Hall C Future

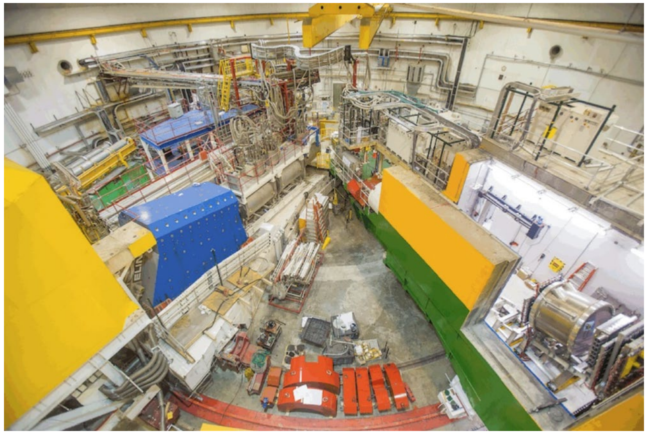
Task Force Update

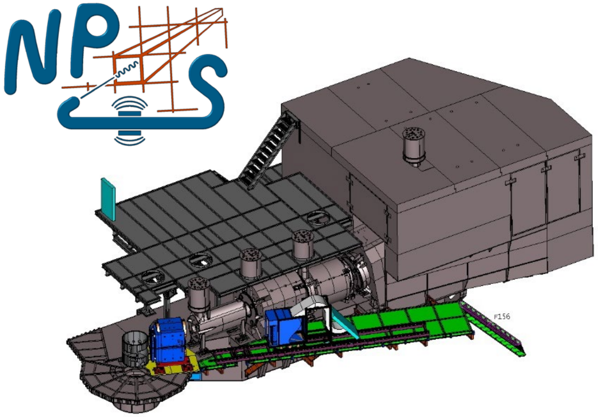
Tanja Horn

(credit: the Hall C Future Task Force)

THE CATHOLIC UNIVERSITY OF AMERICA

Jefferson Lab
Thomas Jefferson National Accelerator Facility





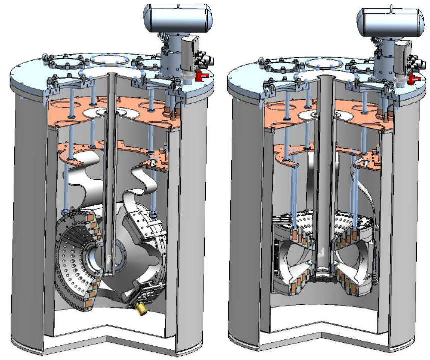


Figure 7: Cut-away of the 2 orientations for the magnet.

JLab Experimental NP and Role of Hall C

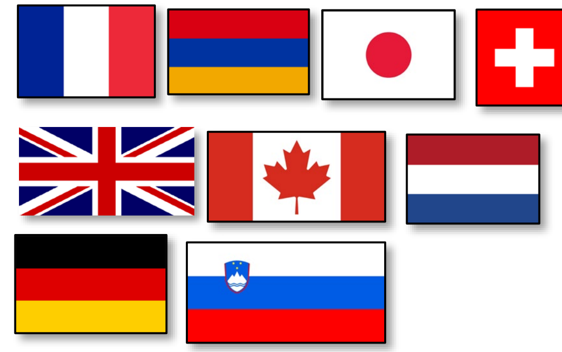
- JLab is the world's leading user facility for studies of the quark structure of matter using continuous beams of high-energy, polarized electrons
  - The electron beam can be converted into a precise photon beam, e.g. Hall D

- CEBAF unique experimental capabilities
  - Highest energy electron probes of nuclear matter
  - Highest average current
  - Highest polarization
  - Ability to deliver a range of beam energies and currents to multiple halls
  - Highest-intensity tagged photon beam at 9 GeV for exotic mesons
  - Stability and control of beam properties and helicity reversal for precision PV studies

Hall C unique capabilities and strengths

- Two high-momentum **magnetic spectrometers** that allow for **precision scattering** experiments
- Flexibility to house **unique large-installation experiments** including large-acceptance devices
- **Strong Staff and Users collaborations** to realize experiments including
  - State-of-the art PID systems, high-power cryogenic targets, polarized targets, high-speed readout and advanced DAQ technologies

Hall C Past, Present, Future



- Approved experiments – many led internationally
  - 6 GeV: 45 experiments (*Rating A:11, A-:14*)
  - 12 GeV: 29 experiments so far (*Rating A:6, A-:11*)
- Publications from experiments over last 20 years
  - 6 GeV: >110 science, >10 instrumentation – including highly cited
  - 12 GeV: 2 science, 2 instrumentation
- "Large" Installations

6 GeV	12 GeV
Qweak	CPS
SANE	NPS
G0	LAD
Hypernuclear x 3	Hypernuclear?
GeN x2	
T20	

Hall C in the EIC Future

High Precision and Versatility at the Luminosity Frontier

- Optimized facility for precision measurements of small cross sections
  - L/T separations, x>1
  - SRC-EMC
  - Polarization Observables
  - PV
  - etc.

- Flexible-configuration hall for new equipment

6 GeV	12 GeV	24 GeV
Qweak	CPS	CPS
SANE	NPS	NPS
G0	LAD	LAD++?
Hypernuclear x 3	Hypernuclear?	Hypernuclear++?
GeN x2		TDIS?
T20		

Hall C Future Task Force

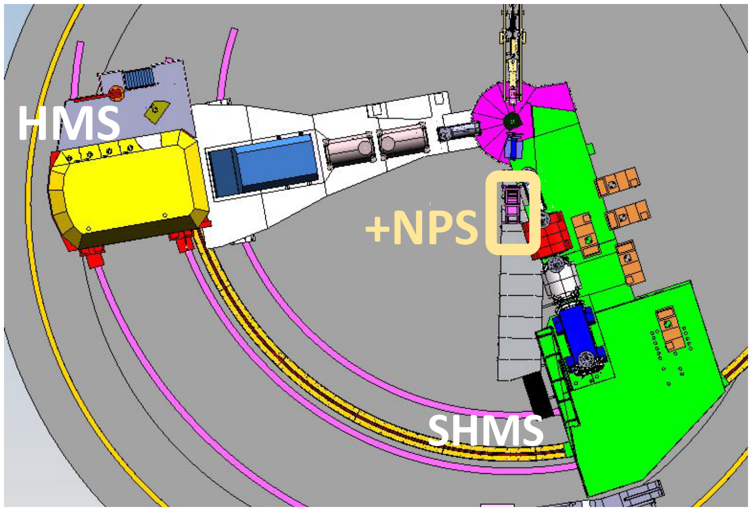
- Chairs: Thia Keppel, Steve Wood
- Members
  - Eric Christy (Hampton U.)
  - Dipangkar Dutta (Mississippi State U.)
  - David Hamilton (U.Glasgow)
  - Or Hen (MIT)
  - Tanja Horn (CUA)
  - Garth Huber (U. Regina)
  - Ed Kinney (U. Colorado)
  - Nilanga Liyanage (Uva)
  - Wenliang Li (W&M)
  - Ellie Long (New Hampshire)
  - Dave Mack (JLab)
  - Carlos Munoz-Camacho (IJCLab-Orsay)
  - Brad Sawatzky (JLab)
  - Karl Slifer (New Hampshire)
  - Holly Szumila-Vance (JLab)
  - Arun Tadepalli (JLab)
  - Bogdan Wojtsekhowski (JLab)

- Task Force has been meeting bi-weekly in 2021
- Main goal: Evaluate opportunities for Hall C shaping its identity in the coming decade
- A White paper is in preparation

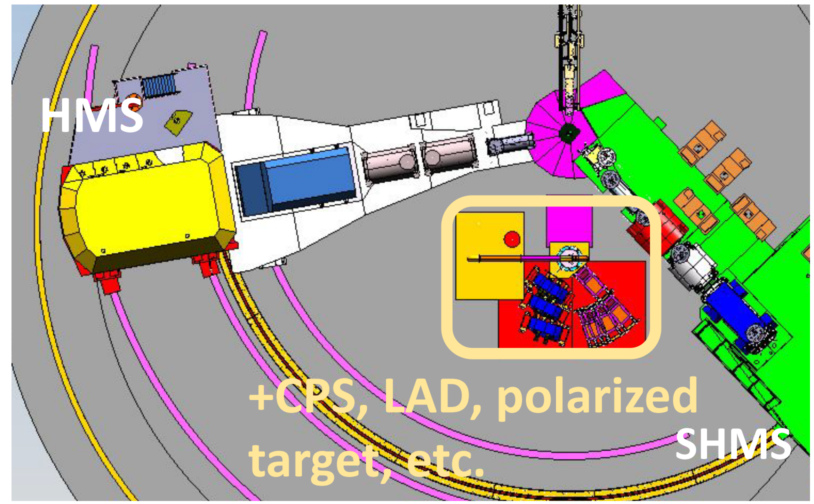
Details on presentations at the HC-FTC:
https://hallcweb.jlab.org/wiki/index.php/Hall_C_Futures

Two pivot configurations of Hall C

Spectrometers with standard pivot



Pivot moved downstream

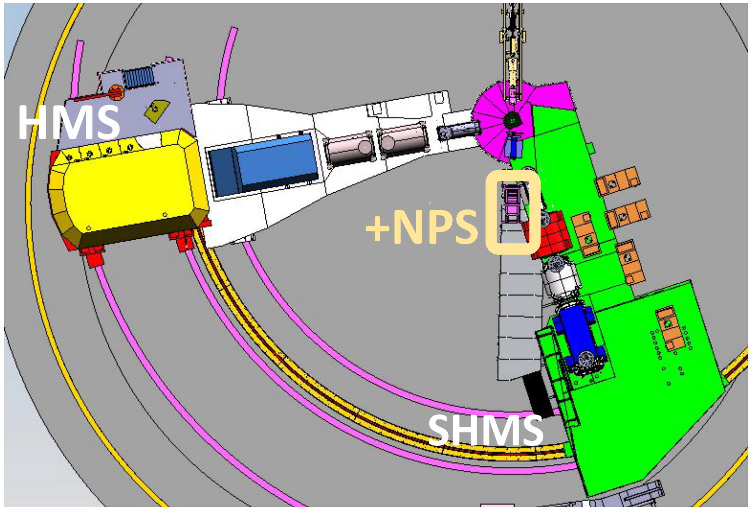


- Spectrometers provide **control over systematic uncertainties** (important for L/T separations)
  - Fixed pivot, precision kinematics, well-shielded detectors
- **NPS adds neutral particle detection**

- **Polarized targets downstream** in combination with **large acceptance detection**
  - LAD or BigBite add large acceptance (backward) detection
- **CPS adds high intensity photons**

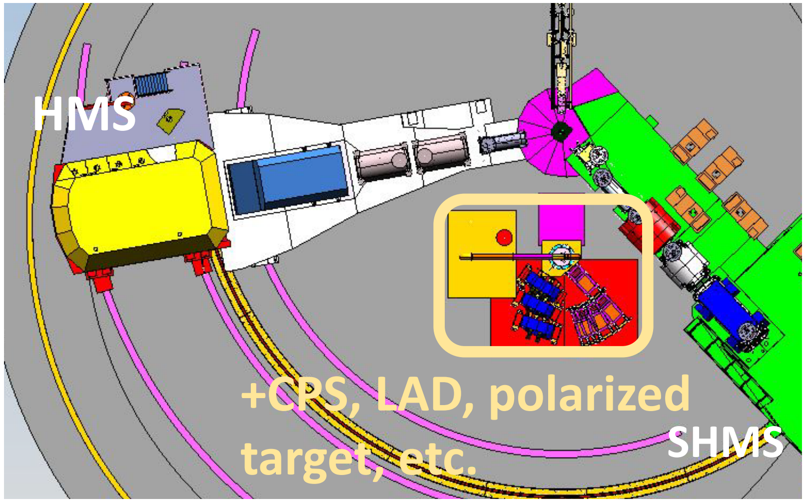
Physics examples with two pivot configurations

Spectrometers with standard pivot



- F$_2$ at x>1
- Pion Form Factor
- Reaction Mechanism validation – Kaon FF, GPD and TMD
- Precision EMC
- DVCS and π^0 cross sections
- …..

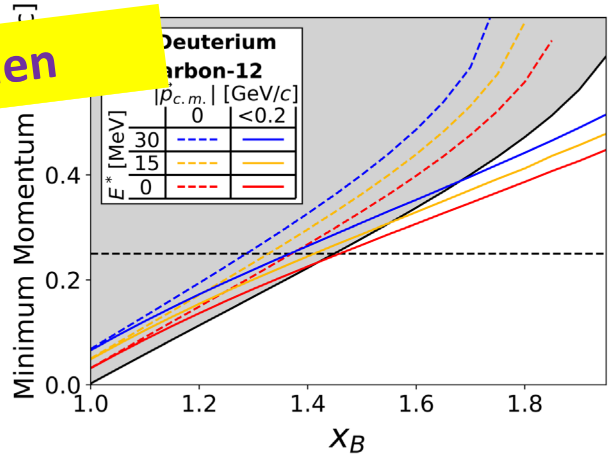
Pivot moved downstream



- Polarized WACS
- 2N-SRC
- Tagging processes
- TCS
- ….

Physics Example: Understanding 2N-SRCs

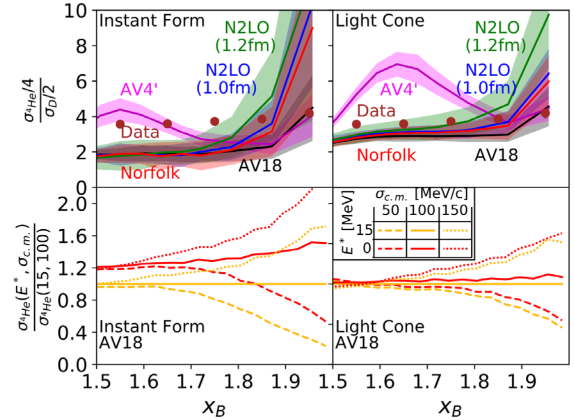
Slide from Or Hen



- Hall C (e,e’) data will scan a wide range of asymmetric nuclei.

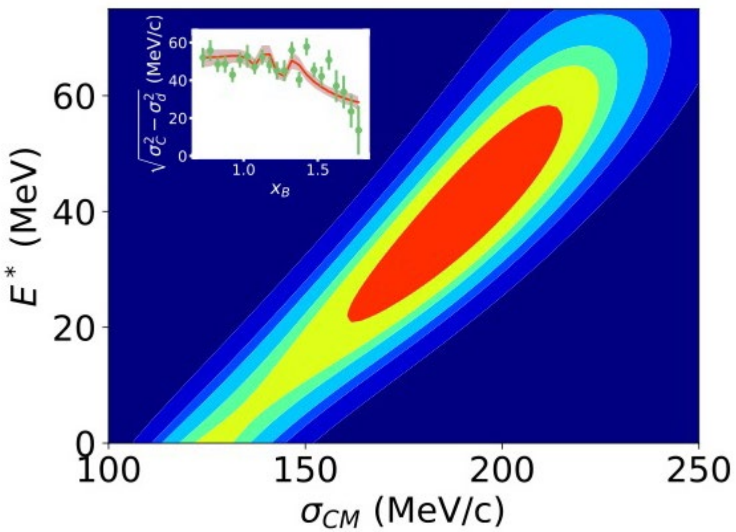
- Recent studies show this data alone has only ~10% accuracy in terms of relating the measured cross-sections to 2N-SRC properties.

- Need to supplement with (e,e’p) and take a global analysis approach.



PRC **103**, L031301 (2021)

E12-17-005
O. Hen et al.



Physics Example: 3D Imaging with Designer Photoproduction Reactions

- High-energy photoproduction plays a unique role in 3D imaging

$$\frac{d\sigma}{dt} = \frac{d\sigma}{dt}_{KN}\left(\frac{1}{2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 + R_A^2\right] - \frac{us}{s^2+u^2}\left[R_V^2 + \frac{-t}{4m^2}R_T^2 - R_A^2\right]\right)$$

$$R_V(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} H^a(x,0,t)$$

$$R_A(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} sign(\mathrm{x})\hat{H}^a(x,0,t)$$

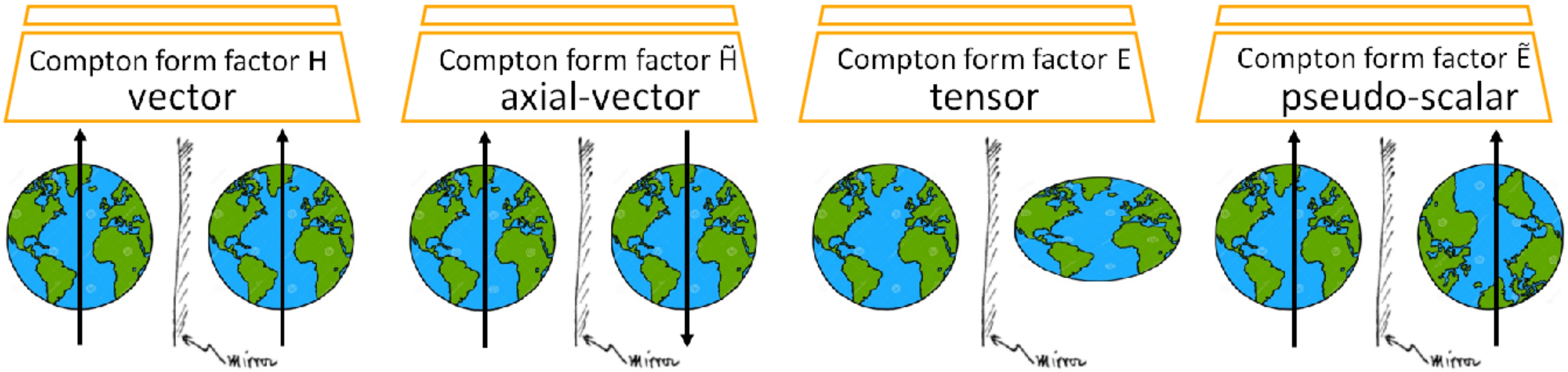
$$R_T(t) = \sum_a e_a^2 \int_{-1}^{1} \frac{dx}{x} E^a(x,0,t)$$

Polarization observables give access to the ratios and so to the GPDs

E12-17-008 D. Hamilton et al.

C12-18-005 M. Boer et al.

Additional ideas?



Complementary approach to small cross sections – high-intensity photon beams

Opportunities with Positrons: DVCS

Deeply Virtual Compton Scattering

Eric Voutier IJCLab Irène Joliot-Curie

Pr12-20-012
J. Grames, M. Mazouz, C. Muñoz Camacho et al.

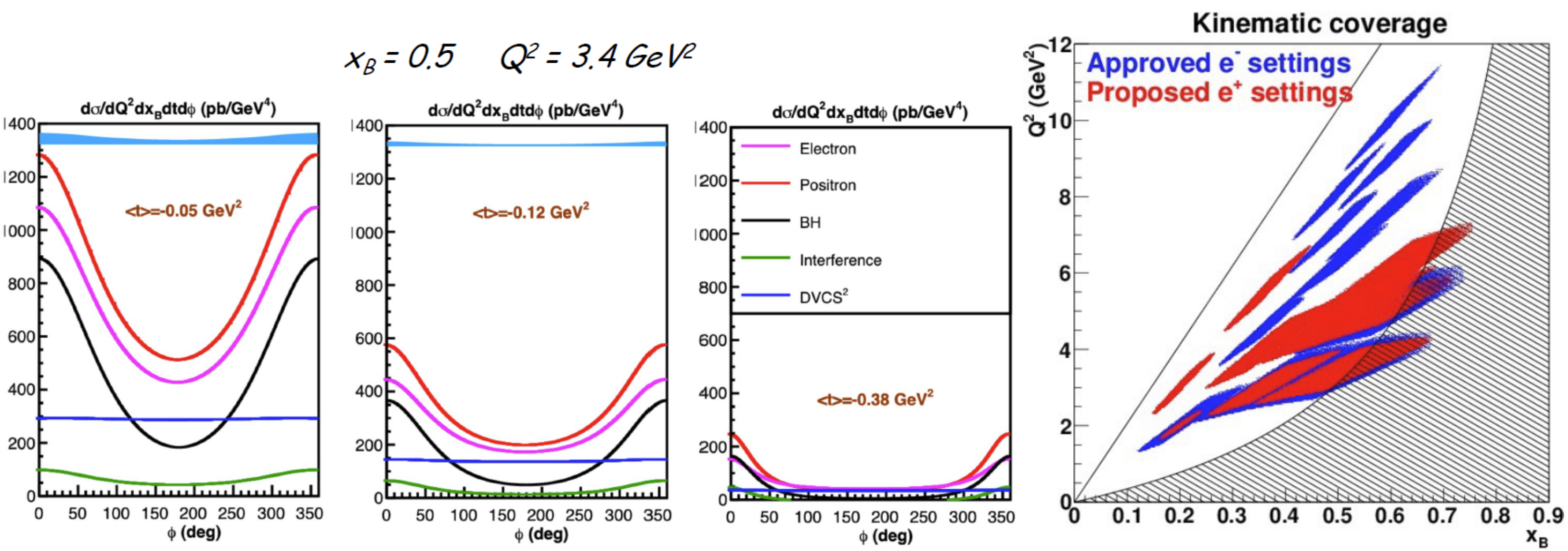
A. Afanasev et al. arXiv:2105.06540 (2021)

C12-20-012 C. Munoz Camacho et al.

Additional ideas?

➢ Combining the HMS and the NPS spectrometers, precise cross section measurements with unpolarized positron beam will be performed at selected kinematics where electron beam data will soon be accumulated.

$$|\mathcal{T}(\pm ep \to \pm ep\gamma)|^2 = |\mathcal{T}^{BH}|^2 + |\mathcal{T}^{DVCS}|^2 \mp \mathcal{I}$$



Physics Examples: Hypernuclear

Slide from Toshiyuki Gogami

- ΛN CHARGE SYMMETRY BREAKING
  - A = 3, 4: the aim depends on the results from Hall A (C12-19-002)
  - A = 9: The need of 500 keV resolution to determine the g.s. energy; TG et al, PRC 103, L041301 (2021)
- CLUSTER STRUCTURE, DEFORMATION
  - $^{27}\mathrm{Al}(e,e'K^{+})^{27}_{\Lambda}\mathrm{Mg}$: Identification of the triaxial deformation of ^{26}Mg (c.f. M. Isaka, et al., PRC 87, 021304R (2013))
  - Ne (A = 20—22) c.f. M. Isaka, PRC 83, 044323 (2011)
  - Si (A = 28—30) c.f. M.T. Win and K. Hagino, PRC 78, 054311 (2008)
- ΛN INTERACTION PROPERTY IN DIFFERENT Λ ENVIRONMENT, MANY-BODY INTERACTION
  - Ca (A = 40—48) (40 and 48: E12-15-008)
  - Ni (A = 58—64)
  - Zr (A = 90—96)
  - Mo (A = 92—100)
  - Ru (A = 96—104)
  - Sn (A = 112—124)
  - Sm (A = 144—154)
  - Pb (A = 204—208) (208: E12-20-013)

No data with sub-MeV resolution

- CERN, BNL, KEK, J-PARC: > a few MeV (FWHM)
- Future plan at HIHR in J-PARC: sub-MeV
  ← In a stage of funding proposal submission
  (No beam line / apparatus exist yet)

➔ **JLab is a unique facility to realize it**

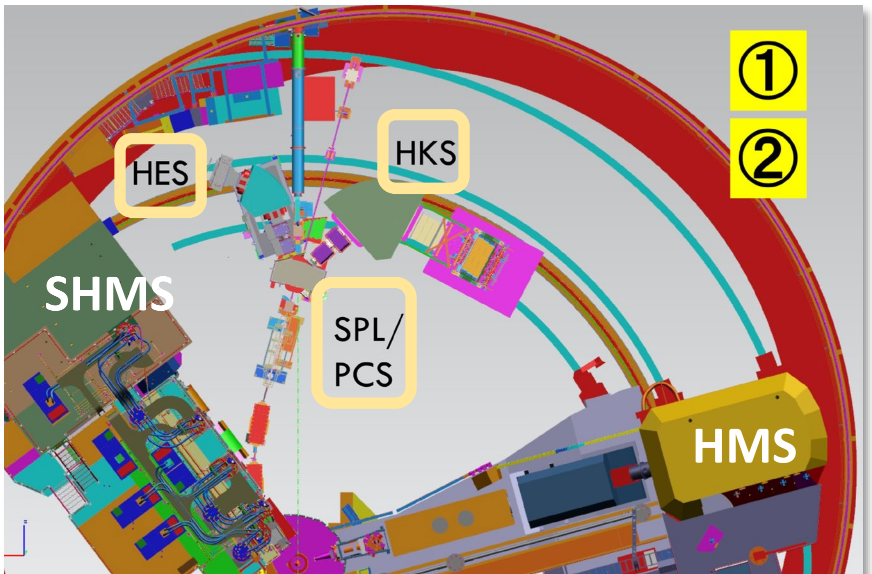
C12-19-002 T. Gogami et al. – proposed for Hall A, evaluating prospects for Hall C

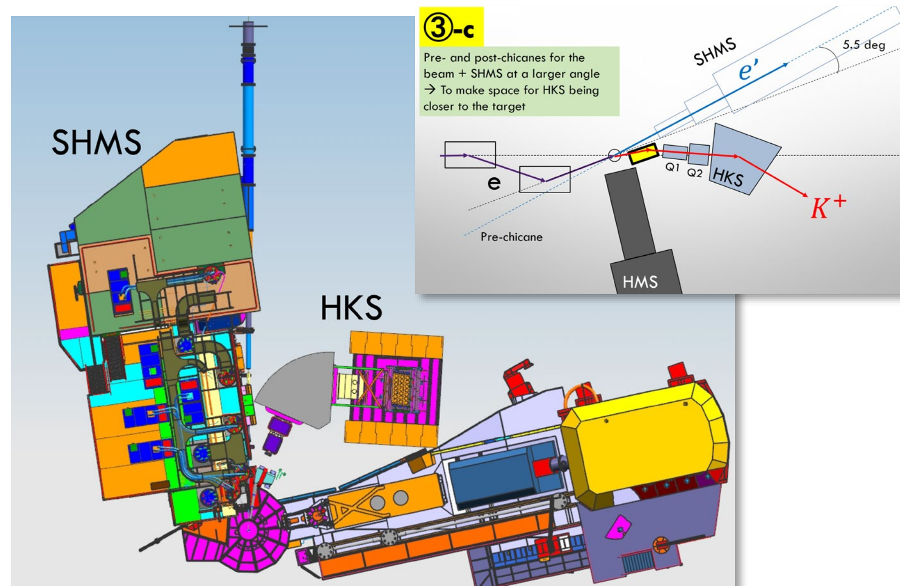
Dedicated configurations: Hypernuclear in Hall C

Slide from Toshiyuki Gogami

The best precision / accuracy spectroscopy is possible at JLab

→ JLab is very unique to investigate the ΛN interaction and hidden features in hypernuclei

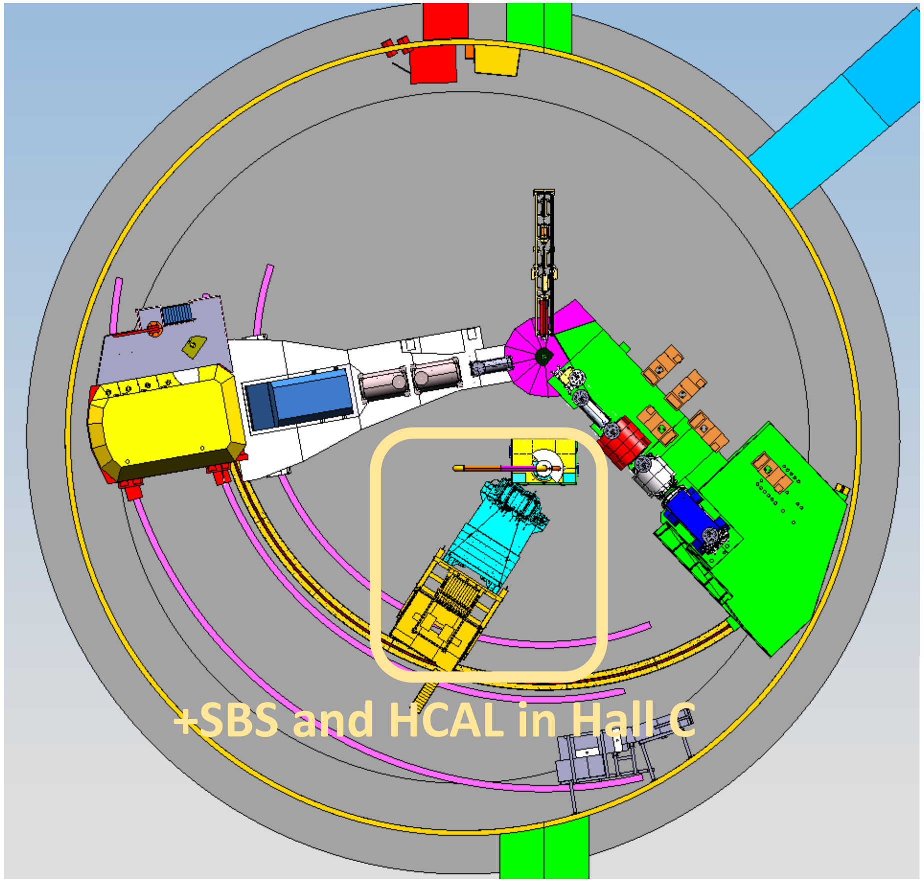




HES+HKS

- Could be the best option
- HKS needs to be modified (vacuum extension modification; VE → He bag)
- w/ PCS → S/N (could be) ↑ , yield ↓
- For gas target, one of spectrometers may need to be modified to the vertical bending

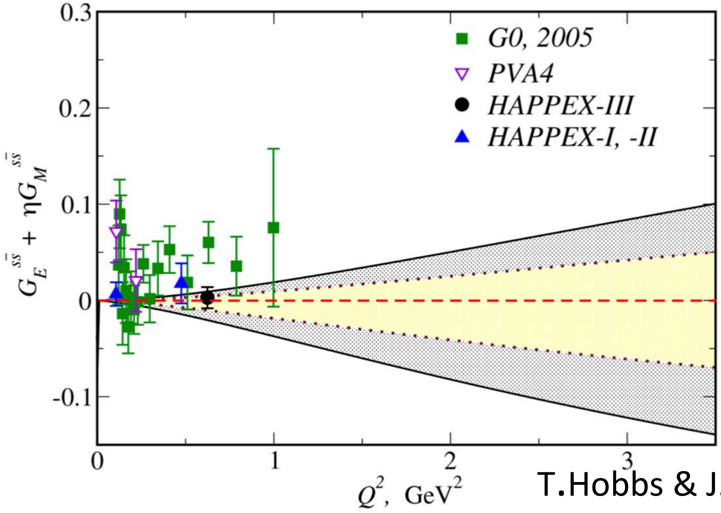
Dedicated configurations: strangeness form factors



SBS & HCal at 32.5 degrees, 2.5m downstream of polarized target

Standard pivot using HCal:
Strangeness form factor via parity, polarized proton detection in HCal – may have a peak at high(ish) Q^2

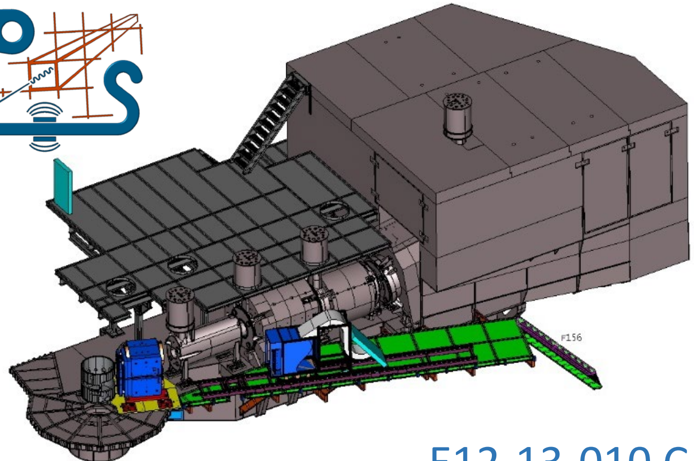
A possible coincidence parity experiment based on PR-06-004 from Bogdan Wojtsekhowski

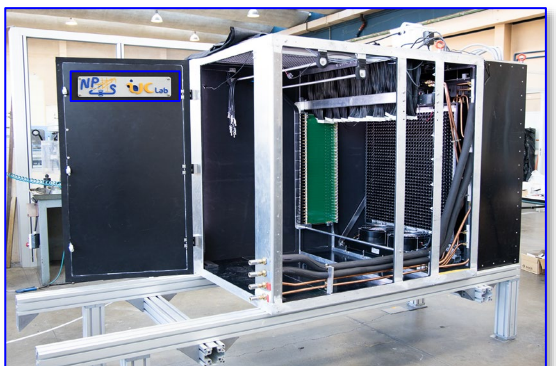


T.Hobbs & J.Miller, 2018

Hall C Instrumentation Examples – near term

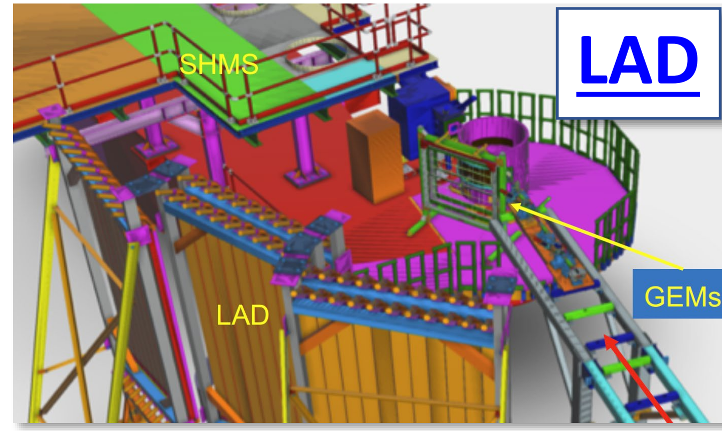
Spectrometers with standard pivot





E12-13-010 C. Munoz Camacho et al.
E12-13-007 H. Mkrtchyan et al.
E12-14-003 B. Wojtsekhowski et al.
E12-14-005 D. Dutta et al.
E12-17-008 D. Hamilton et al.
C12-18-005 M. Boer et al.
E12-20-007 W. Li et al.

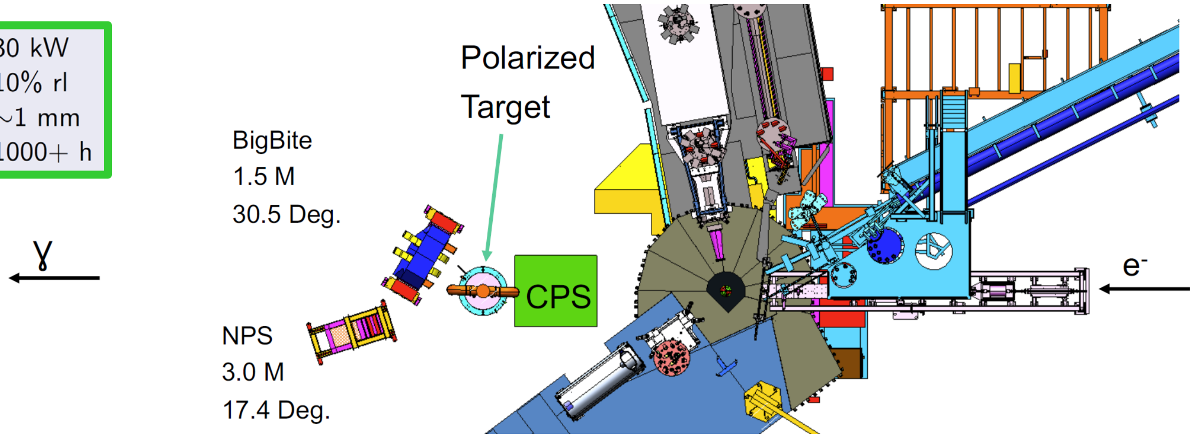
Pivot moved downstream



E12-11-107 O. Hen et al.

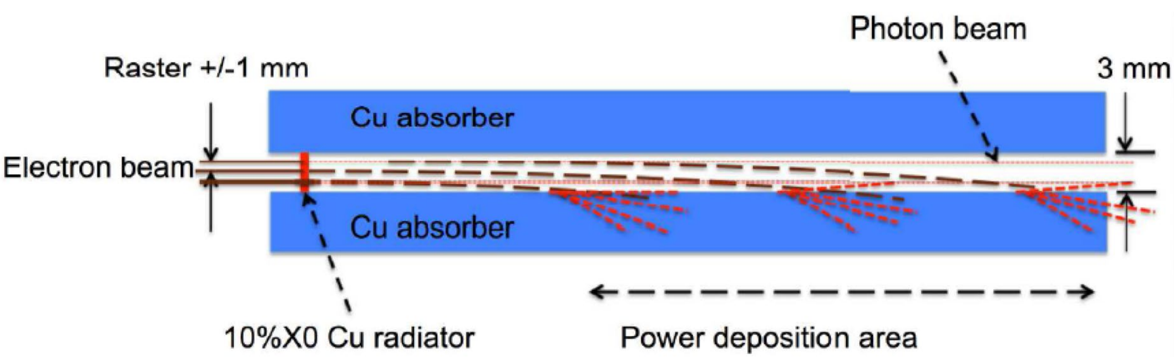
Hall C Instrumentation Examples – longer term

Power	30 kW
Radiator	10% rl
Beam size (@ 2 m)	~1 mm
Lifetime (est.)	1000+ h



Potential use of the magnet: CPS experiments plus Hall B Rungroup H

Compact Photon Source (CPS)



- ❑ Novel arrangement of untagged photon source for: high s,t photon-nucleon interactions
- ❑ Narrow photon beam – exclusivity
- ❑ Optimized for work with polarized targets
- ❑ High intensity (~30x better than alternatives)

Transverse Target

The new magnet will provide acceptances:
±35° for longitudinal polarization (30% smaller)
±25° for transverse polarization (67% larger)

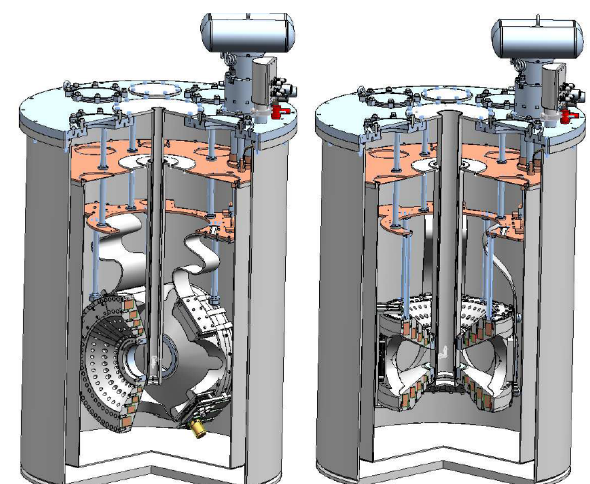
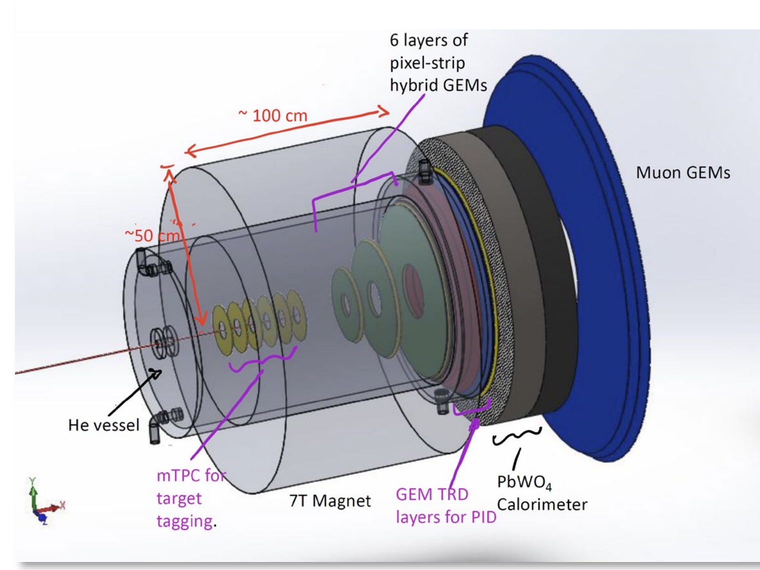


Figure 7: Cut-away of the 2 orientations for the magnet.

Ideas for future instrumentation: High Luminosity Spectrometer - 7T Solenoid

N. Liyanage, P. Souder, W. Xiong



- A high field compact solenoid
  - ~7 T field
  - Total length: 156 cm
  - Bore radius 55cm (inner) and 70cm (outer)
- Charged particle coverage from 12° to 36°
- EMCal coverage from 5° to 36°
- Detectors: High-precision PWO calorimeters, pixel GEM and strip GEM layer pairs: pixel GEM for detecting the track, strip GEM for high precision coordinate detection
  - Minimize multiple scattering through short pathlength from target to detector and filling the bore with Helium
  - Background will be addressed with pixel GEMs and fast electronics
- Early simulations suggest that this setup can handle luminosities up to 10^{38} cm^{-2}/s^{-1}
- Possible physics topics include Tagged DIS, Double DVCS

Hall C: An Outlook towards the Future

12 GeV	24 GeV
DVCS (with e^- and e^+), WACS	DVCS, DDVCS
Some TCS	TCS with polarized targets
L/T separations: DVMP factorization tests	L/T separations: DVMP in scaling region?
L/T separations: Pion form factor	L/T separations: Pion and Kaon form factor
SIDIS basic cross sections ($R = \sigma_L/\sigma_T$, $\pi^{+/-}$ ratios)	SIDIS basic cross sections (R, π and K ratios)
x > 1 & EMC effect	x > 1 & EMC effect & anti-shadowing?
	PV to constrain strange quarks (FF, DIS)
	Tagged Deep Inelastic Scattering
J/Ψ threshold production	Threshold charm states production (Ψ', …)?
ΛN interactions, hypernuclei	
(e,e' backward N) SRC	(e,e' backward particles)

Summary

- ❑ Hall C is ideally suited for JLab's future at high luminosity (+ possibly energy)

- ❑ Hall C: optimized facility for precision measurements of small cross sections
  - ➢ Spectrometer system with standard pivot and moved pivot
  - ➢ Flexibility for dedicated large installations – new and repurposed

- ❑ Plus opportunities with positron beam

Hall C: High Precision and Versatility at the Luminosity Frontier

Details on presentations at the HC-FTC:
https://hallcweb.jlab.org/wiki/index.php/Hall_C_Futures

Photon Sources – two existing options

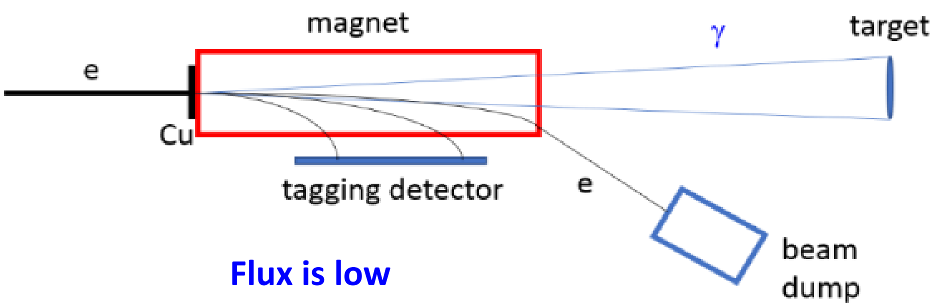
Physics requirements on the photon beam:

- Small beam spot at target (< 2 mm, for background suppression)
- Low radiation at detectors (a practical limit in many experiments)

RMP 50 (1978)

Radiator, Sweeper, (Tagger), Dump

- Early examples: DESY(1971), SLAC(1971), CEA(1972/73)
  - s > 2 GeV^2, low t, Flux ~ 2 x 10^8 γ/s
- Cornell (1975), flux ~ 1.5 x 10^{10} γ/s
- If tagging, usable flux is lower (~ $10^{7\text{-}8}$ γ/s)

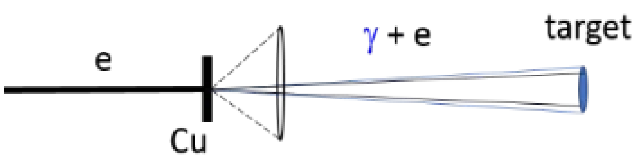


Flux is low

Needs a lot space

Mixed electron/photon beams

- JLab (2002,2008), flux ~ 2 x 10^{13} γ/s
- Competing reactions: π^0 photoproduction, ep – difficult analysis (e.g. low cross section)
- Low analyzing power of proton polarimetry
- Low efficiency with polarized targets



Mixed electron + photon beam

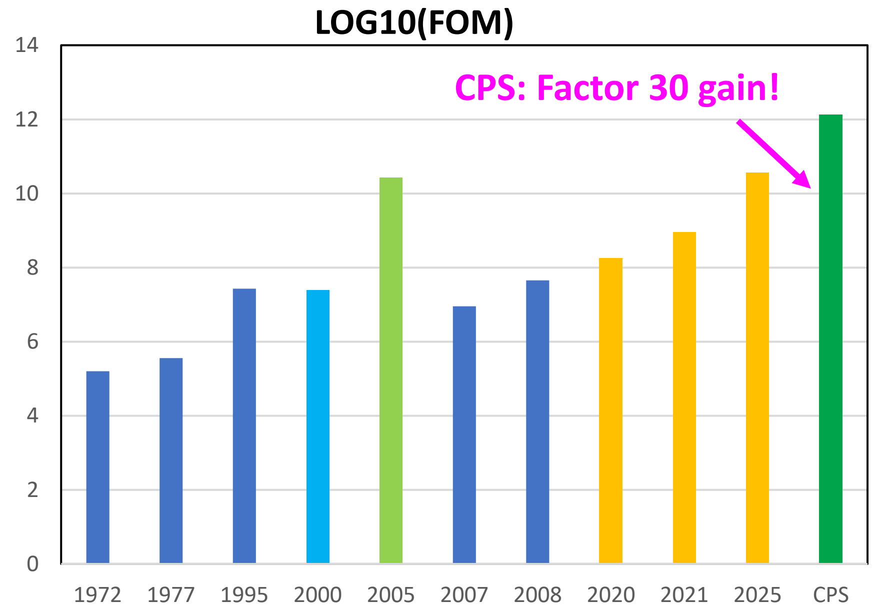
Radiation level high

CPS - Unique Gain in Science Output

CPS with Dynamically Nuclear Polarized Targets has a factor of 30 gain in intensity to image the 3D nucleon substructure

- ❑ Requirements on polarized target:
  - ○High and sustained proton polarization (shorter target annealing procedure)
  - ○Beam intensity (heat/radiation load is a limiting factor for luminosity)

- ❑ Mixed photon beam + polarized target = lots of problems
  - ○Frequent annealing, change of material [SANE exp., J. Maxwell]



The CPS scheme features a combination of target rotation around the horizontal axis and vertical motion of the target ladder to minimize polarization degradation and is anticipated to be used with electron currents up to 2.7uA