Absolute Polarization Measurement at RHIC in the Coulomb Nuclear Interference Region

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DNP 2006
Nashville, Tennessee
October 27, 2006

Polarized Protons in RHIC

TANSTAAFL !!! [(x)]

polarimeters: *two* Carbon ⊕ *one* Jet

fast measurements with fiber targets
needs normalization

normalization with polarized gas jet target
slow measurement

[(x)] ***R. Heinlein***

Polarization Measurement

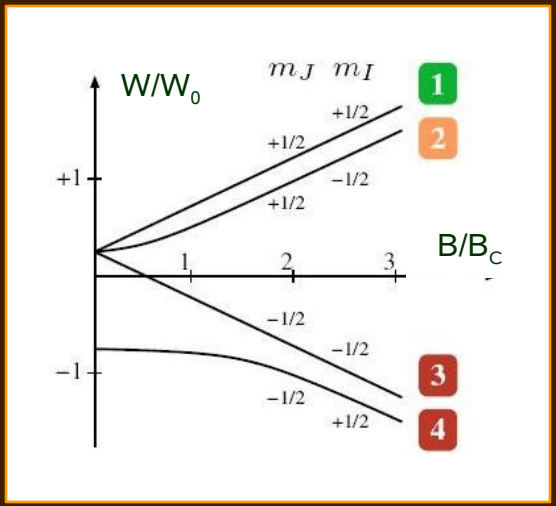
Rabi spectrometer

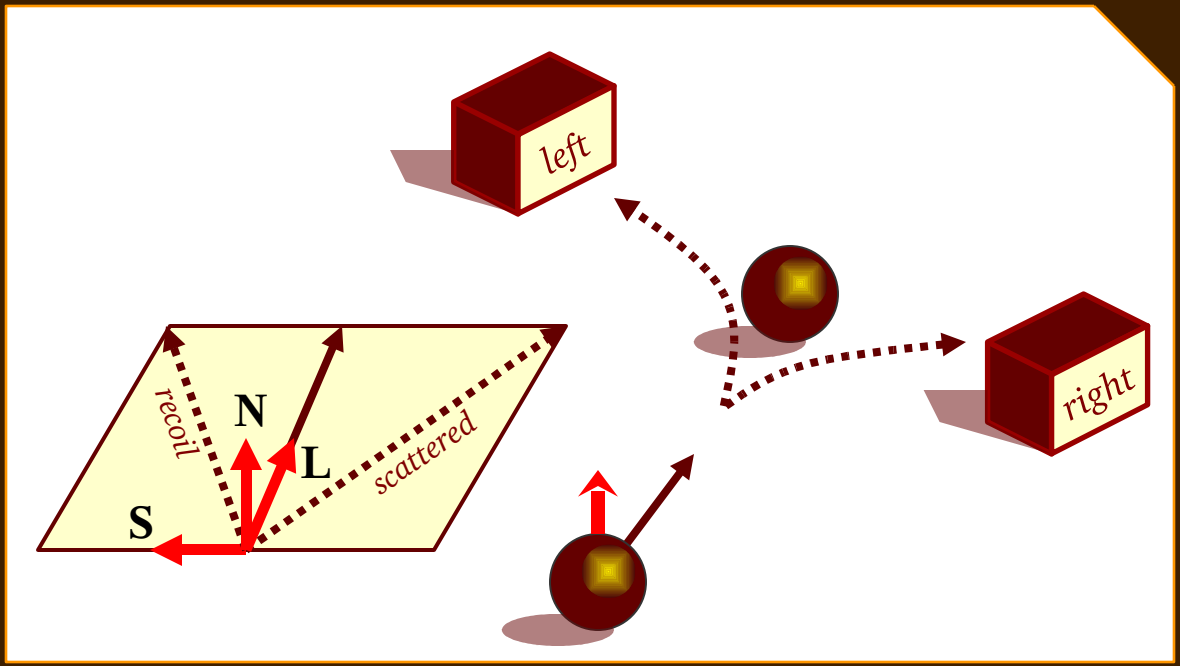
hydrogen hyperfine structure

Scattering process

elastic proton-proton, proton-Carbon, etc.

$$\varepsilon = A_N \cdot P_N$$





CNI

Coulomb Nuclear Interference

maximum A_N at small t

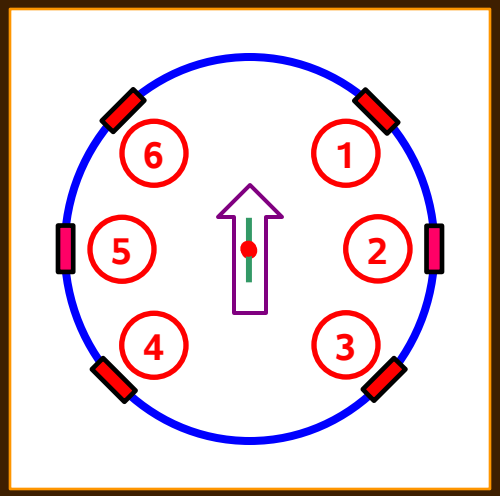
EM spin flip amplitude

Polarimeter Setup

Carbon Polarimeters

one for each RHIC beam

(6 x 12) = 72 silicon strips



recoil Carbon

400 keV < T_R < 900 keV

beam asymmetry: 123-456

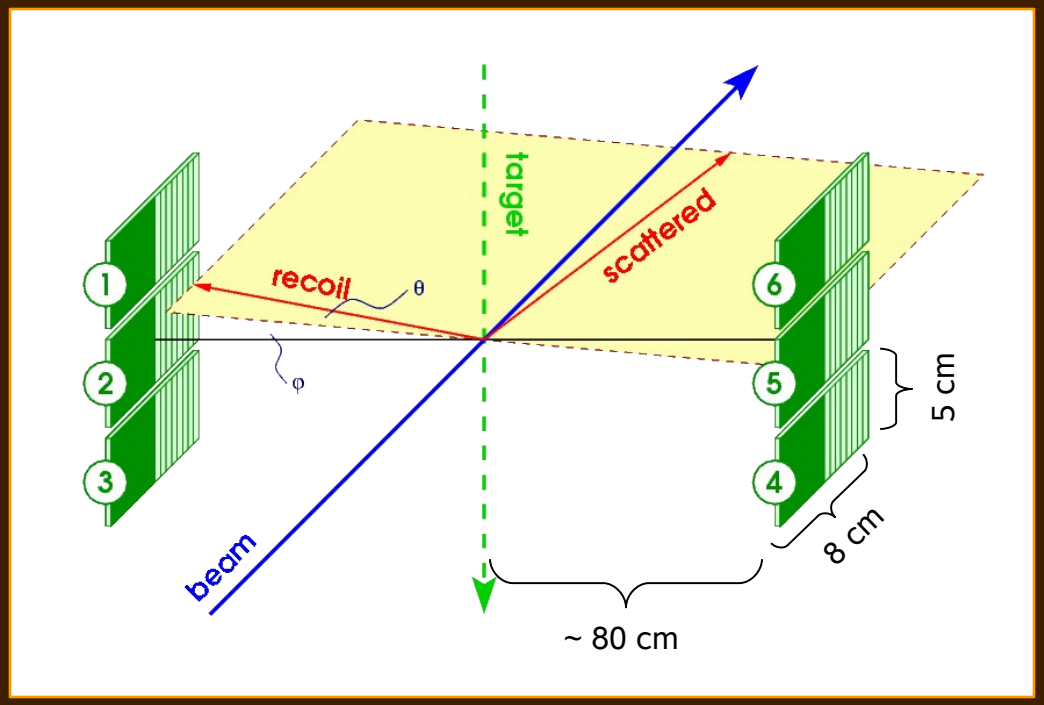
radial asymmetry: 16-34

cross asymmetry: 36-14

Jet Polarimeter

one for both RHIC beams

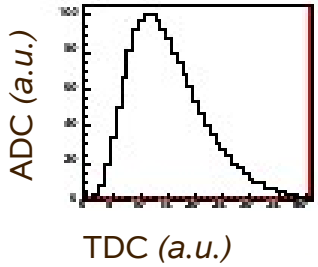
(6 x 2 x 8) = 96 silicon strips



$$\left.\begin{aligned} \varepsilon_{beam} &= A_N \cdot P_{beam} \\ \varepsilon_{target} &= -A_N \cdot P_{target} \end{aligned}\right\} \quad P_{beam} = -\frac{\varepsilon_{beam}}{\varepsilon_{target}} \cdot P_{target}$$

Recoil Particle Identification

a typical waveform



FPGA

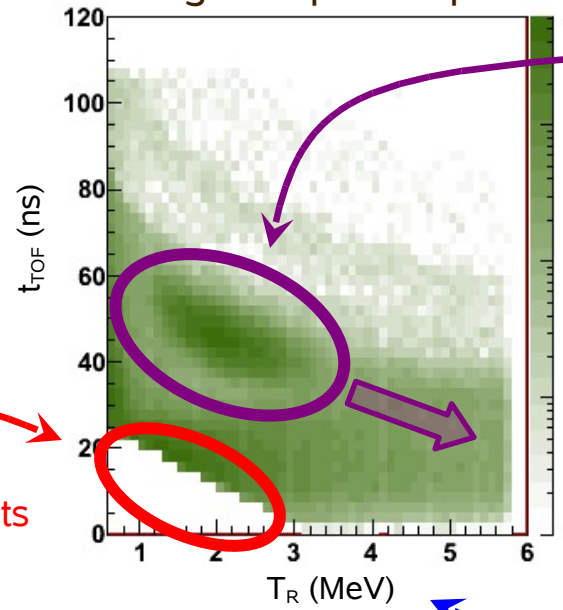
onboard memory

DAQ PC

single strip example

TDC
¼ rise time

scale 1.19 ns



recoil protons
from elastic scattering

$$m_P = 2T_R\left(\frac{t_{TOF}}{d(\vartheta)}\right)^2$$

prompt events
(large yield,
filtered)

ADC
peak *or* integral

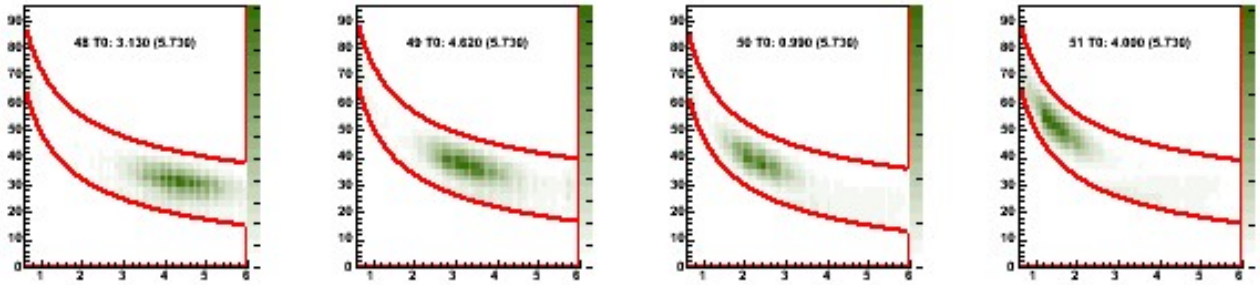
calibration
Am (5.486 MeV)
Gd (3.183 MeV)

T_R-ϑ dependence

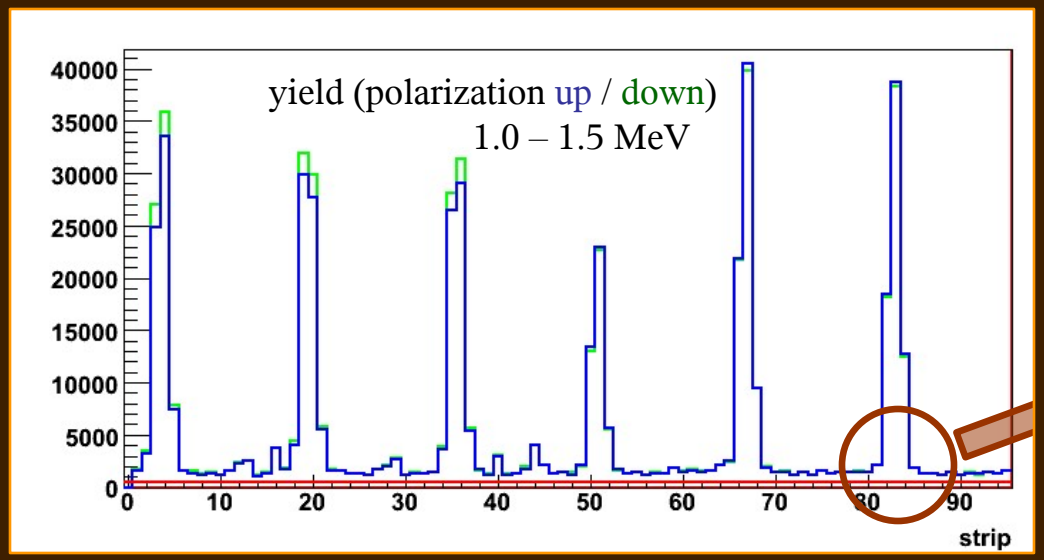
same axis scales as above
(linear z-scale)

T_0 alignment

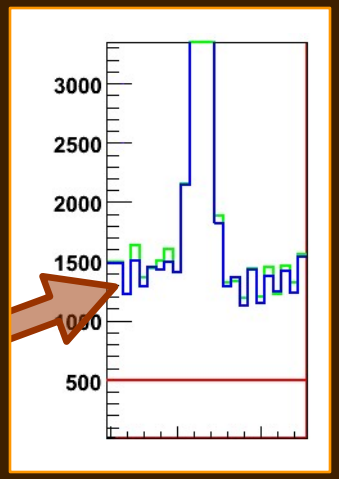
2σ-cut



Background Contributions



beamgas background:

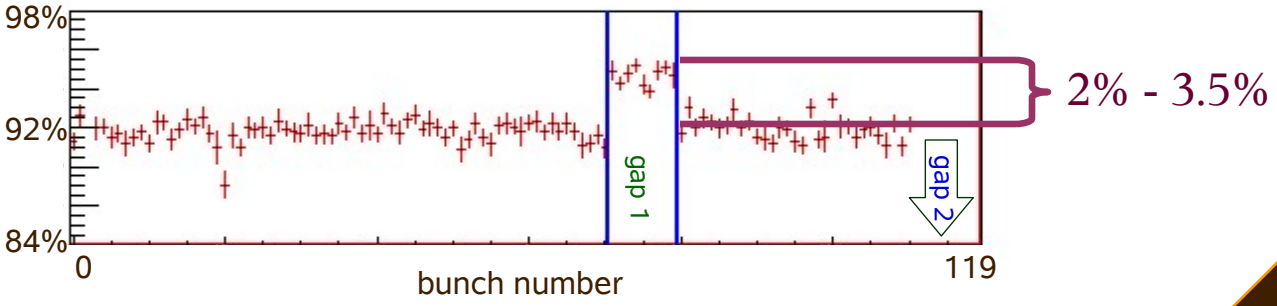


empty target runs normalized with beam intensities

background yield:
2.4% - 3.4%
(0.3 – 0.5 of total bg.)

abort gaps: (unfilled bunches)
prompt background contribution from displaced beam

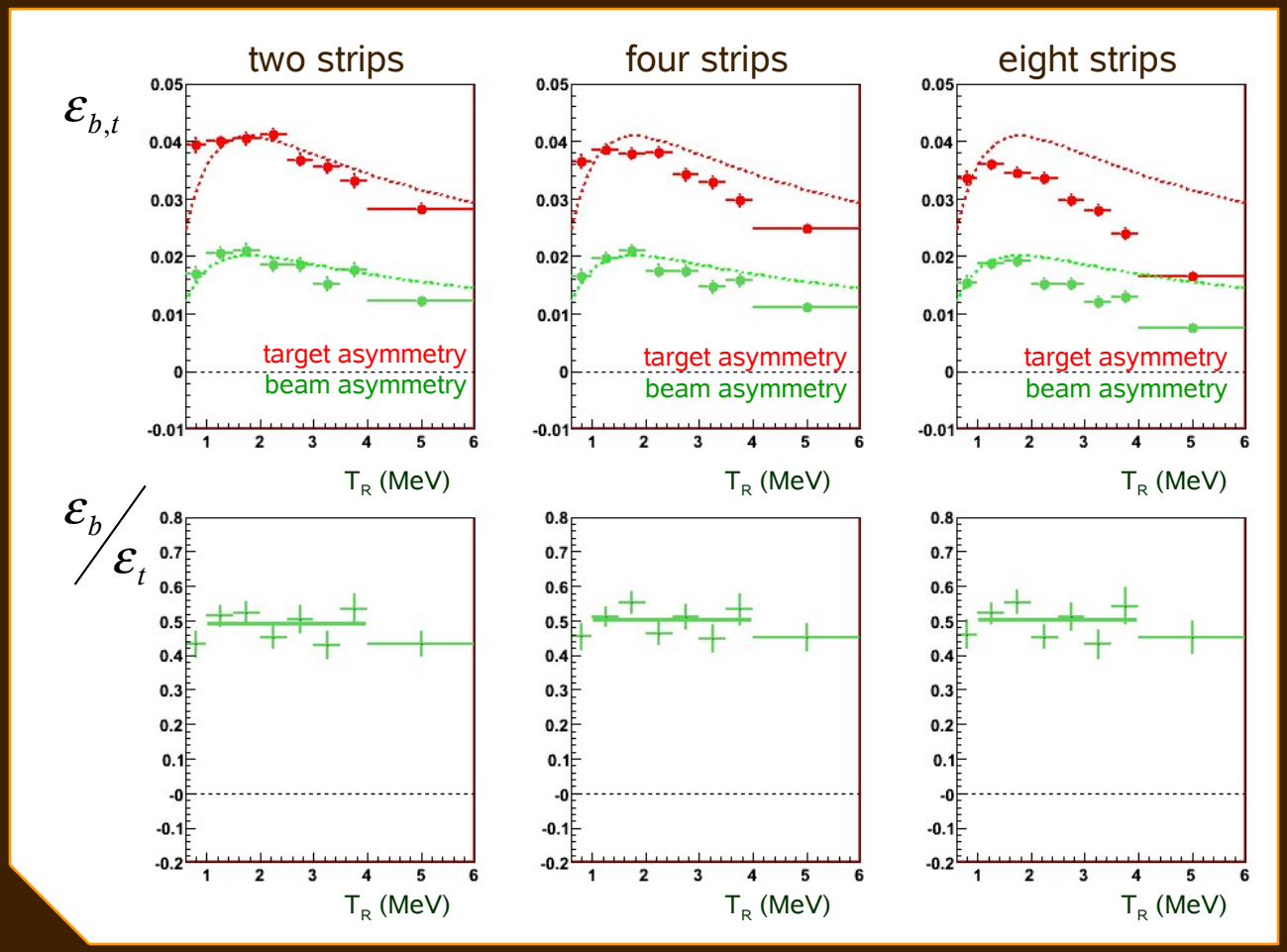
$$\frac{N_{signal} - N_{background}}{N_{signal}}$$



Systematic Error of Beam Polarization

elastic pp scattering signal:

two detector strips (out of eight) in each (of six) detector pads



background evenly distributed
4 strips → 2 x background
8 strips → 4 x background

asymmetries reflect the increase in background

asymmetry ratio is only weakly affected

background yield < 7%
$\Delta P \approx 1.1\%$

Summary

goal:

$$\frac{\Delta P_{beam}}{P_{beam}} = \underbrace{\left(\frac{\Delta P_{target}}{P_{target}}\right) \oplus \left(\frac{\Delta \varepsilon}{\varepsilon}\right)_{pp} \oplus \left(\frac{\Delta A_N}{A_N}\right)_{pC}} \oplus \left(\frac{\Delta \varepsilon}{\varepsilon}\right)_{pC} \leq 5-6\%$$

contains systematic errors of jet and pC normalization uncertainty for pC measurements

yellow beam	P	ΔP_{stat}
period 1	41.9 %	2.9 %
period 2	41.1 %	2.9 %
period 3	45.4 %	1.4 %

blue beam	P	ΔP_{stat}
period 1	43.8 %	2.8 %
period 2	48.2 %	3.8 %
period 3	49.4 %	1.7 %

- Polarizations close to 50% have been measured at RHIC in 2005.
- Systematic uncertainties have been estimated at 1.1%
- Finishing touches to offline Carbon measurements.

- Hadronic helicity amplitudes can be further constrained from data sets.
  H. Okada et al., Phys. Lett. B638, 450 (2006)

Thank You !!!

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(3) RIKEN BNL Research Center
(4) Yale University
(5) University of Wisconsin, Madison
(6) RIKEN
(7) University of Erlangen
(8) Kyoto University
(9) Indiana University, Bloomington

Asymmetry Determination

$$\varepsilon = \frac{\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} - \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}}{\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} + \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}} = A_N \cdot P$$

formal description in terms of
<u>helicity amplitudes</u>

$$A_N \approx C_1 \Phi_{flip}^{em\,*} \Phi_{non-flip}^{had} + C_2 \Phi_{non-flip}^{em\,*} \Phi_{flip}^{had}$$

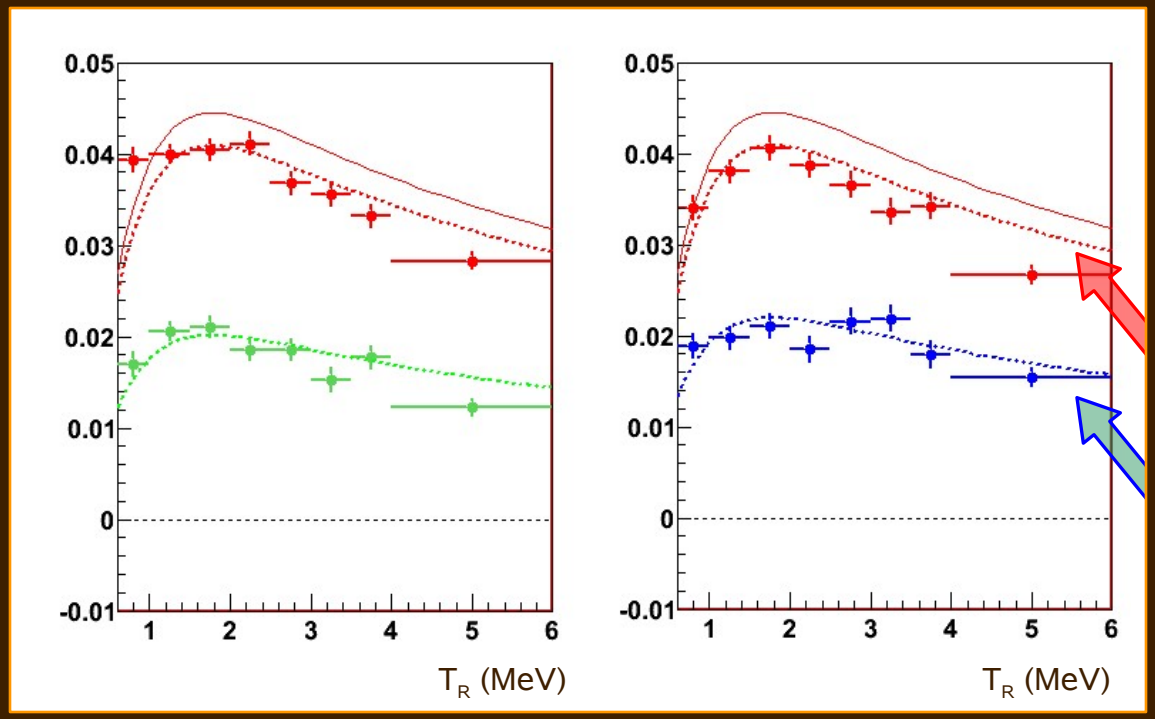
$$\Phi_1 = \langle ++|M|++\rangle$$

$$\Phi_2 = \langle ++|M|--\rangle$$

$$\Phi_3 = \langle +-|M|+-\rangle$$

$$\Phi_4 = \langle +-|M|-+\rangle$$

$$\Phi_5 = \langle ++|M|+-\rangle$$



scaled with target polarization:
96% atomic / *92% effective*

scaled with asymmetry ratio:
beam / target
(1 MeV – 4 MeV)

Systematic Error on Beam Polarization

determination of beam polarization: $P_{beam} = -P_{target} \cdot \frac{\varepsilon_{beam}}{\varepsilon_{target}}$

simple asymmetries:
for cross checks

$$\varepsilon = \left.\frac{N_{left} - N_{right}}{N_{left} + N_{right}}\right|_{\uparrow,\downarrow}$$

(creates acceptance asymmetry)

$$\varepsilon = \left.\frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}\right|_{left,right}$$

(creates luminosity asymmetry)

(s)ignal *and* (b)ackground yields: $N = N^{(s)} + N^{(b)}$
background 5% - 7%

$N^{(b)}$ not polarization dependent

$$P_{beam} = P_{target} \cdot \frac{\left[N_{\uparrow}^{(s)} - N_{\downarrow}^{(s)}\right]_{beam}}{\left[N_{\uparrow}^{(s)} - N_{\downarrow}^{(s)}\right]_{target}} = P_{target} \cdot \frac{\left[N_{\uparrow} - N_{\downarrow}\right]_{beam}}{\left[N_{\uparrow} - N_{\downarrow}\right]_{target}}$$

$$\varepsilon = \frac{\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} - \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}}{\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} + \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}}$$

$$\left[N_{left}^{\uparrow} + N_{left}^{\downarrow} + N_{right}^{\uparrow} + N_{right}^{\downarrow}\right]_{beam} = \left[N_{left}^{\uparrow} + N_{left}^{\downarrow} + N_{right}^{\uparrow} + N_{right}^{\downarrow}\right]_{target}$$

$$\left[\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} + \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}\right]_{beam} \neq \left[\sqrt{N_{left}^{\uparrow} \cdot N_{right}^{\downarrow}} + \sqrt{N_{left}^{\downarrow} \cdot N_{right}^{\uparrow}}\right]_{target}$$

⇒ background contributes in second order to determination of beam polarization