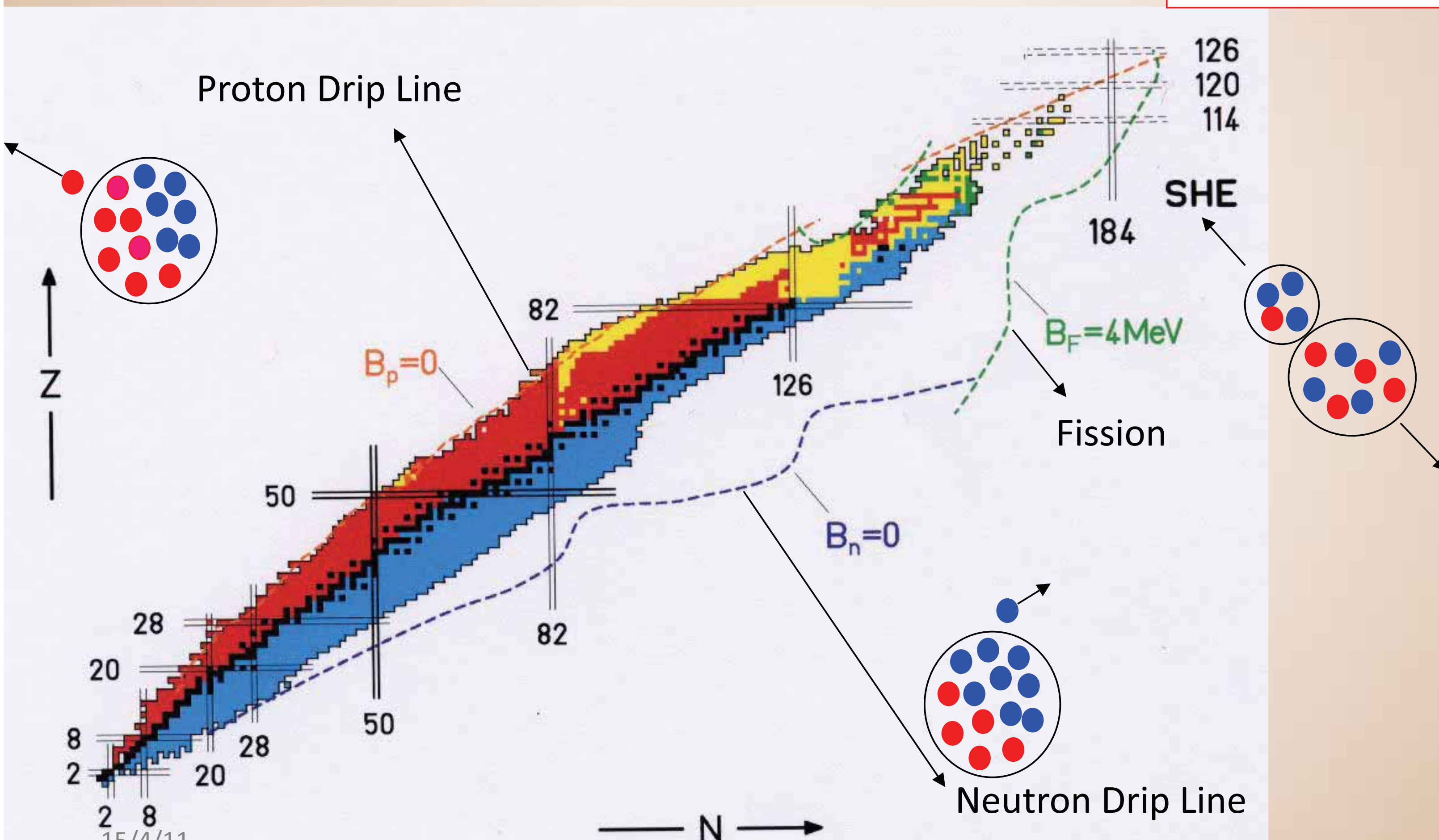
Beta decay studies with the Total Absorption Technique a remedy against "Pandemonium" ANL Colloquium

Berta Rubio
IFIC-Valencia (Spain)

265 stable

Most unstable nuclei decay by either β^+ or β^- decay

About 3000 out of 6000 synthesised in our laboratories.

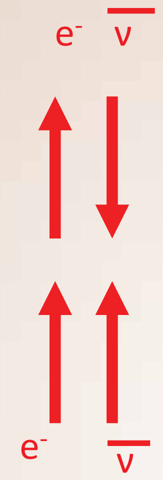


The beta decay process

$\beta^-: n \rightarrow p + e^- + \bar{\nu}$

$\beta^+: p \rightarrow n + e^+ + \nu$

Fermi and Gamow-Teller



Single state, Fermi

Triplet state Gamow Teller

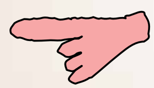
The selection rules

$$\Delta l = 0$$

$$\Delta s = 0,1$$

$$\Delta \pi = 0$$

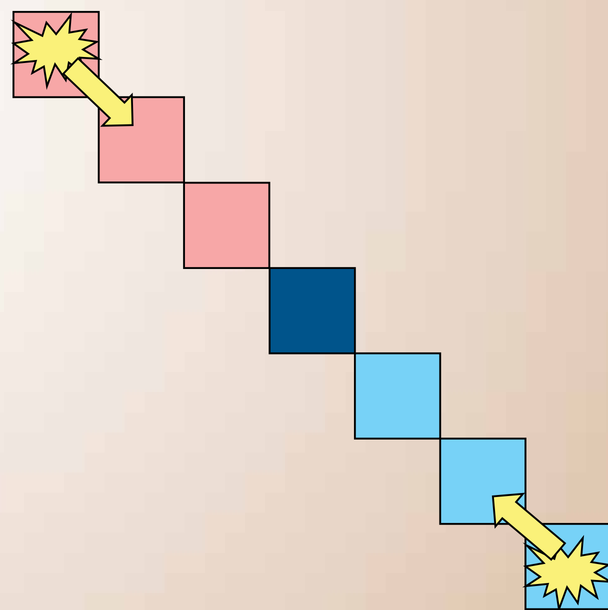
It happens real nuclei



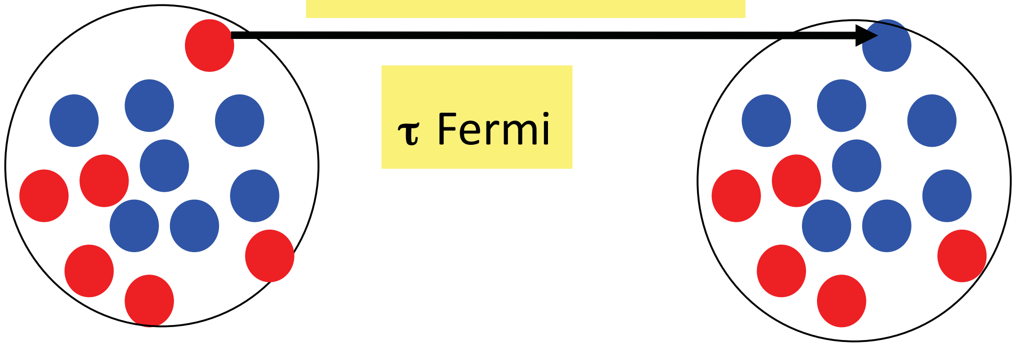
β - : $${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}X^{*}_{N-1} + e^{-} + \bar{\nu}_{e}$$

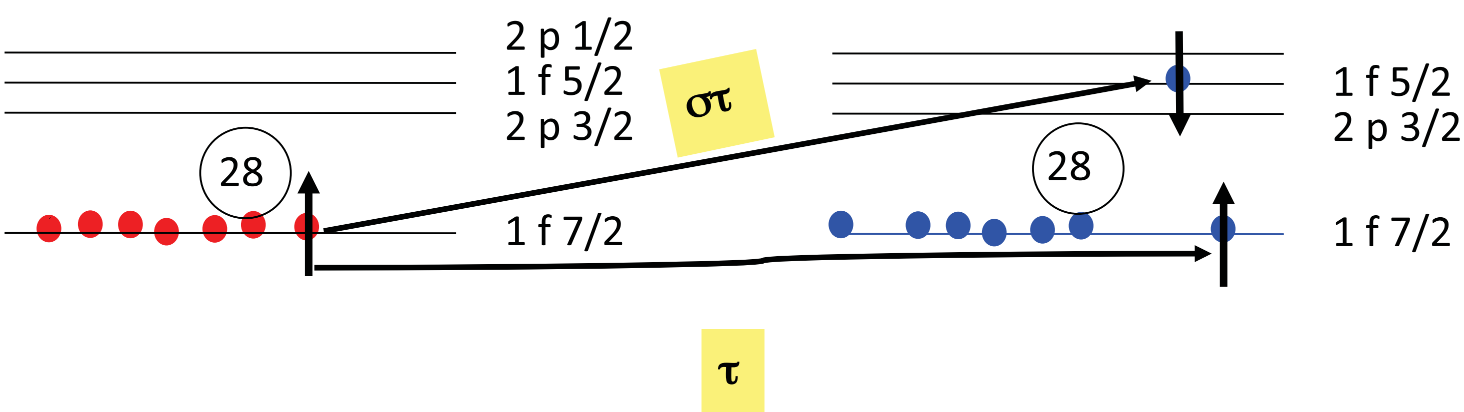
β + : $${}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}X^{*}_{N+1} + e^{+} + \nu_{e}$$

EC : $${}^{A}_{Z}X_{N} + e^{-} \rightarrow {}^{A}_{Z-1}X^{*}_{N+1} + \nu_{e} + X_{ray}$$



From the nuclear structure point of view
the operator responsible for the process is very simple





The beta strength or transition probability
governed by the spin-isospin operator

Theoretically

$$B(GT) = \left| \left\langle \psi_f \right| \sum_k \sigma_k \tau_k^{\pm} \left| \psi_i \right\rangle \right|^2$$

Experimentally

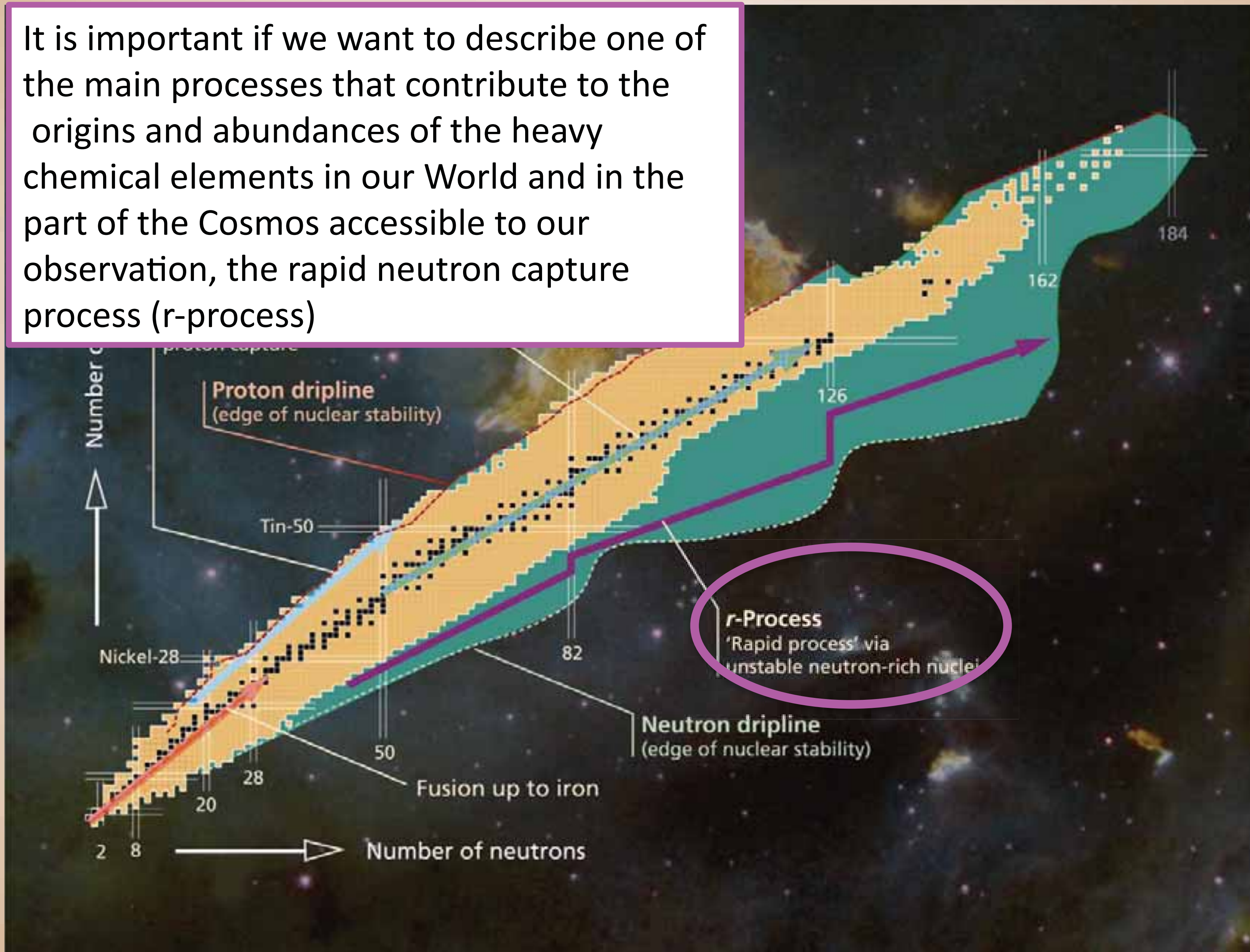
$$B(GT) = k \frac{I_\beta(E)}{f(Q_\beta - E, Z) T_{1/2}} = k \frac{1}{ft}$$

From the experiment

- $I_\beta(E)$ Beta feeding to states in the daughter nucleus
- $T_{1/2}$ Parent half life
- Q_β Q-value

This talk

It is important if we want to describe one of the main processes that contribute to the origins and abundances of the heavy chemical elements in our World and in the part of the Cosmos accessible to our observation, the rapid neutron capture process (r-process)



Nuclear Astrophysics

Astrophysics

Defines stellar conditions
temperature, density, pressure
and chemical composition

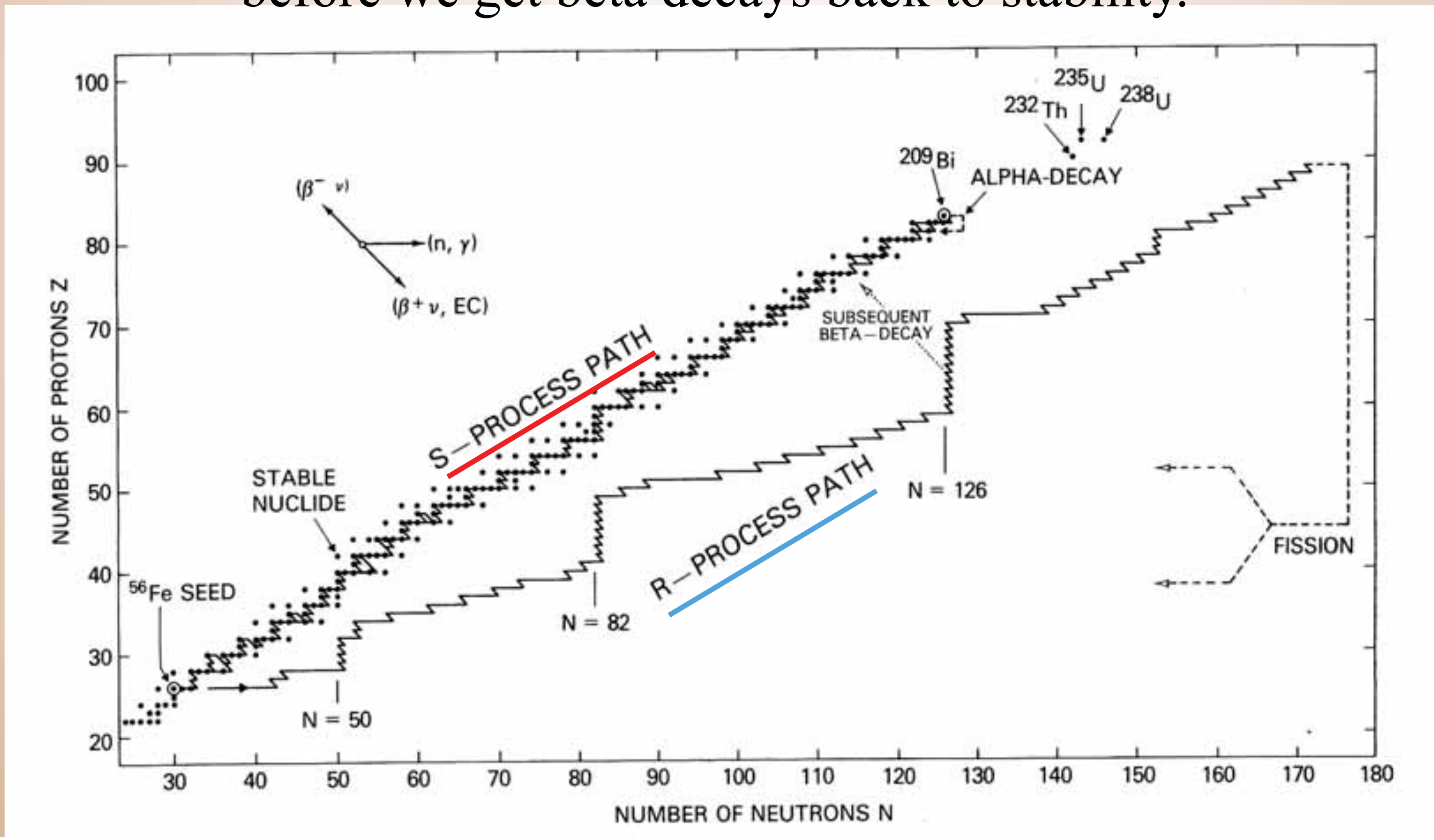
Nuclear physics

Reaction cross sections,
n-capture probabilities, gamma
Absorption probabilities
decay probabilities, masses,
half lives

The pathways for the s- and r-processes

s-process:Neutron flux is low so beta decay occurs before a second neutron is captured. We slowly zigzag up in mass.

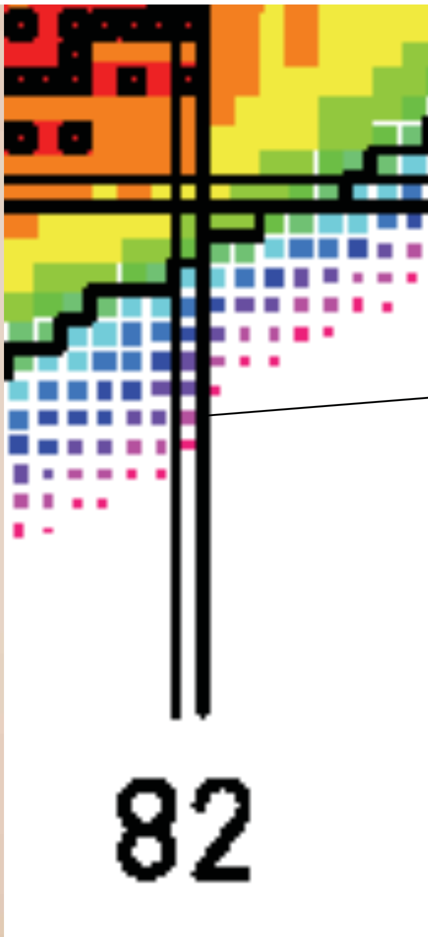
r-process:Neutron flux is enormous and many neutrons are captured before we get beta decays back to stability.

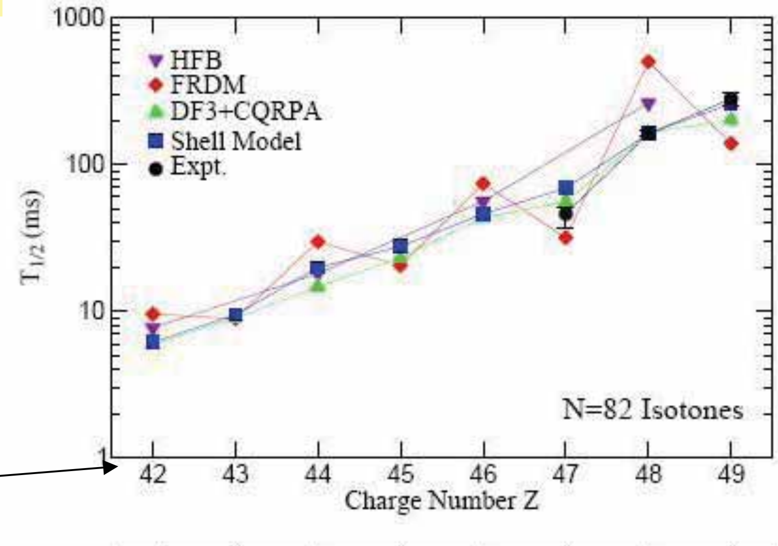


$$B(GT) = \left| \langle \psi_f | \sum_k \sigma_k \tau_k^{\pm} | \psi_i \rangle \right|^2 = k \frac{1}{ft}$$

N=82

Calculations of T1/2 for waiting point nuclei

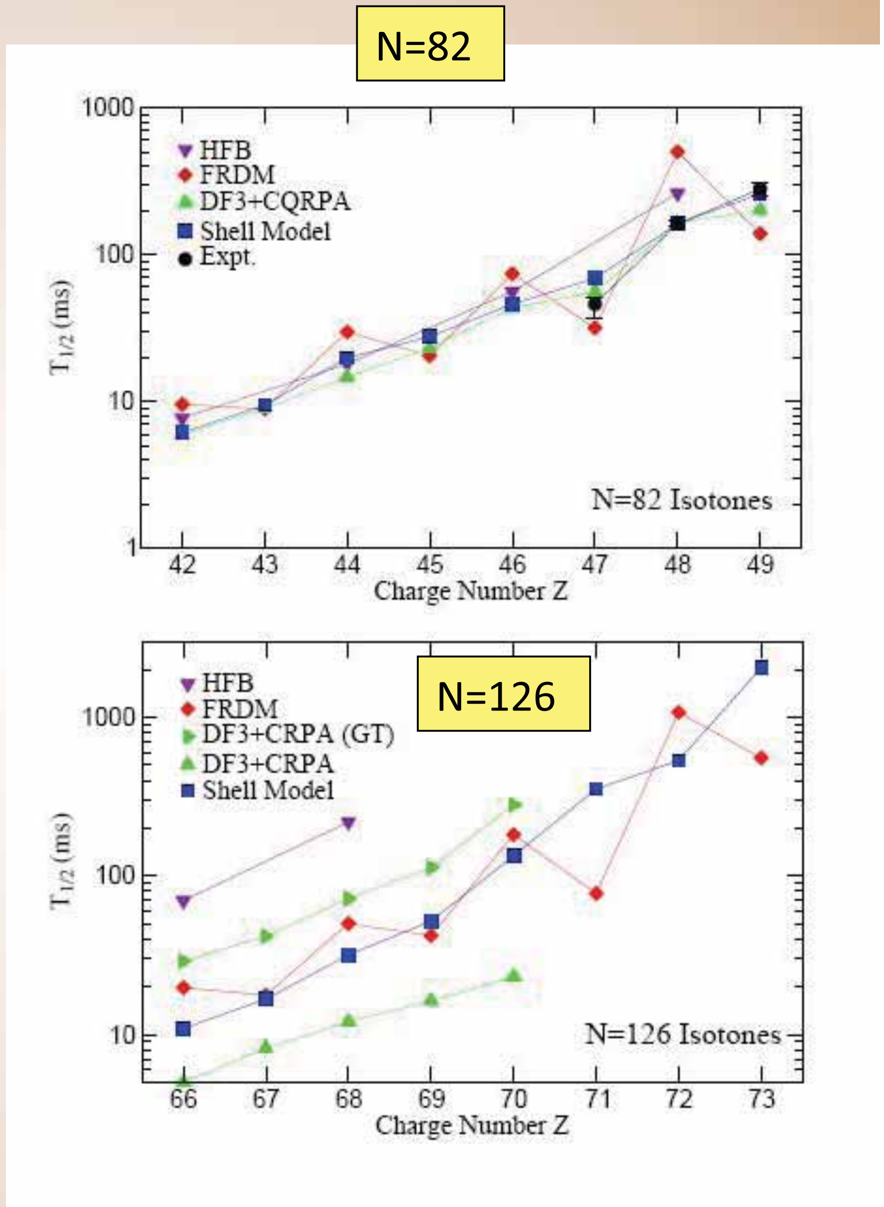




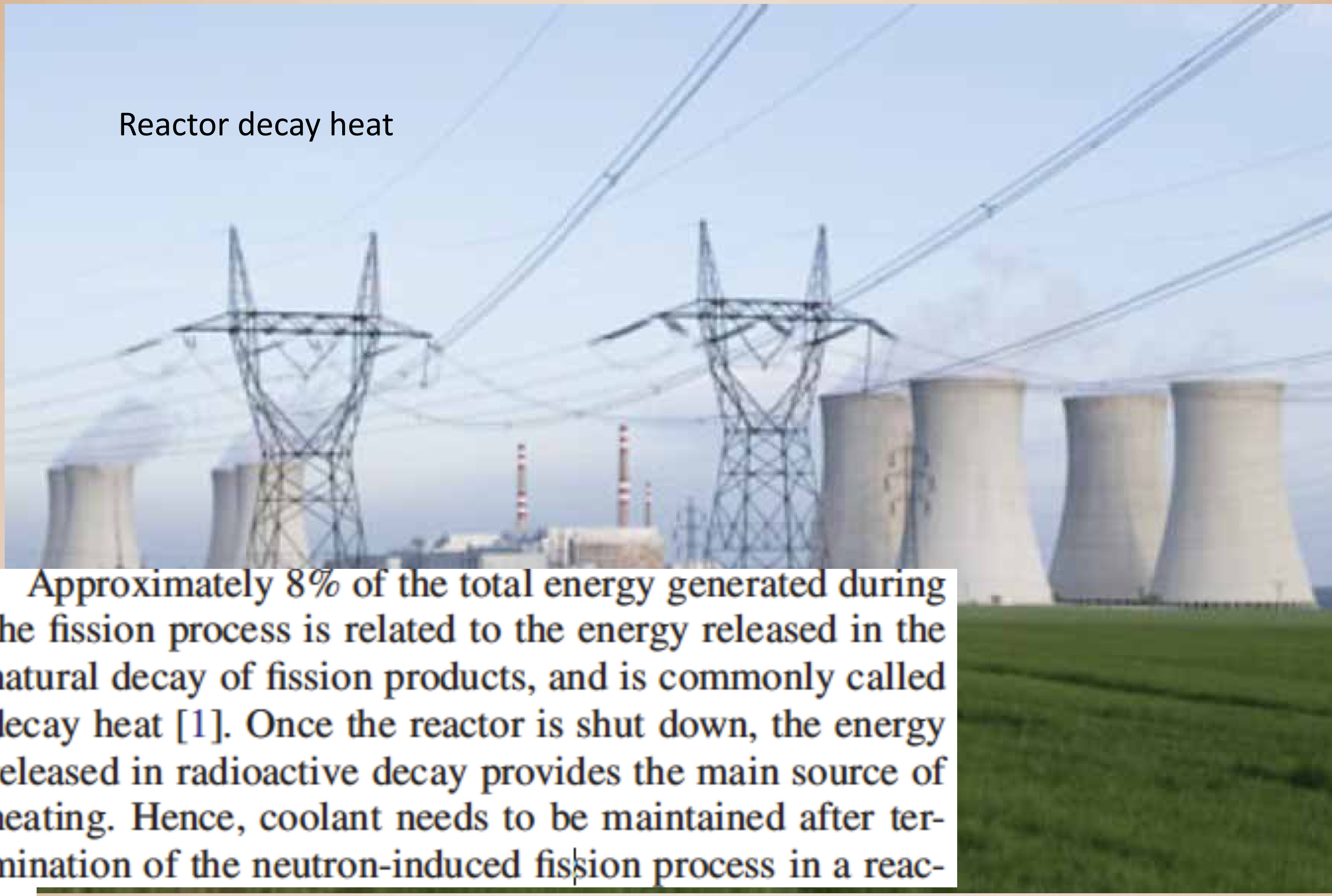
H. Grawe, K. Langanke and G. Martinez-Pinedo
Nuclear Structure and Astrophysics Reports
in Progress in Physics 70 (2007) 1525

Not so bad!!!

Larger differences
(lack of experimental data)



Reactor decay heat



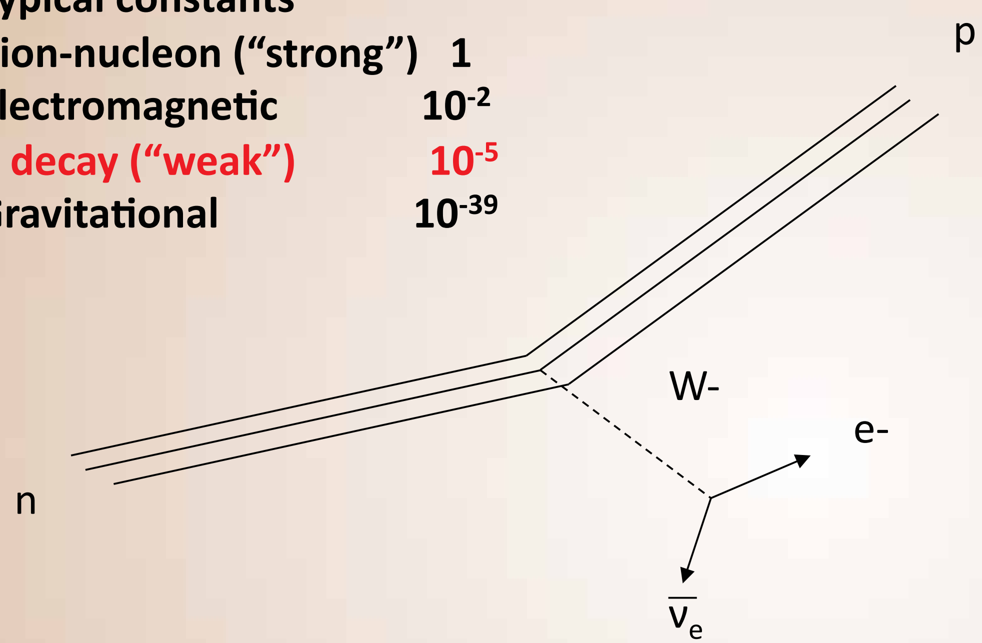
Approximately 8% of the total energy generated during the fission process is related to the energy released in the natural decay of fission products, and is commonly called decay heat [1]. Once the reactor is shut down, the energy released in radioactive decay provides the main source of heating. Hence, coolant needs to be maintained after termination of the neutron-induced fission process in a reactor.

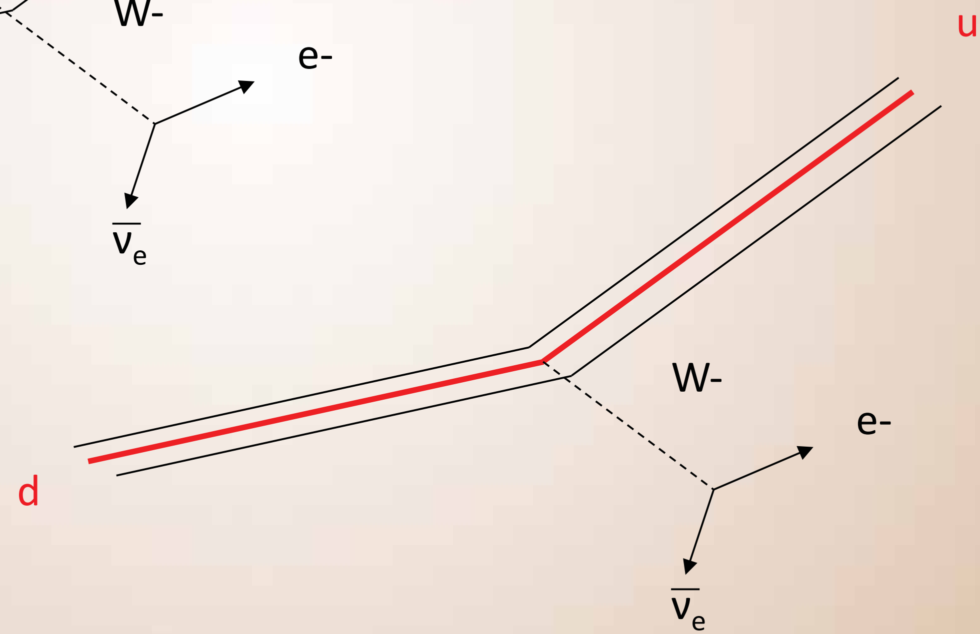
A. Algora et al PRL 105 105 (2010) 202501 Introduction….

Beta decay is a Weak process, and consequently slow

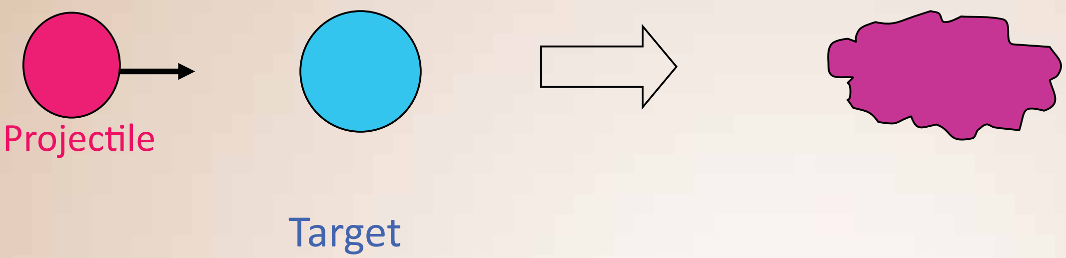
Typical constants

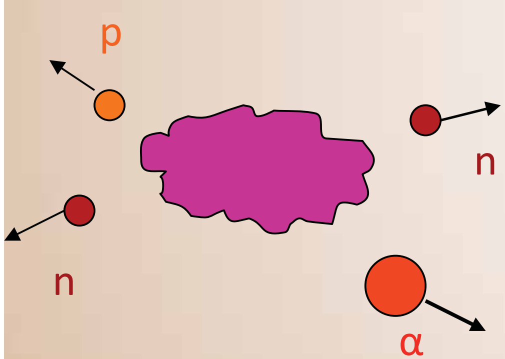
Pion-nucleon ("strong")	**1**
Electromagnetic	**10^{-2}**
β decay ("weak")	**10^{-5}**
Gravitational	**10^{-39}**



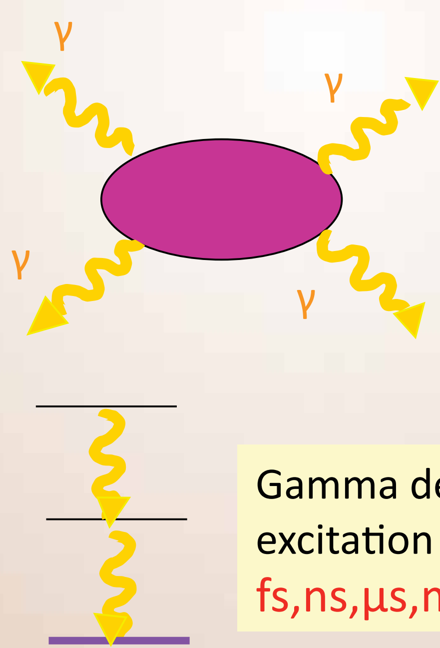


After the nucleus has been created there is some time available
Before it decays

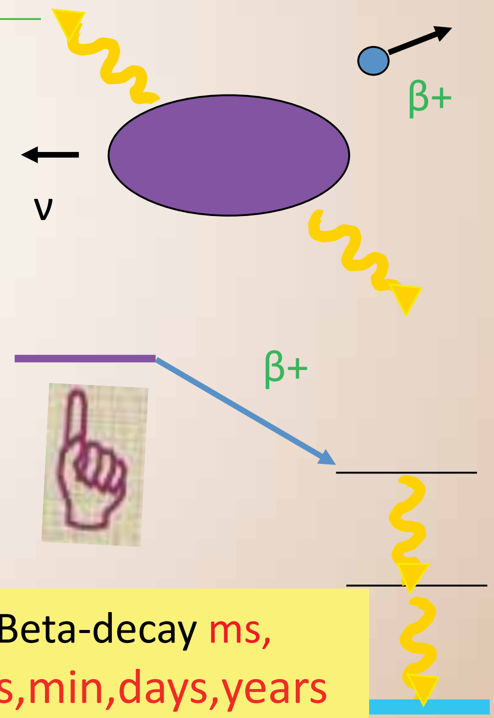




Particle evaporation 10^{-19} s

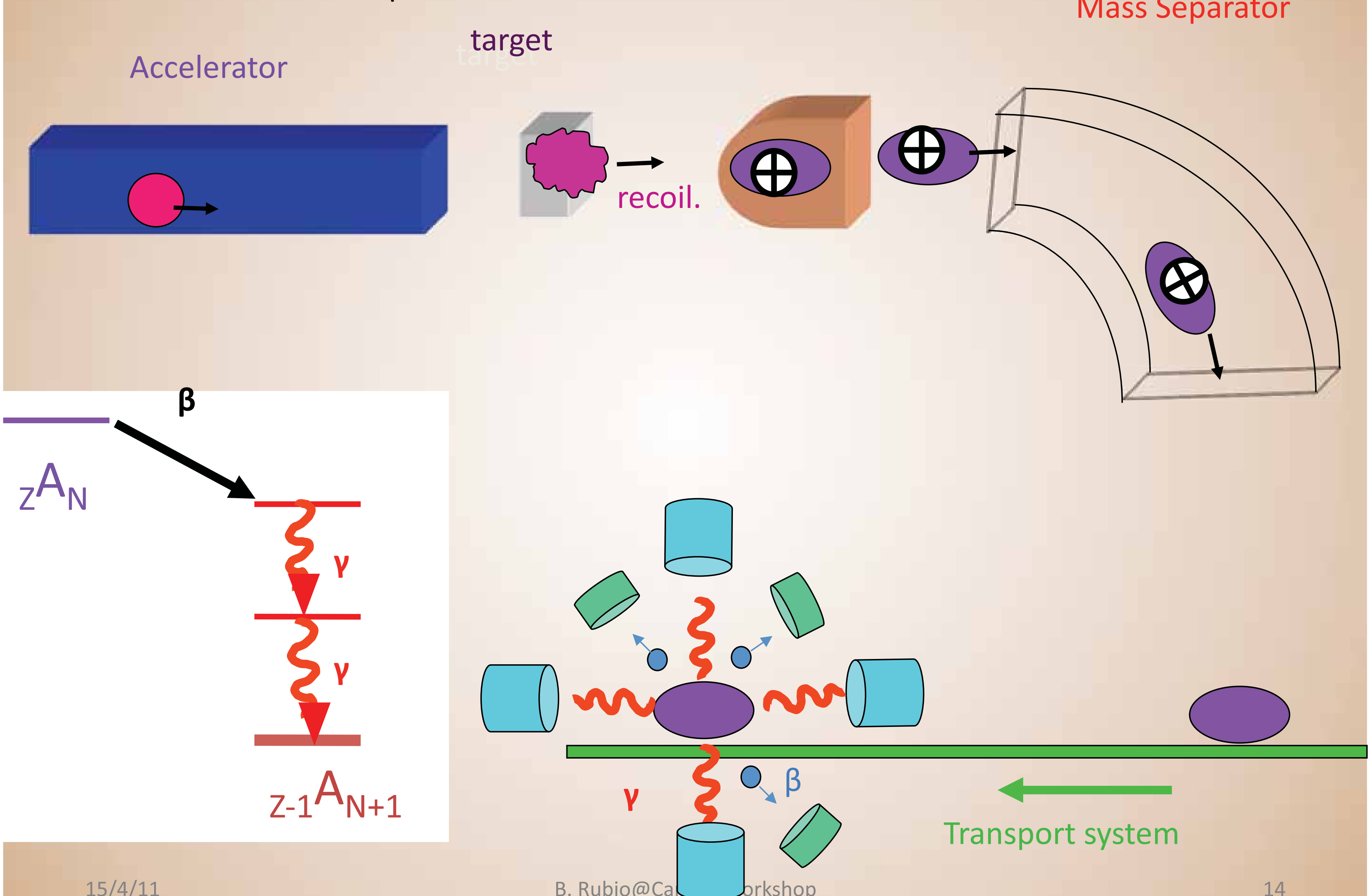


Gamma de-excitation fs,ns,μs,ms



Beta-decay ms, s,min,days,years

This allow us to separate the nucleus of interest
from the rest of the nuclei produced in the reaction



CARIBU

1 Ci ^{252}Cf

Extraction
Less than 100ms

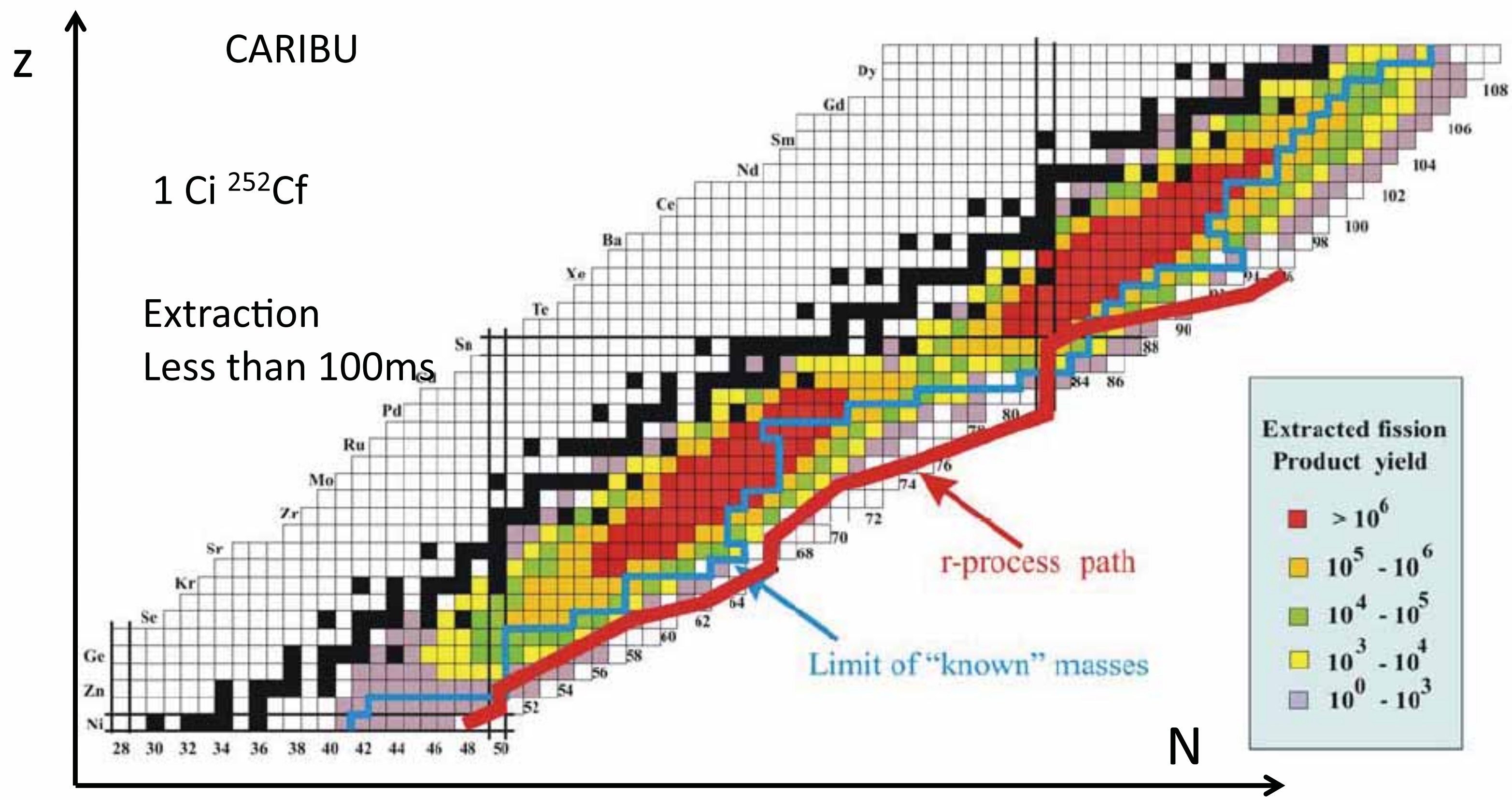
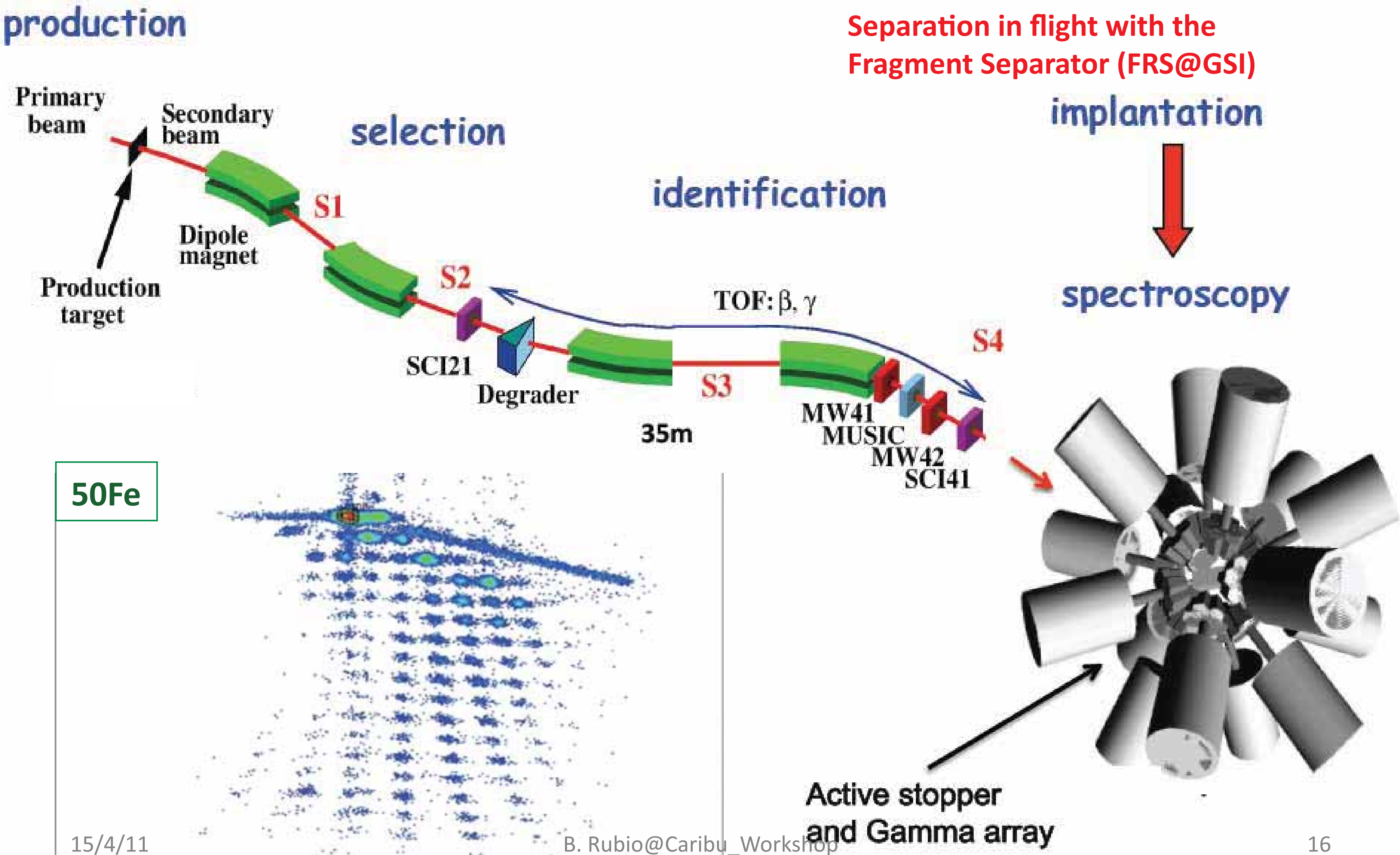


Figure 4. The r-process path together with the yield expected from an ion source system based on a 1 Ci californium fission source and the limit of known masses.

Today, for very unstable nuclei we perform beta decay studies at fragmentation facilities (GSI, MSU, GANIL, RIKEN…)

Separation in flight with the Fragment Separator (FRS@GSI)

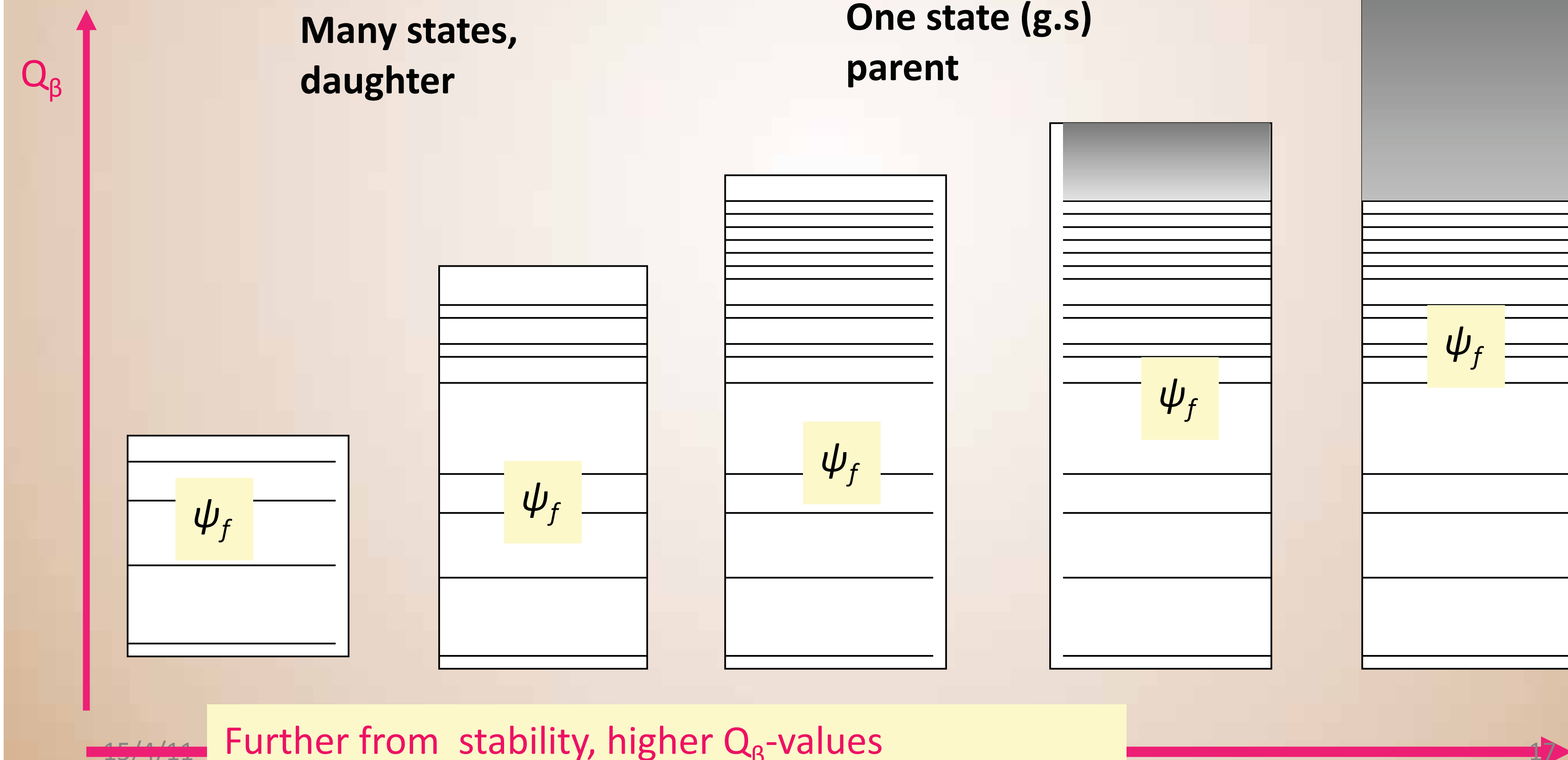


Beta-feeding for from stability

$$B(GT) = \left| \left\langle \psi_f \right| \sum_k \sigma_k \tau_k^{\pm} \left| \psi_i \right\rangle \right|^2 \equiv \left\langle \sigma\tau \right\rangle^2$$

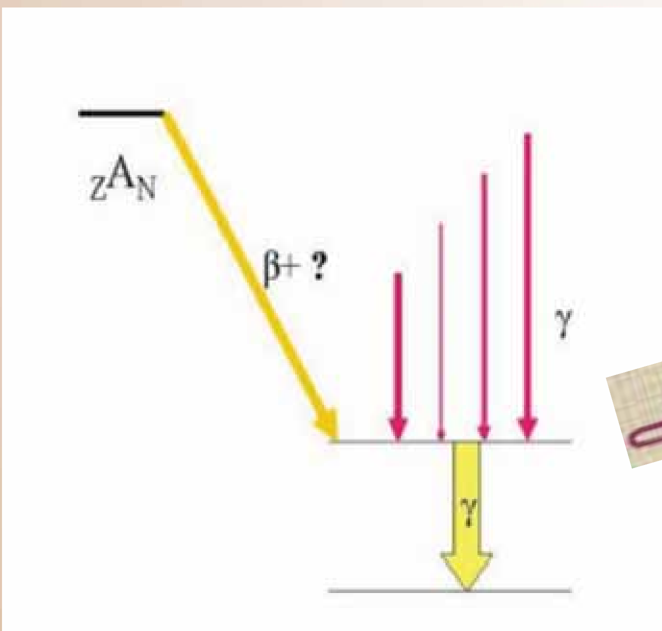
Many states, daughter

One state (g.s) parent



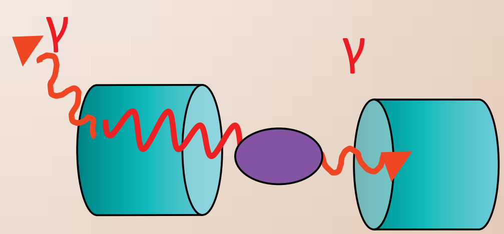
Further from stability, higher Q_β-values

How to measure beta intensity

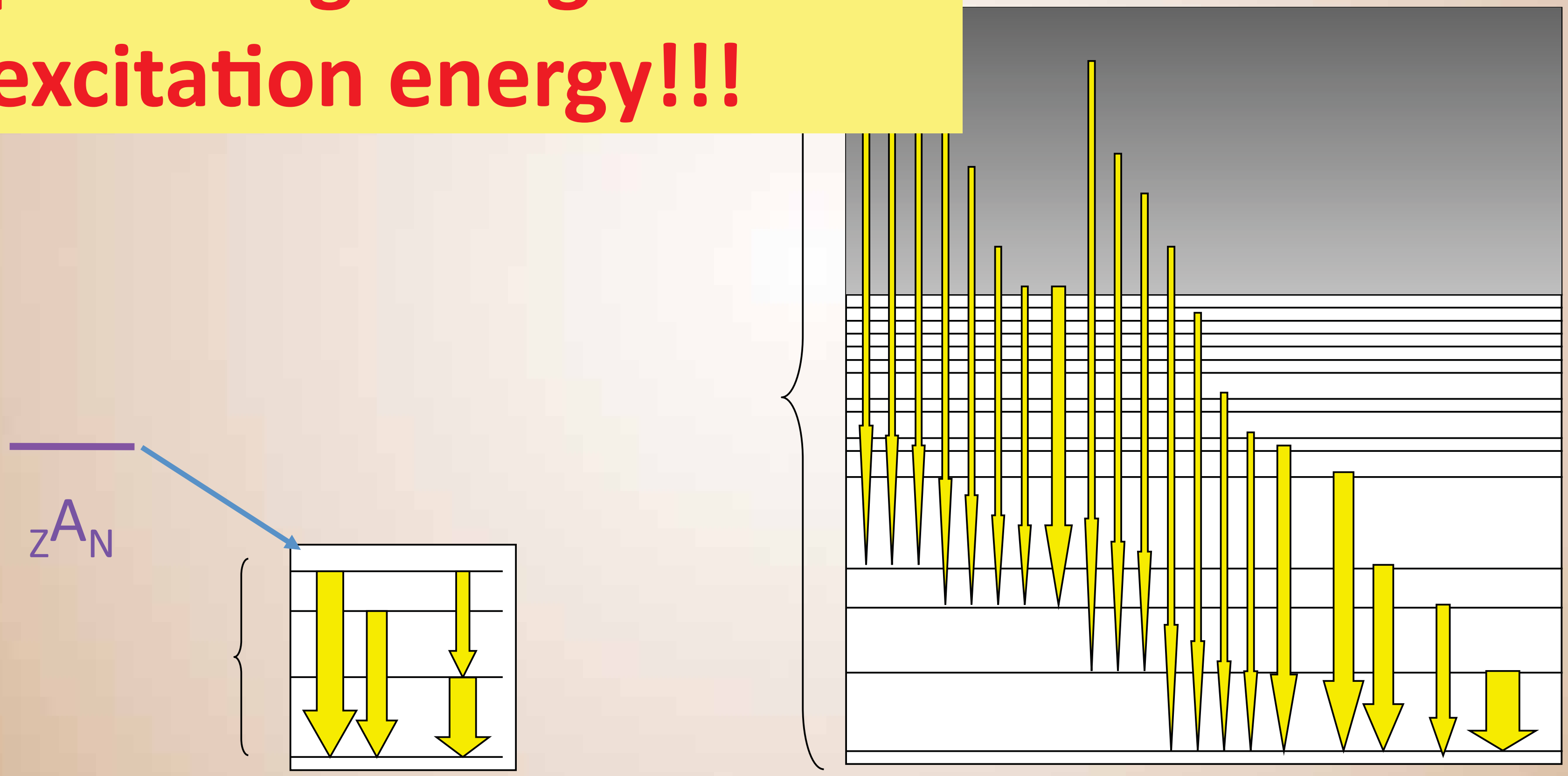


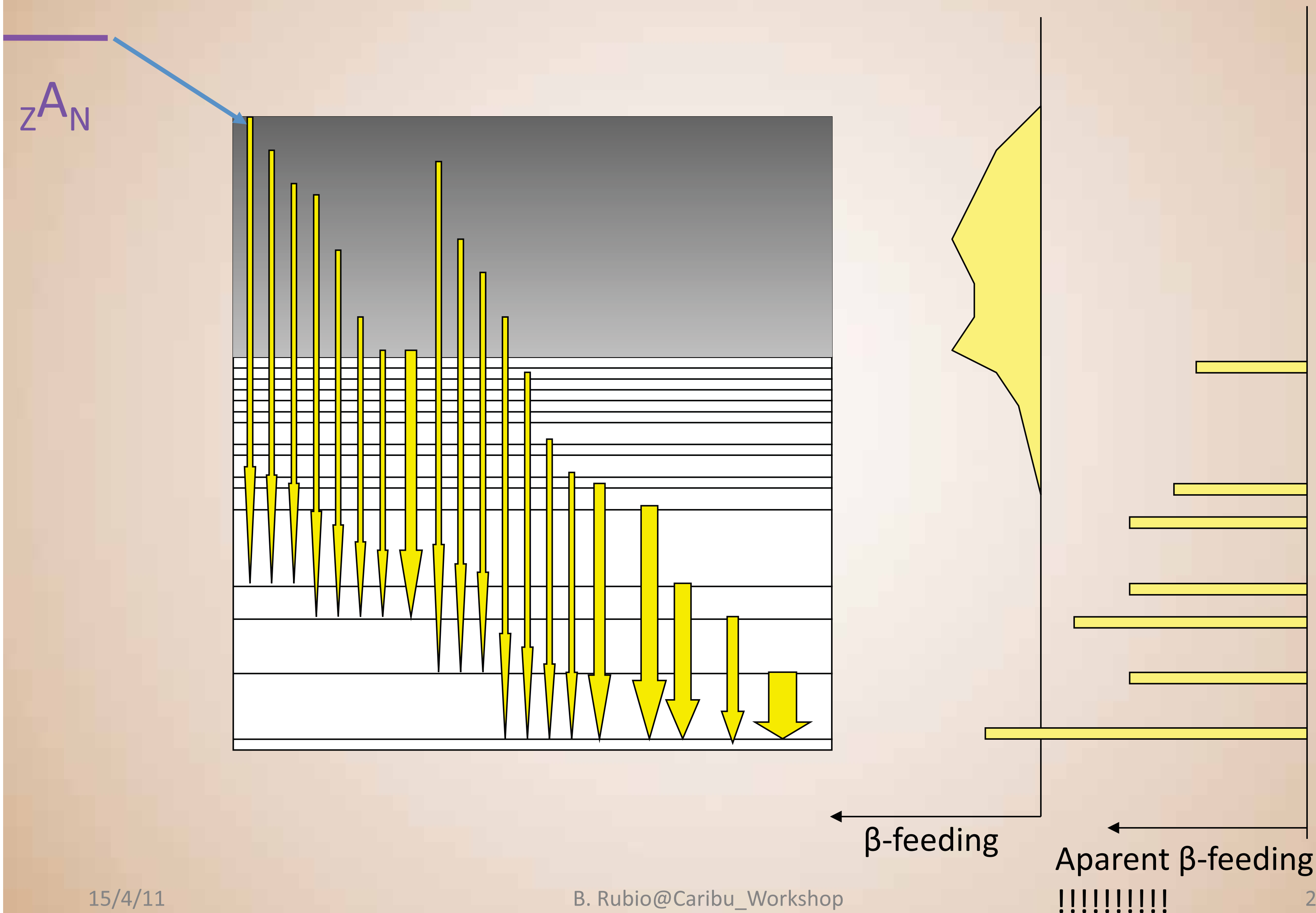
$$B(GT) = k\frac{I_\beta(E)}{f(Q_\beta - E, Z)T_{1/2}}$$

$$I_\beta(E)$$



For high Q-values, Ge detectors fail to detect β-feeding at high excitation energy!!!





$_ZA_N$
β-feeding
Aparent β-feeding
!!!!!!!!!!

John Matin´s 1825 engraving "Pandemonium".

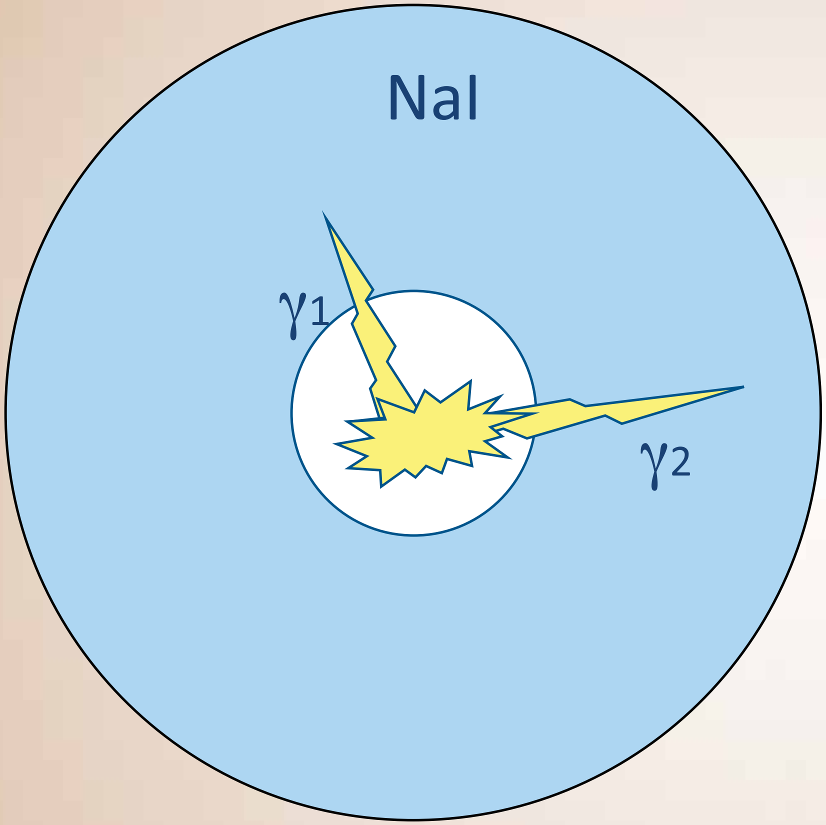
Volume 71B, number 2 PHYSICS LETTERS 21 November 1977

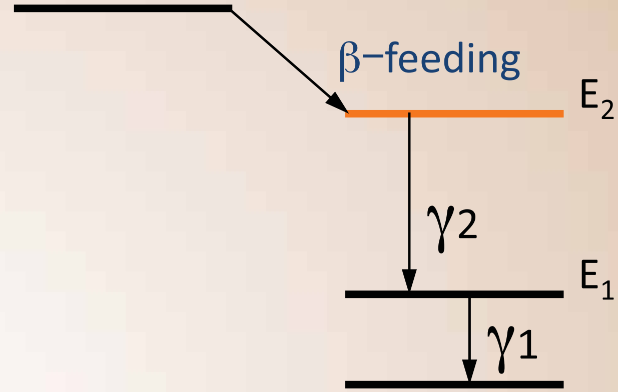
**THE ESSENTIAL DECAY OF PANDEMONIUM:
A DEMONSTRATION OF ERRORS IN COMPLEX BETA-DECAY SCHEMES**

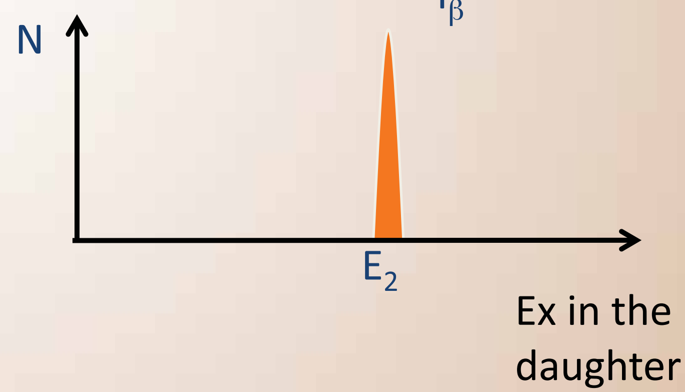
J.C. HARDY *, L.C. CARRAZ, B. JONSON ‡ and P.G. HANSEN ‡
CERN, Geneva, Switzerland

J. Milton, *Paradise Lost, Book I (1667)*

Total Absorption spectroscopy

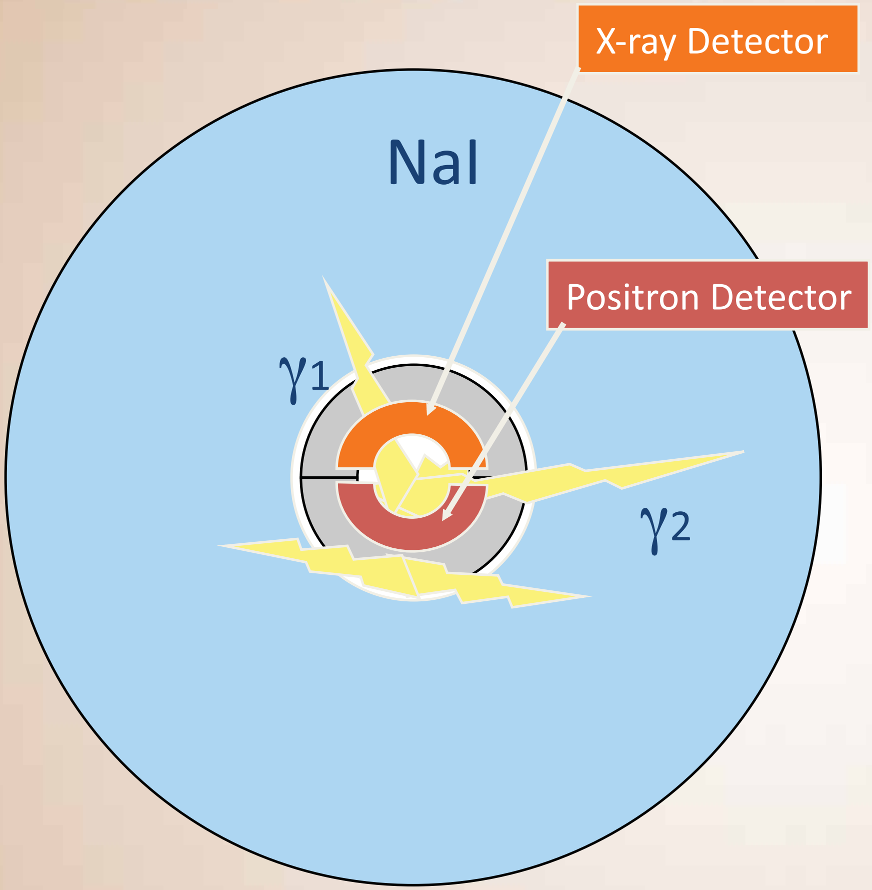


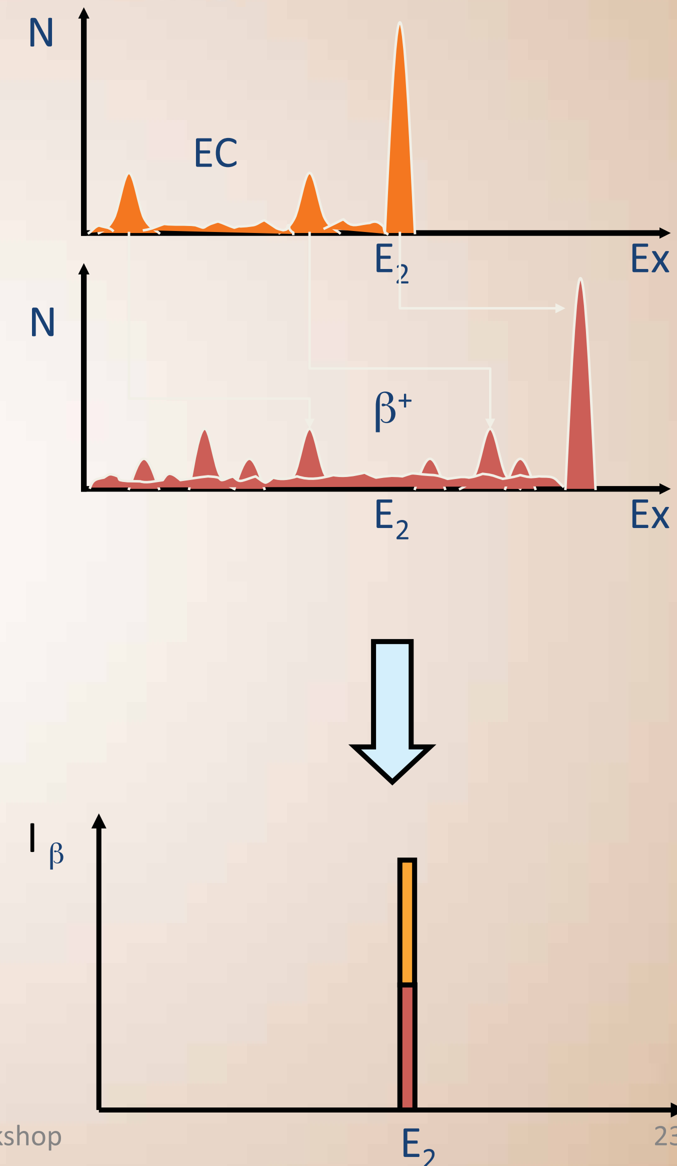




Ideal case

Total absorption spectroscopy



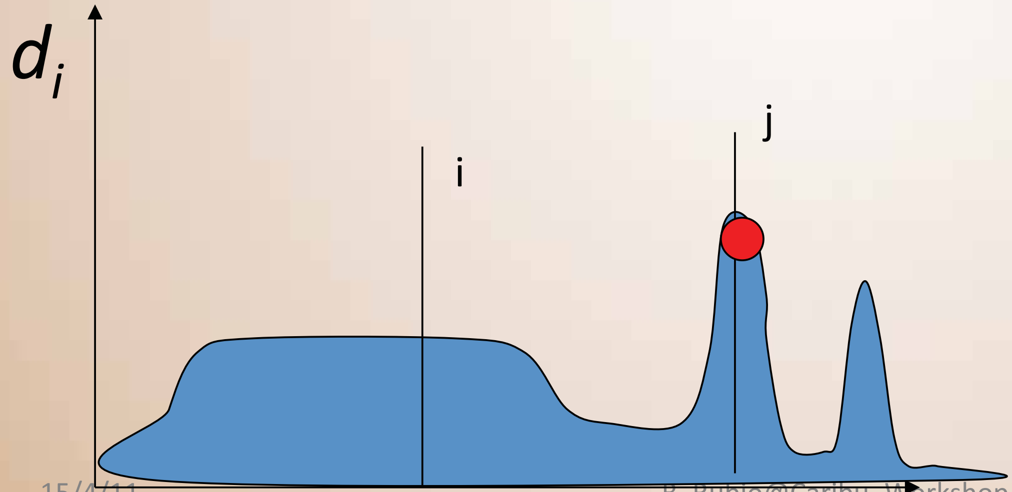


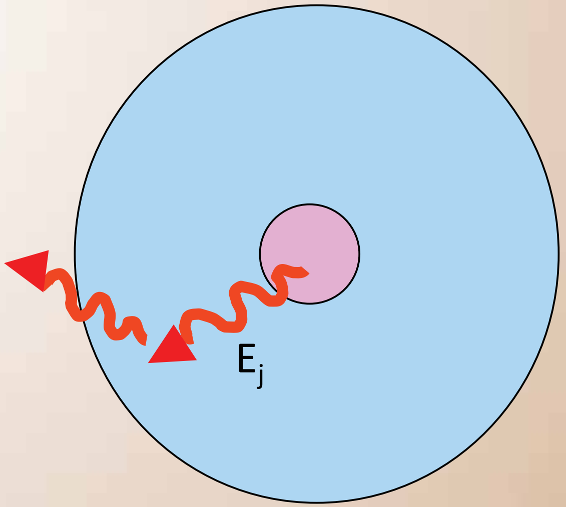
Real case

The main problem is not the intrinsic efficiency
but the material placed inside the detector or the holes
Needed to put the activity inside

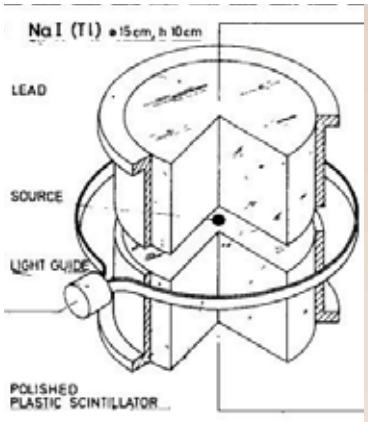
One has to solve the following equation:

$$d_i = \sum_{j=1}^{j_{\max}} R_{ij} f_j$$



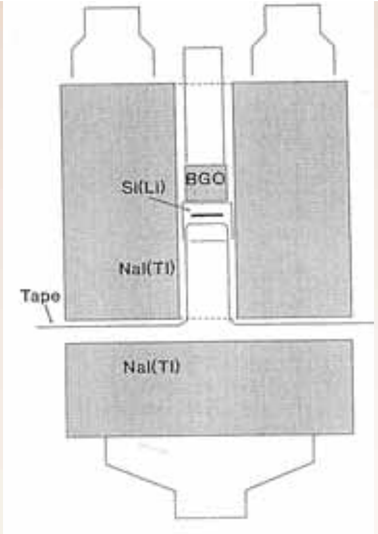


ISOLDE/OSIRIS TAS: St. Petersburg TAS: INEL TAS:



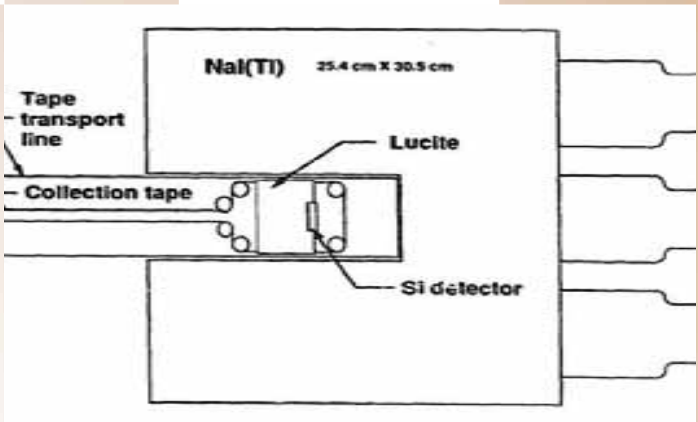
Duke et al. NP A151 (1970) 609
Hornshoj et al. NP A239 (1975) 15

2× Ø15cm×10cm cryst.
+ Plastic scin. ring



Bykov et al. IAN SSSR 44 (1980) 918

Ø20cm×30cm (2 cryst.)
+ Si det



Greenwood et al. NIM A314 (1992) 514 & A390 (1997) 95

Ø25cm×30cm well
+ Si det.

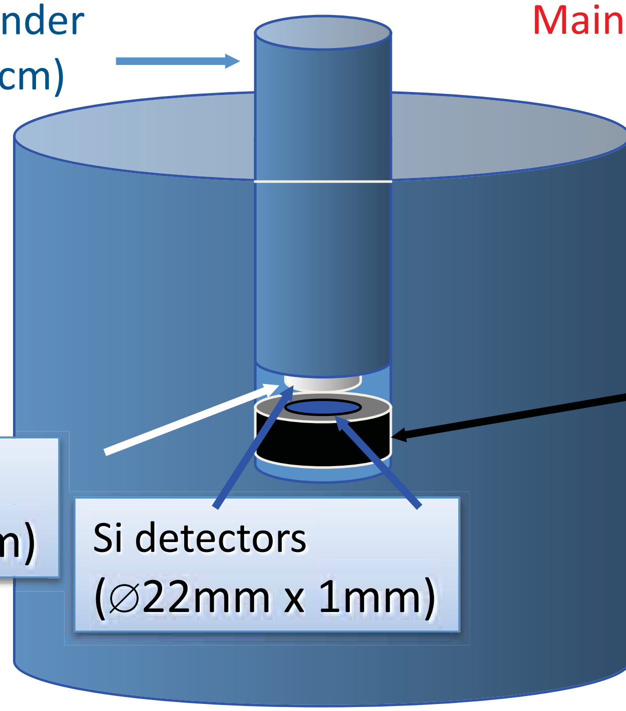
Duke et al in the 70's, Studswik and Isolde
Firestone 1974, 1975
Hardy and 1977
Russians in the 80's
Greengood 90's
GSI 1994

A big step forward came with the construction and exploitation of the Berkeley-GSI TAS 1997

TAS at GSI

Mainly for proton rich nuclei

Detector “Plug”: cylinder of NaI (∅4.7cm x 15cm)



Positron absorber: polyethylene (∅51mm x 21mm)

Ge detector (∅16mm x 10cm)

Si detectors (∅22mm x 1mm)

Main Crystal: NaI cylinder (∅35.6cm x 35.6cm)

Accurate response of the whole apparatus to the gamma rays and the betas: Geant Monte Carlo simulations

Solve the inverse problem:

$$d_i = \sum_{j=1}^{j_{\max}} R_{ij} f_j$$

J.L.Tain, D. Cano-Ott, Nucl. Instr. and Meth. in Phys. Res. A **571**, 719 (2007)
J.L.Tain, D. Cano-Ott, Nucl. Instr. and Meth. in Phys. Res. A **571**, 728 (2007)

LR method: polynomial smoothing

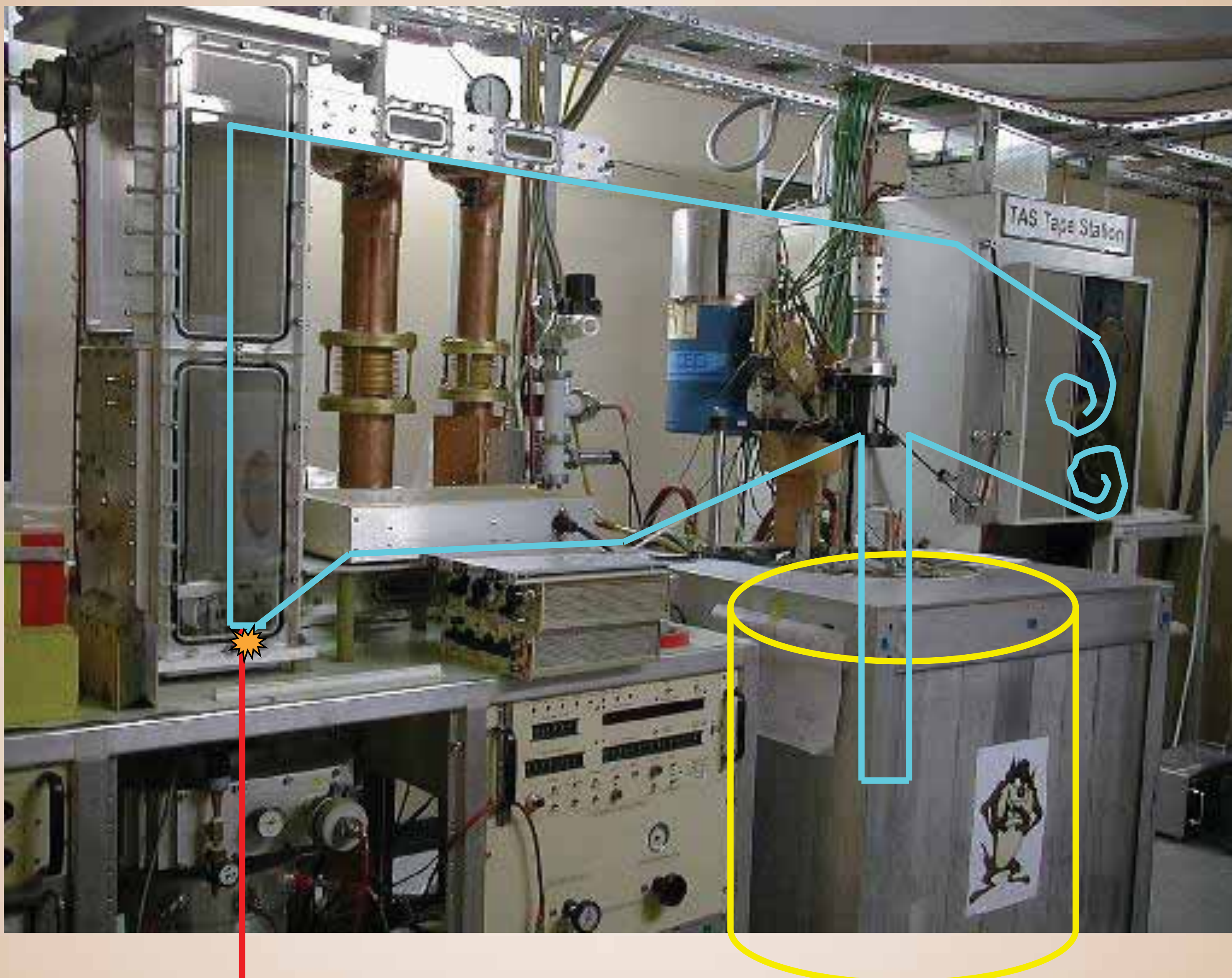
$$\mathbf{f} = \left(\mathbf{R}^T \cdot \mathbf{V}_d^{-1} \cdot \mathbf{R} + \lambda \mathbf{B}^T \cdot \mathbf{B}\right)^{-1} \cdot \mathbf{R}^T \cdot \mathbf{V}_d^{-1} \cdot \mathbf{d}$$

ME method: entropy maximization

$$f_j^{(s+1)} = f_j^{(s)} \exp\left(\frac{2}{\lambda} \sum_i \frac{R_{ij}}{\sigma_i^2} \left(d_i - \sum_k R_{ik} f_k^{(s)} \right) \right)$$

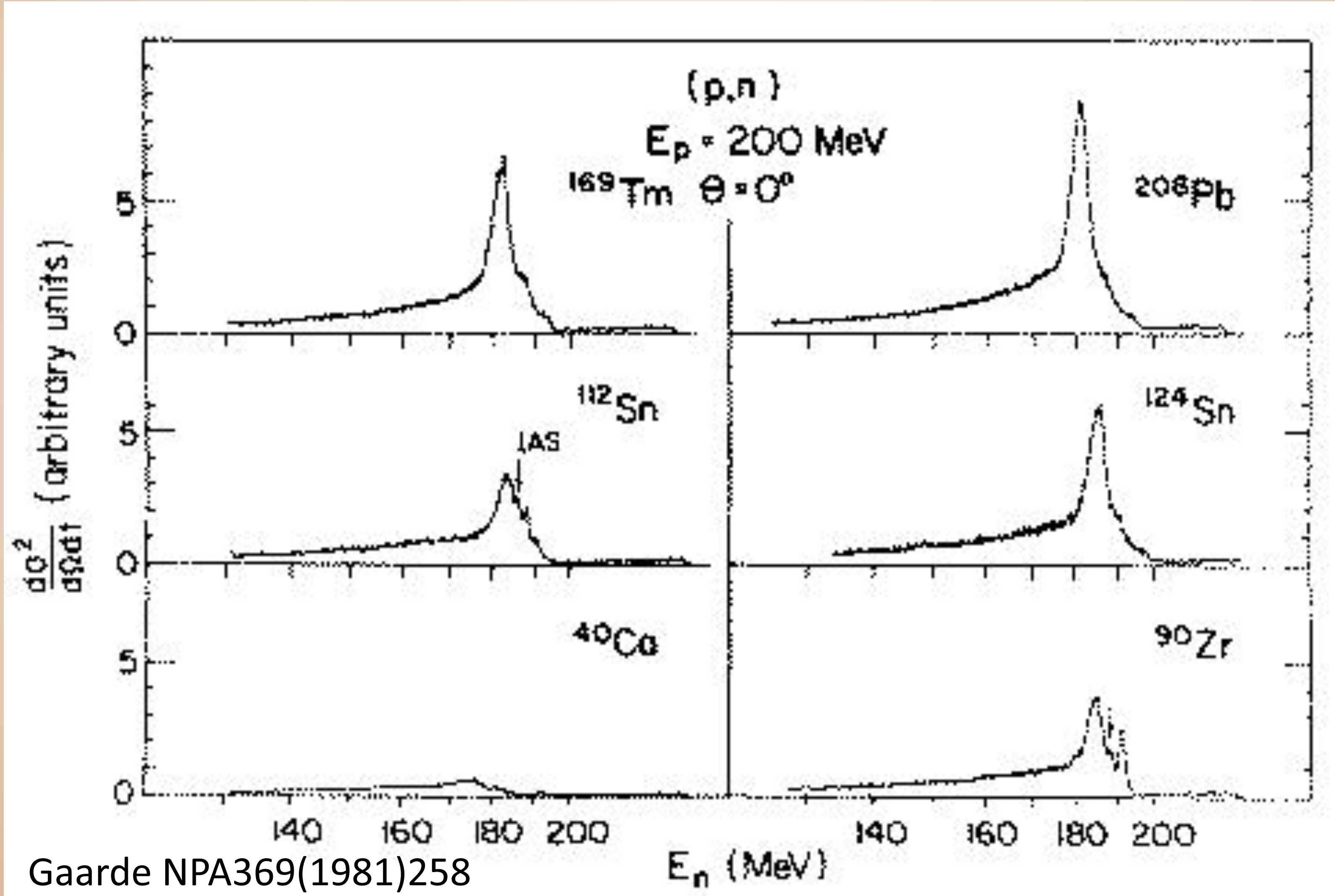
EM method: Bayes Theorem

$$f_j^{(s+1)} = \frac{1}{\sum_i R_{ij}} \sum_i \frac{R_{ij} f_j^{(s)} d_i}{\sum_k R_{ik} f_k^{(s)}}$$



TAS at the On-line Mass separator at GSI
Karny et al. **NIM B126 (1997) 411**

στ excitation viewed from the reaction perspective is a collective spin isospin excitation



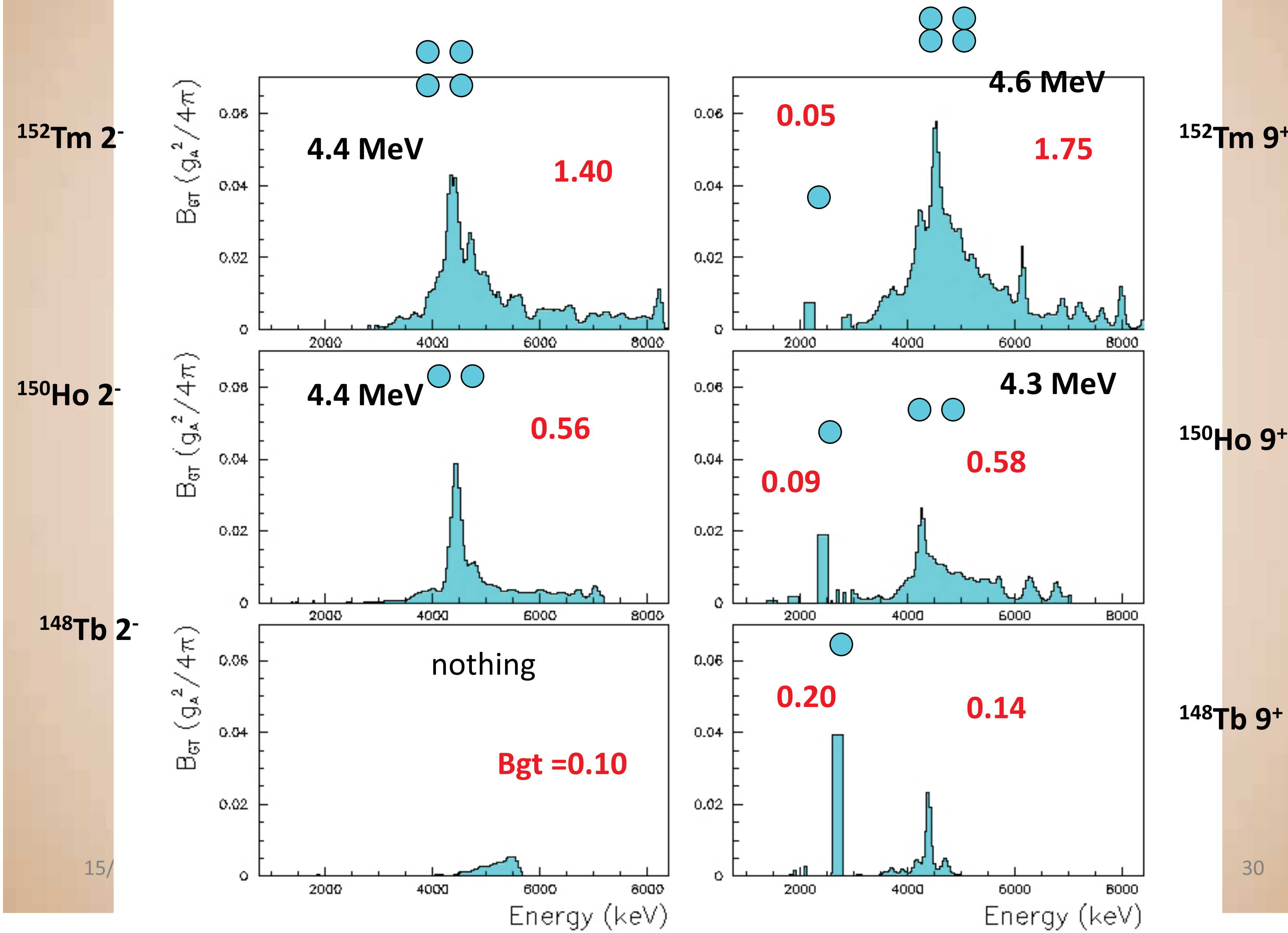
Gaarde NPA369(1981)258

se

hase

19th-27th Aug. 2004

D. Cano Ph.D thesis and E. Nácher Ph.D Thesis, Valencia
B.Rubio "Frontiers of Collective Motions" CM2002 Japan, World Scientific

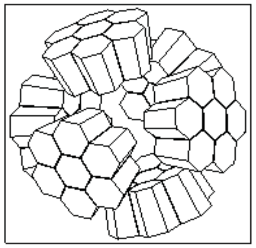


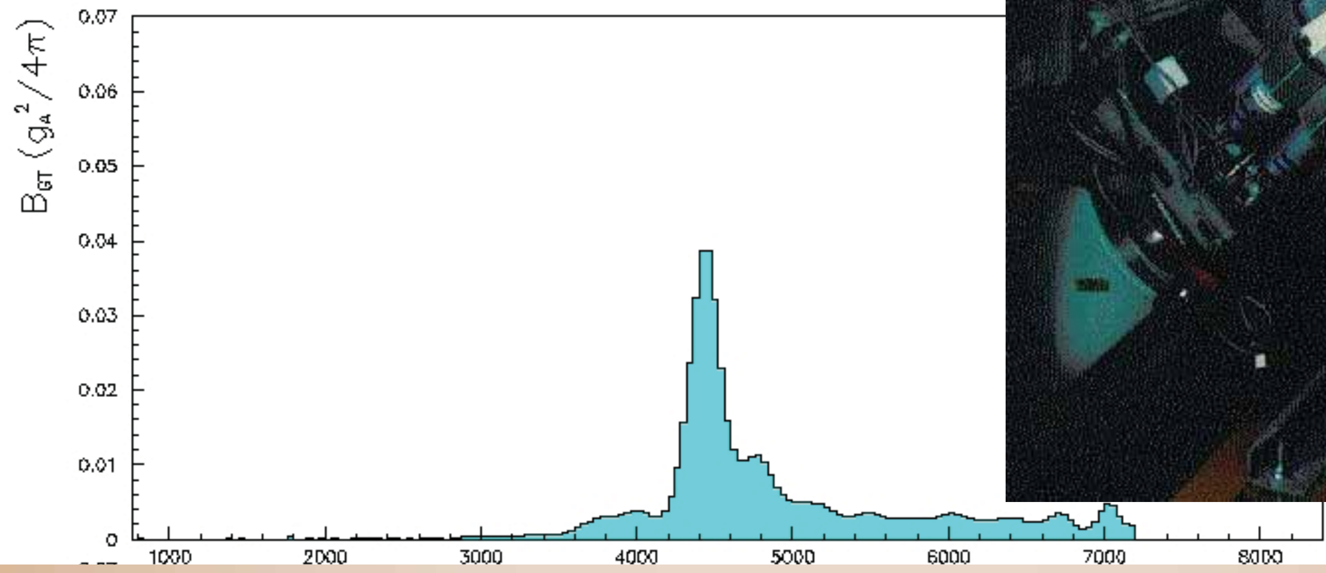
Are we sure our deconvolution method is correct?

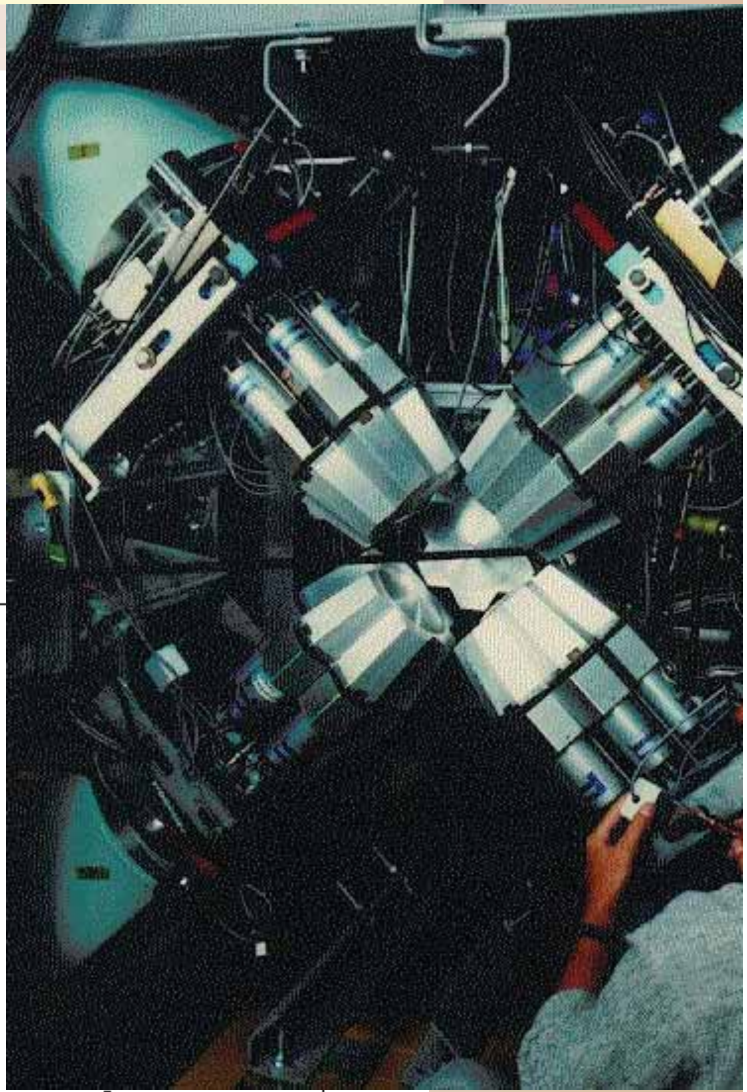
Are we sure that we cannot measure the I_β if we use a very powerful Ge gamma array

THE HIGH RESOLUTION METHOD

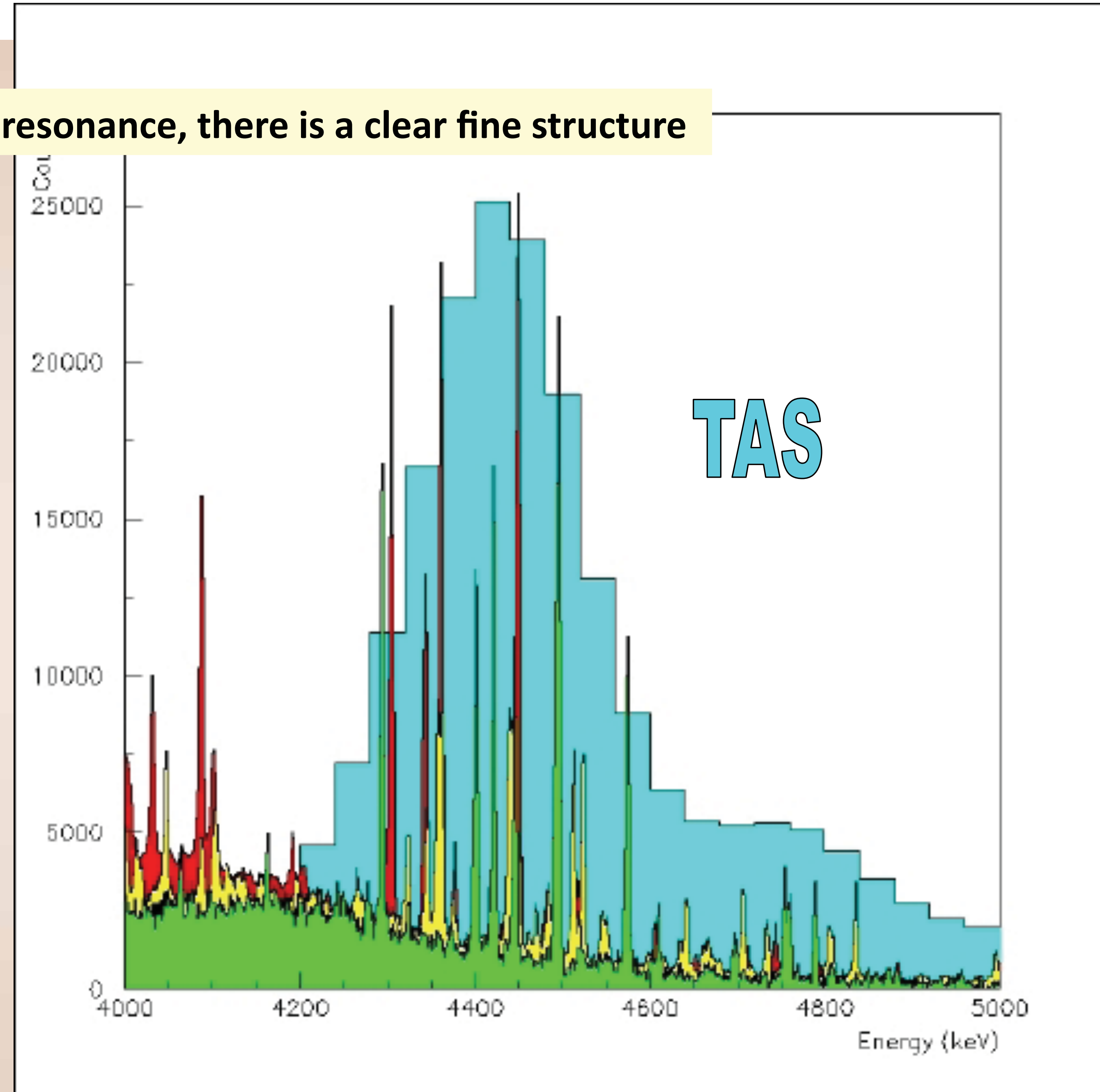
Six EUROBALL CLUSTER detectors
in close geometry



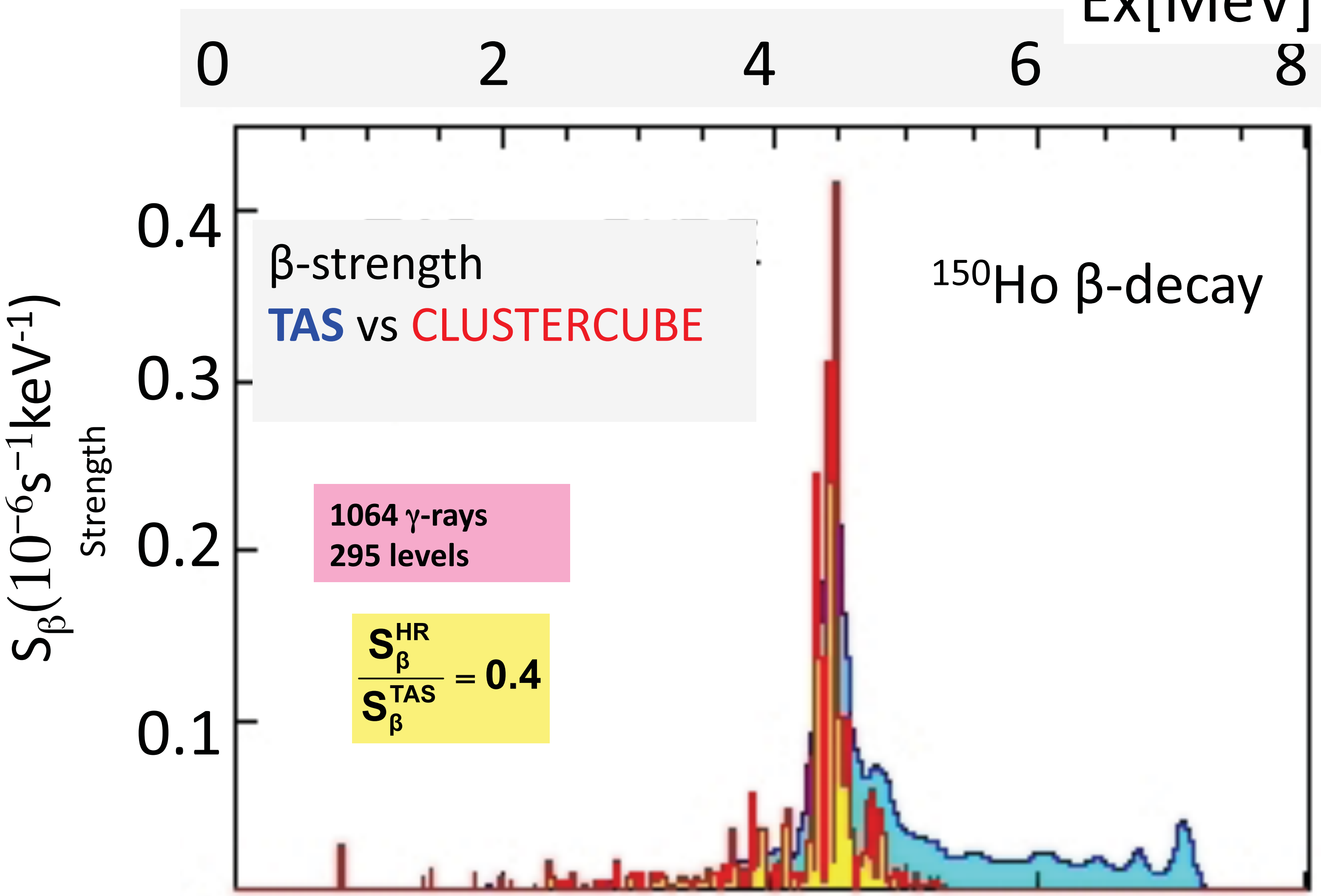




Underneath the resonance, there is a clear fine structure

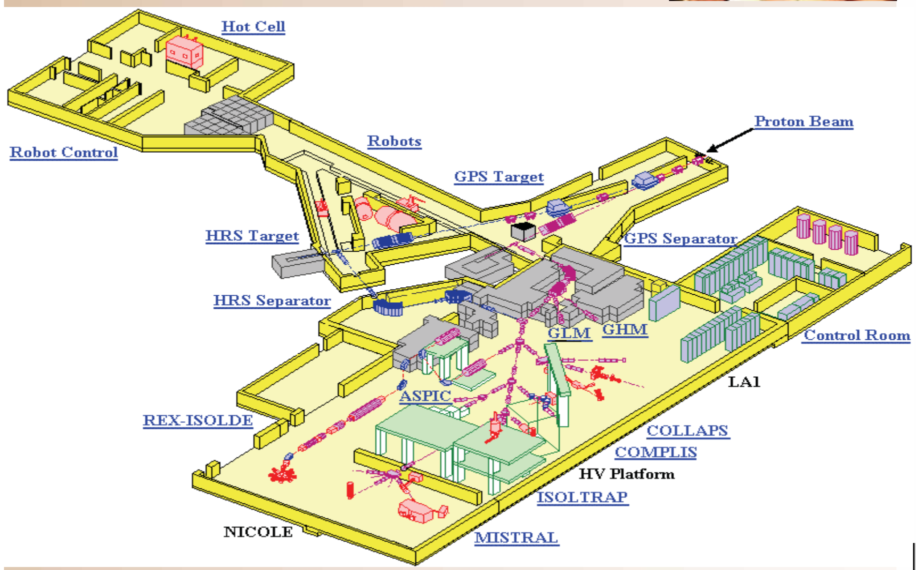


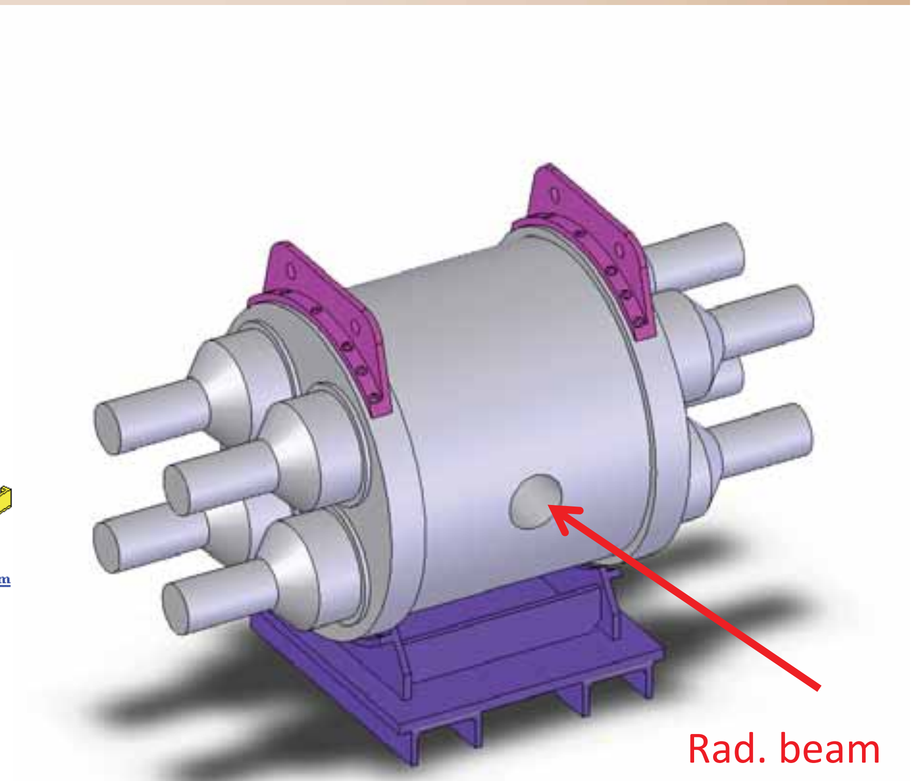
A. Algora, B. Rubio et al PRC 50 (2002)



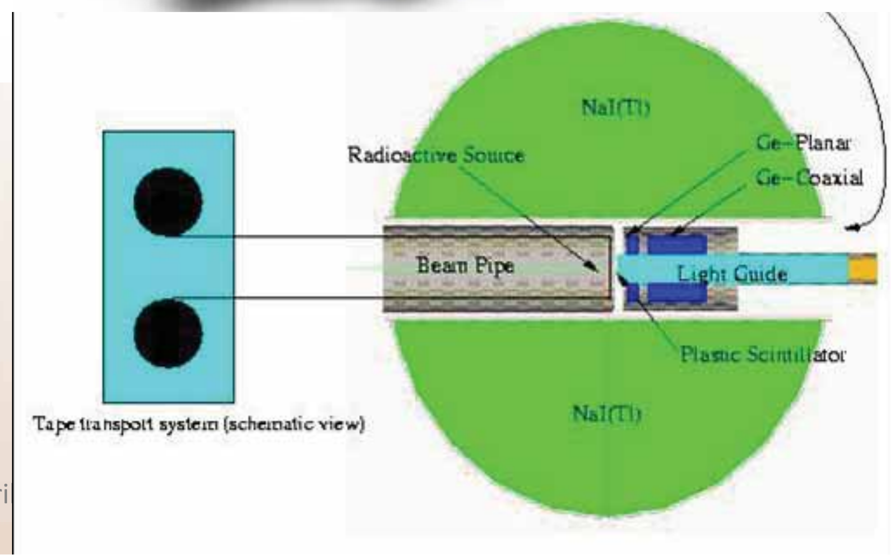
Encouraged by the success of these experiments
and similar experiments carries out by the Warsaw group
(M. Karny, K. Rykaczewski et al)
We decided to construct a new TAS and put it at ISOLDE (CERN),
But this time optimised for short half lives (less than 1 s)

New TAS "Lucrecia"
At ISOLDE at CERN



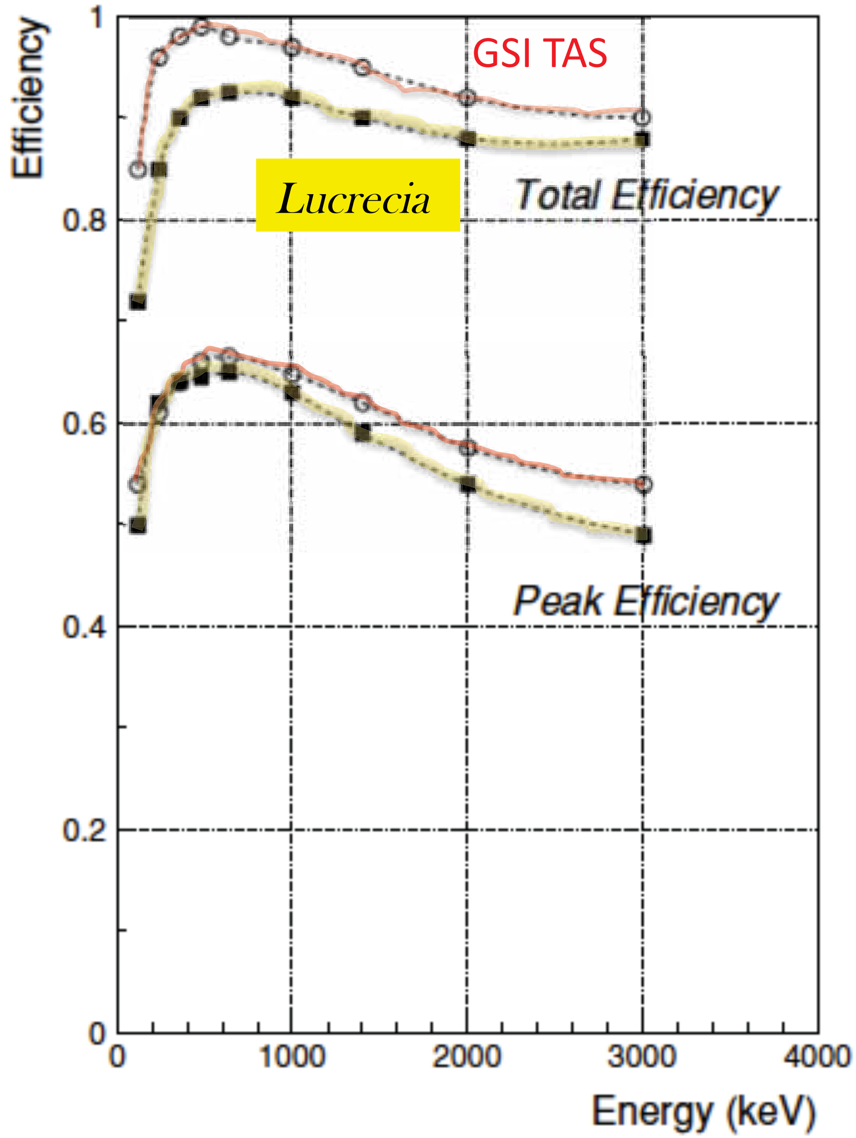


The Lucrecia TAS at Isolde
is a NaI single-crystal Φ38cm x 38cm
(+ ancillary detectors)Ge for X-rays
and plastic for β particles

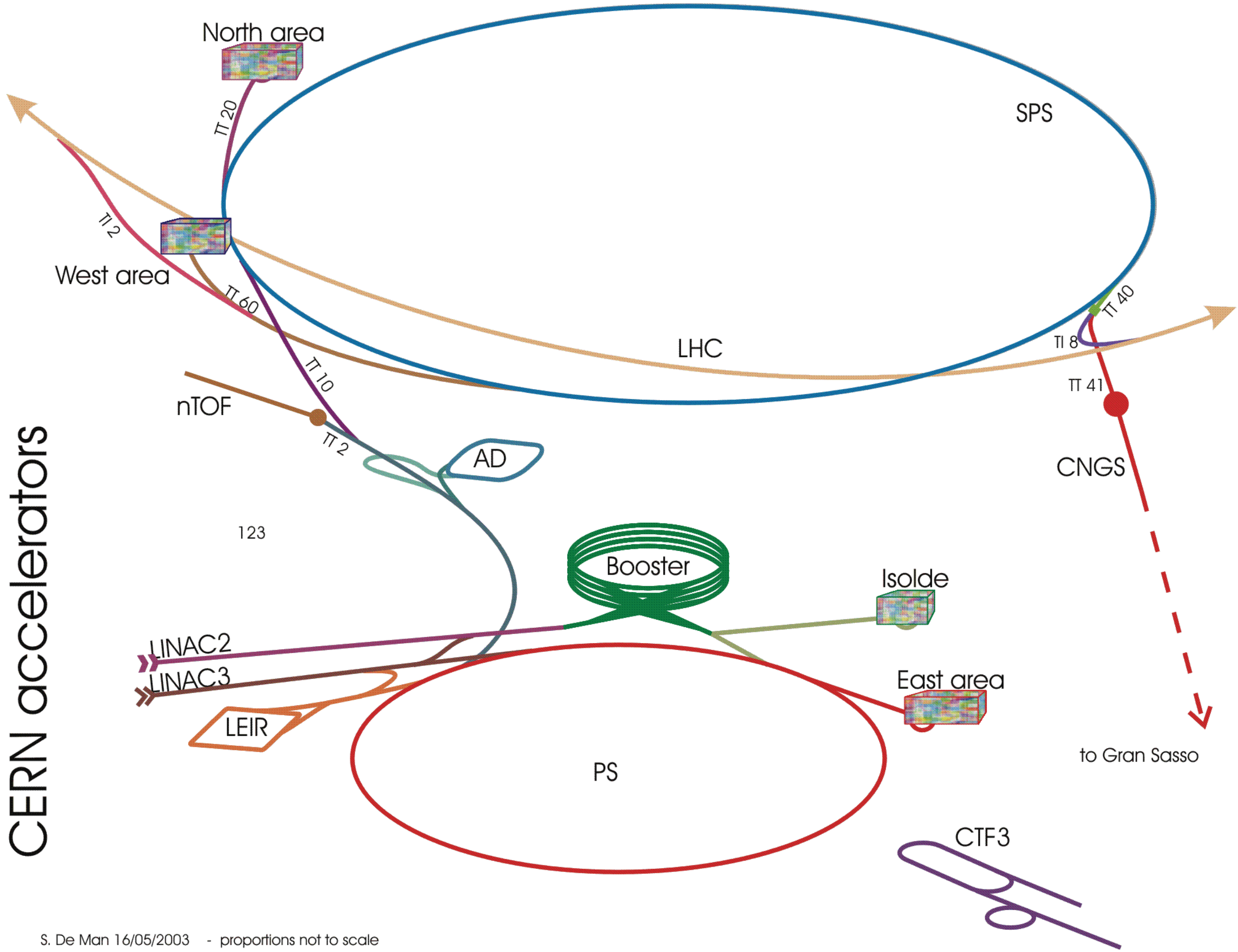



GSI TAS

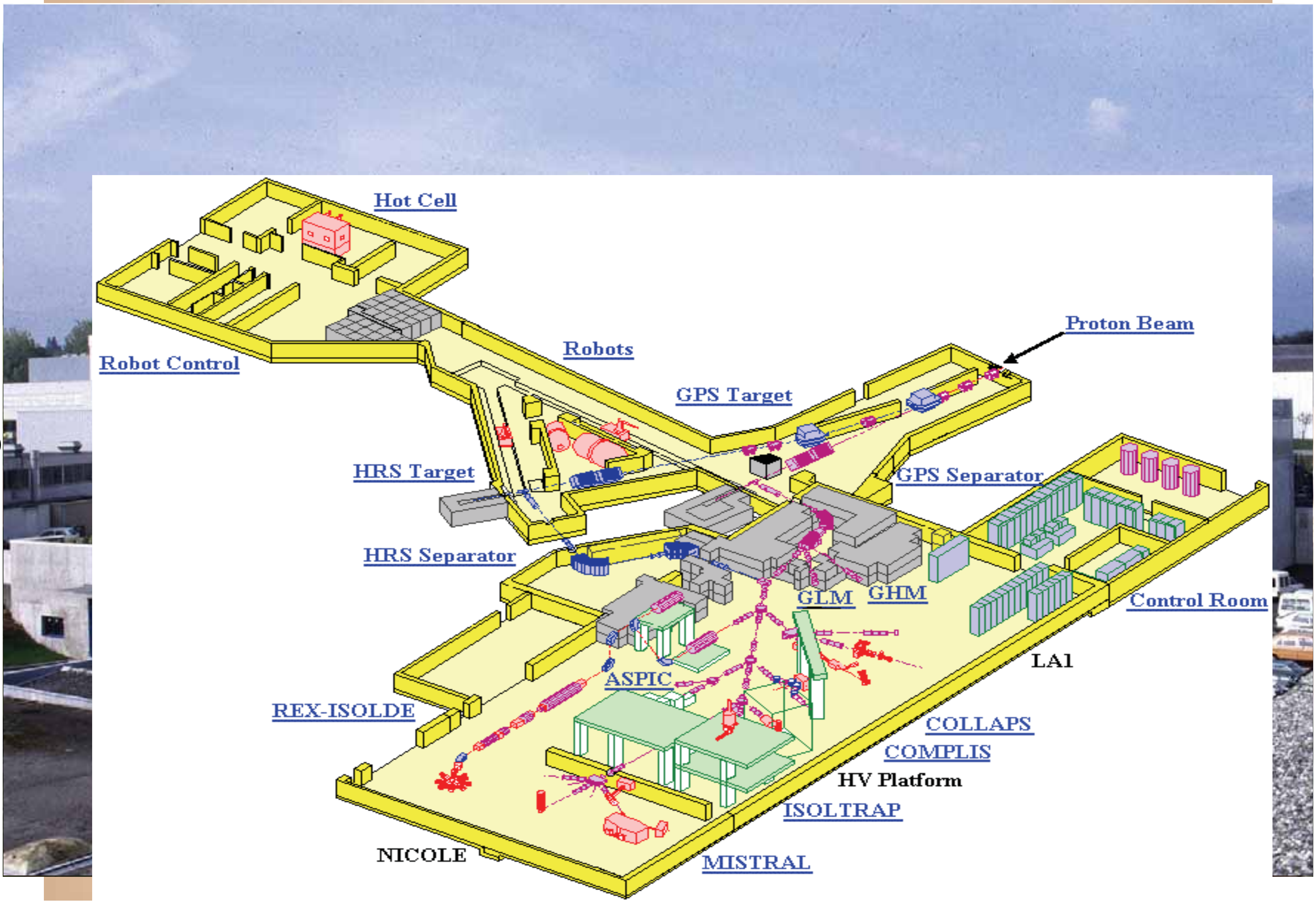

Lucrecia

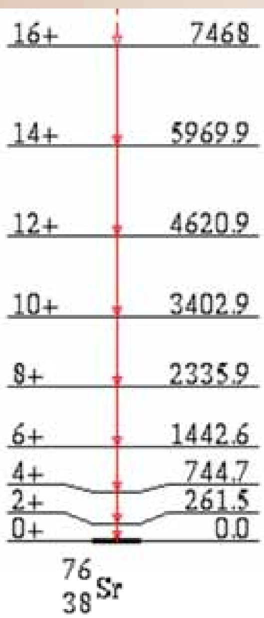

Efficiency
Energy (keV)
GSI TAS
Lucrecia
Total Efficiency
Peak Efficiency
0
0.2
0.4
0.6
0.8
1
0
1000
2000
3000
4000

CERN accelerators

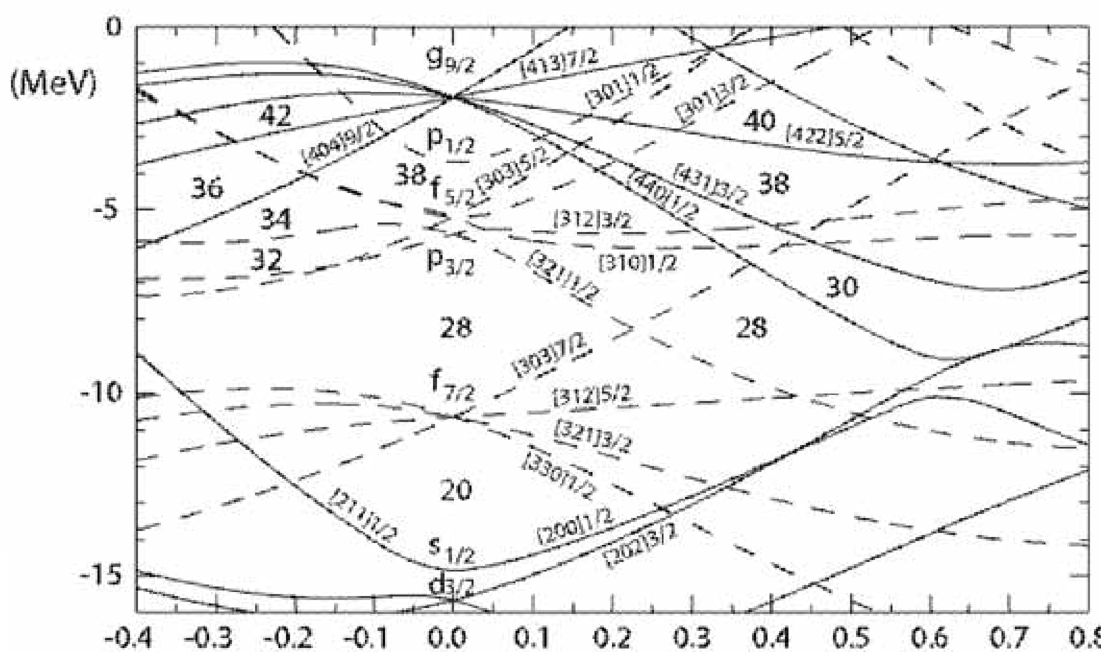


S. De Man 16/05/2003 - proportions not to scale


Hot Cell
Robot Control
Robots
Proton Beam
GPS Target
HRS Target
GPS Separator
HRS Separator
GLM
GHM
Control Room
LA1
ASPIC
REX-ISOLDE
COLLAPS
COMPLIS
HV Platform
ISOLTRAP
NICOLE
MISTRAL

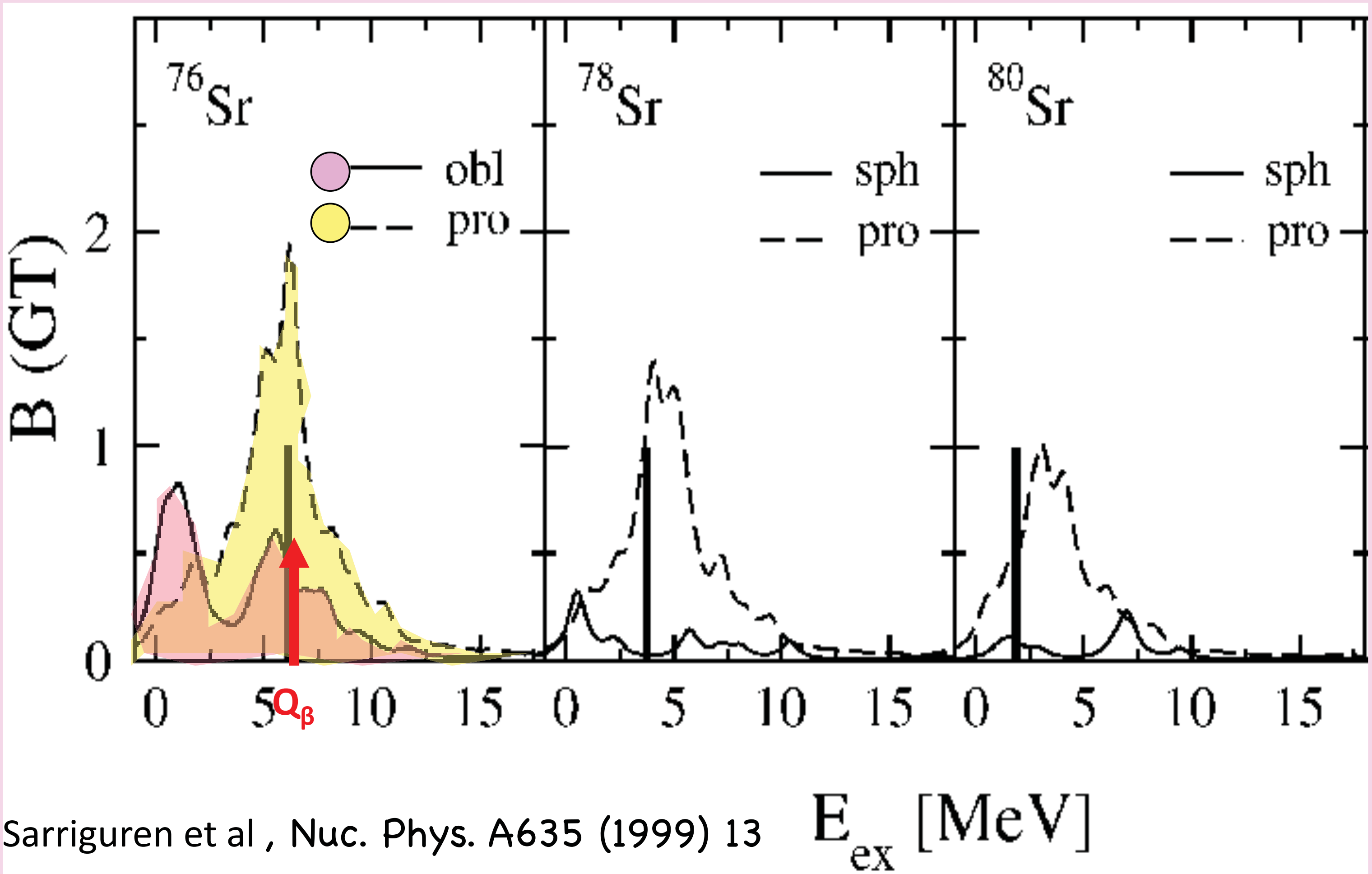


16+ 7468
14+ 5969.9
12+ 4620.9
10+ 3402.9
8+ 2335.9
6+ 1442.6
4+ 744.7
2+ 261.5
0+ 0.0
76 38 Sr



(MeV)
0
-5
-10
-15
-0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
g9/2
p1/2
f5/2
p3/2
f7/2
s1/2
d3/2
42
36
38
34
32
40
38
30
28
28
20
[413]7/2
[301]1/2
[301]3/2
[422]5/2
[404]9/2
[303]5/2
[431]3/2
[440]1/2
[312]3/2
[310]1/2
[321]1/2
[303]7/2
[312]5/2
[321]3/2
[330]1/2
[211]1/2
[200]1/2
[202]3/2

What can we learn from beta decay about the deformation of these nuclei?

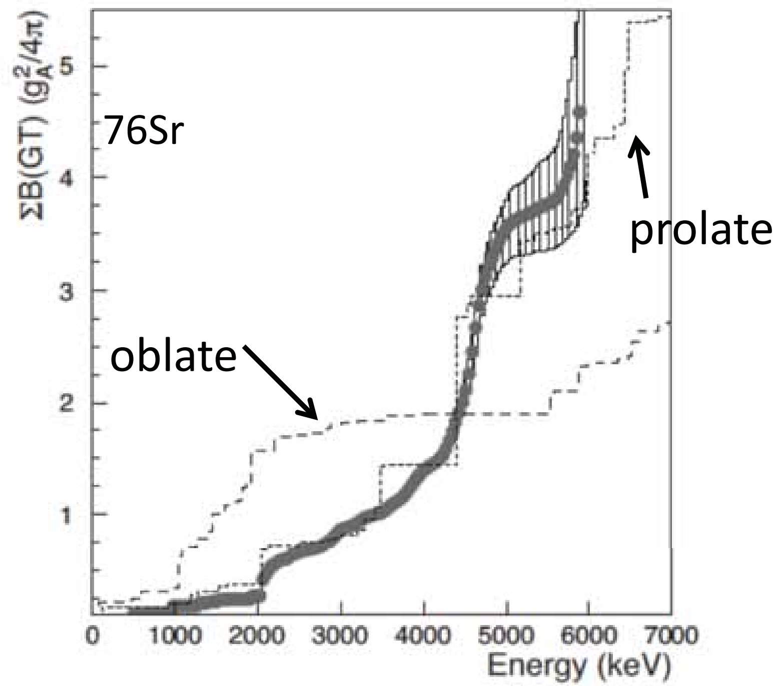


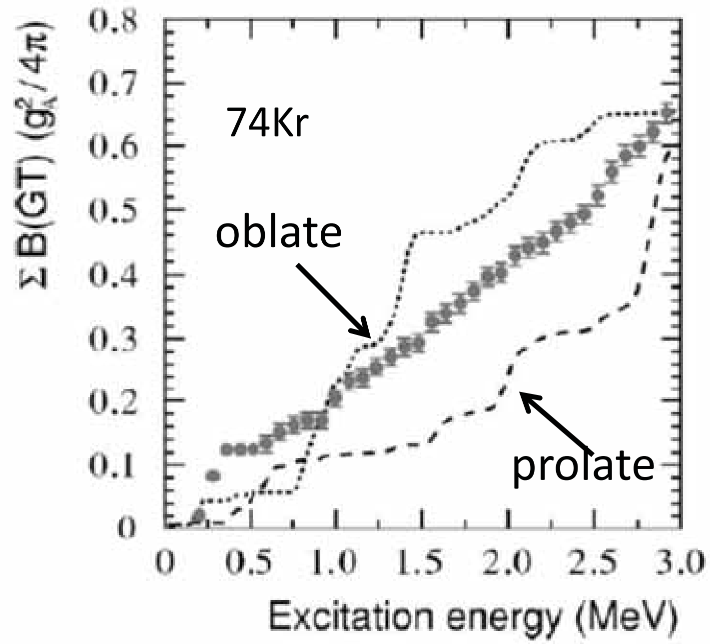
Sarriguren et al , Nuc. Phys. A635 (1999) 13

T)

Clarly prolate

Mixture of prolate and oblate





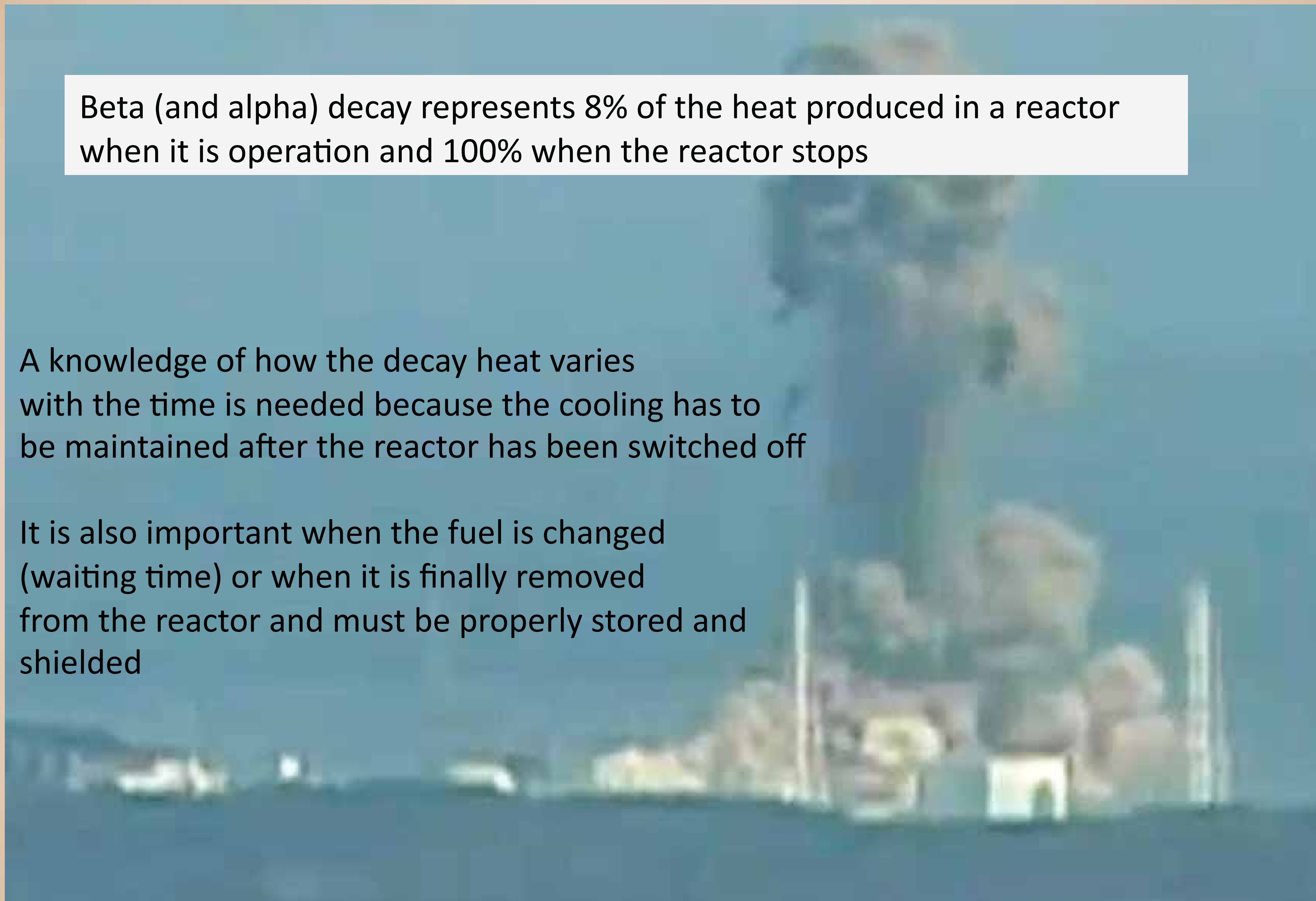
E. Nacher *et al., Phys. Rev. Lett. 92, 232501 (2004)*
Ph.D thesis Valencia

E. Poirier *et al., Phys. Rev. C 69, 034307 (2004)*
Ph. D thesis Starsbourg

Beta (and alpha) decay represents 8% of the heat produced in a reactor when it is operation and 100% when the reactor stops

A knowledge of how the decay heat varies with the time is needed because the cooling has to be maintained after the reactor has been switched off

It is also important when the fuel is changed (waiting time) or when it is finally removed from the reactor and must be properly stored and shielded



Decay heat: definition

$$f(t) = \sum_i (\overline{E_{\gamma,i}} + \overline{E_{\beta,i}} + \overline{E_{\alpha,i}}) \lambda_i N_i(t)$$

$\overline{E_{\gamma,i}}, \overline{E_{\beta,i}}, \overline{E_{\alpha,i}}$ Mean Decay energy of the nucleus i (gamma, beta or alpha)

λ_i Decay constant of the nucleus i

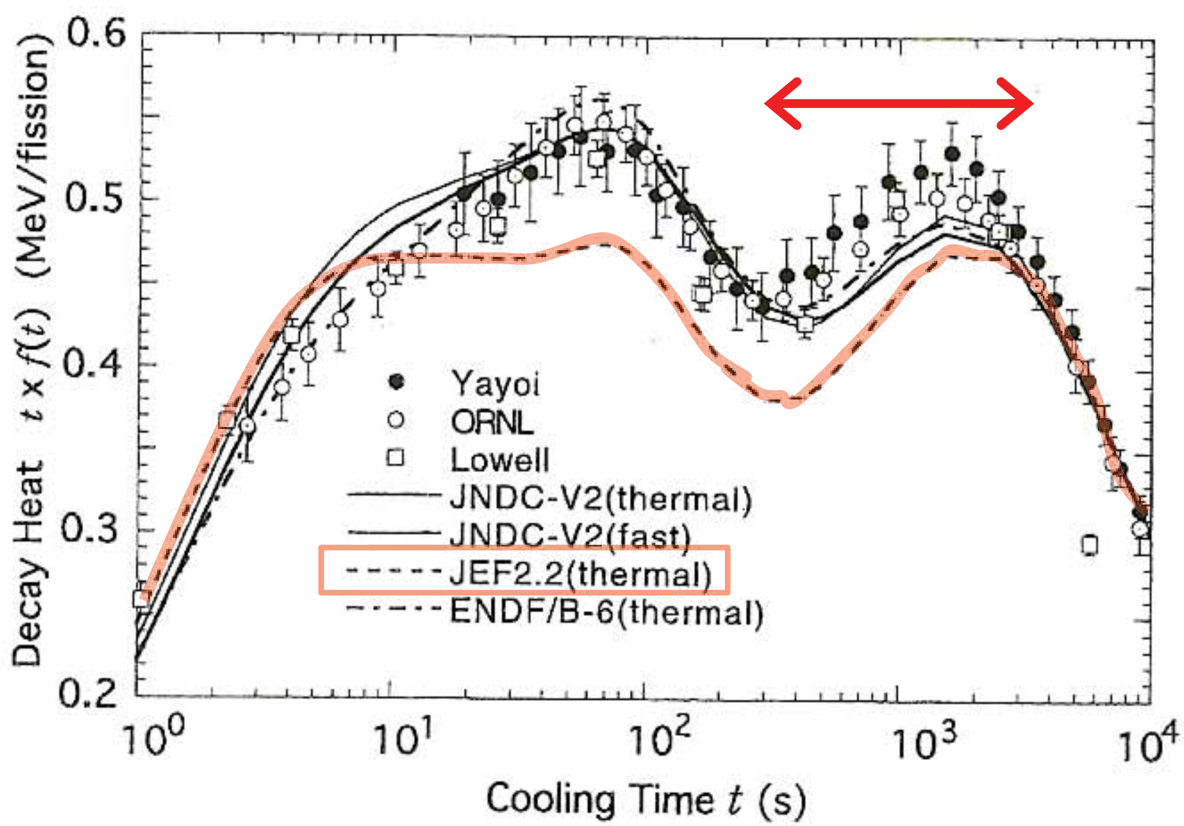
N_i Number of nuclei i at the cooling time t

Requirements for the calculations: large databases that contain all the required information (inventory of nuclides, half-lives, mean γ- and β-energies released in the decay, n-capture cross sections, fission yields, etc, etc …)

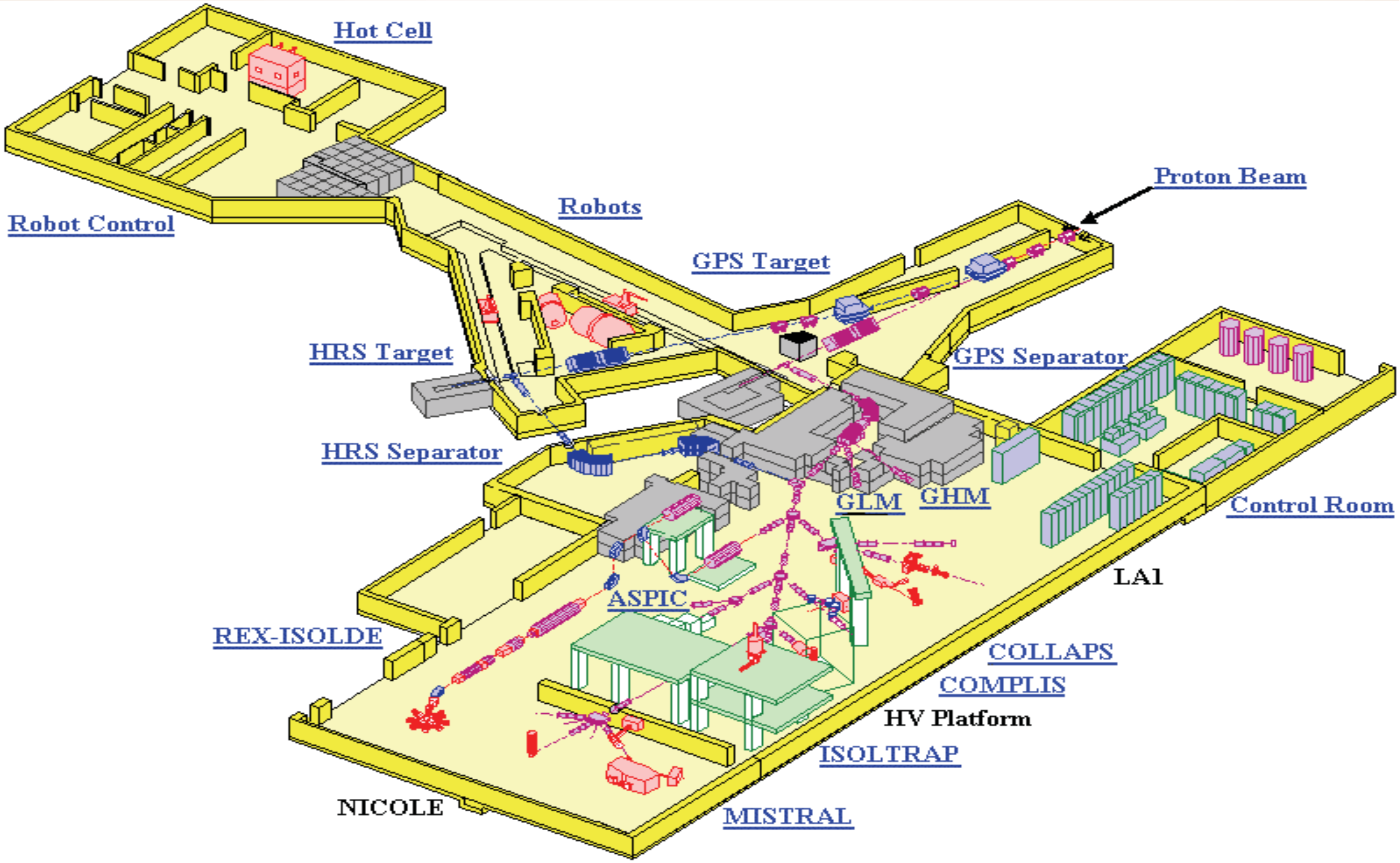
A long standing problem: “The γ-ray discrepancy between decay heat summation calculations and experimental data

^{239}Pu example (γ component)

Yoshida and co-workers (Journ. of Nucl. Sc. and Tech. 36 (1999) 135) and the work of the



Two main difficulties:
a) Refractory elements are difficult to extract in normal isol facilities



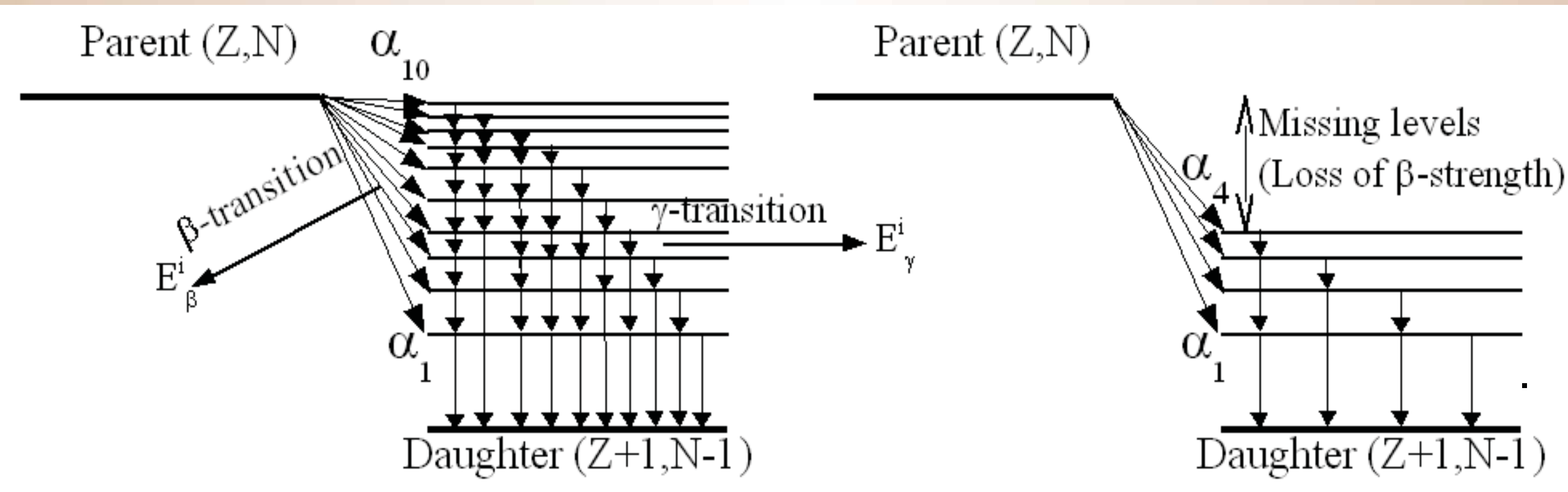
Second difficultie:
b) Pandemonium effect affects decay energy calculations

$$\overline{E}_\beta = \sum_i I_\beta(E_i)\langle E_{\beta,i}\rangle$$

$$\overline{E}_\gamma = \sum_i I_\beta(E_i)E_i$$

$\overline{E}_\beta$ overestimation

$\overline{E}_\gamma$ underestimation



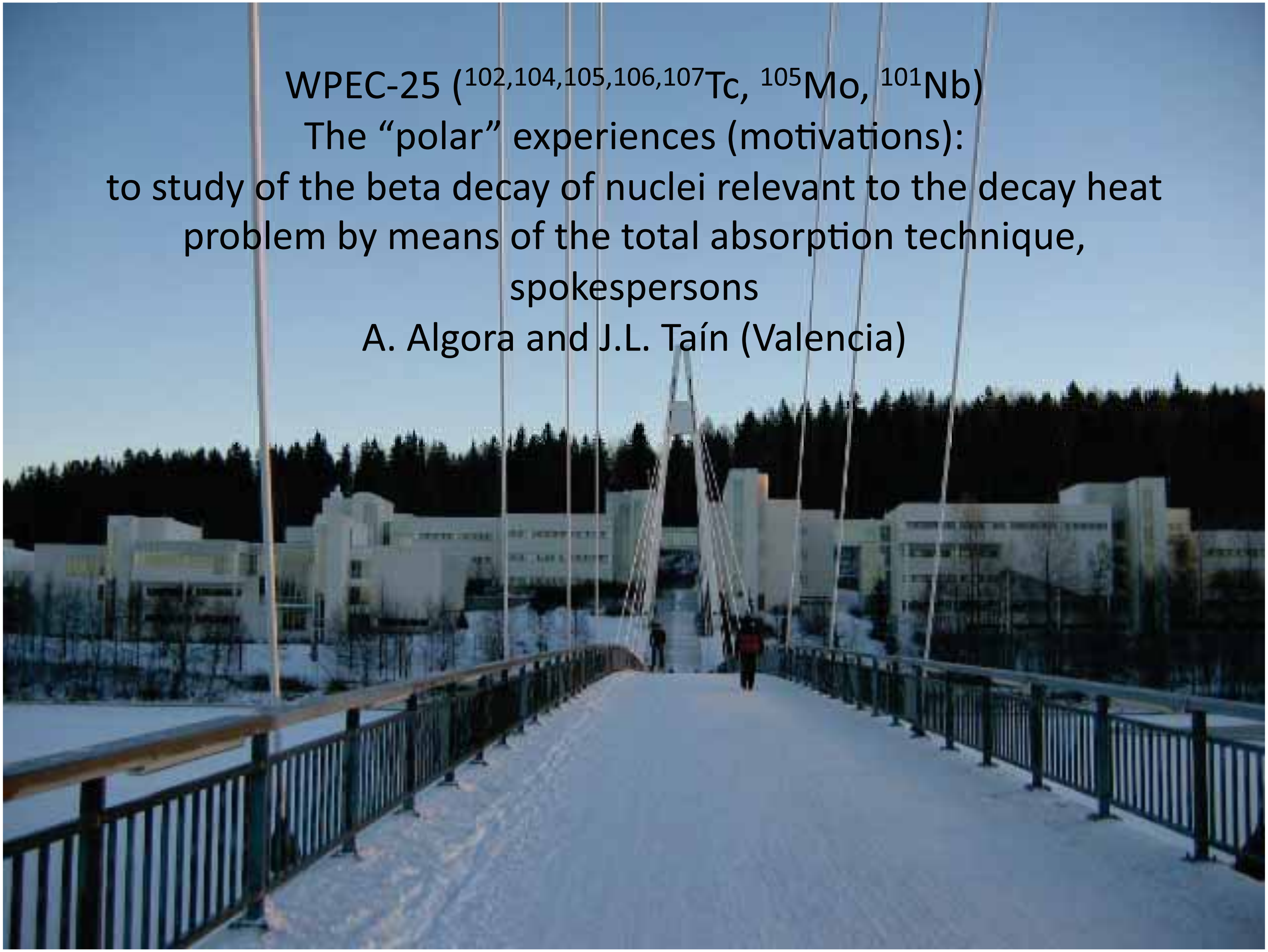
WPEC-25 (^{102,104,105,106,107}Tc, ^{105}Mo, ^{101}Nb)

The “polar” experiences (motivations):

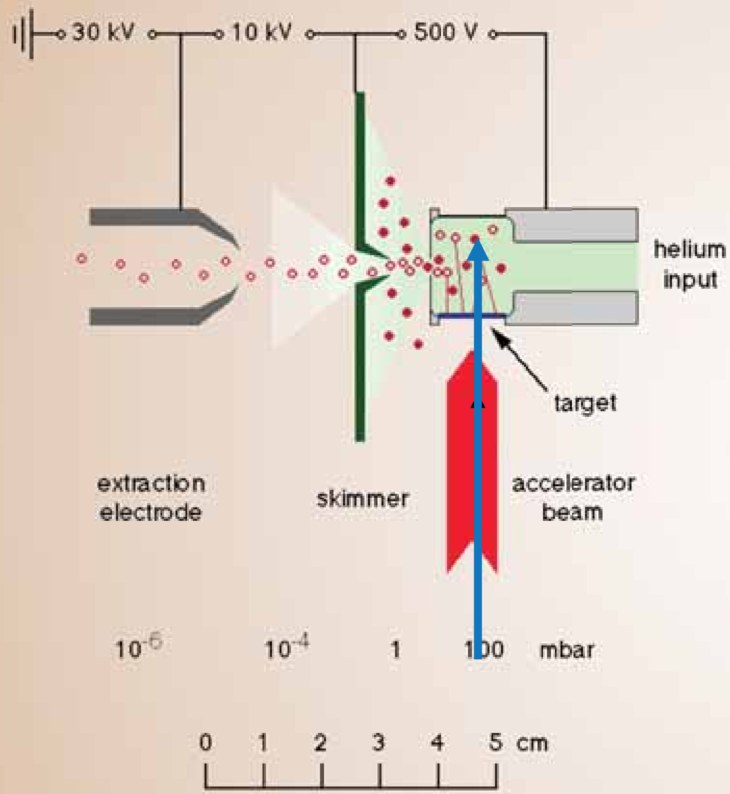
to study of the beta decay of nuclei relevant to the decay heat problem by means of the total absorption technique,

spokespersons

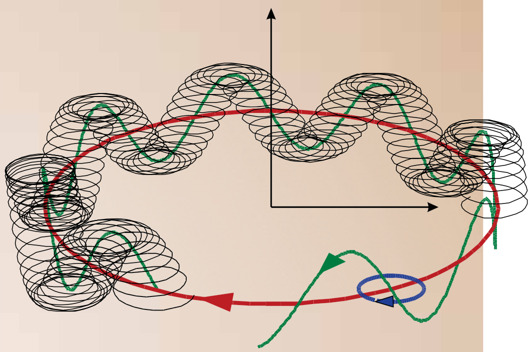
A. Algora and J.L. Taín (Valencia)

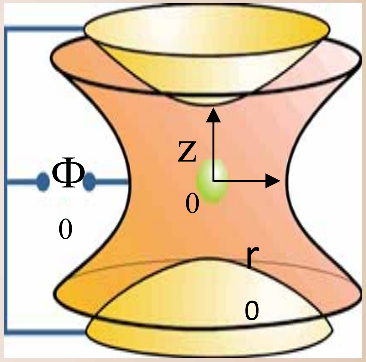


The ion gas guide technique mass separation and isobar separation



The process is fast enough for the ions to survive as single charged ions. The system is chemically insensitive and very fast (sub-ms).

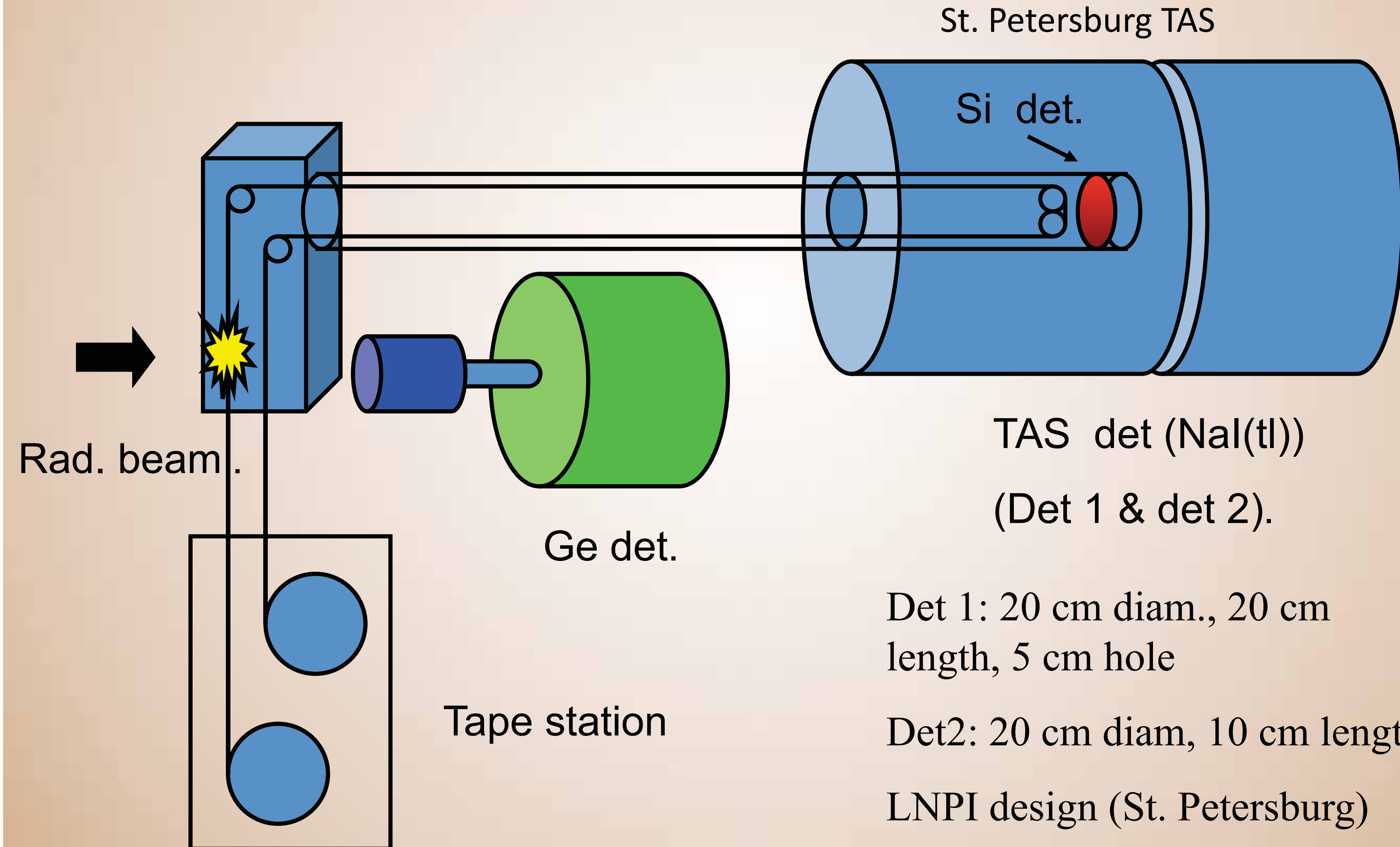




Use of the JYFLTRAP as a high resolution separator (first time that this kind of setup was used combined with a TAS)

50 MeV p on 15 mg/cm^2 nat U target

Experimental setup at Jyväskylä

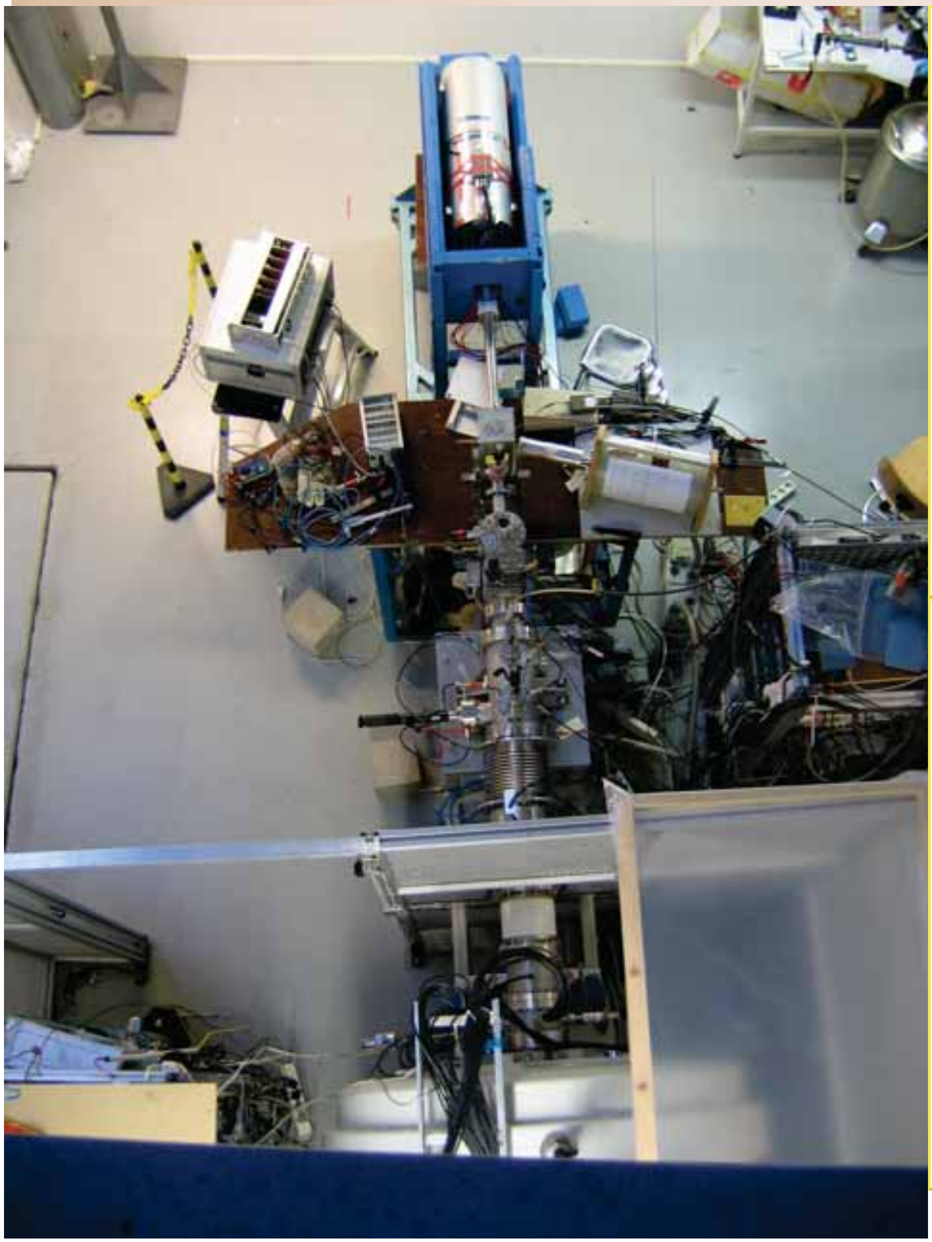


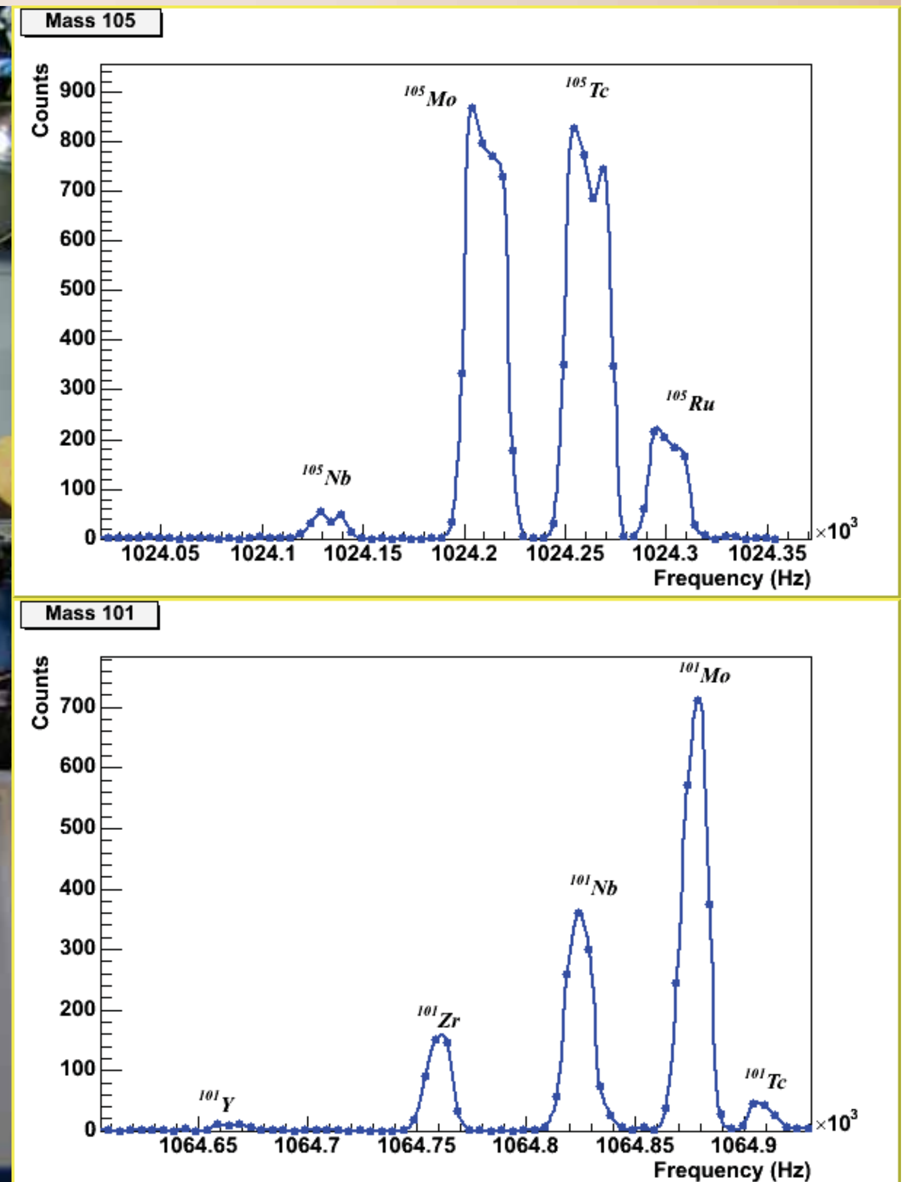
Det 1: 20 cm diam., 20 cm length, 5 cm hole

Det2: 20 cm diam, 10 cm length

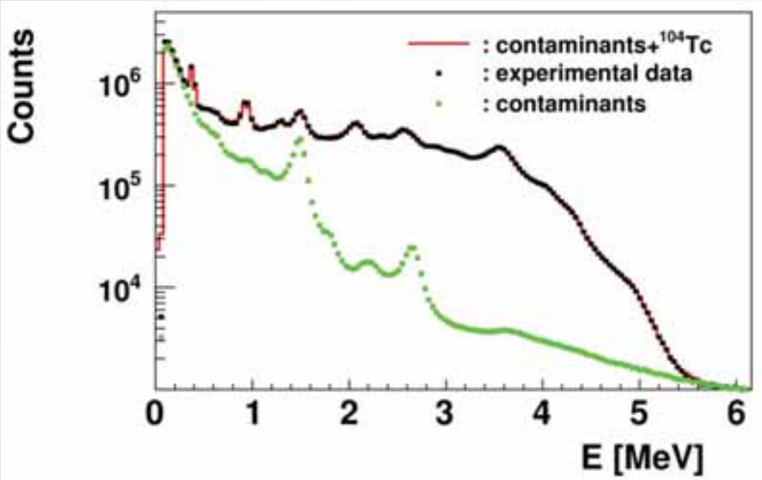
LNPI design (St. Petersburg)

New feature: trap-assisted spectroscopy





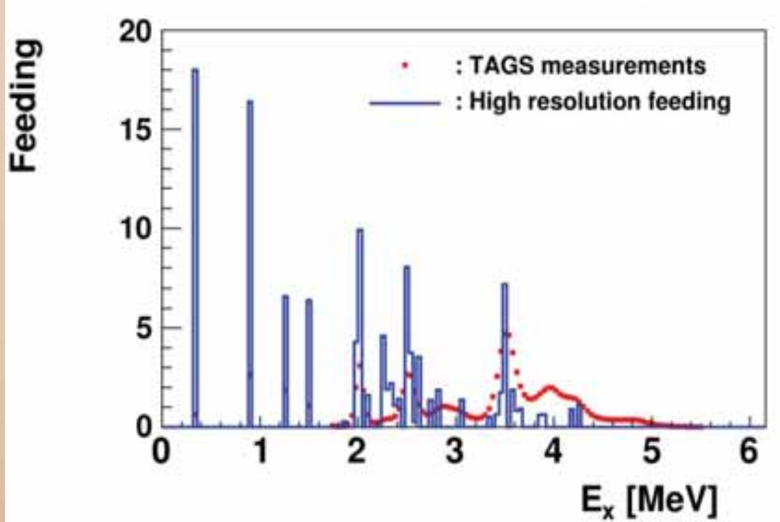
Results of the analysis for ^{104}Tc

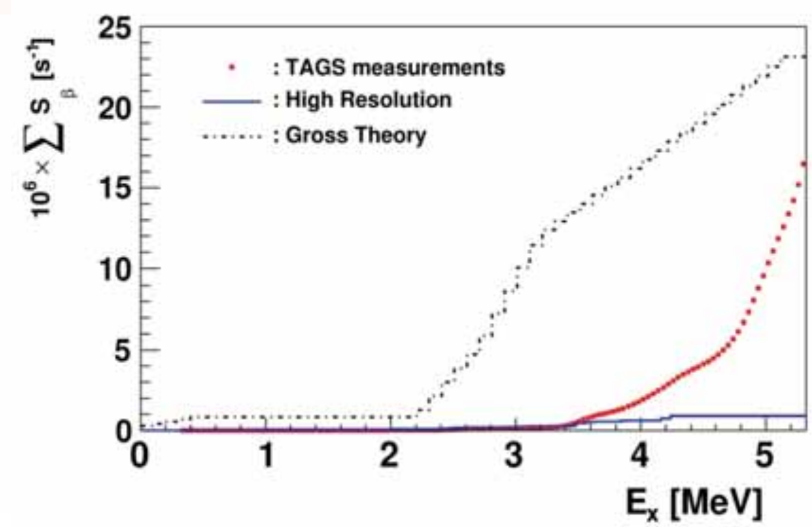


$T_{1/2}$ = 1098(18) s; Q_{β}= 5516(6) keV

E_{β}(TAGS) = 931 (10) keV
E_{β}(JEFF-3.1) = 1595 (75) keV } ΔE_{β} = -664 keV

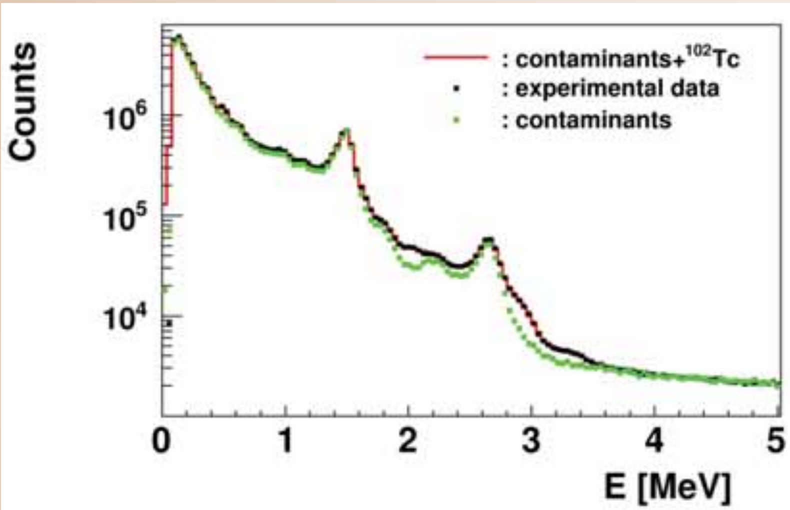
E_{γ}(TAGS) = 3229 (24) keV
E_{γ}(JEFF-3.1) = 1890 (31) keV } ΔE_{γ} = 1339 keV





D. Jordan, PhD Thesis, Valencia, 2010

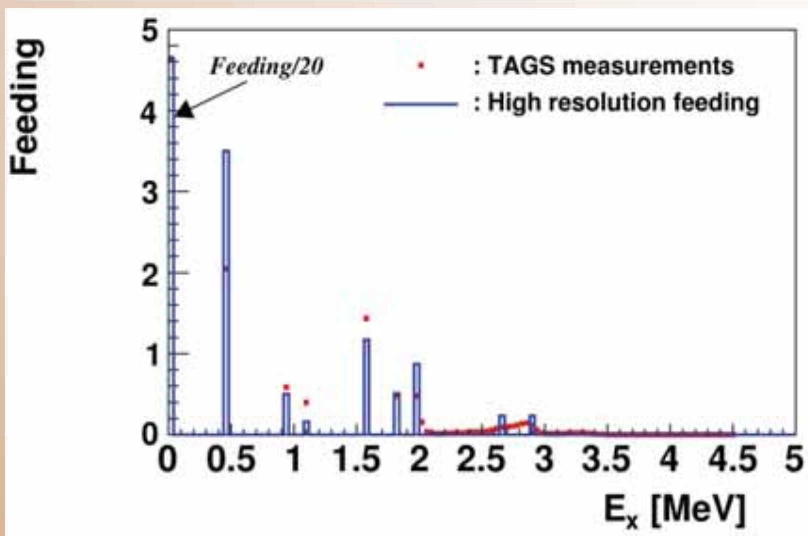
Results of the analysis for ^{102}Tc

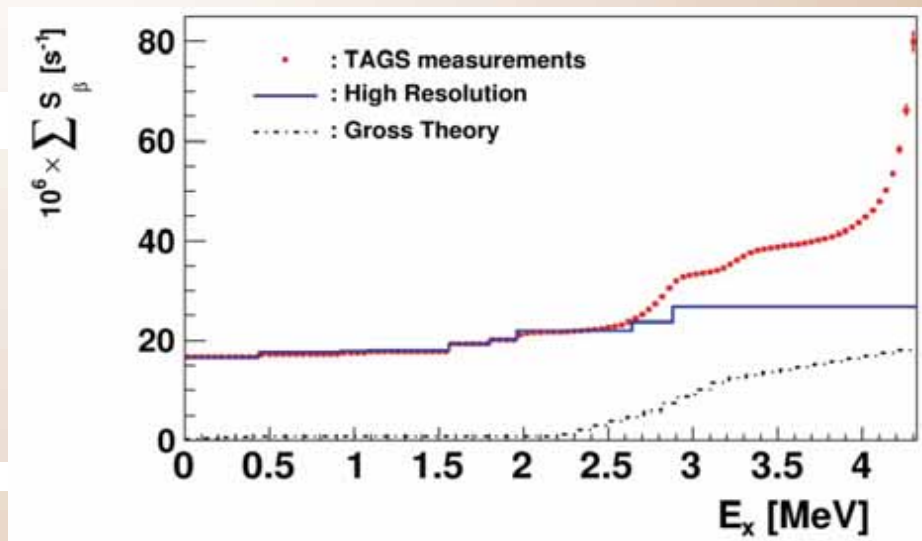


$T_{1/2}$ = 5.28(15) s; Q_β= 4532(9) keV

E_β(TAGS) = 1935 (11) keV
E_β(JEFF-3.1) = 1945 (16) keV } ΔE_β = -10 keV

E_γ(TAGS) = 106 (23) keV
E_γ(JEFF-3.1) = 81 (5) keV } ΔE_γ = 25 keV

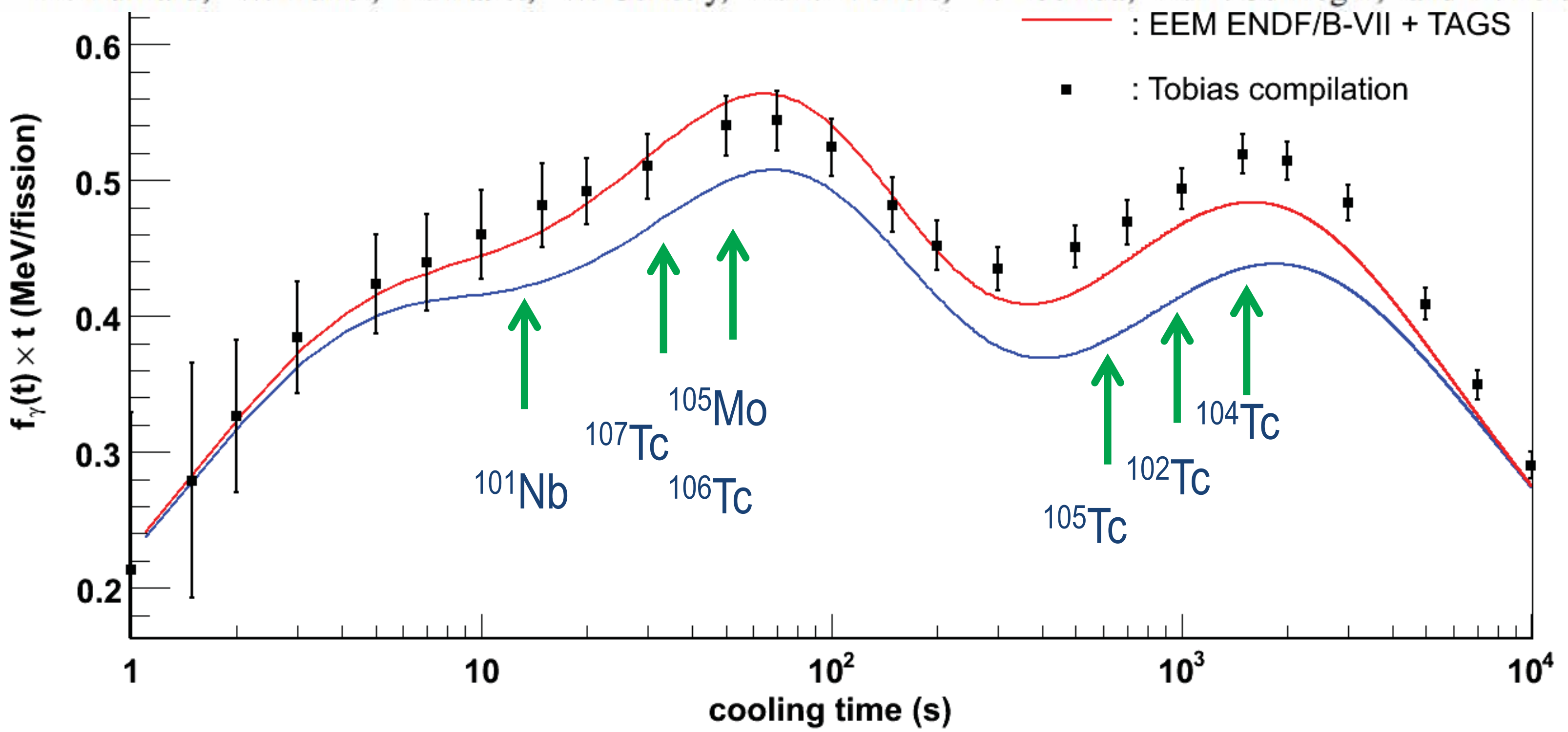




Selected for a Viewpoint in *Physics*
PRL **105,** 202501 (2010) PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010

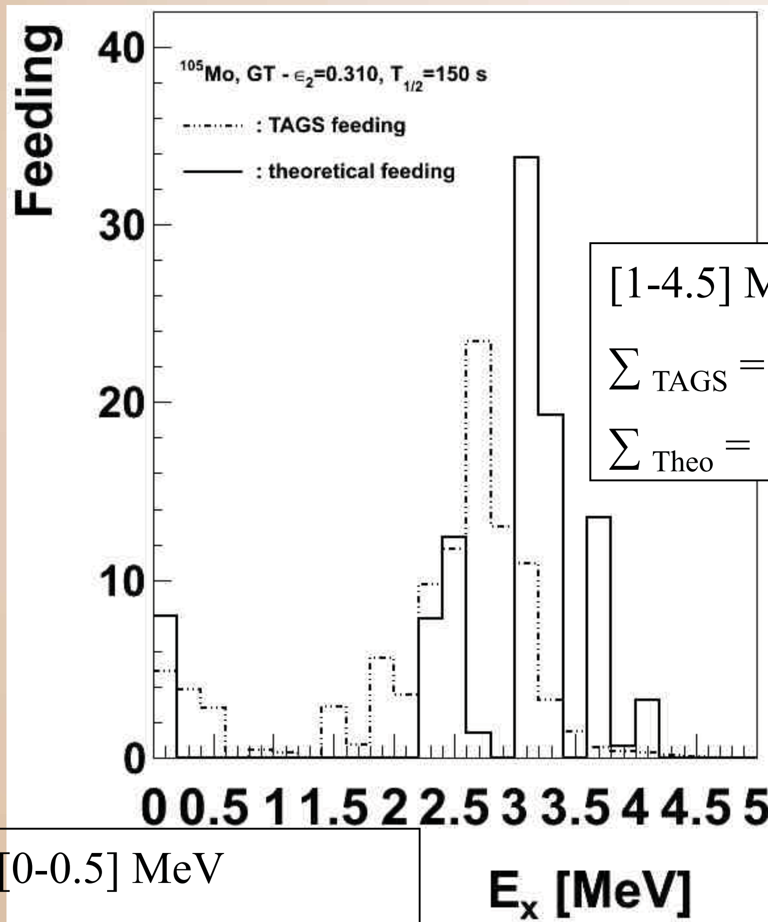
Reactor Decay Heat in ^{239}Pu: Solving the γ Discrepancy in the 4–3000-s Cooling Period

A. Algora,[1,2,*] D. Jordan,[1] J. L. Taín,[1] B. Rubio,[1] J. Agramunt,[1] A. B. Perez-Cerdan,[1] F. Molina,[1] L. Caballero,[1] E. Nácher,[1] A. Krasznahorkay,[2] M. D. Hunyadi,[2] J. Gulyás,[2] A. Vitéz,[2] M. Csatlós,[2] L. Csige,[2] J. Äysto,[3] H. Penttilä,[3] I. D. Moore,[3] T. Eronen,[3] A. Jokinen,[3] A. Nieminen,[3] J. Hakala,[3] P. Karvonen,[3] A. Kankainen,[3] A. Saastamoinen,[3] J. Rissanen,[3] T. Kessler,[3] C. Weber,[3] J. Ronkainen,[3] S. Rahaman,[3] V. Elomaa,[3] S. Rinta-Antila,[3] U. Hager,[3] T. Sonoda,[3] K. Burkard,[4] W. Hüller,[4] L. Batist,[5] W. Gelletly,[6] A. L. Nichols,[6] T. Yoshida,[7] A. A. Sonzogni,[8] and K. Peräjärvi[9]



Courtesy A. Sonzogni

Test of nuclear models:
Preliminary QRPA calculations (K.L. Kratz, priv. Com)
$T_{1/2}(exp) = 35.6$ s



[1-4.5] MeV

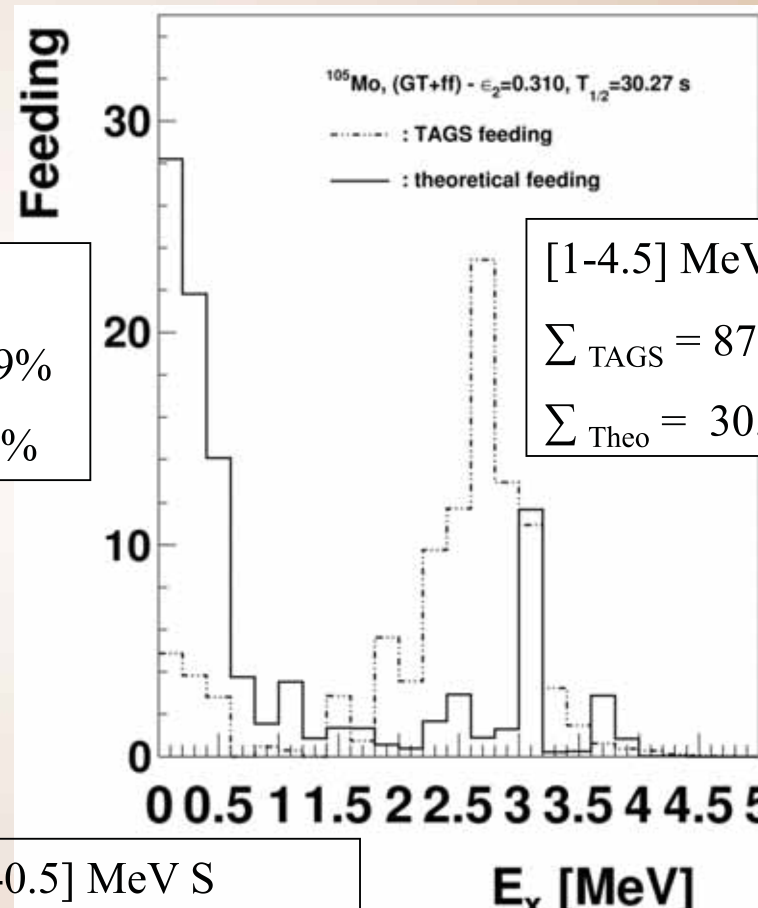
$\sum_{TAGS} = 87.99\%$

$\sum_{Theo} = 92.05\%$

[0-0.5] MeV

$\sum_{TAGS} = 11.51\%$

$\sum_{Theo} = 7.94\%$



[1-4.5] MeV

$\sum_{TAGS} = 87.99\ \%$

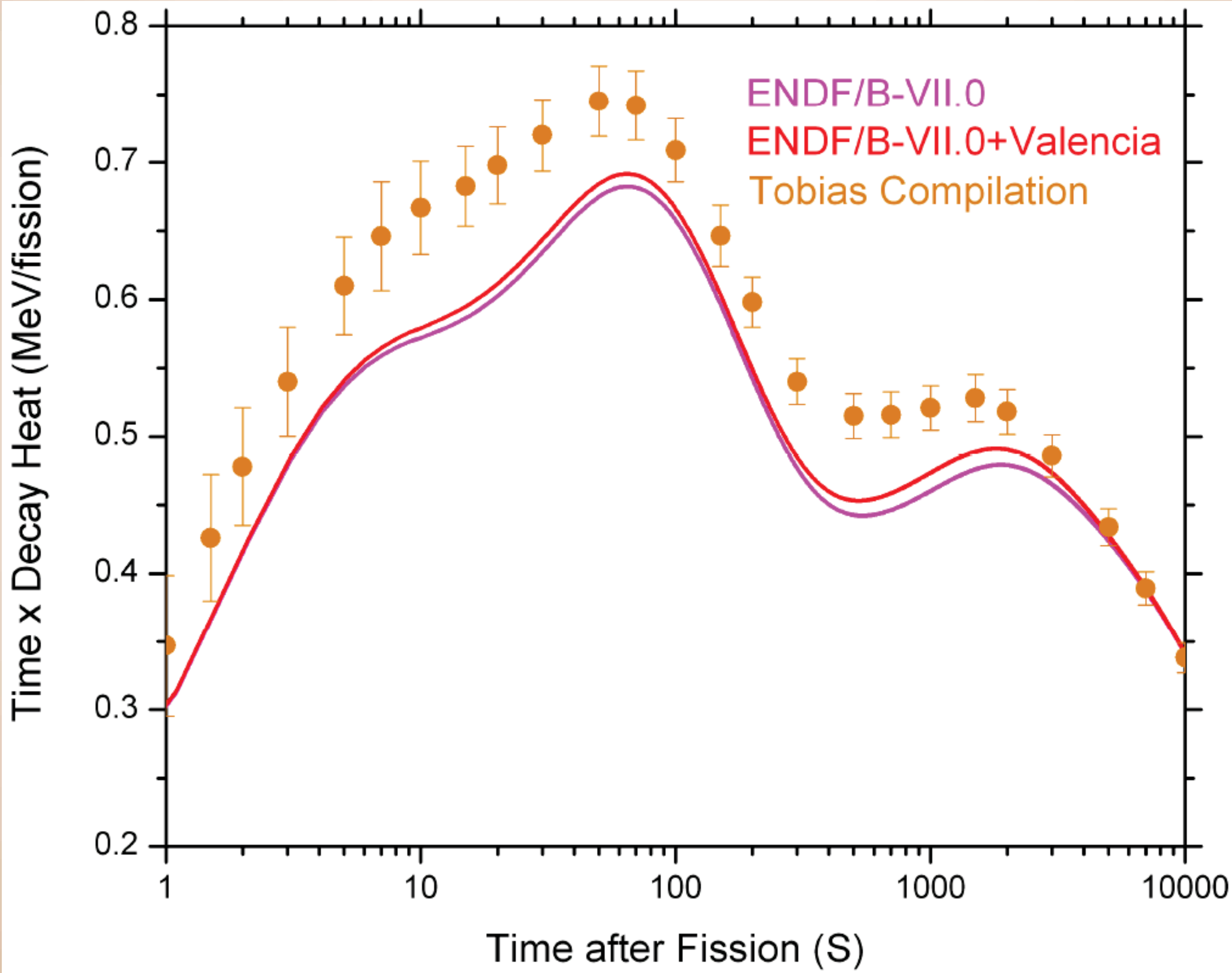
$\sum_{Theo} = 30.62\%$

[0-0.5] MeV S

$\sum_{TAGS} = 11.51\%$

$\sum_{Theo} = 67.84\ \%$

Impact of the results for ^{235}U



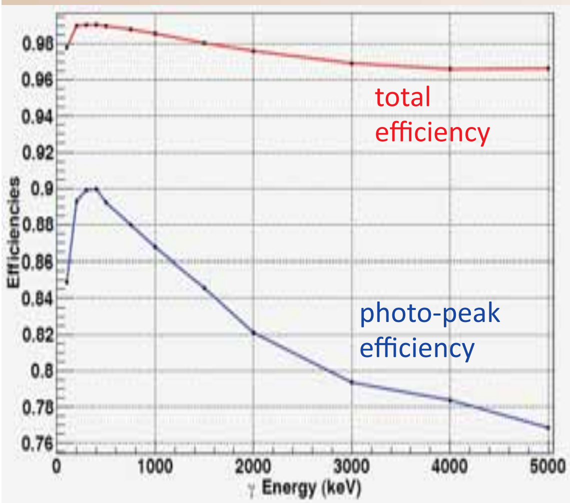
- TAS measurements can play an important role in decay heat calculations.
- Our results show that approximately two thirds of the discrepancy is solved in the range 300-3000 s for ^{239}Pu, and this is mainly related to the impact of the decay of $^{104,105}Tc$.
- From the available information (databases) it is clear that there is still a large amount of work to be done (^{235}U/^{239}Pu, ^{232}Th/^{233}U cycle). It requires close collaboration with the experts of the field in order to determine priorities.

This work has stimulated activities at HRIBF and ANL

ARRA Project: **Decay Studies of Fission Products w/ a new Modular Total Absorption Spectrometer (MTAS)**

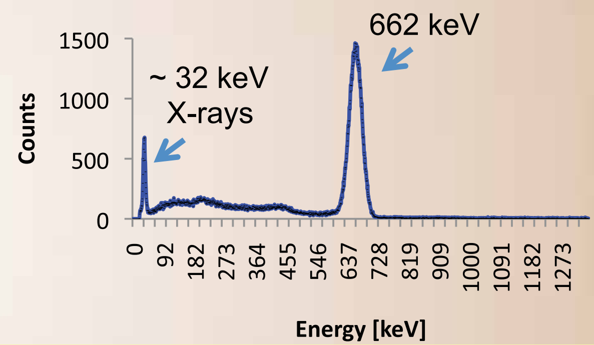
PI's : K. P. Rykaczewski (ORNL) and R.K. Grzywacz (UTK/ORNL)

A **Modular Total Absorption Spectrometer (MTAS**) has been constructed from 19 NaI(Tl) scintillator segments. MTAS is designed to perform decay studies with pure beams of neutron-rich nuclei produced in the ^{238}U fission at HRIBF. The total absorption gamma spectra measured with MTAS will be used to derive a true beta-feeding pattern and resulting beta strength function. The studies are important for the verification and development of **the microscopic description of neutron-rich matter** will be performed as well **as applied studies of decay heat released by radioactive nuclei produced in nuclear fuels at power reactors.**



MTAS has superior g-efficiency according to GEANT4 simulations performed by B. C. Rasco (LSU)

MTAS at the HRIBF, January 2011



g-energy spectrum of ^{137}Cs activity measured with a single MTAS module.
The energy resolution, fwhm(662 keV) ~ 7%, was found to be better than 8% requested in the detector specifications.

Status: the MTAS has been manufactured at the SGC (Hiram, OH) and delivered to the HRIBF. The tests done using digital electronics show the energy resolution superior to requested specs. Two PhDs were hired full time, one PhD part time.

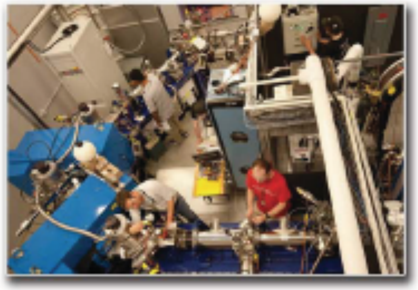
Funding: \$ 698 K capital + \$ 882 K operations (includes \$ 815 K salaries) = \$ 1580 K

Funds committed/spent : \$ 658 K capital and \$ 512 K operations = \$ 1270 K

Workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics"

April 14-16, 2011 at

Argonne NATIONAL LABORATORY



A workshop on "Decay Spectroscopy at CARIBU: Advanced Fuel Cycle Applications, Nuclear Structure and Astrophysics" will be held at Argonne National Laboratory on April 14-16, 2011.

The aim of the workshop is to discuss opportunities for decay studies at the Californium Rare Isotope Breeder Upgrade (CARIBU) of the ATLAS facility with emphasis on advanced fuel cycle (AFC) applications, nuclear structure and astrophysics research. The workshop will consist of review and contributed talks. Presentations by members of the local groups, outlining the status of relevant in-house projects and available equipment, will also be organized. Time will also be set aside to discuss and develop working collaborations for future decay studies at CARIBU.

Topics of interest include:

- Decay data of relevance to AFC applications with emphasis on reactor decay heat
- Discrete high-resolution gamma-ray spectroscopy following radioactive decay and related topics
- Calorimetric studies of neutron-rich fission fragments using Total Absorption Gamma-ray Spectrometry (TAGS) technique
- Beta-delayed neutron emissions and related topics
- Decay data needs for nuclear astrophysics

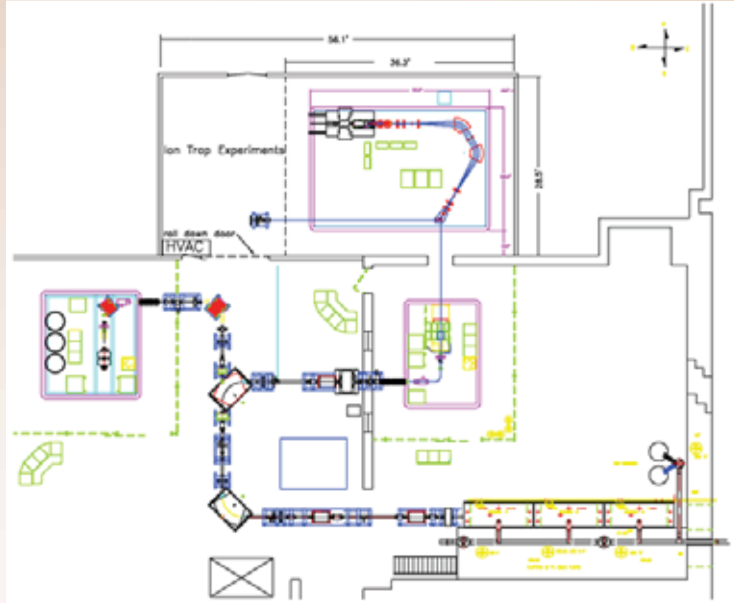
Workshop Organizers

Dr. Michael Carpenter, Argonne National Laboratory
Prof. Partha Chowdhury, University of Massachusetts Lowell
Dr. Jason Clark, Argonne National Laboratory
Dr. Filip Kondev, Argonne National Laboratory
Dr. Kim Lister, Argonne National Laboratory
Dr. Dariusz Seweryniak, Argonne National Laboratory

Please visit the Workshop web site for additional information about registration, program, lodging and transportation to Argonne.

http://www.ne.anl.gov/capabilities/nd/AFC-Apr11/

UChicago ▸ Argonne



Caribu layout

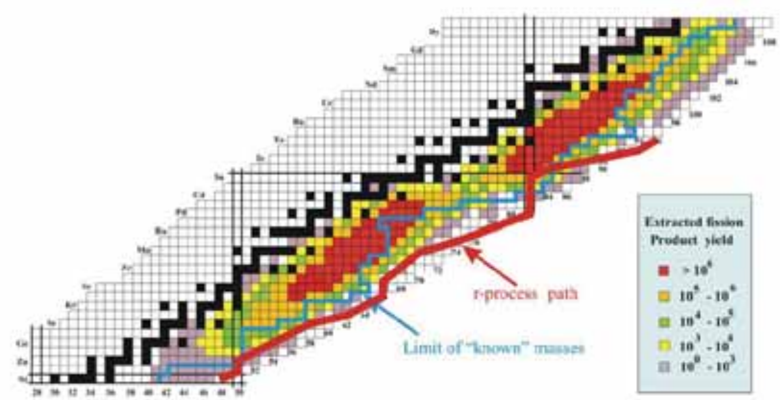
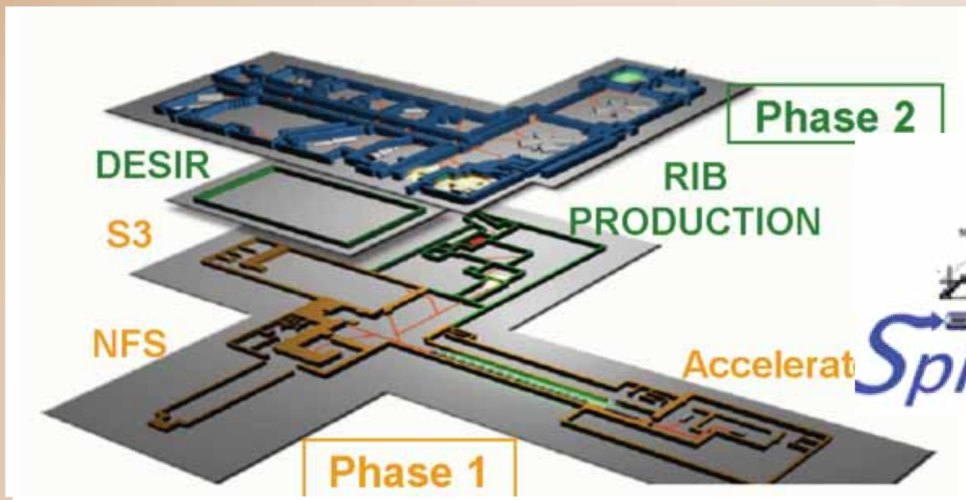


Figure 4. The r-process path together with the yield expected from an ion source system based on a 1 Ci californium fission source and the limit of known masses.

Future

Three LoI presented in Feb 2011
(Tain et al, Algora et al, Rubio et al)



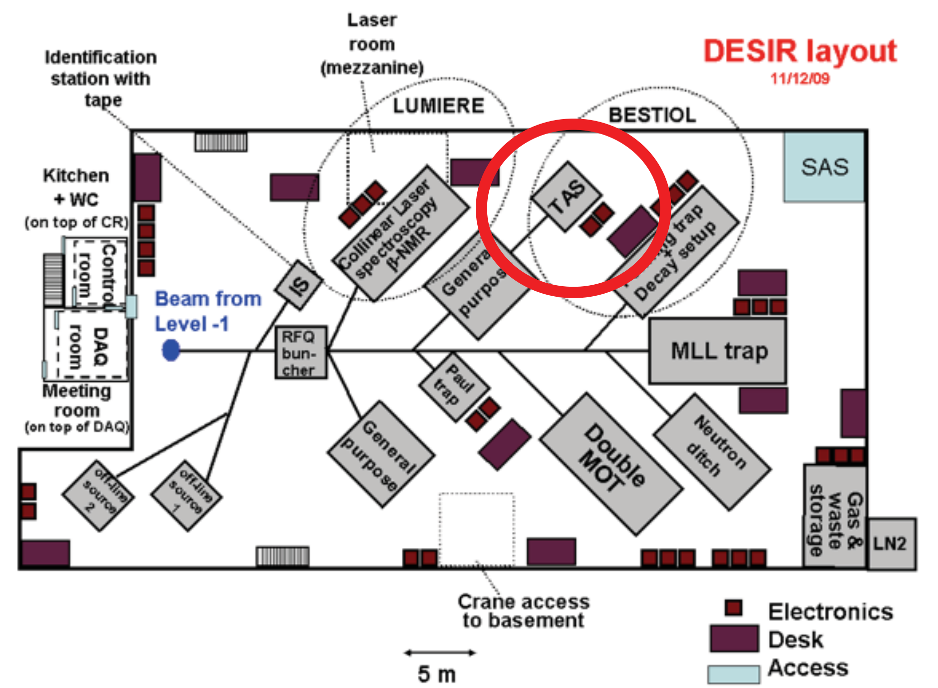
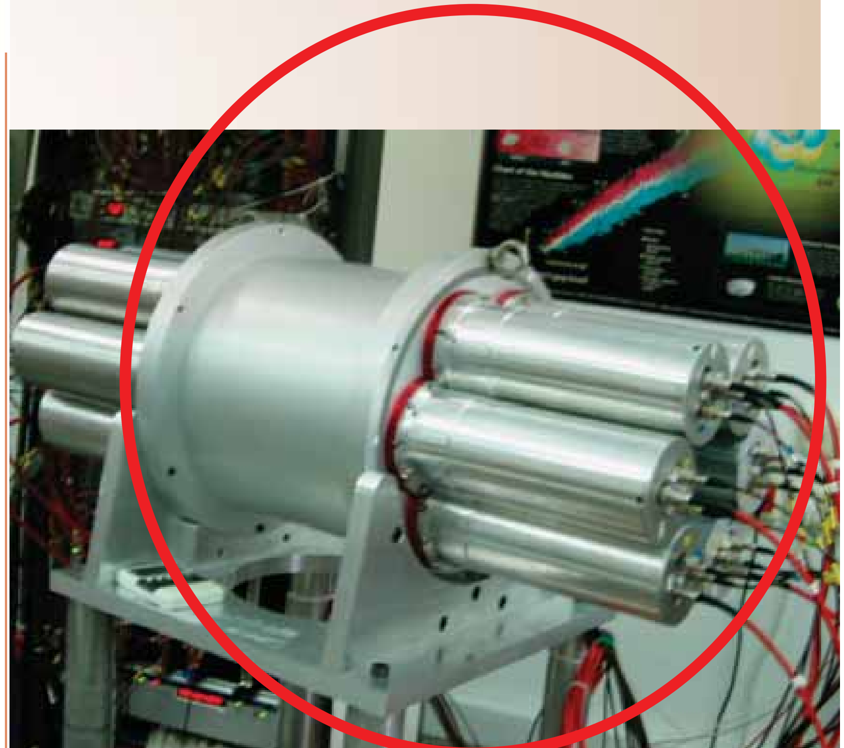


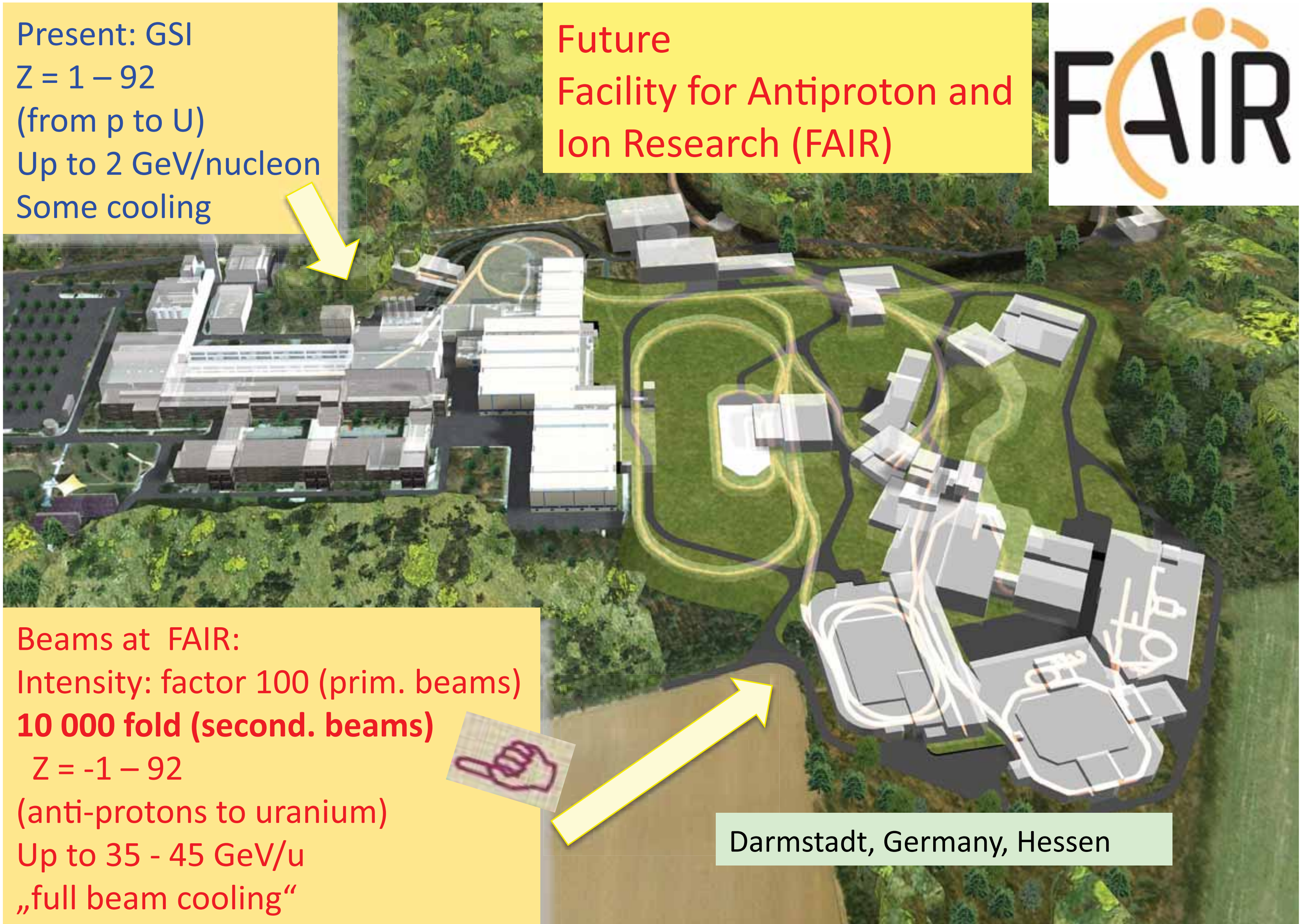
Figure 2: Layout of the DESIR hall with the permanent setups and general purpose places as forseen today.



Valencia-Surrey TAS

Present: GSI
Z = 1 – 92
(from p to U)
Up to 2 GeV/nucleon
Some cooling

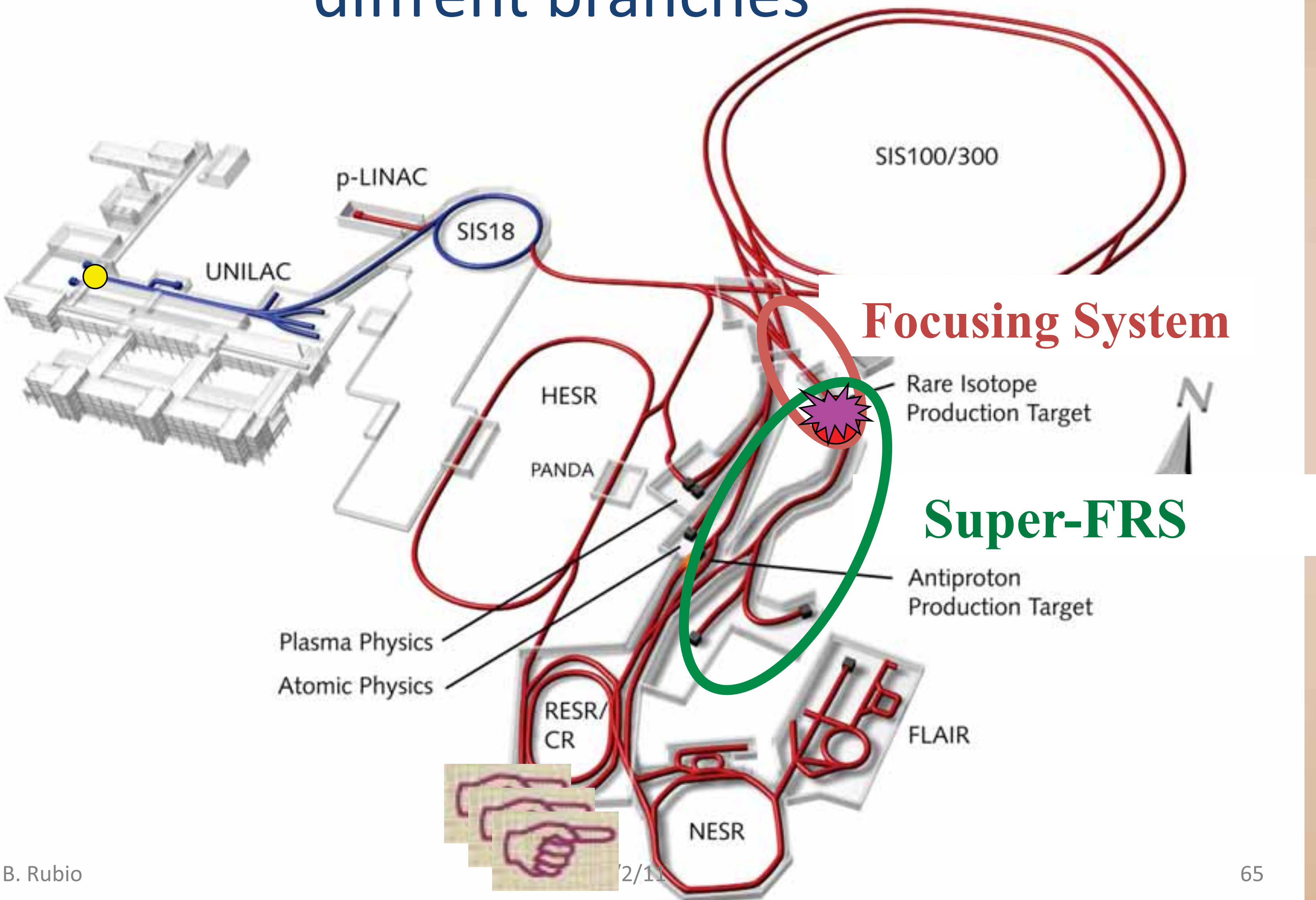
Future
Facility for Antiproton and Ion Research (FAIR)



Beams at FAIR:
Intensity: factor 100 (prim. beams)
10 000 fold (second. beams)
Z = -1 – 92
(anti-protons to uranium)
Up to 35 - 45 GeV/u
„full beam cooling“

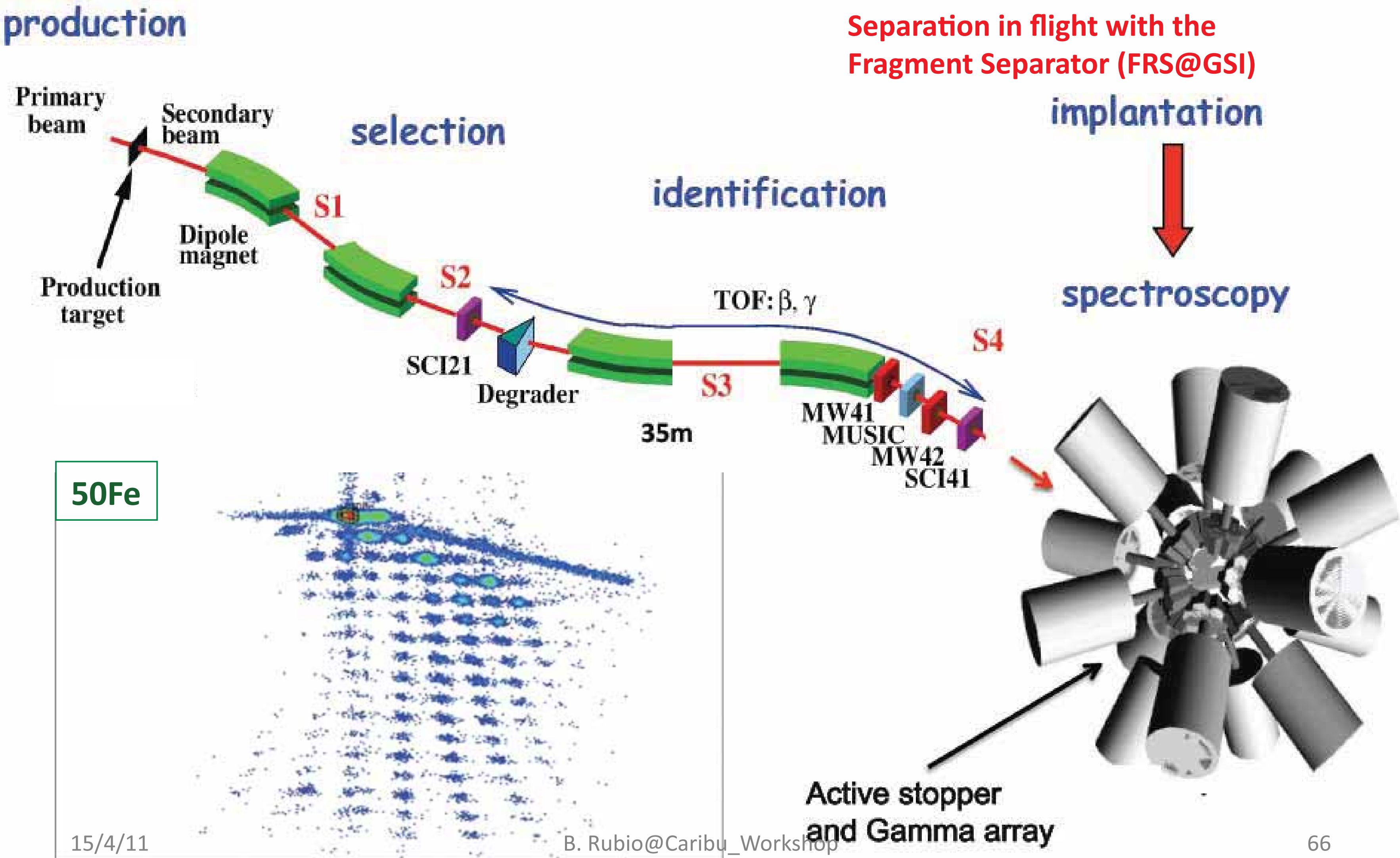
Darmstadt, Germany, Hessen

Super-FRS will deliver beams at three diffrent branches



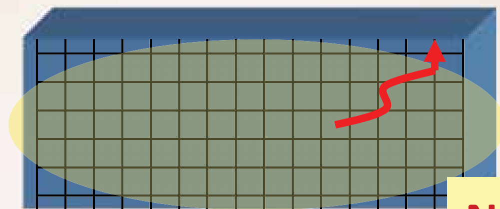
IN a Fragment Separator the ions are identified in Mass and Z, but a cocktail of ions arrive to the focal plane

Separation in flight with the Fragment Separator (FRS@GSI)



Waiting time according with the half-life
Emission of β particle (or proton)
Correlation with gamma radiation

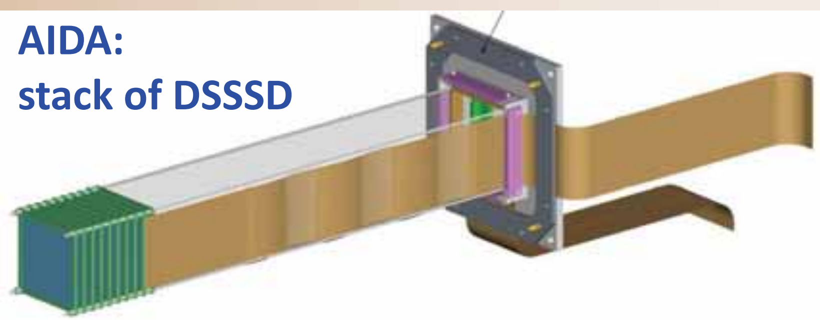
Implantation Detector
Sensitive to betas

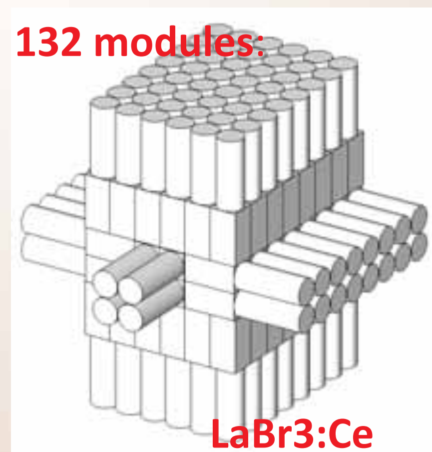


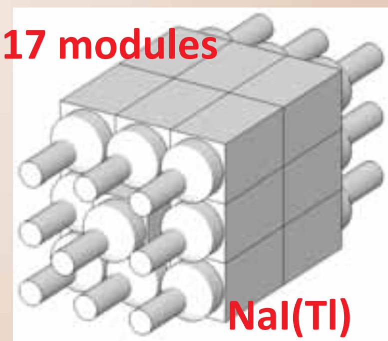
NUSTAR collaboration:
DESPEC experiment

New TAS development

High energy ions (fragmentation, fission, …) separated and identified with the Super-FRS and implanted in an active stopper







Valencia, Madrid, Gatchina, Darmstadt, Debrecen, Jyvaskyla, Surrey

Summary

Total Absorption Spectroscopy is a fundamental tool for beta decay studies of nuclei far from the stability.

These studies are important to test our models far from the stability, and in particular to guide these models when they are applied to r-process nuclei

They are very important as input for decay heat calculations. This has a strong social impact as it has been (sadly) put in evidence in Fukushima. They are needed for the design of advance Fuel Cycle reactors.

There are thee working TAS spectrometers in Europe (plus some Russians)
Two other ones will be built and installed at the two large scale facilities (as defined in the ESFRI road map) in Europe.

Two other ones are being installed in the USA.

The analysis of these experiments is not trivial, but we think it is today under control.

Total Absorption Spectroscopy is an important part of the present and future facility at a number of laboratories including CARIBu@ANL

Thank you for your attention