Study of the unbound proton-rich nucleus ^{21}Al with resonance elastic and inelastic scattering using an active target

Following LoI : CERN-INTC-2010-025/ INTC-I-094
(M. J. Borge et al.)

B. Fernández-Domínguez (Univ. Santiago de Compostela, Spain)
Olof Tengblad (CSIC-Madrid, Spain)
M. Caamaño (Univ. Santiago de Compostela, Spain)

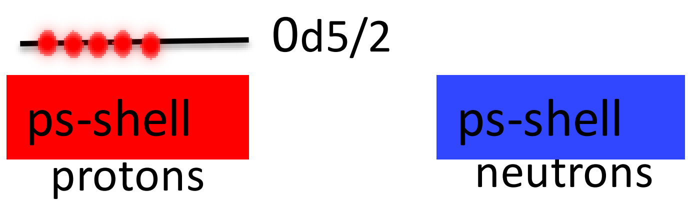
SCIENTIFIC MOTIVATION

The N=8 shell gap at the proton-drip line known up to ^{20}Mg

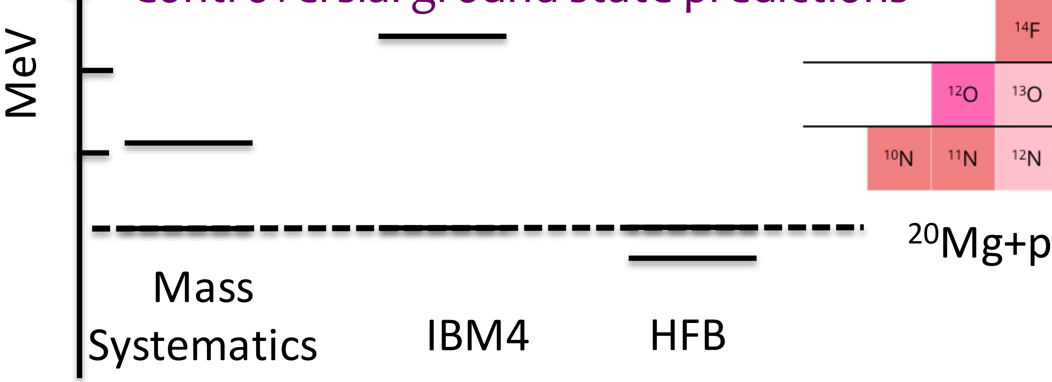
The next isotope in the chain is ^{21}Al -> no experimental data

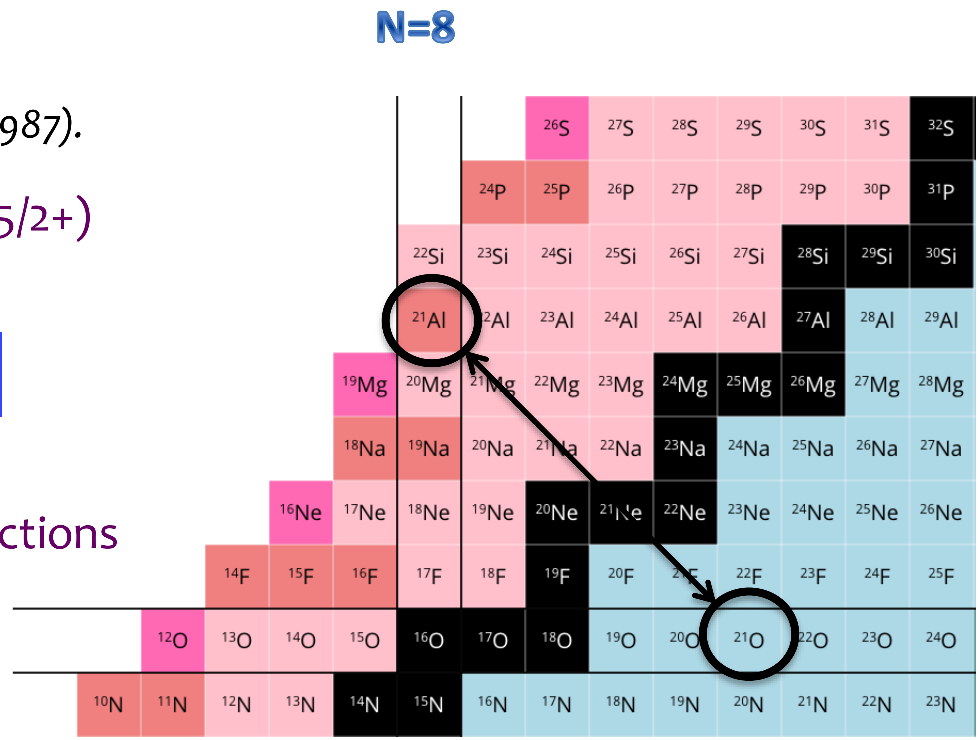
- Upper limit of $T_{1/2}$<35 ns
  M. G. Saint-Laurent, et al., PRL 59, 33 (1987).

- Unknown Spin and Parity -> ^{21}O (5/2+)



- Controversial ground state predictions

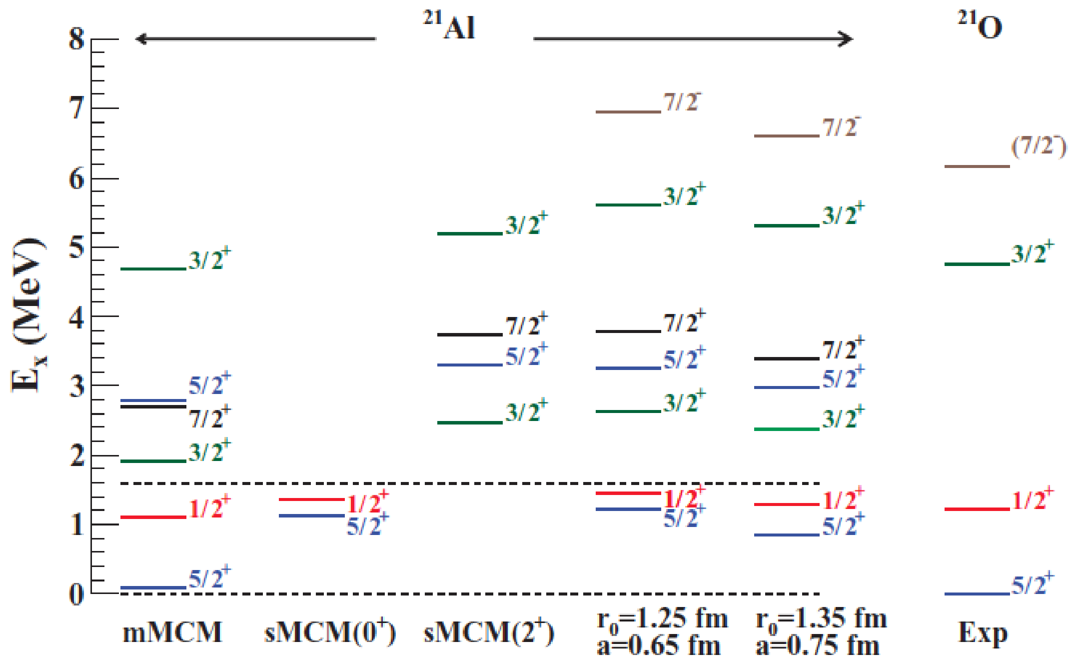




SCIENTIFIC MOTIVATION

Excitation energy spectrum in ^{21}Al

N. Timofeyuk et al. PRC 86, 034305 (2012)   Microscopic Channel Model (MCM)

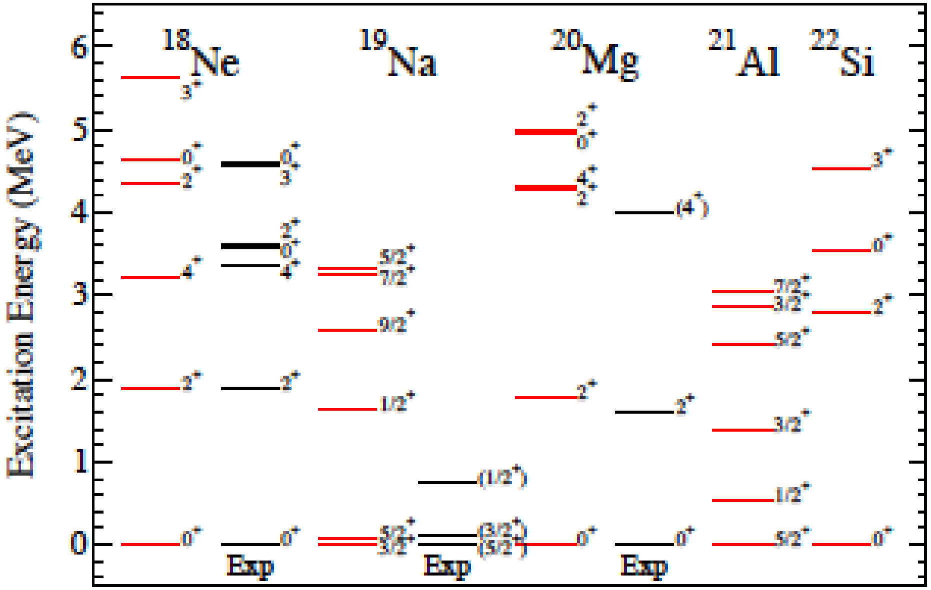


- The ground state energy in mMCM disagrees with the $T_{1/2}$<35 ns.
- sMCM predits a large Thomas-Ehrman Shift
- sMCM energies are in agreement with ^{21}Ne-^{21}Na, ^{19}O-^{19}Na

SCIENTIFIC MOTIVATION

Excitation energy spectrum in ^{21}Al

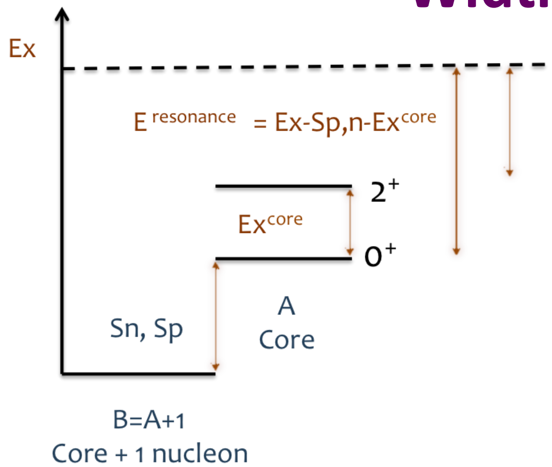
J. D. Holt et al. arXiv:1207.1509v2 [nucl-th] (2012) Chiral (3N-forces)

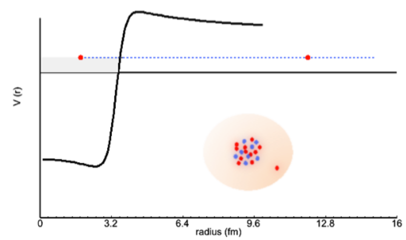


- 3n-forces bring repulsive terms to the N=8 isotones
- Ground state energy placed at -2.46 and -1.69 MeV for sd/sdfp
- The positions of the energies in ^{21}Al influence the binding energy of ^{22}Si

SCIENTIFIC MOTIVATION

Widths of resonances in ^{21}Al





Narrow resonance states

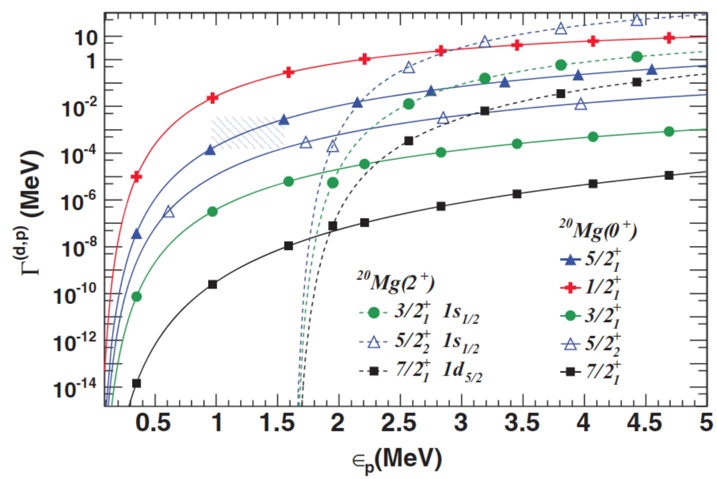
The main decay channel has much smaller energy and is longer hold by the Coulomb barrier

N. Timofeyuk et al. PRC 86, 034305 (2012) based on :

ANC ^{20}O(d,p)^{21}O TIARA collaboration

B. Fernández-Domínguez PRC 84, 029902(E) (2011)

- $\Gamma << E_r$
- $3/2_1$+, $5/2_2$+ s-wave motion around 2+
- $7/2_1$+ d-wave motion around 2+



AIMS OF EXPERIMENT

Clear discrepancies between the models and no experimental data available.

The ^{21}Al is a key nucleus to :

- Understand isospin symmetry-breaking effects.
- Restrict the 3N-forces at the proton drip line along the N=8 isotonic chain.
- Study the effect of core excitations in narrow resonances.

Goals :

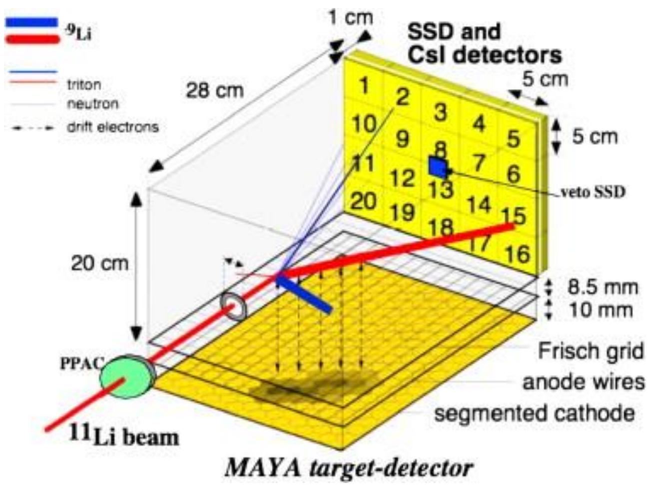
- To locate the 1/2+ level in ^{21}Al that brings information on the Thomas-Ehrman shift.
- To measure the energy spectrum of ^{21}Al which is a N=8 isotone with the resonance elastic scattering reaction.
- To measure the widths narrow unbound resonances to investigate via inelastic scattering the strength of core excitations.

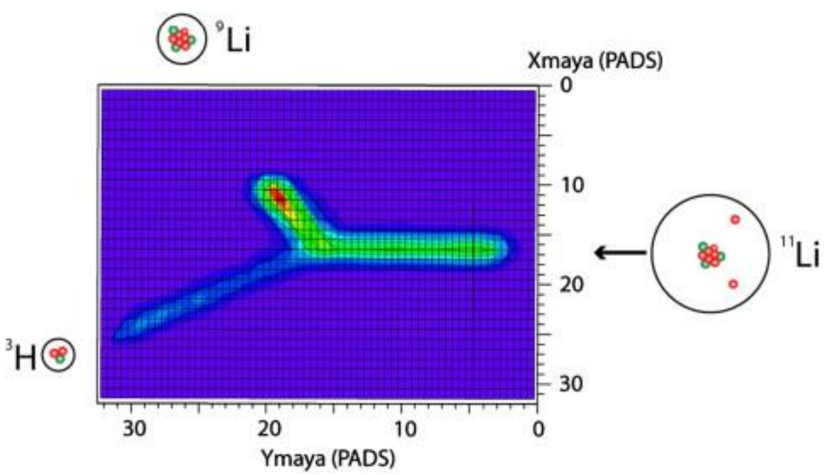
⬇

Resonance elastic , $^{20}Mg(0^+)$, and inelastic, $^{20}Mg(2^+)$, scattering.

EXPERIMENTAL TECHNIQUE

Active Targe -> MAYA (GANIL, France)





MAYA @ ISOLDE

"Study of ^{13}Be through IAR"
(Summer 2012) *R. Raabe IS-203.*

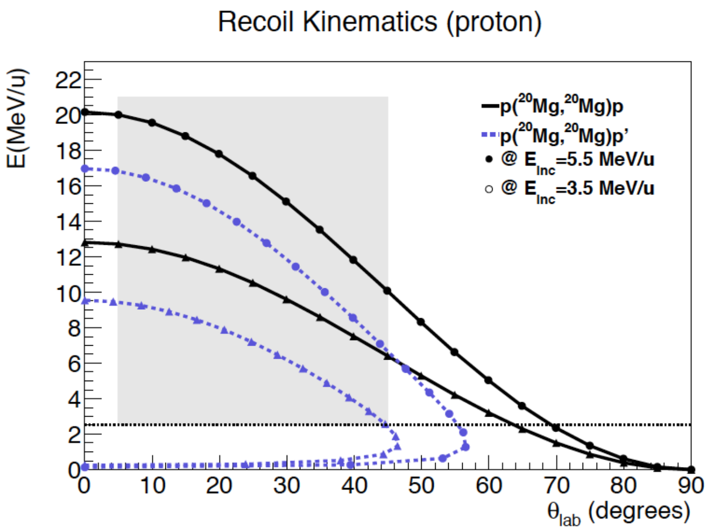
OUR EXPERIMENT

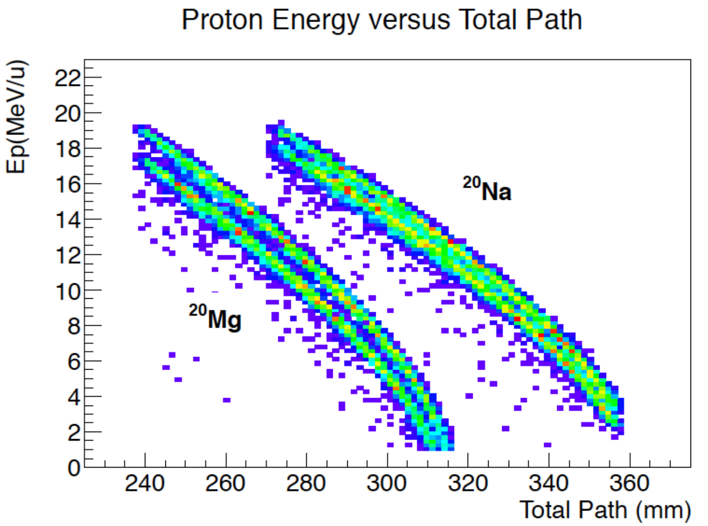
^{20}Mg HIE-ISOLDE beam – (5.5 MeV/n ~50 pps)
MAYA filled with C_4H_{10} @ ~100 mbar
DC+Si+CsI for ΔE-E ($FWHM_{CM}$=50 keV)
Diamond for veto coincidences
MAYA-Range for beam-like particles - (^{20}Mg)

ADVANTAGES compared to conventional thick target method:

1) Background from C can be discriminated.
2) Inelastic and elastic can be separated.

EXPERIMENTAL TECHNIQUE



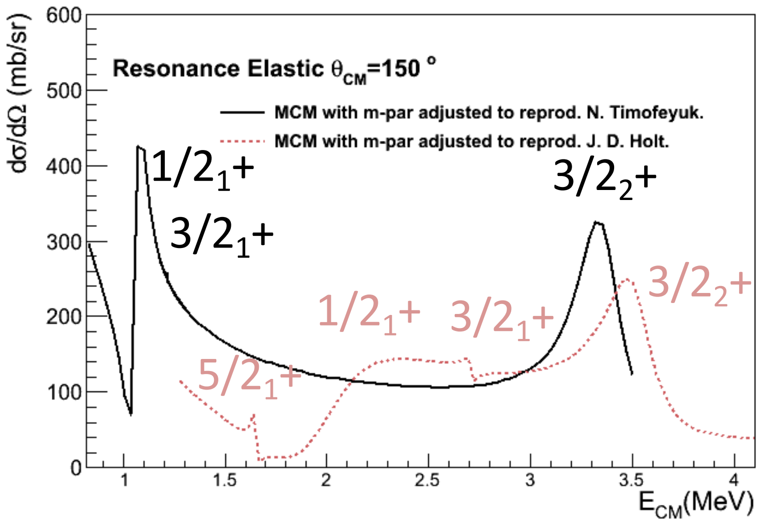


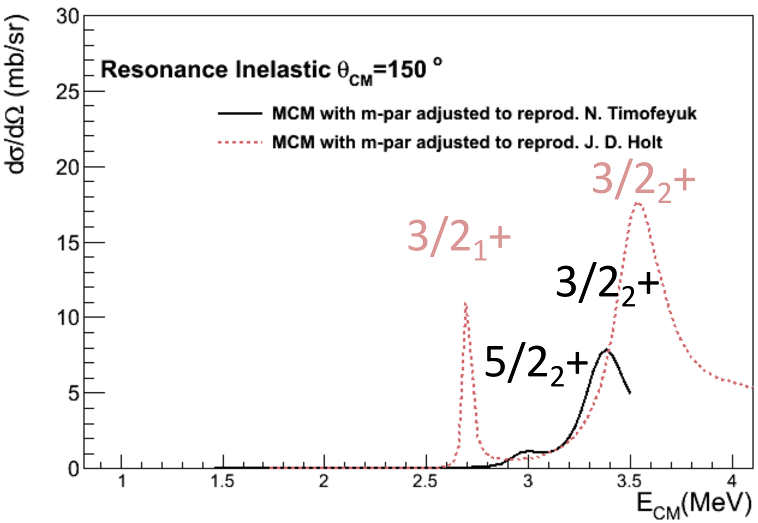
Measurements -> Observables

- Recoil protons E and θ -> Excitation function of the compound nucleus.
- Total path -> Select the inelastic channel and contamination.
- R-Matrix analysis of the excitation function-> Spectroscopic Properties: E_r,J^π,Γ
- Large angular coverage -> Angular distributions.
- $^{20}Mg+^{12}C$ channels -> obtained simultaneously in the same experiment.

CROSS SECTIONS

CROSS SECTION CALCULATIONS (from N. Timofeyuk, Univ. Surrey (UK))





The differences between the models will be clearly seen in our experiment

- The location of the 1/2+ state differs between the models
- The ground state 5/2+ would be seen if closer to J. Holt's predictions
- Narrow resonances are expected above the $^{20}Mg(2^+)$ threshold

COUNTING RATE ESTIMATES

Assuming
- Estimated I : 500 of ^{20}Mg/μC (ε_{REX}= 10%) (T=50% if stripper foil @ linac)
- I (^{20}Mg) =50 pps (25 pps if stripper foil)
- Excitation function built on steps of 50 keV in E_{CM}
- Average cross section $<\sigma_i^{elast/ine}>$ = 203 mb, 8.1 mb
- Angular bin of ± 15 degrees around θ_{CM}= 150°
- ~13 days of measurements

Table: Yield estimates without (white) and with (shadow) stripper foil.
* Double angular bin for the inelastic scattering.

Channel	Yield (c/h/bin)	Yield tot (c/bin)	Error(%)
Elastic	3.0×10^{-1}	100	~ 10 %
Inelastic *	2.5×10^{-2}	10	~ 30 %
Elastic	1.5×10^{-1}	50	~ 15 %
Inelastic *	1.25×10^{-2}	5	~ 45 %

BEAM TIME REQUEST

Reaction Data	= 40 UT
Contamination studies + tunning	= 3 UT
	43 UT

DAY-I Experiment- Readily feasible with MAYA.

COLLABORATION

B. Fernandez-Domınguez[1], O.Tengblad[2], M. Caamaño[1], H. Alvarez[1], J. Benlliure[1], W. N. Catford[3], J. Cederkall[4], D. Cortina[1], F. Delaunay[5], P. Descouvemont[6], F. Farget[7], F.Flavigny[10], H. O. U. Fynbo[8], J. Gibelin[5], G. F. Grinyer[7], D. Loureiro[7], B. Jonson[9], E.Nacher[2], T. Nilsson[9], R. Orlandini[10], N. Orr [5], C. Paradela [1], J. Pancin[7], G. Randisi[10], R. Raabe[10], F. Renzi[10], K. Riisager[8], T. Roger[7], S. Sambi[10], D. Suzuki[11], N. Timofeyuk[3], J. S. Thomas[12], M. Vanderbrouck[11].

1) Universidade de Santiago de Compostela, 15754 Santiago de Compostela, Spain
2) Instituto de Estructura de la Materia, CSIC, Madrid, Spain
3) Department of Physics, University of Surrey, Guildford GU2 5XH, UK
4) Department of Physics, Lund University, SE-221 00 Lund, Sweden
5) LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, 14050 Caen, France
6) PNTPN, C.P. 229, Université Libre de Bruxelles, B-1050 Brussels, Belgium
7) GANIL, BP 55027, 14076 Caen Cedex 5, France
8) Institut for Fysik og Astronomi, Arhus Univ., Arhus, Denmark.
9) Fundamental Physics, Chalmers University of Technology, Goteborg, Sweden.
10) Instituut voor Kern- en Stralingsfysica, K.U.Leuven, Celestijnenlaan 200d - B-3001 Leuven
11) Institut de Physique Nucléaire, Université Paris-Sud-11-CNRS/IN2P3, France
12) Schuster Laboratory, University of Manchester, Manchester, M13 9PL, UK