The LIBRA project:

Upgraded research facilities at the Tandem accelerator laboratory of NCSR "Demokritos"

✓ **LIBRA is funded within the FP7/CAPACITIES/REGPOT programme**

✓ **REGPOT (Research Potential) supports an Action Plan comprising:**

1. **Exchange of know-how and experience with Partner Organizations**
2. **Recruitment of (young) researchers**
3. **Acquisition, development and/or upgrade of equipment and infrastructure**
4. **Organization of Workshops and Conferences**
5. **Dissemination and Promotional Activities**

✓ **LIBRA is a 3-year project**

Start: 1st January 2009 – End: 31st December 2011

… extended to July 31, 2012 ***(43 months)***

The LIBRA project:
research directions

Nuclear Structure

Lifetime measurements to search for empirical proofs of the E(5) critical-point symmetry

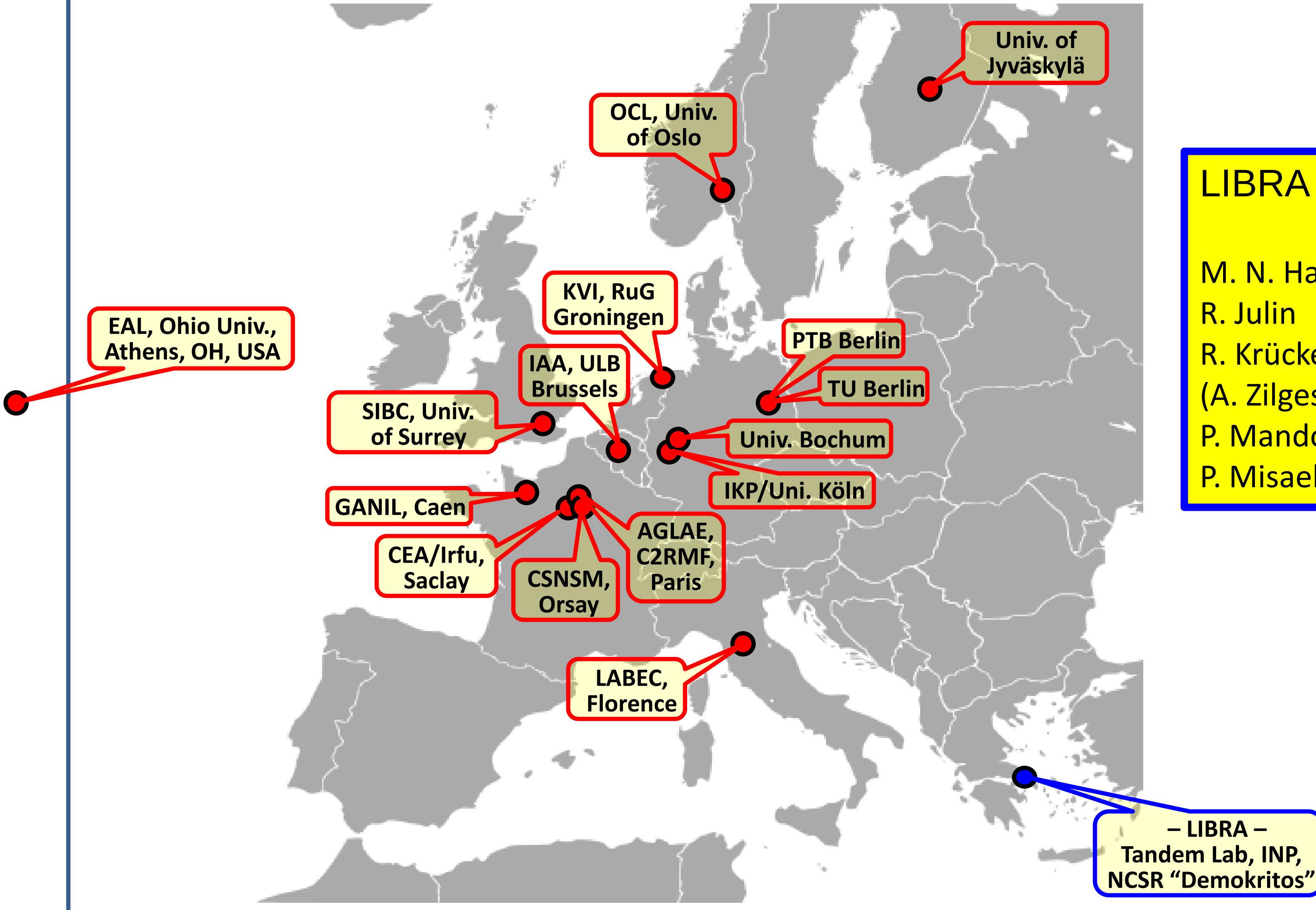
Nuclear Astrophysics

Cross sections measurements of capture reactions for explosive nucleosynthesis (p process)

Ion-beam applications

to build capacity at national and European level
(cultural heritage, materials research, environmental monitoring, …)

LIBRA PARTNER INSTITUTIONS



LIBRA SAC

M. N. Harakeh
R. Julin
R. Krücken
(A. Zilges)
P. Mando
P. Misaelides

Work package list /overview

Work packages	Work package title	Type of activity	Person-months	Start month	End month	Funds allocated
WP 1	Management, co-ordination and assessment	MGT	36	1	43	118750
WP 2	Enhancement of human potential	SUPP	144	1	43	265600
WP 3	Enhancement of research tools and infrastructure.	SUPP	86	1	43	743000
WP 4	Exchange of knowledge and expertise	SUPP	13	4	43	84500
WP 5	Organization of international scientific events	SUPP	6	4	36	45000
WP 6	Dissemination and promotional activities	SUPP	10	1	43	57100
	TOTAL Person-months		295			
	TOTAL Direct and personnel costs					1306400
	Subcontracting (Auditor's costs)					5550
	TOTAL INDIRECT Costs (7%)					91448
	TOTAL BUDGET					**1403398**

WP 3: Enhancement of Research Tools and Infrastructure

Objectives:

1. Development and Acquisition of novel experimental tools (Detectors and Devices)
2. Upgrade of the TANDEM Accelerator Components
3. Installation of the high-current low-energy accelerator PAPAP
4. Acquisition and Installation of a μ-beam system at the TANDEM accelerator

Description of Work

Task 3.1: Development and Acquisition of Novel Experimental Tools

Subtask 3.1.1 : Acquisition of a 4π γ-calorimeter

Subtask 3.1.2 : Development of an He-filled gas-target system

Subtask 3.1.3 : Development of a TPC based on the MICROMEGAS Technology

Subtask 3.1.4 : Installation and Operation of an array of 16 ^{3}He-filled counters at INP

Subtask 3.1.5 : Development – Construction of a plunger device for MINIBALL @ ISOLDE

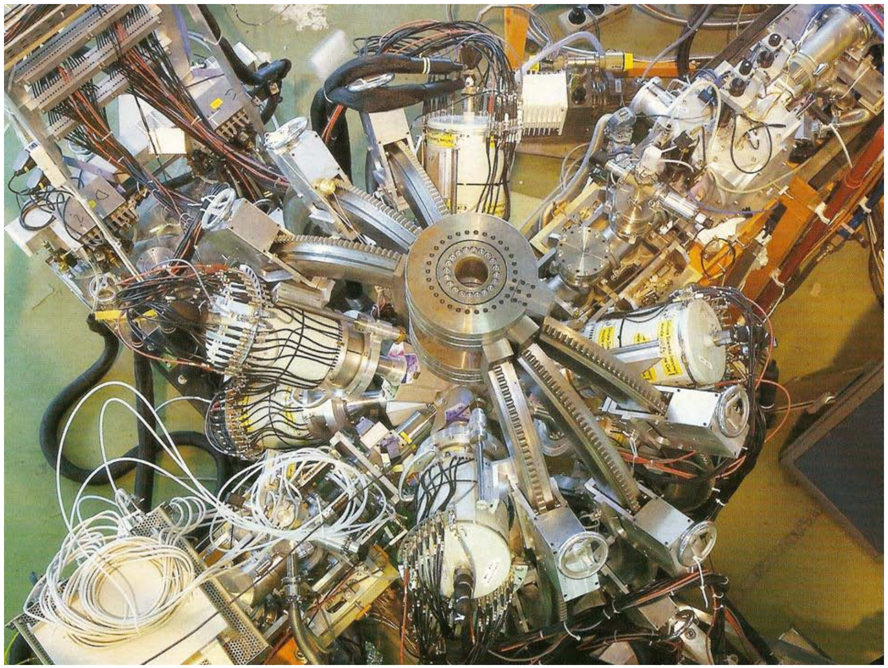
Subtask 3.1.6 : Acquisition – Installation of a new DAQ system

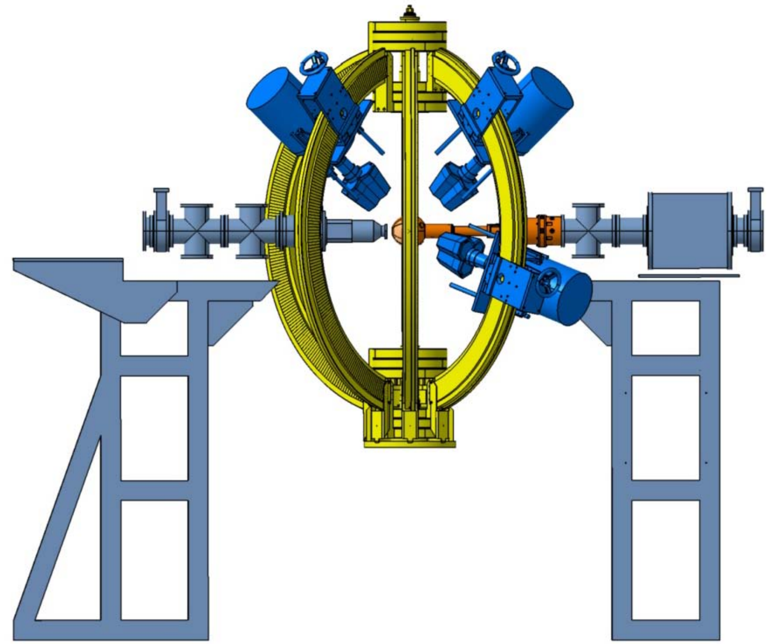
Task 3.2: Upgrade of the TANDEM Accelerator components

Task 3.3: Installation of PAPAP

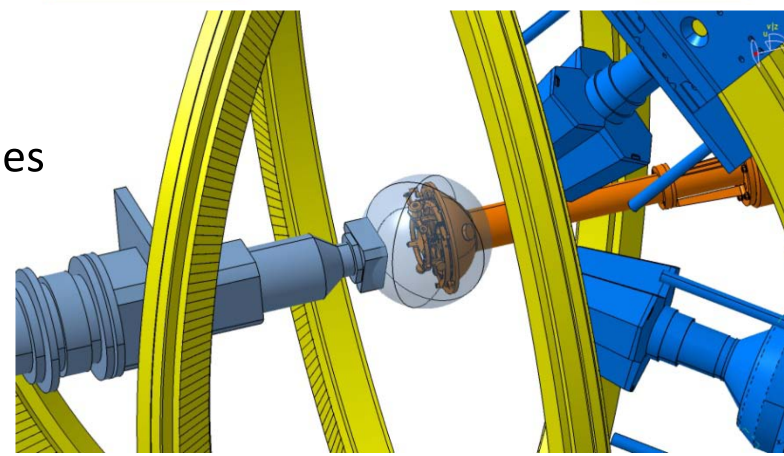
Task 3.4: Acquisition and Installation of a μ-beam system at the TANDEM accelerator

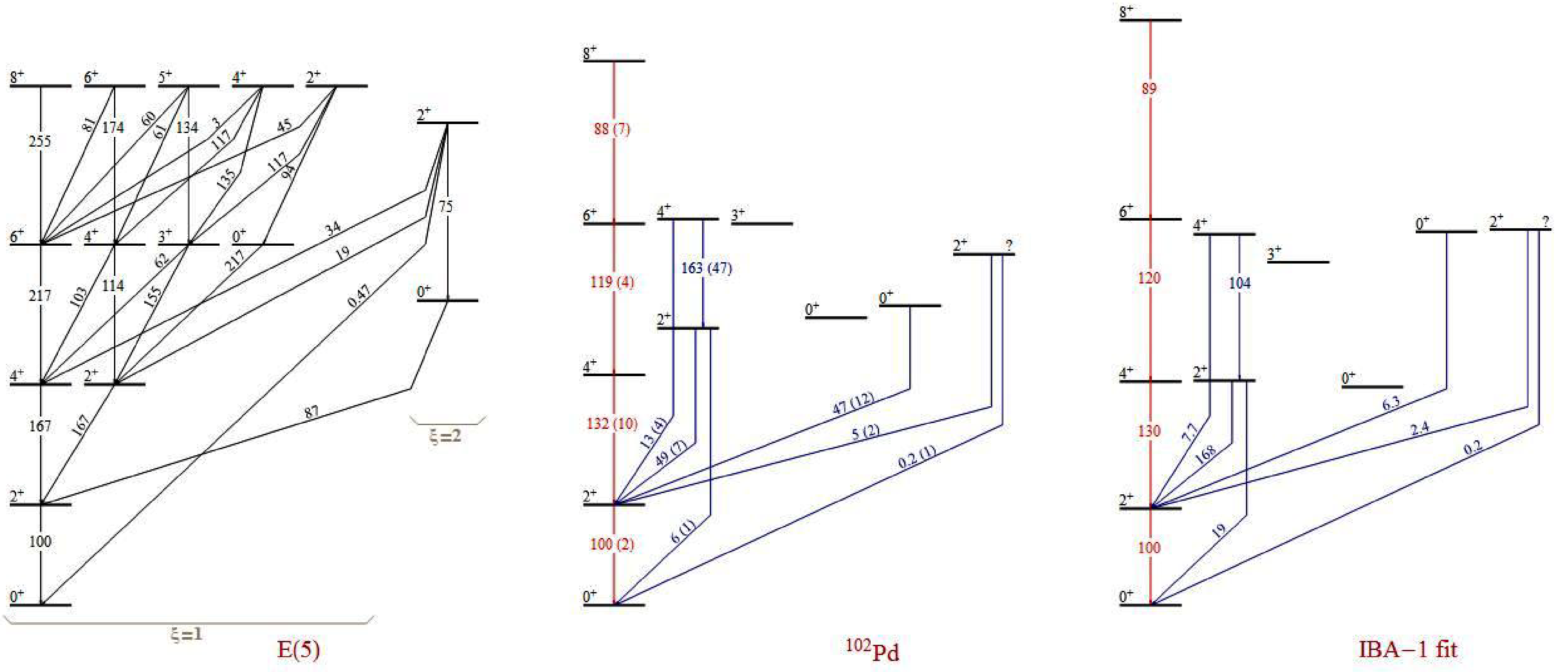
WP3/T3.1.5: Development & Construction of a plunger for MINIBALL @ ISOLDE

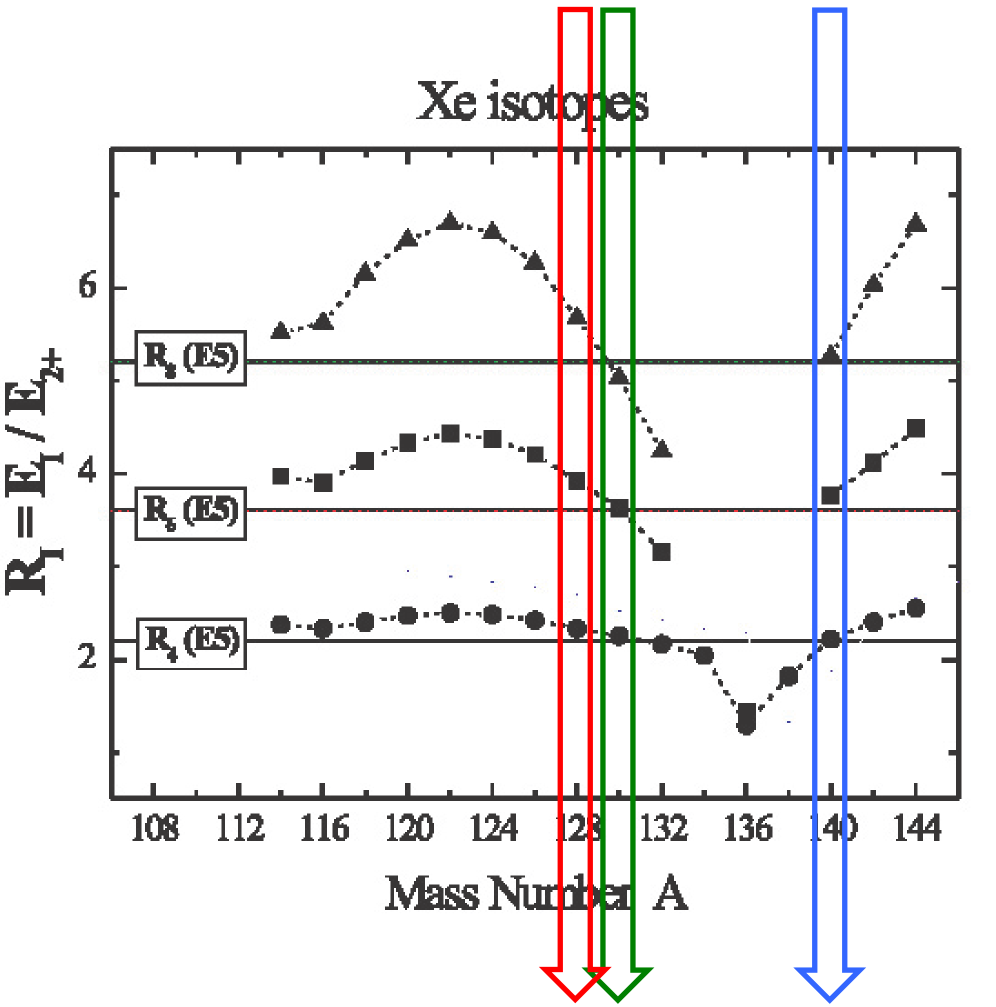




Access to measurements of transition probabilities in regions of the nuclear chart otherwise inaccessibly with Coulomb excitation (deep-inelastic / fusion-evaporation reactions).




8+
6+
5+
4+
2+
255
174
134
81
60
61
3
117
45
135
117
94
75
217
114
103
62
155
217
34
19
0.47
167
167
87
100
0+
ξ=1
ξ=2
E(5)
88 (7)
119 (4)
163 (47)
132 (10)
13 (4)
49 (7)
47 (12)
5 (2)
0.2 (1)
100 (2)
6 (1)
102Pd
89
120
104
130
7.7
168
6.3
2.4
0.2
100
19
IBA−1 fit



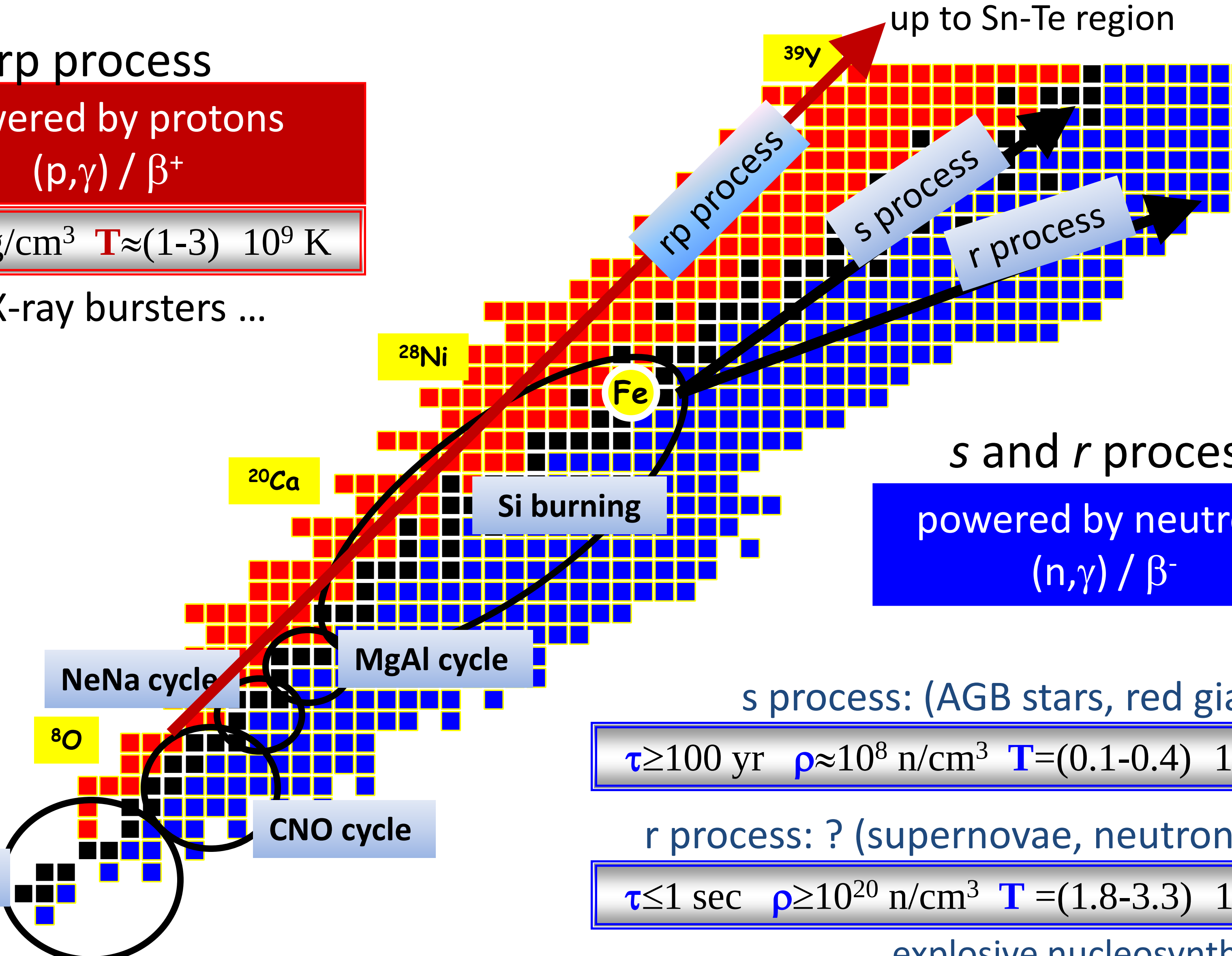
Xe isotopes
$R_J = E_J / E_{2+}$
R_8 (E5)
R_6 (E5)
R_4 (E5)
6
4
2
108
112
116
120
124
128
132
136
140
144
Mass Number A

rp process

powered by protons
(p,γ) / β^+

$\rho > 10^4$ g/cm^3 T≈(1-3) 10^9 K

Novae, X-ray bursters …



s and *r* processes

powered by neutrons
(n,γ) / β^-

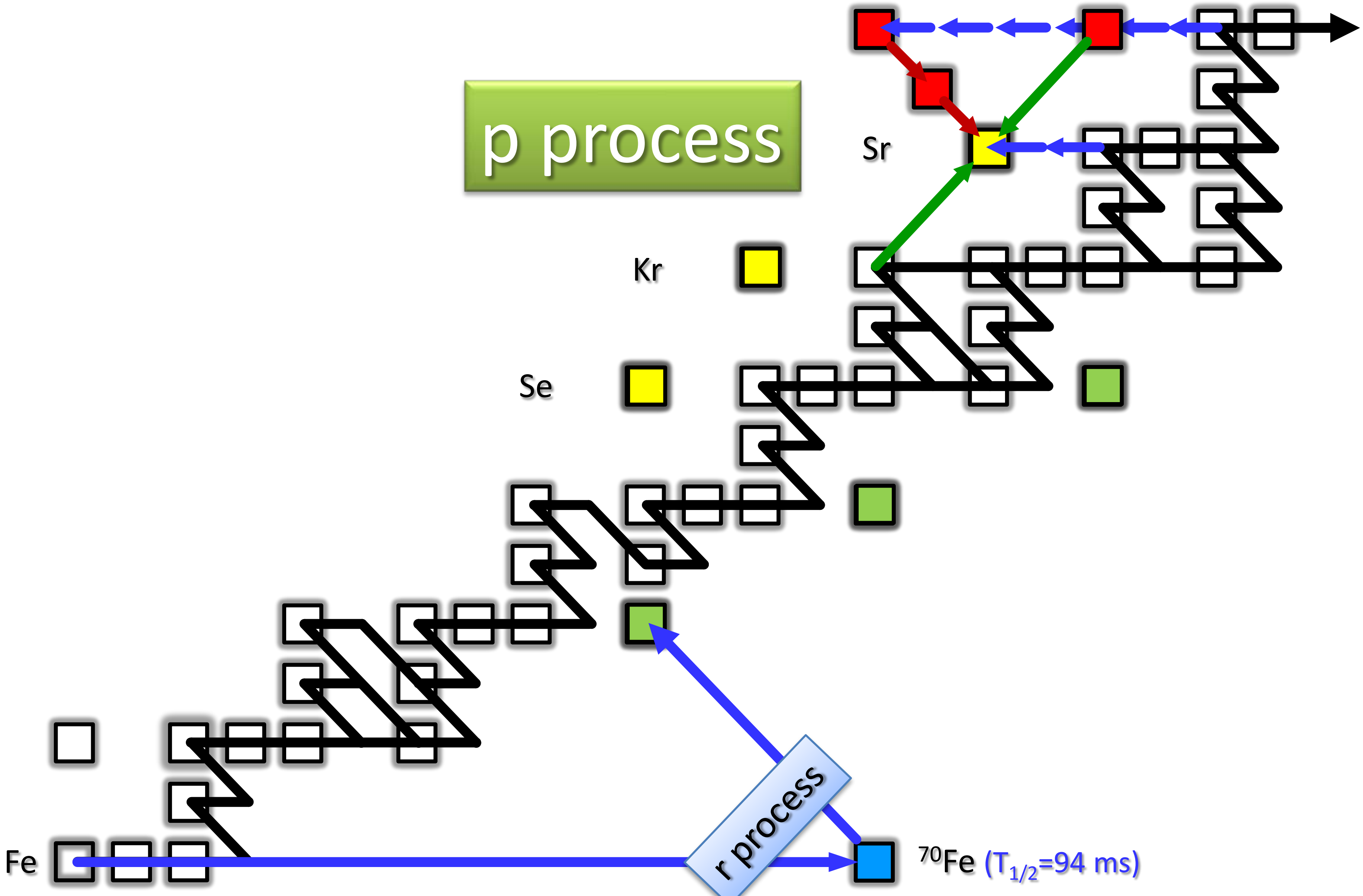
s process: (AGB stars, red giants...)

$\tau \geq 100$ yr $\rho \approx 10^8$ n/cm^3 T=(0.1-0.4) 10^9 K

r process: ? (supernovae, neutron stars)

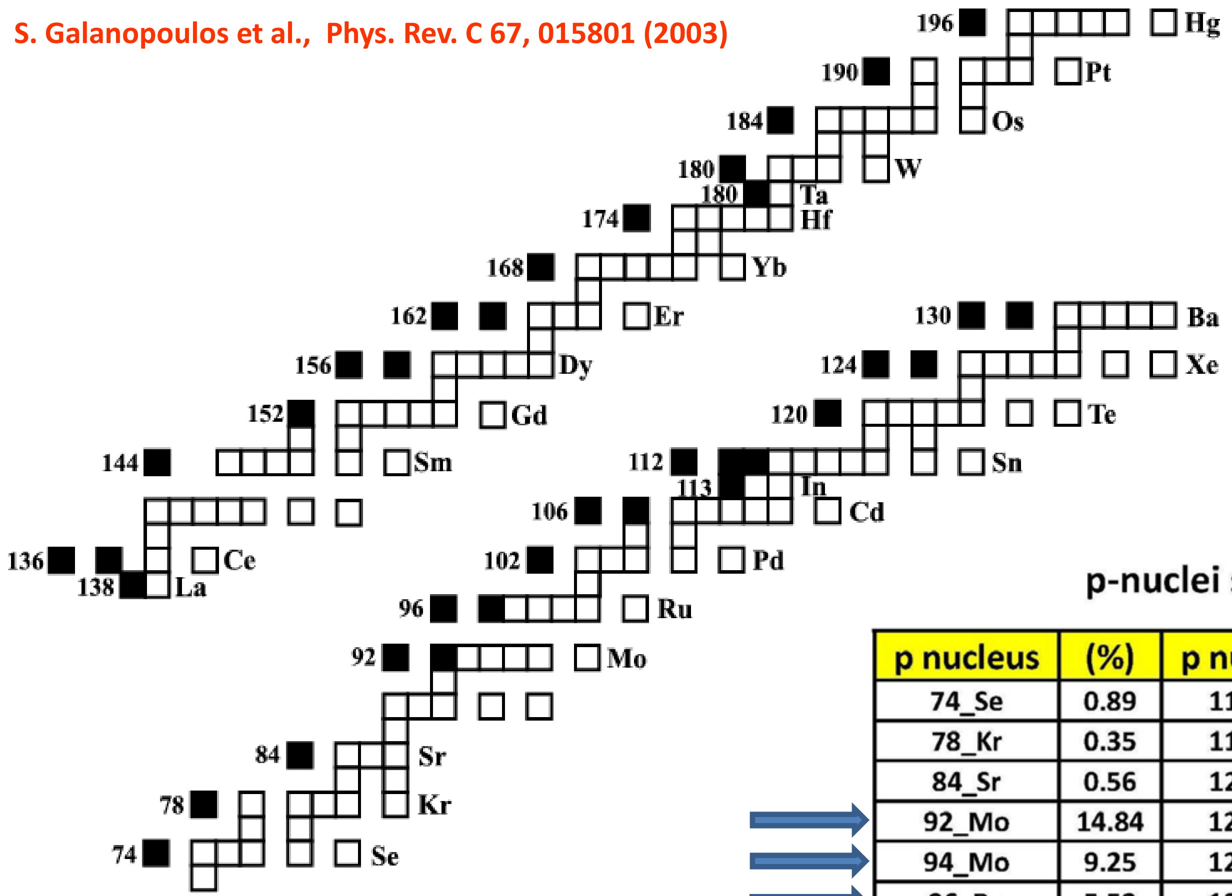
$\tau \leq 1$ sec $\rho \geq 10^{20}$ n/cm^3 T =(1.8-3.3) 10^9 K

explosive nucleosynthesis !!



p process
Sr
Kr
Se
Fe
r process
^{70}Fe ($T_{1/2}$=94 ms)

S. Galanopoulos et al., Phys. Rev. C 67, 015801 (2003)

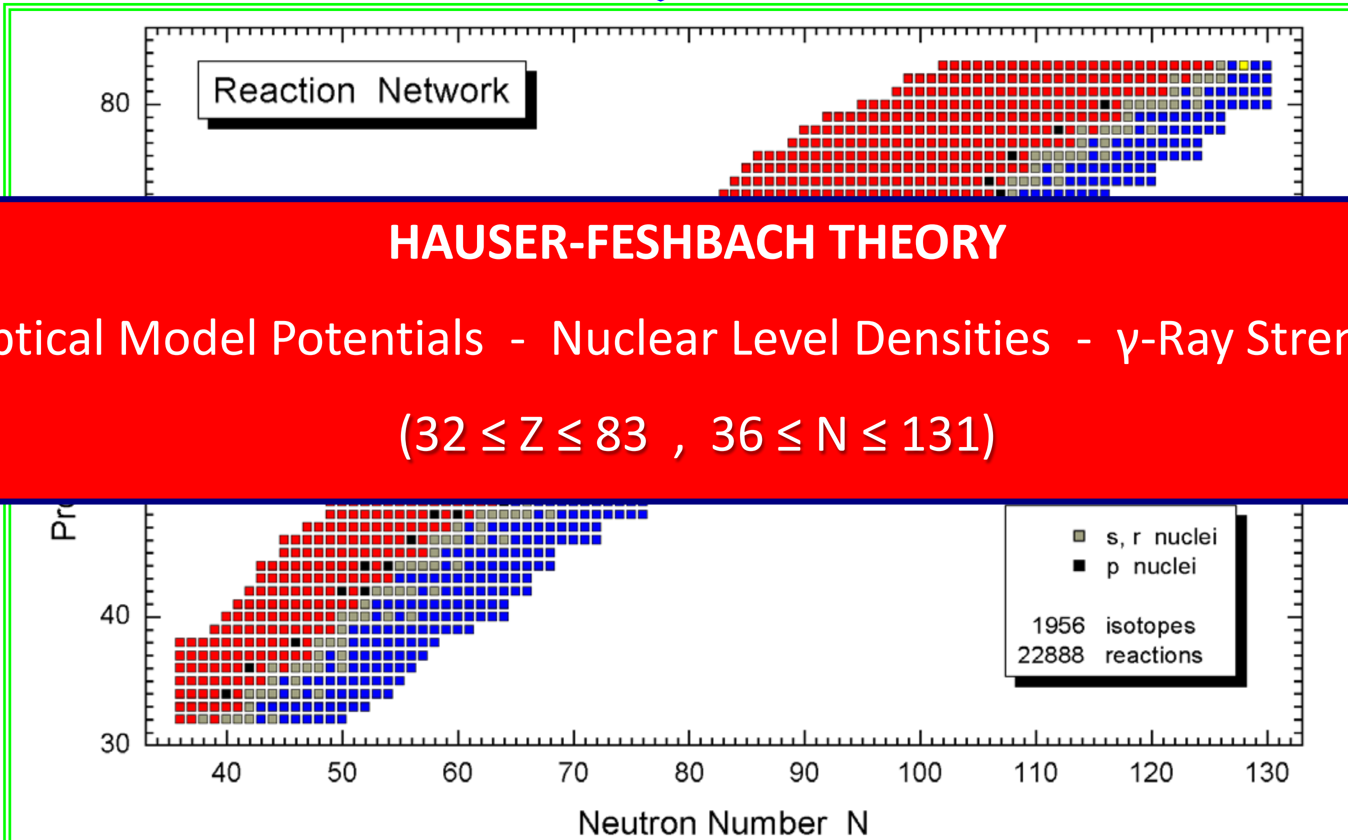


p-nuclei solar abundances

p nucleus	(%)	p nucleus	(%)	p nucleus	(%)
74_Se	0.89	114_Sn	0.65	156_Dy	0.06
78_Kr	0.35	115_Sn	0.34	158_Dy	0.10
84_Sr	0.56	120_Te	0.096	162_Er	0.14
92_Mo	14.84	124_Xe	0.10	164_Er	1.61
94_Mo	9.25	126_Xe	0.09	168_Yb	0.13
96_Ru	5.52	130_Ba	0.106	174_Hf	0.162
98_Ru	1.88	132_Ba	0.101	180_Ta	0.012
102_Pd	1.02	138_La	0.09	180_W	0.13
106_Pd	1.25	136_Ce	0.19	184_Os	0.02
108_Cd	0.89	138_Ce	0.25	190_Pt	0.01
113_In	4.3	144_Sm	3.1	196_Hg	0.15
112_Sn	0.97	152_Gd	0.20		

SEVENTH FRAMEWORK PROGRAMME

"seed" abundances (s process) → reaction network → p-nuclei abundances (p process)



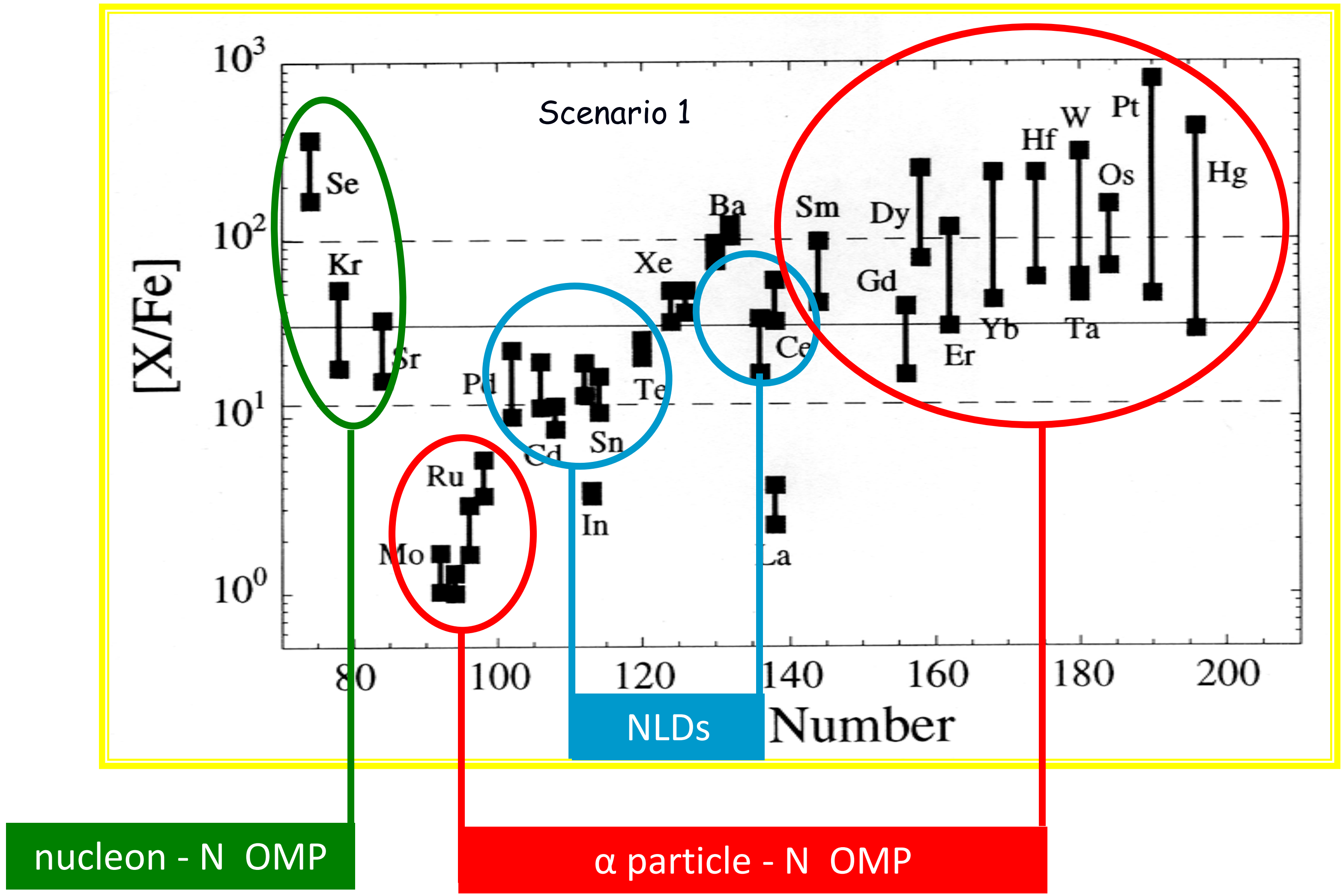
HAUSER-FESHBACH THEORY

Optical Model Potentials - Nuclear Level Densities - γ-Ray Strengths

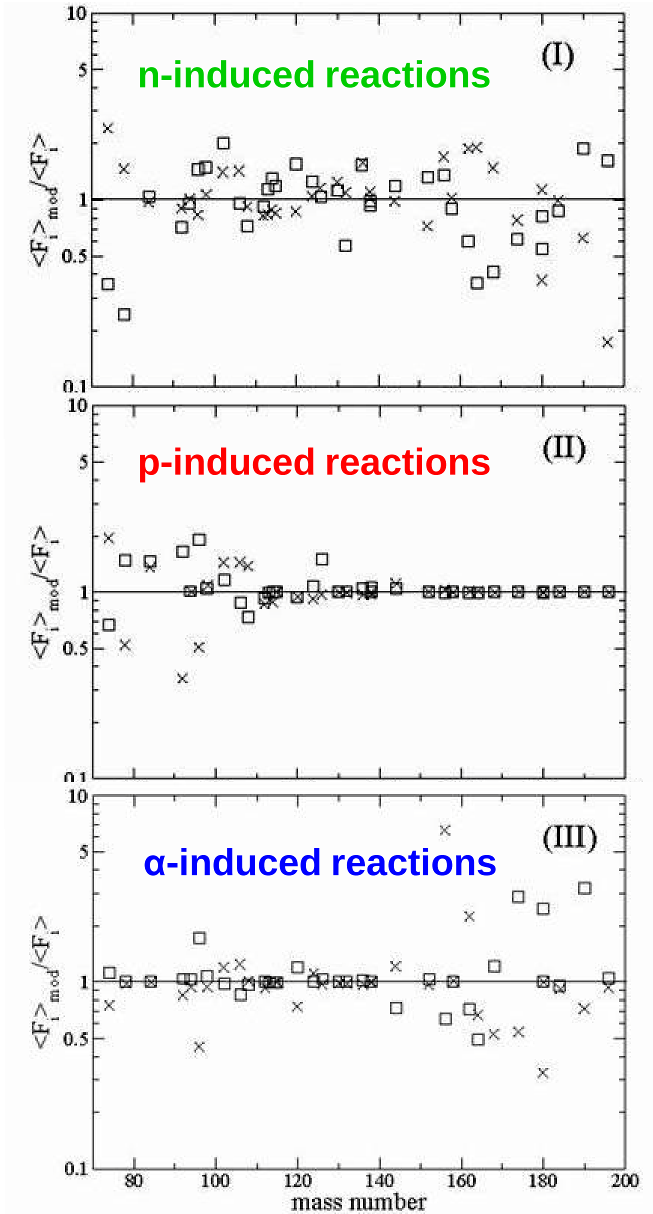
$(32 \leq Z \leq 83\ ,\ 36 \leq N \leq 131)$

S. Goriely, ESF Workshop on p process, Vravron, Greece, 2002 & M. Arnould and S. Goriely Phys. Rep. 384, 1 (2003)

Scenario: SN-II explosions



W. Rapp et al., NPA 758, 545c (2005)



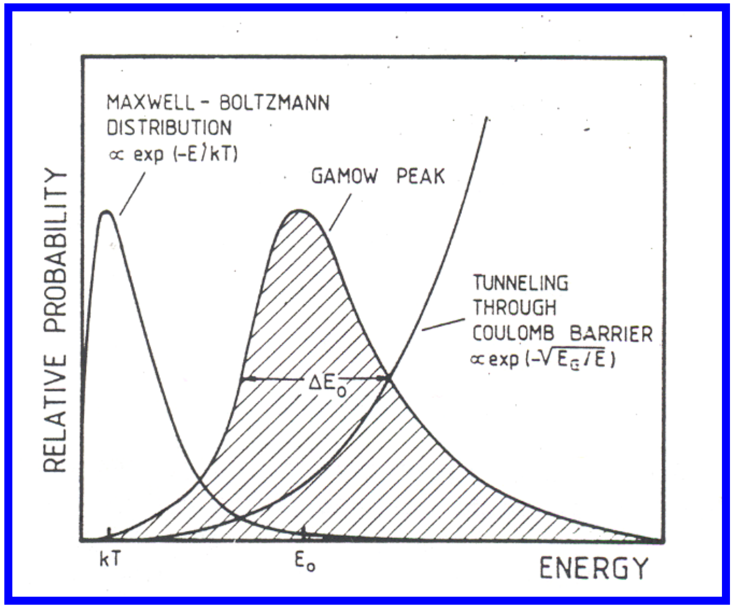
PHYSICAL REVIEW C **73**, 015804 (2006)

Branchings in the γ process path revisited

Thomas Rauscher*
Departement für Physik und Astronomie, Universität Basel, CH-4056 Basel, Switzerland
(Received 15 September 2005; published 19 January 2006)

TABLE III. Suggestions for reactions to be studied experimentally. Shown are sensitive reactions involving stable or long-lived ($T_{1/2} \geqslant 10^6$ a) targets. Unstable targets are marked by an asterisk, naturally occuring unstable nuclides with superscript n. Note that α capture on the unstable targets shown here always has a negative Q value.

	Target nuclei
Priority 1: (p,γ)	^{80}Se, ^{79}Br, ^{84}Kr, ^{89}Y, ^{93}Nb, ^{97}Tc*, ^{110}Cd, ^{118}Sn, ^{128}Xe, ^{134}Ba, ^{138}Ce
(α,γ)	^{76}Se, ^{92}Mo, ^{94}Mo, ^{96}Ru, ^{98}Ru, ^{102}Pd, ^{108}Cd, ^{116}Sn, ^{124}Xe, ^{130}Ba, ^{141}Pr, ^{148}Sm^n, ^{152}Gd^n, ^{150}Gd^n, ^{154}Dy^n, ^{168}Yb, ^{174}Hf^n
Priority 2: (p,γ)	^{96}Mo, ^{106}Pd, ^{150}Gd*, ^{156}Dy, ^{158}Dy, ^{162}Er
(α,γ)	^{72}Ge, ^{90}Zr, ^{118}Sn, ^{120}Te, ^{122}Te, ^{126}Xe, ^{132}Ba, ^{139}La, ^{136}Ce, ^{140}Ce, ^{142}Nd, ^{144}Nd^n, ^{146}Sm*, ^{151}Eu, ^{156}Dy, ^{158}Dy, ^{164}Er, ^{170}Yb, ^{180}W, ^{184}Os, ^{186}Os^n, ^{196}Hg



$$E_0 = (bkT/2)^{2/3}$$

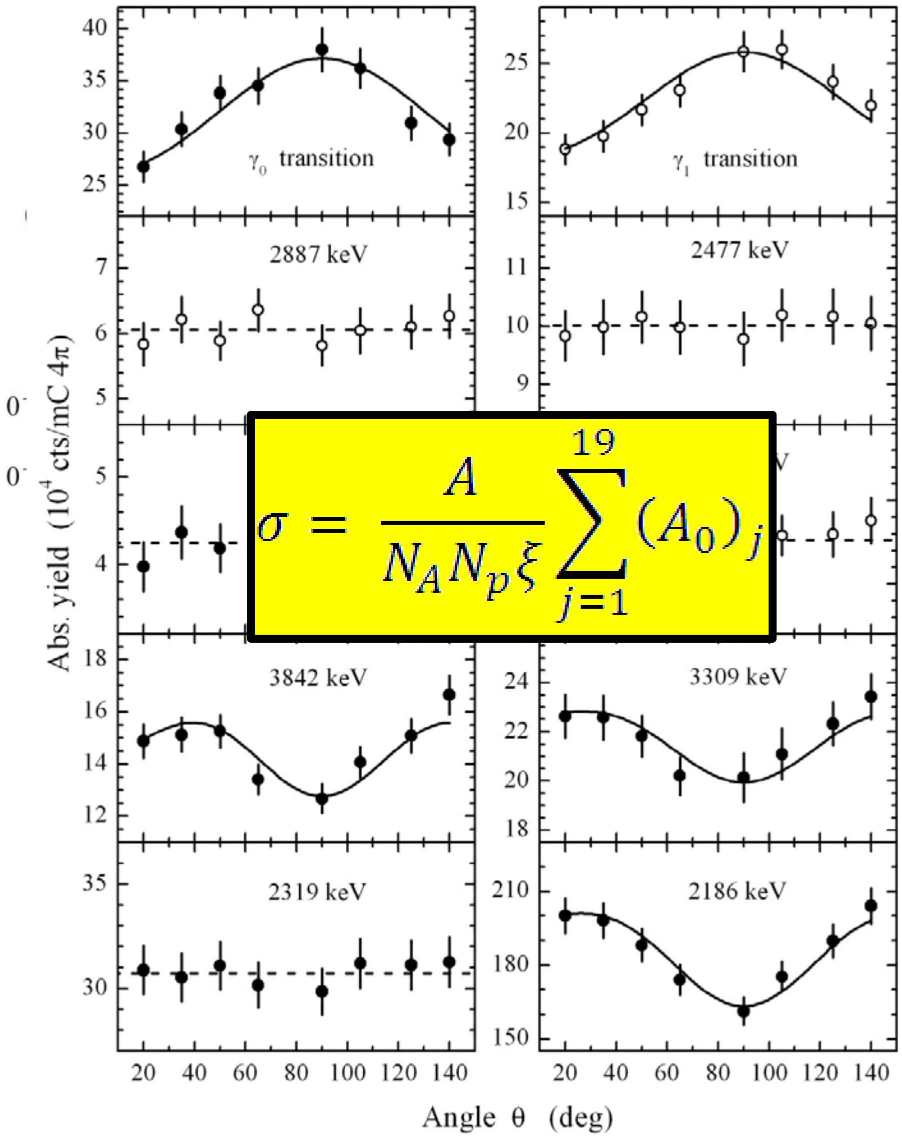
$$b^2 = E_G = 2\mu\pi^2 \frac{e^4 Z_t^2 Z_p^2}{\hbar^2}$$

$$\Delta E = (16 E_0 kT/3)^{1/2} \; exp(-3E_0/kT)$$

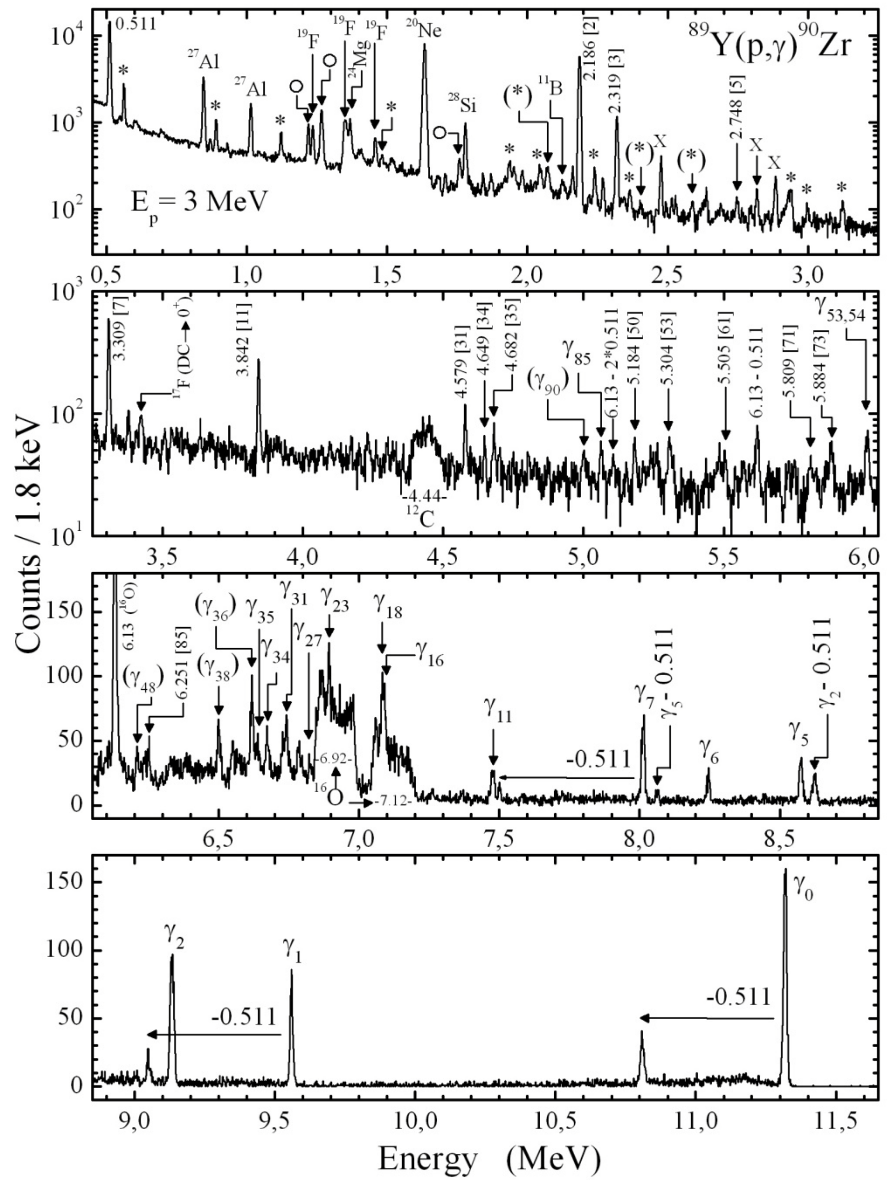
(p,γ) reactions:
E_{CM} = 1 – 5 MeV,
σ = 1 μb 1 mb

(α,γ) reactions:
E_{CM} = 6–12 MeV,
σ = 0.1 100 μb

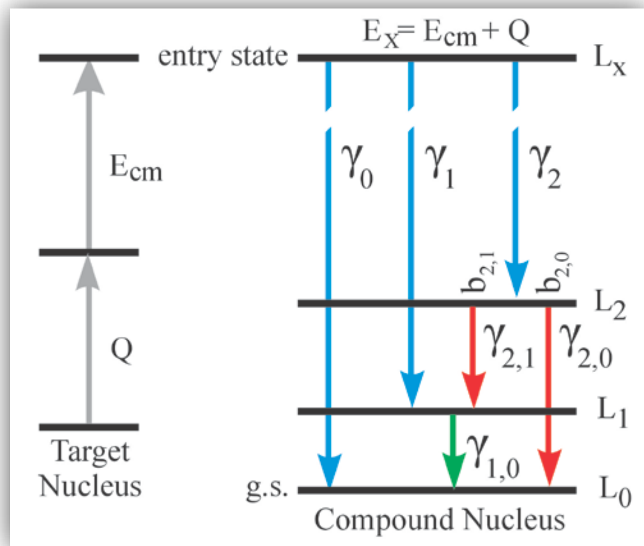
REACTION	$Z_{TARG.}$	E_{COUL} (MeV)	T=1.8 T_9: E_0 (MeV)	T=1.8 T_9: ΔE (MeV)	T=3.3 T_9: E_0 (MeV)	T=3.3 T_9: ΔE (MeV)
^{74}Se + p	34	7.9	1.89	1.27 – 2.52	2.83	1.80 – 3.87
^{90}Zr + p	40	8.8	2.11	1.45 – 2.77	3.16	2.07 – 4.26
^{103}Rh + p	45	9.5	2.28	1.60 – 2.97	3.42	2.28 – 4.56
^{124}Sn + p	50	10	2.45	1.74 – 3.16	3.67	2.49 – 4.85



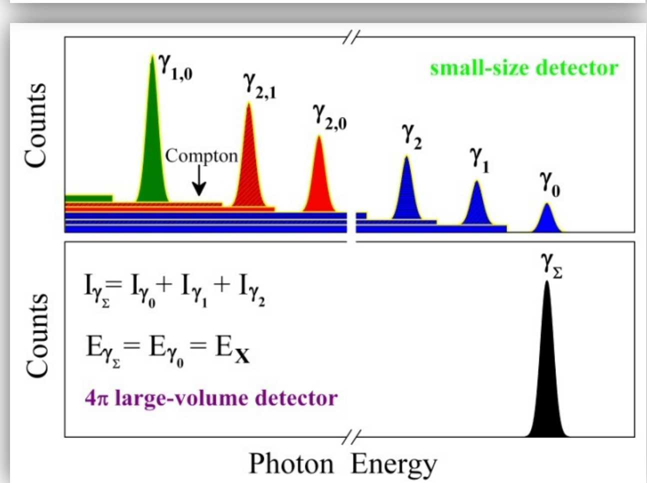
$$\sigma = \frac{A}{N_A N_p \xi} \sum_{j=1}^{19} (A_0)_j$$



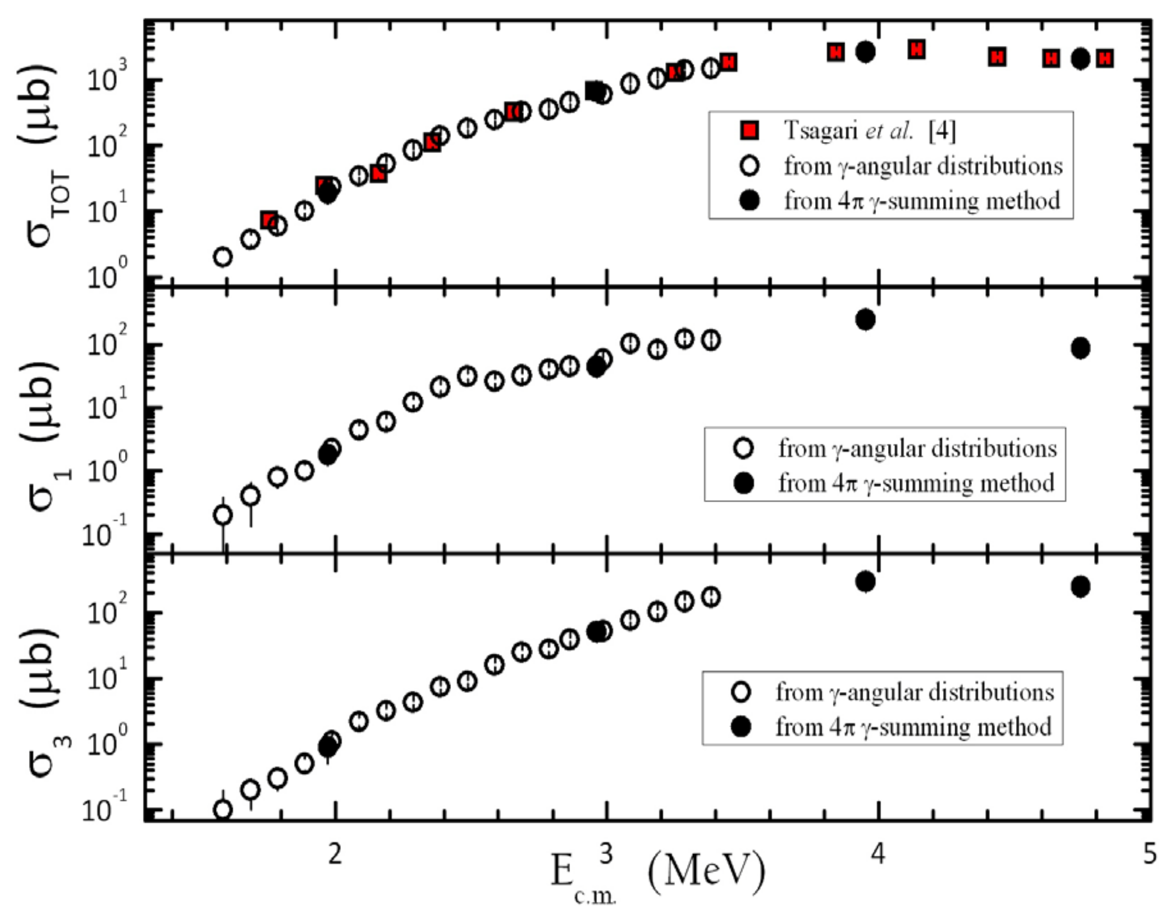

Cryostat
Cryostat



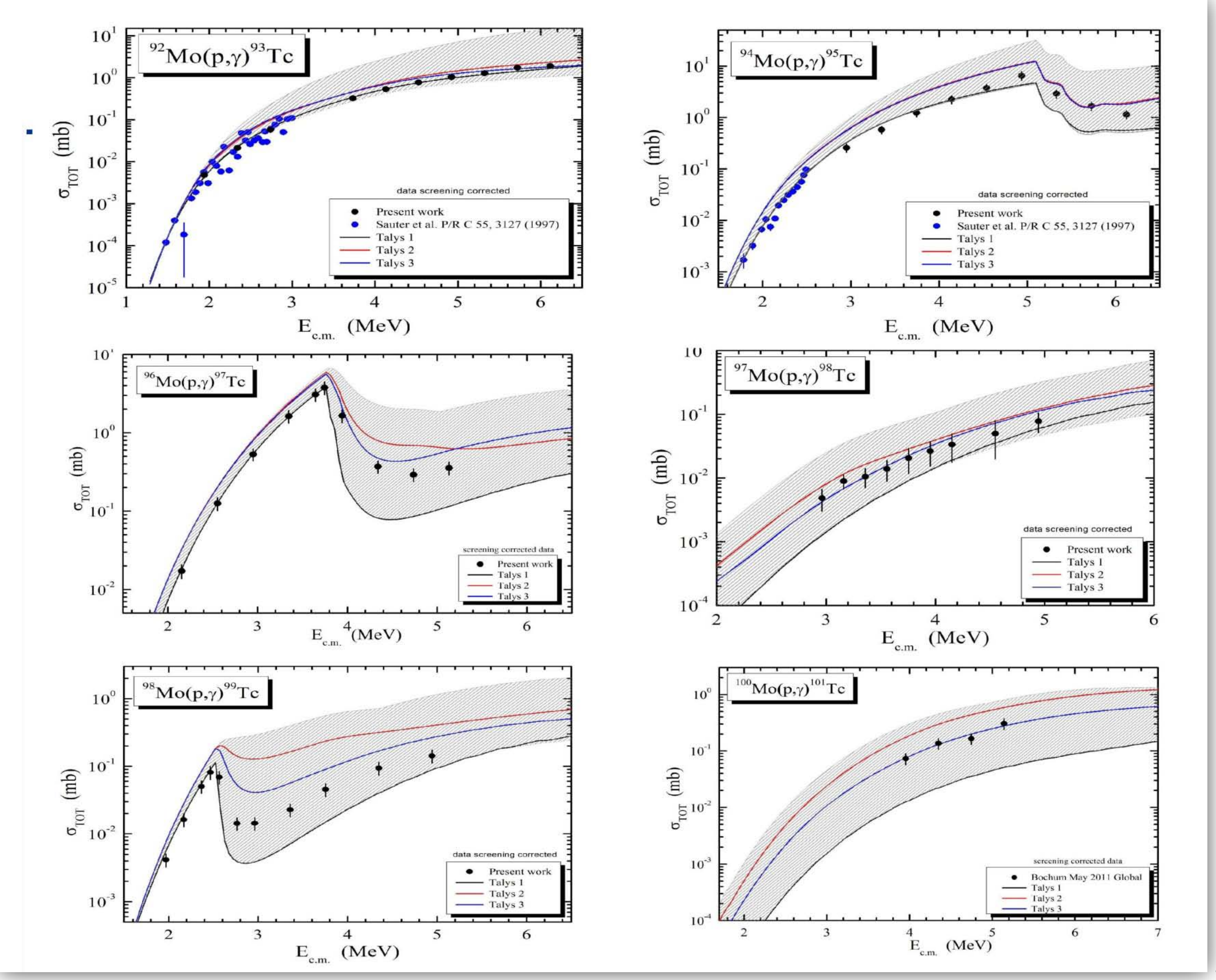
$E_X = E_{cm} + Q$
entry state
L_X
E_{cm}
Q
γ_0
γ_1
γ_2
$b_{2,1}$
$b_{2,0}$
L_2
$\gamma_{2,1}$
$\gamma_{2,0}$
L_1
$\gamma_{1,0}$
Target Nucleus
g.s.
L_0
Compound Nucleus



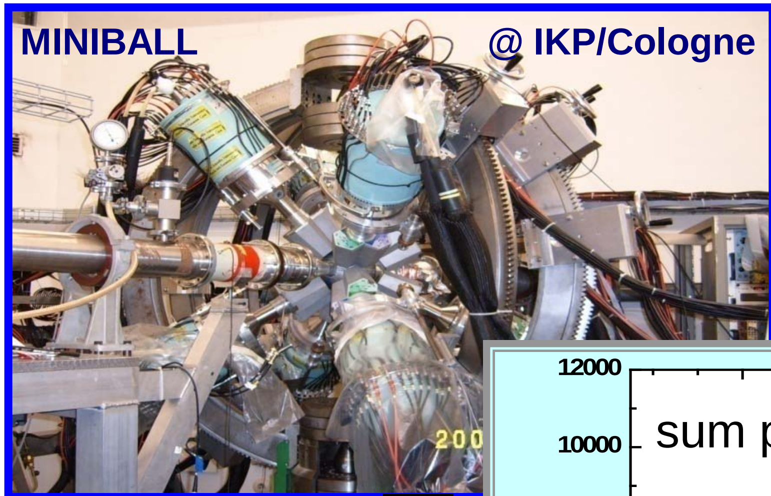
Counts
$\gamma_{1,0}$
$\gamma_{2,1}$
$\gamma_{2,0}$
γ_2
γ_1
γ_0
Compton
small-size detector
Counts
γ_Σ
$I_{\gamma_\Sigma} = I_{\gamma_0} + I_{\gamma_1} + I_{\gamma_2}$
$E_{\gamma_\Sigma} = E_{\gamma_0} = E_X$
4π large-volume detector
Photon Energy

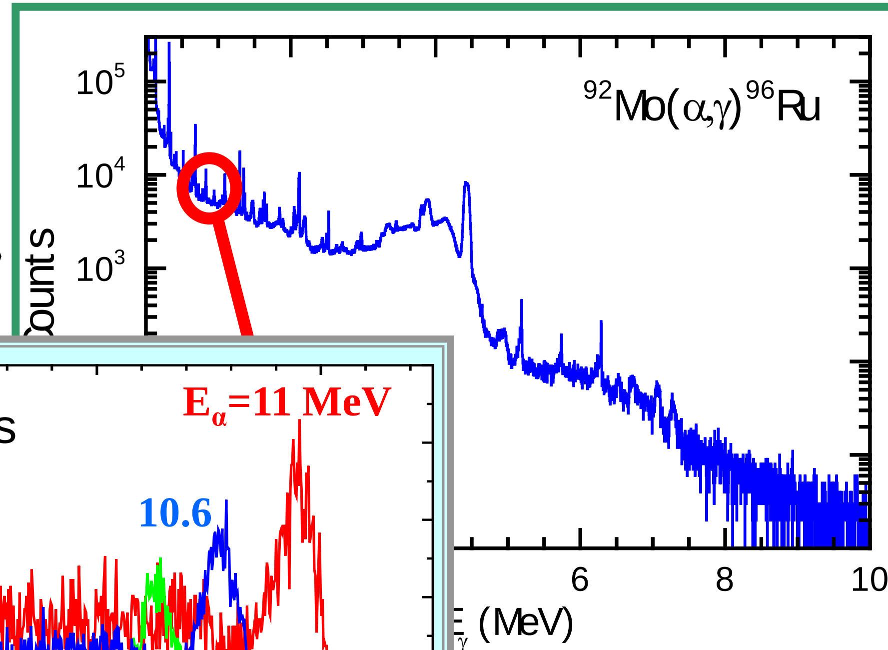


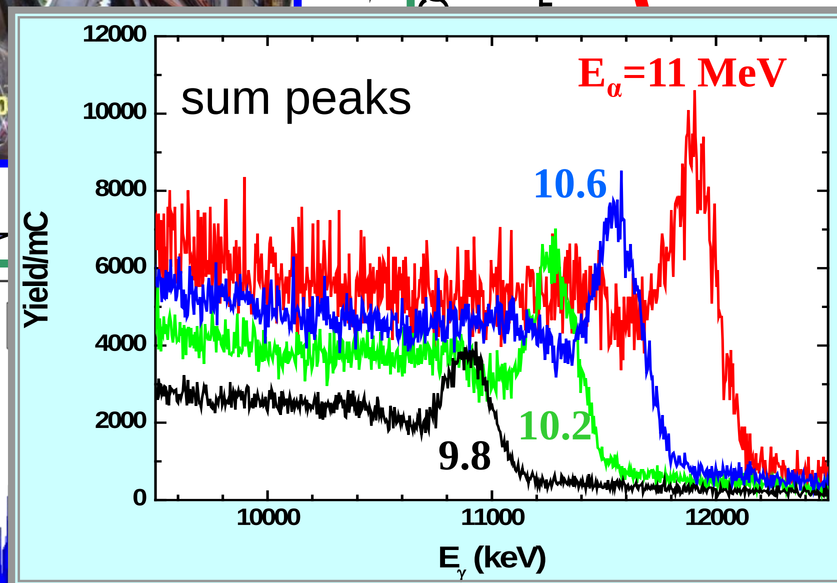
σ_{TOT} (μb)
10^0
10^1
10^2
10^3
Tsagari *et al.* [4]
from γ-angular distributions
from 4π γ-summing method
σ_1 (μb)
10^{-1}
10^0
10^1
10^2
from γ-angular distributions
from 4π γ-summing method
σ_3 (μb)
10^{-1}
10^0
10^1
10^2
from γ-angular distributions
from 4π γ-summing method
2
3
4
5
$E_{c.m.}$ (MeV)

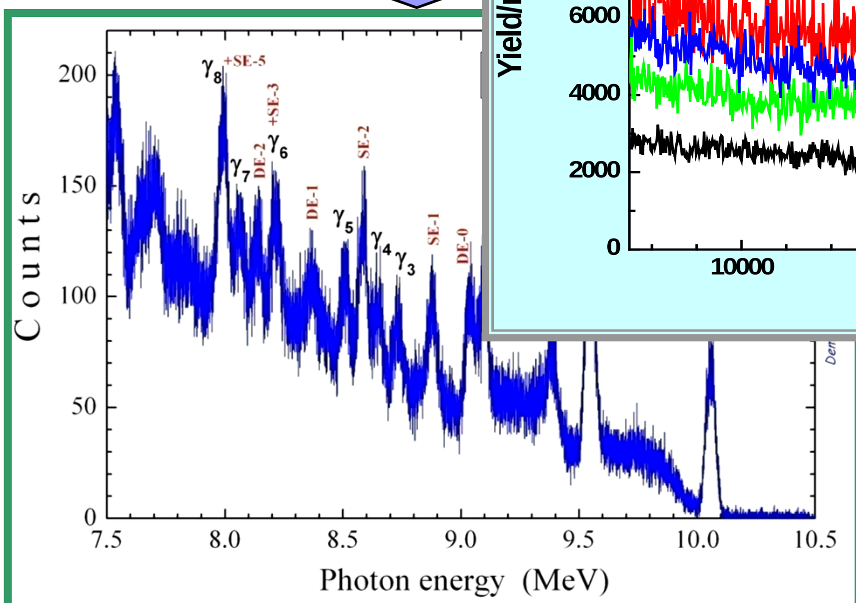


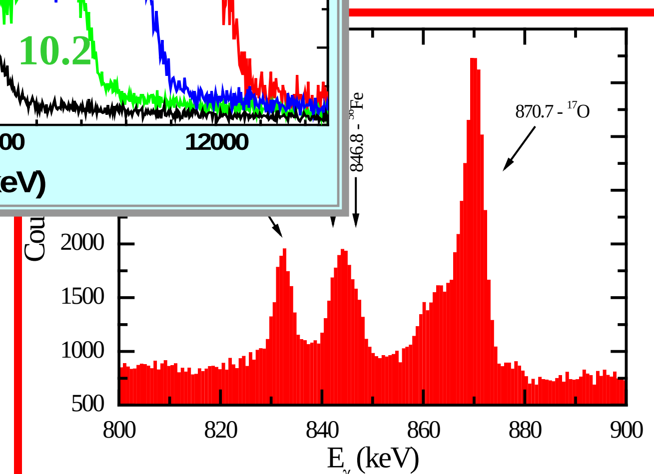
$^{92}Mo(p,\gamma)^{93}Tc$
$^{94}Mo(p,\gamma)^{95}Tc$
$^{96}Mo(p,\gamma)^{97}Tc$
$^{97}Mo(p,\gamma)^{98}Tc$
$^{98}Mo(p,\gamma)^{99}Tc$
$^{100}Mo(p,\gamma)^{101}Tc$
data screening corrected
screening corrected data
Present work
Sauter et al. P/R C 55, 3127 (1997)
Bochum May 2011 Global
Talys 1
Talys 2
Talys 3
σ_{TOT} (mb)
$E_{c.m.}$ (MeV)

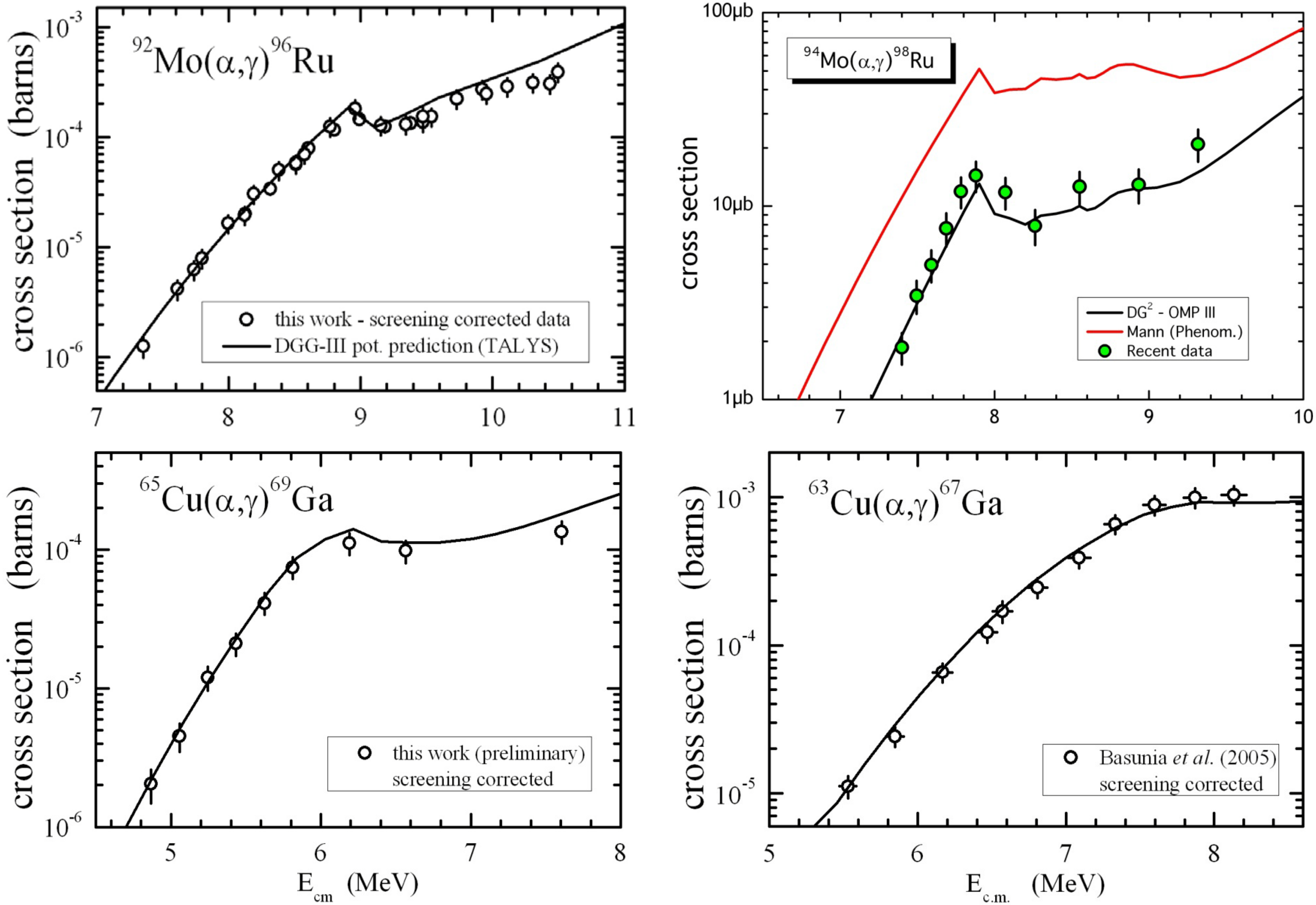

MINIBALL
@ IKP/Cologne


^{92}Mo(α,γ)^{96}Ru
Counts
10^5
10^4
10^3
6
8
10
E_γ (MeV)

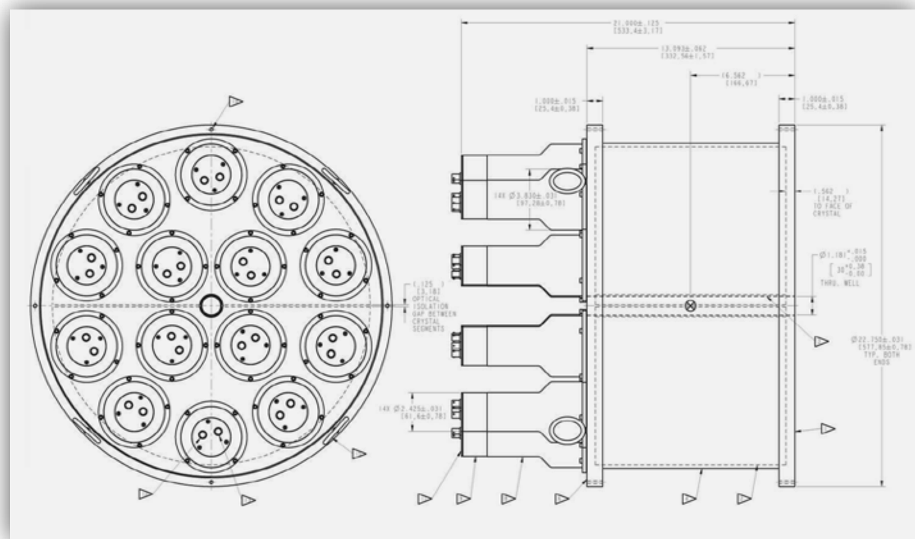

sum peaks
E_α=11 MeV
10.6
10.2
9.8
Yield/mC
E_γ (keV)
0
2000
4000
6000
8000
10000
12000
10000
11000
12000

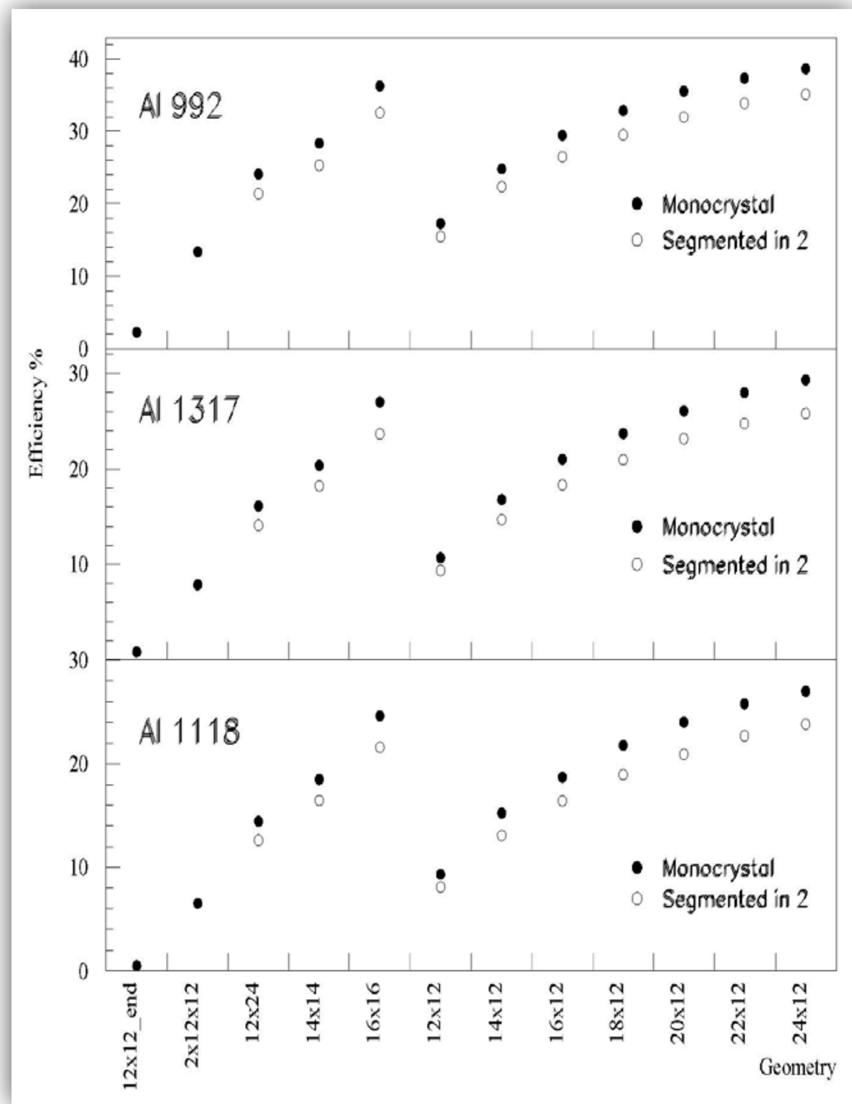

Counts
Photon energy (MeV)
γ8 +SE-5
γ7
DE-2
+SE-3
γ6
DE-1
γ5
SE-2
γ4
γ3
SE-1
DE-0
0
50
100
150
200
7.5
8.0
8.5
9.0
9.5
10.0
10.5


870.7 - ^{17}O
846.8 - ^{56}Fe
E_γ (keV)
500
1000
1500
2000
800
820
840
860
880
900


92Mo(α,γ)96Ru
this work - screening corrected data
DGG-III pot. prediction (TALYS)
cross section (barns)
94Mo(α,γ)98Ru
DG2 - OMP III
Mann (Phenom.)
Recent data
cross section
100μb
10μb
1μb
65Cu(α,γ)69Ga
this work (preliminary)
screening corrected
E cm (MeV)
63Cu(α,γ)67Ga
Basunia et al. (2005)
screening corrected
E c.m. (MeV)

WP 3 / Subtask 3.1.1: The 4π γ-calorimeter NEOPTOLEMOS





WP 3 / Task 3.3: The PAPAP accelerator *(**P**etit **A**ccélérateur **P**our l' **A**stro**P**hysique)*

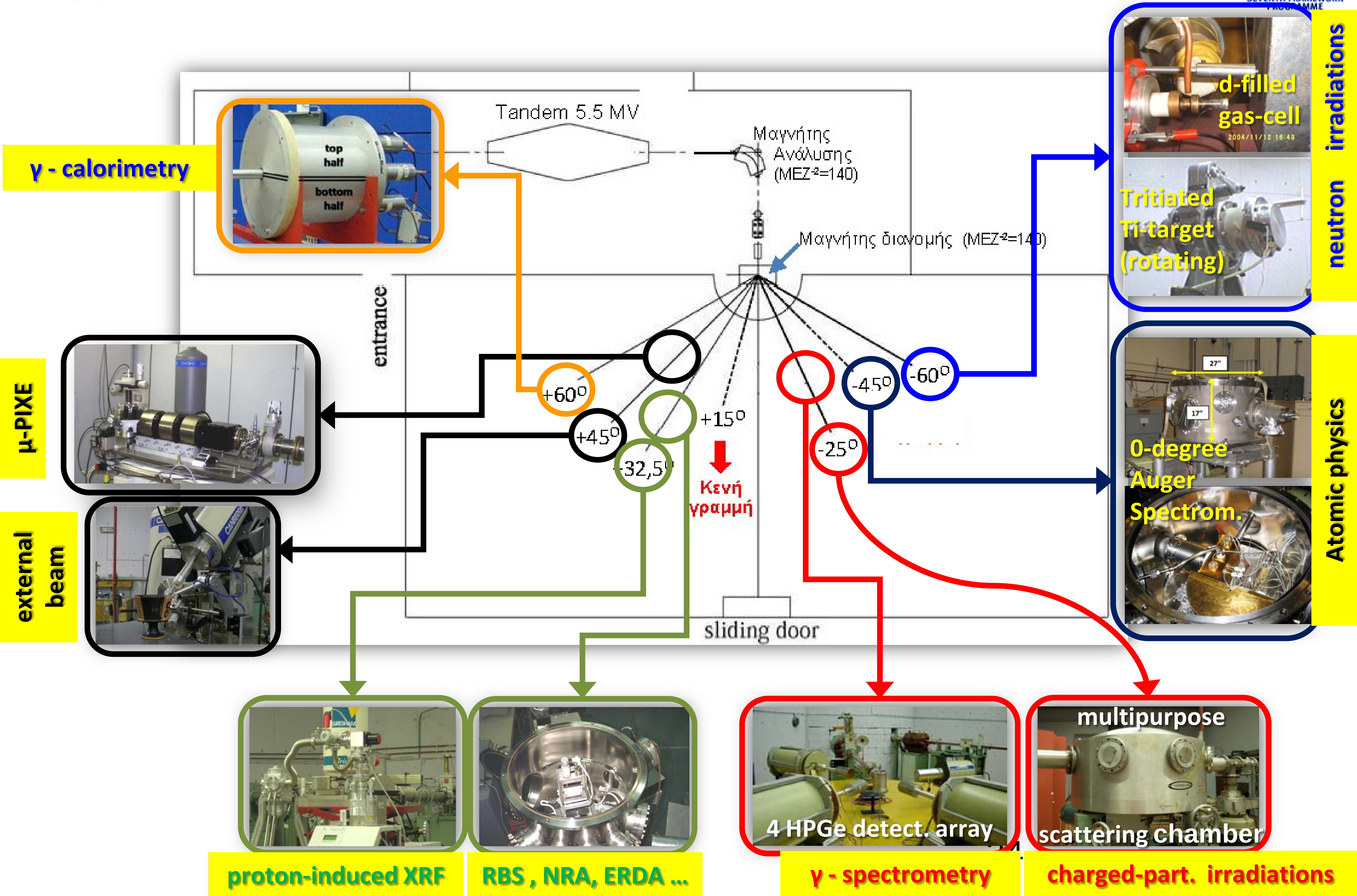
250 kV proton accelerator delivering

- high-current proton beams (≈0.5 mA)
- deuteron and α-beams possible

A 0.5 mA d-beam and a d-filled gas cell could provide ≈10^9 n/cm^{2}sec (E_n ≈ 3.5 MeV)
with a Tritiated-solid target we could obtain ≈10^{11} n/cm^{2}sec (E_n≈14 MeV)

PAPAP arrived in "Demokritos" during last week of July 2009

Center of Excellence in Low-energy Ion-Beam Research and Applications

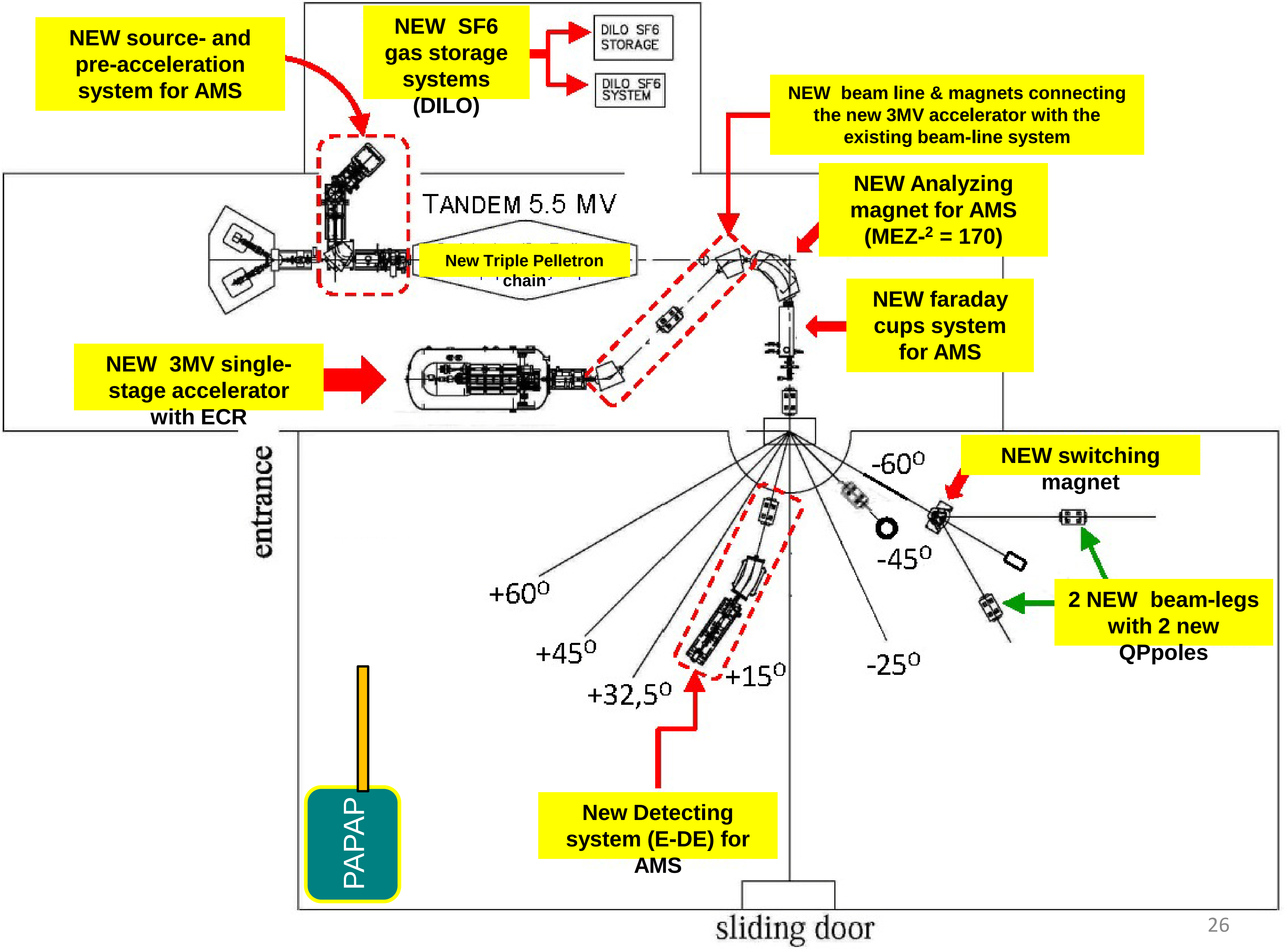


Center of Excellence in Low-energy Ion-Beam Research and Applications

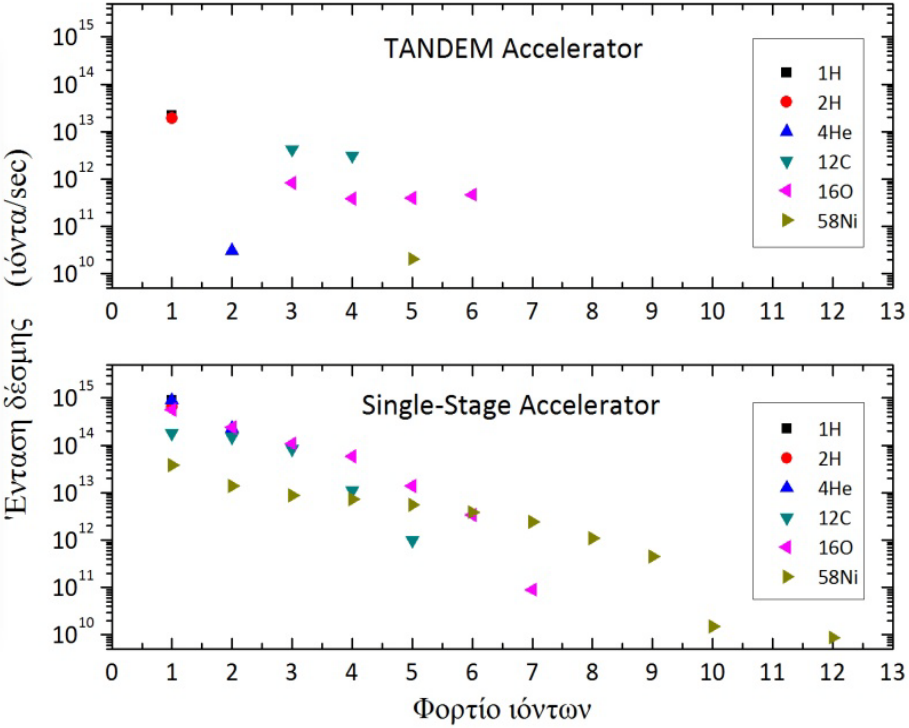
Εργαστήριο Επιταχυντού Tandem

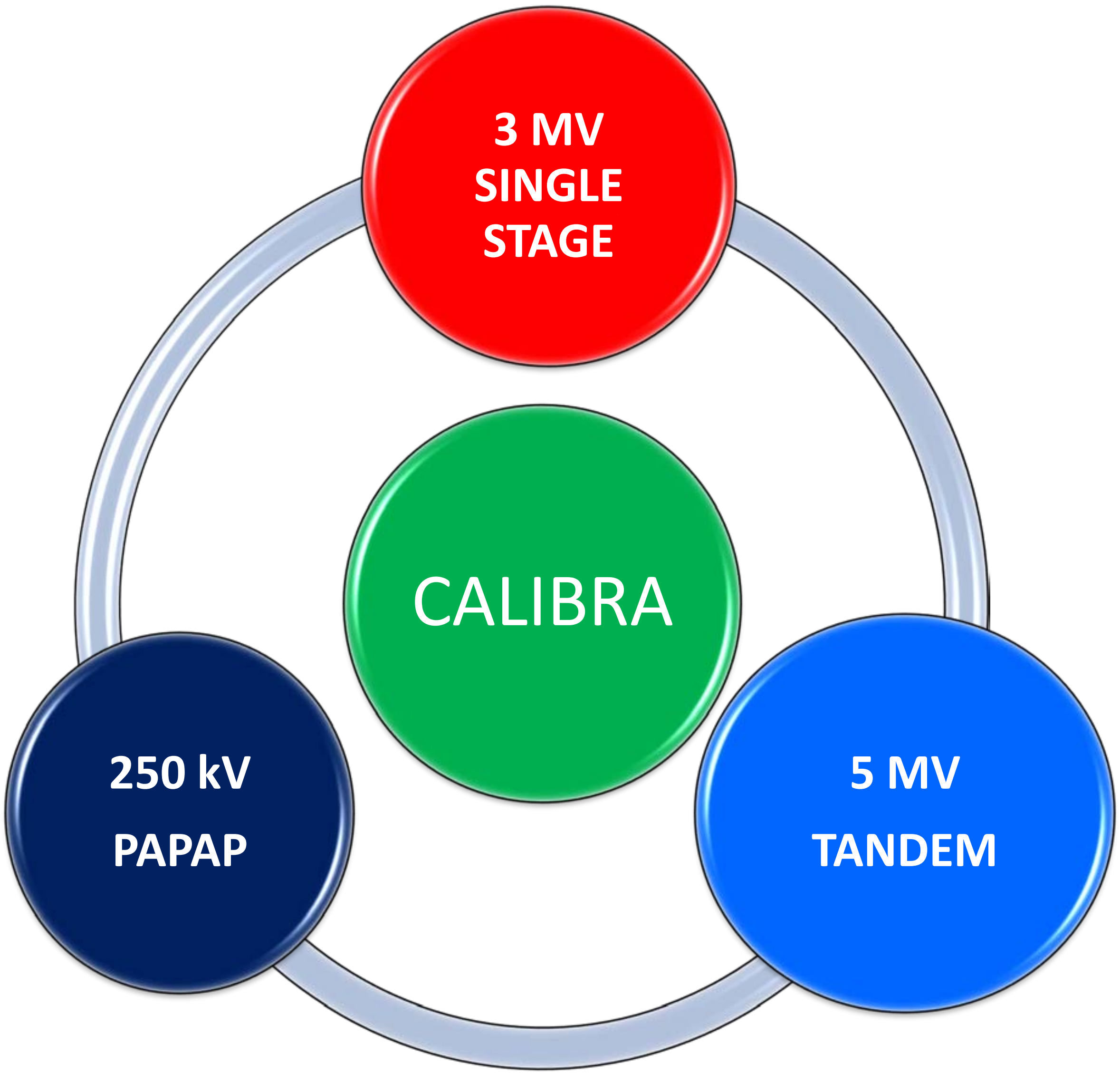
CALIBRA: Central Accelerator Laboratory for Ion-Beam Research and Applications

	GOAL (& title)	TASK	Task description	BUDGET (€)
WORK PACKAGE 1 WP 1	ACCELERATOR SYSTEMS	1.1	Upgrade of existing Tandem Accelerator	650.000
		1.2	Acquisition & installation of a new high-current single-stage 3MV accelerator with ECR source	2.180.000
		1.3	Acquisition of AMS system components and installation at the (upgraded) Tandem *(requires first task 1.1 to be completed)*	1.720.000
			Total budget of WP1	**4.550.000**
WP 2	SUPPORTING FACILITIES	2.1	Upgrade of Workshop.	115.000
		2.2	Upgrade of existing target preparation lab.	135.000
		2.3	Upgrade of existing XRF lab.	145.000
		2.4	Installation of an AMS dedicated independent lab for AMS target preparation and analysis	230.000
			Total budget of WP2	**625.000**
WP 3	INSTRUMENTS	3.1	New detectors for γ- and particle spectroscopy and neutron counting	290.000
		3.2	Upgrade of existing data acquisition system	75.000
			Total budget of WP3	**365.000**
WP 4	BUILDING	4.1	Upgrade of the building hosting the existing Tandem accelerator laboratory	200.000
			Total budget of WP4	**200.000**
			TOTAL BUDGET	**5.740.000**



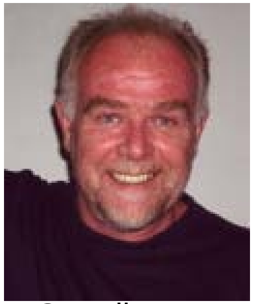
NEW source- and pre-acceleration system for AMS
NEW SF6 gas storage systems (DILO)
DILO SF6 STORAGE
DILO SF6 SYSTEM
NEW beam line & magnets connecting the new 3MV accelerator with the existing beam-line system
TANDEM 5.5 MV
New Triple Pelletron chain
NEW Analyzing magnet for AMS (MEZ-2 = 170)
NEW faraday cups system for AMS
NEW 3MV single-stage accelerator with ECR
entrance
NEW switching magnet
-60°
-45°
+60°
+45°
+32,5°
+15°
-25°
2 NEW beam-legs with 2 new QPpoles
PAPAP
New Detecting system (E-DE) for AMS
sliding door


TANDEM Accelerator
Single-Stage Accelerator
1H
2H
4He
12C
16O
58Ni
Ένταση δέσμης (ιόντα/sec)
Φορτίο ιόντων


3 MV
SINGLE
STAGE
CALIBRA
250 kV
PAPAP
5 MV
TANDEM

Center of Excellence in Low-energy Ion-Beam Research and Applications

LIBRA PEOPLE



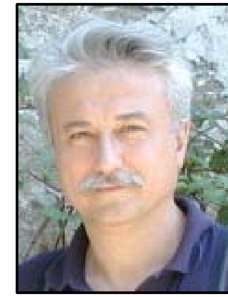
Coordinator:
S. V. Harissopulos

WP2 Leader:
Th. Geralis

WP3 Leader:
A. G. Karydas

WP4 Leader:
A. Lagoyannis

WP5 Leader:
P. Demetriou

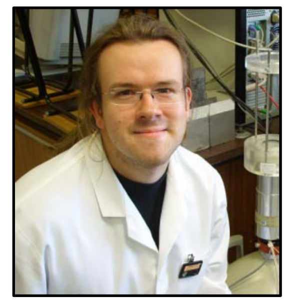


WP6 Leader:
G. Fanourakis

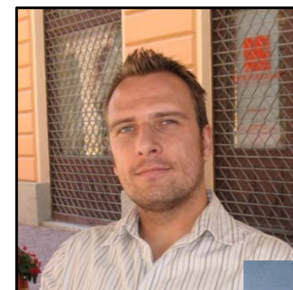
M. Andrianis

Th. J. Mertzimekis

M. Axiotis



S. F. Ashley



R. Huszank

V. Paneta

V. Kantarelou

Th. Konstantinopoulos

V. Foteinou

G. Provatas

D. Sokaras

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

ESF Workshop on
"The future of stable beams in Nuclear Astrophysics"
NCSR "Demokritos", Athens, Greece,
December 14-15, 2007

The Workshop focused on the importance of stable ion-beams on Nuclear Astrophysics studies. ..

Almost half of the time of the Workshop was devoted to round-table discussions on

a) the need to create a new low-energy stable ion-beam facility in Europe that will be dedicated to Nuclear Astrophysics studies,
b) the demanding specifications the new facility will have to meet in order to resolve outstanding open questions in Nuclear Astrophysics and
c) the major scientific problems that can be studied almost exclusively with stable ion-beams.

1) Many nuclear reactions across the periodic table play an important role in the aspects of stellar nucleosynthesis. Some of them (≈25 reactions among light nuclides) are considered as the “key reactions” as they play a decisive role in the energy production in stars as well as in their evolution. The very small cross sections of these reactions initiated a severe number of indirect measurements that improved our knowledge of stellar evolution considerably. Yet, as their results suffer from model dependencies, they cannot replace the direct measurements. The latter are still considered to provide the clearest signatures of many astrophysical phenomena.

2) Direct measurements require intense low-energy stable ion-beams (notably protons, alpha-particles and some other heavier nuclides) with a proper energy resolution (1 keV). Unfortunately, leading nuclear astrophysics laboratories in Europe fulfilling these requirements are already closed or will be closed in the near future, while others have been “transformed” into analytical laboratories or irradiation facilities in order to survive in a highly competitive environment, where the demand for industrial applications has washed out many basic research activities in the field of low-energy nuclear physics. As a result, a flagship facility for nuclear astrophysics studies in Europe is missing and, hence, there is an urgent need for Europe to create a new state-of-the art high-current facility equipped with advanced detection techniques.

Accelerators and Instrumentation for nuclear astrophysics

	Stellar Burning				Explosive Burning				
FACILITY/REACTIONS	H	He	HI	s	r	rp	αp	γ	ν
Low-E Stable Beam									
High-E Stable Beam									
RIB-ISOL									
RIB-Fragmentation									
Spallation n (ν) source									
Free Electron Laser									

SITE	Big Bang	Cosmic Rays	Super-novae	Neutron Stars
Low-E Stable Beam				
High-E Stable Beam				
RIB-ISOL				
RIB-Fragmentation				
Neutrino sources				

Accelerators and Instrumentation for nuclear astrophysics

	LE-SB	HE-SB	RIB ISOL	RIB FRAG	SNS	FEL
Gamma array-segmented						
Silicon-Strip Arrays						
Neutron Array						
Spectrograph						
Mass Separator						
Gas/Liquid Targets						
Radioactive Targets						
Traps						