Beamline for Hypernuclear Experiments in Hall C

Hypernuclear ERR

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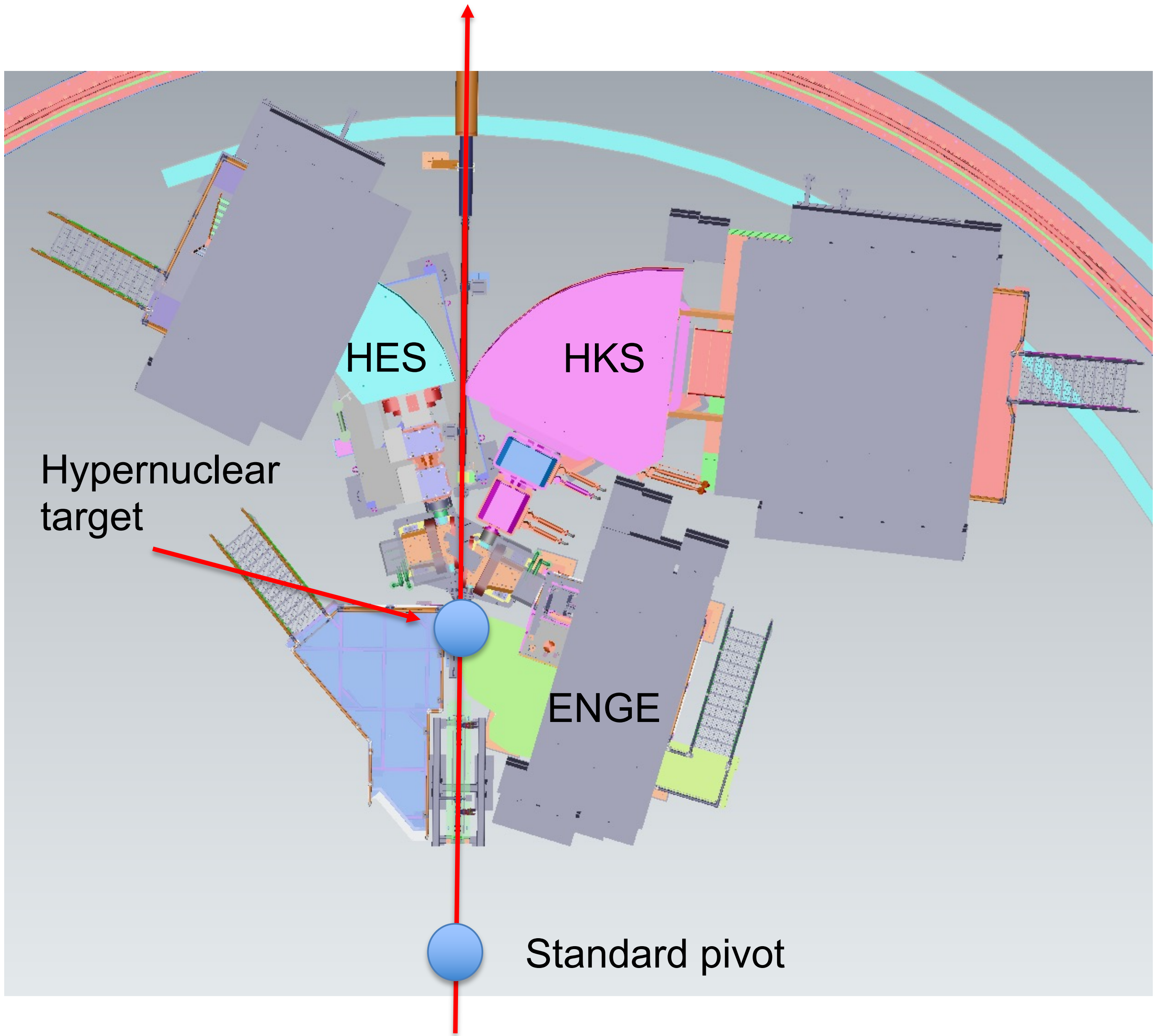
Hypernuclear Setup in Hall C and Beam Requirements

- Hypernuclear target 6.6 meters downstream of nominal targets position

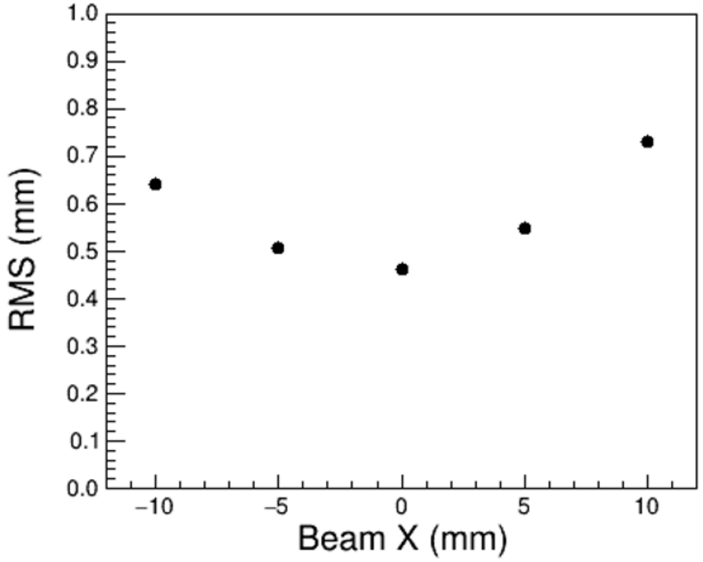
- Key requirements:
  - Successfully transport beam to dump, mitigating stray fields from magnets close to beamline
  - Beam energy spread $\sigma_E/E <= 3 \times 10^{-5}$ (70 keV at 2.24 GeV)
  - Beam position precision and stability at target: $\sigma_x = 0.25$ mm, $\sigma_y = 2$ mm

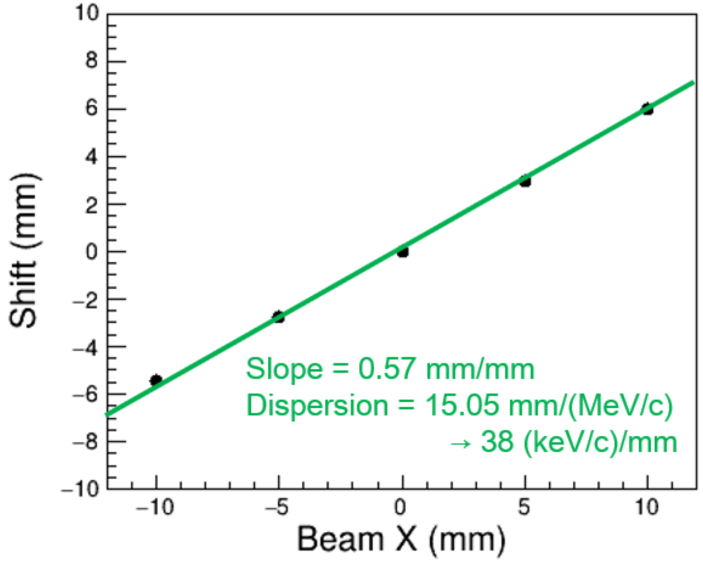


Beam Position Measurement Requirements

Required precision on beam position at target: σ_x = 0.25 mm, σ_y = 2 mm
→ Horizontal precision driven by Decay Pion Spectroscopy measurements
→ 1 mm horizontal shift → momentum shift = 38 keV/c
→ DPS requires 10 keV accuracy → 0.25 mm
→ (e,e'K) experiments only require σ_x = 2 mm, σ_y = 2 mm

Summarized in a note by Shoe Nagao:
https://hallcweb.jlab.org/wiki/images/b/b1/BPM_Requirements_by_Simulation_202605.pdf

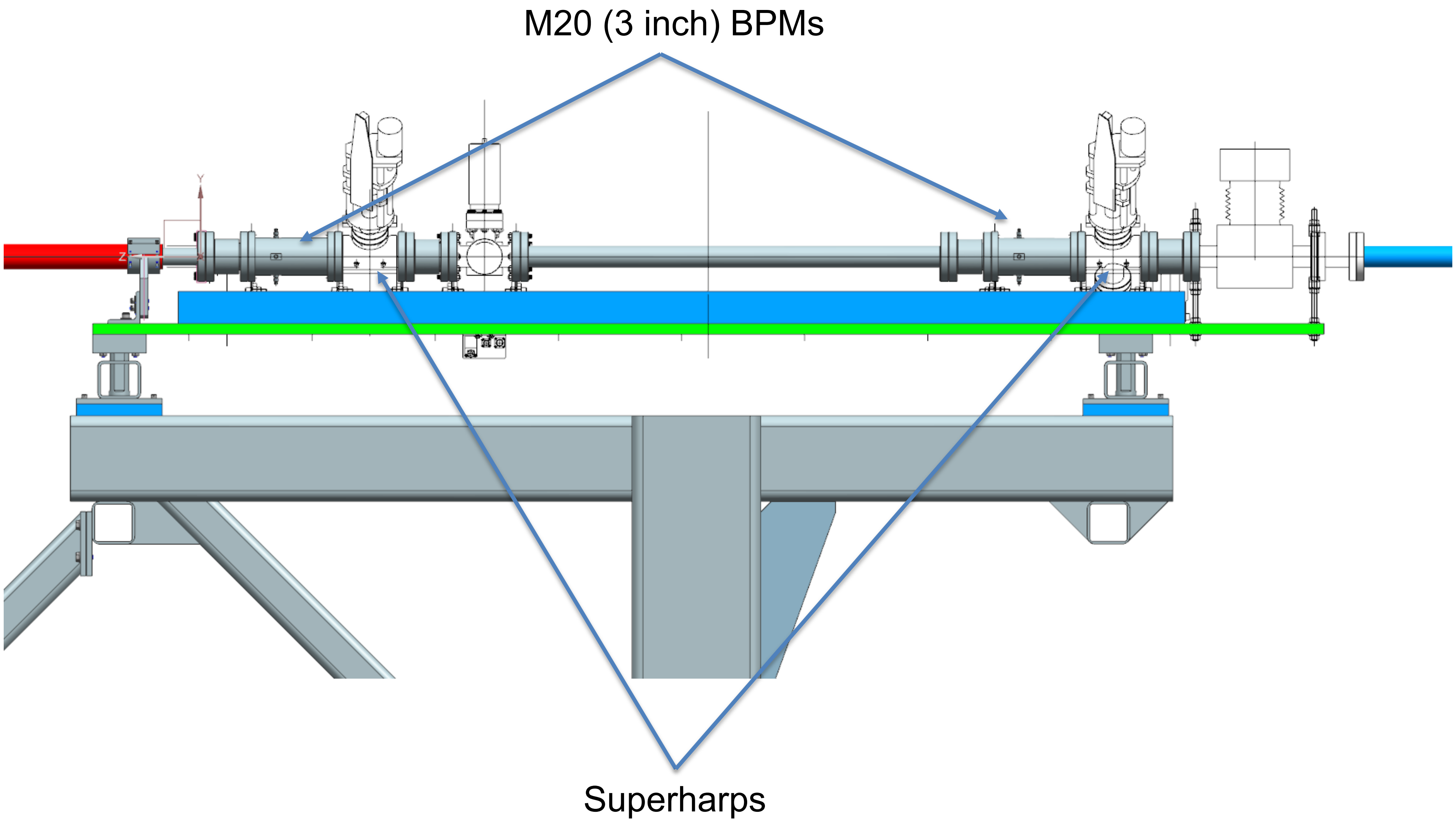




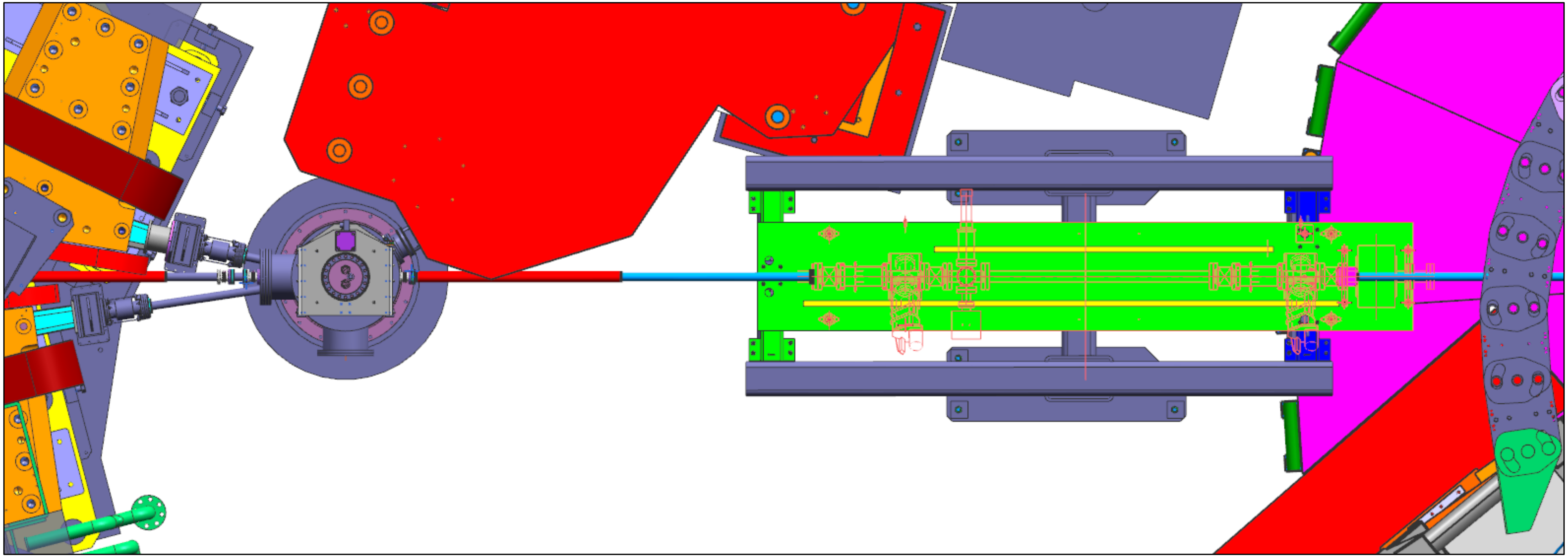
Beam Position Measurement

- Existing BPMs (3H07A/B/C) are too far from hypernuclear target to provide required precision (0.25 mm) by themselves
  - $\Delta z_{BPM\text{-}target}$ = 9.8/8.8/7.9 meters for existing BPMs
  - Assuming $\sigma_{x/y}$=0.1 mm for each BPM, σ_{target} = 0.65 mm
- Additional position monitors will be added between pivot and hypernuclear target
  - Will use existing polarized target girder
  - Has 2 BPMs → 3.9 and 2.2 meters from target
  - Using 3H07A/B/C + new BPMs, σ_{target} = 0.11 mm
- In addition to girder installation work, BPM and harp readout will require support from I&C and Accelerator Software

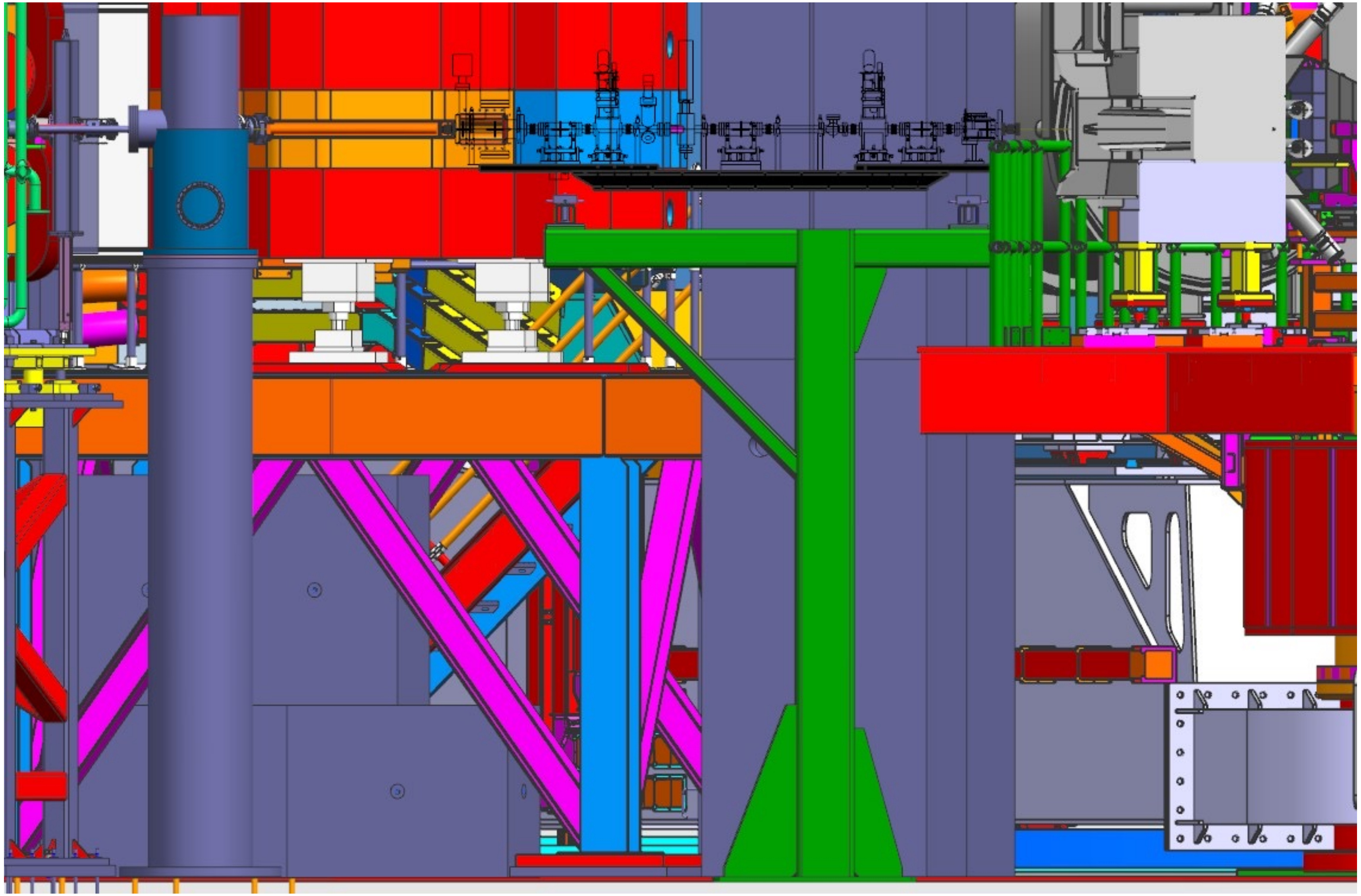
Polarized Target Girder



Downstream Diagnostic Girder



Downstream Diagnostic Girder



Polarized Target Girder

Polarized target girder has been removed from Physics Storage and staged in ESB

→ Significant refurbishment will be required

→ One BPM is missing – I&C has spare 3-inch BPM on hand

→ Spare harps can be taken from Q-Weak girder stored in ESB

→ New spool piece also needed

Work on girder can begin once MOLLER installation is mostly complete (early 2027)

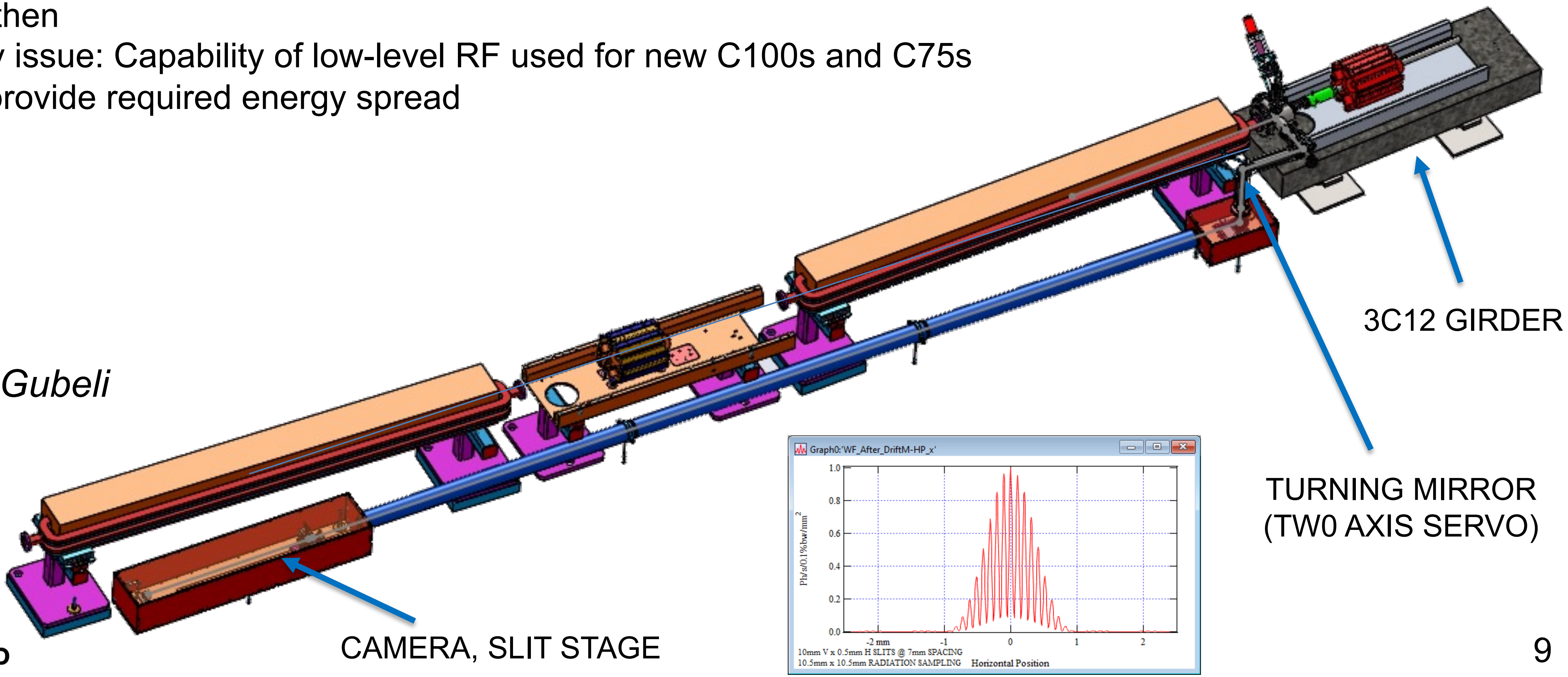
→ Support from ACC software will also be needed to add controls, readout, update screens, etc.

Beam Energy Spread

Beam energy spread will be continuously monitored using new Synchrotron Radiation Interferometer

SLI was installed before FY25 run period
→ Non-invasive **and** invasive tests with beam have beam carried out since then
→ Key issue: Capability of low-level RF used for new C100s and C75s to provide required energy spread

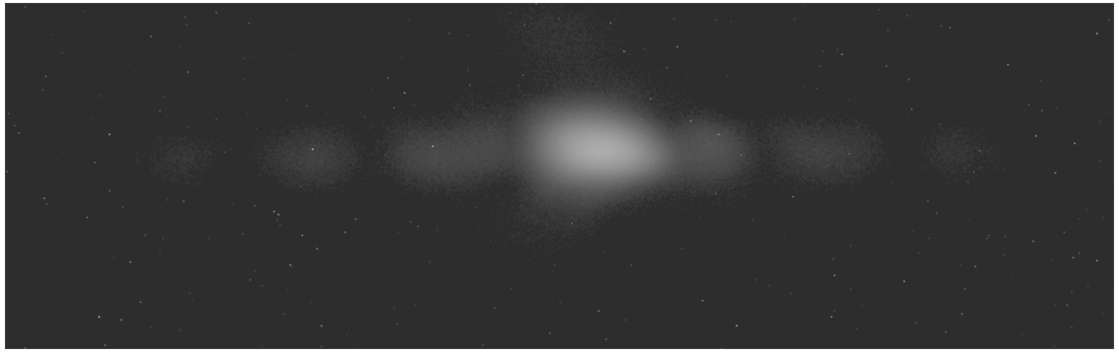
Joe Gubeli

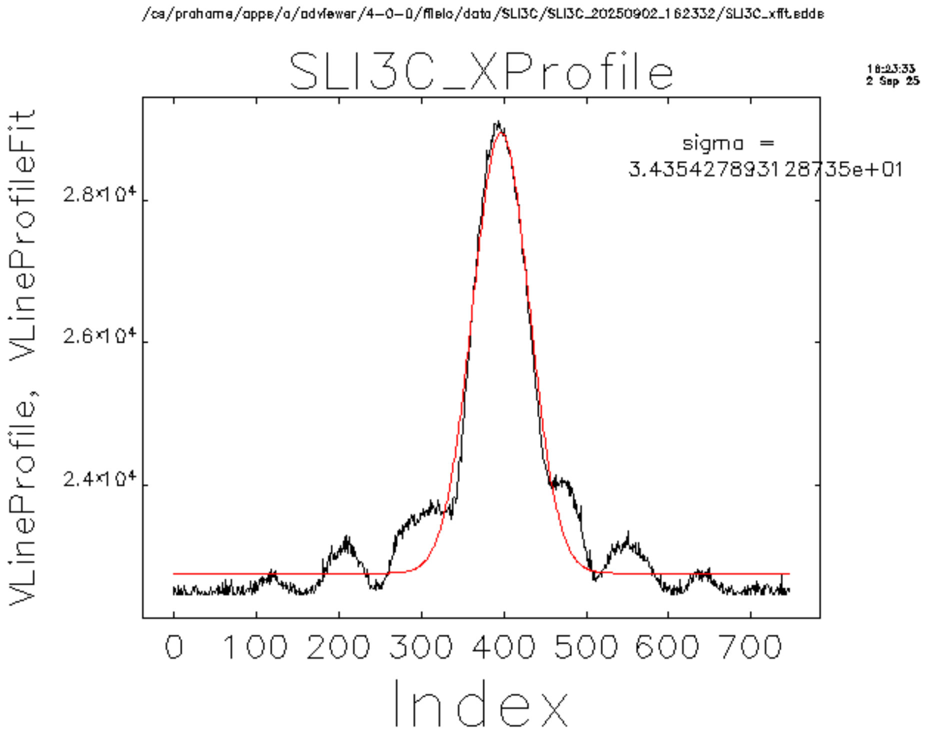


FY25 Beam Test

Dedicated beam test was performed at end of FY25 run to checkout SLI and extract beam energy width
→ 9/2/2025

→ Beam energy = 2.2 GeV, similar to hypernuclear
→ Interference fringes were visible on SLI, but central peak too bright for reliable fit
→ Beam energy width was extracted using beam size from harp scan and measured beam emittance: $\sigma_E/E \sim 3.2 \times 10^{-5}$ → ***meets experiment requirement***
→ Beam size from SLI used to monitor energy spread over several hours → 4.5×10^{-5}
→ Work continuing during this run period to understand source of bright central peak
→ Presentation from Nick Sereno:
https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1318





Beam Energy and Arc Dipole Monitoring: 9th Dipole

Additional information about relative beam energy can be provided using "9th dipole"

→ System used during previous hypernuclear experiment in Hall C

→ Not used for absolute beam energy measurement a la Hall A

→ BE magnet wired in series with Hall C arc magnets

→ NMR probe placed at fixed position in dipole

BE magnet still in place in BSY service building – needs modest amount of work to revive

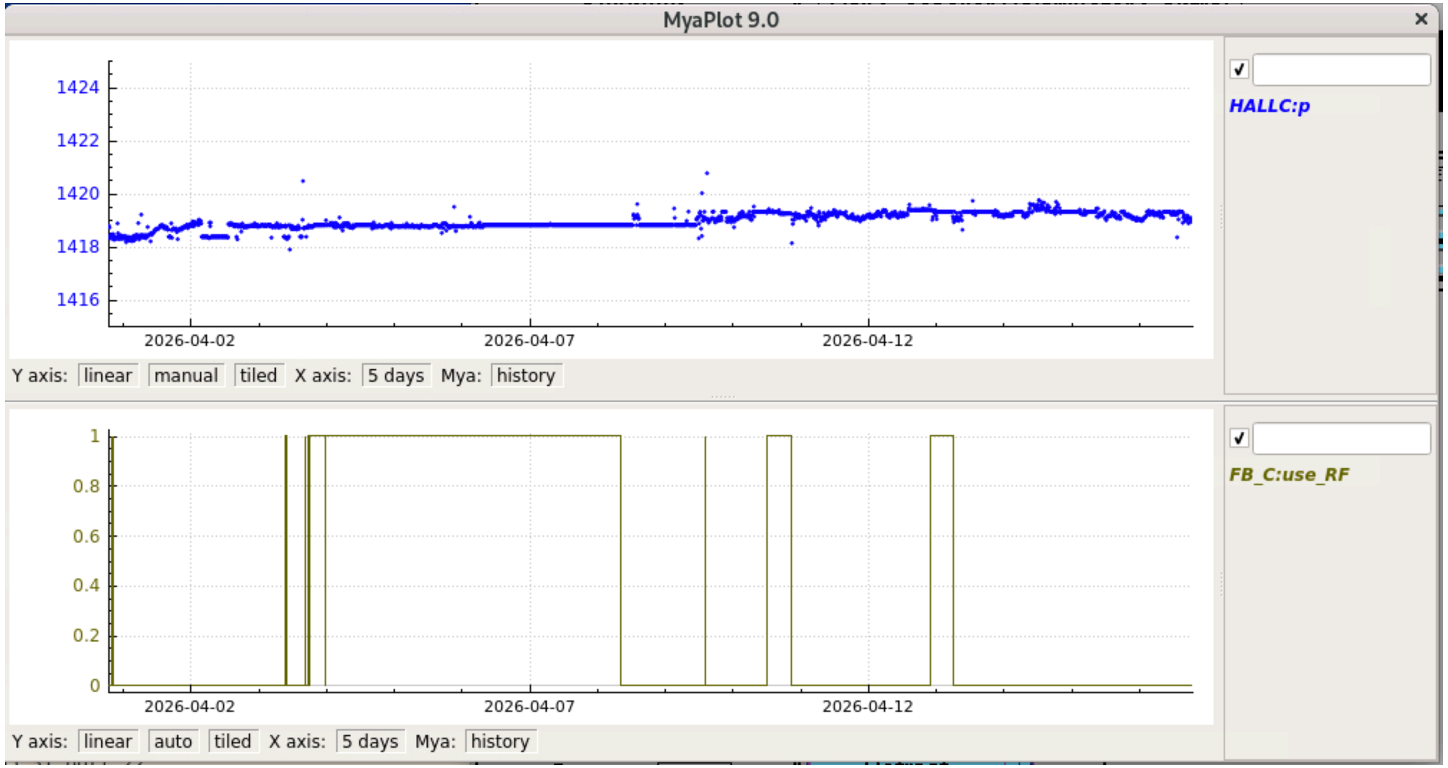
→ Re-cable magnet leads

→ Locate and install NMR

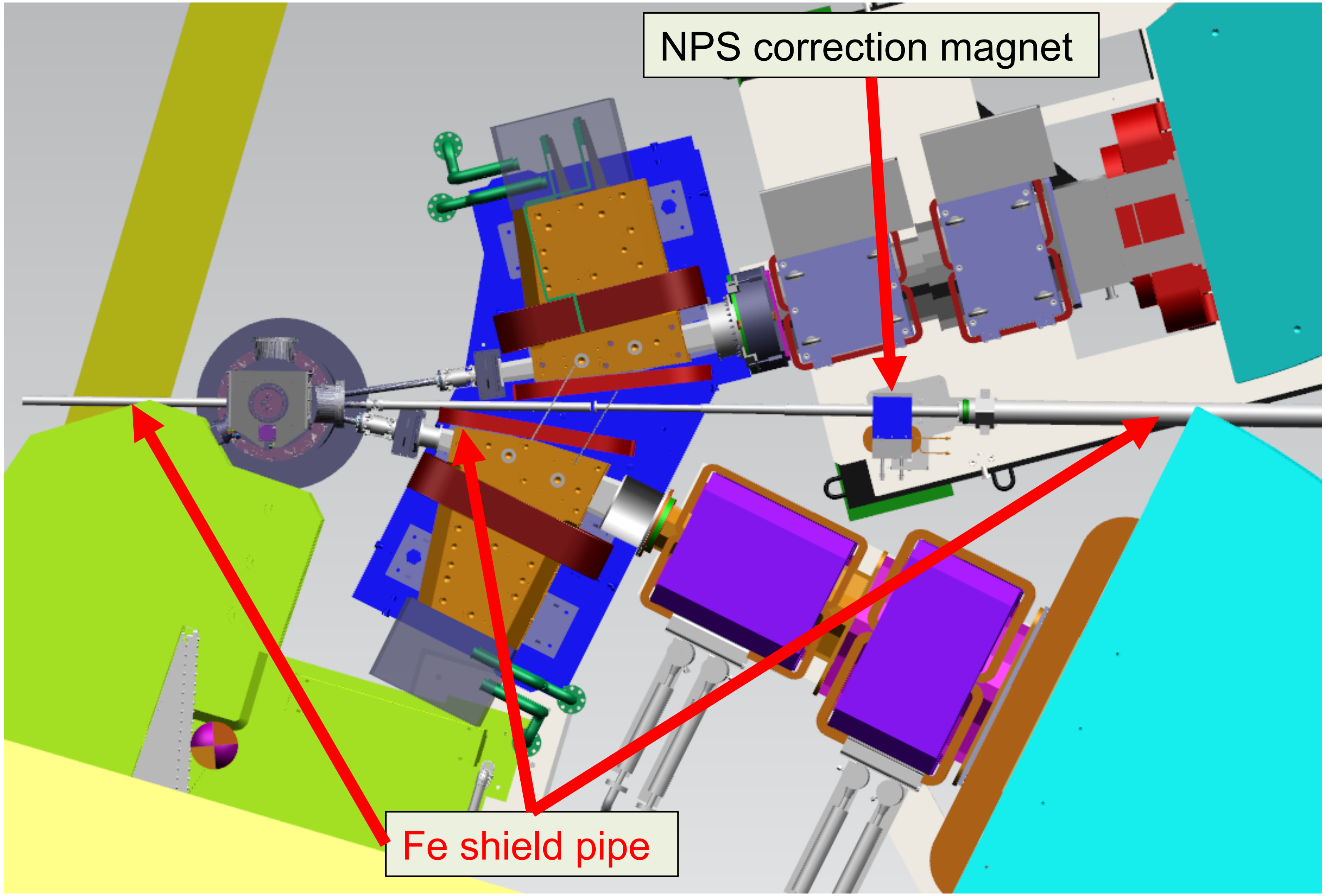
→ Implement remote NMR readout

Beam Energy Stability: Fast Feedback

- Energy fast feedback (@5 pass) in Hall A will be used during MOLLER running
- When Hall A is off for extended periods (on the order of hours), Hall C will request FFB in Hall C be engaged
  - FFB in Hall C recently recommissioned and used during FY26 run
- Switching FFB from Hall A to C may result in small beam energy shift in Hall C
  - This is ok → beam energy will be monitored (HALLC:p, 3C12 position)
  - Energy shifts can be accounted for in data analysis



Stray Fields

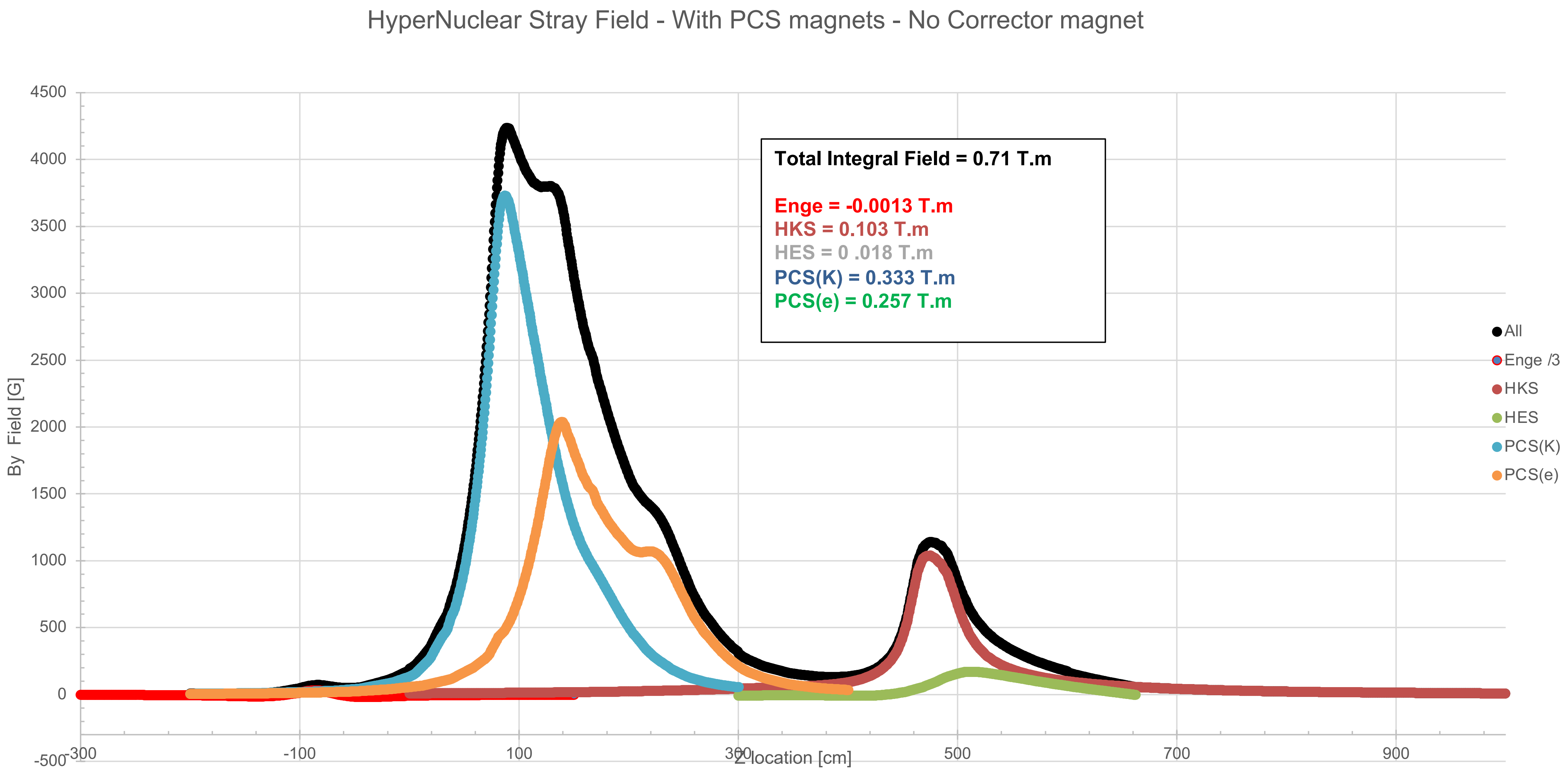


If unmitigated – stray fields from the hypernuclear magnets will results in unacceptably large beam deflection at dump face

→ No stray fields from quads
→ Dominant effects from PCS magnets and dipoles

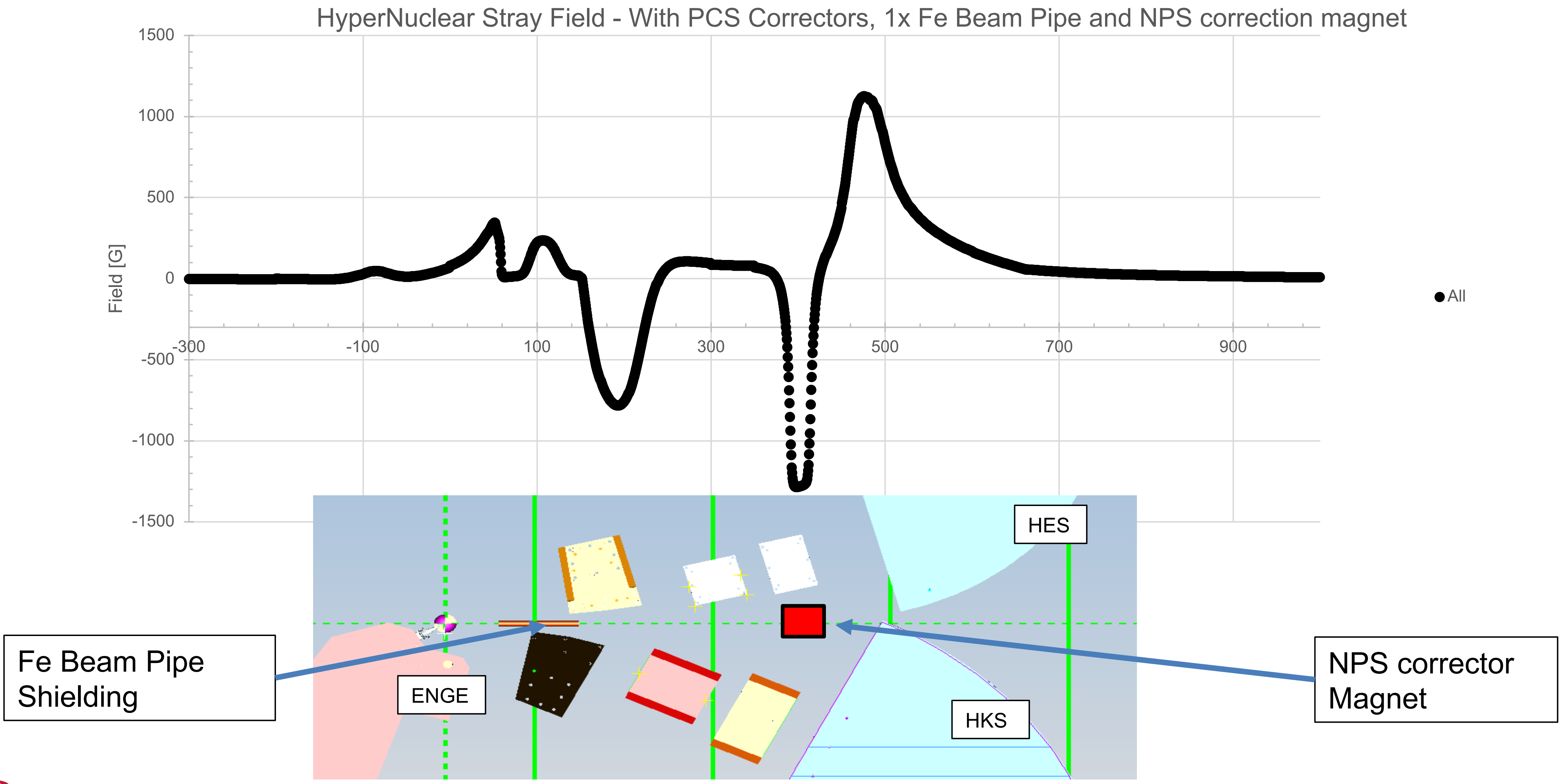
Stray fields can be partially compensated by using the NPS corrector magnet
→ Tosca model predicts integral field @ maximum current of 150 A = ∫ B.dL ~ 0.0424 T.m
→ Need additional mitigation – ***beamline magnetic shielding***
→ Multiple locations for beamline shield and corrector location were investigated

Sum of Stray Fields – No Field Corrections



Slides and calculations from Steven Lassiter

Sum of Stray Fields with Front Fe beam line shielding



Stray Field Updates

- Existing TOSCA model developed by Steve Lassiter before his retirement
- Beamline design has been updated since then → existing TOSCA model not entirely compatible with new design
- Jay Benesch has agreed to work with us to update the TOSCA model and provide field maps
- These new field maps will be used in radiation simulations and beam tracking calculations
- Timeline for TOSCA/field map updates not yet known – existing files under study
  - Radiation and beam tracking simulations complete about a month after that field map updates available

Beam Setup

Draft hypernuclear beamline setup plan has been developed with input from Hall C APELs and Ops Liaisons

Document link: https://hallcweb.jlab.org/wiki/images/4/43/HKS_beamline_tuneup.pdf

Key steps

1. Check ion chamber functionality
2. Steer beam to dump with all hypernuclear magnets ***off***
3. Ramp magnets in steps (25%, 50%, 75%,100%) to nominal currents, while checking beam position at dump
4. Check degree of beam steering from magnets with significant stray field
5. Check beam steering from magnets with small stray field

****DRAFT** Beamline Setup and Commissioning Procedure for HKS**

1. Set up tune beam to Hall C dump with all HKS magnets off.
2. Center beam on Hall C dump viewer – record image in elog.
3. Check functionality of "new" HKS ion chambers (HKS target and relocated Compton electron detector and SHMS ion chambers) as well as existing dump ion chambers.
4. With beam off, ramp **ALL** HKS magnets to 25% of production settings. Magnet settings will be provided by the collaboration. These magnets include:
   a. Both left and right PCS magnets. Each PCS magnet also has an associated corrector.
   b. HES spectrometer magnets (2 quads and dipole)
   c. HKS spectrometer magnets (2 quads and dipole)
   d. New downstream corrector magnet (previously used for NPS experiment).
5. Establish tune beam to Hall C dump and ensure beam is visible on beam dump viewer.
6. If beam is not centered on the dump viewer – attempt to center the beam (as much as possible) using the downstream HKS/NPS corrector magnet. If downstream corrector adjustments are insufficient, adjust associated PCS correctors in roughly equal amounts (likely with different signs)
7. With tune beam off, ramp all HKS magnets to 50% of nominal values. Adjust as needed to recenter beam on dump viewer.
8. Repeat step 7 with HKS magnets at 75% and then 100% of nominal.
9. The most significant stray fields come from the HKS dipole and PCS magnets. By default, these magnet power supplies will be included in the FSD system. The following steps will quantify the degree of beam steering from these magnets and check that the remaining magnets do not steer the beam.
   a. Ramp HKS dipole magnet to zero field in steps of 25% of nominal current. Check dump viewer (and screenshot) at each step. If beam is steered off the dump viewer at any time, restore nominal HKS dipole field and move to next magnet.
   b. Repeat step 9.a for the left and right PCS magnets (one at a time).
   c. Repeat step 9.a for the left and right PCS corrector magnets (one at a time).
   d. Repeat step 9.a for the downstream HKS/NPS corrector magnet.
   e. ***If ramping any of the above magnets to zero does NOT result in steering the beam off the dump viewer, make a note in the elog. These magnets may not***

Machine Protection Configuration

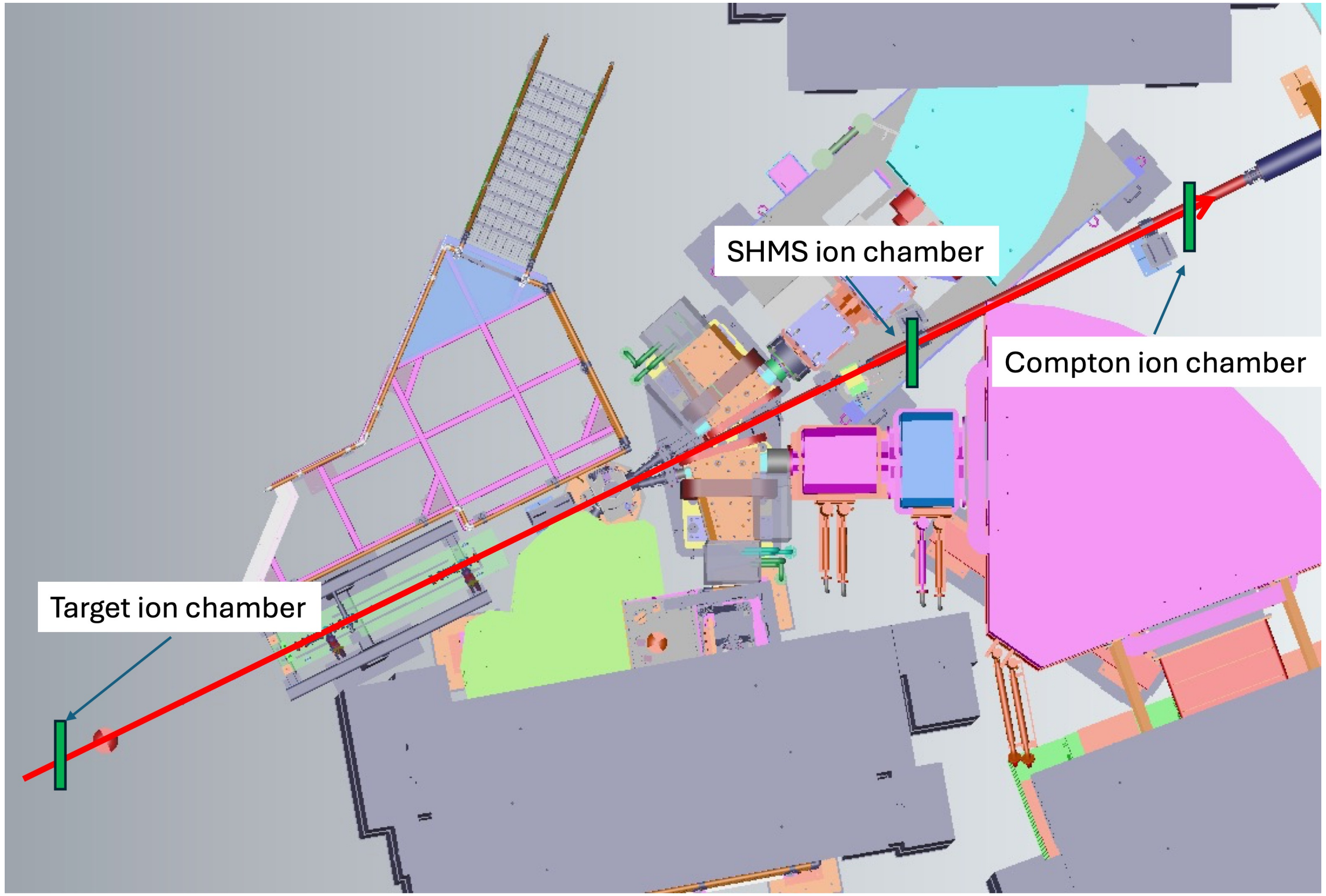
https://hallcweb.jlab.org/wiki/images/a/af/HKS_MPS_plan.pdf

Existing ion chambers in Hall C will be relocated to provide protection for hypernuclear target and detectors

Power supply currents from magnets with large stray fields will be included in FSD system
→ PCS magnets and correctors
→ HKS and HES dipoles
→ NPS corrector

Window around nominal current will be used to determine FSD threshold

All magnets will be controlled by Ops



Other Issues

A few other small issues will need to be addressed before hypernuclear experiments

→ Hypernuclear experiments will require event-by-event readout of BPM information
- → This has not been done in Hall C since Q-Weak experiment (2012)
- → Hardware still in place → spares will become available after MOLLER installation in Hall A (switching to new technology)
- → Have been testing a few BPMs with existing Hall C DAQ and spare FADC channels

→ Fast raster controls will need to be modified to account for longer drift to hypernuclear target
- → Straightforward controls modification → done during Q-Weak

Beamline Support

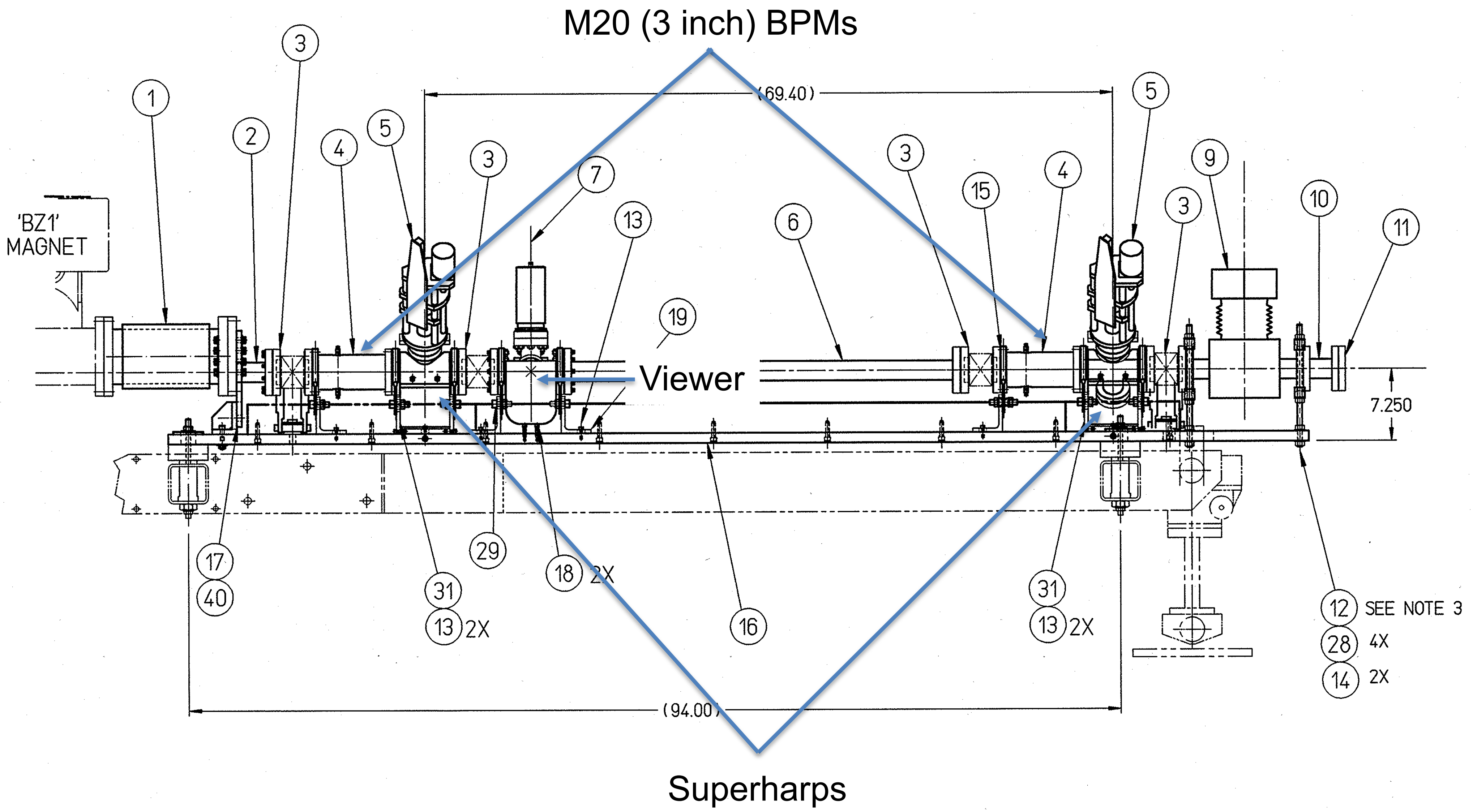
- Support will be required from several groups to ensure beamline readiness
  - Accelerator Operations (Hall C Ops liaison and APEL)
  - Instrumentation and Controls Group (I&C)
  - Accelerator Controls Software Group
  - Diagnostic Development Group
  - Hall C Engineering and Design
- Coordination has begun, and affected groups are aware of requested support for hypernuclear beamline

Summary

- Hypernuclear experiments will require modifications to Hall C beamline
  - All changes to beamline are downstream of standard Hall C pivot
- Additional diagnostic girder will be added downstream of Hall C pivot to provide required precision on beam position measurement
- New Synchrotron Radiation Interferometer (SRI) will be used to non-invasively monitor beam energy spread → currently be commissioned
  - Beam test during FY25 run verified that required beam energy spread is achievable with 12 GeV configuration
  - Tests with SRI still ongoing
- Beam deflection due to stray fields has been investigated and will be mitigated by combination of passive shielding and corrector magnet
  - Draft beam setup procedure has been developed with input from Ops and APEL
  - MPS configuration has been discussed with SSG
- No significant issues anticipated for hypernuclear beamline

Backup

Polarized Target Girder



MEASURING THE BEAM SIZE [NON-INVASIVE]

SYNCHROTRON RADIATION INTERFEROMETER

SYNCHROTRON RADIATION INTERFEROMETRY … PHYS. REV. ACCEL. BEAMS **25**, 080702 (2022)

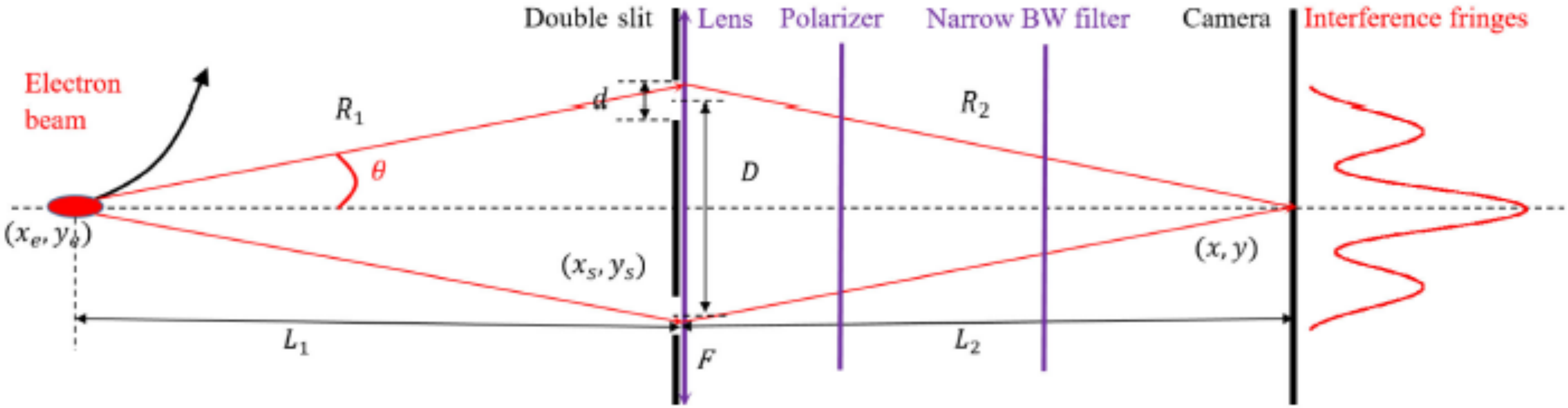
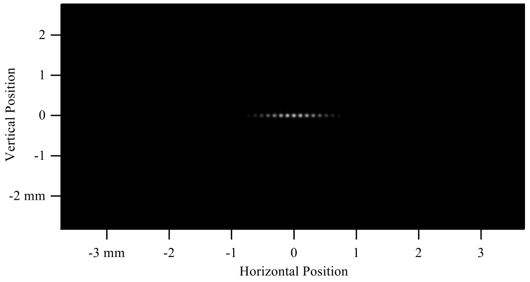


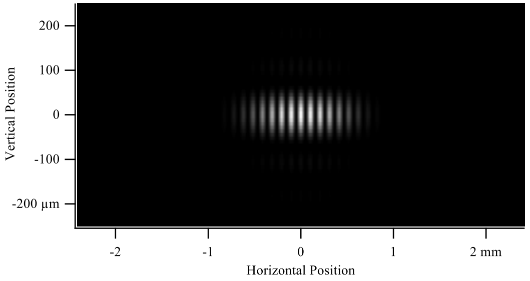
FIG. 2. Optical layout of an SRI-based electron beam size measurement system. Synchrotron radiation from the electron beam propagates through a double slit and a focusing lens, producing an interference pattern on the image plane of the lens, which is captured by a digital camera. A linear polarizer with its polarizing axis aligned horizontally and a narrow bandpass filter are used to improve the system performance.

SYNCHROTRON RADIATION WORKSHOP (SRW) SIMULATIONS

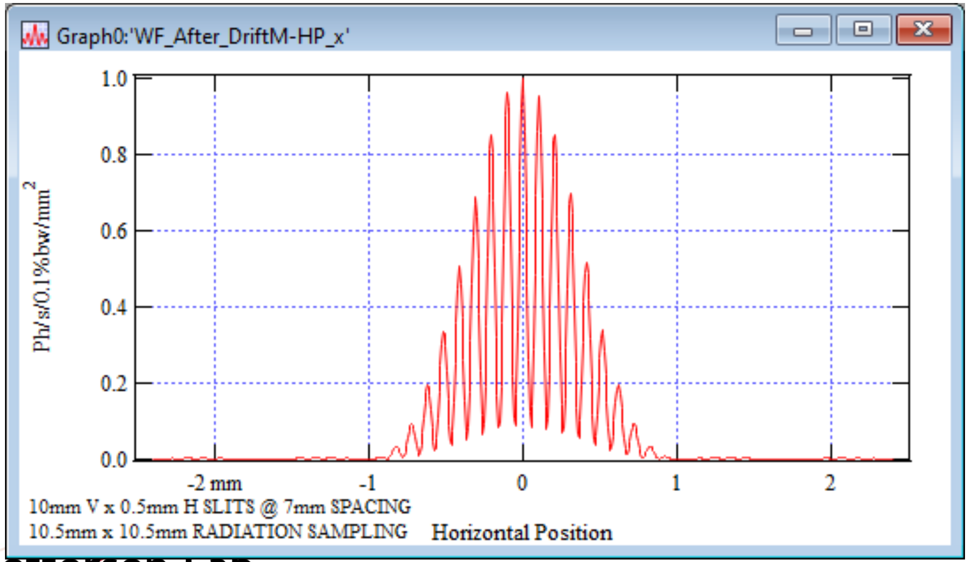
TYPICAL FULL CAMERA FRAME

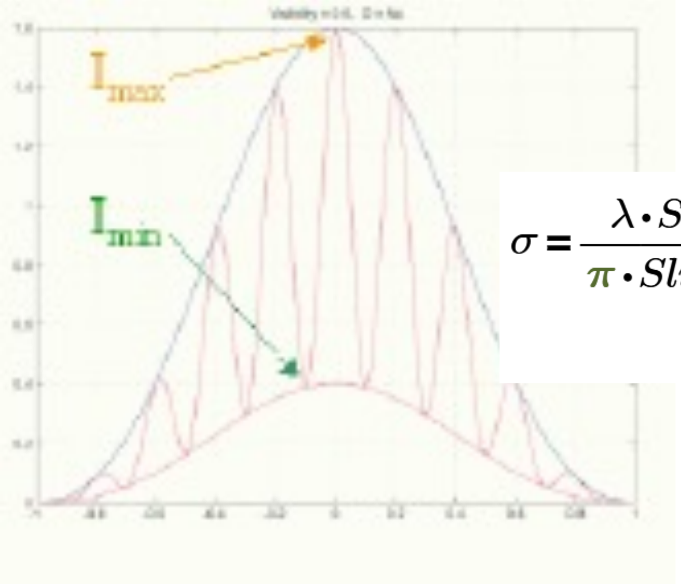


TYPICAL ZOOMED IN CAMERA IMAGE



HORIZONTAL SLICE THROUGH IMAGE CENTER





$$\sigma = \frac{\lambda \cdot Slit\_Distance}{\pi \cdot Slit\_Separation} \cdot \sqrt{0.5 \cdot ln\left(\frac{1}{\left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}}\right)}\right)}$$

Joe Gubeli

Spectrometer Parameters with PCS Correction coils run at full current

- Beam Energy e- @ 2.24 Gev

- HKS Angle at -25.8° K+@1.200 Gev/c PCS(K+) angle is at -11.5°
- PCS (K+):
  Main coil J = -393.50 AT/cm^2,   NI = -109,167.1 A.T,   N = 96, I = -1,137.2 A
  Trim coil J =   666.67 AT/cm^2,   NI = 88,000.0 A.T,   N = 88, I =   1,000.0 A

- HES Angle at +14.9° e- @0.744 Gev/c   PCS(e-) angle is at +8.5°
- PCS (e-):
  Main coil J =   50.50 AT/cm^2,   NI =   14,010.7 A.T,   N = 96 I = 145.9 A
  Trim coil J = -666.67 AT/cm^2,   NI = -88,000.0 A.T,   N = 88, I = -1,000.0 A

- Enge: Angle at 210° (-30°) 110Mev/c Pions