2024-LDRD-11: Low-Mass μRWELL detector for high luminosity ($10^{37} cm^{-2} s^{-1}$) experiments

Florian Hauenstein (PI)
Rafayel Paremuzyan (Co-PI)
Sara Liyanaarachchi (Postdoc)
Kondo Gnanvo (Contributor)

LDRD Review Meeting
07/26/24

Advisers: Stepan Stepanyan (JLab),
Maurizio Ungaro (JLab),
Raffaella De Vita (JLab)

Jefferson Lab

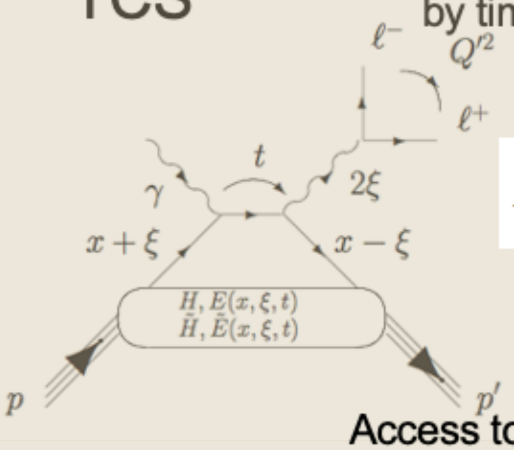
High Luminosity for Generalized Parton Distributions

S. Stepanyan, Hadron Femtography Workshop 2023

First experimental measurement with CLAS12 PRL 127, 262501 (2021)

TCS

Hard scale is defined by time-like photons



$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^{-}(\xi,x) H(x,\xi,t)$$

$$Im\ \mathcal{H}(\xi,t) = i\pi H(\xi,\xi,t)$$

Access to the Re-part of the Compton amplitude

Started in 2001, PRL 87, 182002. Now is the flagship physics program

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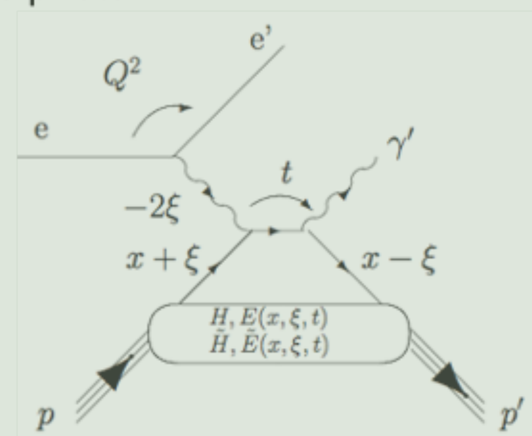
DVCS



CLAS12

GPD studies

~10^{35} luminosity

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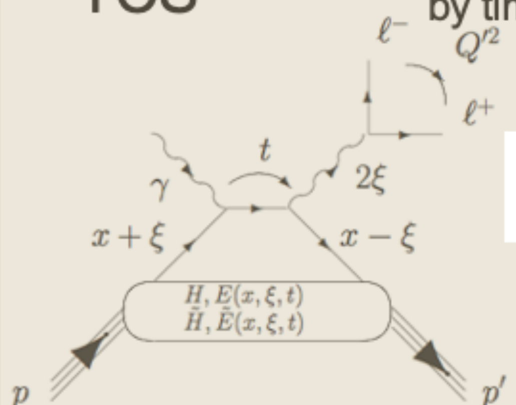

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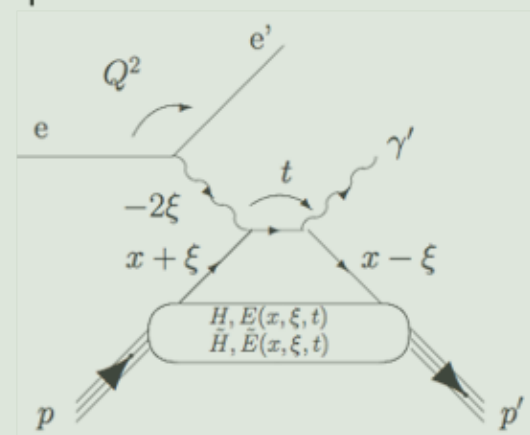
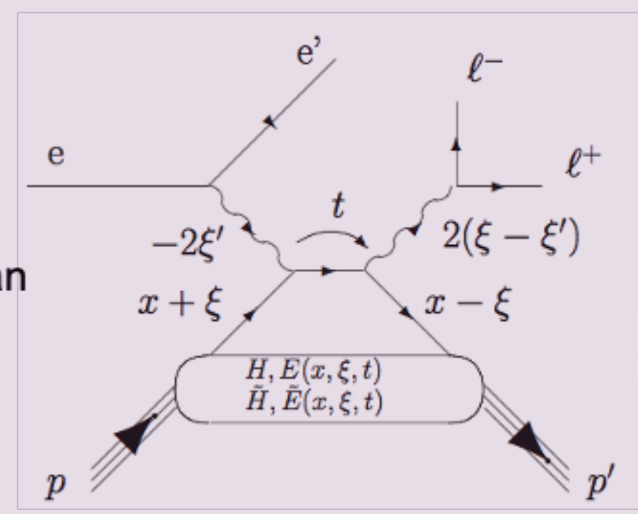


CLAS12
GPD studies
~10^{35} luminosity

DDVCS

Both space-like and time-like photons can set the hard scale



$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

$$H(2\xi'-\xi,\xi,t) + H(-(2\xi'-\xi),\xi,t)$$

- DDVCS is absolutely needed to map out GPDs in *x*, ξ and *t* space (*x* inaccessible with DVCS or TCS)
- DDVCS cross section three orders of magnitude lower than DVCS

High Luminosity for Generalized Parton Distributions

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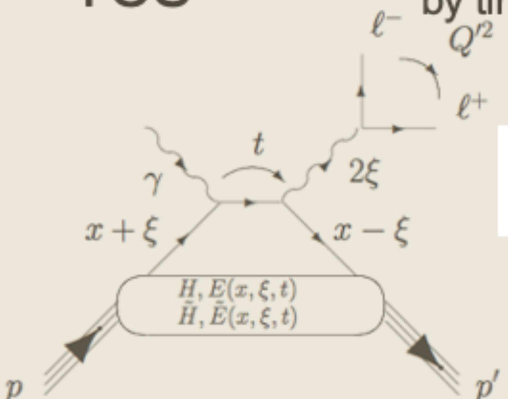

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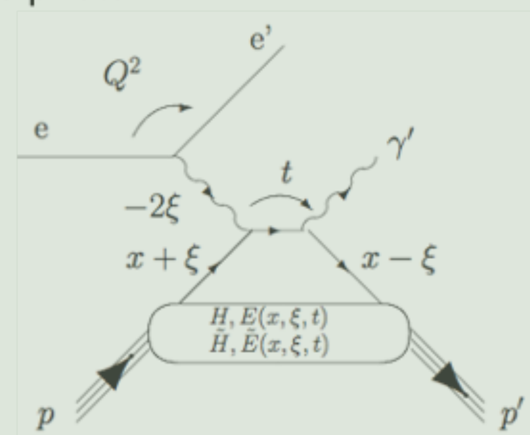

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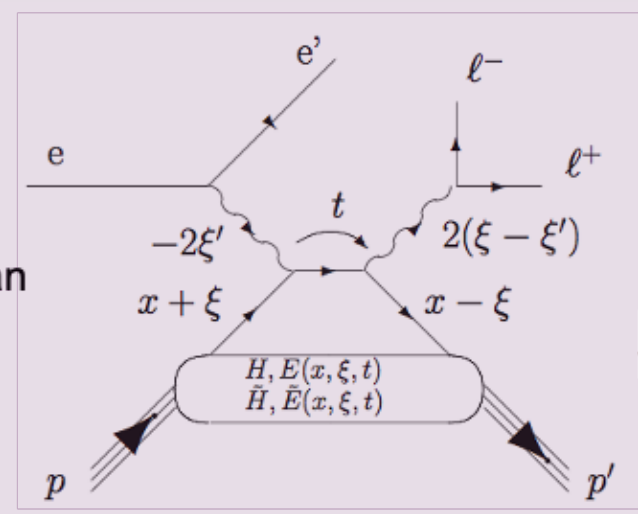

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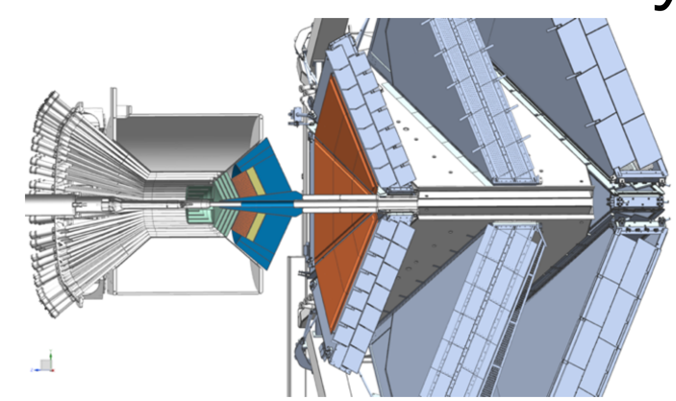
CLAS12
GPD studies
$\sim 10^{35}$ luminosity

Future μCLAS12
$\sim 10^{37}$ luminosity



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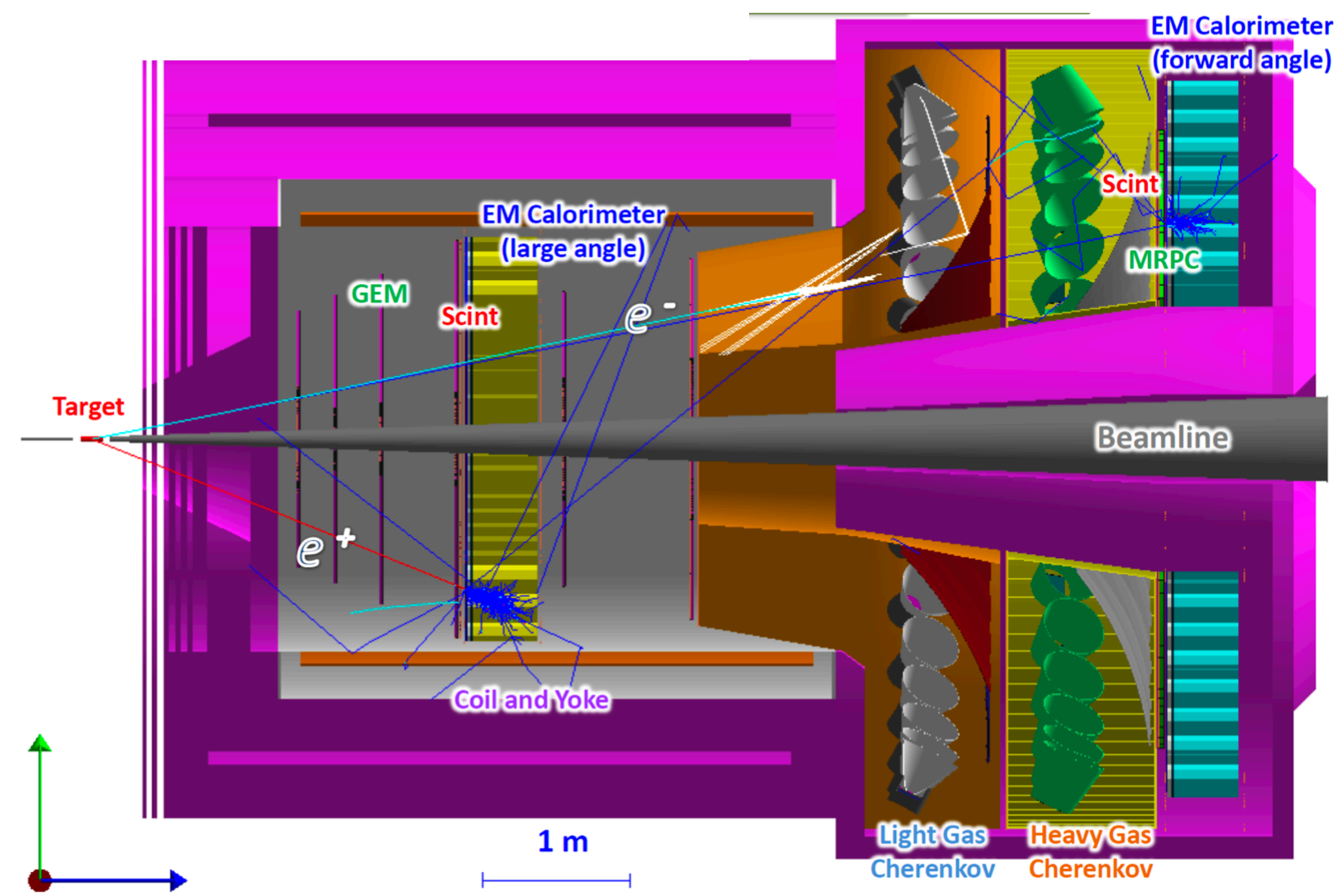
High Luminosity Experiments in Hall A

SoLID at 10^{37} luminosity (open geometry)

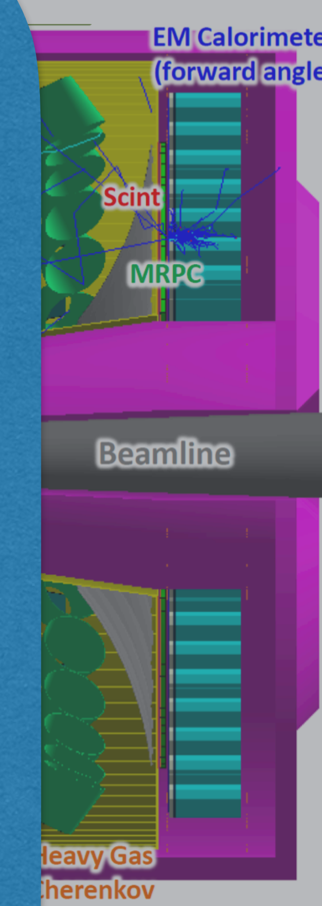
- 3D Hadron Imaging
  - TMDs with SIDIS
  - GPDs (DVCS, TCS, DVMP, DDVCS)
- J/ψ production at threshold

Z. Zhao, Hadron Femtography Workshop 2023



High Luminosity Experiments in Hall A

shop 2023



SoLID at 10^3

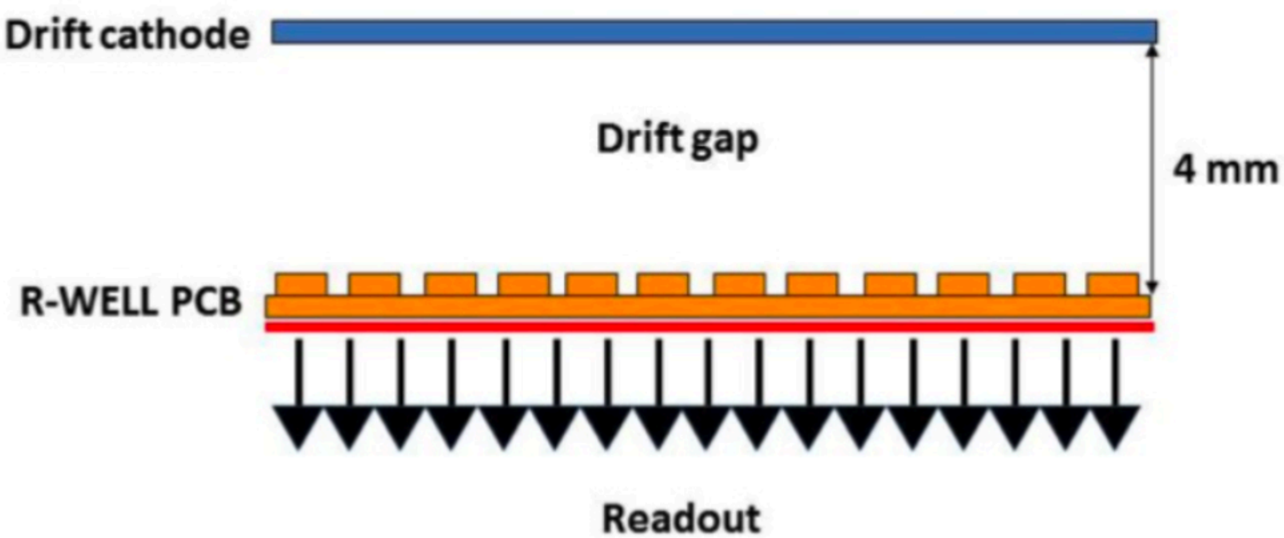
- 3D Hadr
  - TMDs
  - GPDs
- J/ψ proc

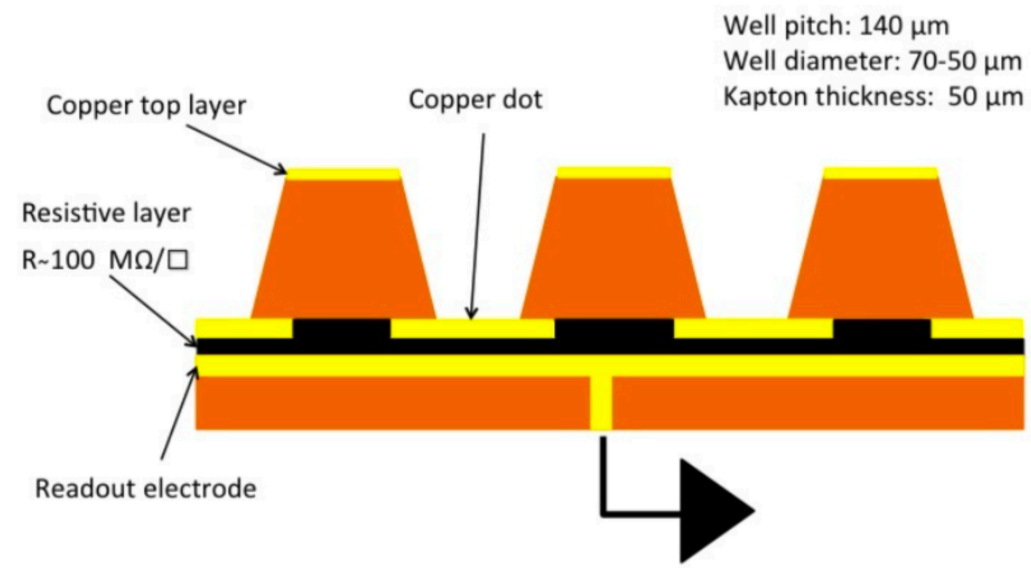
Challenge: High occupancies and rates in detectors (~MHz/cm^2)

Need: Tracking detectors capable of running at these rates

This proposal: μRWELLs

Micro-resistive Well (µRWELL) Detector





- µRWELL is a Micro-Pattern Gaseous Detector
  - Amplification in wells
  - Spark protection due to resistive layer
- Advantages
  - Intrinsic low-mass (low material budget)
  - Good spatial and timing resolution
  - Low production costs
  - No frames needed in active area
- Disadvantages
  - Operability under high particle fluxes > 1MHz/cm^2
  - Relative new detector technology

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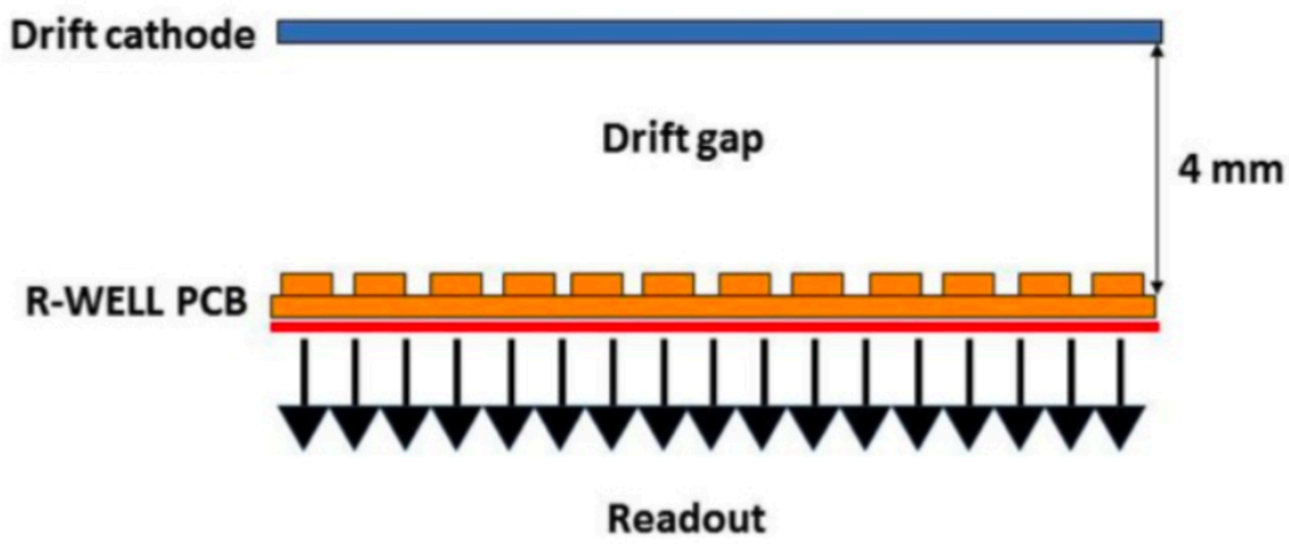

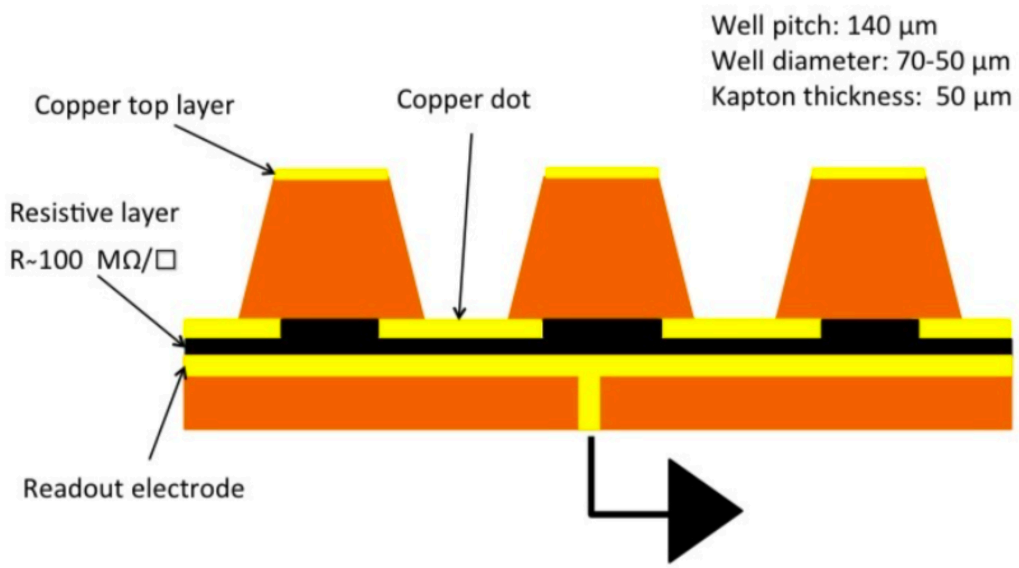

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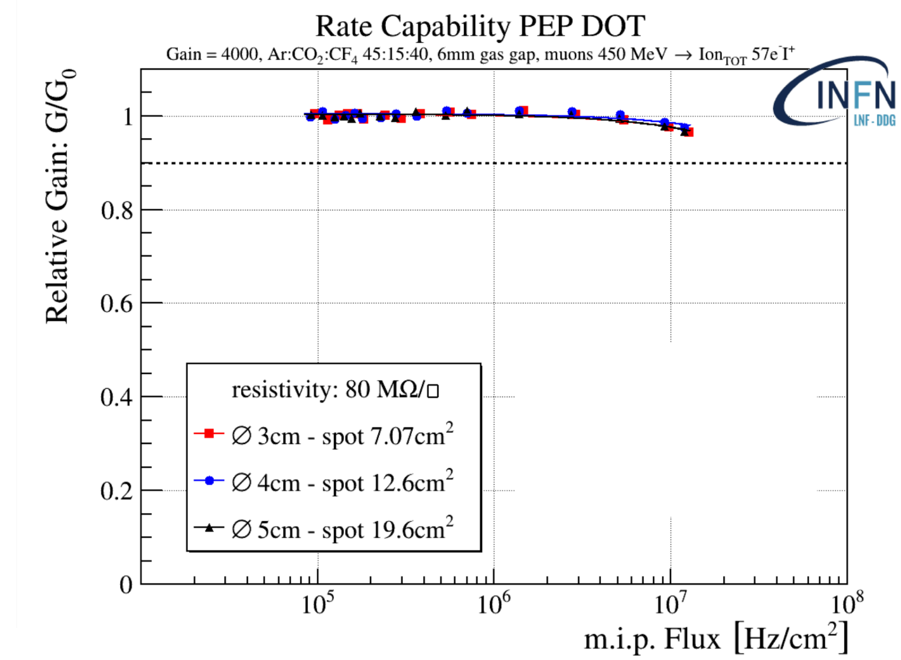
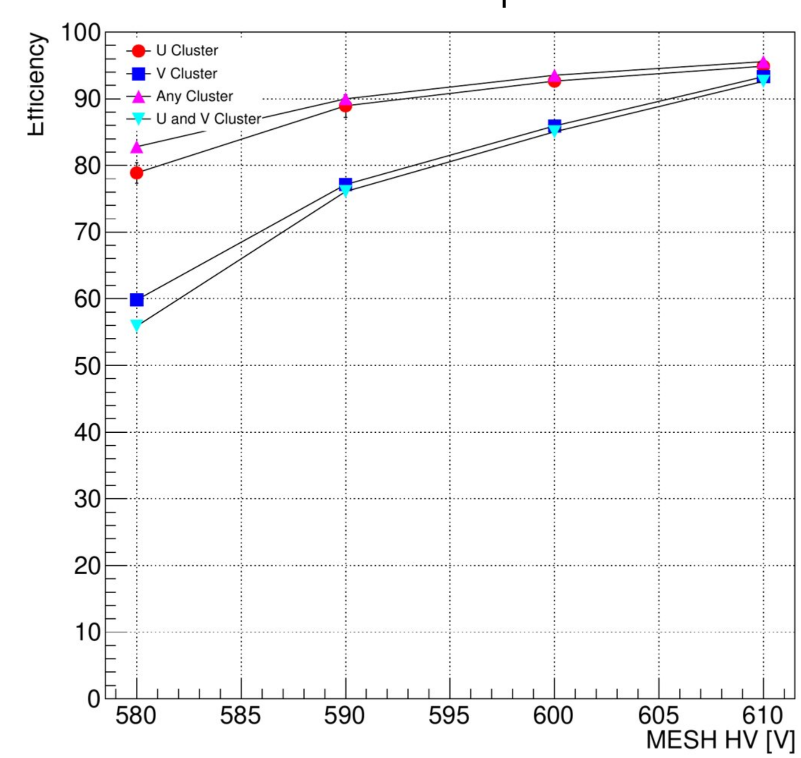
What do we want to study

- Rate capability
  - Stability of operation
  - When does gain drop?
- Efficiency dependence on HV and rate
  - When does efficiency reach plateau?
  - What is the behavior when rates increase?
- Spatial resolution
  - Dependence on HV and rate
  - XYU readout better than XY at high rates due to hit ambiguities?
  - Worse resolution at high rates?
- Dependence on gas mixtures
  - Ar:CO_2 (80:20)
  - Ar:Isobutane (90:10)
  - Ar:Isobutane:CO_2 (93:2:5)
  - What is the optimal gas?

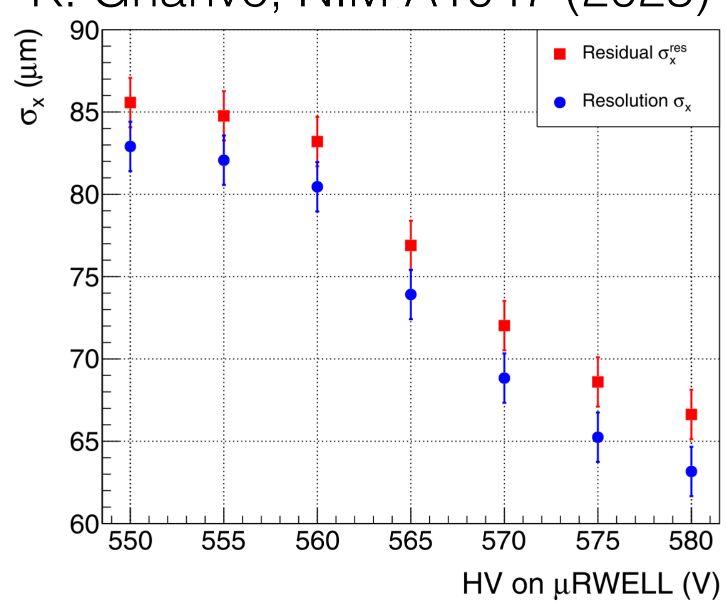
M. Giovanetti's Talk



from CLAS12 μRWELL



K. Gnanvo, NIM A1047 (2023)



1st Year Milestones

- Build 10cm x 10cm prototypes to study effects on “high-rate” capability. Vary
  - Grounding schema (DLC)
  - Readout schema
  - Gap width to cathode
- Test of prototypes
  - Cosmic
  - Beam at Jefferson Lab
- Development of prototype simulation
- Hit reconstruction and tracking software
- Validation of software with real data

prototype	DLC design	readout	gap width
A	1	2D	normal
B	2	2D	normal
C	1	XYU	normal
D	1	2D	thin

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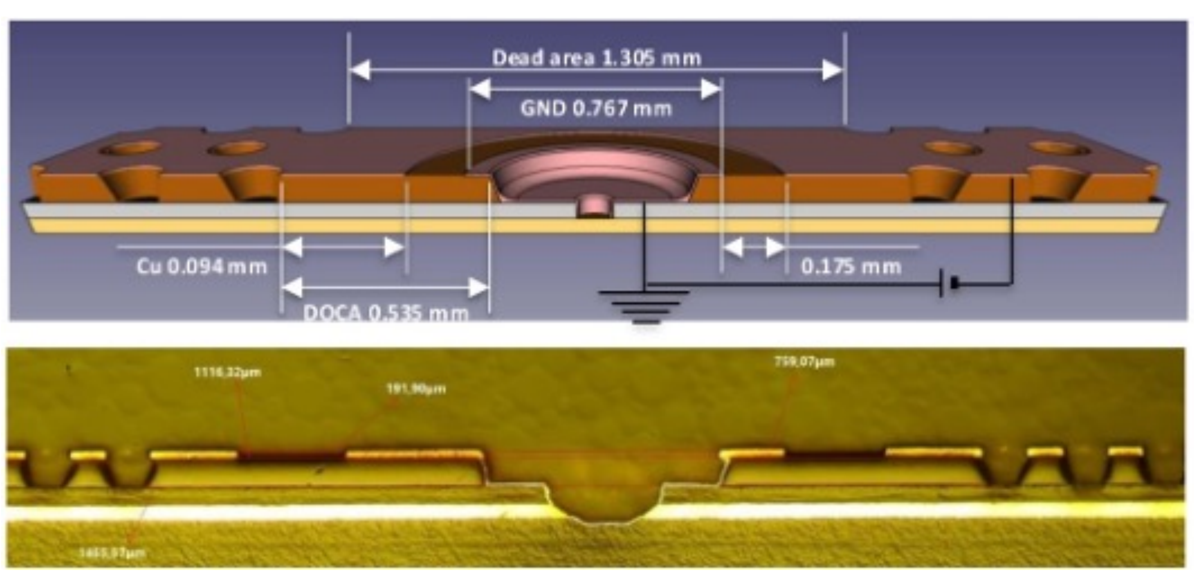
- Challenges in first year:
  - delayed start postdoc (May 2024) —> 1st year budget ~$50k less spending
  - building and shipping of prototypes at CERN delayed to mid July
  - no beam at Jefferson Lab at the end of first year

Status of First Year Objectives (1)

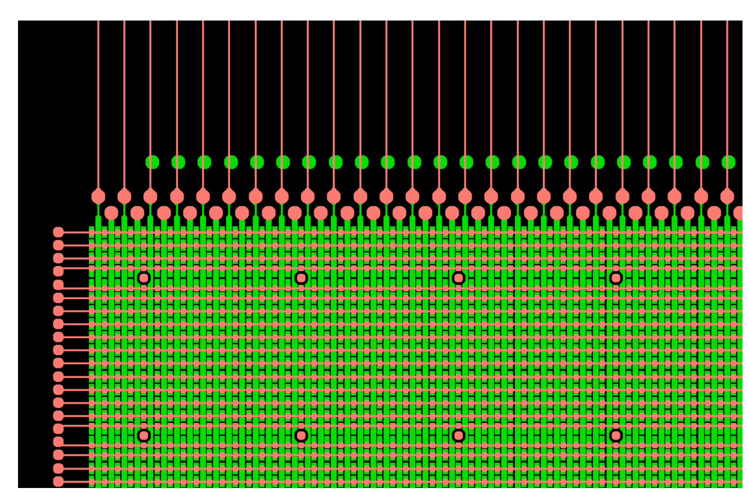
- Design of 10x10cm^2 prototypes
  - Several meetings with CERN during design process
  - Modifications of design compared to initial plans after discussion with experts

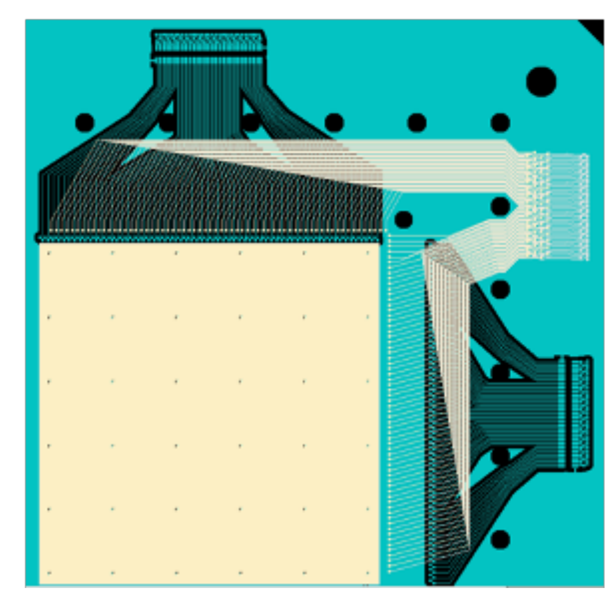
Prototype	Dots pitch	Readout	Readout strip pitch	Well pitch
A	2cm	XY	X=Y=800μm	140μm
B	1cm	XY	X=Y=800μm	140μm
C	2cm	XYU	X=Y=800μm, U=1.6mm	140μm
D	2cm	XY	X=Y=800μm	100μm

- Decided to test prototype with smaller well pitch to increase gain at high rates
- Other designs as planned - two versions of DLC structure and XYU readout



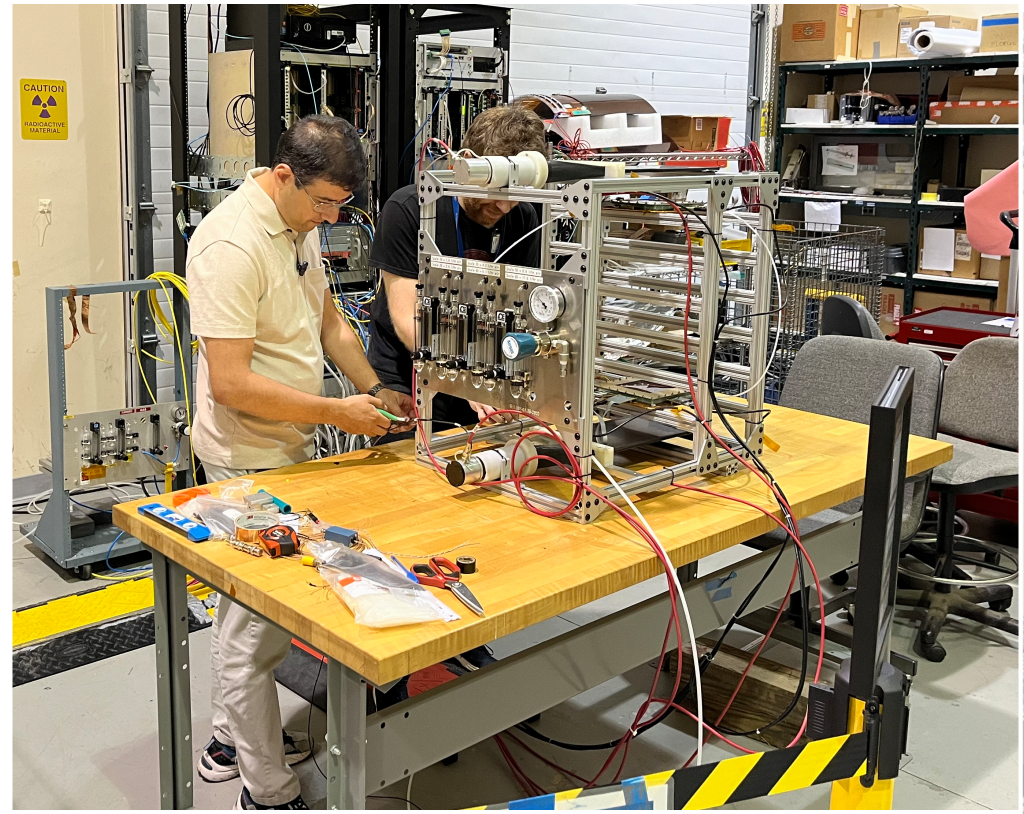
DLC grounding - PEP dot

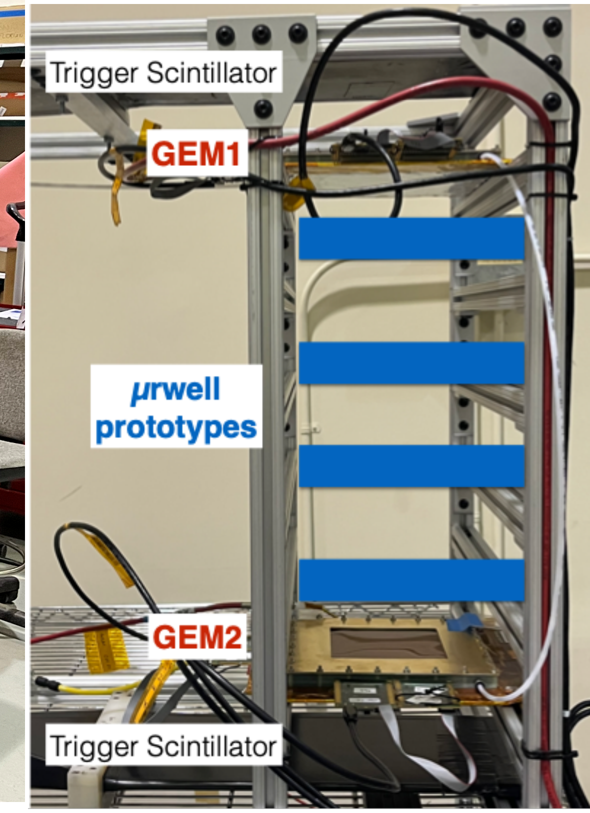

XY Readout


XYU Readout

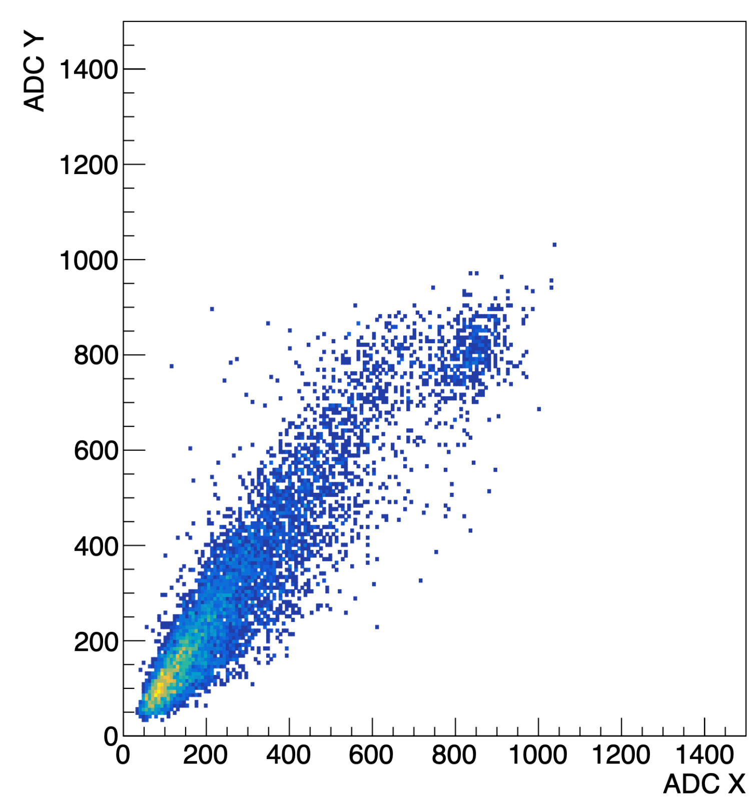
Status of First Year Objectives (2)

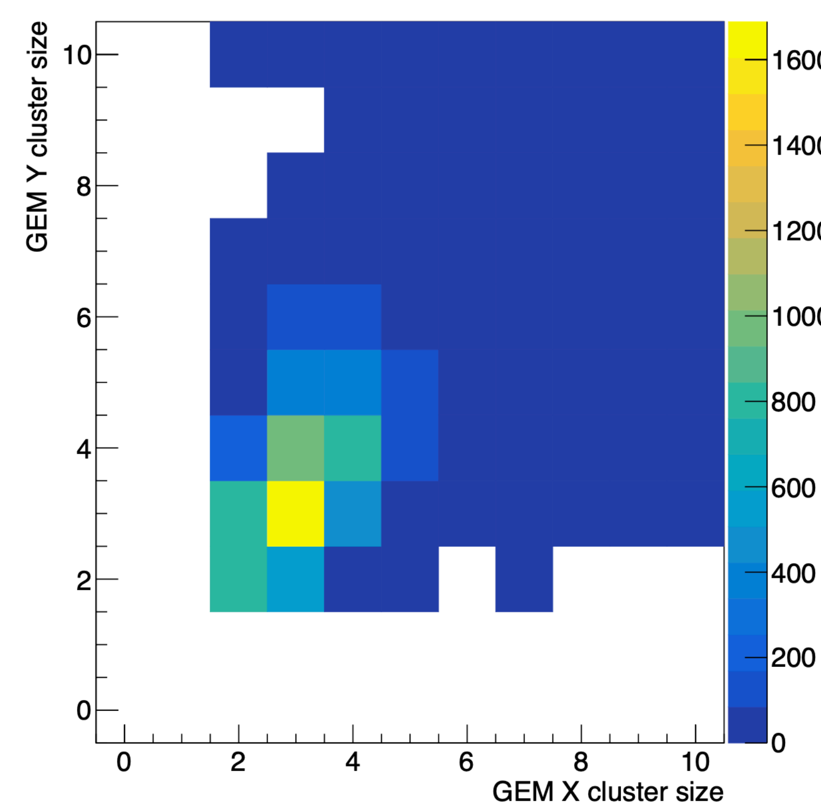
- Test stand
  - GEM reference detectors
  - Scintillators for triggering
  - APV25/SRS readout
  - Gas panel





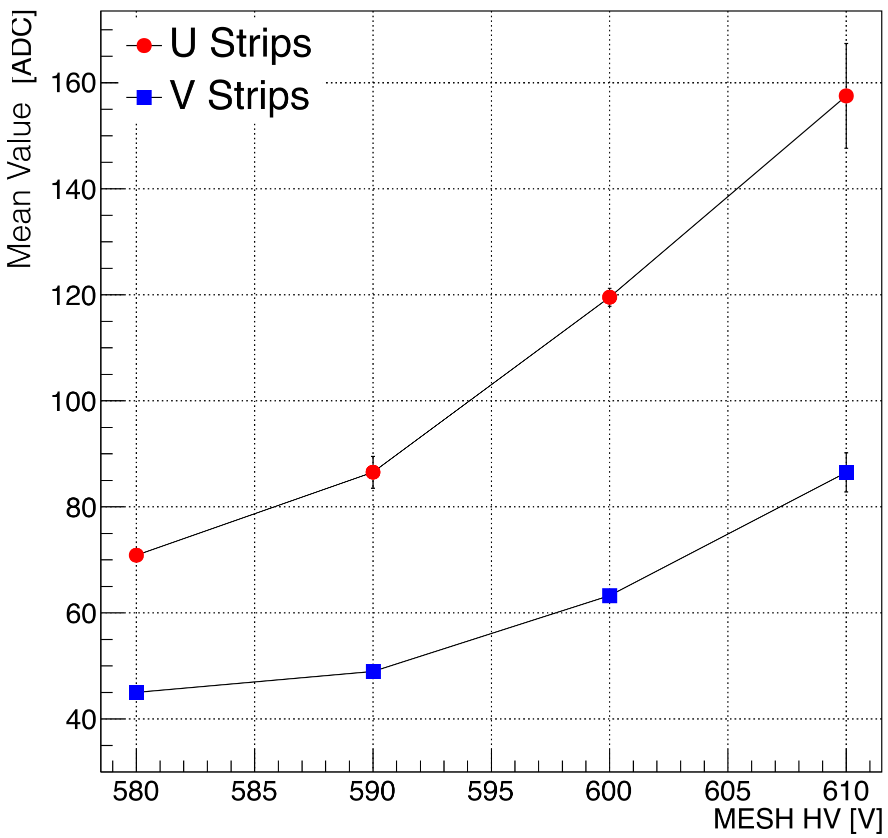
- Cosmic with GEMs

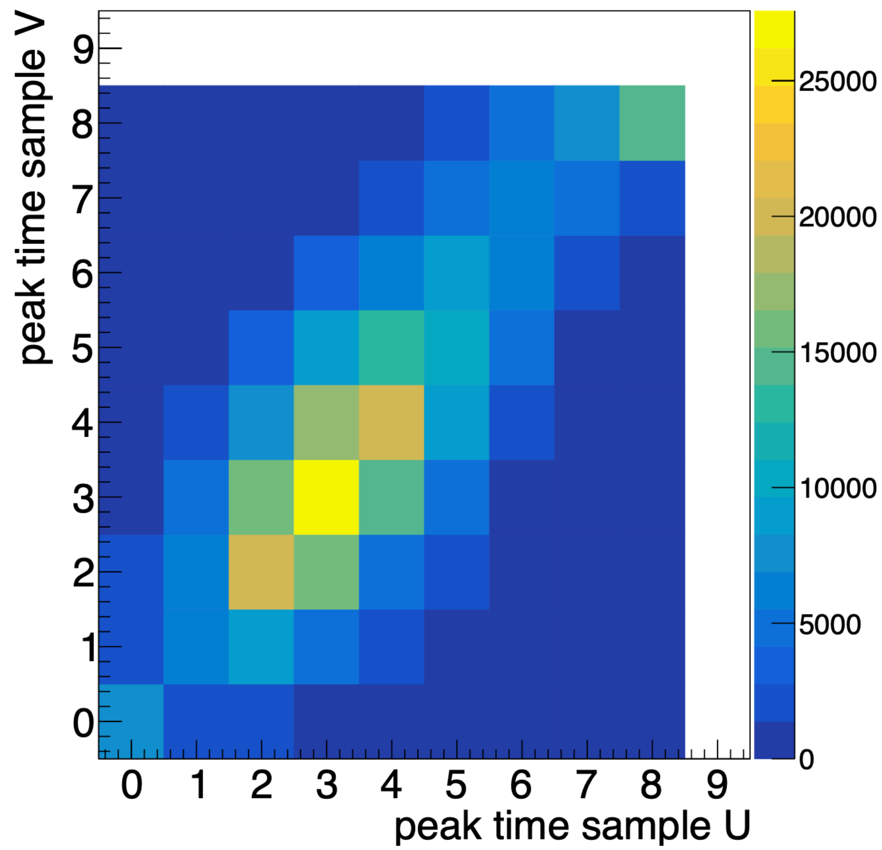


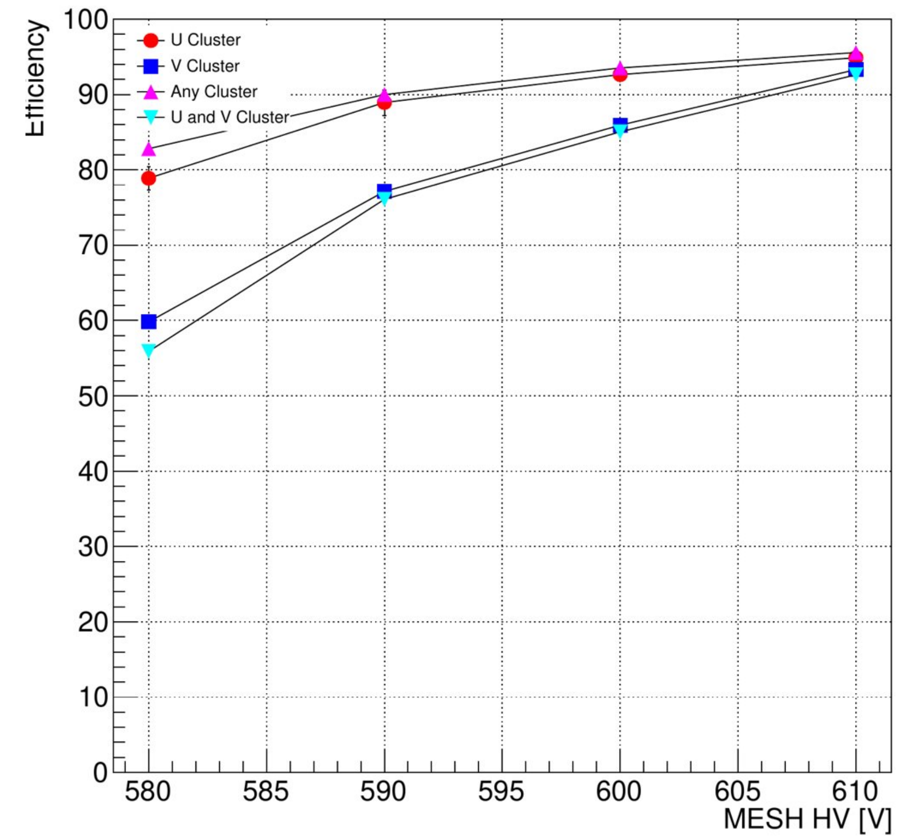


Status of First Year Objectives (3)

- Development of analysis software using CLAS12 µRWELL data



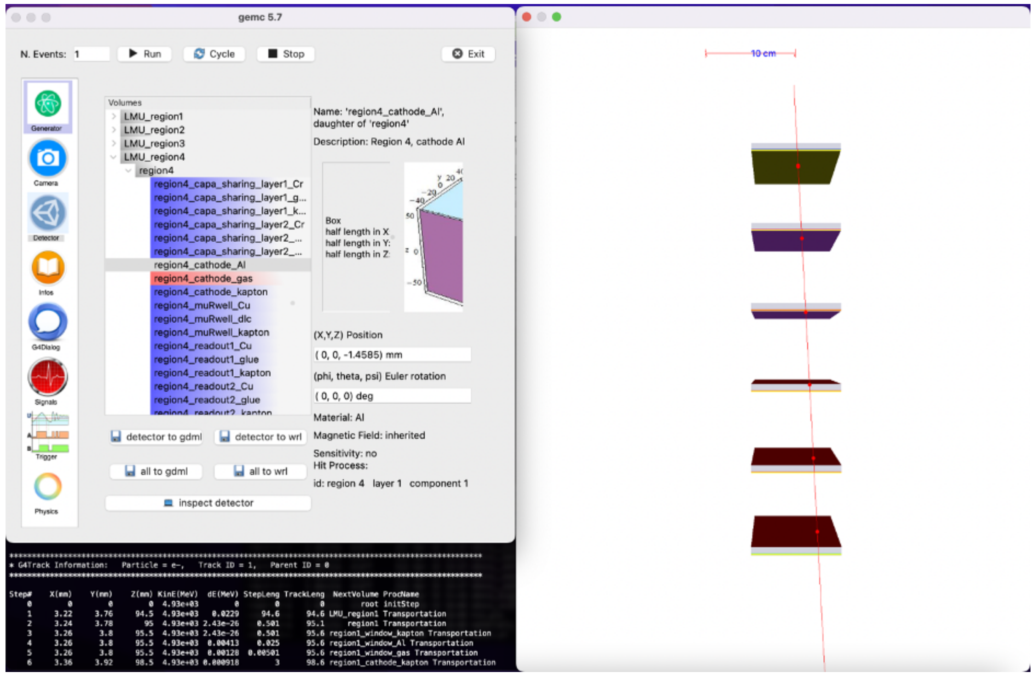




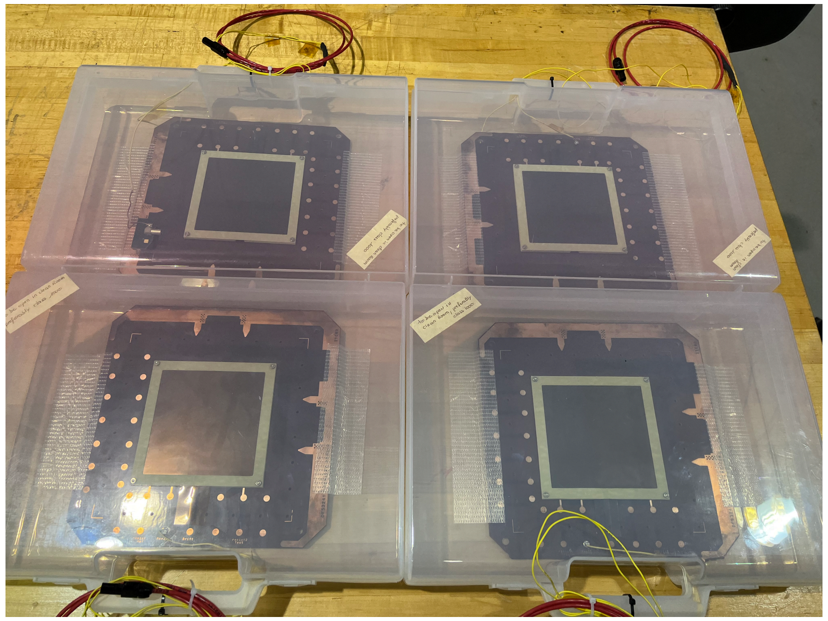
We are ready to take and analyze data when prototypes passed initial tests of leakage currents!

Status of First Year Objectives (4)

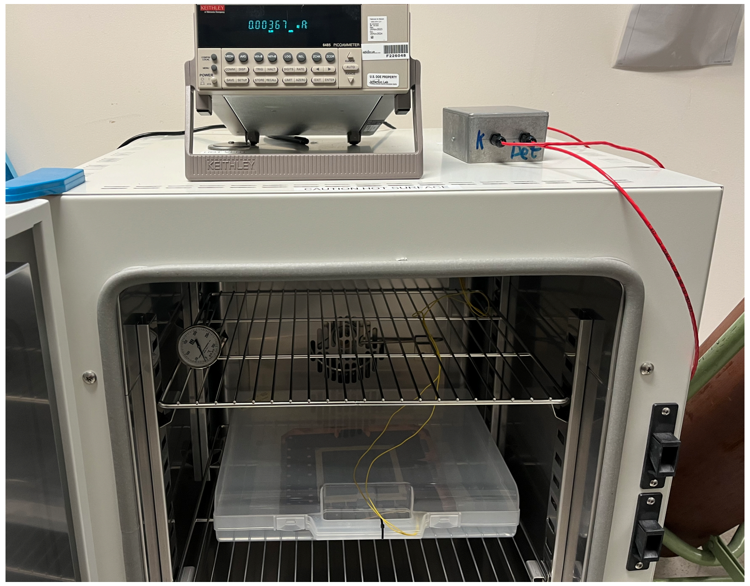
- Integration of detectors in simulation



- Prototypes arrived



Check of leakage currents in oven



- Talk at QNP conference 2024 (https://indico.icc.ub.edu/event/180/contributions/2797/) —> Proceedings to follow
- Submission to DNP 2024

Status and Plans

1. Year:
   - Build 10cm x 10cm prototypes to study effects on “high-rate” capability ✓
   - Test of prototypes
     - Cosmic ✓ (will be completed within 1st year)
     - Beam at Jefferson Lab × (need to be completed in 2nd year)
   - Development of prototype simulation ✓ (details to be improved with cosmic tests)
   - Hit reconstruction and tracking software ✓
   - Validation of software with real data × (need to be completed in 2nd year with beam)

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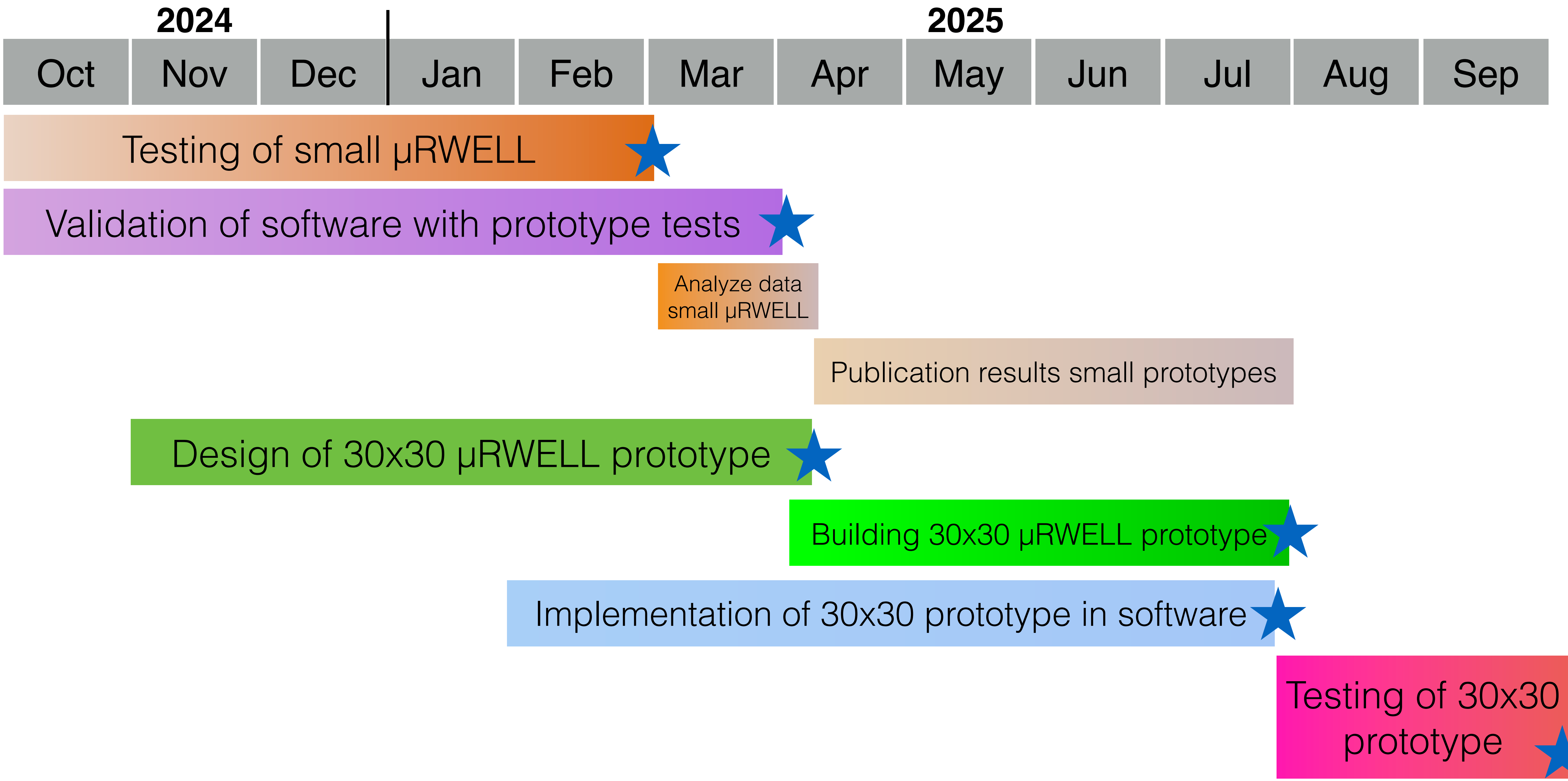
    - Hit reconstruction and tracking software ✓
    - Validation of software with real data × (need to be completed in 2nd year with beam)

2. Year:
    - Test 10cm x 10cm detectors with beam at Jefferson Lab
    - Validate software with beam data
    - Build 30cm x 30cm prototype with optimized design from small prototype tests
    - Implement 30cm x 30cm prototype into simulation
    - Test 30cm x 30cm prototype with cosmic and beam to understand scalability of design
    - Finalize design and software based on tests

Second Year Objectives and Milestones★



End of project deliverable:

- Efficiency and resolution dependence on particle rates, HV settings and gas mixture
- Validation of simulations and reconstruction software
- Optimized and tested high-rate capable µRWELL design for high-luminosity experiments

Budget and Responsibilities

- Total 2nd year budget - $188k
  - $140k personnel

Name	Role	FY Effort (% FTE)	Responsibilities
Florian Hauenstein	PI	15	Oversee project as PI and work on design and test of prototypes
Rafayel Paremuzyan	Co-PI	10	Development of simulation and reconstruction together with Postdoc, support prototype tests
Kondo Gnanvo	Contributor	5	Design of prototypes, support testing of prototypes
Sara Liyanaarachchi	Postdoc	80	Development of software, test measurements of prototypes

  - $40k materials and supplies
    - large prototype ~ $30k
    - test stand materials and transport ~ $10k
  - $8k travel

Backup Slides

Q1: Testplan for prototypes - what do we learn

- General: GEM trackers in test stand are baseline detector for tracking
- Cosmic tests in EEL
  - general functionality of prototypes
  - efficiency and resolution dependence on HV at very low particle rates —> what we can achieve under best case scenario
  - Gas mixture tests —> if bad with cosmic should be also bad for high rates
- (Possibly) Test with X-ray gun at UVA
  - gain dependence on rate —> what is the maximum rate before gain drops
  - rate limits on stable operation before beam tests
- Tests with beam in Hall B(A/C?) at large angle = kHz/cm particle rate
  - establish stable operation conditions
  - HV scans (efficiency, resolution, stability) —> all prototypes should work well at these rates, HV dependence similar to cosmic
  - gas mixture study —> Does one gas has unstable operation?
- Move detector to smaller angles = MHz/cm particle rate (probably move in couple of steps)
  - Repeat the same measurements as at lower angles
  - Learn:
    - At which rate does efficiency drop? Similar to gain drop?
    - Limits in operational stability?
    - How does the resolution depend on the rate at similar HV?
    - What is the effect of the significant hit ambiguities at larger rates? XYU better than XY?
    - Does more gain from more wells increase rate limit?

Q2: Estimation of Particle Rates at 10^37

- Solid PreCDR (https://solid.jlab.org/DocDB/0002/000282/001/solid-precdr-2019Nov.pdf) Table 24 estimated about 1.6 MHz/cm2 rate for forward tracking detectors
- CLAS12 Letter of Intent for high-lumi DDVCS:https://www.jlab.org/exp_prog/proposals/16/LOI12-16-004.pdf, Rates seen in Fig 23 for forward tracker, it highly depends on particle type, expected about 0.6 MHz/cm2 at 5 deg which is dominated by photons and their conversion.
- CLAS12 SVT rate simulations (https://userweb.jlab.org/~ungaro/tmp/GEMC_SVT_review.pdf) gave rates in SVT of 1.5GHz photons, 2.6 MHz e- and 1.4 MHz protons (other particles less) in the inner layers. With a energy cut of 20keV this reduces to 56MHz, 1.4MHz and 1.4 MHz respectively at 10^35 luminosity. From here we can do some estimations for 10^37 luminosity:
  - Just scaling from 10^35 gives 5.6 GHz photons, 140 MHz electrons and 140 MHz protons at 10^37 for the whole surface of SVT
  - The surface size of the inner layer of the SVT is ~40cm * 2 * pi * 60cm = 15000cm**2
  - This gives a rate of 37MHz/cm^2 photons, 0.9 MHz/cm^2 electrons and protons at 10^37 luminosity. The photon conversion rate is around 1% or lower which gives then a photon rate of 0.37 MHz/cm^2
  - Overall we should get around 2 MHz/cm^2 rate of particles in CLAS12 around the target at the SVT
- To conclude: All existing numberes from simulations and estimations give MHz/cm^2 rate of particles in trackers at 10^37 luminosity

Impact of Project on JLab's Scientific Mission

LDRD Call for Proposals

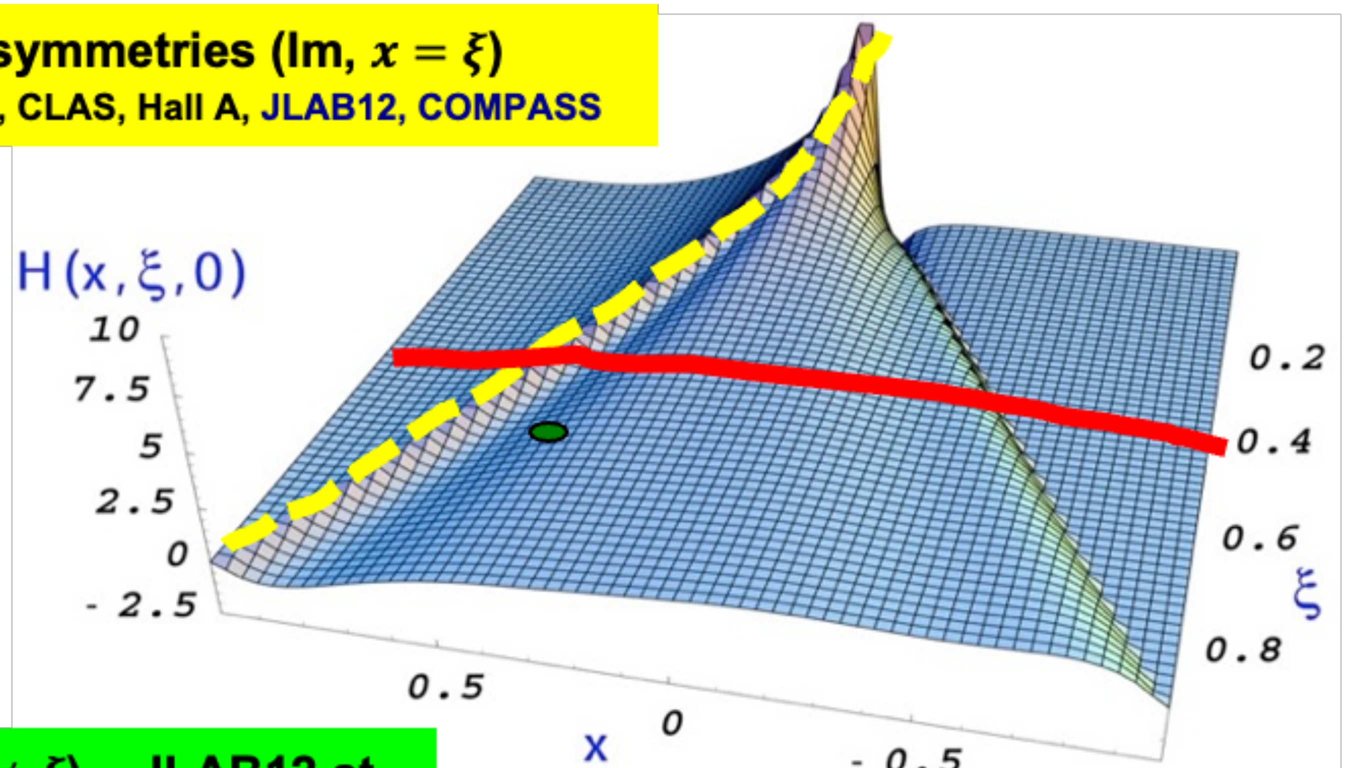
Proposals on a wide selection of potential topics in those areas are welcome. However, relevance to the following topics is given strong consideration in the evaluation of the LDRD proposals as they have been identified as being of strategic value to the future of the Laboratory and would benefit from R&D:

- **Advanced Detector Technologies**: Areas of interest include development of advanced detector and related technologies that facilitate novel approaches in capability, size, performance or cost for the broad TJNAF science program - including science **at 22 GeV energies,** detectors that can accept high luminosity beams, and detector applications in medicine and industry.

- ***Strategic value for the lab*** to develop advanced detectors for high luminosity experiments (>10^{37}cm^{-1}s^{-1})
- CEBAF experiments at the luminosity frontier natural continuation of the 12 GeV physics program - opens up new measurement like DDVCS
- High-rate µRWELL detectors
  - Low material budget
  - Good resolutions
  - Low production costs
- Synergy with recent developments in Detector & Imaging group

GPD Phase-space of Measurements

Spin asymmetries (Im, $x = \xi$)
HERMES, CLAS, Hall A, JLAB12, COMPASS



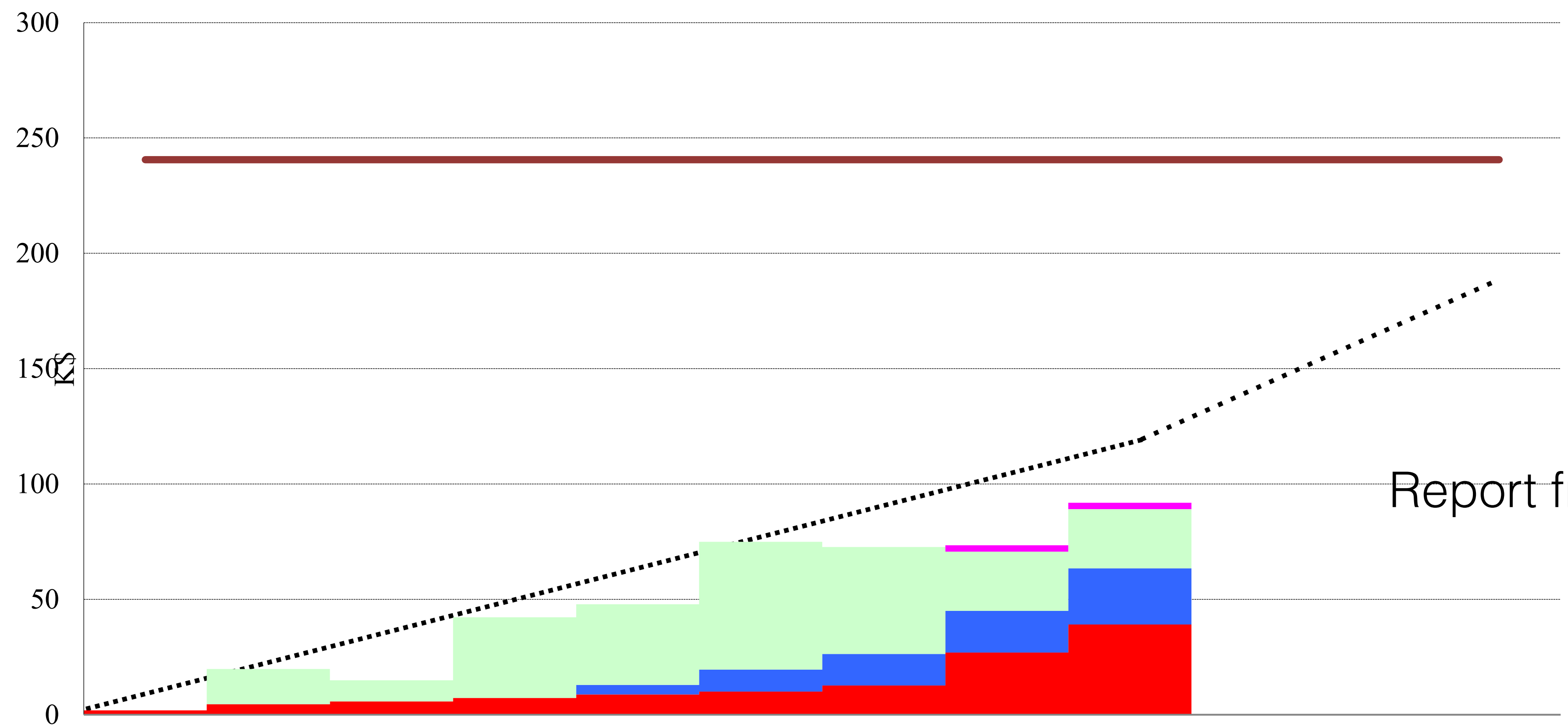
Angular asymmetry in TCS (|Re|)
JLAB12

Charge asymmetry in DVCS (|Re|)
HERMES, COMPASS, JLAB12

DVCS Cross sections (|Re|^2)
H1, Hall A, JLAB12, COMPASS

DDVCS (Im, $x \neq \xi$) – JLAB12 at
$L \geq 10^{37}$ cm^{-2} sec^{-1}

Budget Status - End of July



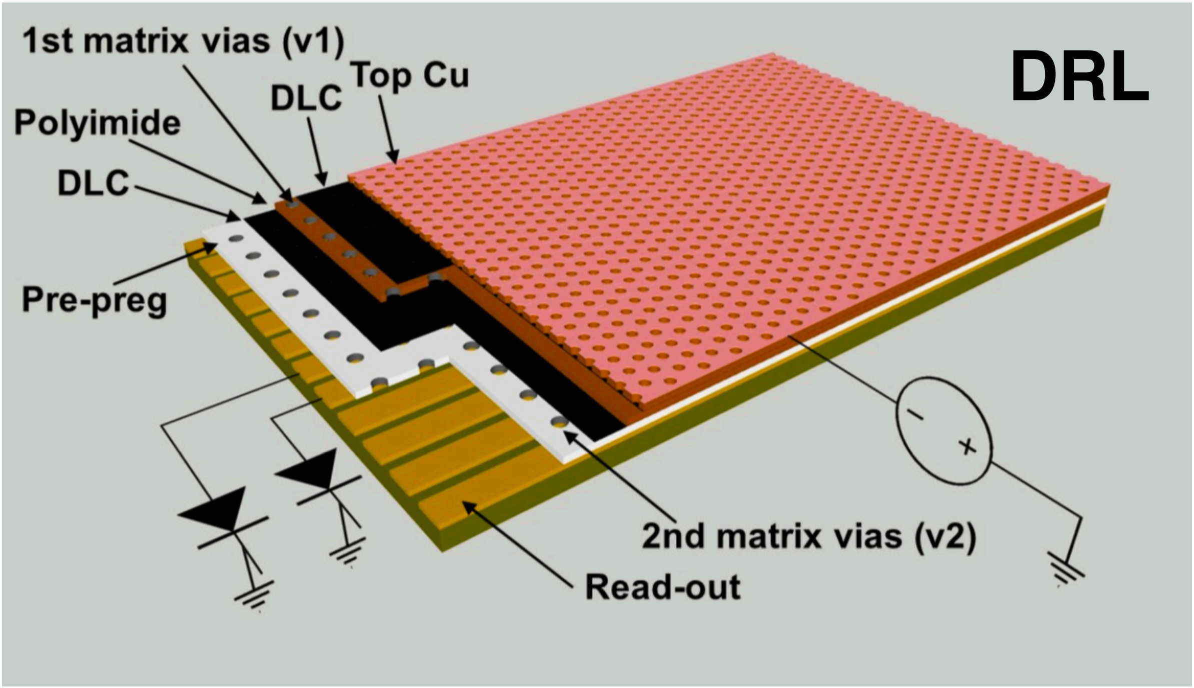
Report from Tanya

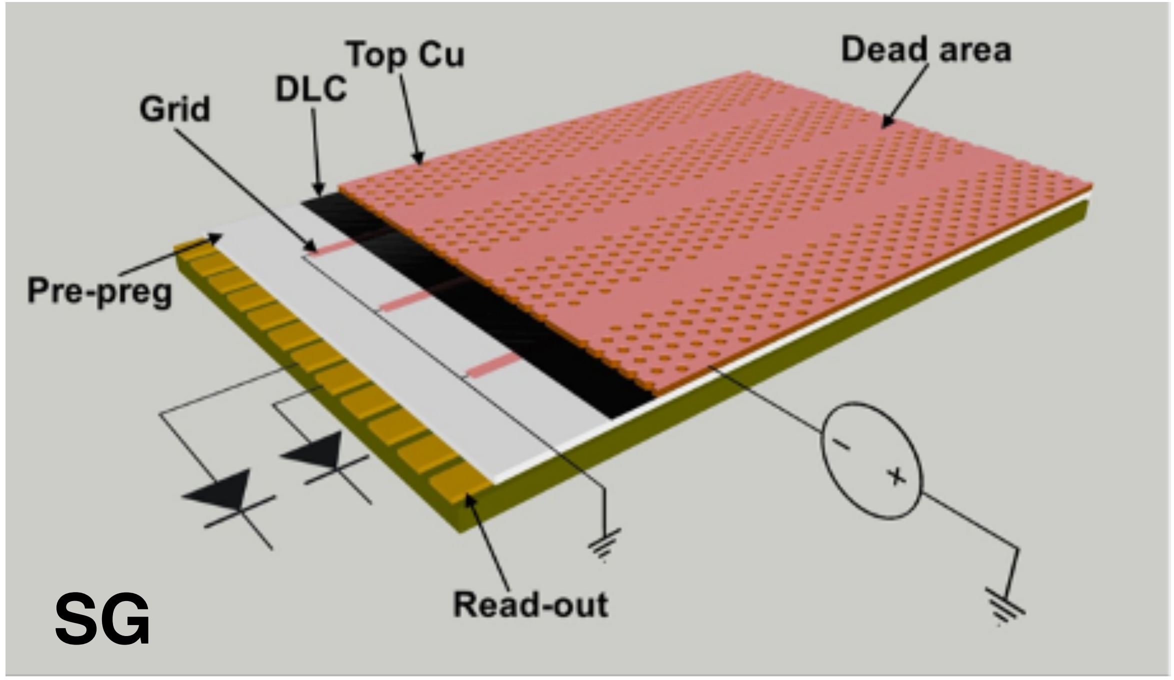
	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24
YTD Spending	2	20	21	49	50	72	79	101	113	0	0	0
Pending	0	0	0	0	0	0	0	3	3	0	0	0
Open Obligations	0	15	9	35	35	55	46	26	26	0	0	0
Expenses	0	0	0	0	4	9	14	18	24	0	0	0
Labor	2	4	6	7	9	10	13	27	39	0	0	0
Funding	241	241	241	241	241	241	241	241	241	241	241	241
3-Mo Avg Projection												

- Open Obligations
  - urwell: $24k
  - VXS crate: $20k
- Labor expenses not on track due to delayed start of postdoc, mismatch of ~$50k
- Expect increased work in the last quarter since prototype arrived —> detailed cosmic tests

Previous Studies of High-Rate µRWELL Resistive Layers

G. Bencivenni et al., JINST 14, P05014 (2019)





- High-rate layouts tested with pion beams at CERN
- >5 MHz/cm² rate capability with maximum 10% gain loss
- SG layout easier to fabricate than DRL