1 Radial TPC Spectator Tracker

Low momentum spectator protons lose energy rapidly as they pass through any material, and therefore leave short tracks or no tracks at all in solid detector components. In a detector based on gas ionization, however, ionization trails of significant length are readily achieved as the particles pass entirely through, or gradually slow down and stop, in the detection medium. Multiple measurements along the track provide a wealth of information about the particle that created it. Therefore, a promising spectator detector would be a gas chamber with appropriate geometry and minimum material content. It would provide position and timing information sufficient to identify backwards-going particles and connect them to an outgoing electron sensed in CLAS. Associated information about the particle's energy loss rate (dE/dx) as it precipitated the ion trail would provide compelling discrimination between protons and lighter charged particles.

A gas chamber configuration that provides all of these needs is a Radial Time Projection Chamber (RTPC). A diagram of the proposed detector is shown in Fig. 1. In outline, it consists of a pair of concentric cylinders with the annular space between the cylinders containing a sensitive gas. The cylinder axis would be placed along the beamline and target. Charged particles produced at sufficient angle (especially backwards) pass through the gas and leave a trail of electron-ion pairs. An electric field between the cylinders forces the electrons to drift towards the outer cylinder where appropriate electrodes cause avalanche multiplication. The resulting signal is collected on the outer surface by either individual pads or a stereo arrangement of conductive strips. The locations of the pads (strips) provides position information (ϕ-z) for the collected drift electrons, and the times of their arrivals provide a measure of the radius (r) at which they were produced. A string of such measurements constitutes multiple position measurements along the particle's track. By recording the amount of charge produced along the track one can estimate dE/dx and thereby constrain the mass of the particle that produced it.

Conventional Time Projection Chambers

Time Projection Chambers (TPCs) have been used for many years and the physical processes involved in their operation (notably electron drift and diffusion) are well understood. In most instances they are cylinders with the electric (drift) field parallel to the axis. This is especially advantageous when the TPC is placed within and parallel to a solenoidal magnetic (**B**) field, as the electrons are constrained to drift along a line of magnetic flux and therefore suffer very little transverse diffusion during their long transit to a readout device on one of the cylinder ends. The readout devices used include Multiwire Proportional Counters with cathode pads or strips, Micro Strip Gas Chambers, and Gas Electron Multipliers (GEMs).

TPCs are typically "slow" devices, owing to the electron drift velocity in most gases (a few cm/μs or less at atmospheric pressure). A 1 m long TPC may require 100 or so microseconds for complete electron drift. However, the slow drift speed provides fine position resolution. The large number of measurements on each track allows tracks to be recognized and correctly associated with other tracks from the same event even when multiple events occur during one drift time interval.

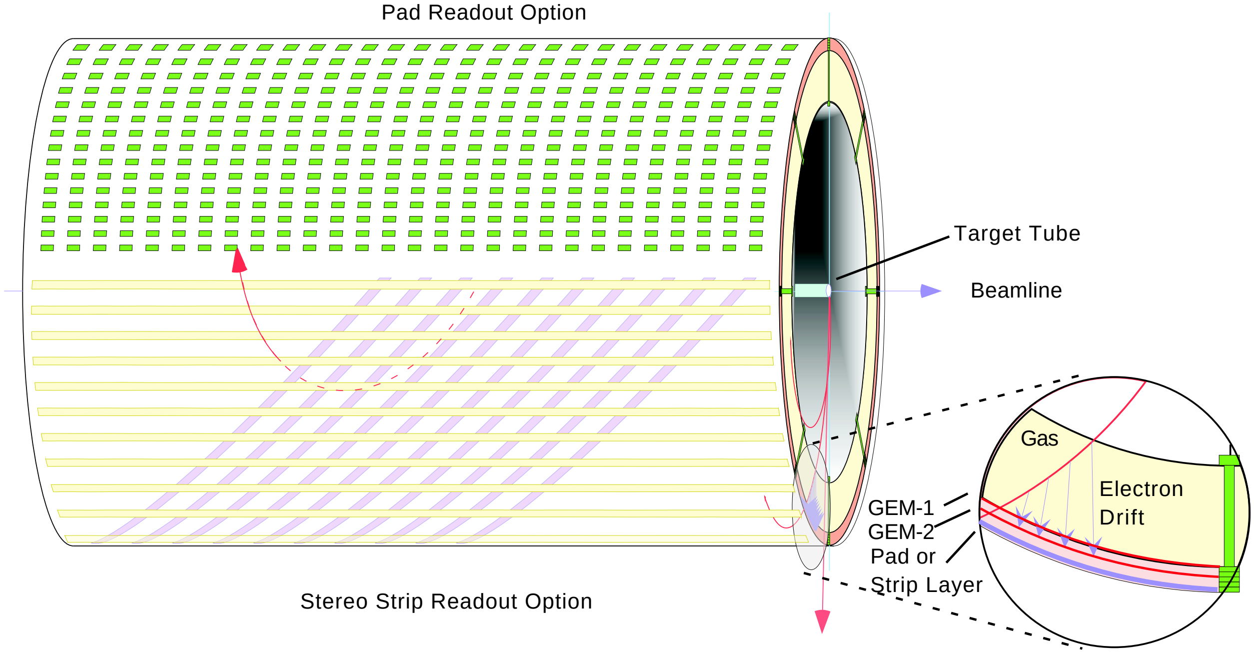

Figure 1: Sketch of the Radial Time Projection Chamber for BoNuS. In this figure the upper portion shows pad readout while the lower portion shows readout by two planes of strip electrodes providing stereo coordinate measurements.

Radial TPC for BoNuS

For BoNuS a modified concept for the TPC is in order. While the BoNuS spectator detector will sit in a solenoidal **B** field, the primary function of this field is to curl up Møller electrons, not to enable magnetic spectrometry. As a result, the field we have to deal with is far from uniform. Drift electrons trapped on **B** field lines would follow a long and complicated path towards the endcaps where sensors would normally be placed. Further, even though a TPC for BoNuS may be only 30 cm long, the time required for electrons to drift this distance may be too long for the charged particle rate expected in the detector.

A *radial* TPC, however, seems to be a natural match for the BoNuS requirements. By drifting radially outward, across the **B**-field lines instead of along them, the electron drift distance is kept short so that understanding the electron trajectories is simplified. Since the drift distance is only 2–3 cm, the drift time is small, of order 2μs or less. Even with a 10 MHz background, the detector volume would contain charge from fewer than 20 tracks at any given moment. Electrons drifting through the crossed **B** and **E** fields will undergo a net deflection at the *Lorentz angle*, but this is a tractable problem to analyze.

Finally, while the radial TPC is a new concept for a spectator proton detector, it is not a new idea, even at Jefferson Lab. A much larger version of what is proposed here was investigated by the Hall D collaboration. Diffusion over the long drift path of their detector would have made the position resolution insufficient, however. In the BoNuS RTPC, drift distances are short and position resolution of only 1 mm is sufficient and easily achieved. The STAR collaboration at RHIC investigated RTPCs, then built and installed two of them

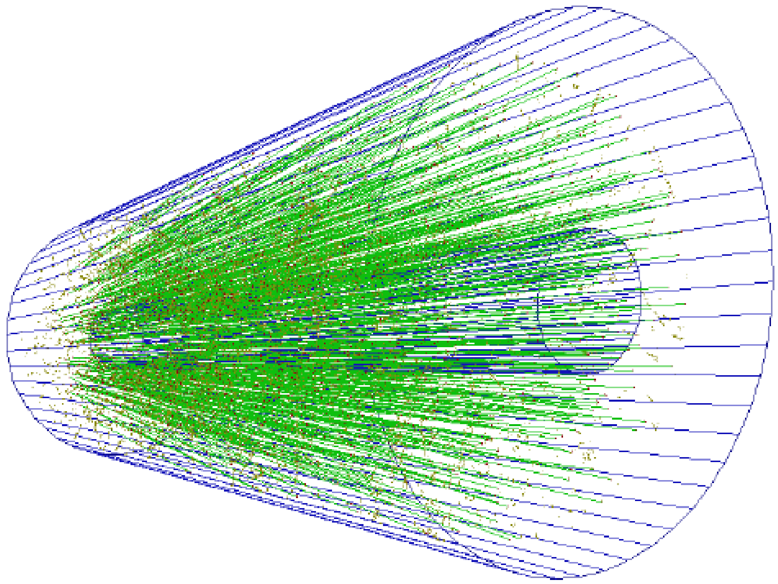

Figure 2: Reconstruction of the Secondary Tracks from a Au-Au Collision in one of the STAR Forward Time Projection Chambers.

(the Forward Time Projection Chambers, or FTPCs). The pair is used to measure very forward/backward tracks in RHIC's nucleus-nucleus collisions. Each one is 1.2 m long and about 60 cm in diameter, yet provides 1 mm spatial resolution. A reconstructed Au-Au event, demonstrating successful reconstruction of some 500 tracks from that one event, is shown in Fig. 2. Again, the detector we propose for BoNuS is smaller and simpler, and will directly benefit from the experience at STAR with the FTPC itself, and with the readout electronics used with it.

Preliminary Design

As shown in Fig. 1, the sensitive volume of the BoNuS RTPC will be an annulus with inner radius $\simeq$ 7.5 cm and outer radius $\simeq$ 9.5cm. The length, shown as 30 cm in the figure, will be matched to the target in order to provide coverage from 90° to ???° for the entire target. (It may be advantageous to shorten the detector so that for at least some portion of the target *only* backwards secondaries are accepted.) The space between the target vessel and the inner cylinder will be filled with helium to minimize the scattering and energy loss of particles before they enter the detector. This space also serves as a dead zone in which Møller electrons can be curled up without affecting any detector elements. Its design outer radius (the inner radius of the RTPC) may be altered as we proceed with simulation studies.

The inner cylinder of the RTPC, which serves both as a gas barrier and as the first drift electrode, will be thin gold-plated kapton. Outside $\simeq$ 2 cm of sensitive gas (probably 50/50 $ArCO_2$) will be the first of two GEMs. Another $\simeq$ 0.2 cm out will be the second GEM followed by the readout pads or strips $\simeq$ 0.2 cm later. While each of these four cylindrical electrode assemblies will be largely self-supporting, they will be constrained by precisely machined endcaps and, periodically in azimuth, by radial frames. The frames will deaden a small and quantifiable part of the chamber volume.

GEMs were chosen as the readout sensors because they are mechanically simple and lend themselves naturally to a curved geometry. A GEM is fabricated by chemically etching closely spaced tiny holes through a kapton sheet clad on both surfaces with a thin layer of copper. A modest voltage (few hundred volts) between the two conductive layers produces a large electric field in the holes. Ionization electrons which enter the holes on the negative-biased side of the GEM initiate a gas avalanche within the holes resulting in a large number of electrons being emitted on the positive side. These secondary electrons can be directed onto a pickup electrode a short distance away, or into another GEM for further amplification. The pickup electrodes collect the resulting charge cloud. Electronics connected to these electrodes sense the charge and record its magnitude and time of arrival.

After significant development efforts over the last few years [1] under the direction of F. Sauli at CERN, GEMs are now deployed in a number of physics experiments. Notably, a large array of multi-stage GEMS[2] is being used in the COMPASS experiment at the CERN SPS. The BoNuS spectator detector would use GEMs wrapped around a cylindrical frame to form a curved surface. While nobody has used a curved GEM to date, it seems to be a natural extension of the technology and no difficulties are foreseen [3].

The precise geometry of readout electrodes we will propose for BoNuS is not yet determined. One method which will clearly work is to place an array of regularly spaced pads or short strips uniformly over the surface of the readout cylinder. This is very similar to the readout scheme in use in the STAR FTPC, which instruments 9600 pads in each radial TPC. However, given the smaller size of the BoNuS device, it may be possible to collect the charge on two arrays of conductive strips placed on the outer cylinder. Drawing upon technology developed for COMPASS, it is possible to place the two arrays on the inner and outer surfaces of the cylinder at stereo angles to one another and cause them to equally share the amplified charge clusters. This would provide two stereo *views* of the collection cylinder surface, thus providing $\phi - z$ and dE measurements, with a modest number of electronics channels. Further analysis and simulation are required before we can determine whether pads or stereo strips are appropriate for BoNuS.

Readout Electronics

The electronics used to read out the RTPC must provide both charge and time information. This problem has been solved for the STAR FTPCs and the main STAR TPC by a system of charge preamplifiers whose output is fed to a switched capacitor array (SCA). The SCA is clocked at 5 MHz, causing the charge collected in each ˜200 ns interval to be transported in a bucket-brigade fashion through the chain of capacitors. Upon receipt of a trigger signal, charge stored in the appropriate capacitors is digitized and the results are passed to the data acquisition system. Readout of this system takes about 10 milliseconds. An upgrade is currently planned for the main TPC which will use flash ADCs and digital storage to significantly reduce the readout time. A very similar (or identical) readout system could be applied to the BoNuS RTPC. Discussions about this possibility are currently ongoing with members of the STAR collaboration.

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