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https://indico.bnl.gov/event/7583/

Absolute polarization measurement of the 200 MeV proton beam at Linac

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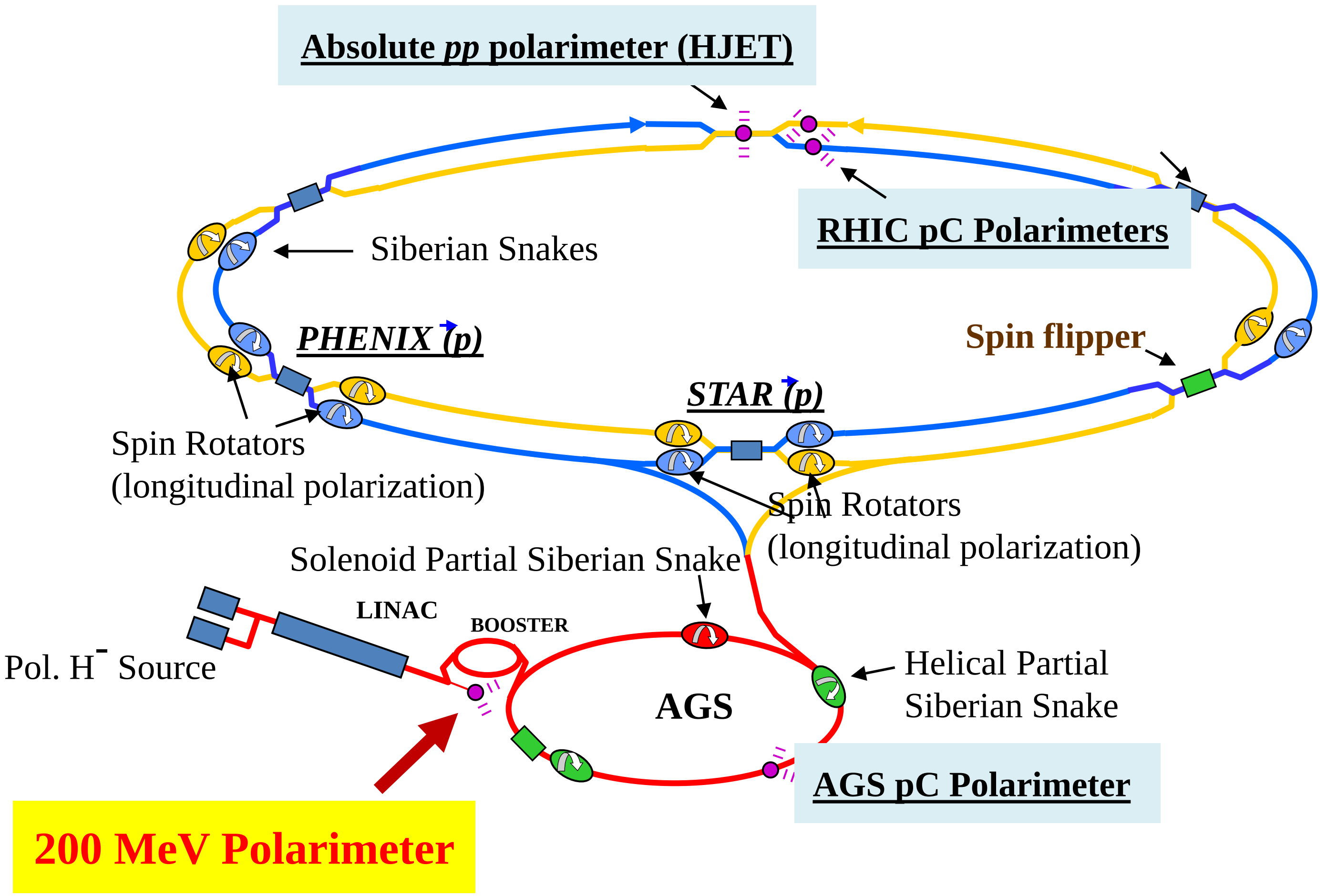
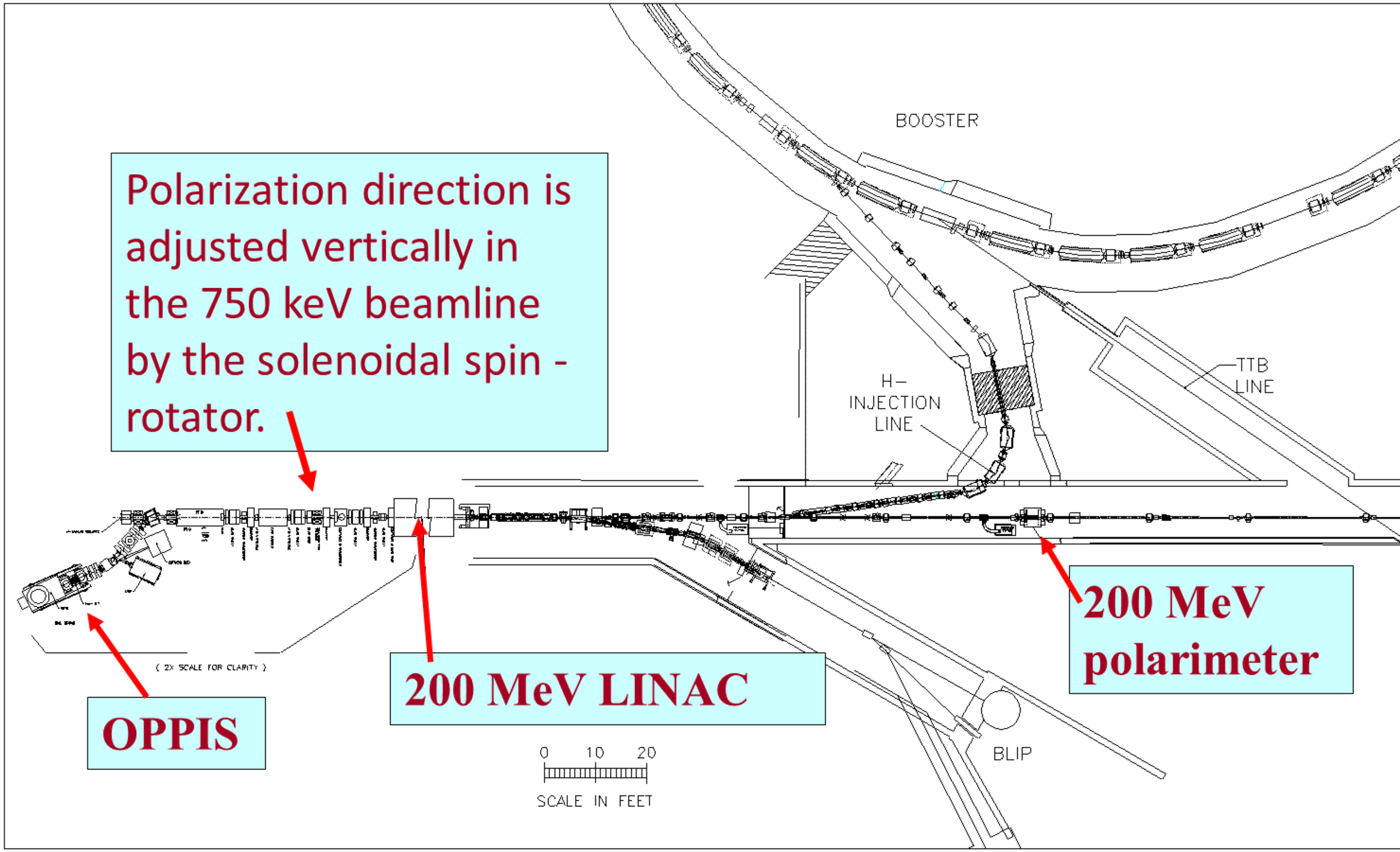
Polarized Proton Beams at RHIC

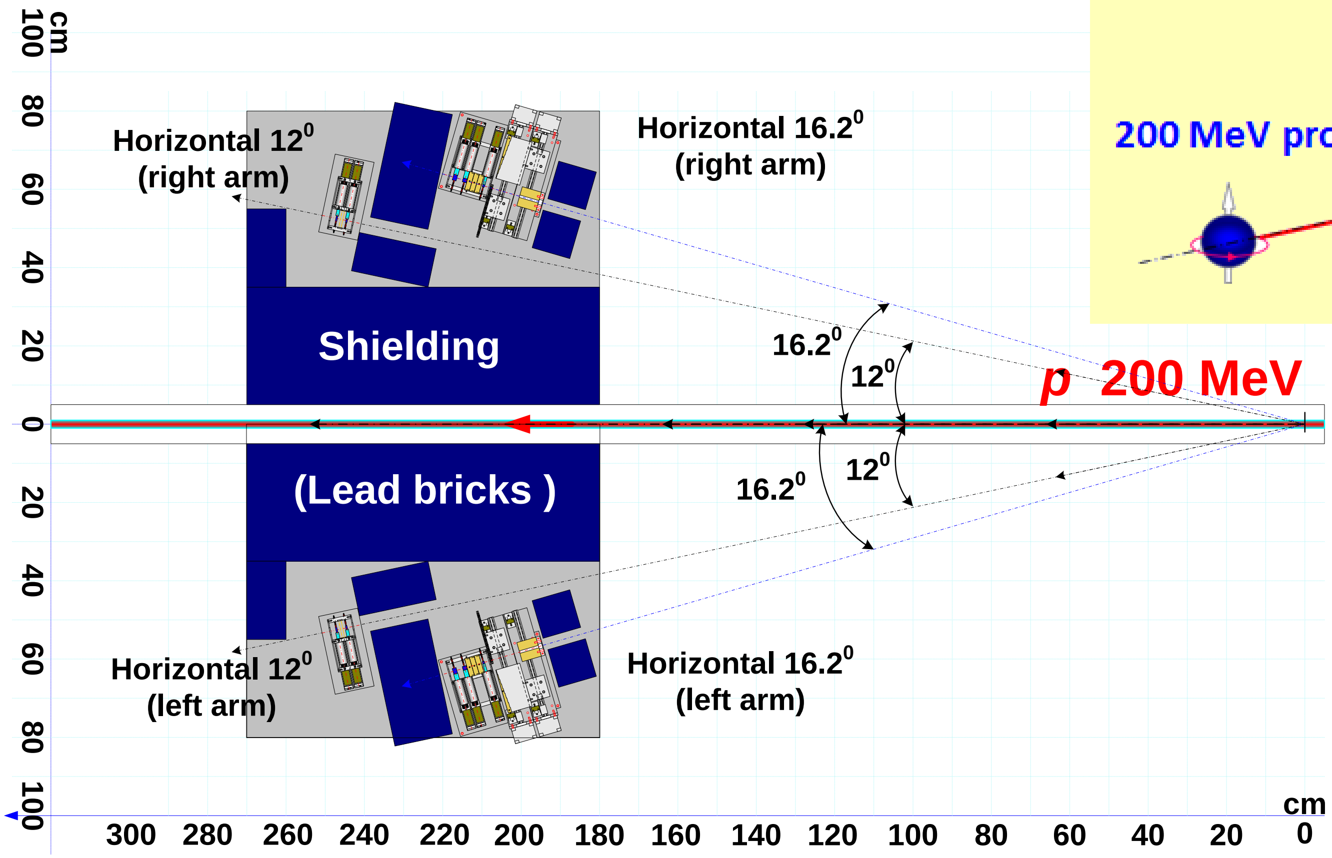


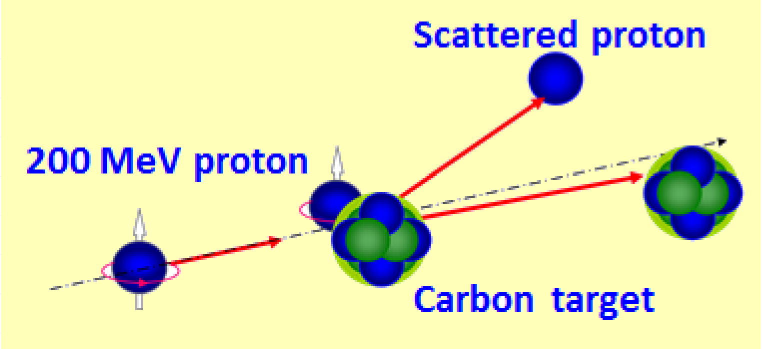
Polarized injector, 200 MeV Linac, and injection lines



Precision, absolute proton beam polarization measurement in the wide beam energy range is important for accelerator tuning to minimize depolarization and, finally, for proper normalization of the spin effects in the experimental results.

200 MeV Polarimeter





12 degree polarimeter

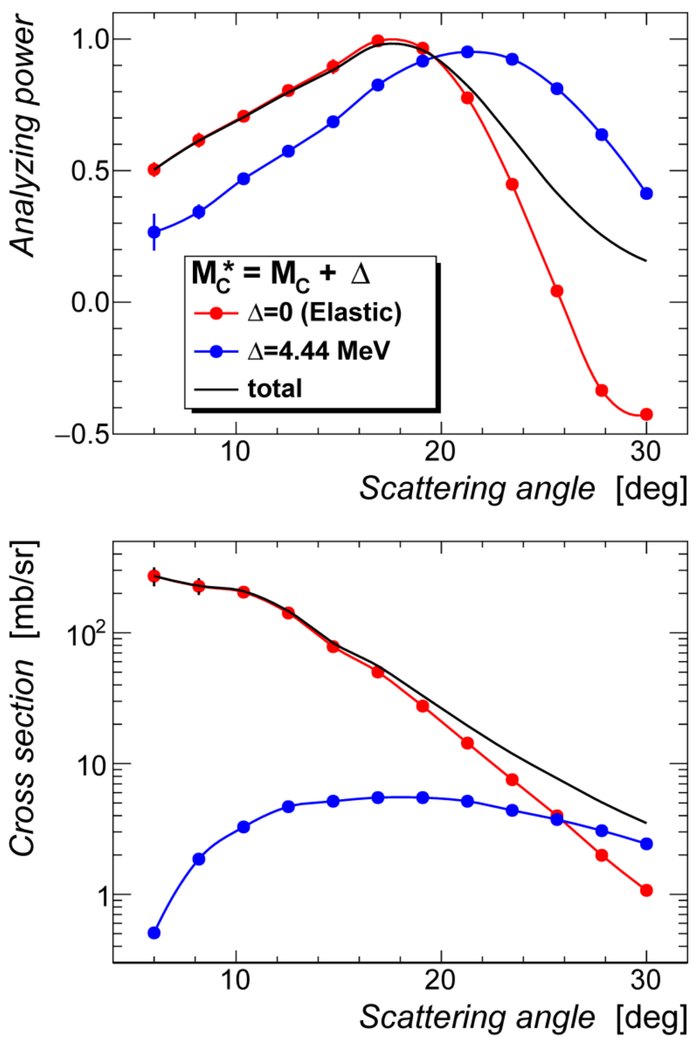
- $\langle A_N \rangle \sim 0.62$
- High rate
- ***Used for the beam polarization monitoring***

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

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



Theory: *For* $\frac{1}{2} + 0 \rightarrow \frac{1}{2} + 0$ *elastic scattering,* $A_{\mathrm{N}} = 1$ *at some values of kinetic energy* T_0 *and scattering angle* θ_0*.*
One such a maximum for proton-Carbon scattering *at* $\mathbf{T_0 \sim 188\ MeV}$ *and* $\boldsymbol{\theta_0 \sim 17^{\circ}}$ *was scrupulously studied in 1980's at Indiana University Cyclotron Facility.*

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

For $T_0 = 187.95$ MeV and $\theta_0 = 17.16°$

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

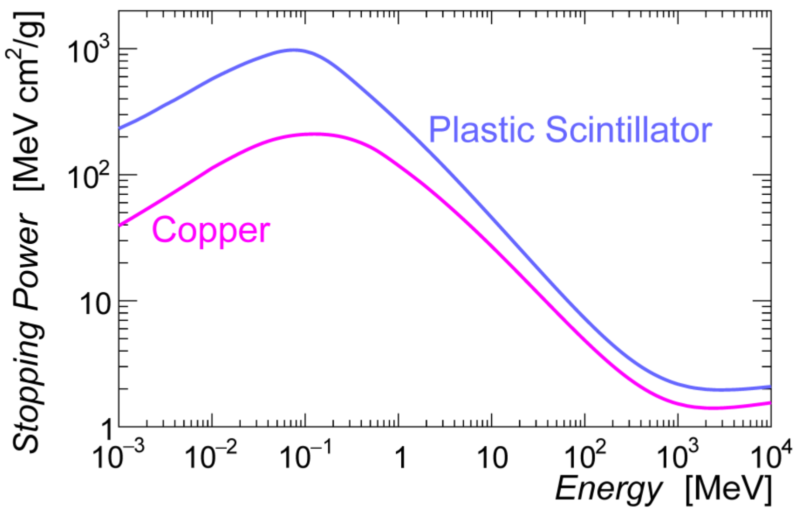
$$A_N^{\mathrm{elastic}}(200\ \mathrm{MeV}, 16.2°) = (99.35 \pm 0.15)\%$$

Taking into account the detector aperture, alignment and multiple scattering, the effective analyzing power may be estimated as

$$A_N^{\mathrm{elastic}} = (99.3 \pm 0.25)\%$$

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

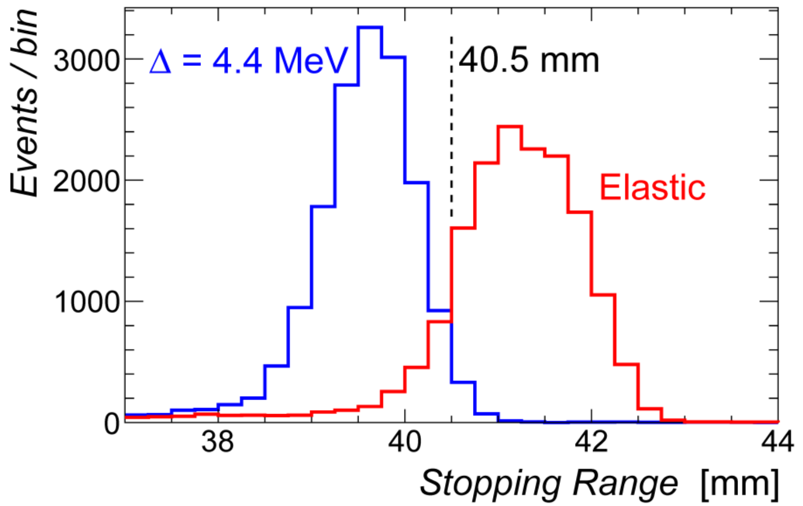
Suppression of the inelastic events



Scattering proton energy T dependence on the Carbon excitation Δ for the 200 MeV beam and $16.2°$ angle.

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

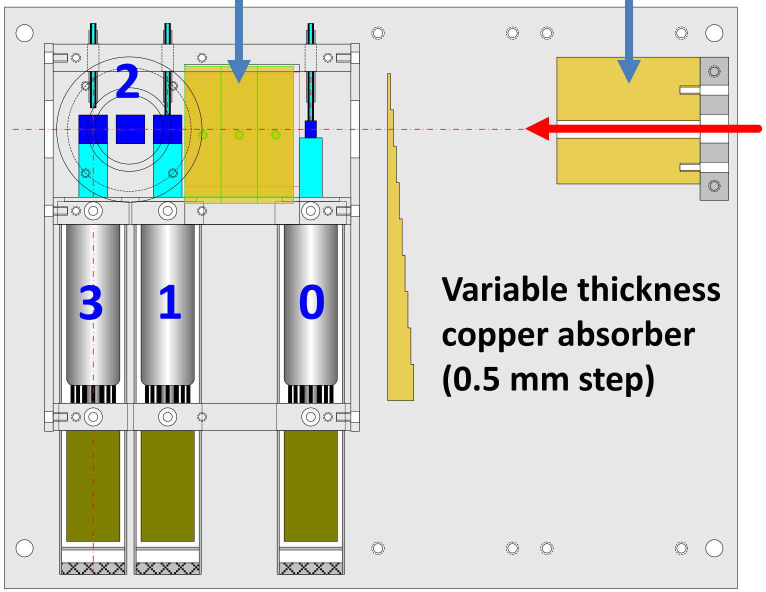
Geant similation of the scattering proton stopping range in Copper for the 200 MeV beam.



Due to stopping power dependence on the scattering proton energy, elastic and inelastic events may be effectively separated using absorber**.**

For the **40.5 mm** Copper absorber, more than **80%** of elastic protons will be detected while the correction to the analyzing power due to inelastic events will be less than **0.06%.**

The $16.2°$ polarimeter (one arm)



Scintillator dimensions:

$$0 \quad - \quad 6 \times 6 \times 4 \quad \mathrm{mm}^3$$
$$1\text{-}3 \; - 10 \times 10 \times 9.5 \; \mathrm{mm}^3$$

The DAQ was based on NIM logic triggers and 250 MHz 12 bit WFD readout of the scintillator signals.

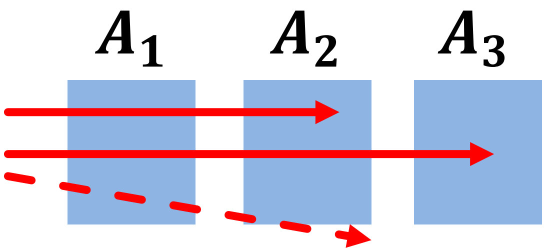
Beam structure: $300\ \mu s$ bunch every 4 s.
Trigger Rate: $\sim 100\ kHz$ (in the bunch)

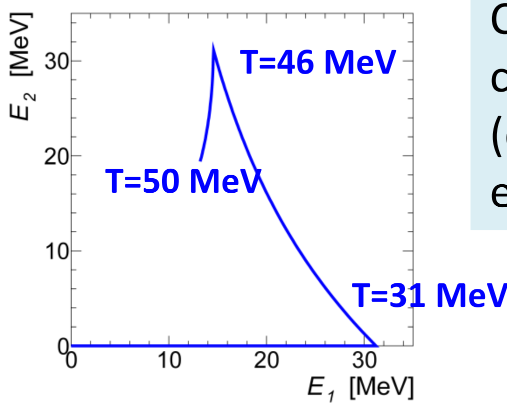
The 16 degree polarimeter (scalers only) was commissioned in 2010. In a special study, it was shown that elastic events are well isolated and systematic errors of the polarization measurement was evaluated to be 0.5%. The results were reported at conferences (e.g. PSTP2013) and were published.

Since the beam intensity was significantly increased after that, we decided to upgrade polarimeter with WFD readout to have permanent control for the rate and background effects. The measurements reported here were done in 2017.

Isolation of the “good” proton signal

Signal Amplitude Correlation in scintillator counters





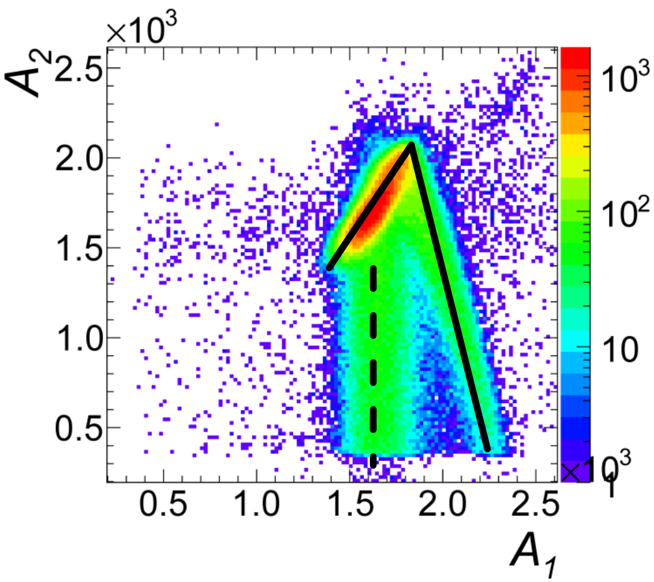
Calculated deposited energy correlation in 2 scintillator counters (depending on proton entry energy)

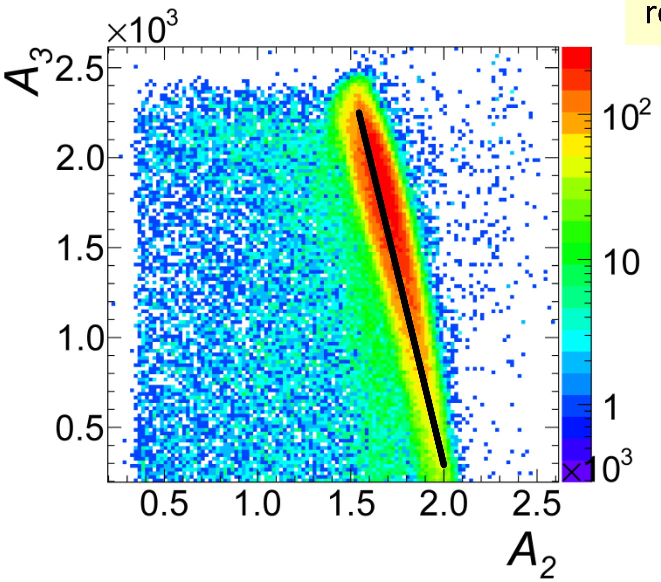
For detailed comparison with experimental data, the light yield dependence on energy losses

$$\frac{dL}{dx} = \frac{A\ dE/dx}{1 + k_B\ dE/dx}$$

(Birk’s law) should be considered. However, the effect is beyond the real needs of this study.

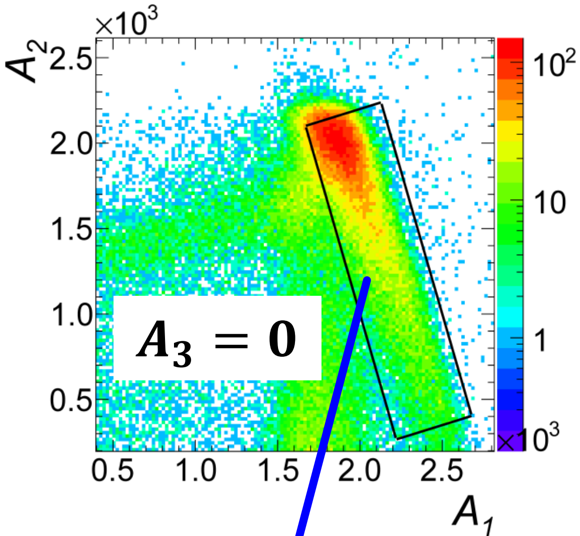
Measured amplitude correlation for minimum absorber thickness (38.1 mm Cu + 4 mm scintillator)

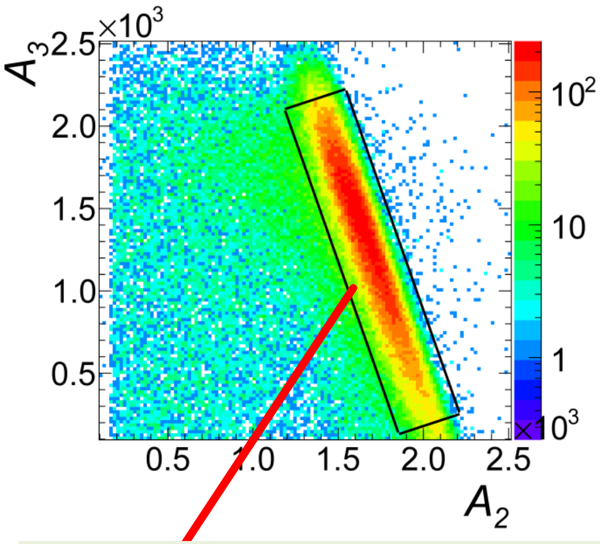




A sharp correlation between the measured amplitudes allows us to control background and/or signal pileup effects.

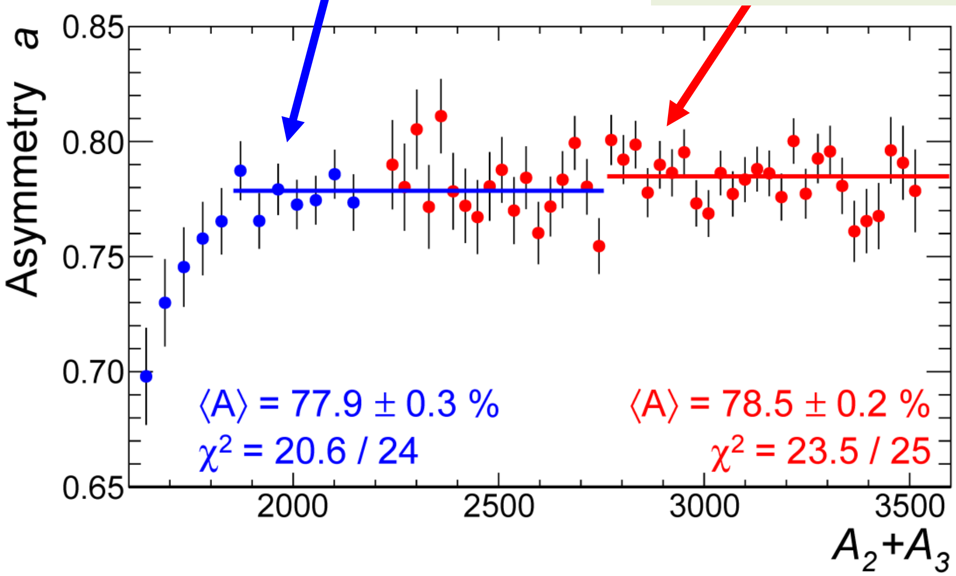
Minimal absorber thickness +0.0 mm Cu





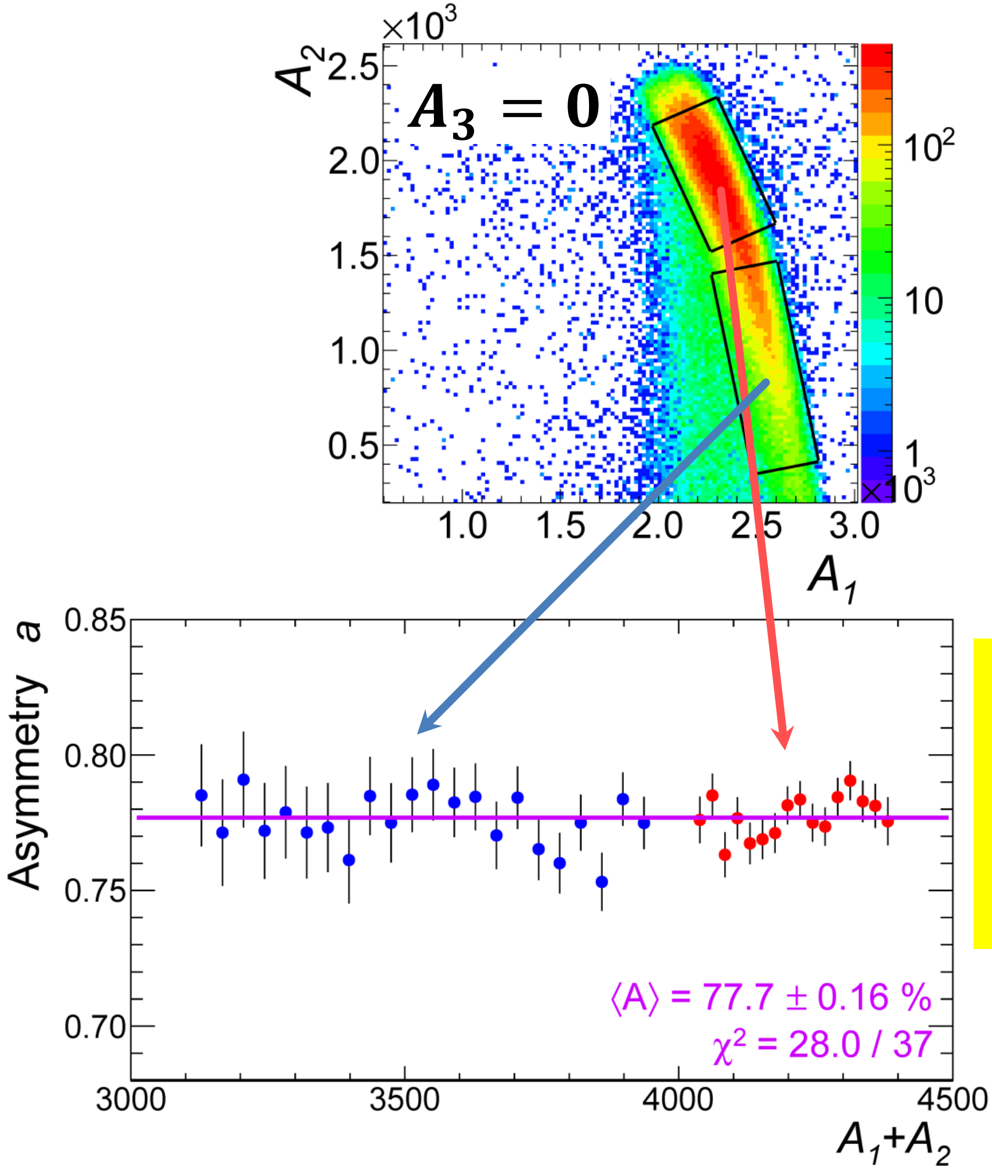
Intensity asymmetry λ can be determined in the two-arm measurement

Measured asymmetry in one arm $a = \frac{N^+ - N^-}{N^+ + N^-} = A_N P \pm \lambda$



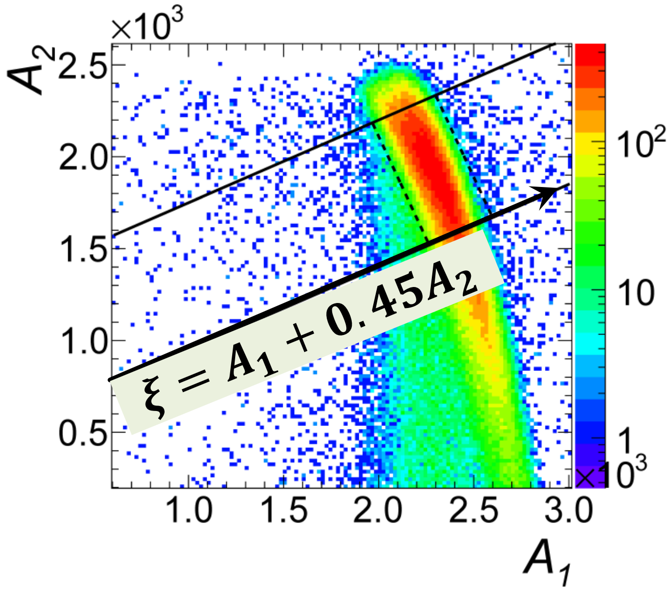
- **The flat asymmetry distribution for large deposited energy $(A_2 + A_3)$ in scintillators should be interpreted as a proof of suppression of inelastic scattering.**
- **A small discrepancy for two fit areas may be attributed to a possible systematic error $\sigma_{syst} \lesssim 0.4\%$**

Absorber Thickness +1.5 mm Cu

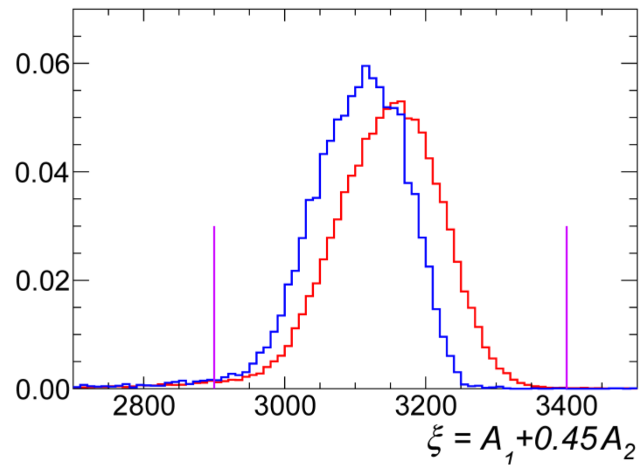


- **No evidence of the asymmetry dependence on the deposited energy $(A_1 + A_2)$.**
- **Inelastic background contribution is expected to be negligible.**

Amplitude dependence on the rate (beam spin)



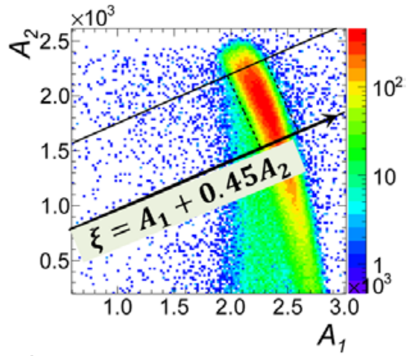
Normalized (unity integral) projection for the beam spin UP and DOWN.

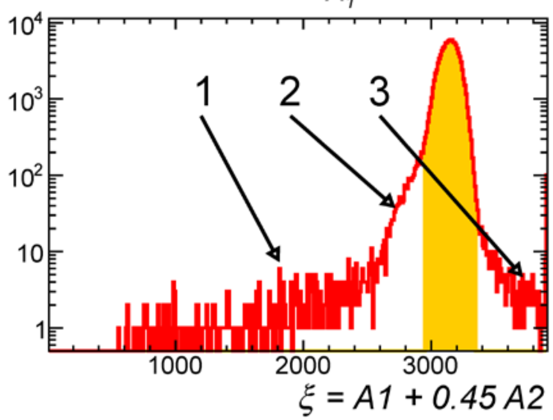


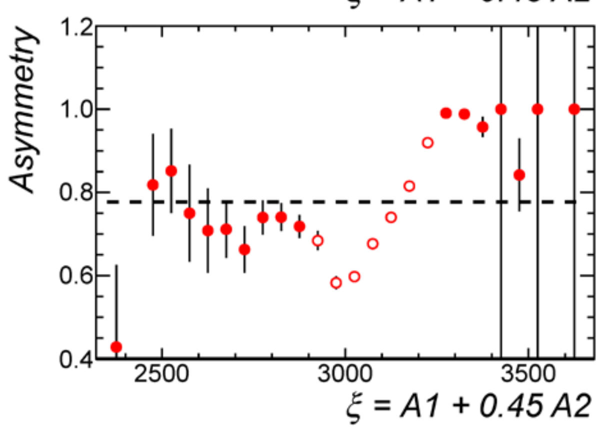
- For the beam spin down the event rate in scintillators are factor 10 higher than for spin up.
- We used 2 different scintillators, the issue was actually observed only for one scintillator.
- For a factor 4 lower beam intensity, no effect was observed.
- **More study of the problem is still needed.**

- The measured asymmetry is sensitive to the ξ cut.
- For the shown cut, the corresponding systematic error is **< 0.1%.**
- Resolving the issue may allow us to use tighter event selection cut and, thus, establish better control for the background related systematic errors.

Background related systematic errors.







The projection to ξ – axis may also be used for an evaluation of the background related systematic errors:

$$\delta A_N^{\mathrm{syst}} = \left(\left\langle A_N^{\mathrm{bgr}}\right\rangle - A_N^{\mathrm{meas}}\right) \times f_{\mathrm{bgr}}$$

where f_{bgr} is the background fraction in the selected events.

For backgrounds **1** and **3** $f_{\mathrm{bgr}} \lesssim 0.001$.

For background **2** (side leakage) $f_{\mathrm{bgr}} \sim 0.05$

$$\sigma_{\mathrm{syst}}^{\mathrm{bgr}} \lesssim 0.3\%$$

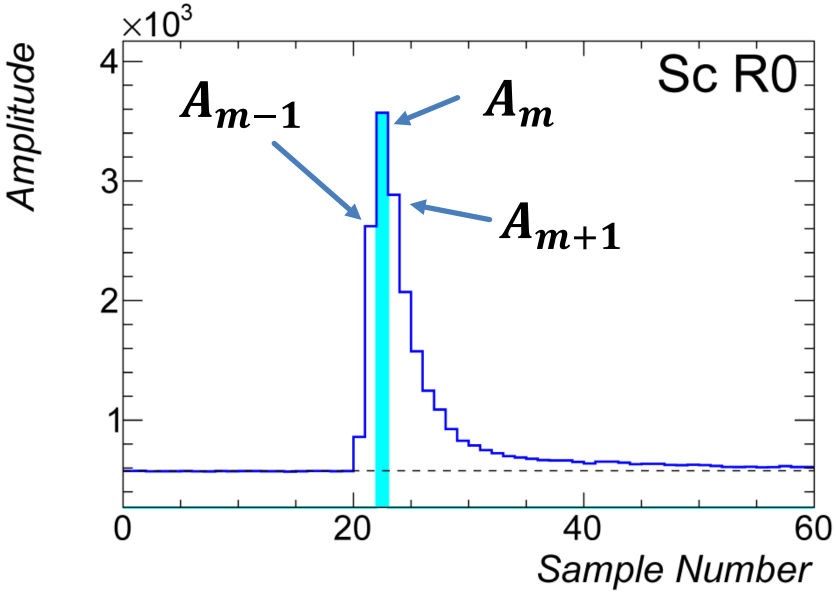
$$\sigma_P^{\mathrm{syst}}/P \lesssim 0.5\%$$

Summary

- A prototype of the upgraded (WFD based DAQ) absolute polarimeter for 200 MeV proton beam at Linac was tested in 2017.
- It was confirmed that 198.5 MeV elastic protons can be reliably isolated from the inelastic background (< 194.1 MeV) by a $\sim$38 mm copper absorber.
- The estimated systematic error of the beam polarization measurement is $\boldsymbol{\sigma_P^{\mathrm{syst}}/P \lesssim 0.5\%}$.
- The statistical error of the polarization measurement was about $\boldsymbol{\sigma_P^{\mathrm{stat}} \sim 0.4\ \%/\mathrm{hour}}$.
- We plan to continue studying/commissioning the 16 degree absolute polarimeter for the 200 MeV proton beam in next proton Run:
  - ✓ Optimizing the scintillator counters, including the choice of scintillator material (in order to resolve the rate problem) and its dimension.
  - ✓ Optimization of the copper absorber thickness.
  - ✓ Test of the DAQ based on a 250 MHz WFD with a 300 μs (75k samples) readout capability.

Backup

Signal waveform processing.



To determine signal time we used sample amplitude ratios:

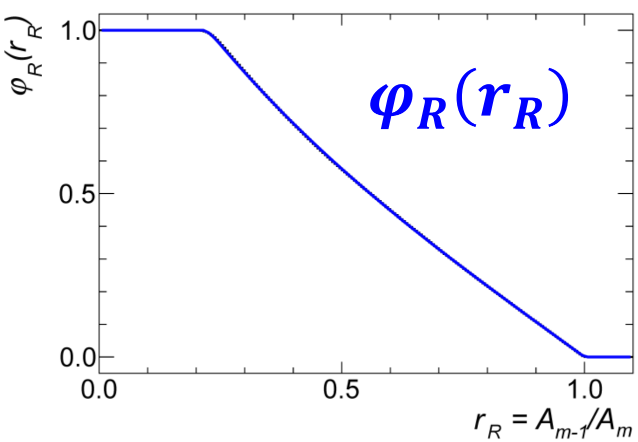
$r_R = A_{m-1}/A_m$ and $r_T = A_m/A_{m+1}$

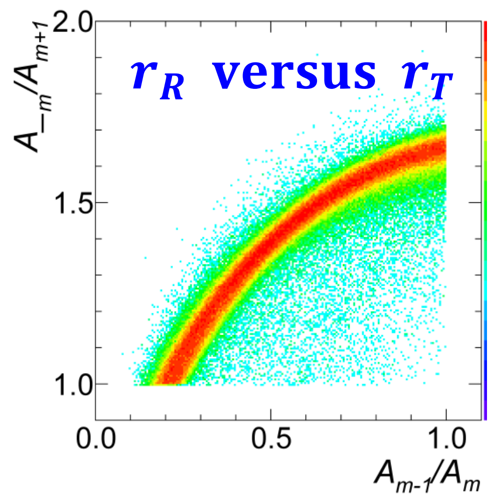
$$t = [m + \varphi_R(r_R)] \times 4\ ns$$

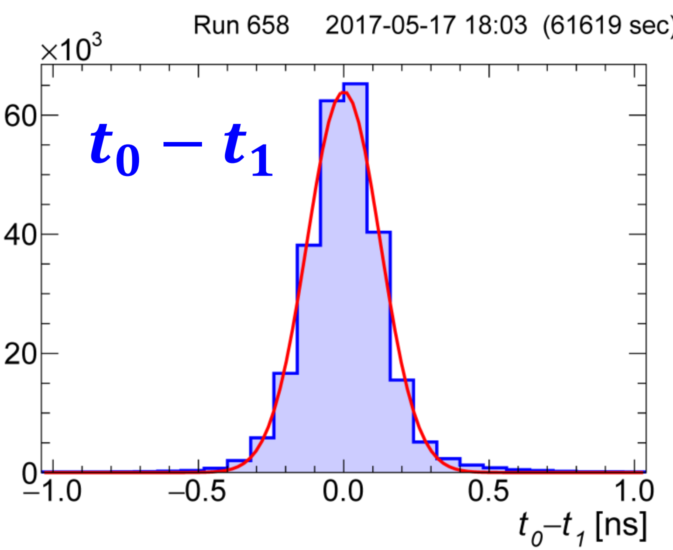
This simple method gives time resolution

$$\sigma_{\text{time}} \sim 100\ \text{ps}$$

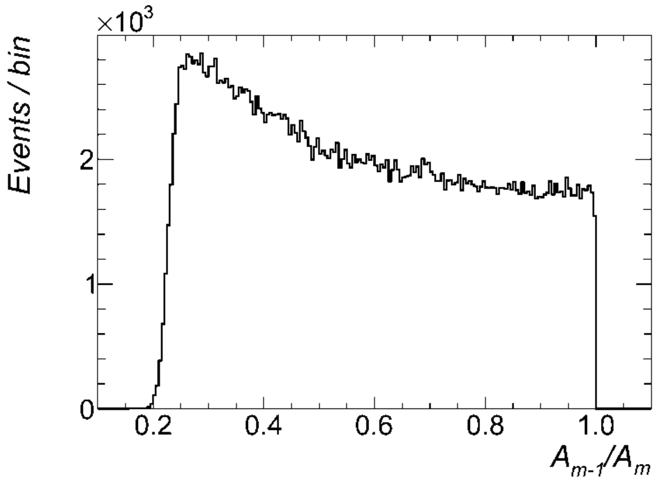
and allows us to control waveform shape.

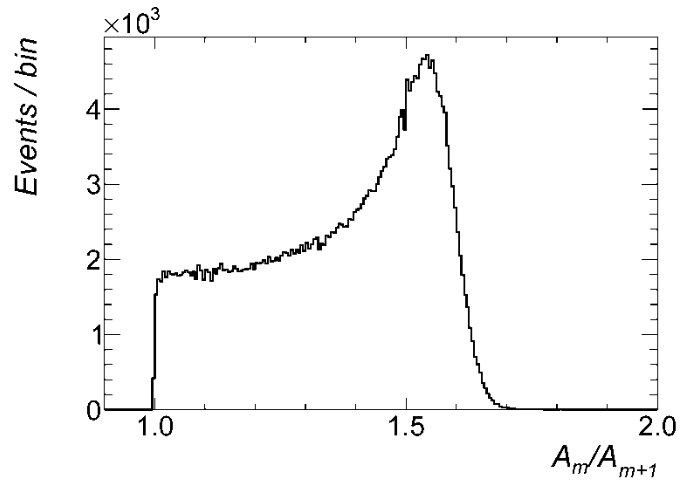






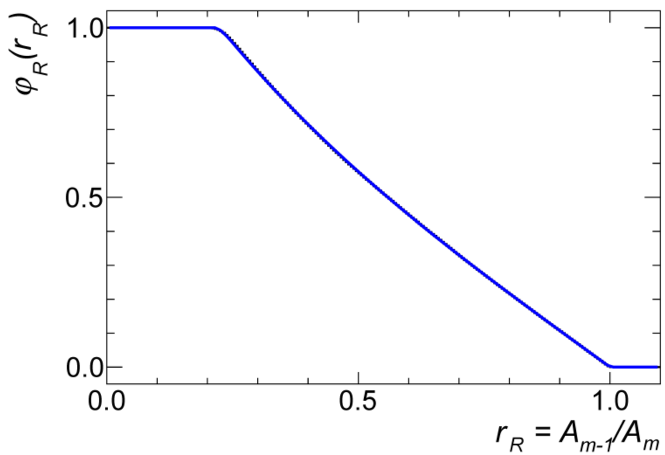
Time Calibration

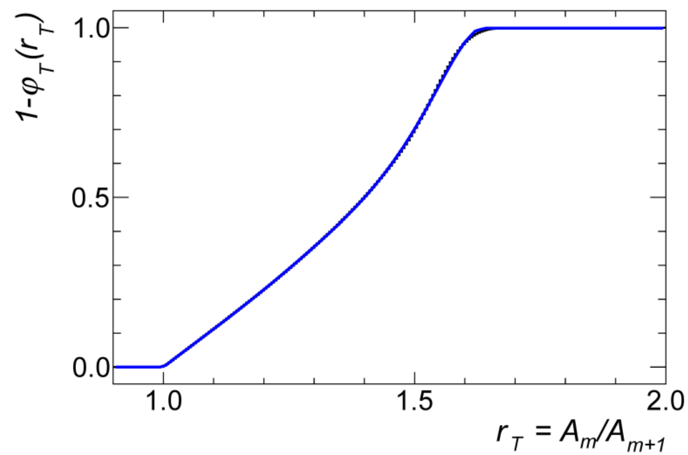




Assuming

$$dN/d\varphi_{R,T} = const$$





Minimal absorber thickness +0.0 mm

Signal amplitude distributions in the right arm scintillators.
A_2 - A_3 correlation cut.