Project SPIRAL2-CZ in NPI CAS

Jaromir Mrazek

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

This work was supported by OP RDE, MEYS, Czech Republic under the project SPIRAL2-CZ, CZ.02.1.01/0.0/0.0/16_003/0001679

What is GANIL/SPIRAL2

1975 - Decision to build „GANIL“

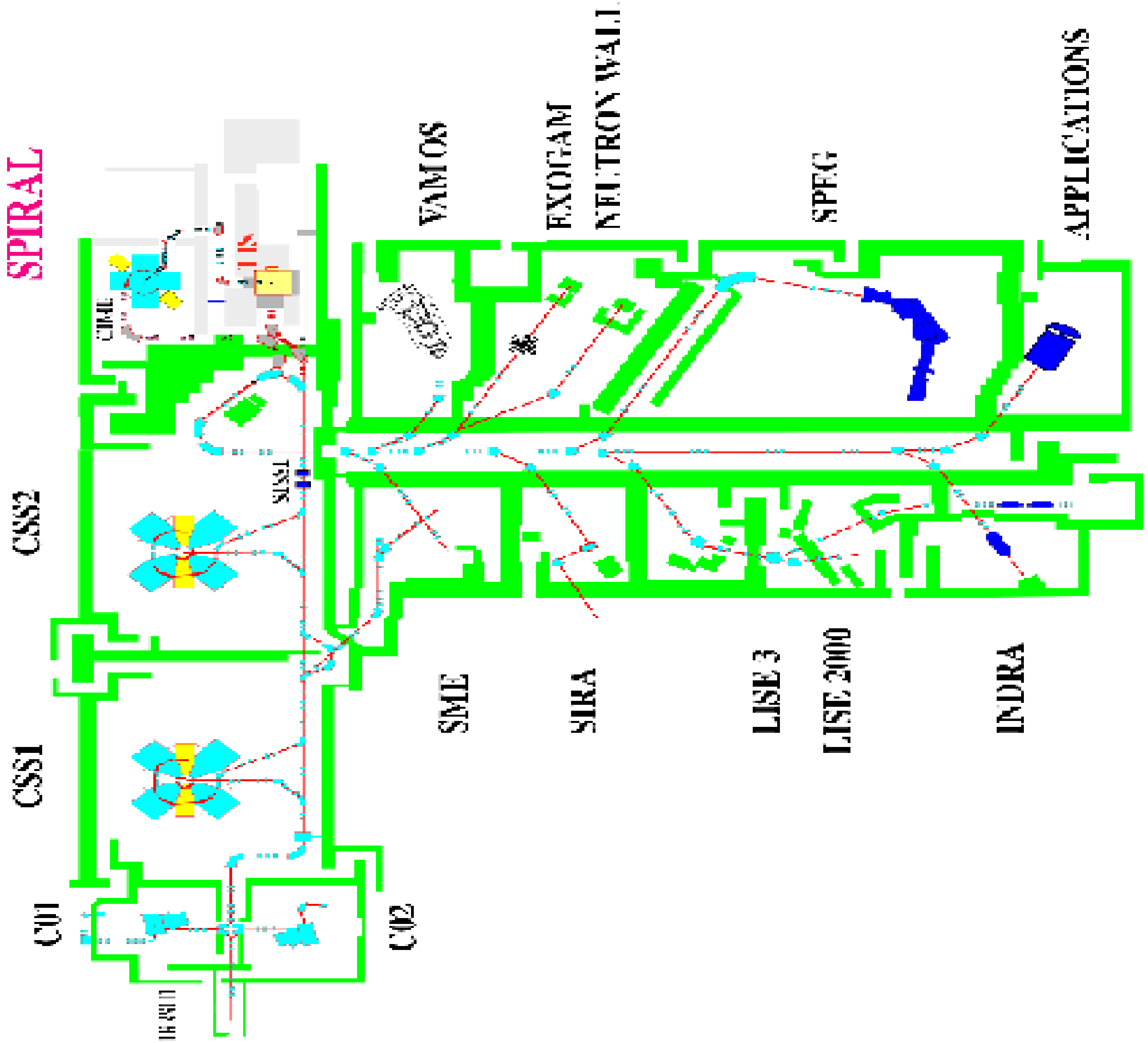
1983 – first experiment

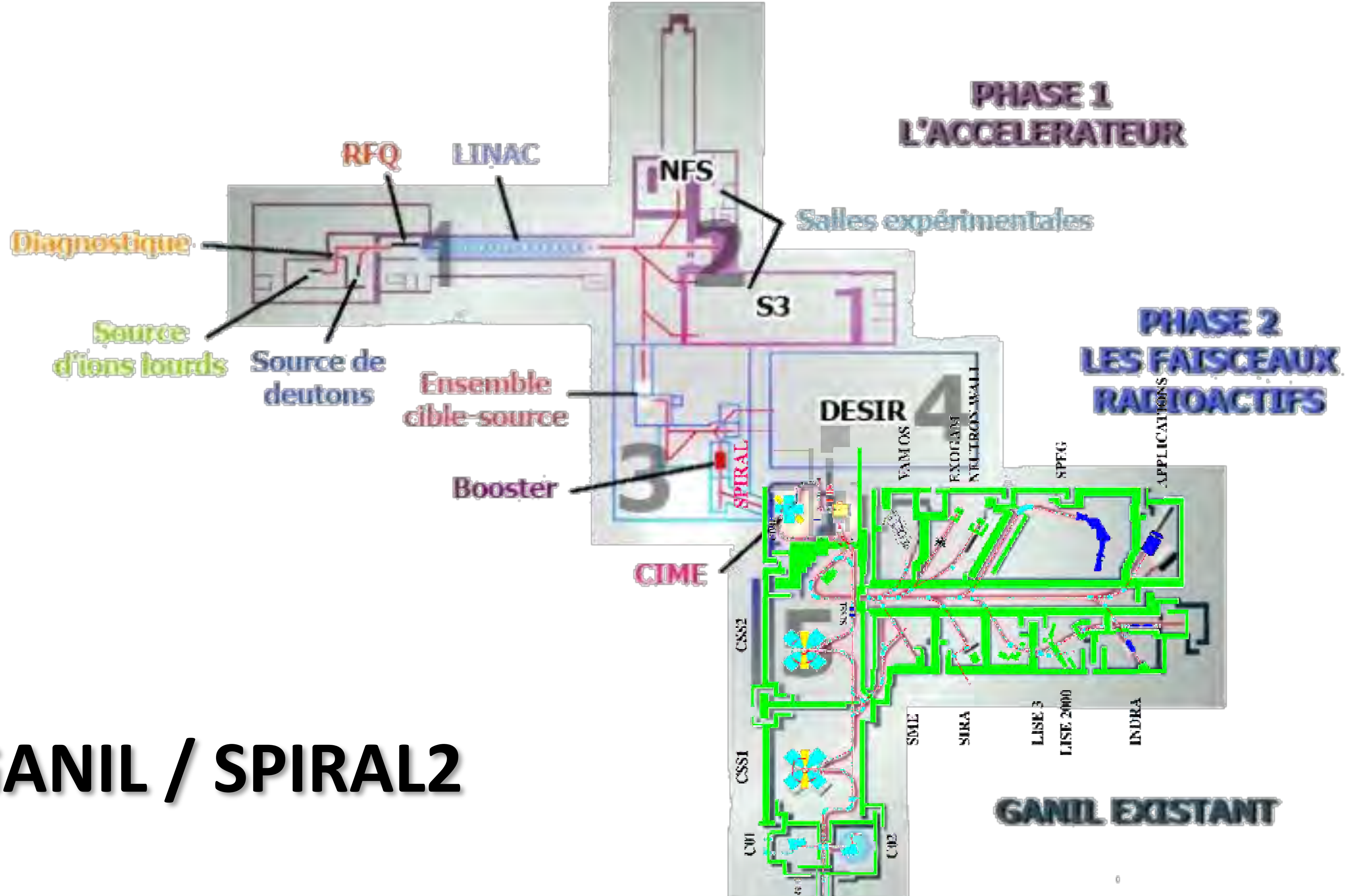
GANIL –
Grande Accélérateur
 National
d‘Ion Lourdes

GANIL

Two cyclotrons CSS1 CSS2
- stable beams
- beams by fragmentation

One post-acceleration cyclotron for radioactive species at low energies "SPIRAL"



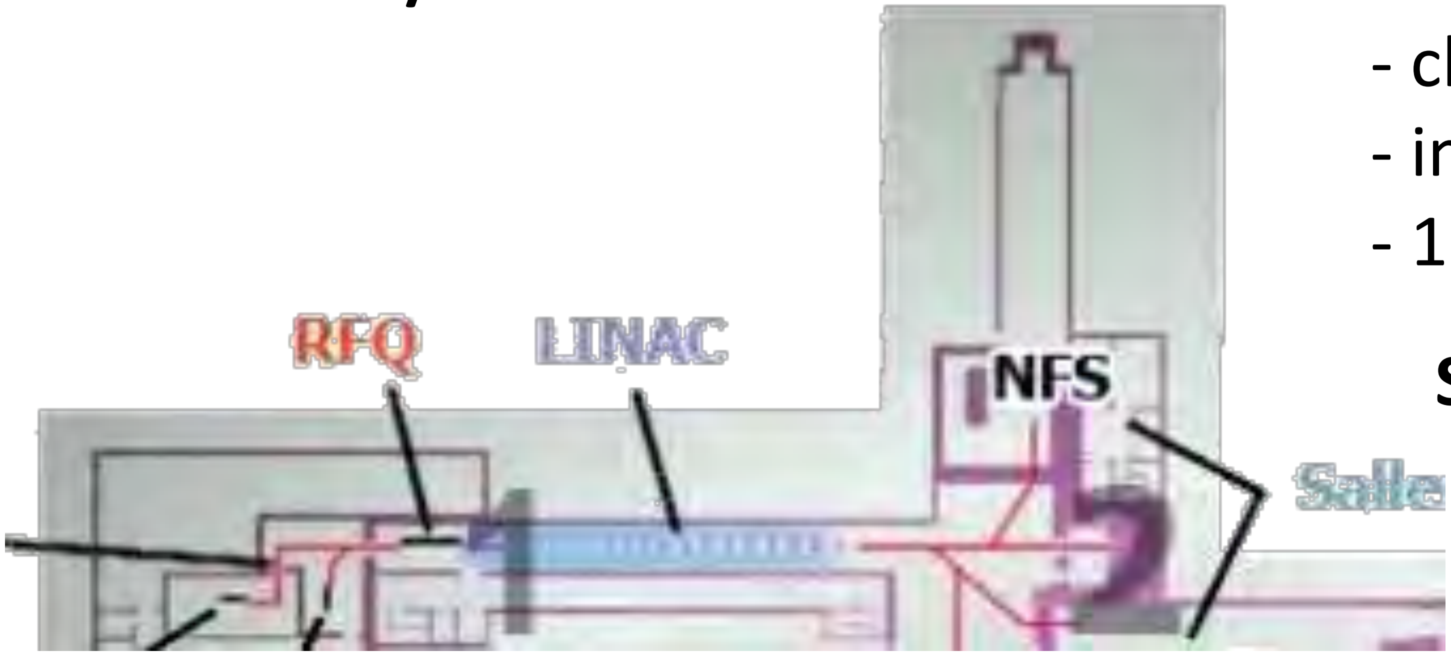


GANIL / SPIRAL2

SPIRAL2/NFS presented by X.Ledoux

Primary goal – neutron beams

2018/2019



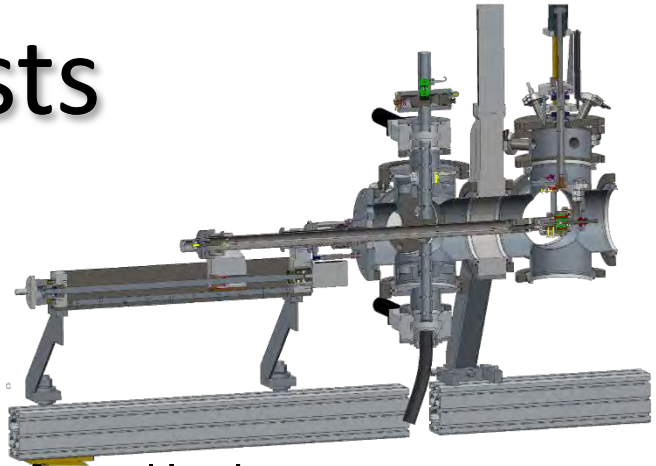
Since

- close to LINAC
- intensive beams (limit 50uA / 5mA)
- 1st equipment to be commissioned

Secondary goal

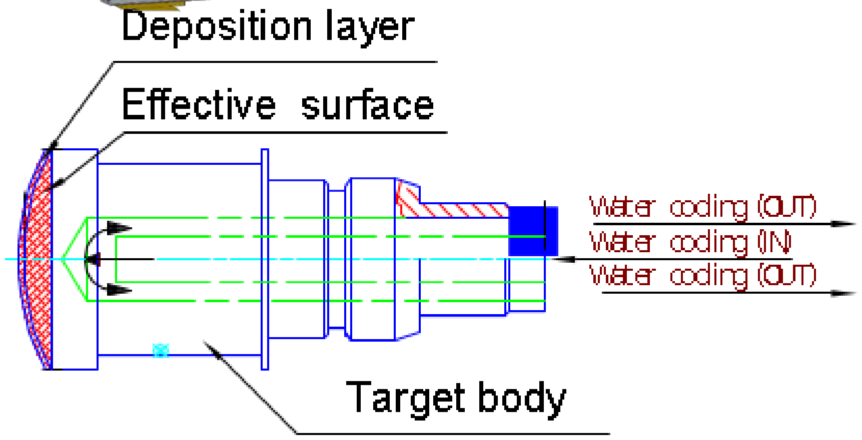
- charged particle experiments

Czech Republic interests



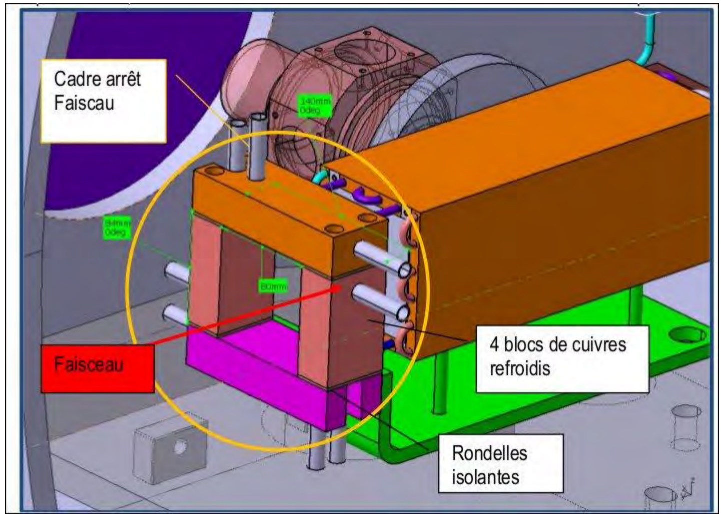
Program of Activation by charged particles

- E.Simeckova, NPI CAS, M+V Avrigeanu, IFIN HH



Radioisotopes for medicine

- O.Lebeda, G. de France



Nuclear astrophysics

- J.Mrazek, F.de Oliveira, B.Bastin

SPIRAL2-CZ

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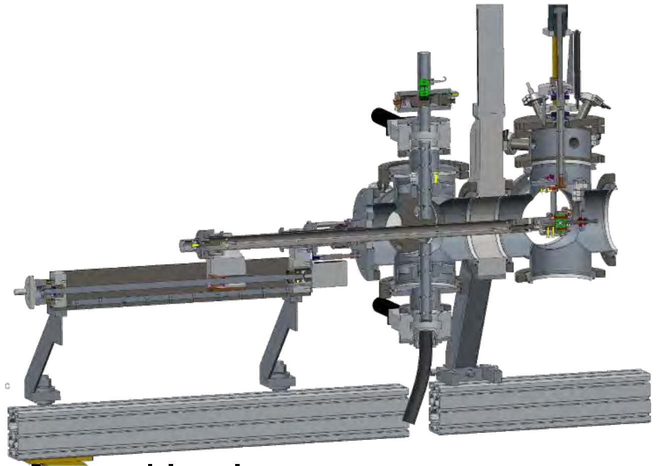

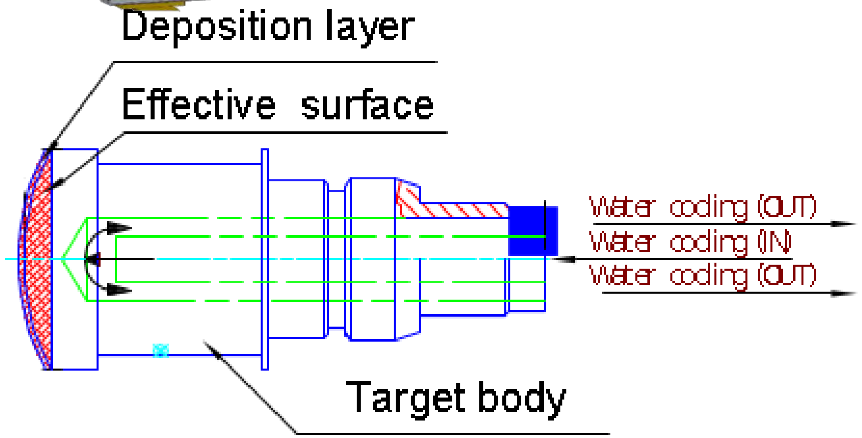

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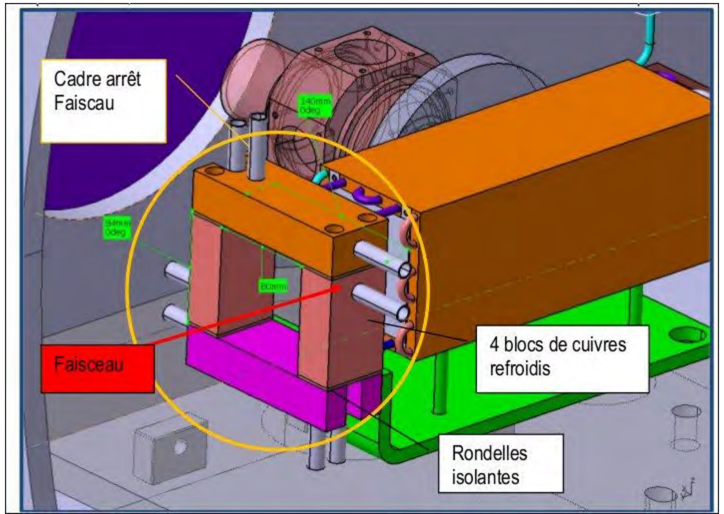

SPIRAL2-CZ

NPI CAS spiral2·CZ

Czech Republic contribution to SPIRAL2

GANIL

SPIRAL2-CZ

has appeared on

the roadmap of large research infrastructures of Czech Republic 2016-2022

Plan of support from MEYS (plan 7 years)

LM SPIRAL2-CZ (4 y., to 7 y)

- infrastructure development

SPIRAL2-CZ-OP (3.r)

Operational program EU

- Investments
- research

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Activation by charged particles in NFS

- experimental equipment: irradiation chamber`+ PTS

Experiments at low energies in NFS

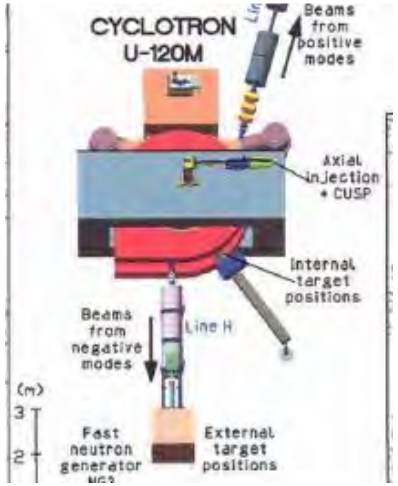
- nuclear astrophysics context

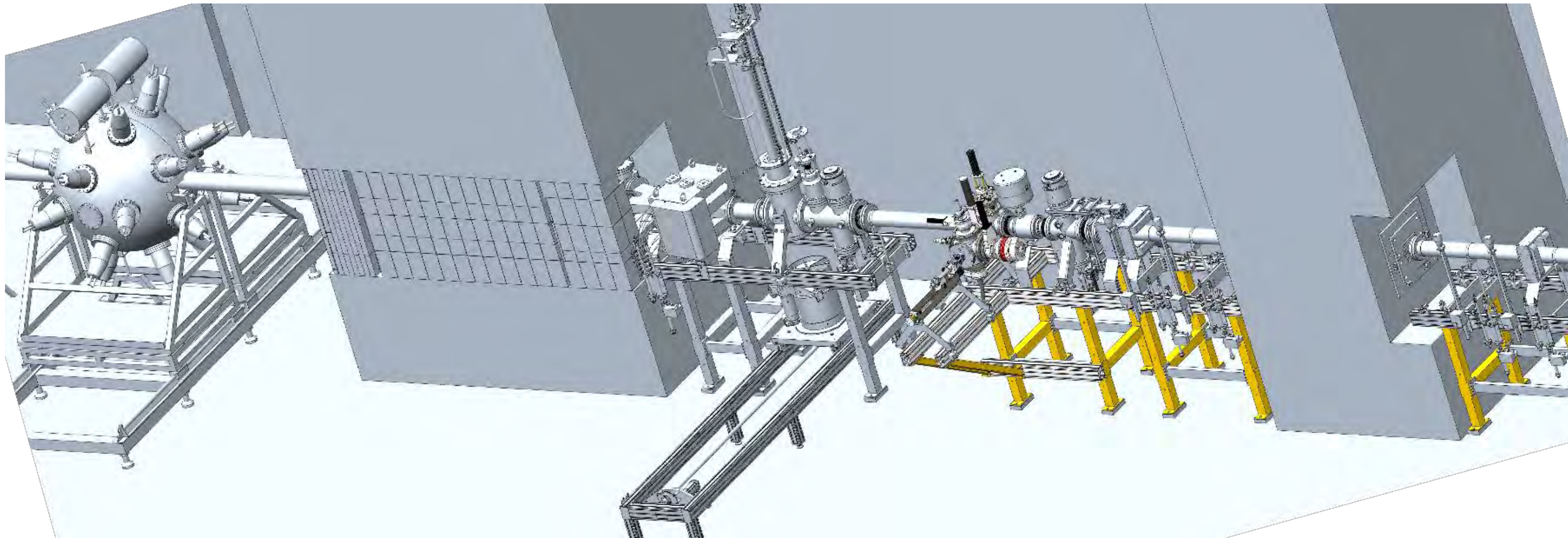
Activation by charged particles: motivation

presentation of M.Avrigeanu

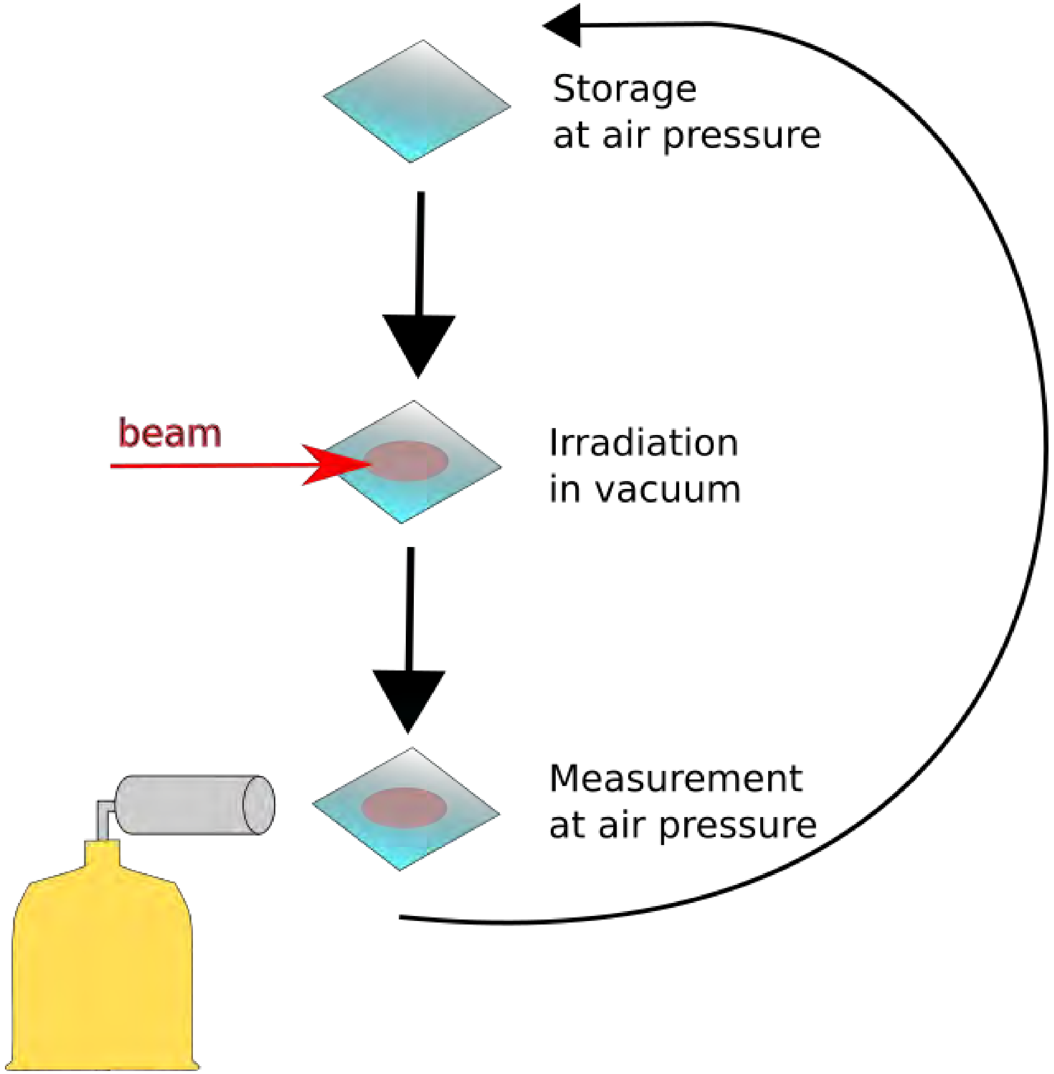
- **NPI CAS Rez**
- deuterons in up to 20 MeV
- half-lives limited by stack handling

- **SPIRAL2/NFS**
- deuterons up to 40 MeV
- short-lived isotopes



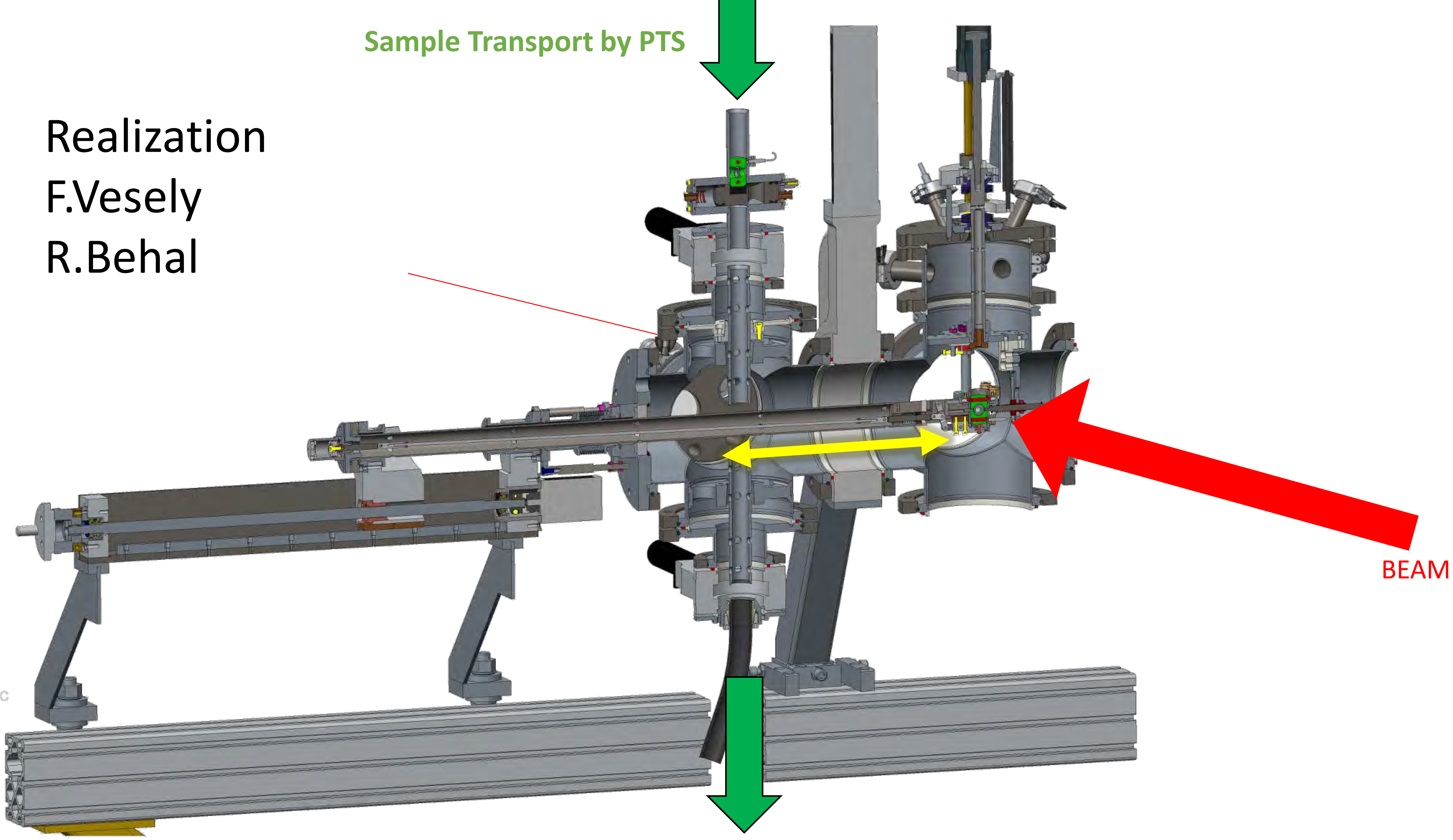


Activation by charged particles - mechanical concept 1

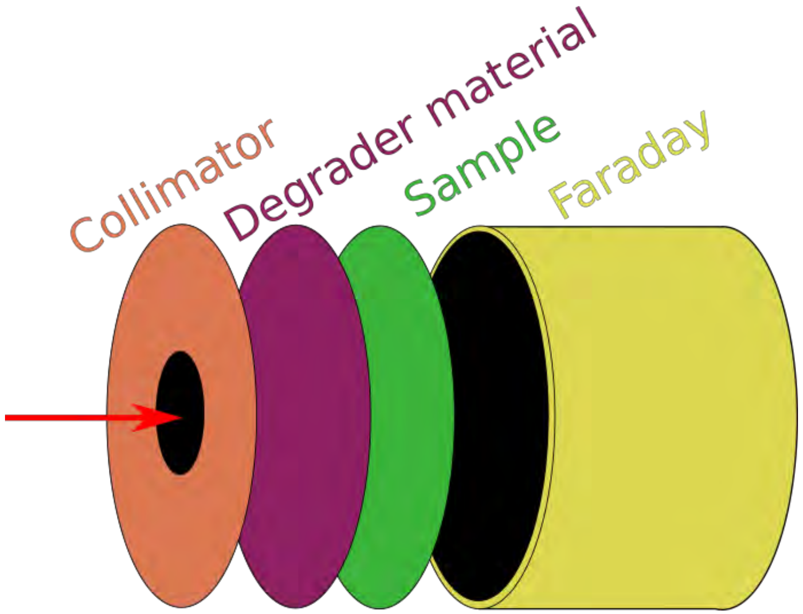


See E.Simeckova presentation

Realization
F.Vesely
R.Behal



Activation by charged particles - mechanical concept 2



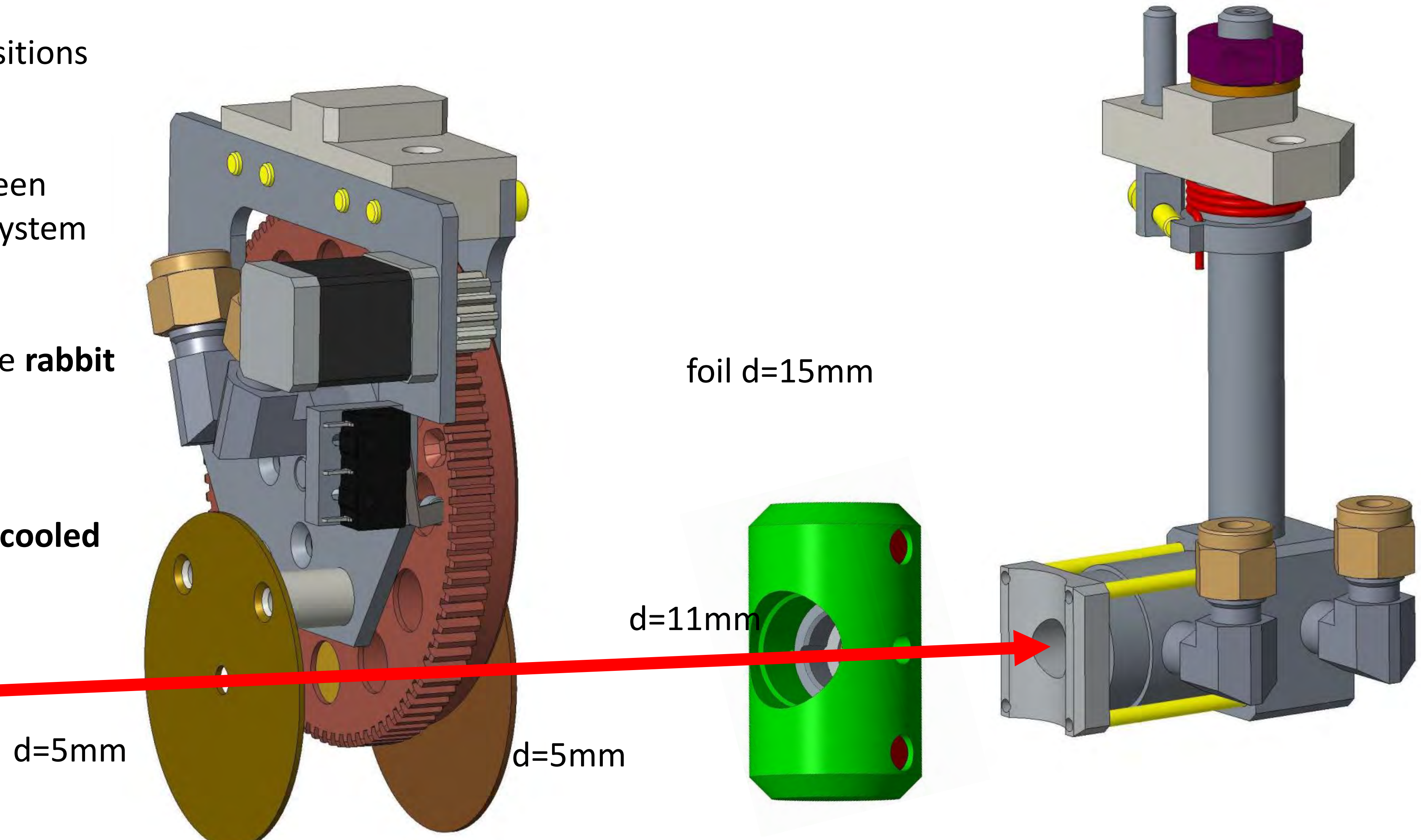
Detail of the irradiation system – R.Behal

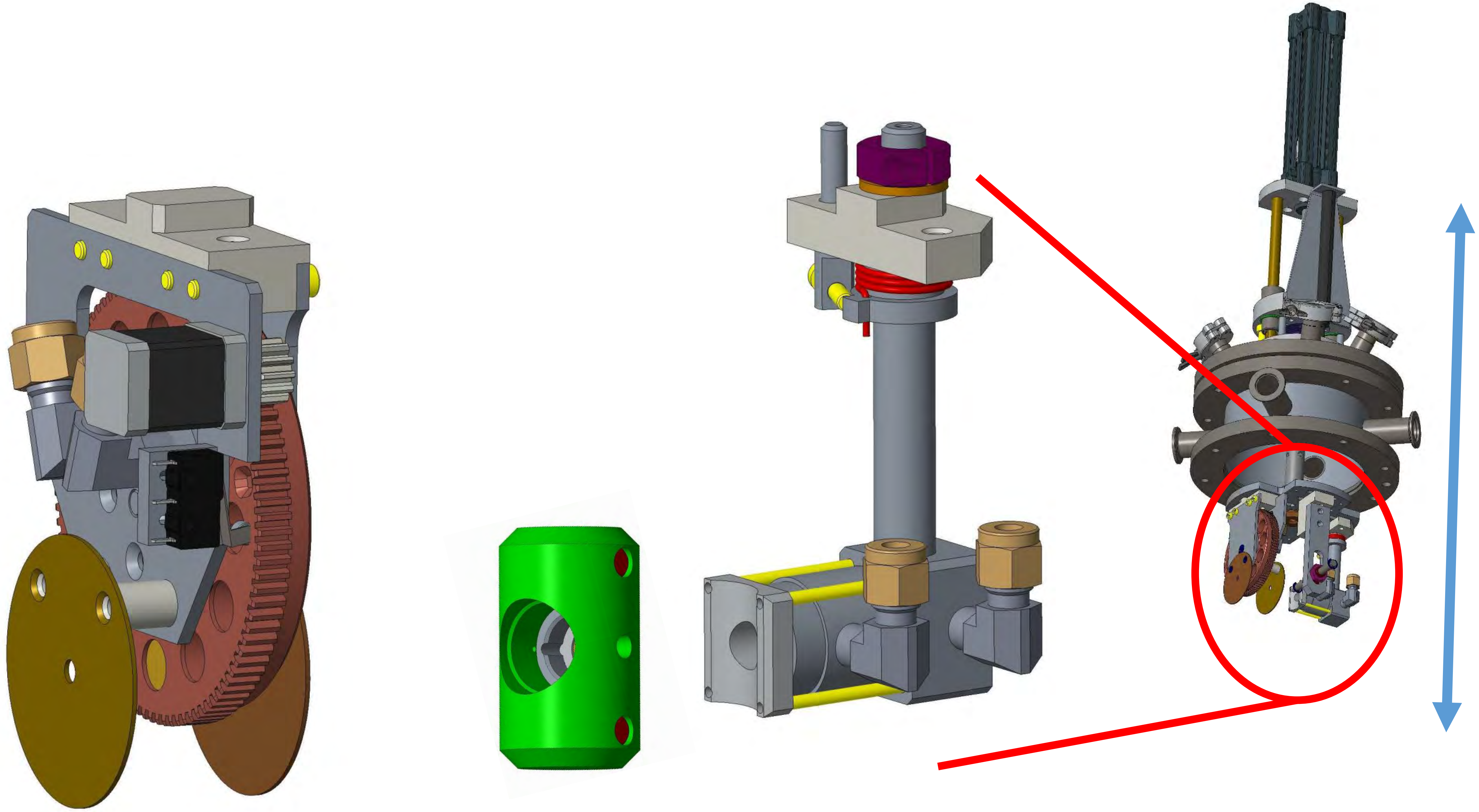
rotating **degrader** – 12 positions

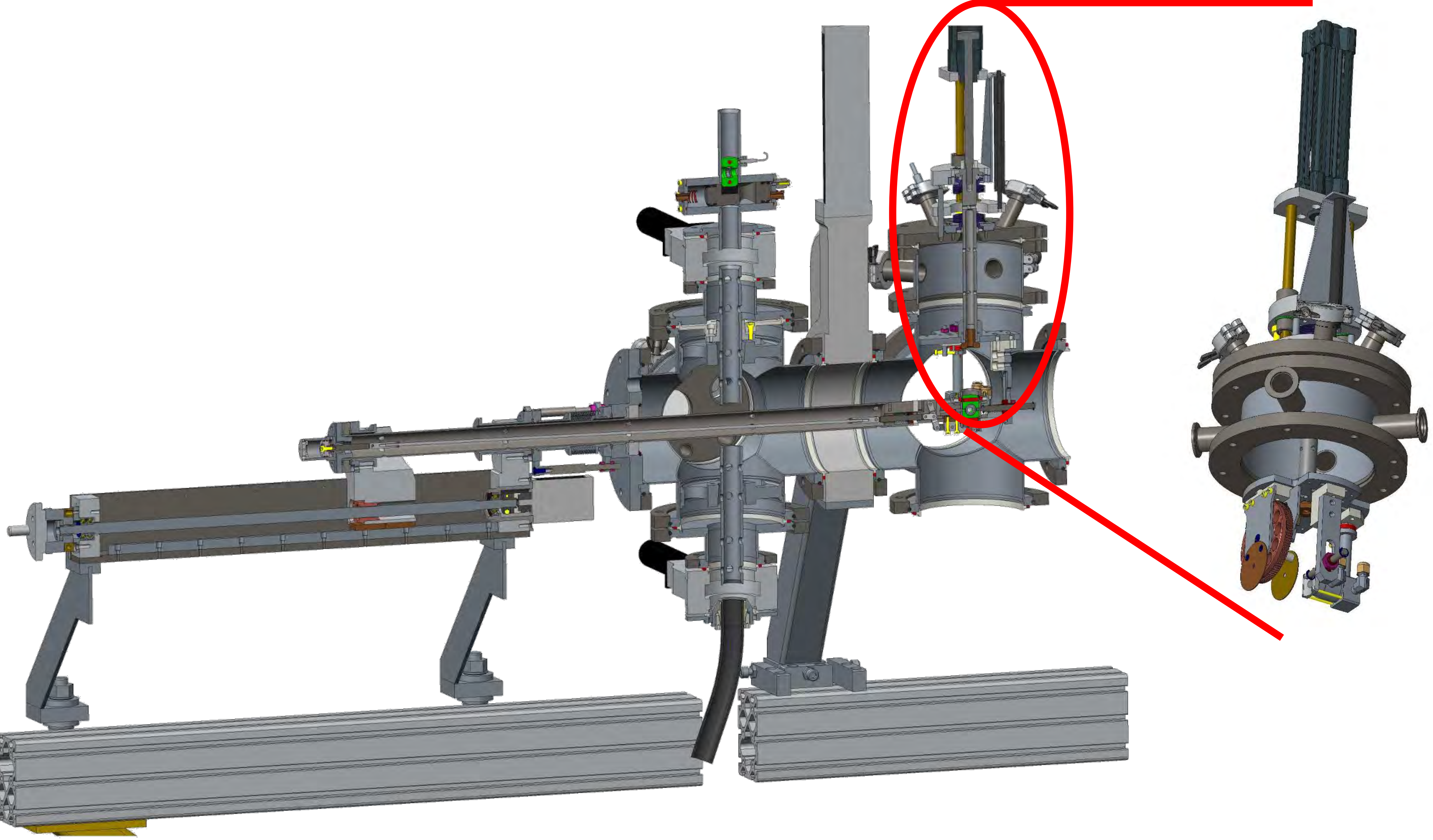
one more **electrode** between
degrader and Faraday system

Faraday in **contact** with the **rabbit**
- **thermal**
- **electrical**

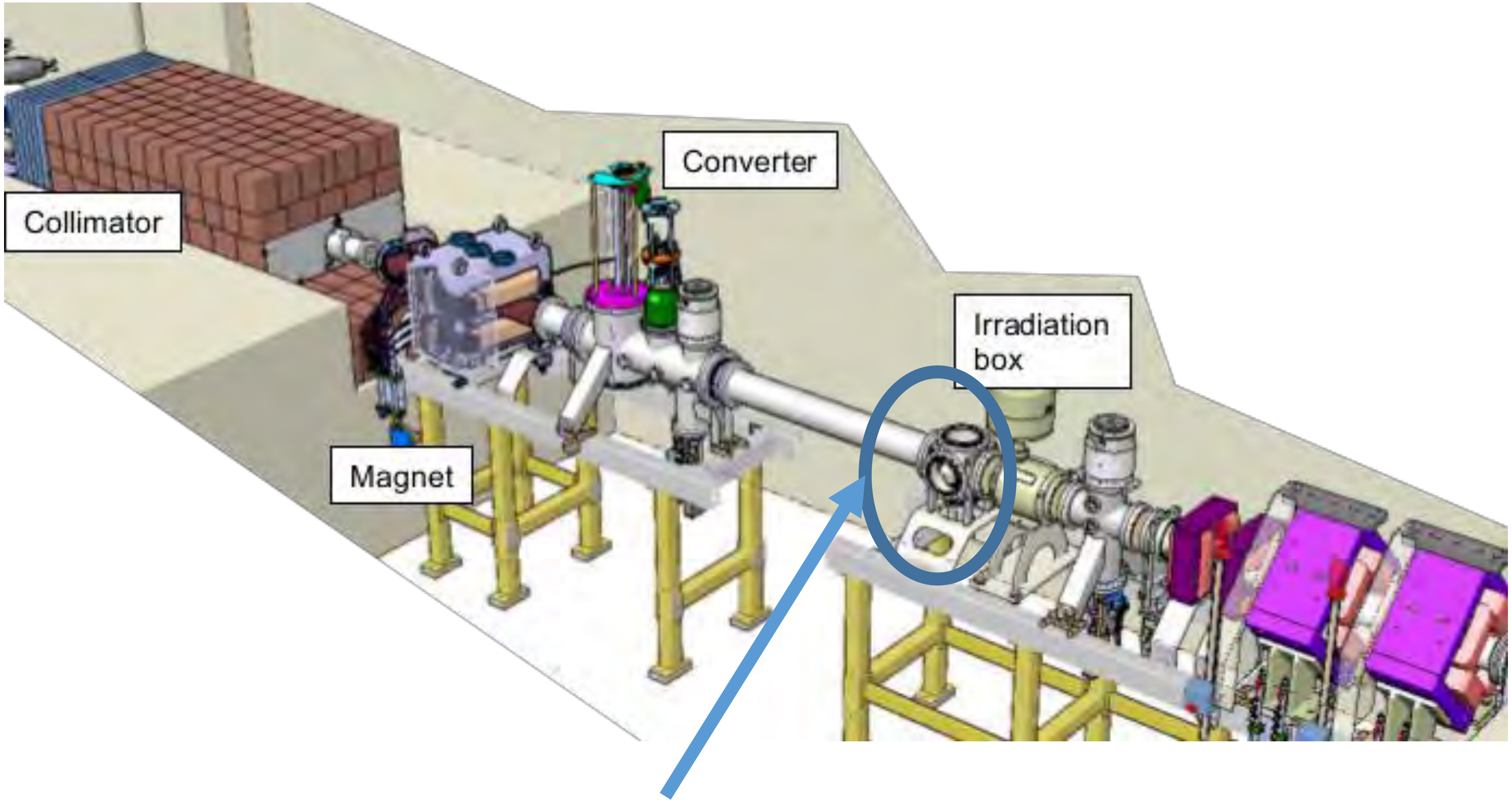
degrader and Faraday are **cooled**



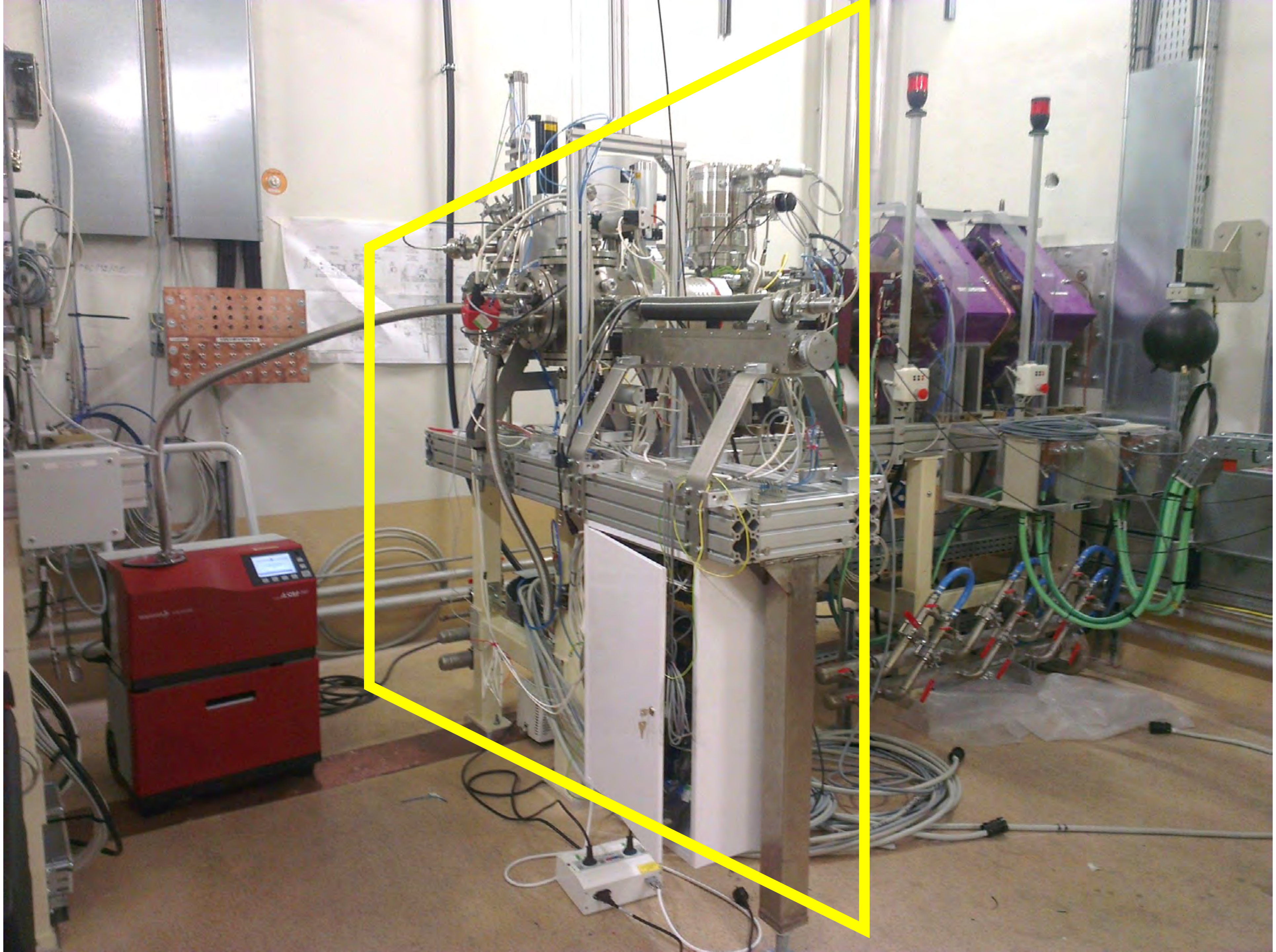




Irradiation Chamber in SPIRAL2/NFS

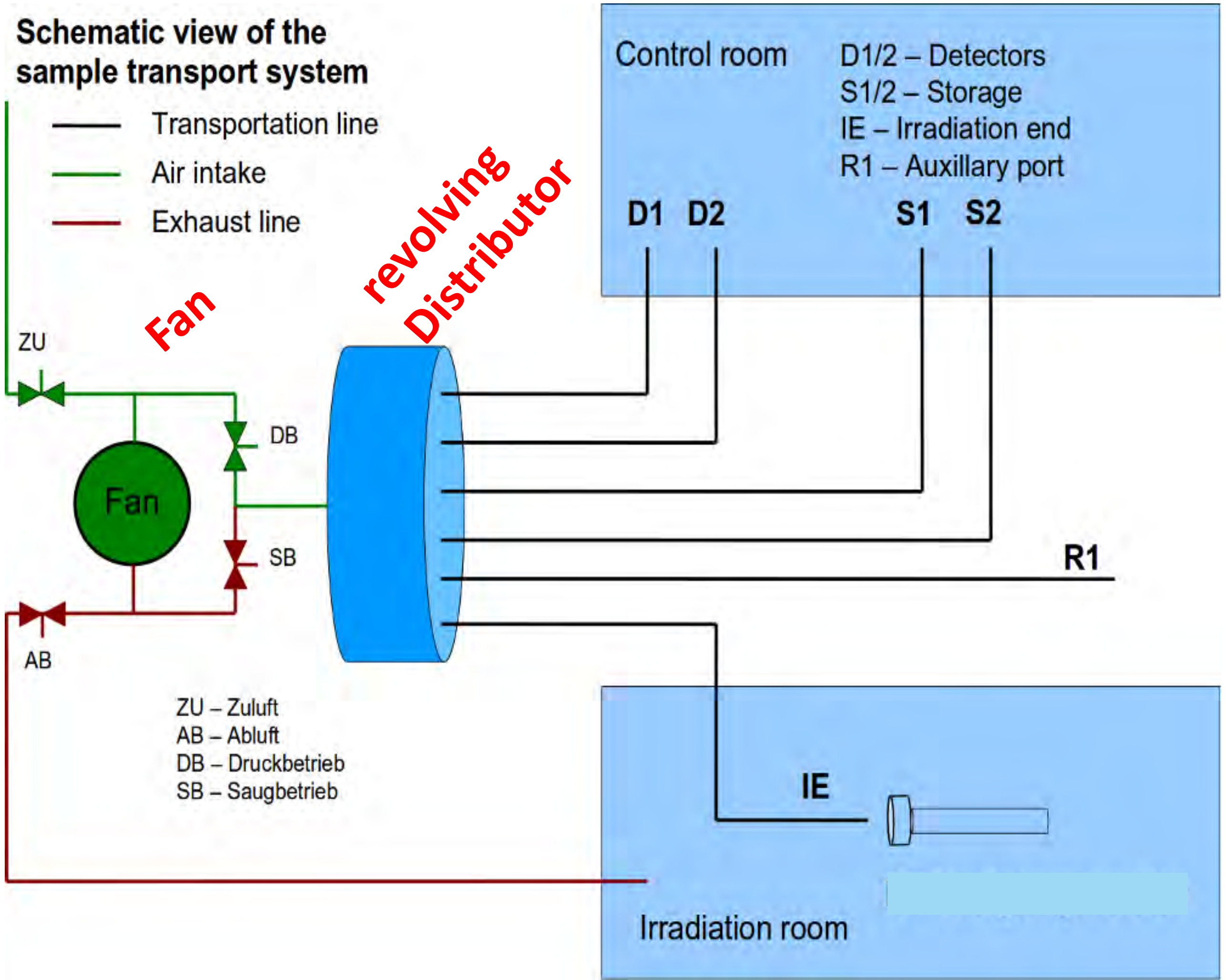


Irradiation Chamber



PTS – Pneumatic Transfer System from KIT for Irradiation Chamber

Delivered by A.Klix, U.Fischer
from KIT Karlsruhe,
based on system of TU Dresden



PTS – Pneumatic Transfer System from KIT for Irradiation Chamber

Delivered by A.Klix, U.Fischer
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TU Dresden:
n – activation photo

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Delivered by A.Klix, U.Fischer
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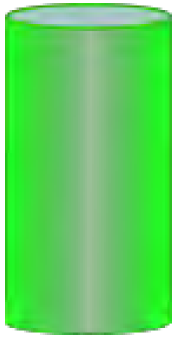
based on system of TU Dresden

Fortunate situation for NPI

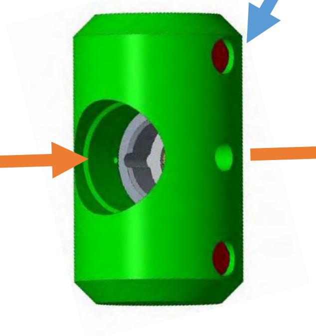
but modifications needed:

- sample – foil placement from side
- rabbit orientation at
    - HPGe station
    - Irradiation Chamber
- rabbit (Aluminium) is heavier
  – new braking system at all points

- PTS coupling to a complex control system

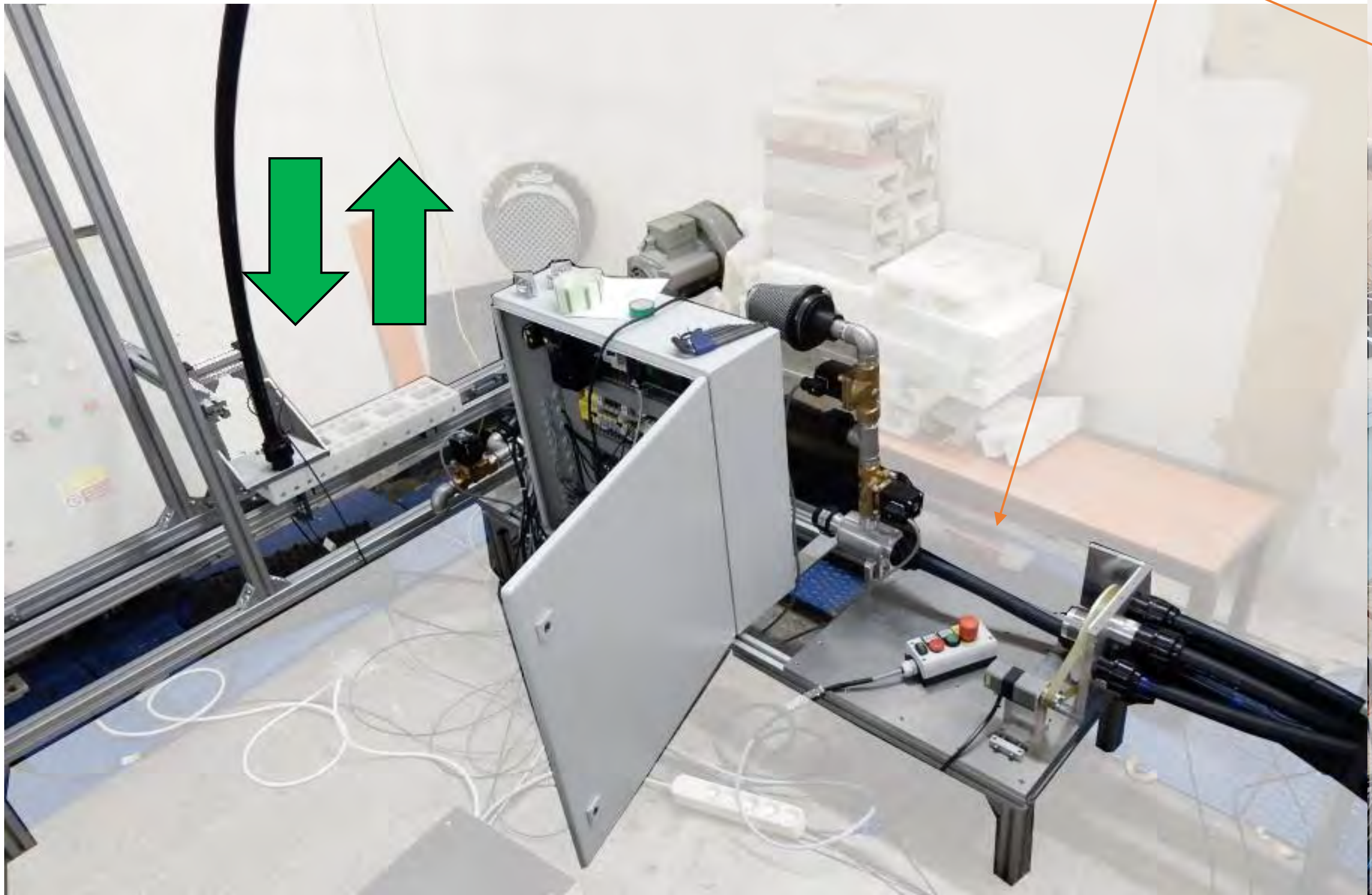


rabbit orientation by magnets

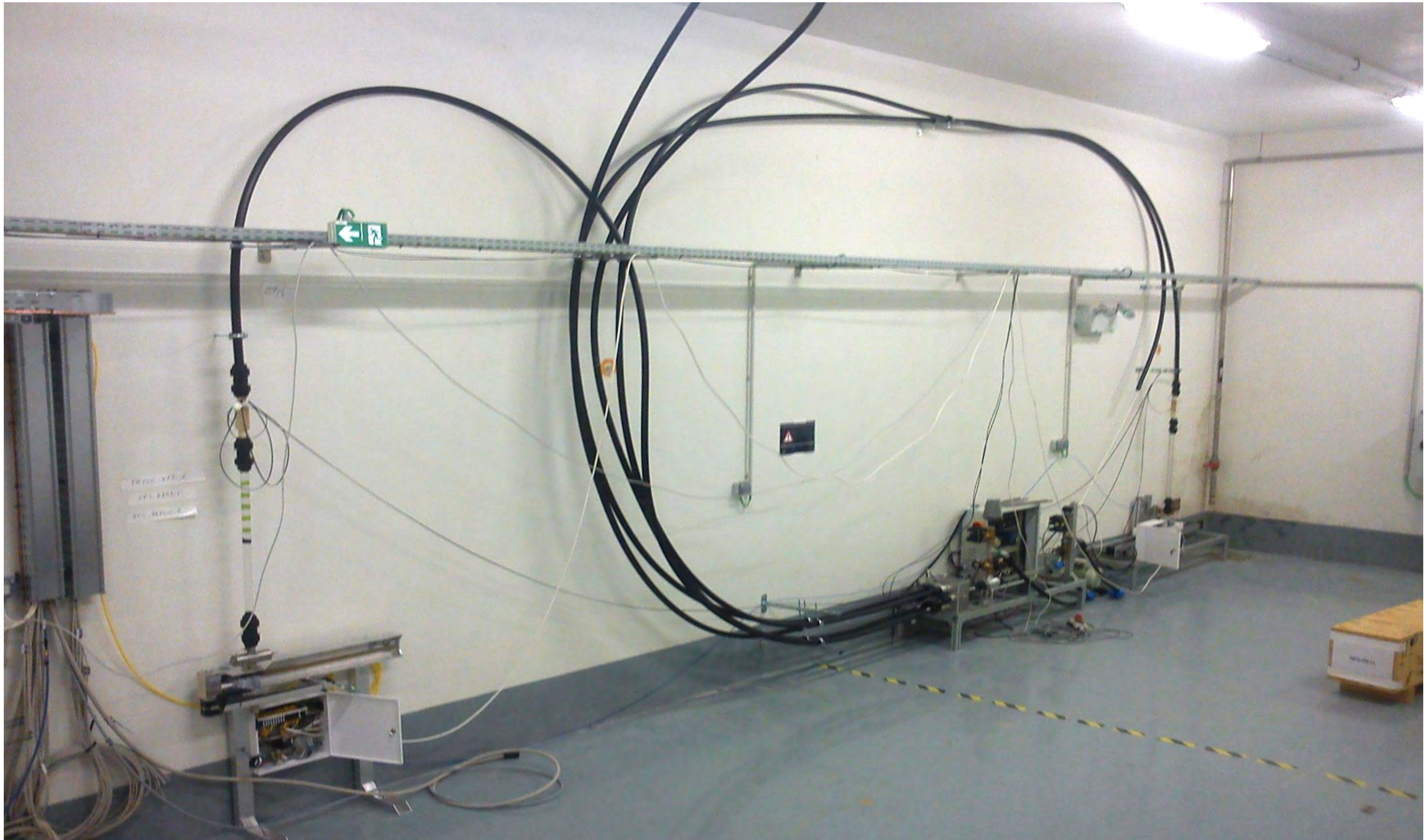


PTS – Pneumatic Transport System from KIT

air brake system for heavy weight rabbits



PTS in SPIRAL2/NFS - TOF hall end



Activation by charged particles in NFS

- experimental equipment: irradiation chamber`+ PTS

Experiments at low energies in NFS

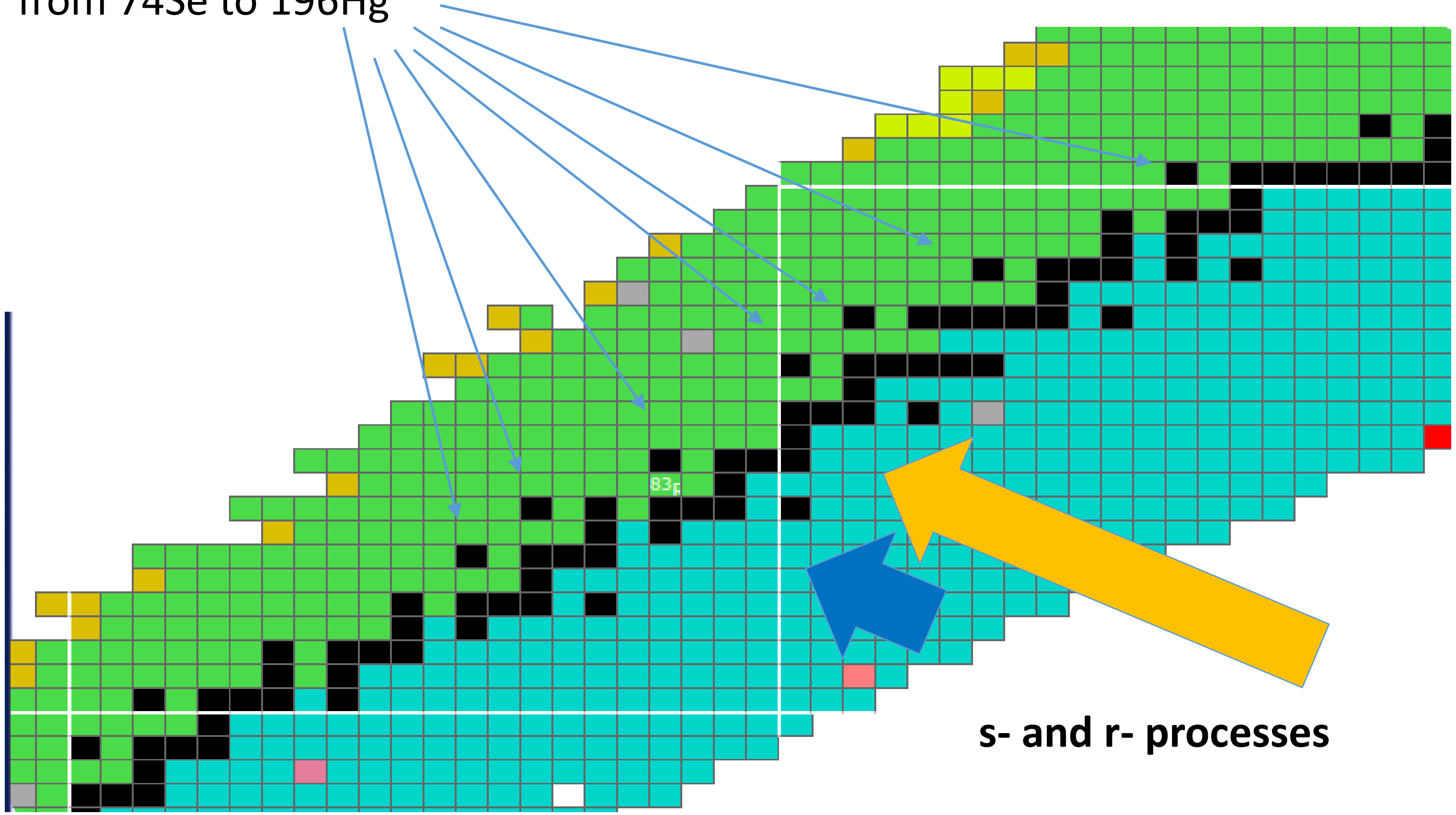
- nuclear astrophysics context

p-process

35nuclei

from 74Se to 196Hg

discrepancies:
Mo, Ru, Sn, La, Gd
underproduced



s- and r- processes

Scenario : (gamma,n) reactions, after (gamma,p) and (gamma,alpha) continue

LoI p-process : direct kinematics measurements @ SPIRAL2-NFS

LoI : B. Bastin, G. Randisi, C. Ducoin, I. Companis, S. Harissopulos *et al.*

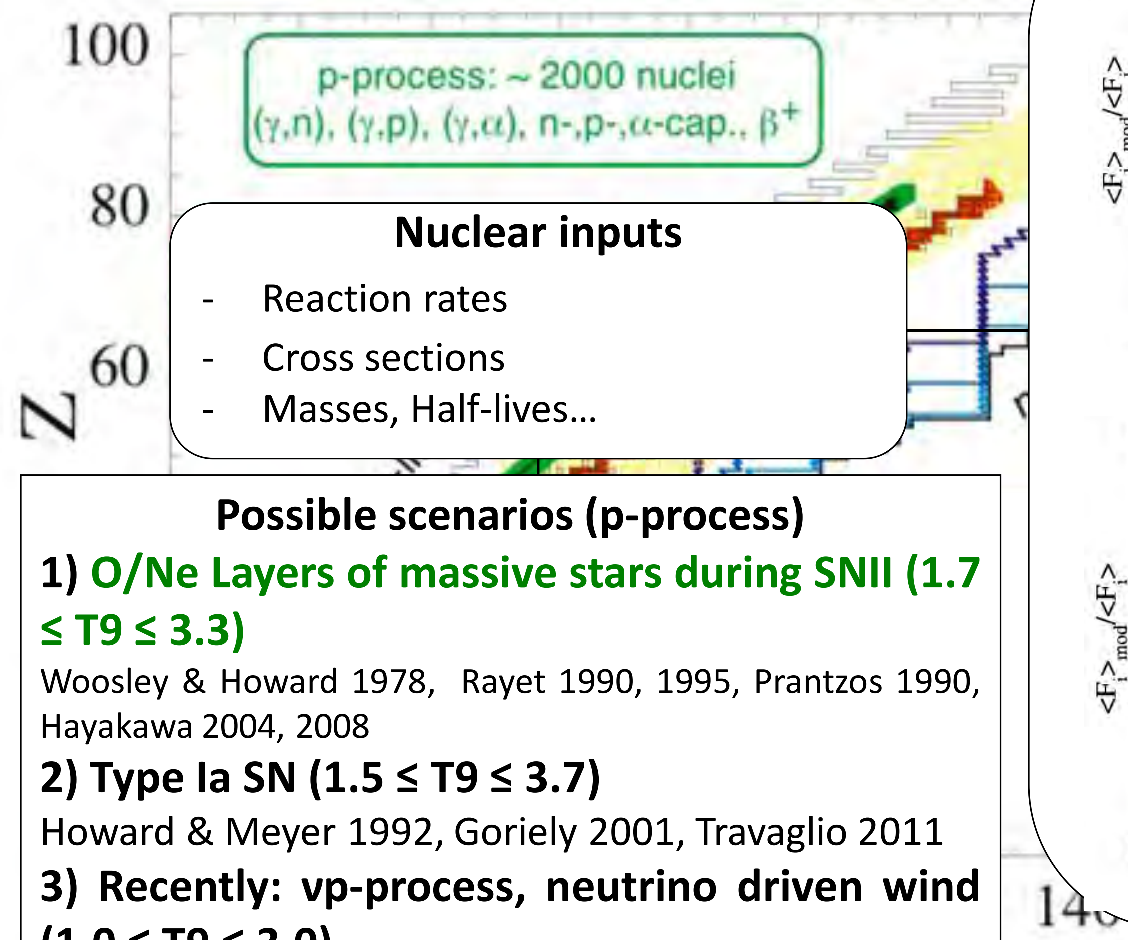
GANIL, INPL, NCSR "Demokritos", Subatech, LPC Caen, CEA-DAM, IFIN-HH, ATOMKI, University of Jyvaskyla, NPI CAS and IPN Orsay.

Reviews :

Arnould-Goriely, Physics Report 384 (2003) 1

Rauscher *et al*, Rep. Prog. Phys. 76 (2013) 066201

Rapp *et al.* AJ 653 (2006) 474



Nuclear inputs

- Reaction rates
- Cross sections
- Masses, Half-lives…

Possible scenarios (p-process)

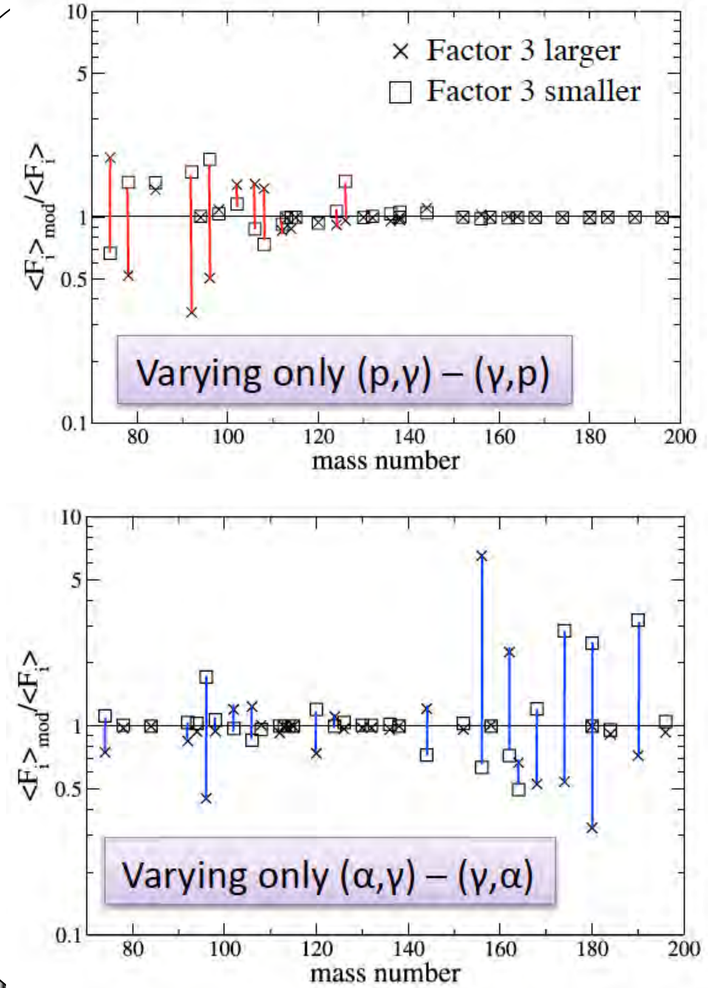
1) O/Ne Layers of massive stars during SNII (1.7 ≤ T9 ≤ 3.3)

Woosley & Howard 1978, Rayet 1990, 1995, Prantzos 1990, Hayakawa 2004, 2008

2) Type Ia SN (1.5 ≤ T9 ≤ 3.7)

Howard & Meyer 1992, Goriely 2001, Travaglio 2011

3) Recently: νp-process, neutrino driven wind (1.0 ≤ T9 ≤ 3.0)



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slide courtesy of Beyhan Bastin, GANIL

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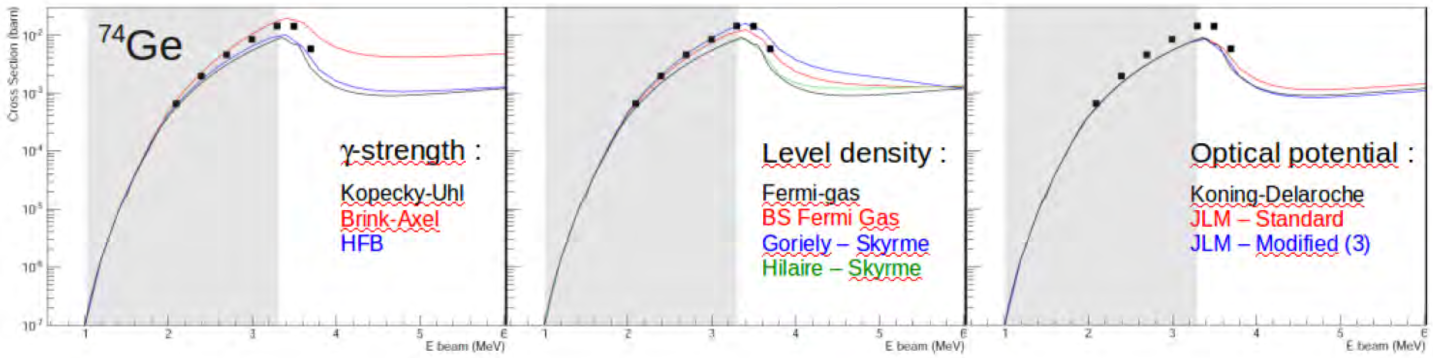

FIG. 3: $^{74}Ge(p,\gamma)^{75}As$ cross section. Symbols : experimental data from [22]. Curves : Talys calculations, varying three input parameters : gamma strength (left), level density (middle) and optical potential (right). The shadowed region indicates the Gamow window for $T_9 = 1.5 - 3.5$.

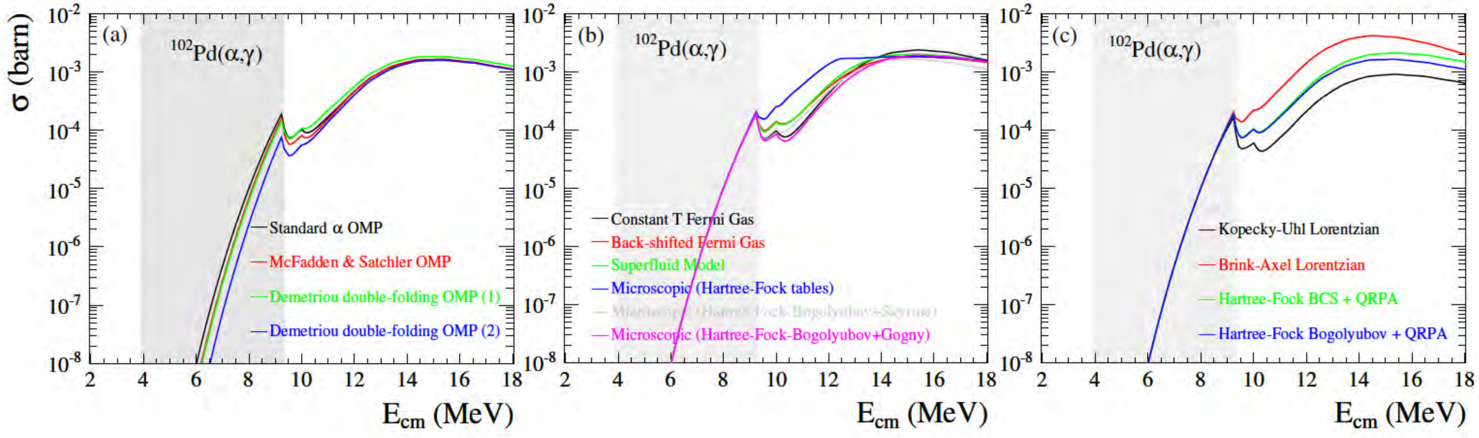

FIG. 4: Sensitivity of the ^{102}Pd(α,γ) cross section to different (a) optical model potentials [20, 21, 23], (b) nuclear level densities [24] and (c) gamma strengths [25–28]. Several phenomenological and semi-microscopic models implemented in the TALYS code [29] are compared. The shadowed area indicates the relevant energy range for (α,γ) reactions at $1.5 \leqslant T_9 \leqslant 3.5$ [30].

slide courtesy of Beyhan Bastin, GANIL

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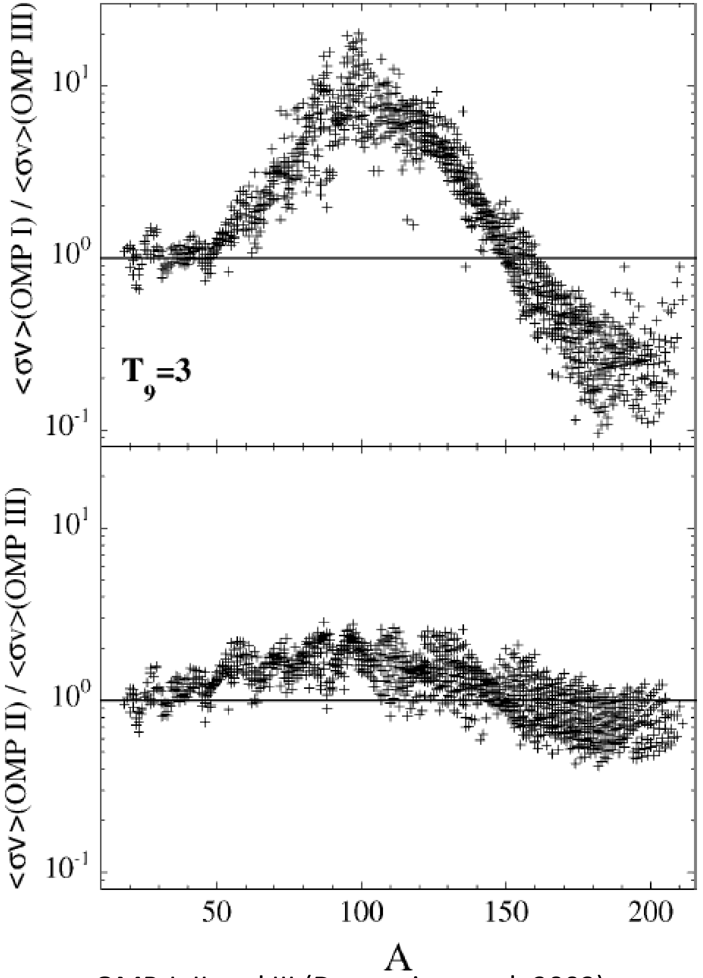
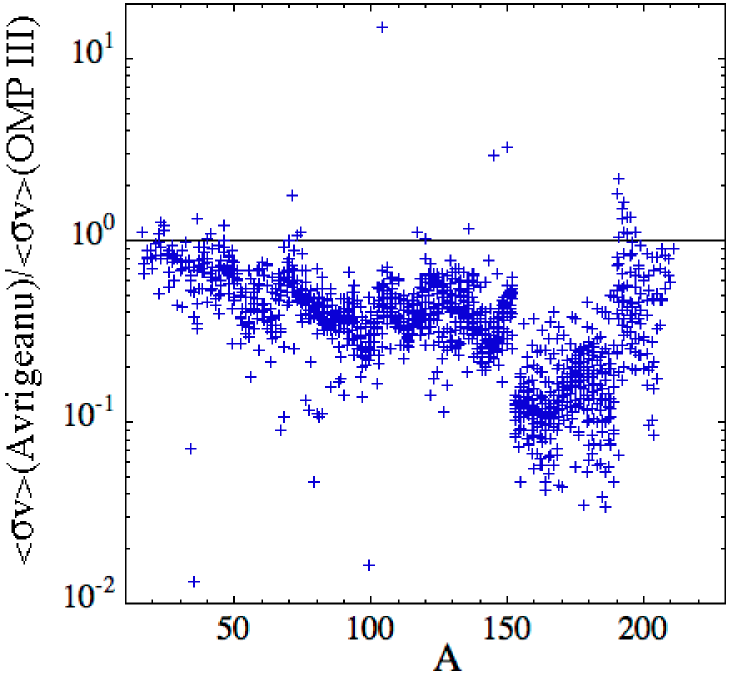
Different GLOBAL α-OMP available: Demetriou et al. (2002); Avrigeanu et al. (2014), etc…fitted on many low-energy cross sections (α,γ), (α,n), (n,α), (α,p), scattering, ...

Relatively different predictions of (α,γ) reaction rates ($2 \leq T_9 \leq 3$)



OMP-I, II and III (Demetriou et al. 2002)

T_9=3; stable & n-deficient nuclei with $8 \leq Z \leq 84$



- New α-OMP (S. Gorieli, V. Demetriou, C. Ducoin…)
- Experiments with ^{4}He beams @ Rez

presentation of V.Avrigeanu

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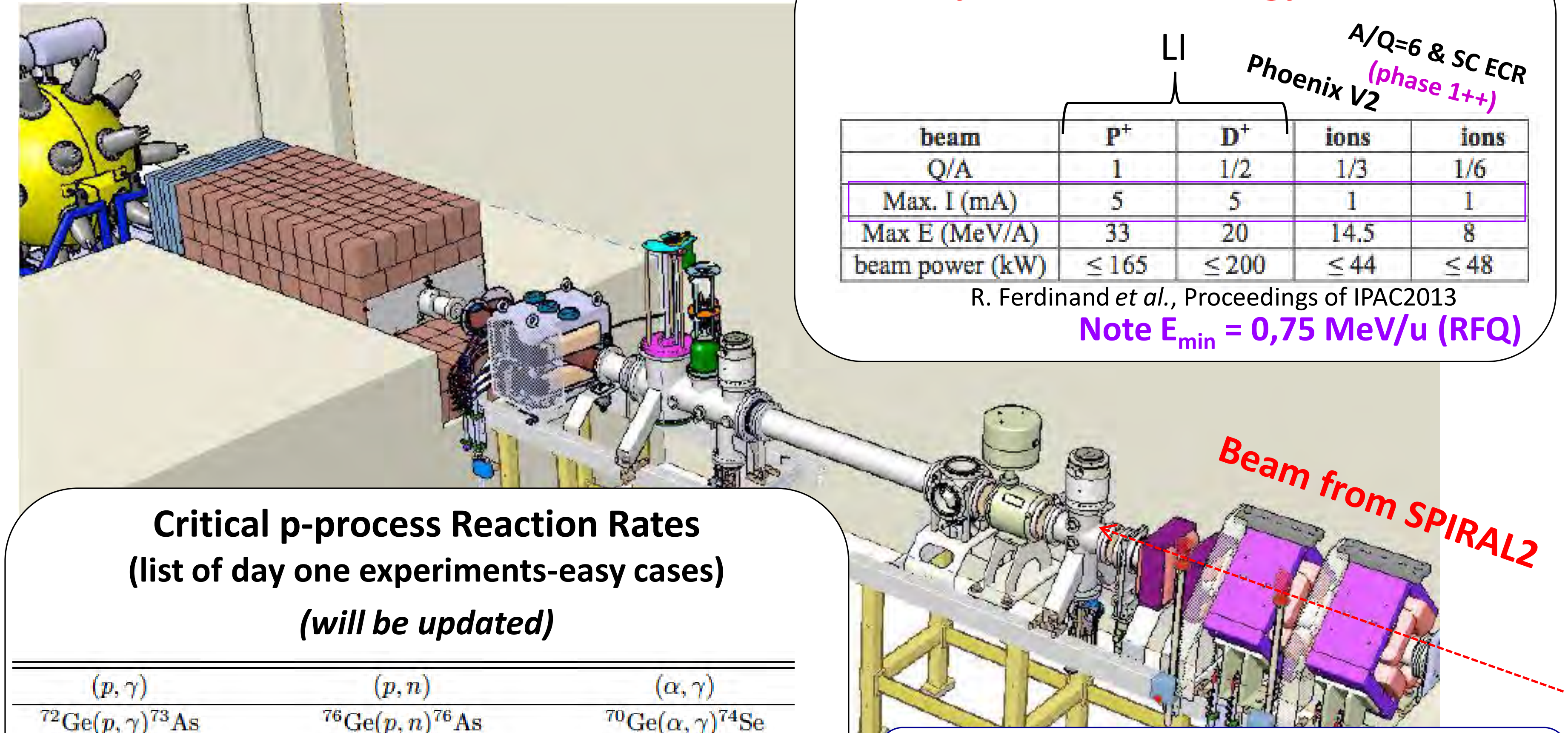
3 experimental campagnes foreseen : Activation and 2 in-beam



Very intense low energy beams

LI: P⁺, D⁺ — Phoenix V2 — A/Q=6 & SC ECR (phase 1++)

beam	P^+	D^+	ions	ions
Q/A	1	1/2	1/3	1/6
Max. I (mA)	5	5	1	1
Max E (MeV/A)	33	20	14.5	8
beam power (kW)	≤ 165	≤ 200	≤ 44	≤ 48

R. Ferdinand *et al.*, Proceedings of IPAC2013

Note E_{min} = 0,75 MeV/u (RFQ)

Critical p-process Reaction Rates
(list of day one experiments-easy cases)

(will be updated)

(p,γ)	(p,n)	(α,γ)
^{72}Ge$(p,\gamma)^{73}$As	^{76}Ge$(p,n)^{76}$As	^{70}Ge$(\alpha,\gamma)^{74}$Se
^{74}Ge$(p,\gamma)^{75}$As	^{75}As$(p,n)^{75}$Se	^{92}Mo$(\alpha,\gamma)^{96}$Ru
^{77}Br$(p,\gamma)^{78}$Kr*	^{85}Rb$(p,n)^{85}$Sr	^{102}Pd$(\alpha,\gamma)^{106}$Cd
^{83}Rb$(p,\gamma)^{84}$Sr*	^{86}Kr$(p,n)^{86}$Rb	^{106}Cd$(\alpha,\gamma)^{110}$Sn

note : (p,γ) : 1.5 - 5.0 MeV (α,γ) : 3.5 - 11.0 MeV

Experiment challenge under study : use of radioactive targets!

contact person : B. Bastin

LoI p-process : direct kinematics measurements @ SPIRAL2-NFS

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measurement methods foreseen

Activation (GANIL)

γ decay
Irradiation setup + OFF LINE

Advantages
Direct measurement
Low Background
Good resolution

Constraints/Disadvantages
Required enriched targets
Difficult if $T_{1/2}$ such that $t_{offline} \geq 1$mois

In-beam spectroscopy

γ from de-excitation IN BEAM (point cible)

"γ-summing"(Demokritos)

Advantages
Covers 4π

Constraints/Disadvantages
Beam purity
DM in case of huge count rate
Low resolution

Angular distributions (IPNL)

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High resolution
(compared to γ-summing)

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Difficulty to cover 4π (compton..)
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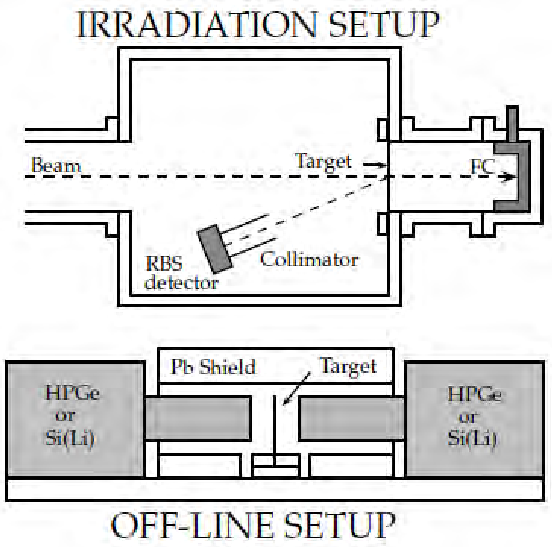
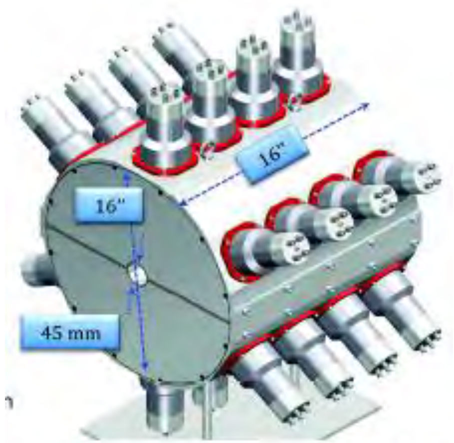
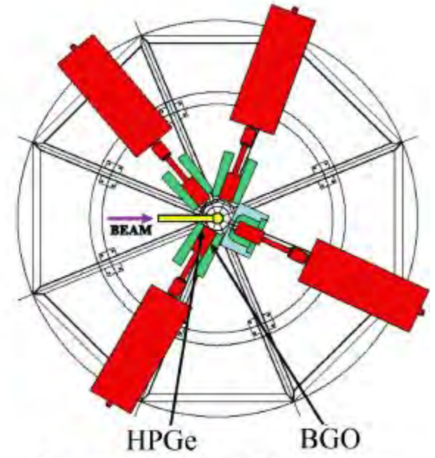




SuN Detector (MSU)



Stuttgart HPGe Array

Support:

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MINISTRY OF EDUCATION, YOUTH AND SPORTS

- **LEA NuAG** - Nuclear Astrophysics and Grids
- new (2016) research infrastructure – in Czech Republic - **SPIRAL2-CZ**
- research infrastructure of NPI CAS Rez – ***open access* CANAM**

NPI CAS Rez – Eva Simeckova, J.Mrazek, M. Stefanik, I.Sivacek, M.Majerle, M.Ansorge, O.Lebeda
F.Vesely, R.Behal, V.Glagolev, M.Rodak, O.Jurencak, M.Gschray, J. Gabrhel...

KIT Karlsruhe – Axel Klix, Ulrich Fischer, Thorsten Reimann

IFIN-HH Bucharest – M.Avrigeanu, V.Avrigeanu, C.Costache (theory support)

GANIL – X.Ledoux, G. de France, J.Grynier, F. de Oliveira, B.Bastin
J.C.Foy, Y.Georget, V.Morell, N.Menard, Gael and Alexandre Lebec ...

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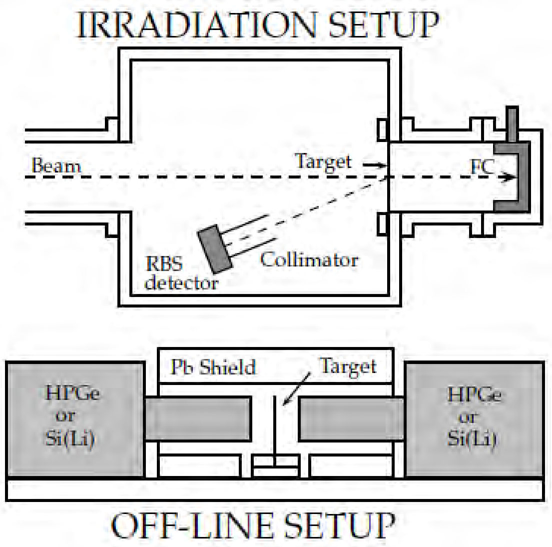

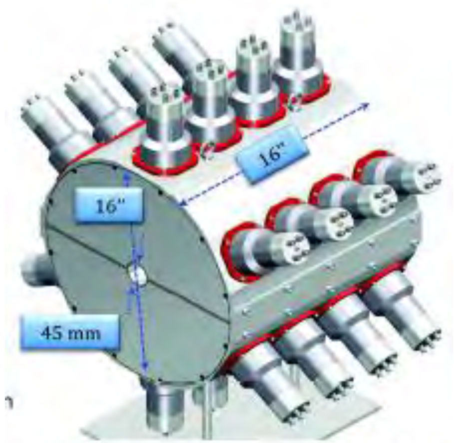

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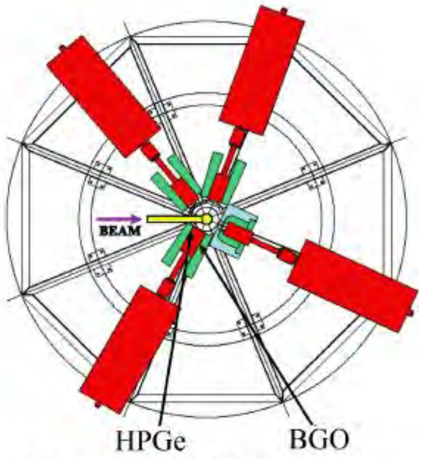
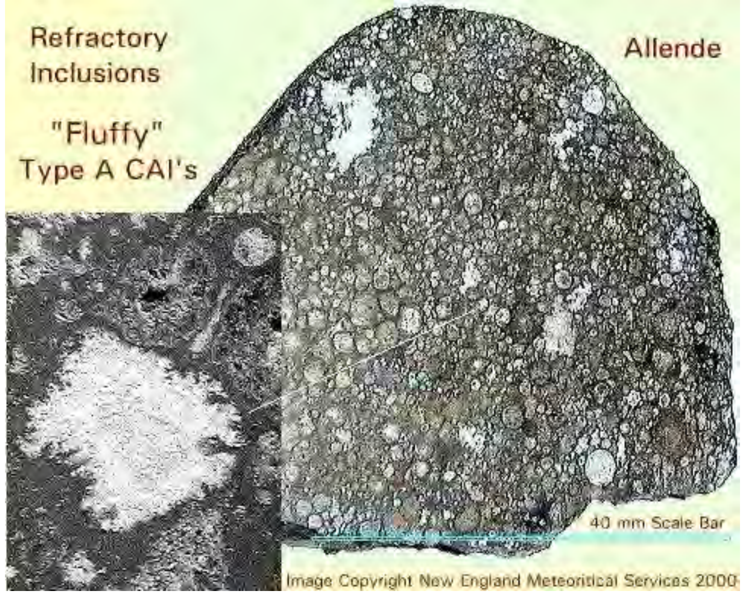


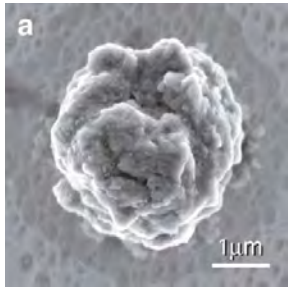
Stuttgart HPGe Array

Courtesy of Beyhan Bastin, GANIL

Isotopic abundances



Carbonaceous chondrites



SiC

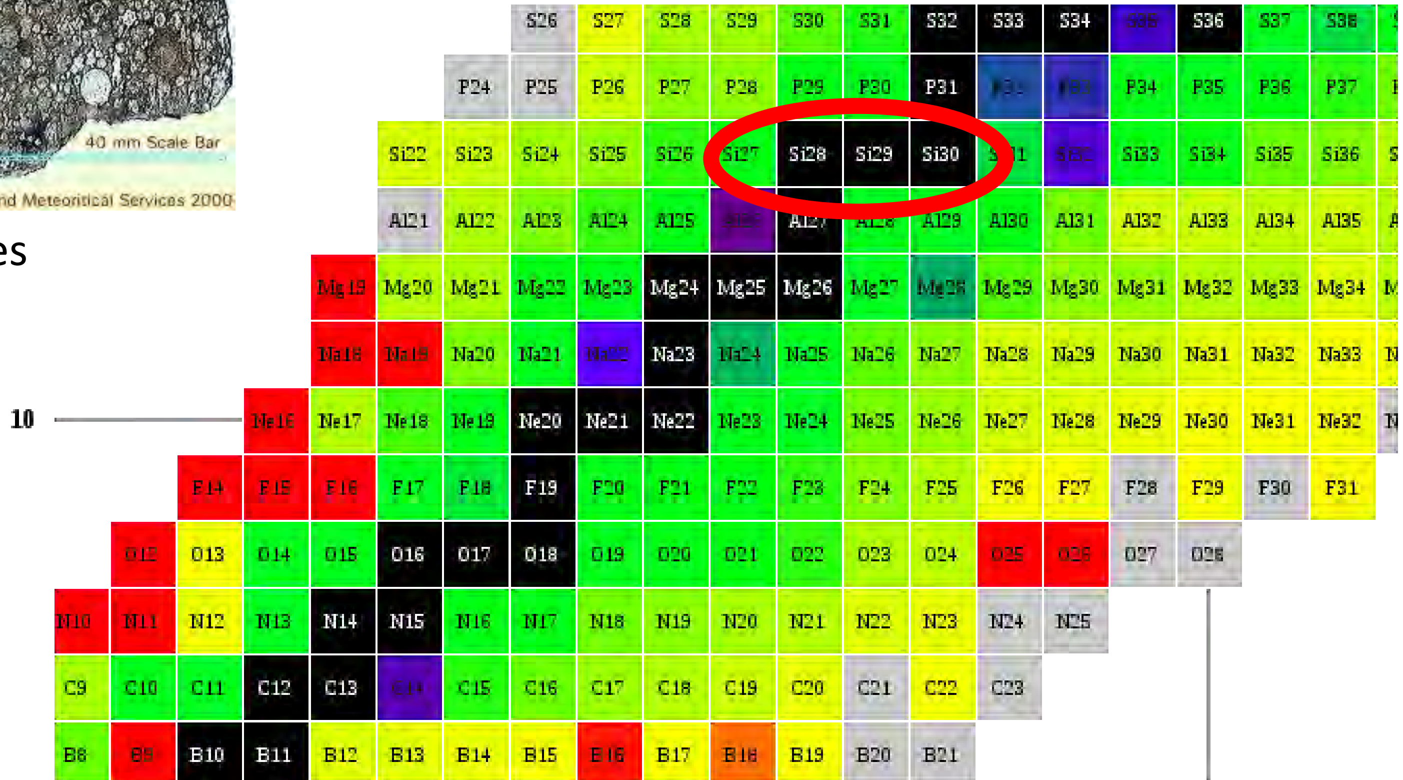
Solar system contains material from multiple dead stars

in Solar system – isotopic ratios are equilibrated

due to mixing during formation

Inclusions in meteorites are of interest

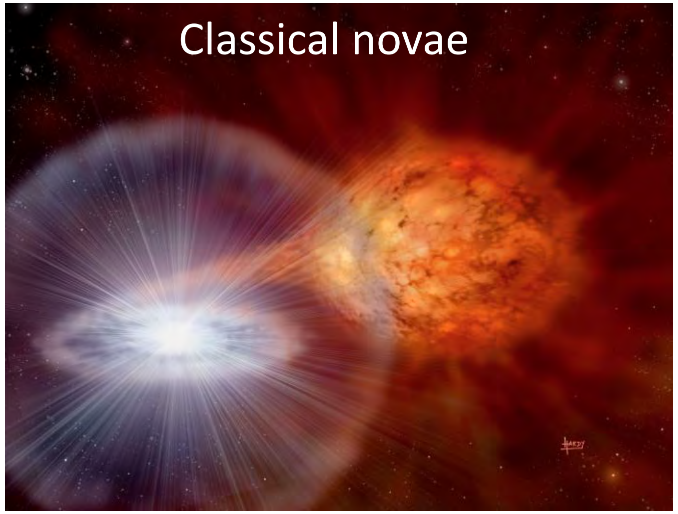
- old (not undergone a complete mixing)
- extrasolar – information on variations

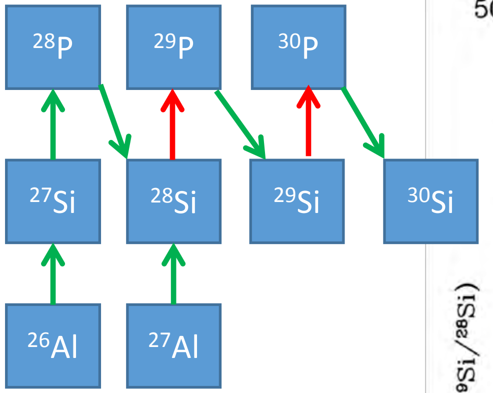


E719 : Precise direct measurements of the key **^{28}Si(p,γ)^{29}P** and **^{29}Si(p,γ)^{30}P** reaction rates to **understand the origin of presolar nova grains**

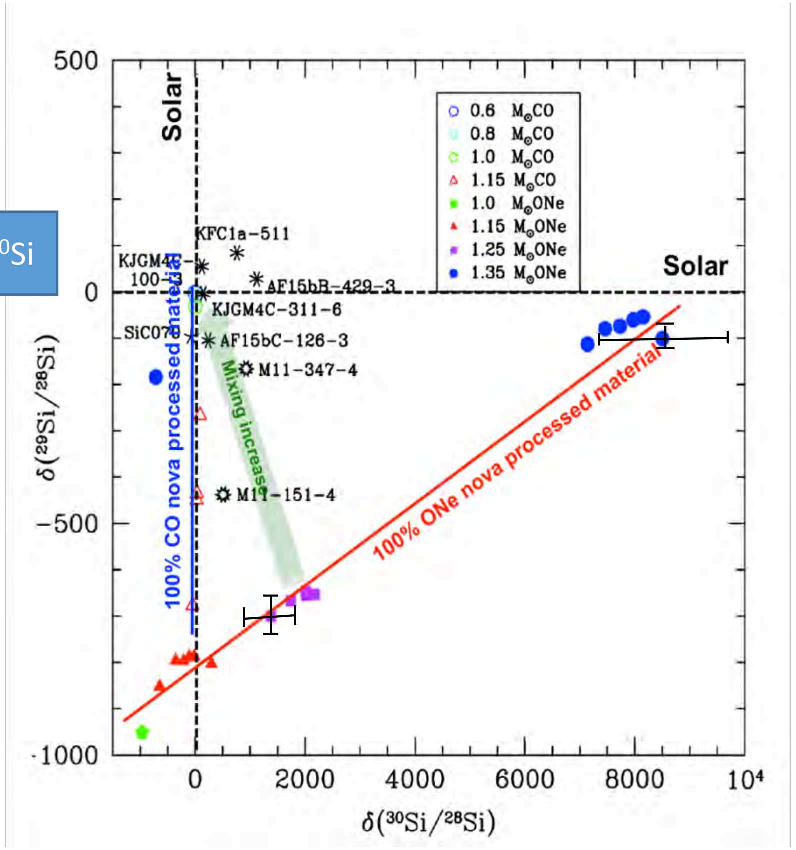
(F. Boulay, B. Bastin, J. Mrazek)

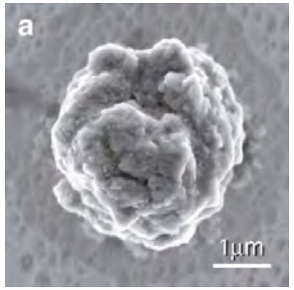
GANIL, CEA-DAM, NPI CAS, LPC Caen, IPN Orsay, CSNSM, IPN Lyon, JYFL, Instituto de Fisica Corpuscular (Valencia) , NCSR "Demokritos" and Subatech





Destruction reactions
^{28}Si(p, γ) ^{29}P, ^{29}Si(p, γ) ^{30}P





Presolar SiC grain

7 micrometeorties collected on Earth are identified coming from nova explosion

Necessity to constrain the reaction rates ^{28}Si(p,γ)^{29}P and ^{29}Si(p,γ)^{30}P which have currently 21 % and 30 % uncertainties.

Aim : reduce the uncertainties on the reaction rates **^{28}Si(p, γ)^{29}P and ^{29}Si(p, γ)^{30}P** as much as possible in the Gamow window (GW) (60 ->560 keV).

Courtesy of Beyhan Bastin, GANIL

E719 : Precise direct measurements of the key ^{28}**Si(p,γ)**^{29}**P** and ^{29}**Si(p,γ)**^{30}**P** reaction rates to **understand the origin of presolar nova grains**

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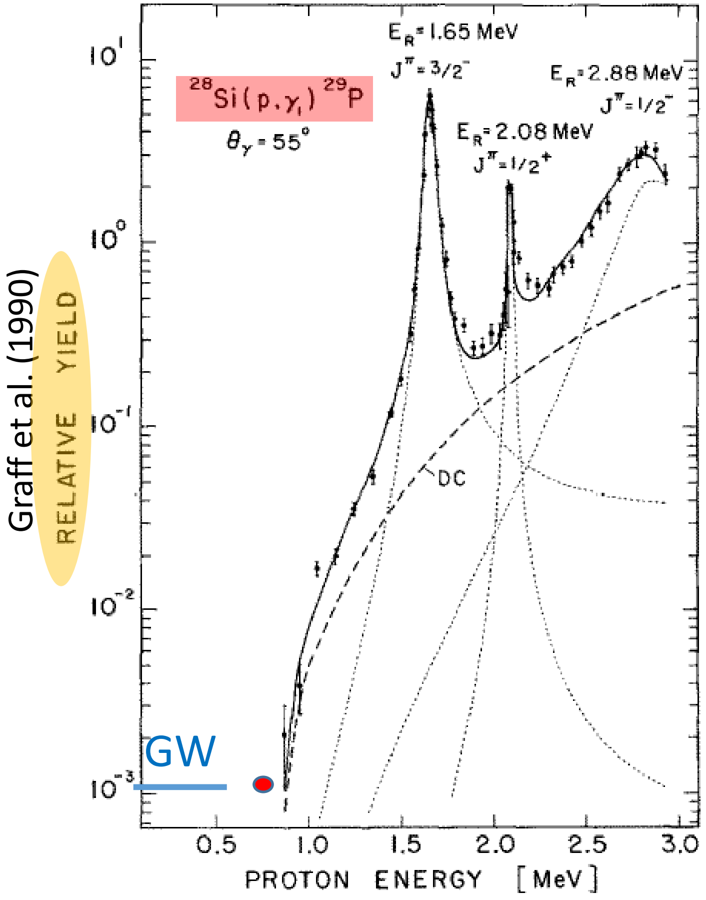
State of art

- No measurement from 1990
- Current measurement at low energy at **LENA facility for** ^{29}**Si(p, γ)**^{30}**P =>** International competition.



$$Y = \frac{N_r}{\eta(E) N_p} = \frac{M_p + M_t}{M_t} \frac{\lambda_r^2}{2} \frac{\omega\gamma}{\varepsilon_r(E)}$$

	Graff et al. (1990) @653 keV
Efficiency detection (η)	5 %
Statistics (Nr)	30 %
Current measurement (Np)	5 %
Total Yield	31 %
Beam energy	0.5 %
Stopping power	10 %
Total gamma strength	31 %

Can be improved

Severals measurements at different energies in the most intense proton beam facilities in the world has to be done

SPIRAL 2 facility will provide the **most intense proton beam at 0.733 MeV** in Europe

Courtesy of Beyhan Bastin, GANIL

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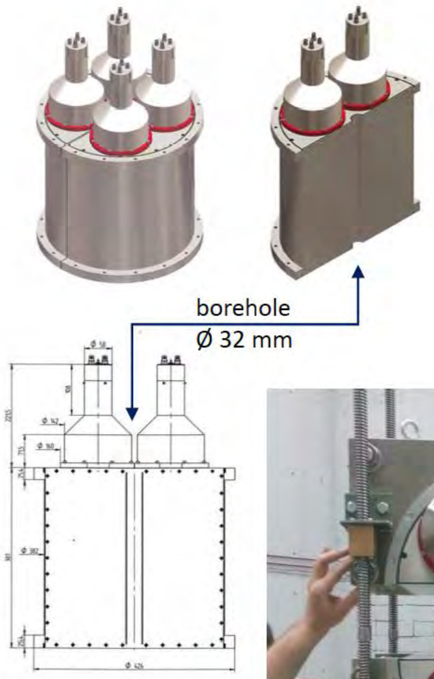
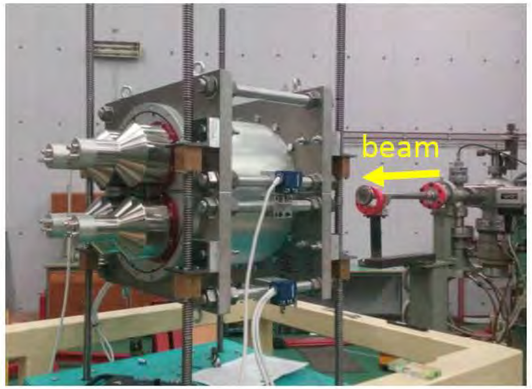
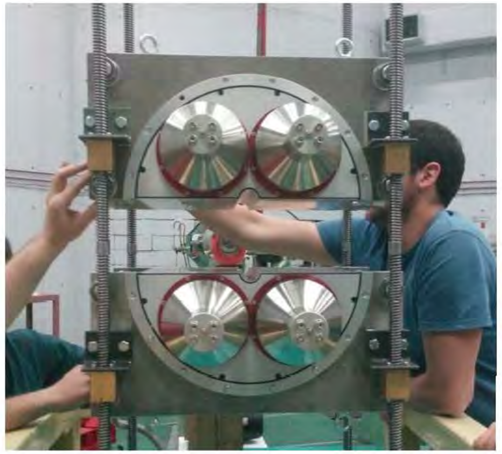
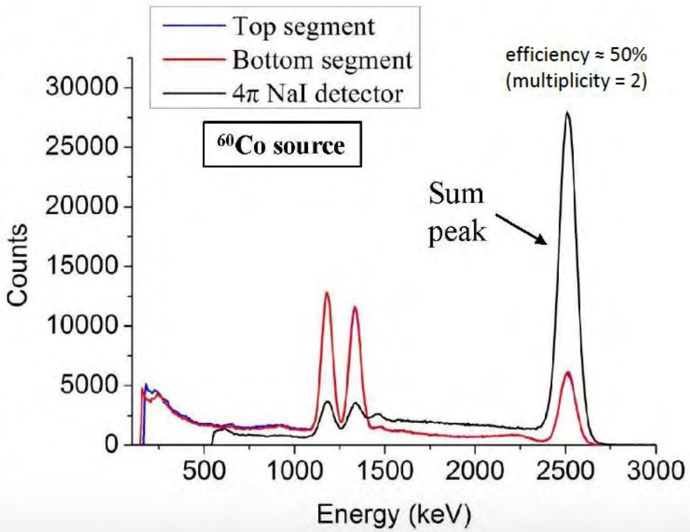
NeoPtolemos: The 4π γ-summing detector at the TANDEM Accelerator Lab. of "Demokritos" .

A 14''x14'' cylindrically-shaped NaI(Tl) crystal segmented in two parts









Courtesy of Beyhan Bastin, GANIL

Sotirios Harissopulos

Support:

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

- **LEA NuAG** - Nuclear Astrophysics and Grids
- new (2016) research infrastructure – in Czech Republic - **SPIRAL2-CZ**
- research infrastructure of NPI CAS Rez – ***open access*** **CANAM**

NPI CAS Rez – Eva Simeckova, J.Mrazek, M. Stefanik, I.Sivacek, M.Majerle, M.Ansorge, O.Lebeda
F.Vesely, R.Behal, V.Glagolev, M.Rodak, O.Jurencak, M.Gschray, J. Gabrhel...

KIT Karlsruhe – Axel Klix, Ulrich Fischer, Thorsten Reimann

IFIN-HH Bucharest – M.Avrigeanu, V.Avrigeanu, C.Costache (theory support)

GANIL – X.Ledoux, G. de France, J.Grynier, F. de Oliveira, B.Bastin
J.C.Foy, Y.Georget, V.Morell, N.Menard, Gael and Alexandre Lebec ...

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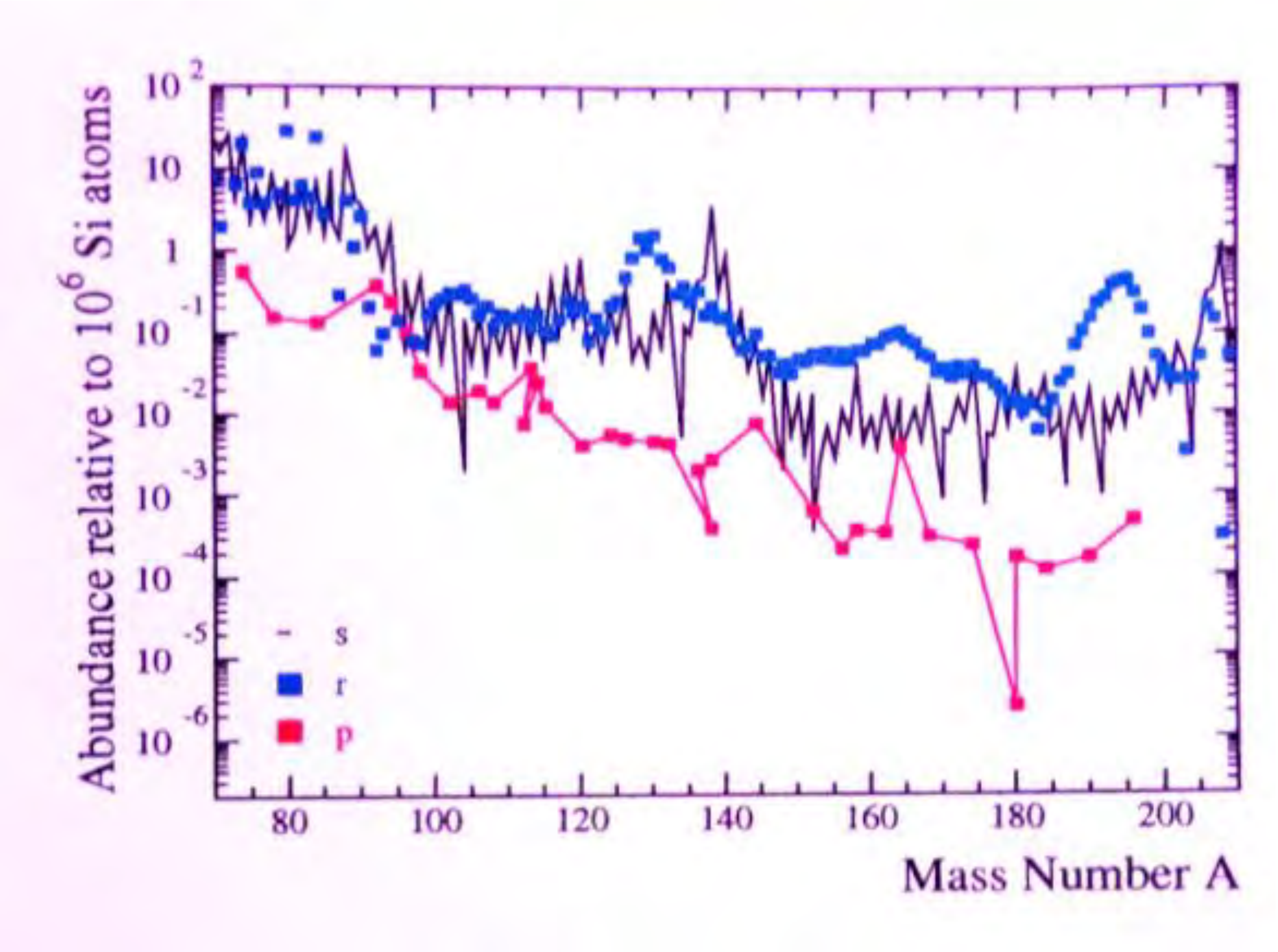
end. thank you

p-process

35nuclei

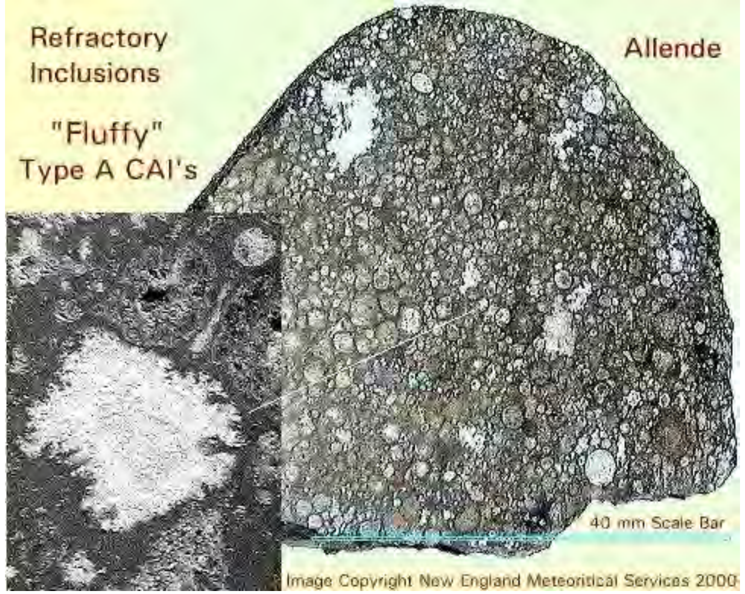
from 74Se to 196Hg

discrepancies:
Mo, Ru, Sn, La, Gd underproduced

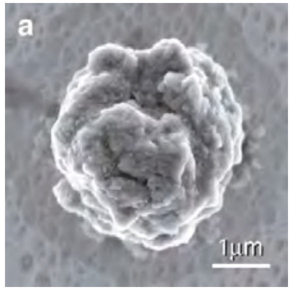


Scenario : (gamma,n) reactions, after (gamma,p) and (gamma,alpha) continue

Isotopic abundances



Carbonaceous chondrites



SiC

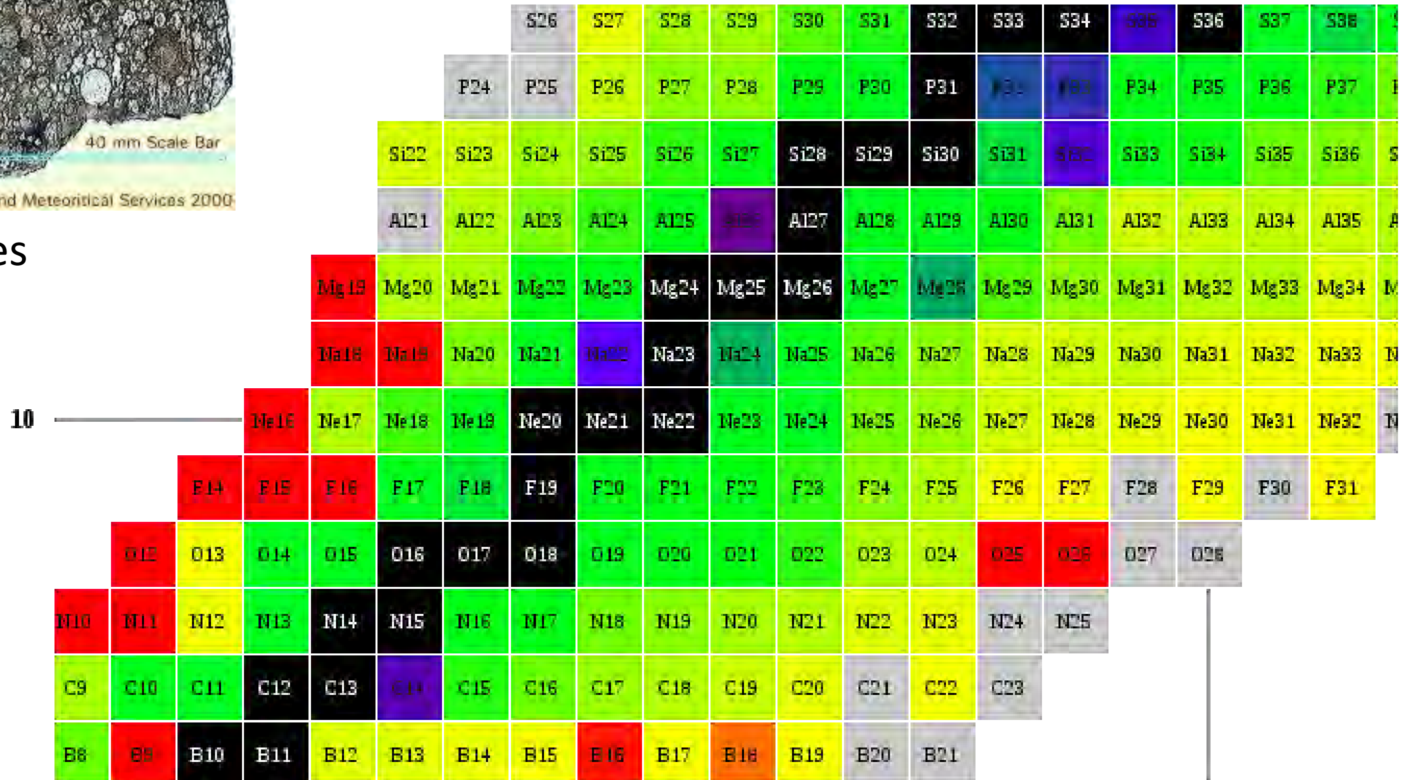
Solar system contains material from multiple dead stars

in Solar system – isotopic ratios are equilibrated

due to mixing during formation

Inclusions in meteorites are of interest

- old (not undergone a complete mixing)
- extrasolar – information on variations



Aktivace nabitými částicemi na NFS

responsible Eva Šimečková

První experiment byl schválen na Progam Advisory Committee

Excitační funkce krátko-žijících izotopů na ^{nat} Fe

- krátkožijící izotopy a izomery Fe, Co, Mn, Cr
- možná vůbec první experiment na SPIRAL2

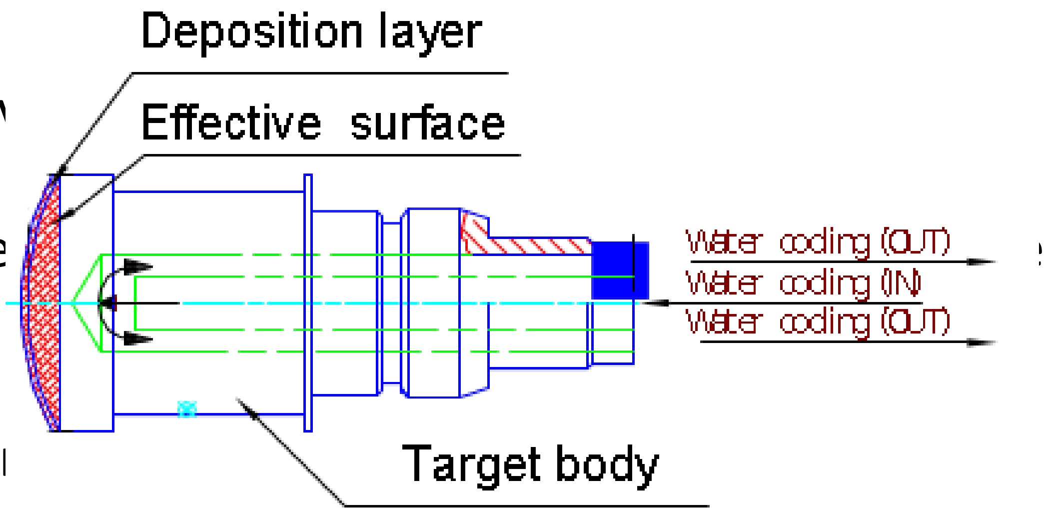
SPIRAL2-CZ-OP

další plány: alfa + Zn, alfa + ^{124}I

Radioizotopy – výzkum pro medicínu

responsible Ondřej Lebeda

Nová tematika v GANIL/SPIRAL2 – v



Odpověď na společenský požadave
Normandie)

Diagnostika a therapeutika = thera

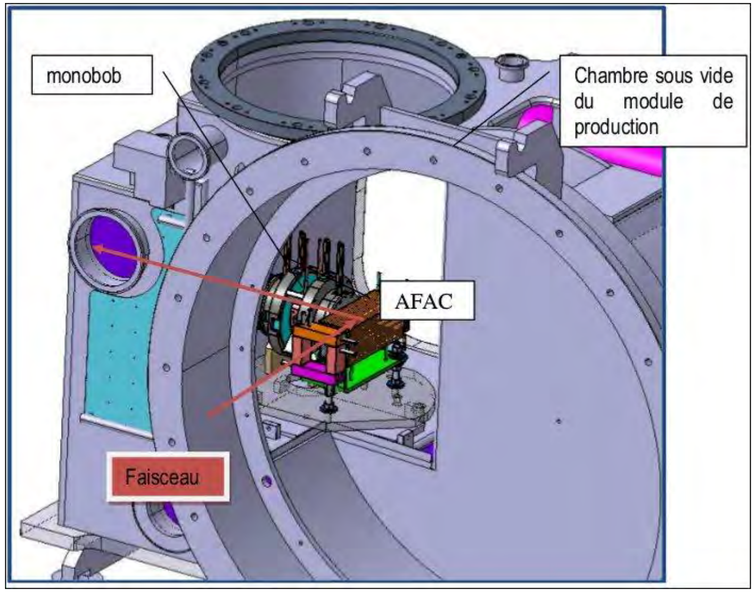
Značené molekuly ^{209}Bi(α,2n) ^{211}At, kandidát na theranostikum ^{68}Ga

ORF ÚJF AVČR – dlouholeté zkušenosti s výzkumem

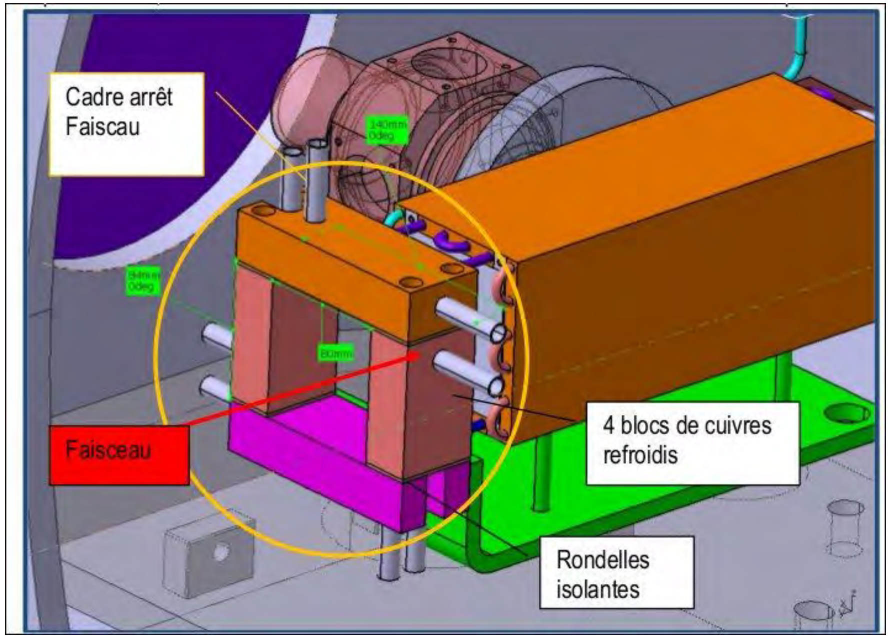
Investice + výzkum SPIRAL2-CZ-OP

Jaderná astrofyzika
responsible Jaromir Mrázek

Produkční terč ROBOT (Řež - Other Beams Other Targets)
produkce izotopů $^{14,15}O$, které hrají roli např. při
hot CNO cyklu a jejichž svazky jinak na SPIRAL2 nebudou.



SPIRAL2-CZ-OP investice



Outlooks