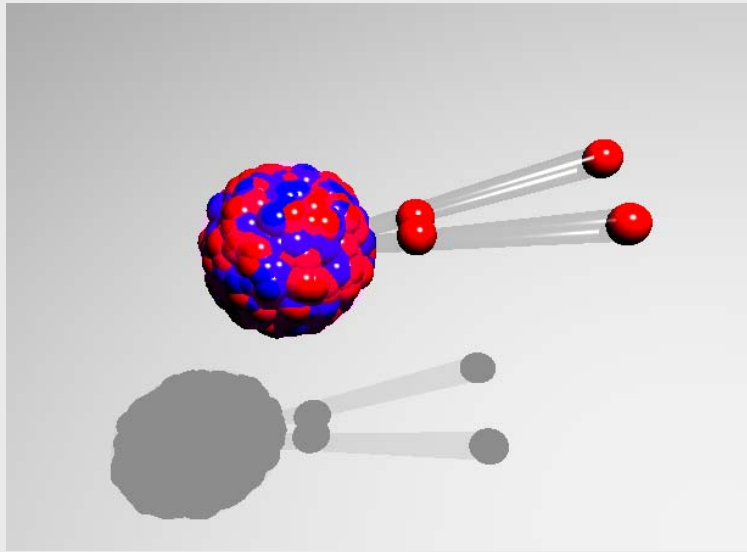
Cyfrowe fotografie rozpadów jądrowych

nowe wyniki na temat promieniotwórczości 2p

Marek Pfützner

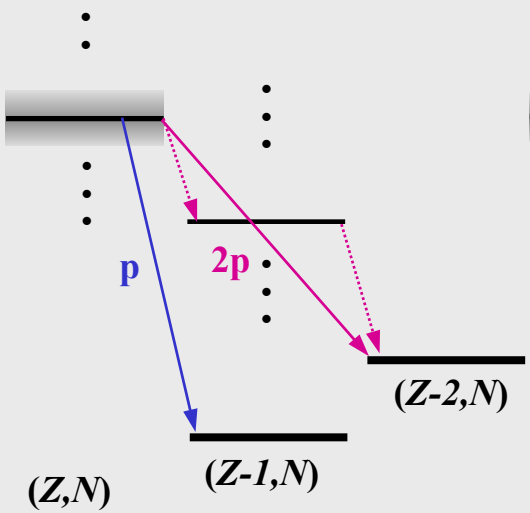
Zakład Spektroskopii Jądrowej, IFD UW

- Promieniotwórczość 2p
- Detektor OTPC
- Testy w Dubnej
- Eksperyment w MSU/NSCL

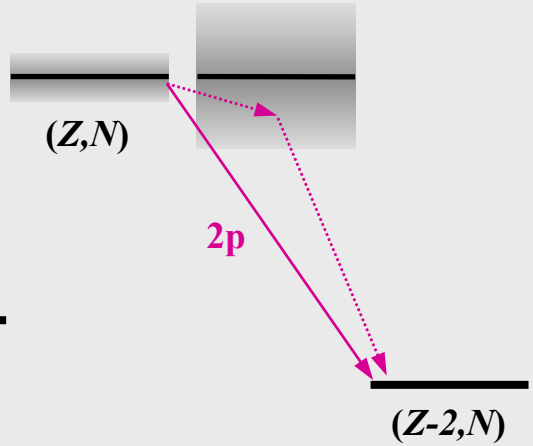


Seminarium Fizyki Wielkich Energii, Wydział Fizyki UW, 23 lutego 2007

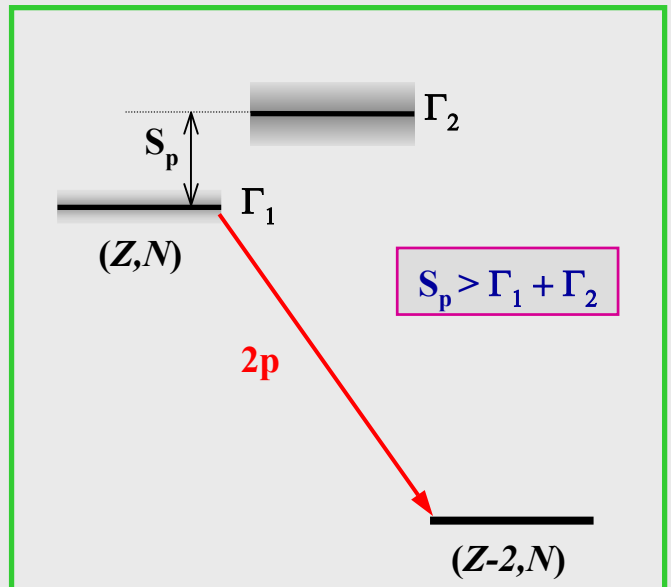
Types of the 2p emission



sequential



democratic



2p radioactivity

^{22}Mg*, ^{26}Si* – Cable 1983
^{31}Cl* – Borge 1990
^{14}O* – Bain 1996
^{18}Ne* – Gómez del Campo 2000
^{17}Ne * – Zerguerras 2003
^{94}Ag* – Mukha 2006

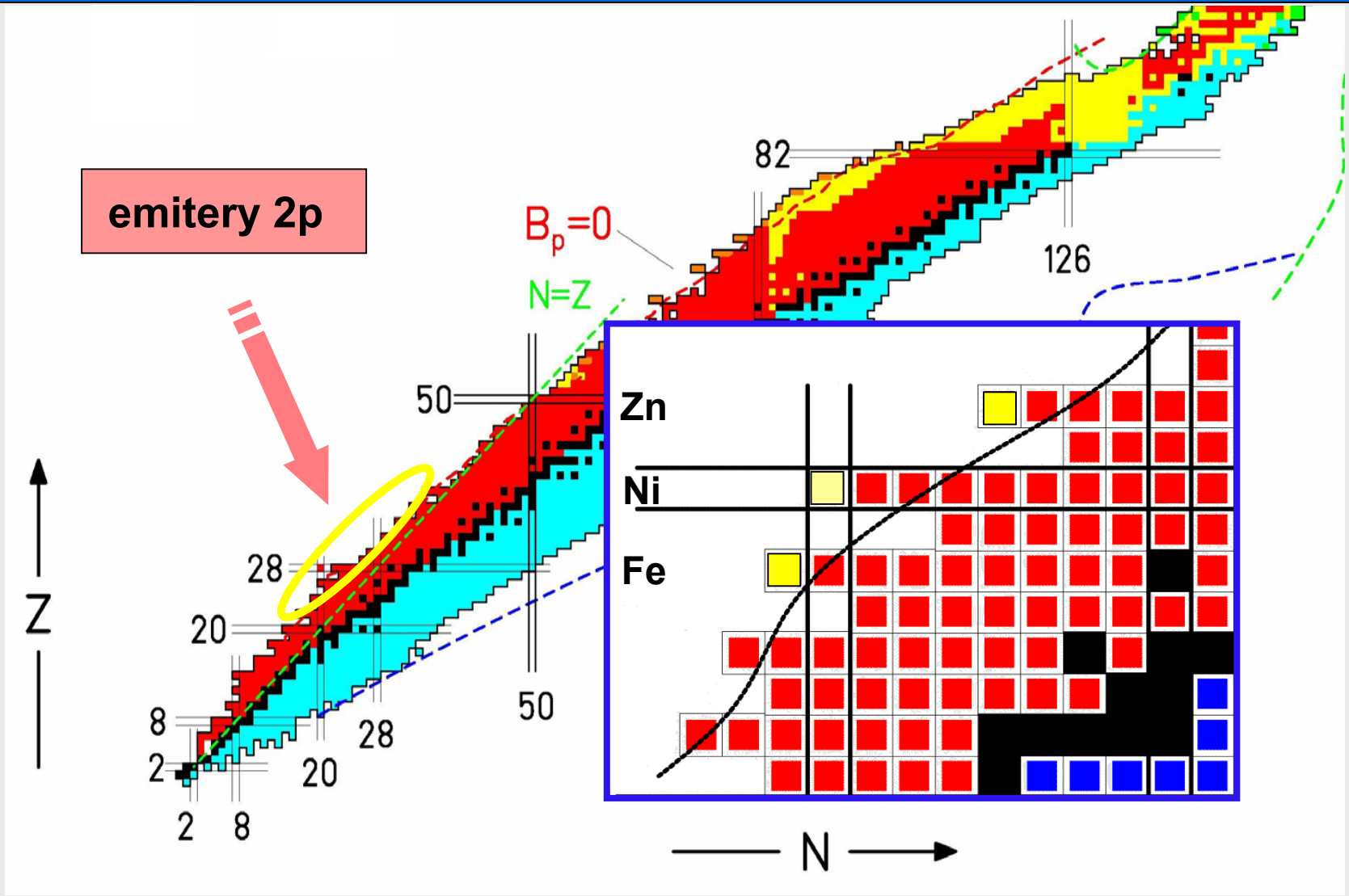
^{6}Be – Bochkarev 1989
^{12}O – Kryger 1994
^{16}Ne – ?

- Single proton branch closed
- Long half-life

- Observed for ^{45}Fe, ^{54}Zn
- Predicted for ^{19}Mg, ^{48}Ni, ...

Basic issue : how are the 2p correlated ?
Does the diproton configuration contribute ?

Chart of nuclei



Decay of ^{45}Fe

GSI: Fragmentation of ^{58}Ni beam @ 650 MeV/u

6 ^{45}Fe ions implanted in a stack of Si detectors

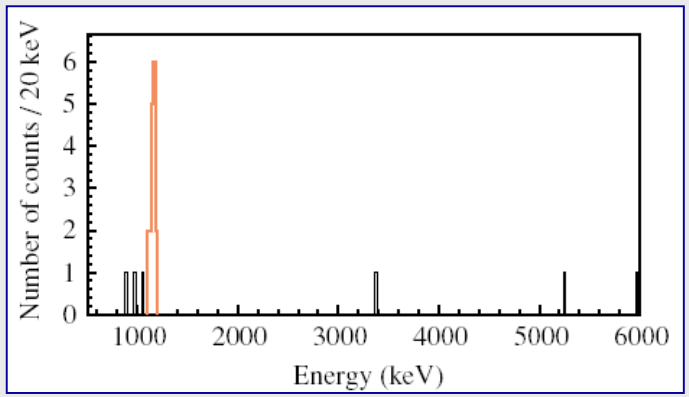
M. P. et al., EPJ A 14 (2002) 279
M. P. et al., NIM A 493 (2002) 155

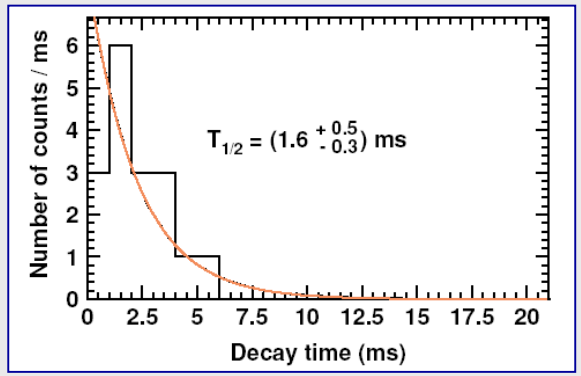
GANIL: fragmentation of ^{58}Ni beam @ 75 MeV/u

22 ^{45}Fe ions implanted in a Si strip detector

J. Giovinazzo et al., PRL 89 (2002) 102501

2nd GANIL experiment: C. Dossat et al., PRC 72 (2005) 054315





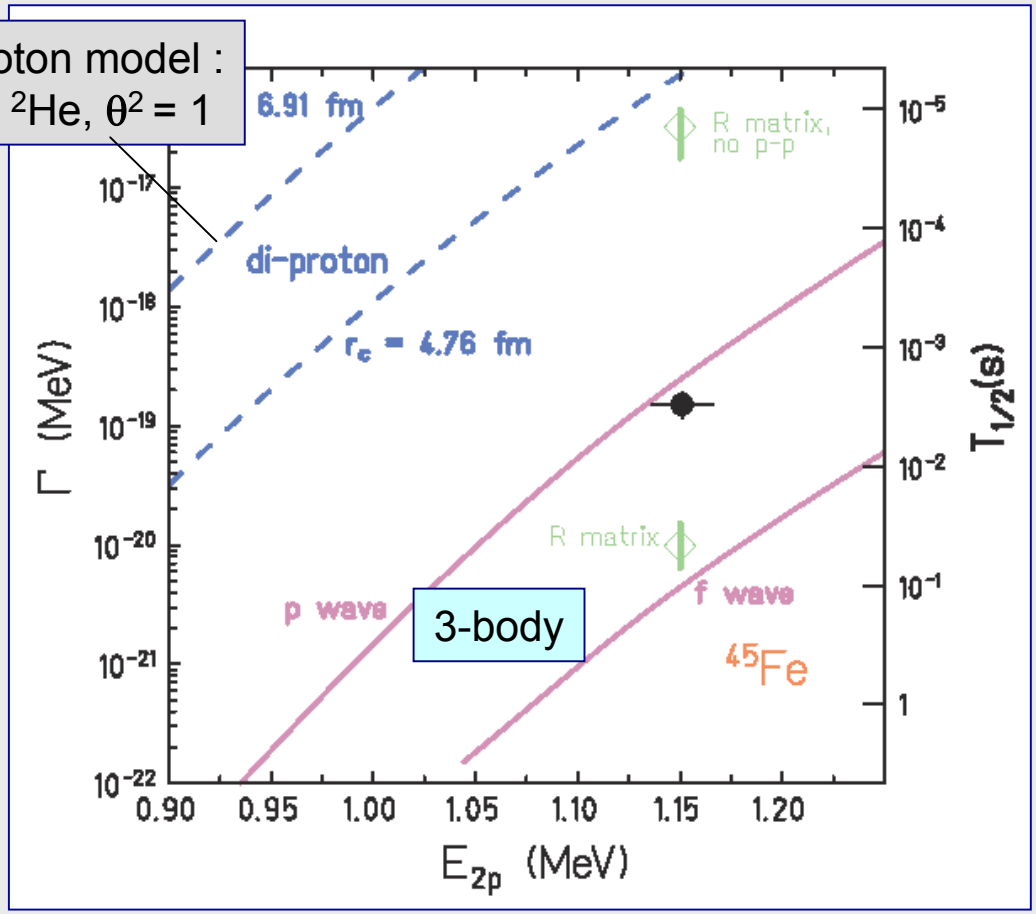
	2*p* decay energy (MeV)	Half-life (ms)	Branching ratio	Partial half-life (ms)
Giovinazzo *et al.* [5]	1.140 ± 0.040	$4.7^{+3.4}_{-1.4}$	0.55 ± 0.12	$8.5^{+6.4}_{-3.2}$
Pfützner *et al.* [6]	1.1 ± 0.1	$3.2^{+2.6}_{-1.0}$	$0.80^{+0.15}_{-0.25}$	$4.0^{+3.3}_{-1.8}$
This work	1.154 ± 0.016	$1.6^{+0.5}_{-0.3}$	0.57 ± 0.10	$2.8^{+1.0}_{-0.7}$
Average	1.151 ± 0.015	$1.75^{+0.49}_{-0.28}$	0.59 ± 0.07	$3.0^{+0.9}_{-0.6}$

$T_{1/2}$ predictions for ^{45}Fe

3-body : L.V. Grigorenko, I.G. Mukha, M.V. Zhukov, NP A714 (2003) 425

R-matrix : B.A. Brown, F.C. Barker, PRC 67 (2003) 041304(R)

simple diproton model :
a pointlike ^2He, $\theta^2 = 1$

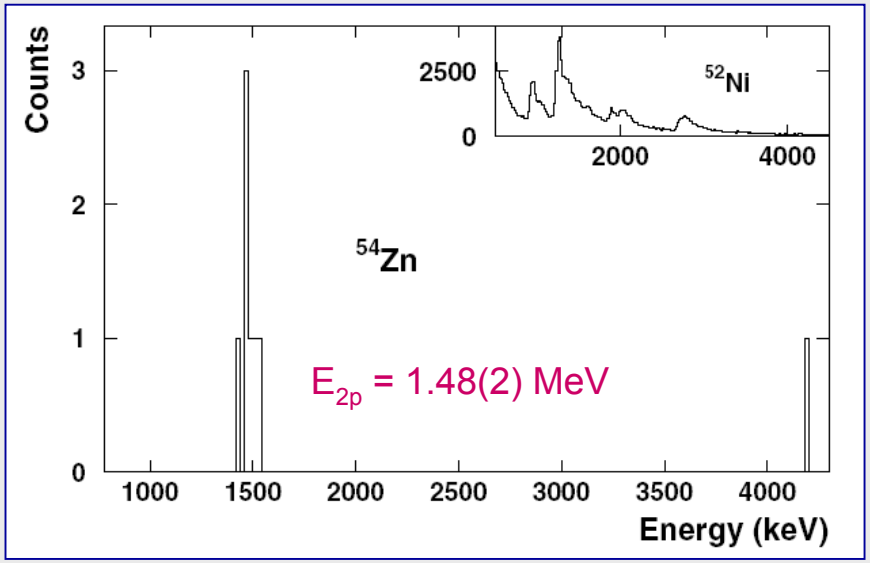


C. Dossat et al., PRC 72 (2005) 054315

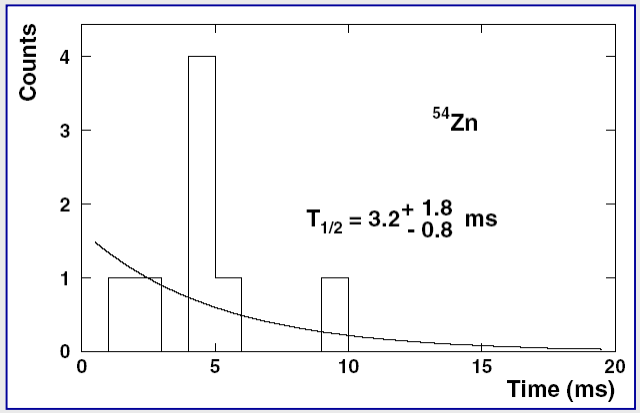
Decay of ^{54}Zn

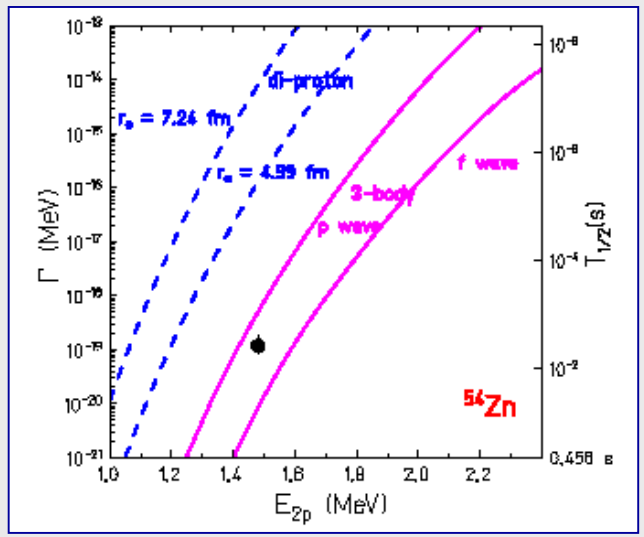
GANIL: fragmentation of ^{58}Ni beam @ 75 MeV/u

8 ^{54}Zn ions implanted in a Si strip detector



B. Blank et al., PRL 94 (2005) 232501



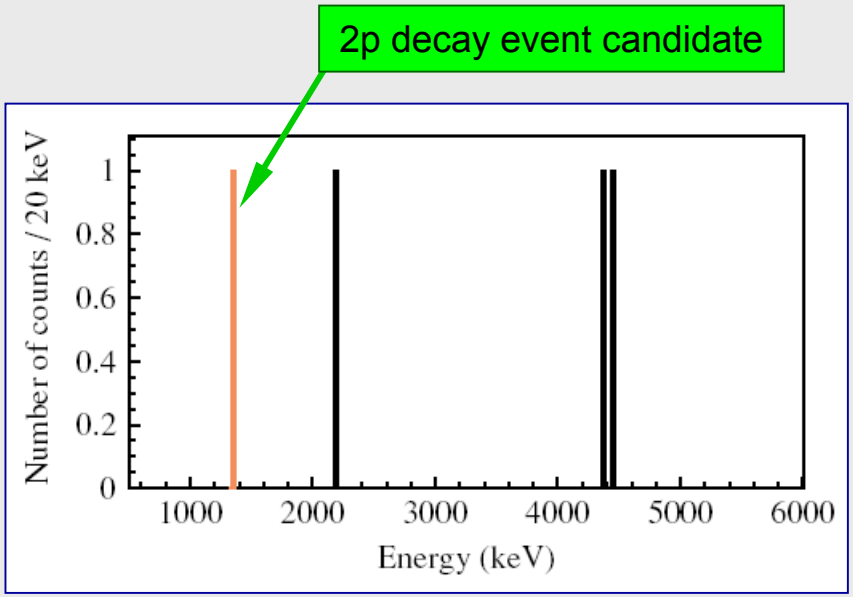


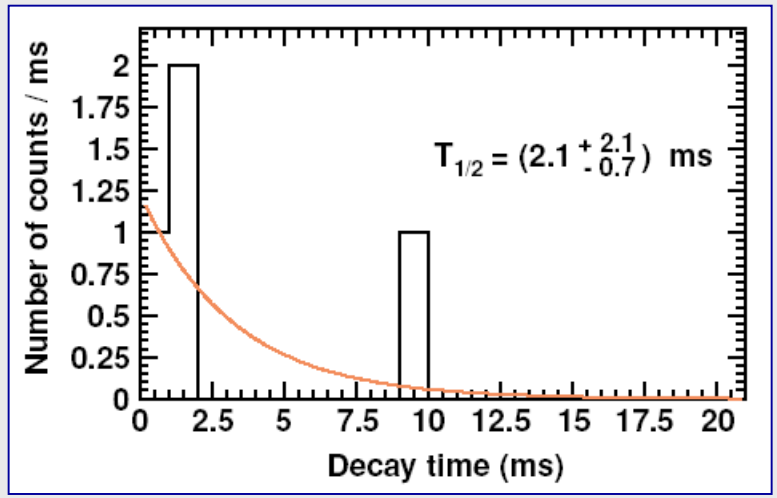
Is ^{48}Ni a 2p emitter?

GANIL: fragmentation of ^{58}Ni beam @ 75 MeV/u

4 ^{48}Ni ions implanted in a Si strip detector

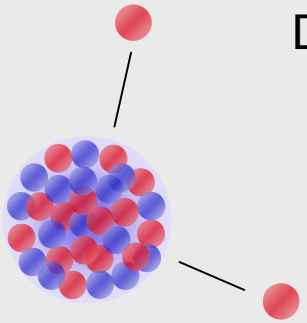
C. Dossat et al., PRC 72 (2005) 054315





Experimental decay energy	Brown [11]	Cole [12]	Ormand [13]	Ormand [14]	Nazarewicz *et al.* [25]
1.35 ± 0.02	1.36 ± 0.13	1.35 ± 0.06	1.14 ± 0.21	1.29 ± 0.33	0.0–2.0

The experimental challenge

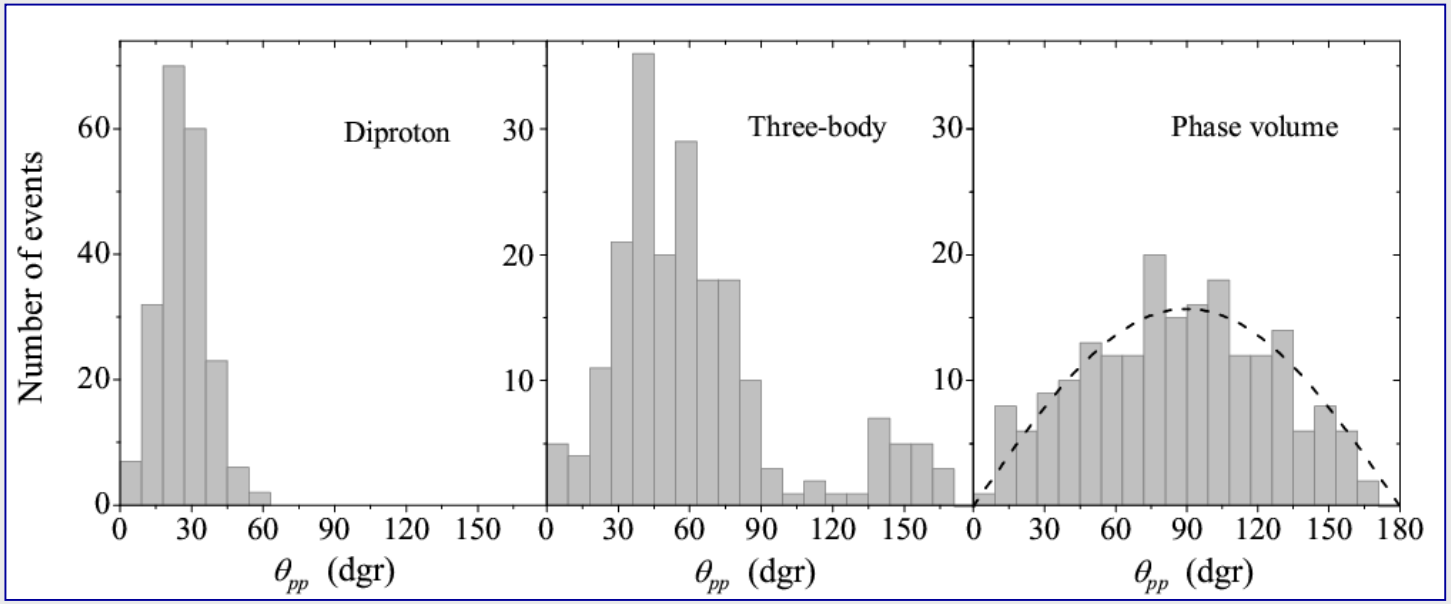


Detect both protons separately, measure their energies and determine their angular distribution

The aim of the NSCL exp. #05016

Competition with the Bordeaux group!

Predicted 2p opening angle for ^{45}Fe



L. Grigorenko : simulation for 200 events

A possible solution

The first idea: W. Dominik at IFD Symposium 13-14 XII 2002

G. Charpak et al., NIM A269 (1988) 142

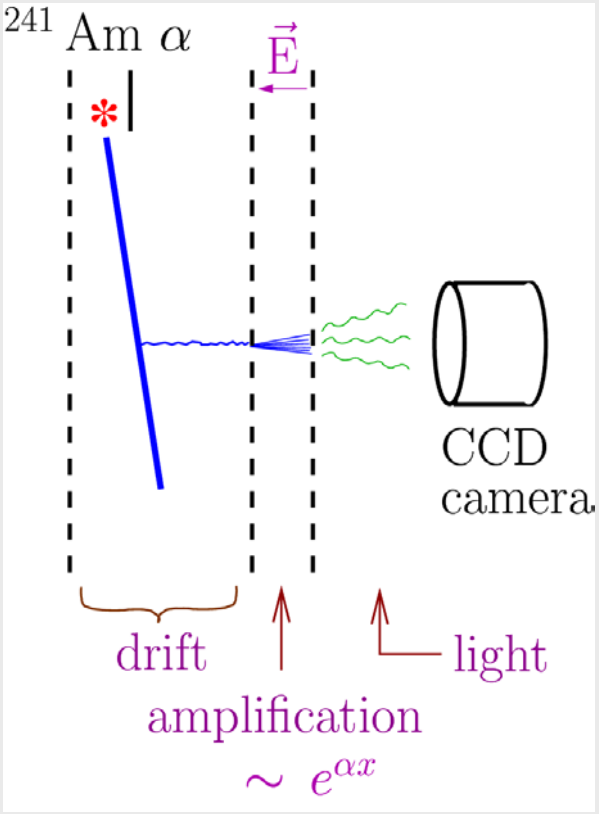
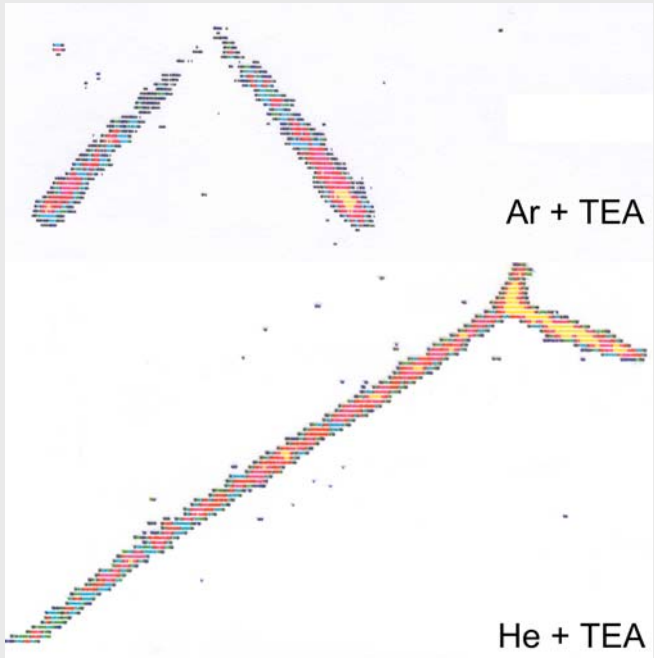
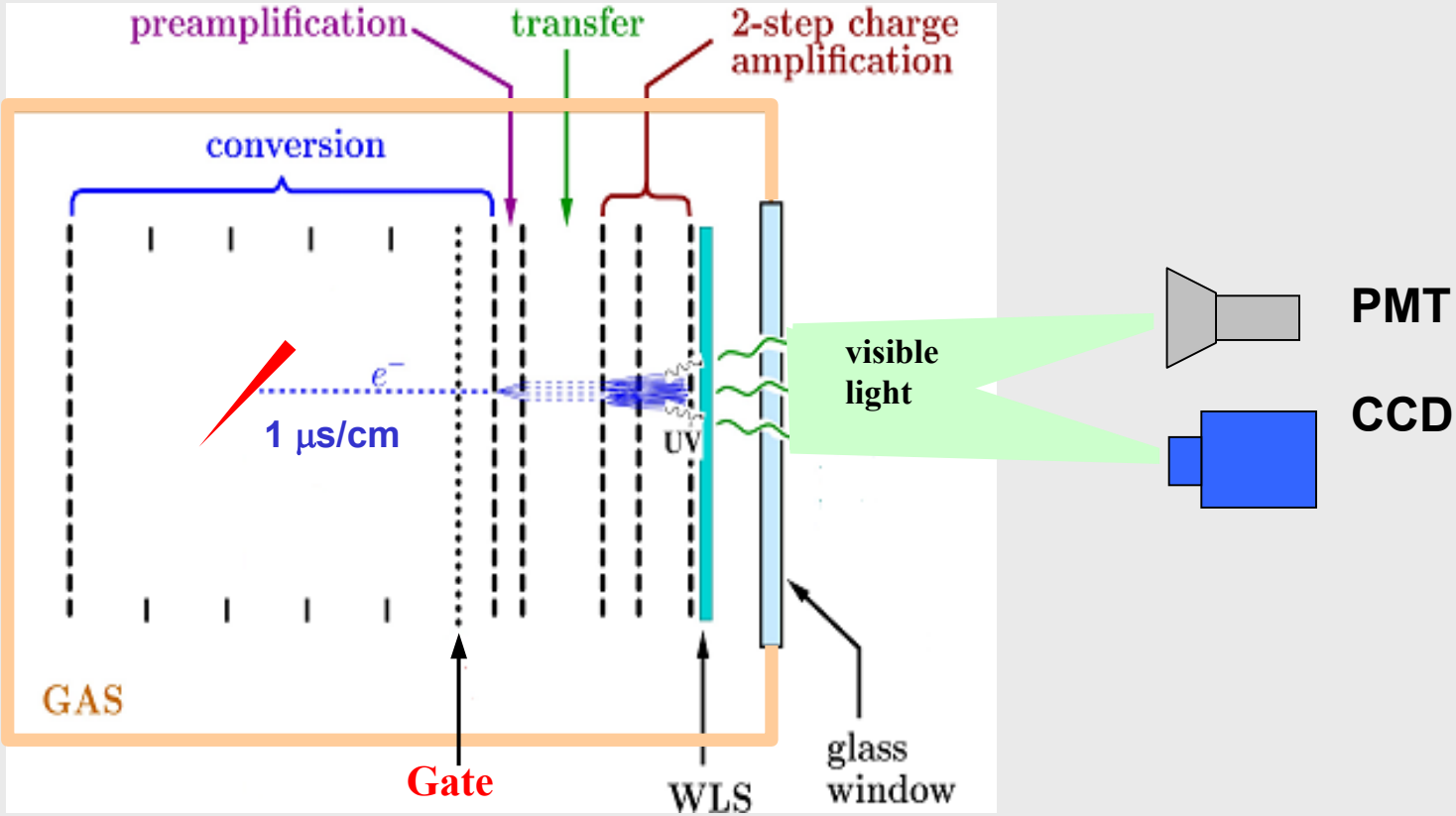


Image examples of α-particle tracks



TEA = Triethylamine $N(C_2H_5)_3$

Optical Time Projection Chamber



1 atm. gas: 49 % He + 49 % Ar + 1 % N2 + 1 % CH_4

M. Ćwiok et al., IEEE TNS, 52 (2005) 2895

The prototype

Chamber active volume:

20 x 20 x 15 cm^3

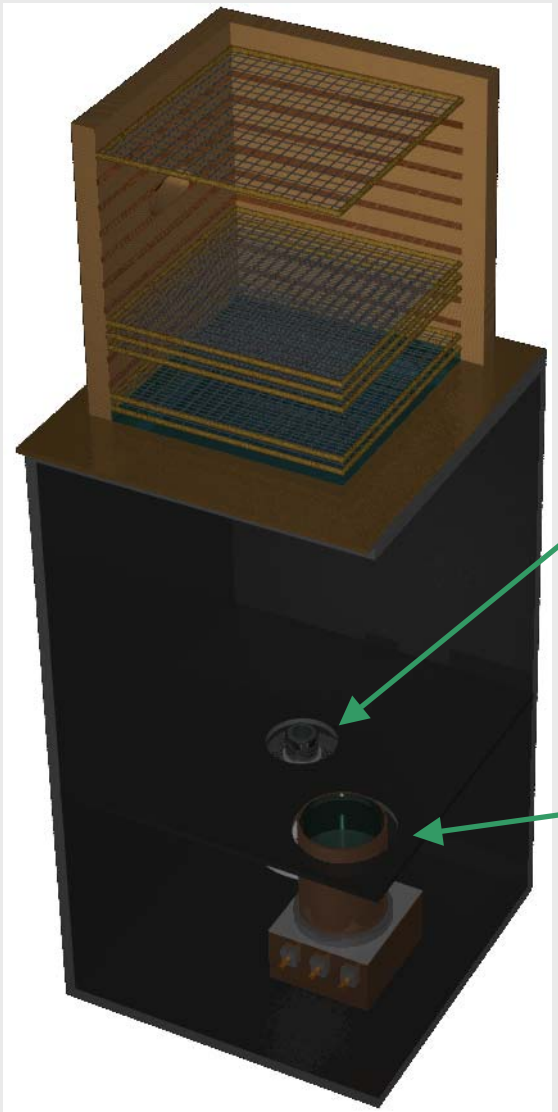
Materials used:

Stesalit fibreglass

PCB plates

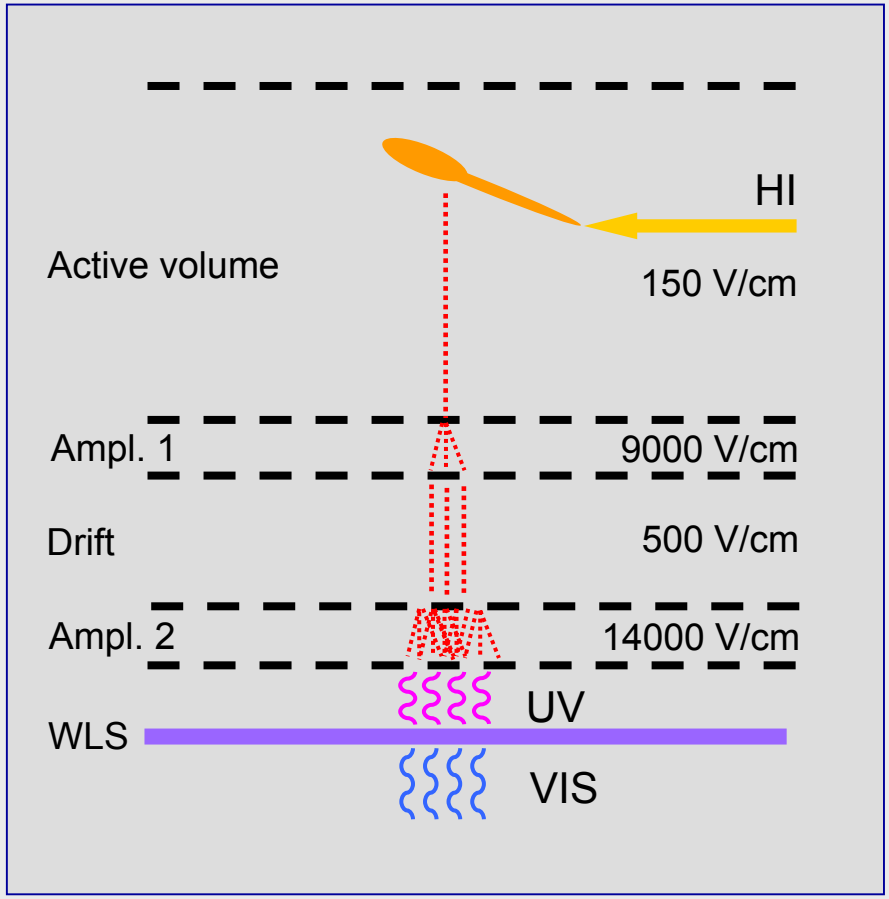
Pyrex optical window

The prototype



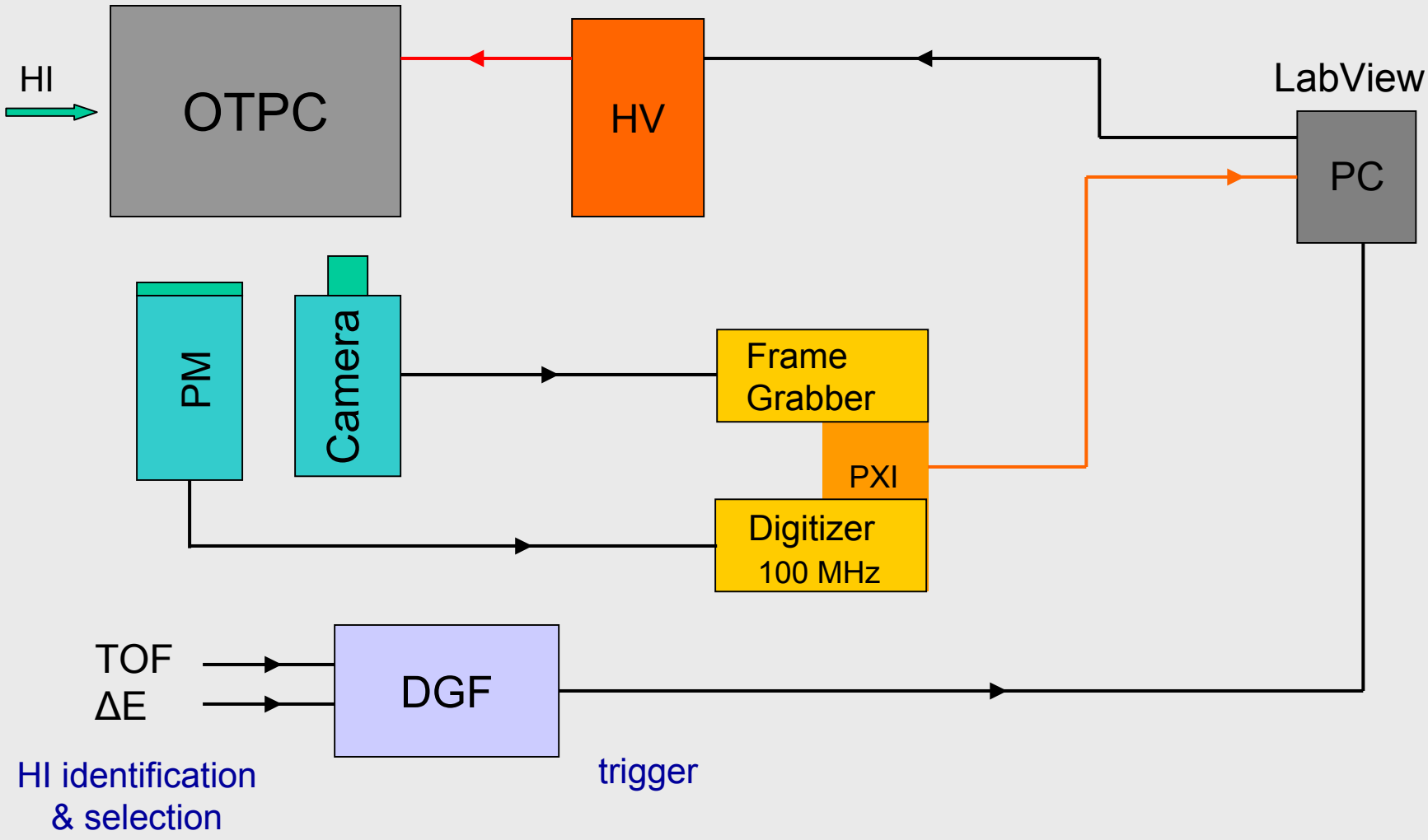
CCD 2/3''
- 1000x1000 pix
- 12-bits
- image ampl. (x2000)

PM 5''

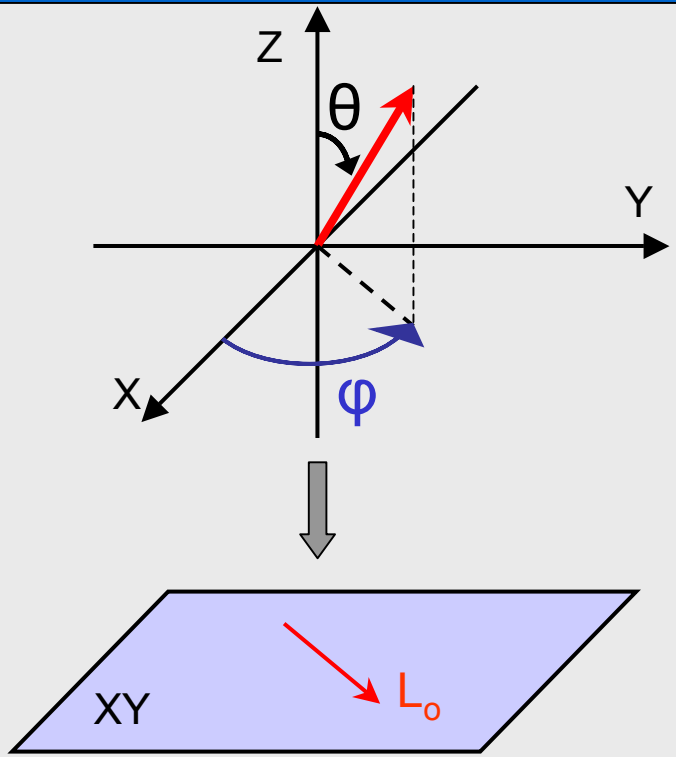


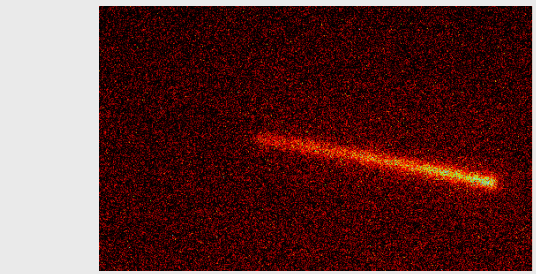
Gas (1 atm) : 49% He + 49% Ar + 1% N_2 + 1% CH_4

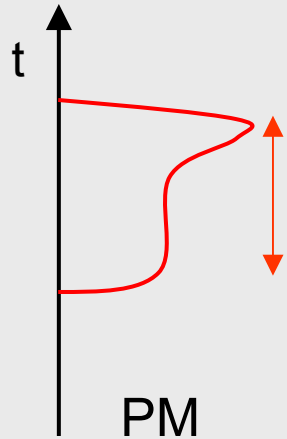
Data acquisition



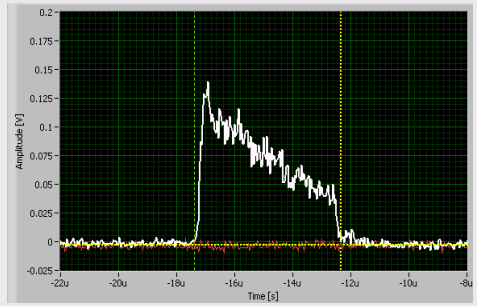
Event reconstruction







$L_{PM} = v_d\, t$



Track coordinates: (r, Θ, φ)

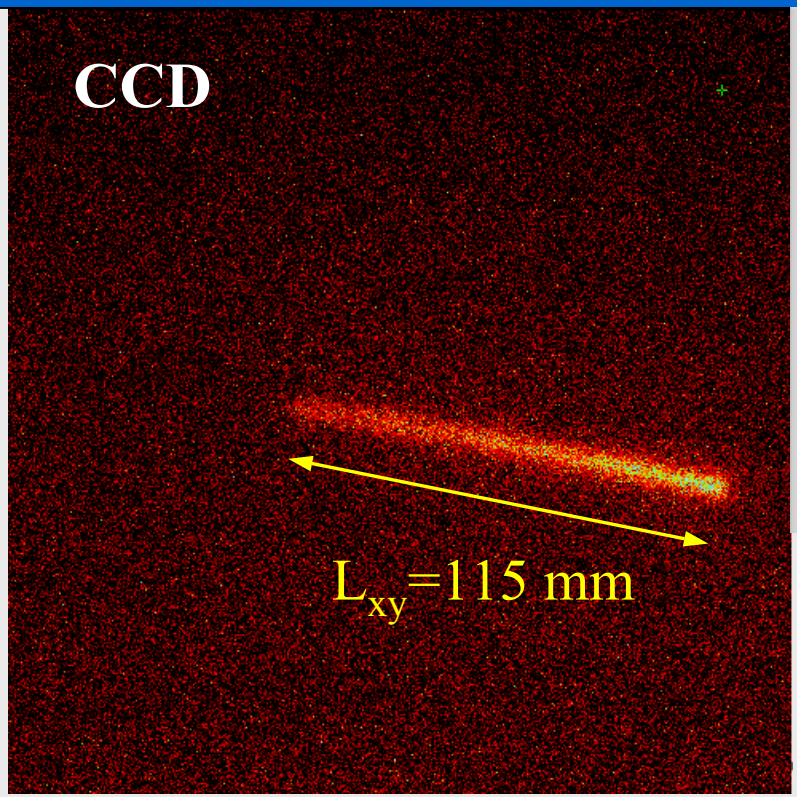
$L_o = r \cos\Theta$

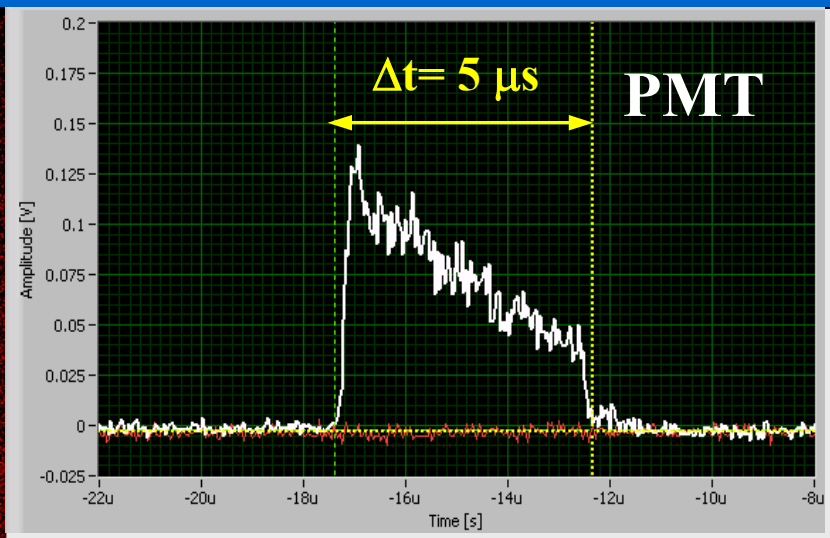
$L_{PM} = r \sin\Theta$

$r^2 = L_o^2 + L_{PM}^2$

$\Theta = \arctan(L_o/L_{PM})$

Example

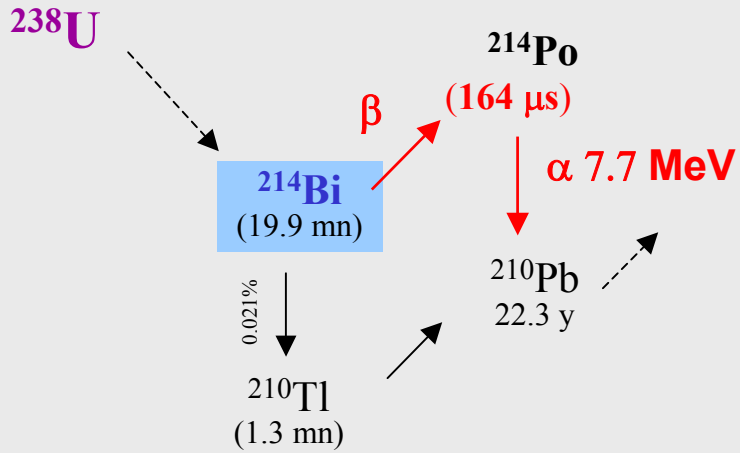




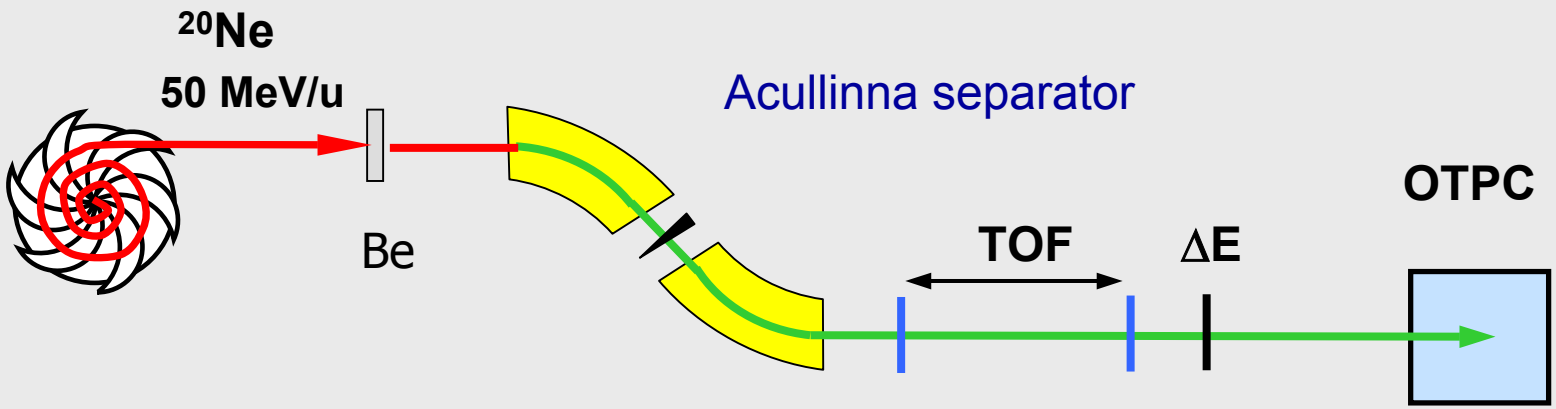
$$L = \sqrt{115^2 + (5 \cdot 10)^2} = 125\,\text{mm}$$

$$\Leftrightarrow \quad E_\alpha = 7.8\,\text{MeV}$$

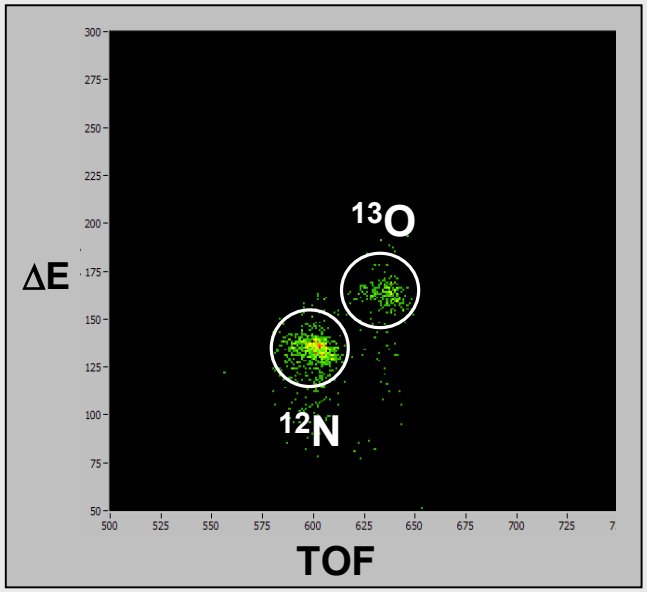
→ ^{214}Po α decay



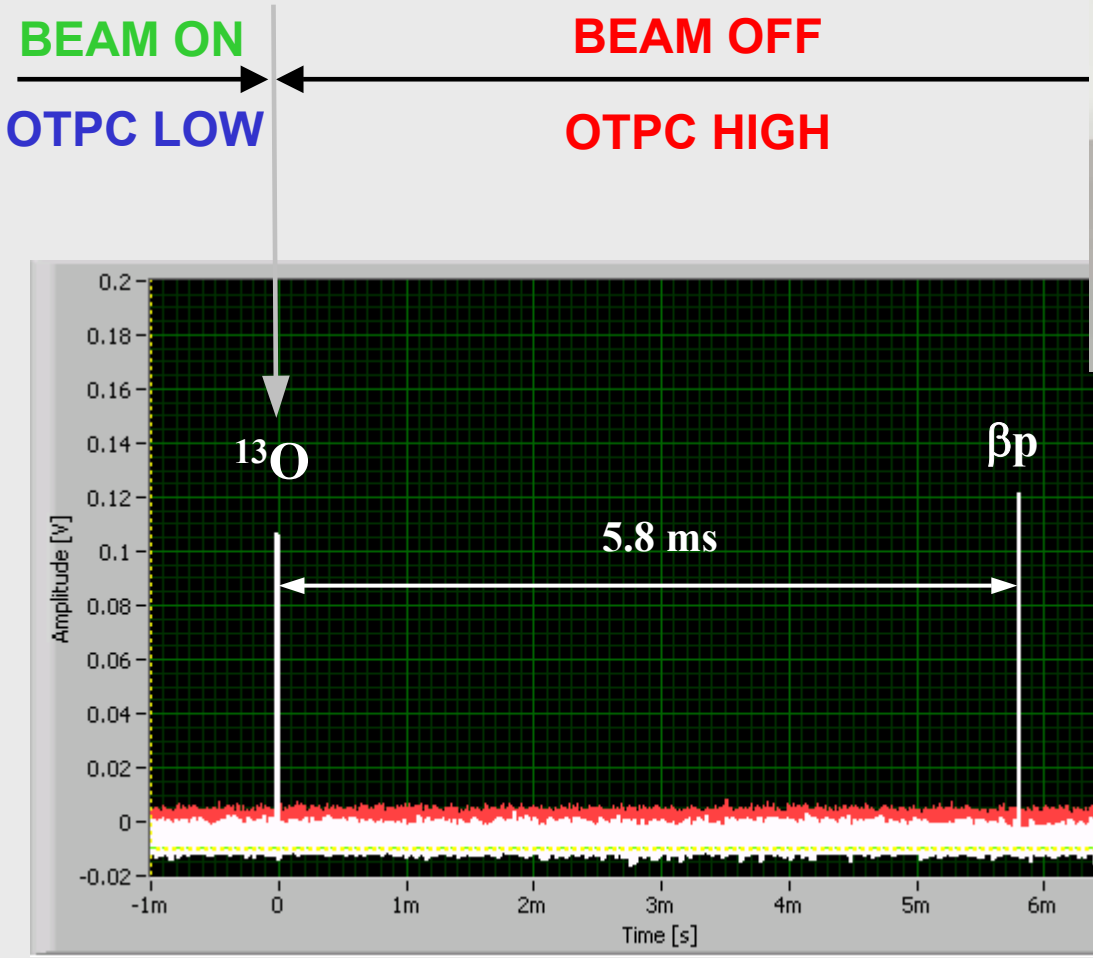
Test at DUBNA



Ion identification

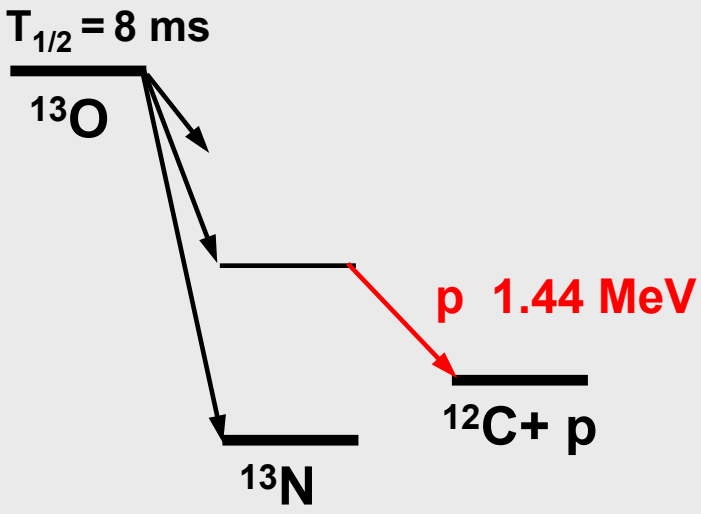


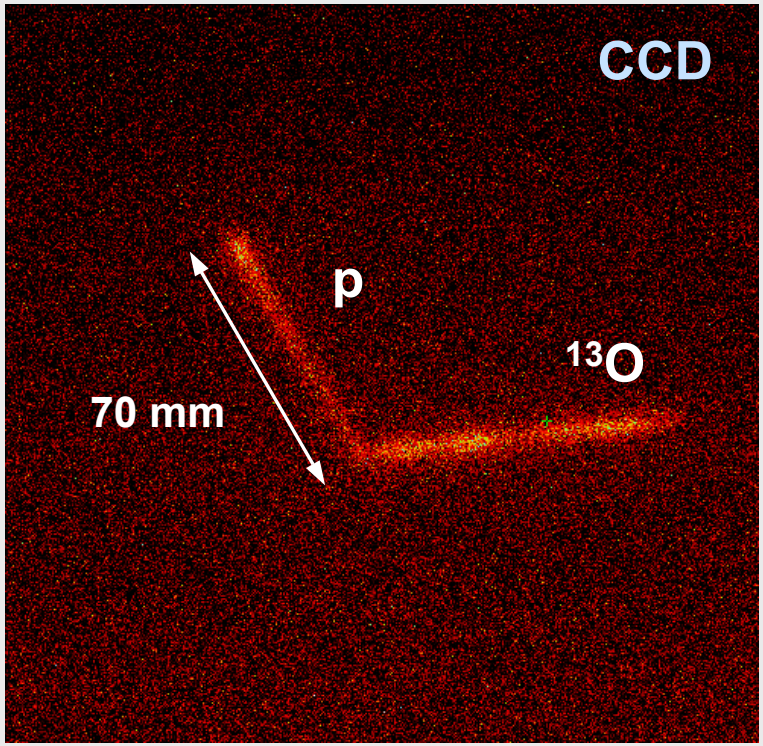
Measurement sequence

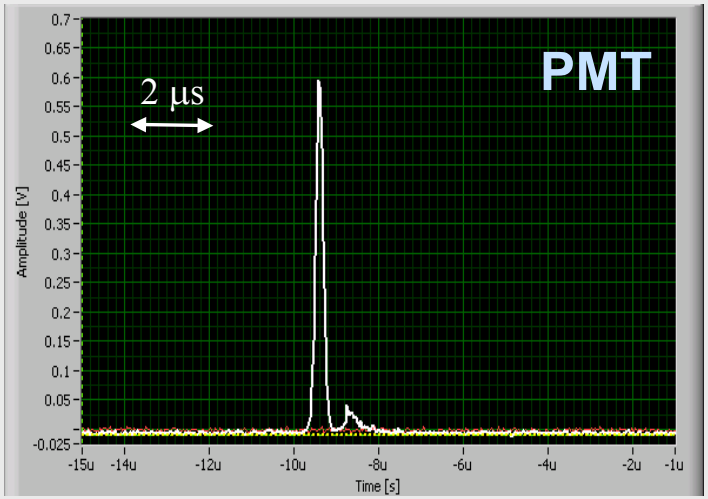


PMT signal

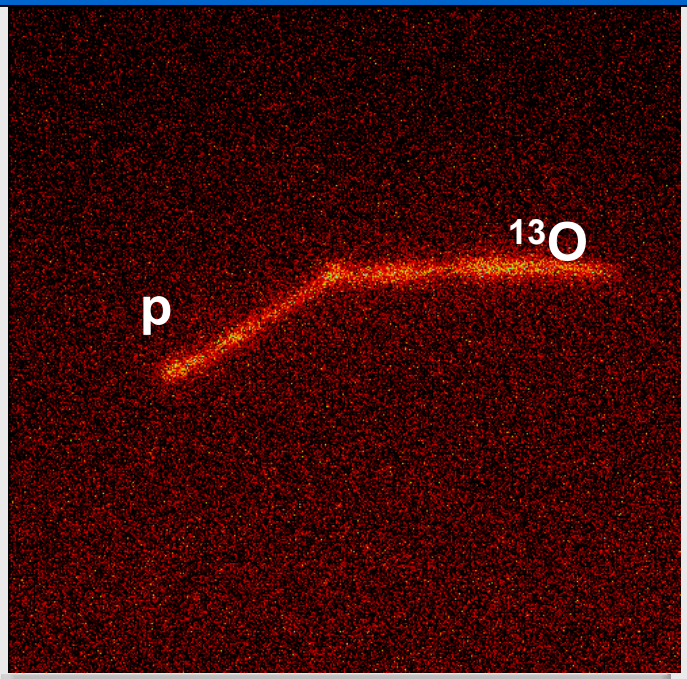
Protons after ^{13}O β decay

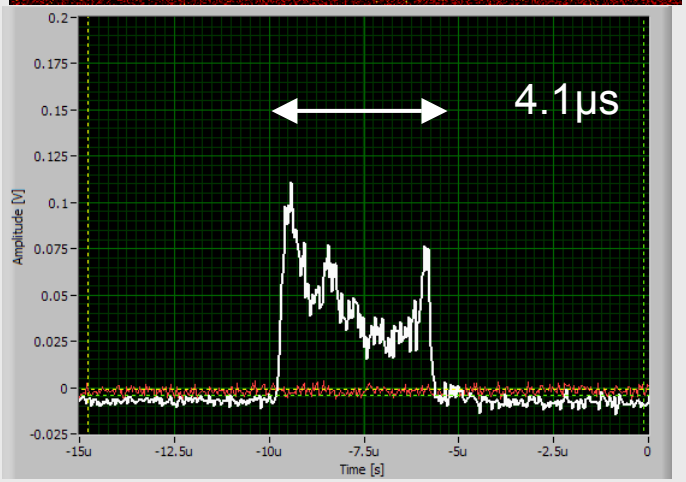


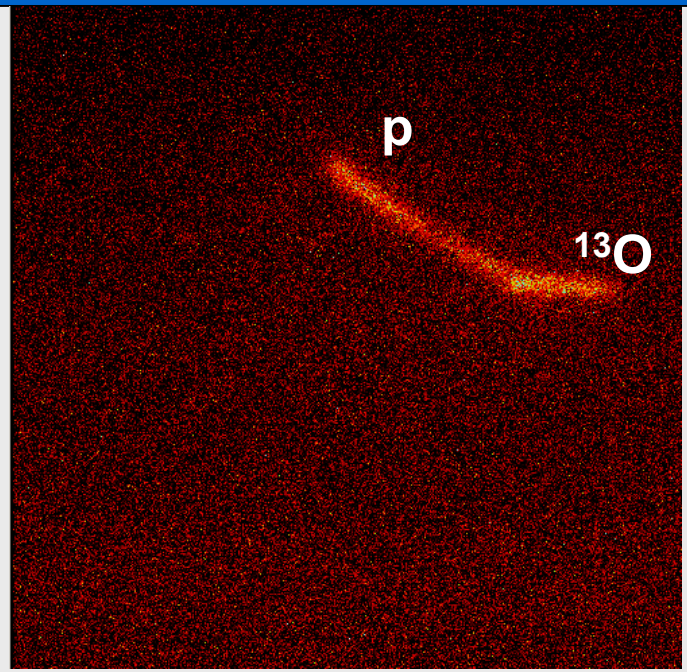


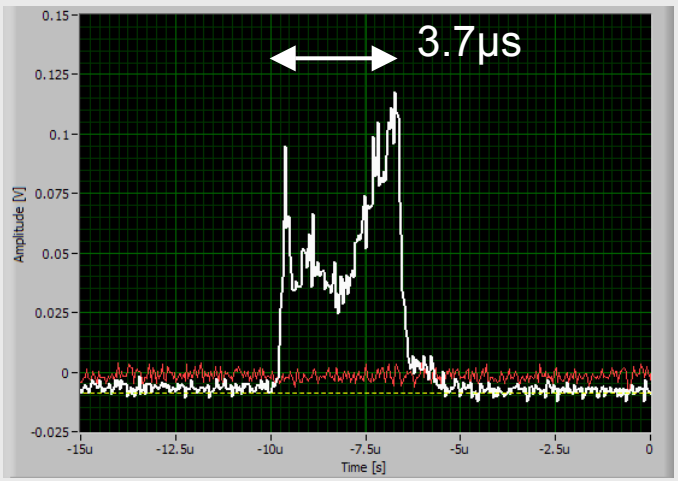


More βp from ^{13}O

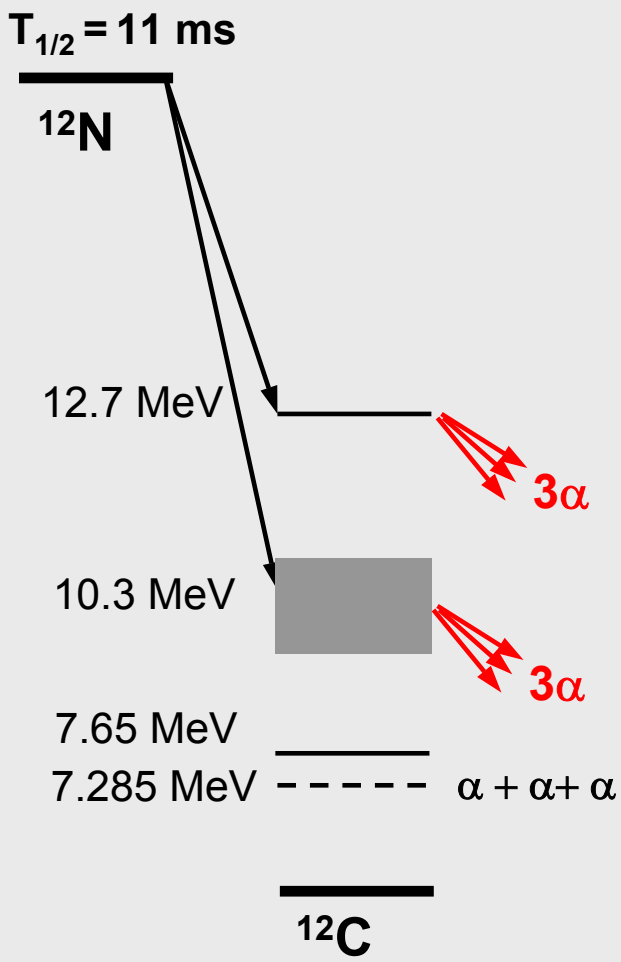


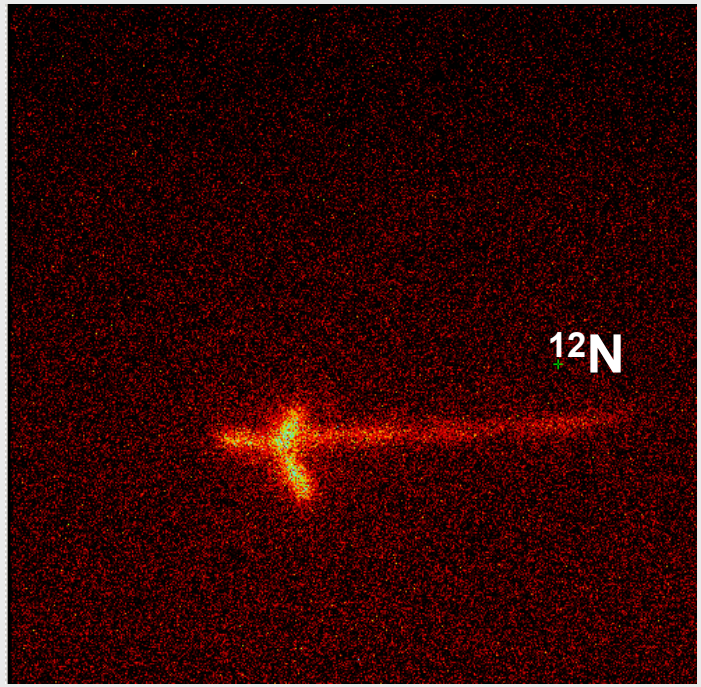


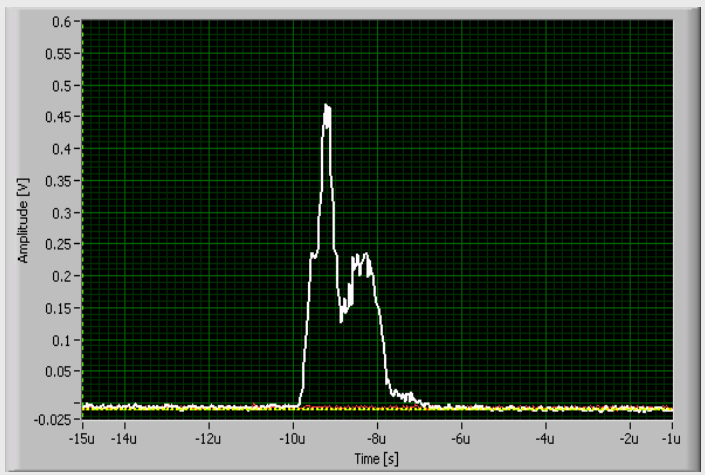




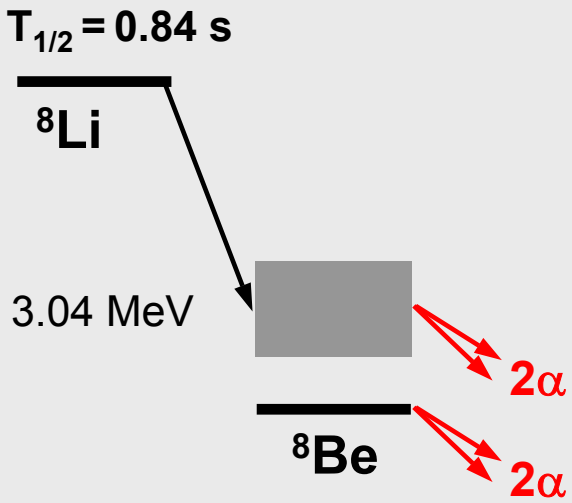
3α decay of $^{12}C^*$

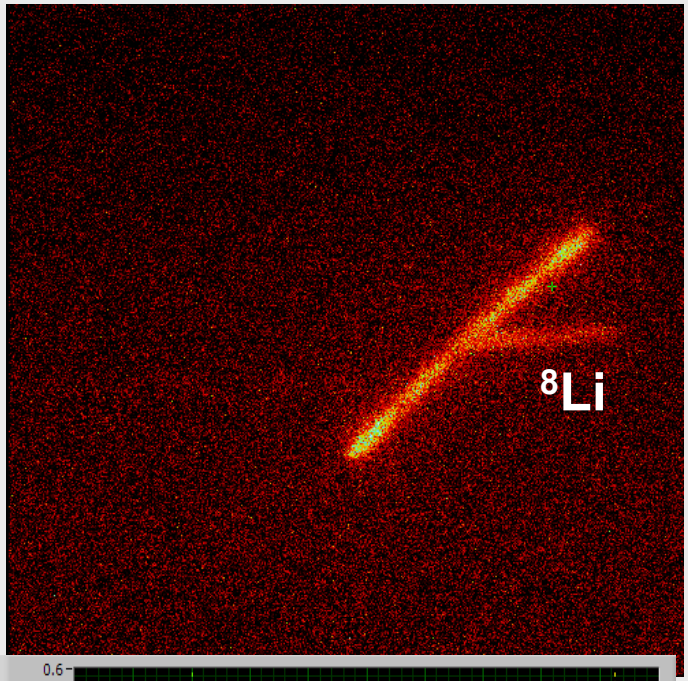


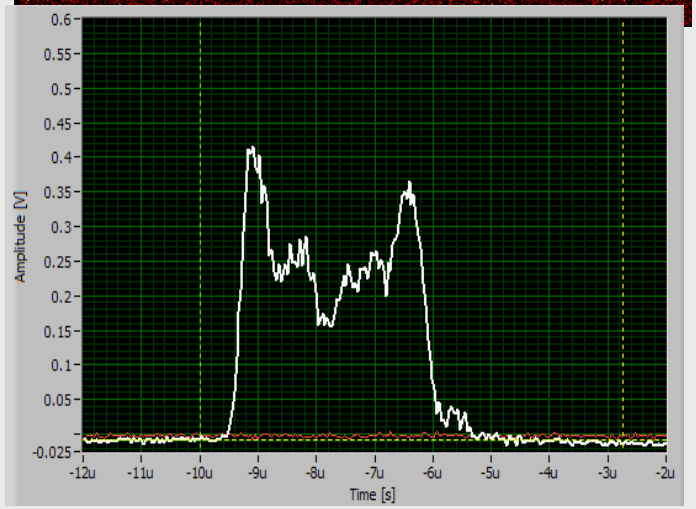




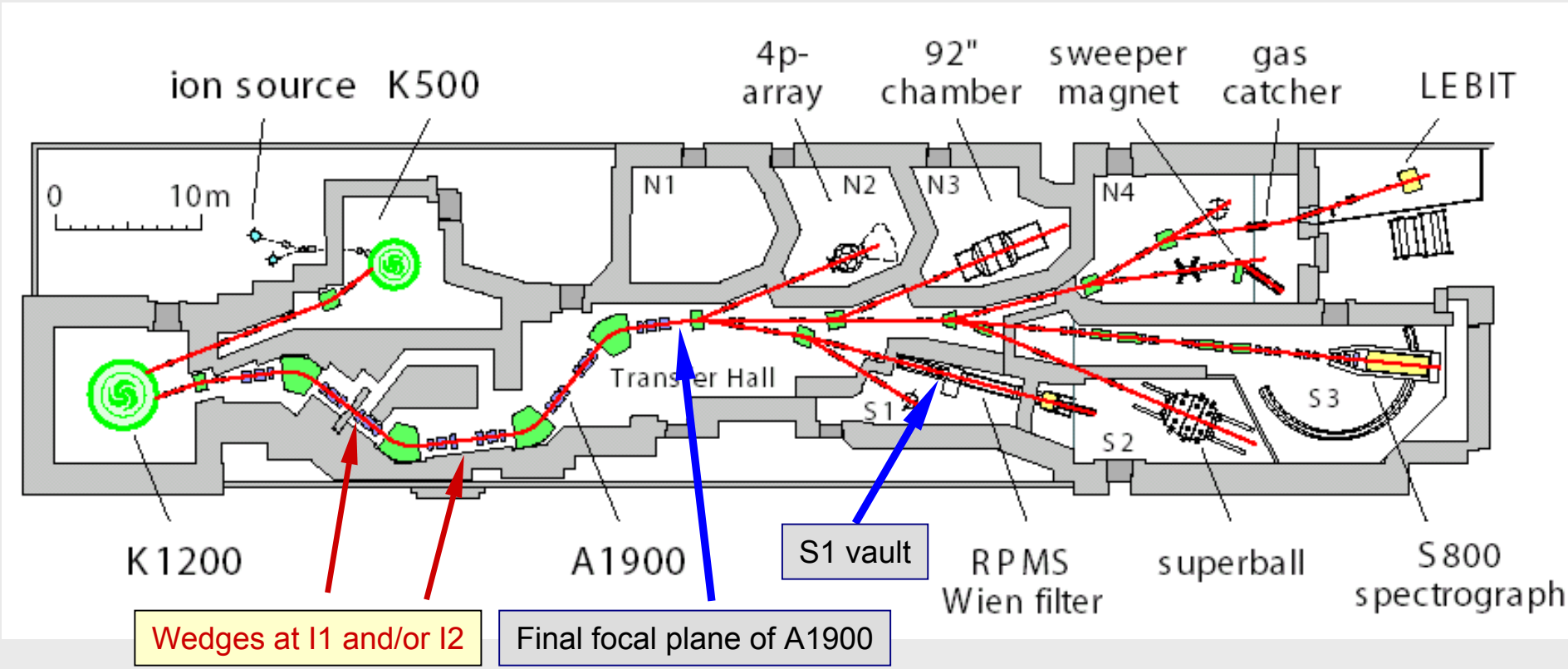
Decay of ^{8}Be


T1/2 = 0.84 s
8Li
3.04 MeV
2α
8Be
2α


8Li


Amplitude [V]
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
-0.025
-12u
-11u
-10u
-9u
-8u
-7u
-6u
-5u
-4u
-3u
-2u
Time [s]

Experiment at NSCL/MSU



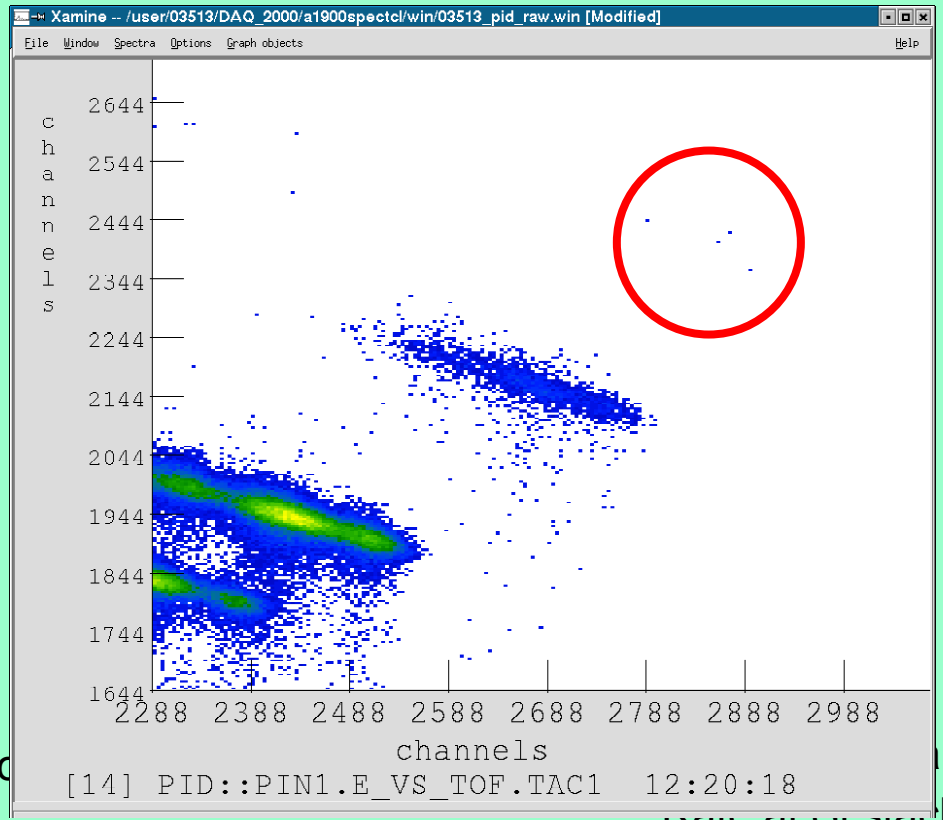
Reaction: ^{58}Ni at 161 MeV/u + ^{nat}Ni → ^{45}Fe

Ion identification in-flight : ΔE + TOF

^{45}Fe production at NSCL

Results of a test measurement, September 2004

Finally : one ^{45}Fe atom per 2 hours @ 7 pnA



A1900 final fo

Rate at Si stack : ≈500 Hz

ult

Rate at Si stack : ≈50 Hz

Rate of ^{43}Cr and ^{45}Fe reduced by a factor of 2

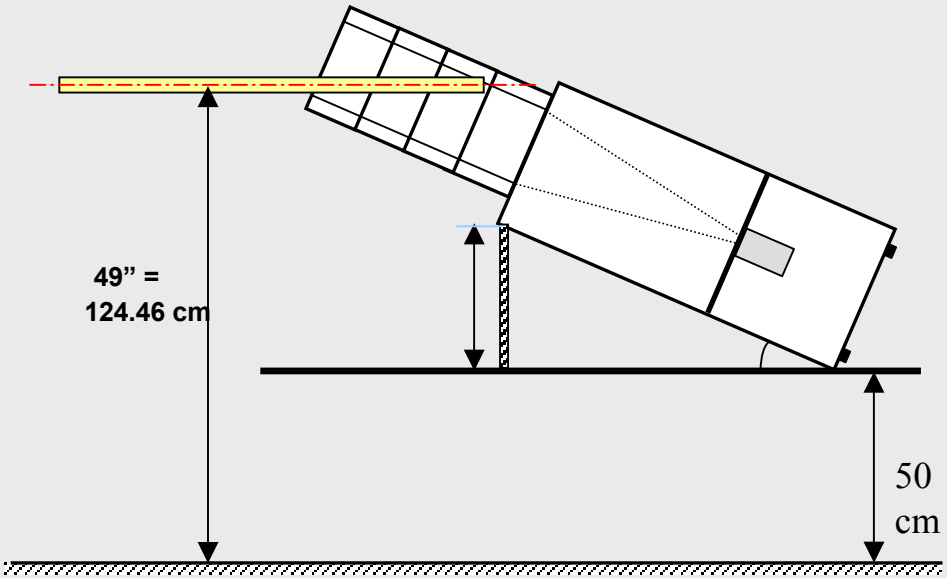
The new „cannon”

Thinner gas:

66% He + 32% Ar + 1% N_2 + 1% CH_4

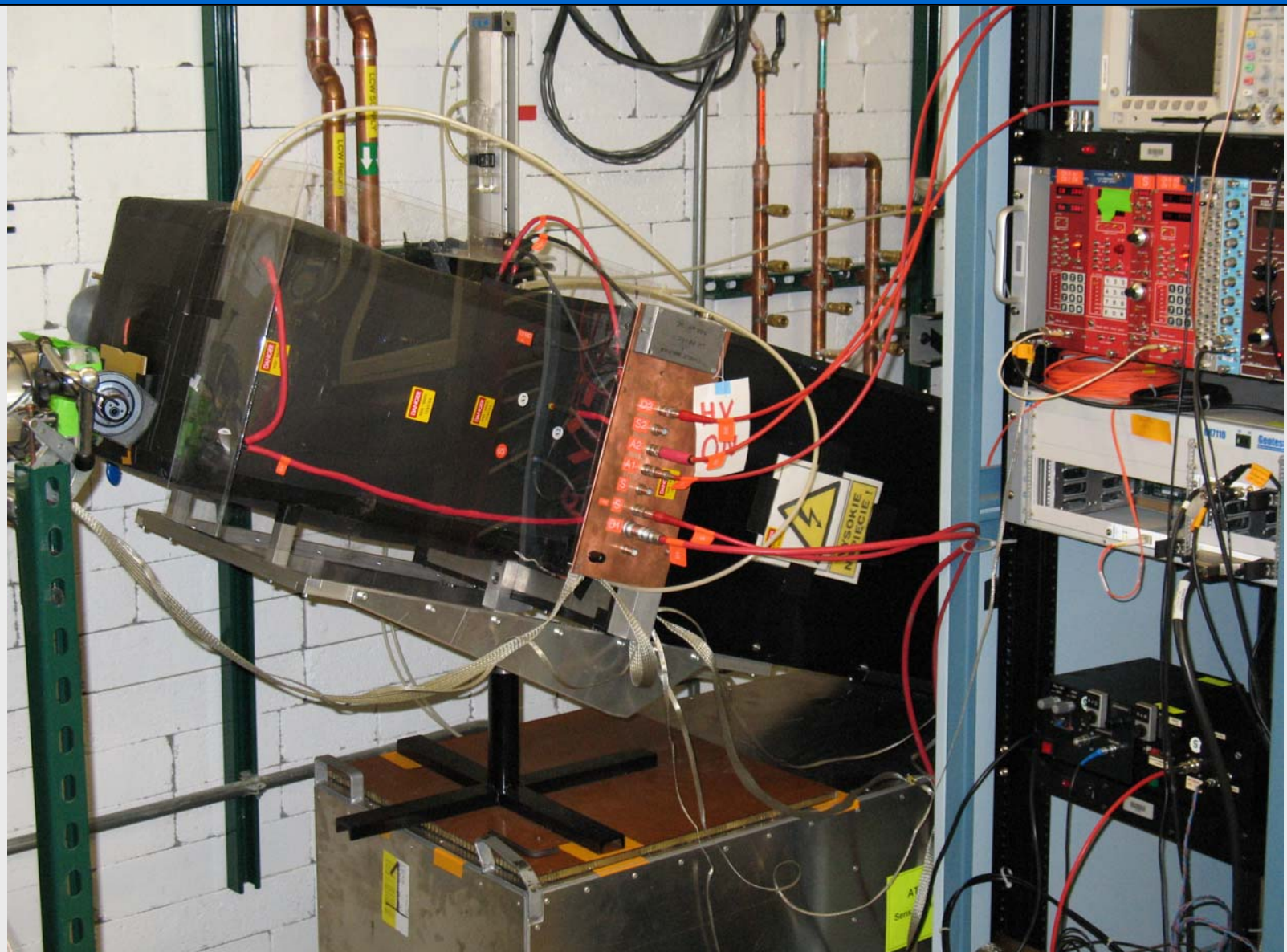
as a compromize for the active length:

- range of 550 keV proton ≈ 2.3 cm
- range of ^{45}Fe ion ≈ 40 cm

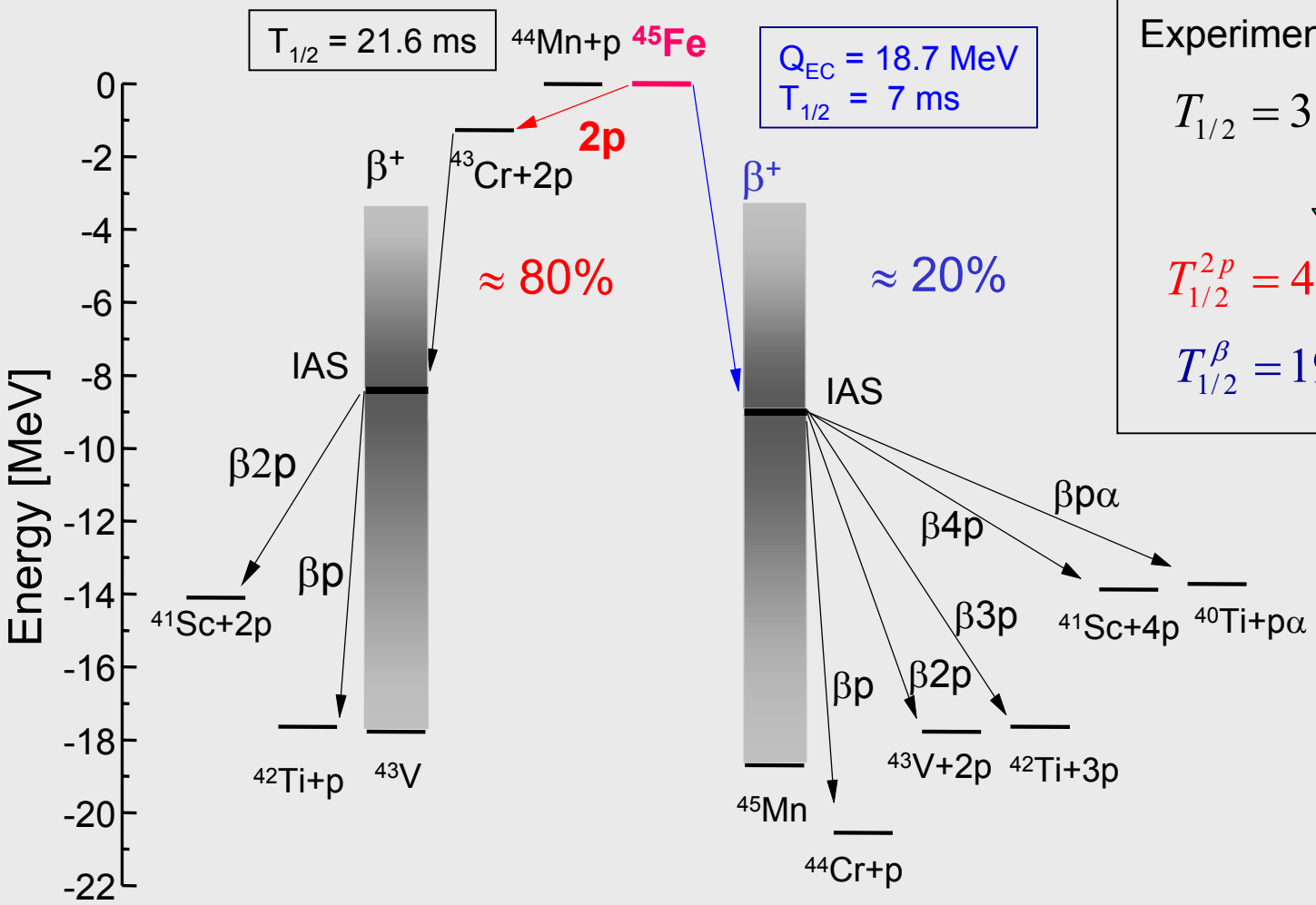


Ready to go!

February 2007



Decay scheme of ^{45}Fe



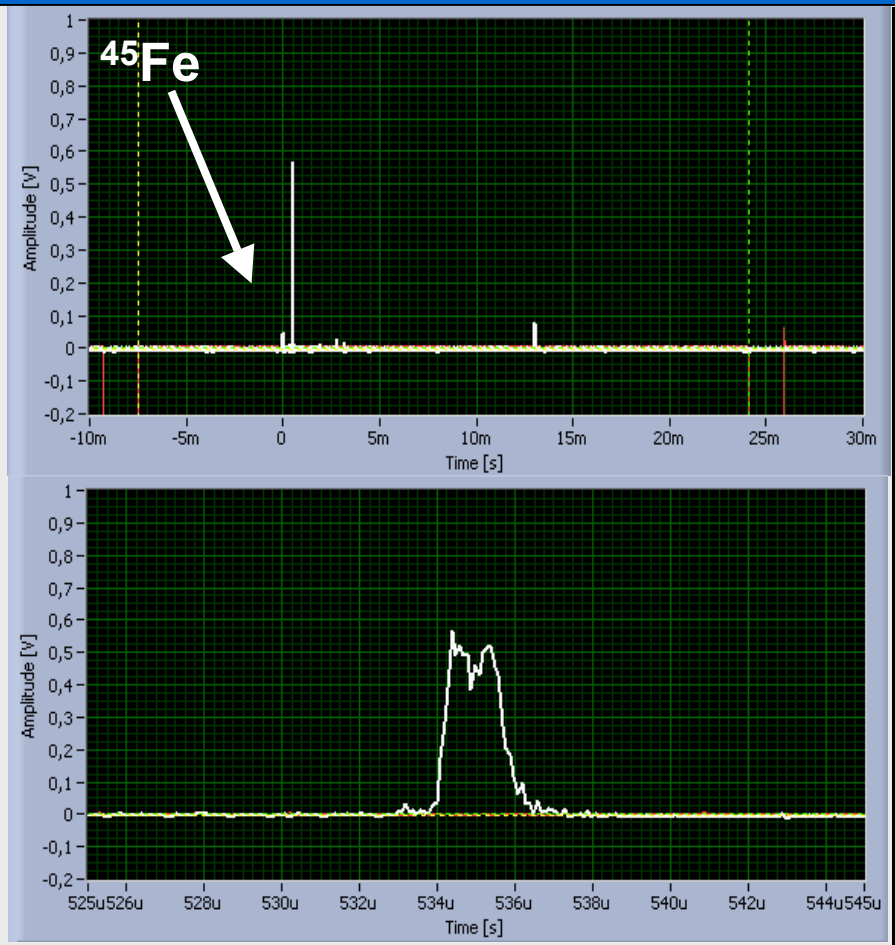
Experimental average :

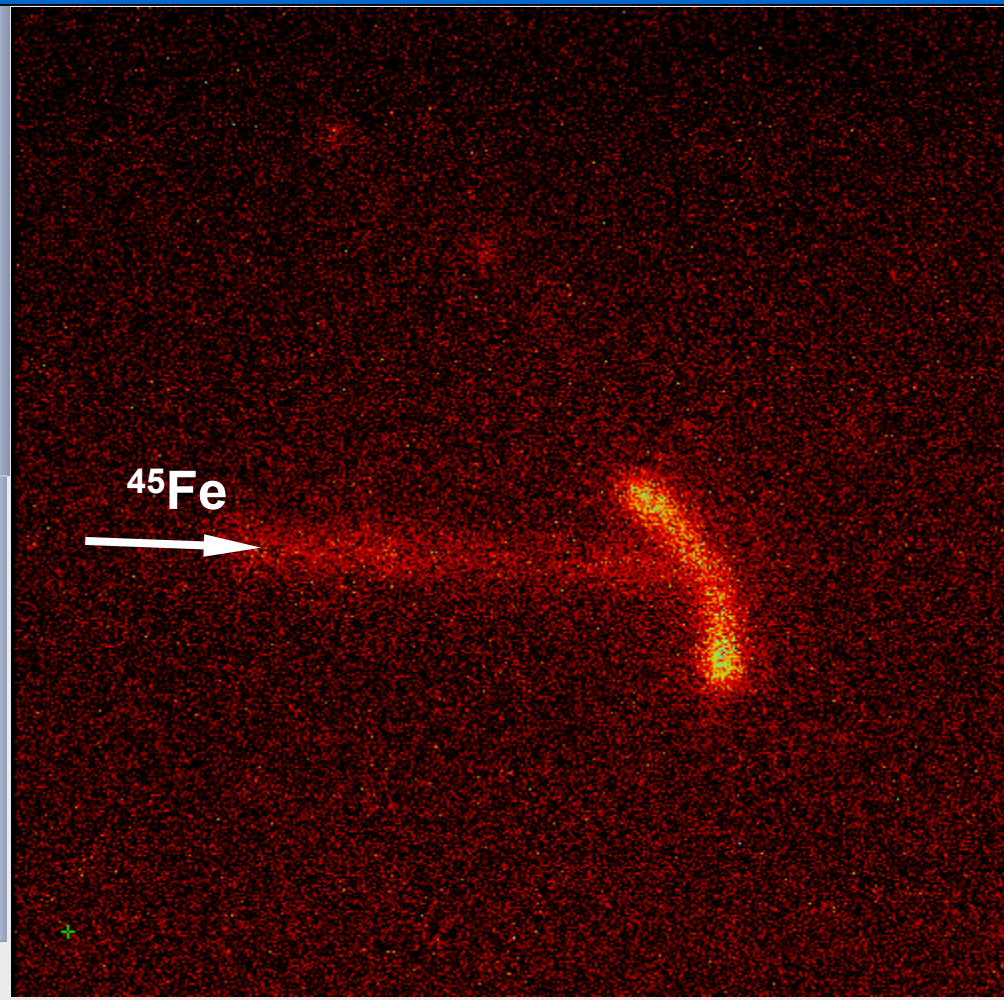
$T_{1/2} = 3.8^{+2.0}_{-0.8}$ ms

$T^{2p}_{1/2} = 4.8^{+2.5}_{-1.0}$ ms

$T^{\beta}_{1/2} = 19^{+10}_{-4}$ ms

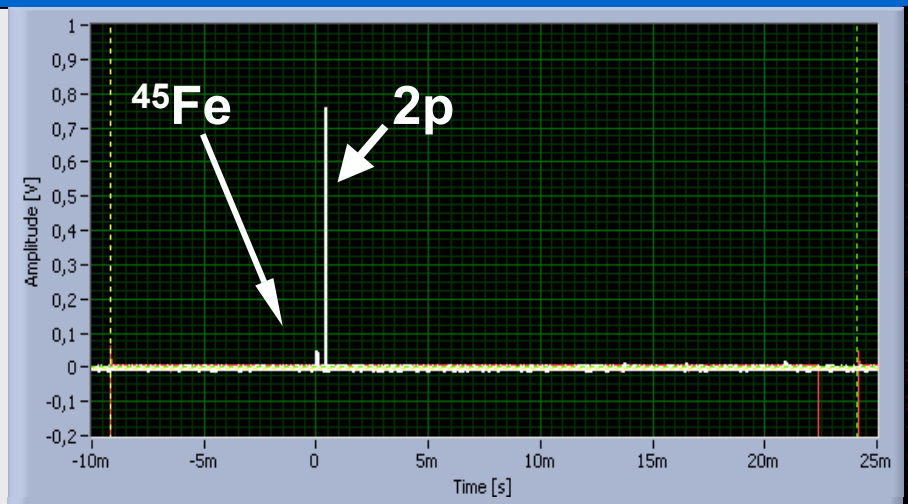
Decay of ^{45}Fe

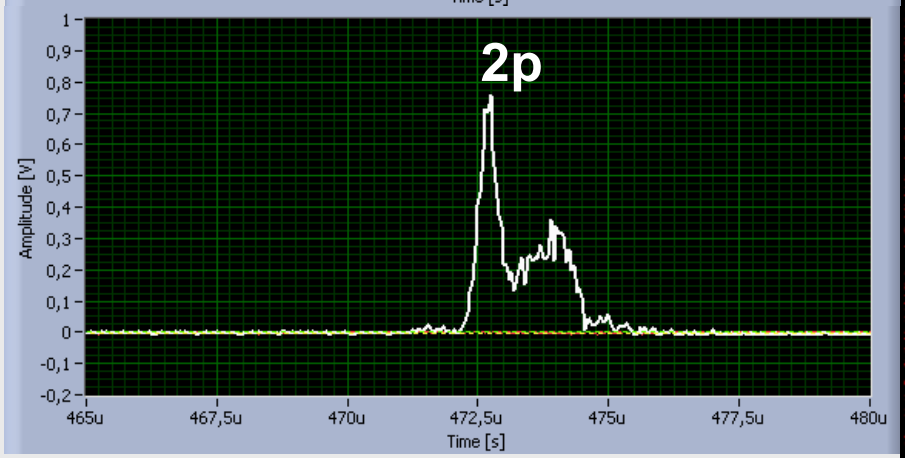


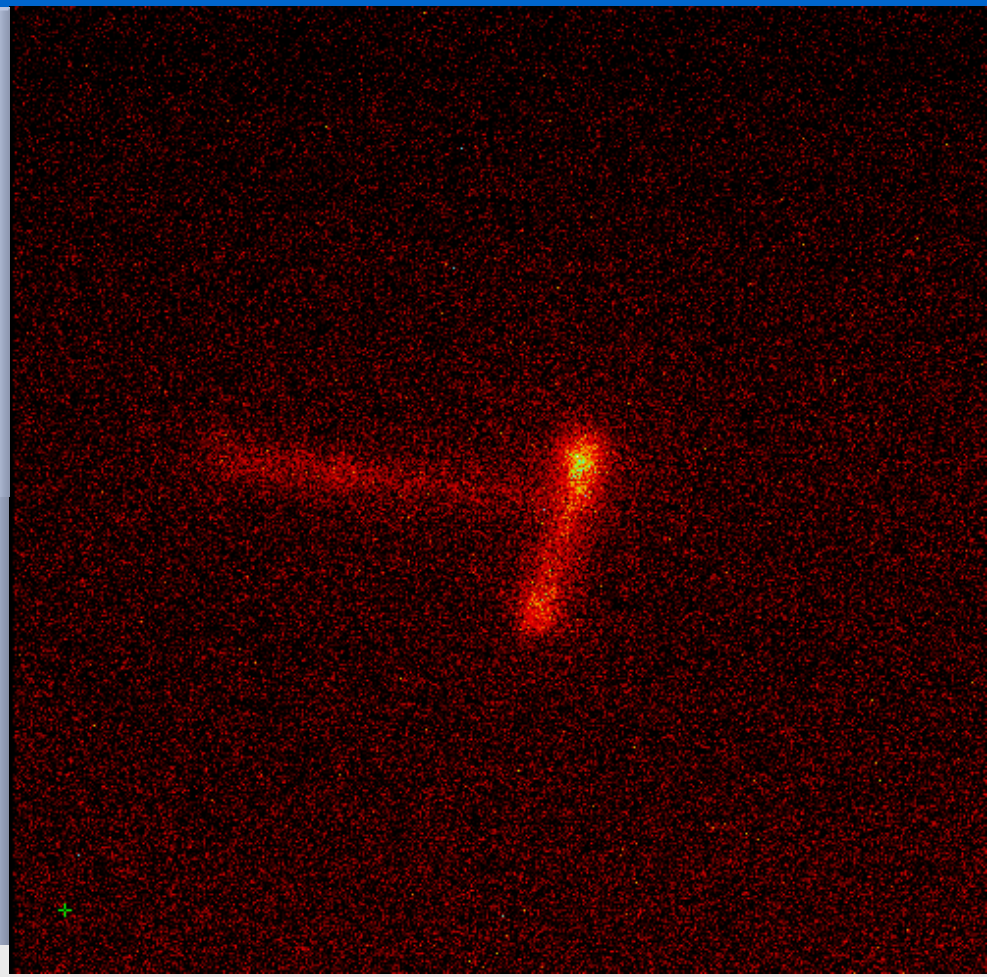


decay 0.53 ms after implantation

Another 2p event

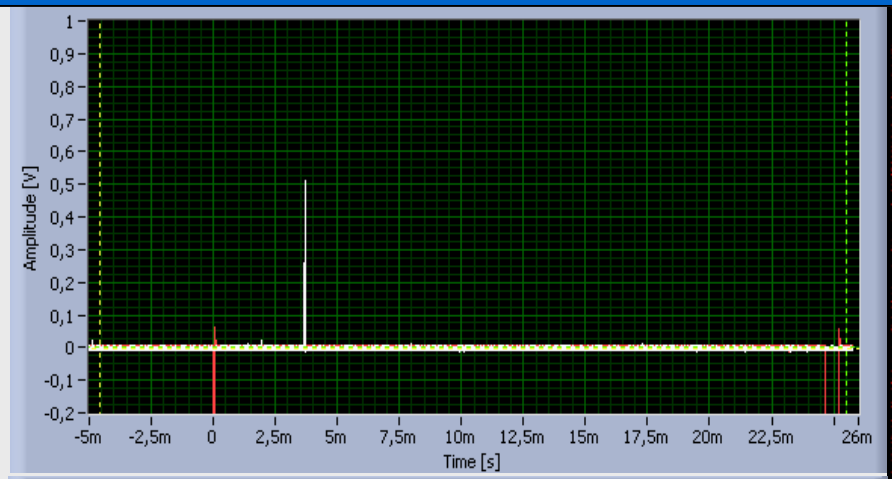


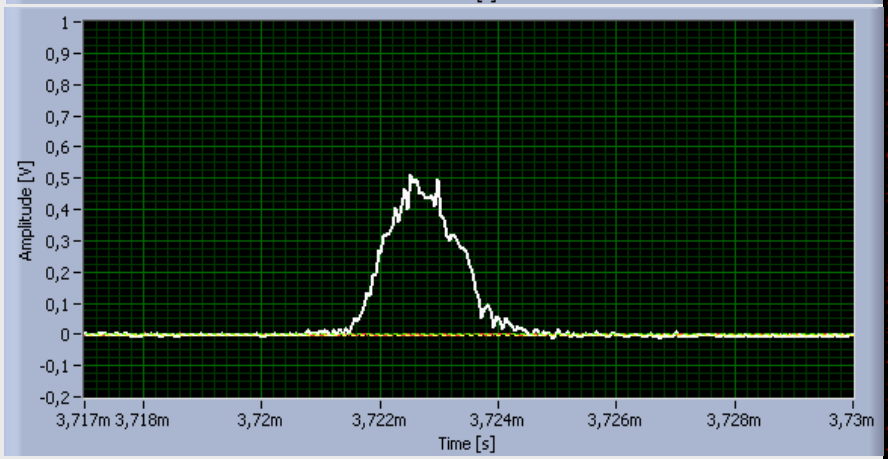


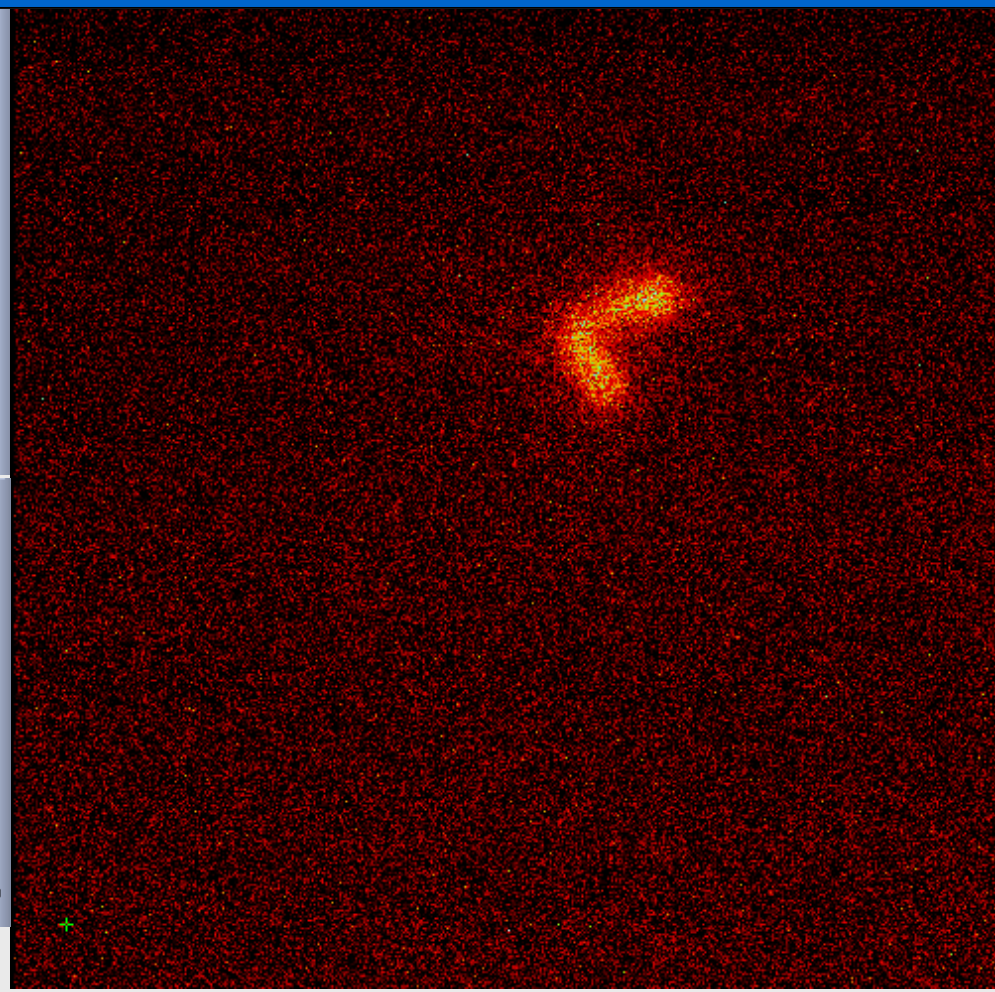


2p decay 0.47 ms after implantation

2p event in the triggering mode

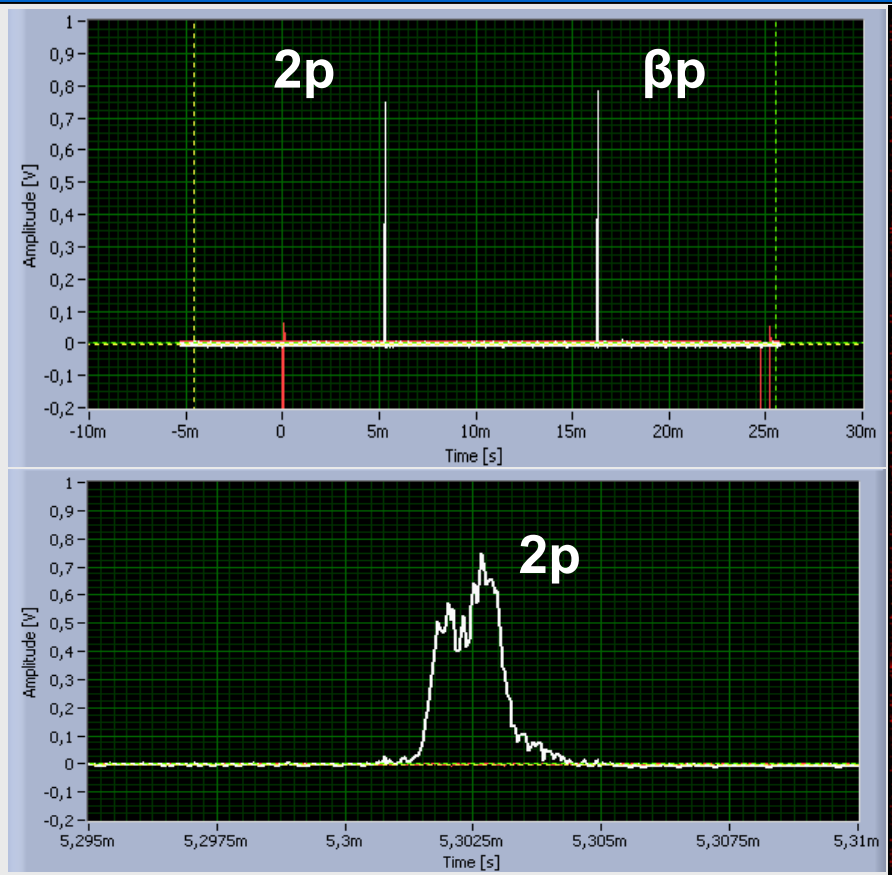


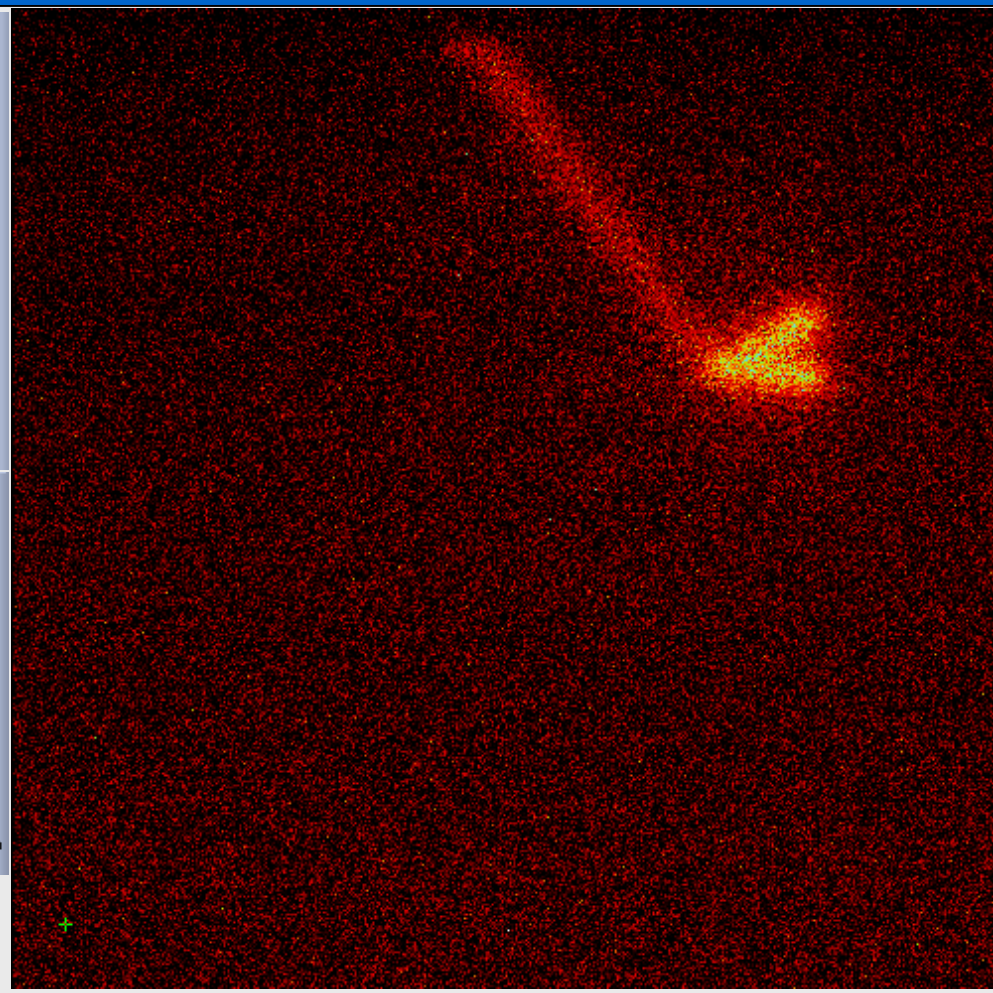




2p decay 3.72 ms after implantation

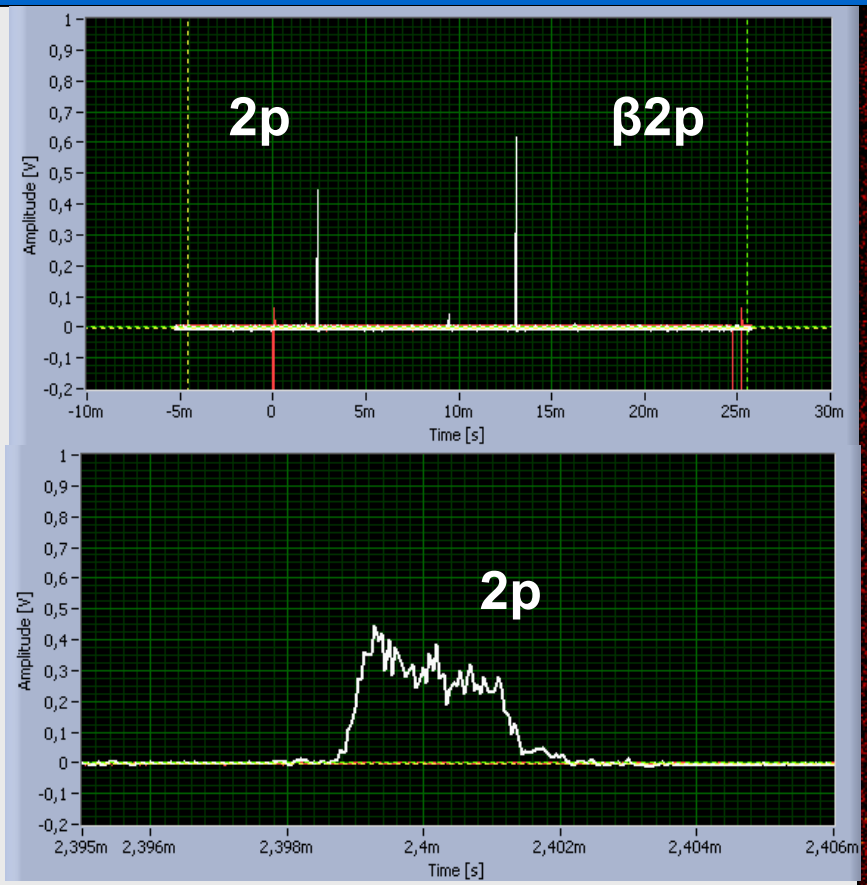
2p followed by βp

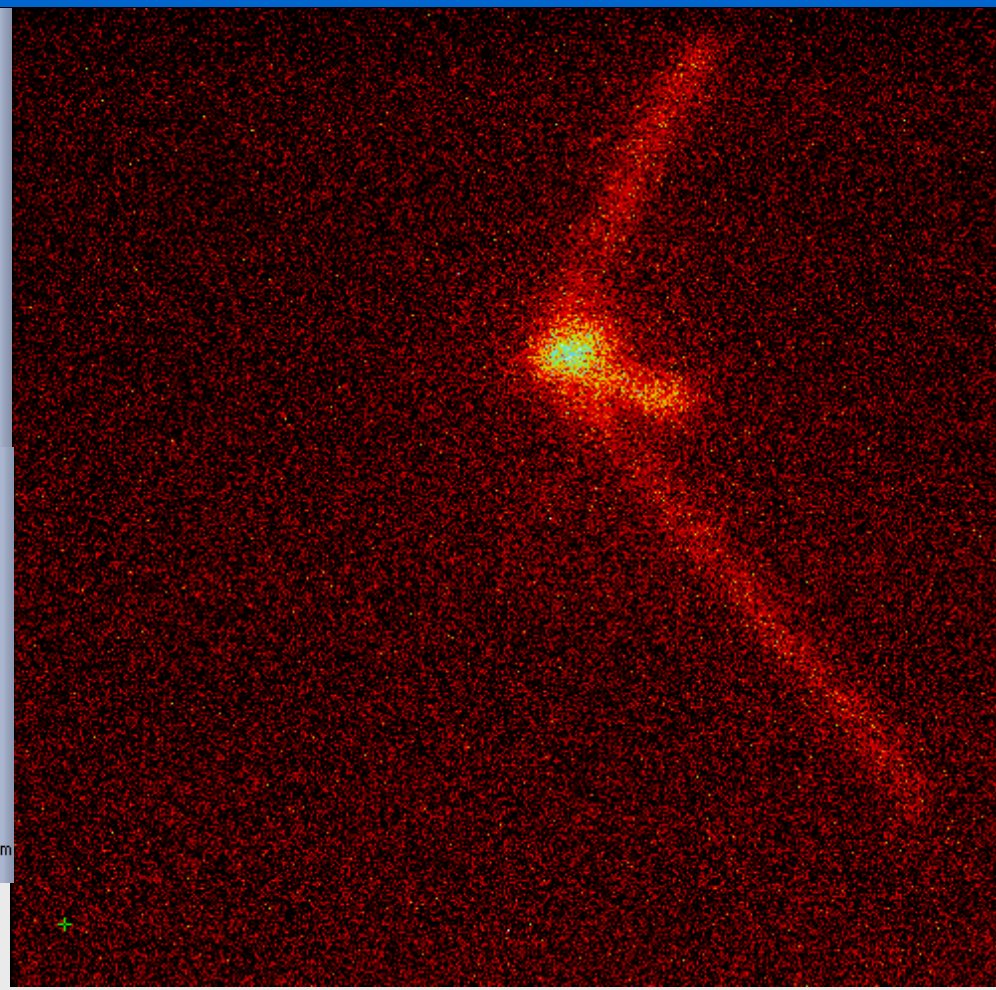




2p decay 5.3 ms after implantation

2p followed by β2p





2p decay 2.4 ms after implantation

Summary

Experiment lasted 9 days ≈ 210 hours

- ^{45}Fe ions identified: 248
- Decays recoreded: 125
  - 2p emission: 95
  - βp decay: 30

Preliminary results

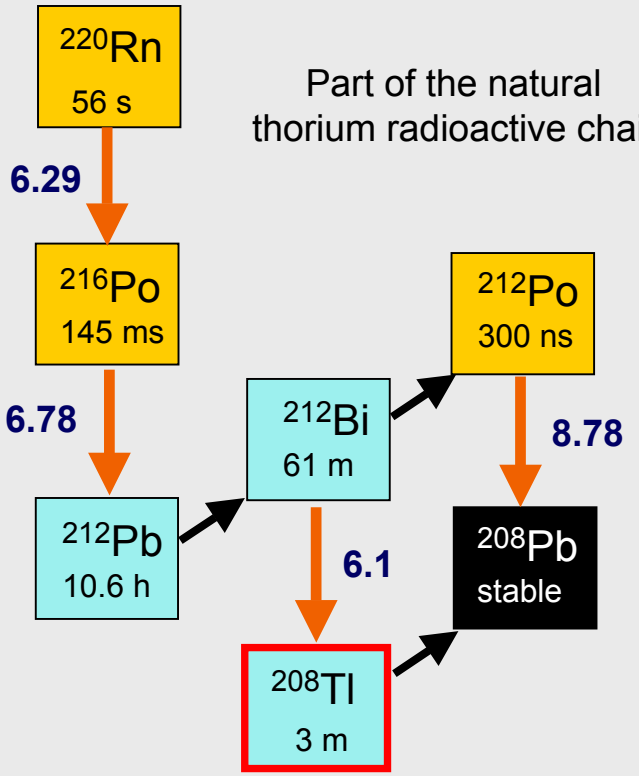
- 2p branching ratio: 0.76 ± 0.10
- half-life: 3.6 ± 0.3 ms
- 2p partial $T_{1/2}$: 4.7 ± 0.4 ms

	2*p* decay energy (MeV)	Half-life (ms)	Branching ratio	Partial half-life (ms)
Giovinazzo *et al.* [5]	1.140 ± 0.040	$4.7^{+3.4}_{-1.4}$	0.55 ± 0.12	$8.5^{+6.4}_{-3.2}$
Pfützner *et al.* [6]	1.1 ± 0.1	$3.2^{+2.6}_{-1.0}$	$0.80^{+0.15}_{-0.25}$	$4.0^{+3.3}_{-1.8}$
This work	1.154 ± 0.016	$1.6^{+0.5}_{-0.3}$	0.57 ± 0.10	$2.8^{+1.0}_{-0.7}$
Average	1.151 ± 0.015	$1.75^{+0.49}_{-0.28}$	0.59 ± 0.07	$3.0^{+0.9}_{-0.6}$

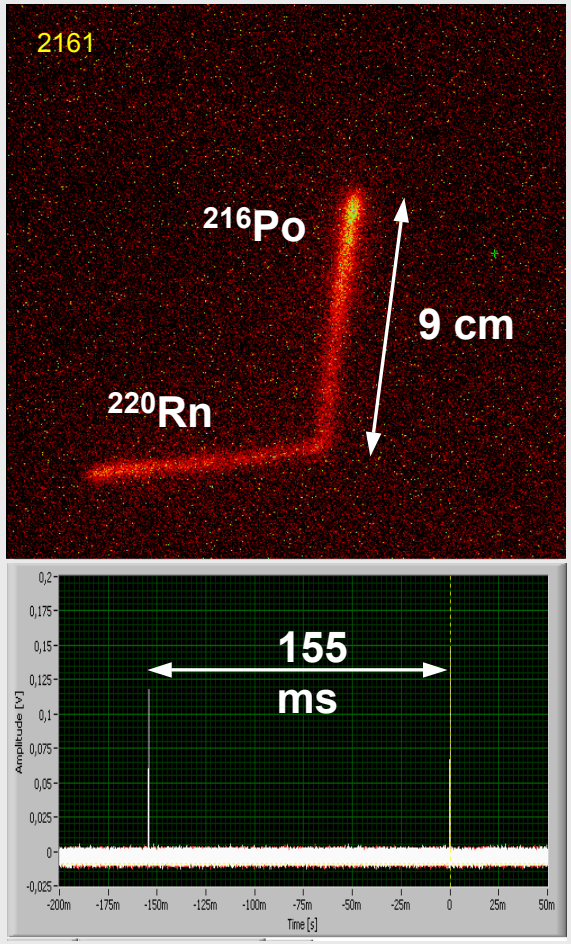
Important application

Z. Janas at the NEMO – SUPERNEMO Collaboration Meeting, Jaca (Spain) XII 2006

Radon contamination in the gas filling the NEMO detector has to be monitored

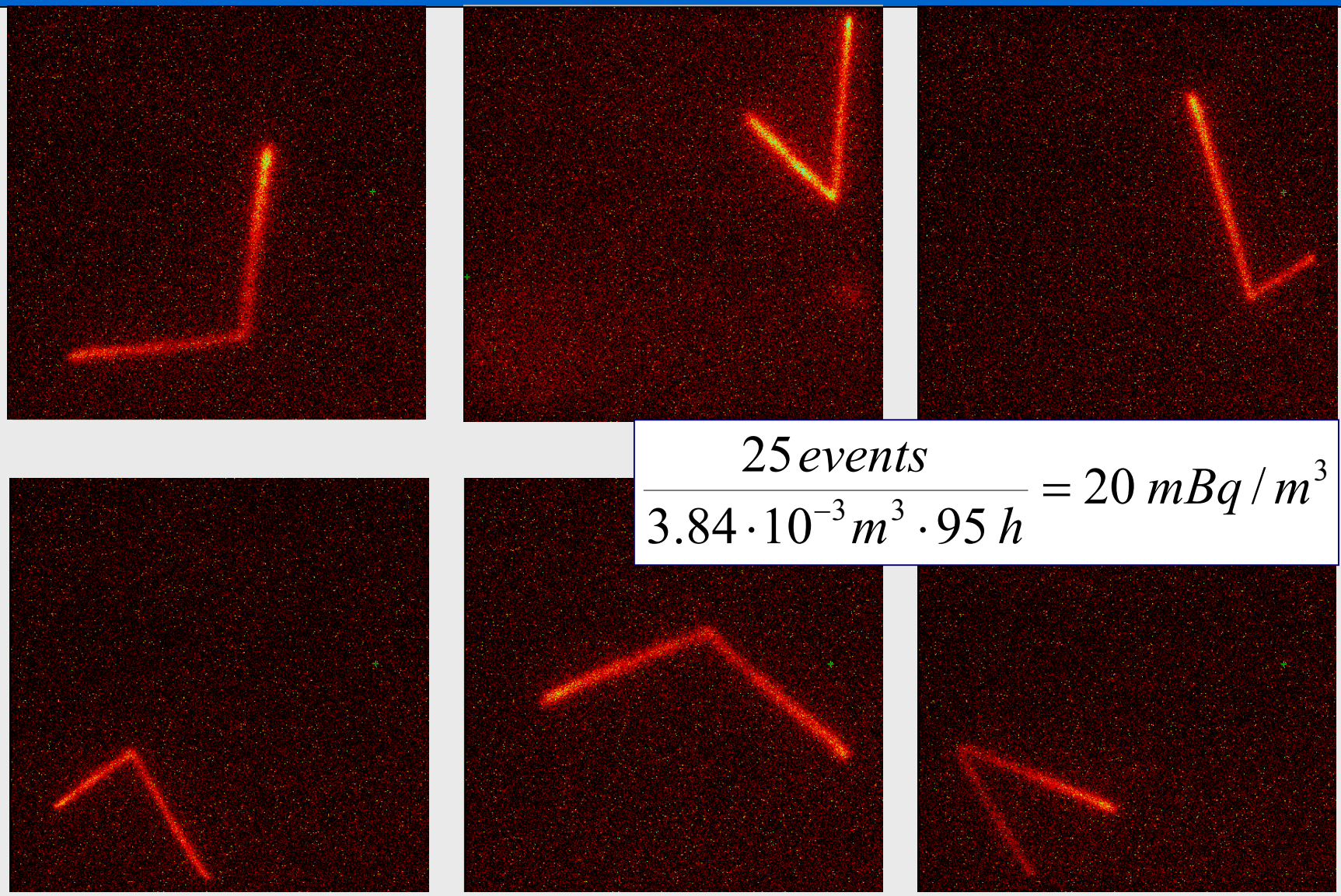


Part of the natural thorium radioactive chain



two triggers within 300 ms gate

Search for ^{220}Rn - ^{216}Po - $\alpha\alpha$ chain



$$\frac{25\,events}{3.84\cdot10^{-3}\,m^3\cdot95\,h}=20\,mBq/m^3$$

The OTPC team

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