΔE ≈ 1%)*







C.H. Dasso, G. Pollarolo, A. Winther, PRL73 (1994) 1907;

L. Corradi, G. Pollarolo, S. Szilner, J. of Phys. G 36 (2009) 113101

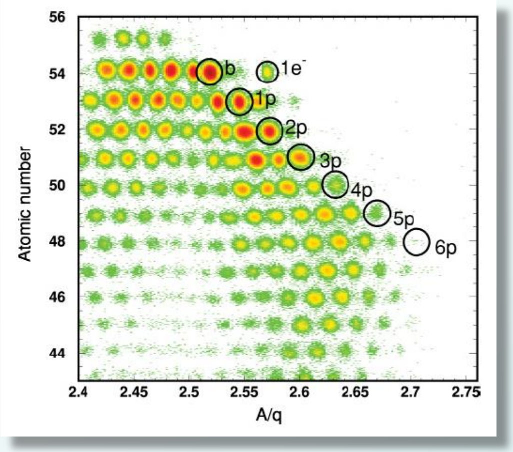
Multi nucleon transfer as a tool to study n-rich species

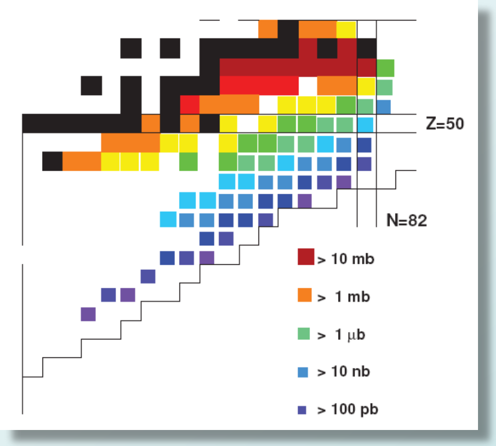
- research topics ...

D. Ackermann, L. Corradi, E. Fioretto, D. Montanari, G. Montagnoli, G. Pllatolo, F. Scarlassara, A.M. Stefanini, S. Szilner

- ***competitive with fragmentation – where and to what extent?***
- ***complementarity***

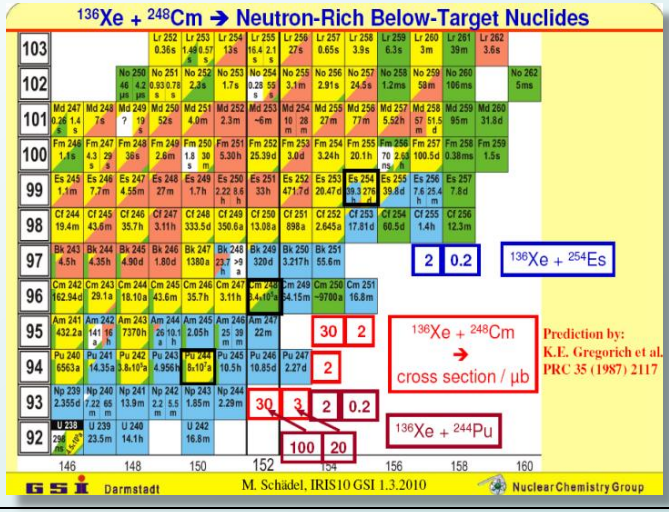
J. Benlliure et al., Phys.Rev.C78 (2008) 054605



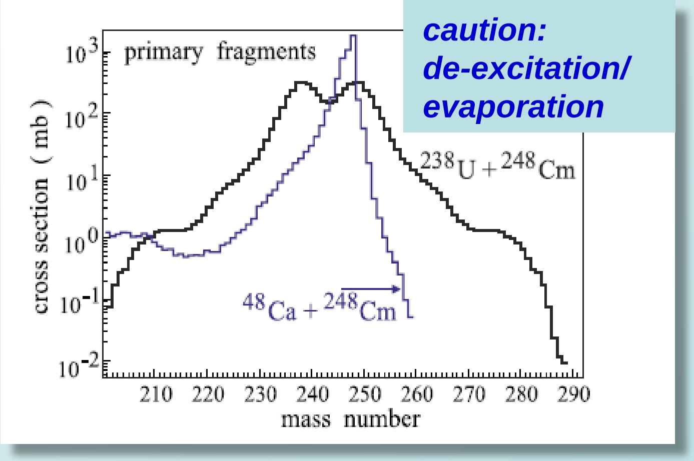


Fragmentation reactions of Xe isotopes at 1 A GeV on light targets

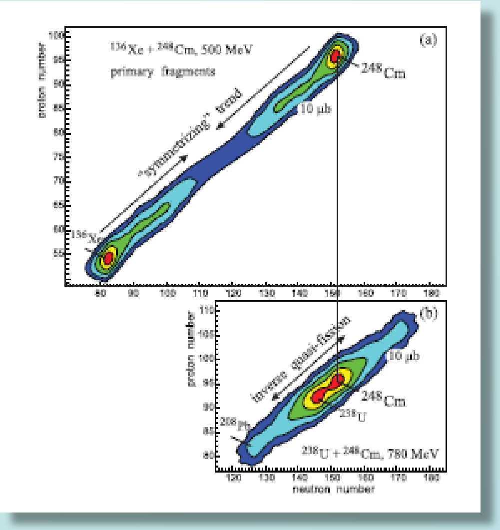
- ***production and nuclear structure of n-rich species (actinides, Z=82, N=126)***



- ***population of high-A/high-Z in the tail of the transfer mass distribution***



caution: de-excitation/ evaporation

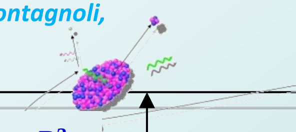


V.I. Zagrebaev and W. Greiner, Phys.Rev.C87 (2013) 034608

Fusion barrier distribution – alternative approach

- the CN spin distribution

D. Ackermann, L. Corradi, E. Fioretto, D. Montanari, G. Montagnoli,
G. Pollarolo, F. Scarlassara, A.M. Stefanini, S. Szilner
A.Gade, Z. Kohley, W. Mittig

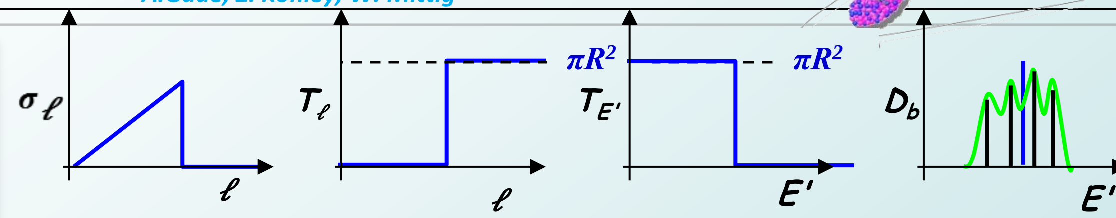


D_b from 1st derivative of the transfer function
T_ℓ equivalent to $E \cdot \sigma_{fus}$

- *high spin part covers complete barrier distribution at one E_{proj} □ V_b rather than many precise cross section measurements at small ΔE*
- *n-rich projectiles for isospin dependent fusion barrier investigations*
- *...*

instrumental requirements:

- *highly efficient (≈80% at E_γ < 500 keV) γ multiplicity array (CAESAR, DA-HD Crystalball, GASP...)*
- *ER trigger*
  - *not evaporation channel selective*
    → only separator
  - *channel selective*
    → e.g. Ge-detector (array) (GASP, AGATA, GRETINA...)
- *separator*
  → E_{pro} ≈ 5 AMeV
  → E_{ER} ≈ 0.1-1 AMeV
  - *gas filled (TASCA, VAMOS, PRISMA)*
    → $B\rho \geq 2.5$ Tm
  - *vacuum type*
    - *v-filter (SHIP, LISE)*
    - *mass spectrometer (FMA/RMS...)*
  - *...*



$$\sigma_\ell(E) = T_\ell(E,\ell)(2\ell+1)\pi\lambda\!\!\!^-{}^2$$

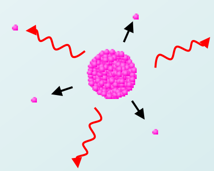
$$T_\ell(E,\ell) = \frac{\sigma_\ell(E)}{(2\ell+1)\pi\lambda\!\!\!^-{}^2}$$

$$T_\ell \rightarrow T_{E'}$$

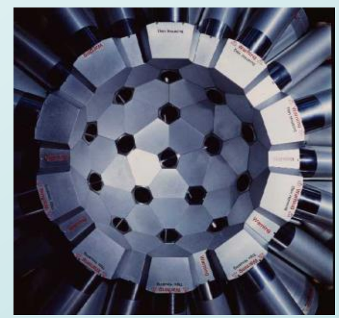
$$\ell \rightarrow E'$$

$$\text{with} \quad E' = E - \frac{\ell(\ell+1)}{2\mu R_b^2}$$

$$D_b = \frac{dT_{E'}}{dE'}$$



→



→ M_γ

γ multiplicity filter + ER trigger

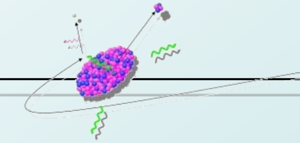
$$\ell_{CN} = (M_\gamma - M_{\gamma s})\Delta\ell_\gamma + M_{\gamma s}\Delta\ell_\gamma + \sum_i \Delta\ell_i + \Delta\ell_{gs/m}$$

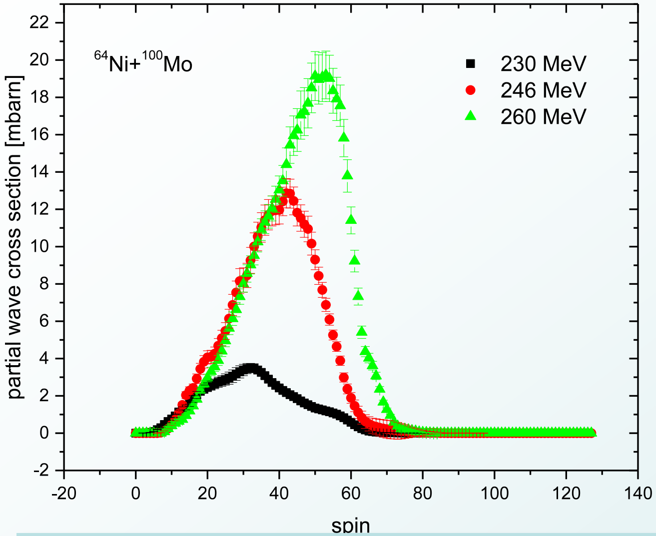
$$i = p, n, \alpha$$

D. Ackermann et al., Eur.Phys.J. A 20 (2004) 151

Extraction of the barrier distribution for $^{64}Ni+^{100}Mo$

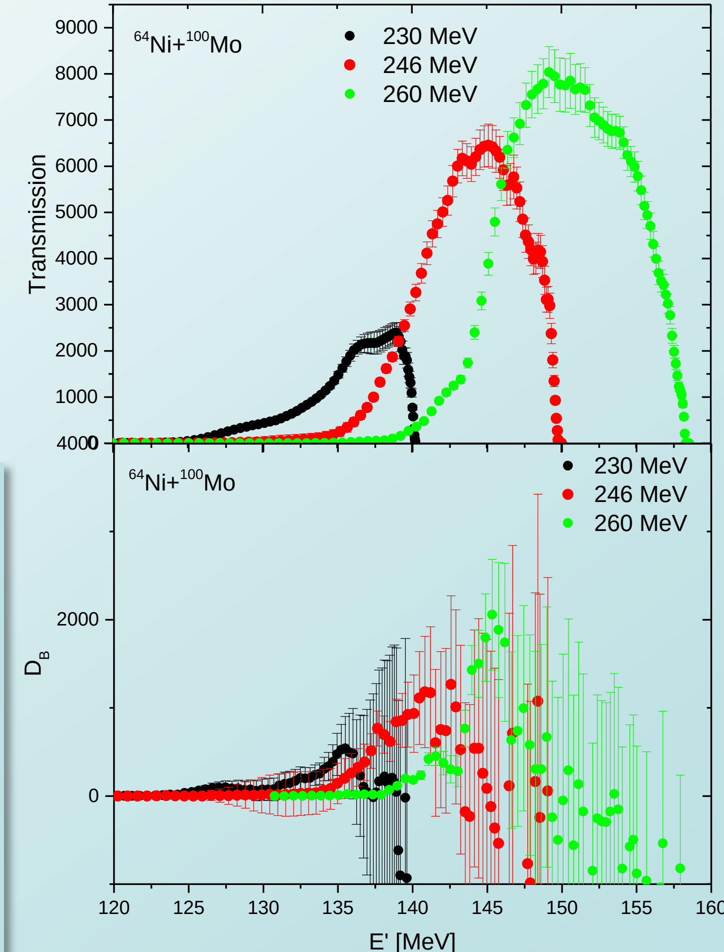
- analysis by Varinderjit Singh, Panjab University, India



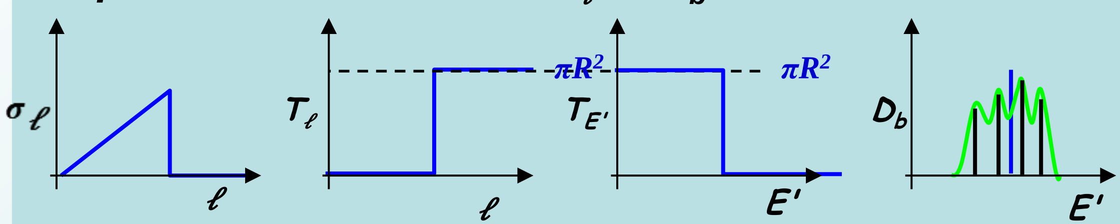


spin $\ell \rightarrow E'$

$$\text{with} \quad E' = E - \frac{\ell(\ell+1)}{2\mu R_b^2}$$



Step wise transformation σ_ℓ to D_b



- *transmission function $T(E')$ $(T(\ell))$*

- *barrier distribution*
  - *covers large energy range E' for one E_{beam}*
  - *sensitive only for fusion-evaporation*
  - *fission cut-off leads to truncation at low E' ↔ high ℓ*

priliminary – analysis ongoing

GSI

Entrance channel effect on ER spin distribution

- G. Mohanto et al., Nucl. Phys. A 890–891 (2012) p. 62–76

Abstract

*… **ER gated gamma-multiplicity** was measured for the reaction **^{30}Si+^{170}Er***

…

*… measured multiplicity distribution was **compared … ^{16}O+^{184}W** and **^{19}F+^{181}Ta** forming the same CN … with **statistical model calculations** … indicate an absence of higher spins in ERs for ^{30}Si+^{170}Er … lowering of spin value is **attributed to non-compound fission**.*

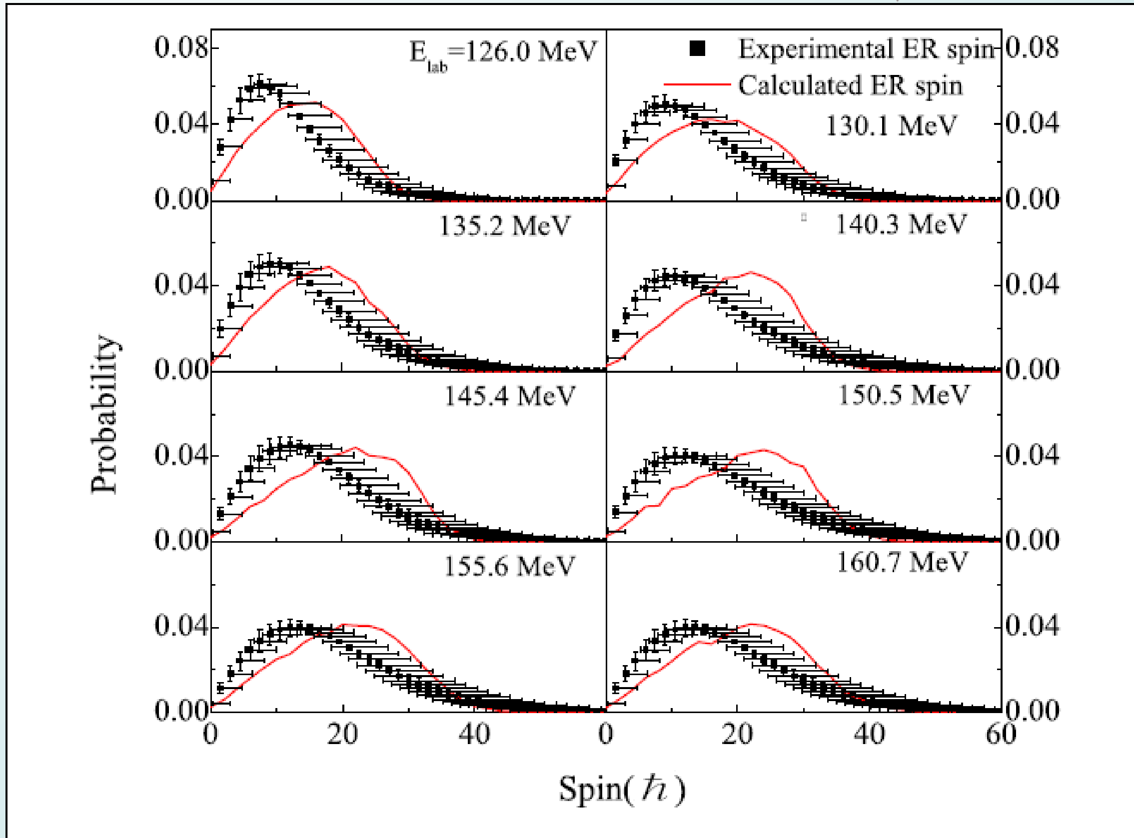


Fig. 11. Calculated and experimentally obtained ER spin distribution for the reaction ^{30}Si+^{170}Er. The experimental ER spin is the spin remaining after particle evaporation. It is obtained by multiplying the gamma-multiplicity by 1.5ℏ.

HYRA + T.I.F.R. 4π spin spectrometer at the IUAC, New Delhi