Polarization Technology Meeting
December 18, 2024

New DAQ for the 200 MeV Polarimeter at BNL Linac

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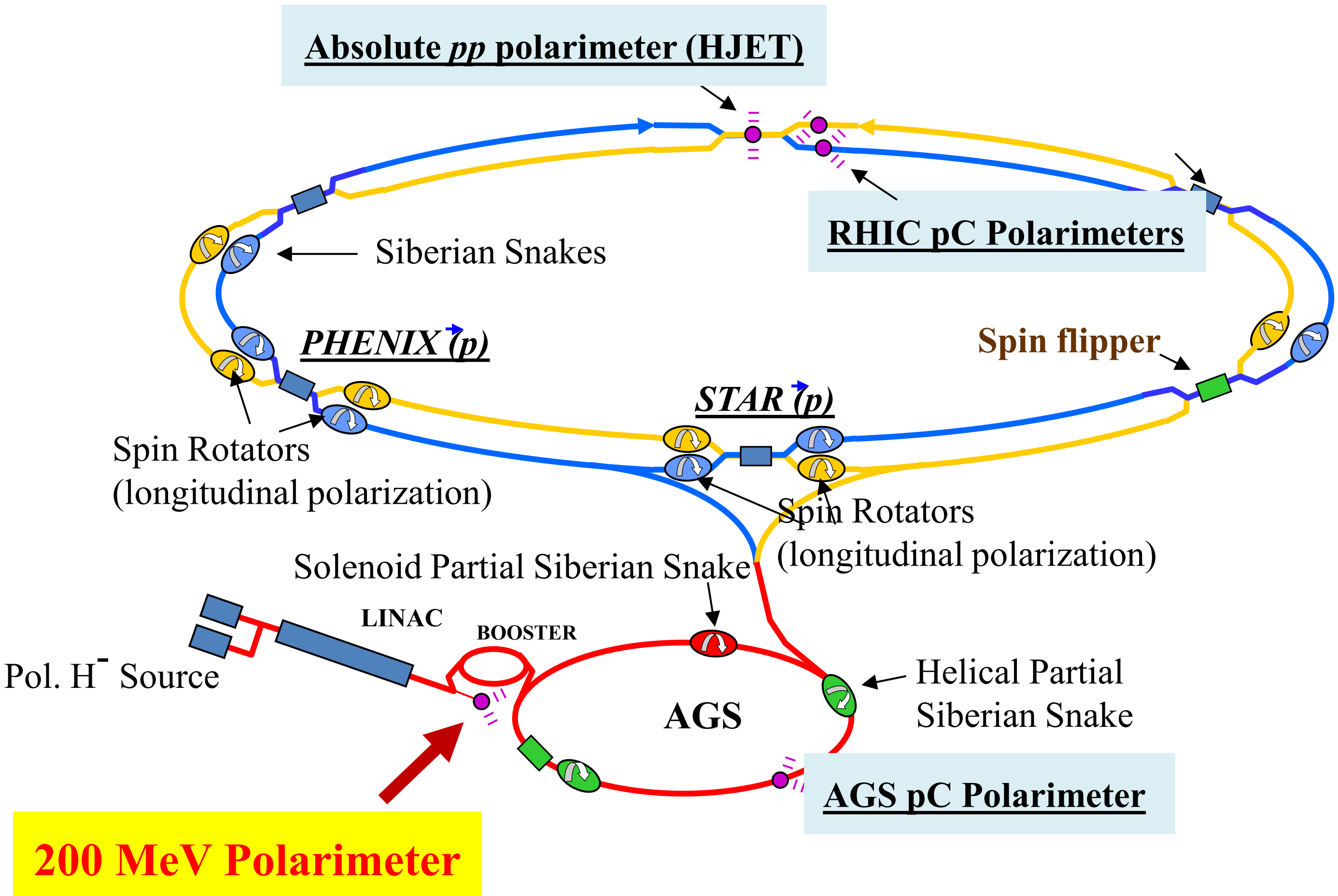
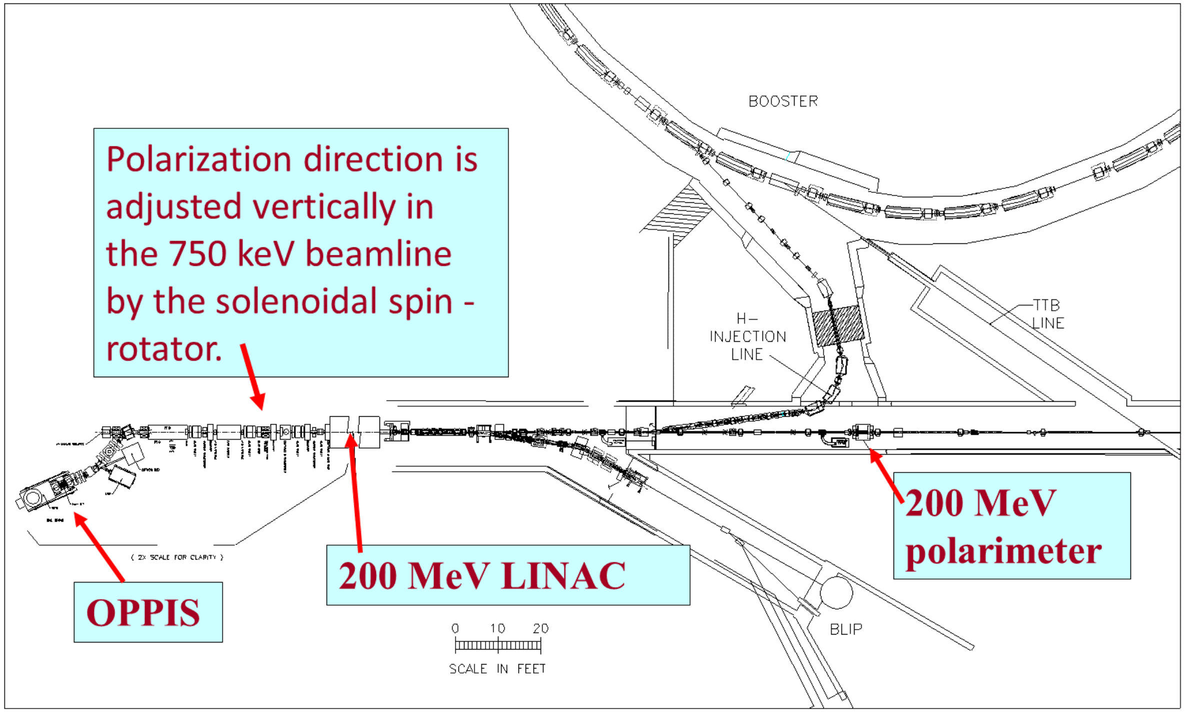
Polarized Proton Beams at RHIC



Polarized injector, 200 MeV *Linac and injection lines*

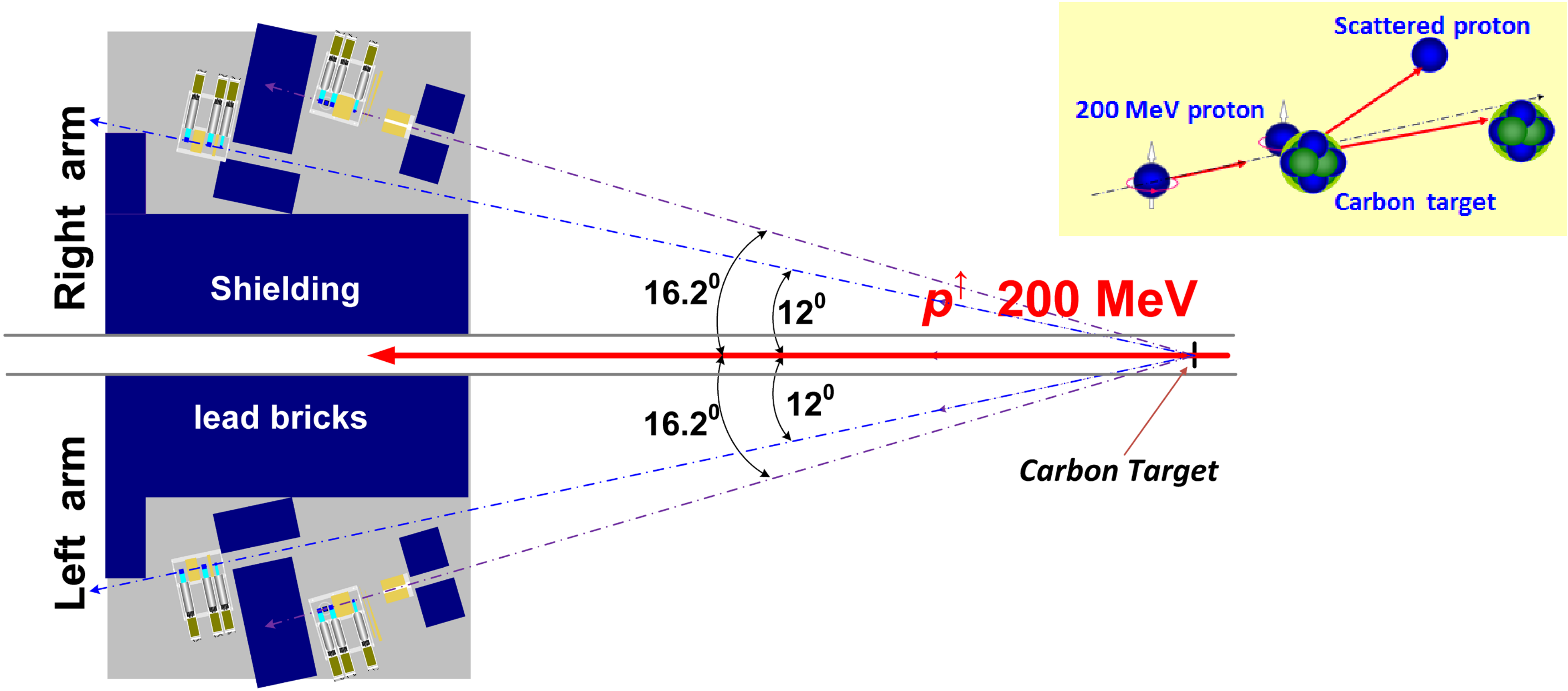


- Linac beam current ~ 350 μA
- Linac pulse duration ~ 300 μs
- The microbunches 200 MHz
- The pulse period 2.1 s
  (every second pulse is directed to the 200 MeV polarimeter)
- The beam polarization ~ 80%

200 MeV *p*-Carbon Polarimeter:

- Initially, inclusive rates (measured by scalers) of scattered protons at $12°$ were used to determine the beam polarization with an accuracy of $\sim 5\%$. For this configuration, $A_N \sim 0.62$.
- In 2010, the polarimeter was upgraded with $16.2°$ arms ($A_N \approx 0.993$ for elastic events) to precisely calibrate $12°$ measurements.
- Later, the increased beam intensity required more accurate monitoring of the measurements. To address this, a new data acquisition (DAQ) system based on VME waveform digitizers was implemented.

200 MeV Polarimeter



12 degree polarimeter

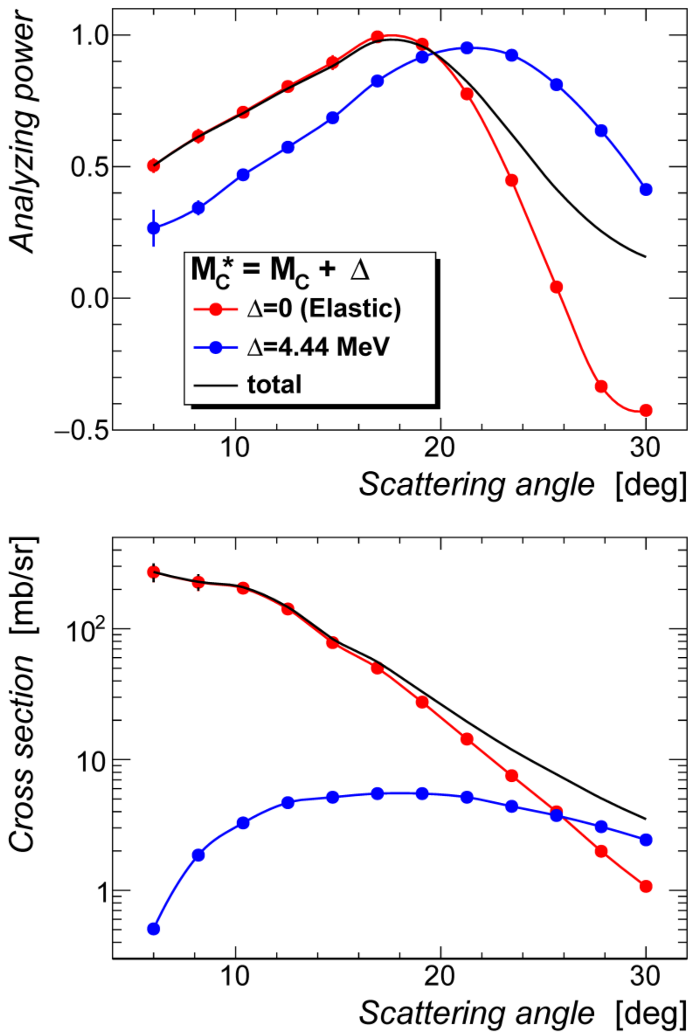
- $\langle A_N \rangle \sim 0.62$
- High rate
- ***Used for the polarization monitoring***

16.2 degree polarimeter

- $A_N = 0.993 \pm 0.003$ (elastic)
- Inelastic events are suppressed by absorber.
- Low rate
- ***Used for the absolute polarization measurement.***

Analyzing Power

$\boldsymbol{p^{\uparrow} + \mathrm{C} \rightarrow p + \mathrm{C}^{*}, \;\; 200\ \mathrm{MeV}}$



- *For ½+0→ ½+0 elastic scattering, the analyzing power must reach* $|A_N(T,\theta)| = 1$ *at some point* (T,θ)*. Such points can be identified through phase shift analysis.*

- *In case of* pC *scattering, one such point occurs at* $T_0 = 187.95\ \mathrm{MeV}$ and $\theta_0 = 17.16°$. Results of the experimental study of $A_N(T,\theta)$ around this point,

$$\boldsymbol{A_N(T,\theta) = 1 - \alpha(T - T_0)^2 - \beta(T - T_0)(\theta - \theta_0) - \gamma(\theta - \theta_0)^2}$$

S.P. Wells et al., Nucl. Instr. And Meth. A325 (1993) 205:

$$\alpha = 1.19(0.11) \times 10^{-4}\ \mathrm{MeV}^{-2}$$
$$\beta = 1.80(0.16) \times 10^{-3}\ \mathrm{MeV}^{-1}\mathrm{deg}^{-1}$$
$$\gamma = 1.09(0.08) \times 10^{-2}\ \mathrm{deg}^{-2}$$

can be used for precision determination of the analyzing power for 200 MeV proton-Carbon beam elastic scattering at $16.2°$.

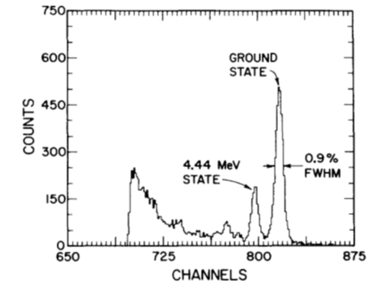
$$\boldsymbol{A_N^{\mathrm{elastic}}(200\ \mathrm{MeV}, 16.2°) = (99.35 \pm 0.25)\%}$$

If not suppressed, the $\Delta = 4.44\ \mathrm{MeV}$ inelastic background dilutes the analyzing power by about 2%.

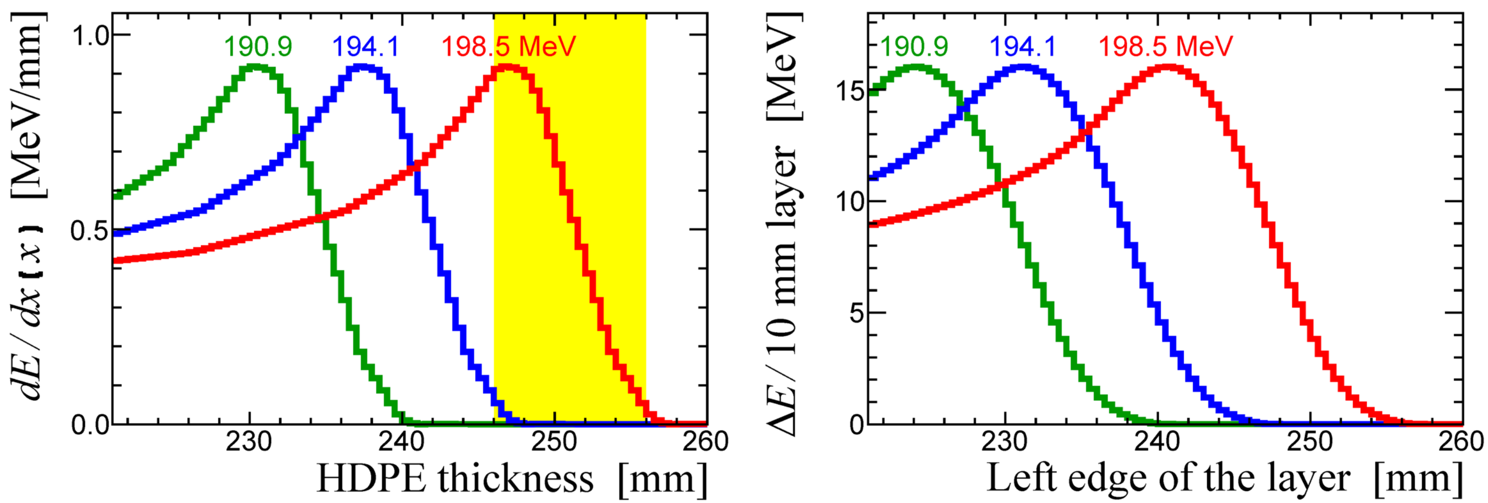
Suppression of the inelastic events

Kinetic energy of the scattering proton depending the Carbon excitation Δ (for the 200 MeV beam energy and 16.2° angle.)

Δ , MeV	T, MeV
0 (Elastic)	198.5
4.44	194.1
7.65	190.9

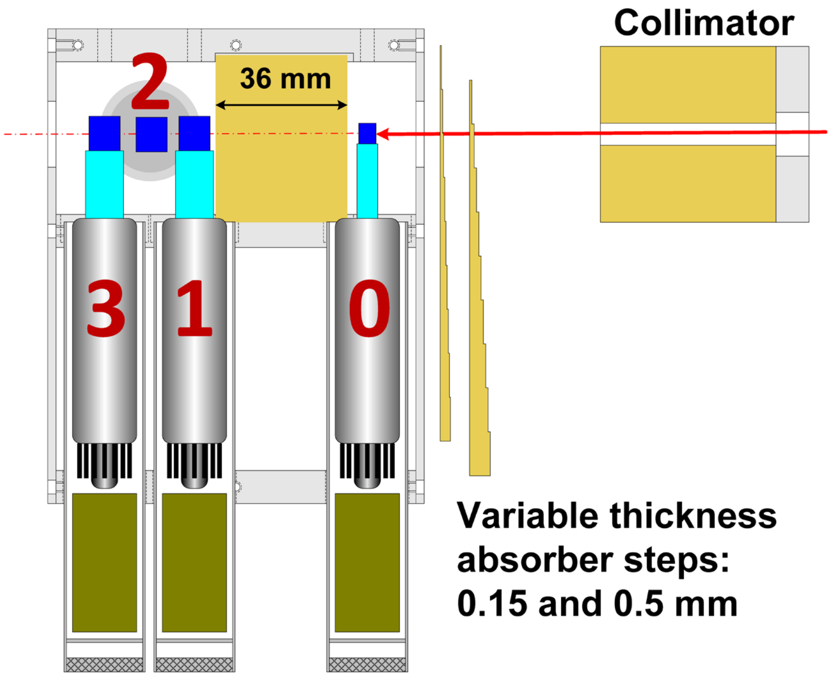


Derived from C. La Tessa et al., Life Sciences in Space Research 11, 18 (2016)



- Proton energy losses in High Density Polyethylene (HDPE)
- Elastic events can be separated from inelastic ones by appropriately selecting the active detector.
- Scintillator detector is well-suited for this purpose.

The $16.2°$ polarimeter (one arm)



Scintillator dimensions:

$0 \; - \; 6 \times 6 \times 4 \; mm^3$

$1\text{-}3 \; - 10 \times 10 \times 9.5 \; mm^3$

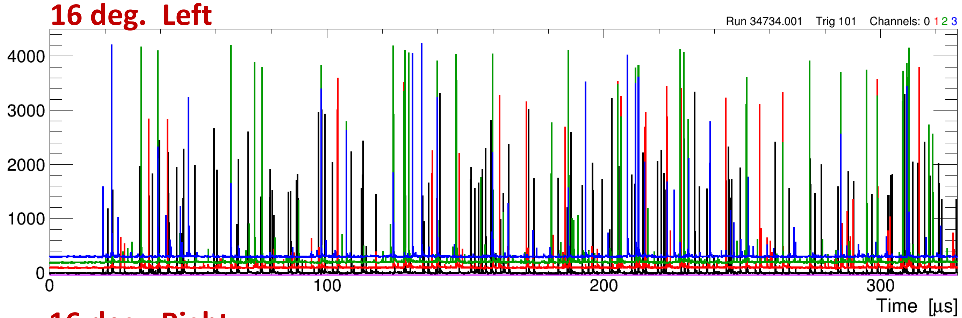
The new DAQ is based on the 250 MHz, 14-bit WFD (SIS 3316)

- A 200 MHz Linac clock was used
- The full waveform of 35,534 samples (spanning 327 μs) was recorded for each scintillator in every bunch.
- The acquired data enabled comprehensive monitoring of the polarimeter's performance.
- Detailed processing of the data from a single bunch takes approximately 50 ms, allowing for real-time, online analysis.

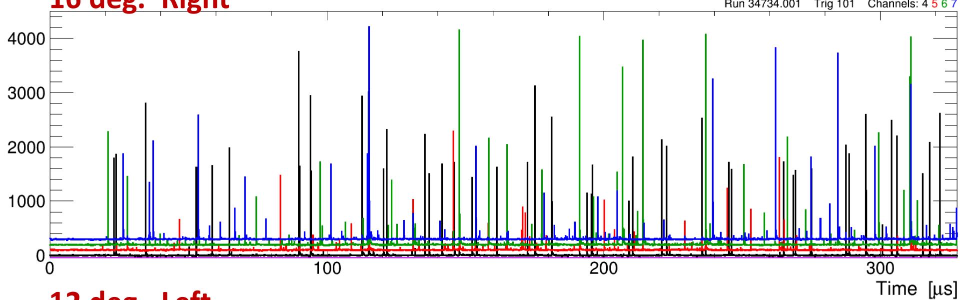
The Typical Readout (spin up)

The bunch waveforms in 16 and 12 degree detectors.

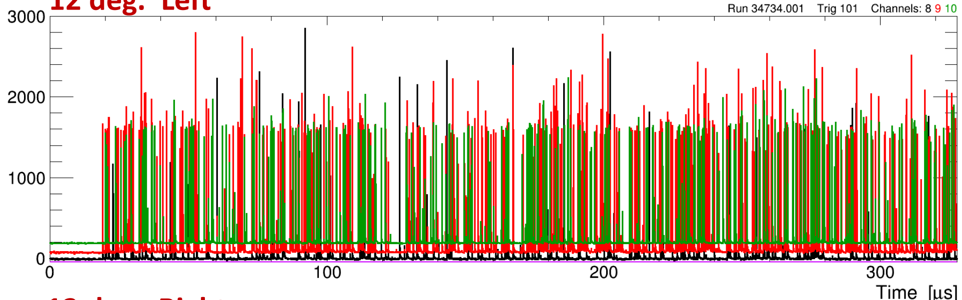
16 deg. Left



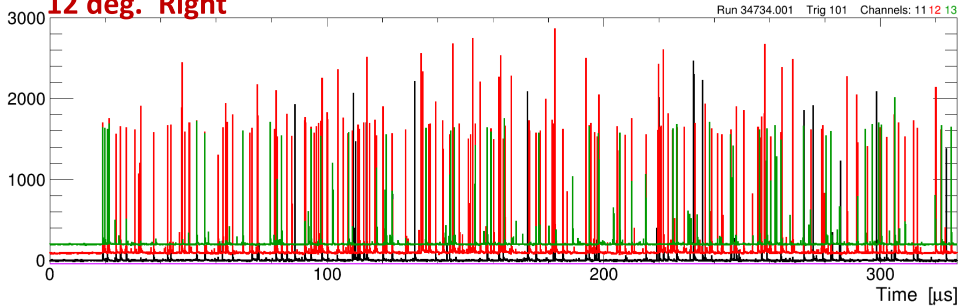
16 deg. Right



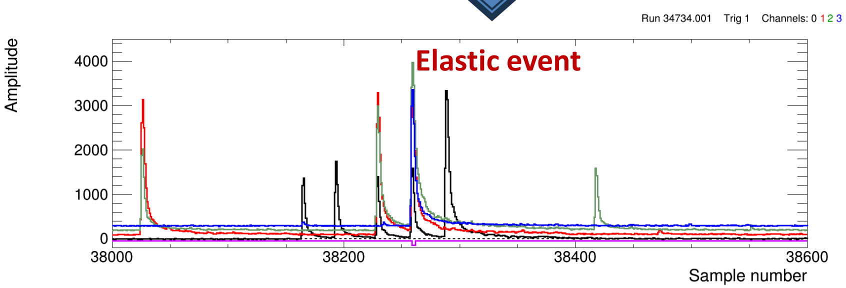
12 deg. Left

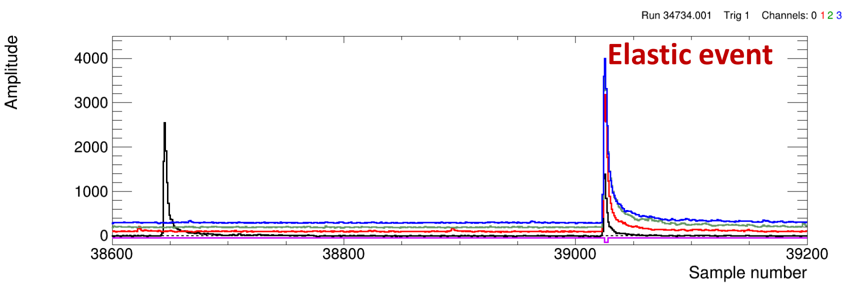


12 deg. Right

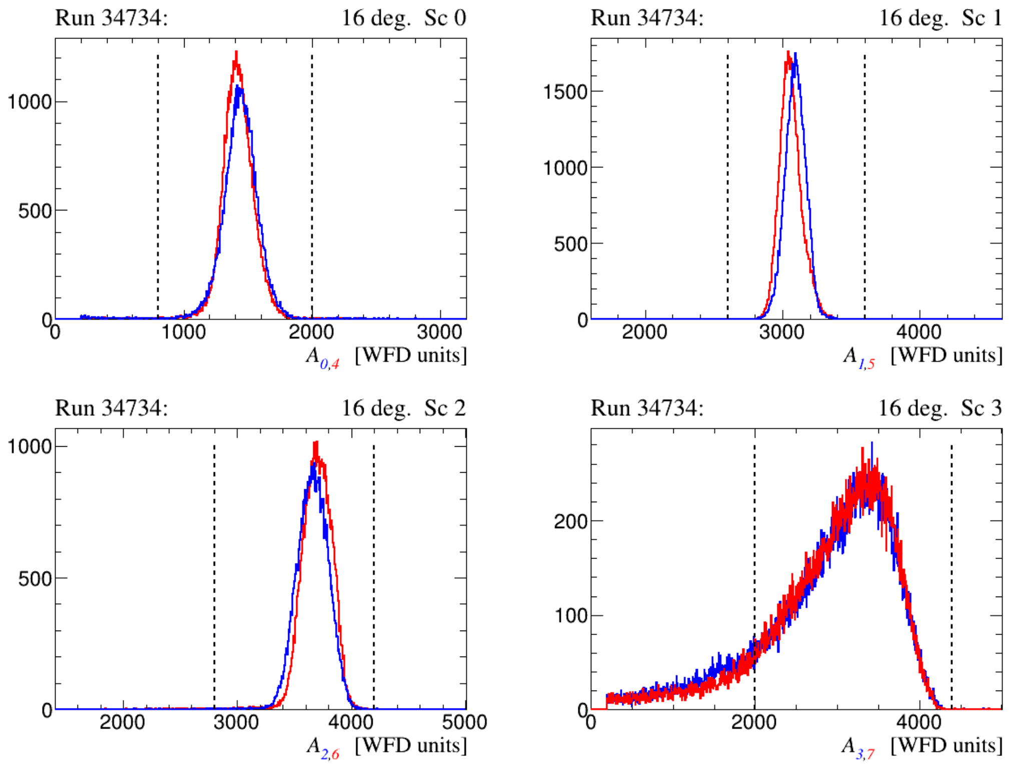


1200 consequitive samples (6 µs) in **16 deg. Left.**





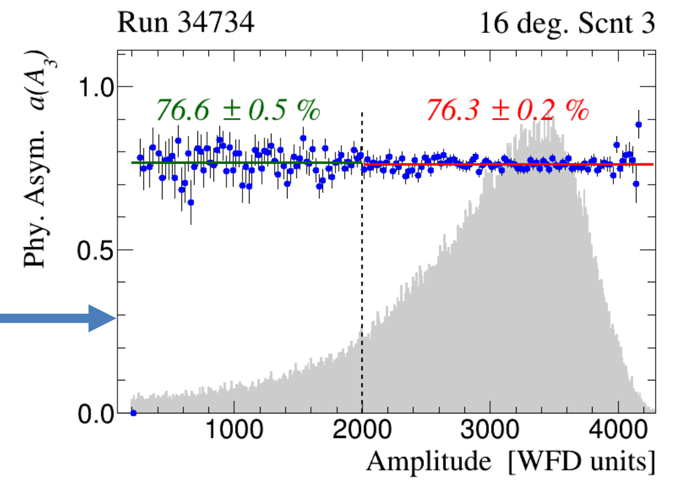
Event selection in the 16 deg. (elastic) polarimeter



- Blue and yellow colors are used for left and right detectors, respectively.
- The vertical dashed lines show event selection cuts.
- The background is strongly suppressed.

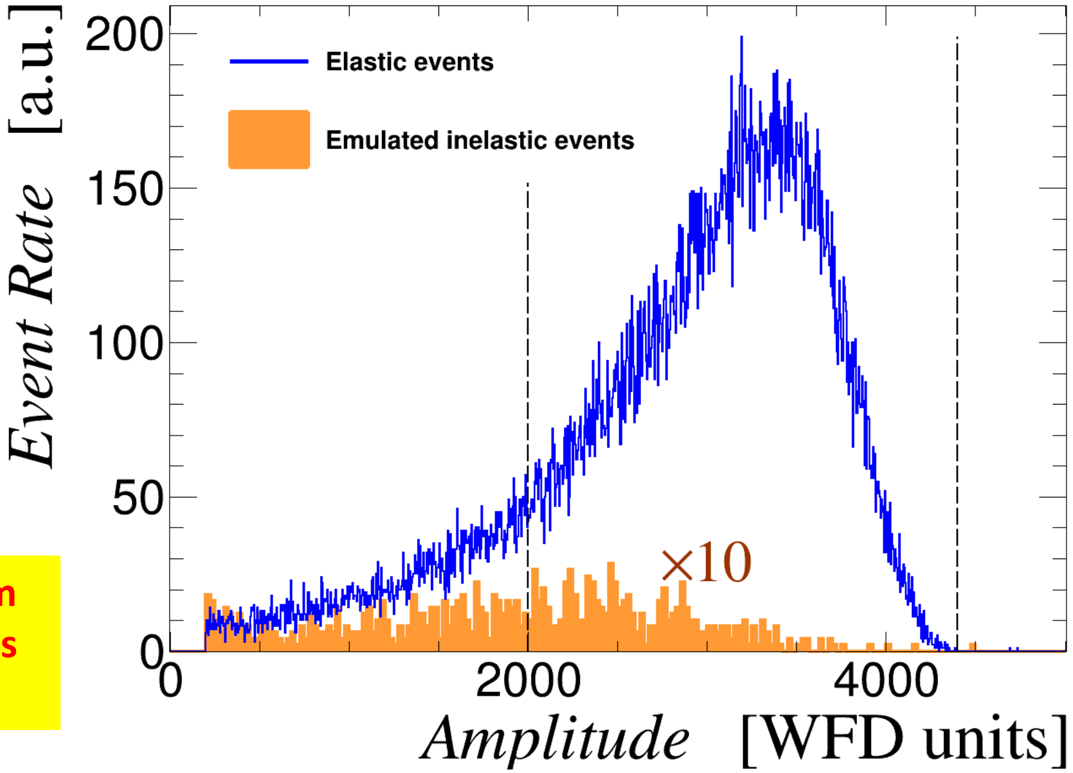
- The measured polarization is stable, within 0.1%, against reasonable variations of the event selection cuts.
- The spin-correlated asymmetry $a = \frac{\sqrt{N_R^\uparrow N_L^\downarrow}-\sqrt{N_L^\uparrow N_R^\downarrow}}{\sqrt{N_R^\uparrow N_L^\downarrow}+\sqrt{N_L^\uparrow N_R^\downarrow}} = A_N P$

  as a function of the amplitude in Scnt. 3.



Inelastic Events in the Elastic data

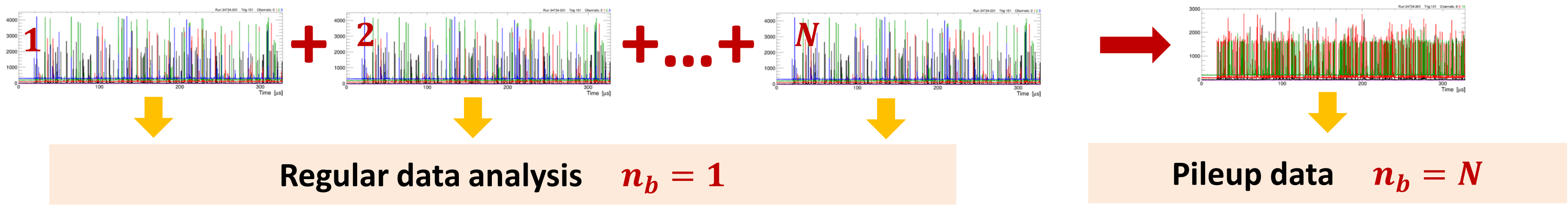
- Increasing thickness of the variable copper absorber by 1.6 mm effectively decreases the energy the elastically scattered proton from 198.5 MeV ($\Delta = 0$) to 194.1 MeV ($\Delta = 4.44$ MeV).
- As a result, the detection of the inelastic events in the 16 deg. polarimeter can be experimentally evaluated.



Possible alteration of the measured beam polarization by the inelastic component is (much) less than 0.1%.

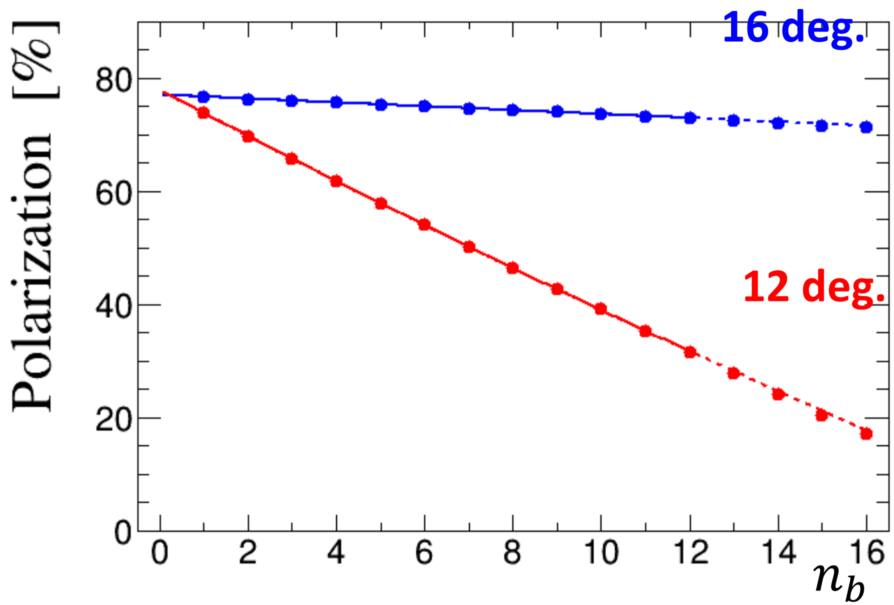
Rate corrections

- Although the polarization measurements are free from dead-time, the results may still be influenced by pileup effect.
- To assess the impact of pileup, several waveforms with the same spin were superimposed, and the resulting composite waveform was processed in the usual manner.
- By analyzing the measured polarization dependence, $P(n_b)$, on the number of piled-up bunches, the corrected polarization value can be obtained by extrapolating to $n_b = 0$.

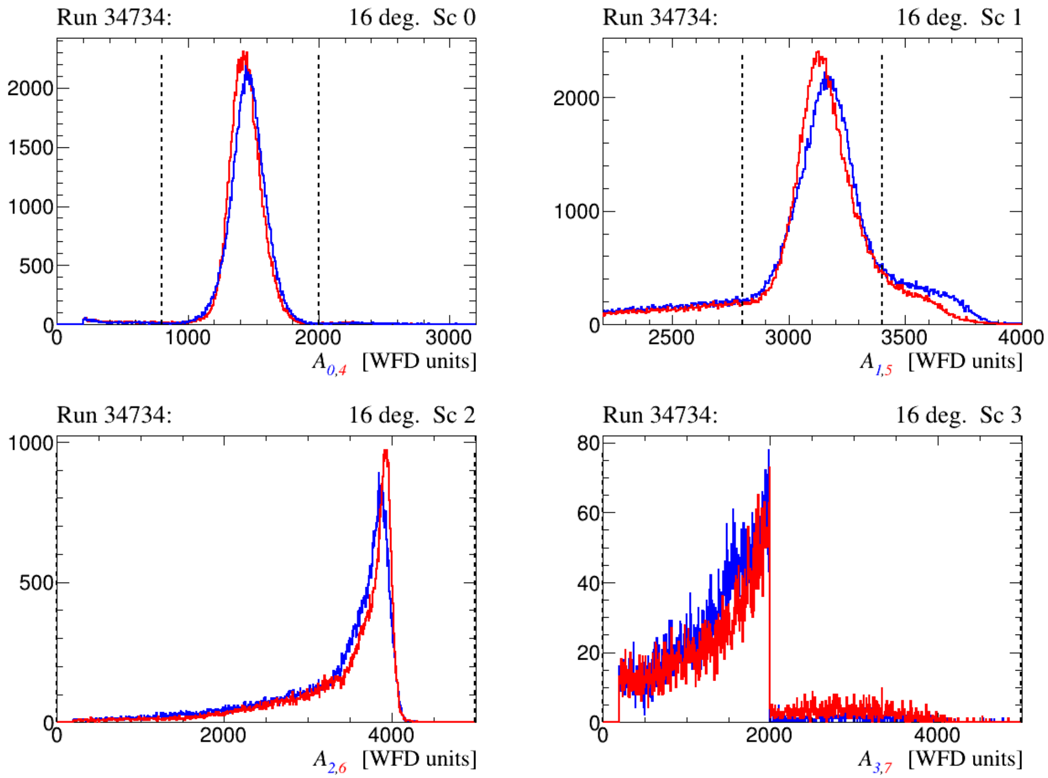


For the 16 deg. measurements:

- The rate corrected polarization can be approximated by $P(0) = 2P(1) - P(2)$.
- This correction is routinely applied during data analysis.
- Typically, the correction, $\Delta P_{\text{rate}} = P(0) - P(1)$, is about $+0.3\%$.
- The correction is calculated with high precision, with an accuracy better than 0.1%.



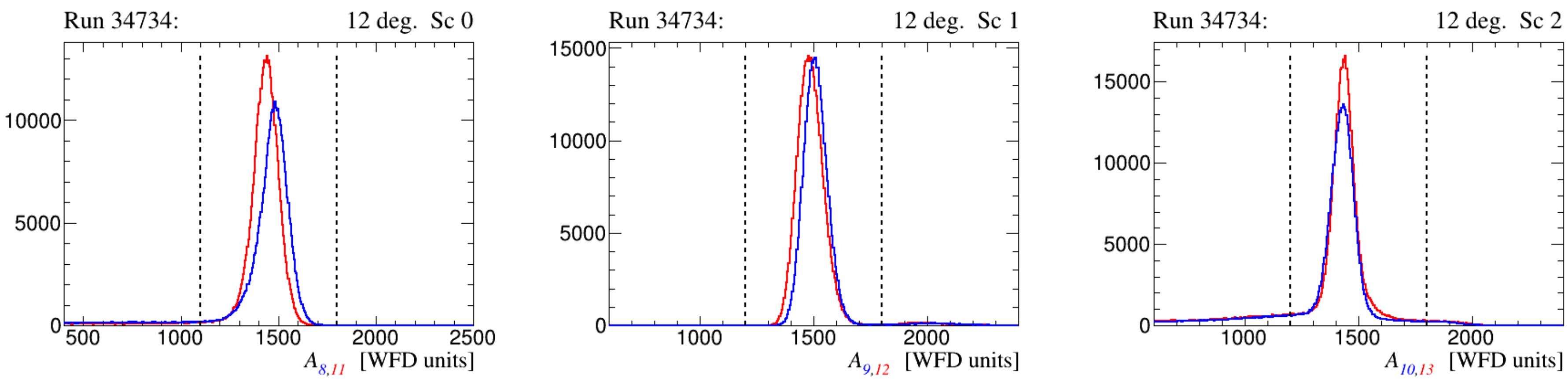
Inelastic 16 deg. polarimeter



- To minimize statistical errors in the measurements, data that did not pass the elastic event selection cuts were processed using looser "inelastic cuts" applied to only two scintillators.
- The effective analyzing power, $A_N = 0.979$, was determined by comparison with the "elastic polarimeter."

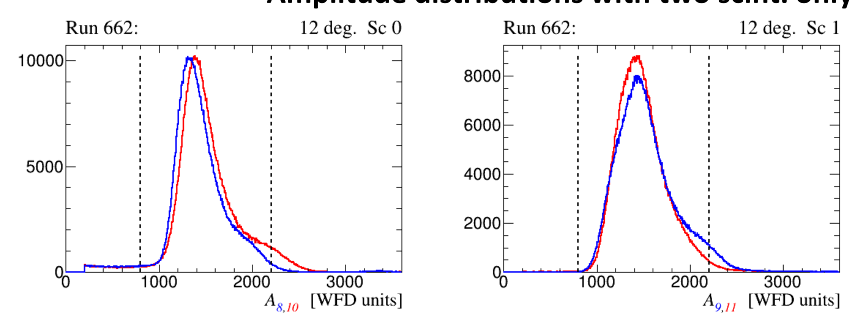
Optimization of the event selection cuts and a study of the stability of the effective analyzing power may be necessary to enhance performance.

12 degree polarimeter



- For RHIC Run 2024, a third scintillator was added to the 12-degree polarimeter, positioned after a 25 mm copper absorber.
- This configuration improved the event quality when using all three scintillators, while maintaining the original polarimeter setup when only the first two scintillators are considered.
- The effective analyzing power for the three-scintillator configuration is $A_N = 0.786$
- **Further optimization of the 12-degree polarimeter configuration is still required**.

Amplitude distributions with two scint. only



Example of the polarization measurement

Run 34734, 18 h

Polarimeter	A_N	$n_b = 1$	$n_b = 2$	$n_b \to 0$
16 deg. (Elastic)	**0.993**	76.66 ± 0.18	76.31 ± 0.19	$\mathbf{77.00 \pm 0.18}$
16 deg. (Inel.)	0.979	76.85 ± 0.13	76.54 ± 0.13	$\mathbf{77.15 \pm 0.13}$
12 deg.	0.786	73.88 ± 0.12	69.80 ± 0.13	$\mathbf{77.04 \pm 0.11}$
			Total:	$\mathbf{77.07 \pm 0.08}$

- "Inelastic polarimeters" reduce the statistical error by more than a factor of two.
- However, the stability of their effective analyzing powers has not yet been studied.

- Systematic uncertainties in determining the ***elastic*** asymmetry, $a = A_N P$, are expected to be small, on the order of 0.1%.
- Therefore, the systematic uncertainty in the polarization measurement is primarily determined by the accuracy of the analyzing power A_N.

Effective analyzing power

$$A_N^{\text{eff}} = (99.35 \pm 0.25)\% \times (1 + \text{corr})$$

Possible sources of systematic corrections to A_N^{eff}:

- **Geometrical misalignment** (beam angle, target and detector positions, detectors size):
  Since $dA_N(\theta)/d\theta = 0$, the correction is expected to be minimal.

  $$\Delta x = 1\text{ cm} \quad (\Delta\theta \approx 5\text{ mrad}) \quad \Longrightarrow \quad \Delta A_N \sim 0.1\%$$

- **Beam Energy:**

  $$\Delta T = 1\text{ MeV} \quad \Longrightarrow \quad \Delta A_N \sim 0.4\%$$

- **Target Composition:**
  Is the target composed of pure ^{12}C ?
  Natural abundance of ^{13}C is 1.1%. However, this has a negligible effect on A_N^{eff} at 200 MeV.

- **… .**

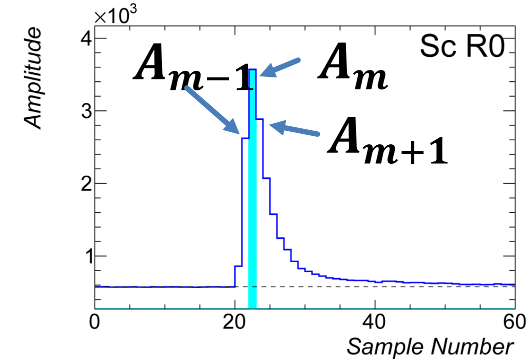
- **Preliminary,** systematic error in value of the analyzing power is $|\Delta A_N| \lesssim 0.5\%.$
- A more detailed analysis is still required.

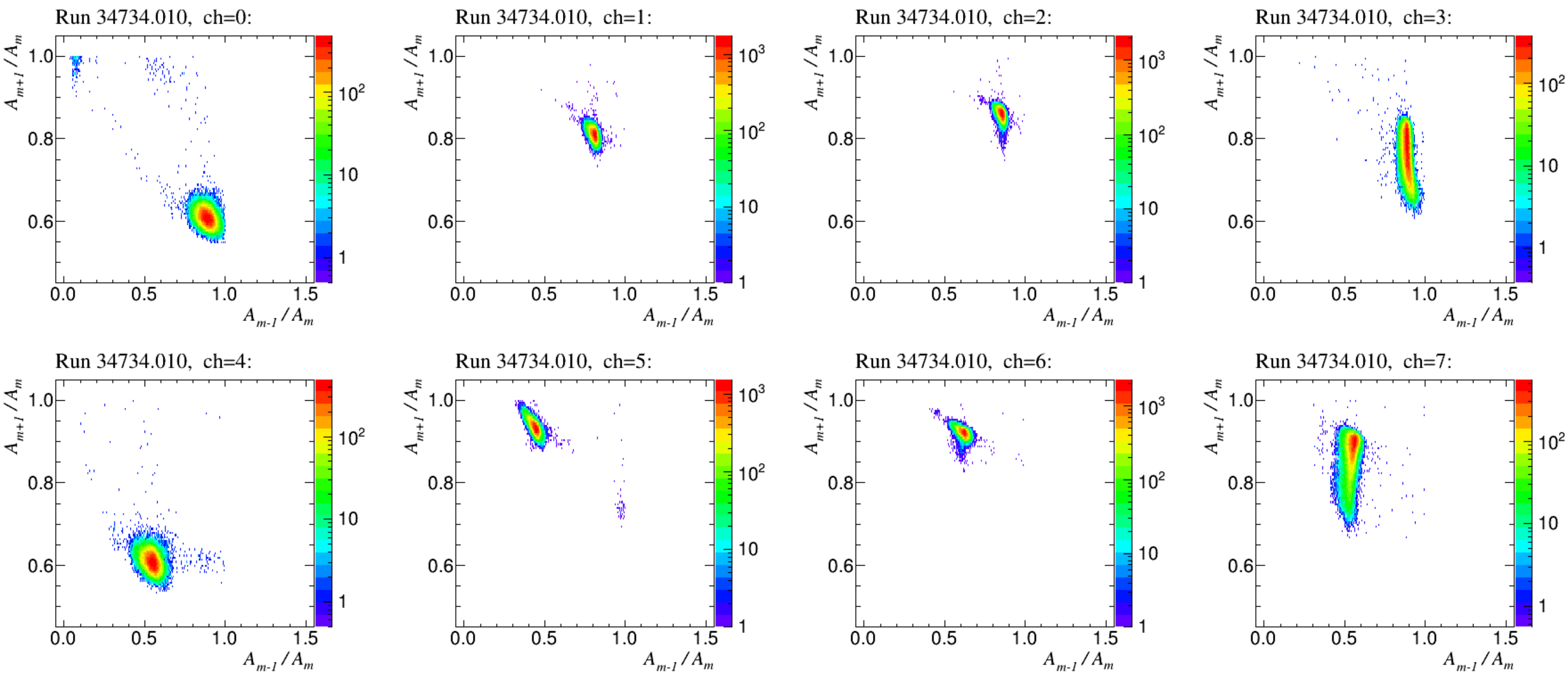
Summary

- During RHIC Run 2024, the new WFD-based DAQ system for the 200 MeV proton-Carbon polarimeter at Linac was successfully commissioned.
- The results indicated that the systematic error in beam polarization measurements could be reduced to as low as 0.5%.
- However, to ensure the required stability and reliability of these measurements, further enhancements in the detector configuration and data processing algorithms may still be necessary.

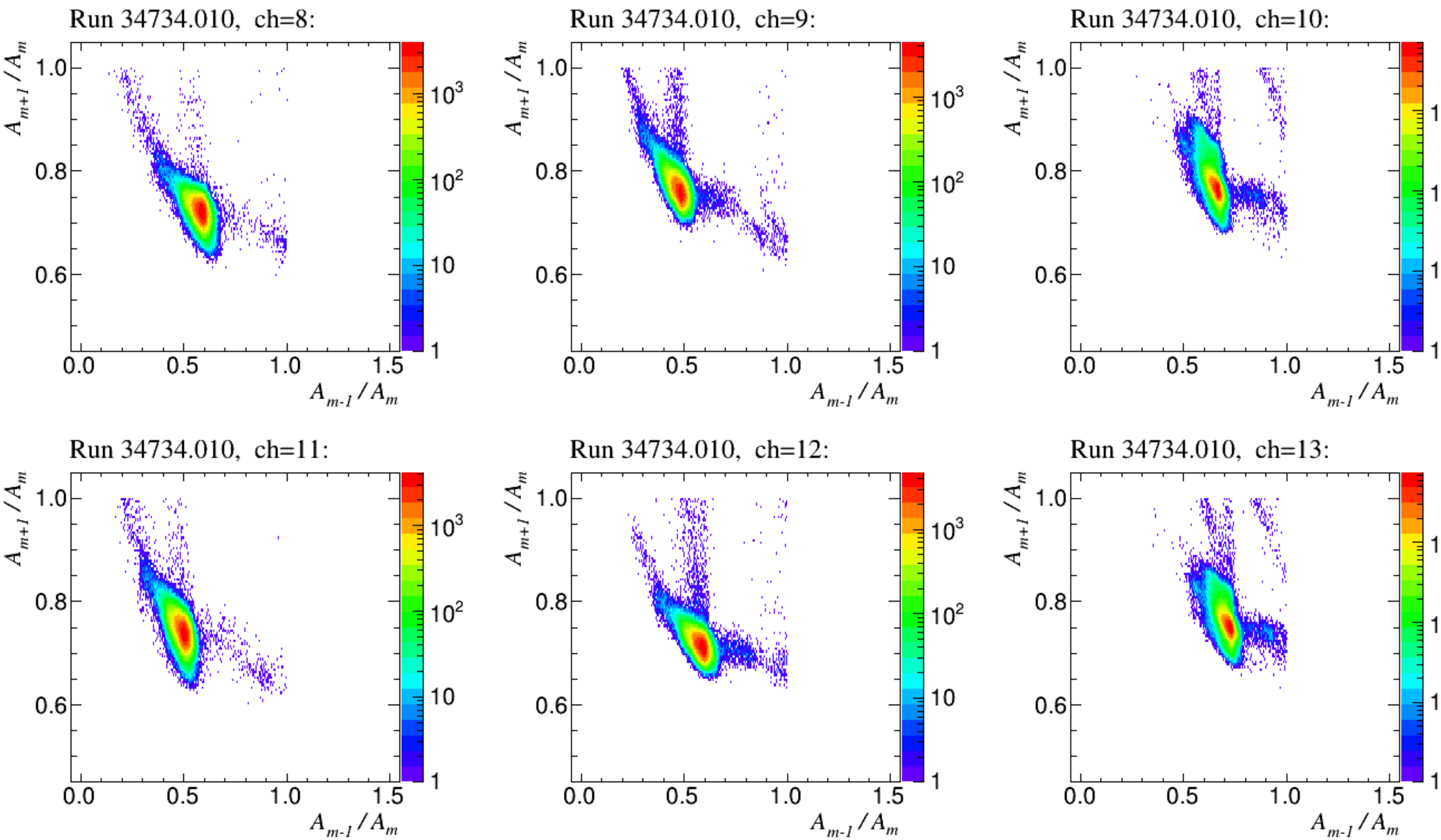
Signal Time Alignment (16 deg)

- At Linac the micro-bunch structure is defined by 200 MHz frequency
- This frequency is also used for WFD clocks
- Thus, the signal phases should be fixed.
- It may be used for background suppression. (not implemented yet)

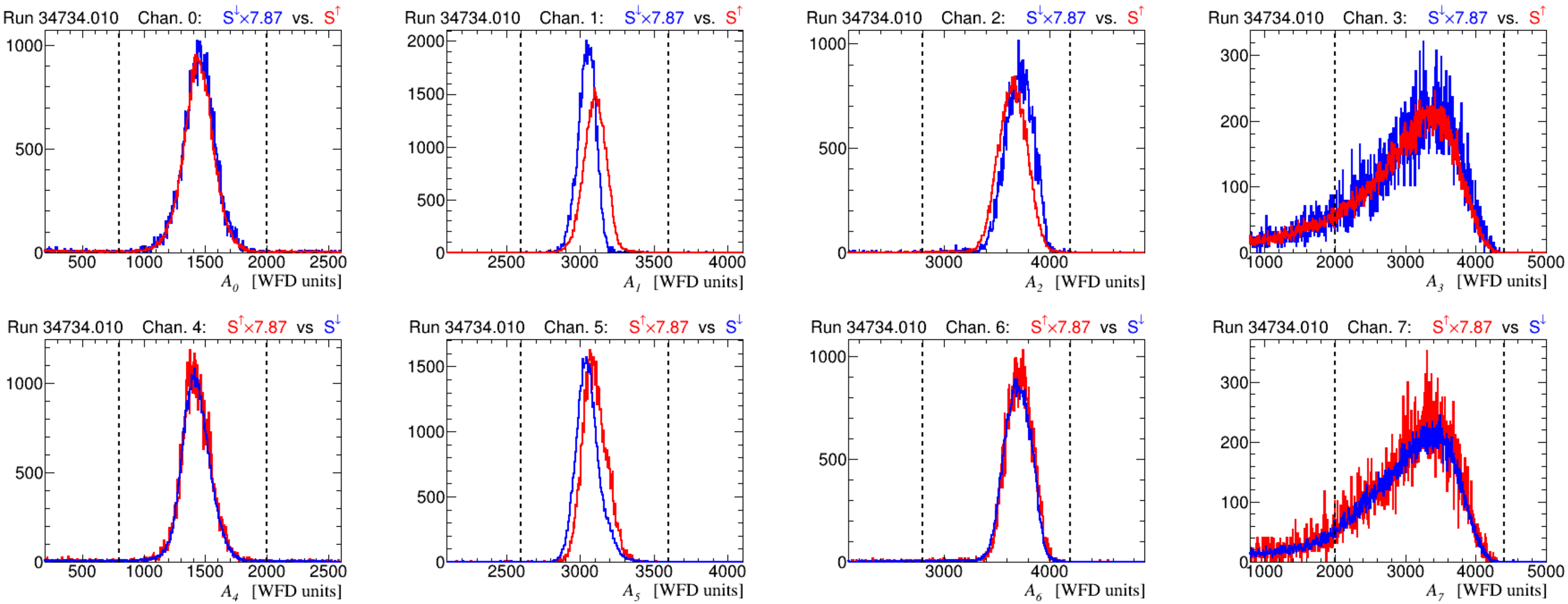




Signal Time Alignment (12 deg.)



The PMT gain dependence on the signal rate (beam spin)

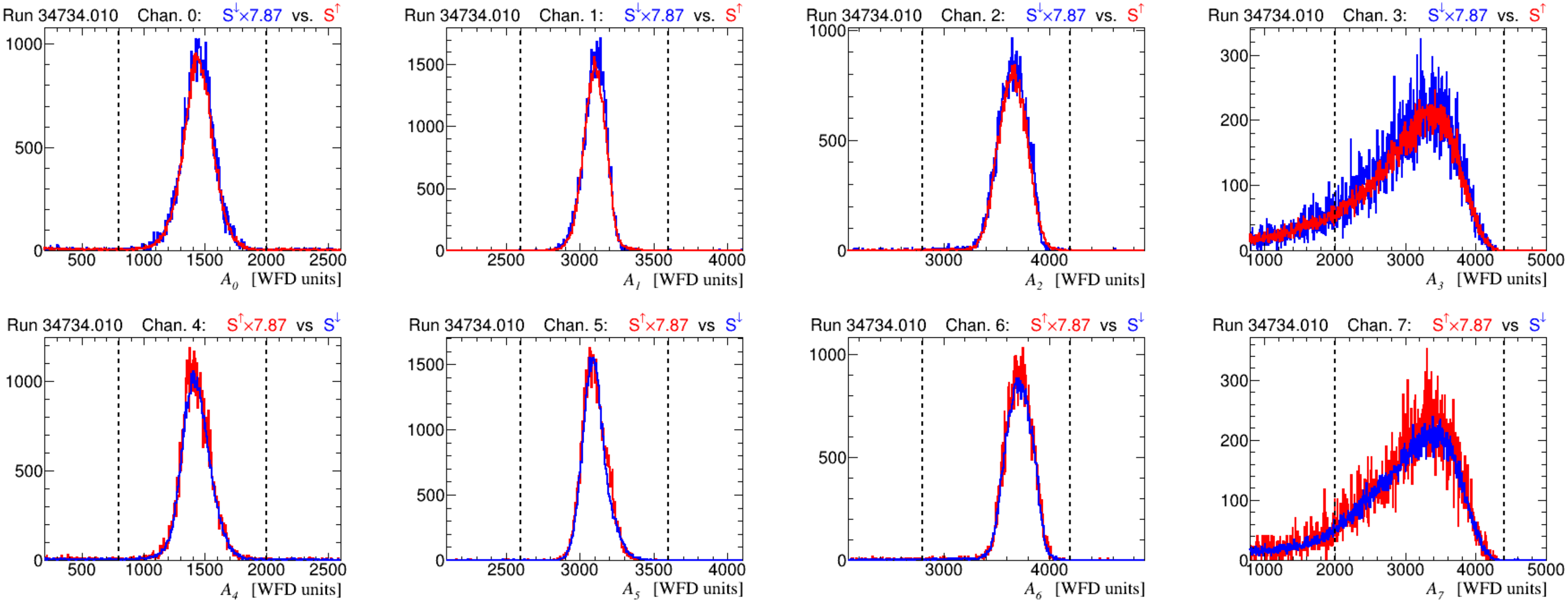


- Although effect is small, few per-cent alteration of the gain, it is clearly seen.
- We do not understand source of the problem.
- Most likely, the problem may be attributed to some properties of the scintillator (channels 0,4 have different scintillator).
- The gain dependence must not affect polarization measurement, if the event selection cuts are sufficiently loose (to keep both distributions).

Correction to the gain

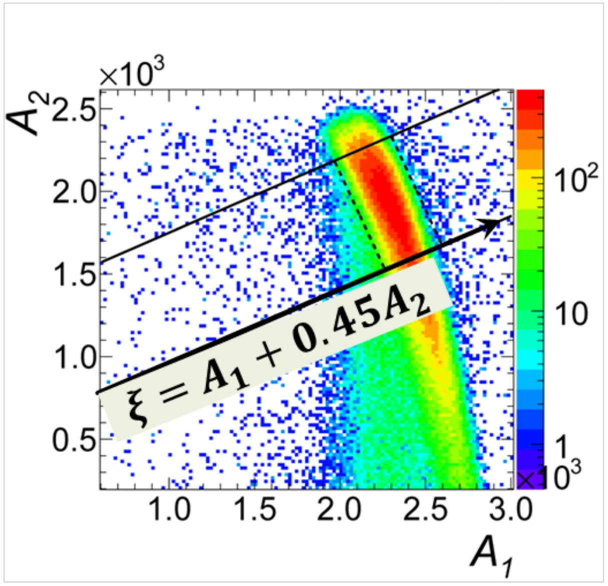
The problem can be easily “eliminated” by a simple linear transformation of the intensive rate amplitudes:

$$A \;\; \rightarrow \;\; A_{\text{corr}} = a + bA$$

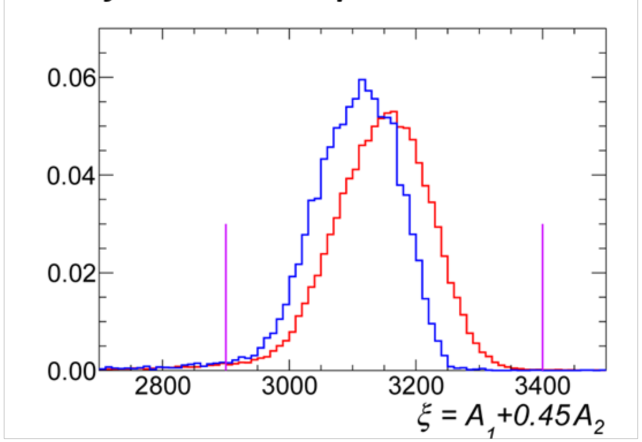


A slide from the PSTP 2017 presentation:

Amplitude dependence on the rate (beam spin)



Normalized (unity integral) projection for the beam spin UP and DOWN.



- For the beam spin down the event rate in scintillators are factor 10 higher than for spin up.
- We used 2 different scintillators; the issue was actually observed only for one scintillator.
- No effect for a factor 4 lower beam intensity.
- **More study of the problem is still needed.**

- **The measured asymmetry is sensitive to the ξ cut.**
- **For the shown cut, the corresponding systematic error is < 0.1%**