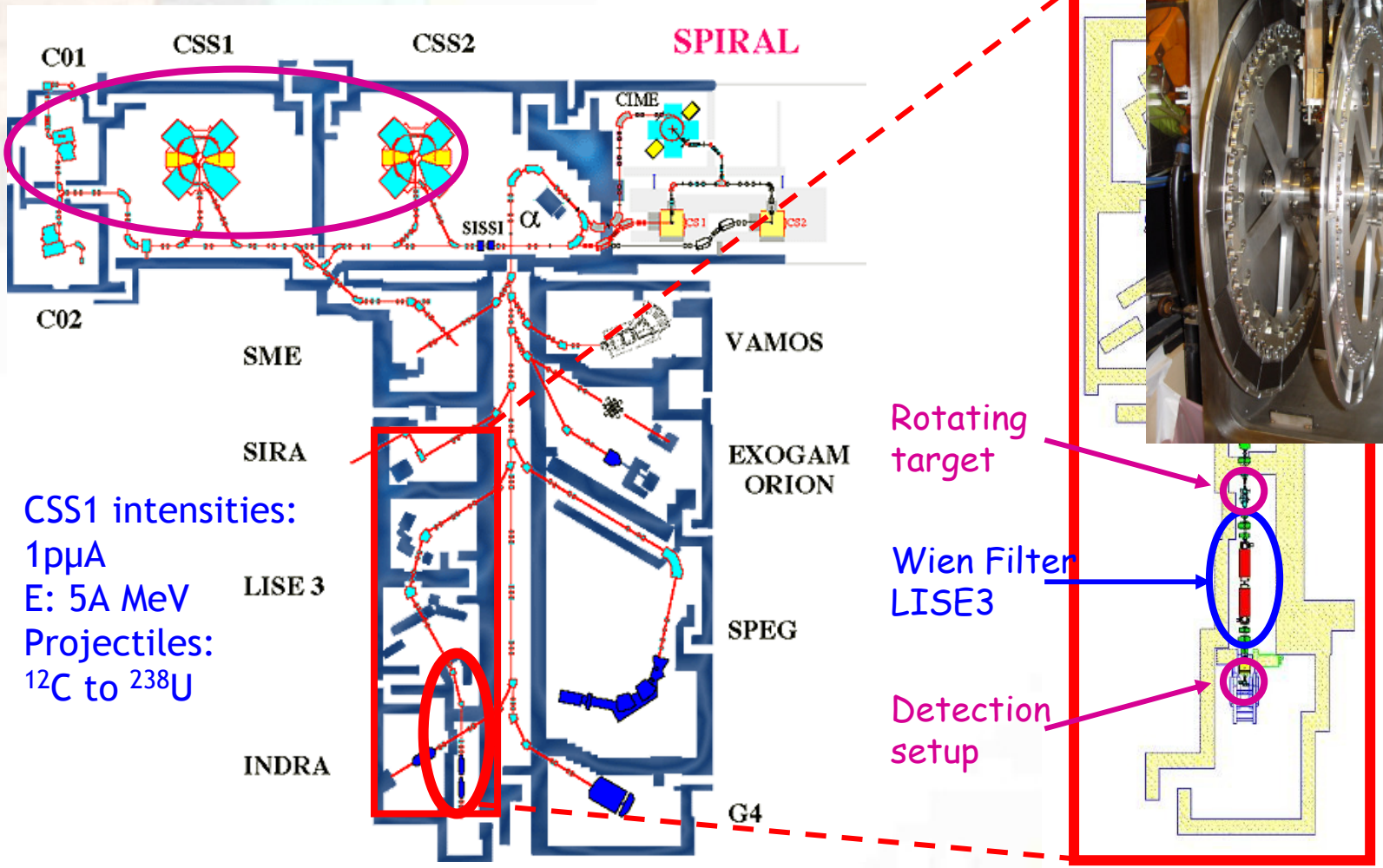
SHE related developments at GANIL: latest experiments, S3 and targets

Ch. Stodel for FULIS and S3 collaboration

GANIL, Caen, France

Latest experiments on SHE

Existing GANIL



CSS1 intensities:
1pμA
E: 5A MeV
Projectiles:
^{12}C to ^{238}U

DAPNIA/SPhN, CEN Saclay; Univ. Jyvaskyla, Finland; JINR, Dubna, Russia; Univ. Liverpool, U.K.; G.S.I., Darmstadt; C.S.N.S.M., Orsay; I.R.E.S., Strasbourg; I.F.U., Krakow; GANIL, Caen; LPC, Caen

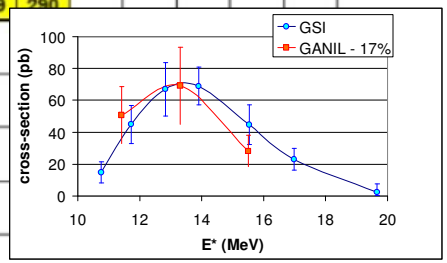
Fusion-evaporation reactions

(1999) $^{86}Kr_{(2p\mu A)} + {}^{208}Pb \rightarrow {}^{293}118 + 1n$

(2003) $^{76}Ge_{(> 1\ p\mu A)} + {}^{208}Pb \rightarrow {}^{283}114 + 1n$

$\sigma_{(276.5 \pm 2\ MeVc.m.)} < 1.2pb$

$RF > 10^{11} \Leftrightarrow bg \approx 70\ pps$



(2003) $^{58}Fe\ (0.5p\mu A) + {}^{208}Pb \rightarrow {}^{265}Hs + 1n$

$\sigma = 60\ pb;\ RF \approx 2*10^{10}$

(2000) $^{54}Cr\ (0.04p\mu A) + {}^{208}Pb \rightarrow {}^{261,260}Sg + 1,2n$

(2002) $^{208}Pb + {}^{51}V \rightarrow {}^{257,258}Db + 1,2n$

$RF \approx 10^6$ / + ^{12}C, $^{18}O \rightarrow {}^{220}Th^*, {}^{226}U^*$

(2003) $^{48}Ca + {}^{209}Bi \rightarrow {}^{255}Lr + 2n$

(2008) $^{136}Xe\ (2p\mu A == 7*10^{11}\ pps) + {}^{124}Sn \rightarrow {}^{258}Rf + 2n$

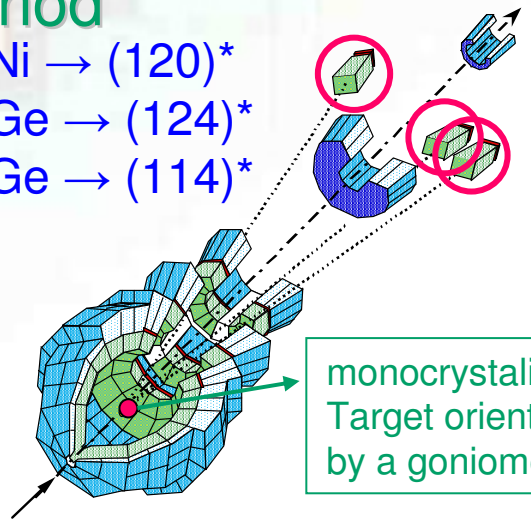
$\sigma_{lim} \approx 170\ pb;\ 0\ evt$

$RF \approx 7*10^7 \Leftrightarrow bg \approx 10^3\ pps$

Ch. Stodel et al, CP891, Tours Symposium on Nuclear Physics VI, 2006, p.55-59
A. Wieloch et al, NIMA517 (2004) 364-371

Fission time by blocking method

$^{238}U + Ni \rightarrow (120)^*$
$^{238}U + Ge \rightarrow (124)^*$
$^{238}U + Ge \rightarrow (114)^*$



monocrystaline Target oriented by a goniometer

^{238}U @ 6.6 MeV/A

DAPNIA/SPhN, GANIL Caen, IPN Lyon, IPN Orsay, GPS Jussieu

M. Morjean et al, Physical Review Letters 101 (2008) 072701; European Physical Journal D 45 (2007) 27-31

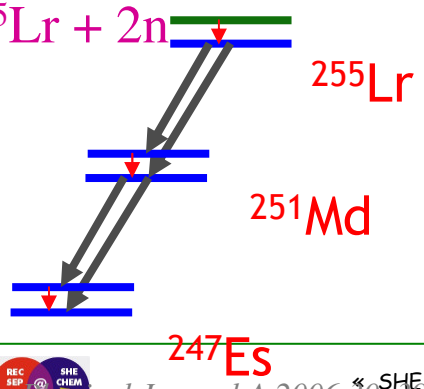
Prompt spectroscopy

- State with one particle
- Same orbitals
- Next experiment ^{255}No

DAPNIA/SPhN – Jyväskylä – Dubna – Krakow – GANIL - Univ. Liverpool – CSNSM – IReS - GSI

Decay spectroscopy

$^{48}Ca + ^{209}Bi \rightarrow ^{255}Lr + 2n$
$\rightarrow ^{251}Md + \alpha$



A. Chatillon et al, European Physical Journal A 2006 30 397-411

Study of superheavy nuclear systems Expérience E511 : $^{238}U+^{238}U$

Ganil – GSI - Dapnia/SphN – CENBG - KVI

Search for a long-lived component in the reaction U+U near the Coulomb barrier, A.C.C Villari et al, *Tours Symposium on Nuclear Physics VI – AIP Conference Proceedings 891 (2007) p.60-67*

SHE Production with symmetric fusion reactions
E533 : ^{136}Xe + ^{124}Sn @ GANIL

M. Assié, **B. Avez**, E. Bonnet, Y. Bulent, E. Clément, R. Dayras, C. Dossat, G. De France, O. Dorvaux, A. Drouart, J. Frankland, C. Golabeck, S. Grévy, K. Hauschild, R. Hue, D. Jacquet, W. Zozik, S. Le Moal, A. Lopez-Martens, K. Lozek, N. Malyshev, V. Morel, M. Morjean, F. de Oliveira, L. Perrot, A. Popeko, T. Roger, C. Simenel, Z. Sosin, M.G. Saint-Laurent, P. Srivastava, C. Stodel, C. Theisen, C. Vandamme, A.C.C. Villari, J.P. Wieleczko, A. Wieloch, A. Yeremin

IRFU, C.E.N. Saclay - GANIL, Caen - Inst. of Phys. Jagiellonian Univ., Krakow - Ins. Fyziki Uniw., Krakow - LPC Caen - CSNSM, Orsay - IPN Orsay - JINR Dubna - Inst. of Phys. Jagiellonian Univ., Krakow.

Synthesis of very heavy elements: Fusion with (nearly-)symmetric channel

Experimental interest

- Mass symmetry
  - ☹ Synthesis of new super-heavy elements (Z)
- Mass symmetry + shell effects
  - ☺ Synthesis of new heavy (…super) heavy isotopes
  - ☺ Study of fusion mechanisms

Advantages and drawbacks….

- ☺ Good transmission (forward focused kinematics)
- ☹ Very difficult velocity separation

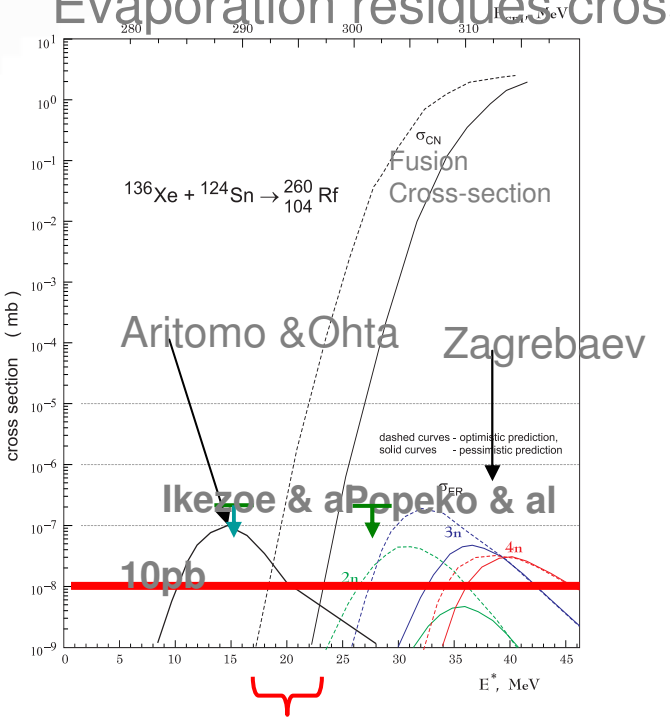
Future : SPIRAL2@GANIL

⇒Highly intense beams of neutron rich nuclei (Xe, Kr)
Systematic study of the neutron influence on fusion
⇒ RIB SPIRAL2 + LISE 3 == Fusion with symmetric channel possible ?

Studied system : $^{136}Xe + ^{124}Sn \rightarrow ^{260}Rf^*$

- Projectile : $^{136}Xe^{18+}$ @ 4.6 MeV/u, ≈ $10^{11\text{-}12}$ pps
- 2 closed shells : N=82 (^{136}Xe) and Z=50 (^{124}Sn)
- $^{260}Rf^*$(Z=104) : towards SHE…..
- Excitation energy of the compound nucleus: ≈ 20 MeV

Evaporation residues cross sections



Limit cross-sections

- ^{257}Rf : $\sigma_{3n} < 172.4$ pb
- ^{258}Rf : $\sigma_{2n} < 80.8$ pb
- ^{259}Rf : $\sigma_{1n} < 235.1$ pb

Conclusion

- Results:
  - ☺ Upper limits of σ_{xn} (E*=20 MeV)
  - ☹ Models ,discrimination
- Experimental set-up Lise3@GANIL
  - ✓ Difficult velocity separation (≈ 1300 pps in Si-implantation)
  - ✓ Need of the ionization chamber

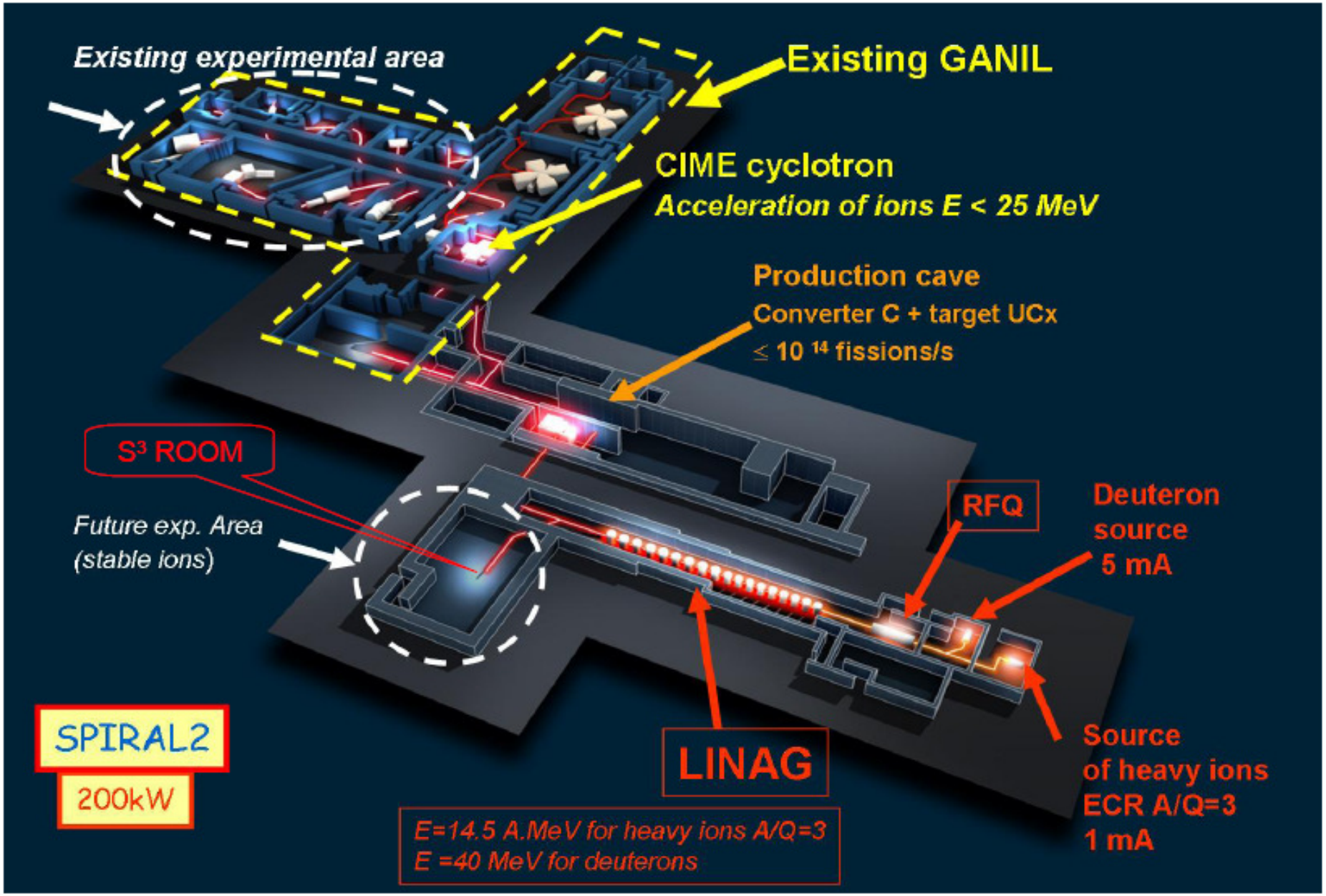
☹ SHE synthesis

☺ Reaction mechanism (synthesis of heavy nuclei)

Perspectives

- LISE3@RIB of SPIRAL2
  - Background?
  - Technical studies/upgrade (Wien filter, detection..), tests
  - Rn and Ra isotopes with Ba*, Xe*, Sn* beams

SPIRAL2 project and S3


Existing experimental area
Existing GANIL
CIME cyclotron
Acceleration of ions E < 25 MeV
Production cave
Converter C + target UCx
≤ 10 ¹⁴ fissions/s
S³ ROOM
Future exp. Area
(stable ions)
RFQ
Deuteron
source
5 mA
SPIRAL2
200kW
LINAG
Source
of heavy ions
ECR A/Q=3
1 mA
E=14.5 A.MeV for heavy ions A/Q=3
E =40 MeV for deuterons

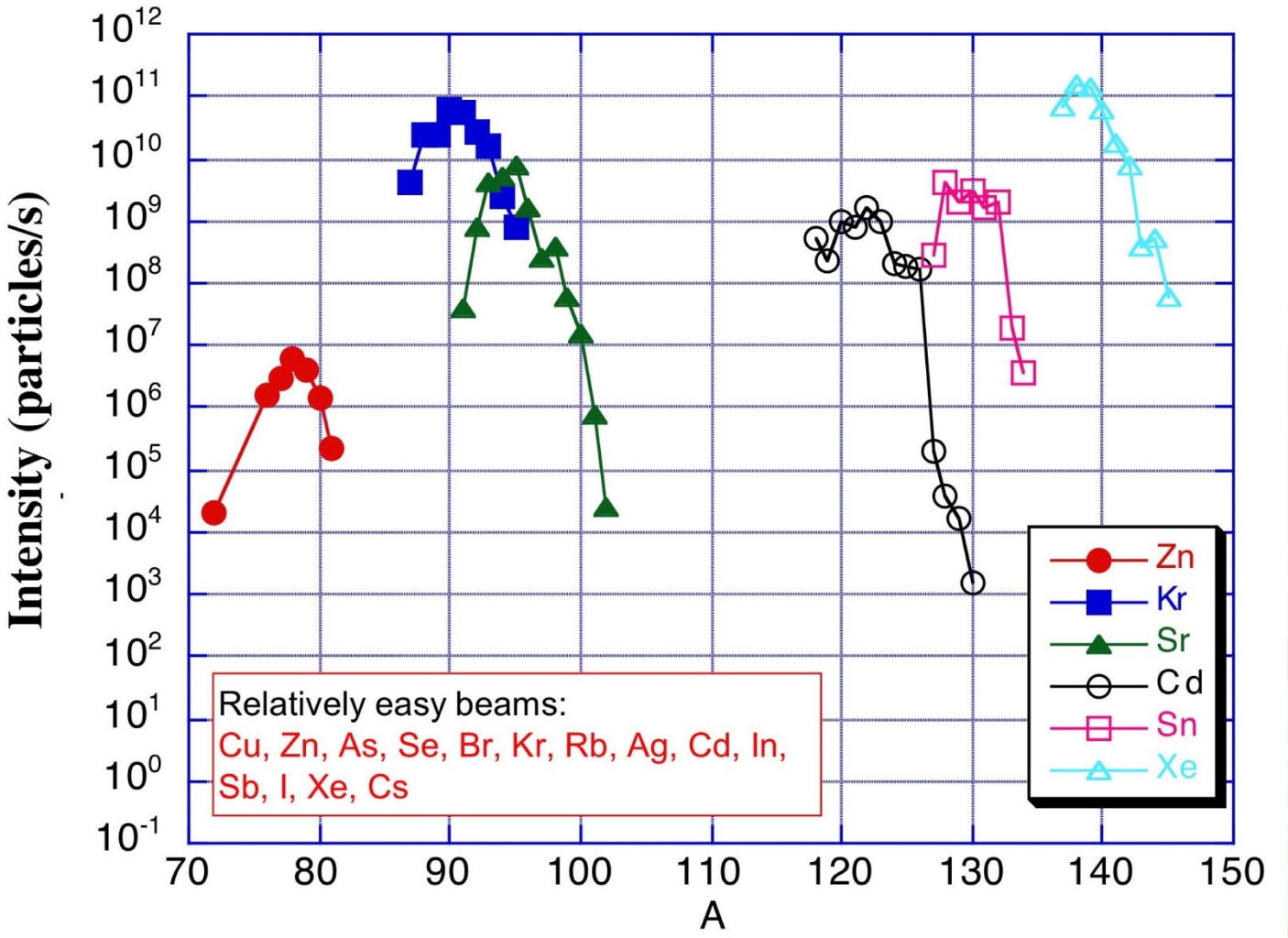
SPIRAL 2 High Intensity radioactive beams

Target
1.5 10^{18} at/cm^2

Cross sections
1 nb

Detection efficiency
50%

Beam
10^{10}pps
↓
Events
0.6/day



Radioactive Beams of SPIRAL2

Dubna
^{48}Ca + Targ

^{90,91}Kr/$^{137-140}$Xe ≈ 10^{10} pps
$^{92-98}$Sr / $^{118-123}$Cd ≈ 10^{8} pps
$^{128-132}$Sn / $^{127-133}$Sb / $^{134-137}$I ≈ 10^{9} pps

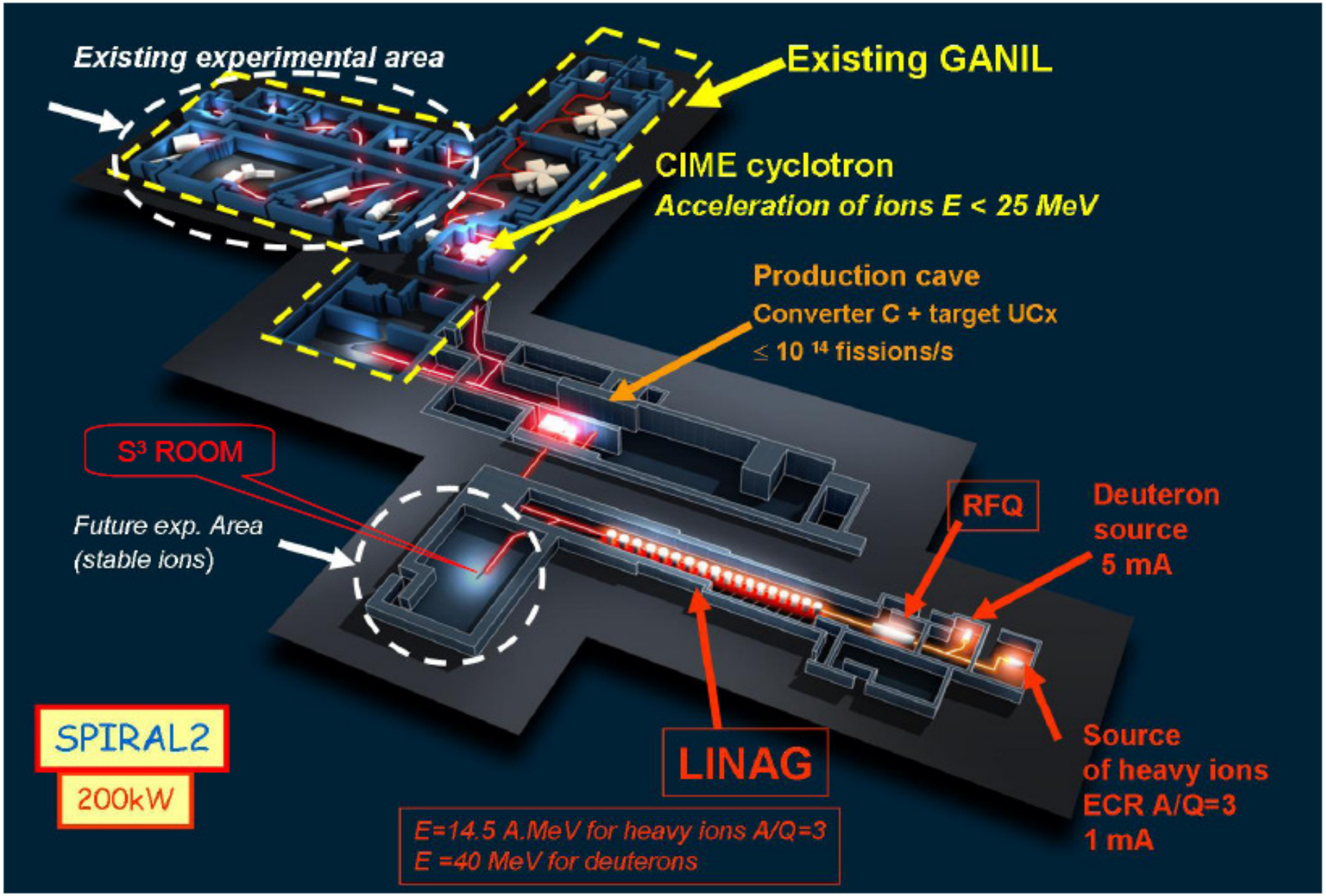
GSI
Proj + ^{208}Pb

Kr/Xe + Hf/Xe
Kr/Xe + Lu/I
Proj + Yb/Er/Ba/Cs/I/Te
Proj + Tm/Ho/Cs/Xe/Te/Sb
Proj + Er/Dy/Ba/Xe/I/Sb/Sn
Proj + Ho/Tb/Cs/I/Te/Sn
Proj + Dy/Gd/Xe/Te/Sb/In/Cd

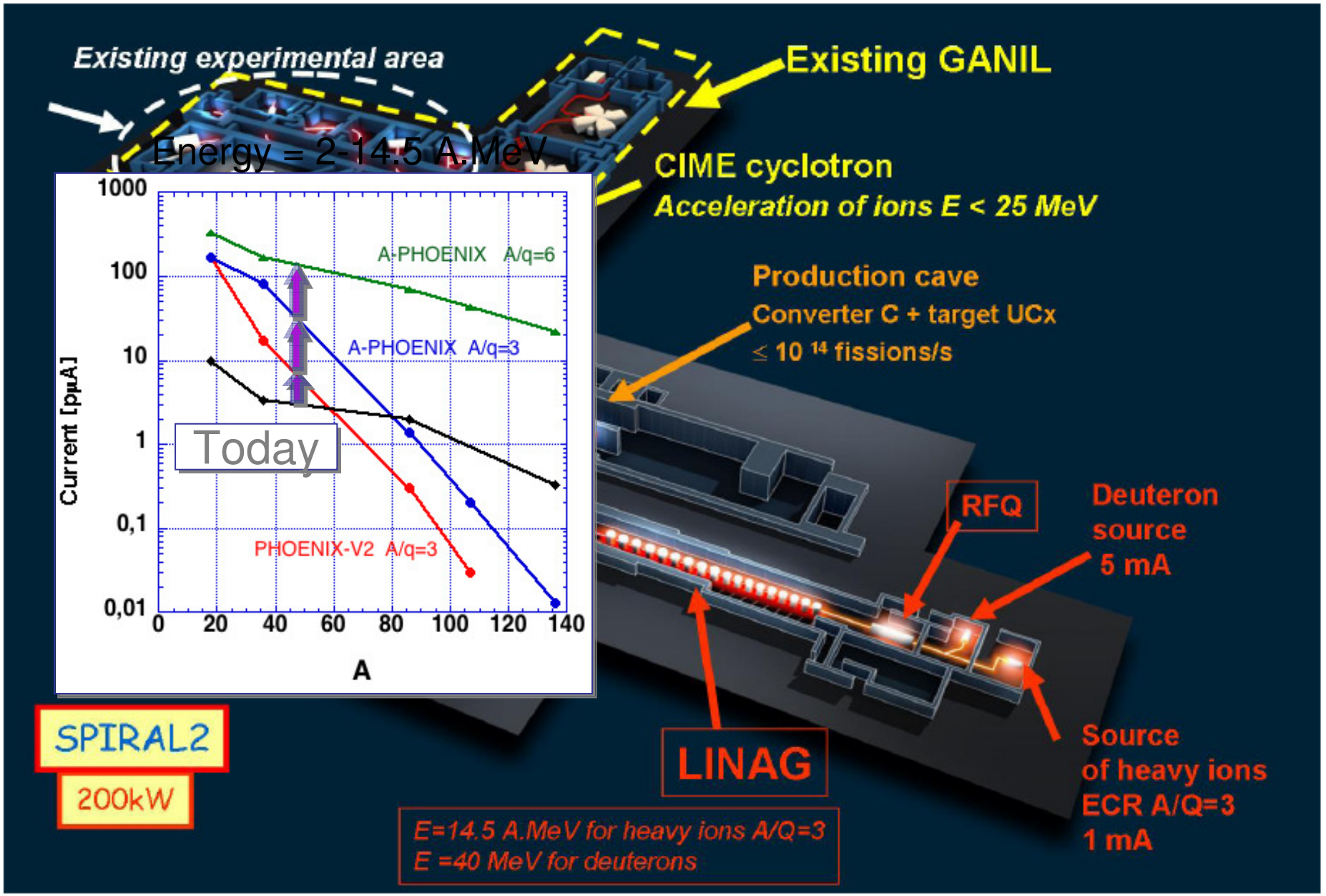
$N_{residue\ (1n)}$

Excitation function ? Spectrometer with RIB?

SPIRAL2 Project LINAG



SPIRAL2 Project LINAG

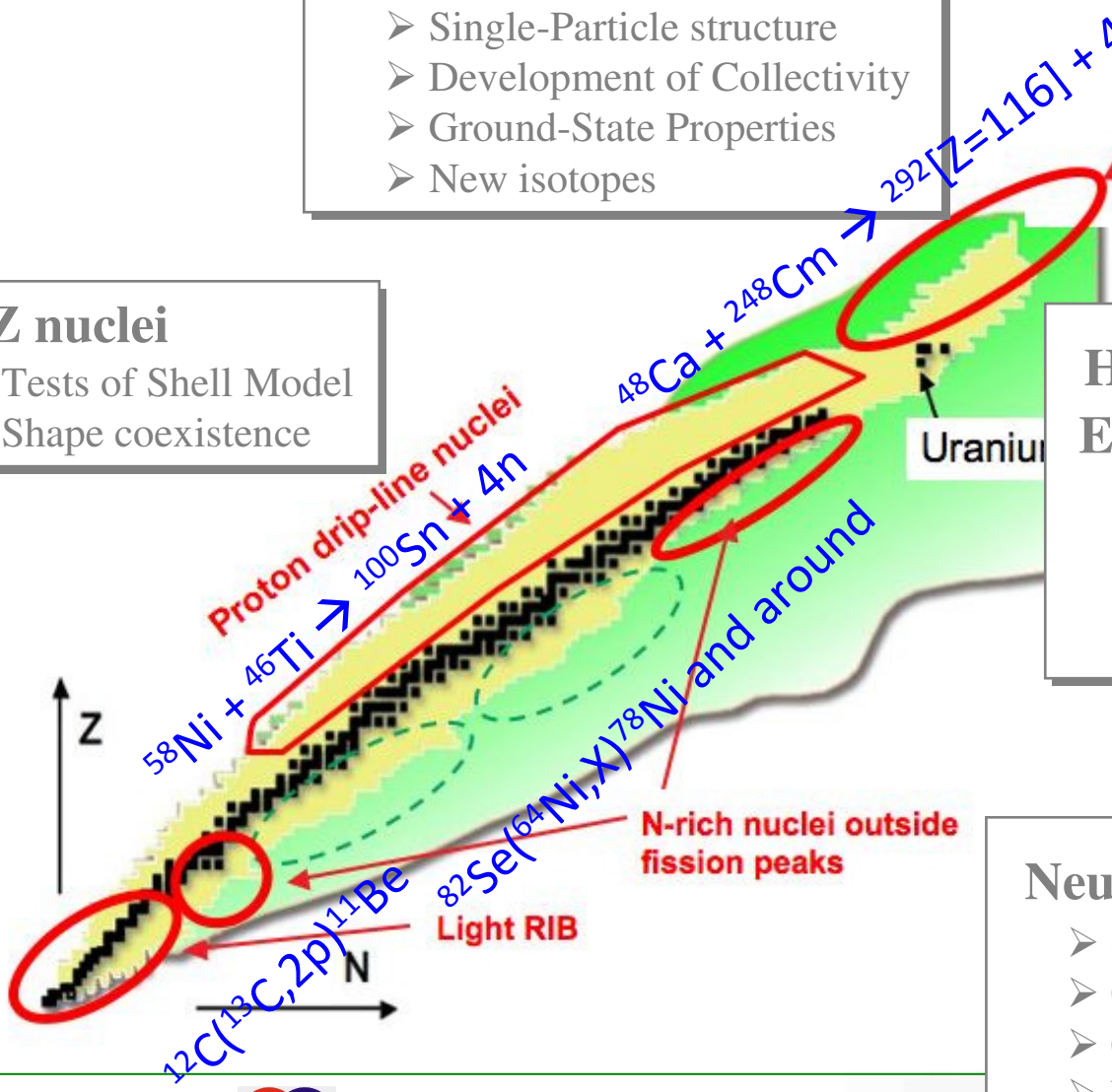


Physics objectives

Proton Dripline
- Single-Particle structure
- Development of Collectivity
- Ground-State Properties
- New isotopes

10^{14}part/s ➔ 10evt/day @ 1pb

N=Z nuclei
- Tests of Shell Model
- Shape coexistence

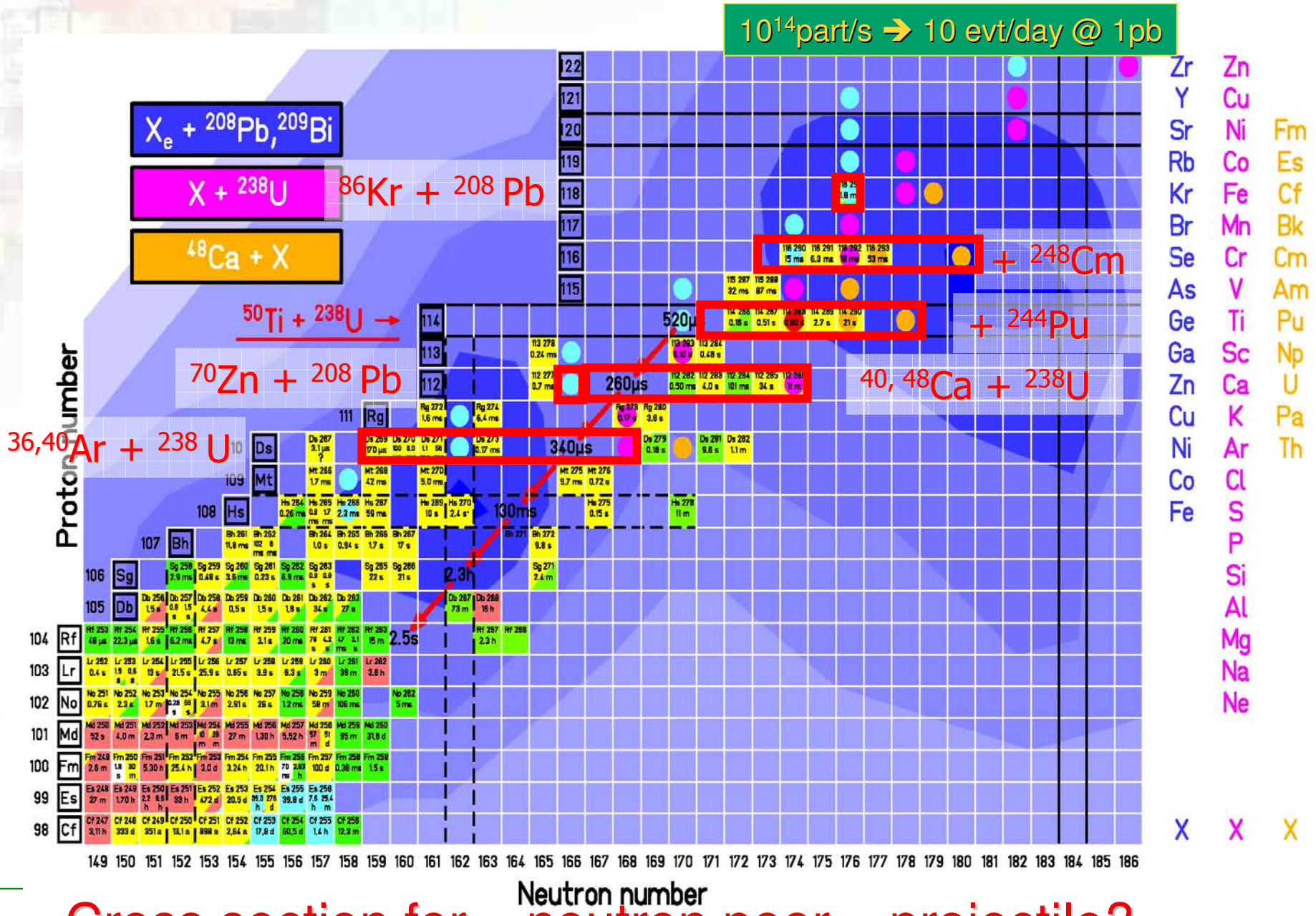


Heavy and Superheavy Elements
- Synthesis
- Spectroscopy and Structure
- Ground-State Properties
- Chemistry

Neutron-Rich Nuclei
- Single-Particle structure
- Quenching of Shell Gaps
- Ground-State Properties
- New isotopes

➲ S3 physics white book, June 2008

Very/Super heavy Elements Studies



Cross section for « neutron poor » projectile?

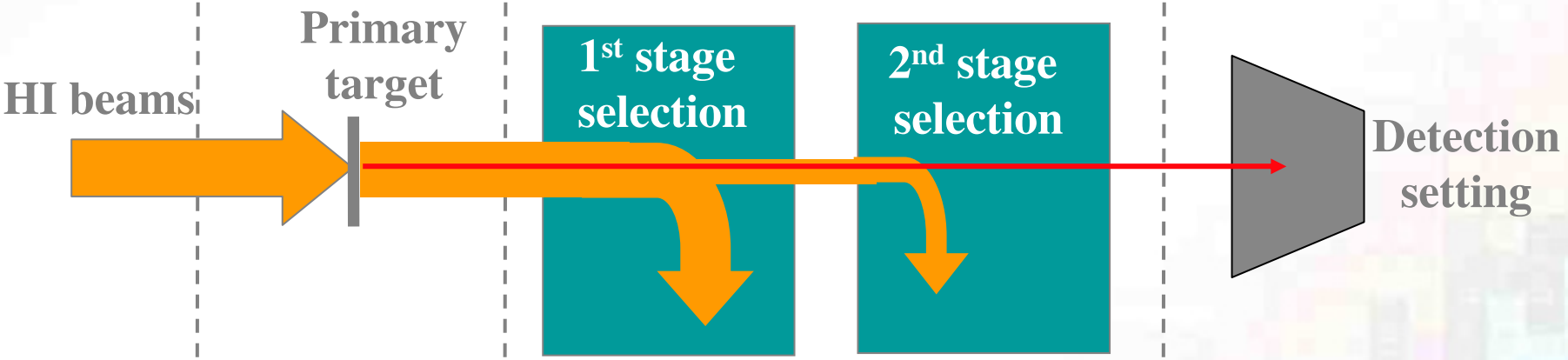
Baseline project & Options

HI source & injector A/q=3

High power target Stable/Actinide

Angular acceptance ±50 mrad
Charge state acceptance : ± 10%
Momentum acceptance ± 10%
Rejection of beam > 10^{13}
Mass resolution Δ M/M = 1/350
Bρmax = 1.5 T.m
Eρmax = 10MV

Detection chamber Low energy branch



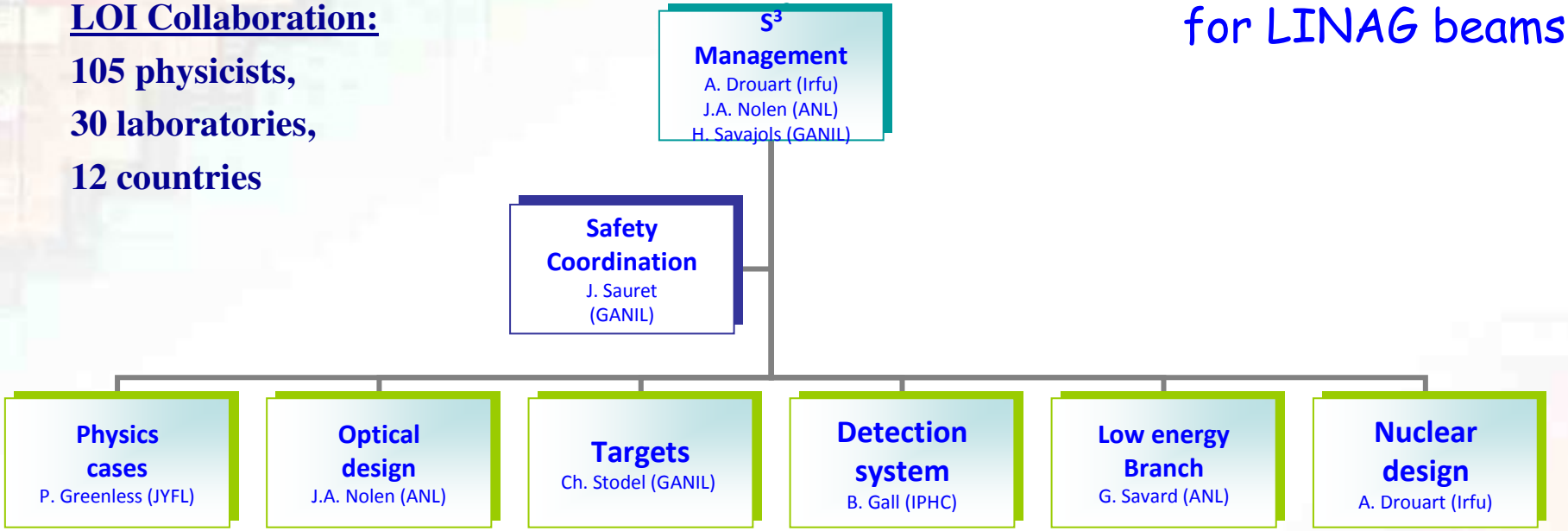
S3: The Super Separator Spectrometer for LINAG beams

LOI Collaboration:

105 physicists,

30 laboratories,

12 countries



Dieter Ackermann (GSI)
Kim Lister, Dareck Seweryniak, Guy Savard, Jerry Nolen (ANL)
Christophe Theisen, Andreas Görgen, Wolfram Korten, Antoine Drouart, Barbara Sulignano (IRFU Saclay)
Araceli Lopez-Martens, Karl Hauschild, A Korichi (CSNSM Orsay)
Christelle Stodel, Hervé Savajols, Gilles de France (GANIL)
Benoit Gall, Gilbert Duchene (IPHC Strasbourg)#

B. Bru (GANIL)
O. Delferrière (Irfu)
A. Drouart (Irfu)
B. Erdelyi (ANL)
J.-F. Libin (GANIL)
F. Lutton (GANIL)
S. Manikonda (ANL)
C. Mary (GANIL)
J. Payet (Irfu)
L. Perrot (IPNO)
H. Savajols (GANIL)
G. Soulioti (TANU)
K. Subotic (VINCA)
D. Uriot (Irfu)
J. Uusitalo (Jyväskylä)
E. Pichot (GANIL)

B. Gall (IPHC)
F. Pellemoine (GANIL)
E. Pichot (GANIL)
A. Popeko (Dubna)
M.-G. Saint-Laurent (GANIL)
A. Yeremin (Dubna)
R. Hue (GANIL)
B. Lommel (GSI)
K. Eberhardt (Mainz)
F.Lutton (GANIL)

D. Ackermann (GSI)
F. Azaiez (IPNO)
G. Defrance (GANIL)
P. Greenless (JYFL)
K. Hausshild (CSNSM)
A. Khouaja (IPHC)
A. Lopez-Martens (CSNSM)
J.F. Libin (GANIL)
F. Lutton (GANIL)
D. Seweryniak (ANL)
H. Savajols (GANIL)
B. Sulignano (Irfu)
C. Theisen (Irfu)

B. Blank (CENBG)
F. Dayras (CSNSM)
S. Franchoo (IPNO)
F. Leblanc (IPNO)
G. Neyens (KU Leuven)
H. Savajols (GANIL)
P. Van Duppen (KU Leuven)
F. Lutton (GANIL)
C. Marry (GANIL)
J.C. Thomas (GANI L)

L. Bouvet (Irfu)
J.-M. Dumas (Irfu)
E. Pichot (GANIL)
P. Roussel-Chomaz (GANIL)
J. Sauret (GANIL)
B. Sulignano (Irfu)
Ch. Stodel (GANIL)
E. Van Lauwe (Irfu)

David Jenkins, Bob Wadsworth, Nara Singh Bondili (York), Giacomo de Angelis, Andres Gadea (Legnaro), Gerda Neyens (KU Leuven), Christelle Schmidt (IPNO Lyon) , Rolf-Dietmar Herzberg (Liverpool), Heloise Goutte (Bruyeres le Chatel), Alexander Yeremin (JINR Dubna), Kruno Subotic (VINCA), Martin Veselsky (SAS Bratislava), Paul Greenlees, Juha Uusitalo (JYFL), O. Tarasov (MSU), F. Azaiez, S. Franchoo, F. Leblanc (IPNO)

http://pro.ganil-spiral2.eu/spiral2/instrumentation/s3

High power target stations

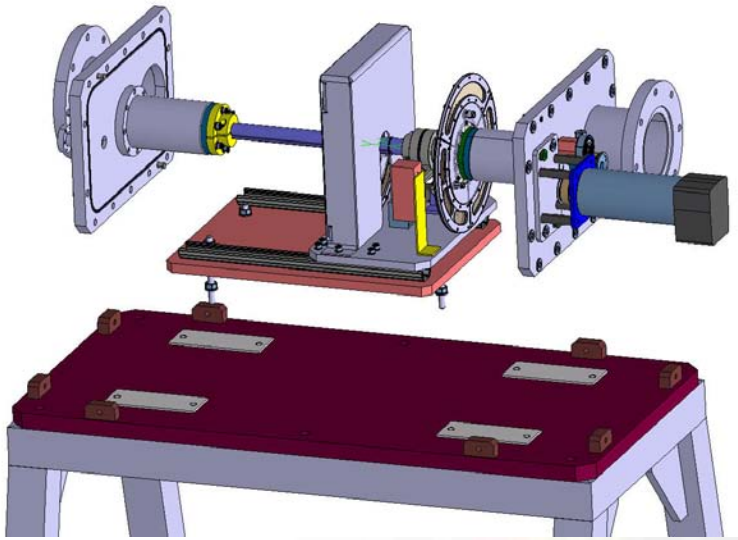
Φ (c m) ,w(rpm),I,
Beam spot size (10*2mm²?)

Stable

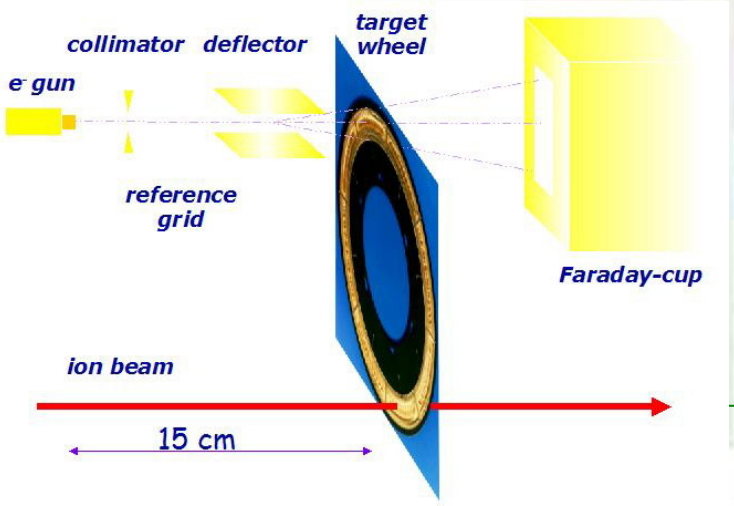
^{208}Pb, ^{209}Bi, Ni, Ca, C
(R ≈ 25 cm)

Actinides

^{232}Th, ^{238}U, ^{239}Pu, ^{242}Pu, ^{244}Pu, ^{248}Cm
≈ 45 mg ≈ 10^2 – 10^9 Bq (R=8 cm)

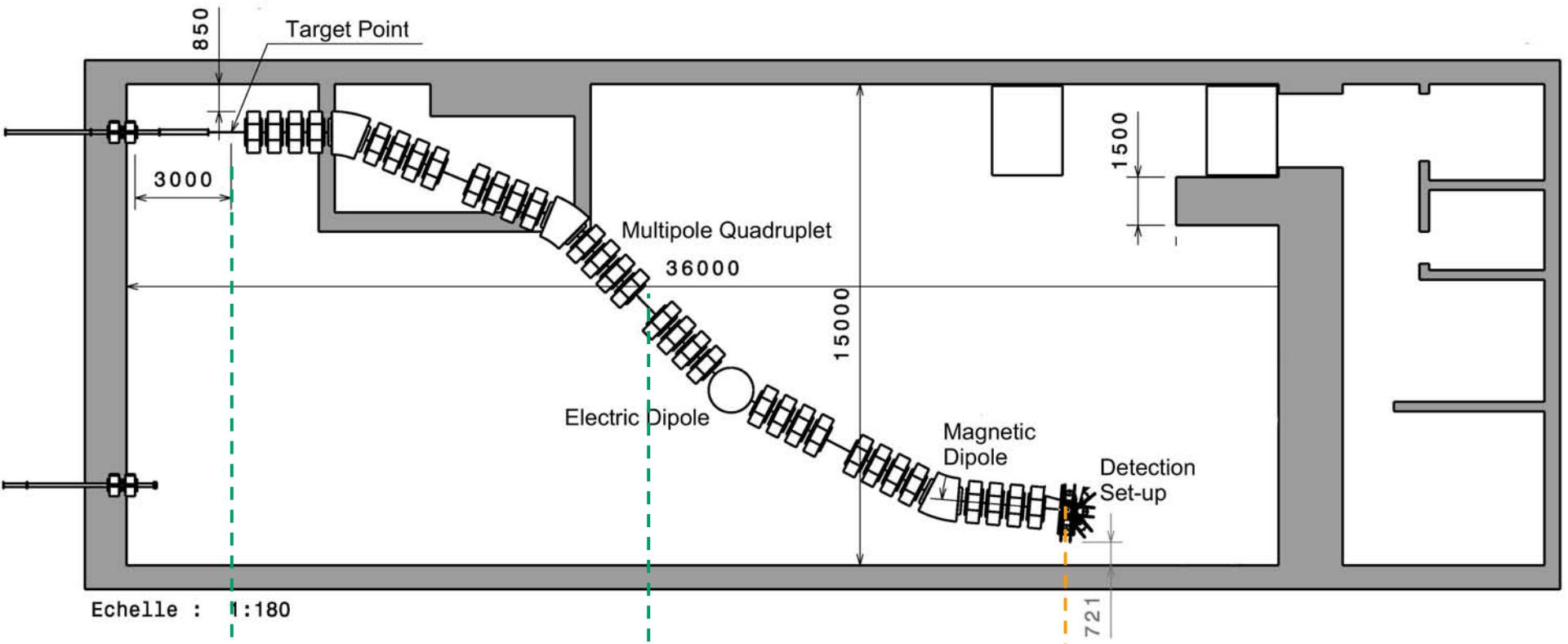


Target thickness and homogeneity
- RBS method
- Electron gun
- Pyrometer
- Infrared cameras
- Scintillators …



e- Beam Diagnosis
R. Mann (patent # DE 102 42 962 A1)

MAMS: Momentum Achromat & Mass Spectrometer

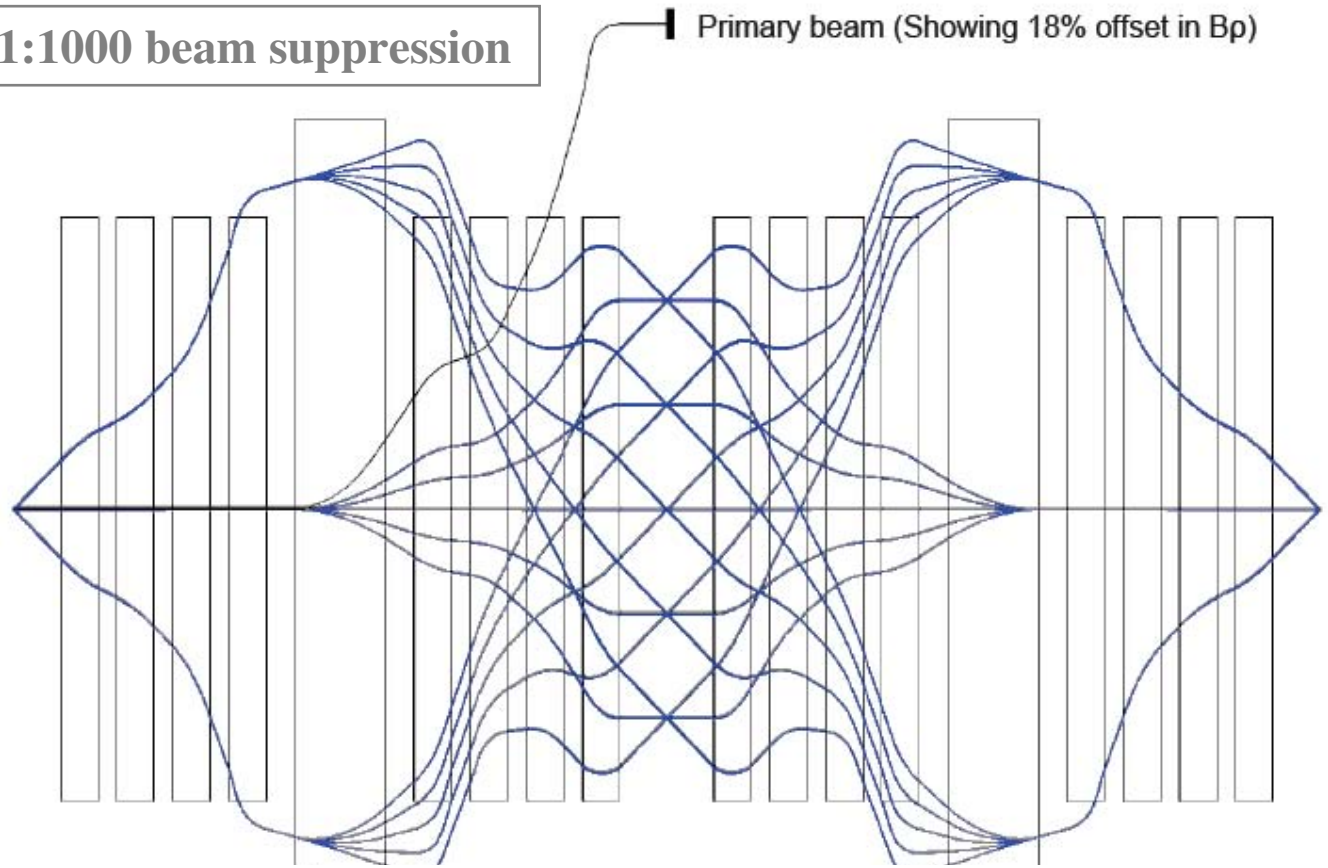


Momentum Achromat Mass Spectrometer

J.A. Nolen, S. Manikonda, B. Erdelyi (ANL)

2 technical solution studied : Superconducting multiplet or Warm magnets

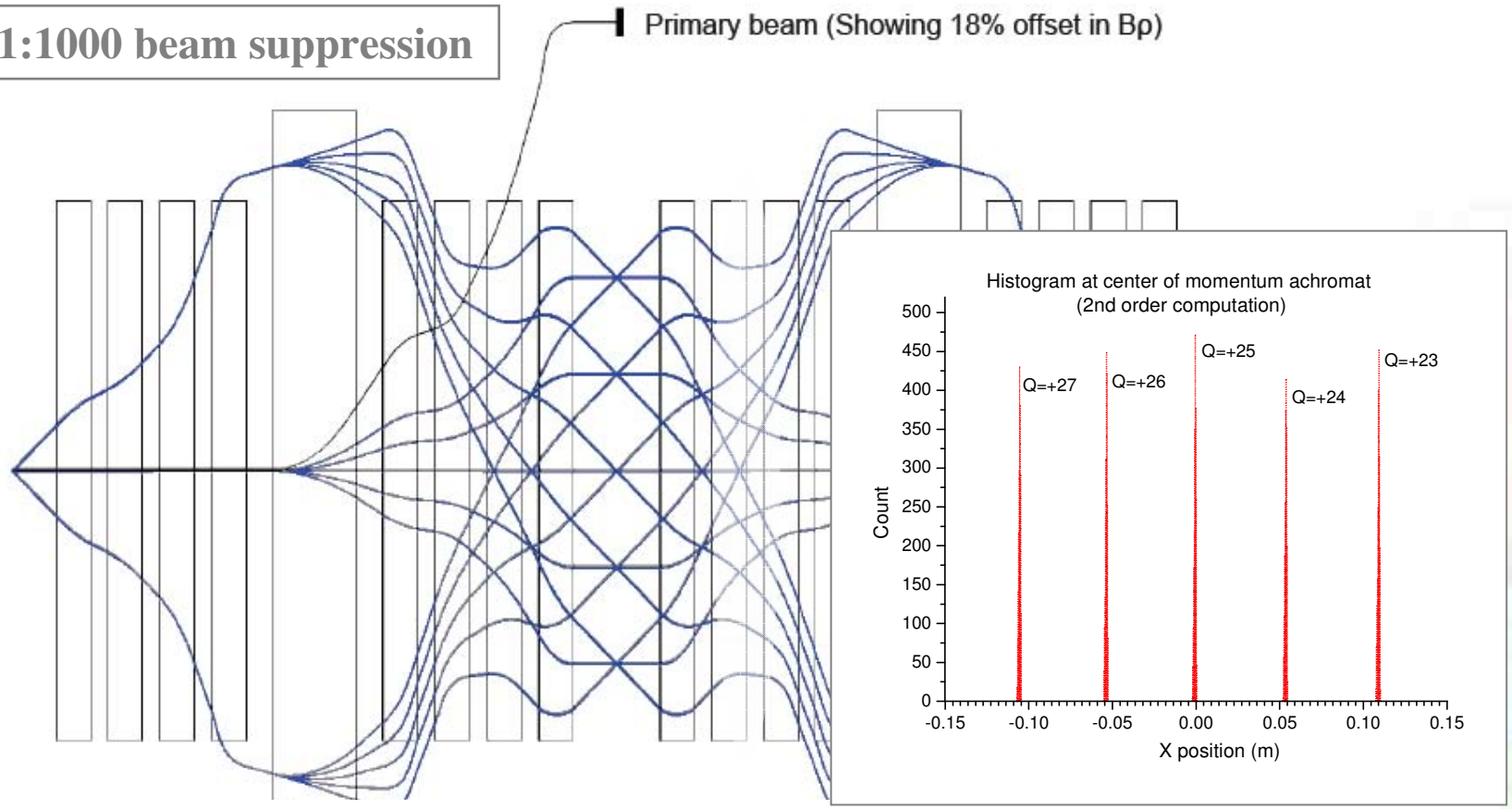
Momentum achromat : First order



- Double mirror symmetric layout with 12 mm/% momentum dispersion at the center
- Beam dump is a water cooled bar following the first dipole
- The final image is fully achromatic in momentum, charge state, and unit magnifictaions in both planes

Momentum achromat : First order

1:1000 beam suppression



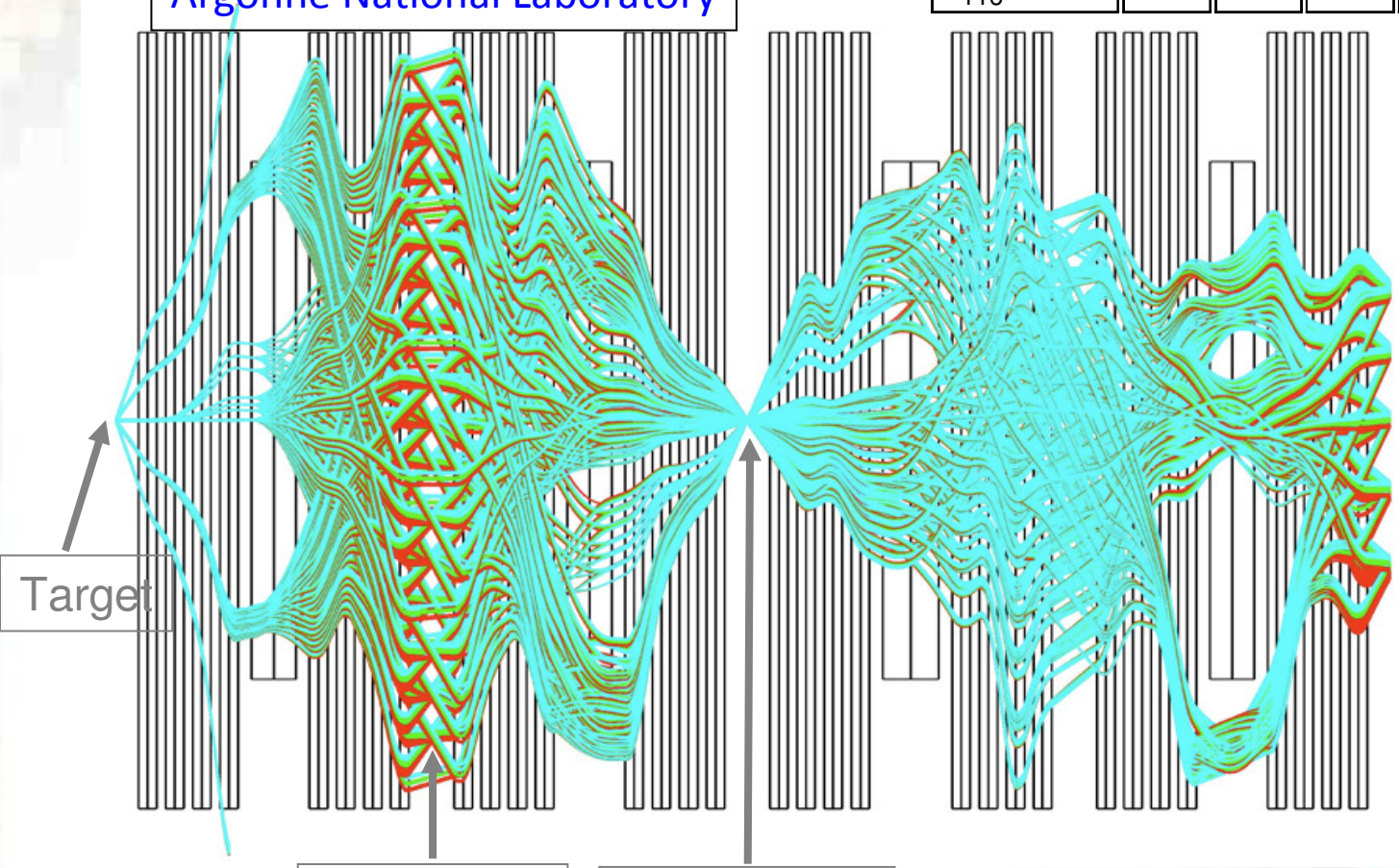
- Double mirror symmetric layout with 12 mm/% momentum dispersion at the center
- Beam dump is a water cooled bar following the first dipole
- The final image is fully achromatic in momentum, charge state, and unit magnifictaions in both planes

Transmission of the full system

$^{48}Ca + ^{248}Cm \rightarrow ^{292}116 + 4n$

	E [MeV/n]	 [Tm]	<Er> [MV]	<Q>	<V> [cm/ns]	Ęq (±2σ) [mrad]	dQ	dp/p[%] (±2σ)
Beam parameters ^{48}Ca	4.92	0.88	27	+17	3.0	± 8		±0.2
Recoil parameters $^{292}116$	0.131	0.58	3	+25	0.5	± 50 (Y) ± 50 (X)	± 2	±2.3

Shashikant Manikonda
Argonne National Laboratory



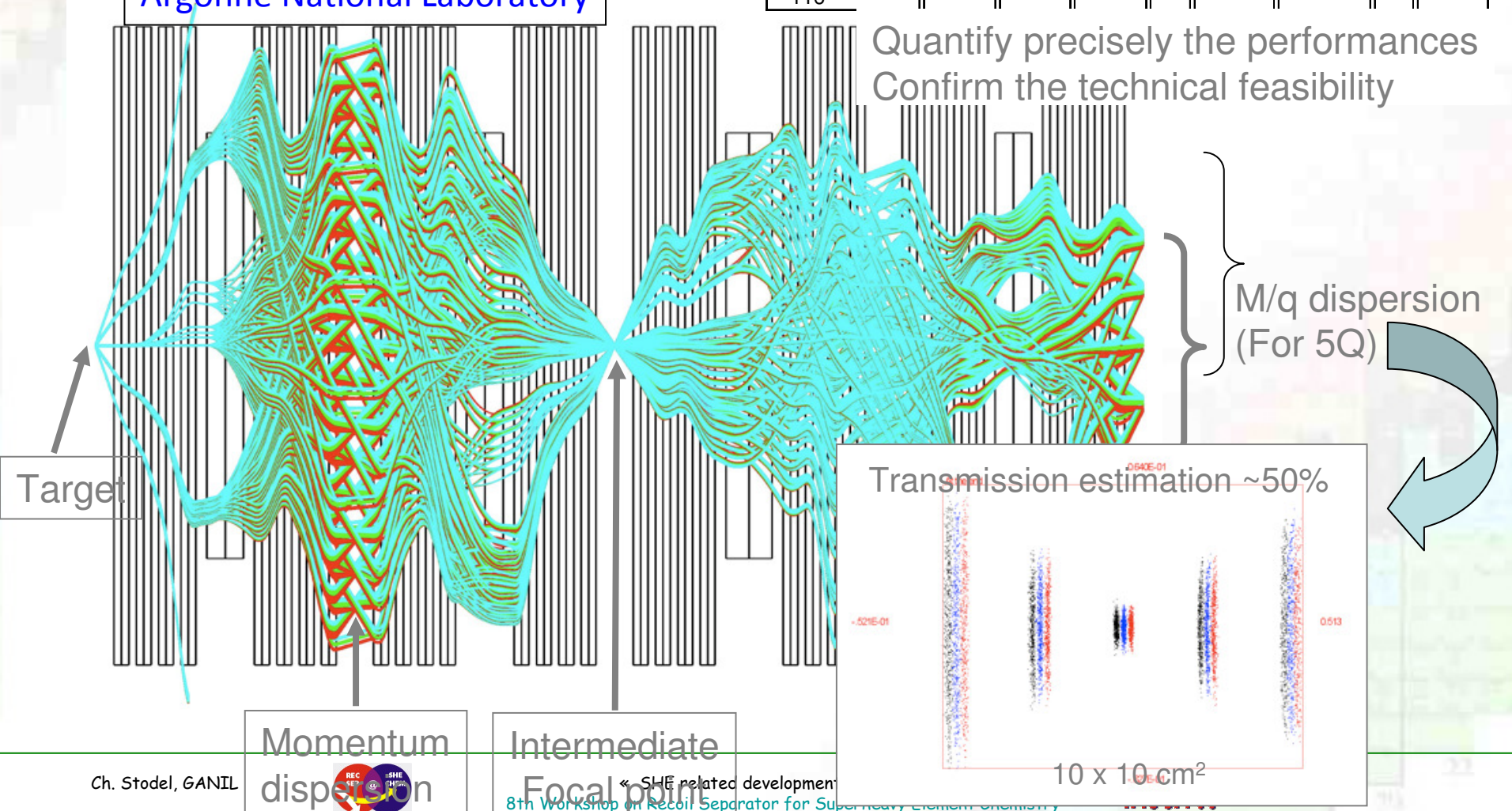
Transmission of the full system

$^{48}Ca + ^{248}Cm \rightarrow ^{292}116 + 4n$

	E [MeV/n]	 [Tm]	<Er> [MV]	<Q>	<V> [cm/ns]	Eq (±2σ) [mrad]	dQ	dp/p[%] (±2σ)
Beam parameters ^{48}Ca	4.92	0.88	27	+17	3.0	± 8		±0.2
Recoil parameters $^{292}116$	0.131	0.58	3	+25	0.5	± 50 (Y) ± 50 (X)	± 2	±2.3

Shashikant Manikonda
Argonne National Laboratory

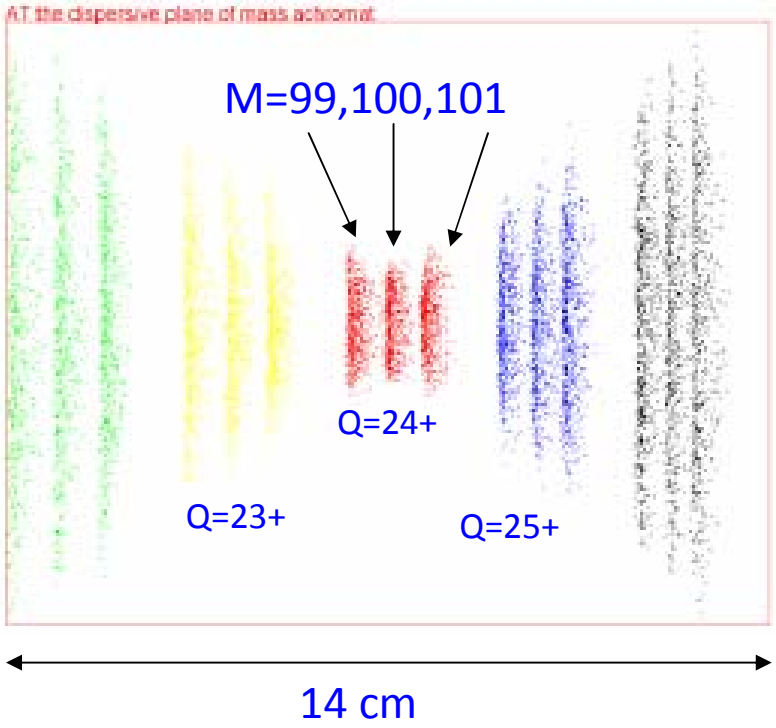
Quantify precisely the performances
Confirm the technical feasibility

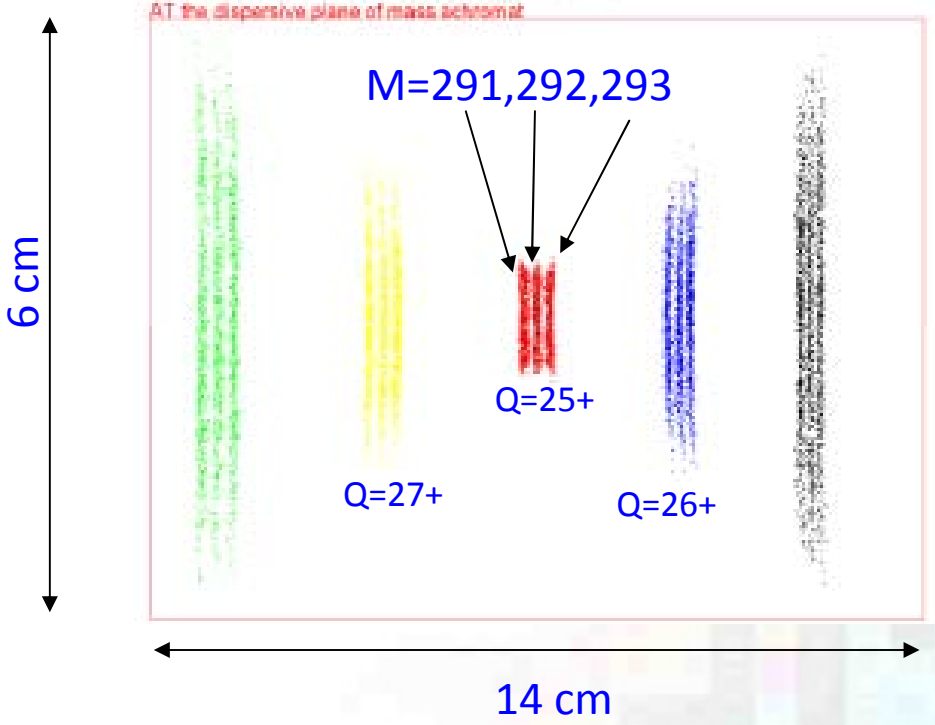


Mass Resolution at final dispersive plane

$^{58}Ni + {}^{46}Ti \rightarrow {}^{100}Sn + 4n$

$^{48}Ca + {}^{248}Cm \rightarrow {}^{292}[Z=116] + 4n$





Suppression of contaminants

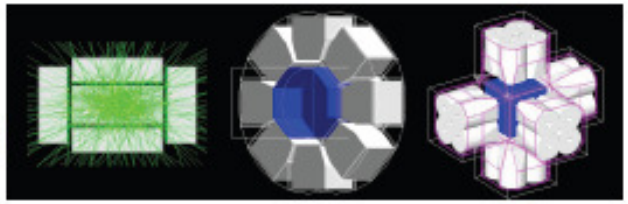
Mass Measurement of SHE

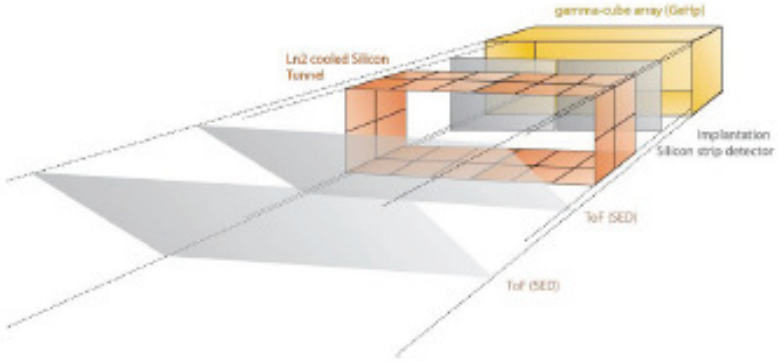
Second order calculations by Shashikant Manikonda, ANL

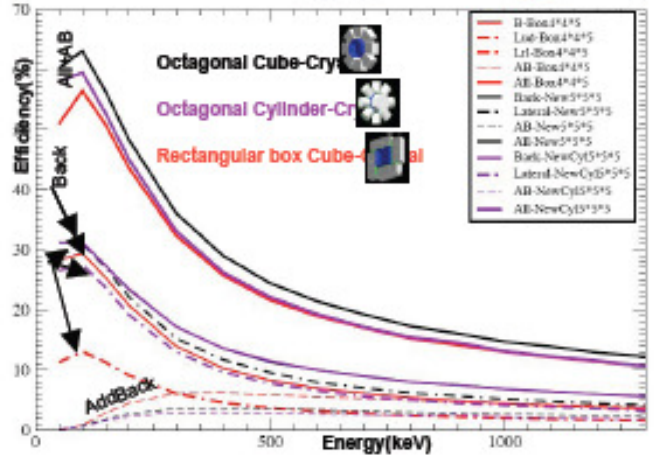
Detection systems

Decay spectroscopy :

α,γ,e- spectroscopy (GREAT, Gabriella, …)

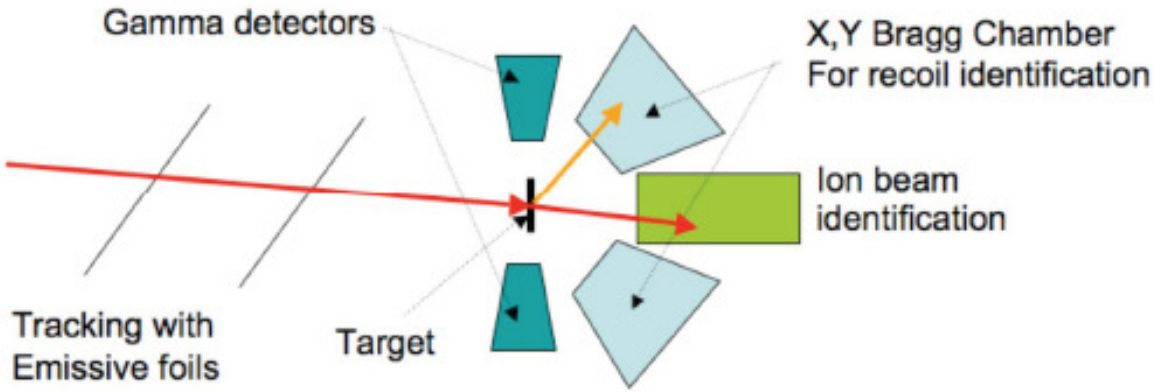






➔ R&D on advance Ge detection

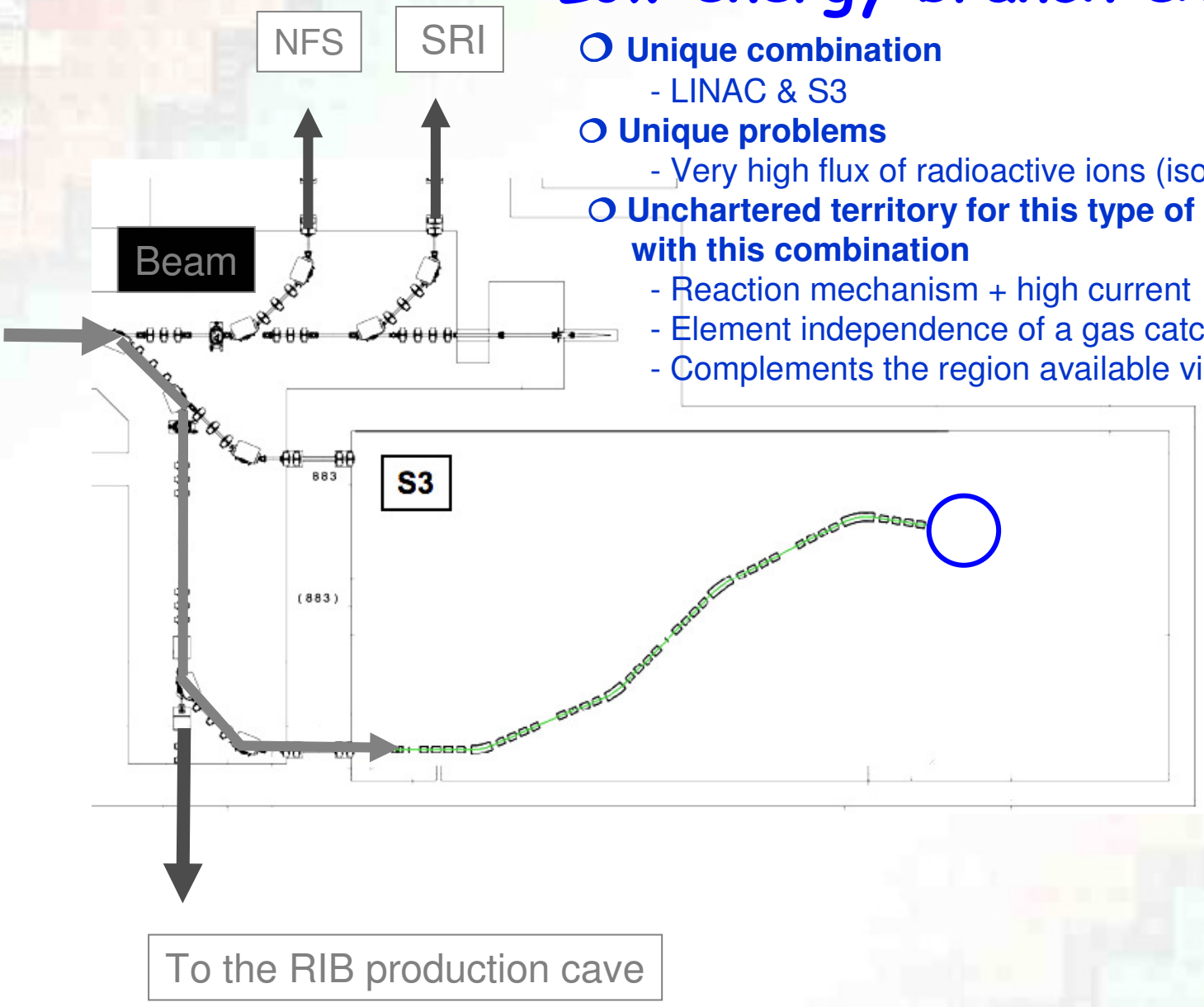
Secondary Target : In beam spectroscopy



➔ **PARIS, AGATA, MUST2/GASPARD and ACTAR**

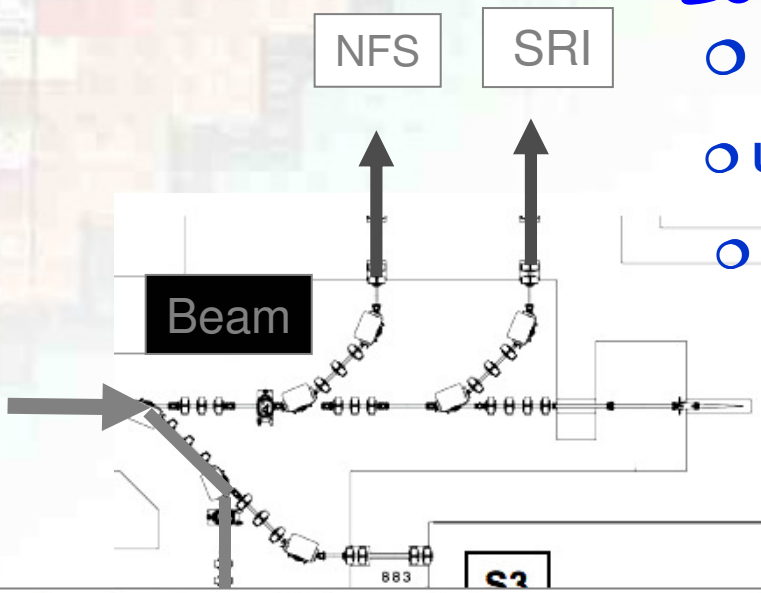
Low energy branch experiments

- **Unique combination**
  - LINAC & S3
- **Unique problems**
  - Very high flux of radioactive ions (isobars)
- **Unchartered territory for this type of physics accessible with this combination**
  - Reaction mechanism + high current
  - Element independence of a gas catcher technique
  - Complements the region available via the ISOL technique



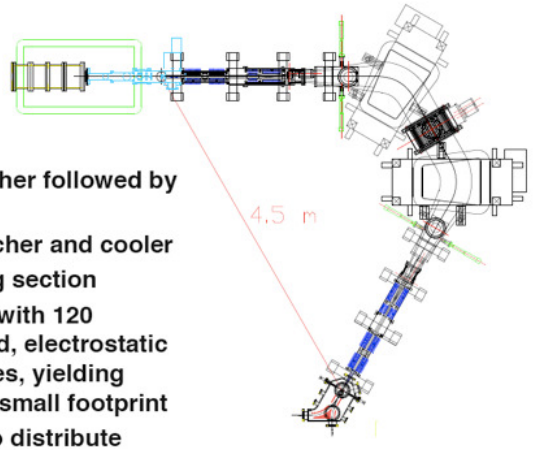
Low energy branch experiments

- **Unique combination**
  - LINAC & S3
- **Unique problems**
  - Very high flux of radioactive ions (isobars)
- **Unchartered territory for this type of physics accessible with this combination**
  - Reaction mechanism + high current
  - Element independence of a gas catcher technique
  - Complements the region available via the ISOL technique



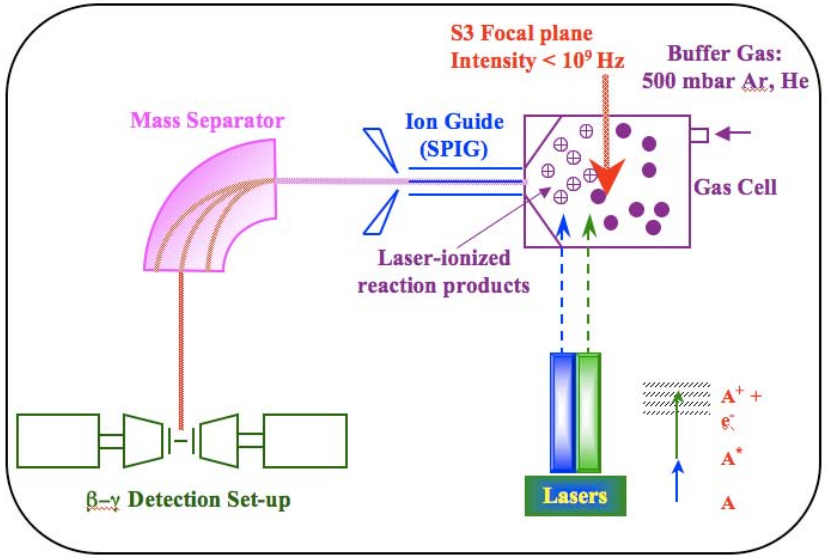
Gas Catcher + high-resolution mass separation

Possible gas catcher and mass separator layout for S³



- High intensity RF gas catcher followed by gas cooler
- 50 kV platform for gas catcher and cooler
- Acceleration and matching section
- High resolution separator with 120 degree total magnetic bend, electrostatic quadrupoles and multipoles, yielding 20000 mass resolution on small footprint
- Electrostatic switchyard to distribute beam to experiments in S3 hall, or in DESIR hall, or to post-accelerator

Laser ion source + mass separation



LISOL (Leuven)

CACAO Project

Chimie des Actinides et Cibles radioActives à Orsay

A laboratory for production and characterization of thin radioactive targets

Ch.O.Bacri, J.Mottier, S.Pierre, V.Petitbon, for the CACAO c

COORDINATION OF THE DIFFERENT … FOR THE ACQUISITION OF RADIOACT… ARGETS

Approved last July !

- **Help to the supply in isotopes**
  → industrials, laboratories, reactors, cyclotrons, …
- **Production** → radiochemistry
  … or others techniques in others laboratories
- **Characterization** (homogeneity, cartography, possible contaminants, …) → α and γ spectrometry, RBS, collaborations with LNHB, LPS
- **Transport**

Target production at IPN Orsay

- **glove boxes in controlled zone**
- radioactive thin layers (up to ~ 1 mg/cm^2, depending on i
  - ⇒ need of a support (backing)
  - ⇒ need to realize **stable thin layers**

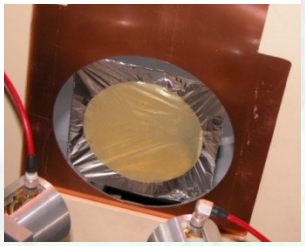
Stable thin layers laboratory at Orsay
V. Petitbon

- **radiochemical techniques:**

electrodeposition and spray in a first step

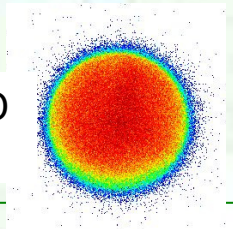
^{235}U target: 0.3 mg/cm^2 , ϕ= 8 cm, 2μm Al backing

Radiochemistry group



Transfer of know-how from the **radiochemical group at Orsay** (actinide chemistry, thermodynamcs), and thanks to collaborations **(Berkeley, Geel, Mayence (?) …**

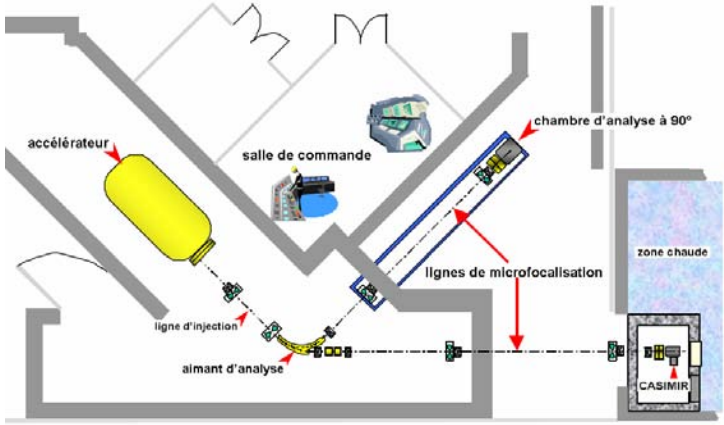
First deposit from CACAO (^{nat}U on Al)



Characterization

(to be developped ...)

- α cartography: in glove box, with a Si detector
- γ spectrometry: IPNO's "detector service" → expertise on Ge detectors
- RBS on 15 MV Tandem Van de Graaf accelerator (E_p>3MeV)
- **« Laboratoire Pierre Süe » (LPS)**
  Van de Graaf ; Vmax : 3,75 MV
  H+, ^{2}H+, ^{3}He+ et ^{4}He+
  X, γ, and charged particles detectors
  Hot line



- **Collaboration with the "Laboratoire National Henri Becquerel" (LNHB)**
  - ✓ laboratory of metrology (CEA Saclay)
    ⇒ knowledge to transmit (quality, precision, …)
  - ✓ β and γ spectroscopy/spectrometry
  - ✓autoradiography possible

Supply in isotopes

Identified isotope suppliers

- industry: Cerca Lea (AREVA), ISOTRAK, Isotopes products,...
- some laboratories (IRMM, FZK, GSI, Mainz, Argonne, Berkeley, Oak Ridge…)
- reactor irradiation → OSIRIS at Saclay
  3 10^{18} n m^{-2} s^{-1} for E<0,625 eV
  4.5 10^{18} n m^{-2} s^{-1} for E>0.1 MeV
- accelerator production: cyclotron ARRONAX
  1 day production: ~ 10 ng to µg (^{22}Na, ^{26}Al, ^{44}Ti, ^{59}Fe, ^{63}Ni, ^{85}Kr, ^{95}Zr)

Open questions … to be solved !

- Purity of isotopes (eg. 10^{-9} needed for fission experiments with non fissile isotope)
  … no more available magnetic separator in Europe !
- Chemical form (problem of contaminants)

Planning

Status :

- CACAO approved by French authorities last July
- Financing acquired for 3 years
- "manpower" obtained

To be done:

- Need to put in standards an existing lab.
- Buy equipments (glove boxes, …)

Planning of realization:

- hope to be fully operational at the end of 2010

… meanwhile, R&D and manufacture of "not too active targets"

Conclusions

- Existing GANIL
  - Low cross section measurements: ≈ pb
  - Spectroscopy studies
  - No dedicated spectrometer (LISE3, VAMOS)
- SPIRAL2
  - RIB: symmetric reaction, new isotopes; which spectrometer? cross-section?
  - LINAG: S3 (I, RF, transmission, …), SHE production with higher counting rate, new isotopes, need for development of target system
- Still open to collaboration for the S3 project: contribution, expertise, chemistry projects…..
- Actinide targets…

Thank you