SpinQuest J/ψ TSSA Study via Newly-built Polarized Target Assembly at Fermilab

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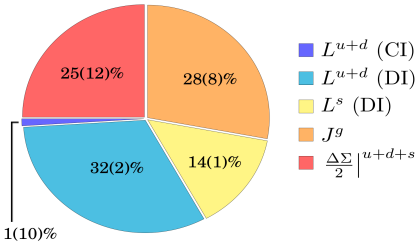
Outline

1. E1039 Experiment: Goals and Setup
2. E1039 Polarized Target System
3. Beam Commissioning Studies
4. Efforts for the ongoing J/ψ TSSA studies
5. Summary and Outlook

Proton Spin Puzzle

- Understanding the contributions to the proton's spin from its internal components—quarks and gluons has been a challenge
- In 1988, the European Muon Collaboration (EMC): Sum of quark spins accounts for ∼30% of the total proton spin, known as "proton spin crisis"
- Gluon spin plays a significant role and the orbital angular momentum of quarks and gluons also contributes significantly



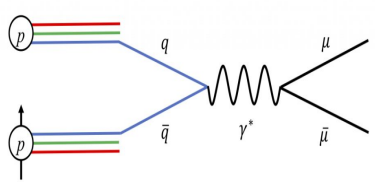
K.F. Liu et al arXiv: 1203.6388

Jaffe-Manohar sum rule:

$$J = \frac{1}{2}\Delta\Sigma + L_q^{JM} + \Delta G + L_G$$

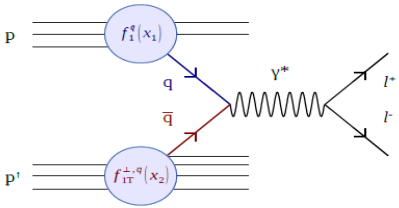
Ji's sum rule:

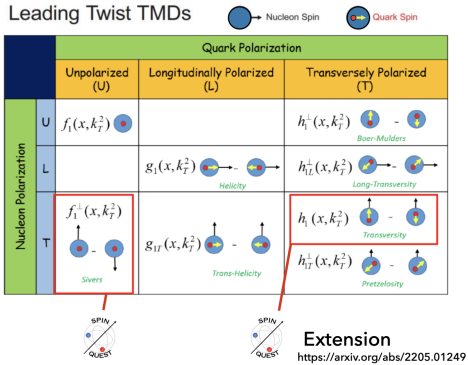
$$J = \frac{1}{2}\Delta\Sigma + L_q^{Ji} + J_G$$



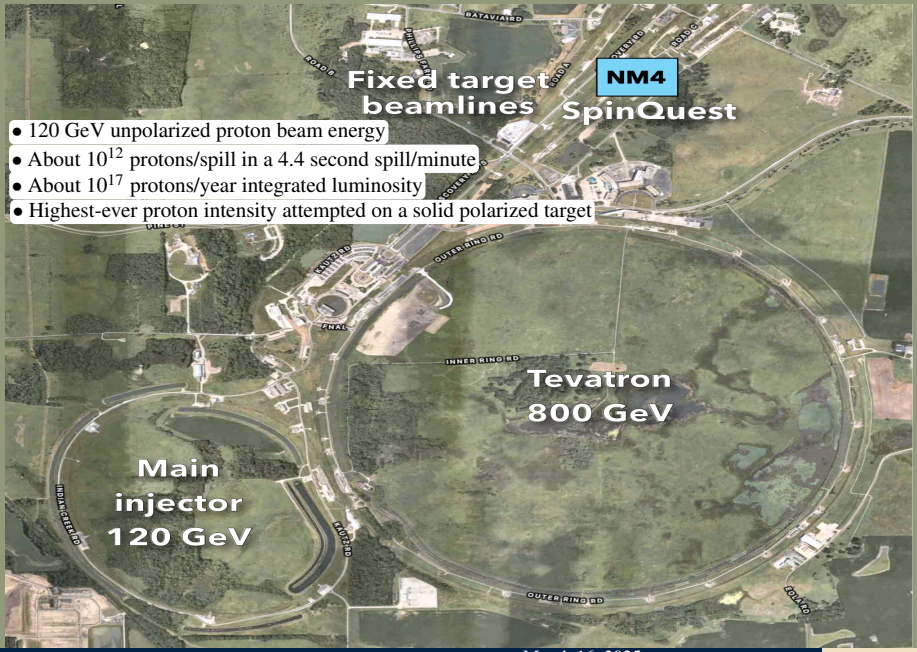
Physics Goals of SpinQuest/E1039 Experiment

- SpinQuest/E1039 is a high luminosity Drell-Yan experiment deploying the transversely polarized NH_3 (as proton) and ND_3 (as neutron) targets to unravel the proton spin puzzle
- SpinQuest aims to measure the Sivers functions of sea quarks in the Drell-Yan process to access their orbital angular momentum, which could contribute up to $\sim 50\%$ of proton spin
- SpinQuest will also measure the Transverse Single Spin Asymmetry in J/ψ production to probe the gluons Sivers function





E1039 Experimental Setup



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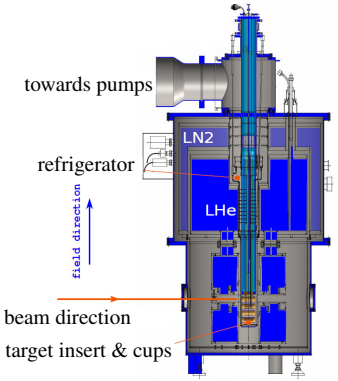
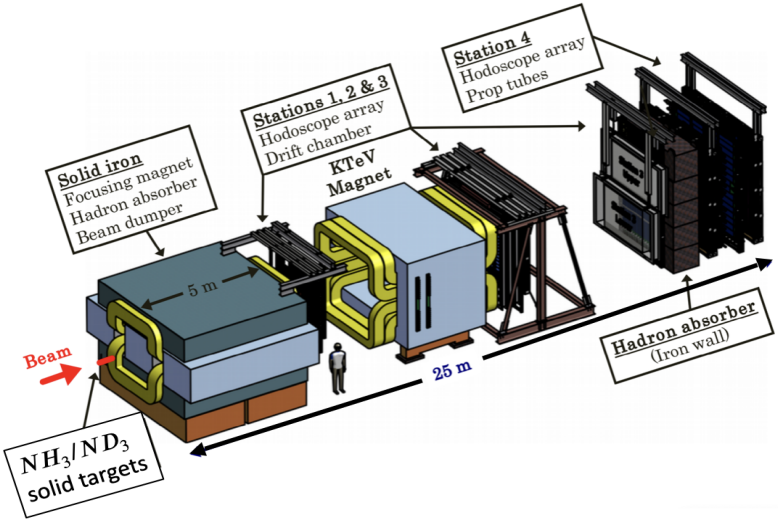
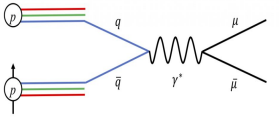


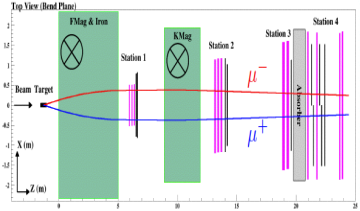


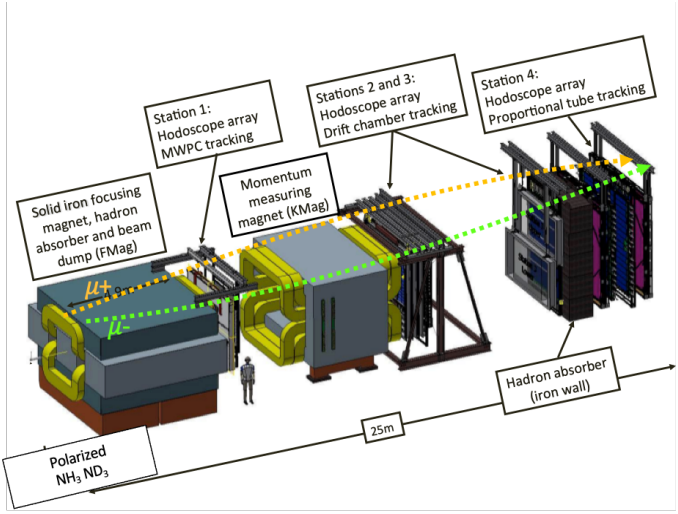
- The polarized target system is newly built for this project
- The spectrometer has been adopted from the SeaQuest (E906) experiment

E1039 Experimental Setup

- The SpinQuest event selection/reconstruction is expected to be the same as the SeaQuest

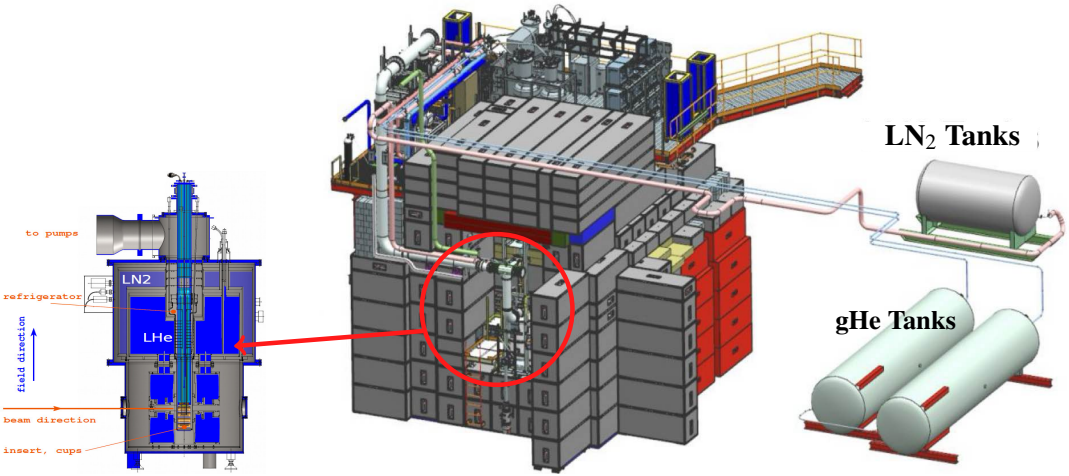






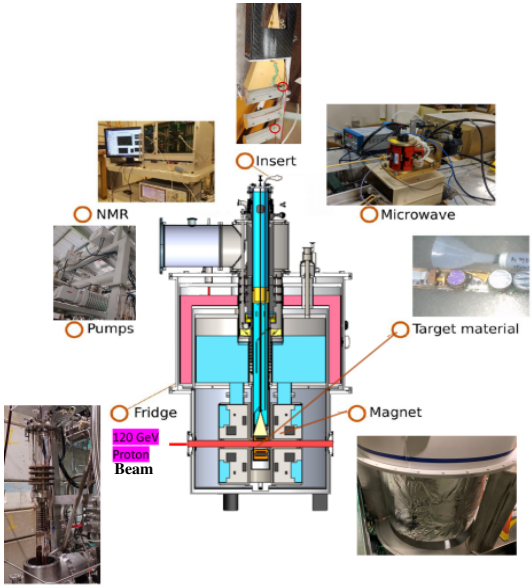
E1039 Polarized Target System

- Target cryostat in "cave" with an evaporation fridge at 1K and 5T, surrounded by concrete blocks for radiation shielding
- "Cryo platform" with helium liquefaction system: Producing about 8 L of liquid ^{4}He (LHe) being stored in two, 205 L capacity dewars and high power root pumps



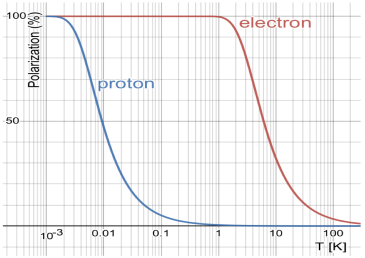
E1039 Polarized Target System

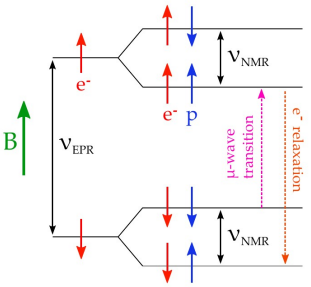
- ^{4}He evaporation refrigerator consists of 5 W of cooling power to keep the target at about 1 K with 17,000 m^3/h capacity root pumps
- The superconducting magnet provides a 5 T uniform transverse magnetic field with $\frac{dB}{B} < 10^{-4}$
- Target stick has three target cups, 8 cm long solid NH_3/ND_3 target material
- 140 GHz Radio Frequency signal is generated by extended interaction oscillator coupled to the target cups via a waveguide
- Three Nuclear Magnetic Resonance coils per cup are connected to the NMR system for polarization measurement
- Dynamic Nuclear Polarization technique is employed for nucleon polarization



Polarized Target: Dynamic Nuclear Polarization

- Due to the proton's small magnetic moment ($\mu_e = 660\ \mu_p$), high B and low T alone can't achieve significant polarization ($P = \tanh\left(\frac{\mu B}{kT}\right)$)
- At 1 K temperature and 5 T magnetic field, $P_e \cong 98\%$ compared to $P_p < 1\%$
- Dynamic Nuclear Polarization: Spin polarization is transferred from electrons to nucleon via RF irradiation and an external magnetic field
- The electron's millisecond and proton's minute-long relaxation times at 1 K are key for sustaining proton polarization.
- A good DNP target material candidate is characterized by the maximum achievable polarization, dilution factor, and resistance to the radiation damage





Beam Commissioning Studies: 05/24 - 07/24

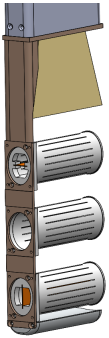
Beam commissioning goals for the target system

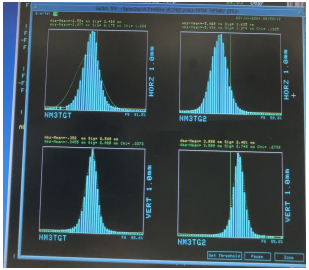
- Alignment of beam & target
- Measurement of beam intensity & profile
- Target material handling
- Beam-induced polarization
- Annealing the target material
- Quench commissioning study to find the maximum sustainable intensity
- Sustainable operation time with the given amount of LHe production & consumption

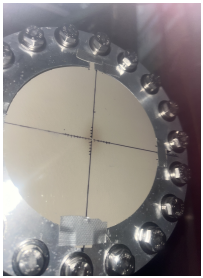
- Improving system stability and efficiency
- Acquisition of “physics" data with a polarized NH_3 target and fully operational spectrometer
- Data analysis and system upgrades are in progress

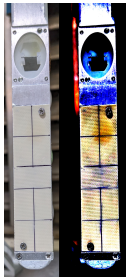
Beam-target Alignment

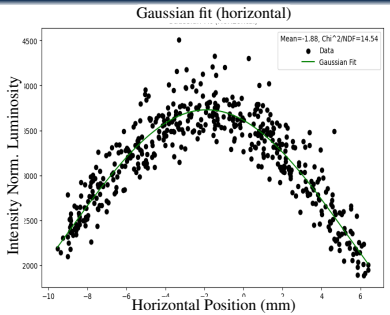
- Target size: $21 \times 27 \times 80$ mm^3
- Beam width: 3 to 4 mm with 1 mm precision
- Tungsten plates placed in top and bottom target cells
- Deployed G10 sheets on the beamline window and target cell
- Used two beam profile monitors

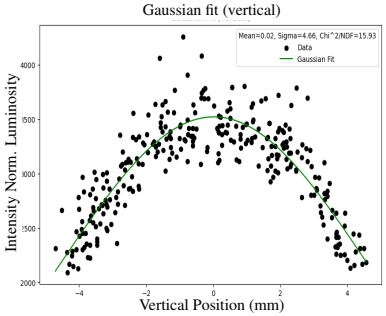










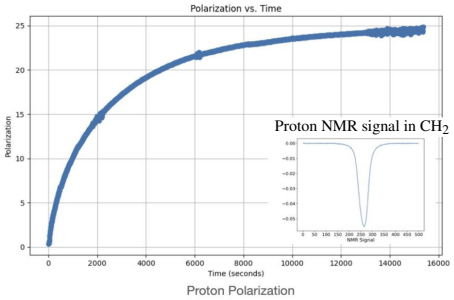


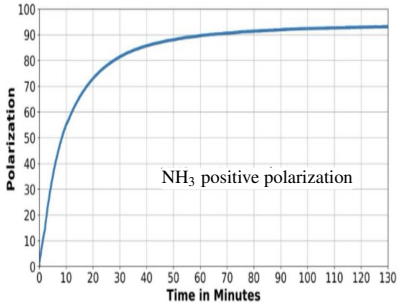
Quench Commissioning

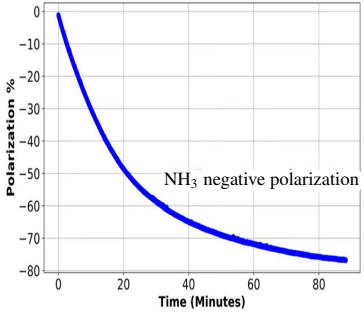
- Determined the sustainable runtime in production data-taking mode based on LHe production and consumption rates
- The Fermilab low-conductive water (LCW) supply for the liquefier, roots pump, and spectrometer magnets was insufficient to operate the system at high summer temperatures. System repairs are ongoing
- Several soft quenches observed by the magnet power supply due to the unstable beam position, the current was gradually reduced by the power supply
- Performed a quench study to determine the beam intensity threshold which is deduced to be about 3.18×10^{12} protons per spill
- Target materials exposed to beam: CH_2, NH_3 and ND_3

Target Polarization

- Production data were collected for both positive (spin up) and negative (spin down) polarizations
- Achieved a maximum of $\sim$ 96% (- 85%) positive (negative) polarization for NH_3

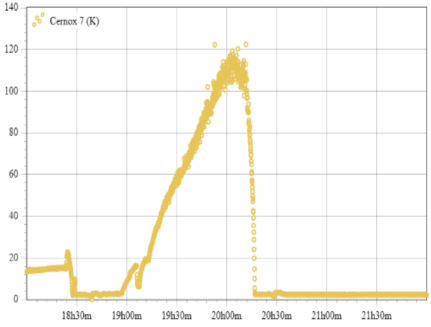


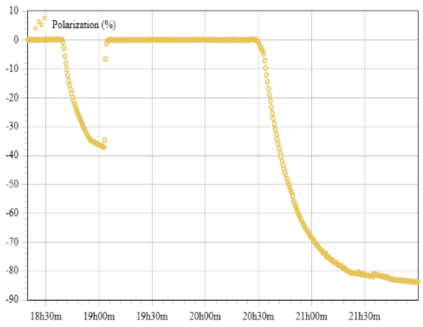




Target Material Annealing and Handling

- The target polarization decays over time due to the radiation damage
- Annealing was performed to help restore the target polarization from 40% to 80%
- For the physics data taking, the annealing will be performed once per day, with the polarization flip
- The annealing system is being upgraded to an automated procedure to prevent the target material damage



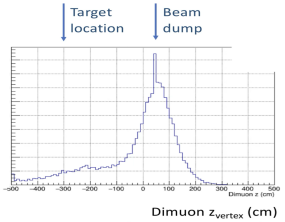


Ongoing System Upgrades

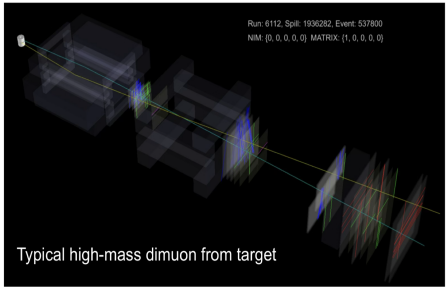
- Repair of Fermilab low conductivity cooling water system
- More LHe storage system: Ordered a third 200L dewar
- Variable attenuator to minimize the power of the DNP microwaves system
- Better heat insulation for the magnet & fridge system
- More advanced target insert with advanced NMR techniques
- Polarization with ND_3 system
- Stable insulation vacuum: Designed and set up a new set of pumps
- Derive the relative luminosity from the LUMI data using the GEANT4 simulation
- More controlled information on beam intensity and beam profile

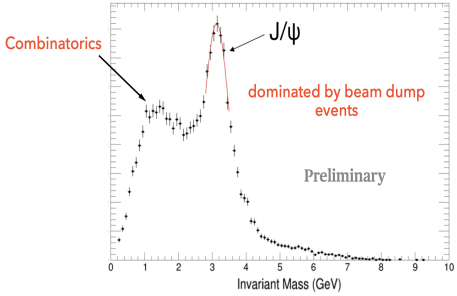
Dimuon Event Reconstruction

- Detect distinct J/ψ and high-mass dimuon events in the online plots, peak dominated by the beam dump events
- Offline analysis for J/ψ TSSA using the 2024 commissioning data is underway



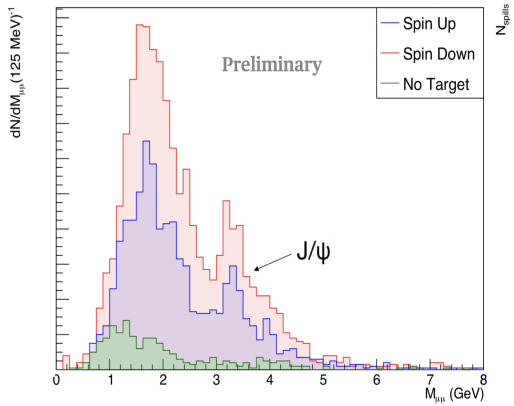
3153 spills (4s); KMag is on; no cuts

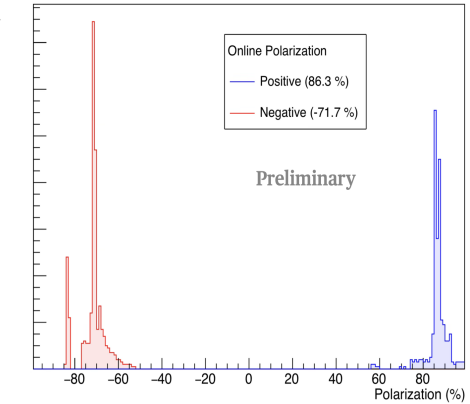




Polarized Target Dimuon Reconstruction

Target-like vertex cuts, $|Z_{\mu^+} - Z_{\mu^-}| < 200$ cm



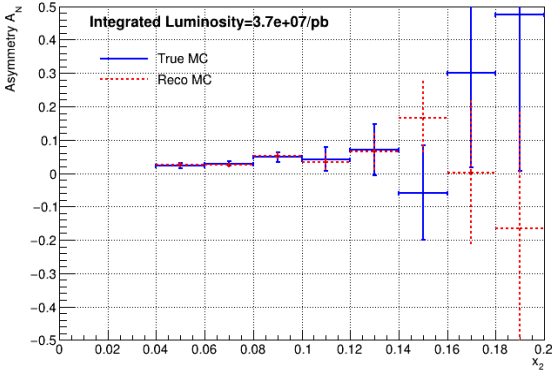


SpinQuest Plans for J/ψ TSSA

- J/ψ, $c\bar{c}$ bound state, is sensitive to the extraction of the gluons Sivers functions
- A precise measurement of the TSSA is expected from one-week of dedicated data taking on J/ψ production. The asymmetry and its uncertainty are evaluated as

$$A_N = \frac{2}{f}\sum_i \frac{N(x_1,\phi_{S_i})\sin\phi_{S_i}}{N(x_1,\phi_{S_i})} \quad \text{and} \quad \delta A_N = \frac{\delta_{A_N^{\text{sim}}}}{fP}\sqrt{\frac{L_{sim}}{L_{\text{one-week}}}}$$

- Kinematics between SpinQuest and PHENIX are complimentary:
  - PHENIX: $\sqrt{s} = 200$ GeV and $x_F < 0.3$
  - SpinQuest: $\sqrt{s} = 15$ GeV and $x_F > 0.4$
- Measure the J/ψ TSSA's with very low absolute error $O(10^{-2})$ or less in the given kinematic region of x_F and p_T
- For J/ψ TSSA background studies, see the next talk by C. Kuruppu



Summary and Outlook

- SpinQuest is a high-intensity frontier polarized target experiment: highest-ever proton intensity attempted on a solid polarized target
- Overall, the target system performed well and achieved the highest polarization for NH_3
- System upgrades are in progress to support physics data collection
- The production data collected is not sufficient to be published, but the analysis framework to extract the TSSA's for J/ψ production is being established
- Production data-taking will resume in November of 2025 and run until the 2026 Fermilab summer accelerator shutdown
- SpinQuest aims to accumulate production data for about two years. Stay tuned for the physics results

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Thank you!

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Backup