THE R&D PROGRAM FOR TARGETRY AT A NEUTRINO FACTORY

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ABSTRACT

The need for intense muon beams for muon colliders [1] and for neutrino factories based on muon storage rings [2, 3, 4] leads to a concept of 1-4 MW proton beams incident a moving target that is inside a 20-T solenoid magnet, with a mercury jet as a preferred example. Novel technical issues for such a system include disruption of the mercury jet by the proton beam and distortion of the jet on entering the solenoid, as well as more conventional issues of materials lifetime and handling of activated materials in an intense radiation environment. As part of the R&D program [5] of the Neutrino Factory and Muon Collider Collaboration, R&D effort related to targetry is being performed within the context of BNL E951 [6], first results of which are discussed here and in other contributions to this conference.

1 THE TARGETRY CONCEPT

A muon collider [1] or a neutrino factory based on a muon storage ring [2, 3, 4] require intense beams of muons, which are obtained from the decay of pions produced in proton-nucleus collisions. To maximize the yield, pions of momentum near 300 MeV/c should be captured [7, 8]. For proton energies above 10 GeV, the pion yield per unit of proton beam energy is larger for a high-Z target [7]. For proton beam energies in the MW range, beam heating would melt or crack a stationary high-Z target [9], so a moving target must be used. A mercury jet target is the main focus of BNL E951 [6], although R&D is also being conducted on a carbon target option [2, 10, 11] as might be suitable for a low-energy proton source [12], and conceptual studies have been carried out for rotating-band targets [13, 14], a tantalum/water target [15], and a liquid-lithium target [16].

The low-energy pions are produced with relatively large angles to the proton beam, and efficient capture into a decay and phase rotation channel is obtained by surrounding the target with a 20-T solenoid magnet, whose field tapers down to 1.25 T over several meters [17, 18], as sketched in Fig. 1. See also Figs. 2 and 3 of [8]. Pion yield is maximized with a mercury target in the form a 1-cm-diameter cylinder, tilted by about 100 mrad with respect to the magnetic axis. To permit the proton beam to interact with the target over 2 interaction lengths, the proton beam is tilted by 33 mrad with respect to the mercury jet axis.

The use of a mercury jet target raises several novel issues. The rapid energy deposition in the mercury target by the proton beam leads to intense pressure waves that can disperse the mercury [6, 19, 20, 21, 22, 23]. Further, as the mercury enters the strong magnetic field eddy currents are induced in the mercury, and the Lorentz force on these currents could lead to distortion of the jet [6, 23, 24, 25, 26, 27, 28]. On the other hand, the magnetic pressure on the mercury once inside the solenoid will damp mechanical perturbation of the jet [20, 29].

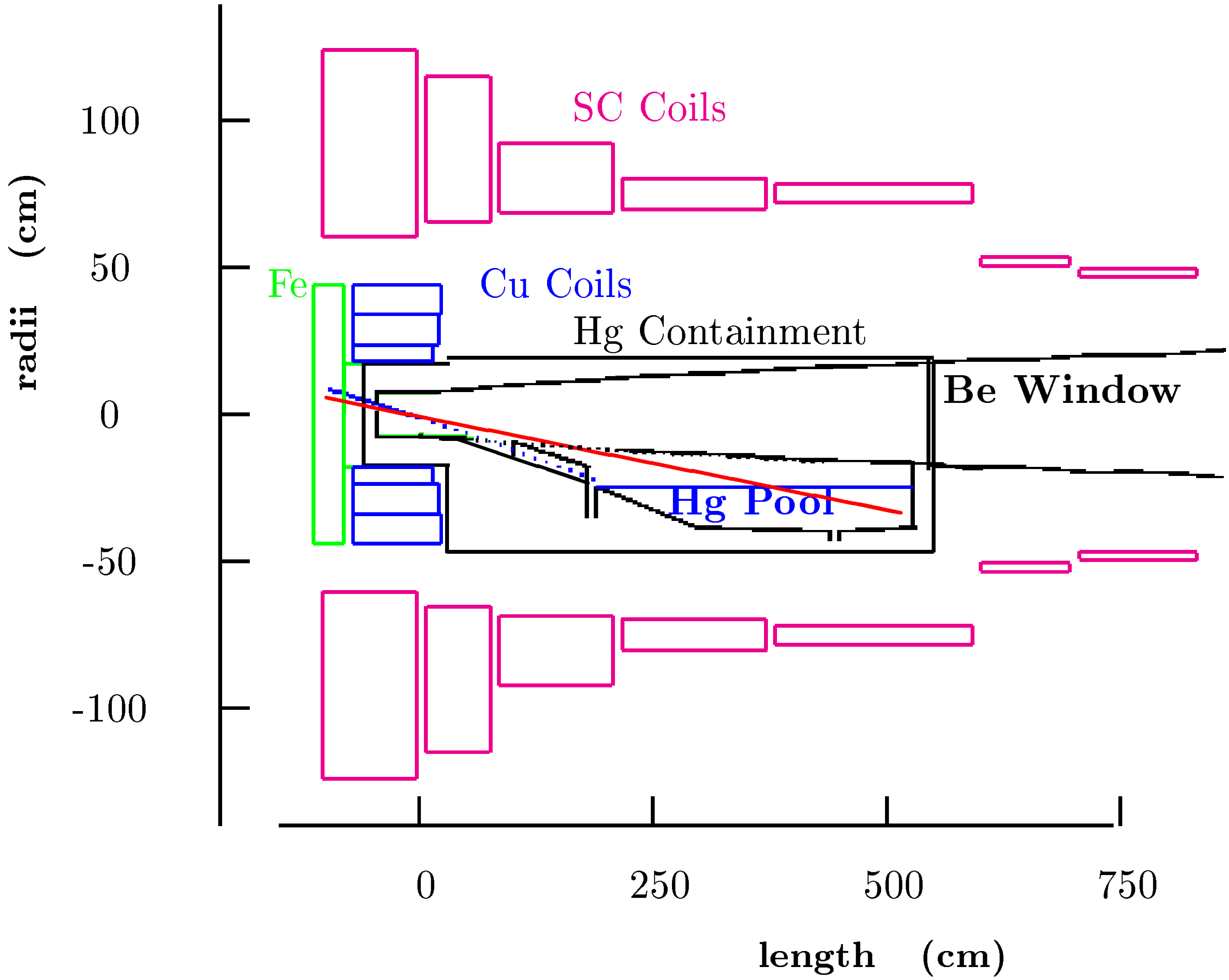

Figure 1: Concept of targetry based on a mercury jet and proton beam at 100 mrad and 66 mrad, respectively, to the axis of a 20-T solenoid magnet.

To address these issues an R&D program is now underway.

2 THE TARGETRY R&D PROGRAM

In the USA, R&D on targetry for a neutrino factory and muon collider has been formalized as BNL experiment 951 [6]. This project maintains close contacts with related efforts in Europe [30] and in Japan [31].

The broad goal of E951 is to provide a facility that can test all the major components of a liquid or solid target in intense proton pulses and in a 20-T magnetic field. A sketch of the eventual facility is shown in Fig. 2.

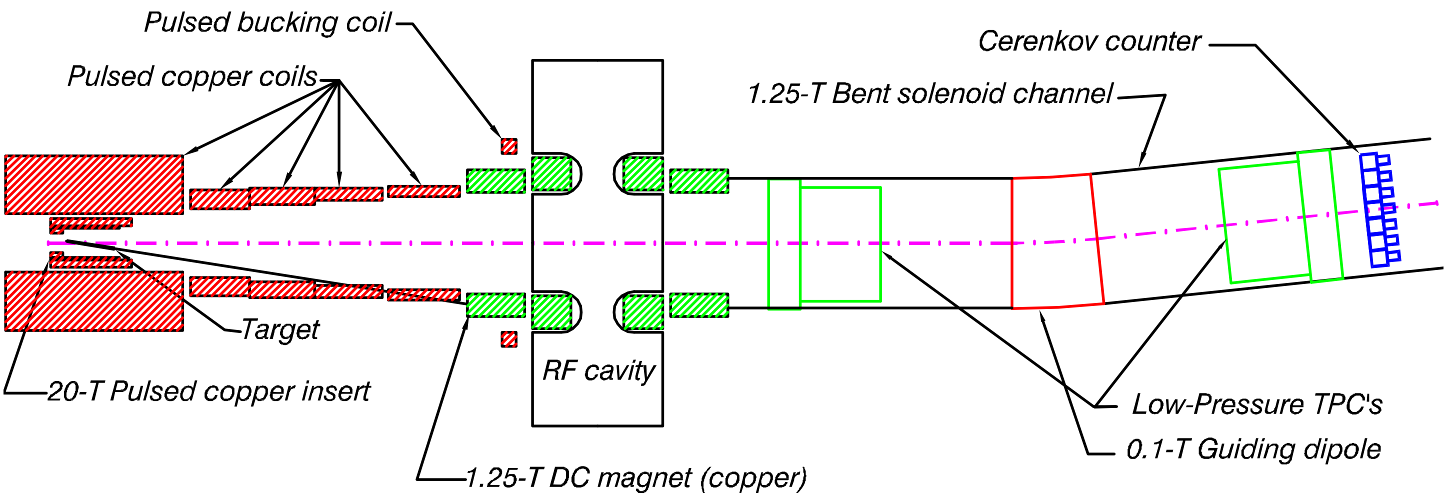

Figure 2: Sketch of the full configuration of BNL E951, the targetry R&D facility.

Present activities in E951 focus on the interaction of intense proton pulses with targets in zero magnetic field. European targetry studies presently emphasize the interaction of mercury jets with a magnetic field, the operation of rf cavities near high-power targets [32], and evaluation of target materials [33].

2.1 Mercury Target Studies

The present R&D program on mercury jets is an outgrowth of work at CERN in the 1980's in which a prototype mercury jet was prepared (Fig. 3), but was never exposed to a beam.

Experiment 951 is conducted in the A3 beamline of the BNL AGS [34] into which a single bunch of up to 5×10^{12} 24-GeV protons can be extracted and brought to a focus as small as 0.6×1.6 mm^2. The dispersal of both static and moving mercury targets by the proton beam was observed via two high-speed cameras using shadow photography with a laser diode [35]. The principal results obtained thus far in 2001 are summarized elsewhere [36, 37]. Figure 4 shows results from a static mercury target. Dispersal velocities of up to 50 m/s were observed. The air in the target cell slowed the droplet velocity by a factor of two over 10 cm. A key result from the jet studies was that the dispersal of mercury by the proton beam was confined to that part of the jet directly

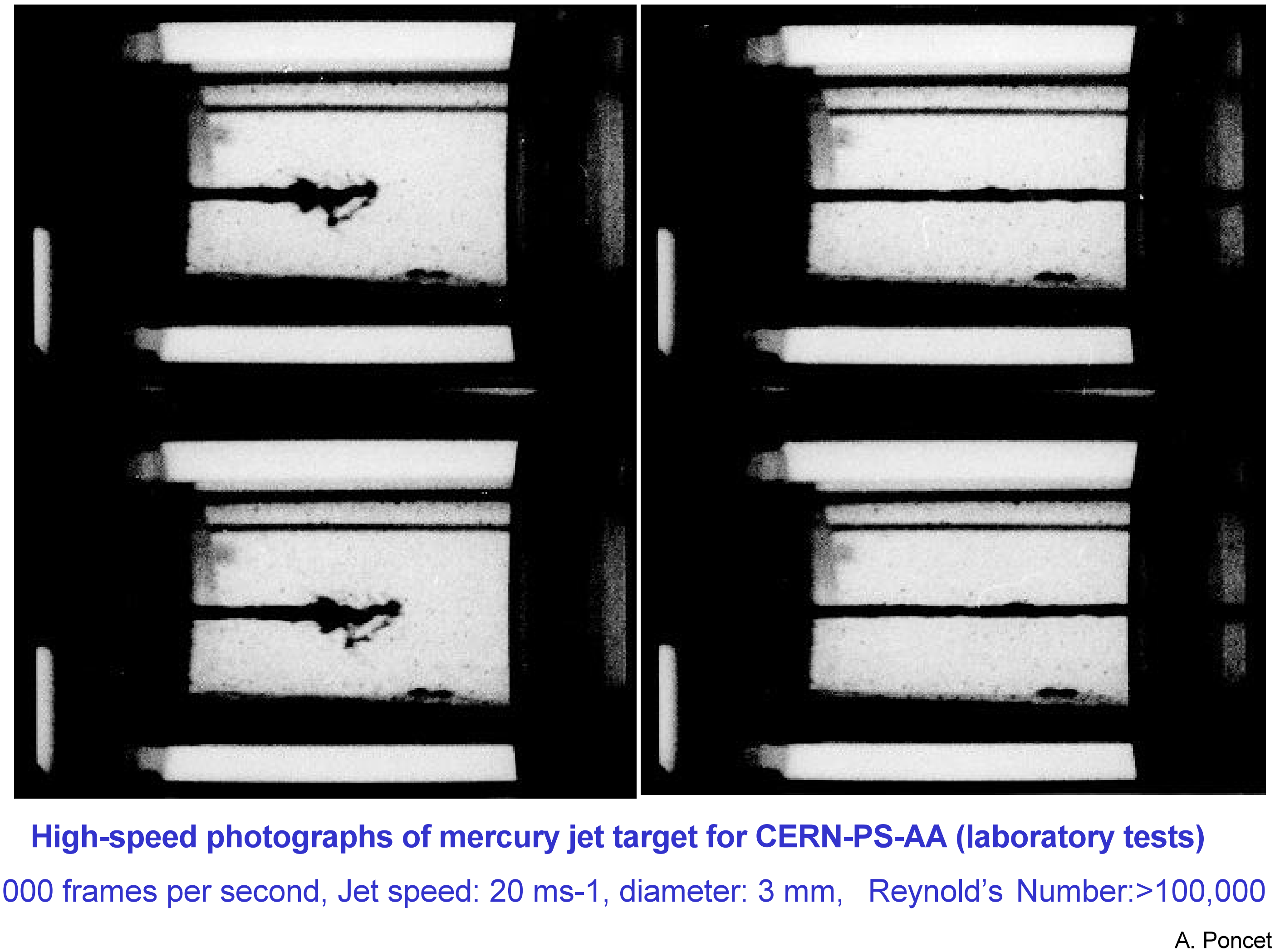

Figure 3: Photographs of a 3-mm-diameter mercury jet (C.D. Johnson, 1988).

intercepted by protons.

Thus, it appears that the dispersal of mercury by a proton beam is dramatic, but not violent, and that the dispersal will be a relatively modest issue for a target facility that operates at 15 Hz [38].

2.2 Solid Target Studies

E951 included exposures of several solid targets to the proton beam, using fiberoptic strain sensors with 500 MHz bandwidth to characterize the transient response of the targets to the pressure waves induced by beam energy deposition [39]. As expected, a carbon-carbon composite target with thermal expansion coefficient of less that 10^{-6}/K showed much less strain than an ATJ graphite

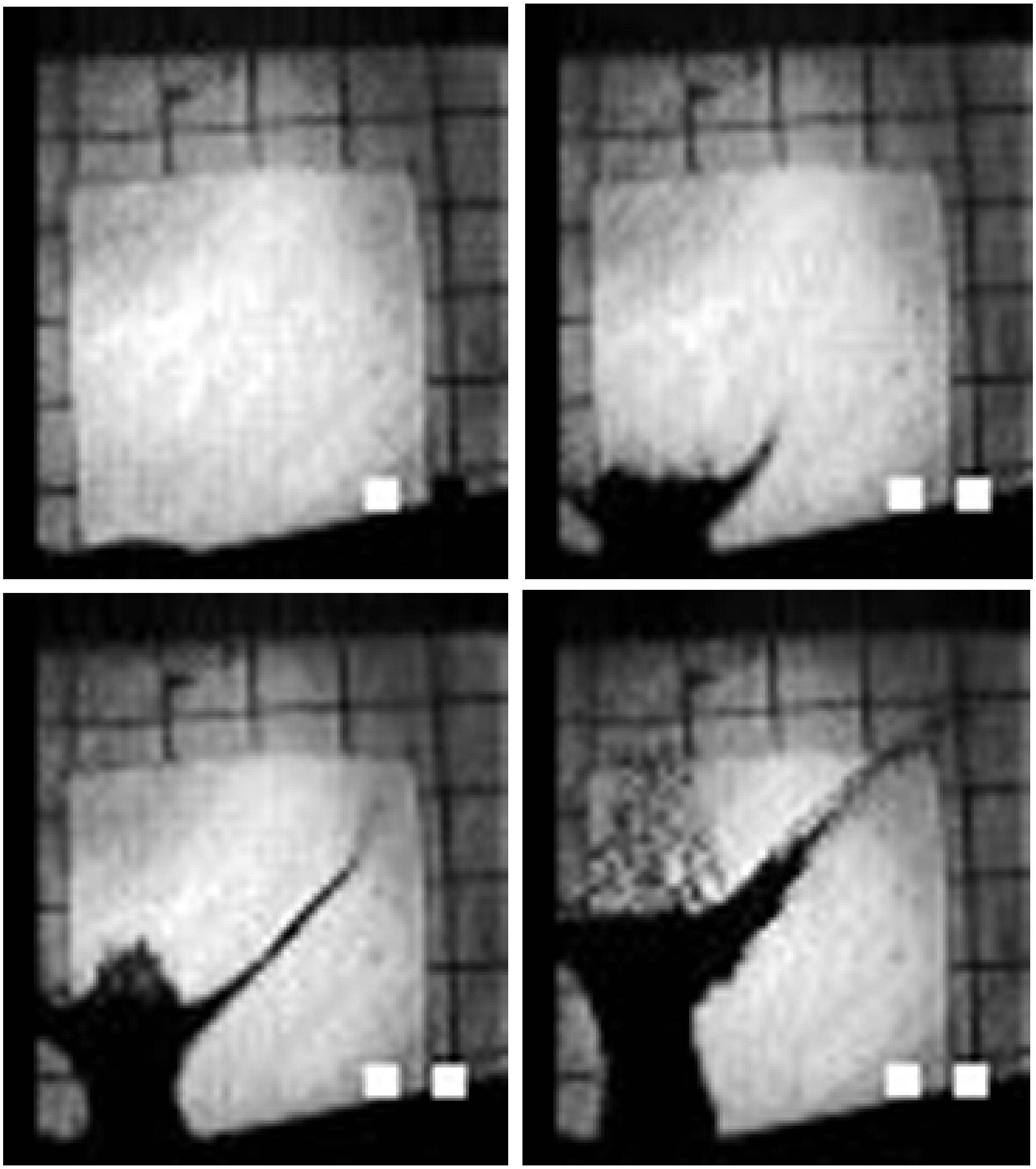

Figure 4: Exposures of 25 μs at $t = 0$, 0.5, 1.6, 3.4 msec after a pulse of 2×10^{12} protons interacted with a "thimble" of mercury 1.0 cm in diameter and 1.5 cm deep.

target.

The issue of the rate of sublimation of carbon targets at the elevated temperatures ($>$ 1900C) caused by exposure to a 1-MW beam is under continuing laboratory study. Calculations indicate that a helium atmosphere can greatly extend the operation life of a carbon target against sublimation [40].

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