Development of Large Area µRWELL Detectors for CLAS12 High Luminosity Upgrade at Jefferson Lab

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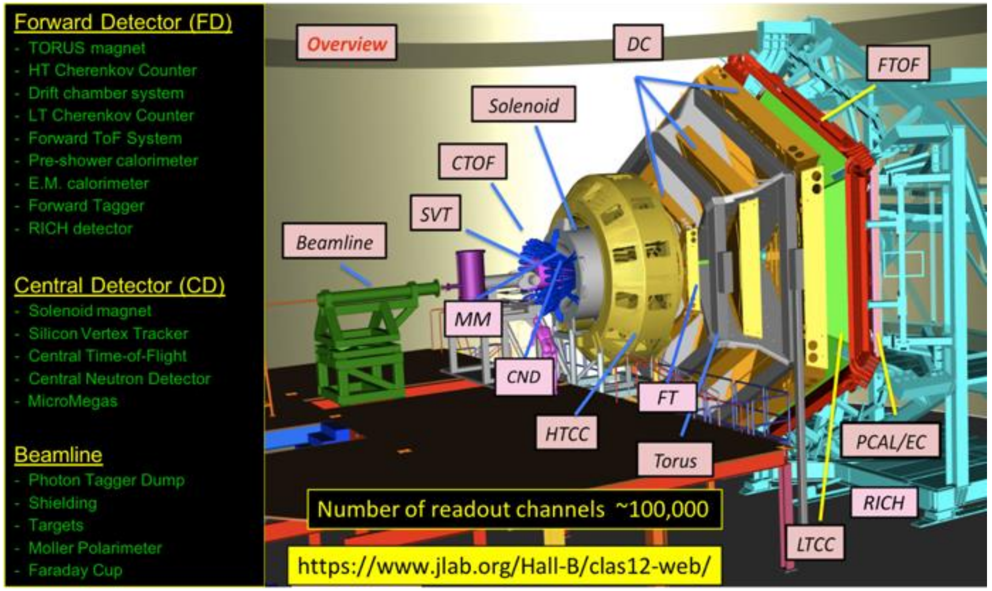
On behalf of

CLAS12 High Luminosity Forward Tracker Upgrade

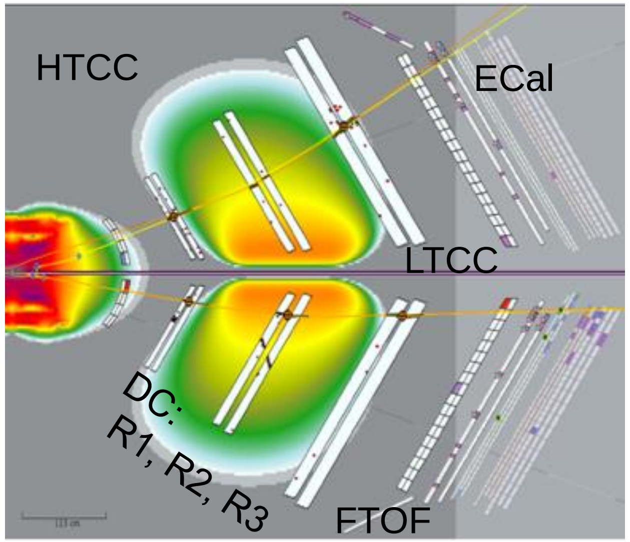
Outline

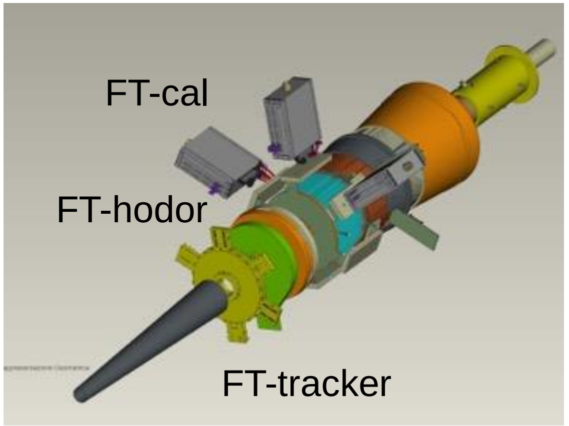
- Motivations for fast tracker in CLAS12 forward region
- Design and fabrication of large µRWELL prototype
- Ongoing R&D on µRWELL detectors for CLAS12

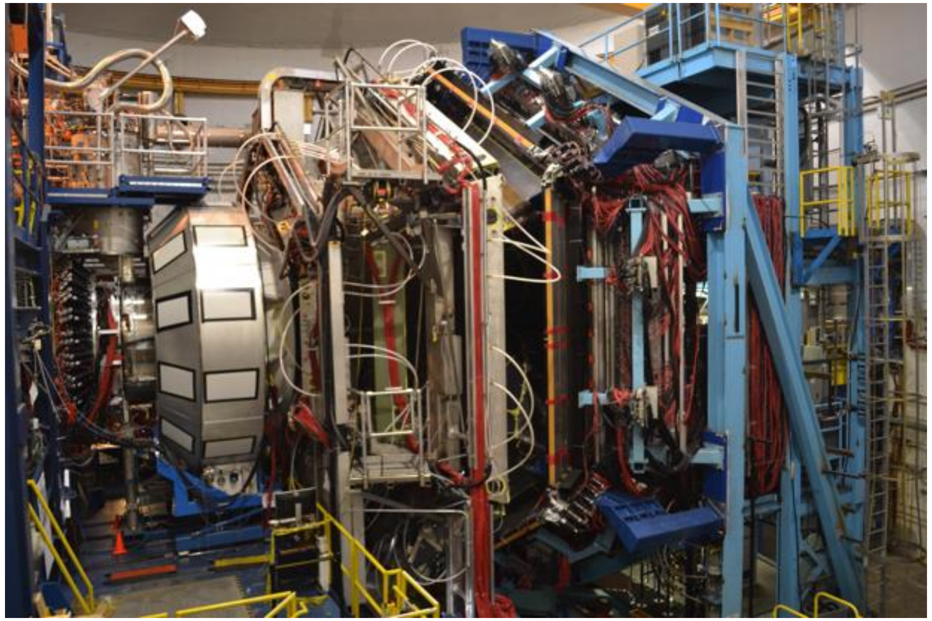
CLAS12 in Hall B @ Jefferson Lab

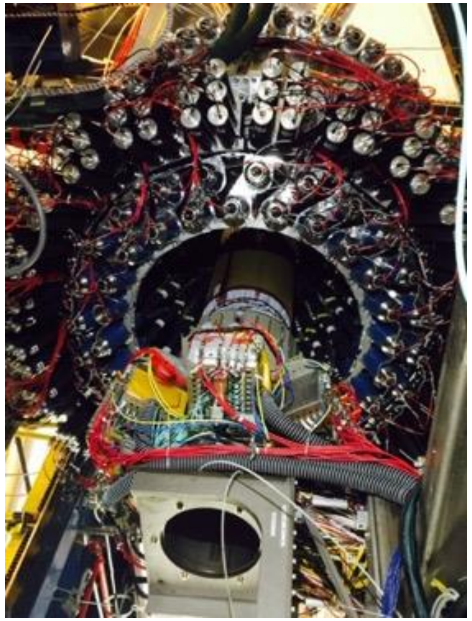


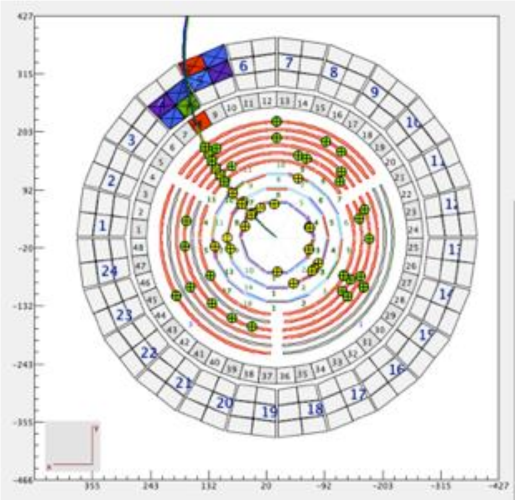
- CEBAF Large Acceptance Spectrometer for the 12 GeV era in Hall B @ JLab
- Designed luminosity of 10^{35} cm^{-2} sec^{-1}
- Physics targets:
  - LH_2, LD_2, LHe, LAr, D, ^4He
  - ^{12}C to ^{208}Pb
  - Pol. NH_3, ND_3, ^6LiH, ^7LiD, ^3He-gas











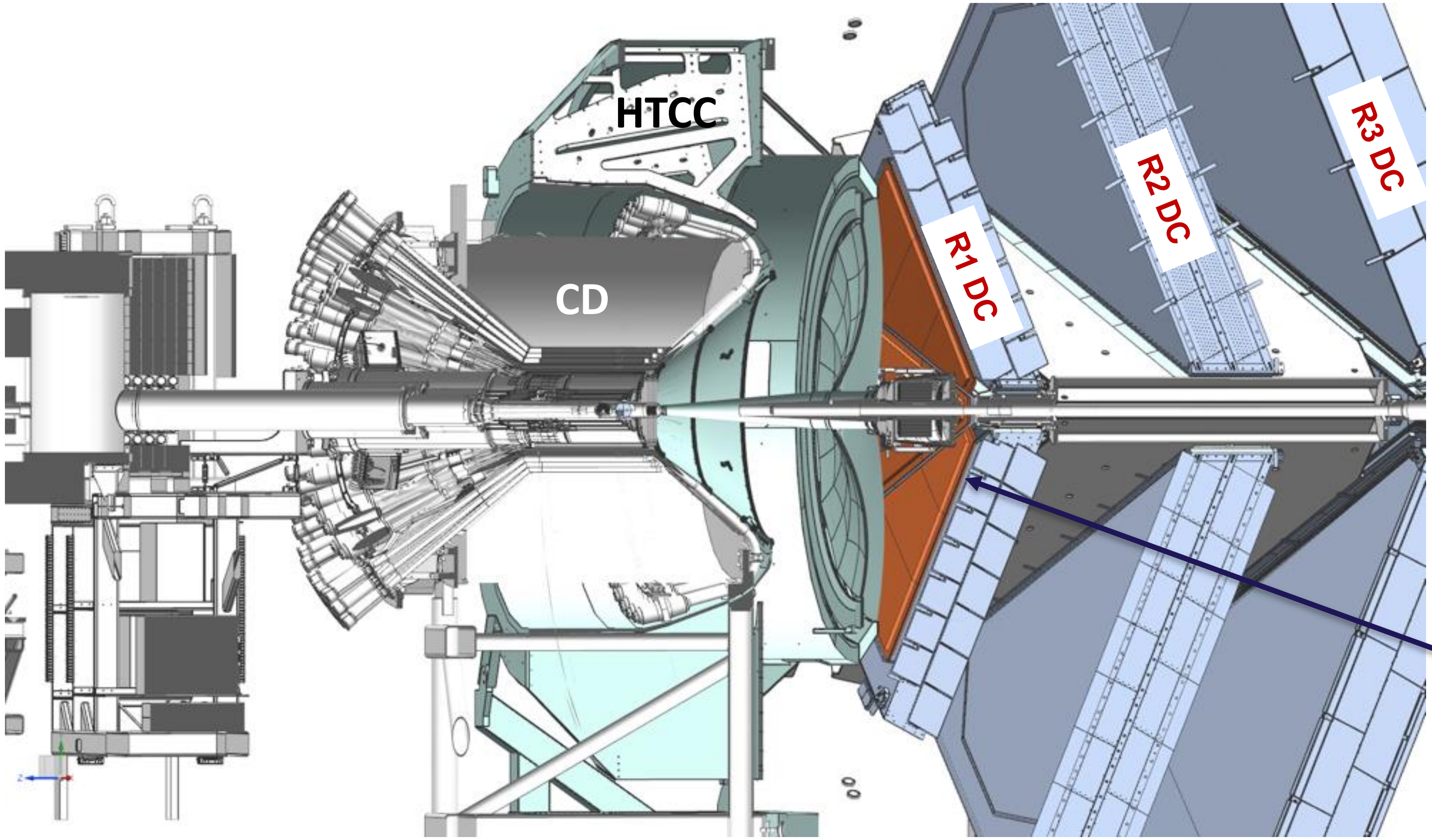
CLAS12 Luminosity Upgrade: Motivations

- Learned quite a bit regarding detector efficiencies and detection rates of key reactions with the first years of runs.
- In reality, detection rates is a factor 2 below expectation from original proposals. *Most of these proposals, approved more than a decade ago, assumed 100% detection efficiency and idealistic geometrical acceptances.*
- The proposed upgrade is to help run groups, e.g., RGA and RGB, to catch up and fulfill the goals of experiments.
- **Phase-I upgrade** aims to reach a luminosity of ~2×10^{35} cm^{-2} sec^{-1} for CLAS12 normal running conditions with charged particle reconstruction efficiency of > 85%.
- To get there, we need to upgrade the forward tracking system. Other subsystems claimed to be able to perform at × 2 higher luminosities. These must be revisited with the more or less final reconstruction software and alignment.
- The time frame for the Phase-I upgrade is 2 to 3 years.
- **Phase-II upgrade** in a later stage will see an increase of the luminosity by two order of magnitudes up to ~10^{37} cm^{-2} sec^{-1}. This would require a more substantial subdetector upgrade, specially in the central detector

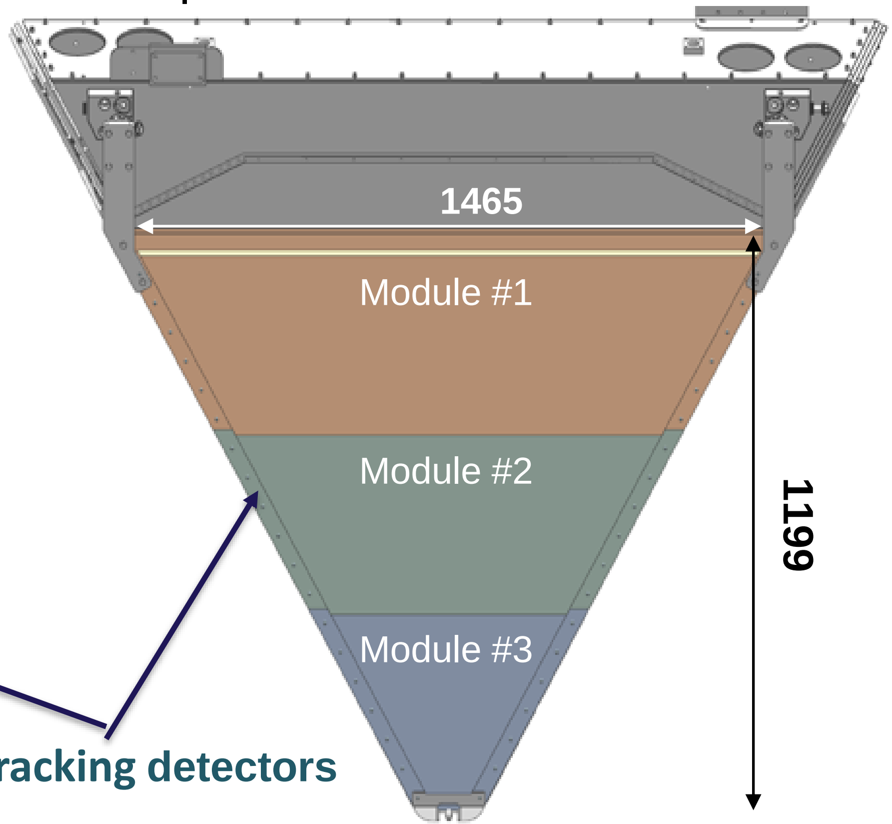
CLAS12 Luminosity Upgrade: Fast Forward Tracker

Phase I: How to get to a luminosity 2 × 10^{35} cm^{-2} sec^{-1} with 85% tracking efficiency

❖ To mitigate occupancy-related inefficiency of FD tracking, we plan to add faster tracking detectors to the forward drift chambers.



μRWELL sector mounted on R1 DC



New tracking detectors

❖ The target, CD, and HTCC will move upstream by about 10-15 cm to make room for new MPGD layer (s).

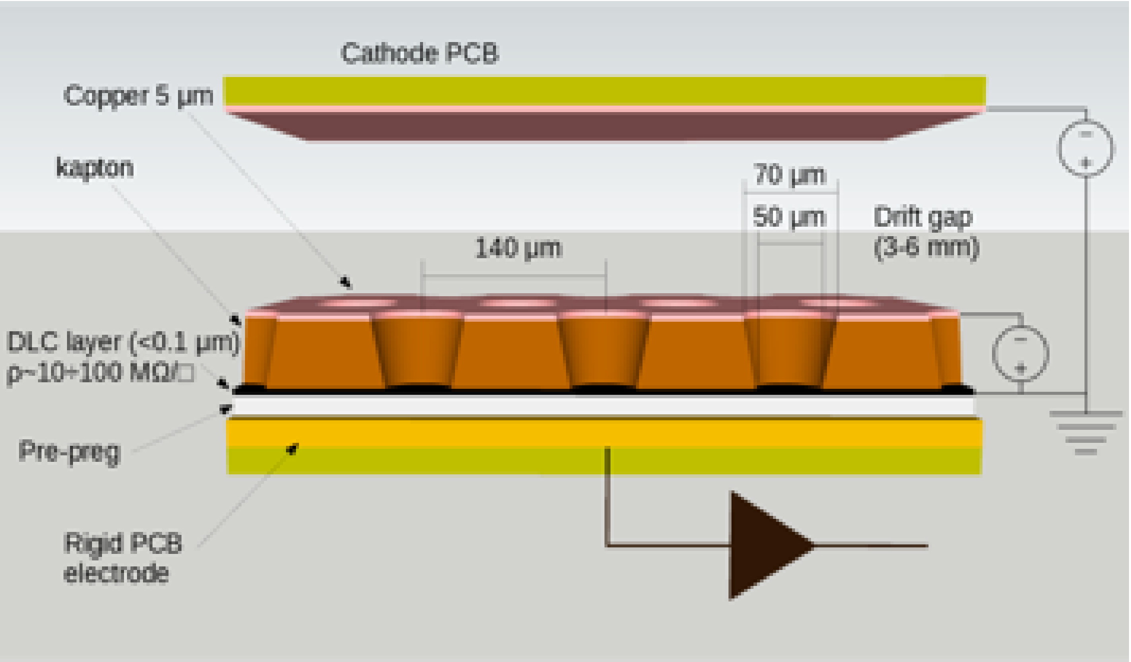
❖ Each layer will consist of six triangular large sectors.

❖ Each sector will consist of three modules (there are no foils large enough to cover the whole R1).

CLAS12 Luminosity Upgrade: µRWELL Forward Tracker

µRWELL is the chosen MPGD technology because of:

- ❖ Large area capability
- ❖ Low mass & compactness,
- ❖ Easy assembly, easy powering
- ❖ Robustness ➔ intrinsic spark quenching @ high gain → 10^4
- ❖ Excellent spatial resolution → < 100 µm
- ❖ Good time resolution → < 10 ns
- ❖ Rate capability for HR version of µRWELL →100 kHz/cm^2



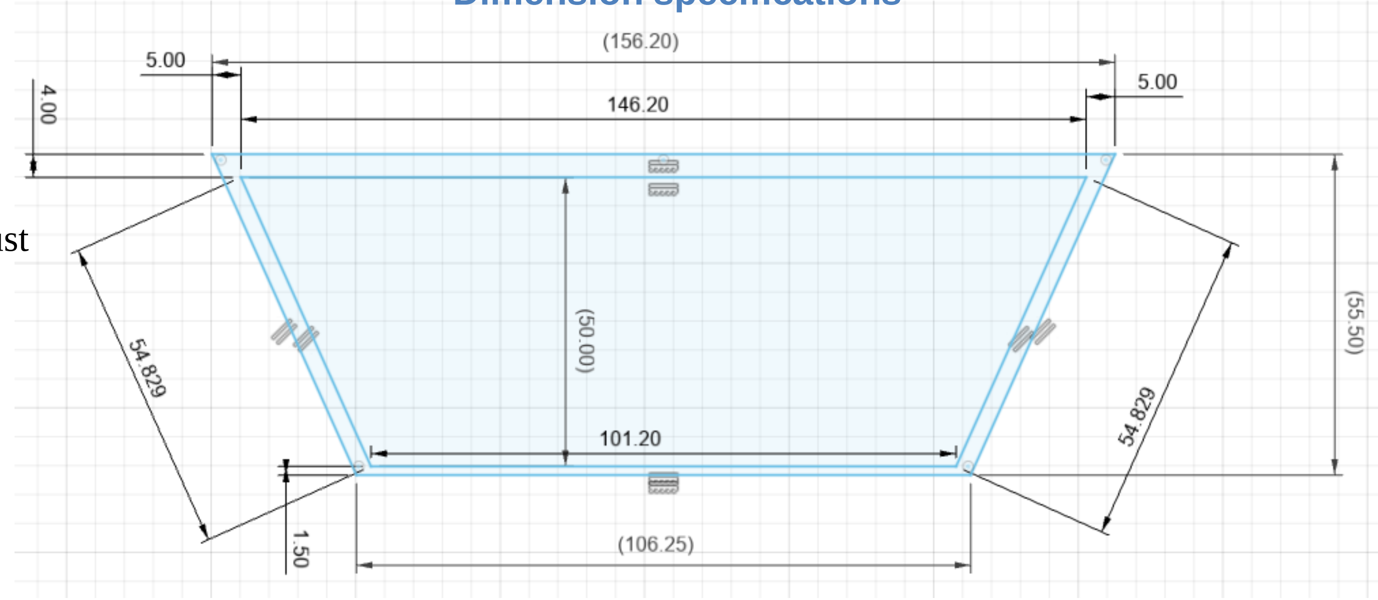
G. Bencivenni et al 2019 JINST 14 P05014

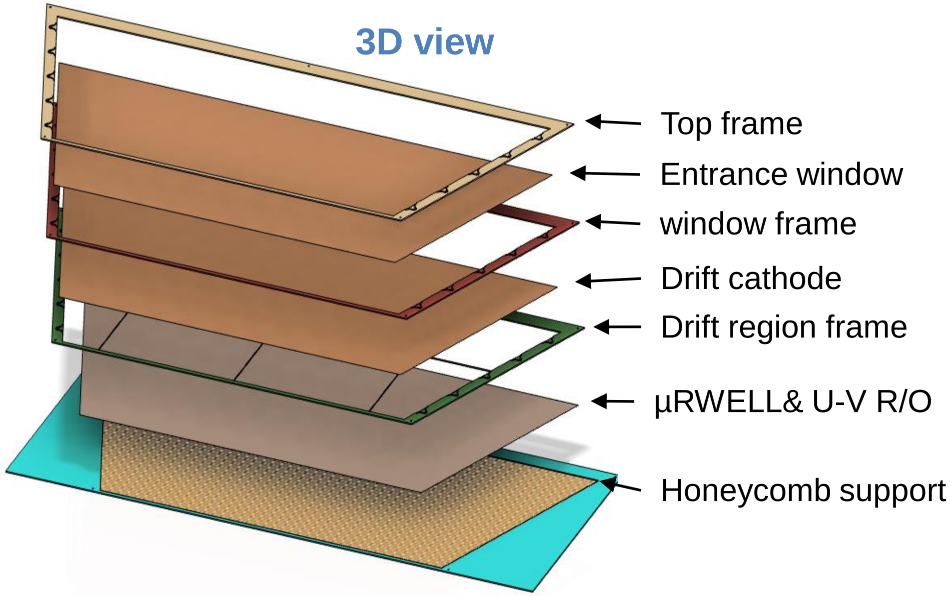
CLAS12 Luminosity Upgrade: Large µRWELL prototype

University of Virginia — Jefferson Lab, Exploring the Nature of Matter

- **Prototyping of µRWELL Module #1**
  - Largest module of CLAS12 Forward Tracker layer
  - Trapezoid with an active area of [1460 mm – 1012 mm] × 50 mm
  - **Goal:** Demonstrate large area µRWELL operate well and is a robust
- **µRWELL amplification: PEP fabrication technique**
  - µRWELL sector segmentation pitch = 2 cm
  - Ground lines pitch = 4 cm
- **U-V strip readout with strips along the long sides of the chambers**
  - U & V strips at 10-degree stereo pitch = 1 mm
  - Connectors for all strips on the two short sides of the detector
  - Capacitive-sharing R/O scheme based small X-Y prototype design
- **Assembly:**
  - Pre-assembly i.e., preparation of the Honeycomb support frames, cathode foil done @ UVa (mid Nov. 2022)
  - Full assembly @ CERN just completed the past week (04 Dec 2022)
- **Tests & Characterization:**
  - Prototype is shipped to JLab for test
  - Cosmic test in January 2023 & in beam in Hall B in February 2023

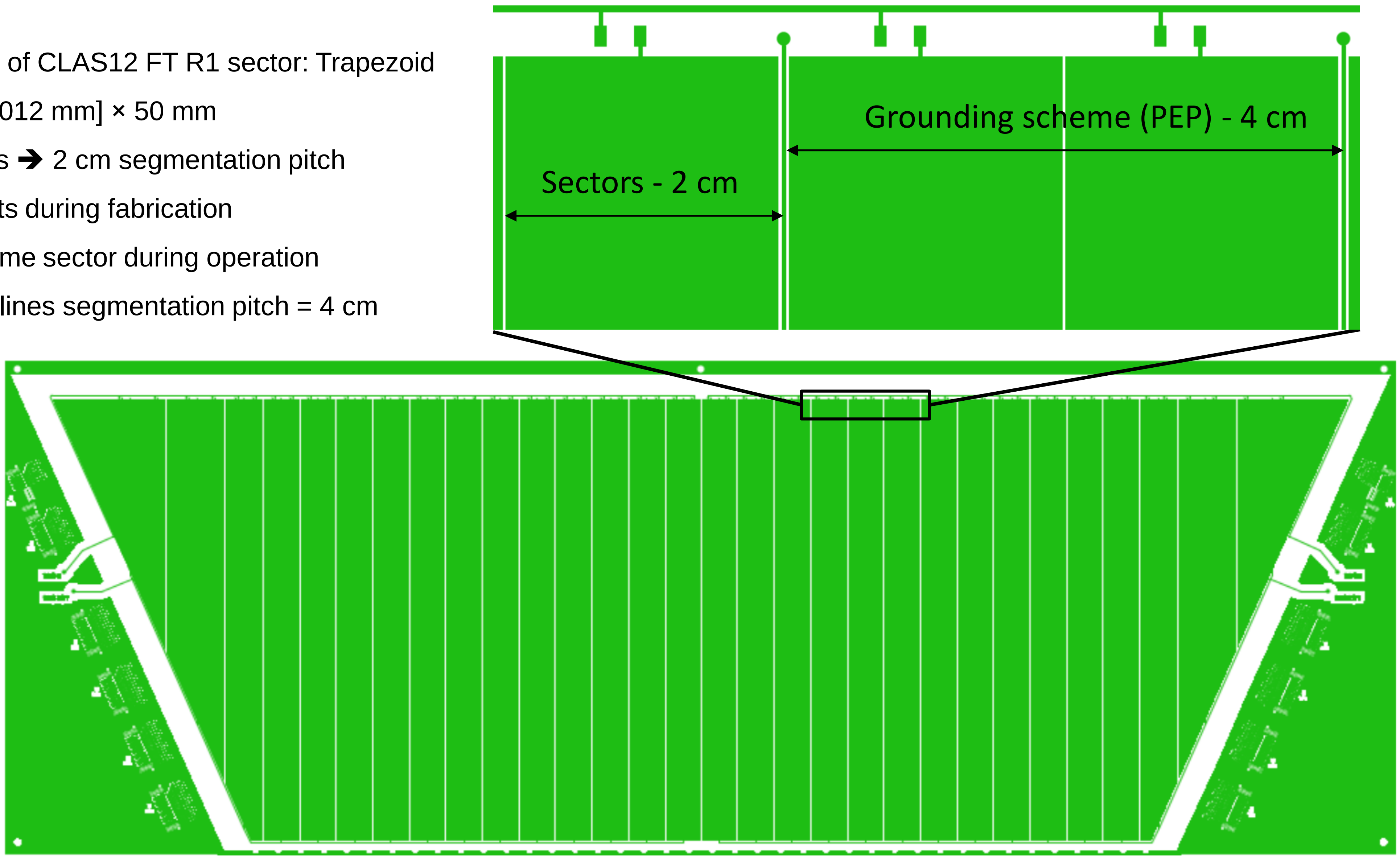
Dimension specifications





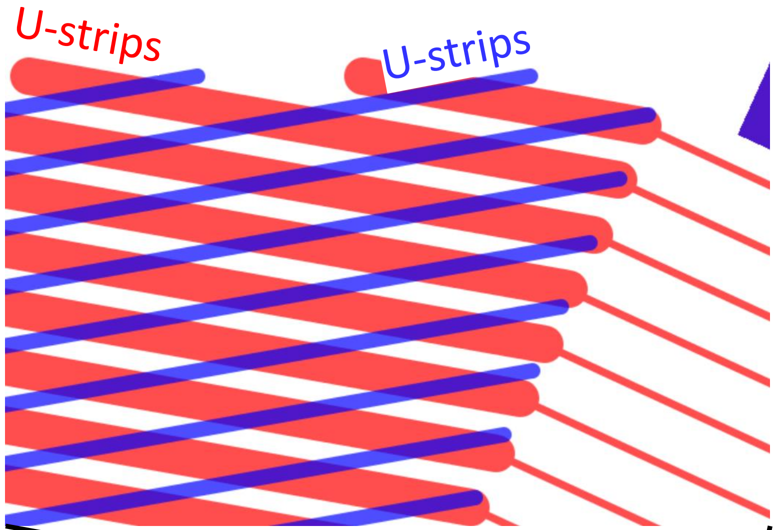
µRWELL amplification foil:

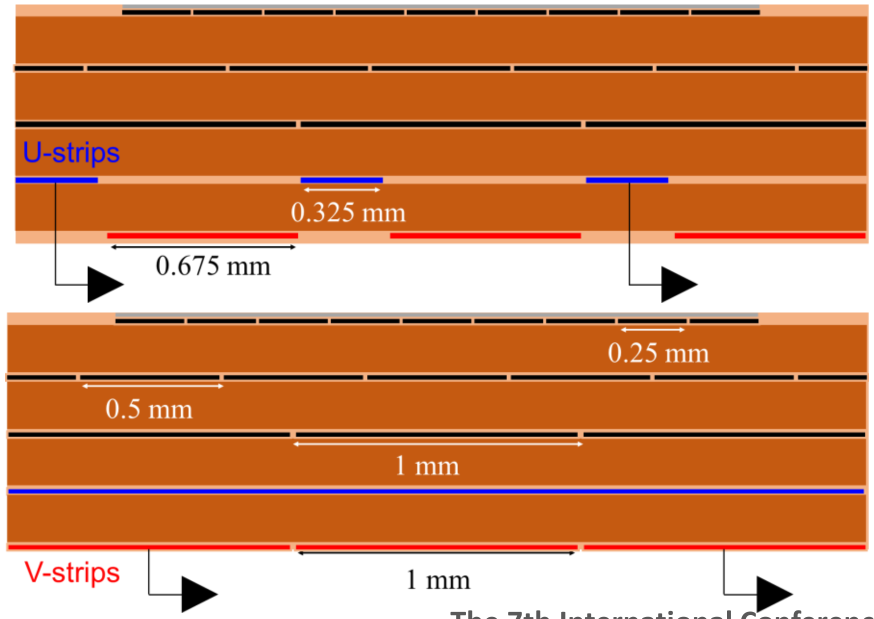
- Prototyping of the largest module of CLAS12 FT R1 sector: Trapezoid shape Active area: [1460 mm – 1012 mm] × 50 mm
- µRWELL amplification: 60 sectors ➔ 2 cm segmentation pitch
  - Easy identification of defects during fabrication
  - Easy isolation of troublesome sector during operation
- PEP grounding scheme: Ground lines segmentation pitch = 4 cm
  - High-rate capability

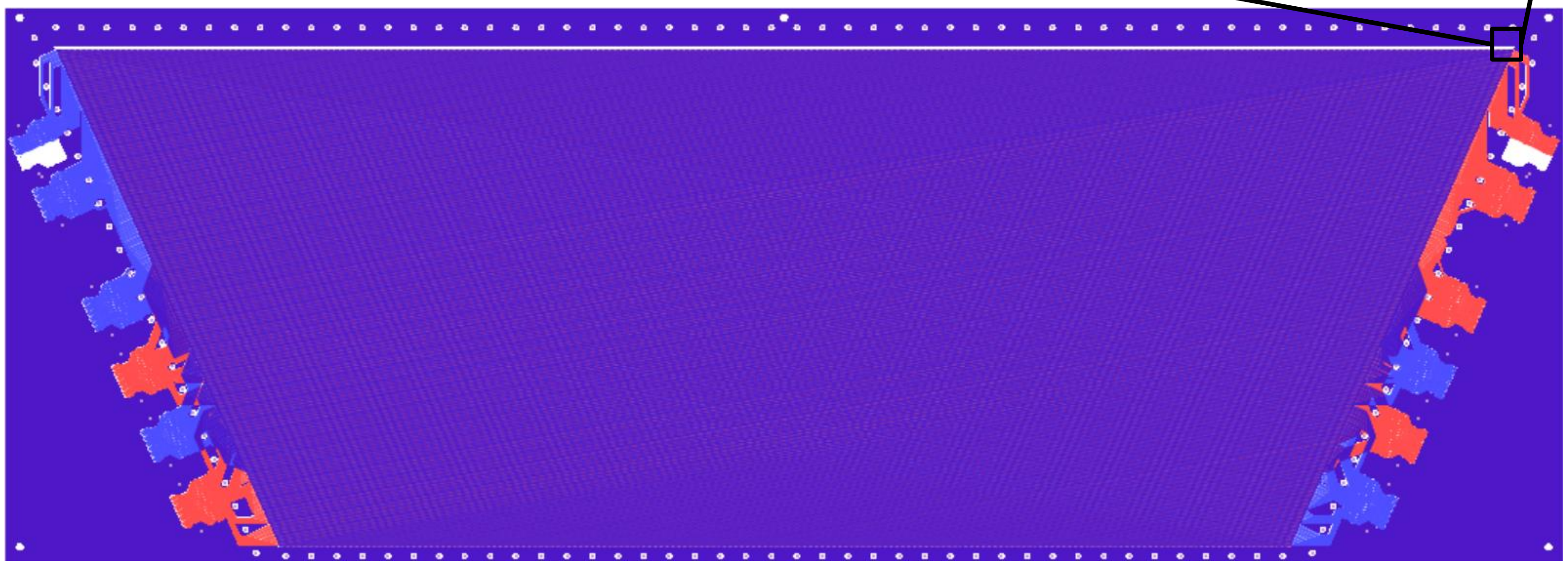


U/V strip readout with 3 capacitive-sharing layers:

- To reduce number of strips and and save electronics cost ➔ while maintaining spatial resolution capabilities
- The U/V readout multi-layer PCB is composed of a stack of:
- Three capacitive layers with pad size of 0.25, 0.5 and 1 mm from top to bottom (black pads on the drawing)
  - Signal propagate longitudinally through capacitive coupling and transversely through geometrical arrangement of capacitive pads
- 1 mm pitch U- and V-strips on different layers separated by 50 µm Kapton foil (blue and read on the cartoons
  - no Kapton ridge underneath top strips but plain Kapton out between top and bottom strips





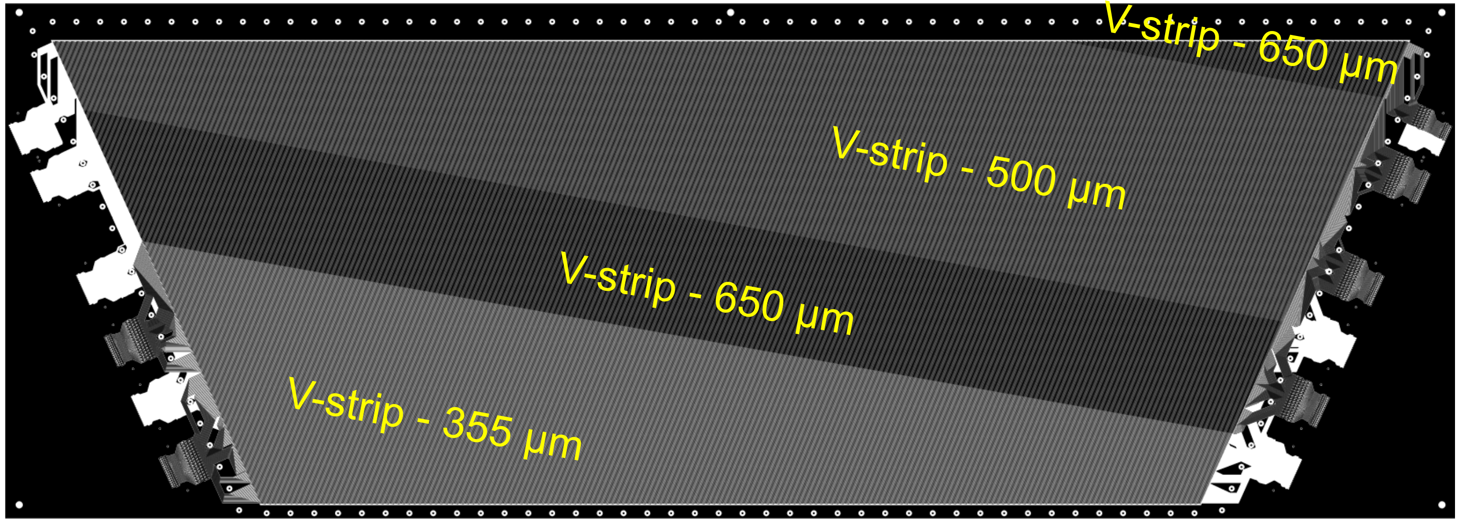


CLAS12 Luminosity Upgrade: Large µRWELL prototype

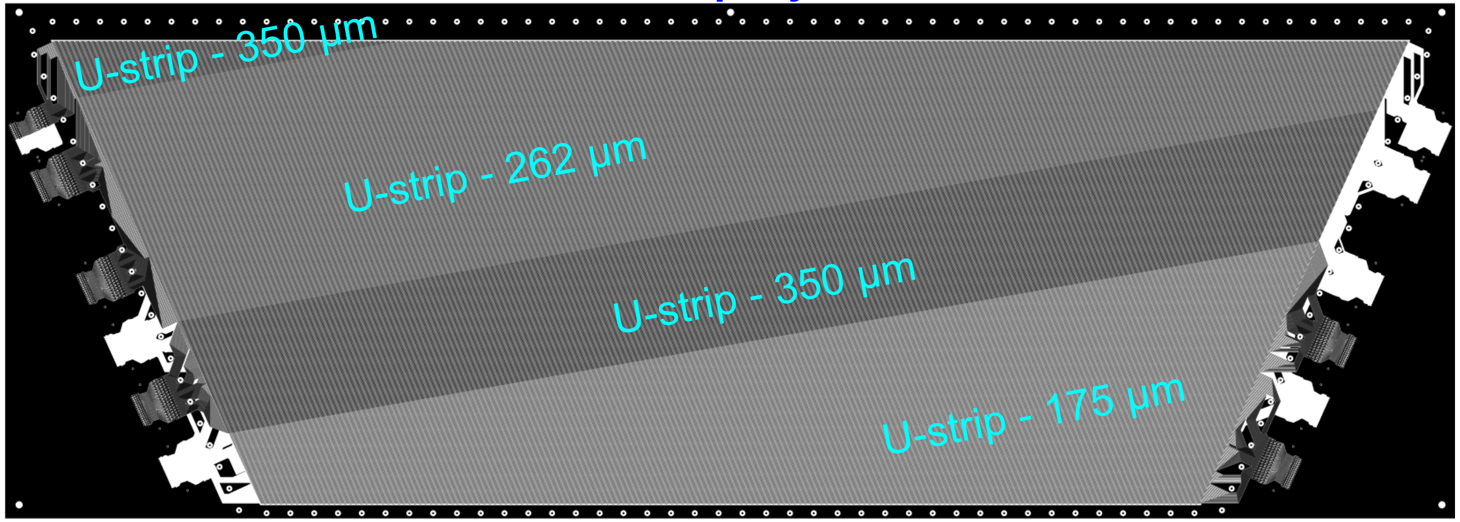
U/V strip readout with 3 capacitive-sharing layers:

- 1 mm strip for both pitch for U-strip and V-strip layers
- Each layer split in 3 regions with different strip widths
- 9 U/V strip combination to
  - Optimize U / V equal sharing combination
  - Minimize strip input capacitance
  - maximize charge collection
- Each Panasonic connector with only type of strip

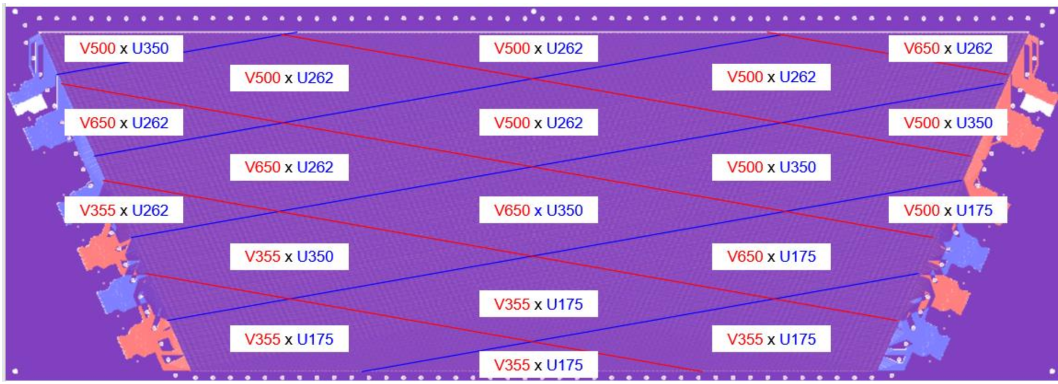
V-strip layer



U-strip layer

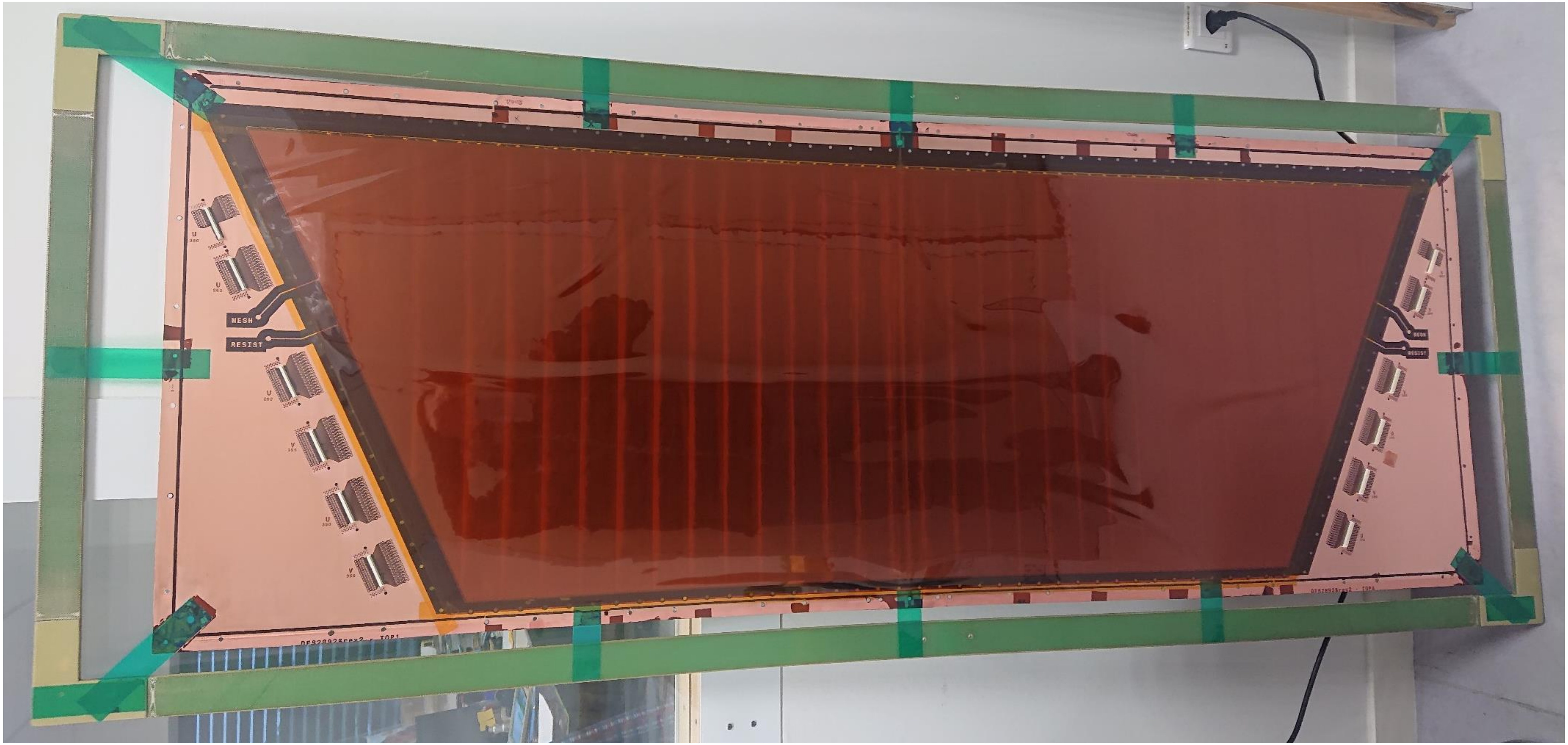


9 U/V strip combination



CLAS12 Luminosity Upgrade: µRWELL prototype assembly

CLAS12 large µRWELL foil with U/V readout produced at Rui's MPT workshop at CERN

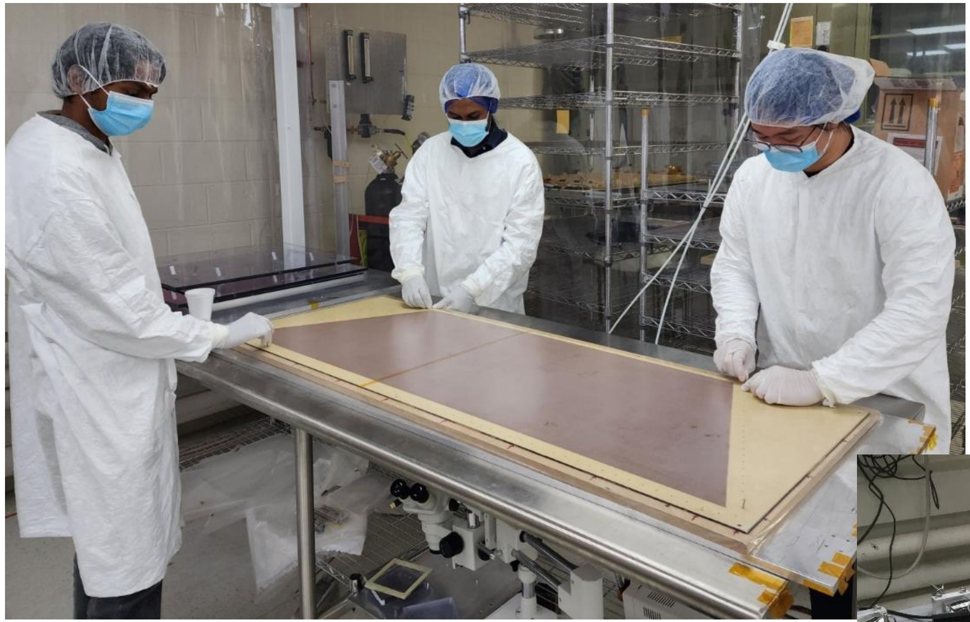


CLAS12 Luminosity Upgrade: µRWELL prototype assembly

Frames preparation @ UVa

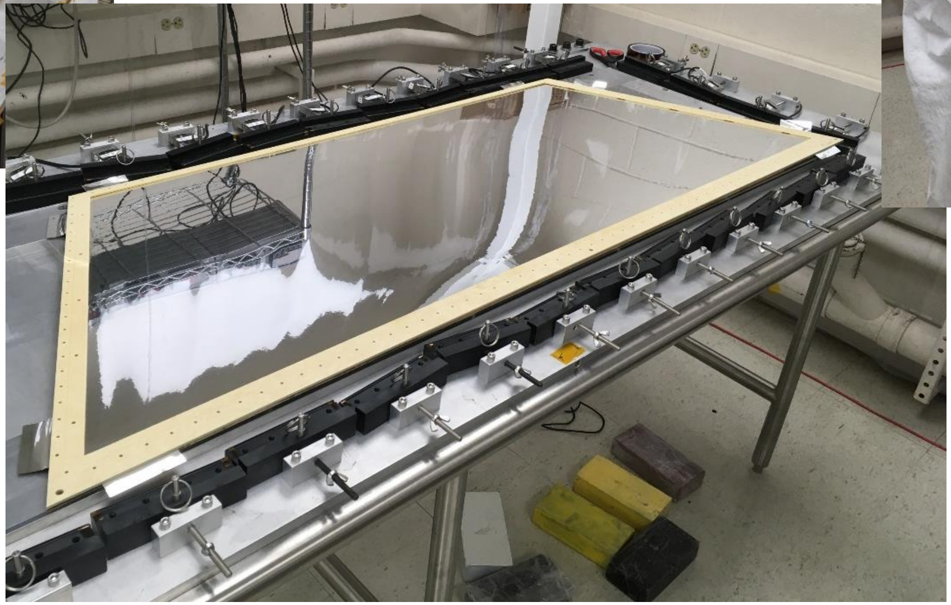
(Nov. 2023)

Honeycomb support frame



Cathode bock:

- Alu-Kapton foil: Kapton side is glued to honeycomb frame
- 3 mm spacer frame with the gas circulation structure and O-ring grooves glued to the Alu side of the Alu-Kapton



Mock-up assembly:
Test the two step-assembly procedure

CLAS12 Luminosity Upgrade: µRWELL prototype assembly

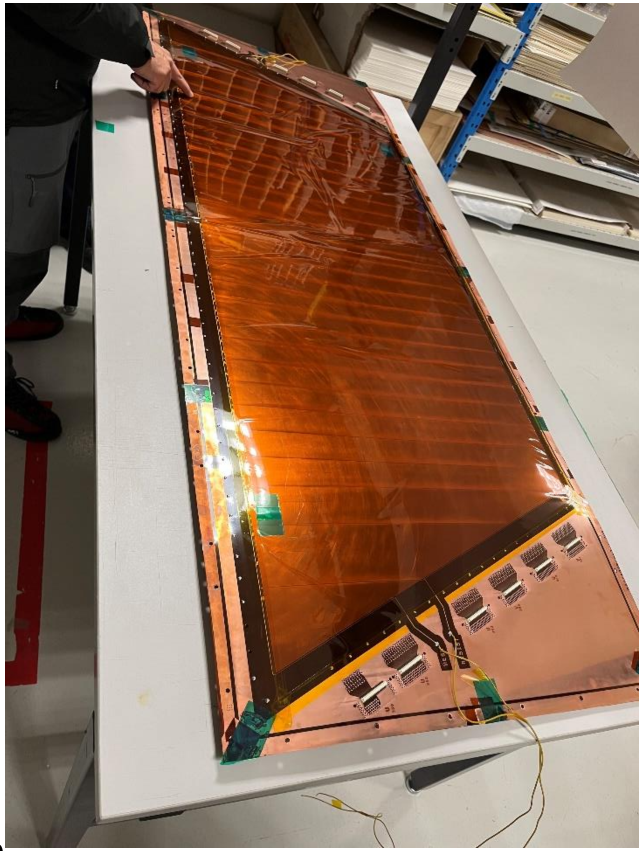
Full assembly at CERN

(Dec. 2022)

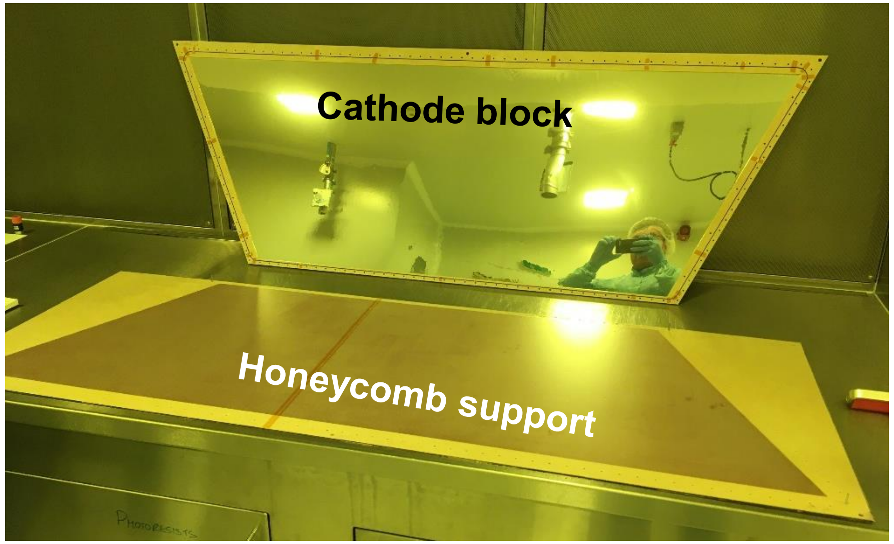
2 week-long HV test in oven at 90^{O}

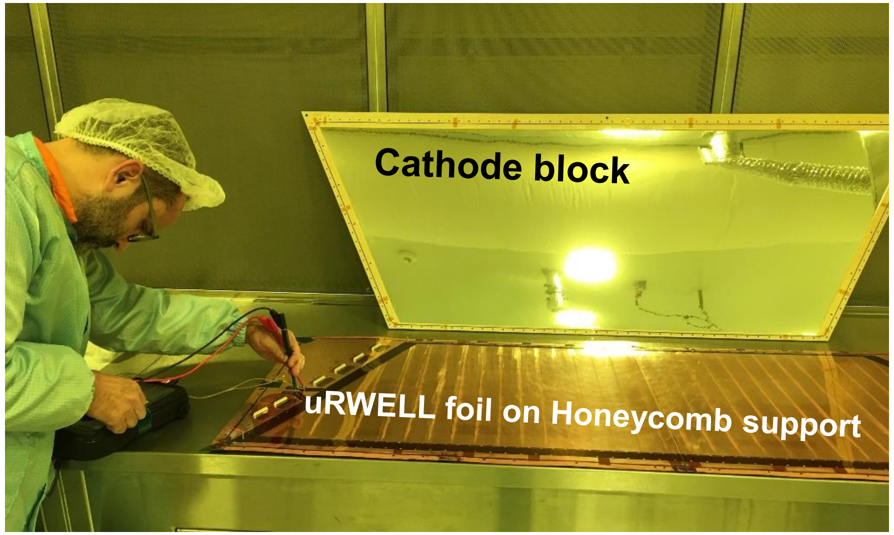
to maintain dry condition

HV test outside the oven ➔ 100 GΩ @ 500V in air



In clean room



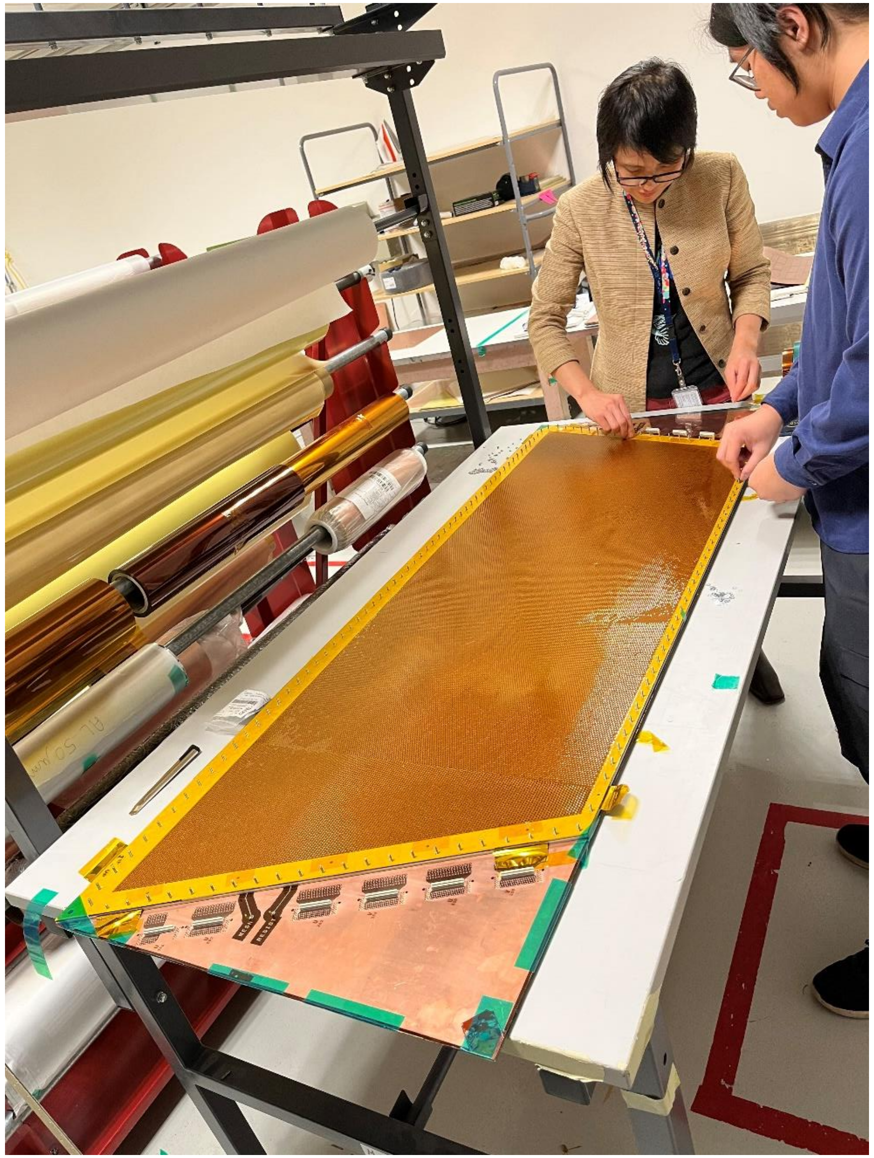


Assembly: Two simple steps

- uRWELL foil is laid on the support Honeycomb
- Close the detector with the cathode block using O-ring, screws and nuts

CLAS12 Luminosity Upgrade: Next for the project

Full assembly at CERN

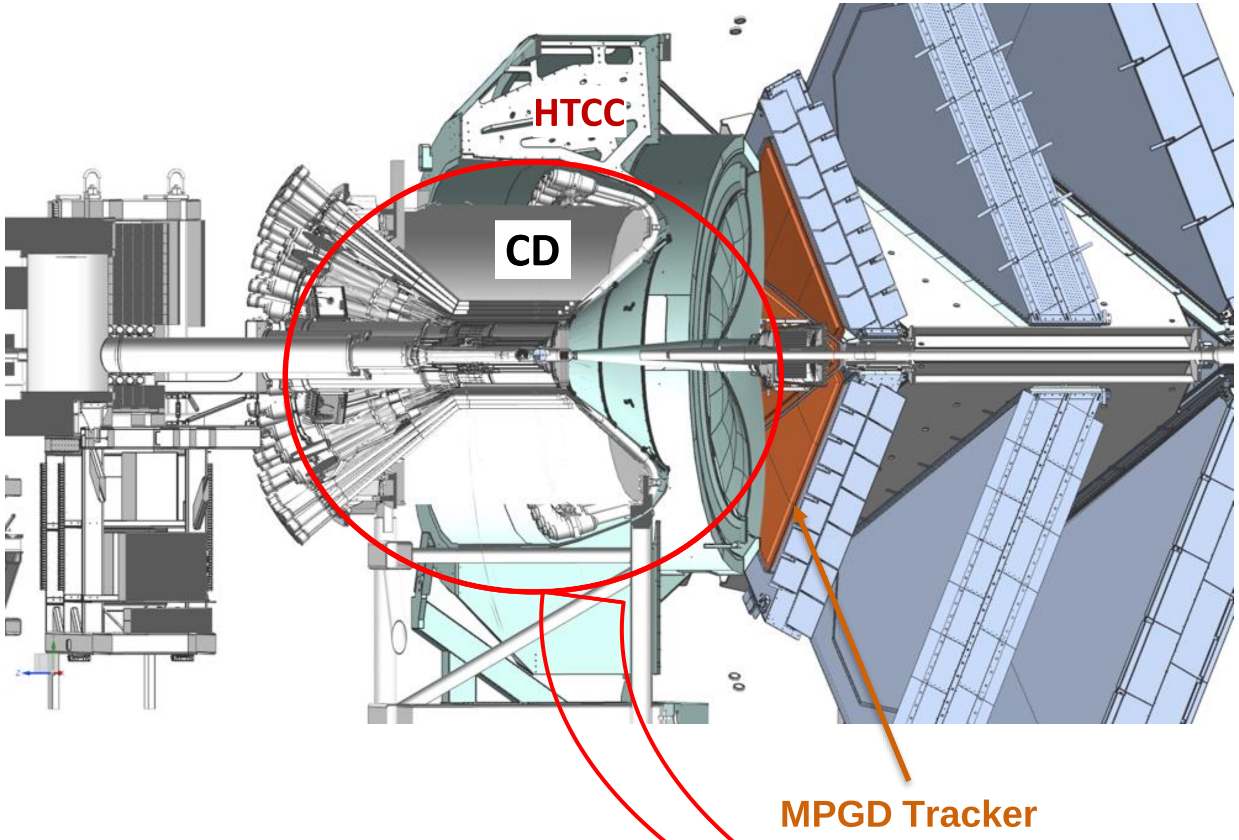


- Complete testing of the prototype, UVA-JLAB – *March 2023*.
- Investigating possible options for a twin-chamber detector. Studying options for light-weight detectors, INFN – *CY23*.
- Design, fabrication and testing of a full-scale module, *detector-0*, JLAB with help of UVA (design started) – *end of CY23*.
- Design of the front-end board based on VMM3 chip, JLAB.
- First boards ready to be used for the full-scale prototype – *end of CY23*.
- Testing of the full-scale prototype – *end of CY23 – beginning of CY24*.
- Refinement of the µRWELL module design based on the lessons learned with the full-scale prototype, JLAB – *beginning of CY24*.
- Start procurement of parts for the six-sector upgrade, JLAB – *before summer 2024*.
- Fabrication of detectors, JLAB – *CY25.*
- **Ready for installation in 2026.**

CLAS12 Luminosity Upgrade(s)

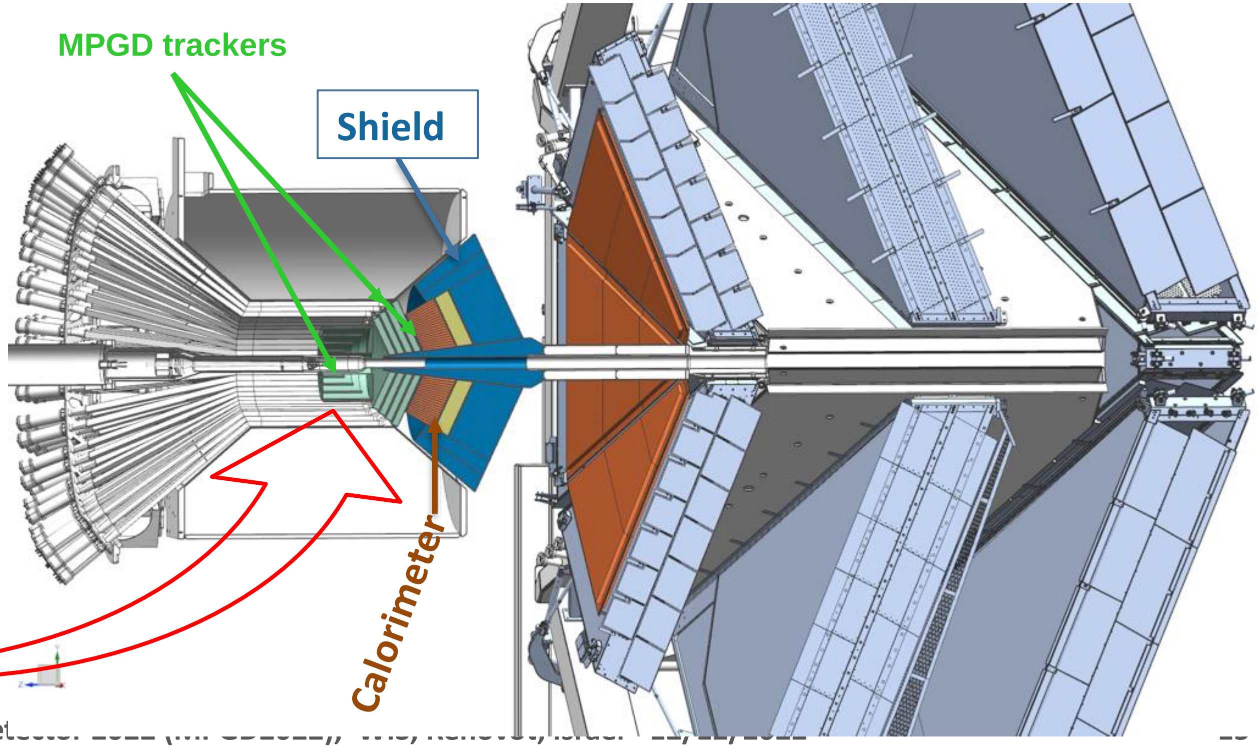
Phase I: @ Luminosity = 2×10^{35} cm^{-2} sec^{-1}

- First phase with only new trackers in the forward region
- 2 μRWELL layers in front of the Drift Chamber



Phase II: @ Luminosity > 10^{37} cm^{-2} sec^{-1}

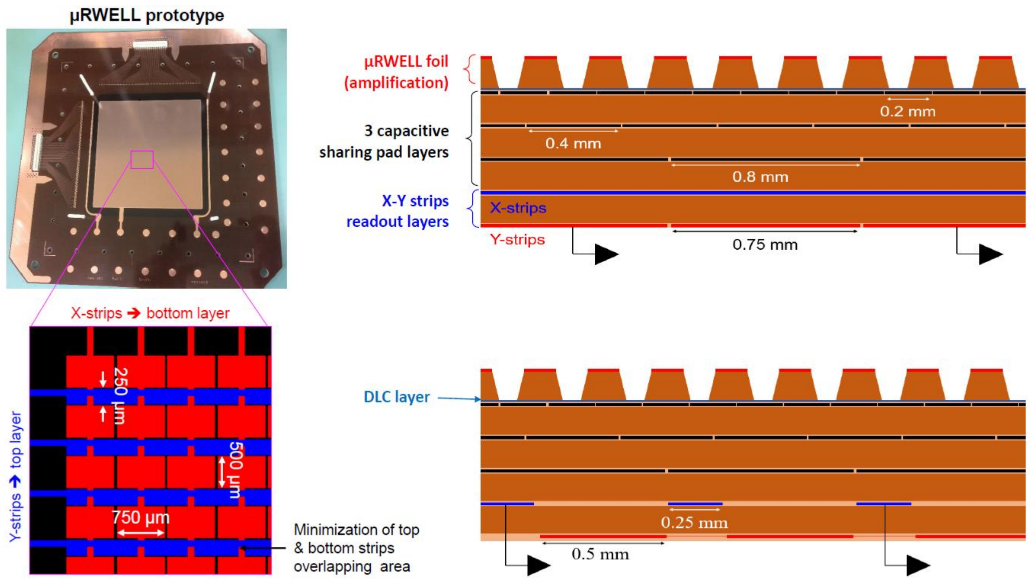
- New Moller cone that extends to larger polar angles, $\sim 7^o$;
- Shield forward detector from electromagnetic & hadronic background;
- New $PbWO_4$ calorimeter to cover 7^o to 30^o polar angles for electron and photon detection;
- High rate MPGD trackers in front of the calorimeter for vertexing and inside the solenoid for recoil tagging (with simple PID and CND?).



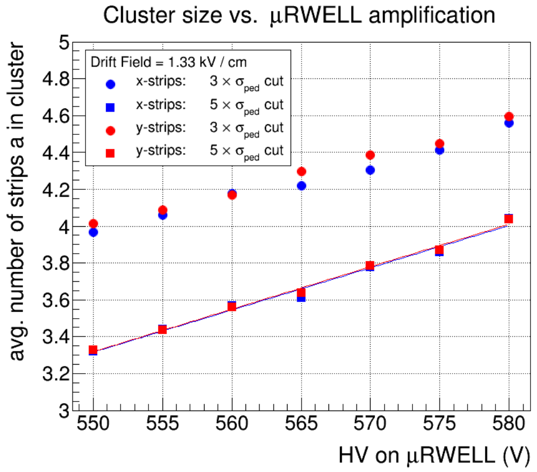
Ongoing µRWELL R&D efforts

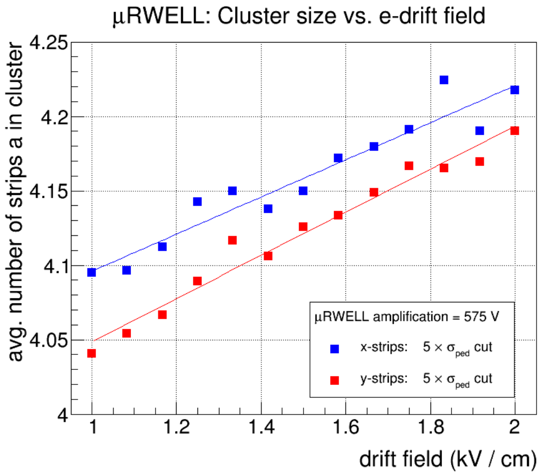
µRWELL with 2D capacitive-sharing strip readout

- 3-layer stack capacitive sharing strip readout ➔ black pads on the cross-section view
- X-strips and Y-strips on different layers separated by 50 µm. Kapton foil is not etched out between top and bottom strips ➔ Signal on top and bottom strip collected through capacitive coupling: **pitch = 800 µm**
- Average number of strips with hits ("cluster size") > **3** over a wide gain range
- Spatial resolution: residuals ~63 µm, resolution after corrections. $\boldsymbol{\sigma_{X(Y)}}$ **= ~61 µm**
- **Next:** Study large pitch / narrow strip performance for low input capacitance noise

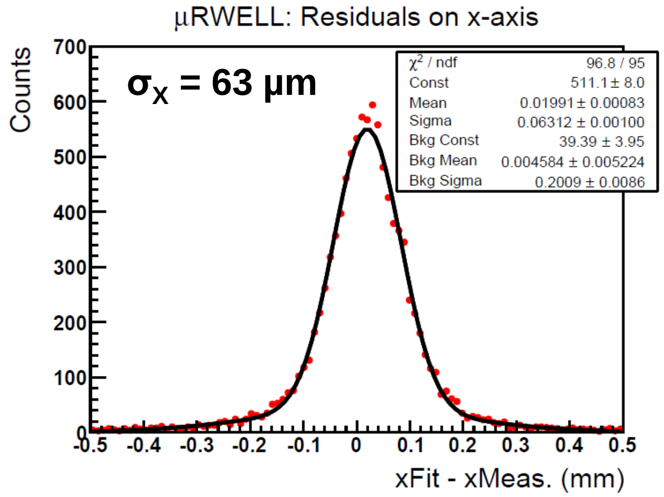


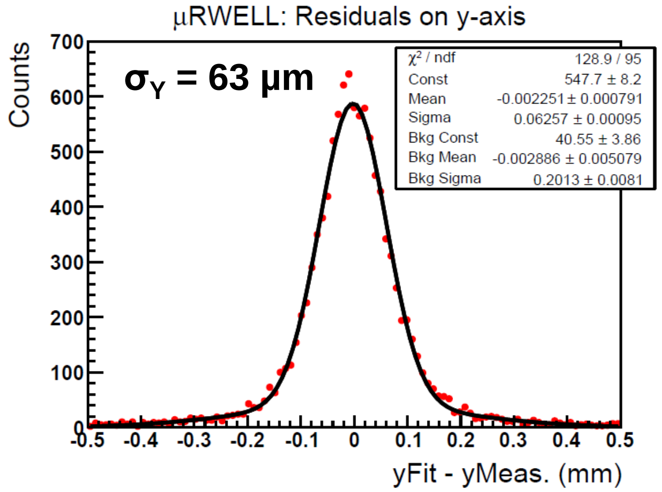
Average nb of strips per cluster vs. HV scan





Tracking residual distribution in x and y before track fit correction





K. Gnanvo et *al*. Nuclear Inst. and Methods in Physics Research, A 1047C (2023) 167782 https://doi.org/10.1016/j.nima.2022.167782

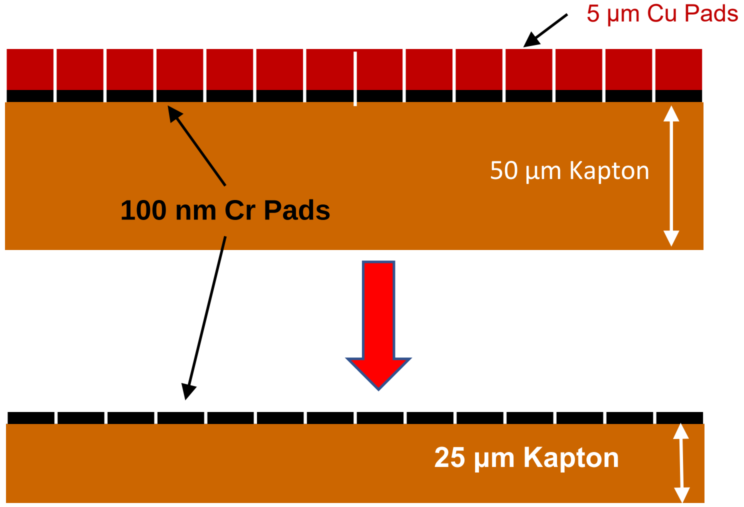
Ongoing µRWELL R&D efforts

Low-mass (Chromium-based) Cr-Capacitive-sharing readout:

- Replace 5 µm Cu-pad of by the residual 200 nm Chromium pads
  - Cr layer is part base material of the Cu-clad Kapton used for the capacitive-layers ➔ Cu is just chemically etched out
- Thin dielectric layer (12.5 µm Kapton + 12.5 µm glue) instead of 50 µm Kapton + 12.5 µm glue
- Readout strip ➔ Cu-strip ~0.1 mm / Cr-strip 1 mm
  - Narrow Cu-strip in the center of Cr-strip for electrical continuity
- Prototype under design in collaboration with Rui's team

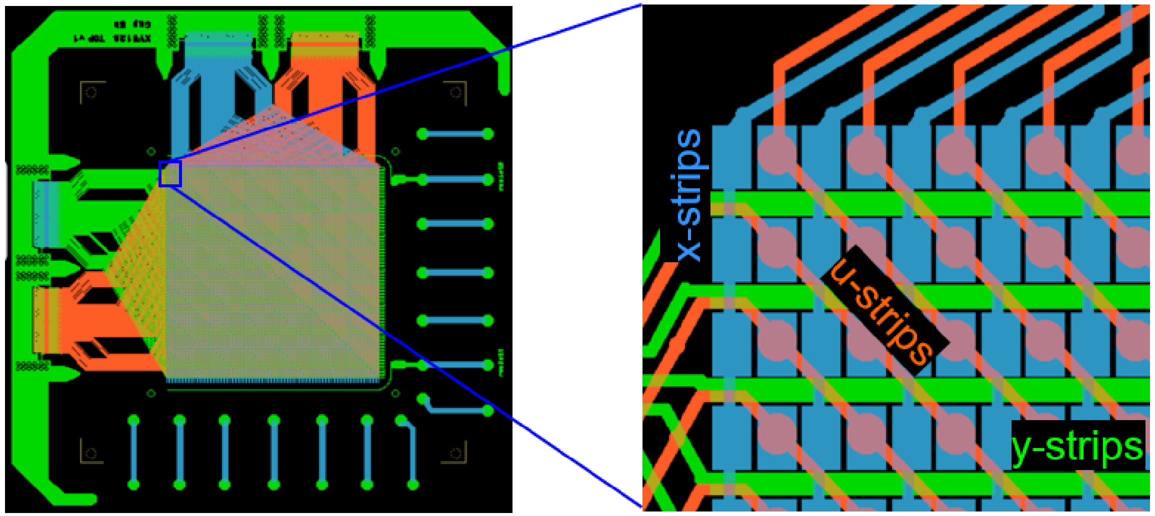
Standard Cu-pads foil
- 5 µm Cu and
- 50 µm Kapton
- 100 nm Cr in between

(Chromium) Cr-pads foil
- 5 µm Cu is removed
- 100 nm pads
- 25 µm Kapton



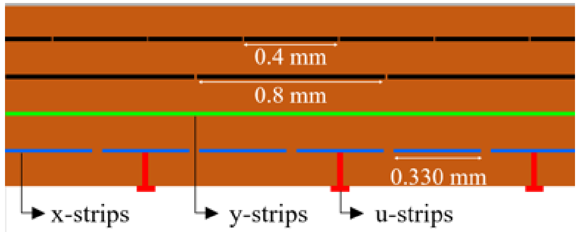
3-coordinates XYU-strip readout with capacitive-sharing

- Address multi-hits ambiguities in high rate and large area detectors
- Capacitive-sharing ➔ reduction of electronics channel number
- Will explore 3-layer strip instead of 2-layers Y-plane / XU-plane

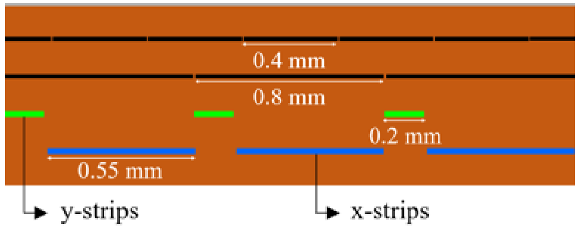


Gerber view of XYU-strip design

Zoomed view of XYU-strip design



cross-section view along horizontal axis

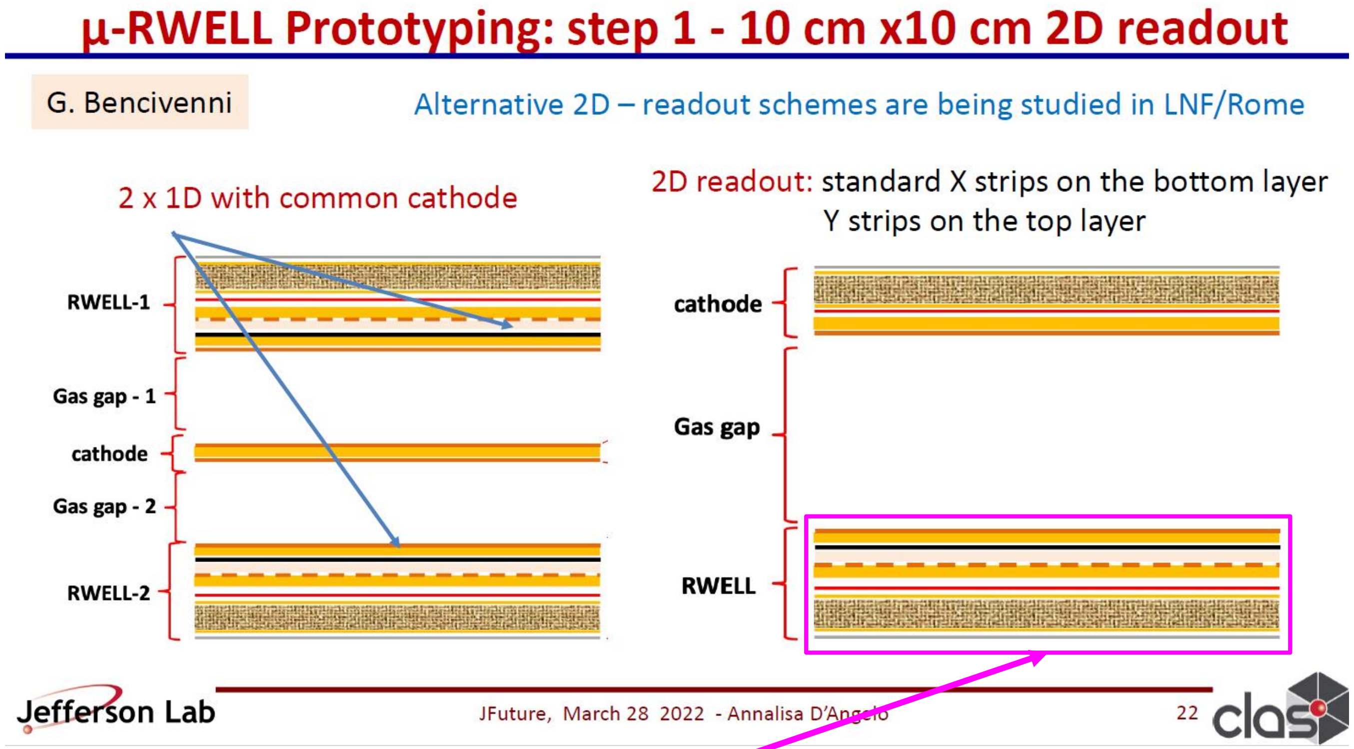


cross-section view along vertical axis

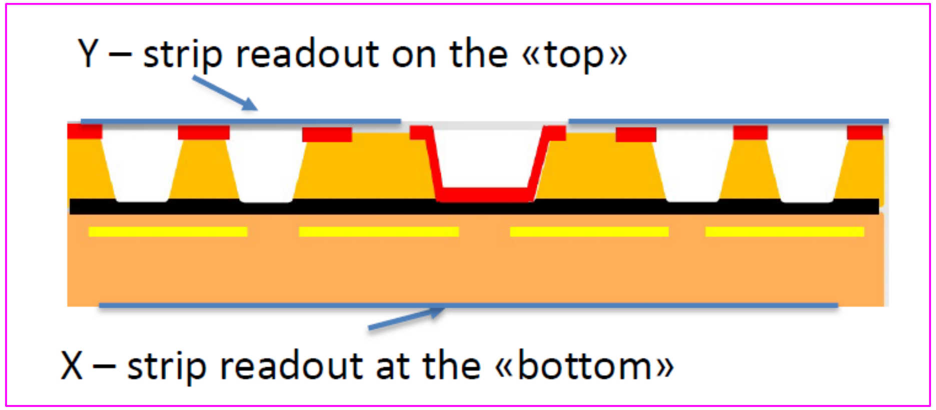
µRWELL R&D efforts

R&D effort @ Italy: Several INFN institutions & Universities

- ❖ Effort led by Annalisa D’Angelo (University of Rome Tor Vergata & INFN Rome Tor Vergata)
  - Effort involve **G. Bencivenni’s** group (INFN Frascati)
- ❖ Focus is to develop alternative to 2D capacitive-sharing strip readout.
- ❖ Two approaches under investigation:
  - **First option:** develop a single module with 2 × 1D µRWELL amplifications sharing the same drift cathode and gas volume, each µRWELL has 1D strip layer
  - **Second option:** develop one module with the µRWELL amplification segmented in strip (1 mm) configuration providing 1 D coordinate information, the second coordinate is provided by a stand 1D PCB readout
- ❖ Prototypes of the two approaches is under fabrication at Rui’s lab, will be tested in beam this October



µRWELL segmented in strips ➔ provide 1D coordinate



Courtesy Anna D’Angelo: Instrumentation for high luminosity upgrade of CLAS12, Messina, Italy, March 2022
https://indico.jlab.org/event/520/contributions/9444/attachments/7687/10751/DAngelo_Jfuture_2022.pdf

Summary

- Design of large µRWELL prototype for fast tracker for the CLAS12 Luminosity Upgrade
- The prototype will test capacitive-sharing U-V strip readout structure on large detectors
- Assembly and preliminary tests of the prototype just completed at CERN last week Dec 04, 2022
- The prototype will be tested in beam in the first quarter of 2025
- Largest µRWELL detector fabricated ➔ Lessons to be learned from operation in beam
- Designing of the full CLAS12 R1 sector (3 modules) has already started
- Ongoing R&D on small scale prototypes for the second phase of the CLAS12 Luminosity upgrade

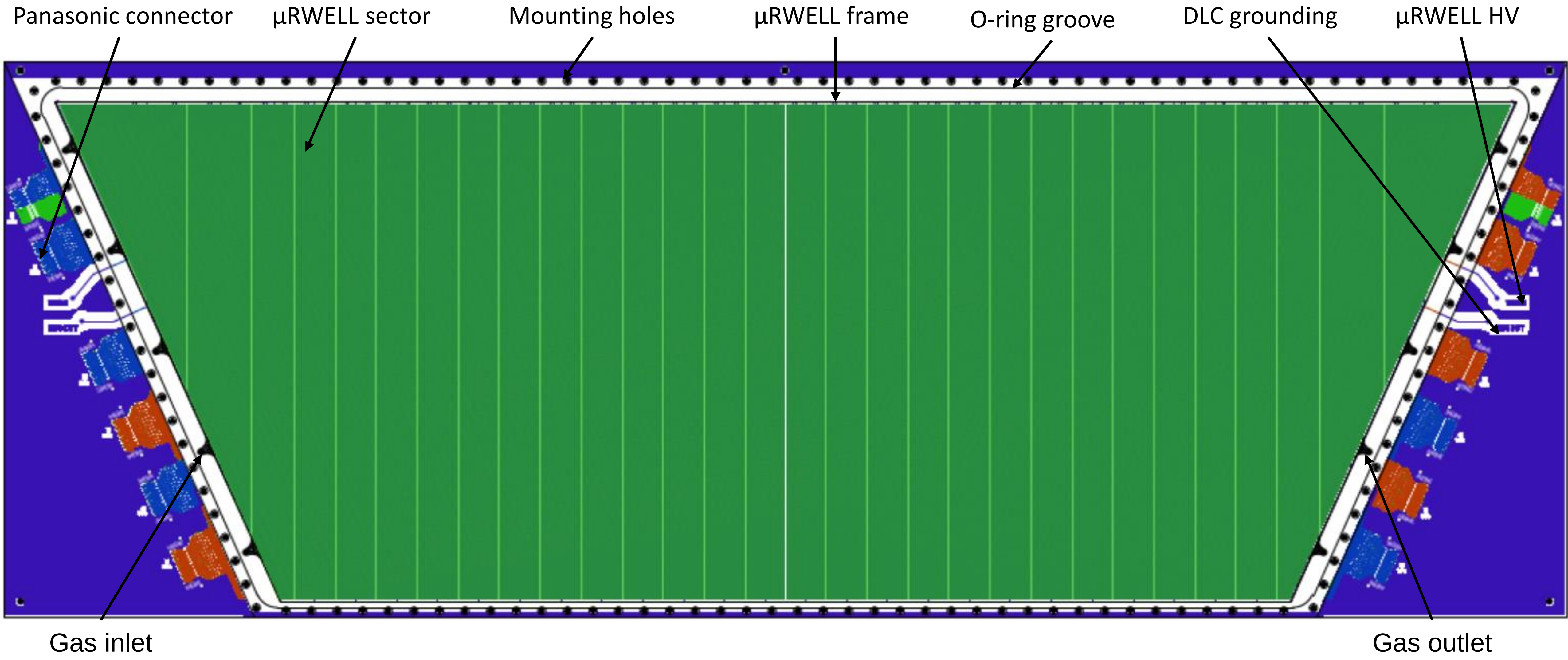
CLAS12 µRWELL Teams

- **JLab:**
  - Stepan Stepanyan, Florian Hauenstein, Rafael Paremuzyan … *(Hall B CLAS12 High Lumi)*
  - Kondo Gnanvo *(RDI Group)*
- **UVa:**
  - Nilanga Liyanage, Huong Nguyen, Salina Ali, Bhasitha Dharmasena, Vimukthi Gamage, Minh Dao …
- **INFN team:**
  - Anna D'Angelo, Mariangela Bondi, Raffaella De Vita, Gianni Bencivenni …

Backup

CLAS12 Luminosity Upgrade: Large µRWELL prototype

All layers & assembly parts together



CLAS12 Luminosity Upgrade(s): Motivations

Jefferson Lab Exploring the Nature of Matter

1. PRESENT: CLAS12 Performance

Improving the **performance** of CLAS12 in terms of

$\mathcal{L} \times \eta$ (luminosity x reconstruction efficiency)

will significantly **enhance the physics reach** of experiments in Hall B

- All CLAS12 proposals assumed $\mathcal{L} = 10^{35}$ cm^{-2}s^{-1}
  - RG-A /RG-B ran on a 5cm LH2/LD2 w
    - an average luminosity of $\mathcal{L}$
  - $\eta = 0.8$ for a single track
    - → 64% efficiency for two char
- **at present** experiments with 2-particles in the
- **AI – assisted tracking** has been developed to i
- **significant efforts** are underway to improve tra

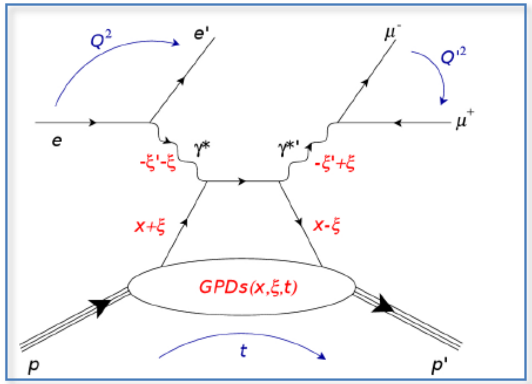
Jefferson Lab JFuture, March 28

2. FUTURE : Large scale CLAS12 Upgrade

It is **never too early** to think and to plan for the future

- Large scale upgrades need to start ≥ 5 years earlier
- New cutting edge physics is expected to surface after few years of CLAS12 running (e.g. physics program of CLAS12 have been seeded after few years of CLAS running)
- **CLAS12 can be very relevant** in several key areas of future physics at JLAB.

DDVCS



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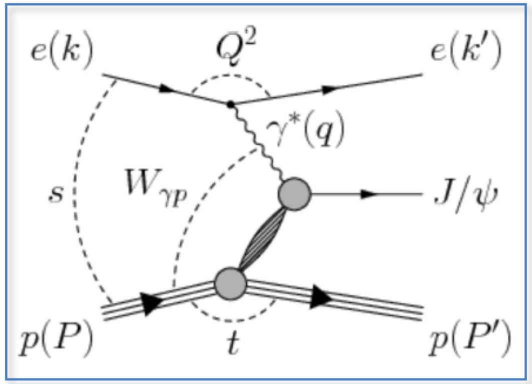
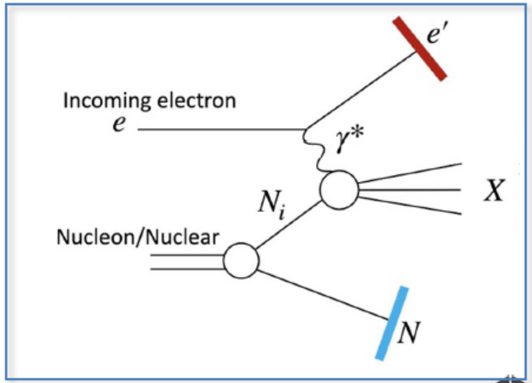


tagged-nuclear DIS



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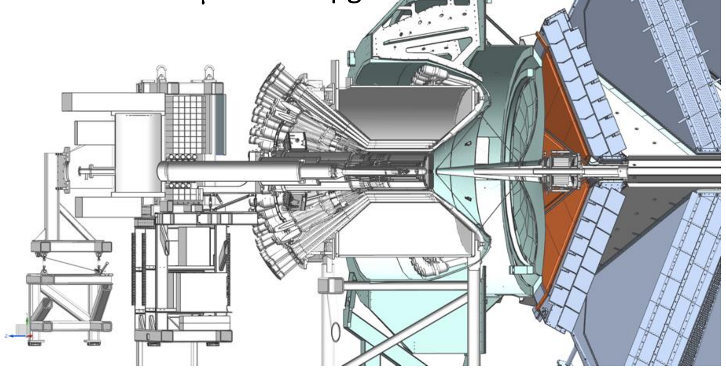
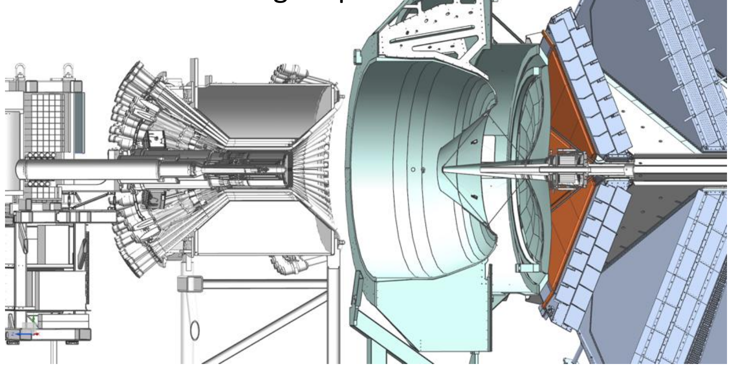
clas

CLAS12 High Luminosity Upgrade

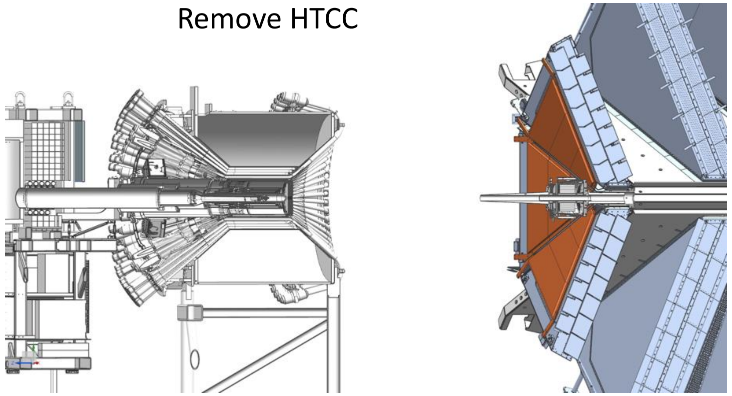
CLAS12 with μRWELL upgrade



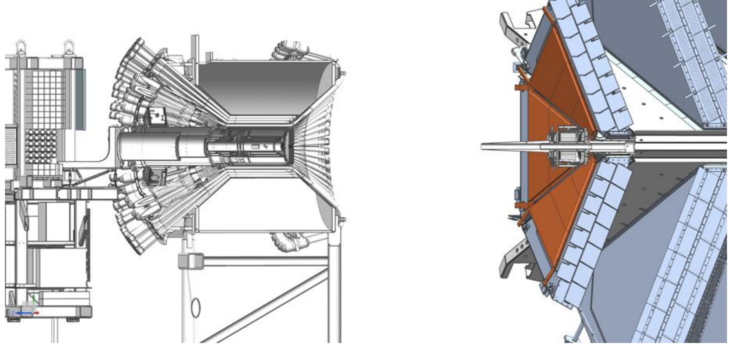
Move CD and the target upstream



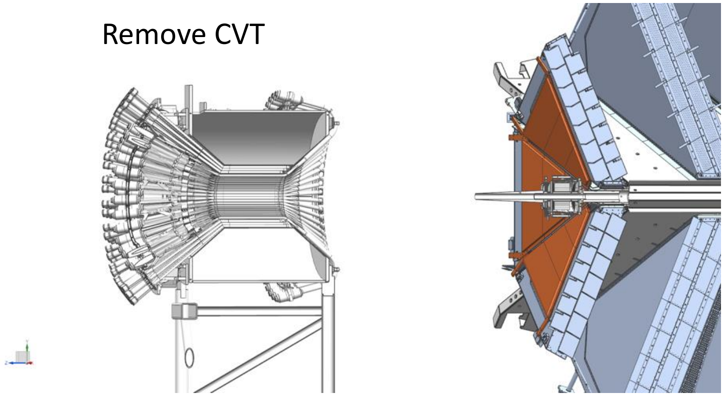
Remove HTCC



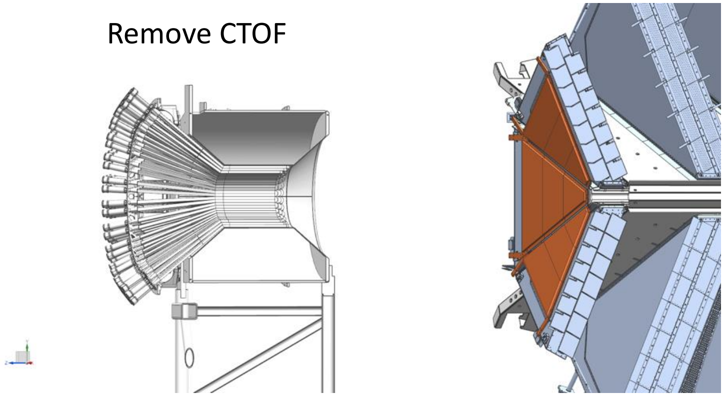
Remove target



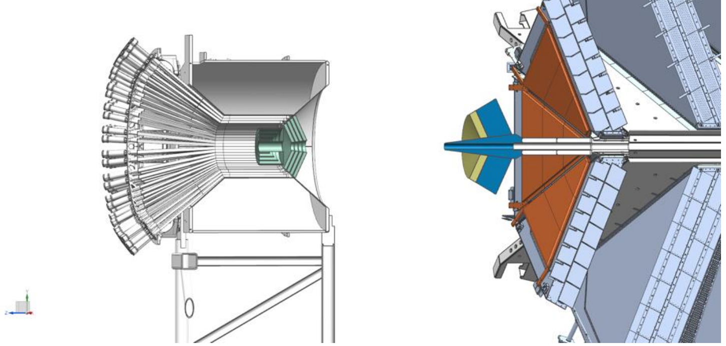
Remove CVT



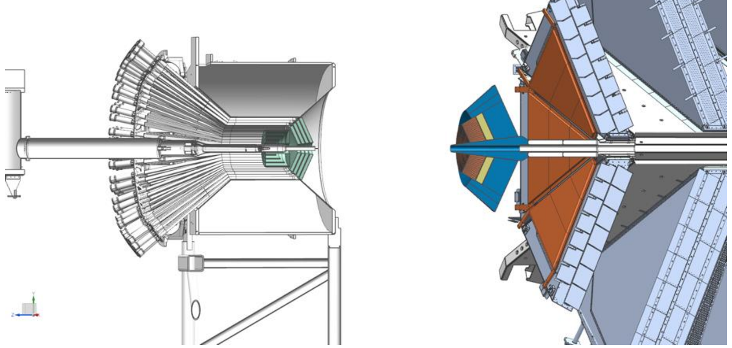
Remove CTOF



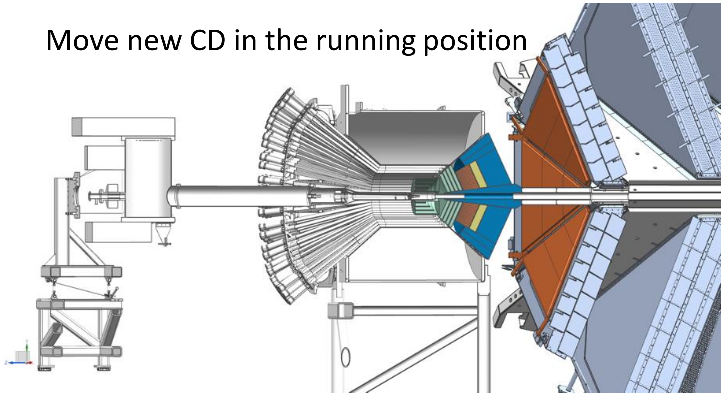
Install a new, high rate MPGD trackers



Install shield and a calorimeter in front of FD



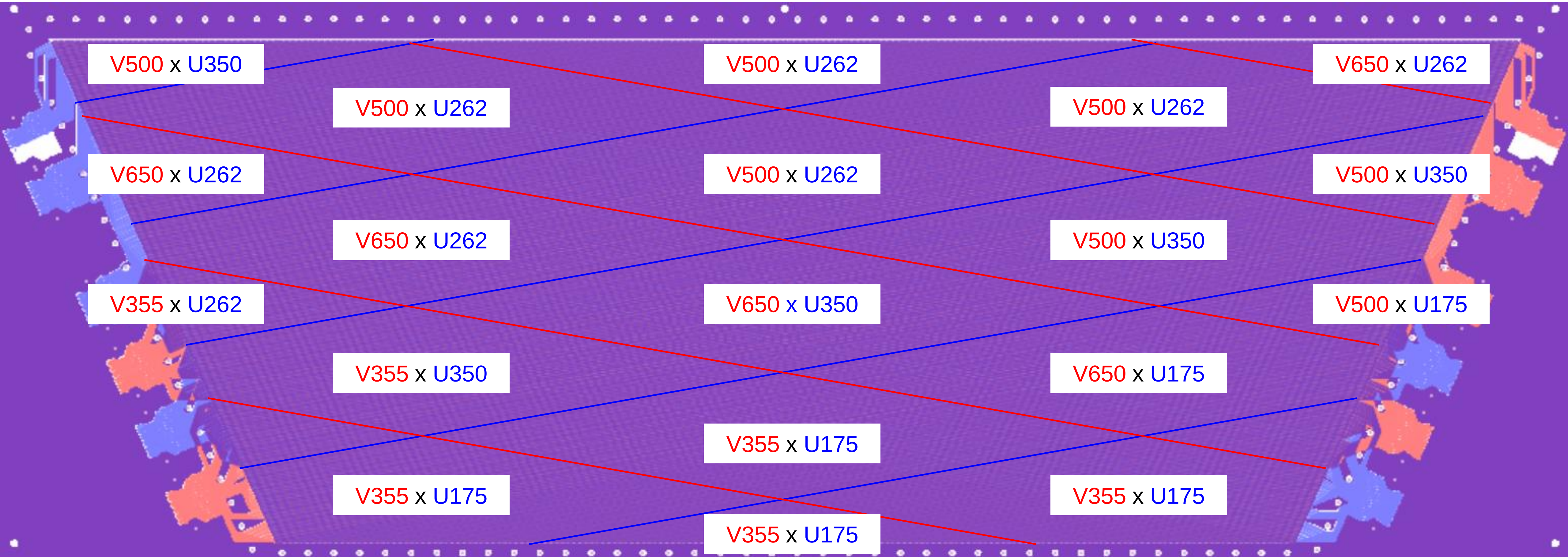
Move new CD in the running position



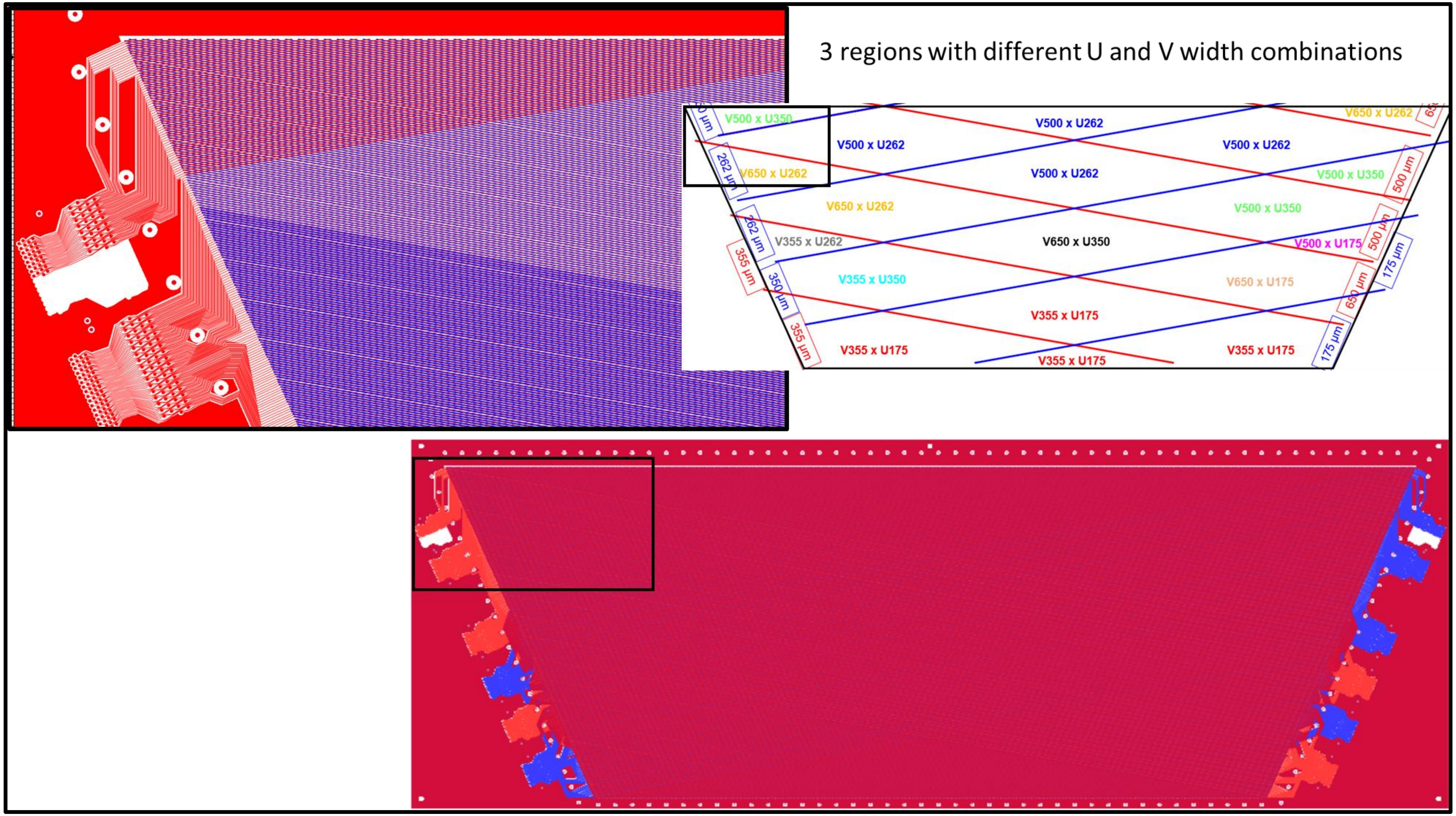
CLAS12 µRWELL: Design & construction of large prototype

Drawings:
- Salina Ali, UVa
- B. Mehl, CERN

Details on the distribution of the strip width in U (blue) and in V (red)



CLAS12 µRWELL: Prototype of largest module



CLAS12 µRWELL: Prototype of largest module