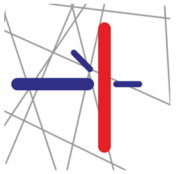
Nuclear Physics Institute of the CAS
public research institution



Center of Accelerators and Nuclear Analytical Methods (CANAM)

Proton and deuteron activation measurements on the NPI

E. Šimečková, P. Bém, J. Mrázek, M. Štefánik, J. Novák, R. Běhal, V. Glagolev

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

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

Former research

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

PHYSICAL REVIEW C **79**, 044610 (2009)

Low and medium energy deuteron-induced reactions on ^{27}Al

PHYSICAL REVIEW C **84**, 014605 (2011)

Low and medium energy deuteron-induced reactions on ^{63,65}Cu nuclei

PHYSICAL REVIEW C **88**, 014612 (2013)

Low-energy deuteron-induced reactions on ^{93}Nb

PHYSICAL REVIEW C **89**, 044613 (2014)

Low energy deuteron-induced reactions on Fe isotopes

PHYSICAL REVIEW C **94**, 014606 (2016)

Deuteron-induced reactions on Ni isotopes up to 60 MeV

M. Avrigeanu,[1,*] E. Šimečková,[2,†] U. Fischer,[3] J. Mrázek,[2] J. Novak,[2] M. Štefánik,[2] C. Costache,[1] and V. Avrigeanu[1]
[1]*Horia Hulubei National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, R-077125 Bucharest-Magurele, Romania*
[2]*Nuclear Physics Institute CAS, CZ-25068 Řež, Czech Republic*
[3]*Euratom/FZK Fusion Association, Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz, 1, D-76344 Eggenstein-Leopoldshafen, Germany*
(Received 11 June 2016; published 12 July 2016)

ND 2016

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2·CZ Czech Republic contribution to SPIRAL2 GANIL ujf

d + W, Zn, Zr

Proton and deuteron activation measurements at the NPI and future plans in SPIRAL2/NFS

Eva Šimečková[1,*], *Pavel* Bém[1], *Jaromír* Mrázek[1], *Milan* Štefánik[1], *Radomír* Běhal[1], and *Vadim* Gladolev[1]

[1]Nuclear Physics Institute, CAS, 250 68 Řež, Czech Republic

interest for the assessment of induced
s as well as isotope production for
sections on zinc were investigated by
gy from the cyclotron U-120M of NPI
iron is presented. The comparison of
ated data libraries is discussed. The
nterval 20-35 MeV at SPIRAL2/NFS
transport system to measure isotopes

The activation of W and Zr by deuterons at energies up to 20 MeV

Eva Šimečková[1,*], *Milan* Štefánik[1], *Pavel* Bém[1], *Jaromír* Mrázek[1] and *Jan* Novák[1]

[1]Nuclear Physics Institute CAS, 250 68 Řež, Czech Republic

Abstract. The proton and deuteron induced reactions are of a great interest for the assessment of induced radioactivity of accelerator components, target and beam stoppers. In order to investigate the important nuclides, we have carried up the irradiation experiments with the variable-energy cyclotron U-120M of the NPI CAS Řež. The production cross sections of the nuclides ^{179,181,182m,182,183,184m,184,186}Re and ^{187}W from reaction on natural W were investigated by deuteron beams of 20 MeV energy. A part of preliminary results of deuteron activation of natural Zr is also shown. The stacked-foil technique was utilized. The comparison of present results to data of other authors and to predictions of evaluated data libraries is discussed.

Natural Zr

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2·CZ Czech Republic contribution to SPIRAL2 GANIL ujf

Isotope	Natural abundance (%)
^{90}Zr	51.45
^{91}Zr	11.22
^{92}Zr	17.15
^{94}Zr	17.38
^{96}Zr	2.80

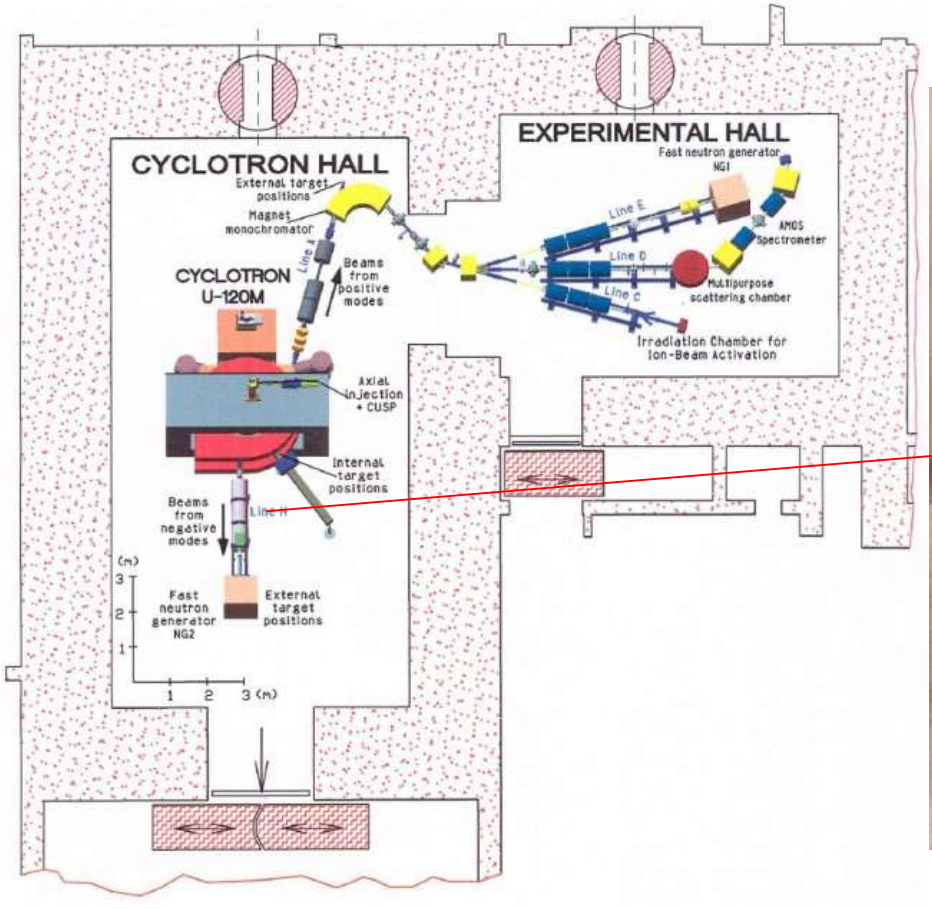
18 production excitation functions, 6 for the first time

NPI energy variable cyclotron U120M

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2·CZ GANIL ujf

Czech Republic contribution to SPIRAL2

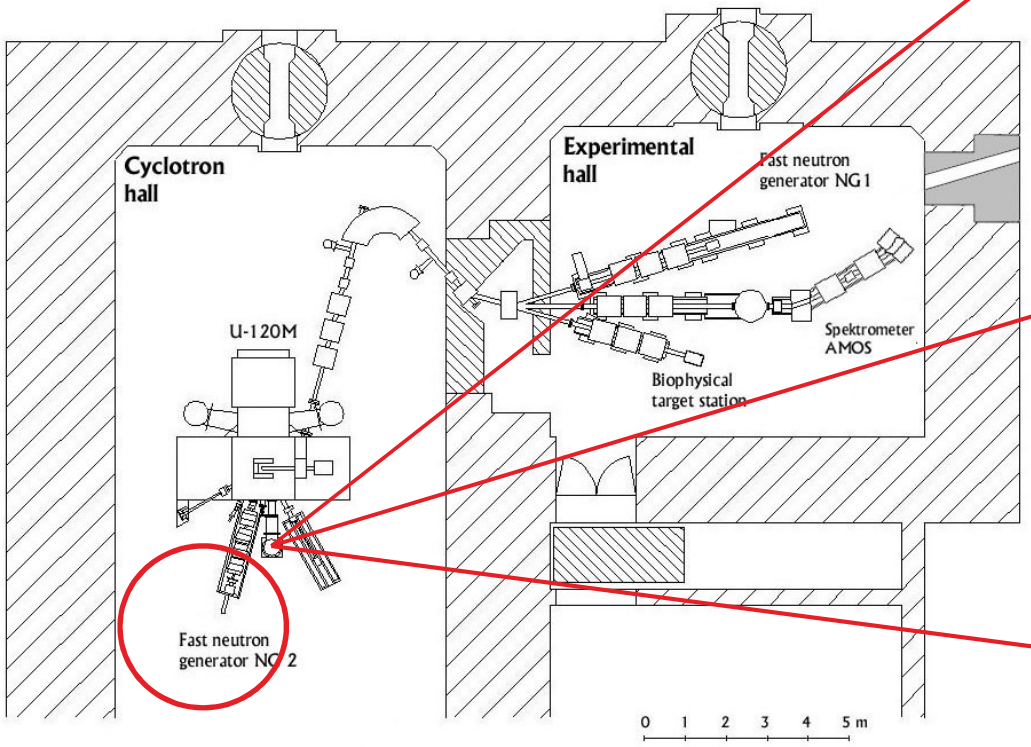


NPI energy variable cyclotron U120M

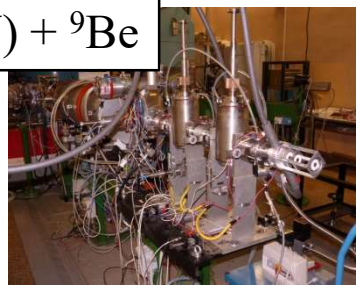
Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2·CZ Czech Republic contribution to SPIRAL2 GANIL ujf

Negative ion mode: stripping foil
H^- /H^+ 6-37 MeV, up to 20μA
D^-/D^+ 11-20 MeV, up to 10μA



p(18-35 MeV) + ^{9}Be

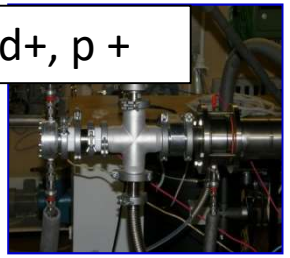


Broad neutron spectrum
Neutron flux density up to $5x10^{11}$ $ncm^{-2}s^{-1}$ at the distance of 15 mm

p(6-37MeV) + ^{7}Li

Neutron flux density in the QME peak:
10^9 $ncm^{-2}s^{-1}$ for 8μA (p) at the distance 48 mm

d+, p +



~ 0.4 μA

NPI energy variable cyclotron U120M

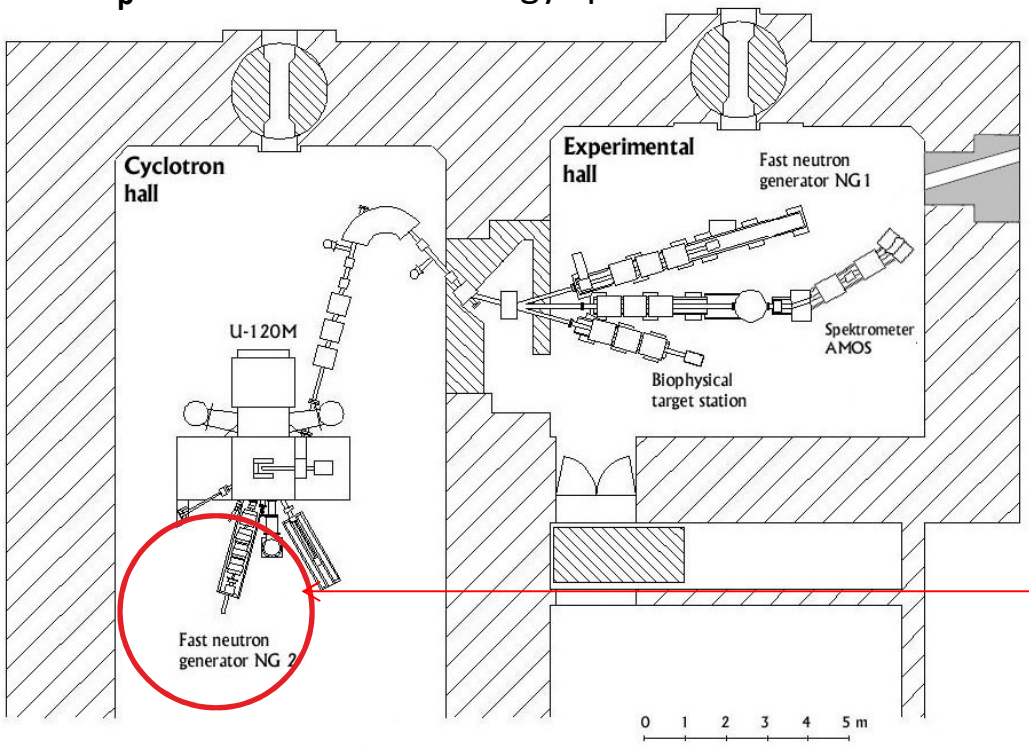
Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2·CZ Czech Republic contribution to SPIRAL2 GANIL ujf

Negative ion mode: stripping foil

E_d = 20.0 MeV Energy uncertainty 1 %

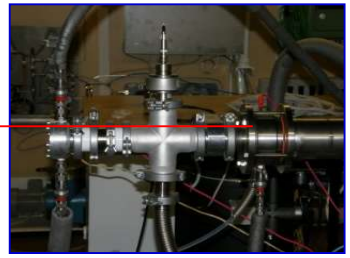
E_p = 35.0 MeV Energy spread 1.8 %



The energy is determined with the calculation of trajectory and position of cyclotron extraction foil.
This correctness of energy determination was tested using the scattering of extracted beam on CH2 radiator.

Disadvantage
- E_d < 20MeV
- few orbits
- not transfer system

NFS – SPIRAL2
Linear accelerator
d up to 40 MeV
Transfer system

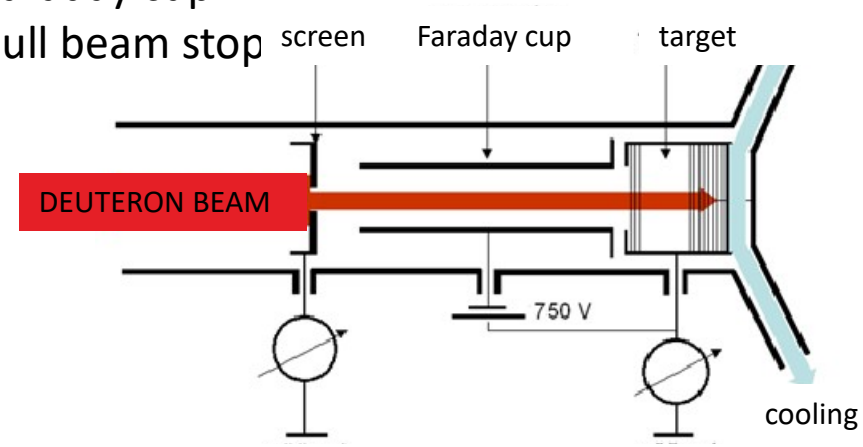


Charged particle chamber

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2.cz Czech Republic contribution to SPIRAL2 GANIL ujf

- Faraday cup
- Full beam stop

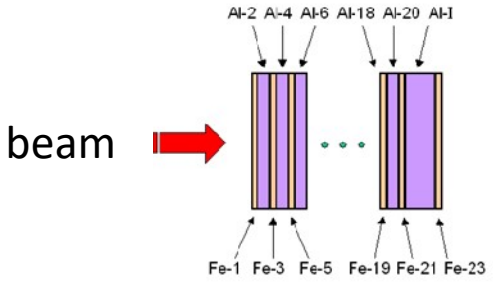


Current measurement

During an irradiation, the beam current was recorded with the uncertainty of 5 % in a PC keeping time synchronization with the γ-ray spectrometry device.
Energy attenuation, target density - **SRIM**

The cross-sections for proton provoked reactions on Fe and Cu were measured by the stacked-foil technique and its absolute values were calculated from the measured induced activities, charges and material characteristics.

Stacked-foil technique



stacks of measured and monitoring foils placed by turns
monitoring foils served for additional monitoring of beam current and for appropriate reduction of proton energy, as well.

Natural Cr

Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

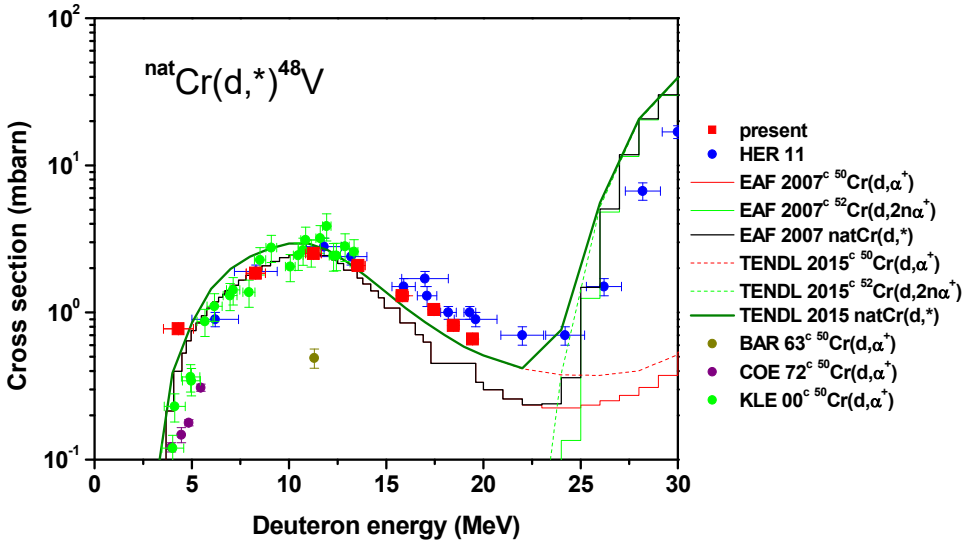
Isotope	Natural abundance (%)
^{50}Cr	4.345
^{52}Cr	83.789
^{53}Cr	9.501
^{54}Cr	2.365

d + ^{nat}Cr

Center of Accelerators and Nuclear Analytical Methods (CANAM)

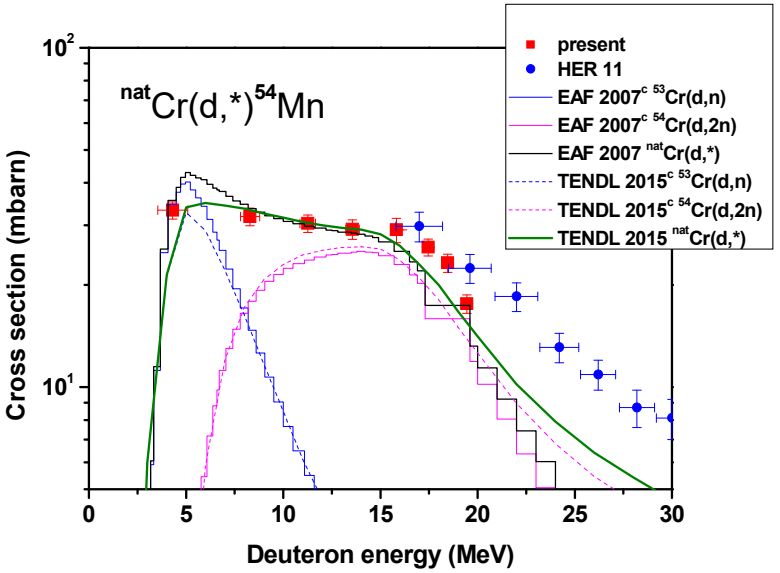
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 15.9735 d



E_γ (keV)	I_γ (%)
983.52	99.98
1312.96	97.5

$T_{1/2}$ = 312.3 d



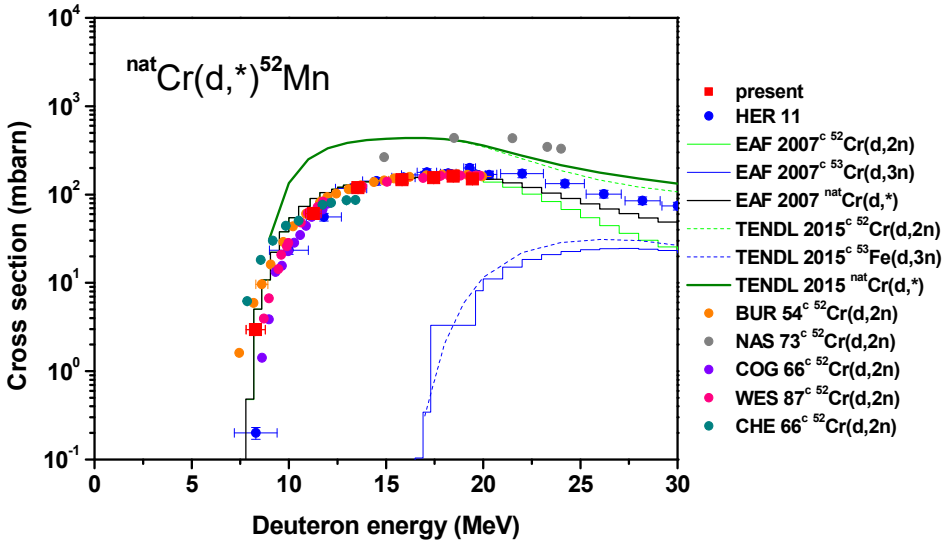
E_γ (keV)	I_γ (%)
834.85	99.98

d + ^{nat}Cr

Center of Accelerators and Nuclear Analytical Methods (CANAM)

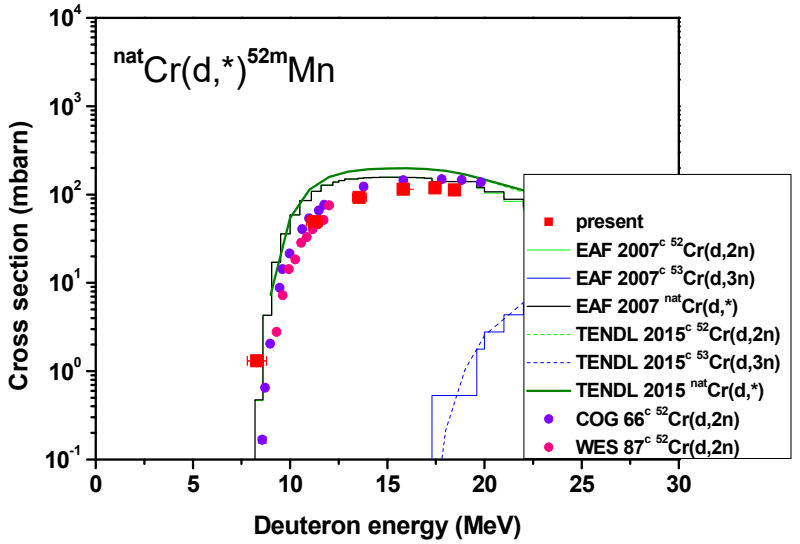
NPI CAS spiral2.cz Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 5.591 d

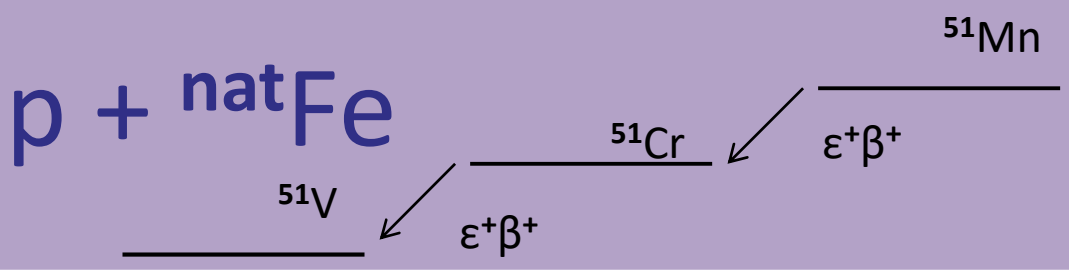


E_γ (keV)	I_γ (%)
1434.07	100
935.54	94.5
744.23	90.0

$T_{1/2}$ = 21.1 min



E_γ (keV)	I_γ (%)
1434.07	98.3
377.75	1.7



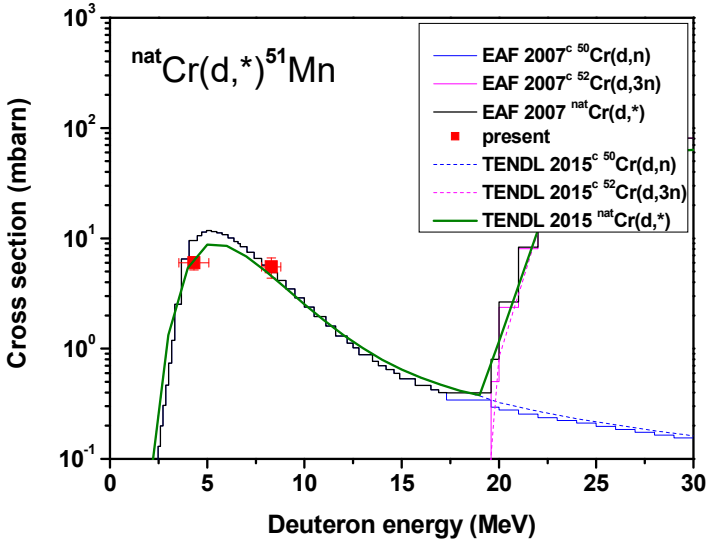
Center of Accelerators and Nuclear Analytical Methods (CANAM)

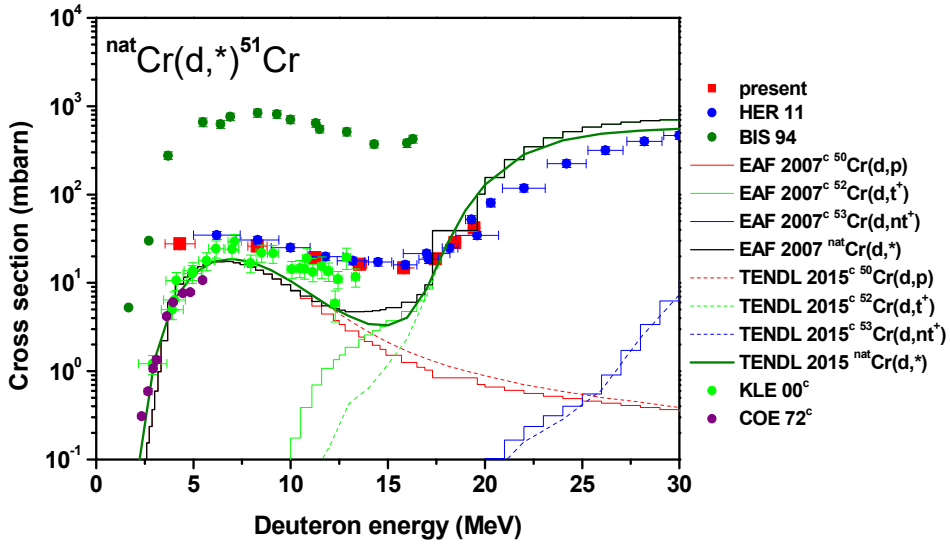
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 46.2 min

$T_{1/2}$ = 27.7025 d

cumulative





E_γ (keV)	I_γ (%)
749.1	0.26
1148.0	0.078
320.1	10

E_γ(keV)	$I_\gamma^{(\%)}$
320.1	10

Natural Ni

Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

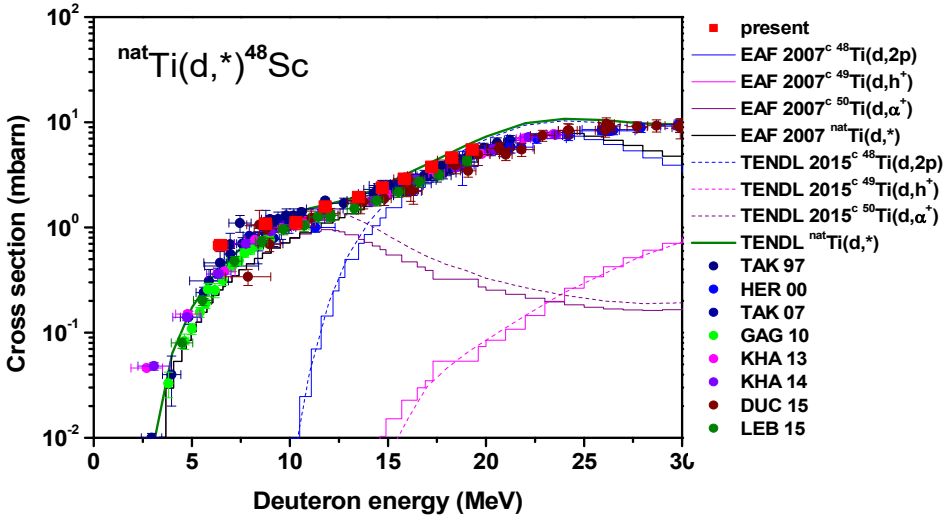
Isotope	Natural abundance (%)
^{46}Ti	8.25
^{47}Ti	7.44
^{48}Ti	73.72
^{49}Ti	5.41
^{50}Ti	5.18

d + ^{nat}Ti

Center of Accelerators and Nuclear Analytical Methods (CANAM)

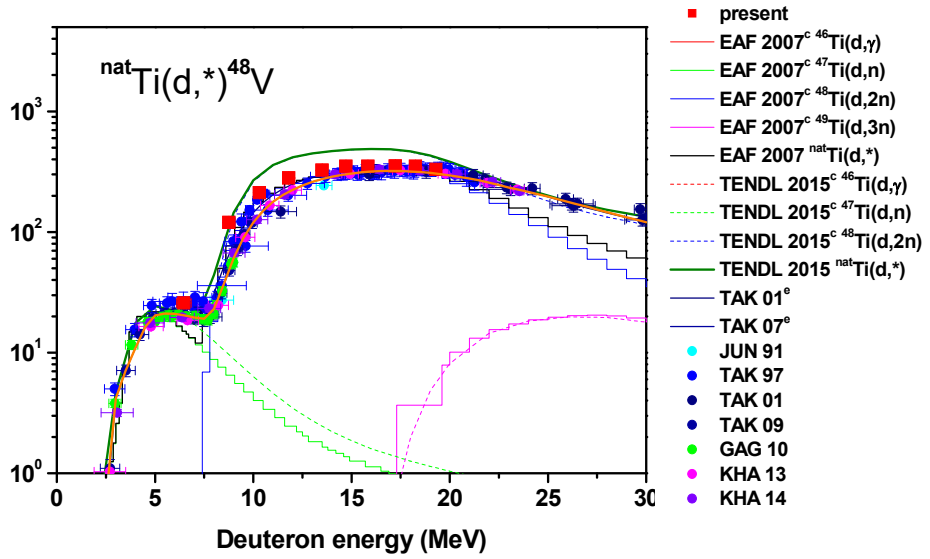
NPI CAS spiral2.cz Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 43.67 h



E_γ (keV)	I_γ (%)
1037.60	97.6
175.36	7.48
983.52	100

$T_{1/2}$ = 15.9735 d



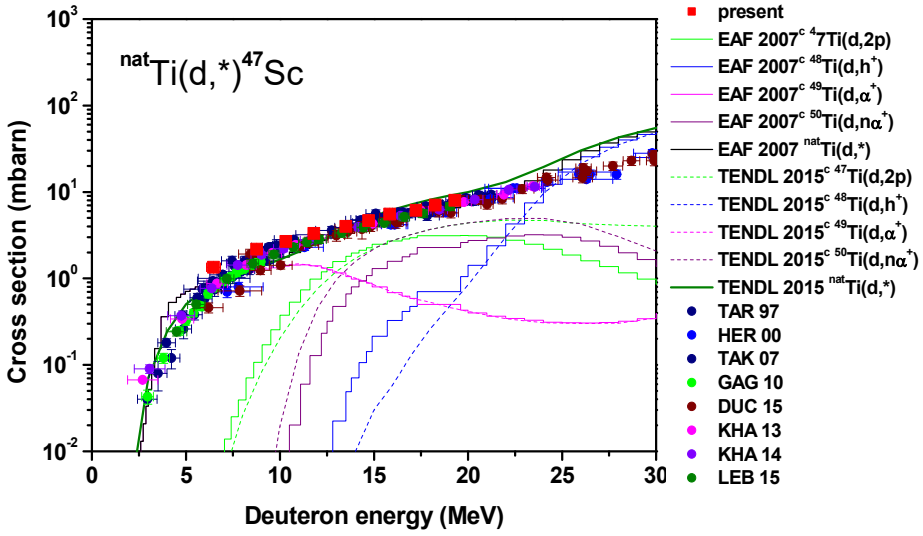
E_γ (keV)	I_γ (%)
944.10	7.76
983.52	99.98

d + ^{nat}Ti

Center of Accelerators and Nuclear Analytical Methods (CANAM)

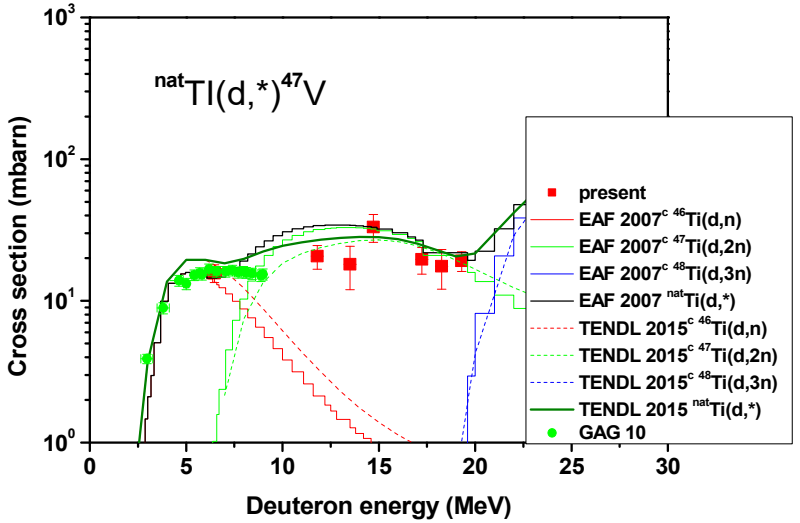
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 3.3492 d



E_γ (keV)	I_γ (%)
159.38	68.3

$T_{1/2}$ = 32.6 min



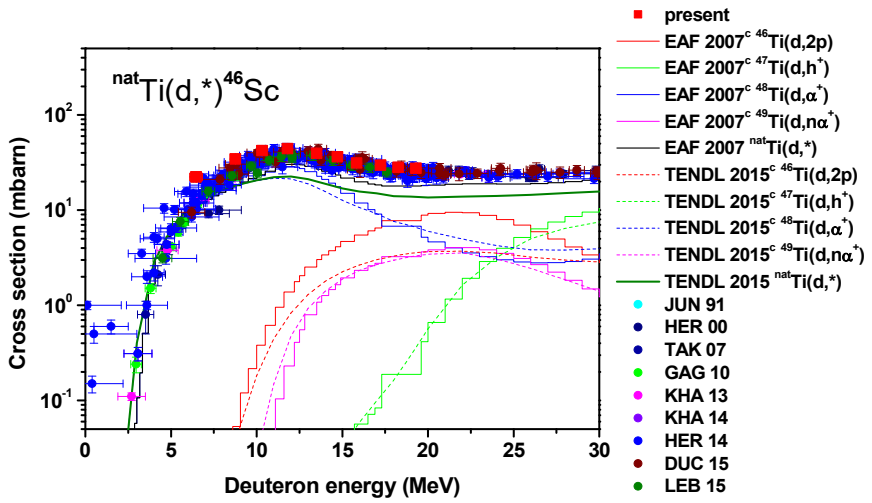
E_γ (keV)	I_γ (%)
1793.9	0.19

d + ^{nat}Ti

Center of Accelerators and Nuclear Analytical Methods (CANAM)

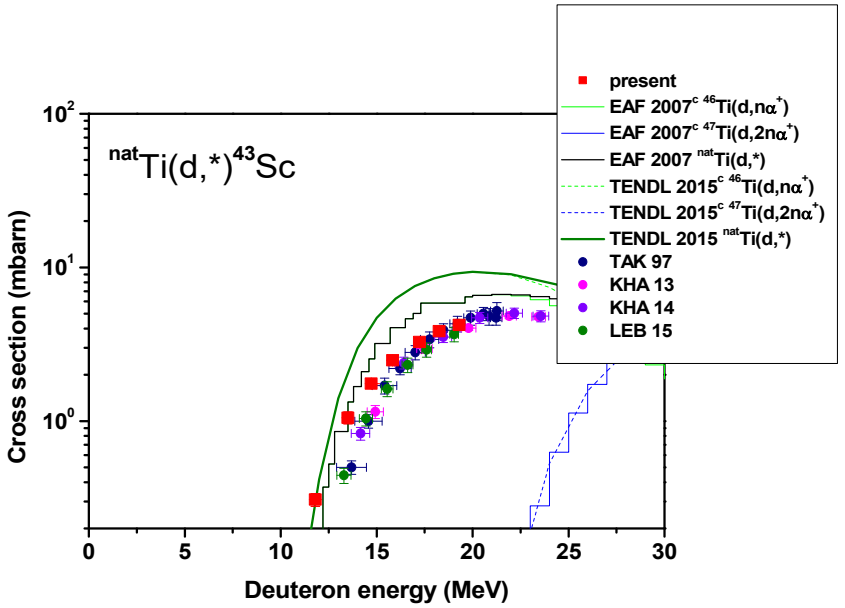
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 83.79 d



E_γ (keV)	I_γ (%)
1120.55	99.99
889.28	99.98

$T_{1/2}$ = 3.891 h



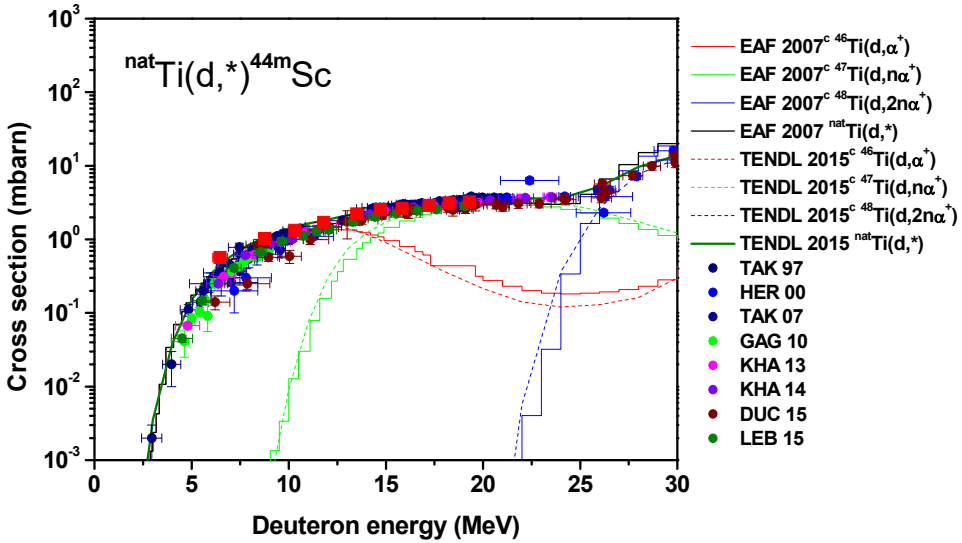
E_γ (keV)	I_γ (%)
372.76	23

d + ^{nat}Ti

Center of Accelerators and Nuclear Analytical Methods (CANAM)

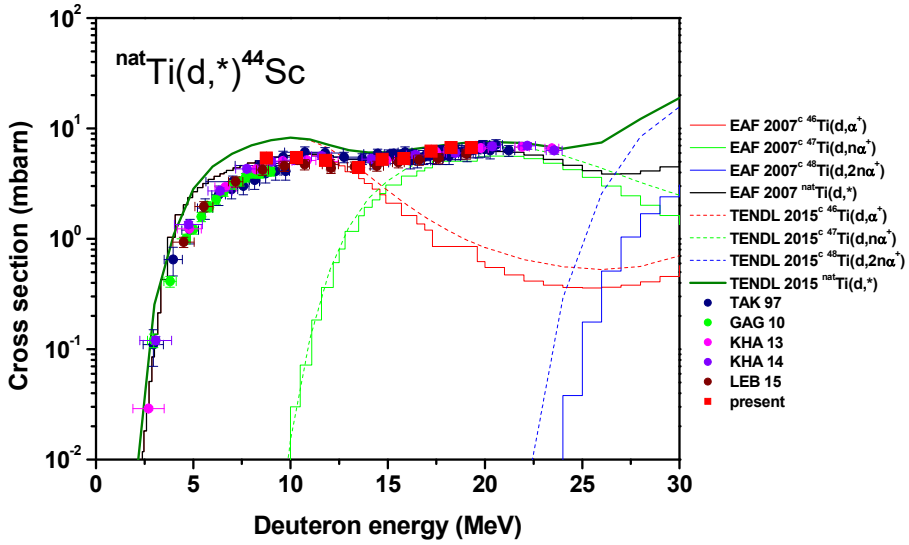
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 58.6 h



E_γ (keV)	I_γ (%)
271.13	86.7

$T_{1/2}$ = 3.927 h



E_γ (keV)	I_γ (%)
1157.03	99.9

Natural Fe

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS Spiral2-CZ Czech Republic contribution to SPIRAL2 GANIL ujf

Isotope	Natural abundance (%)
^{54}Fe	5.845
^{56}Fe	91.754
^{57}Fe	2.229
^{58}Fe	0.282

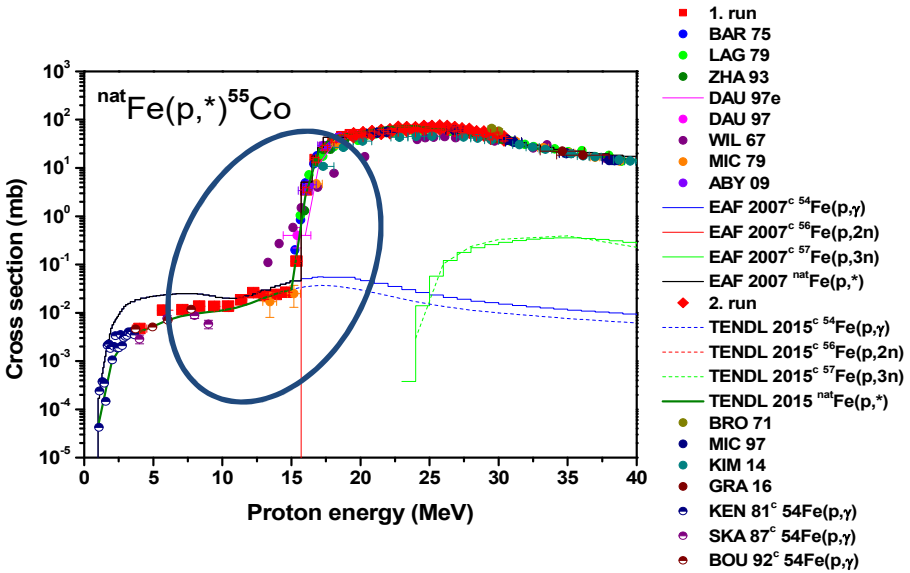
	1. run	2. run
E_{max}	20.067 MeV	30.513 MeV
Q	473.3 µQ	431.803 µQ
ΔT	26.98 min	20.00 min
I_{mean}	0.292 µA	0.360 µA

$^{nat}Fe(p,x)^{55}Co,^{57}Co$

Center of Accelerators and Nuclear Analytical Methods (CANAM)

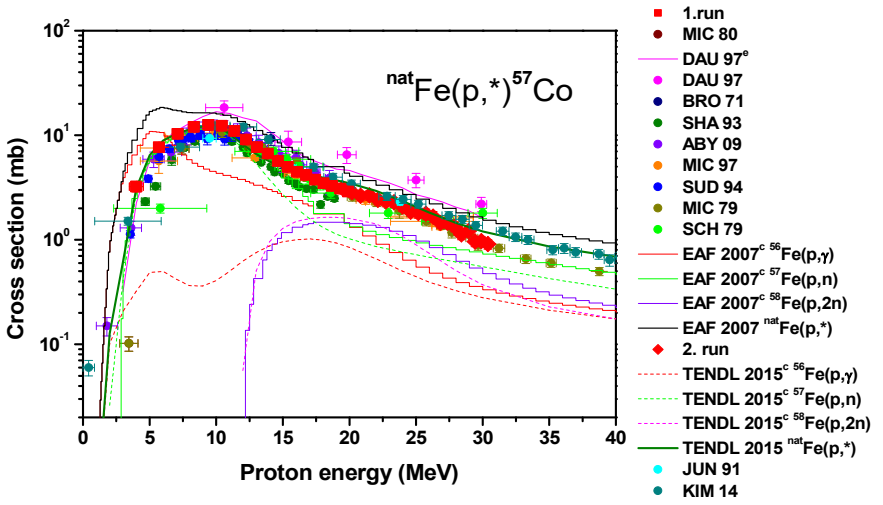
NPI CAS spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 17.53 h



E_γ (keV)	I_γ (%)
931.3	75
477.2	20.2

$T_{1/2}$ = 271.79 d



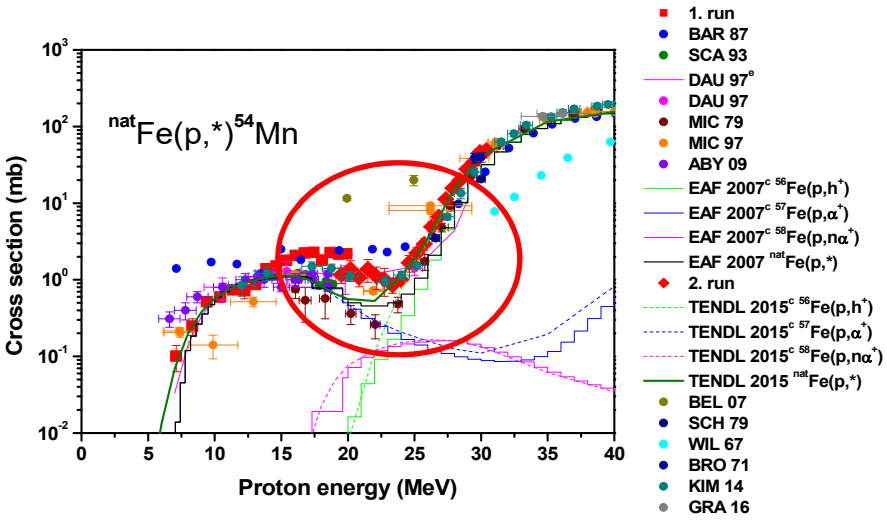
E_γ (keV)	I_γ (%)
122.06	85.6098
136.5	10.68

$^{nat}Fe(p,x)^{54}Mn,^{52}Fe$

Center of Accelerators and Nuclear Analytical Methods (CANAM)

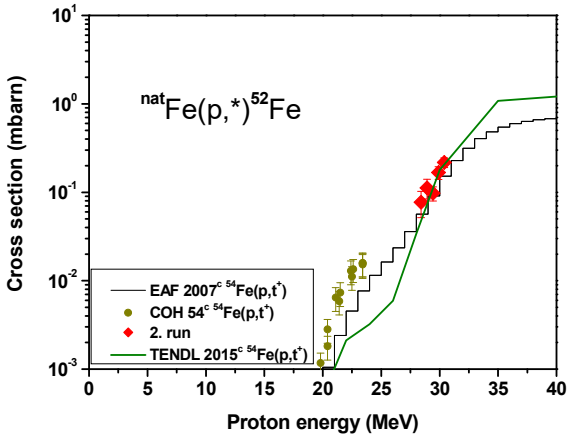
NPI CAS spiral2.cz Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 313.3 d



E_γ (keV)	I_γ (%)
834.85	99.976

$T_{1/2}$ = 8.275 h



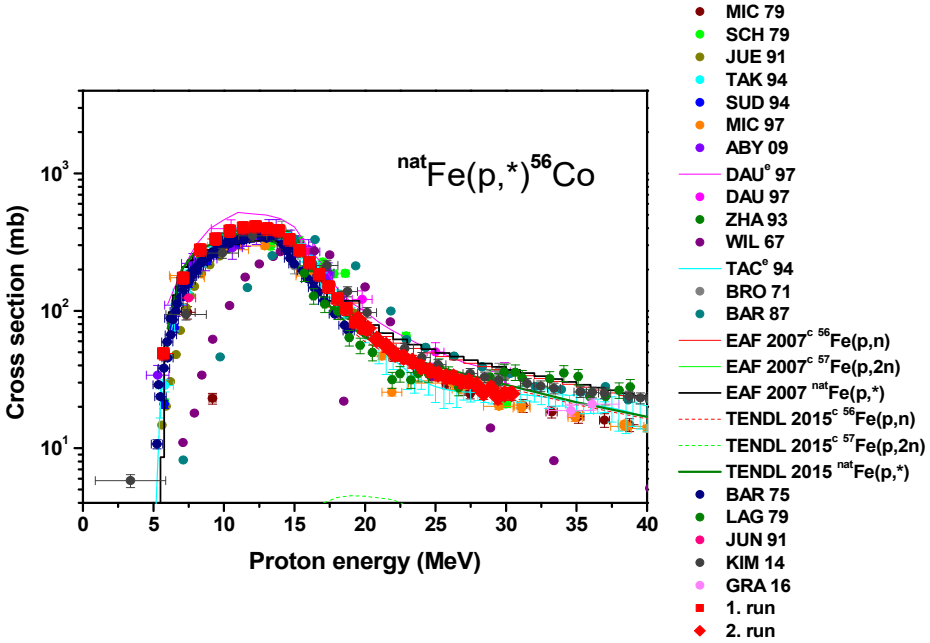
E_γ (keV)	I_γ (%)
168.69	99.2

$^{nat}Fe(p,x)^{56}Co,^{56}Mn$

Center of Accelerators and Nuclear Analytical Methods (CANAM)

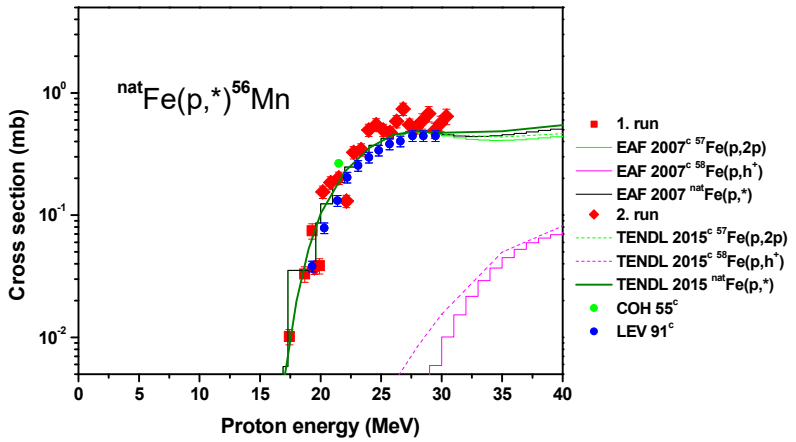
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 77.27 d



E_γ (keV)	I_γ (%)
846.77	100
1771.35	15.69
1037.84	13.99

$T_{1/2}$ = 2.5785 h



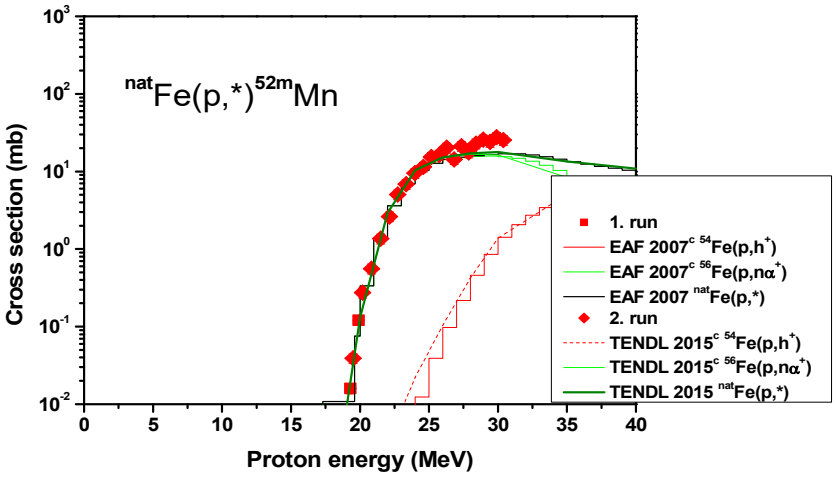
E_γ (keV)	I_γ (%)
846.77	98.9
1810.77	27.2

$^{nat}Fe(p,x)^{52m}Mn,^{52}Mn$

Center of Accelerators and Nuclear Analytical Methods (CANAM)

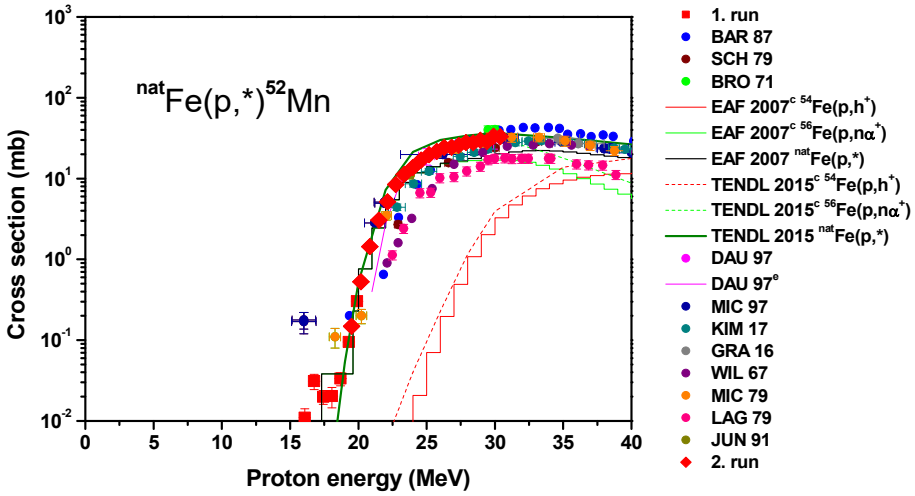
NPI CAS spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 21.1 min

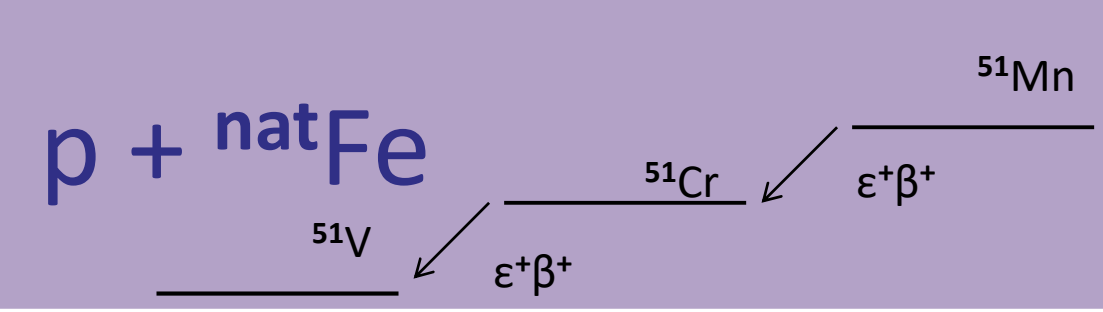


E_γ (keV)	I_γ (%)
1434.07	98.3
377.75	1.7

$T_{1/2}$ = 5.591 d



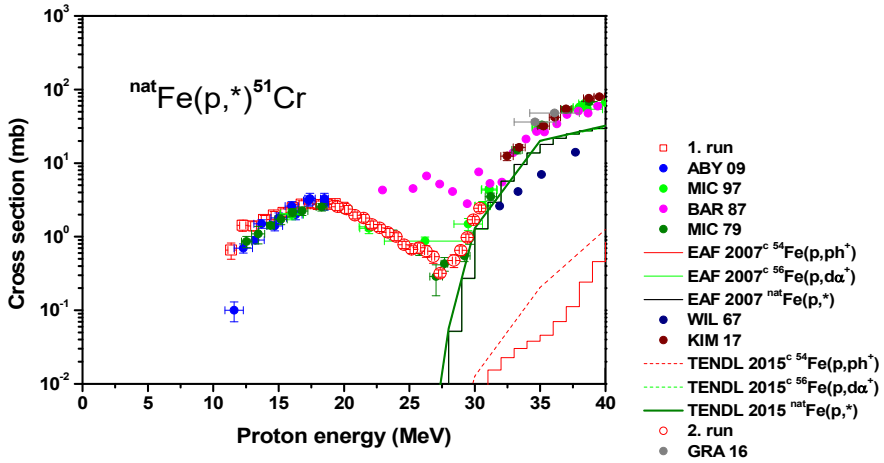
E_γ (keV)	I_γ (%)
1434.07	100
935.54	94.5

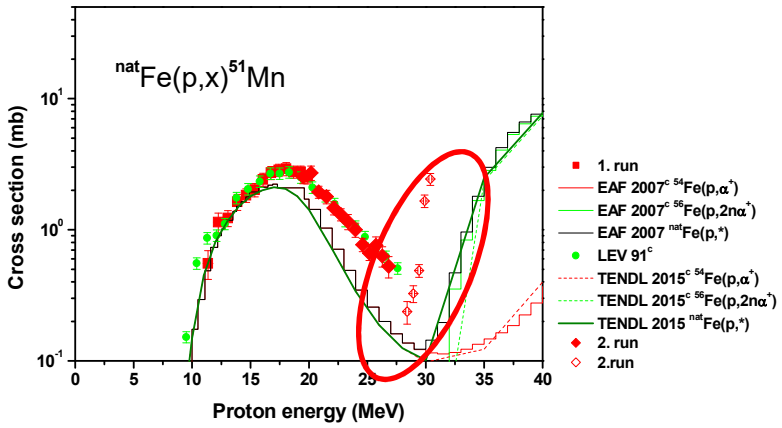


Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

?



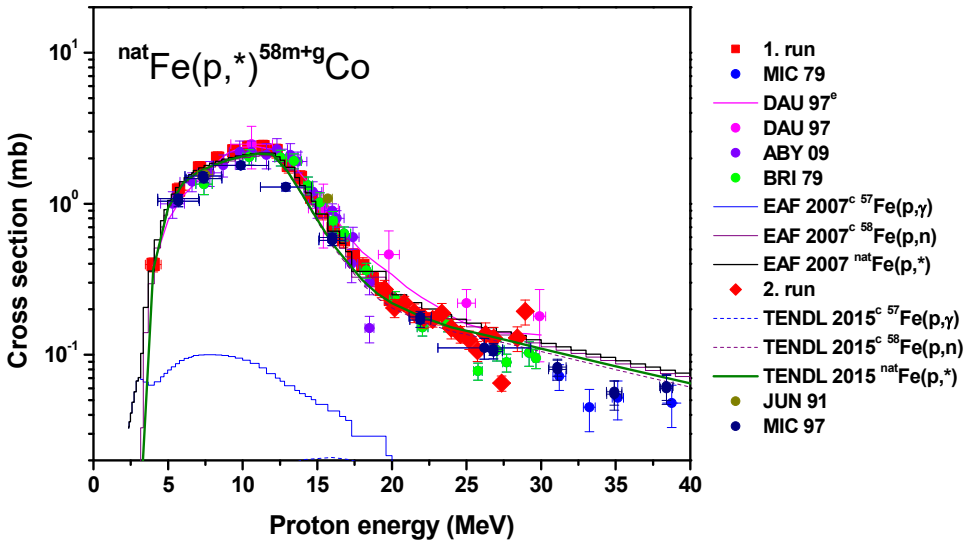


Isotope	$T_{1/2}$	E_γ (keV)	I_γ (%)
^{51}Mn	46.2 m	749.1	0.26
		1148.0	0.078
^{51}Cr	27.7025 d	320.1	10

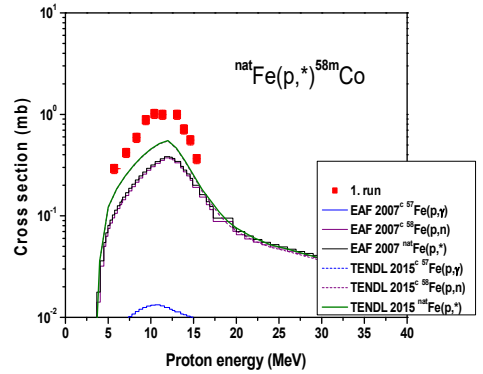
$$A_{g(Cr)} = \frac{\lambda_{g(Cr)}}{\lambda_{g(Cr)} - \lambda_{m(Mn)}} A^0_{m(Mn)}\left(e^{-\lambda_{m(Mn)}t} - e^{-\lambda_{g(Cr)}t}\right) + A^0_{g(Cr)} e^{-\lambda_{g(Cr)}t}$$

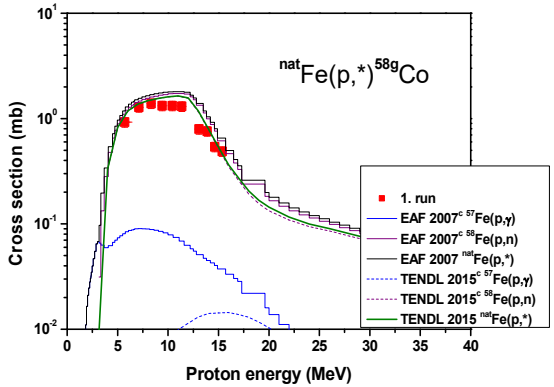
Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2.cz
Czech Republic contribution to SPIRAL2
GANIL
ujf



Isotope	$T_{1/2}$	E_γ (keV)	I_γ (%)
^{58m}Co	9.04 h	24.9	0.0389
^{58}Co	70.86 d	810.8	99



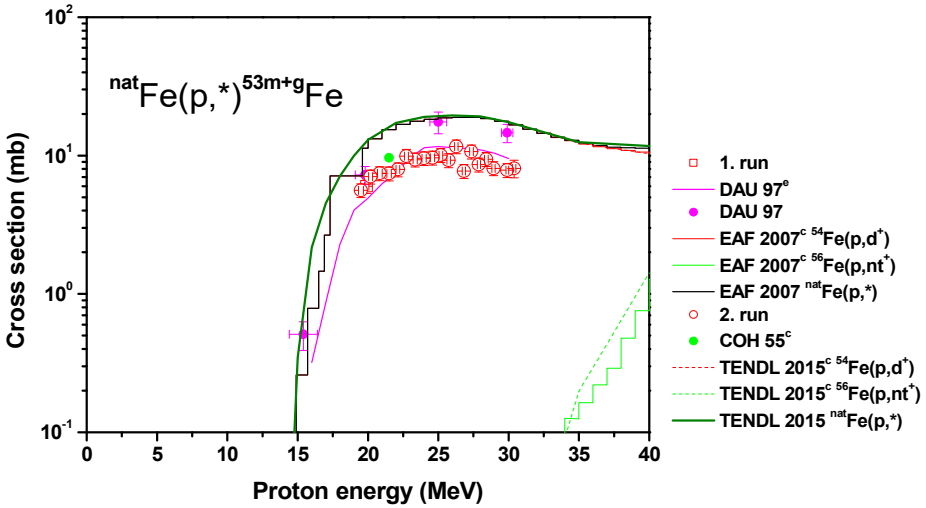


$^{nat}Fe(p,x)^{53}Fe$

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 8.51 min



E_γ (keV)	I_γ (%)
377.88	42

First experiment

Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

NPI CAS spiral2·CZ
Czech Republic contribution to SPIRAL2
GANIL ujf

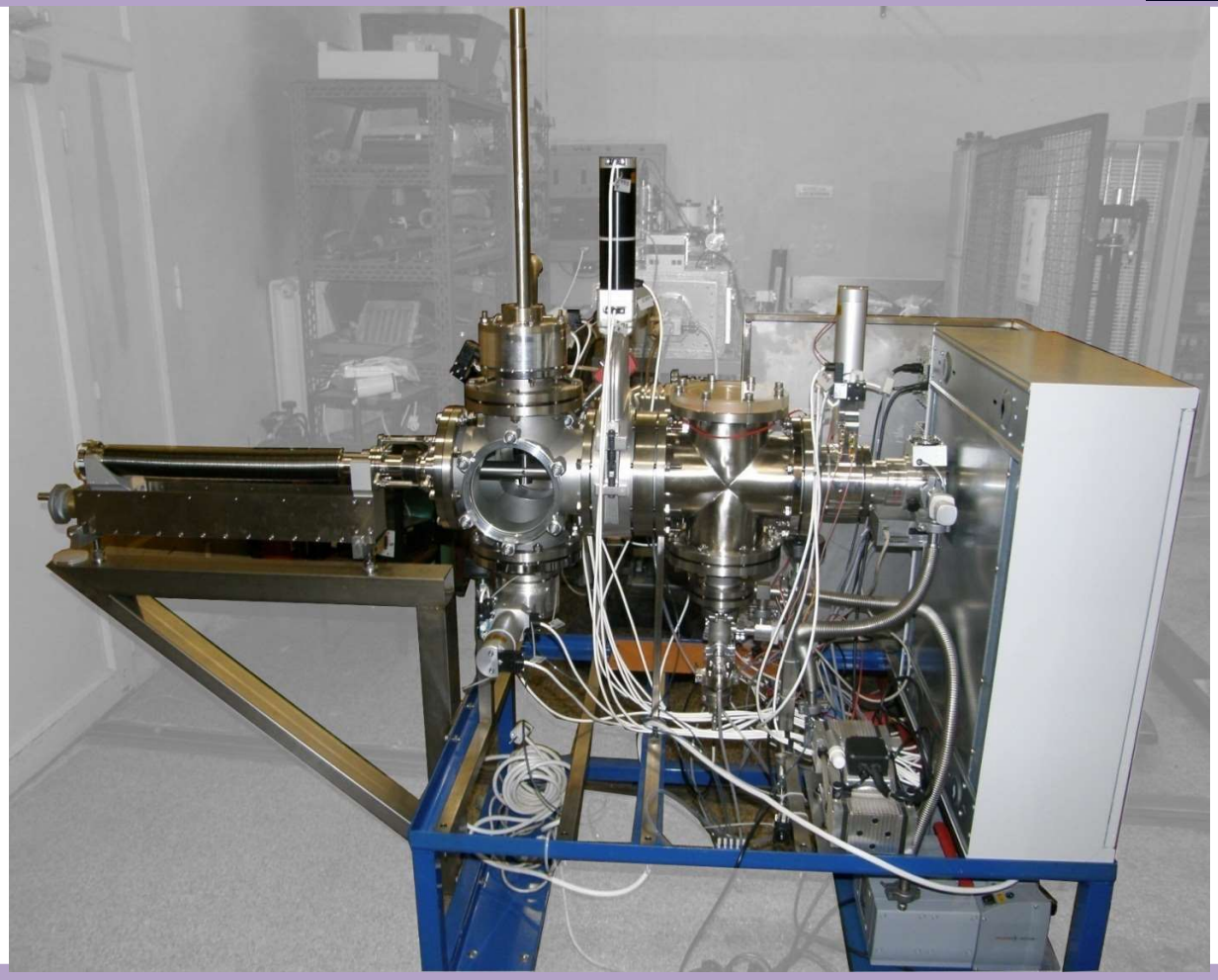
PROPOSAL FOR AN EXPERIMENT

Title: Excitation functions of short-lived isotopes in proton-induced reactions on ^{nat}Fe		
Spokesperson: Eva Simeckova **Address: NPI CAS, 250 68 Rez, Czech Republic**		
Phone:	Fax:	Email: simeckova@ujf.cas.cz
Backup Spokesperson: Jaromir Mrazek **Address: NPI CAS, 250 68 Rez, Czech Republic**		
Phone:	Fax:	Email: mrazek@ujf.cas.cz
GANIL Scientific Coordinator: **X.Ledoux**		
Collaboration : Participant names, institutions, and indicate students (S), and post-doctoral fellows (PDF): NPI CAS: M.Stefanik (PDF), J.Mrazek, D.Thomas (S), O.Lebeda, M.Majerle, P.Alexa, G.Thiamova GANIL: X.Ledoux, F.Oliveira, B.Bastin, J.Grinyer KIT: U. Fischer, A. Klix IFIN-HH: M.Avrigeanu, V.Avrigeanu		

NFS irradiation chamber test

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf



p + Cu, Fe

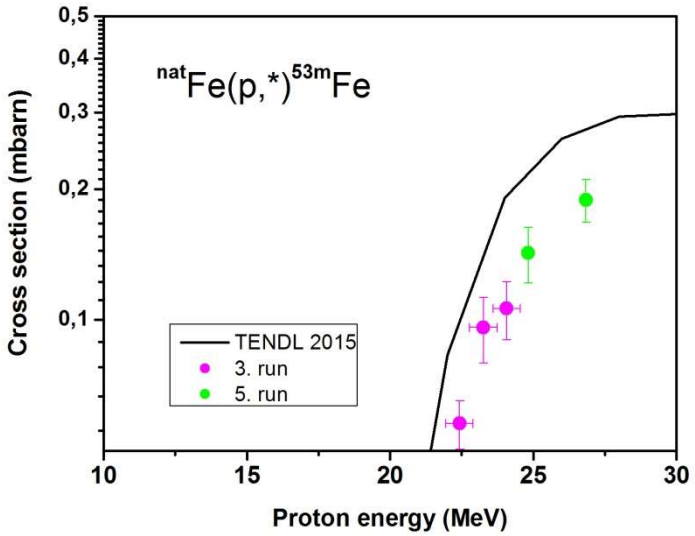
1. run – 24.69 MeV
2. run – 24.40 MeV
3. run – 24.55 MeV
4. run – 27.02 MeV
5. run – 26.97 MeV

$^{nat}Fe(p,x)^{53m}Fe,^{53(m+g)}Fe$

Center of Accelerators and Nuclear Analytical Methods (CANAM)

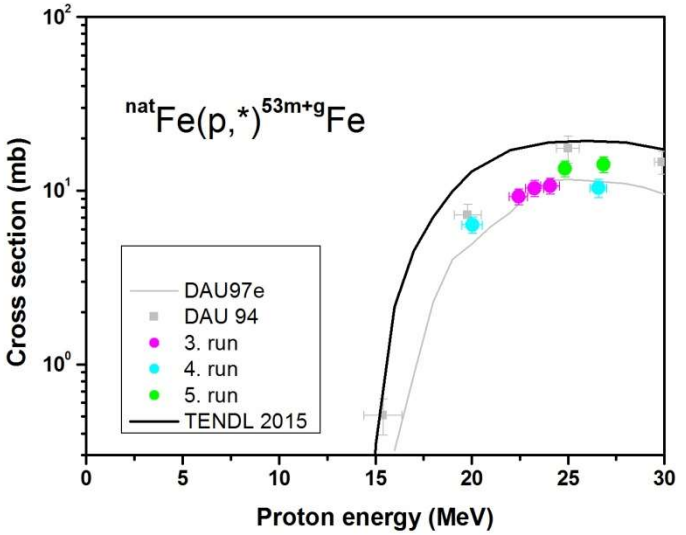
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 2.58 min



E_γ (keV)	I_γ (%)
701.1	99
1328.2	87
1011.2	86

$T_{1/2}$ = 8.51 min



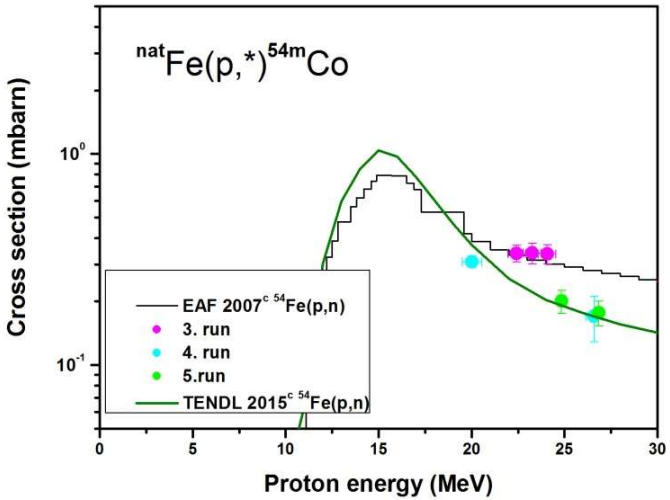
E_γ (keV)	I_γ (%)
377.88	42

p + ^{nat}Fe

Center of Accelerators and Nuclear Analytical Methods (CANAM)

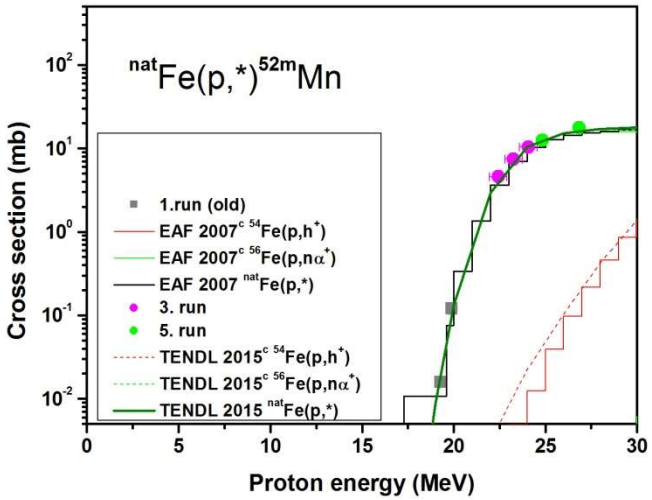
NPI CAS spiral2.cz Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 1.48 min



E_γ (keV)	I_γ (%)
1129.9	98

$T_{1/2}$ = 21.1 min



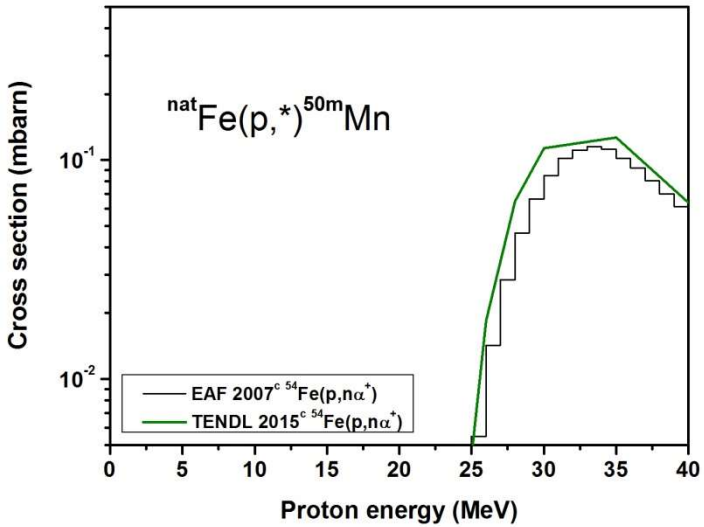
E_γ (keV)	I_γ (%)
1434.068	98.3
377.748	1.7

p + ^{nat}Fe

Center of Accelerators and Nuclear Analytical Methods (CANAM)

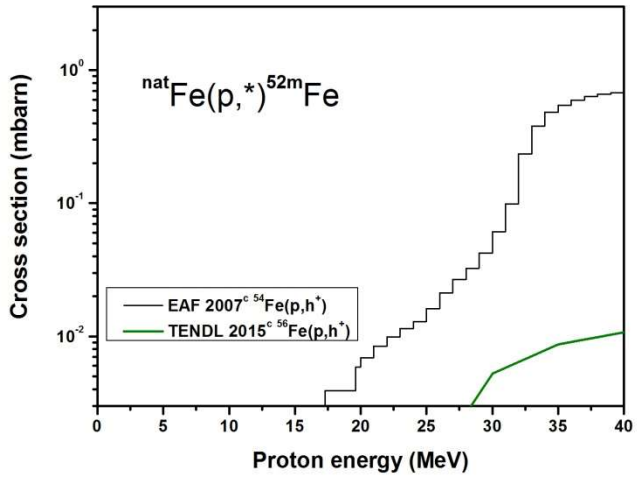
NPI CAS Spiral2.CZ Czech Republic contribution to SPIRAL2 GANIL ujf

$T_{1/2}$ = 1.75 min



E_γ (keV)	I_γ (%)
783.29	100
1097.97	98.5
1443.28	69

$T_{1/2}$ = 45.9 s

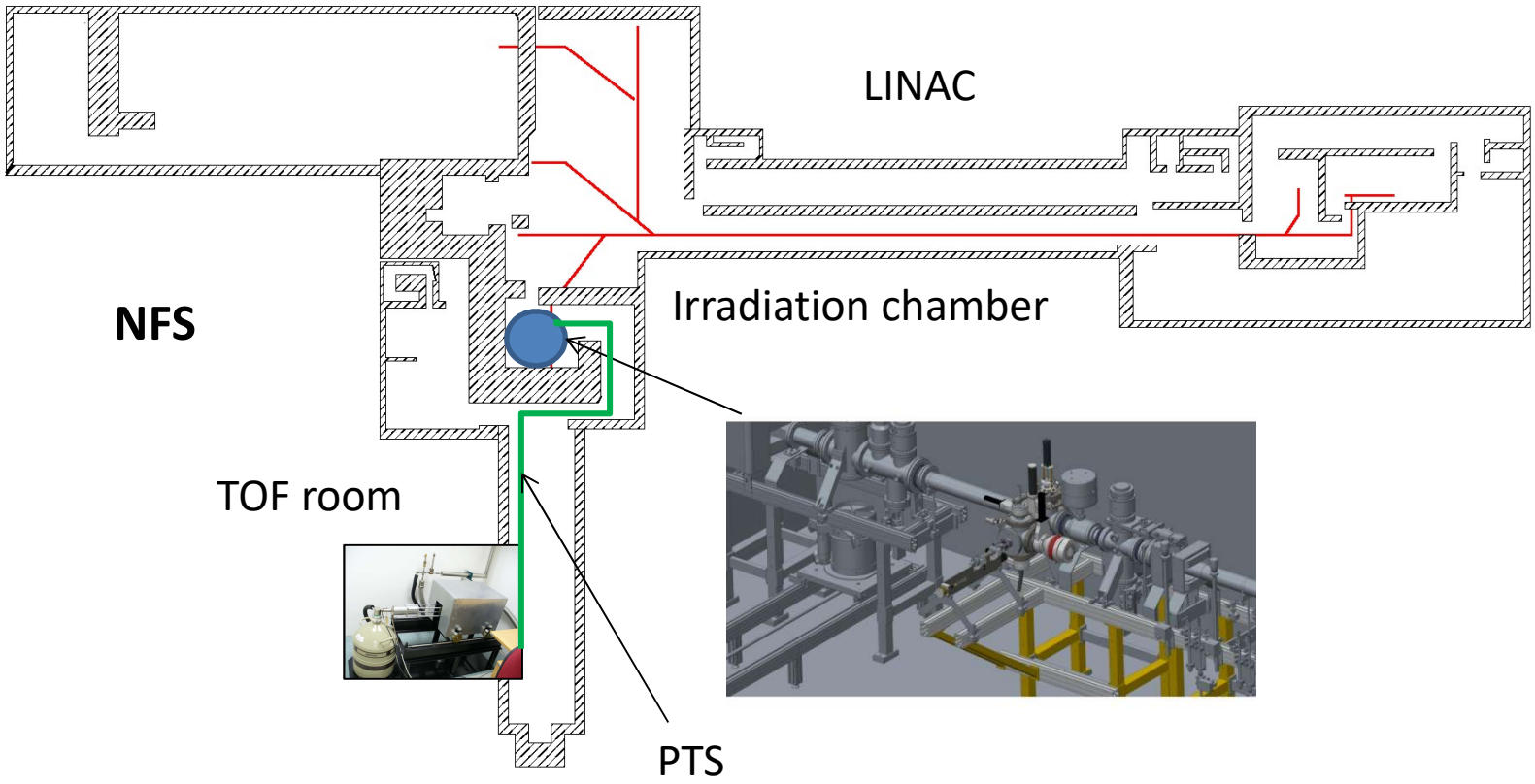


E_γ (keV)	I_γ (%)
929.5	100
869.9	93
621.7	51

SPIRAL2/NFS

Center of Accelerators and Nuclear Analytical Methods (CANAM)

NPI CAS spiral2.cz Czech Republic contribution to SPIRAL2 GANIL ujf



SPIRAL2/NFS

Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

NPI CAS spiral2·cz GANIL ujf
Czech Republic contribution to SPIRAL2

Future

Center of Accelerators
and Nuclear Analytical Methods
(CANAM)

NPI CAS spiral2·CZ GANIL ujf
Czech Republic contribution to SPIRAL2

Study of excitation functions (isomer ratio) for p + Fe reactions at NFS Spiral 2 facility.

Continuation of d provoked activation cross section measurements on Cr and other Li loop impurities at NPI up to 20 MeV and at NFS Spiral2 up to 40 MeV (short lived isotopes).

Thank you for your attention.

www.canam.ujf.cas.cz

www.spiral2.cz