PAUL SCHERRER INSTITUT

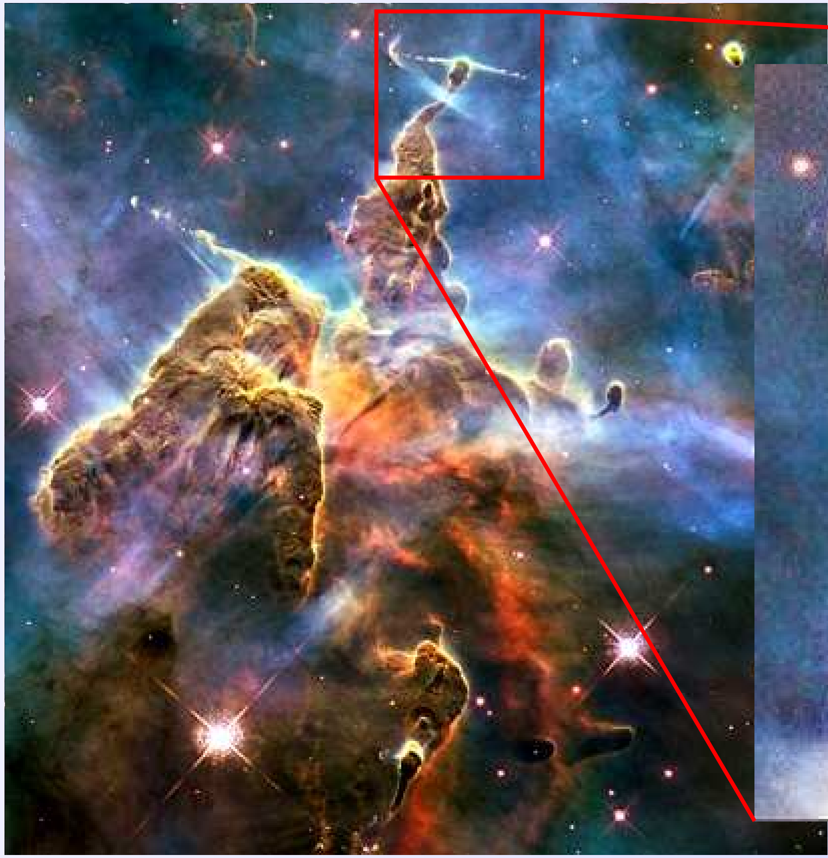
Plan to measure the half-life and neutron capture cross section of ^{53}Mn

Rugard Dressler

Outline

- Introduction
- MeaNCoRN
- Plans for ^{53}Mn
- ^{63}Ni as benchmark
- Summary

Formation of Stars



combined visible and near infrared pictures

star-forming pilar with a jet (HH 901)

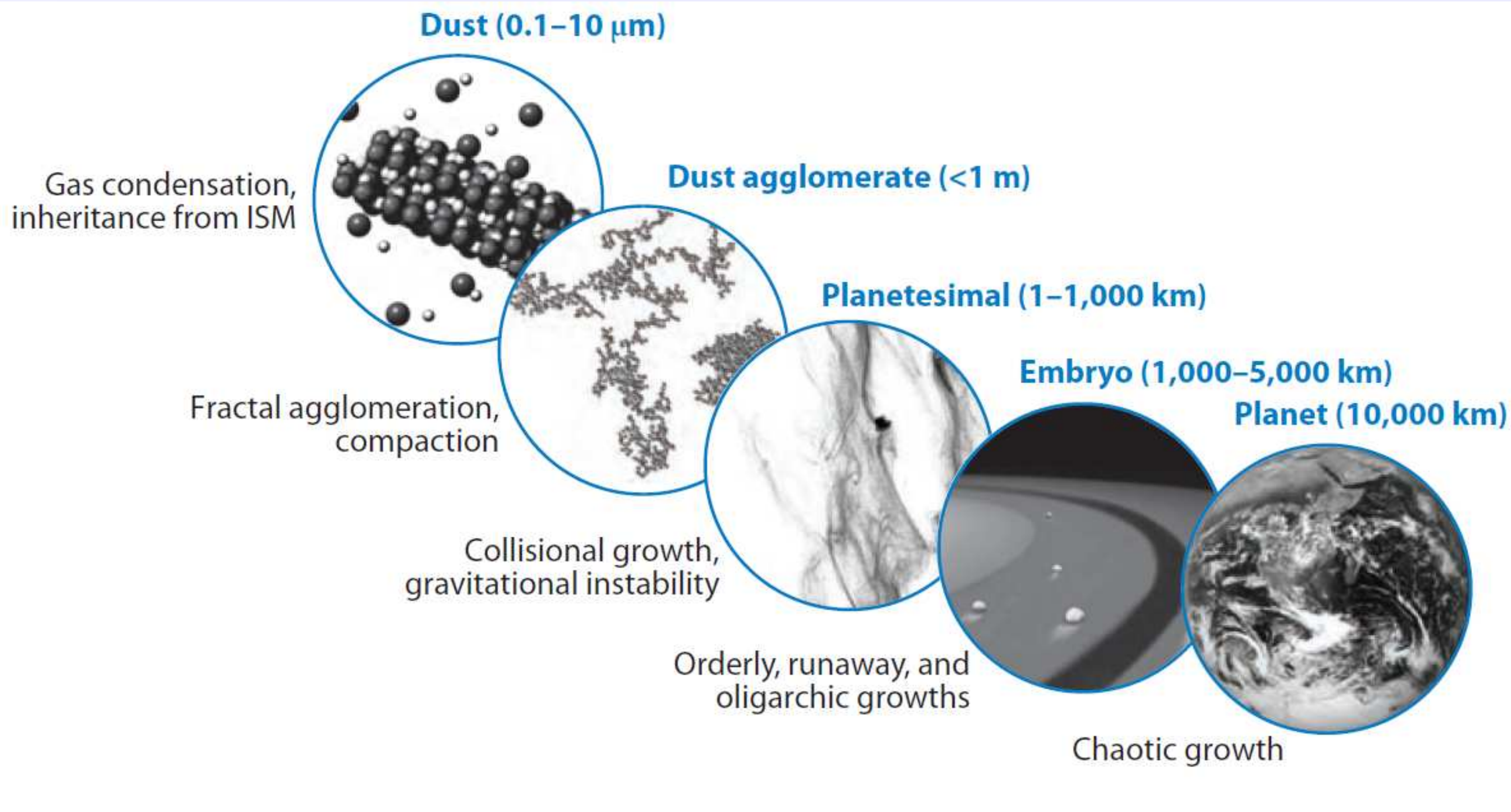
Carnia nebula: birthplace of stars

Hubble Space Telescope: http://hubblesite.org

Cosmogenic Radio-Nuclides (CoRN)

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

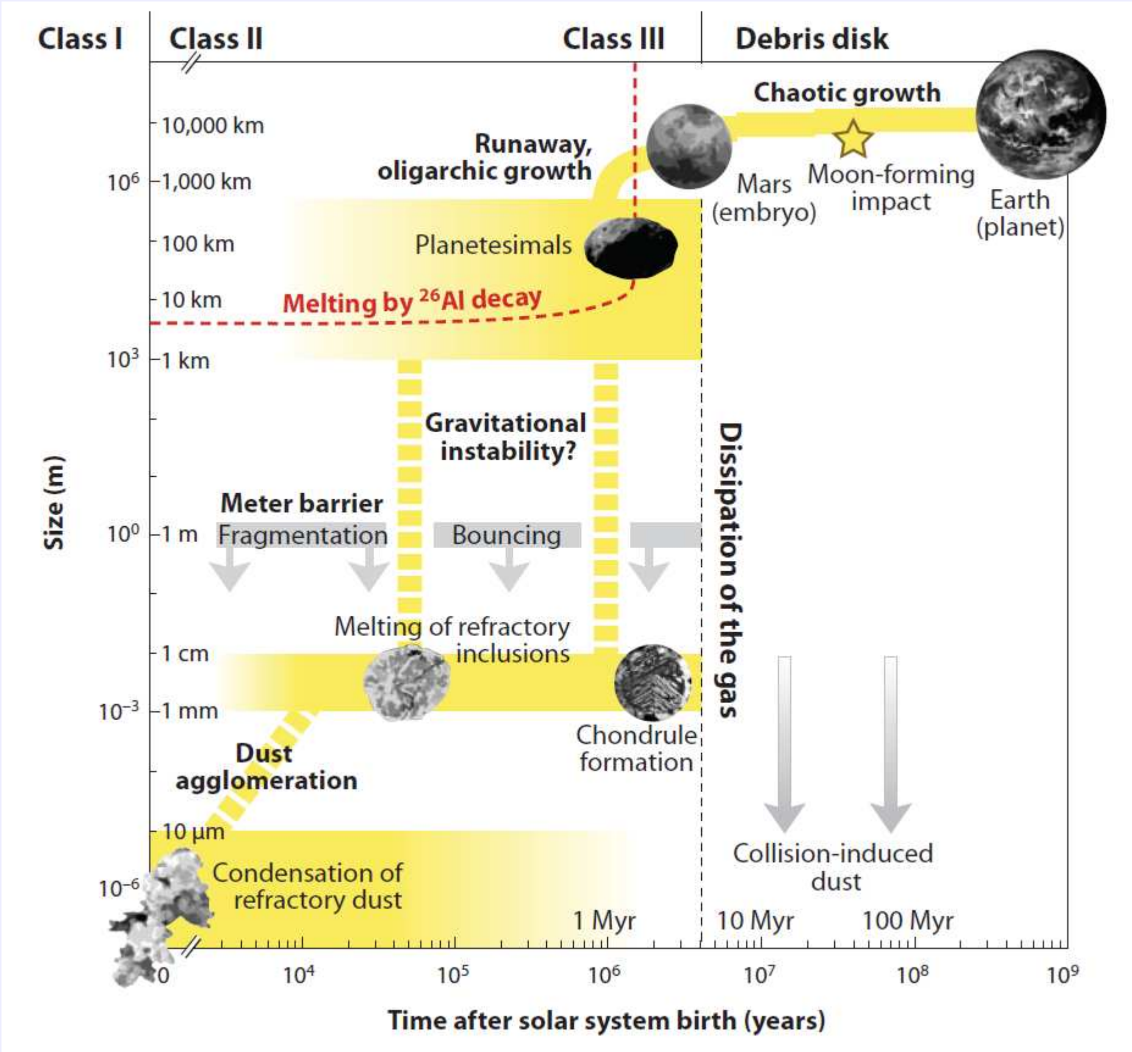
Formation of Planets



Evolution of matter in the inner part of the solar protoplanetary disk

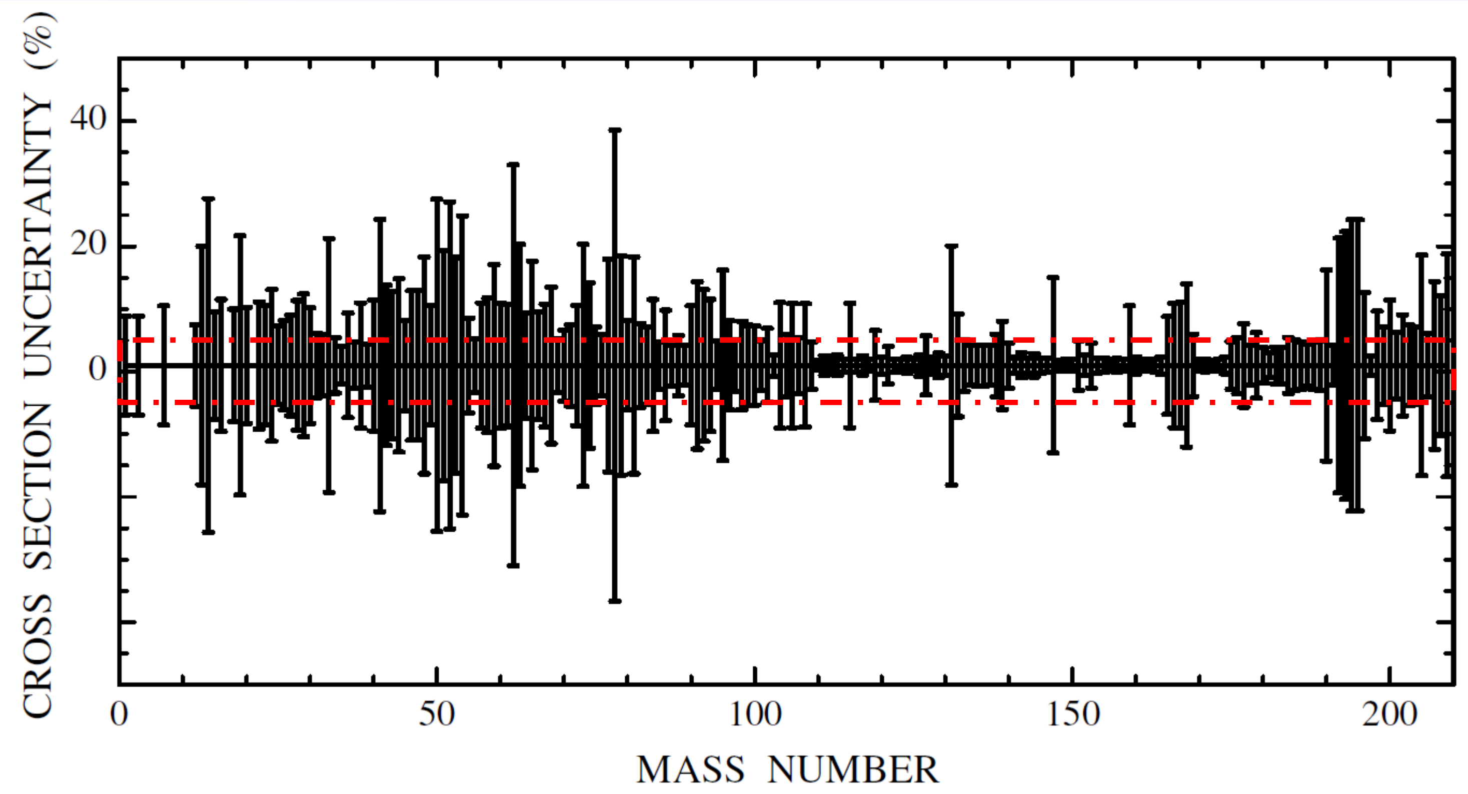
N. Dauphas, M. Chaussidon: Annu. Rev. Earth Planet. Sci. 39 (2011) 351

Role of CoRN in Planet Forming



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

Short Lived Cosmogenic Radio-Nuclides $t_{1/2} < 100$ Ma

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

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

parent nuclide	half-life (Ma)	daughter nuclide	estim. init. abundance	Reference	at PSI
^{146}Sm	103	^{142}Nd	$^{146}Sm / ^{144}Sm = 8.4 \cdot 10^{-3}$	Boyet et al. 2010, Lugmair & Galer 1992, Prinzhofer et al. 1992	□
^{92}Nb	34.7	^{92}Zr	$^{92}Nb / ^{93}Nb = 1.6 \cdot 10^{-5}$	Harper 1996, Schönbächler et al. 2002	?
^{129}I	15.7	^{129}Xe	$^{129}I / ^{127}I = 1.19 \cdot 10^{-4}$	Brazzle et al. 1999, Jeffery & Reynolds 1961	?
^{182}Hf	8.9	^{182}W	$^{182}Hf / ^{180}Hf = 9.72 \cdot 10^{-5}$	Burkhardt et al. 2008, Kleine et al. 2002, Yin et al. 2002	□
^{107}Pd	6.5	^{107}Ag	$^{107}Pd / ^{108}Pd = 5.9 \cdot 10^{-5}$	Chen &Wasserburg 1996, Schönbächler et al. 2008	?
^{205}Pb	15.1	^{205}Tl	$^{205}Pb / ^{204}Pb = 1.0 \cdot 10^{-3}$	Baker et al. 2010	□
^{135}Cs	2.3	^{135}Ba	$^{135}Cs / ^{133}Cs = 4.8 \cdot 10^{-4}$	Hidaka et al. 2001	?
^{97}Tc	4.21	^{97}Mo	$^{97}Tc / ^{92}Mo < 3 \cdot 10^{-6}$	Dauphas et al. 2002	?
^{98}Tc	4.2	^{98}Ru	$^{98}Tc / ^{96}Ru < 2 \cdot 10^{-5}$	Becker &Walker 2003	?
^{126}Sn	0.23	^{126}Te	$^{126}Sn / ^{124}Sn < 7.7 \cdot 10^{-5}$	Fehr et al. 2006	?

MeaNCoRN

*Mea*surement of *n*eutron capture cross sections and determination of half-live of short-lived *co*smogenic *r*adio-*n*uclides

Rugard Dressler, Dorothea Schumann

Laboratory of Radiochemistry and Environmental Chemistry — *BIO*

Jost Eikenberg

Division of Radioprotection and Safety — *LOG*

Ines Günther-Leopold

Hot Laboratory Division — *NES*

Klaus Kirch

Laboratory of Particle Physics — *NUM*

Gunther Korschinek

Physics Department, Technical University Munich, Germany

René Reifarth

Institute for Applied Physics, Goethe University Frankfurt, Germany

Subjects of MeaNCoRN

- **Neutron Capture Cross Section**
  - *thermal neutron: NAA, PNA at PSI*
  - *cold neutrons: BOA, ICON at PSI; FRM II in Munich*
  - *ultra cold neutrons: UCN at PSI*
  - *neutrons at cosmic energies: FRANZ at SGC Frankfurt*

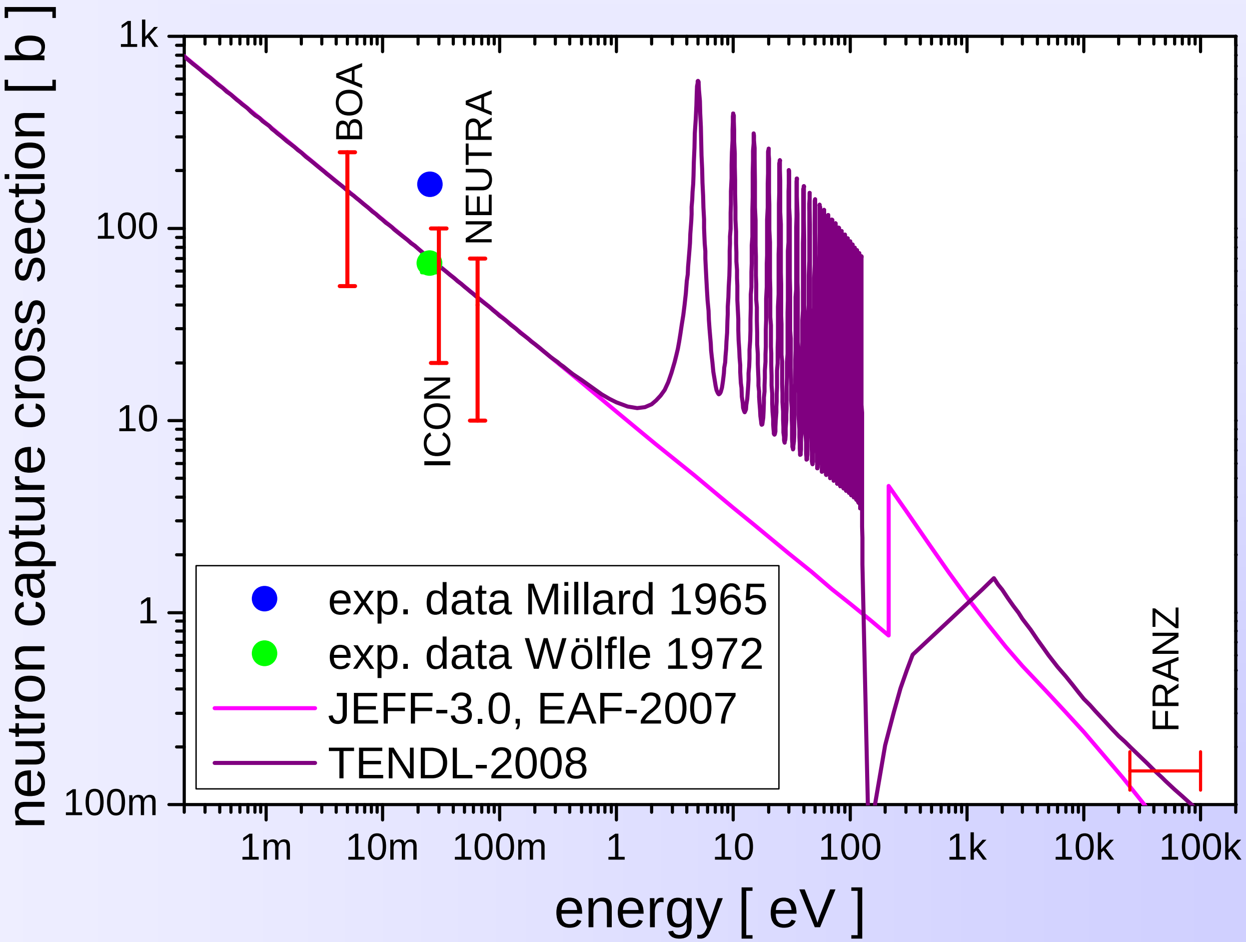
- **Half-Life**
  - *^{60}Fe, ^{63}Ni*
  - *^{10}Be, ^{53}Mn*
  - *^{26}Al, ^{32}Si, ^{59}Ni*
  - *^{41}Ca, ^{79}Se, ^{126}Sn, …*

- ***Financial & Manpower Support***
  - *SNSF founding (rejected)*
  - *PSI Cross Project*
  - *??? other sources ???*

^{53}Mn

- **Capture Cross Section**
  - *^{53}Mn(n; γ)^{54}Mn*
    - ^{54}Mn well known reference nuclide
    - measurable with high sensitivity
- **Half-Life**
  - *^{53}Mn – ^{53}Cr chronometer*
    - used to date events in solar system (20 Ma)
  - *^{53}Mn / ^{55}Mn isotopic ratio*
    - used to determine the terrestrial exposure time Dry Valleys, Southern Victoria Land, and Antarctica

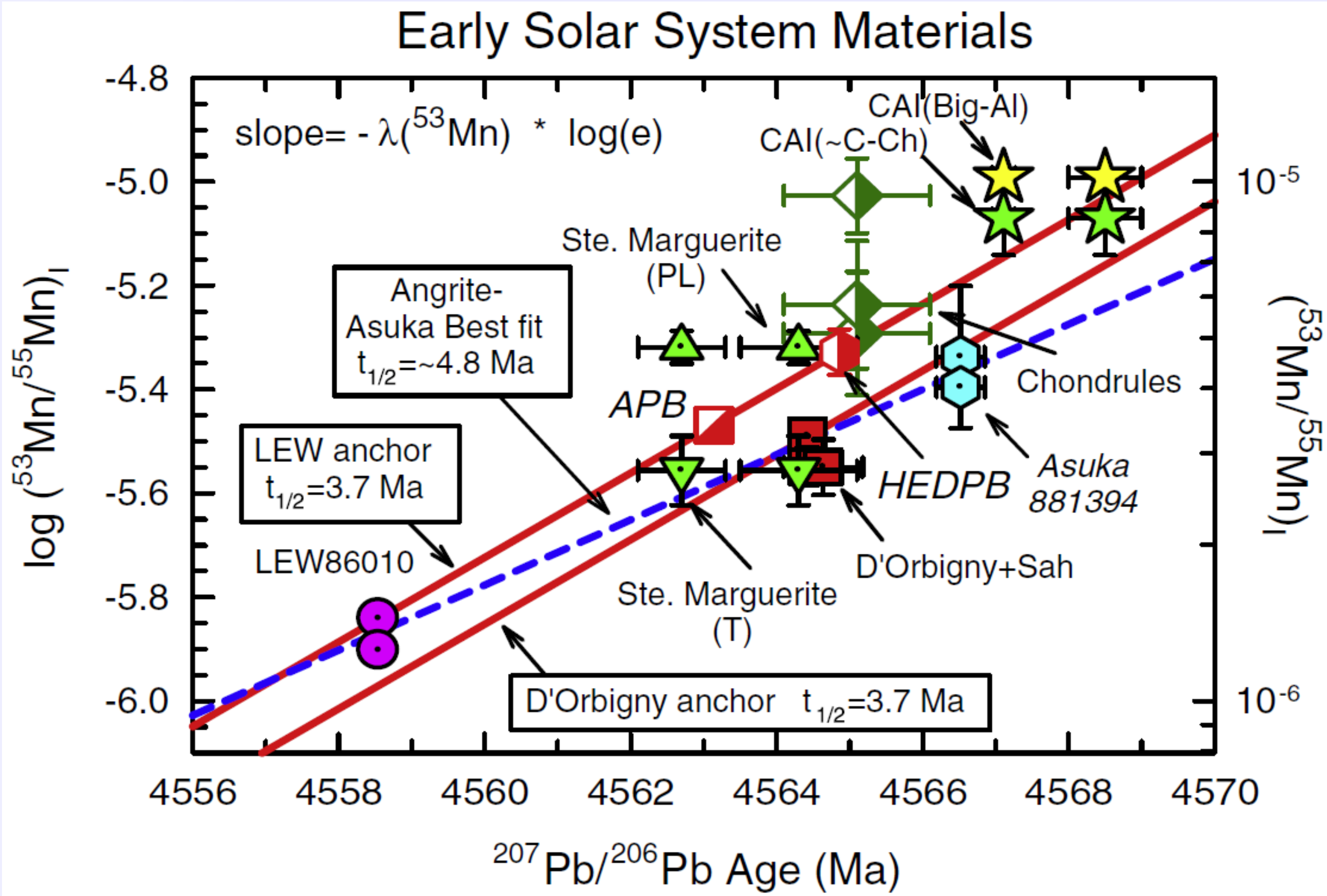
Neutron Capture Cross-Section ^{53}Mn



History of ^{53}Mn Half-Life Measurements

Author (Year)	Method	$t_{1/2}$ [Ma]
Wilkinson, et al. (1955)	Compared nuclear reaction yield with ^{54}Mn	0.00014
Sheline, et al. (1957)	Calculated nuclear reaction yield	~2
Kaye, et al. (1965)	Spallation yield of meteorites	1.9±0.5
Hohlfelder (1969)	Mass spectrometry (MS) of meteorites	10.8±4.5
Matsuda, et al. (1971)	MS of 730 MeV proton activation products	2.9±1.2
Honda, et al. (1971)	MS of artificial and meteoritic samples	3.7±0.37
Wölfle, et al. (1972)	Neutron activation of meteoritic samples	3.9±0.6
Heimann, et al. (1974)	decay of meteoritic ^{53}Mn	3.85±0.4

Dating Problem
$^{53}Mn/^{55}Mn$ vs. $^{207}Pb/^{206}Pb$



L.E. Nyquist, et al.: Geochim. Cosmochim. Acta **73** (2009) 5115

CoRN Storehouses

Fe samples of STIP
see talk Maruta Bunka

total material ~ 60 g steel

radio nuclides available

^{26}Al	300 Bq	~ 10^{16} atoms
^{44}Ti	100 MBq	≈ $8.4 \cdot 10^{17}$ atoms
^{54}Mn	70 MBq	
(^{53}Mn		~10^{19} atoms)
^{60}Co	**70 MBq**	

Cu beam dump
see talk Marin Ayranov

total material ~ 500 g copper

radio nuclides inventory

^{26}Al	7 kBq	≈ $2.3 \cdot 10^{17}$ atoms
^{32}Si	10 MBq	≈ $7.8 \cdot 10^{16}$ atoms
^{44}Ti	100 MBq	≈ $2.8 \cdot 10^{17}$ atoms
^{53}Mn	500 kBq	≈ $8.4 \cdot 10^{19}$ atoms
^{59}Ni	8 MBq	≈ $2.7 \cdot 10^{19}$ atoms
^{60}Fe	5 kBq	≈ $5.9 \cdot 10^{17}$ atoms
^{60}Co	**5 GBq**	

CoRN
Storehouses

STIP samples

pro

- *low ^{60}Co content*
- *separated from matrix*
- *purified final product*

cons

- *high amount of stable isotopes*
- *storage time ~12 a EoB Dec 1999*
- *high ^{54}Mn activity*

Cu beam dump

pro

- *storage time ~20 a EoB Dec 1992*
- *low ^{54}Mn activity*
- *non carrier added*

cons

- *high activity of ^{60}Co*
- *not separated from Cu*
- *not purified*

Half-Life Measurement $t_{1/2} > 50$ a

Determination of sample activity

- α- / β- / γ-Spectroscopy or Liquid Scintillation Counting

Determination of number of atoms

- AMS / ICP-MS / HI-ERD

  - *^{10}Be $t_{1/2}$ = 1.388 ± 0.018 Ma*
    G. Korschinek, et al.: Nucl. Instr. and Methods B 268 (2010) 187
  - *^{10}Be $t_{1/2}$ = 1.386 ± 0.016 Ma*
    J. Chmeleff, et al.: Nucl. Instr. and Methods B 268 (2010) 192
  - *^{79}Se $t_{1/2}$ = 0.327 ± 0.008 Ma*
    G.Jörg, et al.: Applied Radiation and Isotopes 68 (2010) 2339
  - *^{60}Fe $t_{1/2}$ = 2.62 ± 0.04 Ma*
    G. Rugel, et al.: Phys. Rev. Lett. 103 (2009) 072502

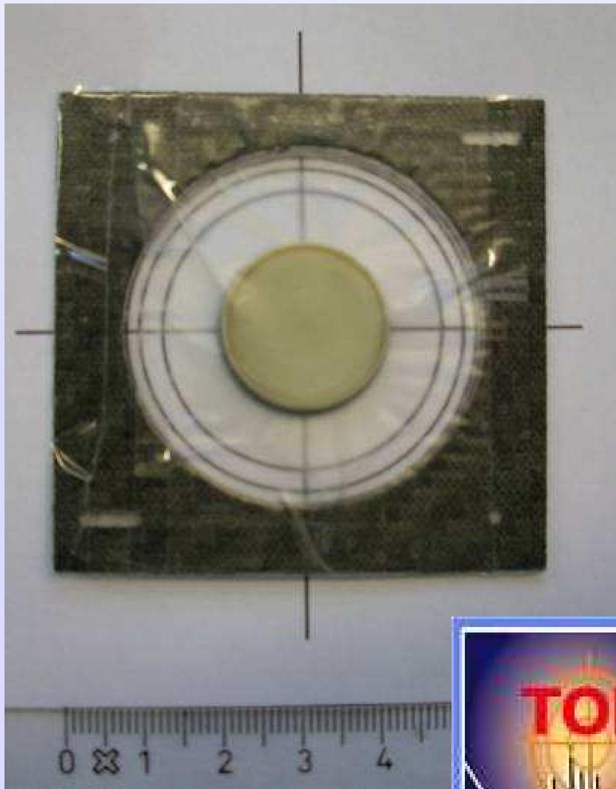
^{63}Ni Half-Life Measurements at PSI

^{63}Ni pure β^- emitter

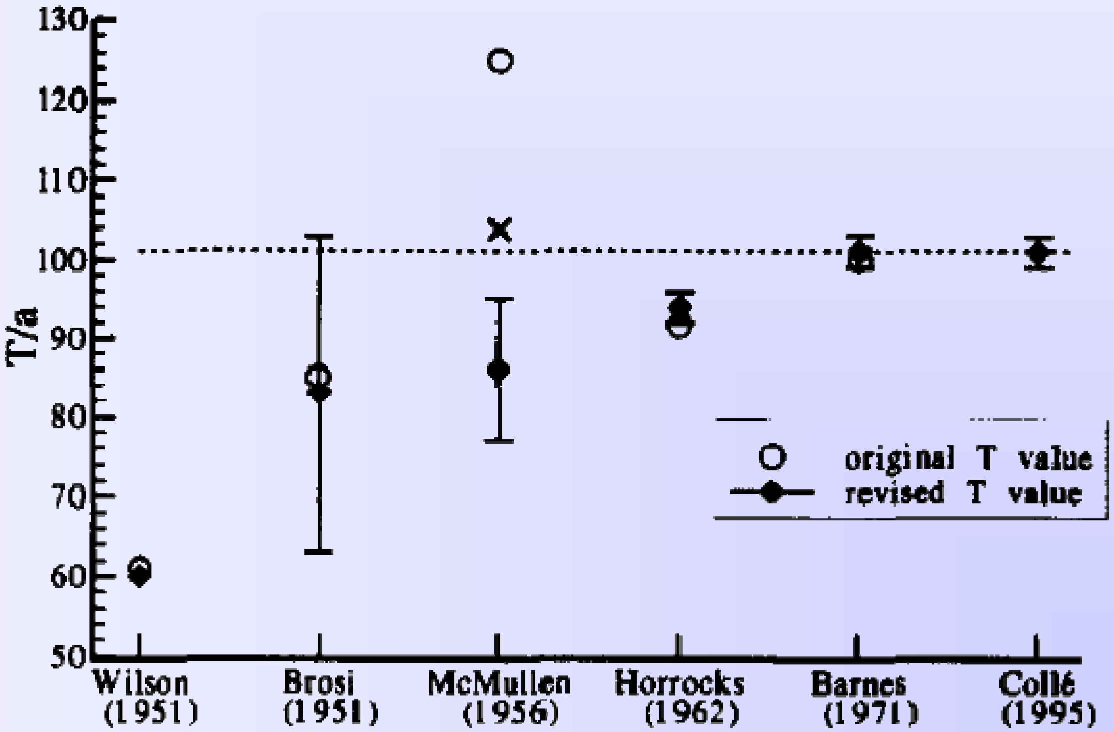
$E_{max} = 66.9$ keV

^{63}Ni target for n_ToF

- production
  - *988 mg enriched ^{62}Ni metal pellets neutron activated*
  - *109 mg ^{63}Ni ≈ 10^{21} atoms ≈ 230 GBq*
  - *separation of ^{63}Cu*
- about 0.5% left as waste ≈ $5 \cdot 10^{18}$ atoms ≈ 1 GBq
- can be used for other measurements

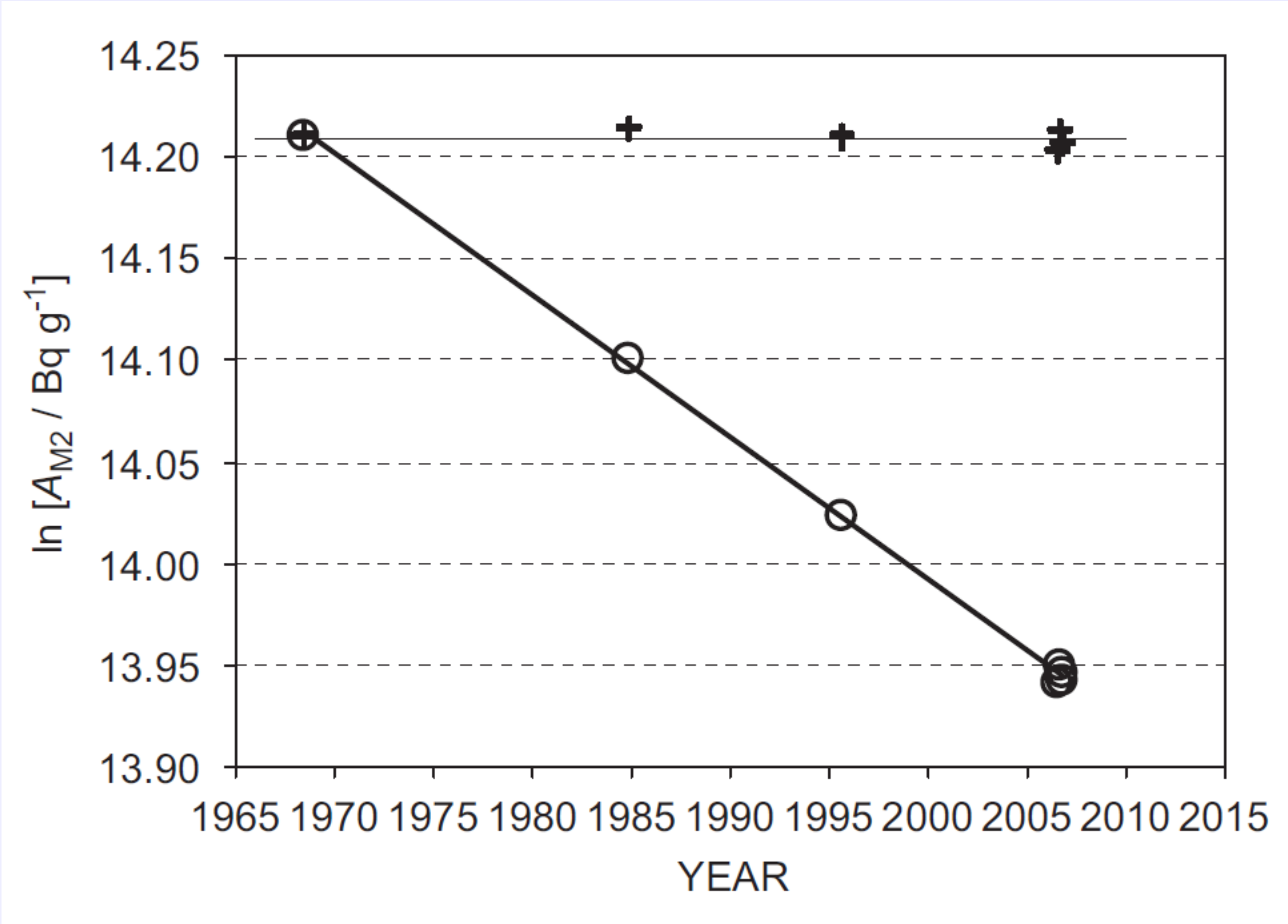


History of ^{63}Ni Half-Life Measurements



R. Collè et al.: Applied Radiation and Isotopes **47** (1996) 677

^{63}Ni Half-Life and Standardization



R. Collè et al.: Applied Radiation and Isotopes 66 (2008) 60–68

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Ni-63
63
CoRN
ction

Why additional Measurements?

- Collè et al. 1996:
  new value based on the revised value from Barnes et. Al
  own ones using decay measurements with LSC technique
  3 data points over 27 years: **101.1 ± 1.4 a**
- Collè et al. 2008:
  new re-standardization of the used NIST solutions
  additional data points for the decay measurement
  4 points over about 40 years: **101.2 ± 1.5 a**

1. Additional measurements using other techniques would be useful to support the result of Collè.
2. ^{63}Ni is an excellent play ground to prove the precision of our used instruments and methods.

Half-Life Measurements at PSI

1. Approach $t_{1/2} = \Delta t \cdot \ln 2 / \ln(N_0/N)$

- ICP-MS measurements:
  1. isotopic ratio before purification: $({}^{63}Ni + {}^{63}Cu) / {}^{62}Ni \rightarrow N_0$
  2. isotopic ratio after purification: ${}^{63}Ni / {}^{62}Ni \rightarrow N$
- Time from EoB to separation: ??? $\rightarrow \Delta t$

sample	$^{63/62}$Ni (K)	uncertainty	$^{63/62}$Ni (L)	uncertainty
after dissolving	0.145366	0.000037	0.124784	0.000266
after CuS separation	0.125098	0.000010	0.107667	0.000013
after purification	0.122395	0.000289	0.107846	0.000169
N_0/N	1.1877	0.0028	1.1590	0.0025
Δt	? (25 a)		? (21.5 a)	
$t_{1/2}$	(101.2 a)		(101.2 a)	

Planned Half-Life Measurements

2. Approach $t_{1/2} = N \cdot \ln 2 / A$

- **Isotope dilution**
  1. Ad 12 mg ^{nat}Cu
  2. Separation of Cu with H_2S (several times)
  3. final purification
  4. stock solution for measurements
- **ICP-MS measurement:** → N (pending)
  interference correction of mass 63
  comparison with certificated Ni reference material
- **LSC measurements:** → A = 520.7 ± 0.7 Bq/g
  calibration of quench effects
  comparison with certificated standards of other β^- emitters

preliminary

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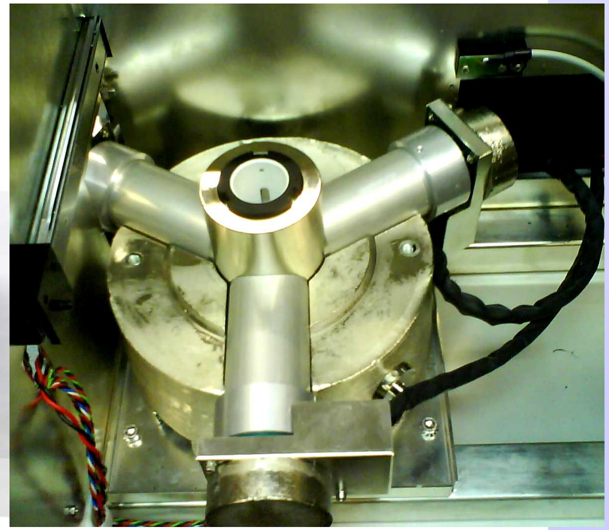
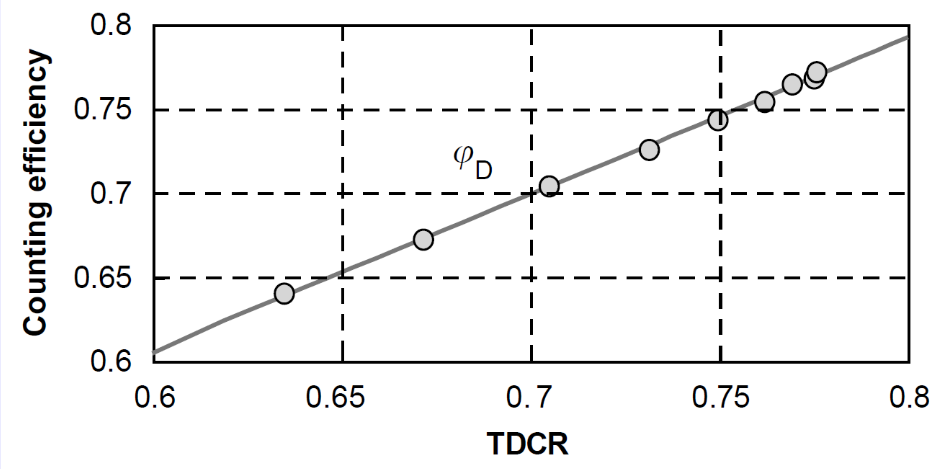
Liquid Scintillation Counter
Hidex 300 SL





counting efficiency of a ^{63}Ni source
in Ultima Gold liquid scintillator

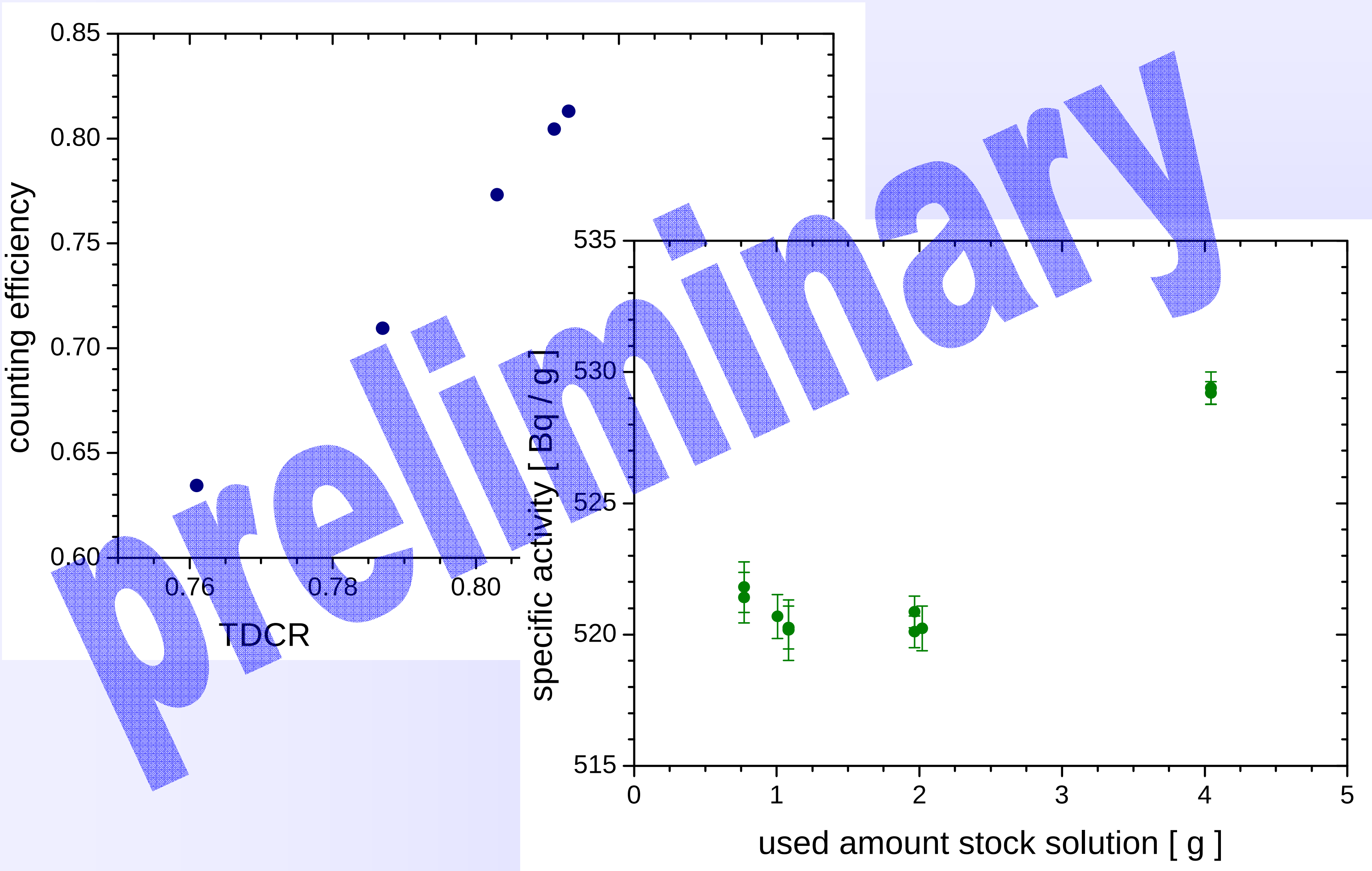
R. Broda: Applied Radiation and Isotopes 58 (2003) 585

Sample	TDCR	Eff_D [s^{-1} Bq^{-1}]	Dev
10 ml UG^{AB}	0.83	0.805	-0.030
10 ml UG^{TM}	0.84	0.820	-0.027
Hisafe	0.83	0.800	-0.035

results obtained for ^{63}Ni (10ml UGAB) using TDCRB-02

I.A. Kharitonov, T.I.Shilnikova: (2009)

First Results of LSC



Summary

- ^{26}Al, ^{32}Si, ^{44}Ti, ^{53}Mn, ^{59}Ni, ^{60}Fe available at PSI (10^{16} – 10^{20} atoms)
- MeaNCoRN
  - *experiments at PSI*
- ^{53}Mn
  - *up to 10^{20} available*
  - *re-measurment of half-life*
- ^{63}Ni
  - *model isotope for performance tests*
  - *re-measurment of half-life (on going)*