Measuring Masses with Z≈104 using MLLTRAP at DESIR

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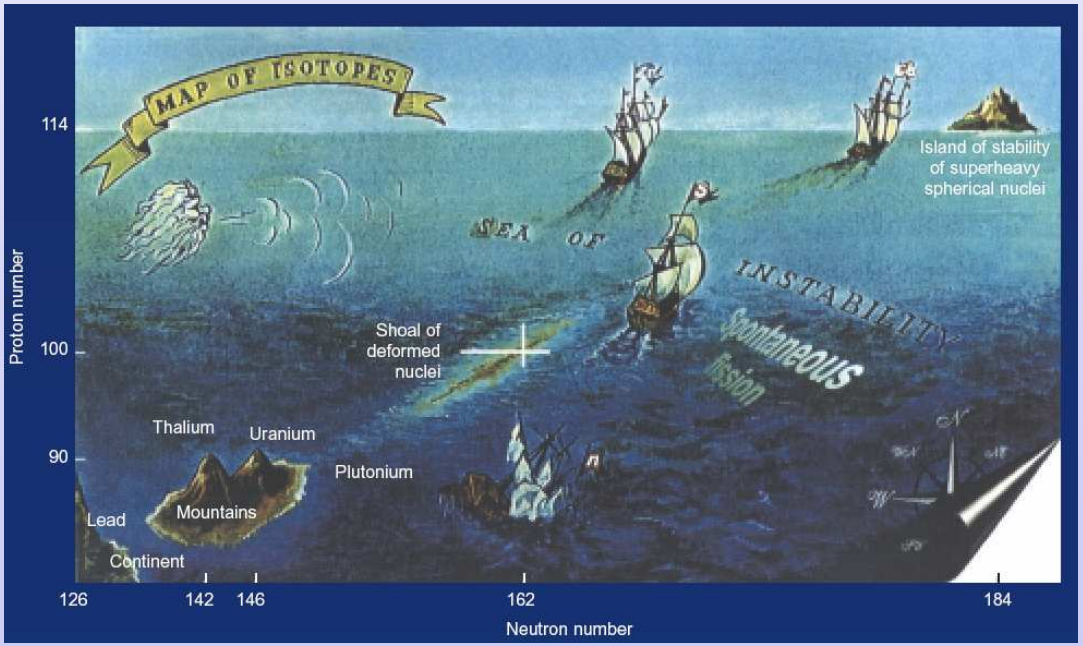
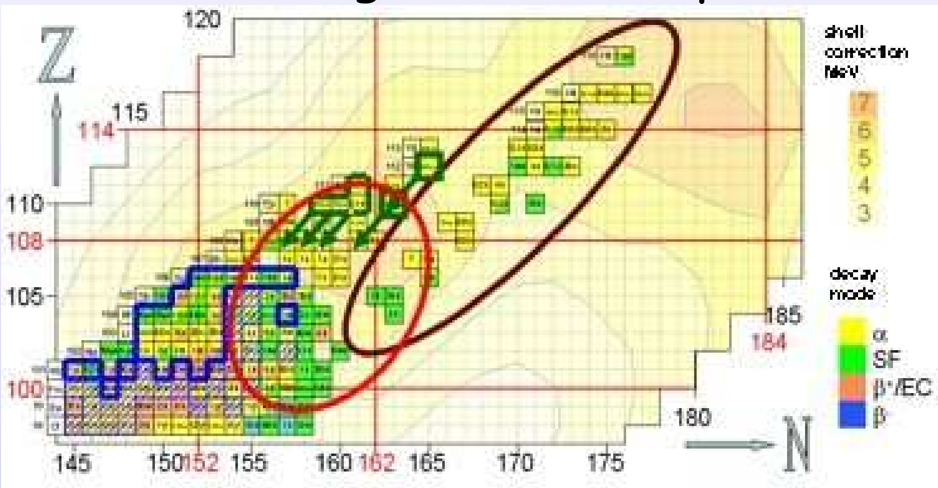
Outline:

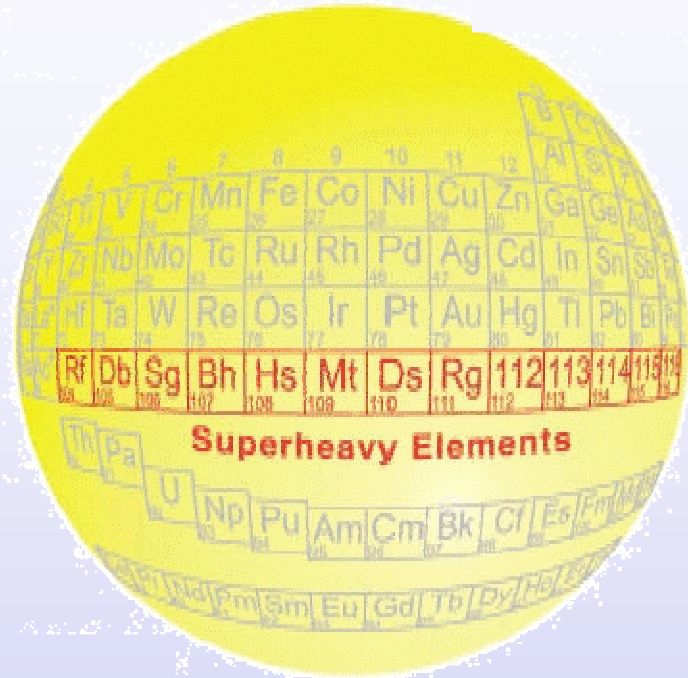
- Motivation of (S)HE mass measurements
- Environment for studies with MLLTRAP at S^3/DESIR
- Status of MLLTRAP system
- Status of transuranium mass measurements: SHIPTRAP results
- Identification of candidates for MLLTRAP
- Feasibility considerations
- Conclusion



Mass Measurements of (S)HE

SHE: stabilized by shell effects
understanding fission barriers:
-> precise binding energies needed
-> contribution to fundamental knowledge of nuclear potential





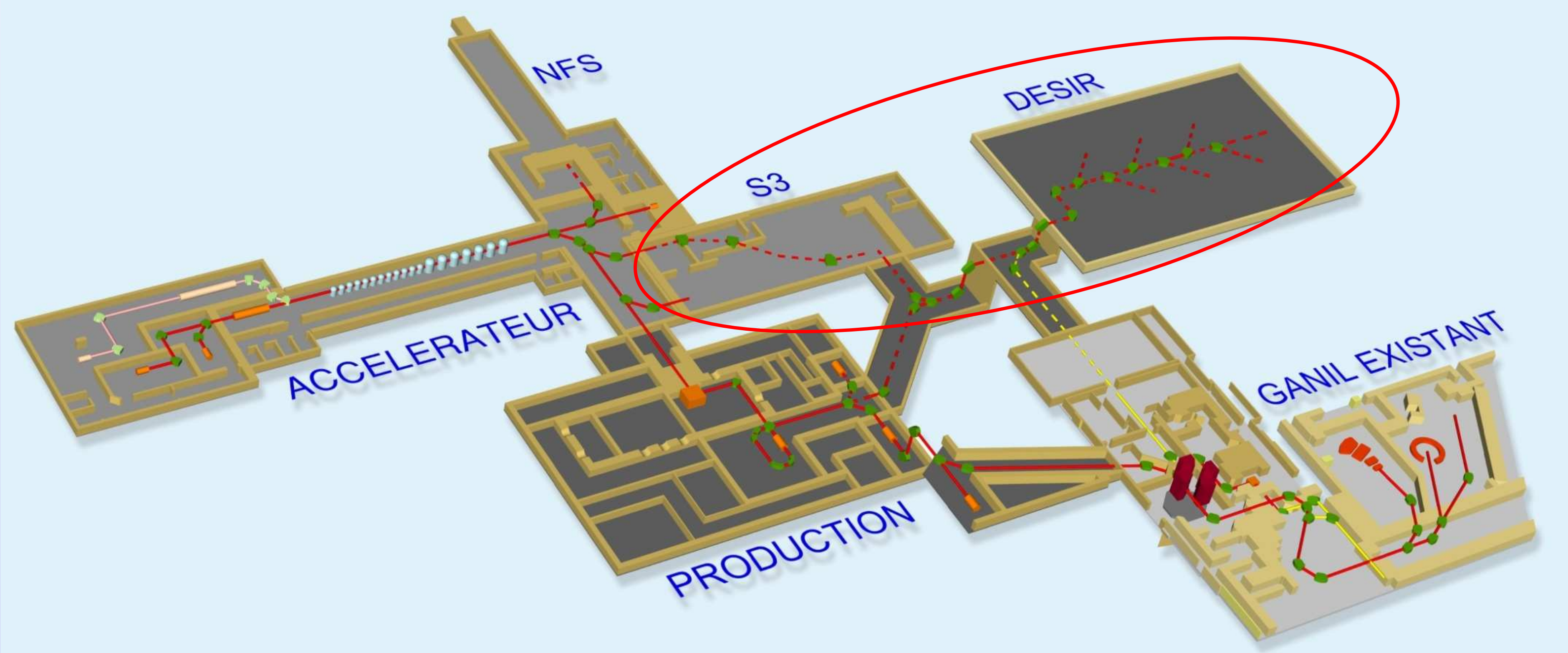
- so far: (S)HE masses from α decay chains to known masses
- odd nuclides: decay often to excited daughter levels
- direct mass measurements:
  unambiguous data independent of nuclear level schemes

→ high precision Penning trap mass measurements

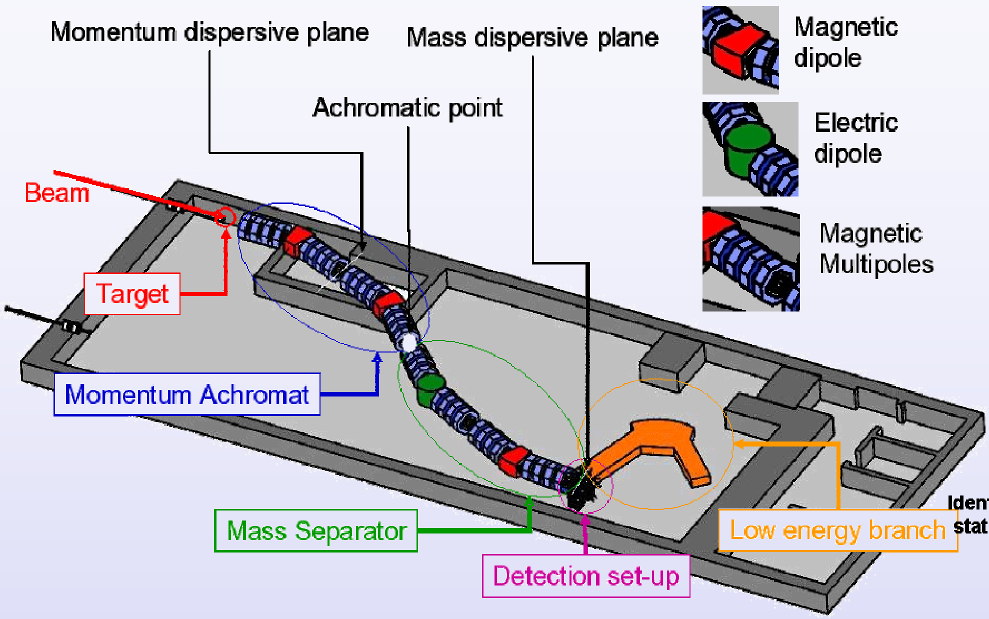
SPIRAL 2 @ GANIL

exploit synergies of S^3 and DESIR:

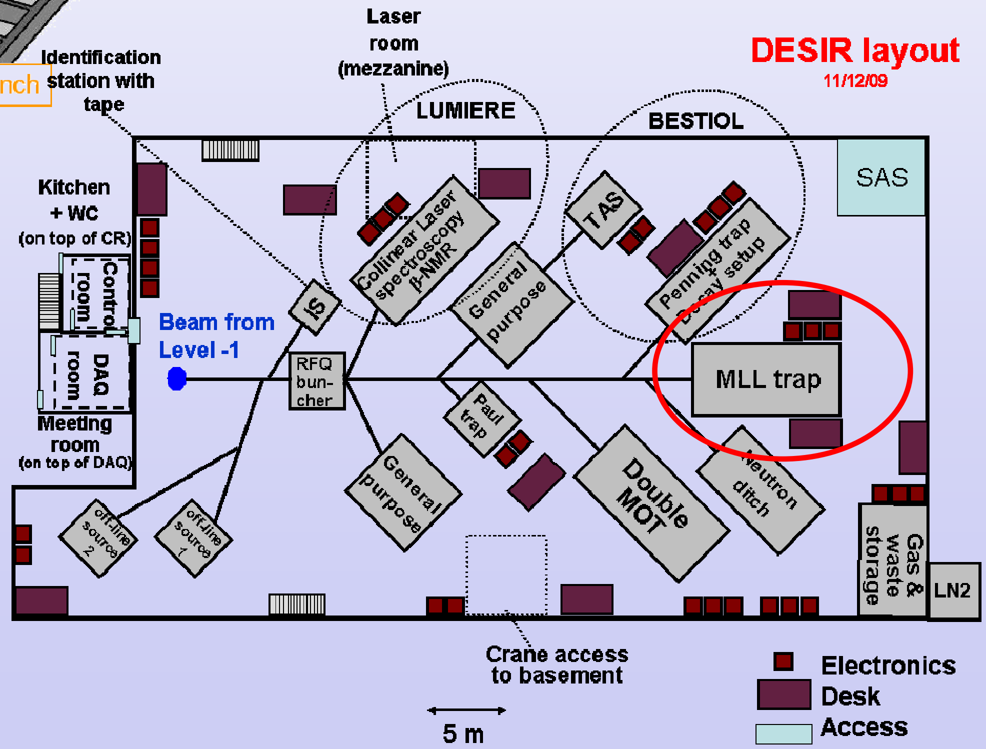
- high intensity stable primary beams
- highly efficient S^3 separator for fusion products
- experimental infrastructure at DESIR: mass measurements



Coupling between S^3 and DESIR



transfer of mass separated heavy fusion products from S^3 to DESIR



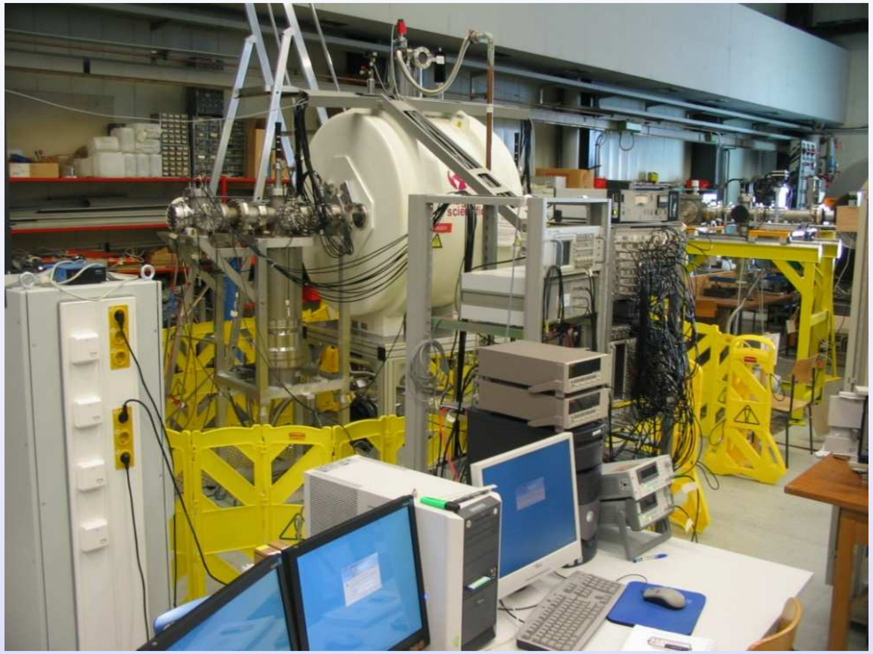
precision Penning trap mass measurements in MLLTRAP

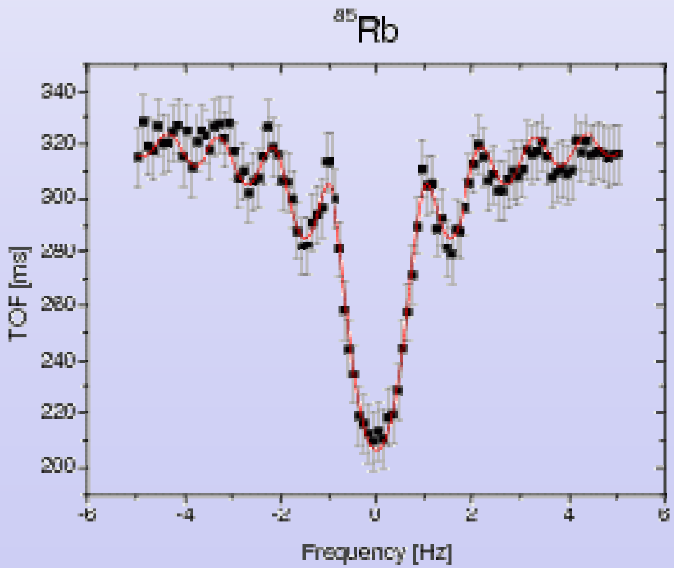
Status of MLLTRAP

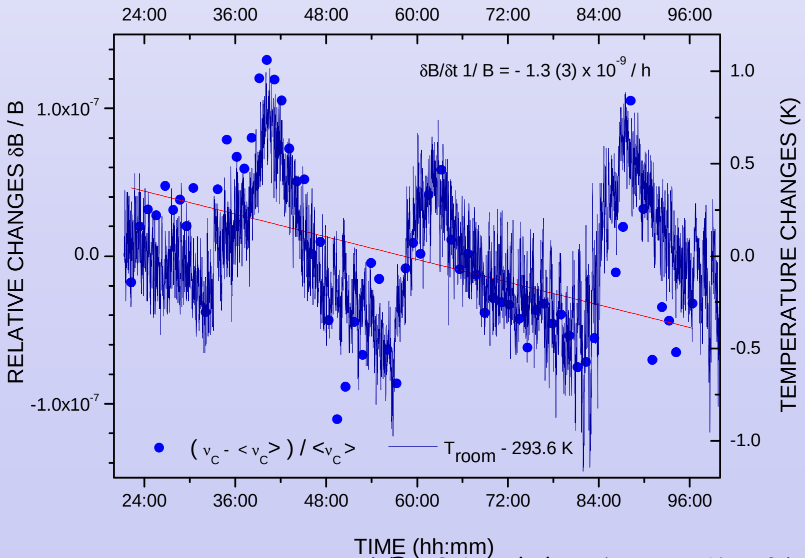
- 7T trap magnet, identical to SHIPTRAP, JYFLTRAP

Status:

- operational with $\Delta m/m \sim 5 \cdot 10^{-8}$ (without systematic errors)
- systematic effects on B field studied



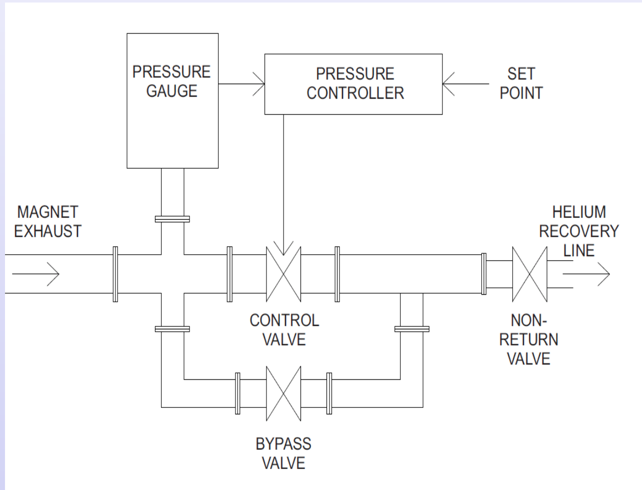




Temperature and Pressure Stabilization

Temperature stabilization:
- blow warm air into magnet bore
- PID stabilization: goal ≈ ± 10 mK

Pressure stabilization:
- stabilize He reservoir pressure via controlled valve in helium exhaust line
- goal: ± 0.2 mbar

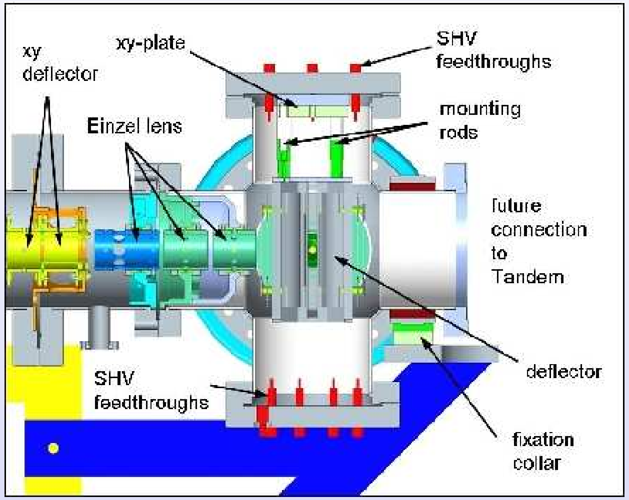


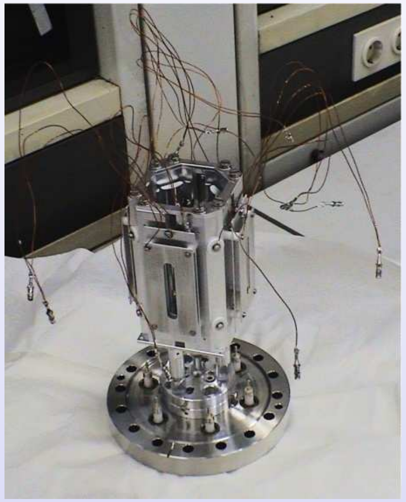
(work in progress)

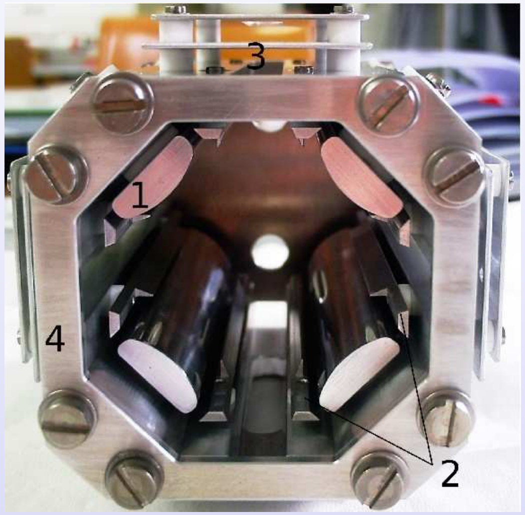
diploma work: K. Krug (2010)

Quadrupole beam deflector

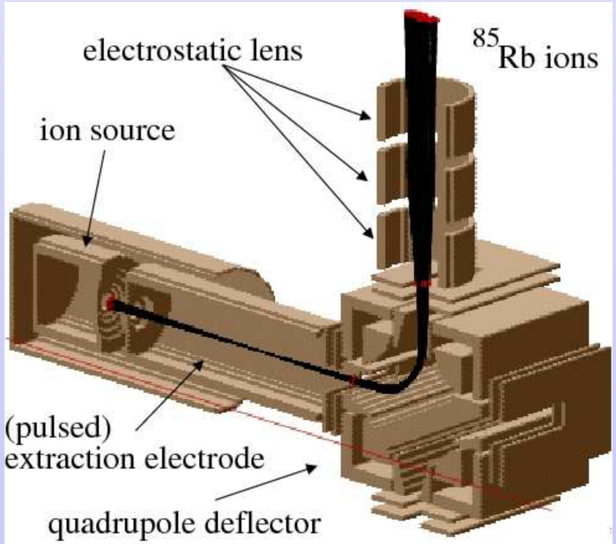
- electrostatic 4-way beam bender in injection line
- enables use of multiple ion sources







- ion trajectories (SIMION):

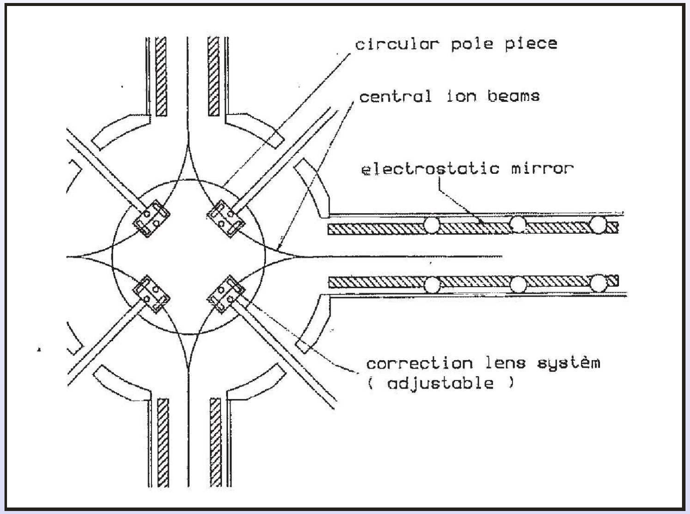


- measured transmission: ~ 80 %

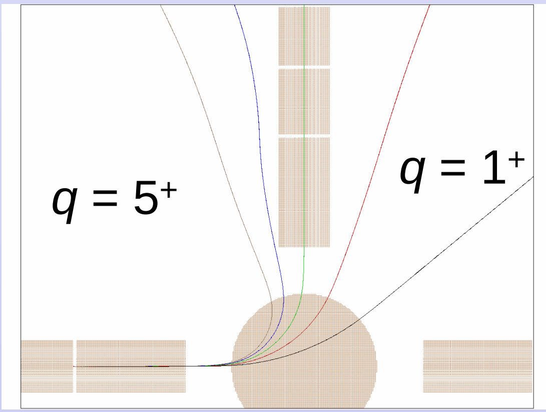
diploma work: E. Gartzke (2009)

Multi-Passage Spectrometer (MPS)

prerequisite for future use of trap with highly charged ions:
q/A separator



SIMION studies (C. Weber):

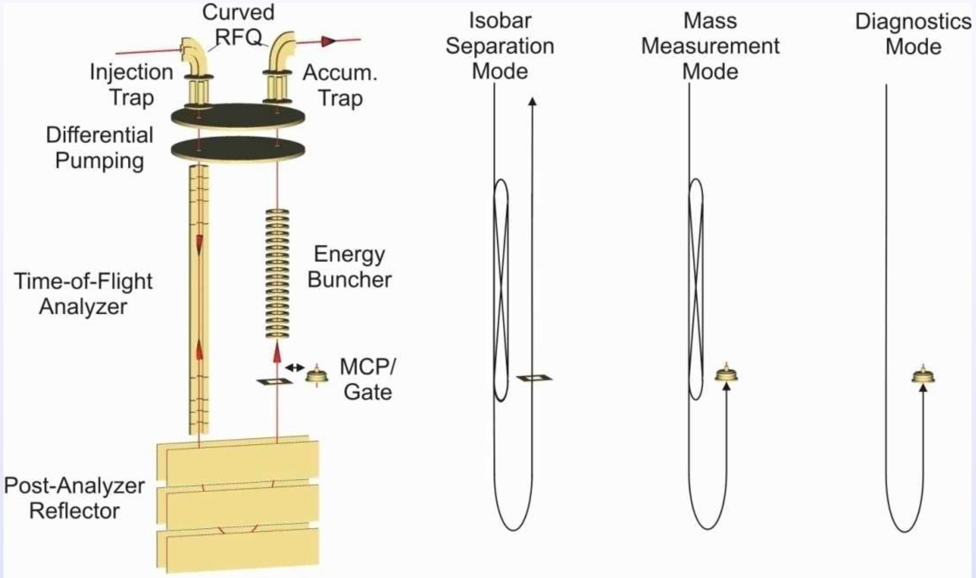


- fast cycling magnet: 0 - 1.2 T in 50 ms
  (laminated yoke: 0.5 mm, SigmaPhi)
- round pole tip (diam. 250 mm)

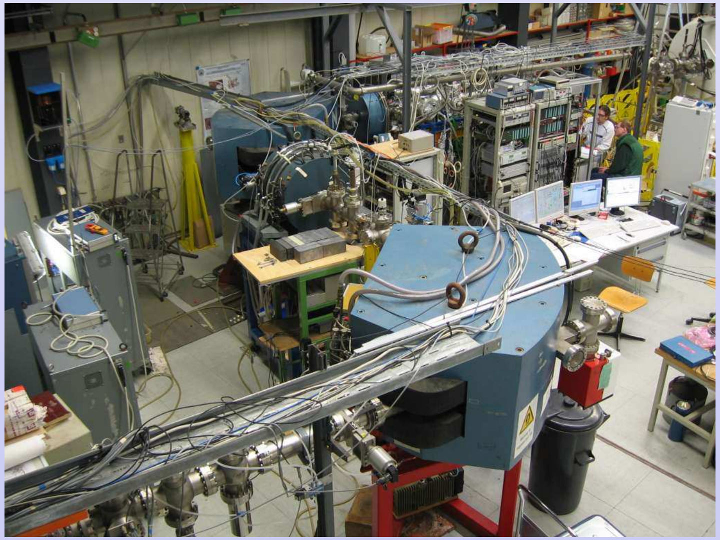
Multi-Reflection TOF Spectrometer

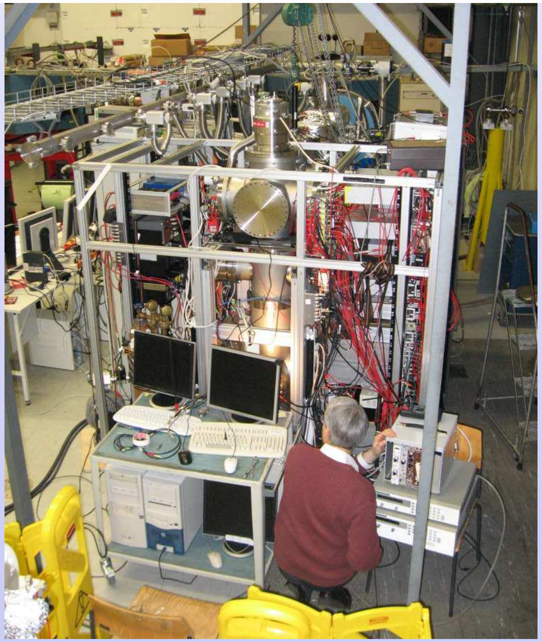
W. Plaß et al., Uni Giessen

- analyzer with 2 electrostatic reflectors
- length: ca. 0.5 m, short TOF: ~ 1 ms
- ca. 100 turns: $m/\Delta m > 10^5$ achievable
- efficiency > 50%
- setup in collaboration with Giessen team

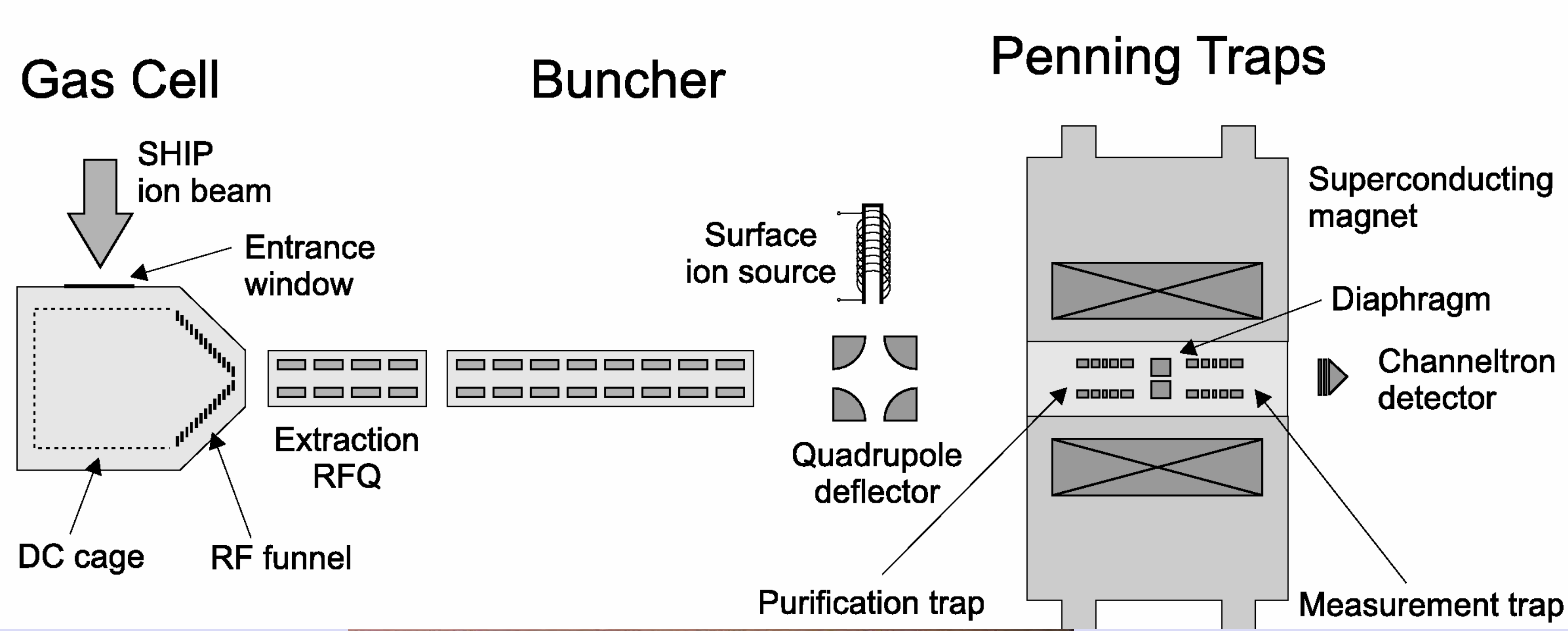


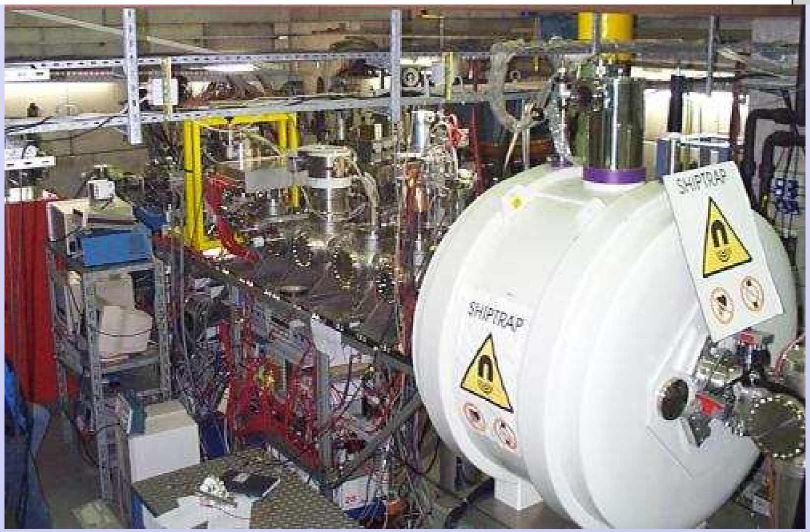
beamtime march '09 at Garching:
prototype test of MR-TOF
→ $m/\Delta m > 3 \times 10^5$





First direct Transuranium Mass Measurement: at SHIPTRAP

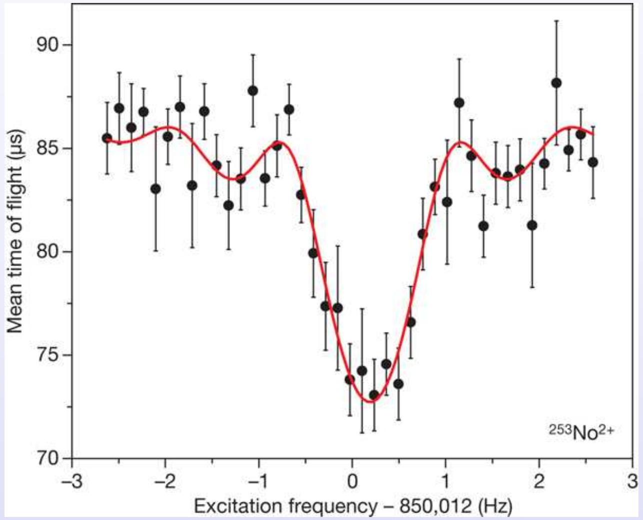




$^{252-254}$No Mass Measurements @ SHIPTRAP

- $^{206-208}$Pb(^{48}Ca,2n) $^{252-254}$No (Z=102):
  - E_{beam} = 4.55 MeV/u
  - E* = 22 MeV
  - I_{beam} = $6 \cdot 10^{12}$ pps

isotope	$T_{1/2}$ (gs)	$T_{1/2}$(isomer)	σ
^{254}No	2.44(4) s	110(10) ms	1.8 μb
^{253}No	1.62(15) min.	715(30) μs	1.0 μb
^{252}No	51(10) s	266(2) ms	400 nb



→ production: ~ 1 atom/sec.
- ε(Shiptrap) ~ 1-2%

→ ca. 1 ion/min. detected behind trap

accuracy:
Δm/m ~ $5 \cdot 10^{-8}$ - 10^{-7}
(Δm~13-30 keV)

- present limit:

^{255}Lr: ^{209}Bi(^{48}Ca,2n) at 4.55 MeV/u:

σ ~ 200 nb

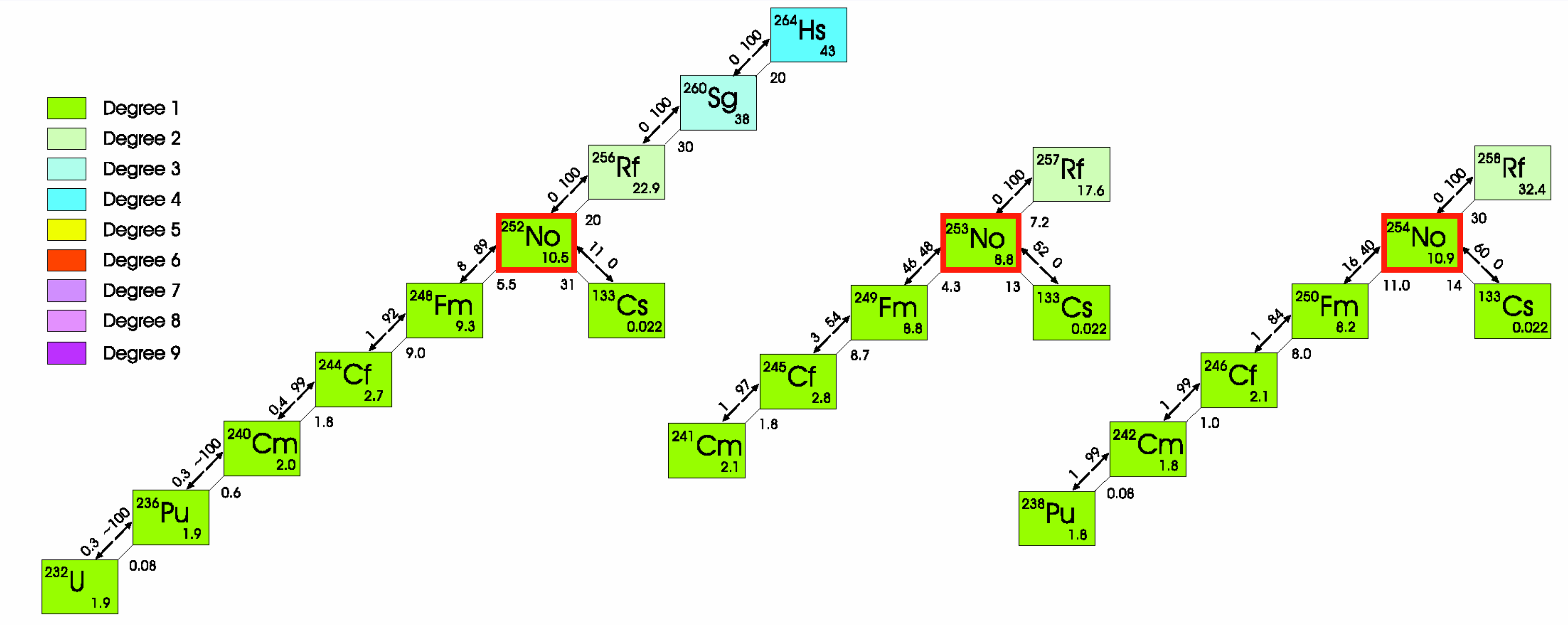
→ 0.3 ions/s detected in front of SHIPTRAP

→ ~ 10 ion/hour detected behind trap (May 2010)

M. Block et al., Nature 463 (2010) 785
M. Dworschak et al., subm. to PRC

Updated Mass Evaluation

- before: No masses indirectly via Q_α values from decay spectroscopy
- new Nobelium masses: 'primary' nuclides in mass evaluation
- including new SHIPTRAP results:



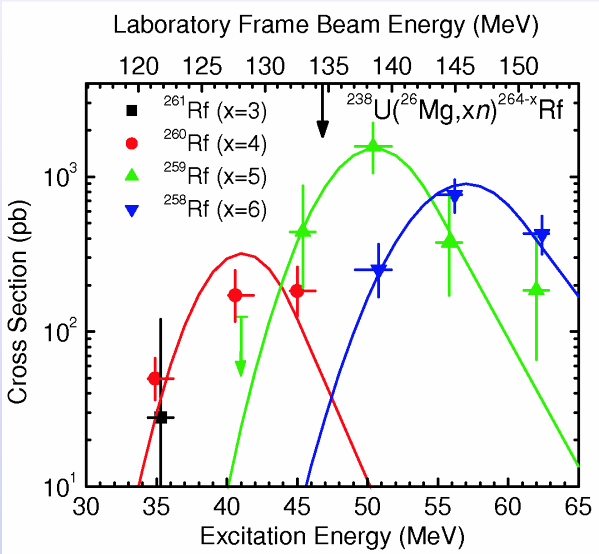
Rf masses: ~ factor 2 less accurate than No

M. Dworschak et al., PRC in print

Candidates for measurements with Z≥104 @ MLLTRAP

- Sg-isotopes (Z=106):
  K. Gregorich et al. (PRC 2006):
  $^{238}U(^{30}Si,xn)^{268-x}Sg$: 10 - 40 pb
  B. Streicher et al. (2007):
  $^{208}Pb(^{54}Cr,1n)^{261}Sg$: 2.0(1) nb

- Db, Rf isotopes (Z=105,104):
  i) Nagame et al. (JNRS 2002):
  $^{248}Cm(^{18}O,5n)^{261}Rf$ (94 MeV): 13(3) nb
  $^{248}Cm(^{19}F,5n)^{262}Db$ (106 MeV): 1.3(4) nb



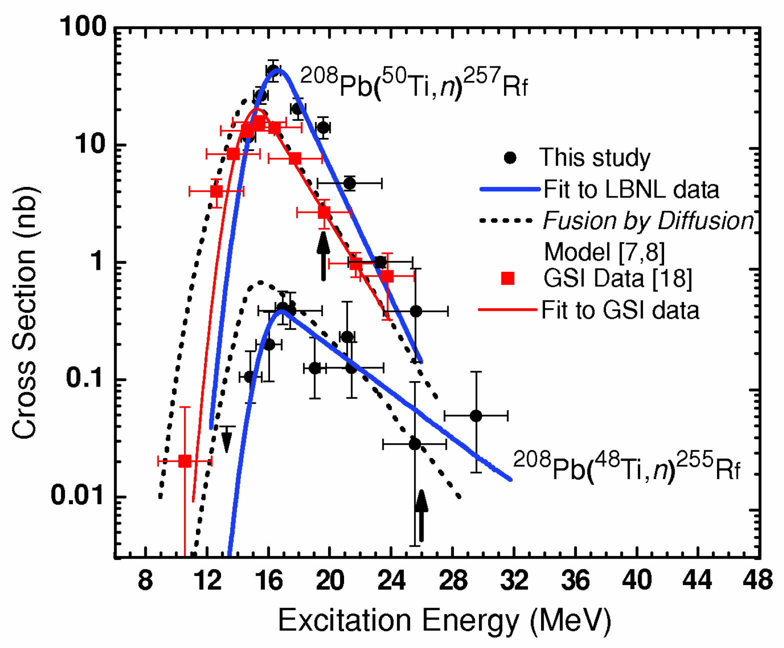
ii) Gates et al. (PRC 2008)

$^{238}U(^{26}Mg,3n)^{261}Rf$: ~ 28 pb
$^{238}U(^{26}Mg,4n)^{260}Rf$: 180(80) pb (133.0 MeV)
$^{238}U(^{26}Mg,5n)^{259}Rf$: 1.56(50) nb (138.5 MeV)
$^{238}U(^{26}Mg,6n)^{258}Rf$: 0.77(20) nb (144.5 MeV)

Production of Light Rf Isotopes

iii) Dragojevic et al. (PRC 2008):

^{208}Pb(^{50}Ti,2n)^{256}Rf :	15.7(2) nb	(E_{beam}= 239.0 MeV)
^{208}Pb(^{50}Ti,1n)^{257}Rf :	43(10) nb	(230.5 MeV)



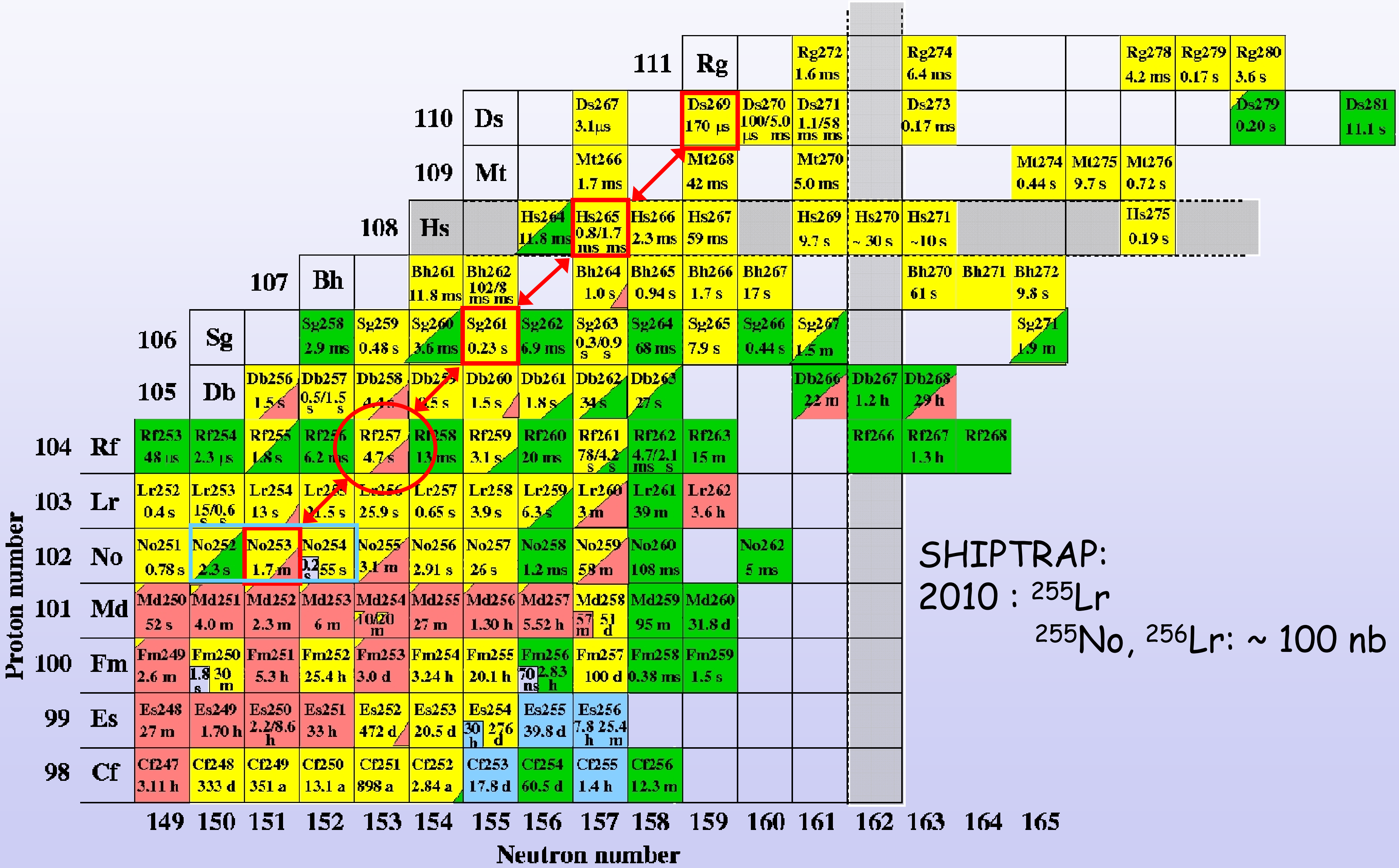
crucial:
optimized target thickness

Candidates: Rf isotopes (Z=104)

- ^{257}Rf:
  - reaction : ^{50}Ti + ^{208}Pb (40 nb)
    - S^3 transmission : 50-60%
    - target: PbS (for high beam intensity)
    - gas cell efficiency: ~ 10%-30%
    - drawback : ^{50}Ti beam needs development (expected: 1-10 pμA)
- ^{259}Rf:
  - reaction : ^{26}Mg + ^{238}U (1.5 nb)
    - S^3 transmission: ~ 15%
    - target: UO_2 (will be tested)
    - ^{26}Mg: high intensity (>10 pμA), available in 2013

→ clear preference for ^{257}Rf (via ^{50}Ti reaction)

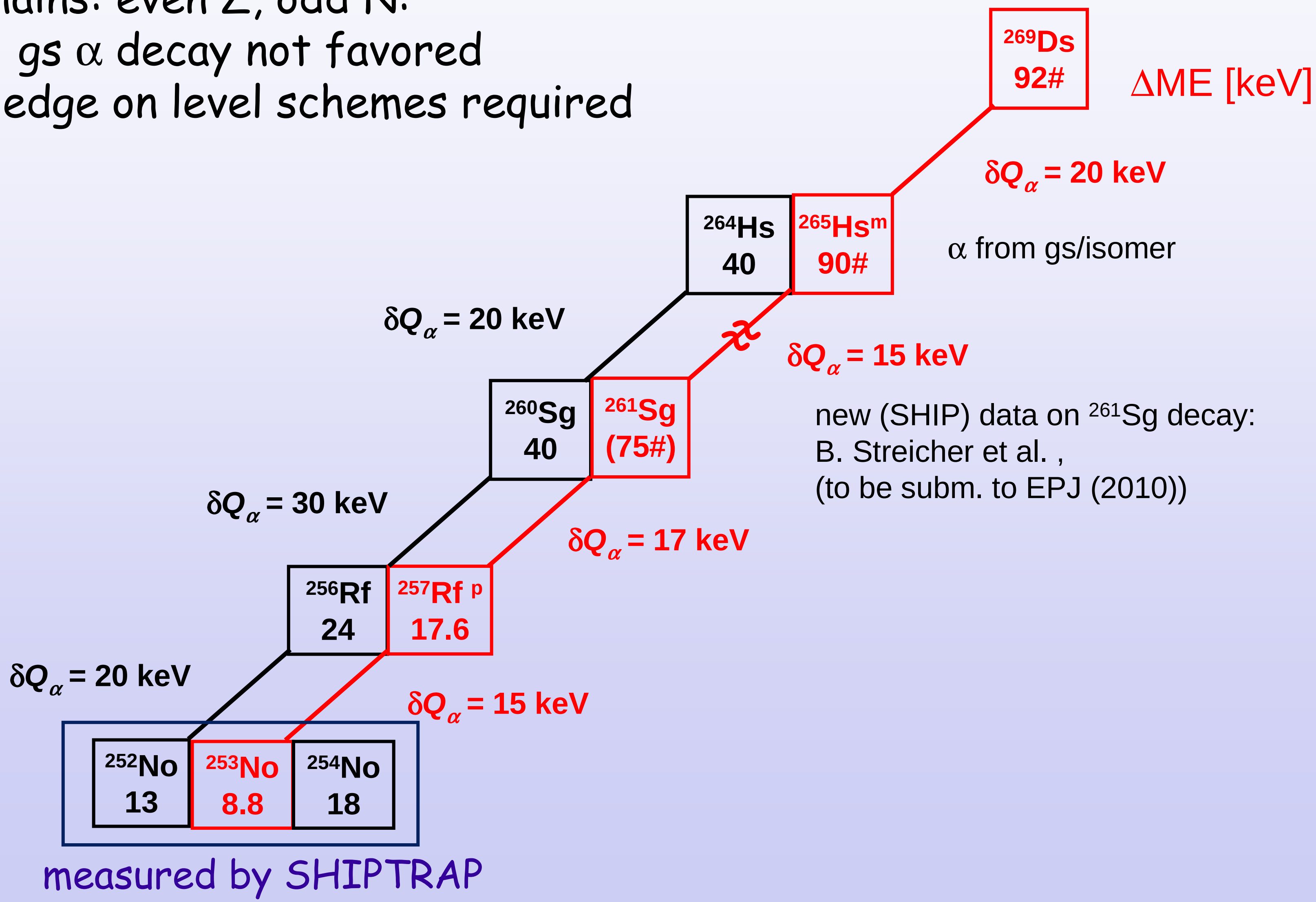
Candidate: ^{257}Rf



SHIPTRAP:
2010 : ^{255}Lr
^{255}No, ^{256}Lr: ~ 100 nb

^{257}Rf: connecting α decay chains

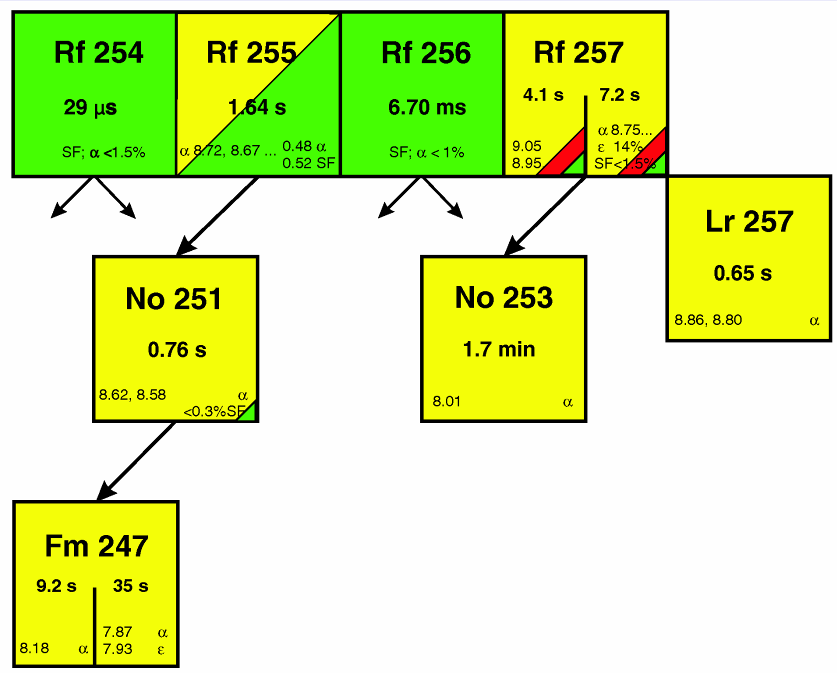
decay chains: even Z, odd N:
- gs → gs α decay not favored
- knowledge on level schemes required

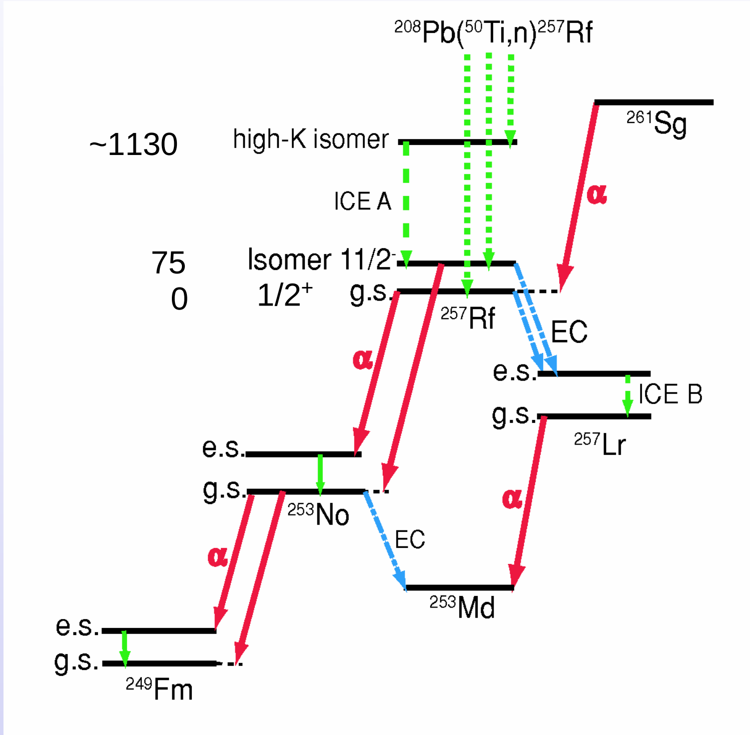


Decay Properties of ^{257}Rf

Qian et al. (PRC 2009):

- isomer in ^{257}Rf: 160(40) µs
  ($t_{1/2}$ (^{257}Rf) ≥ 4.1 s)





Yield Considerations

Example: (from: P. Greenlees et al., S^3 LoI 2009)

target: ^{238}U, 0.25mg/cm^2
S^3 transmission: 30%
primary beam intensity: 10 pμA
α decay events detected at focal plane (ε=0.55):
10 nb → 23460 events/week detected
→ ~ 43000 events/week at focal plane

^{257}Rf :
- S^3 transmission: ε ~ 0.5
- gas cell stopping: ε ~ 0.3
- 40 nb: ~ 84000/week after gas cell
→ assume transport/bunching efficiency ~ 15%
→ 10000/week at trap : ~ 1/min. at trap

transport efficiency to MLLTRAP to be studied

Conclusion

- coupling between S^3 and DESIR can be exploited for program on precise nuclear mass measurements of heavy elements

- high primary beam intensities, large separator efficiency: isotopes with Z≈104 within reach for Penning trap studies using MLLTRAP@DESIR

- candidate: ^{257}Rf (σ_{max}~ 40 nb)

- staged approach:
  - day-1: commissioning with known Nobelium isotopes:
    $^{206-208}$Pb(^{48}Ca,2n)$^{252-254}$No : 0.4- 1.8 μb
  - beam development: ^{50}Ti
  - day-2: ^{208}Pb(^{50}Ti,1n)^{257}Rf : ~ 40 nb

Thanks to ...

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