The Online Reconstruction Software at the E1039/SpinQuest Experiment

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(on behalf of the E1039/SpinQuest Experiment)
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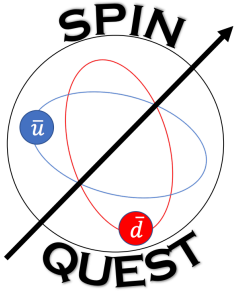


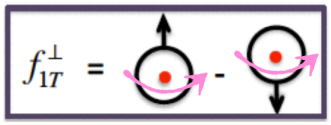
Overview

1. The SpinQuest Experiment
   - SpinQuest Motivation Recap
   - Sivers Function at SpinQuest
   - The SpinQuest Spectrometer
2. Online Reconstruction (OR) on GPUs at SpinQuest
   - Tracking Framework
   - Improving Tracking and OR at SpinQuest
   - Features of GPU Tracking Framework
   - Status of OR Software
3. Conclusion

SpinQuest Motivation Recap

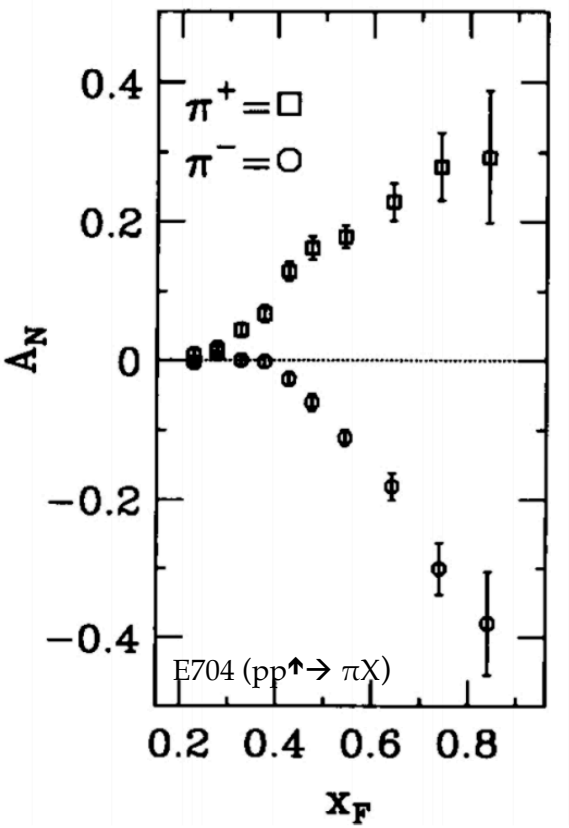
- Explore the **Sivers function,** $f_{1T}^{\perp}$:

$$A_N = \frac{d\sigma^{\Uparrow} - d\sigma^{\Downarrow}}{d\sigma^{\Uparrow} + d\sigma^{\Downarrow}}$$

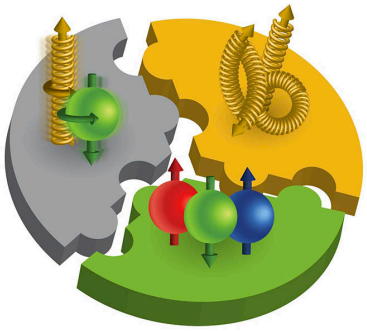


  - Large transverse single spin asymmetries (TSSAs), $A_N (\propto f_{1T}^{\perp})$, observed in polarized pp-collisions
  - Constrain antiquark and gluon orbital angular momentum contributions to proton spin

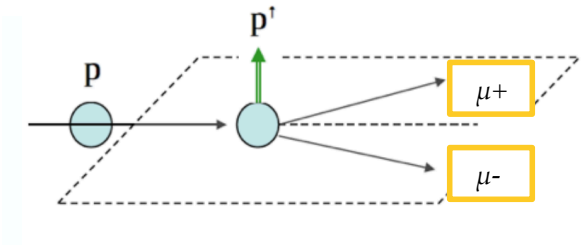
Phys. Lett. B 264, 462 (1991)



Refer back to Noah Wuerfel's presentation

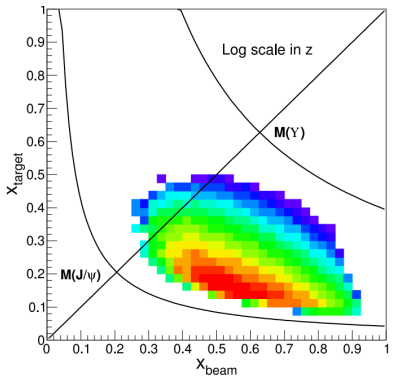


Sivers Function at SpinQuest



$x_{Bjorken} = p_{parton}/p_{proton}$
$N_{u\ (or\ d)}$ = # of dimuons for spin ↑(↓)
$L_{u\ (or\ d)}$ = live protons for spin ↑(↓)

SpinQuest Coverage



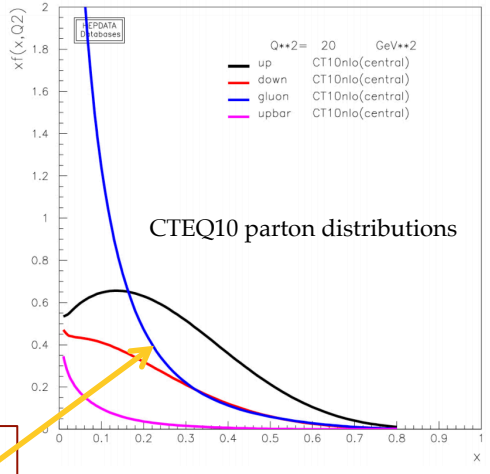
Refer back to Abinash Pun and Forhad Hossain's presentations

For Drell-Yan Process: $p(q)p^{\uparrow}(\bar{q}) \rightarrow \mu^+\mu^-$

$$A_n = \frac{\frac{N_u}{L_u} - \frac{N_d}{L_d}}{\frac{N_u}{L_u} + \frac{N_d}{L_d}} \propto \frac{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_{1T}^{\perp,\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftrightarrow 2 \right]}$$

Small due to SpinQuest coverage!

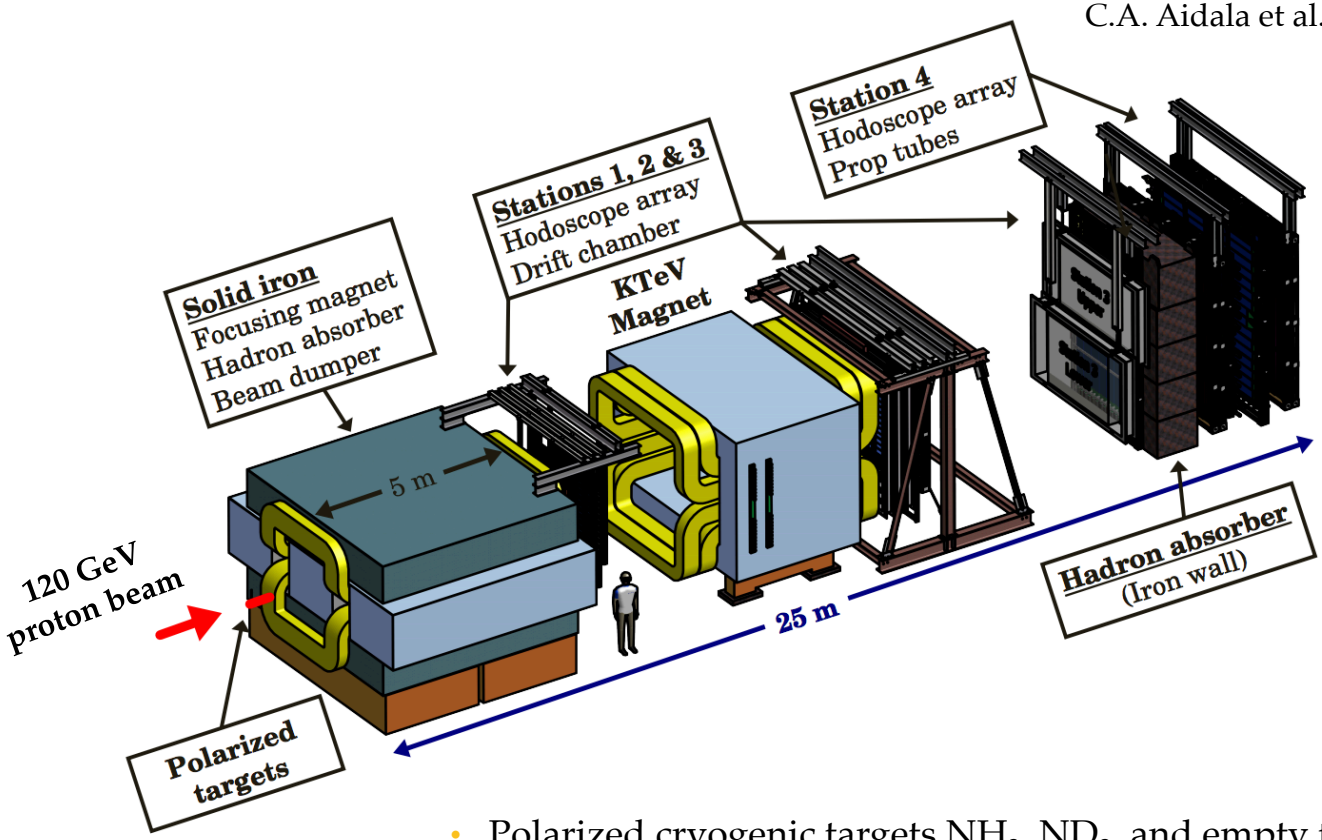
- Measure azimuthal asymmetry in:
  - DY dimuon production → extract anti-quark Sivers
  - J/ψ meson (charm-anticharm bound state) dimuon decay → extract gluon Sivers
    - TSSAs (up to ~40%) observed in light hadron production in $0.1 < x_{Bjorken} < 0.5$
    - Gluon-gluon fusion: can be dominant mechanism for J/ψ at SpinQuest



Many gluons below 0.22!

The SpinQuest Spectrometer

C.A. Aidala et al., Nu In, volume 930, 49 (2019)

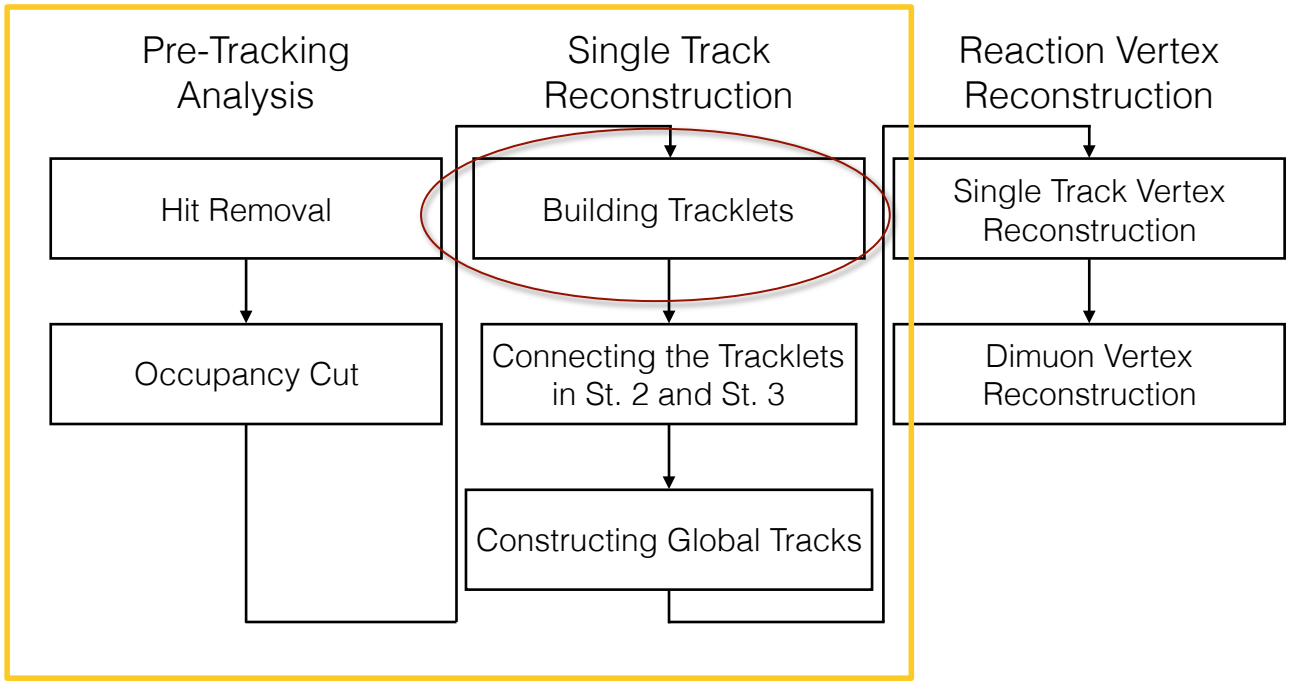


Located in NM4 enclosure at Fermi National Accelerator Laboratory (Fermilab)

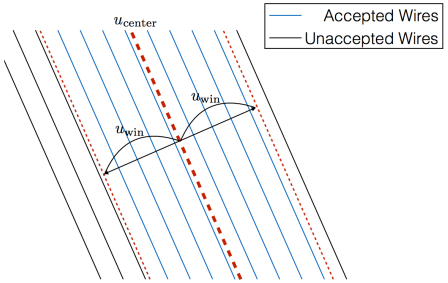
See Zulkaida Akbar and Min Jung Kim's presentations

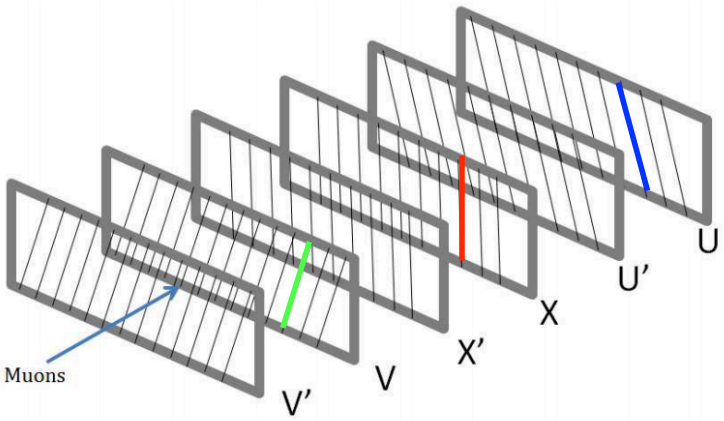
- Polarized cryogenic targets NH_3, ND_3, and empty target
- Dynamic nuclear polarization (~ 80% target polarization at 4% uncertainty)
- Kept at 1K in 5 T field, polarization flip every 8 hours

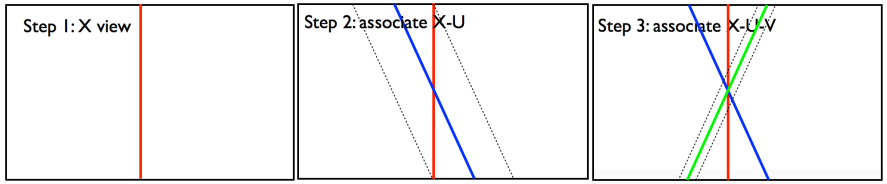
Tracking Framework



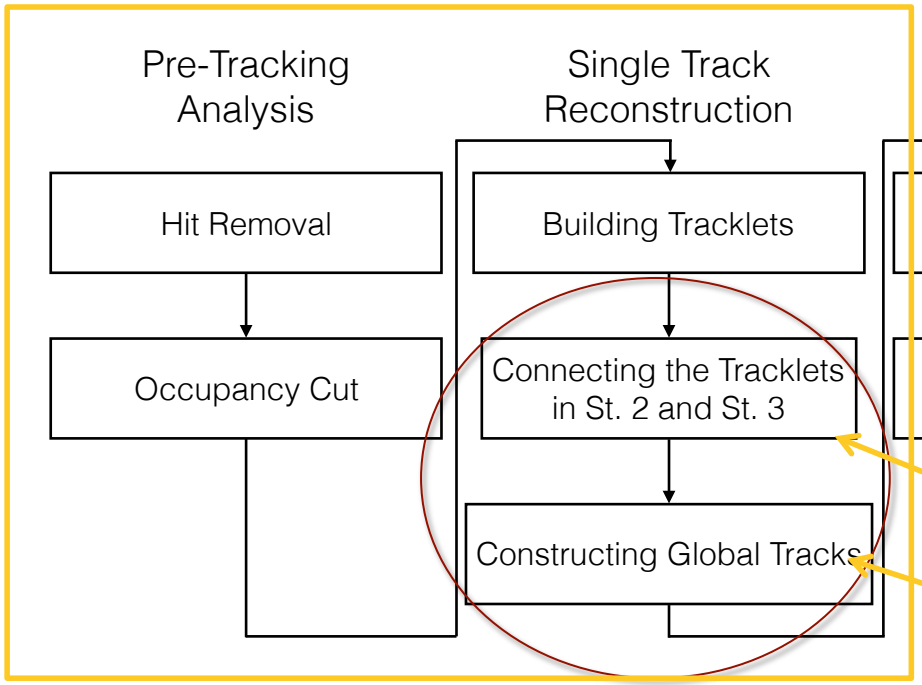
Online reconstruction (OR) framework will focus first on improved single track reconstruction







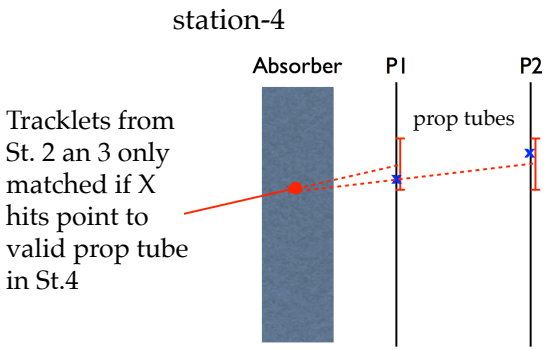
Tracking Framework

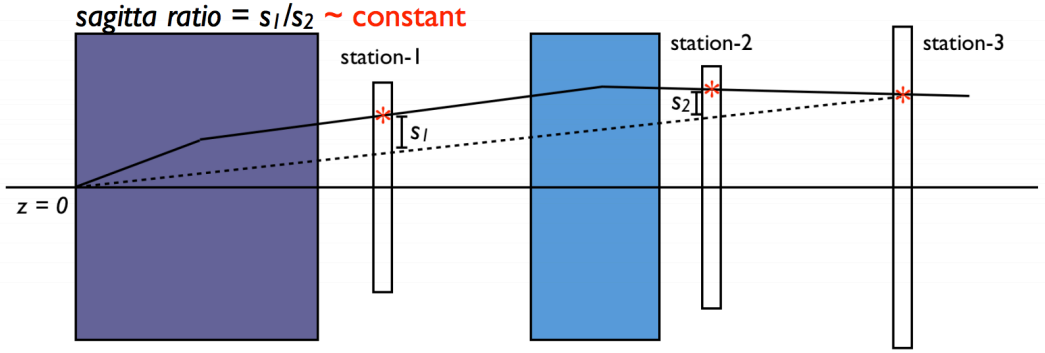


Online reconstruction (OR) framework will focus first on improved single track reconstruction

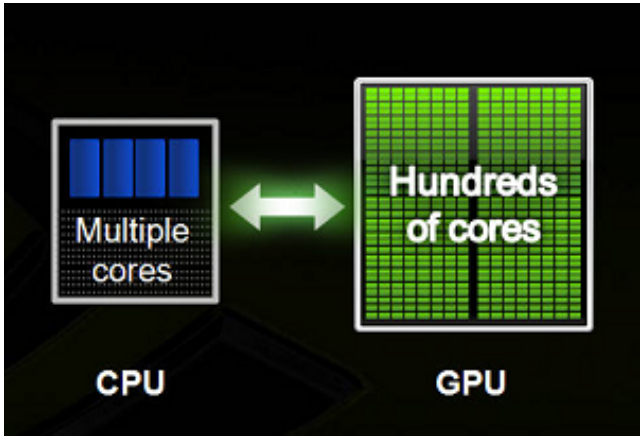
"Back Partial Tracks"

Tracklets in St.1 + Back partial Tracks = Global Tracks



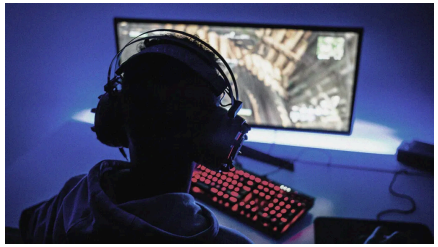


Improving Tracking and OR at SpinQuest



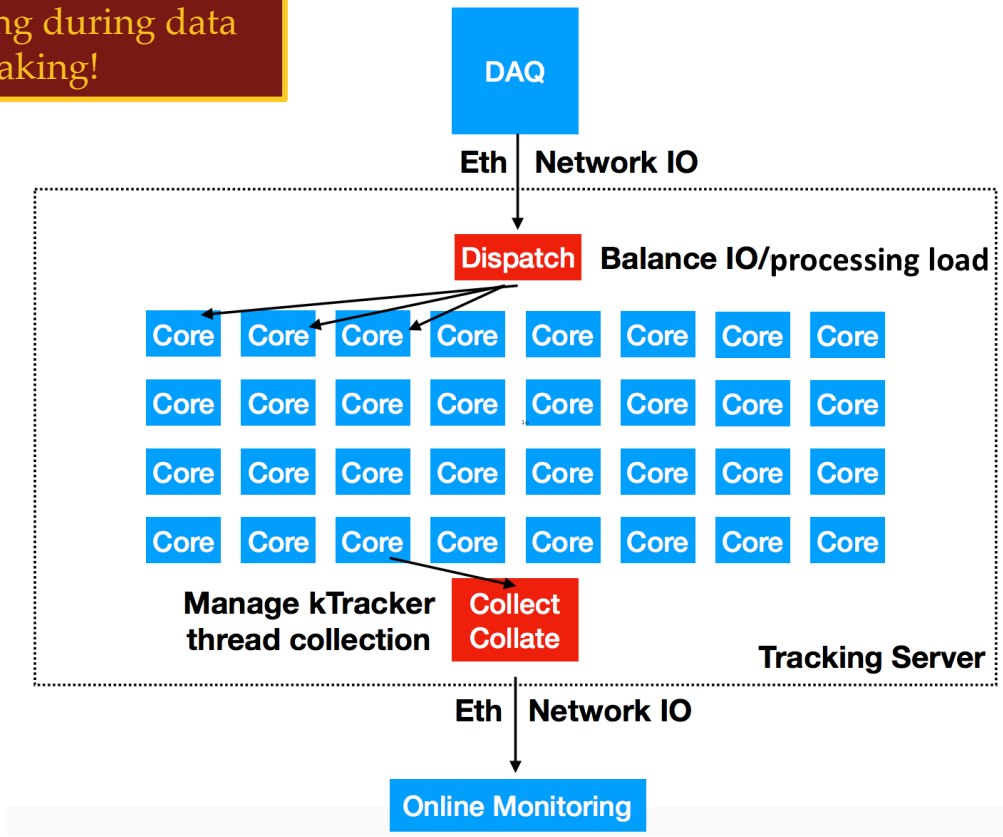
- Use multi-threaded application to:
  - Improve performance/speed of event "cleaning" and single track reconstruction
  - Test using data files from SeaQuest
- Implement in CUDA with Nvidia GPUs
- Other GPU applications: gaming, driverless cars, AI training…

$349, 1920 cores



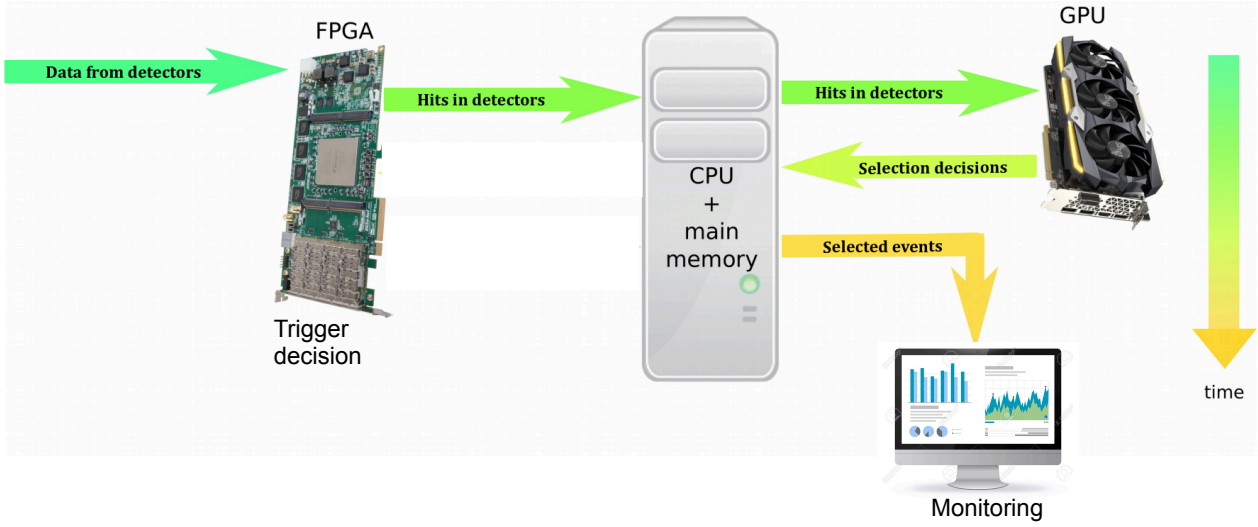
Eventually...

Fast and efficient online monitoring during data taking!

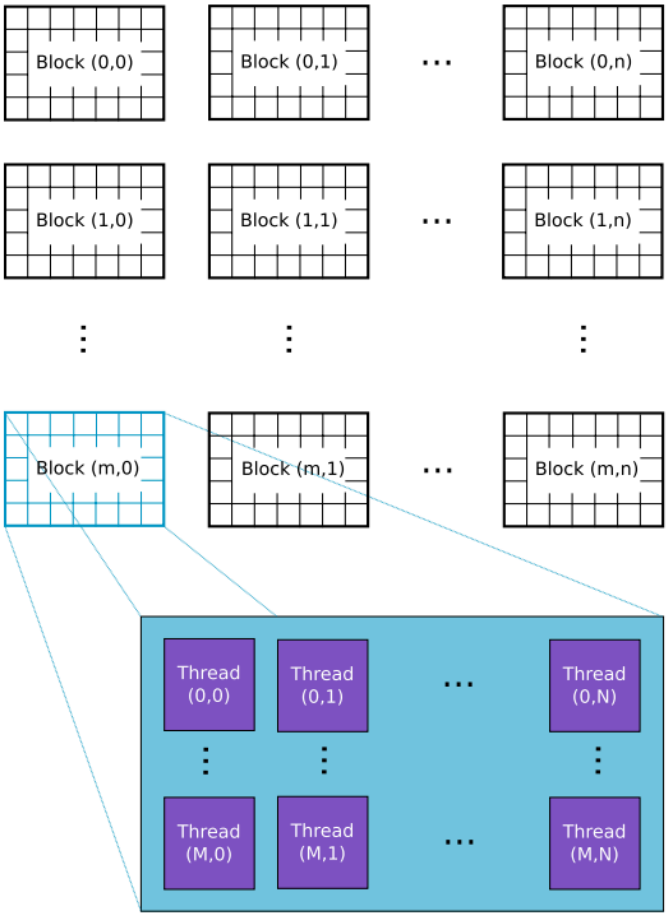


Features of GPU Tracking Framework

- Framework structure motivated by *The Allen project* at LHCb
- Multithreading and multistreaming
- Cross-platform compatibility with CPU architectures
- Single transfer of data to GPU device
- No dynamic memory allocation
- Pass through events that will not finish in time via scheduling



Features of GPU Tracking Framework



arXiv:1912.09161

- Parallelization (SIMT):
  - Run each event in one block
  - Intra-event parallelism mapped to the threads within one block
    - i.e. Hit information in each event for a given detector region

Status of OR Software

- GPU parallelization of event reducer (pre-tracking event cleaning)
- GPU parallelization of tracklet building for detector stations 2 and 3
  - Testing and optimization of block dimensions underway
  - Performance comparisons to CPU multithreading underway

Process	Time (s)
Loading data from disk to memory	2.28
Read and prepare events from loaded file (CPU)	2.25
Transmitting data with graphic memory	0.81
Event reducer (GPU)	0.02

GPU parameters: 20 blocks, 512 threads per block, 10240 threads (9607 events processed, 114MB)

A factor of 100 improvement on the processing speed!

Conclusion

- Polarized DY and J/ψ data at SpinQuest will help constrain important anti-quark and gluon Sivers functions
- Track reconstruction software on GPUs will:
  - Allow for efficient monitoring of data quality
  - Improve reconstruction speed and performance
  - Lay groundwork for next tracking stage: vertex reconstruction
  - Help pave the way for robust analyses at SpinQuest

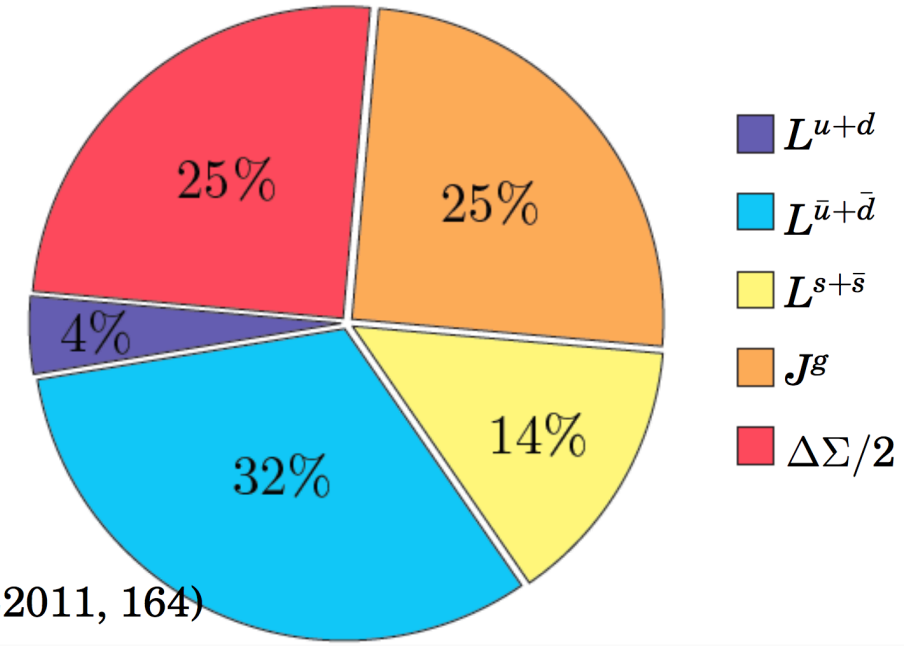
This work is supported in part by the US DOE contract # DE-FG02-07ER41528

Backup Slides

Importance of Gluons and Seaquarks

- Proton spin puzzle:

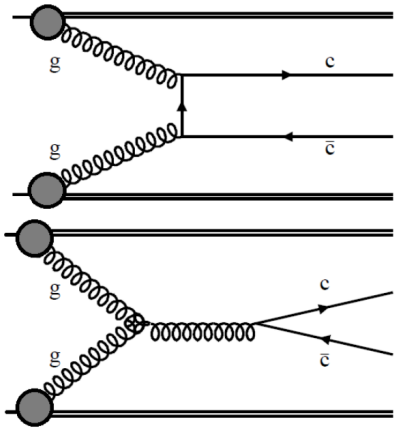
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + J_G + L_q + L_{\bar{q}}$$



Lattice QCD
(PoS LATTICE2011, 164)

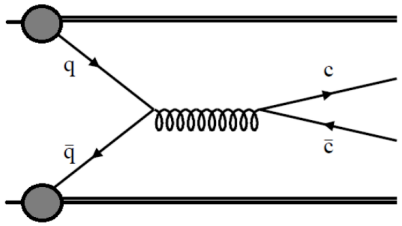
Probing Gluon Sivers with J/ψ

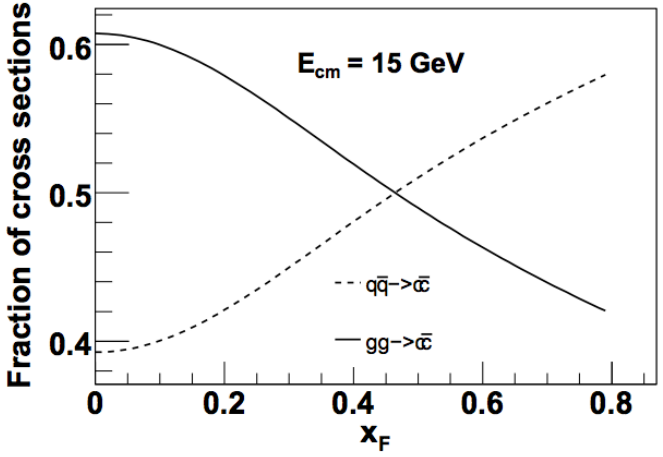
- SpinQuest can also measure dimuons resulting from the decay of the **J/ψ meson**, a charm-anticharm bound state
- Expected SpinQuest J/ψ productions are dominated by gluon-gluon fusion at $x_F < 0.45$ and the center of mass energy, E_{cm}, of 15 GeV
- Improved J/ψ TSSA measurement accuracy and acceptance studies ares currently underway



Gluon-gluon Fusion

Quark-antiquark Annihilation





$x_F \approx x_{beam(or\ 1)} - x_{target(or\ 2)}$