1 Physical Description

The entire detector including the pressure vessel and internals are all supported on a support flange of the pressure vessel. There is a large copper shield ring having extension ”fingers” around its periphery which rest in a groove of this support flange. This shield ring provides a base for mounting the SiPM plane, EL mesh and field cage. The SiPM front end electronics boards have some activity and are located behind this shield ring. The copper shield provides a heatsink for the F.E. electronics and will conduct heat to the support flange which is in contact with both water and the other pressure vessel parts, providing passive cooling.

2 Pressure Vessel Design

2.1 Layout

The pressure vessel comprises four parts, all of pure titanium, ASTM grade 3 (or 2) which are bolted together:

- An upper head which contains the PMTs,
- A main cylindrical vessel, which incorporates at its base a thick section which allows penetrations for services (Xe gas flows, power and signal feedthroughs, EL HV cable, etc.),
- A support flange, upon which the detector is built, and to which floor supports connect to,
- A lower inverted elliptical head, designed to withstand pressure on its convex surface; the inverted design minimizes wasted Xe volume. This lower head is removed to access the SiPM plane and front-end electronics.

All flange pairs are bolted together with grade 3 titanium bolts and nuts, and have O-ring pairs for sealing. PCTFE is the preferred O-ring material, having the lowest leakage of any polymer. A small pumpout port samples the annulus between the O-rings to check for either Xe (out) or water (in) leakage.

2.2 PMT Head

The choices for this head shape (in axial cross section) are elliptical, torispheric or flat. The torispheric head has a spherical center section called a ”crown” with a toroidal edge section (”knuckle”), to transition to a short cylindrical section that is welded to the flange. It was chosen over an elliptical shape because the spherical shape of the crown allows all edges of radial openings drilled into it (normal to the surface) to be circular; this simplifies the machining of these openings and any flanges that mate to them. The torispheric (and elliptic) shape is far more mass efficient than a flat plate for holding pressure; a thickness of 15mm is required, whereas a flat plate requires close to 100 cm or more. It is only somewhat harder to machine the openings than for a flat head, CNC machining is not required.

The crown has 3 concentric rings of openings that accommodate pure titanium CF (NW100 size, 15 cm O.D.) flanges with diffusion bonded sapphire windows, for a total of 36 PMTs. A central opening having a large inside radius is used for the high voltage feedthrough, either the TAMU designed feedthrough, or a standard cable receptacle for a 100 kV medical X-ray machine (e.g. Federal Standard or Euro RXX designs) as pictured here: 1 which can be made in radiopure materials, and rated for pressure. CF flanges are also used on the outer surface of the crown (with a welded-in housing) to both seal the PMT's against water, and to provide a secondary

H454 federal and extended federal standard receptacles: 100KV, 160KV and 250KV.

H1365 R24/R12 HV receptacles. Grooved style furnished for applications requiring additional creepage coverage.

Figure 1: Hydraulic Bolt Tensioner

containment for Xenon, should a sapphire window break or gasket leak. This design is chosen as the nominal design since, apart from the-beam welding of the head shell to the flange, no further welding is required and all the openings for PMTs and CF flanges can be machined into the crown.

An optional head having 60 PMT heads is also feasible, but will require the e-beam welding of custom machined PMT housings into bored holes in the torispheric head, since the close spacing disallows the use of CF flanges. Polymer gaskets , such as PCTFE or PEEK would be used to seal the sapphire windows instead of CF metal seals. Windows or gaskets are replaceable without removing the head in this design. This head has a further advantage in that the PMT faces need not be flush with the crown, and can be inserted down into the cathode buffer space, up to where the faces are roughly in a plane, thus reducing wasted Xenon volume. This head will be significantly more expensive to fabricate and require significant prototyping.

2.3 Design Requirements

The pressure vessel is designed to safely maintain a maximum operating internal pressure of 15 bar (absolute), with atmospheric pressure on the outside, and also to withstand an external pressure of 1.5 bar (5 m H_2O hydrostatic pressure on outside, with full vacuum on inside). It also serves as ground potential, on its inside surface for the field cage, and must be compatible with the insulation gas, here Xenon, and withstand any breakdown. There is over 2 MJ of stored energy, which would be catastrophic if suddenly released by vessel rupture. It is designed in full accordance with American Society of Mechanical Engineering (ASME) Pressure Vessel (PV) Code, section VIII- Division 2 (or equivalent European Standard), and will be pressure tested to a minimum of 1.25x the maximum allowable pressure.

The Pressure Vessel will necessarily be a welded construction due to the size. Shells will be roll formed and seam welded, machined, then welded to machined flanges. There may be a final machining of each flange face after welding. Welds will be exclusively electron beam, made in high vacuum, and all welds will be fully radiograph inspected afterwards; this allows the welds to have full strength, reducing the wall thickness needed. Titanium is very easily e-beam welded, even in thick sections, with excellent resulting properties. Laser or diffusion bonding (welding) methods are also possible, however laser welding typically does not have the penetrating power of e-beam, and diffusion bonding is not mentioned as an allowable process in the ASME PV code.

The pressure vessel must also be corrosion resistant in ultrapure water. Titanium has excellent corrosion resistance in pure water; copper corrodes in ultrapure water, and would need some sort of radiopure barrier coating.

The pressure vessel interior surface also serves as a ground boundary for the field cage and must withstand potential sparkovers. It is not known whether titanium has better spark damage resistance than copper, it has a higher melting point, but lower thermal conductivity; testing is warranted.

2.4 Pressure Vessel Construction Issues

The final design of the Pressure Vessel will only be released after close consultation with the fabricator, to assure that no unexpected difficulties arise. A detailed specification will be drafted and potential manufacturers will be required to submit a full fabrication plan. Crucial details must be worked out with fabricators, material suppliers etc. to not only assure that the vessel is constructed in full accordance withe the PV code but remains radiopure when finished. Many important details must be worked out based on practical realities of supplier and manufacturer capability, such as where to place flange welds, what prototyping and testing must be done to assure the vessel is made correctly, what material samples are to be taken, what are permissible cleaning and preparation processes, etc. Below are some initial concerns with fabrication and assembly of the various sections:

2.4.1 CF Flange 36 PMT Torispheric Head

This head requires no welding of PMT housings into the crown, but is limited to 36 PMTs due to the large CF flange OD. The shell is formed by metal spinning, the crown is thicker than the knuckle and cylindrical section, so these sections my be formed separately and e-beam welded together. Due to the flange stud holes, which limit the reinforcing area around the PMT opening, a thicker shell is required, 20mm instead of 13mm for the welded 60 PMT head. It still requires welding the formed shell to the flange; this will be e-beam welded. However flange welds should not require a CNC controlled e-gun (as in the 60 PMT head), a fixed gun will work, with a rotary table holding and spinning the head. If the knuckle cannot be formed integral to the crown, it can be e-beam welded to it in the same manner. Machining of the CF flange ports should be straightforward, and could be done with a mill having a tilting head, with the PV head. The ports can be machined using milling cutters, for less chatter, but the final surface of the knife-edge will need be machined, ground, or burnished using a single axis (spindle) rotating tool such as a boring/facing head, to avoid scratches across the knife edge. Gaskets for the outer CF flanges should be chosen to be as soft as possible, as the knife edges may be more delicate in titanium than in stainless steel. Silver may be a good choice, especially for the outer CF flange gasket which must not create galvanic corrosion in either the Ti or gasket. Copper will corrode in ultrapure water. Tin may be an option as well, as it can be made radiopure. An option is to use O-ring seals; these may even be used in CF flanges. The inside surface of the head may need machining after welding to assure that a smooth ground surface results.

2.4.2 Welded-in 60 PMT Torispheric Head (option)

This head will likely require a CNC controlled e-gun to make the PMT housing to crown welds. The crown will be bored for the PMT holes; and then accurately measured in a coordinate measuring machine (CMM) afterwards as most of the crown metal is being removed, and nominal dimensions will change once all the holes are bored (Swiss cheese effect). The PMT housings will be machined to fit snugly in the bores, and they will need to be held in place with individual fixtures. Some provision for the e-beam to be absorbed without damaging these holding fixtures may need to be incorporated. There will be some degree of shrinkage around the welds, as the metal cools; this will require several intermediate CMM measurements of the remaining bores to assure that the welds are being made in the right place (unless welder can otherwise assure precise positioning). Thus the fixturing of PMT housings in bores will need to be staged, and the sequence of welding will need to be carefully thought through to assure accurate welding. It is likely that each ring of PMT's will need to be fixtured and welded separately, and welds should be done around each ring in a staggered fashion, as is typically done in tightening bolted flanges uniformly. The PMT housings themselves will need to be machined from thick pipe or perhaps even solid bar, since the reinforcement section (large fillets on weld flange) must have a substantial radial dimension and cannot be formed as part of the crown.

2.4.3 Main cylindrical Vessel

There will be a longitudinal seam weld made after roll forming the cylinder which may need to be ground smooth. Edges will need machining to allow precise welding to flanges and to the lower thick section, which will likely be made separately.

2.4.4 Support Flange

This is a relatively straightforward machined plate, though required thickness may be high as this plate supports the entire detector, including the large internal copper shield, transferring weight to the outside legs. There will be a significant edge moment in the plate, and we desire to maximize the internal radius so as to provide clear access to the feedthroughs.

2.4.5 Lower Flat/Elliptical Head

This is also a relatively straightforward to fabricate. Shell thickness is nominally 6mm so this should be easy to spin. Carrying an external pressure requires tight tolerances on out of roundness or ellipticity, so CMM measurements should be made before welding. A method for safely lowering this head and moving it out of the way for SiPM service access is needed, as crane access is difficult.

2.5 Assembly of Pressure Vessel

There are currently 84 M20 bolts on each set of flanges which must be tightened uniformly around each flange. All bolts and nuts are also titanium which has a very high propensity for galling, which must be avoided. Silver plating should be considered on all nuts, and testing should be performed to see how many repeated bolt torqueings are allowable. Polymer coatings may be possible, but can have a friction coefficient that is too low to prevent nuts from backing off. No coating prove acceptable however, and it may be necessary to avoid all wrench torquing of large bolts by using a hydraulic tensioning/nut runner system as shown in fig. 2. Such systems work by screwing small hollow hydraulic cylinders (load cells) onto each bolt, above the nut (which is surrounded by the bridge), then pressurizing them all simultaneously through a common manifold, thus tensioning the bolts, then running the nuts down to the flange to maintain the bolt tension when the hydraulic pressure is released and the hydraulic cylinders are removed. This will also have the advantage of being much faster, far less strenuous, and give better results for bolt tension. It is envisioned that groups of these hydraulic cylinders will be loosely mounted to sections of a ring, so as to be easy to handle and install.

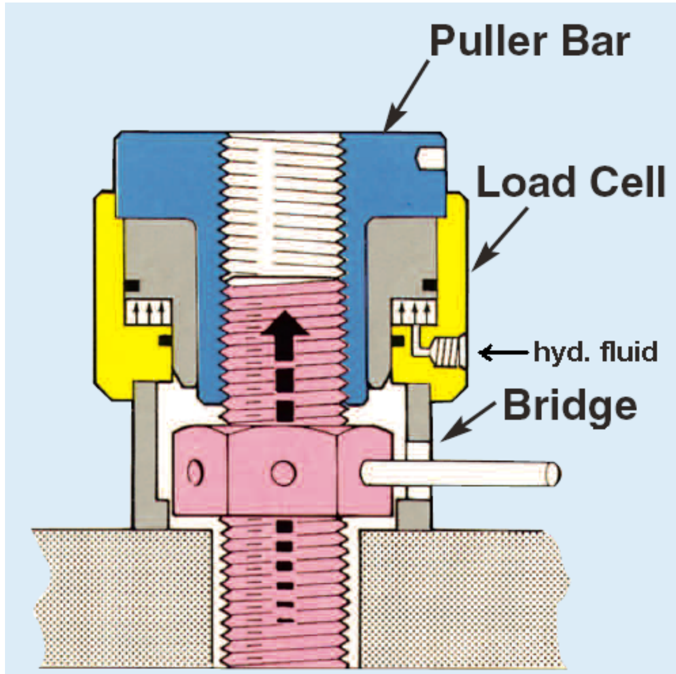

Figure 2: Hydraulic Bolt Tensioner