Measurement of Transverse Single Spin Asymmetries for J/ψ production in polarized $p + p^{\uparrow}$ collisions at $\sqrt{s} = 15$ GeV

(On behalf of the SpinQuest Collaboration)

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Outline

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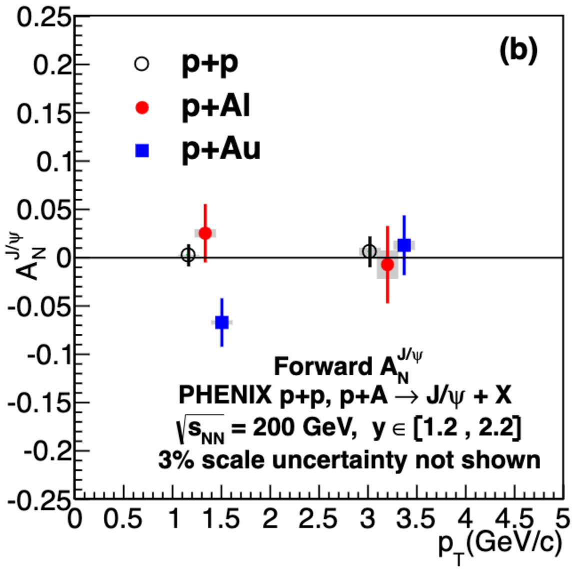
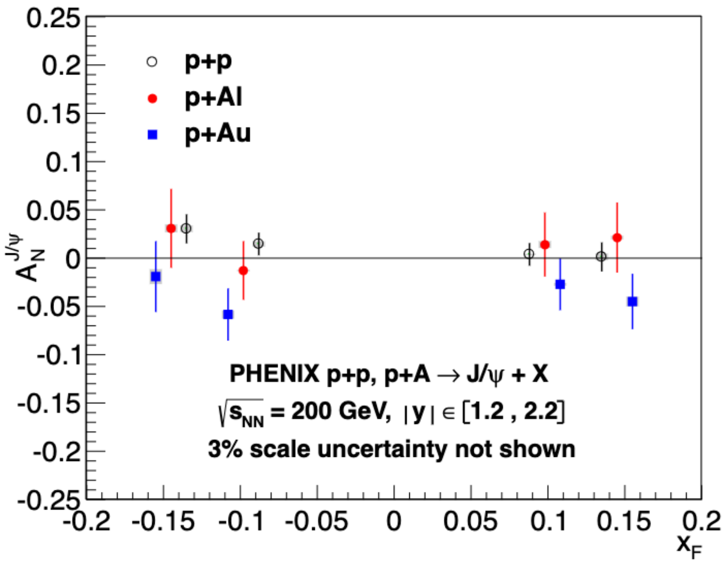
Transverse Single Spin Asymmetry in J/ψ Production

- In proton-proton interactions, the Transverse Single Spin Asymmetry (TSSA), denoted as A_N, characterizes the extent of azimuthal modulation in the scattering cross-section of outgoing particles relative to the transverse spin orientation of the polarized proton.
- The asymmetry is defined as a function of ϕ_S: $A(\phi_S) = \frac{N^{\uparrow}(\phi_S) - N^{\downarrow}(\phi_S)}{N^{\uparrow}(\phi_S) + N^{\downarrow}(\phi_S)} = A_N Sin(\phi_S)$, Here, $\phi_S = \phi_{spin} - \phi_{J/\psi}$
- TSSA is relates to Siver's function and helpful to understand spin momentum correlation
- PHENIX results demonstrates $A_N^{J/\psi}$ as a function of P_T and x_F





Aidala et al., Phys. Rev. D 98, 012006, arXiv: 1805.01491 (hep-ex) (2018)

Motivation

- **Theoretical Interests:**

TSSA for direct J/ψ production Sensitive to both the Sivers effect and J/ψ production mechanisms

Role of gluons in creating A_N is not well understood, while quarks relatively well understood (only the Sivers effect is responsible for any TSSA)

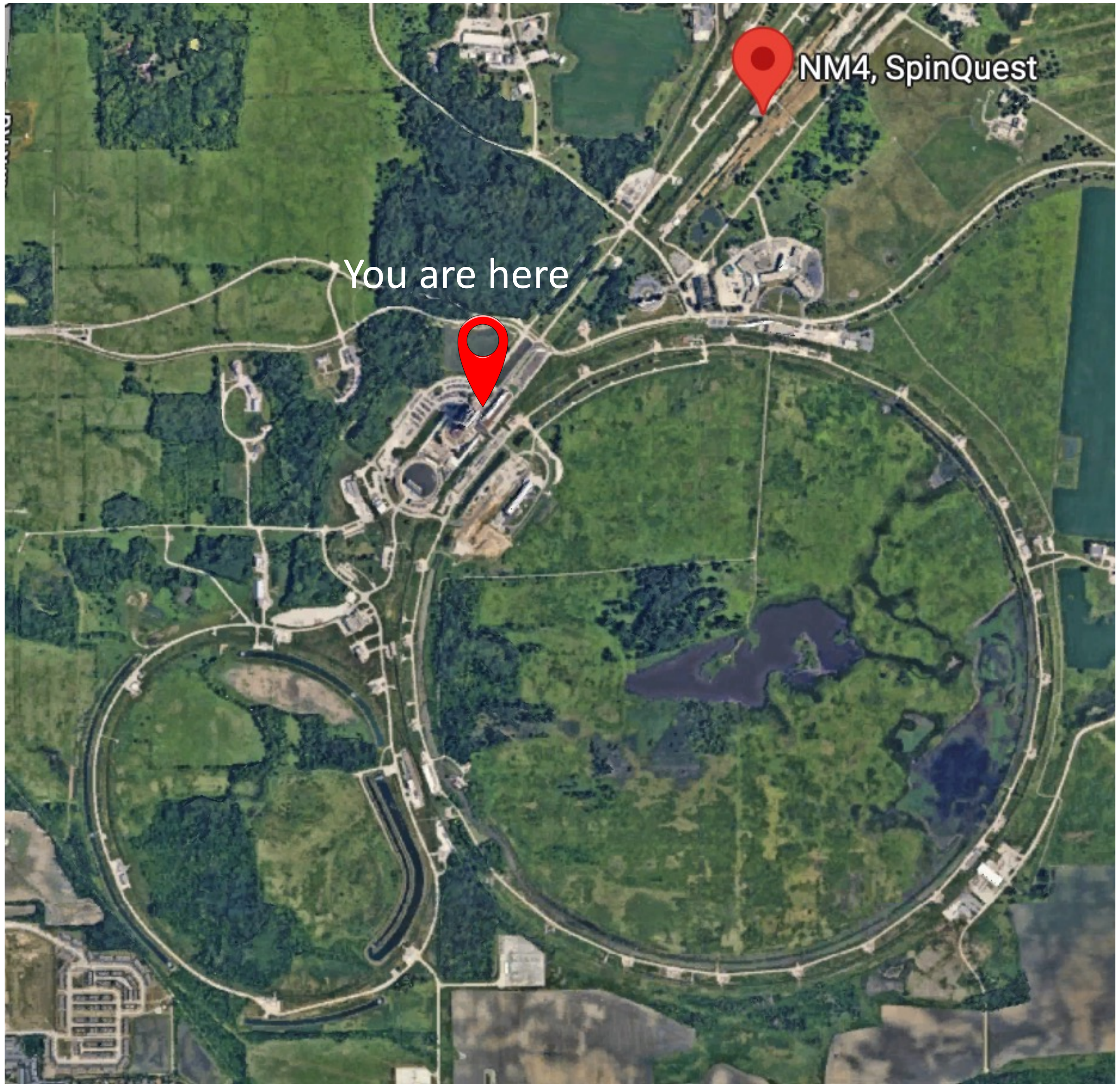
- **Experimental Interests:**

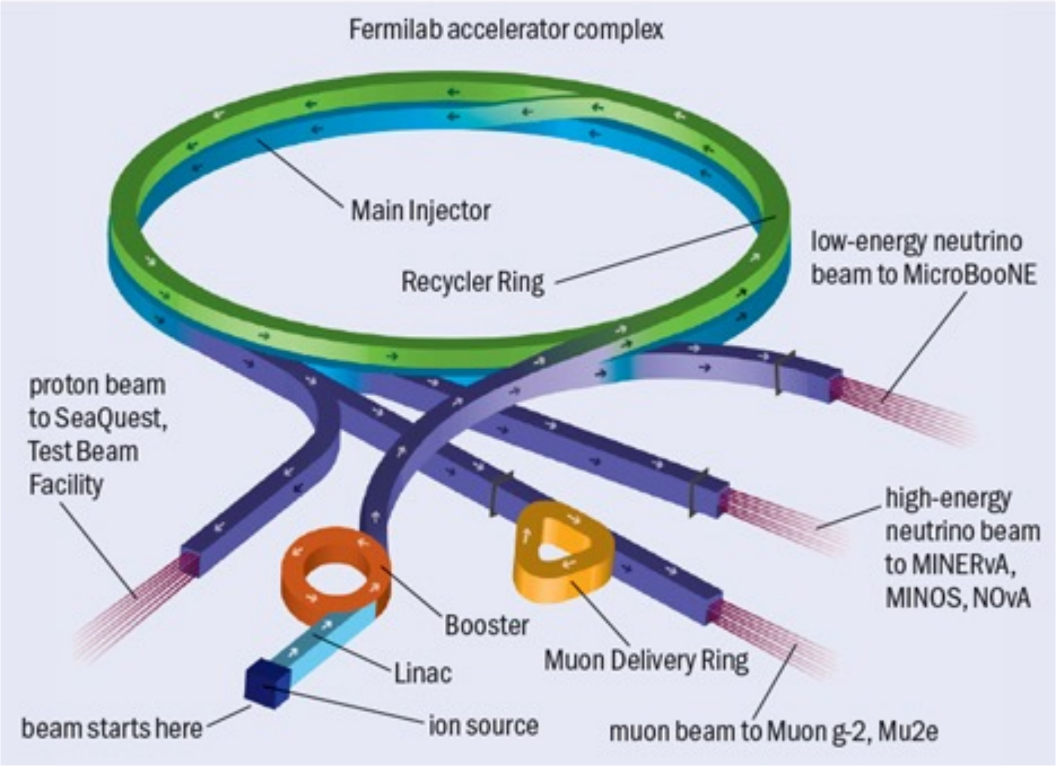
TSSA asymmetry in J/ψ production complementary to PHENIX measurement in unique kinematic region (i.e. $X_F > 0.4$)

Spectrometer is well tested and calibrated to detect physics events with final-state di-muons

J/ψ results will be relevant for future experiments like EIC

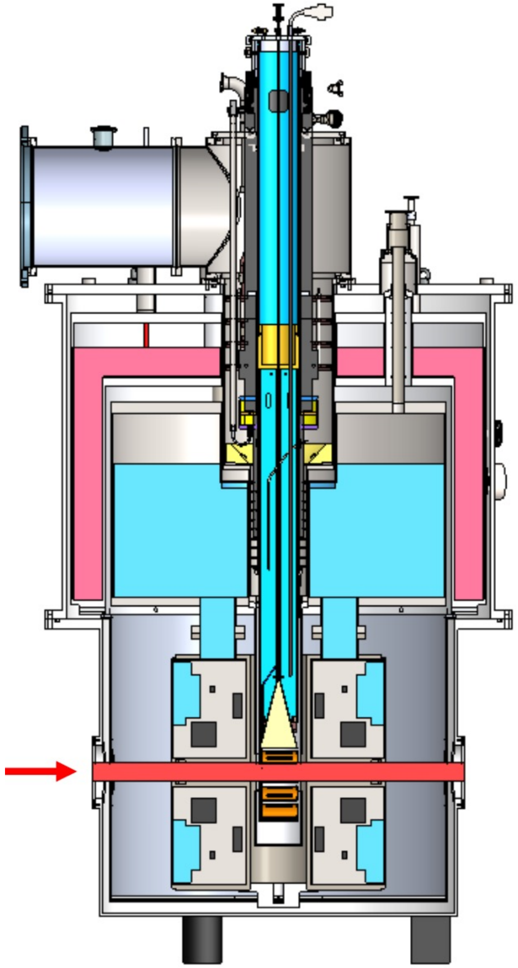
SpinQuest Experiment (Beamline)

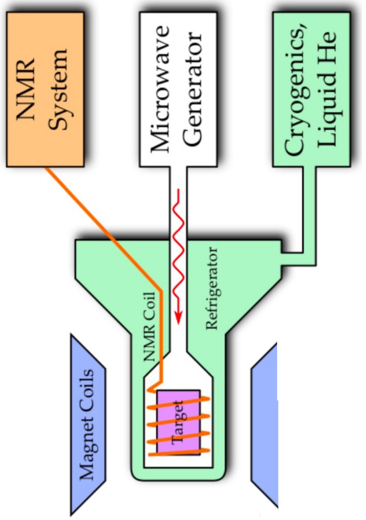




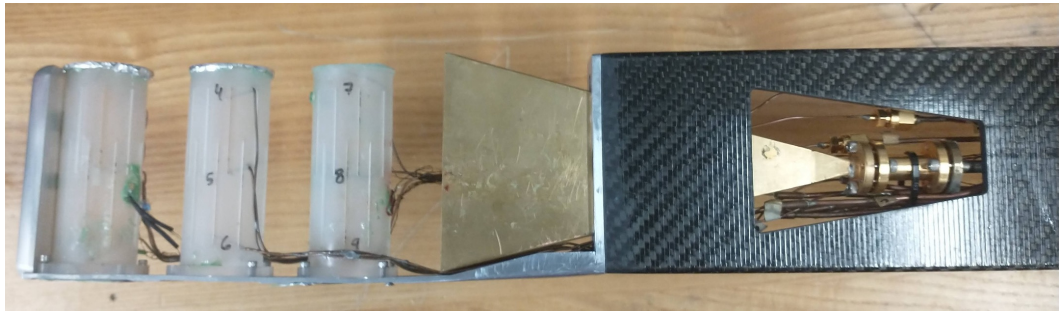
- proton beam energy 120 GeV
- $\sqrt{s}$ = 15 GeV (fixed-target)
- Consisting of $5\times10^{12} protons/spill$
- Beam spill $\approx 4.4s/min$
- Expect $7\times10^{17}\ POT/Year$
- **Fermilab's first polarized, Drell-Yan experiment.!**

SpinQuest Experiment (Cryogenic Polarized Target)



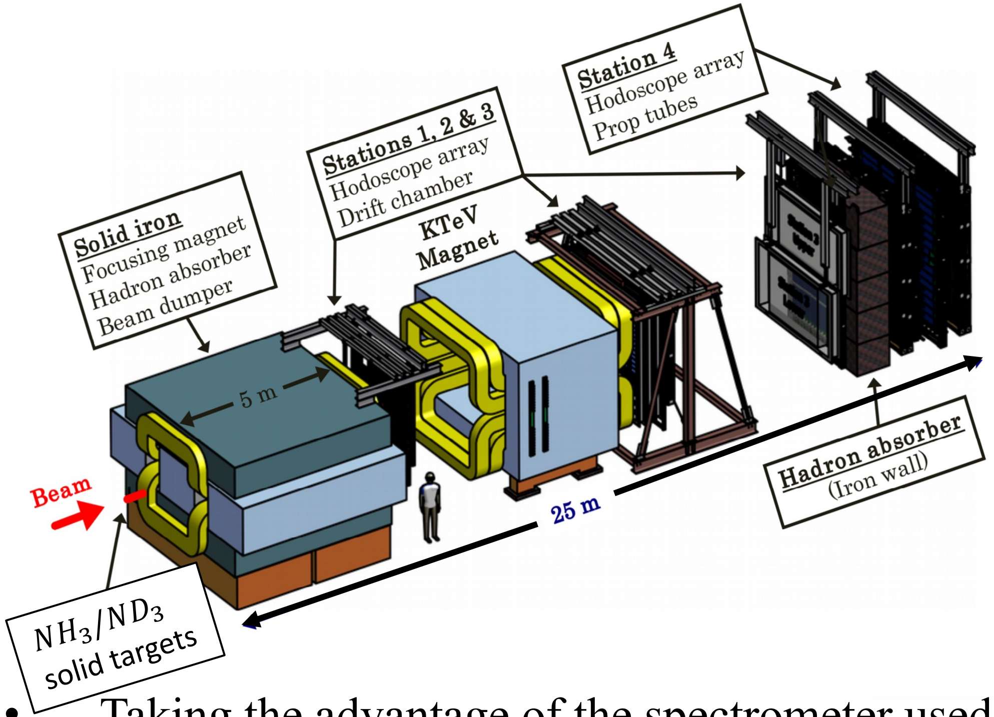


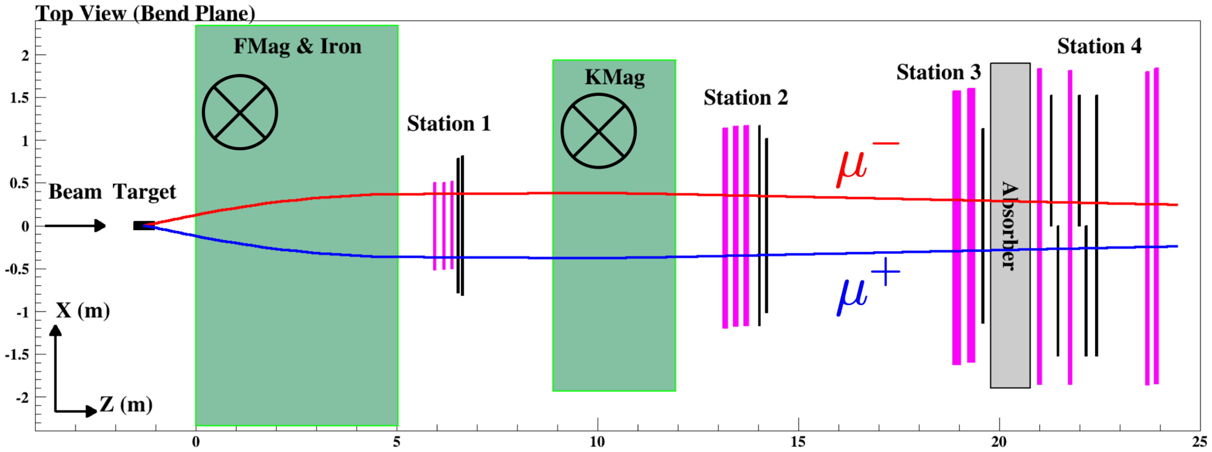
- 8 cm long solid NH_3 and ND_3 target cells
- Magnetic Field: B = 5 T with uniformity $dB/B < 10^{-4}$ T over 8 cm
- Maintaining the target at 1.1K using ^{4}He evaporation refrigerator
- Expected polarizations:
  - NH_3: 80%
  - ND_3: 32%

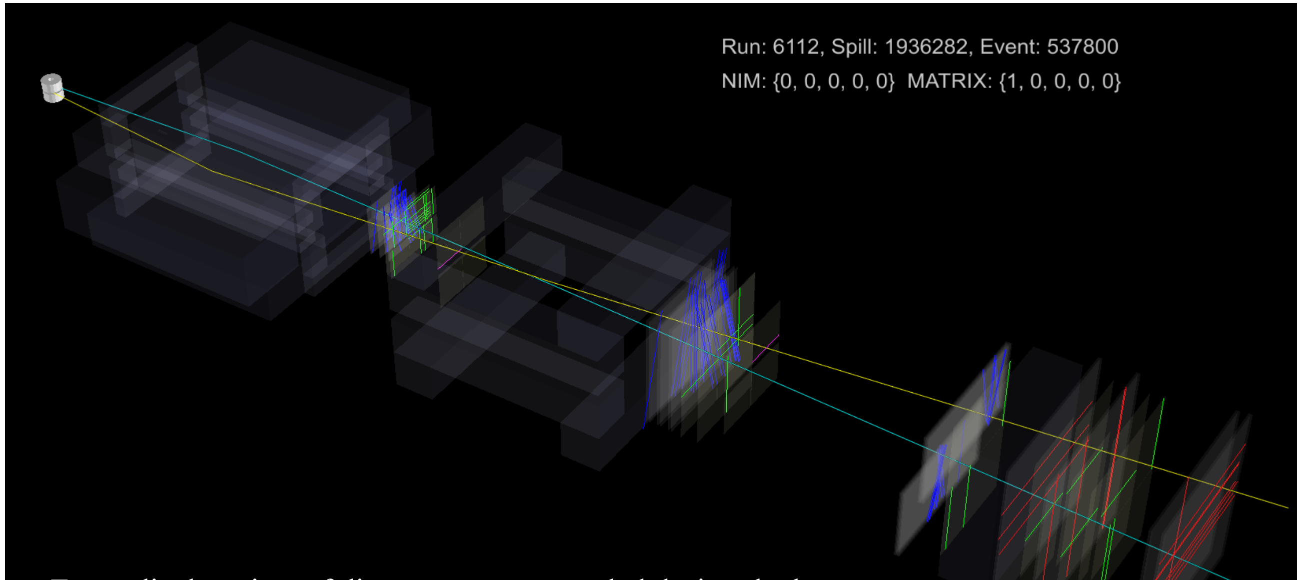


Material	Density	Dilution factor	Packing fraction	Polarization	Interaction length
NH_3	0.867 g/cm^3	0.176	0.60	80%	5.3%
ND_3	1.007 g/cm^3	0.300	0.60	32%	5.7%

SpinQuest Experiment (Spectrometer Setup)



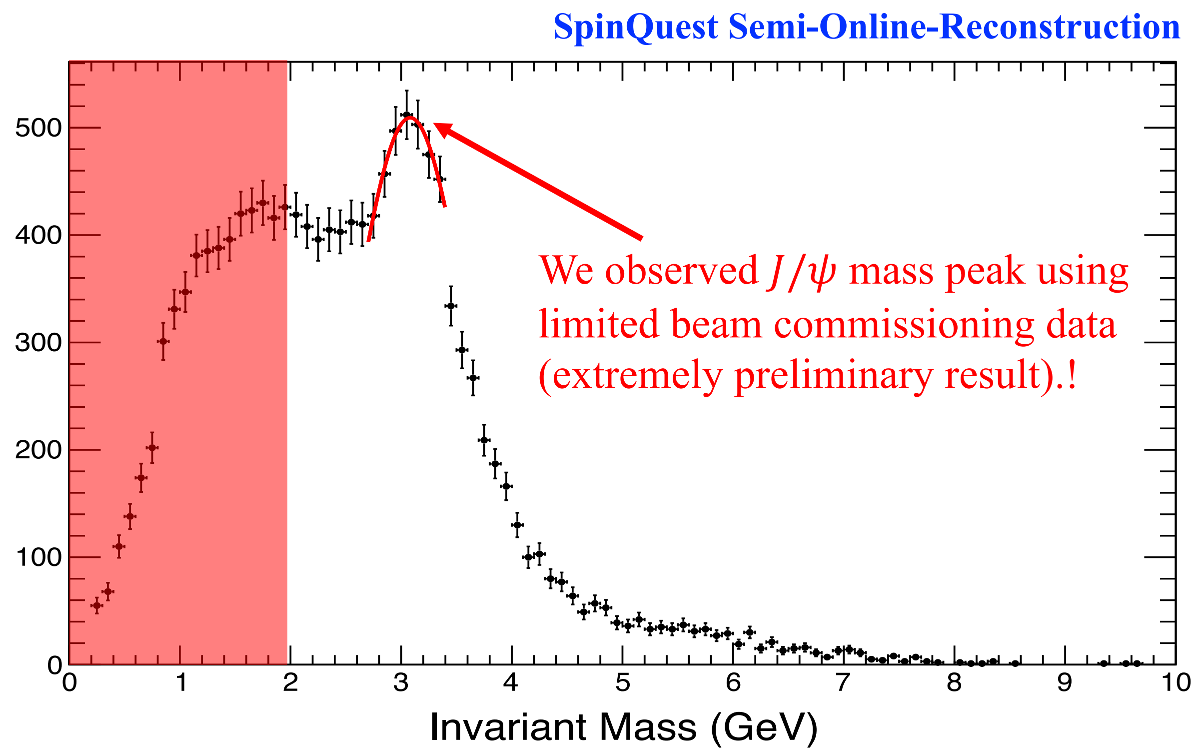


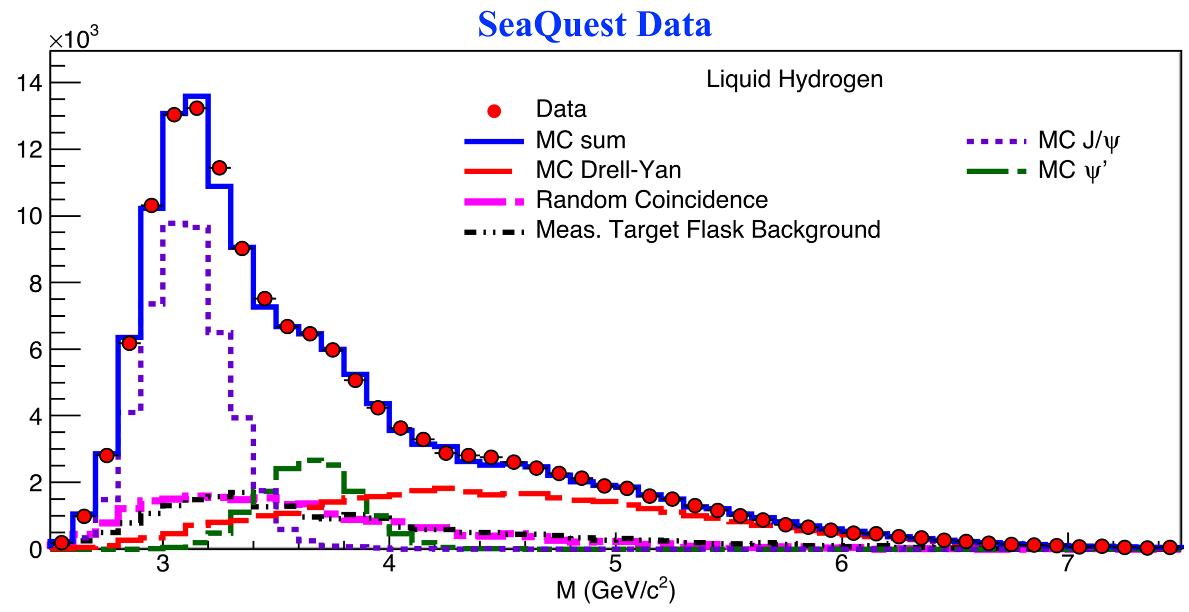


Event display view of di-muon event recorded during the beam commissioning period

- Taking the advantage of the spectrometer used by SeaQuest experiment
- Made by 24 wire chamber planes, 16 hodoscope planes and 8 planes with proportional tubes
- FMag generates magnetic field of 1.8T to select muons in appropriate momentum region
- KMag generates magnetic field of 0.4T and useful to evaluate momenta of muon candidates

Commissioning Status





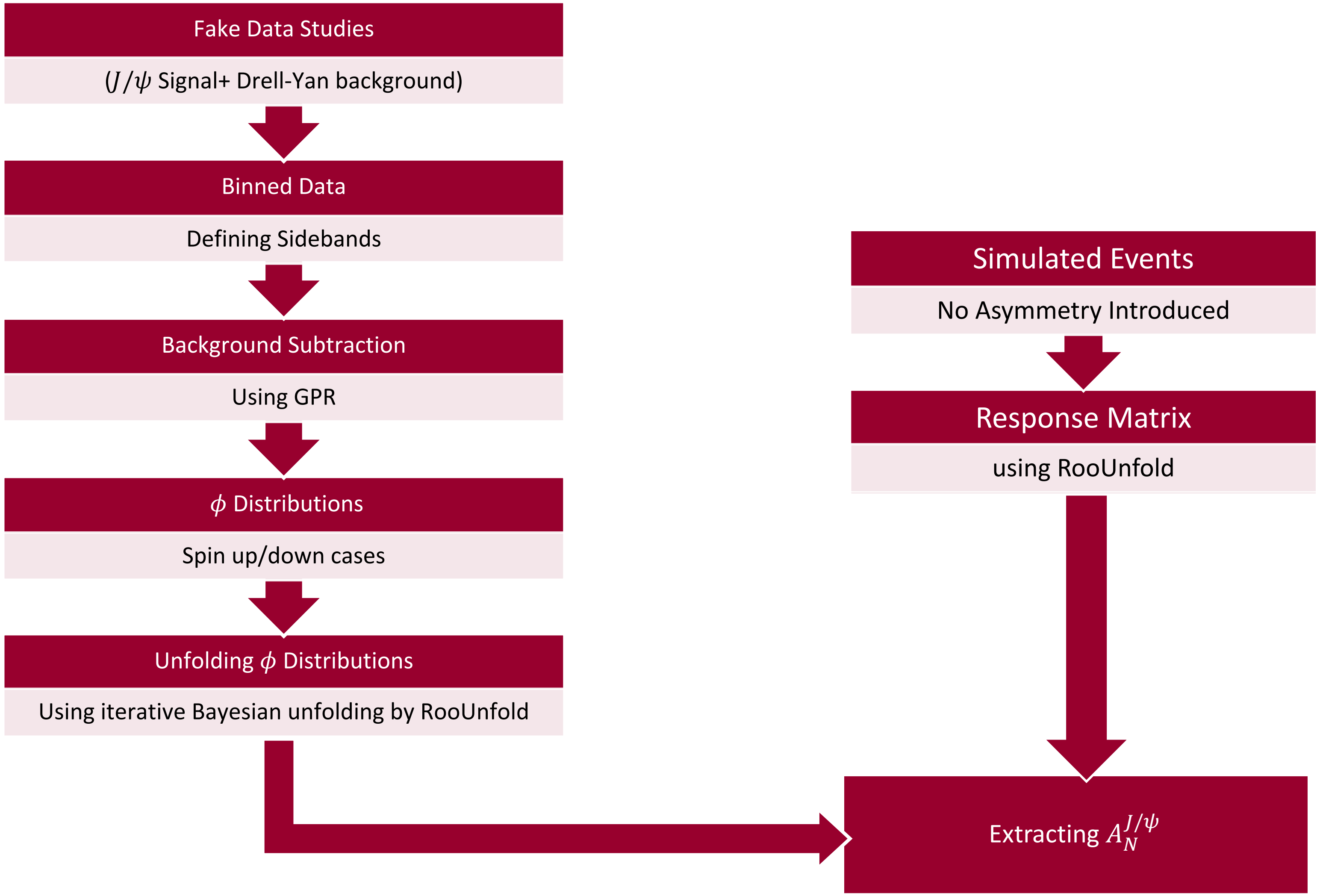
- Wider acceptance range (compared to SeaQuest) below 2 GeV to better understand backgrounds with sideband studies
- Projected event selection/reconstruction is expected to be the same for SpinQuest from SeaQuest

- $\delta\sigma_M(J/\psi) \sim 220$ MeV
- Already collected data during the beam commissioning and analyzed invariant mass spectrum with the limited data collected for online reconstruction (not a full reconstruction)
- We expect better efficiency and resolution from offline analysis

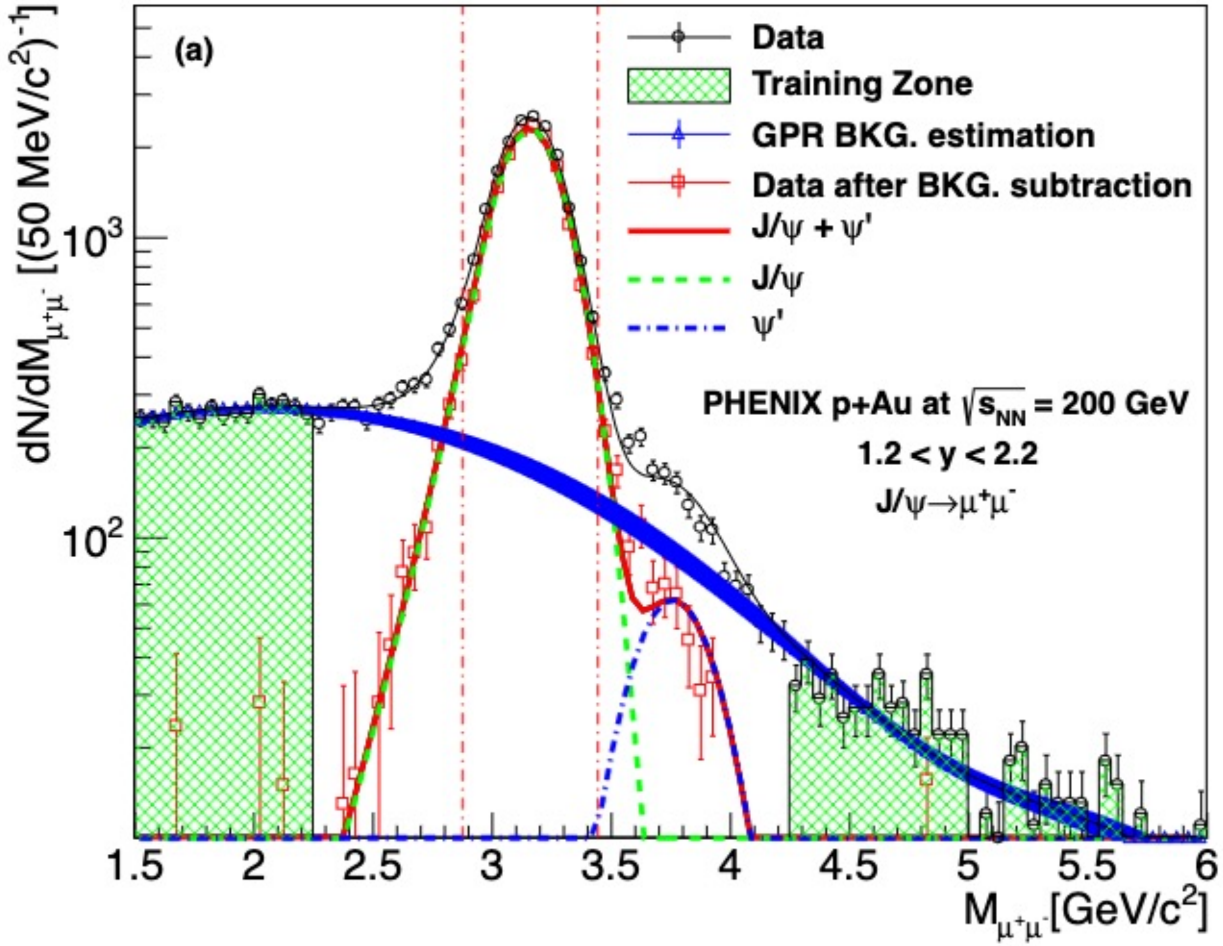
Simulation Studies for $A_N^{J/\psi}$ Determination

- SpinQuest commissioning data is statistically limited
- Currently using SeaQuest data to benchmark the background subtraction
- Already generated Monte-Carlo events for:
  - J/ψ signal events
  - Drell-Yan combinatory background events
- Everything scaled down to 2.873×10^{17} POT
- Asymmetry was introduced by weighting MC events (Initially we set $A_N = 0.2$ for simulation):
  - $w_{A_N} = 1 + A_N \times P \times Sin(\phi_{spin} - \phi_{J/\psi});\ where\ \phi_{spin} = \pm\frac{\pi}{2};\ P = 1.0$
  - $w_{total} = w_{A_N} \times w_{event}(mass, x_F)$

Current Strategy



Background Subtraction using GPR



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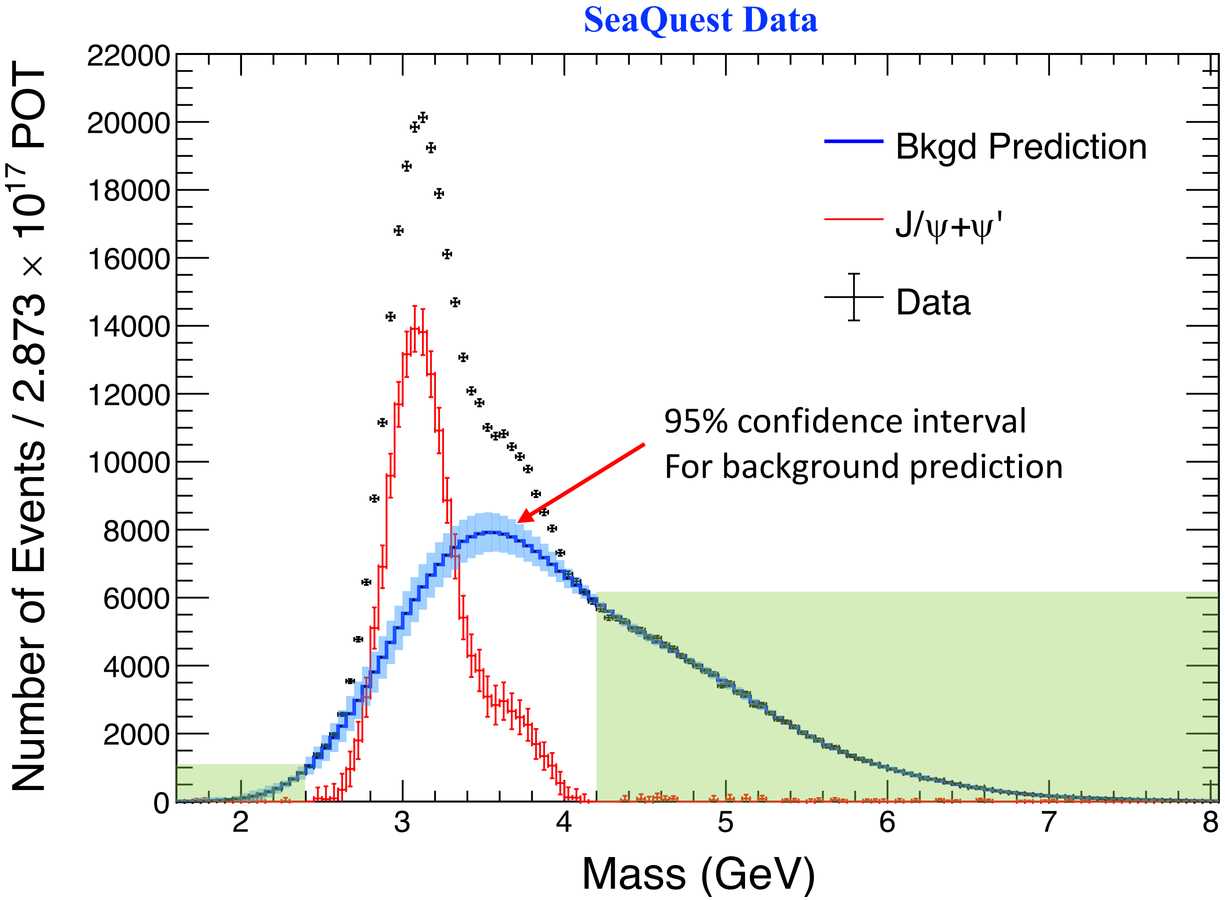
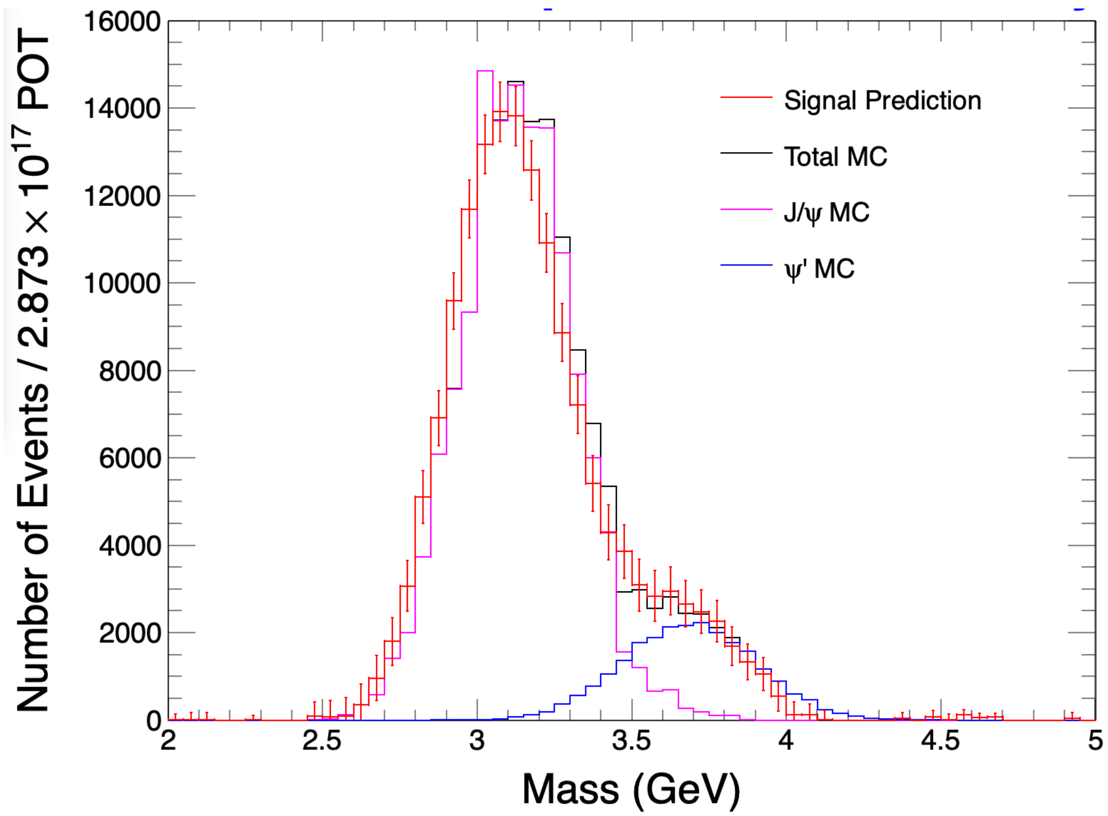
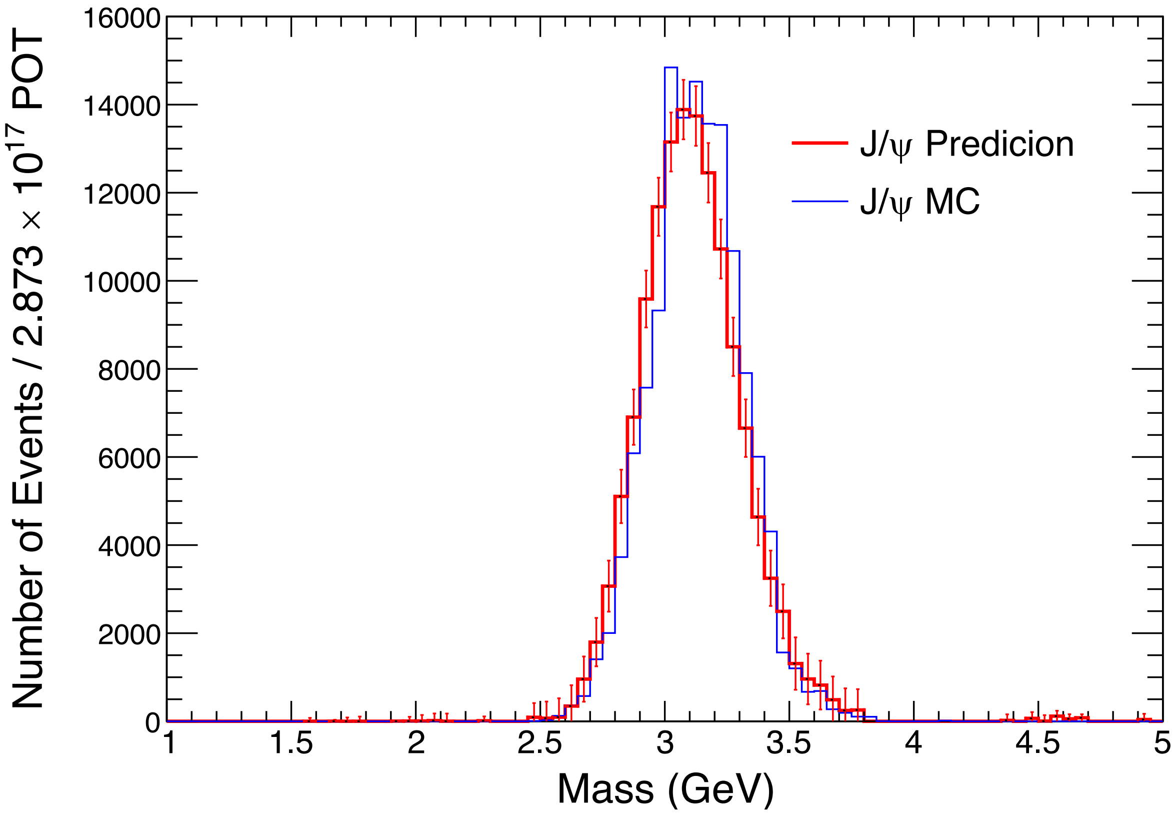


- Sideband regions: 0-2.4GeV and 4.2-8GeV
- We selected GPR (Matern Kernel) among other regression techniques based on hyper parameter optimizations

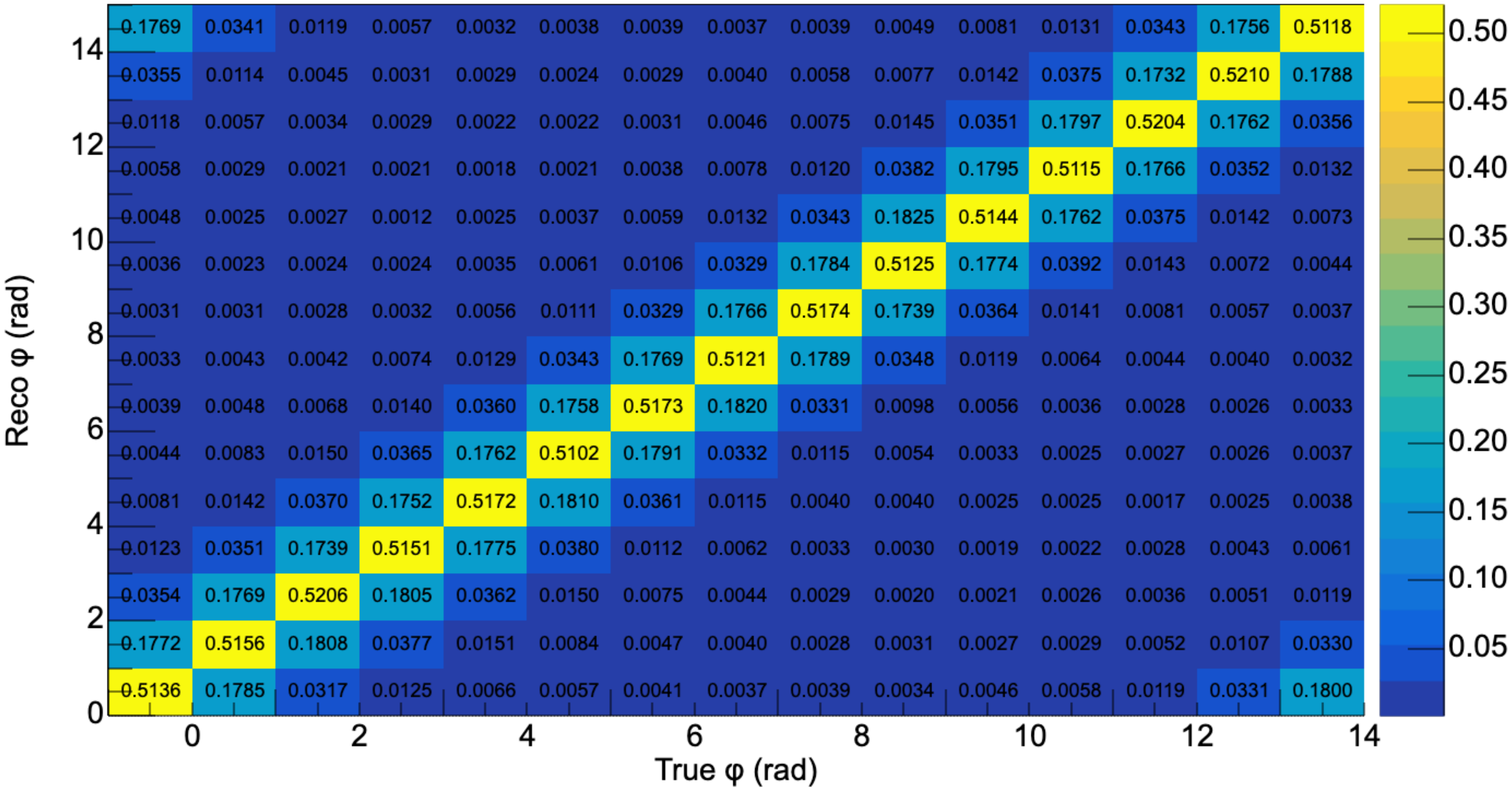
Comparing Background-Subtracted Spectrum to Monte Carlo





- Applied template fit to remove the tail due to ψ' background events
- Obtained a good agreement between data-based prediction and MC

Iterative Bayesian Unfolding using RooUnfold

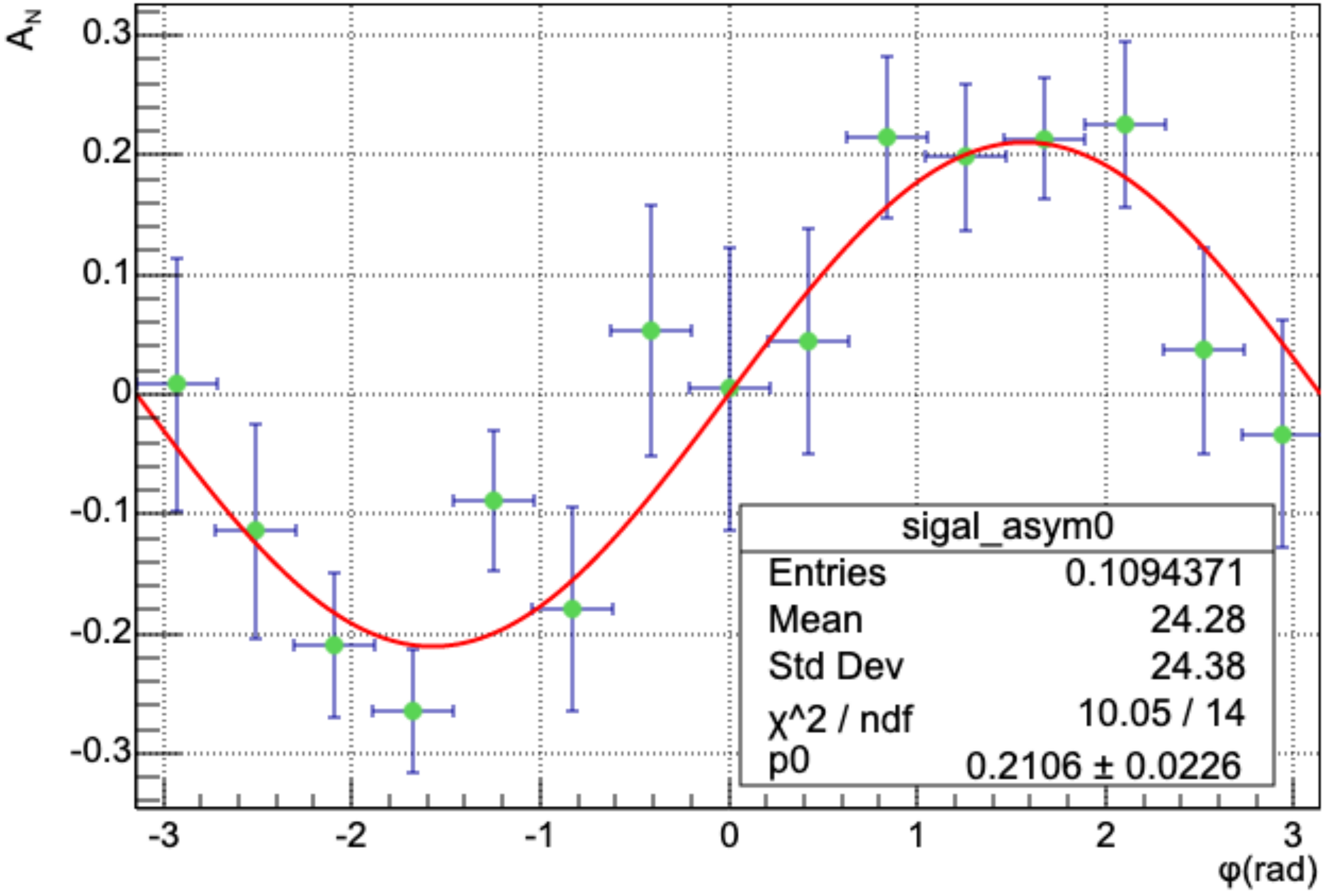


- Initially defined 15 bins between: $\{-\pi, \pi\}$
- Selected Kinematic region:

$$0 < P_T < 6 \text{ GeV}$$

- Response matrix will be used to calculate unfolded ϕ distributions

Unfolded $A_N^{J/\psi}$ for selected P_T bin

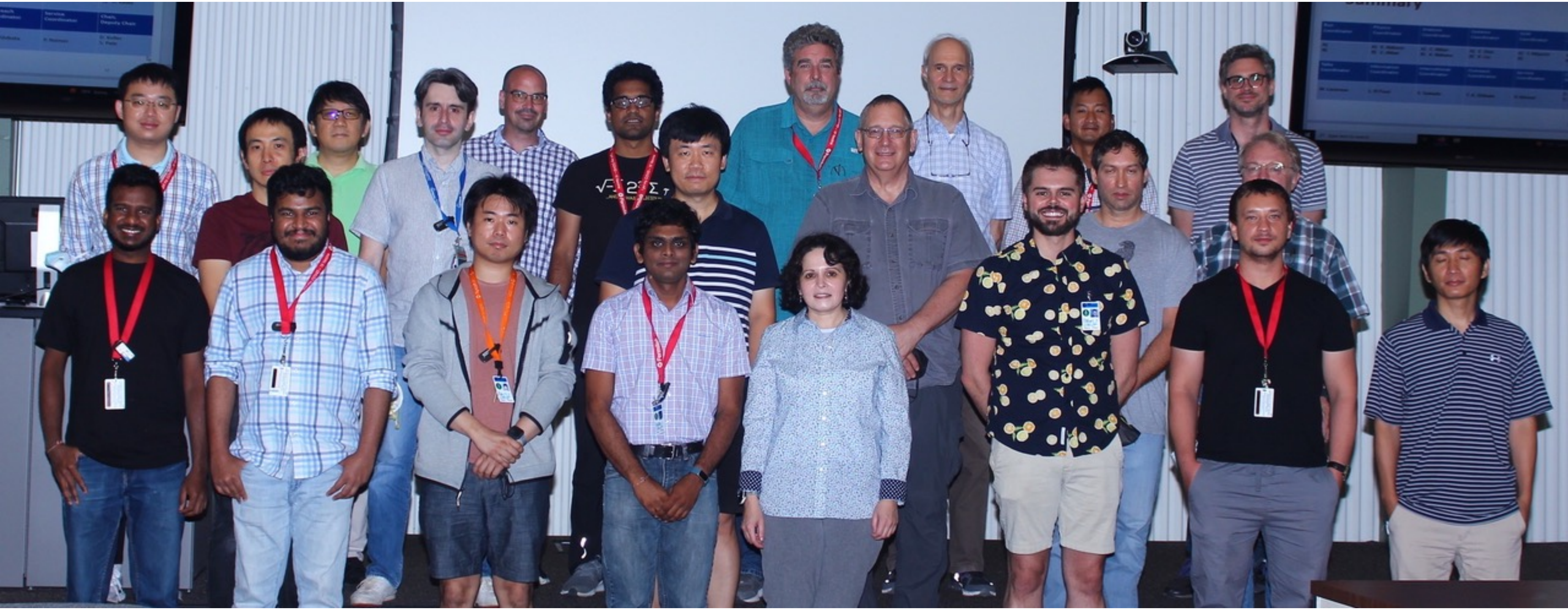


- Measured $A_N^{J/\psi} = 0.21 \pm 0.02$
- Injected $A_N^{J/\psi} = 0.2$
- $0 < P_T < 6$ GeV

Conclusions and next steps

- We have a robust tool (GPR) to extract J/ψ peak and using GPR method with Matern kernel, background of the J/ψ mass can be predicted with 95% confidence interval
- Using iterative Bayesian unfolding we can correct the bin-by-bin migration
- $A_N^{J/\psi}$ can be determined for different P_T and X_F bins
- Benchmark GPR with new regression models to further improve background subtraction
- SpinQuest experiment is now fully commissioned and ready to start taking physics data in the 2024/2025 beam period at Fermilab.
- $A_N^{J/\psi}$ is sensitive to both the Sivers effect in the nucleon and J/ψ production mechanisms
- Beam commissioning in progress, stay tuned with the latest updates!

Thank you.!



Please Join The Effort

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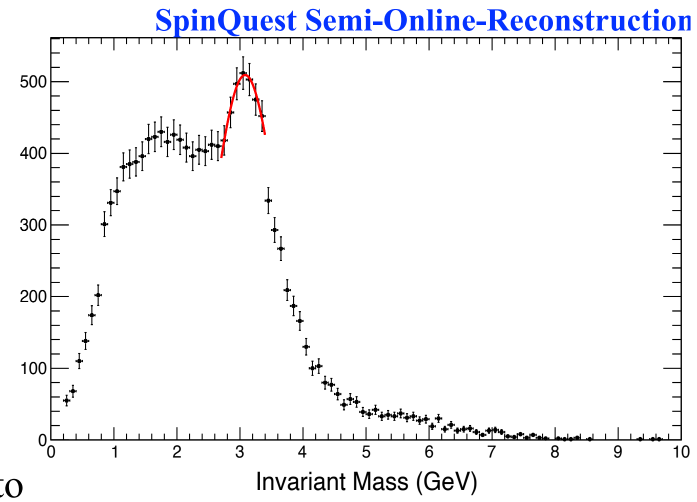
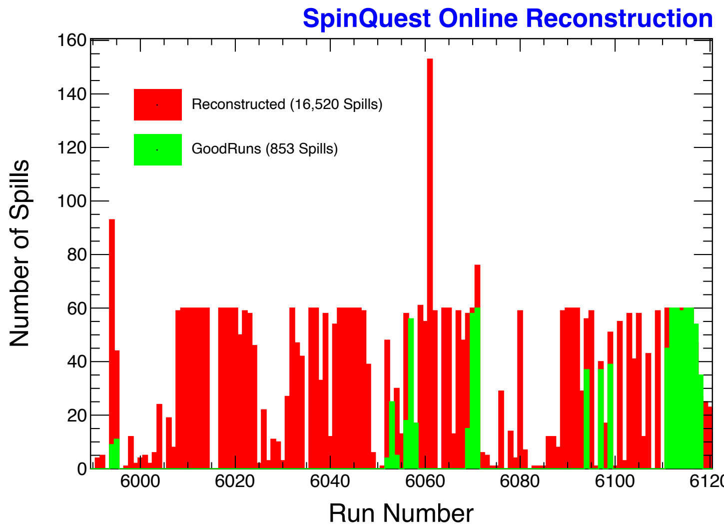
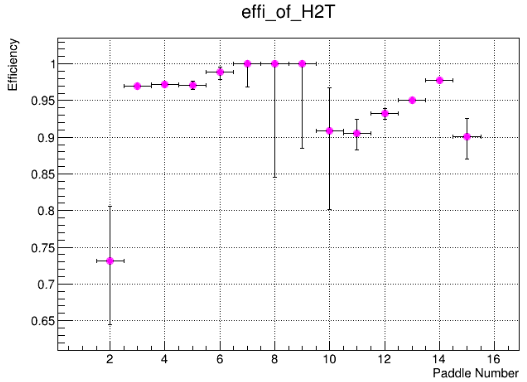
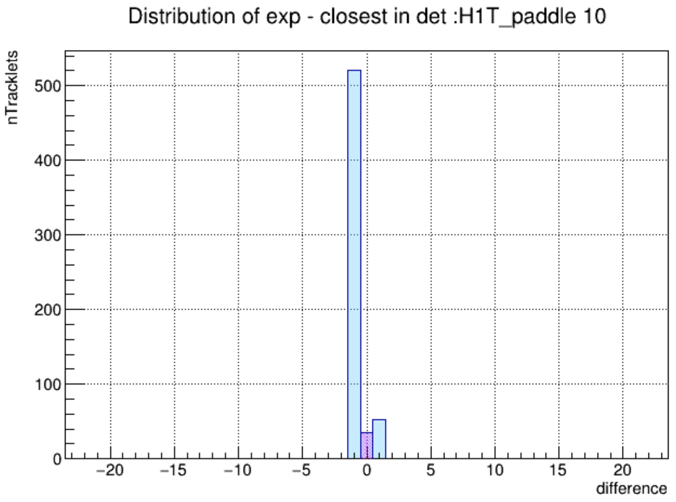
Online Reconstruction Updates

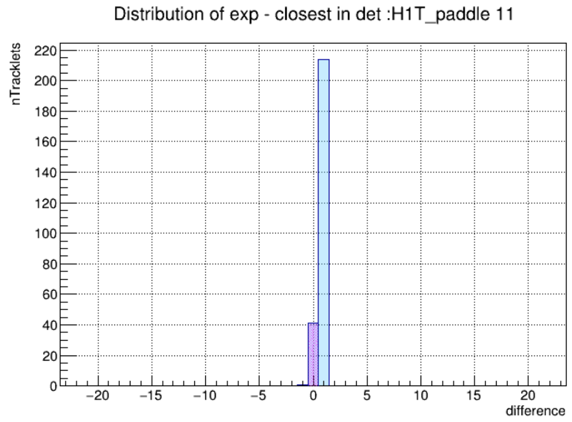
- Two different reconstructions working together to process decoded files:
  - Online reconstruction (local, fast, limited by occupancy)
  - Semi-Online reconstruction (Fermigrid, time consuming, no occupancy constraints)
  - Already completed reconstructing goodruns (853 spills).!
- Provides data quality and online monitoring (track-level information event-by-event basis)
- Monitor the impact on Physics when introducing constraints (invariant mass spectrum when K-Mag runs half of the current to reduce heat load)
- Wire chamber and hodoscope efficiency calculations
- Troubleshooting spectrometer by using online reconstruction:
  - Beam gate malfunctioning identified (Elog 5599)
  - Swapped cables found at hodoscope stations (Elog 5666)
  - Chamber connections mistakenly swapped found
  - Correcting wire-chamber alignment by studying residual plots (work on progress!)
- Stay tuned to receive more exciting news.!











Benchmarking Regression Models