Measurement of $\pi^{+}\pi^{-}$ Photoproduction in Double-Polarization Experiments using CLAS

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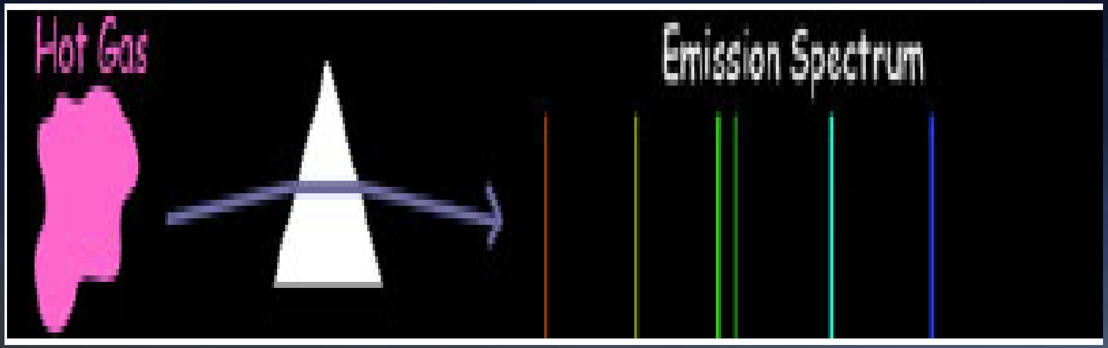
Florida State University
11/07/06

The Plan :

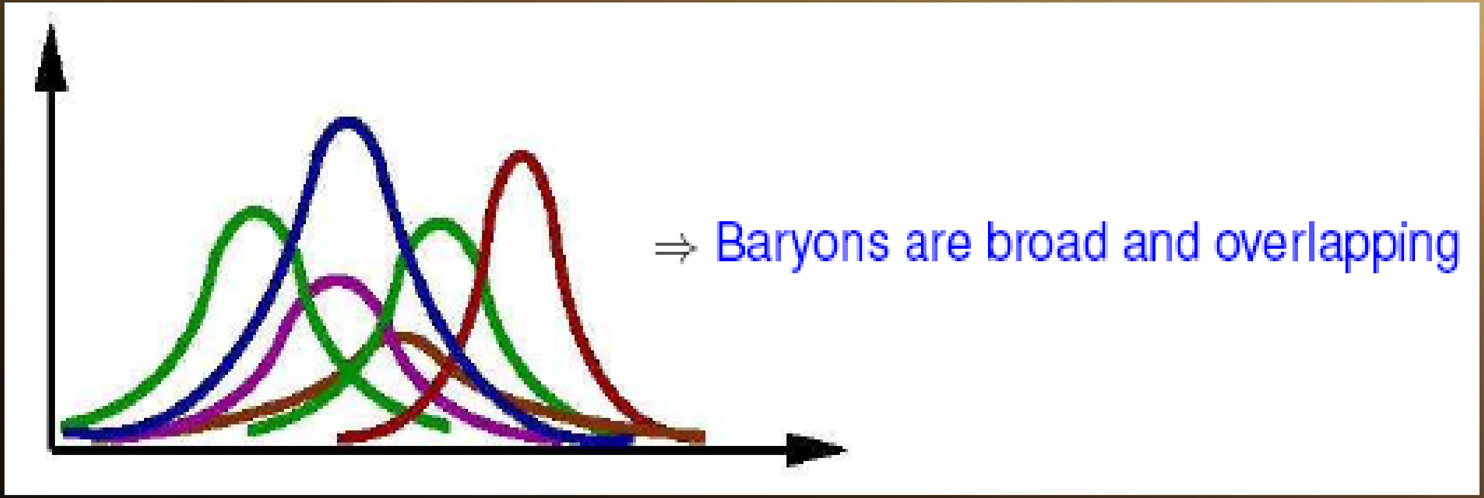
- Introduction
- Motivation for double-pion experiments
- Analysis of polarization data
- Experimental Setup
  - ➞ Polarized Photon Beam
  - ➞ Frozen Spin Target (FROST)

Problems in Hadron Spectroscopy

Excited states of the nucleon are not seen as cleanly separated spectral lines



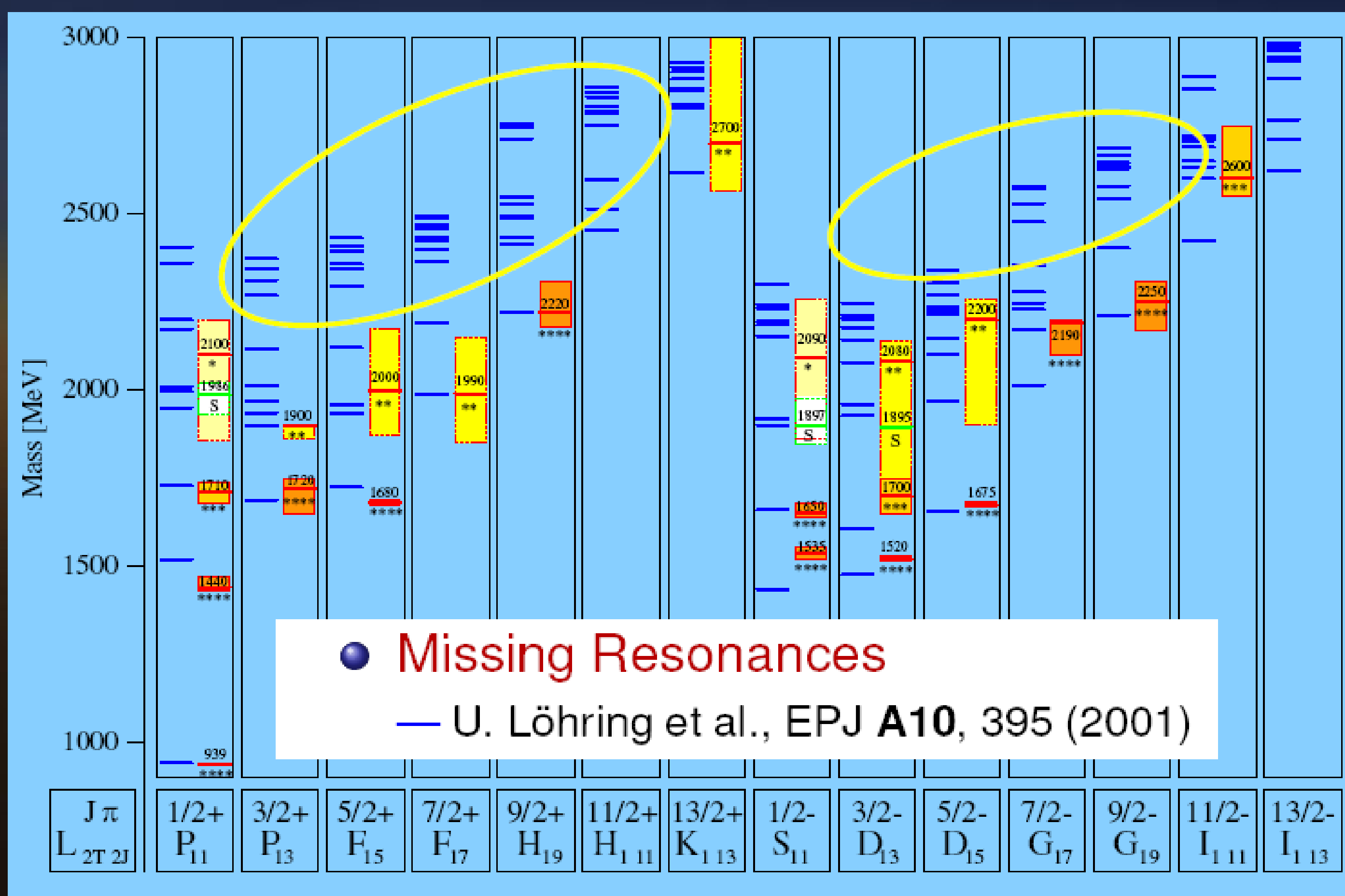
Instead we are faced with something like this:



We must find ways to identify excited states!!

Problems in Hadron Spectroscopy

- The QCD Lagrangian is not solvable at low energies
  ➞ No usable lattice-QCD predictions derived from fundamental quantum field theory yet.
- We do have Constituent Quark Models which show an overall good agreement with the well-established states.



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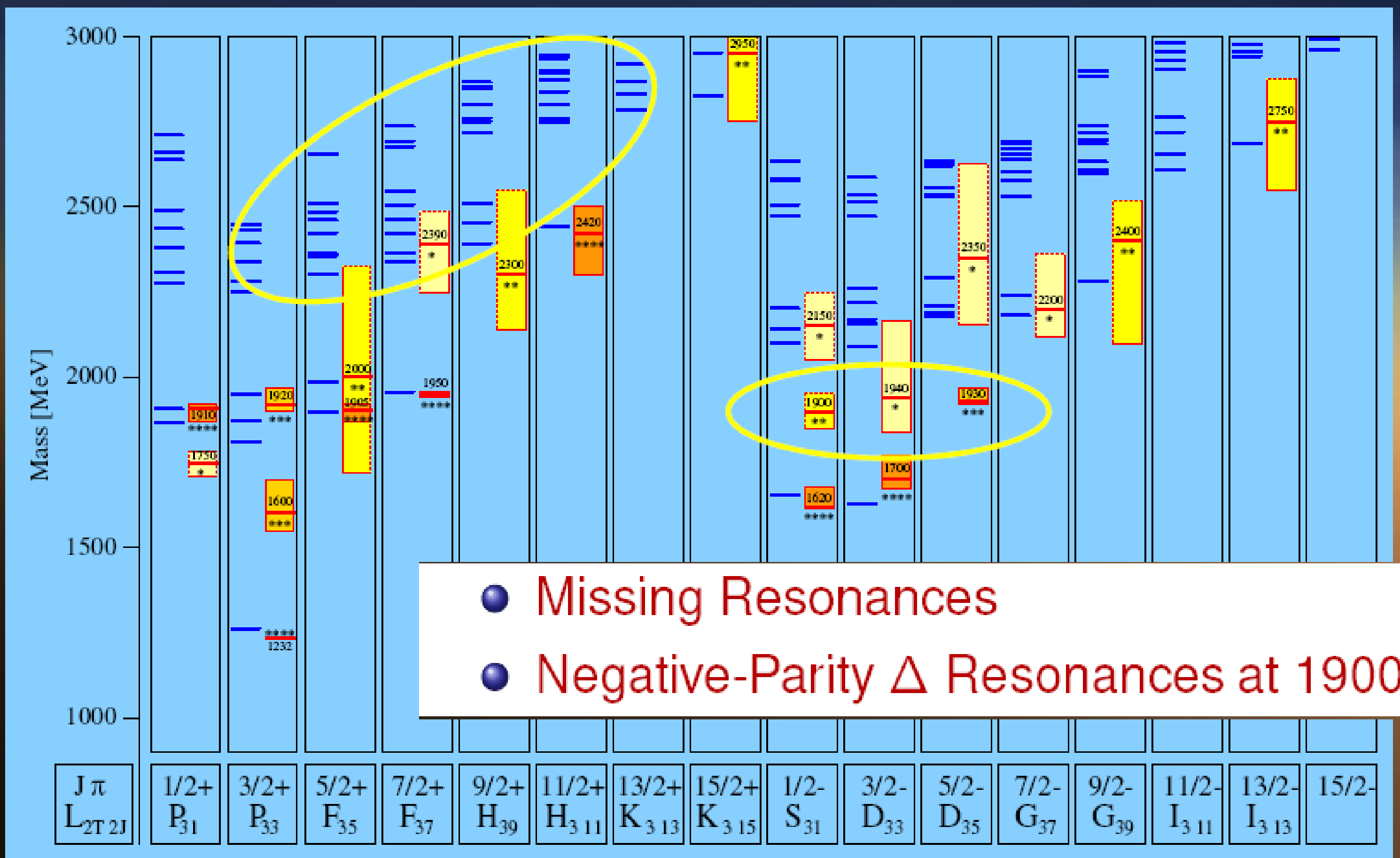


- Missing Resonances
- Negative-Parity Δ Resonances at 1900 MeV/c^2

Why have we not yet seen these states?

- Almost all existing data in baryon resonance production stems from πN scattering experiments (missing resonances may not couple to πN)
- Existing photoproduction data mainly covers a mass range up to 1800 MeV/c^2, while most of the missing states lie in the region $>$ 1900 MeV/c^2.
- Polarization has been available only for low energies → knowing the polarization observables is more crucial at higher energies for identifying these broad, overlapping resonances.
- Channels with more than one meson in the final state are still not explored ($\pi^+\pi^-$N, $\pi^0\pi^0$N, $\pi\eta$N).

Approved Photoproduction Experiment using Double-Polarization and the CLAS Spectrometer

- E02-112 : Search for Missing Nucleon Resonances in Hyperon Photoproduction
- E03-105 : Pion Photoproduction from a Polarized Target
- E04-102 : Helicity Structure of Pion Photoproduction
- E05-012 : Measurement of polarization observables in η-photoproduction with CLAS
- **E06-013 : Measurement of $\pi^+\pi^-$ Photoproduction in Double-Polarization Experiments using CLAS**

Analysis

- We have an equation for two meson final states which relates the reaction rate to the polarization observables.

$$I = I_0 \{(1 + \Lambda_i \bullet \mathbf{P}) + \delta_{\odot}(\mathbf{I}^{\odot} + \Lambda_i \bullet \mathbf{P}^{\odot}) + \delta_l [\sin 2\beta(\mathbf{I}^{s} + \Lambda_i \bullet \mathbf{P}^{s})$$

$$\cos 2\beta(\mathbf{I}^{c} + \Lambda_i \bullet \mathbf{P}^{c})]\} \rightarrow$$ <u>15 Observables!!!</u>

I_0 = unpolarized reaction rate

Λ_i = degree of polarization of target

$\mathbf{P}$ = polarization observable

$\delta_{\odot, l}$ = degree of polarization of photon beam

$\mathbf{I}^{\odot, s, c}$ = observable arising from use of polarized photons

β = orientation of linear polarization

Analysis

- Using different polarization configurations, we can begin to isolate each polarization observable.
- For example: circularly polarized photon beam incident on longitudinally polarized target.

$$(\rightarrow\Rightarrow \; - \; \leftarrow\Rightarrow) := \frac{d\sigma(\rightarrow\Rightarrow)}{dx_i} - \frac{d\sigma(\leftarrow\Rightarrow)}{dx_i} = 2\cdot\sigma_0\{\delta_\odot(\boldsymbol{I}^\odot + \Lambda_z\cdot\boldsymbol{P}_z^\odot)\}$$

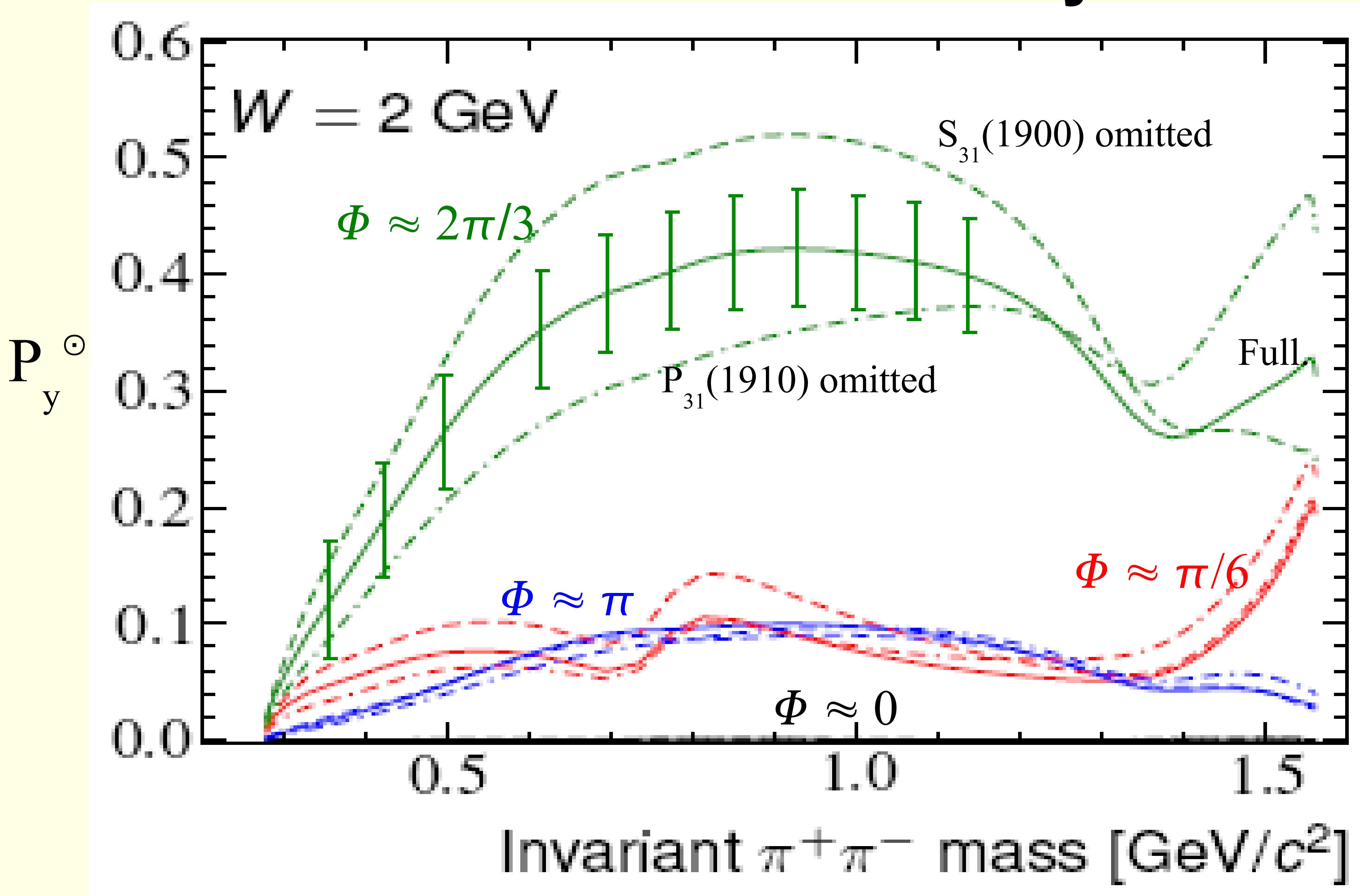
$$(\leftarrow\Leftarrow \; - \; \rightarrow\Leftarrow) := \frac{d\sigma(\leftarrow\Leftarrow)}{dx_i} - \frac{d\sigma(\rightarrow\Leftarrow)}{dx_i} = 2\cdot\sigma_0\{\delta_\odot(-\boldsymbol{I}^\odot + \Lambda_z\cdot\boldsymbol{P}_z^\odot)\}$$

$$\Downarrow$$

$$(\rightarrow\Rightarrow - \leftarrow\Rightarrow) + (\leftarrow\Leftarrow - \rightarrow\Leftarrow) := \frac{d\sigma_{3/2}}{dx_i} - \frac{d\sigma_{1/2}}{dx_i} = 4\cdot\sigma_0\cdot\delta_\odot\cdot(\Lambda_z\cdot\boldsymbol{P}_z^\odot)$$

Now we can determine the value of the polarization observable (like $\boldsymbol{P}_z^\odot$*)*

Resonance Sensitivity



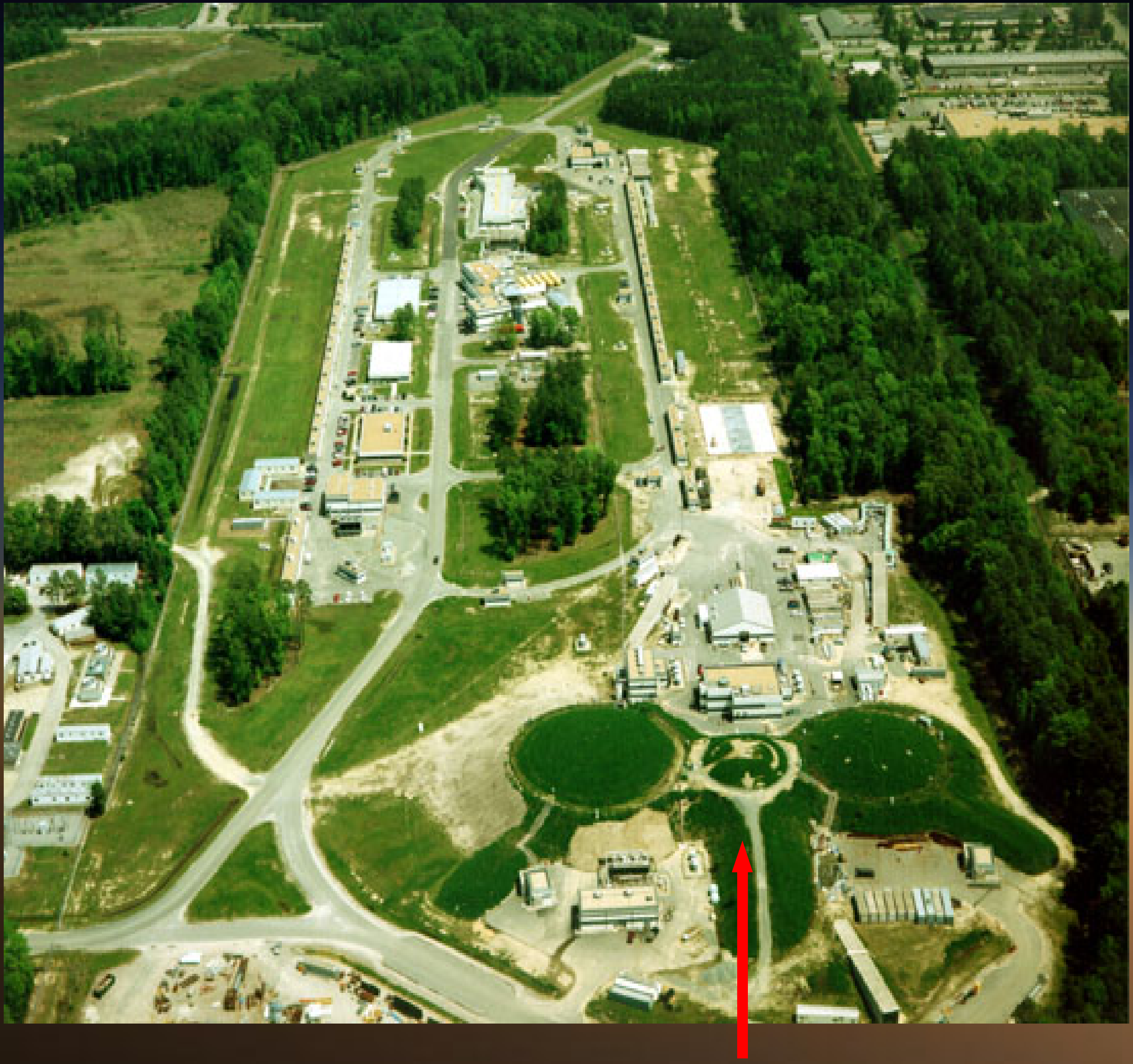
Theory : Dr. W. Roberts
PAC Proposal E05-013

Absolute anticipated error of 0.05

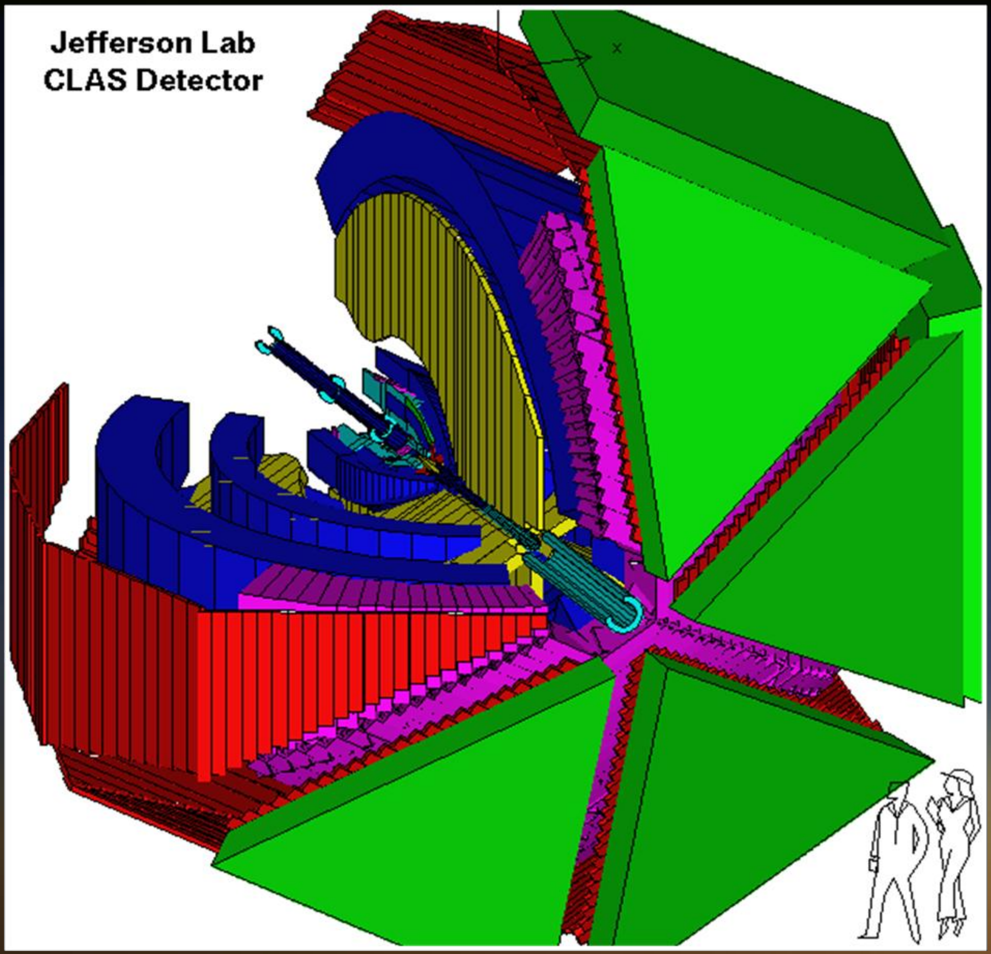
How can we determine the polarization observables?

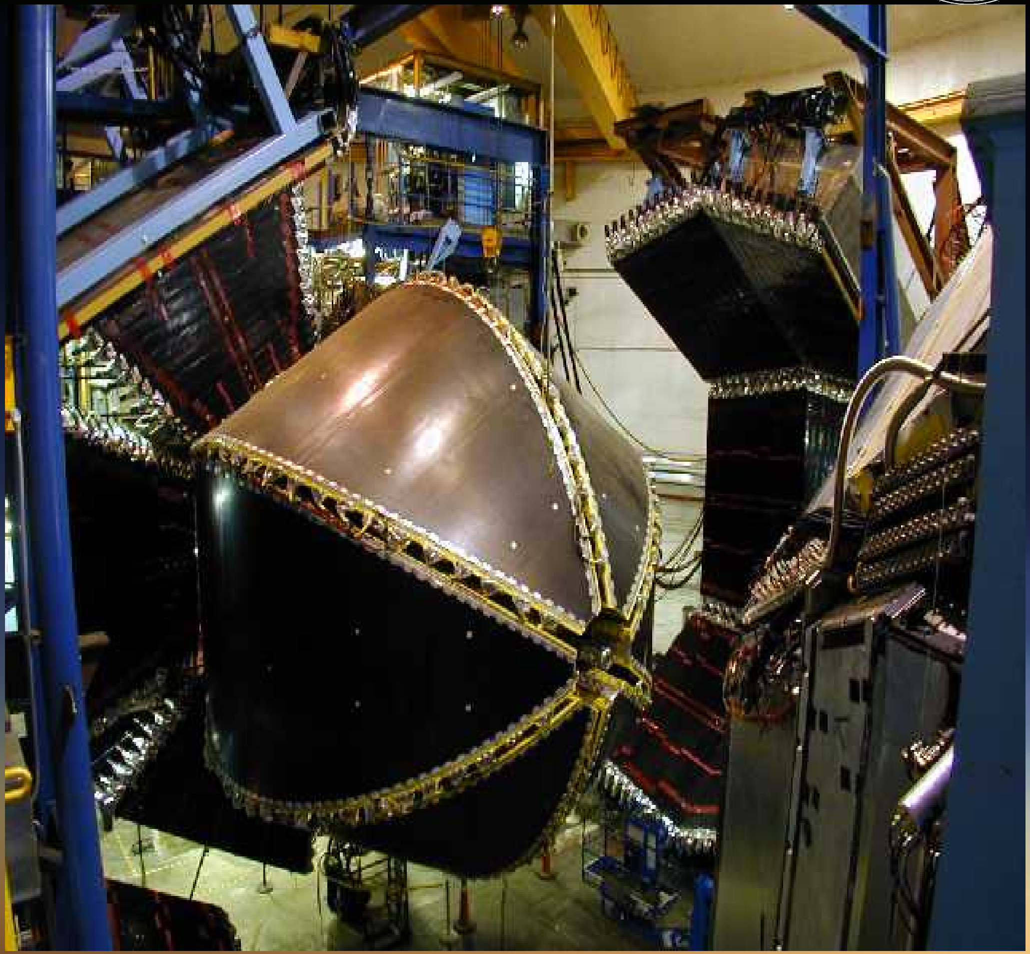
We need both a polarized beam and target!!!

The Facility : Jefferson Lab in Newport News, VA



The Hall : Hall B





- Yellow : Torus Magnet
- Blue : Drift Chambers
- Purple : Cerenkov Counters
- Red : Time of Flight Scintillators
- Green : Electromagnetic Calorimeters

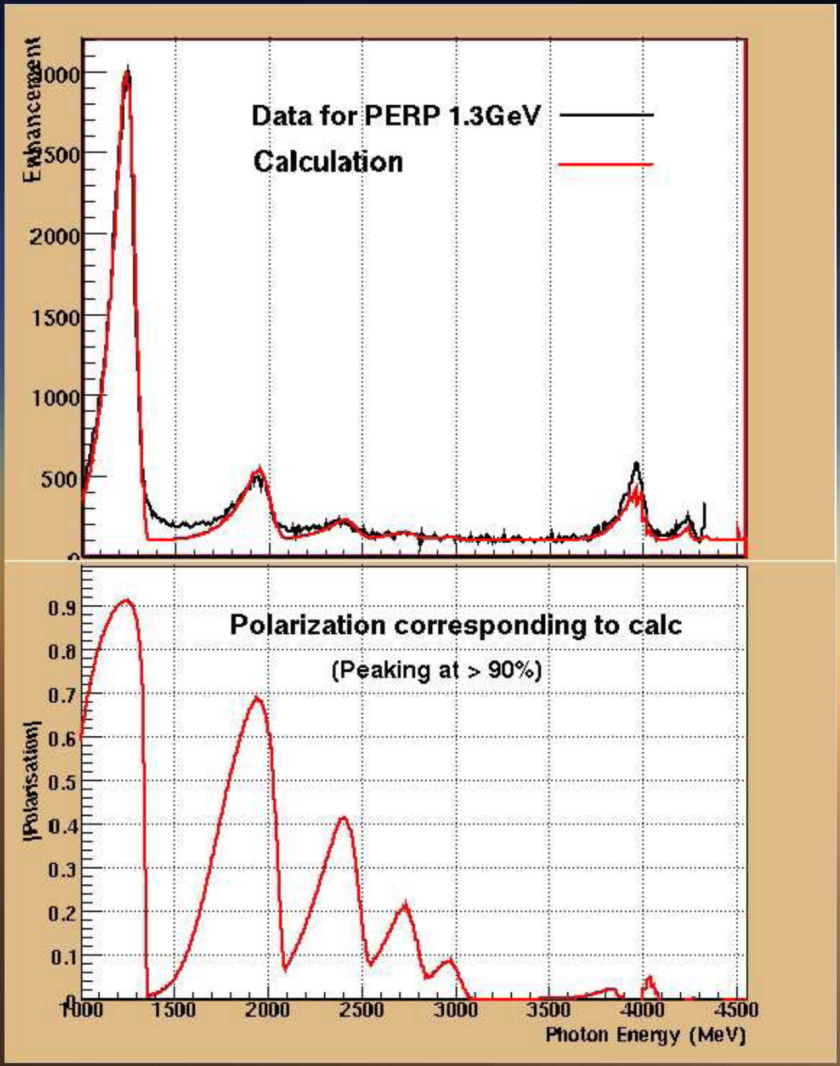
Polarized Photon Beam

- Longitudinal electron beam + gold foil radiator = circularly polarized photon beam

Can obtain 60 – 90% of electron beam polarization with a maximum electron polarization of 85% ➞ max photon polarization : 76.5%

- Unpolarized electron beam + diamond radiator = linearly polarized photon beam

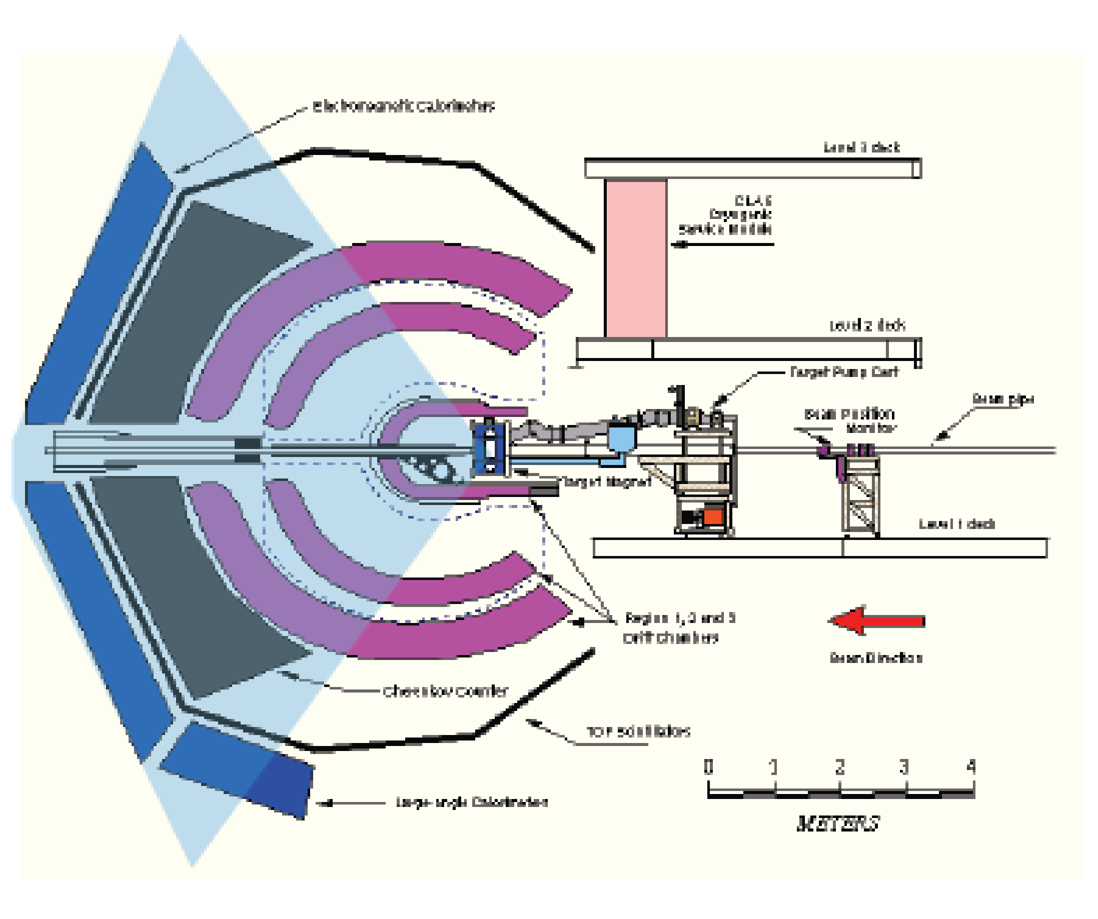
Can obtain 90% polarization



Current Hall B Polarized Target

- Uses superconducting solenoid magnet resulting in a longitudinally polarized target.
- Protons (and deuterons) in NH_3 (ND_3) are continuously polarized by 140 GHz microwaves at 5 T and 1 K.
- Used for several experiments over a 10 month period at a beam current of 3 nA.

Current Hall B Polarized Target



- Opening limited to 55 degrees in the forward direction.
- We have a 4π detector so therefore we should have a 4π target.

Frozen Spin Target (FROST)

- Uses a butanol (C_4H_9OH) target.
- Can produce a longitudinally as well as transversely polarized target.
- Polarization occurs outside of CLAS which greatly minimizes the amount of material between the target and CLAS.

Polarization Technique : Brute Force

- Any atom or nuclei with a magnetic moment can be polarized via the Zeeman effect.
- Because of EM fields produced from atomic vibrations, polarization degrades quickly.
- Requires a very large magnet, which severely limits detection capabilities.
- No good for us!!

Dynamic Nuclear Polarization (DNP)

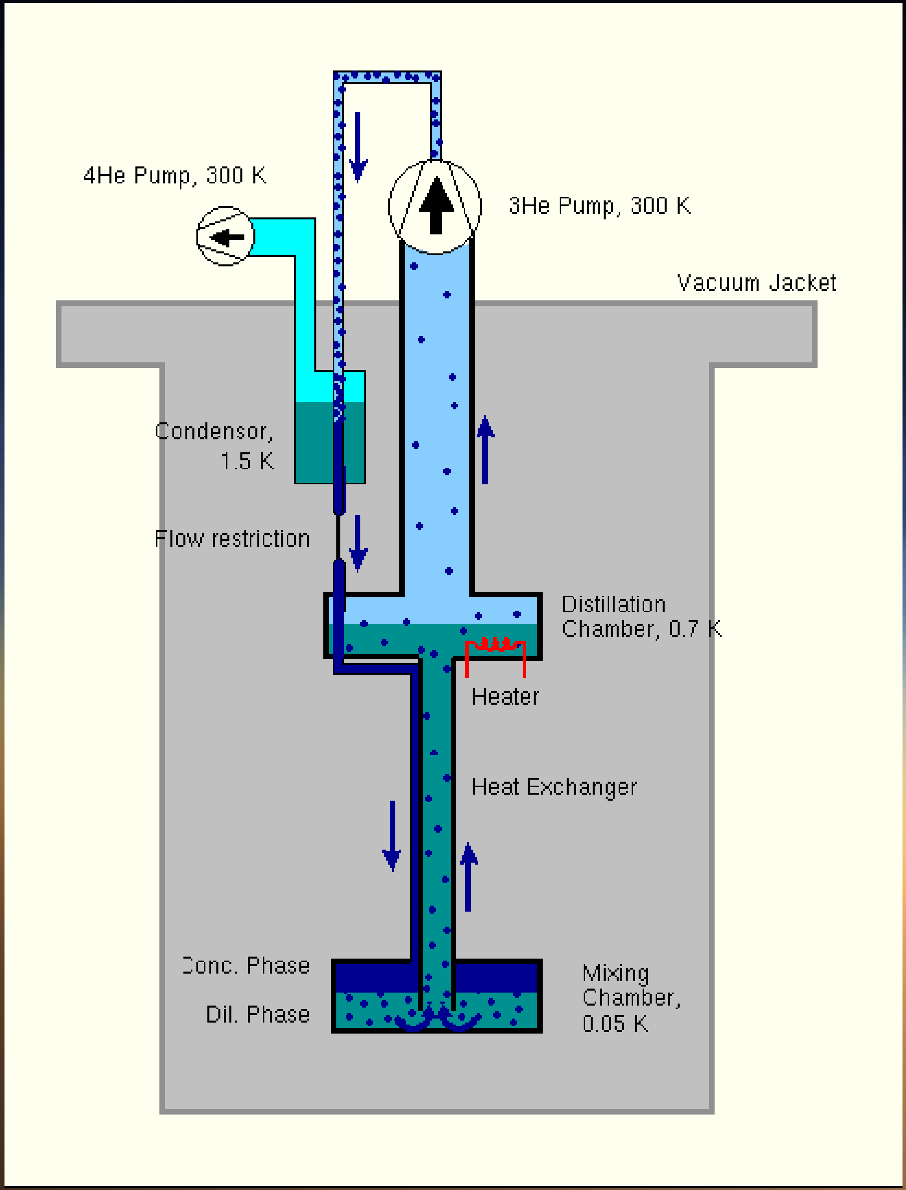
- Brute force is used to polarize the free electrons in target with a 5 T magnetic field at a temperature of $\leq$1 K.
- Use microwaves to “transfer” this polarization to the nuclei.
- Free electrons must be embedded into target material.
- Typically 1 free electron can “service” about 10^3 free protons.

Frozen Spin Target (FROST)

1) Use pump cart to bring in liquid helium (4.2 K)

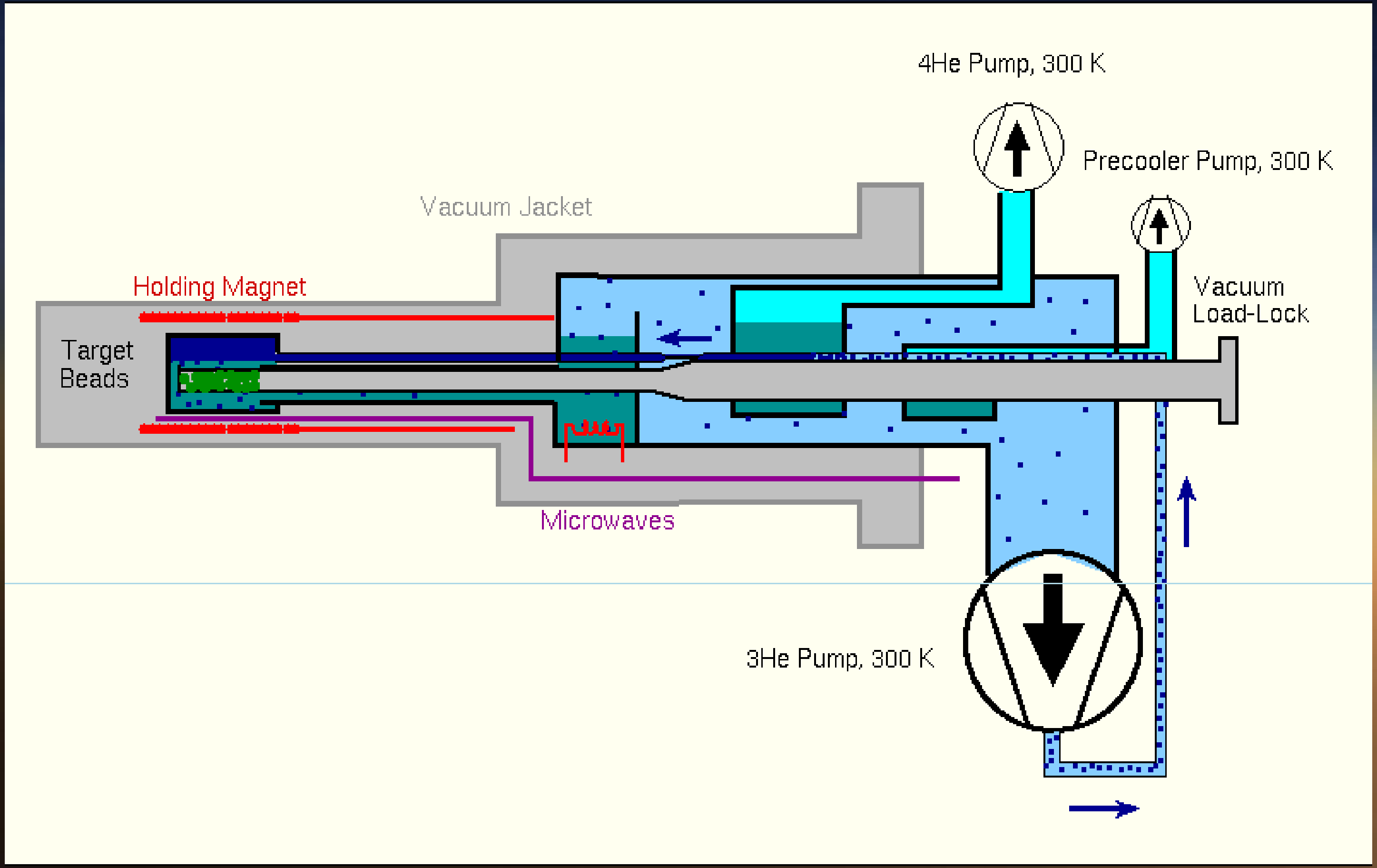
2) Evaporative cooling and heat exchange to ~ 1.2 K

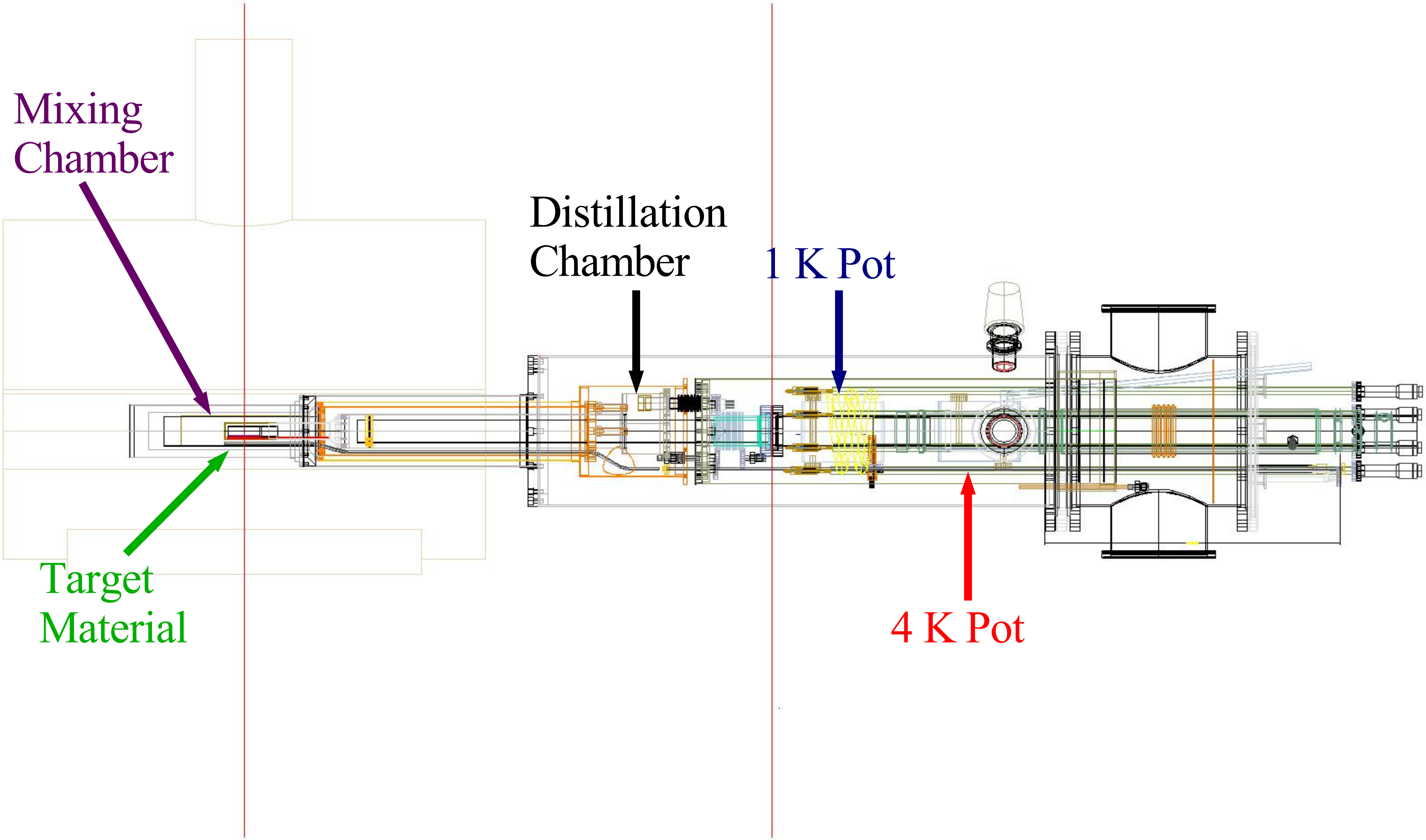
3) Dilution refrigeration at 50 mK



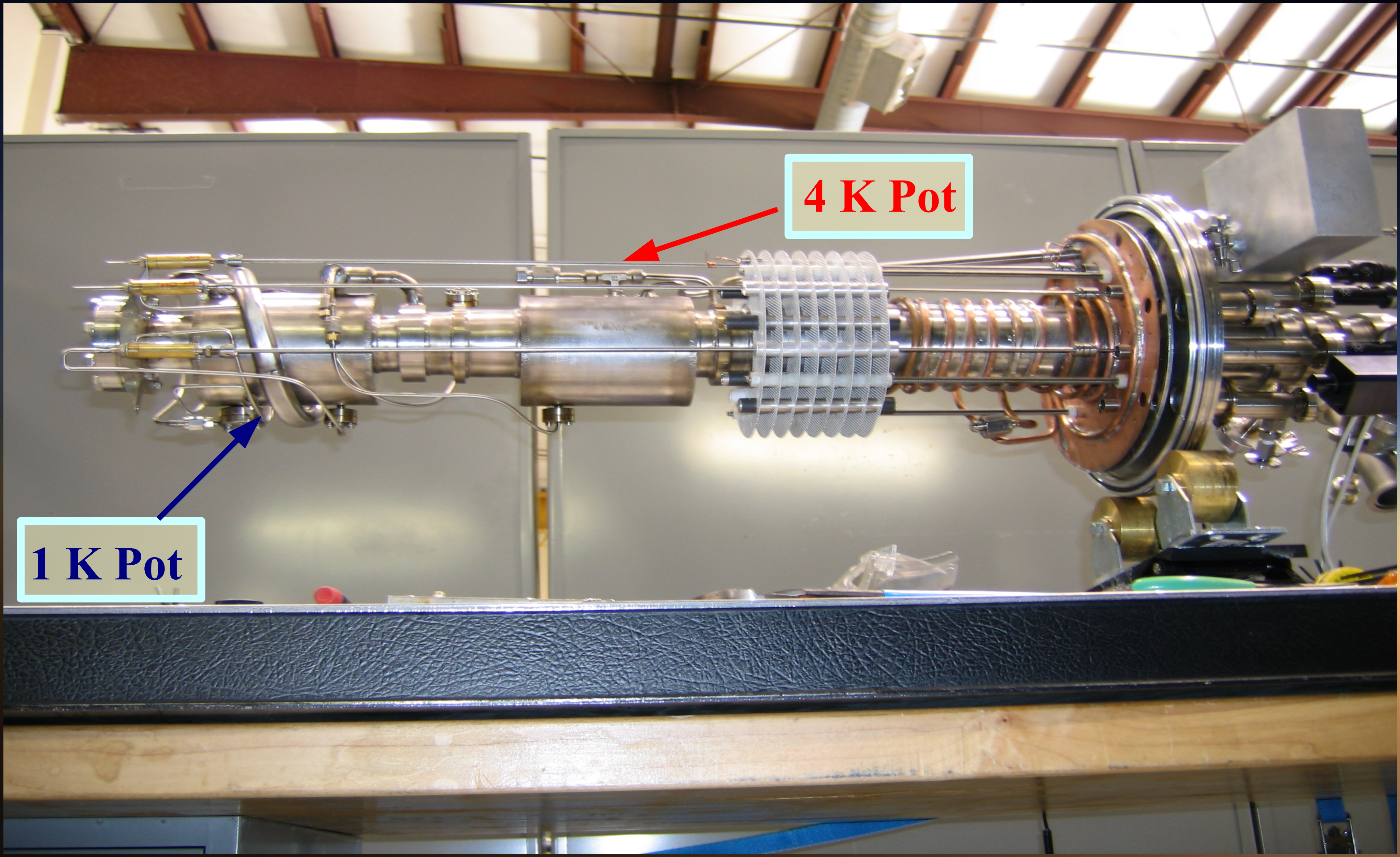
Frozen Spin Target (FROST)

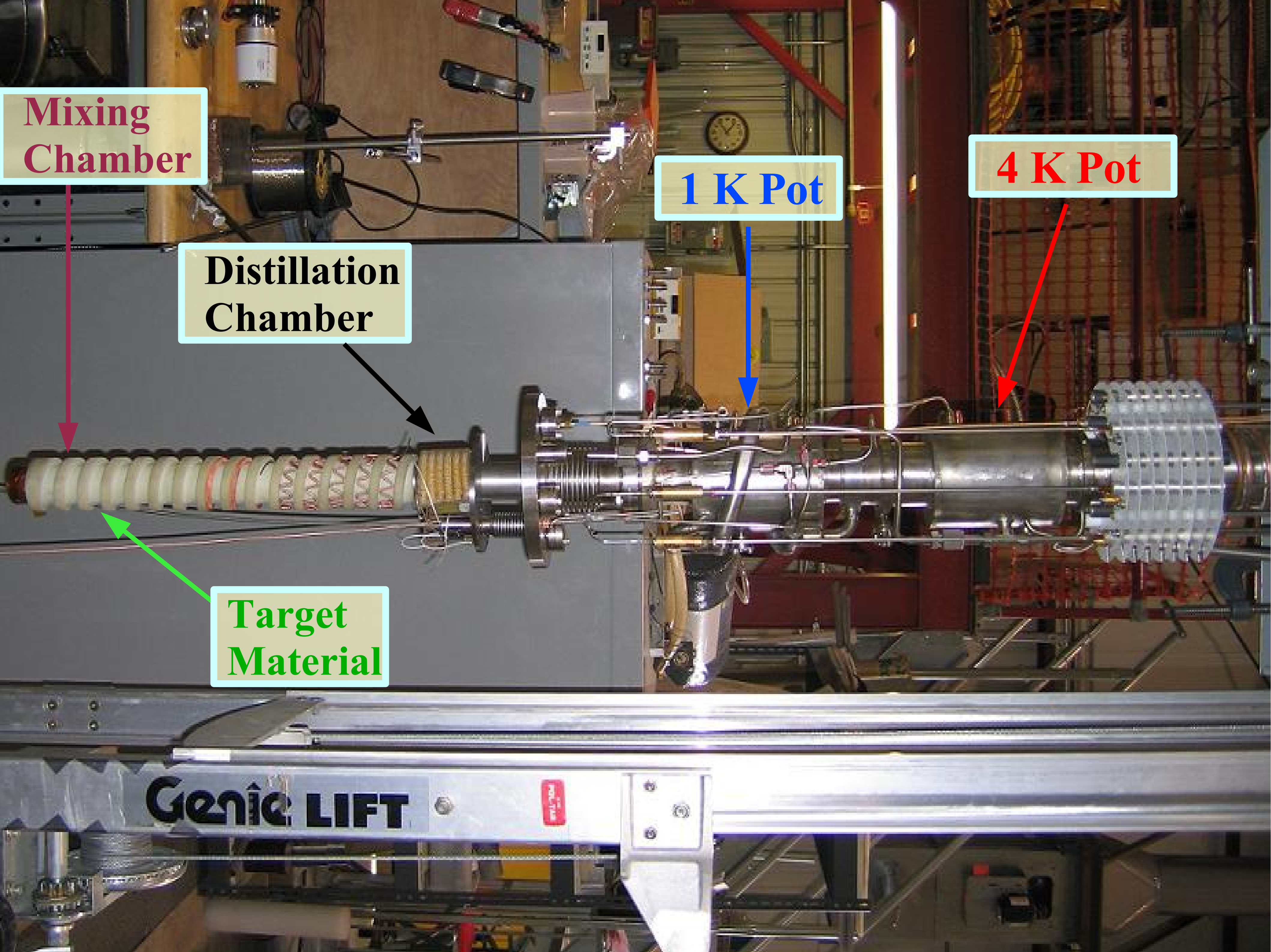
Horizontal dilution refrigeration is more difficult because it does not follow the natural path of warm/cold.




Mixing Chamber
Distillation Chamber
1 K Pot
Target Material
4 K Pot

Frozen Spin Target (FROST)




Mixing Chamber
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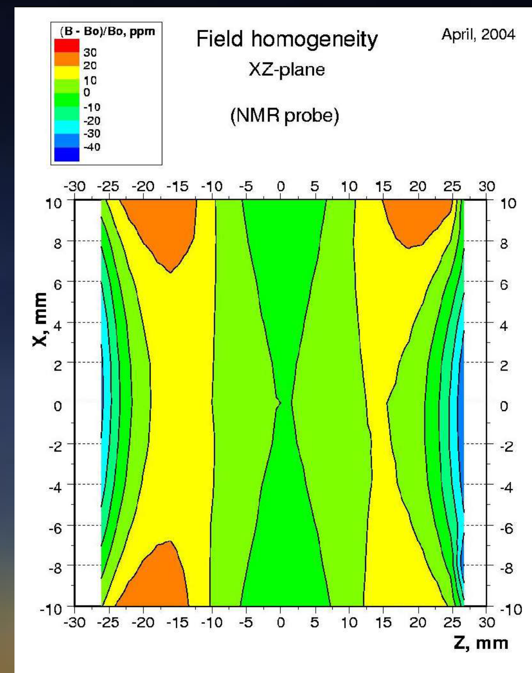
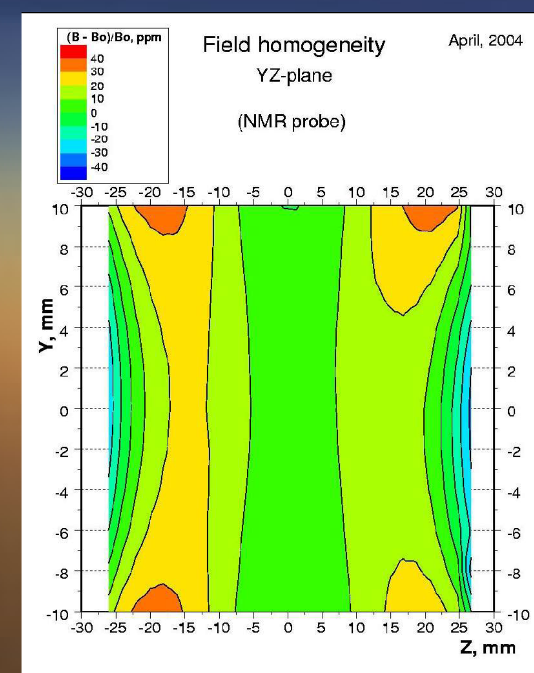
Genie LIFT

The Magnets

- Polarizing Magnet

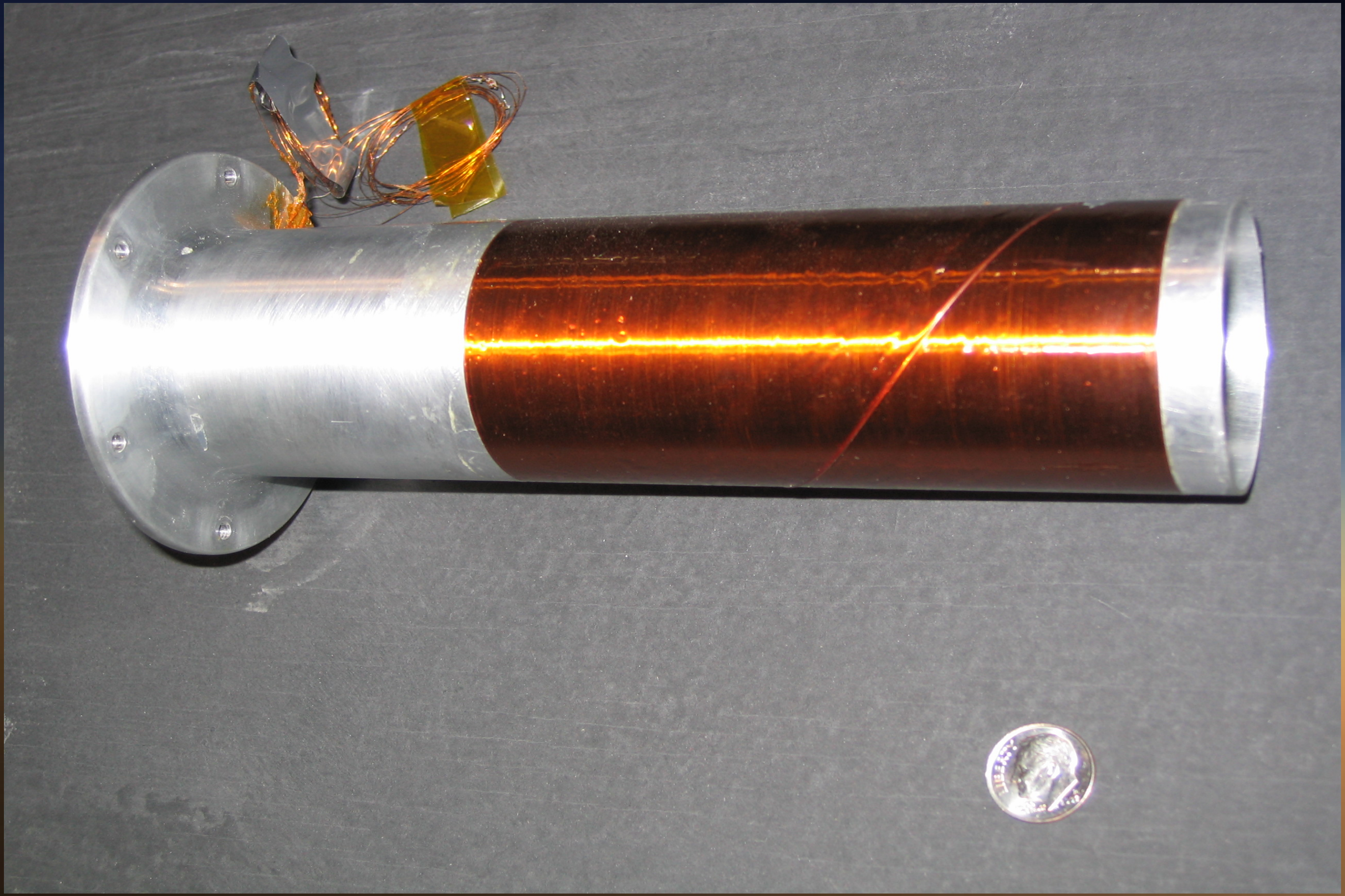




$B \simeq 5.1$ T

The Magnets

- Longitudinal Holding Magnet



$B \simeq 0.32$ T

Homogeneity $< 0.5\%$

The Magnets

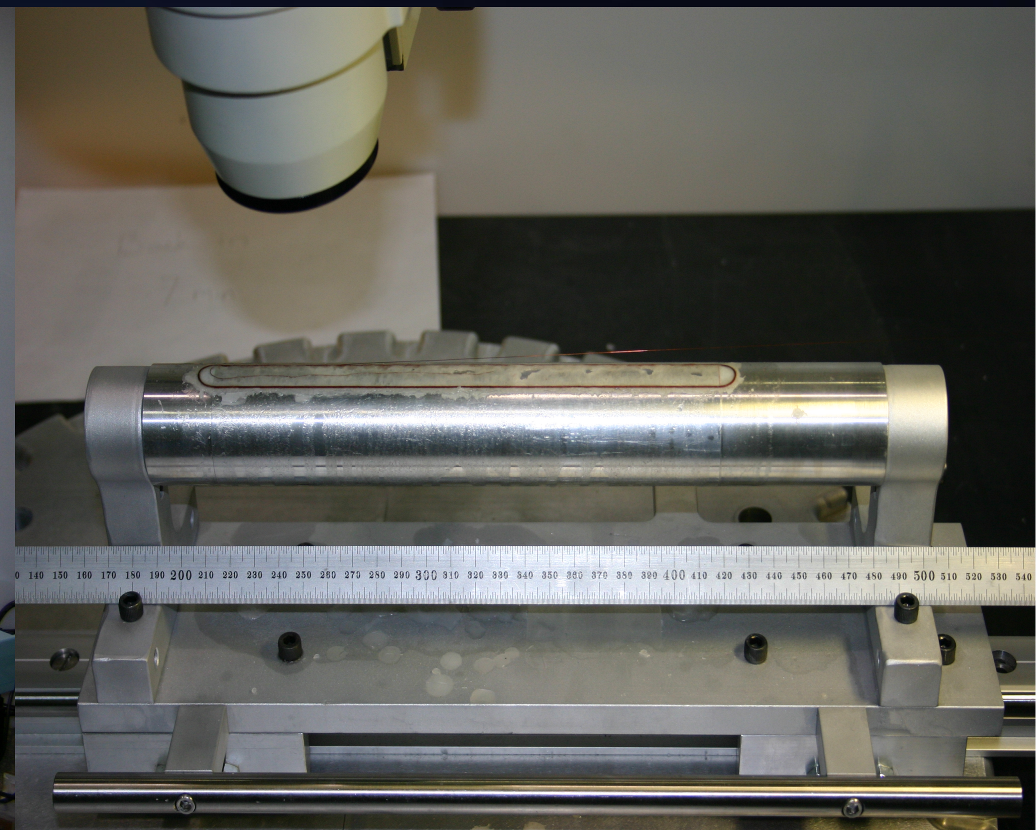
- Transverse Holding Magnet

$B \approx 0.5$ T

Homogeneity < 0.8%

Currently undergoing cold testing . . . . .

Construction of Transverse Holding Magnet



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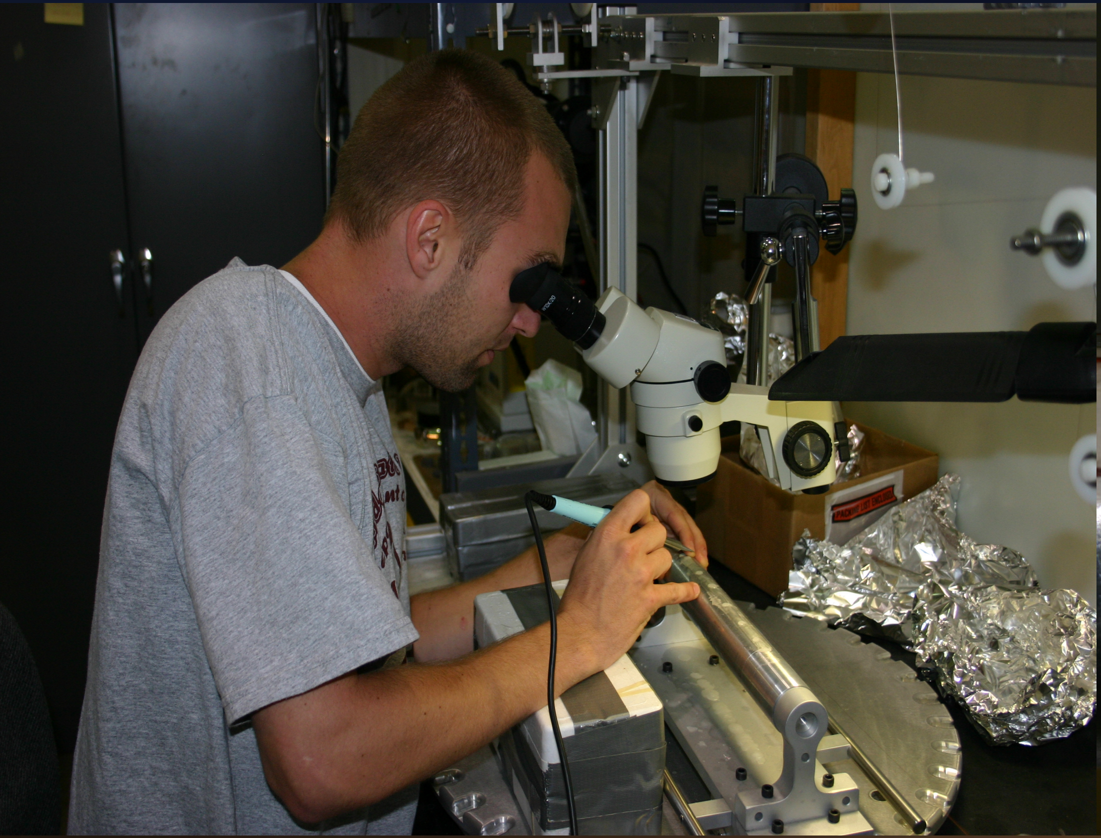
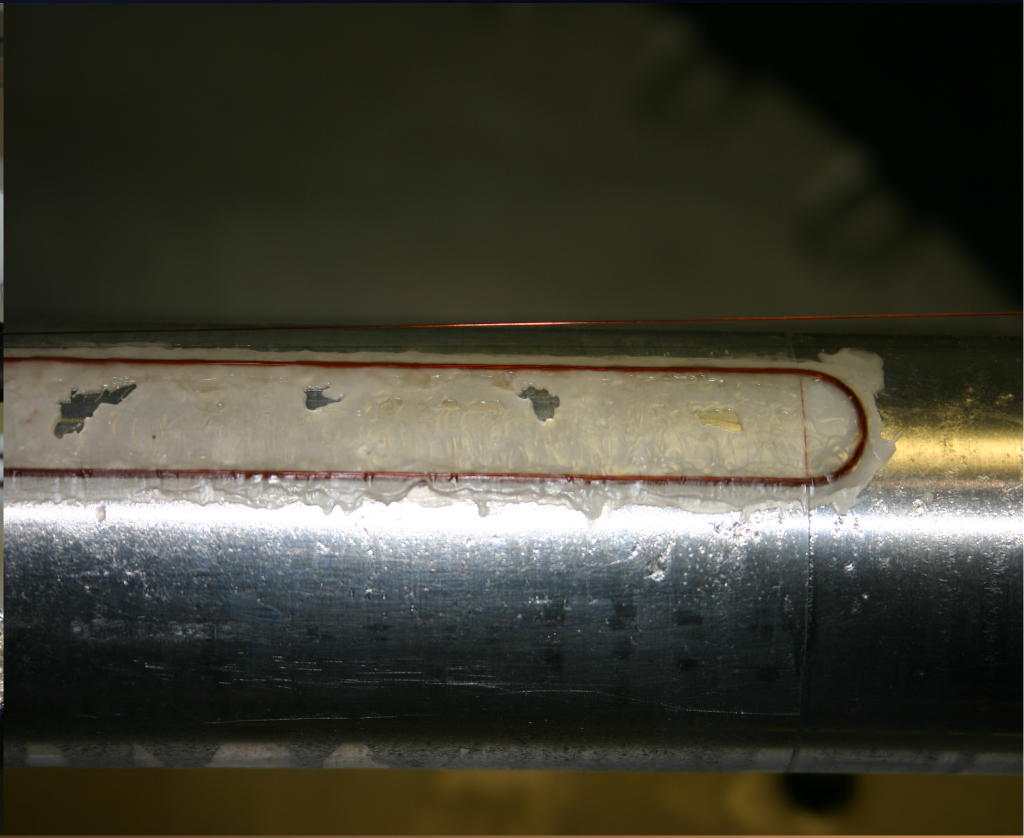
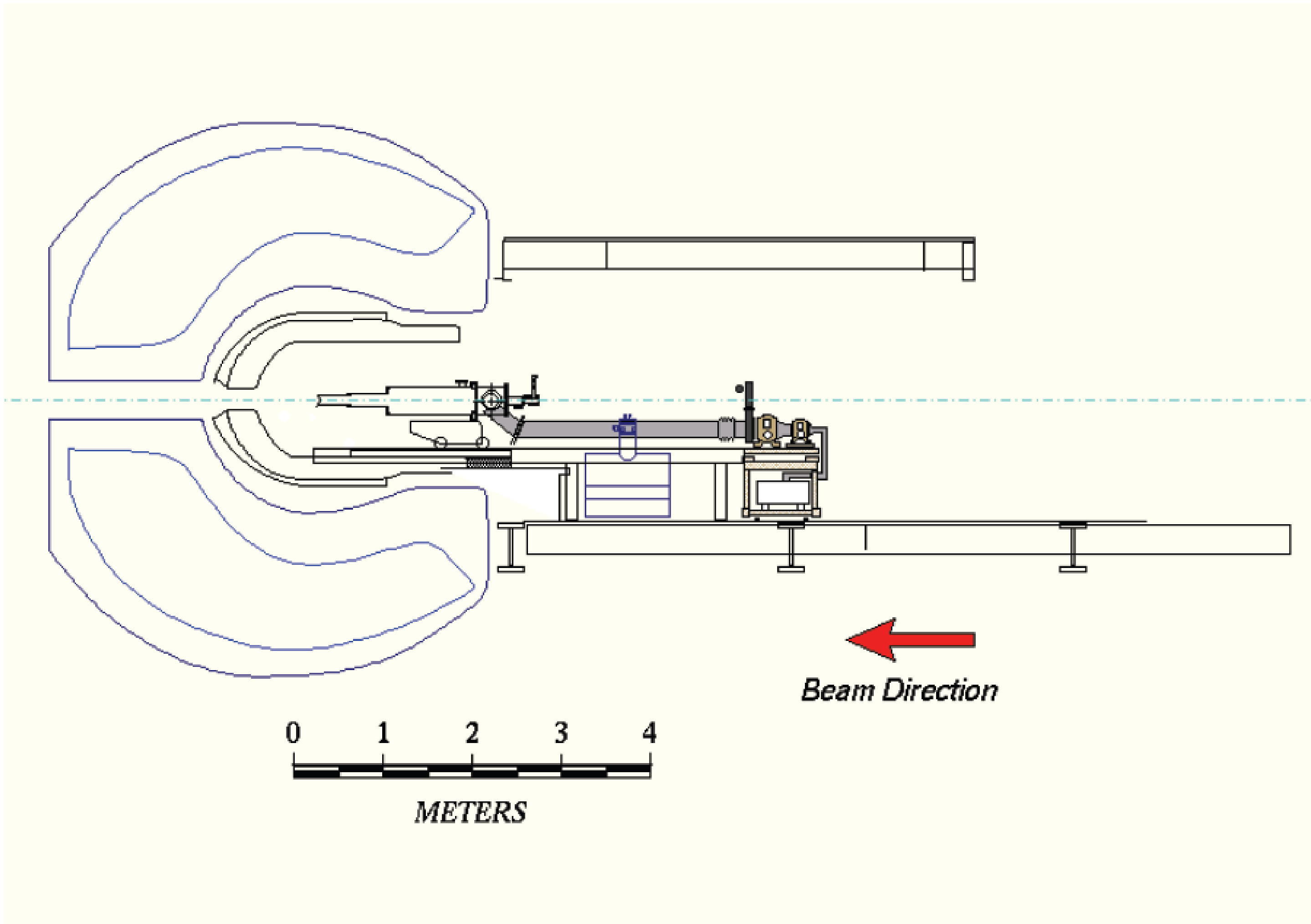




Polarization Process

- Once target polarization has reached ½ of original degree of polarization, it is removed from CLAS.
- Polarizing magnet is lifted to beam height and target is inserted.
- Polarize target via DNP.
- Once optimum polarization is achieved, turn off microwaves and ramp down magnet.
- Ramp up holding magnet (~0.5 T) and lower target temperature to 50mK, “freezing” the spin.
- Fully retract target, lower polarizing magnet.
- Insert target into center of CLAS



Beam Direction
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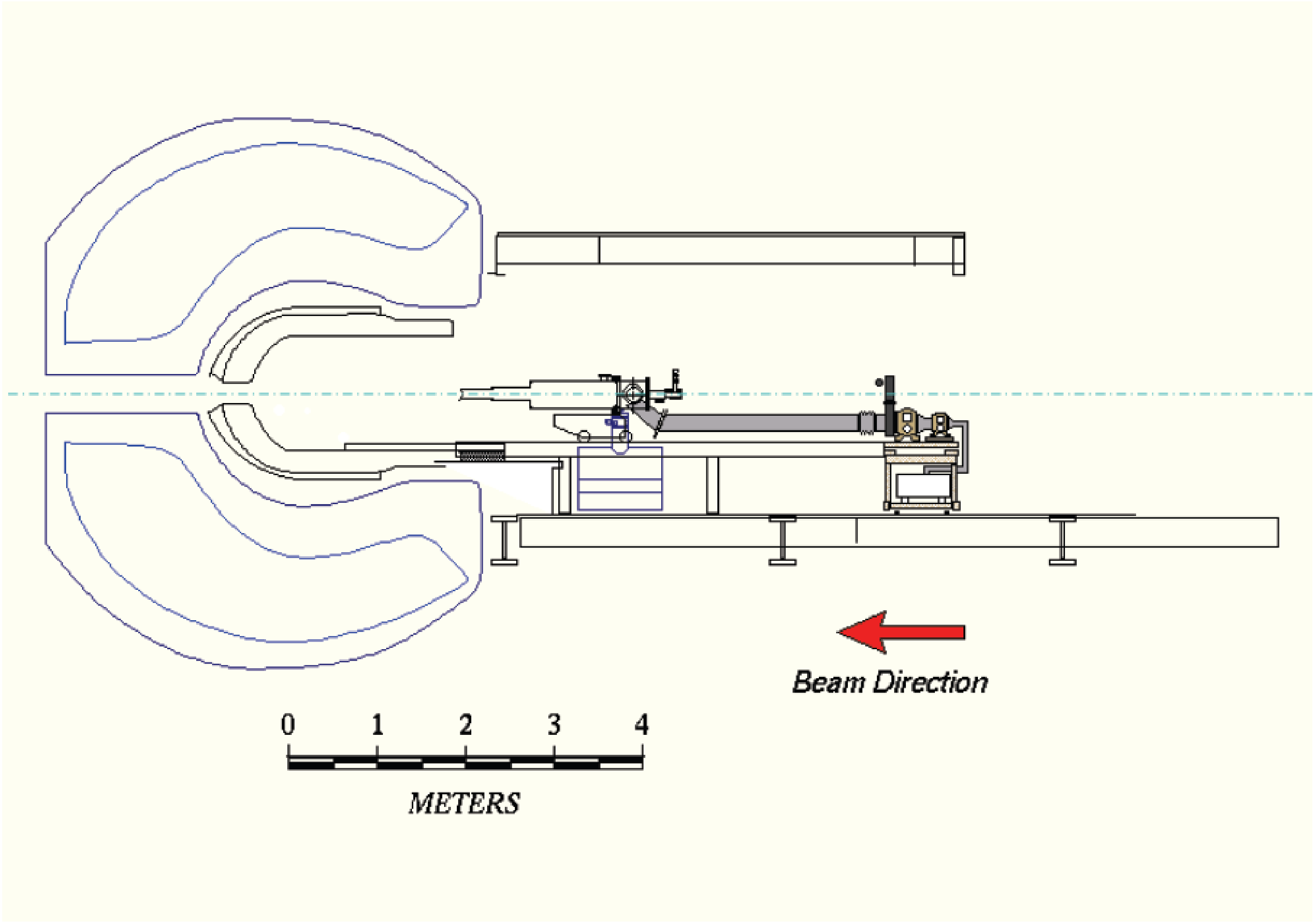
1
2
3
4
METERS



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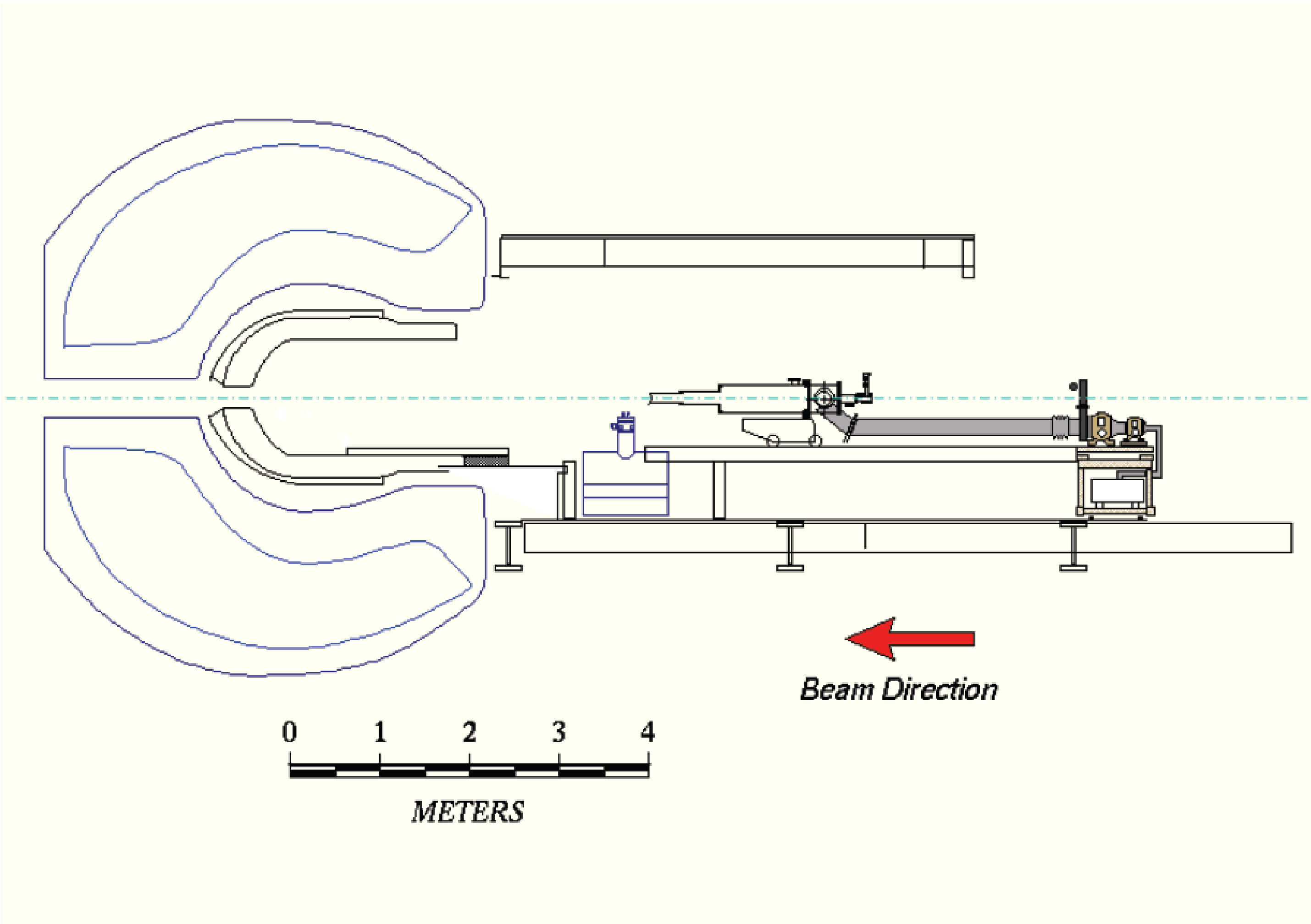

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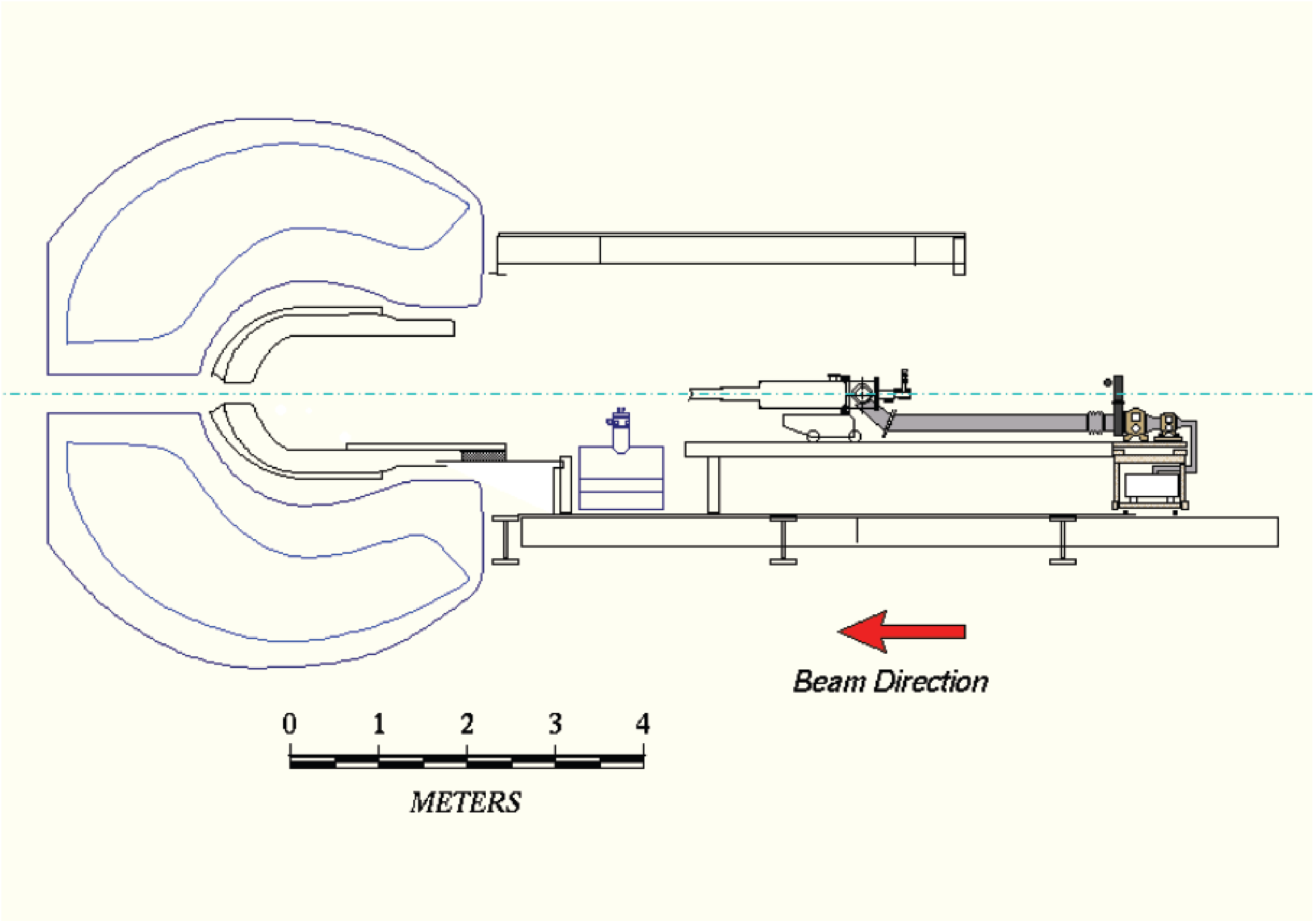

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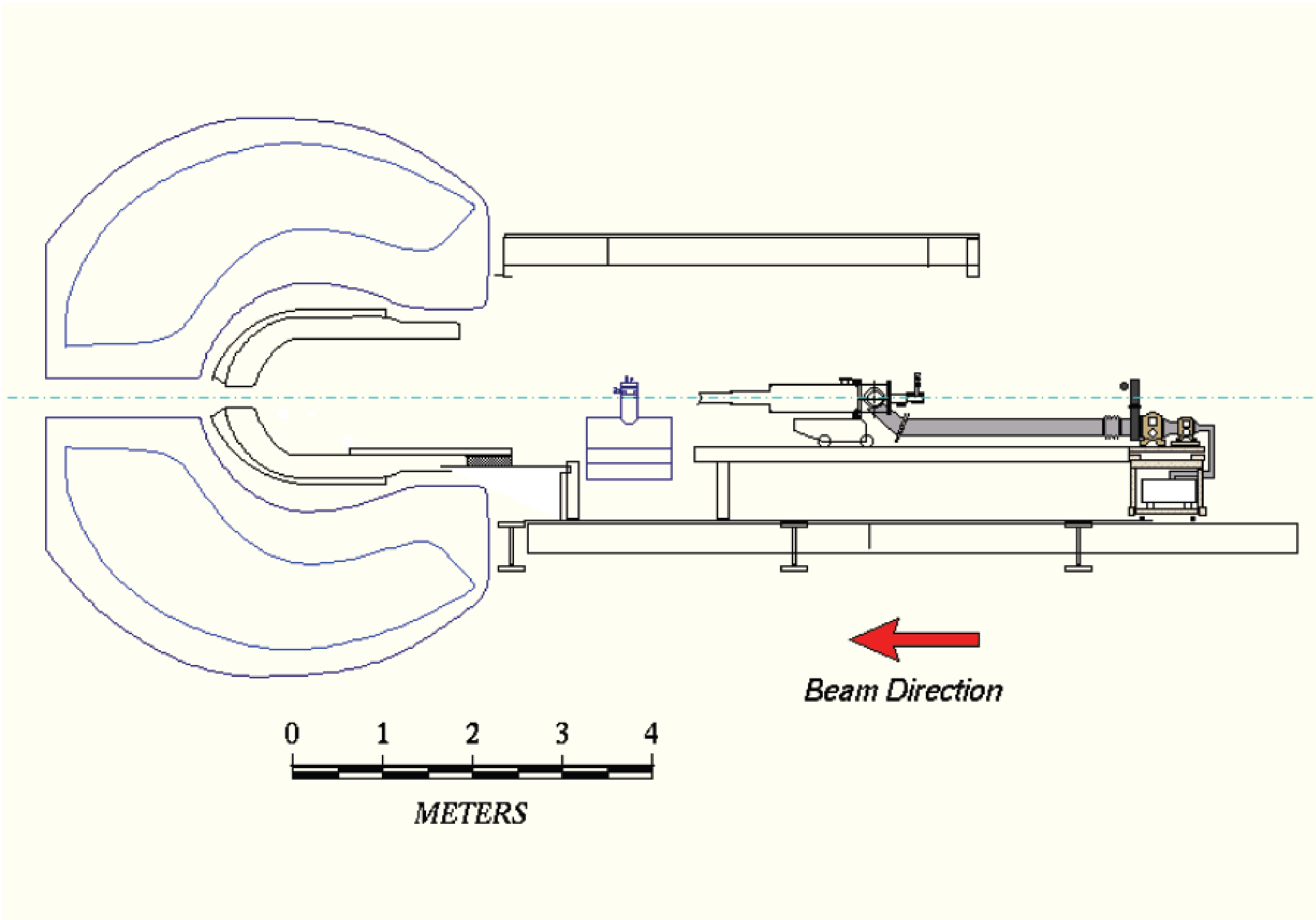
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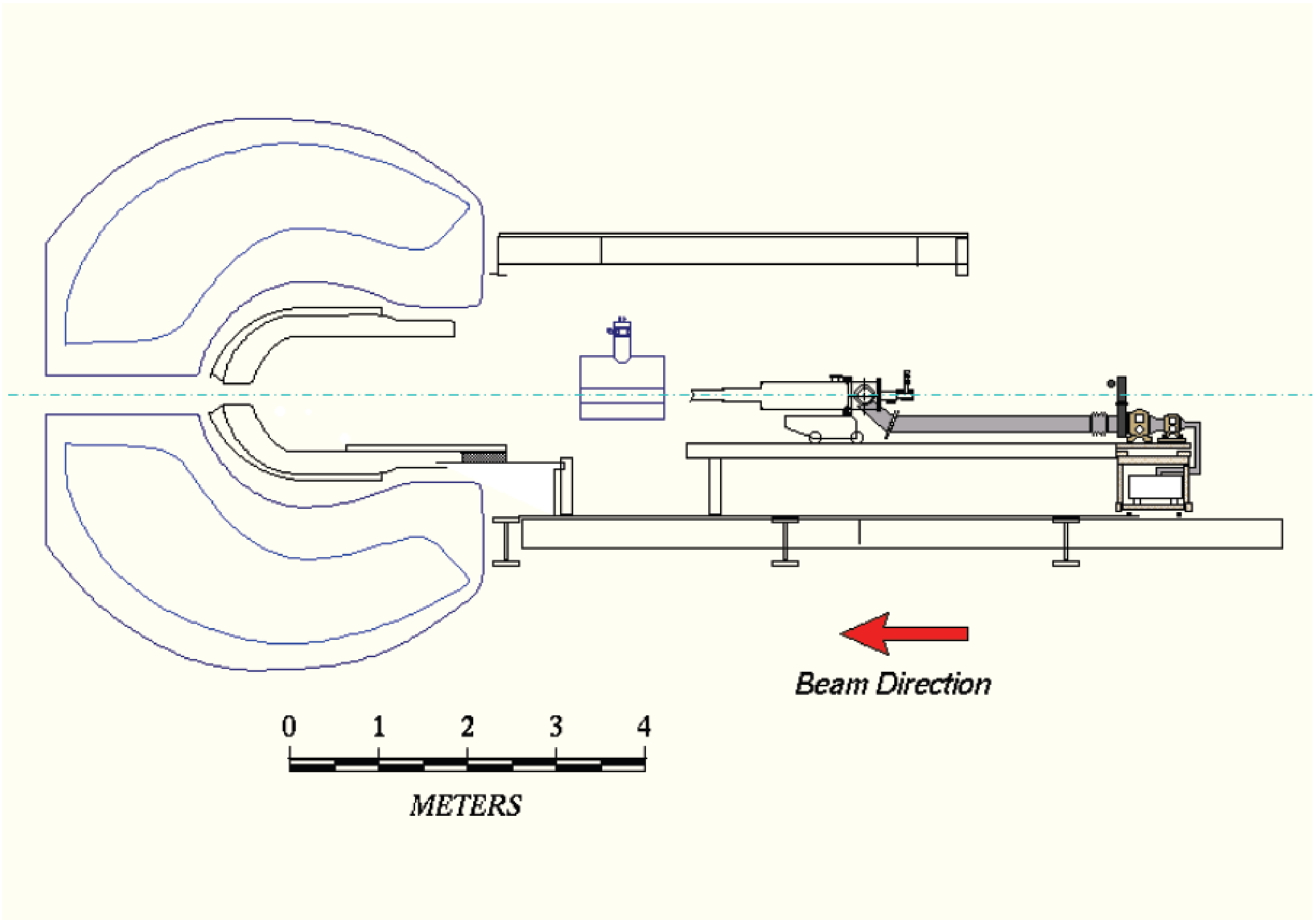
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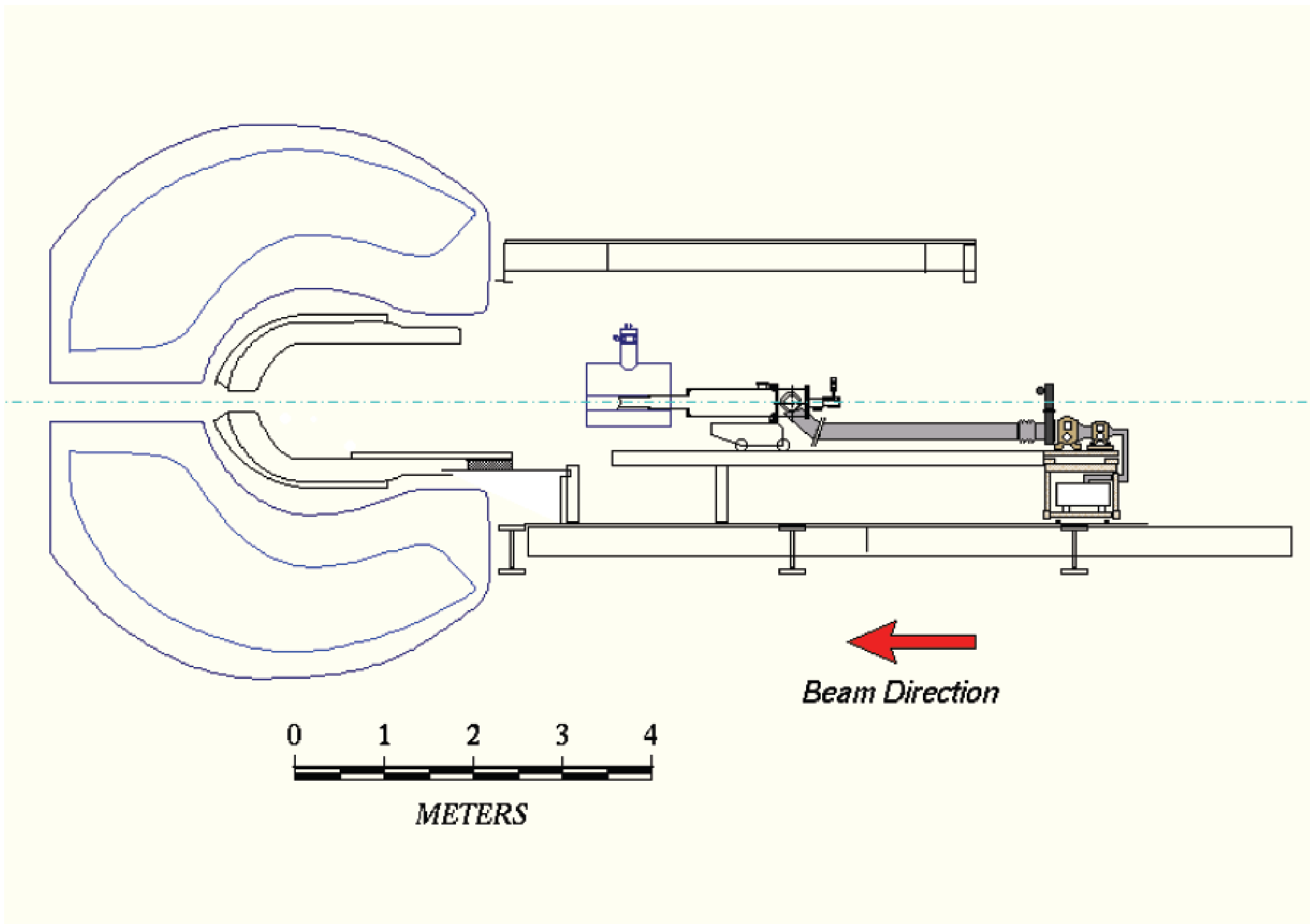

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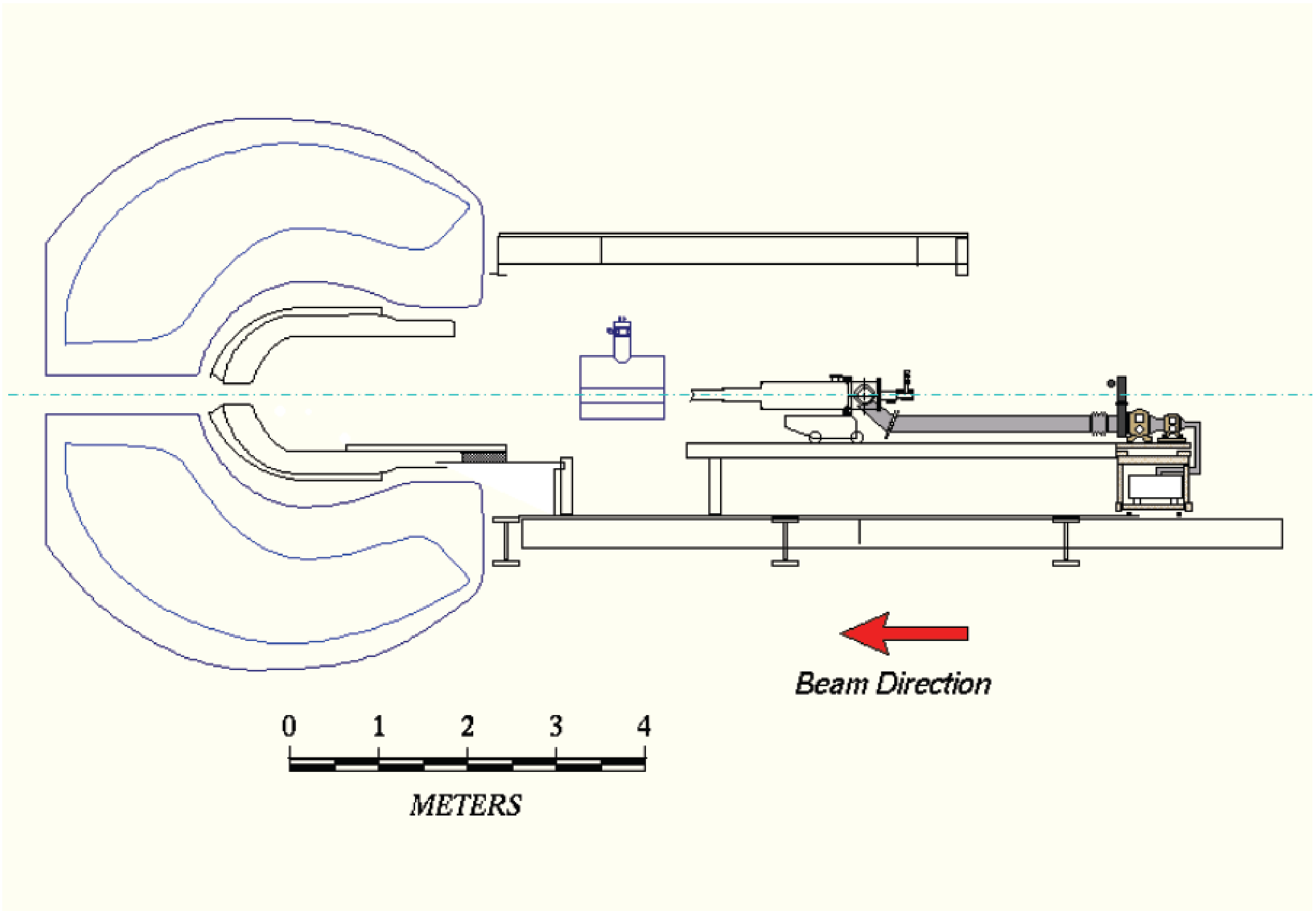

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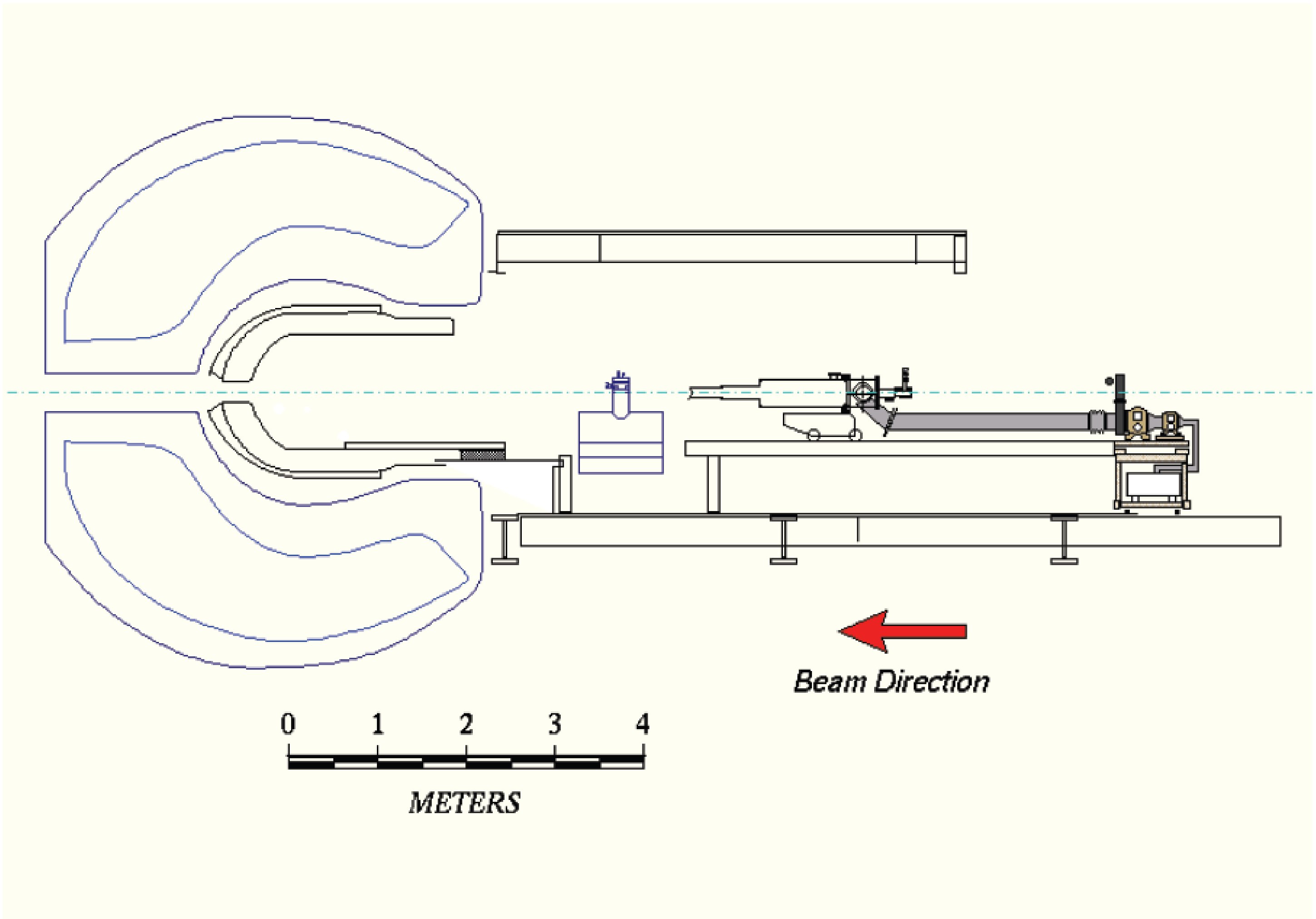

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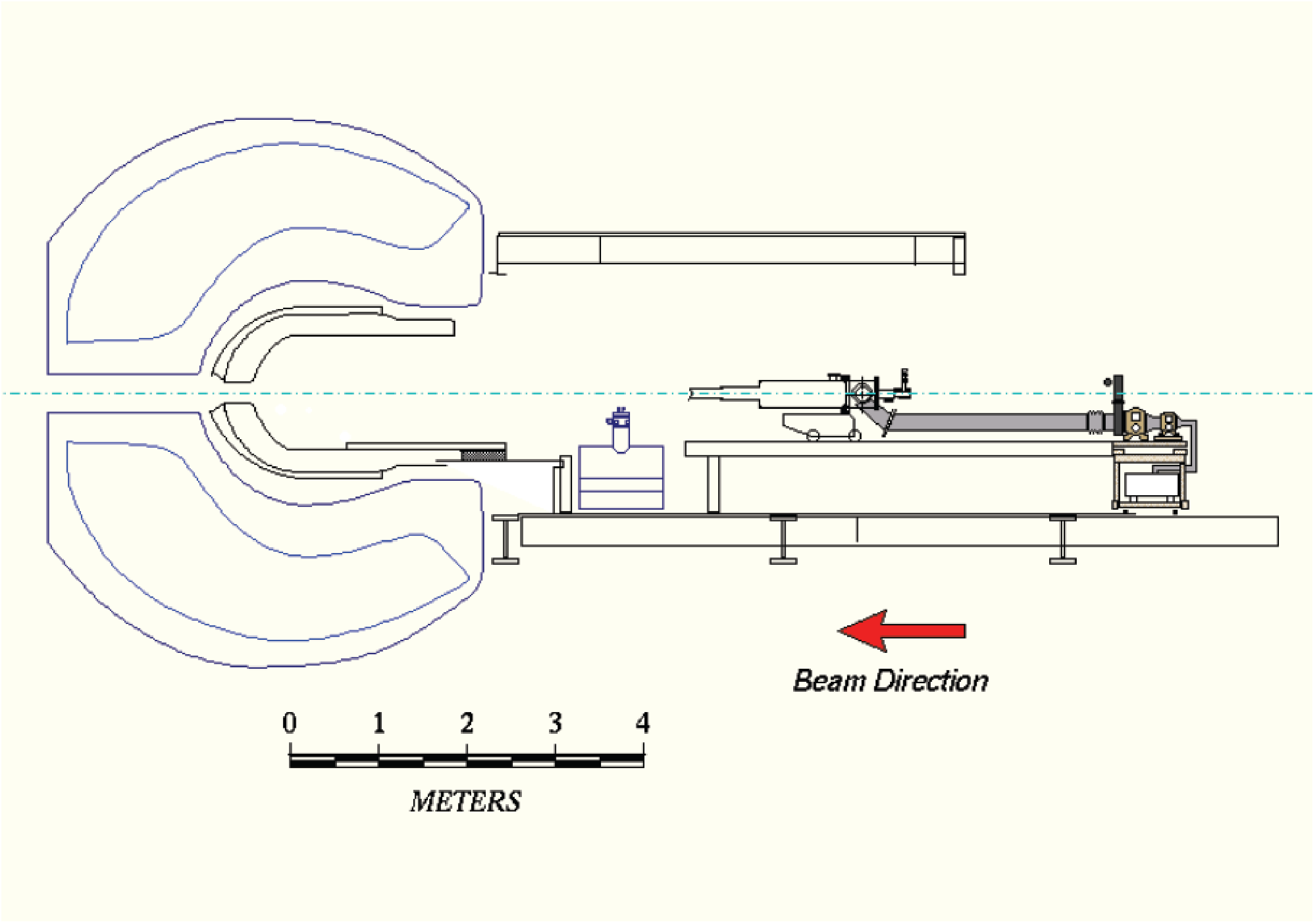
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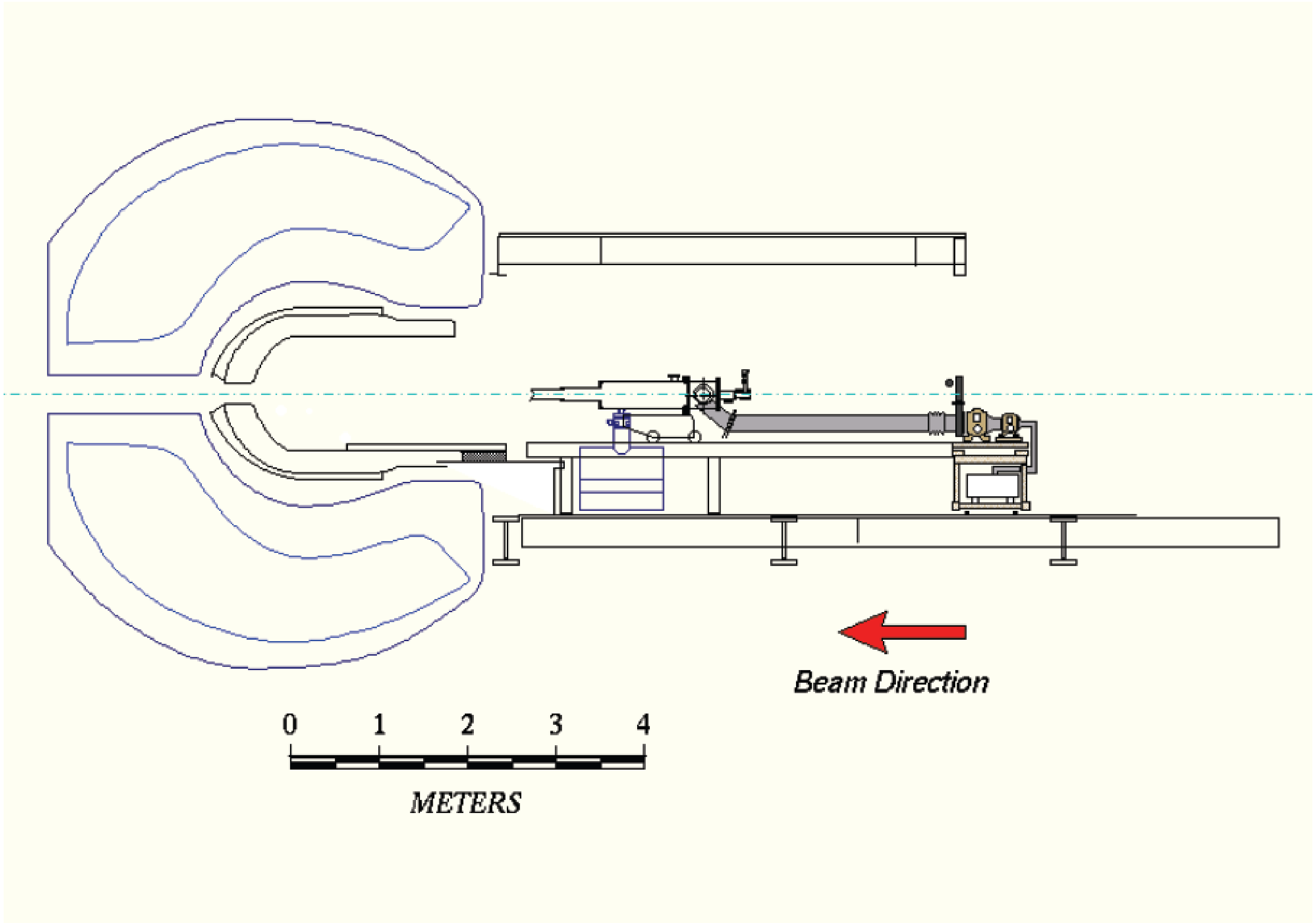
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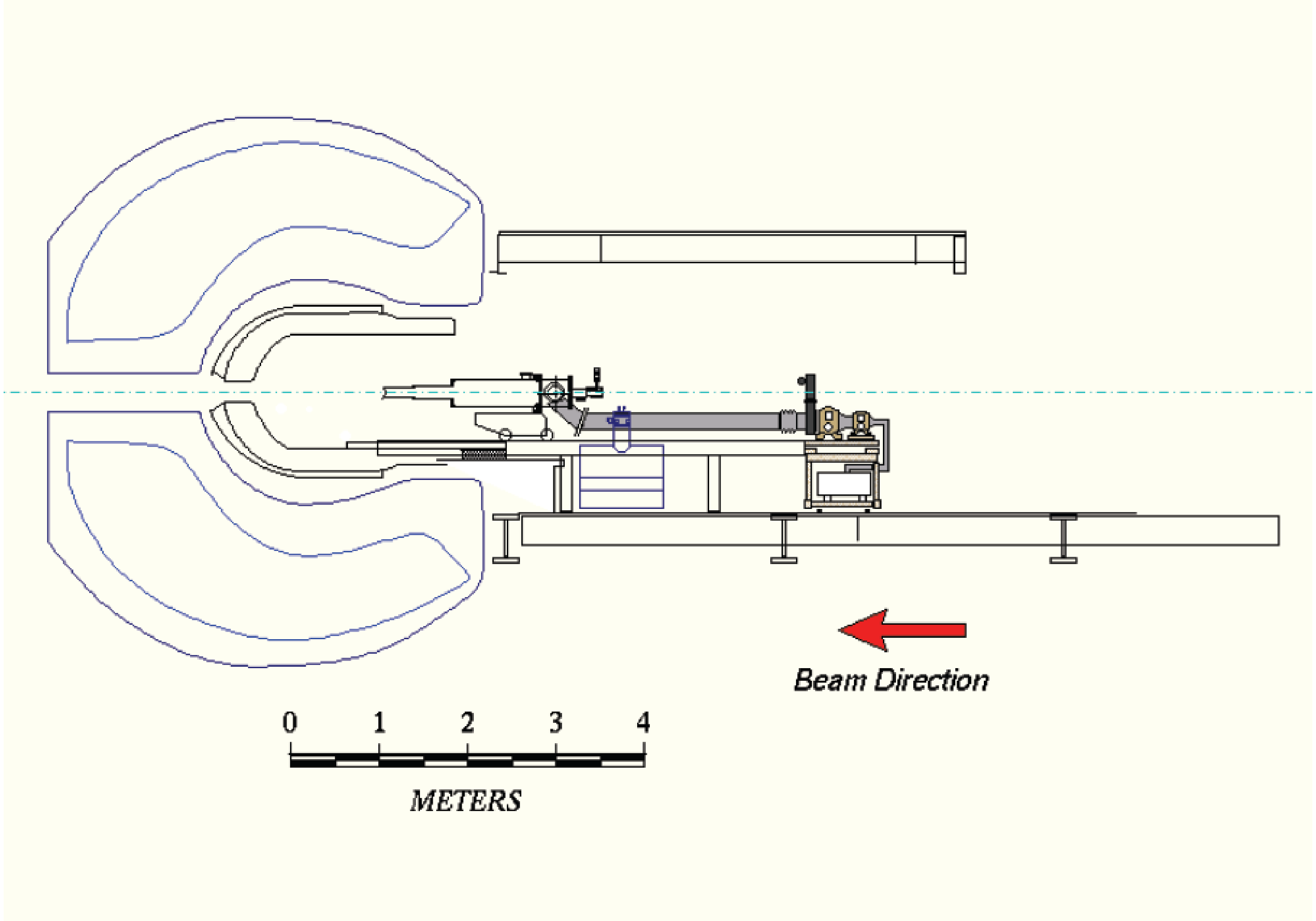

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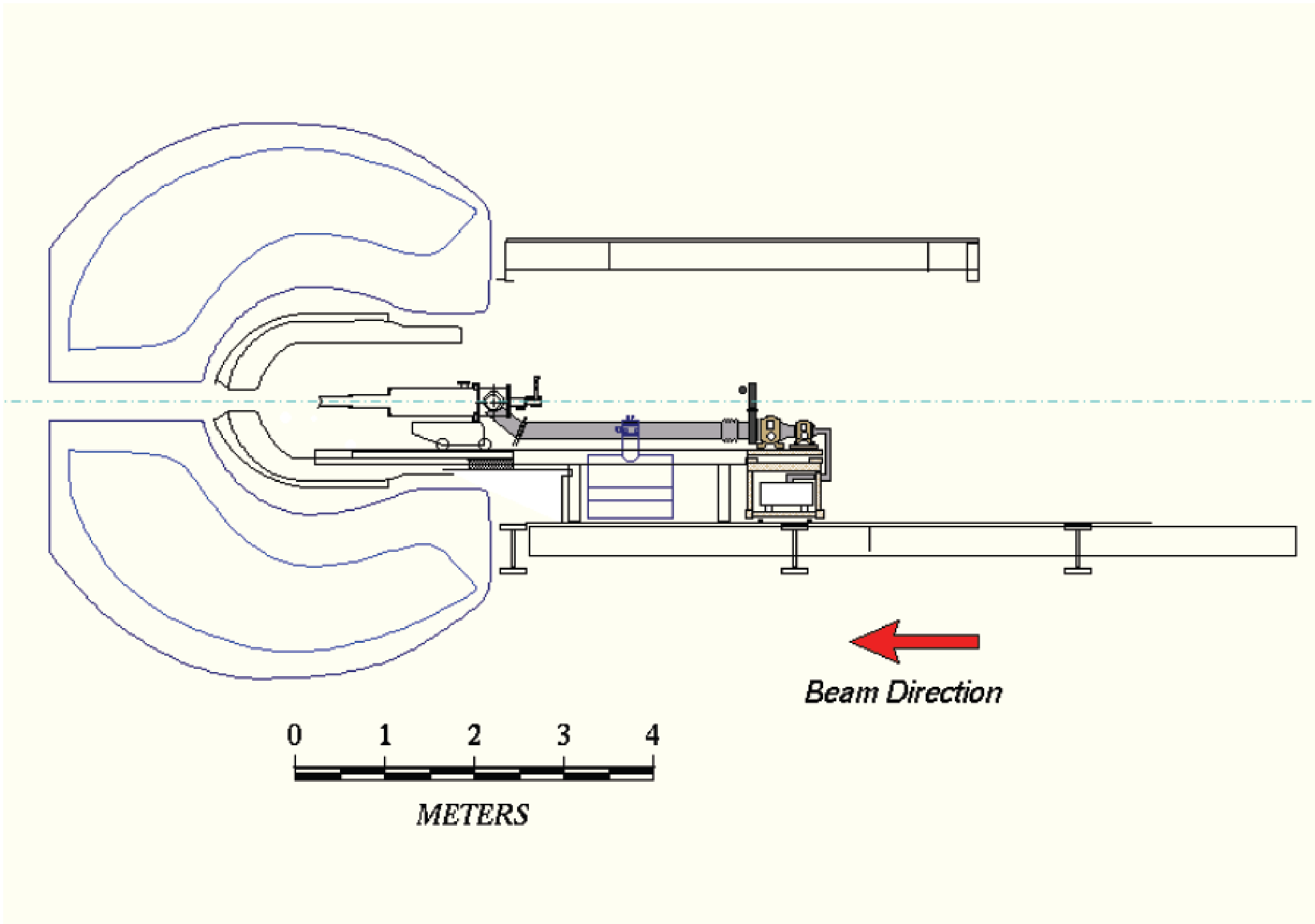

Beam Direction
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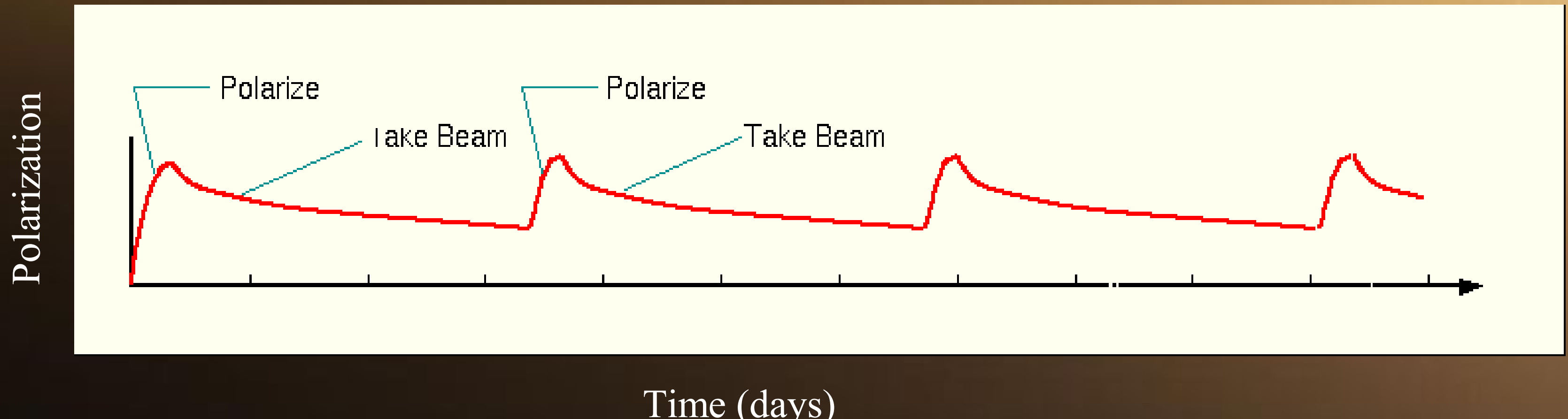
4
METERS

Polarization Process

- Repolarization process takes about 4 hours:
  - ➞ Pump cart and cooling system moved using hand cranks (~ 20 min each way).
  - ➞ Polarization via DNP estimated to take about 3 hours.
  - ➞ Depends on how cooling system responds to changing magnetic fields.
- Repolarization needed about every 4-5 days.



Summary

- Determination of polarization observables crucial in determining missing resonances.
- Double-polarization photoproduction experiments using FROST will offer insight into spectrum.
- Construction complete Nov. 2006
- Testing and cold leak checking to be done Nov./Dec. 2006
- Install in Hall B early Jan. 2007
- Data taking will begin late Feb. 2007