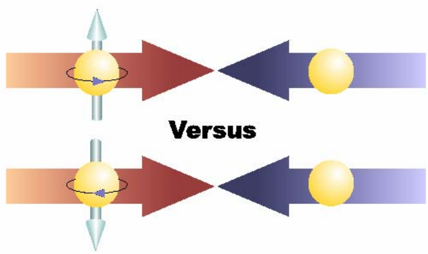
Proton Polarimetry at RHIC

1. provides polarization measurements for experiments
   goal: 5% precision on P_{BEAM}

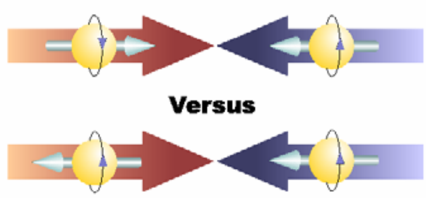
2. provides polarization and beam properties measurement for accelerator

Polarimetry : Impact on Spin Physics

Single Spin Asymmetries



Double Spin Asymmetries



Physics Asymmetries

$$A_N = \frac{1}{P_B}\left(\frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}\right)$$

$$A_{LL} = \frac{1}{P_B{}^2}\left(\frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}}\right) \Rightarrow \boxed{\Delta G}$$

measurements

- measured spin asymmetries normalized by P_B to extract Physics Spin Observables
- RHIC Spin Program requires $\Delta P_{BEAM} / P_{BEAM} \sim 0.05$
- normalization $\Rightarrow$ scale uncertainty

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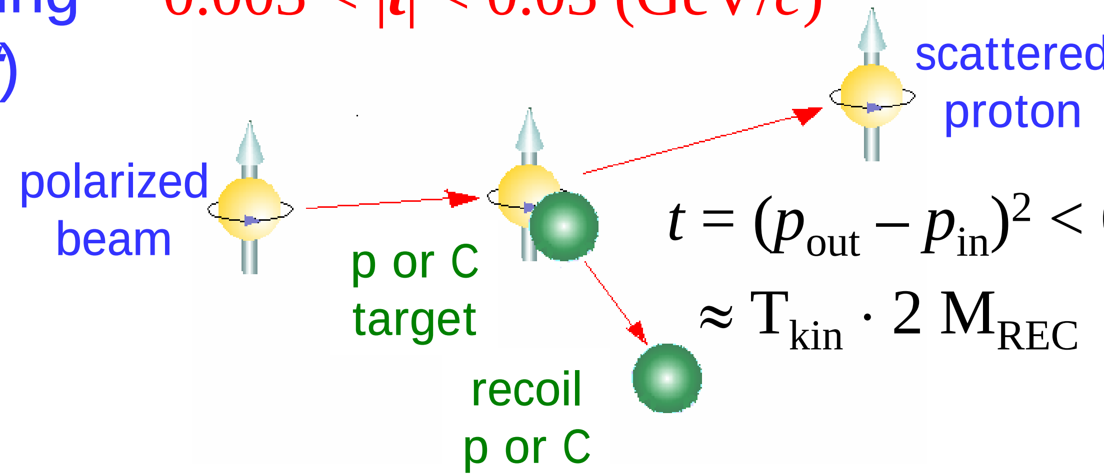
How does it work?

Elastic *pC* and *pp* scattering
in CNI region (very low ***t***)

$$P_B = -\frac{1}{A_N} \cdot \frac{N_{left} - N_{right}}{N_{left} + N_{right}}$$

$0.003 < |t| < 0.03\ (\mathrm{GeV}/c)^2$



$t = (p_{out} - p_{in})^2 < 0$

$\approx T_{kin} \cdot 2\, M_{REC}$

clean, well understood scattering process

still an experiment !

detection of recoil alone identifies the elastic process at this low ***t***

polarimetry requires large F.o.M. = $A_N^2 \times$ *rate* for fast measurement

i.e. large σ (fast) + sizable and known A_N

pC elastic scattering in CNI region

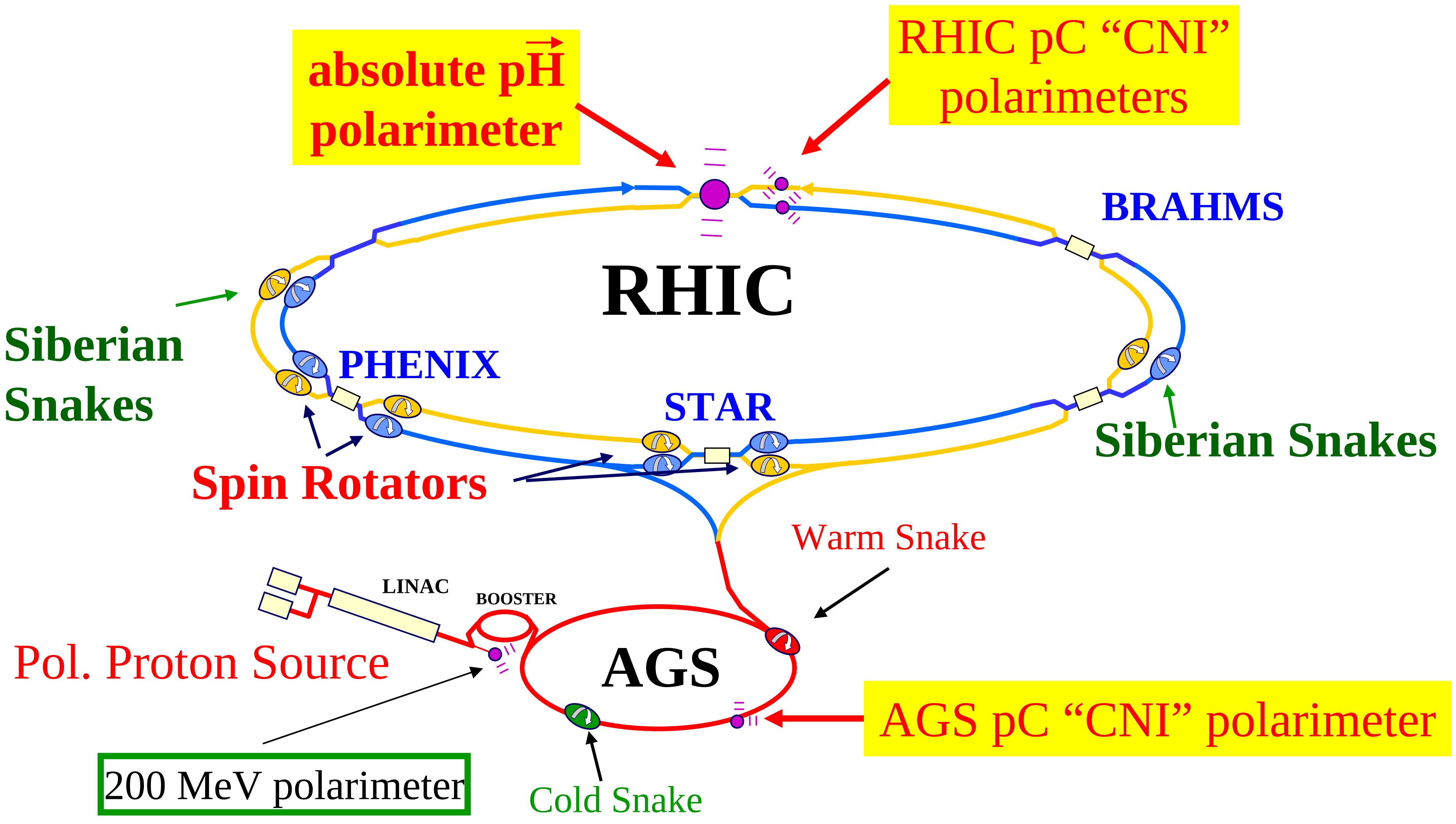
$A_N \sim 1.2\ \% \rightarrow$ large statistics > 10^7 events per measurement

large $\times$ – section $\rightarrow$ fast measurement

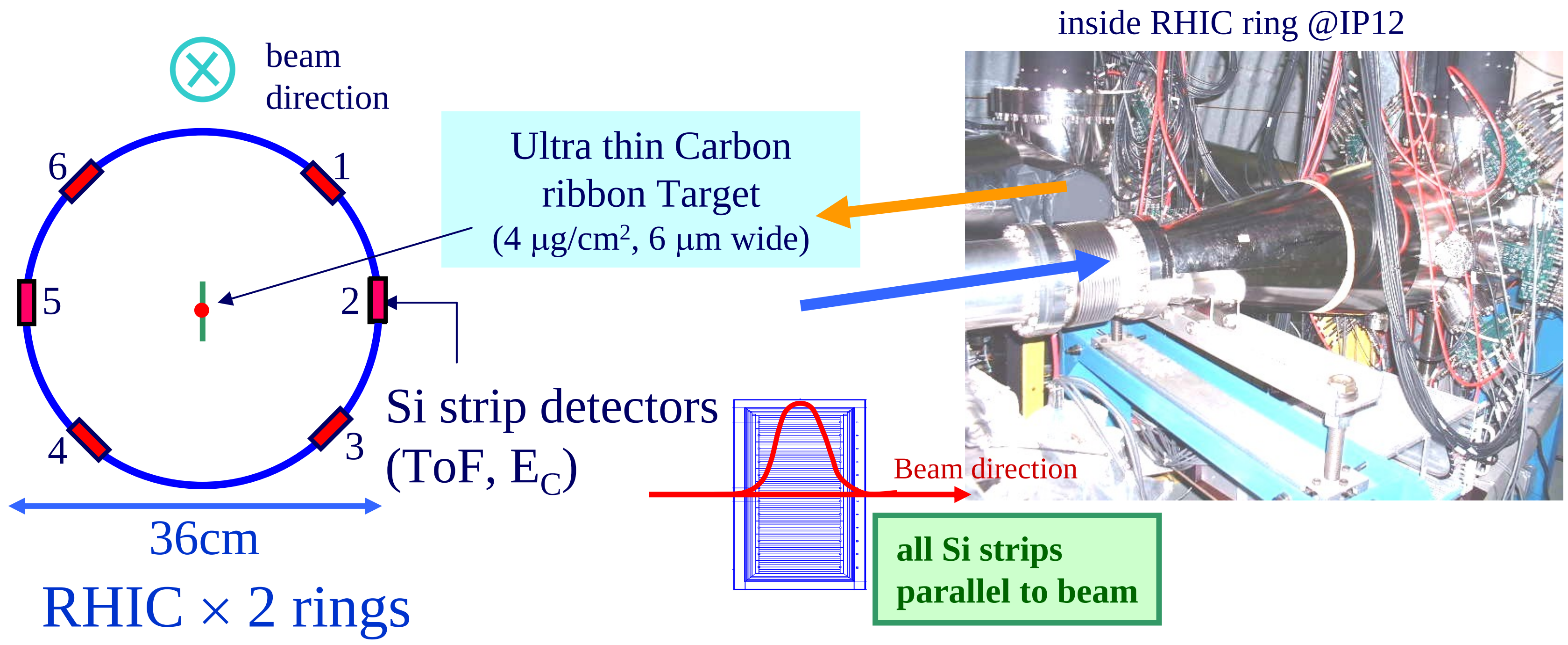
absolute calibration $\rightarrow$

pp elastic scattering with polarized gas jet target

RHIC *pp* accelerator complex & Polarimeters

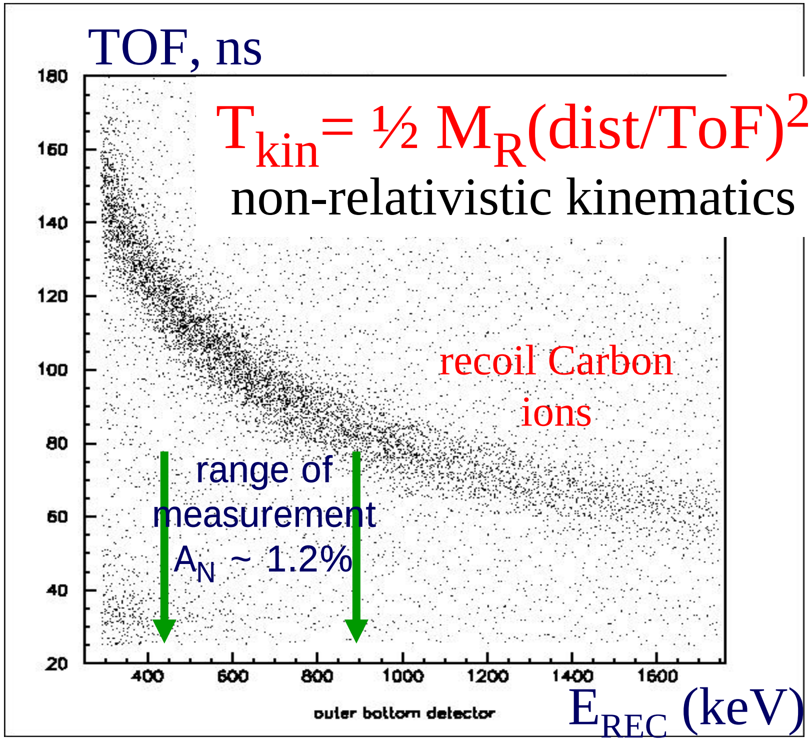


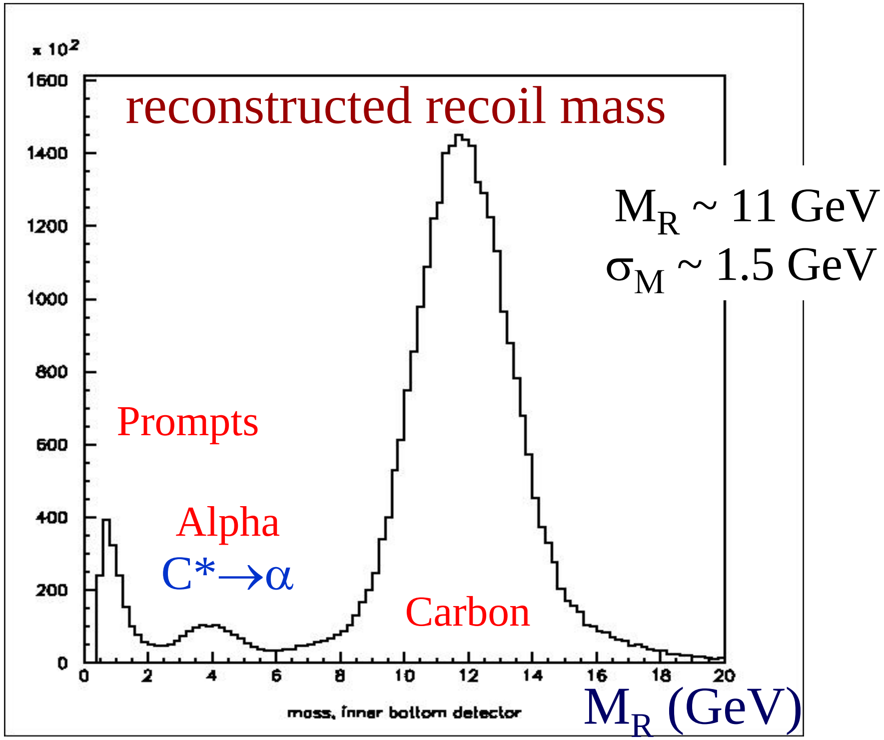
Setup for pC scattering – the RHIC polarimeters



- recoil carbon ions detected with Silicon strip detectors
- 2 × 72 channels read out with WFD
- very large statistics per measurement (~ 20 × 10^6 events) allows detailed analysis
  - bunch by bunch analysis
  - channel by channel (each channel is an "independent polarimeter")
  - 45° detectors: sensitive to vertical and radial components of $\vec{P}_{BEAM}$
    → unphysical asymmetries

Event Selection & Performance





- very clean data, background < 1 % within "banana" cut

  good separation of recoil carbon from α (C* → α + X) and prompts
- δ (ToF) < 3 ns: intrinsic + beam longitudinal profile (⇒ σ_M ~ 1.5 GeV)
- very high rate: up to 10^5 ev / ch / sec

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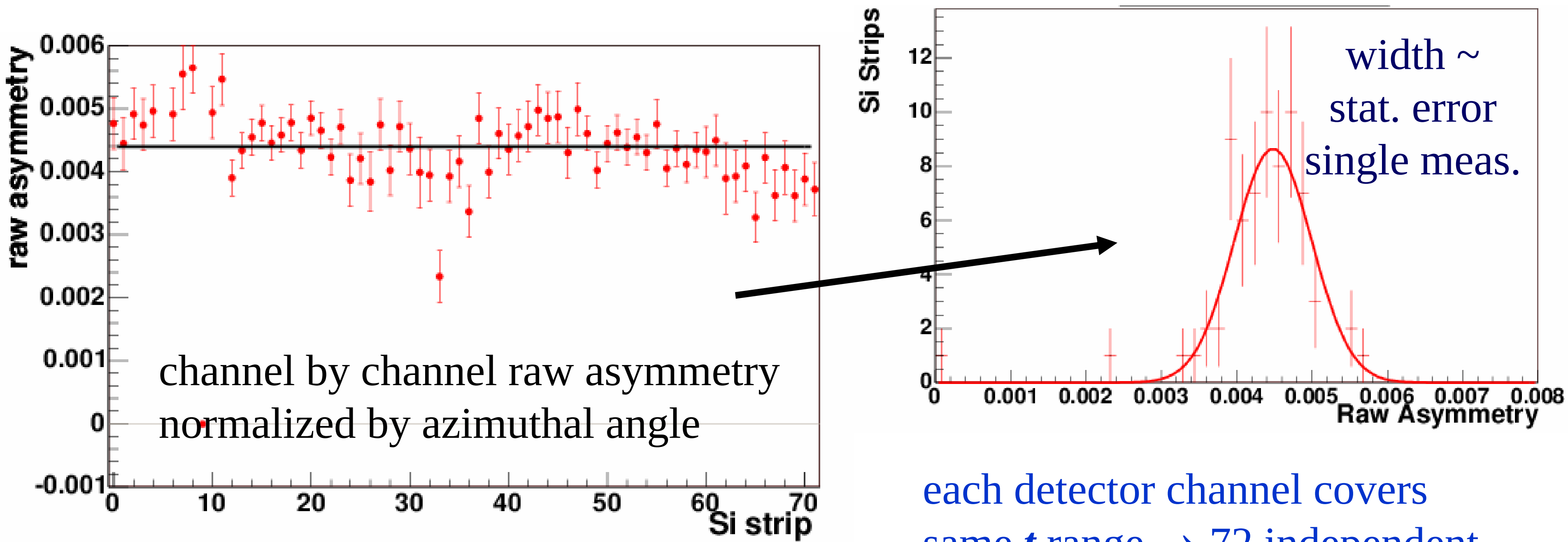
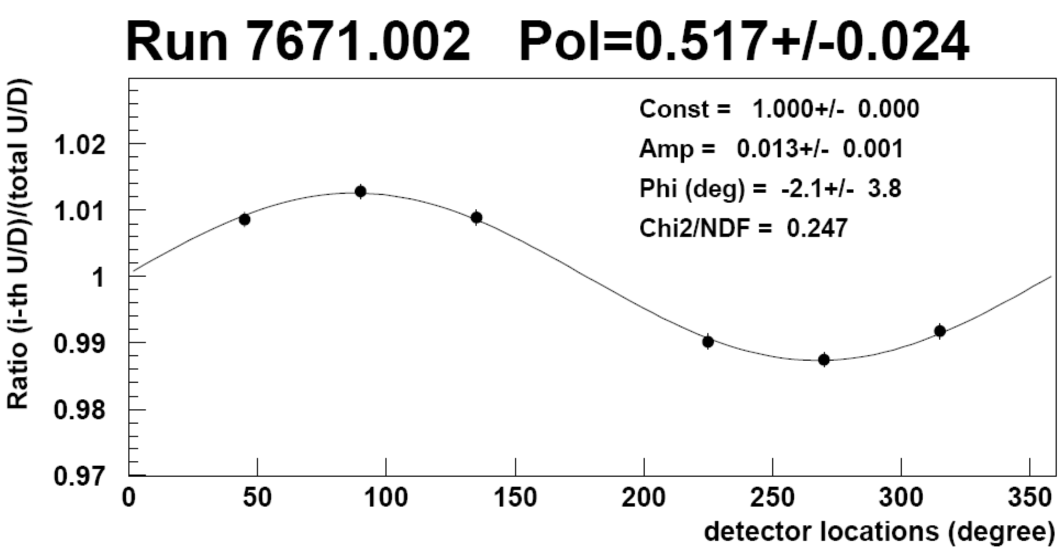
*p*C Systematics in RHIC:



each detector channel covers same ***t*** range → 72 independent measurements of ε_N



measured asymmetries fluctuations statistical only

sin ϕ fit with free phase gives also tilt of spin vector

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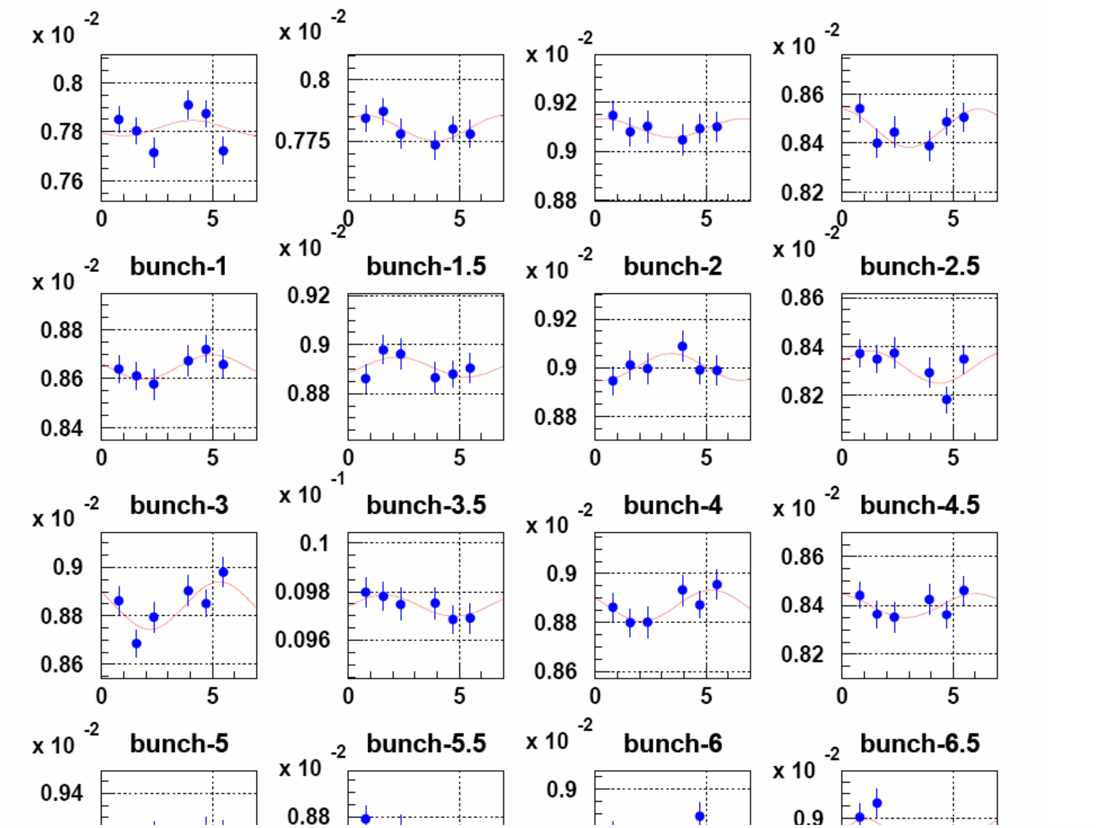
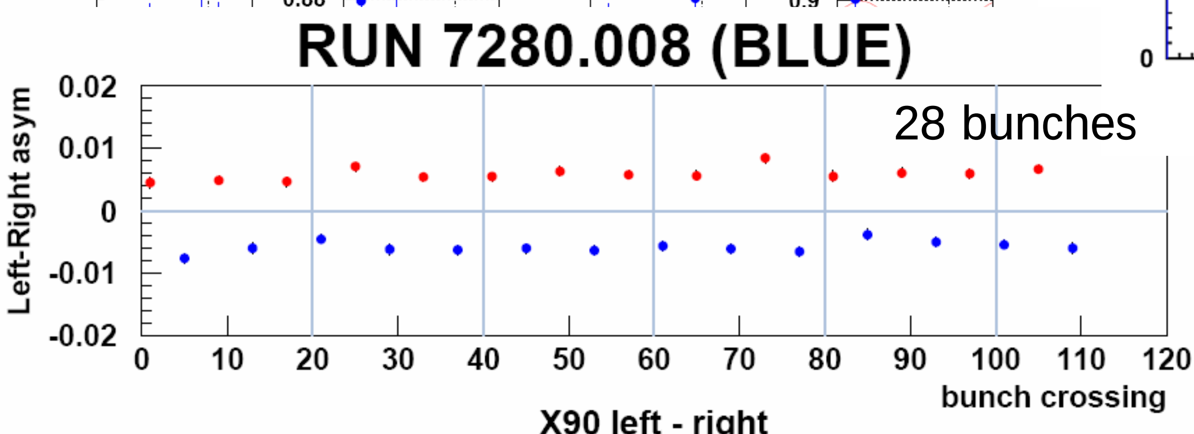
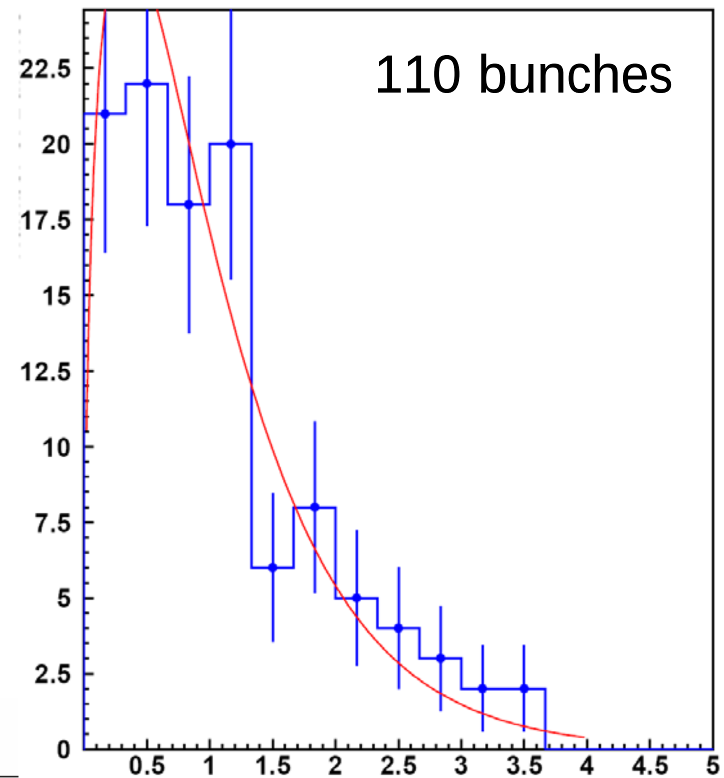
Bunch by Bunch Polarization





reduced χ^2 distribution of azimuthal fits



consistent with statistical fluctuations only

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pC Polarimeter systematic issues

- fluctuations in measured "raw" asymmetries statistical only
  - sources of systematical errors external in origin
- absolute calibration at 100 GeV to ~ 15% (2004 run)
  - expect absolute calibration of to ~ 5% (2005 and 2006 run)
- energy scale: 5% to 10% uncertainty
  - Si entrance window correction for measured recoiling carbon ion energy
  - small change $\rightarrow$ small change in $|t|$ $\rightarrow$ significant change in $A_N(t)$
  - probably the biggest limitation to become an absolute polarimeter
- beam polarization profile
  - each measurement taken by sweeping the target through the beam
  - $\rightarrow$ average bunch polarization
- measured systematic error of relative measurements to $\Delta P < 3\%$
  - event selections, scalar vs. event analysis, strip by strip analysis, etc.
- target system: some issues still remain $\rightarrow$ work in progress

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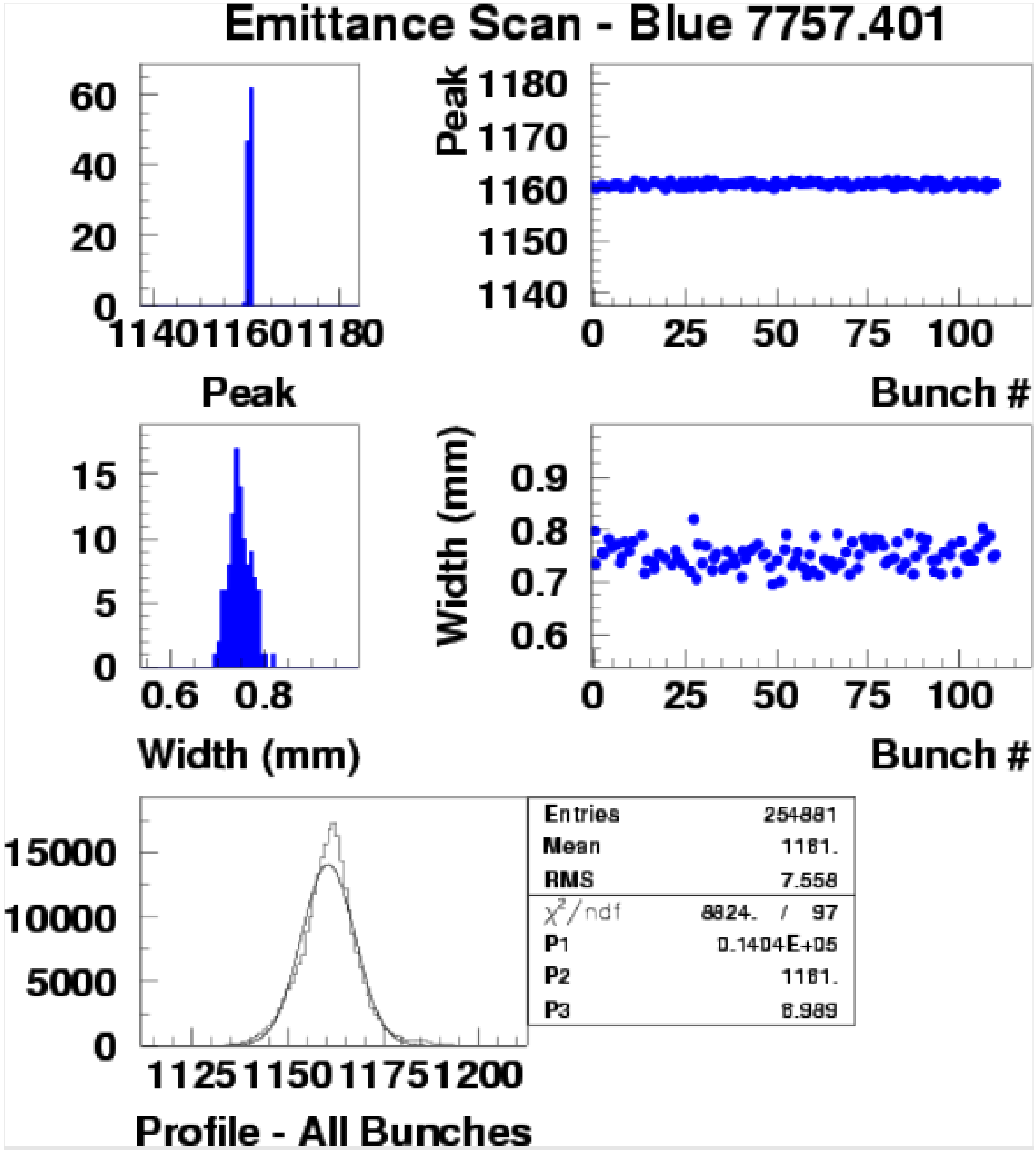
Beam Emittance



measured by sweeping the carbon target through the beam

~ 1 sec. measurement

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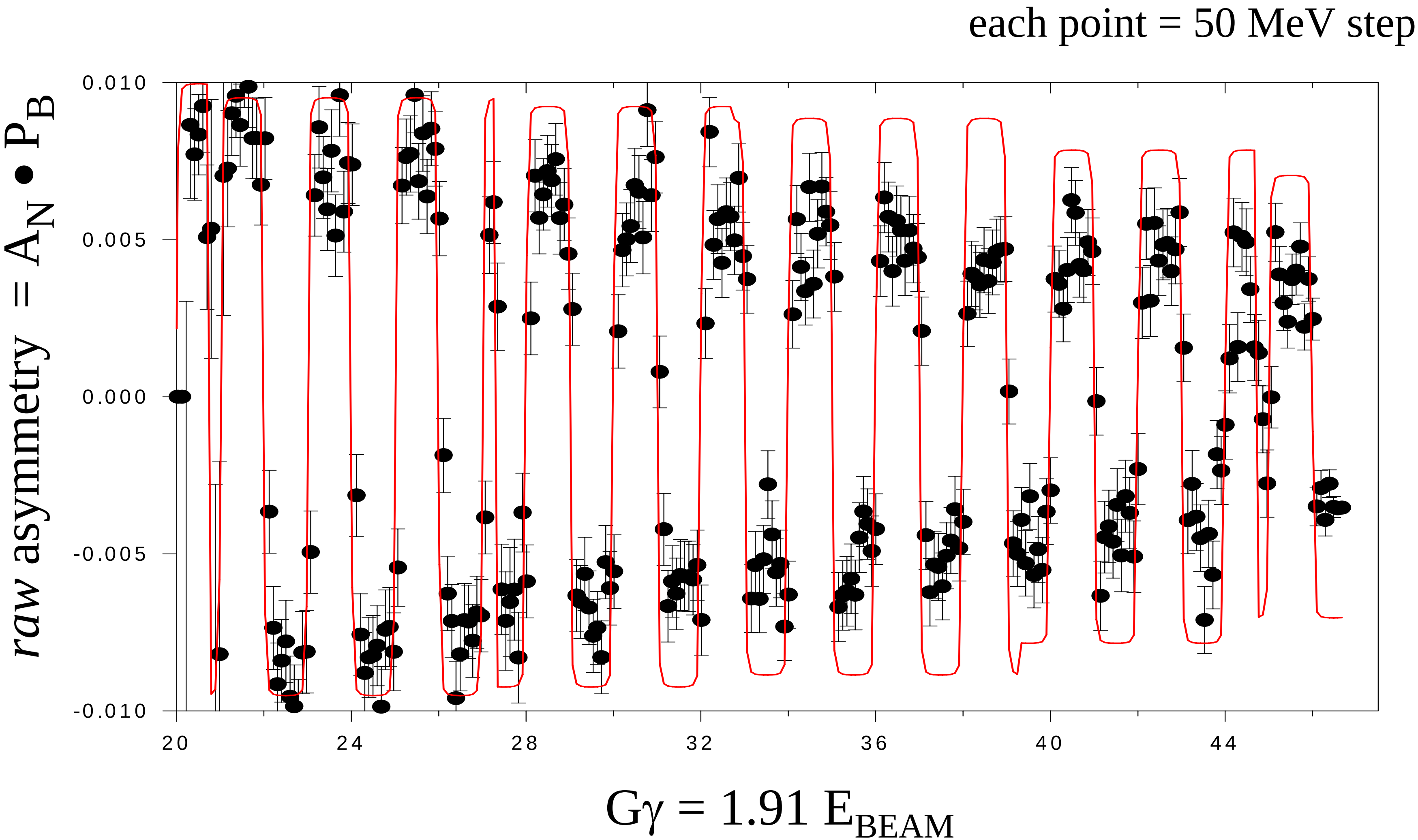
AGS polarization during acceleration (ramp)



red line: simulation of polarization losses assuming constant A_N

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Calibrating pC with the Polarized Gas Jet Target

sequence of simultaneous measurements:

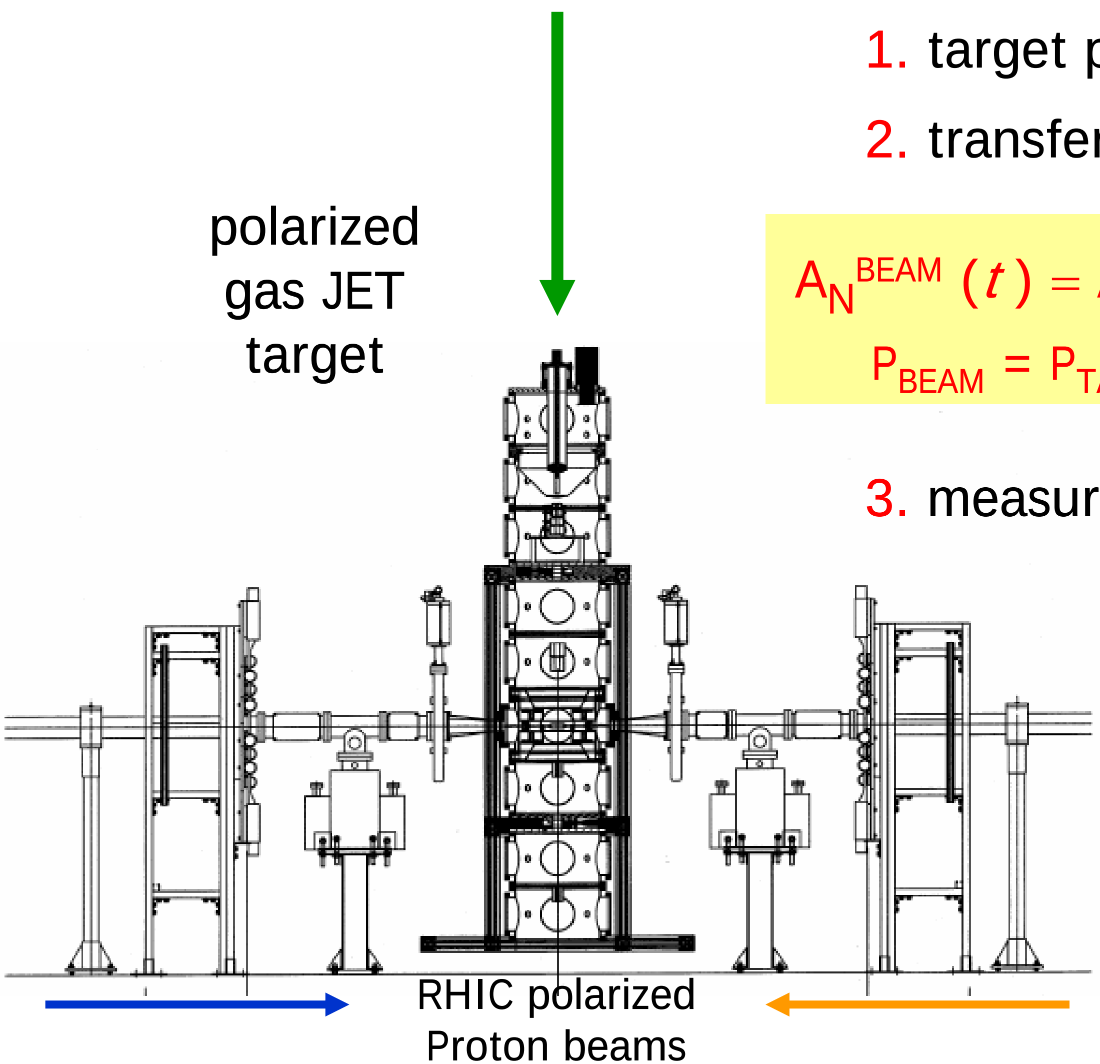
1. target polarization
2. transfer P_{TARGET} to P_{BEAM}

$A_N^{BEAM}(t) = A_N^{TARGET}(t)$ for pp elastic scattering

$P_{BEAM} = P_{TARGET} \cdot \varepsilon_B / \varepsilon_T$ ("self – calibrating")

3. measure A_N for pC with same beam

$\Rightarrow$ CALIBRATION



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JET target polarization & performance

the JET ran with an average intensity of 1×10^{17} atoms / sec

the JET thickness of 1×10^{12} atoms/cm^2 record intensity

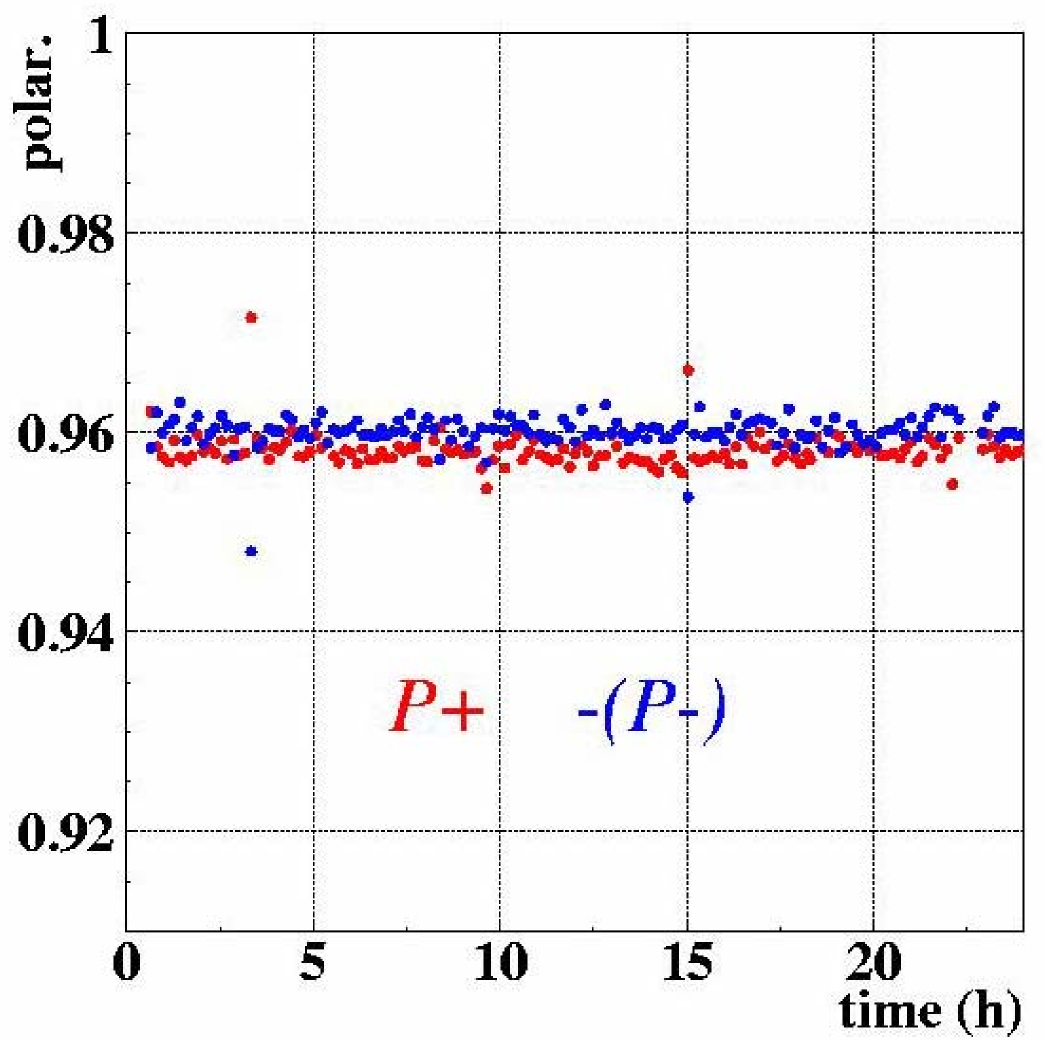
target polarization cycle
+/0/- ~ 500 / 50 / 500 sec

polarization to be scaled down due to a ~3% H_2 background:

$P_{TARGET} \sim 0.924 \pm 0.018$
(current understanding)

no depolarization from beam wake fields observed

no effect on RHIC beams:
“can run parasitically”



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Recoil Si spectrometer

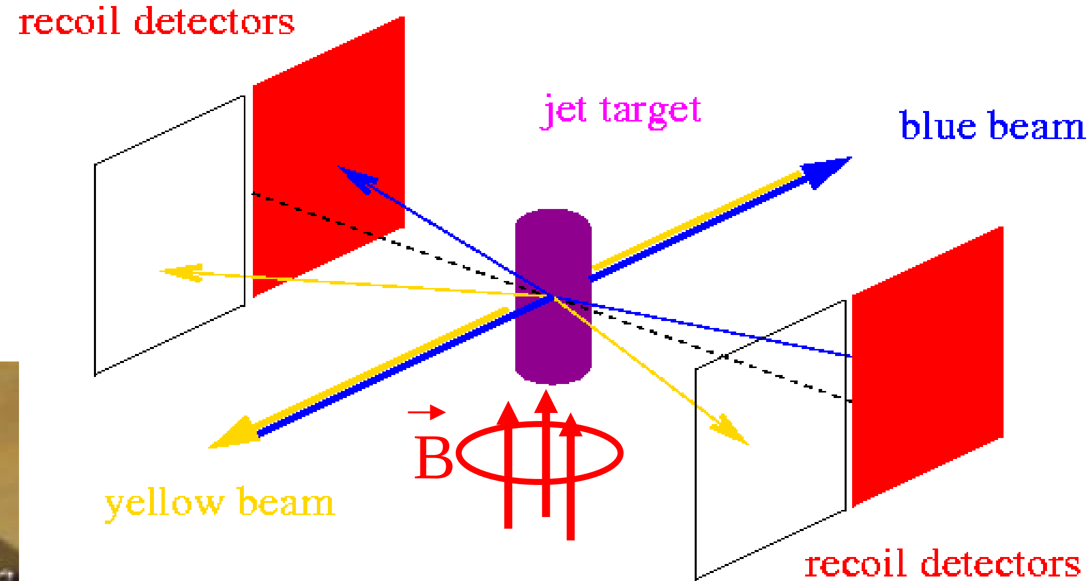
6 Si detectors covering both beams

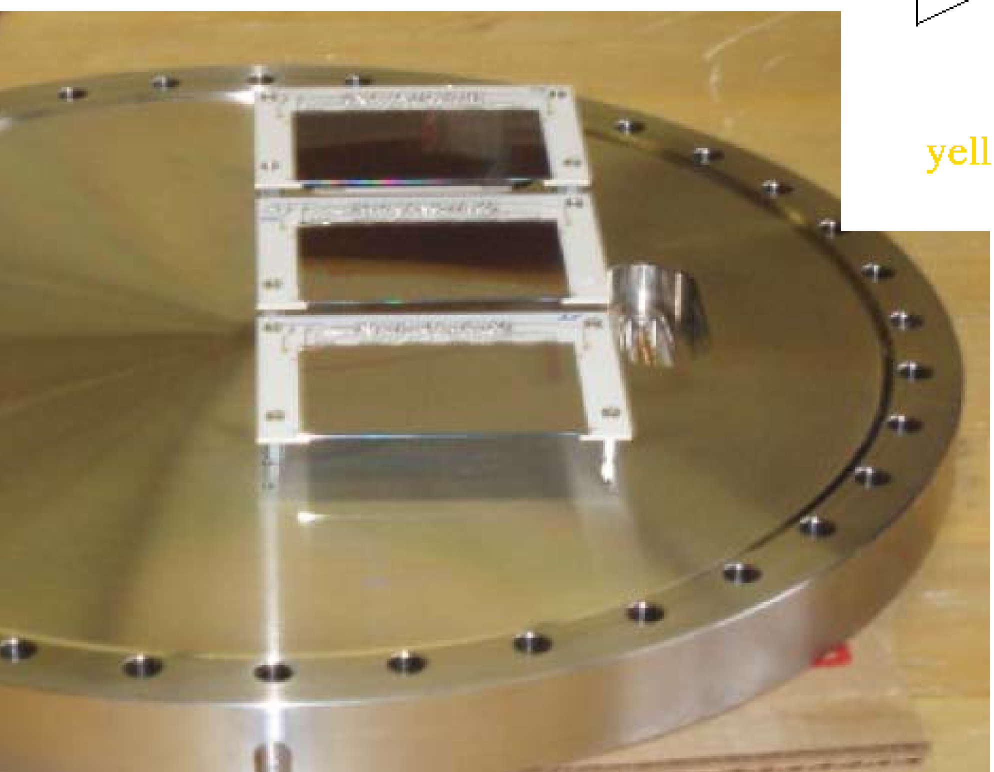
MEASURE

- energy (res. < 50 keV)
- time of flight (res. < 2 ns)
- scattering angle (res. ~ 5 mrad)

of recoil protons from

$pp \rightarrow pp$ elastic scattering





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P_{BEAM}

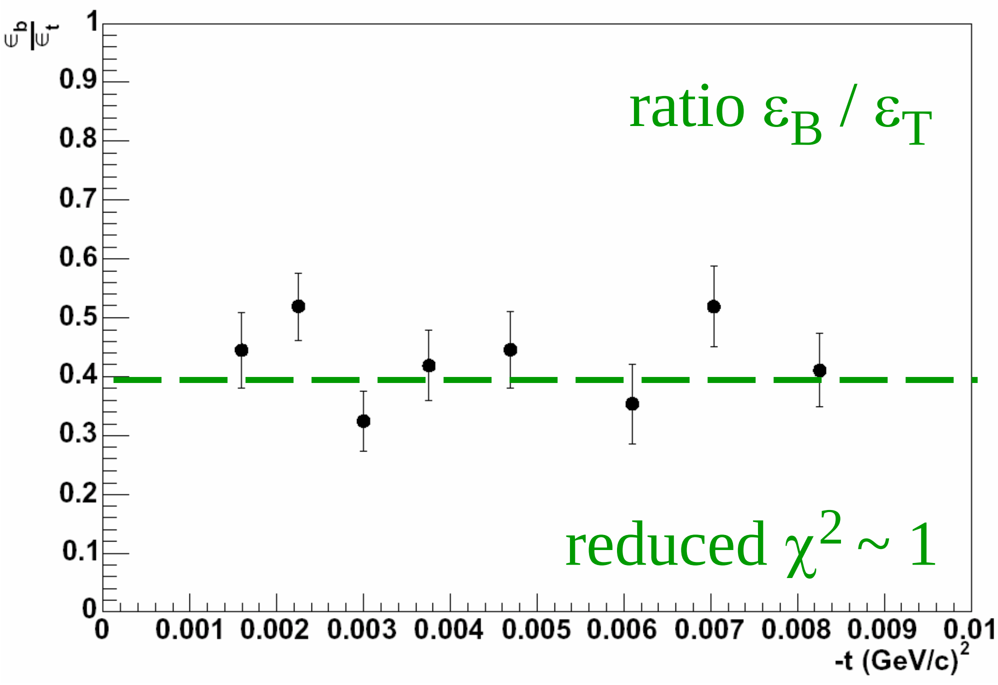
"self calibrating"

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

"Target": ε_T – target asymmetry
average over beam polarization

"Beam": ε_B – beam asymmetry
average over target polarization

largest systematic issue:
background below elastic peak,
in part included in P_{TARGET}



tot sys = 0.016

$P_{BEAM} = 0.392 \pm 0.021\ (stat) \pm 0.008\ (\Delta P_{TARGET}) \pm 0.014\ (sys) = 0.392 \pm 0.026$

2004 ERROR: $\Delta P_{BEAM} / P_{BEAM} = 6.6\ \%$

2005, 2006: work in progress D $P_{BEAM} / P_{BEAM} < 5\ \%$!

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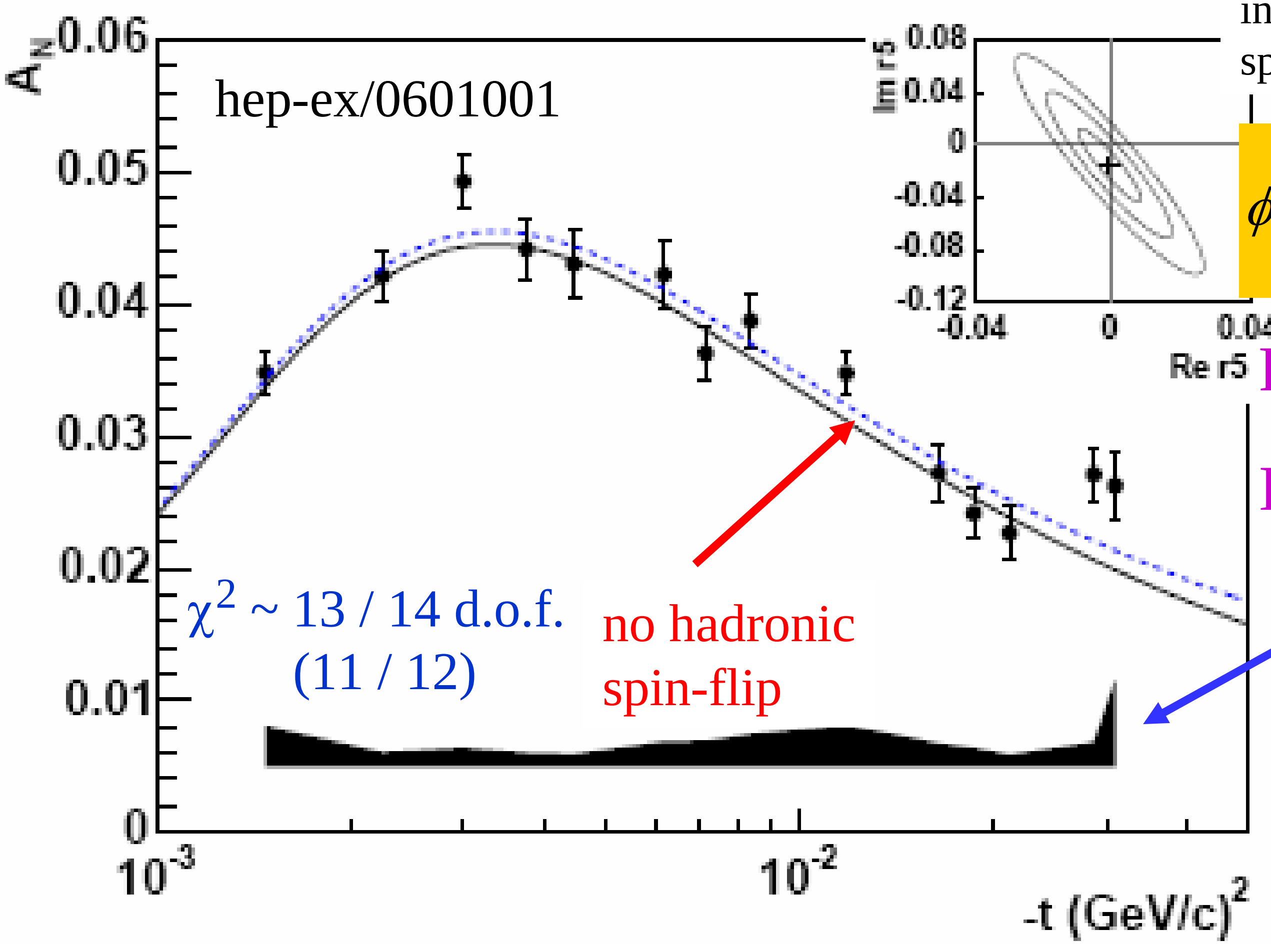
A_N for $p\uparrow p \rightarrow pp$ @ 100 GeV



in the simplest assumption:
spin-flip prop. to non-flip amplitude

$$\phi_5^{had} = r_5(s)\frac{\sqrt{-t}}{2m_p}\left(\phi_1^{had} + \phi_3^{had}\right)$$

Re r_5 = -0.001 ± 0.009

Im r_5 = -0.015 ± 0.029

source of systematic errors:
1 $\Delta P_{TARGET} = 2$ %
2 from backgrounds & event selection < ± 0.0016
3 false asymmetries: small
similar to statistical errors

no need of a hadronic spin – flip contribution to describe these data

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Conclusions

- Very stable operation of carbon polarimeters in 2005 and 2006
- Continuous effort to understand and address systematic issues,
  in particular correlate with beam properties
  Believe most of issues are understood are addressed
- 2004 normalization error on A_{LL} (PHENIX) ~ 24%
- With combined use of carbon polarimeters + jet target expect to achieve a ~5% relative error on P_{BEAM} (2006 run)
- Carbon polarimeter alone ~ 8 %
  (absolute calibration and energy scale)
- Major hardware developments / constructions completed
- Need to further develop analysis tools

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