» Proton Polarimetry with the Hydrogen Jet Target at RHIC in Run 2015«

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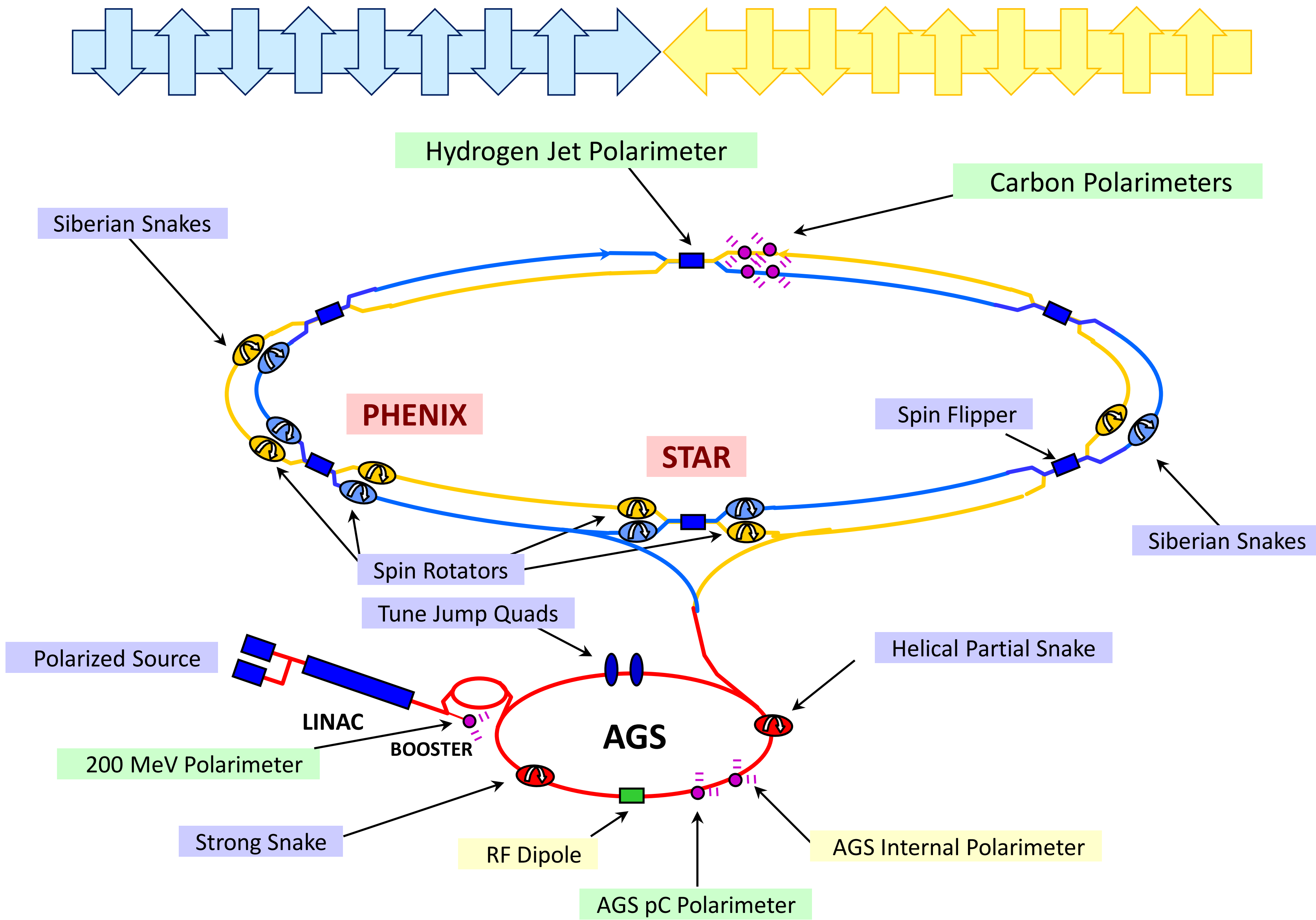
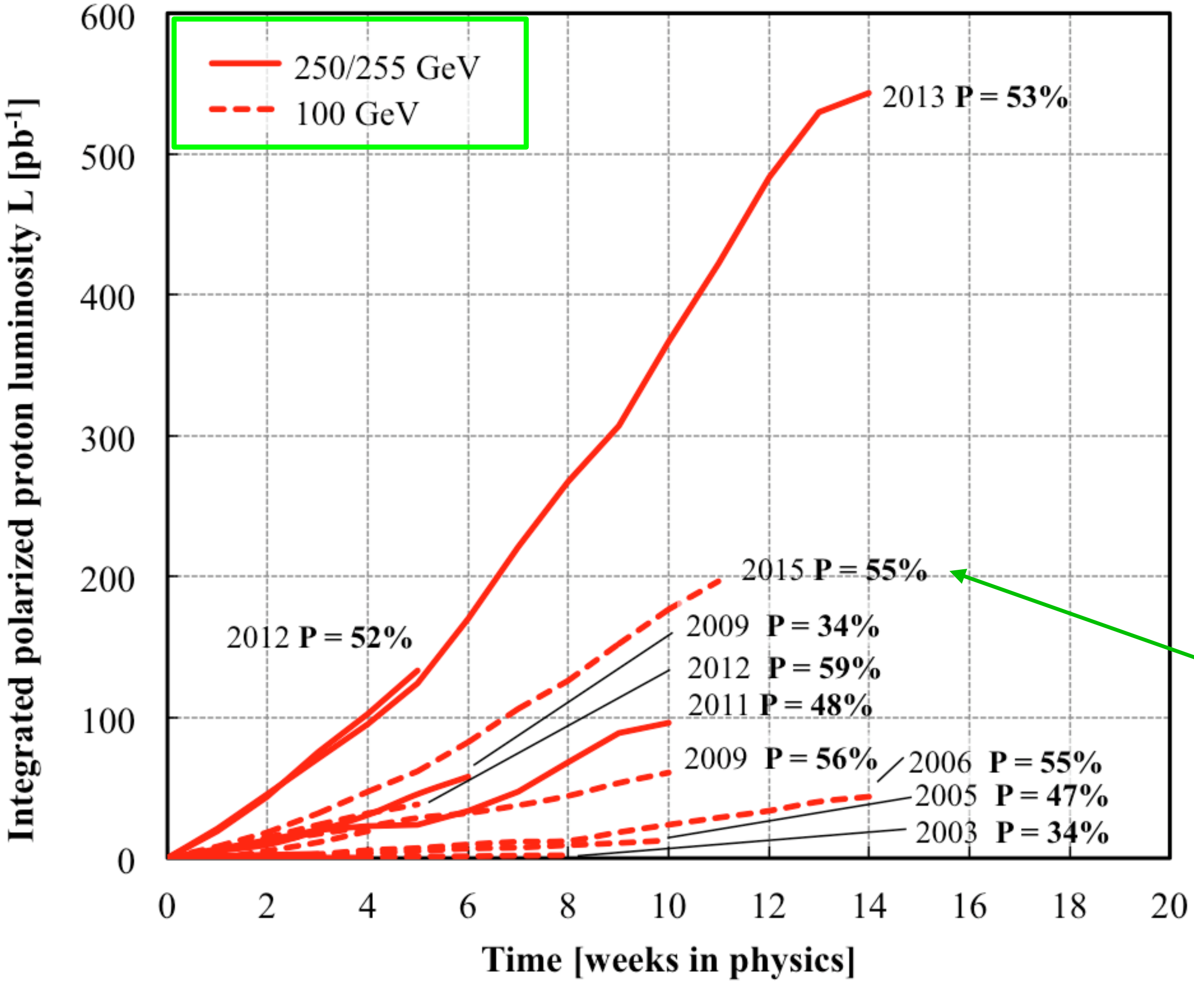
BROOKHAVEN NATIONAL LABORATORY

Polarized Protons in RHIC



Improvement in Beam Polarization



recent RHIC run 2015

Beam energies:

up to 255 GeV

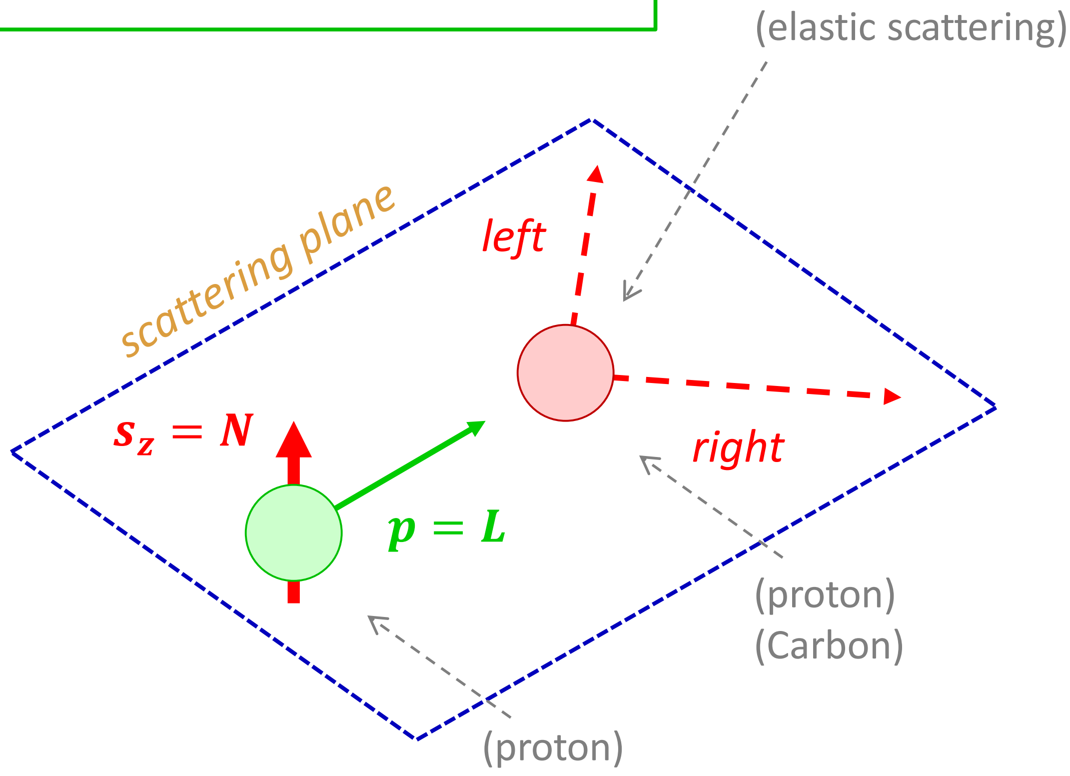
Figure of merit for double helicity observables:

$\sim\mathcal{L}\cdot P^4$

Consistent improvement in delivered luminosity and beam polarization.

Polarization & Asymmetries

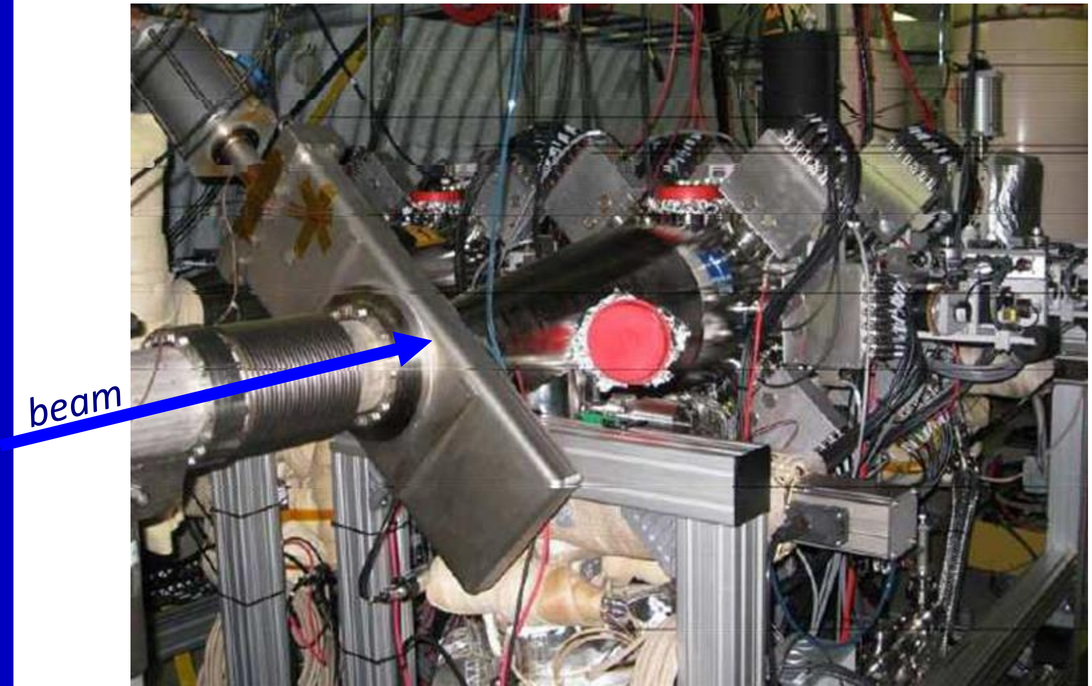
$$s_z = \pm\frac{1}{2}\hbar \Rightarrow P = \frac{n^{\uparrow} - n^{\downarrow}}{n^{\uparrow} + n^{\downarrow}}$$



$$A_N = \frac{d\sigma_{left} - d\sigma_{right}}{d\sigma_{left} + d\sigma_{right}}$$

$$\varepsilon = A_N \cdot P = \frac{N_L - N_R}{N_L + N_R}$$

(*) perpendicular to polarization vector



Carbon polarimeters

Two per ring

Fast measurement

$\delta P/P \approx 4\%$

Beam polarization profile

Polarization decay (time dependence)

← normalization

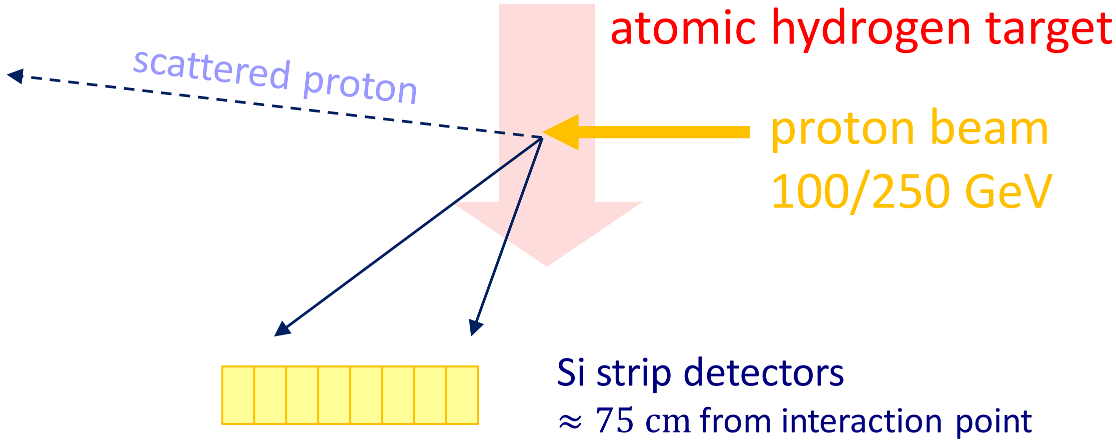
Hydrogen jet polarimeter

Polarized target

Continuous operation

$\delta P/P \approx 5-8\%$ per fill

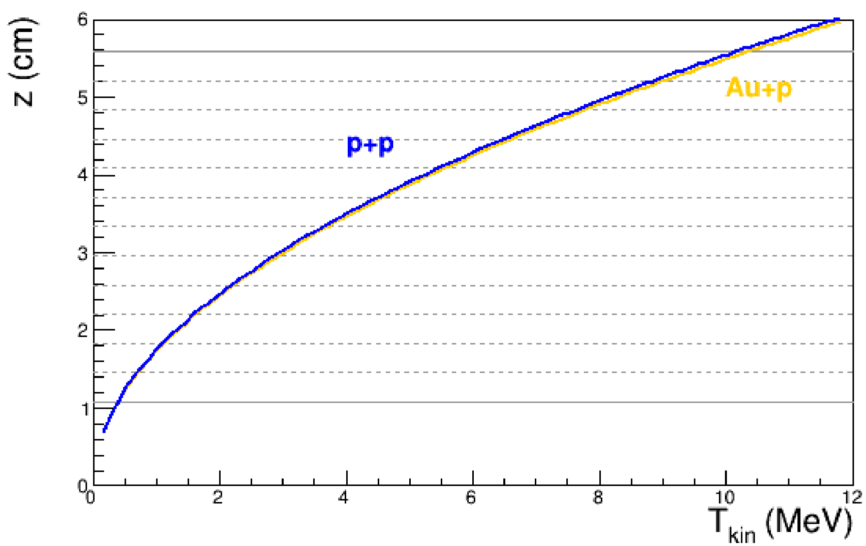
Elastic Recoil Protons

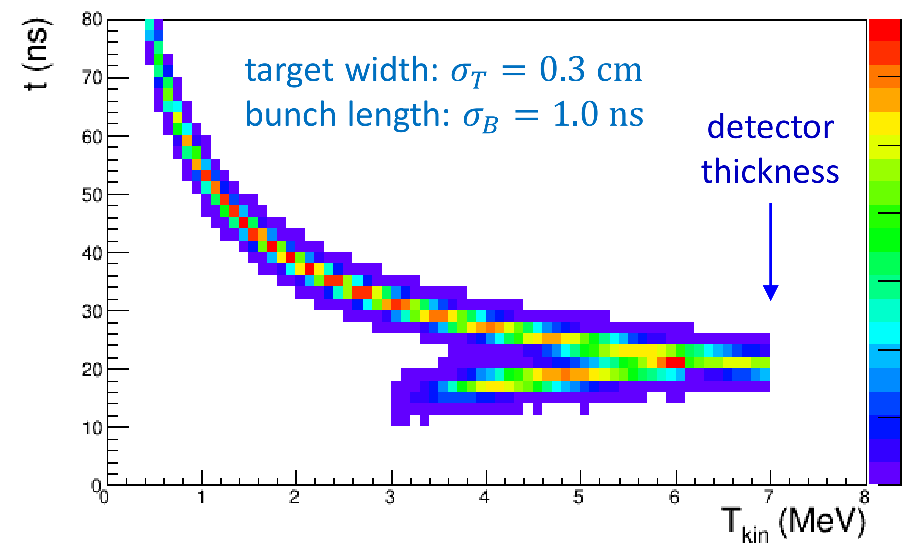


Recoil proton from elastic scattering

Independent of beam energy, species

Non-relativistic: $T_{kin} = \frac{1}{2} m v^2$



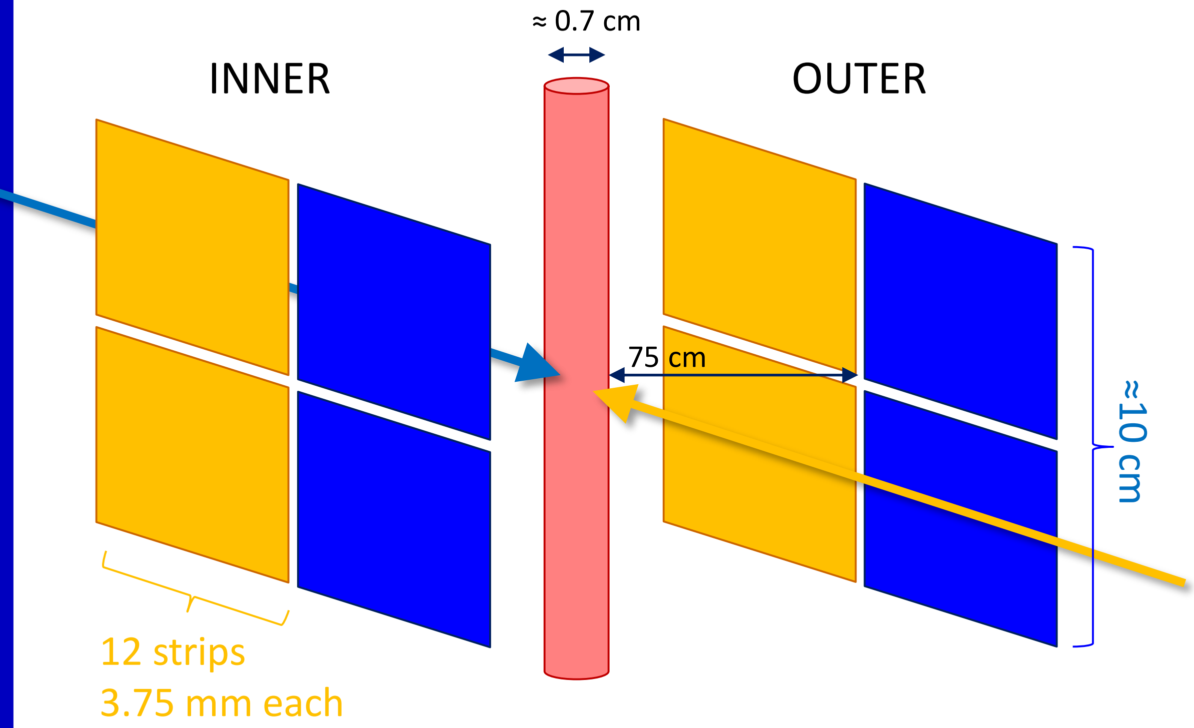


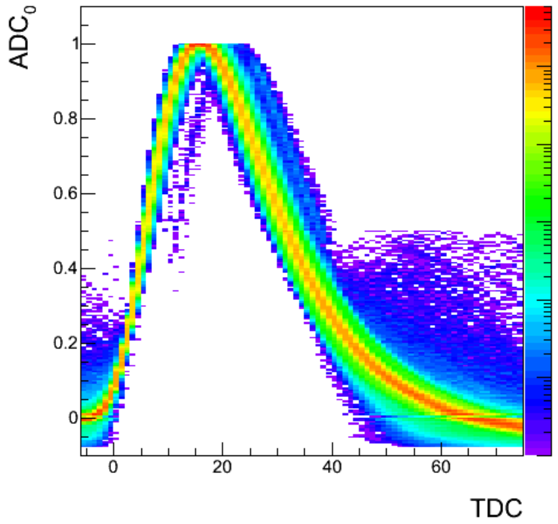
Detector Setup

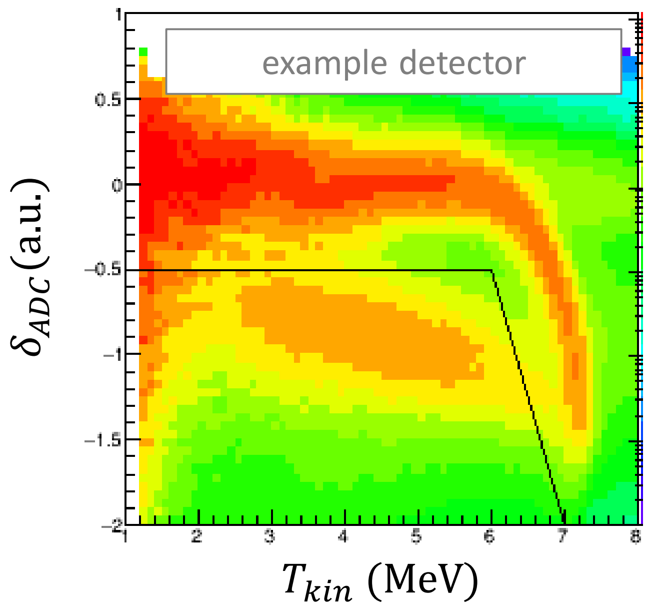
Set of eight Hamamatsu Si strip detectors

12 strips, each 3.75 mm wide, 500 μm thick

Uniform dead layer ≈ 1.5 μm







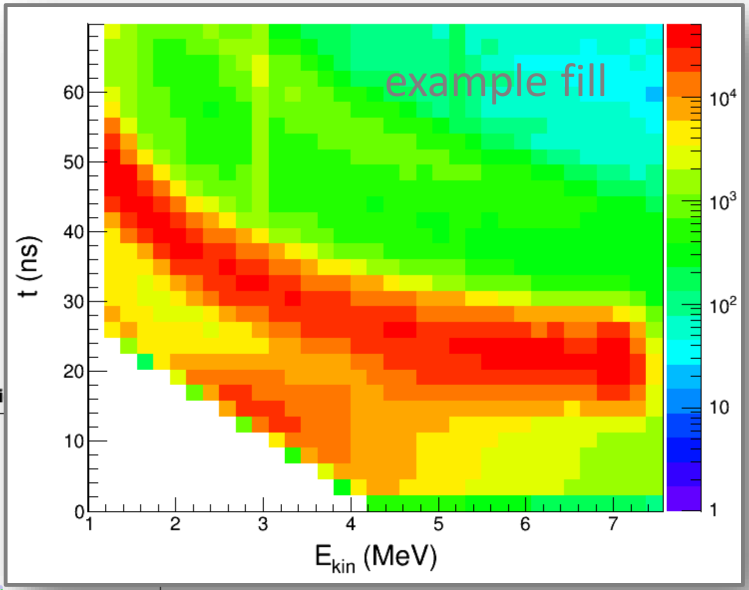
QA: Kinematics

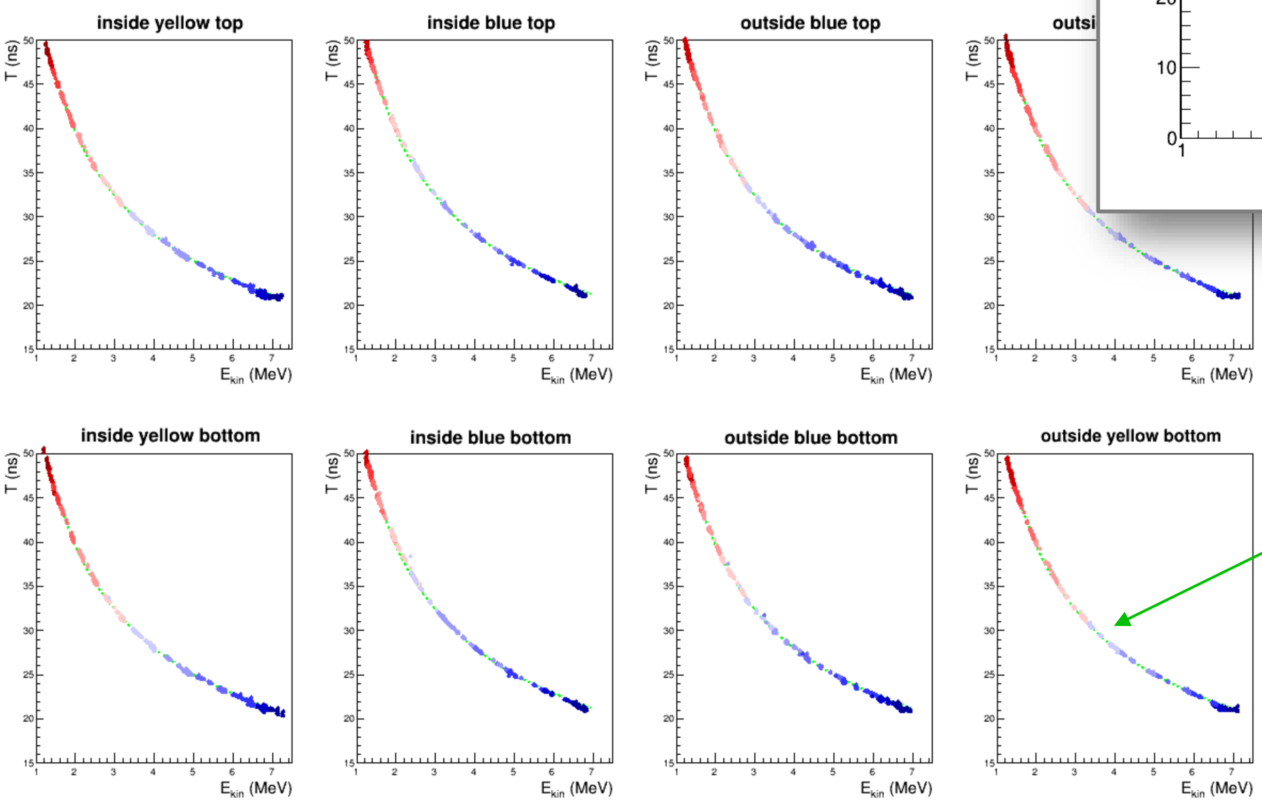
Elastic proton recoil selection:

After energy and T_0 calibration

$$|M_{miss} - m_p| < 100\ \mathrm{MeV}/c^2$$

$$|\Delta t| < 5\ \mathrm{ns}$$





Fit to ALL data, plotted under the distributions in each detector

Si-strips:
red – central to
blue – downstream

Detector Alignment

Magnetic holding field for target polarization changes acceptance of detectors on left and right sides

Outer correction field is adjusted for compensation

For missing proton mass:

$$\sin\theta = \frac{p'}{2 \cdot m_p \cdot p_B}(2 \cdot E + 2 \cdot m_p - T_R)$$

Missing mass:

$$M_{miss}^2 = \begin{pmatrix} E + m_p - E' \\ p_B - p' \end{pmatrix}^2$$

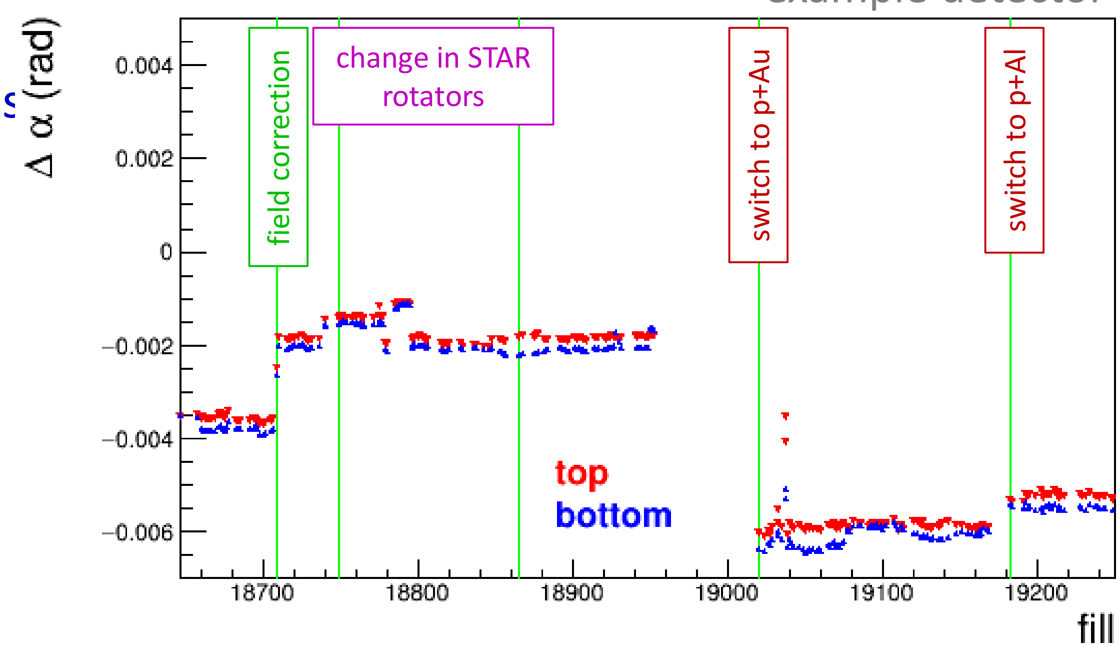
Non-relativistic recoil:

$$p' = \sqrt{2 m_p T_R}$$

Compare with geometry of detector (averaged over 12 strips)

p+Au and p+Al operation had a significant beam angle on the jet target

example detector



Asymmetries & Polarization

$$\varepsilon = A_N \cdot P$$

$$P_{Beam} = -\frac{\varepsilon_{Beam}}{\varepsilon_{Target}} P_{Target}$$

measure

from Breit-Rabi measurement

1

Polarization independent background

$$\varepsilon = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow} + 2 \cdot N_{bg}} \Rightarrow \frac{\varepsilon_B}{\varepsilon_T} = \frac{N_B^{\uparrow} - N_B^{\downarrow}}{N_T^{\uparrow} - N_T^{\downarrow}}$$

2

Polarization dependent background

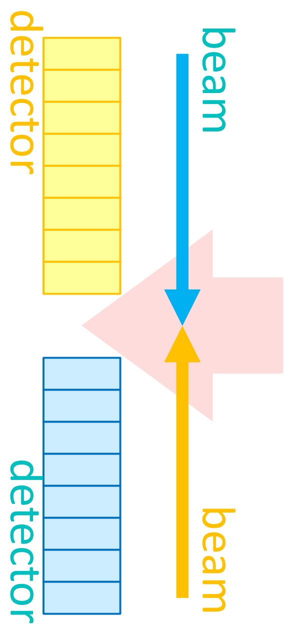
$$\varepsilon = \frac{\varepsilon_{inc} - r \cdot \varepsilon_{bg}}{1 - r}$$

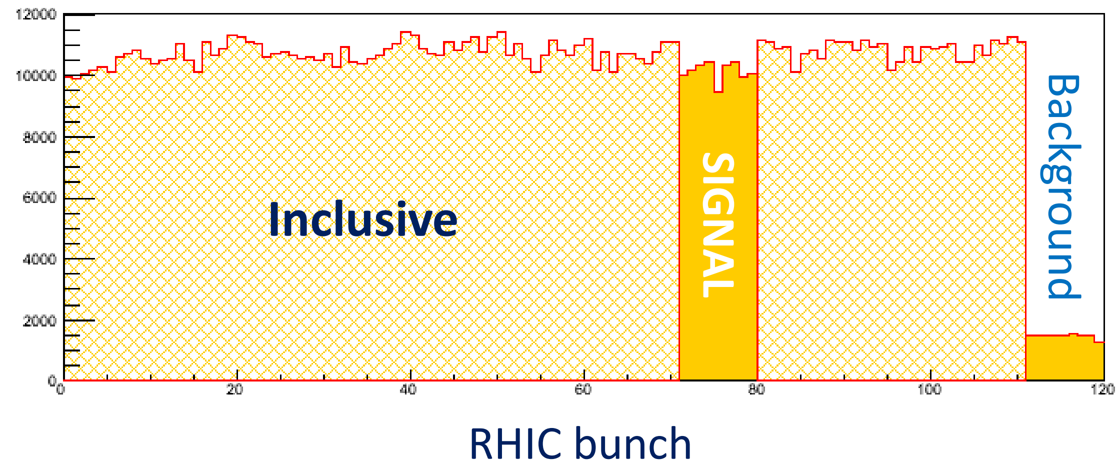
background fraction $r = N_{bg}/N$

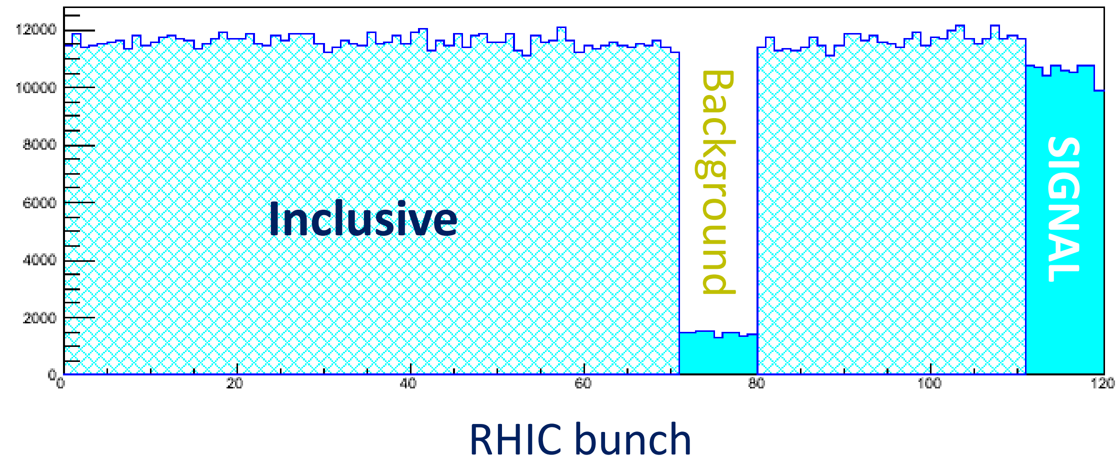
Signal & Background I

Abort gaps are not aligned at polarimeter location

Use abort gaps for background and clean signal identification





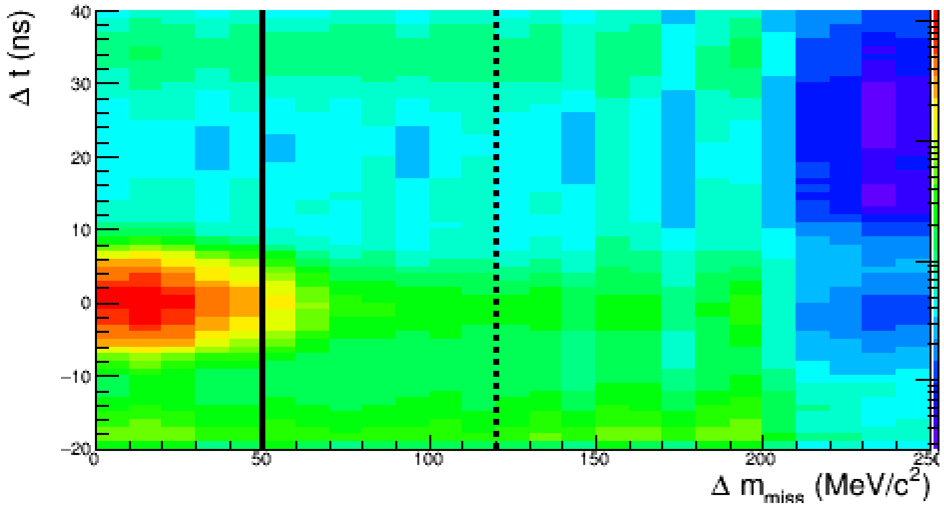


Signal & Background II

Δt: difference of measured time-of-flight to elastic signal, $t(T_R)$

Δm_{miss}: difference of missing mass to scattered proton (geometry after alignment correction)

Example (logarithmic z-scale)



Position of elastic proton signal is independent of energy and detector

Vertical stripes are a remnant of the spatial detector resolution

Punch through cuts are already applied

Define signal and background regions by missing mass

$$|M_{miss} - M_p| < 50\ \mathrm{MeV}/c^2$$

$$|M_{miss} - M_p| > 120\ \mathrm{MeV}/c^2$$

Signal & Background III

- inclusive (normalized to peak)

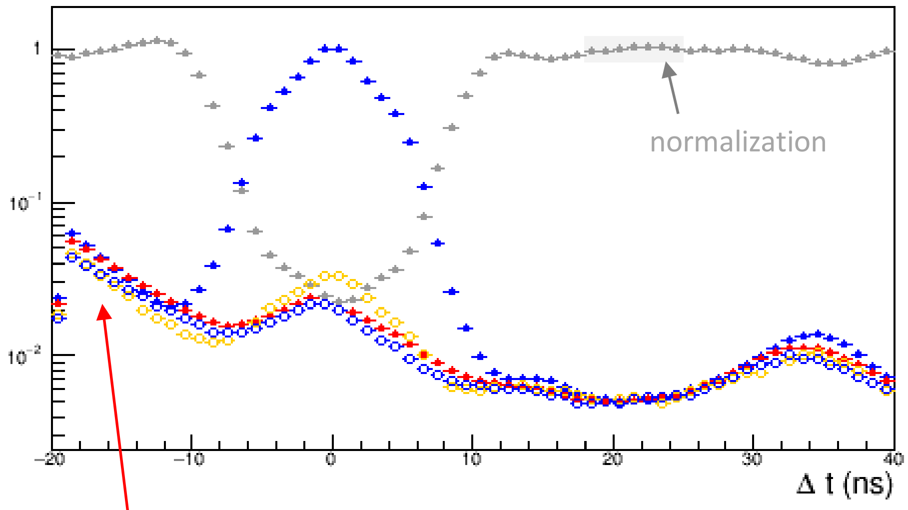
$$|M_{miss} - m_p| < 50\ \mathrm{MeV}/c^2$$

- background (normalized to signal at $18 < \Delta t < 25$ ns)

$$|M_{miss} - m_p| > 120\ \mathrm{MeV}/c^2$$

- background fraction

Example (blue beam, $2 < E_{kin} < 3$ MeV)



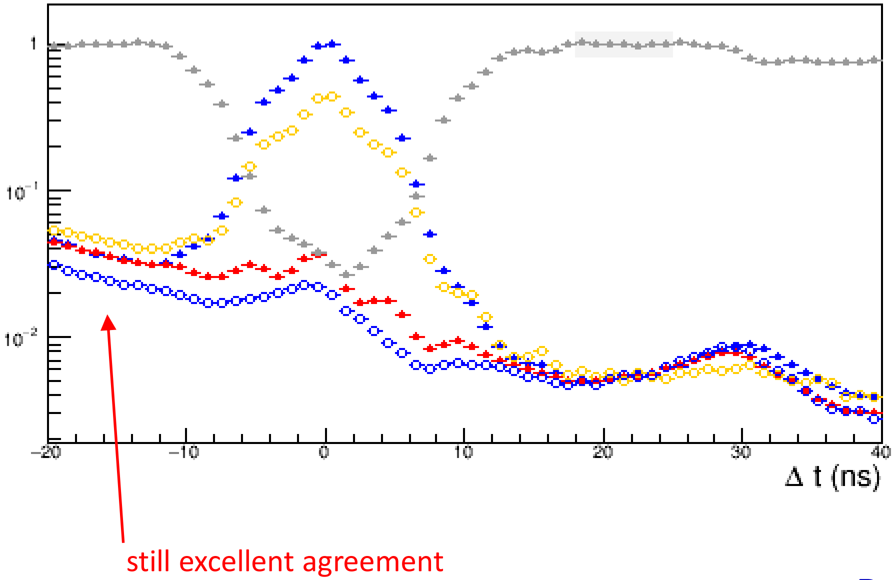
well described by normalization at $18 < \Delta t < 25$ ns

- ○ Background in yellow abort gap (should be clean blue signal)
- ○ Signal in blue abort gap (should be only background from yellow beam)

The normalization is same as above → only for comparison of shape and source of background

Background Sources

Example (blue beam, $3 < E_{kin} < 4$ MeV)



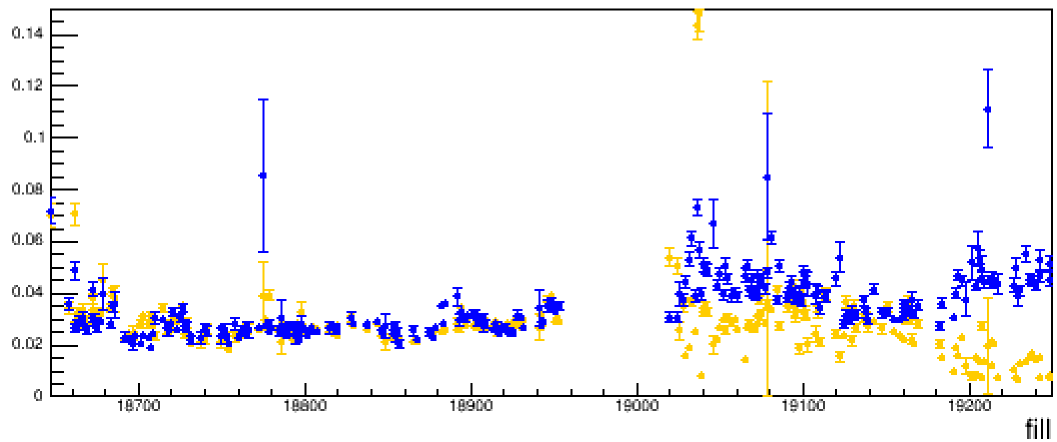
From $p + Au$ operation

Typical bunch shape of Au-beam seen in full background, dominates *early* background

Late background mainly from signal beam

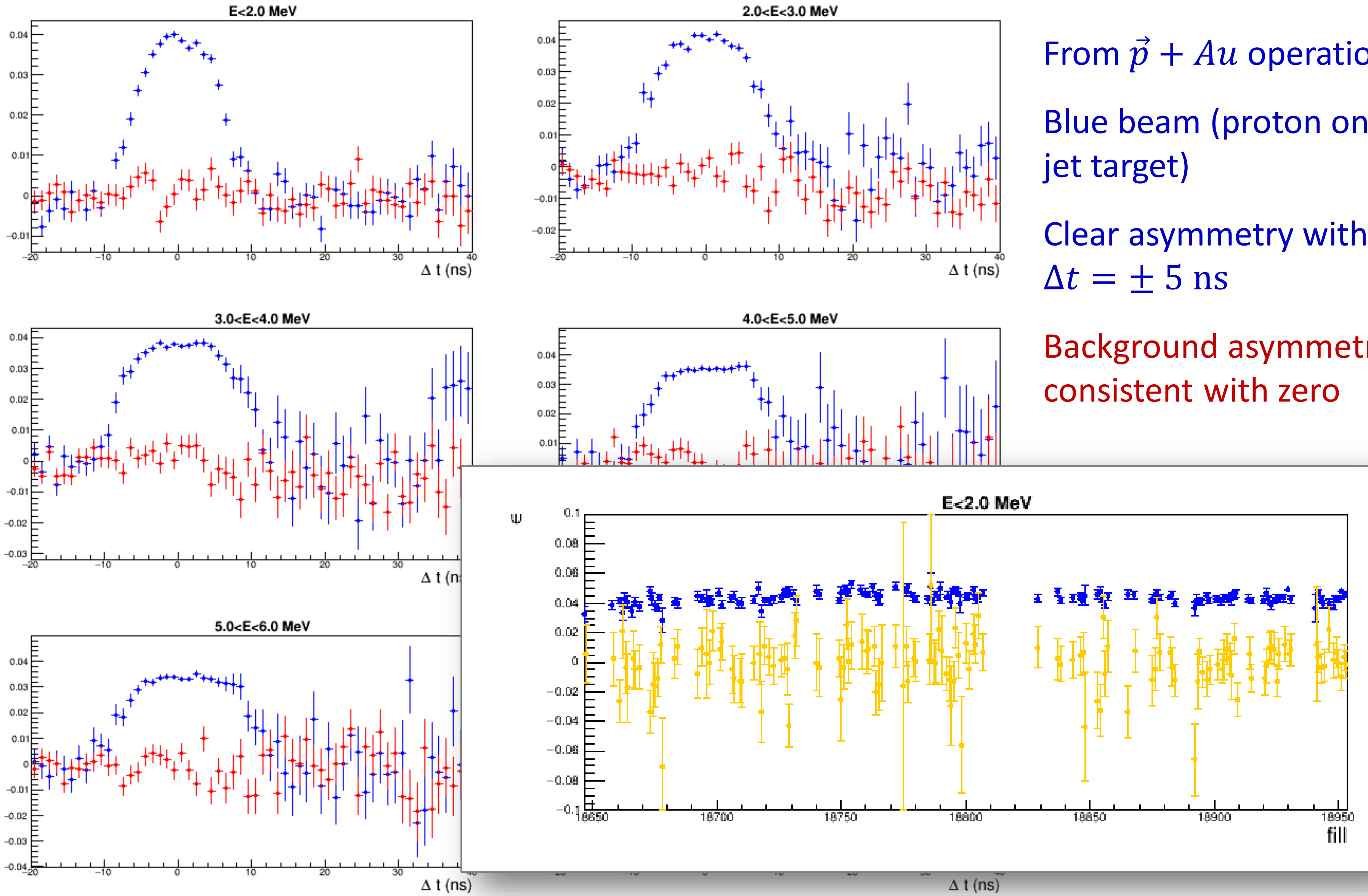
Using signal cuts in blue abort gap: $|M_{miss} - m_p| < 50\ \mathrm{MeV}/c^2$

Background fraction $r = N_{bg}/N$



Fill-by-fill background fraction depends on conditions of both beams → important for beam polarization measurement

Asymmetry Examples



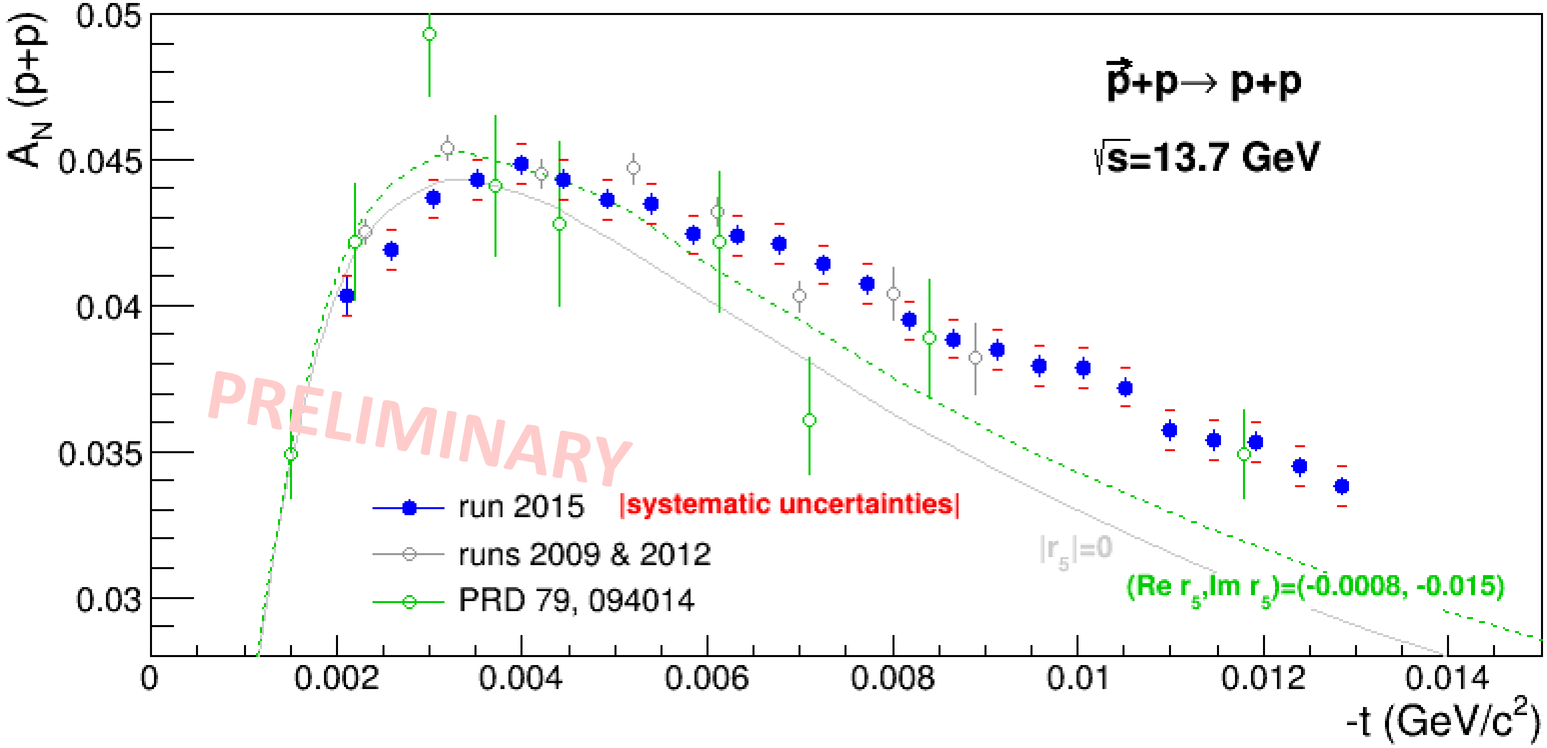
From $\vec{p} + Au$ operation

Blue beam (proton on jet target)

Clear asymmetry within $\Delta t = \pm 5$ ns

Background asymmetry consistent with zero

Analyzing Power: $A_N(\vec{p}+p)$



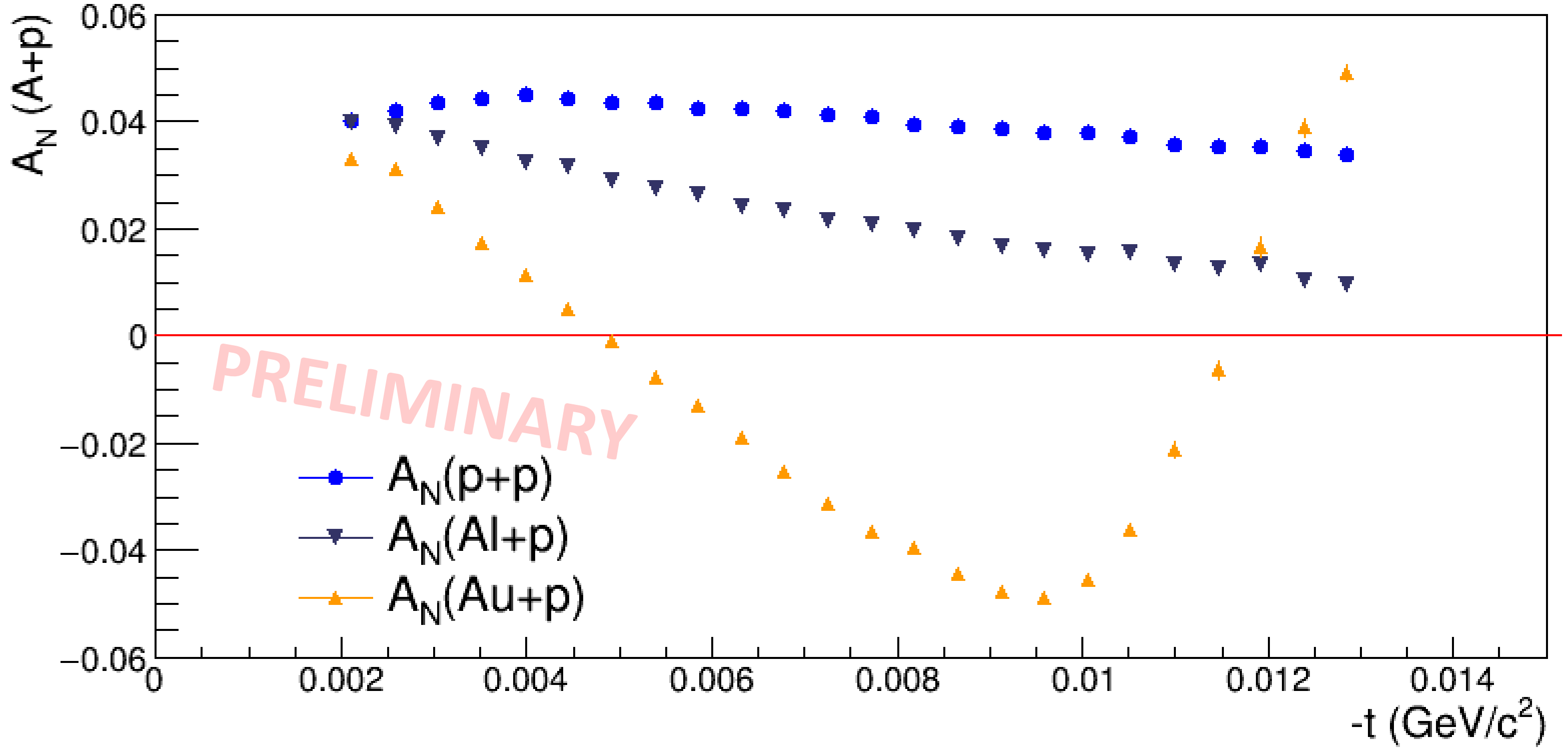
Atomic hydrogen target polarization $P = 96\%$

Molecular component $R_{H_2} = 3\%$ (by mass)

Global uncertainty from target polarization not included

$-t$-range can be extended with punch-through protons

Analyzing Power: $A_N(\vec{p} + A)$



Atomic hydrogen target polarization $P = 96\%$

Molecular component $R_{H_2} = 3\%$ (by mass)

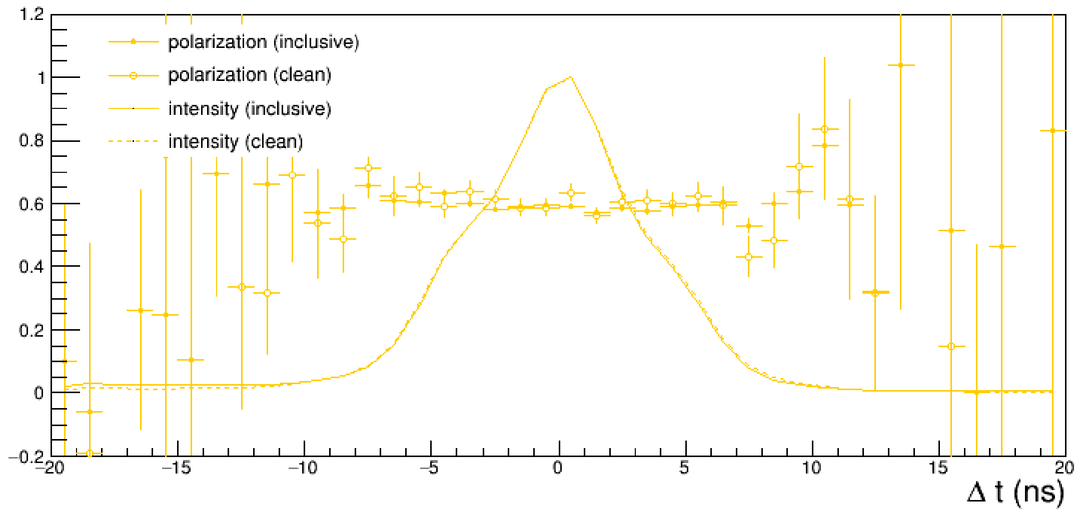
Global uncertainty from target polarization not included

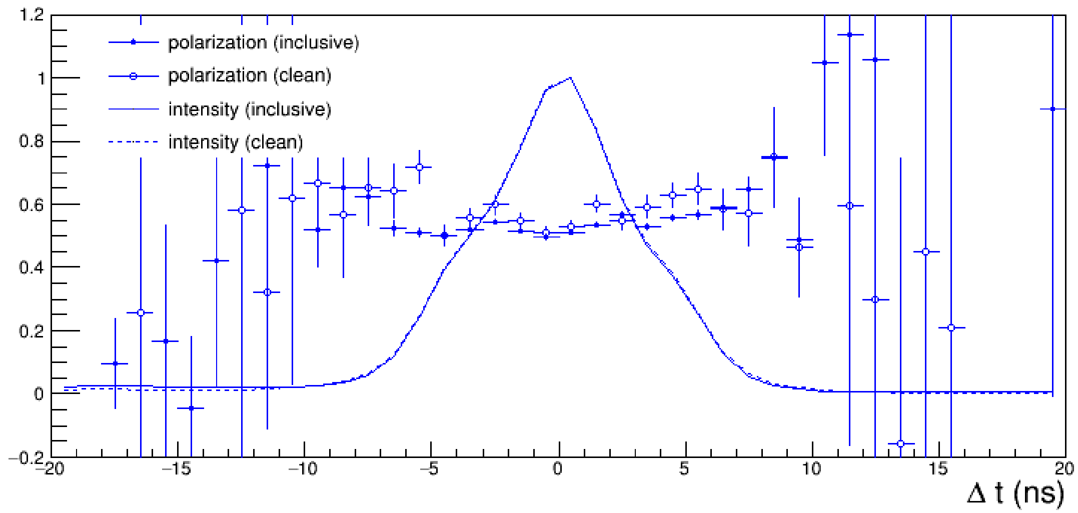
$-t$-range can be extended with punch-through protons

→ A. Poblaguev

Longitudinal Bunch Profile: $p + p$

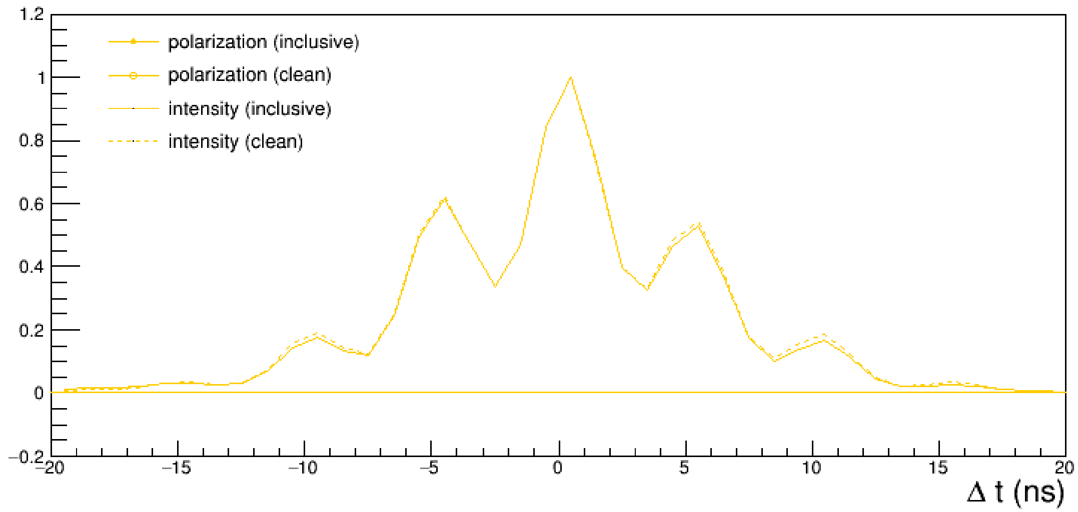
- Full run 15 statistics: $\boldsymbol{p} + \boldsymbol{p}$
- $1 < T_R < 7$ MeV
- Comparison of inclusive and clean bunches
- Beam intensity: normalized number of events
- First measurement of longitudinal bunch profile
- No significant longitudinal polarization profile has been found.

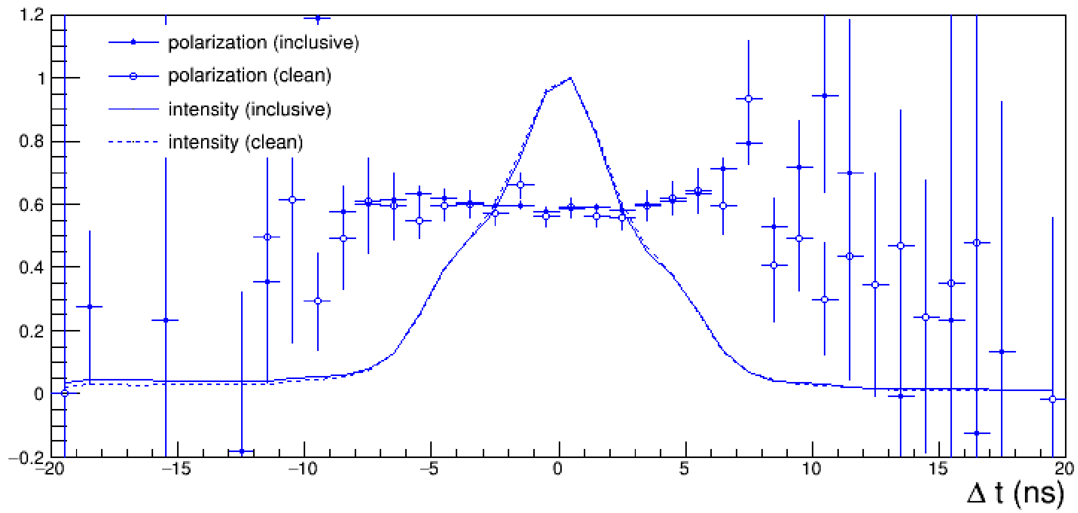




Longitudinal Bunch Profile: $p + Au$

- Full run 15 statistics: $\boldsymbol{p + Au}$
- $1 < T_R < 7$ MeV
- Comparison of inclusive and clean bunches
- Beam intensity: normalized number of events
- No significant effect from colliding bunches can be seen.

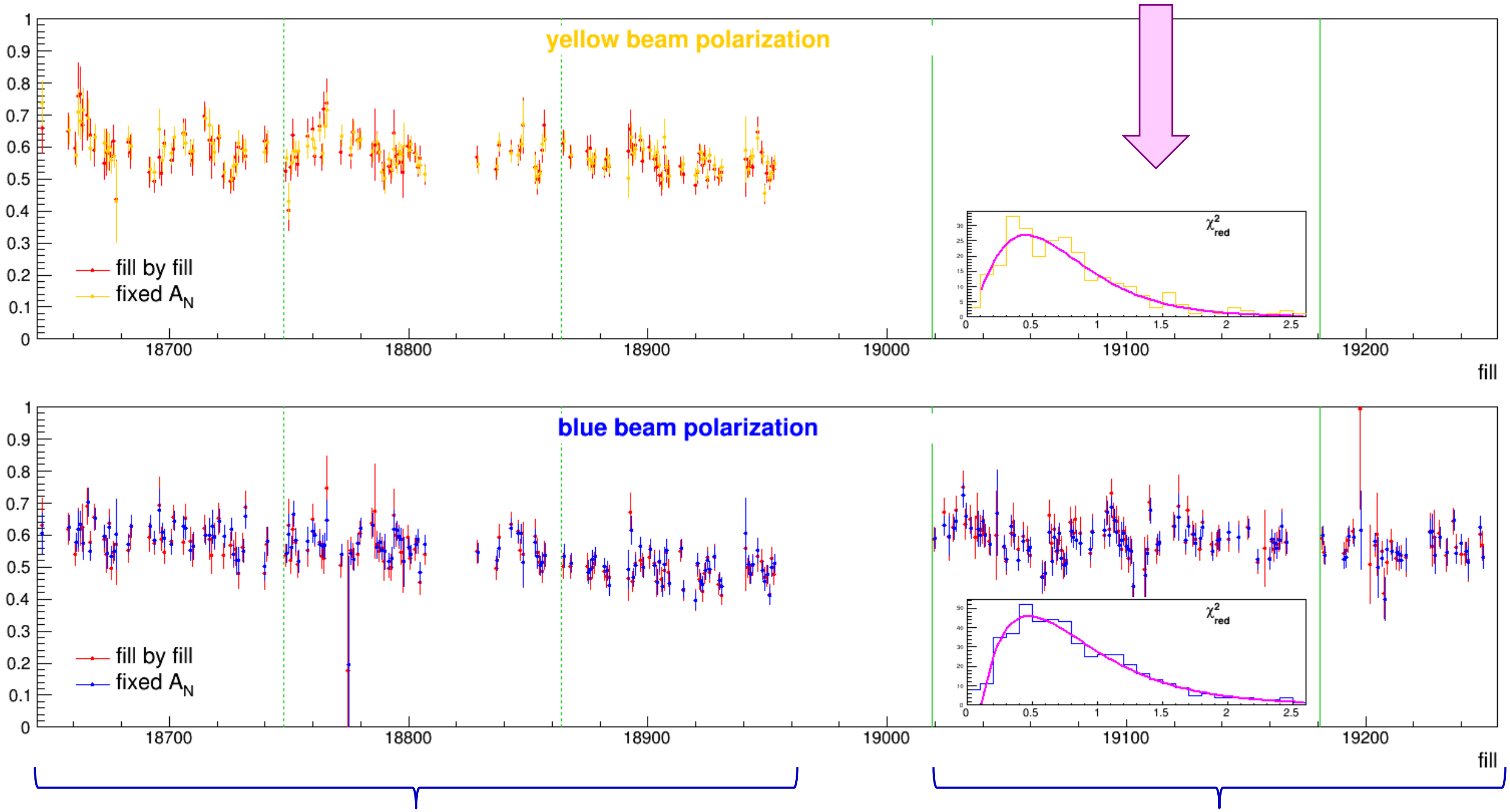




Final Beam Polarizations

Atomic hydrogen target polarization 96%
H_2 content 3% (mass)

Ratio of target/beam asymmetries
$1 < E_{recoil} < 7$ MeV (six bins)
Fit to constant

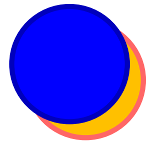


use fixed A_N for $p + p$

use fill by fill ratio for $p + A$

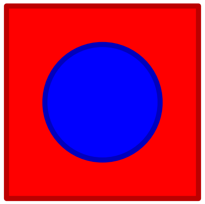
Luminosity Weighted Polarization

Experiments



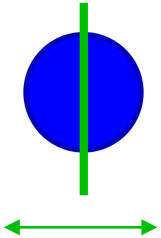
$$P = \frac{\int P(x,y,t)\cdot I_B(x,y,t)\cdot I_Y(x,y,t)dxdydt}{\int I_B(x,y,t)\cdot I_Y(x,y,t)dxdydt}$$

HJET Polarimeter

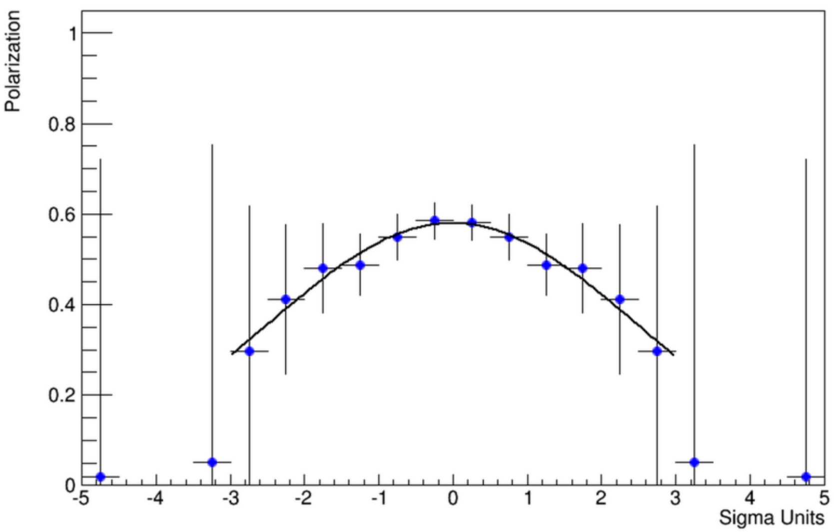


$$P = \frac{\int P(x,y,t)\cdot I(x,y,t)dxdydt}{\int I(x,y,t)dxdydt}$$

Carbon Polarimeter

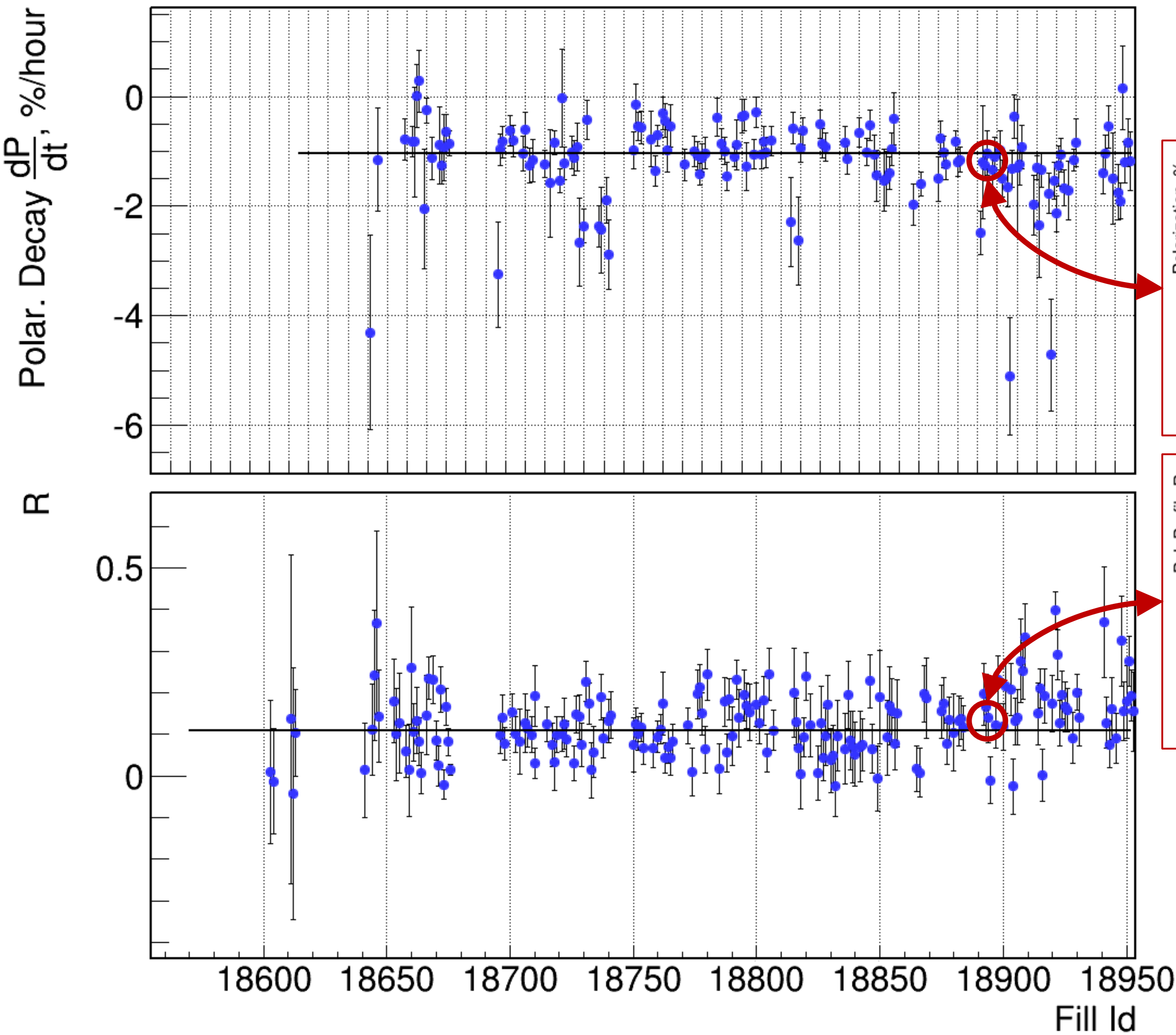


$$P = P_{max}\cdot\left(\frac{I}{I_{max}}\right)^R$$

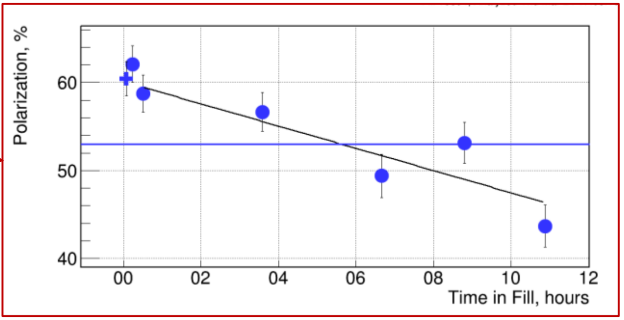


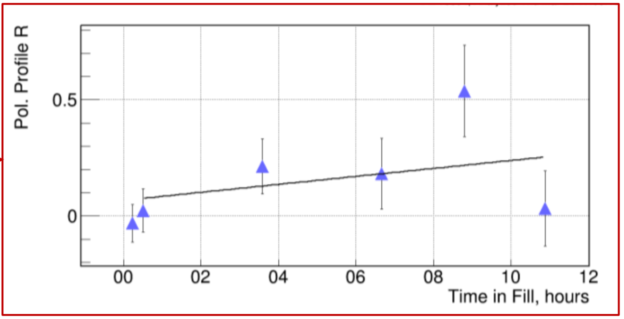
beam width

Polarization Decay & Profile



Example fill 18894





Summary

- Polarimetry at RHIC
  - Essential input for experiments
  - Fast feedback during collider operation

Fast polarization measurement with Carbon targets

- Polarization decay and transverse profile

Absolute normalization with polarized hydrogen jet target

- Analyzing power with new detectors in 2015 → improved precision and systematic studies
- New asymmetries from elastic proton-heavy-ion scattering
- Longitudinal polarization profile
- Final beam polarizations are fully background corrected

BACK UP

Elastic Proton-Proton Scattering

$$\varphi(s,t) = \langle \lambda_C \lambda_D | \varphi | \lambda_A \lambda_B \rangle$$

$$\varphi_1(s,t) = \left\langle +\frac{1}{2} + \frac{1}{2} \middle| \varphi \middle| +\frac{1}{2} + \frac{1}{2} \right\rangle$$

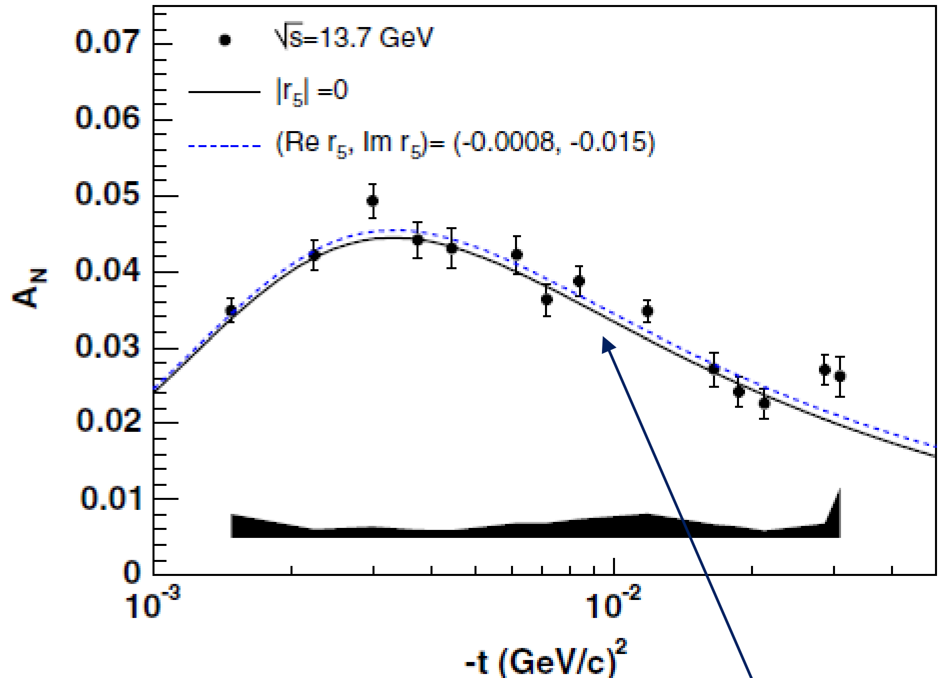
$$\varphi_2(s,t) = \left\langle +\frac{1}{2} + \frac{1}{2} \middle| \varphi \middle| -\frac{1}{2} - \frac{1}{2} \right\rangle$$

$$\varphi_3(s,t) = \left\langle +\frac{1}{2} - \frac{1}{2} \middle| \varphi \middle| +\frac{1}{2} - \frac{1}{2} \right\rangle$$

$$\varphi_4(s,t) = \left\langle +\frac{1}{2} - \frac{1}{2} \middle| \varphi \middle| -\frac{1}{2} + \frac{1}{2} \right\rangle$$

$$\varphi_5(s,t) = \left\langle +\frac{1}{2} + \frac{1}{2} \middle| \varphi \middle| +\frac{1}{2} - \frac{1}{2} \right\rangle$$

Phys. Rev. D 79, 094014 (2009)



First data from 2004 (100 GeV beam)

$$A_N \frac{ds}{dt} = -\frac{4\pi}{s^2} \mathrm{Im}\left[\varphi_5^{em*}(s,t)\varphi_+^{had}(s,t) + \varphi_5^{had*}(s,t)\varphi_+^{em}(s,t)\right]$$

no-flip amplitude: $\varphi_+(s,t) = \frac{1}{2}[\varphi_1(s,t) + \varphi_3(s,t)]$

Transverse single-spin asymmetries are driven by an interference of amplitudes and can be compared to Regge theory.

- Reconstruction
  - Energy calibration
  - Time of flight adjustment
  - Geometry alignment
  - Pedestal noise QA
- Signal selection
  - Remove punch through hits
  - Missing mass $\left|M_{miss} - M_p\right| < 50\ \mathrm{MeV}/c^2$
  - Time of flight $|\Delta t| < 5\ \mathrm{ns}$
- Asymmetry calculation
  - Inclusive and signal bunches
  - Background asymmetry correction
- Beam polarization calculation
  - Asymmetry ratio $1 < E_{recoil} < 7\ \mathrm{MeV}$

$$\epsilon_S = \frac{\epsilon_I - r\epsilon_B}{1 - r}$$

$$r = \frac{B}{S + B}$$

Energy Calibration

Calibrations are done every few days:

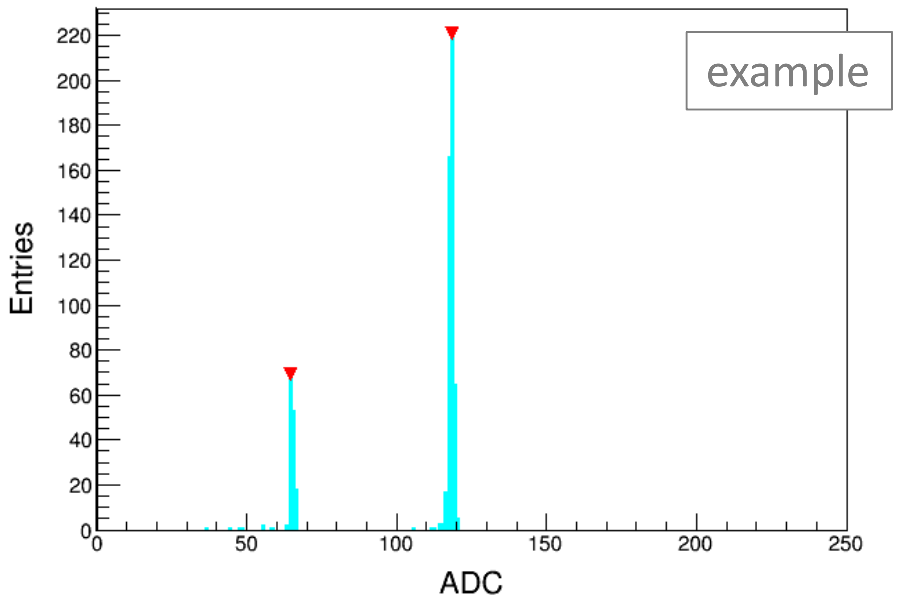
- Gain
- Entrance window (dead layer)

Two different α-sources

$$E_\alpha(Gd) = 3.183 \text{ MeV}$$

$$E_\alpha(Am) = 5.486 \text{ MeV}$$

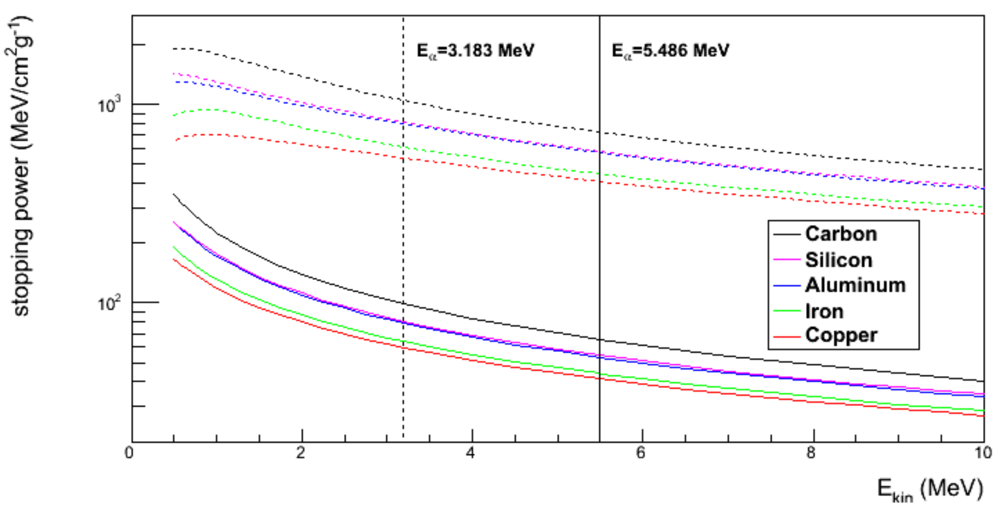
Resolution of peak finding is within 1 ADC count



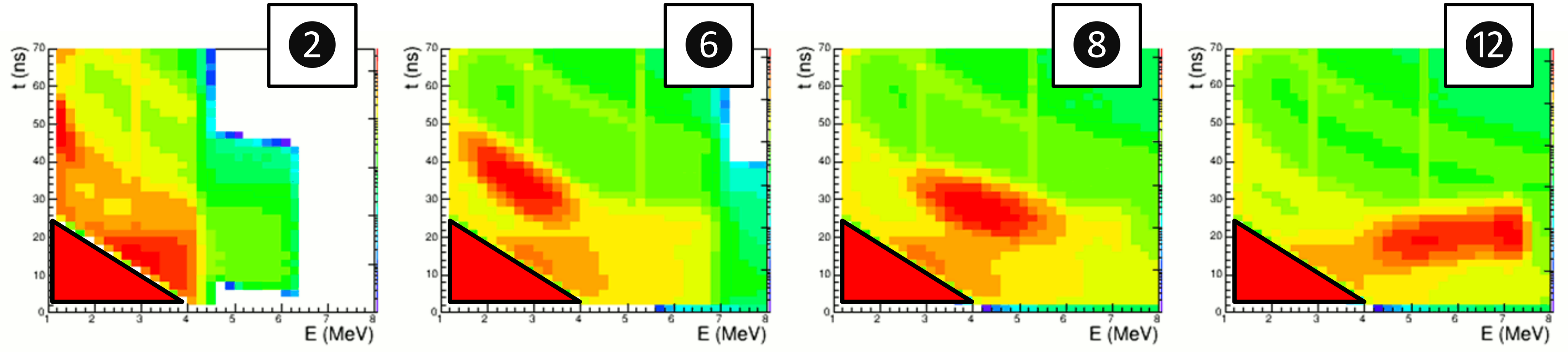
Stopping power for protons and α-particles from NIST database:

$$\Delta E_{\alpha(Am)} = 0.72 \cdot \Delta E_{\alpha(Gd)}$$

$$\Delta E_P = 0.44 \cdot \Delta E_{\alpha(Gd)} \cdot E[MeV]^{-0.64}$$



Kinematics

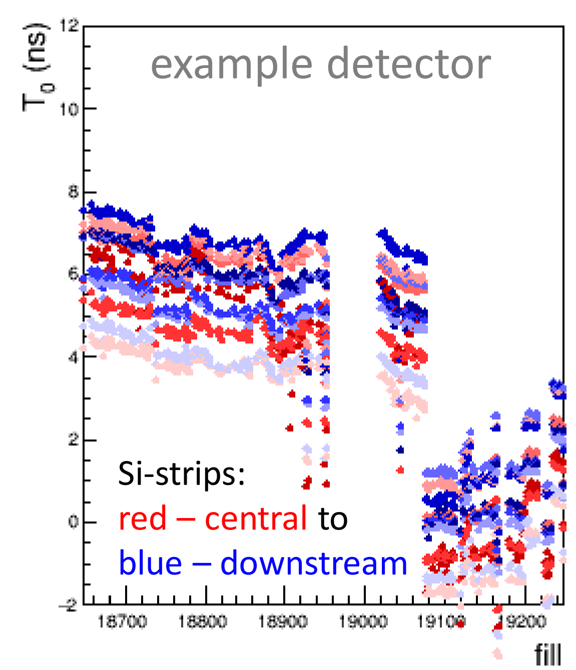


12 strips per detector

Removed peak in prompt hits at low ADC/TDC region

Using elastic p-recoil signature for time-of-flight offset determination

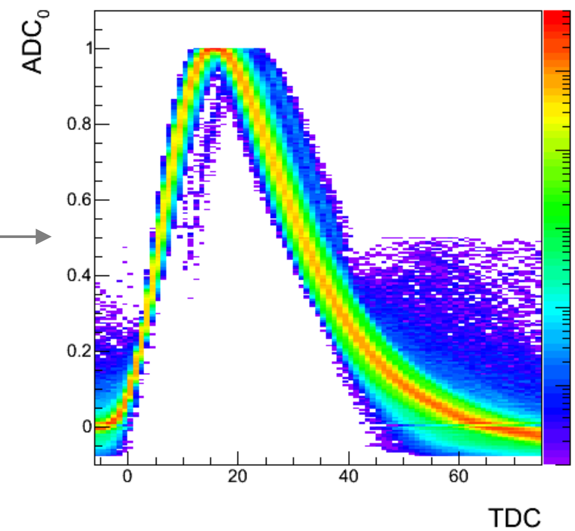
- Slow drift with time (detector/read-out)
- Big jumps when changing the DAQ system



Stopped Recoil Protons

Normalized to $ADC_{\max}$

Slope δ_{ADC} calculated in six TDC bins around ½ $ADC_{\max}$



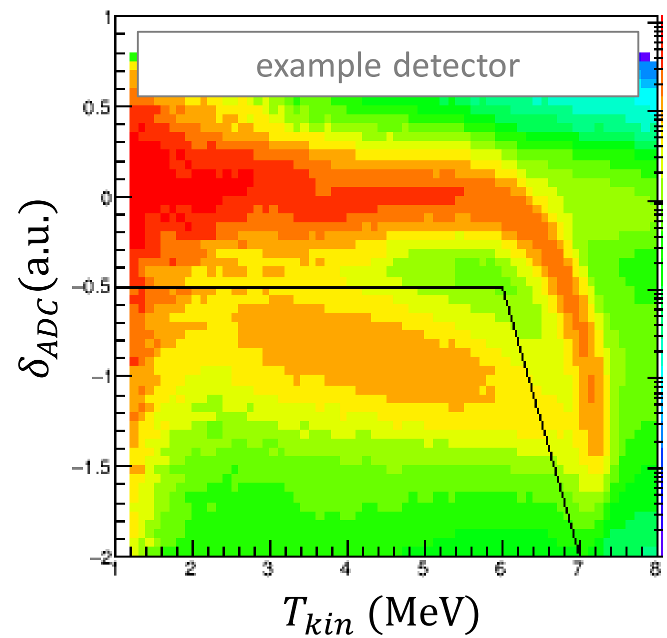
Slope of rise in waveform can be used to identify punch-through particles

Normalized waveform rise ($4.5 < E < 5.5$ MeV) in each detector

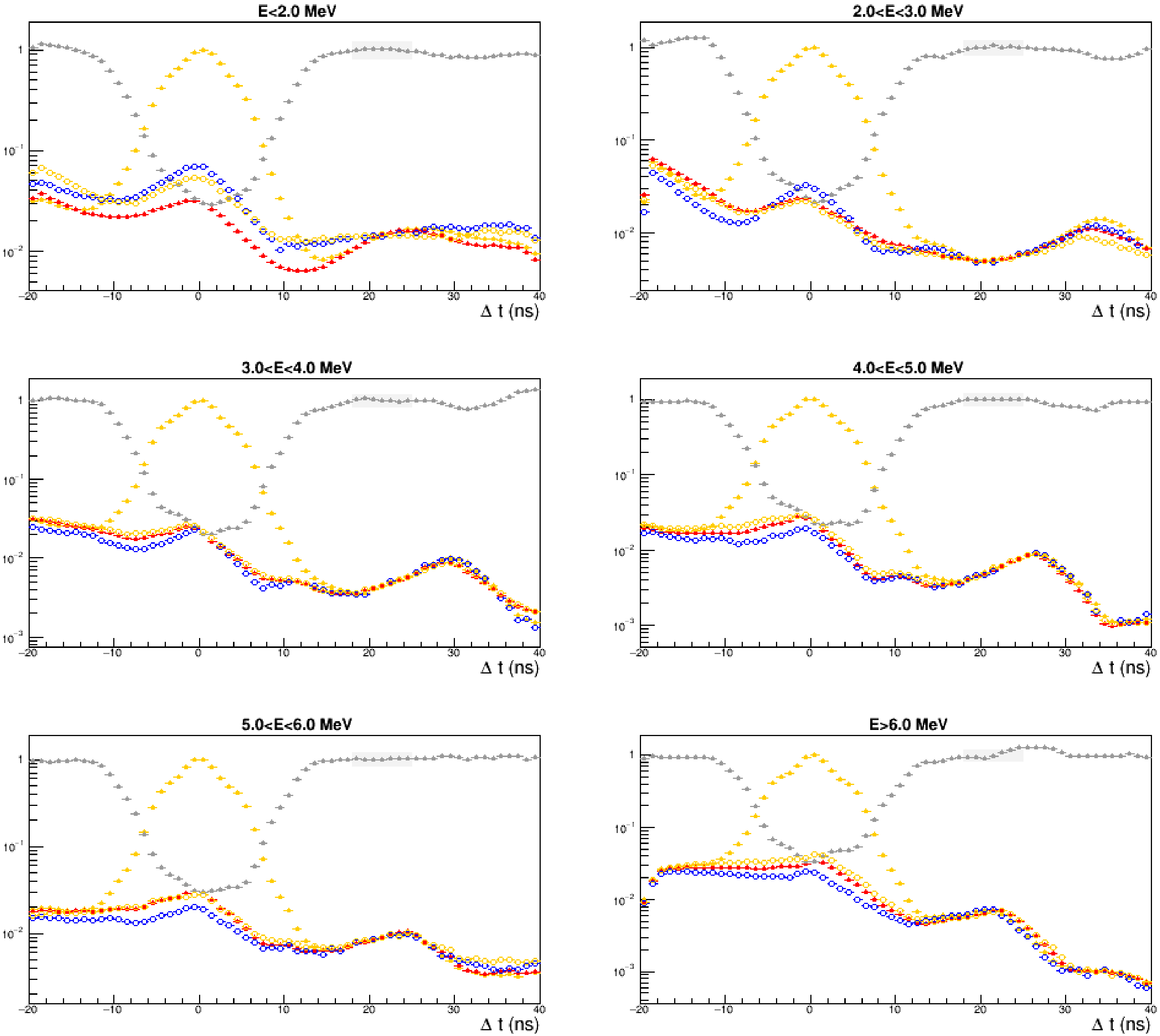
Independent of DAQ system (CAMAC/VME)

Remove punch-through particles:

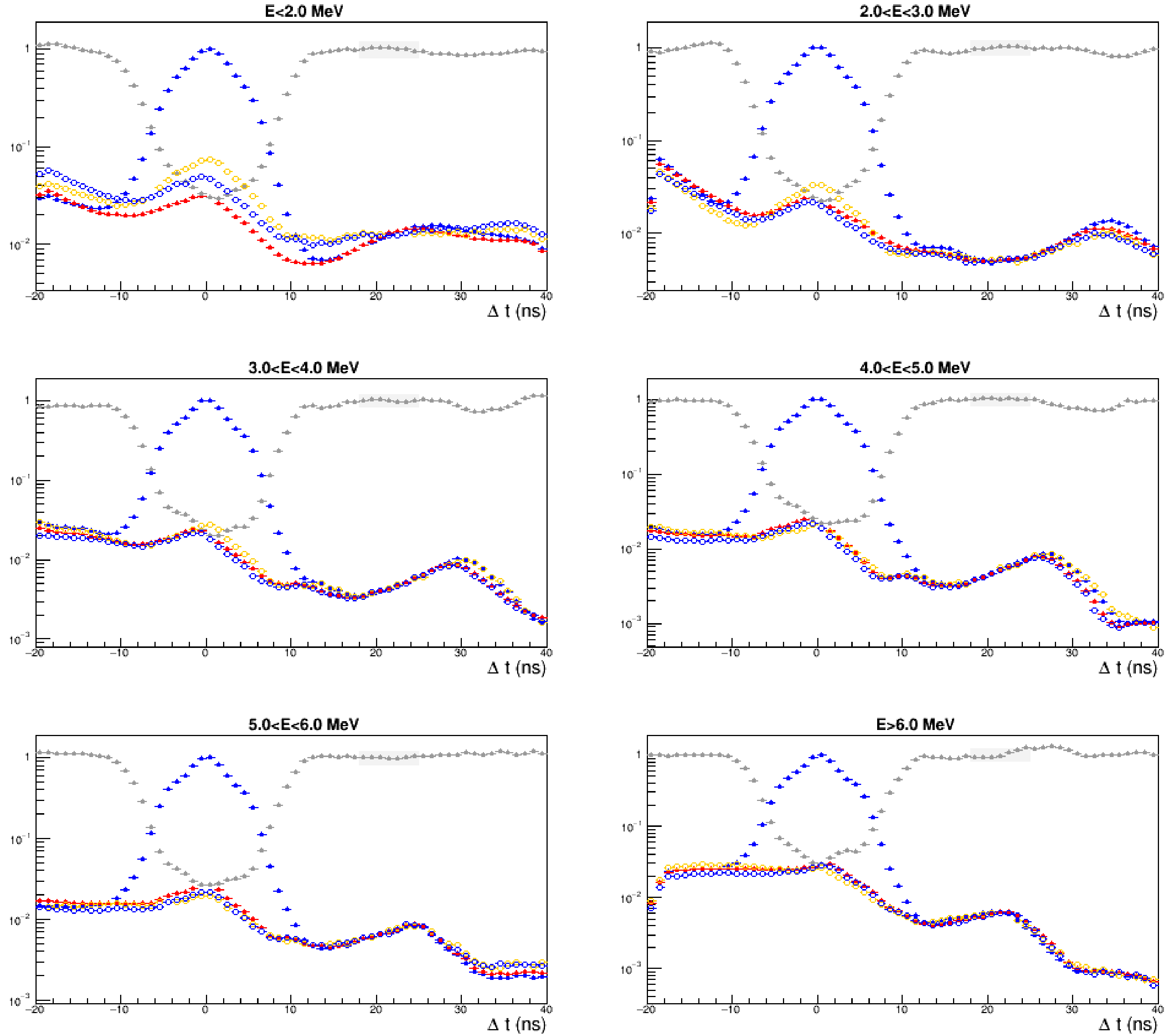
$$(\delta_{\mathrm{ADC}} < -0.5) \wedge (\delta_{ADC} < 8.5 - 1.5 * T_{kin})$$



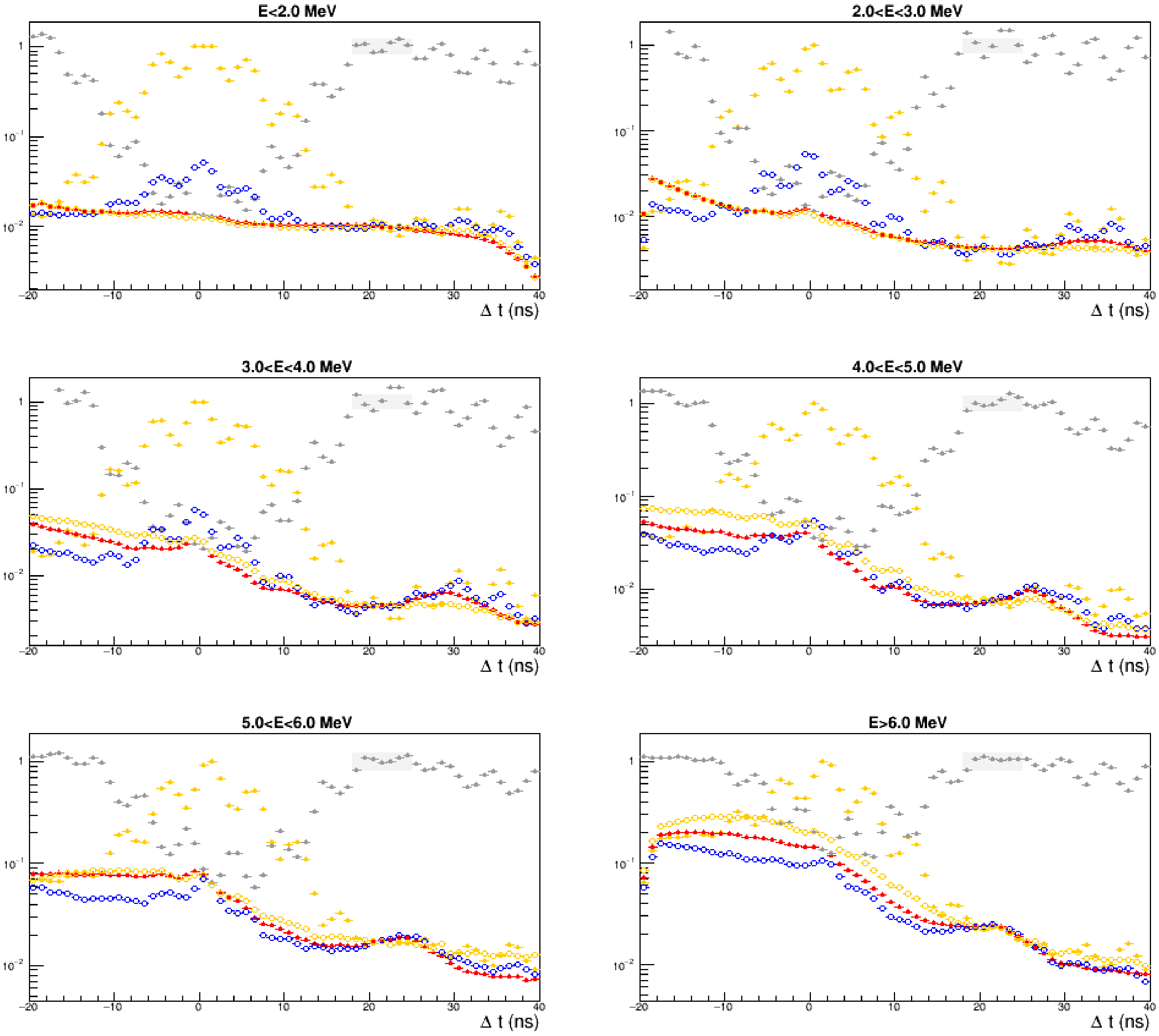
$\vec{p} + p$, yellow beam



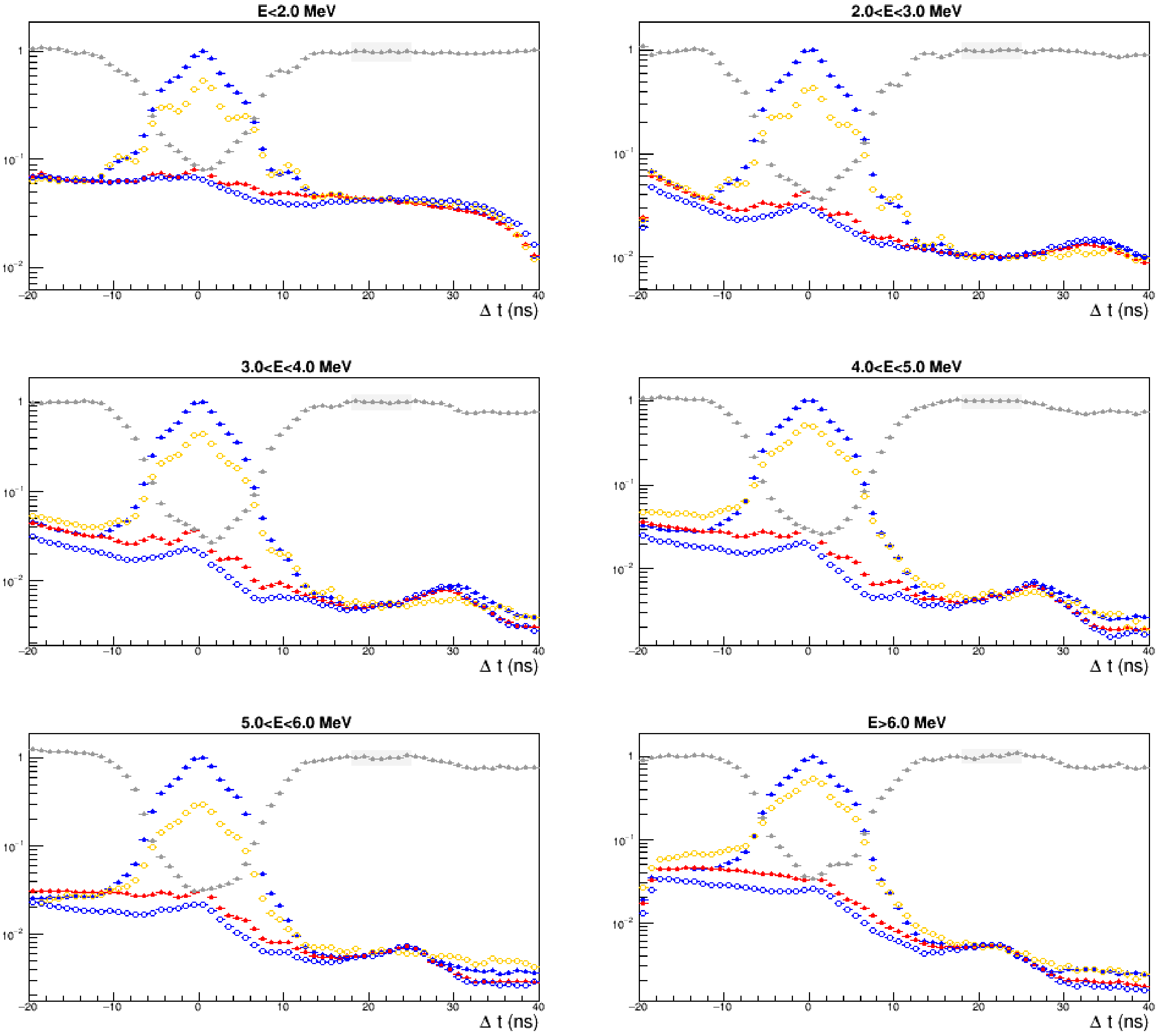
$\vec{p} + p$, blue beam



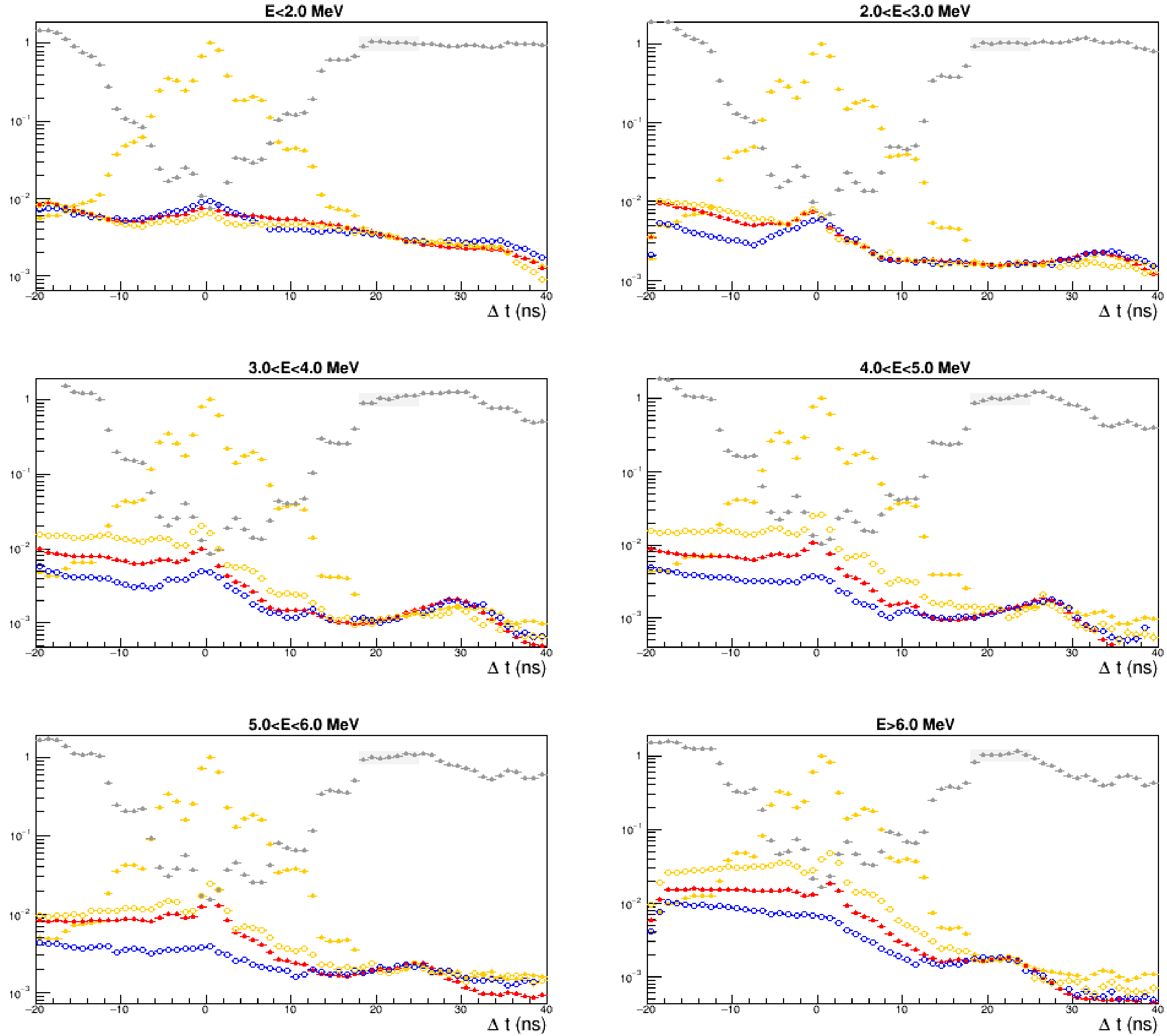
$\vec{p} + Au$, yellow beam



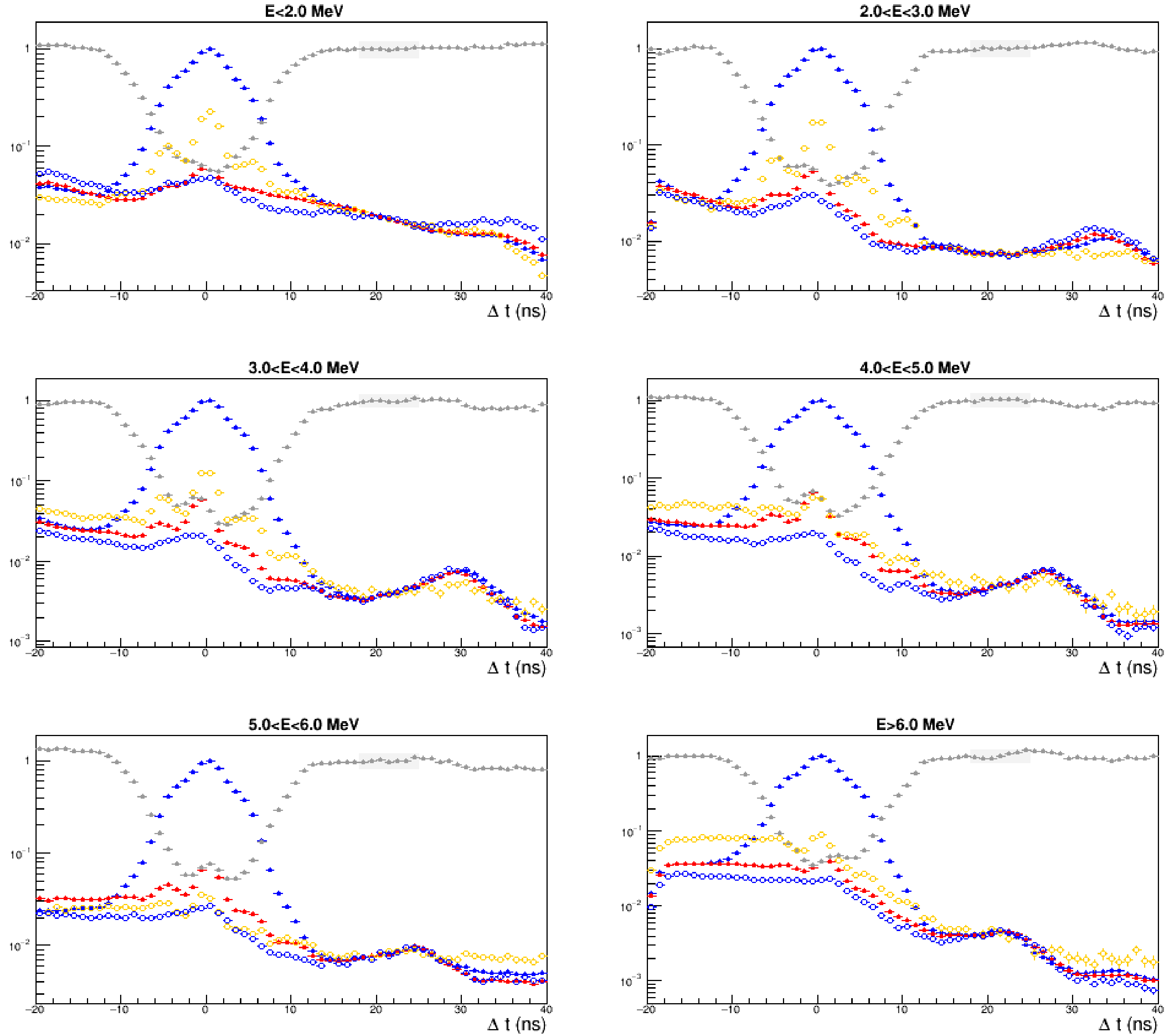
$\vec{p} + Au$, blue beam



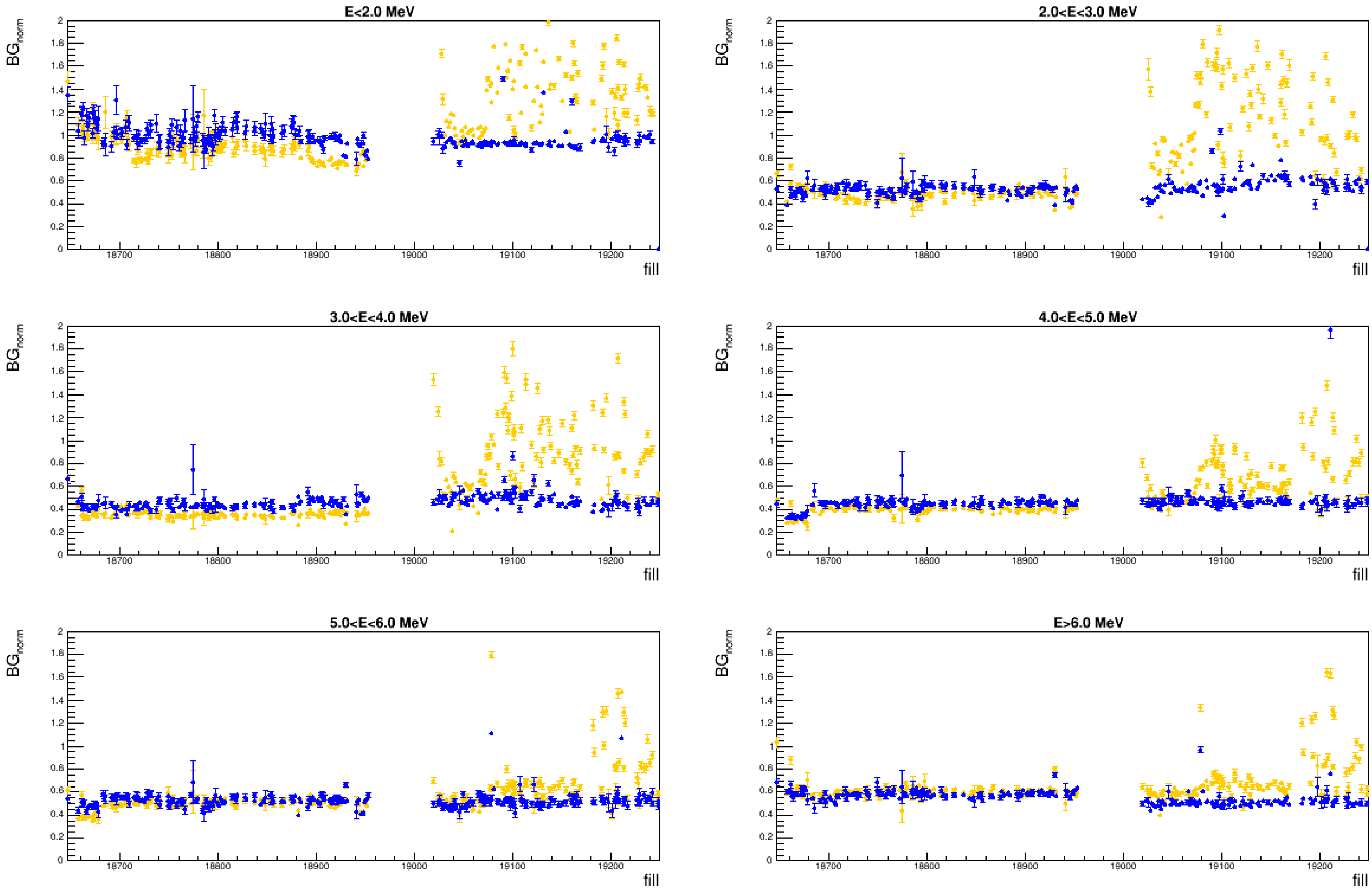
$\vec{p} + Al$, yellow beam



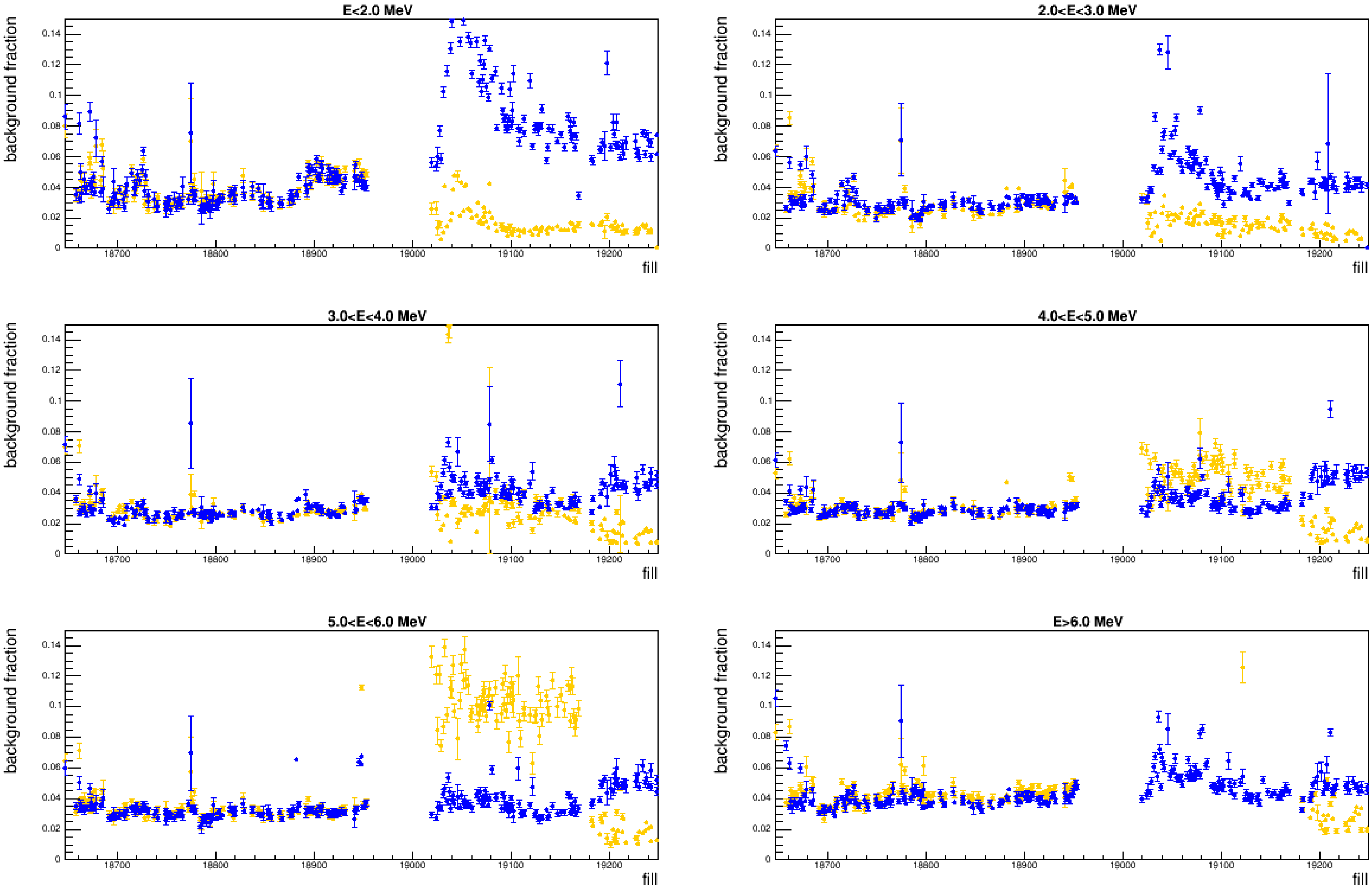
$\vec{p} + Al$, blue beam



Background Normalization ($18 < \Delta t < 25$ ns)

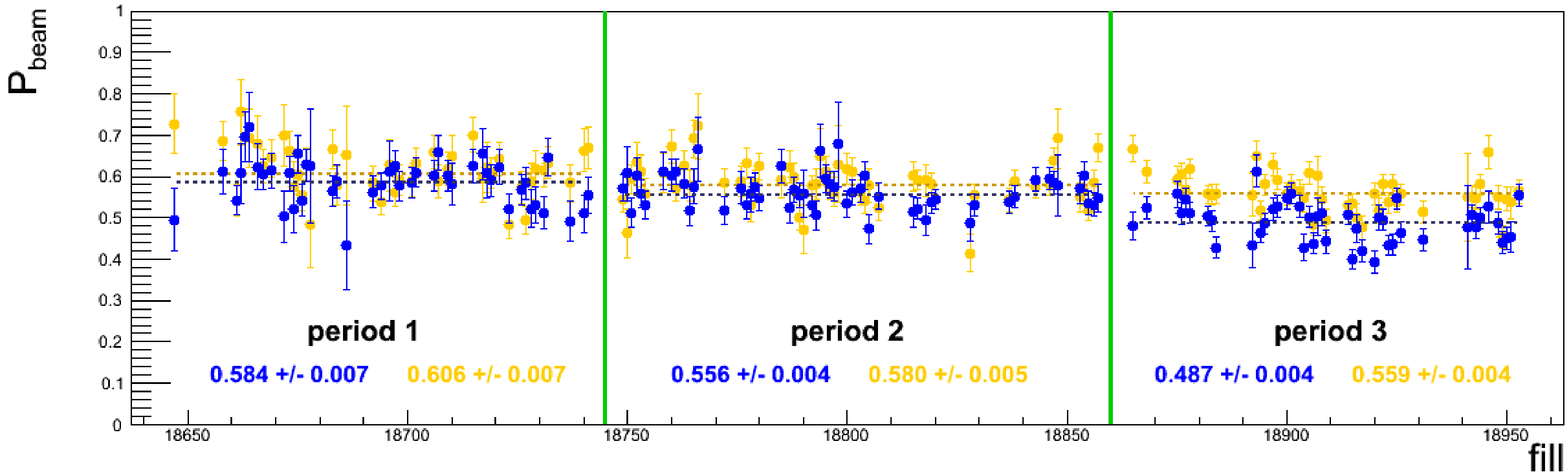


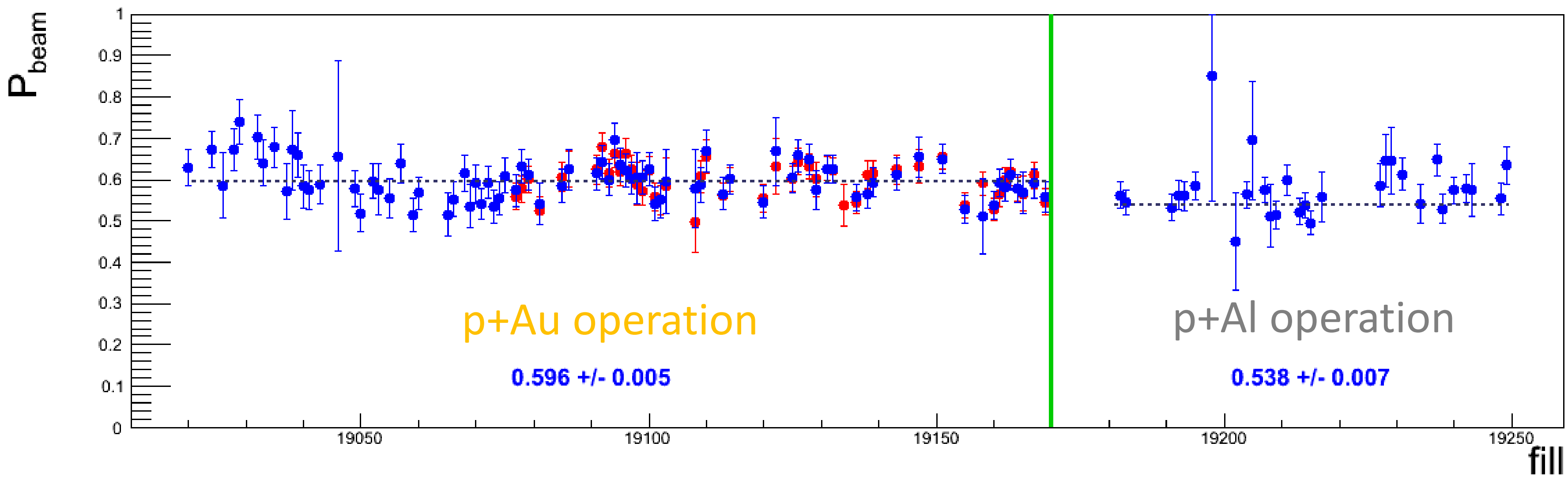
Background Fraction ($|\Delta t| < 5$ ns)



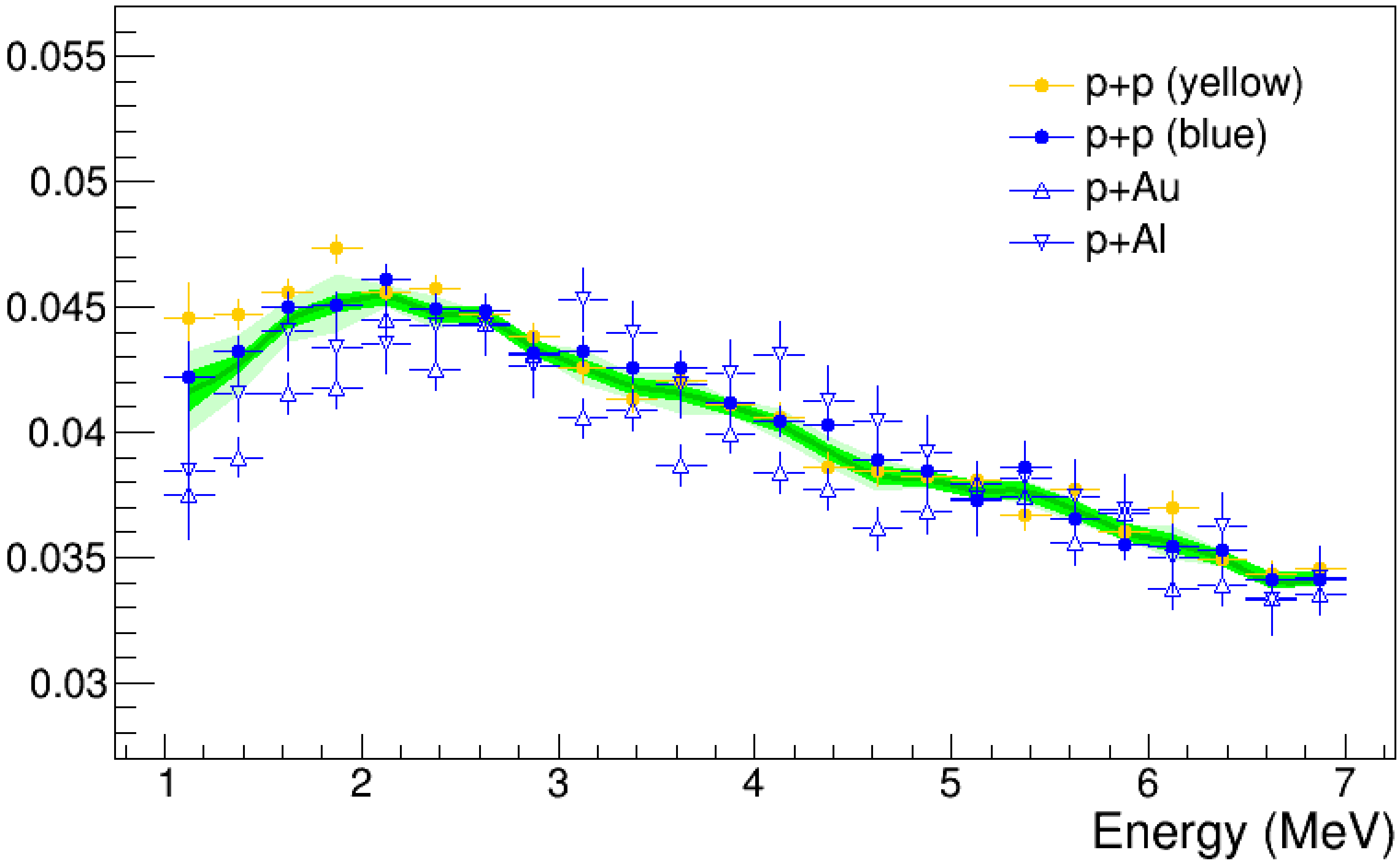
Beam Polarizations

Online results from 2015, no background correction included





A_N in Elastic $\vec{p} + p$ Scattering



Noise threshold cut: 0.20 for $p + p$, 0.15 for $p + A$

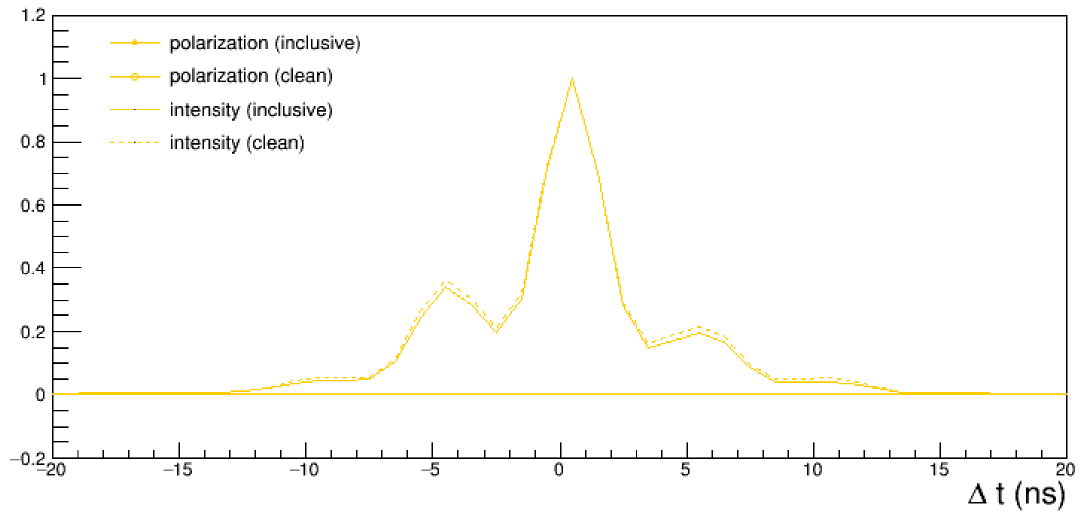
p+A may still have some issues with high background fractions and changing beam conditions

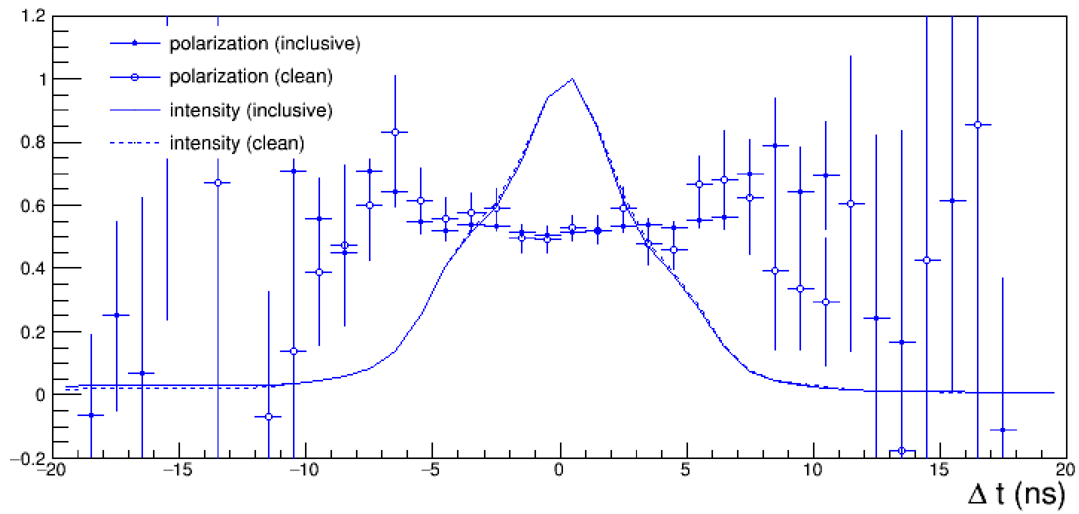
Summary p+Al

Beam polarizations

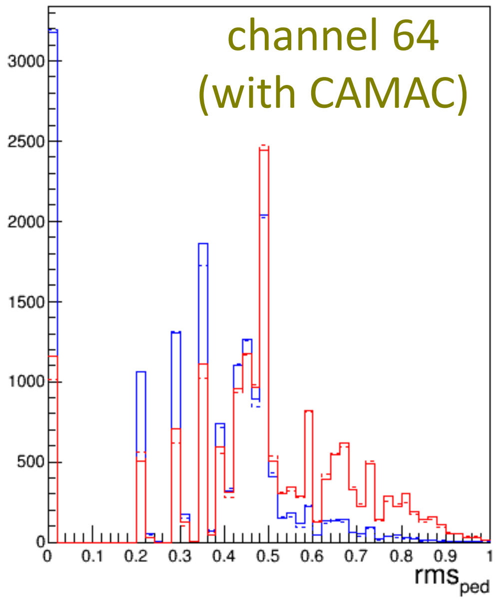
Full run 15 statistics, p+Al

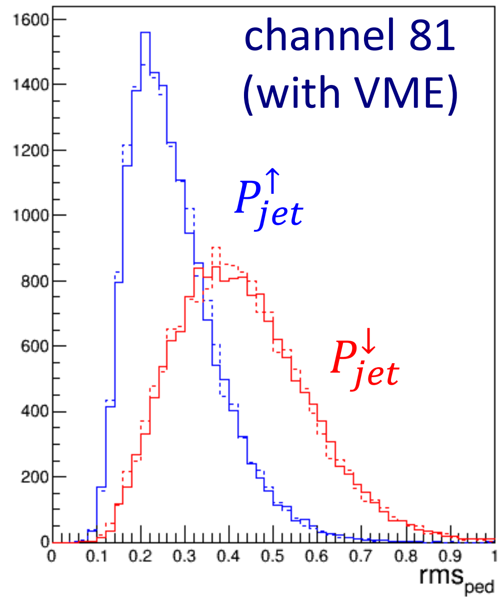
Comparison of inclusive and clean bunches





Pedestal Noise



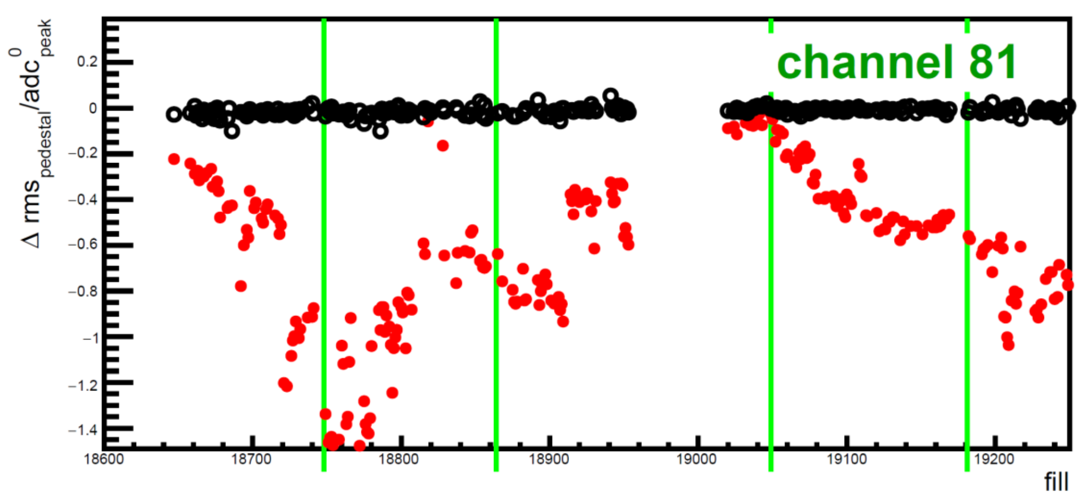


solid/dashed: $P_{beam}^{\uparrow}/P_{beam}^{\downarrow}$

The noise is mainly on one side of the detector (outside).

It changes the waveform quality (slope) for low energies and leads to asymmetric loss of events.

$\langle rms_{ped}^{\uparrow}\rangle - \langle rms_{ped}^{\downarrow}\rangle$



(*) can use a fit for VME data, but resolution of CAMAC is too small

Polarization Decay & Profile