# Forward and backward tracking at the EIC using small strip Thin Gap Chamber detector

*Lijuan Ruan (PI), Elke-Caroline Aschenauer, Alexander Kiselev, Jerome Lauret, Rongrong Ma, Victor Perevoztchikov, Gene Van Buren, Jason Webb, Zhangbu Xu, Shuai Yang*
Brookhaven National Laboratory

*Fangang Kong, Changyu Li, Fuwang Shen, Shuai Wang, Qinghua Xu, Chi Yang, Qian Yang, Chengguang Zhu*
Shandong University

**Abstract:**
We propose to develop a concept for forward and backward tracking detector near a collision vertex at pseudo-rapidity 1<|η|<3.5 using the small strip Thin Gap Chamber (sTGC) detector technology. The sTGC detectors present an attractive option for building a tracking device as they have minimum material budget, are easy to build, and most-importantly are cost effective. We focus on the detection of all charged hadrons and will study tracking performances such as tracking efficiency and momentum resolution. As part of our proposal, a prototype sTGC will be designed and constructed. Cosmic ray and beam tests will be carried out to demonstrate the position resolution. A prototype sTGC detector will be installed at the STAR experiment and tested in the 2019 and 2020 runs. Results will be analyzed and compared to those from cosmic ray and beam tests. The conceptual design of sTGC disks will be laid out, including the disk location, detector size, and readout.

## 1. Introduction

The 2015 Long Range Plan for Nuclear Science in US recommended a high-energy high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction after the completion of FRIB [1]. For the first time in our field, the EIC will enable us to measure gluonic substructures in nucleons and nuclei [2]. The facility is foreseen to be located at either the Brookhaven National Laboratory (BNL) or at the Thomas Jefferson National Accelerator Laboratory (JLAB). The EIC is expected to be online around 2025-2030. The BNL STAR group plans to take a leading role in doing scientific research at the EIC. In this proposal, we offer to develop key instrumentations for the tracking system at forward and backward rapidity 1<|η|<3.5 at the EIC. We request funding support to start the program. The strength of our proposed work is that we would be building upon our past experience and successful track record in tracking system and detector technology and in constructing the wire chamber for the inner Time Projection Chamber (iTPC) upgrades at STAR, the Time of Flight (TOF) Detector, and Muon Telescope Detector (MTD) at STAR.

We focus on detection of all charged hadrons and studying tracking performance such as tracking efficiency and momentum resolution. Specifically, we are interested in detection of electrons from the collisions. sTGC technology is an attractive option for building a tracking detector as it has minimum material budget, is easy to construct, and most-importantly is cost effective. The proposed research will be the first step in developing an sTGC based detector for an EIC experiment. It will be combined with other tracking detectors to provide a complete tracking system for a future EIC experiment.

There are several conceptual designs for an EIC experiment. We will focus on the eRHIC experiment since the larger center of mass energies put more stringent constraints on the tracking requirements. The magnetic field might range from 0.5 to 3 T. We will carry out simulations by combining the sTGC detector with other tracking devices and studying tracking performance using different magnetic field and position settings. We propose to develop a conceptual design using multiple disks based on sTGC technology together with other tracking devices for tracking in the forward and backward rapidity.

The high-energy physics group at Shandong University (SDU) has experience with design, construction, and operation of Thin Gap Chamber (TGC) detector at the ATLAS experiment. Currently the same group at SDU is constructing the sTGC detectors for the tracking upgrades at ATLAS, which is beneficial for muon identification [3]. In addition, the nuclear physics group at SDU is producing wire chambers for the STAR iTPC upgrades. The BNL Software and Computing group has extensive expertizes in tracking and software integration with a solid track record of delivering physics with the TPC, Heavy Flavor Tracker and other tracking detectors in STAR. In addition, BNL will carry out the test of iTPC before its installation. The PI of this proposal played a leading role in the TOF and MTD construction and operation at STAR. The above expertise makes our group well suited for carrying out the proposed research.

Even though ATLAS is using sTGC for their tracking upgrades, the configuration and design at ATLAS cannot be directly used for an EIC detector, hence a R&D effort is needed to understand how to make best use of this technology for an EIC detector. The sTGC is proposed for muon identification at ATLAS while we propose it for charged hadrons and electrons detection for an EIC detector. The goal of this proposal is to have a conceptual design for multiple disks of sTGC detector as part of the forward and backward tracking for an EIC experiment.

### 1.1 Physics observables and tracking requirements

The EIC white paper has laid the most important physics topics. They can be divided into three categories: inclusive, semi-inclusive, and exclusive measurements [2]. The inclusive case ($ep/eA \rightarrow e' + X$) requires either detection of the scattered lepton or the full scattered hadronic debris with high precision in order to extract x, $Q^2$ and y, in which x, $Q^2$, and y are parton momentum fraction, the square of the momentum transferred by the electron to the proton or the nucleus, the inelasticity respectively. The physics goal is to study the structure functions as a function of x and $Q^2$. The semi-inclusive one (ep/eA → e′ + h + X) requires detection of the scattering electron and at least one hadron. The physics goal is to study quantities such as the transverse momentum ($p_T$) dependent parton distributions, helicity parton distribution functions, fragmentation functions or di-hadron correlations. For the exclusive case, which requires detection of all final-state particles coming out of the reaction, the physics includes deeply virtual Compton scattering, exclusive (diffractive) vector-meson production for generalized parton distributions and parton imaging in transverse position.

The PI has expertise and played a leading role in the measurements of dileptons, vector mesons, and quarknoia in heavy ion collisions at STAR. Very recently, the PI's group presented J/ψ production at very low $p_T$ in peripheral Au+Au collisions. It was found that there is a very significant enhancement of J/ψ for $p_T$<0.15 GeV/c in 60-80% Au+Au collisions which cannot be accounted for by hadronic interaction mechanisms [4]. Instead, the significant enhancement can be described by coherent photo-nuclear production mechanism [5], which can be systematically studied in e+p and e+A collisions.

Our group is interested in semi-inclusive and exclusive physics processes. In the semi-inclusive case, we are interested in measurements of vector mesons (J/ψ, ρ, and ϕ) through either hadronic or leptonic decays. It requires excellent particle identifications for hadrons and leptons over a broad range of rapidity, $p_T$, and momentum. For the exclusive process, we are interested in measurements of diffractive vector-meson production. It minimally requires large rapidity coverage and good momentum resolution.

Previous study demonstrates that for an EIC experiment, in the $1<|\eta|<2.5$, the momentum resolution is required to be $\sigma_p/p = 0.05\%p+1\%$ while for $2.5<|\eta|<3.5$, it is required to be $\sigma_p/p = 0.1\%p+2\%$ [6]. We will use these requirements as specifications for our tracking design with sTGC.

**1.2 sTGC Detector technology**

The sTGC designed by the ATLAS experiment is taken as a practical choice of forward tracking combined with inner silicon-strip sensors. One big advantage is the reduction of the cost with good momentum resolution as required.

The basic structure of sTGC at ATLAS is shown in Fig. 1, and some details can be found in Ref. [7]. It consists of a grid of 50 μm diameter gold plated tungsten wires, with a 1.8 mm pitch, sandwiched between two cathode planes located at a distance of 1.4 mm from the wire plane. The operating voltage is 2,900 V for the wires. The cathode planes are made of a graphite-epoxy mixture with a typical surface resistivity of 100 kΩ/□ sprayed on a 100 μm thick G-10 plane. Behind the cathode planes on one side of the anode plane there are copper strips for precise coordinate measurements that run perpendicular to the wires and on the other side of the anode plane there are copper pads used for fast trigger purposes. The copper strips and pads act as readout electrodes. The pads cover large rectangular surfaces on a 1.5 mm thick printed circuit board (PCB) with the shielding ground on the opposite side.

The strips have a 3.2 mm pitch, much smaller than that of the ATLAS TGC. This strip pitch was optimized for good position resolution (<100 μm) using charge division between strips while maintaining a minimal number of read-out channels [8]. Single strip-layer position resolutions of better than 50 μm have been obtained, uniform along the sTGC strip and perpendicular wire directions from recent prototype test [7]. The operational gas is a mixture of 55% $CO_2$ and 45% n-pentane.

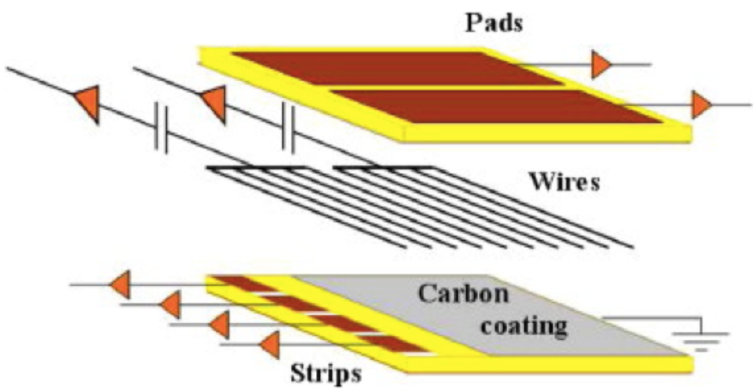


Figure 1: The sTGC internal structure.

The high-energy physics group at Shandong University is responsible for 40 module (each consists of 4 layers) of new small wheel sTGC.

## 2. R&D goals for this proposal

### 2.1 sTGC specifications

We will use the sTGC design at ATLAS as a starting point. The specifications are detailed in the Sect. 1.2. For the forward tracking at an EIC experiment, two layers of sTGC module with strips perpendicular to each other will be combined into one sTGC disk, which will provide 2-dimensional position reconstruction from strip charge read out. In addition, we propose to do a minimal re-design of sTGC for an EIC experiment, for example a square shape of 60 cm x 60 cm, with 3.2 mm strip pitch perpendicular to wire direction. An sTGC with a square shape of 60 cm x 60 cm will be significantly easier to construct mechanically.

### 2.2 Readout electronics of the sTGC

At ATLAS, the application-specific integrated circuit (ASIC) is used for strip and wire readouts of the sTGC detectors. At STAR for the iTPC upgrade, the SAMPA chips are used.

All these readout options could be considered for the sTGC for an EIC experiment in the future. For a prototype, we will use the current STAR TPC electronics.

### 2.3 The plan for the next three years

In the first year 10/1/2017-9/30/2018, we propose to do the following two things:

- Build an sTGC prototype with a square shape of 60 cm x 60 cm, with 3.2 mm strip pitch perpendicular to wire direction. We will use the current STAR TPC electronics for the readout. A cosmic ray test will be performed to obtain the spatial resolution. Specifically, we will study the spatial resolution as a function of angle of incidence. Understanding this is necessary for a conceptual design of the sTGC disk for an EIC experiment.
- With the information obtained from the above step, we will carry out a simulation of sTGC in an EIC experiment. As a first step, we will use knowledge acquired in the tracking efforts made in STAR (track finding) into an EIC framework context and further develop a fast simulator in which the spatial resolution obtained from the cosmic ray tests will be used. The next step is to study the tracking performance at $1<|\eta|<3.5$ by combining the sTGC disks and other tracking devices for an EIC experiment.

In the second year 10/1/2018-9/30/2019, we propose to install the sTGC prototype at STAR in Run 2019. We will also analyze data from the heavy ion collisions to obtain its performance at STAR. We will build another module. The specification might be slightly modified depending on the test results from the first year. A beam test will be carried out. Finally, and to address the full response (hence efficiency) of the prototype, we propose to develop a slow simulator for the sTGC in that same year.

In the third year 10/1/2019-09/30/2020, we would gain experience of running sTGC in the forward rapidity at STAR in its 2019 run. If there were any issues preventing us from obtaining useful data from STAR during Run 2019, we would need to resolve the corresponding issues and take data again with the sTGC prototype in Run 2020. We propose to come up with a conceptual design in using sTGC disks as part of the forward and backward tracking detectors that year.

## 3. Funding request

First year:

25,000 $ for the materials, assembly, and test of an sTGC prototype at Shandong University

0.5 post-doc FTE: to work on the cosmic ray test of the sTGC at BNL.

0.25 post-doc FTE: to work on simulations by developing a fast simulator.

3 trips to enable post-docs to attend two workshops (2000 $/trip) in US and to visit colleagues at Shandong University (4000 $/trip)

Second year:

25,000 $ for the materials, assembly, and test of another sTGC prototype at Shandong University.

0.5 post-doc FTE: to install and commission the sTGC at STAR and carry out a beam test.

0.25 post-doc FTE: to work on simulations by developing a slow simulator.

4 trips to enable post-docs to attend two workshops (2000 $/trip) in US and one international conference (4000 $/trip), and to carry out a beam test (4000 $/trip)

Third year:

0.25 post-doc FTE: to install and commission the sTGC at STAR.

0.25 post-doc FTE: to work on simulations by developing a conceptual design in using sTGC as part of the tracking detectors at forward rapidity for an EIC experiment.

3 trips to enable post-docs to attend two workshops (2000 $/trip) in US and one international conference (4000$/trip)

Note that the post-doc will be jointly supported by SDU and BNL. The post-doc will be hired by SDU and stay at BNL. We request the funds to cover his housing (1600 $/month), per diem (1600 $/month), and medical insurance (100 $/month) for his stay at BNL.

Table 1 lists the cost in detail. The total funds we request for 3 years are 161 k$.

Table 1: The cost information for different years and categories.

| Category | Cost (year 1, $) | Cost (year 2, $) | Cost (year 3, $) | Cost (years, $) |
|---|---|---|---|---|
| Material | 25 k | 25 k | 0 | 50 k |
| FTE | 31 k | 31 k | 21 k | 83 k |
| Travel | 8 k | 12 k | 8 k | 28 k |
| Total | 64 k | 68 k | 29 k | 161 k |

The above is for a realistic nominal budget scenario. Under the scenario of a nominal budget – 20%, for the first year, it will affect the proposed activity on the simulation. Fast simulation results will not be delivered for the first year and will be delivered for the second year. The slow simulation results will be delivered for the third year. We will not be able to make possible revisions and run a prototype of sTGC at STAR for Run 2020.

Under the scenario of a nominal budget – 40%, for the first year, it will affect the proposed activity on the simulation. Fast simulation results will not be delivered for the first year and will be delivered for the second year. The slow simulation results will be delivered for the third year. We will not be able to carry out a beam test for the proposed three years. We will not be able to make possible revisions and run a prototype of sTGC at STAR for Run 2020.

References:

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