Dustin Keller
University of Virginia

September Collaboration Meeting

- My Group Introduction
- Interest in COMPASS
- Some current Activities
- Building the Network

- Faculty: Retired Faculty: (50 year +)

  Dustin Keller Don Crabb, Donal Day
- Research Scientist:

  unnamed scientist
- Postdocs:

  Z. Akbar, J. Hoskins
- Gradstudents:

  L. Dias, A. Conover, D. Abrams,…
- Undergrad:
- Usually about 10 with the group at one time

Solid Polarized Targets:

We are unique among university based research groups as we have the capability to develop, build, and maintain the cryogenic polarized targets critical for investigating spin physics and helicity correlations. We focus primarily on high cooling power evaporation systems and low temperature frozen spin systems. We are also heavily involved in target material research and optimizing polarization techniques improving the overall figure of merit in large scale scattering experiments.

Spin Physics and Polarized Observables:

The group focuses on studies of spin effects in highly polarized proton, neutron, and deuteron targets. These polarized scattering experiments use the world-class solid polarized targets, which are developed and tested right here in our Lab. We concentrate on experiments that use spin degrees of freedom (i.e. using polarized targets and beams) with photon, electron, and nucleon beams on nucleon targets to extract new information about the properties of the fundamental building blocks of nature.

Nuclear and Particle Physics Experiments:

We are interested in a wide energy range and have projects and affiliations at Fermi National Accelerator Facility, Dukes Triangle Universities Nuclear Laboratory, Jefferson National Accelerator Facility, Los Alamos National Labs, and Oak Ridge National Labs.

Theory and Phenomenology in Nuclear and Medium Energy:

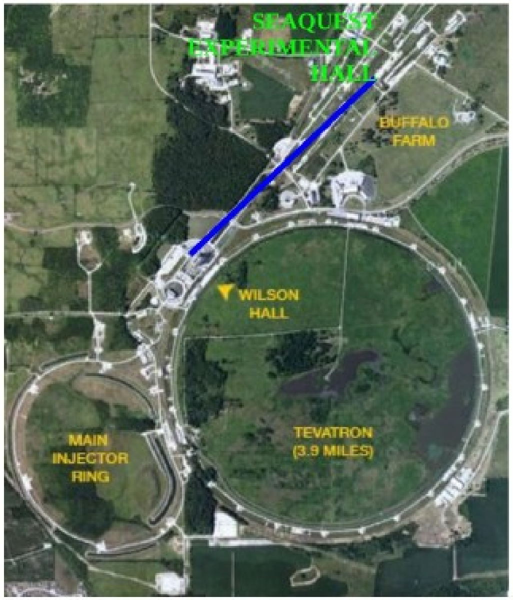
We are involved in studying the quark and gluon structure of hadrons. Our group works with the nuclear theory group researching techniques to exploit helicity correlations using machine learning to support our experimental effort. We are interested in the quark and gluon structure of nuclei including generalized parton and transverse momentum distributions.

Theory and Computational in Nuclear Spin Dynamics:

We are involved in theoretical research of the polarization mechanisms in solid materials at low temperature. This work requires modeling different aspects of dynamic nuclear polarization and nuclear magnetic resonance for the purpose of optimizing and measuring bulk spin alignment in a variety of materials. We are also developing simulations of these mechanisms which can be used to better understand spin dynamics in a variety of field and temperature conditions. This research can be used to improve the overall figure of merit of helicity sensitive particle physics experiments.

Facilities

Fermilab

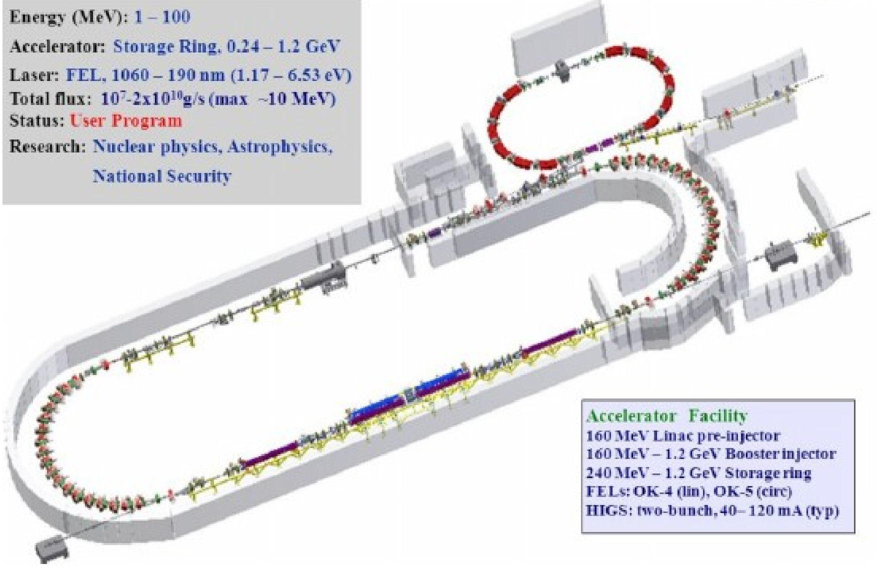


- 120 GeV proton beam
- $\sqrt{s} = 15.5$ GeV
- Projected Beam for E1039
  - Beam: 5×10^{12} p/spill; spill is 5 s/min
  - Protons on target per year
    - 9.7×10^{17}

12 GeV electrons (photons)
Hall A: Hi Res
Hall B: Large Acc
Hall C: Hi Res
Hall D: Large Acc

Jefferson Lab

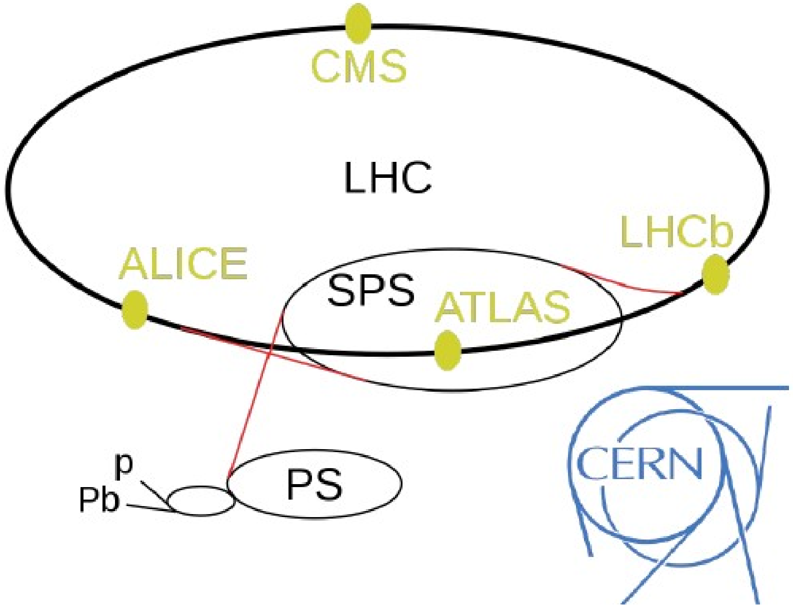
TUNL at Duke



Energy (MeV): 1 – 100
Accelerator: Storage Ring, 0.24 – 1.2 GeV
Laser: FEL, 1060 – 190 nm (1.17 – 6.53 eV)
Total flux: 10^7-2×10^{10}g/s (max ~10 MeV)
Status: User Program
Research: Nuclear physics, Astrophysics, National Security

Accelerator Facility
160 MeV Linac pre-injector
160 MeV – 1.2 GeV Booster injector
240 MeV – 1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIGS: two-bunch, 40– 120 mA (typ)

LHC at Cern



- Hall A
  - (E12-11-108) SIDIS with transversely polarized proton target
  - (E12-11-108A) Target single spin asymmetries using SoLID
  - (LOI-12-16-004) Timelike Compton Scattering with SoLID
- Hall B
  - (E12-06-109) Longitudinal spin structure of the nucleon
  - (E12-07-107) Spin-Orbit Correlations with a longitudinally PT
  - (E12-09-009) Spin-Orbit Correlations in kaon electroproduction in DIS
  - (E12-12-001) EMC effect in spin structure functions
  - (C12-15-004) DVCS on the neutron with a longitudinally PT
  - (C12-11-111) SIDIS on a transversely polarized target
  - (C12-12-009) Di-hadron production in SIDIS on transversely PT
  - (C12-12-010) DVCS on a transversely polarized target in CLAS12

(E-02-112) *Search for Missing Nucleon*

- Hall C
  - (E12-14-006) Helicity correlations in wide-angle Compton scattering
  - (E12-17-008) Polarized Observables in WACS
  - (C12-13-011) The deuteron tensor structure function b1
  - (C12-15-005) Tensor Asymmetry in the x<1 Quasielastic Region
  - (C12-18-005) Timelike Compton Scattering with T-PT at 11 GeV
  - (LOI-12-14-001) Search for exotic gluonic states in the nucleus

(E-08-027) *Proton spin structure function g2p*

(E-08-007) *Proton spin SF ratio GE/GM *

- Hall D
  - (LOI-12-15-001) Physics Opportunities with Secondary KL beam at JLAB
  - (LOI12-16-005) Target Helicity Correlations in GlueX

Low Temp Dilution Fridge

Group Interest in COMPASS

- General Spin Physics
- 3D Structure

  - TMD/GPD
- Hadron Spectroscopy

  - Polarized Observables

  - Search for missing/exotic states

Group Interest in COMPASS

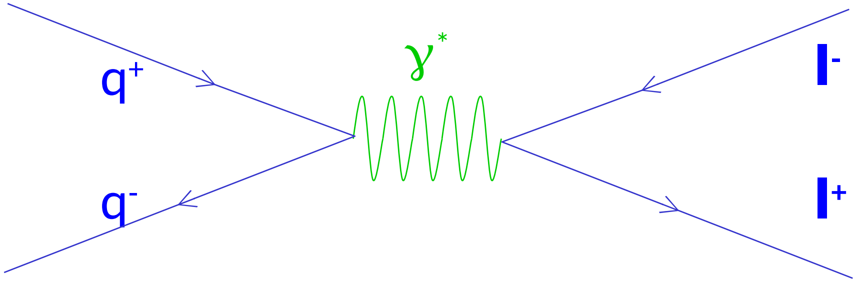
- General Interest in COMPASS polarized target
- Helping to contribute: labor, operations, expertise
- Help consolidate global polarized target experts
- Help with present polarized target program and maybe extend

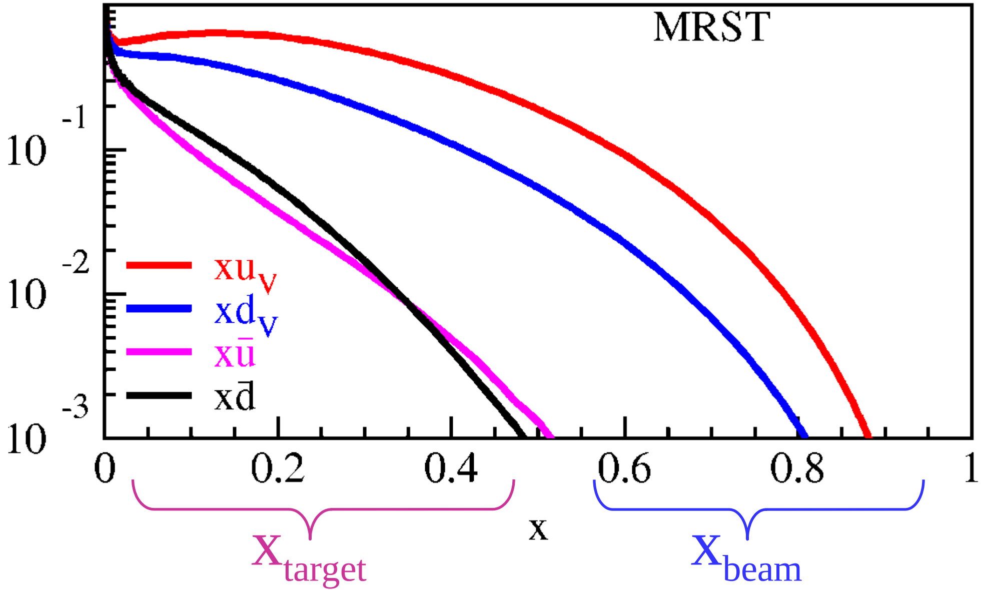
- Hear to learn what the needs are/will be

Example Project at FNAL

- 120 GeV proton beam
- $\sqrt{s} = 15.5$ GeV
- Projected Beam for E1039
  - Beam: $5\text{x}10^{12}$ p/spill; spill is 5 s/min
  - Protons on target per year
    - $7\text{x}10^{17}$

Drell-Yan





- Cross section is a convolution of beam and target parton distributions

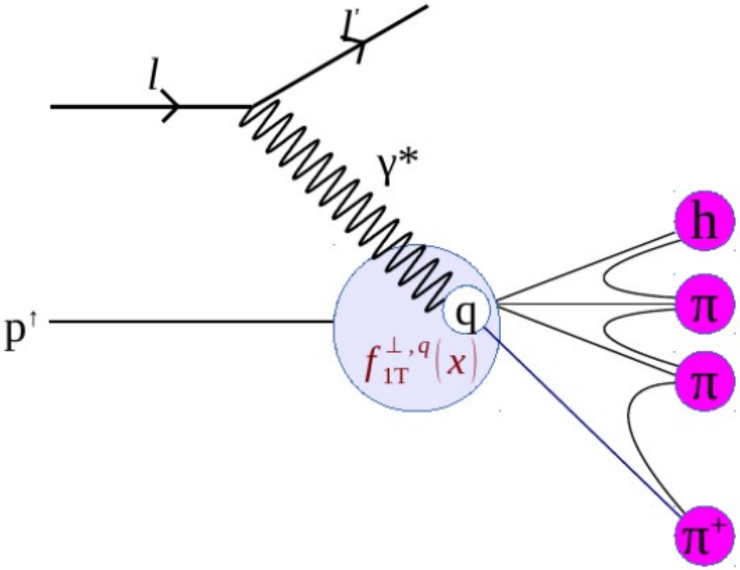
$$\frac{d^2\sigma}{dx_b\, dx_t} = \frac{4\pi\alpha^2}{x_b x_t s} \sum_{q\in\{u,d,s,\dots\}} e_q^2 \left[\bar{q}_t(x_t) q_b(x_b) + \bar{q}_b(x_b) q_t(x_t)\right]$$

- u-quark dominance
  $(2/3)^2$ vs. $(1/3)^2$

Beam	**Sensitivity**	**Experiment**
Hadron	Beam quarks target antiquarks	Fermilab, J-PARC RHIC (forward acpt.)
Anti-Hadron	Beam antiquarks Target quarks	J-PARC, GSI-FAIR Fermilab Collider
Meson	Beam antiquarks Target quarks	COMPASS, J-PARC

Accessing Quark Sivers TMDs

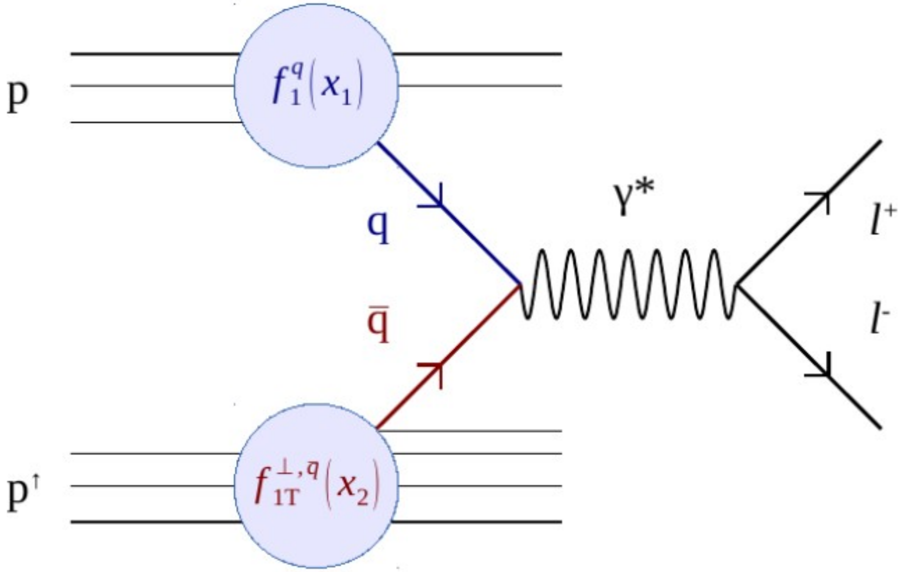
Polarized Semi-Inclusive DIS



$$A_{UT}^{SIDIS} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp,q}(x)\otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x)\otimes D_1^q(z)}$$

- L-R asymmetry in hadron production
- Quark to Hadron Fragmention function
- Valence-Sea quark: Mixed

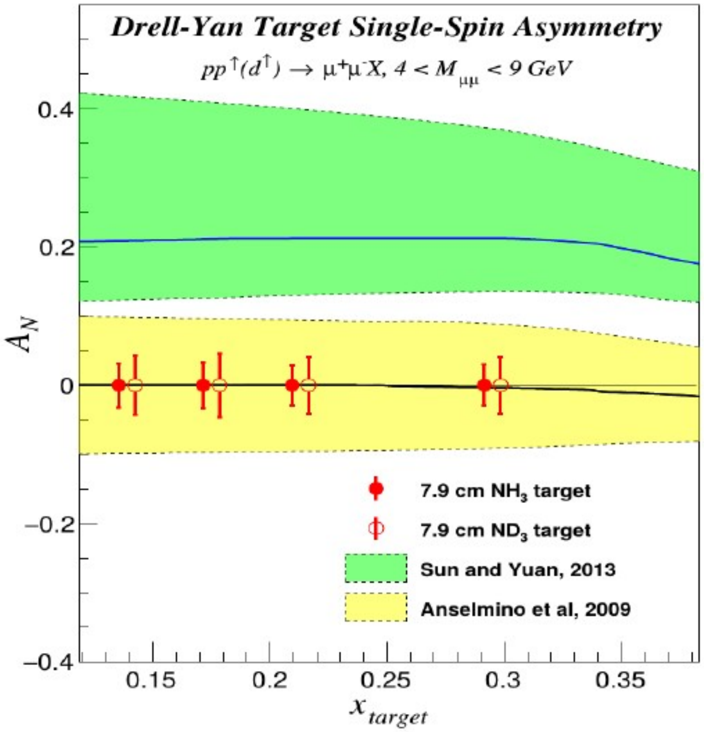
Polarized Drell-Yan

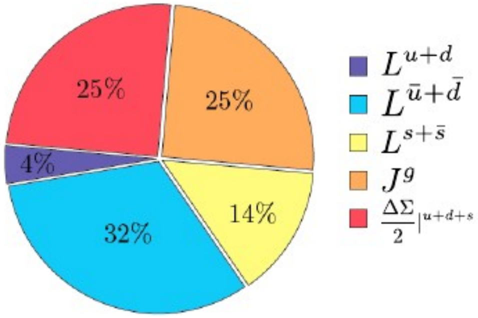


$$A_N^{DY} \propto \frac{\sum_q e_q^2\left[f_1^q(x_1)\cdot f_{1T}^{\perp,\bar{q}}(x_2)+1\leftrightarrow 2\right]}{\sum_q e_q^2\left[f_1^q(x_1)\cdot f_1^{\bar{q}}(x_2)+1\leftrightarrow 2\right]}$$

- L-R asymmetry in Drell-yan production
- **No Quark Fragmention function**
- Valence-Sea quark **Isolated**

Polarized Drell-Yan





$$A_N\left(p_{beam}+p^{\uparrow}_{target}\rightarrow DY\right)\propto\frac{N_L^{DY}-N_R^{DY}}{N_L^{DY}+N_R^{DY}}\propto\frac{f_{1T}^{\perp,\bar{u}}\left(x_t\right)}{f_1^{\bar{u}}\left(x_t\right)}$$

$$A_N\left(p_{beam}+d^{\uparrow}_{target}\rightarrow DY\right)\propto\frac{N_L^{DY}-N_R^{DY}}{N_L^{DY}+N_R^{DY}}\propto\frac{f_{1T}^{\perp,\bar{d}}\left(x_t\right)}{f_1^{\bar{d}}\left(x_t\right)}$$

- First measurement of sea quark Sivers (ū, d̄)
- Sign and value
  - Result has strong implications for O.A.M. in spin puzzle
- If nonzero, “smoking gun” for Sea quark O.A.M.
- If zero, where is proton spin coming from?

SpinQuest Goals

- Separately measure Sivers function for the sea
- Measure Sign and Magnitude
- Measurement of Sivers function for gluons (J/psi SSA)
- Polarized dbar to ubar ratio

Extensions: transversity, tensor charge, tensor polarized observables, dark sector, polarized proton beam,...

Physics Case

- Exploring the contribution of orbital angular momentum
- Interference between spin-flip and non-flip amplitudes with phase dependence
- Soft gluons

  - Gauge link required for color gauge invariance

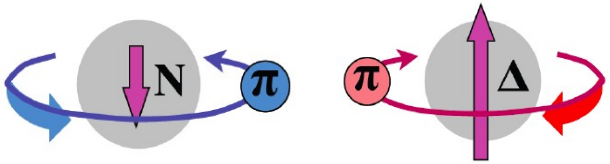
  - Testing interplay between time-reversal symmetry and gauge symmetry

SpinQuest Goals

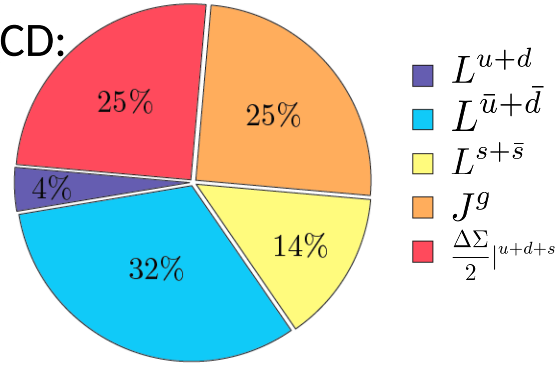
- Consider a nucleonic pion cloud
  $|p\rangle = |p_0\rangle + |N\pi\rangle + |\Delta\pi\rangle + \ldots$

  Pions $J^p=0^-$ Negative Parity
  Need L=1 to get proton's $J^p=½^+$

Sea quarks should carry orbital angular momentum.



Lattice QCD:



$\Delta\Sigma_q \approx 25\%$

$2\, L_q \approx 46\%$ (0%(valence)+46%(sea))

$2\, J_g \approx 25\%$

K.-F. Liu *et al* arXiv:1203.6388

QDC Gauge Invariance

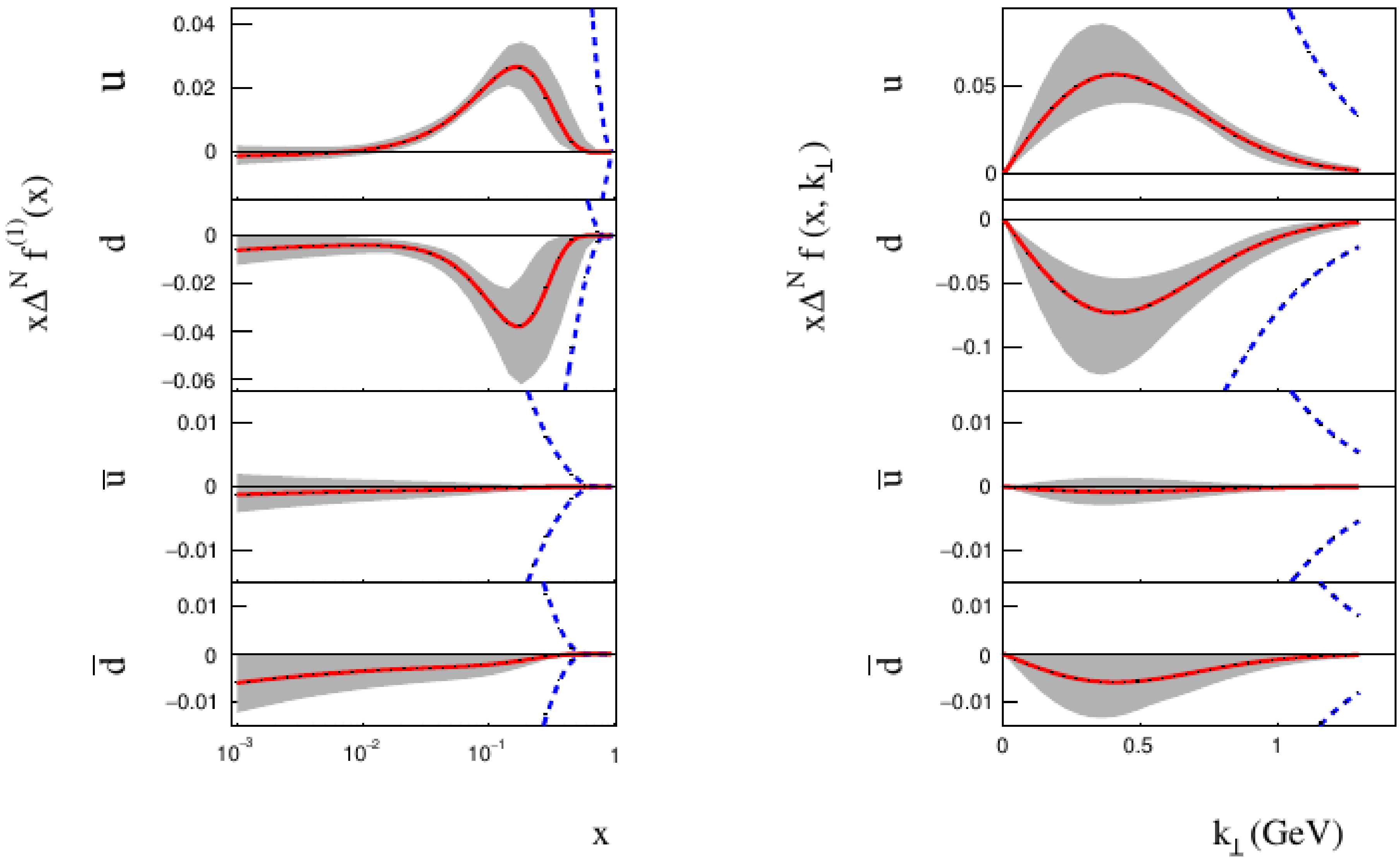
- Interference between spin-flip and non-flip amplitudes w/different phases
- Soft gluons
  - "gauge links" required for color gauge invariance
  - Re-interactions are final (or initial) state … and may be process dependent!

$$f_{1T}^{\perp}\Big|_{\mathrm{SIDIS}} = -\, f_{1T}^{\perp}\Big|_{\mathrm{DY}}$$

New World Data Fit

M. Anselmino,[a,b] **M. Boglione,**[a,b] **U. D'Alesio,**[c,d] **F. Murgia**[d] **and A. Prokudin**[e,f]

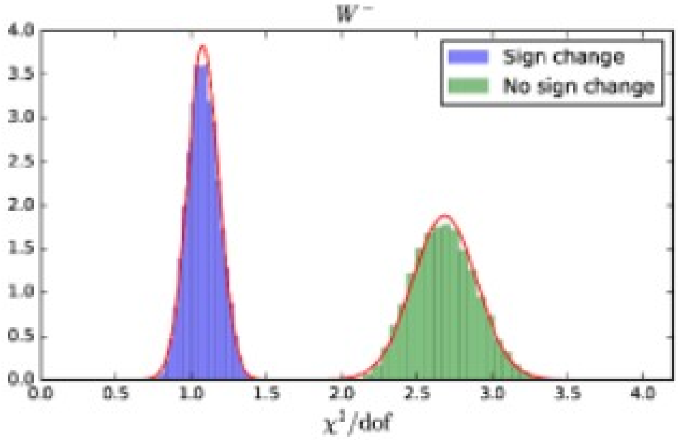
ArXiv ePrint: 1612.06413

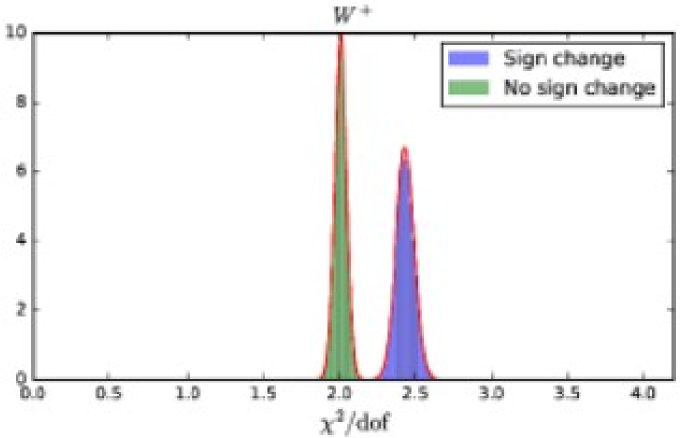


New World Data Fit

“Interesting” example by M. Anselmino et al (2017)

The sign-change (QCD prediction) is tested using the DY data of the W production from RHIC





- The chi-square pdf with/without sign-change assumption applied to the DY data from RHIC which are the only available data of Sivers asymmetry from the DY process
- No solid conclusion about the sign-change as predicted by QCD
- Our SpinQuest data will have a big impact

Advantage of the Main Injector

The (very successful) past:

Fermilab E866/NuSea

- Data in 1996-1997
- ^{1}H, ^{2}H, and nuclear targets
- 800 GeV proton beam

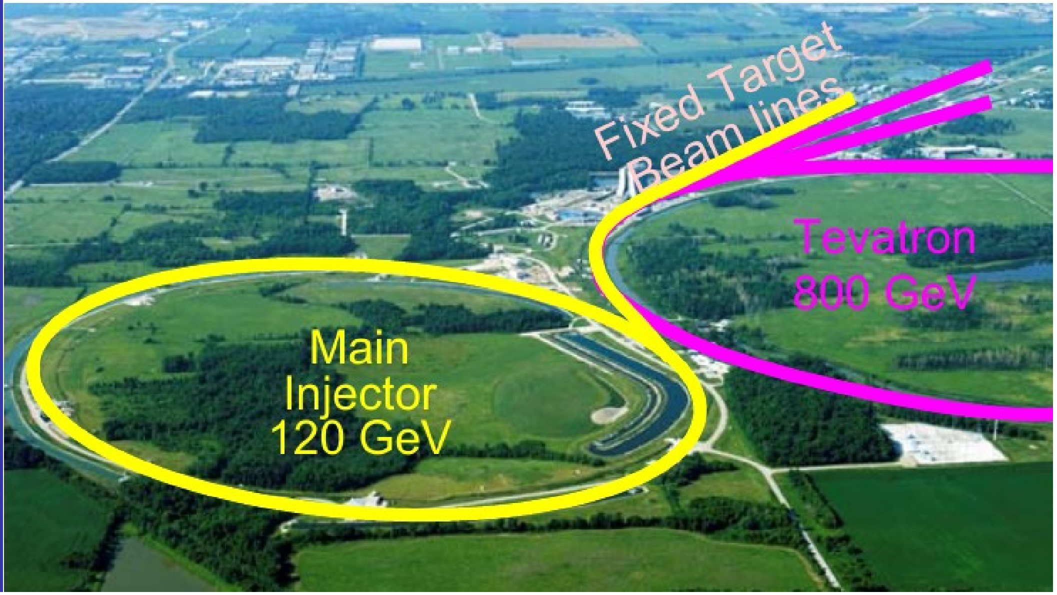
Fermilab E906

- Data in 2010
- ^{1}H, ^{2}H, and nuclear targets
- 120 GeV proton Beam And E1039

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\times\sum_i e_i^2\left[q_{ti}(x_t)\bar{q}_{bi}(x_b)+\bar{q}_{ti}(x_t)q_{bi}(x_b)\right]$$

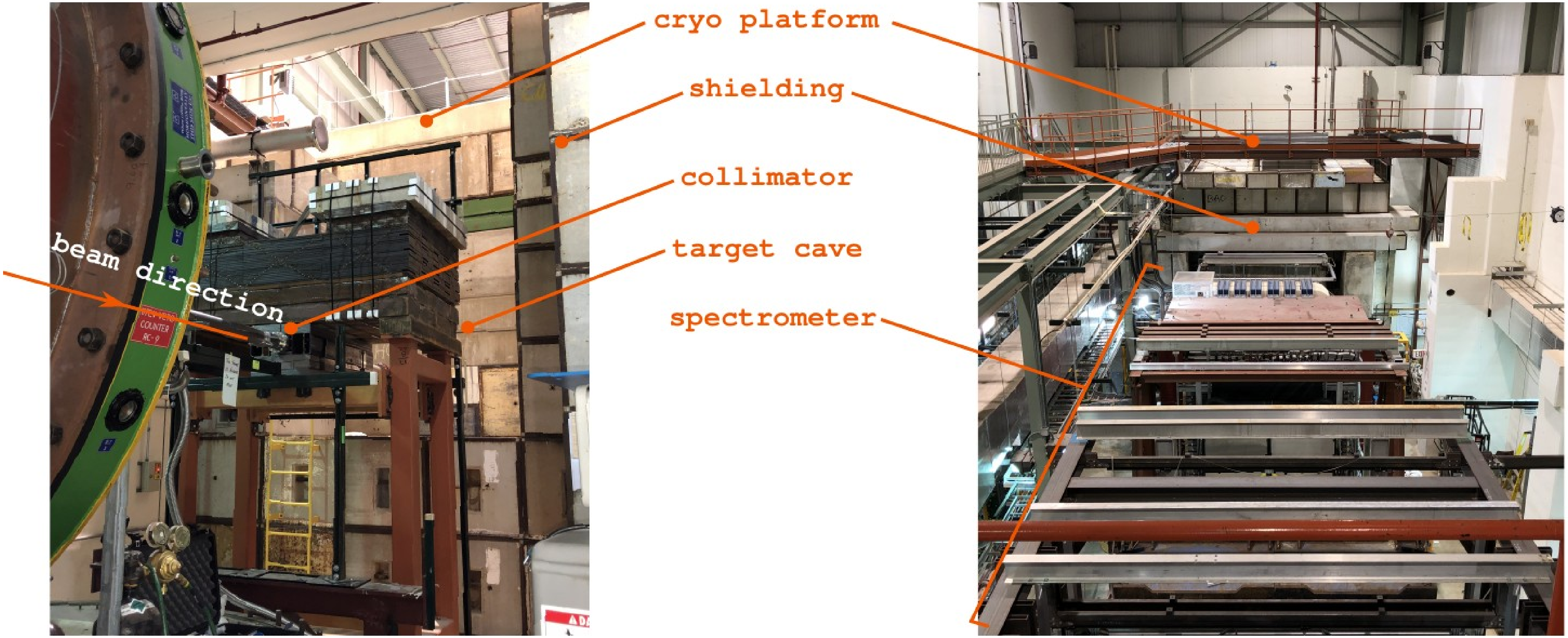
- Cross section scales as 1/s
  - *7× that of 800 GeV beam*
- Backgrounds, primarily from J/ψ decays scale as s
  - *7× Luminosity for same detector rate as 800 GeV beam*

50× statistics!!

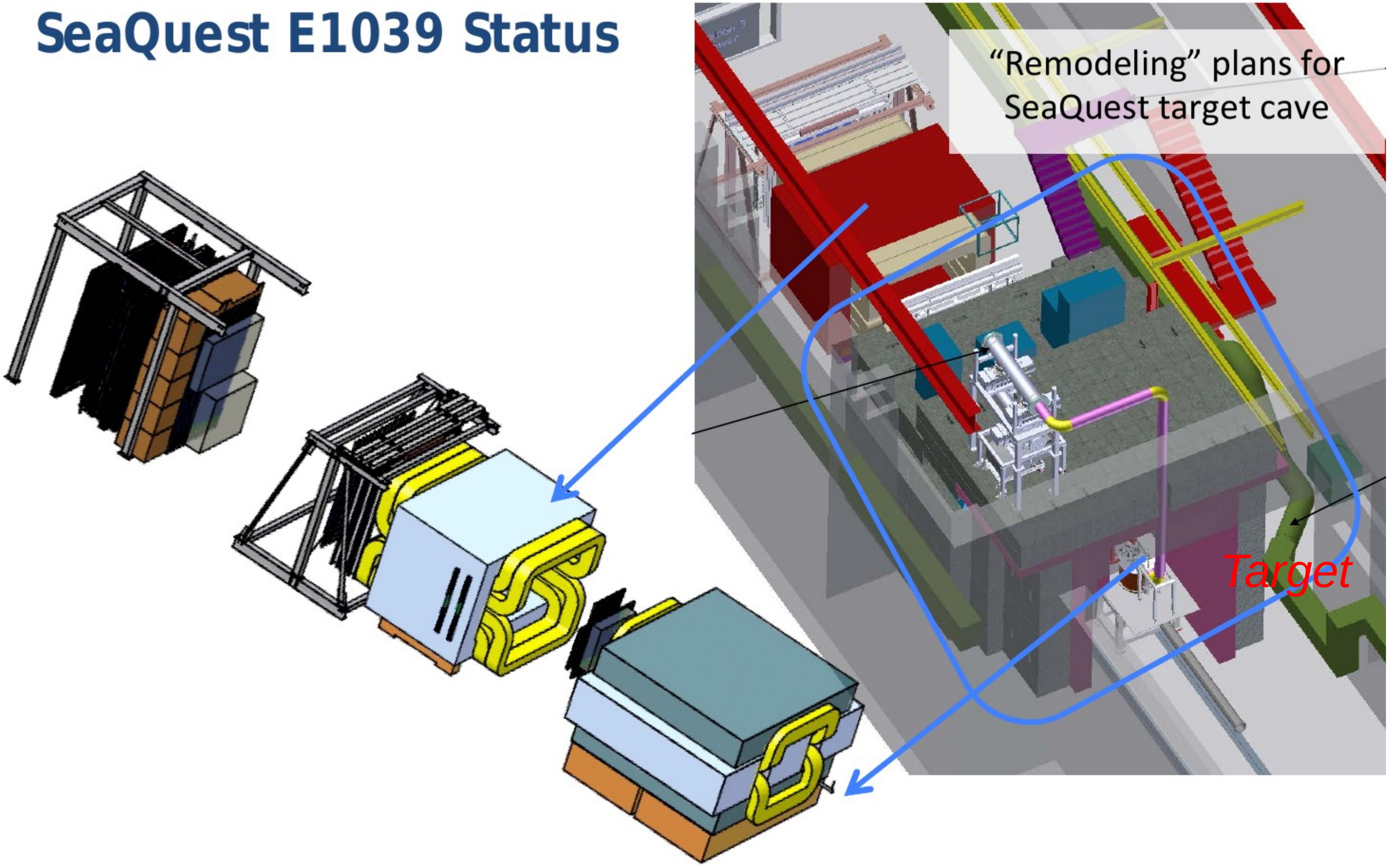


- special thanks to Fermilab support
  - beamline: new collimator
  - new radiation shielding design
  - new cryo platform for polarized target infrastructure
  - polarized target cave: new location 300cm upstream of FMAG

NM3: looking downstream **NM4: looking upstream**



Experimental Setup for E1039

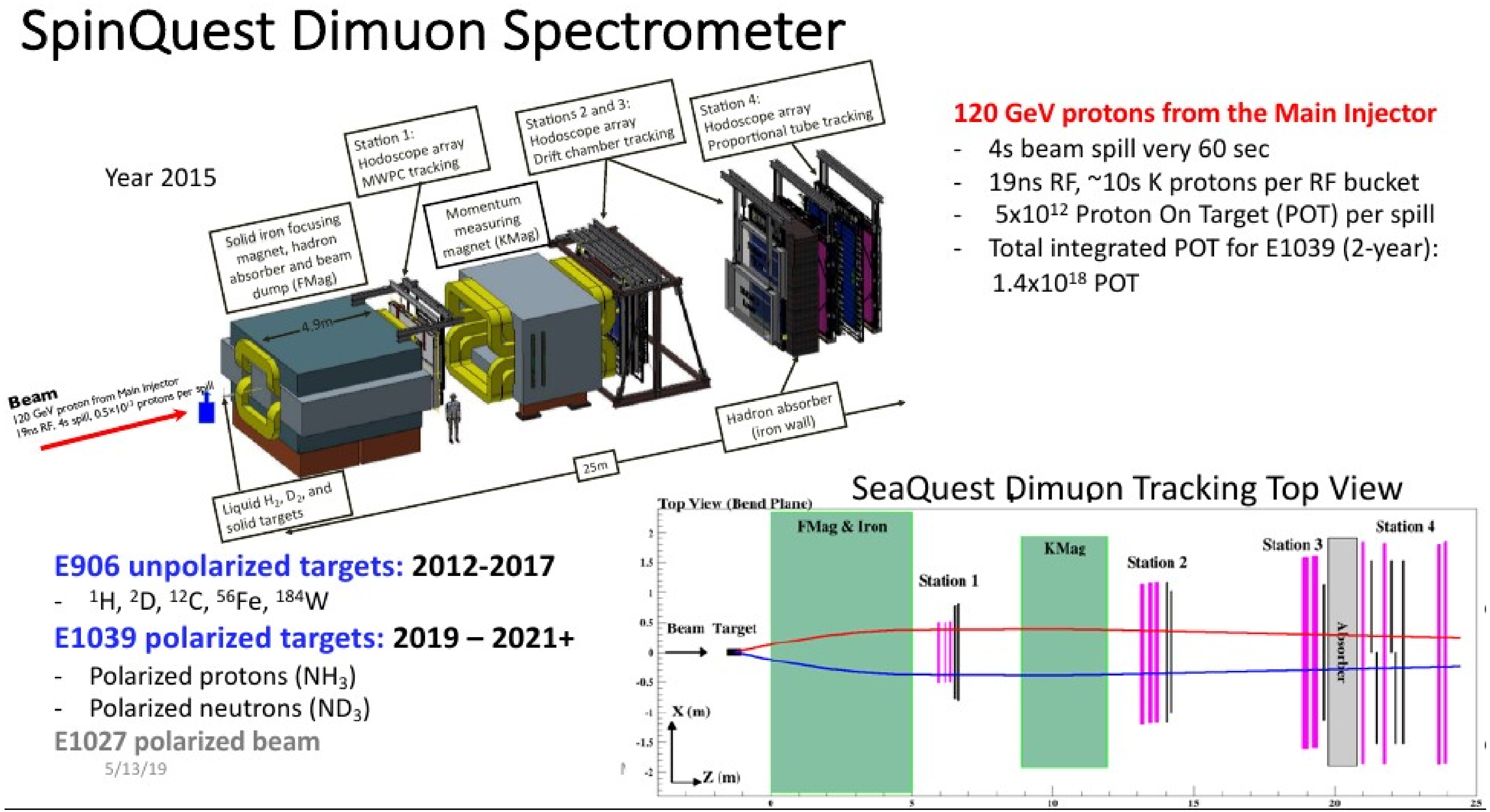


SeaQuest E1039 Status

“Remodeling” plans for SeaQuest target cave

Target

NM4 Detector



SpinQuest Dimuon Spectrometer

120 GeV protons from the Main Injector

- 4s beam spill very 60 sec
- 19ns RF, ~10s K protons per RF bucket
- $5\text{x}10^{12}$ Proton On Target (POT) per spill
- Total integrated POT for E1039 (2-year): $1.4\text{x}10^{18}$ POT

E906 unpolarized targets: 2012-2017

- ^{1}H, ^{2}D, ^{12}C, ^{56}Fe, ^{184}W

E1039 polarized targets: 2019 – 2021+

- Polarized protons (NH_3)
- Polarized neutrons (ND_3)

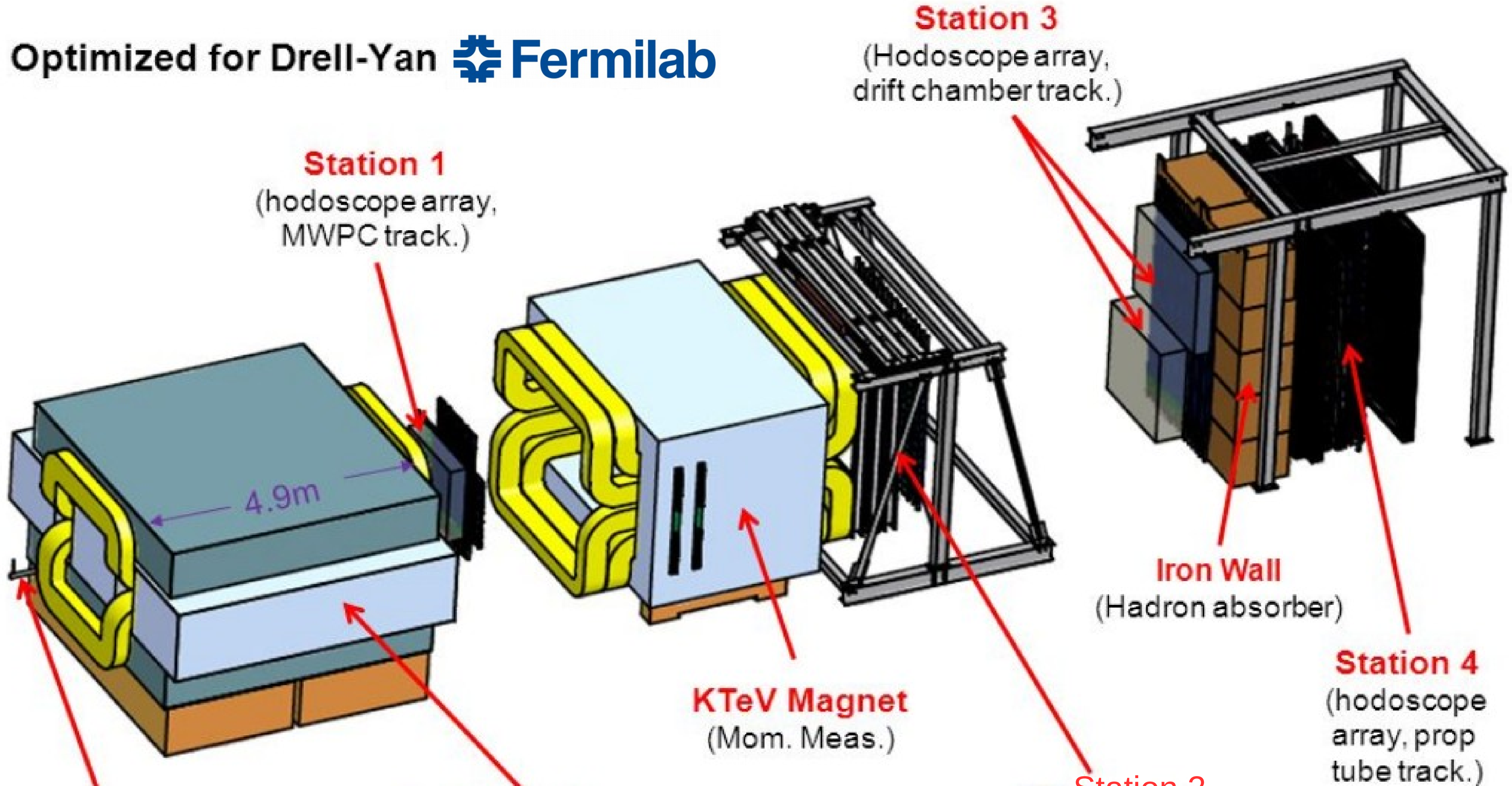
E1027 polarized beam

SeaQuest Dimuon Tracking Top View

5/13/19

Experimental Setup for E1039

Detector Pack

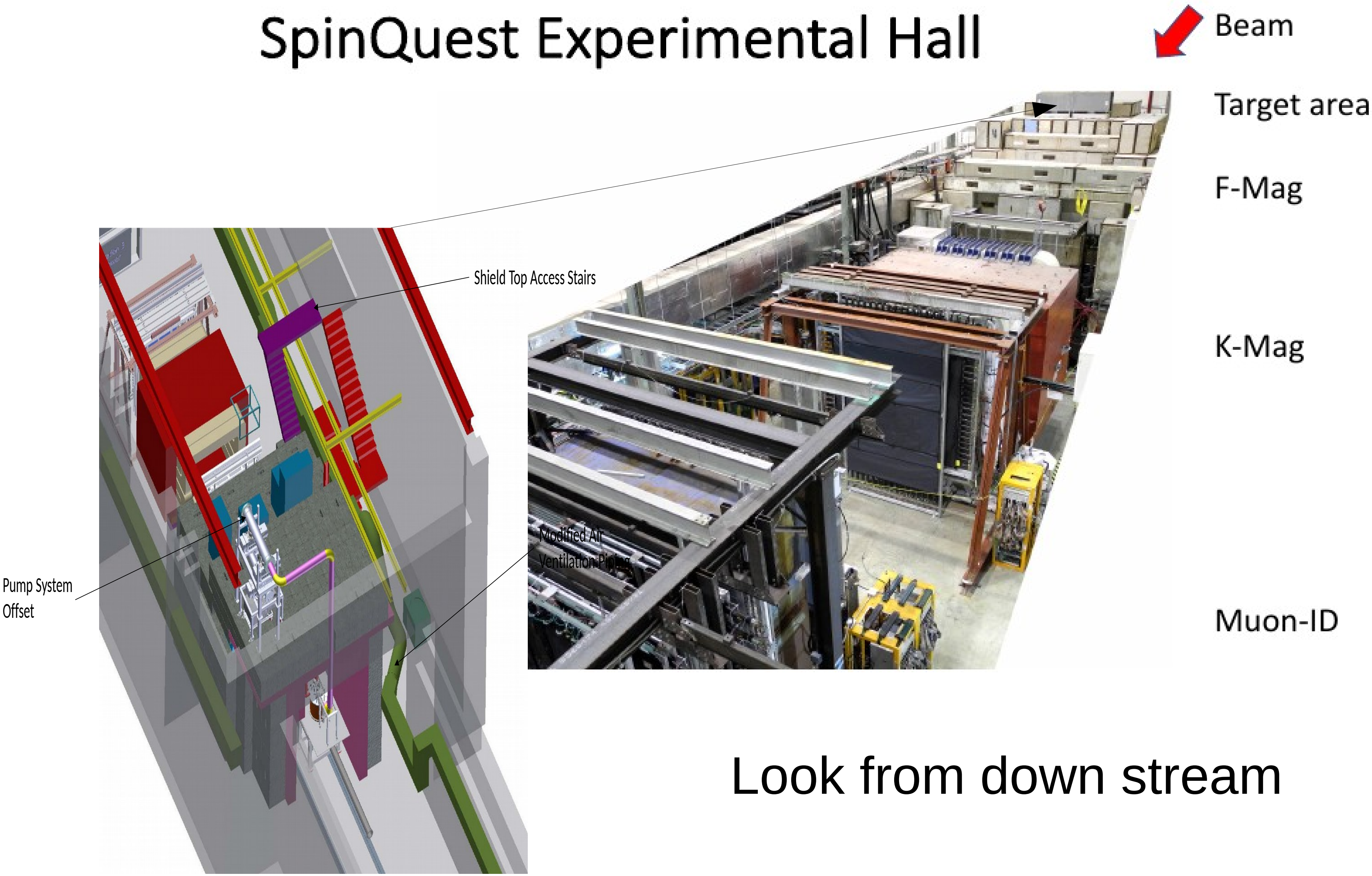


Target Cave: Under Construction

Solid Iron Magnet
(focusing magnet, hadron absorber and beam dump)

Station 2
(Hodoscope array, drift chambers track)

SpinQuest Experimental Hall

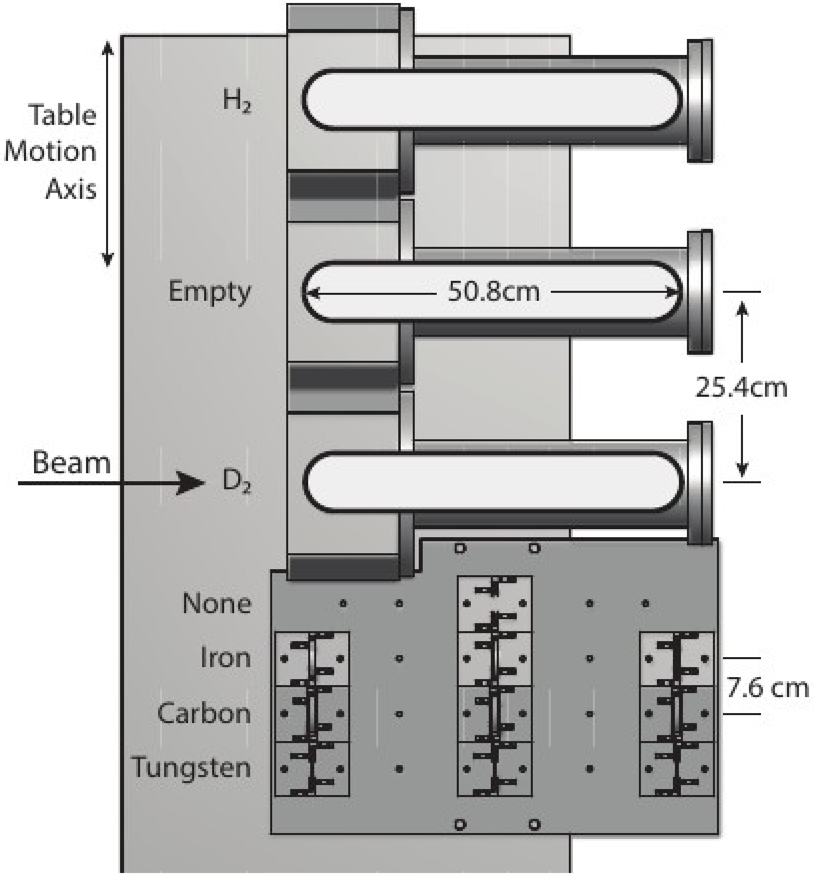


Look from down stream

Target Cave

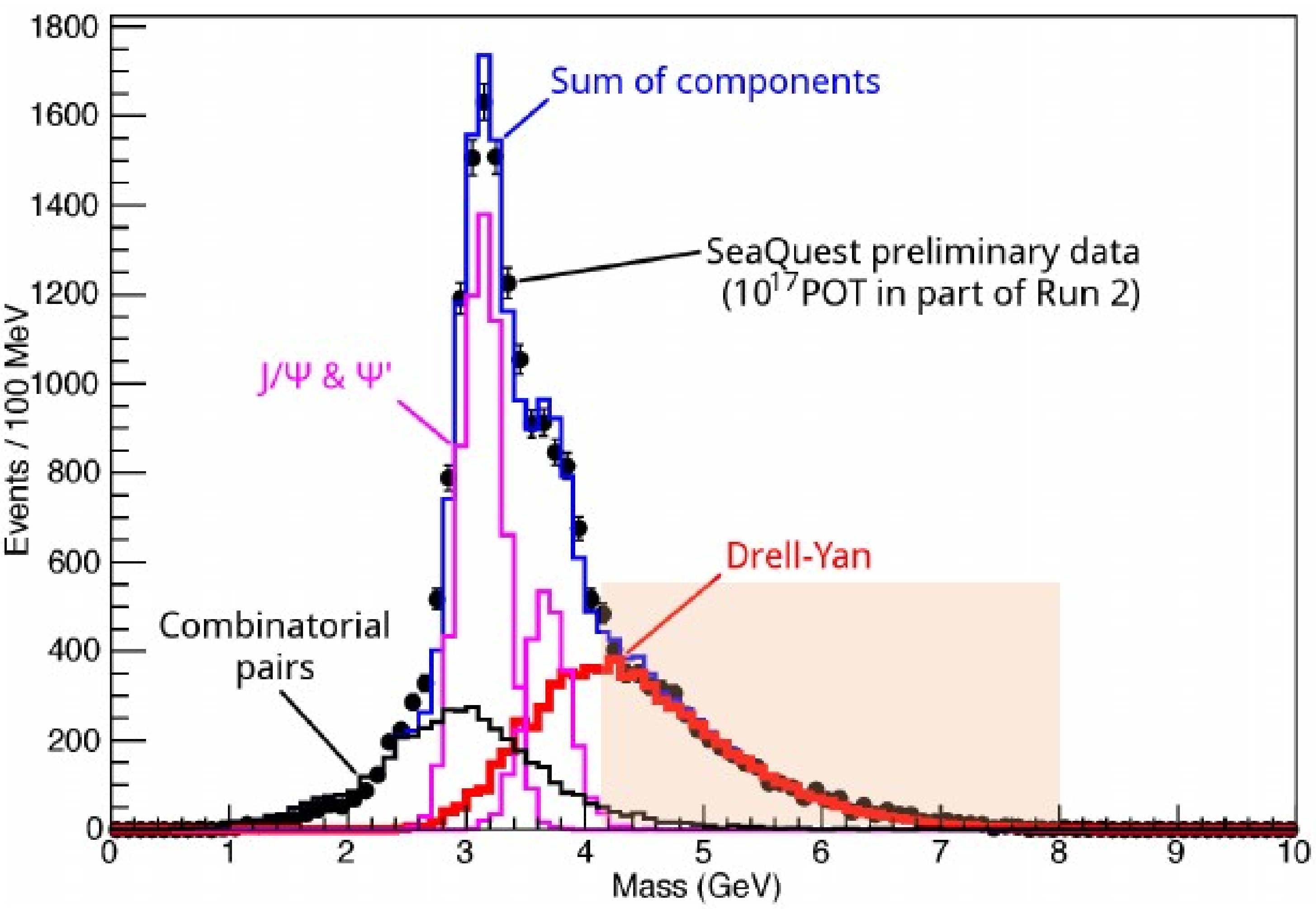
E906 Unpolarized Physics Program

- Thin targets: ~10% interaction length
  - Liquid H/D
  - Solid C, Fe, W
- Physics
  - Sea quark flavor asymmetry, dbar/ubar
  - Quark energy loss in p+A collisions, dE/dx
  - TMD and more …
- Experimental runs – 6 years
  - 2012 – commissioning
  - 2017 – completed



Preliminary Look from SeaQuest

Dimuon Mass from SeaQuest/E906



SeaQuest Status (E906)

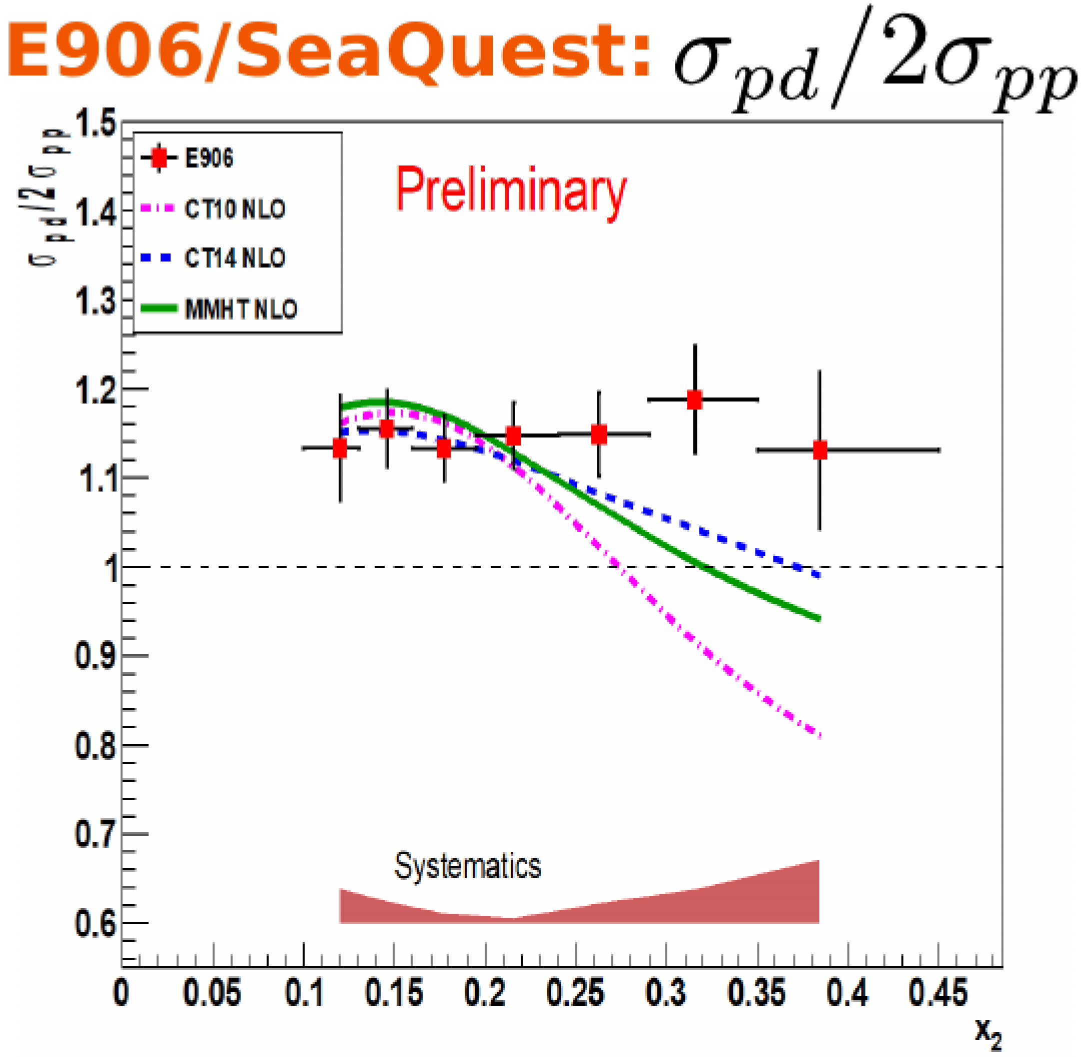
Main Injector beam in a slow spill—difficult to obtain good duty factor

- 1.4×10^{18} of the 5.3×10^{18} approved "live protons"
- 1.7×10^{18} of the 7×10^{18} protons with good duty factor

3.5 x 10^{17} live protons
¼ of recorded protons

Caveats:

- Rate dependence correction has a kinematic dependence
- Leading order extraction
  - NLO code tested
- Correct method -> global fit
- Large x_{beam} dbar/ubar
- . . .

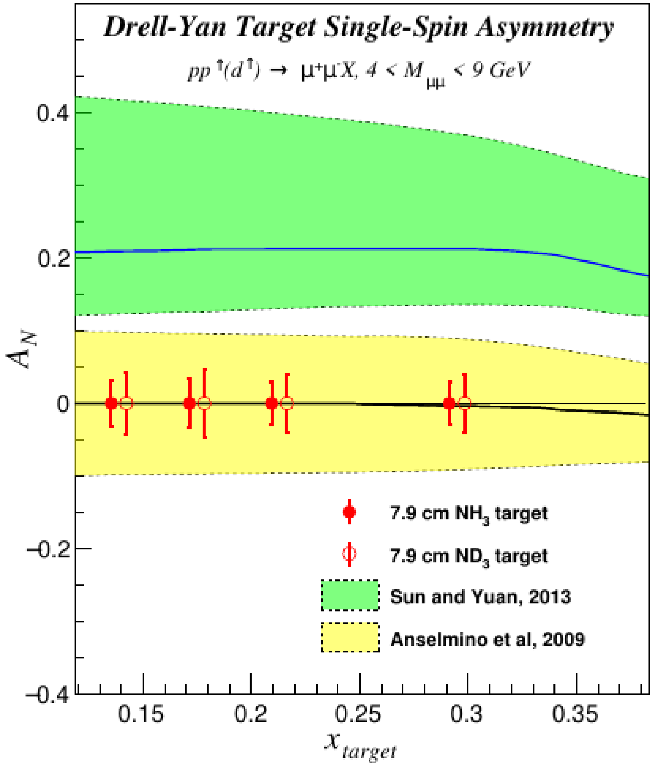


SpinQuest Projections

Projected Drell-Yan Transverse Single Spin Asymmetry

$$A_N^{DY} \propto \frac{u(x_b)\cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b)\cdot \bar{u}(x_t)}$$

$$\delta A = \frac{1}{f}\frac{1}{P}\frac{1}{\sqrt{N^+ + N^-}}$$



x_2 bin	$< x_2 >$	NH_3 $(p^{\uparrow})$		ND_3 $(d^{\uparrow})$		$n^{\uparrow}$
		N	ΔA (%)	N	ΔA (%)	ΔA(%)
0.10 - 0.16	0.139	5.0×10^4	3.2	5.8×10^4	4.3	5.4
0.16 - 0.19	0.175	4.5×10^4	3.3	5.2×10^4	4.6	5.7
0.19 - 0.24	0.213	5.7×10^4	2.9	6.6×10^4	4.1	5.0
0.24 - 0.60	0.295	5.5×10^4	3.0	6.4×10^4	4.1	5.1

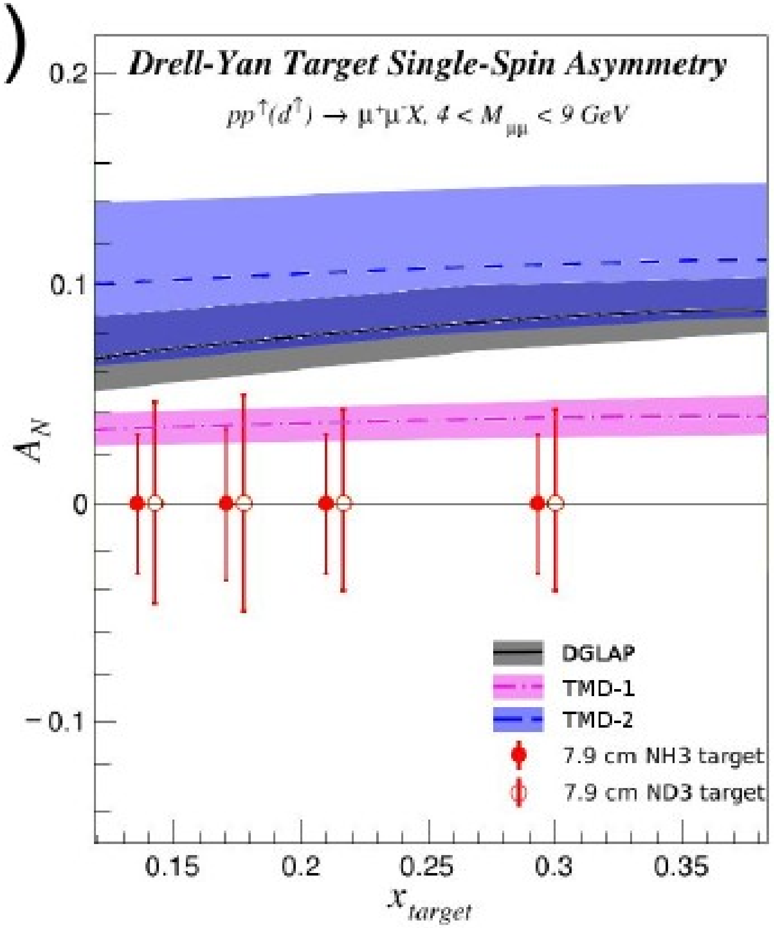
$$f = \frac{N_D\sigma_{D,H}}{N_N\sigma_N + N_D\sigma_D + \Sigma N_A\sigma_A}$$

Others: Nitrogen, Helium, Target cell, Aluminum, Thin beam window, NMR coil, …

Projections of Systematics

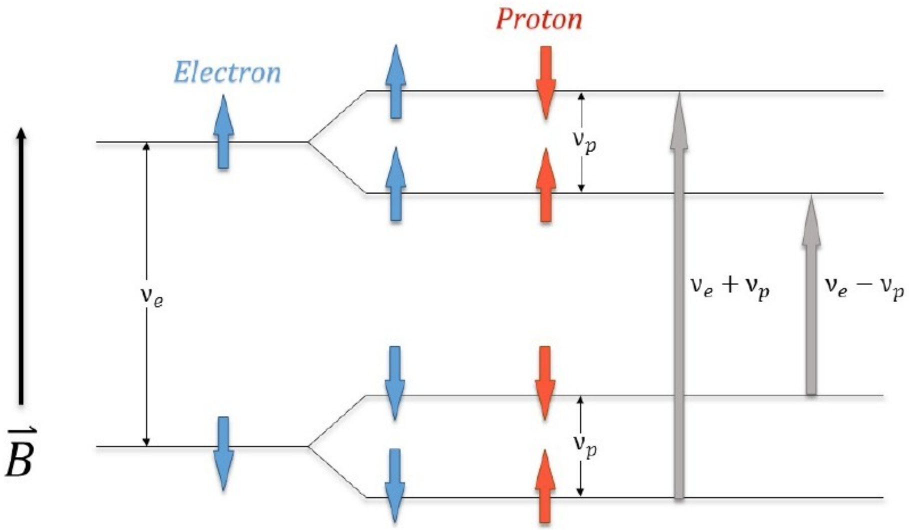
Error estimates (non-exhaustive)

- Statistical: 3%-5% absolute error
  - Dependent on polarization, dilution, events
  - Dependent on run time
- Systematic: Mostly relative error, some absolute. Numbers listed hopeful upper bounds
  - Target: ~6/7% (P/D)
    - Dilution: 3%
    - Packing Fraction: 2%
    - Density: 1%
    - Polarization: 2.5%/4.5% (P/D)
    - Polarization Homogeneity: 2%
    - Uneven Decay: 3%
    - Alignment: small absolute possible
  - Beam: 2.5%
    - Relative Luminosity: 1%
    - Drifts: 2% (Absolute possible)
    - Scraping: 1%
  - Detector: 1% (Some relative, Absolute possible)



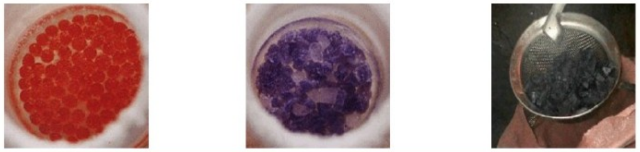
DGLAP: M. Anselmino et al arXiv:1612.06413
TMD-1: M. G. Echevarria et al arXiv:1401.5078
TMD-2: P. Sun and F. Yuan arXiv:1308.5003

Dynamic Nuclear Polarization



Successful material for DNP characterized by three measures:

1. Maximum polarization
2. Dilution factor
3. Resistance to ionizing radiation

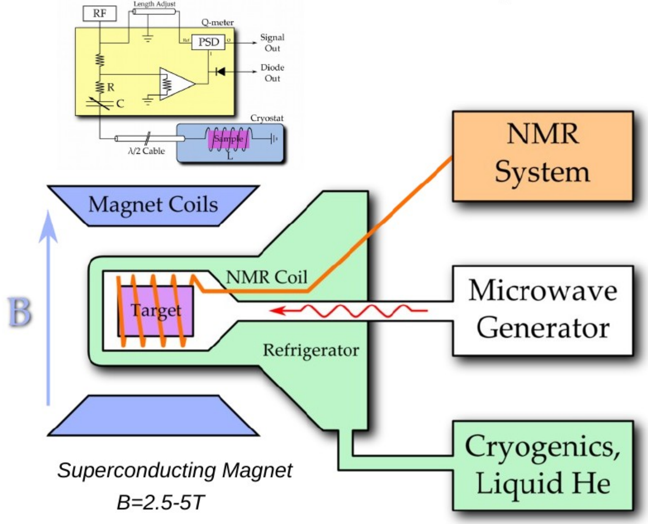


Material	Butanol	Ammonia, NH_3	Lithium Hydride, ^7LiH
Dopant	Chemical	Irradiation	Irradiation
Dil. Factor (%)	13.5	17.6	25.0
Polarization (%)	90-95	90-95	90
Material	D-Butanol	D-Ammonia, ND_3	Lithium Deuteride, ^6LiH
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55
Rad. Resistance	moderate	high	very high
Comments	*Easy to produce and handle*	*Works well at 5T/1K*	*Slow polarization, but long T_1*

- Dynamic Nuclear Polarization
  - Dope target material with paramagnetic centers:
    chemical or irradiation doping to just the right density (10^{19} spins/cm^3)
  - Polarize the centers: Just stick it in a magnetic field
  - Use microwaves to transfer this polarization to nuclei:
    mutual electron-proton spin flips re-arrange the nuclear Zeeman populations to favor one spin state over the other
- Optimize so that DNP is performed at *B/T* conditions where electron t_1 is short (ms) and nuclear t_1 is long (minutes or hours)

$$P_{TE} = \frac{e^{\frac{\mu B}{kT}} - e^{\frac{-\mu B}{kT}}}{e^{\frac{\mu B}{kT}} + e^{\frac{-\mu B}{kT}}} = \tanh\left(\frac{\mu B}{kT}\right)$$

General System



Superconducting Magnet
B=2.5-5T

Polarization Detection

Tuned To Larmor of spin species

Proton (42.6 MHz/T)

Larmor-ESR

50-185 GHz

~140 GHz at 5T

T=0.03-1K

Polarized Target

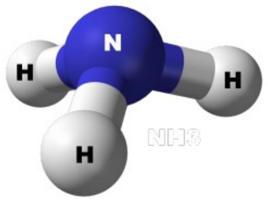
Material	Dens. (g/cm^3)	Length (cm)	Interaction Length (cm)	Dilution Factor	Packing Fraction	$< P_z >$
NH_3	0.867	7.9	91.7	0.176	0.6	80%
ND_3	1.007	7.9	82.9	0.3	0.6	32%

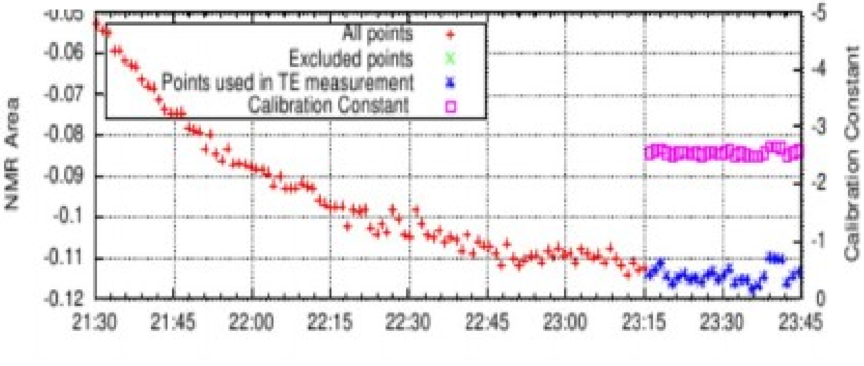
- 3 probes over length of target.
- NMR expected to have 2-3% error for proton 4-5% for deuteron. Deuteron signal order of magnitude smaller.
- If coils moved outside cup, possible increase in uncertainty for deuteron.
- Need time to thermalize. Need 3xt1 (relaxation rate, ~10 min for proton, 1 hour for deuteron). 2-3x more error if rushed.
- Built-in error for neutron polarization from deuteron.

$$\Delta A_N = \frac{1}{f}\frac{1}{P}\frac{1}{\sqrt{N}}$$

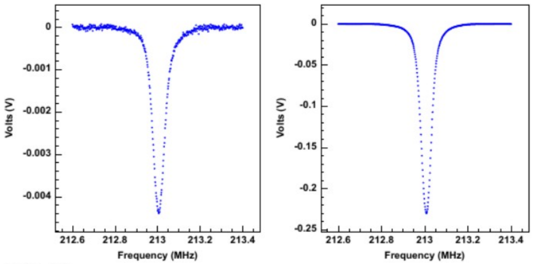
$$f \equiv \frac{N_{p,polarizable}}{N_p + N_n} = \frac{p \times 3}{p \times (7+3) + n \times 7} = \frac{3}{17}$$

$$f \equiv \frac{N_{p,polarizable}\ \sigma_{\pi p}^{DY}}{N_p \sigma_{\pi p}^{DY} + N_n \sigma_{\pi n}^{DY}}$$





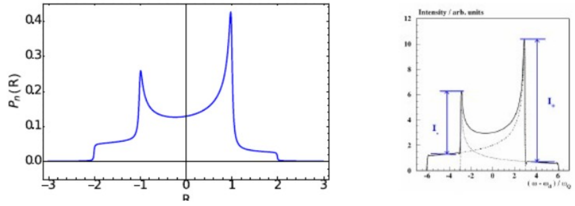
~0.3%



Proton

$$P_{TE} = \tanh\left(\frac{\mu B}{kT}\right)$$

~0.05%



Deuteron

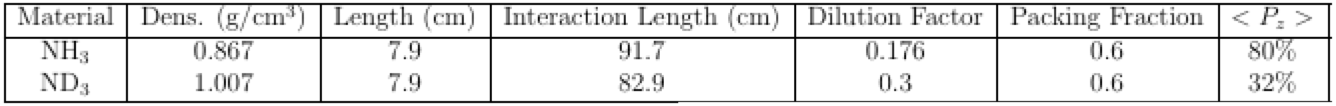
$$P_{TE} = \frac{4 + \tanh\frac{\mu B}{2kT}}{3 + \tanh^2\frac{\mu B}{2kT}}$$

$$P_z = \frac{R^2 - 1}{R^2 + R + 1}$$

Neutron

$$P_n = (1 - 1.5\alpha_D)P_d \approx 0.91 P_d$$

Polarized Target



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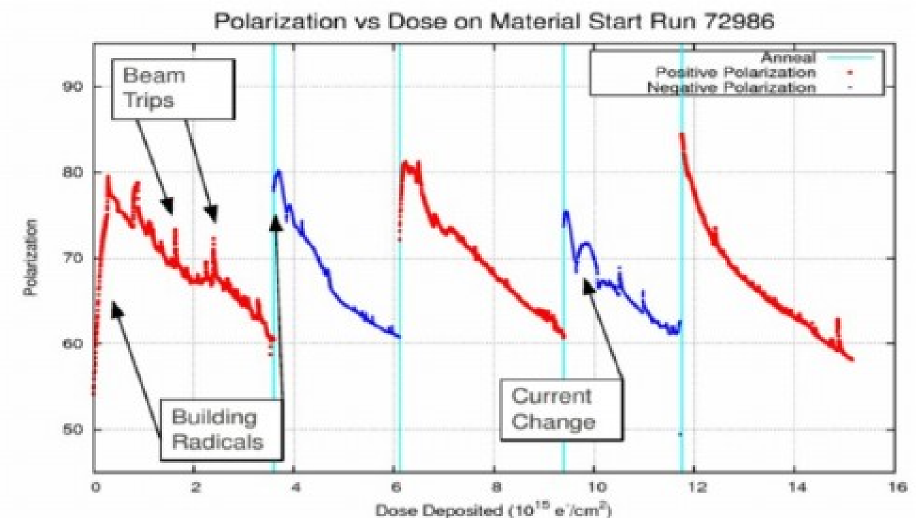
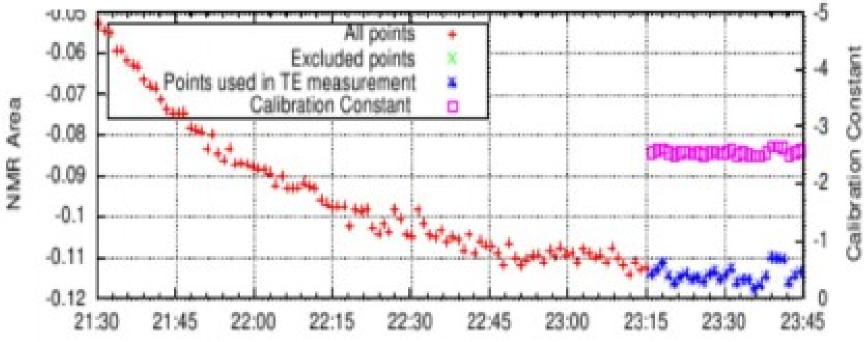
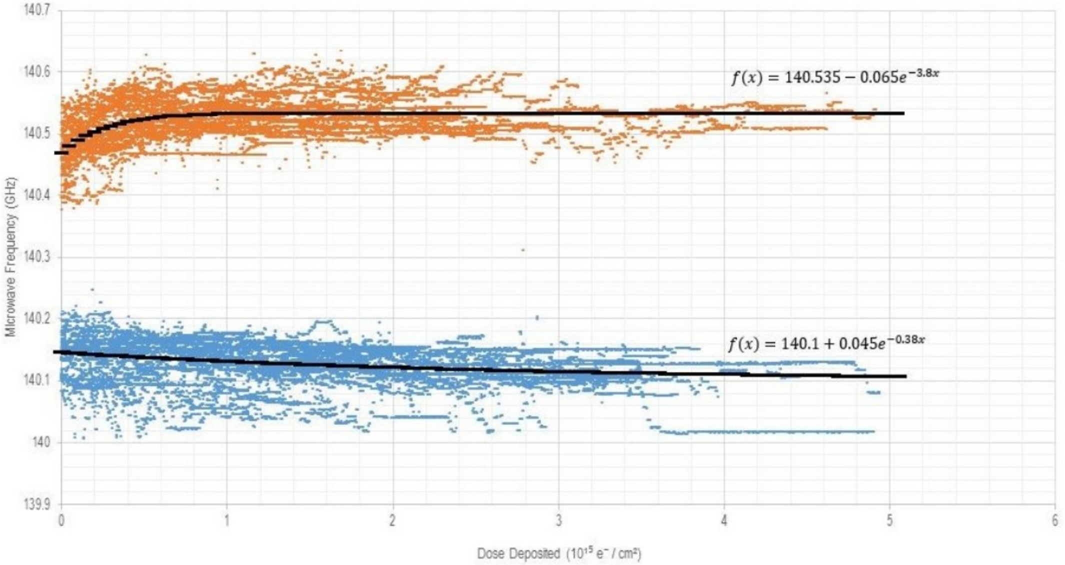
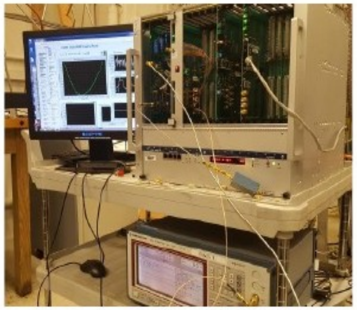






Firsts for Polarized Targets

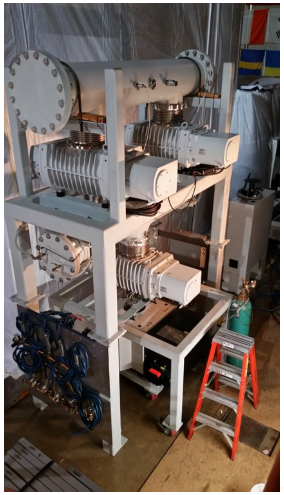
UVA-LANL: Three completely new NMRs



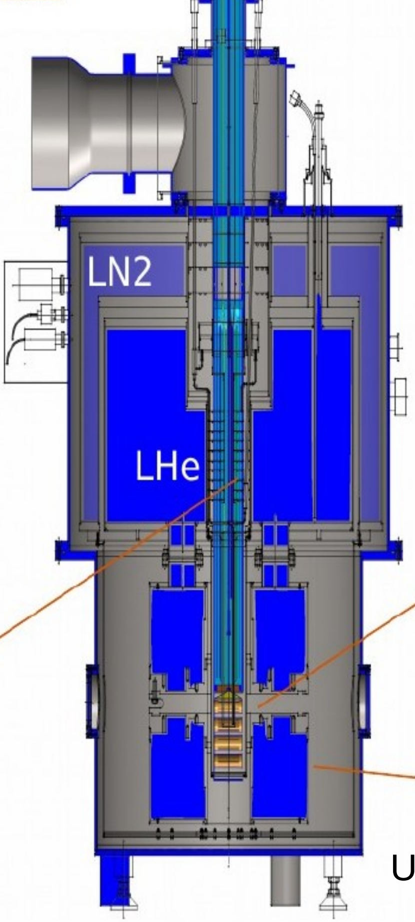
UVA: Design

CPI

UVA: Tune System and Automation



NIST National Institute of Standards and Technology U.S. Department of Commerce



oerlikon

14,000 providing the highest cooling power for 1K system

UVA: Target Insert with longest cell at 8 cm for 5T

UVA: Configure Fridge and Insert, Commission for Optimal running, setup with Actuator

OXFORD INSTRUMENTS

UVA: Commissioning, Slow Controls, Quench Study, Beamline interface,...

Polarized target on the Intensity Frontier

Highest Intensity proton beam on polarized target with $4.4x10^{12}$ over 4.4s spill

- 8 cm long target cell of solid:

  NH_3 and ND_3

- Several watts of cooling power:

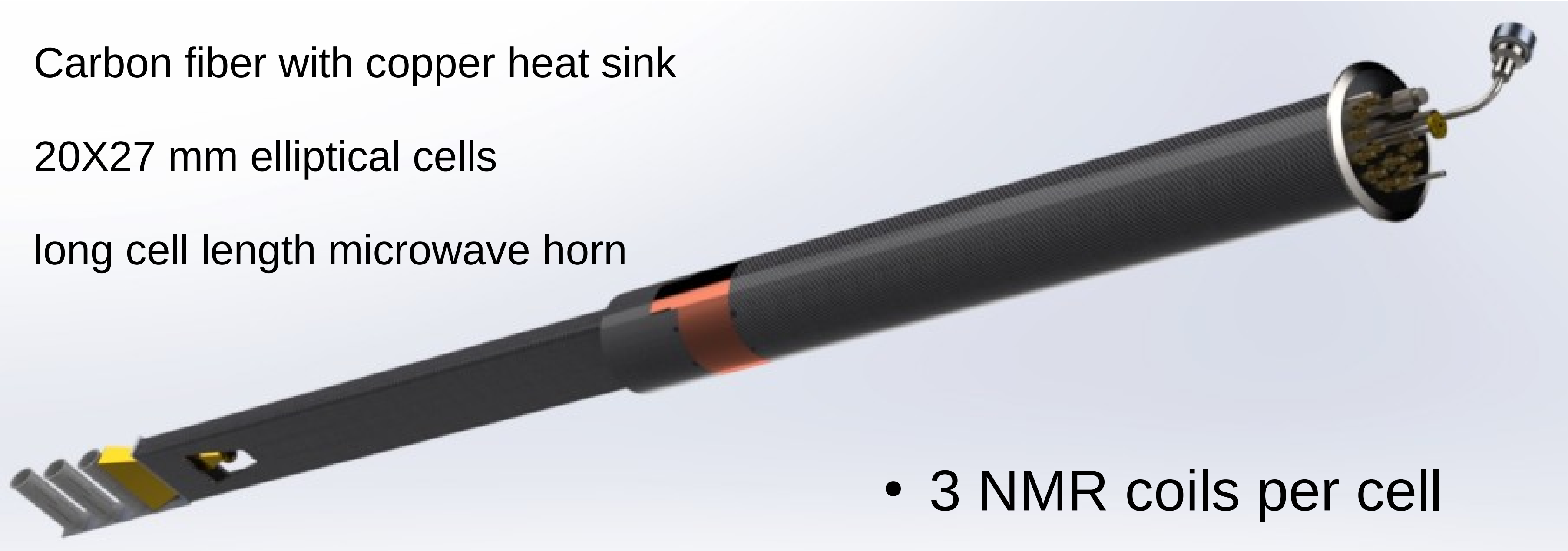
  14,000 m^3 /hour pumping

- 5T vertically pointing SC magnet:

  Pushing critical temp each spill

- Luminosity of around $2X10^{35}$ cm^{-2} s^{-1}

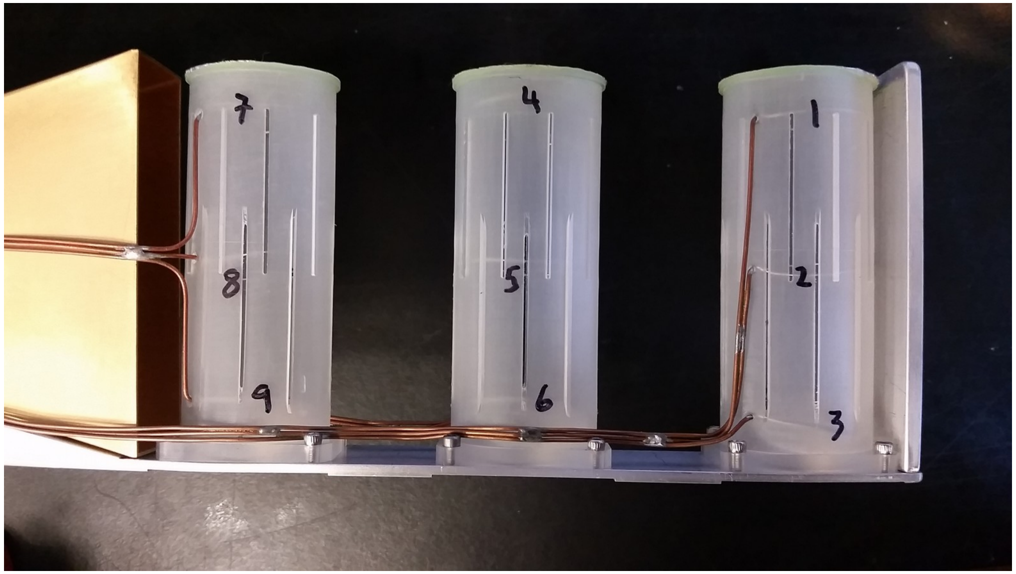
Target Insert



Carbon fiber with copper heat sink

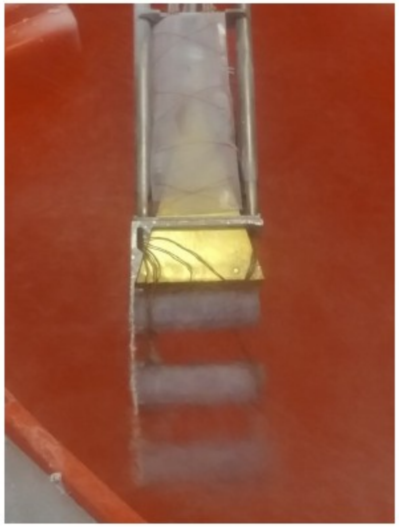
20X27 mm elliptical cells

long cell length microwave horn



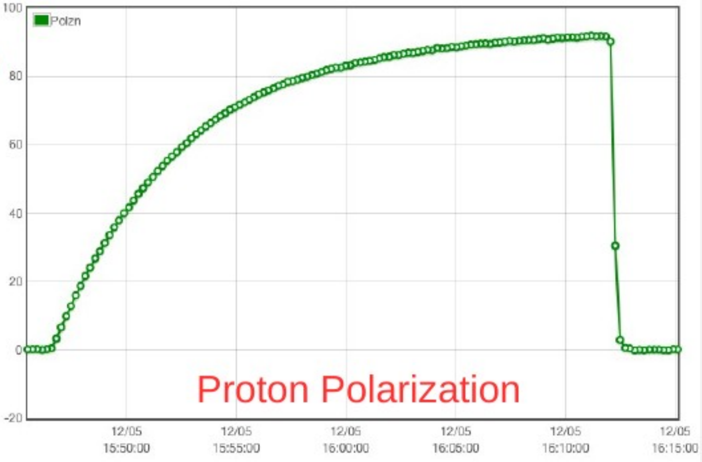
- 3 NMR coils per cell
- 8 cm long target cell of solid:
  NH_3 and ND_3
- Standard Insert has 3 cells
- One centering cell
- Elliptically shaped to match profile

Target Performance



Insert in LN2

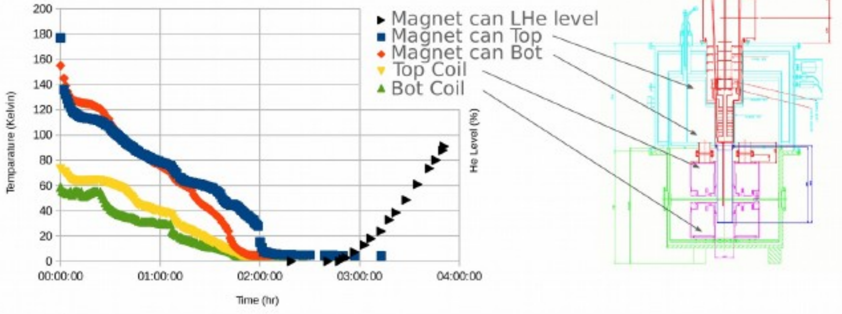
95%



Proton Polarization

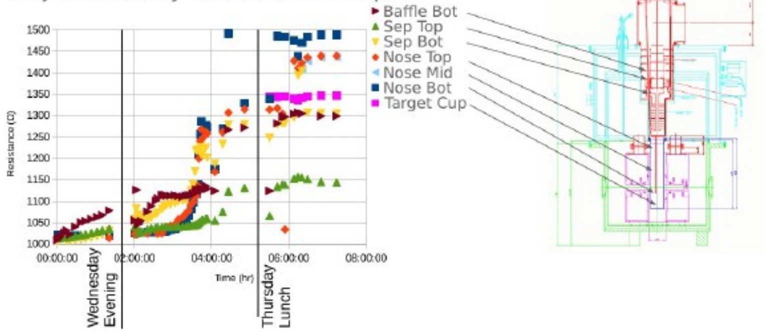
~2.5

~1 hr to to fill magnet can

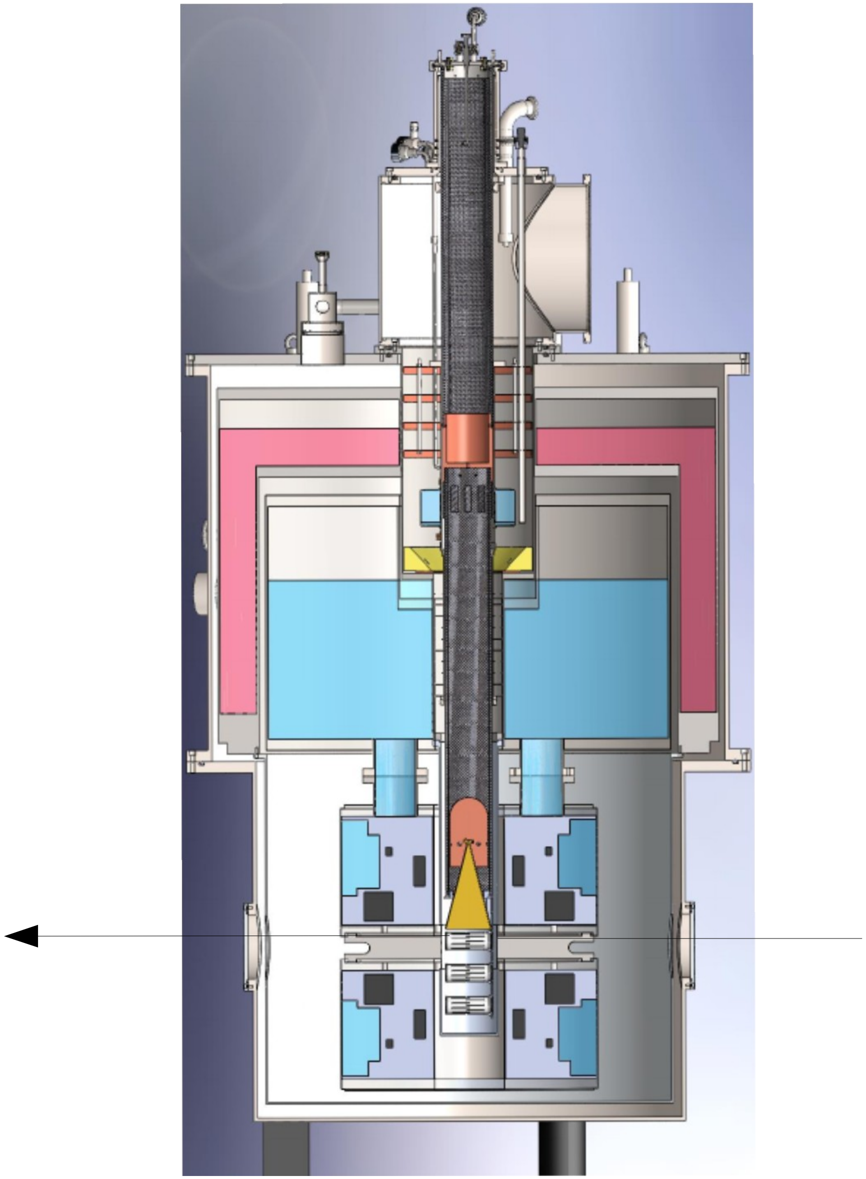


~1hr to fill the nose after a night on standby

very stable, very little attention required

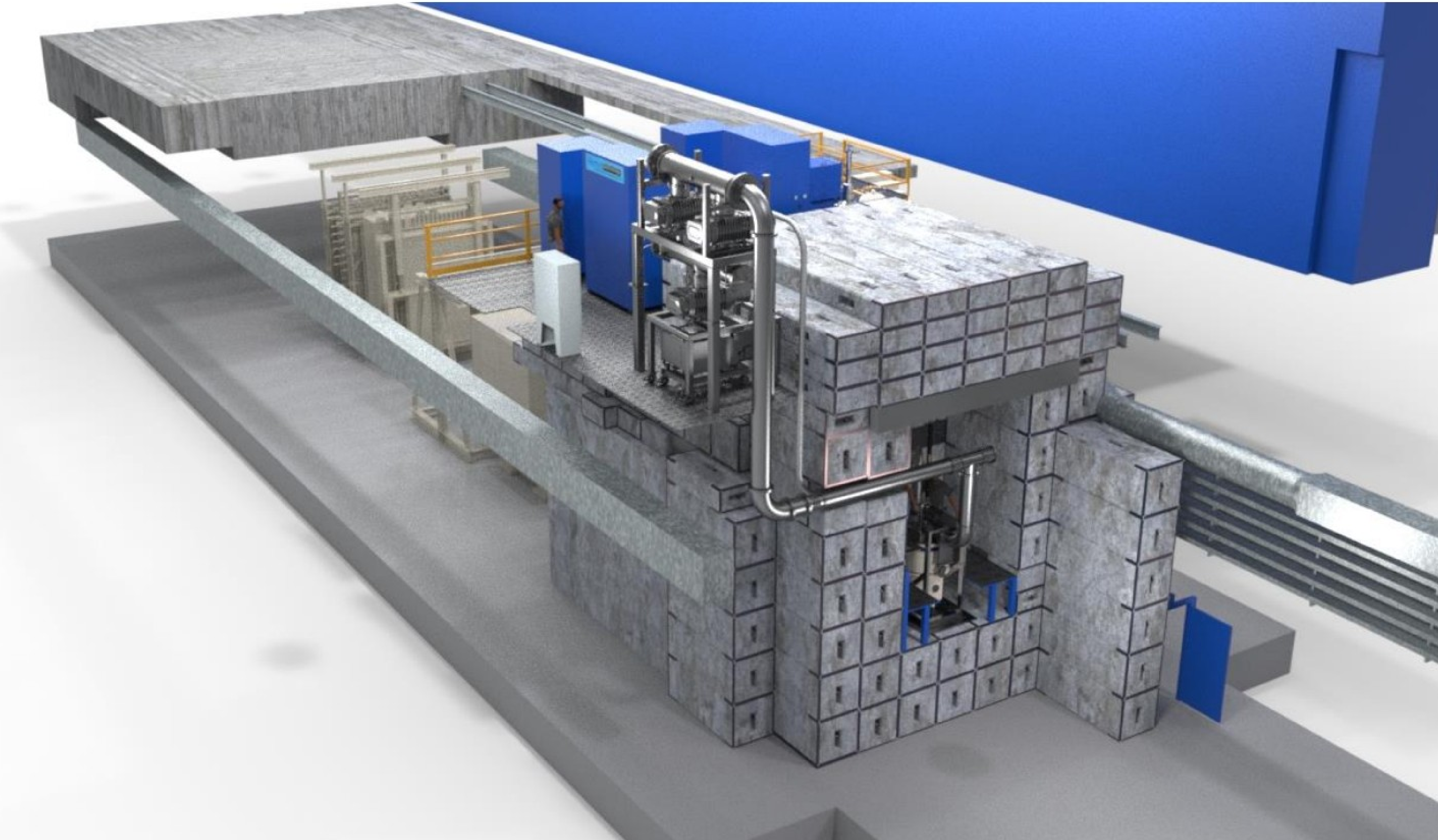


Polarized target on the Intensity Frontier



DNP Refrigerator

Cave Setup in Fermilab NM4

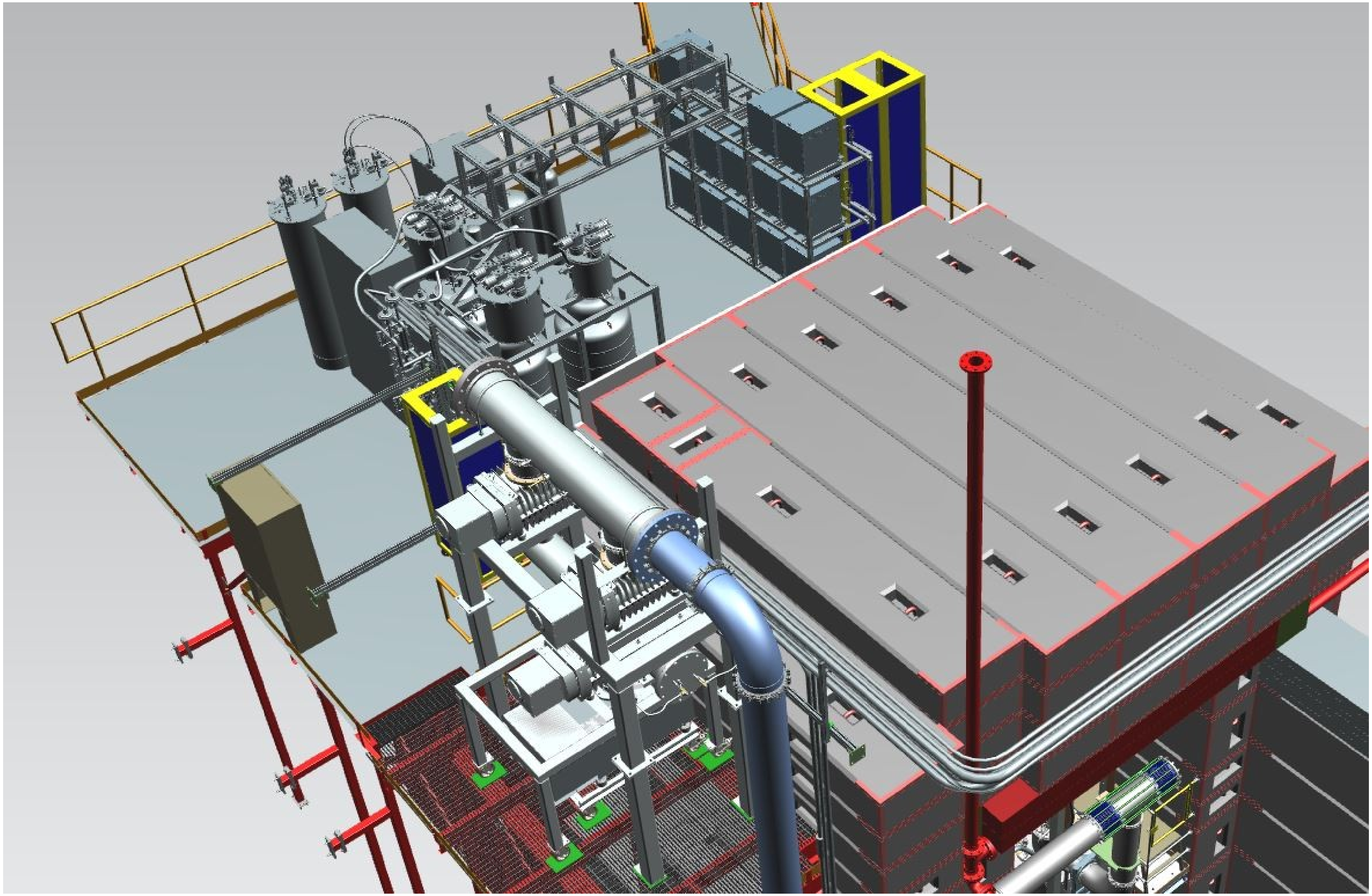


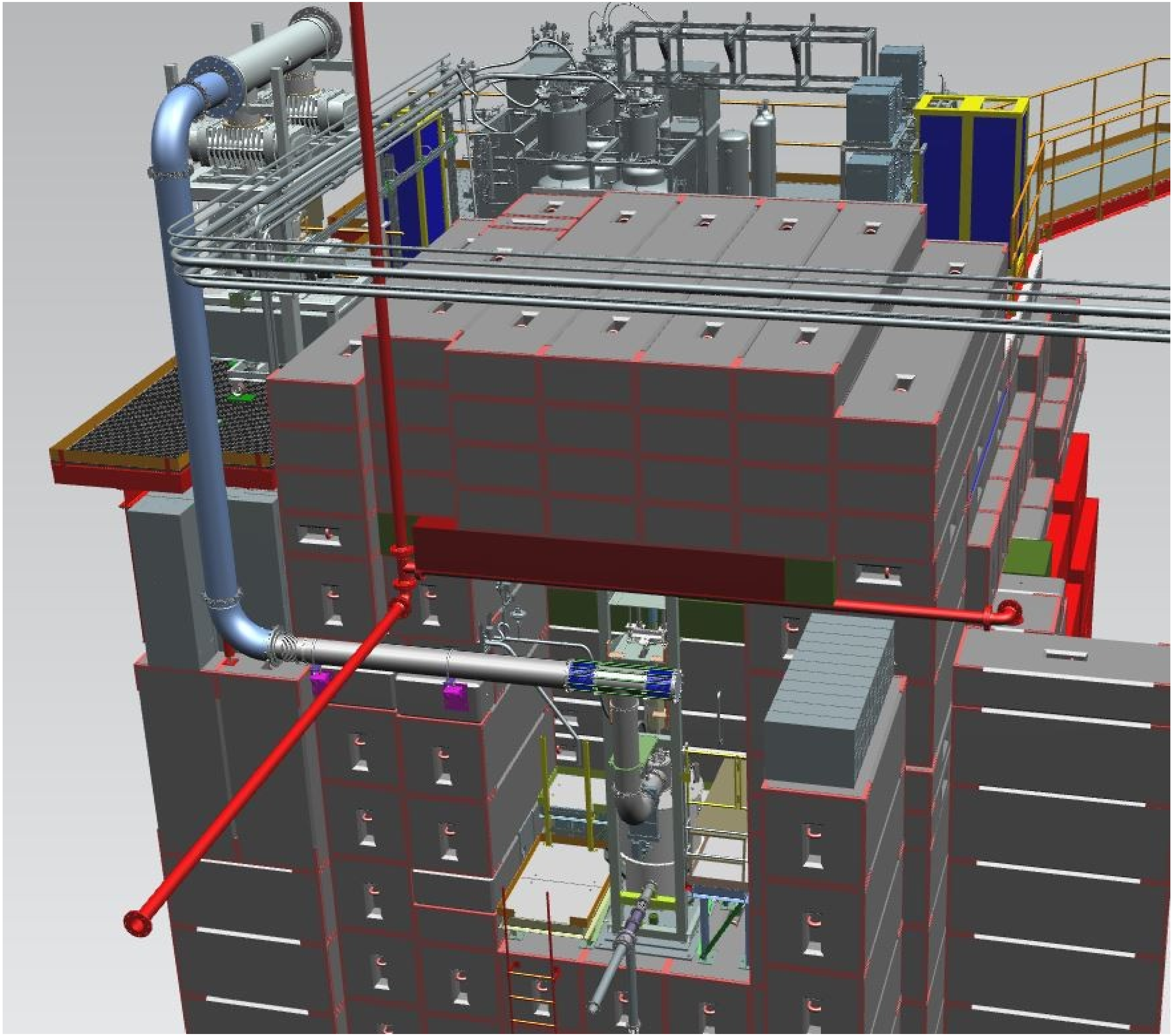
SpinQuest He-Liquefier

Modern He-Gas Recovery, Purification and Liquefier system

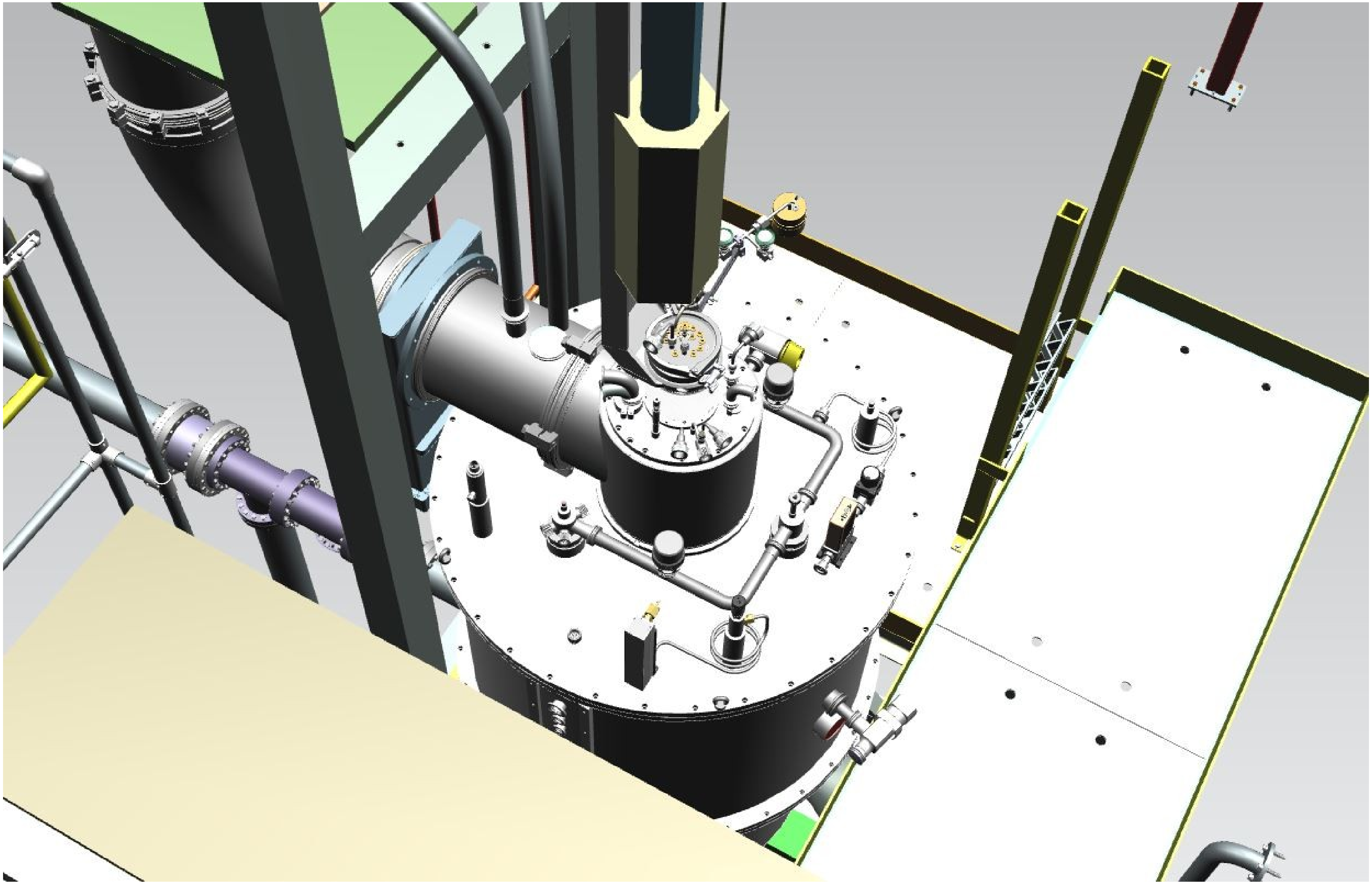
- Model QDHRR100 (2 units: 200 LPD)
- Turn-key/low maintenance system
- 135 LPD required at target for sustainable running
- **200 LPD need before transfer (fill over 60 min.)**
- LANL/UVA purchase for SpinQuest

Cryo-Platform

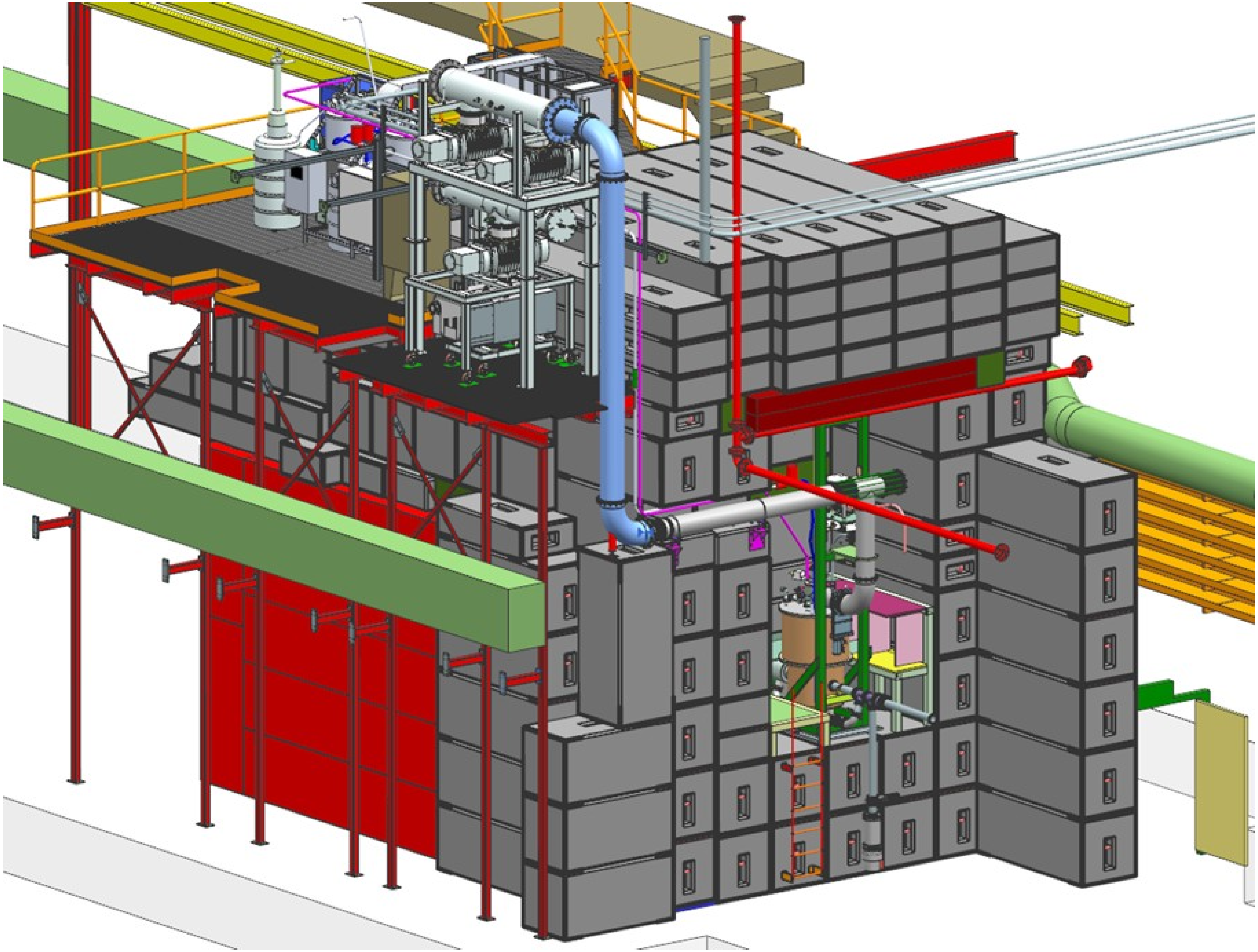




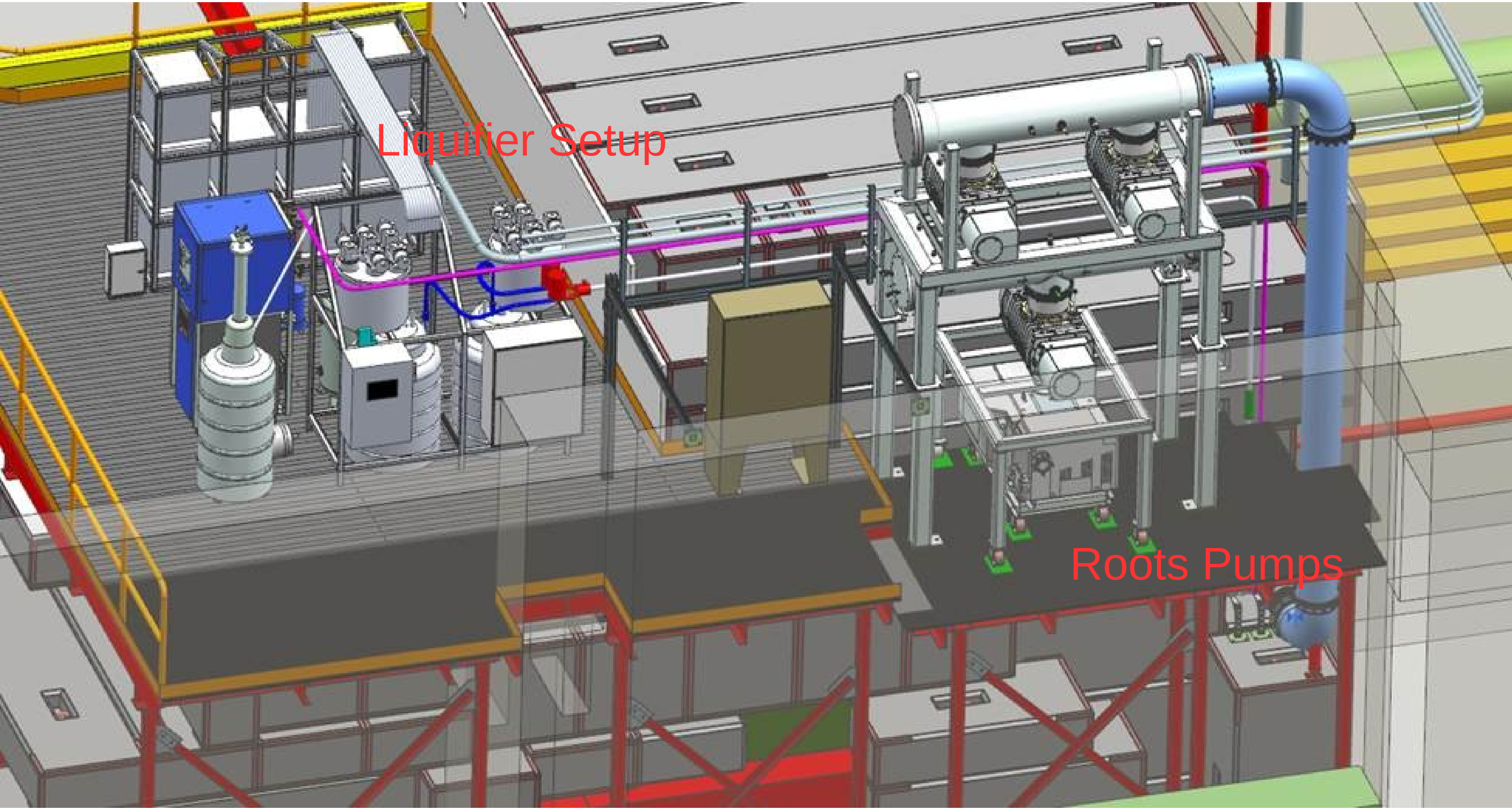
DNP Fridge Access



Target Cave from Upstream



Cryo-platform



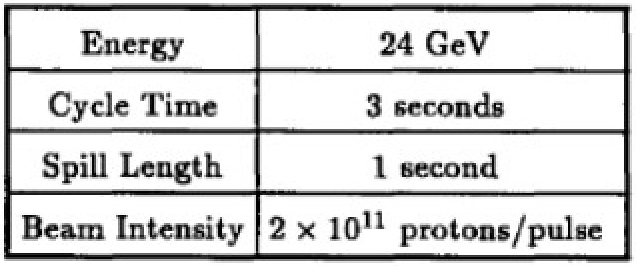
Polarized Target Frontier

SpinQuest

- Cycle Time: Every 55.6 seconds
- Spill Length: 4.4 seconds
- Beam Intensity: $1.0X10^{12}$ protons/sec

VS

BNL:



Energy	24 GeV
Cycle Time	3 seconds
Spill Length	1 second
Beam Intensity	2×10^{11} protons/pulse

Limiting Factors: - Fridge Cooling Power
- Heat load to SC Magnet
- Cycle Time

BNL : $4.0X10^{12}$ protons/min - 4 cm
FNAL : $5\text{-}4.4X10^{12}$ protons/min - 8 cm

Highest Cooling Power DNP Evaporation System:

- Running at 20 SLPM have 1.4 W of cooling power
  - For 4.4 sec receive 0.4 W of heat load from protons
  - Continuous DNP microwave heat load 0.65 W
- Super conducting magnet critical temperature 7.5 K @ 5T
- Cycle gives time to cool

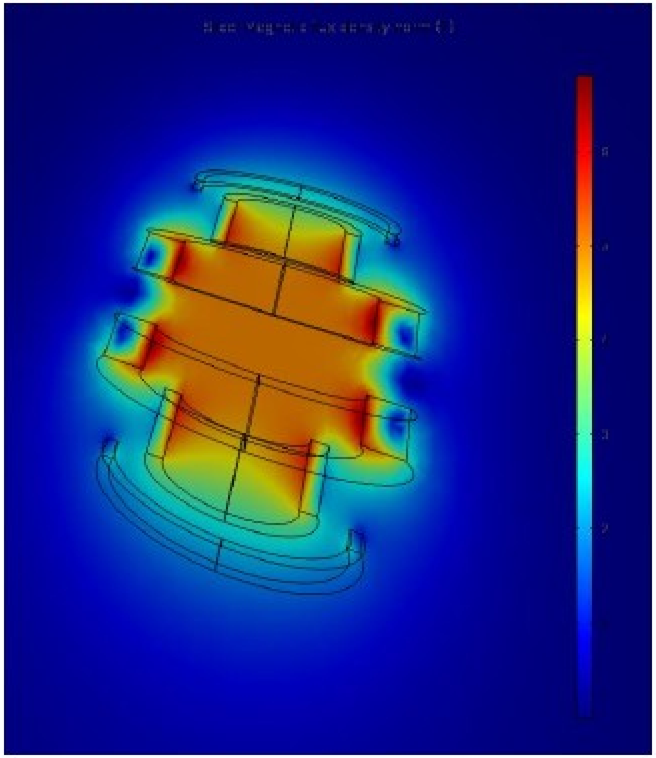
Field Measurement and Map

Measure Homogeneity using NMR and Hall Probe

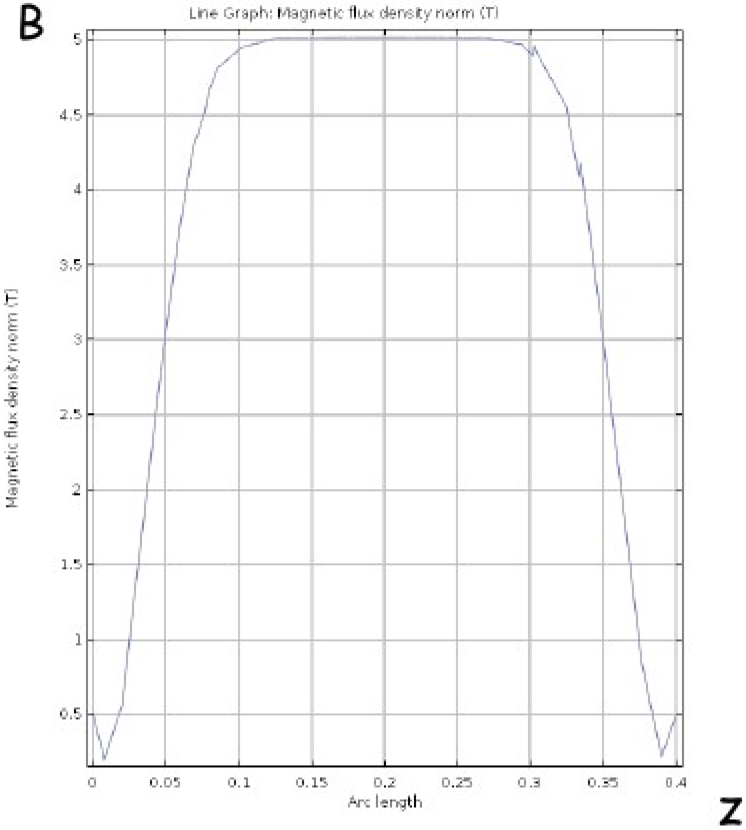
Measure outside fringe field and map to simulated field

Accurate Field Map ✓

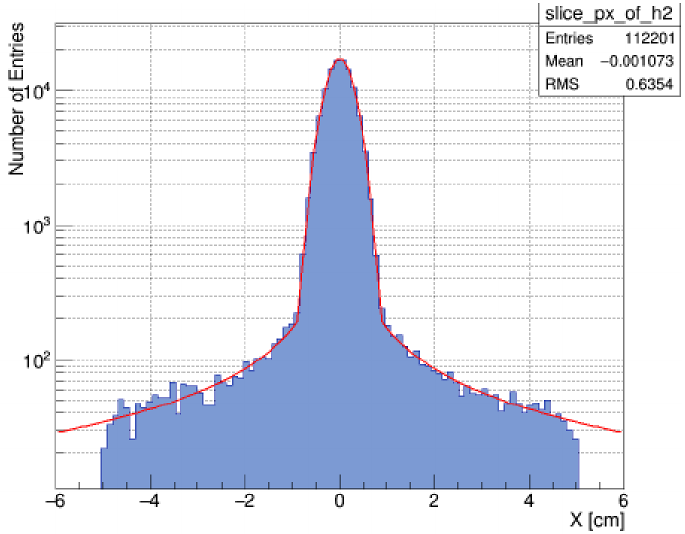
We achieve a high level of homogeneity around the target area & along the beam line:

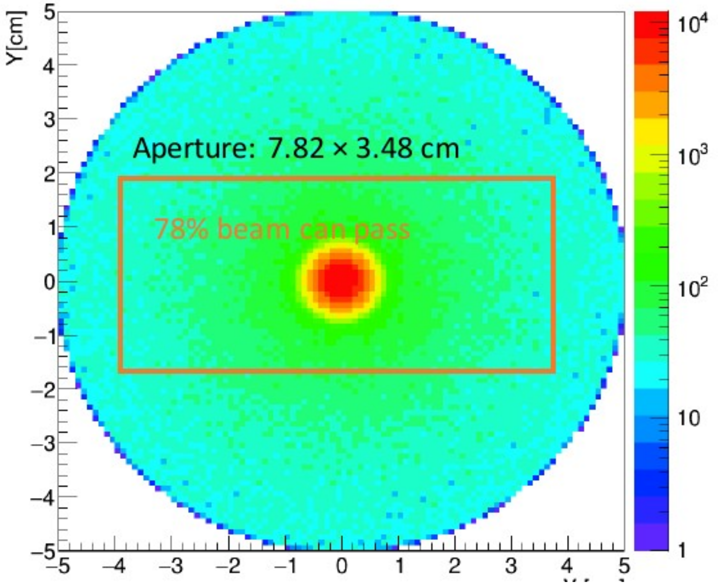


High level of homogeneity in the target area



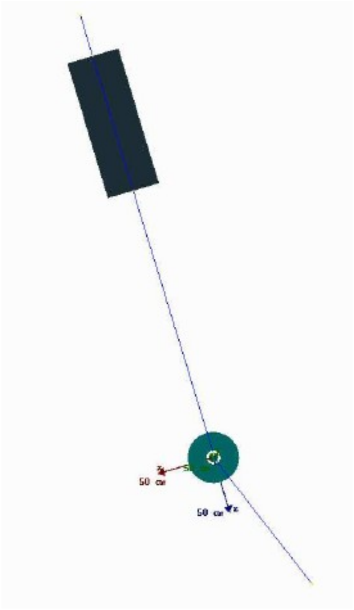
Geant → COMSOL

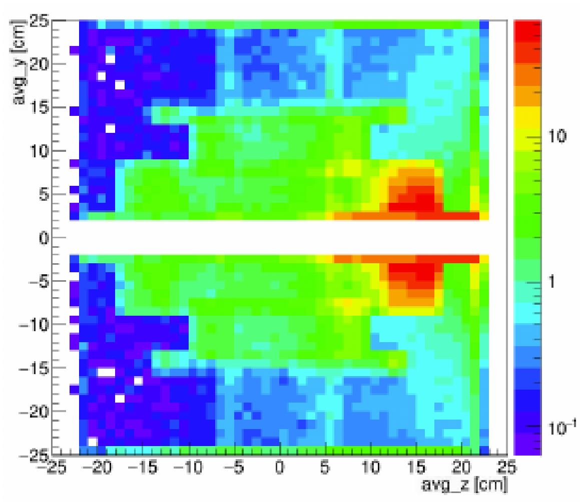


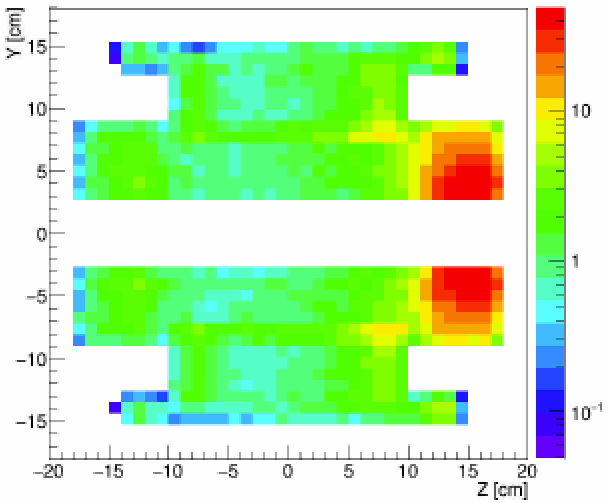


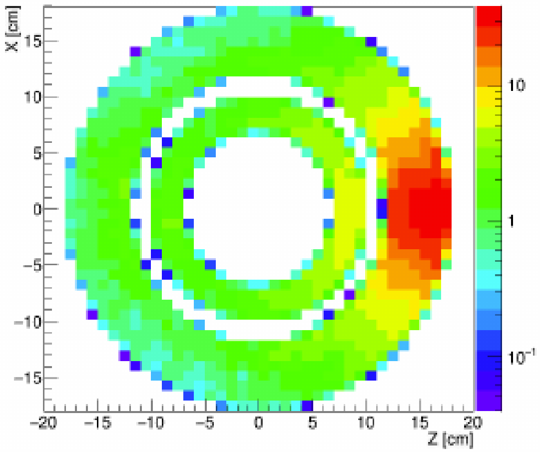
Aperture: 7.82 × 3.48 cm

78% beam can pass

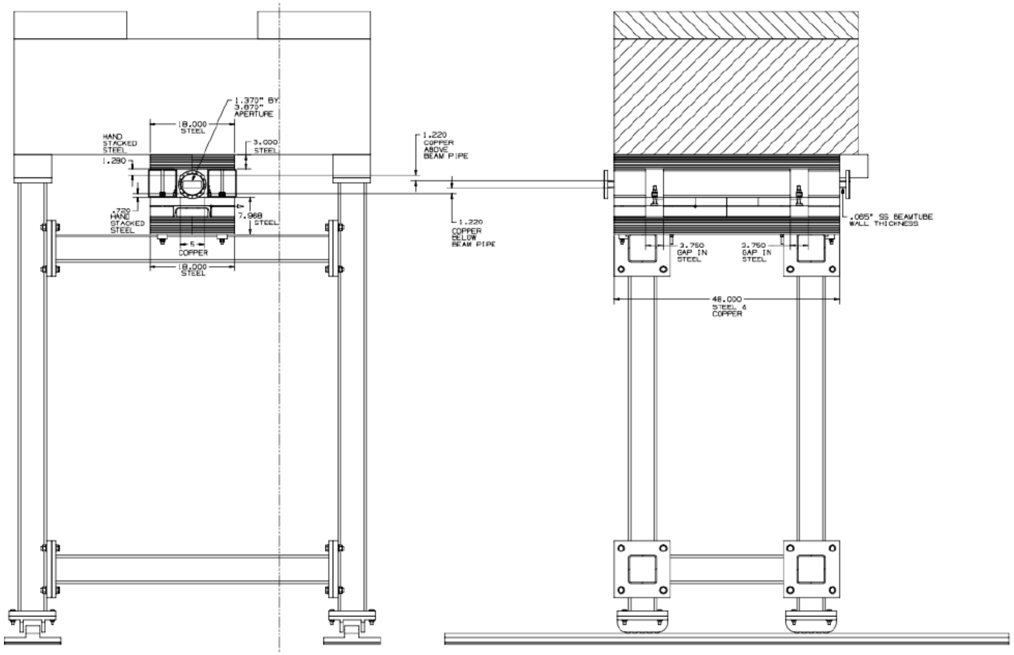


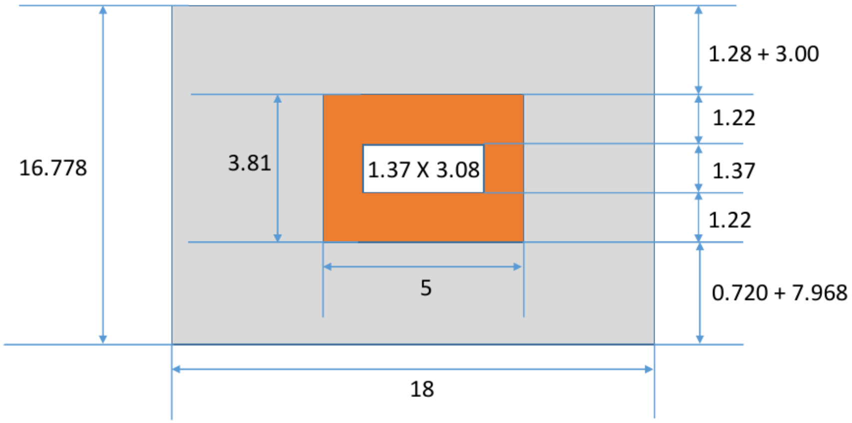


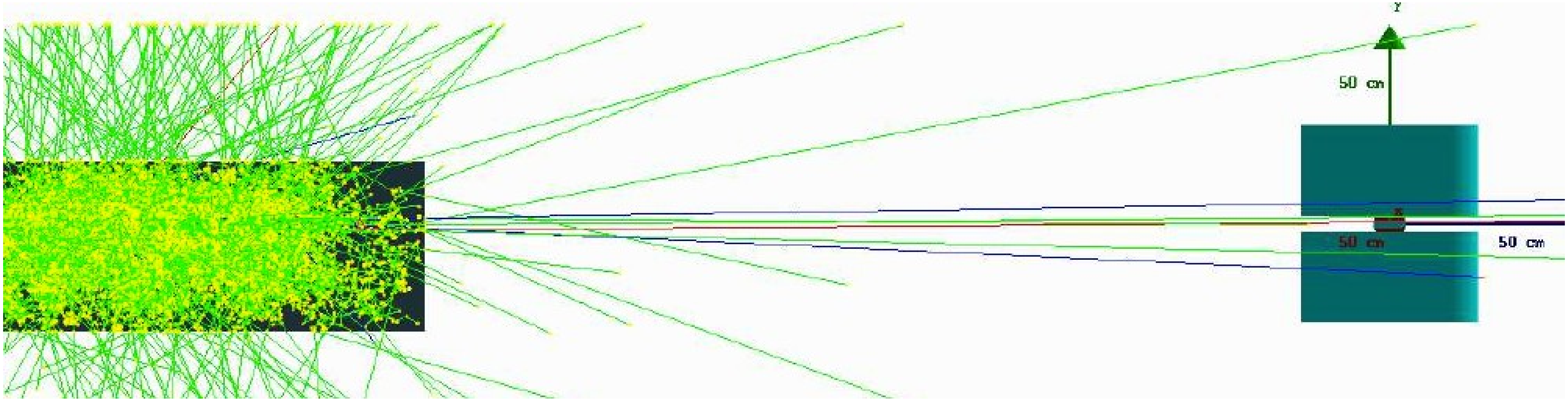




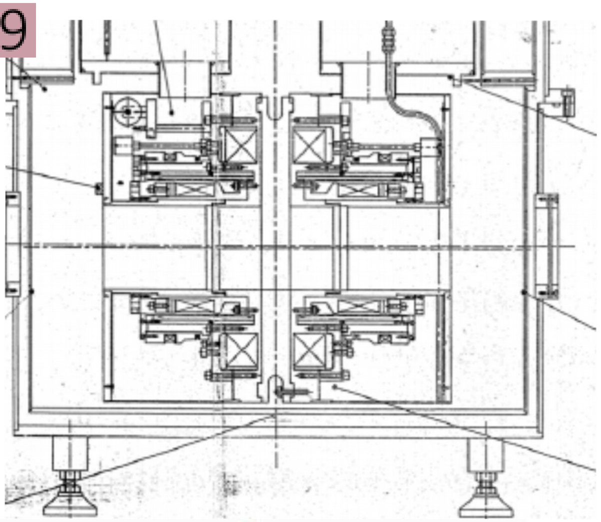
SpinQuest Beam Collimator



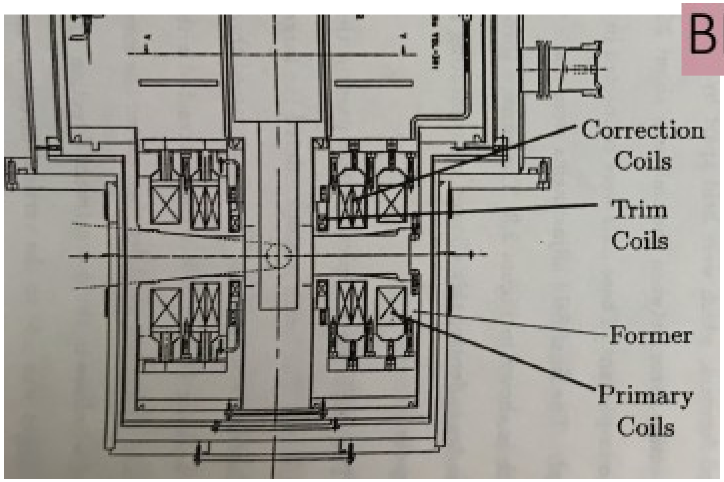




E1039

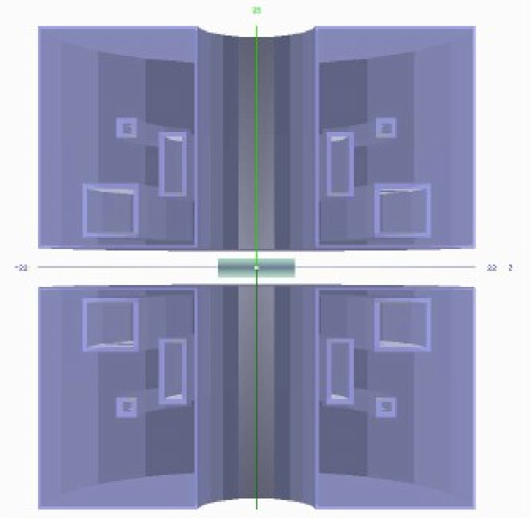


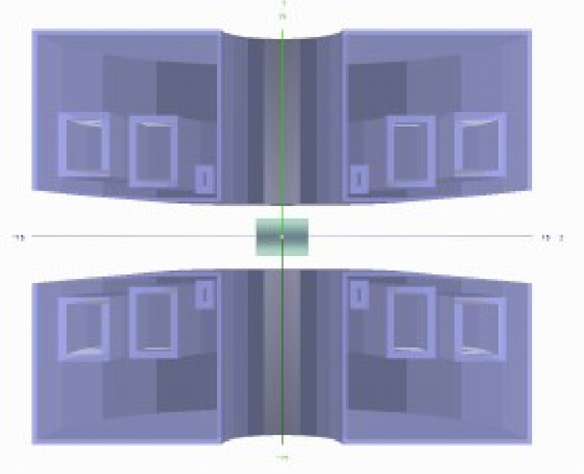
BNL target



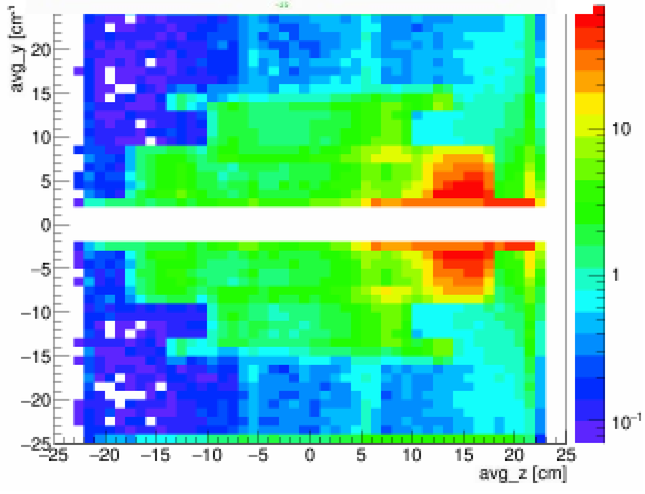
Solidworks → Geat4

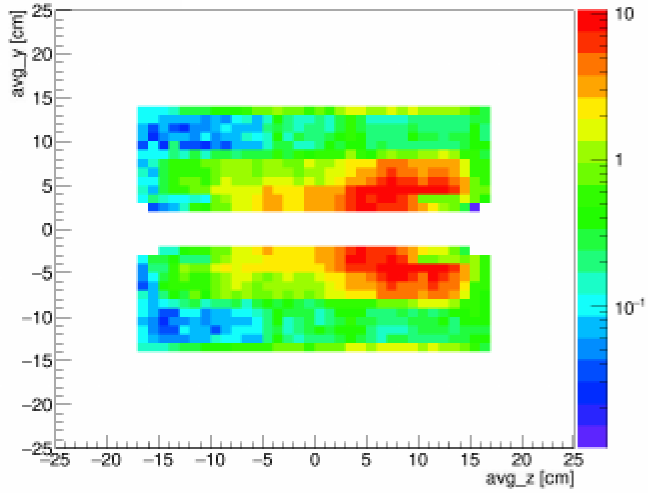
Based on drawings and measurements





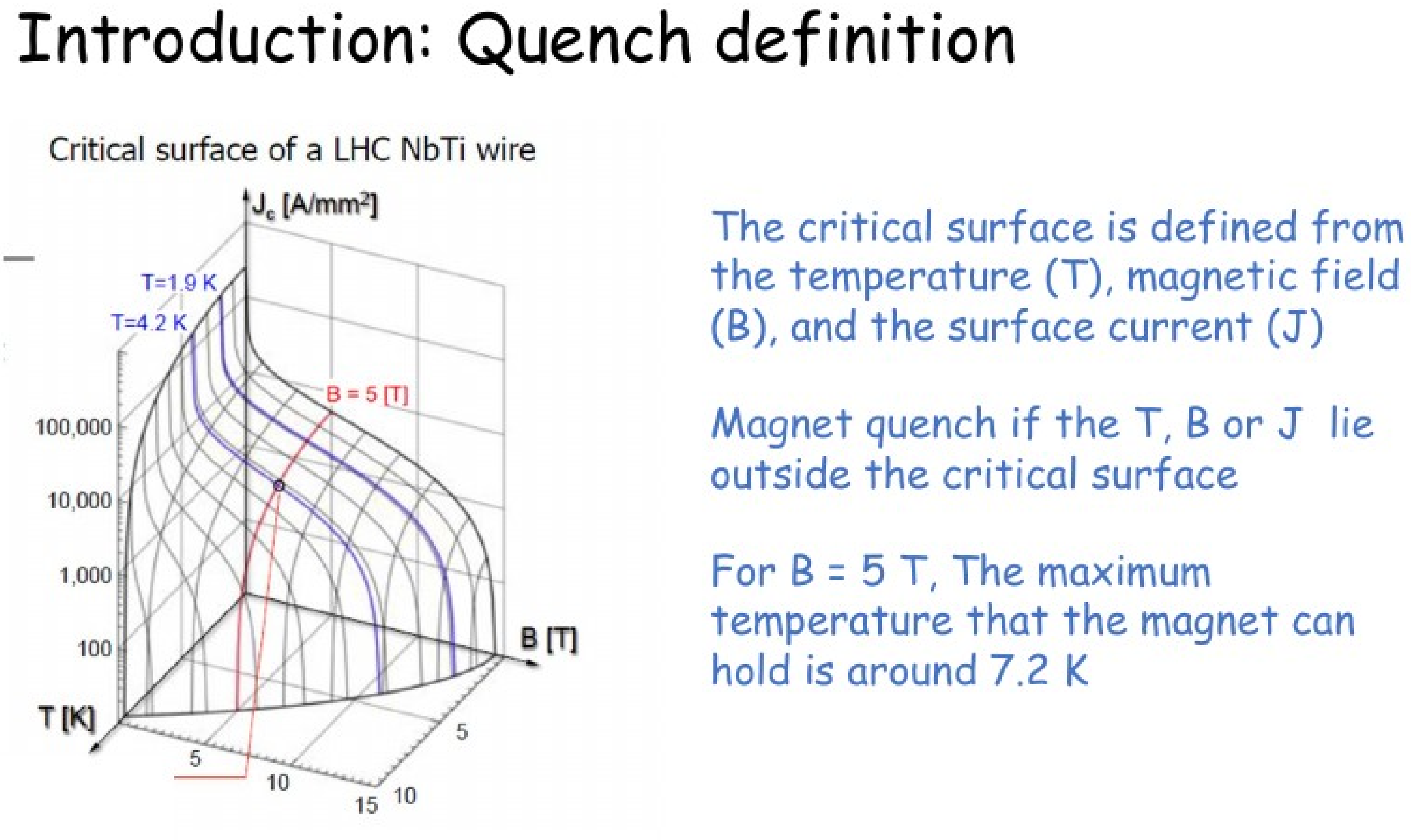
Simulation contain SS former, LHe, vessels, target cell, target material





Then look at energy deposition in the SC coils

Quench Threshold



Introduction: Quench definition

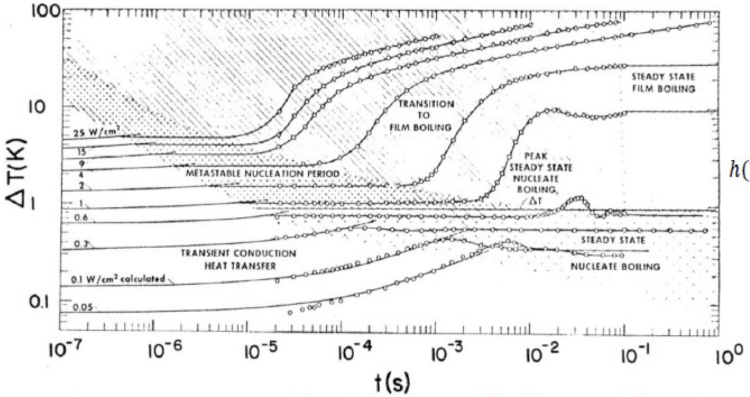
The critical surface is defined from the temperature (T), magnetic field (B), and the surface current (J)

Magnet quench if the T, B or J lie outside the critical surface

For B = 5 T, The maximum temperature that the magnet can hold is around 7.2 K

Physics of the Quench

Approximation Strategy

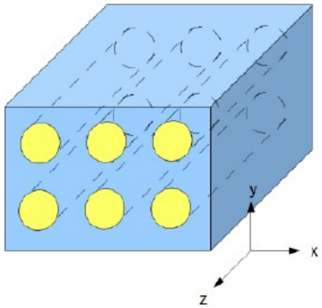


Various regimes of the heat transfer from solid to LHe

First, Steady state Film boiling regime is applied

$$h(T_s, T_{\mathrm{He}}) = a_{\mathrm{FB\text{-}I}}(T_s - T_{\mathrm{He}}).$$

Second, we consider the superconducting magnet as a composite material with the effective thermal parameter



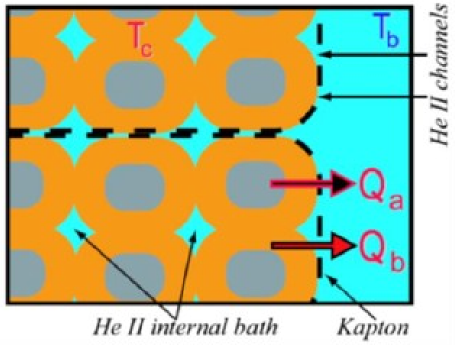
Rayleigh's model consist of parallel cylinders embedded in a continuous matrix

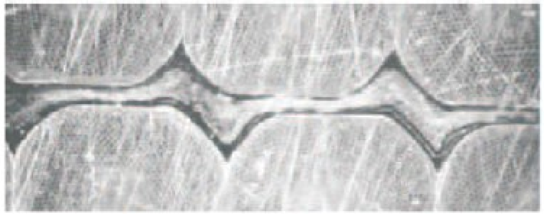
Rayleigh's formula

$$\frac{k_{eff}}{k_m} = 1 + \frac{3\phi}{\left(\frac{k_1 - 2k_m}{k_1 - k_m}\right) - \phi + 1.569\left(\frac{k_1 - k_m}{3k_1 - 4k_m}\right)\phi^{\frac{10}{3}} + \ldots}$$

Third, we parameterize some of the unknown properties by the effective surfaces that are in direct contact with the LHe:

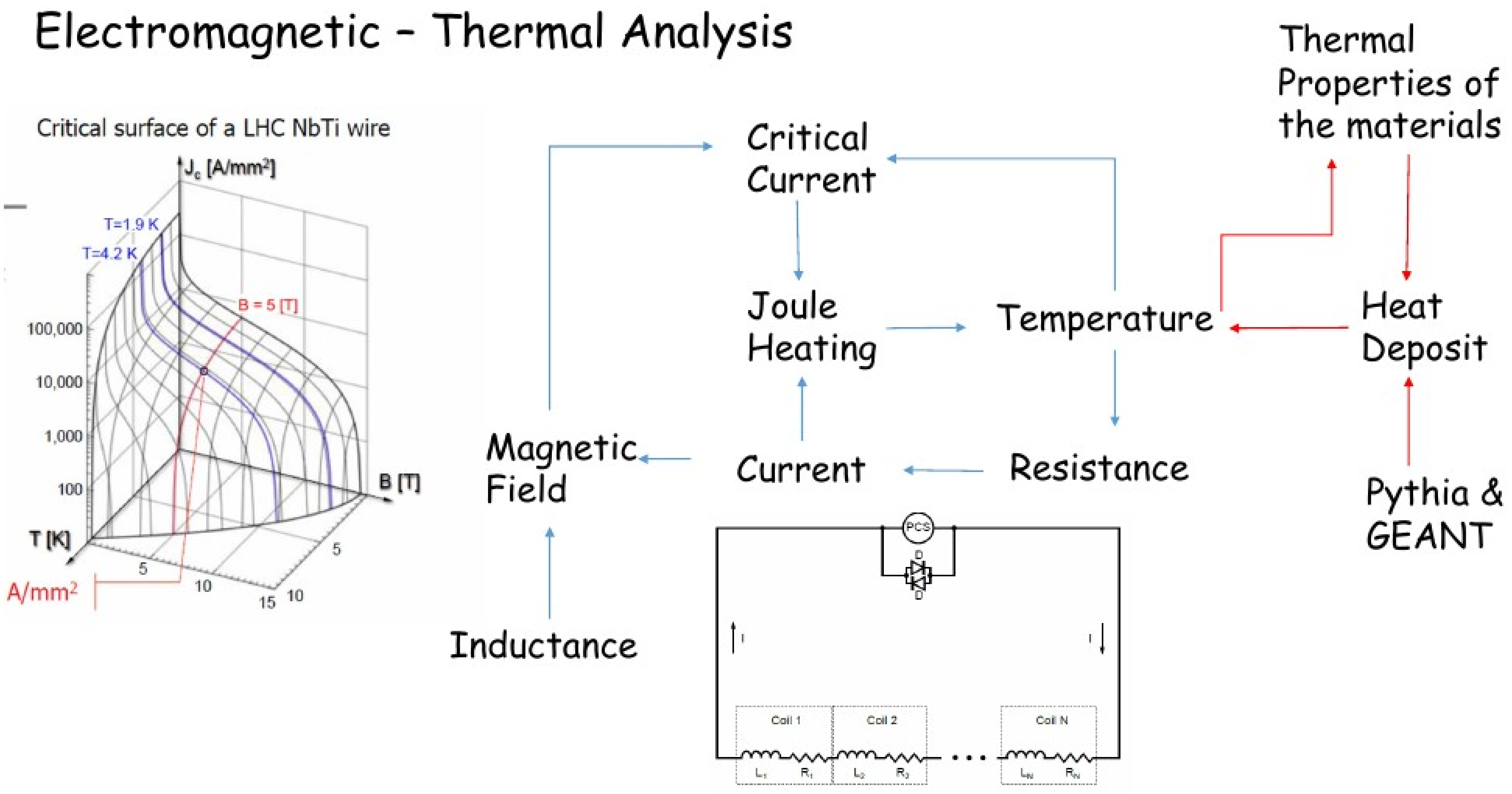
- Perimeter of the He void
- Insulation
- Former





Microscopic view of the cable

SpinQuest Target Manget Analysis



Electromagnetic – Thermal Analysis

Critical Current

Joule Heating

Temperature

Heat Deposit

Thermal Properties of the materials

Pythia & GEANT

Resistance

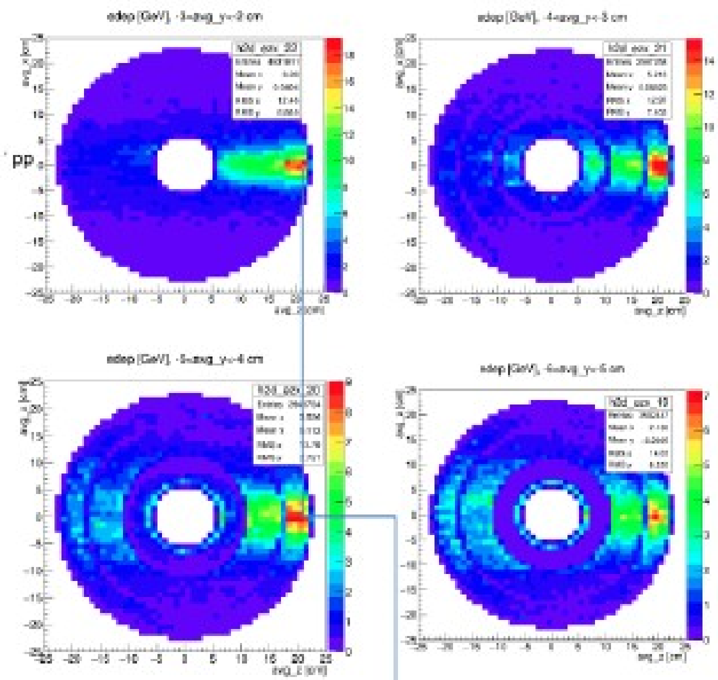
Current

Magnetic Field

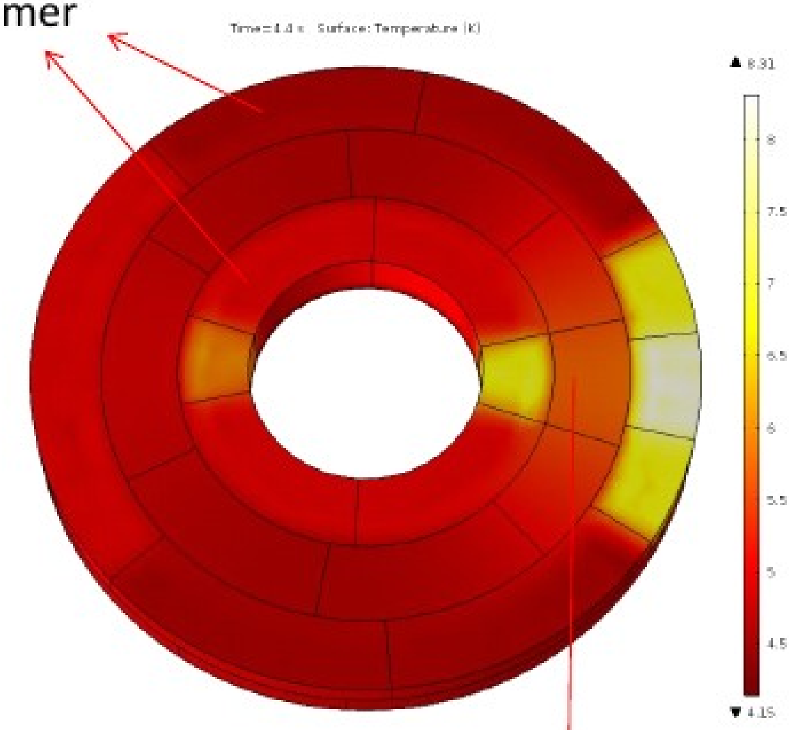
Inductance

Determine Heat load

What we have currently



Former



Simulation result

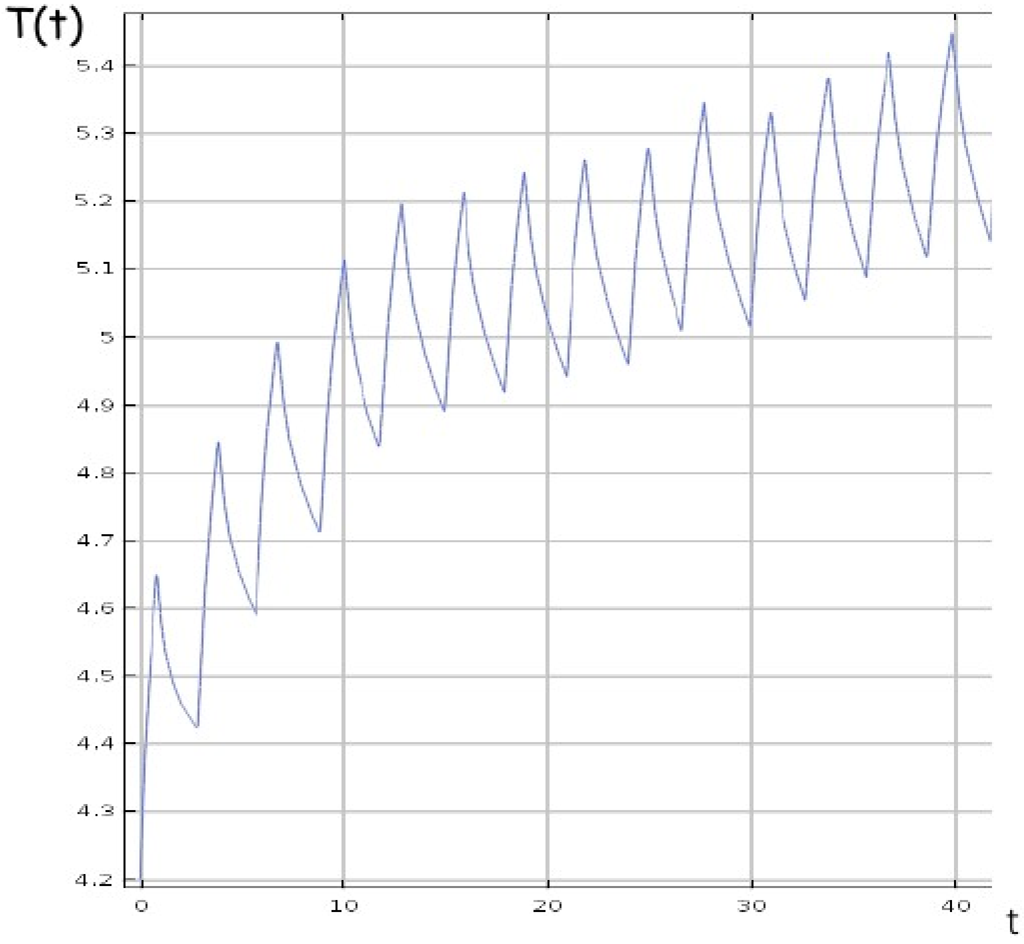
Maximum hot spot
around 18000 W/m^3

Maximum temperature of
coil around 5.7 K

Historical Test

Results on BNL experiment

The maximum temperature of the coil as a function of time



Maximum Temperature profile Tmax(t) for BNL:

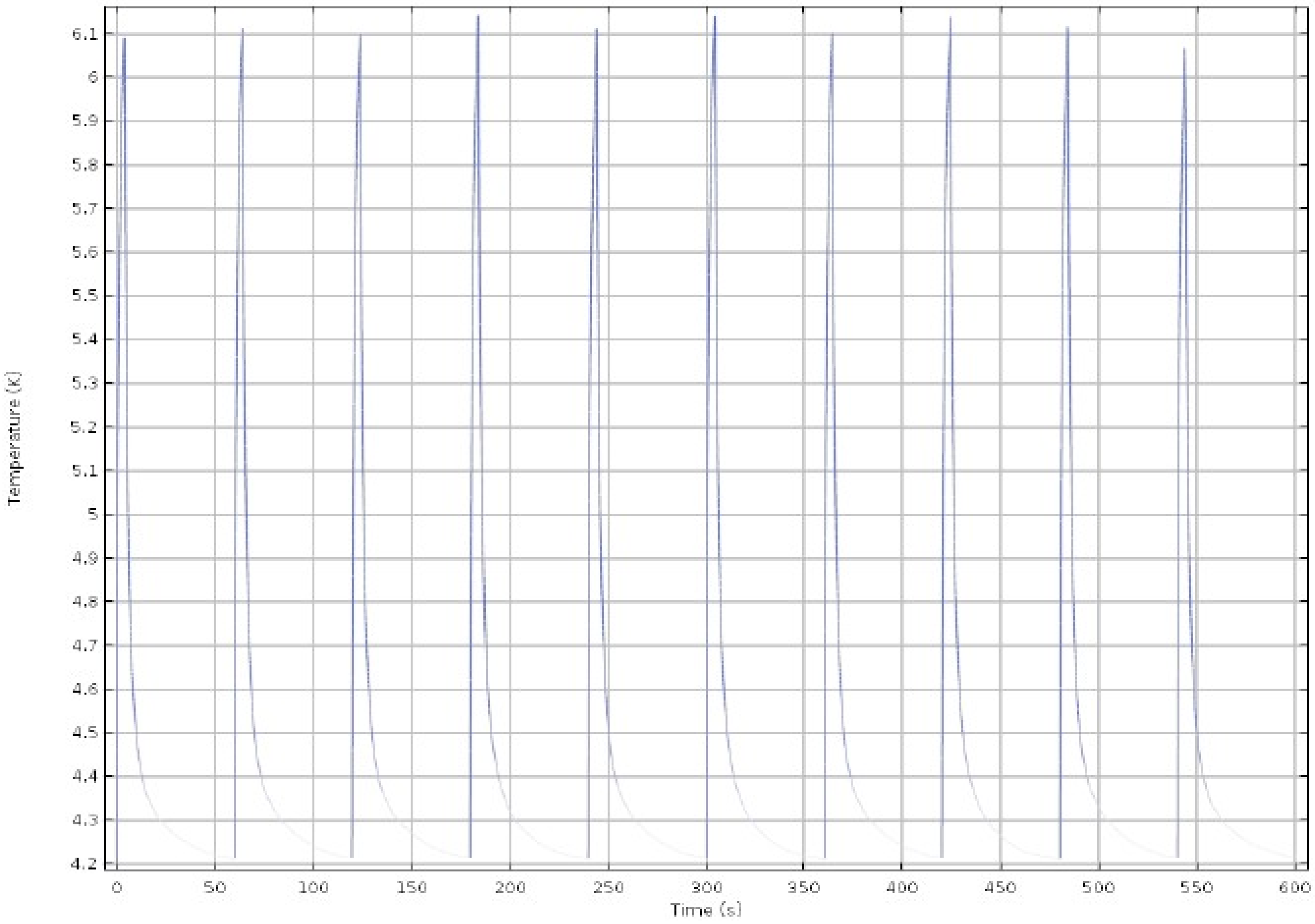
- 24 GeV proton
- 2e11 proton/s
- Teflon Target

Notes:

- The BNL magnet was quenched in this setup (Teflon target & 2e11 proton/s)
- The simulation results "indicate" quench -> The heat is accumulated over time
- There is an issue about numerical convergence issue for longer run that need to be fixed -> require extremely fine Mesh and time step

SpinQuest Target Magnet

The maximum temperature of the coil as a function of time



Maximum Temperature profile Tmax(t) for E1039:

- 120 GeV proton
- 1e12 proton/s
- NH3 Target

Conclusion: It is save to run at 1e12 proton/s but I recommend this intensity to be considered as the upper limit

Prep for Quench Commissioning

Before Commissioning run

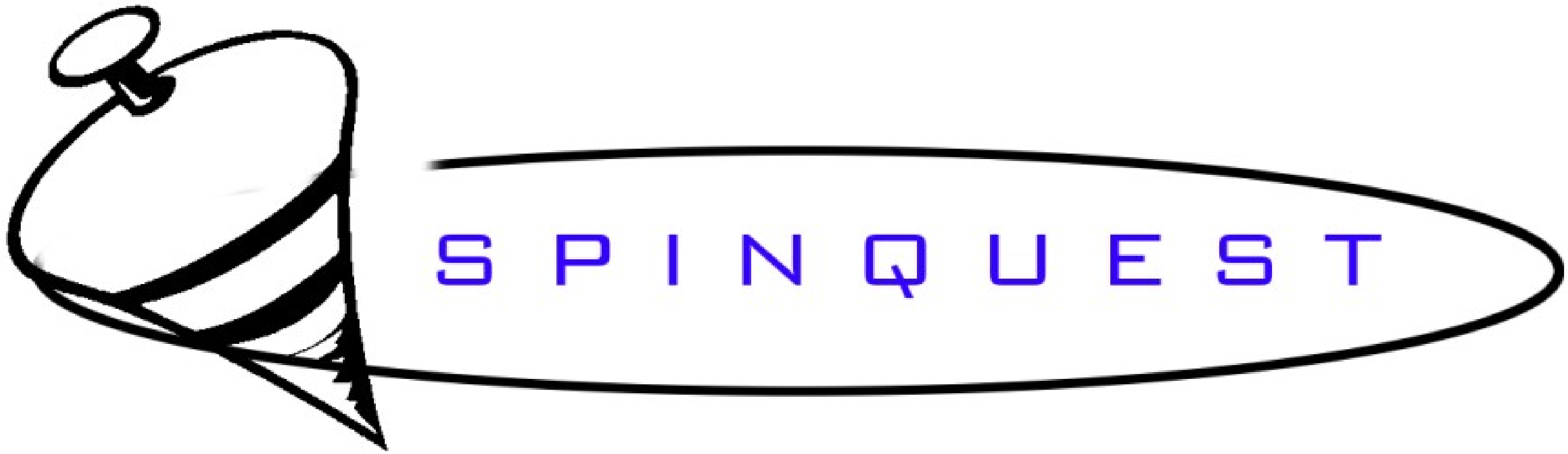
- Fix the numerical convergence issue
- Overleaf documentation (collaborative LaTex editor)
- Fine tuning geometry
- Systematic study
- Install 8 temperature sensor (Carlos)
- Create Temperature prediction for those sensors as a function of beam intensity

During Commissioning run

- Compare the simulation prediction vs experiment

Prep for Quench Commissioning

Type-T Thermocouples Cu-CuNi



Please Join The Effort (dustin@virginia.edu)

- https://spinquest.fnal.gov/
- http://twist.phys.virginia.edu/E1039/

Let us build our network