Relative Polarization Measurements of Proton Beams Using Thin Carbon Targets at RHIC

Grant Webb

Brookhaven National Laboratory

for the RHIC Polarimetry Group

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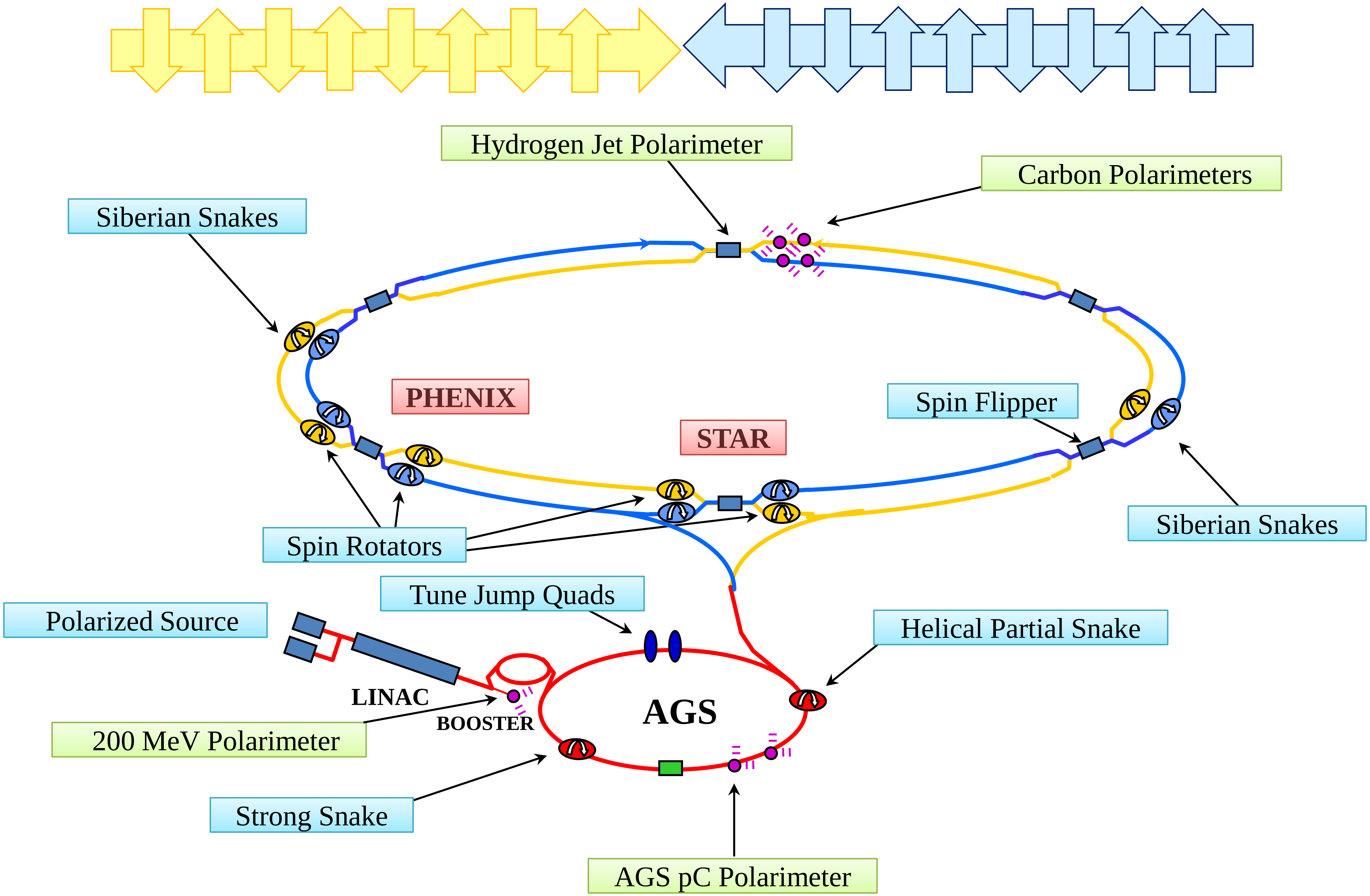
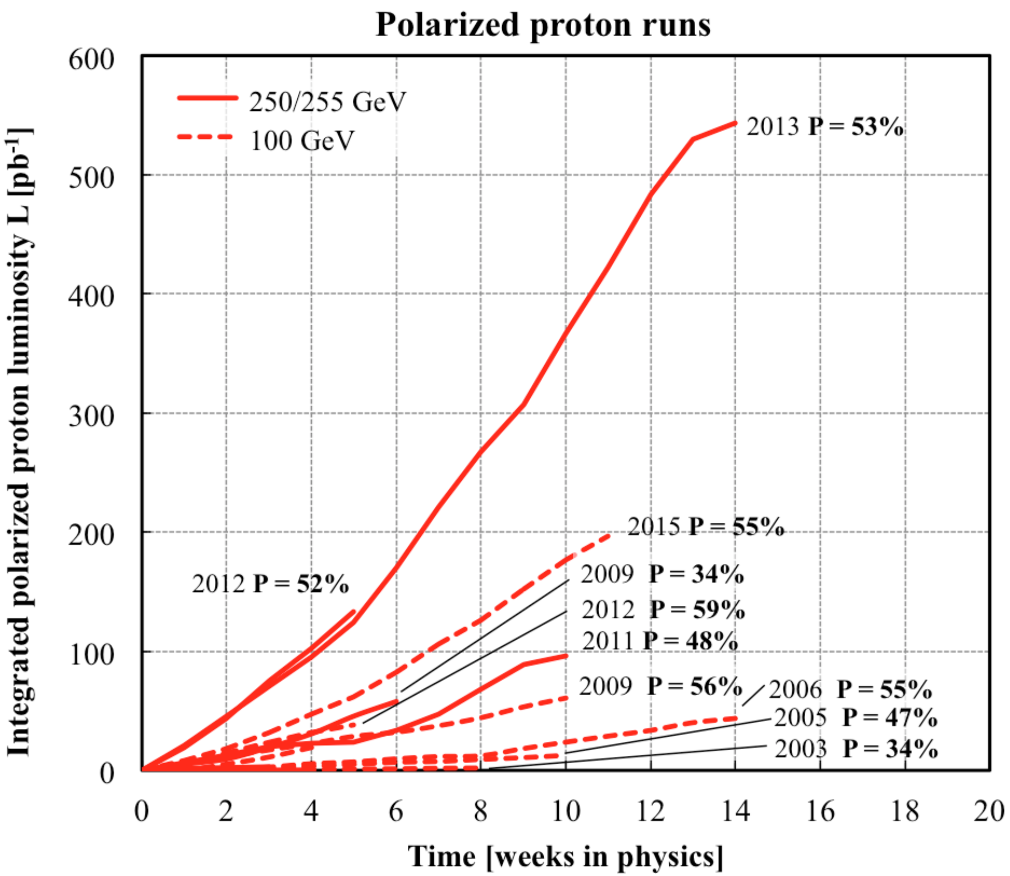
The Relativistic Heavy Ion Collider



Recent RHIC Performance

- Each year RHIC has had steady luminosity improvements



- 2015
  - P = 55.8% at √s = 100 GeV
  - P = 55.2%
- 2013
  - P = 52.3% at √s = 255 GeV
  - P = 54.4%
- 2012
  - P = 57.0% at √s = 100 GeV
  - P = 55.8%
  - P = 49.9% at √s = 255 GeV
  - P = 52.2%
- 2011
  - P = 47.0% at √s = 250 GeV
  - P = 52.2%
- 2009
  - P = 55.6% at √s = 100 GeV
  - P = 54.0%
  - P = 37.8% at √s = 250 GeV
  - P = 38.9%

RHIC Polarimetry

Polarized hydrogen Jet Polarimeter (HJet)

Source of absolute polarization (normalization of other polarimeters)

Slow (low rates ⇒ needs looong time to get precise measurements)

Proton-Carbon Polarimeter (pC) @ RHIC and AGS

Very fast ⇒ main polarization monitoring tool

Measures polarization lifetime and profile **(polarization is higher in beam center)**

Needs to be normalized to HJet

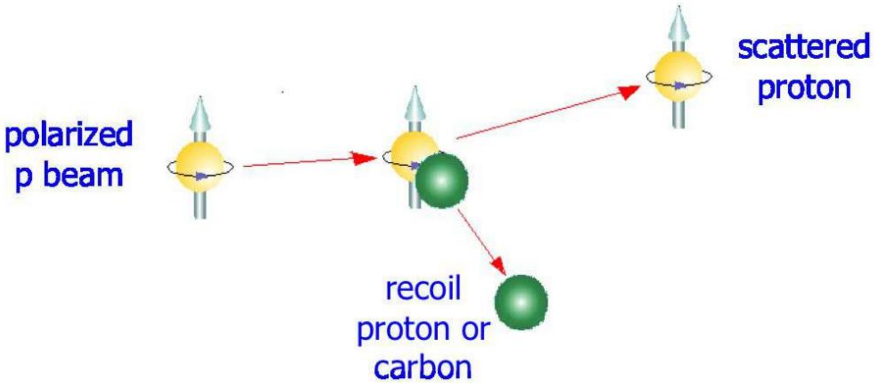
Local Polarimeters (in PHENIX and STAR experiments)

Defines spin direction in experimental area

Needs to be normalized to HJet

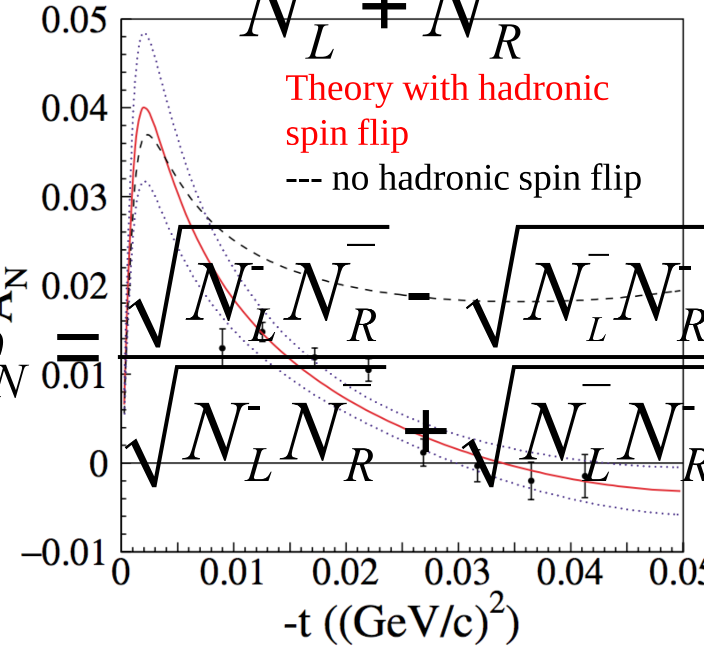
All of these systems are necessary for the proton beam polarization measurements and monitoring

CNI Polarimetry at RHIC



- The maximum analyzing power is expected in Coulomb-Nuclear Interference (CNI) region

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$

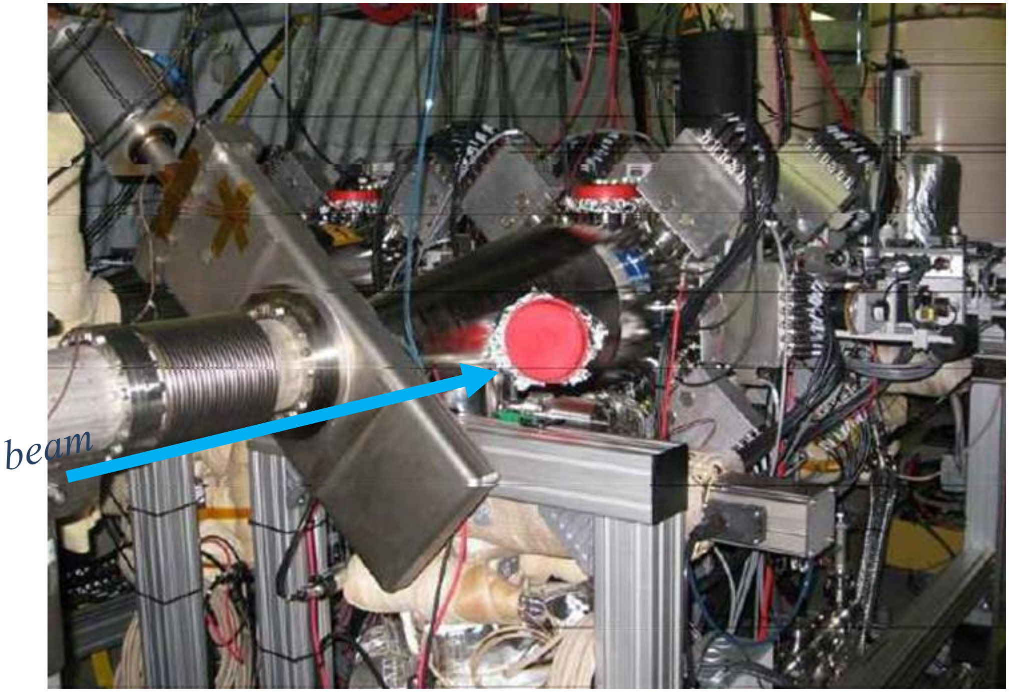


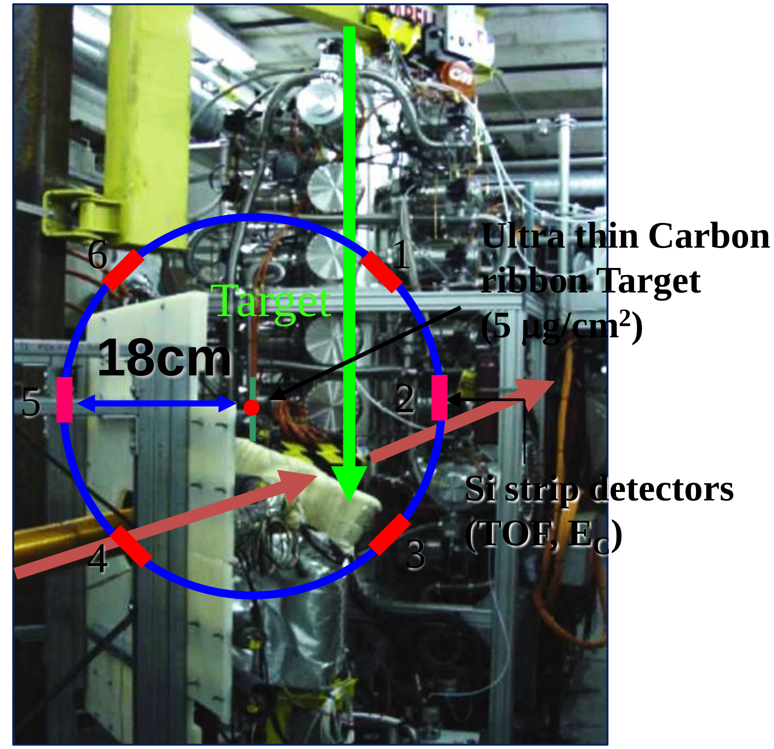
$$\varepsilon_N = \frac{\sqrt{N_L^{-} \bar{N}_R^{-}} - \sqrt{\bar{N}_L^{-} N_R^{-}}}{\sqrt{N_L^{-} N_R^{-}} + \sqrt{\bar{N}_L^{-} N_R^{-}}}$$

- Measured Polarization $P_{beam} = \dfrac{\varepsilon_N}{A_N^{pC}}$

- The analyzing power, A_N , **must be known**

Polarized Proton Beams





Carbon polarimeters

Two per ring

Fast measurement (3-4 measurements per RHIC store)

Each Polarimeter uses six vertical and six horizontal ultra thin carbon targets

normalization

Hydrogen jet polarimeter

Polarized target

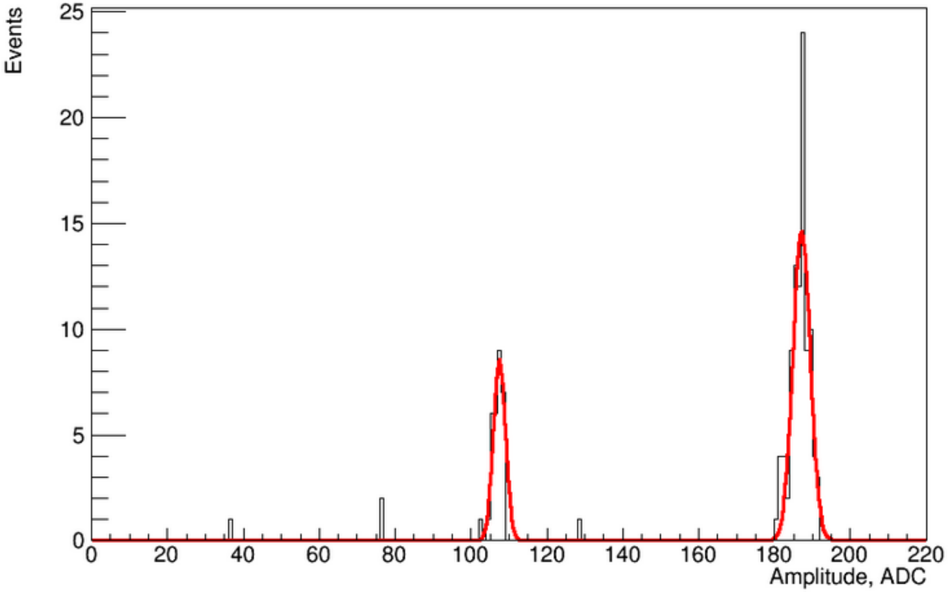
Continuous operation

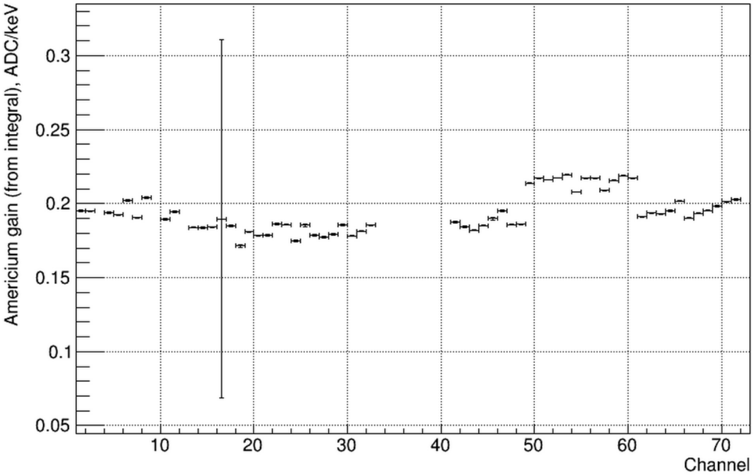
$\sigma \approx 5 - 8\%$ per fill

Beam polarization profile

Polarization decay (time dependence)

Silicon Strip Detectors and Calibrations

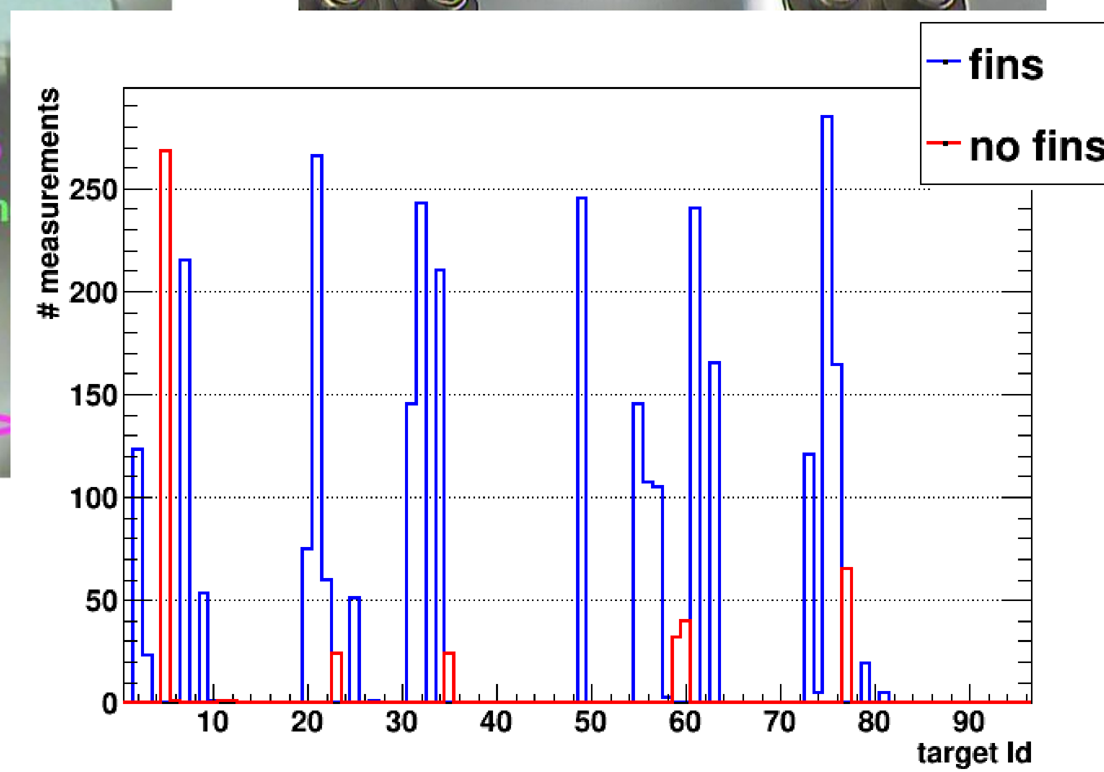




- Two α sources, Am(5.5 MeV) and Gd (3.3), used for energy calibration of detector
- Detectors are ≈ 20 cm from the beam in a vacuum chamber
- 2 mm good gain stability, coarse segmentation
- 1 mm poor gain stability (but monitored), fine segmentation

Hardware improvements in 2015

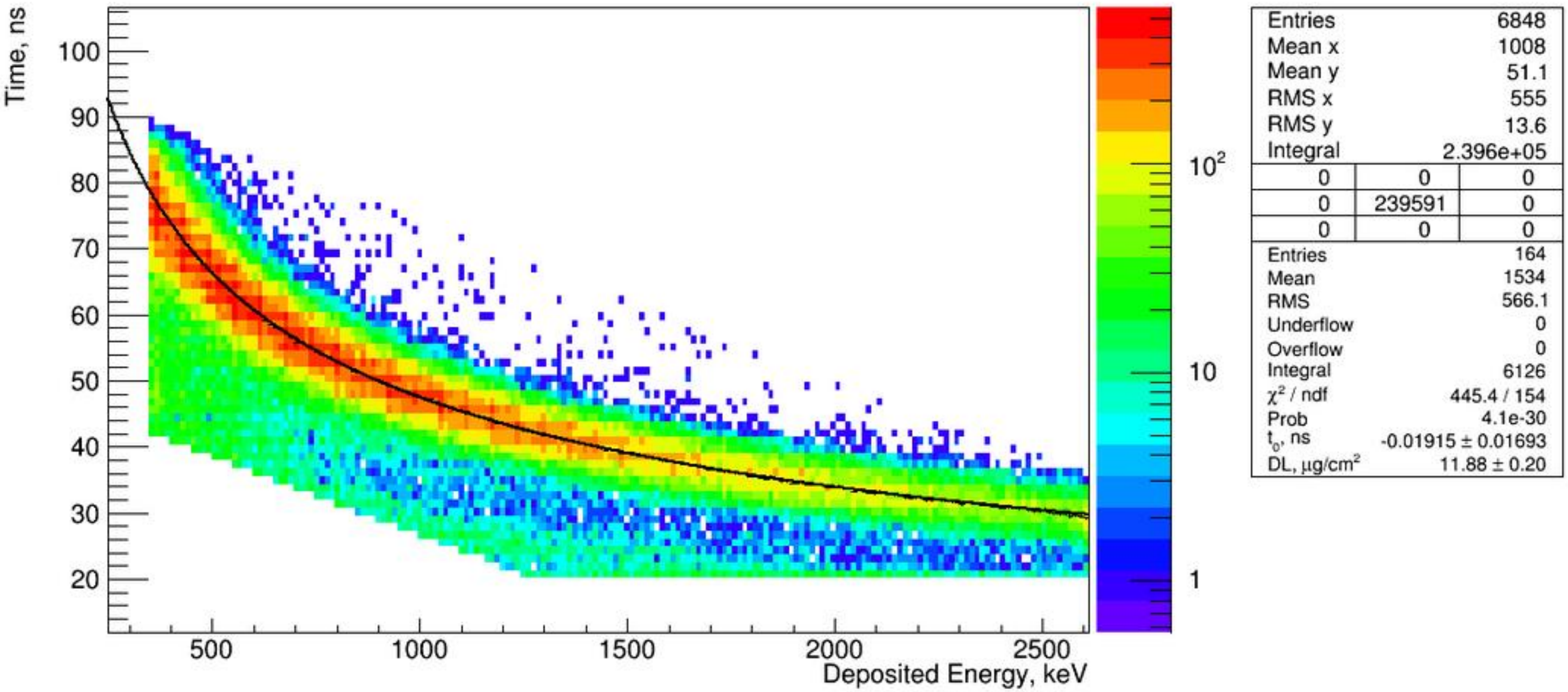
- Again use 2mm Si-detectors because of very good gain stability
- new target holders
  - EM simulation (J. Kewisch) showed beam charge induced high EM fields at target → frame attachment (lightning rod)
  - high fields ⇒ high current in target ⇒ heating
  - Such fins installed for 32 of 48 targets in 4 pC polarimeters (no room for fins other targets, hit chamber wall)



Targets survival

E.C. Aschenauer

Carbon Event Selection



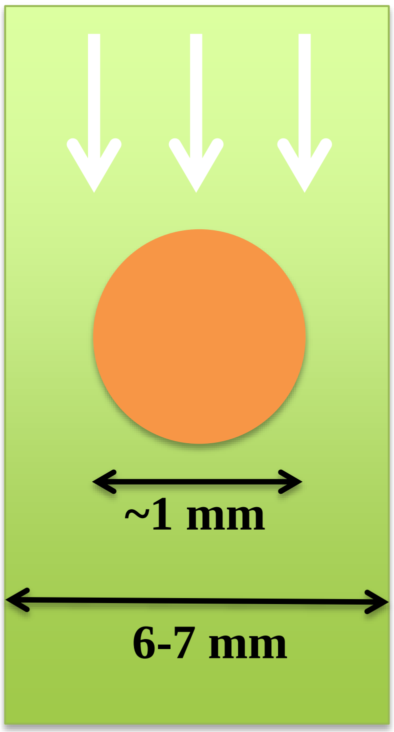
- The effective energy losses E_{loss} and time offset t_0 are determined from the kinematical fit to the banana-like band

$$E_{kin} = E_{meas} + E_{loss} = \frac{1}{2} M \times \frac{L^2}{\left(t_{meas} + t_0\right)^2}$$

- Carbon Events are selected within a Time-Energy window, 400 < T < 900 keV, optimized for minimal background

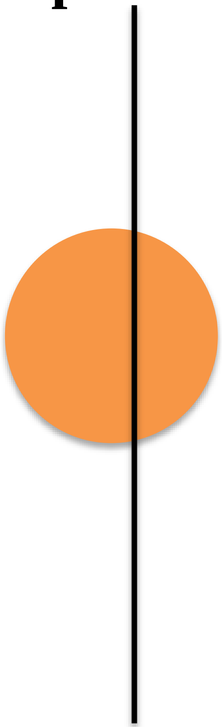
Beam Polarization Profile

H-Jet



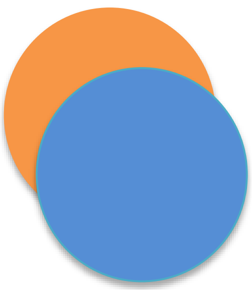
$$P = \frac{\int P(x,y)\, I(x,y)\, dxdy}{\int I(x,y)\, dxdy}$$

p-Carbon



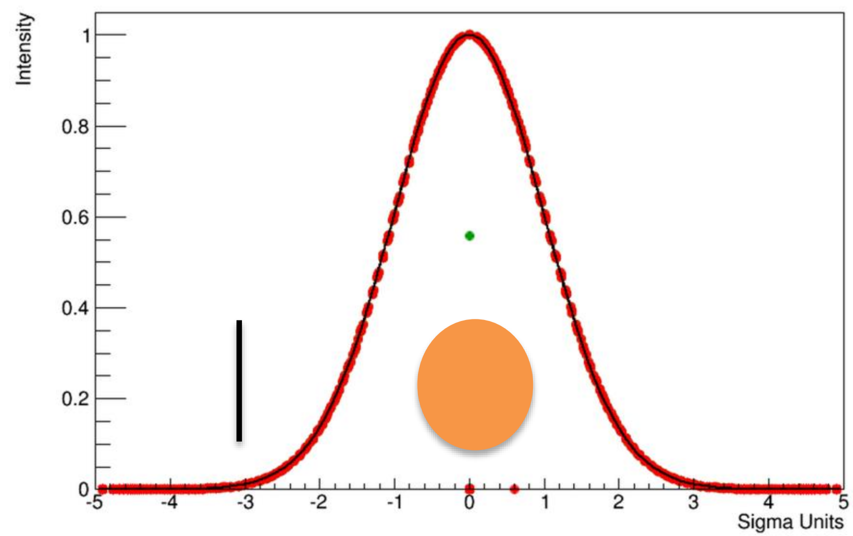
$$P_{sweep} = P$$

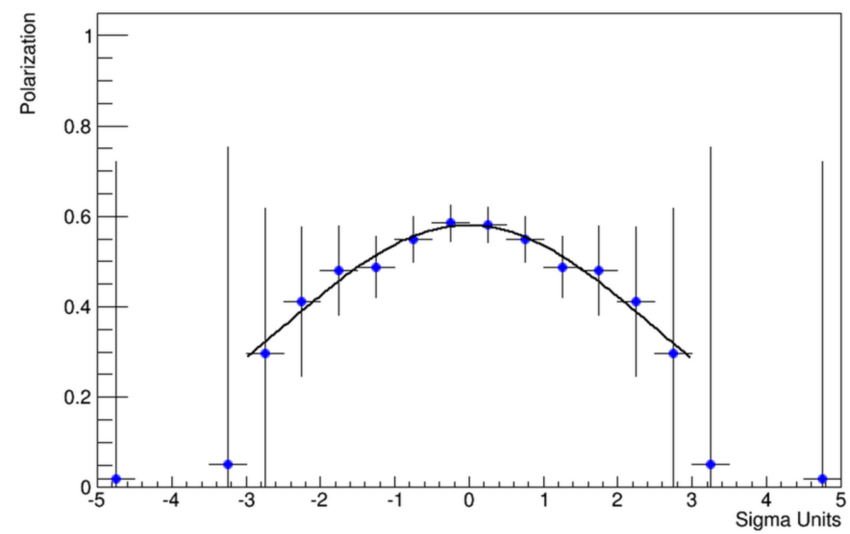
Beam Collisions

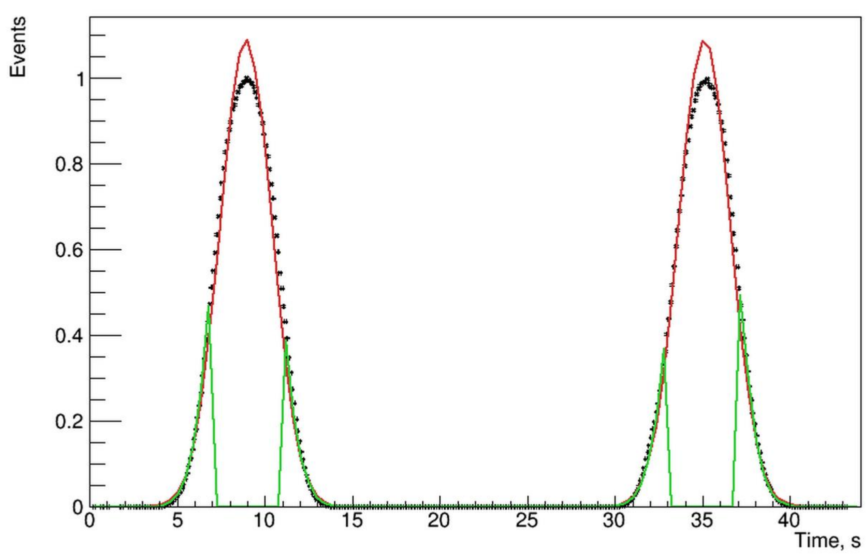


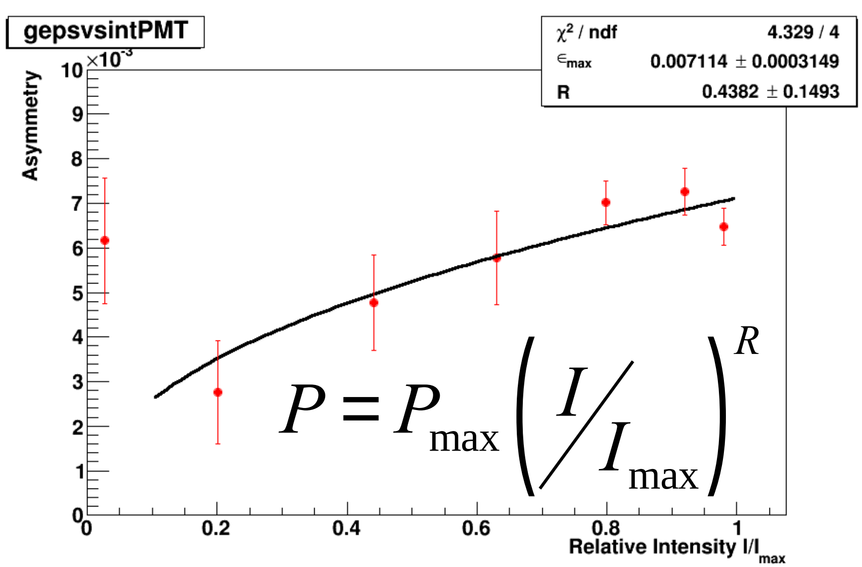
$$P_{coll} = \frac{\int P(x,y)\, I_1(x,y)\, I_2(x,y)\, dxdy}{\int I_1(x,y) I_2(x,y)\, dxdy}$$

Measuring Beam Polarization Profile

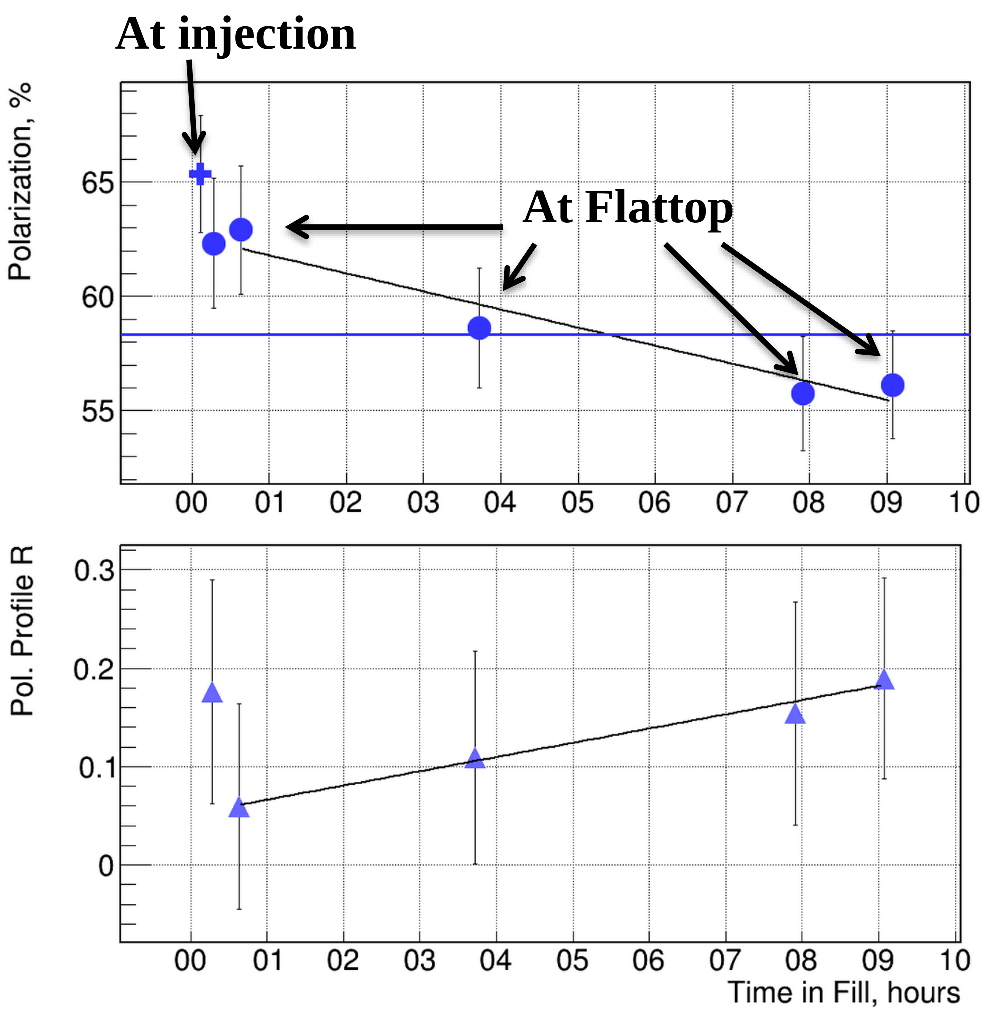






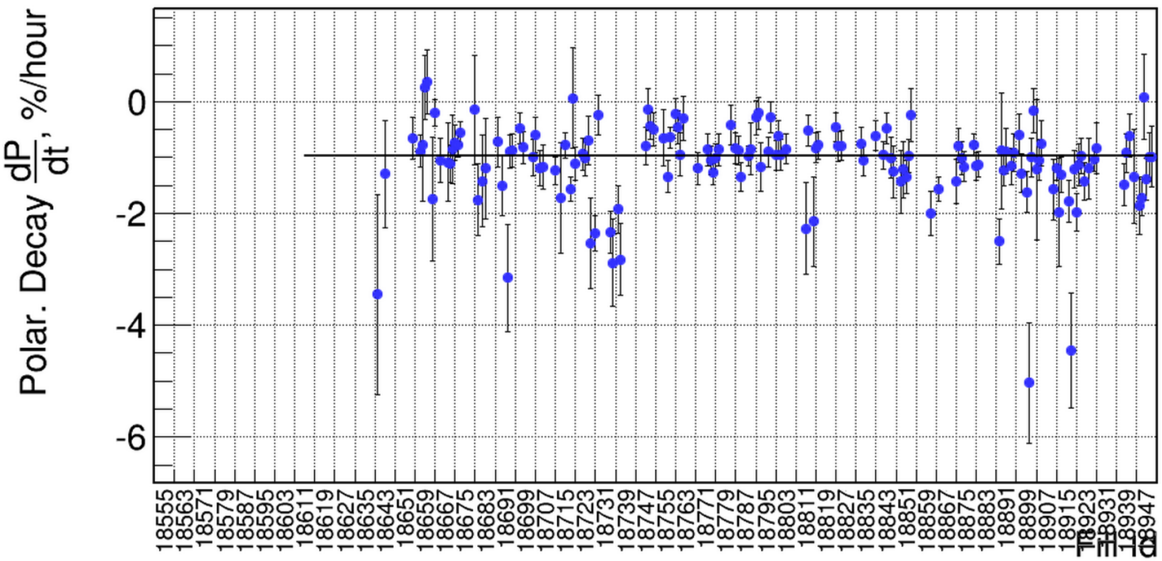


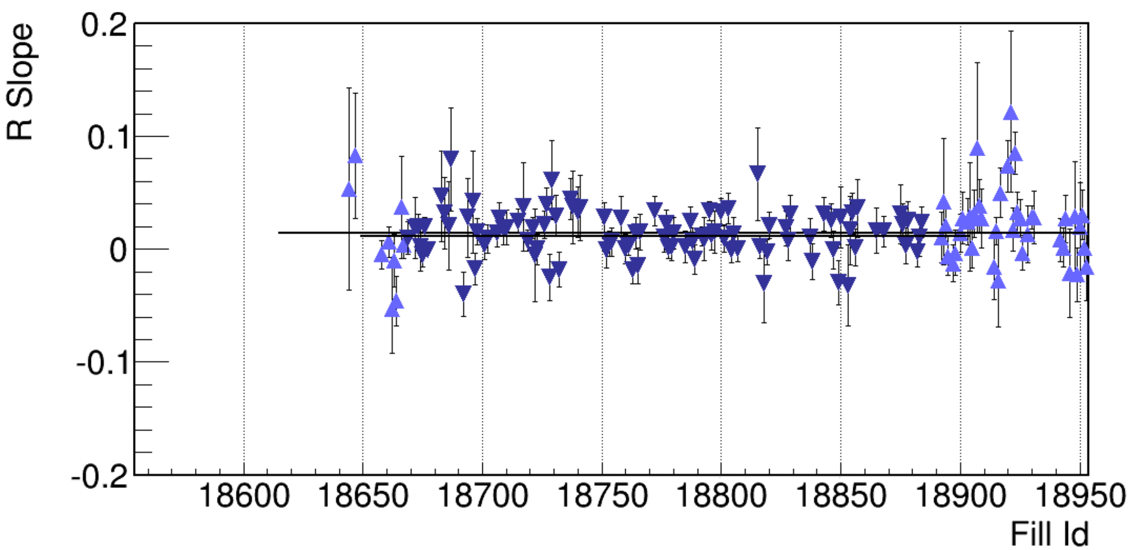
Polarization Loss in Fill



- During beam acceleration polarization is lost
- Polarization decreases while R increases
- Losses consistent with beam profile broadening
- RHIC experiments can use the dP/dt and P_0 to reweight individual fills according to their recorded luminosity

Polarization Loss in a Fill for Run 15





Linear approximation for polarization P and profile R in a fill:

$$P = P_0 + \frac{dP}{dt} t$$

$$R = R_0 + \frac{dR}{dt} t$$

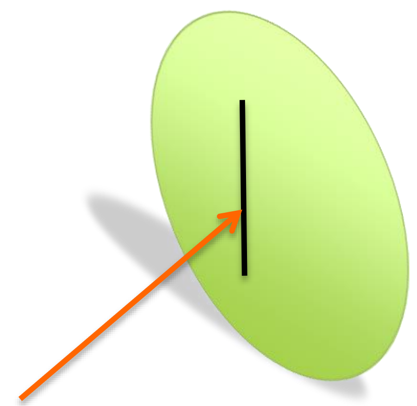
- Average change in P and R is :

$$\frac{dP}{dt} \sim -1.00 \pm 0.03\% \text{ per hour}$$

$$\frac{dR}{dt} \sim +0.012 \pm 0.002 \text{ per hour}$$

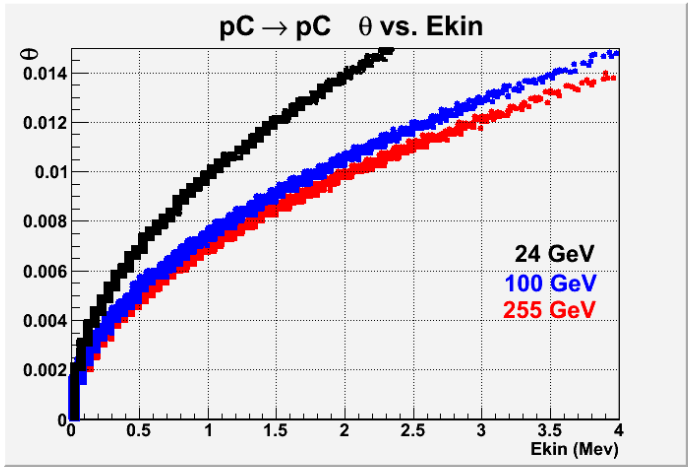
Measuring the Target Thickness

- Scattered carbons have a uniform azimuthal angle, j ,distribution:



$$\frac{dN}{dj} = 1 + PA_N \cos(j)$$

- Polar scattering angle very narrow range θ ~90°:
  - 4 < θ < 6 mrad for 0.4 < T < 0.9 MeV
- Finite target thickness results in Multiple Coulomb Scattering (MCS) smearing the q distribution:



$$q_{RMS} = \frac{K\sqrt{L_{\text{target}}}}{E_{\text{kin}}}$$

Effects on Analyzing Power

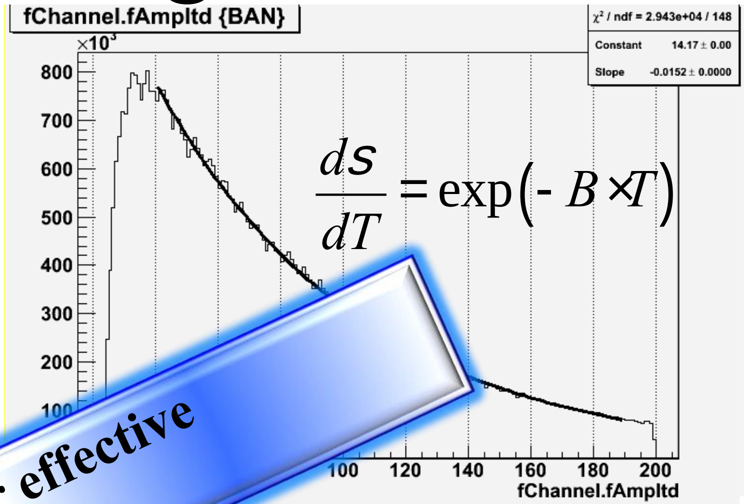
- The p-Carbon scattering $A_N(T)$ falls a function of T
- Detectors measure in the window of (solid lines)

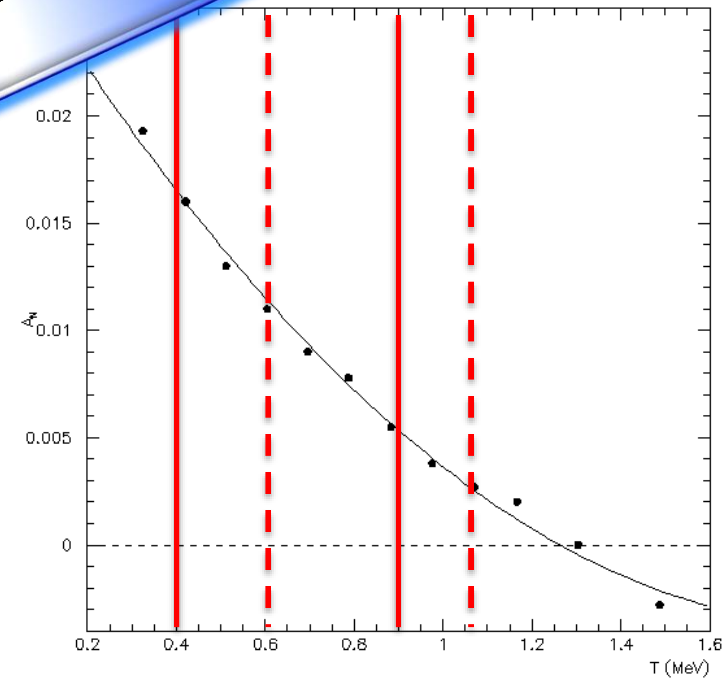
  0.4 < T < 0.9 MeV
- The effective analyzing power

$$A_N \mu \frac{ds}{\ldots} \ddot{A}$$

- Carbons ... higher T (dot... are shifted down to the m...ured T window
- These carbons have a smaller effective A_N

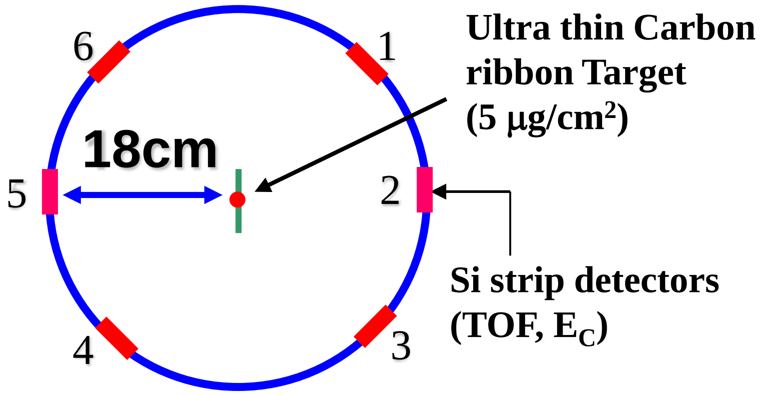
Thicker Targets Lead to a lower effective Analyzing Power

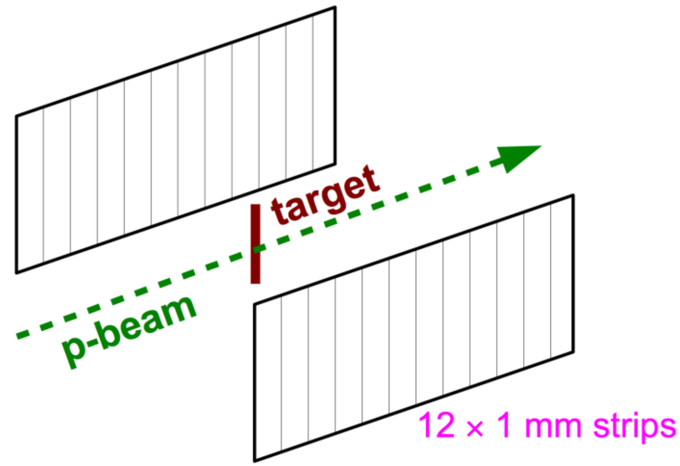




Detectors Used

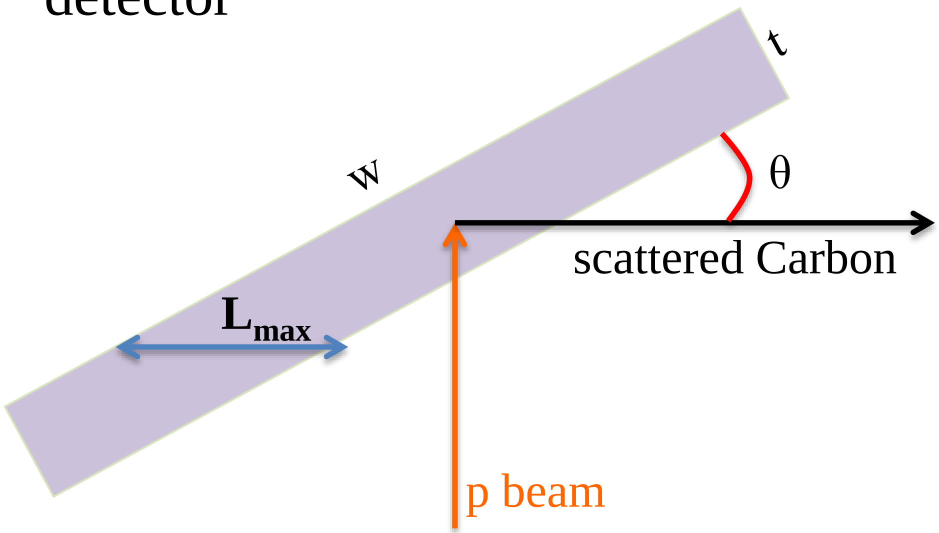
- The top 45° detectors (1 &6) are 1 mm detectors segmented along the beam line
- Strip polar $\Delta\theta \approx 5$ mrad
- # hits/channel distribution provides information on:
  - Centroid => longitudinal Z position of target
  - Width => amount of MCS through target

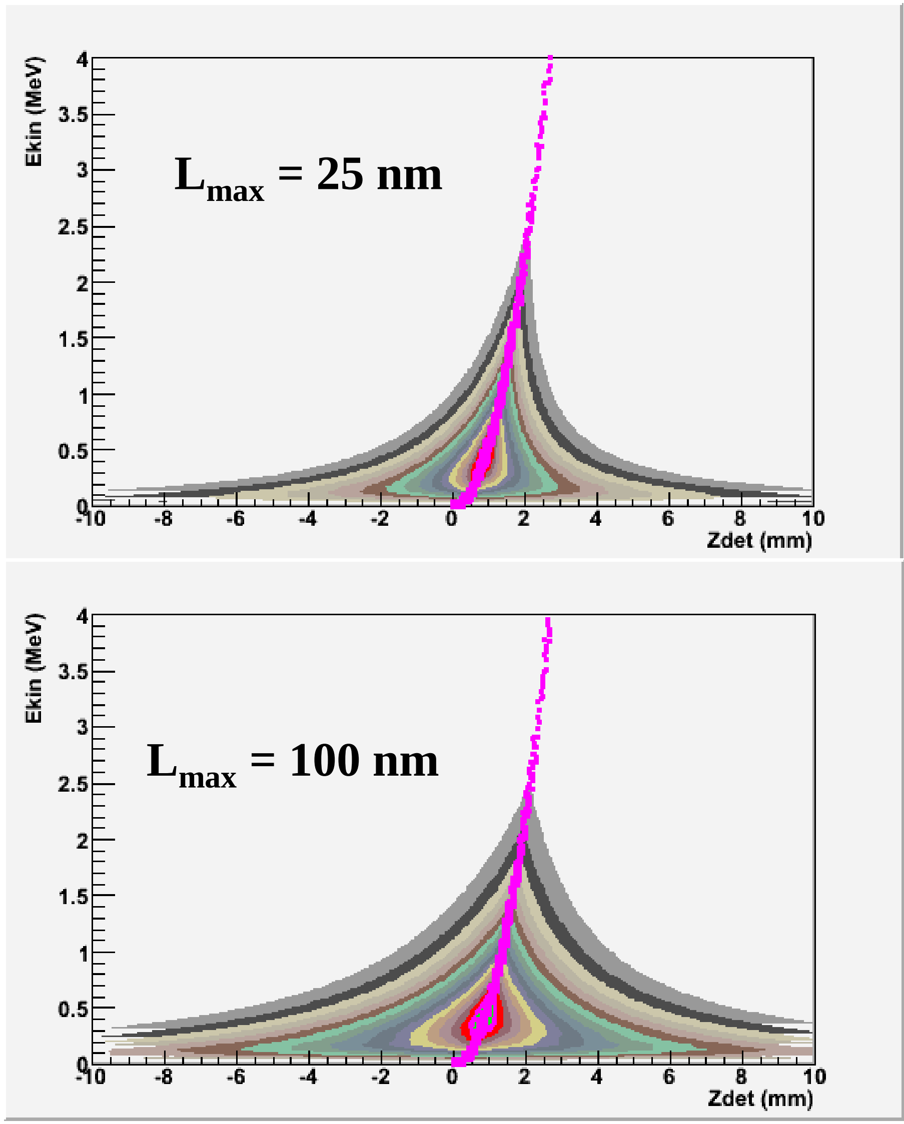




Toy Monte Carlo Model

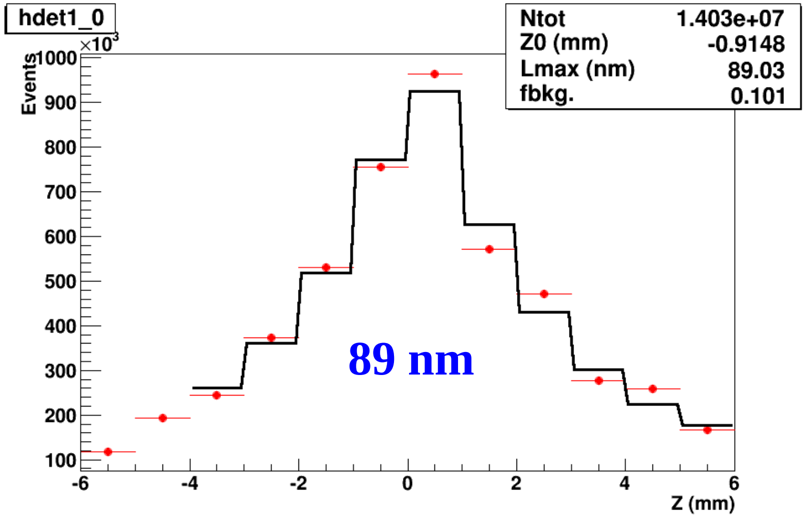
- Exponential distribution in scattered carbon energy
- E<->θ scattering angle dependence (kinematics)
- Passage of scattered carbon through varying target thickness 0 < L < Lmax with:
  - Small angle MCS in target material
  - dE/dx carbon energy loss
- 19.2 mm distance from target to detector

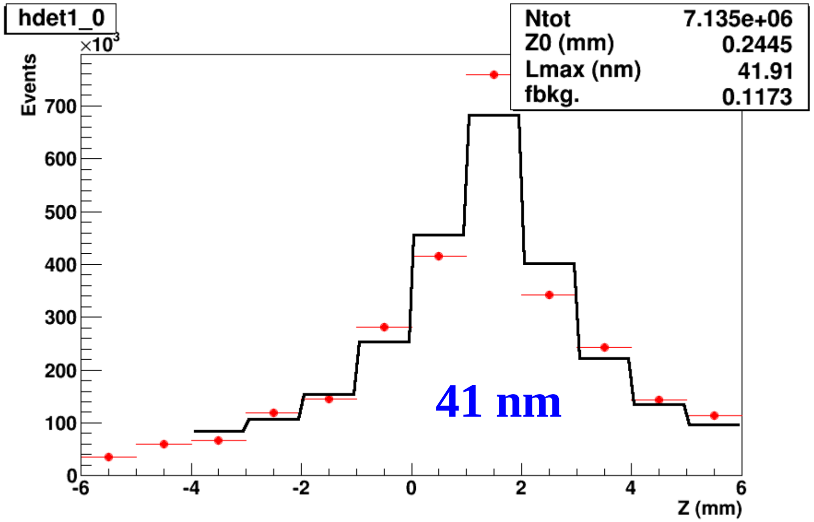




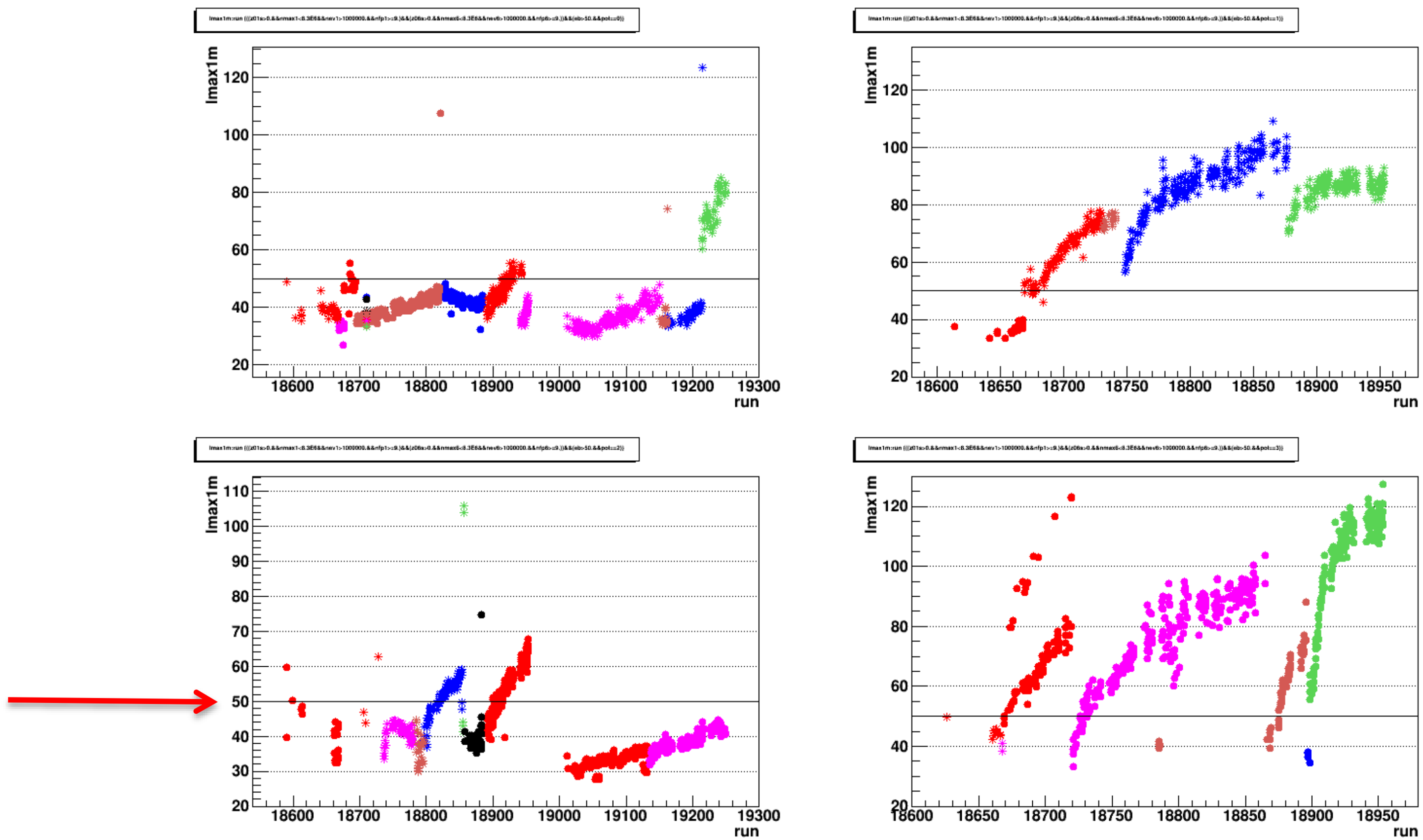
Hit Distributions and Fits

- <u>Fit Parameters:</u>
  - N_{tot}: total number of events (normalization)
  - Z_0: target longitudinal position
  - L_{max}: target -> detector thickness
  - Fbkg: flat background



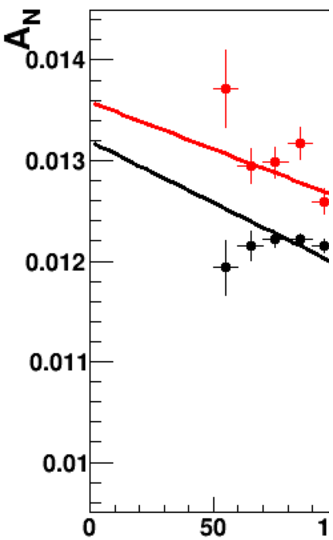


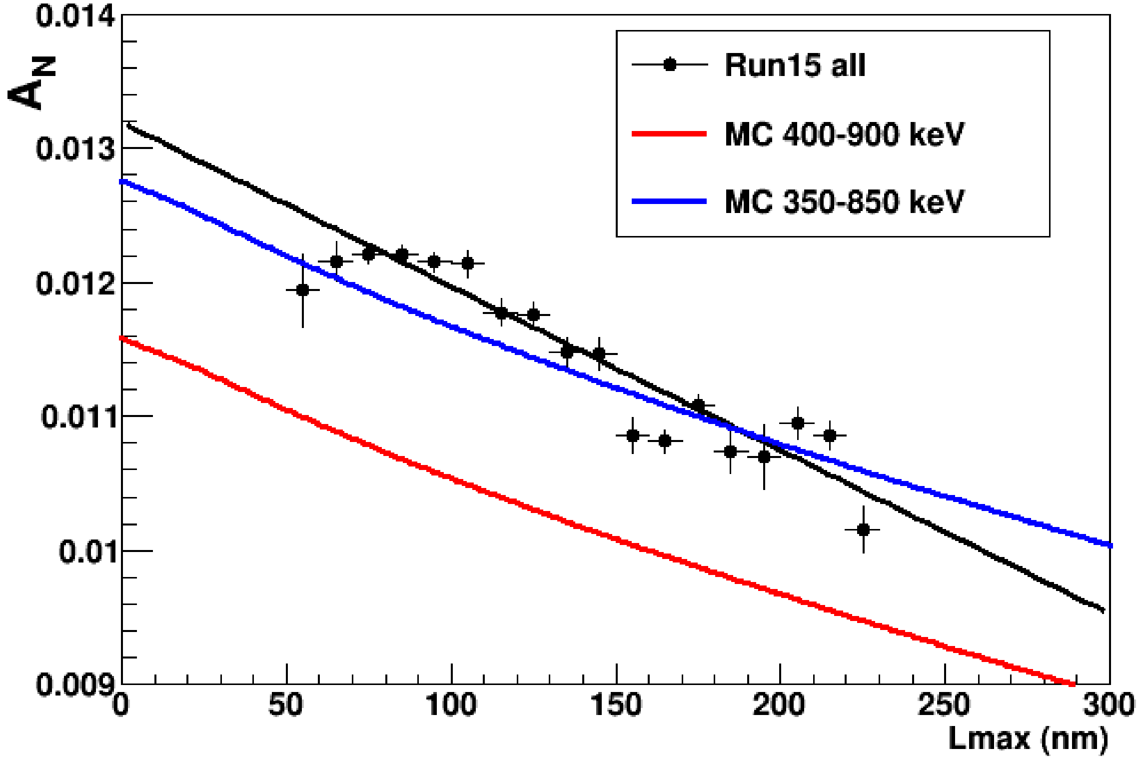
Run 15 History for L_{max}

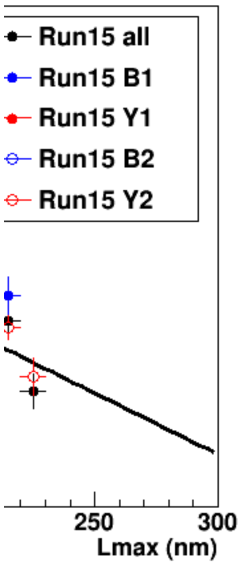


- L_{max} is a property of the target
- MCS parameters are uncertain for these low energies, adjusted L_{max} -> $2*L_{max}$ for model comparisons
- L_{max} increases with target use? Why?
- Target manufactured at 50 ± 4 nm , but we see some measurements < 30 nm.

A_N vs. L_{max}





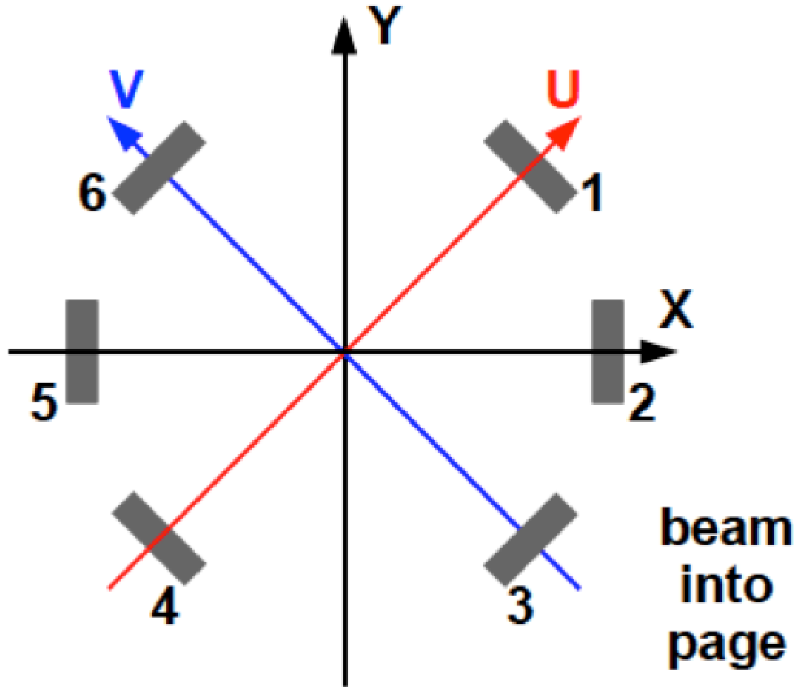


- Averag … each
  indivi

A_N has a 10% change over 100 nm range in target thickness
Shifted Energy window describes data well!

Spin tilt @ pC Polarimeters

- 3 180° detector pairs:
  - det 1+4, 2+5, 3+6
- Measure 3 separate asymmetries:
  - $\varepsilon_{25} = A_N P_Y$
  - $\varepsilon_{14} = A_N P_V$
  - $\varepsilon_{36} = A_N P_U$
- All detector pairs measure the same beam and polarization vector P, which provides two measures of $\varepsilon_Y = A_N P_Y$ where $P_Y = 1/\sqrt{2}(P_U+P_V)$:
  - $\varepsilon_{Y90} = \varepsilon_{25}$
  - $\varepsilon_{Y45} = 1/\sqrt{2}(\varepsilon_{14}+\varepsilon_{36})$



- H-jet polarimeter can only measure the y components
- Thanks to the 45° detectors the pC polarimeter can measure both P_X and P_Y

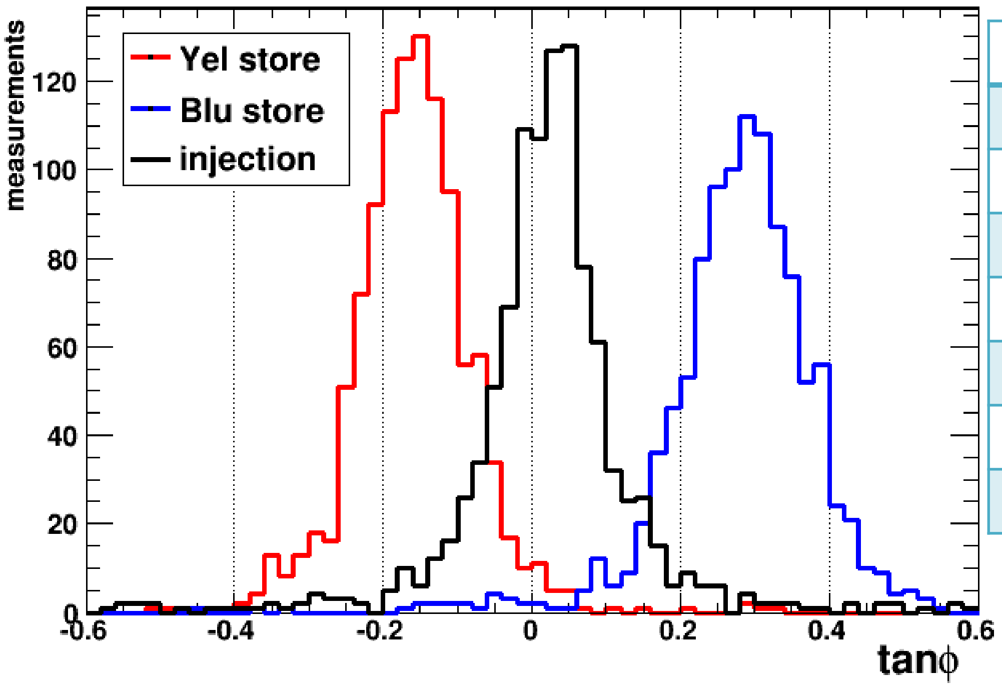
tan(φ) from 45° detectors

Using 45° detectors → measure P_x, P_y and spin tilt from vertical

$$\tan\phi = P_x / P_y = (P_u - P_v)/(P_u + P_v) = (\varepsilon_{36} - \varepsilon_{14})/(\varepsilon_{36} + \varepsilon_{14})$$

independent of scale of A_N

2013 Results:



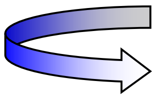
Year	Energy	Blue	Yellow	Injection
2011	250	-2.9	-1.07	0.92
2012	100	3.05	-0.97	0.85
	255	13.81	-6.49	
2013	255	16.14	-9.01	1.25
2015	100 (1)	3.76	1.92	
	100 (2)	3.72	1.27	
	100 (3)	4.86	3.19	

Many additional studies in 2015 (3) to understand polarization lifetime

In geographical coordinates:

@ pC polarimeter

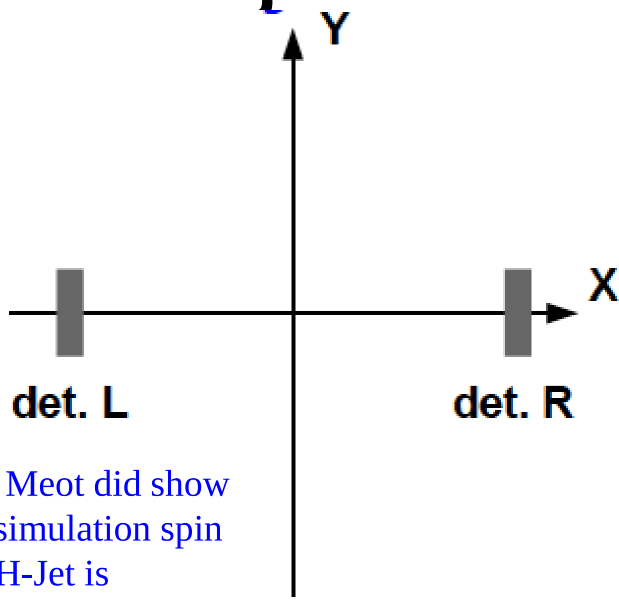
@ store both Blue and Yellow spin vectors tilted toward RHIC ring center



What about H-Jet

Spin vector tilt @ IP12=H-jet

- H-jet polarimeter is at IP12:
  has only 90° horizontal detectors,
  measures $\epsilon_Y \propto P_Y$
- The H-jet measurements normalize scale of pC measurements (determine pC A_N)
- To date we have assumed H-jet measures polarization magnitude |P|
- If there is a spin tilt $\phi \neq 0$ @ IP12 we have a |P| scale shift of $\cos\phi$
  e.g. Yel @ store: ϕ = -9° $\cos\phi$ = 0.99 1% scale shift
  Blu @ store: ϕ = +16° $\cos\phi$ = 0.96 **4% scale shift**



Francois Meot did show through simulation spin angle at H-Jet is identical to the one at pC

- A 4% shift is significant,
  need to account for in polarization measurements...
  has been done for the final 2013 polarization numbers

Experiments measure the spin tilts through the ZDC asymmetries

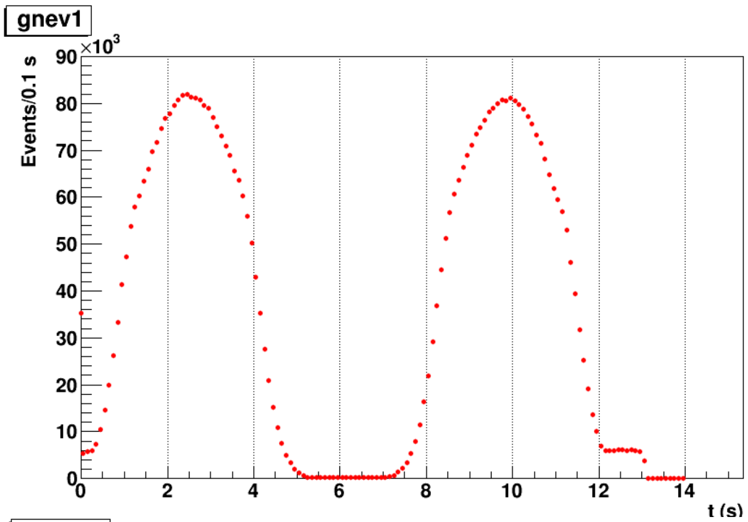
Summary

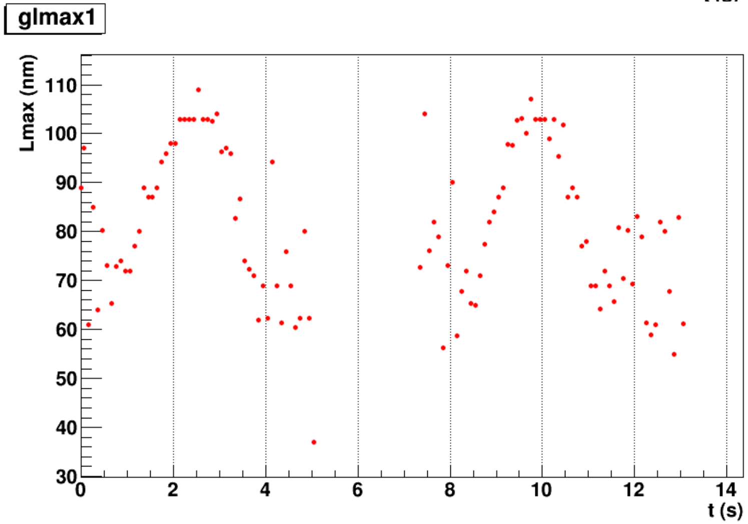
- p-Carbon polarimeters at RHIC have consistently performed well in 2011, 2012, 2013, and 2015
- They provide information on the beam polarization profile and measures the polarization loss during a RHIC store
- Target lifetime has improved thanks to the new fin design of the target holder
- Studies to determine the amount of material in the flight path to detectors are ongoing and show promising results.
- Potential to precisely measure p-Carbon A_N at very high beam energies

Back-Up

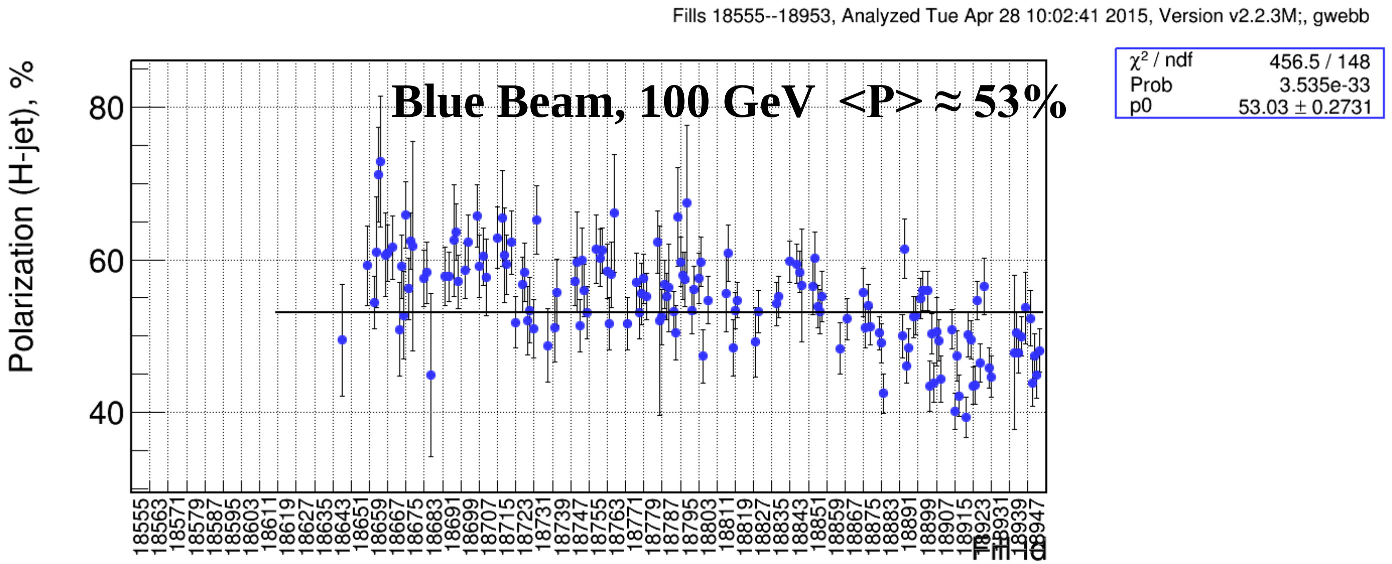
$\langle L_{max} \rangle$ in Sweep

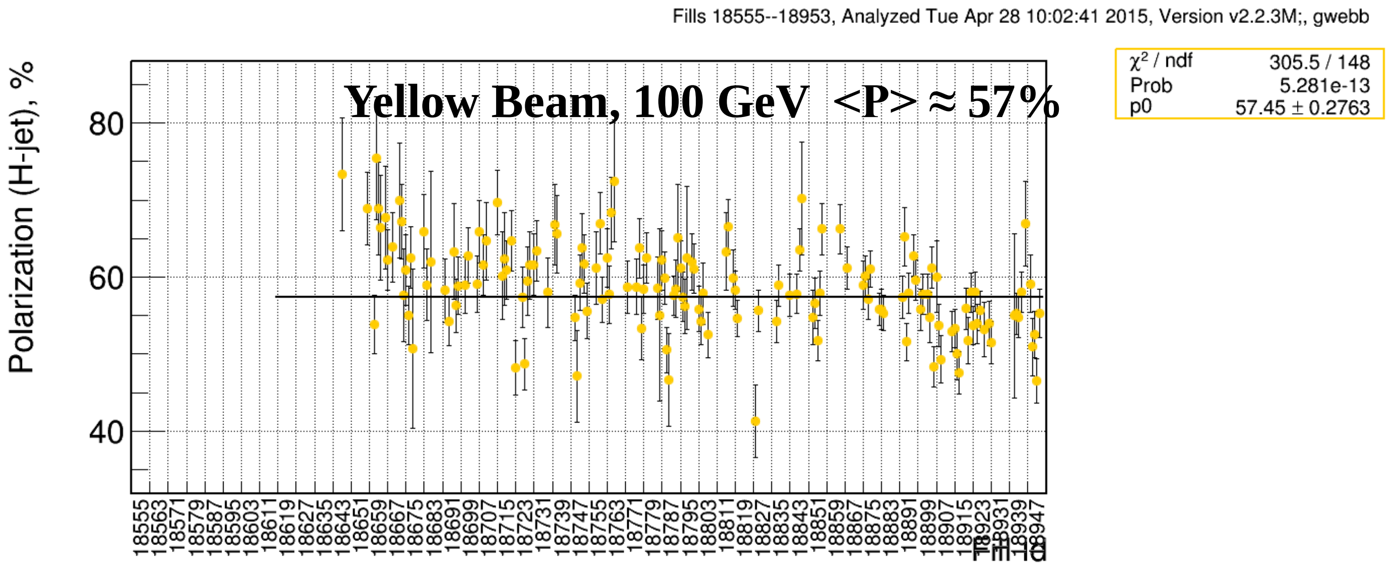
- The target twists, turns, etc. as it enters the beam
- The value of L_{max} varies as target sweeps across the beam
- Rate averaged L_{max} is used





verage Polarization in 2015 at E_{beam} = 100 Ge





Spin tilt @ pC Polarimeters

uare root (cross ratio) formula

f detectors (L,R), 180° apart:
ent detector acceptances a_L,a_R
sed to up/down be
ent up/down lumi
polarization alon
cs asymmetry ϵ
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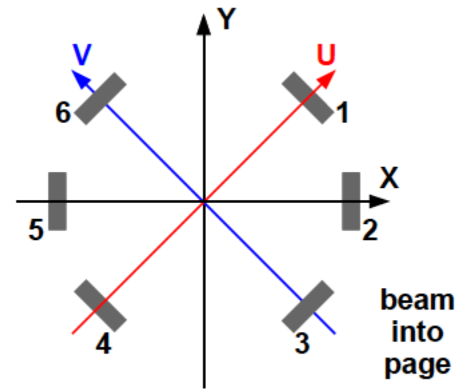
ure 4 event count
am up: N_{R+} = a_R
down: N_{R-} = a_R

ct 3 asymmetries
sics asym. ϵ = A_N
nosity (beam cur
eptance asym. α

pC polarim.: 3 detector pairs

- 3 180° detector pairs, det.1+4, 2+5, 3+6:
- Measure 3 sets of asymmetries:

$$\epsilon_{25} = A_N P_Y\ ,\ \lambda_{25}\ ,\ \alpha_{25}$$
$$\epsilon_{14} = A_N P_V\ ,\ \lambda_{14}\ ,\ \alpha_{14}$$
$$\epsilon_{36} = A_N P_U\ ,\ \lambda_{36}\ ,\ \alpha_{36}$$



Cross checks:

- All detector pairs measure same beam, lumi asym. λ
  compare λ_{14}, λ_{25}, λ_{36}: agree within stat. uncert. (↘ extra slide)
- All detector pairs measure same beam, polarization vector P
  two measures of $\epsilon_Y = A_N P_Y$, using $P_Y = 1/\sqrt{2}(P_V+P_U)$
  - from 90° det. 2+5: $\epsilon_{Y90} = \epsilon_{25}$ (vertical targets only)
  - from 45° det. 1+4, 3+6: $\epsilon_{Y45} = 1/\sqrt{2}(\epsilon_{14}+\epsilon_{36})$
  - compare ϵ_{Y90}, ϵ_{Y45}: agree within stat. uncert. (↘ extra slide)

Also: A_N ~same all detector pairs

3