# GPU-based Online Reconstruction for J/ψ TSSA at the SpinQuest Experiment

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# Outline

- Motivation:
  - The Nucleon Spin Puzzle and the Sivers Function
  - The SpinQuest Experiment
- SpinQuest Online Reconstruction (OR) with GPUs
  - Motivations and Challenges
  - Features and Performances
- Summary and Outlook

# **Nucleon Spin Puzzle**

#### Spin Sum Rule:





- $\Delta\Sigma$ : spin of quarks and antiquarks  $\Delta G$ : spin of gluons
- $L_a$ : angular momentum of
  - quarks and antiquarks;
- $L_a$ : angular momentum of gluons

Measurements of  $\Delta\Sigma$ :

- EMC: Nucl. Phys. B328, 1 (1989):  $\Delta\Sigma = 0.12 \pm 0.09 \pm 0.14$ ,
- COMPASS: Phys. Lett. B753, 18 (2016):
  0.26 < ΔΣ < 0.36</li>



 $\Delta G + L_q + L_g$  contributes to more than half of the nucleon spin

# **Sivers Function**

The Sivers function  $f_T^{\perp_q}$  provides information on the angular momentum of partons. The Sivers function can be accessed with Transverse Single Spin Asymmetries (TSSA) measurements on polarized Drell-Yan (DY).



09/26/2023

More details in I. Fernando's talk earlier in this session

# The E1039/SpinQuest Experiment: Spectrometer



# The E1039/SpinQuest Experiment: Polarized Target

Polarized targets:

- NH<sub>3</sub>: Ammonia;
- ND<sub>3</sub>: Deuterated Ammonia;
- NH<sub>3</sub> polarization: average 78% (maximum 97%)
- ND<sub>3</sub> polarization: average 30% (maximum 50%)
- Polarization flip every 8 hours.

More details in M. Farooq's talk, 9/26, 14:30; Polarized Ion and Lepton Sources and Targets



# **The SpinQuest Experiment: DY Measurement**

Measurement of the antiquark Sivers function  $f_T^{\perp_q}$  on proton (NH<sub>3</sub>) and neutron (ND<sub>3</sub>). Contributions of the quark Sivers function suppressed by acceptance.



# The SpinQuest Experiment: J/ψ Measurement

 $J/\psi$  TSSA is dominated by gluon fusion in the SpinQuest kinematical coverage:

- gluon Sivers function;
- gluon angular momentum  $(L_a)$ .





# The SpinQuest Experiment: $J/\psi$ Measurement

 $J/\psi$  TSSA is dominated by gluon fusion in the SpinQuest kinematical coverage:

- gluon Sivers function;
- gluon angular momentum  $(L_a)$ .

TSSA statistical uncertainties for one week of  $J/\psi$  data for the first SpinQuest publication.



# **GPU-based Online Reconstruction Program**

Scope of the project: monitor SpinQuest data *in real-time* with an ultra-fast analysis program using Graphics Processing Units (GPU) instead of Computer Processing Units (CPU).



# **GPU Programming Challenges**

Memory management much more "rigid" on GPU than on CPU:

- Memory *must be pre-allocated* on GPU (input+output);
- Input data copied from CPU to GPU;
- Data processed on GPUs;
- Output data can be copied back to the CPU and stored in a file.



# **GPUs Speed Optimization: Per-Event Multithreading**

Multithreading is pivotal to achieve the required processing speed:

- Search of tracks candidates on a definite portion of the acceptance for each thread (32 threads in total);
- Track candidates spread evenly over the existing threads to optimize GPU resources.



# **Track Reconstruction for E1039/SpinQuest**

#### Main steps:

- Reconstruct straight tracks in from station 2 Drift Chambers (D2) to station 3 DC top/bottom (D3p/D3m);
- Associate hits with station 1 DC (D0) to straight tracks;
- Combining D2-D3p/m 3 tracks and D0 track segments => momentum.



X: vertical wires

- U: wires at +14 degrees with respect to X wires
- V: wires at -14 degrees with respect to X wires

# **Track Reconstruction for E1039/SpinQuest (2)**

#### D2-D3p/m tracking

- 2D track using the hits in XX' in station 2 and station 3 => x slope  $(t_x)$ , position  $(x_0)$ ;
- Evaluate Y from U/V hits from intersection of 2D track with U,V wires
  => y slope (t<sub>v</sub>), position (y<sub>0</sub>);



## **Tracking Results GPU OR vs CPU Ktracker**

• Single tracks parameters, E906/SeaQuest data (run 12525)





Green: Ktracker (reference) Red: GPU OR (this work) D0 multiplicity <= 210; D2 multiplicity <= 120; D3p multiplicity <= 90; D3m multiplicity <= 90; ~55% of the total statistics

# **GPU Vertex Reconstruction on E1039/SpinQuest experiment**

#### Main steps:

- Propagate the track through the FMAG (focusing magnet);
- Extrapolate the track to the target;
- Distance of closest approach (DOCA) from beam line => vertex.



## Vertexing Results GPU OR vs. CPU Ktracker

- Single tracks vertex and momentum, E906/SeaQuest data (run 12525)
- Wider transverse vertex distributions, due to the GPU approach compared to the Ktracker Kalman filter fitting.



## **Dimuon Reconstruction**

- Implemented the dimuons reconstruction in the GPU OR program by
  - pairing tracks of different charge;
  - evaluating the vertex as the DOCA between the two muons tracks;
  - reconstructing the momentum of each track as the momentum at the position of the dimuon vertex, not at the single-track original vertex.



### **Dimuons GPU OR vs. CPU Ktracker**

• **Dimuon** variables, E906/SeaQuest data (run 12525)



## **Dimuons GPU OR vs CPU Ktracker**

• **Dimuon** vertex and momentum, E906/SeaQuest data (run 12525)



# **GPU Online Reconstruction Performance**

- Installed the GPU OR program on a top-end GPU tower for processing the incoming E1039/SpinQuest data;
- Processes the equivalent of a spill of E906/SeaQuest data within a fraction of the time between two spills (below 50 seconds);
- Full deployment is underway with the necessary packages to process the E1039/SpinQuest data format.



# **Summary and Outlook**

# The SpinQuest experiment will provide great insight into the quest of the nucleon spin puzzle:

- Study DY on the proton and the neutron => antiquark Sivers function;
- Probe  $J/\psi =>$  Gluon Sivers function!

#### **GPU** online reconstruction program is being finalized:

- GPU offers significant performance improvement compared to CPU;
- Its reconstruction algorithms are ready and results compare reasonably well with Ktracker;
- GPU OR program is being deployed on GPU machine for upcoming E1039 processing
- Logic for its display interface is still under development

# THANK YOU!

# $J/\psi$ asymmetry $x_2$ bin migration

Asymmetric  $x_2$  bin migration (reconstructed  $x_2$  on average larger than generated  $x_2$ ). This causes the error bars to be smaller for reconstructed dimuons than for generated ("true") dimuons at higher  $x_2$ .

Cause: dimuon energy loss due to the muons multiple scattering in FMAG. (Variation of measured  $x_2$  correlated with the variation of relativistic boost  $\gamma$  of the dimuon)



# Track Reconstruction for E1039/SpinQuest (3)

#### Sagitta calculation for D0 hit selection:

- Expected position (and window) of hits in station 1 chambers using the positions of the hits from station 2 and station 3 + origin;
- Two possible origins: target or dump: hit selection window calculated for each origin (both windows combined).



# **Momentum Calculation:**

- Point of intersection  $X_{_{i\scriptscriptstyle D}}$  between back partial track and the station 1 track segment to be built;
- XX' hits in station 1 fitted with  $X_{ip} =>$  station 1 track segment
- Calculation of momentum with the slopes of the back partial track and of the station 1 track segment
- Update of  $y_0$ ,  $t_v$  with D0 UV hits and D0 track segment



## **Tracking results GPU OR vs CPU Ktracker**



#### Single track parameters, E906 data (run 12525)

## Vertexing results GPU OR vs CPU Ktracker

#### Single track vertex and momentum, E906 data (run 12525)



## Vertexing results GPU OR vs CPU Ktracker

#### Single track vertex and momentum, pure Monte Carlo dimuons



# **Ktracker tracking algorithm**



## **Dimuon selection**

- Implemented the dimuons reconstruction in the GPU OR program based on these criteria
  - Mass selection  $M_{dim} < 10 (GeV/c)^2$ ;
  - □ |X<sub>F</sub>| < 1;
  - $\quad \ \ 0 < x_1 < 1, \ 0 < x_2 < 1;$
  - $\ \ \, |\cos\,\theta_{dim}|<1;$
  - $\square$  30 GeV/c <  $p_z^{dim}$  < 120 GeV/c
  - $|p_x^{dim}| < 3 \text{ GeV/c and } |p_y^{dim}| < 3 \text{ GeV/c};$
  - $|v_x^{\text{dim}}| < 15 \text{cm and } |v_y^{\text{dim}}| < 15 \text{cm}$

### **Dimuons GPU OR vs CPU Ktracker**

• Dimuon parameters, E906 data (run 12525)



## **Dimuons GPU OR vs CPU Ktracker**

• Dimuon vertex and momentum, E906 data (run 12525)



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