# Summary: Instrumentation

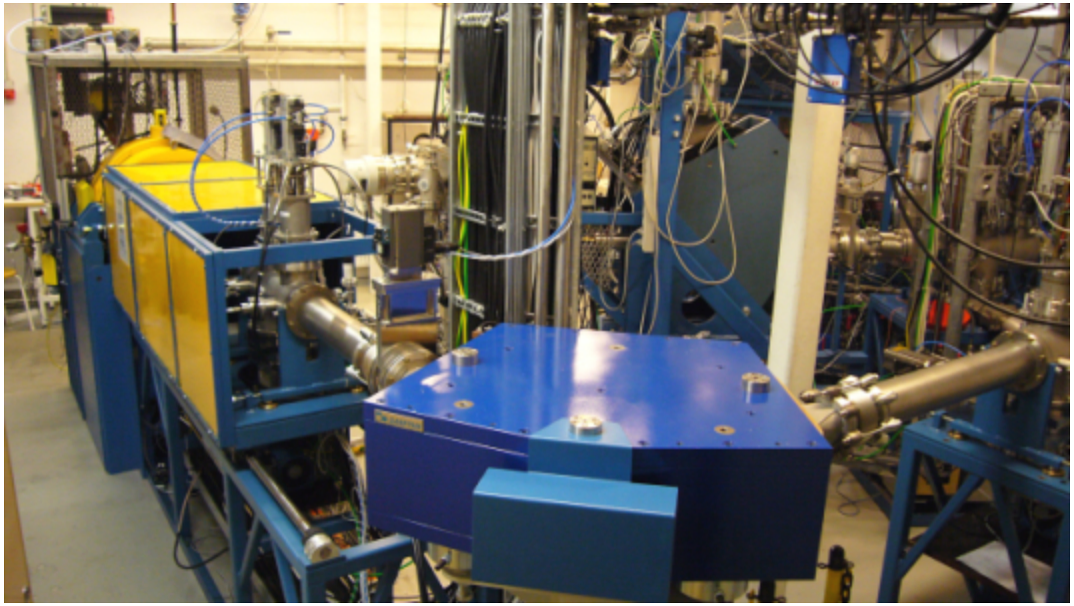
## Juha Uusitalo, JYFL

- -Beams
    - - Ion sources and accelerators
- - Targets
- - Separators
- - Spectroscopy (instrumentation)
    - -In-beam spectroscopy
    - - Delayed spectroscopy
        - - ”fast” delayed spectroscopy (~ 1 µs)
        - - ”slow” delayed spectroscopy
- - Data taking

-A lot of experts from different fields are needed
-How to attract young people?

In near future several superconducting high frequency ECR ion-sources on operation
Factor of 10-100 increase in output

JYFL 14 GHz source



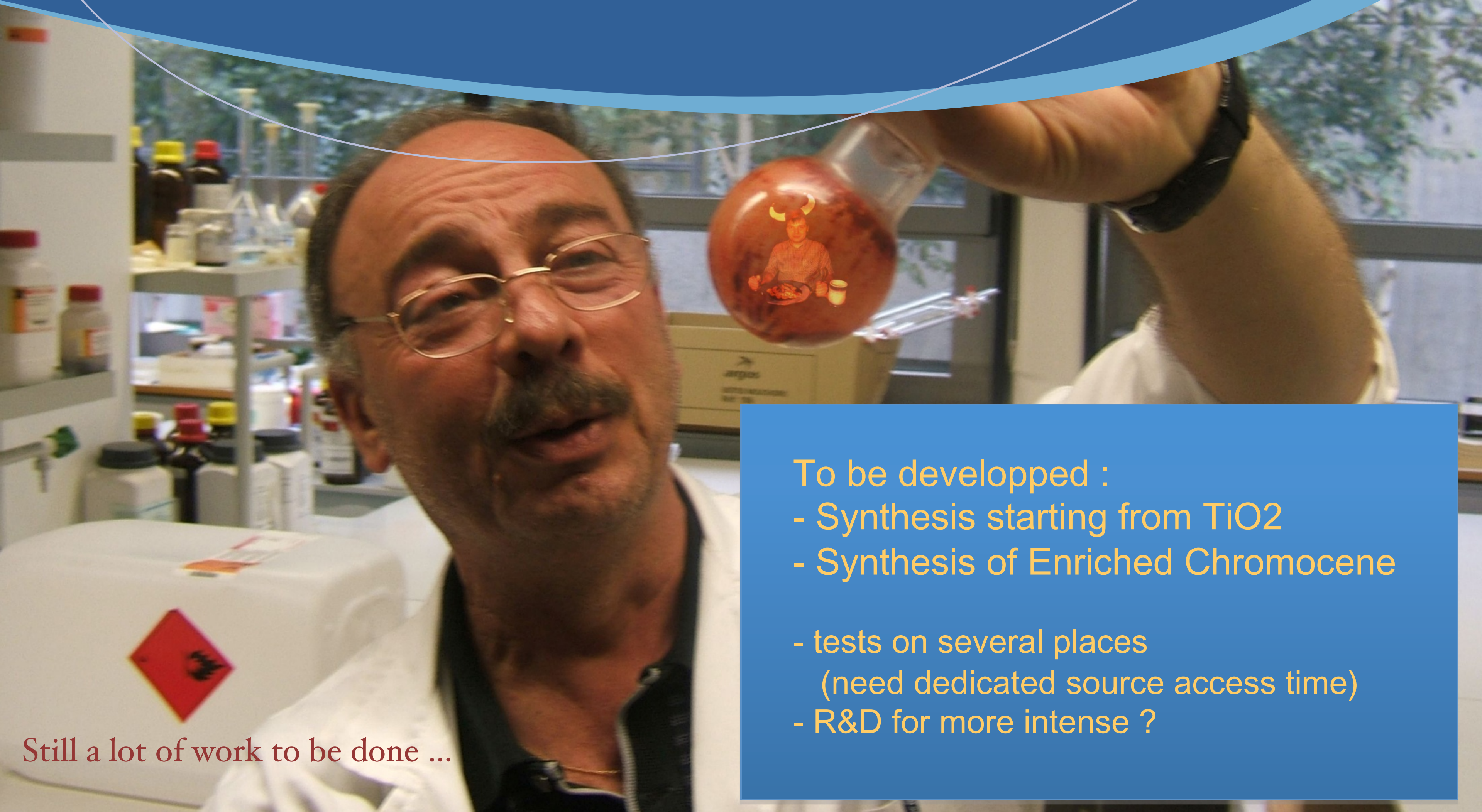
How the handle the intensive output from the source?
Plasma effects ?, hollow beams?.....
Reconstruction of the injection line…?

# Summary

-Access to MIVOC $^{50}$Ti beams at pµA level expected on target

-Start from TiCl4 …

*IPHC (J. Rubert, Z. Asfari, B. Gall)*
*JYFL (J. Ärje, R. Seppälä, P T Greenlees)*
*GANIL (J. Piot, F. Lemagnen, P Leherissier C. Barue B. Osmond )*
*FLNR (S. Bogomolov)*



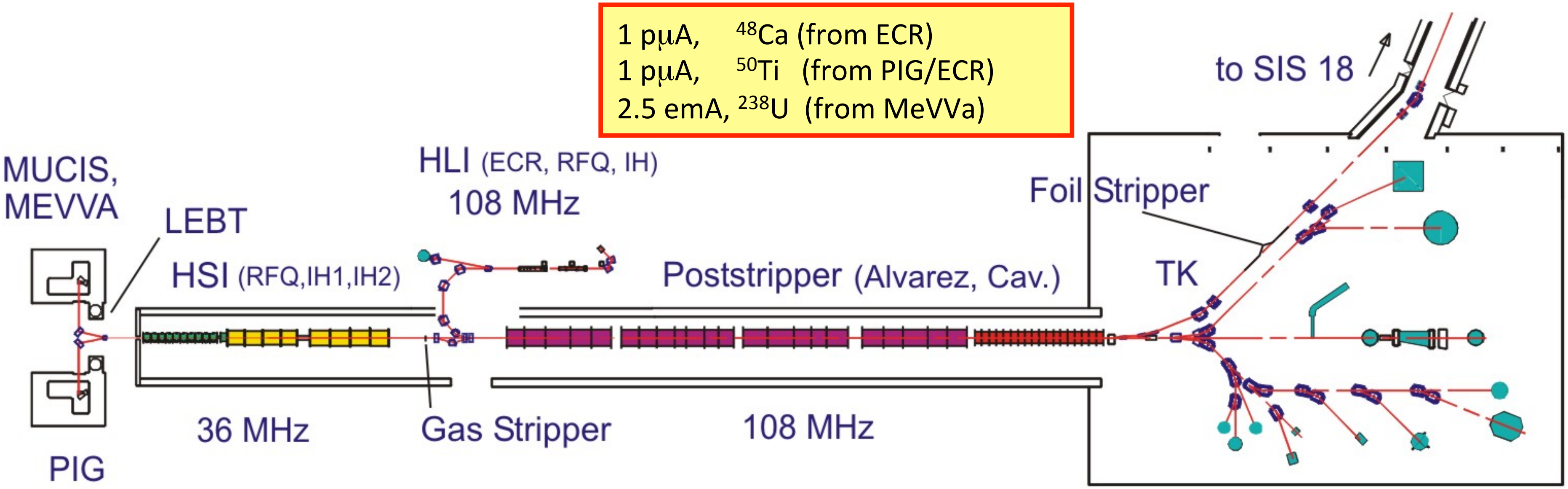
Still a lot of work to be done …

To be developped :
- Synthesis starting from TiO2
- Synthesis of Enriched Chromocene

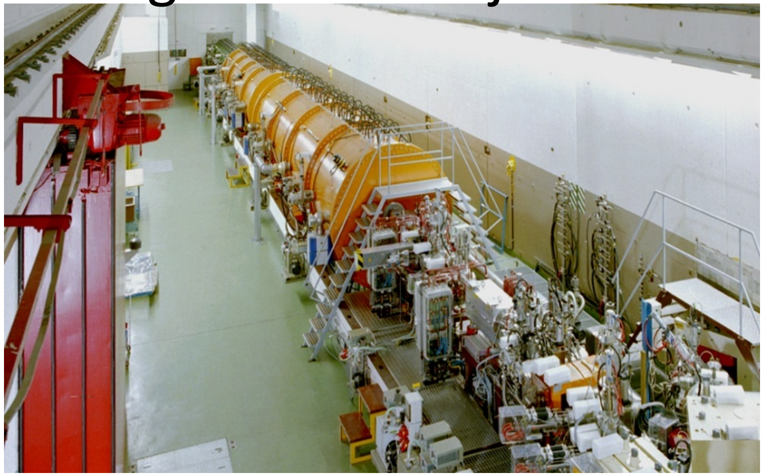
- tests on several places
  (need dedicated source access time)
- R&D for more intense ?

# The GSI UNIversal Linear ACcelerator

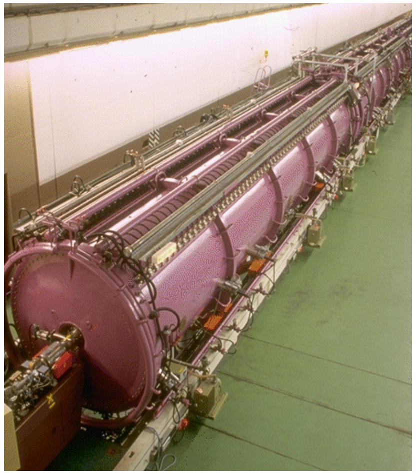
1 pμA, $^{48}$Ca (from ECR)
1 pμA, $^{50}$Ti (from PIG/ECR)
2.5 emA, $^{238}$U (from MeVVa)



High Current Injector

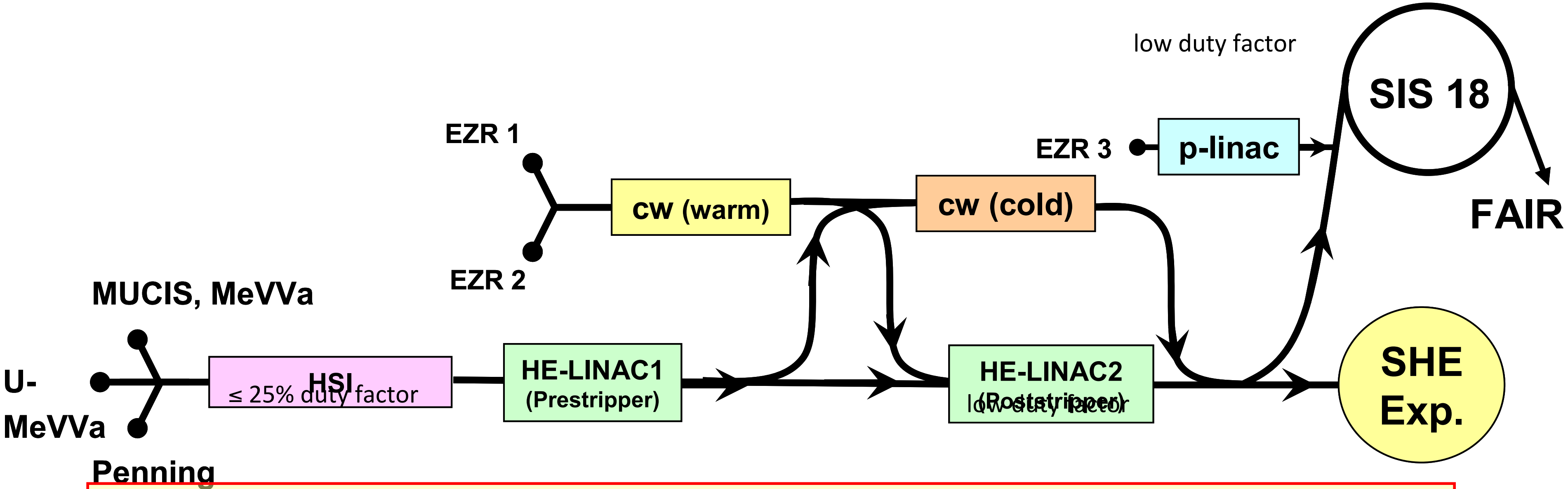


Alvarez

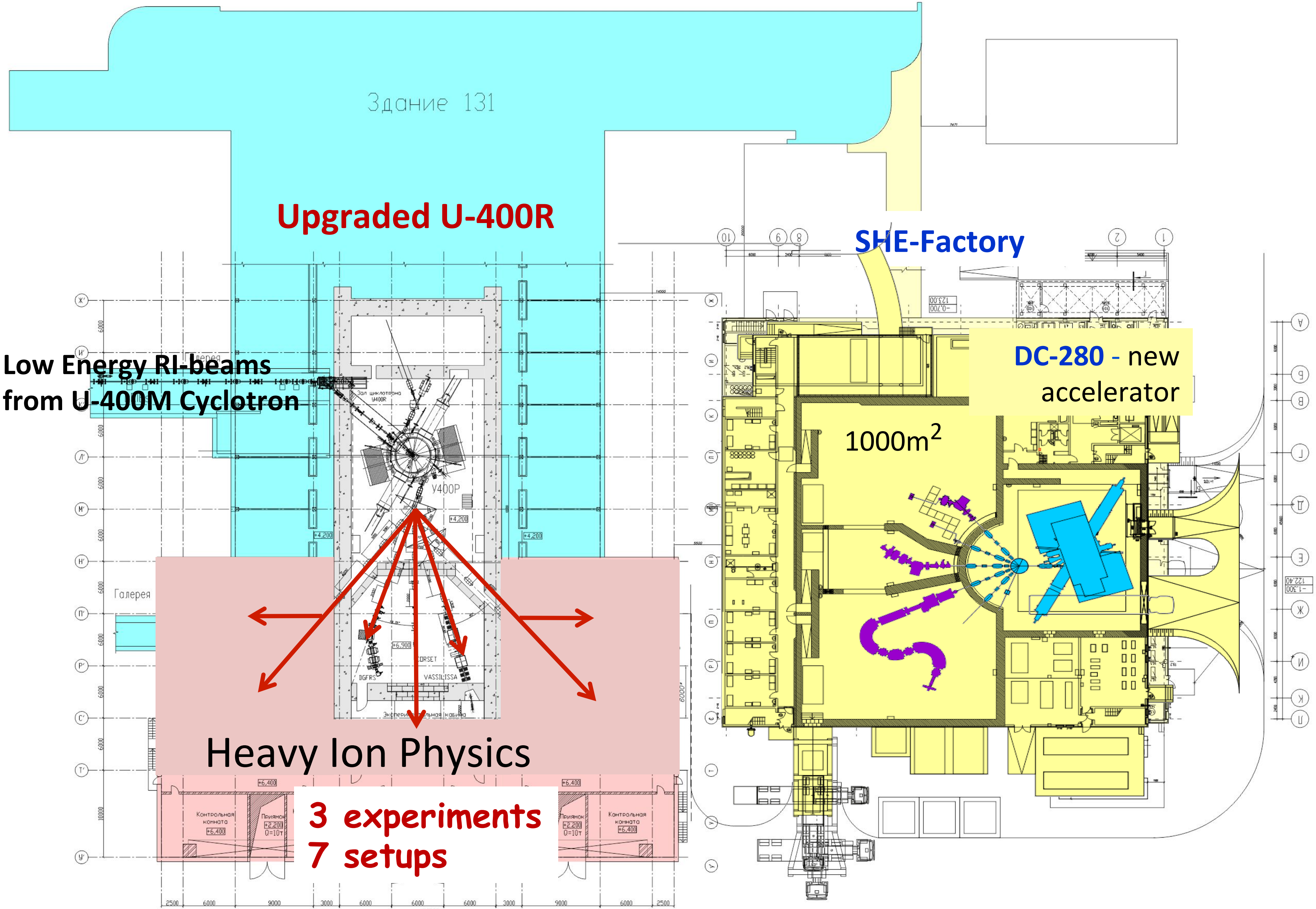


Single Gap Resonators

# GSI-Future Option



- **Proton linac-injector for FAIR (FAIR-pbar-physics)**
  - **70 MeV, 35 (70) mA, 325 MHz, 0.1% duty factor**
- **High Energy injector linac (replacement of Alvarez DTL)**
  - **Prestripper: 3 MeV/u, A/q = 60 (18 emA), 108 MHz, 1% duty factor**
  - **Poststripper: 11.4 MeV/u (max. 22 MeV/u), A/q = 6.3 (20 mA, 108/325 MHz, 1% duty Factor**
- **sc-cw-linac (for Super Heavy Element program)**
  - **3.5 – 7.5 MeV/u, 1 mA, 217 MHz, 100 % duty cycle**



**Upgraded U-400R**

**SHE-Factory**

**Low Energy RI-beams from U-400M Cyclotron**

**DC-280** - new accelerator

1000m$^2$

Heavy Ion Physics

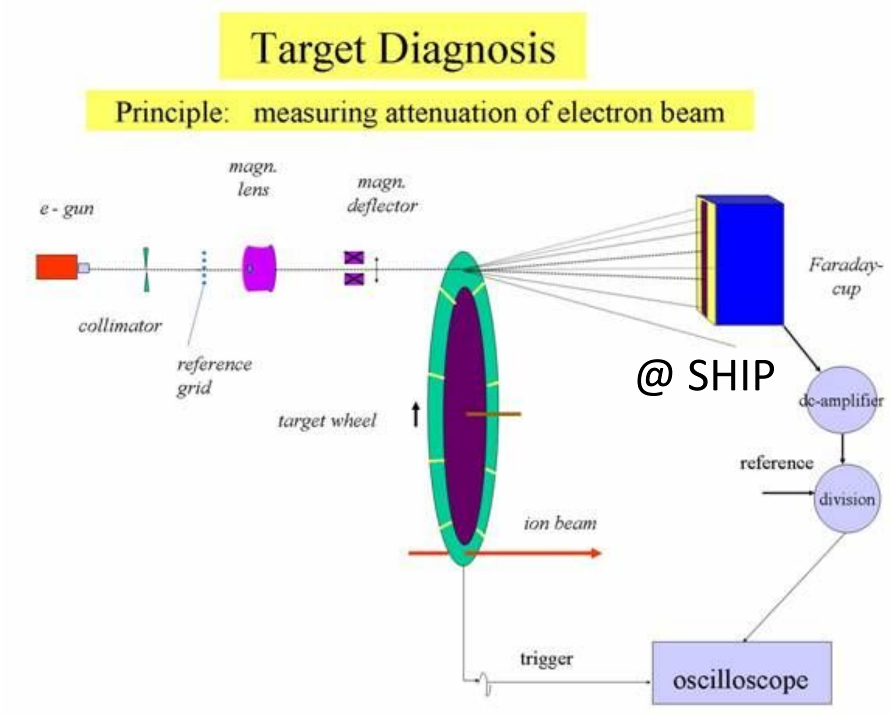
**3 experiments**
**7 setups**

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

# ACCELERATORS

| Beam parameters | HI-Physics<br>U-400R | SHE-Factory<br>DC-280 |
|---|---|---|
| Projectiles | Stable and<br>RIB ($T_{1/2}$ > 0.1s) | Stable only |
| Projectile masses | 4He – 238U | 40Ar – 86Kr |
| Energy range | 0.5 – 27.0 MeV/n | 5 – 8 MeV/n |
| Energy resolution | 0.5% | 1.5% |
| Beam intensity (for 48Ca) | 2.5 pμA | 10-20 pμA |
| SHE-research program | ≤30% | ~100% |
| Registered decay chains of SHN (per year) | 120 (now **30**) | **3000 - 5000** |
| State of readiness | 75% | In course of design |

# ”Gold” fusion: Hg, Tl, Pb, Bi targets



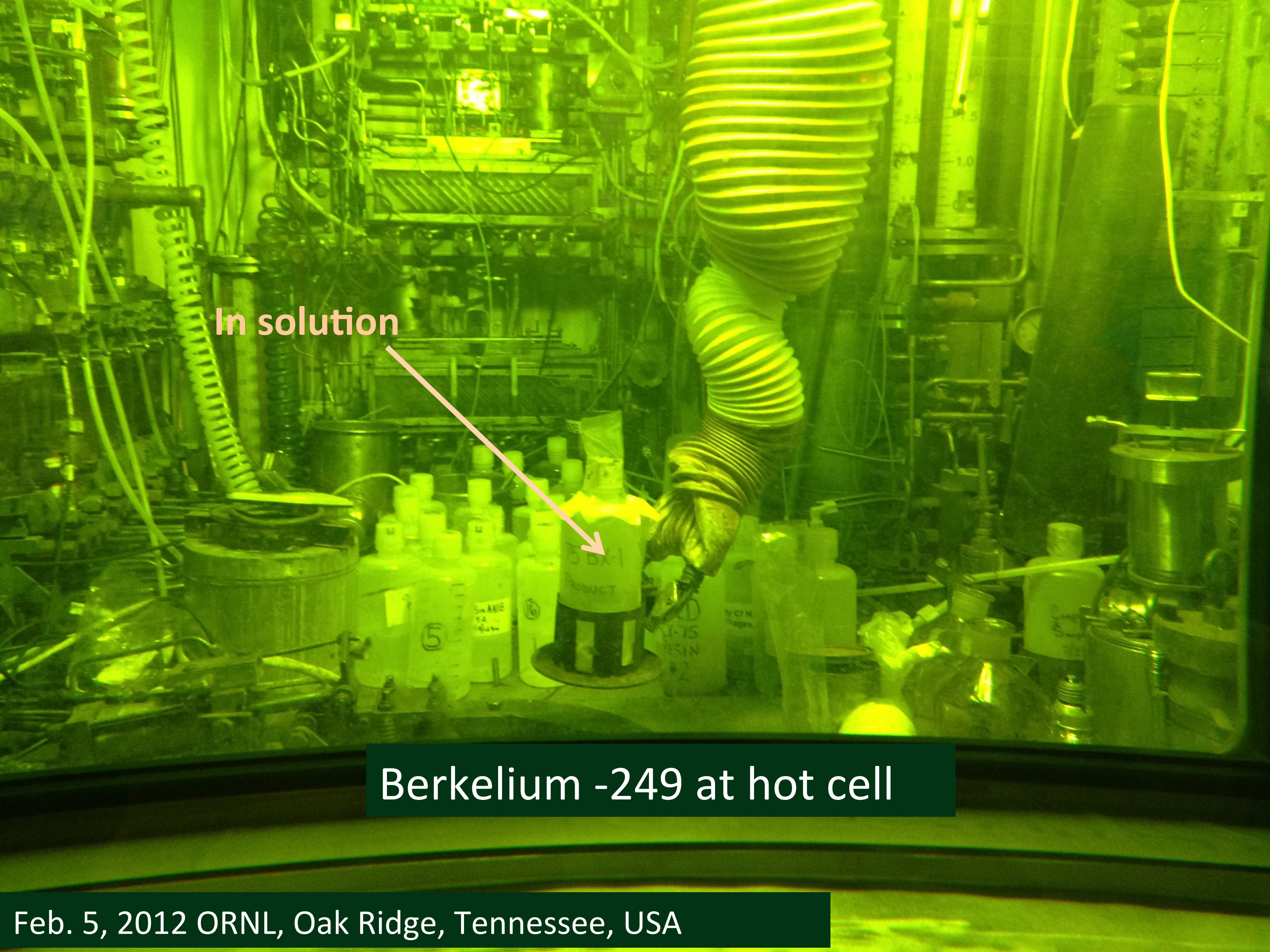
Target Diagnosis

Principle: measuring attenuation of electron beam

@ SHIP

Demonstrated: 2.5 pμA (25 % duty sycle) 40Ar beam on PbS

”Hot” fusion; transactinide targets with (Ti)-backing
Produced at reactors, availablity, expensive, joint efforts?



In solution

Berkelium -249 at hot cell

Feb. 5, 2012 ORNL, Oak Ridge, Tennessee, USA

# Rotating target wheels for high beam intensities

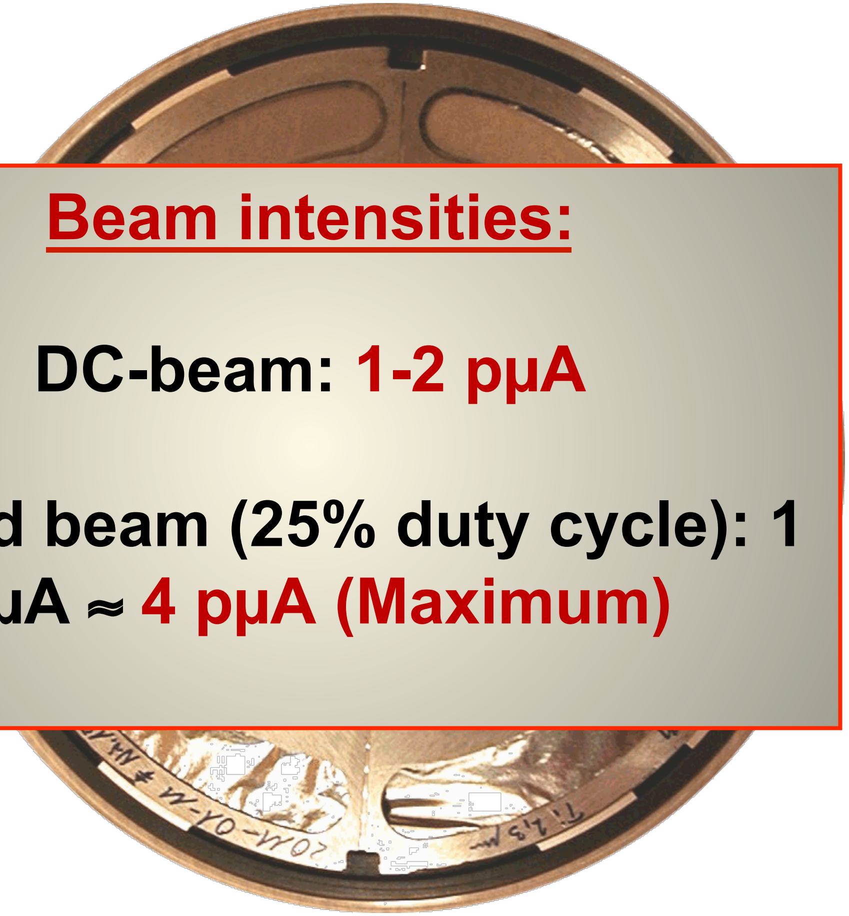
**Backing:**

- Ti-foils (2 μm) or C-foils
- Foils are glued onto Al-frame

***TASCA* target wheel @ GSI:**

- Target area: 6 $cm^2$
- 4 targets per wheel
- 12 mg per wheel @ 500 $\mu g/cm^2$

**Target wheel @ GANIL**



## Beam intensities:

DC-beam: **1-2 pμA**

Pulsed beam (25% duty cycle): 1 pμA ≈ **4 pμA (Maximum)**

# Deposition of actinides by MP

OAK RIDGE National Laboratory

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

GSI

**Molecular Plating**

- **Deposition Yield: up to 90% for actinides**
- **Thickness: 500-1000μg/cm$^2$ possible in a single deposition step**

# In-flight Recoil Separators

- Gas-filled recoil separators
  - TASCA, GARIS, DGRS, RITU, BGS
  - GARISII, AGFA, VAMOS (gas-filled mode), SHANS
  - helium cooling, beam spot size~ 100 mm Ø
- Vacuum-mode separators
  - Velocity filters
    - SHIP
    - VASSILISSA (upgraded), new SHIP ?
    - beam spot size~ 100 mm Ø
  - Mass separators
    - FMA
    - S3, (MARA)
    - beam spot size ~ 2mm dispersive plane
  - Non-zero angle magnetic separators
    - multi-nucleon transfer, deep-inelastic….
    - VAMOS, PRISMA….CHEMISTRY
    - IRiS

# Some notes

Already now

- the existing separators give a 40 -60 % transmission for 48Ca based reactions (maximum gain < 2)
- the total-rate level of < 1 Hz/ 10 pnA beam has been reached in running separators in heavy element experiments (can this be improved ?)

Bigger acceptance → more unwanted products enter the separator

In gas-filled separators the straggling in the gas filling is not a problem,
If you know the angular cone of the products and the acceptance of the separator, you can calculate the transmission, NOTE: RITU QDQQ, GARISII QDQQD..

Short separator:

- background (beam, target like, reactions from backing..) suppression ?
- shielding the focal plane setup?

In-flight mass separators

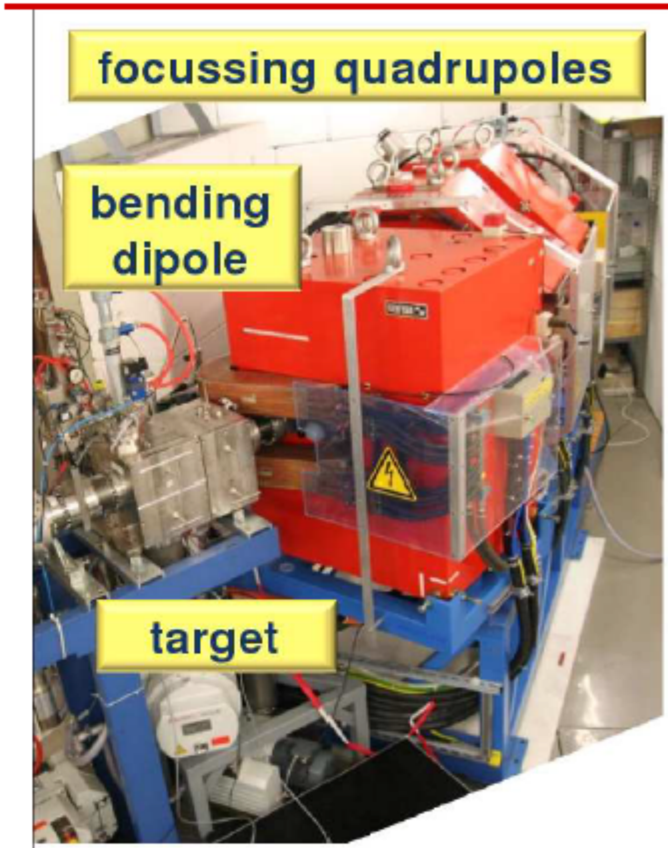
- rule of thumb ?

First order mass resolving power Δm/m ~ 240-270
when beam spot size is Ø 2 mm

- due to the abberrations and how well you handle them a mass resolving power of Δm/m ~300 – 500 FWHM can be reached
- ( couple events with mass 300 ? )
- in big acceptance separators single ion ray tacing is needed get the A (and Z), VAMOS, PRISMA

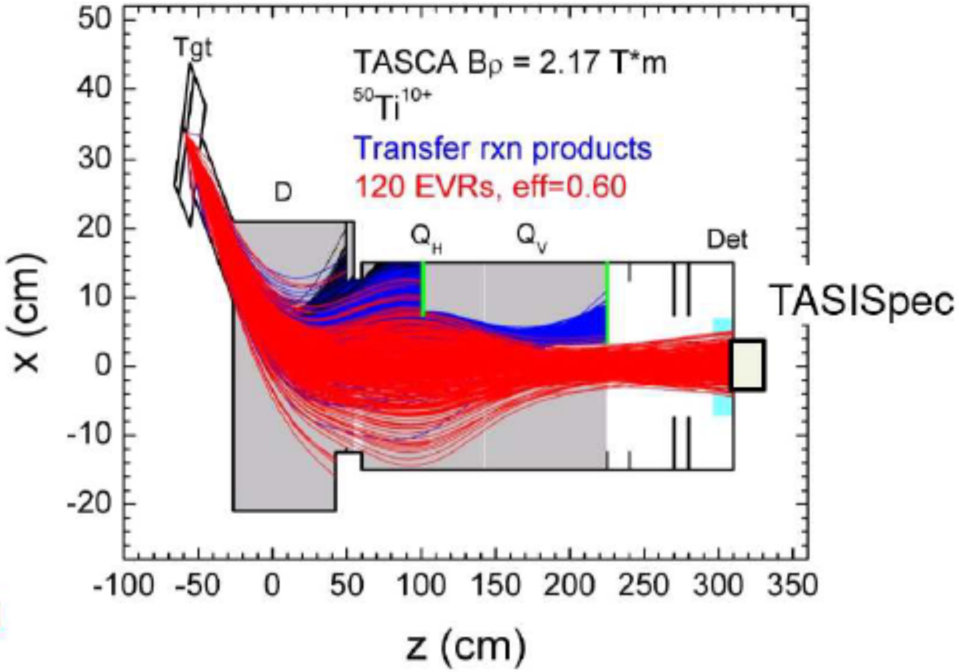
# TASCA Beackground Reduction (June 2011)

## Courtesy: Spokesperson D. Rudolph, Lund Uni, Sweden



**Gas-filled separator**
***TASCA***

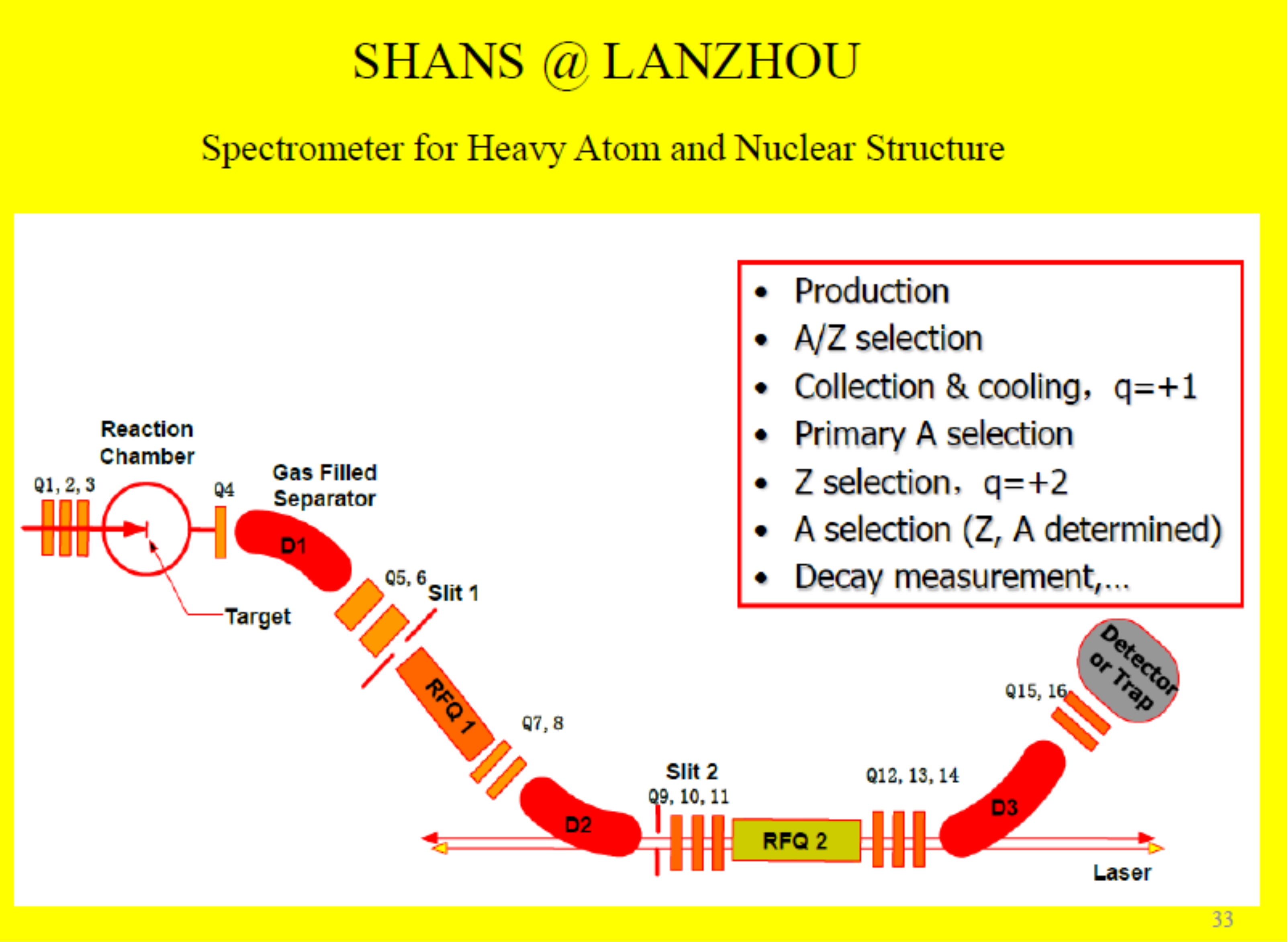
Background reduction successful by introducing two slits; concluding tests during E115 week.



J.M. Gates *et al.*: use SLITS !!

Simulations E115: U. Forsberg

# New player in the game

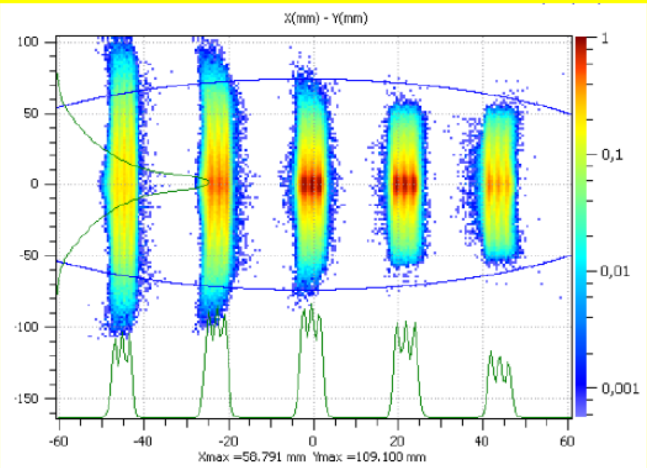


## SHANS @ LANZHOU

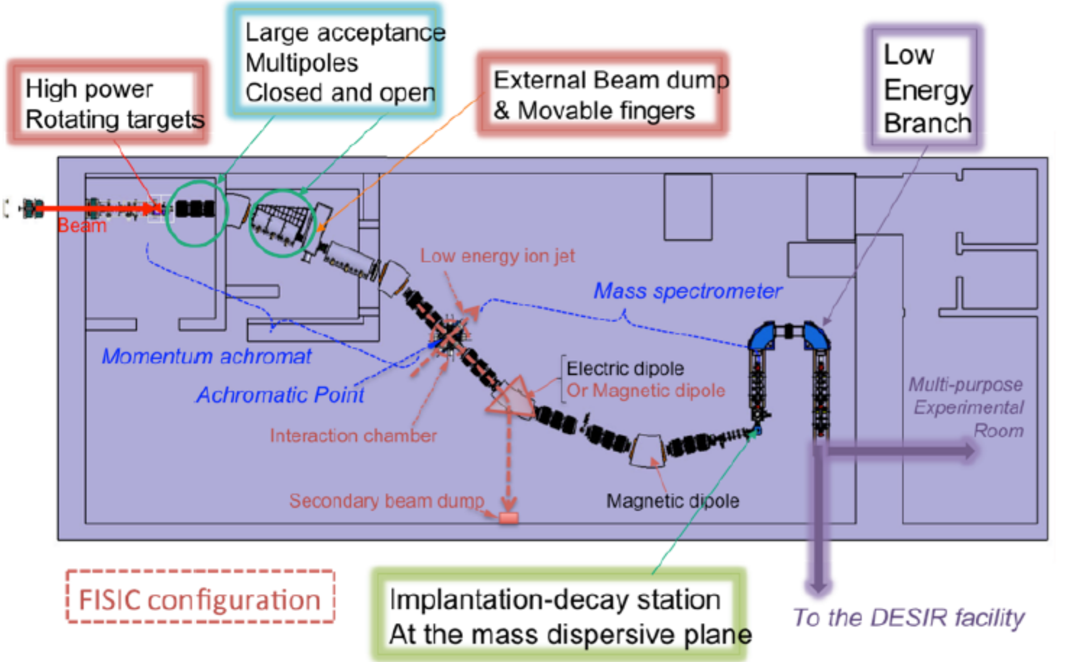
Spectrometer for Heavy Atom and Nuclear Structure

- Production
- A/Z selection
- Collection & cooling, q=+1
- Primary A selection
- Z selection, q=+2
- A selection (Z, A determined)
- Decay measurement,…

# Mass determination

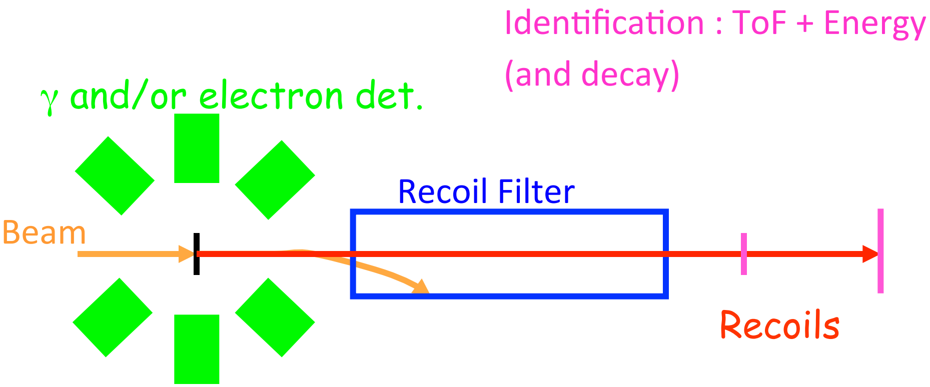


S$^3$ simulation; $^{48}$Ca + $^{248}$Cm $\rightarrow$ $^{291,292,293}$116 with q = 22+…26+ M/$\Delta$M $\approx$ 300

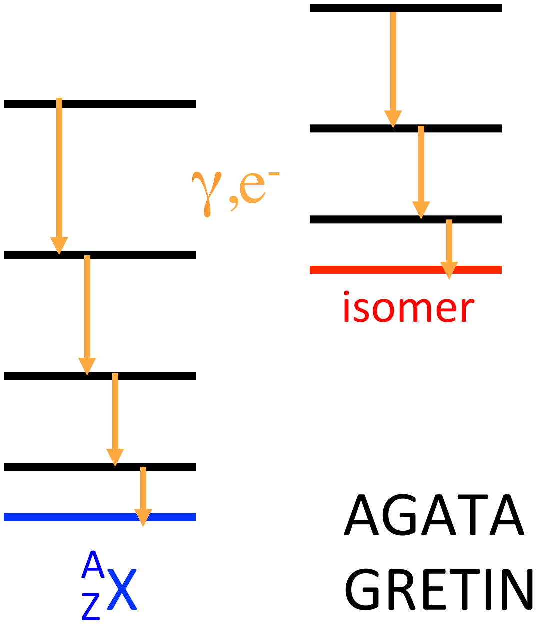


# In-beam spectroscopy

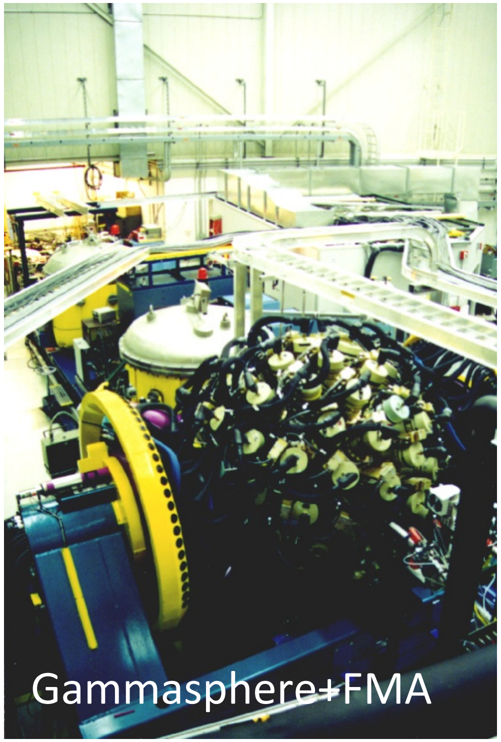
Finding the needle in the haystack
with a recoil filter ~ 10 nb level reached



Recoil
(decay)
Tagging



AGATA
GRETINA

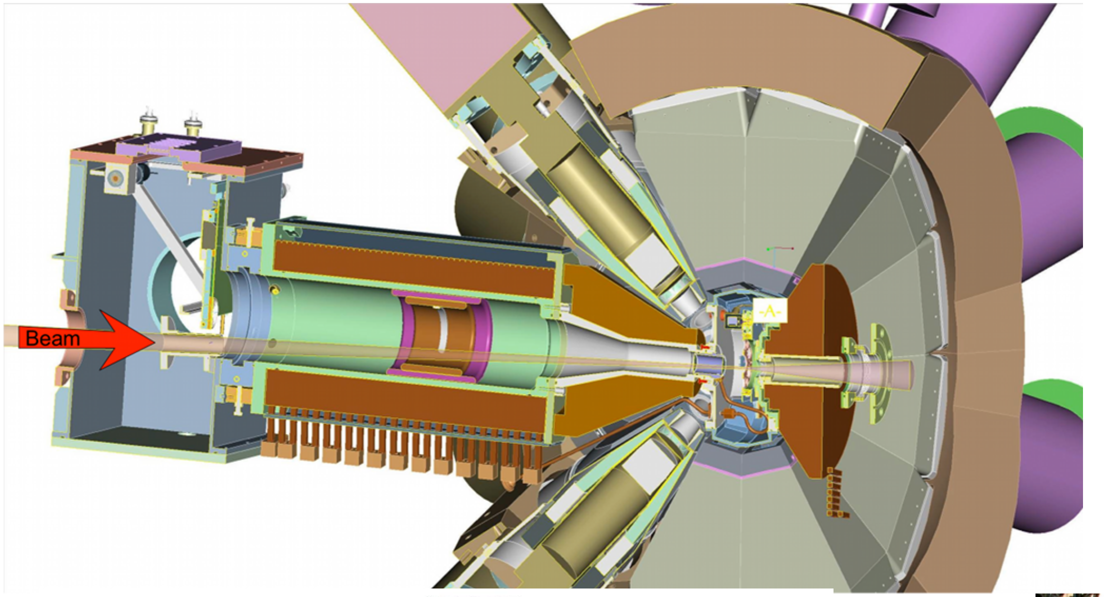


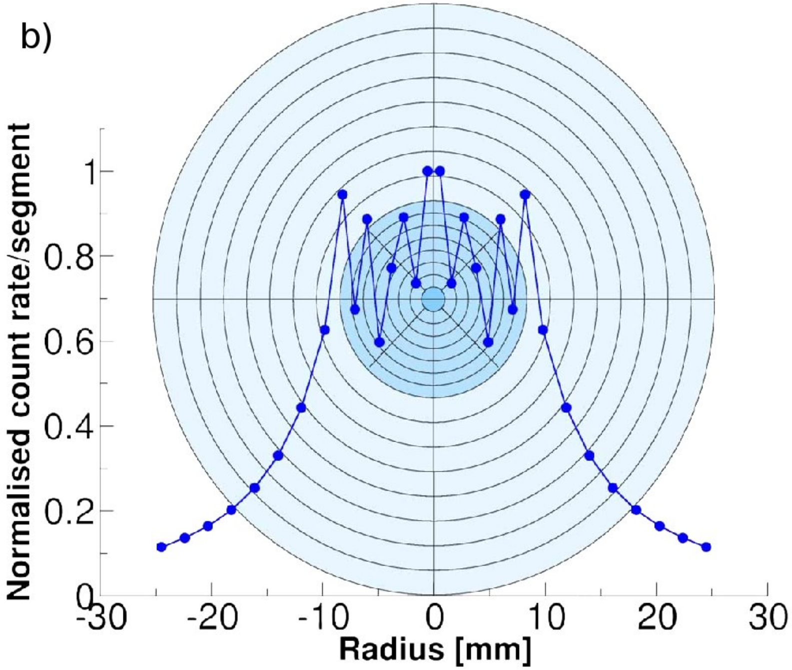
Gammasphere+FMA

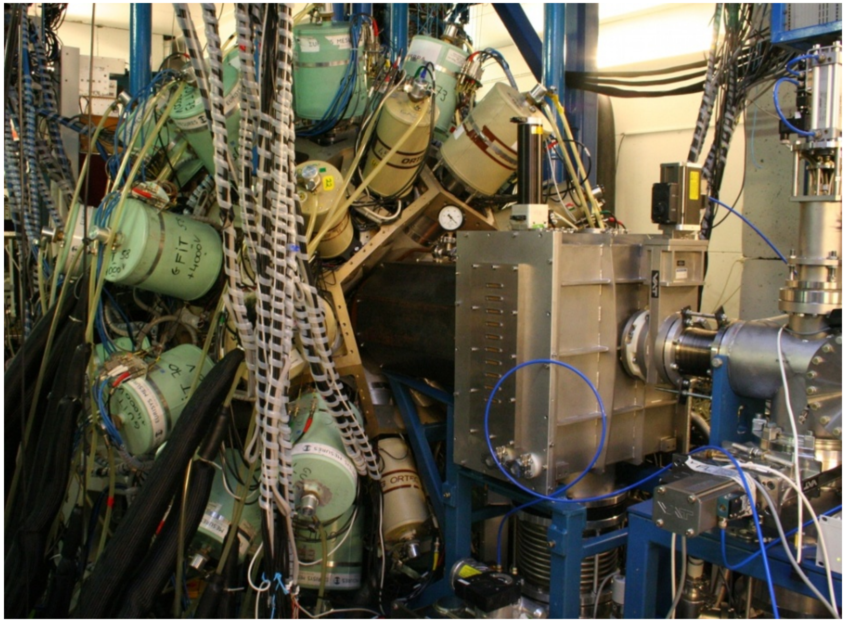
Jurogam + RITU

eff = 5% @ 1.3 MeV

# Conversion Electron Detection







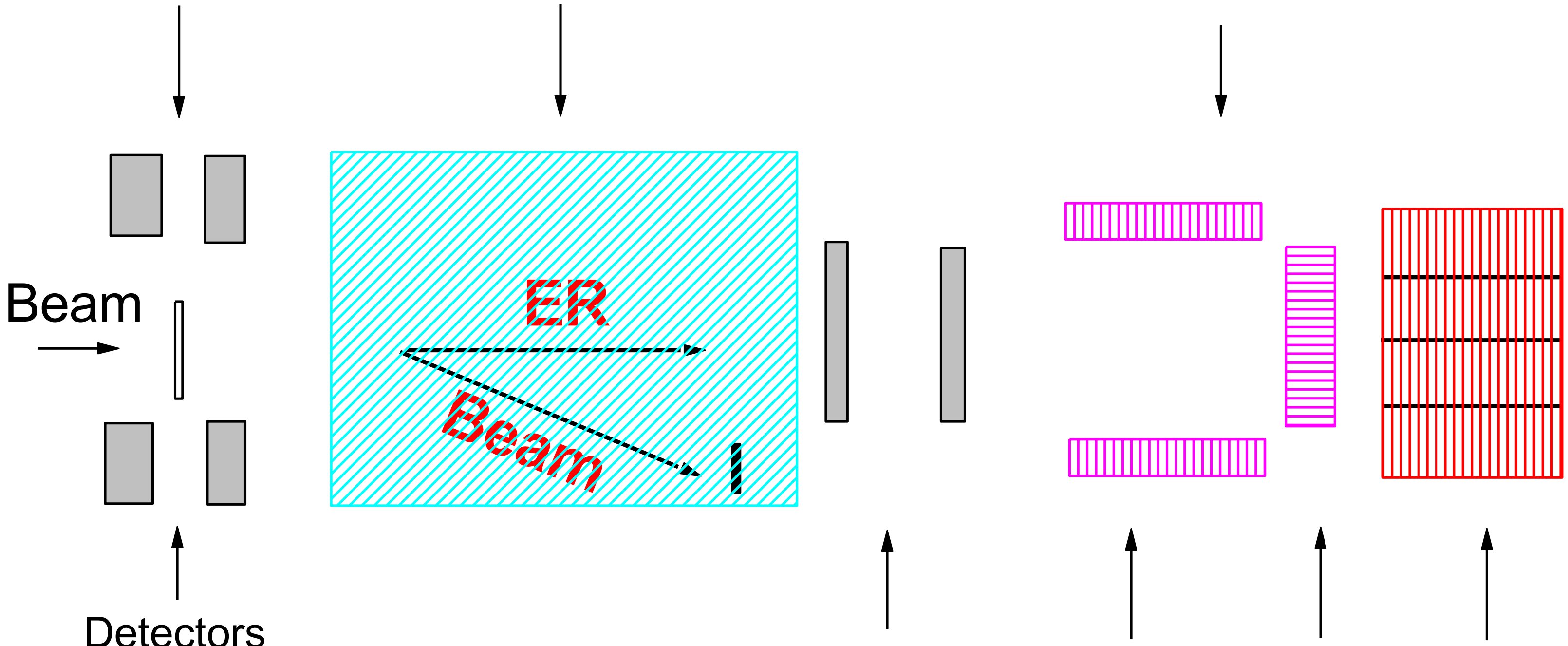
”fast” delayed spectroscopy (~ 1 μs)

# Schematic Experimental Set-up for SHE – Decay measurments

Target

Separator

Focal Plane Detectors



Detectors
γ, CE
(in beam spectroscopy)

TOF
(anti-coincidence)

'Backward'
α , CE
sf

'Stop'
α
sf

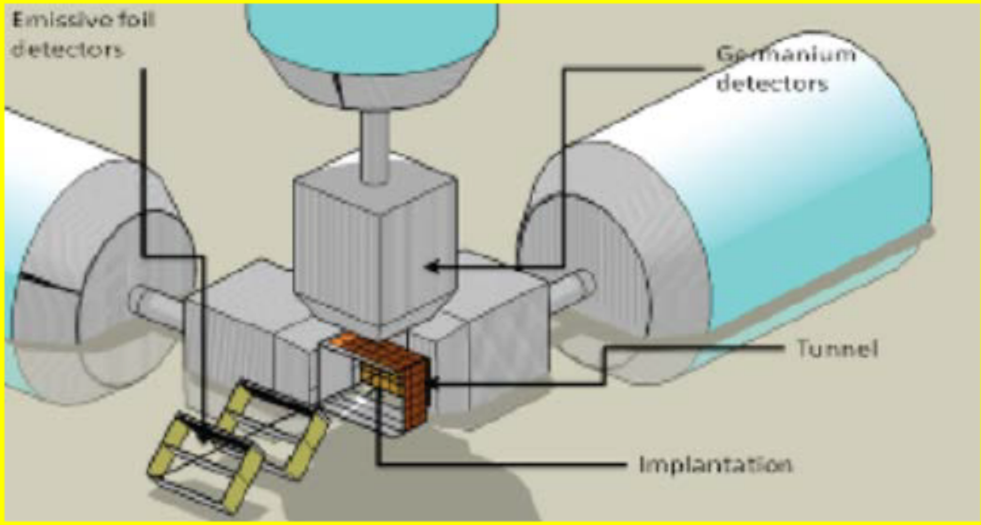
γ - ray
(segmented)

# Focal plane detectors

Size is an interesting question

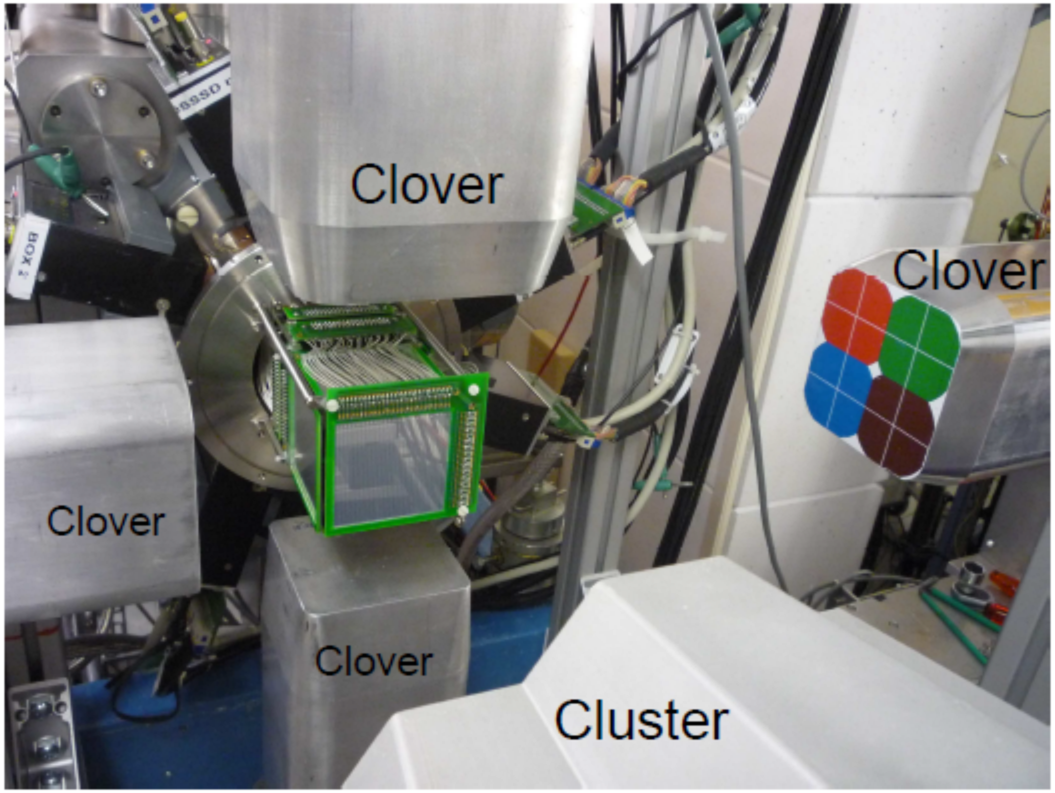
Si is cheap
Electronics is not that cheap? (large size → large number of channels)
Many pixels → low accidental count rate
But: Need a reasonably high $\gamma$ detection efficiency

An example: $S^3$ $< 10\times20\ \mathrm{cm}^2$



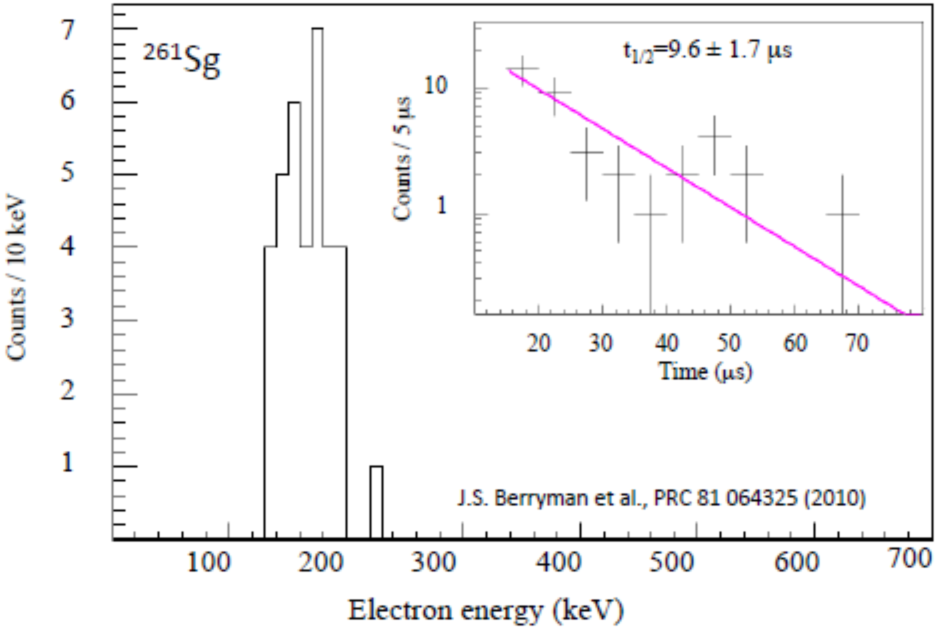
# The **TASISpec** Detector Set-up

## Details of the construction

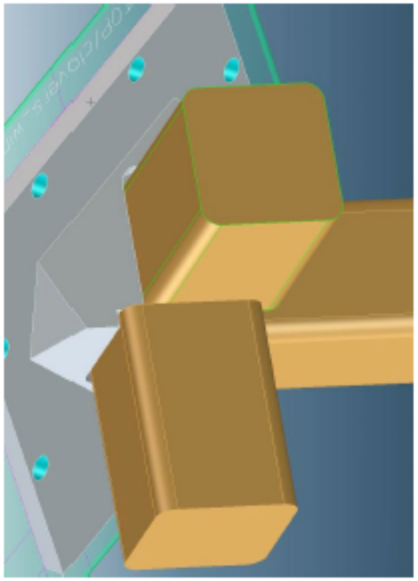


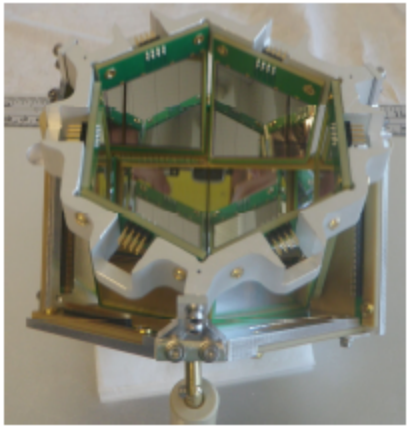
# New Focal Plane Detector System at LBNL

Seaborgium (Z=106) is the current limit for spectroscopy



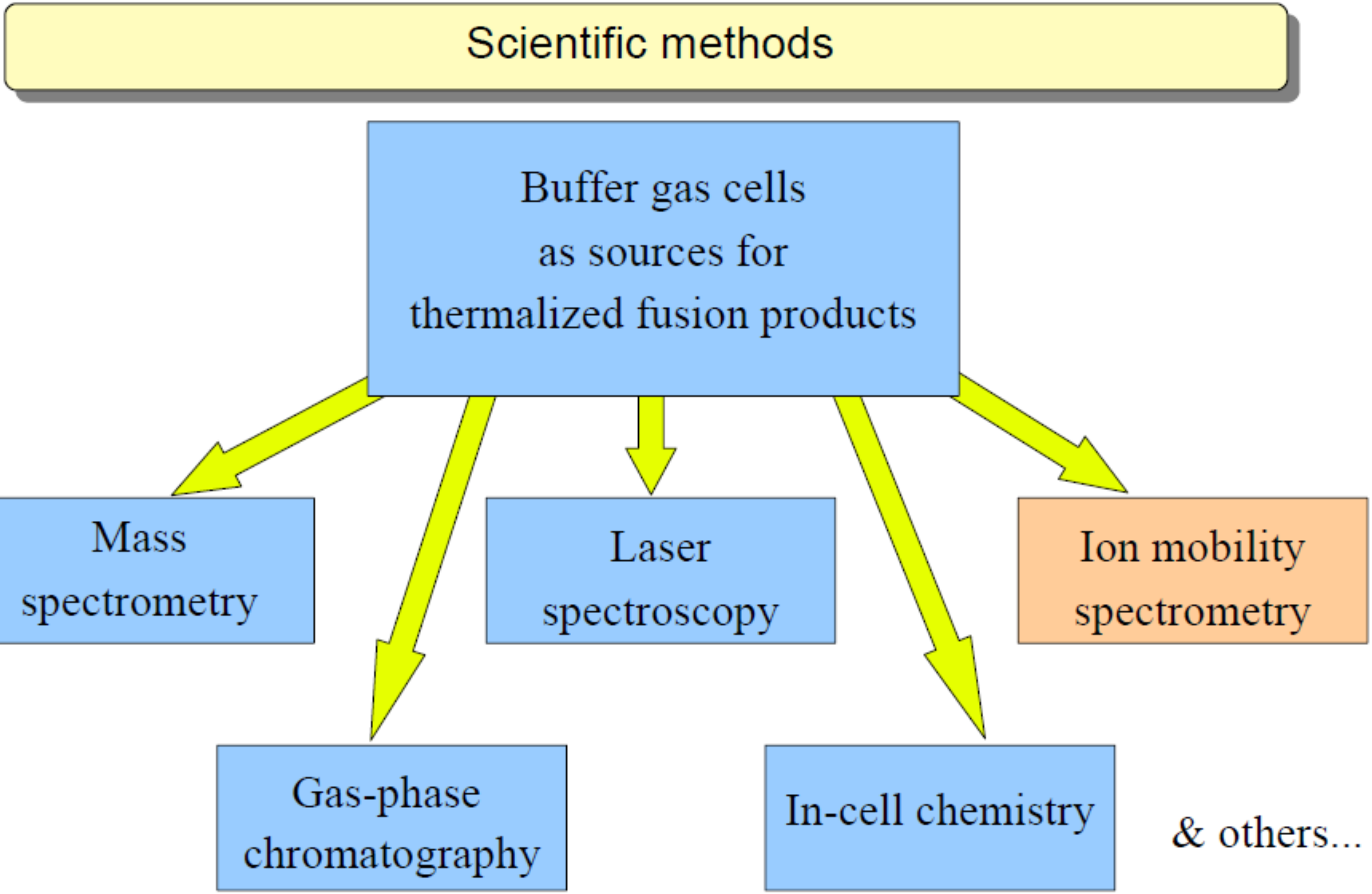
J.S. Berryman et al., PRC 81 064325 (2010)





- New focal-plane detector system $C^3$ (> factor 6 in r-$\gamma$-$\alpha$ efficiency)
- Cyclotron intensity upgrade (> factor 4 for $^{48}$Ca)
- Improved sensitivity for isomer studies (> factor 10)
  - → detailed $\gamma$ spectroscopy of Rf (Z=104)
  - → first $\gamma$ spectroscopy of Sg (Z=106)
  - → first observation of isomers in Hs (Z=108)

# ”slow” delayed spectroscopy



Scientific methods

Buffer gas cells
as sources for
thermalized fusion products

Mass spectrometry

Gas-phase chromatography

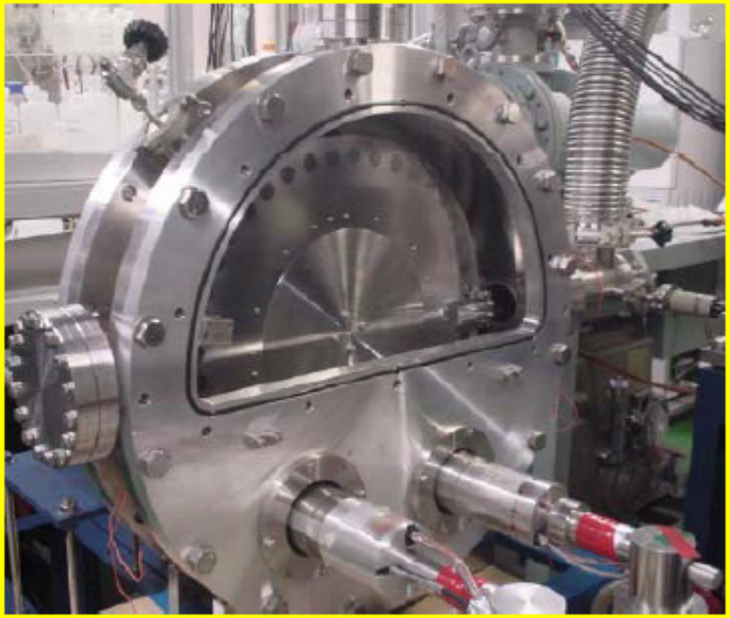
Laser spectroscopy

In-cell chemistry

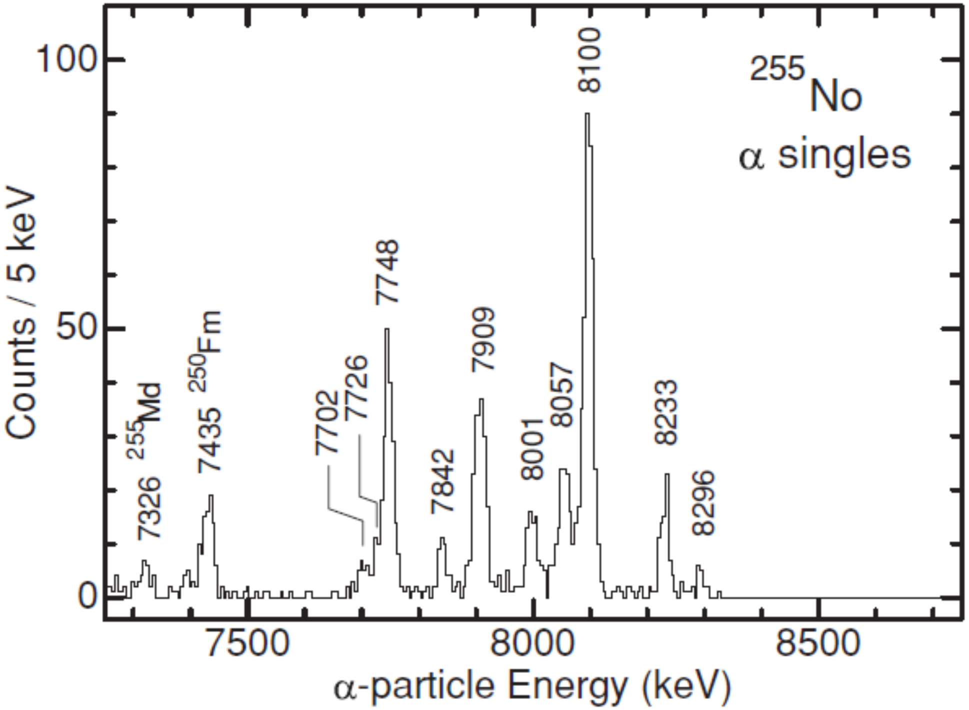
Ion mobility spectrometry

& others…

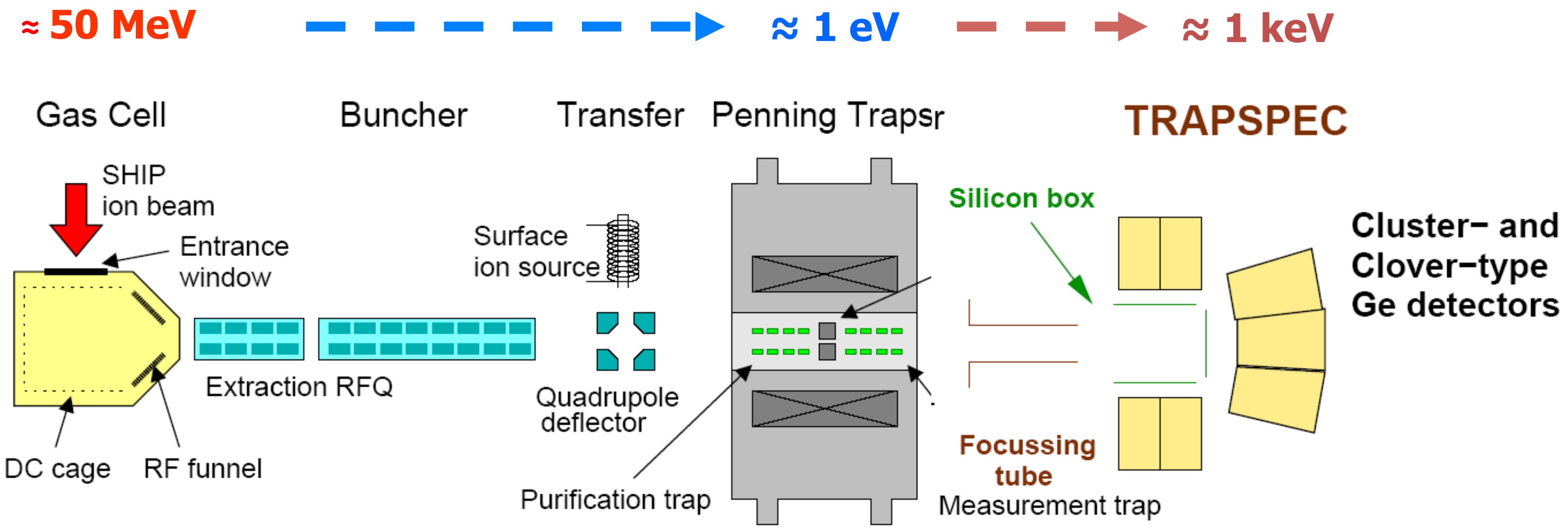
# He-jet technique

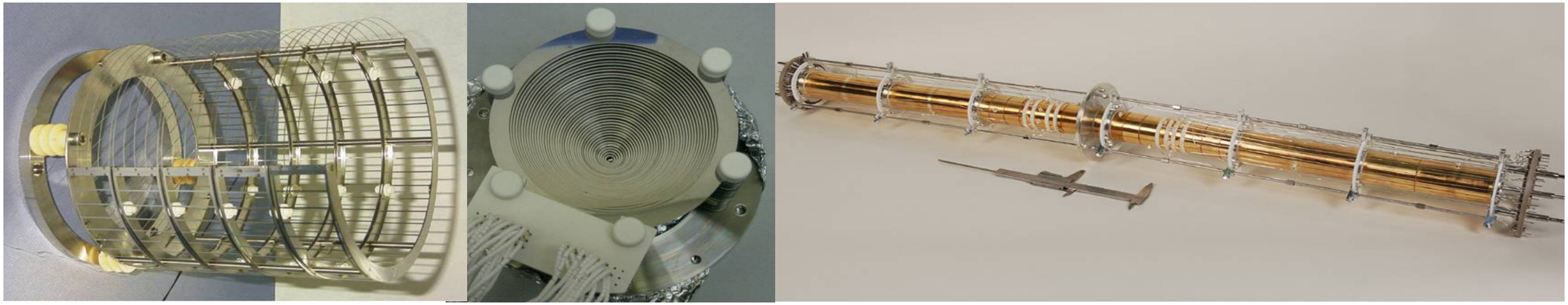


α-γ detection system
at JAEA Tandem laboratory



# SHIPTRAP SETUP

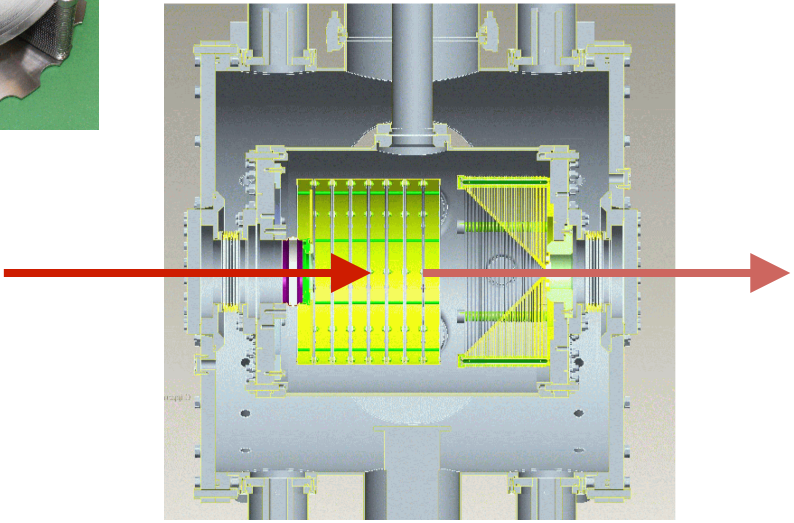




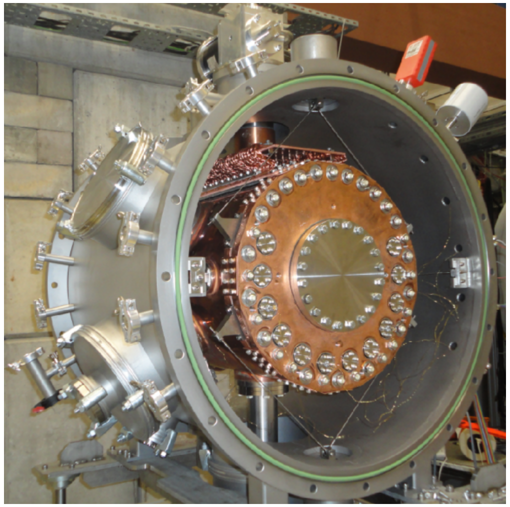
# FUTURE: SHIPTRAP GRYOGENIC GAS  CATCHER

Cryo cooler (40 K)

Ion
beam



Low-energy
beam



outer chamber ≈ 650 mm long / 500 mm
in diameter

Gain in overall efficiency factor: 3-5

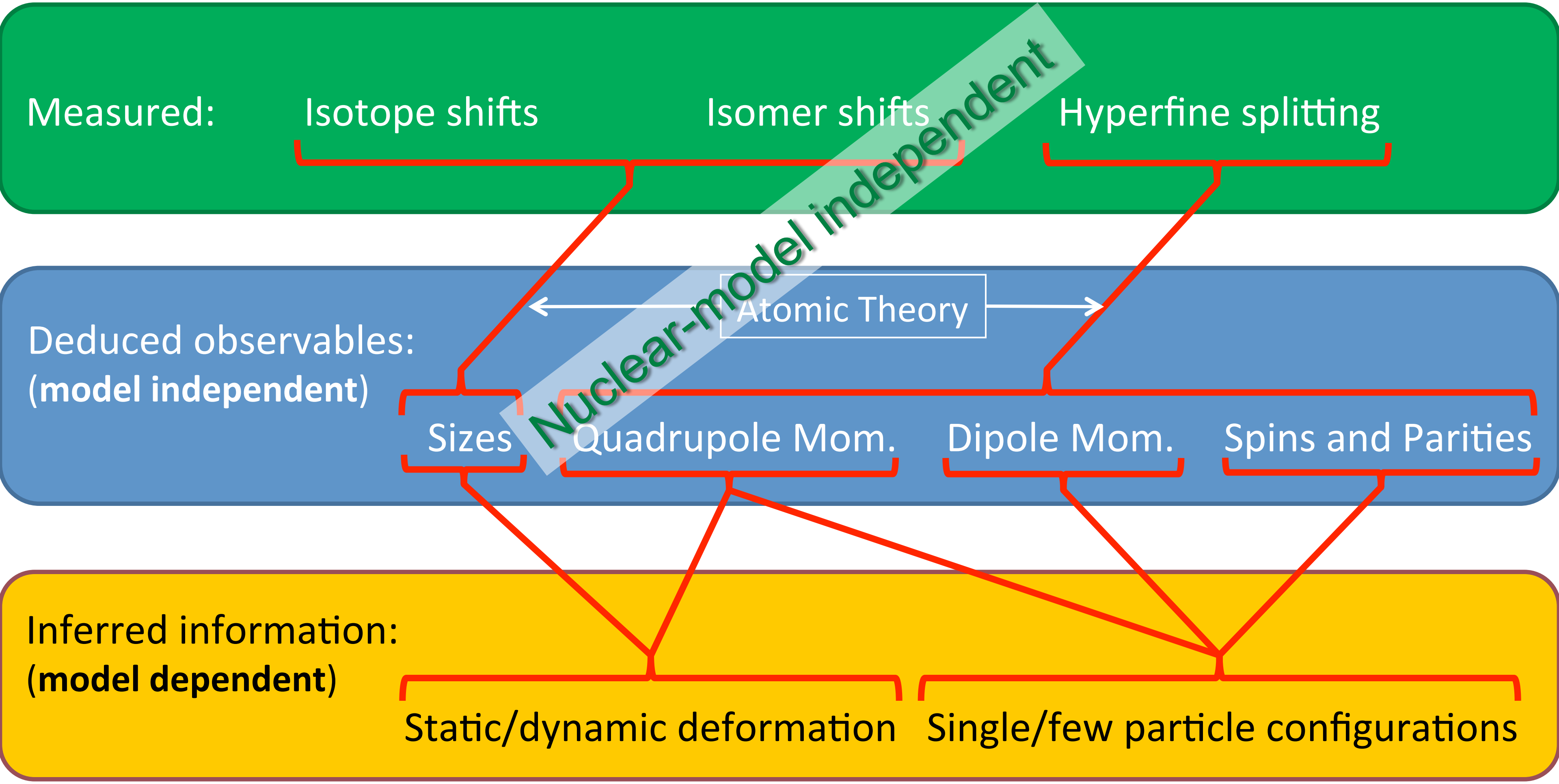
S. Eliseev et al., Nucl. Instr. and Meth. B 266 (2008) 4475–4477

Max-Planck-Institut
für Kernphysik

LMU

S. Eliseev, C Droese,
M. Laatiaoui, E. Minaya et al.

# Laser Spectroscopy


Measured:
Isotope shifts
Isomer shifts
Hyperfine splitting

Nuclear-model independent

Atomic Theory

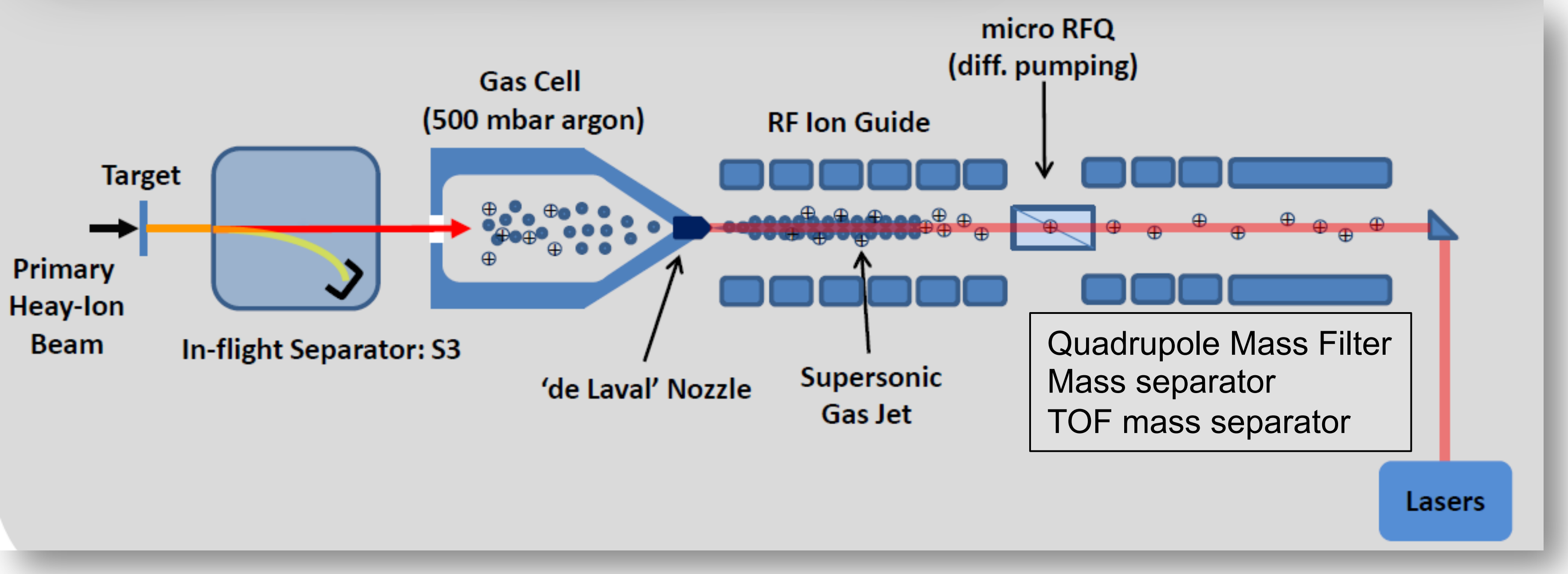
Deduced observables:
(**model independent**)
Sizes
Quadrupole Mom.
Dipole Mom.
Spins and Parities

Inferred information:
(**model dependent**)
Static/dynamic deformation
Single/few particle configurations

Otten E.W., Treatise on Heavy Ion Science vol 8 (1989) 517
Billowes J and Campbell P, J. Phys. G21 (1995) 707
Kluge H-J., Nörtershäuser, W. Spectrochim. Acta B 58 (2003) 1031
Kluge H-J., Hyperfine Interact. 196 (2010) 295
Cheal B.and Flanagan K., J. Phys. G. 37 (2010) 113101

# The HELIOS concept

- Production of the heavy elements: heavy-ion fusion evaporation reactions
- Separation of the primary and secondary beam: e.g. S3-GANIL
- Thermalization in the gas cell
- Repelling unwanted ions
- Formation of a cooled atomic beam through e.g. a ‘de Laval’ nozzle (gas jet)
- Resonant laser ionization: high-repetition rate laser system (>10 kHz)
- Ion capture and transport in the RF Ion Guide followed by mass separation
- Detection of the ions: radioactivity / ion counting

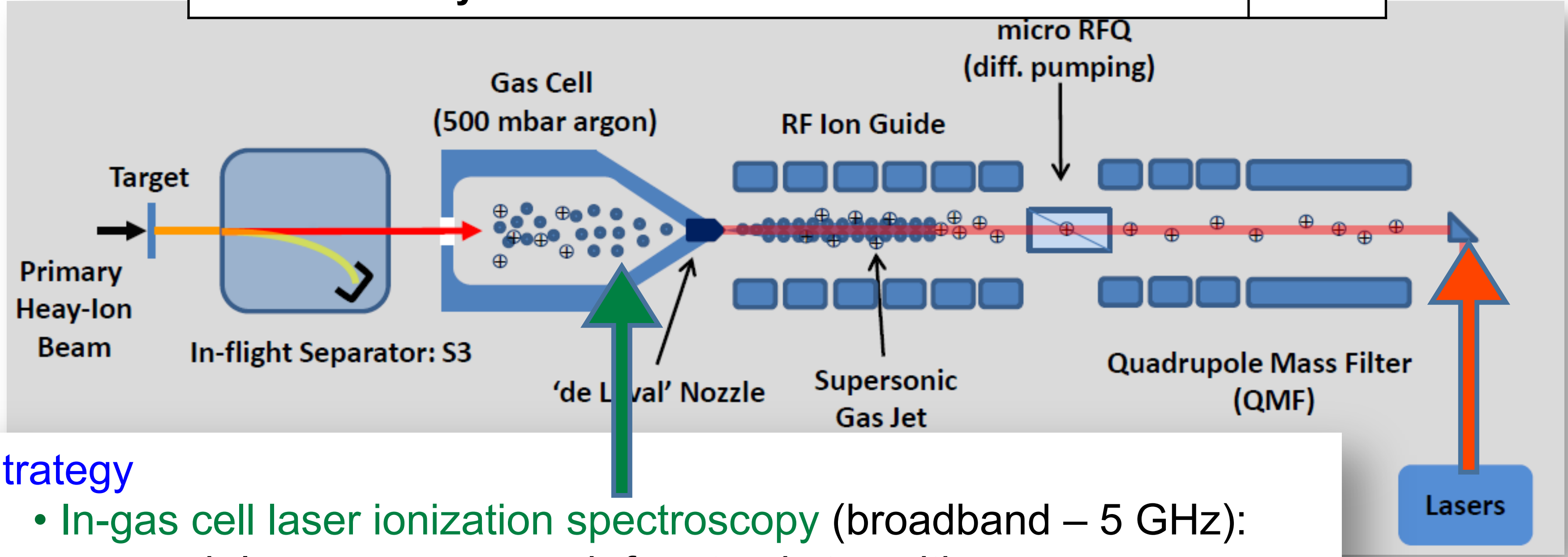


Quadrupole Mass Filter
Mass separator
TOF mass separator

# Heavy Element Laser IOnization Spectroscopy - HELIOS

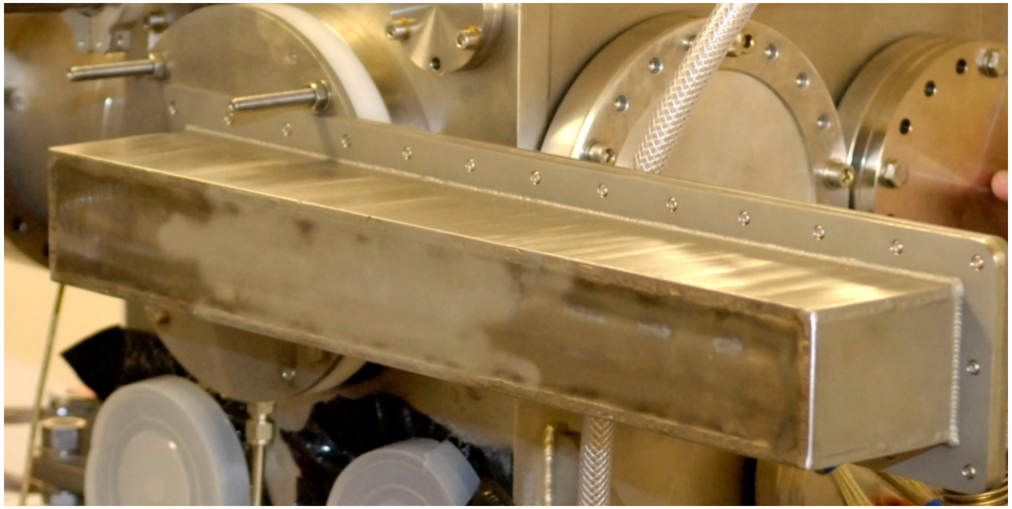
- Expected performances

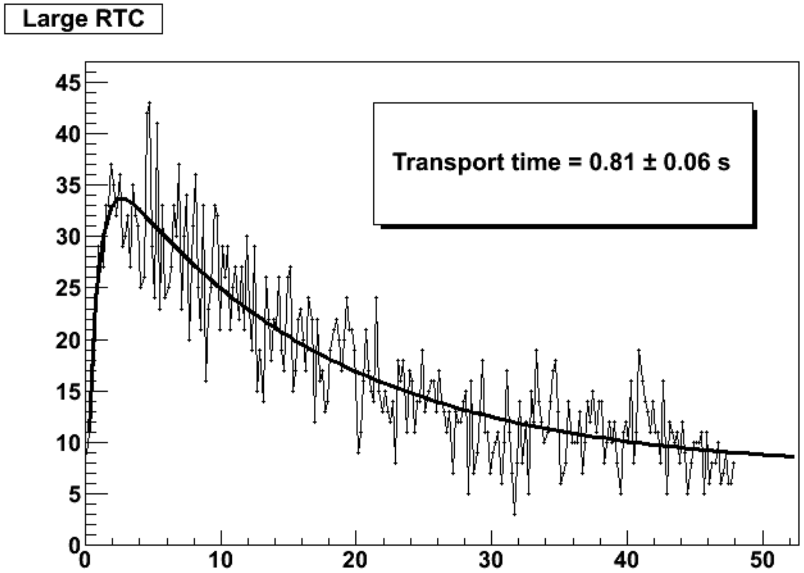
| | |
|---|---|
| Transport through the in-flight separator | 50 % |
| Thermalization, diffusion and transport towards the exit hole | 90 % |
| Neutralization in to the atomic ground state | 30 % |
| Formation of the gas jet | 90 % |
| Laser ionization | 50 % |
| Capturing efficiency | 80 % |
| Detection efficiency | 85 % |
| **Total efficiency** | **4 %** |



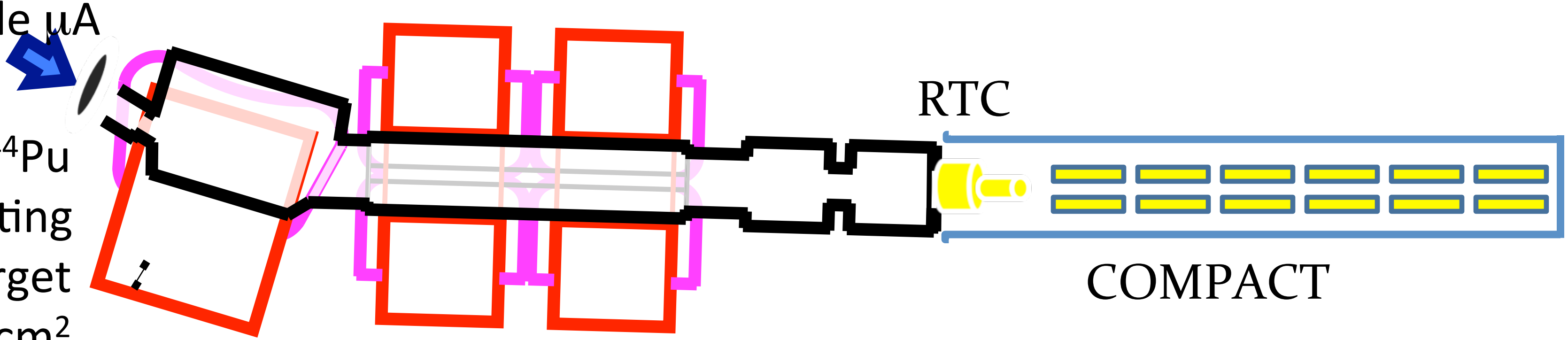
- Strategy
  - In-gas cell laser ionization spectroscopy (broadband – 5 GHz): rough laser scans, search for atomic transitions
  - In-gas jet laser ionization spectroscopy (narrow band – 200 MHz)

# 2009: E114 chemistry at TASCA





$^{48}$Ca beam
0.4 particle μA



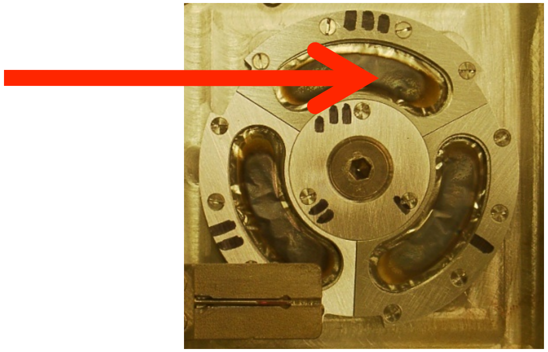
$^{244}$Pu
rotating
target
0.5 mg/cm$^2$

RTC

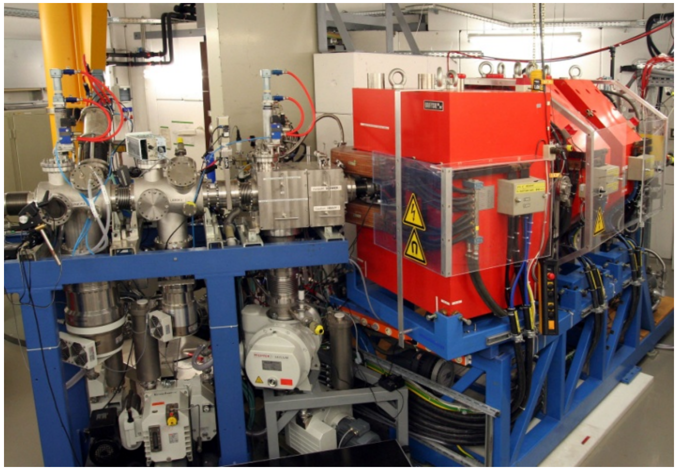
COMPACT

# Experimental setup

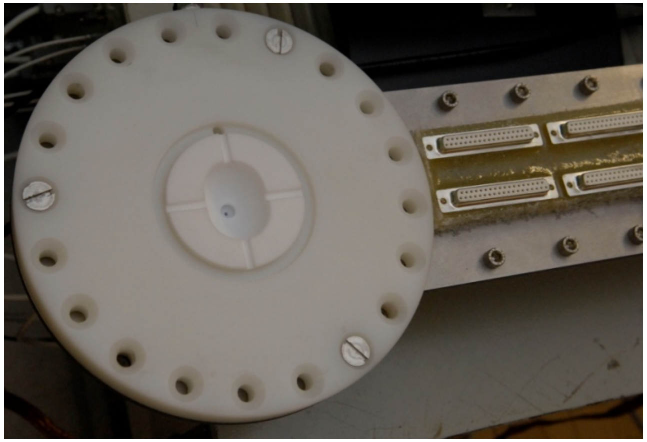
Beam: $^{48}Ca^{+10}$
(5.475 MeV/u)



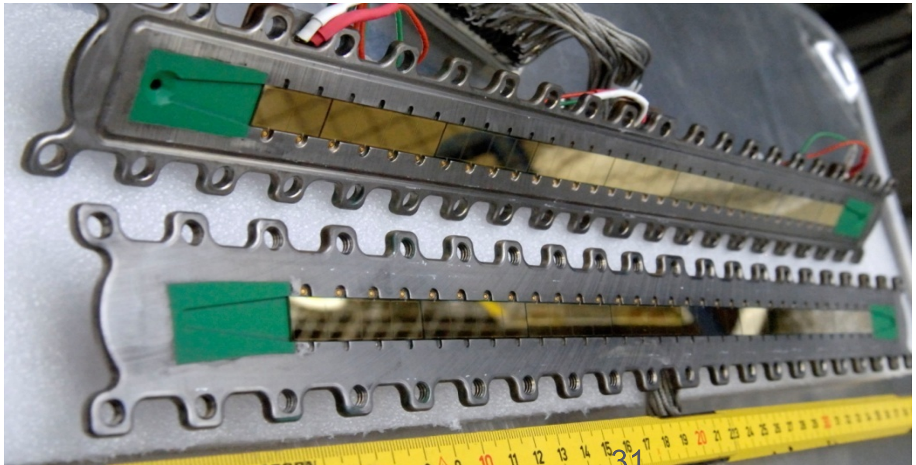
TASCA / SIM



RTC / COMPACT



Target: $^{244}PuO_2$
Backing 2.5 μm Ti
Segment 1: 440 μg/cm$^2$
Segment 2: 771 μg/cm$^2$
Segment 3: 530 μg/cm$^2$



## Data taking

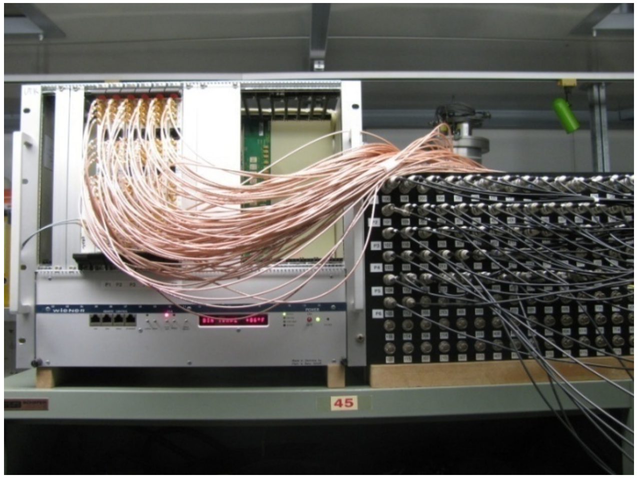
# Update on new detection system for short-lived super heavy nuclei

***Krzysztof P. Rykaczewski***
*Physics Division, Oak Ridge National Laboratory*
in collaboration with
***Robert Grzywacz, Krzysztof Miernik and David Miller***
*and*
***Alexander Polyakov, Yuri Tsyganov, Alexey Voinov***

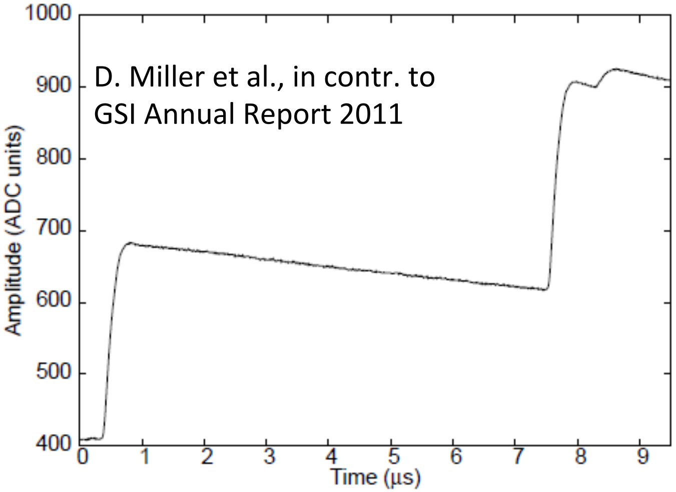
**Status of new detection/digital acquisition system**

- **MICRON DSSD + Si detectors in the test chamber**
- **Pixie16 system + Dell Power Edge computer**
- **test of digital data acquisition at SHIP (search for Z=120)**

# SHIP (GSI): search for μs-activity of element Z=120
# April/May 2011 and April 2012



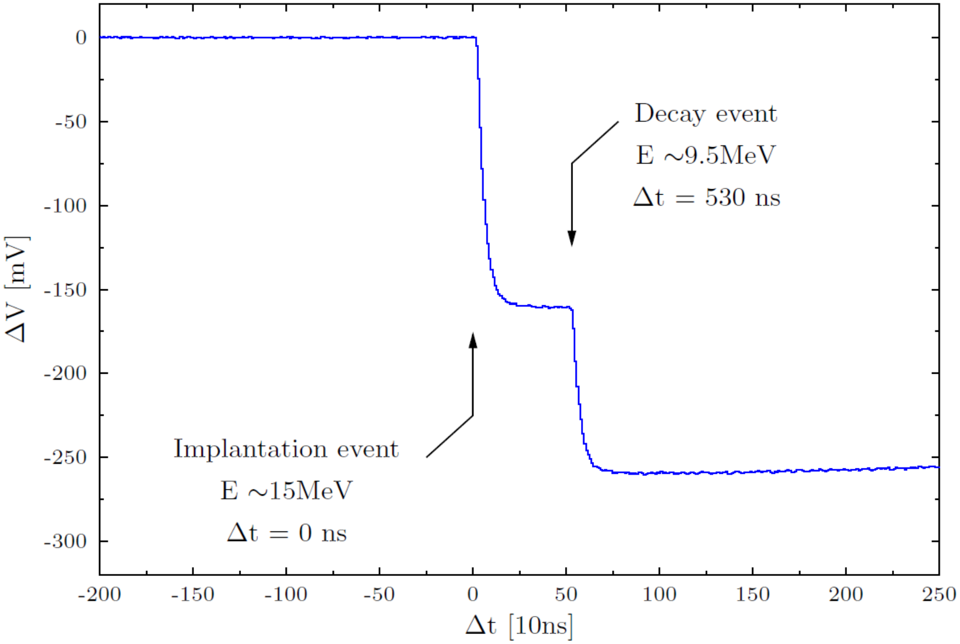
*ORNL/UTK digital system*
*capable to detect sub μs-decays*
*was used in parallel*
*to analog data acquisition at SHIP*

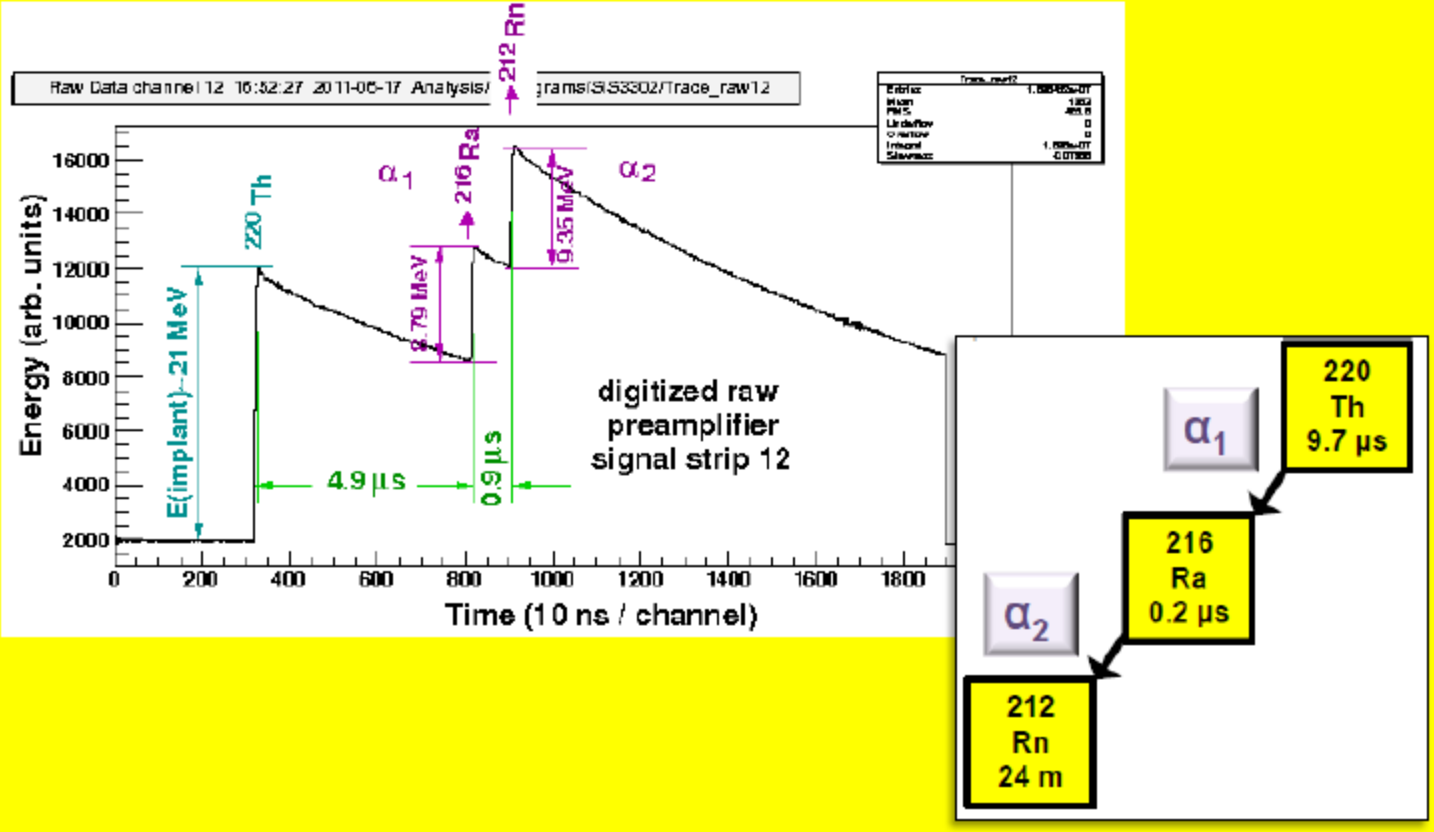


D. Miller et al., in contr. to
GSI Annual Report 2011

Figure 1: Trace capture selectively triggered from the pileup inspector with two successive implants followed by a low-energy alpha decay.

$^{48}$Ca + $^{175}$Lu → $^{223}$Pa* → $^{220}$Pa + 3n @ JYFL



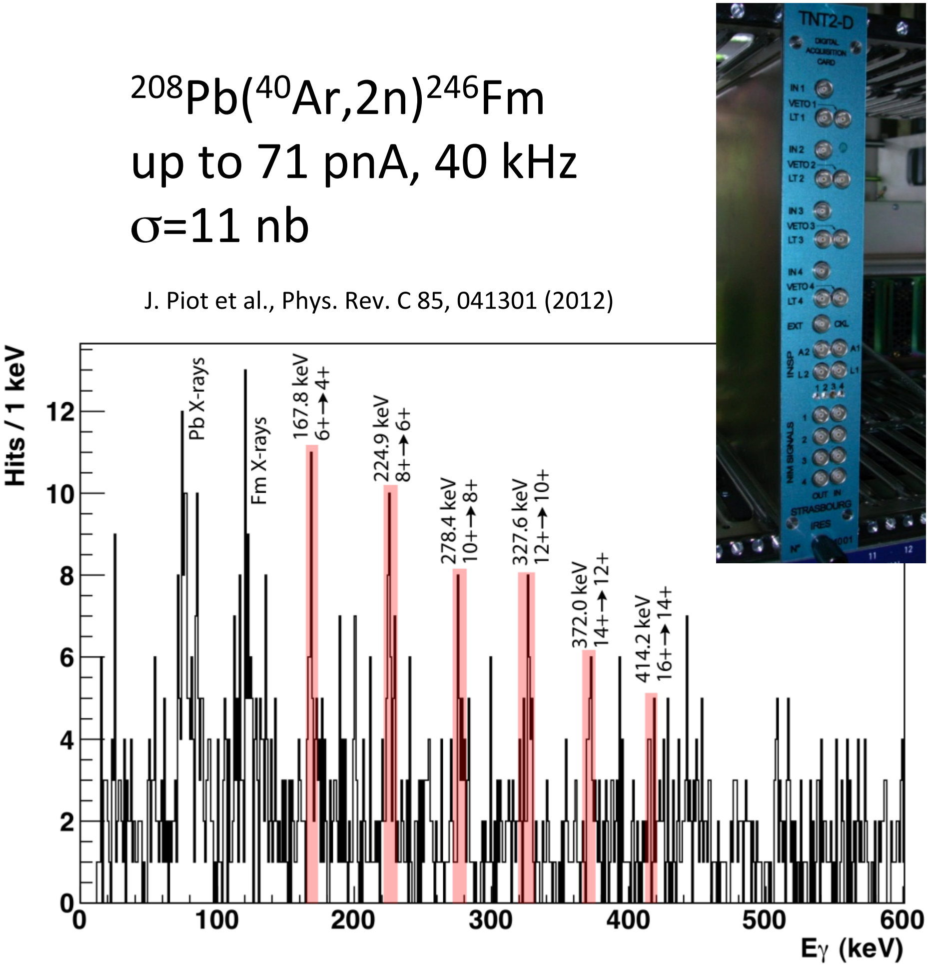


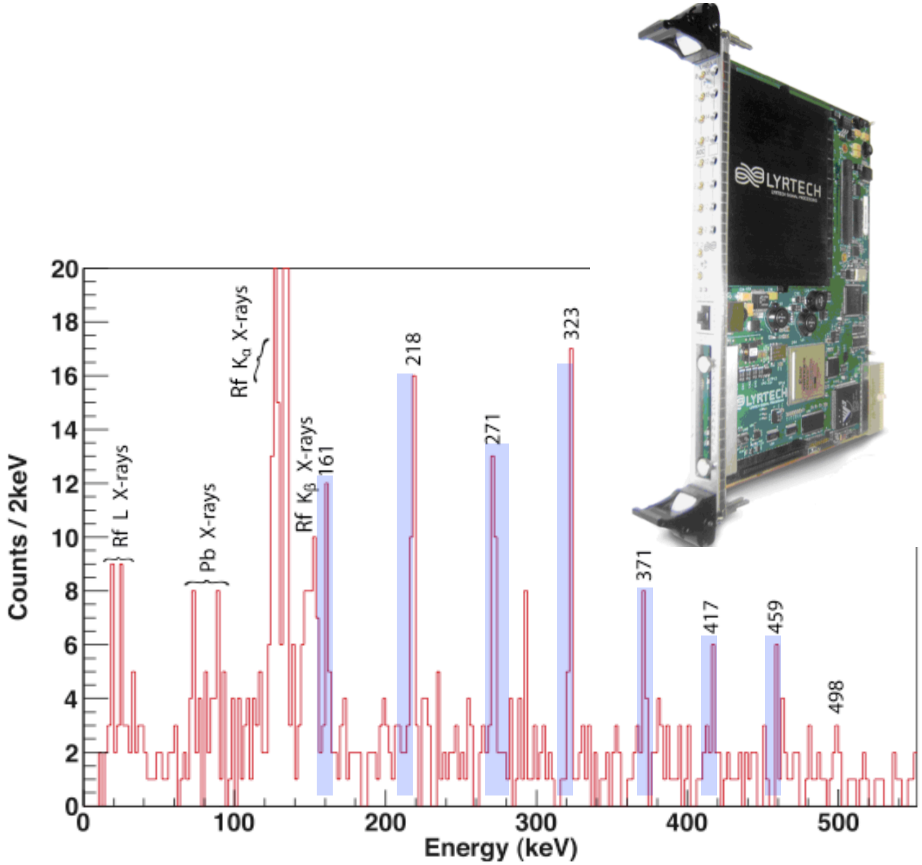
The 2011 Z=120 TASCA experiment was performed with dead-time free sampling ADC cards developed at GSI-EE N. Kurz *et al.*

# Current limit for in-beam spectroscopy

$^{208}$Pb($^{40}$Ar,2n)$^{246}$Fm
up to 71 pnA, 40 kHz
σ=11 nb

J. Piot et al., Phys. Rev. C 85, 041301 (2012)





$^{208}$Pb($^{50}$Ti,2n)$^{256}$Rf
up to 45 pnA, 50 kHz
σ=15 nb

P.T. Greenlees, submitted to Phys. Rev. Lett.

# Cross section limits

| Type of study | Today | Near future |
|---|---|---|
| New elements | ~ 50 fb | ~10 fb |
| "Fast" delayed spectroscopy | 100 pb-1 nb | 10 pb - 100 pb |
| In-beam spectroscopy | 10 nb | 1 nb |
| Mass measurements | 50 nb | 10 nb |
| Gas Phase Chemistry | 10 pb | 1 pb |
| Laser spectroscopy | | $^{254}$No 6 pps, 2 μb |

Distant future ?

How low cross-sections (production yeilds) can be measured ?

- New elements, new isotopes

How high in sensitivity we can go?

- Spectroscopic studies