# Outline: 2-proton emitter

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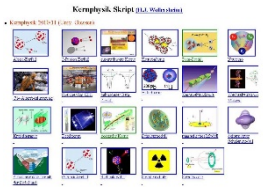
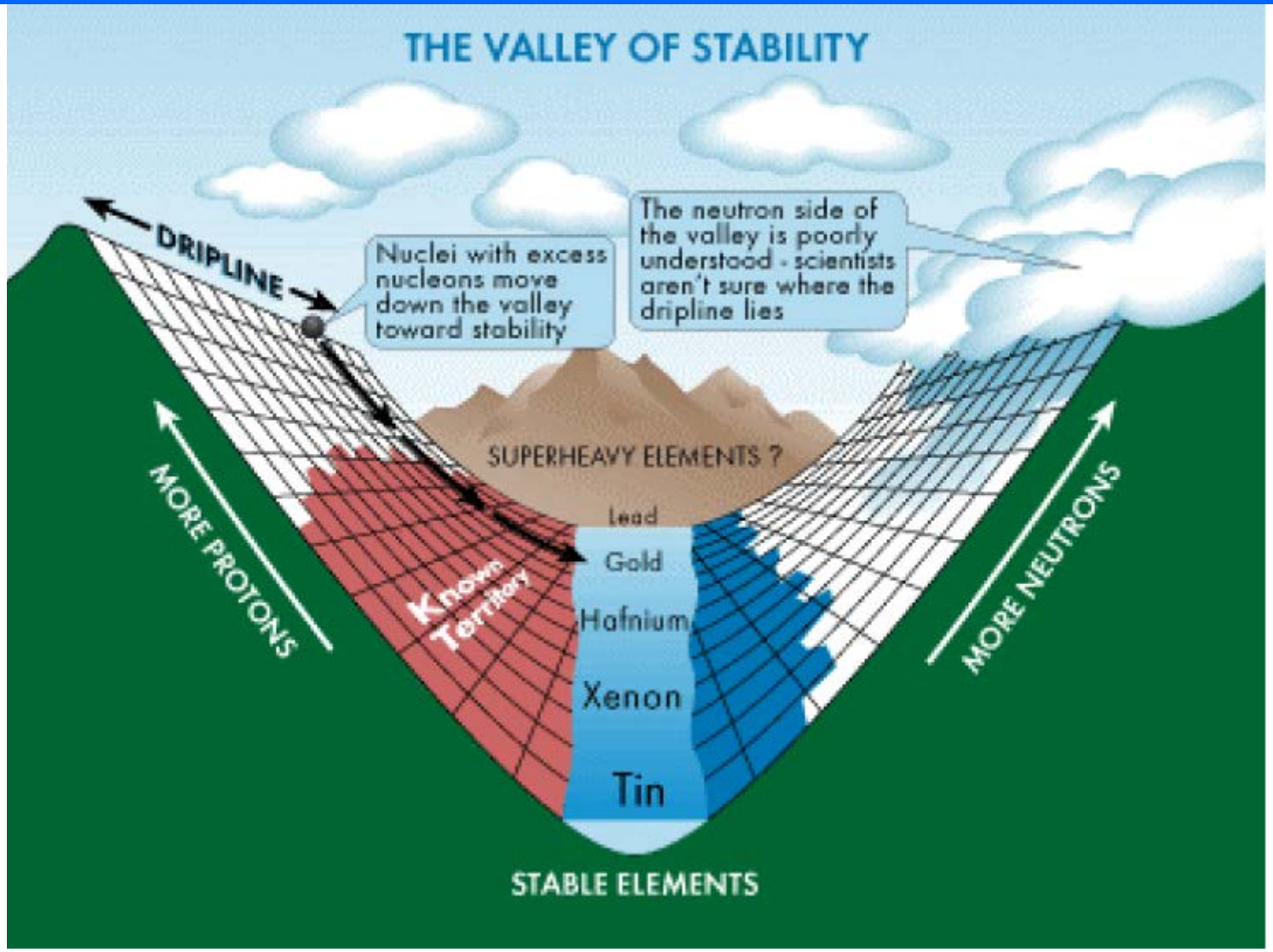
web-page: https://web-docs.gsi.de/~wolle/ and click on

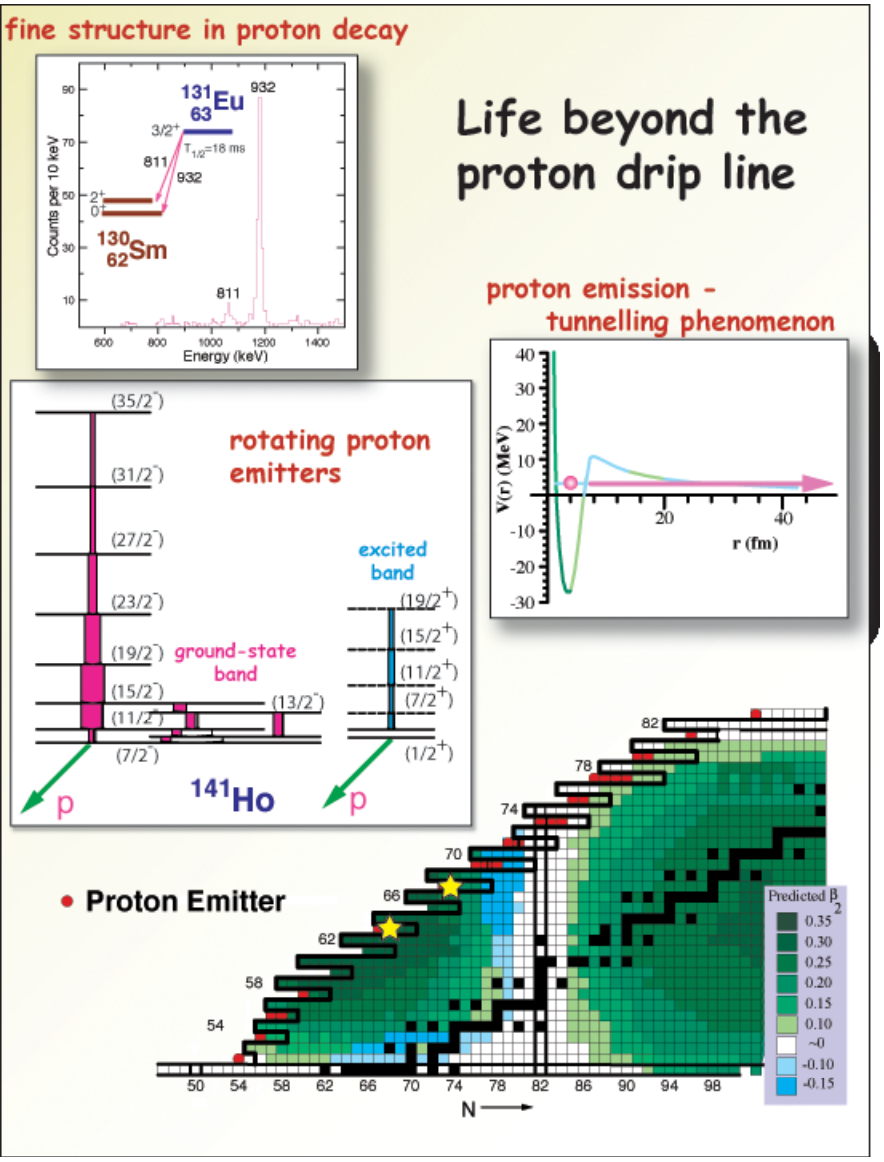


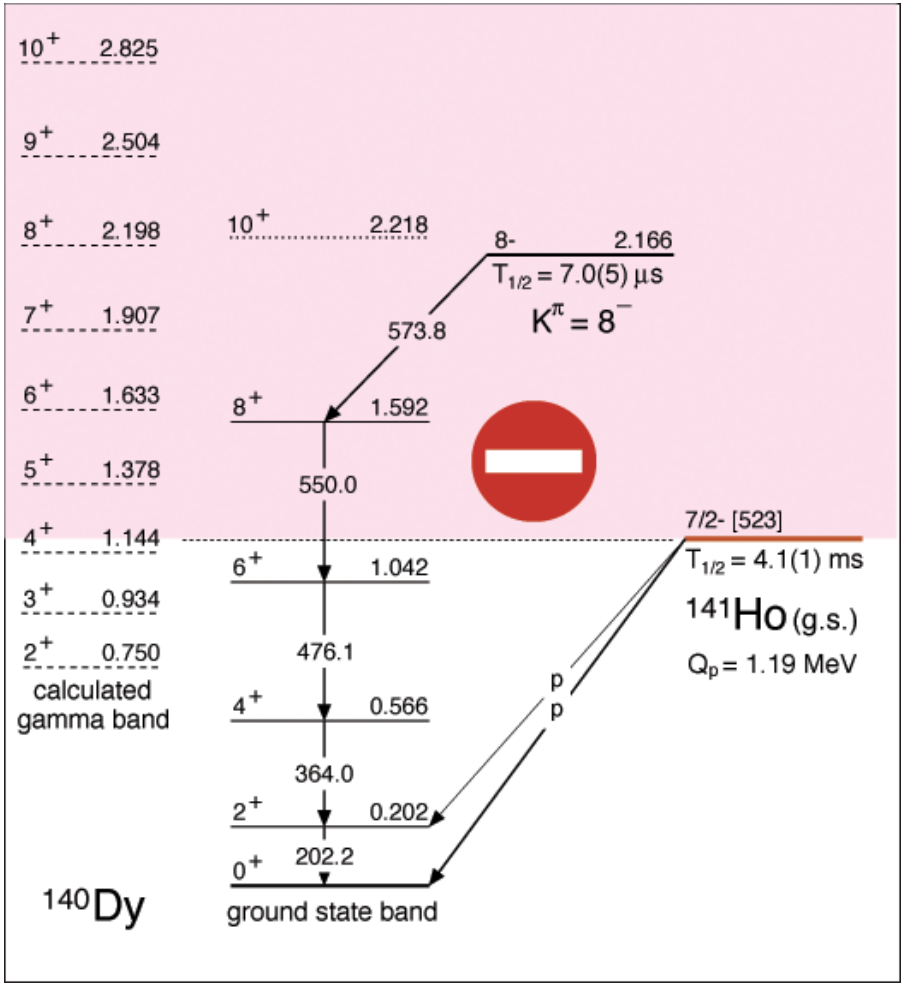
1. spectroscopy of open systems: proton emitters
2. proton radioactivity: isomer decay in $^{54}$Ni
3. 2-proton radioactivity in $^{45}$Fe
4. optical time projection chamber
5. angular correlation




Proton drip line is well established. For all elements occurring naturally on earth and having an odd number of protons, at least one species with proton separation energy less than zero have been experimentally observed.

# Spectroscopy of open systems: proton emitters



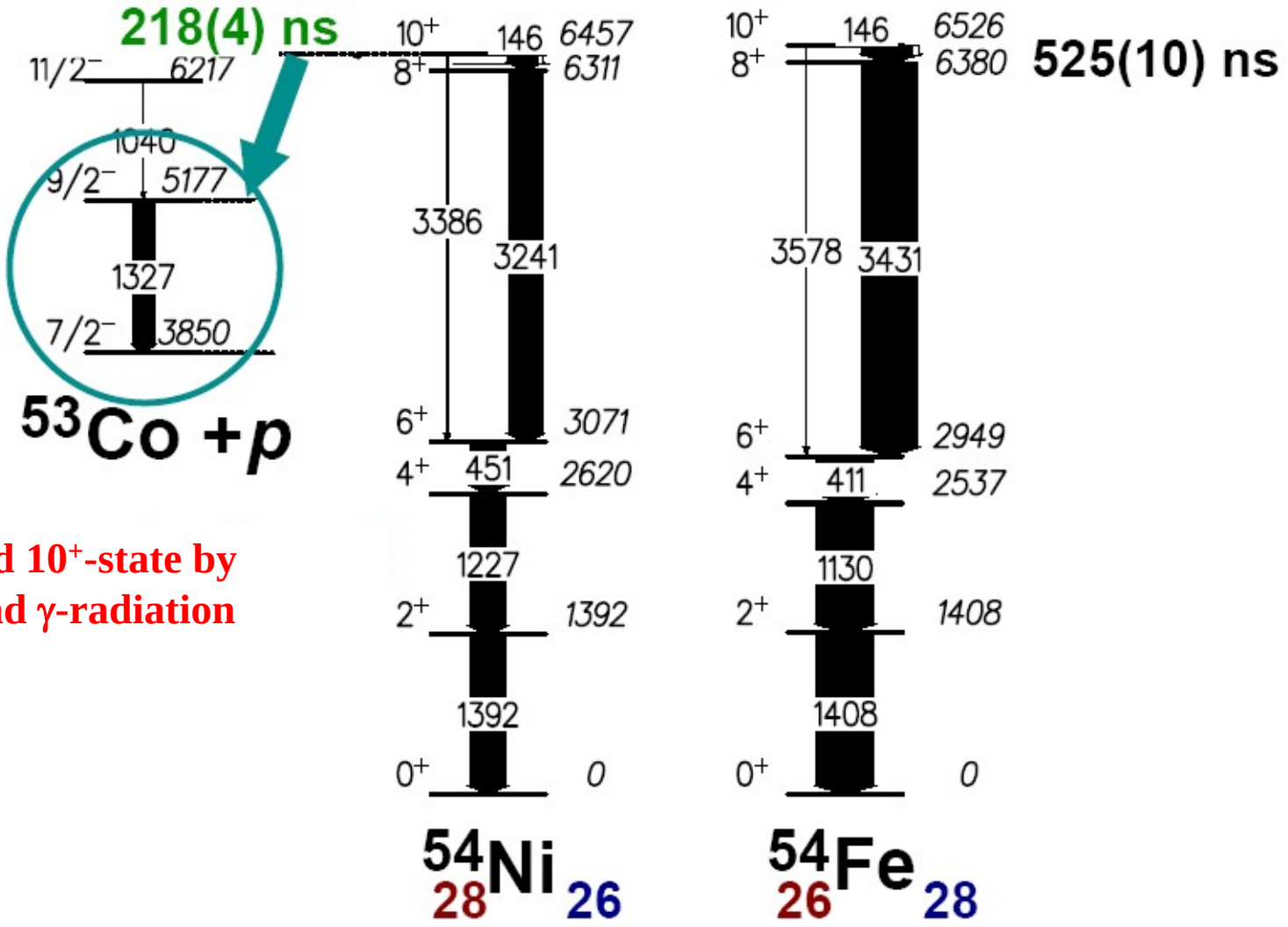




**Non-adiabatic theory:**

B.Barmore et al., Phys.Rev. C62, 054315 (2000)

A.T. Kruppa and WN, Phys. Rev. C69, 054311 (2004)

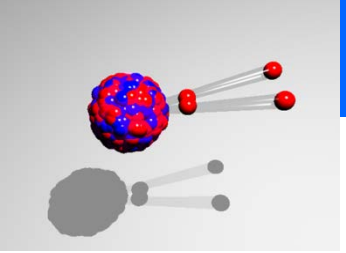
# Proton radioactivity – decay of the $I^{\pi}=10^{+}$ isomer in $^{54}$Ni

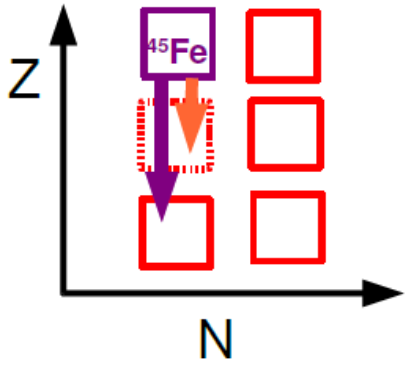



**decay of the excited $10^{+}$-state by proton emission and γ-radiation**

D. Rudolph, R. Hoischen et al., Phys.Rev.C78 (2008), 021301

# 2-proton radioactivity of $^{45}$Fe






*1-proton emission:*

$$^{45}_{26}Fe_{19} \rightarrow {}^{44}_{25}Mn_{19}$$

-120 keV < $S_p$ < 70 keV

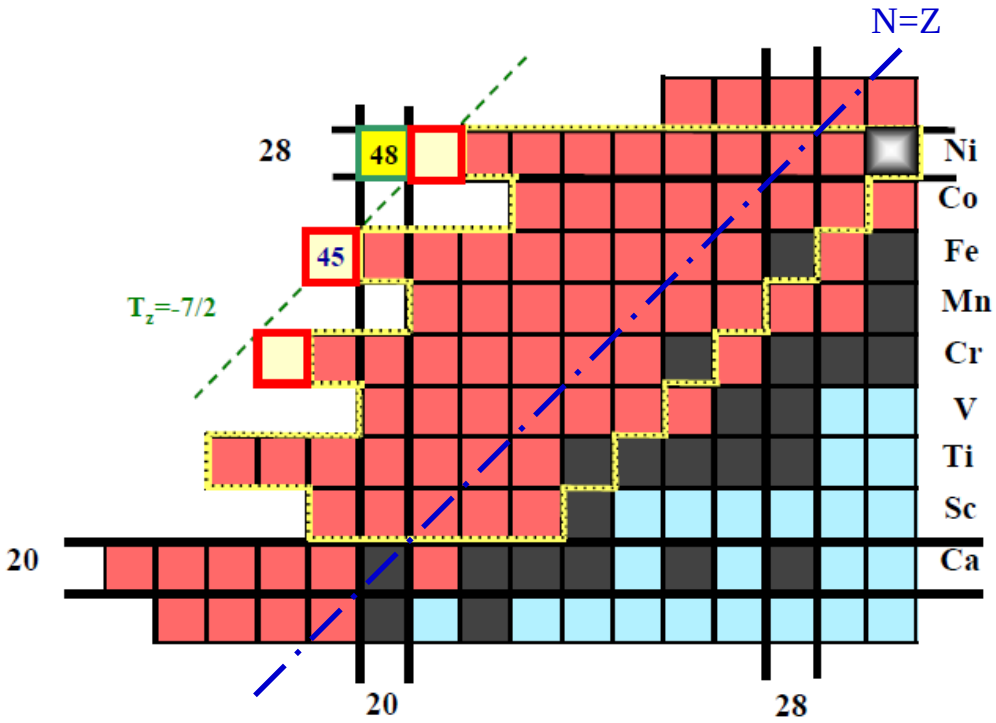
$t_{1/2}$ > 100s

*2-proton emission:*

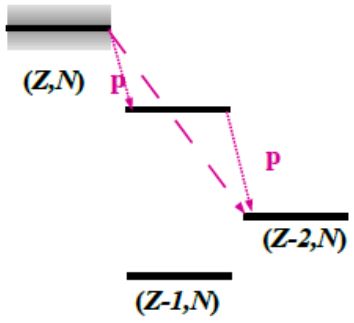
$$^{45}_{26}Fe_{19} \rightarrow {}^{43}_{24}Cr_{19}$$

-1000 keV < $S_{2p}$ < -1300 keV

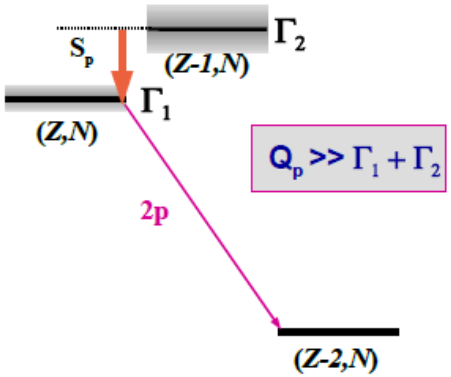
$t_{1/2}$~$10^{-6}$s – 1s



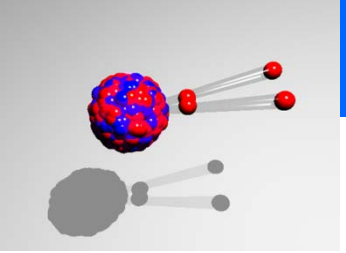

sequential




simultanious




proposed by V.I. Goldansky; Nucl. Phys. 19 (1960), 482 Nucl. Phys. 27 (1961), 648 discovered by M.Pfützner et al., EPJA 14 (2002) 279

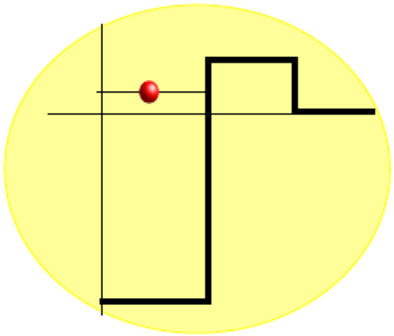


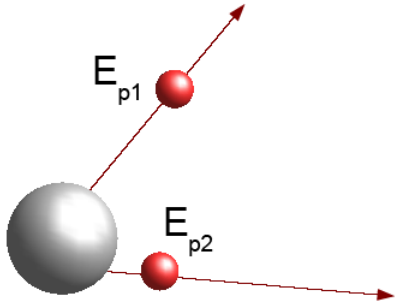
# 2-proton radioactivity of $^{45}$Fe

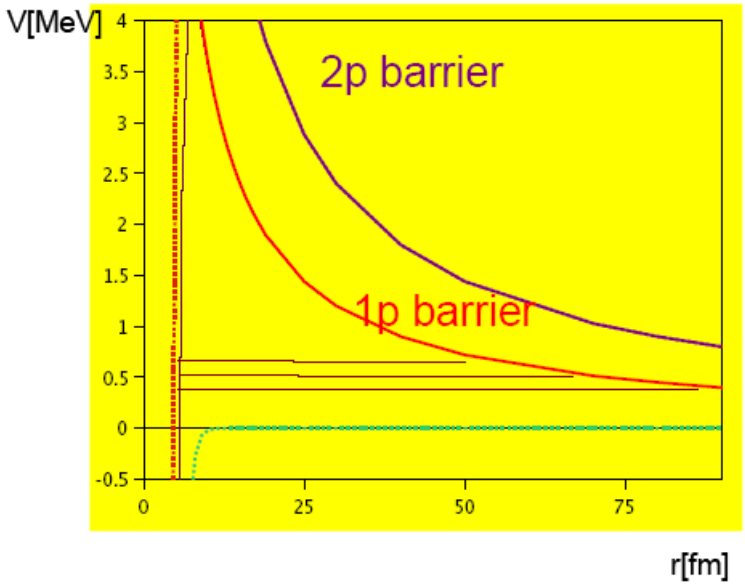
*Tunneling through a potential barrier:*

$$\lambda = S \cdot \omega \cdot P$$

- S spectroscopic factor for 2-proton creation
- ω frequency, with which both protons hit the barrier
- P is the penetrability, the probability for a tunneling process

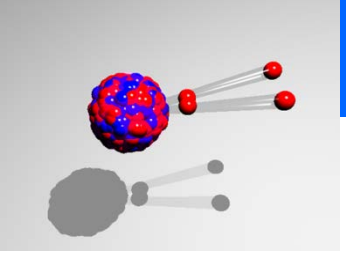


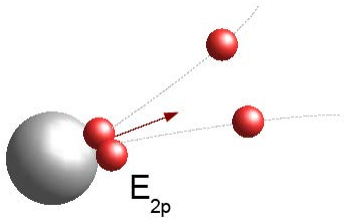


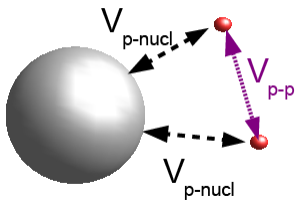



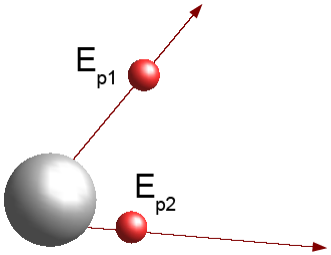

proposed by V.I. Goldansky; Nucl. Phys. 19 (1960), 482 Nucl. Phys. 27 (1961), 648 discovered by M.Pfützner et al., EPJA 14 (2002) 279

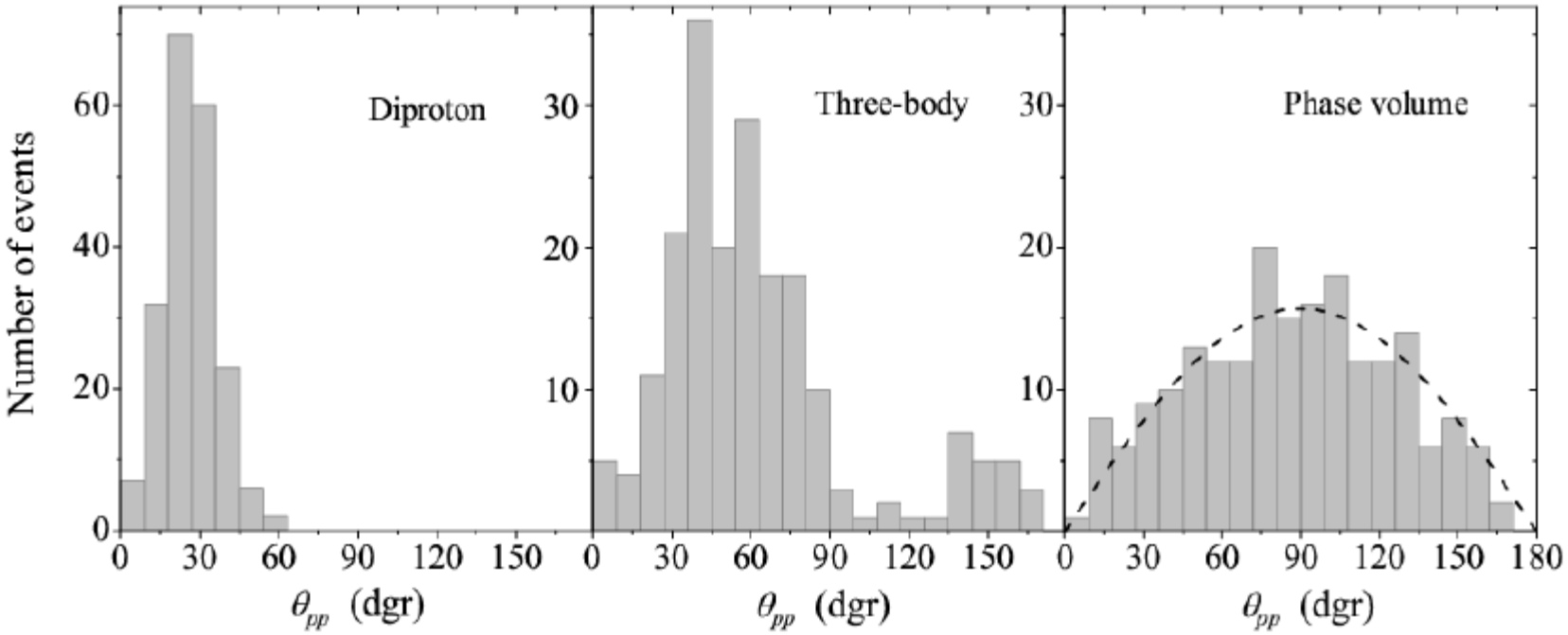
# 2-proton radioactivity of $^{45}$Fe





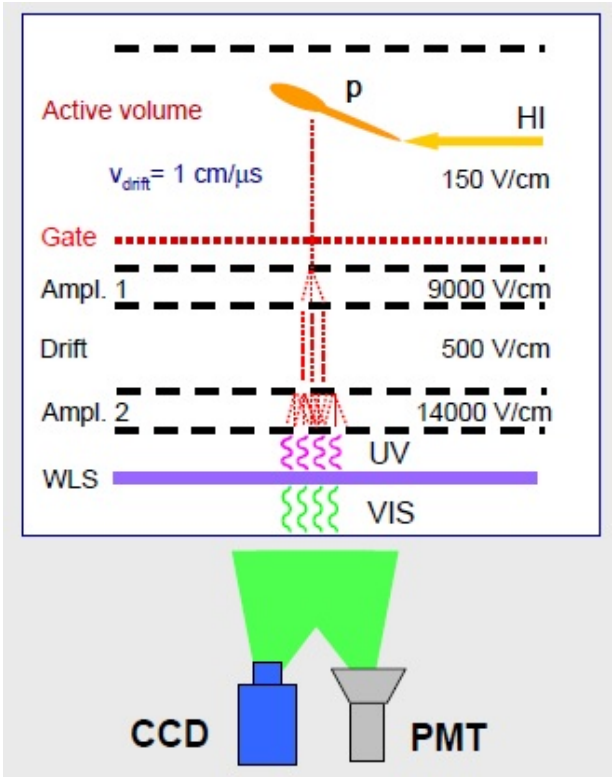



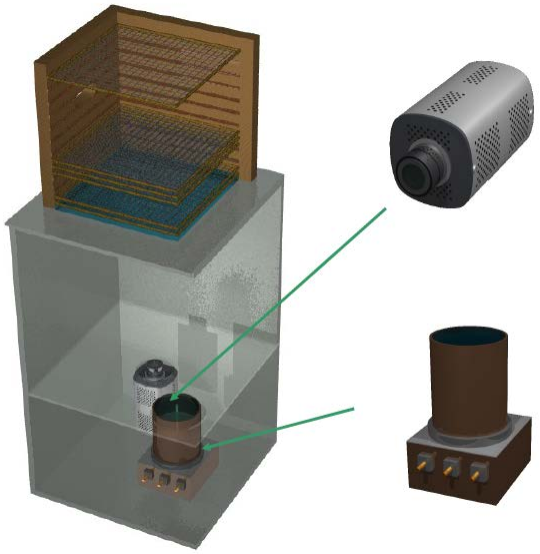




Monte Carlo simulation (200 events) of the opening angles between both protons for the $^{45}$Fe decay

L. Grigorenko et al. Phys. Rev. Lett. 85 (2000), 22, Nucl.Phys. A714 (2003), 425

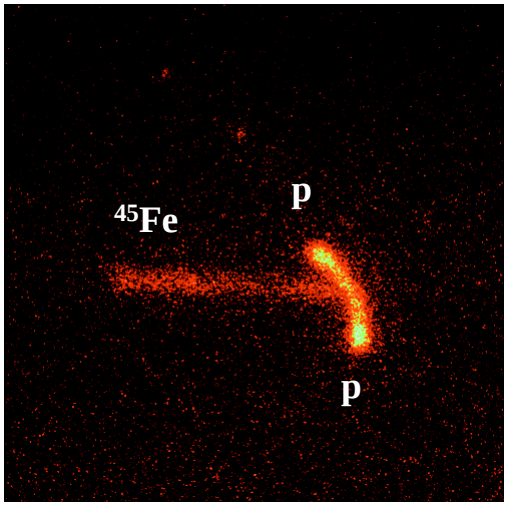
# Exotic nuclear decays in digital photography



CCD Camera
- 1000x1000 pix
- 12-bits
- image amplification (x2000)

Photomultiplier 5''

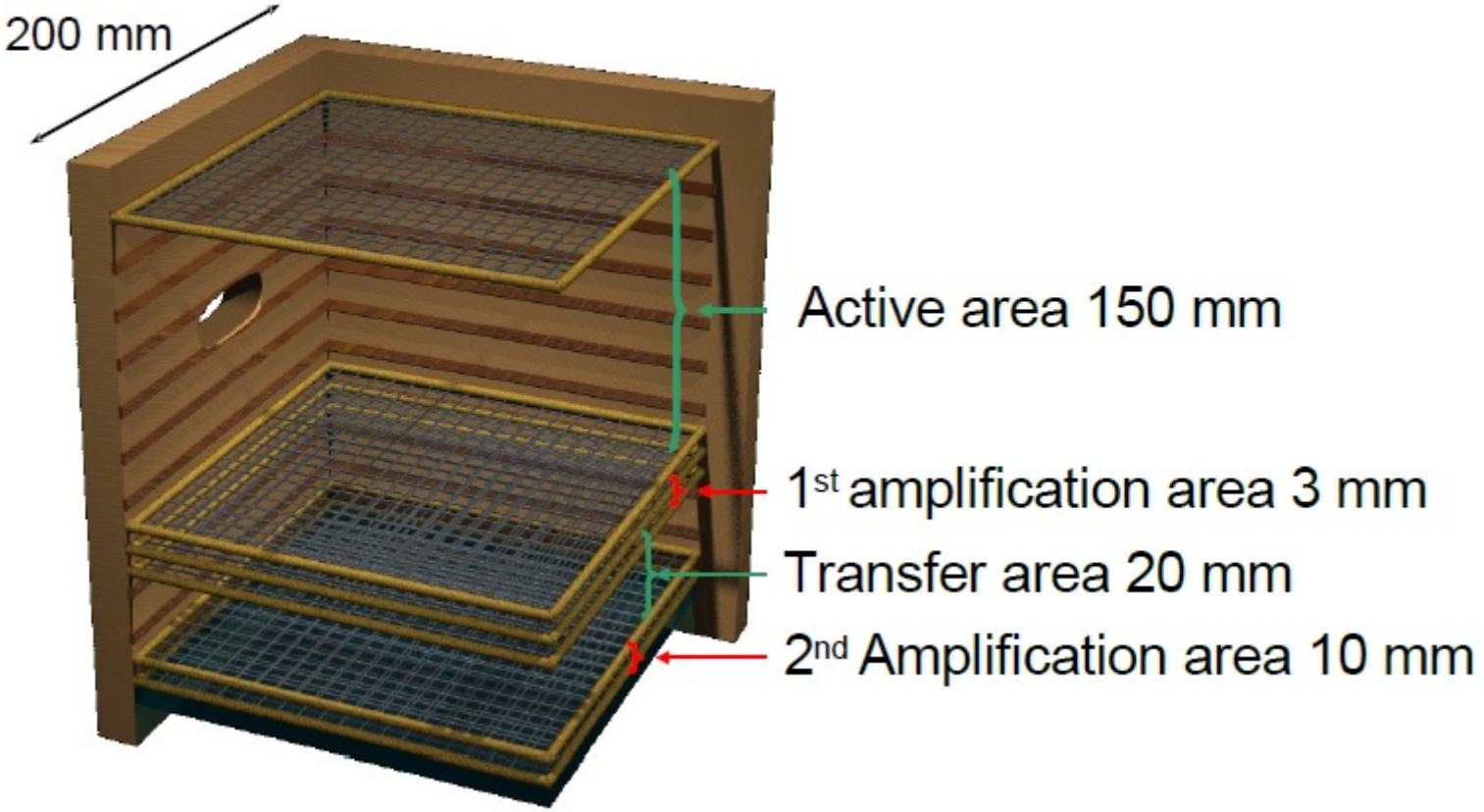



Gaseous ionization detector (TEA = Triethylamine $N(C_2H_5)_3$) developed to measure the angular and energy correlations between the protons emitted in 2p decay of $^{45}$Fe.

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

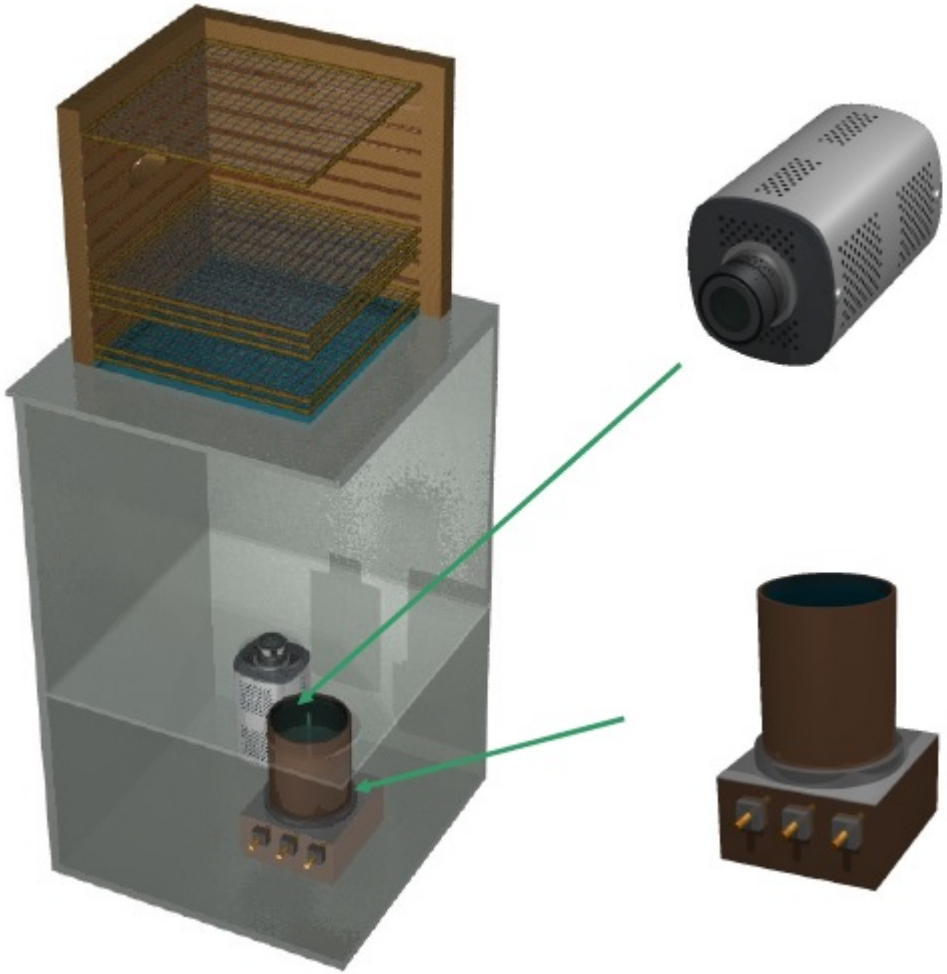
# Optical time projection chamber

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




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

# Optical time projection chamber



CCD Camera
- 1000x1000 pix
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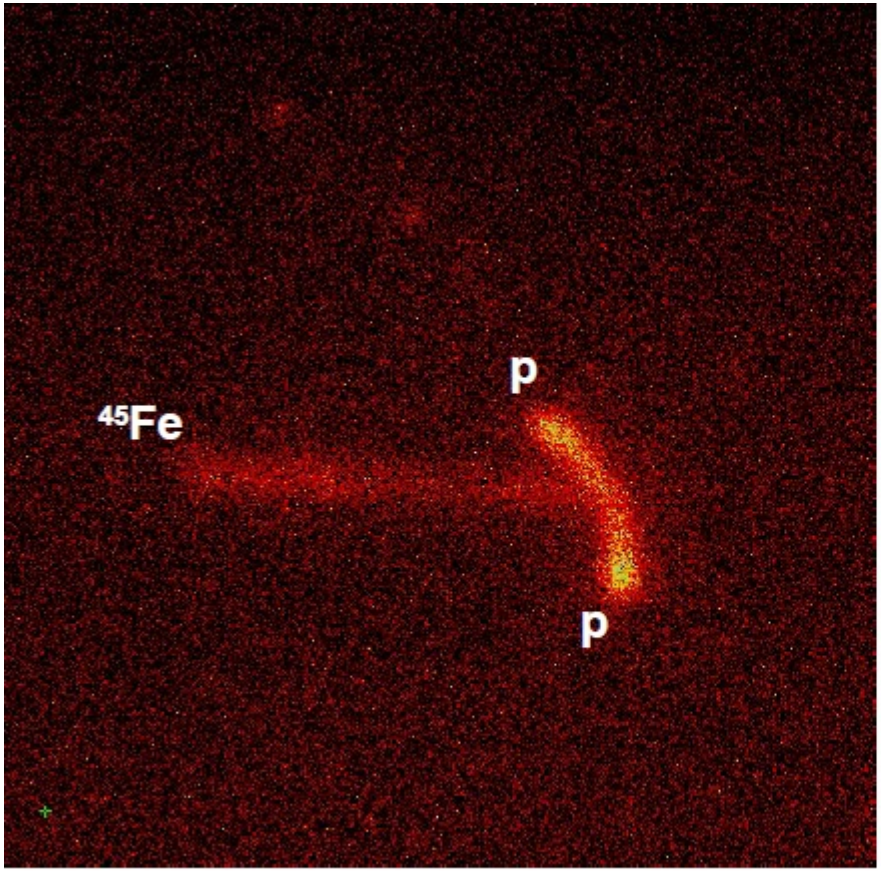
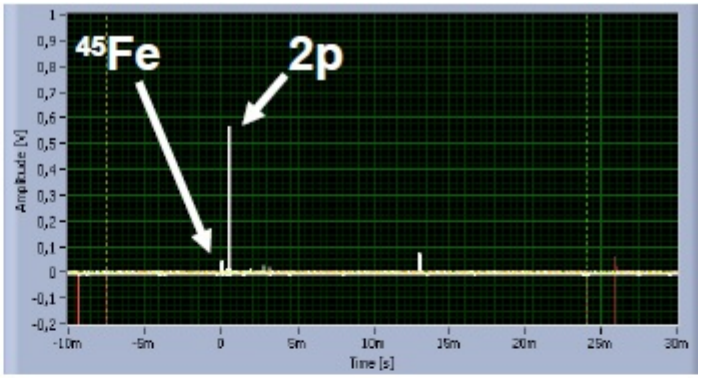
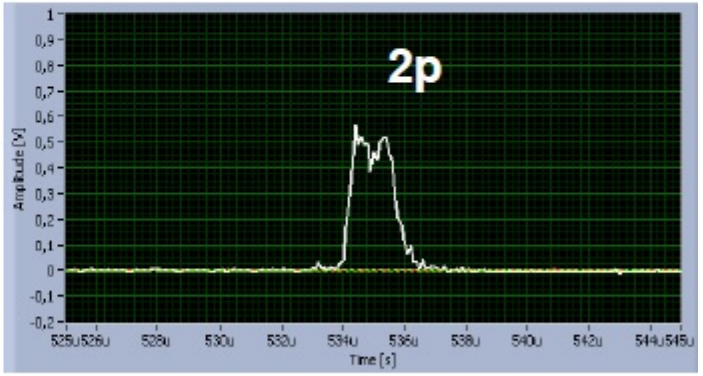
Photomultiplier 5”

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

# 2p decay of $^{45}$Fe

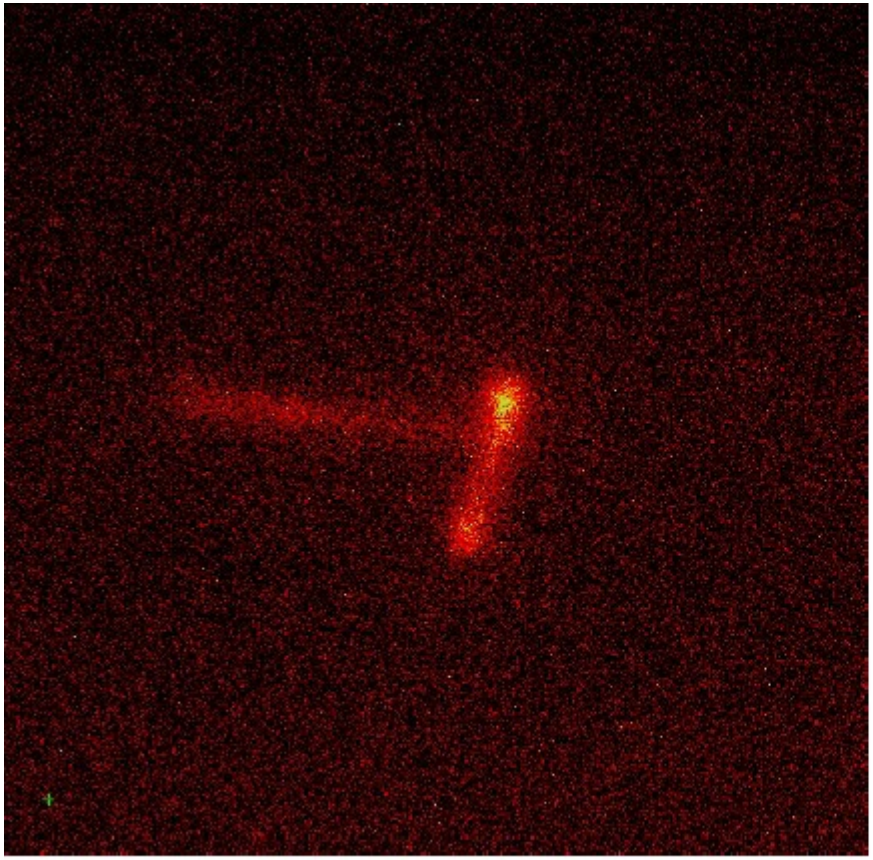


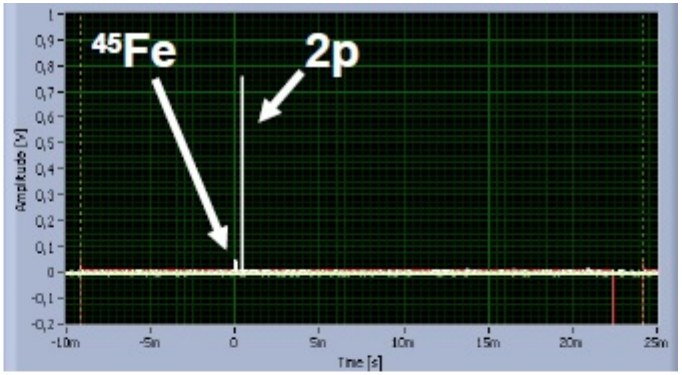



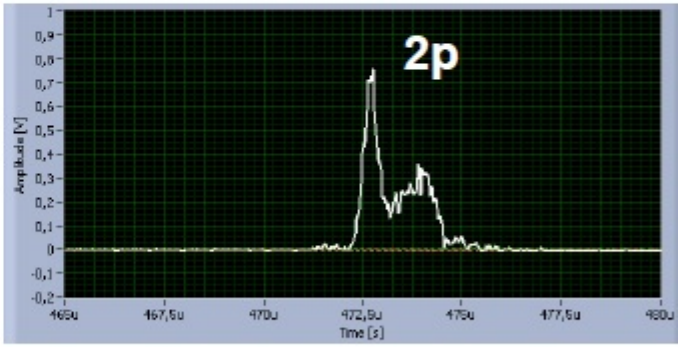




2p decay 0.53 ms after implantation

# 2p decay of $^{45}$Fe

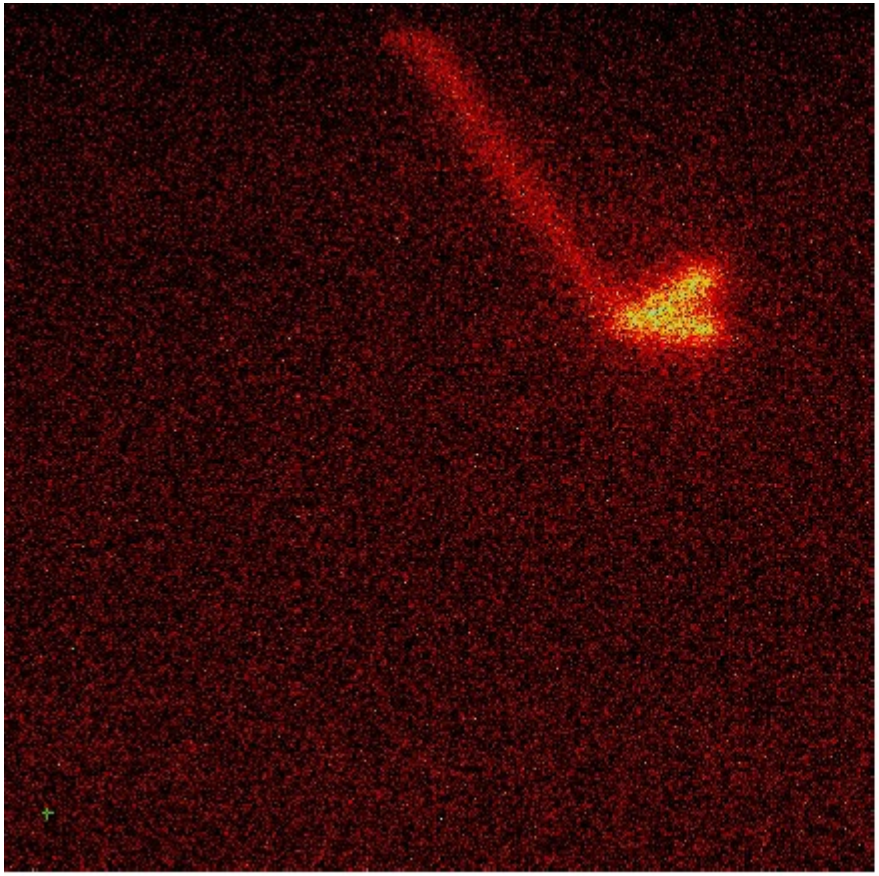


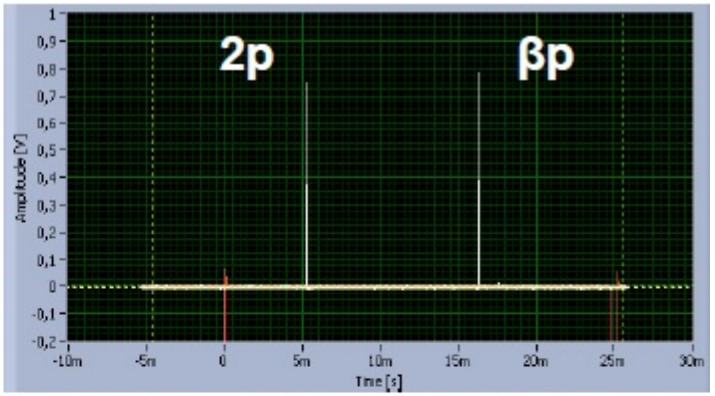


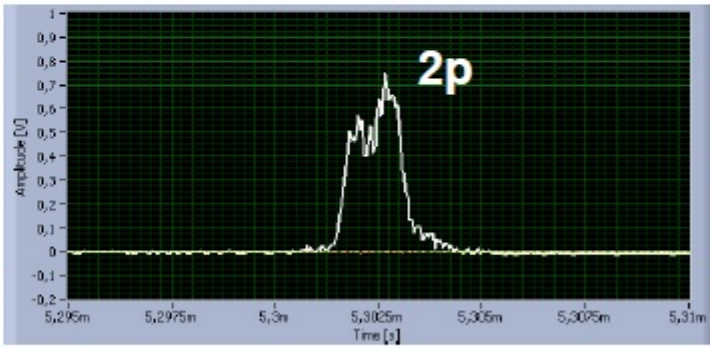




2p decay 0.47 ms after implantation

# 2p decay of $^{45}$Fe

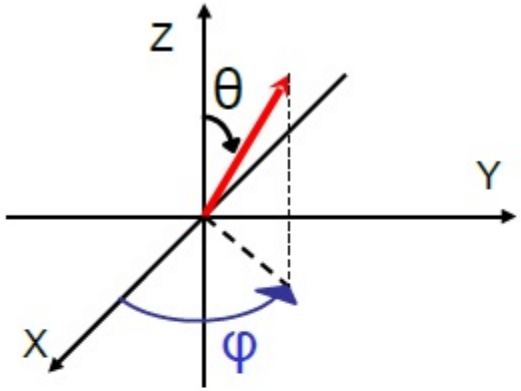


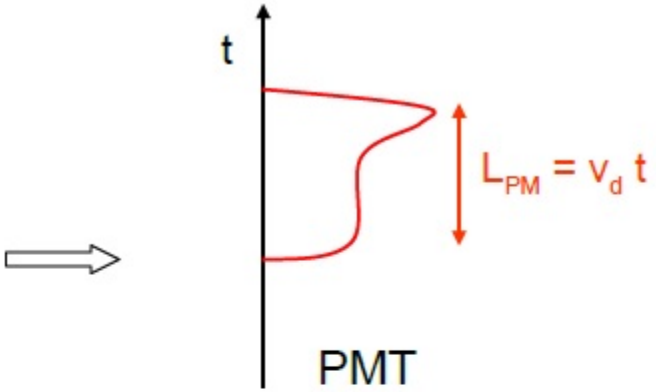


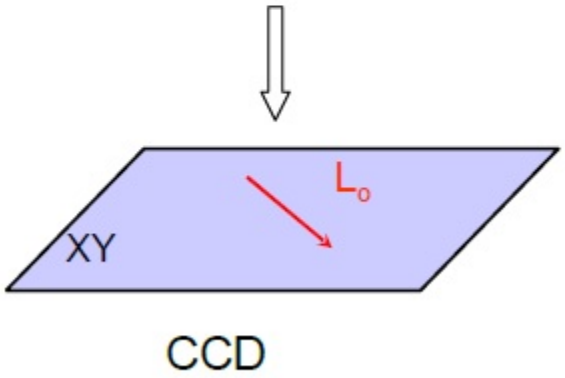




2p decay 5.3 ms after implantation

# Event reconstruction



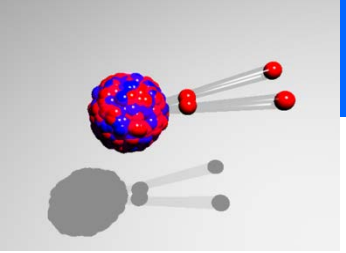

Track coordinates: (r, Θ, φ )

$L_o = r \cos\Theta$

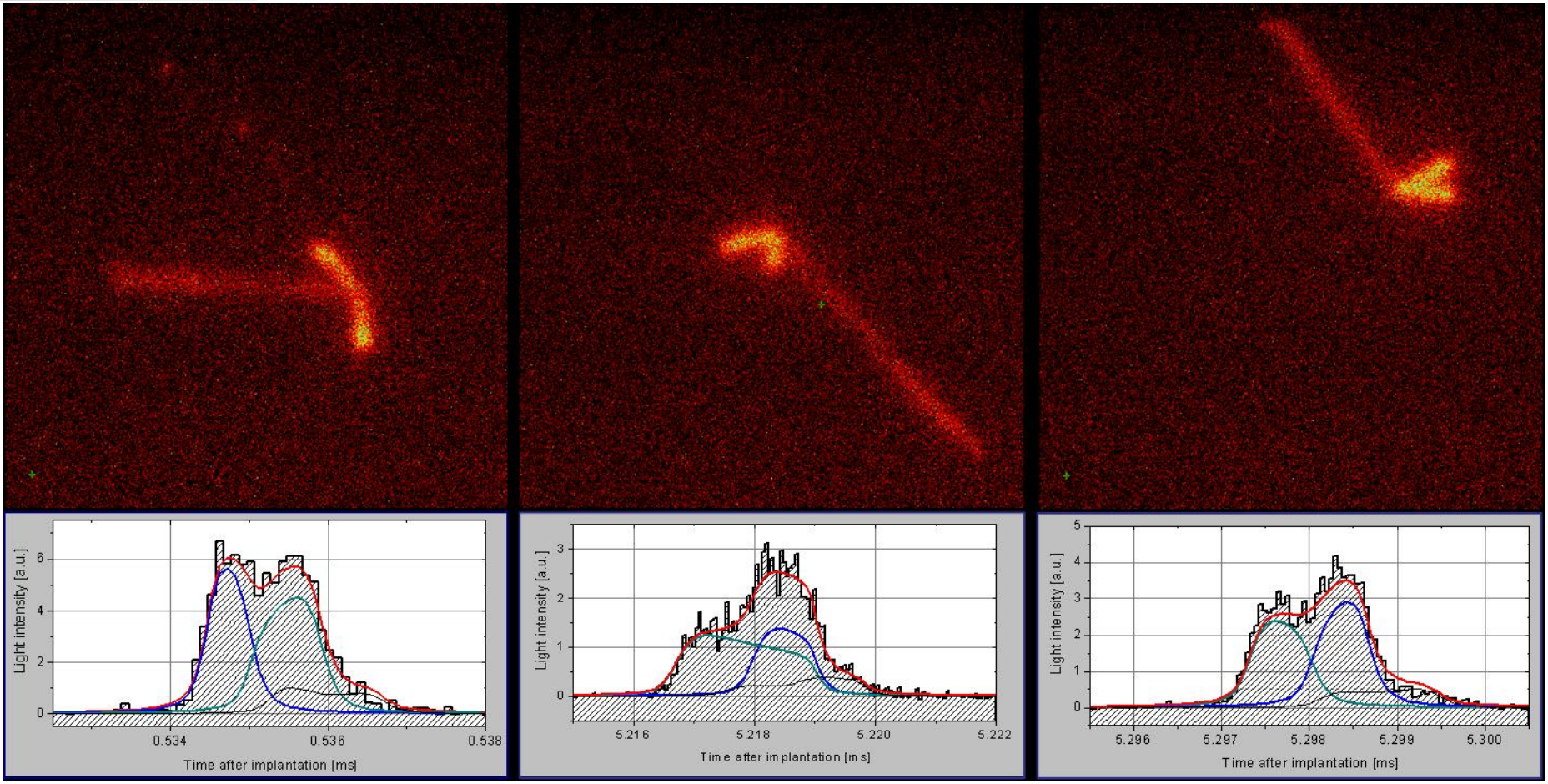
$L_{PM} = r \sin\Theta$

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

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

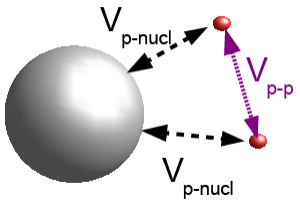


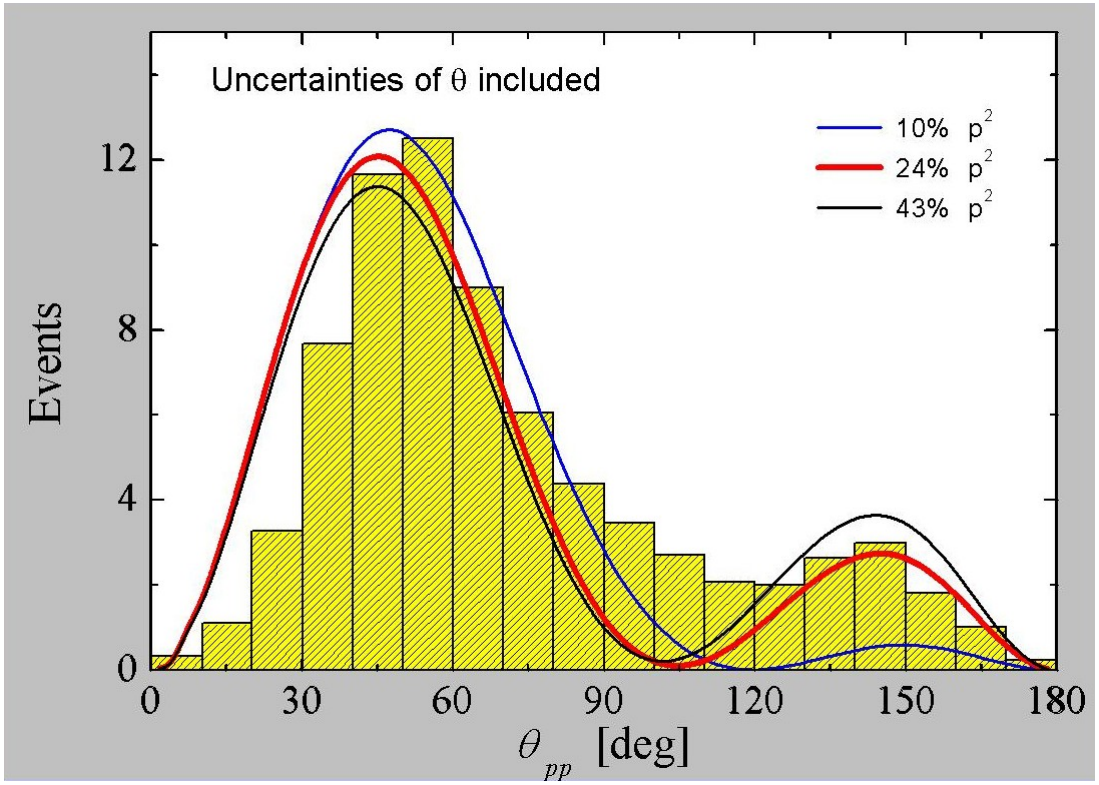
# Optical time projection chamber

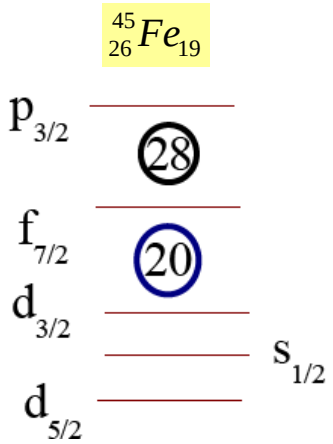



K. Miernik et al., Phys.Rev.Lett. 99 (2007) 192501

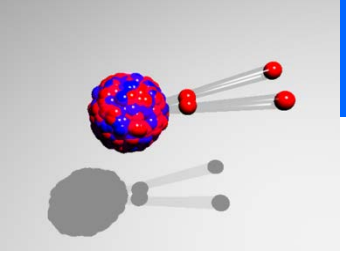
# 2-proton radioactivity of $^{45}$Fe



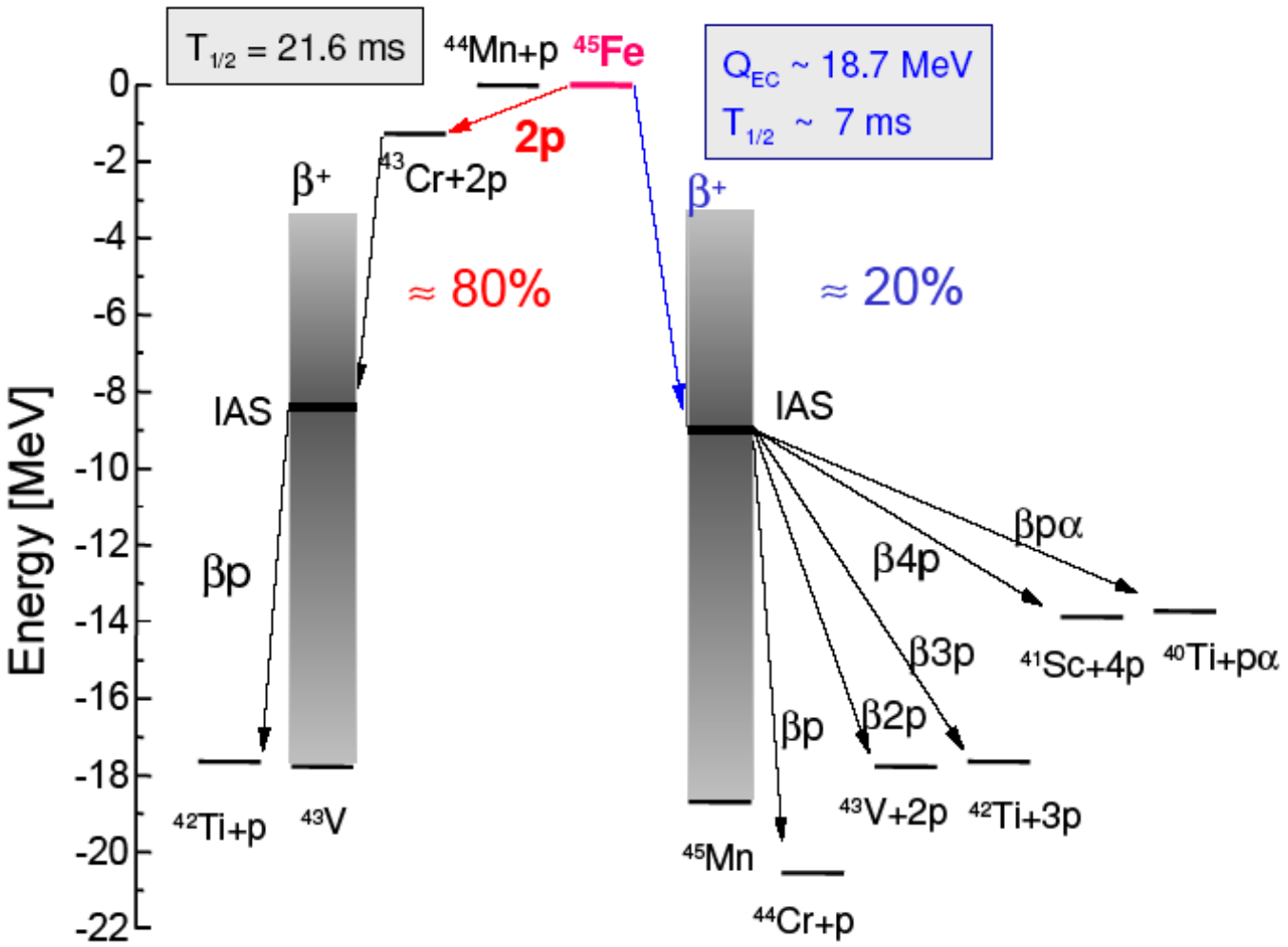




K. Miernik et al., Phys.Rev.Lett. 99 (2007) 192501



# $^{45}$Fe decay channels observed



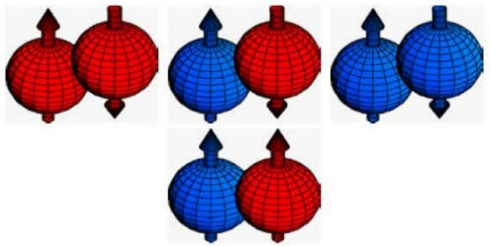

$Q_{2p}$=1.15±0.09 MeV und $T_{1/2}$ consistent with 2p-emission [sensitive between 1µs (2p-decay) and 10 ms (β-decay)]

K. Miernik et al., Phys.Rev.Lett. 99 (2007) 192501

# Isobar Analog States IAS

The IAS has the isospin $T = T_Z+1 = (N-Z)/2 + 1$

The isospin of the ground state is $T = T_Z = (N-Z)/2$



T=1, S=0

T=0, S=1

$^2$He D nn