DESIR workshop, May 2010

High efficiency ^{3}He neutron detector TETRA for DESIR.

Yuri Penionzhkevich
Joint Institute for Nuclear Research, Dubna

Beta Decay of Exotic Nuclei: Goal to study

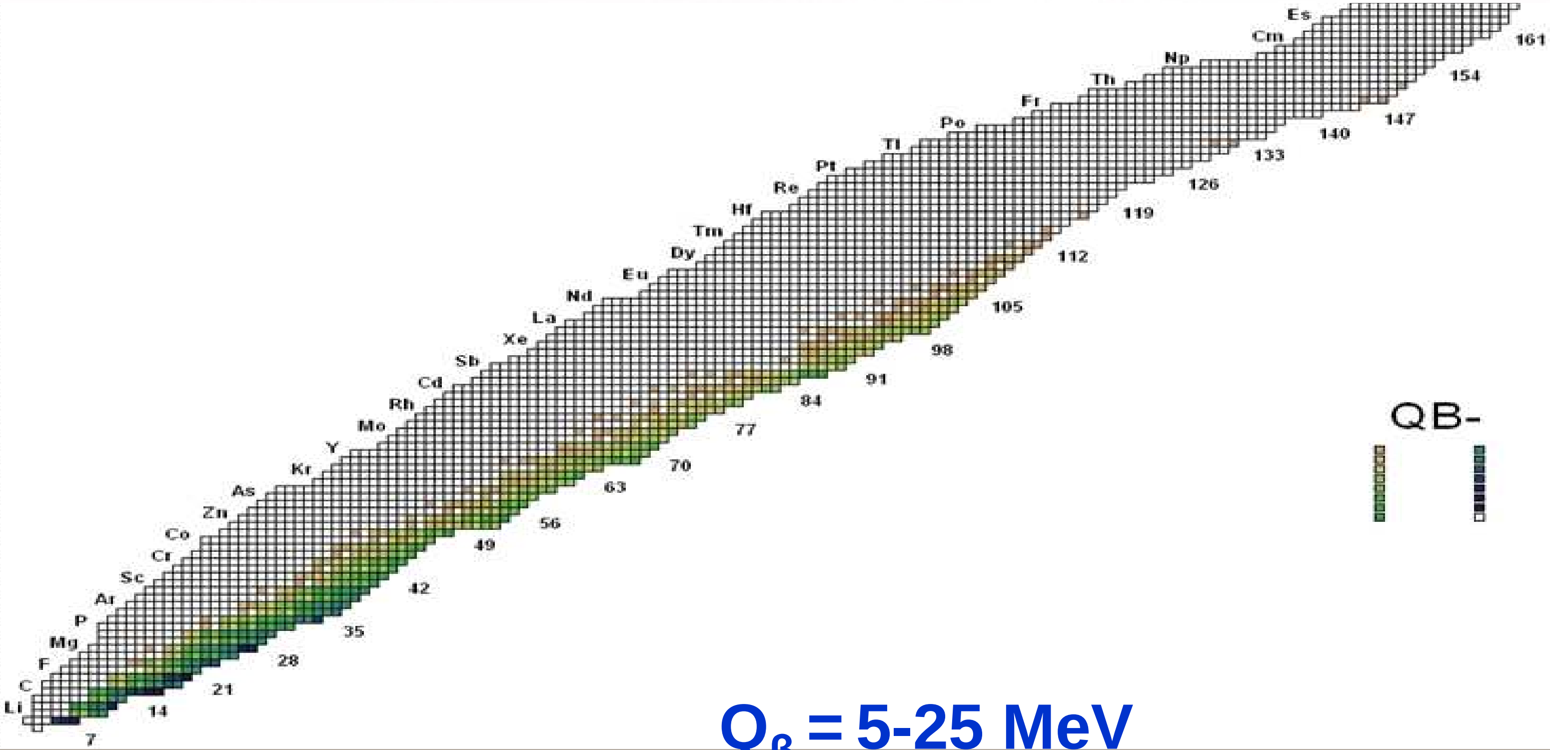
Neutron emission from unstable nuclei far from stability can provide with valuable insight into nuclear shell structure and nuclear deformation changes toward the drip line.

Precise beta-decay half-lives, end point energies, probability of neutron emission are crucial input parameters for calculations of the astrophysical rapid neutron capture process.

Also investigation of 2,3 and 4 neutron emission, as well as correlations between the emitted neutron will allow obtaining information on the possibility of existence of multi-neutron clusters and the size of the zone from which they are emitted (interference experiments).

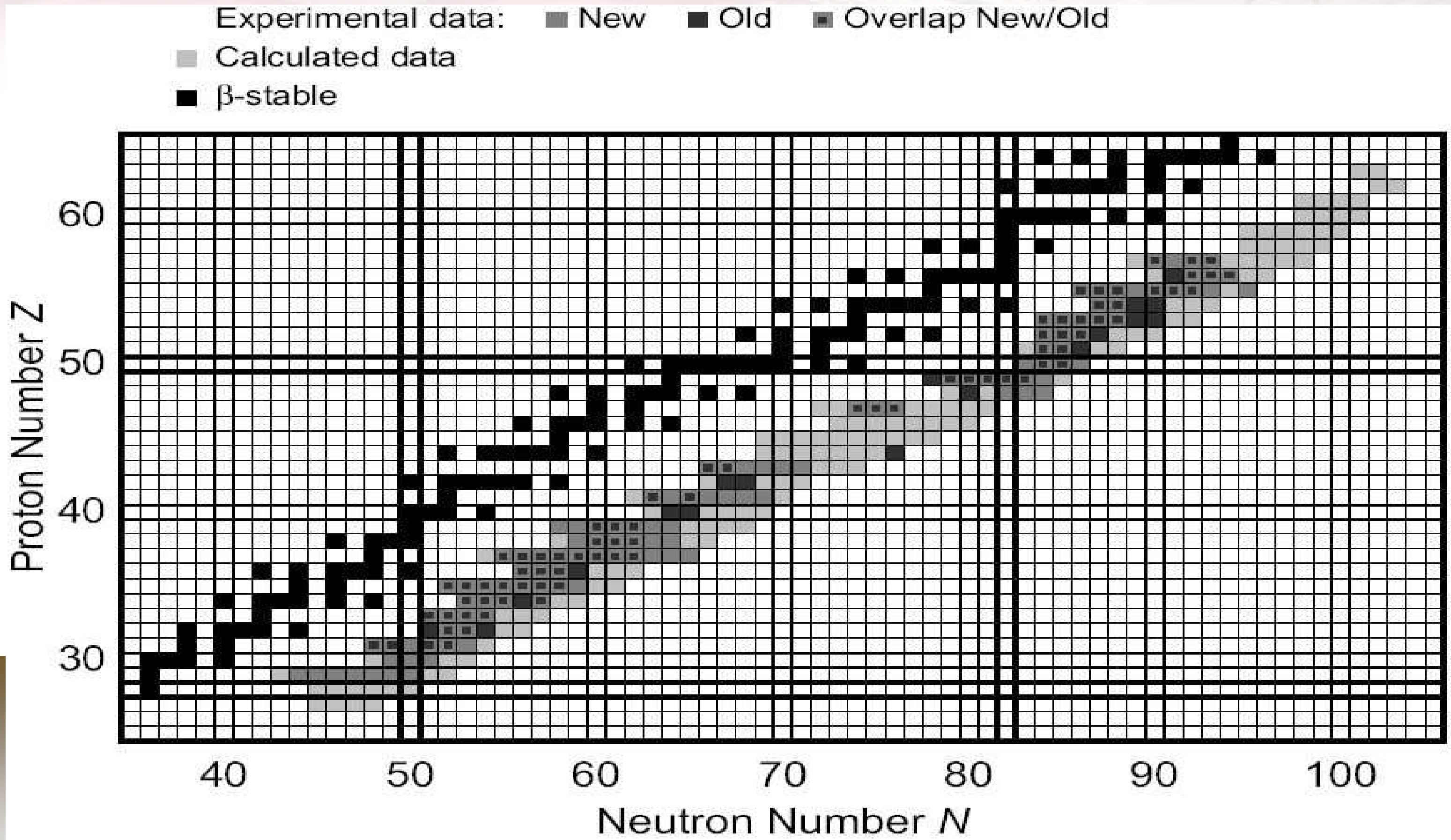
The selective method of beta decay, in combination with spectroscopic measurements of gamma-rays and neutrons, will open new opportunities to study exotic nuclei

β-DECAY ENERGY



Q_β = 5-25 MeV

Delayed- Neutron Data



Known β–delayed multiple neutron emitters

Nuclides	$T_{1/2}$,ms	*xn*	P_{xn},%
^{11}Li	8.5	2n 3n	4.1(4) 1.9(2)
^{14}Be	14.5	2n 3n	0.80(8) 0.2(2)
^{15}B	10.4	2n	0.4(2)
^{17}B	5.1	2n 3n 4n	11(7) 3.5(7) 0.4(3)
^{30}Na	48	2n	1.17(16)
^{32}Na	13.5	2n	8(2)
^{34}Na	5.5	2n	~ 50
^{98}Rb	110	2n	0.38(6)
^{100}Rb	**51**	**2n**	**2.7(7)**

Predicted β-2n-emitters in fission fragments

- P.Moller, J.Nix, K.-L.Kratz, Atomic Data & Nucl.Data Tabl., 66, 131 (1997)
- Yu.Lyutostansky and I.Panov, Z.Phys.A, 313,235 (1983)

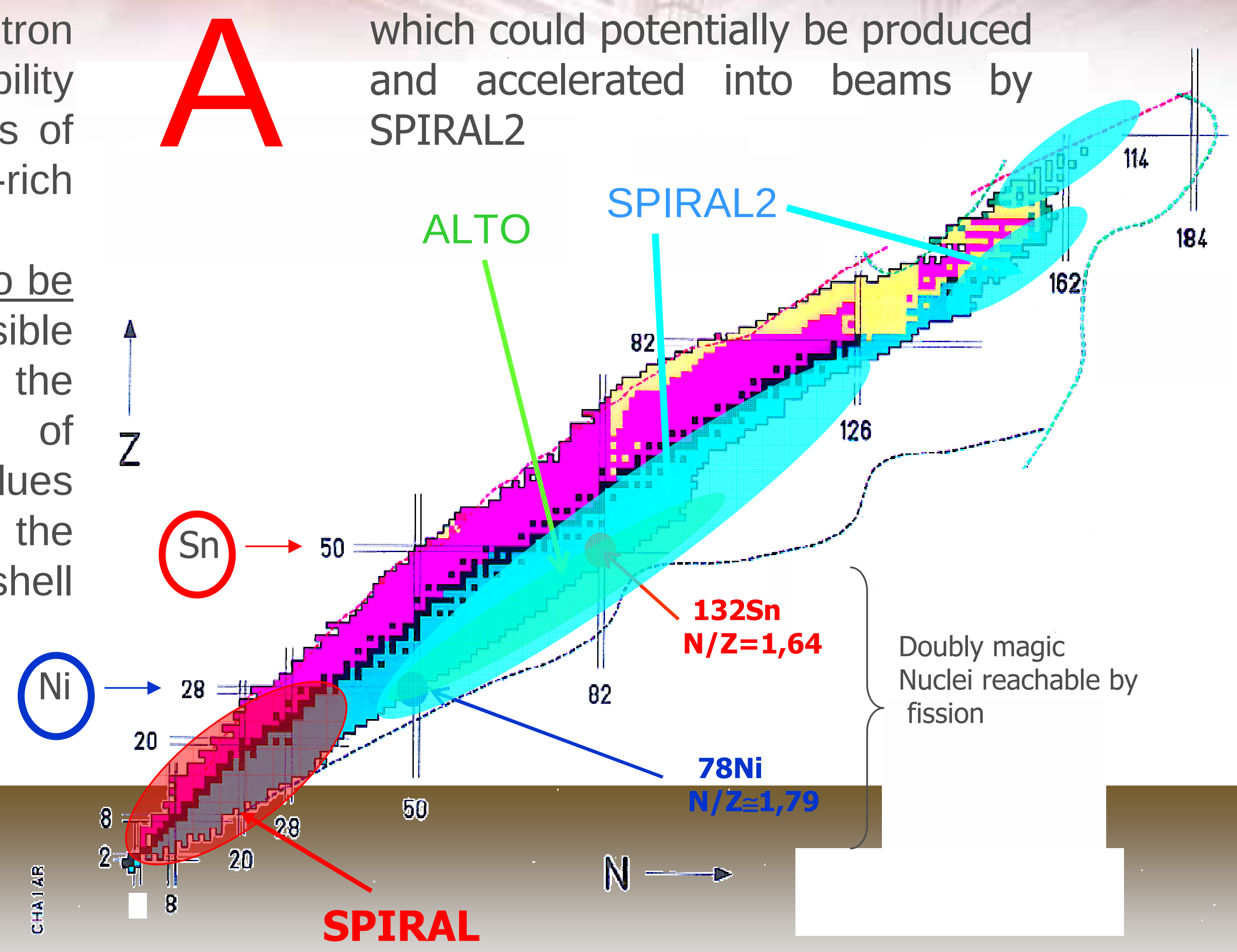
Nuclides	$T_{1/2}$,s	$Q_\beta - B_{2n}$,MeV	P_{2n},%	Y, 1/f
^{86}As	0.90	1.33	0.02	$4.0\ 10^{-4}$
^{94}Br	0.07	3.78	3.12	$1.3\ 10^{-5}$
^{112}Nb	(0.10)	3.79	1.28	$6.1\ 10^{-10}$
^{134}In	0.1	5.54	99	$2.7\ 10^{-7}$
^{136}Sb	0.8	2.25	10.6 0.28	$3.3\ 10^{-4}$
^{142}J	0.2	2.28	0.76	$5.3\ 10^{-5}$
^{150}Cs	(0.15)	2.97	1.48	$1.3\ 10^{-8}$

beta-delayed neutron emission from fission products in the ^{132}Sn region

To measure the β -delayed neutron emission probability along the chains of very neutron-rich isotopes.

<u>The effects to be detected</u>: possible irregularities in the A-dependence of the Ptotal-values after crossing the major neutron shell of N=82.

The blue areas indicate the nuclei which could potentially be produced and accelerated into beams by SPIRAL2



This will enable us to provide a full theoretical support to the proposed experimental measurements of the:

- Properties of the spherical and deformed **ground and isomeric states** of nuclides in the vicinity of exotic shell closures;
- Neutron number dependence of **the magnetic moments** of the odd-A neutron rich nuclides in the vicinity of Z=28, N=40 and Z=50,N=82 shells.
- **Neutron emission from fission products,** nameley the total β-decay half-lives ($T_{1/2}$) and **delayed neutron emission probabilities** (P_n, P_{2n}…) for the nuclei near the closed Z=28, N=50 and Z=50, N=82 shells.

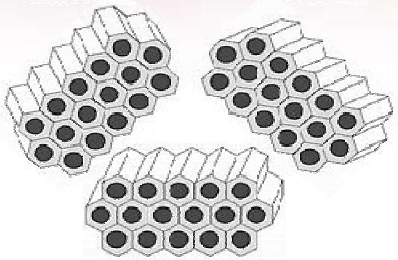
- References: S.A.Fayans et al.Nucl.Phys.676,p.49 (2000)

  I.N.Borzov,Phys.Rev. C71,065801 (2005)

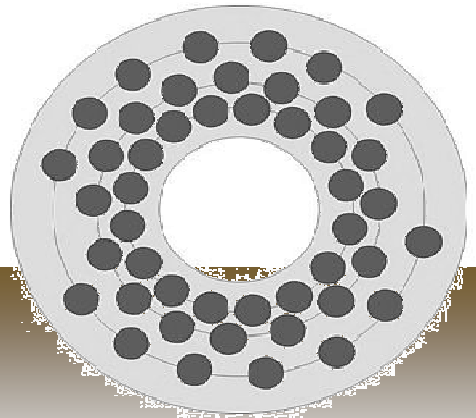
JINR-GANIL and JINR-RIKEN
βn-experiments

30P T1/2=2.498 m Sn=11320.8 8	**31P** T1/2=stable Sn=12311.8 4	**32P** T1/2=14.262 d %B-=100 QB-=1710.66 2 Sn=7935.65 4	**33P** T1/2=25.34 d 1 %B-=100 QB-=248.5 11 Sn=10103.7 11	**34P** T1/2=12.43 s 8 %B-=100 QB-=5374 5 Sn=6291 5	**35P** T1/2=47.3 s 7 %B-=100 QB-=3988.8 19 Sn=8371 5	**36P** T1/2=5.6 s 3 %B-=100 QB-=10413 13 Sn=3465 13	**37P** T1/2=2.31 s 13 %B-=100 QB-=7900 40 Sn=6820 40	**38P** T1/2=0.64 s 14 %B-=100 %B-N<10 QB-=12390 140 Sn=3540 140	**39P** T1/2=0.16 s +3 %B-=100 %B-N=41 24 QB-=10510 160 Sn=6250 200	**40P** T1/2=200 ms 8 %B-=100 %B-N=30 10 QB-=14500 300 Sn=3760 250	**41P** T1/2=120 ms 2 %B-=100 %B-N=30 10 QB-=13800 500 Sn=4600 500	**42P** T1/2=110 ms 3 %B-=100 %B-N=50 20 QB-=17300 SY Sn=3100 SY	**43P** T1/2=33 ms 3 %B-=100 %B-N=100 QB-=15600 SY Sn=5100 SY	**44P** QB-=20100 SY Sn=1000 SY	**45P** QB-=18900 SY Sn=3230 SY
29Si T1/2=stable Sn=8473.56 3	**30Si** T1/2=stable Sn=10609.18 3	**31Si** T1/2=157.3 m %B-=100 QB-=1492.03 1 Sn=6587.40 5	**32Si** T1/2=172 y 4 %B-=100 QB-=224.5 22 Sn=9203.2 22	**33Si** T1/2=6.18 s 18 %B-=100 QB-=5845 16 Sn=4483 16	**34Si** T1/2=2.77 s 20 %B-=100 QB-=4601 15 Sn=7536 21	**35Si** T1/2=0.78 s 12 %B-=100 QB-=10500 40 Sn=2470 40	**36Si** T1/2=0.45 s 6 %B-=100 %B-N<10 QB-=7850 100 Sn=6110 110	**37Si** QB-=12470 130 Sn=2190 160 *%B-N=8* *4*	**38Si** QB-=10700 300 Sn=5500 300 *%B-N=15* *4*	**39Si** QB-=14800 SY Sn=2200 SY *%B-N=31* *8*	**40Si** QB-=13700 SY Sn=4800 SY *%B-N=28* *6*	**41Si** QB-=16700 SY Sn=1600 SY *%B-N=54* *30*	**42Si** QB-=14900 SY Sn=4900 SY	29	30
28Al T1/2=2.2414 m Q=0.175 14 %B-=100 QB-=4642.24 1 Sn=7725.05 6	**29Al** T1/2=6.56 m 6 %B-=100 QB-=3679.5 12 Sn=9436.3 12	**30Al** T1/2=3.60 s 6 %B-=100 QB-=8561 14 Sn=5728 14	**31Al** T1/2=644 ms 2 %B-=100 QB-=7995 20 Sn=7153 25	**32Al** T1/2=33 ms 4 %B-=100 QB-=13020 90 Sn=4180 90	**33Al** QB-=11990 70 Sn=5510 110	**34Al** T1/2=60 ms 18 %B-=100 %B-N=27 5 QB-=17090 90 Sn=2430 110	**35Al** T1/2=150 ms 5 %B-=100 %B-N=65 35 QB-=14300 150 Sn=5273 170	**36Al** QB-=18300 300 Sn=2100 300 *%B-N=29* *5*	**37Al** QB-=16100 900 Sn=4400 600 *%B-N=29* *5*	**38Al** QB-=19500 SY Sn=1900 SY *%B-N=44* *12*	**39Al** QB-=18300 SY Sn=3400 SY *%B-N=51* *14*		28		
27Mg T1/2=9.458 m %B-=100 QB-=2610.33 1 Sn=6443.35 4	**28Mg** T1/2=20.91 h 3 %B-=100 QB-=1831.8 20 Sn=8503.6 20	**29Mg** T1/2=1.30 s 12 %B-=100 QB-=7550 30 Sn=3710 30	**30Mg** T1/2=335 ms 1 %B-=100 QB-=6990 70 Sn=6290 70	**31Mg** T1/2=230 ms 2 %B-=100 %B-N=1.7 3 QB-=11740 80 Sn=2400 100	**32Mg** T1/2=120 ms 2 %B-=100 %B-N=2.4 5 QB-=10270 130 Sn=5650 120	**33Mg** T1/2=90 ms 20 %B-=100 %B-N=17 5 QB-=13710 160 Sn=2070 170	**34Mg** T1/2=20 ms 10 %B-=100 %B-N= *30 6* QB-=11800 300 Sn=4800 300	**35Mg** QB-=16400 SY Sn=200 SY *%B-N=27* *6*	**36Mg** QB-=13000 SY Sn=3300 SY *%B-N=25* *6*	**37Mg** QB-=19500 SY Sn=-100 SY	26				
26Na T1/2=1.072 s 9 Q=0.08 5 %B-=100 QB-=9312 14 Sn=5616 14	**27Na** T1/2=301 ms 6 Q=0.06 5 %B-=100 QB-=9010 40 Sn=6750 40	**28Na** T1/2=30.5 ms Q=0.02 4 %B-=100 QB-=13990 80 Sn=2520 80	**29Na** T1/2=44.9 ms Q=+0.03 5 %B-=100 QB-=13280 90 Sn=4420 120	**30Na** T1/2=48 ms 2 %B-=100 QB-=17480 110 Sn=2100 130	**31Na** T1/2=17.0 ms %B-=100 %B-N=37 5 %B-2N=0.9 2 QB-=15880 180	**32Na** T1/2=13.2 ms %B-=100 %B-N=24 7 %B-2N=8.3 21 QB-=19100 500	**33Na** T1/2=8.2 ms 4 %B-=100 %B-N=52 20 %B-2N=12 5 QB-=20300 150	**34Na** T1/2=5.5 ms 10 %B-=100 %B-2N=? QB-=24300 SY Sn=1100 SY	**35Na** T1/2=1.5 ms 5 %B-=100 %B-N=? QB-=24900 SY Sn=-600 SY	25					
25Ne T1/2=602 ms 8 %B-=100 QB-=7300 40 Sn=4180 50	**26Ne** T1/2=197 ms 1 %B-=100 %B-N=0.13 3 QB-=7330 60 Sn=5580 70	**27Ne** T1/2=32 ms 2 %B-=100 %B-N=2.0 5 QB-=12670 100 Sn=1410 110	**28Ne** T1/2=17 ms 4 %B-=100 %B-N=22 3 QB-=12310 140 Sn=3890 140	**29Ne** T1/2=0.2 s 1 %B-=100 QB-=15400 300 Sn=1300 300 *%B-N= 27*	**30Ne** QB-=13600 800 Sn=3900 900 *%B-N=9*	**31Ne** QB-=18200 SY Sn=-500 SY	**32Ne** QB-=18900 SY Sn=1700 SY	23	24						
24F T1/2=0.34 s 8 %B-=100 QB-=13490 70 Sn=3860 100	**25F** T1/2=59 ms 40 %B-=100 %B-N=15 10 QB-=13330 90 Sn=4330 100	**26F** QB-=17850 140 Sn=1030 150 *%B-N=11*	**27F** QB-=18800 400 Sn=1300 400 *%B-N=* *90 +30*	**28F** QB-=21900 SY Sn=-100 SY	**29F** QB-=22300 SY Sn=1000 SY	21	22								
23O T1/2=82 ms 37 %B-=100 %B-N=31 7 QB-=11290 130 Sn=2740 120	**24O** T1/2=61 ms 26 %B-=100 %B-N=58 12 *%B-N=10*	**25O** QB-=15900 SY Sn=-100 SY	**26O** QB-=16900 SY Sn=100 SY	19	20										

The β-delayed neutrons from light nuclei

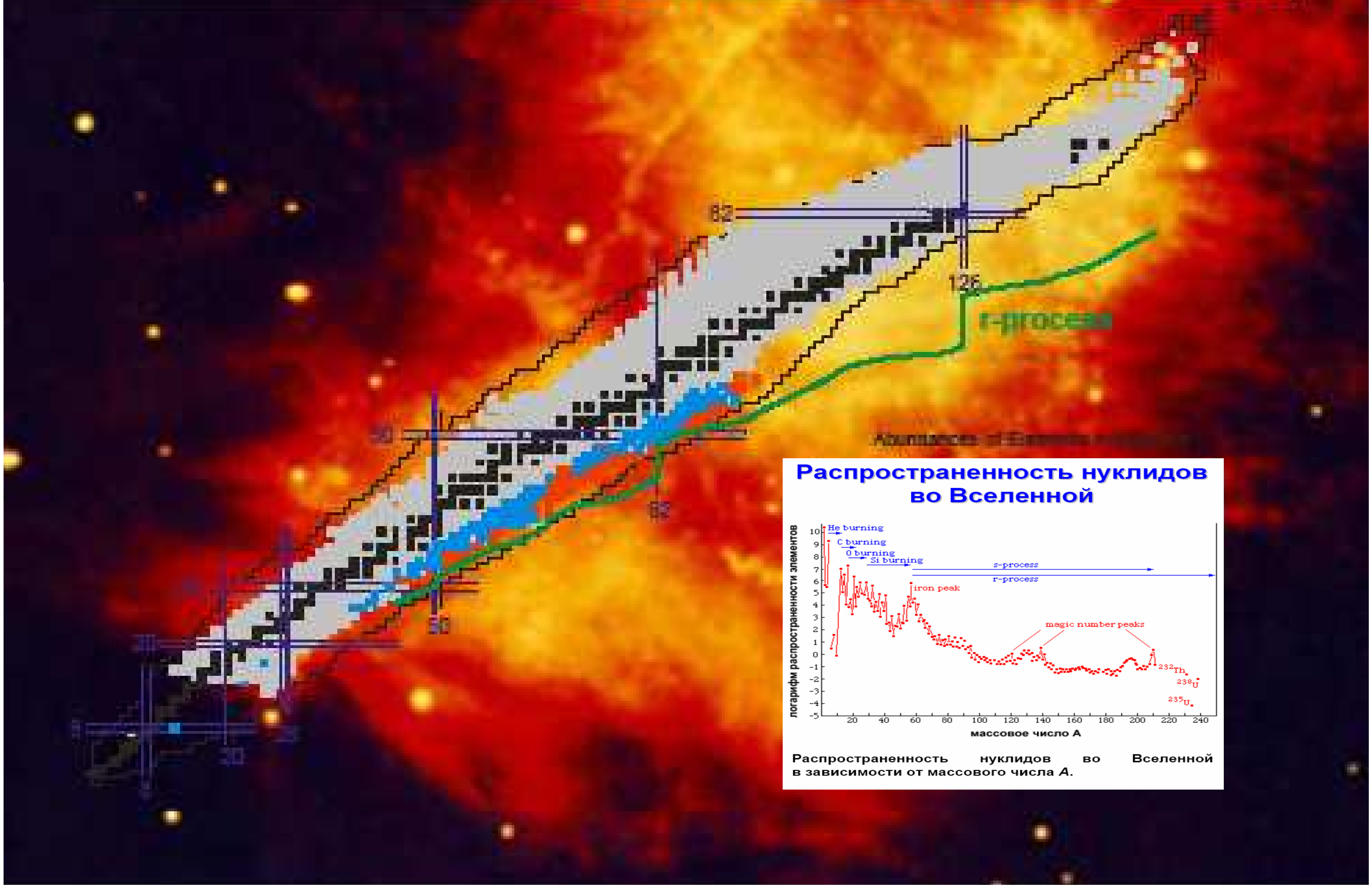


	Previously known data	GANIL experiment
^{28}Ne		11±8%
^{29}Ne		27±9%
^{30}Ne		9[illegible] %
^{24}O	24±8 58±12	18±6%
^{25}F	15±10	14±5%
^{26}F		11±4%.
^{27}F		90[illegible] %

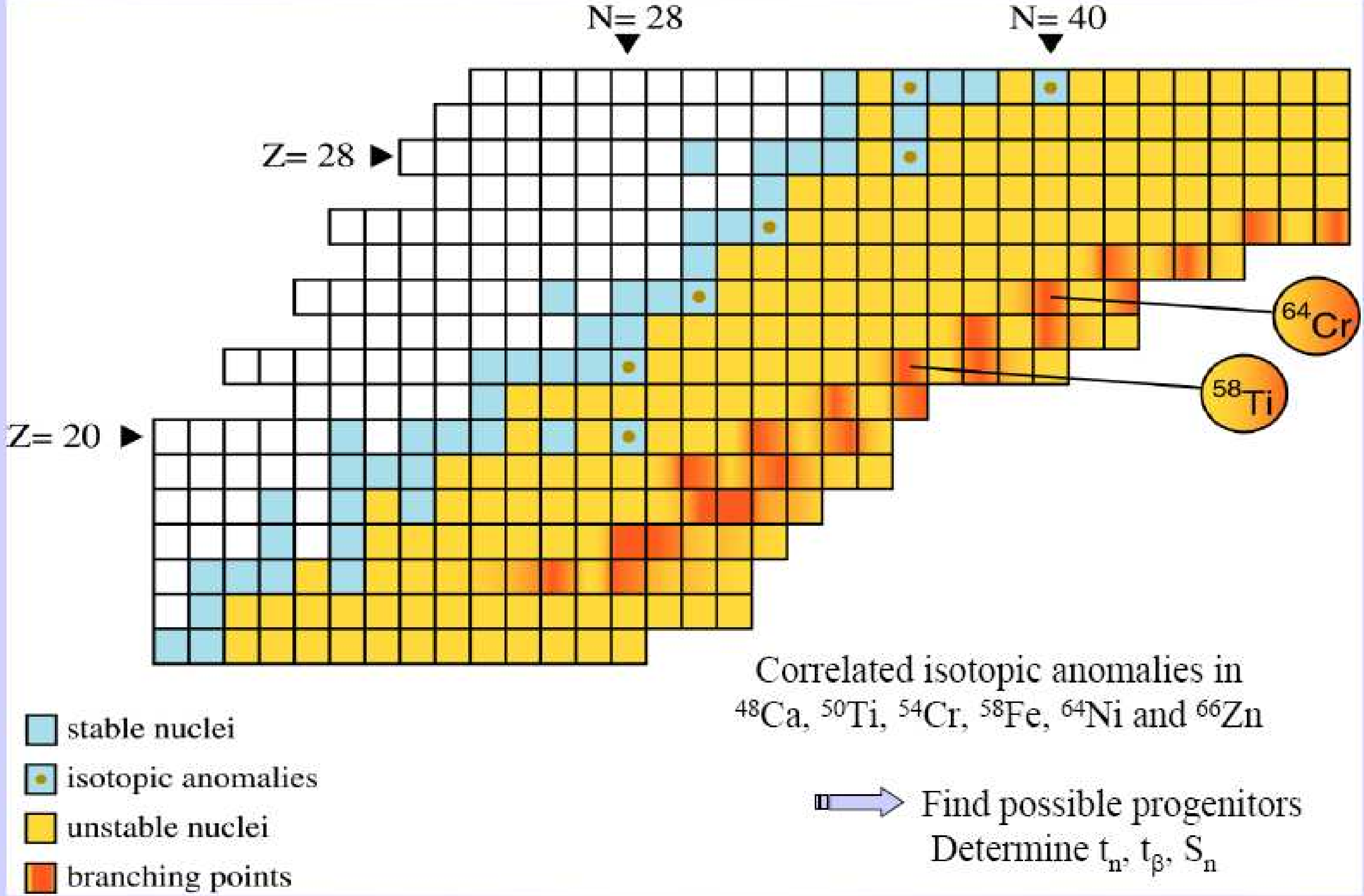


	Previously known data	RIKEN experiment	
		^{14}Be standard	^{14}B standard
^{31}Na	38±5	43±12 %	82±42
^{32}Na	40±11	31±8 %	59±17
^{33}Na	77±30	72±28 %	136±34
^{32}Mg	2.4±0.5	3±0.5%	6 ±4
^{33}Mg	17±5	26±6 %	50±18
^{34}Mg		30±6%	58±12
^{35}Mg		27±6%	52±11
^{36}Mg		25±6%	48±12
^{34}Al	12.5±2.5	16±2%	30±6
^{35}Al	26±4	23±3%	43±9
^{36}Al		29±5%	55±11
^{37}Al		29±5%	55±11
^{38}Al		44±12%	84±19
^{39}Al		51±14%	97±22
^{37}Si		8±4%	15±3
^{38}Si		15±4%	28±7
^{39}Si		31±8%	60±13
^{40}Si		28±6%	53±12
^{41}Si		54±30%	103±48
^{41}P	30±10	37±12%	71±21
^{42}P	50±20	30±12%	57±13
^{43}P	100±50	44±30%	84 ±47

Production of heavy elements in the r-process



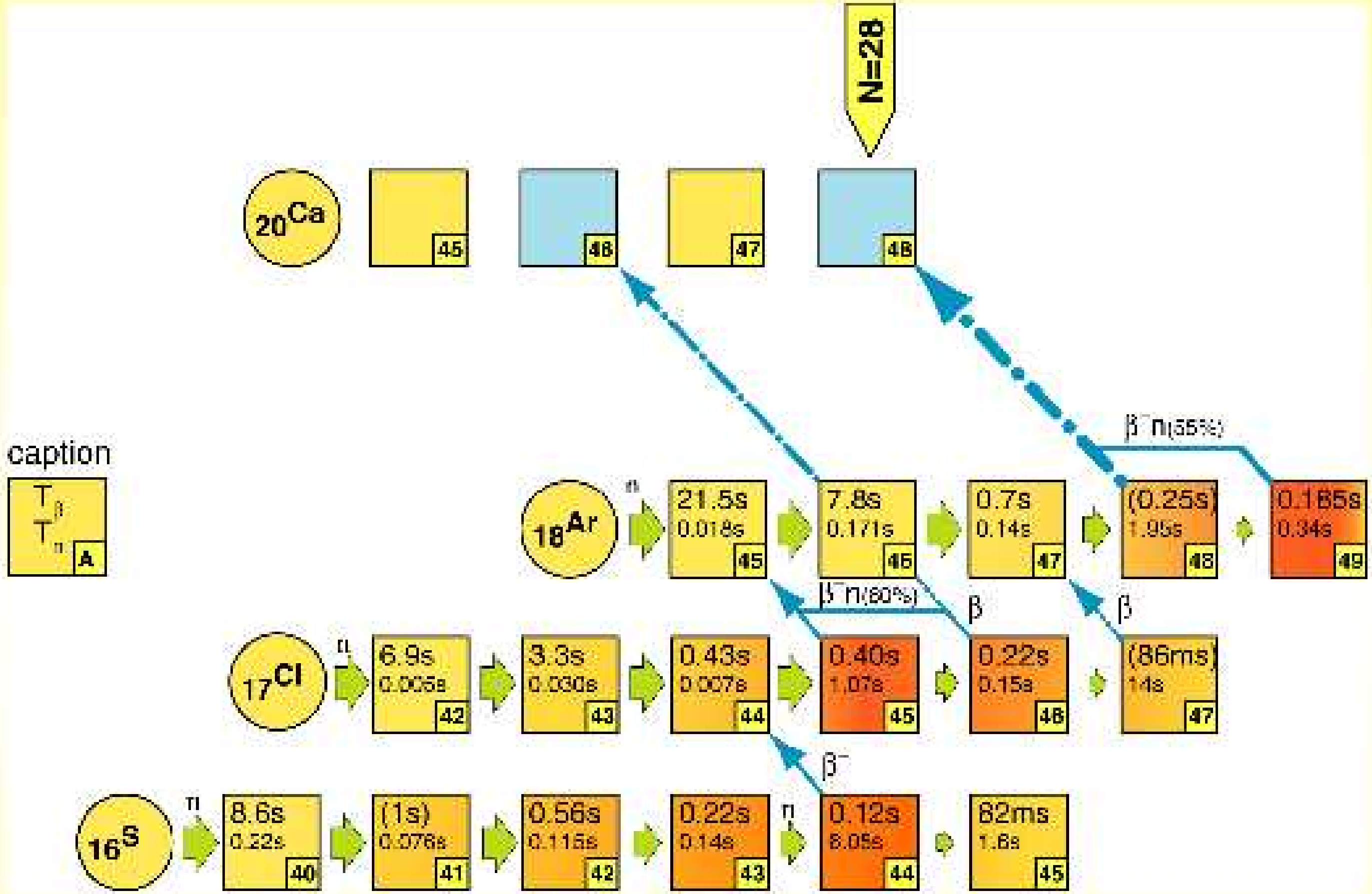
A weak r-process component to produce correlated isotopic anomalies in the Ca-Ti… -Zn region ?



Correlated isotopic anomalies in ^{48}Ca, ^{50}Ti, ^{54}Cr, ^{58}Fe, ^{64}Ni and ^{66}Zn

⇨ Find possible progenitors
Determine t_n, t_β, S_n

Understand the $^{48}Ca/^{46}Ca$ = 250 isotopic ratio in EK1-4-1



Short half-lives of $^{44}S_{28}$ and $^{45}Cl_{28}$: reduce the production of ^{46}S and ^{46}Cl genitors of ^{46}Ca

(O. Sorlin et al. PRC 47 (1993) 2941)

Measurements of $^{48,49}Ar$ half-lives, genitors of ^{48}Ca. *(S. Grévy, L. Weissmann)*

Rôle of the shell closure N=28 in neutron-capture rates: leakage to ^{46}Ca depends on $^{46}Ar(n,\gamma)^{47}Ar$

It is proposed:

- To measure the two-neutron emission probability along the chains of very neutron-rich isotopes in Z≈50,N>82 region.

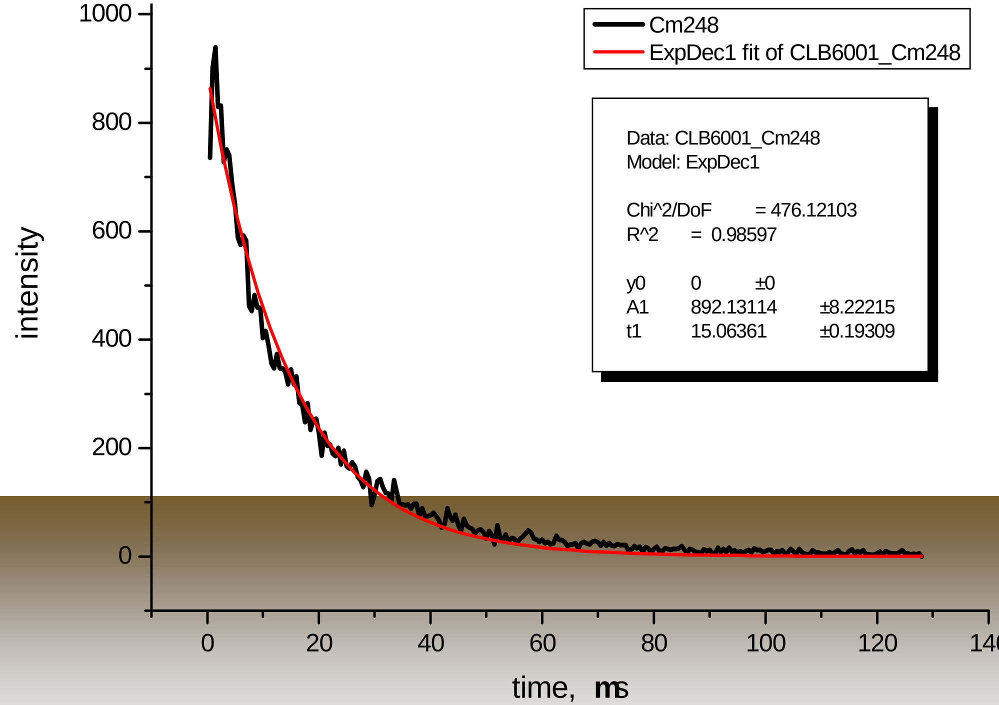
  The effects to be detected: the possible odd-even effects in the P_{2n}-values

- To measure the β -delayed neutron emission probability along the chains of very neutron-rich isotopes.

  The effects to be detected: possible irregularities in the A-dependence of the P_{total}-values after crossing the major neutron shell of N=82.

Neutron detectors with ^{3}He filled counters

- Zero energy threshold
- Zero cross-talk
- Low gamma sensitivity
- Free geometry
- Easy in use
- High efficiency
- Low internal background
- Angular correlations



^{3}He + n = ^{3}H + p + 780 keV

σ_{th} = 5320 barns

Pressure of ^{3}He 7 atm

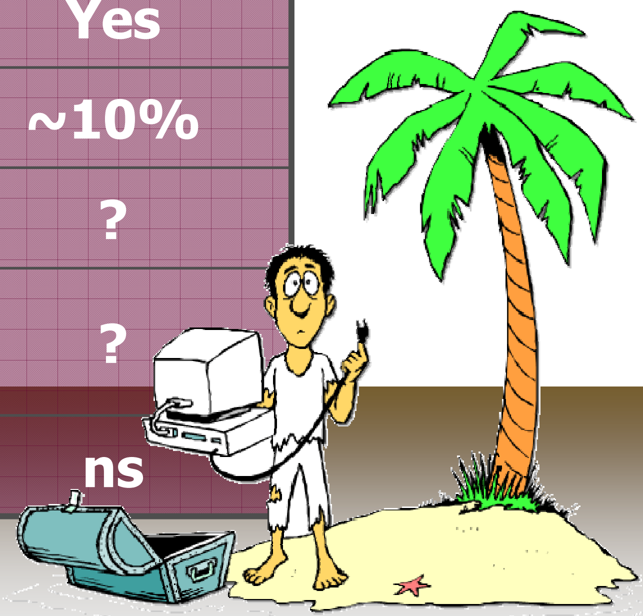
Eff. 60% (0.4 – 1.5 MeV)

Preprint JINR P13-2007-154

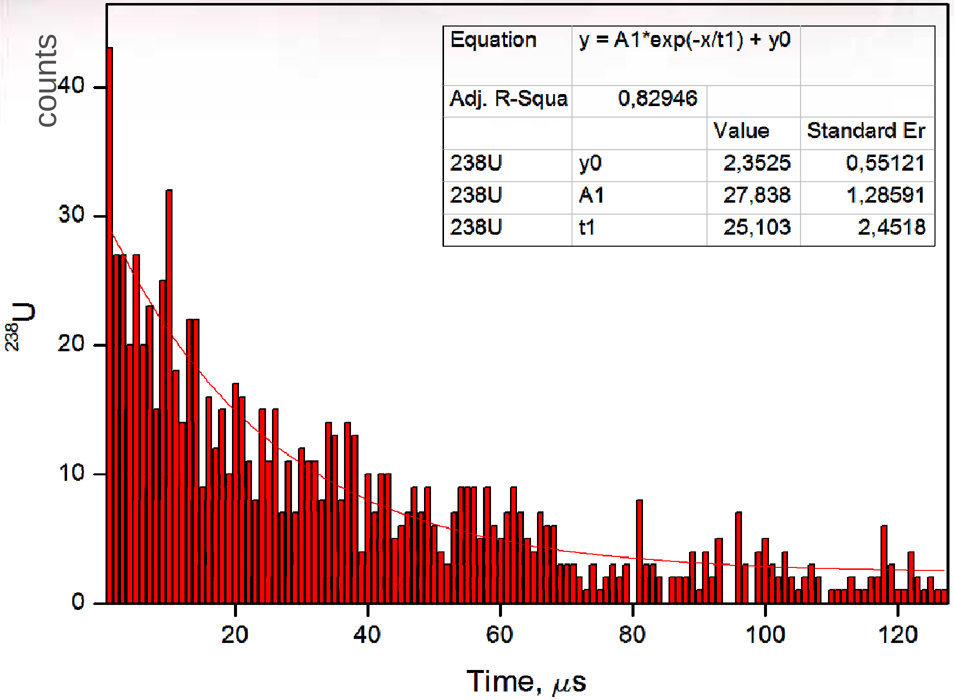
Comparison of Detectors

	^{3}He-detector	"Large" scintillator	"Small" scintillator
Neutron energy	?	Yes	Yes
Threshold	0	High(~300 keV)	Low(~30 keV)
Cross talk	0	Yes	Yes
Efficiency	30-60%	30-60%	~10%
Multiplicity	Yes	?	?
Angle correlation	Yes (<20^0)	?	?
Time scale	10 μs	ns	ns

A



Neutron Capture Time, calibration for SF neutrons of ^{238}U, November 2009



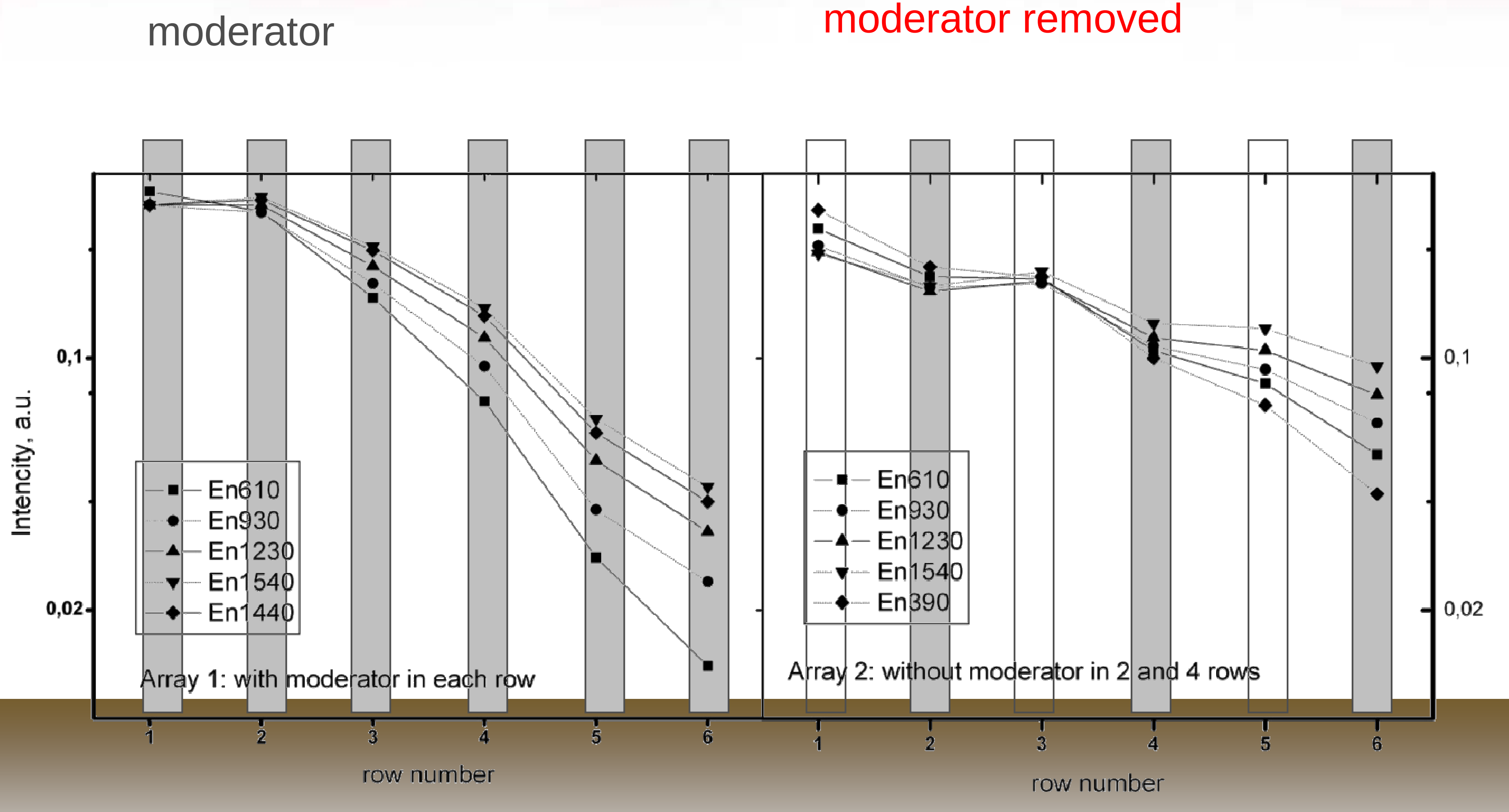
Efficiency in the center of the detector (consists of 60 counters placed in moderator) for single neutrons measured (62±4)%

Life time of a neutron in the detector measured 25 μs

The detector is used at low background laboratory (LSM, Modane) to detect neutron flashes of high multiplicity.

Detector response functions for different neutron energies

En=400-1500 keV

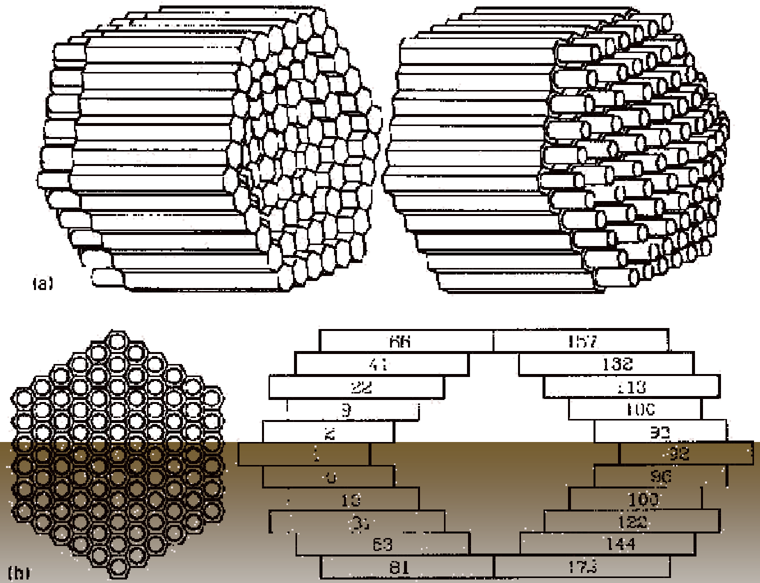


Nucl. Instr.& Meth. in Phys. Research A, v.400, 1997, p.96

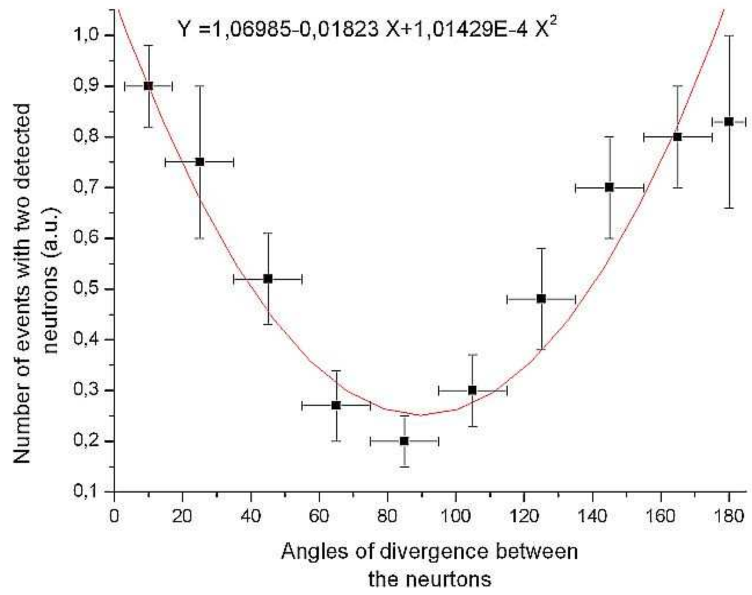
Angle correlations

Efficiency strongly depends

on energy of neutron

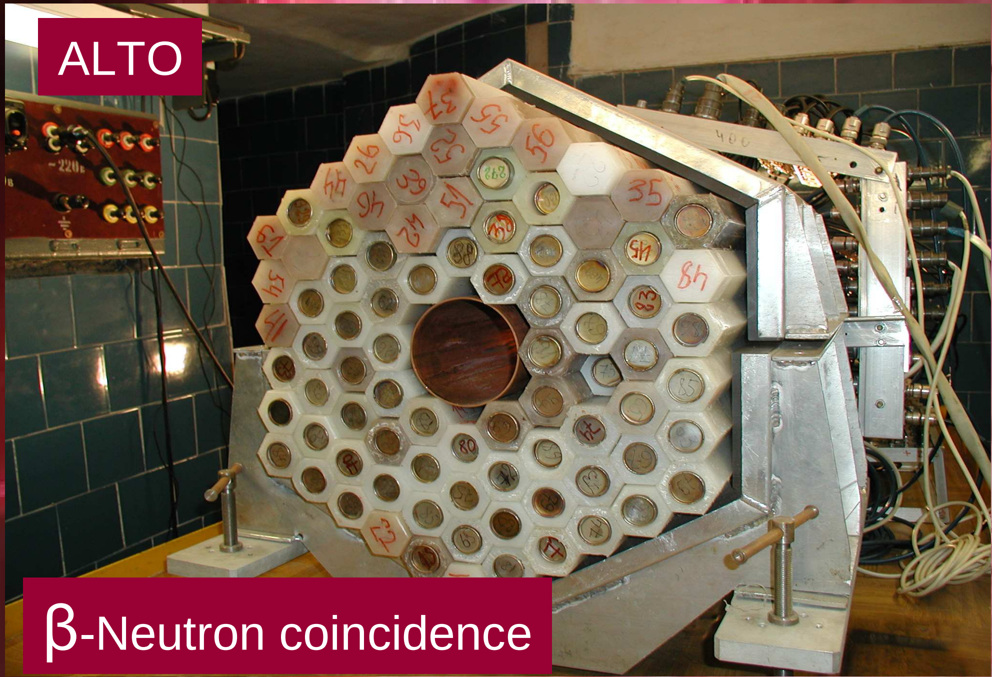


Angular distribution



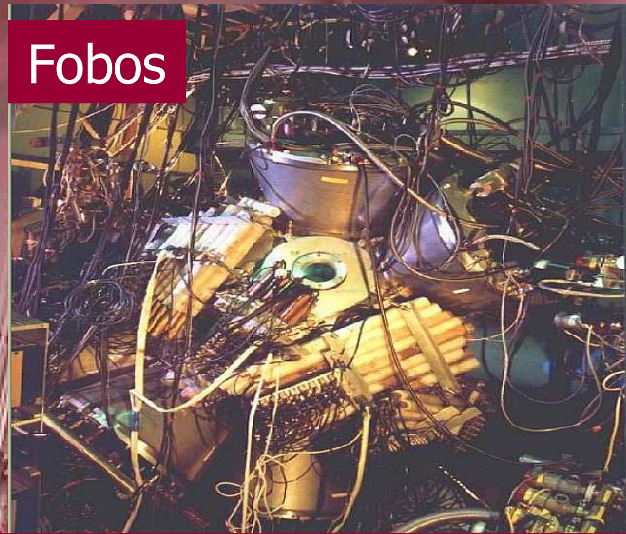
A detector for measuring the multiplicities and the angular correlation of neutrons
Nucl. Instr.& Meth. in Phys. Research A, v.400, 1997, p.96-100

Uses of ^{3}He detectors in different setups



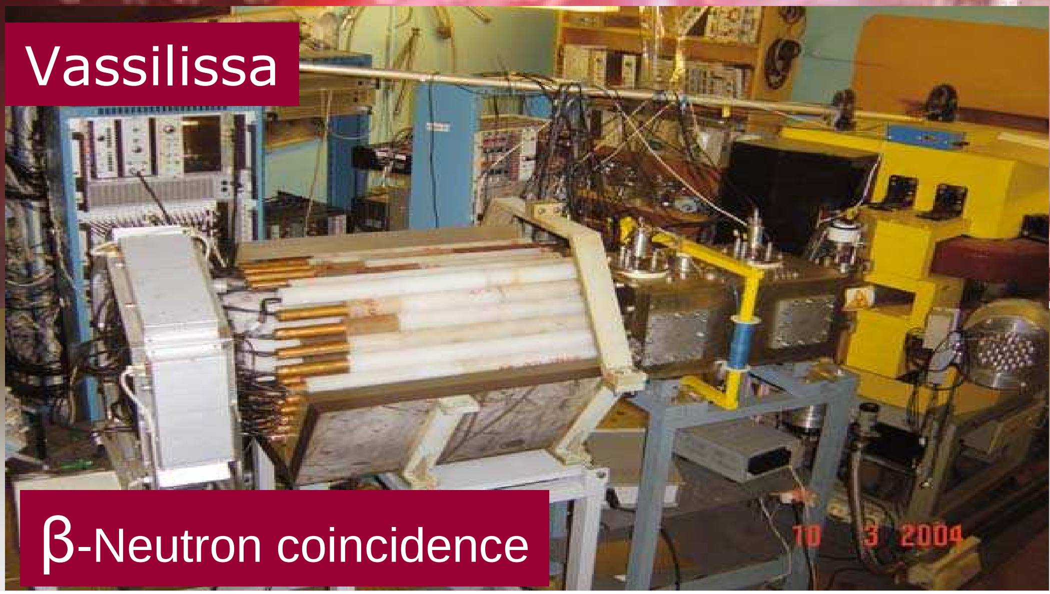
ALTO

β-Neutron coincidence



Fobos

Neutron-Fragments coincidence



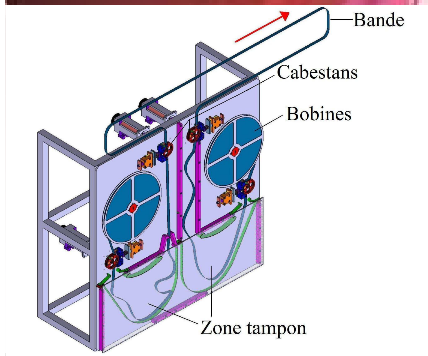
Vassilissa

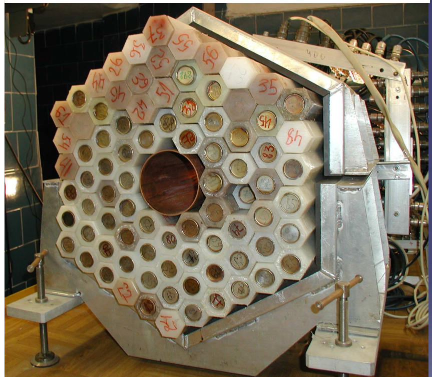
β-Neutron coincidence

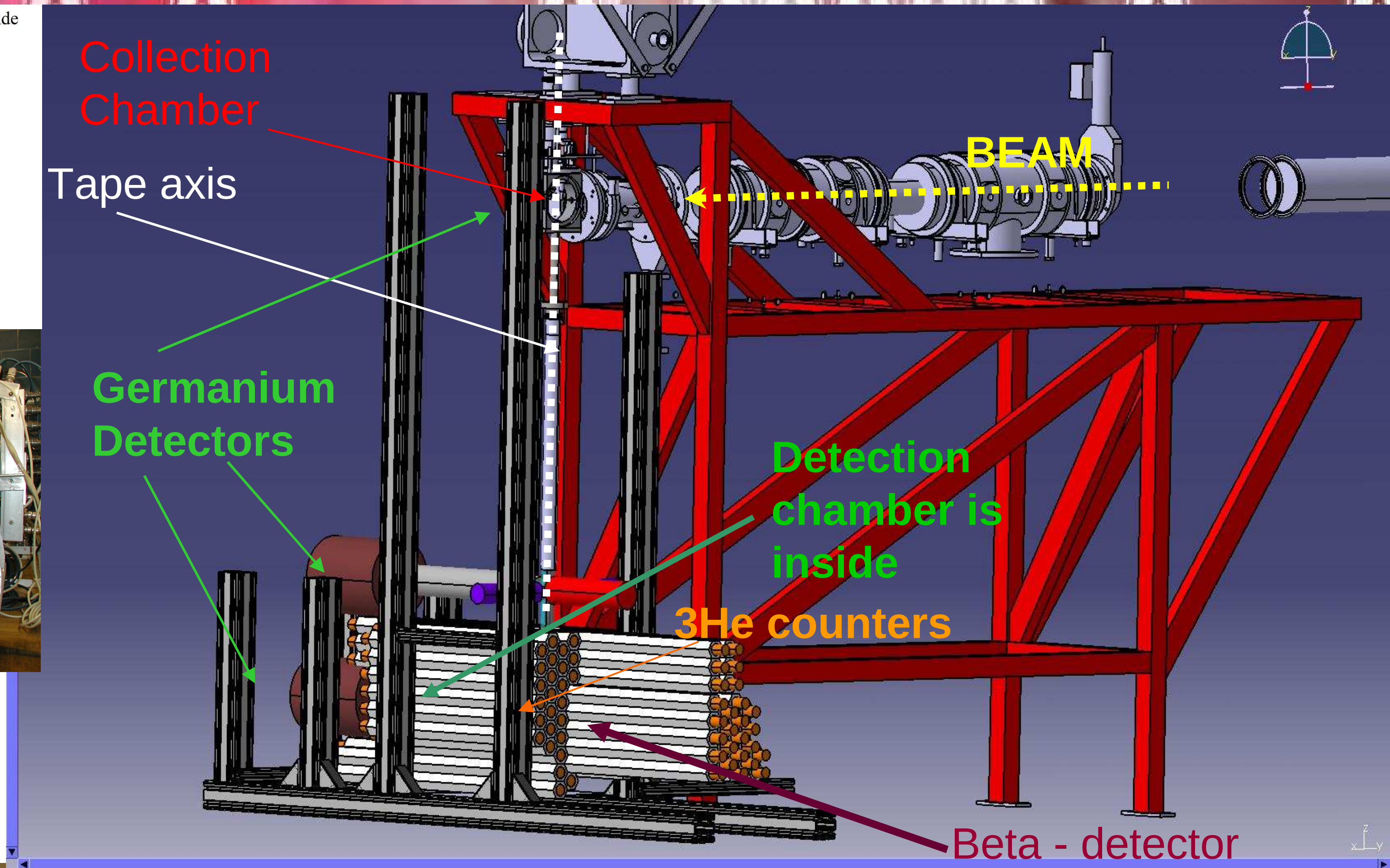
Shin

Neutron-Neutron coincidence

First beta-neutron-gamma coincidence detection trial at ALTO, setup





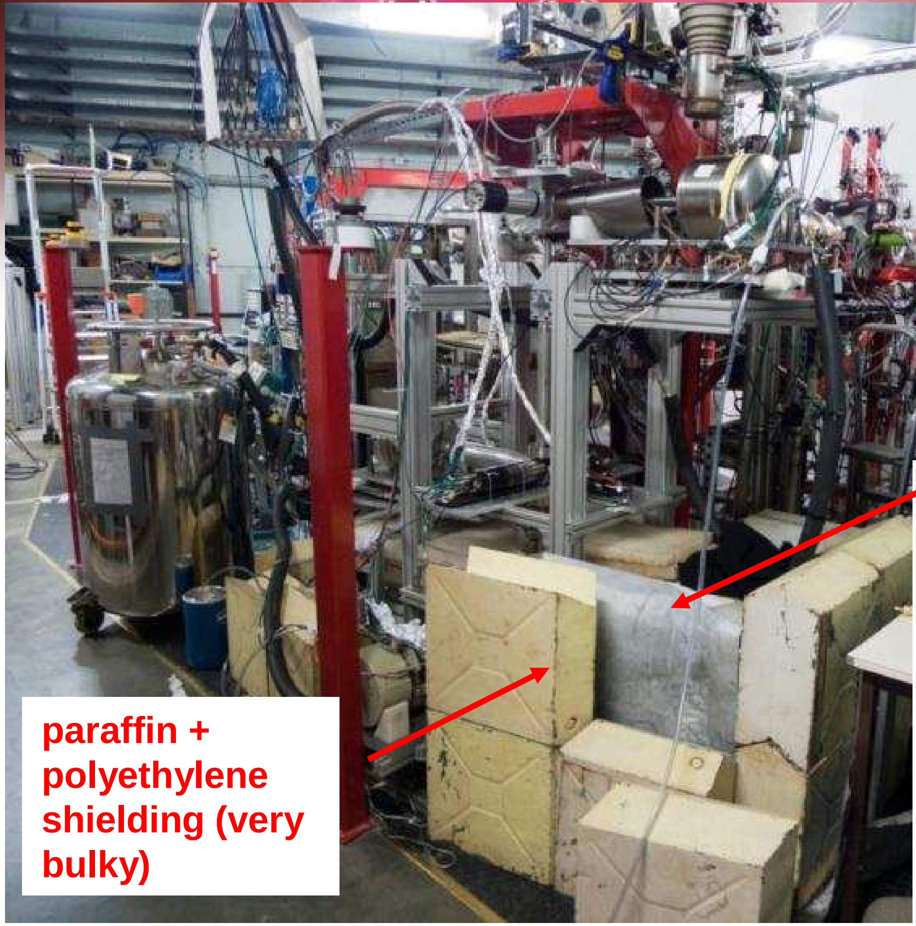


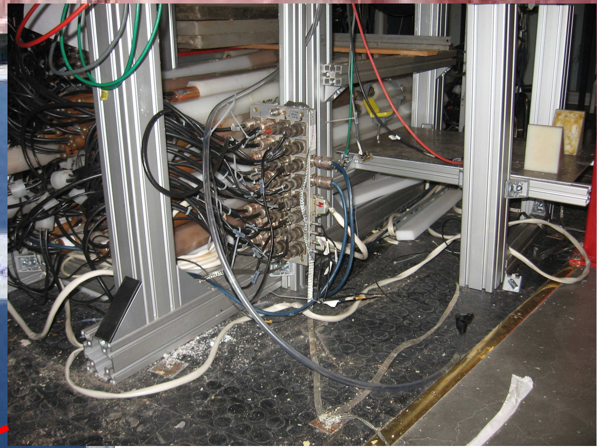
Collection/measuring time - 3s; - 10s

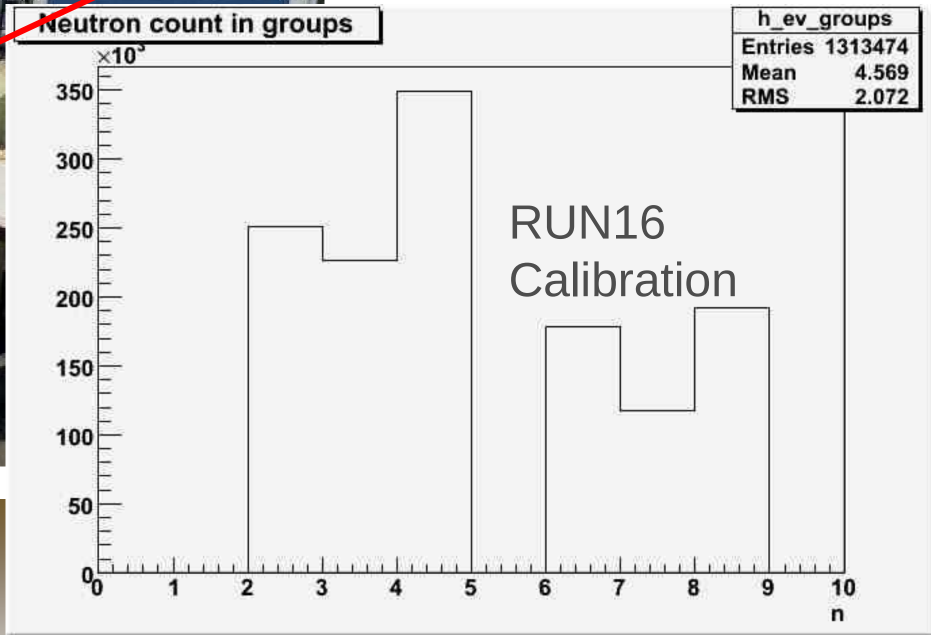
Transport time -1,5s

ALTO

Neutron detector setup at ALTO







The efficiency measured is up to 35%

Neutron lifetime in the detector is 35 μs

Detector consisted of 6 groups
15 counters each

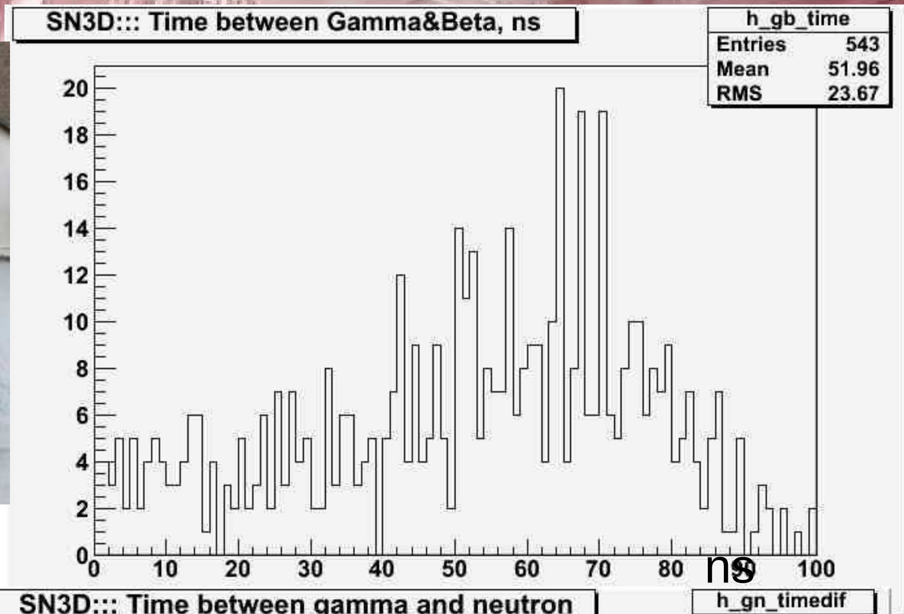
ALTO

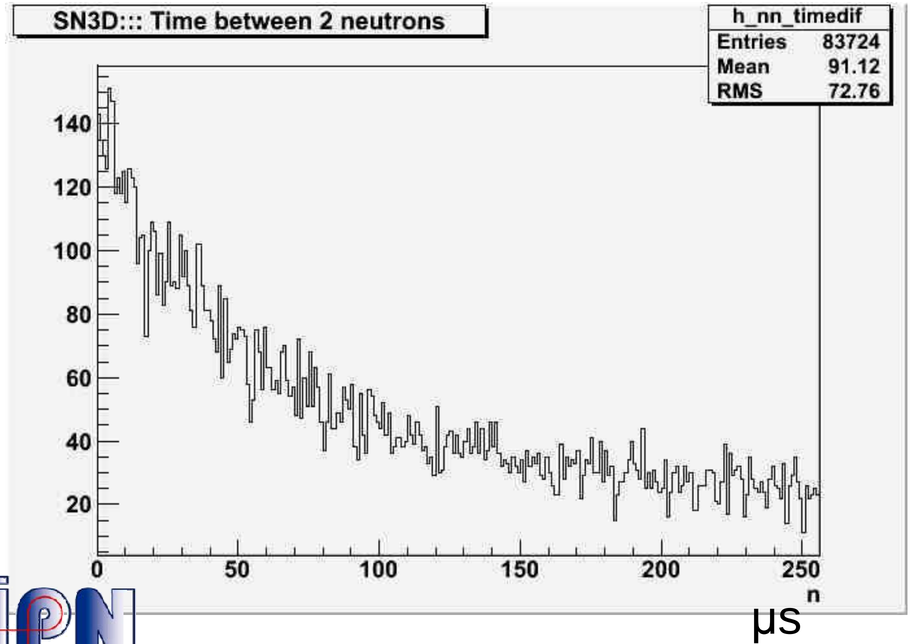
Gamma-β-neutron coincidence:: preliminary results ^{136}Te

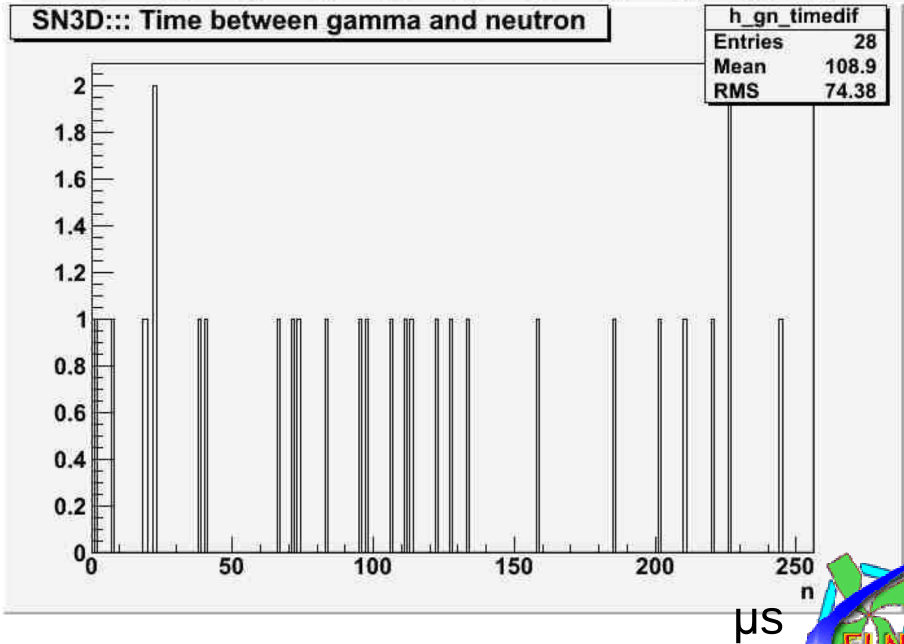
GAMMA

BETA

NEUTRON

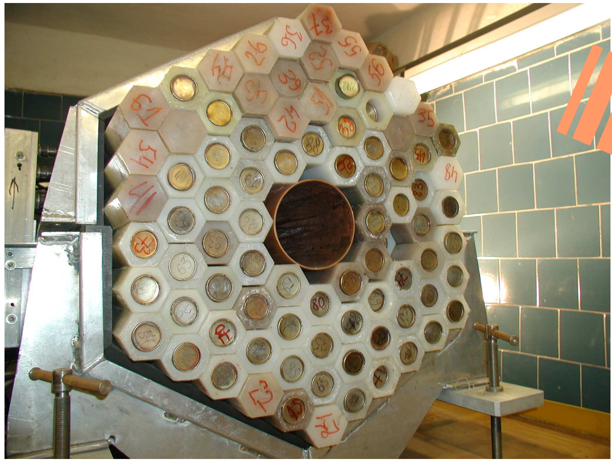




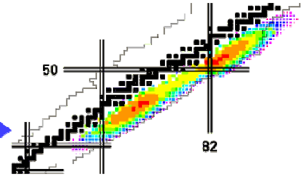


ALTO Neutron Detector Setup: prototype for DESIR

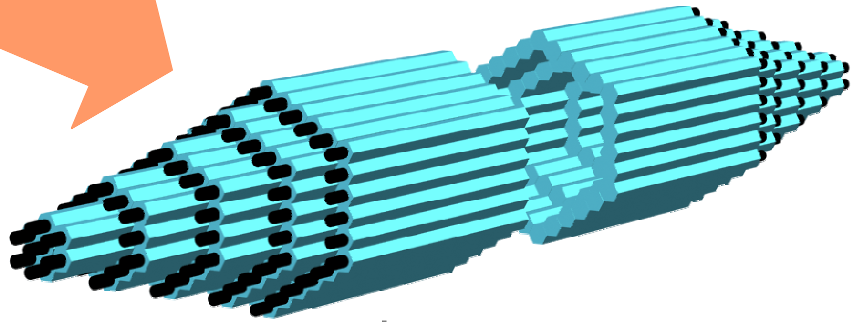
ALTO



Spiral2



TETRA Detector



close to 4-π geometry

Total number of counters: 90 | 342

Geometry: Ø 3 cm, ^3He at 7 atm, length 50 cm | Ø 3 cm, 3He at 7 atm, length 25 cm

Moderator: polyethylene, distance between parallel faces - 5 cm.

Efficiency: 30-60% (depends on geometry)

Life time: 15-30 μs (depends on geometry)

Neutron Detector TETRA for DESIR : cost estimates (2010- 2013)

Investment:	
Array of neutron counters	280 000€
Control system	50 000€
Manpower cost:	
Stuff 2 per/year	60 000€
Travel and indirect coast:	50 000€
TOTAL	440000€

Technical specifications

A detector prototype with 90 counters (gas pressure 7 atm, length 50 cm, diameter 3.2 cm) is for experiments at ALTO in Orsay starting from 2009.
To get better angular resolution with high and constant efficiency in a wide neutron energy range, it is necessary to change the counters to shorter ones (20-25 cm in length) and increase the total numbers of counters up to 300 - 350.

Neutron Detector Setup for DESIR: schedule

Spiral2

2010	2011	2012	2013	2014

ETAPE 1 Tests of a detector prototype at ALTO, 2009 - 2010.

ETAPE 2 Construction and manufacturing of the neutron detector for DESIR: 1 man year, 2011.

ETAPE 3 Tests of the DESIR neutron detectors at ALTO: 0.5 man year, 2011- 2012

ETAPE 4 Installation of TETRA detectors in the DESIR hall: 0.5 man year, 2013- 2014.

Neutron Detector Setup for DESIR

Risks of the project

Neutron detectors of this type have been used at GANIL and will be tested at ALTO. We have prepared the last detector of this type for the low background measurements of spontaneous fission in LSM (Modane, France) in 2004. The detector for DESIR will be constructed and manufactured with this experience.

Beam requirements

Beam intensities: To perform the experiments described above, beam intensities of the RNB of interest of about 10^5 - 10^7 pps will be optimum.

Specific requirements

- Required floor space: 2x3 m^2
- Weight: total with shielding – 2000 kg
- We will need a spontaneous fission source for calibrations (^{248}Cm or ^{252}Cf) with an intensity of about 20-100 spontaneous fissions per second)

Neutron Collaboration at ALTO

S. Ancelin, D. Guillemaud-Mueller, F. Ibrahim, M.Niikura, Yu.Penionzhkevich, V. Smirnov, E. Sokol, B. Tastet, D. Testov , D. Verney

Cooperation

FLNR (Dubna)

GANIL (Caen)

IPN (Orsay)

Katholieke Universiteit (Leuven)

Cyclotron Laboratorie (Jyvaskyla)

NPI of ASCR, Czech Republic

YerPhI, Armenia

INRNE (Sofia)

At the verge of discoveries…

EYJAFJALLAJOKULL

Thank you!