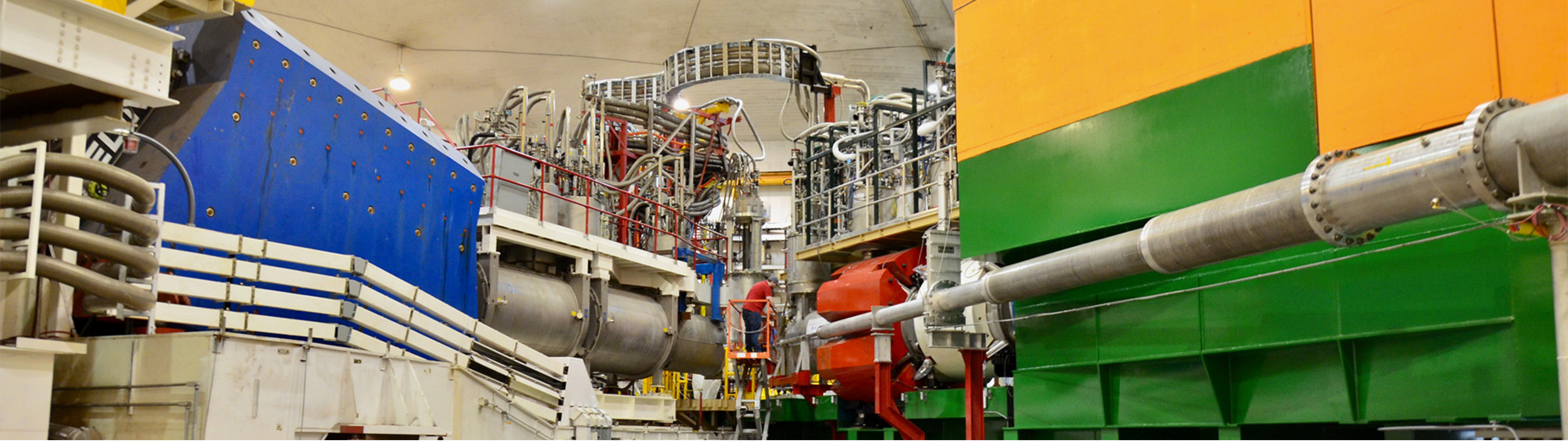


# Hall C Futures Overview

Arun Tadepalli – Jefferson Lab

(on behalf of the Hall C Future Task Force)

Jefferson Lab

*Borrowed heavily from Tanja Horn's presentation
at Hall A/C collaboration meeting June 2021

# Hall C Futures Taskforce

- Chairs: Cynthia Keppel, Steve Wood, Mark Jones
- 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)
  - Your name!

Ask Thia or Mark to become a member
https://hallcweb.jlab.org/wiki/index.php/Hall_C_Futures

# Hall C: High Precision at the Luminosity Frontier

SHMS, HMS, CPS, NPS, HCAL, ECAL etc. versatility of new equipment

High Precision polarimetry


+ AI/Machine learning

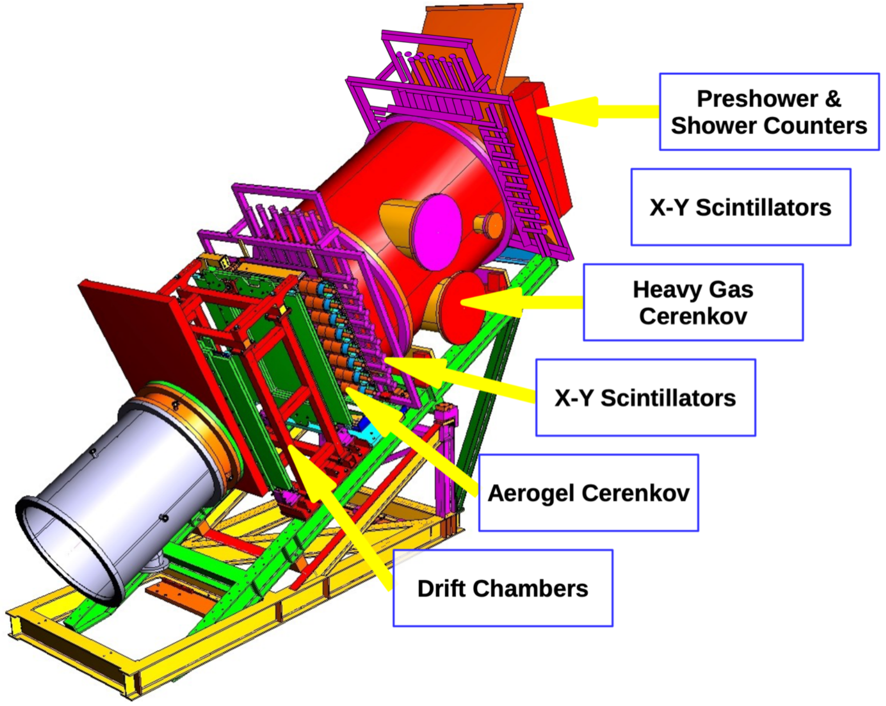
High Precision measurements of small cross sections

High power and polarized targets ($LH_2$, $LD_2$, $NH_3$, $ND_3$, Pol $^3He$ etc)

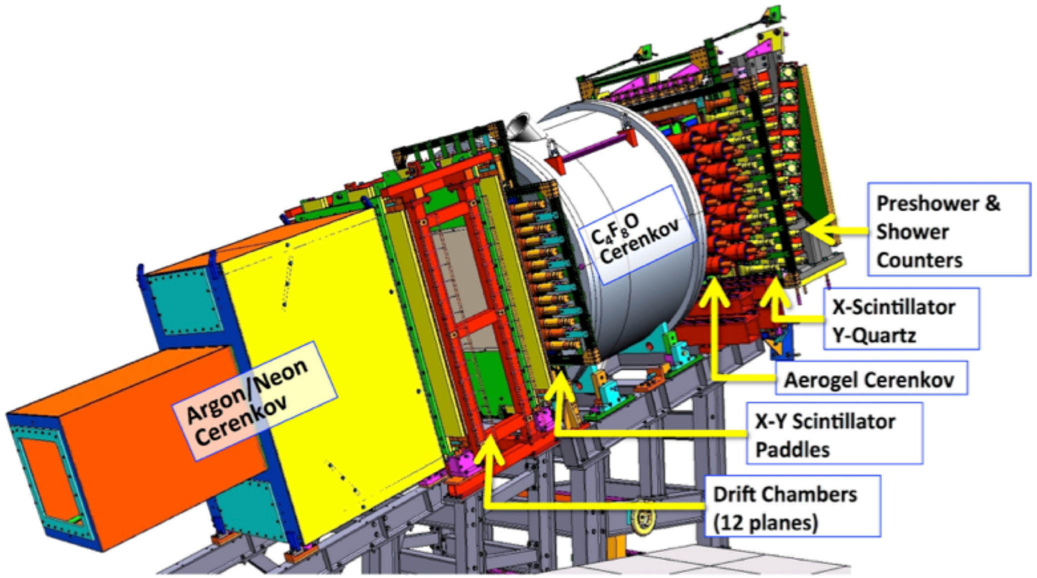
Space for new installations

# HMS and SHMS (base spectrometers)

- HMS and SHMS that can reach 6+ and 11+ GeV/c with 10% momentum bites (single and coincidence mode)
- 0.1% reconstruction efficiency easily demonstrated
- Excellent PID
- Cerenkov and lead glass shower counters
- Can go up to 5.5 and 10.5 deg with sub-mrad pointing accuracy




HMS

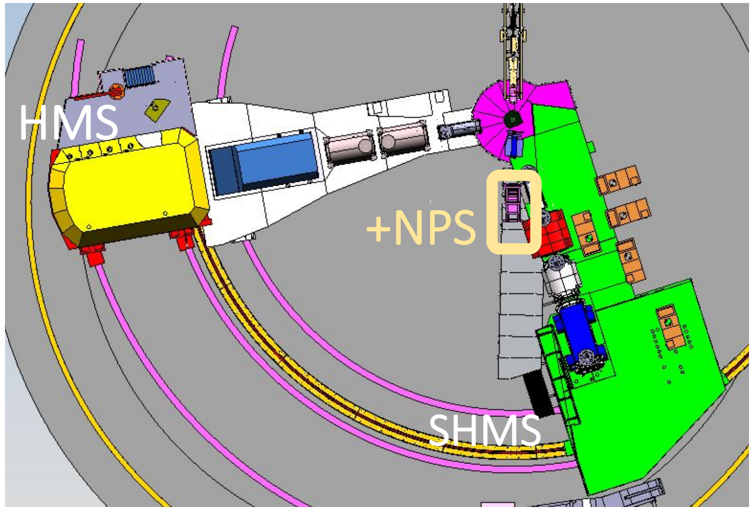



SHMS

Slide from Tanja

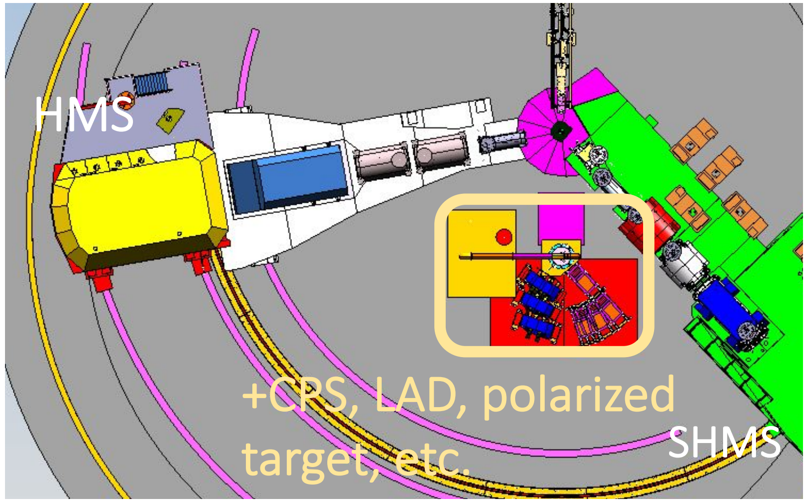
# Two pivot configurations

**Spectrometers with standard pivot**




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

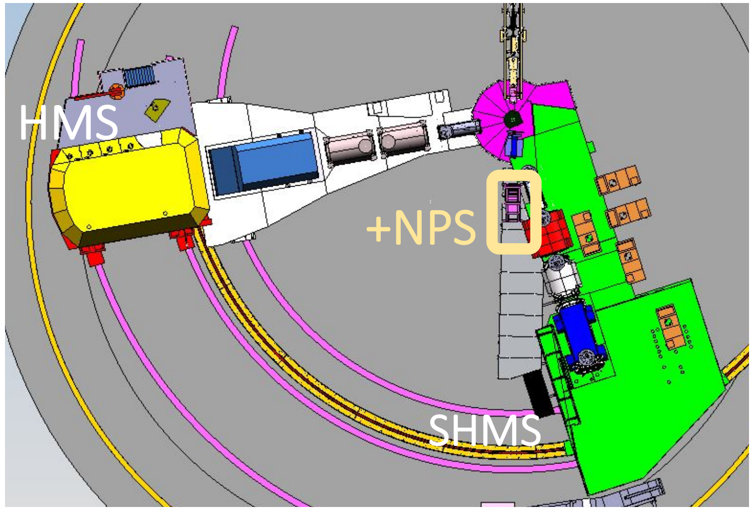
**Pivot moved downstream**




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

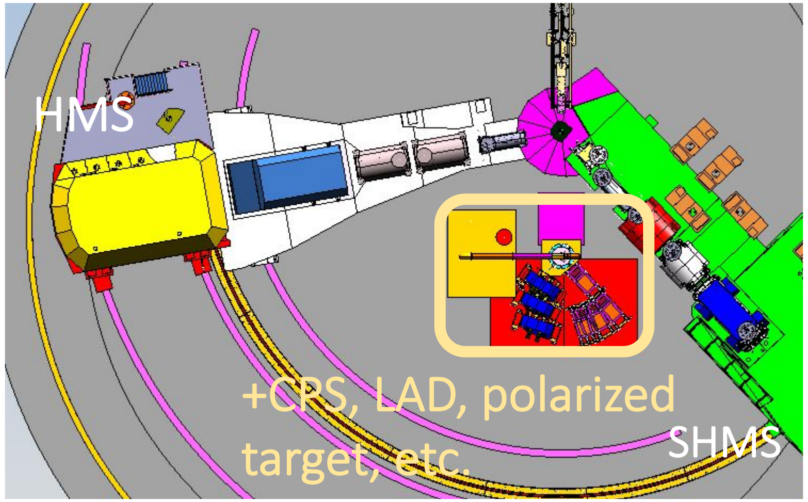
# Two pivot configurations

Spectrometers with standard pivot



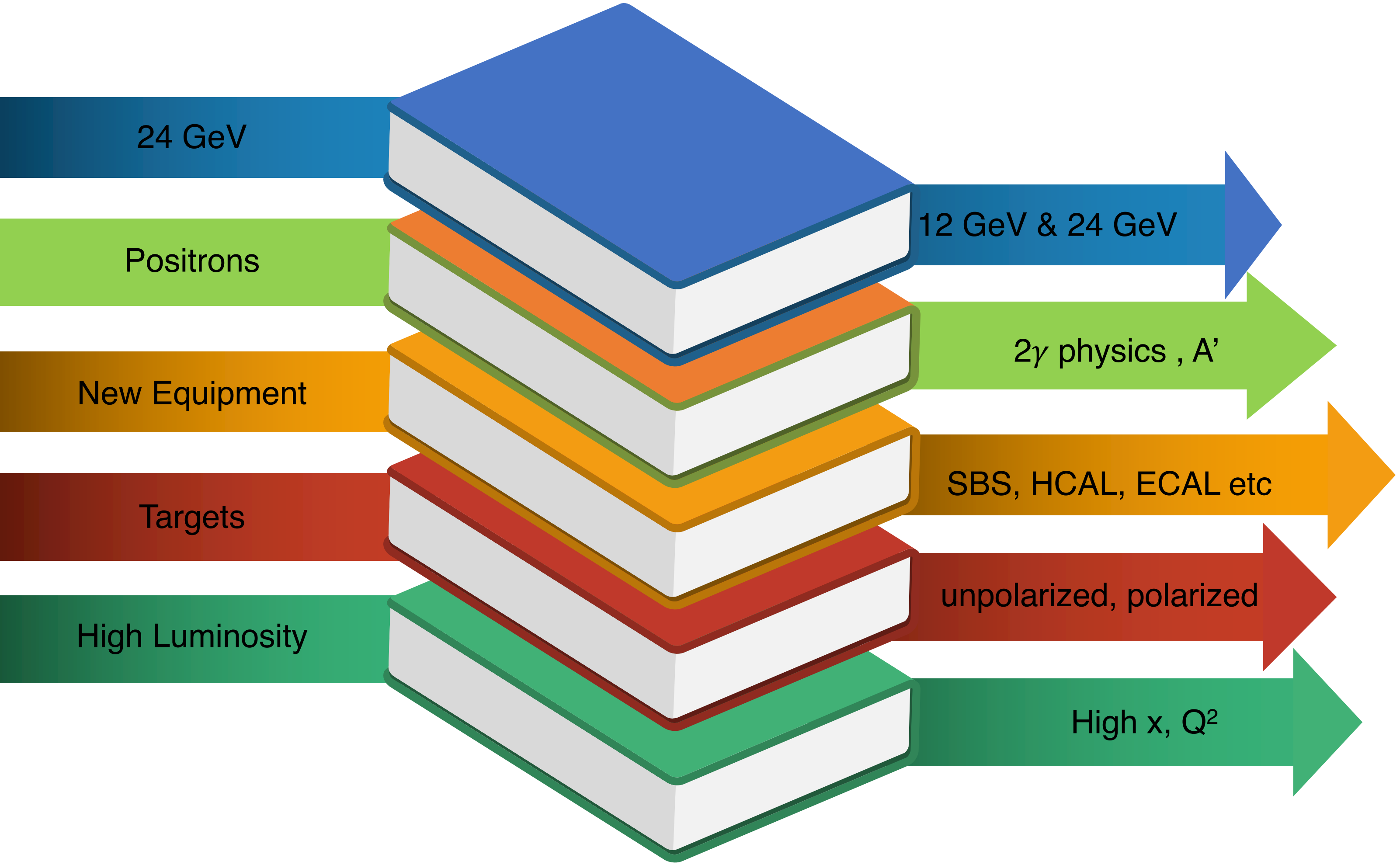

- F$_2$ at x>1
- Pion Form Factor
- Reaction Mechanism validation – Kaon FF, GPD and TMD
- Precision EMC
- DVCS and p$^0$ cross sections
- …..

Pivot moved downstream

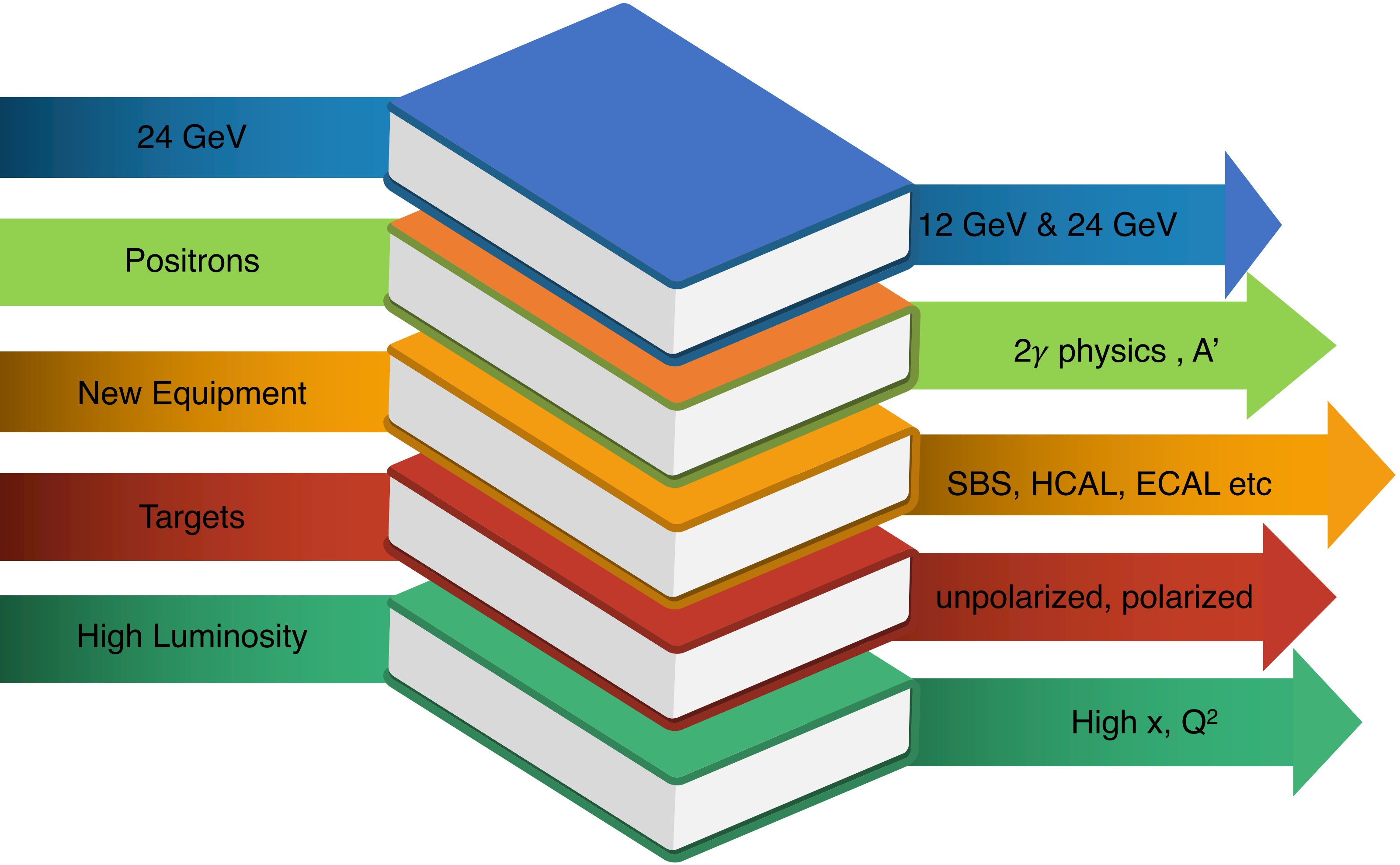



- Polarized WACS
- 2N-SRC
- Tagging processes
- TCS
- ….

# New Frontiers



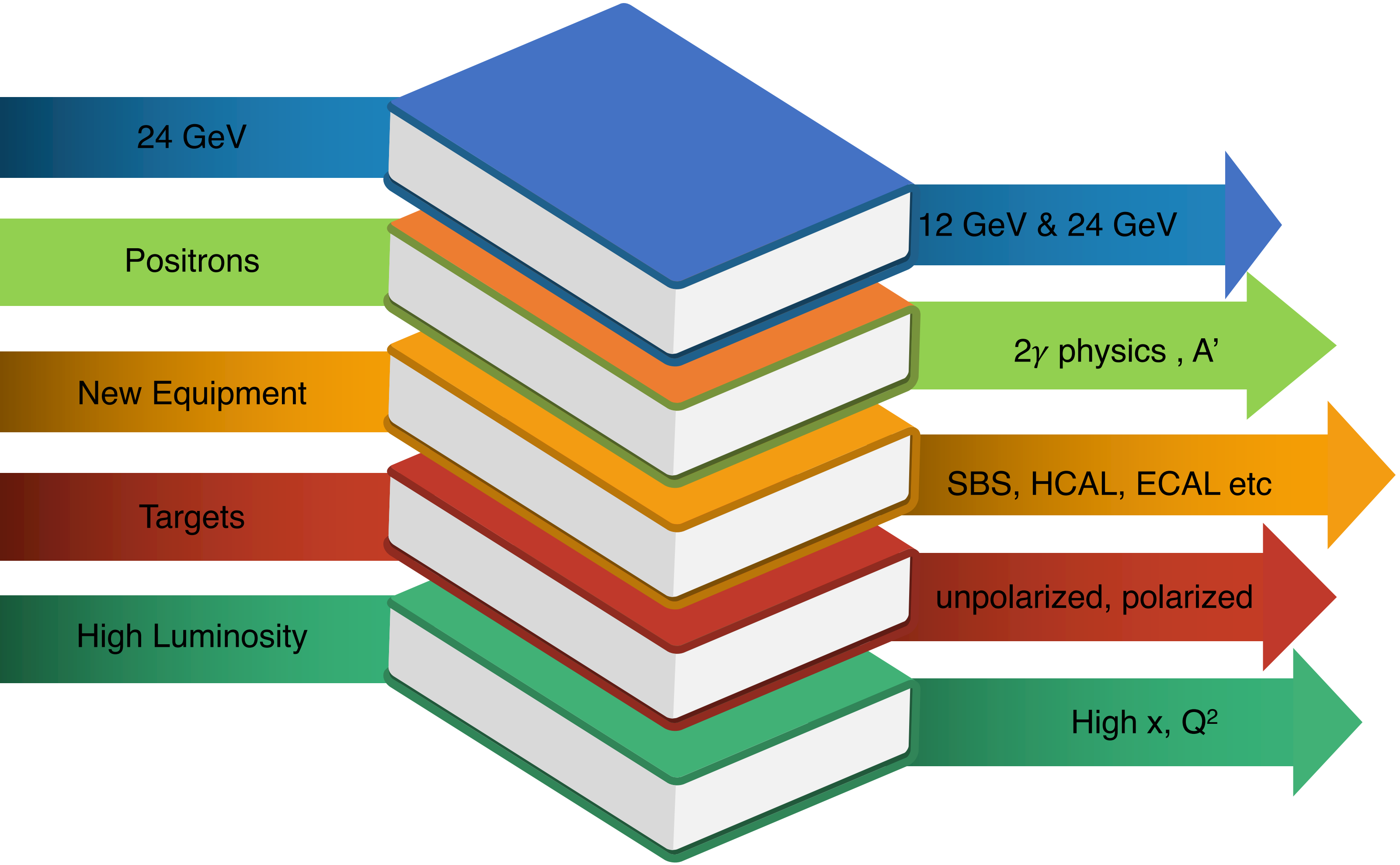
# New Frontiers



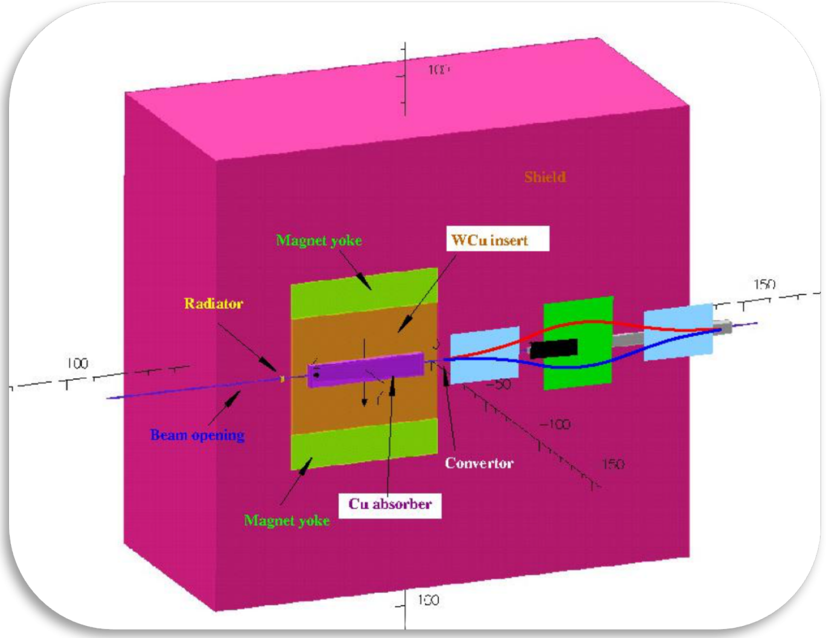

| 12 GeV | 24 GeV |
|---|---|
| DVCS (with $e^-$ and $e^+$), WACS | DVCS, DDVCS |
| Some TCS | TCS with polarized targets |
| L/T separations: DVMP factorization tests | L/T separations: DVMP in scaling region? |
| L/T separations: Pion form factor | L/T separations: Pion and Kaon form factor |
| SIDIS basic cross sections ($R = \sigma_L/\sigma_T$, $p^{+/-}$ ratios) | SIDIS basic cross sections (R, p 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/Y threshold production | Threshold charm states production (Y', …)? |
| LN interactions, hypernuclei | |
| (e,e' backward N) SRC | (e,e' backward particles) |

Table credit: Tanja

# New Frontiers



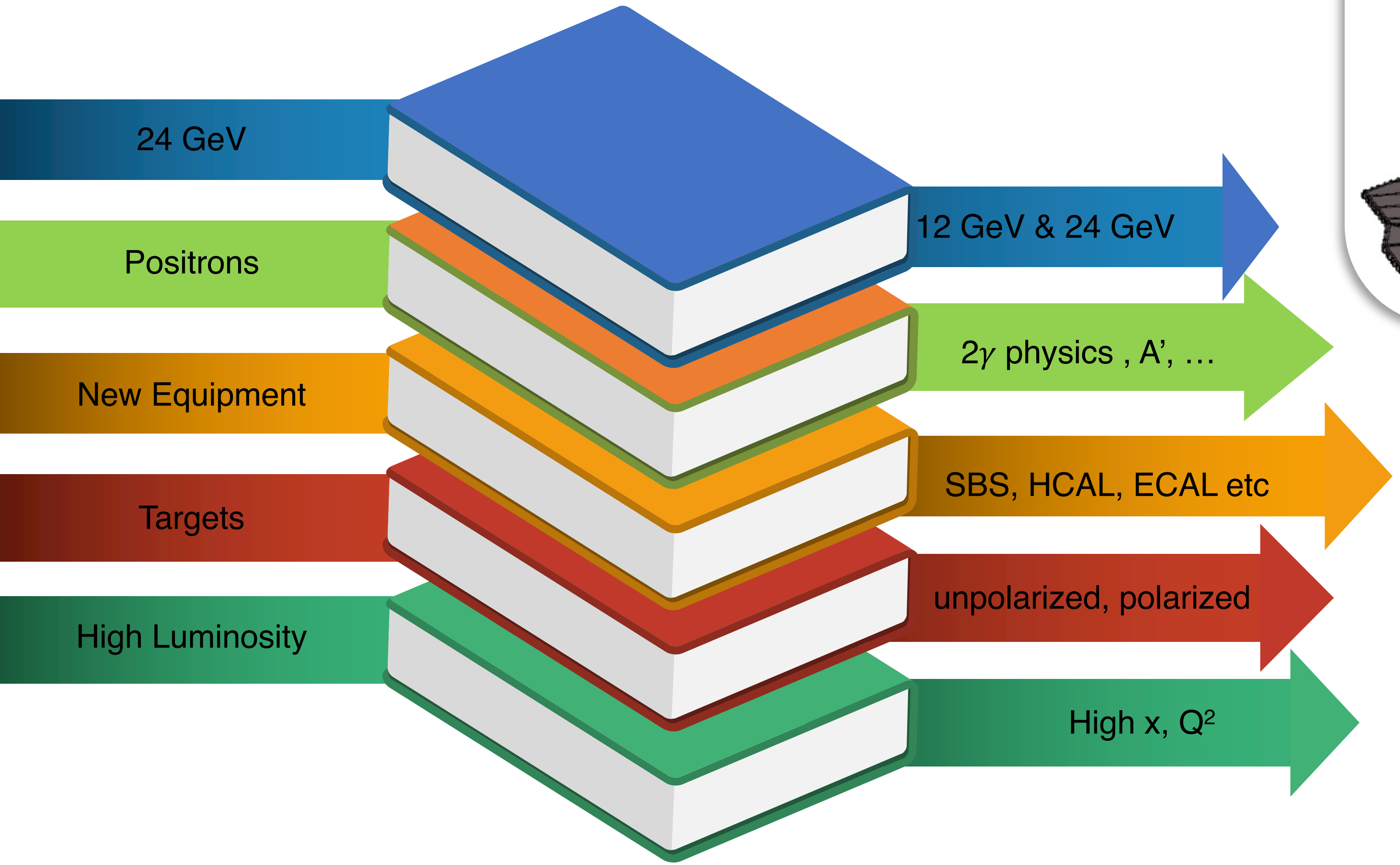

See Gabriel Niculescu's talk

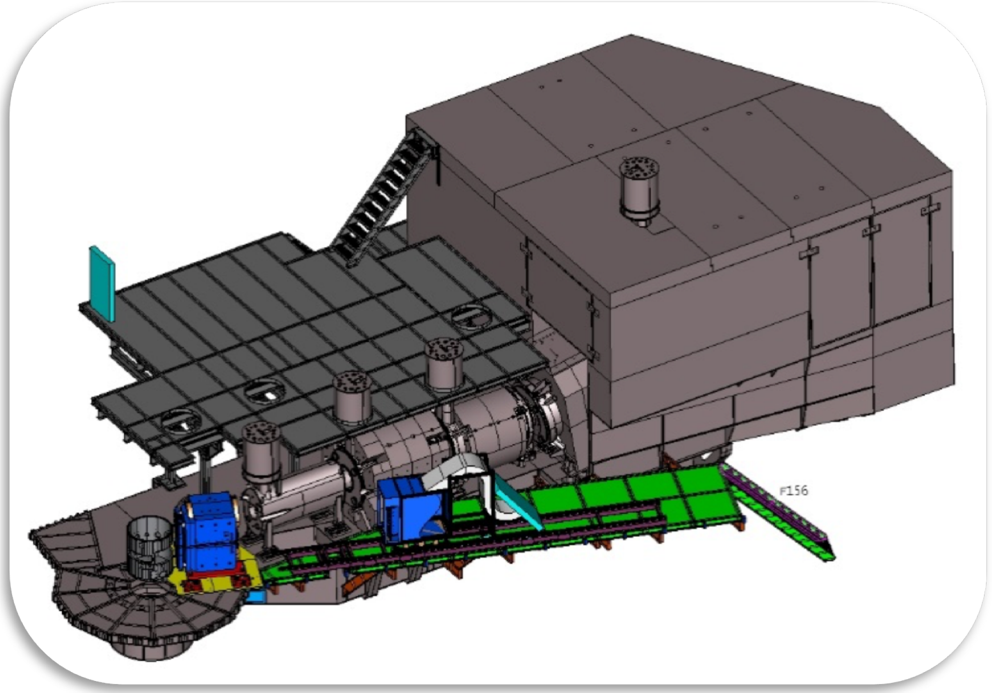



- CPS with a small addition could allow us to make a positron beam
- e+/e- physics to pursue 2$\gamma$ physics
- Search for dark photons

See Vladimir Berdnikov and David Hamilton’s talks

# New Frontiers



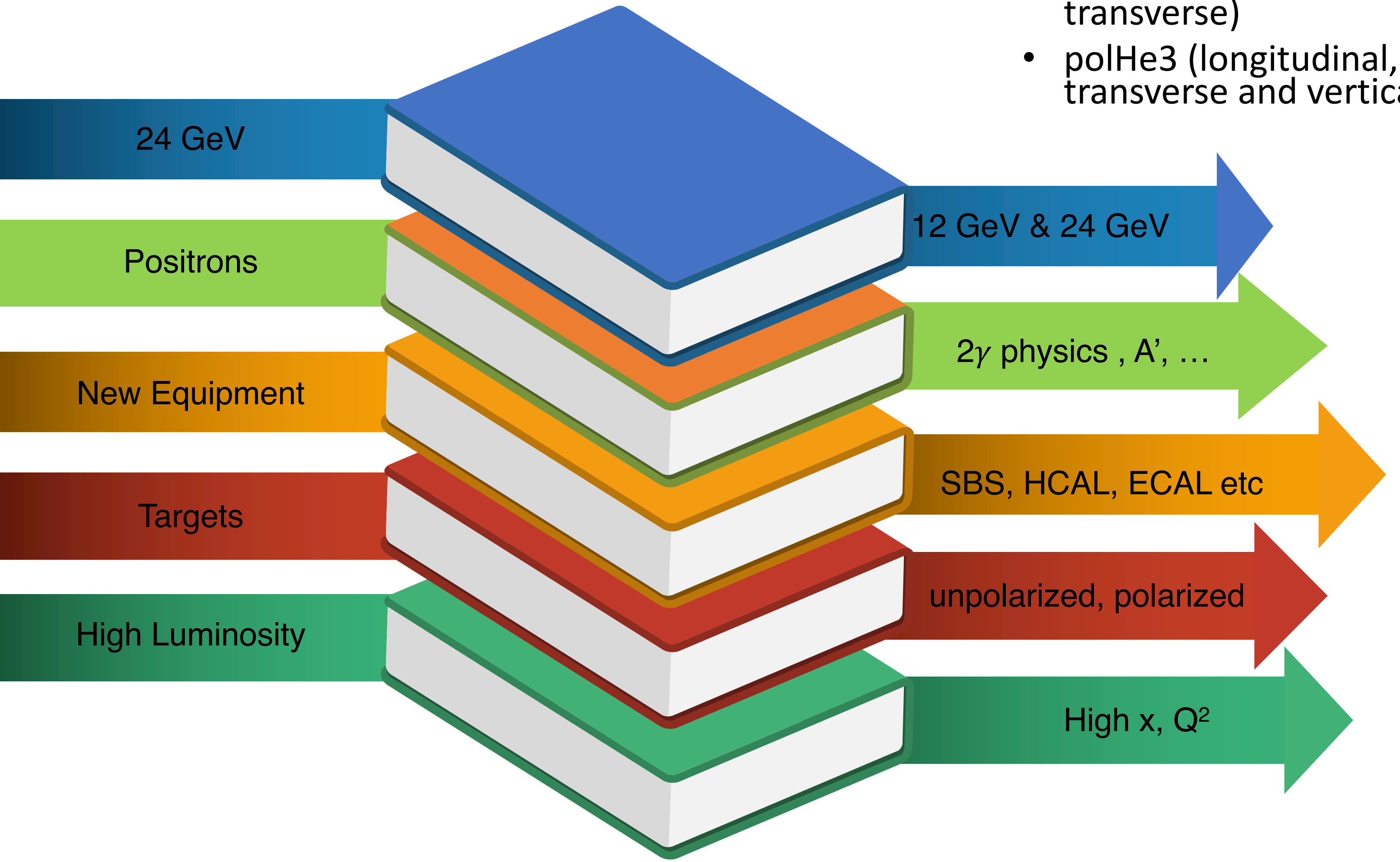



NPS (Neutral Particle Spectrometer)

- Precision measurement of cross sections with neutral final states
- 6 fully approved proposals + 1 conditionally approved
- Exclusive DVCS, $\pi^0$ cross sections to highest $Q^2$, $\pi^0$ electroproduction, factorization, WACS, TCS (GPD universality), exclusive production of $\pi^0$ ($\gamma$ p-> $\pi^0$ p)

# New Frontiers

- High power targets
  - Standard cryogenic (LH2, LD2)
  - Variety of solid targets
- Polarized targets
  - $NH_3$, $ND_3$ (longitudinal or transverse)
  - polHe3 (longitudinal, transverse and vertical)



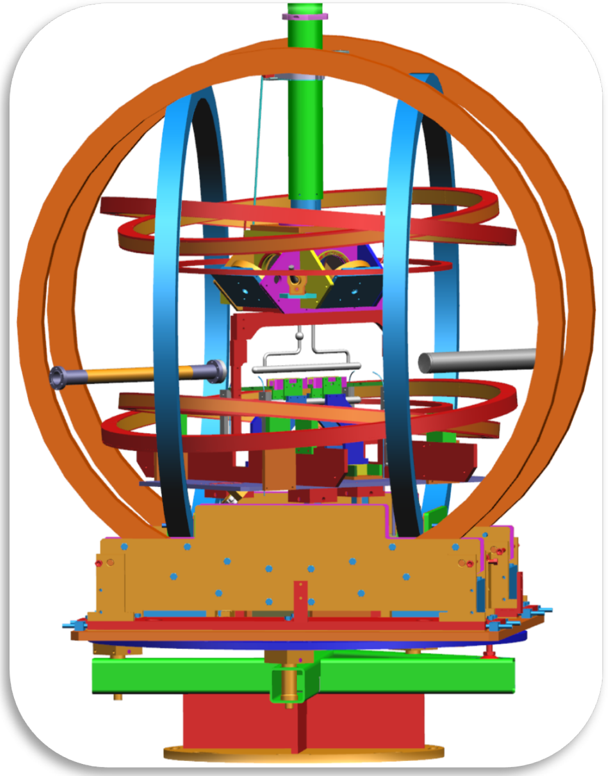


CAD rendering of PolHe3 setup

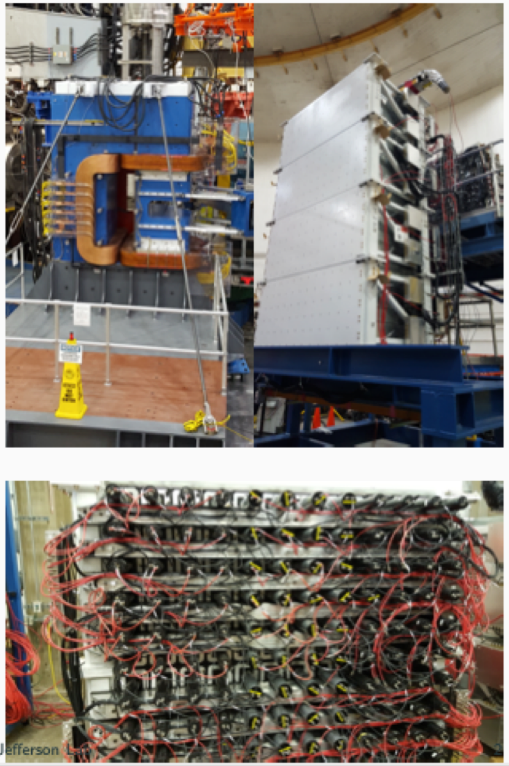
TABLE II. Parameters of several high power targets.

| Target | Length or Radiation Length | Nominal Maximum Current (Power) |
|---|---|---|
| *LH2, LD2* | 10 cm (1.5%) | 100 muA (400 W) |
| $^3$He | 10 cm (0.105 g/cm$^3$) | TBD |
| $^4$He | 10 cm (0.140 g/cm$^3$) | TBD |
| Carbon | 0.5% | 80 $\mu$A (38 W) |
| Carbon | 5% | 60 $\mu$A (380 W) |
| Aluminum | 1.5% | 40 $\mu$A ( 32 W) |

# SBS + HCAL for GMn run

## HCal Overview

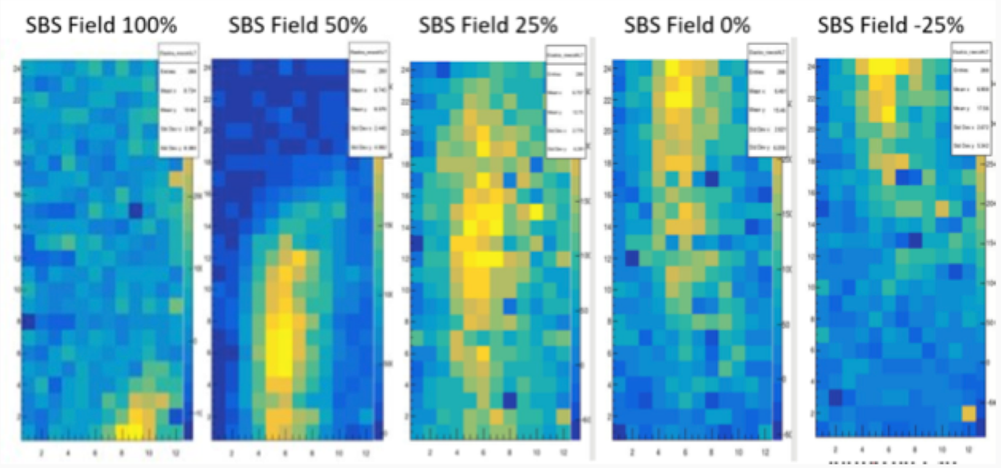
- Design based on COMPASS HCAL1 (Vlasov *et al.* 2006).
- Segmented calorimeter designed to detect multiple GeV protons and neutrons.
  - 288 PMT modules (24×12).
  - LED fiber optics system.
- SBS dipole magnet separates scattered hadrons by charge.
- High time resolution (0.5 ns).
- High position resolution (3-4 cm at 8 GeV).
- Neutron to proton detection efficiency ratio 0.985 at 8 GeV.
- Energy resolution ≈30%.



Scott Barcus Jefferson Lab

## Proton Sweep

- Using a $LH_2$ target sweep the magnetic field to illuminate all of HCal with elastic protons.
- These elastics are well understood and can be used for calibrations and detector characterization.

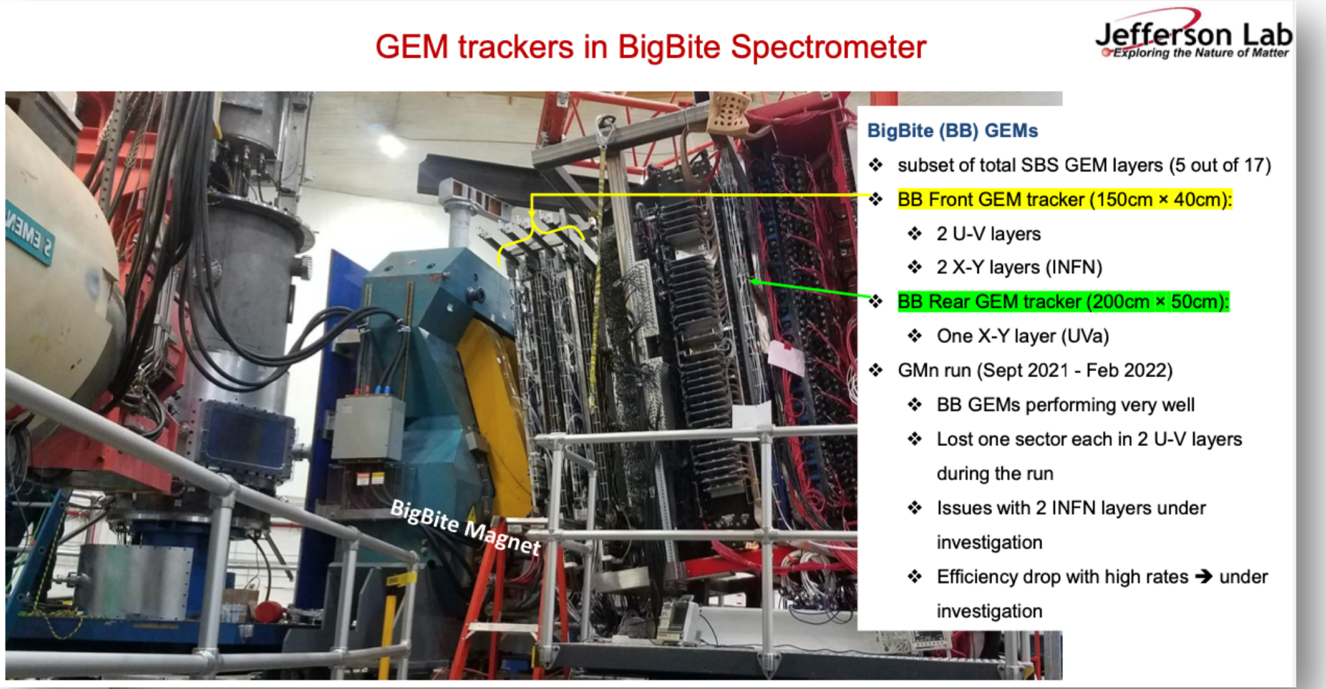


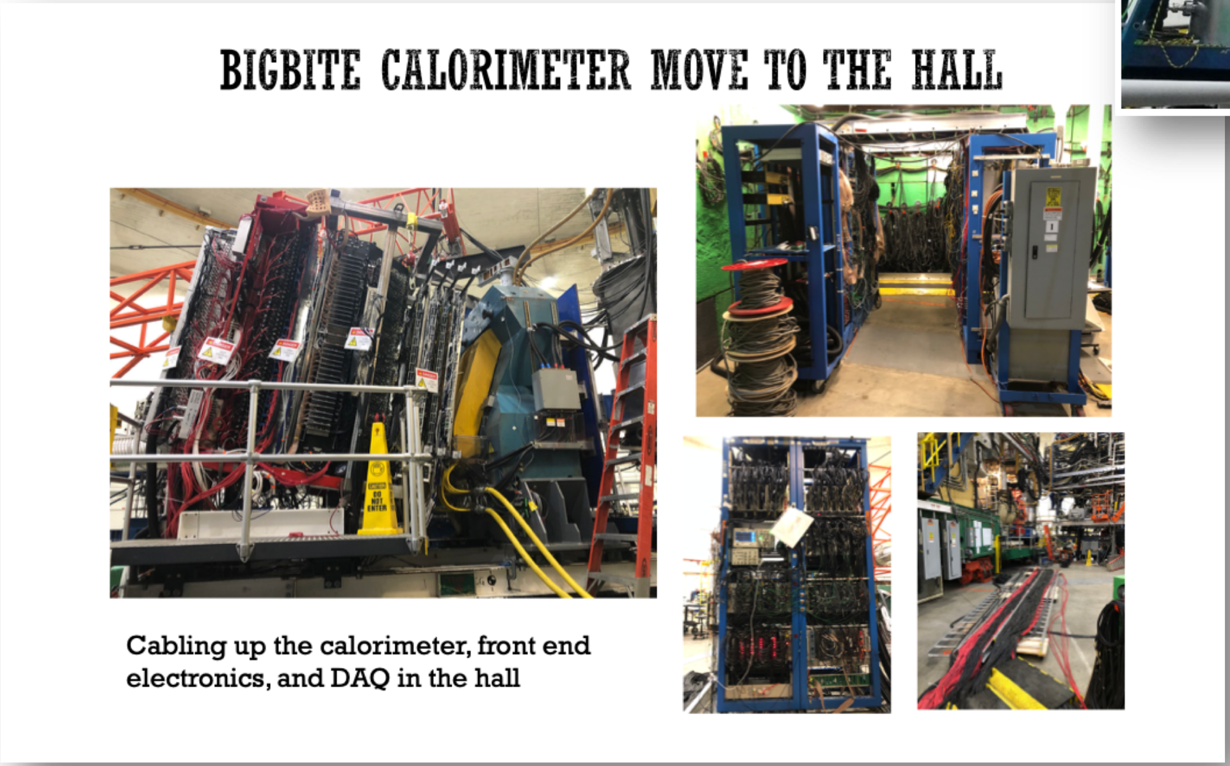

Scott Barcus Jefferson Lab 7

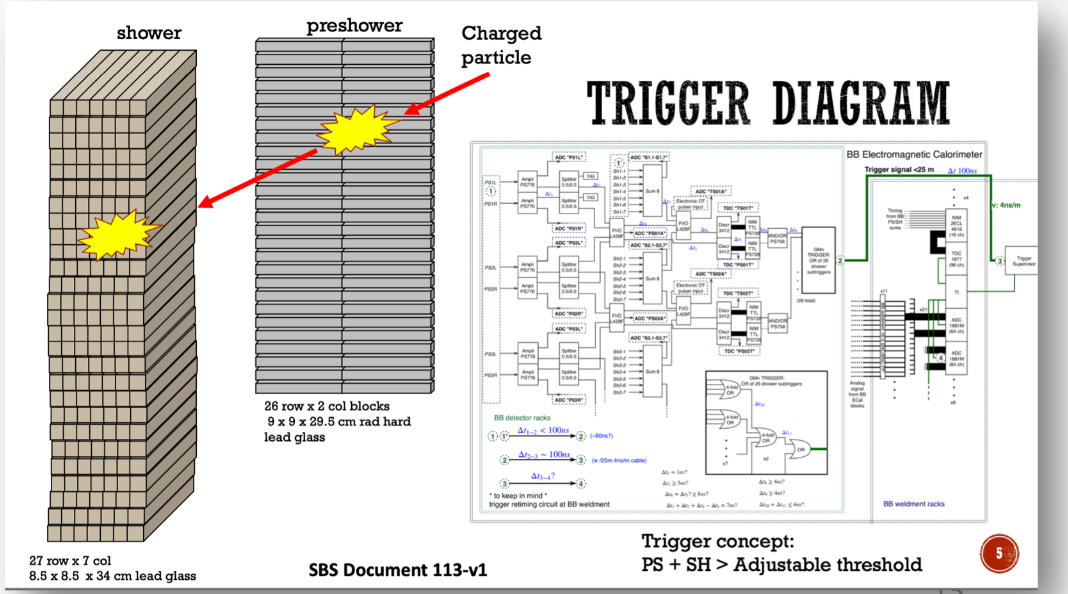
Slides taken from Scott Bacrus's talk at Hall A Collaboration meeting (Feb 11th, 2022)

# BigBite in Hall A

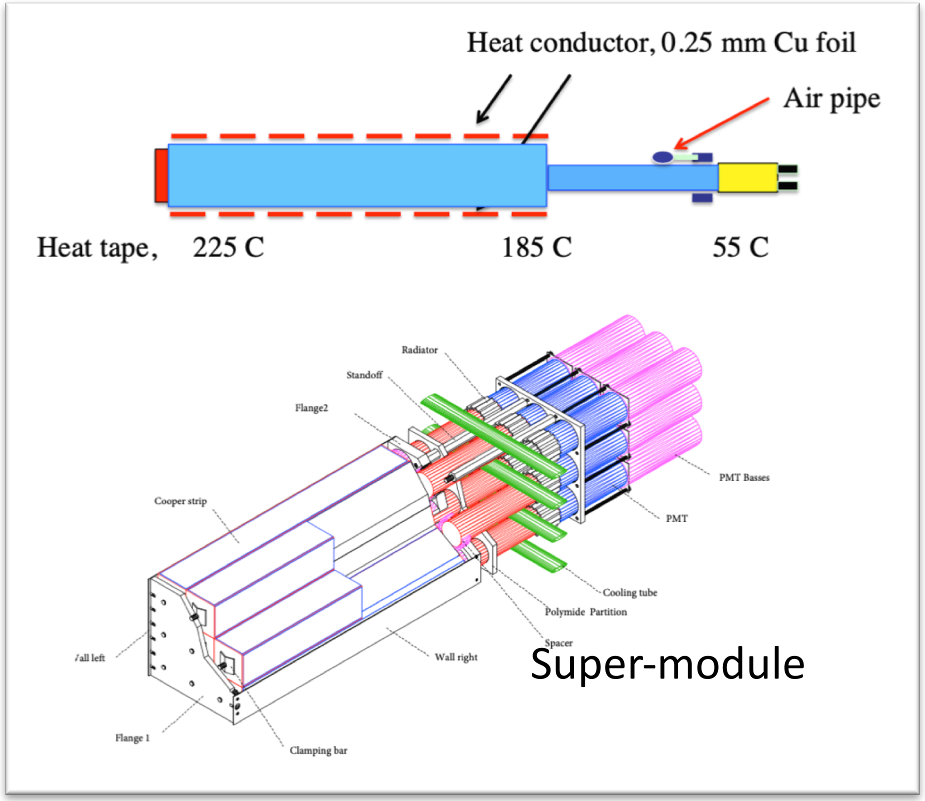
- See Arun Tadepalli's talk
- See Kondo's talk
- See Bogdan Wojtsekhowski's talk
- See Robin Wines's talk

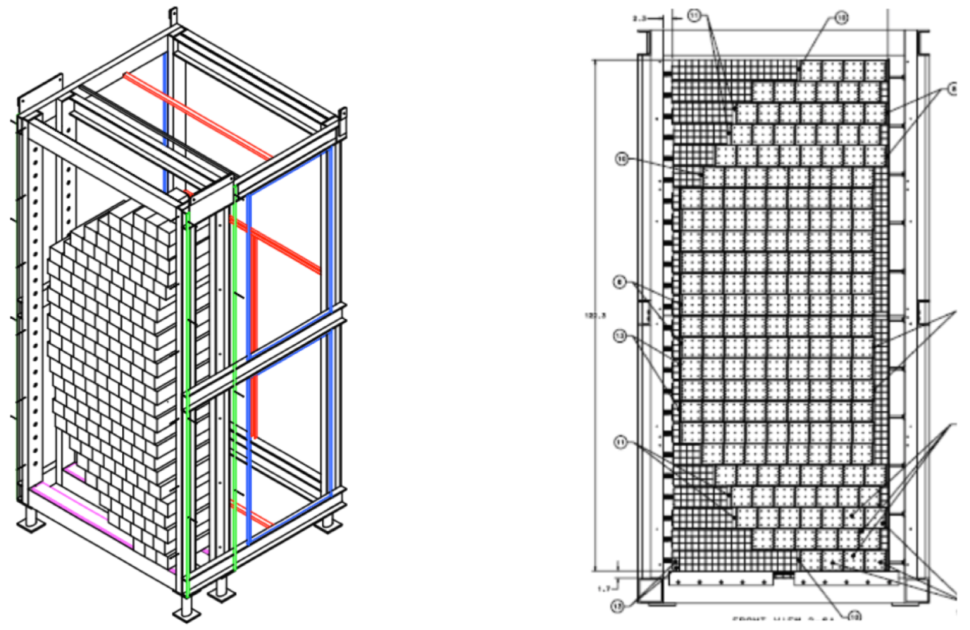


# ECAL for GEp



1737 lead-glass modules
Elevated temperature of the glass (225-185 C)

- Full scale calorimeter under construction for the proton GEp experiment
- Radiation damage induced cured by exposing lead glass to UV-light and/or elevated temperature
- 15 cm long light guide, additional copper foil to increase heat conductivity

# Recent talk/ideas

- KLL measurement following C-GEn experiment (Oct 14, 2021) - Arun Tadepalli [link]
- Final State Interactions in QCD and Other Explorations (Aug 12, 2021) - Dipangkar Dutta [link]
- Overview of a Brooks-style approach to a broadband mixed e+ and e- beam: what measurements it can do, and what it cannot do (Jul 15th, 2021) - Dave Mack [link]
- Possibilities for Hypernuclear Physics in Hall C (July 1st, 2021) - Toshiyuki Gogami [link]
- Solid Polarized Targets for the Jlab 12 GeV Era (June 17th, 2021) - Karl Slifer, Elena Long [link]
- Proton strangeness from elastic electron scattering (Jun 3rd, 2021) - Bogdan Wojtsekhowski [link]
- 20 24 GeV FFA CEBAF Energy Upgrade (May 20th, 2021) - Alex Bogacz [link]
- Future Studies of Nuclei in Hall C [focusing on nuclear aspects] (May 6th, 2021) - Or Hen [link]
- A Triple Coincidence Experiment: u-channel DVCS at Hall C (Apr 22nd, 2021) - Garth Huber, Bill Li, Justin Stevens [link]
- Opportunities with High Intensity Photons and Polarized Target (Apr 8th, 2021) - Tanja Horn [link]
- A high luminosity spectrometer based on a compact, high-field Solenoid for DVCS, DVMP, TDIS and more (Mar 25th, 2021)- Nilanga Liyanage [link]
- Positron Beams at Jefferson Lab - Status Report (Mar 11th, 2021) - Joe Grames [link]
- Positron Machine, Future Prospects (Mar 11th, 2021) - Yves Roblin [link]
- Electro-weak (e+-, e') Measurements with Unpolarized Target (Feb 25th, 2021) - Dave Mack [link]
- Hall C Future Experiments - Cynthia Keppel [link]

https://hallcweb.jlab.org/wiki/index.php/Hall_C_Futures

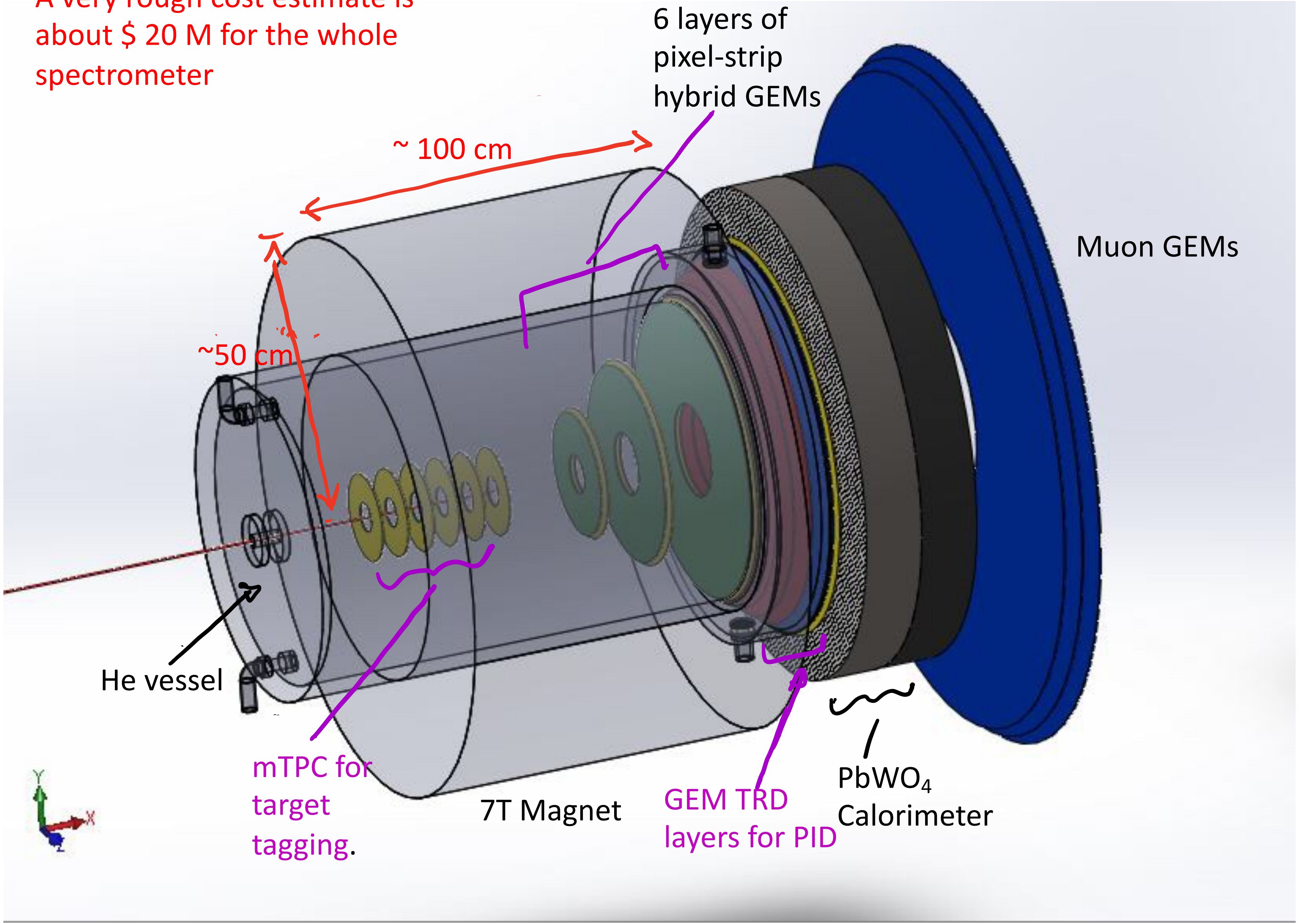
One new idea, from N. Liyanage and collaborators

# A high luminosity spectrometer based on a compact 7T Solenoid magnet for DVCS, DVMP, TDIS and more

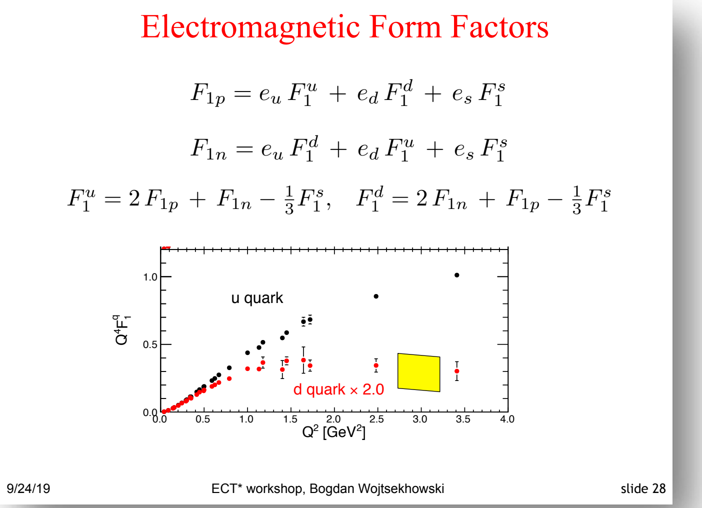
Nilanga Liyanage, Paul Souder, Weizhi Xiong

- A high field compact Solenoid ( ~ 7 T field, bore diameter and length ~100 cm) has a $\int b \cdot dl$ similar to a large solenoid like SoLID, but has some important advantages:
  - Costs much less (estimate from manufacturer ~ $ 3.8 M for the magnet)
  - Much easier to install, instrument and run
  - The area needed to be covered by the detectors is much smaller: this allows for state of the art detectors such as $PbWO_4$ calorimeters, pixel GEMs etc. with high granularity.
  - The path length from target to detectors is very short: much less multiple scattering – better resolution- clean missing mass identification
  - We propose to fill the bore with Helium – reduce multiple scattering even further.
- Given the short distance to detectors the background rates will be high: but can handle with pixel GEMs and fast electronics etc: rate estimations already done.
- Early simulations show that this setup can handle luminosities up to $10^{38}$
- Will allow comprehensive measurements of DVCS and DVMP covering the entire valance quark region
- Adding several layers of muon GEMs will allow DDVCS.
- The multi-TPC for target tagging fits in nicely within this solenoid – measure TDIS, pion and Kaon structure functions, tagged neutron DVCS, DVMP and more
  - mTPC and the GEMs sitting in the He atmosphere with no windows; ideal conditions for detecting very low momentum spectators.

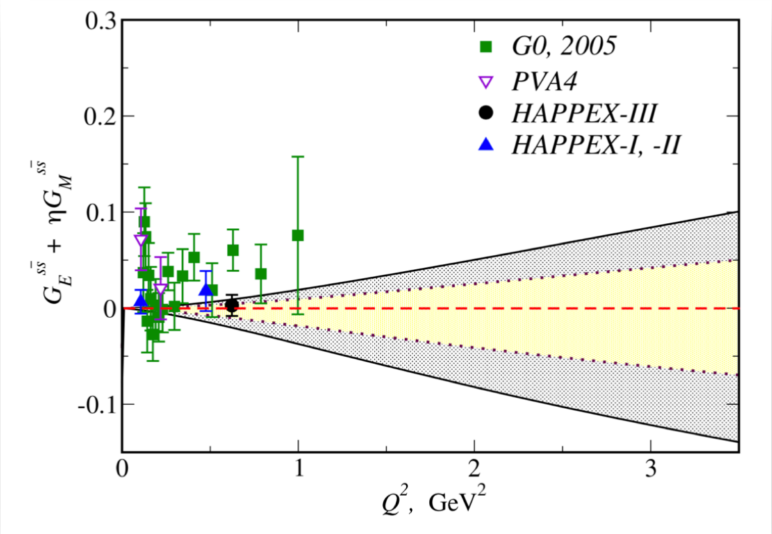
A very rough cost estimate is about $ 20 M for the whole spectrometer

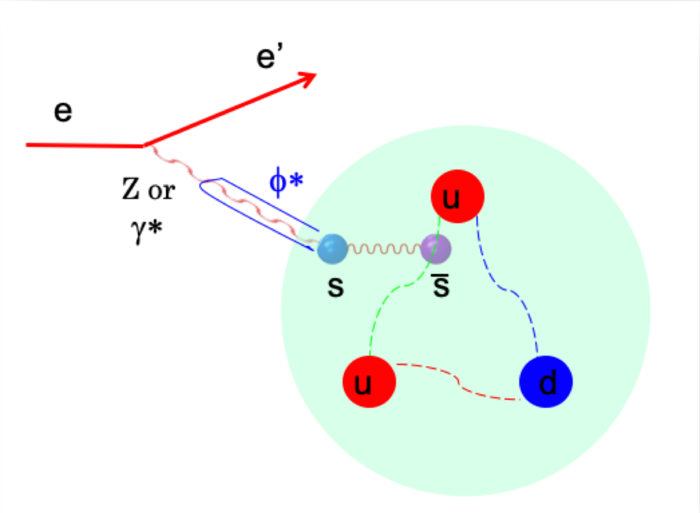


# Strangeness Form Factors



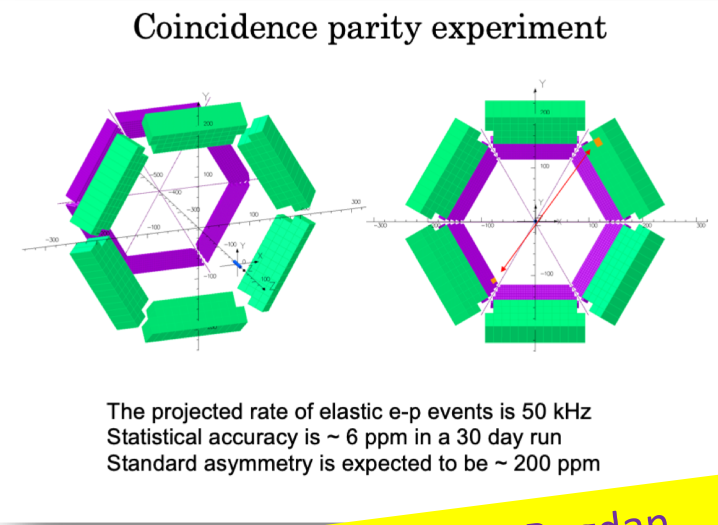

T.Hobbs & J.Miller, 2018

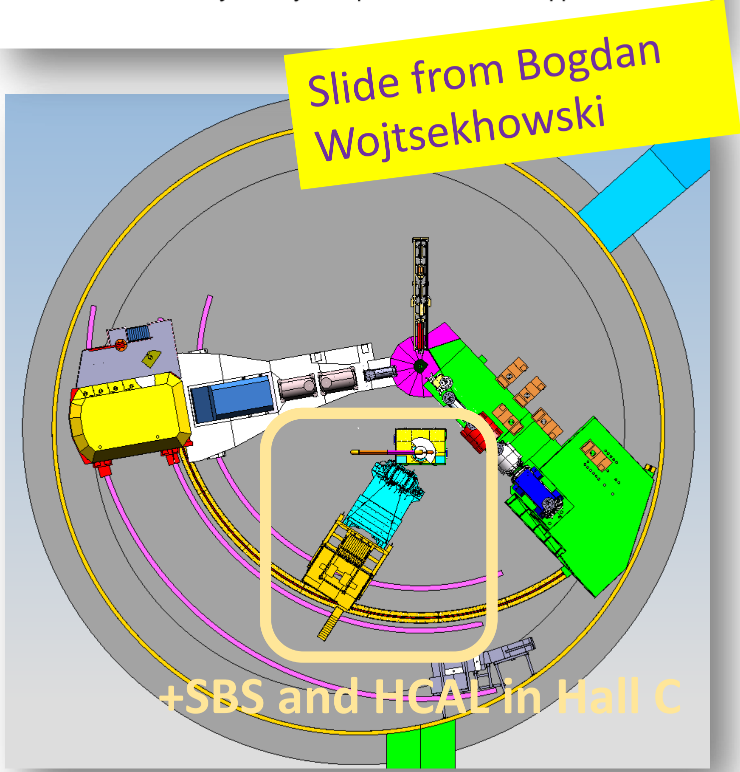



**SBS & HCAL** at 32.5 degrees, 2.5m downstream of polarized target

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



Slide from Dipangkar Dutta

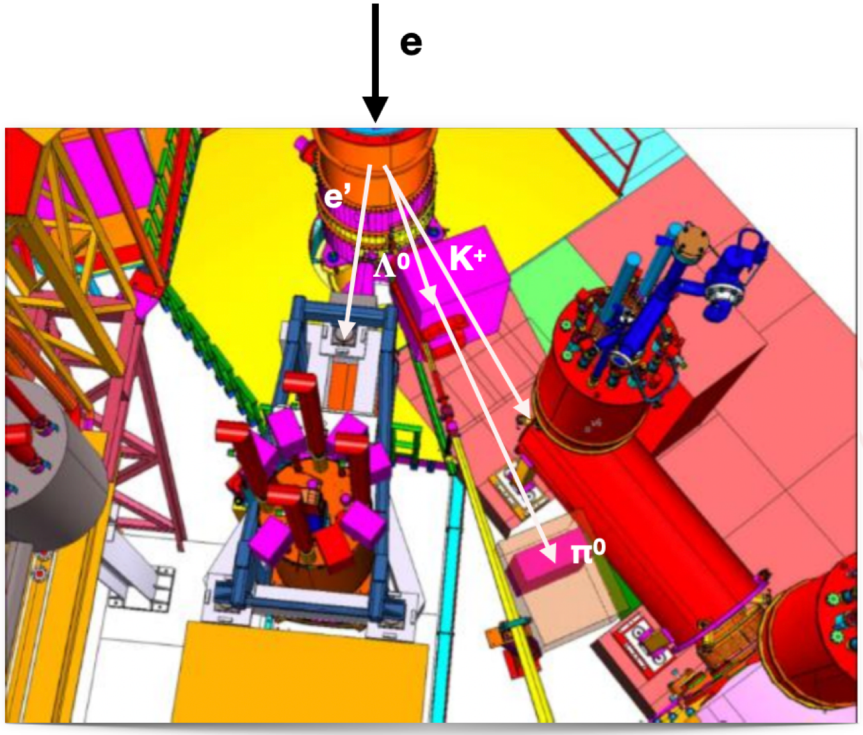
# Hall C with SHMS+NMS can provide a new unique window into $\Lambda^0$ polarization.

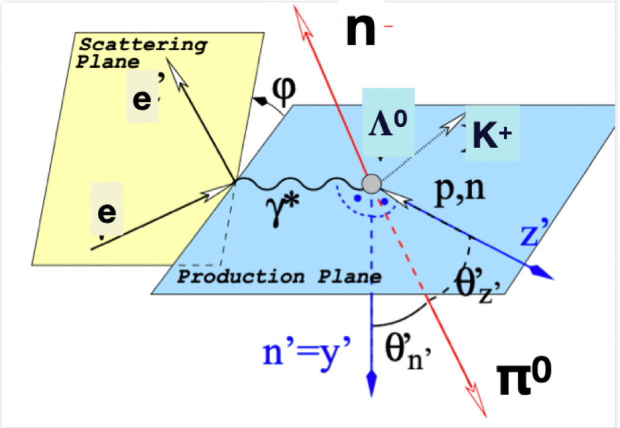
p($\vec{e}$, e' $K^+$ $\pi^0$)n ($\vec{\Lambda}^0$ decay)
p($\vec{e}$, e' $K^+$ $\gamma$)$\Lambda^0$ ($\vec{\Sigma}^0$ decay)

e' in HMS, $K^+$ in SHMS and $\pi^0/\gamma$ in NMS, invariant mass of (n/$\Lambda^0$)

n($\vec{e}$, e' $\vec{p}$ $\pi^0$)$K^-$ ($\vec{\Sigma}^+$ decay)
p($\vec{e}$, e' $\vec{p}$ $\pi^0$)$K^0$ ($\vec{\Sigma}^+$ decay)

e' in HMS, $\vec{p}$ in SHMS and $\pi^0$ in NMS




Hyperon rest frame (RF)

$$\frac{dN^{\pm}}{d\cos\theta^{\mathrm{RF}}_{\pi^0}} = N[1 + \alpha(P^0 \pm P_b P')\cos\theta^{\mathrm{RF}}_{\pi^0}],$$

induced (self) polarization

transferred polarization

beam polarization

analyzing power
(parity violating decay parameter)

# Hyper-nuclear

Slide from Toshiyuki Gogami

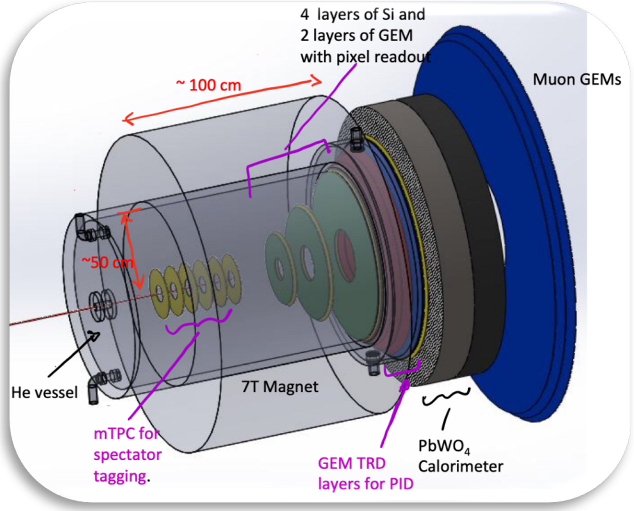
- ΛN CHARGE SYMMETRY BREAKING
  - A = 3, 4: the aim depends on the results from Hall A (C12-19-002)
  - A = 9: The need of 500 keV resolution to determine the g.s. energy; TG et al, PRC 103, L041301 (2021)
- CLUSTER STRUCTURE, DEFORMATION
  - $^{27}\mathrm{Al}(e,e'K^{+})^{27}_{\Lambda}\mathrm{Mg}$: Identification 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)

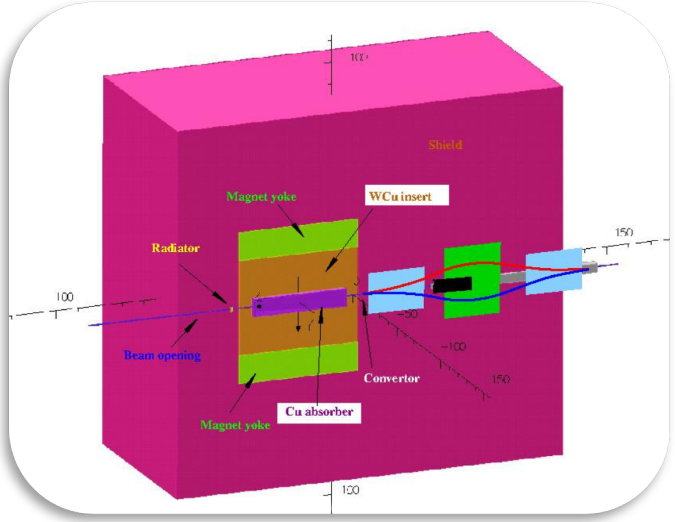
**No data with sub-MeV resolution**

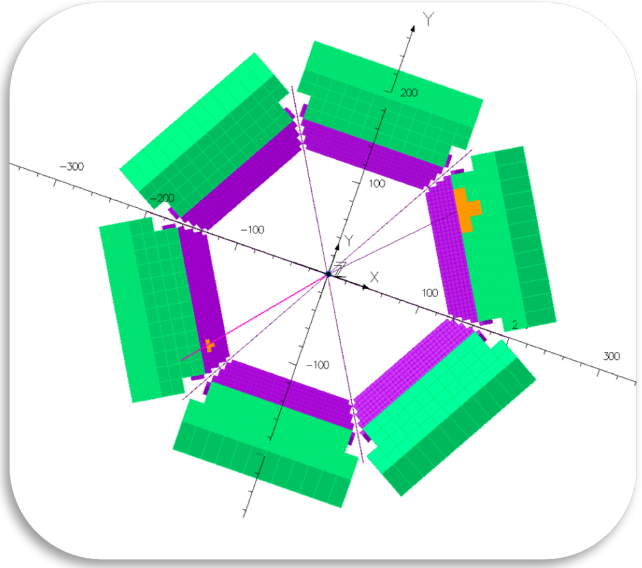
- CERN, BNL, KEK, J-PARC: > a few MeV (FWHM)
- Future plan at HIHR in J-PARC: sub-MeV
  ← In a stage of funding proposal submission
  (No beam line / apparatus exist yet)

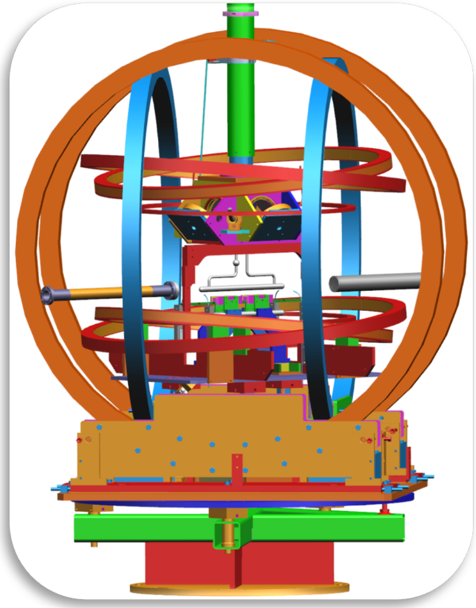
➔ **JLab is a unique facility to realize it**

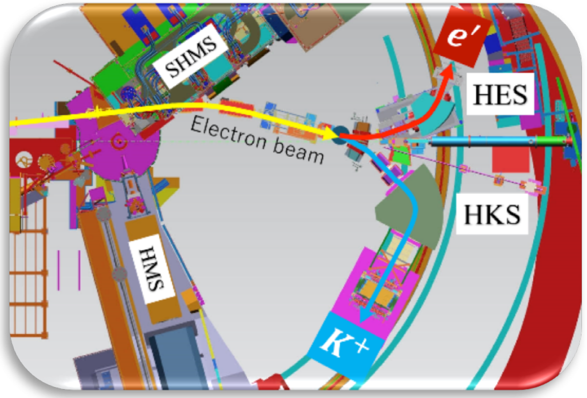
# Novel equipment & configuration ideas

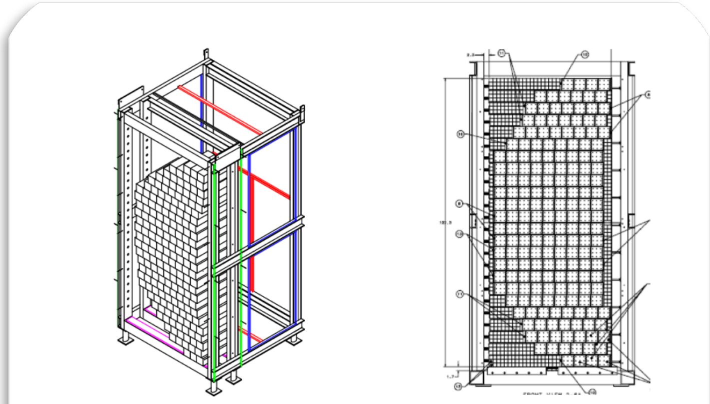


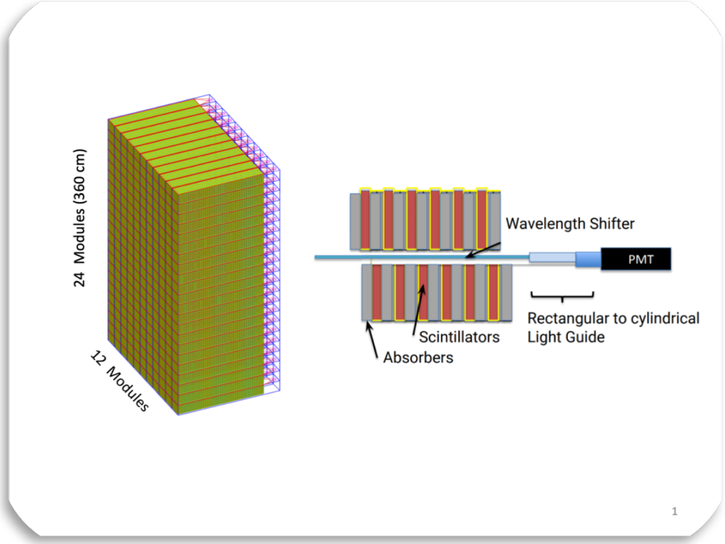



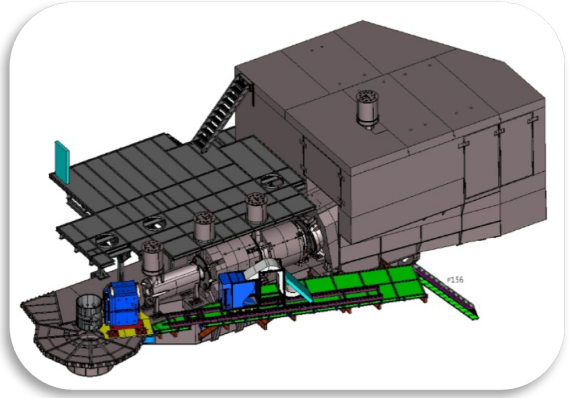




1737 lead-glass modules
Elevated temperature of the glass (225-185 C)
provides continuous annealing of radiation damage



# Summary

- Hall C is optimized for precision measurements of small cross sections
- Unique equipment in SHMS, HMS, NPS, CPS, with flexible configurations that include fixed and moved pivots and space for new installations
- New ideas being explored using novel detectors which could be coupled with AI/machine learning
- Positrons, higher energy, high power targets, and more