Instrumentation for high luminosity upgrade of CLAS12

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Jefferson Lab

clas

J-FUTURE

March 28, 2022 - March 30, 2022 • Messina, Italy

Outline:

- Need of the upgrade: CLAS12 performance and physics cases
- History: High-luminosity upgrade task force operation and outcome
- Stage 1 – DC tracking update to obtain x2 CLAS12 luminosity
- Stage 2 – x10 CLAS12 luminosity
- Outlook & conclusions

Motivation for high luminosity upgrade

1. PRESENT: CLAS12 Performance

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

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

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

- All CLAS12 proposals assumed $\mathcal{L} = 10^{35}$ $cm^{-2}s^{-1}$ and $\eta = 1$ for their projections
  - ➢ RG-A /RG-B ran on a 5cm LH2/LD2 with
    - an average luminosity of $\mathcal{L} = 0.7 \times 10^{35}$ $cm^{-2}s^{-1}$ A (nucleon target)
  - ➢ $\eta = 0.8$ for a single track
    - → 64% efficiency for two charged tracks, 50% for three charged tracks, ..
- **at present** experiments with 2-particles in the final state will get only ~40% of the expected statistics
- **AI – assisted tracking** has been developed to improve reconstruction efficiency
- **significant efforts** are underway to improve tracking detector hardware

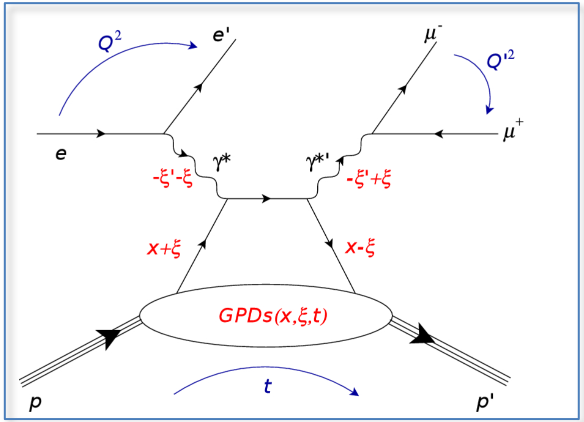
Motivation for high luminosity upgrade

2. FUTURE : Large scale CLAS12 Upgrade

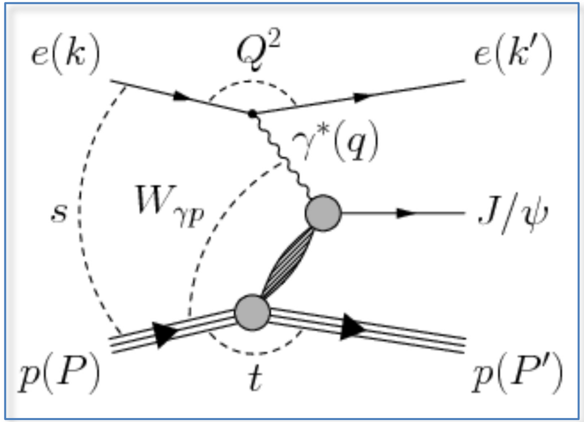
It is **never too early** to think and to plan for the future

- 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.

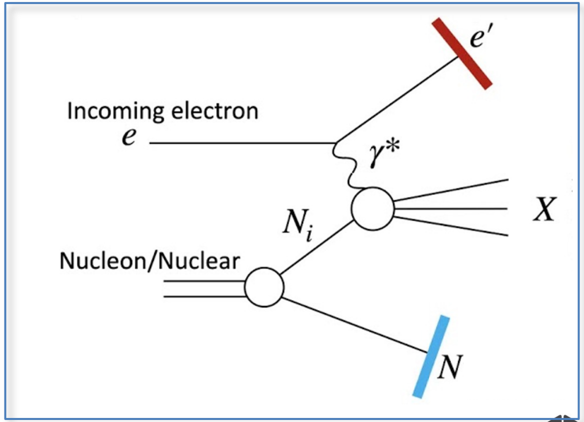
DDVCS



e-J/ψ



tagged-nuclear DIS



A bit of history

2012 - … CLAS12 luminosity upgrade goes back to days of CLAS12 construction

2016 **LOI12-16-004** for DDVCS and J/ψ electroproduction showing that running at $\mathcal{L} \geq 10^{37}$ cm^{-2} sec^{-1} is possible for μ-CLAS12

2019 Laboratory **agenda item** for Hall-B had to develop a strategy towards the most promising option for CLAS12 to achieve operations at higher luminosities

↓

A task-force (S. Stapanian PI, V. Burkert, L. Elouadrhiri, M. Mestayer, M. Ungaro, V. Ziegler) was organized to address this question.

2020 The **TF** proposed a **two-stage** upgrade ***CLAS12 Note 2020-006***

I. increase the luminosity by x2 with high reconstruction efficiency
II. proceed with >x10 increase

The High Luminosity Task Force

https://wiki.jlab.org/physdivwiki/index.php/Task_Forces_2020#tab=High_Luminosity

Task Forces 2020

Overview | Artificial Intel | High Luminosity | Trigger/DAQ

Goal

stage-1: Achieve luminosity of ~2x10E35 cm-2 sec-1 for CLAS12 normal running with charged particle recontruction efficiency of >85%.

stage-2: Configuration of CLAS12 for two orders of magnitude higher luminosities (10E37 cm-2 sec-1)

Charge

1. Assess the current CLAS12 luminosity and identify the limiting factors (tracker granularity, integration time, readout, …)
2. Assess existing tracking technologies identifying the most suitable to upgrade CLAS12 trackers
3. Quantify the expected improvement (luminosity, acceptance, resolution, efficiency) by mean of realistic MC simulations and using data collected in the current configuration
4. Define a work plan to test the proposed solution with a time chart and milestones for:
   1. on-beam tests in current config;
   2. required R&D (if any);
   3. prototyping
   4. full implementation
5. Estimate costs and identify resources needed in the different phases of the project
6. Evaluate synergies with other projects at the lab providing a list of shared resources and common goals

Members

- S. Stepanyan (PI)
- Y. Gotra
- M. Mestayer
- V. Burkert
- L. Elouadrhiri
- V. Ziegler
- M. Ungaro

Advisors

- Nilanga Liyanage
- Evaristo Cisbani
- Eric Fuchey

Meetings

- Remote meetings every other Mondays starting on April 6 end os September

Meeting On October 05 2020
Meeting On August 24 2020
Meeting On August 10 2020
Meeting On July 27 2020
Meeting On July 13 2020
Meeting On June 29 2020
Meeting On June 15 2020
Meeting On June 01 2020

Documentation

- Report -
  - PDF of the full report [1]
  - TF report 4-page summary [2]
  - Report to Hall-B, October 9
- Report to Hall-B, April 17, 2020 [3]
- Worklist for simulations [4]
- ECAL studies [5]
- FTOF/CTOF document [6]
- DAQ system upgrade plan pdf
- High beam current in Hall B

CLAS12 Upgrade for High Luminosity Operations

Task Force Report

Task Force group: S. Stepanyan (PI), V. Burkert, L. Elouadrhiri, M. Mestayer, M. Ungaro, V. Ziegler

Advisors: N. Liyanage, E. Cisbani, E Fuchey

Contributors: S. Boyarinov, D.S. Carman, V. Kubarovsky, E. Pasyuk, R. De Vita, M. Bondi, K. Gnanvo

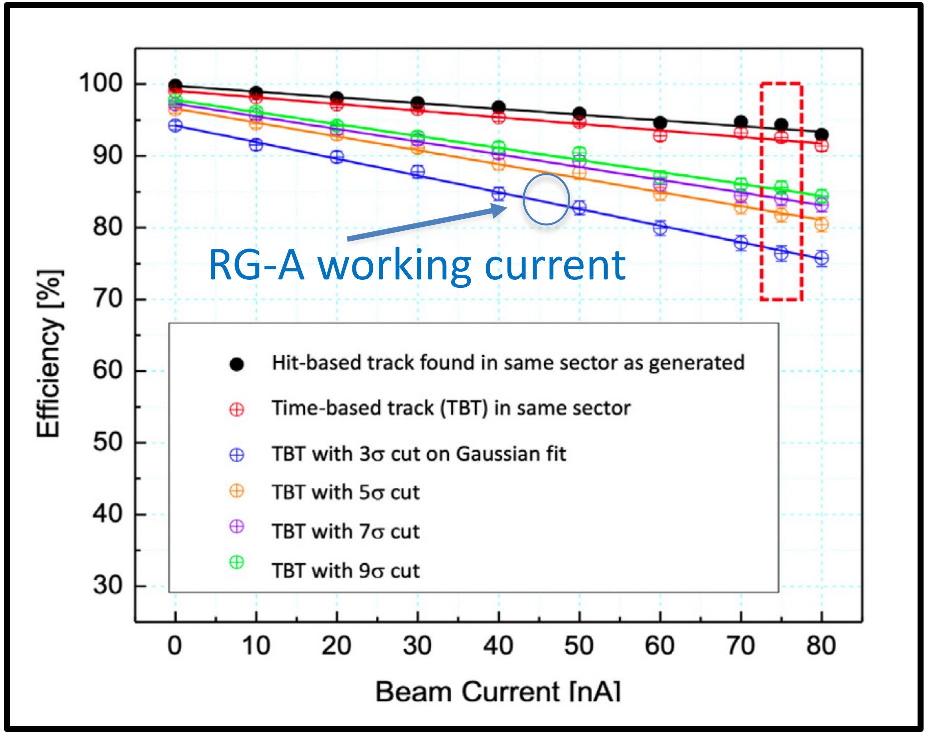
(Dated: October 8, 2020)

Improving the performance of CLAS12 in terms of $L \times \eta$ (luminosity times the reconstruction efficiency) will significantly enhance the physics reach of experiments in Hall B. In the proposal stage, experiments assumed operations at a luminosity of $L = 10^{35}$ cm^{-2}s^{-1} (the design luminosity of CLAS12) with a particle reconstruction efficiency of $\eta \simeq 1$. As it turns out, the reconstruction efficiency of charged particles (both in the Forward Detector and in the Central Detector) have a strong dependence on the luminosity and at the design luminosity is presently $\sim 75\% - 80\%$. This amounts to $> 35\%$ loss of the reconstructed events for two-prong final states. This higher than expected inefficiency has limited the operating luminosity on the LH_2 target, for example, to $\sim 0.6 \times 10^{35}$ cm^{-2}s^{-1}. It was also realized that with improved tracking detectors and track reconstruction algorithms, this inefficiency can be reduced significantly. Below is a report of the task force dedicated to study various options for improving the response of the CLAS12 detector for efficient operation at much higher luminosity than was originally proposed.

CLAS12 Note 2020-006

CLAS12 Luminosity - Detectors Limitations

Nominal CLAS12 luminosity $\mathcal{L} = 10^{35}\ cm^{-2}\ sec^{-1}$ is achieved on a 5 cm LH2 target at I_e = 75 nA



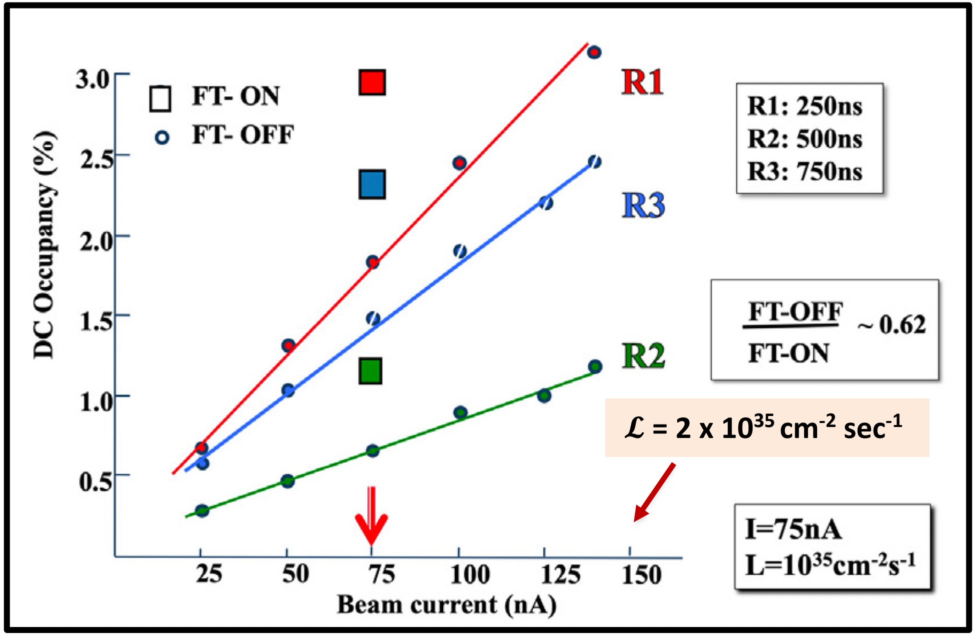
RG-A/RG-B limited the current on target to I_e = 45 nA to maximize the figure of merit $\mathcal{L} \times \eta$ for three-prongs events.

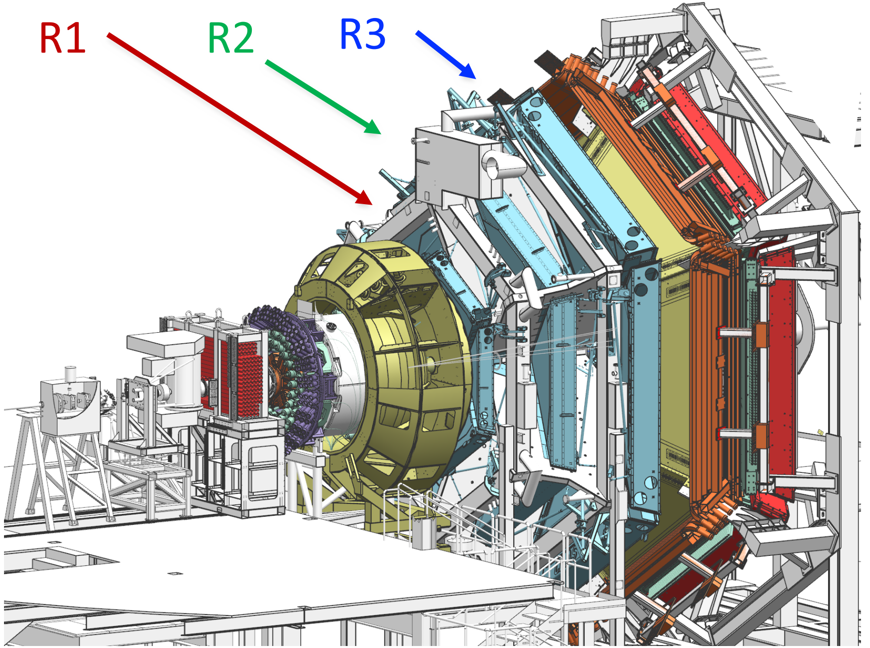
$\mathcal{L} = 0.7\ 10^{35}\ cm^{-2}s^{-1}$

$\eta_{3p} = 0.85^3 = 0.55$

CLAS12 Luminosity - Detectors Limitations

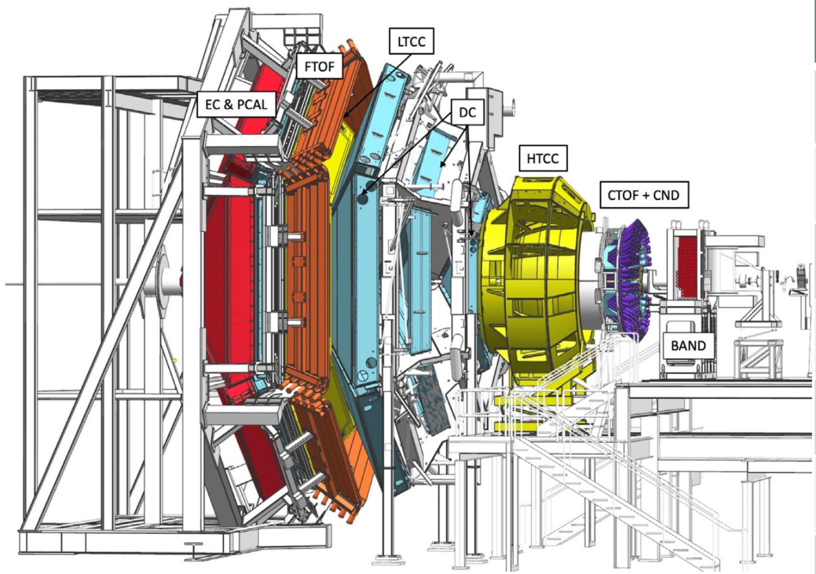
Main efficiency limitation is due to DC occupancy in R1





CLAS12 luminosity $\mathcal{L}$ **= 2 x 10^{35} cm^{-2} sec^{-1}** is achieved on a 5 cm LH2 target at **I_e = 150 nA**

CLAS12 x2 Luminosity - Detectors Limitations



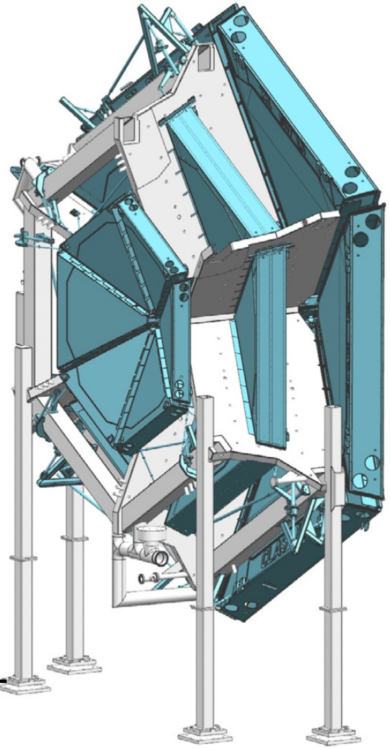
Detector	Upgrade limitation	$I_{max.}$ LH2 tgt	$I_{max.}$ LD2 tgt
FTOF	PM max rate 2 MHz	350 nA	200 nA
CTOF	PM max rate 0.5 MHz	200 nA	100 nA
Ecal/Pcal	PM stand x2 rate	≅ 150 nA	≅ 100 nA
HTCC	Low rates – no lim.	≅ 150 nA	≅ 100 nA
SVT/CVT	After align. no lim.	≅ 150 nA	≅ 100 nA
RICH	Low rates – no lim.	≅ 150 nA	≅ 100 nA
FT	No changes needed	≅ 150 nA	≅ 100 nA
Beamline	Beam dump upgrade	≅ 450 nA	≅ 450 nA

DAQ/trigger → replace some of the L1 hardware, TDCs, the readout of MVT, and need L3 trigger

- **Drift Chambers timing response** is *the limiting factor* for a x2 luminosity upgrade

CLAS12 x2 Luminosity - Detectors Limitations

DC – will need upgrades:



- ❑ more segmentation of HV system
  x2 more channels (replacement of old HV system started)

- ❑ possible improvements to the DC readout
  time-over-threshold (tests are in progress)

- ❑ replace or add new tracking planes to DC R1 (with MPGD tracker) – **major project**, R&D started

The CLAS12 Luminosity Upgrade

CLAS12 Luminosity Upgrade

Contents [hide]

Meetings (zoom meeting link: https://jlab-org.zoomgov.com/j/1613389022?pwd=UDBFaGJwVlhwQ0QxWFRHWFEyVTJCdz09, passcode 308283)

March 24 2022

March 10 2022

February 24 2022

February 10 2022

January 27 2022

January 13 2022

2021 Meetings

The **CLAS12 Luminosity Upgrade Working Group** meets every 2 weeks.

Supporting documents

- Kondo's seminar [[1]]
- Prototype design parameters [[2]]

Other Links

- uWell design meetings

Old pages

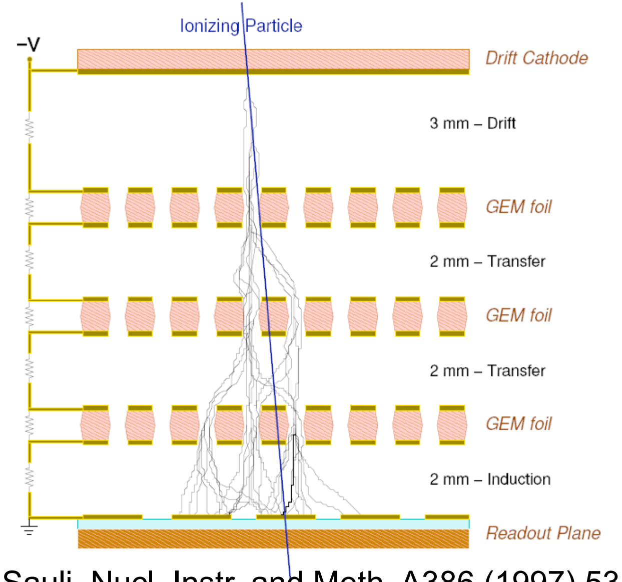
High Luminosity Task-force wiki .

https://clasweb.jlab.org/wiki/index.php/CLAS12_Luminosity_Upgrade

The CLAS12 DC TRACKING UPGRADE

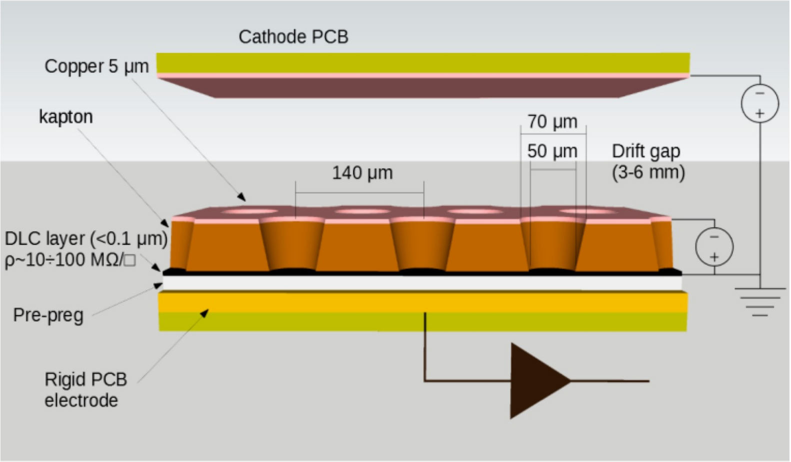
Two MPGD detector technologies have been discussed, triple-GEM and μ-RWELL

- Large area triple-GEM detectors have been used in experiments (PRad, SBS, …).



F. Sauli, Nucl. Instr. and Meth. A386 (1997) 531

- μ-RWELL technology is new, only small prototypes have been tested:
  → will require extensive R&D.
- μ-RWELL detector is best suited for CLAS12:
  – low material budget, easy to build, less support structures in the active volume of the detector.



G. Bencivenni et al.; 2015_JINST_10_P02008

The μ-RWELL

The device is composed of two elements:

- μ-RWELL_PCB
- drift/cathode PCB defining the gas gap

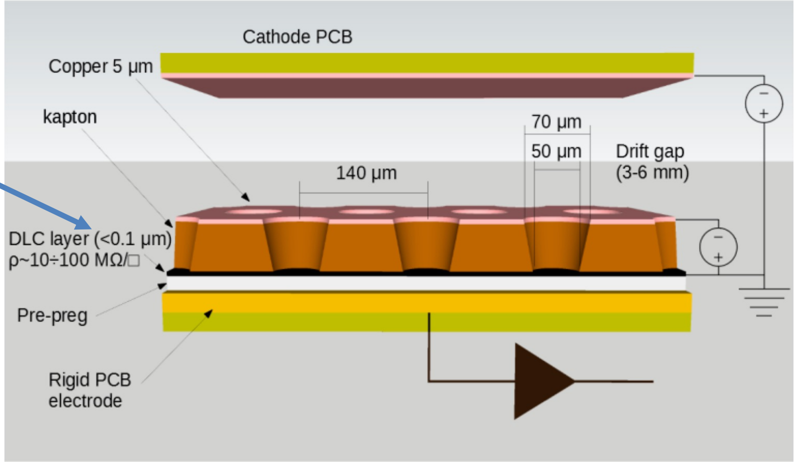
μ-RWELL_PCB = GEM like amplification-stage ⊕ resistive film ⊕ readout PCB

Resistive stage → 50 μm thick Apical® foil

✓ DLC film sputtered on one side

✓ 5 μm thick Cu layer on the other side the

The DLC (Diamond-like coating) resistivity, typically 10÷100 MΩ/□, is parametrized as a function of the DLC thickness, can reach a uniformity at level of ± 30% on large foils, 1.2x 0.6 m2.



G. Bencivenni et al.; 2015_JINST_10_P02008

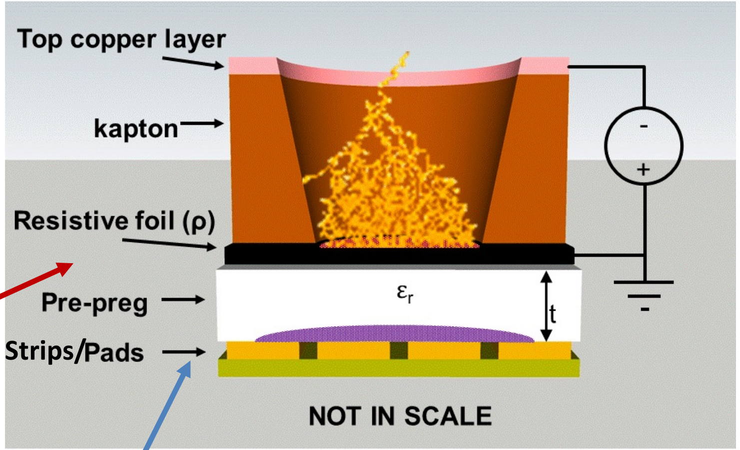
The μ-RWELL principle of operation

The “WELL” acts as a multiplication channel for the ionization produced in the gas of the drift gap

The charge induced on the resistive layer is spread with a time constant,

$$\tau \sim \rho \times C$$

[M.S. Dixit et al., NIMA 566 (2006) 281]:



$\rho \rightarrow$ the DLC surface resistivity

$C \rightarrow$ the capacitance per unit area, depending on the distance between the DLC and the readout plane $C = \varepsilon_0 \times \varepsilon_r \times \frac{S}{t} = 70\, pF \times L(m) - w{=}0.2\, mm,\ \ p{=}0.4\, mm$

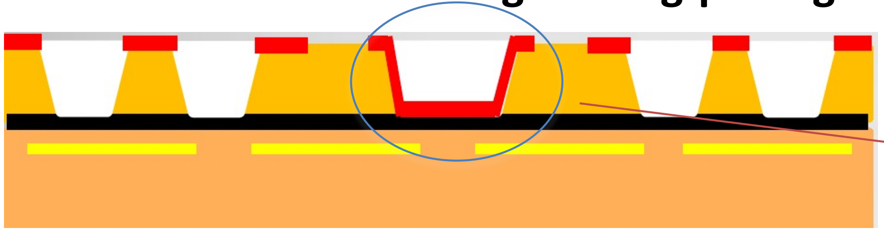
- The resistive stage ensures the quenching of the spark amplitude
- As a *drawback,* the capability to stand high particle fluxes is reduced, but appropriate grounding schemes of the resistive layer solves this problem

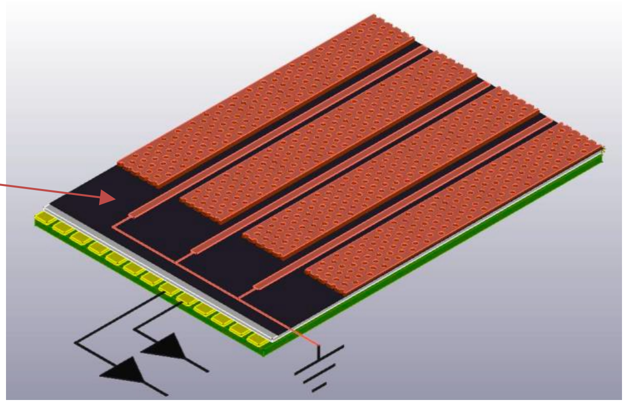
The High-Rate solution

The solution is to reduce as much as possible the current path towards the ground connection introducing a high density "grounding network" on the resistive stage of the detector

The micro-RWELL layouts for high particle rate, G.Bencivenni et al., 2019-JINST-14-P05014

GPEP – Groove-Patterning-Etching-plating





grid-like grounding from the top mesh

A small dead zone on the amplification stage must be introduced for high stability operation

The grounding grid of the DLC is patterned by **etching a groove** in the **base material from the top avoiding alignment problems between bottom/top patterned layouts**

The pitch of the grid lines can be less than 1cm.

The μ-RWELL features & performances

The μ-RWELL exhibits several interesting features:

- Compactness
- Easy assembly
- Easy powering
- Intrinsic spark quenching

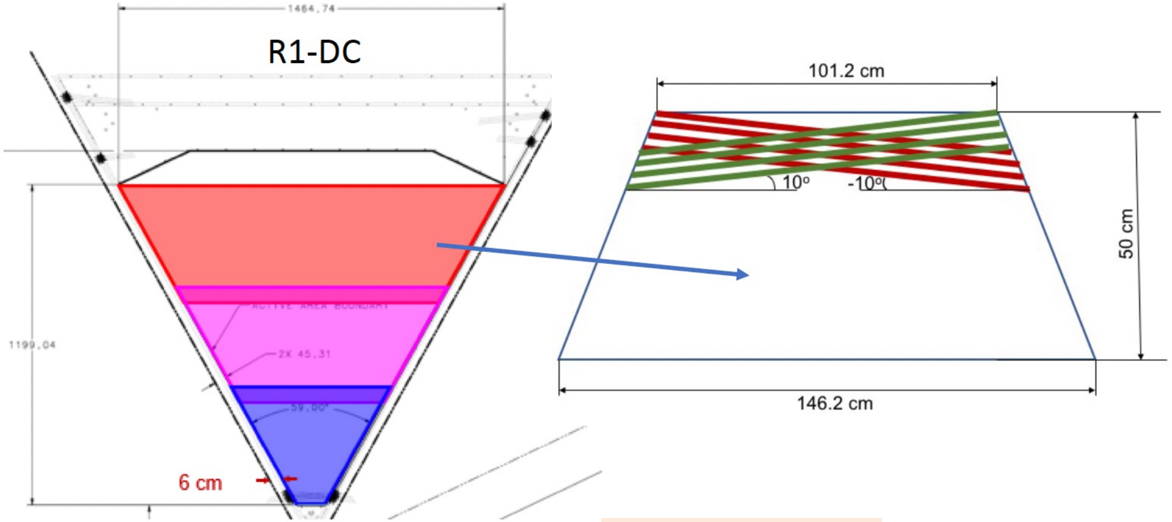
μ-RWELL performances:

- Gas gain → 10^4
- Rate capability HR version →10 MHz/cm2
- Spatial resolution → down to 60 μm
- Time resolution → 5-6 ns

Fast time response and high spatial resolution make this detector **suitable** for the high luminosity upgrade.

μ-RWELL Prototyping

- The DC-R1 active area is a trapezoid with a height of 151 cm, a large base of 146.2 cm, and a small base of 10.4 cm
- With available foil sizes for MPGD detectors, such an area cannot be covered with a single foil. The whole module can be constructed from three sections
- The largest of the three sections will be prototyped as part of the initial R&D. The readout will be based on APV25 chip, currently used in many GEM detectors. Exploring newer chips (SAMPA and VMM3) for the main detector.



S. Stepanian

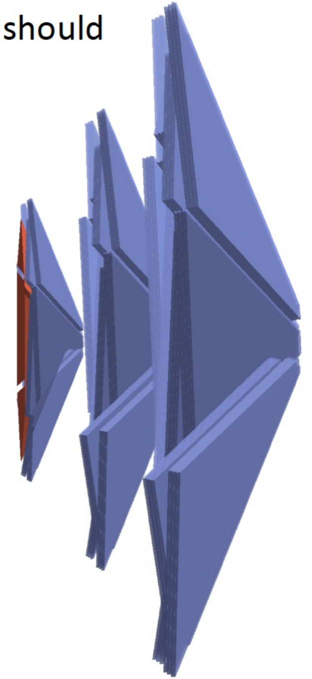
- The largest segment is a trapezoid with a large base of 146.2 cm, the height of the chamber will be 50 cm, the small base of 101.2 cm
- The readout concept is U-V strips with ±10° stereo angles relative to the base of the trapezoid, strips traced on two sides of the readout plane will be used.
- The charge share will be through capacitive coupling. The pitch size of the readout 0.8 mm, the strip width 0.4 mm.
- The total number of U&V readout strips is about 685.

Initial performance studies with GEMC

- Momentum reconstruction accuracy with MPGD tracking layers upstream of the R1 DC were studies by increasing material thickness of DC volume by 2% (assuming 4 modules of MPGD detectors)
- No degradation in the momentum or angular resolutions have been observed, only slight worsening of the vertex resolution
- More studies are underway with fully implemented μRWELL detectors in GEMC and in the tracking - should understand how many detectors will be needed for efficient running at high luminosities

	Quantity	Thickness μm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Al	1	3	2.7	89	1	0.0034	0.0008
μRWELL							
Copper	1	3.2	8.96	14.3	0.8	0.0179	0.0023
Kapton	1	50	1.42	286	0.8	0.0140	0.0057
G10 total							
G10	3	100	1.7	194	1.008	0.1559	0.0514
Readout							
Copper	2	5.8	8.96	14.3	1	0.0811	0.0104
Kapton	5	50	1.42	286	1	0.0874	0.0355
NoFlu glue	6	50	1.5	200	1	0.1500	0.0450
Gas							
70Ar30CO2)	1	4000	1.84E-03	141270	1	0.0028	0.0007
					Total	**0.530**	**0.159**

GEMC: pair of μRWELL detectors in front of R1 DC. This arrangement will require moving HTCC and CD upstream by about 10 cm



μ-RWELL Prototyping: step 1. 10 cm x10 cm 2D readout

Objective: ***Study the capacitive sharing – gain, efficiency, cluster size and spatial resolution***

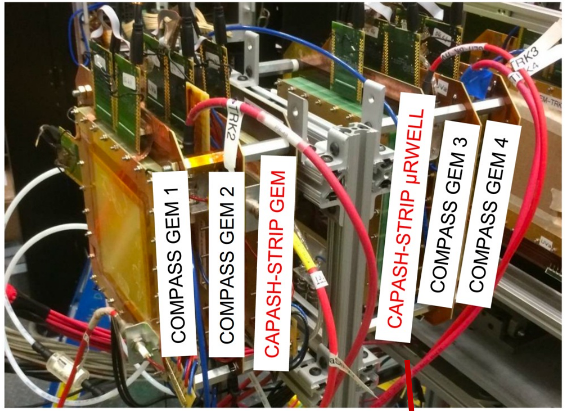
K. Gnanvo

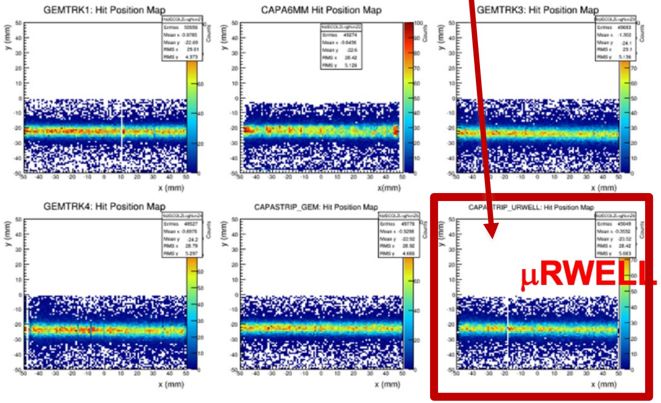
Beam test setup in Hall D:

- Hall D pair spectrometer: 3 -6 GeV clean electron beam
- 2 capacitive sharing readout, X-Y (μRWELL & GEM) & 4 X-Y COMPASS GEMs for precise tracking
- Standard APV25-SRS readout with standard DATE and amoreSRSDAQ
- All detectors run with Ar-CO2 (80/20)
- HV on μRWELL from 550 V to 580 V

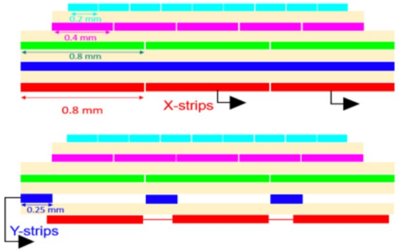
Capacitive-sharing X-Y μRWELL prototype:

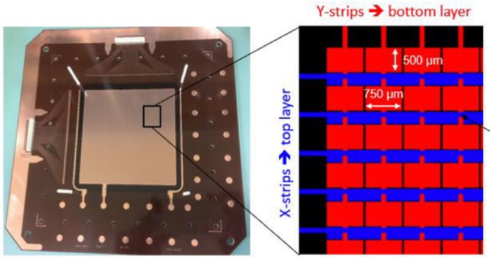
- HV scan for the field in the ionization / drift region
- HV scan for μRWELL amplification





Pitch 800μm, x-strip 250μm, y-strip 750μm



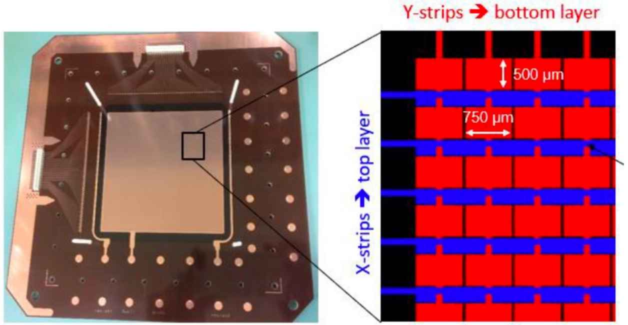


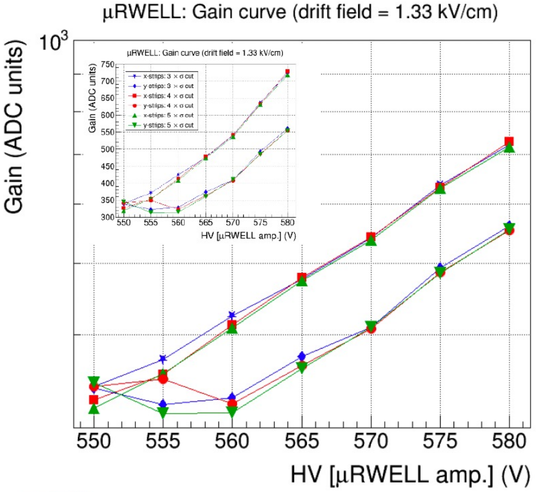
μ-RWELL Prototyping: step 1. 10 cm x10 cm 2D readout

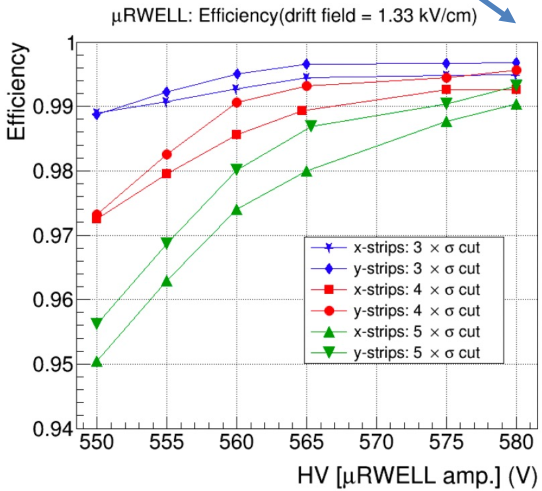
K. Gnanvo

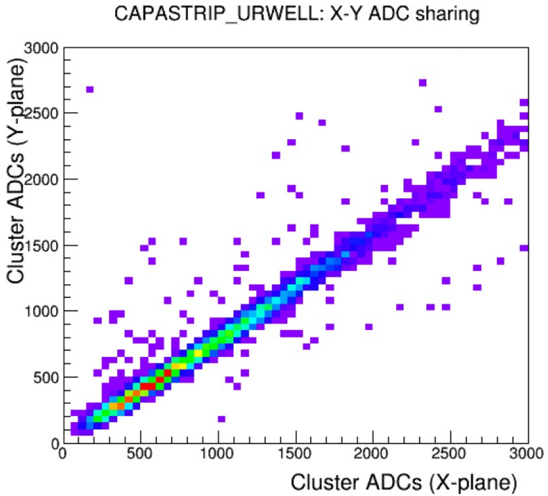
Capacitive-sharing X-Y μRWELL proto: with Ar-CO2 (80/20)

- HV on μRWELL (amplification) from 550 V to 580 V ➔ very stable operation in all HV settings
  - Did not go higher because the signal on APV was already large enough
  - Did not go lower than 540 V to not waste beam time
- Efficiency > 95% for 550 V and > 99% for 580 even at 5 × σ pedestal cut
  - Minimum 2-hit cluster requirements for a good event
- X/Y charge sharing ratio: ~ 0.55 / 0.45 ➔ mostly due to relative strip width

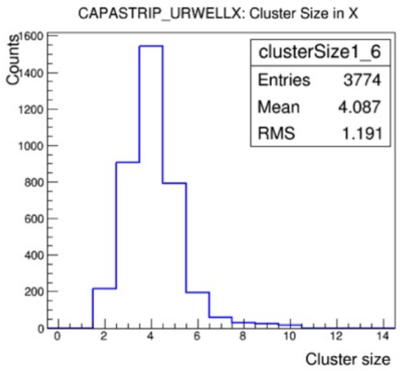


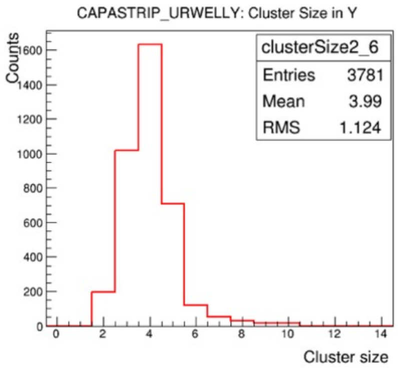






μ-RWELL Prototyping: step 1. 10 cm x10 cm 2D readout

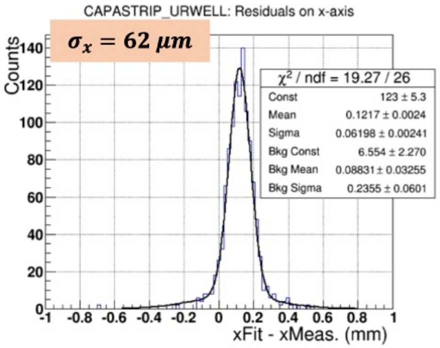


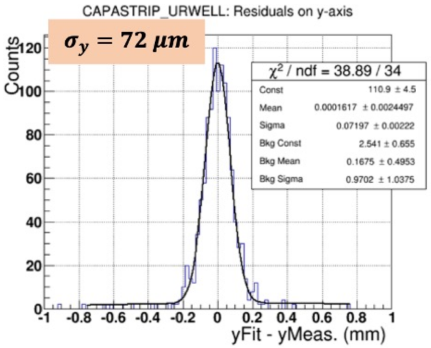


Even at lower gain when the signal is significantly reduced (specially for y-strips) cluster size is still large. (> 3 @ 550 V)

K. Gnanvo

XY Residuals are calculated with respect to COMPASS GEMs used for the tracking





Capacitive sharing allows for 60-70 μm resolution, starting from 800 μm strip

↓

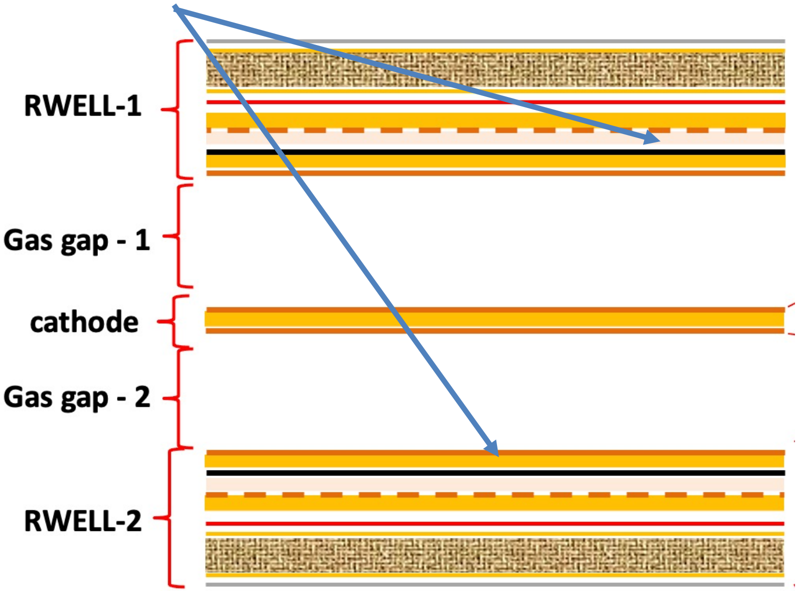
Electronic read-out channels minimized

μ-RWELL Prototyping: step 1 - 10 cm x10 cm 2D readout

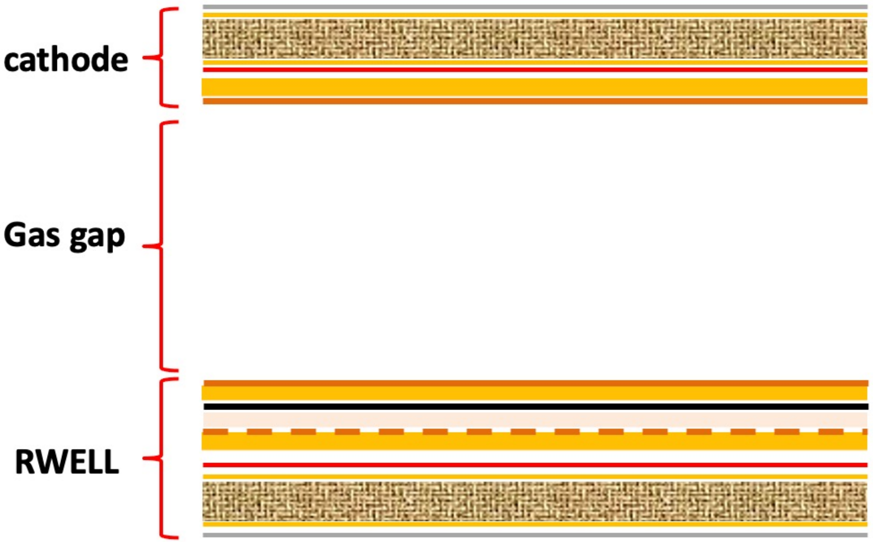
G. Bencivenni

Alternative 2D – readout schemes are being studied in LNF/Rome

2 x 1D with common cathode

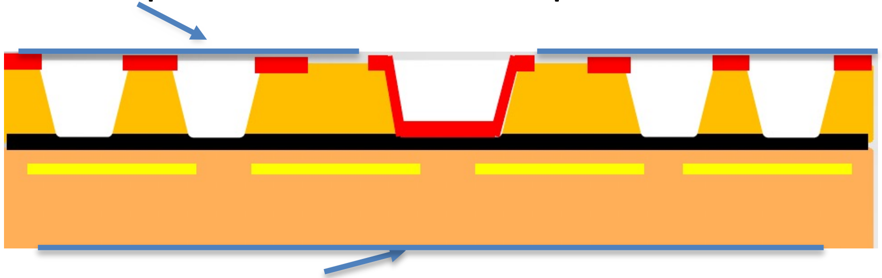


2D readout: standard X strips on the bottom layer
Y strips on the top layer



μ-RWELL Prototyping: step 1 - 10 cm x10 cm 2D readout

Y – strip readout on the «top»



X – strip readout at the «bottom»

G. Bencivenni

2D readout:

X strip are collected in a standard way at the bottom layer

Y strips are collected on the top layer

No charge capacitive sharing concept is applied

The prototype is being designed and will be studied against couples of 1D detector in X-Y configuration.

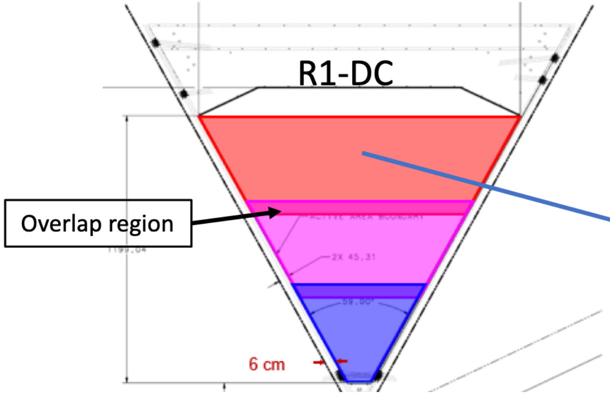
Detectors prototypes will be tested @ CERN test beam run in fall 2022

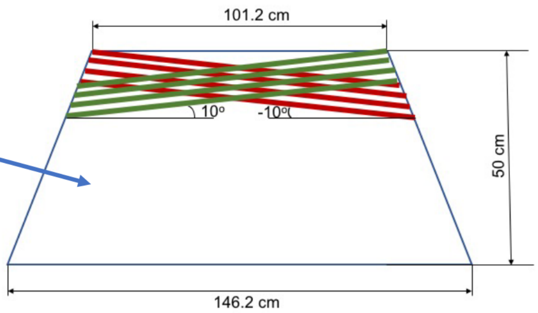
μ-RWELL Prototyping: step 2 Largest segment of R1

Objective: ***Study the capacitive sharing readout for long strips. Determine the gain, efficiency, cluster size, and the spatial and time resolution of the detector***

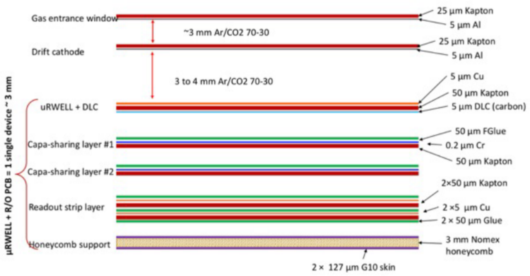
Requirements: $\sigma_s < 100\mu m$, $\Delta t \lesssim 10\ ns$, $eff > 95\%$

- The readout concept is U-V strips with ±10° stereo angles relative to the base of the trapezoid, strips traced on both sides of the readout plane. The charge share will be through capacitive coupling.
- Will use Aluminized mylar, 6 μm, for gas entrance window and drift cathode to lower the material budget
- Minimize the width and the thickness (tbd) of the support frame in the active area of the module (overlap region)
- Performance studies with cosmic muons and with the beam (in Hall-D using PS or Hall-B downstream of the R3) **in 2022**





low material budget detector



μ-RWELL Prototyping: following steps of the R&D

Following steps

2023

3. Small-size prototype, 10x10 cm2, high rate
4. Small-size prototype, 10x10 cm2, with 200 nm chromium pads instead of 5 μm Cu

Objective: ***Study the performance of a detectors for high rate, low material budget. Determine the gain, efficiency, cluster size, and the spatial and time resolution of the detector.***

6. A large prototype (~100x50 cm^2) of a "twin" chamber

Objective: ***Study the performance of a detector with the single layer readout, U and V on both sides of the honeycomb support. An alternative to the capacitive sharing readout. Determine the gain, efficiency, cluster size, and the spatial and time resolution of the detector.***

7. if #3 and #4 are successful, build another version of #2 with chromium pads and without honeycomb

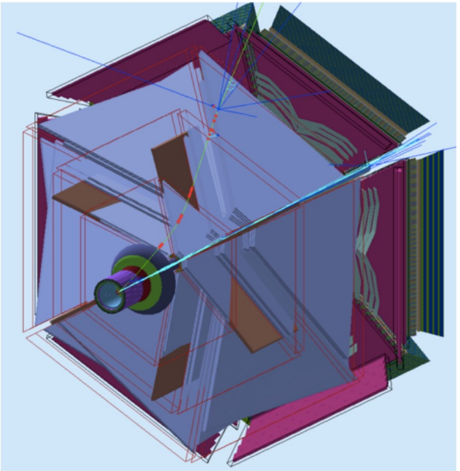
Objective: ***Study the performance of the lightest possible detector. Determine the gain, efficiency, cluster size, and the spatial and time resolution of the detector.***

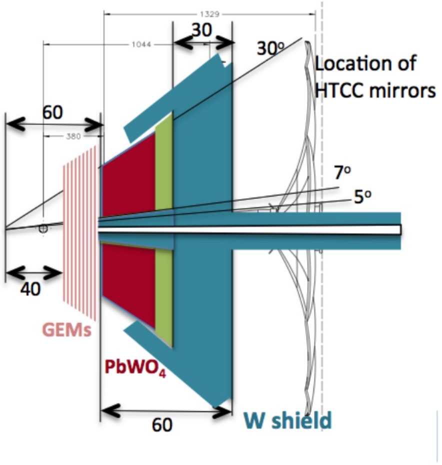
Stage 2 – CLAS12 x10 Luminosity Increase

A new configurations for two orders of magnitude higher luminosities (≥ 10^{36} cm^{-2} sec^{-1}). Will open up new physics opportunities for CLAS12

A. **μCLAS12, L ≥ 10^{37} cm^{-2} sec^{-1} for DDVCS and e^-–*J/ψ* (LOI12-16-004)**

- large acceptance calorimeter, "FTCal-large", for electron detection combined with an absorber as a shield/π-absorber in front of the CLAS12 FD – converting the CLAS12 FD into a muon detector
- No CD, instead a high rate recoil detector inside the solenoid
- time frame 7-10 year





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B. **Open acceptance mode, L~10^{36} cm^{-2} sec^{-1}, need more thoughts and well defined physics case**

- New forward tracker, most likely MPGD based tracking system
- replace aging PMTs (FTOF/ECal)
- No CD, instead a high rate recoil detector of some kind
- No HTCC and FT, instead a larger Moller cone that will limit FD acceptance to $\geq 8^o$
- new Cherenkov counter for e^- ID (sort of LTCC with CO_2)
- need streaming DAQ and AI for event construction
- time frame > 10 years

Summary & Conclusion

- Two stage Luminosity upgrade has been foreseen by JLAB following the outcome of the high-luminosity Task Force:

  I. increase the luminosity by x2 with high reconstruction efficiency
  II. proceed with >x10 increase

- **Phase 1**
  - DC R1 should be backed or substituted by a faster MPGS
  - μ-Rwell detectors have been identified as the most suited MPGS
  - R&D activity is on-going –both at JLAB and INFN - to identify the best 2D – large scale configuration of μ-Rwell detect to cover R1 region (2 years study + final production)

- **Phase 2**
  - μCLAS12 / open acceptance configurations require major changes and streaming read-out DAQ electronics