# Design and Construction of a Vacuum System for Coincidence Velocity Map Imaging with TPX3CAM

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## Motivation

- Velocity map imaging (VMI) is a charged-particle detection scheme in which ions or electrons that are generated in a small volume of space (in the focus of a laser beam) are imaged to a 2D position-sensitive detector according to their transverse momentum. The VMI spectrometer designed in this work for a high-average-power laser system will enable experiments aimed at measuring the full vector momentum of electrons and ions in coincidence to better understand the coupled nuclear-electron dynamics of photoexcited molecules and non-adiabatic dynamics, which describes how electrons cannot adiabatically follow all nuclear motion. This nuclear motion affects the phase relationship between electronic states, which governs electronic motion. These coupled dynamics are responsible for a wide range of phenomena from photosynthesis to the photoprotection of DNA.

## Abstract


- Design a high vacuum chamber that houses the VMI spectrometer
- Design and construct a roughing line that backs high vacuum regions
- Design a vacuum interlock solution to prevent oil back-streaming in the event of power failure
- Integrate PymePix, a Python 3 library that provides control for Timepix3-SPIDR hardware, into current data acquisition processes


## Roughing Line Design/Results

Experiments are performed in a high vacuum chamber with a velocity map imaging detector. The chamber is pumped by a turbo pump down to a base pressure of 1 x $10^{-10}$ torr. Turbo pumps have an operation range between 100 millitorr to 1 x $10^{-10}$ torr. Therefore, a roughing line must be employed to evacuate the chamber from atmospheric pressure to "rough" vacuum prior to turbo pumping.

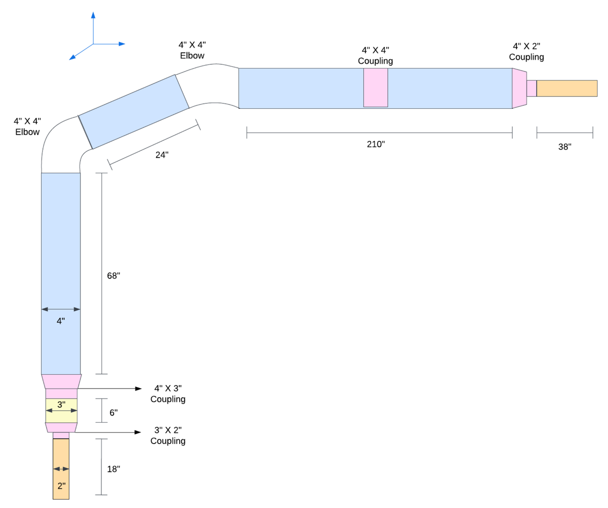


**Figure 1**: Schematic of roughing line

The roughing line was constructed using PVC pipe. Oatey Purple Primer and Heavy-Duty Clear PVC Cement were used as an adhesive for joints. A pressure of roughly 19 millitorr was measured upon under-pressure testing.

## Vacuum Interlock

In the event of a power failure, the roughing pump or diffusion pump should be isolated from the chamber to prevent oil backstreaming. This can be done by implementing a vacuum foreline interlock circuit that deactivates a valve if a roughing line gauge records a foreline pressure above a specified set point.

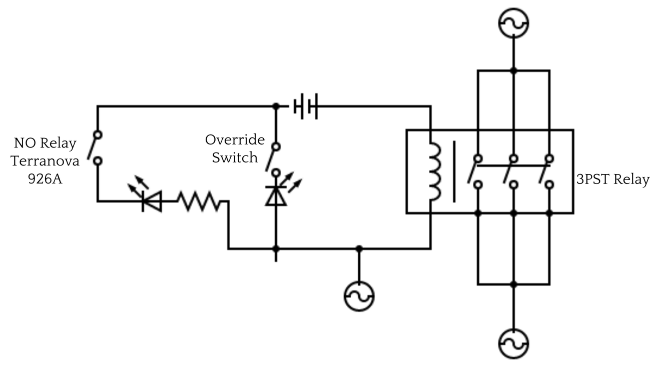



**Figure 2**: 208 VAC 3-phase vacuum foreline interlock for diffusion pump

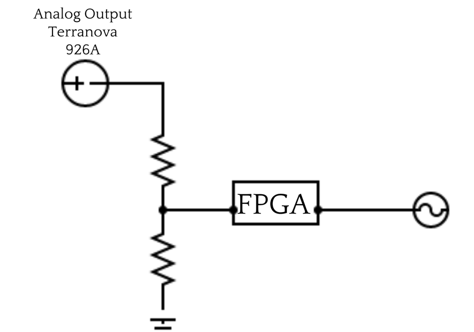



**Figure 3**: Vacuum interlock for roughing pump

## Vacuum Chamber Design

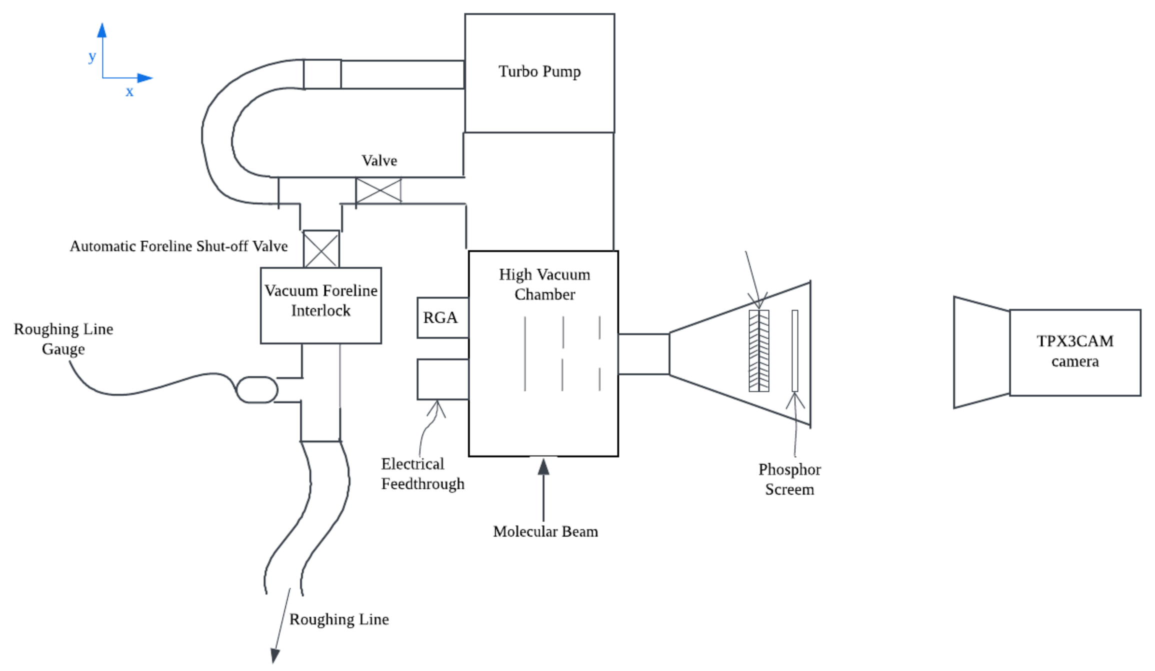



**Figure 4:** Vacuum system diagram

(a) (b)

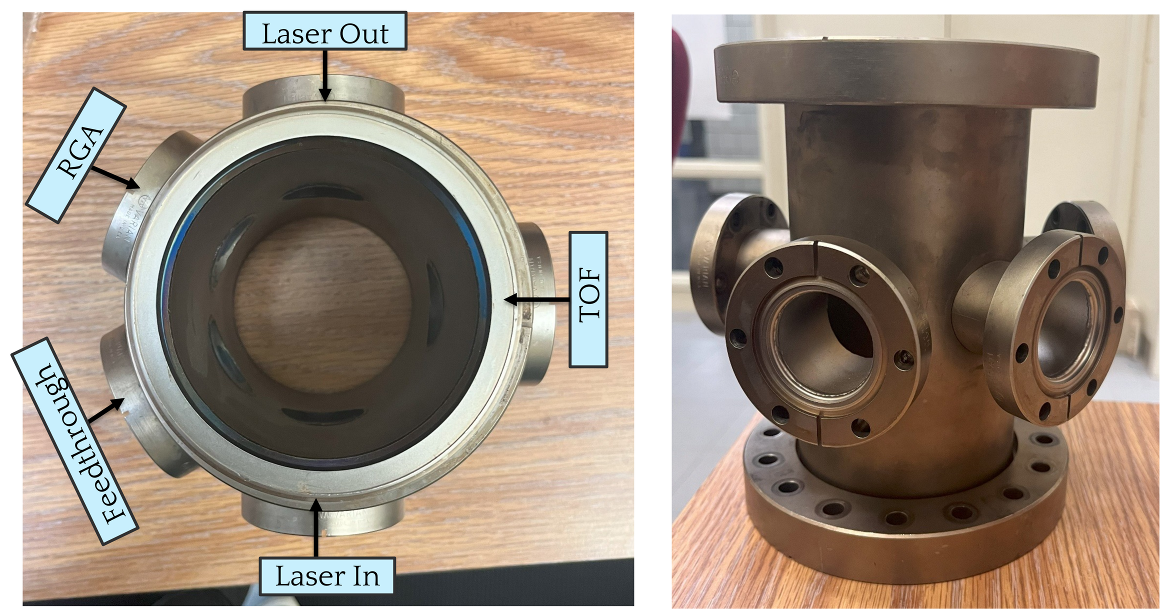



**Figure 5:** (a) Top view of the 5-way cross Vacuum Chamber with labeled ports. The design utilizes two ports for the entrance and exit of the ionization laser, one for electrical feedthrough, one port for a residual gas analyzer (RGA) for the detection of contaminants or process gasses, and one port for the exit of charged particle trajectories. (b) Side view of 5-way cross vacuum chamber

(a) (b)

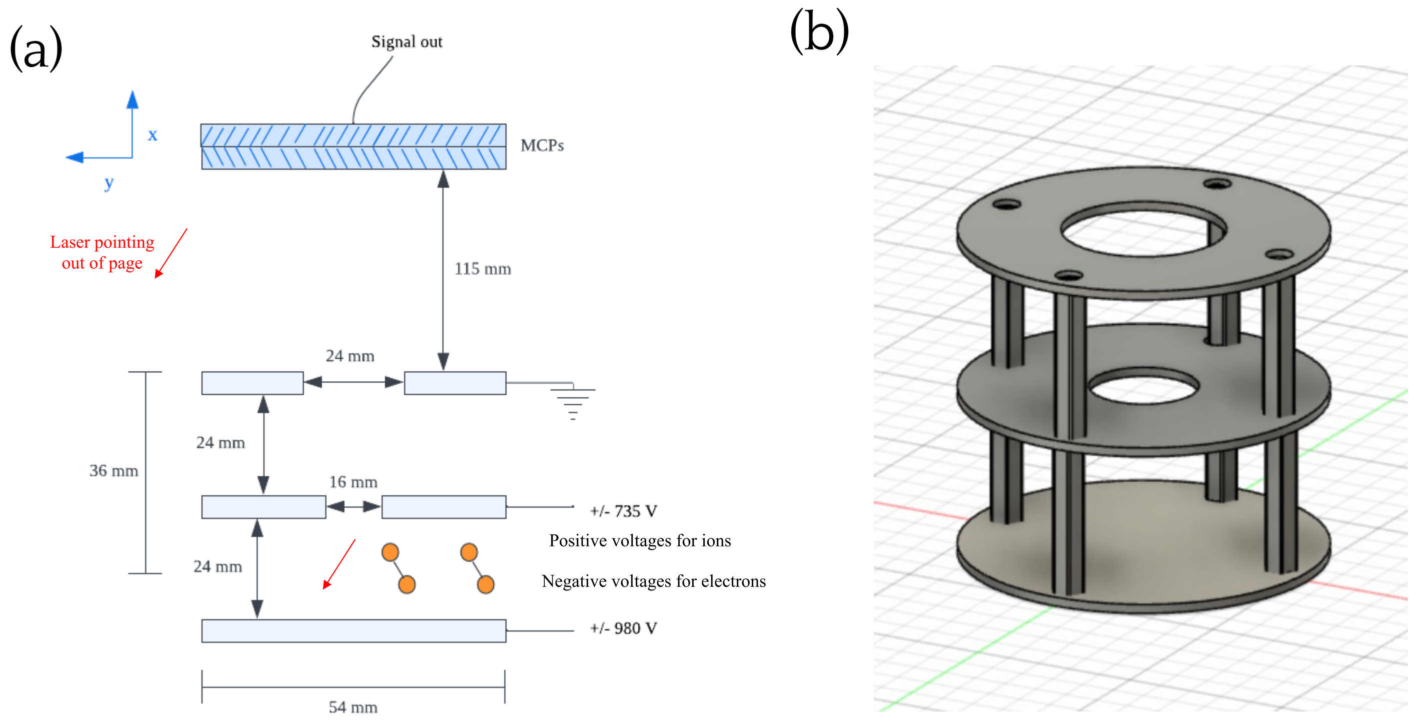



**Figure 6**: (a) Schematic of VMI spectrometer (not to scale). Functionally important dimensions are marked. (b) 3-D Model of VMI Spectrometer with appropriate dimensions

In the proposed velocity map imaging spectrometer, a focused laser beam crosses the path of an effusive molecular beam. Within the focus of the beam (the interaction region) molecules are ionized into charged particles. A set of electrostatically charged plates image the generated charged particles (ions/electrons) to a 2D position-sensitive detector. Variations in momentum along the electrostatic lens are encoded in time-of-flight information. The signal is detected and digitized by an arrangement of a dual stack of MCPs. The MCPs function like a photomultiplier: converting each incoming charged particle into a shower of electrons. The phosphor screen converts these electrons to photons, and the TPX3CAM camera images the phosphor screen. The TPX3CAM is a data-driven camera with 1.5 ns time resolution, allowing for direct measurement of the 3D momentum of ions.

## VMI Spectrometer Analysis

For optimal momentum mapping: $\frac{V_{ext}}{V_{rep}} \approx 0.75$

The three-electrode lens utilizes inhomogeneous electric field structures to map charged particles with different transverse momentums to different locations independent of the initial position. Furthermore, charged particles originating from different positions with the same initial vector momentum, are focused to the same final position on the detector. VMI exhibits a linear relationship between the electron momentum and position (for the axes perpendicular to the lens axis) .

(a) (b) (c)

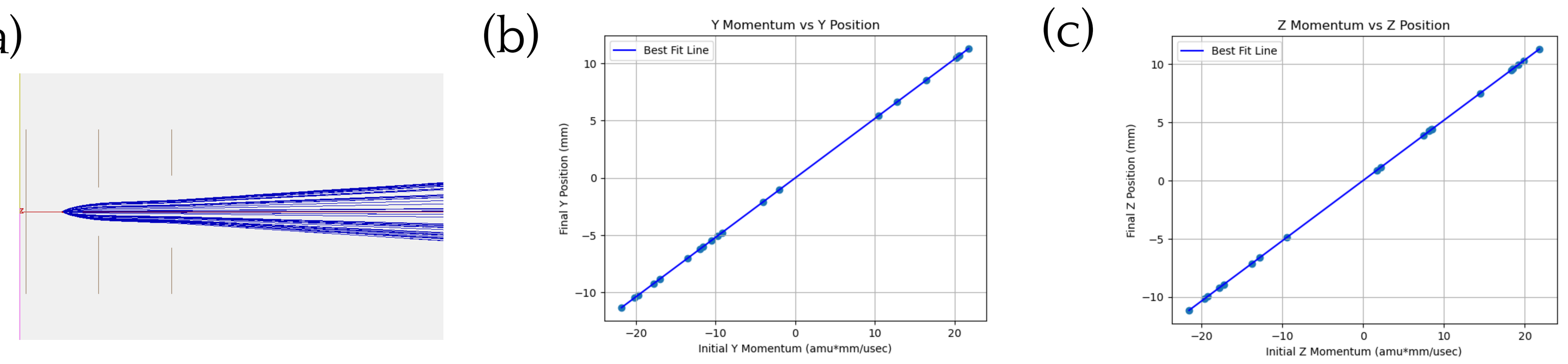



**Figure 8**: (a) Trajectories of ions with a conical distribution of transverse momentum (b) linear relationship between initial y momentum and final y position of ions (c) linear relation between initial z momentum and final z position of ions

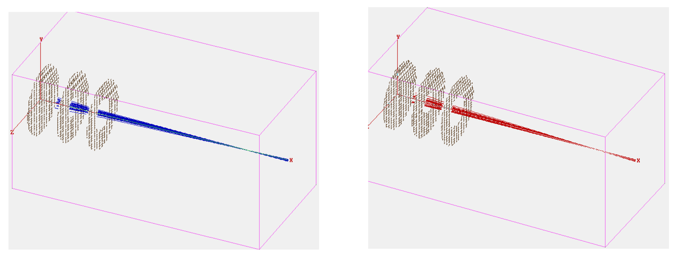


**Figure 7**: Electrons (red) and ions (blue) with the same single vector momentum being focused to a point

(a) (b) (c)

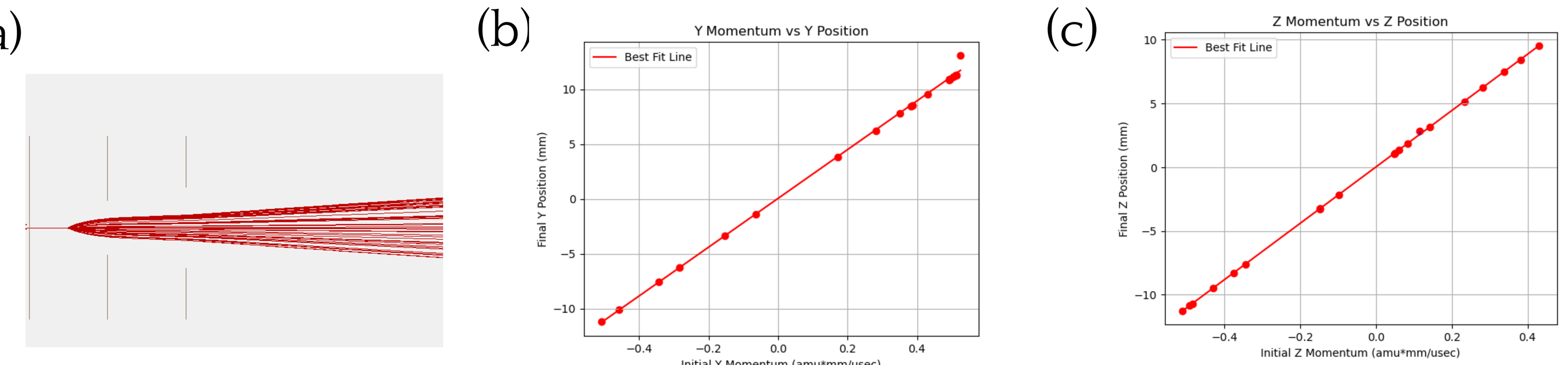



**Figure 9**: (a) Trajectories of electrons with a conical distribution of transverse momentum (b) linear relationship between initial y momentum and final y position of electrons (c) linear relation between initial z momentum and final z position of electrons

## PymePix Results

PymePix is a Python 3 package developed to handle connection, control, data acquisition, and post-processing with the TPX3CAM. PymePix has the capability to configure the Timepix camera, alter DAC parameters, acquire data in multiple formats (pixel, TOF, centroided, raw), perform DBSCAN centroiding, and perform a time-walk correction

To test the performance of PymePix, the package was used to acquire and analyze data created by a pulsed laser pointer.

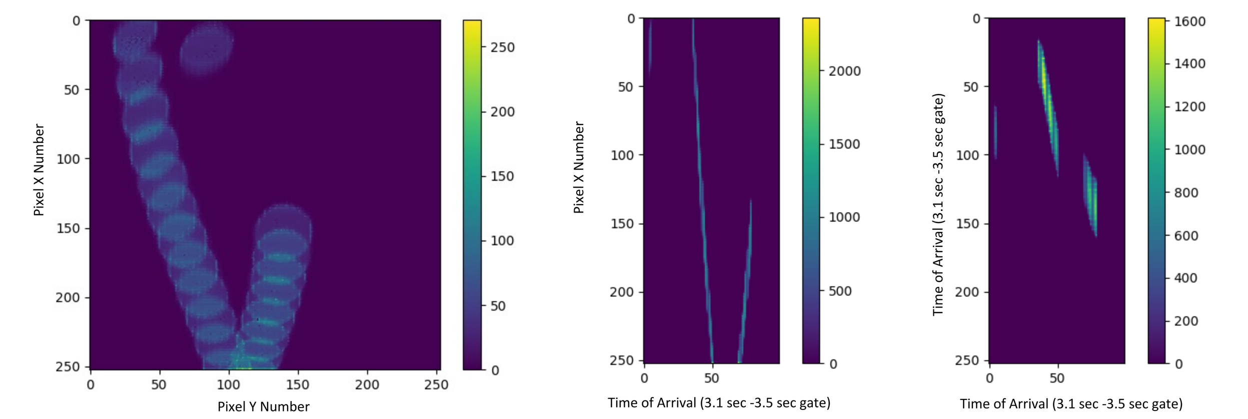



**Figure 10**: (a) Pixel Y vs. Pixel X data (b) Pixel X vs. Time of Arrival (c) Pixel Y vs. Time of Arrival

Figure 10 shows one instance of data acquisition. Upon further repeated testing, PymePix was unable to record data from the TPX3CAM. The figure below shows a failure to register hits, with the exception of two hot pixels.

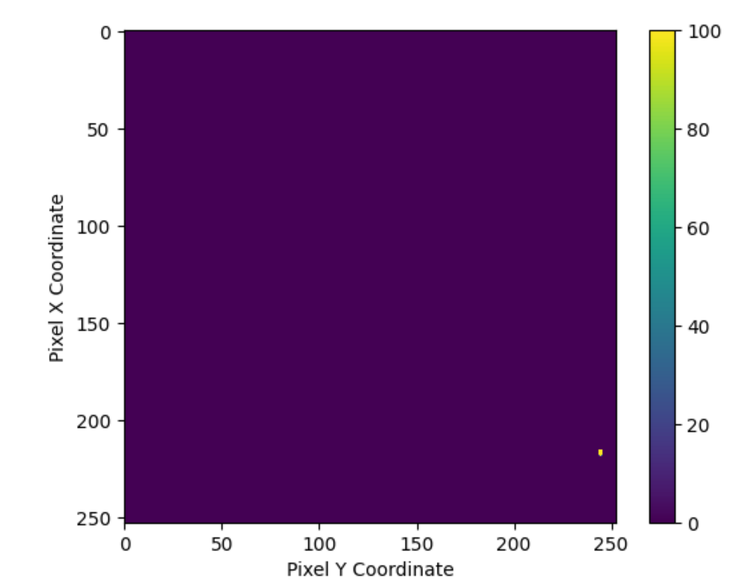
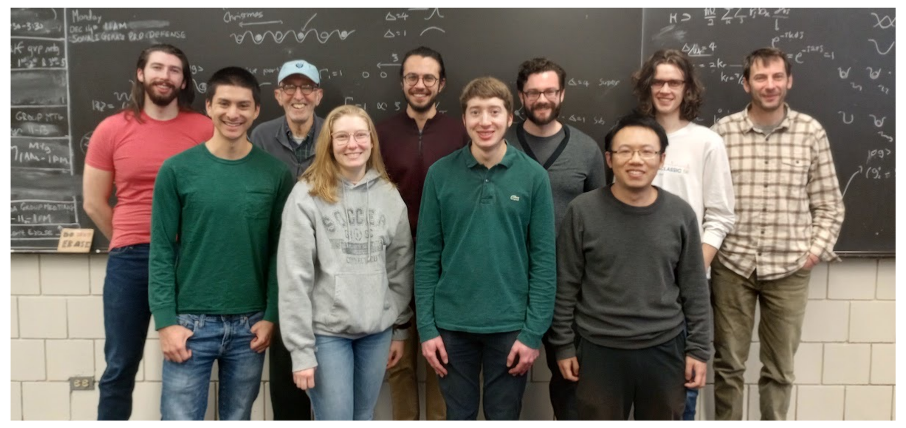



**Figure 11**: (a) Pixel Y vs. Pixel X data

## Acknowledgements



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## References

[1] Michael Davino, Edward McManus, Nora G. Helming, Chuan Cheng, Gönenç Moğol, Zhanna Rodnova, Geoffrey Harrison, Kevin Watson, Thomas Weinacht, George N. Gibson, Tobias Saule, Carlos A. Trallero-Herrero; A plano-convex thick-lens velocity map imaging apparatus for direct, high-resolution 3D momentum measurements of photoelectrons with ion time-of-flight coincidence. *Rev Sci Instrum* 1 January 2023; 94 (1): 013303.

[2] Chuan Cheng, Gönenç Moğol, Thomas Weinacht, Andrei Nomerotski, Carlos Trallero-Herrero; 3D velocity map imaging of electrons with TPX3CAM. *Rev Sci Instrum* 1 January 2022; 93 (1): 013003.

[3]Al-Refaie, A.F., Johny, M., Correa, J., Pennicard, D., Svihra, P., Nomerotski, A., Trippel, S., & Küpper, J. (2019). PymePix: a python library for SPIDR readout of Timepix3. *Journal of Instrumentation, 14*, P10003 - P10003.

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