PAUL SCHERRER INSTITUT

Measurement of the neutron capture cross-sections of ^{53}Mn at EAR-2

Proposal to INTC P-408

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Short Lived Cosmogenic Radio-Nuclides

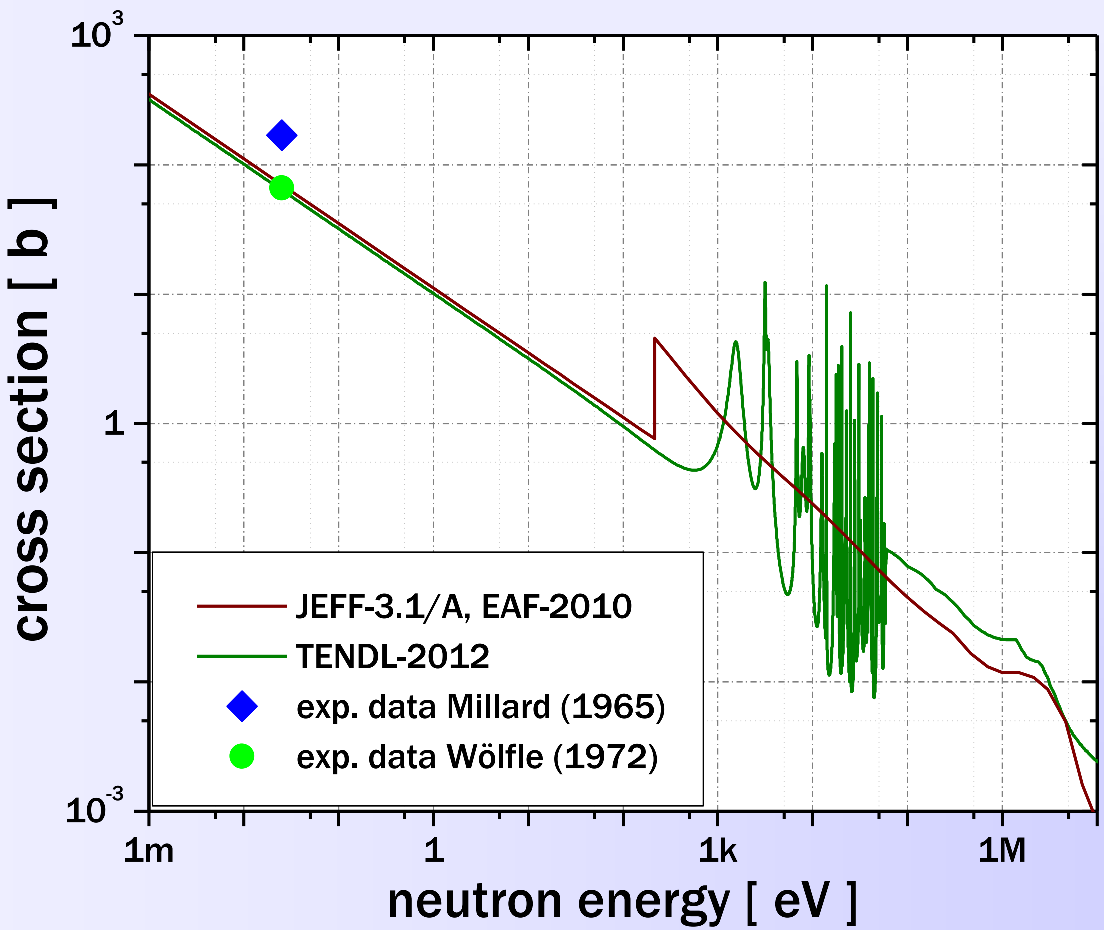
$t_{1/2} < 100$ Ma

- Produced
  - *via neutron capture reaction*
  - *during explosive phases of star evolution*
  - *in spallation reactions with high energetic particles*
- Present in the Universe
  - *as constitute of molecular cloud formed our Sun*
    e.g. found in meteorites
  - *injected from nearby super novae to our Solar System*
    e.g. ^{26}Al, ^{44}Ti, ^{60}Fe
  - *continuously produced at Earth from cosmic rays*
    e.g. ^{7}Be, ^{14}C, ^{53}Mn

^{53}Mn

- discovered by Wilkinson and Sheline (1955)
  - *$^{53}Cr(p,n)^{53}Mn$*
- Shedlovsky (1960) analyzed iron meteorites
  - *amount of ~5×10^{11} atoms ^{53}Mn per gram*
- radioactive isotope
  - *Honda et al. (1971)* $t_{1/2} = (3.7\pm0.37)$ *Ma*
  - *Wölfle et al. (1972)* $t_{1/2} = (3.9\pm0.6)$ *Ma*
  - *Heimann et al. (1974)* $t_{1/2} = (3.85\pm0.4)$ *Ma*
- neutron cross-section at thermal energies
  - *Millard (1965)* $\sigma_{th} \approx 170$ *b*
  - *Wölfle et al. (1972)* $\sigma_{th} = 66\pm7$ *b*
- samples used so fare 2.5×10^{11} to 1.3×10^{13} atoms ^{53}Mn
- envisaged samples of 5×10^{17} atoms ^{53}Mn

Neutron capture cross-section ^{53}Mn

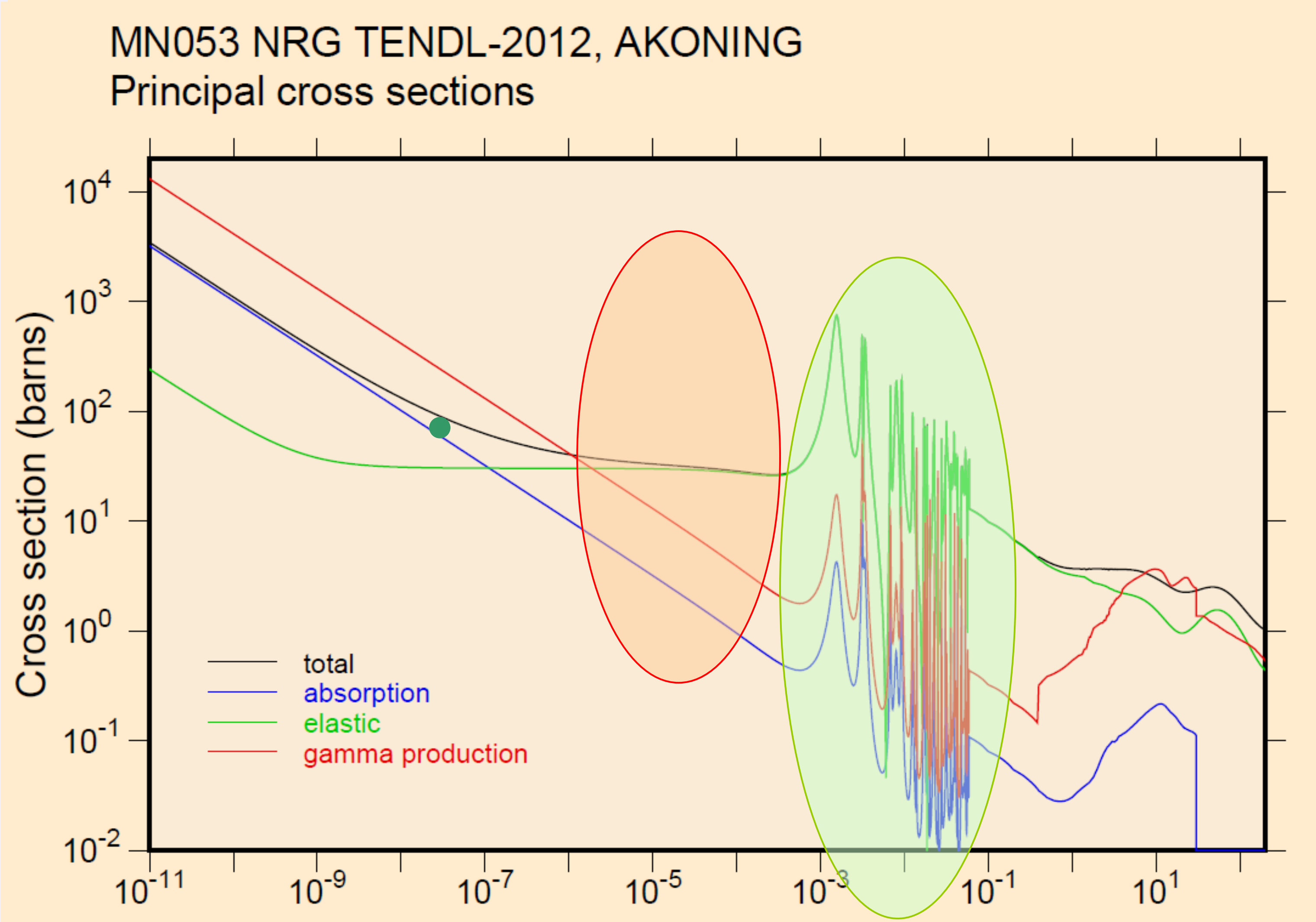


JEFF-3.1/A = R. A. Forrest, J. Kopecky, J.-Ch. Sublet (2003) UKAEA FUS 486

EAF-2010 = J.-Ch. Sublet, et al. (2010) CCFE-R (10) 05

TENDL-2012 = A.J. Koning, D. Rochman (2012) Nucl. Data Sheets 113, 2841

Changes in TALYS predictions



taken from www.talys.eu

SINQ Target-Irradiation Program

STIP sample

- diff. structure materials investigated
- placed at diff. positions in SINQ targets
- irradiated with up to 570 MeV protons
- average current 1.5 mA for up to 2 years
- mechanically tested after cool down
- radioactive waste afterwards

STIP analytics

- irradiated till 17.12.1999
- appl. dose 2.3×10^{23} protons
- total available material ~ 60 g
  bulk material Fe, additional
  9.5% Cr, 1% W, 0.5% Mn, 0.25% V
- EOB Dec. 1999
- radio nuclides available

^{26}Al 350 Bq ≈ 9.8×10^{15} atoms
^{44}Ti 280 MBq ≈ 1.1×10^{18} atoms
^{53}Mn 180 kBq ~ 3×10^{19} atoms

R. Dressler et al.: J. Phys. G **39** (2012) 105201

Chemical separation

- content of STIP-samples 3×10^{19} atoms ^{53}Mn

1.8×10^{21} atoms V	6.6×10^{22} atoms Cr
3.3×10^{21} atoms ^{55}Mn	5.7×10^{23} atoms Fe

- chemical yield: 70%
  suppression of other elements 10^{-4}

- stock solution: 2×10^{19} atoms ^{53}Mn

1.8×10^{19} atoms V	6.6×10^{18} atoms Cr
2.3×10^{21} atoms ^{55}Mn	5.7×10^{19} atoms Fe

- backing material: 2.0 µm deuterated Mylar foil (98%)
- final targets: 5×10^{17} atoms ^{53}Mn (44 µg ^{53}Mn)

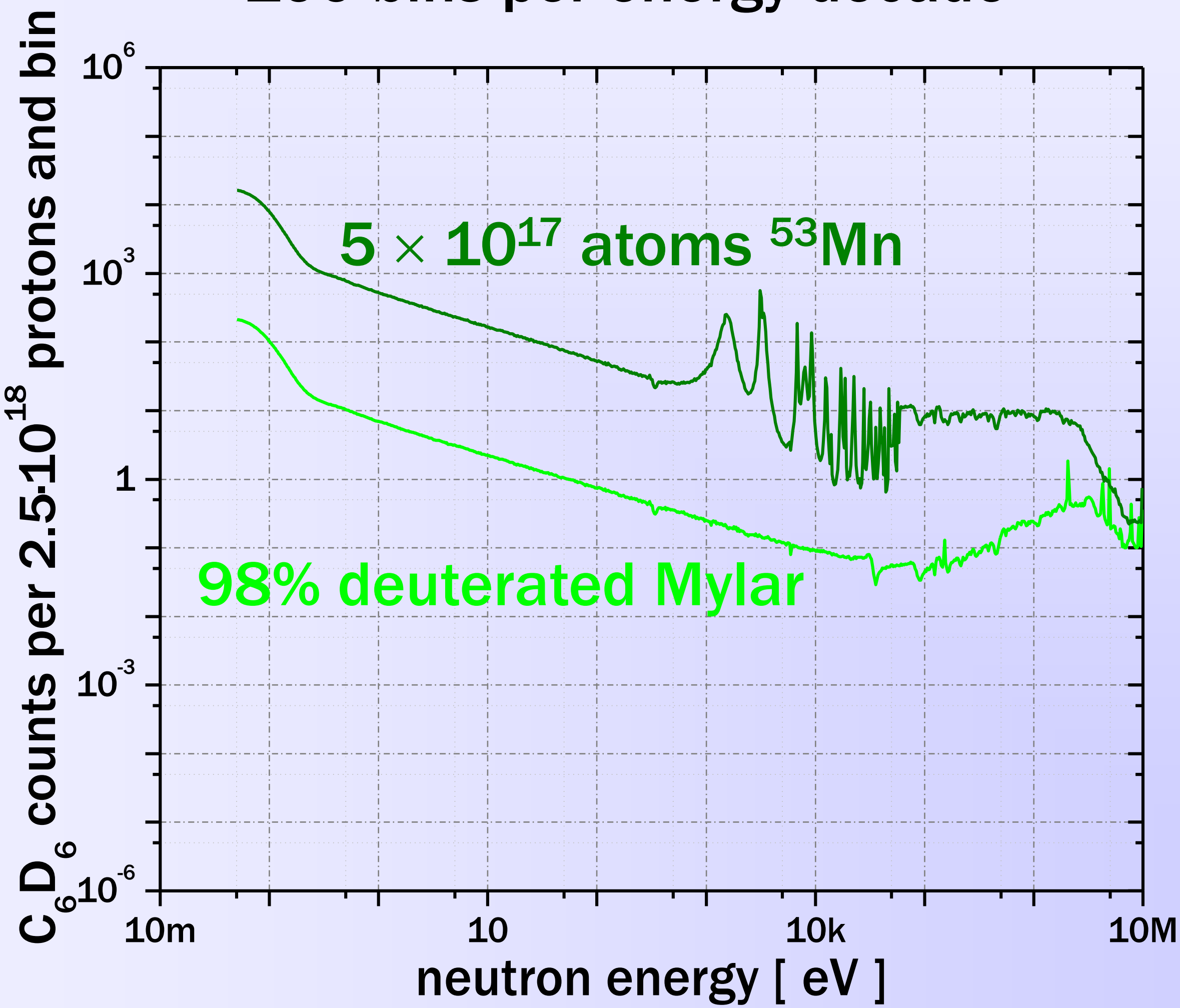
$^{53}Mn(n, \gamma)$ at EAR-2

Simulation of event numbers:

- 2.5×10^{18} protons on n_TOF target
- $27\times$ neutron flux of EAR-1 (without borated H_2O)
- 5×10^{17} atoms ^{53}Mn in sample (diameter 2.0 cm)
- two C_6D_6 detectors total detection efficiency 18%
- capture cross section of stable elements ENDF-B/VII.1
- capture cross section of ^{53}Mn from TENDL-2012
- no ambient background from installation considered
- elastic scatter to capture cross section ratio < 100
- 100 bin per energy decade

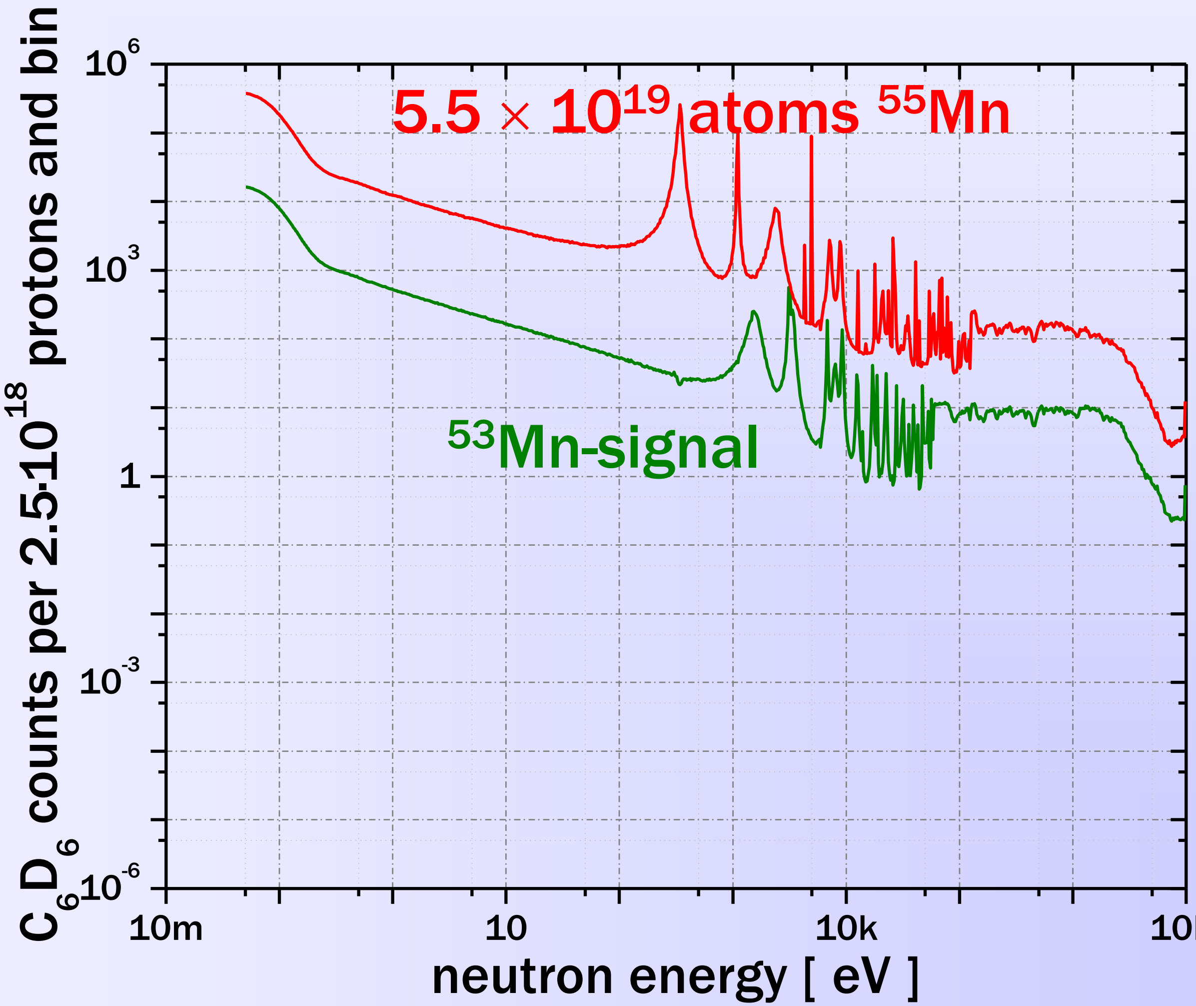
^{53}Mn signal @ EAR-2

100 bins per energy decade



TENDL-2012 = A.J. Koning, D. Rochman (2012) Nucl. Data Sheets 113, 2841

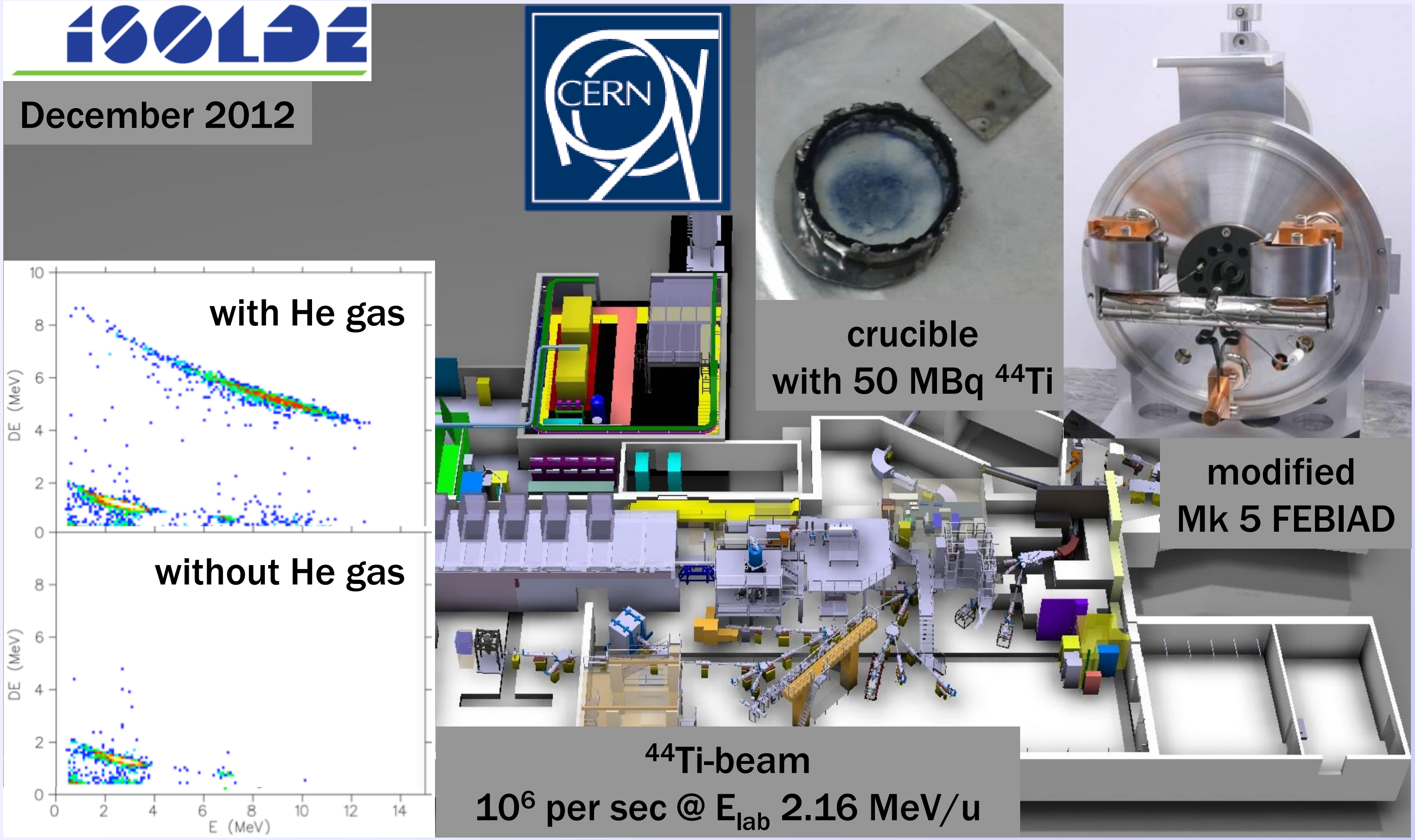
Contribution of ^{55}Mn



ENDF-B/VII.1 = M.B. Chadwick, et al. *Nuclear Data Sheets* **112** (2011) 2887

Inverse kinematics of $^{44}\text{Ti}(\alpha,\text{p})^{47}\text{V}$

IS543 collaboration



Off-line ISOLDE mass separator

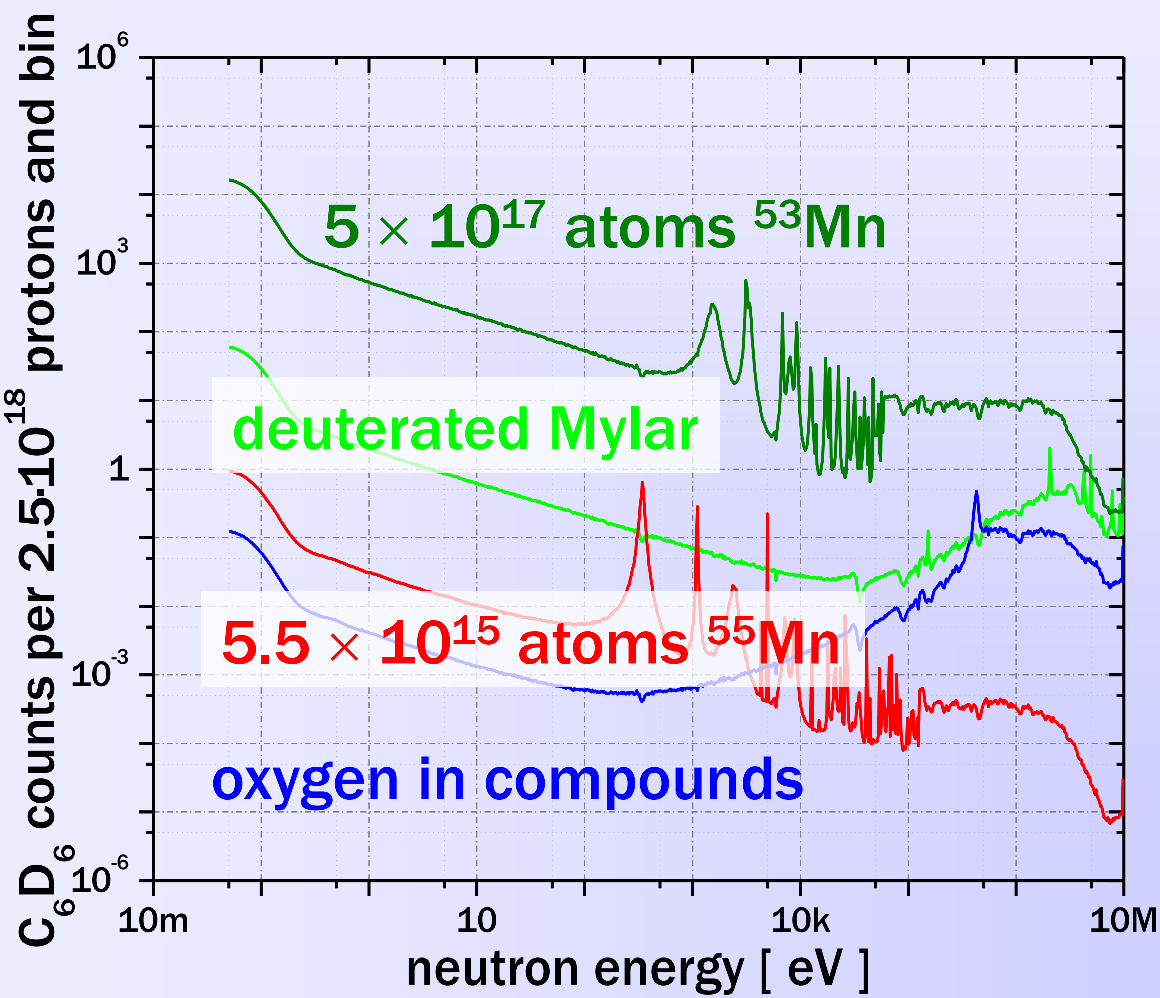
- FEBIAD output: 100 µA
  (single charged Mn) 6.2×10^{14} part. per sec

- suppression Δmass = 1 : $> 10^3$
- suppression Δmass > 1 : $> 10^4$

- separation yield ISOLDE: 2.5% Mn
- separation time: 10 days per 10^{17} atoms ^{53}Mn

- final sample: 5×10^{17} atoms ^{53}Mn
  8.7×10^4 atoms V — 2.4×10^{12} atoms Cr
  5.8×10^{15} atoms ^{55}Mn — 4.9×10^9 atoms Fe

Signal of final sample



Proton budget
total 3.5×10^{18}

sample	purpose	protons
5×10^{17} atoms ^{53}Mn (on 2.0 µm D-Mylar foil)	$^{53}Mn(n, \gamma)$	2.5×10^{18}
1×10^{18} atoms ^{197}Au (Au foil or on 2.0 µm D-Mylar foil)	^{197}Au (n, γ)	2.0×10^{17}
7.4×10^{21} atoms ^{197}Au (0.1 mm Au foil)	saturated resonance analysis ^{197}Au (n, γ)	2.0×10^{17}
1×10^{21} atoms ^{55}Mn (on 2.0 µm D-Mylar foil)	background $^{55}Mn(n, \gamma)$	2.0×10^{17}
2.3×10^{22} atoms ^{12}C (0.1 mm D-Mylar foil)	Background backing	4.0×10^{17}
none	background w/o beam	
	total dose	3.5×10^{18}

Summary of proposal

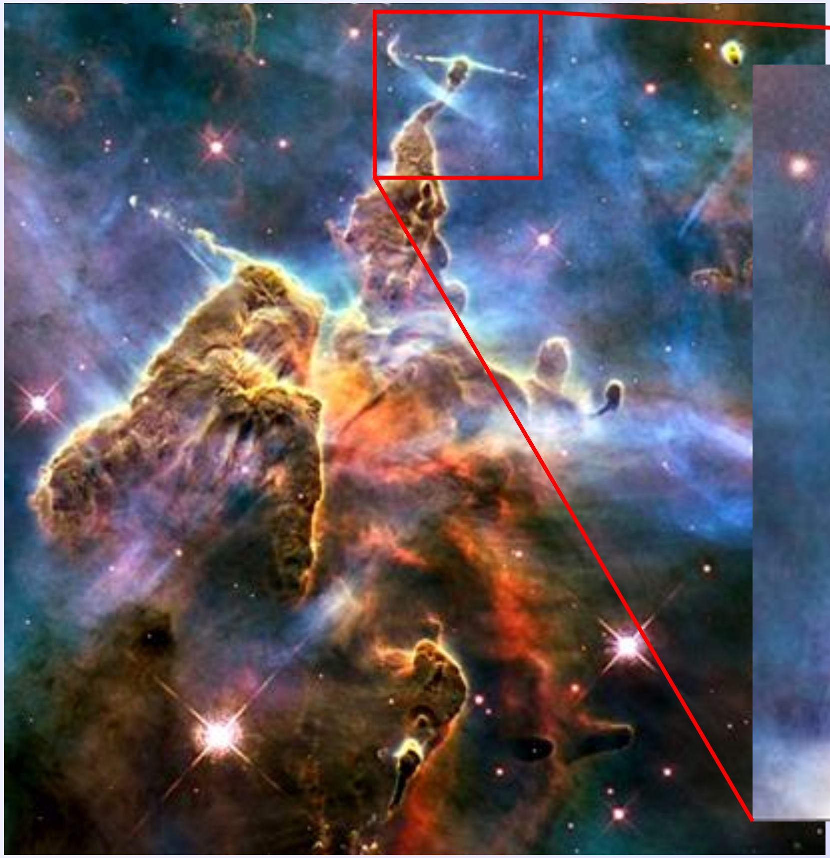
Proposal:

- stock solution 3×10^{19} atoms ^{53}Mn from STIP
- depletion of ^{55}Mn using off-line mass separator
- radioactive target with 5×10^{17} atoms = 44 µg ^{53}Mn
- experiment at EAR-2 using 3.5×10^{18} protons

Goal:

- cross section measurement from 25 meV to 250 keV
- date to perform 2015/2016

Thank you for attention



combined visible and near infrared pictures

star-forming pillar with a jet (HH 901)

Carina nebula: birthplace of stars

Hubble space telescope: http://hubblesite.org

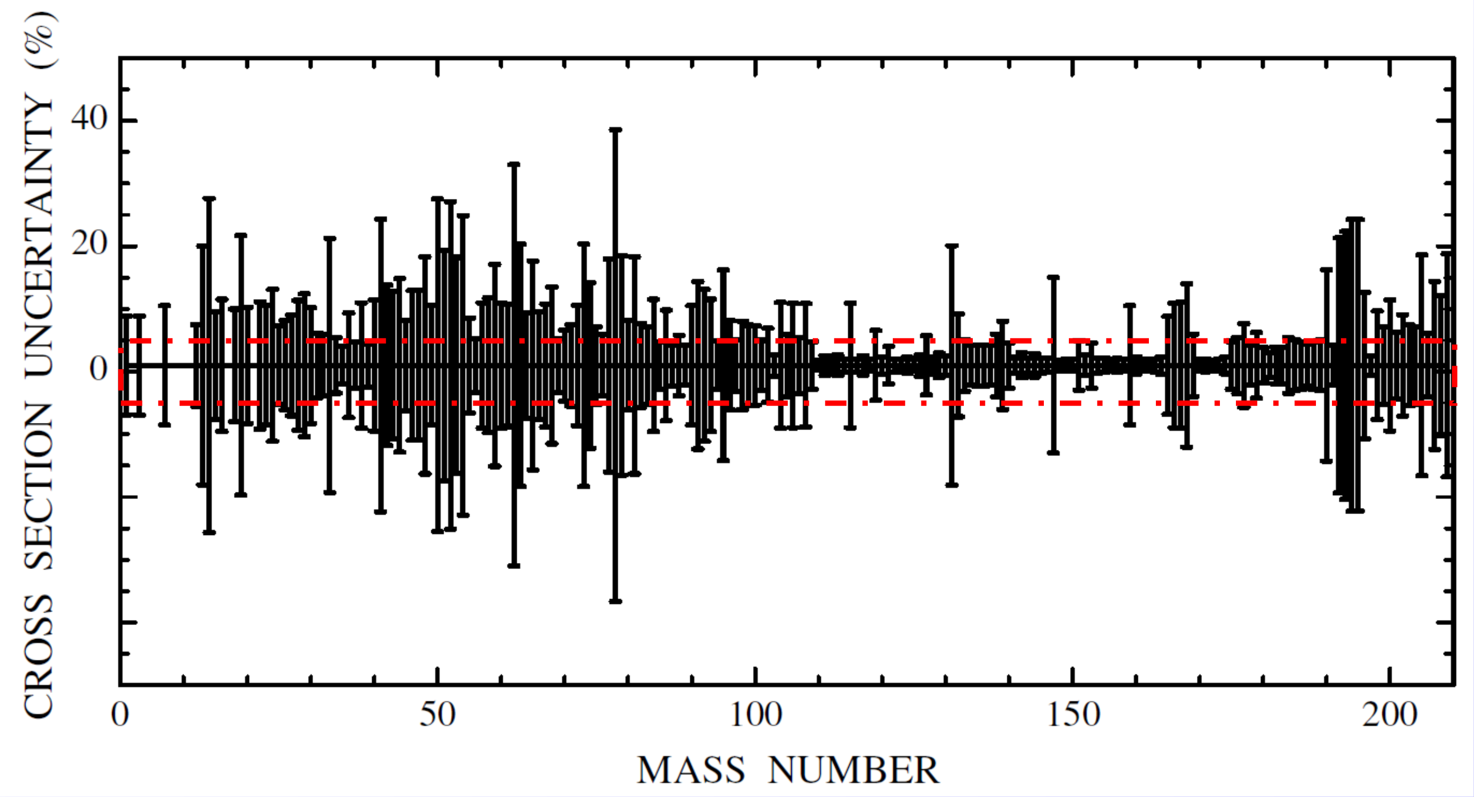
Short Lived <u>Co</u>smogenic Radio-<u>N</u>uclides

$t_{1/2}$ < 100 Ma

parent nuclide	half-life (Ma)	daughter nuclide	estim. init. abundance	Reference	at PSI
^{53}Mn	3.74	^{53}Cr	^{53}Mn / ^{55}Mn = 6.28×10^{-6}	Birck & Allègre 1985, Shukolyukov & Lugmair 2006, Trinquier et al. 2008	☑
^{10}Be	1.387	^{10}B	^{10}Be / ^{9}Be = 7.5×10^{-4}	McKeegan et al. 2000, Chaussidon & Gounelle 2006, 2007	☑
^{26}Al	0.717	^{26}Mg	^{26}Al / ^{27}Al = 5.23×10^{-5}	Jacobsen et al. 2008, Lee et al. 1976	☑
^{60}Fe	2.62	^{60}Ni	^{60}Fe / ^{56}Fe = 5.8×10^{-9}	Quitt´e et al. 2010, Shukolyukov & Lugmair 1993, Tang & Dauphas 2011	☑
^{36}Cl	0.301	^{36}S (~2%) ^{36}Ar (~98%)	^{36}Cl / ^{35}Cl > 17.2×10^{-6}	Jacobsen et al. 2009, Lin et al. 2005	☑
^{41}Ca	0.102	^{41}K	^{41}Ca / ^{40}Ca = 1.41×10^{-8}	Srinivasan et al. 1994, 1996	☑
^{7}Be	$1.46 \cdot 10^{-7}$	^{7}Li	^{7}Be / ^{9}Be = 6.1×10^{-3}	Chaussidon et al. 2006	☑

adapted from N. Dauphas, M. Chaussidon Annu. Rev. Earth Planet. Sci. 39 (2011) 351

Neutron capture cross-sections at stellar neutron energies



F. Käppeler: Nucl. Instr. and Methods **B 259** (2007) 663

Separation scheme of STIP samples

STIP sample

↓ dissolution in 8 M HCl + conc. HNO_3

Fe, Cr, Ni, Mo, Mn, Co, Al, Ti

extraction into di-ethyl-ether

- organic phase $FeCl_4$ MoO_2Cl_3
- aqueous phase Cr Ni Mn Co Al Ti traces of Fe and Mo

precipitation with NH_3

- filtrate CrO_4^{2-} $[Ni(NH_3)_6]^{2+}$ MoO_4^{2+} $[Co(NH_3)_6]^{2+}$
- precipitate $Al(OH)_3$ $Fe(OH)_3$ $Ti(OH)_4$ $Cr(OH)_3$ $Mn(OH)_2$

dissolution in 1 M HCl
precipitation with H_2O_2 + NaOH

- filtrate $[Al(OH)_4]^-$ CrO_4^{2-}
- precipitate $Fe(OH)_3$ $Ti(OH)_4$ MnO_2

dissolution in 7 M HCl
extraction with di-ethyl-ether

- organic phase Fe
- aqueous phase Ti?, Mn?, Cr?

↓ ion exchange DOWEX 1 with 10 M HCl

aqueous phase Mn^{2+}, Cr^{3+}

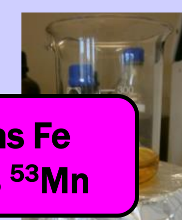
precipitation with

- precipitate $Cr(OH)_3$
- filtrate Mn^{2+}

10^{24} atoms Fe

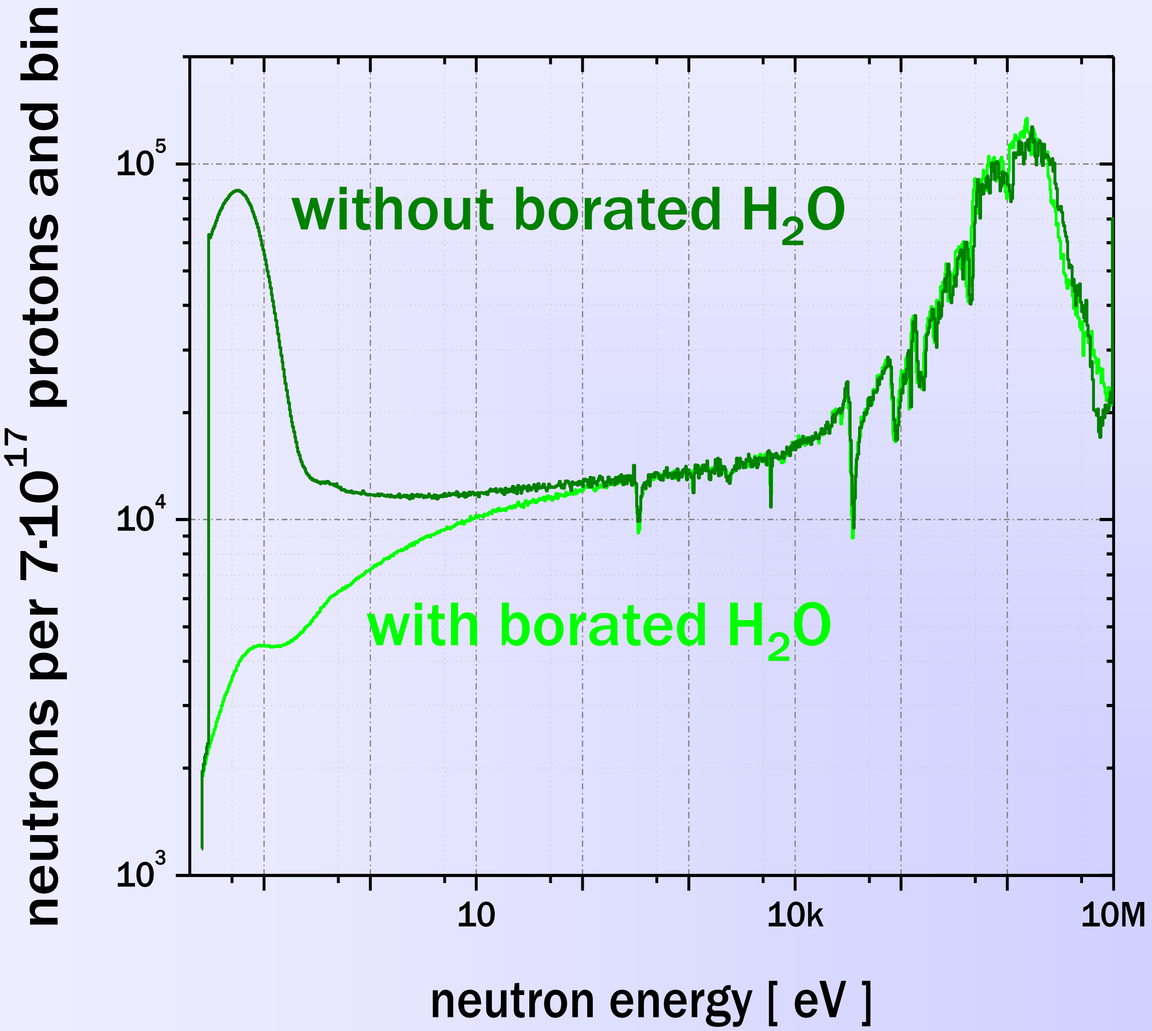
Mn : Fe separation 1 : 10^4

~10^{24} atoms Fe



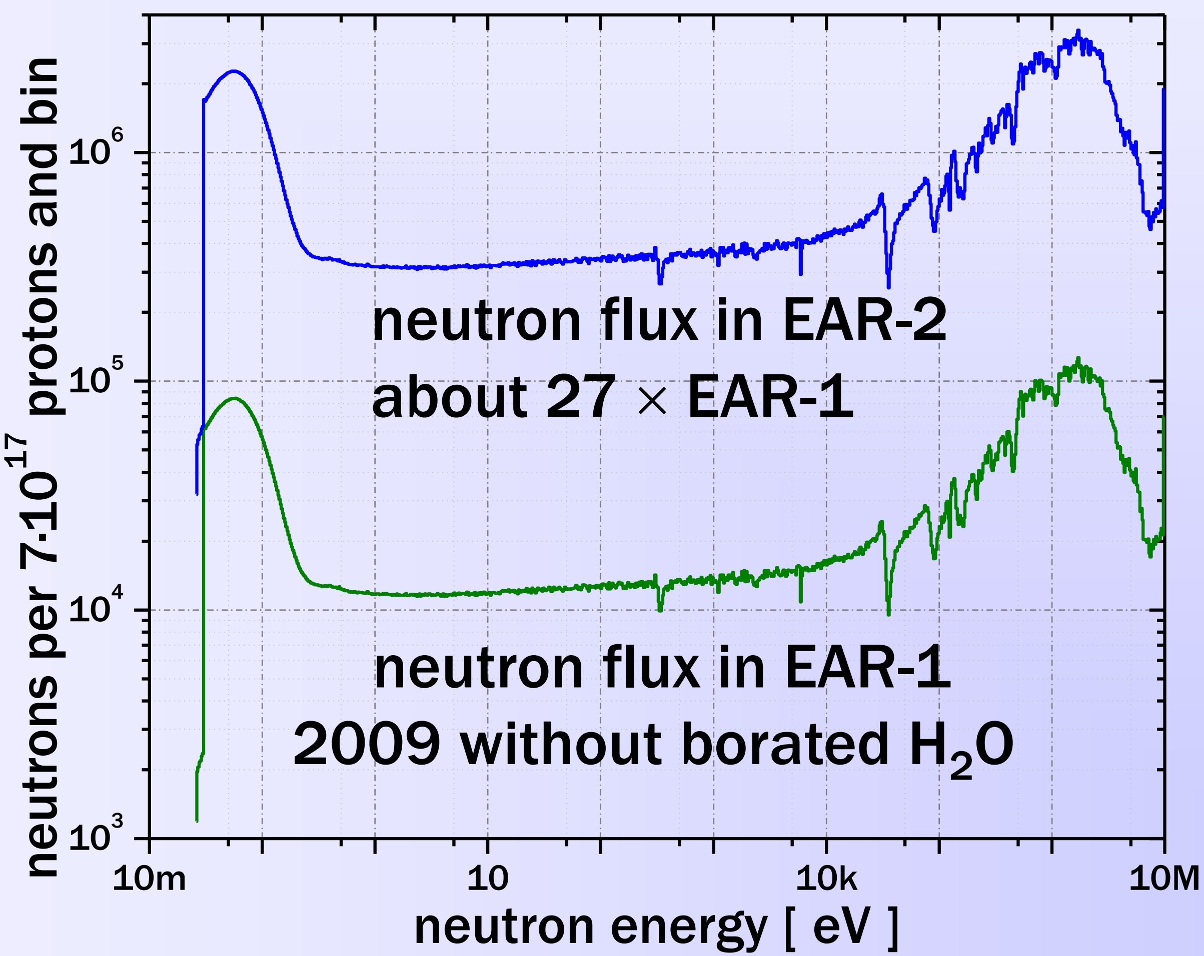
10^{20} atoms Fe
10^{19} atoms ^{53}Mn

Neutron spectrum EAR-1



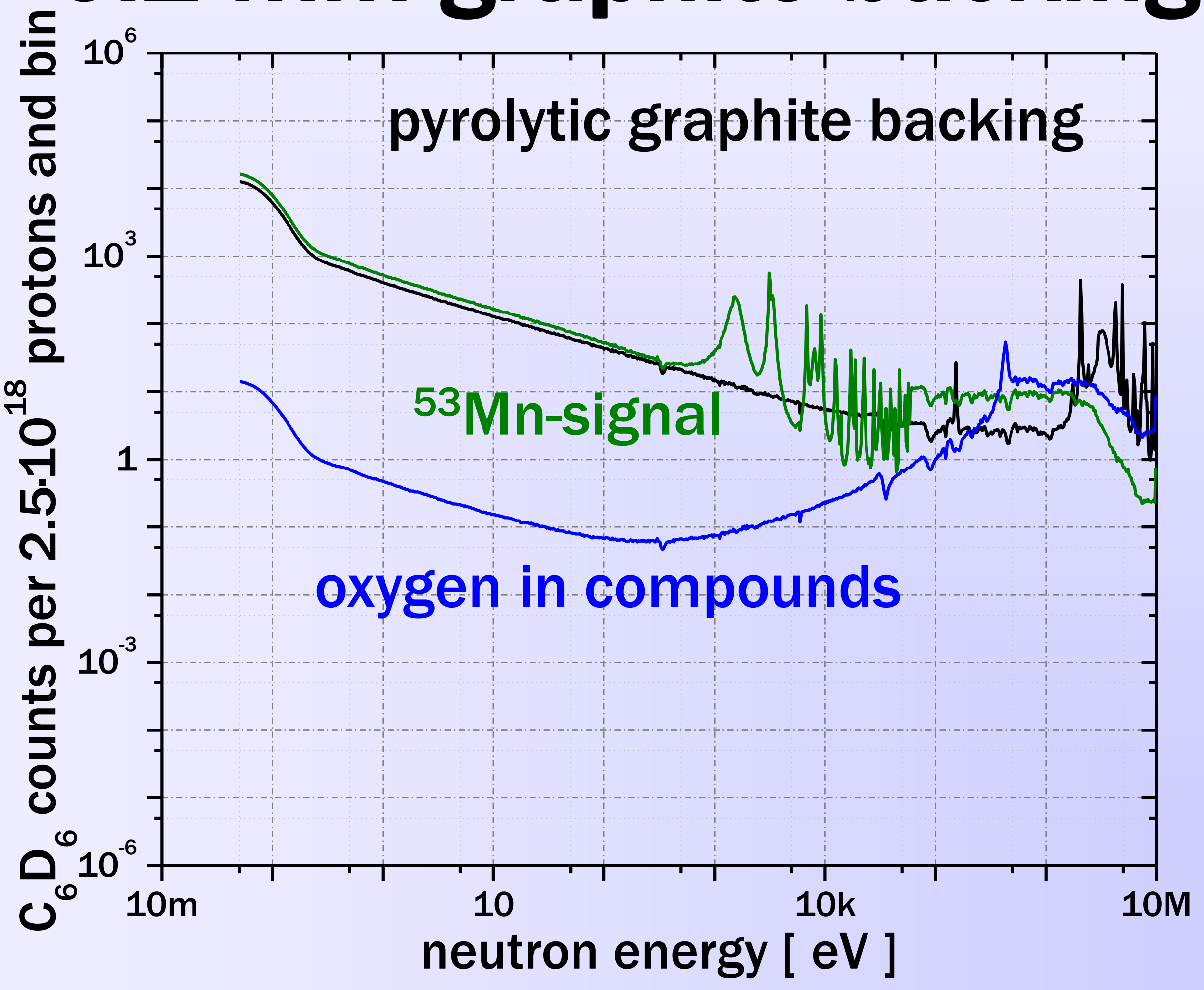
M. Barbagallo, et n_TOF: to be published

Expected Neutron flux in EAR-2



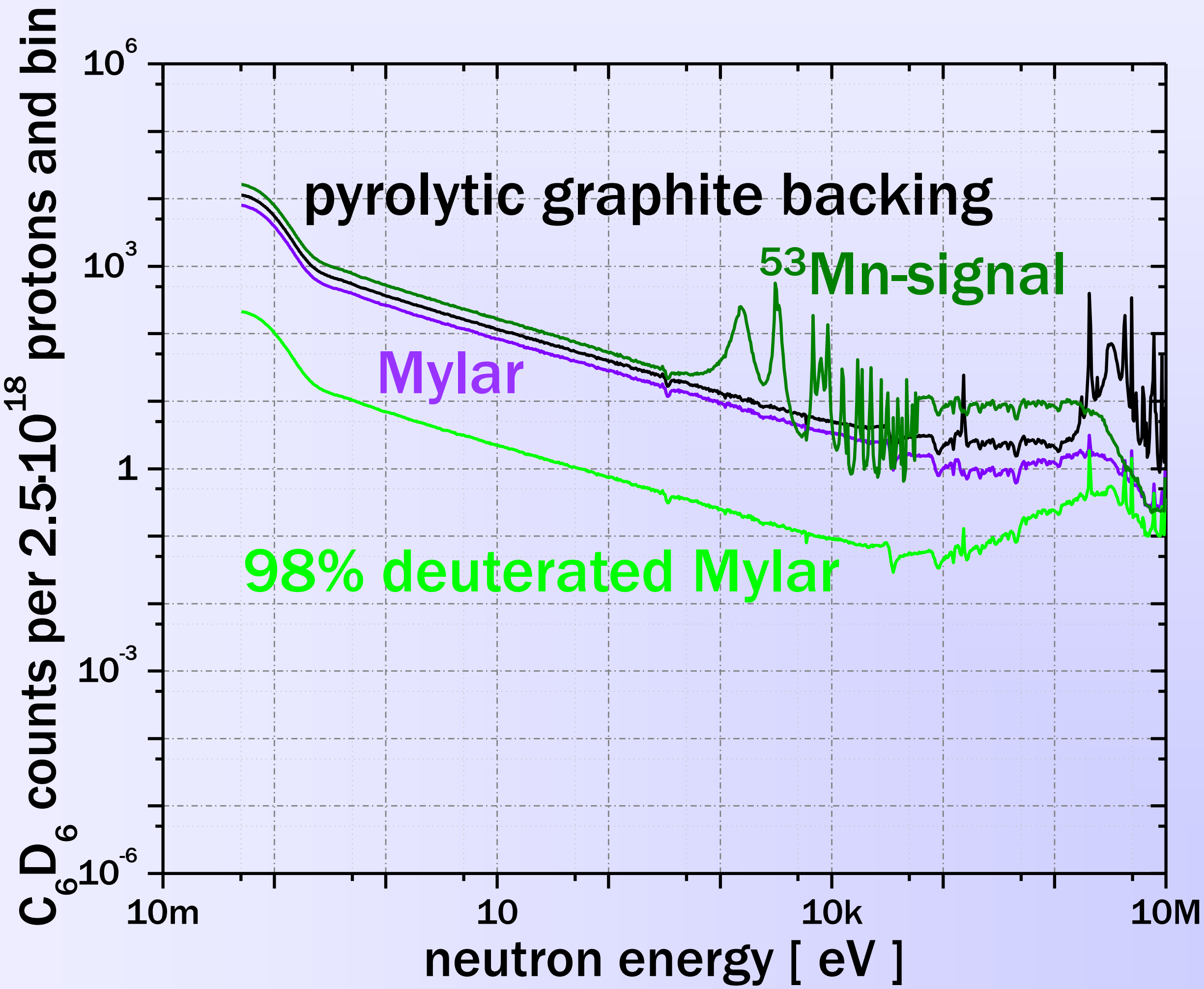
M. Barbagallo, et n_TOF: to be published

Contribution of oxygen and 0.2 mm graphite backing



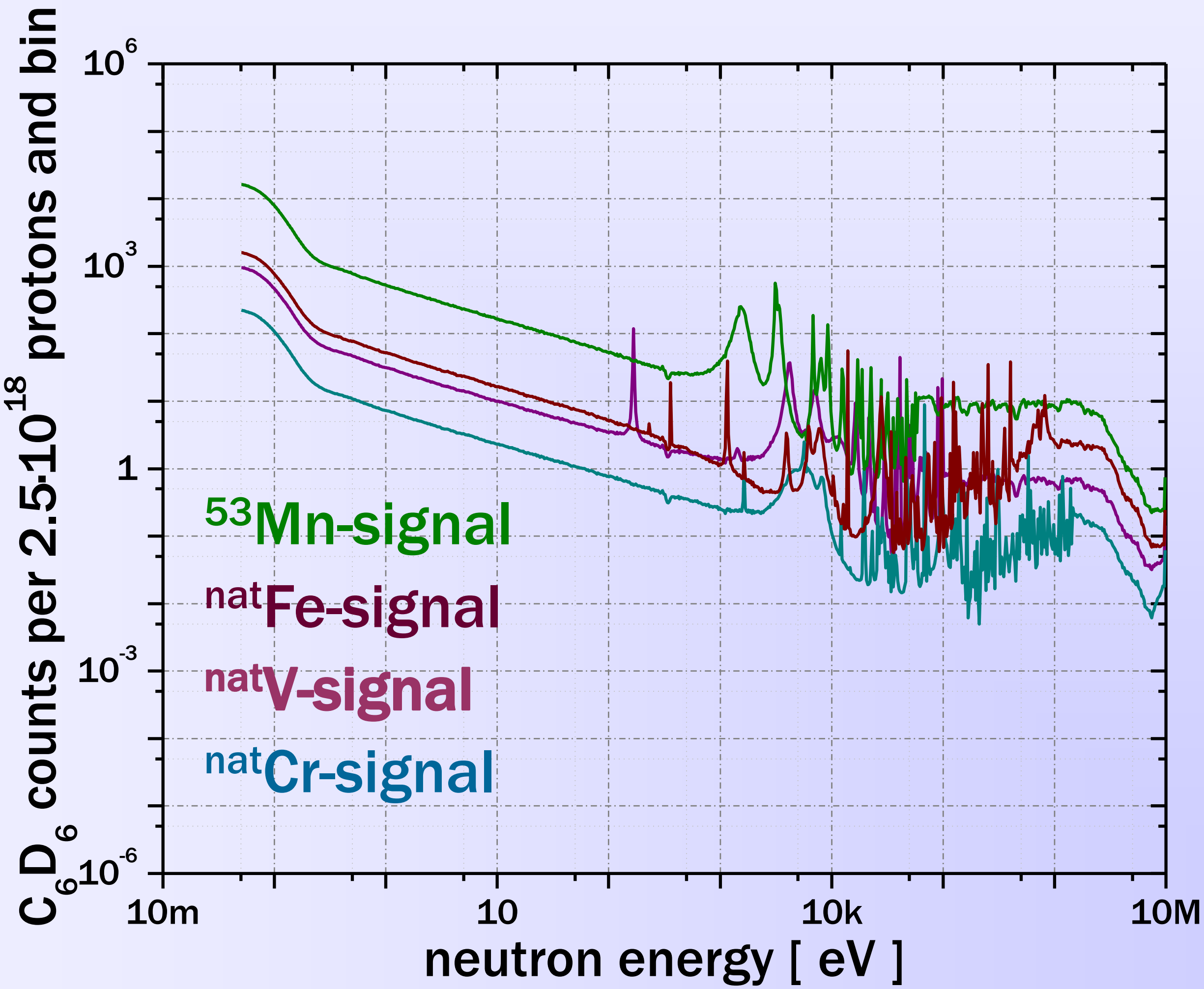
ENDF-B/VII.1 = M.B. Chadwick, et al. *Nuclear Data Sheets* **112** (2011) 2887

Contribution of 2 μm Mylar backing



ENDF-B/VII.1 = M.B. Chadwick, et al. *Nuclear Data Sheets* **112** (2011) 2887

Contribution of other elements



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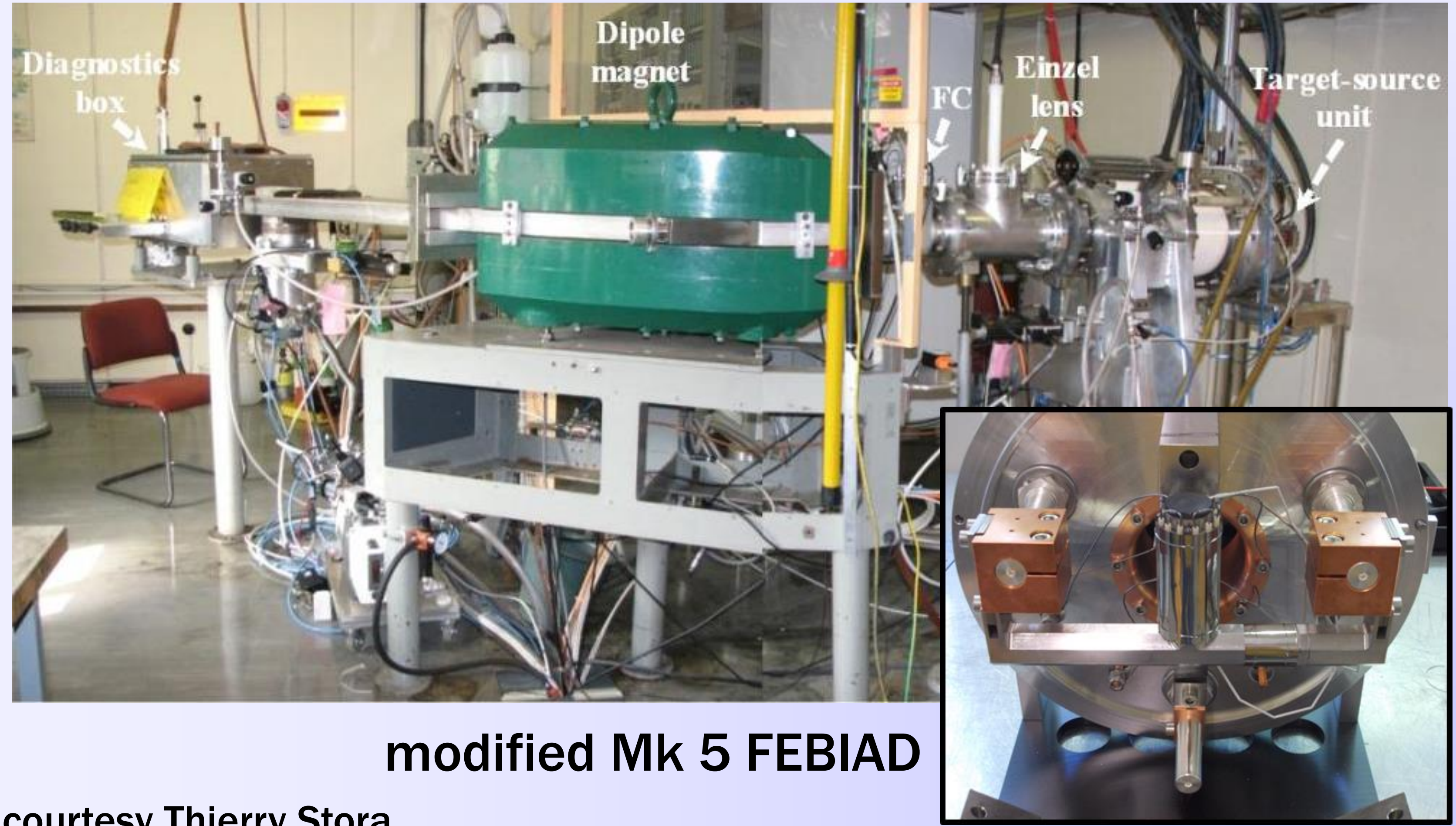
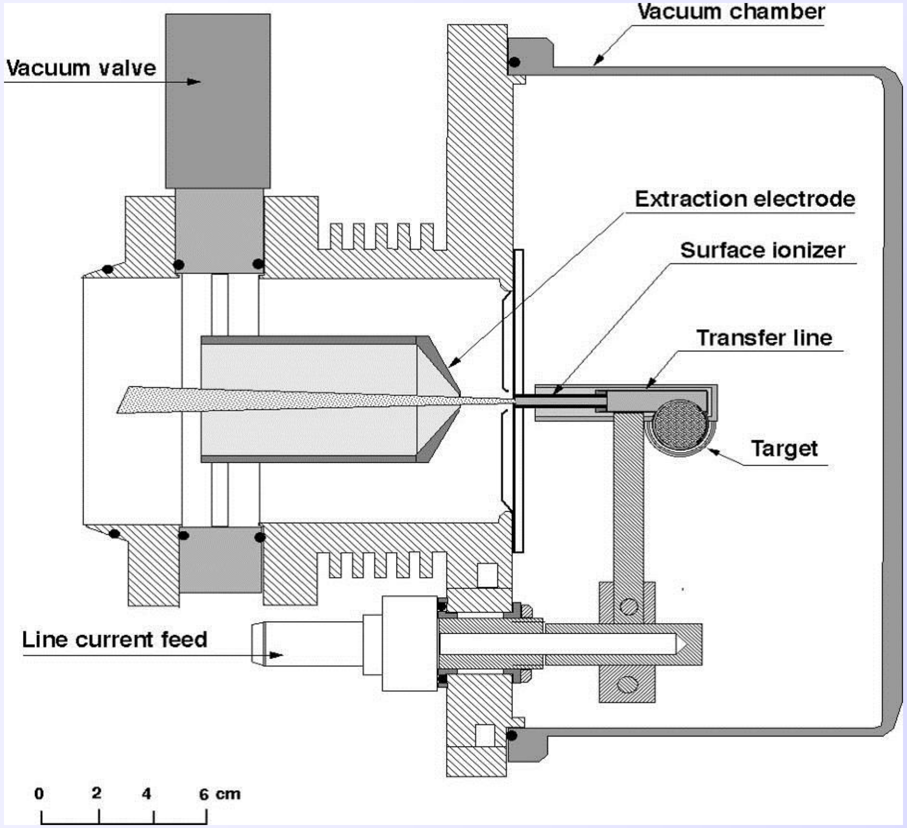
Off-line ISOLDE setup as a mass separator

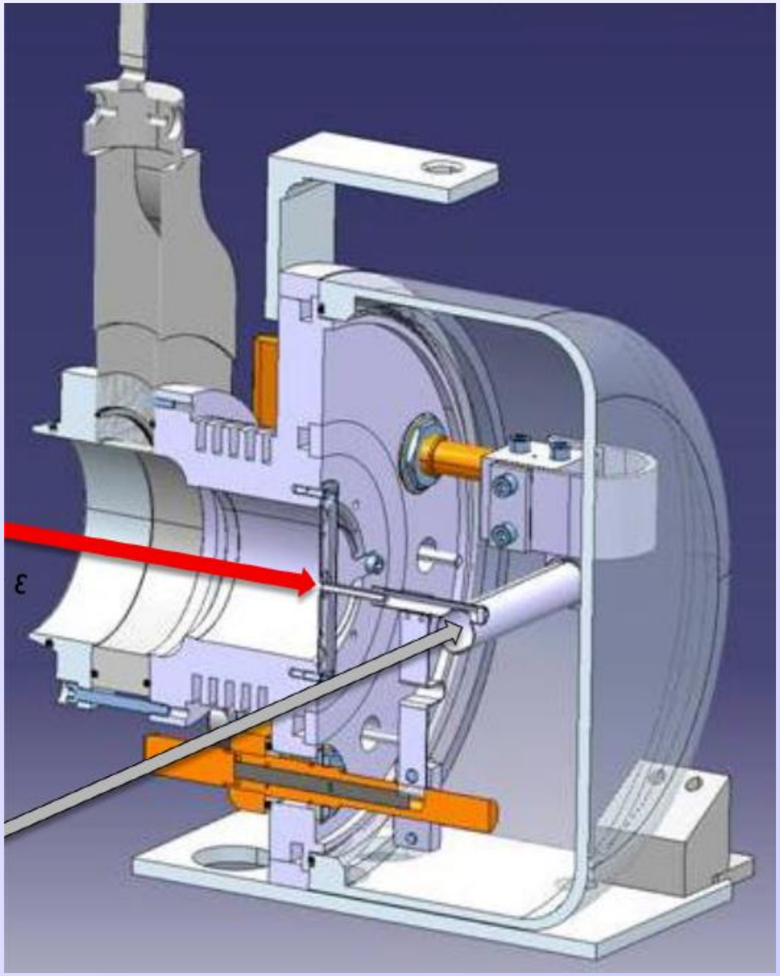


modified Mk 5 FEBIAD

courtesy Thierry Stora

FEBIAD source





FEBIAD ion source parameters

- operation temperature: 1000 °C – 2300 °C
- operation pressure: 10^{-6} mbar – 10^{-2} mbar
- extraction hole: 0.5 mm – 3.0 mm
- ohmic cathode Heating: 100 W – 1000 W
  (e^- bombardment)
- plasma density : 10^{7} cm^{-3} – 10^{10} cm^{-3}
- electron energy: 10 eV – 300 eV
- total beam current: 1 µA – 300 µA

G.D.Alton, NIM A382 (1996) 207

L.Penescu et al, NIM B **266**, 4415 (2008)