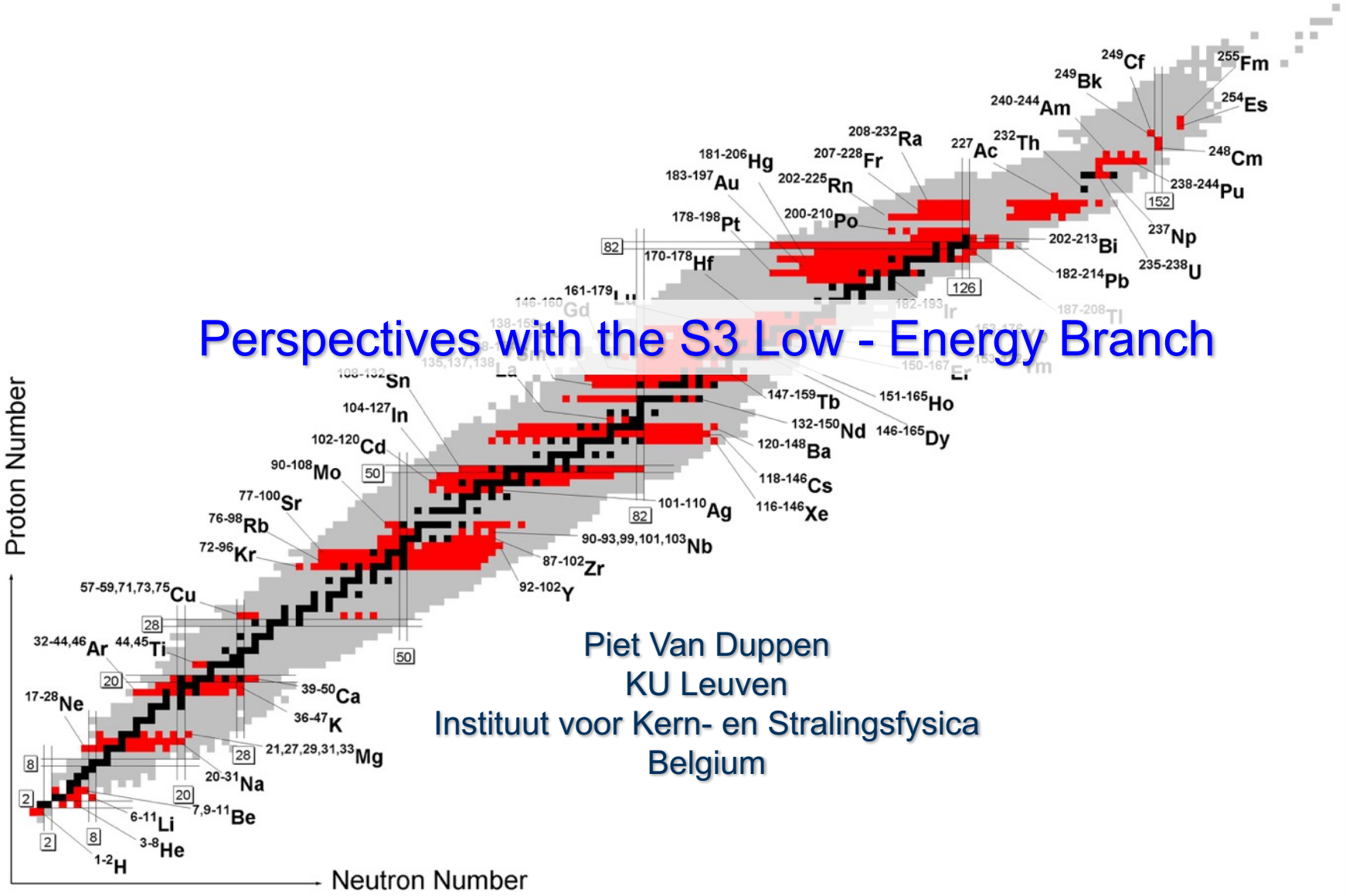
Perspectives with the S3 Low - Energy Branch



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Belgium

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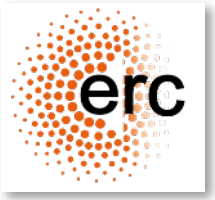
Outline

- The S3 LEB concept
- A short introduction to Laser Ionization Spectroscopy
- The S3 Low Energy Branch project
  - Expected performance, status and ongoing work
- Opportunities with S3 LEB
- Conclusion



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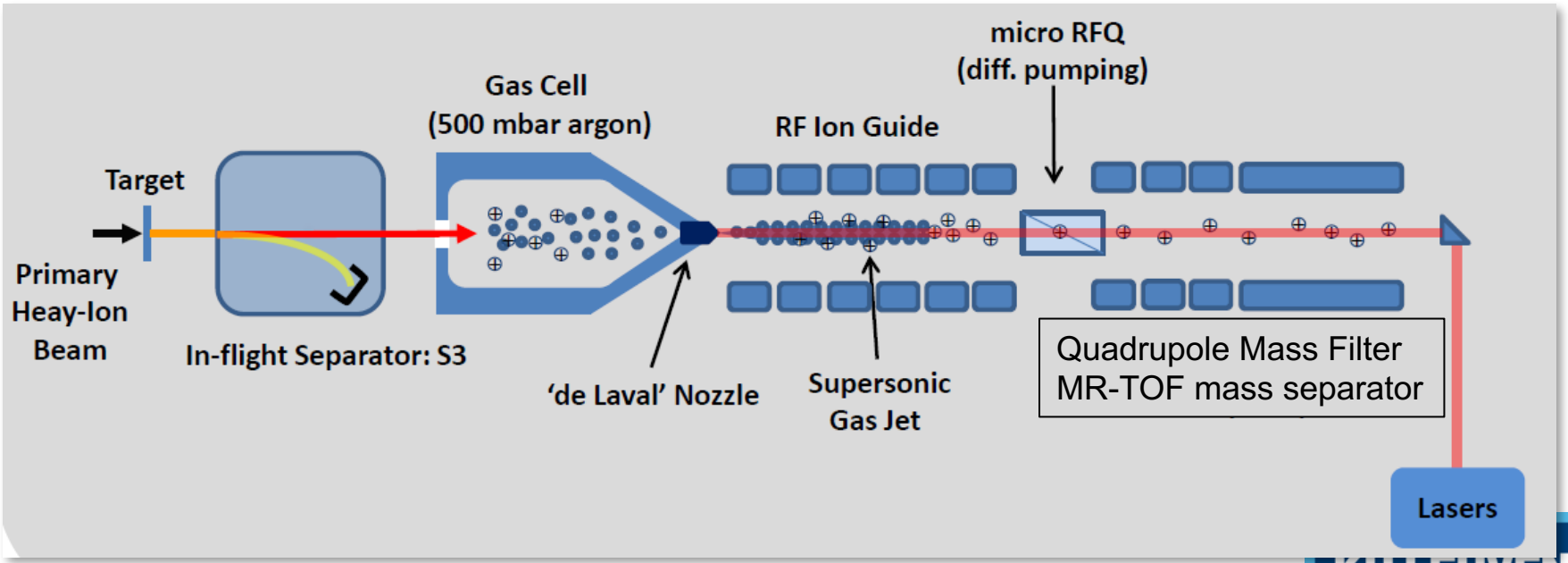
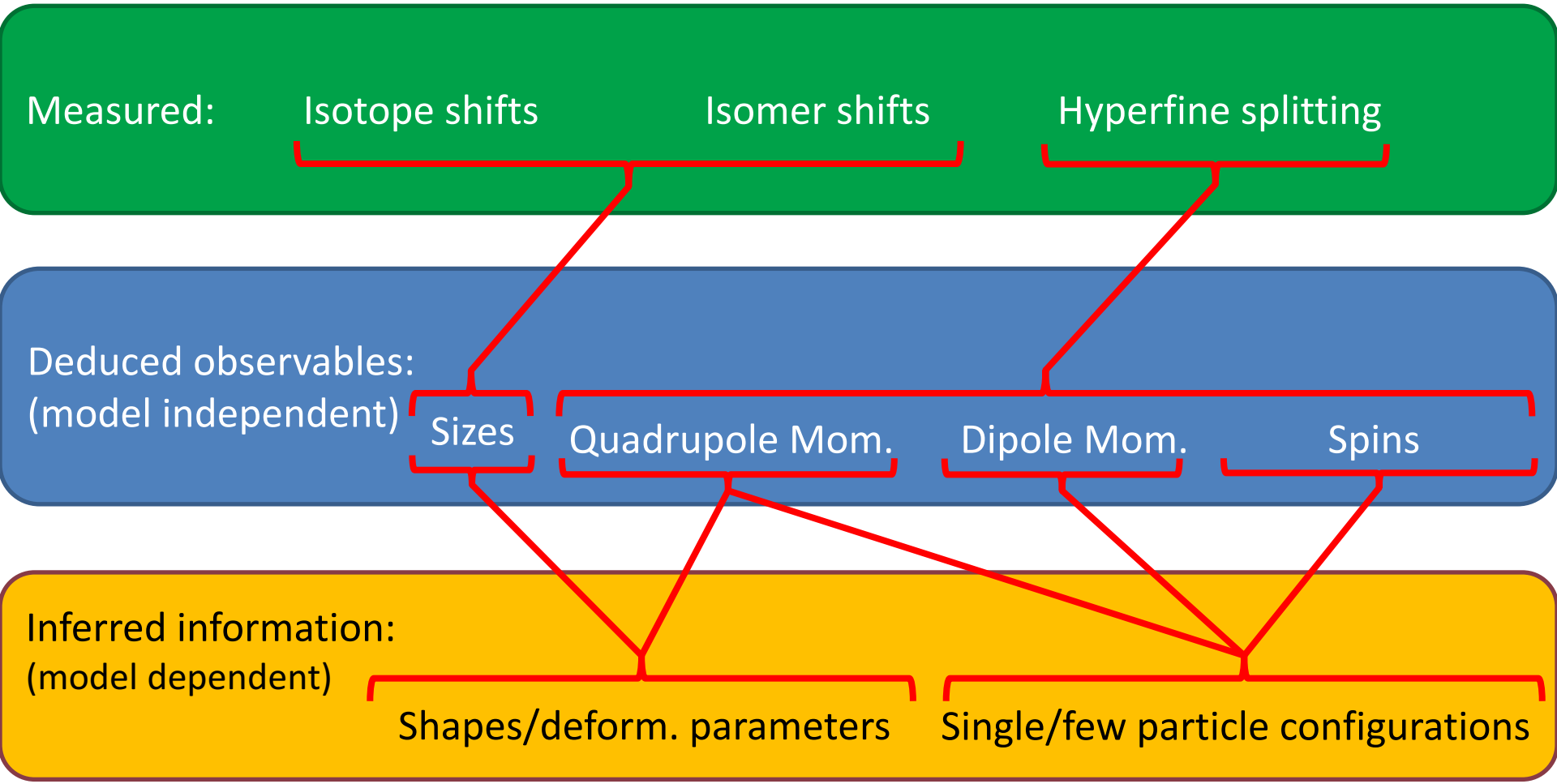
The S3 LEB concept

- Production of the heavy elements (or neutron deficient isotopes):
  heavy-ion fusion evaporation reactions
- Separation of the primary and secondary beam: S3
- 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



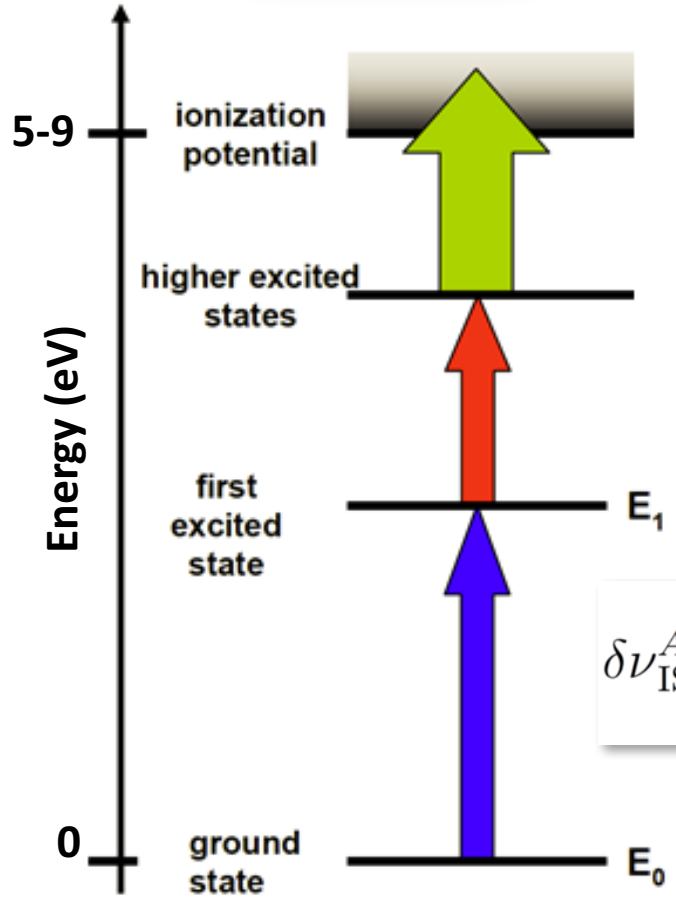
Y. Kudryavtsev et al., NIM B297 (2013) 7, R. Ferrer et al, NIM B 291 (2012) 29
K. Blaum et al., NIM B 204 (2003) 331, I. Moore et al., AIP Conf. Proc. 831 (2006) 51

Laser Spectroscopy

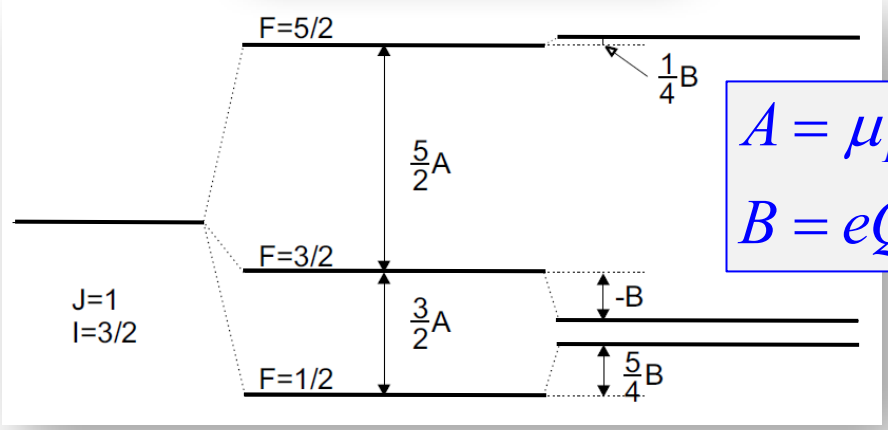


Laser Ionization Spectroscopy: basics

Sensitivity



Hyperfine Splitting



$$A = \mu_I B_e(0) / (IJ)$$

$$B = eQ_S V_{ZZ}(0)$$

Isotope Shift

$$\delta\nu_{\mathrm{IS}}^{AA'} = K_{\mathrm{MS}} \cdot \frac{M_{A'} - M_A}{M_A M_{A'}} + \frac{2\pi Ze}{3} \Delta |\Psi(0)|^2 \; \delta \left\langle r^2 \right\rangle^{AA'}$$

$$\delta \left\langle r^2 \right\rangle^{A,A'}$$

courtesy I. Moore

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Nuclear Moments of Ac^{227}†

MARK FRED AND FRANK S. TOMKINS, *Chemistry Division, Argonne National Laboratory, Lemont, Illinois*

AND

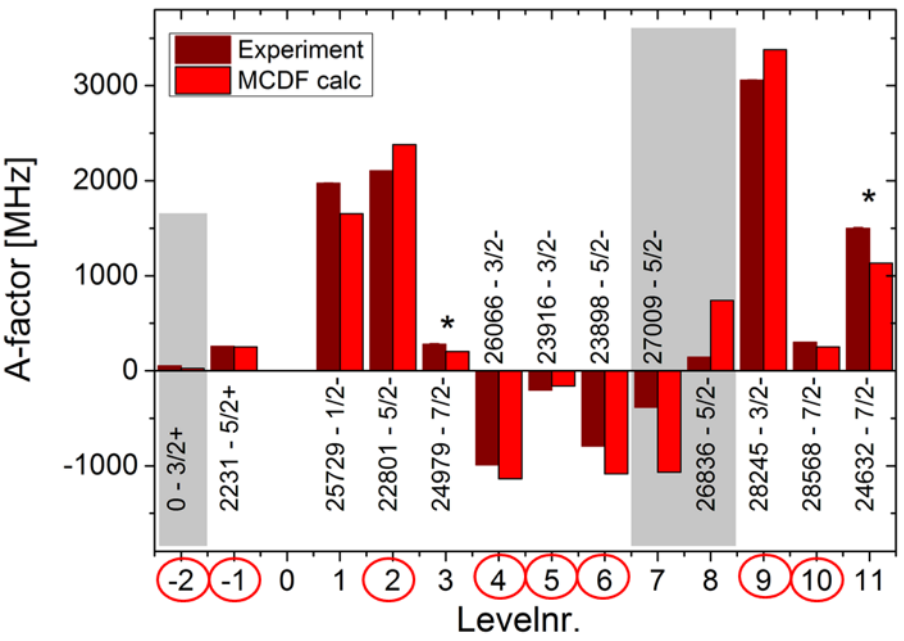
WILLIAM F. MEGGERS, *National Bureau of Standards, Washington, D. C.*

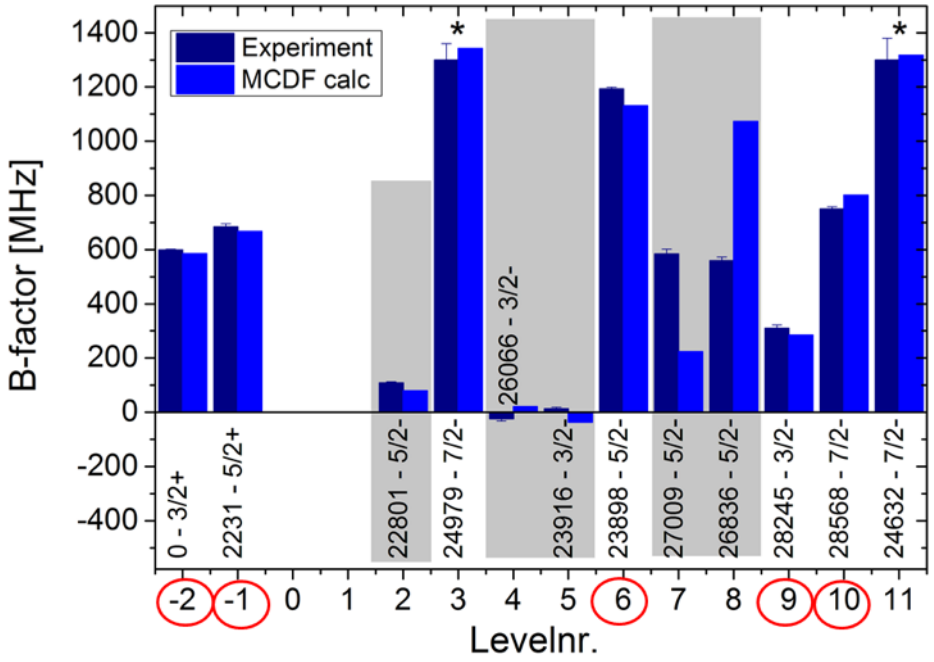
(Received April 11, 1955) Phys. Rev. 98, 1514

The values derived for the moments from the conventional treatment of hfs in intermediate coupling are $+1.1$ nm and -1.7×10^{-24} cm^2. The experimental error is believed to be less than 10 percent, but it is difficult to estimate the total error because of the configuration interaction and the large relativity corrections. No correction for closed shell distortion was made.

It is hoped that improved values can be obtained, but meanwhile it appears useful to offer the present results. We should like to acknowledge helpful discussions with Dieter Kurath and R. E. Trees.

Multi-Monfiguration Dirac Fock atomic physics calculations: ^{227}Ac





Fred,- Phys. Rev. 98 (1955) ^{227}Ac	MCDF calculations + experimental data on ^{227}Ac
$\mu_{lit.} = 1.1(1)\ \mu_N$	$\mu_{calc.} = 1.07(18)\ \mu_N$
$Q_{lit.} = 1.7(2)$ eb	$Q_{calc.} = 1.74(10)$ eb

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R. Beerwerth and S. Fritzsche (2016), R. Ferrer,- Nature Communications (2017)

KU LEUVEN (Gas cell studies, laser system)

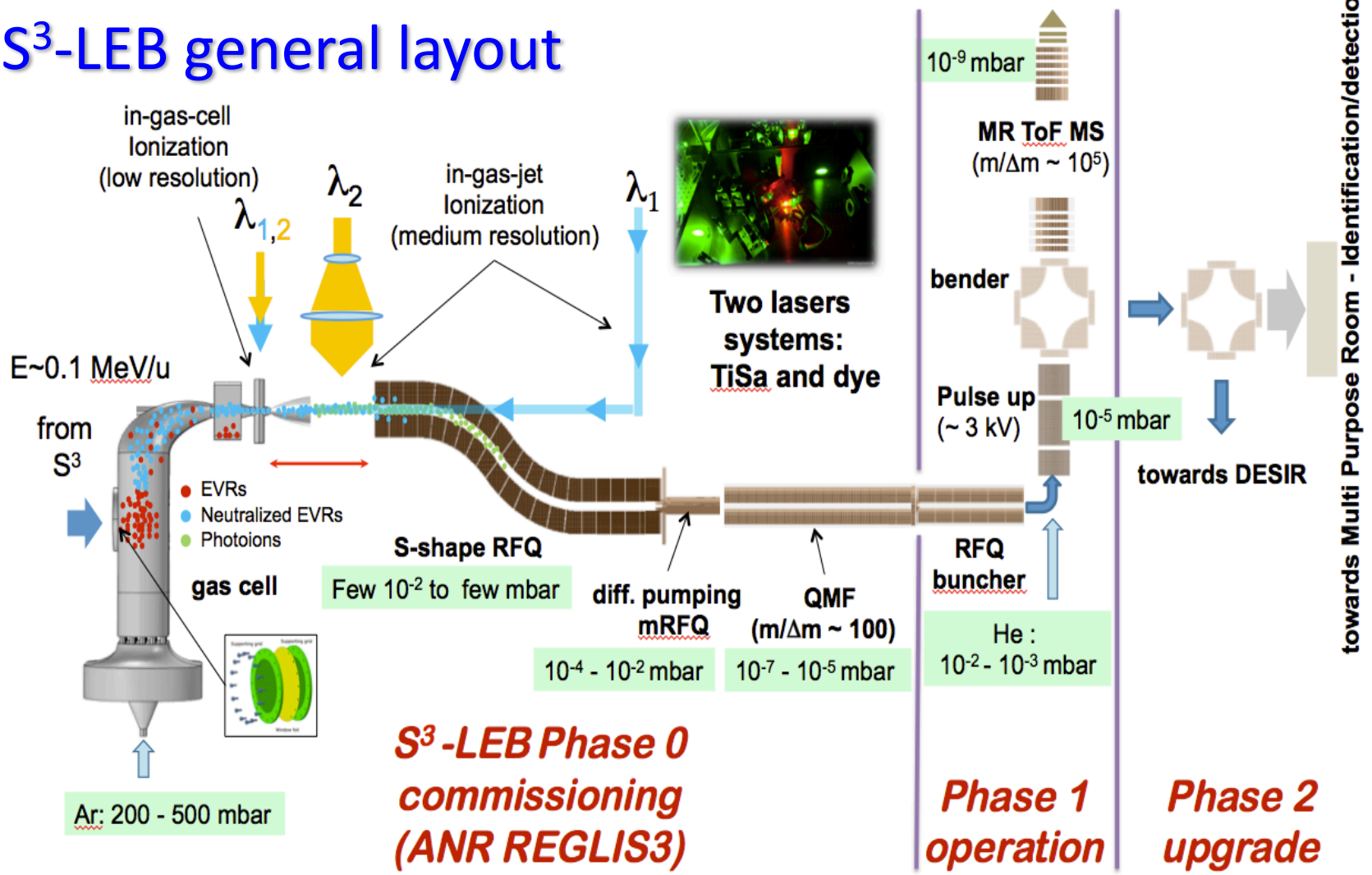
IPN ORSAY (Gas cell)

lpc caen (RFQs)

GANIL Spiral2 (mr-TOF-ms, laser system, infractructure, safety)

LARISSA JGU JOHANNES GUTENBERG UNIVERSITÄT MAINZ UNIVERSITY OF JYVÄSKYLÄ (narrow band-width laser pre-studies at MARA)

S^3-LEB general layout



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R. Ferrer et al., NIM B 317 (2013) 570
Y. Kudryavtsev et al., NIM B297 (2013) 7

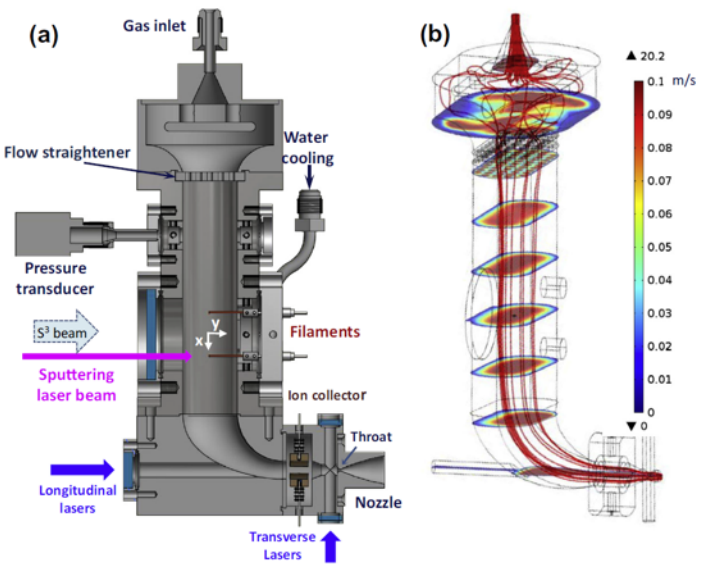
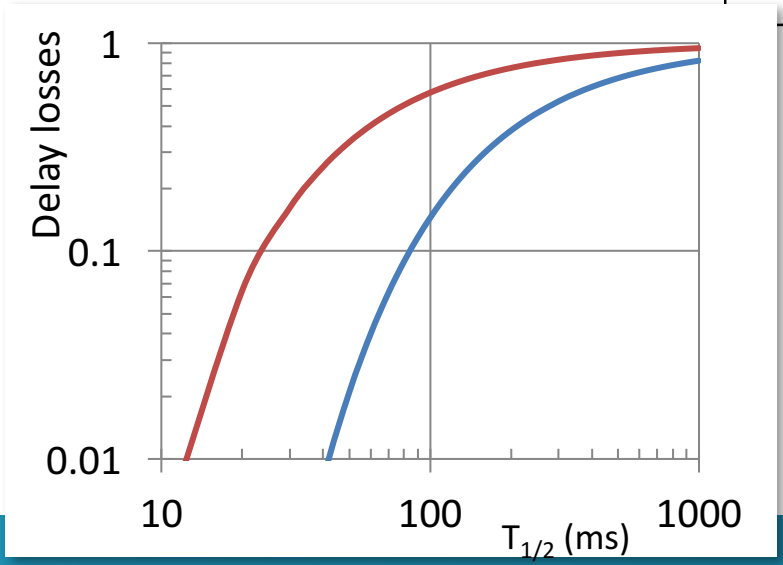


Table 1 | Actual and expected performance of IGLIS on ^{215}Ac.

R. Ferrer,- Nat. Comm. (2017)

	Gas cell	Gas jet (this work)*	Gas jet (projected)†
Ionization volume			
Pressure (mbar)	350 (15)	0.7–1	~0.05
Temperature (K)	350 (25)	25–30	~9
Jet divergence (deg.)	—	10–11	<1
Linewidth (FWHM)			
Total (MHz)	5,800 (300)	394 (18)	~100
Lorentz‡ (MHz)	4,000 (400)	42 (6)	<10
Gauss§ (MHz)	1,400 (100)	280 (30)	~100
Selectivity‖	8.3 (17)	121 (27)	>3,000
Efficiency¶ (%)	0.42 (13)	0.40 (13)	>10



- Delay losses due to evacuation of the gas cell

Average evacuation time:

- converging mode 279 ms (d=1.5 mm)
- one charge state 79 ms (d=1.5 mm)

Y. Kudryavtsev,- NIM B376 (2016)

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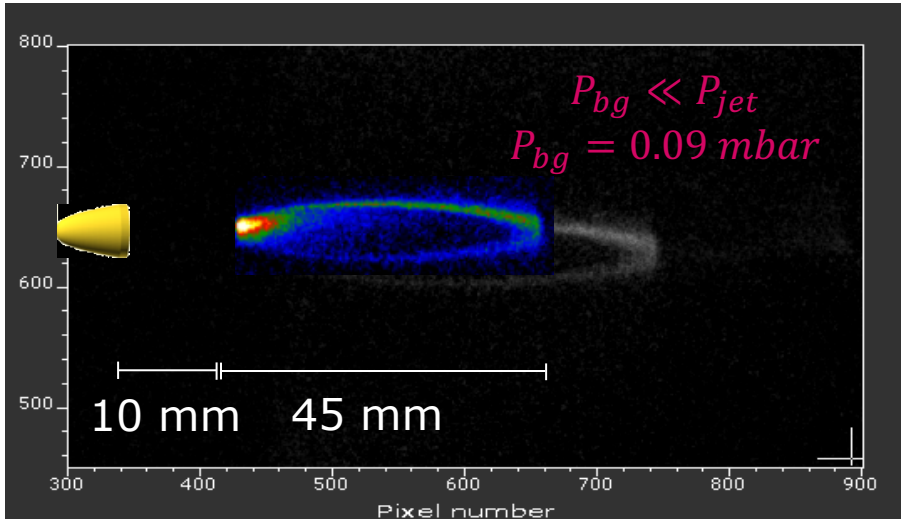
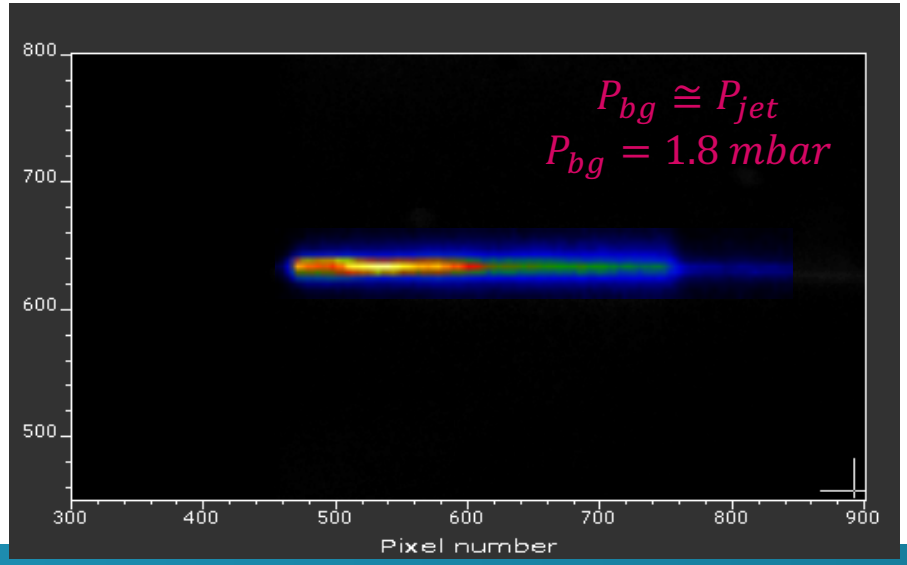
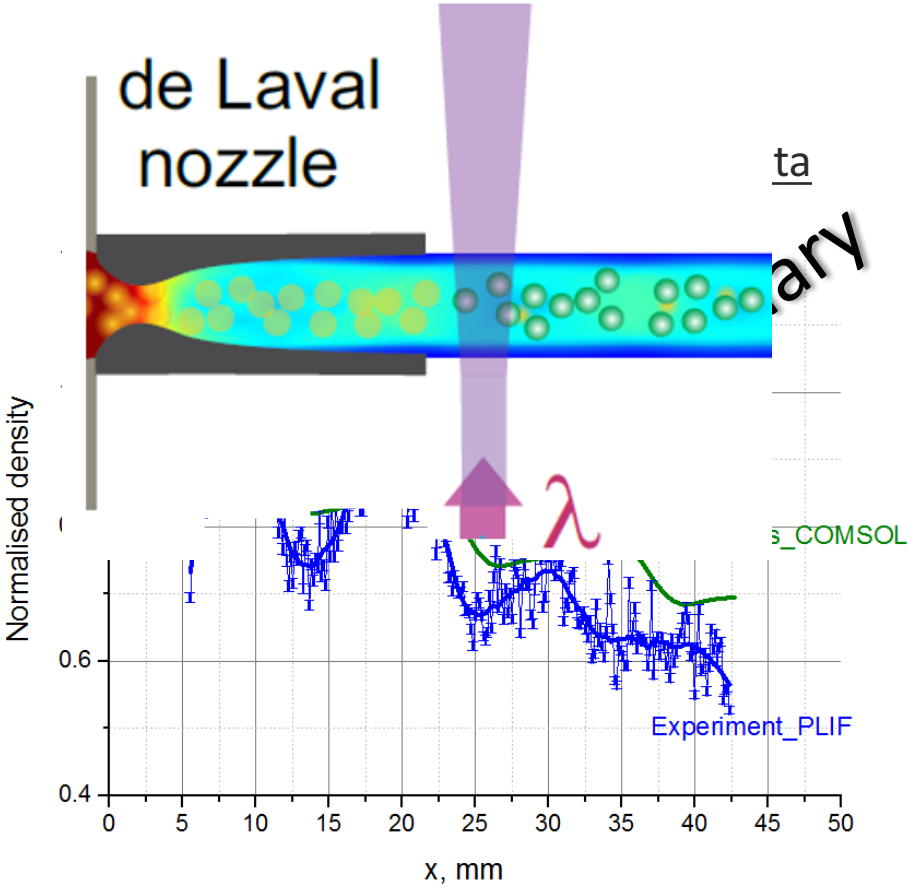
‘de Laval’ nozzle – gas jet characterization

Stagnation pressure 290 mbar, P_{jet}~ 1 mbar, Mach 5.5

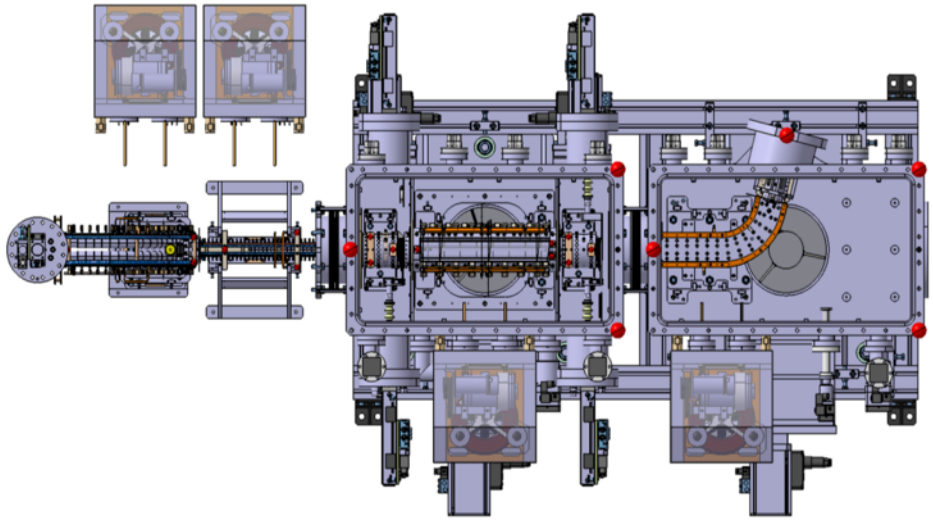






- de Laval nozzle characterization: density, temperature (laser spectroscopy)

- Main Work Packages and Status
  - Gas cell and front-end/pumping system
  - RFQ system
  - Laser system (Wednesday):
    - TiSa (Giselle), dye laser (KU Leuven)
    - narrow band system
  - MR-TOF (P. Delahaye next talk)
  - Detection system
    - tape system (alpha, beta and gamma)
    - multi-purpose room / connection to DESIR (Wednesday)



KU LEUVEN (Gas cell, laser system)

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY (Gas cell)

lpc caen (RFQs)

GANIL SPIRAL2 (mr-TOF-ms, laser system infractructure, safety, RFQsdetectors)

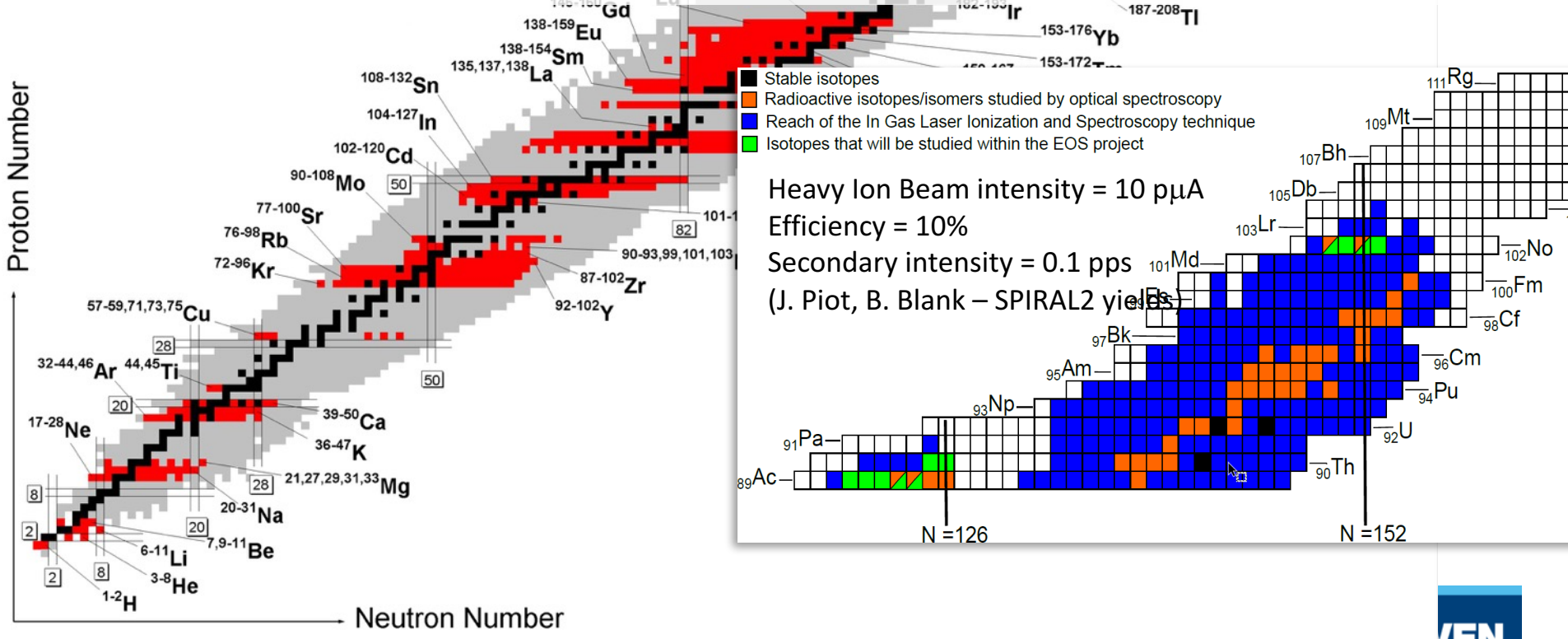
LARISSA JGU JOHANNES GUTENBERG UNIVERSITÄT MAINZ UNIVERSITY OF JYVÄSKYLÄ (narrow band-width laser pre-studies at MARA)

S3-LEB deliverables:

- Optical spectra
  - $\delta\langle r^2\rangle$, nuclear magnetic dipole and electric quadrupole moments, spins
- Masses (MR-TOF)
- Pure (isomer) beams at low-energy: 3 – 50 keV for further studies

S3-LEB physics opportunities (LOI's)

- N=Z region: shell evolution, nucleosynthesis, symmetries (Wednesday)
- Heavy neutron-deficient refractory elements: shapes/shape coexistence, exotic decay modes
- Heavy and Super Heavy Element region: single-particle versus deformation, atomic physics (Tuesday)



- Time plan (depending on S3 time line – see H. Savajols)
  - Commissioning with $^{116}Sn(^{40}Ar,4n)^{152}Er$
  - Possible "first day**S**" experiments: e.g. N=Z (Ag, Sn), Ac and Th (physics around the N=126 shell closure)
  - "Day two" experiment: e.g. $^{252\text{-}255}No$ (including the study of the K-isomer)

- Goals of the workshop are :
  - Creation of new collaboration, re-enforcing the already existing
    - enlarge the S3-LEB collaboration: interested groups welcome to join – physics/detection system/... – connection to DESIR
  - Development of future proposals, definition of needs to accomplish the experiments, theoretically and technically wise.
    - moving from LOI's to full proposals and proposing new proposals
    - develop an efficient operational mode for S3 with the different instrumentation

Conclusion and outlook

- S3 Low Energy Branch is very well advanced

- Opens new route for precision laser spectroscopy measurements of neutron-deficient isotopes and study of pure isomeric beams produced in heavy-ion fusion evaporation reactions
  - N=Z line around and below ^{100}Sn
  - neutron-deficient deformed region A~150
  - very heavy element region

- S3-LEB is an open collaboration and welcomes new research groups
  - extending the physics cases
  - new instrumentation

KU Leuven LISOL team

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