Question 1: Cost of commercial Outgassing evaluation

Questions:

Please show us the costs of a commercial evaluation for outgassing of samples.

Answer:

We have contacted two companies (Element and Integrity Testing Laboratory) inquiring about the cost to perform TML and CVCM measurements on FR4 like materials. I have heard back from Integrity Testing Laboratory. They are quoting $550 per sample. I am still in the process of following up with Element, but will send that information once I receive it.

Question 2: On Outgas Test Proposal Choice

Questions:

Why have you not considered a 'canary' TPC and an RGA for the outgassing system?

Answer:

We envision the TML and CVCM outgassing test measurements to be the first part of a two-part, staged validation process. The second part of the validation process would be based on the outgassing setup that was presented last year, which is based on the single-wire detector. This single wire test follows the setup used by CMS for their life time and outgassing tests. This would allow one to quantify the effect that a material's outgassing has on a detector. The test material is placed in the single-wire detector and the gain is monitored. We did not see a need for an RGA when using these two validation tests since these tests will allow us to determine if a material is adequate for use in an MPGD detector. The RGA would allow us to determine what the contamination is. While knowing what the makeup of the contamination is informative, what is more critical is to know if a material will produce contamination which will shorten or destroy the detector performance. This information can be determined using a single-wire chamber and by measuring its TML and CVCM, the materials outgassing properties can be well quantified.

However it is clear that a canary TPC + RGA system would be beneficial and we would be willing to use any allocated money towards the assembly of a canary TPC + RGA system.

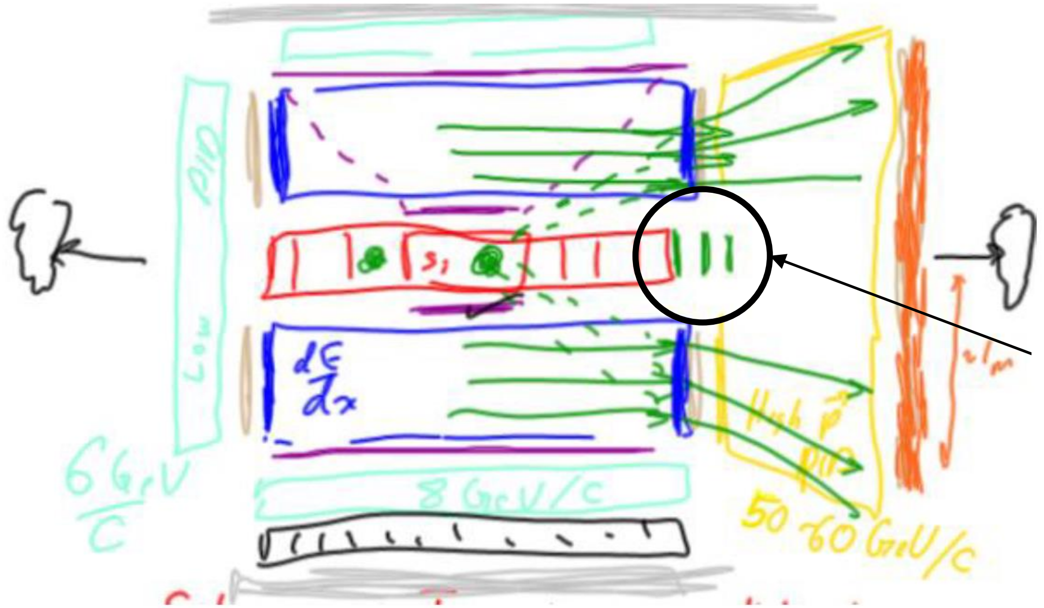
Question 3: On Cr-GEM in Far Forward Region

Questions:

On slide 22 it is stated that "Cr-GEMs are being considered for the far forward region as an additional layer to the forward MAPS layers provide a fast tracking element." Please define "far forward". Also, please provide a qualitative comparison of the possible technology options for that region.

Answer: ***Extracted from our submitted July 2017 progress report***

"Taking MAPS as the technology of choice for high eta tracking again **requires that the technology be "backed up" by devices with single event response properties**. This is especially **true for the far forward angles.** Here we mimic the implementation in the far forward region by introducing a MPGD for pattern recognition among the MAPS layers as indicated by the green lines in the cartoon**.** The Cr-GEM would make for an ideal device, since even at high momentum one wishes to keep the multiple scattering below the pixel resolution. **Radiation length of a Cr-GEM layer is 0.2%, similar to a MAPS layer**. MAPS layers will provide the excellent spatial resolution and one or two Cr-GEMs will complement to provide the fast time information with good spatial resolution (40 µm) . Therefore, we are reinvigorated to pursue and make robust the Cr-GEMS."



Far forward

Color	Name	Deliverable	Favored Tech	Comment
Red	Silicon Pixels	Displaced Vertex	MAPS	Must be thinnest technology to remain consistent with soft electrons
Blue*,**	Volume Tracker	dE/dx, pattern recognition	TPC* or straws, Timepix**	R&D will pursue and determine viability of using reconfigured sPHENIX TPC
Purple*,**	Single Event Barrel Tagger	Single event response, momentum resolution	µRWELL*, µMEGAS**	µRWELL in eRD6, µMEGAS w/in eRD3 goals.
Brown*	Fast Endcap Tagger	Single event response, track stub.	Mini-drift GEM detector	Alteration to ongoing development, yields beampipe region to silicon.
Green*	Forward Tagger	Single event response, patt. recognition at extremely low mass	Chromium GEMs	Interstitial layers between MAPS devices with even less
Gold*	High mom. RICH	PID up to 50 GeV/c	COMPASS RICH Technology	Investigate new possibilities with diamond powder cathodes.
Orange**	RICH Seed Tagger	Seed point for RICH, eID for J/ψ	TRD**	Pursued under different cover.

Question 4: On low-mass, large-area GEMs

Questions:

On slide 21 it is noted that two low-mass large area triple-GEM detector prototypes are being constructed, each of which uses a different assembly procedures and readout schemes. Please describe how and on what time-scale you will downselect and how the construction of these two chambers will help you in the downselect.

Answer:

For clarification, we would like to point out that original construction of the two low-mass large-area triple-GEM detectors was actually completed about a year ago. Characterization of one is basically complete. The other is currently being refurbished. Its performance still needs to be characterized. If basic characterization (gain curve, uniformity) with X-rays can be done successfully, then we would like to return to Fermilab next summer (2020) to measure its resolution. Once these data are analyzed, the performance of the two prototypes can be compared. We estimate that a `downselect' could be possible in fall 2020 based on ease of construction, performance, and estimated system cost (detector + electronics).

Question 5: On Prioritization of MPGD R&D

Questions:

What strategy do you propose for prioritizing the R&D for the various MPGD technologies?

Answer:

Our strategy is to bring the less developed MPGD technologies to a more mature level on a par with current GEM ~~technolog~~ies. At this point the MPGD technologies could be benchmarked and a selection could be made.

For the forward region:

- We are proposing low mass and large area GEMs, which at this point has been proven to be a mature technology thanks to the development by experiments such as CMS for large area GEMs and the extensive R&D for low mass GEMs by the eRD6. µRWELL technology could also be an option for the forward trackers but would require more R&D to reach the same level of maturity as for GEMs.
- For the far forward region, the consortium is proposing to explore further fast signal Cr-GEMs as a complement to the MAPS disk layers. Cr-GEMs an would be ideal for minimizing the multiple scattering as required in the far forward region but would require significant R&D to fully characterize the Cr-GEM foils and address the concerns on the robustness of this technology.

For the Central region: We are considering basically two options.

- The first option would be the well established TPC technology with MPGD-based readout for which the 4-GEMs configurations is at this point the most advanced. However, an alternative TPC readout with less mature MPGD technologies such as µRWELL or micromegas or hybrid MPGDs are also being considered. The second option would be a system of cylindrical MPGD trackers such as cylindrical µRWELLs or cylindrical micromegas.
- The eRD6 consortium is focused on the development low mass µRWELLs which would require significant R&D to bring this technology to the same level of maturity as the GEMs or micromegas but may much simpler in term of construction and operation in the cylindrical configuration.

Question 6: On µRWELL sensitivity

Questions:

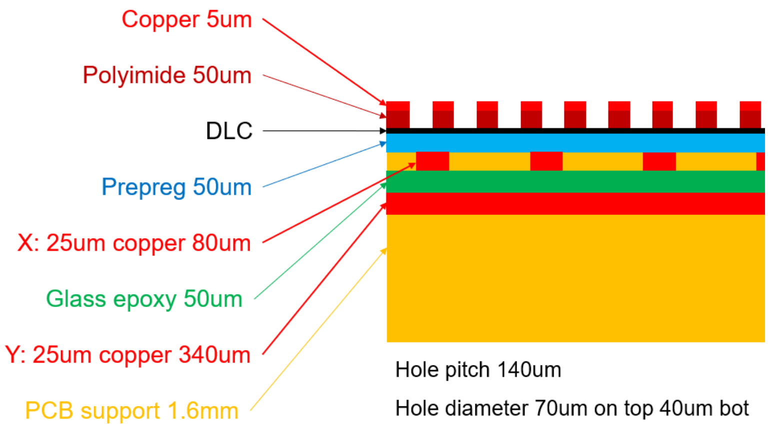
Micro-Rwell: what is the sensitivity of the detector, especially the Kapton, to the charge from the beam? Or, in other words, how does a Kapton-based detector perform in a noisy environment? Pease explain the low efficiency and non-uniformity in gain for the micro-Rwell detectors and/or the plan to uncover the source.

Answer:

- On sensitivity: In fact the same polyimide base material (Apical) is used for GEM foils and for µRWELL. Kapton is a generic name used for GEM foils. We don't expect any issue with sensitivity with this Apical material. GEM foils have been extensively tested and used in very harsh environment so we don't anticipate any issue related to charge from beam, especially in the relatively low rate EIC environment. µRWELL is a new technology and properties of its resistive layer material, the diamond-like carbon (DLC), need to be thoroughly tested in harsh particle flux environment. We plan to carry out these studies related to aging and stability of the detector performance.

- On low efficiency and non-uniformity: We reported the preliminary results on the performances of our µRWELL with 2D readout strip structure. We are still investigating the non-uniformity of the detector response and low efficiency. We suspect that the non-uniform gain, which certainly can be correlated to the low gain can originate from different sources such as the non-uniformity of the DLC layer or the 2D strip layer structures Our plan for the coming cycle is to investigate further and work together with experts at CERN to identify the sources of these non-uniformities

Cross section of UVa µRWELL prototype



Hole pitch 140um
Hole diameter 70um on top 40um bot
Read-out line pitch 400um X and Y

Question 7: TPC R&D work vs LDRDs

Questions:

What is the overlap of the TPC R&D work at BNL and Yale on the optimization and study of zigzag readout using different MPGDs for TPC with sPHENIX and ongoing LDRDs?

Answer:

The current readout design for the sPHENIX TPC is a 4-stage GEM with a zigzag readout pattern with a 1.24 mm pitch (tip to tip distance) and a 0.15 mm "stretch parameter" (essentially the penetration depth between adjacent zigzag strips, **see slide below**) and is expected to deliver single point resolution of ~ 120 um in the sPHENIX TPC, including diffusion with the magnetic field. The readout boards will be manufactured using standard chemical etching, although they will push the limit on making the gaps between strips as narrow as possible (~ 0.003").

The design of the readout for the sPHENIX TPC is now essentially fixed and the plan for the procurement of the GEMs, readout boards and construction of the all the detectors is now built into the overall sPHENIX cost and schedule and the final TPC is expected to be ready for installation in June 2021. As such, there is very little possibility to make any design changes at this stage. While the zigzag readout boards for the sPHENIX TPC are more or less state of the art for what can be manufactured in a production process today, our R&D from eRD6 and LDRD has shown that this can be improved considerably using laser etching or through further improvements in chemical etching technology. We've carried out extensive measurements both in the lab and in test beams on studying the various parameters for optimizing the zigzag parameters and have shown that it is possible to achieve a spatial resolution of < 50 um with virtually no differential non-linearity using a fully optimized pattern. This has never been studied in a TPC configuration before and we therefore wish to study this using our small TPC prototype for future applications at EIC.

However, in addition to studying more optimized zigzag readout patterns for a TPC using GEMs, we also wish to study other gas amplification structures for TPCs, such as Micromegas, GEM + Micromegas hybrid detectors and uRWELLs. Each of these configurations offers certain advantages and disadvantages, such as reduced IBF with the GEM+Micromegas design, lower discharge probabilities with resistive Micromegas, and simpler and easier construction with uRWELLs.

Question 7: TPC R&D work vs LDRDs (cont'd)

Questions:

What is the overlap of the TPC R&D work at BNL and Yale on the optimization and study of zigzag readout using different MPGDs for TPC with sPHENIX and ongoing LDRDs?

Answer: (cont'd)

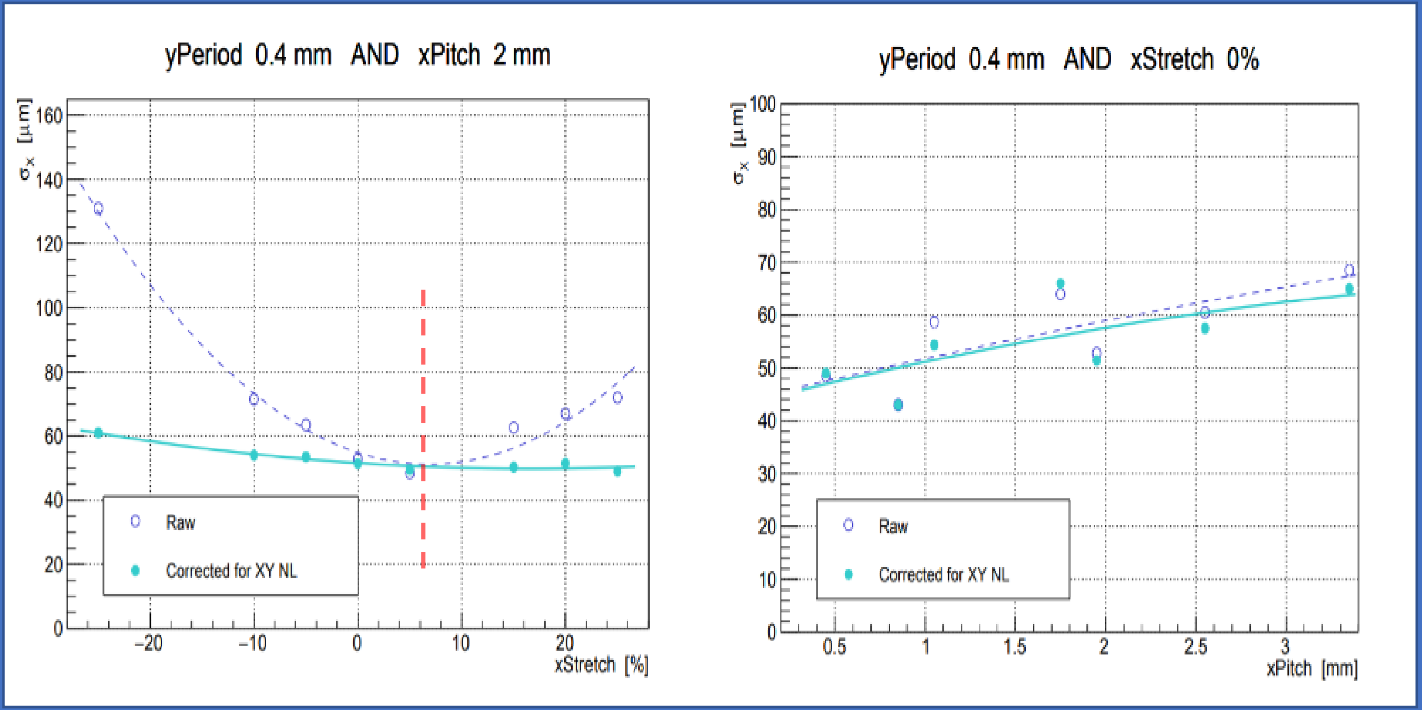
However, each of these detectors produces a different charge distribution on the readout plane, which depends on the operating gas, drift length and HV operating conditions, and therefore requires a different optimization of the zizgzag readout pattern. We have just begun to study these other detectors using zigzag readouts and hope to find an optimal design for each of them as we have done with the GEM readout. However, none of them have ever been studied in a TPC configuration, so we therefore wish to implement some of these designs in our TPC prototype detector and explore them as possible alternatives for a TPC for EIC.

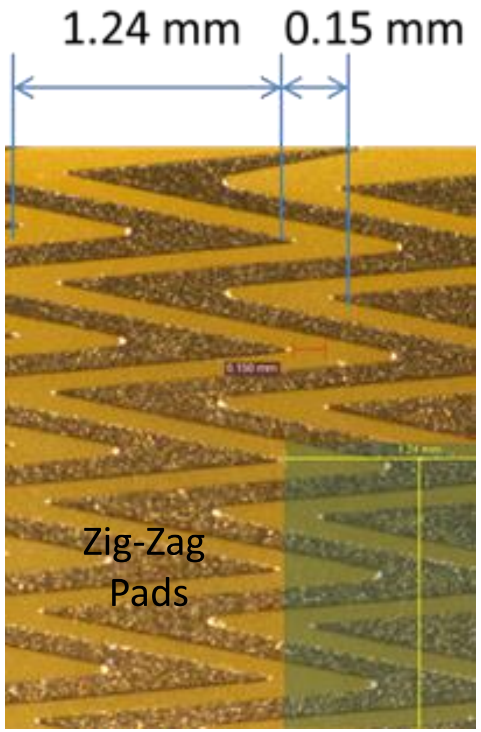
Our LDRD at BNL covers a broad range of applications of MPGDs for EIC and provides an opportunity to explore new MPGD applications and new ideas that are not necessarily focused on a specific detector. As such, we have not included an investigation of a readout design specific to a TPC as part of this program. We have therefore included this as part of our eRD6 program, which benefits from many of the other activities taking place in eRD6. However, since the current effort on the sPHENIX TPC is very closely related to our TPC R&D activity for EIC, we also share many common resources which are of mutual benefit to both efforts. Some examples of this are the development of the SAMPA readout chip for sPHENIX, which we are now using for our EIC prototype TPC, our GEM tracking telescope, which we built using eRD6 funds for cosmic ray studies in the lab, but has now been used for the recent sPHENIX TPC beam test at Fermilab, as well as for several other eRD6 beam tests, and the laser calibration system for our EIC TPC prototype which we have just started to set up our lab that will surely be of benefit to the design of the laser calibration system for the sPHENIX TPC. We feel all three of these activities are closely connected with each other, but each have a rather different focus. Each also has its own constraints in terms of cost and schedule and we therefore hope that we can continue with each one of them on its own separate path as they are currently being pursued today.

Questions:

What is the overlap of the TPC R&D work at BNL and Yale on the optimization and study of zigzag readout using different MPGDs for TPC with sPHENIX and ongoing LDRDs?

Zigzag parameter optimization for GEMs





sPHENIX TPC Zigzag Pads

Question 7: TPC R&D work vs LDRDs (cont'd)

Questions:

What is the overlap of the TPC R&D work at BNL and Yale on the optimization and study of zigzag readout using different MPGDs for TPC with sPHENIX and ongoing LDRDs?

Answer: (cont'd)

The priorities for studying various MPGD+zigzag options for a TPC should be driven by the performance requirements for the readout of the TPC. More specifically, ion back flow, energy resolution, spatial resolution, stable operation, gain uniformity, and the ability to disambiguate multiple tracks are among the criteria that must be looked at. At least initially at the EIC, ion back flow may be less of a concern than spatial resolution, energy resolution, and gain uniformity so these latter characteristics would be a top priority.

The 4 MPGD options mentioned in the report (i.e. 4-GEM, micromegas, uRWELL, and 2-GEM+MM), each present certain advantages over the other options. For example, we have found that the 4-GEM detector typically provides the best spatial resolution over the other options but is also the most complex detector arrangement. MM detectors are typically low cost and extremely robust, however the pillars can perturb the charge cloud if they are not arranged in a strategic way. The uRWELL detector should provide the best gain uniformity and possibly the best energy resolution, however there are concerns for how fast the charge may be evacuated in relatively high rate environments. We believe the 2GEM+MM option would provide the best IBF characteristics, but this would probably be beneficial only after the high luminosity upgrades at EIC.

Much of these claims still need to be validated by measurements and studies, which is essentially what we are proposing to do as part of the eRD6 R&D. In addition, since the formation of the charge cloud collected on the readout plane can vary substantially for one MPGD to the next, the zigzag pattern will also need to be modified accordingly for each case, so the matrix of possibilities is becoming large. However, because of all the advantages and disadvantages mentioned, we are broadly evaluating all options initially, but will gradually focus in on the optimal configuration as the R&D evolves. Ultimately, we have a reasonable understanding of what the priorities for the performance should be at an EIC, but it is not yet obvious at all what the optimal detector arrangement will be at this stage, which is why we believe it is critical to pursue this R&D.

Question 8: On Missing Software Tools

Questions:

What software tools are currently missing and impede your progress in the detector development effort?

Answer:

FIT and TU have been struggling for about a year to complete a fairly simple simulation task but without success so far because of lack of support from the simulation experts.

We would appreciate it if the software community could make the following tools available:

- An interface tool that allows easy user access to track parameters and track residuals, and that can be used to interpolate and extrapolate tracks to any region of the detector.
- A related tool that allows misalignment studies for trackers.
- Additional support from simulation experts on how to use and extract relevant information form simulation frameworks, such as EicRoot, would be extremely beneficial to our R&D program. Perhaps a youtube like video tutorial of the simulation package would be helpful.