Transition Radiation Detector for the GlueX experiment

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Abstract

We propose to build a Transition Radiation Detector (TRD) with Gaseous Electron Multiplier (GEM) amplification, referred as GEM-TRD, to improve the electron-pion separation in the GlueX experiment. It will allow to study precisely reactions with electron-positron pairs in the final states; such reactions like J/ψ photoproduction near threshold have significant impact in many fields of the particle physics. The motivation for such an upgrade is followed by a technical description the detector and the electronics. Preliminary requirements for the GEM-TRD gas system are specified.

I. MOTIVATION

Important features of the GlueX detector include full acceptance, charge and neutral particle registration, and high-rate electronics and DAQ, however it has limited PID capabilities. A DIRC detector was built for the phase-II of the GlueX experiment and used for pion/kaon separation that will extend the GlueX program by including strangeness physics. Another important extension of the program would be the di-electron physics. The GlueX detector has the unique possibility to study the J/ψ photoproduction off the proton near threshold in the full kinematic space. As the J/ψ-proton interaction is mediated predominantly by gluons, such studies allow to probe the gluonic content of the proton: mass radius, anomalous contribution to the mass of the proton, the gluonic GPD; all these properties are not accessible with electro-magnetic probes. First results of the J/ψ photoproduction near threshold, published by GlueX in 2019, collected already 100+ citations. Such studies, however, are limited by the huge pion background that can mimic the electron-positron pairs used to identify the J/ψ particle. The suppression of the pion background would allow to study the Bethe-Heitler process that has the same e^+e^-p particles in the final state. As an electro-magnetic process it is fully calculable and would allow to reduce the systematics of the J/ψ photoproduction significantly.

The pions are about four orders of magnitude more numerous than the electrons. The electro-magnetic calorimeters reduce the background pion pairs by a similar magnitude, when selections are applied to both, the electron and the positron candidates. In this case statistical analysis are needed to estimate the electron-positron yields, with a signal-to-background ratio of about one, resulting in significant systematic uncertainties. Another factor of 10 suppression is needed to be able to study reactions with e^+e^- pairs in the final state on event-by-event basis. This can be achieved with a Transition Radiation Detector (TRD) consisting of a radiator, drift volume filled with Xe gas mixture, and an amplification stage employing Gaseous Electron Multiplier (GEM) technology. Such GEM-TRD detector will serve not only as a particle-identification device, but also as a tracker with a potential to improve the momentum resolution and the precision of the tracks extrapolated to the DIRC detector.

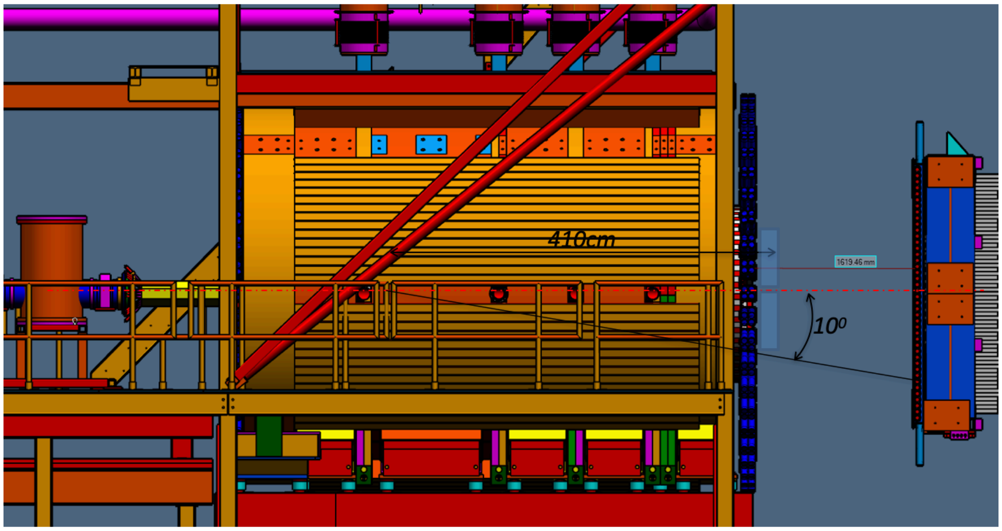

FIG. 1: Side view showing the approximate position of the proposed GEM-TRD detector (light blue boxes), at 410 cm downstream of the target, covering 86% of the forward GlueX acceptance of $\sim 10^\circ$ polar angle.

II. THE GEM-TRD DETECTOR

The proposed detector will be placed in the forward region of the GlueX detector just at the downstream face of the solenoid, see Figs. 1,2. It will consists of two separate chambers, each providing 1392×528 mm^2 sensitive area. The frames of the chambers holding the front-end electronics will be outside of the acceptance (Fig. 2).

The detector has a radiator layer 15 cm thick, followed by a 2 cm drift volume, and a GEM stage combined with a readout board. The Transition Radiation (TR) photons in the keV region produced in the radiator are absorbed by the Xe gas mixture in the drift volume emitting electrons that drift to and are amplified by the GEM. The signals are readout from X- and Y-strips on the readout board. The horizontal (Y) strips are separated in the middle and readout from the left and right side of the chambers (Fig. 2). The strip pitch is 1 mm, resulting in $2,448$ electronic channels per chamber, or $4,896$ in total. The signals are amplified on-board and then digitized with flash ADCs using the same electronics as for the GlueX drift chambers: GASII preamps and flashADC-125. Thus we record the energy

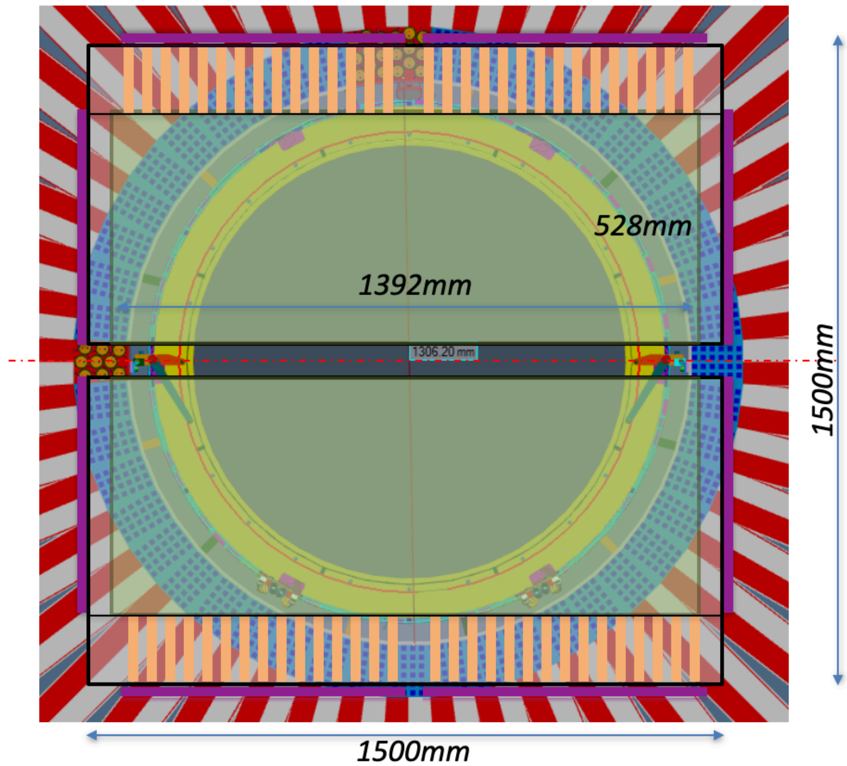

FIG. 2: Front view of the GEM-TRD detector placed at the face of the solenoid magnet. It consists of two separate chambers with 1392×528 mm^2 sensitive area. All the frames holding the front-end electronics (purple thick lines) of sizes $\sim 1500 \times 1500$ mm^2 are outside of the GlueX forward acceptance.

deposition along the track (measured by the drift time) that has different profile for the TR photons absorbed predominately at the entrance, and the track ionization that has uniform distribution. At the same time such detector works as a Time Projection Chamber, allowing to reconstruct the track segment within the drift volume.

The main parameters of the GEM-TRD detector are given in Table I. They are based on tests with small prototypes (10×10 cm^2) done during the past several years and are preliminary. Further optimization of the detector will be done with a large-scale prototype that will be built and tested during the 2022 and 2023 running periods. This prototype will cover a quarter of the final detector (Fig.3), allowing to be used for real physics data taking. The electronics of the prototype will be re-used in the final detector.

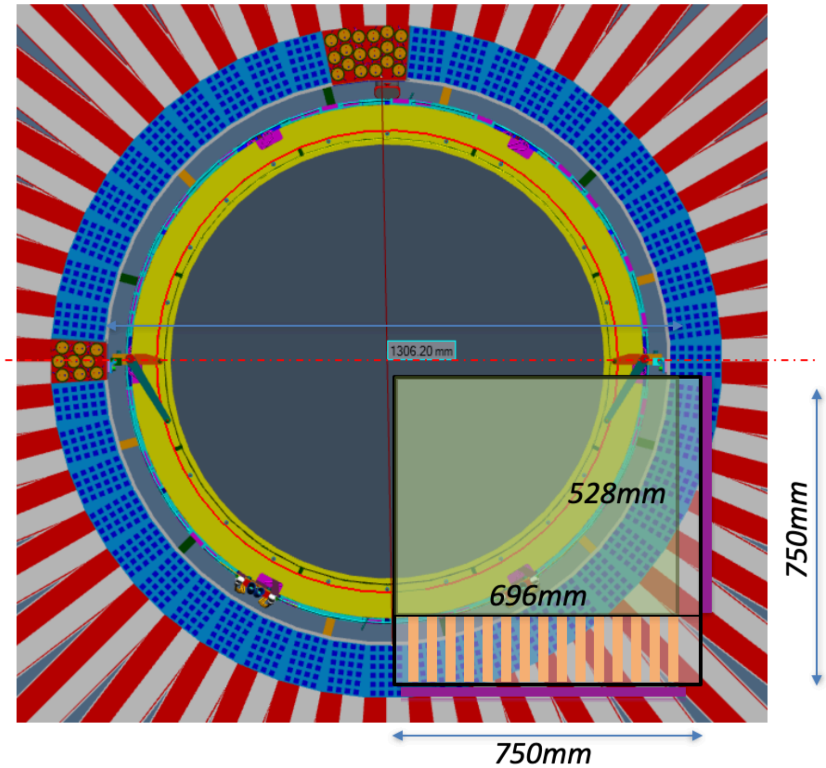

FIG. 3: Front view of the GEM-TRD large-scale prototype that has 696 × 528 mm^2 sensitive area.

parameter	value	comment
sensitive area	$2 \times (1392 \times 528\ mm^2)$	two separate chambers
frame-free area	$1500 \times 1500\ mm^2$	except some minimal support
distance from the target	4100 mm	
forward acceptance coverage	86%	for e^+e^- invariant mass > 1.2 GeV
radiator thickness	150 mm	
drift volume thickness	20 mm	
total detector thickness	< 4% R.L.	
drift field	1.5 kV/cm	
gas mixture	Xe/CO_2 90/10	
maximum drift time	800 ns	
gas amplification	$\sim 5.10^4$	
strip types	X and Y	on the same layer with capacitive coupling
strip pitch	1 mm	
readout channels	4,896	2,448 per chamber
GASII pre-amps (24 channels)	204	102 per chamber
GASII amplification	2.4 mV/fC	
flashADC-125 (72 channels)	68	34 per chamber
VXS crates	5	

TABLE I: Main parameters of the GEM-TRD detector.

III. GAS SYSTEM REQUIREMENTS

The high price of the Xe gas requires system that recirculates and purifies the gas mixture. Each GEM-TRD module has two gas volumes - the main one filled with Xe/CO_2 gas mixture of 90/10% containing the drift and the amplification volumes, and the second one for the radiator filled with CO2. The thickness of the drift and amplification volume is 20 mm and 10 mm respectively. Thus, we estimate the Xe/CO_2 gas volume to be 25 l per chamber, or 50 l in total. For the CO_2 volume it has a thickness of 150 mm or 125 l per module and 250 l total. For the Xe/CO_2 volume we aim to have 8 volume exchanges per day, i.e. 20 l/h. The CO_2 volume can be exchanged once per day or 5 l/h.

The entrance and exit gas windows will be made of 100 μm Mylar, possibly enforced with Rochacell material. The detector will allow operation with overpressure between 0.5 and 2 mbar. The two gas volumes will be separated by 50 μm Mylar, covered with 1 μm Al. To limit the variations of the drift field, we require the pressure difference between the two gas volumes to be less than 0.2 mbar.

Oxygen contamination and water vapor should be kept less than 50 ppm, to minimize the electron recombination in the drift volume. The Nitrogen contamination should be kept less than 0.5%.

The elements of the gas system that operate above 1 bar should be kept in a separate gas room, elevated approximately 7 m above the detector. They will be connected to the detector with gas lines of about 50 m length.

The parameters and requirements of the gas system are summarized in Table II.

item	requirement	comment
total Xe/CO_2 gas volume	50 l	
total CO_2 gas volume	250 l	
Xe/CO_2 gas flow	20 l/h	
CO_2 gas flow	5 l/h	
Operating overpressure	$0.5 - 2$ mbar	
Pressure difference b/n two volumes	< 0.2 mbar	
Oxygen contamination	< 50 ppm	
water vapor	< 50 ppm	
Nitrogen contamination	$< 0.5\%$	

TABLE II: General parameters and requirements for the GlueX TRD gas system.