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The Hydrogen Pellet Target

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Background.

The initially suggested [1] reaction for π^0 production,

$$d(p,\pi^0)^3He,\ T_p = 300\ \mathrm{MeV},$$

would have as its optimum target a pure deuterium one with high density. A candidate for such a target was proposed [2], the deuterium droplet target, using droplet diameters of $\sim$20 μm to satisfy the desired luminosity and reaction vertex definition requirements. A principal outline of the idea is shown in Fig. 1.

In investigating the possibilities for using deuterium droplets as internal targets, it was found that a group at the University of Illinois, Urbana, USA, had developed an apparatus with very attractive properties, a hydrogen pellet generator. This device produced solid hydrogen pellets with sizes ranging from $\sim$70 μm up to several hundred μm for the purpose of refueling tokamak fusion machines. The pellet velocities ranged up to $\sim$100 m/s and the production rates up to $\sim$100 kHz. Some of the pellets were delivered into a vacuum of $\sim 10^{-3}$ torr [3,4]. Hydrogen droplets introduced into vacuum will freeze because of the violent evaporation. Further theoretical investigations of the thermodynamics of the deuterium pellets under assumed experimental conditions at CELSIUS showed that the pellets will stay solid when passing through the ion beam giving vapor load rates into the the target chamber that should be possible to handle [5].

Discussions with Professor R.J. Turnbull of the Urbana group lead to the conclusion that the target idea has a good chance of being successfully realized, and a collaboration was established with the aim to set up a deuterium pellet target generator at the CELSIUS facility in the beginning of 1989. The initial part of this collaborative work has been going on in Urbana since January '86 and will last until September '86.

π^0 production through the reaction

$$p(p,\pi^0)2p, \; T_p = 500 \text{ MeV}$$

is now considered to be a better choice and therefore the pellets should be made of hydrogen. From the point of view of generating the pellet target, this does not at the moment seem to impose any additional difficulties compared to the deuterium case, although the working temperatures have to be lower.

Target Properties.

The internal hydrogen pellet target for studies of rare π^0 decay modes at CELSIUS will, if the development work is successful, have characteristics according to the following:

i) The target is made up entirely from the desired target nuclei in the densest possible configuration.

ii) The target reaction gives a high π^0 production cross section, ~ 1 mb.

iii) The luminosity is high, $\sim 10^{32}$ $cm^{-2}s^{-1}$ with 21 μm pellets, 3 mm beam diameter and 10^{10} stored 500 MeV protons in CELSIUS.

iv) For a chosen luminosity there is the least possible Coulomb scattering of the outgoing reaction products. This is especially important for the leptons from the π^0 decays inside the target.

v) For a chosen luminosity there is the least possible risk of confusion with far more frequent decay modes through e^+e^- - conversion of γ-rays in the target.

vi) The target itself defines the reaction coordinates within ~ 10 μm, since only one pellet at the time is allowed in the beam.

vii) The narrow tube construction, which introduces the target into the ion beam, occupies a minimum solid angle. It is therefore possible to cover a solid angle close to 4π with the detector system.

viii) For a chosen luminosity there is the least possible Coulomb scattering in the target of the stored proton beam. The beam lifetime should therefore be at its maximum.

ix) Hydrogen as residual gas in the ring is the most favourable case with respect to beam lifetime. The CELSIUS vacuum requirements are therefore moderate, enabling larger evaporation rates in the target area.

Target Development.

Extensive development work will, of course, be necessary on the Urbana construction in order to meet the requirements of the π^0 experiment. Computer control of temperatures and pressures will be introduced to allow for stable operating conditions. The diameter of the pellets has to be substantially reduced. The production rate must also match the pellet velocity in order to give the desired pellet separation distance of one beam diameter. A differentially pumped construction that transports the pellets from the high pressure production region to the high vacuum target area under controlled conditions has to be developed. This will almost certainly have to include some kind of trajectory control of the pellets. The intention is to solve this by using electrostatic forces. A pellet position recording system at the beam intersection will also be required. This is assumed to be built on optical techniques. Finally, the pellets have to enter the target area under such conditions, that it is possible to maintain the ring vacuum at an acceptable level.

Temperature and Pressure Control.

The pellet generator construction described in Ref. [3] is now beeing rebuilt at the University of Illinois, Urbana, Illinois. Besides a general review of the generator, this reconstruction includes the installation of remote controlled valves. Programs and additional hardware are beeing developed for computer control of the temperatures and pressures of the pellet generating system.

Pellet Diameter and Luminosity.

With 10^{10} stored 500 MeV protons in CELSIUS, the luminosity L, beam diameter D and pellet diameter d are related as

$$L \times D^2 = 1.0 \times 10^{39} \times d^3 \qquad (s^{-1})$$

with units in s and cm. Requiring a luminosity of $10^{32}\ s^{-1}cm^{-2}$ thus leaves the pellet diameter depending on the proton beam diameter at the interaction point. The beam diameter has been assumed to be 3 mm, thus a pellet diameter of 21 μm is desired. Decreasing the pellets to this size is not anticipated to be a major problem, although nozzles with a diameter of 13 μm have to be constructed, a four-fold reduction as compared to earlier work [3]. Such nozzles have, in fact, now been manufactured and the main problem turned out to be preventing them from getting plugged by alien particles. It remains, however, to have the performance of a nozzle confirmed in producing a liquid hydrogen jet of sufficient quality. Having a beam diameter of 0.3 mm, as will for example be the case in $p(p,2p)\pi^0$ studies close to threshold at the IUCF Cooler Facility in Indiana [6], will greatly increase the technical difficulties in the nozzle construction if the other parameters remain the same. The π^0 experiment whould then require a pellet diameter of 4.5 μm, i.e. a nozzle diameter of 2.6 μm! An attractive solution is then to have the pellet diameter unchanged and decrease the number of stored protons, since the upper luminosity limit is likely to be set by the target evaporation rate as will be discussed below. The cooling "force" of CELSIUS is claimed to be able to handle at least 10 times the luminosity discussed above [7], corresponding to more than twice those pellet diameters.

Pellet Transport into Vacuum.

One of the more difficult problems to solve is thought to be the transportation of the pellets into vacuum. Since the droplets are produced at roughly triple point conditions (14 K, 54 torr) while the beam crossing occurs at high vacuum conditions, this pressure difference has to be maintained by some kind of a differentially pumped construction along the path of the pellets. Based on experiments [8] and calculations [9] it has been concluded, that the hydrogen droplets must be allowed to at least partially freeze in the droplet chamber [10]. This can be achived by slightly decreasing the pressure below the triple point value as was reported in [3]. It is not considered possible to design a differentially pumped system where purely liquid drops would be prevented from disintegrating due to the turbulent, high velocity gas flow arising at the pressure gradient of the first aperture. This turbulent, high velocity gas flow together with shock wave formation at the exit of the first aperture in the differentially pumped system is, however, also likely to cause problems in introducing a momentum spread to the pellet stream. Altering of the pressure gradient, centering of the pellet flow, changing the width and length of the aperture and the employment of a skimmer are possible measures of counteraction.

Trajectory Control and Position Determination.

Still, the need of a momentum diagnositic and control system, acting on the individual pellets, is anticipated. The diagnostics will be based on optical techniques along the same line as is intended for the final position determination in the beam. The pellet position recording system is assumed to be built on arrays of optical fiber guided laser beams and light sensitive detector elements. For control purposes, electrostatic forces acting on charged pellets will be used. This requires a method of introducing electrical charge into the droplets/pellets. The Urbana group has already done some promising work on the charging of hydrogen droplets, which is not trivial, since hydrogen is an insulator [11,12]. A new nozzle unit for the pellet generator has been constructed, in order to allow for the production of charged hydrogen pellets, using field emission injection of charge into the liquid hydrogen jet in conjunction with Rayleigh's method of droplet production as described in Ref. [11].

Vapor Load Rate in Target Chamber.

The conclusion, made in Ref. [5], that acceleration of the deuterium pellets would significantly decrease the vapor load rate in the target area is not supported by more recent calculations. This is due to the crude assumptions, that were made earlier, concerning the low temperature deuterium heat capacity, since no data were available at that moment. The new calculations are based on more reliable thermodynamical data and include the effects of radiated heat from the vacuum chamber walls. Provided that the other assumptions made in Ref. [5] not significantly effect the conclusions, increasing the pellet speed from 30 m/s to 300 m/s in the beam crossing region, reduces the vapor load rate there from $\sim 3 \times 10^{-3}$ to $\sim 1 \times 10^{-3}$ torr x l/s, a factor of about 3 instead of 30, as was obtained earlier. A recent investigation

[13] of the possibilties of accelerating charged hydrogen pellets to high velocities in electric fields has furthermore indicated great technical difficulties. Gas load rates of the magnitudes mentioned should, however, not jeopardize the proposed experiment, since a proton beam life time of the order of one hour is expected at a residual hydrogen pressure as high as 10^{-7} torr in the ring [14]. The new calculations also indicate, that the gas load rates will be about the same in the target area, regardless of whether one uses hydrogen or deuterium as pellet material. Limited attention will therefore be given to the problems connected with acceleration of the pellets, until calculations taking into account the finite thermal conductivity of hydrogen have been made or pellet - ion beam interaction experiments have been performed. Concerning the dependence of the vapor load rate in the target area on the pellet diameter under fixed luminosity conditions, calculations indicate that it is advantageous to increase the pellet size while decreasing the stored proton beam intensity.

Schematic Outline of Target.

Fig. 2 shows a sketch of a conceptual deuterium pellet target mounted on the general purpose CELSIUS target chamber [15], which is presently under construction for use together with the fiber and gas cluster jet targets. The experiment indicated is the rare π^0 decay measurements as they were initially planned to be performed, using the $d(p,{}^3He)\pi^0$ reaction, with the vertex, electromagnetic shower and forward recoil detectors. This general outline is not thought to be drastically altered by the new experimental set up.

Apprehensions have been expressed about the effect of the up to 5 T strong superconducting solenoid magnetic field on the charged pellets. As the worst case, a deviation from the straight path at the beam intersection of < 3 mm has been calculated [13], assuming a pellet flight path of 0.5 m in the magnetic field. Since the deflection occurrs in a predictable way, this will not have any hazardous implications on the target performance.

Schematic Outline of Experiments.

The continued development work will deal with:

1) Testing the rebuilt pellet generator with its new control and diagnostics system when producing $\sim 100\ \mu m$ hydrogen pellets.
2) Testing the pellet generator with the reconstructed nozzle unit when producing $\sim 20\ \mu m$ hydrogen pellets.
3) Experiments on producing charged $\sim 20\ \mu m$ hydrogen pellets under long term stable conditions.
4) Experiments on transporting charged $\sim 20\ \mu m$ hydrogen pellets into vacuum.
5) Experiments on control of the charged pellet trajectories.
6) Pellet - ion beam interaction experiments.
7) High precision pellet position determination in the ion beam.
8) Dumping of the pellets.

The ongoing first phase is hopefully engaged in 3), when it ends in September '86.

REFERENCES:

1. L. Bergström, CELSIUS-Note 83-22 (1983)

2. S. Kullander, CELSIUS Information Day, Uppsala (1984)

3. C.A. Foster, K. Kim, R.J. Turnbull and C.D. Hendricks, Rev. Sci. Instrum. 48 (1977) 625

4. R.P. Gilliard, K. Kim and R.J. Turnbull, Rev. Sci. Instrum. 52 (1981) 183

5. B. Trostell, CELSIUS-Note 85-46 (1985), Report GWI-PH 2/85 (1985)

6. R.E. Pollock, Private communication (1986)

7. S. Kullander, Private communication (1986)

8. A.R. Hanson, E.G. Domich and H.S. Adams, Physics of Fluids 6 (1963) 1070

9. E.Y. Harper, G.W. Grube and I.-D. Chang, Journal of Fluid Mechanics 52 (1972) 565

10. R.J. Turnbull, Private communication (1986)

11. J.P. Woosley, K. Kim and R.J. Turnbull, Journal of Electrostatics 5 (1978) 381

12. J.P. Woosley, R.J. Turnbull and K. Kim, IEEE Trans. Ind. Appl. IA-18 (1982) 314

13. Y. Gavel, Private communication (1986)

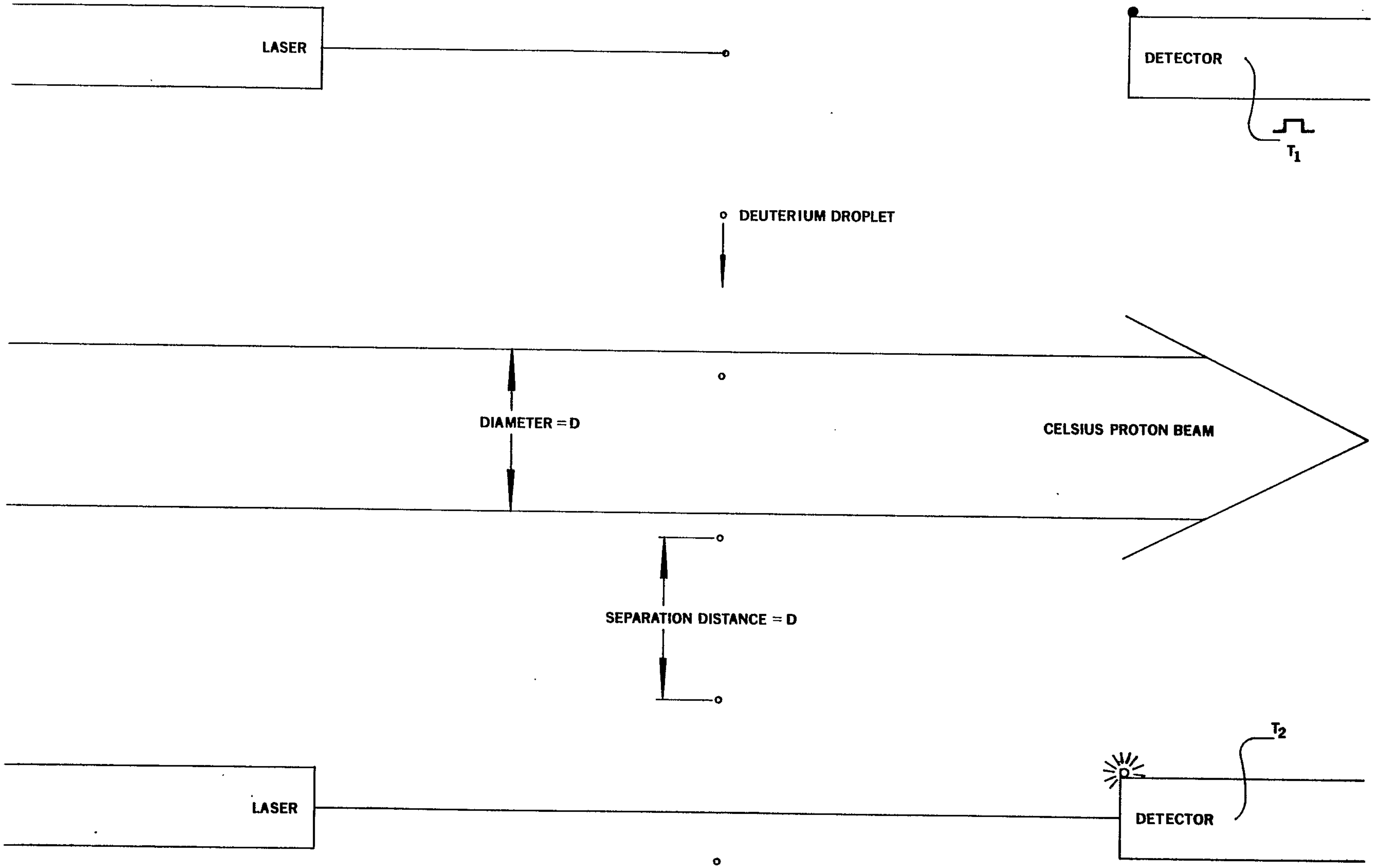
14. H.O. Meyer, Proc. AIP Conf. #128 (1984)

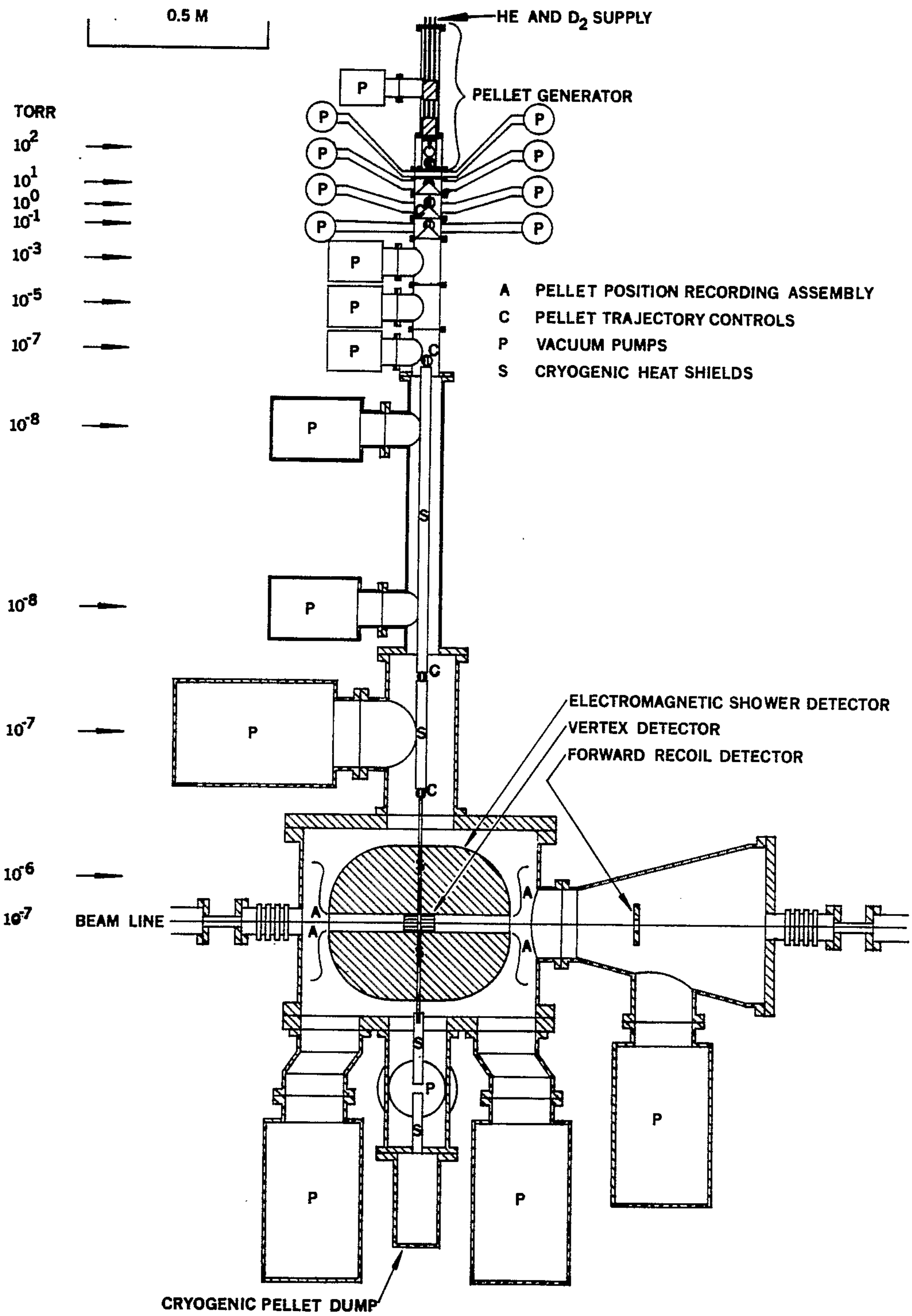
15. C. Ekström, CELSIUS Information Day, Lund (1985)

FIGURE CAPTIONS:

Figure 1: Outline of the deuterium droplet target idea [2].

Figure 2: A conceptual hydrogen pellet target mounted on the general purpose CELSIUS target chamber equipped with detectors for the rare π^0 decay measurements, as they were initially intended to be performed.


LASER
DETECTOR
T_1
DEUTERIUM DROPLET
DIAMETER = D
CELSIUS PROTON BEAM
SEPARATION DISTANCE = D
T_2
LASER
DETECTOR



0.5 M
HE AND D_2 SUPPLY
PELLET GENERATOR
TORR
10^2
10^1
10^0
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-8}
10^{-8}
10^{-7}
10^{-6}
10^{-7}
BEAM LINE
A PELLET POSITION RECORDING ASSEMBLY
C PELLET TRAJECTORY CONTROLS
P VACUUM PUMPS
S CRYOGENIC HEAT SHIELDS
ELECTROMAGNETIC SHOWER DETECTOR
VERTEX DETECTOR
FORWARD RECOIL DETECTOR
CRYOGENIC PELLET DUMP