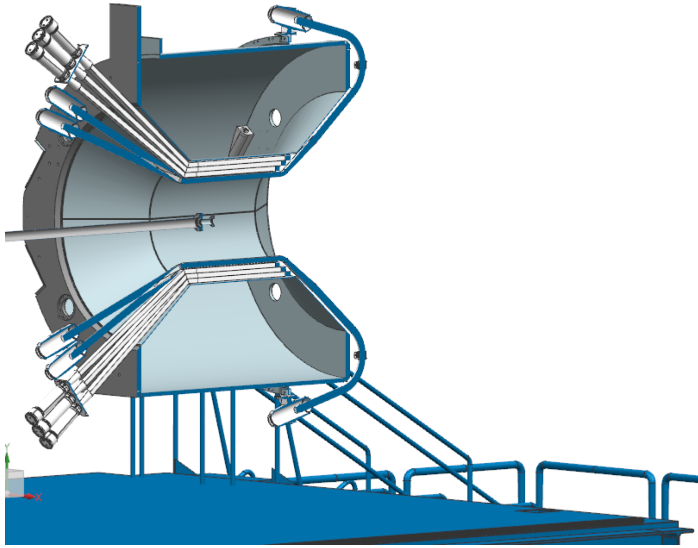
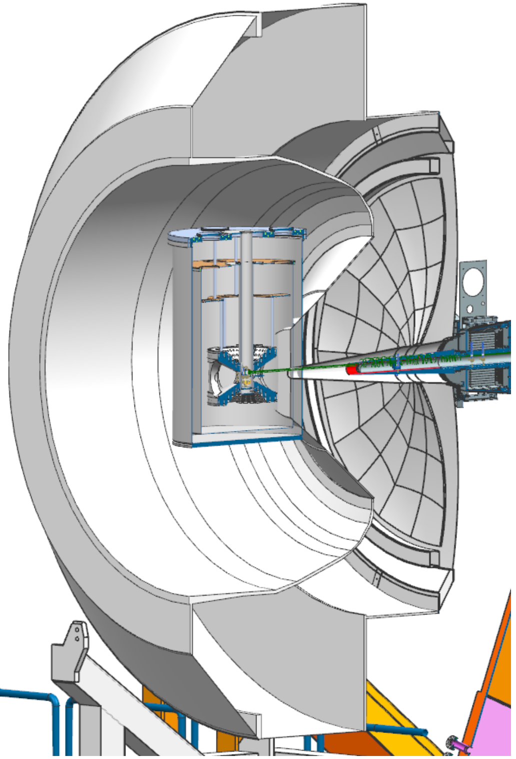
Polarized targets for CLAS12

Eugene Pasyuk

JLab





Outline

- Task forces
- Experiments requiring polarized targets
- Longitudinally polarized target (RGC, RGG)
- 3He polarized target (RGN)
- Transversely polarized target (RGH)

CLAS12 Polarized Targets Task Force

Charge

1. Assess different option for polarized proton and neutron longitudinal/transverse polarized targets to be used with CLAS12
2. For each option quantify:
   a. necessary steps to demonstrate the technology (prototyping, on-beam tests, design, and construction
   b. timeline and milestones
   c. expected results
3. Evaluate the impact of each option on CLAS12 (modification) and operations (downtime)
4. Estimate costs and identify resources needed for each option
5. Evaluate synergies with other projects at the lab providing a list of shared resources and common goals

Resources

- Time: 6 months (March-August)
- Deliverable: **2-page** report, wiki page with full documentation and minutes of meetings/presentations

Members

- E. Pasyuk (PI), X. Wei (core), V. Burkert (core), H. Avakian (core), B. Miller (core), C. Keith (external), J. Maxwell (external)
- *Additional external members: M. Lowry, R. Fair, P. Ghoshal, M. Ungaro, S. Lee, P. Moran, B. Johnston, L. Elouadrhiri, M. Contalbrigo*

Documentation

Hall-B Task Forces 2020

Overview | Analysis Framework | Central Tracking | Data Preservation | Forward Tracking | Novel Tracking | Polarized Targets | Particle ID | Software | Streaming GEMC | BG Merging & Efficiency

Goal

To propose polarized proton and neutron longitudinal/transverse polarized targets for CLAS12

Members

- E. Pasyuk (PI)
- X. Wei (core)
- V. Burkert (core)
- H. Avakian (core)
- B. Miller (core)
- C. Keith (external)
- J. Maxwell (external)

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Proposals

Approved experiments with polarized targets

- Run Group C: Longitudinally polarized NH3/ND3, (185 days approved) E12-06-109, E12-06-109A, E12-06-119(b), E12-07-107, E12-09-007(b), E12-09-009
- Run Group G: Longitudinally polarized 7LiD/6LiH (55 days approved) E12-140-01
- Run Group H: Transversely polarized HD (110 days conditionally approved) C12-11-111, C12-12-009, C12-12-010
- Run Group N(?): Polarized 3He (30 days conditionally approved) C12-20-002

Documentation

- RGC (NH3/ND3) longitudinal target
- RGG (6LiH/7LiD) longitudinal target
- Polarized HDIce status
- Polarized 3He Target for CLAS12
- Transverse target options
- Preliminary dimensions of the HDIce cell and transverse magnet
- Preliminary study of IBC interference
- Interference with CTOF
- Initial transverse target geometry. HDIce option
- Transverse DNP Target
- Winding information for 6 GeV Hall B polarized target magnet.
- Evaluation of MgB2 cylinder in CLAS12 solenoid
- Magnetic field of Frascati magnet
- Central detector radial dimensions
- Impact on CLAS12 configuration and physics
- DVCS without CVT from RGA - *Latifa*
- Meeting with Physics division July 24th
- HD-Ice budget to completeion
- General assumptions for the estimated HD-Ice budget
- Final task force report

Meetings

Bluejeans link: https://bluejeans.com/7572696020/webrtc

March 2, 2020
- Agenda: Kick off meeting
- Minutes

April 7, 2020
- Agenda: Transverse target options
- Minutes

April 21, 2020
- Agenda:Simulation of transverse target
- Minutes

May 5, 2020
- Agenda:Transverse target options
- Minutes

May 19, 2020
- Agenda:Transverse magnetic field
- Minutes

June 2, 2020
- Agenda:Transverse magnetic field
- Minutes

June 9, 2020
- Agenda:Transverse magnetic field
- Minutes

June 16, 2020
- Agenda:Transverse magnetic field
- Minutes

June 23, 2020

Polarized targets task force report

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Additional external members: M. Lowry, R. Fair, P. Ghoshal, M. Ungaro, S. Lee, P. Moran, B. Johnston, L. Elouadrhiri, M. Contalbrigo

Approved Experiments

- Run Group C: Longitudinally polarized NH_3/ND_3, (185 days approved) E12-06-109, E12-06-109A, E12-06-119(b), E12-07-107, E12-09-007(b), E12-09-009
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- Run Group N(?): Polarized ^3He (30 days conditionally approved) C12-20-002

Longitudinally polarized targets for RGC and RGG

For RGC and RGG the target is essentially the same, a conventional dynamically polarized target. The only difference is the target material: Run Group C will utilize NH_3 and ND_3, while RGG will use ^6LiH and ^7LiD.

RGC target

The design and construction of the target is well underway, and it has been successfully tested on three occasions in the Target Group Laboratory. The tests included characterization of the 1 K refrigerator, new NMR electronics designed and built by the JLab Target and Fast Electronics Groups, and dynamic polarization of polymers doped with the paramagnetic radical TEMPO. Future effort on the target will focus on construction of the insertion cart for Hall B, replacement of certain prototype components with final, beam-ready versions, and dynamic polarization of butanol and ammonia samples.

Timeline and resources for System Completion:

Workforce resources: JLab Target Group and RGC collaboration. Estimated cost to completion: $195k
Oct. 2020: System tests with electronics cart, improved target insert, TEMPO-doped butanol, TEMPO-doped D-butanol ($75k).
Dec. 2020: Lower half target cart complete($25k) and pumps mounted
Dec. 2020: Design and fabrication of beam-ready sample cups (6) complete($5k).
Jan. 2021: Final version of JLab Q-meter on-hand (two complete systems) ($10k).
Nov. 2020: Lower half target cart complete($25k)
Feb. 2021: Beam-appropriate helium bath complete: ($10k)
Feb. 2021: Shim coils installed ($5k)
March 2021: Tests in EEL ($10k)
April 2021: FPGA NMR ready for tests
May 2021: Beam-ready bath for target samples
June 2021: Tests in EEL ($10k)
Aug. 2021: Pumps on pump cart ($20k)
Sept. 2021: Dress rehearsal -- Complete system test in EEL ($10k)
Nov. 2021: Construction and installation of carbon fiber extension to vacuum chamber ($10k)
Nov 2021: Design and construction for Hall B transfer line (buffer Dewar to refrigerator) complete($5k)
Jan. 2022: System ready for installation in Hall B (six weeks to install, three weeks to remove)
Feb. 2022: System ready for beam in Hall B

RGG target

While the modifications to the longitudinally polarized target will be minimal, a considerable effort will be needed to obtain and prepare the ^6LiH and ^7LiD samples for dynamic polarization. First, a vendor for the raw material must be identified. Second, irradiation must be used to create the F-centers in the material that are necessary for dynamic polarization. It is hoped that the

New task forces

- RGC task force (longitudinal target) – V. Burkert
- RGH task force (transverse target) – E. Pasyuk
- RGN task force (polarized 3He target) – H. Avakian

Approved Experiments requiring Polarized targets

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While the modifications to the longitudinally polarized target will be minimal, a considerable effort will be needed to obtain and prepare the ^{6}LiH and ^{7}LiD samples for dynamic polarization.

First, a vendor for the raw material must be identified.

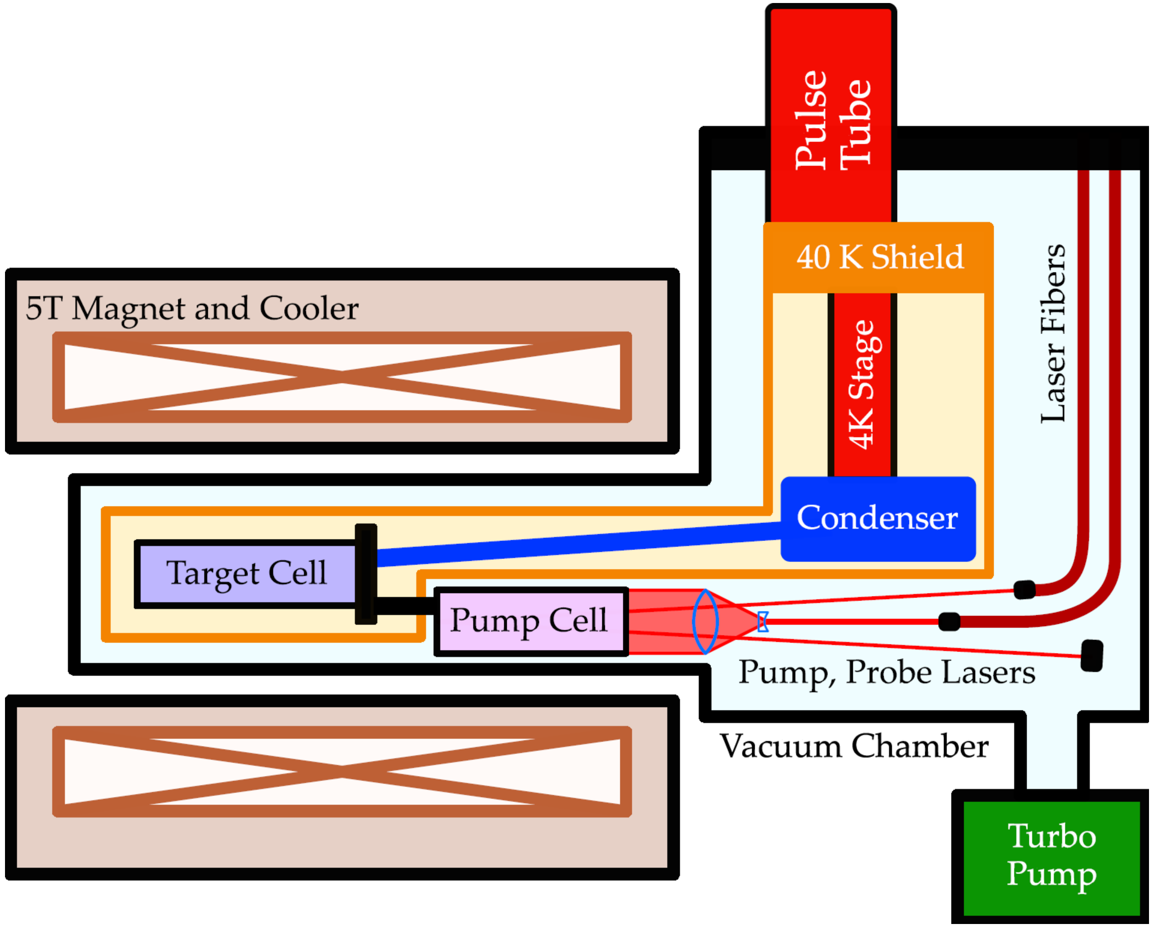
Second, irradiation must be used to create the F-centers in the material that are necessary for dynamic polarization.

It is hoped that the second step can be performed at the Upgraded Injector Test Facility and will require construction of a variable temperature irradiation cryostat. Construction and/or modification of a UITF beamline suitable for the irradiations will also be required.

Polarized ^{3}He target for RGN

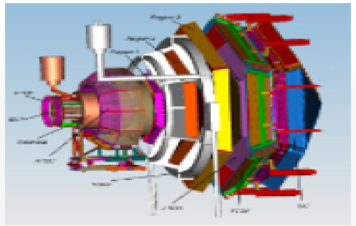
The CLAS12 ^{3}He polarized target would utilize recent improvements in high-field metastability exchange optical pumping to create 60% polarized 3He gas and reach the spectrometer's luminosity limit with a 2.5 μA beam current. The gas will be polarized within the 5 T solenoid in a glass pumping cell at room temperature and 100 mbar, before being convectively transferred to an aluminum target cell held at 5 K through heat exchange with a liquid helium supply. A scheme to provide transverse polarization is being pursued, adapting the HD-Ice transverse proposal to cancel the longitudinal solenoidal field and establish a transverse holding field using bulk superconductor shielding. Experiment C12-20-002 received C1 approval from PAC 48, approved on the condition of demonstration of this target technology.

This project requires R&D



Transversely polarized target for RGH

- The HDIce option was considered as the primary option. (Plan A)
- We also considered several alternative options described below. (Plan B)



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- Permanent link

Page | Discussion

Hall-B Run Group Task Forces

Overview | RG-C | RG-H | RG-I | RG-L | RG-M | RG-N

(click here to edit this task force)

Members

- E. Pasyuk (PI)
- L. Elouadrhiri
- X. Wei
- H. Avakian
- M. Ungaro
- B. Miller (engineering)
- M. Contalbrigo (external RGH contact)
- C. Keith (external target group)
- S. Lee (external)
- P. Moran (external)
- R. Johnston (external)
- I. Korover (external)

Documentation

- Charge
- DOE S&T review recommendation
- Figure of merit critera
- Final version of the report to S&T recommendation
- Preliminary layout of transverce magnet

Meetings

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Weekly meetings Tuesdays 13:00 JLab time   https://bluejeans.com/7572696020
```

HDIce target

- The HDice target, polarized inside a dilution refrigerator at 15 Tesla and ~10 mK, with more than 1-year relaxation time, was used with photon beams in CLAS during G14 experiments.
- Potentially attractive features when used as a transversely polarized frozen-spin target with electron beams are:
  - small holding magnetic field (1 Tesla), relatively high temperature (<=200 milli Kelvin),
  - small HTC MgB_2 superconducting shield design with small *BdL* to produce less beam deflection.

Transverse + axial field

From Eugene and Team

The solid HD dimensions:

D=25mm

L=25mm

Centered inside MgB2 shield

- MgB_2 retains the "memory" of fields present when it was cooled below T_c and became a diamagnetic SC

- MgB2 shield dimensions:
  D=86mm
  d=72mm
  L=250mm

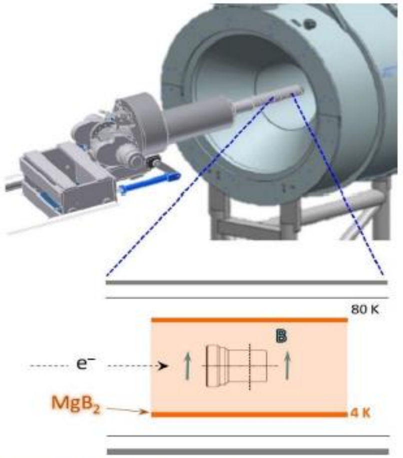


Figure 1: Geometry of the cell and MgB2 shield

The magnetic shield geometry is shown in Figure 2.

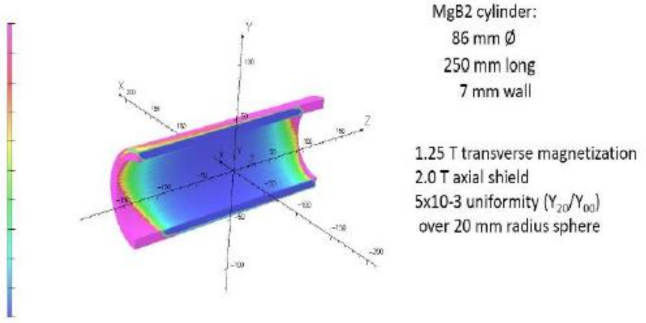


Figure 2: Magnetic shield

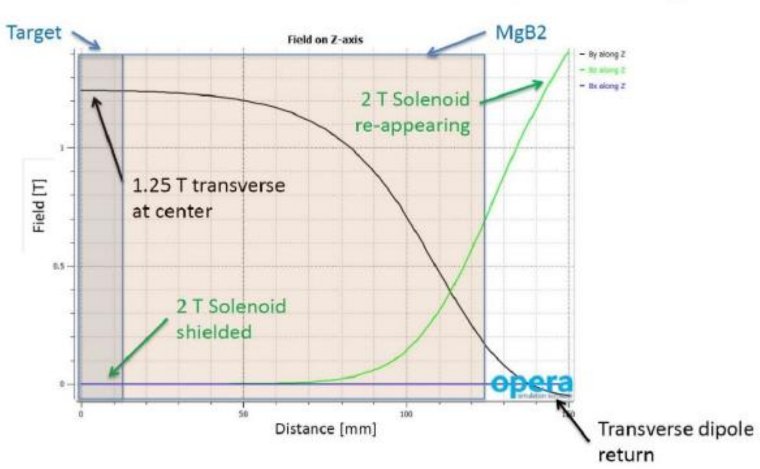


Figure 3: Magnetic field along the beam axis

Jefferson Lab
MAGNET GROUP

Information provided by Hall B team (Document saved at the following location) –
O:\Magnet_Design_Tools\Magnet Projects\Hall B\Transversely Polarized target\MgB2 magnet polarization

Acknowledge/Support - Information shared and made available with data along with a few comi files by M. Lowry

Alternatives to HDIce transversely polarized target for RGH

While the HDIce target is considered as the primary version, three alternative for the transversely polarized targets were considered:

1. A frozen-spin target of NH_3 and ND_3 (or other material, LiH?) inside the CLAS12 solenoid and operating at approximately 0.1 K and 1 T;
2. A target of NH_3/ND_3 that is continuously polarized at 0.3 K and 2.5 T inside the CLAS12 solenoid;
3. A target of NH_3/ND_3 that is continuously polarized at 1.0 K and 5 T in place of the CLAS12 solenoid. The latter is disconnected and move as far upstream as possible to make room for the target.

More details are presented in https://clasweb.jlab.org/wiki/images/3/32/TransverseCLAS12.pptx

Options 1 and 2 would utilize the Type II superconductor MgB_2 to shield the solenoid's longitudinal field and simultaneously provide a transverse field for dynamic polarization or to hold the polarization in frozen spin operation. Option 1 will be sensitive to the same beam heating and radiation damage problems as HD-Ice, but the repolarization time will be significantly shorter. Option 2 probably has the greatest risk. It requires that a highly uniform, persistent field can be generated and maintained by the MgB_2 shield. Option 3 is viewed as having the lowest risk from the target point-of-view but may compromise the achievable physics goals, as it is incompatible with the Central Detector and limits the acceptance to approximately ± 25° in the forward direction.

Estimated timeline

OPTIONS 1 & 2: Target equipment are the same. They only differ in the performance and utilization of the MgB2.

Assuming NO R&D on MgB2 or beam heating

Cost estimate: $2.5 - 3M (completely untrustworthy):

- MgB2 (??? $250k)
- Dilution refrigerator $1-2M
- Transverse polarizing magnet $300k
- Hall B infrastructure $250k

Timeline: 7-8 years

2022: Start design (two years)

2024: Start fabrication (three years)

2027: Start tests (one year)

2028: Install Hall B

OPTION 3: Use as much existing equipment as possible, *in the interest of time.*

Cost estimate: $0.6M (bare minimum)

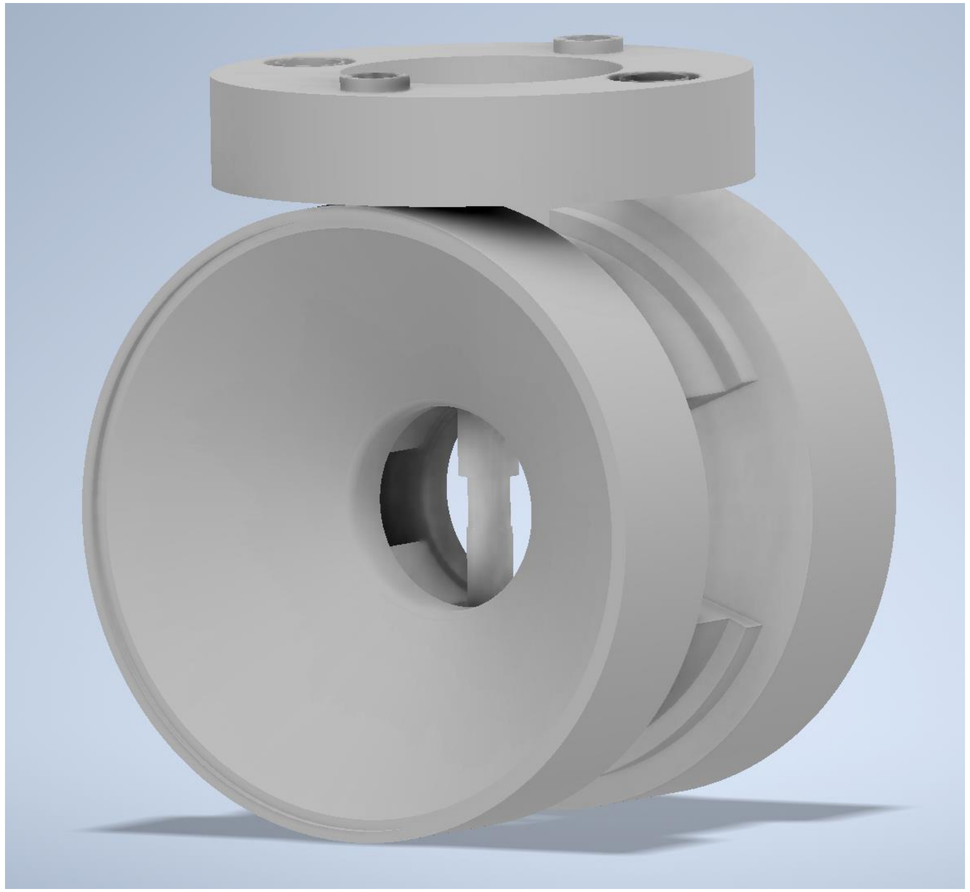
Basic infrastructure from the g2p/GEp experiments in Hall A w/ mods for Hall B

- 1 K refrigerator: in house
- Pumps: in house
- New vacuum piping: $25k
- Magnet: on order (5 T only, ± 25°, vertical or horizontal field)
    - Due end of 2021?
- Vacuum Chamber: in house. (New chamber needed for vertical field -- $200k?)
- New Hall B specific support structure (tough to estimate w/o a conceptual design for experimental layout: $250 K?)
- New gas handling system and some new electronics: $50k
- Ancillary stuff like cables, vacuum & gas piping, etc: $50k

If a completely new system is designed and constructed, add $2M and 2+ years

5 T transverse magnet simulation

- The CAD model of 5 T magnet was imported into gemc. Some preliminary simulation results can be found in https://clasweb.jlab.org/wiki/index.php/PTTF_063020_Minutes and https://clasweb.jlab.org/wiki/index.php/PTTF_070720_Minutes.



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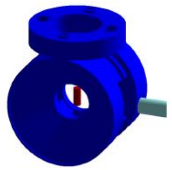
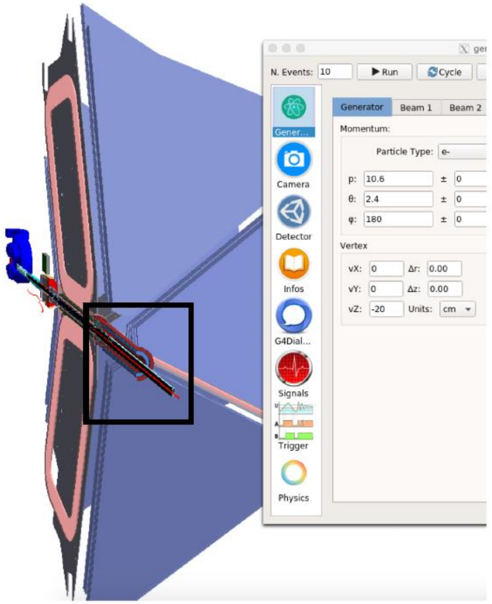
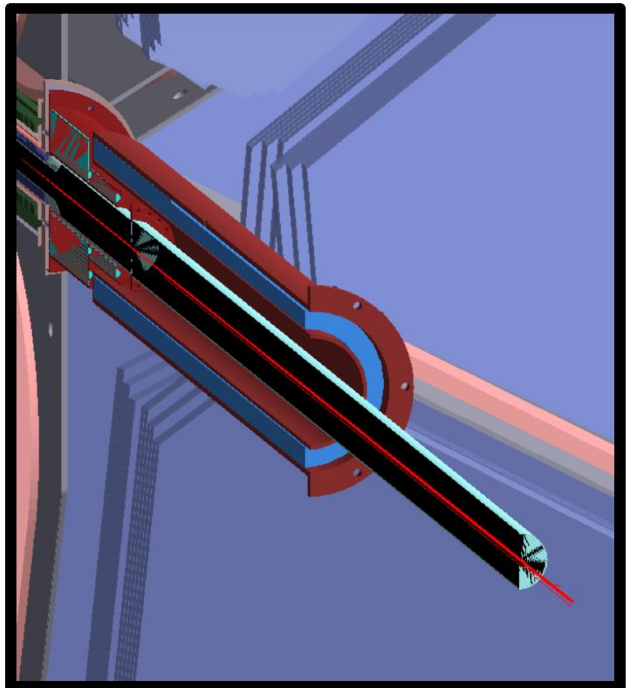
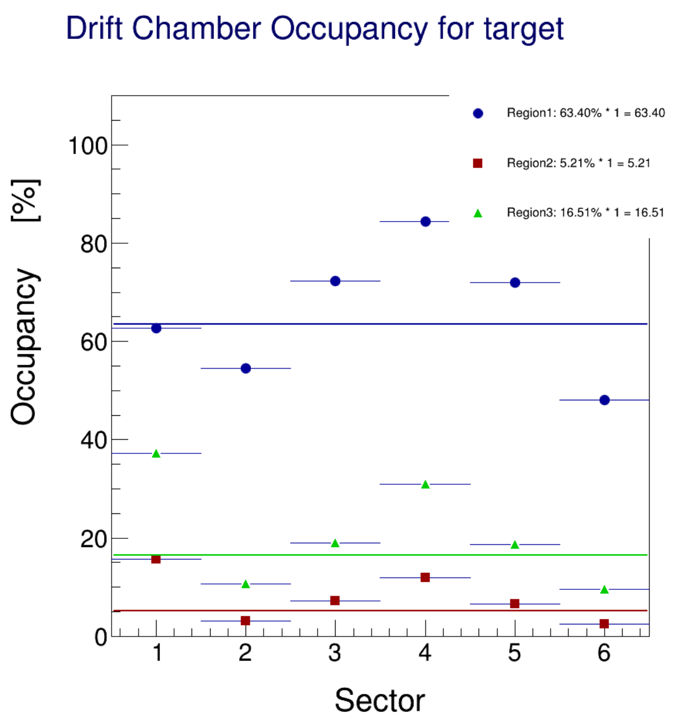
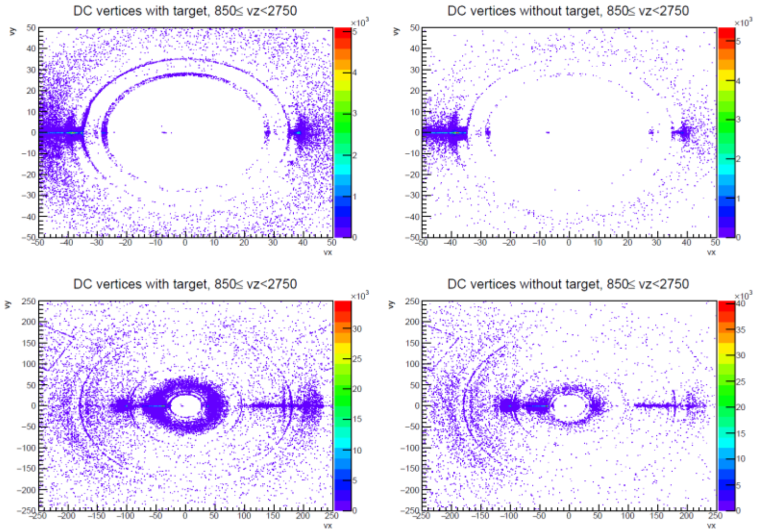


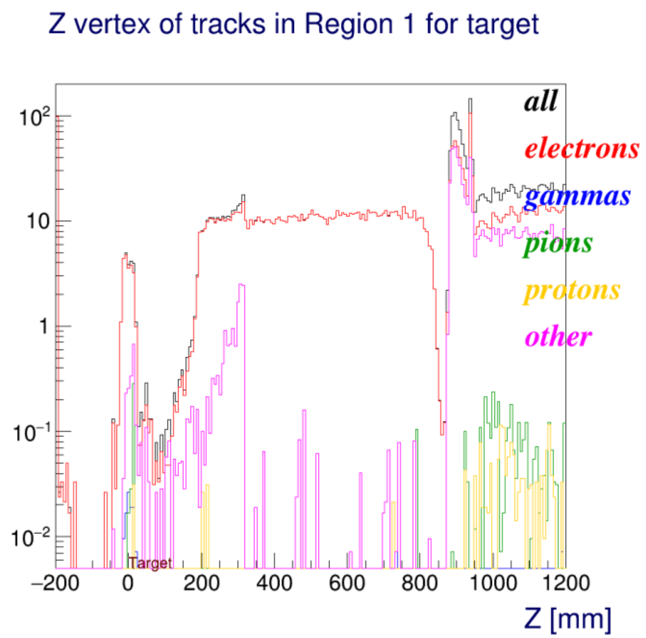


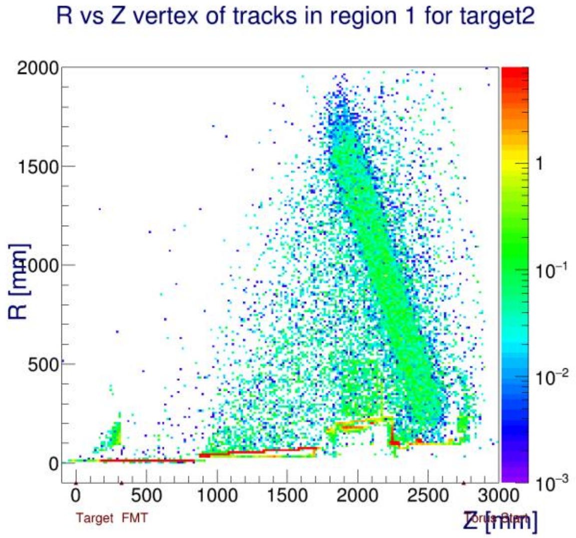


5 T transverse magnet simulation









Report to the DOE S&T review recommendation

- ***Develop a definite plan for moving forward the transverse polarized 3D imaging measurements in parallel with HDIce testing.***
- ***The plan should consider options for alternate targets with an analysis of the scientific impact and the timeline for carrying out the PAC approved experiments.***
- ***Submit to DOE-NP by January 15, 2021.***

Transversely polarized target options for CLAS12

V2.9 Jan 15, 2021

Summary

This document is in response to a recommendation from the 2020 TJNAF biennial Science and Technology Review to *"Develop a definite plan for moving forward the transverse polarized 3D imaging measurements in parallel with HDIce testing. The plan should consider options for alternate targets with an analysis of the scientific impact and the timeline for carrying out the PAC approved experiments. Submit to DOE-NP by January 15, 2021"*. The document reports status and preliminary results of a study to assess possible transversely polarized target options for CLAS12, the envisaged timeline and the impact on the planned physics program. Three configurations of dynamically polarized solid ammonia, NH3, are considered. The third configuration is preferred based on risk, cost, and schedule. In this configuration the NH3 target figure-of-merit is similar as HDice, and the main limitation comes from the maximum operational luminosity due to the background generated in CLAS12 with a 5 T transverse field. More detailed studies will be available in approximately 6 months.

The three alternatives are listed below, discussing advantages and disadvantages of each:

1. A frozen-spin target of NH_3 inside the CLAS12 solenoid and operating at approximately 0.2 K and 2 T.
2. A target of NH_3 that is continuously polarized at 0.3 K and 2.5 T inside the CLAS12 solenoid.
3. A target of NH_3 that is continuously polarized at 1 K and 5 T in place of the CLAS12 solenoid. The latter is disconnected and moved as far upstream as possible to make room for the target.

Full report: https://clasweb.jlab.org/wiki/images/0/01/TPT-shortreport-v2.9.pdf

Dynamically polarized NH_3 target

While all the considered options look realistic and have a potential to support proposed experiments, they differ in the resources and time necessary and the risk factors for their implementation. Options 1 and 2 require a substantial amount of R&D related to the MgB_2. This R&D is in progress by INFN but will require an additional 2-3 years to complete. The viability of these options depends critically on the results of this R&D and come with a significant risk. A tentative estimate of time and cost to design and build either option 1 or 2 is 7-8 years (beyond the R&D phase) with a cost of the order of $3M.

Option 3 will utilize an existing JLab target system and does not pose technological risk. We anticipate some modifications are necessary to integrate it in Hall B. An estimate to adapt and install the target is 4-5 years with available resources. The estimated cost is under $1M for the target assuming use of a transverse polarized target magnet under construction for Hall C experiments.

The tentative timeline is:

- 1st year and ongoing: optimization of the experimental configuration
- 2nd year: target integration and engineering.
- 3rd year: fabrication of parts and assembly.
- 4th year: assembly and testing.
- 5th year: installation.

After considering the possible options we think that **Option 3 (dynamically polarized NH_3 at 5 T and 1 K) is the most viable and requires less time and resources to support the RG-H physics program**.

All three options require a Hall B beam line modification, particularly installation of the magnet chicane to compensate for the primary beam deflection by the transverse target magnetic field. The estimated cost for these modifications is $1M.

Physics impact

Physics Impact

In the case of the HDice target the anticipated maximum operating luminosity of $4x10^{33}$ $cm^{-2}s^{-1}$ was limited by the HD polarization that can be sustained during beam operation. In the case of the NH_3 dynamically polarized target, the maximum luminosity will be limited by the electromagnetic background and the hit occupancies in the first 12 layers (Region 1) of the CLAS12 drift chambers system. Preliminary studies indicate a luminosity of $1x10^{33}$ $cm^{-2}s^{-1}$ provides a conservative estimate of the equivalent background as measured during the standard operation with liquid hydrogen target. We expect that optimizing the CLAS12 shielding will allow RG-H to run at a higher luminosity.

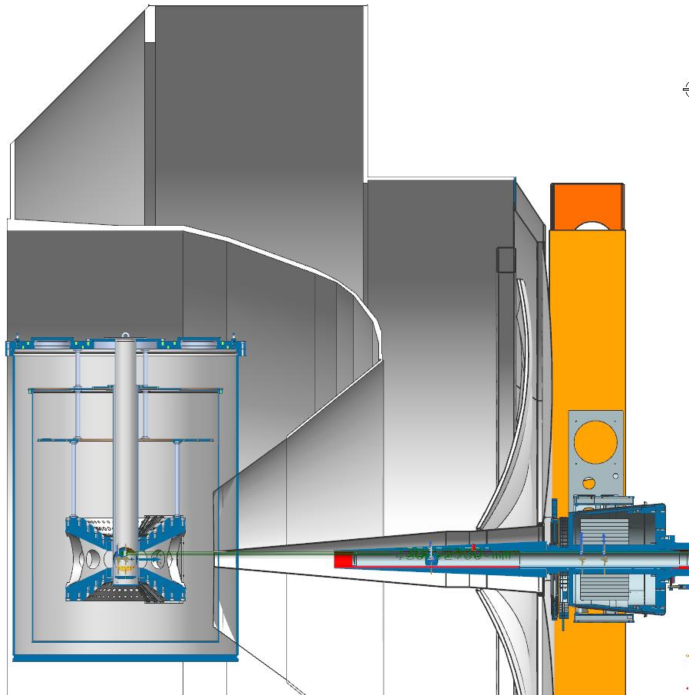
The requirements set by PAC-39 for the HDice target are 60% maximum polarization and 500 hours lifetime in 1 nA beam. The in-beam polarization of HDice is expected to decay in an exponential fashion, and we interpret the 500 hours lifetime as the time for the polarization to drop to 1/e of its initial value. With an initial polarization of 60%, the polarization after 500 hours will be 22%, giving an average of 41%. It takes about 48 h to replace the HD sample, meaning a 10% overhead for this operation. The higher polarization of NH3 and the lower overhead of its operation will largely offset its larger dilution. From the previous performances of NH3 targets at Jefferson Lab, we anticipate an average in-beam polarization of 86% can be achieved with a 3-5% overhead for routine target operations during RG-H.

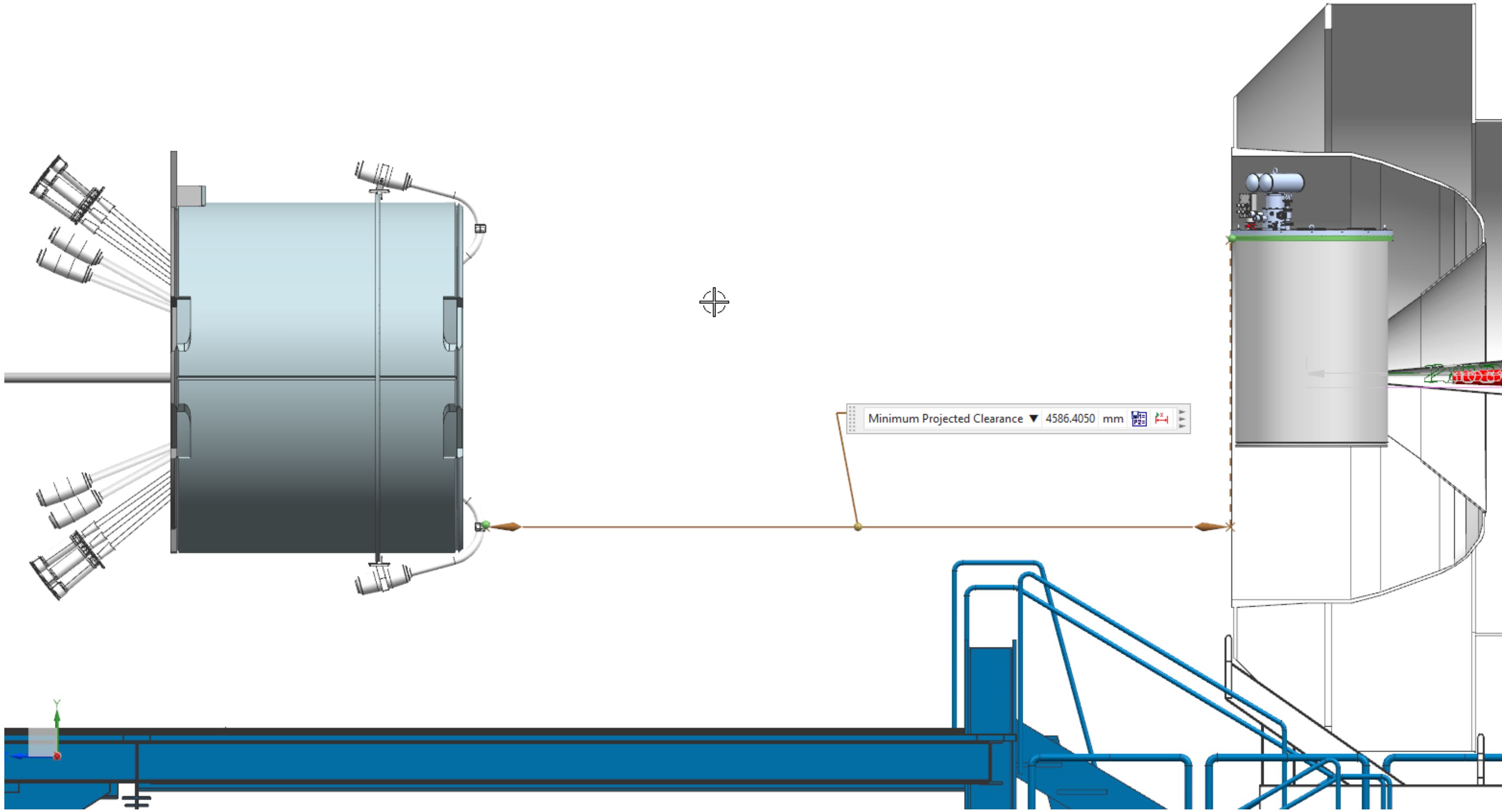
Based on a preliminary study, running the RG-H physics program with an NH_3 dynamically polarized target instead of HDice implies the following changes to the experiment parameters:

- Reduction in luminosity from $4x10^{33}$ $cm^{-2}s^{-1}$ to $1x10^{33}$ $cm^{-2}s^{-1}$;
- Increase in average target polarization from 41% to 86%;
- Change in the dilution factor from 1/3 to 3/17;

In summary: even with the present assumed conservative reduced effective luminosity, **CLAS12 with a dynamically polarized NH_3 target will provide significant measurements in the valence quark kinematics, significantly extending the kinematical region covered by HERMES and COMPASS measurements and providing a unique and crucial input for studies of the 3D structure of the proton**.

Magnet can only





Chicane

The deflection angle is 2.2° then effective BdL integral comes out to be 1.36 Tm. For the symmetric 3-magnet chicane the middle magnet would need to have 2.72 Tm field integral. The first magnet needs to provide 1.36 Tm.

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7.5 Tesla Split Pair Cryogen-FREE Magnet System Dual RTB

January 21, 2020 By Steve Short Leave a Comment

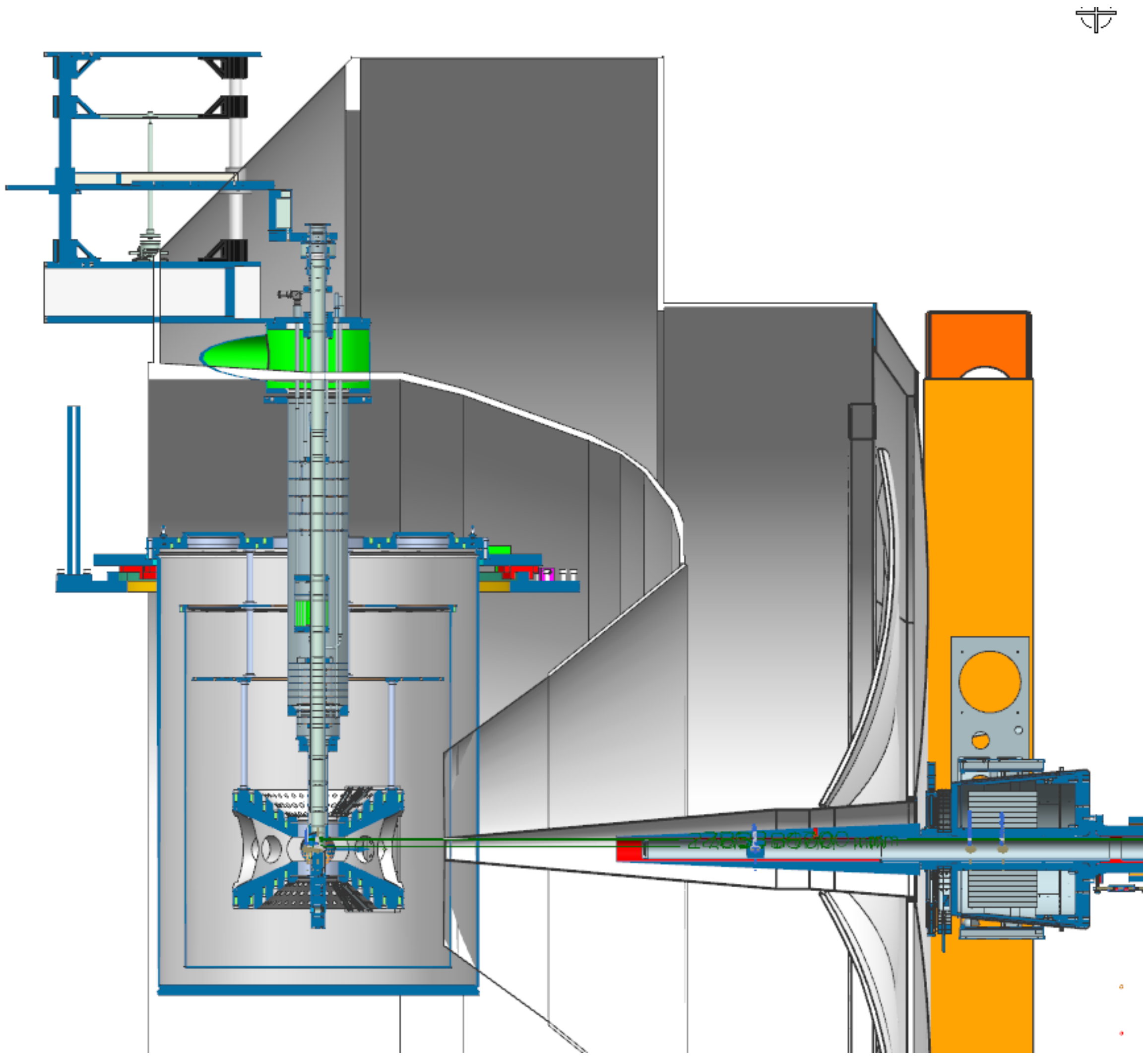
7.5 Tesla, Split Pair Cryogen-FREE Superconducting Magnet System with dual room temperature bores. Compact design allows for use with optical cryostat.

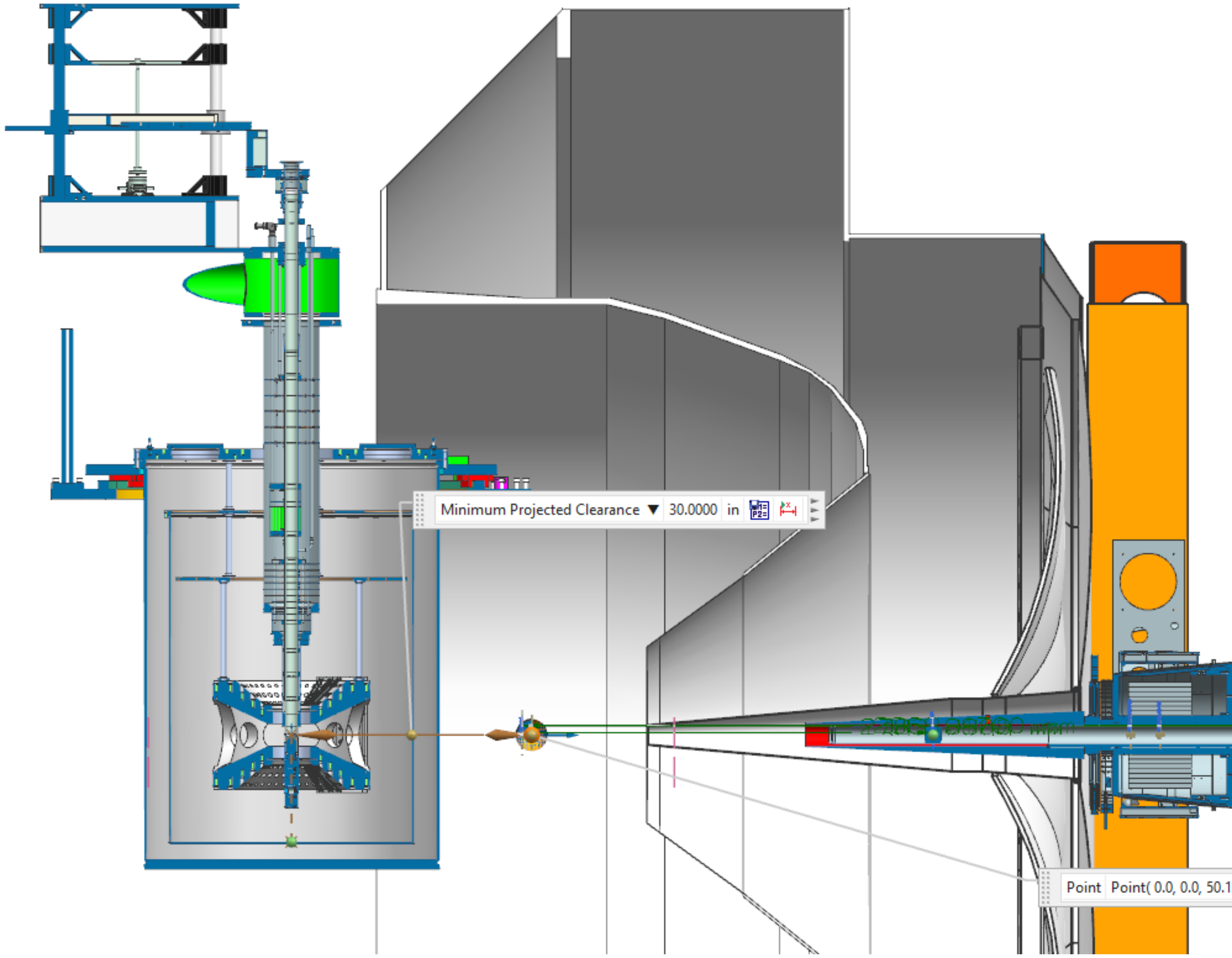
Customer Location: Florida, USA

- 7.5 Tesla Split Pair Magnet.
- 2.375 inch (60.3mm) ID Vertical (Radial to Field) Room Temperature Bore.
- 9.5 inch (241mm) Distance to Field Center.
- 2.00 inch (50.8mm) ID Horizontal (Axial to Field) Room Temperature Bore.
- 8.0 inch (203mm) Distance to Field Center.
- + 0.1 % Central Field Homogeneity Over 10 mm DSV.
- Single, Sumitomo Pulse Tube Cryocooler, Remotely Mounted.

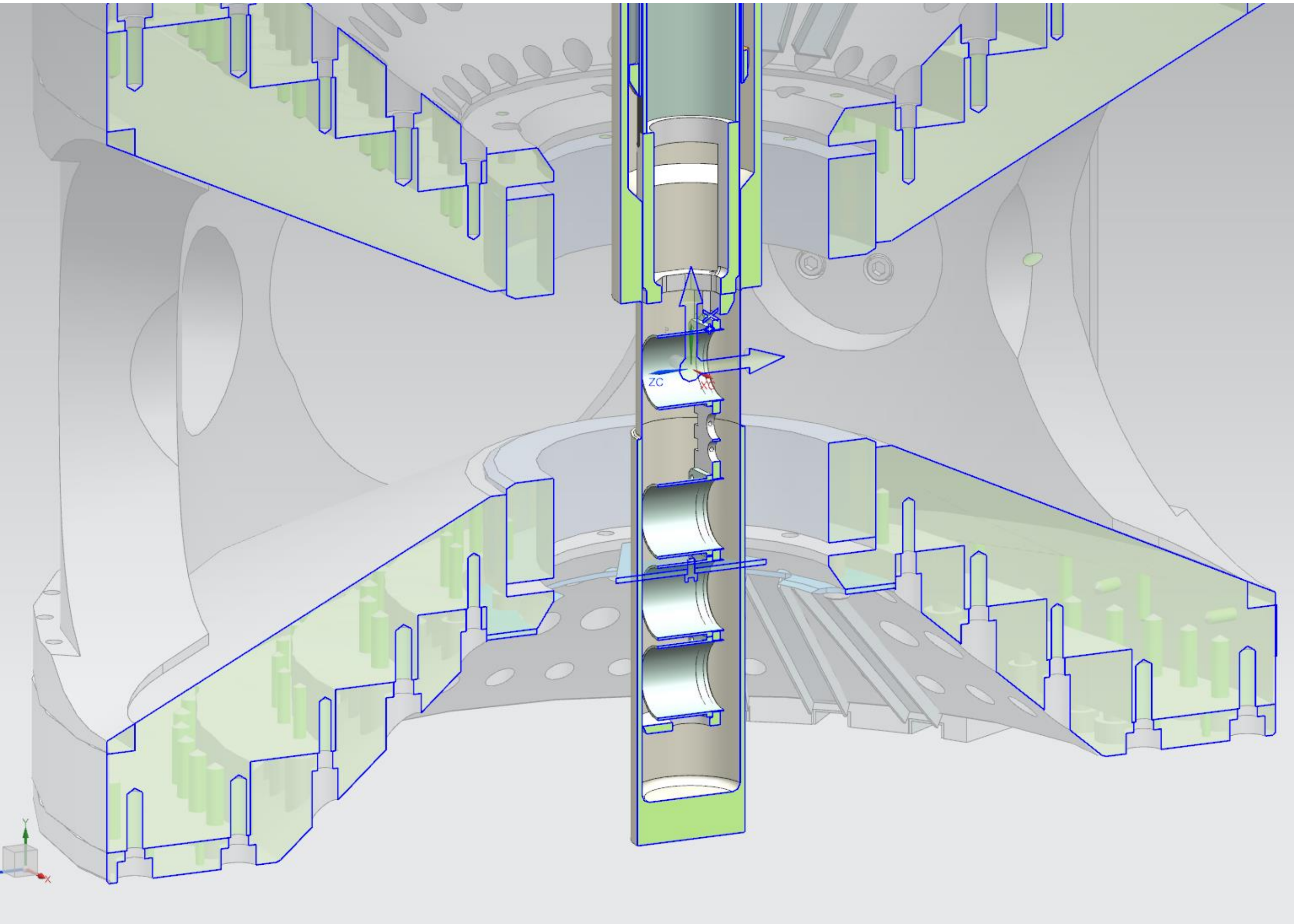
Delivered: June 2018

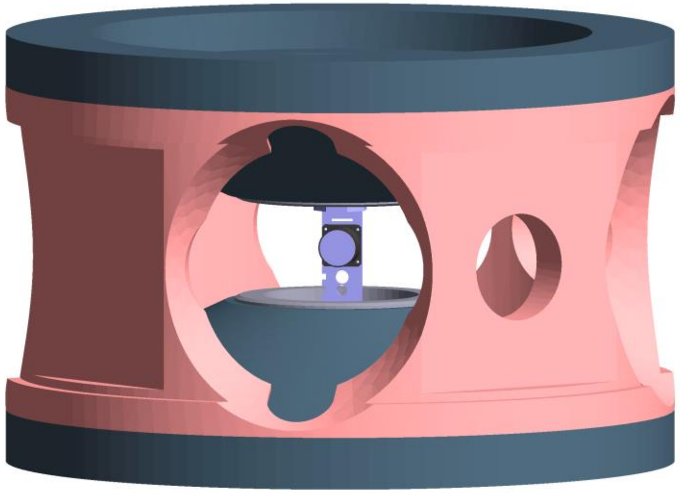
Full assembly

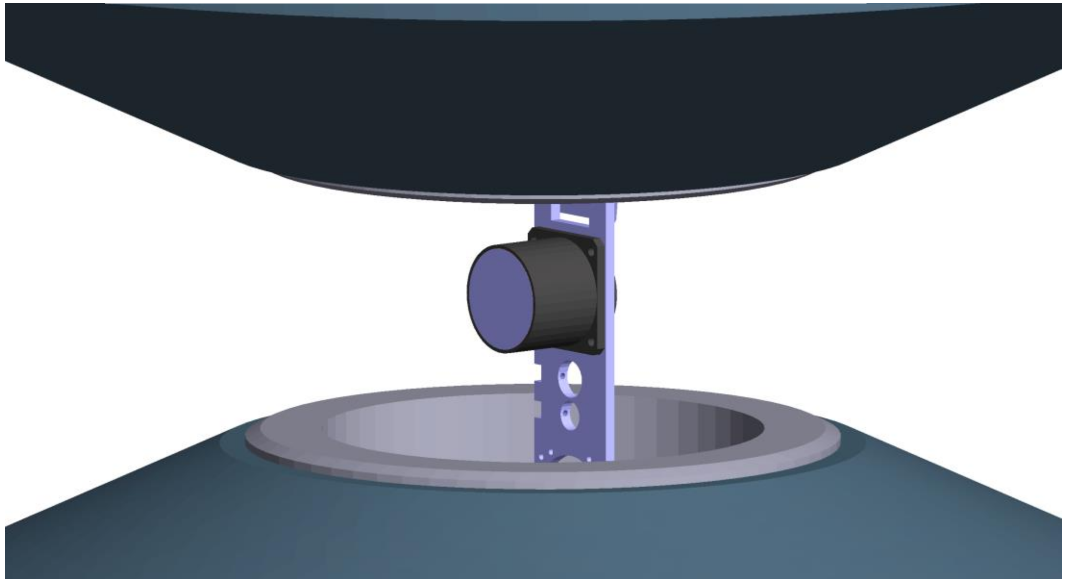




Central part

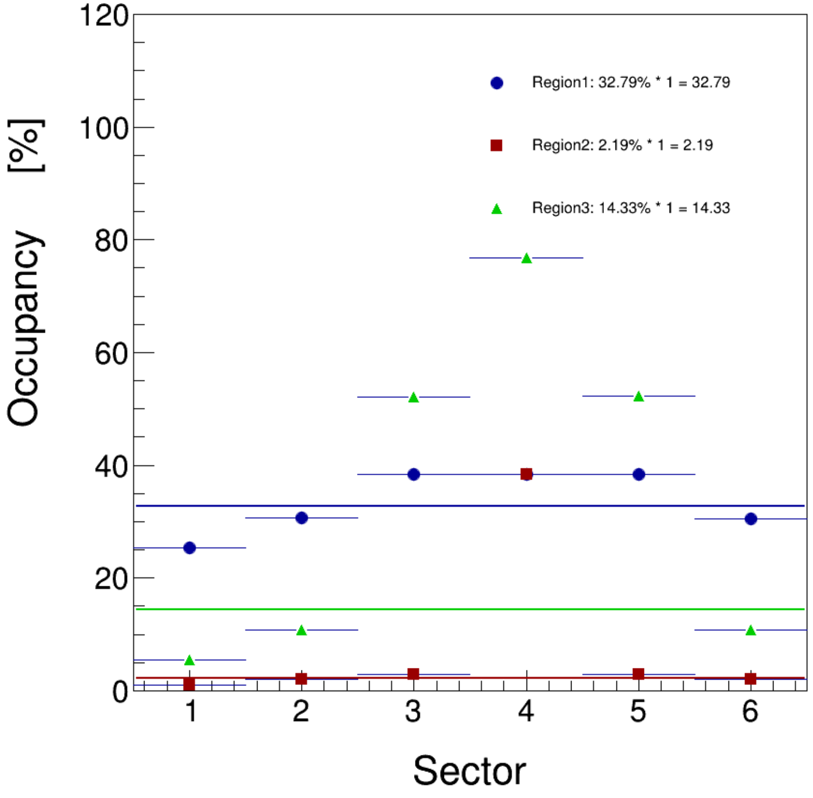




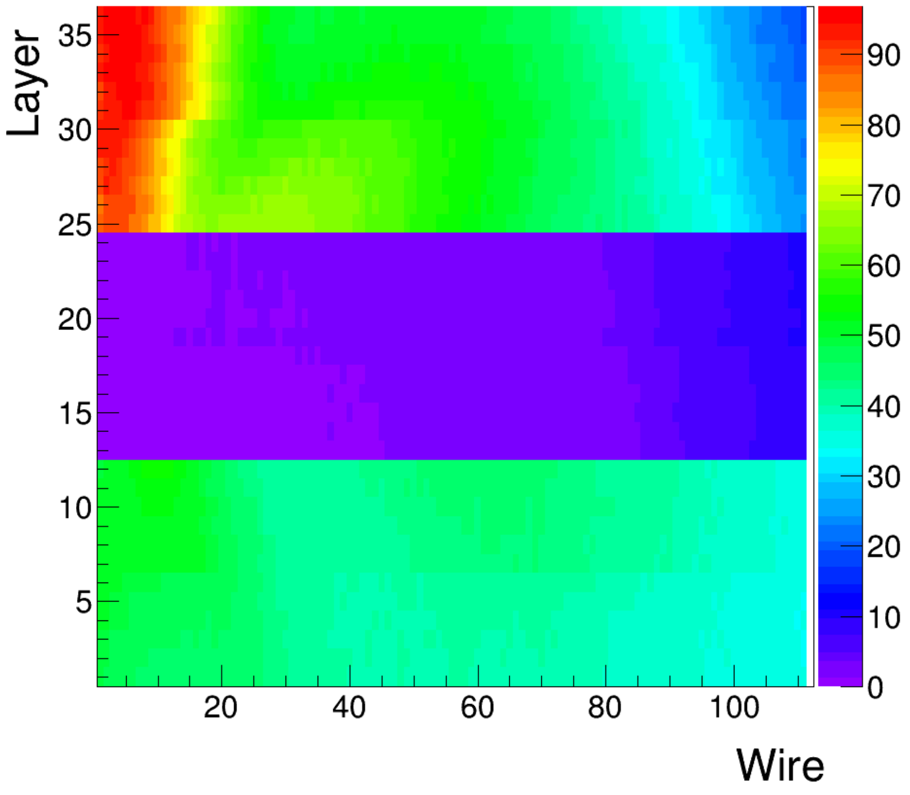


Polarized target configuration – Background simulations

DC Occupancies/region/sector



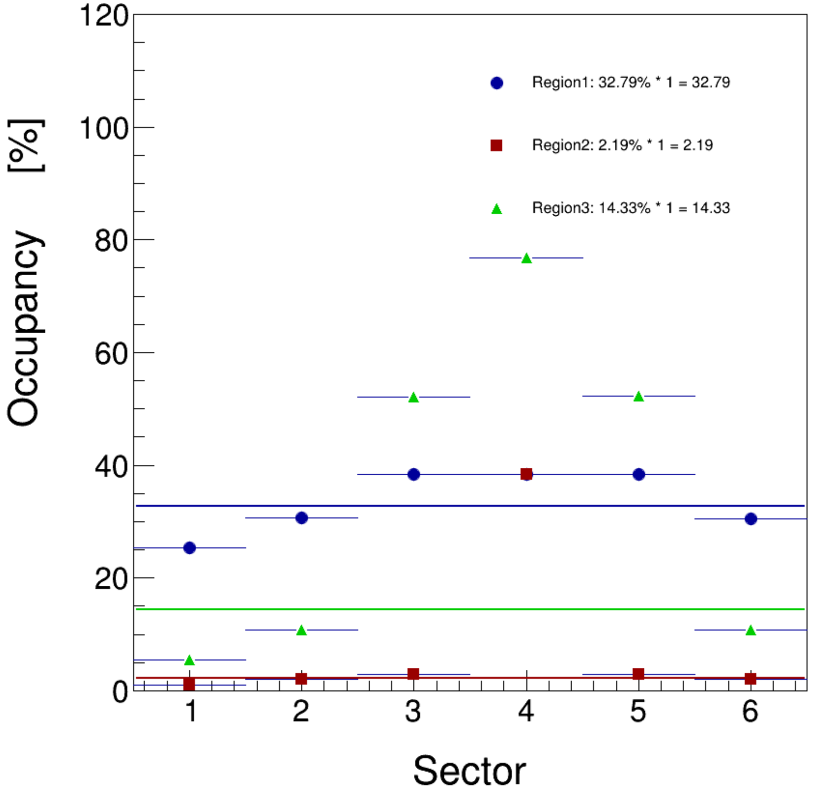
DC Occupancy map: Sector 2



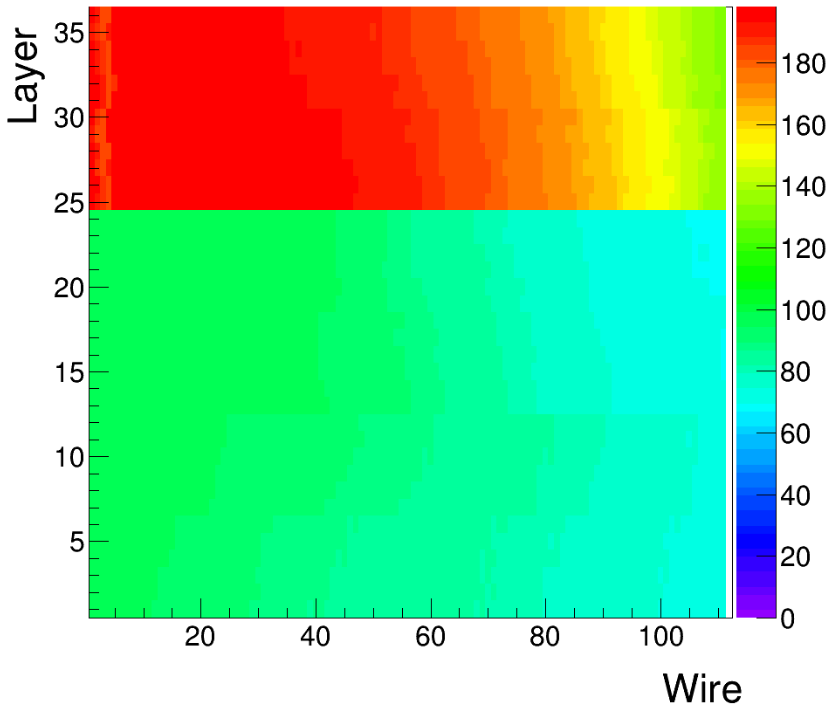
Luminosity ~10^{33}

Polarized target configuration – Background simulations

DC Occupancies/region/sector

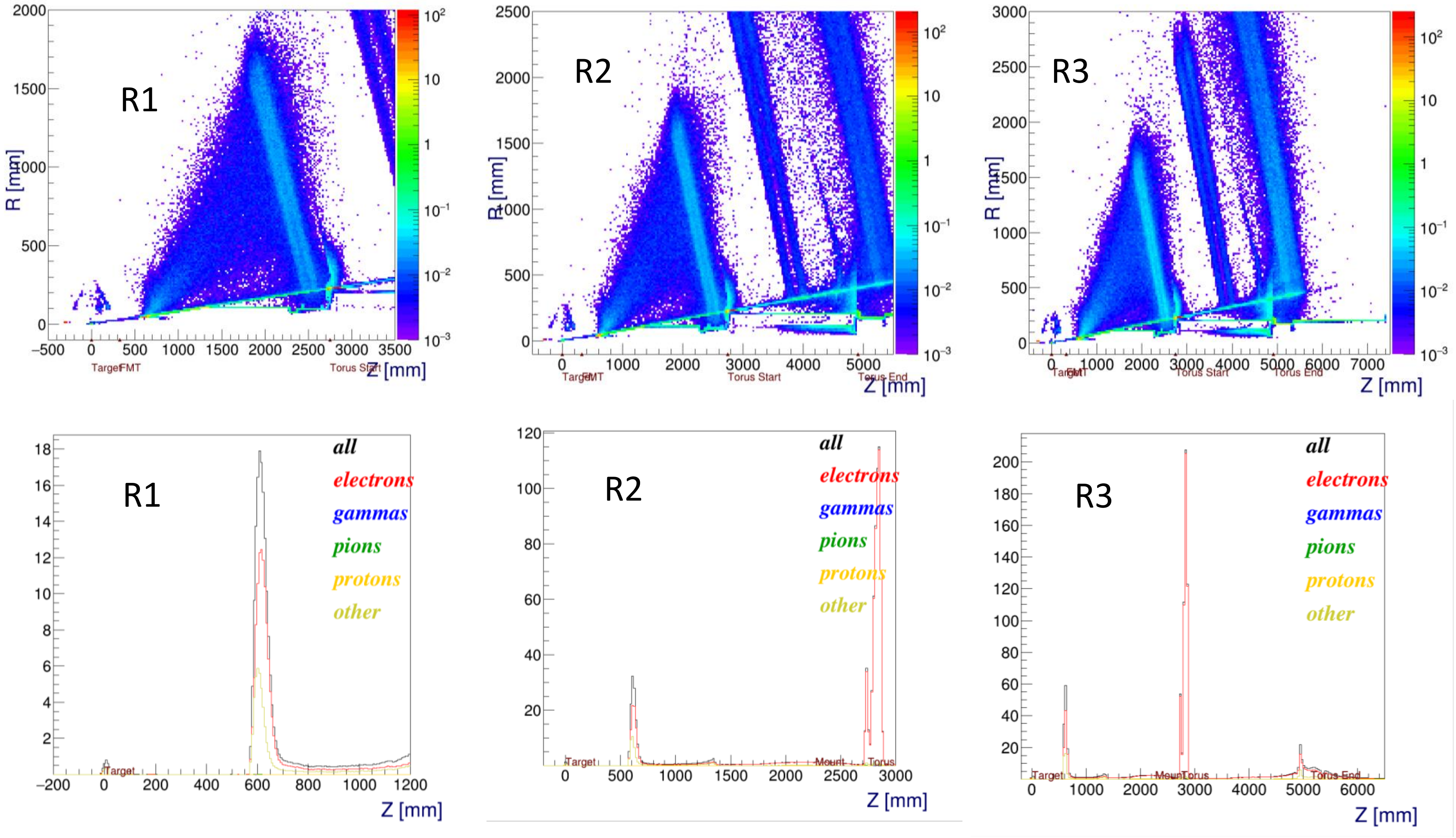


DC Occupancy map: Sector 4



Luminosity ~10^{33}

Polarized target configuration – Background simulations



Summary

- The task force evaluated various options of polarized targets for RGC, RGG, RGH and RGN
- RGC target is on track to completion
- RGG target work is well defined and does not pose any risks
- Polarized ^{3}He target for RGN requires substantial R&D work for proof of principle
- In January submitted report about alternatives to HDIce in response to the S&T review recommendations
- Follow-up report with more advanced studies is due mid summer
- Work on defining experiment configuration for RGH is on-going
    - Baseline geometry and magnetic field defined in gemc
    - To study physics impact need to include transverse magnetic field into reconstruction

Thank you!