DE LA RECHERCHE À L'INDUSTRIE

Simulations of the SEASON detector @ S^3 LEB and results from ^{249}Md experiment @ Jyväskylä

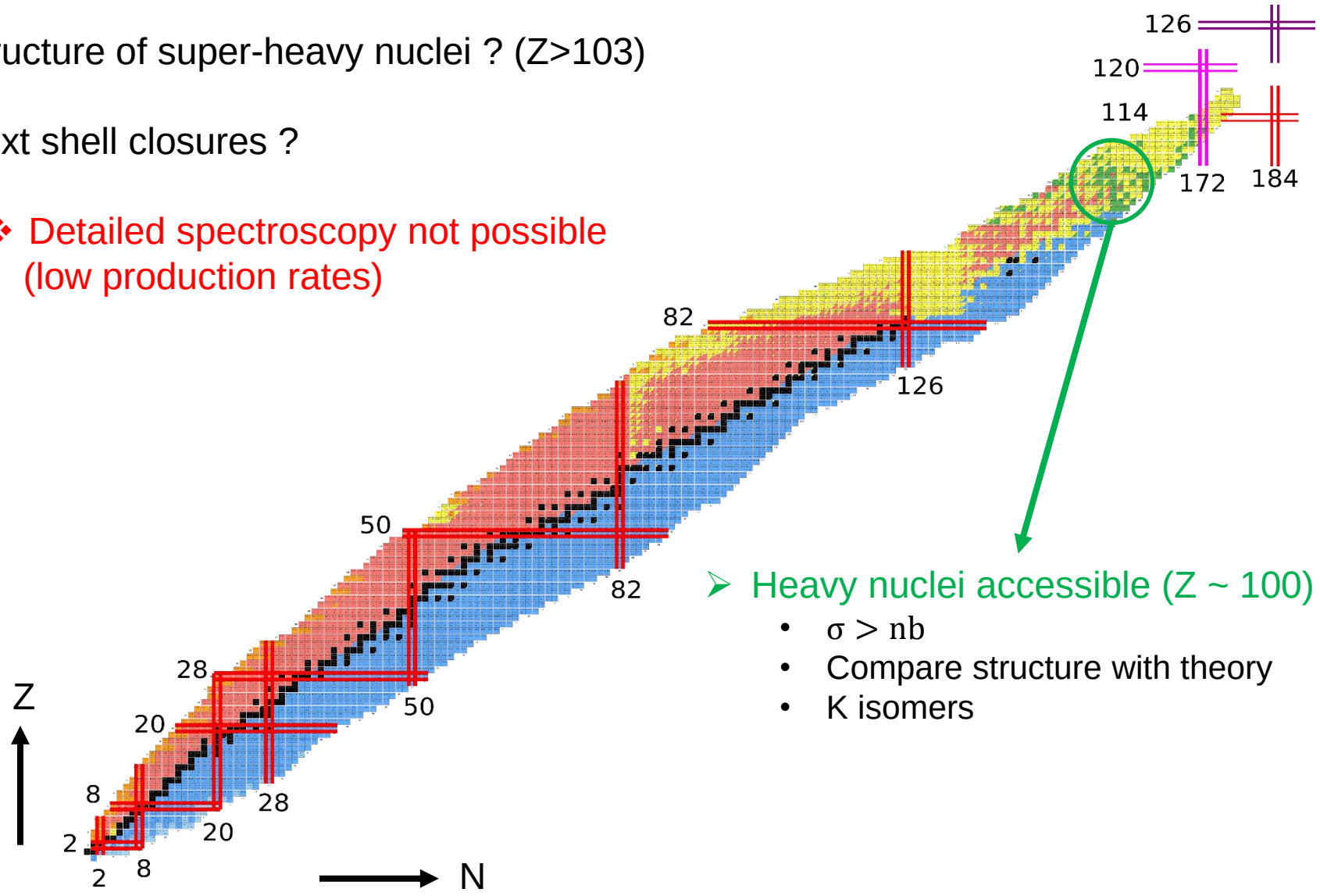
T. Goigoux, A. Drouart, Z. Favier, B. Sulignano, Ch. Theisen, M. Vandebrouck

ENSAR2 NUSPRASEN workshop
25/02/2019

FROM HEAVY TO SUPER-HEAVY NUCLEI

- Structure of super-heavy nuclei ? (Z>103)
- Next shell closures ?

❖ Detailed spectroscopy not possible (low production rates)



➢ Heavy nuclei accessible (Z ~ 100)

- $\sigma >$ nb
- Compare structure with theory
- K isomers

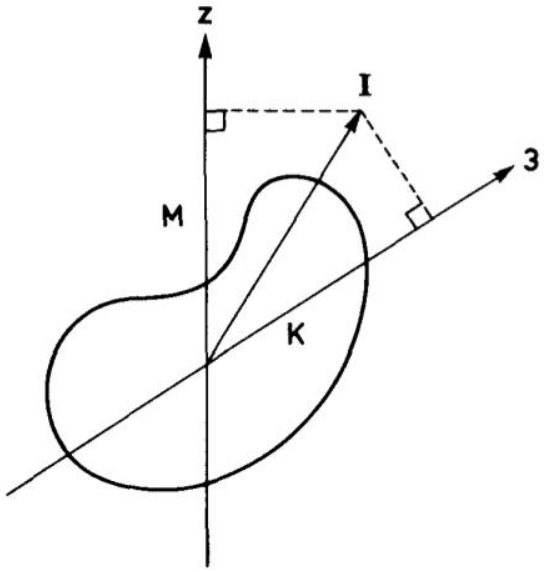
K ISOMERS

- Metastable states due to deformation

$$K = I, I-1, \ldots, -I$$

- Occurrence predicted in region Z=100-108
  - Enhance stability against fission

(e.g. ^{250}No, ^{254}Rf , ^{270}Ds isomers have longer lifetime than g.s.)
Xu et al., PRL 92(25), 252501 (2004)



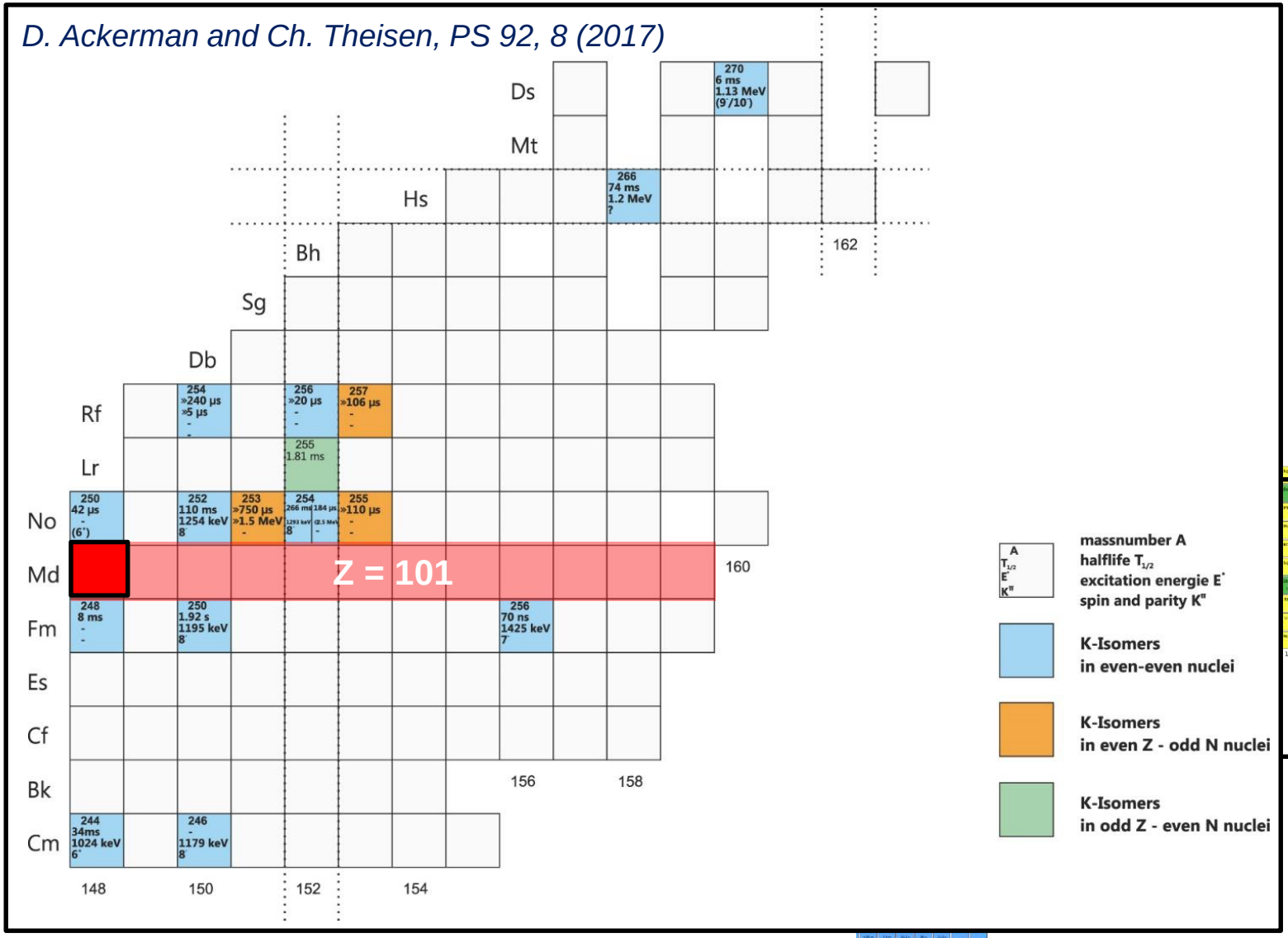
  - Structure study
    - Quasi-particle (qp) states
    - Pairing correlations
    - Single-particle states (especially odd nuclei)

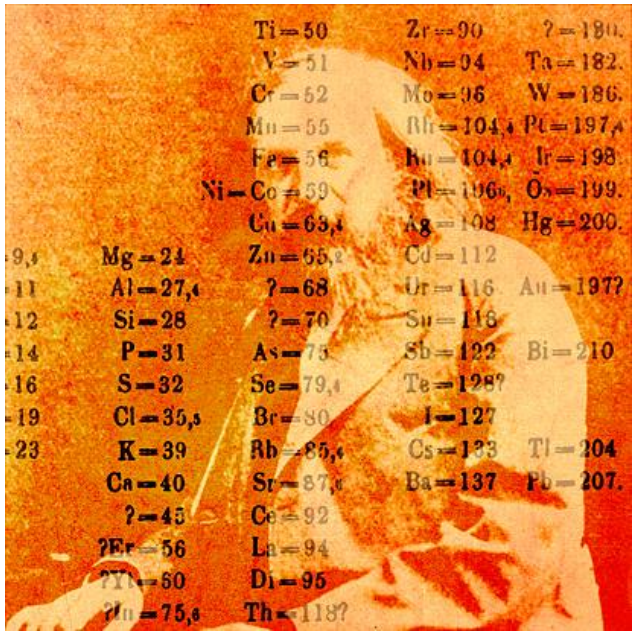
- Highly converted transitions (emission of conversion e^-) for heavy nuclei

  ➢ Detection by calorimetric method
  Jones, NIM A 488, 471 (2002)

K ISOMERS: PRESENT KNOWLEDGE

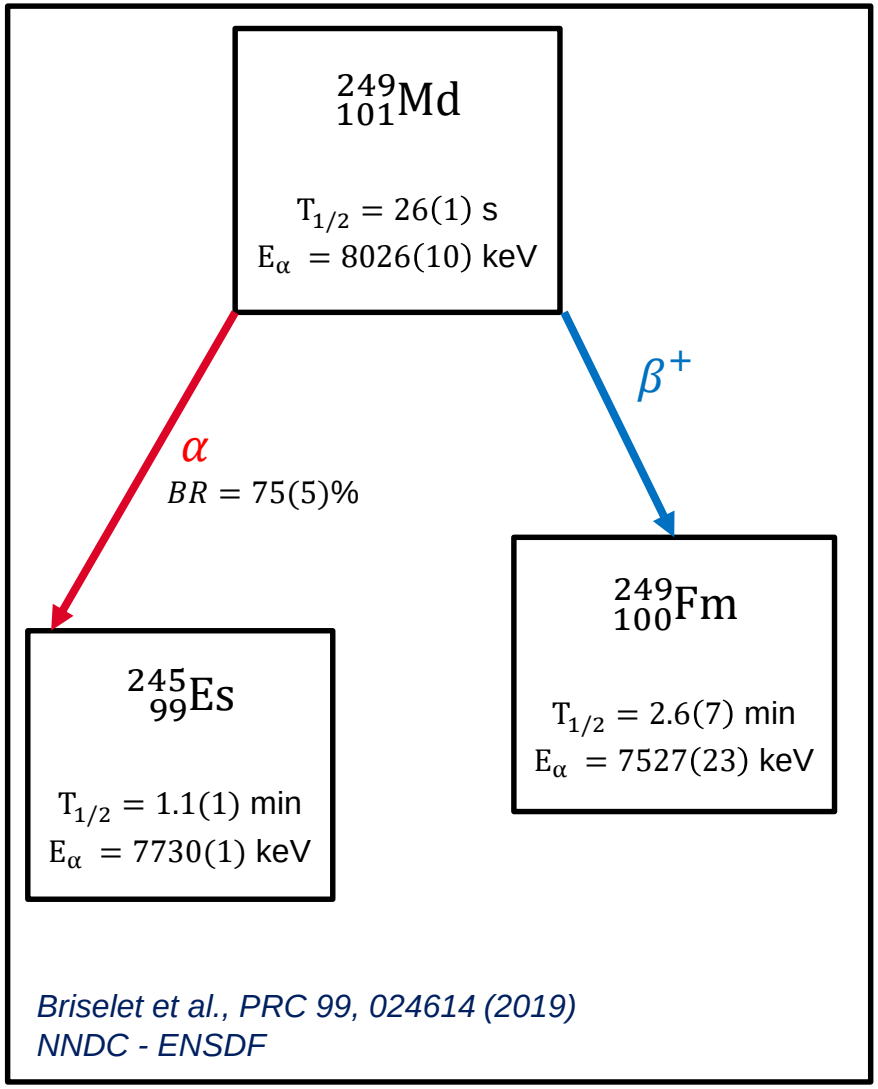
D. Ackerman and Ch. Theisen, PS 92, 8 (2017)

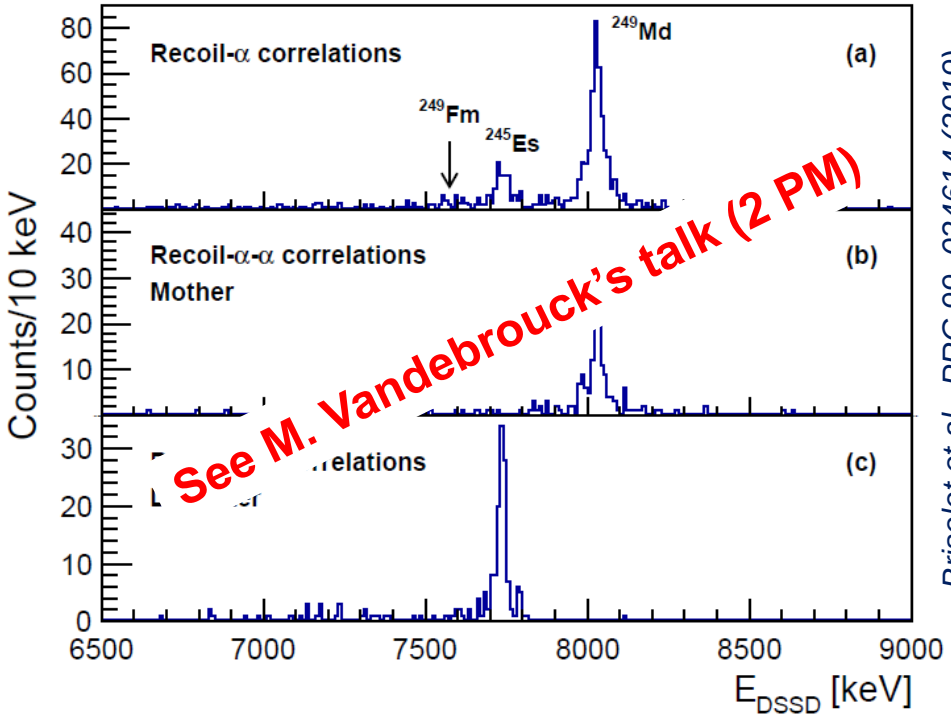




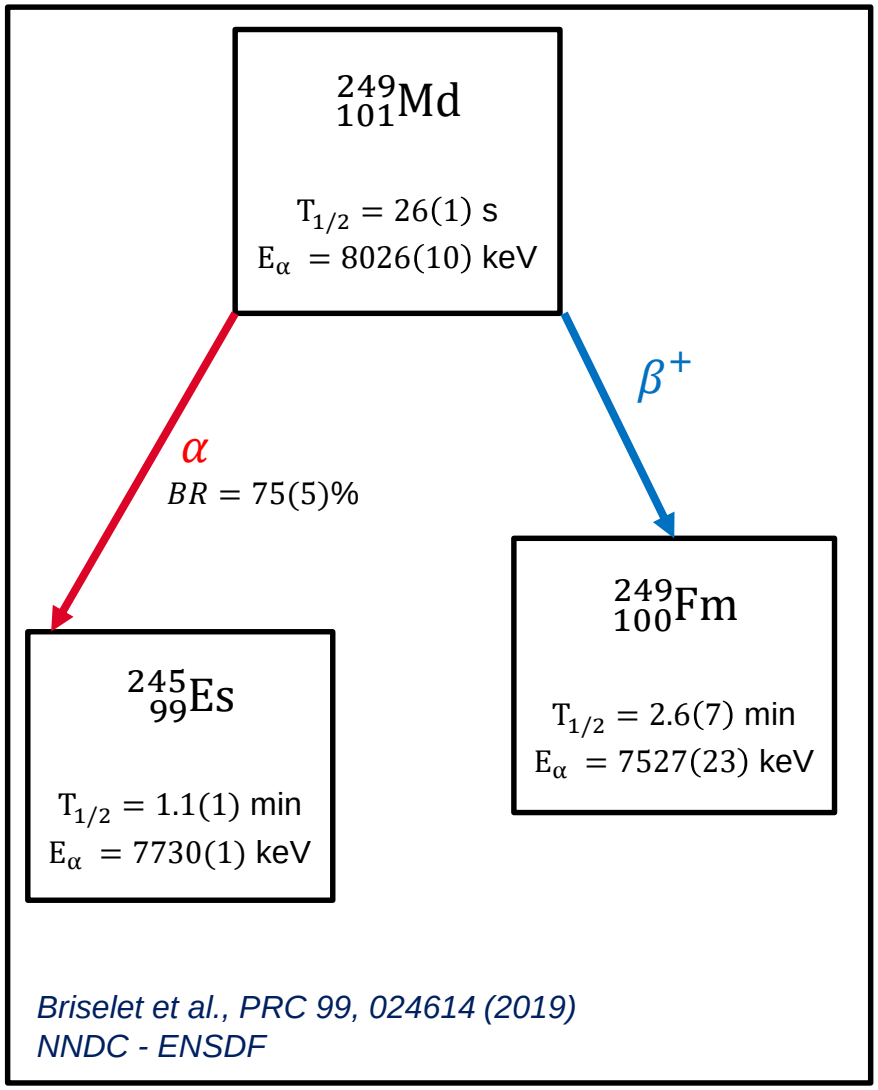
DISCOVERY OF AN ISOMERIC STATE IN MENDELEVIUM 249

KNOWLEDGE ON MENDELEVIUM 249



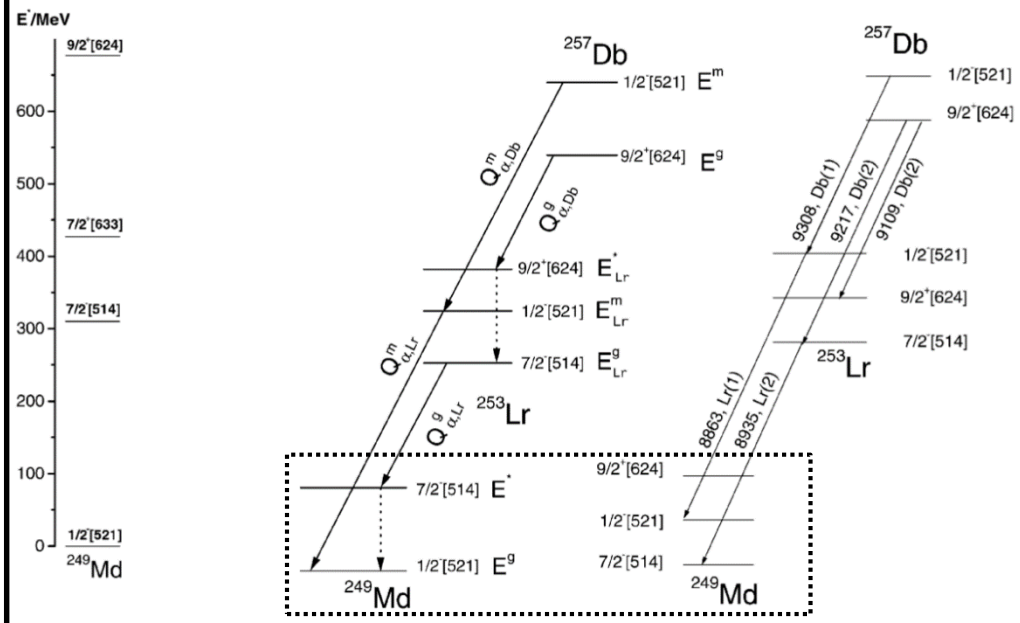


KNOWLEDGE ON MENDELEVIUM 249



Briselet et al., PRC 99, 024614 (2019)
NNDC - ENSDF

Heßberger et al., EPJ A 12, 57 (2001)



Model Exp.

- No precise structure scheme
- Isomeric state ?

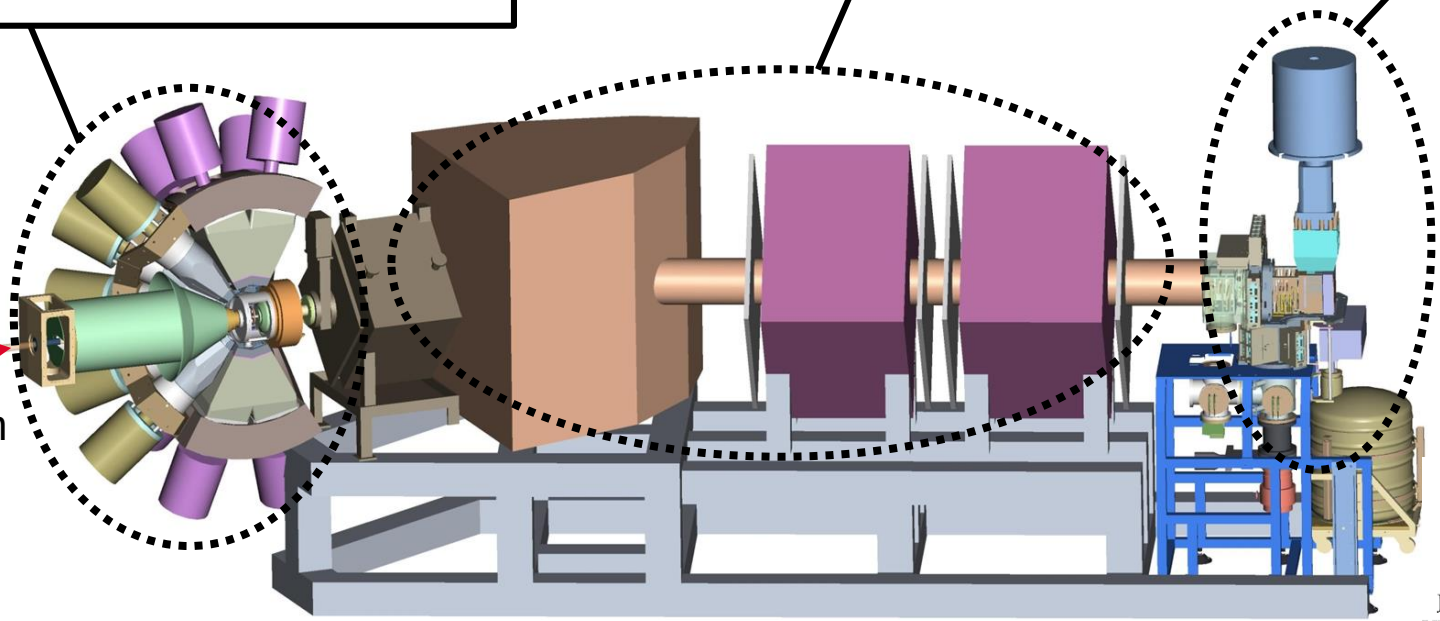
➢ **New experiments performed at Jyväskylä in 2013 and 2016**

EXPERIMENT @ UNIVERSITY OF JYVÄSKYLÄ

- $^{203}_{81}$Tl target
  - Fusion reaction $^{203}\mathrm{Tl}(^{48}\mathrm{Ca}, 2\mathrm{n})^{249}\mathrm{Md}$
- Prompt spectroscopy with **SAGE** (Silicon And GErmanium spectrometer)
  - JUROGAM Ge array
  - Silicon detectors for e^-

RITU (Recoil Transport Unit) gas-filled separator

- Delayed spectroscopy with **GREAT** (Gamma Recoil Alpha-Tagging)
  - Recoil tagging
  - Decay tagging



$^{48}_{20}$Ca beam

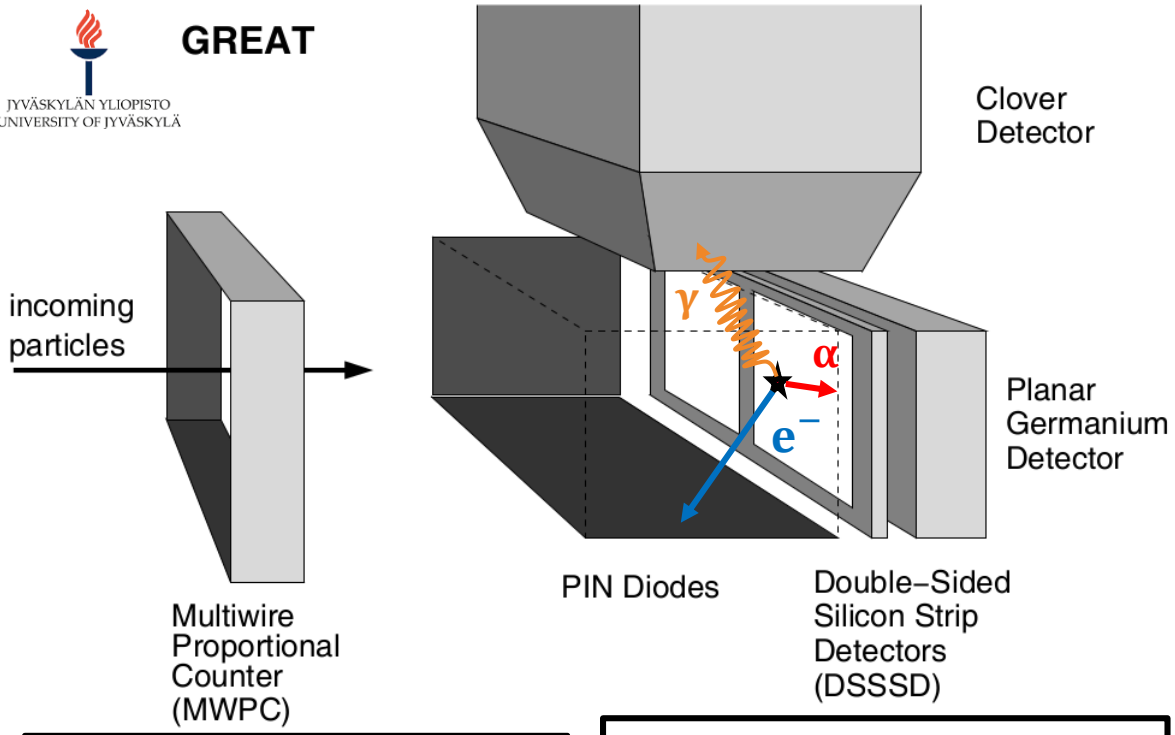
214 MeV
< 10^{11} pnA

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

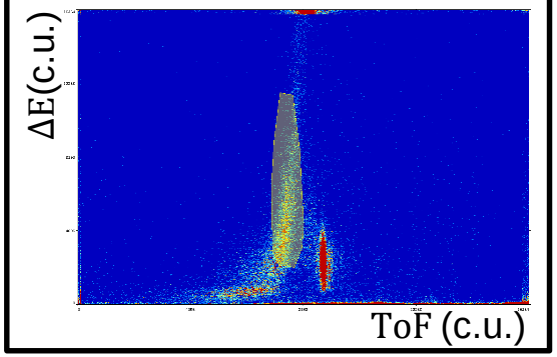
EXPERIMENT @ UNIVERSITY OF JYVÄSKYLÄ

GREAT

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ



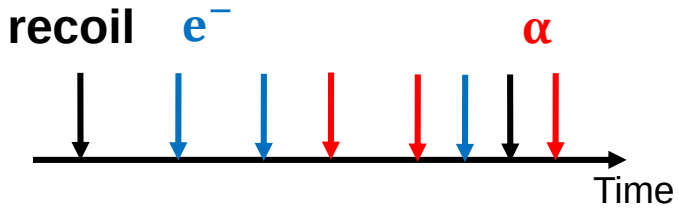
1) Separation from scattered particles

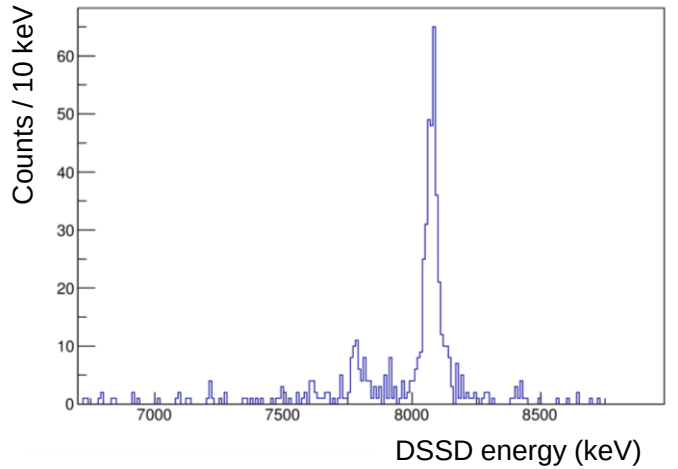


2) Implantation & decays

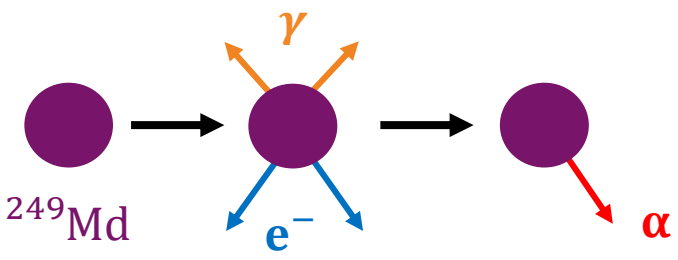
- 2 DSSSDs 60x40 mm², 300 µm thick
- 28 PIN diodes 500 µm thick
- Planar Ge 24x12 strips, 120x60 mm²
- 4 Ge clovers

3) Correlations in time and position in DSSSD

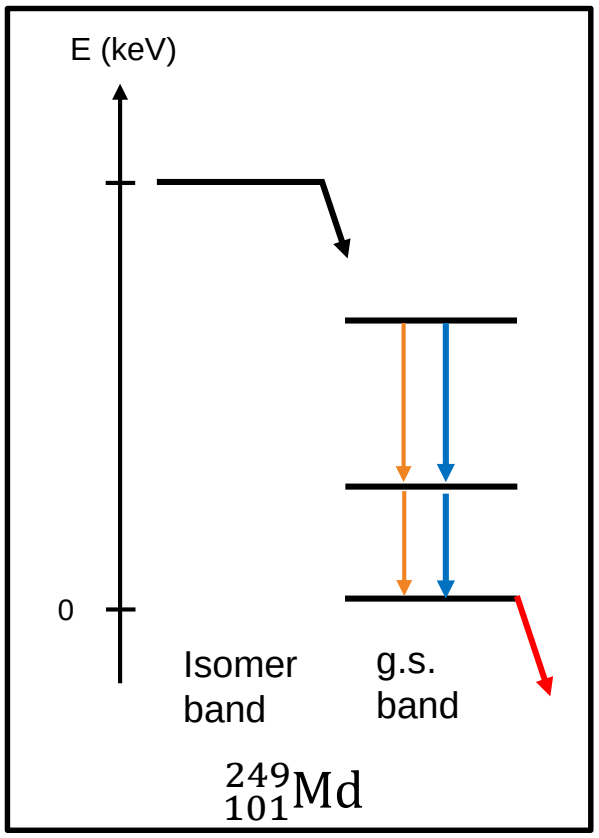


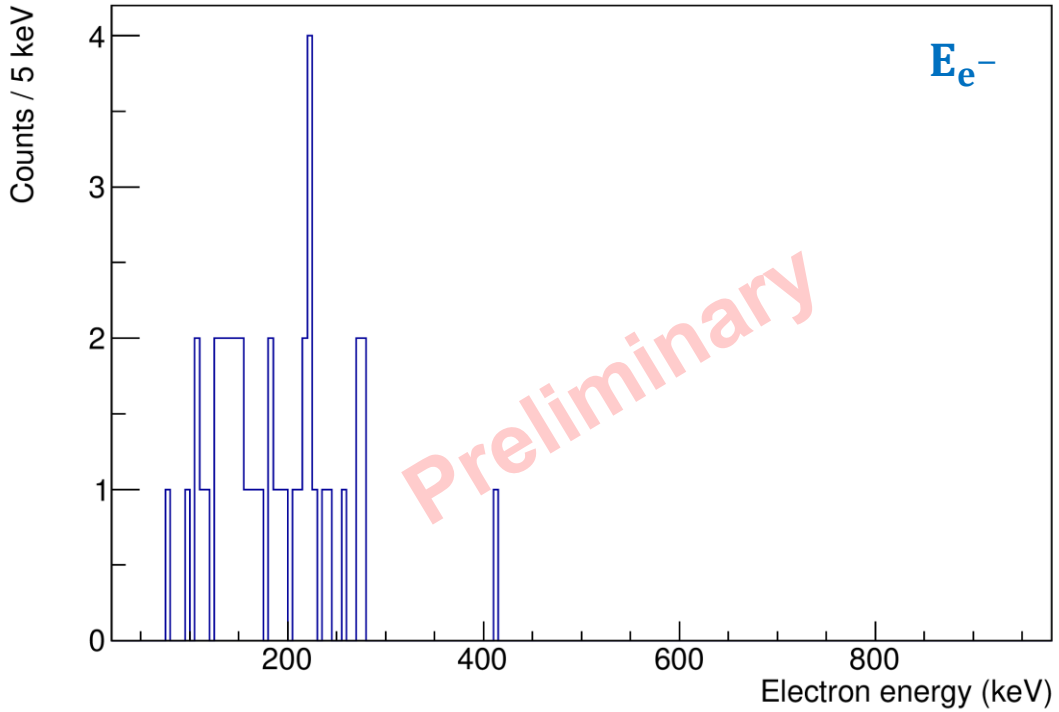


RESULTS

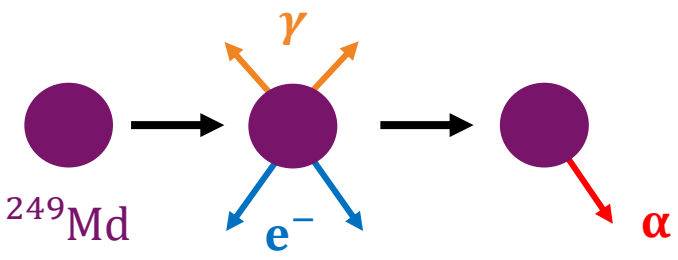


- Tagging of ^{249}Md with its α decay
- Search for an isomeric state
  - **Electron signal in DSSSD**
  - Coincidence with γ rays and PIN diodes

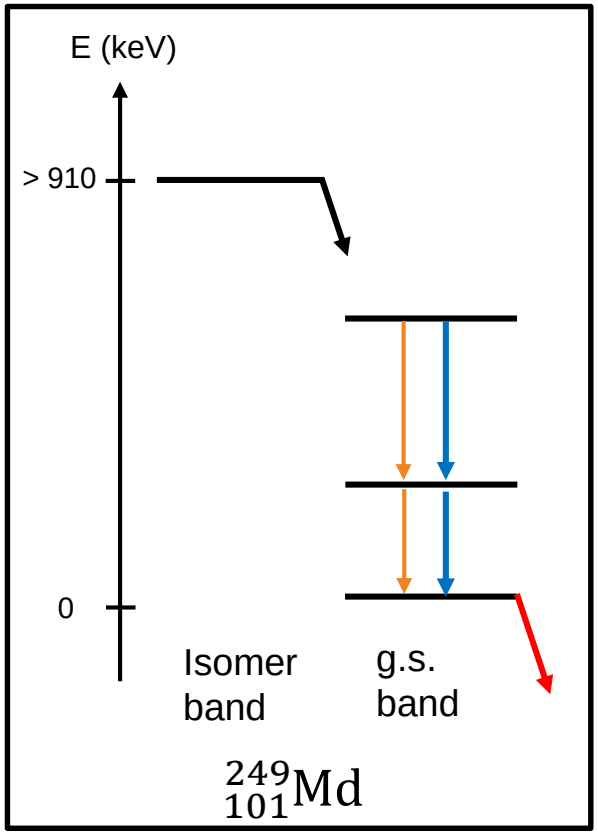


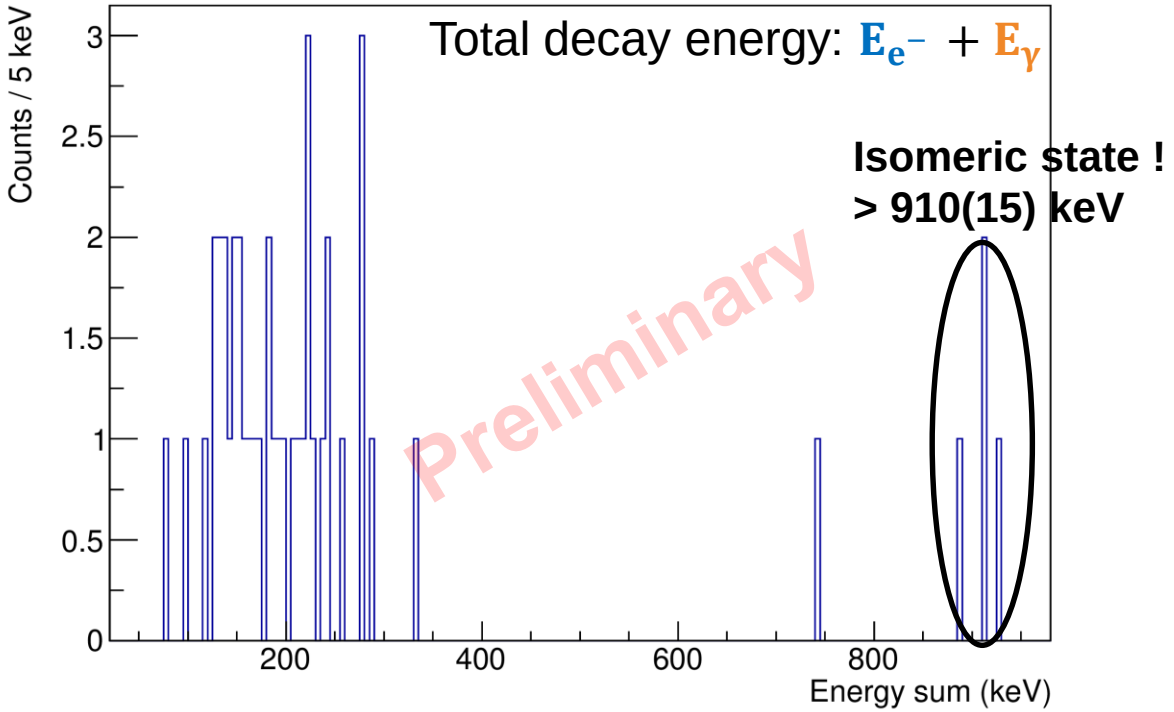


RESULTS



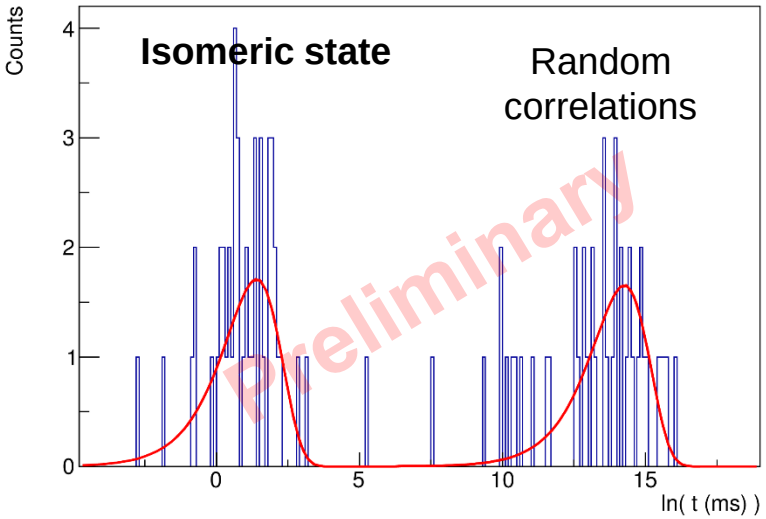
- Tagging of ^{249}Md with its α decay
- Search for an isomeric state
  - Electron signal in DSSSD
  - **Coincidence with γ rays and PIN diodes**

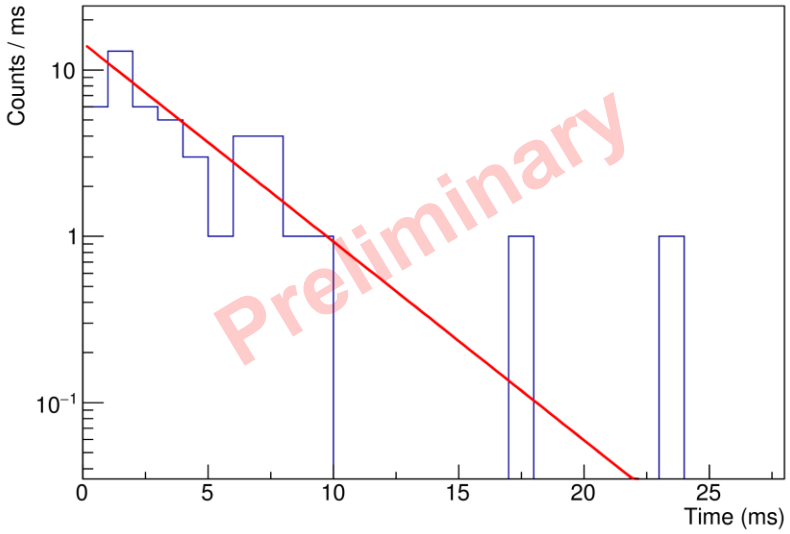


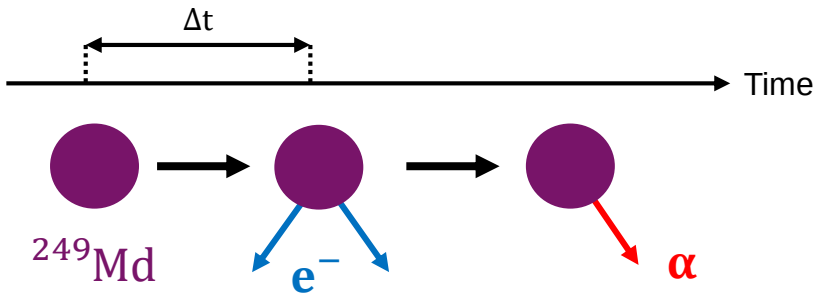


RESULTS

Time distributions of ^{249}Md electrons







Fit of time distributions:

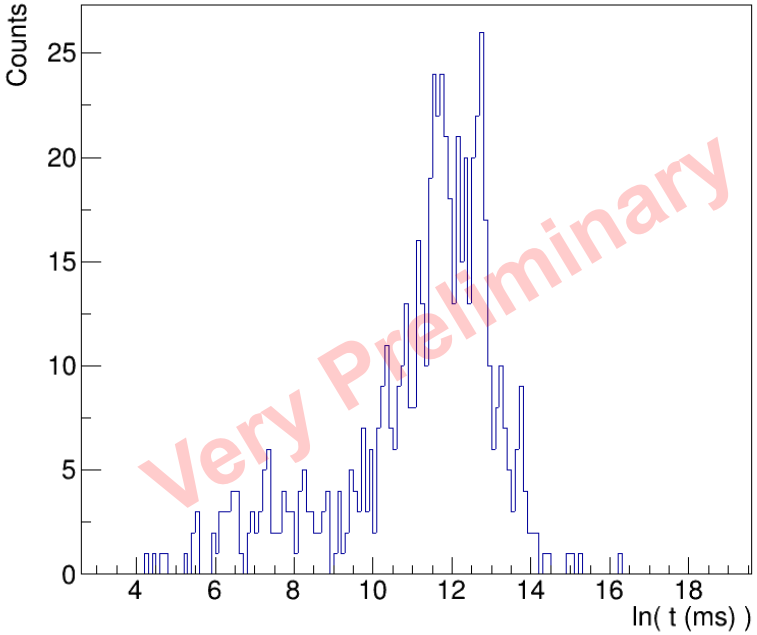
- Logarithm scale (K.-H. Schmidt method)
- Linear scale
  - ➢ Compatible results: $\mathbf{T_{1/2} = 2.5(5)\ ms}$

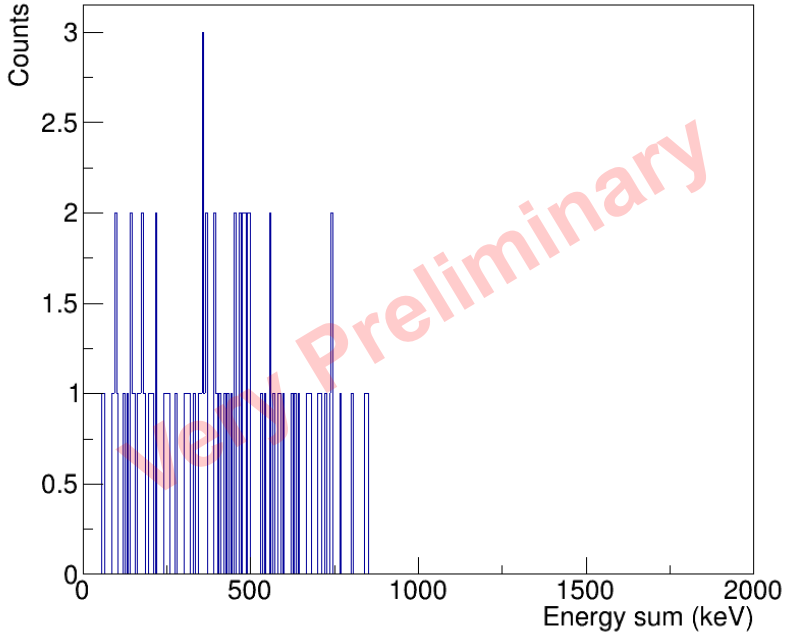
K-isomeric state of ^{249}Md

- **Half-life $2.5(5)$ ms**
- **Excitation energy > 910(15) keV**

- Interpretation of ^{249}Md results has to be done:
  - 3 quasi-particle (qp) excitation ?

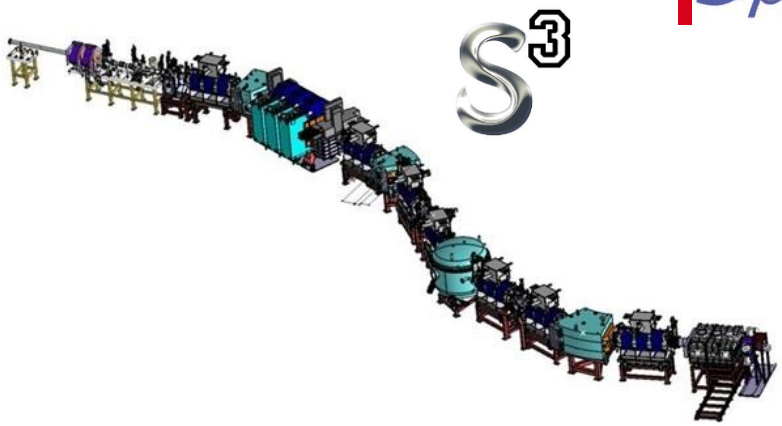
- ^{251}Md experiment under analysis:
  - ➢ Probable K-isomeric state



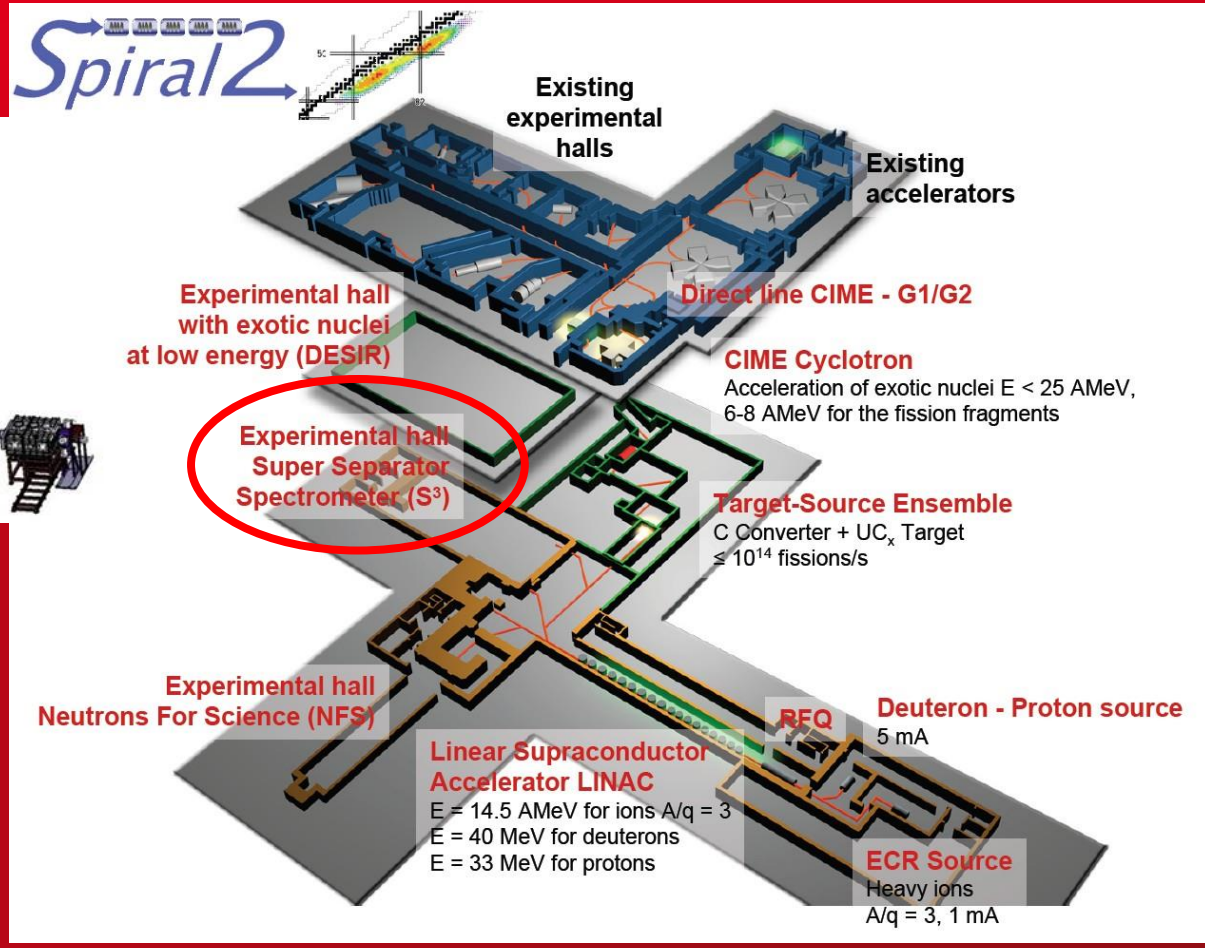


SEASON DETECTOR @ LOW ENERGY BRANCH OF S^3 (GANIL-SPIRAL2)

GANIL laboratoire commun CEA/DSM spiral2 CNRS/IN2P3

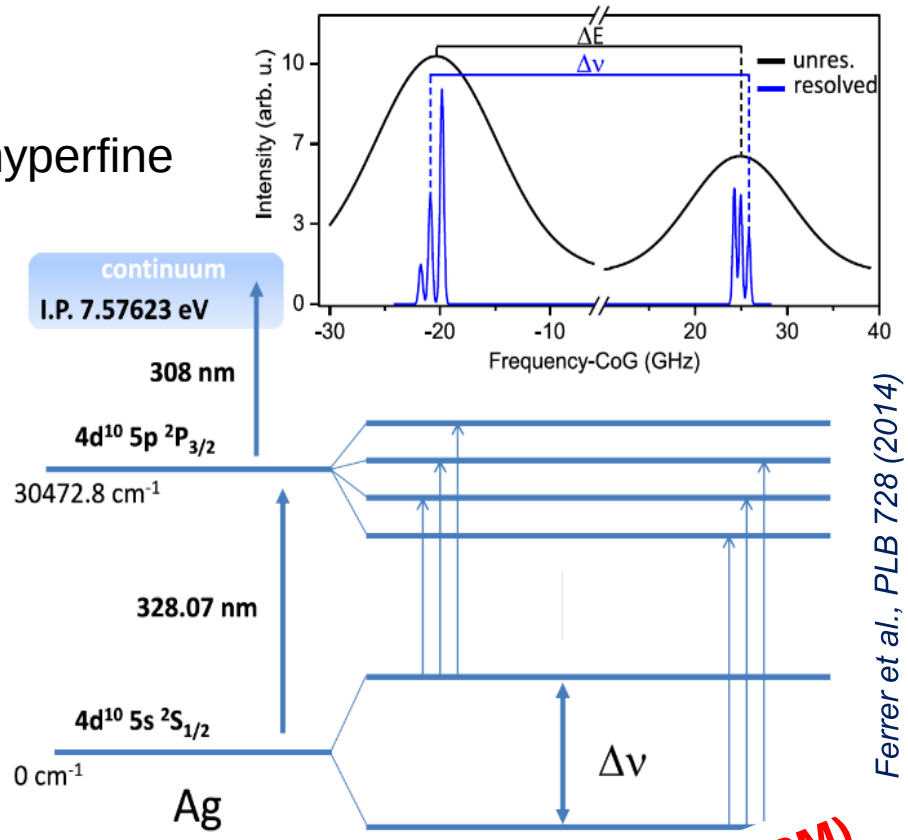


S^3



LASER SPECTROSCOPY

- Counting of laser-ionised atoms
- Measurement of isotope/isomer shift and hyperfine structure
  - Charge radii
  - Quadrupole magnetic moment
  - Dipole electric moment
  - Spins
- High selectivity
  - Spectroscopy of heavy elements at LEB (Low Energy Branch) of S^3



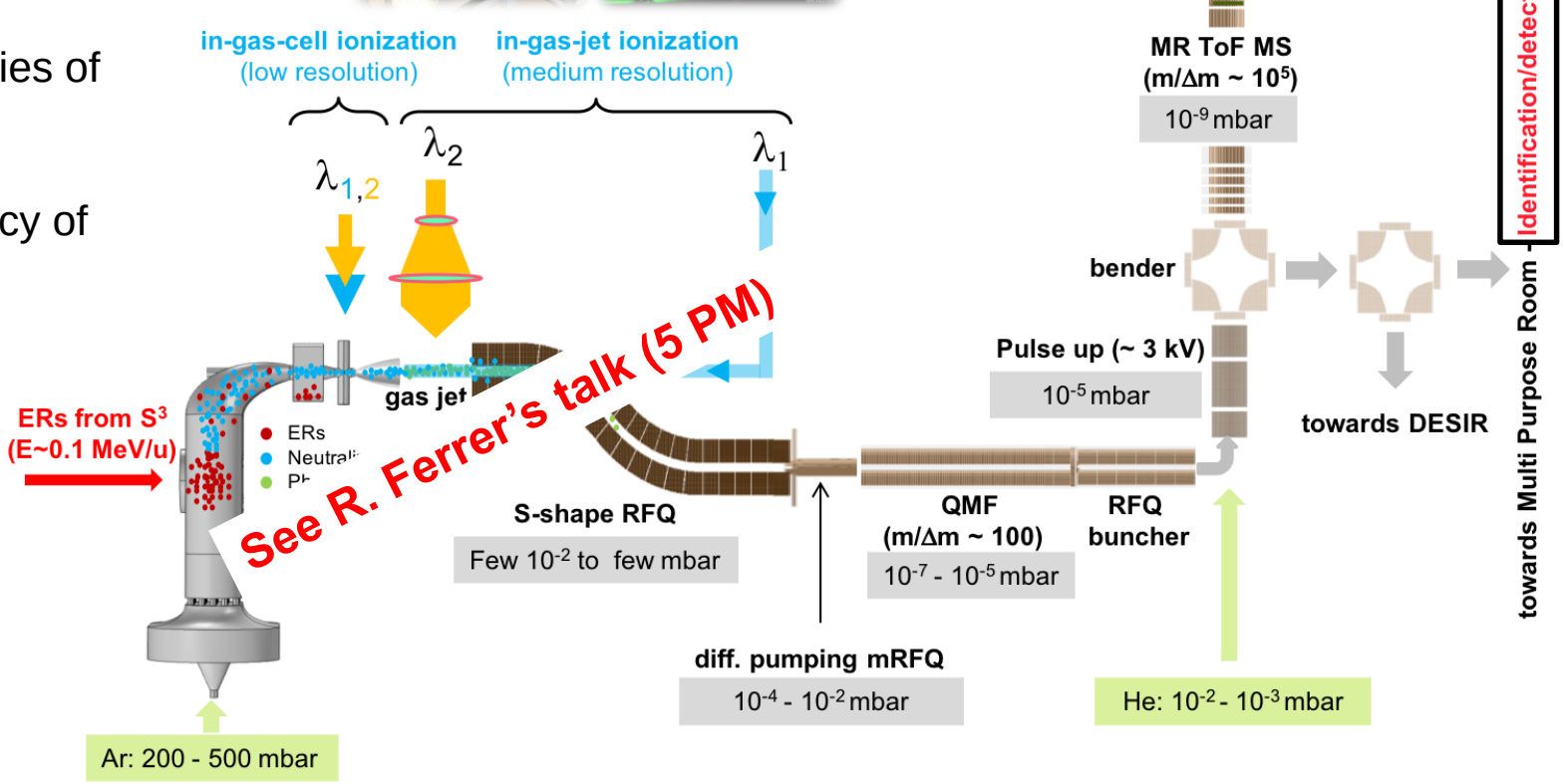
Ferrer et al., PLB 728 (2014)

See R. Ferrer's talk (5 PM)

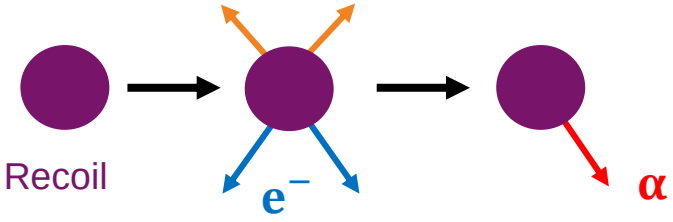
SEASON PROJECT @ S³ LEB

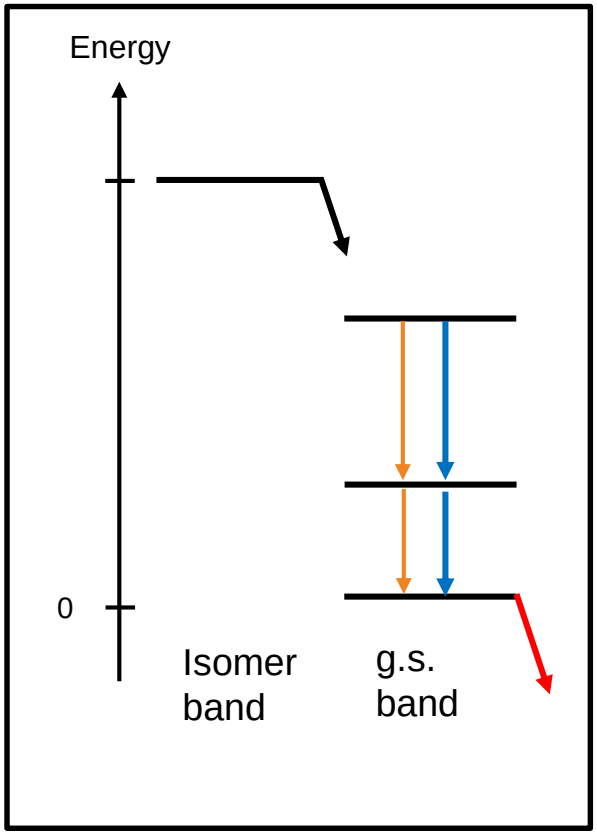
SEASON (Spectroscopy Electron Alpha in Silicon bOx couNter)

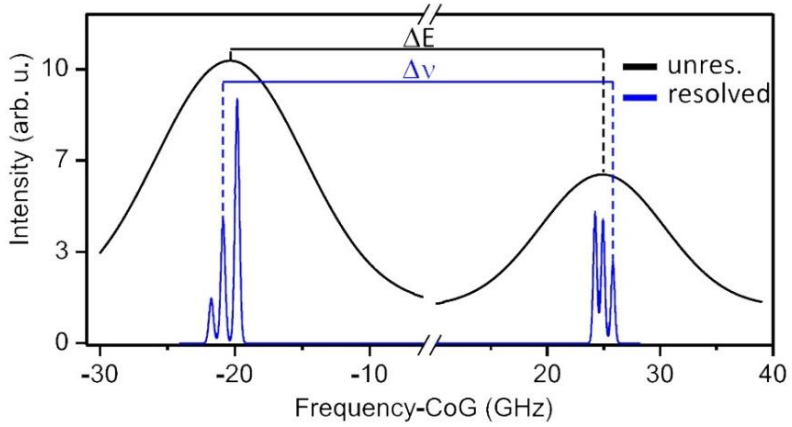
- Physics studies
  - **Heavy nuclei**
  - $N = Z$ nuclei
- High intensities of S³ beams
- High efficiency of LEB



SEASON PROJECT @ S³ LEB

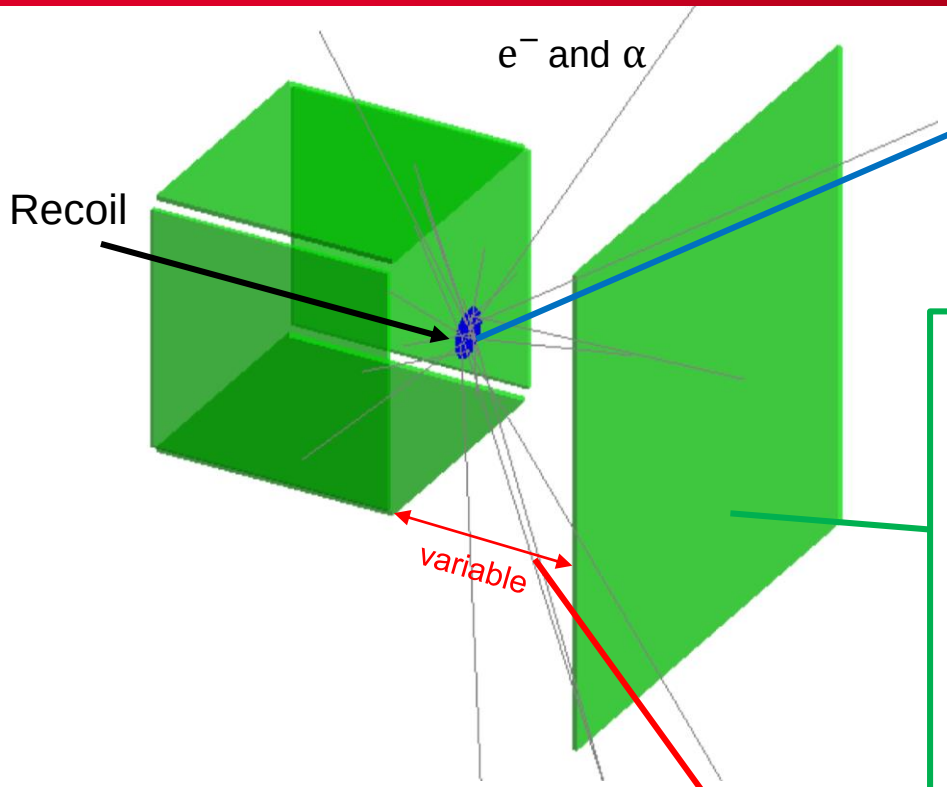






- Laser ionisation spectroscopy with best efficiency
  - **Ground state (α particles)**
  - **Isomeric state (conversion e⁻)**
    - ➢ Need best counting efficiency for each laser frequency
- **+ Nuclear spectroscopy**
  - ➢ Energy of emitted particles

SEASON PROJECT @ S³ LEB



Implantation foil

- **Carbon 20 mg/cm²**
- Mounted on a **wheel**

Si detectors

- **Cubic configuration** to optimize geometric efficiency
- **1mm thick** to stop e^- up to 600 keV and α particles
- **Digital electronics**

Energy resolution (FWHM)	15 keV(α from 5 MeV to 12 MeV) 5 keV(electron from 20 keV to 600 keV)
Energy threshold	20 keV
Time resolution (FWHM)	20 ns

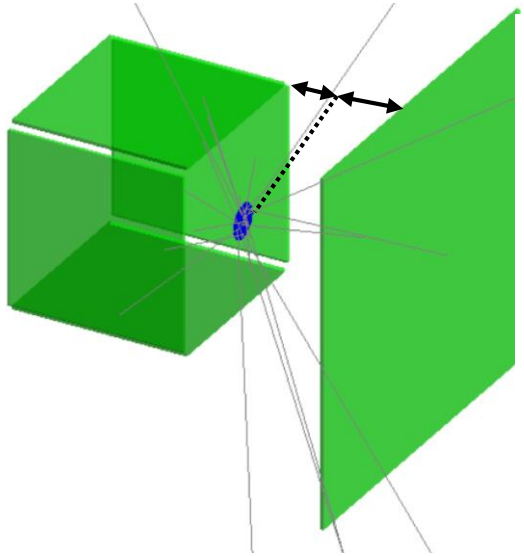
Variable distances between foil and detectors

- Adaptability to counting rate

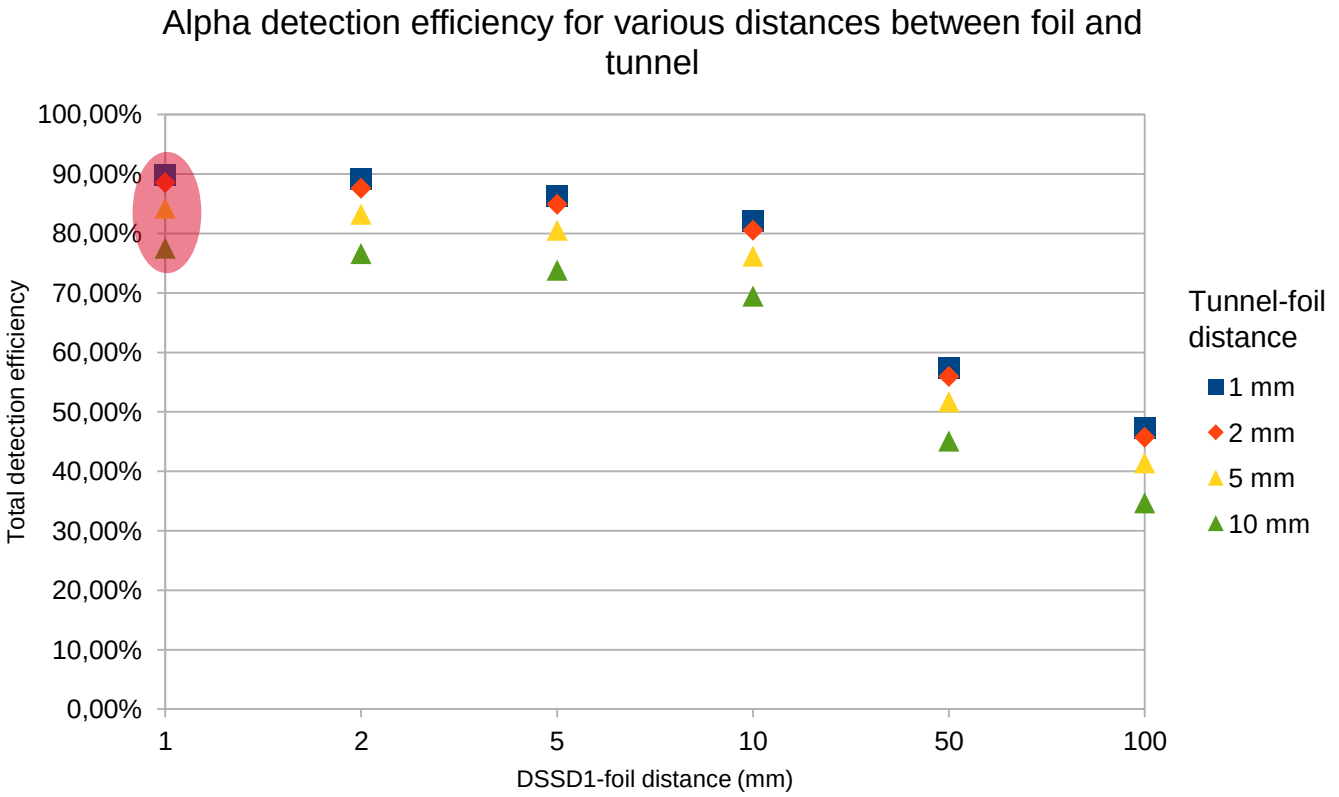
Characterisation:

- Simulations with nptool kit (Matta et al., JP G 43, 4 (2016) GEANT4)
  - α source (8 MeV)
  - e^- source

CHARACTERISTICS WITH ALPHA DETECTION

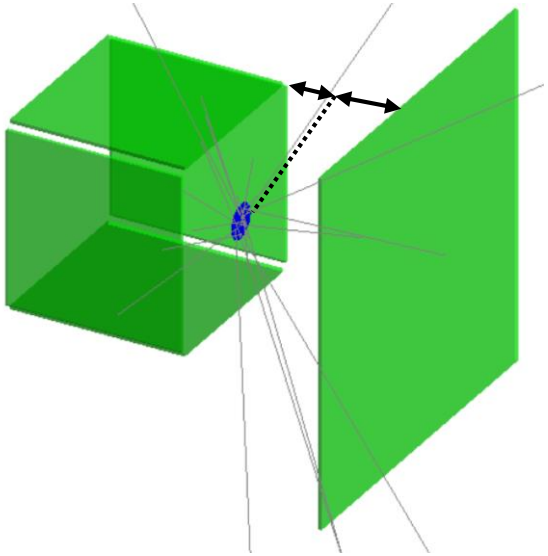


- 8 MeV mono-energetic source (isotropic)
- Variation of distances

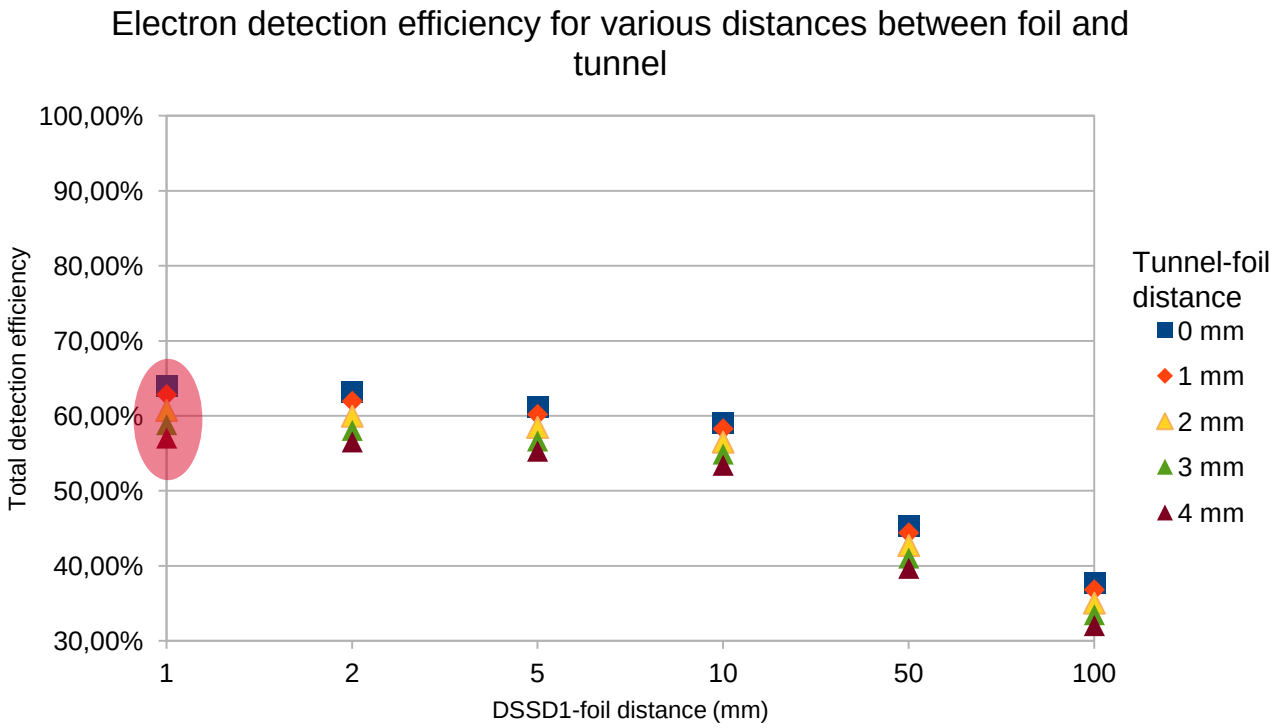


Up to 90% efficiency in compact configuration

CHARACTERISTICS WITH ELECTRON DETECTION

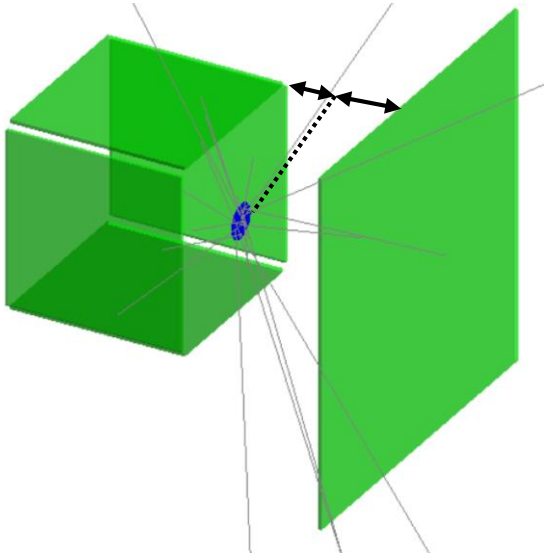


- 50 keV mono-energetic source (isotropic)
- Variation of distances

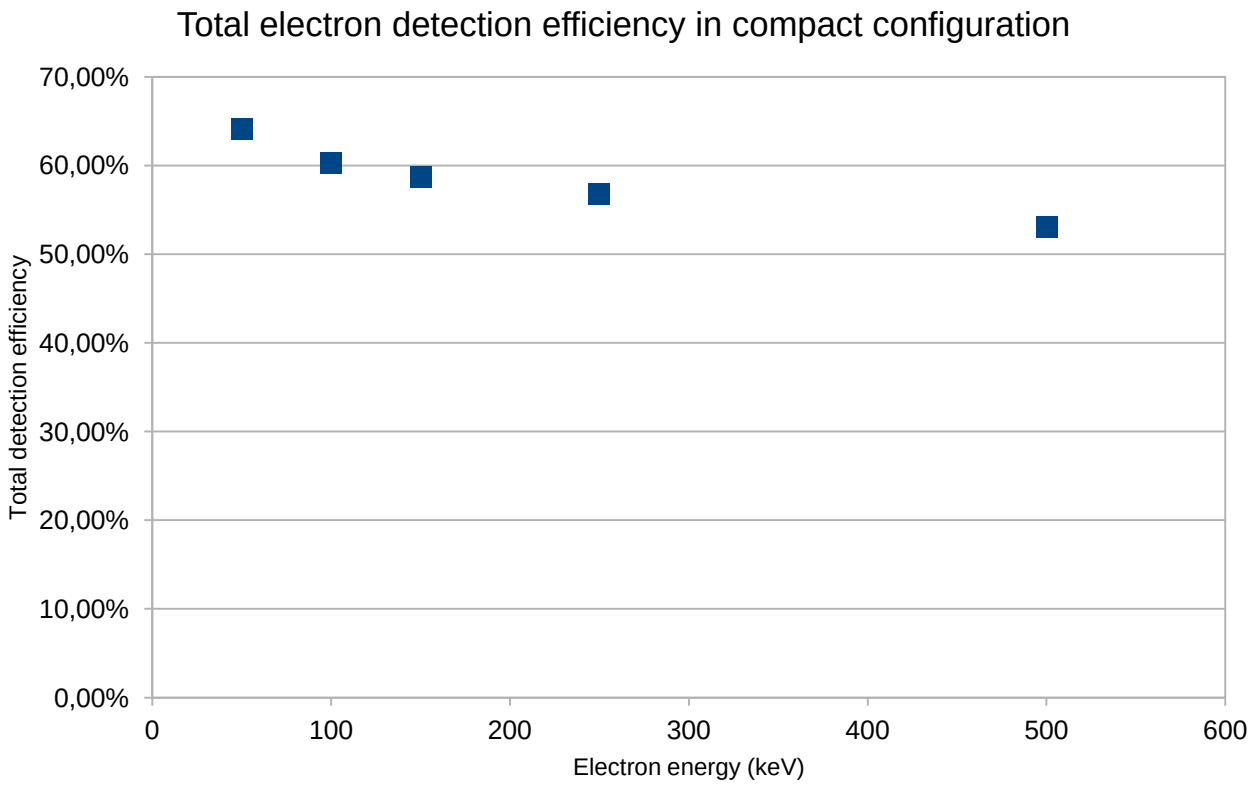


Up to 65% efficiency in compact configuration

CHARACTERISTICS WITH ELECTRON DETECTION

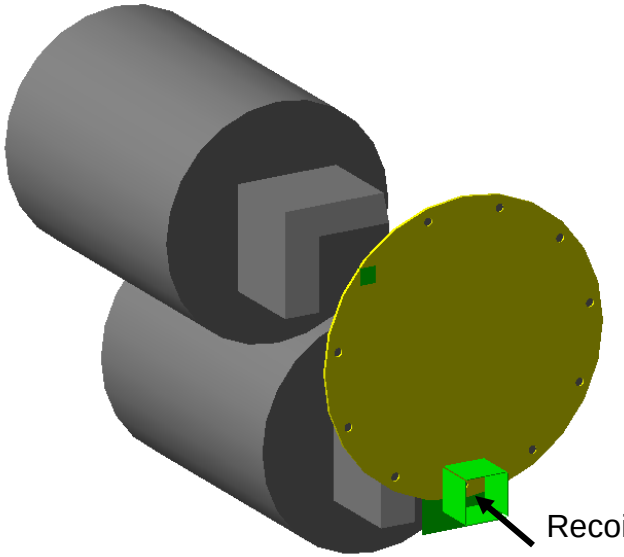


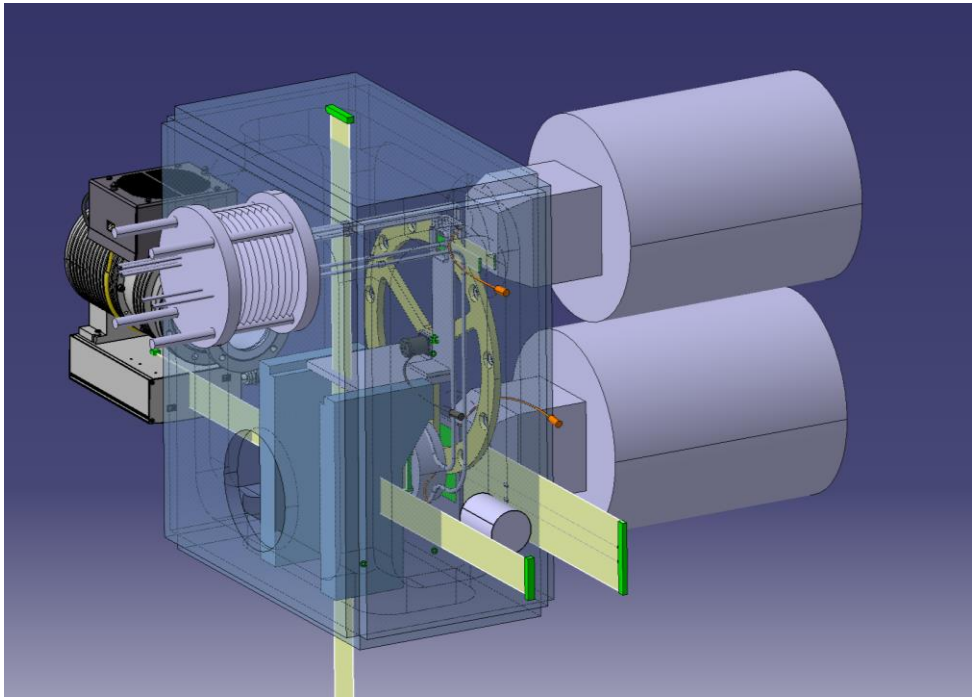
- 50 keV mono-energetic source (isotropic)
- Variation of distances



> 55% efficiency in compact configuration for 50-500 keV

OUTLOOK



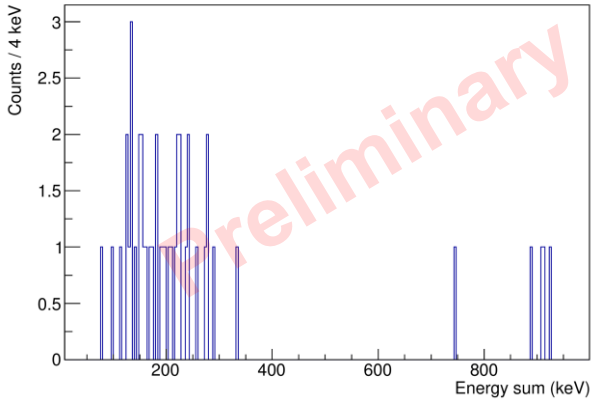


- Germanium detectors for γ rays
- Rotating wheel with optimized size
  - Change foil between laser frequencies
  - Evacuate decays from previous runs
- 2nd decay station for long-lived decays

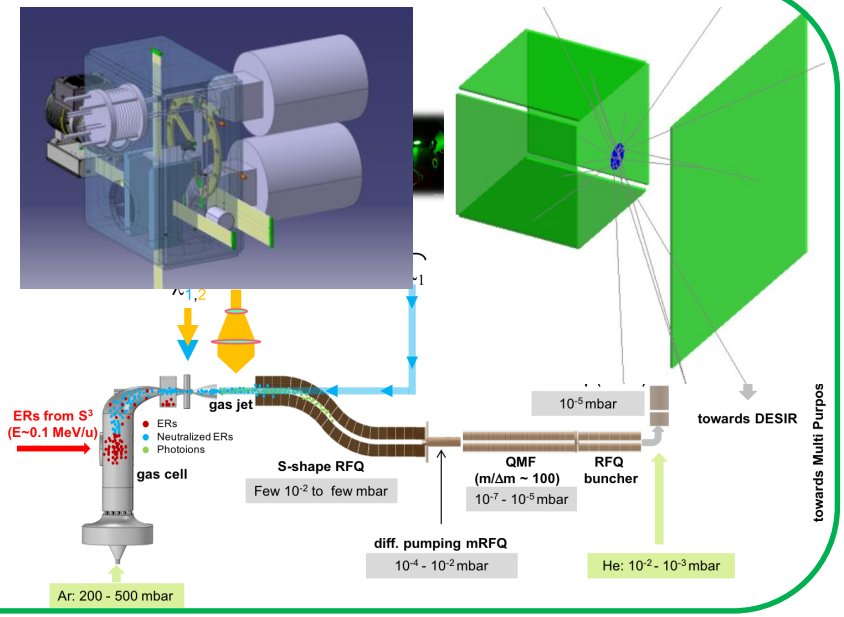
- First mechanical studies done

CONCLUSION

- **Discovery of a K isomeric state in ^{249}Md**
  - Only 2nd known isomer in odd-Z heavy nuclei besides ^{255}Lr



- Future: spectroscopy of heavy elements with laser ionisation
  - Low-energy branch (LEB) of S^3
  - **SEASON detector (Spectroscopy Electron Alpha in Silicon bOx couNter)**



THANK YOU FOR YOUR ATTENTION !

Commissariat à l'énergie atomique et aux énergies alternatives
Centre de Saclay | 91191 Gif-sur-Yvette Cedex

Etablissement public à caractère industriel et commercial | R.C.S Paris B 775 685 019

Direction de la Recherche Fondamentale
Institut de recherche
sur les lois fondamentales de l'Univers
Service