16th International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications (EMIS2012)

from Sunday, 2 December 2012 at **13:00** to Friday, 7 December 2012 at **18:40** (Japan)

Concluding remarks

Interesting, well organized, and stimulating presentations

- Remarkable advances and challanges in instrumentation for RIB physics
- Technical progresses essential for the physics program at RIB facilities

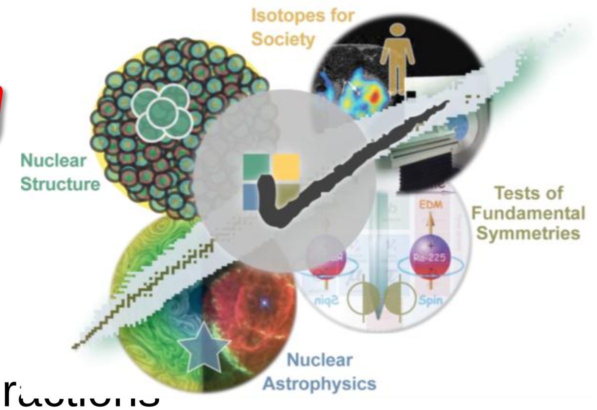
Angela Bracco – University of Milano and INFN

TOPICS

1. On and off-line mass separation
2. Preparation of energetic radioactive beams
3. Target techniques and ion sources
4. Techniques related to high-power beams
5. Ion guides and gas jets
6. In-flight separators and storage rings
7. Ion optics and spectrometers
8. Mass spectrometry
9. Traps and laser techniques
10. Equipment for radioactive beam experiments
11. Applications
12. Reactions for radioactive isotope productions
13. Facility initiatives

Topics well focussed on relevant items on instrumentation for RIB physics

Key Physics questions driving the technical developments



Properties of nuclei

- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.
- The limits of elements and isotopes

Astrophysical processes

- Origin of the elements in the cosmos
- Explosive environments: novae, supernovae, X-ray bursts …
- Properties of neutron stars

Rich scientific program for the next decade !

Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei

Societal applications and benefits

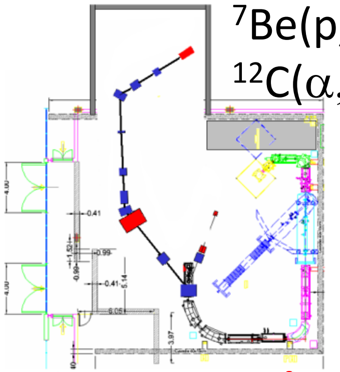
- Bio-medicine, energy, material sciences, national security

Recoil separators :

- Low energy
- High energy

Recoil separators are devices which separate nuclear reaction products (recoils) leaving a target from the unreacted beam particles.

~25 years of separators dedicated for nuclear astrophysics
Strong interaction between stable and RI Beam community



ERNA separator in Napoli

Radiative capture and fusion reactions

First step in chemical evolution of our universe

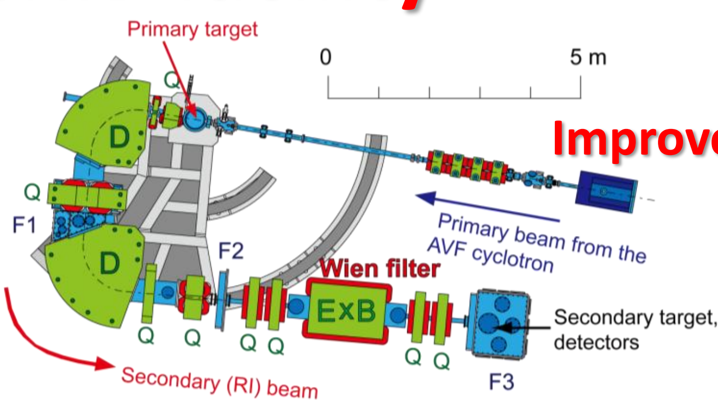
New recoil separators are coming.... among them one in Korea

Manoel Kouder

Low energy reactions for nuclear astrophysics

Hidetoshi Yamaguchi

CRIB facility



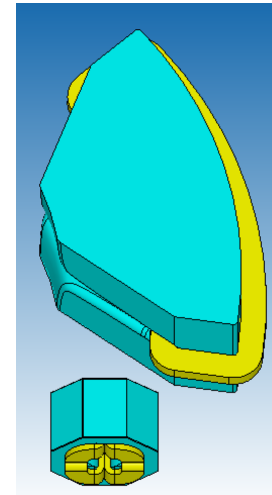
Improvements in

- Ion source
- Accelerator/Beam line
- Cryogenic target.
- Wien filter
- Active target (GEM-MSTPC)

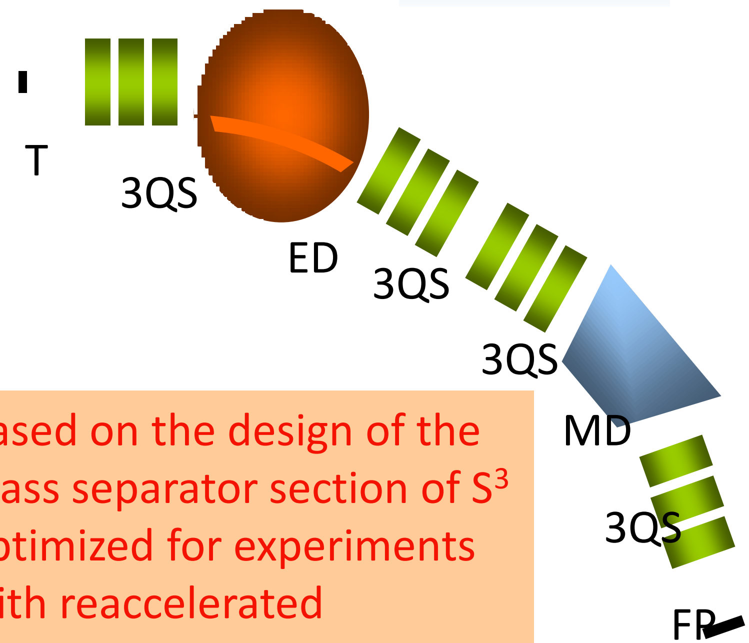
Used in (α,p) reaction measurements with RI.

Recoil separators at ANL (Darius Seweryniak)

- FMA is almost ready to accept high-intensity beams from ATLAS
- AGFA (**Argonne Gas Filled Separator**) will complement FMA for experiments with heavy nuclei



SUPERB (similar to S3) combines advantages of FMA and AGFA for experiments with reaccelerated radioactive beams



Based on the design of the mass separator section of S^3 optimized for experiments with reaccelerated radioactive beams at Rea12

Super heavy elements

Separators for stable beams to measure small cross sections

RIKEN (gas filled recoil separatoror GARIS) – (Morita Kosuke)

Lanzhou (**GAN Zaiguo and IMP SHN group)**

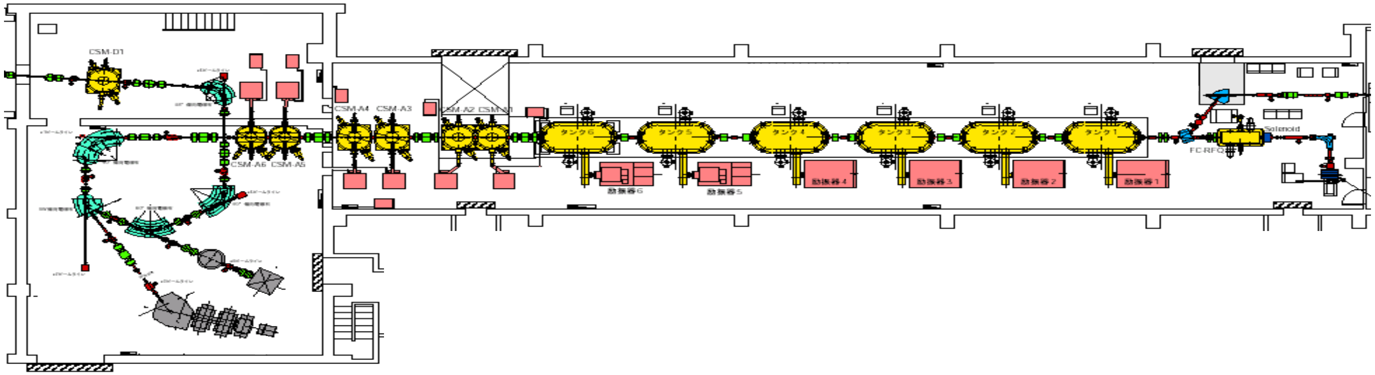
ASCA (GSI)(**A. Yakushev and Julia Even)**

New Result in Production and Decay of an Isotope, of the 113th Element

Kosuke Morita

Superheavy Element Laboratory
RIKEN Nishina Center for Accelerator-Based Science, RIKEN

Program of SHE search and spectroscopy at RIKEN



New isotope search of the heaviest nuclei and detailed spectroscopy with cold and hot fusion reactions.

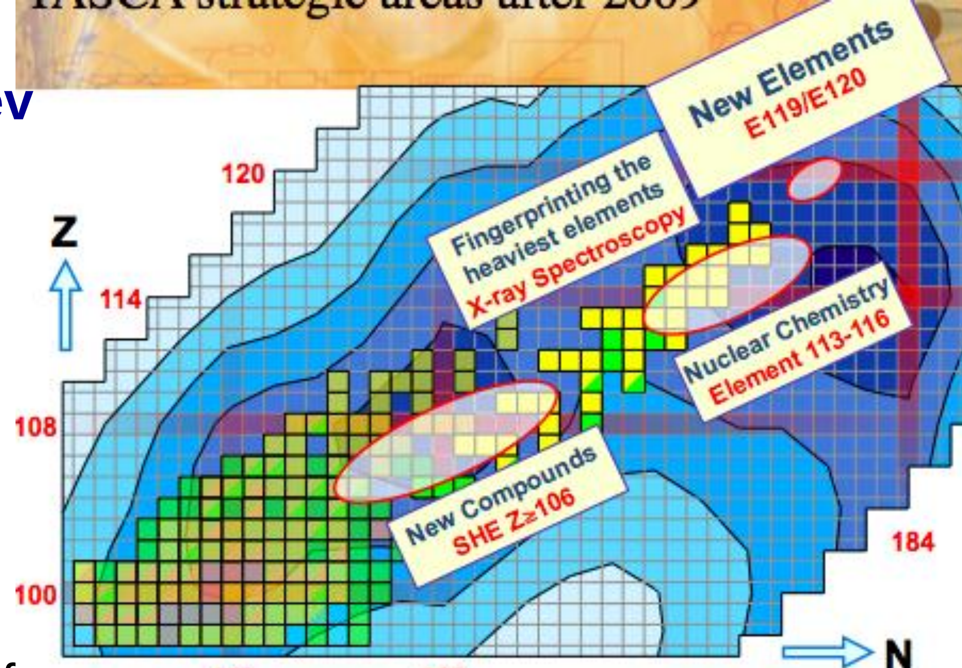
Mass measurement of the heaviest nuclei with m-TOF system coupled to GARIS (Wada-san's group)

Study of heavy ion transfer reaction with GARIS for the study of neutron rich nuclei around N=126 region.

Try to measure X-ray from evaporation residues (in collaboration with W. Henning).

Developing FPD detector system for α-γ-e coincidence experiment

TASCA at GSI A. Yakushev



- Many improvements

  new target wheel
  new digital electronics
  stable and intense Ti-50 beam….

- **First search for E119 and E120 with ^{50}Ti beam**

  2011: ^{50}Ti+^{249}Cf; a cross section limit of
  2012: ^{50}Ti+^{249Bk}; a cross section limit of 55 fb reached in 4 monts

- Confirmation experiments: synthesis of E117 and spectroscopy of E115

  2 events of E117 in 4 weeks
  25+ events of E115 in 3 weeks

Coupling of the gas-filled recoil separator TASCA to chemistry and spectroscopy devices with a gas-jet

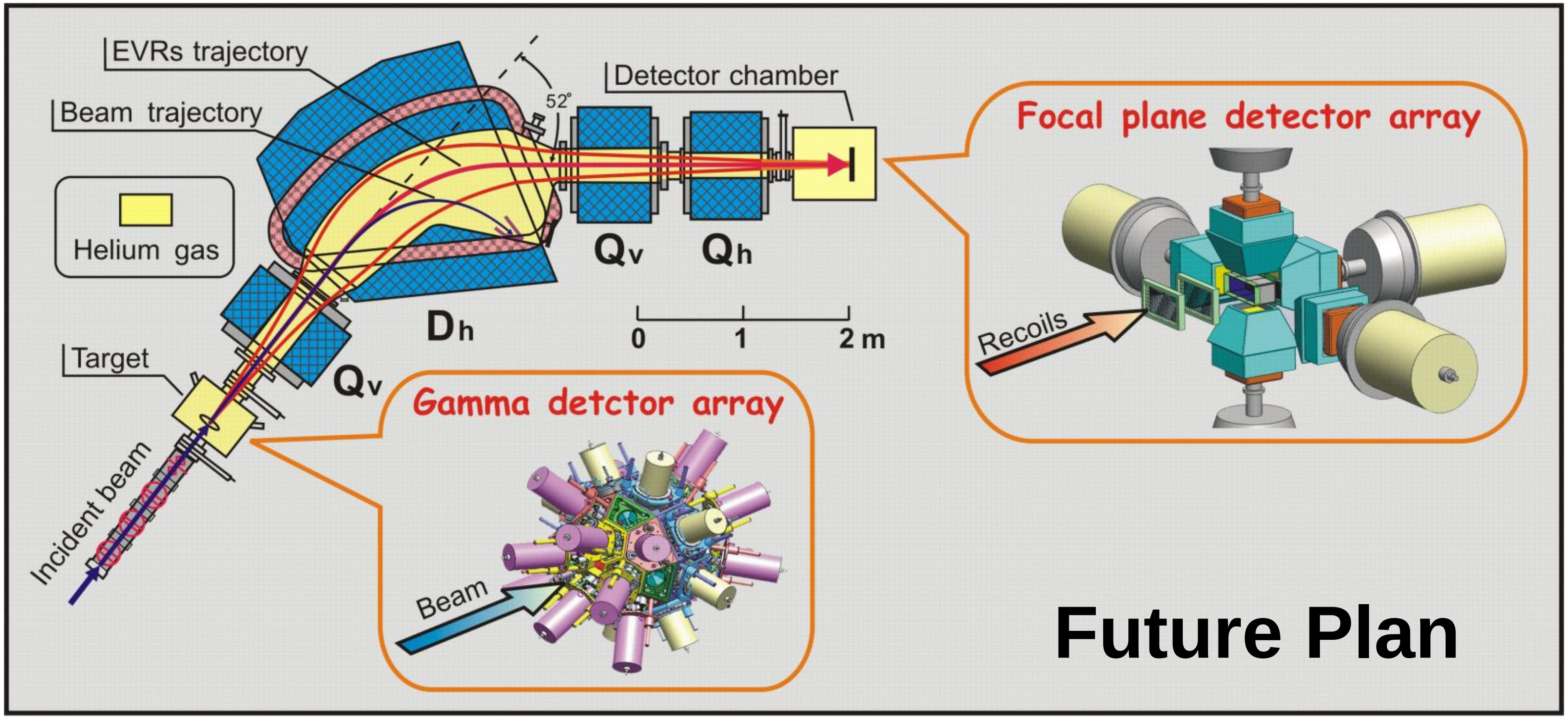
Julia Even Helmholtz-Institute Mainz

Gas Filled Separator at Institute Modern Physics

(GAN Zaiguo)

First test experiment: $^{208}Pb(^{64}Ni, n)^{271}Ds$

One α-decay chain assigned to ^{271}Ds



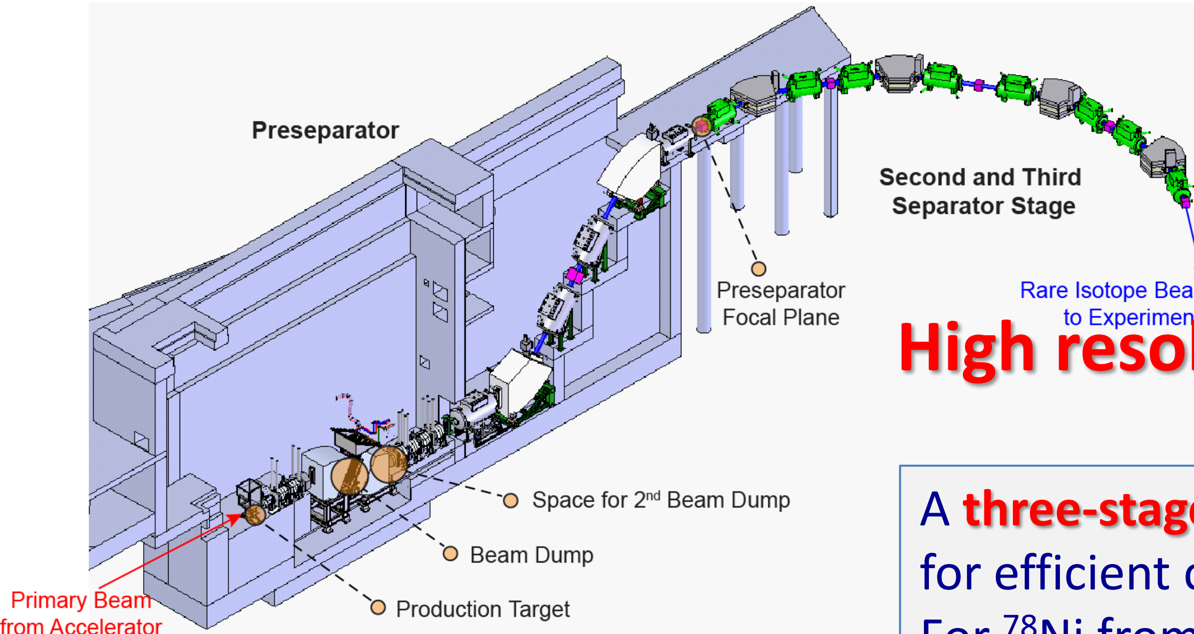
- Study the chemical properties of SHE,
- the reaction mechanism to produce SHN
- the structure in heavy nuclei.

Secondary Beam preparation :

- **Fragment separators:**

FRIB
Super-FRS
Big-RIPS

FRIBS fragment separator design (M. Hausmann, MSU)



High resolution and high purity

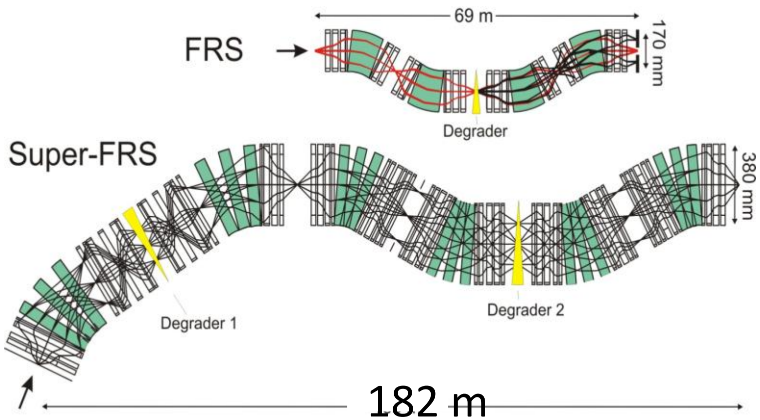
A vertically bending preseparator (first stage) compresses the accepted momentum width of up to ± 5% of the beam by a factor of three in the standard operational mode.

A **three-stage** fragment separator for efficient collection and **purification**
For ^{78}Ni from from 38/270000 to 33/590

high-resolution separator stage including momentum
tagging and the in-flight particle identification (**important for gamma decay in flight**!).

Comparison of FRS with Super-FRS

Hans Geisel



Higher acceptance and trasmission

More than one order of magnitude !!

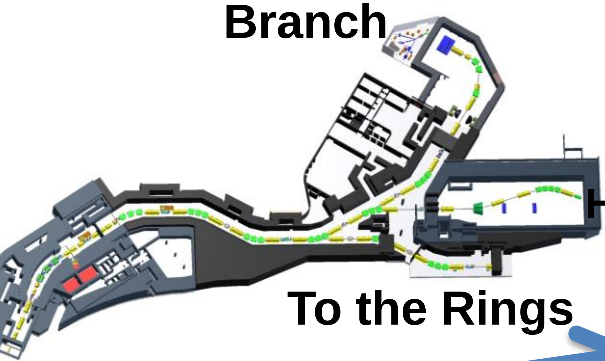
Separation with two degrader stages

Separator Experiments:

- Search for New Isotopes, map the Driplines
- Measure Production Cross Sections,
- Reaction Kinematics,
- Mass
- Rare Decay Modes (In-Flight Decay)
- Interaction, nucleon removal, charge-changing cross sections

PIONIC ATOMS (also at BigRIPS, Takahiro Nishi)

Low Energy Branch



HISPEC
DESPEC
LASPEC
MATS

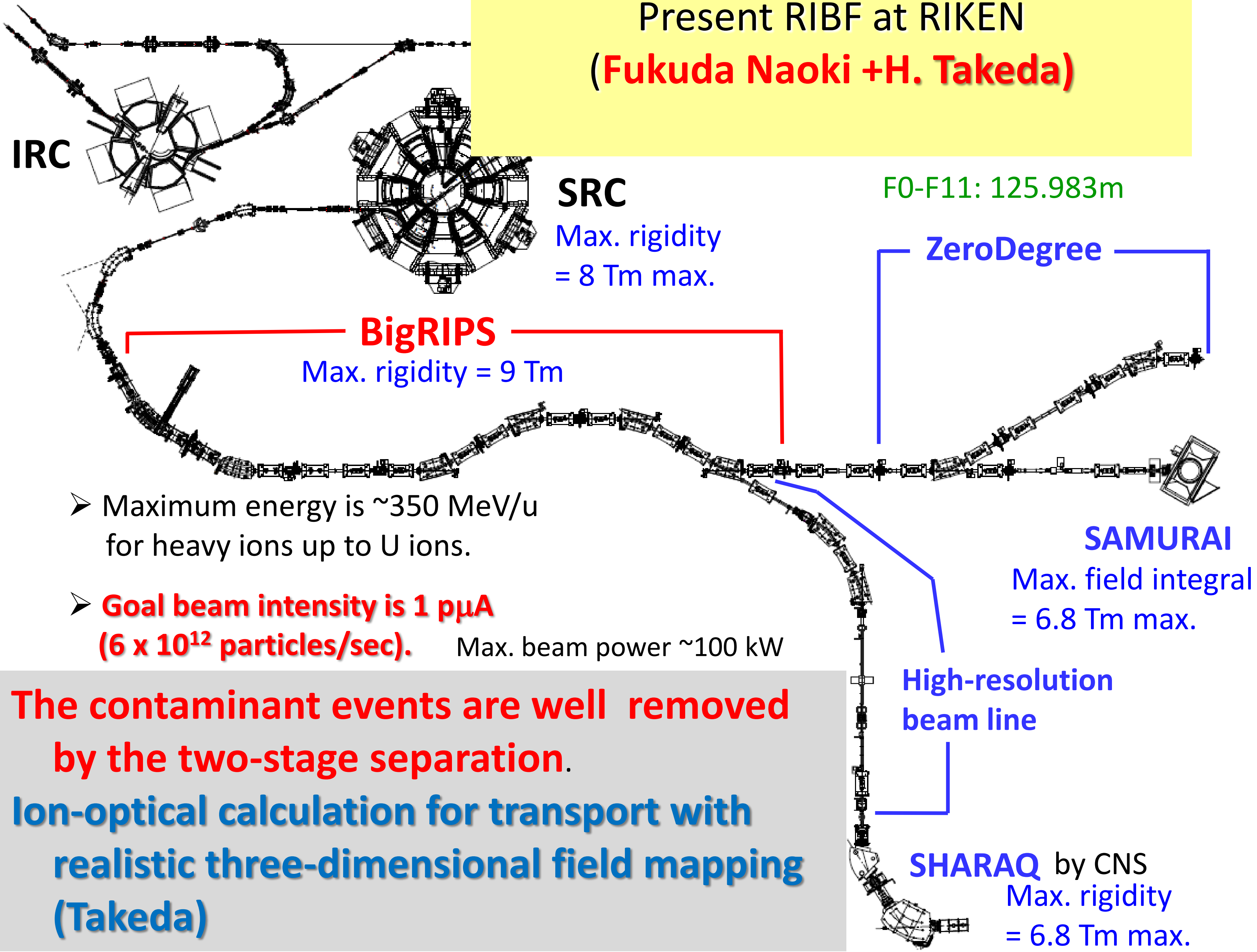
R3B
High Energy Branch

To the Rings

ILIMA
EXL
ELISE
AIC

NUSTAR program at FAIR

Present RIBF at RIKEN
(**Fukuda Naoki +H. Takeda)**



- Maximum energy is ~350 MeV/u
  for heavy ions up to U ions.
- **Goal beam intensity is 1 pμA**
  (6 x 10^{12} particles/sec). Max. beam power ~100 kW

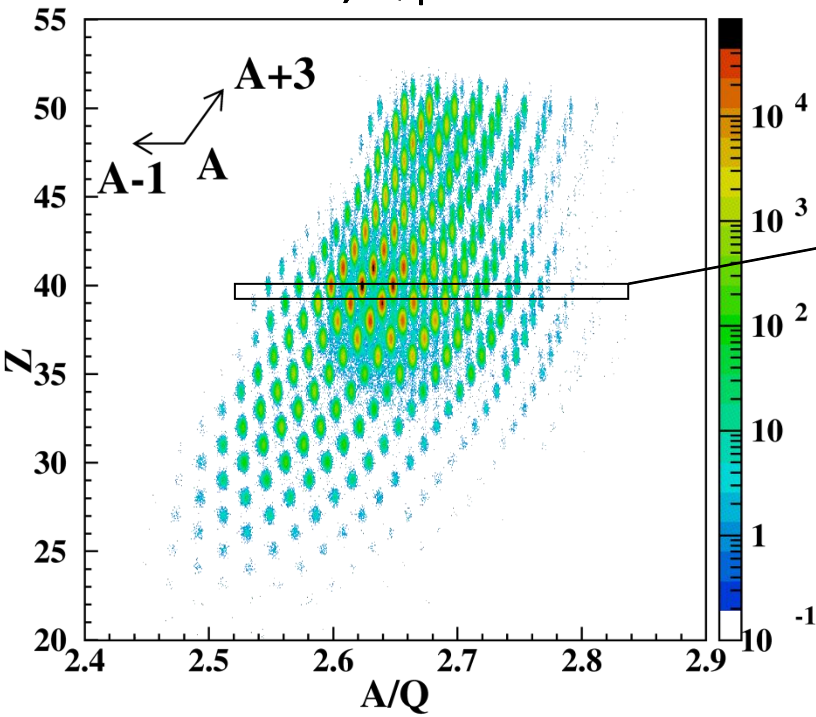
The contaminant events are well removed by the two-stage separation.

Ion-optical calculation for transport with realistic three-dimensional field mapping (Takeda)

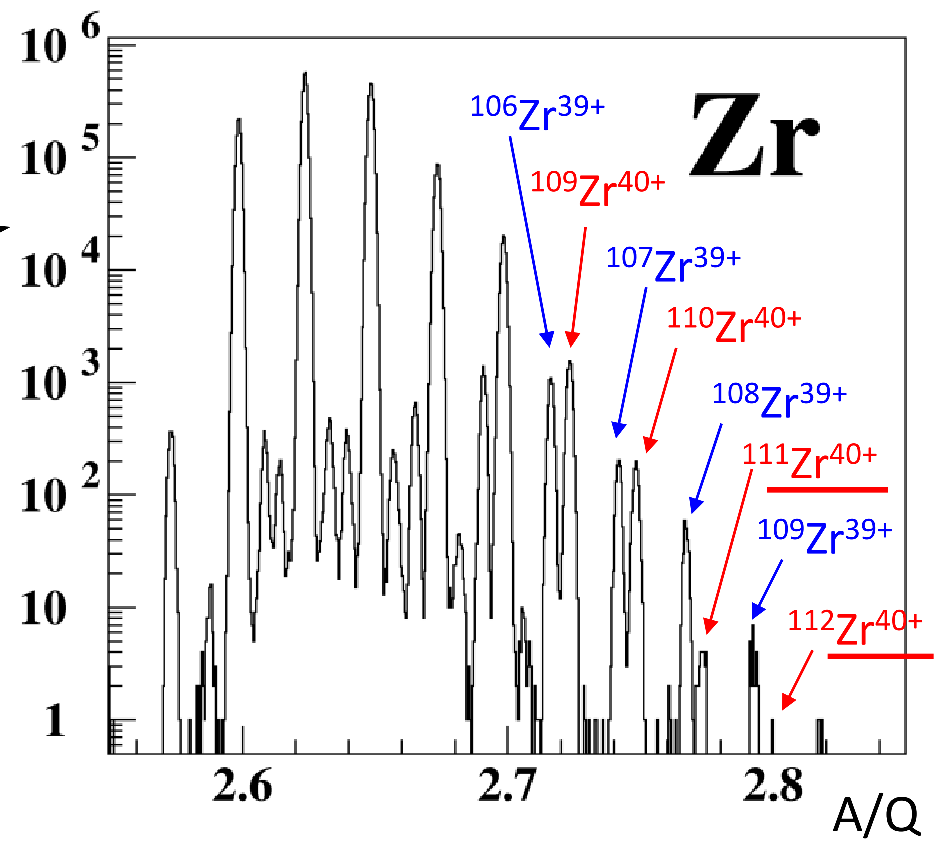
PID power for fission fragment

High enough to well identify charge states
thanks to the track reconstruction!

Z vs. *A*/*Q* plot



A/*Q* spectrum for Zr isotopes (*Z*=40)



U+Be 2.9 mm Br 01 = 7.990 Tm
F1 deg Al 2.18mm $\Delta p/p = \pm 3\%$
G2 setting in J. Phys. Soc. Jpn. 79 (2010) 073201.

r.m.s. *A*/*Q* resolution: 0.035 %

Secondary Beam preparation :

- ISOL beams (GANIL, ISOLDE)
- Gas catchers

Tierry Stora, Olivier BAJEAT + Daniel Flink

Towards Isobar Free Ion Beams

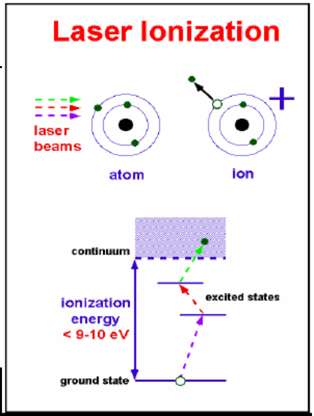
ISOL(DE) targets and ion sources

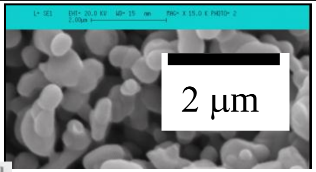
Target materials (30):

- Refractory oxides carbides (Al_2O_3, SiC, UCx, nano Y2O3)
- Solid metals (Ta, Nb, Mo)
- Molten metals (Pb, La, Sn)
- Molten salt (NaF-LiF)

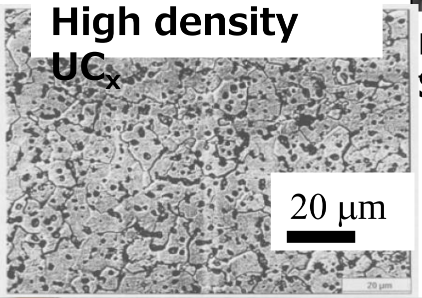
Ion sources (>5):

- Surface (W, Re, GdB6)
- FEBIAD, RF Plasma
- LIST (talk D. Fink)





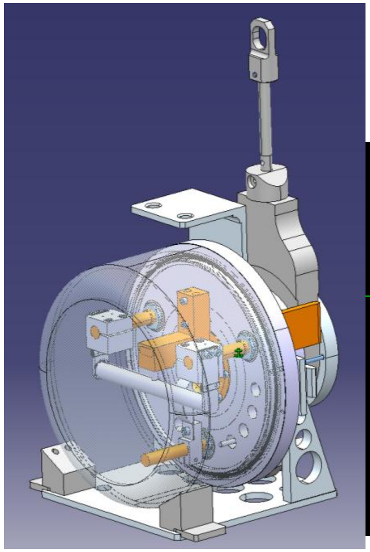
nm/sub-µm SiC

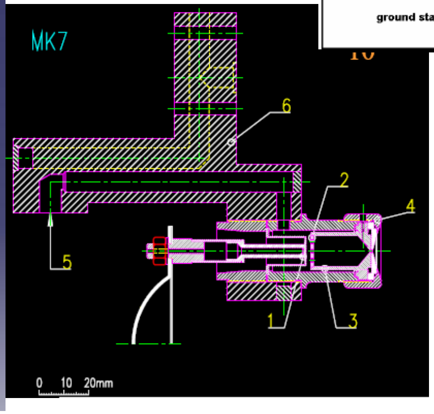


High density UC_x

Ta foils

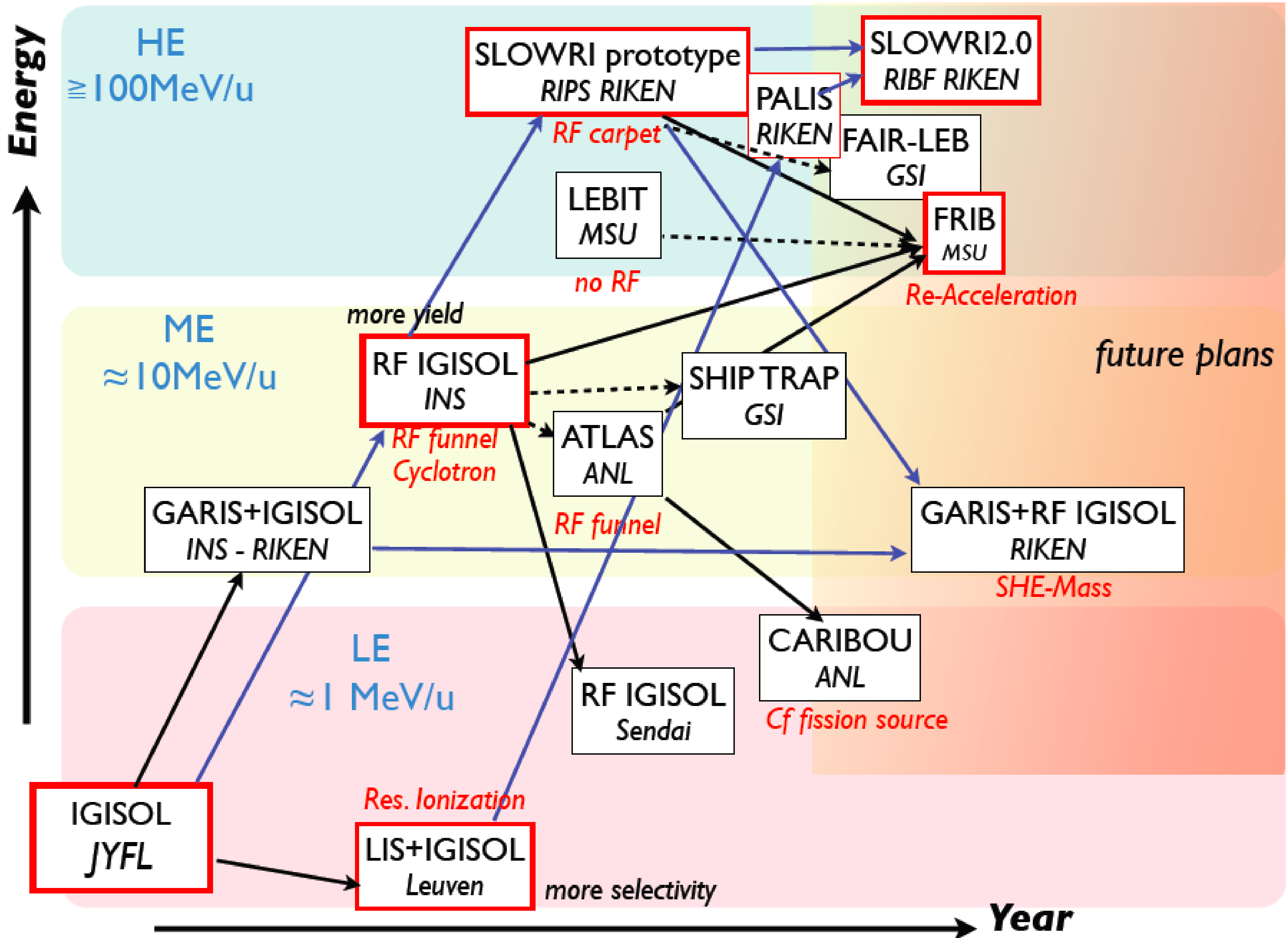
ISOLDE UC_xpressed





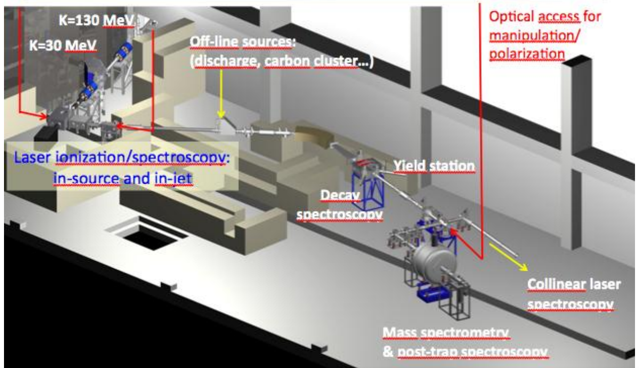
Michiharu Wada

Gas Cell Genealogy ~personal view~



IGISOL-4: a new facility 2012

Ian Moore



- Stable beam testing to collinear line and to JYFLTRAP (not yet through)
  Beam from both cyclotrons to target chamber
- ^{58}Ni(p, n)^{58}Cu used to check IGISOL-4 yields
- First on-line implantation experiment last week (light-ion induced fusion-evaporation to ^{100}Pd)

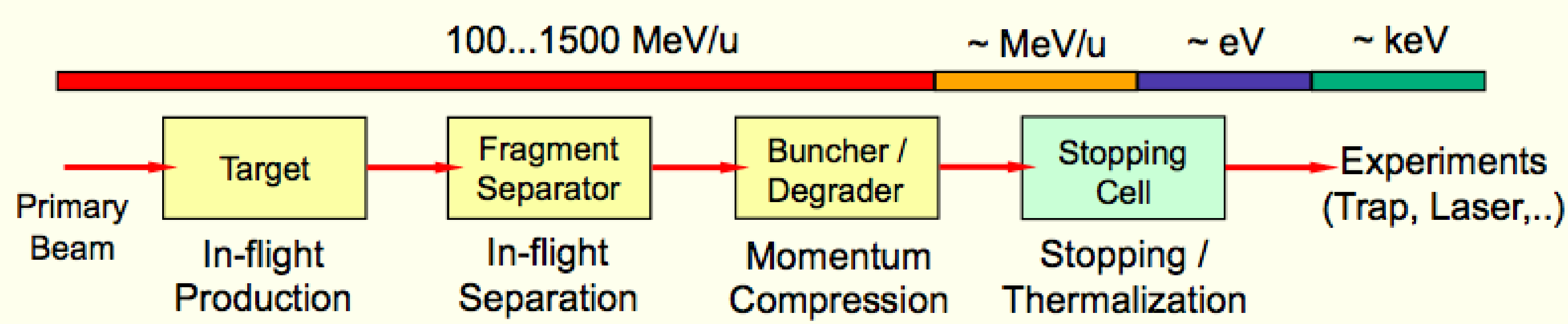
(first) Cryogenic stopping cell at GSI/FAIR

Wolfang Plas

- Systematic study of the cryogenic stopping cell (e.g. intensity limitations, temperature effects)
- Increase stopping efficiency even further (higher densities)

MR-TOF-MS

- Systematic study of mass measurement accuracy



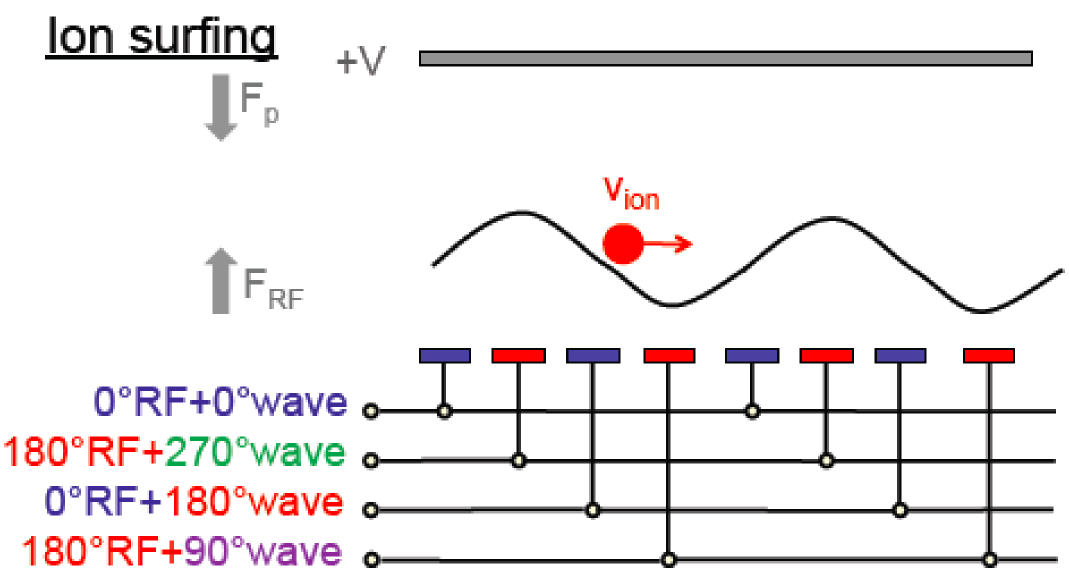
The NSCL cyclotron gas stopper + traveling wave ion transport

(Schawarz Stefan +Brodeure Maxime)

Stefan Schwarz

- Why gas stopping at NSCL
- Linear cells and their limitations
- Cyclotron stopper
    - Simulations
    - Design
    - Construction
- Status

Maxime Brodeure



- *Novel* approach (for RIB) [5]
- Transport using travelling wave
- Simpler circuitry and lower C
- Ion speed not discharge-limited

(can extract shorter-lived isotopes)

[5] G. Bollen, IJMS 299, 131 (2011)

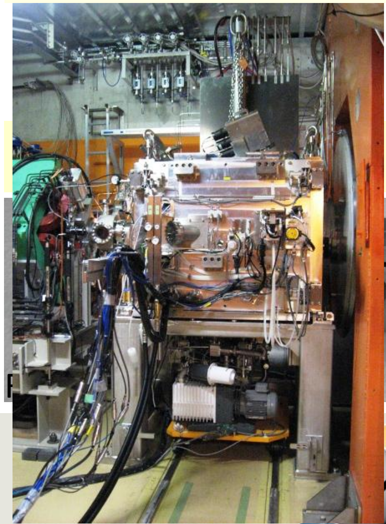
Dealing with High power :
targets
Beam dumps
magnets
others…

High Power Target Technology

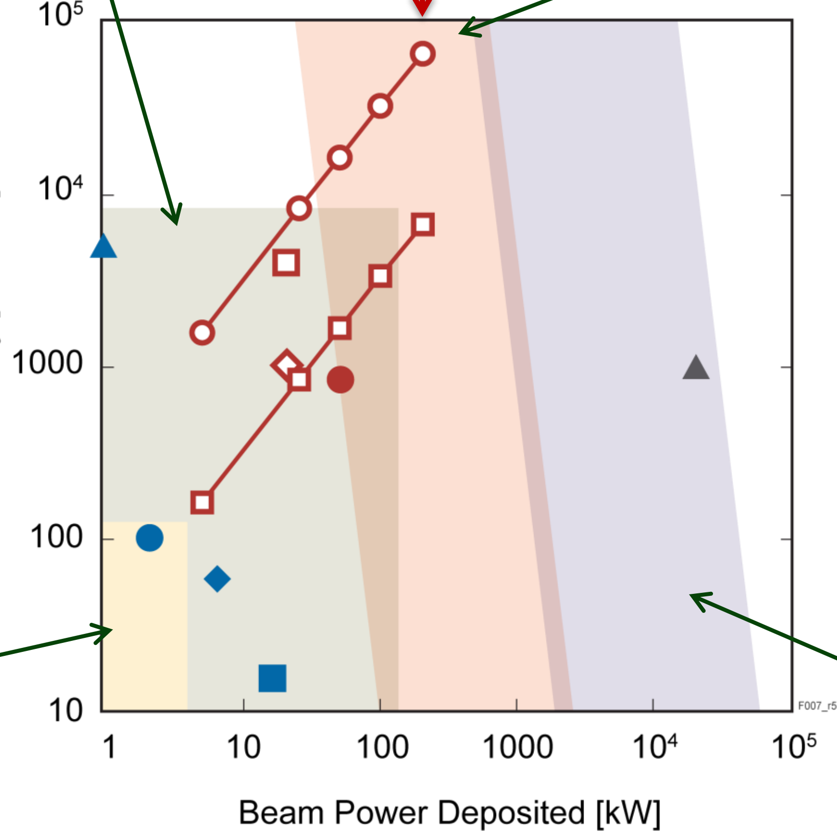
Federique Pellemoine
Koichi Yoshida

Rotating single-slice targets

BigRIPS Target System



FRIB - 400 kW



Rotating multi-slice targets

Running devices
- ● MSU - CCF
- ◆ SPIRAL - GANIL
- ▲ SISSI - GANIL
- ■ LAMPF

Existing Prototypes
- ◇ GSI - FAIR
- □ RIKEN - RIBF
- -○- FRIB - U
- -□- FRIB - O
- ● SPIRAL2 - GANIL

To be developed
- ▲ IFMIF

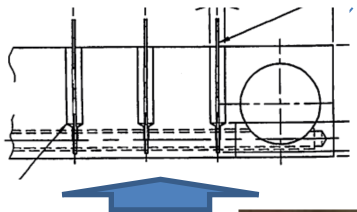
Liquid Li targets

Koichi Yoshida

Beam Dump Temperature for ^{238}U 345MeV/n 8.3pnA

Exit-Dump is operated with water of 13°C, 0.7MPa, and 2.6m/s. (Design: 1MPa, 10m/s)

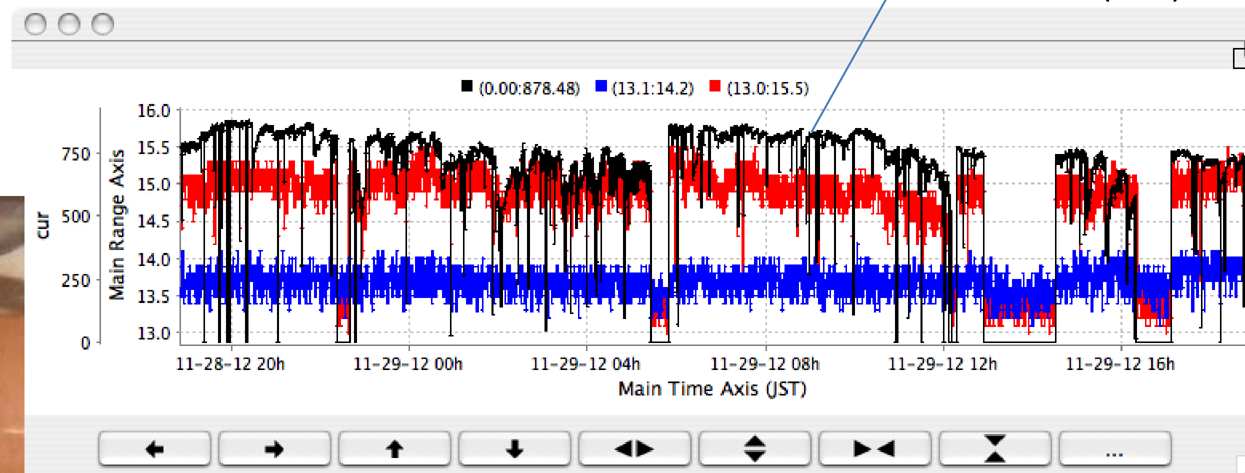
Thermo-couples mounted on the exit beam dump



1mm from the surface

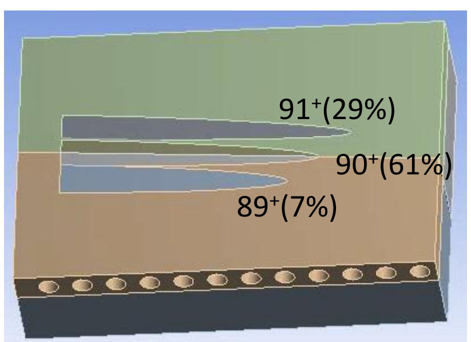
Beam

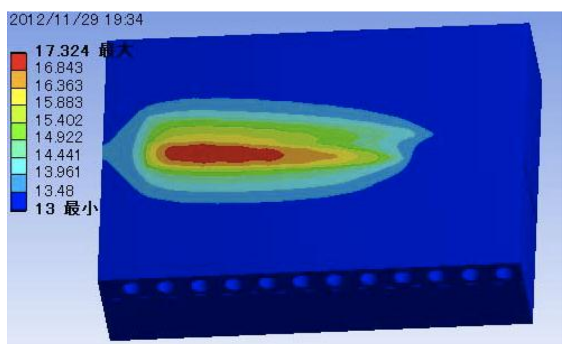
Beam Current (enA)

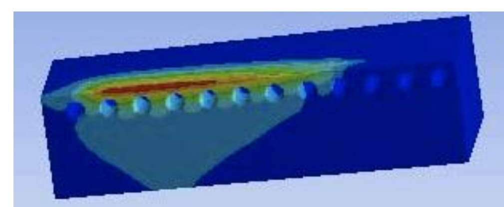


Temperature increase 15.1 – 13.6 =1.5 °C

Estimated beam spot at dump
Heat load : 522W







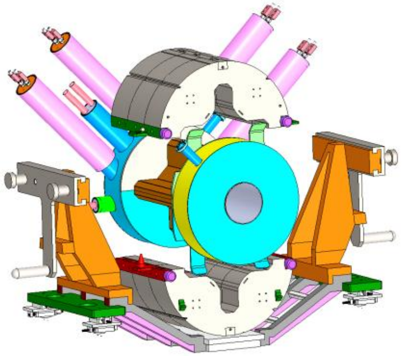
Kazuhiro Tanaka

ANSYS simulation: Temperature increase 15.0-13.0 = 2 °C (not bad, although large ambiguity)

Fragment Separator Magnets

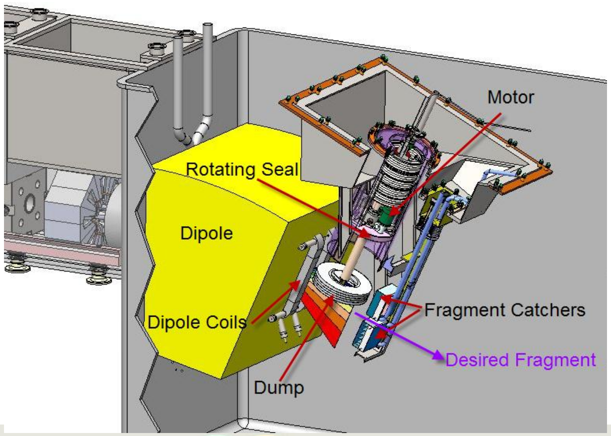
Radiation tolerant magnets in frontend crucial for efficient operation

- High temperature superconductor (HTS) and low temperature superconductor (LTS) with radiation tolerant epoxy
  - HTS radiation hardness verified at Brookhaven National Laboratory.
  - Expected HTS magnets lifetime ~ facility lifetime
- Remote handling design in collaboration with ORNL



Primary Beam Dump

Water-filled Rotating Drum for 400 kW operation



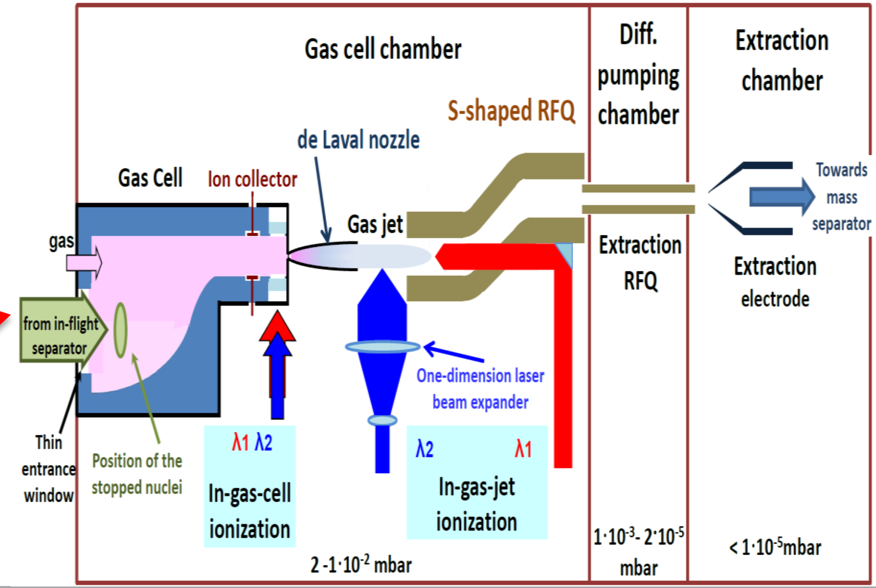
Also allows harvesting of rare isotopes from cooling water

LASER ionization techniques

LASER techniques

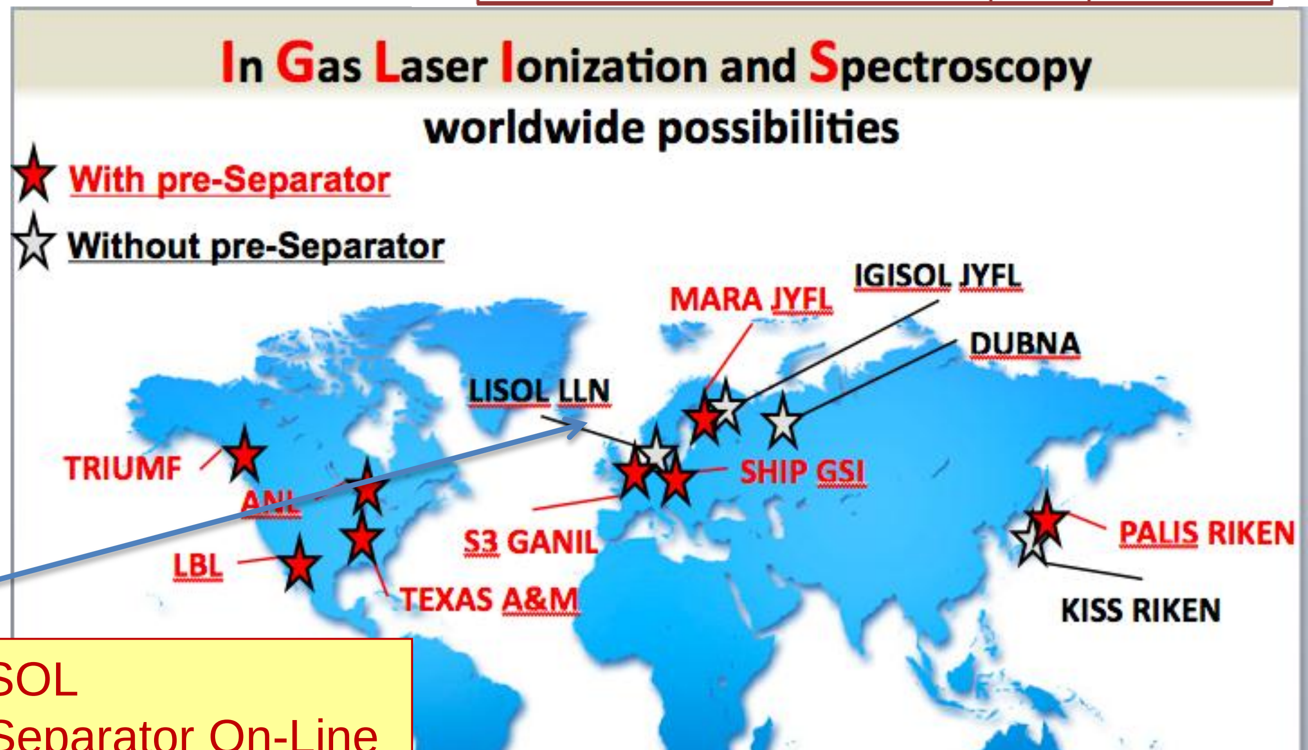
Mark Hyse, Yuri Kudryavtsev,
Jens Lassen Bruce Marsh,

- Production of pure radioactive ion beams in gas jet (innovative result!)



- Ground state properties of nuclei

- atomic physics



LISOL
Leuven Isotope Separator On-Line

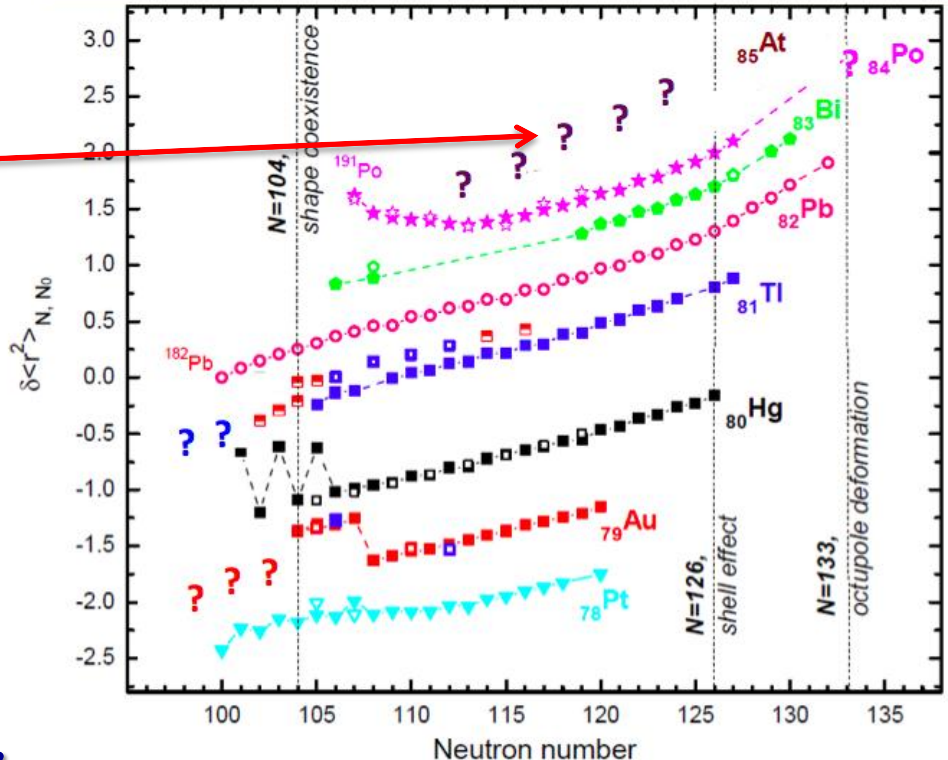
Bruce Marsh

Properties of Astatine isotopes

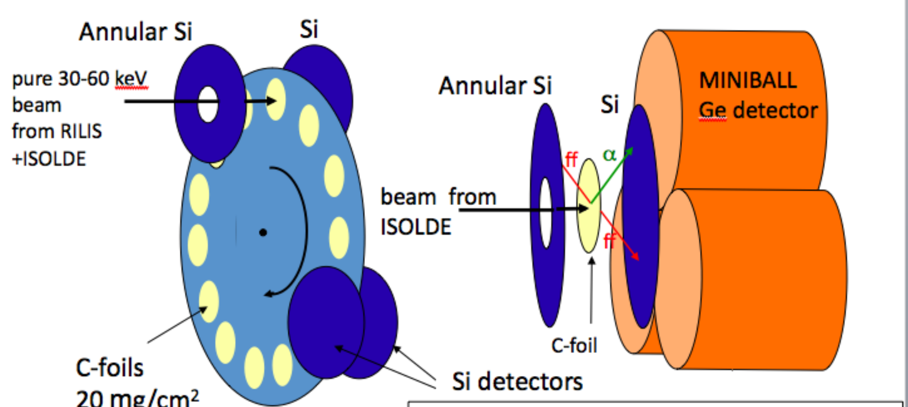
Charge radius (from isotope shifts)

Decay spectroscopy – alpha and gamma decay

Overview of results for charge radii measurements

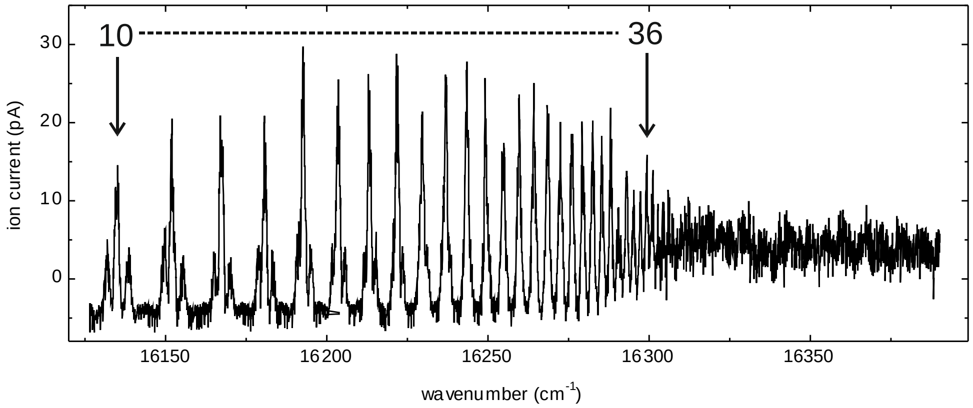


Windmill for α- and γ- decay spectroscopy

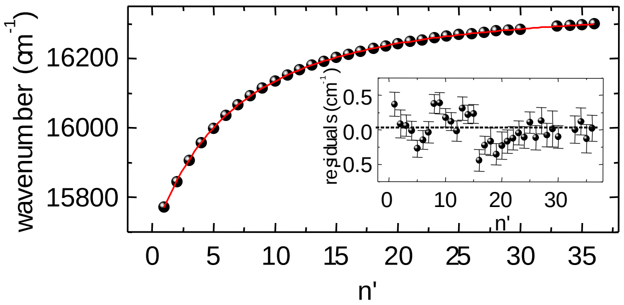


Klaus Wendt talk

In-source Spectroscopy on Astatine



Advanced atomic physics evaluation of the Ionization Potential



$E_{IP}(At) =$

75151(1) cm^{-1}

Thomas Cocolios

Collinear laser spectroscopy

Probing the nucleus with atomic levels

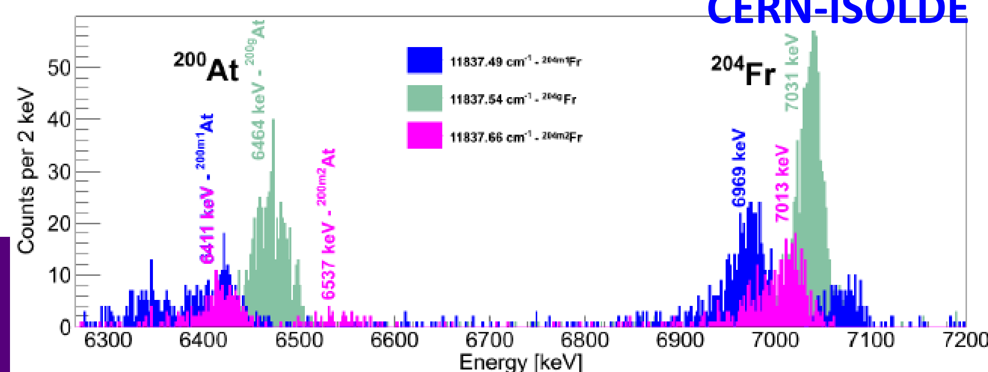
α tagging

Charge radius

Identifying hyperfine components with the DSS

Astatine and Francium

CERN-ISOLDE



"OROCHI" nuclear moment and spin for low intensities

EMIS2012, 2012 12/2-7, T. Furukawa

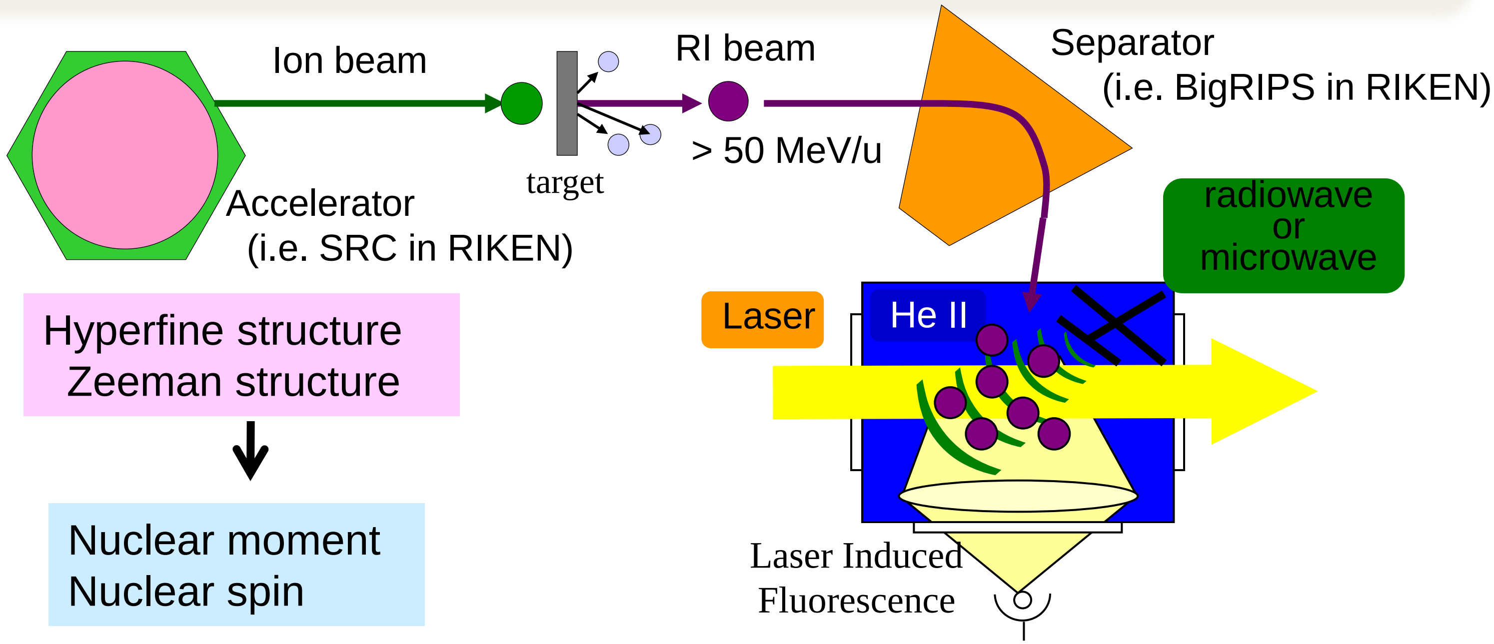
(Traditional) laser spectroscopy of rare and exotic nuclei…

- Tiny fluorescent signal
  - Low yield & low trapping efficiency/interaction time
- Huge background photons
  - Mostly due to strong stray laser light

Our solution : "Laser spectroscopy in superfluid helium (He II)"

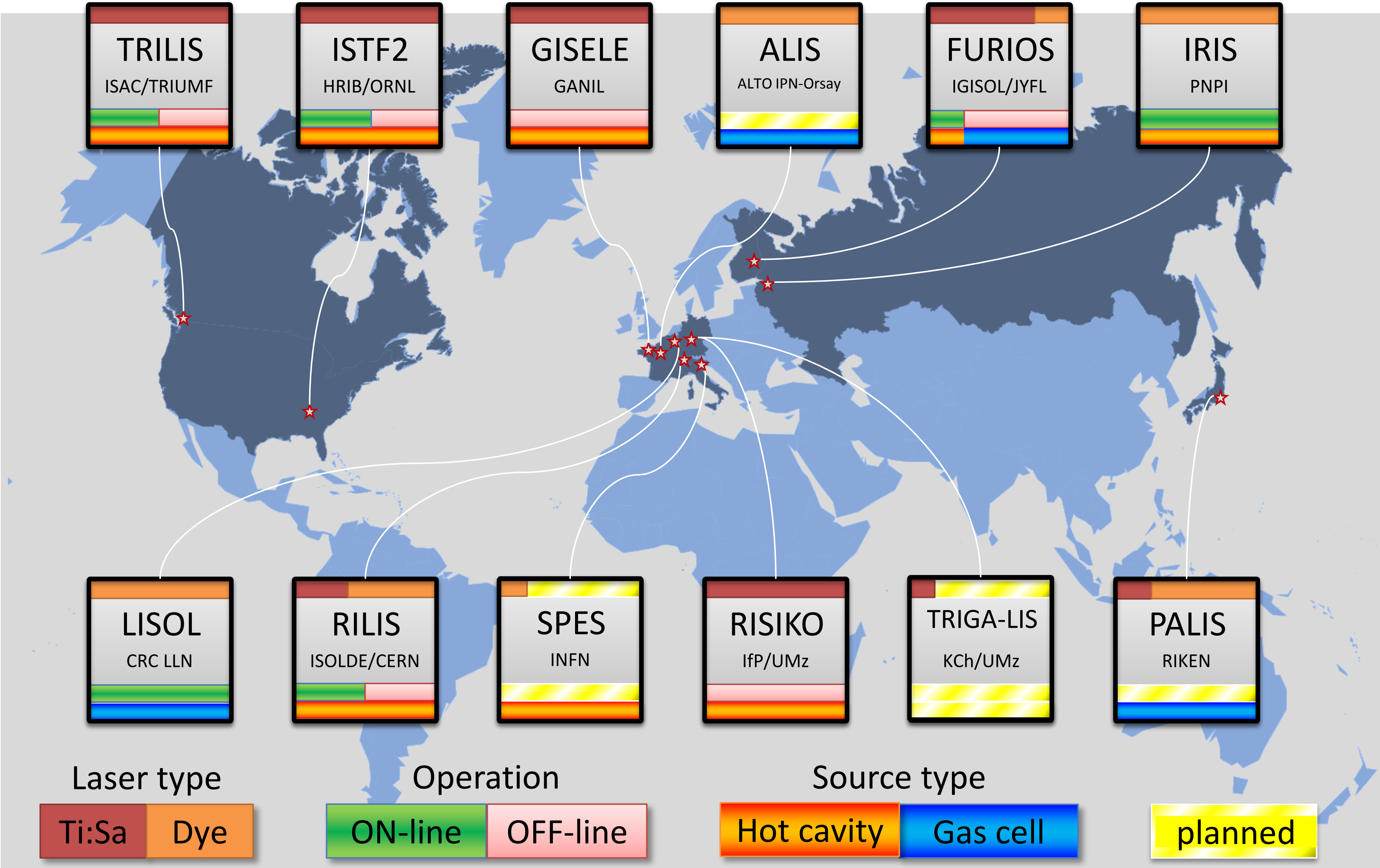
"OROCHI"

Optical RI-atom Observation in Condensed Helium as Ion-catcher



Klaus Went

Laser Ion Sources Worldwide 2012 and beyond



Slide: S. Rothe

TRAPS

TRAPS

Szilard Nagy, Susanne Kreim
Daniel Rodriguez, Anna Kwiatkowsky
Veli Kolhinen, Mathhew Redshow
Peter Schury, Timo Dickel
Jun Aoki

Challenges for Penning traps
- Low Production Rates
- Short Lifetimes
- Contamination

FACILITY FOR RARE ISOTOPE BEAMS

LEBIT(MSU)
Single ion penning trap project

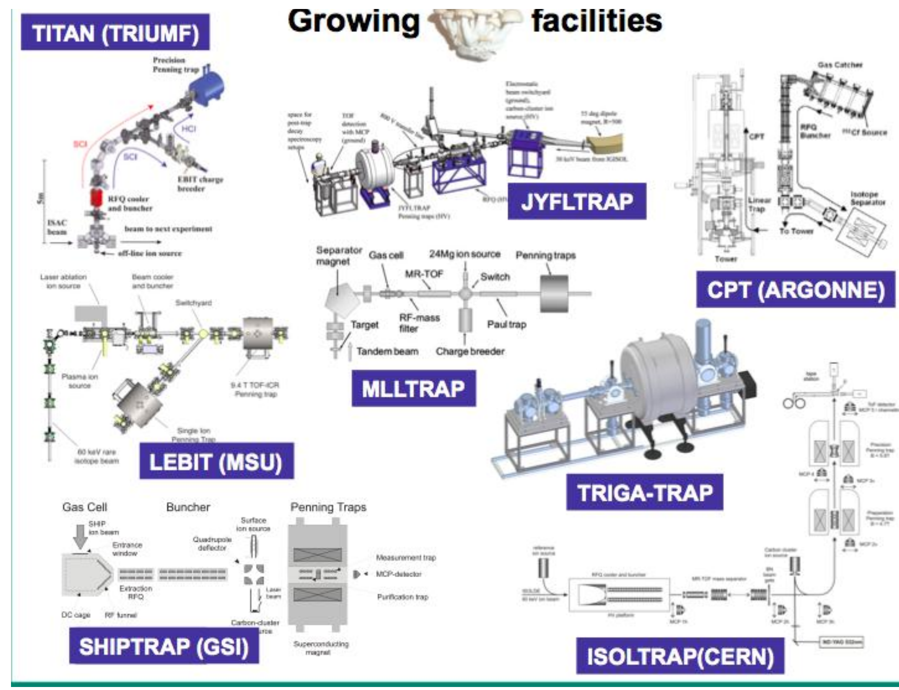
Upgrade of JYFLTRAP for IGISOL4

Complementarity of traps at radioactive ion beam facilities

Production	ISOLTRAP CERN	TITAN TRIUMF	SHIPTRAP GSI	MLLTRAP LMU	JYFLTRAP	LEBIT NSCL	CPT ANL	TRIGA-TRAP
ISOL	X	X						
Fusion-evaporation			X	X				
IGISOL					X			
Fragm.						X		
Spontan. fission							X	
Neutron induced fission								X
HCI		X						

THeTRAP, FSU-TRAP, SMILETRAP II

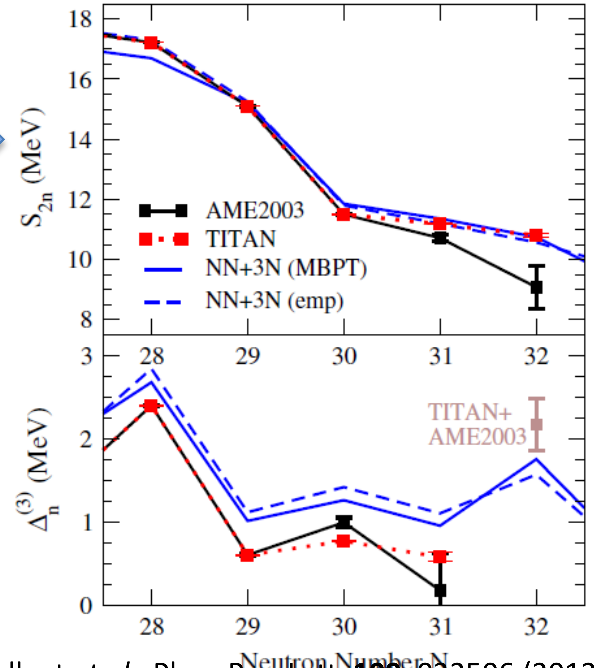
HITRAP, PENTATRAP, TRAPSENSOR, MATS, Lanzhou-TRAP, RIKEN-TRAP



Penning trap and MR-TOF MS

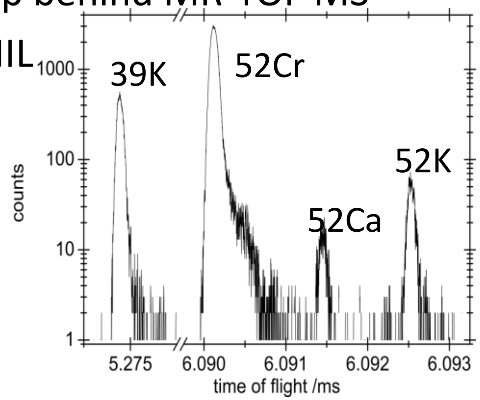
Susanne Kreim + Anna Kwiatkwski

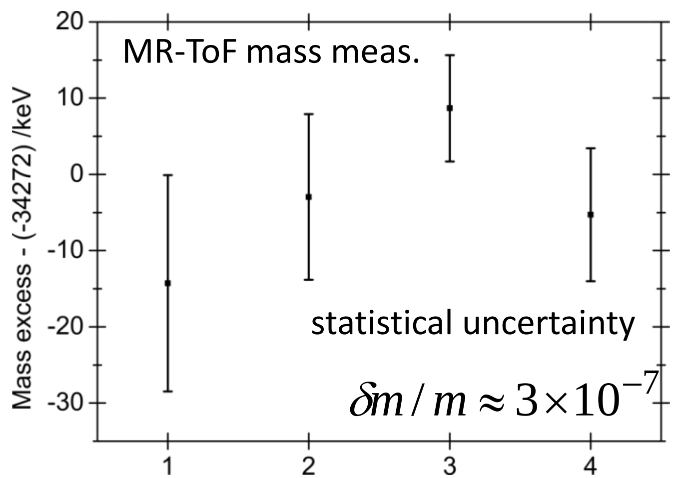
- Great advances in PTMS experiments
  - High-precision mass measurements
  - Techniques for fast measurement of „first masses“



A. T. Gallant *et al.*, Phys. Rev. Lett. **109**, 032506 (2012)

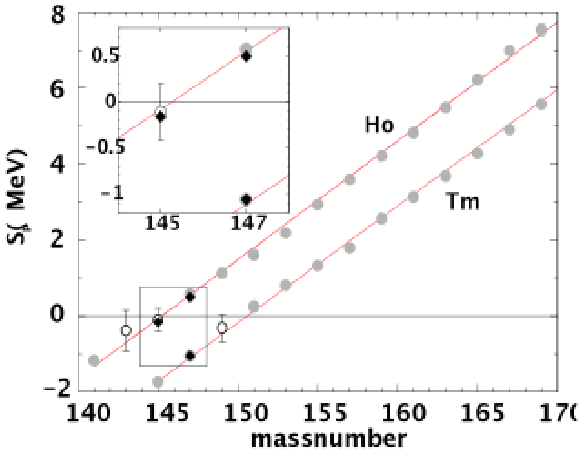
- Multiple Reflection -TOF Mass Spectroscopy
  is a versatile tool which offers new possibilities
  - Support existing PTMS program
    - ^{82}Zn for astrophysics
    - ^{54}Ca for nuclear-structure studies
  - MR-TOF MS plus detector as stand-alone system
  - Decay spectroscopy setup behind MR-TOF MS
  - MR-TOF MS @ S^3 at GANIL





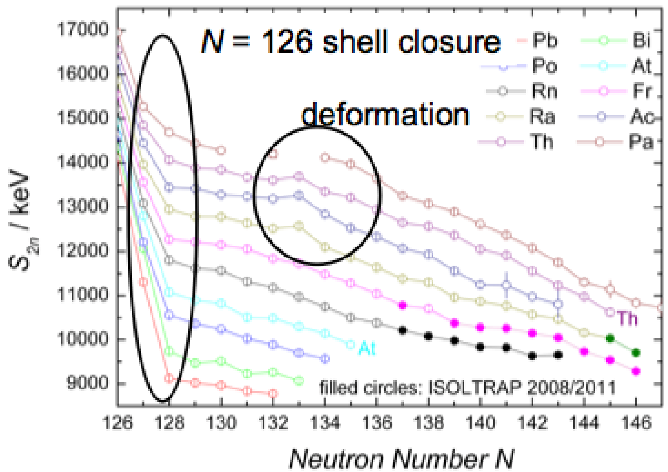
Some high lights from Penning Trap Mass Spectroscopy

$S_p = B(Z,N) - B(Z-1,N)$



SHIPTRAP: First direct mass measurement beyond the proton dripline.

$S_{2n} = B(Z,N) - B(Z,N-2)$

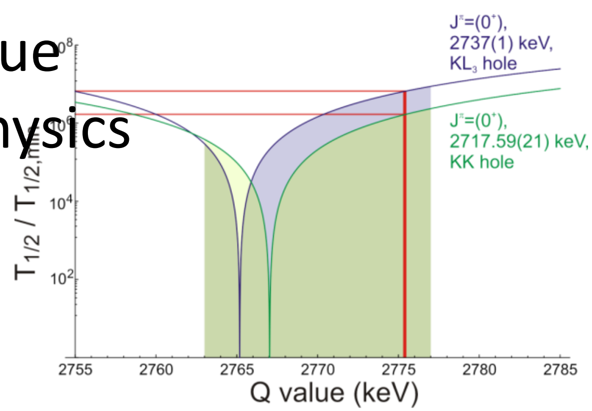


CPT/ISOLTRAP/JYFLTRAP/LEBIT/TITAN: Investigation of shell closures, halos, …

The Penning-trap industry" is booming!

- nuclear structure,
- halos,
- neutron stars,
- stability of superheavy elements,
- neutrino physics.

Accurate Q-value for neutrino physics

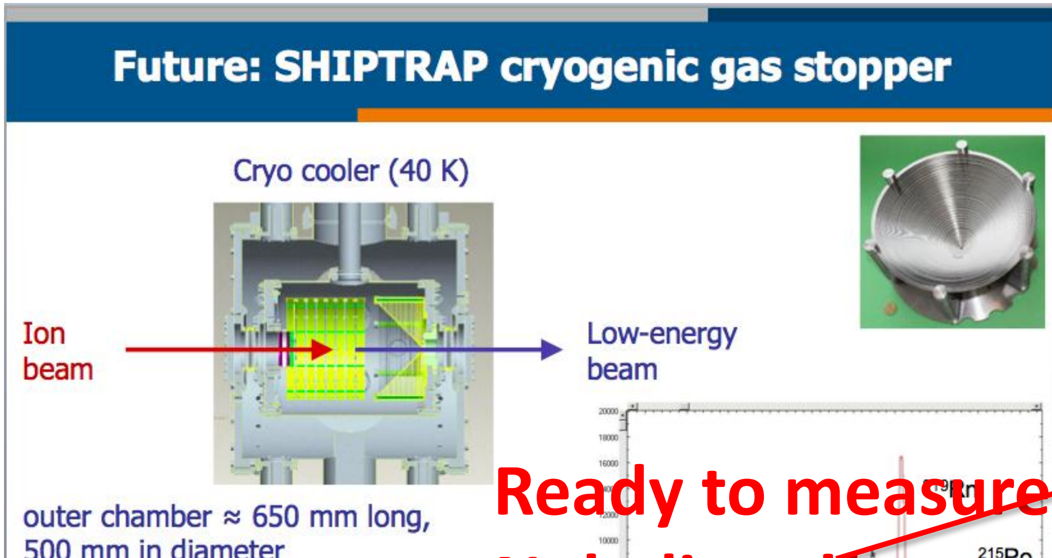


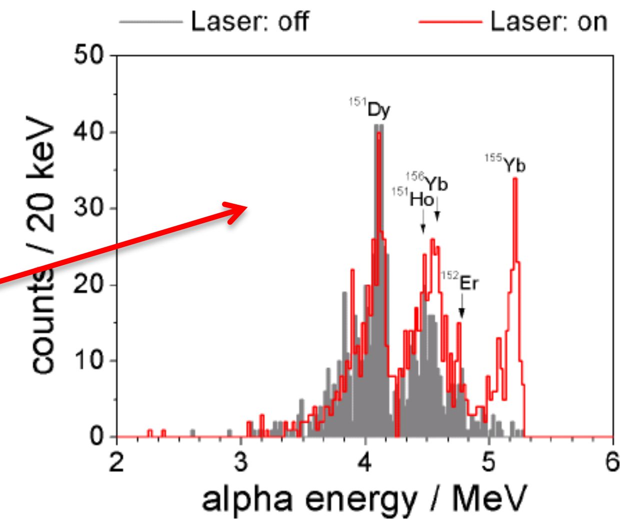
Literature:
Q = 2770(7) keV
TRAP:
Q = 2775.39(10) keV

Dedicated trap in Granada

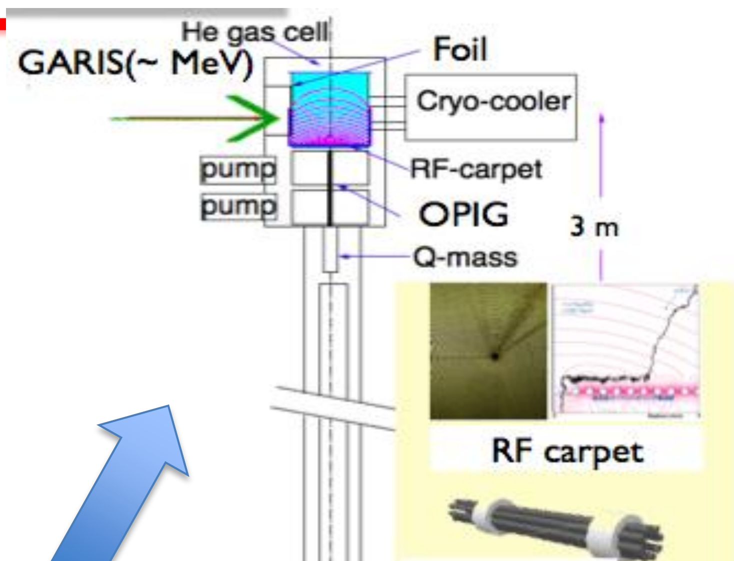
Rodriguez Daniel

Improvements for super-heavy nuclei





Ready to measure Nobelium !!



Candidate Nuclei:

$^{252-254}$No: ~6 cps

$^{255-257}$Rf: ~0.04 cps

etc ...

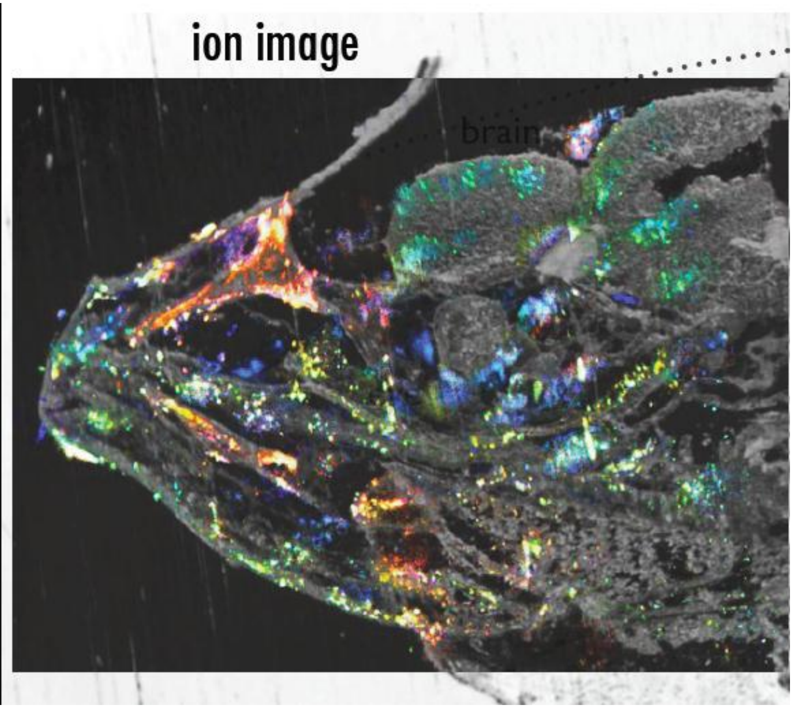
GARIS (RIKEN Gas-filled Recoil Ion Separator) + MR-TOF

Compact TRAP instruments for applications

Imaging mass Spectrometry

Jun Aoki

1 Micron m resolution



New Applications of a Multiple-Reflection Time-of-Flight Mass Spectrometer in Environment Sciences and in Medicine

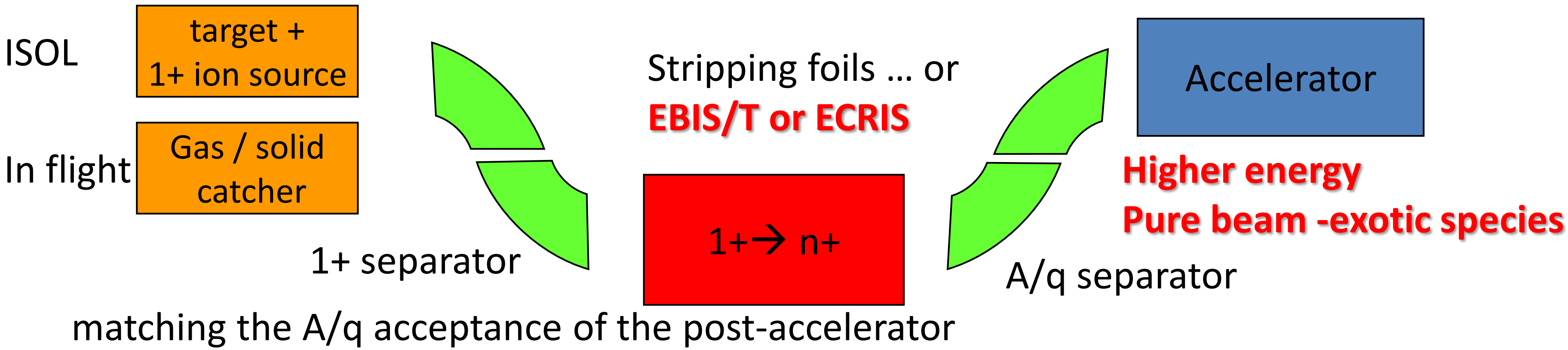
T. Dickel

- Various in-situ applications planned
  - Real-time tissue recognition
  - Waste water monitoring

Charge breeders and post accelerators

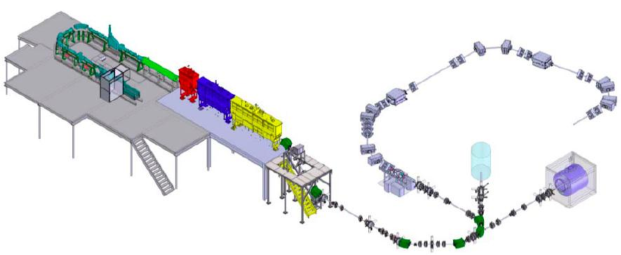
Charge breeders and post accelerators

(P.Delahaye- Daniela Leitner- Tim Giles)



- Post acceleration (Cyclotron at GANIL and LINAC at ISOLDE and TRIUMF) ReAccelerating facility (ReA) at Michigan State used with the Coupled Cyclotron Facility at NSCL

- Automatic tuning of beam lines with many parameters to be adjusted including not conventional beam line elements



Storage rings

- GSI-FAIR
- HIRFL-CSR
- RARE-RI at RIKEN
- SCRIPT at RIKEN

STORAGE RINGS (Yuri Litvinov)

Single-particle sensitivity

Long storage times

Very short lifetimes

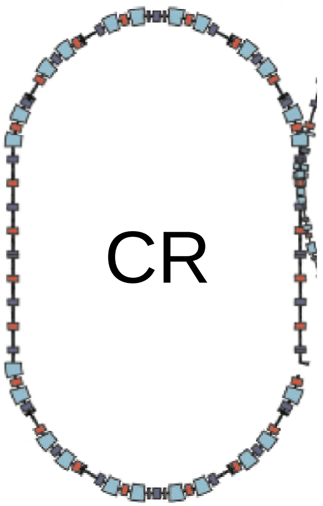
High atomic charge states

Broad-band measurements

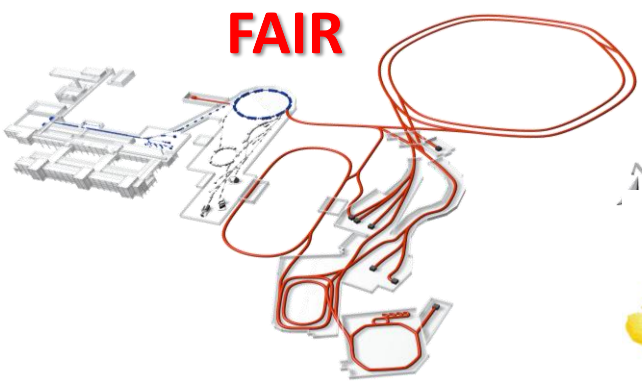
High resolving power

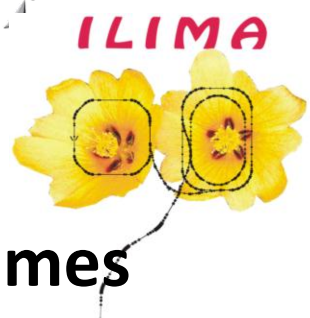
- Direct mass measurements of exotic nuclei
- Charge radii measurements [DR, scattering]
- Experiments with polarized beams
- Experiments with isomeric beams [DR, reactions]
- Nuclear magnetic moments [DR]
- Astrophysical reactions [(p,g), (a,g) ...]

- In-ring nuclear reactions



FAIR



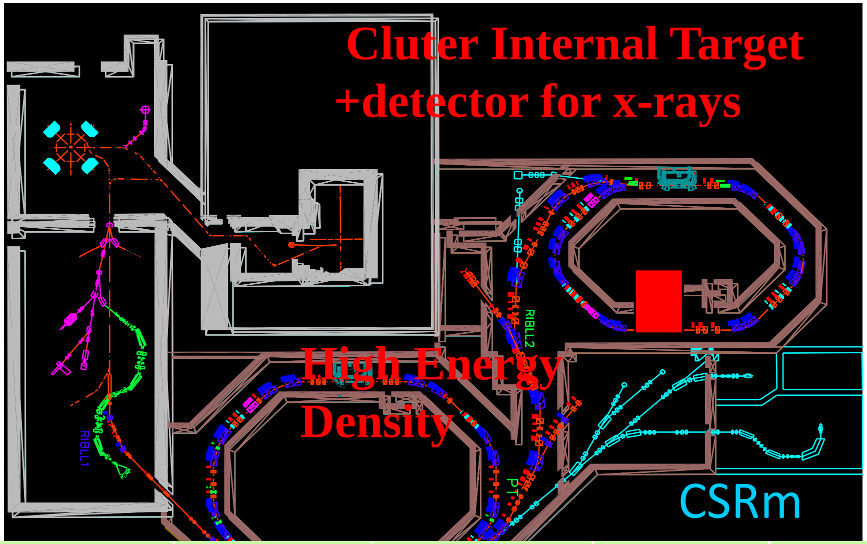


Masses and lifetimes

Isochronous Mass Spectrometry in the Collector Ring

HIRFL-CSR Storage Ring Cluster internal target

by Lu Rongshun (IMF)



Target	H_2	N_2	Ne	Ar	Kr
Thickness	06×10^{13}	1.2×10^{13}	2.0×10^{13}	1.0×10^{13}	1.0×10^{13}

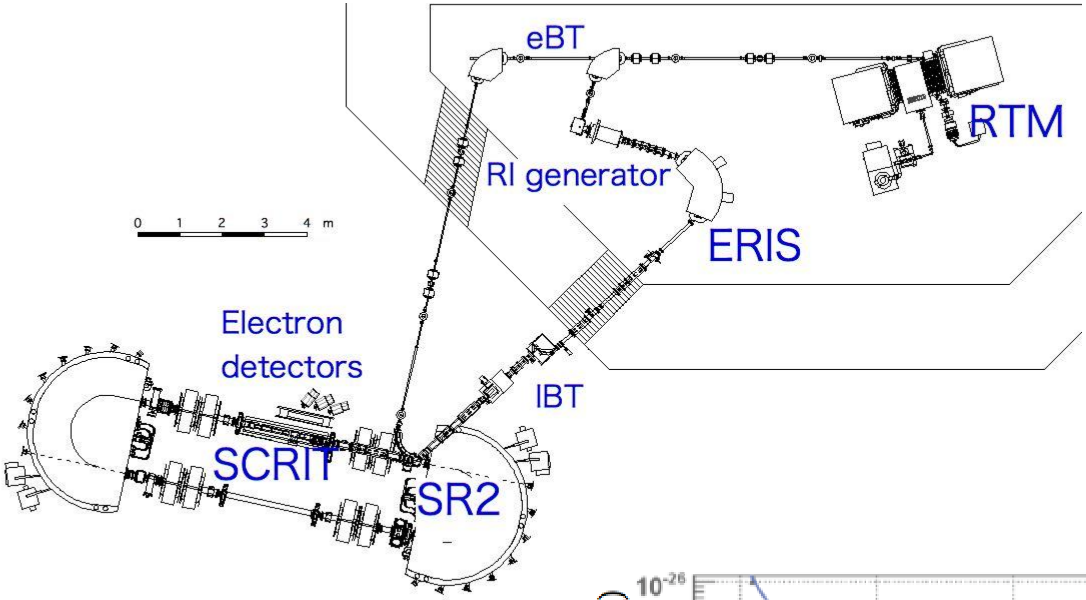
Construction of Rare-RI Ring at RIKEN RI beam factory

Measure the mass for very neutron-rich nuclei !

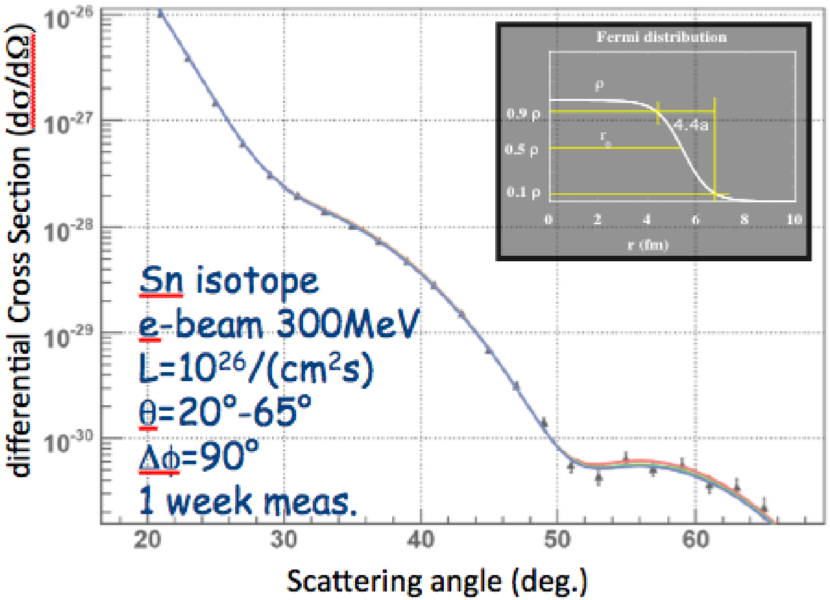
very short life-time, very small production rate

2014	2015
Preparation / Commissioning	Mass measurements
Primary beam injection Check of isochronism	^{78}Ni & nuclei near to A=80

The SCRIT Electron Scattering Facility



Electron Scattering off unstable Nuclei



Luminosity
> 10^{26} /(cm^2s)

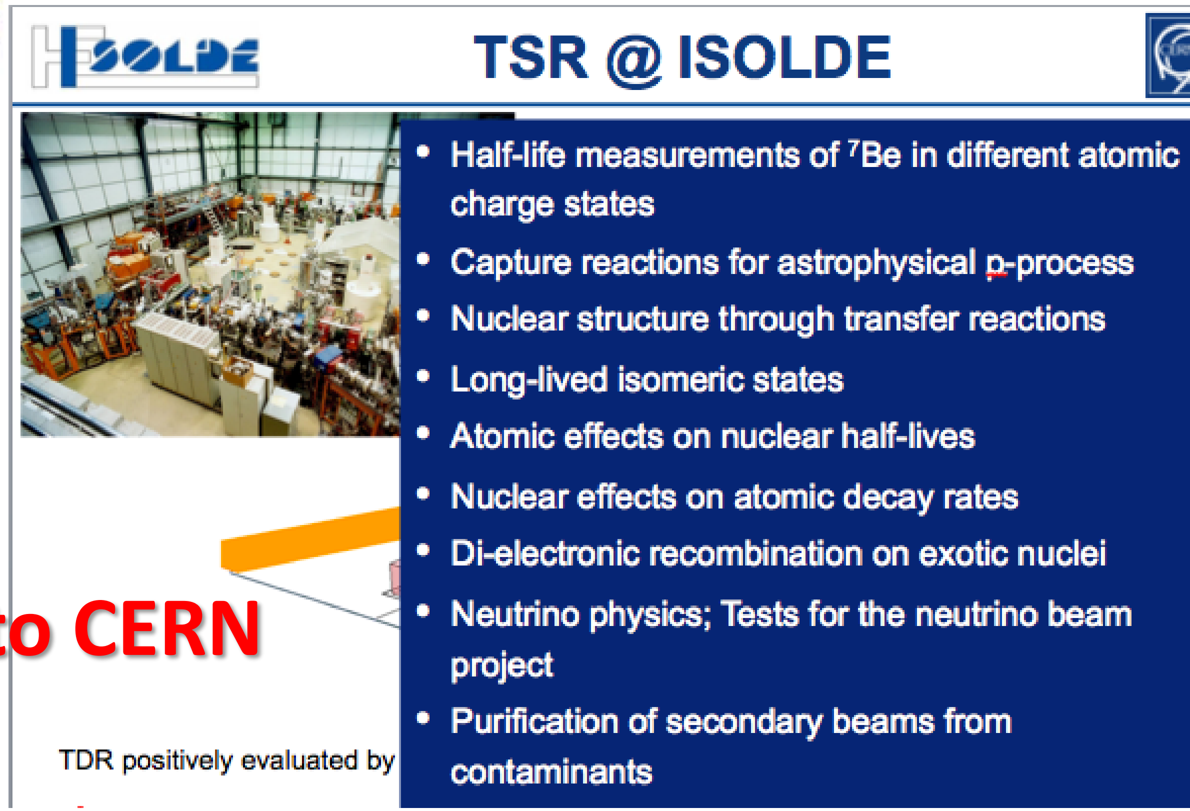
Cross section until the second maximum

Determination of radii and diffuseness with a few % accuracy

Masanori Wakasugi

Interest for use existing storage rings at new facilities

From Sweden to FAIR



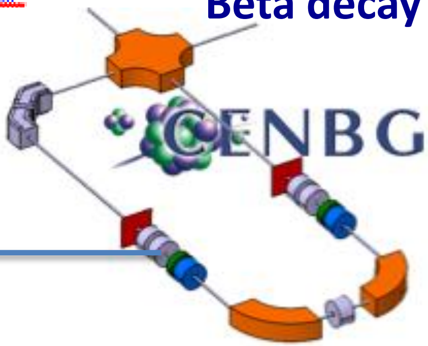
From Heidelberg to CERN

High resolution spectrometers

High resolution
Magnetic spectrometers (Turkutian Nieto Teresa + Michimasa Shinichiro+

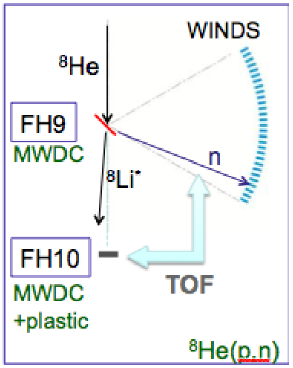
SPIRAL2/DESIR-High Resolution Separator

- Installation at CENBG during 2014.
- Tests (transmission, resolution) 2014-2015 and then GANIL



Beta decay

Spin
Isospin
excitation

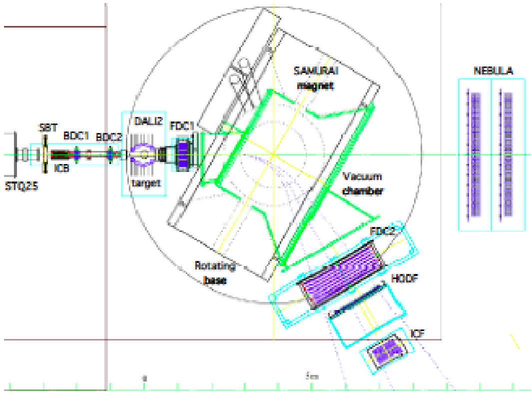


SHARAQ at RIKEN + WIND

= *Spectroscopy with High-resolution Analyzer and RadioActive Quantum beams*

Six physics experiments were successfully completed.

SHARAQ demonstrates new types of reaction probes by involving RI



SAMURAI at RIKEN

for kinematically complete measurements
in RI-beam induced reactions.
heavy ion detectors and neutron/proton detectors
commissioned in March 2012. First 3 physics experiments

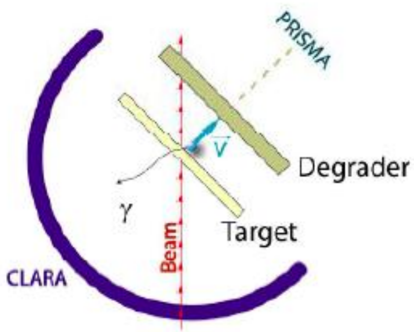
Knock out
GDR

MNT and other reactions

+ applications

Reactions for radioactive beam production : mnt

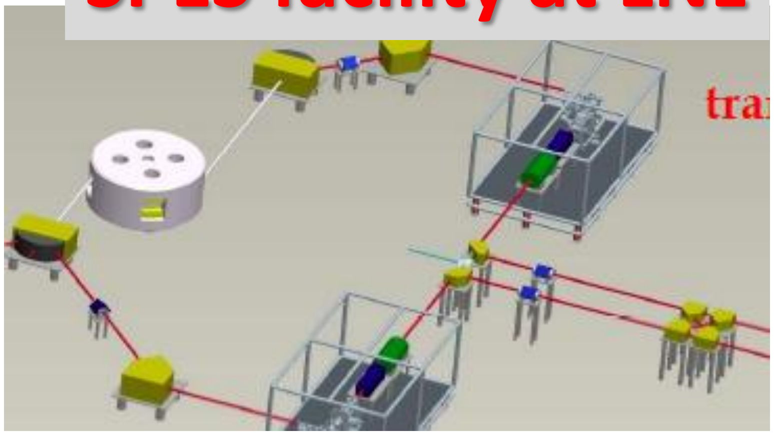
Multinucleon Transfer
Lorenzo Corradi



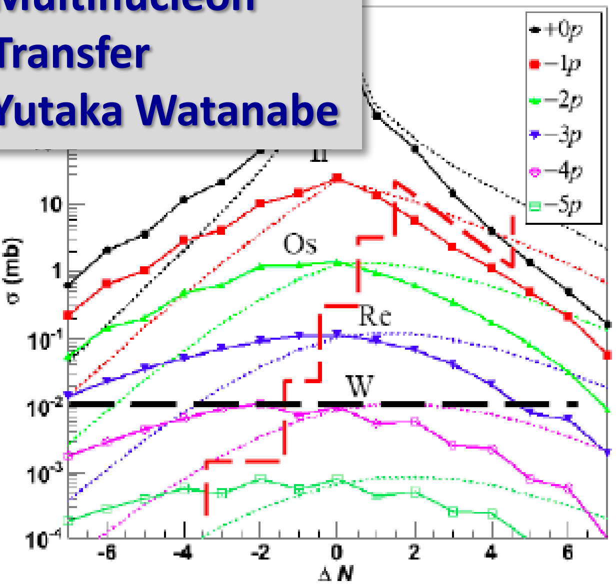
- Evolution of shell structures
- Lifetime measurements
- Strength function
- Polarization effects in MNT

Future plan : measurements with SPES

SPES facility at LNL



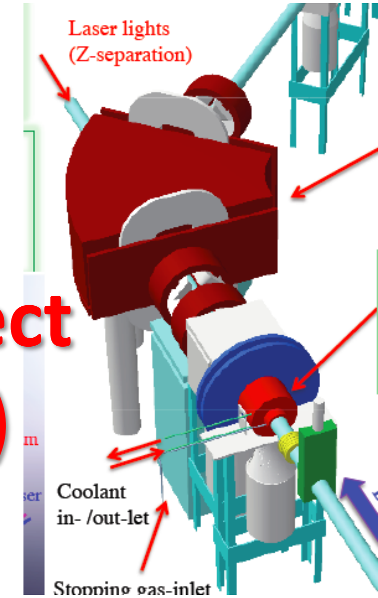
Multinucleon Transfer
Yutaka Watanabe



136Xe+198Pt reaction at 8 MeV/u

Reaching the N=126 for the peak formation around mass number of 195 on the solar r-abundance

The KISS Project (KEK)



Reactions for radioactive beam production

Fragmentation Hiroshi Suzuki	Projectile fragmentation of as ^{48}Ca and ^{124}Xe at 345 MeV/u and in-flight fission of a ^{238}U Compared with the EPAX2 for fragmentation and LISE+ for the in-flight fission.
Charge changing Cross sections Takayuki Yamaguci	RI produced from ^{56}Fe and ^{70}Ge at 500 MeV/nucleon. The cross sections showed a dramatic change of the even-odd staggering effect as a function of Z/N ratio.
Proton polarization Satoshi Sakaguchi	A proton polarization in photo excited aromatic molecule at room temperature of several percent (14%) has been achieved (five orders of magnitude higher than the thermal polarization).
Spin aligned RI Hidechi Ueno	8(1)-% spin-aligned ^{32}Al beam was produced through the two-step fragmentation of $^{48}Ca \rightarrow {}^{33}Al \rightarrow {}^{32}Al$. reduction in the production yield was minimized to ~1/50 compared with single-step scheme

Applications

Ion beam mutagenesis and mutagenomic

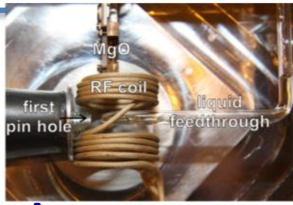
Tomoko ABE

mutation induction using heavy-ion beams.
Fast heavy ions cause dense, localized ionization to break the DNA double strand

(more effective at inducing mutations thansingle-strand DNA breaks)

Nuclear Radioactive Methods in materials and Biophysics

Martins Correira

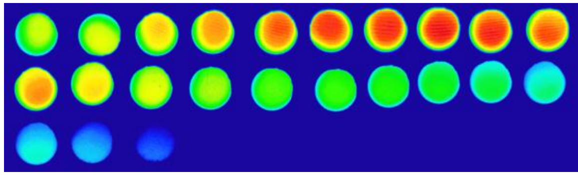


Many examples
61Cu/61Ni (3.3h) probe at ISOLDE . β-NMR
used to study the hyperfine structure in liquid samples opening new possibilities for investigating metal-protein interactions of ions

Wear dignostic of Industrial material with RI ^{7}Be and ^{22}Na

Atsushi Yoshida

The near surface of the parts within 10 – 100 μm is activated
wear-loss evaluated by the change of the γ-ray intensity.
dose rate of 5 kBq/h.
implantation depth controlled by using a rotating energy degrader

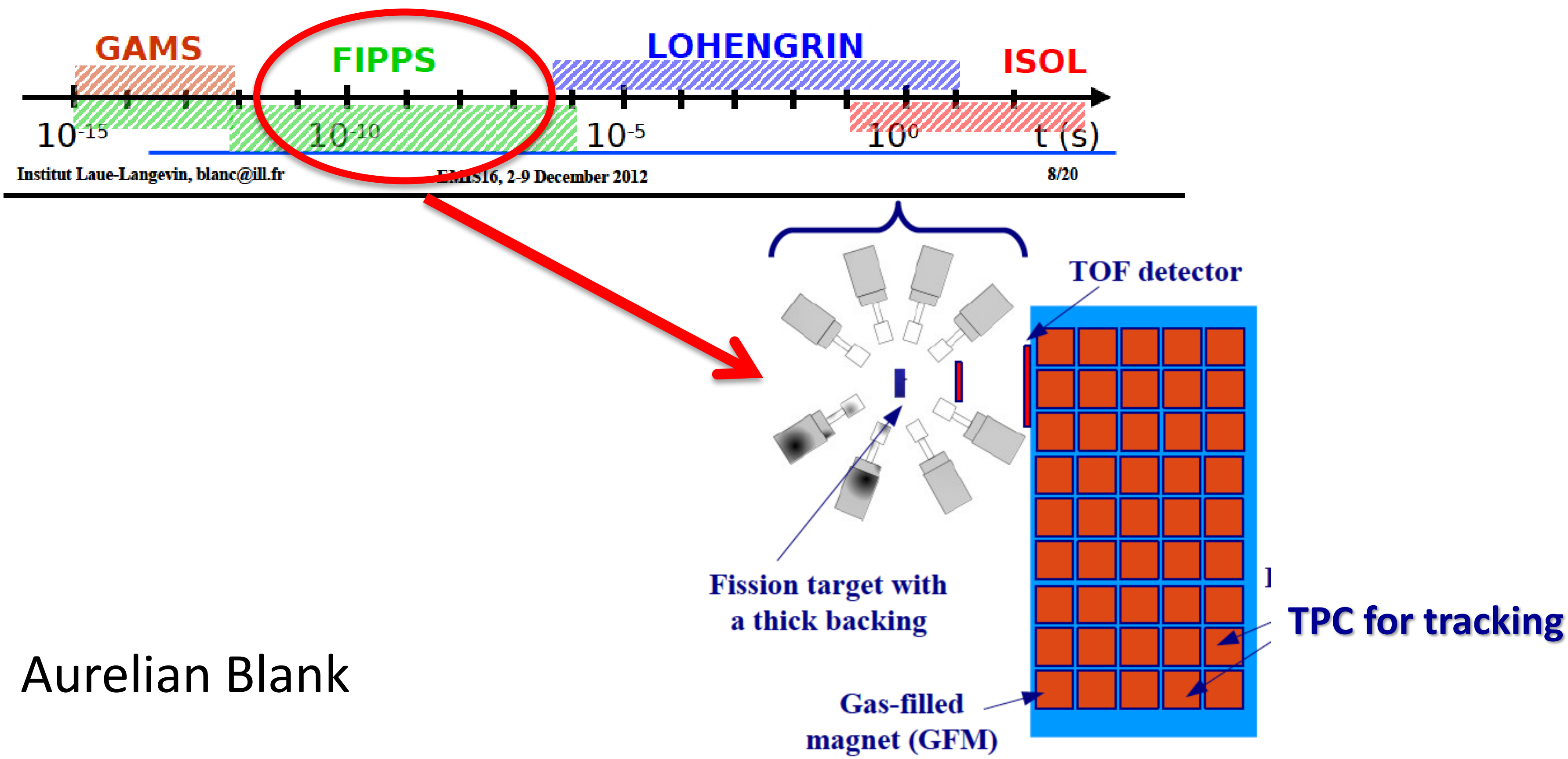


A comment from Wolfy Mittag :

Find a balance between high resolution and high performances of detectors
and performances of accelerators and separators

GAMMA-RAYS and electromagnetic separators

Fission products (short lived)at ILL with a gas filled magnetic Spectrometer and prompt gamma-ray spectroscopy

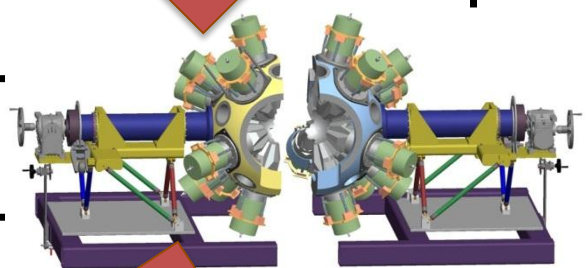


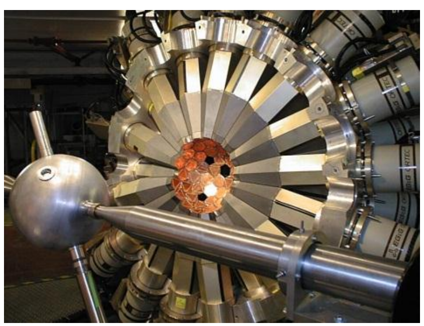
Aurelian Blank

Gamma-ray detector arrays

Detector	efficiency	Peak/total	Resolution Slow beams	Resolution fast beams
Compton shielded Ge	5 – 10%	0.50	2.5-5.0 keV	10%
Segmented Ge	3- 5%	0.20	2.5 keV	1-2%
Scintillation(NaI, CsI) ($LaBr_3$)	50%	0.50	100 keV	10%
Tracking Ge (now) (4π)	5 –7% 50%	0.50		

Gretina-GRETA





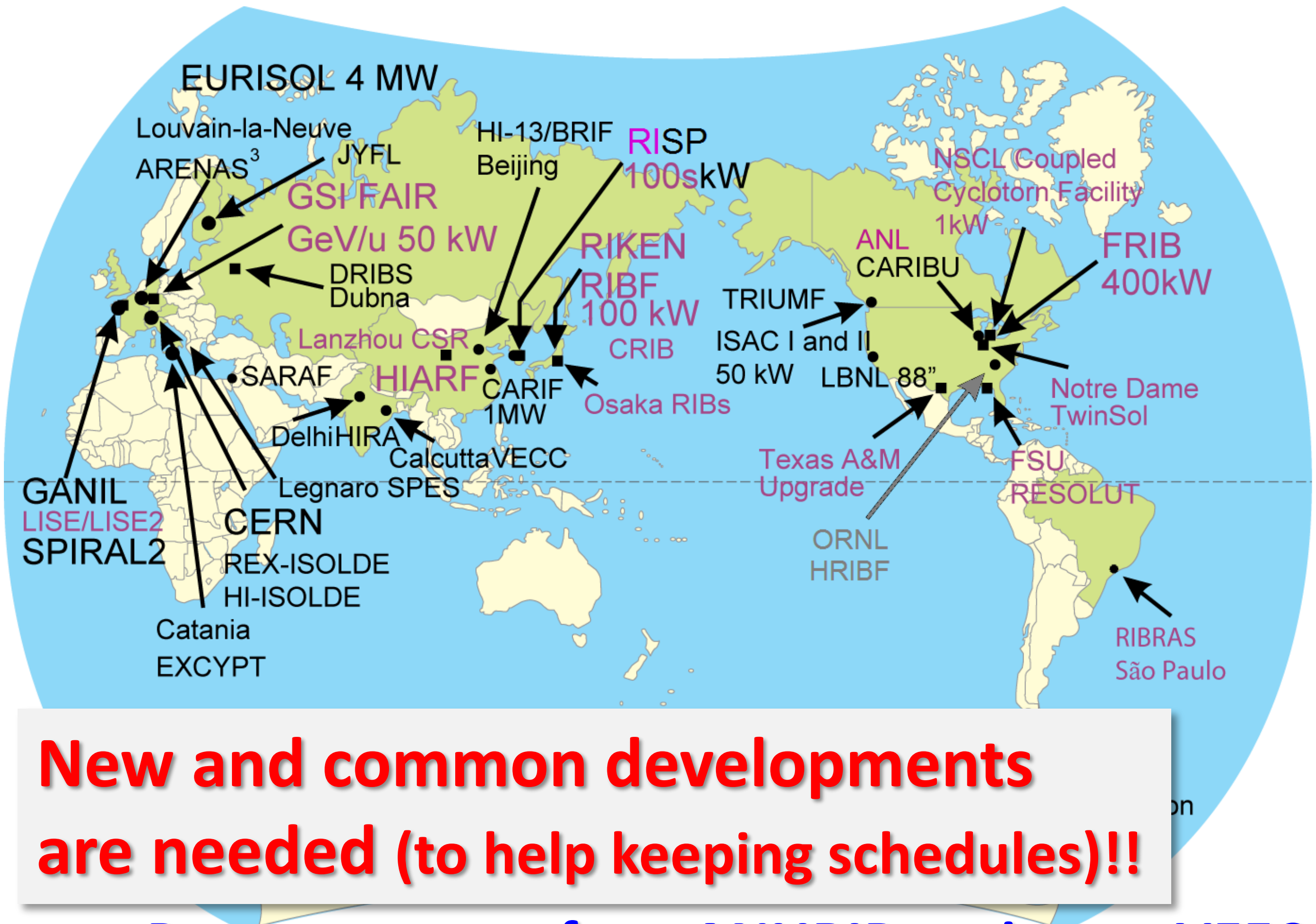
Gammasphere

GRAPE

DALI

AGATA Demonstrator

RIB Facilities in the world



New and common developments are needed (to help keeping schedules)!!

Overview :

Roadmap

Thomas Nilsson
Europe

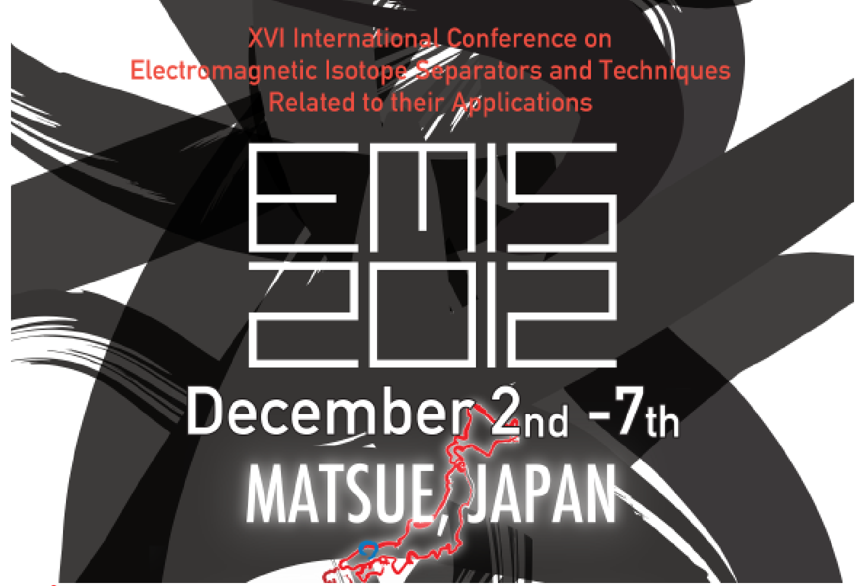
Yanlin Ye
Asia

Georg Bollen
USA

Progress report for : ANURIB project at VEEC (Nabhiraj Yalagoud)
HIE-ISOLDE (Richard Catherall)
ATLAS (R.C. Pardo)
RISPS(Corea) (Yong-Kyun Kim)

Thanks to :

the speakers ,
poster presentations
the session chairs,
the participants !



Thanks to the organizers !

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- Y. Hirayama
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- Y. Watanabe

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