

At the limits of nuclear stability: The observation of two-proton emission

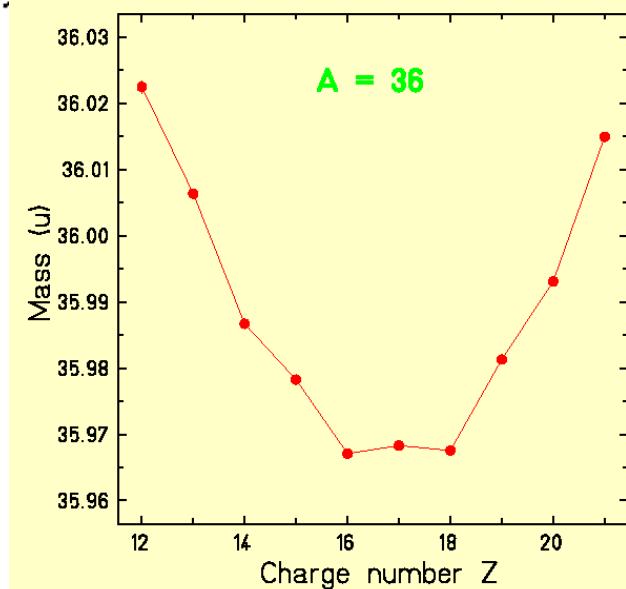
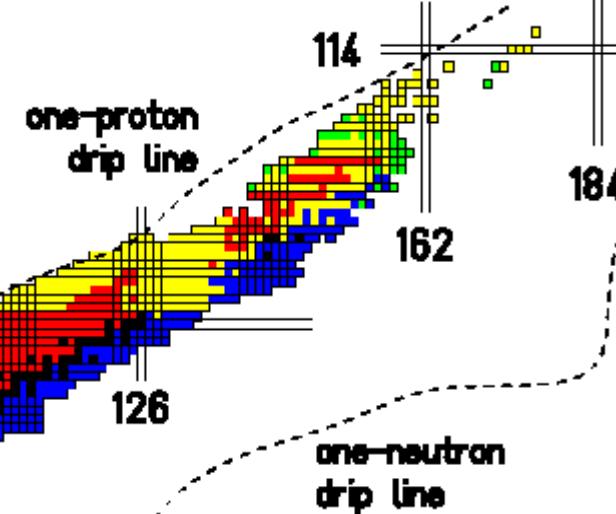
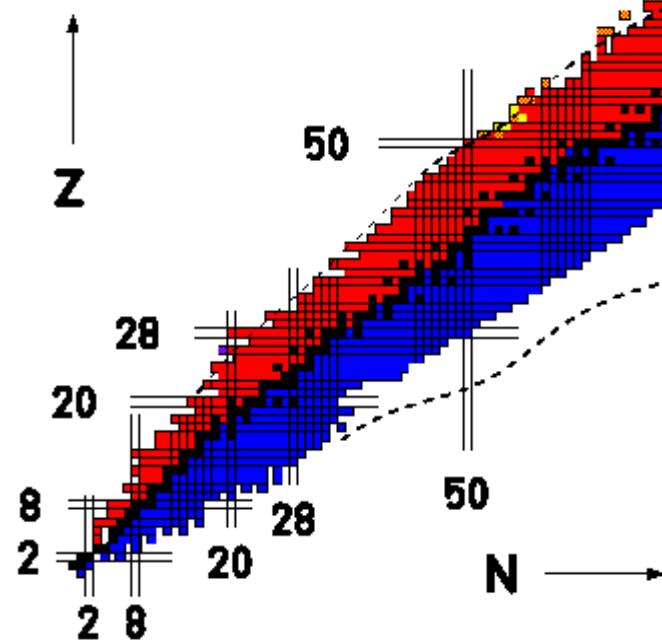
**Bertram Blank
CEN Bordeaux-Gradignan**

- Two proton radioactivity – a new decay mode
- Two-proton radioactivity of ^{45}Fe
- Two-proton emission from ^{17}Ne
- Future perspectives and developments

RNB6, September 22-26, 2003

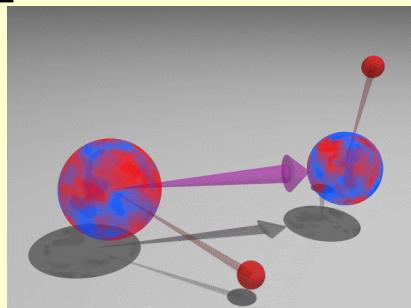
Leaving the valley of stability....

All observed nuclei:
- stable
- β unstable
- particle unstable

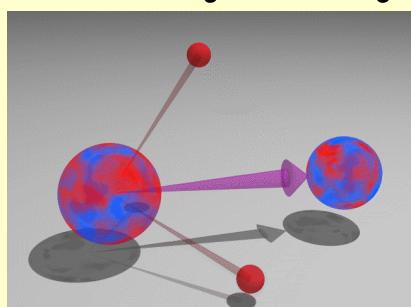


Two-proton radioactivity

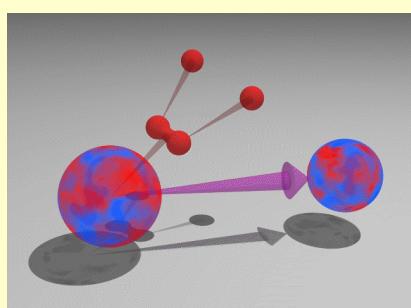
Sequential emission:



Three-body decay:



^2He emission:



Two types of 2p emission:

- ground-state emission
 - long lived: ^{45}Fe , ^{48}Ni , ^{54}Zn
 - short lived: ^6Be , ^{12}O , ^{16}Ne , ^{19}Mg
- emission from excited states
 - β delayed: ^{22}Al , ^{31}Ar , ...
 - others: ^{14}O , ^{18}Ne , ^{17}Ne

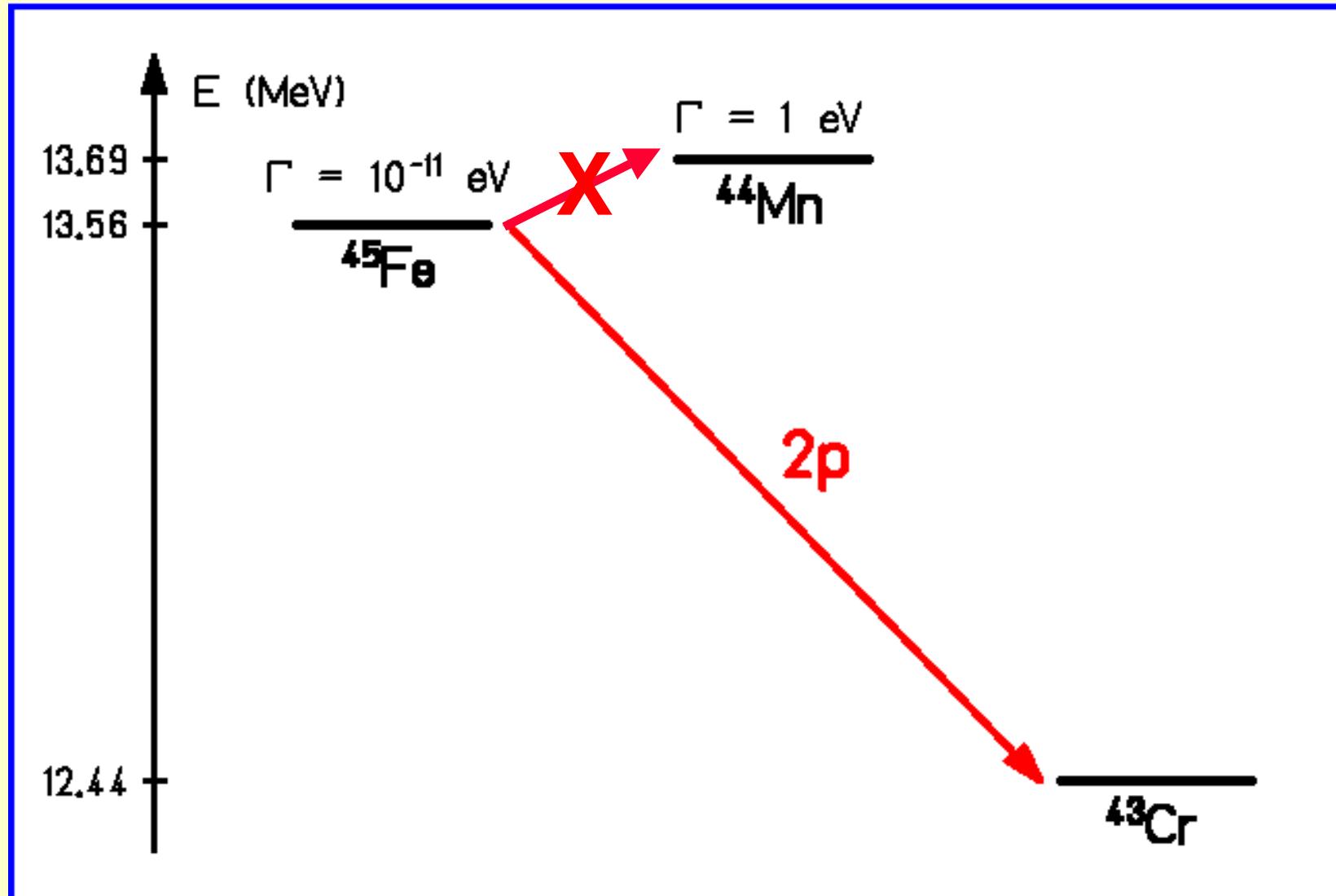
To be measured:

- proton energies
- proton-proton angle

Two-proton radioactivity of ^{45}Fe :

- long half-life
- production in fragmentation reactions
- selection with separator
- implantation and decay technique

Two-proton emission from ^{45}Fe ground state



Two-proton decay of ^{45}Fe

Two experiments:

- GANIL in July 2000
- GSI in July 2001

GSI:

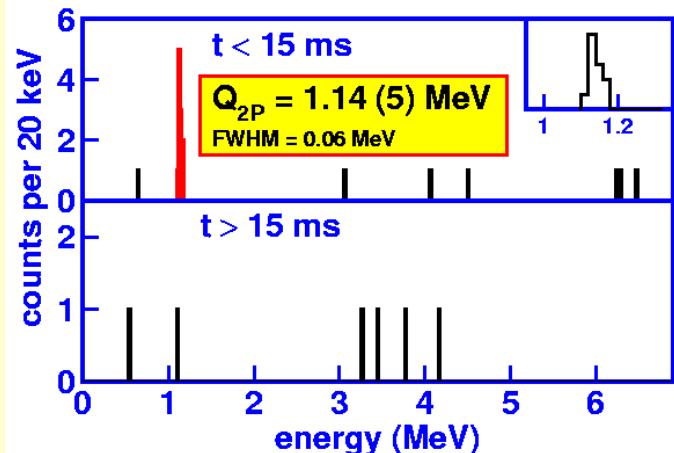
- low production rate: 6 ^{45}Fe implantations in 6 days
- fast data acquisition based on XIA modules

GANIL:

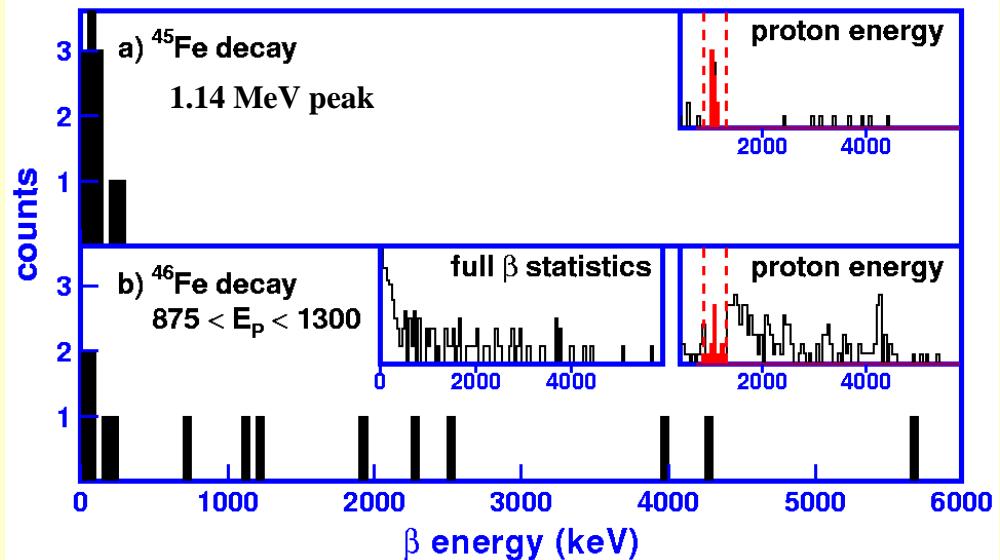
- high production rate: 15 ^{45}Fe per day
- standard data acquisition (CAMAC – VME)

Two-proton radioactivity of ^{45}Fe : GANIL data

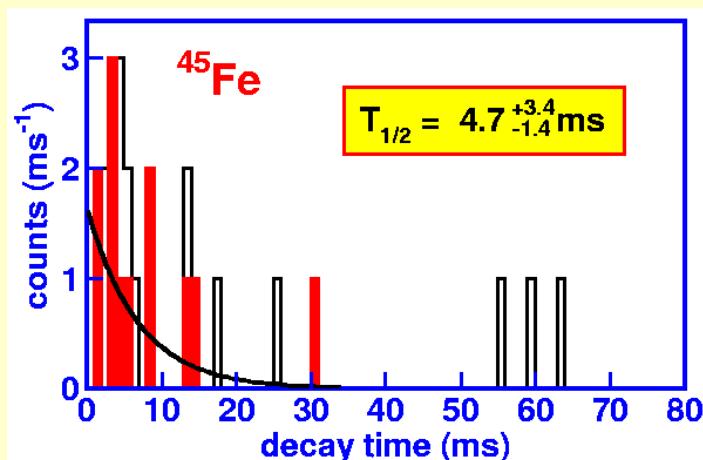
Decay-energy spectrum:



β spectrum:

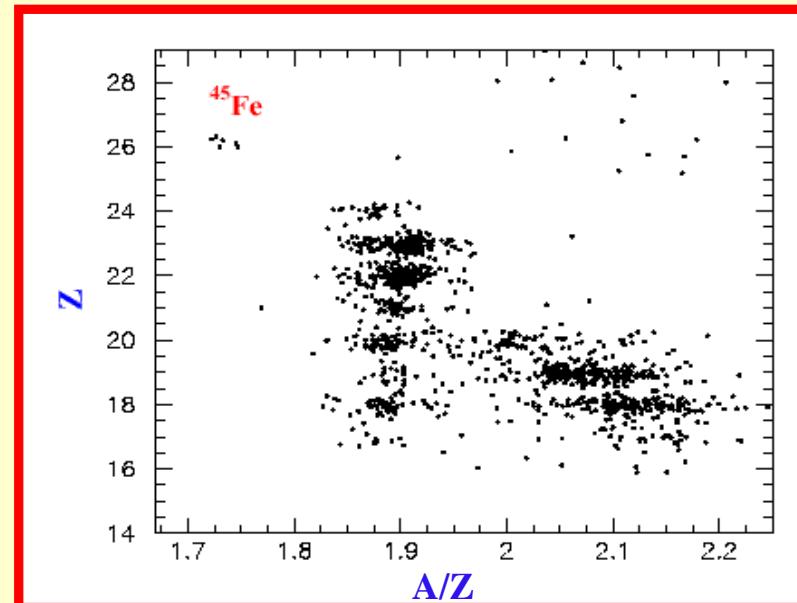


Decay-time spectrum:



- 22 implantations
- 14 decay events at 1.14 MeV
- 4 events at 6 MeV
- 7 events at 3-4 MeV

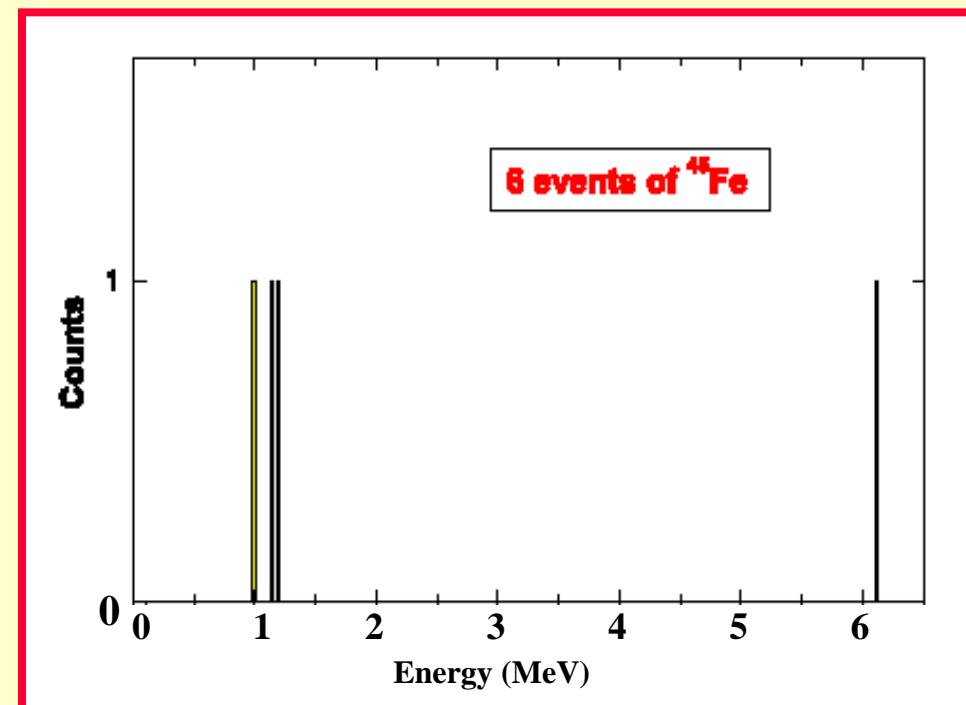
Two-proton decay of ^{45}Fe : GSI data



6 implantation events identified

5 correlated decay events:

- four decays at 1.1 MeV
- one decay event at 6 MeV



Two-proton radioactivity of ^{45}Fe

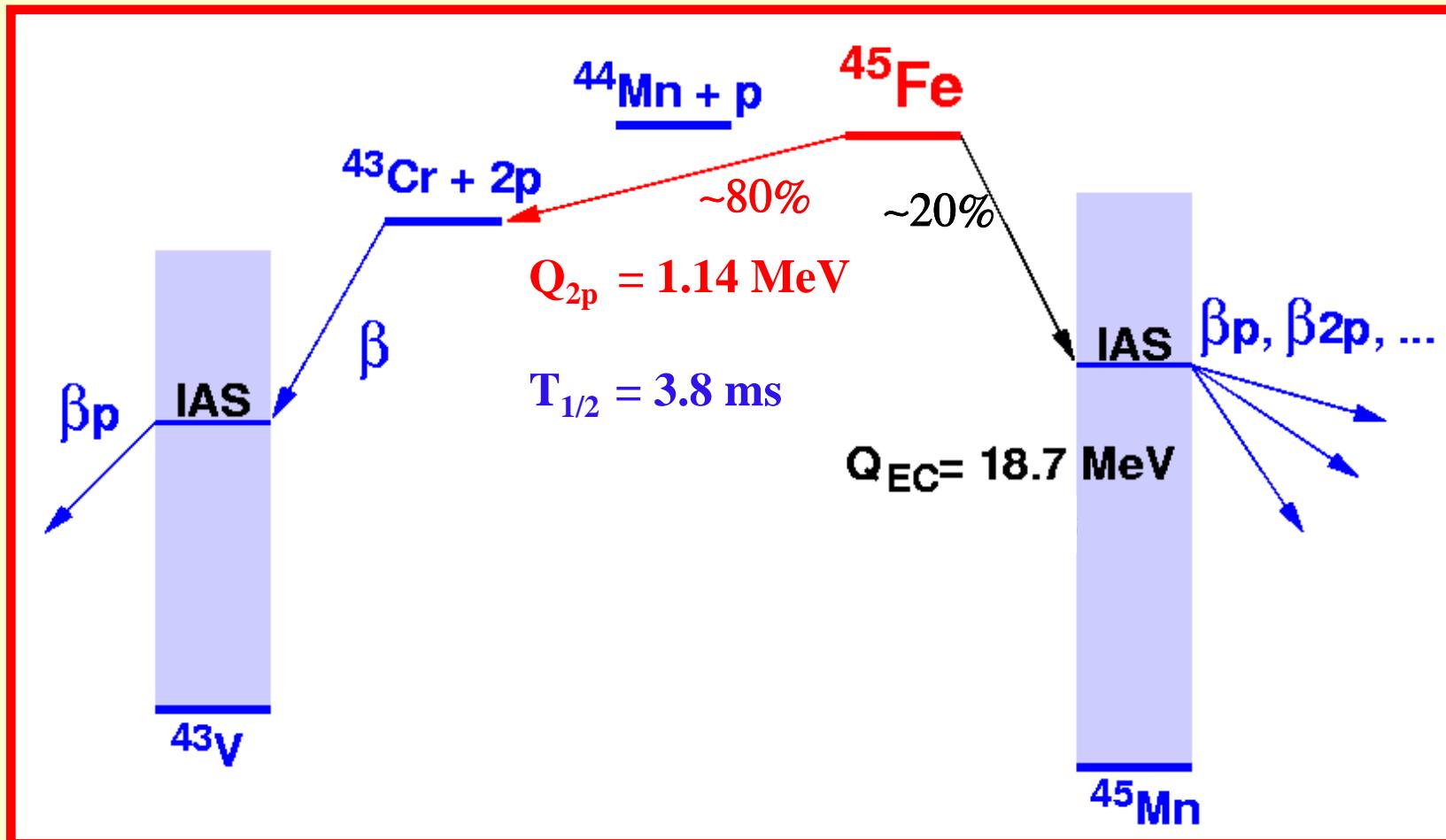
- § Q value in agreement with predictions
- § half-life short enough for 2p emission
- § data in agreement with daughter decay
- § no β pile up for peak
- § no β 's in coincidence with 1.14 MeV peak

No β in coincidence with 1.14 MeV peak:
⇒ one-proton, two-proton, or α emission

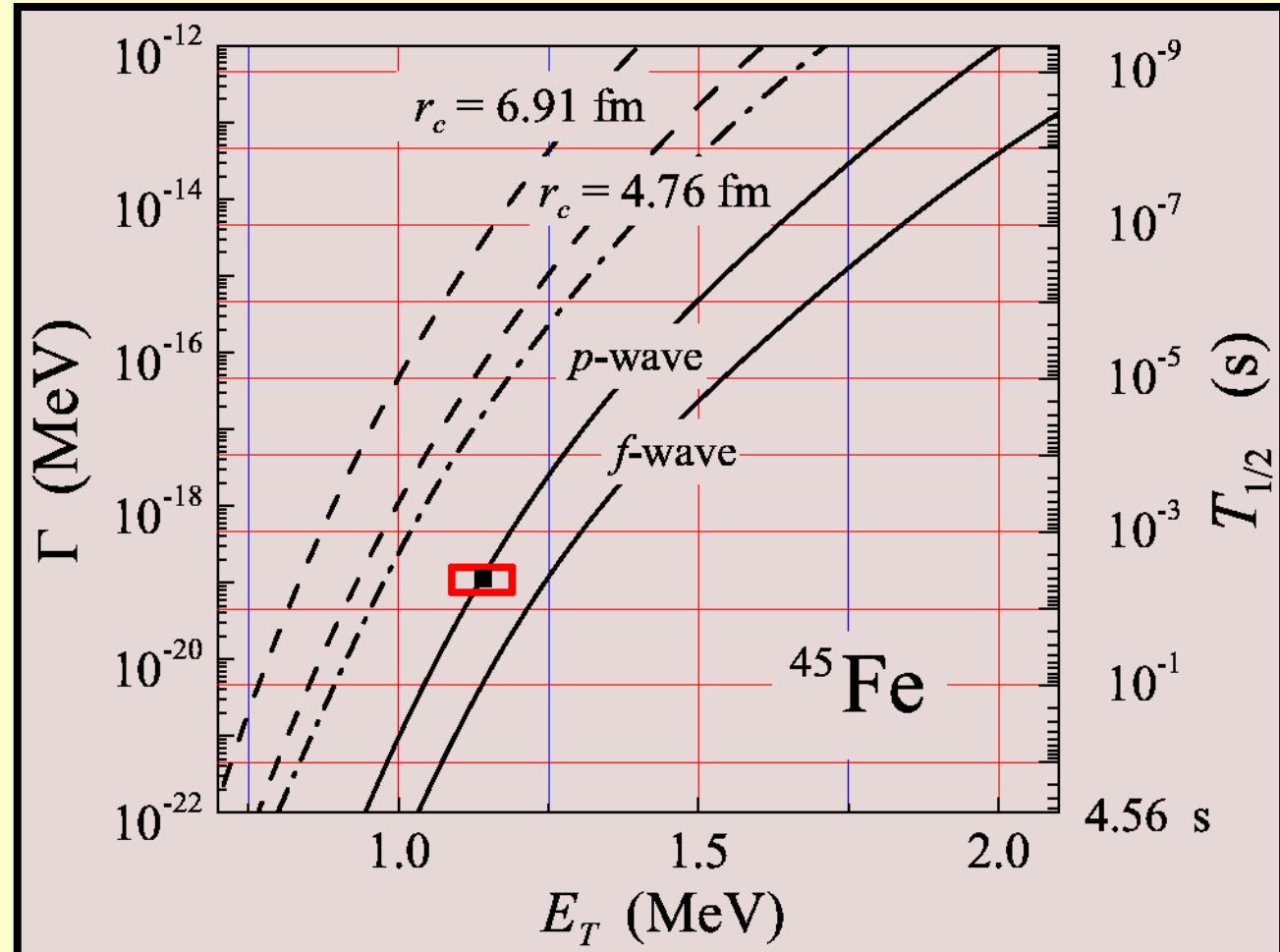
- α decay: $Q_\alpha = -8 \text{ MeV}$
- p decay: $Q_p = -0.1 \text{ MeV}$

⇒ Only 2p emission possible

Two-proton radioactivity of ^{45}Fe



Two-proton radioactivity of ^{45}Fe



di-proton: - - -
3-body: —

Nice agreement between exp. data and predictions for p wave protons
but: f-wave protons expected..... however,

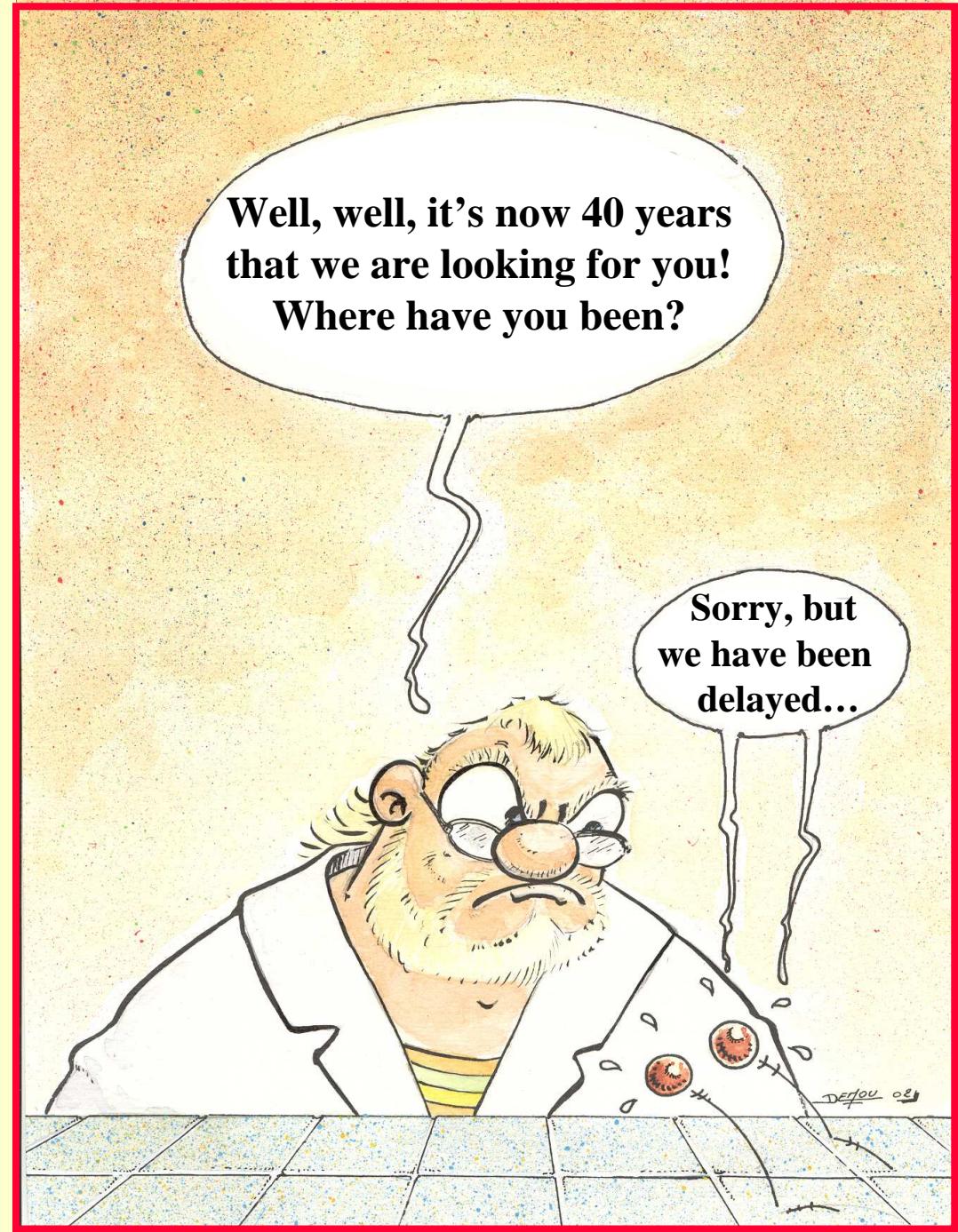
L.V. Grigorenko et al.

Conclusions

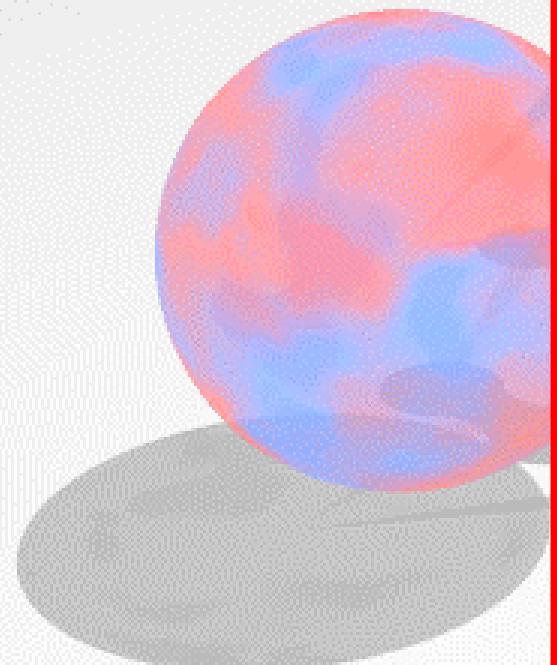
- clear evidence for 2p radioactivity of ^{45}Fe : a new radioactivity

not yet measured:

- individual proton energies
- angle between protons



Two proton emission from light nuclei



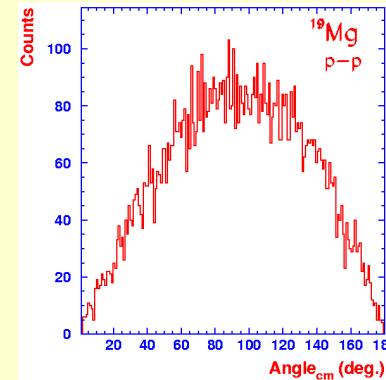
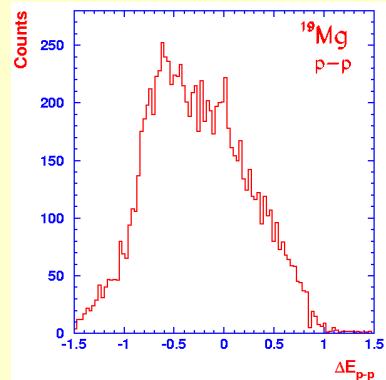
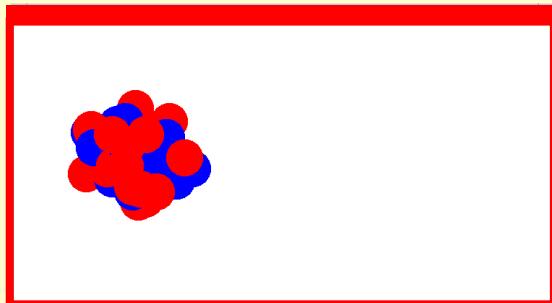
Mass: $A = 6 - 20$

- à $Z = 4 - 12$
- à low Coulomb (+ centrifugal) barrier
- à broad states - short half-lives
- $T_{1/2} = 10^{-21}s - 10^{-12}s$
- à decay already in the target

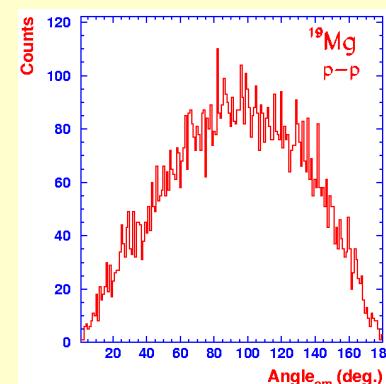
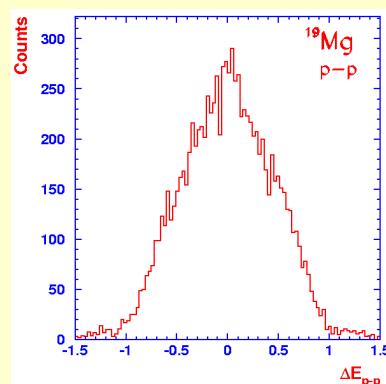
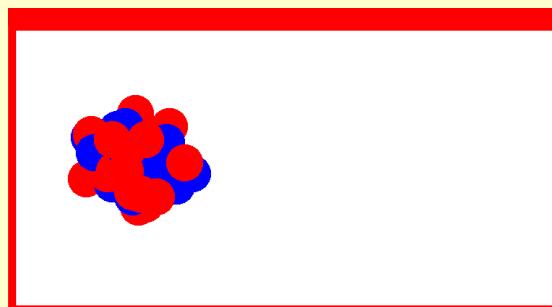
- à complete-kinematics measurements behind production target

Two-proton radioactivity

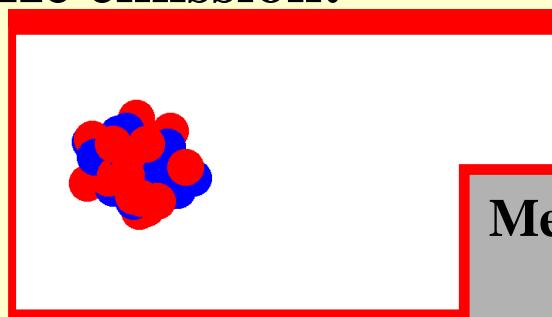
Sequential emission:



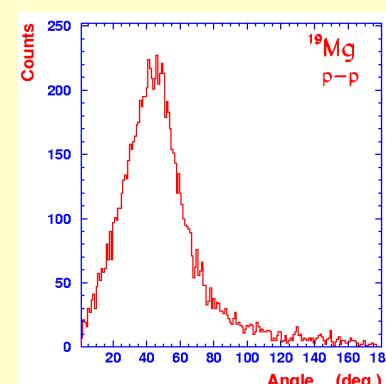
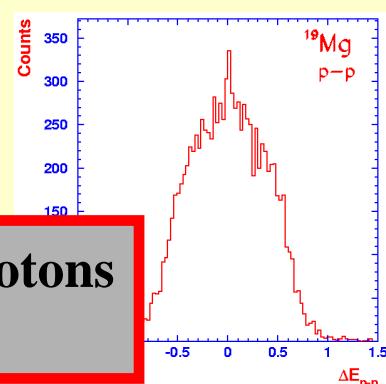
Three-body decay:



^2He emission:

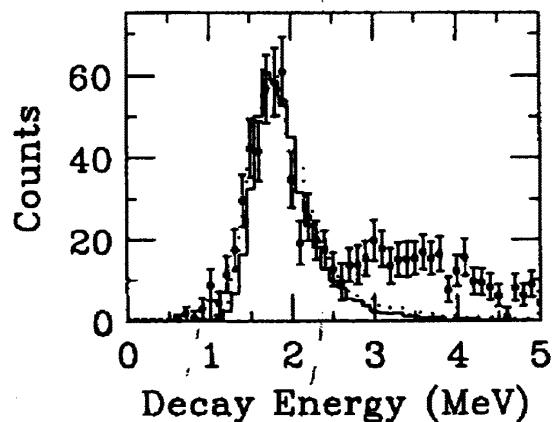


Measurement of protons
and recoil



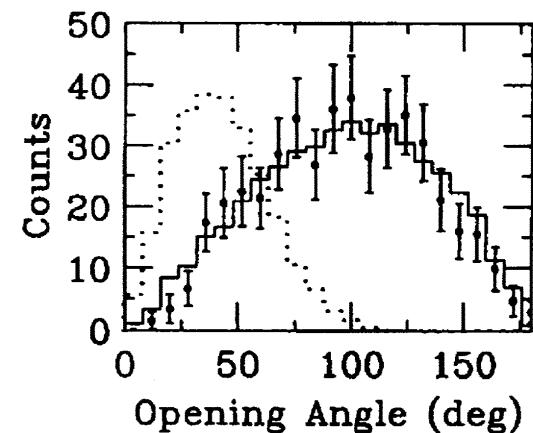
2p emission from ^{12}O

Total decay energy:



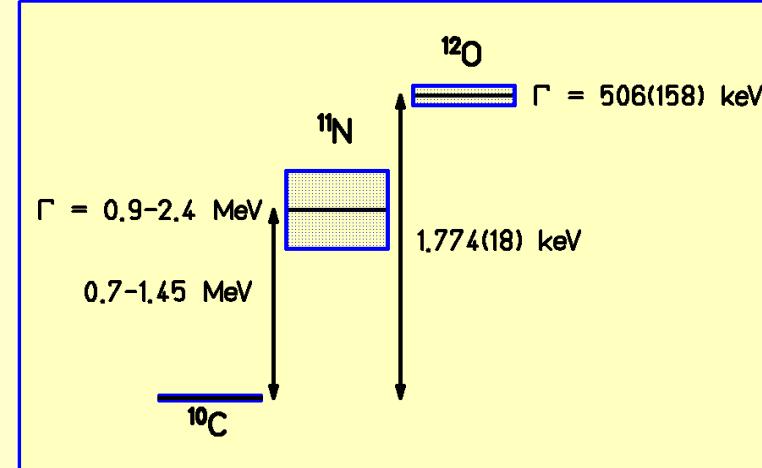
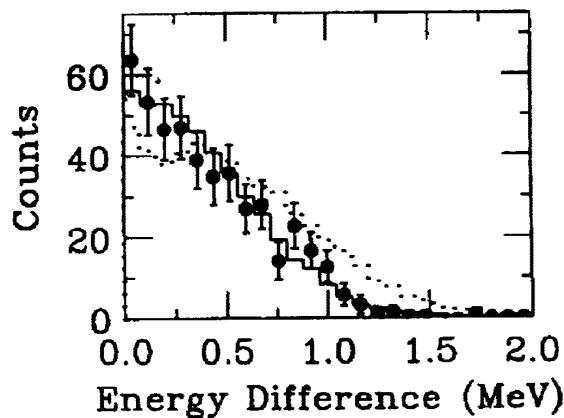
— seq. decay
···· ··· ^2He decay

Proton-proton angle:



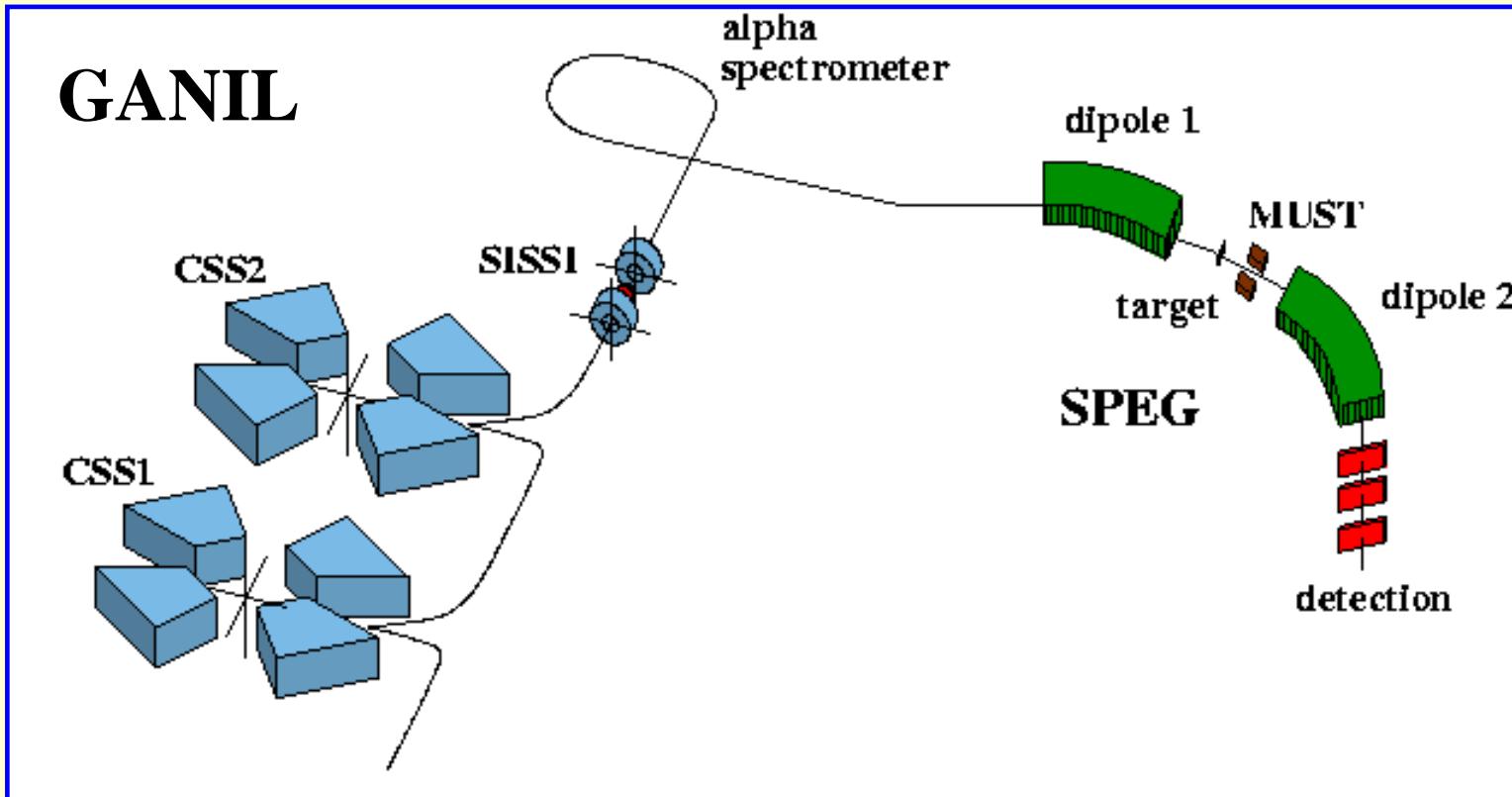
à Data consistent with 3-body or sequential decay

Proton-proton energy:



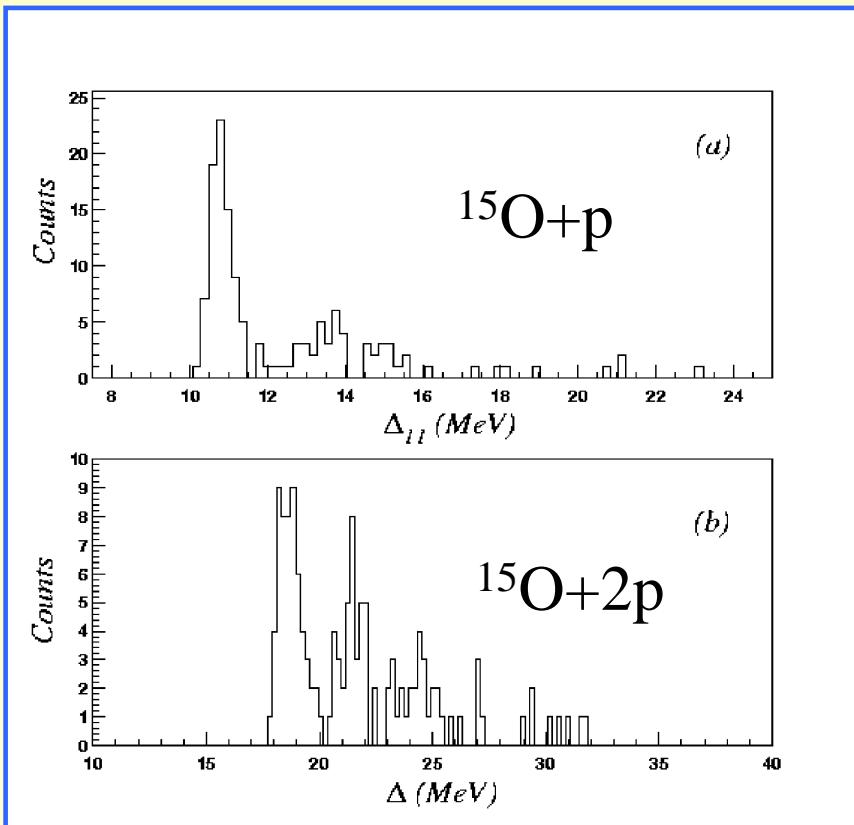
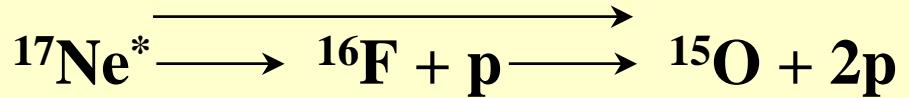
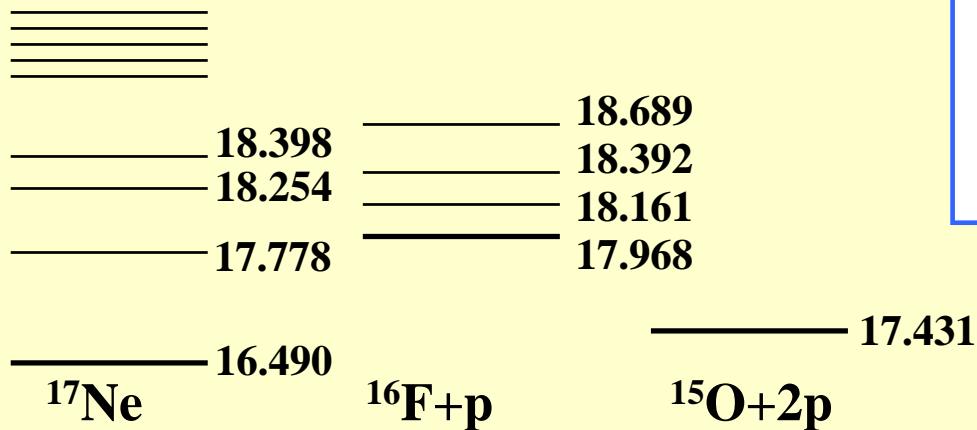
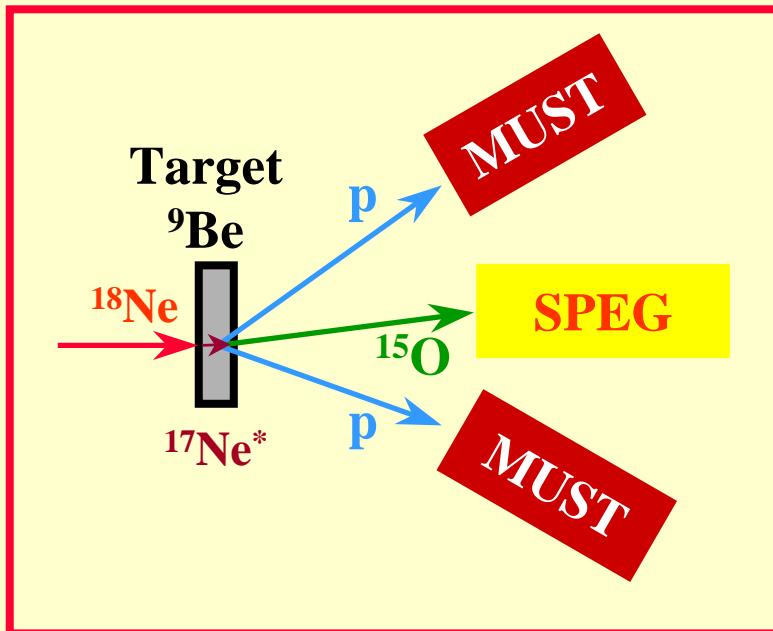
R.A. Kryger et al., Phys. Rev. Lett. 74 (1995) 860

Experimental Procedure



^{24}Mg fragmentation in SISSI at 95 MeV/u
Selection with Alpha spectrometer : ^{17}F , ^{18}Ne , ^{20}Mg
Stripping reactions at entrance of SPEG

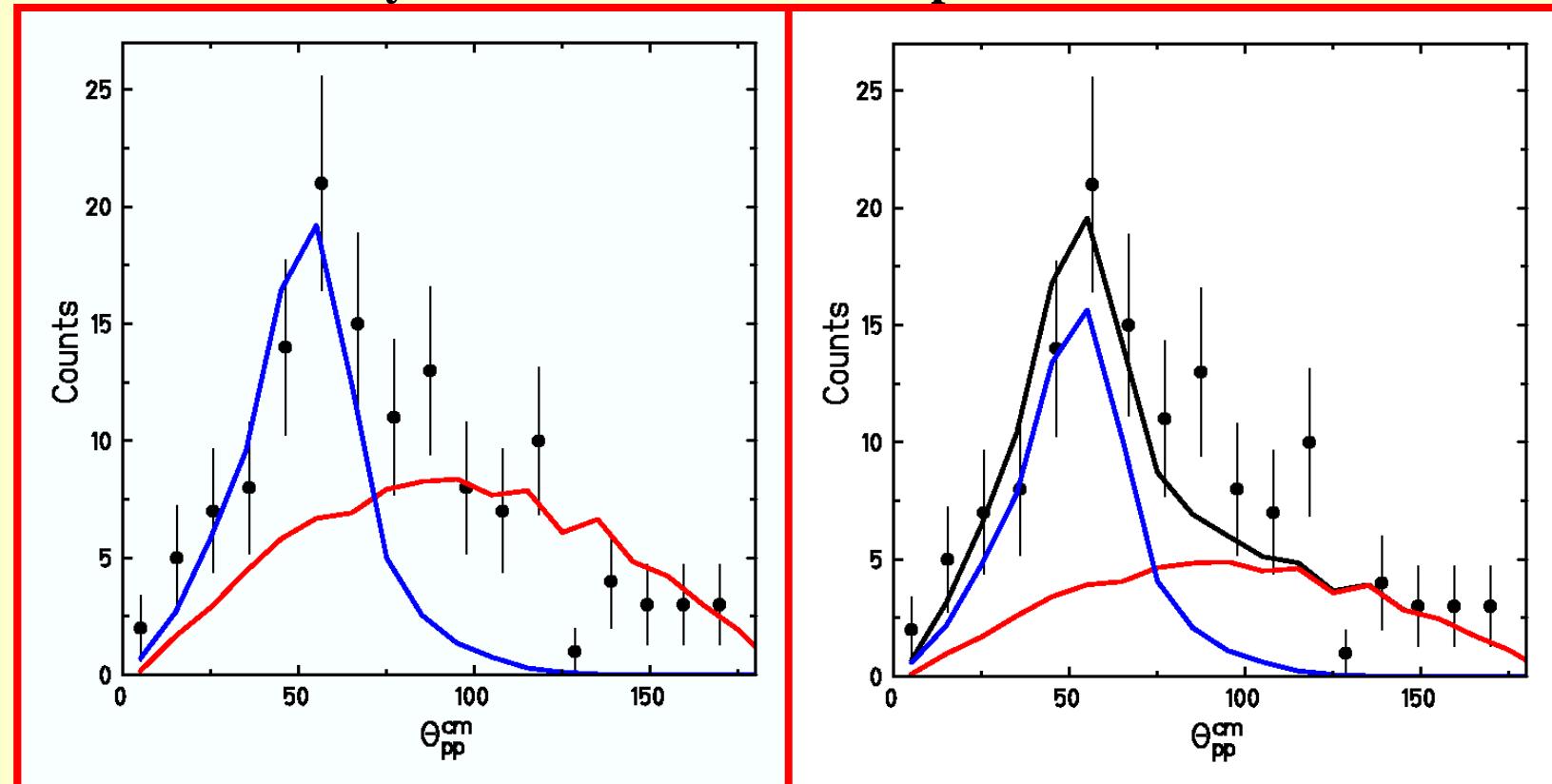
2p emission from ^{17}Ne



Good agreement with known separation energies and ^{16}F

Proton-proton angle distribution

Three-body center of mass frame: 2p emission from $^{17}\text{Ne}^*$

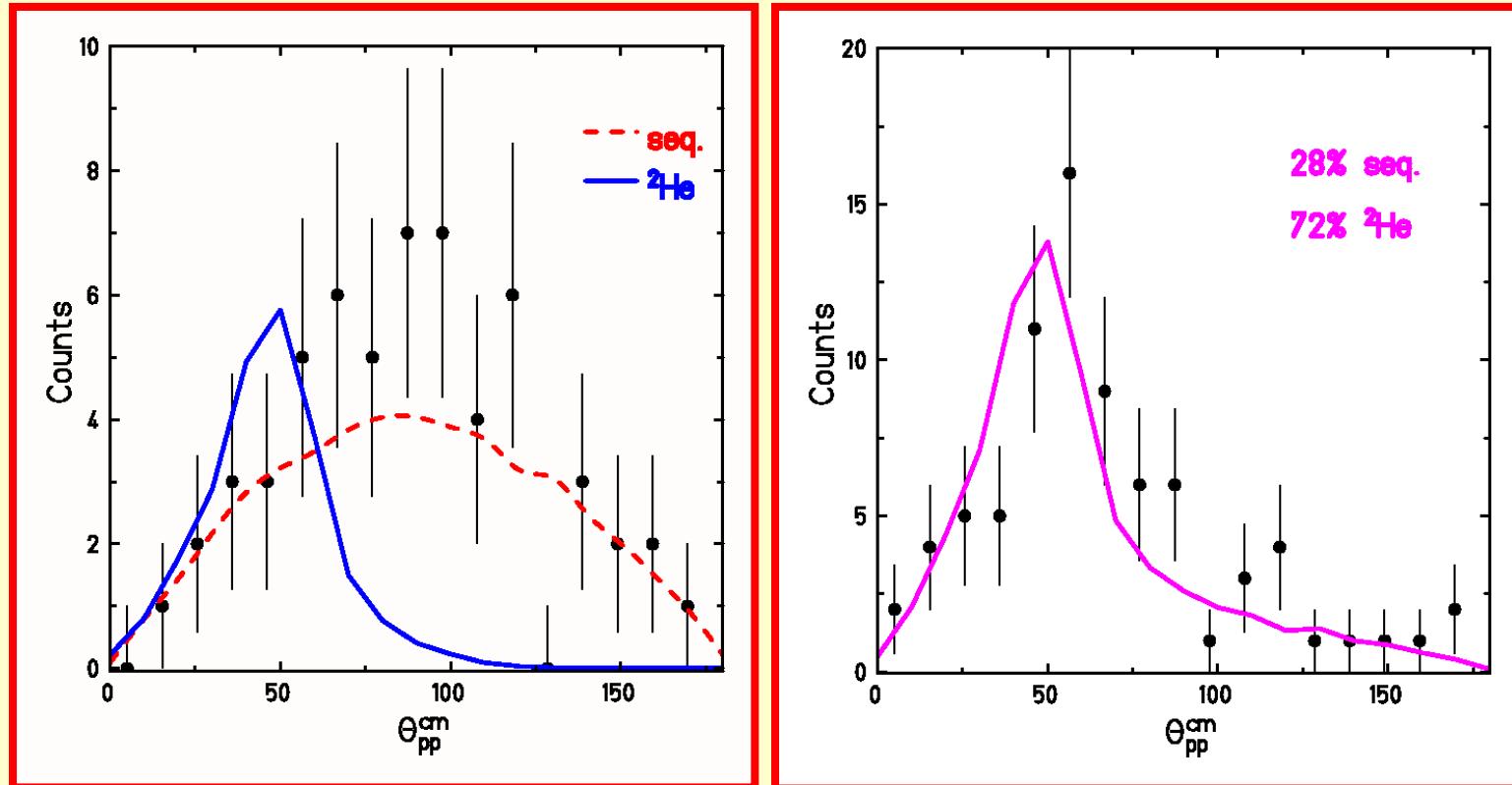


— ^2He
— Sequential / 3-body

— ^2He ($\approx 53\%$)
— Sequential ($\approx 47\%$)
— Sum

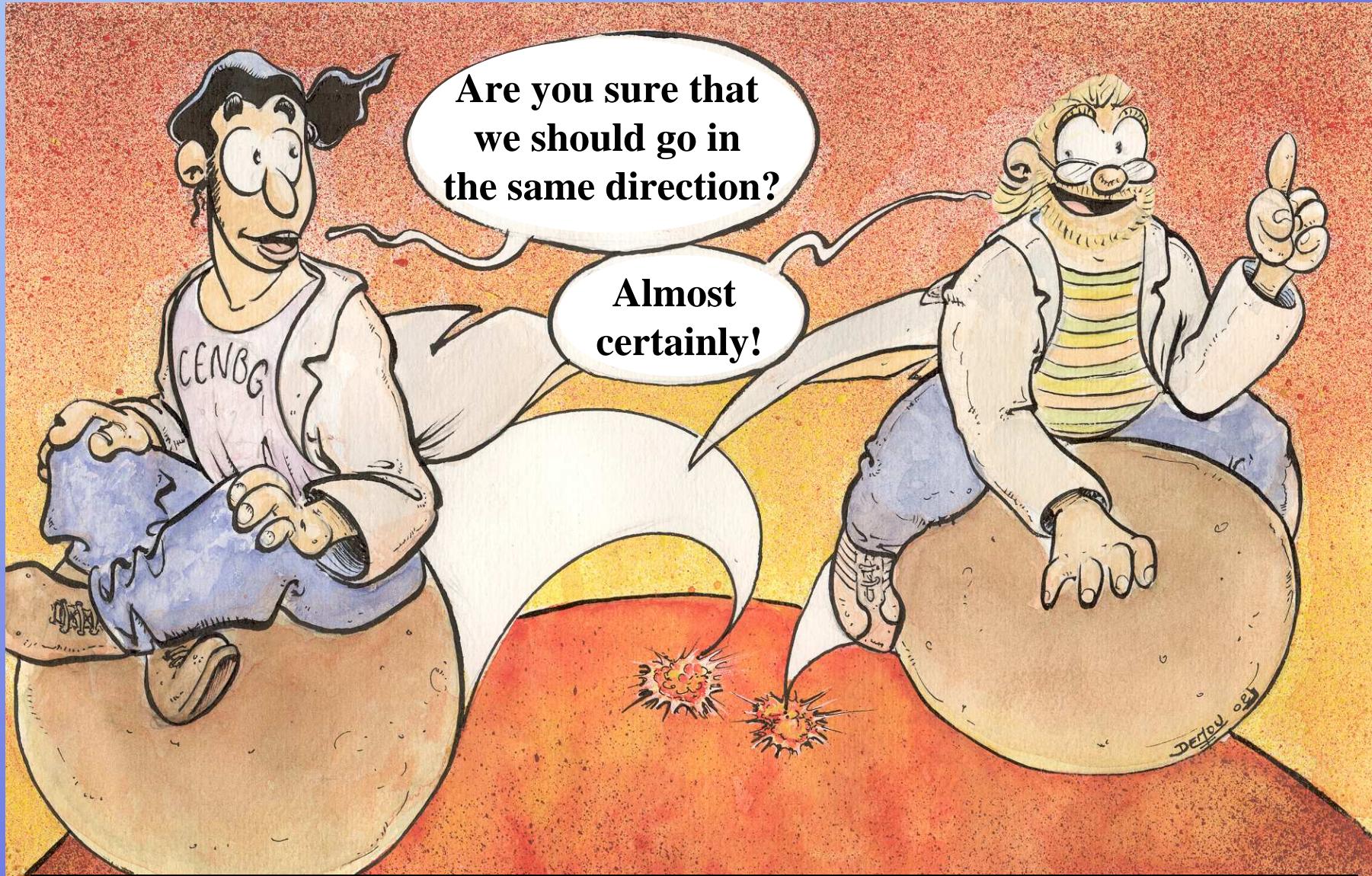
Proton-proton angle distribution

Three-body center of mass frame: 2p emission from $^{17}\text{Ne}^*$



- Agreement with MSU data : no angular correlation for $Q_{2p} = 0.9 \text{ MeV}$ states
- Indication of angular correlation for higher lying states.....

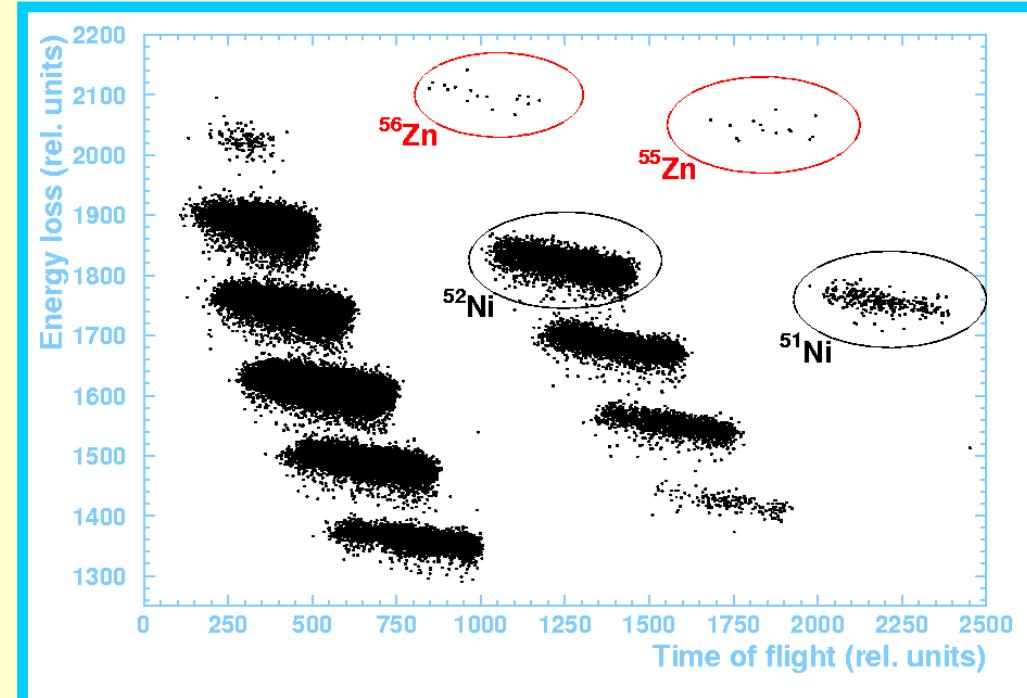
2p or not 2p.....



Possible explanation: halo-like structure for excited state(s)

Future studies

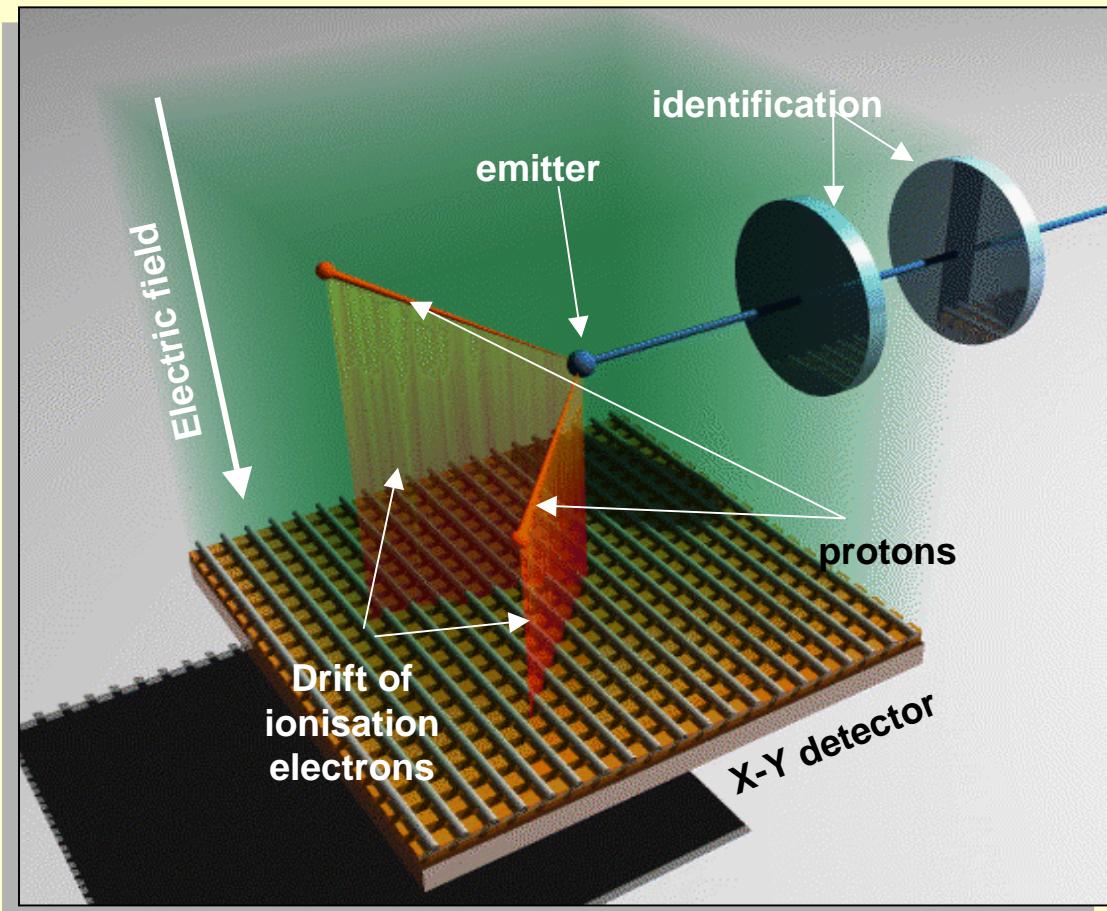
- other candidates:
 ^{48}Ni , ^{54}Zn
- decay mechanism:
 ^2He or 3-body
- setup to measure
p – p angle and
individual energies
→ TPC
- 2p emission from
 $^{16,17}\text{Ne}$ with MUST &
VAMOS



Expected production rate for ^{54}Zn :
10-15 per day

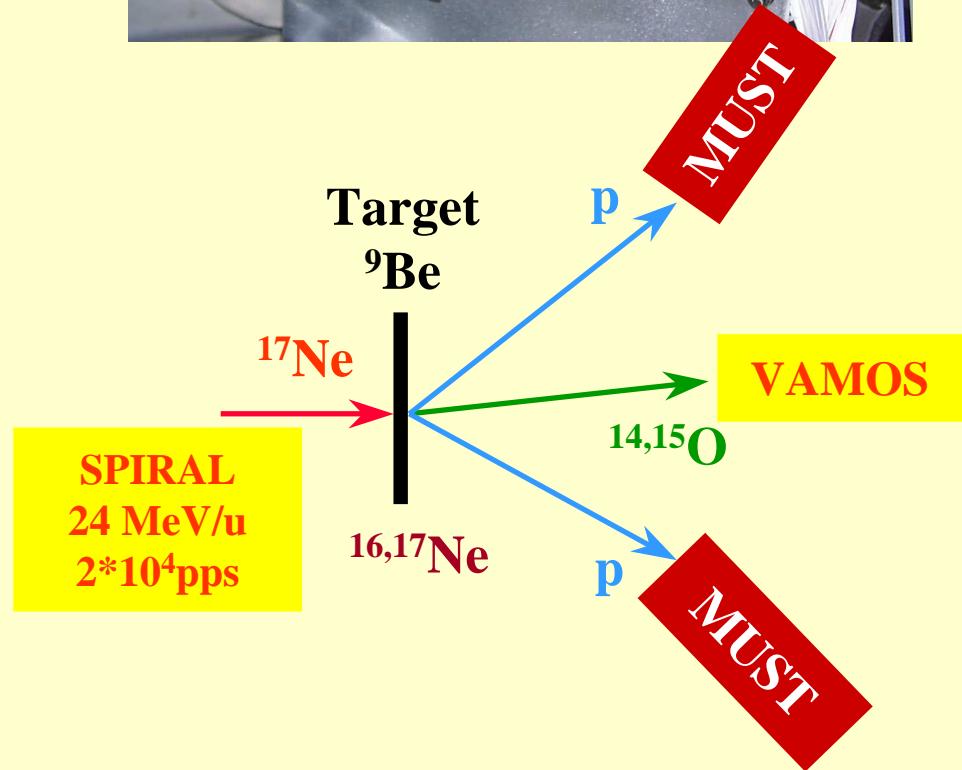
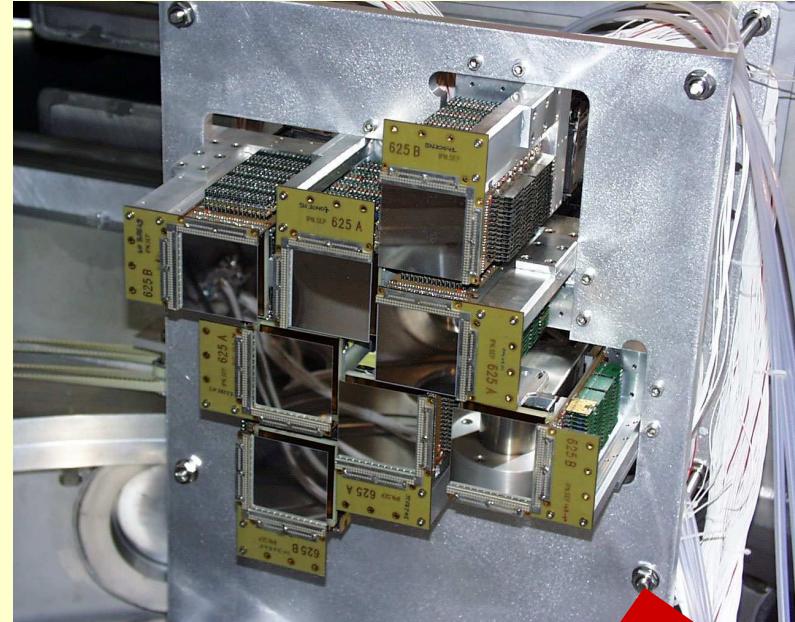
Future studies

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