# Luminosity upgrade for CLAS12

Rafayel Paremuzyan: Jefferson Lab

International workshop on CLAS12 physics and future perspectives at JLab
Mar. 21 – 24, 2023. Paris

# Outlook

- Necessity for the Luminosity upgrade
- Recent Re-Assessment of subsystem performances for x2 Luminosity
- The $\boldsymbol{\mu}$Rwell detector
    - Status and prototyping
- x100 Lumi upgrade
- Summary

# Why increase Luminosity?

The design luminosity of CLAS12 is $10^{35} cm^{-2} s^{-1}$, corresponds to 75 nA on Hydrogen target

- CLAS12 has a broad physics program: 42 approved experiments distributed among 11 Run groups sharing the same target, detector configuration and the trigger.
    - Nucleon structure: GPDs, TMDs, FFs...
    - Hadron Spectroscopy, Exotics …
    - NN correlations, hadronization, color transparency...

- Most of them are not fully completed yet (some even did not start).

- CLAS12 initially reached only 75% of the design luminosity $10^{35} cm^{-2} s^{-1}$ (DC occupancies).

- Most of proposals which were approved long before CLAS12 1st run, assumed 100% detector efficiencies, and not very realistic geometric acceptance of CLAS12
- Already taken data shows that in average we are down by about factor of two.
    - As a consequence, experiments won't get expected statistics at the completion of the run.
        - Experiments with low x-sec, multi particle final states especially got hit hard.

- In order to get the desired statistics back and make the remaining program to run faster, CLAS12 should be able to take data at significantly higher Lumi.

- The upgrade is also to open opportunities for measuring a new, low rate reactions.

# New Task force: High Luminosity

A new task force is formed lead by Stepan.

## 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

# Reassessment of subsystem performances

- In 2021 subsystems were assessed from the perspective of the Luminosity upgrade
  - Some of subsystems were not understood good enough, in order to make a proper assessments of subsystem performances at higher luminosities:
    - Needed SW improvement, better alignment
  - Some subsystems don't need major upgrades,
    - E.g. Cherenkov Detectors.
  - Some subsystems needed to be upgraded
    - DAQ, DC

Now with the SW improvements and better understanding of subsystem performances, we started a new series of meetings to Reassess subsystem performances

SS Stepan Stepanyan

To: Cole Smith <lcsmith@jlab.org>; Daniel Carman; Valery Kubarovsky; Maurizio Ungaro; Florian Hauenstein; Youri Sharabian; Raffaella De Vita; Yuri Gotra **+4 others** Fri 1/20/2023 8:33 PM

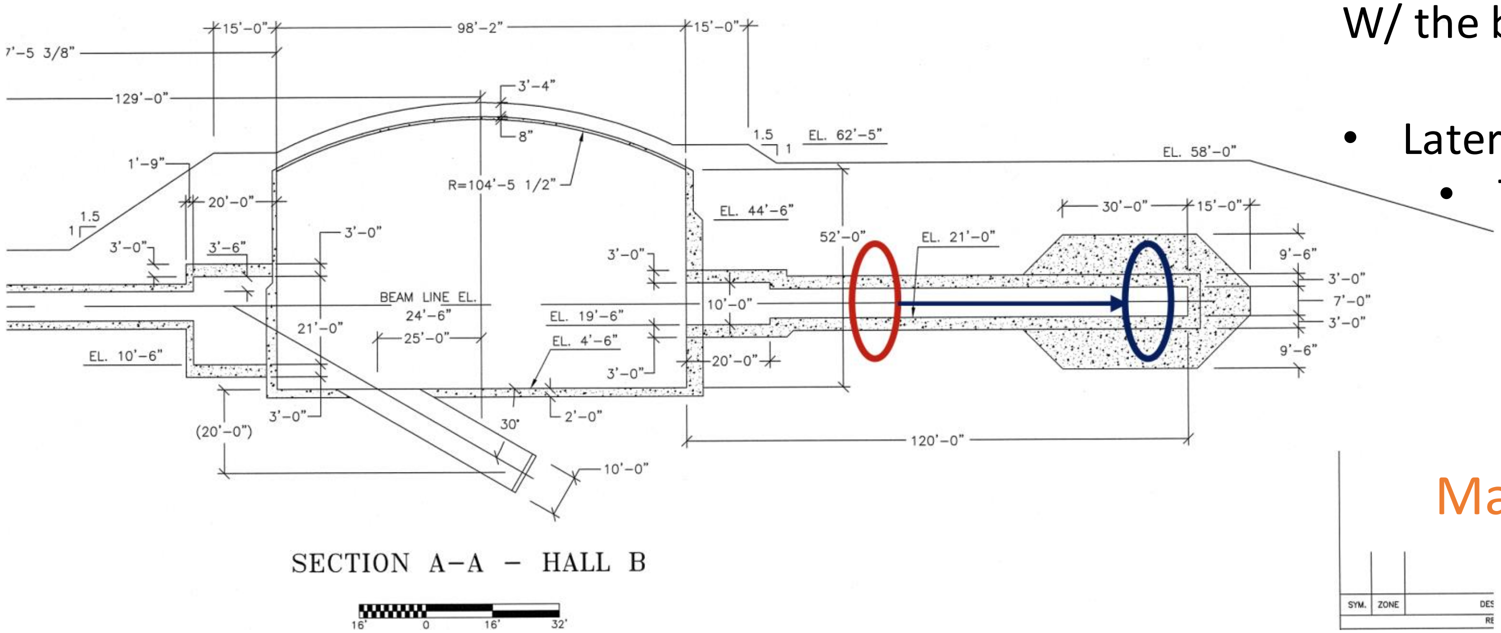
Cc: Veronique Ziegler; Patricia Cheeseboro; Gagik Gavalian; Nathan Baltzell

Dear all,

During the "High luminosity upgrade" TF work about 2 years ago, we assessed the performance of subsystems with x2 higher luminosity operations. Back then, we concluded that the detectors would operate and maintain their performances (resolutions and efficiencies) with x2 higher than the designed luminosity of CLAS12 (see reports at https://wiki.jlab.org/physdivwiki/index.php/Task_Forces_2020#tab=High_Luminosity%7CCLAS12%7CCLAS12). There was one caveat though, we were not sure about software performance for some of the subsystems. Now that our software is ready for pass2 and as good as it can be for the future, I believe it is time to return to the performance discussions again. I propose to use the Hall-B round table, Wednesdays at 2:30 pm, and TF, Fridays at 1:30 pm, meetings in February for such discussions.

# Beamline


- The Hall-B beam dump is located in the downstream tunnel, closer to the beginning of the entrance.
- Concrete walls are x3 thick at the end of the tunnel. Better radiological isolation will be reached, if the dump will be moved to the end of the tunnel. This will be done during this SAD.
- There might be a need of installation of a "single-use" camera for initial beam tuning.




- Current limit w/o beam blocker is 1 KW which is about 90nA at 11 GeV.

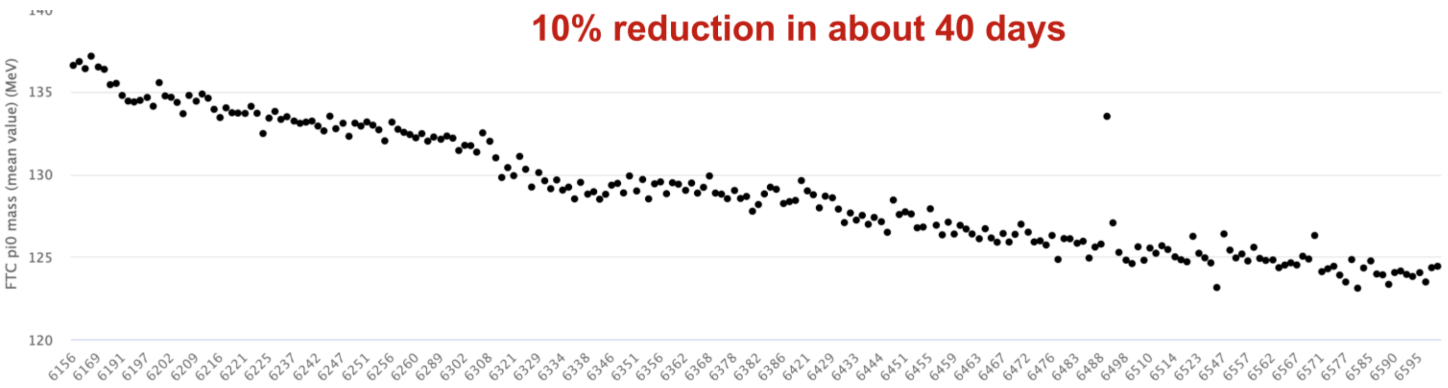
W/ the blocker up to 1.3 $\mu$A is possible.

- Later the beam dump is planned to upgrade to 60 KW.
  - This will require BCM, as the dump will be blocked.

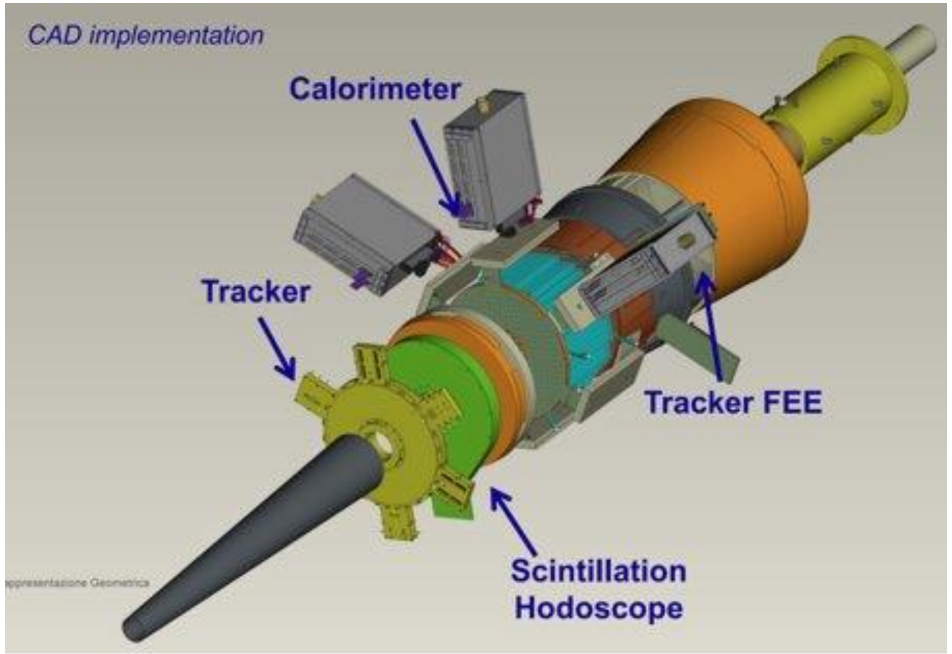
Two more stripline BPMs are ordered.

Materials from E. Pasyuk's presentation

# Forward tagger




Light reduction in FTC because of the radiation damage, though not permanent, recoverable through thermal annealing.
At $2*10^{35}cm^{-2}s^{-1}$ the loss is expected to be ≈ 1%/day, though the loss is expected to become less at higher dosses.
Will require frequent energy calibrations




There is Gain dependence on the FTH SiPm current.

A work is planned to replace/redesign FTH FEE, to suppress gain dependence on the SiPm current.

Pileup: might require special decoding, e.g. pulse fitting.

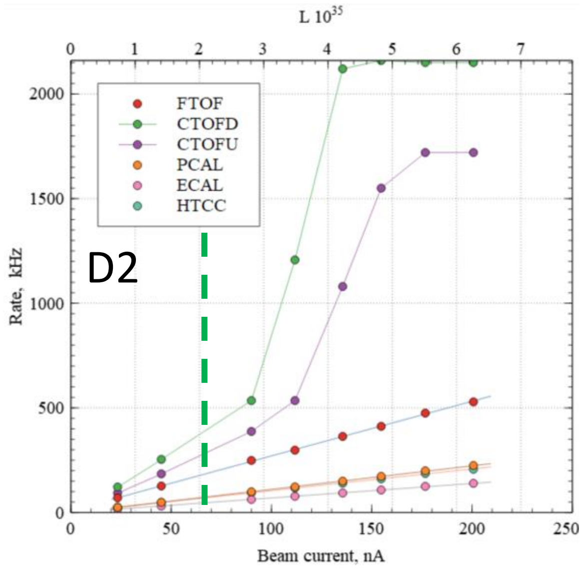
FTC: 7% with 150 ns pulses
FTH: 13% with 250 ns pulses

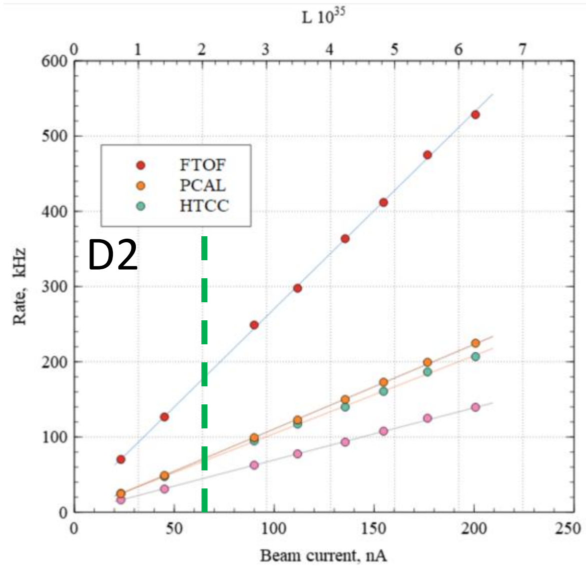
About 10% trg non-linearity

Materials from R. Devita's presentation

# PMT based detectors

Nuclear target test report
CLAS12 Note 2021-001




CND, P(E)Cal, F(C)TOF, H(L)TCC, RICH

- Most of PMT based detectors will perform at x2 luminosity

- Main concern of some of PMT based detectors is the aging
  - Some of ECal PMTs arrived, and test setup in EEL is ready.
    - Tests swill start soon

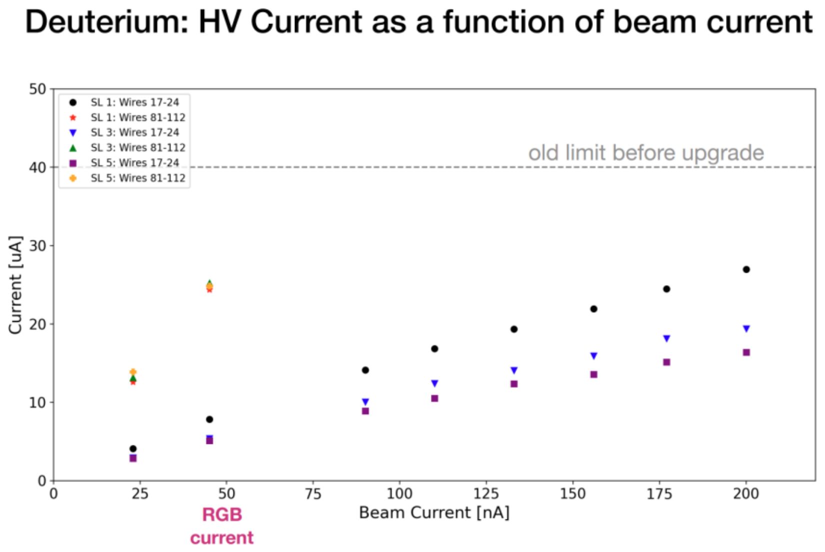
  - During the "Detector Reassessment" meetings it was decided to make a plan for replacement of aging PMTs.

- FTOF CTOF ECal (and not only PMT based detectors ) requested a special high lumi beamtime for more dedicated studies. A plan is being prepared for running

  - Most probably during this summer run

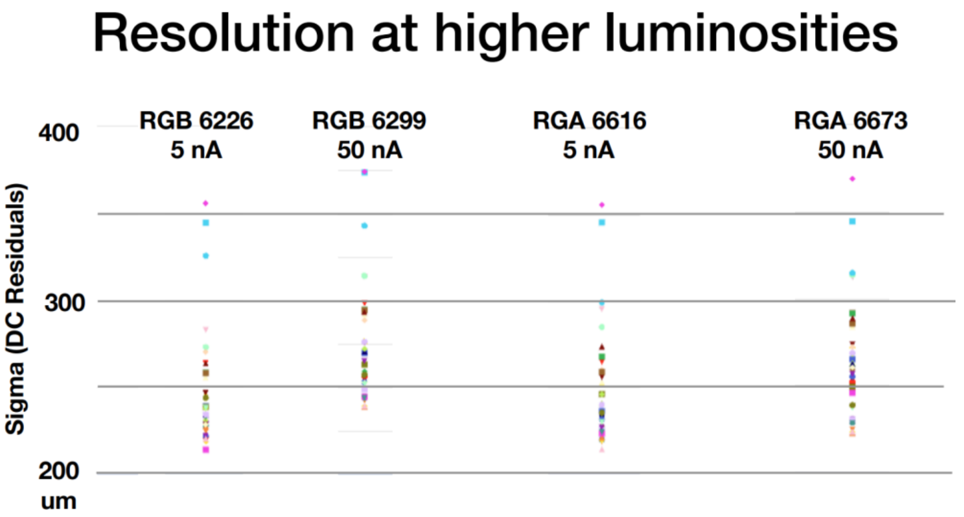
# Drift Chambers

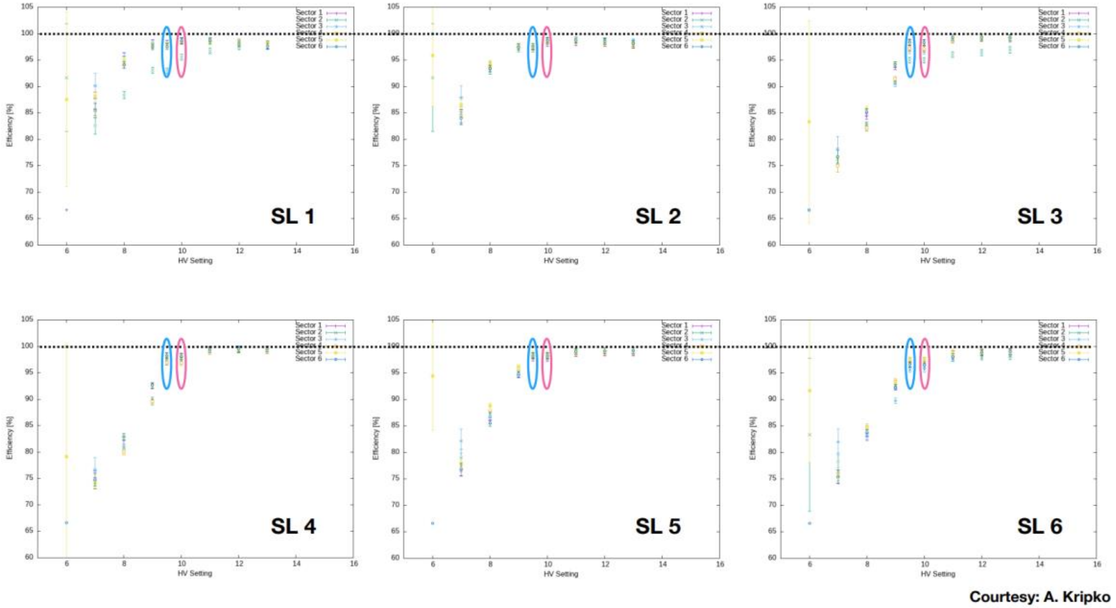
- Upgraded with new Power supplies: trip limit 350 uA (was 40 uA on old Power Supplies s)
  - At x2 Luminosity there should not be problems from the perspective of HV trips.
- Combining $\mu$RWell, AI and denoising will allow to get 85% eff at x2 Lume for a single track.




Effect on the resolution should be studied more, studies with different Run periods gave inconsistent trends.

Better residuals with higher HVs, the effect on physics quantities should be studied.

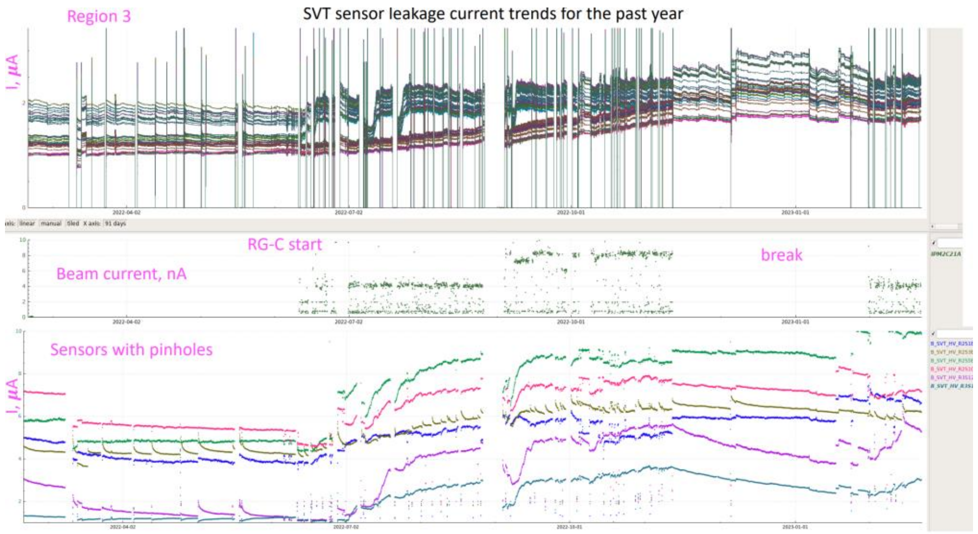


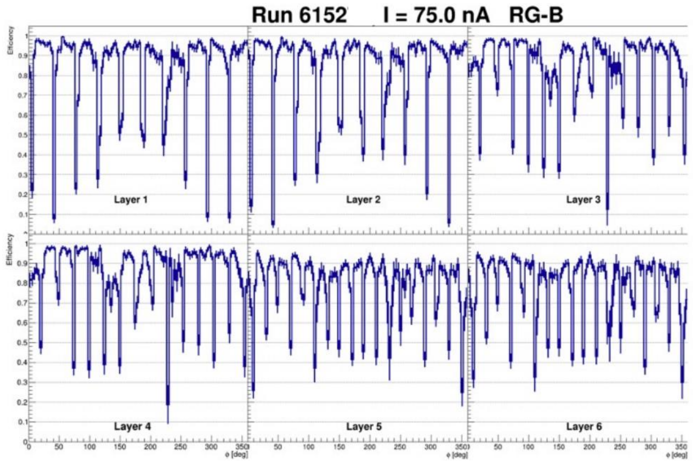

Materials from Florian Hauenstein's presentation

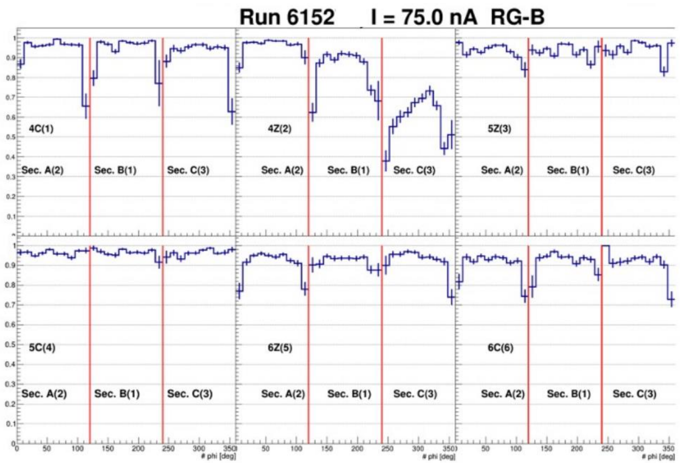
# Central Vertex Tracker

SVT leakage currents should be good enough for x2 Luminosity. Sensors with pinholes draw higher current.




Testing tolerance of preAmp on DC Voltage is needed.

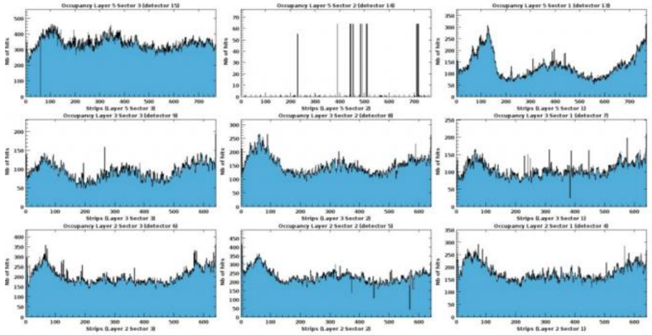


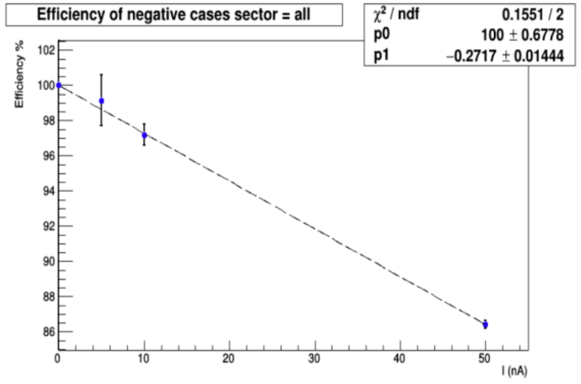




Det. Efficiencies tested up to 75 nA in RG-B ($2x10^{35}cm^{-2}s^{-1}$)

Although At NTT SVT collected data at much higher than 75 nA on D2, dedicated studies probably (during RG-D) will be more precise w/ full CVT tracking.

- It is expected that more tiles will fail in a coming years, as they have exceeded tot. Integ. charge limit.
- Already replaced several tiles
- Need spares for all layers.
- S2L5 failed this summer w/ No spare






- CVT tracking needs development of background rejection algorithms (AI)
  - Otherwise w/ the current recon at x2 Lumi less than 60% efficiency is expected.

Materials from Yuri Gotra's presentation

# DAQ

- Current CLAS12 trigger is reliable up to 30 KHz
- Expected rate at $2x10^{35}cm^{-2}s^{-1}$ will be up to 85 KHz
- Need to upgrade to have 100 kHz with lifetime of >90%
- Trigger upgrade is possible
  - Calorimeter (MIP like particle trigger, individual atten. length rather than the avg, etc. )
  - Improve Road accuracy, Add $Q^2$ cut on Roads

## Required Hardware changes

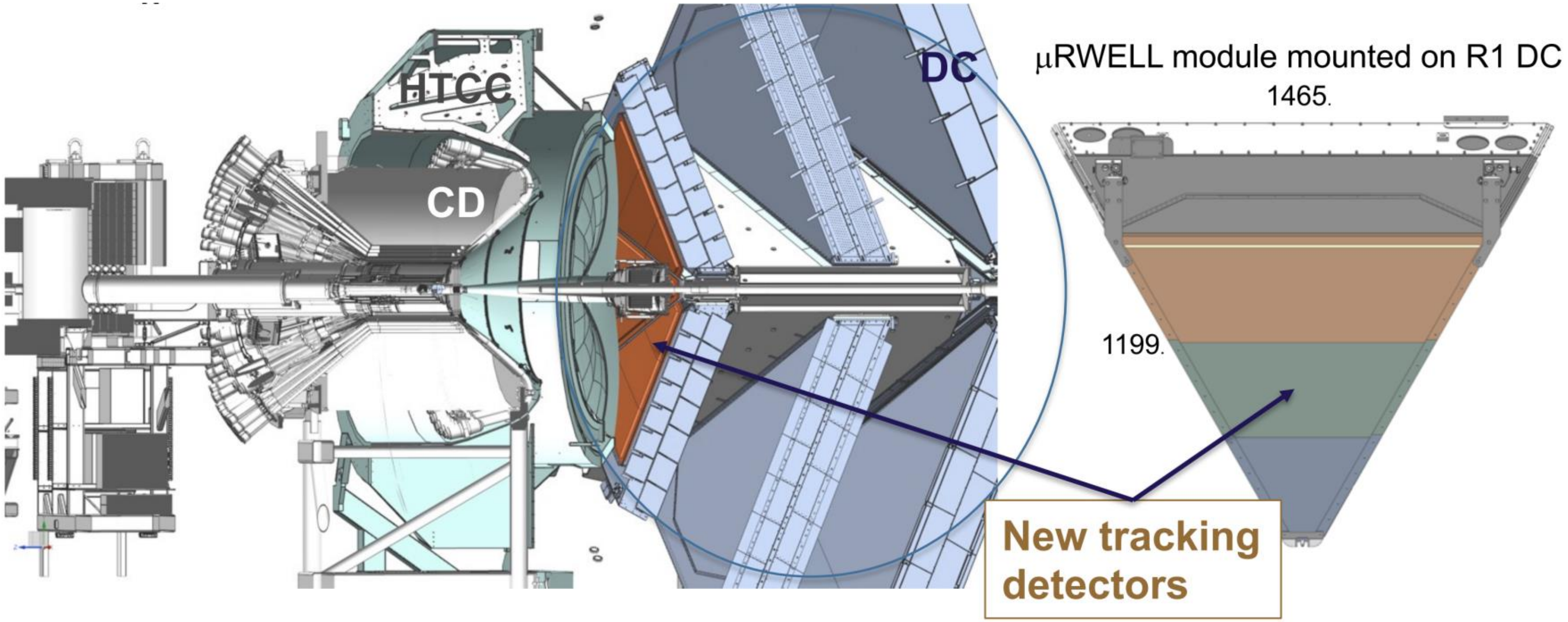
- CAEN TDCs have to be replaced with JLAB vfTDCs: 8 in hand, 20 ordered
  - Faster readout, also supports streaming readout
- MM readout to be decided, proposed solution is new SAMPA ASIC based front-end board.
  - We might get SAMPA chips soon
- Some VTPs have to be used as both trigger and readout modes
  - 6 are already connected to be used for readout, the rest will be connected with new network switch (ordered)"
- New readout boards for the $\mu$RWell.
  - Readout board design is close to be finalized, critical parts are ordered

Materials from Sergey Boyarinov's presentation

# The $\mu$RWell detector

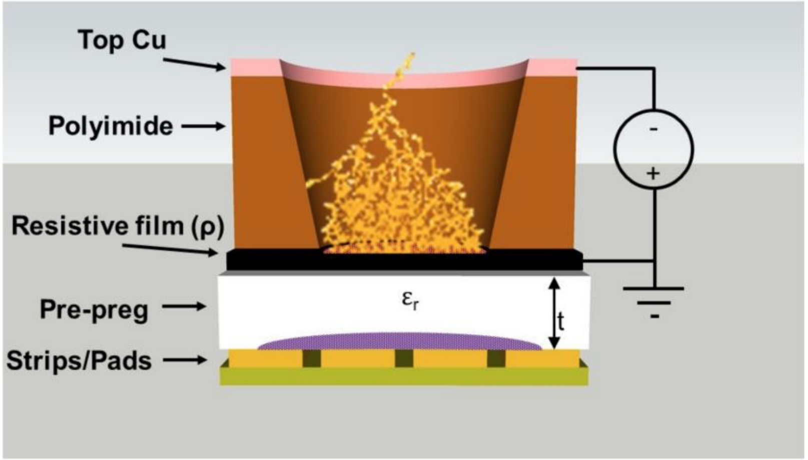
SW improvements, AI implementation, denoising of course help significantly to increase the DC R1 occupancy related tracking efficiency, however only SW is not enough to reach 85%/1 charged (0.1%/nA) particle at $2x10^{35} cm^{-2} s^{-1}$.

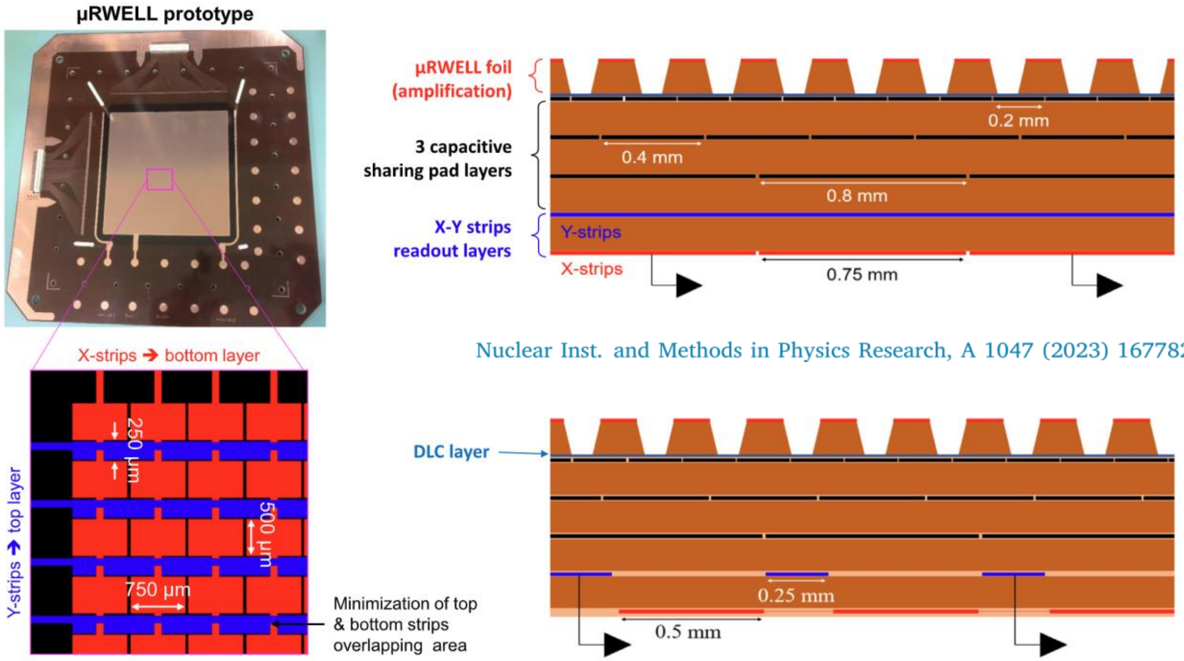
A new MPGD detector is proposed to install in front of DC RG1 in order to aid fwd tracking




- Six sectors, each sector consists of three sections
- Will be installed just upstream of DC R1
- The target, CD and HTCC will be moved upstream by about 10-15 cm to make a room for the $\mu$RWell

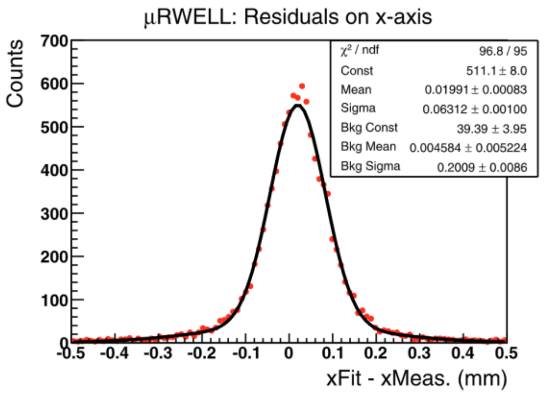
# A small $\mu$RWell prototype testing in Hall-D

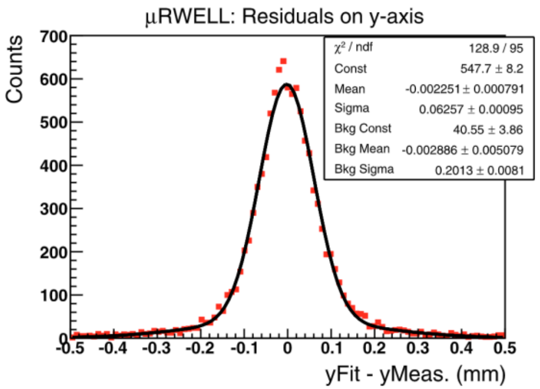



Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167782

- A small 10cm x 10cm was successfully tested in Hall-D
- 2D capacitive sharing readout
- Good position resolution

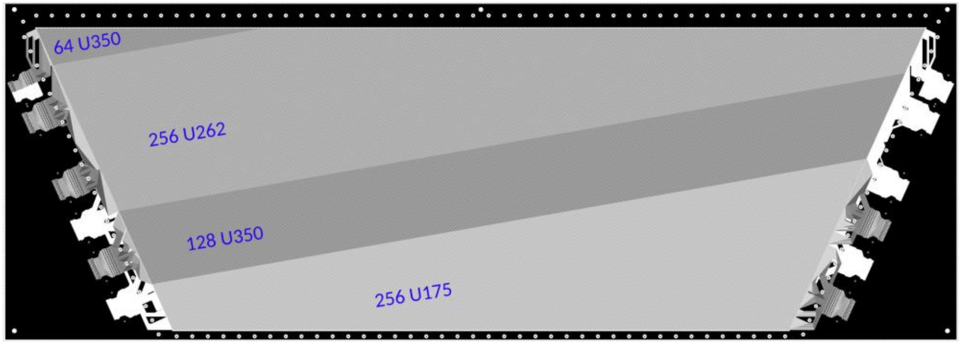


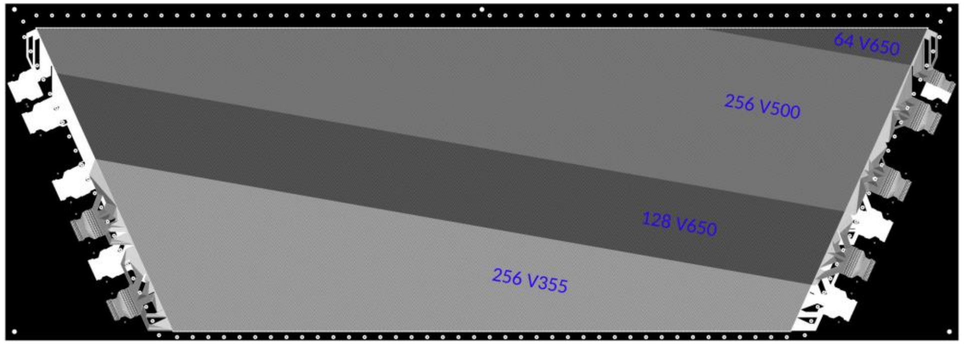
# The 1st prototype

- U/V readout: strips are arranged +/- 10 deg
- Different Strip widths
- SRS based readout with - APV25 Hybrids
- Florian and Kondo went to CERN for assembly
- Transported to JLab early January

U strips

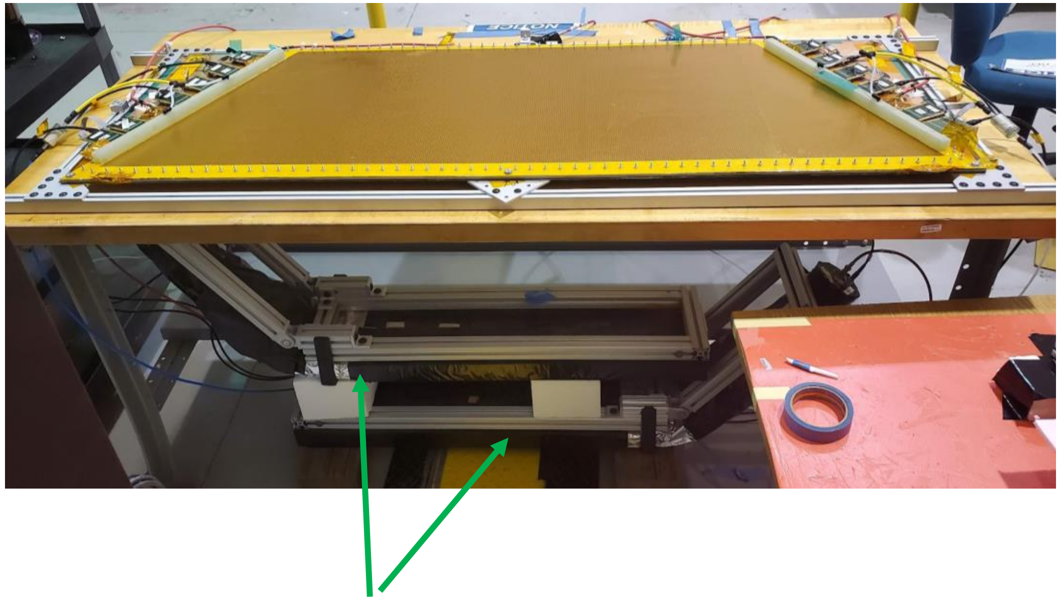



V strips




Kondo and Florian glue gas connectors

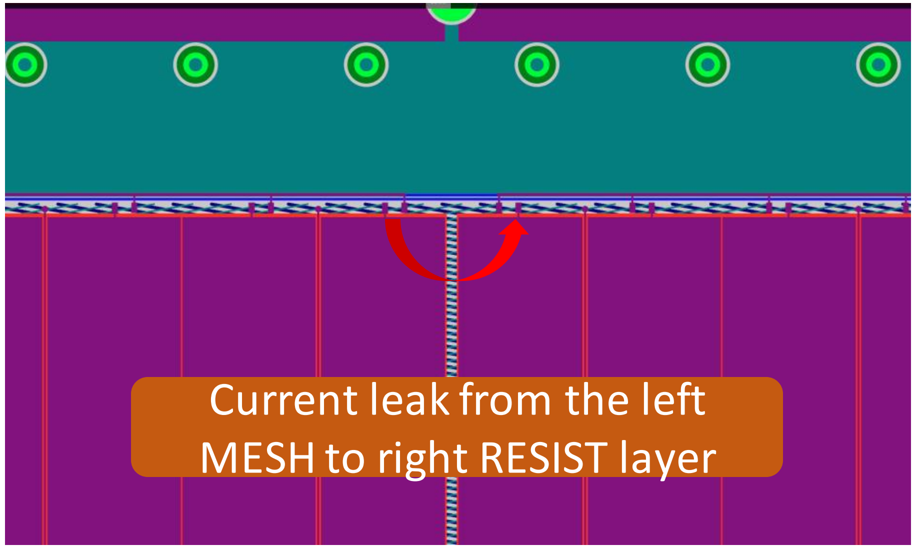
The test bench in EEL 125

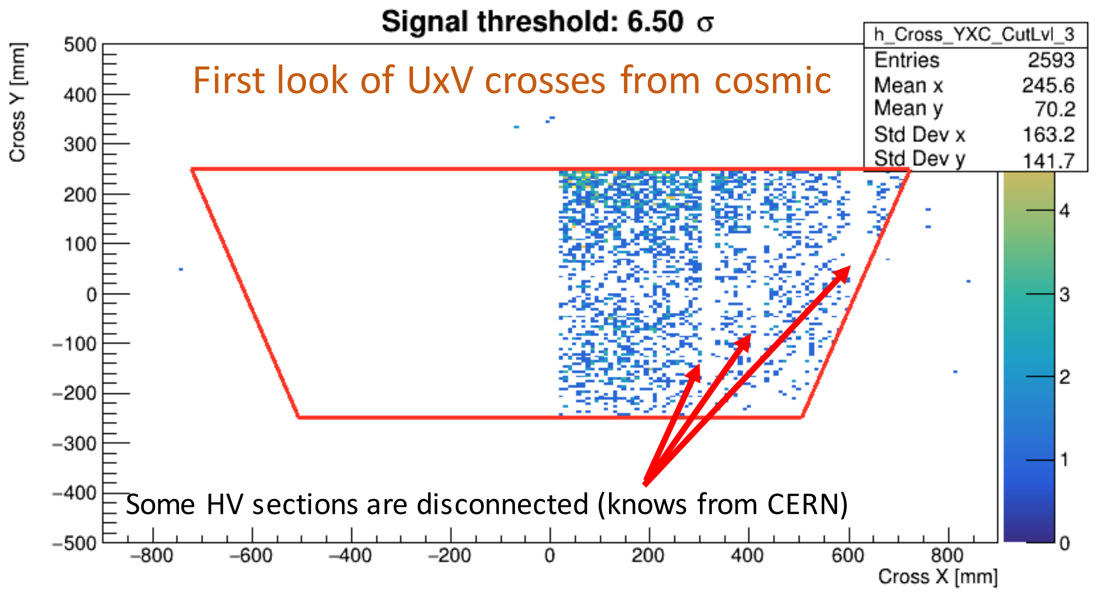


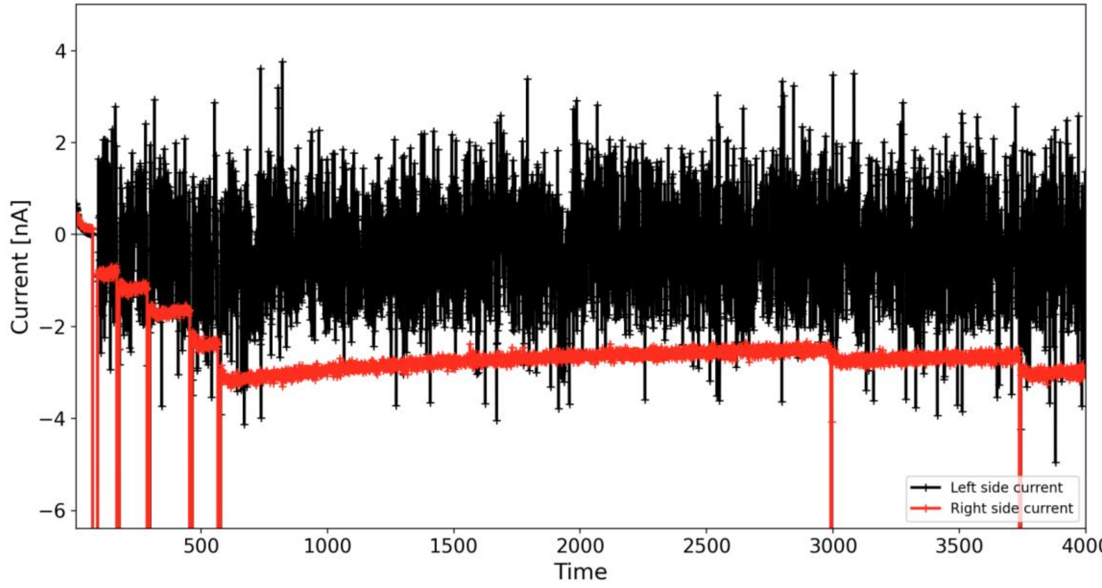
HPS ECal Cosmic scintillators

# Tests in EEL 125

- Flush with N2 about 3 weeks
- Then Started HV tests!
  - No issues with the right side
  - Supplying HV on the left side MESH, produces a current on the Right side resistive layer, but not other way around.
  - Should not happen in principle, but the exact cause will be more clear when we open chamber for inspection.
  - We decided to use only one half of the chamber for now.



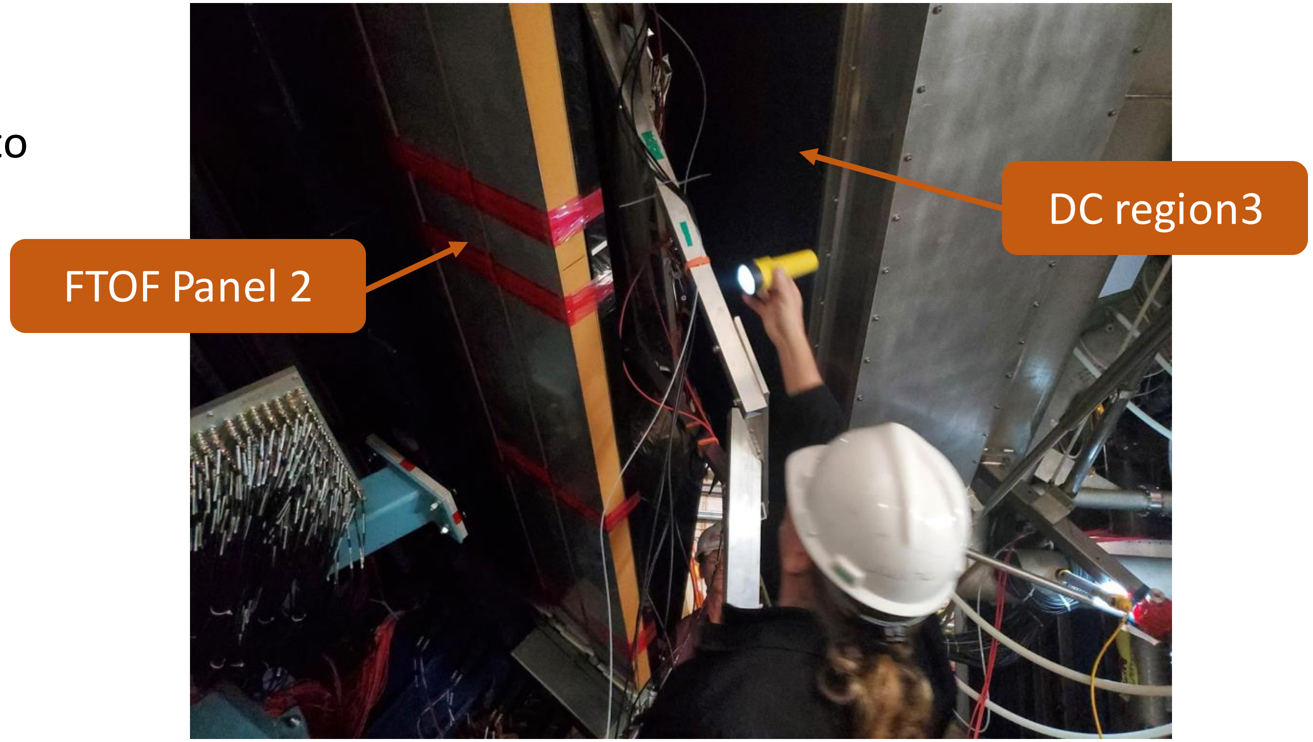



# In the hall

The detector is installed in Sec 6
between R3 DC and FTOF Panel 2

- Initially Intolerable level of noise in the hall:
- Had to create a Faraday cage from an Aluminum foil to bring the noise level at an acceptable level




The performance was not as expected, but offline analysis will show how far we are from expectations

# Simulations

Raffaella's studies show that matching DC hits to $\mu$Rwell hits, w/ the combination of AI assisted tracking and denoising brings the single track reconstruction inefficiency less than 0.1%/nA

Tongtong started the development of the Fwd tracking w/ $\mu$RWell.

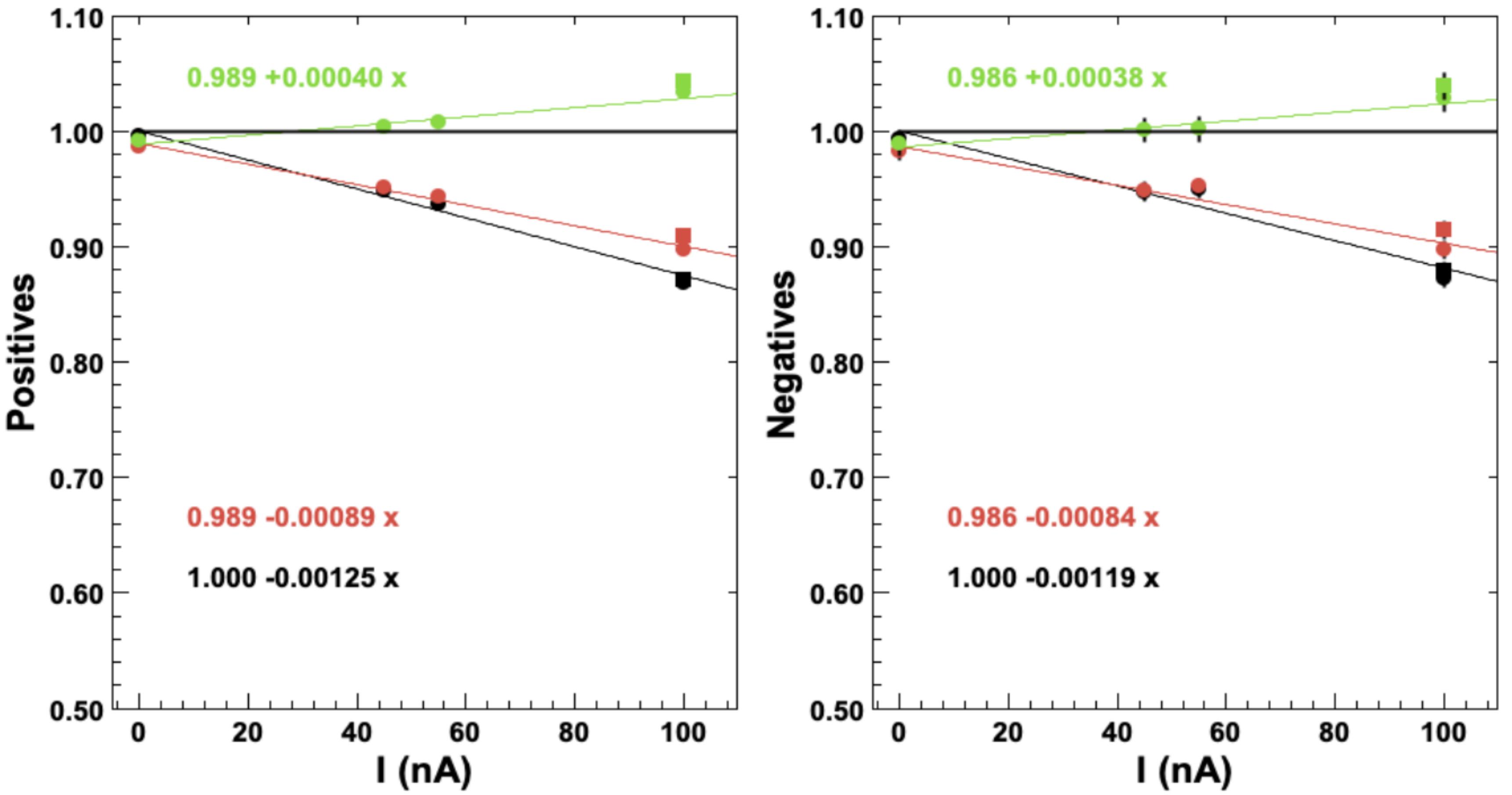
Studies are in progress:

- Optimizing the matching cuts
- Adding bgr maerging to $\mu$Rwell
- Addition of new banks (done)
- Etc...

Sidis events with RG-A background:

- **Only matched hits without denoising**
- **Only matched hits with denoise**

R. Devita

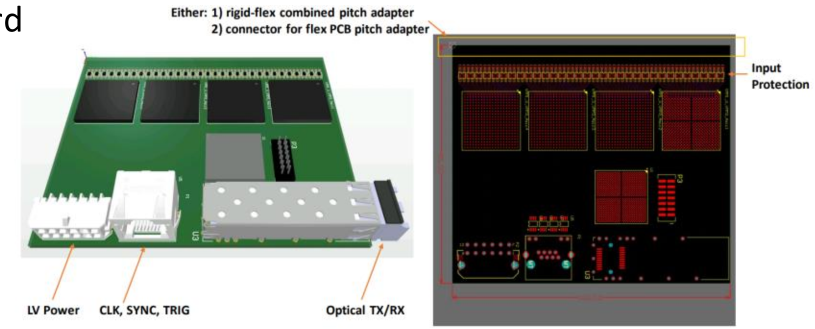


# Next steps of the project

- The current prototype has been tested under the cosmic and the beam recently
  - During this SAD will assess the performance, and if needed take more data with cosmic and w/ beam too during the summer run.

- The design of next prototype (which can also serve as a production detector), is well advanced
  - Critical decisions on the readout design are made: will make Front End Electronics using VMM3

4 VMM3 ASICs per Readout board

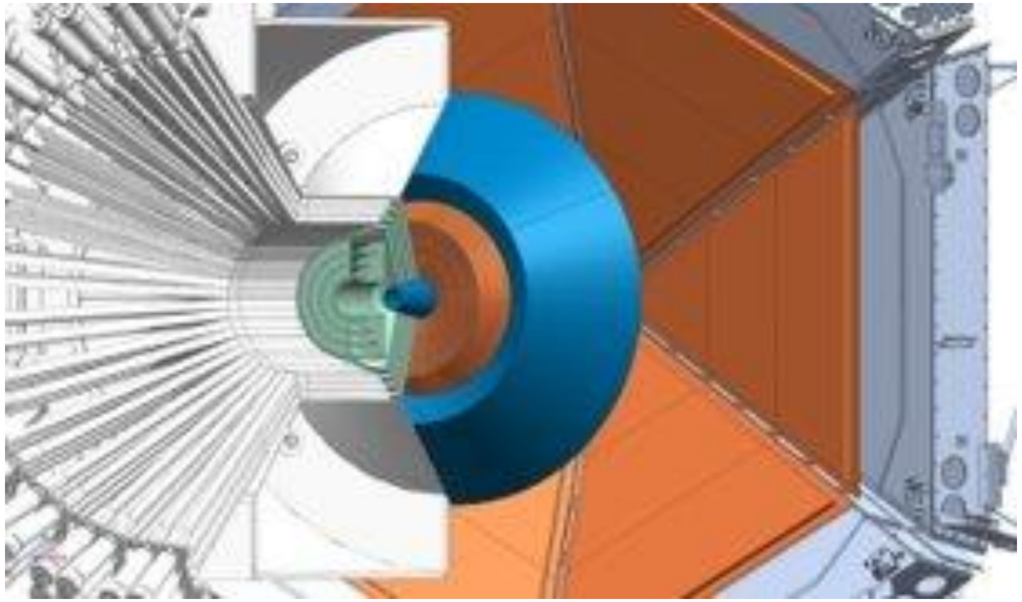



Ben Raydo

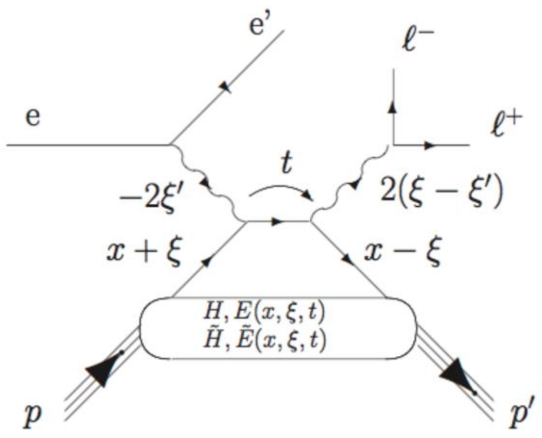
- Final strip widths should be decided based on the test prototype analysis. (End of summer 2023)
- Finalize routing of strips to the Readout connectors (Summer 2023)
- Have the full scale prototype ready to be tested in the 1st half of 2024
- Start procurement of parts for the six-sector upgrade, end of CY 2024
- Fabrication of detectors, CY25.
- Ready for installation in 2026.

# Phase 2 Lumi upgrade

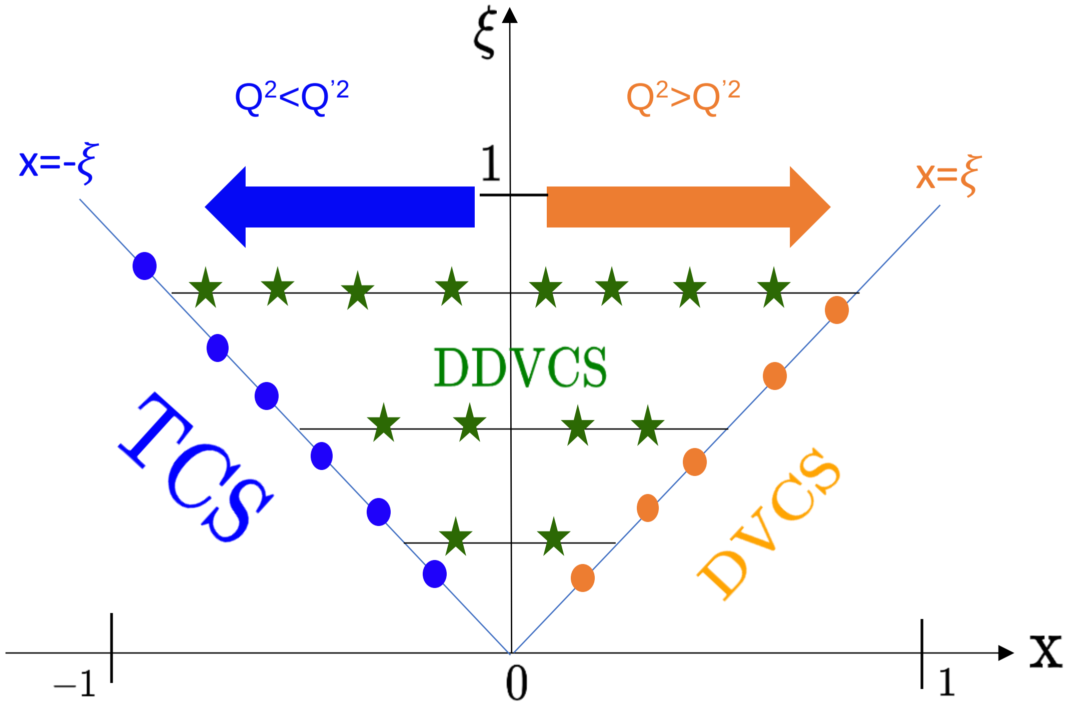
- CEBAF can deliver x1000 more current than what CLAS12 takes now with current targets.
- Upgrading CLAS12 luminosity limit by orders of magnitude will allow studies of very low x-sec reactions, and hence making JLab unique place (SOLID and CLAS12) for studying such reactions.
- In the 2nd phase of the luminosity upgrade, CLAS12 will be capable to run at 100 time of the designed luminosity, and detect muon pairs in the forward detector, $\mu$CLAS12
- In particular this upgrade will allow the measurement of Double Deeply Virtual Compton Scattering



# Double DVCS




Kinematics of two photons are described by $\xi$ and $\xi'$.




$$\xi' = \frac{x_B}{2 - x_B}$$

$$\xi = \xi' \frac{Q^2}{Q^2 + Q'^2}$$

Quark propagators between two photons now reads as:

$$\frac{1}{x - (2\xi' - \xi) + i\epsilon} + \frac{1}{x + (2\xi' - \xi) - i\epsilon}$$

Observables (e.g. BSA) proportional to the Im part of the amplitude, allow direct measurement of GPDs at ($x=2\xi' - \xi$, $\xi$, t) points.

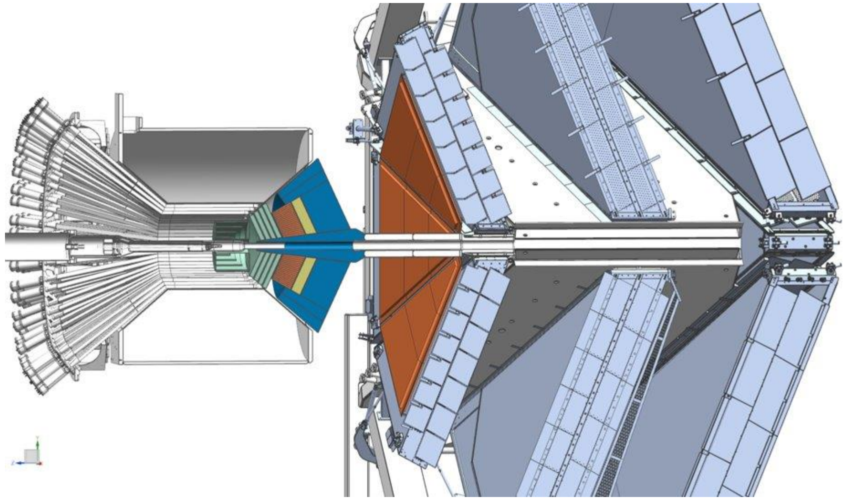
Here one can get away from the $x=\xi$ line by varying virtualities of incoming and outgoing photons

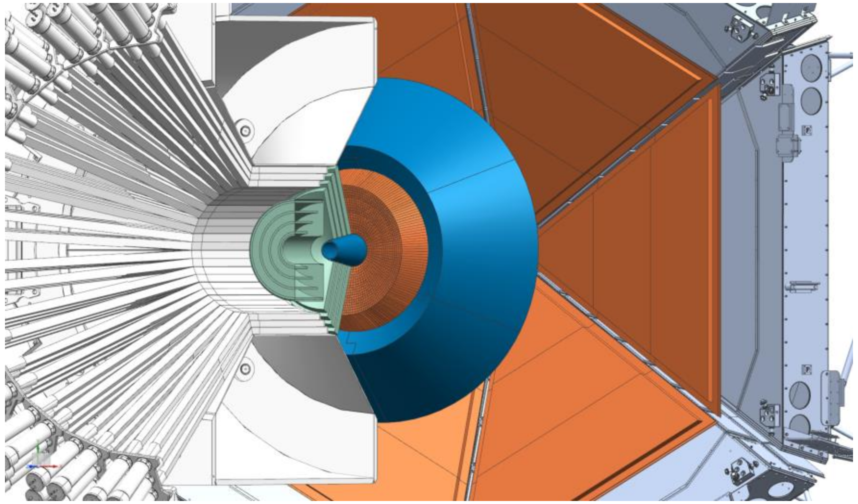
# Proposal for $\mu$CLAS12

- Detector should handle luminosities $10^{37}$ $cm^{-2}s^{-1}$.
  - Main limiting factor is occupancies and rates in detectors
- Should be able to detect muons

- Remove HTCC
- Install a Moeller cone (tungsten material) extending up to 7.5 deg polar angel
  - In order to reduce huge rate of Moeller electrons
- Add a new $PbWO_4$ calorimeter that covers 7$^{\circ}$ to 30$^{\circ}$ polar angular range with 2π azimuthal coverage
  - In order to recover electron detection
- Next to the $PbWO_4$ calorimeter add thick tungsten shield/absorber covering the full FD region
  - In order to absorb all electromagnetic and hadronic background originating from the target.
- Install a new MPGD detectors in front of the calorimeter
  - In order to be able to reconstruct vertex parameters (angles and positions)

- 7$^{\circ}$ – 12$^{\circ}$, crystals are 13 mm x 13 mm to keep rates per crystal at an acceptable level
- Above 12$^{\circ}$, crystals 20mm x 20 mm will be used
- Readout: APD from the downstream face of crystals
- Similar crystals and readout were used during the DVCS calorimeter, and HPS electromagnetic calorimeter
- Expected rates at 7$^{\circ}$ is around 1.5 MHz
  - Similar rates were observed in HPS experiment on close to the beam crystals.





Timeframe: 7-10 years

# Summary

- The x2 luminosity upgrade is very important for the successful completion of approved CLAS12 program

- In 2020 a task force for Luminosity upgrade is formed and for different subsystems works started
  - DAQ
  - ECal PMT change

- With a better Software and a better knowledge of detector performance, recently all subsystems were assessed again.
  - Items on critical path
    - µRWELL detector development (R&D and prototyping started);
    - The BMT HV breakdowns: no spares and no big chance of replacing degraded tiles.

- Using AI assistance, denoising and the uRwell, the tracking inefficiency estimates are under 0.1%/nA

- x100 luminosity upgrade will make JLab a unique place to measure the DDVCs, an important reaction for the Nuclear structure studies.

# Backup

Daniel Carman's slide

# CLAS12 TOF High Lumi Summary

- Higher luminosity operations (for $LH_2$):
  - FTOF: PMTs for panel-1b should operate stably at a factor of *x3 higher lumi* with similar timing performance *(at present settings/environment)*
    - Situation with panel-1a/2 not so clear due to divider issues at higher rates
    - Note also that the panel-1a/2 PMTs/voltage dividers are all CLAS "left-overs"
  - CTOF: PMTs should operate stably at a factor of *x2 higher lumi* with similar timing performance *(need further study here with new gains)*
  - Need to study FADC pile-up effects
  - Need to study radiation levels at HVPS locations (radiation damage/SEU effects)
- PMT remaining life (for $LH_2$):
  - If we continue operations at the RG-A production luminosity:
    - FTOF p1b PMTs have a remaining life: *~8+ yrs*
    - CTOF PMTs have a remaining life: *~4 yrs*
  - If we triple the luminosity, the remaining life of these PMTs will be *$\lesssim$2-3 yrs*

# Summary

- PCAL PMT gain degrades 7%/yr at present luminosity.
- DC response is linear so far up to beam current=100 nA or anode current=3 uA (280 kHz).
- Pulse linearity vs current never studied. Affects calibration stability for highest energy pulses.
- PCAL gain drifts can be managed with HV adjustments for 10+ years at 3x current luminosity.
- ECAL PMT lifetimes unknown (30 years old). Some ET tubes show mild after-pulsing.
- ECAL scintillator degradation evident from decrease in attenuation length and light yield.
- Impact from accidentals on event-by-event pedestals needs further study. Use fixed pedestals?

# Summary and Outlook

Florian Hauenstein's slide

- **Operation at higher luminosity**
  - **New power supply removed limits from HV for operation at factor 2-3 higher luminosities with current HV setting**
  - **Nuclear target data shows that we can run at factor 2-3 luminosity**
  - **Tracking efficiency reasonable with AI and denoising (+urwell)**
  - **Effect on resolution not fully understood (needs more simulation and data)**

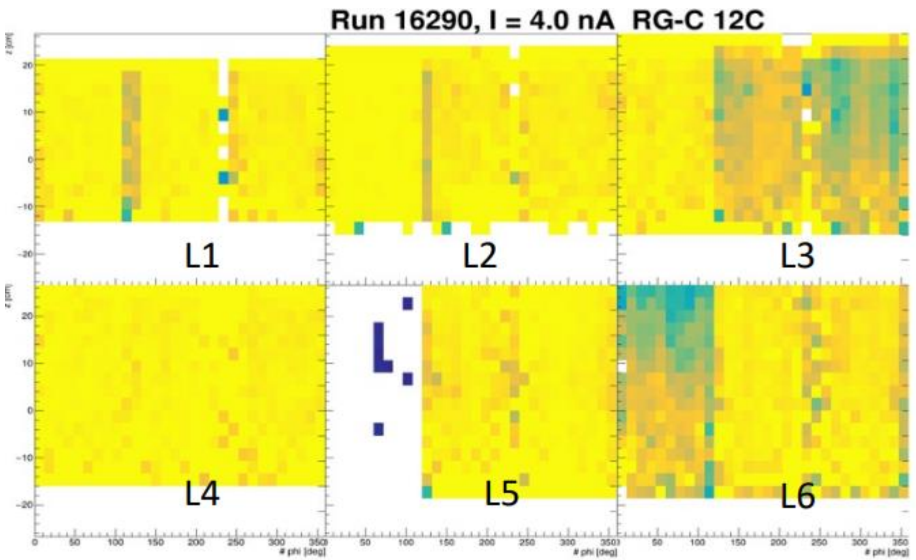
- **Other challenges:**
  - **Aging** —> no monitoring at the moment, want to look at development of dark currents
  - **Increase of HV setting to improve resolution (and efficiency) might limit luminosity again due to power supply limit**
  - **Sudden damages from discharges, unwanted gas contamination**
  - **Improve on HV settings for equal gains**

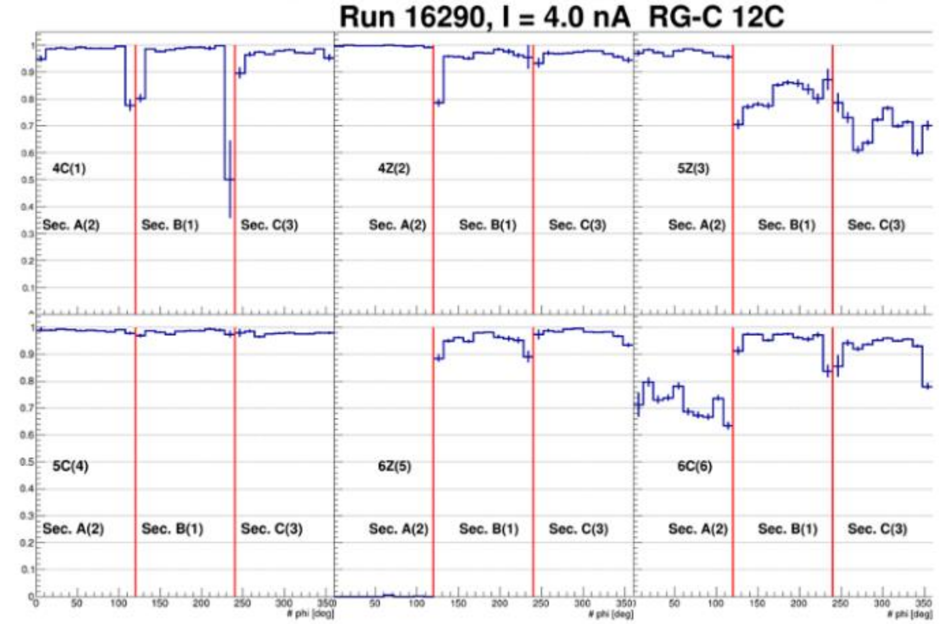
- **Next steps/plans:**
  - **Resolution study with data + background merging**
  - **HV + luminosity scan data with RGD (deuterium) and RGK (hydrogen) for 1-2 shifts**
    - **dependence of currents**
    - **resolution of physic quantities like W**
    - **grid scan with several HV settings and luminosity settings, details to be developed**

Yuri Gotra's slide

# Summary

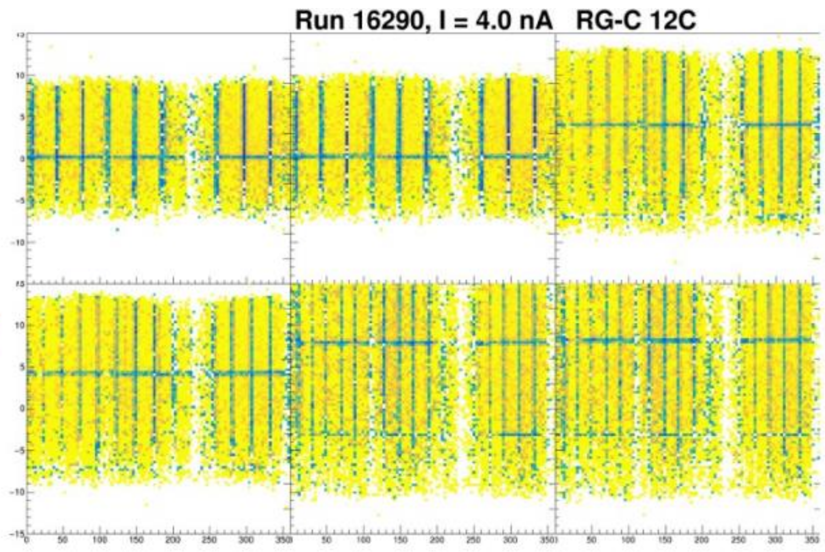
- Performance of the central tracker matches physics requirements:
  - Track and vertex resolutions are within the specs
  - Track reconstruction and alignment algorithms are mature, event processing time is acceptable
  - Fraction of operational detector channels: 99.8% for SVT, 95% for BMT
  - Most of the sensors have high detector efficiency at production luminosity
  - Detector noise levels do not affect tracking performance (please do not name physics backgrounds as CVT noise)
  - No DAQ failures observed, all readout channels are functioning
  - Ambient conditions were stable over the past years of beam operations
  - All detector services, safety and interlock systems are operational
  - SVT sensor leakage currents are acceptable, sensors with pinholes are operational at nominal bias voltage
- Reasonable agreement between MC and NTT data on neutron flux, the differences in dose rates on deuterium target have to be understood
- Estimated from SVT currents dose rates overall agree CLAS12 data and in reasonable agreement with simulation
- Background occupancies are linear with bean current, good agreement between CLAS12 and NTT runs, MC estimates have to be assessed
- Leakage current trends of the SVT during RG-M are within NTT estimates of the dose rates for solid and liquid targets
- Further improvement of background rejection algorithms are required to reach the specs on tracking efficiency, critical for operation at high luminosity
- Development of background rejection algorithms (AI) require allocation of adequate resources
- MVT DAQ would require hardware upgrade to operate at high luminosity (SAMPA, VTP, see Sergey's report)
- Operational stability of BMT is affected by HV breakdown effects (both strip and drift) at high luminosity
- Lack of spare BMT tiles and complications related to production and testing the new detectors can affect BMT performance at high luminosity
- We expect feedback from MM detector experts on debugging the failed tiles and possible radiation damage of strip resistive layer
- More studies are needed to evaluate detector dead time at higher trigger and data rate
- Some tracker performance questions require further studies (BMT gain, occupancy, cluster size, BMTZ residuals, Lorentz angle, detector efficiency, hit timing)
- An estimate of dose rates and integrated dose are needed and the rates from the tagger dump have to be taken into account:
  - for RG-D and RG-E (consider radiation lengths of solid targets) to assess CVT performance by next RG-A/RG-B
  - for the planned RG-A/RG-B at high luminosity (stage 1) to assess CVT performance
- Performance of the central tracker after RG-D, RG-E, RG-K have to be re-evaluated and compared with estimates
- A dedicated luminosity scan during upcoming RG-D on deuterium target to study detector operation stability, efficiencies, and dead time should be scheduled

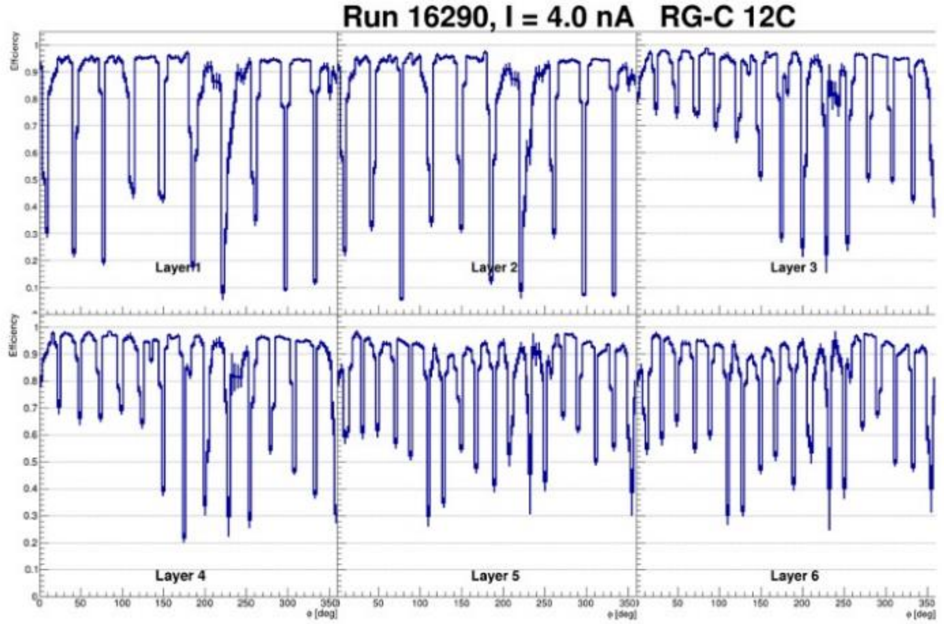

Run 16290, I = 4.0 nA RG-C 12C
L1
L2
L3
L4
L5
L6


Run 16290, I = 4.0 nA RG-C 12C
4C(1)
4Z(2)
5Z(3)
5C(4)
6Z(5)
6C(6)
Sec. A(2)
Sec. B(1)
Sec. C(3)

BMT

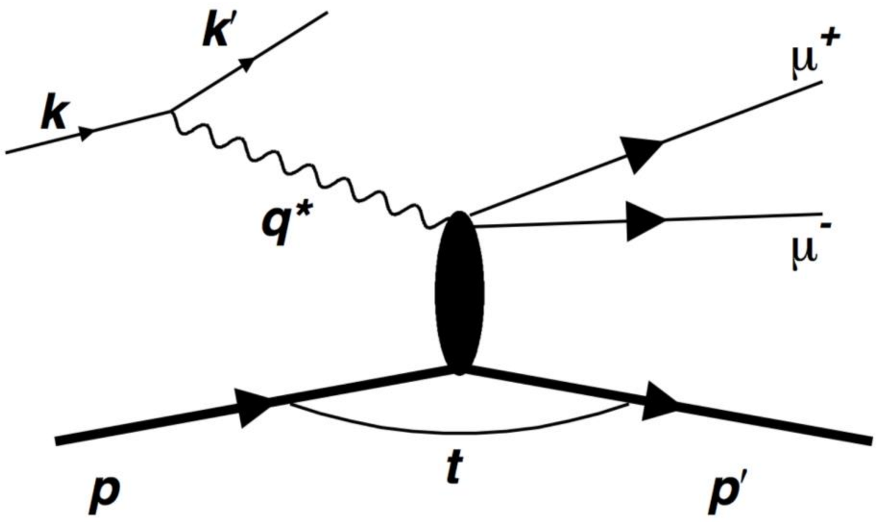
SVT


Run 16290, I = 4.0 nA RG-C 12C


Run 16290, I = 4.0 nA RG-C 12C
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6

# The proposed measurement

The reaction of interest is ep → e′$\boldsymbol{\mu}^-\boldsymbol{\mu}^+$p

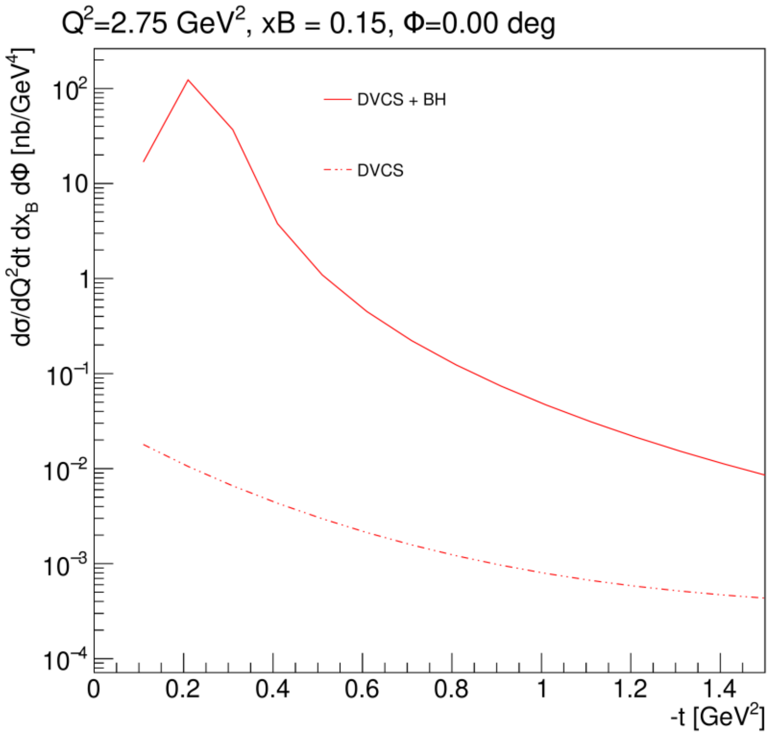


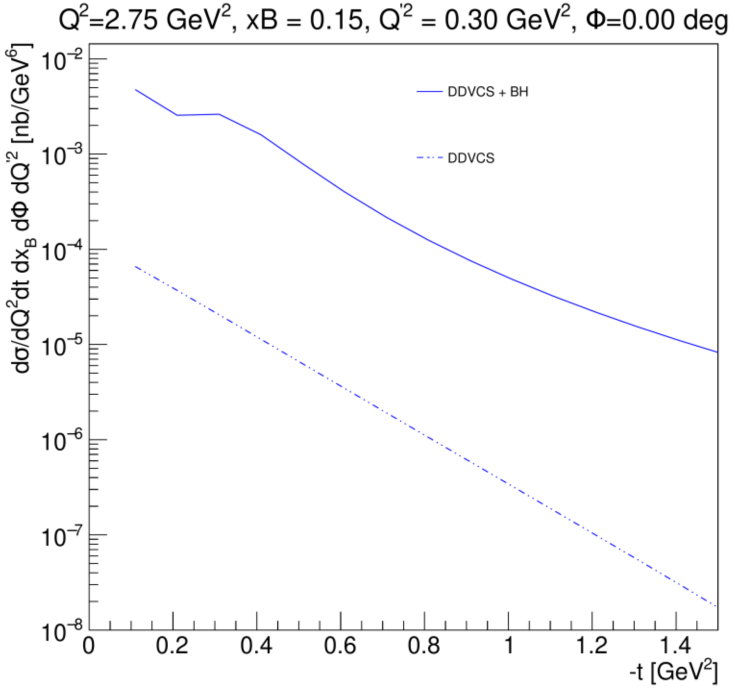

- In order to avoid ambiguity arising from the detection of two electrons in the final state, the timelike photon is identified through the detection of $\boldsymbol{\mu}$-$\boldsymbol{\mu}$+ pair.
  - **Requires a muon detection**
- Proposed Luminosity: $10^{37}$ $cm^{-2}s^{-1}$.
- We plan to detect at least e′$\boldsymbol{\mu}^-\boldsymbol{\mu}^+$, and the proton kinematic will be deduced from the missing momentum analysis, if proton is outside of the acceptance.

# Cross-sections

The downside of the DDVCS is it involves an additional $\alpha_e$ which makes the DDVCS cross-section 2-3 orders of magnitude smaller than the DVCS cross-section.

With standard CLAS12 detector package it is unrealistic to get sufficient statistics in a reasonable data taking time




Based on these arguments, on 2016 we have submitted a LOI "LOI-12-16-004" to upgrade the CLAS12 detector which will allow to take luminosities of the of the order of $10^{37}$ $cm^{-2}s^{-1}$.

# GEM vs $\mu$RWell

| Cost estimate for 10 modules (150 cm x 50 cm) | | |
|---|---|---|
| | **Triple GEM**<br>Based quote for SBS U-V GEM of similar size | **µRWELL**<br>Based on approximate quote for a (65 cm x 55 cm) prototype |
| GEM foils /module | 2k$ / foil (×3) = **5k$** | |
| 2D U-V (or X-Y) Readout + connectors assembly / module | **7.5k$** | (include uRWELL device) = **13k$** |
| Support frames / module | (set of 7 frames) = **8k$** | (set of 4 frames) = **3.5k$** |
| Drift cathode / HV divider / Gas tubing… / module | **0.5k$** | **0.5k$** |
| **Total** | **21k$ / module** | **17k$ / module** |

Low Mass GEM with 80 MΩ DLC & NO Capacitive Sharing:
0.4 mm strips, 0.8 mm pitch

| | Quantity | Thickness µm | Density g/cm3 | X0 mm | Area Fraction | X0 % | S-Density g/cm2 |
|---|---|---|---|---|---|---|---|
| **Window & Drift** | | | | | | | |
| Kapton | 3 | 25 | 1.42 | 286 | 1 | 0.0262 | 0.0107 |
| Al | 2 | 3 | 2.7 | 89 | 1 | 0.0067 | 0.0016 |
| **GEM Foils** | | | | | | | |
| Copper | 6 | 5 | 8.96 | 14.3 | 0.8 | 0.1678 | 0.0215 |
| Kapton | 3 | 50 | 1.42 | 286 | 0.8 | 0.0420 | 0.0170 |
| **DLC + prePreg** | | | | | | | |
| Kapton | 1 | 25.2 | 1.42 | 194 | 1 | 0.0130 | 0.0036 |
| **Readout** | | | | | | | |
| Copper-350 | 2 | 5.4 | 8.96 | 14.3 | 1 | 0.0755 | 0.0097 |
| Kapton | 3 | 25 | 1.42 | 286 | 1 | 0.0262 | 0.0107 |
| NoFlu glue | 3 | 60 | 1.5 | 200 | 1 | 0.0900 | 0.0270 |
| **Gas** | | | | | | | |
| 70Ar30CO2) | 1 | 6000 | 1.84E-03 | 141270 | 1 | 0.0042 | 0.0011 |
| | | | | | **Total** | **0.452** | **0.103** |

Low Mass µRWELL with 80 MΩ DLC & 2-Pad layers Capacitive Sharing
0.4 mm strips, 0.8 mm pitch

| | Quantity | Thickness µm | Density g/cm3 | X0 mm | Area Fraction | X0 % | S-Density g/cm2 |
|---|---|---|---|---|---|---|---|
| **Window & Drift** | | | | | | | |
| Kapton | 3 | 25 | 1.42 | 286 | 1 | 0.0262 | 0.0107 |
| Al | 2 | 3 | 2.7 | 89 | 1 | 0.0067 | 0.0016 |
| **uRWELL Foil** | | | | | | | |
| Copper | 1 | 5 | 8.96 | 14.3 | 0.8 | 0.0280 | 0.0036 |
| Kapton | 1 | 50 | 1.42 | 286 | 0.8 | 0.0140 | 0.0057 |
| **DLC + prePreg** | | | | | | | |
| Kapton | 1 | 25.2 | 1.42 | 194 | 1 | 0.0130 | 0.0036 |
| **Readout** | | | | | | | |
| Copper-350 | 2 | 5.8 | 8.96 | 14.3 | 1 | 0.0811 | 0.0104 |
| Kapton | 4 | 25 | 1.42 | 286 | 1 | 0.0350 | 0.0142 |
| NoFlu glue | 4 | 60 | 1.5 | 200 | 1 | 0.1200 | 0.0360 |
| **Gas** | | | | | | | |
| 70Ar30CO2) | 1 | 6000 | 1.84E-03 | 141270 | 1 | 0.0042 | 0.0011 |
| | | | | | **Total** | **0.328** | **0.087** |