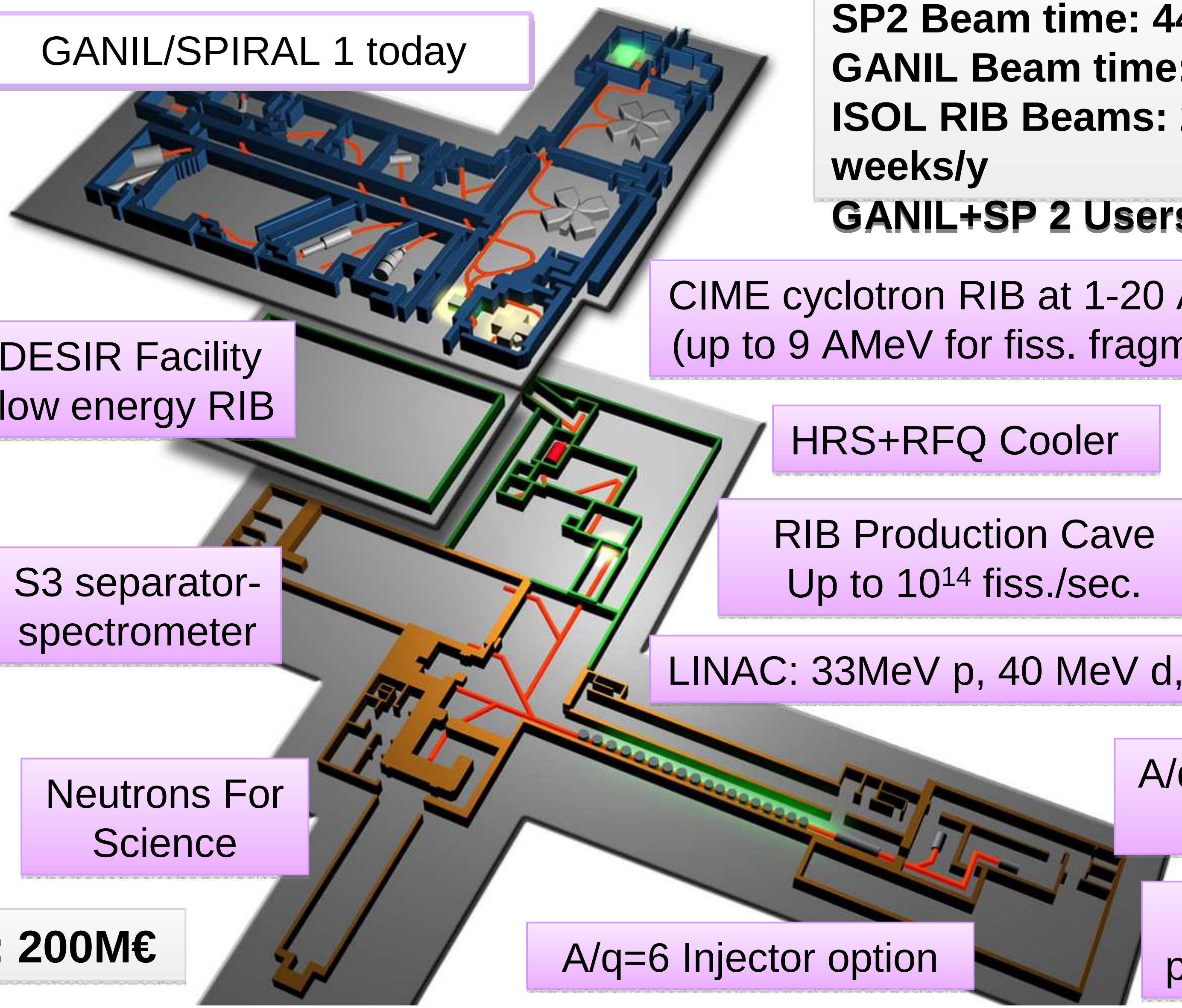
Beams from the Super Separator Spectrometer

Hervé Savajols
GANIL, France
on behalf the S^3 Collaborations

GANIL/SPIRAL1/SPIRAL2 facility

SP2 Beam time: 44 weeks/y
GANIL Beam time: 35 weeks/y
ISOL RIB Beams: 28-33 weeks/y
GANIL+SP 2 Users: 700-800/y



GANIL/SPIRAL 1 today

DESIR Facility
low energy RIB

S3 separator-spectrometer

Neutrons For Science

CIME cyclotron RIB at 1-20 AMeV
(up to 9 AMeV for fiss. fragments)

HRS+RFQ Cooler

RIB Production Cave
Up to 10^{14} fiss./sec.

LINAC: 33MeV p, 40 MeV d, 14.5 A MeV HI

A/q=3 HI source
Up to 1mA

A/q=2 source
p, d, ^{3,4}He 5mA

A/q=6 Injector option

Cost: 200M€

SPIRAL2 is one of the ESFRI list projects (40 most important EU research infrastructure projects)

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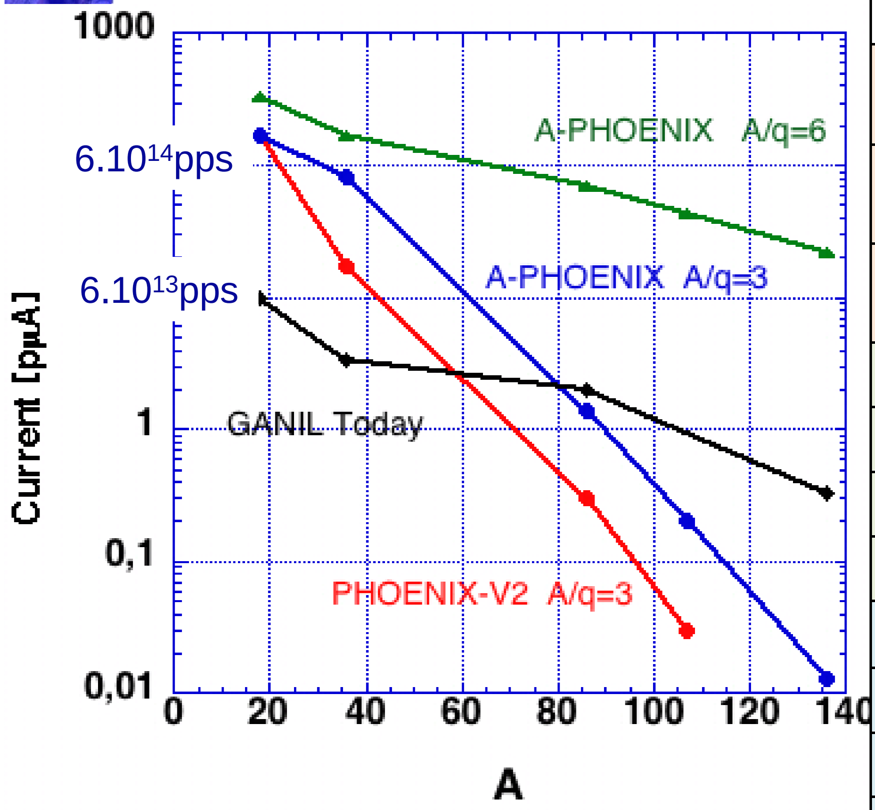
LINAC stable beams

Energy = 2-15 *A.MeV*



Above one or two order of magnitudes higher than present facilities

LINAC beams for the Day 1 SPIRAL2 Phase 1 experiments*)
Based on the recommendations of SPIRAL2 SAC for the LoI
M.L. version 05/10/2009

Ion(s)	Energy Range (MeV/nucleon)	Maximum Intensity (pμA)	Date of availability***)	Remarks
$^{1}H^{1+}$	20-33	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{2}H^{1+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{4}He^{2+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{12}C^{4+}$	5-7	³10 **)	February 2013	S3 beam line
$^{18}O^{6+}$	5-7	³10 **)	February 2013	S3 beam line
$^{22}Ne^{8+}$	5-7	³10 **)	February 2013	S3 beam line
$^{40}Ar^{14+}$	4-5	³10 **)	February 2013	S3 beam line
$^{28-30}Si^{10+}$ or $^{32-36}S^{12+}$	5-7	³10 **)	November 2013	S3 beam line
$^{40}Ca^{14+}$	5-7	³10 **)	November 2013	S3 beam line
$^{48}Ca^{16+}$	5-7	³10 **)	November 2013	S3 beam line
$^{58}Ni^{18+}$	4-14	³1 **)	November 2013	S3 beam line

GANIL Spiral2

Physics objectives

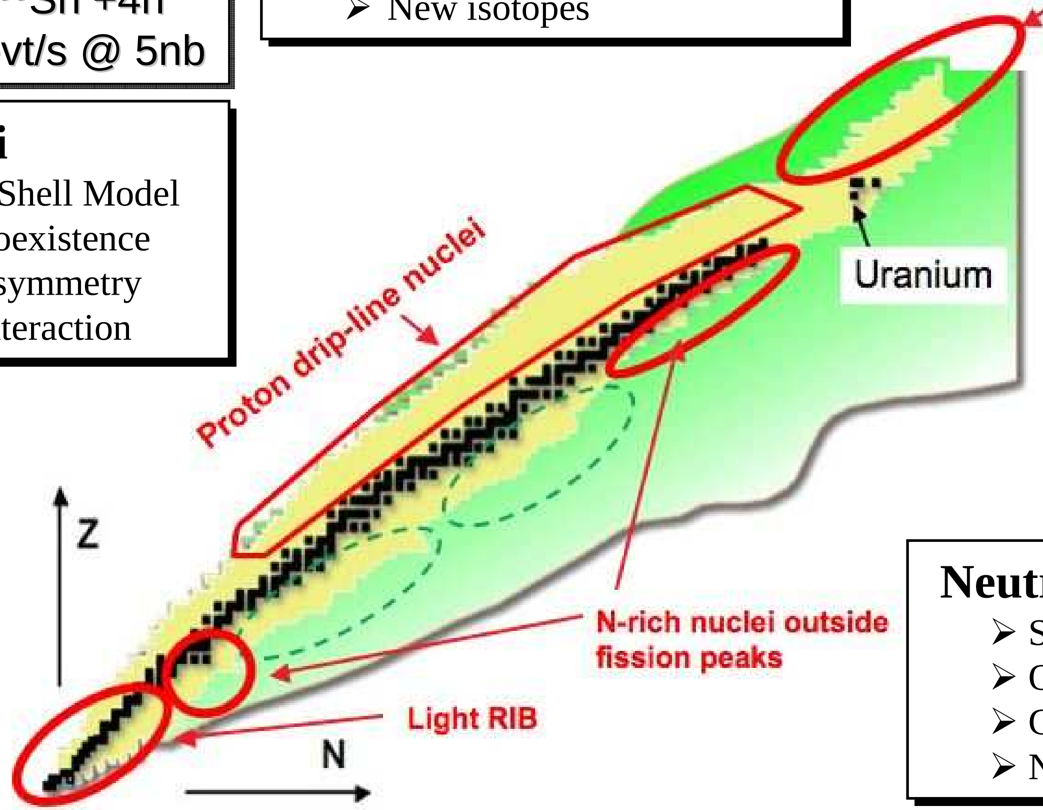
$^{58}Ni + ^{46}Ti \rightarrow ^{100}Sn$ +4n
10pμA ➔4evt/s @ 5nb

N=Z nuclei
- Tests of Shell Model
- Shape coexistence
- Isospin symmetry
- Weak interaction

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

10pμA➔ 6evt/day @ 1pb

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 Letter of Intent for SPIRAL2, 2006
- ➲ S3 Physics white book, June 2008
- ➲ LINAC/SPIRAL2 Day1 LoIs, Sept 2009

http://www.ganil.fr/research/developments/spiral2/loi_texts.html

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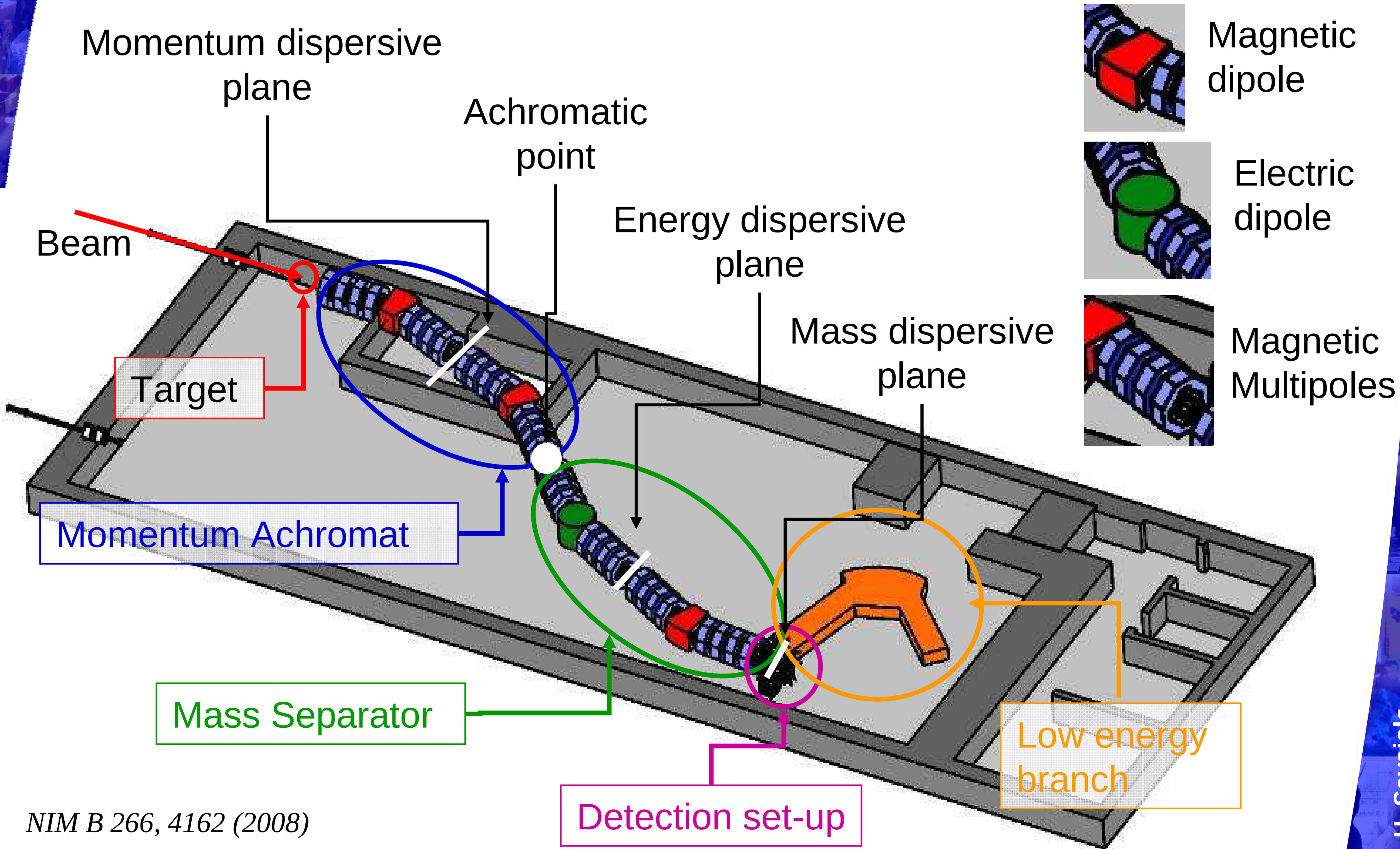
Optics : Basic design (Argonne NL)

Principle : Two-stage selection (Bρ & m/q) that will achieve very good rejection of both the beam and adjacent mass channels of reaction products



NIM B 266, 4162 (2008)

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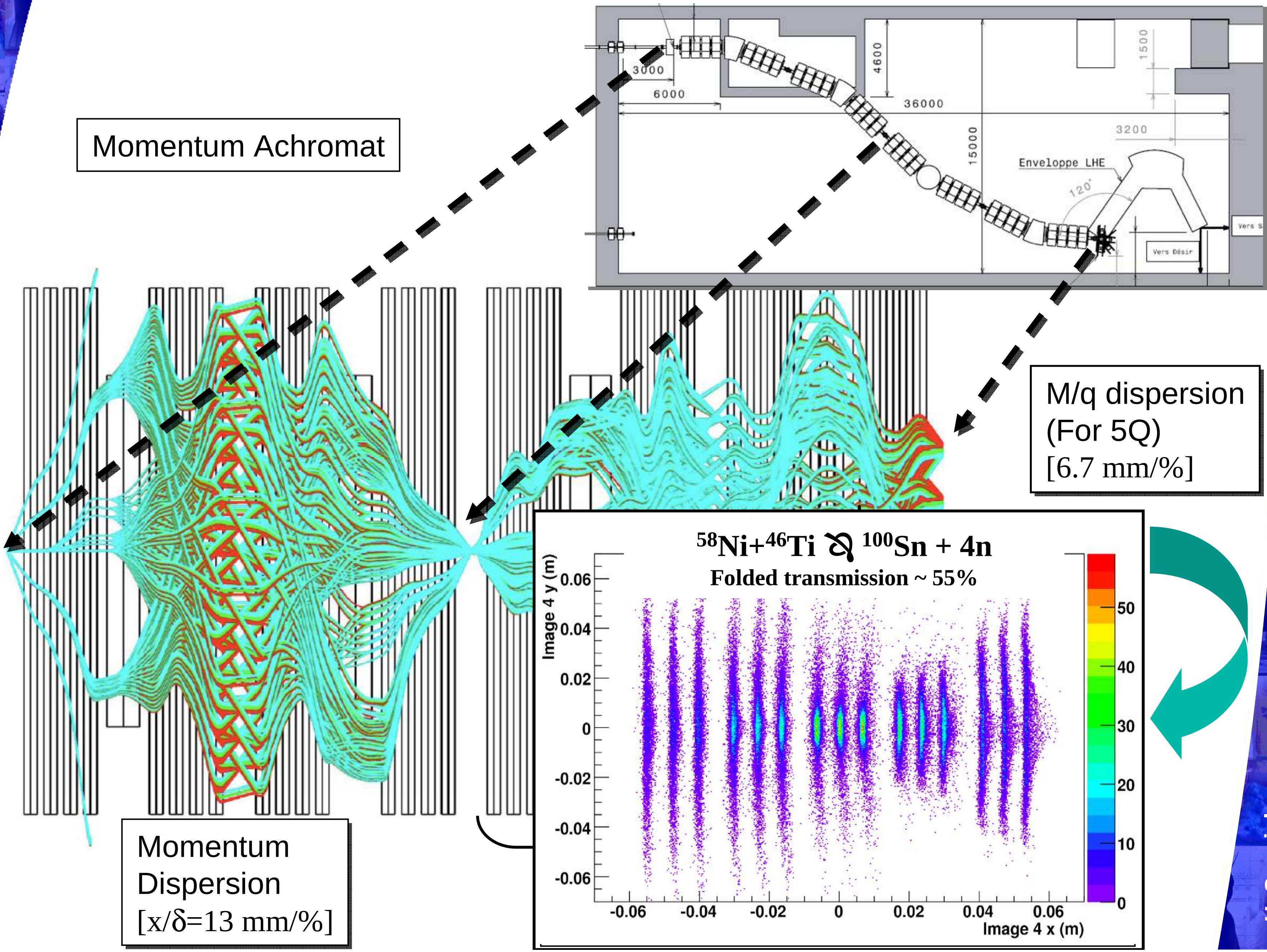
Optical calculations



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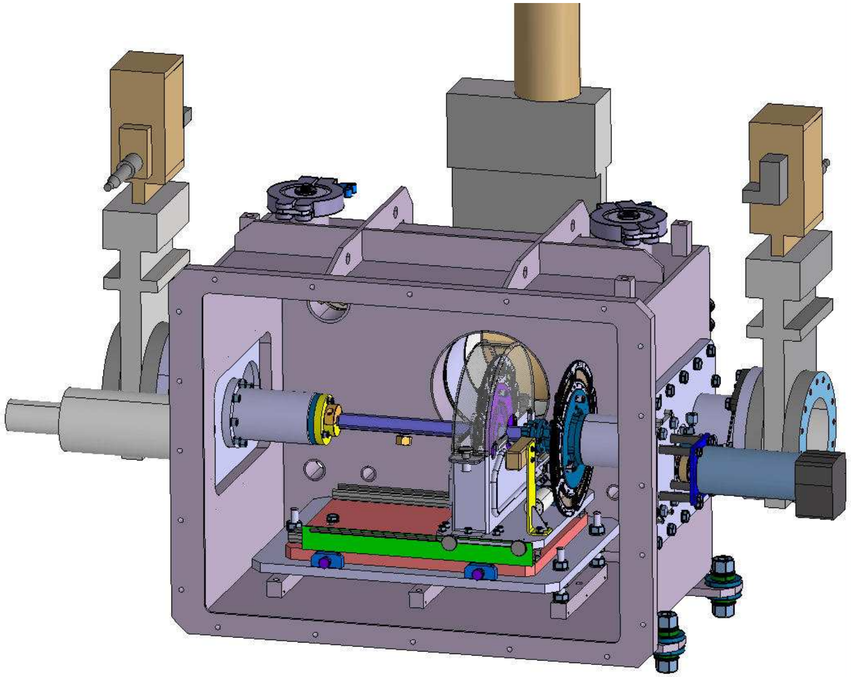
High power target stations

Stable

^{208}Pb, ^{209}Bi, Ni, Ca, C
(R ≈ 35 cm)

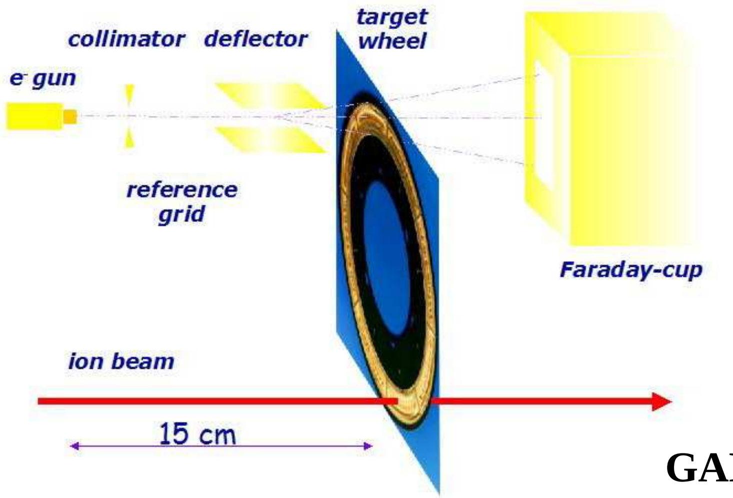
Used as prototype in 2009

Prototype ready May 2010

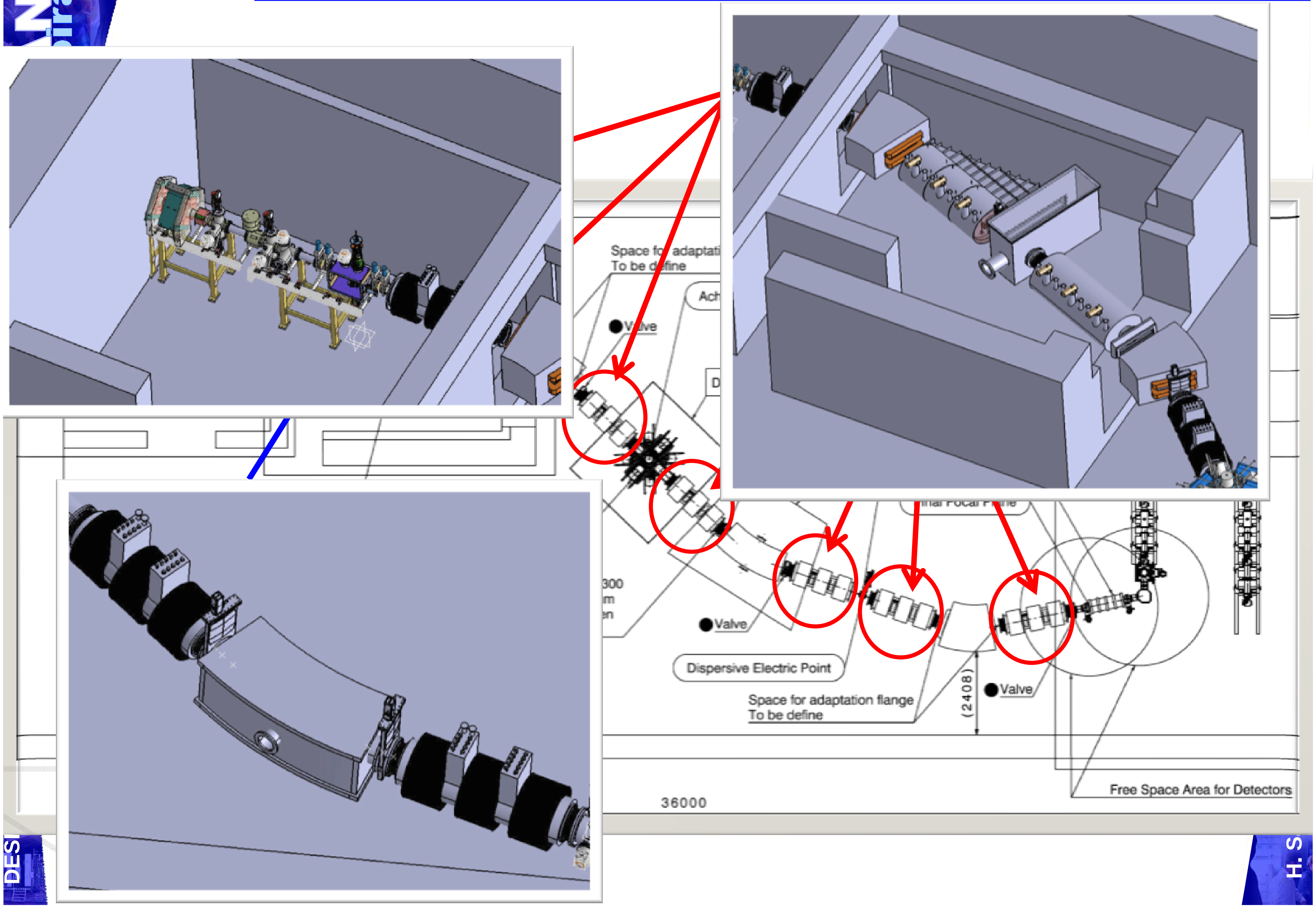


Target thickness and homogeneity
- RBS method
- Electron gun
- Pyrometer
- Infrared cameras
- Scintillators …

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

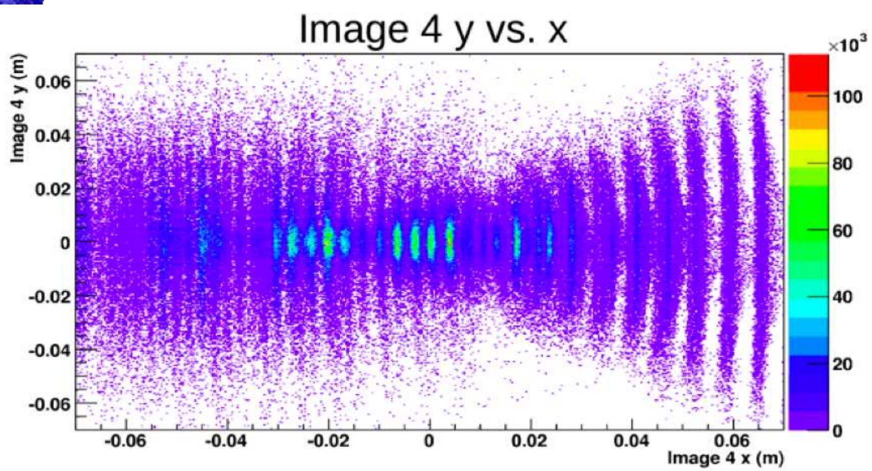


S3 layout based on SC triplets



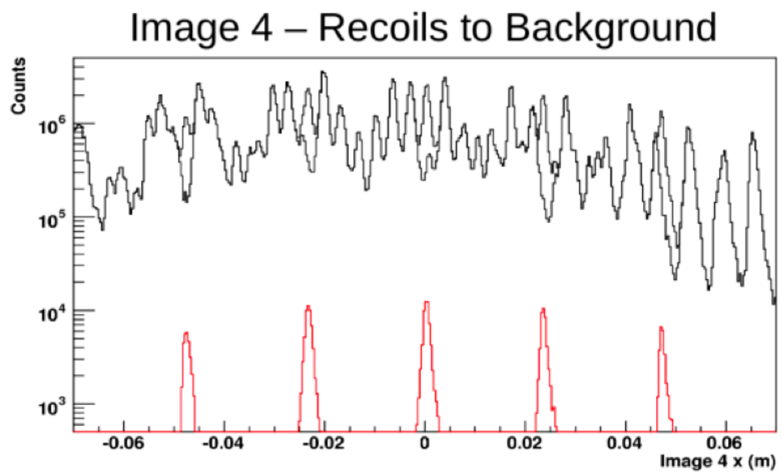
Isobar contaminant issues

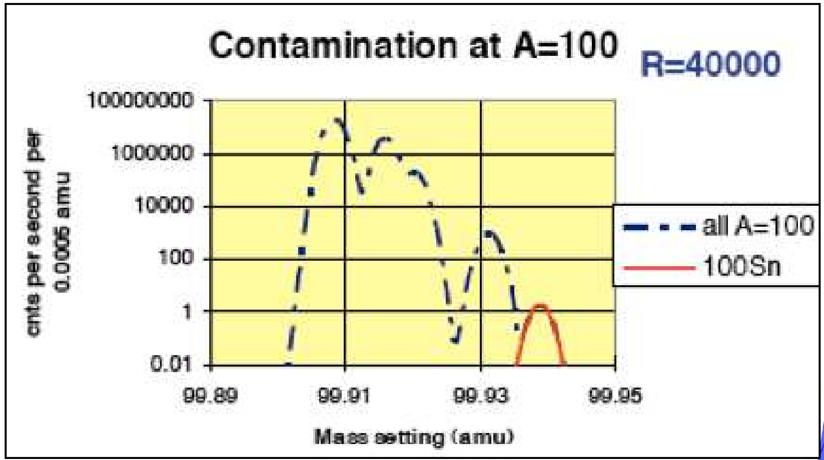
^{58}Ni + Ti ⇨ ^{100}Sn (1 Mev/A, 4 pps + 10^8 isobars/s)



Isotope	Mass (amu)	Separation (M/ΔM)
Sn100	99.938954	-----
In100	99.931149	12800
Cd100	99.920230	5330
Ag100	99.916069	4370
Pd100	99.908505	3280

A=100 Isobar mass contamination @ FP

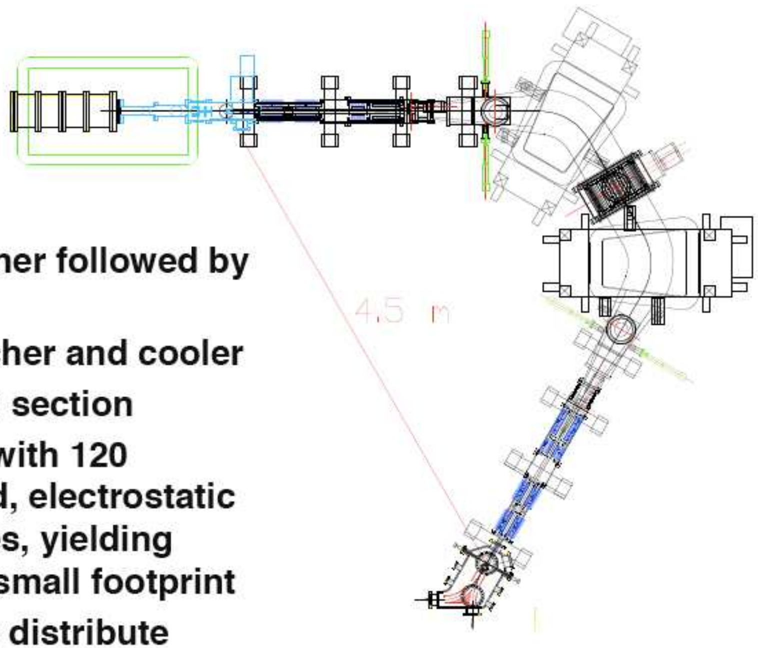




90% of contaminants are isobar
10% of contaminants are from M/Q neighbors

S^3 Low energy branch

Possible gas catcher and mass separator layout for S^3



- 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

ANL

Operation

- Chemical independent
- Isobar selection
- Fast extraction time

Applications

- selectivity
- Laser spectroscopy system
- some decay correlations
- mass measurements
- Merging to a common small spot

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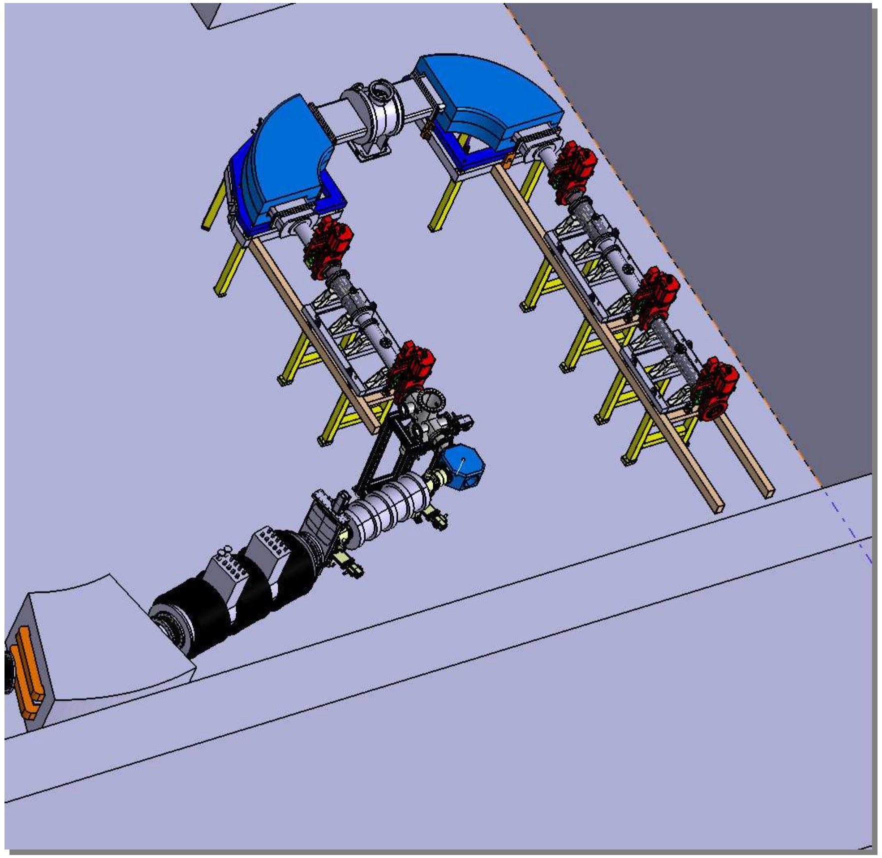
S³ Low energy branch



CARIBU geometry :

- 120 degrees total bend
- Bending radius 50 cm
- Dispersion about ~ 22 meters, 1mm slit size R ~20000

New geometry (HRS DESIR)

- 180 degrees total bend
- Dispersion about ~ 32 meters, 1mm slit size R ~31000

- magnetical design of dipole on the way
- mechanical design and integration to be completed
- for the end of the year: « cahier de charge » for dipole magnets
- detailed drawings of all elements for end 2010
- ordering of dipoles in 2011

Laser Ion Gas Cell

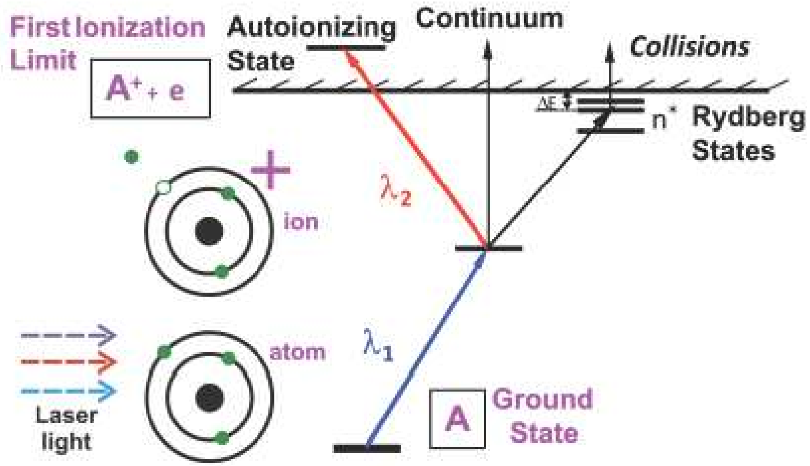
Resonant Laser Ionisation

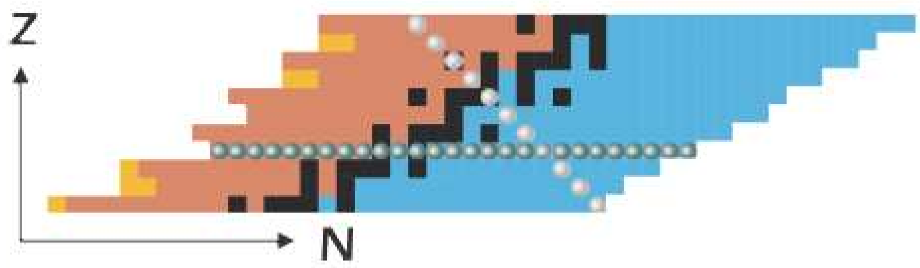
Operation

- universal
- element dependent scheme (atomic)
- multi-step schemes
- + mass separator = Isotope selection

Applications

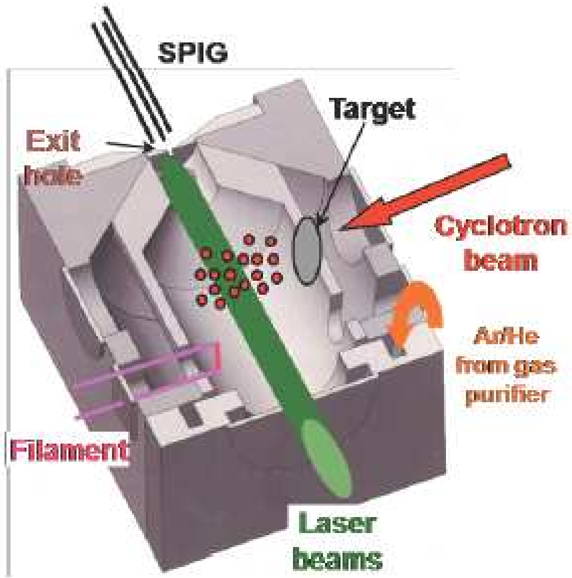
- selectivity (broad)
- spectroscopy (narrow)
- spin assignments
- magnetic moments
- charge radii
- quadrupole moments - collinear

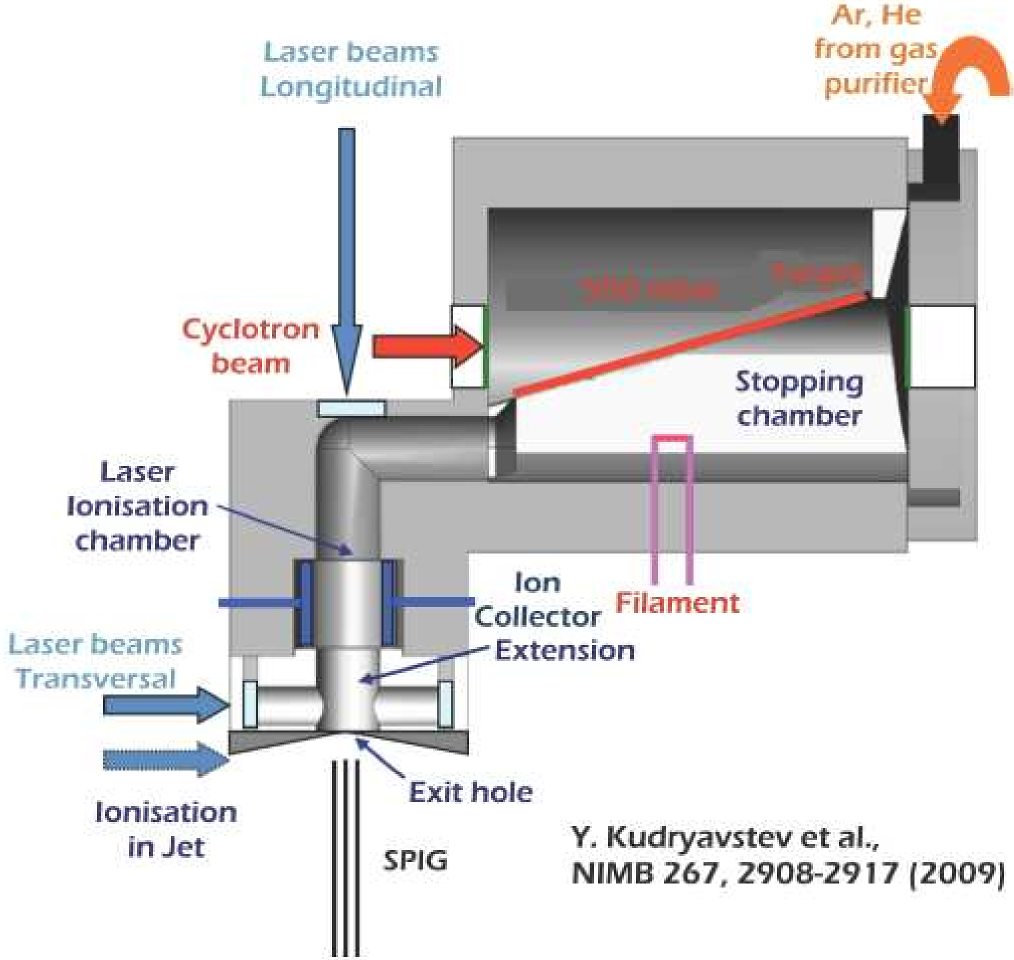




Laser Ion Gas Cell

LISOL Gas Cells

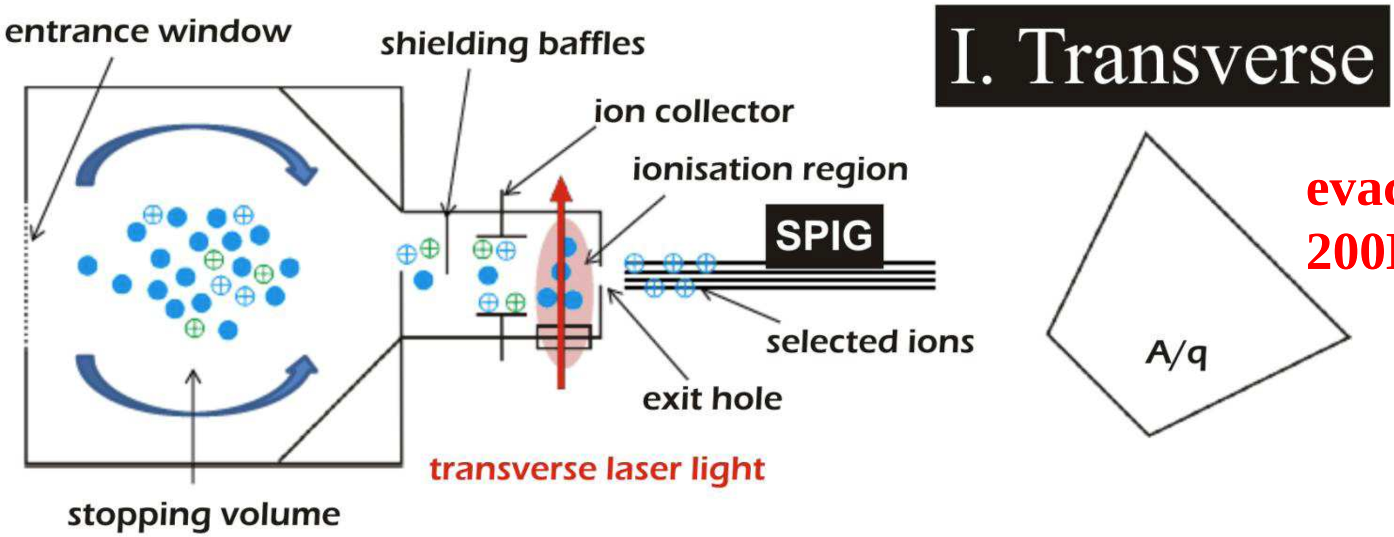




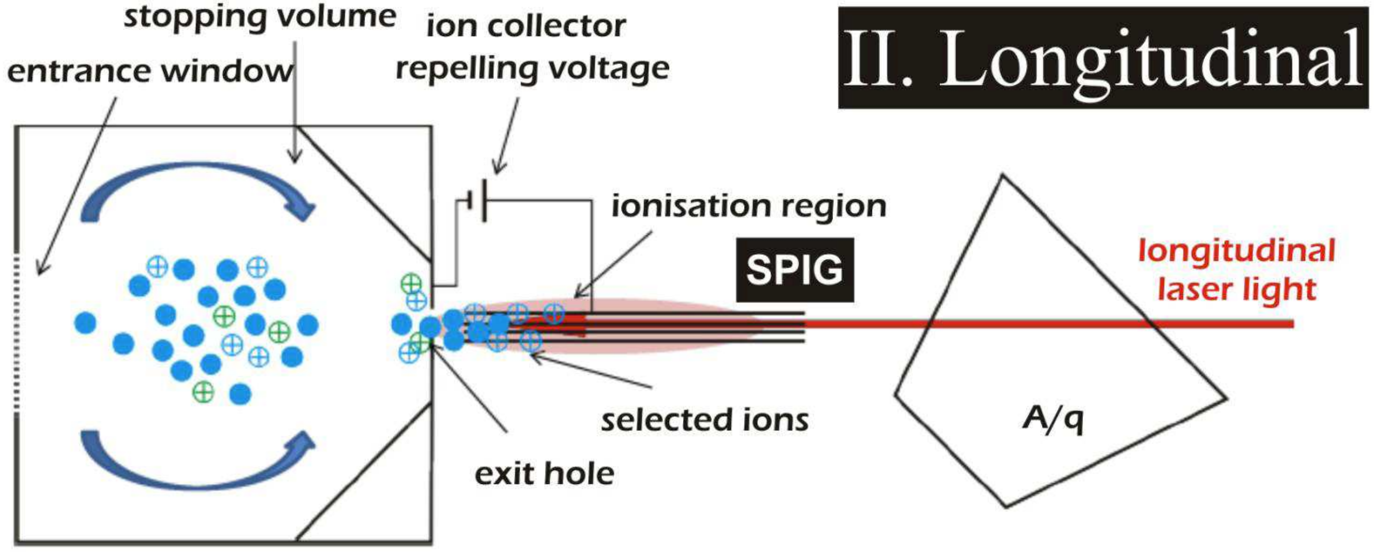
Y. Kudryavstev et al.,
NIMB 267, 2908-2917 (2009)

- eff independent of beam current >10%
- separation of stopping/ionisation zone
- application of electrical fields
- selectivity >1/10,000

S3 options – Laser Ion Gas Cell



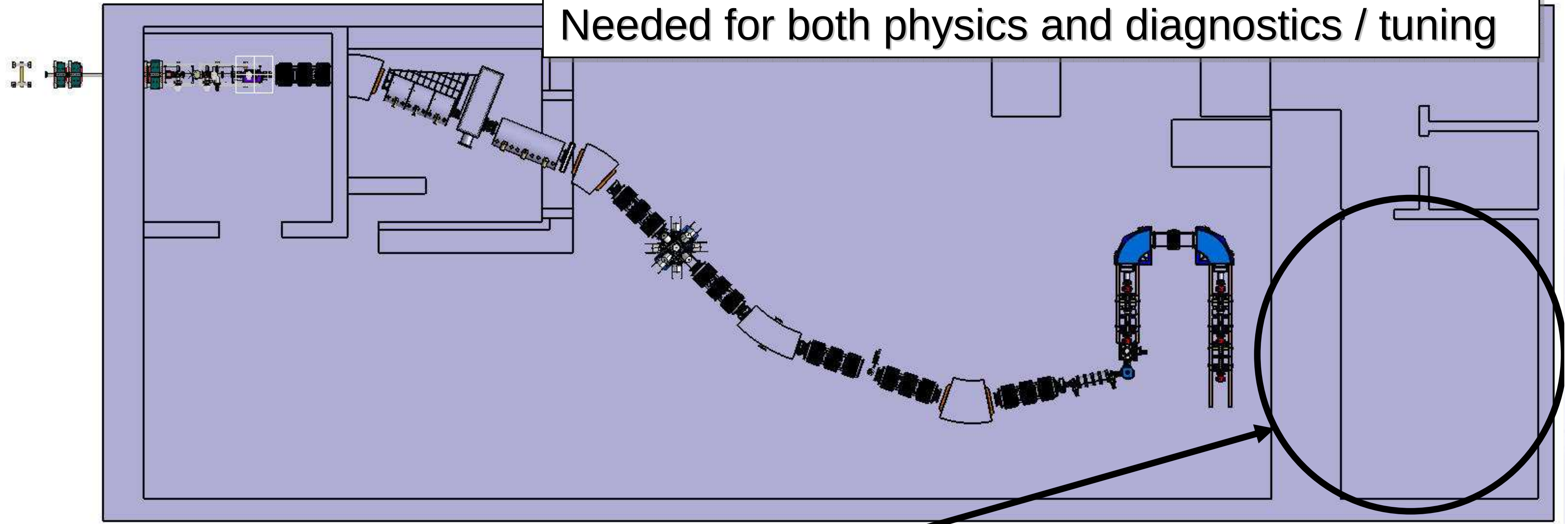
evacuation time > 5ms
200Hz lasers OK

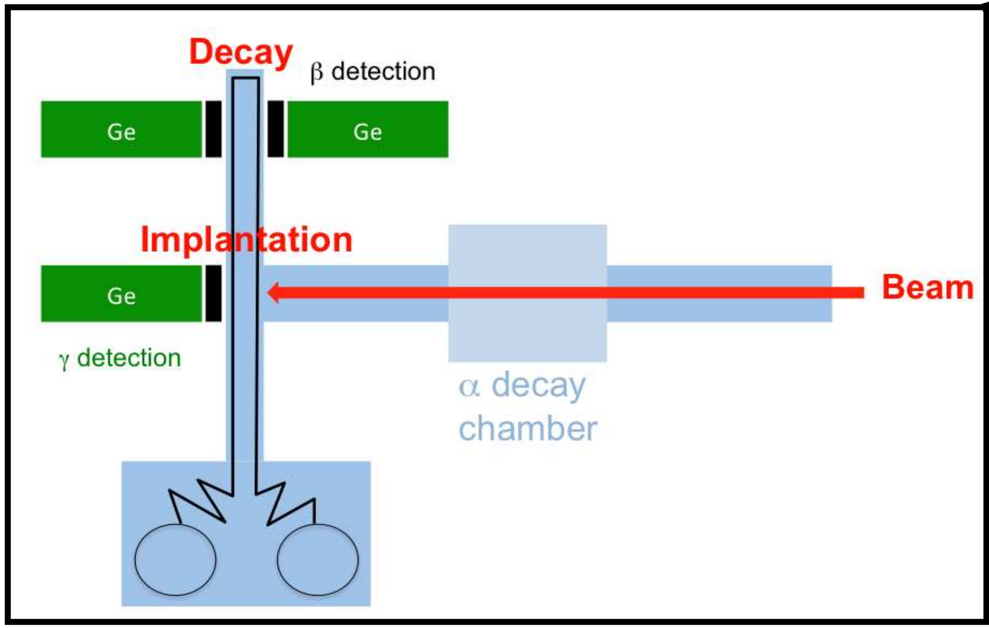


NEW LASERS
HIGH REP
~10kHzLIGHT

Measuring station

Needed for both physics and diagnostics / tuning





Measurements

- β / ion counting
- $\beta - \gamma$ correlations
- *β-p correlations*
- *slow correlations*
- *$\alpha - \gamma$ correlations*

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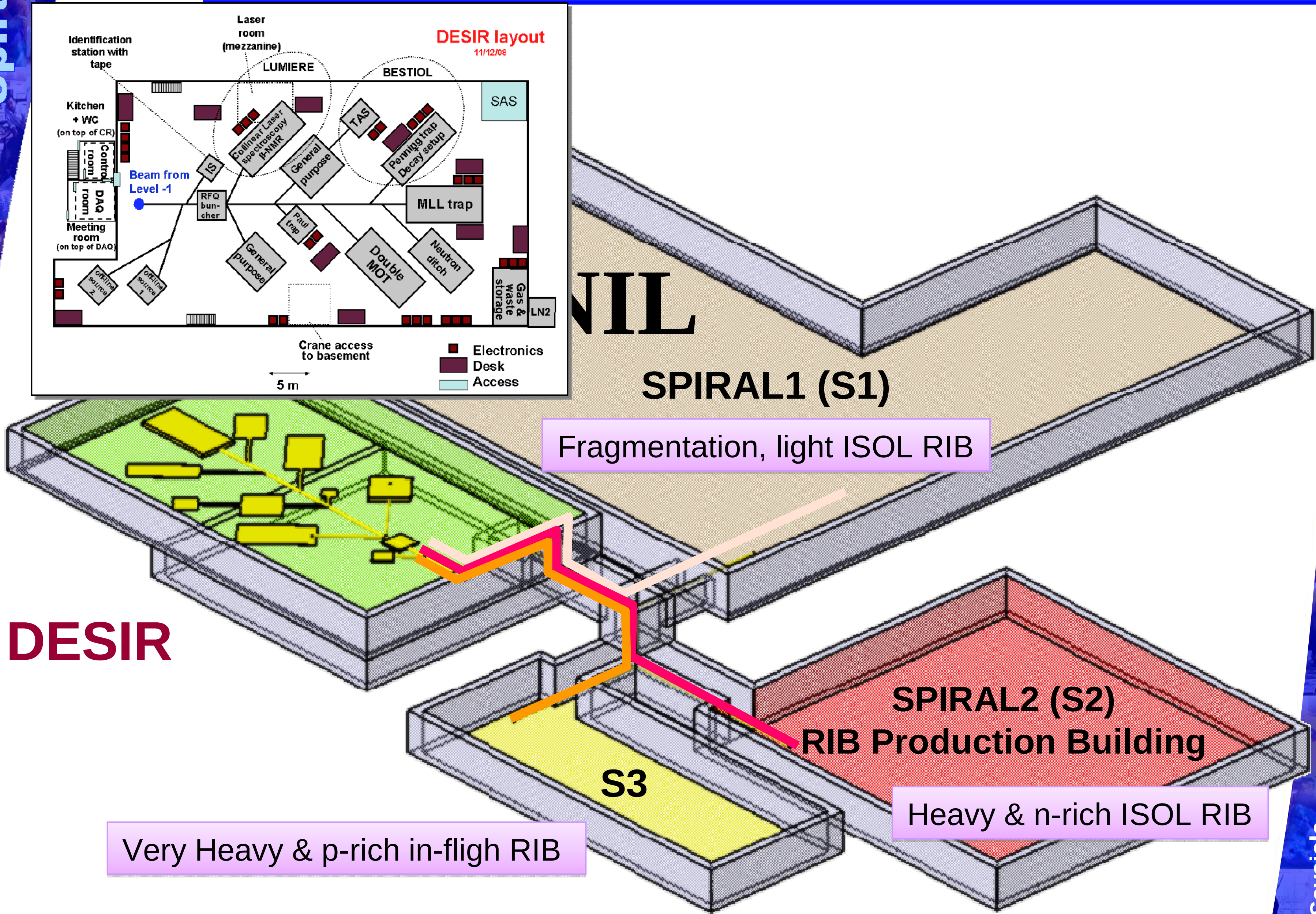
Various RIB beams in DESIR



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S^3: Letter of Intents (LoIs)

Day 1 experiments - SPIRAL2 phase 1

Spectroscopy

LoI_Day1_2 : Production and spectroscopy of heavy and superheavy elements using S3 and LINAG (P. GREENLEES)

- Neutron deficient nuclei around Z=92 N=126 (K. Hauschild)
- K-isomerism studies in the Z=100-110 region (Ch. Theisen)
- Study of neutron rich isotopes produced by asymmetric reactions (A. Korichi)
- Production of SHE with Z=106-108-112 with Uranium target (C. Stodel)

In-beam Spectroscopy

LoI_Day1_11 : ^{100}Sn factory - studies of the structure of nuclei in the ^{100}Sn region (D. SEWERYNIAK)

LoI_Day1_6 : Single particle states and proton-neutron interaction in the ^{100}Sn region (L. CACERES, F. Azaiez)

LoI_Day1_8 : Shell structure, Isospin symmetry and shape changes in N=Z nuclei (G. DE ANGELIS, B. Wadsworth)

- Coulomb excitation of ^{104}Sn: probing large scale shell model calculation
- Coulomb excitations of the T=1 bands of the odd-odd ^{62}Ga, ^{66}As and ^{70}Br nuclei

LoI_Day1_7 : In-beam gamma spectroscopy of neutron-rich nuclei studied with PARIS at the intermediate focal plane of S3 (I. STEFAN, B. Fornal)

LoI_Day1_9 : Quadrupole Moments of isomeric states using the Tilted-foils Technique at S3 (G. GEORGIEV, M. Hass)

GS properties

LoI_Day1_3 : In-source resonant laser ion spectroscopy of ^{94}Ag (I. G. DARBY)

LoI_Day1_4 : In-source resonant laser ion spectroscopy of the light Sn isotopes A =101-107 (I. G. DARBY)

LoI_Day1_5 : In source resonant laser ion spectroscopy of Z >=92 (I. G. DARBY)

LoI_Day1_10 : Precision study of the superallowed beta decay of heavy odd-odd N=Z nuclei (B. BLANK)

DESIR

LoI_Day1_1 : Fast ion-slow ion collisions -FISIC project (E. LAMOUR)

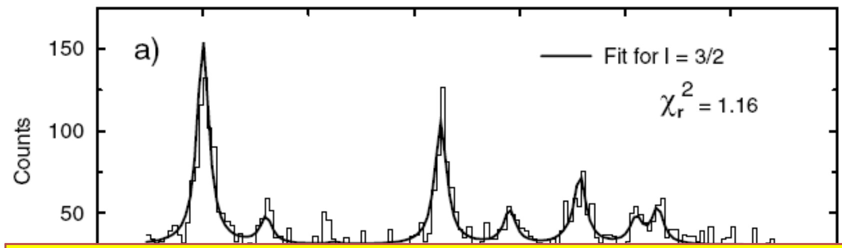
Evolution of the Z=40 subshell while approaching the p-dripline

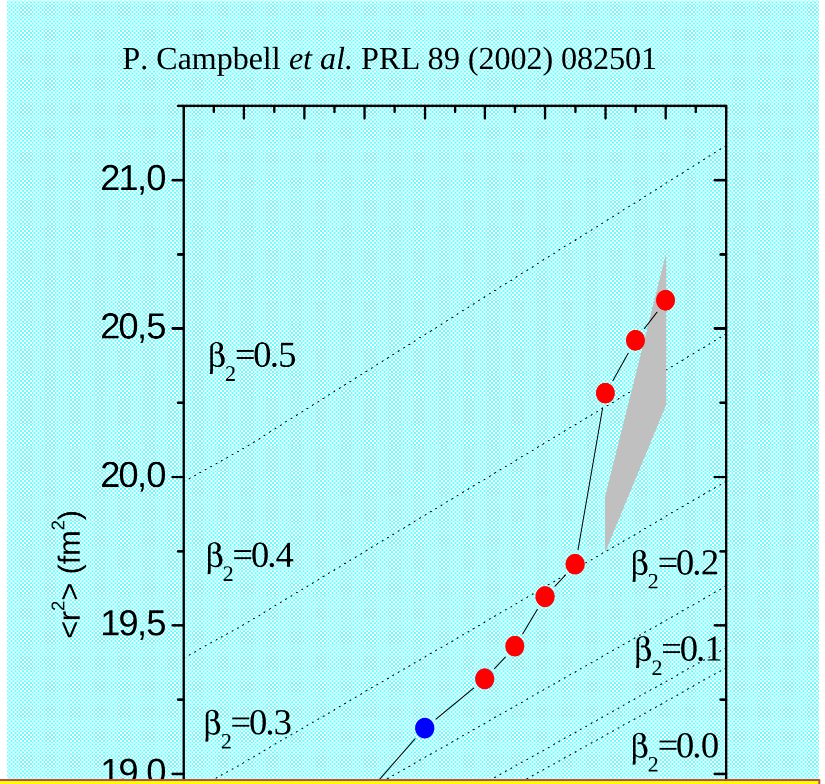
B. Bastin(GANIL)

With SPIRAL2, the study of the **ground state properties of refractory elements** such as n-deficient Zr isotopes will become accessible

Phase I - S3 / in-source spectroscopy:
isotope shifts, $\delta\langle r^2\rangle$…

Phase II - DESIR via S^3 / lumière :
nuclear spin, magnetic moment, quadrupole moment…



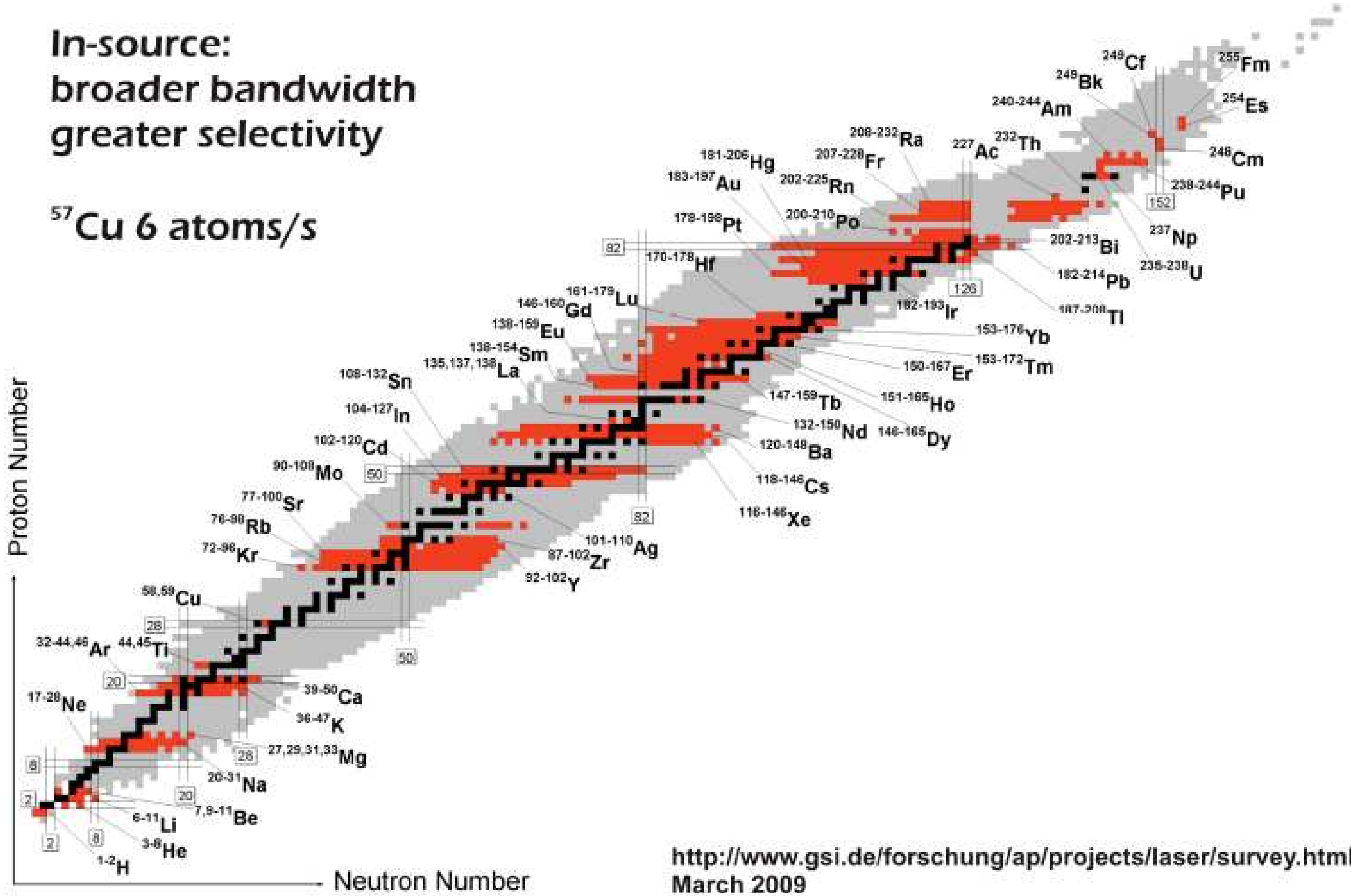


Ions	Energy (MeV)	Intensity (pμA)	Target	Thickness (mg/cm²)	Rate (1+) (pps)
$^{36}Ar^{12+}$	120	100	^{50}Cr / ^{46}Ti	1	3,76E+03
$^{58}Ni^{18+}$	190	10	^{24}Mg	1	7,83E+02
$^{40}Ca^{14+}$	130	10	^{46}Ti	1	1,0E+03

Laser Spectroscopy of radioactive Isotopes Survey

In-source:
broader bandwidth
greater selectivity

^{57}Cu 6 atoms/s



http://www.gsi.de/forschung/ap/projects/laser/survey.html
March 2009

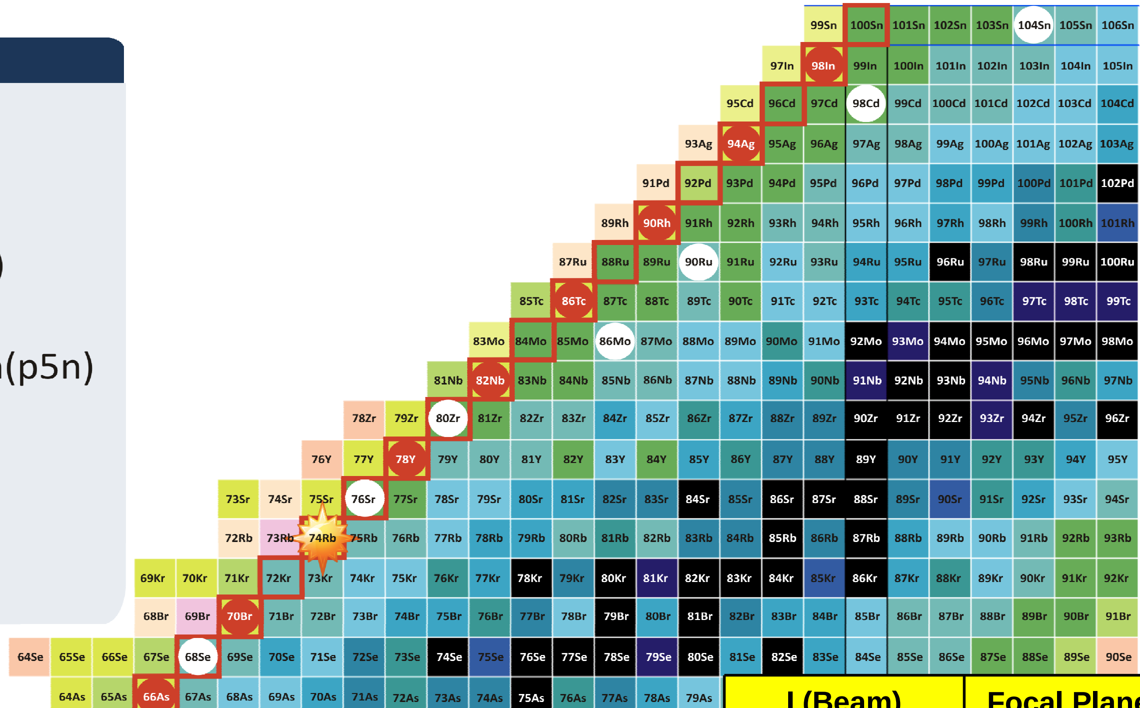
Medium mass N=Z region

Precision study of the superallowed -decay of heavy odd-odd N = Z nuclei

B. Blank (CENBG) & J. C Thomas (Ganil)

Nuclei & Measurements

- Branching ratio, half-life
  - (subsequently Q-value@DESIR)
- ^{66}As, ^{78}Y, ^{82}Nb & ^{86}Tc: $t^{m}_{1/2}$ short
  - ^{28}Si(pn), ^{40}Ca(pn), ^{46}Ti(p3n), ^{50}Cr(p3n)
- ^{70}Br, ^{90}Rh, ^{94}Ag & ^{98}In: $t^{m}_{1/2}$ x 10^{2-3}
  - ^{36}Ar(αpn), ^{58}Ni(αp3n), ^{58}Ni(p3n), ^{64}Zn(p5n)
- Target: durable CaO or CaB_6
- Beam energies ~5MeV/A
- σ ^{66}As 10mb → ^{98}In 0.5μb
- counting rates ~ 100pps



β–decay Q values with MLLTRAP
C. Weber

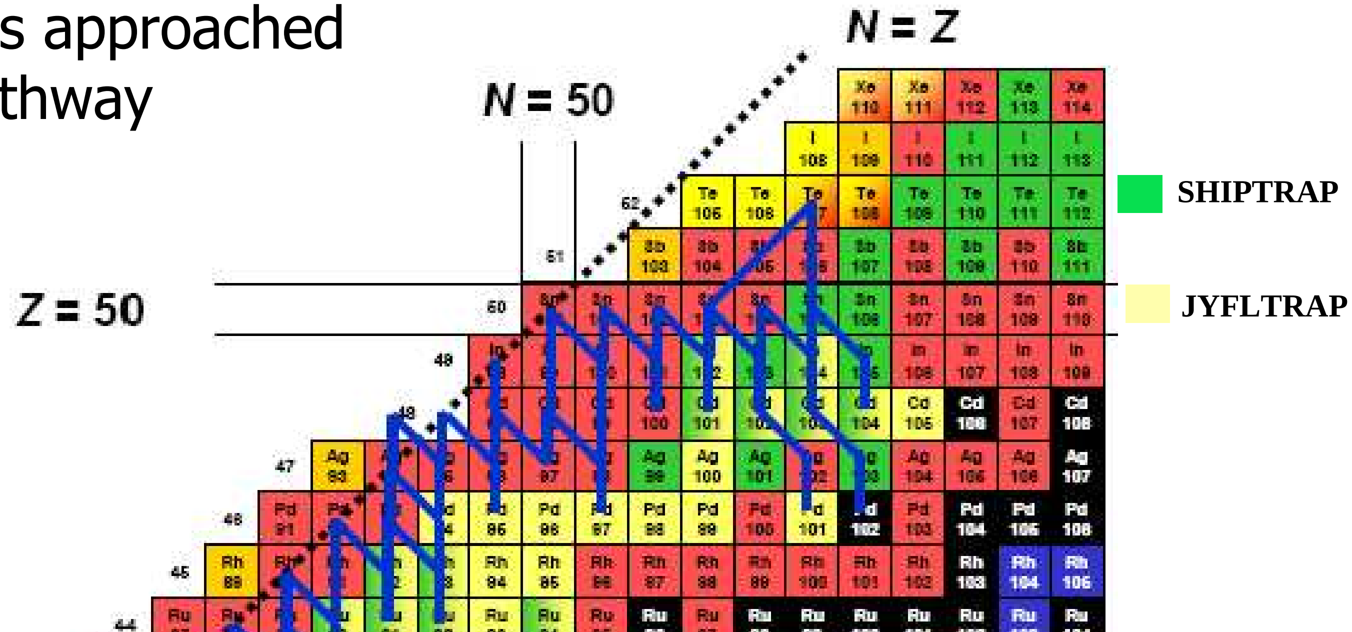
			I (Beam)	Focal Plane
• ^{62}Ga:	^{40}Ca(^{28}Si,αpn)^{62}Ga	14mb	10pμA	6,6E+06
• ^{66}As:	^{40}Ca(^{28}Si,pn)^{66}As	9mb	10pμA	4,2E+06
• ^{70}Br:	^{40}Ca(^{36}Ar,αpn)^{70}Br	5mb	30pμA	7,1E+06
• ^{74}Rb:	^{40}Ca(^{36}Ar,pn)^{74}Rb	0.2mb	30pμA	5,6E+05
• ^{78}Y:	^{40}Ca(^{40}Ca,pn)^{78}Y	0.1mb	10pμA	9,3E+04
• ^{82}Nb:	^{40}Ca(^{46}Ti,p3n)^{82}Nb	0.1mb	10pμA	9,3E+04
• ^{86}Tc:	^{40}Ca(^{50}Cr,p3n)^{86}Tc	0.1mb	10pμA	9,3E+04
• ^{90}Rh:	^{40}Ca(^{58}Ni,αp3n)^{90}Rh	0.02mb	10pμA	1,9E+04
• ^{94}As:	^{40}Ca(^{58}Ni,p3n)^{94}As	0.007mb	10pμA	6,5E+03
• ^{98}In:	^{40}Ca(^{64}Zn,p5n)^{98}In	0.0005mb	10pμA	4,6E+02

GANIL Spiral 2

Mass measurements in the vicinity of the rp-process

C. Weber et al.PRC78, 054310 (2008)

Measurements approached rp process pathway



58Ni + 50Cr or 58Ni + 46Ti (same ER but without alpha emission)

Ebeam = 249-350 MeV (267 MeV for 102Sn)

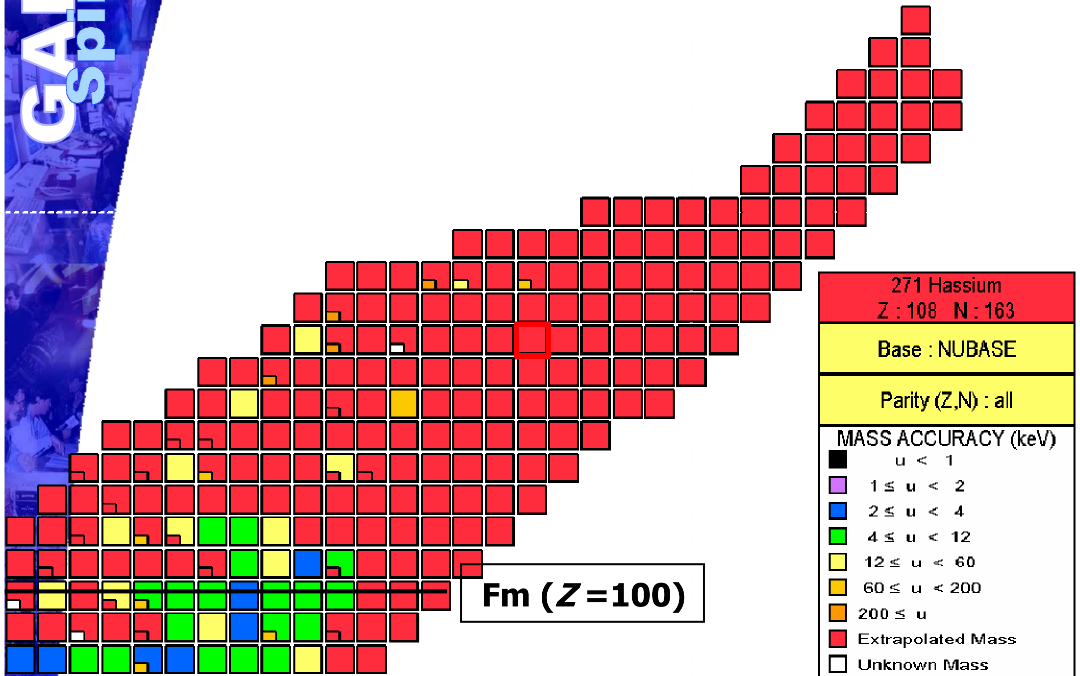
I = 10 pμA (6.10^{13} pps) **(A/Q=3)**

T = 1mg/cm^2

Nucleus	Evaporation	XS (mb)	rate (pps)	Focal plane	1+ (10%)
102In	αpn	1,30E+00	9,00E+05	4,50E+05	4,50E+04
99Cd	2αn	3,00E-02	2,18E+04	1,09E+04	1,09E+03
100In	αp3n	3,00E-03	2,08E+03	1,04E+03	5,40E+02
101Sn	α3n	6,00E-05	4,51E+01	2,26E+01	2,26E+00
102Sn	α2n or 2p3n	5,00E-04	3,76E+02	1,88E+02	1,88E+01
104Sn	2p2n	5,00E-01	3,76E+05	1,88E+05	1,88E+04

GANIL Spiral 2

Mass measurements for Z>100



- no direct mass measurement yet
- some masses indirectly determined from Q_α values
- many masses only known from extrapolations

Nuclear structure studies through mass measurements:

- shell structure evolution

VHE nuclei					
T = 0,5mg/cm^2					MLLTRAP P. Thirolf
reaction	Z	XS (mb)	rate (pps)	Focal plane	1+ (10%)
I = 10 pµA (6.10^{13} pps)					
48Ca + 176Yb	Th (90)	1,00E+00	2,05E+05	1,03E+05	1,03E+04
48Ca + 208Pb	No (102)	2,50E-03	4,50E+02	2,25E+02	2,25E+01
48Ca + 209Bi	Lr (103)	4,00E-04	7,20E+01	3,60E+01	3,60E+00
50Ti + 208Pb	Rf (104)	4,00E-05	3,61E+00	2,61E+00	2,10E-01
I = 100 pµA (6.10^{14} pps)					
26Mg + 238U	Rf (104)	1,50E-06	1,18E+00	1,77E-01	1,77E-02
16O + 238U	Fm (100)	1,00E-02	1,51E+04	1,50E+03	1,50E+02

H. Savajols

S3 low energy branch

S^3 offers unique potential for important isotopes produced with low cross section, in particular proton rich nuclei and very heavy elements.

The low-energy branch of S3 will allow the production of beams of refractory elements as well as of very short-lived isotopes at ISOL energies

Link between S3 and DESIR

We believe that such a scheme enriches significantly the capabilities of SPIRAL2 in terms of experiments with low-energy beams and provides unique possibilities for the study of fundamental properties of heavy elements, refractory elements or very short-lived isotopes at SPIRAL2 with intensities not available at any other facility worldwide. The DESIR and S3 communities are convinced that the coupling of the two facilities is the most efficient way to take advantage of these possibilities

- Equipment to be fed by the device
  - Penning trap
  - Laser spectroscopy system
  - Decay station