Polarized 3He Target at JLab

Jian-ping Chen, Jefferson Lab

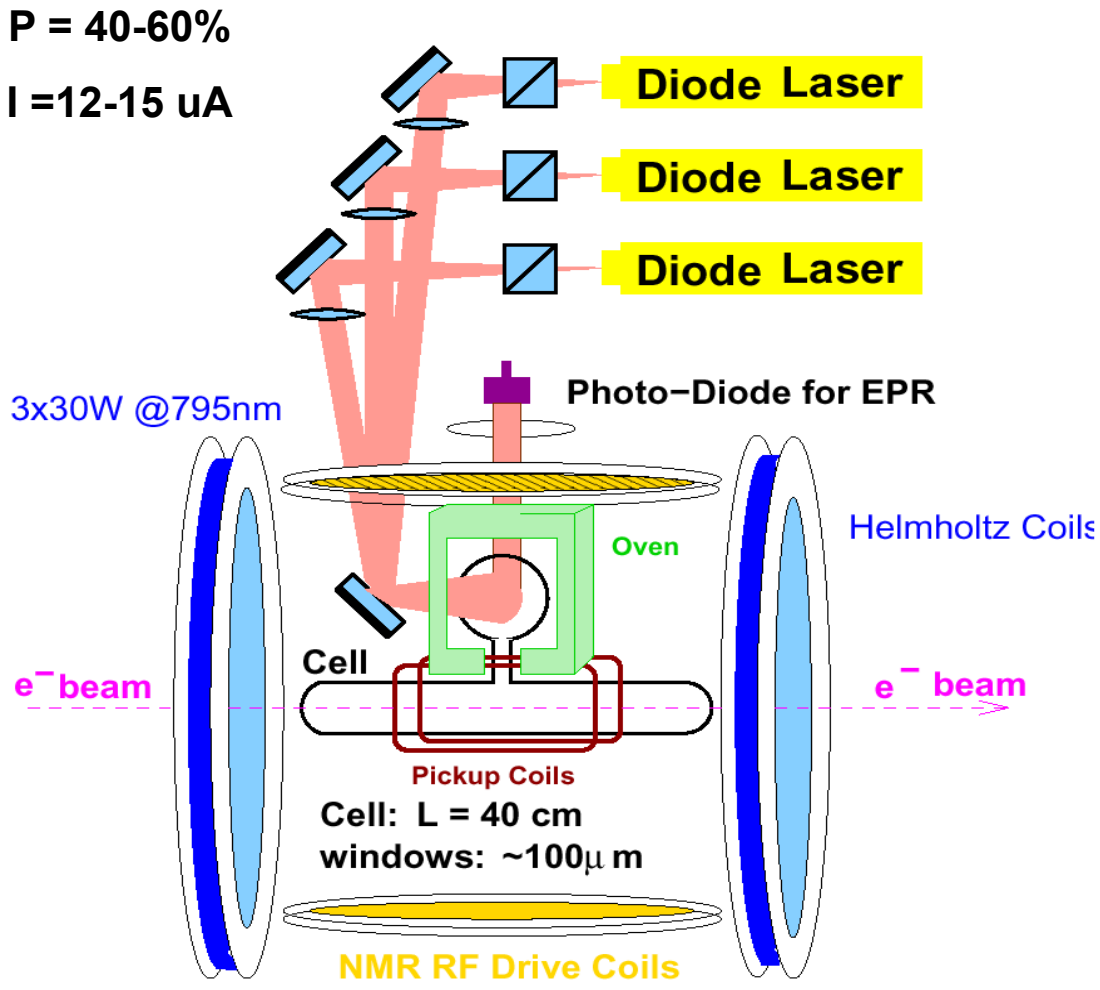
Spin2016, UIUC, Sept. 25-30, 2016

- Overview and Introduction
- Progress and performance
- Upgrades for future experiments

Overview and Introduction

JLab Polarized 3He Target System
and Physics Program

JLab polarized ^{3}He target (1998 – Now + Future)



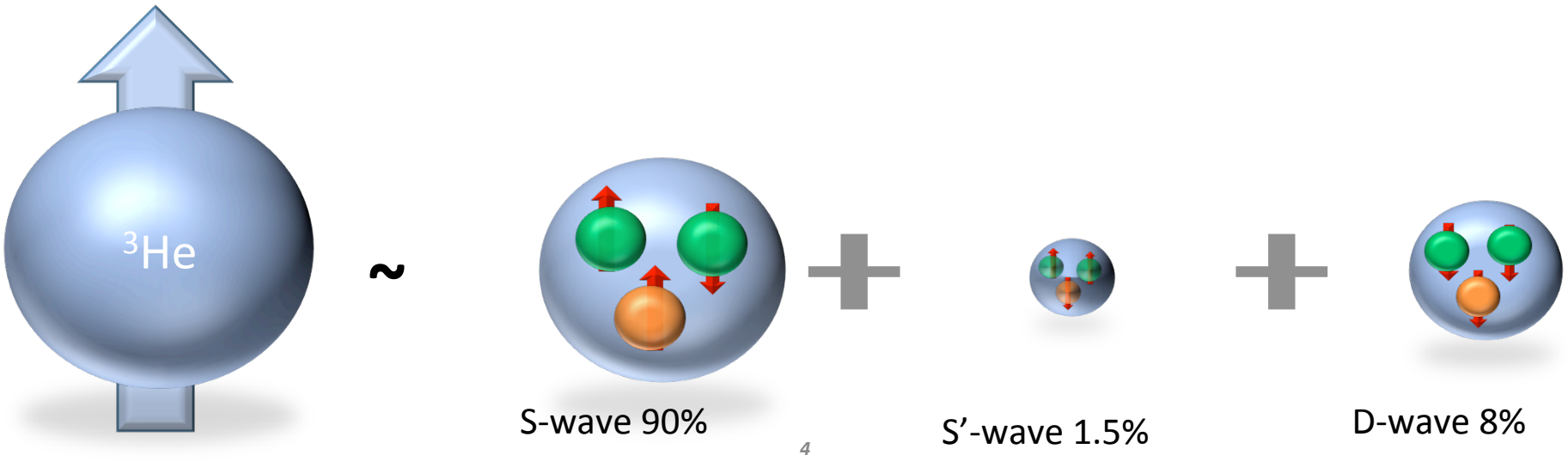
- ✓longitudinal, transverse and vertical
- ✓Luminosity=10^{36} (1/s) (highest in the world)
- ✓High in-beam polarization 60%
- ✓Effective polarized neutron target
- ✓13 completed experiments
  7+2 approved @12 GeV (A/C)

Polarized ^{3}He Target

Slide from Nguyen Ton

- ✓ ^3He as an effective polarized neutron target.
- Neutron decay time ~ 15 mins (no free neutron target).
- Deuteron (1p+1n → uncertainty comes from extracting n and there is more than 50% contribution from p).

^{3}He wavefunction =



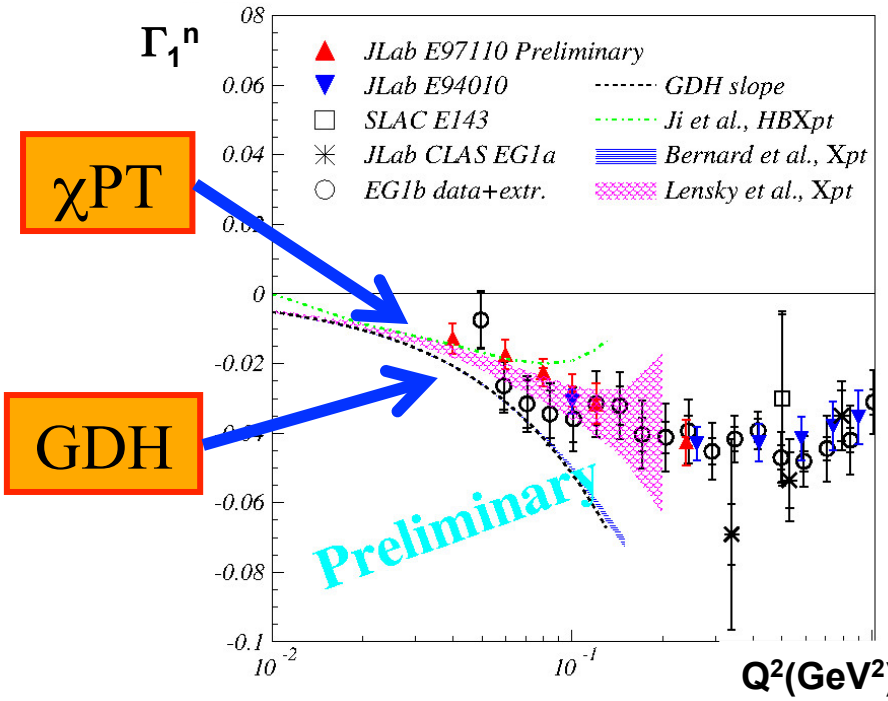
JLab Polarized 3He (n) Physics Program

- **Neutron Spin Structure**
  - Valance quark: A1n, E99-117
  - GDH sum rule: E94-010, E97-110
  - Quark-hadron duality: E01-012
  - Higher-twist, g2/d2: E97-103, E06-014

Reviews:
Sebastian, Chen, Leader,
PPNP 63 (2009) 1;
J. P. Chen, IJMPE 19 (2010) 1893

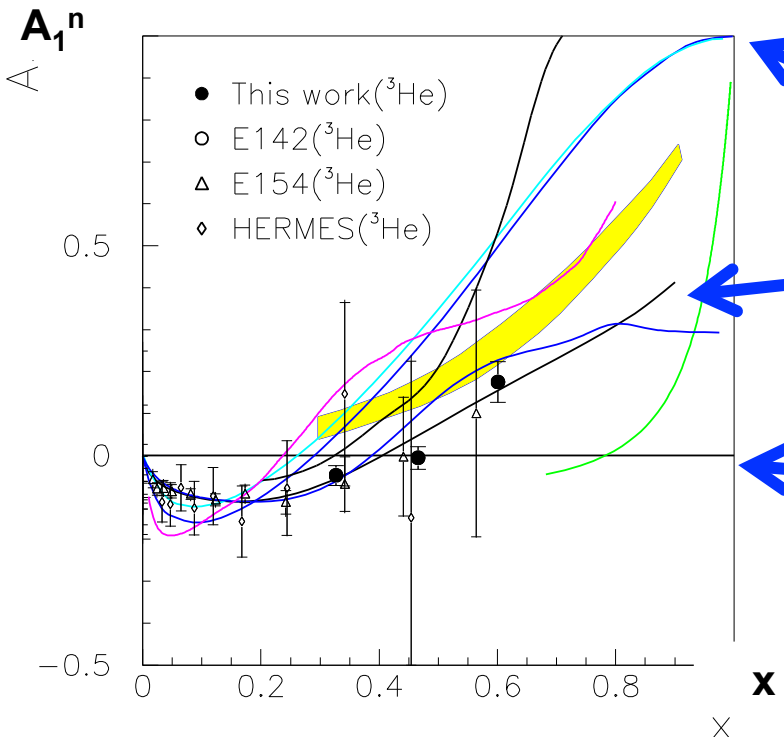
- **Single Target Spin Asymmetries**
  - Transversity and TMDs: E06-010
  - 2-γ exchange, Inclusive Ay: E05-015, E07-013
- **3He Spin/Wave Function Study**
  - Ax/Az in QE: E05-102; Ay in QE: E08-005
- **From Factors**
  - GMn: E95-001; GEn: E02-013

Highlights of JLab Neutron Spin Study



χPT

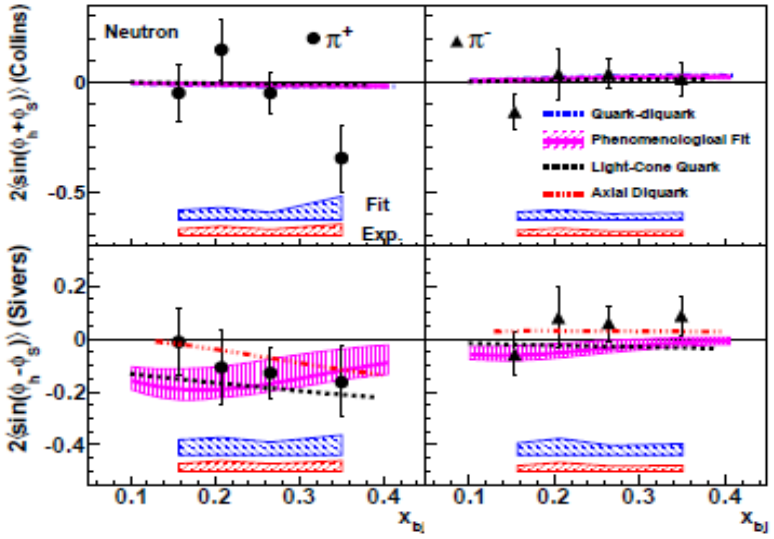
GDH



pQCD

VCM

SU(6)



- GDH sum rule: test χPT, study transition region
- Valence quark: pQCD vs non-pQCD
- Transversity and TMDs: 3-d

Polarized ^{3}He

- Polarized atomic electrons, then spin exchange with ^{3}He nuclei

  Issue: ground state, two electrons (full shell),

  opposite spin, can not be polarized (exclusion principle)

- Solutions:
  1) Alkali (Rb) Optical Pumping Spin Exchange
  2) Meta-stability Exchange Optical Pumping

History/Progress in Polarized ^{3}He

- Spin-Exchange Optical Pumping

  1960: Bouchiat/Carver/Varnum (Princeton), PRL 5, 373 (1960)

  2.8 atm ^{3}He, optically pumped 0.001 mm partial pressure of Rb, **P=0.01%**

> we have observed enhancement of the nuclear polarization by a factor of 10^4 above the initial Boltzmann distribution of 10^{-8}.

  Now: **10 atm ^{3}He**, Rb-K optical pumping, **P > 70%** **(JLab/UVa/W&M…)**

- Meta-stability Exchange Optical Pumping

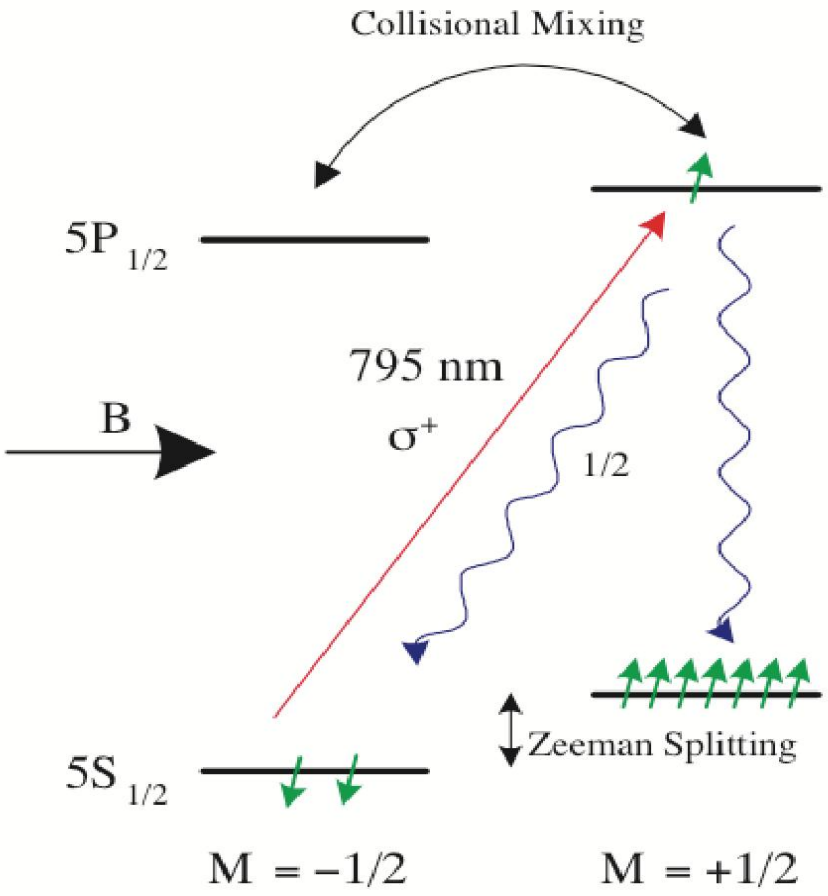
  1963: Colegrove/Schearer/Walters (Texas Instruments), PR, 132, 2561 (1963)

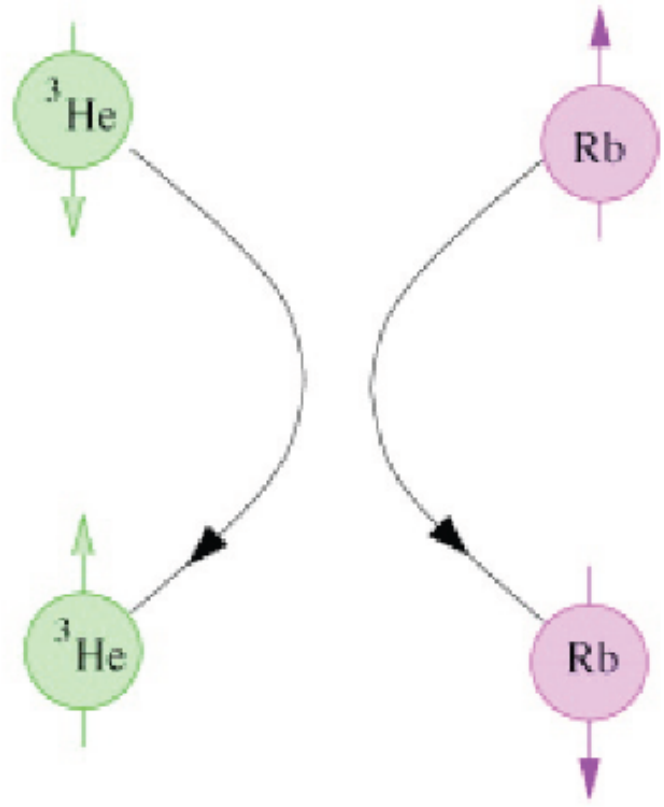
  ~0.001 atm ^{3}He, achieved ~40% polarization

> The highest polarization measured by nuclear magnetic resonance was 40±5% in a 5 cm-diam Pyrex sphere with the He^3 gas pressure at 1 mm Hg.

  Now: **~1 atm ^{3}He**, mass production with MEOP, **P > 70%** **(Mainz)**

Spin exchange Optical Pumping for ^{3}He



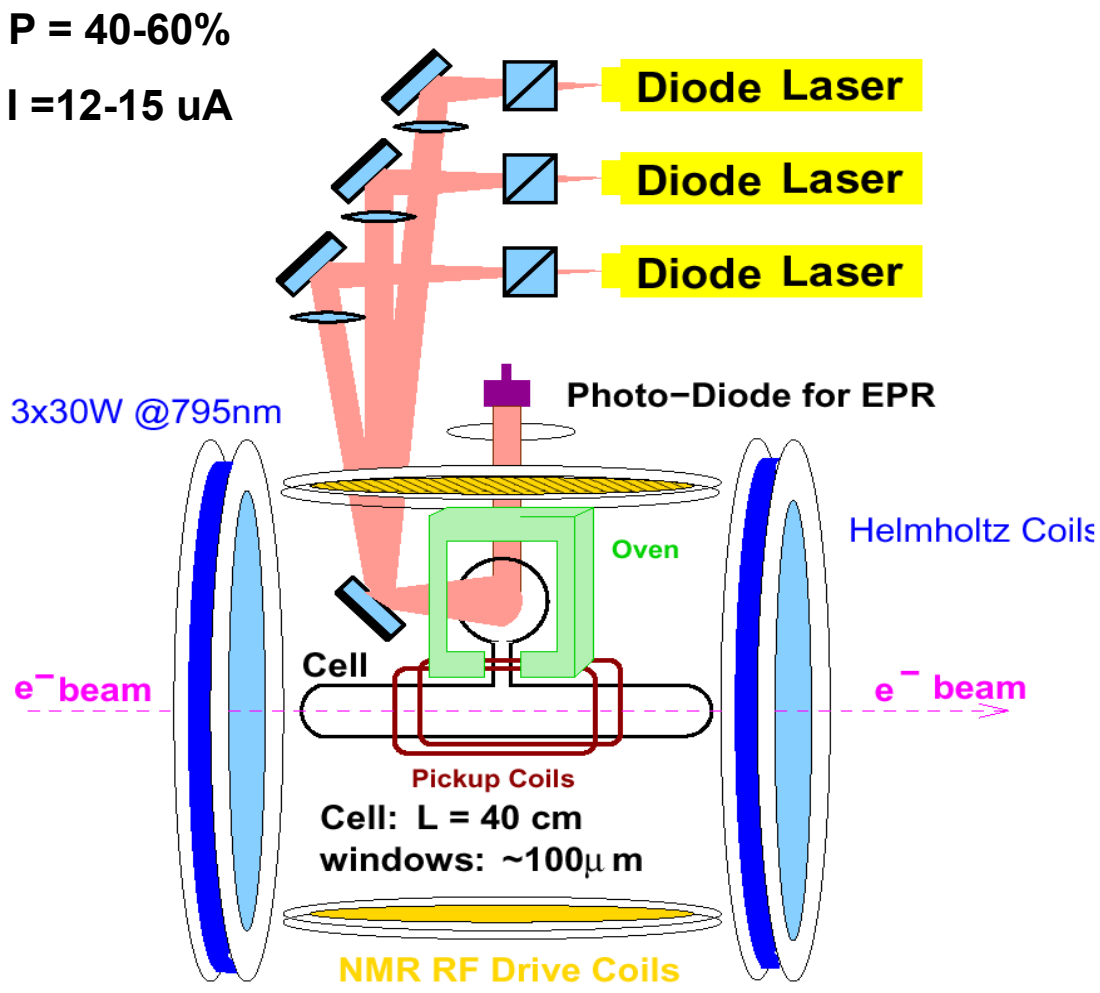


JLab Polarized 3He Target:

Progress and Performance

https://hallaweb.jlab.org/wiki/index.php/Hall_A_He3_Polarized_Target
http://hallaweb.jlab.org/equipment/targets/polhe3/polhe3_tgt.html

JLab polarized ^{3}He target (1998 – Now + Future)



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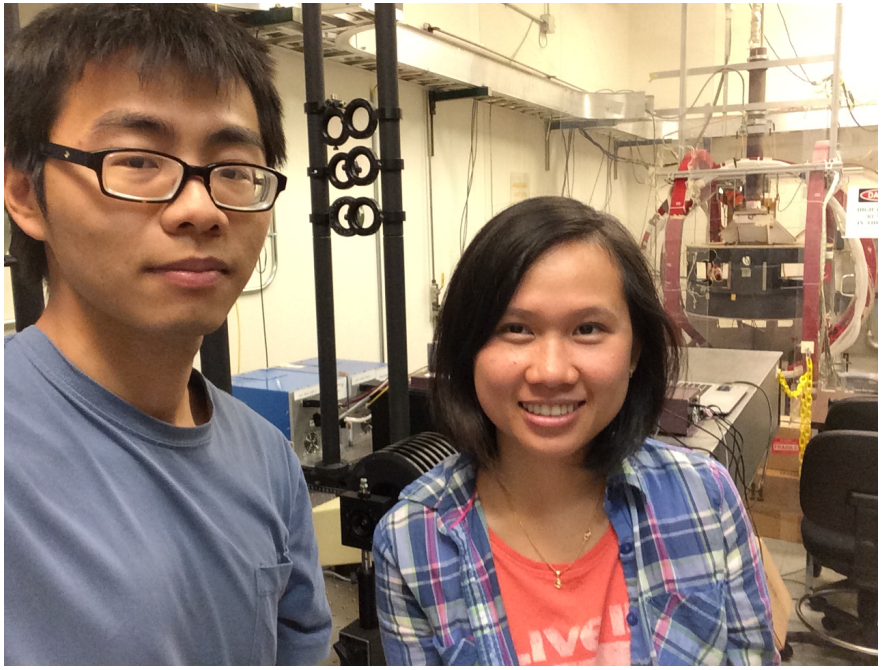
- ✓High in-beam polarization 60%
- ✓Effective polarized neutron target
- ✓13 completed experiments
  7+2 approved @12 GeV (A/C)

People

- Collaboration: Caltech (E. Hughes), JLab (J. P. Chen), Kentucky (W. Korsch), MIT/Duke (H. Gao), Temple (Z. Meziani), Princeton/UVa (G. Cates), W&M (T. Averett)
- Students and postdocs, who have been doing most of the work at JLab

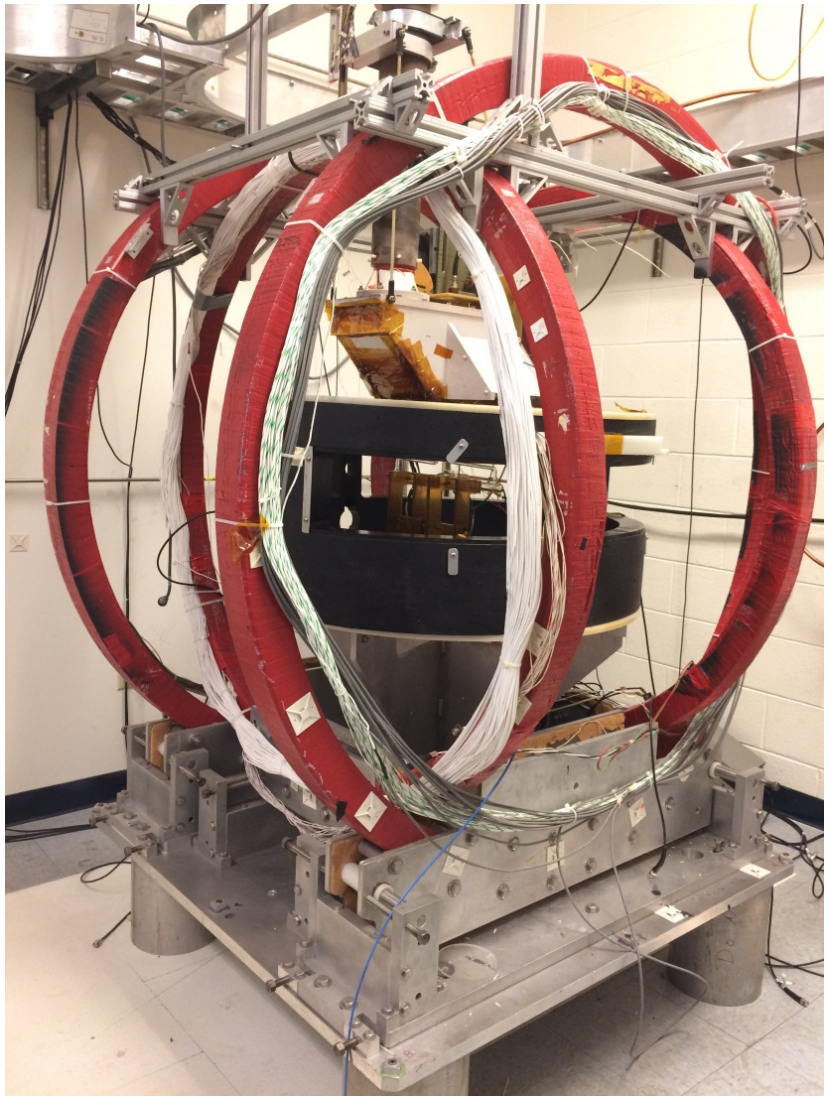
  25+ PhD students, 7+ postdocs, 10+ undergraduates and 3 high school students

  at this conferences (A. Deur, J. Huang, K. Slifer, N. Ton, Z. Zhao, …)

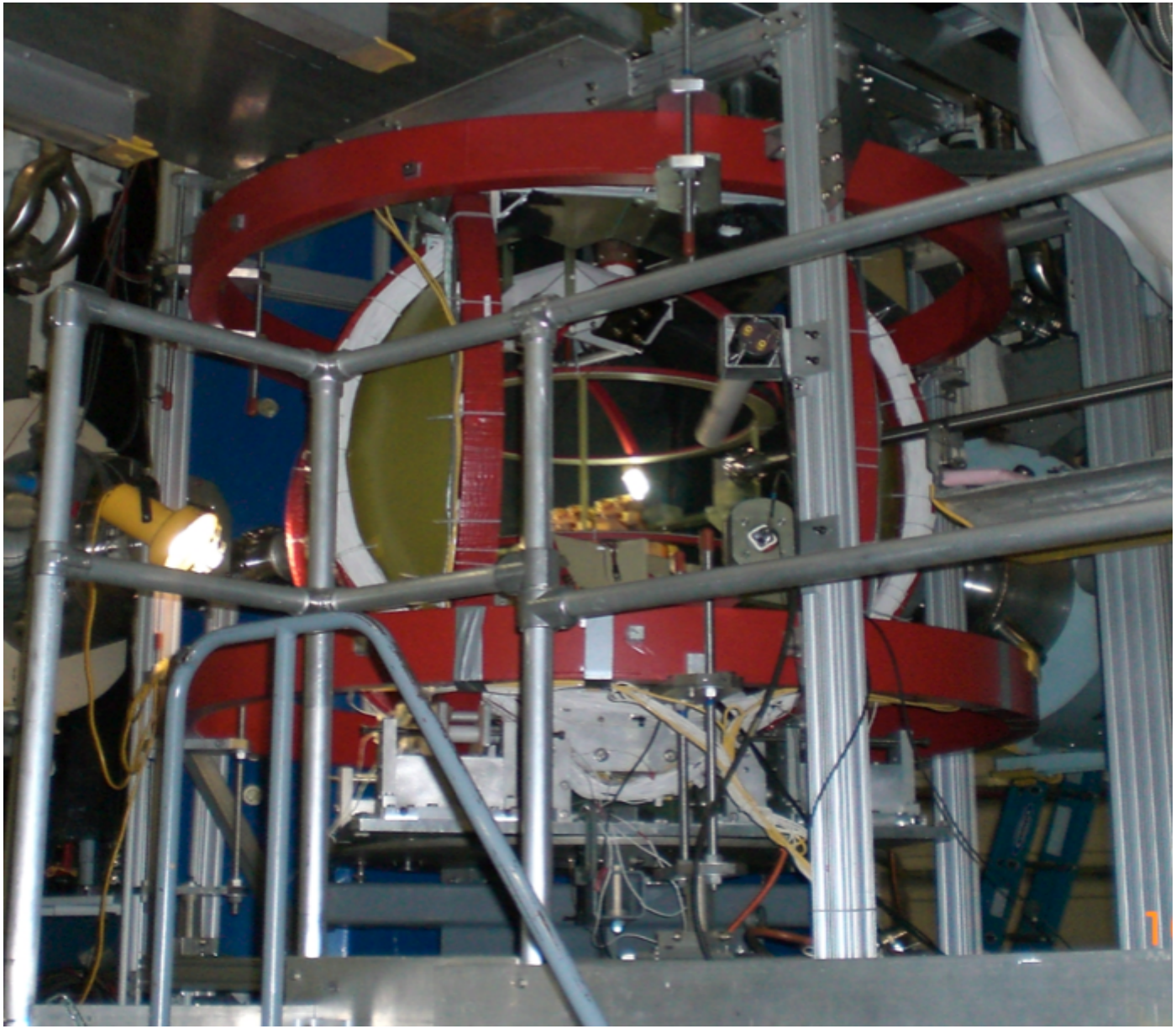


Kai Jin (UVa)
Nguyen Ton (UVa)

Polarized ^{3}He Set-up in Target Lab

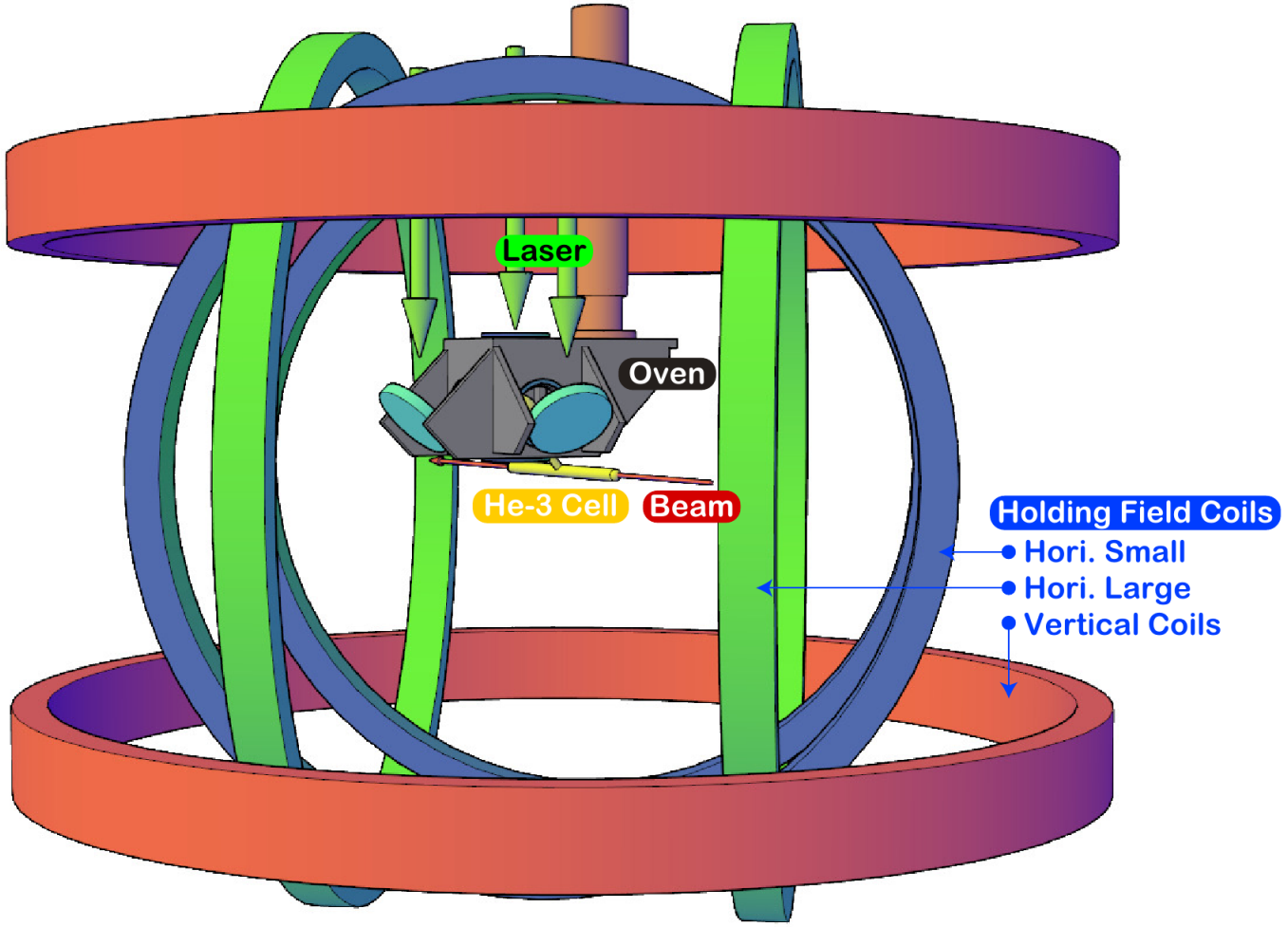


Polarized ^{3}He Set-up in Hall A



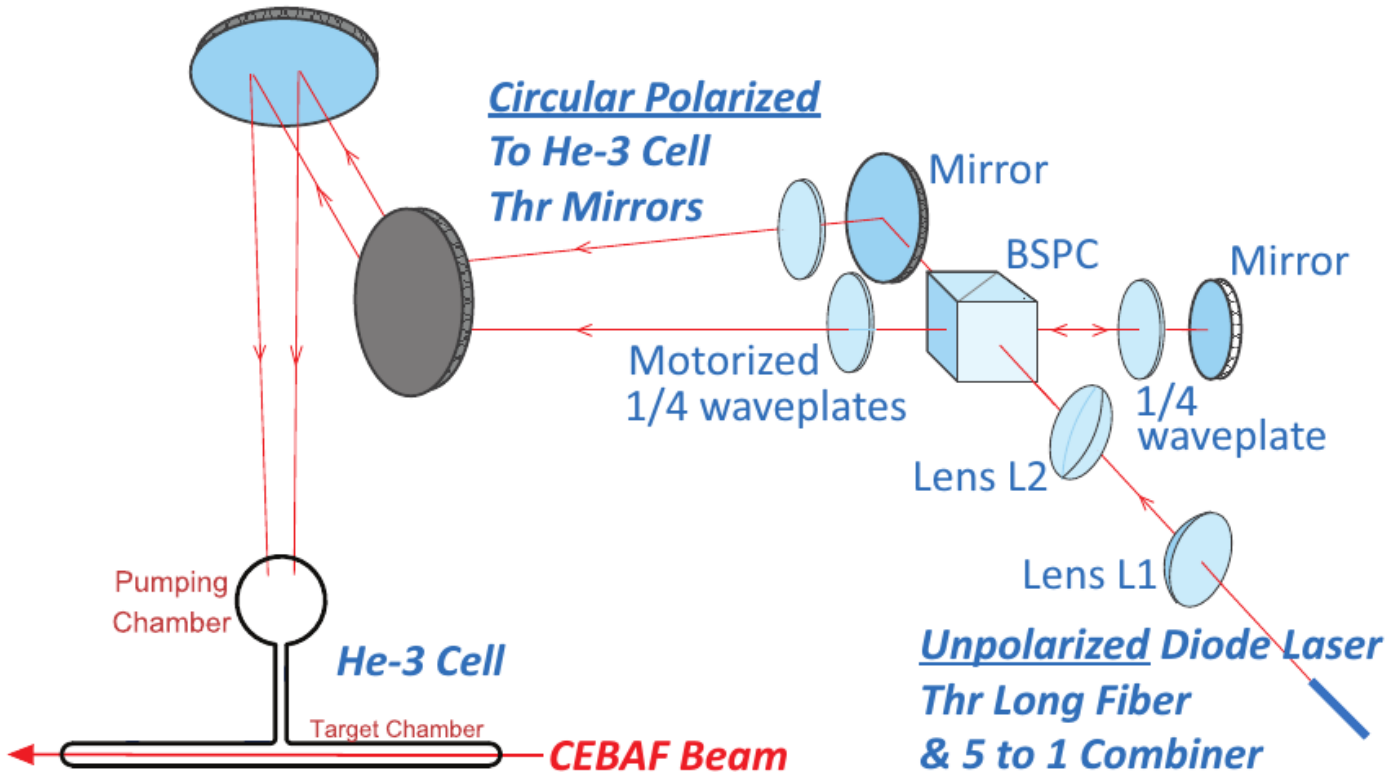
Polarized ^{3}He Target Setup

Three sets of Helmholtz coils to provide polarization in 3-d



Laser Optics

- Three-five 30 watts diode lasers per polarization direction
- Local laser hut → long optical fiber to transport to the experimental hall
- 5-to-1 combiner
- Improvement with narrow-width lasers



Target Cell / Field Uniformity

Double-chamber

Target chamber:

40 cm long, ~2 cm diametter

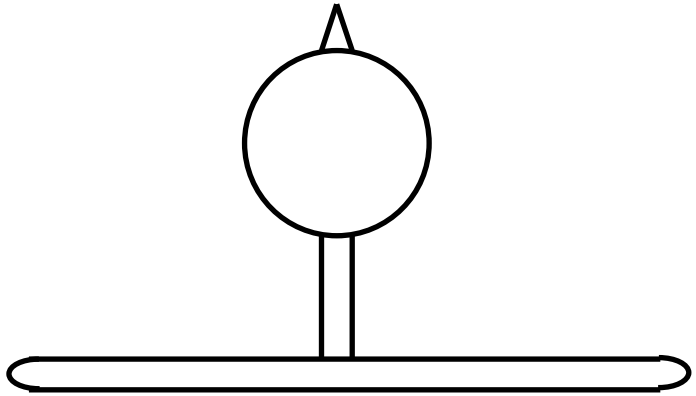
thin (0.1mm) windows, thick wall (~1mm)

Pumping chamber:

2.5” diameter sphere for early experiments

3.5” for GEn

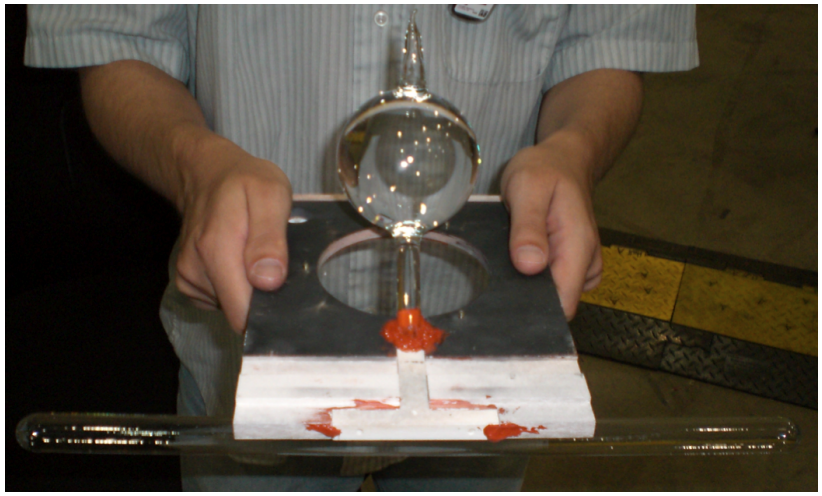
3.0” for transversity series



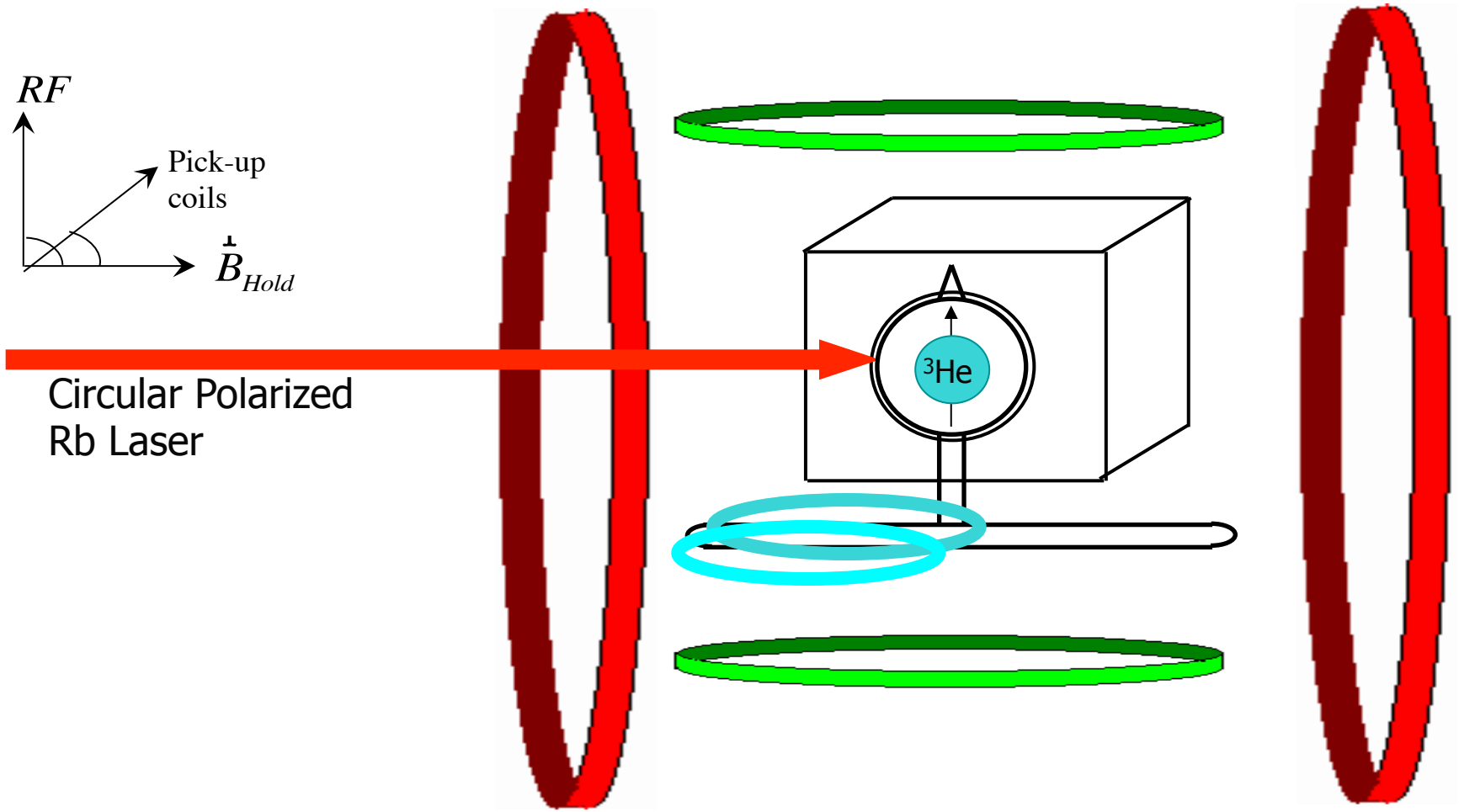
Uniform field region: 10^{-3} level

gradient: < 30 mg/cm

All three coils have been mapped, well studied



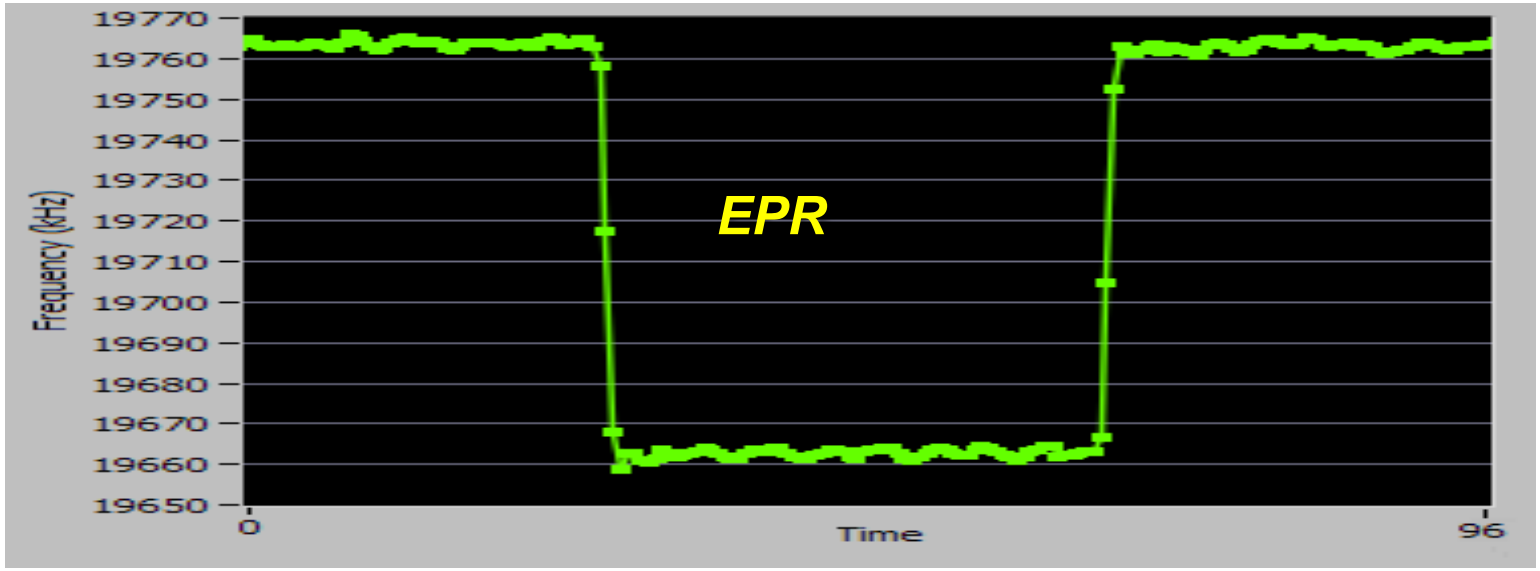
Helmholtz, RF and Pick-up coils

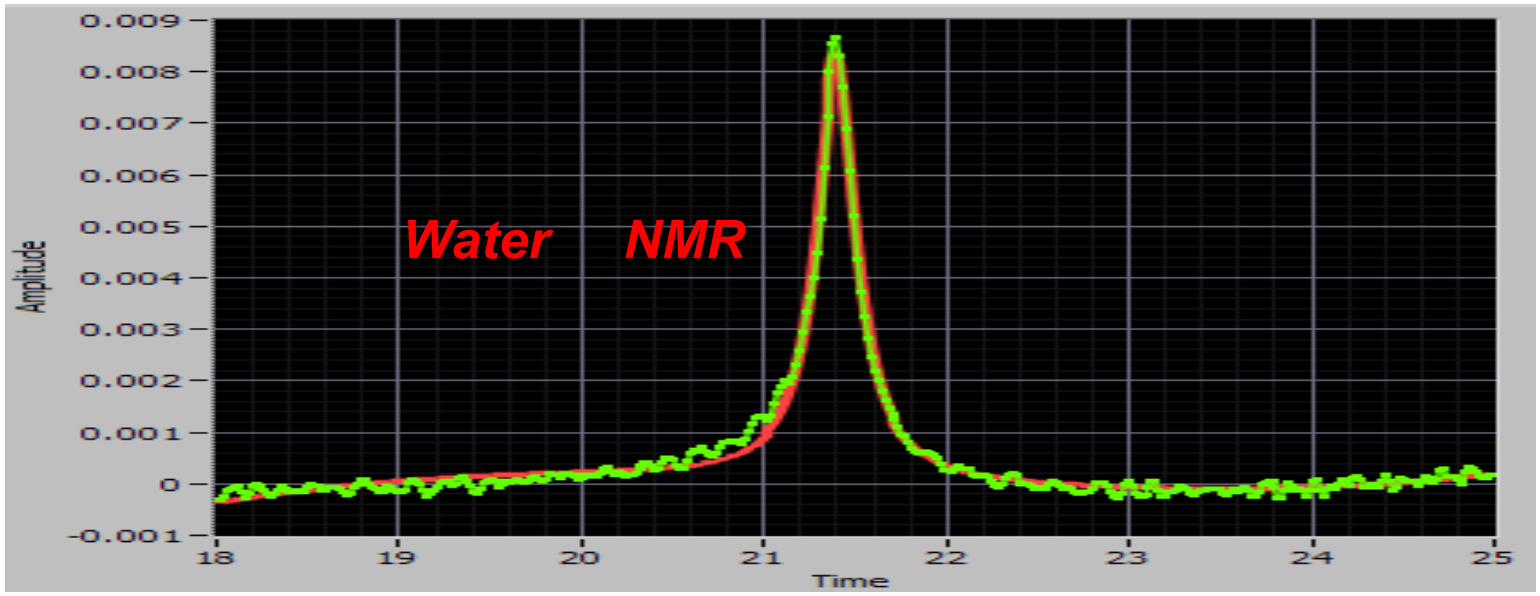


Polarimetry

- Two methods: NMR and EPR, precision 2-3%
- NMR (nuclear magnetic resonance)
  - RF field
  - AFP (adiabatic fast passage) sweep through resonance when target spin flips, induced signal through pickup coils
  - Needs calibration from a known (water calibration)
- EPR (electron-paramagnetic resonance)
  - Rb energy level splitting (D2 light) corresponding to main field +/- a small field due to 3He polarization
  - Using AFP to flip ^{3}He spin. Frequency difference of lights emitted proportional to ^{3}He polarization
  - No calibration needed
- Cross checking with elastic asymmetry measurements

EPR and Water NMR





Fast Spin-Flip

- Single target spin symmetry measurements requires fast spin flip to reduce spin-state-correlated systematic effects
- Using AFP flip target spin every ~20 minutes
  - Added bonus: free polarimetry with each flip!
- Due to AFP loss, equilibrium polarization is ~5% (relative) lower
  - depends on AFP loss, spin-up time and flip frequency
- Can also be done with field rotation
  - tested to flip every 1 minute with negligible loss

Progress with Polarized ^{3}He

- Initial polarized ^{3}He, 40 years ago

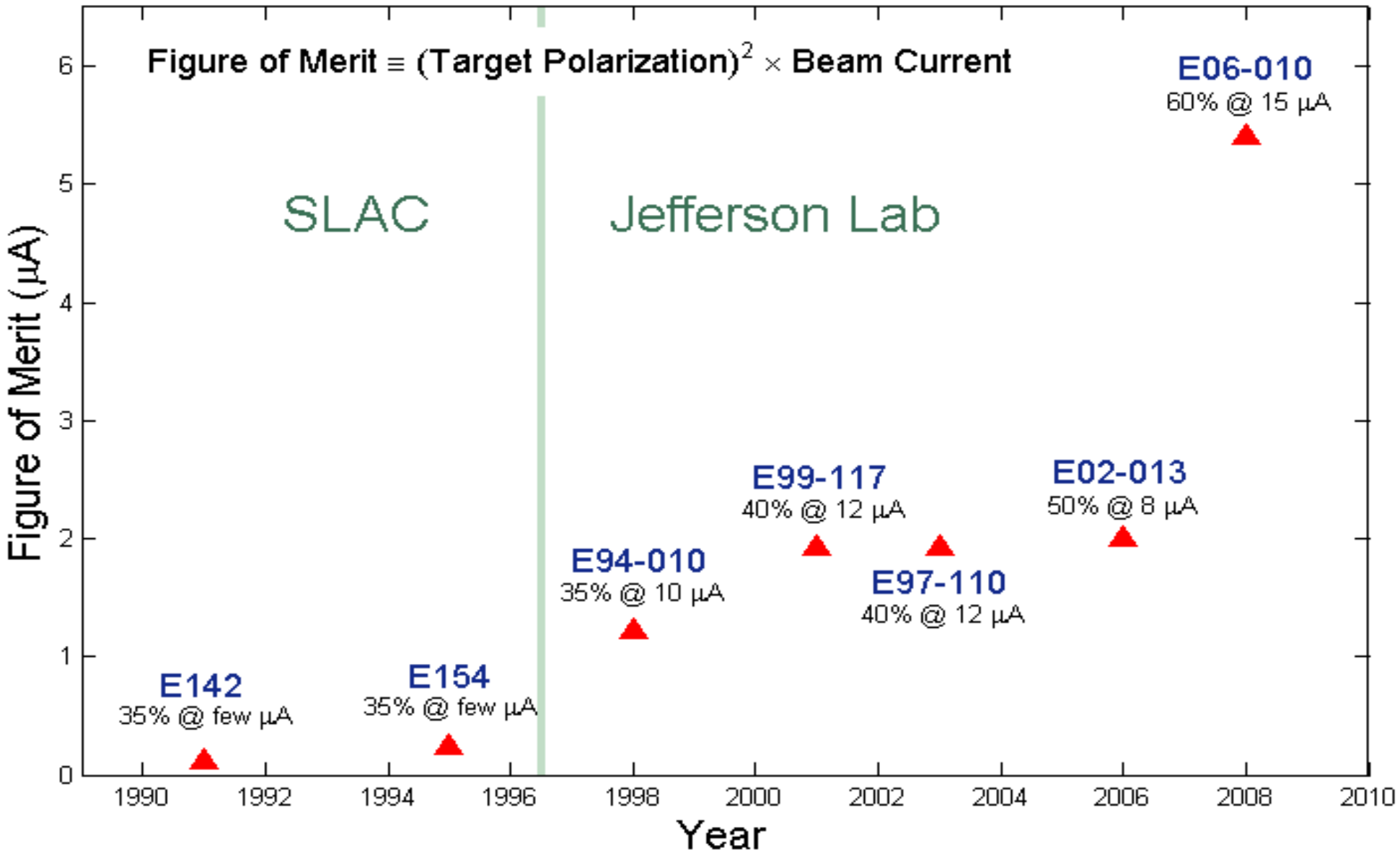
  ρ ~ 0.1 amg, P <1%
- SLAC E142/E154 (1990s)

  ρ ~ 10 amg, P~ 30%, L~ 10^{35} $cm^{-2}s^{-1}$
- JLab (1998-2008)

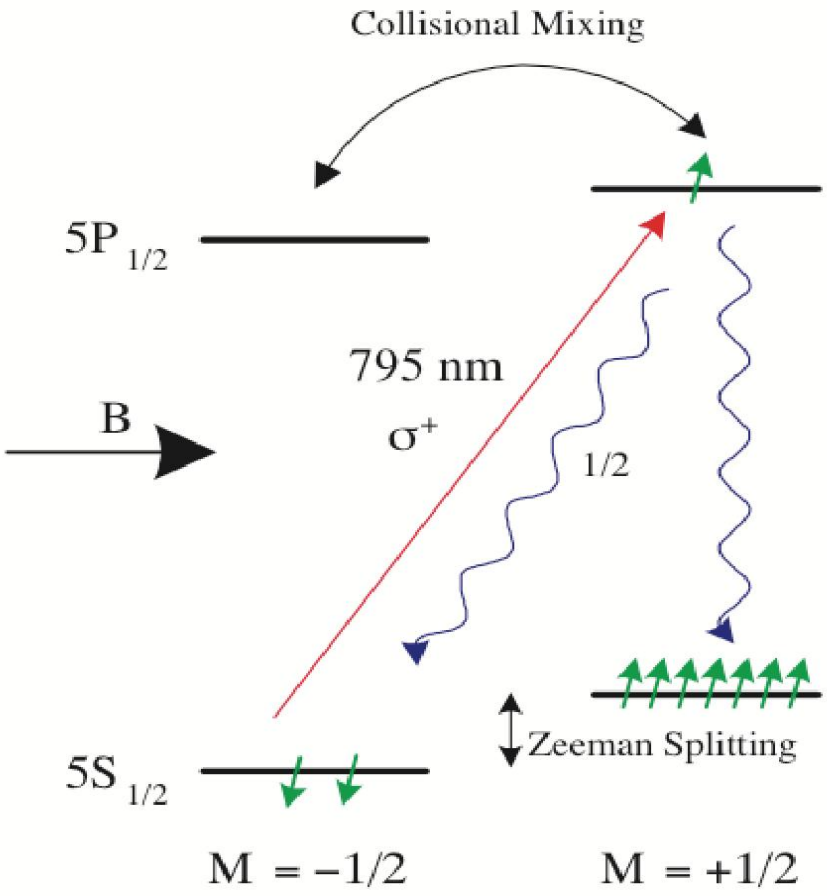
  ρ ~ 10 amg, L ~ 10^{36} $cm^{-2}s^{-1}$

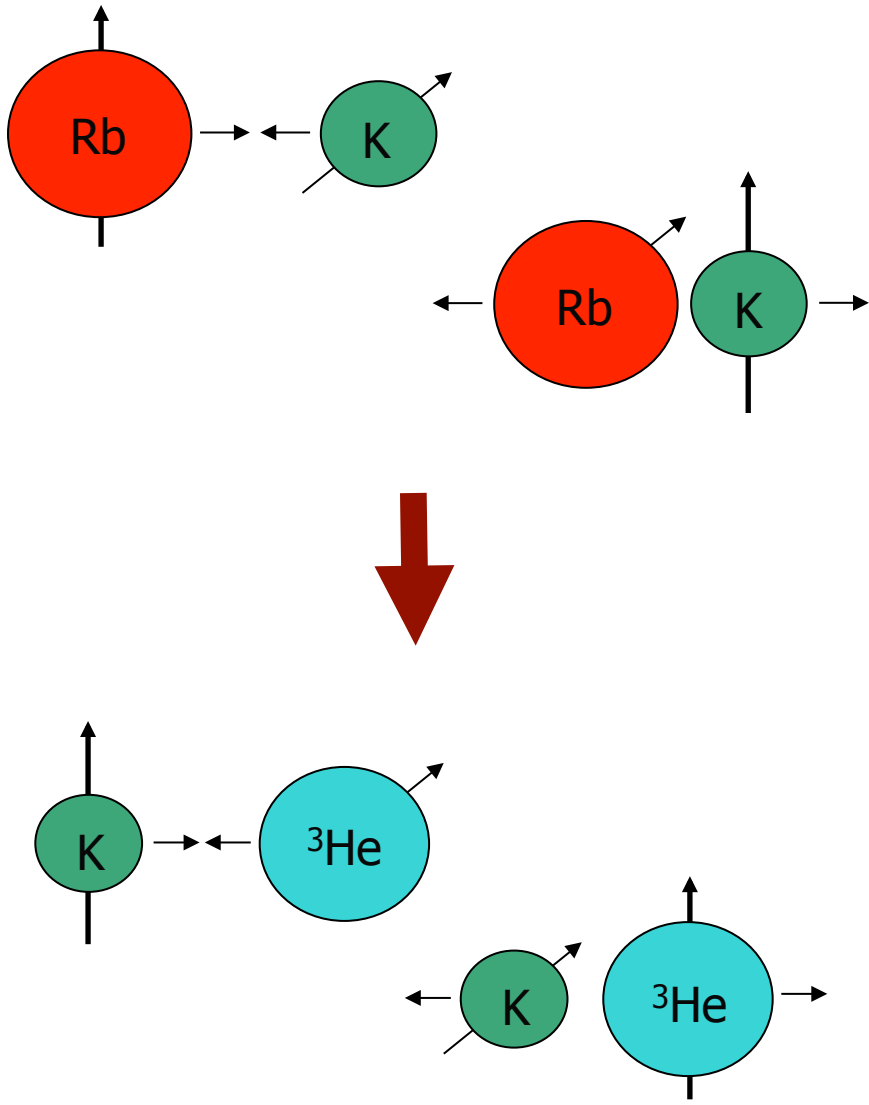
  Initially P~35%, improved to ~ 60% in-beam
- JLab Future (2016+): improve luminosity by a factor of 6-8 in two stages

Figure-of-Merit History for High Luminosity Polarized ^{3}He



Hybrid (Rb/K Mixing) Optical Pumping



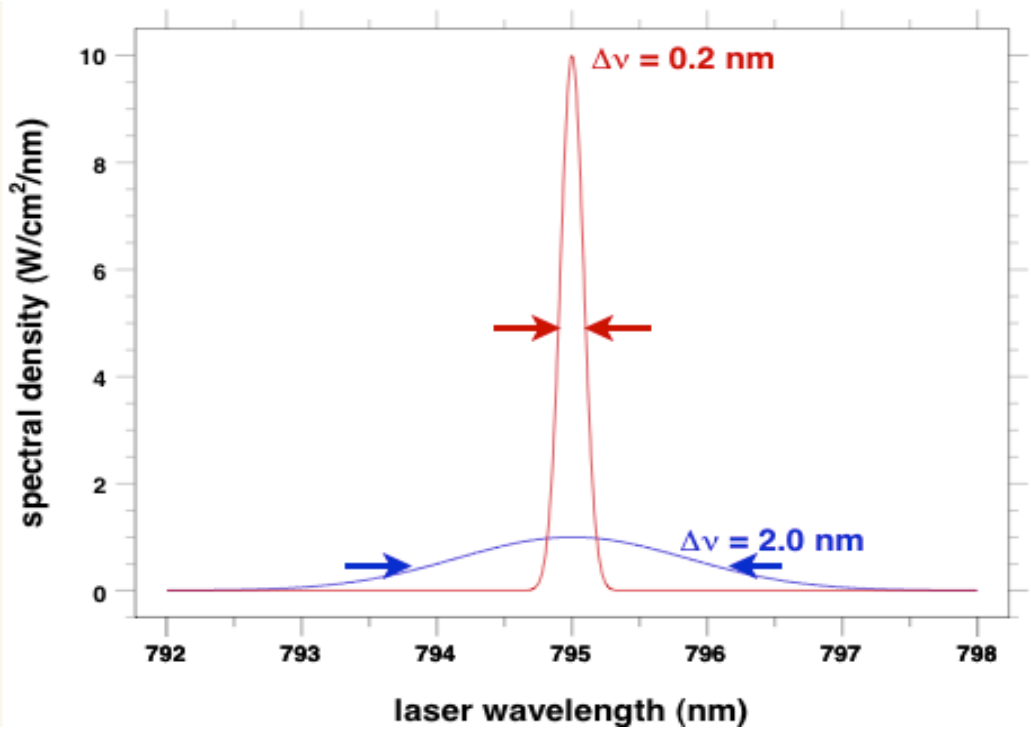


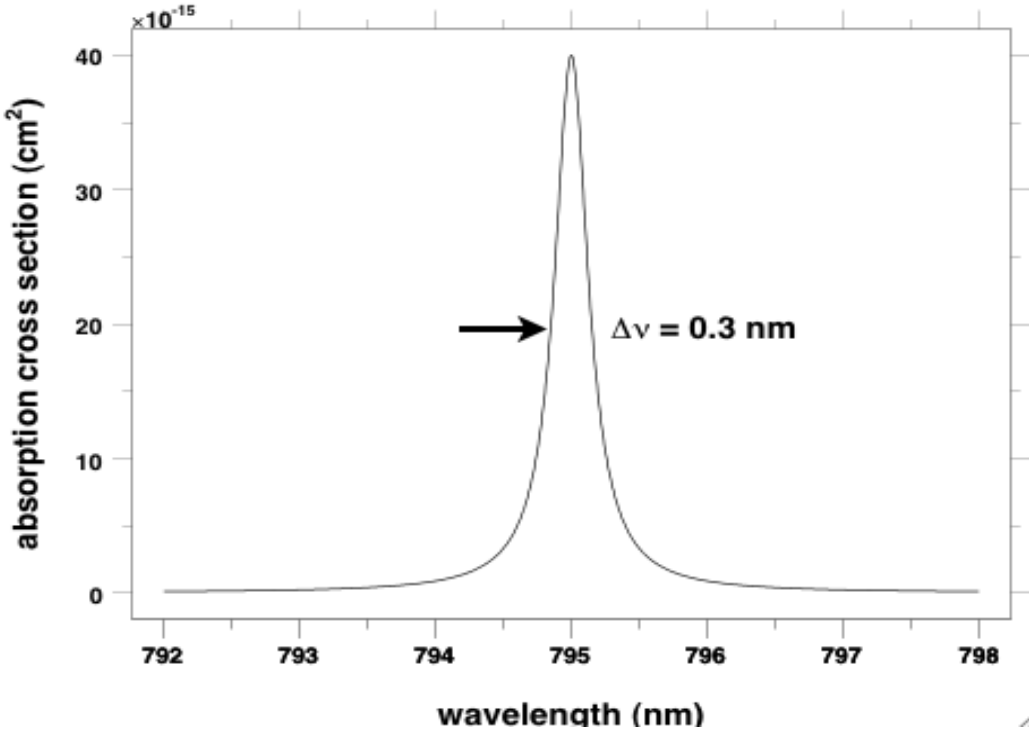
Narrow Width Lasers

With narrow-width lasers, polarizations > 70%

Left: Blue is current lasers, Red is Comet laser

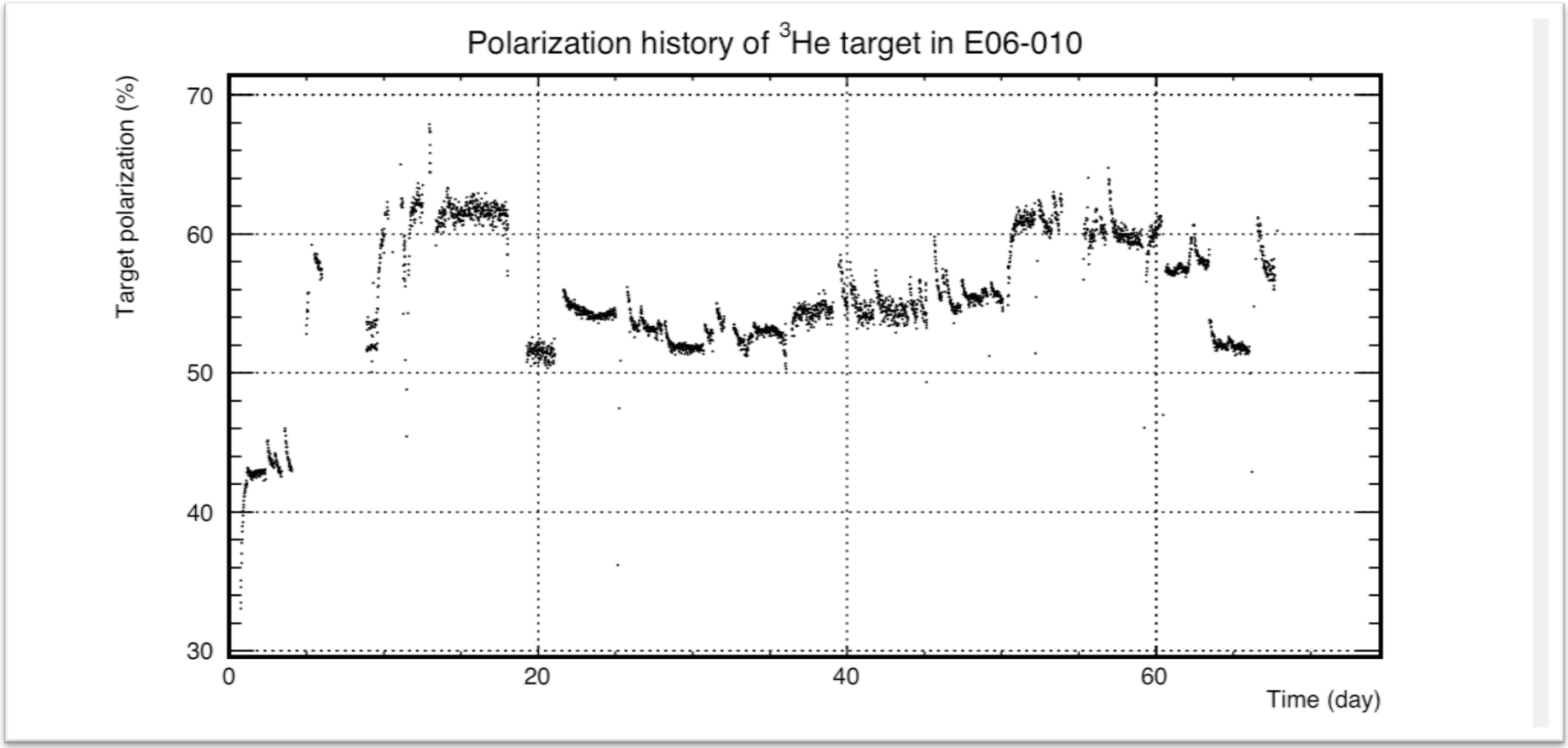
Right: Absorption spectrum of Rb





Target Performance During Transversity (2008)

- Both EPR/NMR analysis
- Polarization reach over 70% in pumping chamber without beam (over 65% with beam)
- Target chamber in-beam polarization reached over 60% with 12-15 μA beam and 20 minute spin flip (over 65% without beam), average ~55%.



Future Polarized 3He (n) Physics Program

- **Neutron Spin Structure**
  A1n in Hall C and Hall A
  d2n in Hall C
  requires stage-1 upgrade (FOM improve by a factor of 2-3)
- **From Factors**
  GEn with SBS
  requires stage-2 upgrade (FOM improve by a factor of 6-8)
- **Single Target Spin Asymmetries (stage-2 + special requirements)**
  Transversity with SBS
- **Transversity/TMDs with SoLID** (achieved performance ok)
  Transverse pol 3He
  Longitudinal pol 3He
  2 Run-group: di-hadron, inclusive A_y

Update on Polarized He3 Target

Stage I:

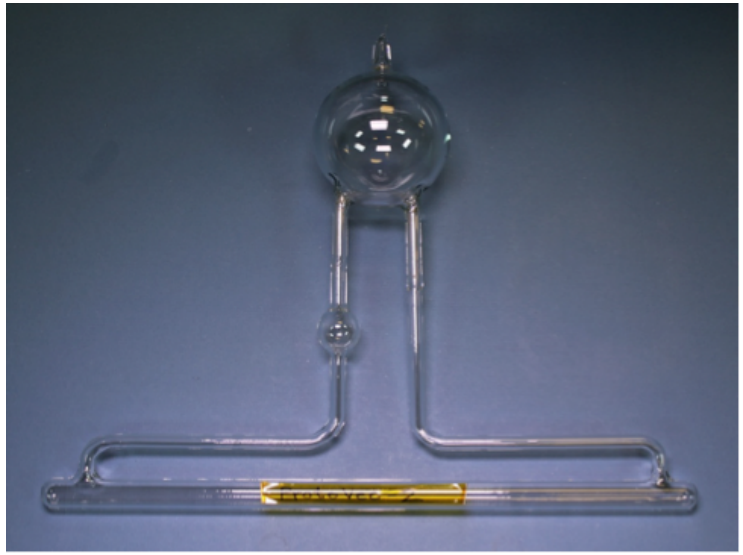
30 uA on 40 cm,
L ~ 2.2×10^{36} $cm^{-2}s^{-1}$
In-beam polarization 60%

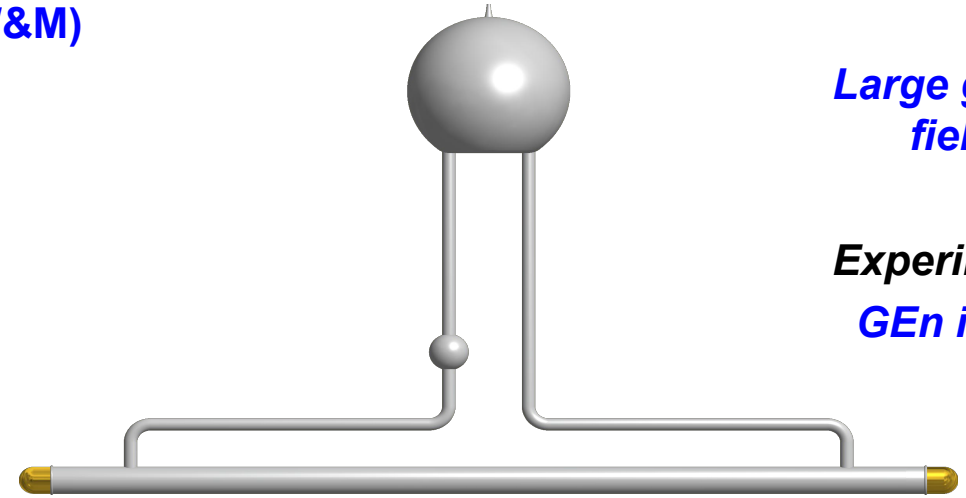
Glass cell, convection flow,
pumping chamber 3.5”

Polarimetry ~ aim for 3%
Pulse NMR/AFP NMR
calibrated with EPR
and water (optional)
κ_0 measurement (UVa/W&M)

Hall A/C compatible
significant engineering
needed to fit into Hall C

Experiments:
A1n in Hall C and A
d2n in Hall C





Stage II:

60 uA on 60 cm
L ~ 6.6×10^{36} $cm^{-2}s^{-1}$
In-beam polarization ~60%

Glass cell metal windows (UVa)
convection flow
pumping chamber 4.4” sphere
two-side pumping

Polarimetry ~ 3%

Large gradient from SBB fringe field : Magnet shield box:

Experiments:
GEn in Hall A

Stage I Progress Summary

Engineering/Design: Mostly complete

- pivot area modification: complete
- laser/optics line and platform design: complete
- oven: ordered
- target ladder design: complete
- field gradients at target area: study on-going

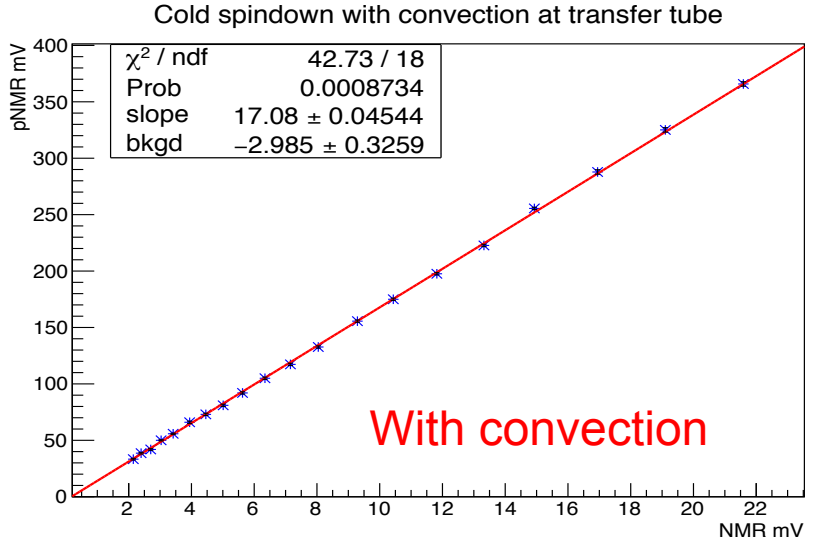
Target cells

- prototyping convection flow cell extensively tested,
  - convection speed study
  - improved heating system: foil heater instead of mini-oven
  - AFP lose study
- cell design finalized,
- cell production started (Princeton /UVa)

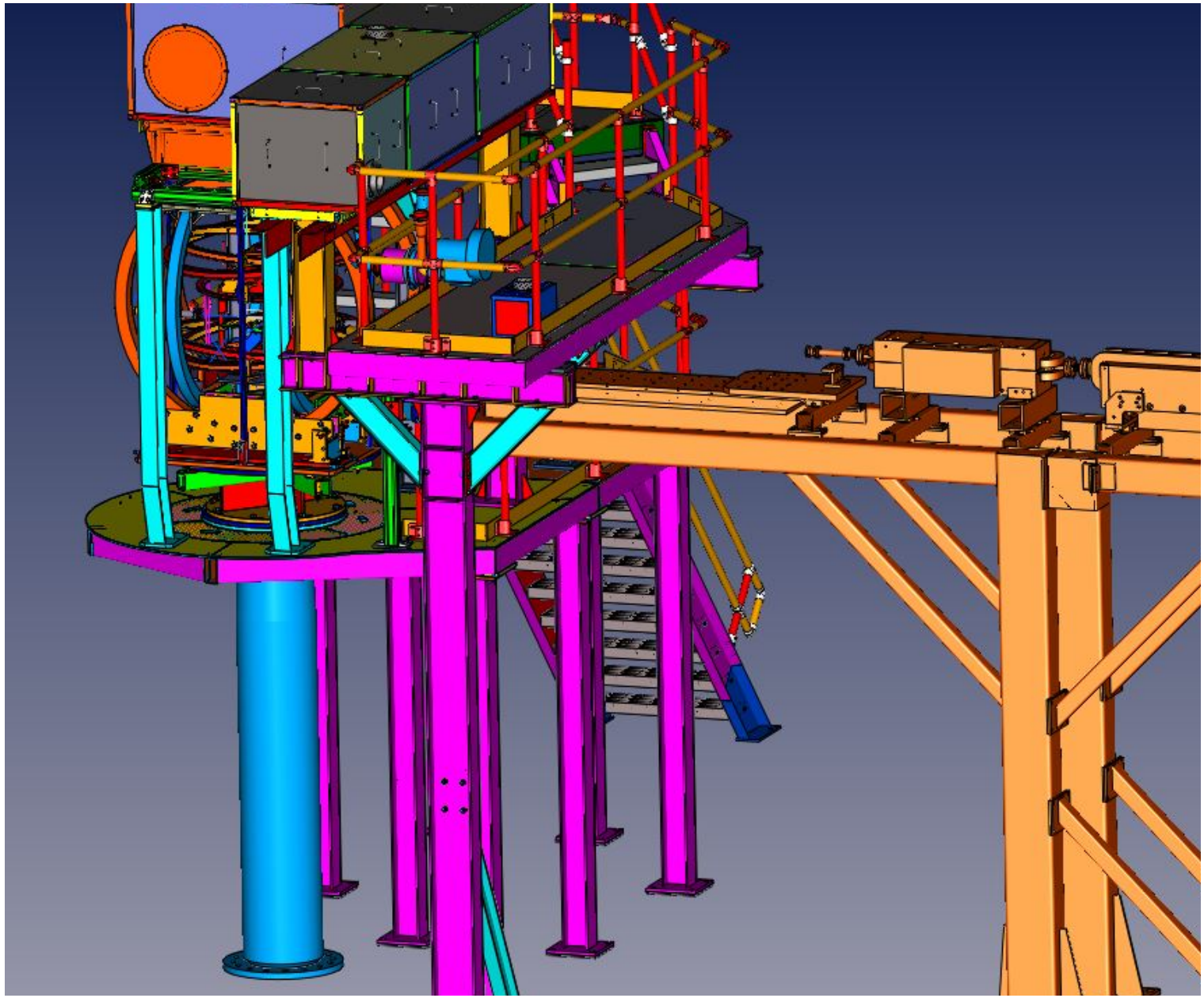
Lasers/optical fibers/He3: delivered

Polarimetry:

- pulse NMR study and calibration (N. Ton's talk)
- absolute calibration with EPR study
- κ_0 measurement (UVa/W&M) in progress



Polarized 3He in Hall C



Stage II Upgrade Status

Approaches:

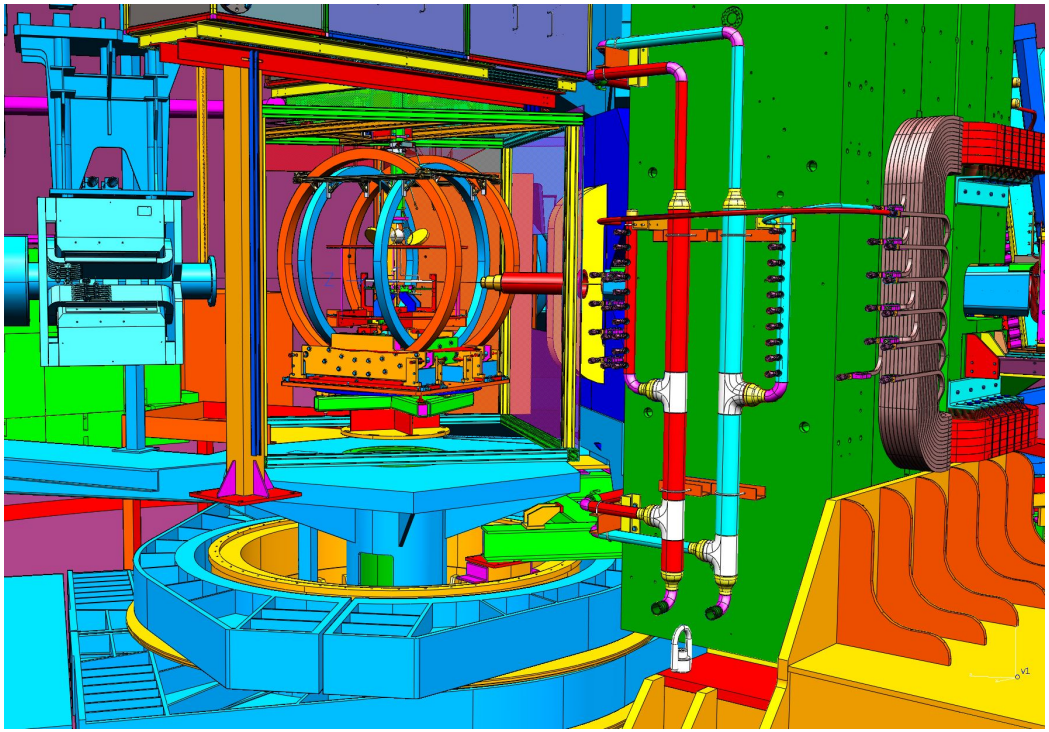
Re-use existing Helmholtz coils, a new shielding box to shield SBS fringing field

Convection flow

Target cell, pumping chamber size 4.2”

metal end-windows for target chamber

Two-side optical pumping



Status:

Conceptual Design Complete

Mechanical design started

New optical fibers delivered, started to order lasers/He3 gas

Metal window R&D on-gong at UVa

Two-side optical pumping tested

Summary

- Polarized 3He target: heart for neutron spin structure study
- JLab polarized 3He program: highlights
  - Valence spin structure
  - Sum rules
  - Transversity/TMDs
  - ….
- Target progress
  - In-beam polarization: 30% → 60-65%
  - Highest polarized luminosity: 10^{36}
  - 3-d polarization direction, fast spin-flip
- Future JLab polarized 3He:
  - Physics program requires a factor of 6-8 improvement in luminosity (FOM)
  - 2-stage upgrade on-going