Search for unknown proton-unbound nuclei by tracking their decay products with micro-strip detectors in-flight

UNIVERSIDAD DE SEVILLA

Ivan Mukha for the S271 collaboration

- **Discovery of a new isotope ^{19}Mg by using a tracking technique with micro-strip detectors.**

- **Observation of two-proton radioactivity of ^{19}Mg by measuring decay vertex and its fragment correlations.**

- **Three-body correlations in 2p decays of ^{16}Ne and ^{19}Mg.**

- **Spectroscopy of proton-unbound nuclei ^{15}F, ^{16}F, ^{18}Na, ^{19}Na.**

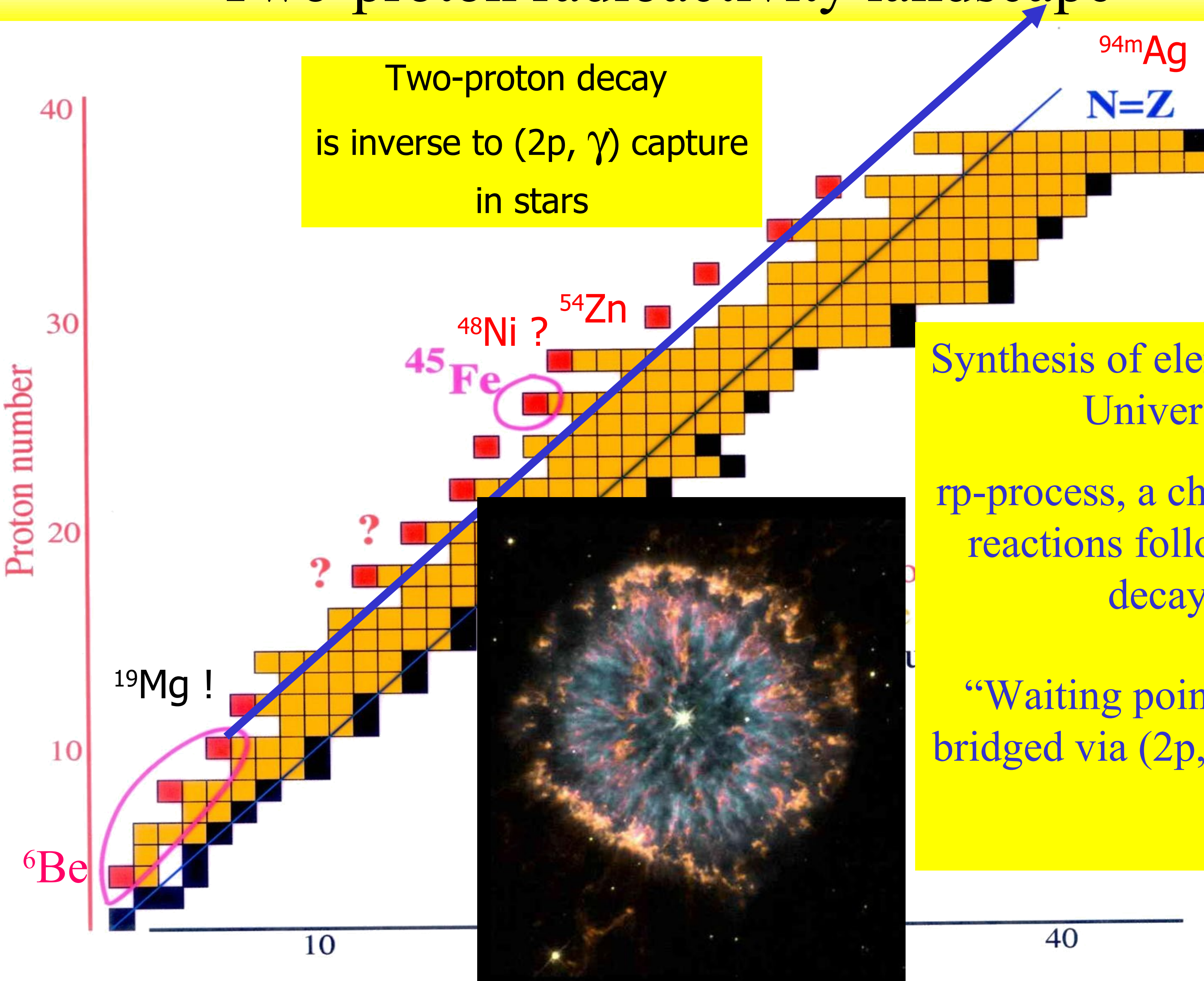
- **Prospective experiments on nuclei beyond the proton drip line with this technique: ^{30}Ar, ^{34}Ca, ^{69}Br.**

Two-proton radioactivity landscape

Two-proton decay

is inverse to (2p, γ) capture

in stars



Synthesis of elements in the Universe:

rp-process, a chain of (p,γ) reactions followed by β decays.

“Waiting points” can be bridged via (2p, γ)

Prospective studies of 2p-radioactivity

Short-lived nuclei:

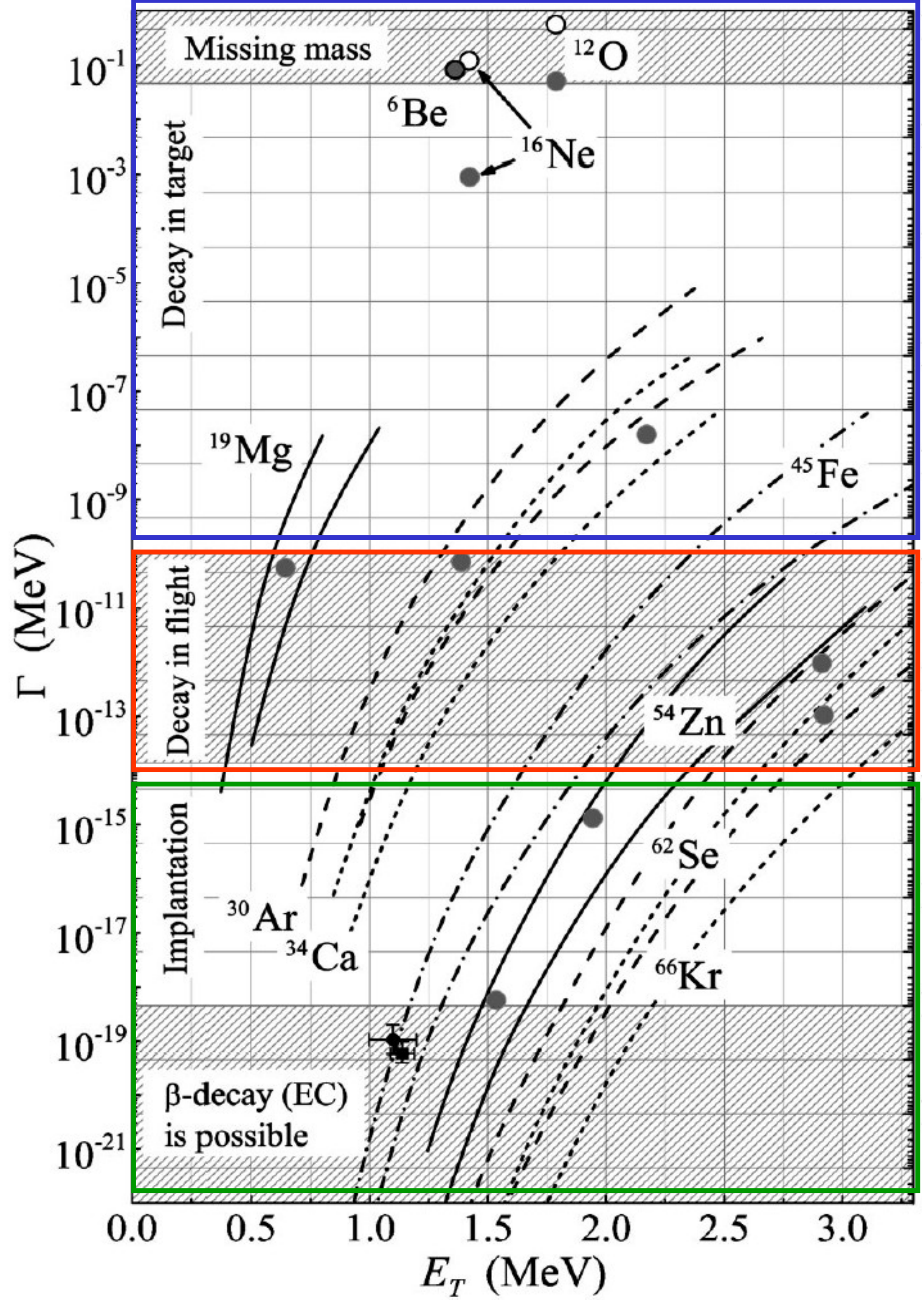
^{6}Be, ^{12}O, ^{16}Ne, ^{34}Ca

In-flight decay candidates:

^{19}Mg, ^{30}Ar, ^{34}Ca ^{58}Ge,^{68}Se,^{66}Kr

Experiments with stopped ions:

^{45}Fe,^{48}Ni,^{54}Zn,^{58}Ge,^{62}Se,^{66}Kr,^{94m}Ag



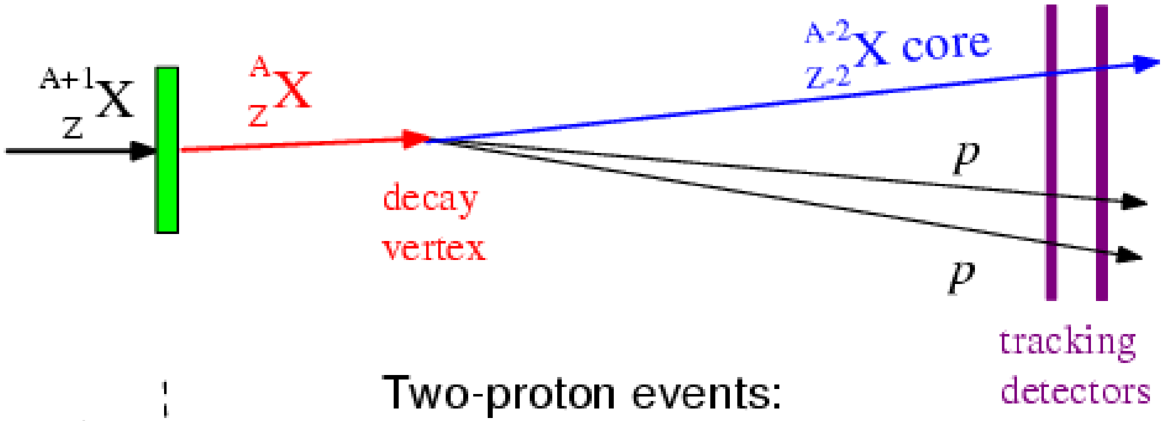
L.V. Grigorenko, I.G. Mukha, M.V. Zhukov, Proc. PROCON'03 (AIP **681**, NY 2003) 126.

B.A. Brown and F.C. Barker, *ibid*., p. 118.

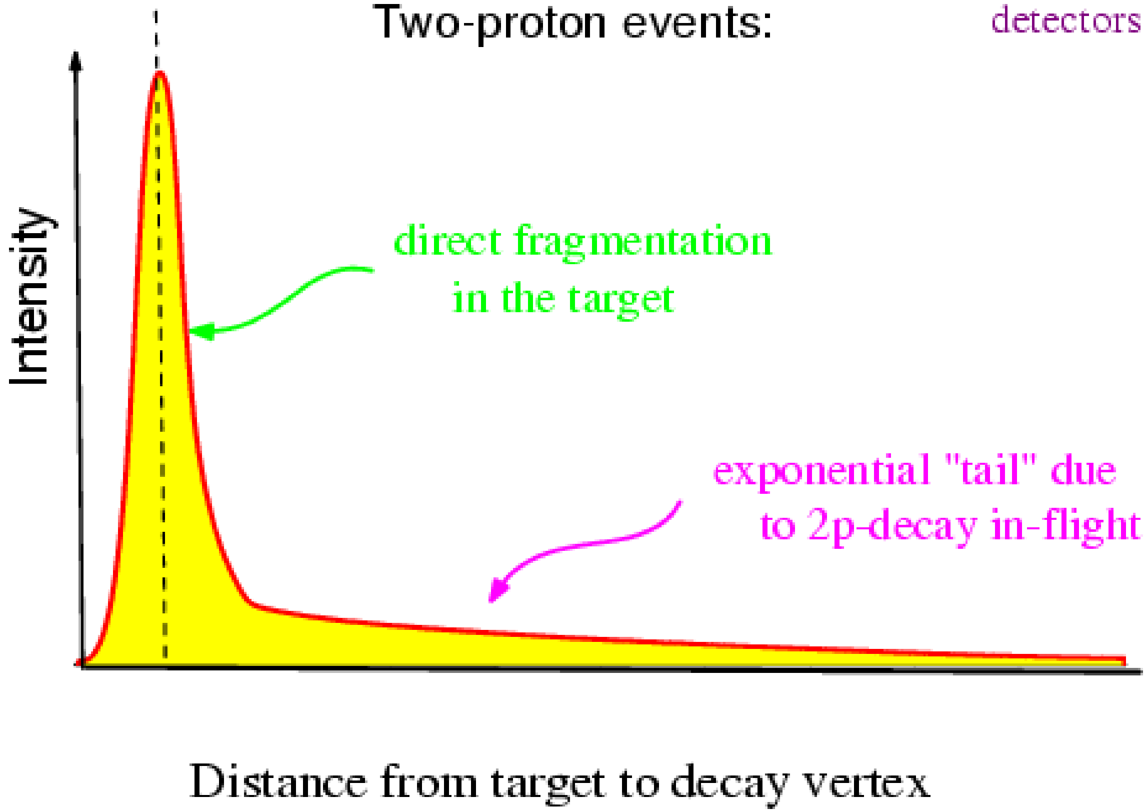
L.V. Grigorenko and M.V. Zhukov, PRC **68** (200

Idea of experiment

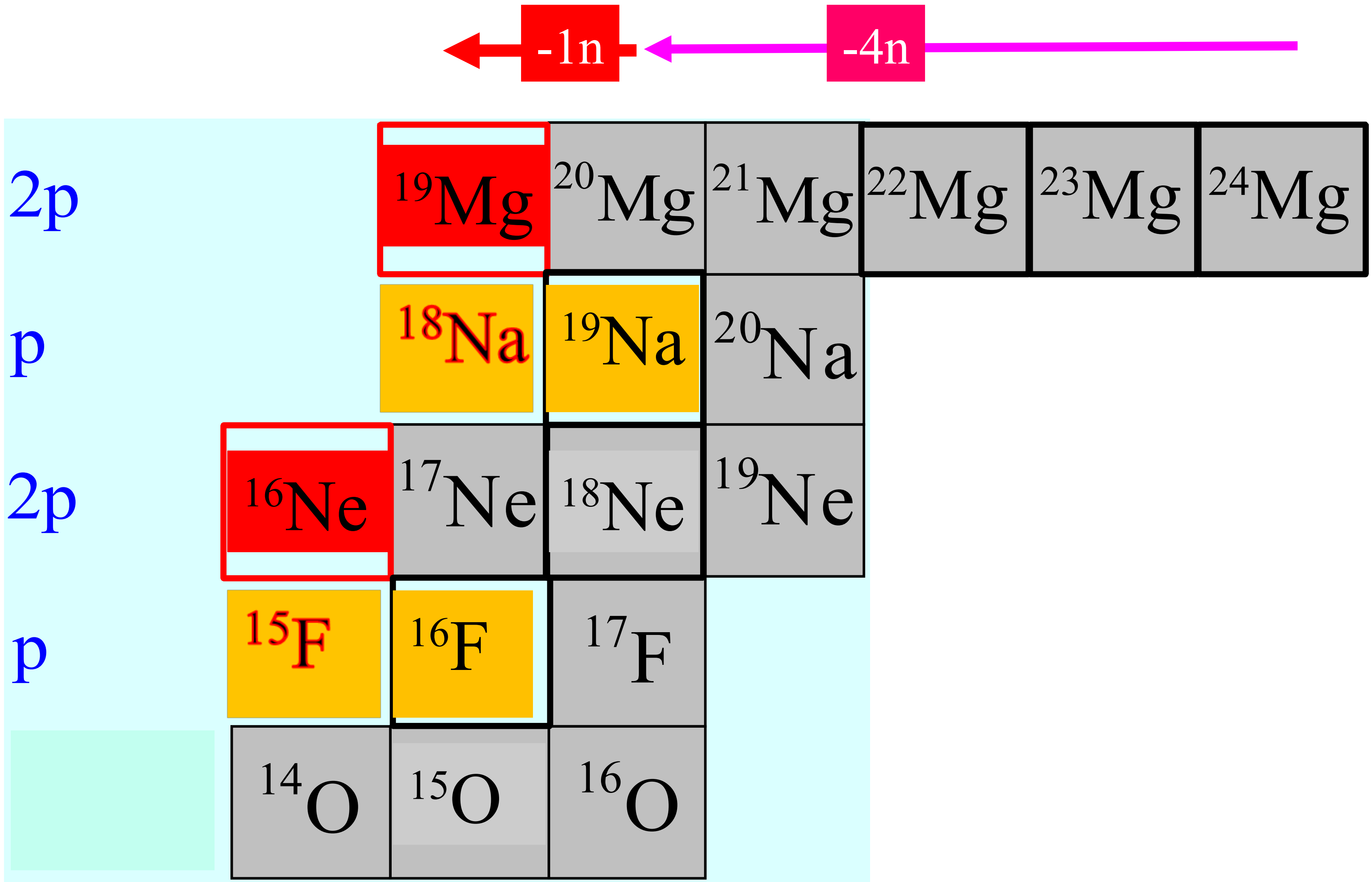
Schematic layout



Two-proton events:

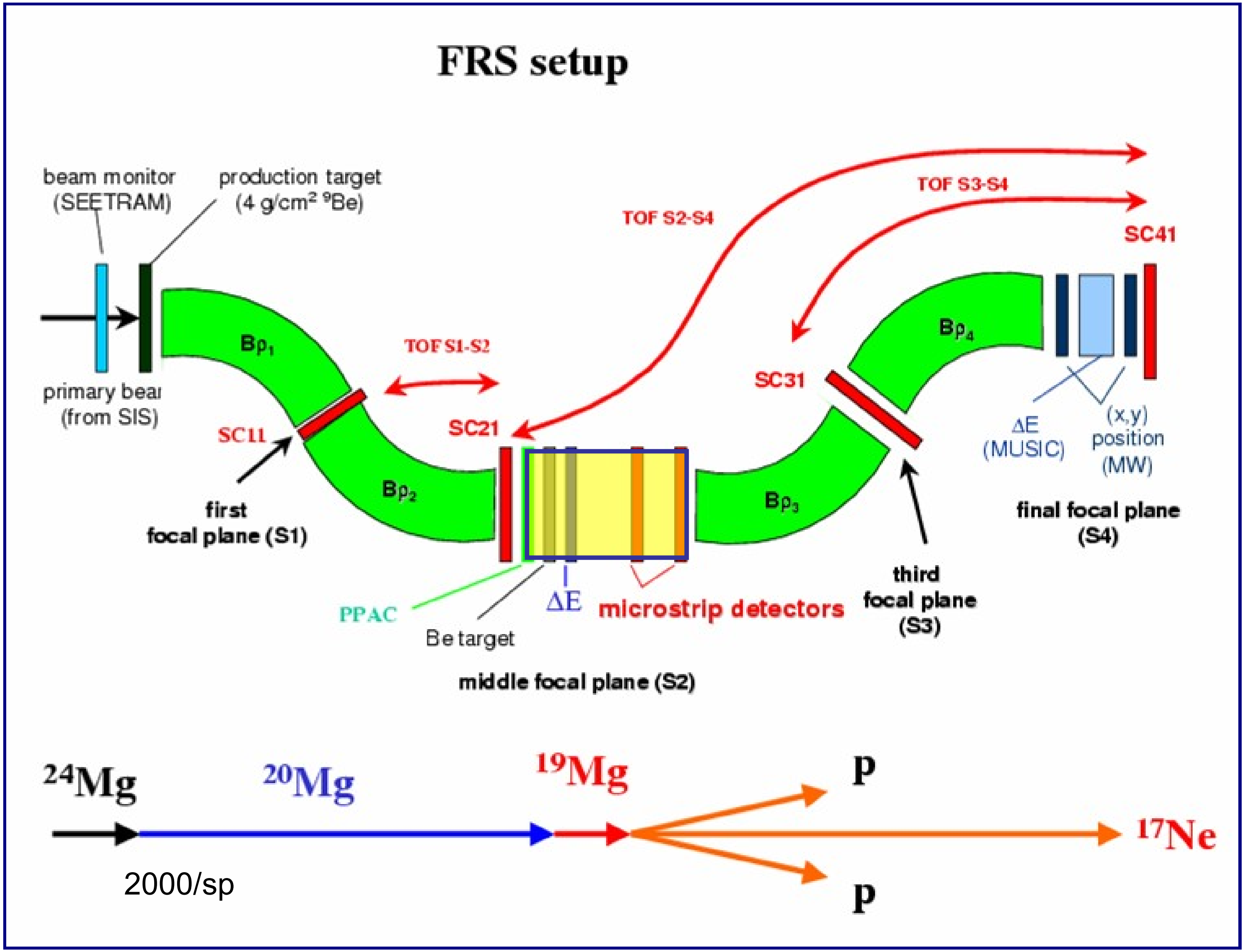


Life-times accessible : 0.5 – 10000 ps


-1n
-4n
2p
p
2p
p
^{19}Mg
^{20}Mg
^{21}Mg
^{22}Mg
^{23}Mg
^{24}Mg
^{18}Na
^{19}Na
^{20}Na
^{16}Ne
^{17}Ne
^{18}Ne
^{19}Ne
^{15}F
^{16}F
^{17}F
^{14}O
^{15}O
^{16}O

Santiago08

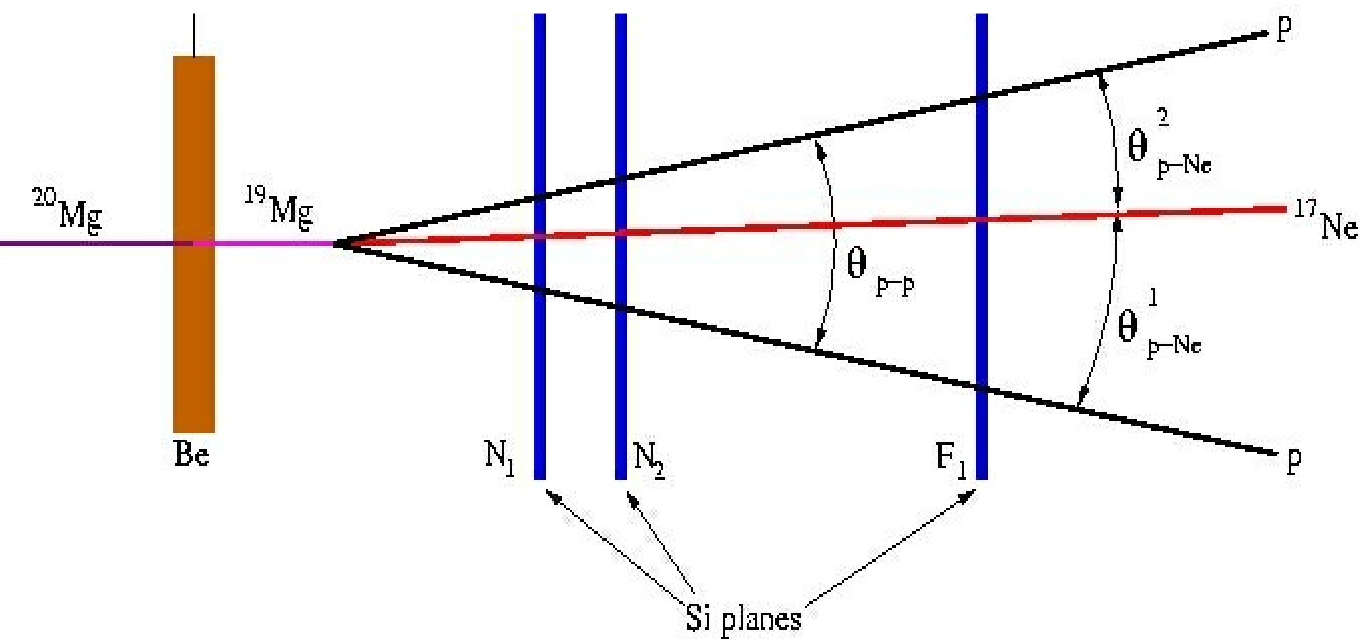
The S271 experiment at GSI, 2006.

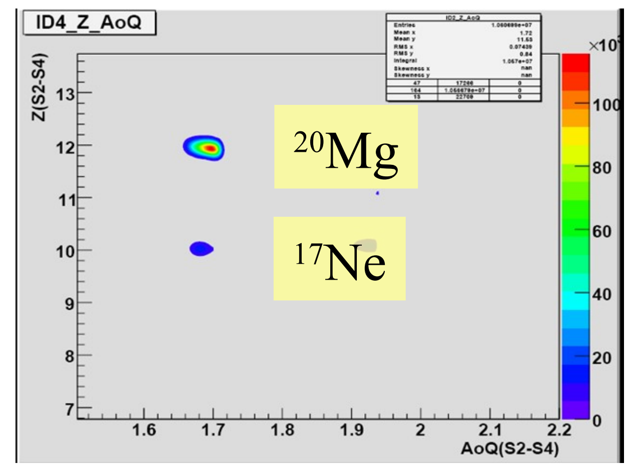


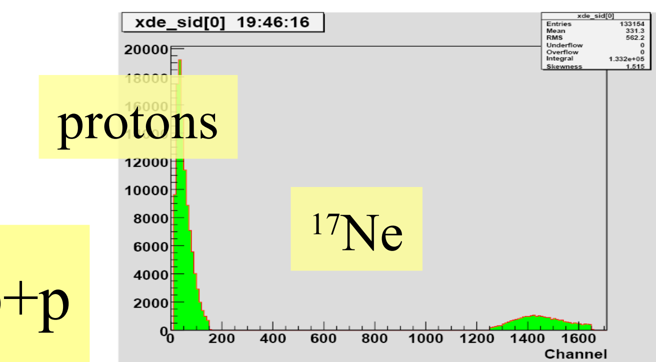
<u>Collaboration:</u> GSI, Sevilla, Huelva, Edinburgh, Moscow, Warsaw, Dubna, Santiago de Compostela.

Close-up view

Identification of fragments



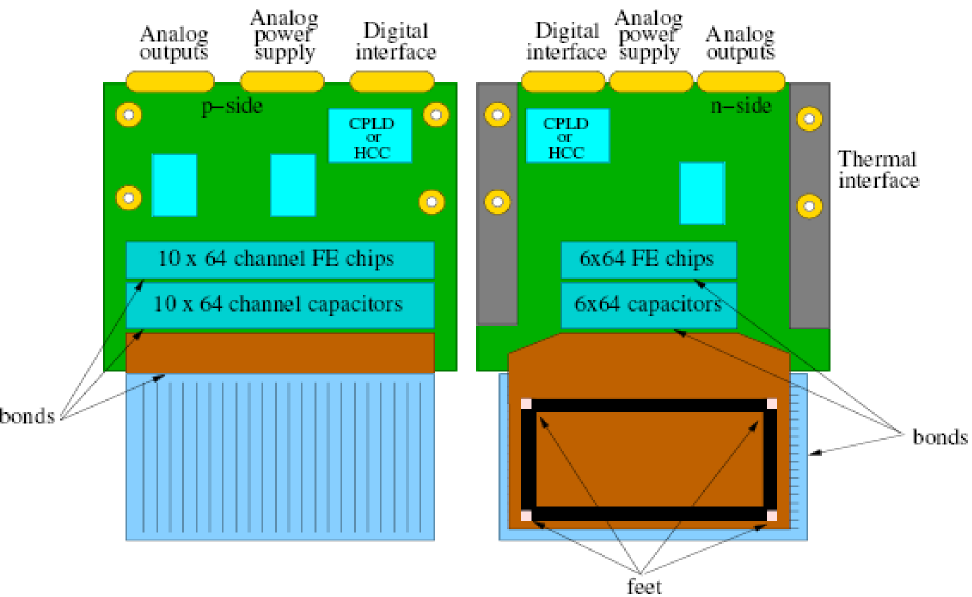


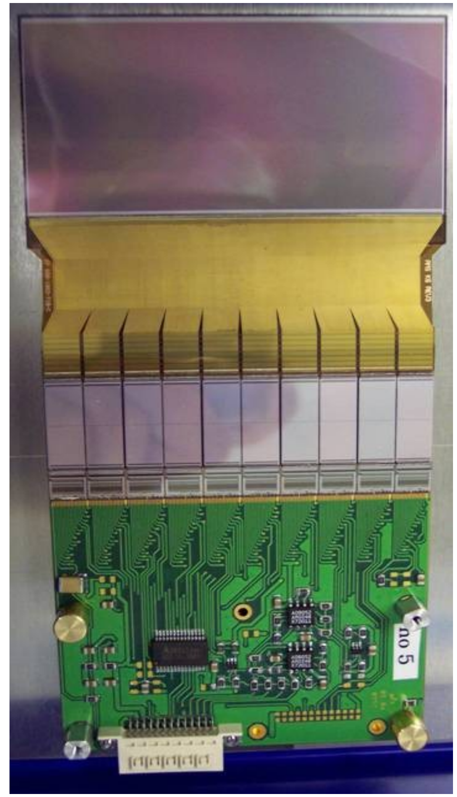


One-neutron removal reaction $^{20}Mg \rightarrow ^{19}Mg \rightarrow ^{17}Ne+p+p$

Fragmentation $^{20}Mg \rightarrow ^{17}Ne+p+p+n$

The micro-strip detectors used for tracking





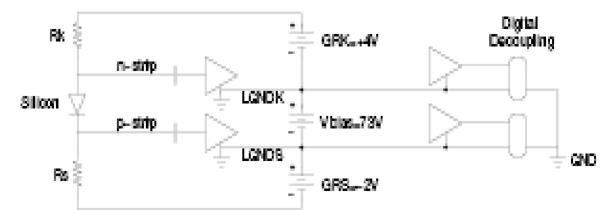
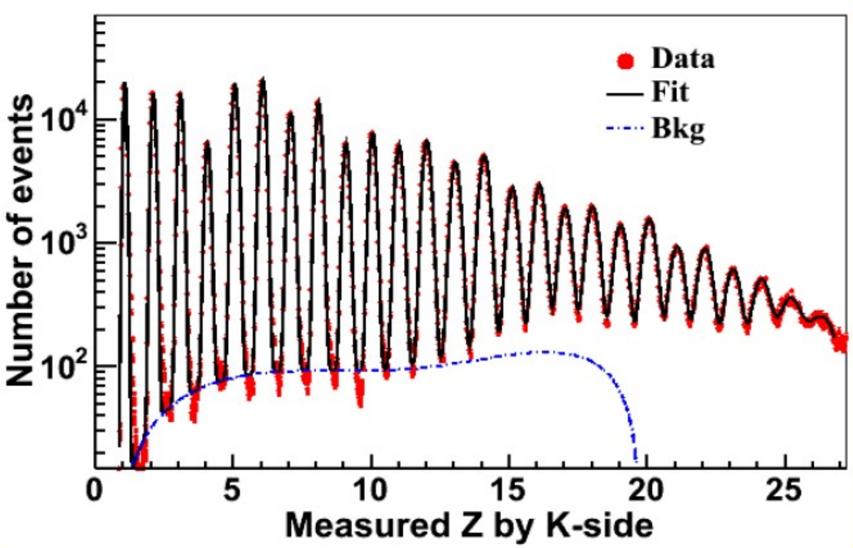


Figure 8: Grounding scheme. (to be checked)

Elements resolved by the AMS02 tracker, GSI data 2003



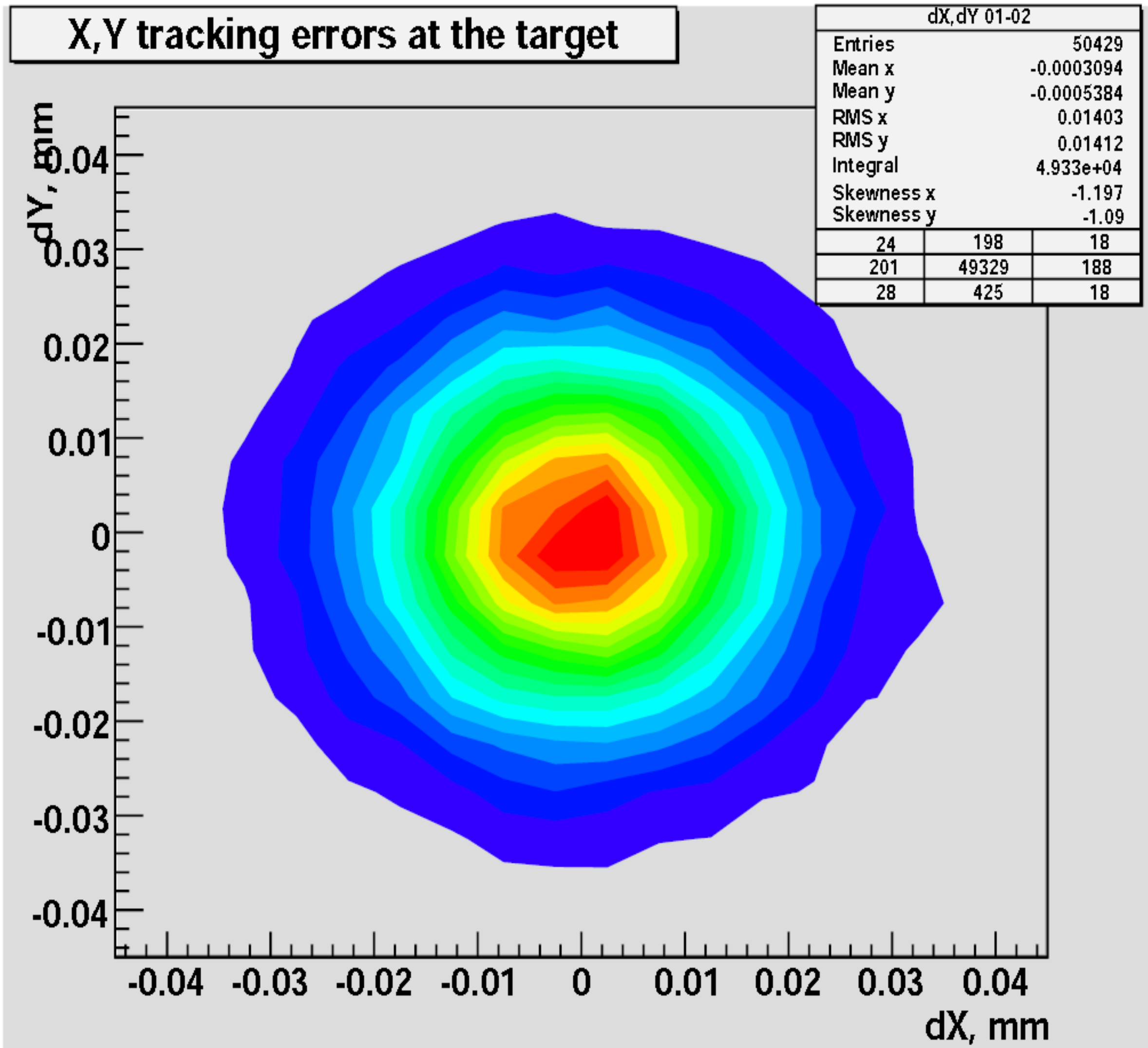
Dimensions 70x40 mm², 100 micron strip pitch, in total 1000 channels

http://dpnc.unige.ch/ams/GSItracker/www/

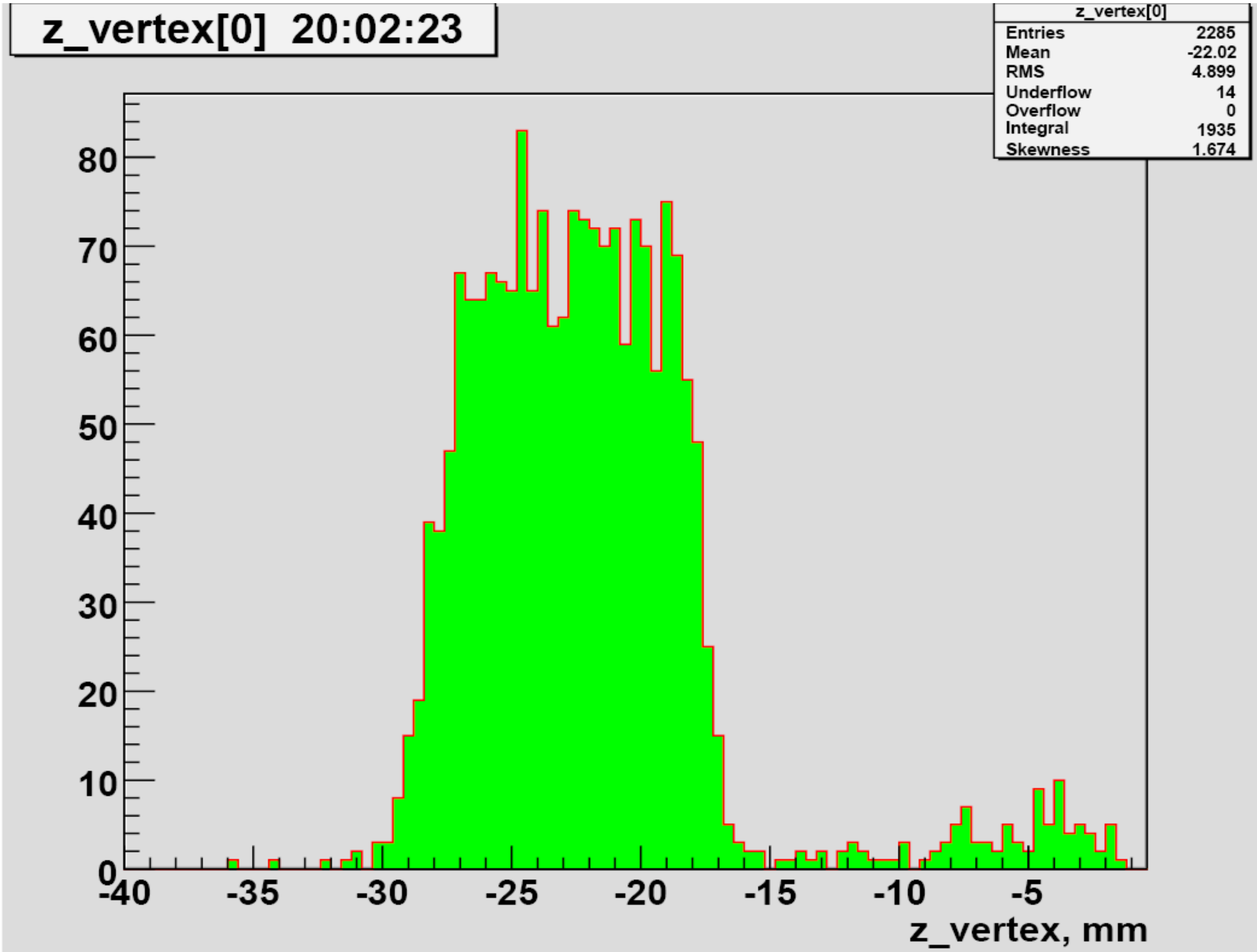
Front-end electronics: VA64_hdr9 chips from IDE AS. Serial read-out, digitalization, pedestal and common-noise subtraction made by the GSI electronics and integration with the GSI DAQ.

X,Y uncertainties of tracking

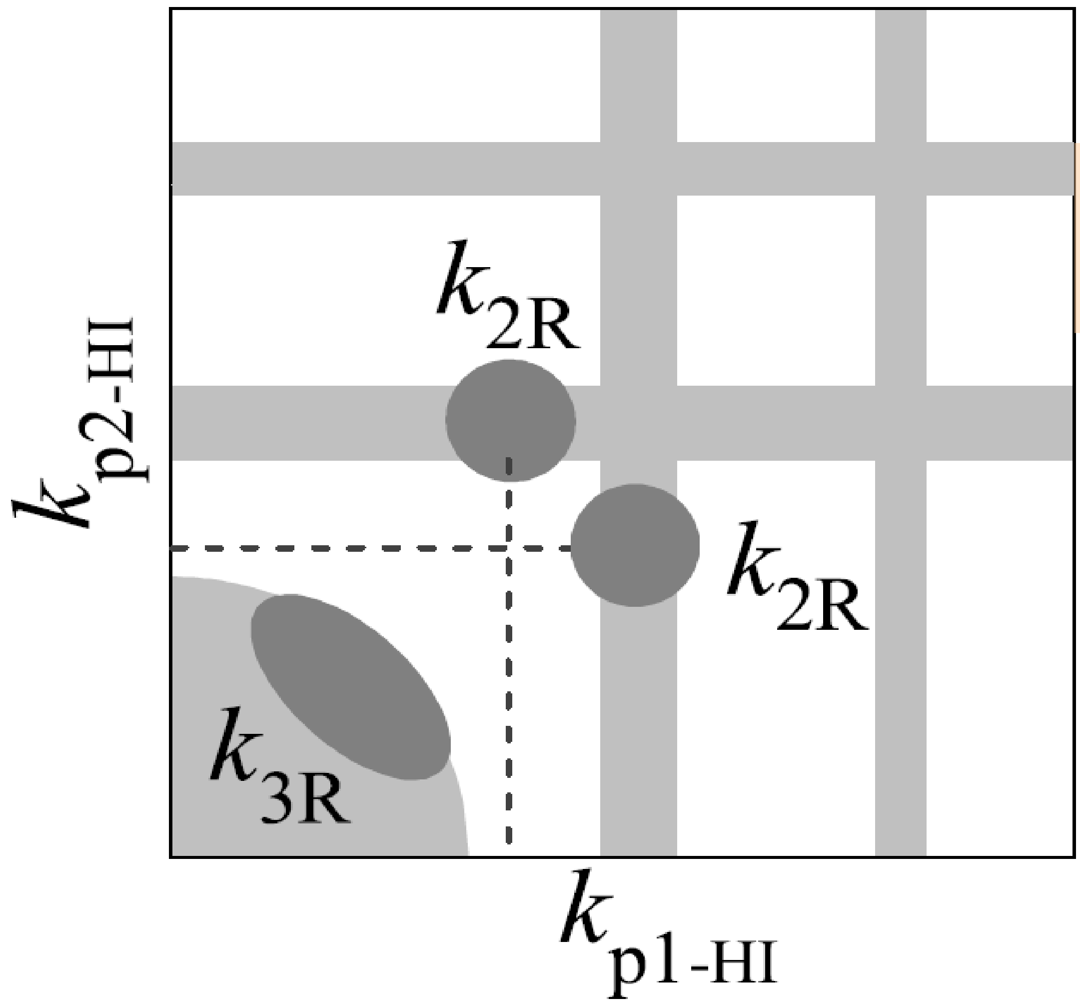
for heavy-ions ~14 μm, for protons ~30 μm



Vertex distributions of ^{18}Ne+p+p events from the target. Radioactivity events are excluded.



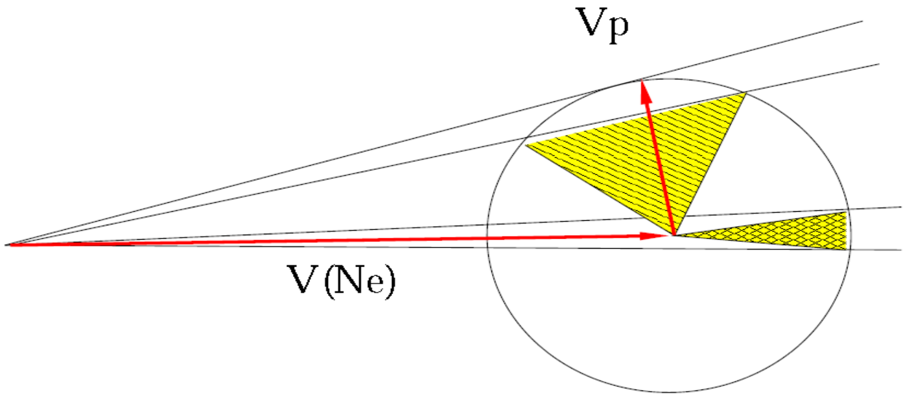
How to identify a reaction channel ? Momentum correlations of fragments in 2p decays, a complete kinematics case

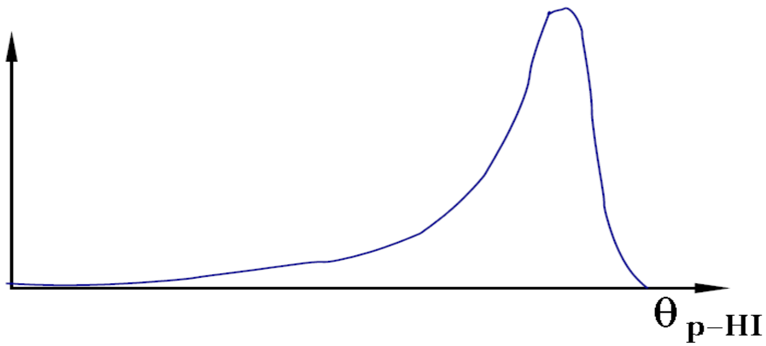


k_{2R} - sequential 2p emission via an intermediate 1p resonance

k_{3R} - direct 2p emission, three-body decay mechanism

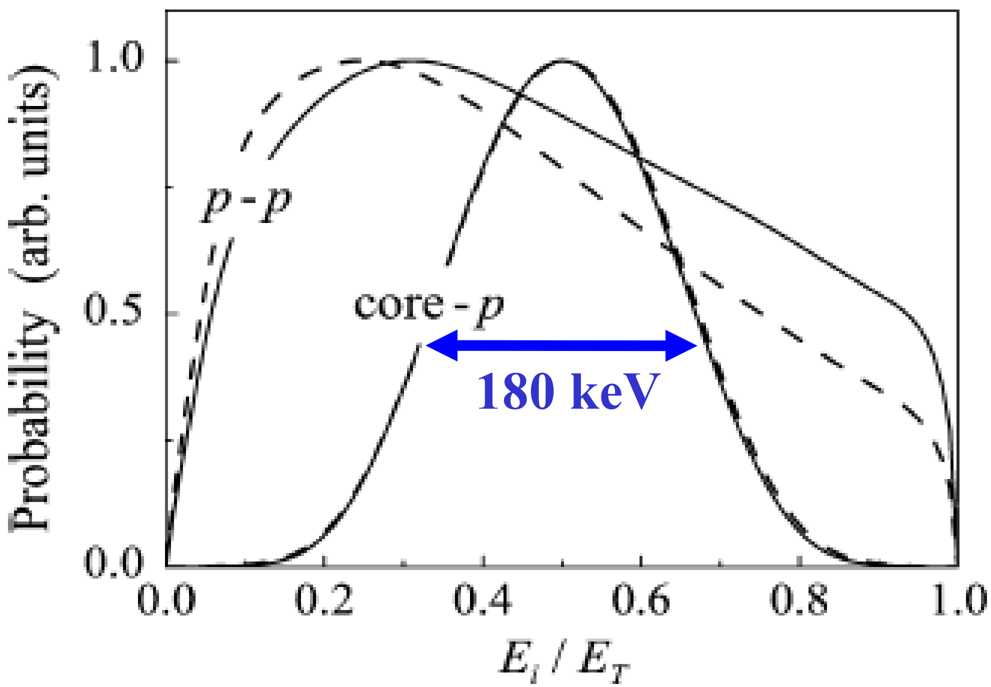
Angular correlations of fragments reflect the decay energy





Predicted p-^{17}Ne correlations for ^{19}Mg,

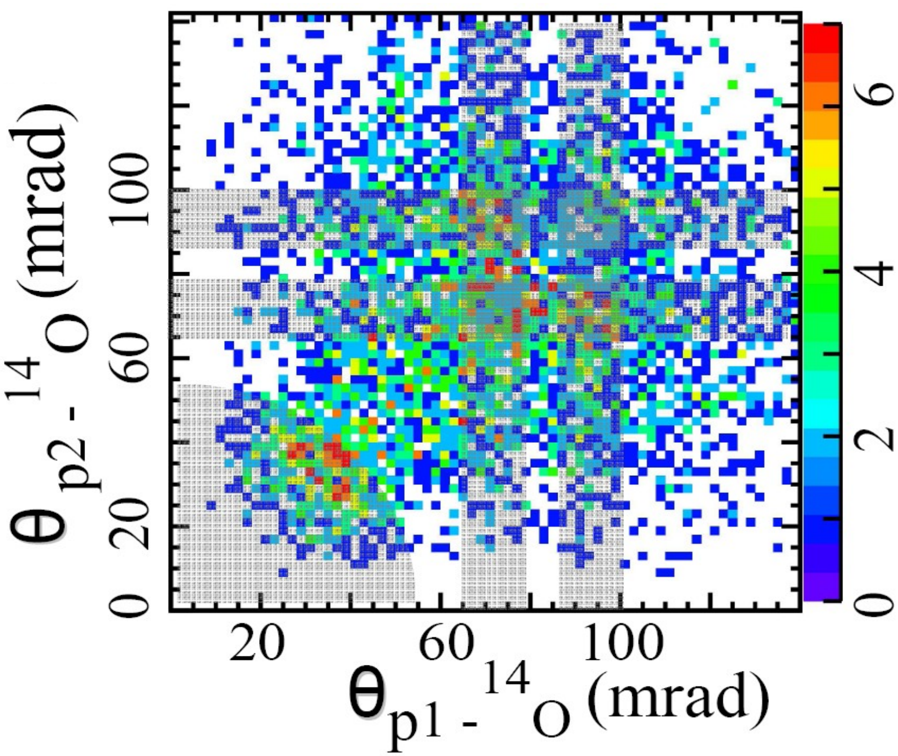
L.V.Grigorenko, I.G.Mukha, M.V.Zhukov,
Nucl.Phys. **A** 713 (2003)



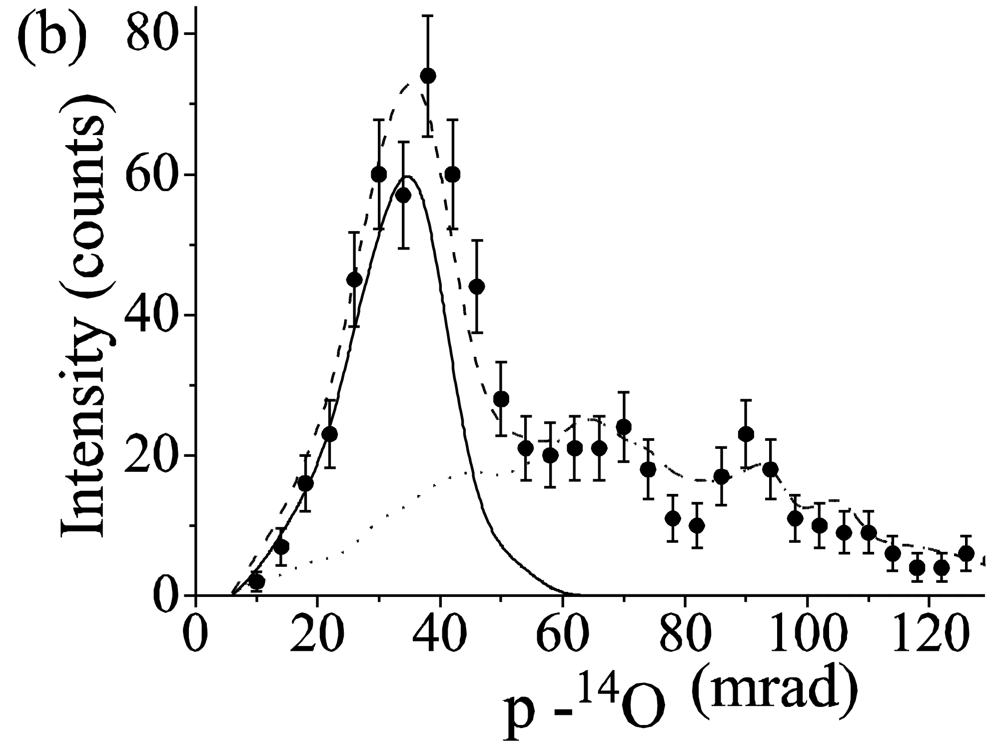
Kinematical enhancement around a maximum angle

Calibration of angular p-HI correlations by using the known 2p-decay of ^{16}Ne with Q_{2p}=1.4(1) MeV

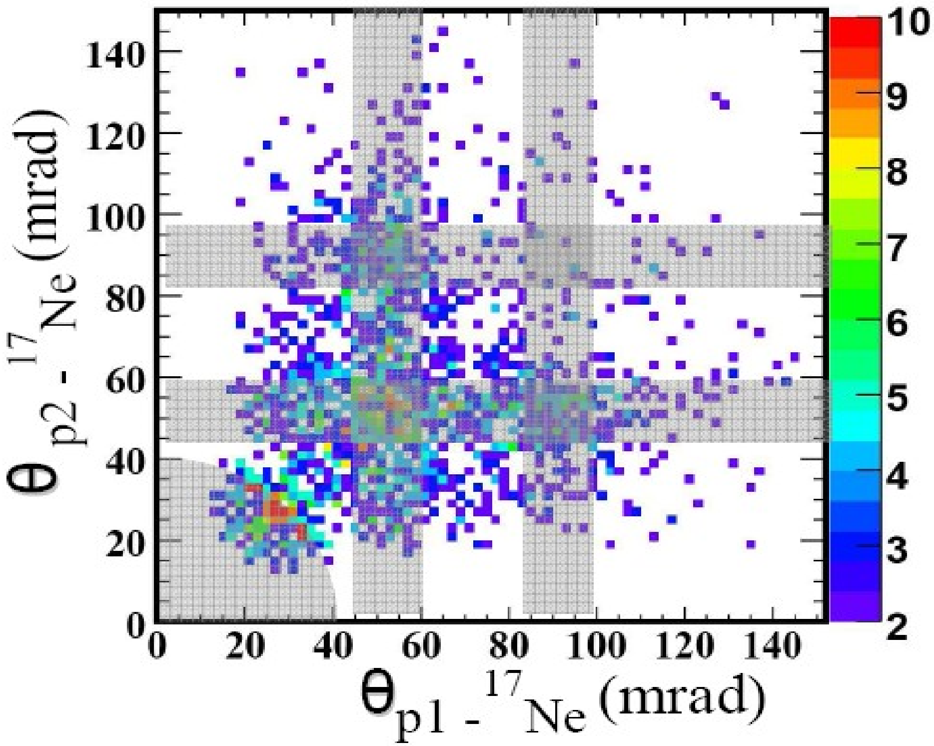
Angular p-(p-^{14}O) correlations from $^{17}Ne \rightarrow ^{16}Ne \rightarrow ^{14}O+p+p$ events

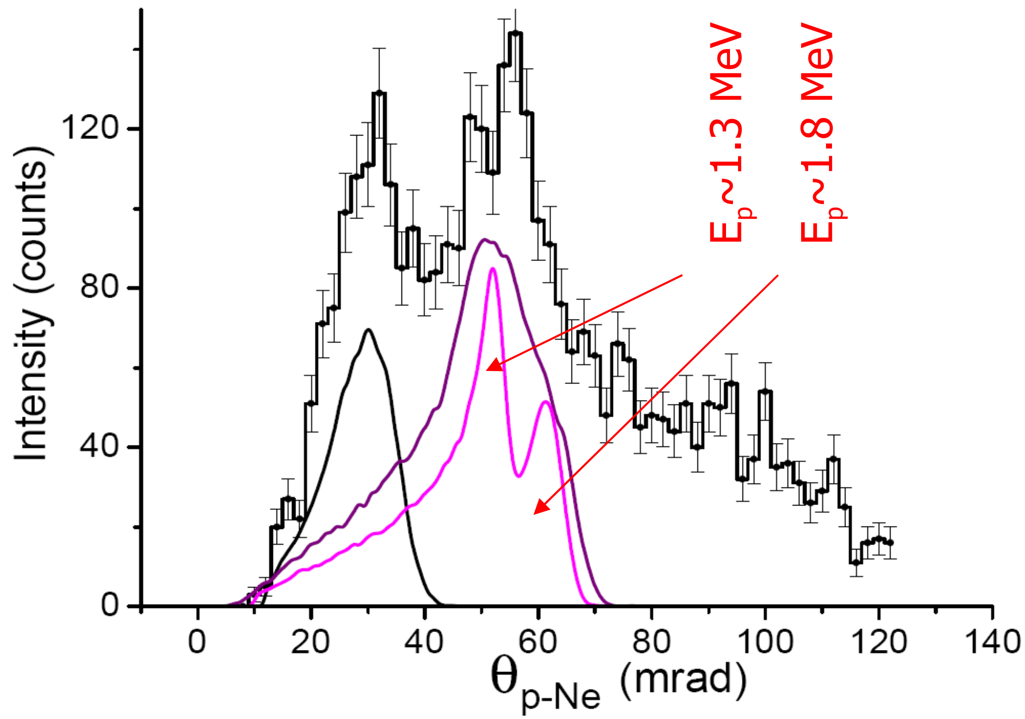


Measured Q_{2p}=1.35(8) MeV



States in ^{19}Mg observed in ^{17}Ne+p+p correlations

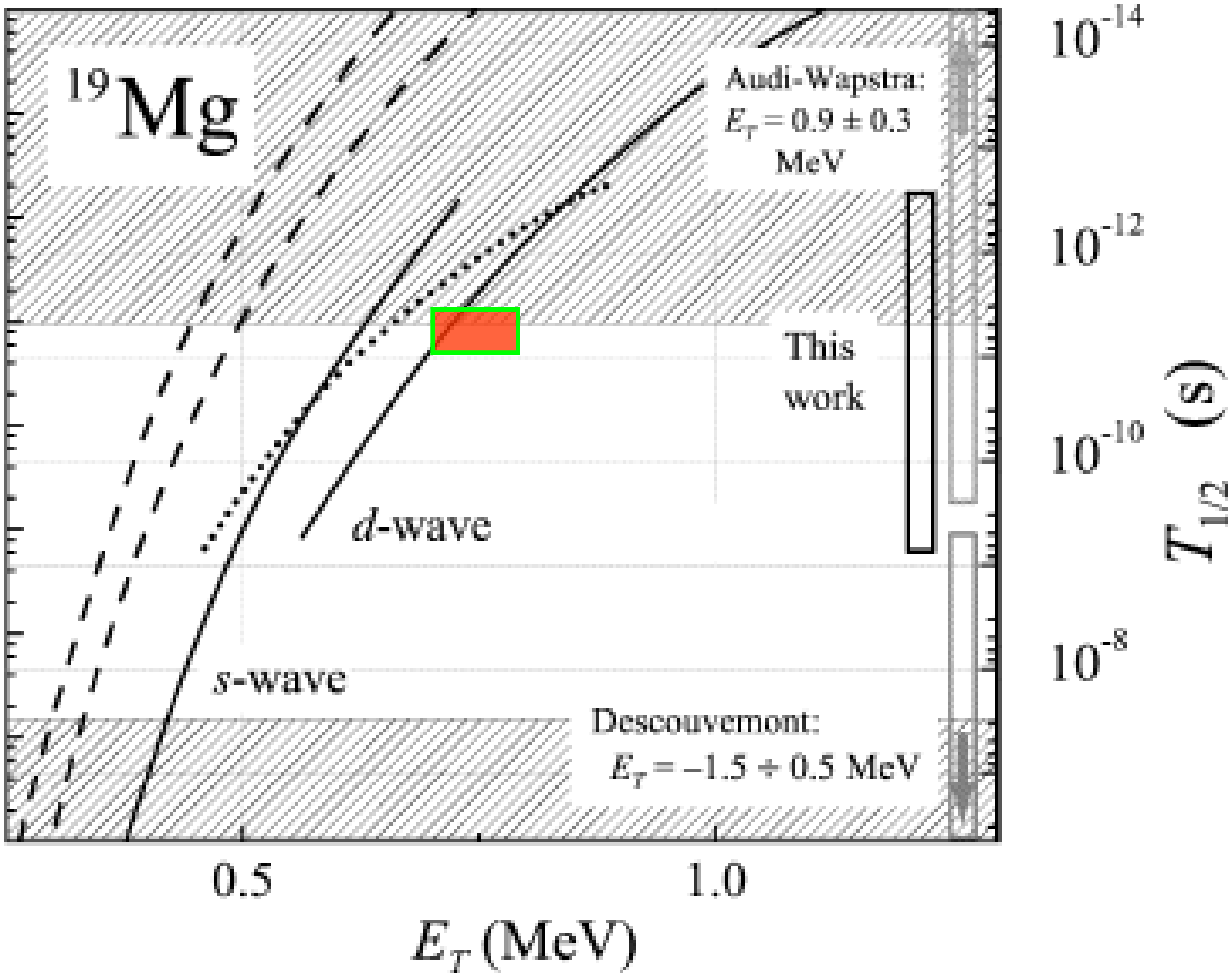




Sequential 2p-decay

via the ^{18}Na g.s.

Comparison of the data with the theoretical predictions:



Theory predictions:

L.Grigorenko, I.Mukha, M.Zhukov, Nucl.Phys. **A** 713 (2003)

Experiment

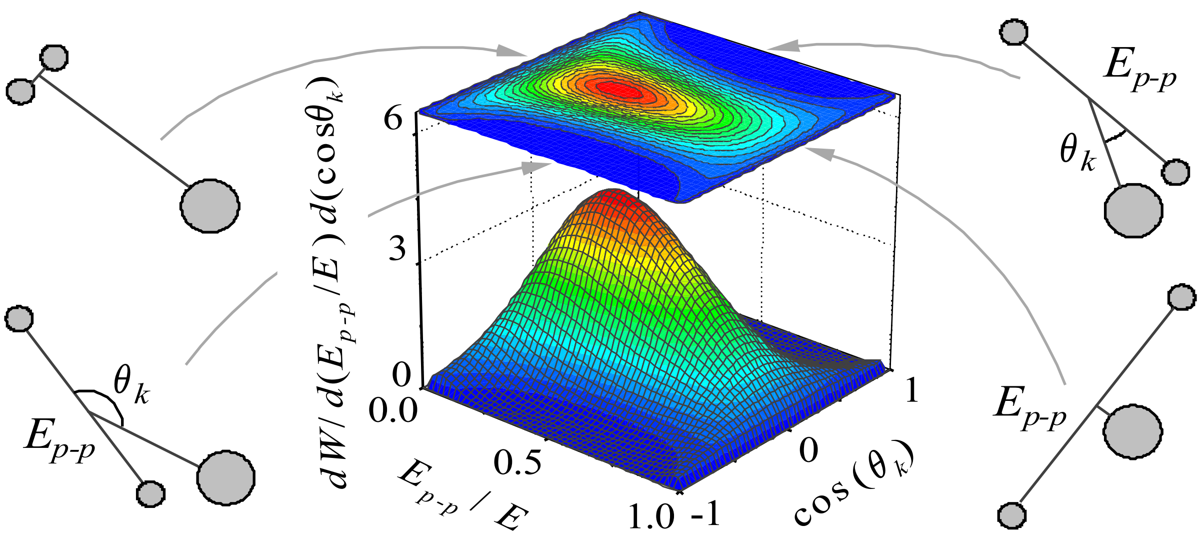
Q2p=750(50) keV

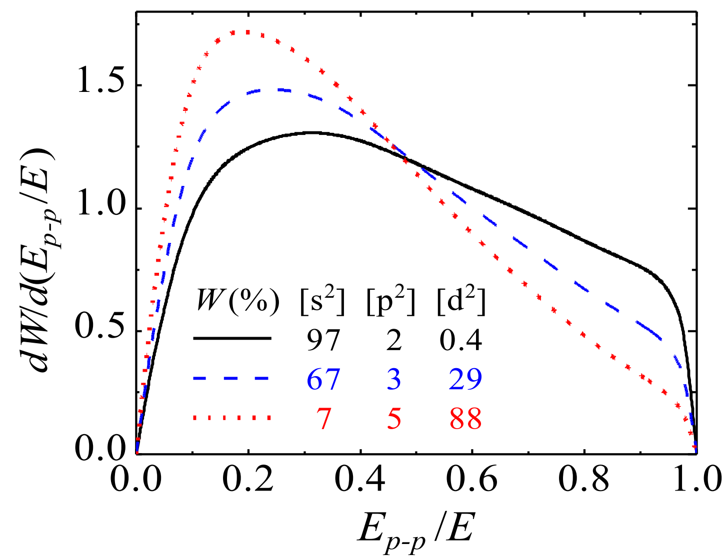
I.Mukha et al., PRL **99**, (2007)

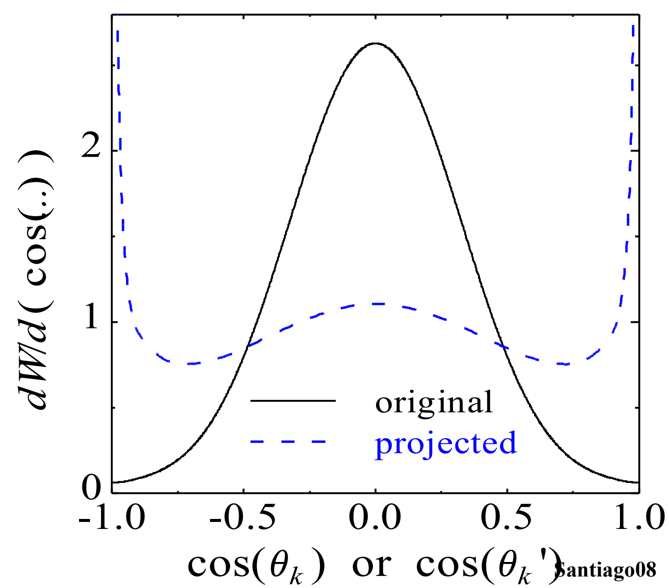
AME2003:

Q2p=2000(250) keV

Structure of ^{19}Mg revealed in fragment correlations





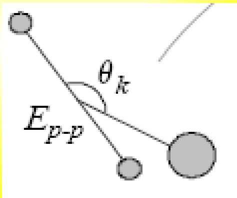


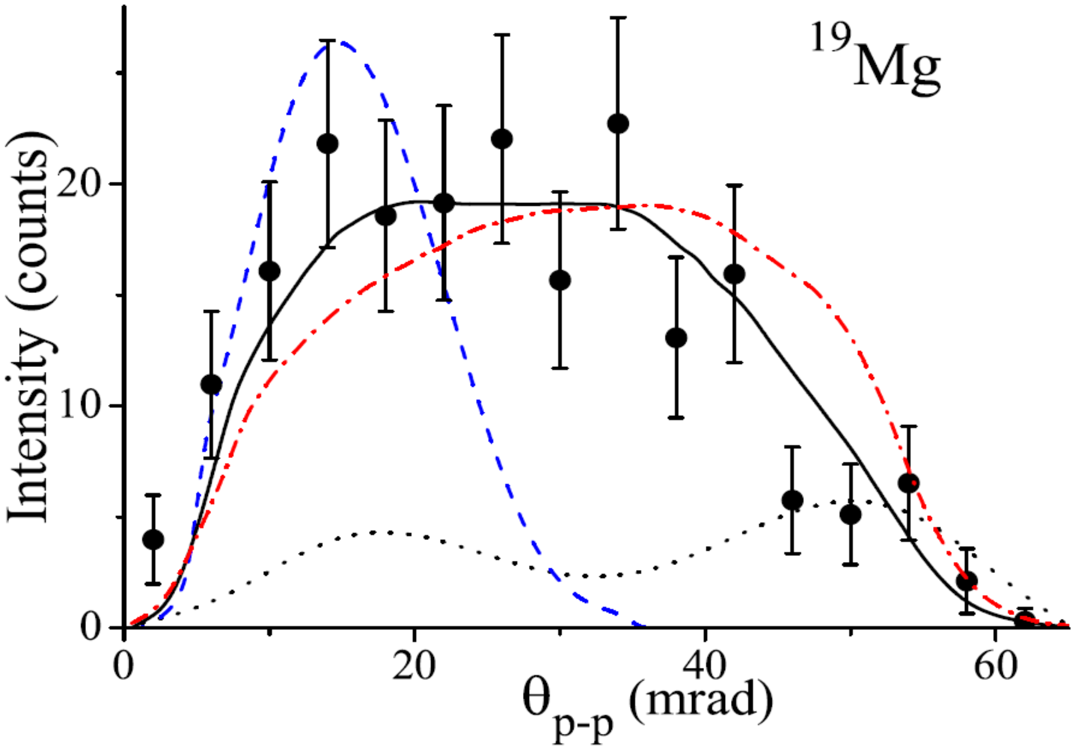
- Structure and decays of ^{19}Mg:
  L.Grigorenko, I.Mukha, M.Zhukov, Nucl. Phys. A**713** (2003) .
- Strong Coulomb repulsion effects.
- Moderate sensitivity of the distributions to the ^{19}Mg structure
- Certain features of correlations are retained in the projected spectra

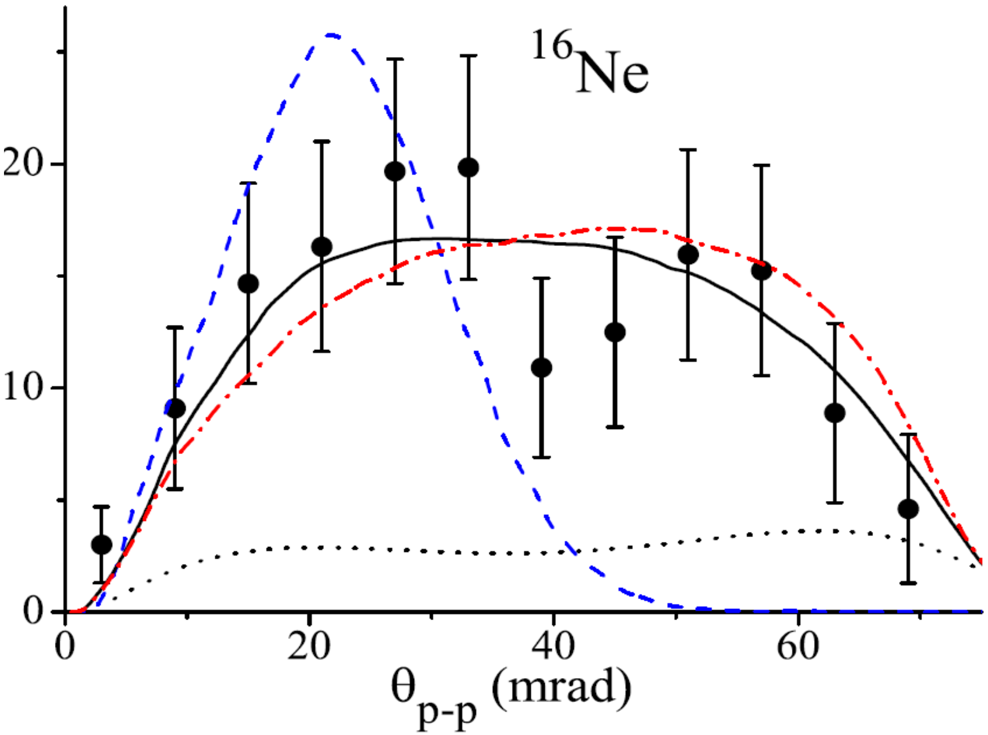
Proton-proton correlations from ^{19}Mg and ^{16}Ne 2p decays:

No diproton emission!

Structure: *s/d* mixture of valent protons is defined!







Diproton emission

Three-body model, 88% of d-wave

Three-body model, 54% of d-wave

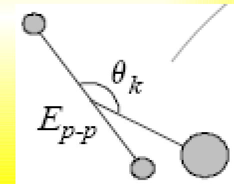
Isotropic 2p emission (phase space)

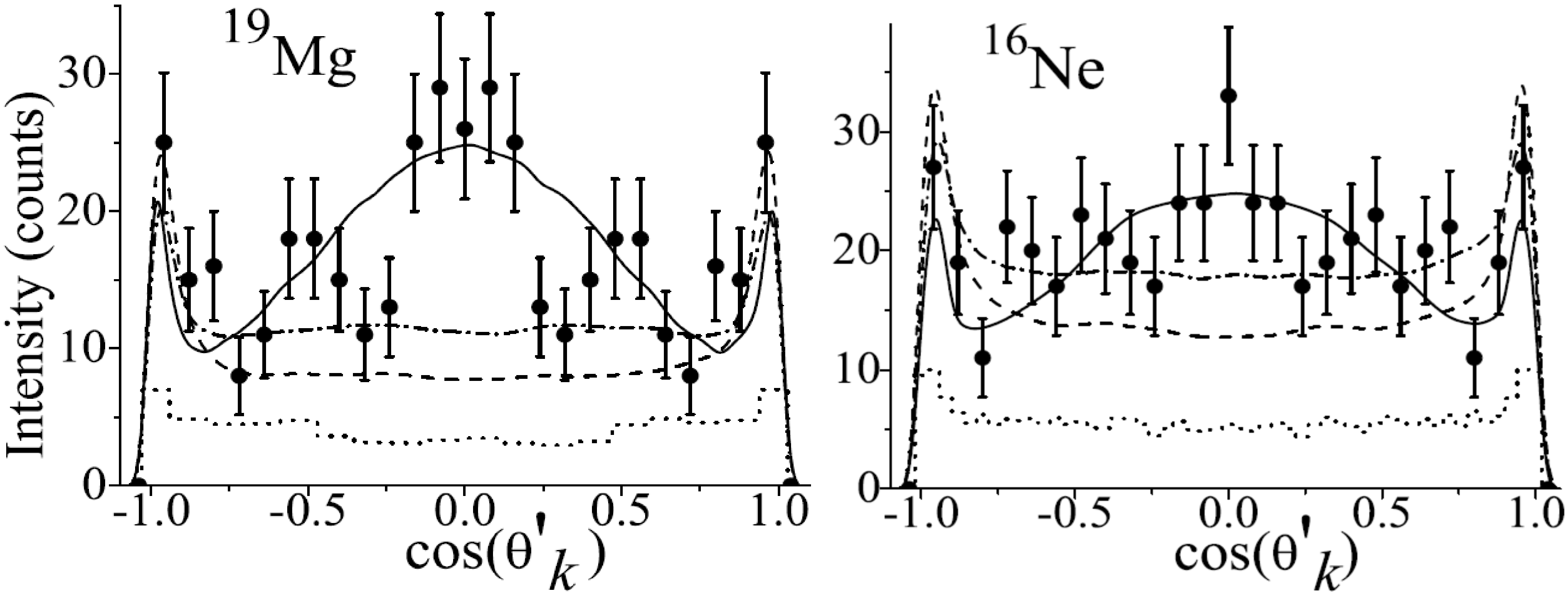
I.Mukha et al., Phys.Rev. C **77**, 061303(R) (2008)

Three-body correlations from ^{19}Mg and ^{16}Ne 2p decays:

No sign of diproton emission!

Three-body model exclusive predictions are fine!





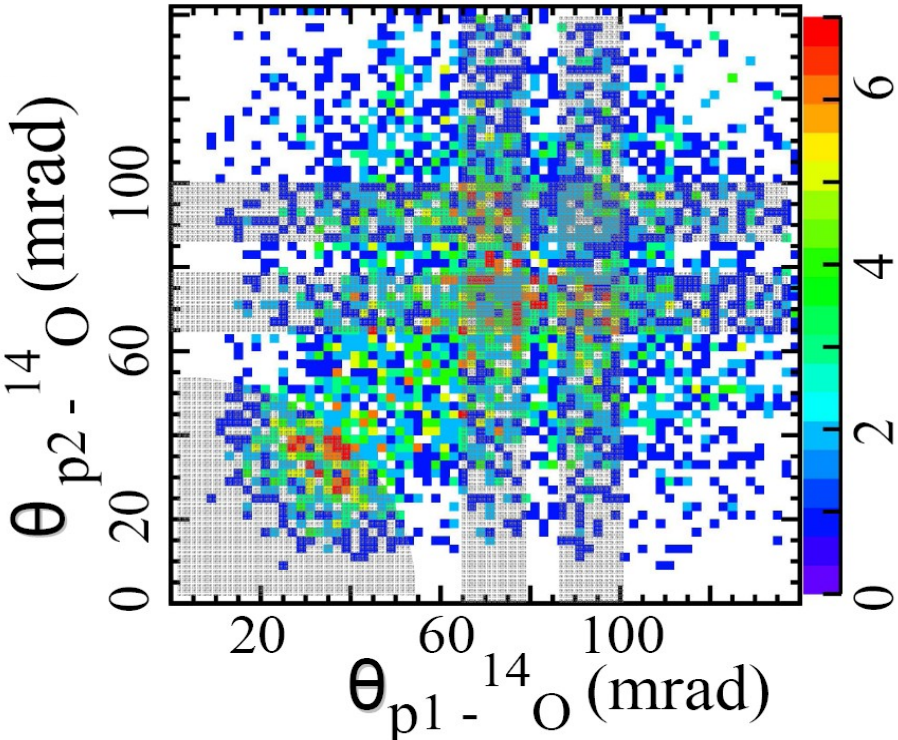
Diproton emission

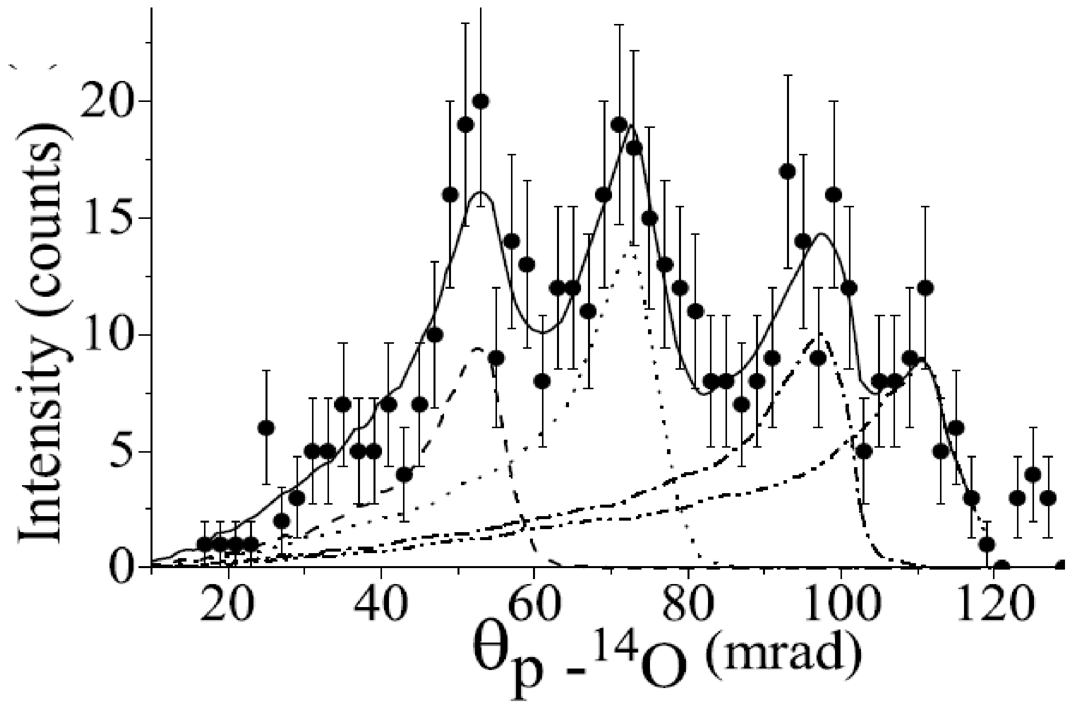
Three-body model, 88% of d-wave

Three-body model, 54% of d-wave

Isotropic 2p emission (phase space)

States in ^{15}F observed in $^{14}O+p+p$ correlations





The ground state and in ^{15}F

Experiment: Q_(p)=1300(170) keV

AME2003: Q_(p)=440(60) keV

Powerful technique in studies of proton-unbound nuclei

- Very thick targets and low-quality beams are acceptable
- Large registration efficiencies of multi-particle events
- High precisions of the measured decay energy,
- Total energy of protons not required
- Nuclear-structure and decay-mechanism information

We propose:

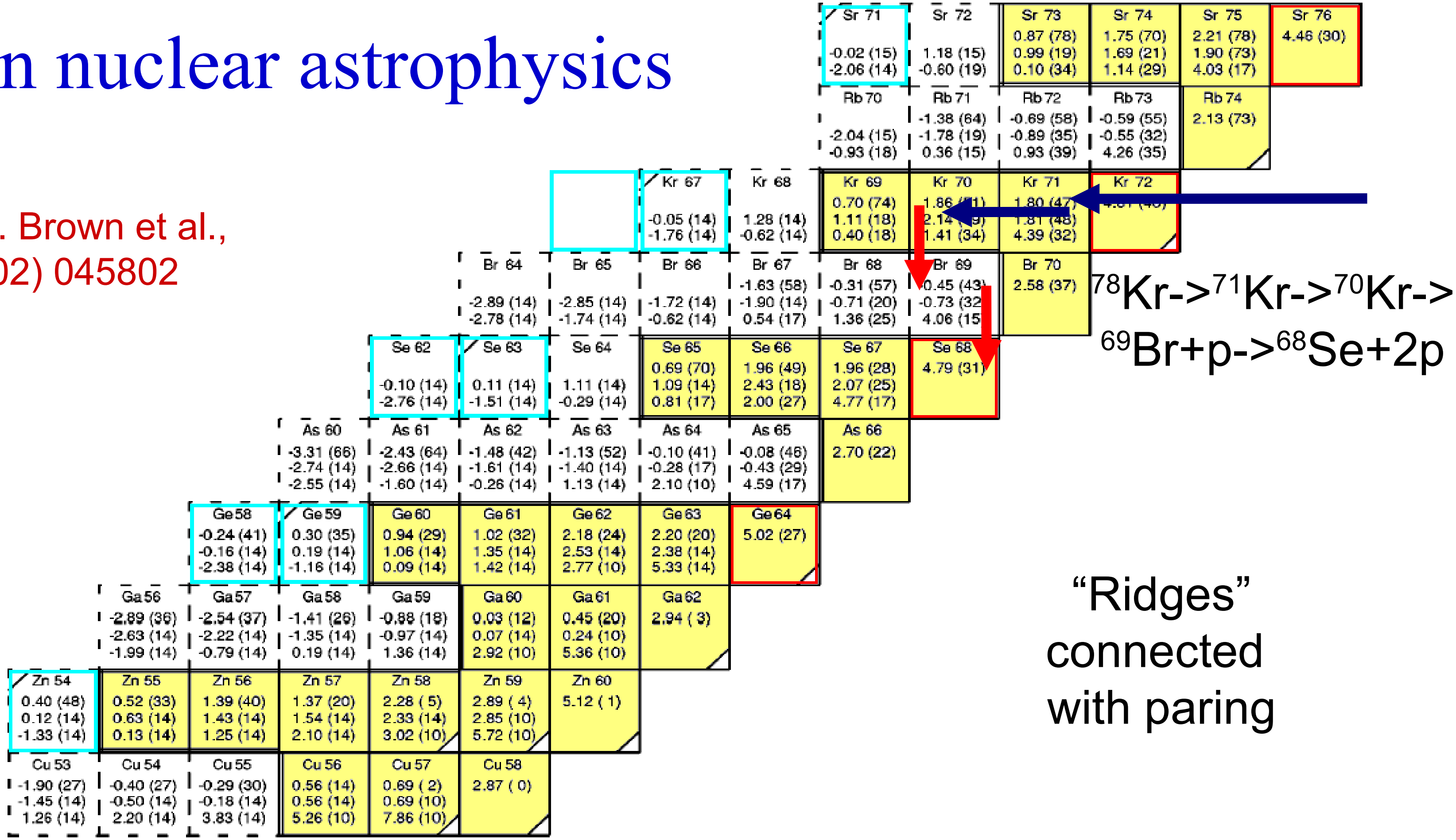
- A search for the unknown ground states of ^{30}Ar and ^{34}Ca by using secondary beams of ^{31}Ar and ^{35}Ca produced with the primary beams of ^{36}Ar and ^{40}Ca, respectively. The ^{30}Ar,^{34}Ca nuclei are predicted to be unbound respective two-proton emissions. Their decay products will be measured in-flight by detecting the triple ^{28}P(^{32}Ar)+p+p coincidence. The ^{30}Ar, ^{34}Ca are prospective candidates for observation of "direct" two-proton radioactivity. Extensive studies made in the framework of a realistic three-body model predict their half-lives to be in the range 0.5–700 ps which overlaps reasonably with the decay-time range measurable at FRS. We intend to observe the direct two-proton emissions and to measure the half-lives of ^{30}Ar, ^{34}Ca, their decay energies as well as proton-proton correlations. The half-life values will be derived from the distribution of the decay vertices. The vertices will be extrapolated from the precisely measured (by means of silicon micro-strip detectors) trajectories of all fragments.

- We suggest a search for the unknown isotope ^{69}Br and spectroscopy of its excitation spectrum. Properties of the ^{69}Br ground state are important for the nuclear astrophysics studying synthesis of elements during X-ray bursts in rapid proton capture reactions (i.e., *rp*-process), namely on the waiting-point N=Z nucleus ^{70}Kr (see, e.g., [5]. We intend to observe the ^{69}Br states in two-proton decays of excited states of ^{70}Kr produced in a secondary one-neutron knock-out reaction of a radioactive beam of ^{71}Kr ions which can be made in primary fragmentation reactions of a primary beam of ^{78}Kr. Such a way of population is in analogy with the successful observation of the ^{15}F spectrum by using the chain of reactions ^{24}Mg→^{17}Ne→^{16}Ne*→^{15}F+p→^{14}O+2p [2, 4]. The ^{69}Br decay products will be measured in-flight by detecting the triple ^{68}Se+p+p coincidence following sequential 2p-decays of ^{70}Kr.

The estimated beam time is about 10 days divided in two runs. For the first run, the evaluated time is 16 shifts of 1000 MeV/u of ^{40}Ca beam with an intensity 10^{10} ions per spill. For the second run, the request is 16 shifts of 1000 MeV/u of ^{78}Kr beam with an intensity 10^{10} ions per spill.

Prospects in nuclear astrophysics

B.A. Brown et al.,
PRC 65 (2002) 045802



- Lifetimes: ^{64}Ge $T_{1/2}$ = 63.7 s, ^{68}Se $T_{1/2}$ = 35.5 s, ^{72}Kr $T_{1/2}$ = 17.2 s, ^{76}Sr $T_{1/2}$ = 8.9 s
- Lifetimes of the nearby drip line nuclei are typically tens of milliseconds
- **To calculate astrophysical capture rates leading to nuclei in the "ridges" at high temperatures we must know at least the 2p and gamma widths of the excited states**
- For temperatures below 0.1-1 GK the non-resonant interactions may become important

Thank you, co-authors !

K. Sümmerer, L. Acosta, M.A.G. Alvarez; E. Casarejos; A. Chatillon; D. Cortina Gil; J. Espino; A. Fomichev; J.E. Garcia-Ramos; H. Geissel; J. Gomez-Camacho; L. Grigorenko; J. Hoffmann, O. Kiselev; A. Korsheninnikov; N. Kurz; Yu. Litvinov; I. Martel; C. Nociforo; W. Ott; M. Pfützner; C. Rodriguez; E. Roeckl; M. Stanoiu; H. Weick; P. Woods

University of Sevilla, Spain; Kurchatov Institute, Moscow, Russia; GSI, Darmstadt, Germany; University of Huelva, Spain; University of Santiago de Compostela, Spain; JINR, Dubna, Russia; University of Mainz, Germany; University of Warsaw, Poland; University of Edinburgh, UK

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