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μCF THOUGHTS FROM BIRMINGHAM AND THE RUTHERFORD APPLETON LABORATORY

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ABSTRACT

This paper gives some ideas to be learnt from magnetic confinement fusion and briefly describes the pulsed muon beam at ISIS, progress with the measurement of W_s (the $\mu\alpha$ sticking coefficient), future beam plans and possible experiments.

INTRODUCTION

μCF has had considerable progress; its continuation requires new ideas to be widely discussed at workshops like this. Thought must be given to collective and critical planning, exploiting resources, expanding funding and to acquainting those in authority or having influence, non readers of the specialised science publications, of μCF. Inter alia, there have been general articles in Nature, the New Scientist and Scientific American. Amusingly it was the latter that led to articles in the Economist, the (British) Times and BBC radio.

IDEAS FROM MAGNETIC CONFINEMENT FUSION

This subject was investigated last November at JET (Joint European Torus and 20km from ISIS) in a STOA Workshop of the European Parliament and EEC. Significant points included there no longer being an urgent need for fusion. Although magnetic confinement research has made considerable expensive progress, it has technical problems and a goal in the distant, costly future. Nevertheless it should not be abandoned but slowed and savings made. However research is not viable at less than the current European spend. The USA STARFIRE had reached similar conclusions. Mention was made of ITER - the start of a joint European, Japanese, USA, USSR project. The lesson for μCF is obvious - we must plan a world programme. Invited as an alternative method of fusion, μCF was presented as interesting physics with basic parameters made with relatively small scale, low cost equipment divorced from the large, expensive apparatus, the accelerator, which was provided anyway for other purposes. Progress was rapid with 'a low cost, long shot' possibility of energy production. Support for ISIS experiments by Culham, the British fusion centre, was mentioned.

In the future 550 fusions/μ could provide energy break-even, heat → heat. If > 20% of the power output is required to drive the complex then the financial cost of such becomes too high. Therefore, in some sense, economic break-even requires 2500 fusions/μ.

THE ISIS PULSED MUON BEAM

The synchrotron sends protons in 50Hz pulses to make neutrons by spallation and fast fission at a distant uranium target: each pulse contains 2 bunches, 330ns apart. Recently the complex has run for appreciable periods at 750 Mev and 90 μa. The surface/cloud muon beam[1,2] is taken off a thin, intermediate transmission target. The raison-d'être of ISIS, so far, is to appear as a pulsed reactor; so the aims are long, steady runs and very low backgrounds. There is a very good cave around the muon target from which leak-paths are enthusiastically sought and blocked. Improved exit collimation from the cave to protect downstream magnets has also decreased external backgrounds.

The performance of the muon beam is given in table 1; ± 55kv on the velocity separator and a simple collimator reduced the electron contamination by x50. With little advertising for its first full year, the beam has been oversubscribed by x2½, mainly μSR experiments. A problem with having no switchyard is interchanging experiments.

A DIRECT MEASURE OF W_s, THE μα STICKING COEFFICIENT

This continues the LAMPF[3] determination of the ratio of $\frac{\mu\alpha - n}{\alpha - n}$

coincidences with a small, low density gas target described at the workshop. That experiment had a large 'α'-n background from the > 99.9% of the μ^- that stopped in the target walls with general accelerator background contributing to the high neutron count rate. Data were taken at 490mm Hg target pressure to see α-n coincidences and at 1800mm for $\mu\alpha$-n since the event rate increased approximately as the square of the D-T density.

These backgrounds could be avoided by using a pulsed beam, target walls having high Z and delaying counting by $\frac{1}{2}$ μs. As the atomic number of an elemental stopping medium is increased the effective muon life-time falls from τ=2 μs for Z ~ 6 to 100ns for Z ~ 48 where it then flattens.

Figure 1 shows the apparatus modified for use at RAL. The target flask is made from silver since this is the structural material having τ_μ (effective) < 100ns and of the lowest Z to reduce showering. There are 2 NE213 neutron counters to improve timing and the Si surface barrier α-detector was thinned to 50μ to reduce background.

The neutron backgrounds were examined as functions of energy and time after the muon pulse. That which was non muon-induced became softer with increasing time and came principally from the muon production target. The muon-induced background had an energy spectrum of time-independent shape but magnitude decaying with the τ_μ ~ 1μs characteristic of μ^--Al interactions. So the beam-pipe end-flange and target outer vessel were covered with 3mm of Pb. For E_n > 3 Mev this was still the dominant background and tests indicated an origin in the downstream beam-pipe - this will be lined with copper in future.

There is a tremendous flux of particles and energy during the beam burst - principally from the e/π contamination. Inhibiting each of the signal paths inside the LINK n/γ discriminator protected the neutron channel. Little background can get above the 0.6 Mev α counter threshold and pile-up was measured at 1$\frac{1}{2}$%. However the very many sub-threshold pulses during the burst cause a 50ns time walk and jitter in the pre-amp. If this cannot be inhibited then a thin scintillator will be used to take advantage of a photo-multiplier's stability.

$\mu\alpha$-n events at 1520mm Hg target pressure and α-n coincidences at 765 and 490mm were clearly seen in the raw, on-line data as were fusion neutron singles at the same densities. The neutron data should provide the cross normalisation between high and low pressure required for this and the LAMPF experiments and also explore this region of epithermal production.

THE FUTURE

A grant application is being prepared for a kicker magnet to spatially separate the muon bunches; this will double the number of completed μSR experiments, as they use only a fraction of the available beam, and considerably improve their frequency range. The undeflected beam position would then be available for more permanent experiments such as μCF.

There are space and plans for a purpose-built muon beam on the other side of the proton beam and sharing the production target; a switch-yard would reduce background and permit the beam to alternate between 'permanent' experiments. Table 1 also gives the parameters of a 'conventional' decay channel at ISIS with a superconducting solenoid. The total fluxes of decay and cloud beams are comparable. As μCF experiments use only a small fraction of the μ^- stopping volume then the cloud beam would give much higher event rates and better signal to noise because of its smaller $\frac{\Delta p}{p}$ and spot size. The major advantage of the decay channel is the negligible π^- and e^- contamination (the latter only with an ultra-thin, solenoid window) n.b. a π^- gives 140 Mev of background but a large fraction of the muon mass goes into the neutrino. For the present beam a recently installed double collimator should enable higher separator volts to reduce the e^- contamination by much more than x50. Next year we aim to considerably reduce the π^- contamination with a thin degrader at an upstream focus at the expense of ~ 25% increase in $\frac{\Delta p}{p}$. The choice of beam is open.

SOME POSSIBLE EXPERIMENTS

These are mentioned to illustrate the power of the facility.

μ^3He and μ^4He cascade x-rays

(A) Scavenging by He from excited (μ-hydrogen isotope) atoms can be distinguished from that via the ground or meso-molecular state; the former will dominate during the burst and the latter afterwards. Suppression of e/π contamination from the target and charged particles from the detector - GSPC or Compton suppressed SiLi - by a solenoid magnet will be required.

(B) The state of the 'stuck' μα, following D-T fusion, as it slows may be followed from the changes in yield of several spectral lines as functions of density.

Exploration of epithermal production and low temperature plasma.

The 'μt' intermediate state is created with 19ev and its thermalisation is sufficiently slowed at low densities that it spends significant time with energies equivalent to the required high temperatures. Neutron singles will explore $10 \rightarrow \frac{1}{2}\rho_{STP}$ and α-n coincidences densities below $1\rho_{STP}$.

Low temperature plasma.

This can be achieved with the pulsed, Θ-pinch of a solid D-T filament.

Hyperfine studies

A pulsed CO laser could induce $(\mu t)_s \rightarrow (\mu t)_t$ with polarized $(\mu t)_t$ being detected by transverse μSR.

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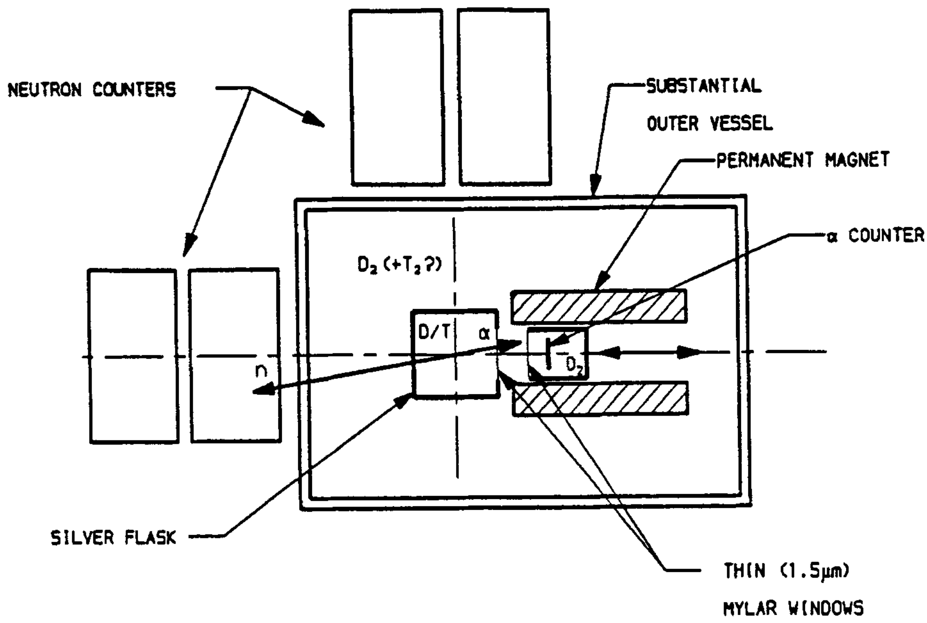

Fig. 1. Apparatus for measuring W_s.

Table 1

Column 1 - Performance of the ISIS surface/cloud pulsed muon beam
Column 2 - Calculate performance of a decay beam using an existing superconductor solenoid.
Both from a 1cm production target and 90 μa protons.

		Surface/Cloud		Decay
Beam spot		$2x3cm^2$	FWHM	$6x6cm^2$
Δp/p		5%(cloud)		12%
Intensity	29	~1.5 $10^6 \mu^+/s$		negligible
at MeV/c	40	6 $10^4 \mu^-/s$		30% less
	60	1.5 $10^5 \mu^-/s$		equal
	100	"cloud" 30% less than "decay"		
π contam.		between 3:1 and		very low
e contam.		1:1 π or e : μ		low (?)
Polarized μ		at 29 Mev/c only		yes