Neutral Particle Spectrometer (NPS)

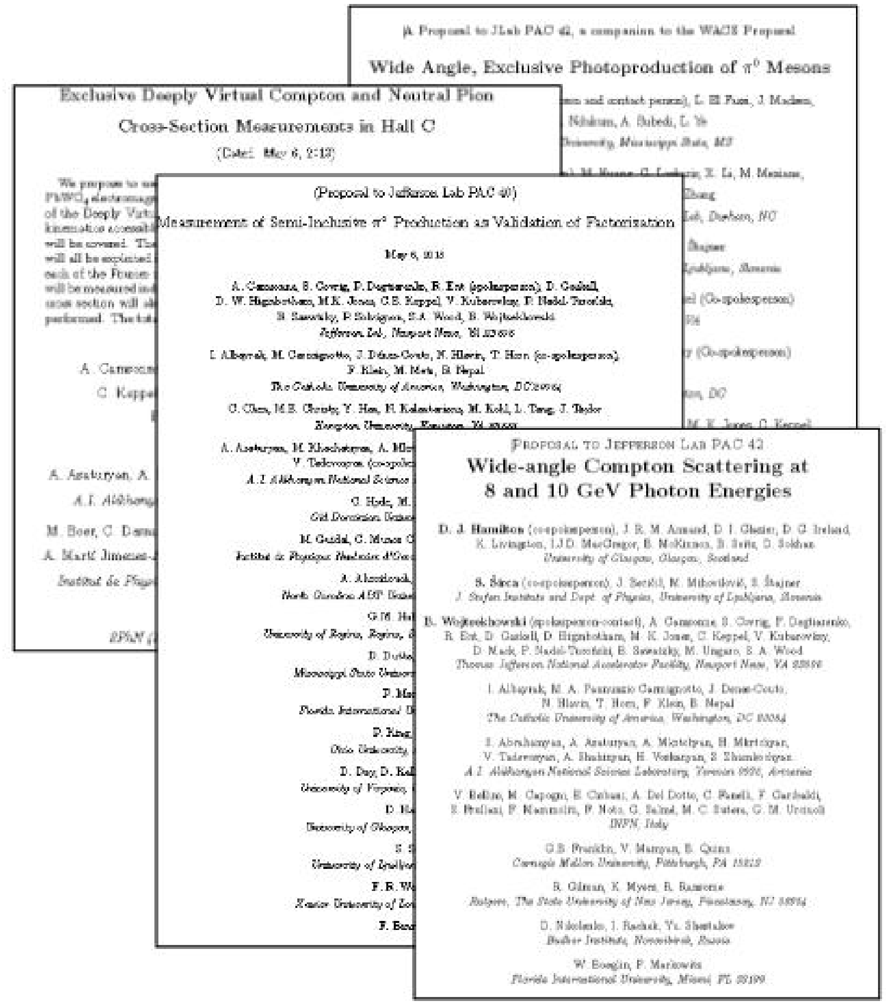
Vladimir V. Berdnikov
on behalf of the NPS collaboration

Hall C Users Meeting
February 18-19 2022

NPS collaboration

- Consist of members involved in NPS construction plus additional collaborators on the six experiments

1. Ibrahim Albayrak (Akdeniz Univ/Turkey)
2. Salina Ali (CUA)
3. Moskov Amaryan (ODU)
4. Vladimir Berdnikov (CUA)
5. William J. Briscoe (GWU)
6. John R.M. Annand (U Glasgow)
7. Arshak Asaturyan (AANL, YerPhI)
8. Vincenzo Bellini (INFN-Catania)
9. Kai Brinkmann (Giessen U.)
10. Marie Boer (CUA)
11. Alex Camsonne (JLab)
12. Marco Carmignotto (JLab)
13. Donal Day (UVa)
14. Dipangkar Dutta (MSU)
15. Stefan Diehl (Giessen U.)
16. Rolf Ent (JLab)
17. Michel Guidal (IPN-Orsay)
18. David J. Hamilton (U Glasgow)
19. Tanja Horn (CUA)
20. Charles Hyde (Old Dominion University)
21. Dustin Keller (UVa)
22. Cynthia Keppel (JLab)
23. Mitchell Kerver (ODU)
24. Edward Kinney (U. of Colorado)
25. Greg Kalicy (CUA)
26. Ho-San Ko (IPN-Orsay)
27. Mireille Muhoza (CUA)
28. Arthur Mkrtchyan (AANL, YerPhI)
29. Hamlet Mkrtchyan (AANL, YerPhI)
30. Carlos Munoz-Camacho (INP-Orsay)
31. Pawel Nadel-Turonski (Stonybrook)
32. Gabriel Niculescu (James Madison U.)
33. Rainer Novotny (Giessen U.)
34. Rafayel Paremuzyan (NH)
35. Ian Pegg (CUA)
36. Hashir Rashad (Old Dominion University)
37. Julie Roche (Ohio University)
38. Oscar Rondon (UVa)
39. Simon Sirca (U Ljubljana)
40. Alex Somov (JLab)
41. Igor Strakovsky (GWU)
42. Vardan Tadevosyan (AANL, YerPhI)
43. Richard Trotta (CUA)
44. Hakob Voskanyan (AANL, YerPhI)
45. Rong Wang (IPN-Orsay)
46. Bogdan Wojtsekhowski (JLab)
47. Steve Wood (JLab)
48. Simon Zhamkochyan (AANL, YerPhI)
49. Carl Zorn (JLab)
50. Jixie Zhang (UVa)



- **Collaboration meetings since 2012**

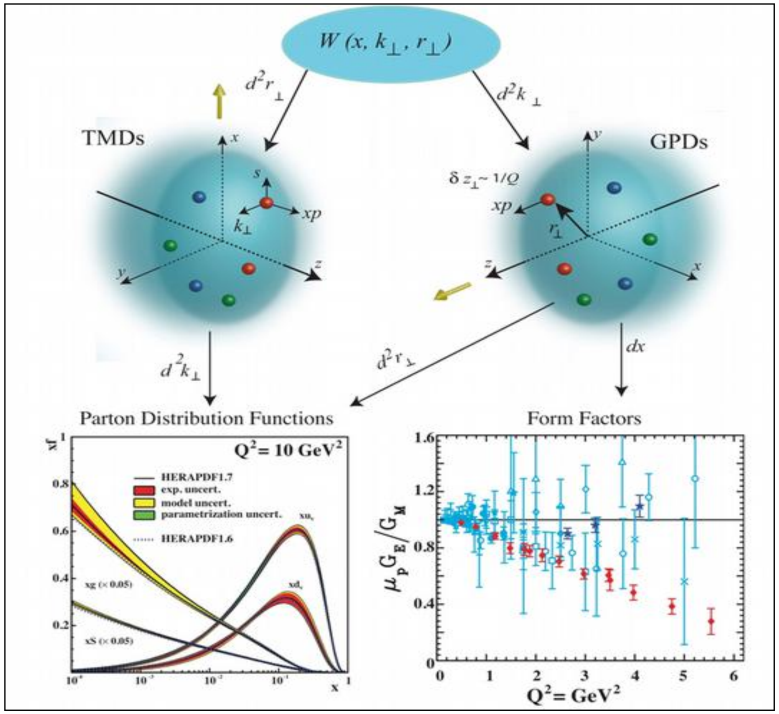
Experiments overview

Experiment	Exp #	Beam	Target	PAC Days	Rating
π^0 SIDIS	E12-13-007	$\vec{e}^-$	L H_2	(26)	A^-
DVCS and Exclusive π^0	E12-13-010	$\vec{e}^-$	L H_2	53	A
Wide Angle Compton Scattering (WACS)	E12-14-003	e^-, γ	L H_2	18	A^-
Wide Angle Exclusive π^0 photoproduction	E12-14-005	e^-, γ	L H_2	(18)	B
DVCS – days moved from Hall A	E12-06-114	$\vec{e}^-$	L H_2	35	A
A_{LL} & A_{LS} Polarization Observables in WACS at large s, t, and u	E12-17-008	CPS: $\vec{\gamma}$	$N\vec{H}_3$	46	A^-
Timelike Compton Scattering (TCS) off a Transversely Polarized Proton	C12-18-005	CPS: $\vec{\gamma}$	$[N\vec{H}_3]_T$	35	C2

- ❑ Scheduling request submitted for E12-13-010/E12-13-007 (NPS Phase-I)
- ❑ Assembly out of the hall now in June/July 2022
- ❑ Could run as soon as 2023

More details on physics in David`s talk

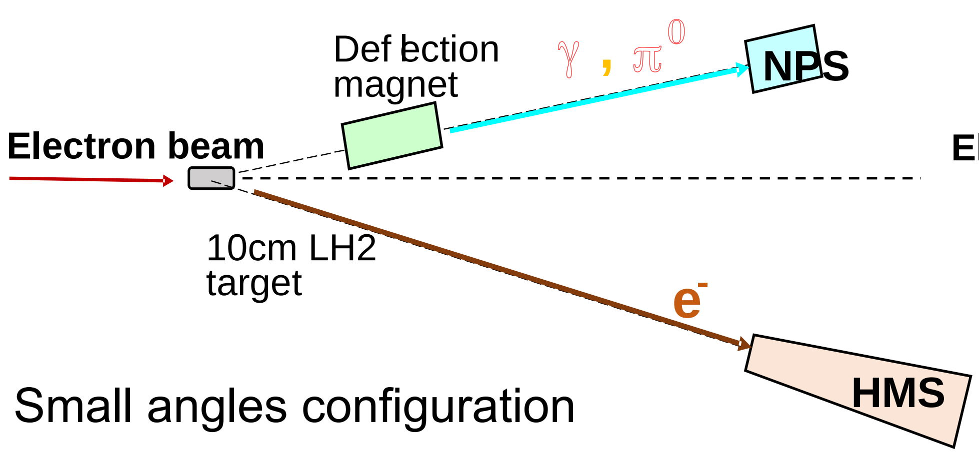
Motivation of NPS Experiments: Validation of Reaction mechanism



- To extract the rich information on nucleon structure encoded in **GPD** and **TMD**s one needs to show that the scattering process is understood
  - Neutral final states offer unique advantages

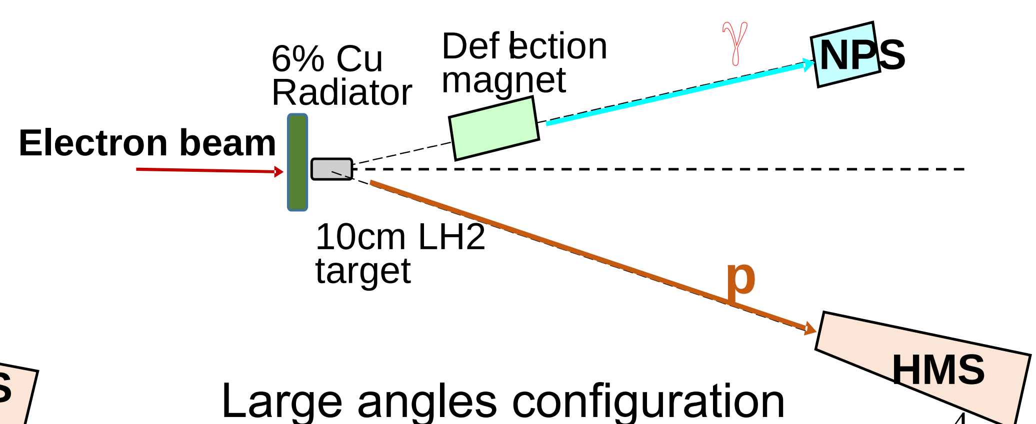
- Two arm combination of high resolution neutral particle spectrometer and a magnetic spectrometer offers unique scientific capabilities for studies of the transverse spatial and momentum structure of the nucleon in Hall C

E12-13-010 and E12-13-007



Small angles configuration

E12-14-003 and E12-14-005

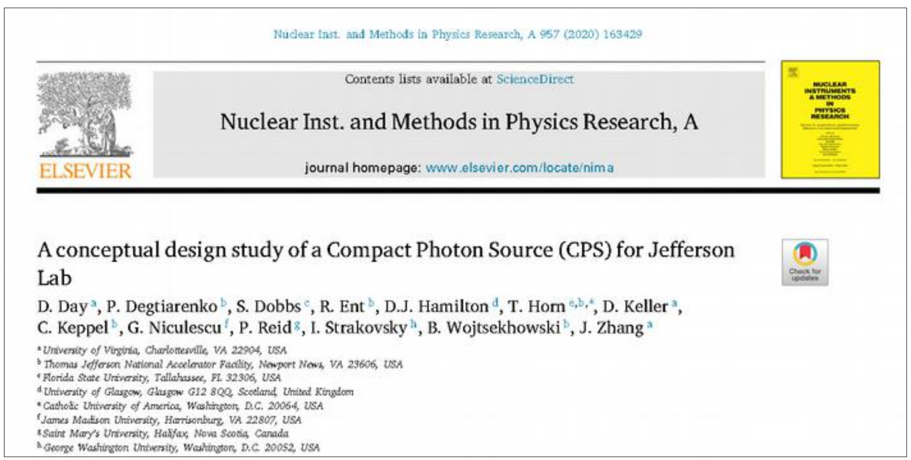


Large angles configuration

More details on physics in David`s talk

Combine NPS with Compact Photon Source (CPS)

- Much progress in imaging nucleon structure can be made with electron-scattering reactions, yet experiments with high-energy photons play a unique complementary role
- Small scattering probabilities of exclusive reactions demand high-intensity photon beams
- Understanding strengthened by imaging longitudinally-polarized and transversely-polarized nucleons


Nuclear Inst. and Methods in Physics Research, A 957 (2020) 163429

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

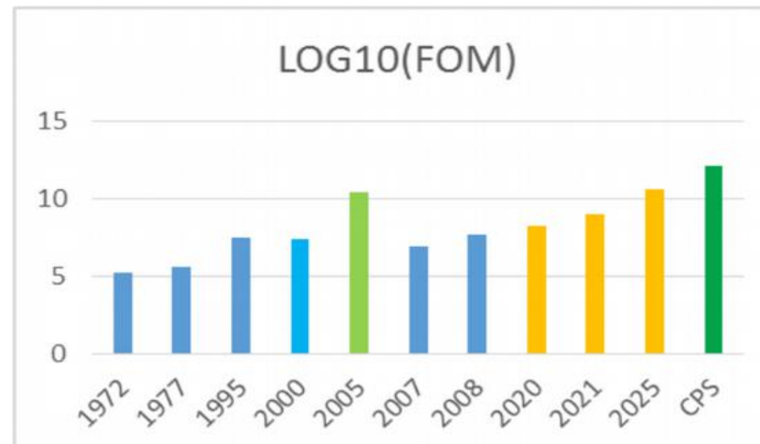
journal homepage: www.elsevier.com/locate/nima

A conceptual design study of a Compact Photon Source (CPS) for Jefferson Lab

D. Day[a], P. Degtiarenko[b], S. Dobbs[c], R. Ent[b], D.J. Hamilton[d], T. Horn[e,b,*], D. Keller[a], C. Keppel[b], G. Niculescu[f], P. Reid[g], I. Strakovsky[h], B. Wojtsekhowski[b], J. Zhang[a]

[a] University of Virginia, Charlottesville, VA 22904, USA
[b] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[c] Florida State University, Tallahassee, FL 32306, USA
[d] University of Glasgow, Glasgow G12 8QQ, Scotland, United Kingdom
[e] Catholic University of America, Washington, D.C. 20064, USA
[f] James Madison University, Harrisonburg, VA 22807, USA
[g] Saint Mary's University, Halifax, Nova Scotia, Canada
[h] George Washington University, Washington, D.C. 20052, USA

CPS conceptual design Published in NIMA 2020



CPS enables a gain of a factor of 30 in figure-of-merit! Enables a new suite of high-energy photon scattering experiments to image and understand the dynamical nucleon structure

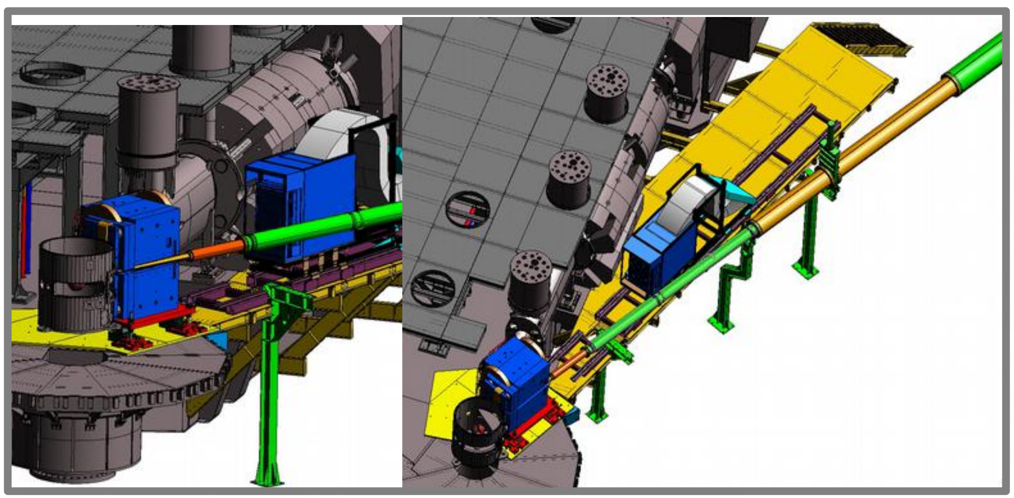
- **E12-17-008** - investigate the mechanisms behind RCS – provides crucial insight into the nature of exclusive reactions and proton structure
- **C12-18-005** - first fundamental test of the universality of the GPDs, as the GPDs extracted from TCS should be comparable with those extracted from the analogous space-like (electron) scattering process - DVCS

More details on physics in David`s talk

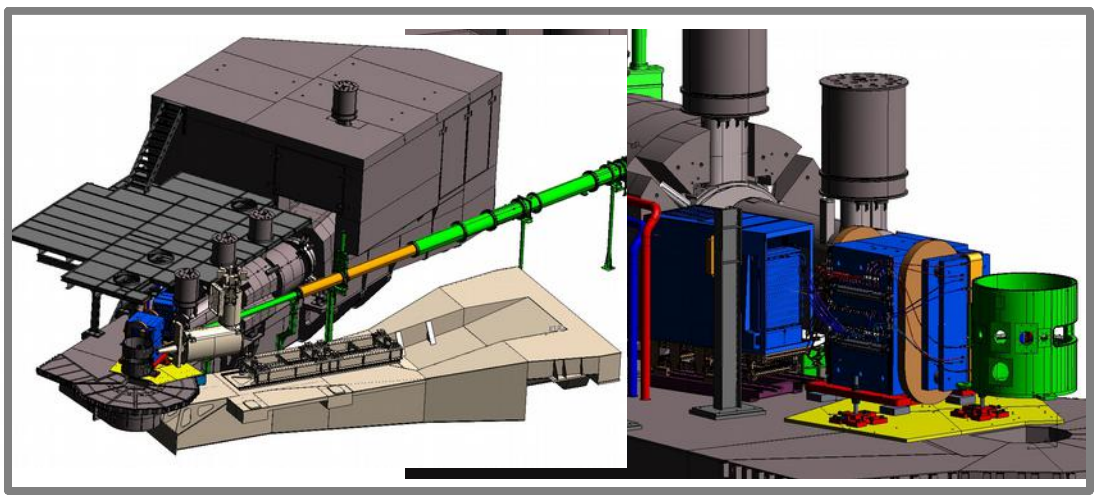
The Neutral Particle Spectrometer

- Neutral particle detector - lead tungstate electromagnetic calorimeter consisting of 1080 crystals placed in a temperature controlled frame including gain monitoring and crystal curing systems
- Crystals read by photomultipliers. HV distribution bases with external power amplifiers for operations in a very high rate environment
- Essentially dead time less digitizing electronics to independently sample the entire pulse form for each crystal. Jlab developed readout electronics
- Beam pipe with as large as possible opening/critical angle for the beam exiting the target/scattering chamber region to reduce beam line associated backgrounds
- Vertical-bend sweeping magnet with integrated field strength of 0.3 Tm to suppress an eliminate charged background
- Cantilevered platforms off the Super High Momentum Spectrometer (SHMS) carriage to allow for remote rotation.

Supported by NSF MRI PHY-1530874



Small angles (6° -23°) configuration (Left)

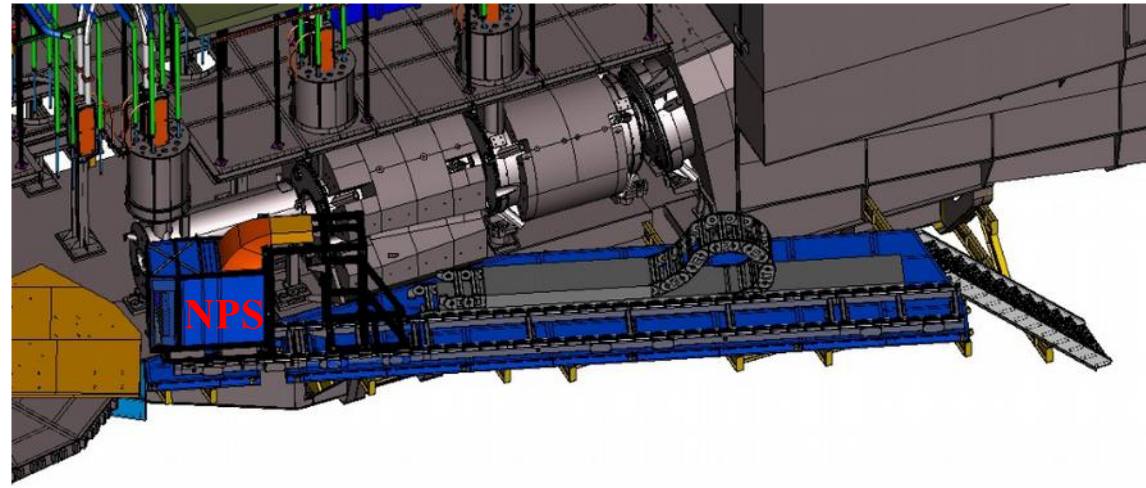


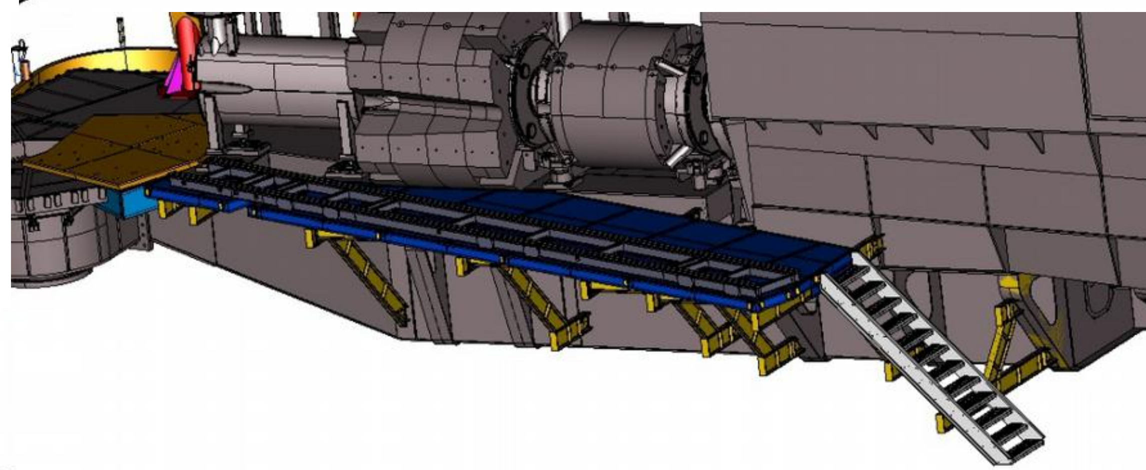
Large angles (23° -57.5°) configuration (Right)

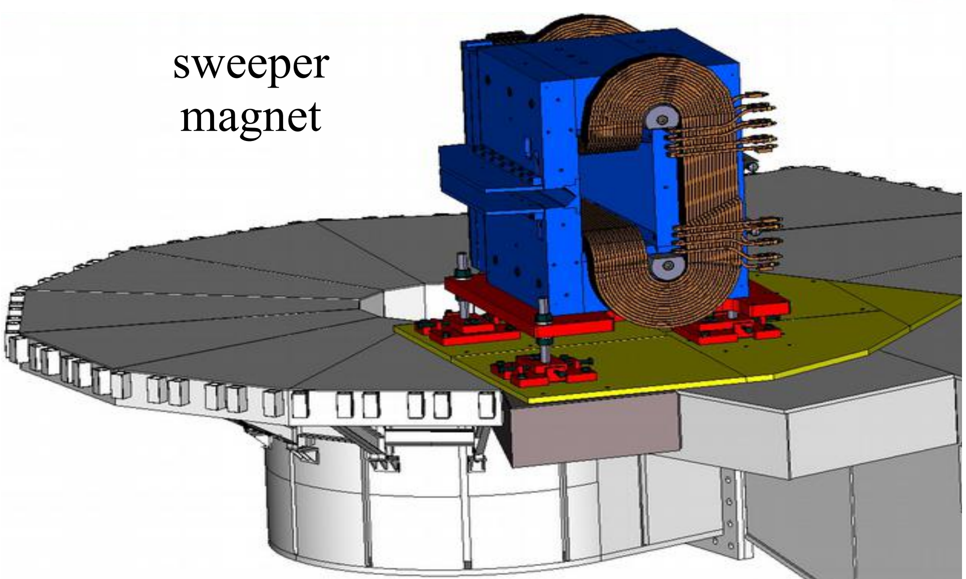
Mechanical design status overview

Tasks to be done during upcoming SAD:

- Target access platform support needs to be reinforced
- Target access platform section need to be removed and replaced with larger and heavier duty section







All hardware components for detector support structure on site

NPS sweeper magnet

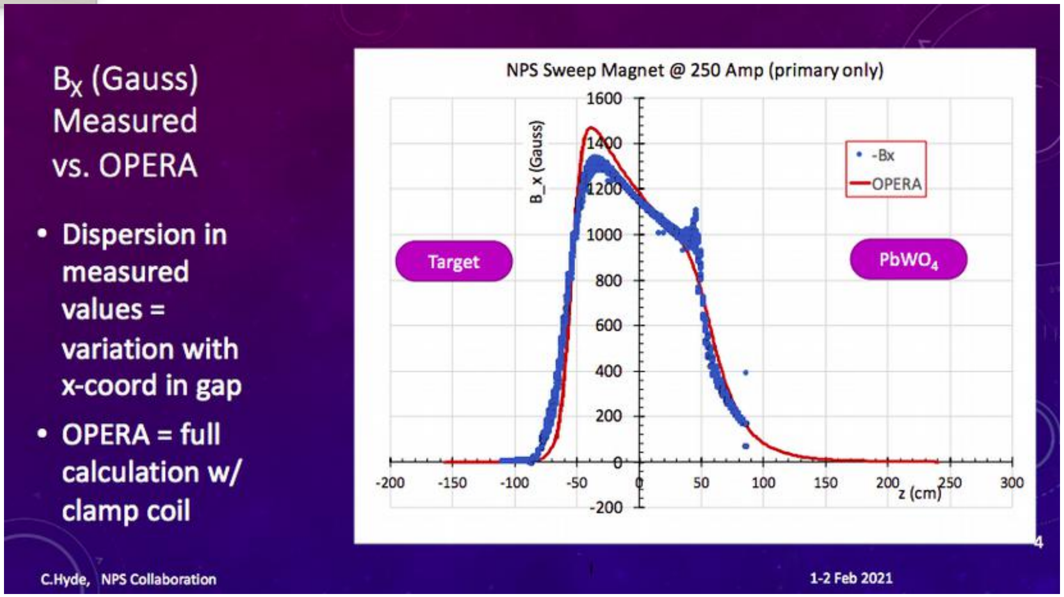
Supported by NSF MRI PHY-1530874


NPS magnet and power supply in test lab

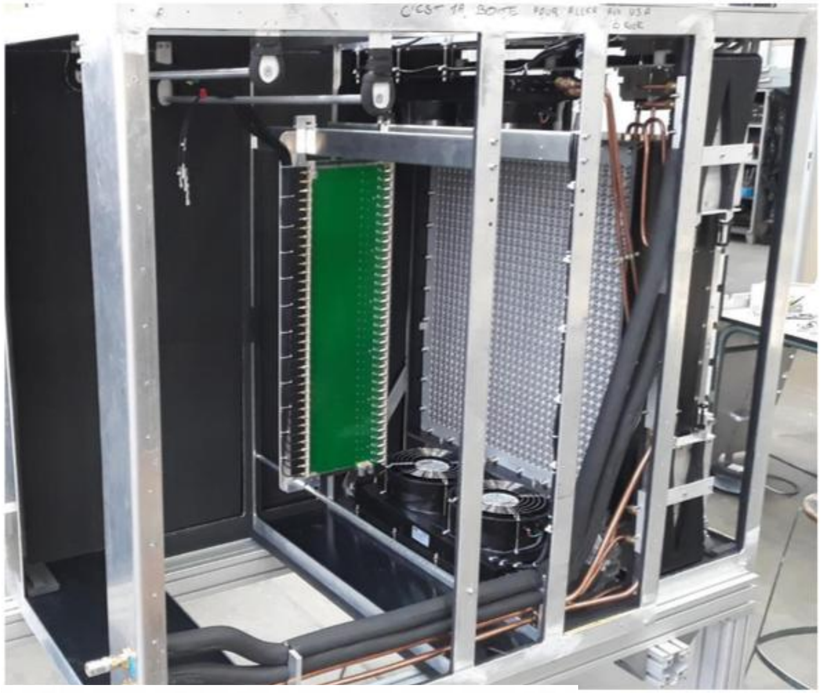
- Normal resistive iron dominated magnet provided by CUA and ODU
- Fully assembled,tested and awaiting installation for full field test in the hall
- Completed fringe field mapping at 25% of full current and compared to calculation

Max Current (Amp)	990
R @ 20°C (Ohm)	0.1
ΔV Max (V)	110
Cooling medium	LCW
ΔP (psi) ΔT (°C)	130 30
Corrector Max (Amp)	520

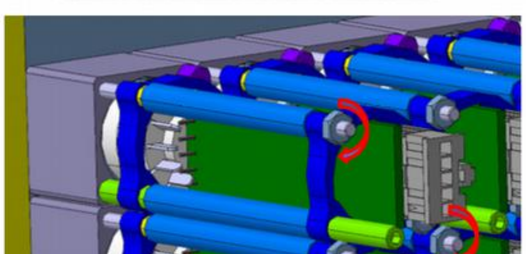

Mapping equipment

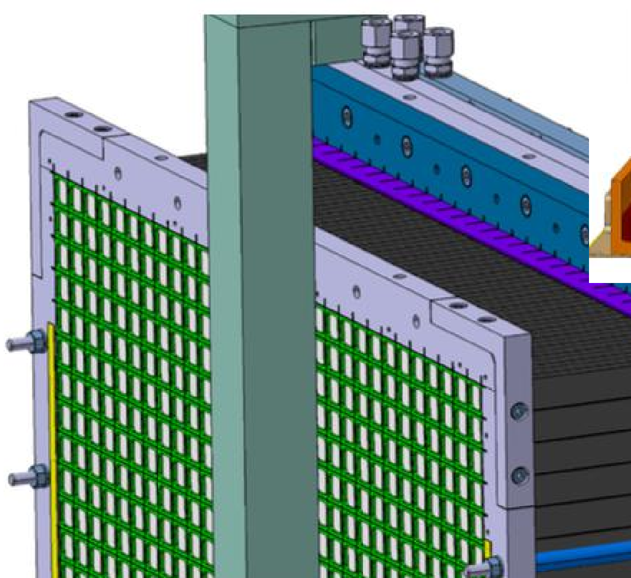


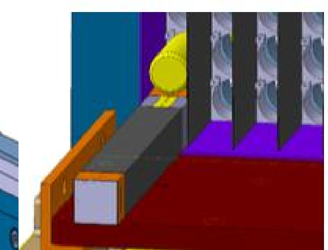
NPS calorimeter conceptual design

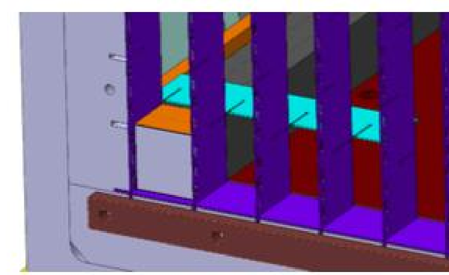


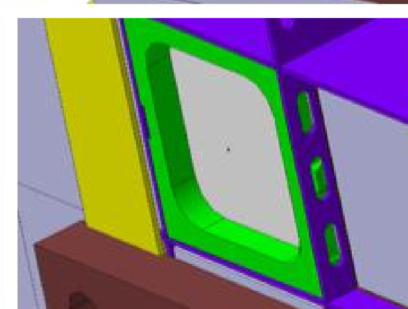
- 30x36 (1080) $PbWO_4$ crystals of size: 2x2x20 cm3
- Hamamatsu R4125 PMTs with custom HV bases
- Design completed at IJCLab-Orsay
- Crystals placed in a 0.5mm thick carbon frame to ensure good positioning
- PMTs accessible from the back side for maintenance
- Calibration and radiation curing with blue LED light though quartz optical fibers (concept originally designed by Yerevan)
- Frame delivered to Jlab in 2021







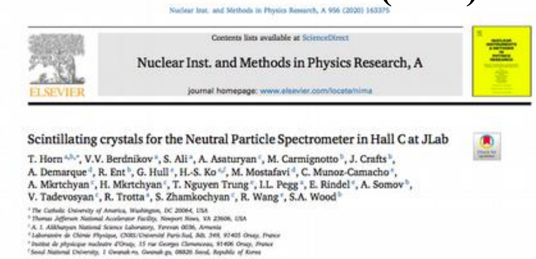




NPS lead tungstate (PWO) crystals

- Only two vendors worldwide
- All crystals for NPS calorimeter delivered to Jlab
- QA protocols and crystal storage in the NPS cleanroom
- Total number of crystals
  - CRYTUR **1379** pcs (ready to go)
  - SICCAS **446** pcs (portion of crystals questionable)

NIMA 956 (2020) 163375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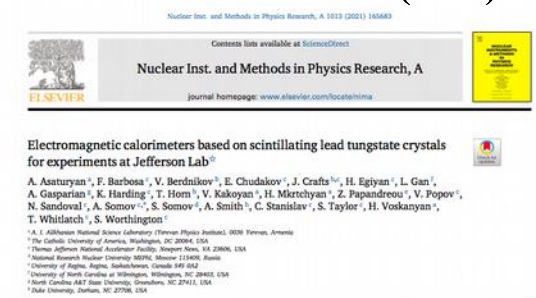
Scintillating crystals for the Neutral Particle Spectrometer in Hall C at JLab

T. Horn[a,b,*], V.V. Berdnikov[a], S. Ali[a], A. Asaturyan[c], M. Carmignotto[b], J. Crafts[b], A. Demarque[d], R. Ent[b], G. Hull[e], H.-S. Ko[e,f], M. Mostafavi[d], C. Munoz-Camacho[e], A. Mkrtchyan[c], H. Mkrtchyan[c], T. Nguyen Trung[e], I.L. Pegg[a], E. Rindel[e], A. Somov[b], V. Tadevosyan[c], R. Trotta[a], S. Zhamkochyan[c], R. Wang[e], S.A. Wood[b]

[a] The Catholic University of America, Washington, DC 20064, USA
[b] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[c] A. I. Alikhanyan National Science Laboratory, Yerevan 0036, Armenia
[d] Laboratoire de Chimie Physique, CNRS/Université Paris-Sud, Bât. 349, 91405 Orsay, France
[e] Institut de physique nucléaire d'Orsay, 15 rue Georges Clemenceau, 91406 Orsay, France
[f] Seoul National University, 1 Gwanak-ro, Gwanak-gu, 08826 Seoul, Republic of Korea

NIMA 1013 (2021) 165683


Nuclear Inst. and Methods in Physics Research, A 1013 (2021) 165683

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Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Electromagnetic calorimeters based on scintillating lead tungstate crystals for experiments at Jefferson Lab☆

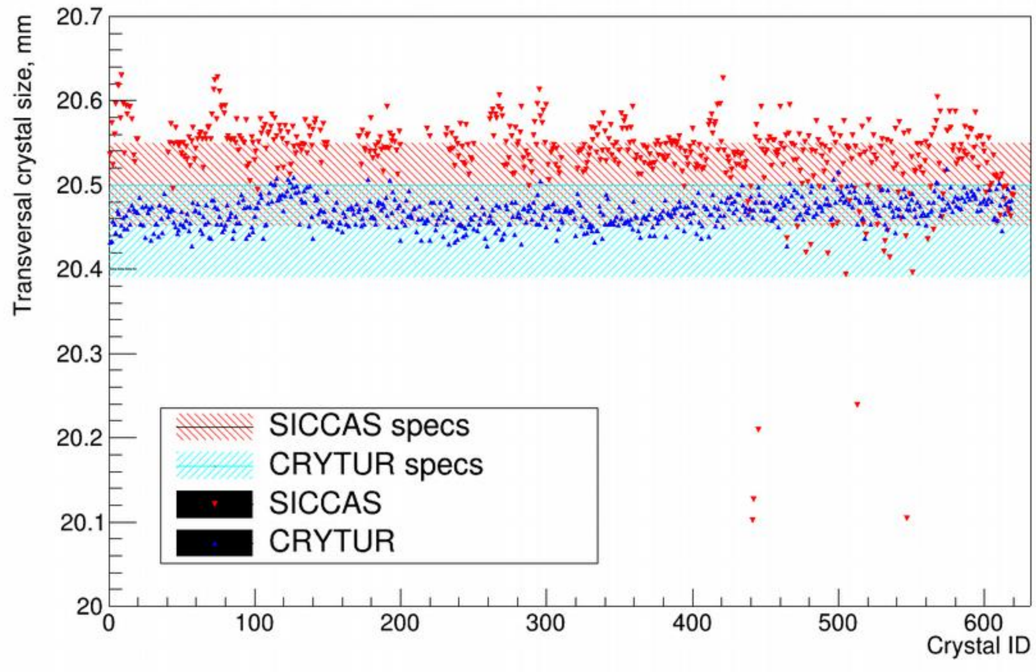
A. Asaturyan[a], F. Barbosa[c], V. Berdnikov[b], E. Chudakov[c], J. Crafts[b,c], H. Egiyan[c], L. Gan[f], A. Gasparian[g], K. Harding[c], T. Horn[b], V. Kakoyan[a], H. Mkrtchyan[a], Z. Papandreou[e], V. Popov[c], N. Sandoval[c], A. Somov[c,*], S. Somov[d], A. Smith[h], C. Stanislav[c], S. Taylor[c], H. Voskanyan[a], T. Whitlatch[c], S. Worthington[c]

[a] A. I. Alikhanian National Science Laboratory (Yerevan Physics Institute), 0036 Yerevan, Armenia
[b] The Catholic University of America, Washington, DC 20064, USA
[c] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[d] National Research Nuclear University MEPhI, Moscow 115409, Russia
[e] University of Regina, Regina, Saskatchewan, Canada S4S 0A2
[f] University of North Carolina at Wilmington, Wilmington, NC 28403, USA
[g] North Carolina A&T State University, Greensboro, NC 27411, USA
[h] Duke University, Durham, NC 27708, USA

2019

2022

Characteristics of PWO crystals

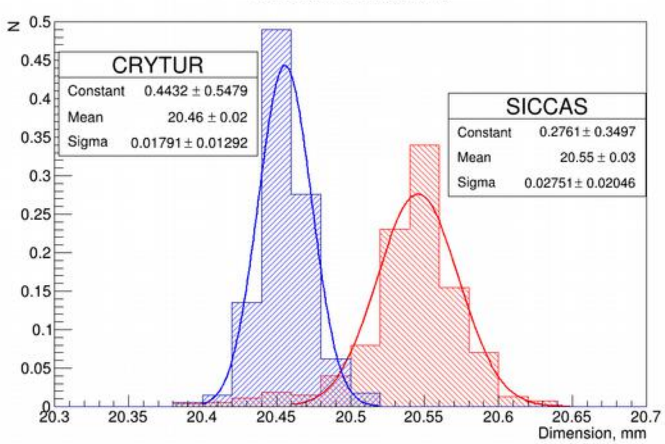


CRYTUR crystals are excellent quality

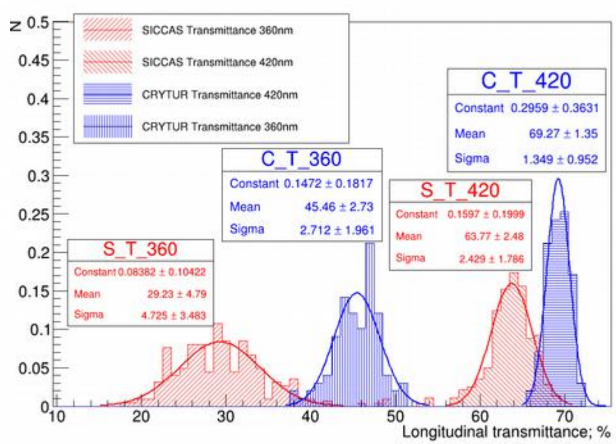
- Great transmittance
- Uniform LY and light collection
- Characteristics within specification
- Rejection rate 0%

SICCAS crystals are low medium quality

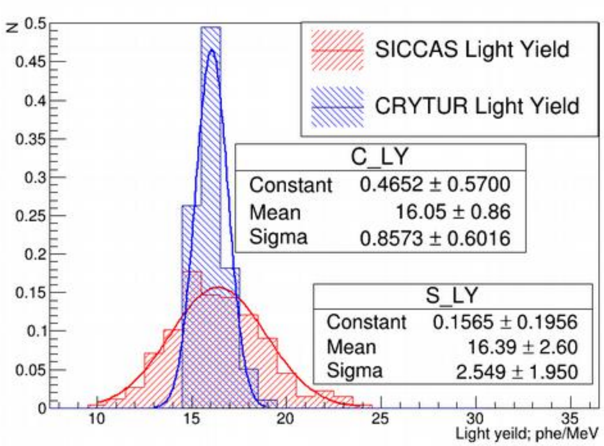
- Lower transmittance compare to CRYTUR
- Non-uniform LY and light collection
- Characteristics outside of specification for significant portion of crystals
- Preselection required
- Rejection rate 30%



Crystal size



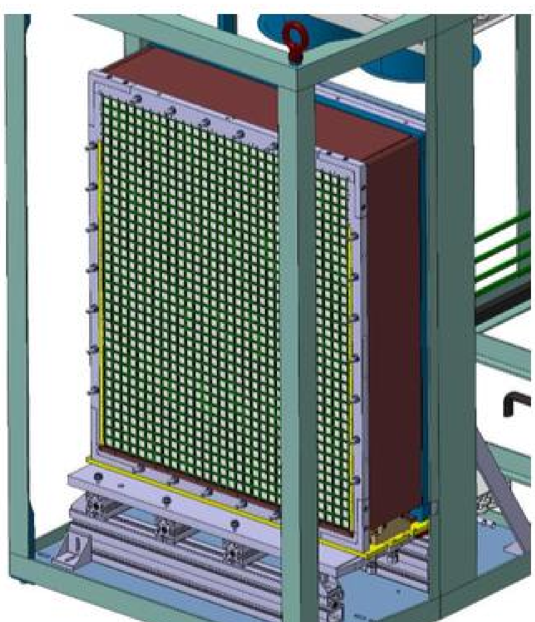
Transmittance



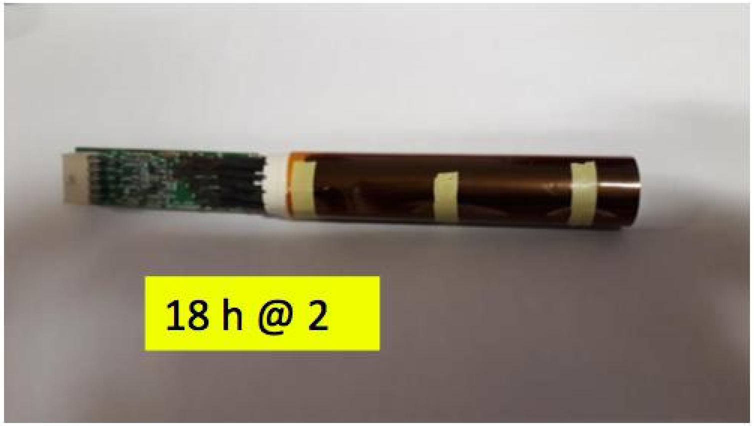
Light yield

NPS calorimeter stacking

- NPS Collaboration decision is to stack NPS with all **CRYTUR** crystals
    - Satisfied to quality requirements
    - All crystals have uniform characteristics
    - Radiation hard
    - Crystal preselection not needed
    - Good control of the constant term
- NPS Calorimeter will consist of 1080 towers, matrix of 36 vertical and 30 horizontal crystals



PMTs and HV dividers



PMT + base assembly (1080)

Kapton sheet/tape protection on PMT (1080)

NPS 8-Stage Active Divider　　FJ Barbosa

NPS 8-Stage Active HV Divider - Summary

Table 2: Measured divider ratios

	K–Dy1	Dy1-Dy2	Dy2-Dy3	Dy3-Dy4	Dy4-Dy5	Dy5-Dy6	Dy6-Dy7	Dy7-Dy8	Dy8-Dy9	Dy9-Dy10	Dy10-GND
Active	1.8	1	1	1	1	1	1	1	2	4.3	3.5
Hamamatsu	1.4	1	1	1	1	1	1	1.2	1.8	3.3	3.1

- Dynodes 9 and 10 are connected to Anode and no amplifier for the following tests.
- Preserved PMT biasing of other electrodes (see above table).
- Test Results (Vladimir, Carlos, Chris):
  - PMT Gain ~ 2 x 10^3 (with reference to Hamamatsu divider: 10^5 @1.1kV).
  - HV: 630 V @ 405 uA.
  - Source (LED, Laser): set at 10% of maximum expected in the experiment.
    - Signal Amplitude = 7 mV nominal (10% of maximum).
    - Residual Noise = 2.5 mV peak.

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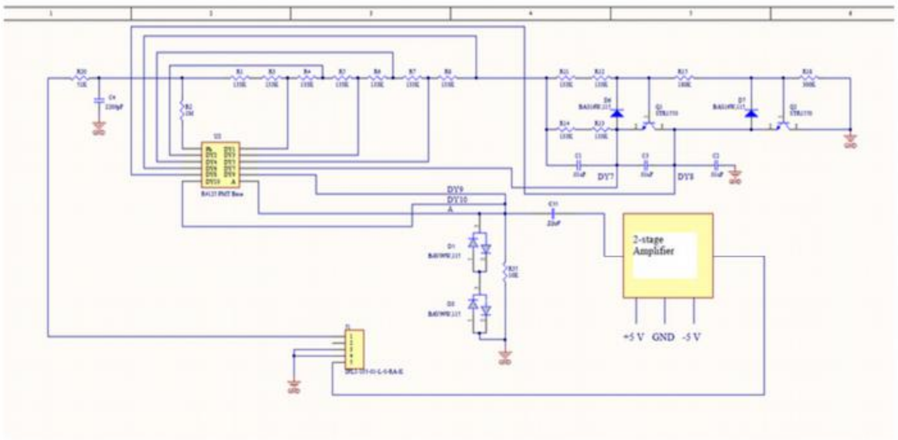
NPS 8-Stage Active Divider　　FJ Barbosa

- Proposed divider simplified:



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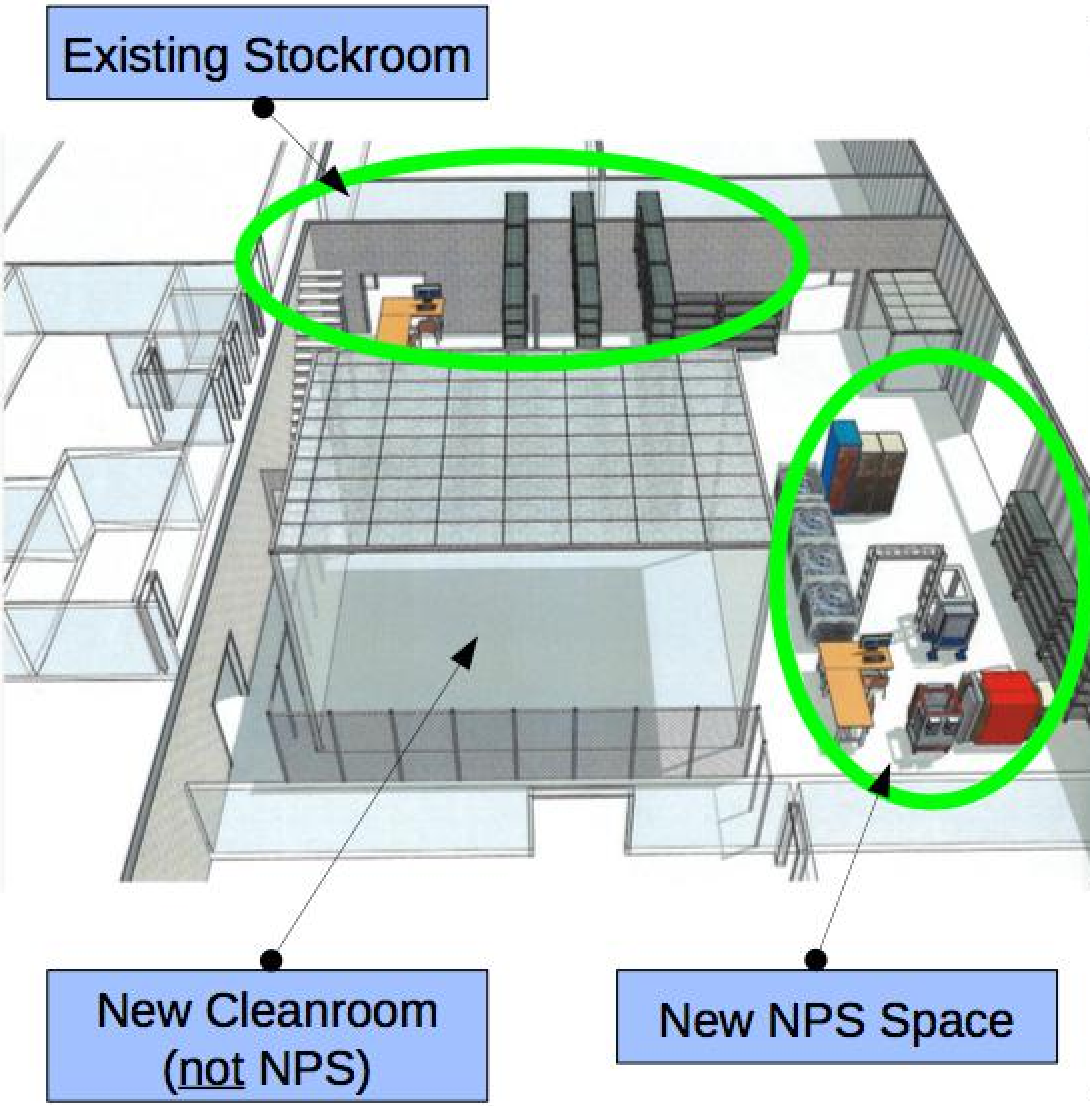
Pre-assembly preparations



- Space will become ready for occupancy in late-Apr
- "To do" list
  - → Need to design/build cable bridge
  - → Unbox and bundle signal cables
  - → NPS detector assembly timeline / personnel
  - → Stage/Test DAQ

- **NPS assembly in June/July 2022**

Reconstruction software development

- The Hall C Neutral Particle Spectrometer (NPS) clustering algorithm is in development

- Initial results are presented and compared to the standard algorithm using SHMS calorimeter data.

8

What has been done ?

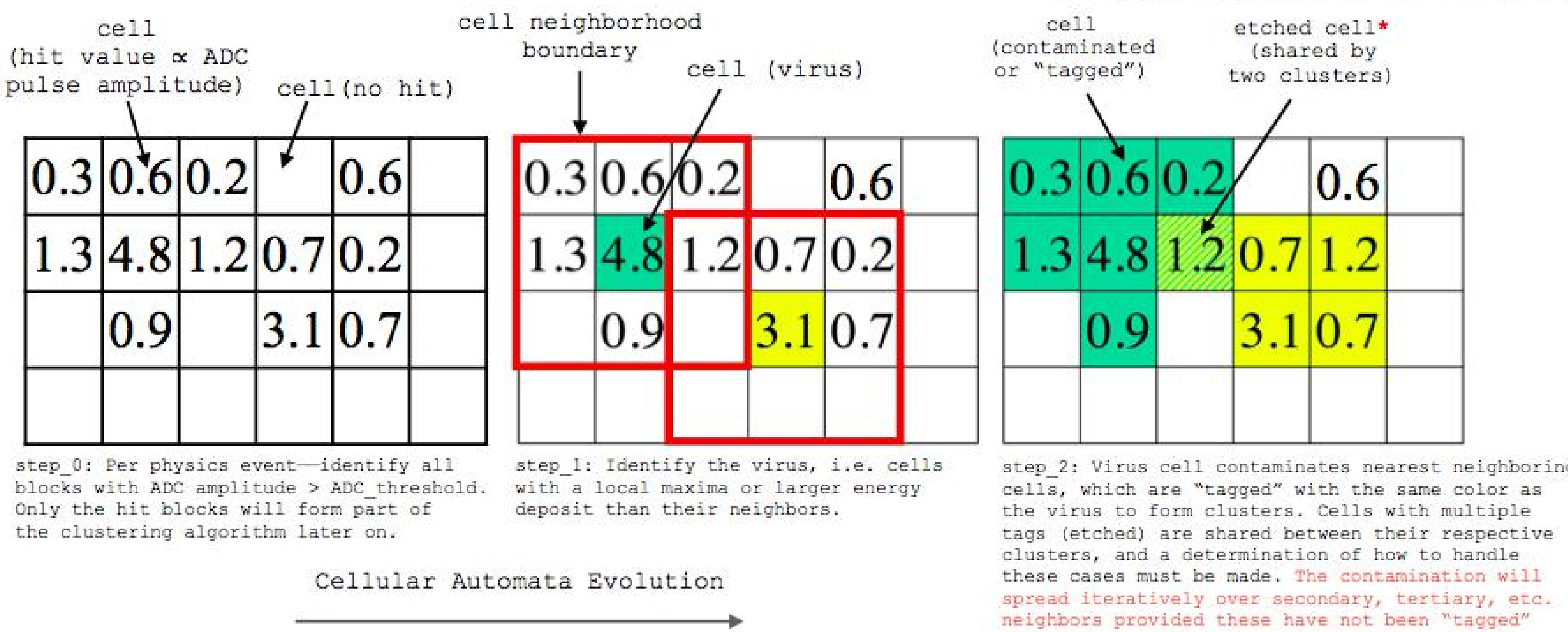
- developed NPS calorimeter cluster algorithm (*"Cellular Automata"*)
    - rules may be flexible (e.g., may need to re-define what constitutes neighboring cells)
    - How to treat cells with shared clusters ?
        - Do we apply rule 3? or determine how to share energy between two clusters ?

Y. Roblin et al. (1995). Nucl.Instrum.Meth. A362: 478-486

Rule–I A given cell is only sensitive to its eight neighbours. A cell is a virus if its value is higher than the value of each of its neighbours.

Rule–II At a given step, a cell will take the value of its highest energy neighbour.

Rule–III A cell already contamined in an earlier stage by a virus is immunized against any other virus (restriction to Rule II)



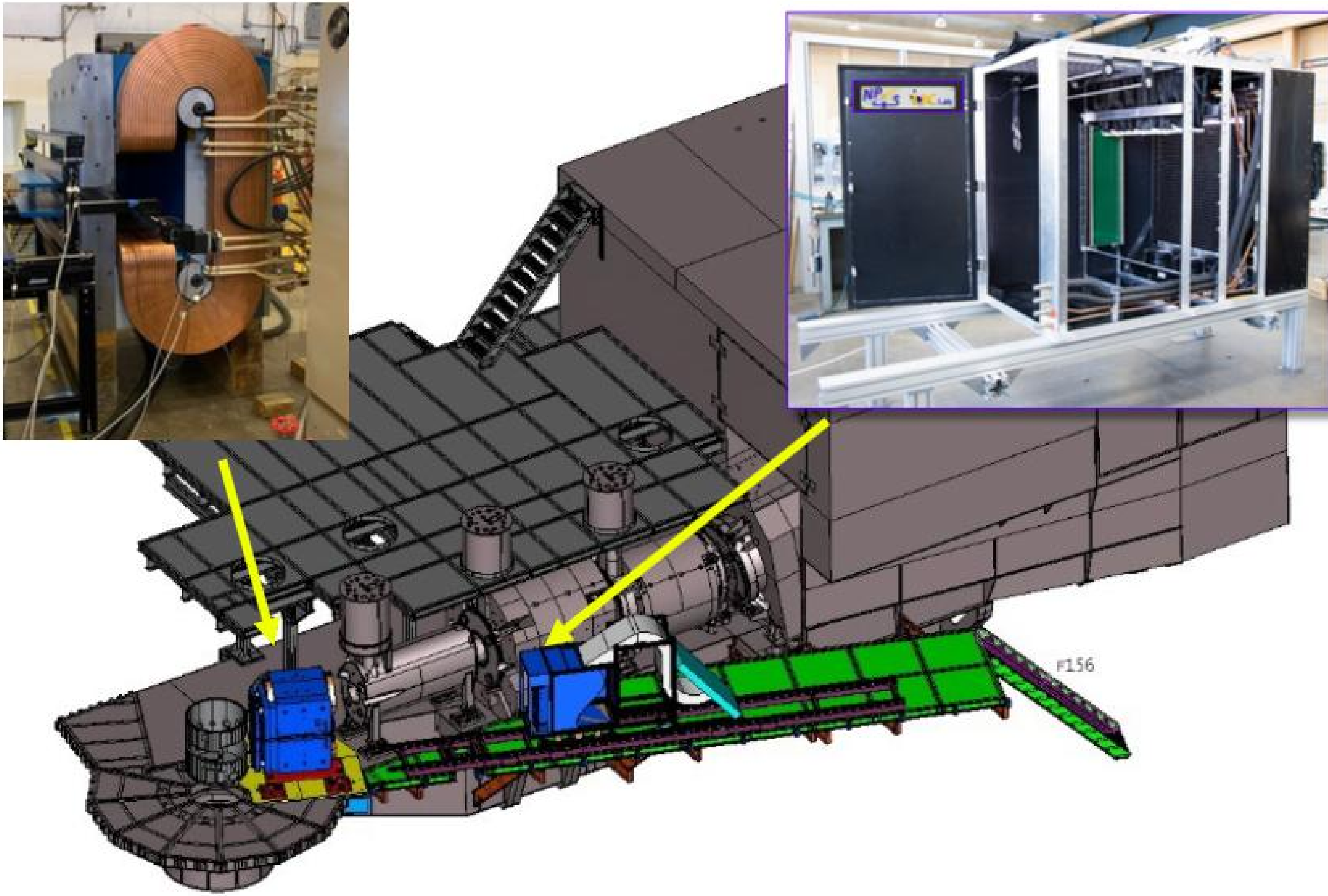
Slide adapted from Carlos Y. & Steve W. talk at 2020 NPS colab meeting

Outlook

- NPS experiments (E12-13-007, E12-13-010, E12-14-003, E12-14-005) passed ERR in May 2019 and beam time scheduling requests has been submitted
- HallC infrastructure becoming real - work will be done during SAD 2022
- Sweeper magnet ready for full current test in Hall C
- Calorimeter frame delivered on-site
- All PMT`s received and spot checked (25%) - no rejections
- All crystals delivered, NPS will be stack with CRYTUR crystals
- Calorimeter assembly scheduled for Summer 2022

More details about NPS and its assembly:

https://wiki.jlab.org/cuawiki/index.php/NPS_Collaboration_Meeting_(online,_2/16_2022)



Thank you !