Beam Commissioning Result of Polarized Target at SpinQuest

PSTP 2024 @ JLab

2024/Sep/25

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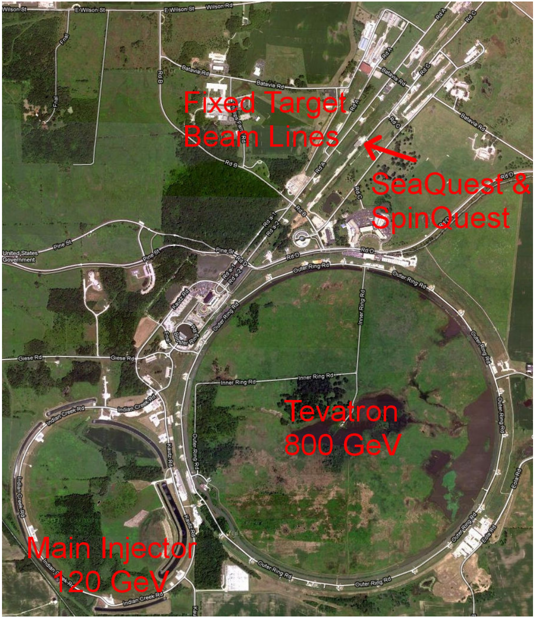
Outline

- "SpinQuest Polarized Target System" by V. Bandara
    - Structure & performance of system components

1. Quick overview of SpinQuest experiment
    - (Unpolarized) high-intensity proton beam
    - Polarized target
    - Data-taking schedule
2. Achievements during beam commissioning
    - Beam-target alignment
    - Polarization under beam & material annealing
    - Beam characteristics & magnet quench
3. Conclusions

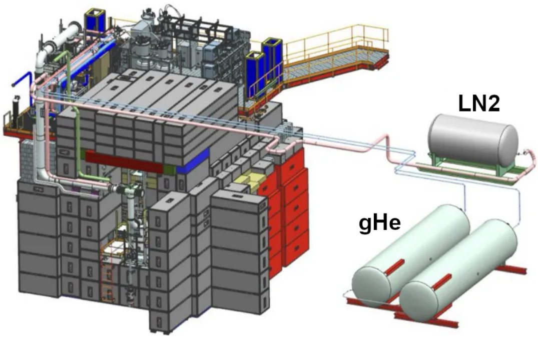
Proton Beam for SpinQuest @ FNAL



- From Main Injector
- Unpolarized
- Energy $E = 120$ GeV ($\sqrt{s} = 15$ GeV)
- Bunch
  - Interval: 19 nsec (53 MHz)
  - $\sim$10k protons per RF bucket
  - $\sim 2 \times 10^{12}$ protons per spill (in 4 sec)
- Duty cycle
  - 4 sec for SpinQuest
  - 56 sec for ν exp.

SpinQuest Target System

- Target cryostat in “Cave”
  - Surrounded by concrete blocks for radiation shielding
  - Evaporation fridge at $T \approx 1$ K & $B = 5$ T
- On “Cryo Platform”
  - Helium liquefaction plant
  - Roots pump for evaporation fridge
- Gaseous helium tank at outside
  - Closed helium system



SpinQuest Schedule

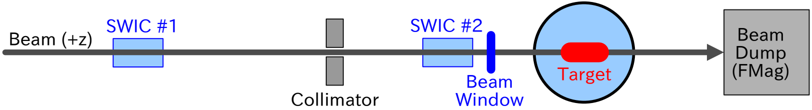
Year	Month	Event
2023		Commissioning of spectrometer using cosmic rays
2024	03	Lab approval for beam operation for SpinQuest
	05	Delivery of first proton beam to SpinQuest
	05-07	Commissioning of target & spectrometer using beam
	07	Accelerator summer shutdown
	11	Start of physics data taking
		$\Downarrow$ 8 months
2025	07	Accelerator summer shutdown

- Carried out the beam commissioning in May-July this year
  - Improvements about stability & efficiency of system operation
  - Acquisition of "physics" data
    - With NH3 target polarized
    - With spectrometer fully operational
  - Data analysis & system upgrades are ongoing

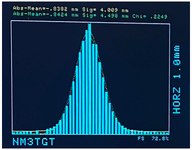
Objectives of Beam Commissioning about Target

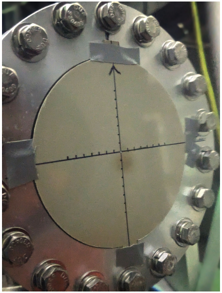
- Alignment of beam & target
- Measurement of beam intensity & profile
- Handling of target material
- Polarization under beam
- Annealing of target material
- Test of high beam intensity & magnet quench
- Sustainable operation of LHe production & consumption

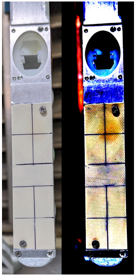
Beam-Target Alignment



- Requirement:
  Control within a few mm
  - Target size = 21×27 mm
  - Beam width = ±3-4 mm
- Multiple devices to adjust & confirm the alignment
  - Two beam profile monitors (“SWIC”) at 2 & 6 m from target
  - G10 plate on beam window at 2 m
  - G10 plate on target cell
  - Tungsten plate in target cell

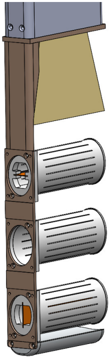




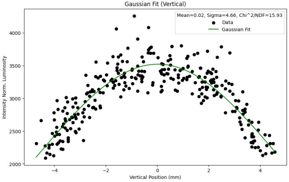


- Multiple devices to adjust & confirm the alignment
  - Two beam profile monitors ("SWIC") at 2-4 m from target
  - G10 plate on beam window at 2 m
  - G10 plate on target cell
  - Tungsten plate in target cell

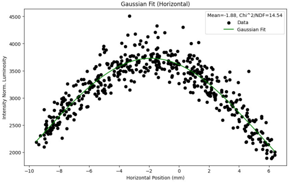
- Achieved precision $\approx$ 1 mm



Vertical



Horizontal



Handling of Target Materials

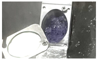
- In physics data taking
  - Replace materials in target cells every week
  - Need regular material handling
- Materials tested in beam commissioning:

CH_2  , NH_3  & ND_3

- Material production & transport

NIST ⟺ UVA ⟺ FNAL ES&H ⟺ SpinQuest Storage ⟺ Target Cells

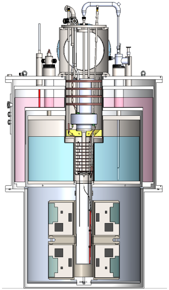
Irradiation



  - The procedure for material transport has been established, in accordance with FNAL safety criteria

- Loading of materials to target cells
  - Designated area & procedure for safety
  - Many people trained

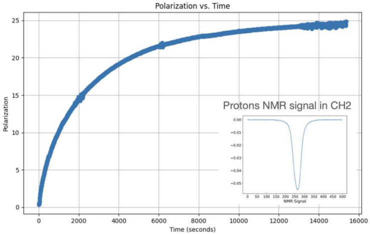
- Loading of target insert to fridge
  - Designated procedure
  - Many people trained



- The handling procedures have been established & conducted repeatedly

Polarization

- CH_2
  - $P = 26\%$

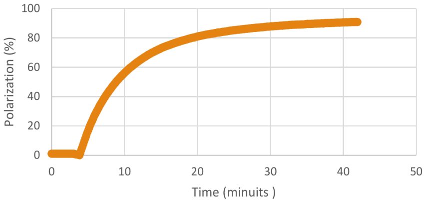


Proton Polarization

- NH_3

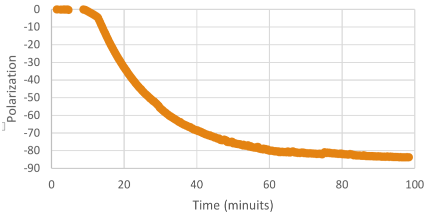
$P = +96\%$

Positive Polarization



-85%

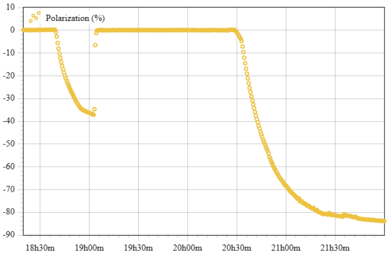
Negative Polarization

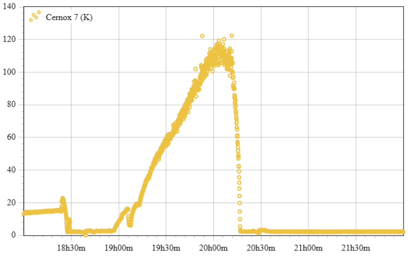


  - No polarization drop was observed under beam with 3×10^{12} protons/spill

Annealing of Target Material

- In physics data taking
  - Do the annealing once per day
  - Together with polarization flip
- Annealing was carried out once during commissioning
  - $|P| \sim 40\%$ before annealing
  - $|P| \sim 80\%$ after annealing. Clear recovery



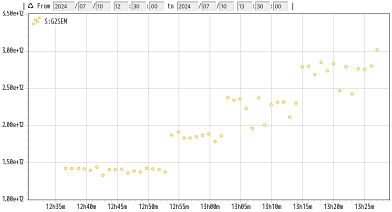


Quench Commissioning of Target Magnet

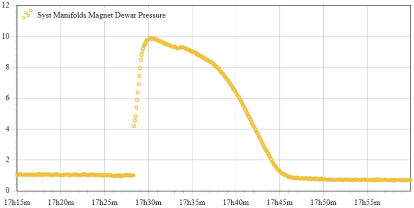
- Soft quenches
  - ∼10 times
  - Mostly caused by unstable beam position control
  - Beam intensity: $0.5 \cdots 1.5 \times 10^{12}$ protons per spill
  - No helium loss, since the current was slowly taken out by the PS
- Hard quenches
  - Three on purpose to measure the max intensity.
    One by accidental loss of beam control
  - Beam intensity: 3.0-3.3 $\times 10^{12}$ protons per spill
    — As anticipated by heat-load simulation

Oxford Mercury iPS

Beam-intensity scan



Magnet pressure $\sim$ 10 psig



Operation of LHe System

- Production of LHe
  - Two liquefiers (“A” & “B”) with each volume = 200 L
  - 4 L per hour ($\sim$ 50 SLM) by each liquefier
- Consumption of LHe
  - Transfer efficiency from liquefier to magnet
    - 50% typically & 60% at best, due to long ($\sim$20 m) transfer line
  - In the target cryogenics

Magnet boil-off	7 SLM	
Separator flow	20 SLM	
Fridge evaporation	20 SLM	
DNP microwave	0-20 SLM	
Beam proton	$\sim$0	(0.4 W in only 4 s per 1 m)
Total	50-60 SLM	= 5 L/hour of LHe

- Production rate $\sim$ Consumption rate

- One problem – Overtemperature
  - Cooling water is supplied by Fermilab for roots pump, liquefier & spectrometer magnets (FMag & KMag)
  - Not powerful enough to always operate the systems due to
    - High outdoor temperature in May-July
    - Faults on cooling water system
  - Liquefier off $\Longrightarrow$ LHe shortage in magnet/fridge
- Improvements
  - Repair of cooling water system
  - Variable attenuator to minimize the power of DNP microwave
  - Better heat insulation for magnet & fridge
  - More LHe storage

Conclusions

- SpinQuest is high-intensity frontier of polarized target
  - Evaporation refrigerator with highest cooling power
  - Longest target cell for 1K system
- The high polarization has been achieved

  NH_3: $+96\%$ & -85% / CH_2: 26%
- The practical operations have been established
  - Handling of target materials
  - Behavior of magnet under high-intensity beam
  - Sustainable operation of LHe system
- Upgrades are ongoing toward the physics data taking

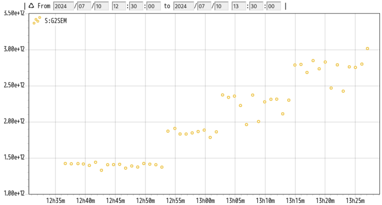
- If you are interested in target and/or physics at SpinQuest, please contact me or spokespersons;
  - Dustin Keller (UVA, dustin@virginia.edu) & Kun Liu (LANL, liuk@lanl.gov)
- This work is supported by DOE contract DE-FG02-96ER40950

Backup

Beam Intensity & Profile

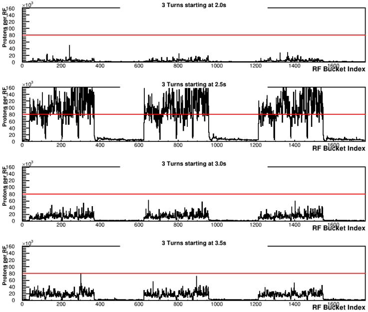
- Stable beam $\Longrightarrow$ Stable magnet operation (and physics data taking)

- Intensity scan



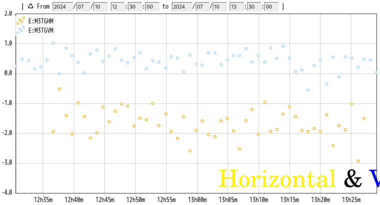
  - 10^{12} per spill (4 sec)
  - Larger fluctuation at higher intensity

- RF-bucket intensity

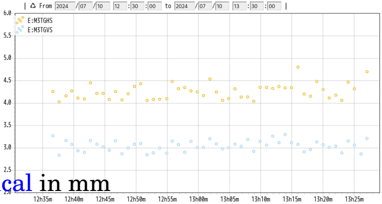


  - 1,764 RFs (33 μsec) $\times$ 4 samples
  - Large ($\times$10) fluctuations with fast & slow periods

- Beam position



- Beam width



Horizontal & Vertical in mm

- Beam position
  - Stable within 1 mm
  - Larger shift during spill was observed
- Beam width
  - 3-4 mm
- The fluctuations had been anticipated to this level, based on the previous experiment (SeaQuest)
- Improvements under consideration
  - More monitoring parameters
  - Better stability with fine tunings of accelerator parameters