Coulomb-Nuclear Interference (CNI) Polarimetry for the RHIC Spin Program

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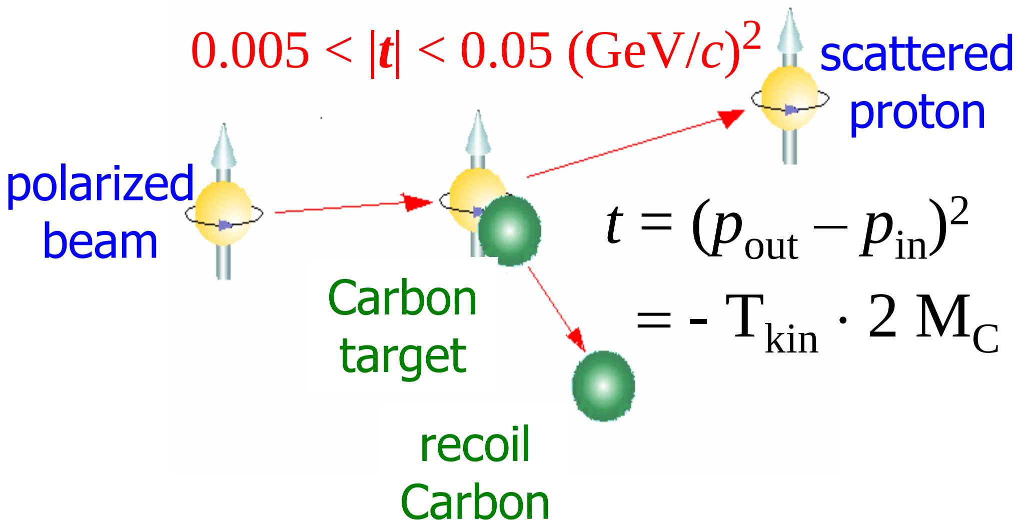
Outline

- CNI Polarimetry Process
- Overview of Polarimetry for RHIC Spin
- CNI Polarimeter Set Up
  - Event selection
  - DAQ
- Results
  - 2003 Polarization in AGS and RHIC
  - AGS acceleration measurement
- Summary

The CNI Polarimetry Process

pC elastic scattering at low $-t$



$$t = (p_{out} - p_{in})^2$$
$$= - T_{kin} \cdot 2\, M_C$$

Analyzing power, A_N

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

At low $-t$ A_N arises from interference of:

- EM (coulomb) spin-flip amplitude
- hadronic (nuclear) non-flip amplitude

$\Rightarrow$ Coulomb-Nuclear Interference (CNI)

Need to know A_N to extract P_B from raw asymmetry measurement

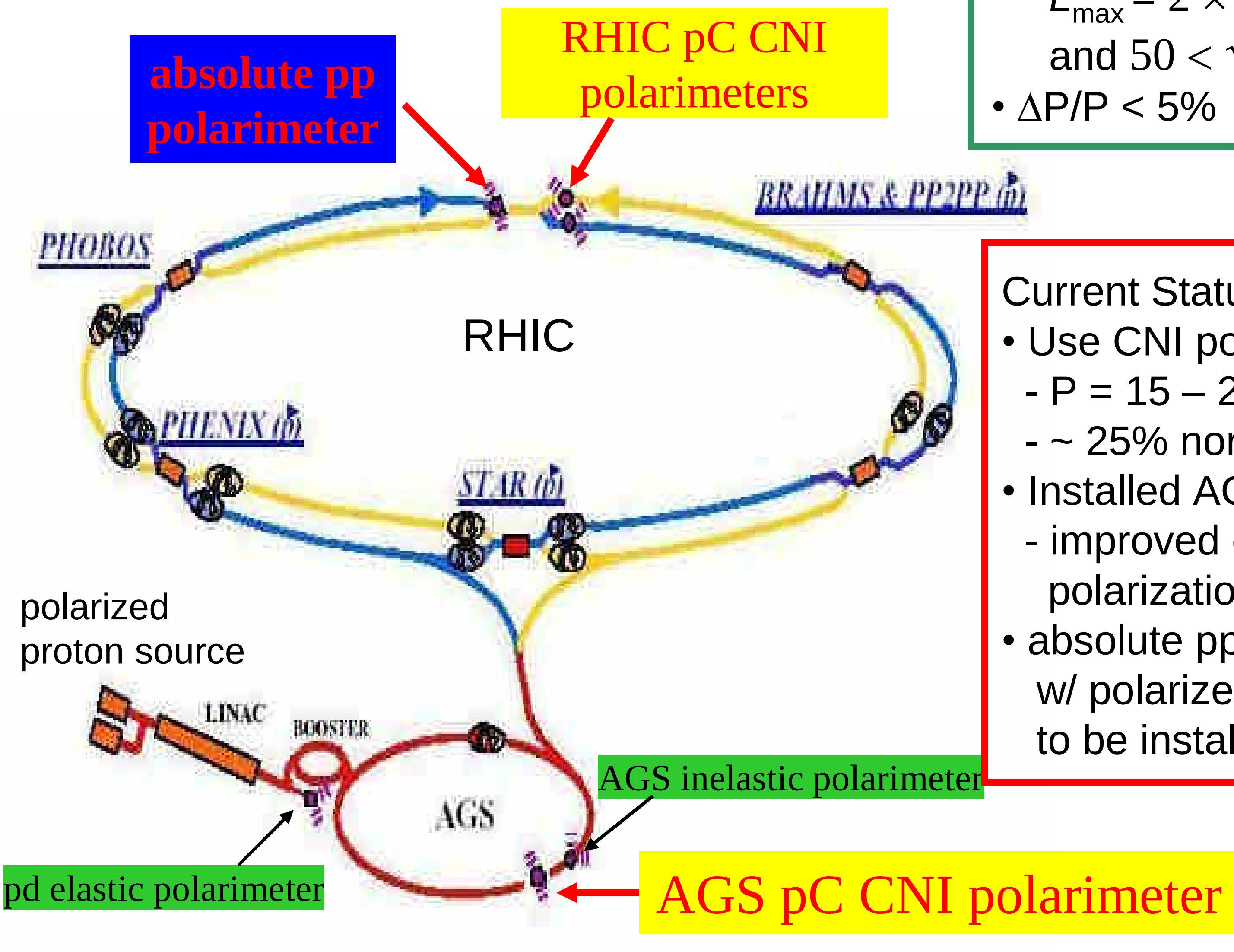
- A_N from fit to E950 data (L. Trueman hep-ph/0305085)
- ~25% relative error

RHIC Spin Facility

RHIC Spin Goals:
- 70% Polarization at

  $L_{max} = 2 \times 10^{32}\ s^{-1}cm^{-2}$

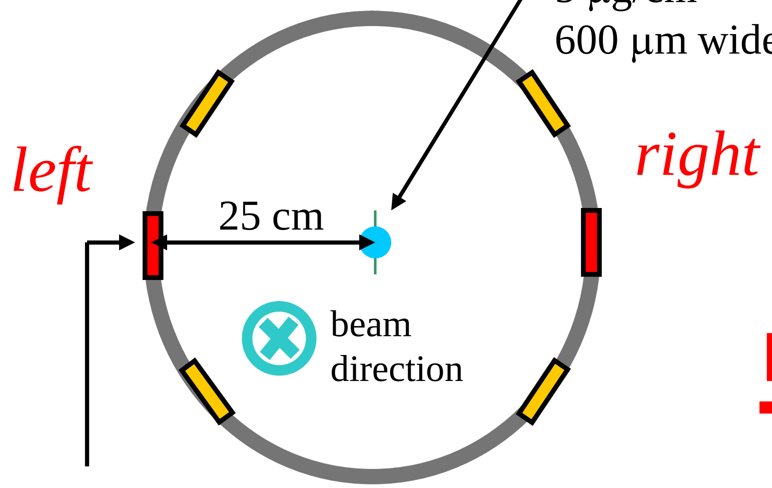
  and $50 < \sqrt{s} < 500$ GeV
- $\Delta P/P < 5\%$



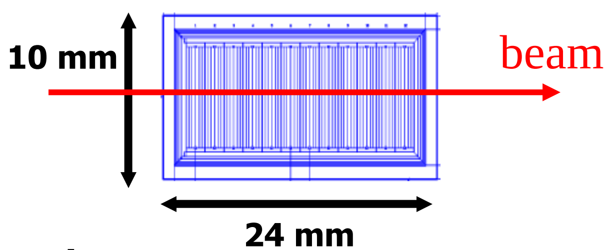
Current Status:
- Use CNI polarimeters
  - P = 15 – 27% in RHIC 02
  - ~ 25% norm. error
- Installed AGS CNI in 03
  - improved diagnostics and polarization
- absolute pp polarimeter w/ polarized H jet target to be installed in 04

Setup of the AGS CNI Polarimeter

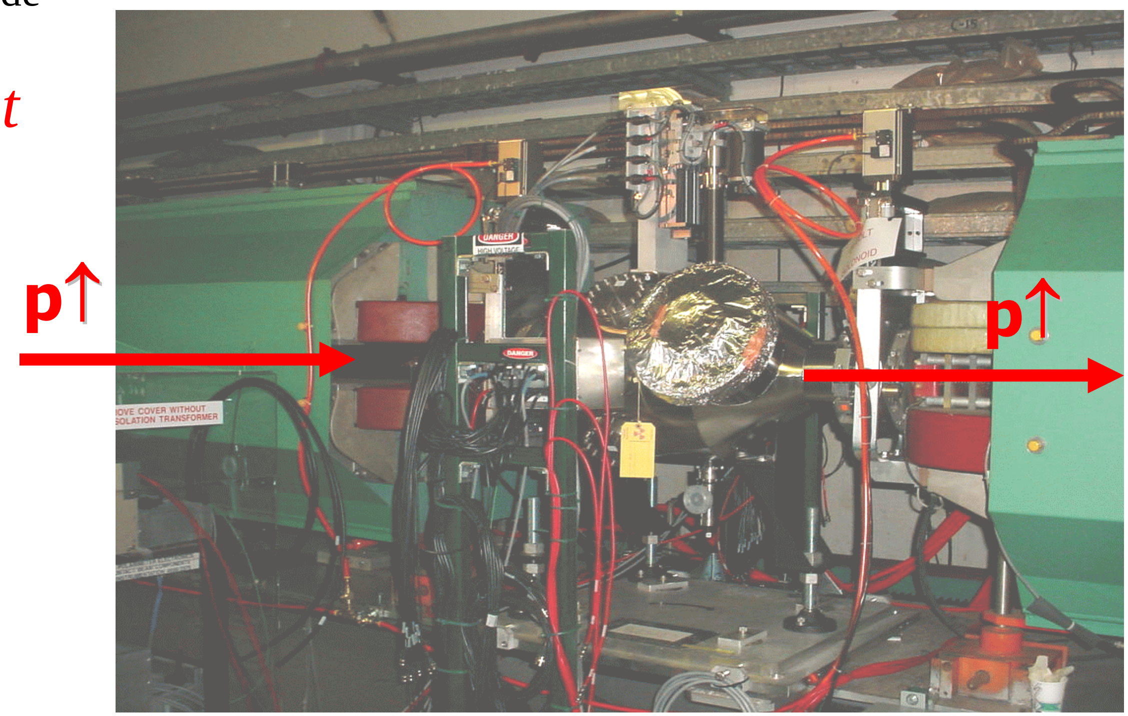
ultra-thin Carbon
ribbon (target)
5 $\mu g/cm^2$
600 μm wide



Si strip detectors
12 vertical strips



read-out with
waveform digitizers



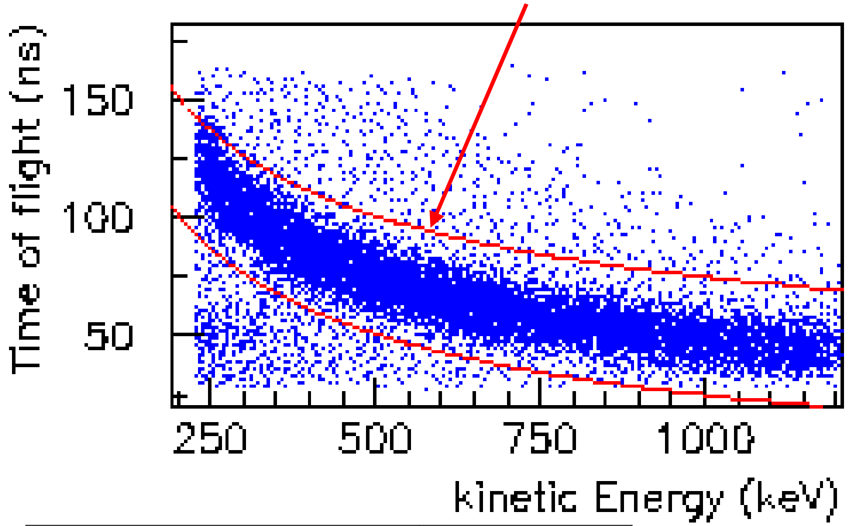
similar setups in RHIC for each beam

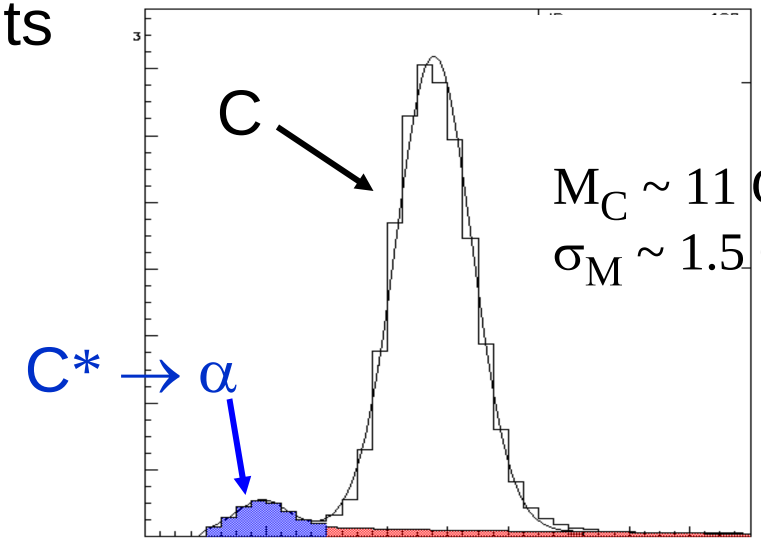
Event Selection

- Recoil carbons detected with Si detectors
- Select carbons with tof vs. T_{kin} correlation
- Δtof ~ 20 ns from bunch length
- ~ 3 % background events within "banana" cut
- Very high event rate (> 10^5 event/s/ch)

non-relativistic kinematics

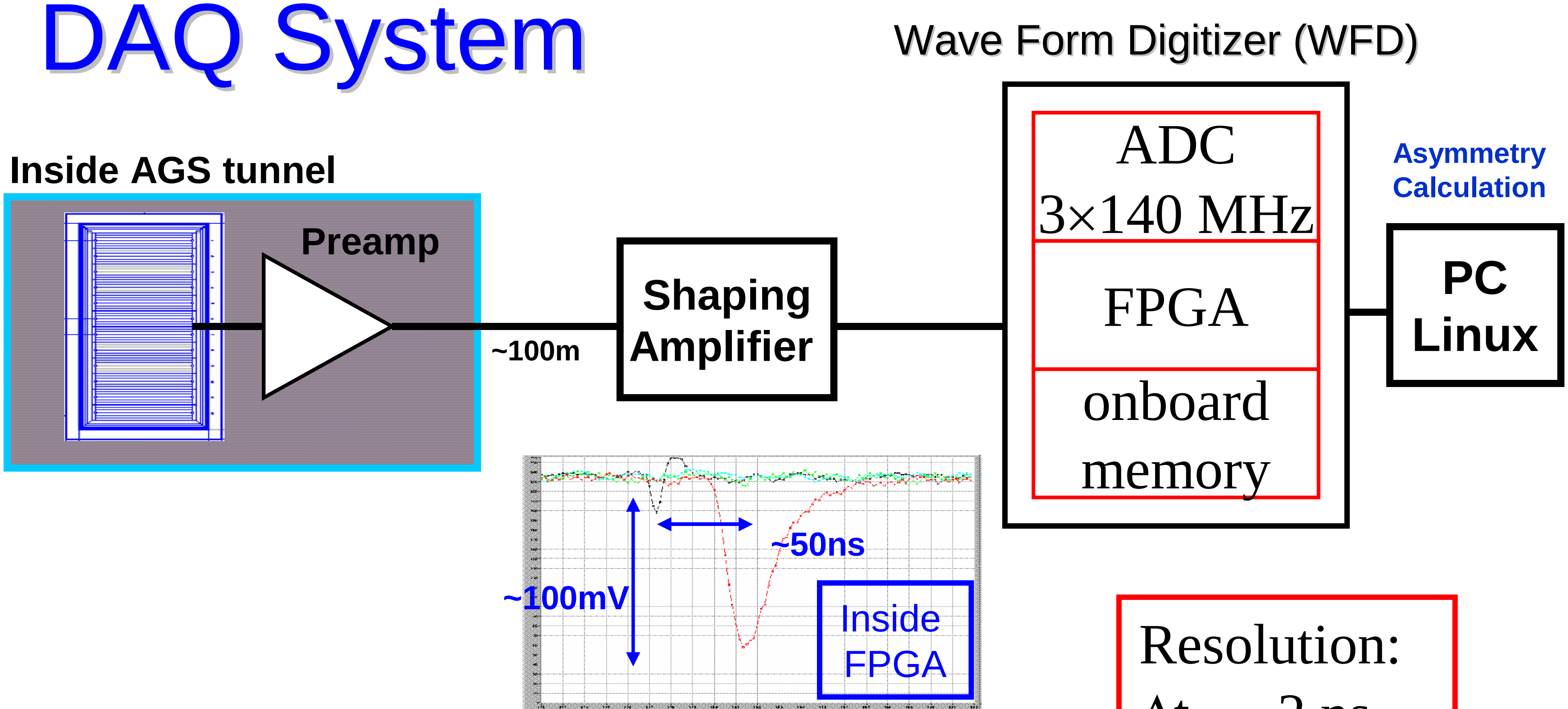
$$tof = \sqrt{\frac{M_C}{2T_{kin}}}L$$





mass distribution

DAQ System



Resolution:
$\Delta t \sim 2$ ns
$\Delta E < 50$ keV

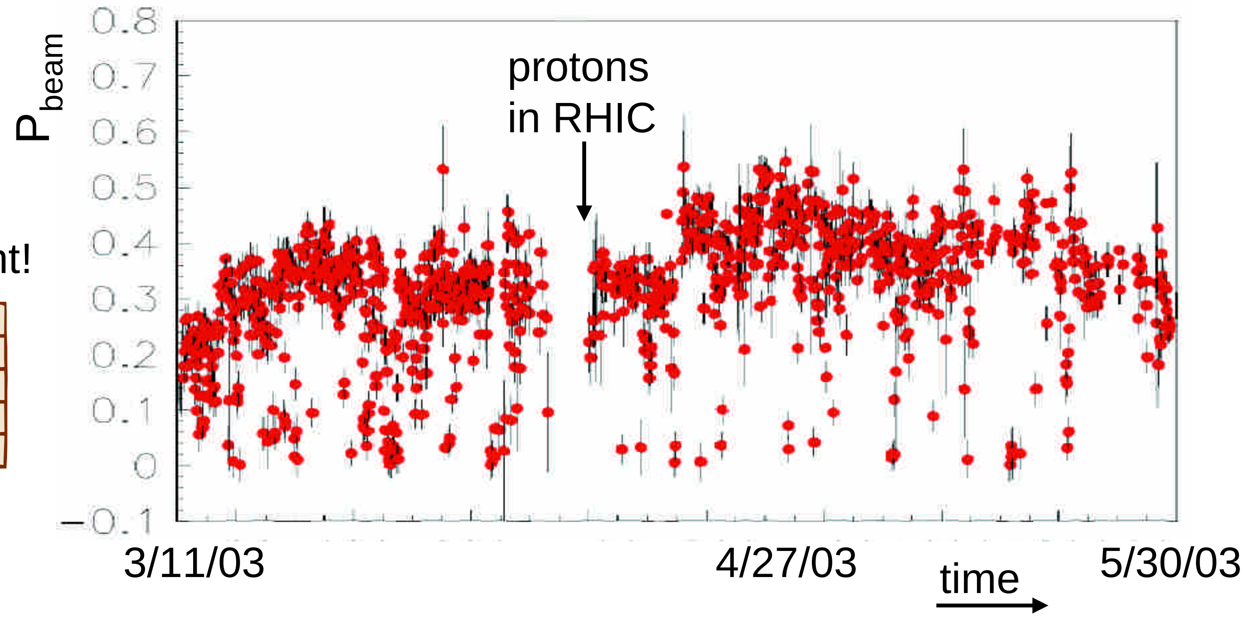
Features of WFD system:

- use accelerator clock to trigger
  bunch crossing ⇒ start TDC
- "online" waveform analysis between each bunch crossing
  pulse height, total charge, tof
- deadtimeless DAQ system
  can accept, analyze and store 1 event / Si channel for each bunch crossing

2003 Polarization Results

Polarization in the AGS

Improvement!



- Fast feedback ⇒ tune many machine parameters
- Polarization generally increased throughout the run

Polarization in RHIC

At injection:

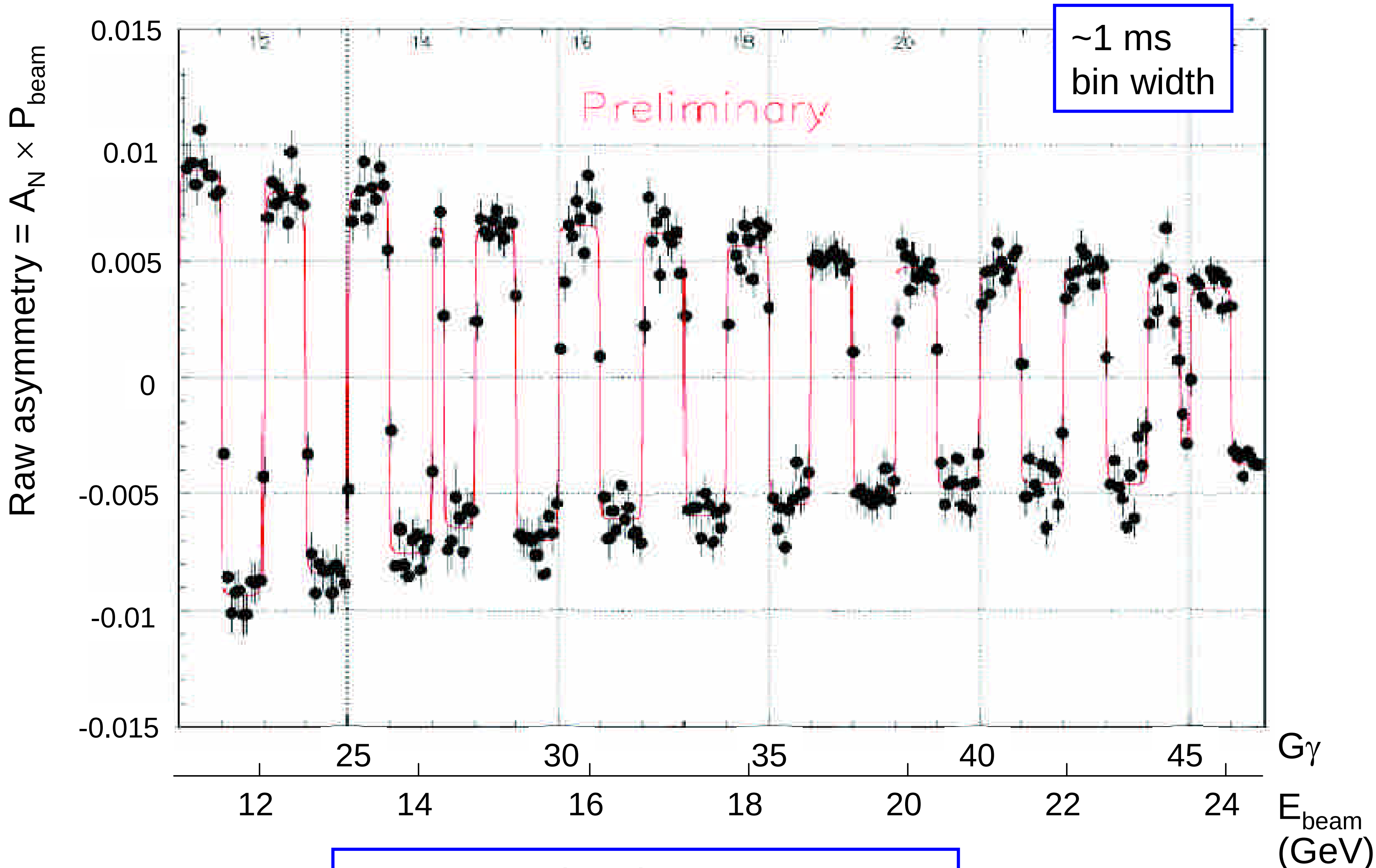
- Blue ~ 35 – 40%
- Yellow ~ 35 – 40%

At flattop:

- Blue ~ 25 – 35%
- Yellow ~ 20 – 30%

Almost 2 × improvement (on average) from 02 run

Asymmetry during AGS Acceleration



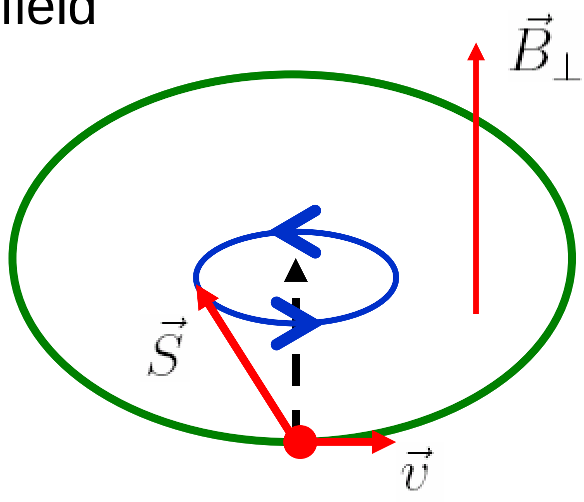
Asymmetry flips sign at every Gγ = n

Spin Dynamics

- Spin precesses as it moves through vertical field

Define "spin tune" ν_{sp}:
number of spin precessions / revolution

$\boxed{\nu_{sp} = G\gamma}$ (for pure vertical field)



- Horizontal focusing fields and fringe fields can "kick" spin away from stable direction

Depolarizing resonance condition:

spin precession in phase with horizontal perturbing field

e.g. imperfection resonances – from magnet errors and misalignments

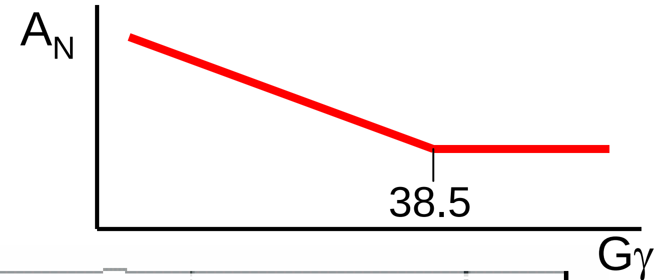
$\boxed{\nu_{sp} = G\gamma = n}$

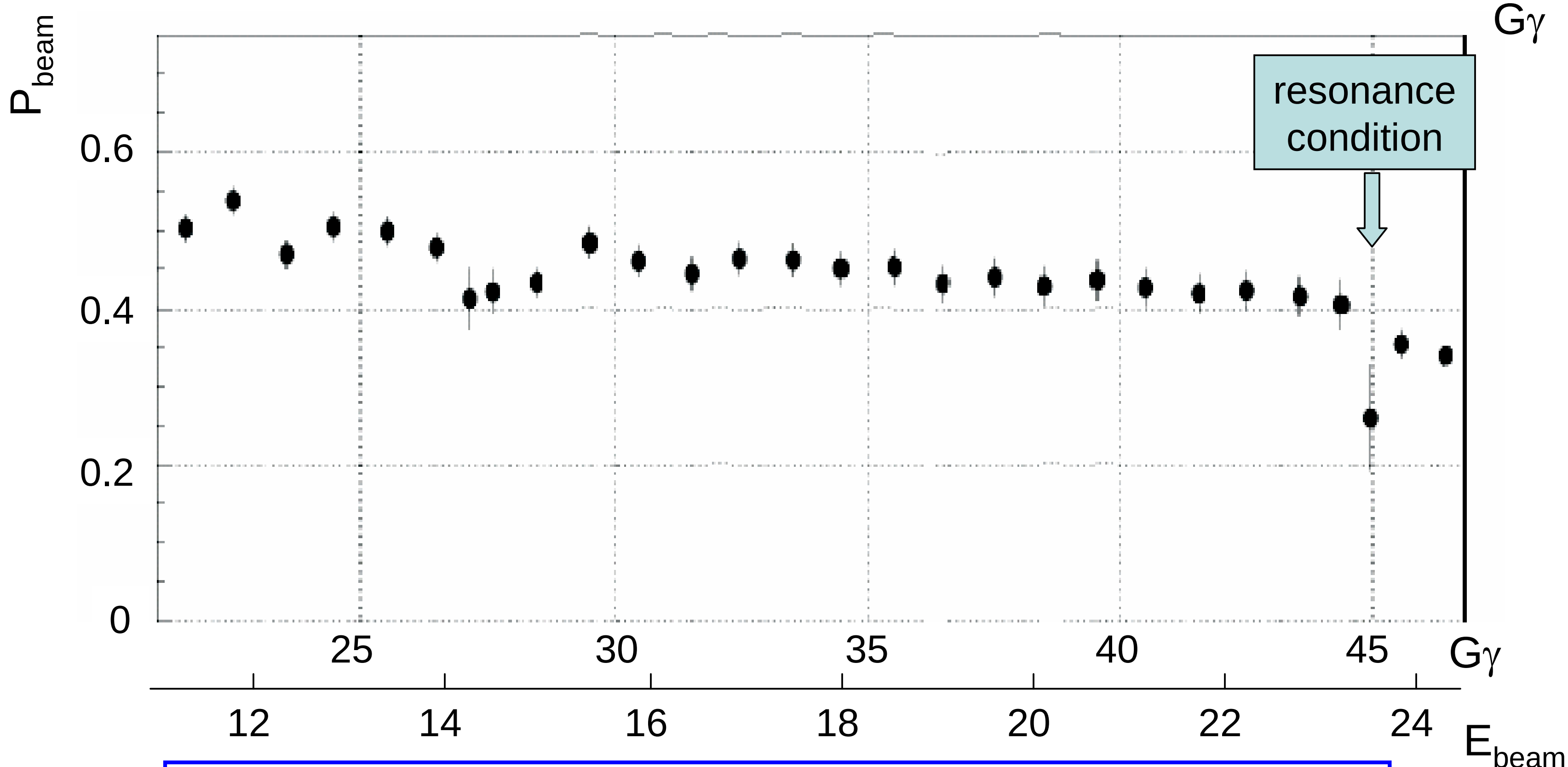
Correcting for resonance conditions:
devices in AGS (partial Siberian snake, pulsed RF dipole)
cause strong enough kick to flip stable spin direction 180°
as resonances are crossed $\Rightarrow$ polarization preserved

Polarization during AGS Acceleration

Model for Gγ dependence of A_N

- Interpolate A_N from measurements at Gγ = 18.5, 24.5 and 41.5
- A_N constant for Gγ = 38.5 – 46.5





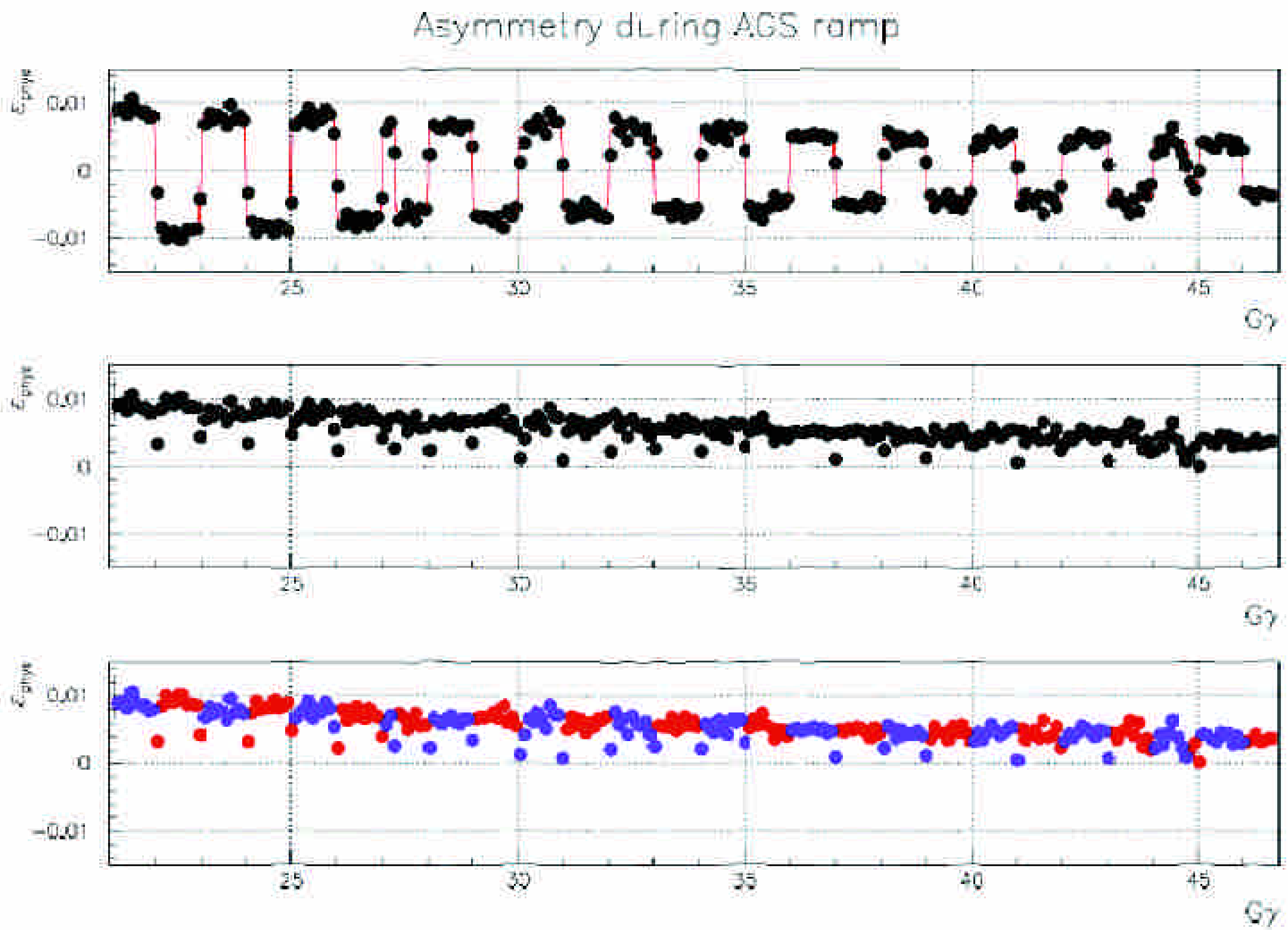
- Consistent with smooth polarization loss from 11 to 23 GeV
- ~15% loss at strong intrinsic resonance

Summary

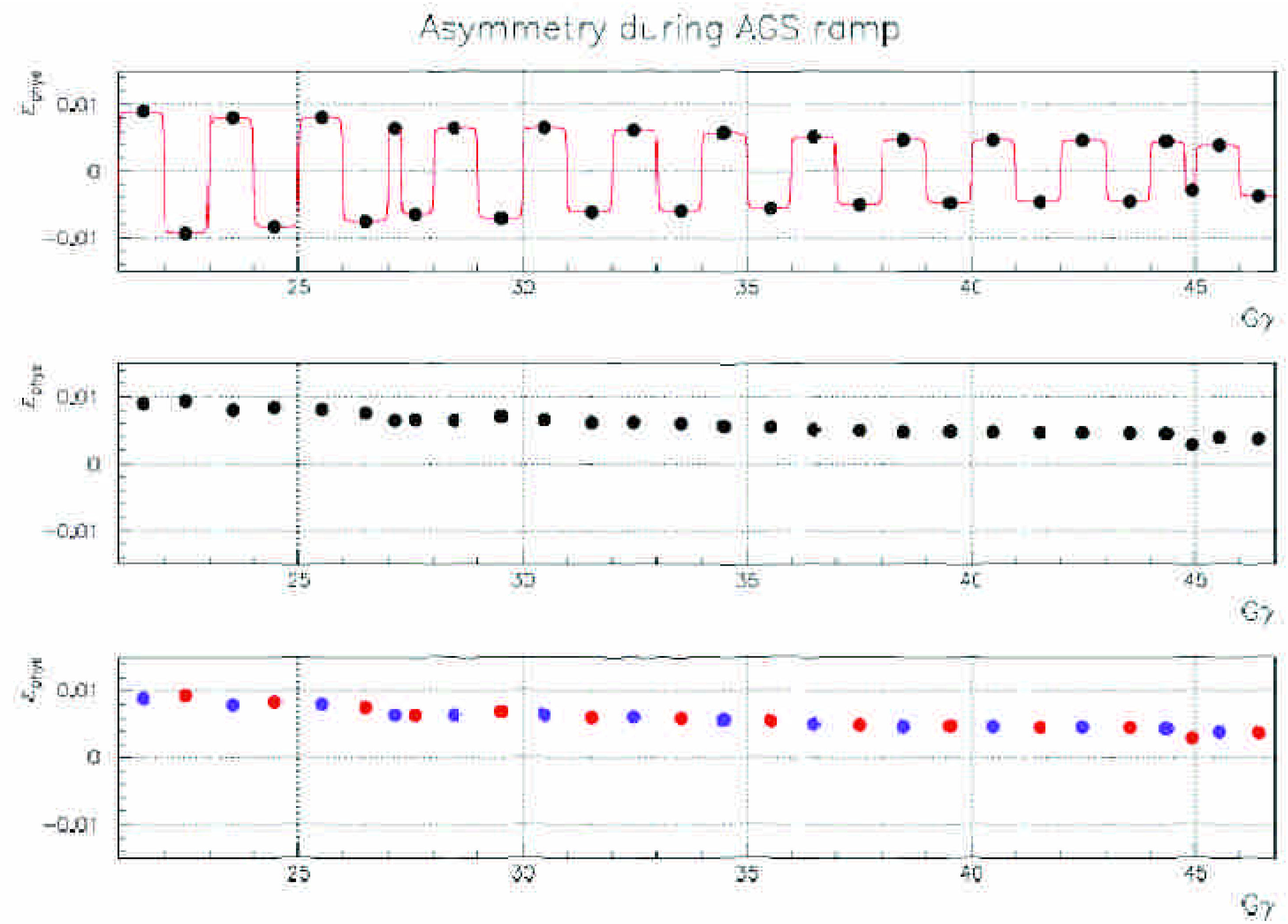
- CNI Polarimetry
  - pC elastic scattering at $-t \sim 10^{-3}$ $(\mathrm{GeV}/c)^2$
  - Very thin carbon target (5 μg/cm^2)
  - Si strip detectors – recoil carbons
  - Deadtimeless DAQ with WFDs
- CNI Results
  - Provided P_{beam} info for RHIC 02 and 03 runs
  - Fast diagnostic tool in AGS
  - Detailed study of spin dynamics in AGS

Supplemental Slides …

Asymmetry during AGS Ramp



Asymmetry averaged each spin flip

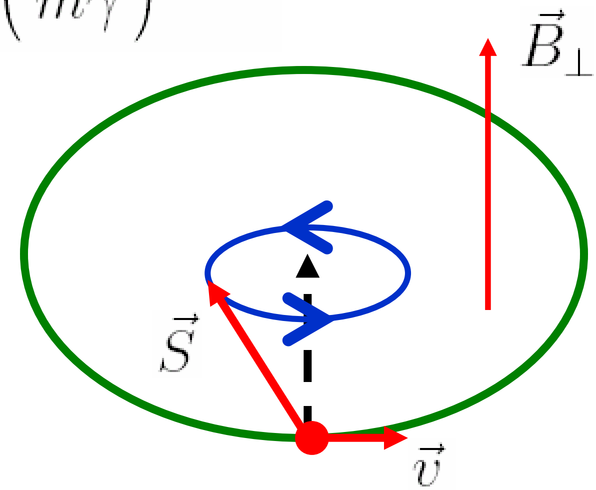


Spin Dynamics

Spin direction and orbital motion governed by:
(for pure vertical field)

Thomas-BMT Equation
$$\frac{d\vec{S}}{dt} = -G\gamma\left(\frac{e\vec{B}_\perp}{m\gamma}\right)\times\vec{S}$$

Lorentz Force Equation
$$\frac{d\vec{v}}{dt} = -\left(\frac{e\vec{B}_\perp}{m\gamma}\right)\times\vec{v}$$



Define "spin tune" ν_{sp}:
number of spin precessions / revolution

$$\boxed{\nu_{sp} = G\gamma}$$

Depolarizing resonance condition:
focusing fields and fringe fields can "kick" spin away from stable direction

$\boxed{\text{spin precession in phase with horizontal perturbing field}}$

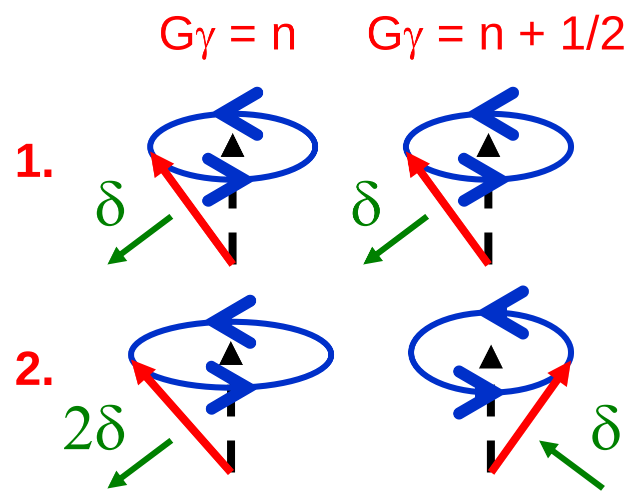
Resonance Conditions

Imperfection resonances

Cause: magnet errors and misalignments, closed orbit errors, …

$$\boxed{\nu_{sp} = G\gamma = n}$$

Correction: partial Siberian snake – gives strong enough kick to flip stable spin direction 180° at $G\gamma = n$



Intrinsic resonances

Cause: vertical focusing fields, finite beam emittance

$$\boxed{\nu_{sp} = G\gamma = Pn \pm \nu_y}$$

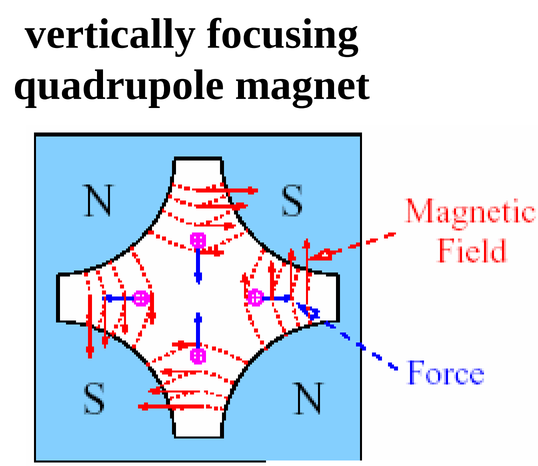
P = Superperiodicity (= 12 for AGS)

ν_y = vert. Betatron tune (= 8.7 for AGS)

Correction: pulsed RF dipole – increases vertical oscillation amplitude

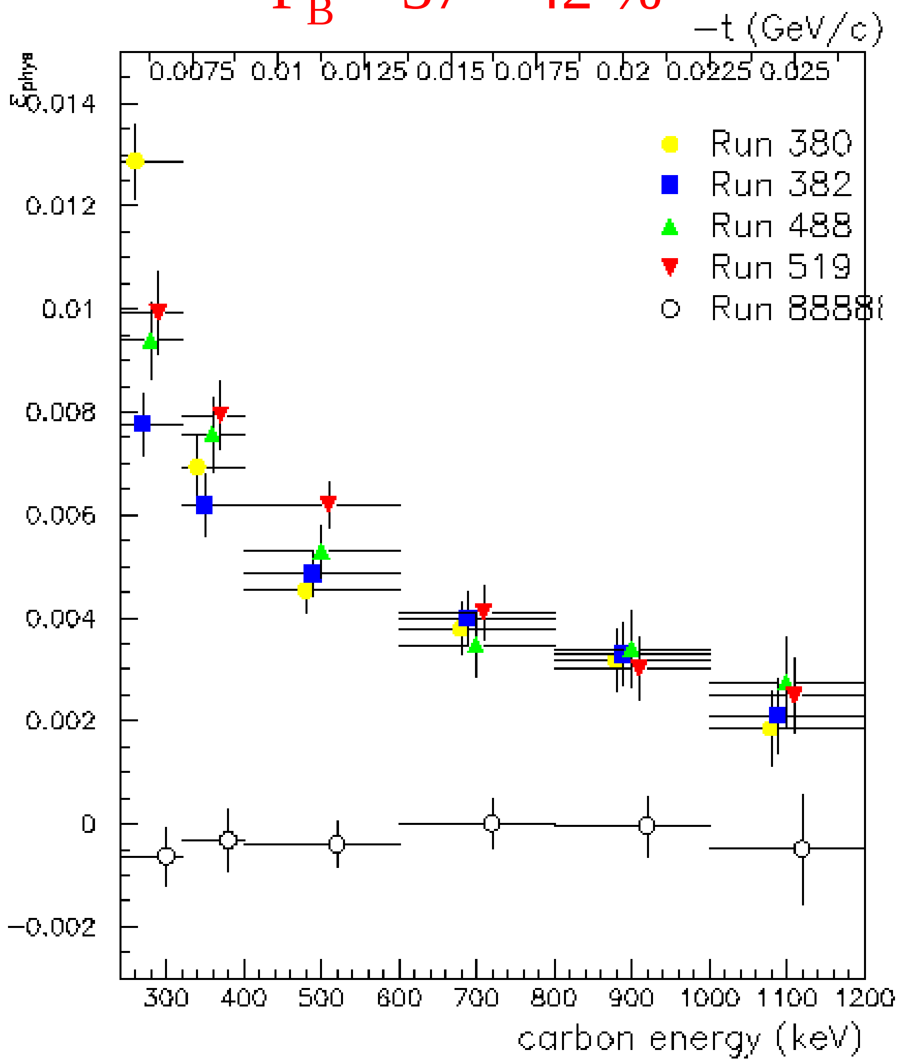
stronger kick from quad. focusing field

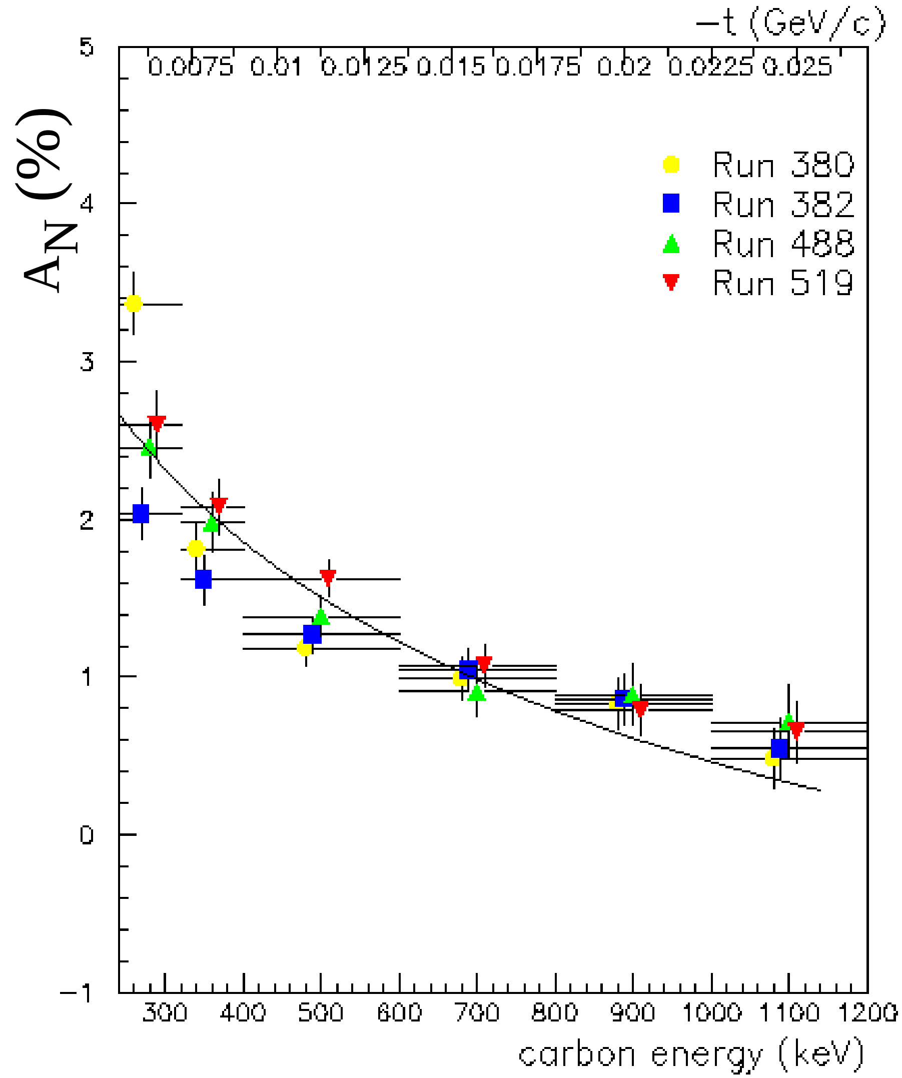
$\Rightarrow$ full spin flip & polarization preserved



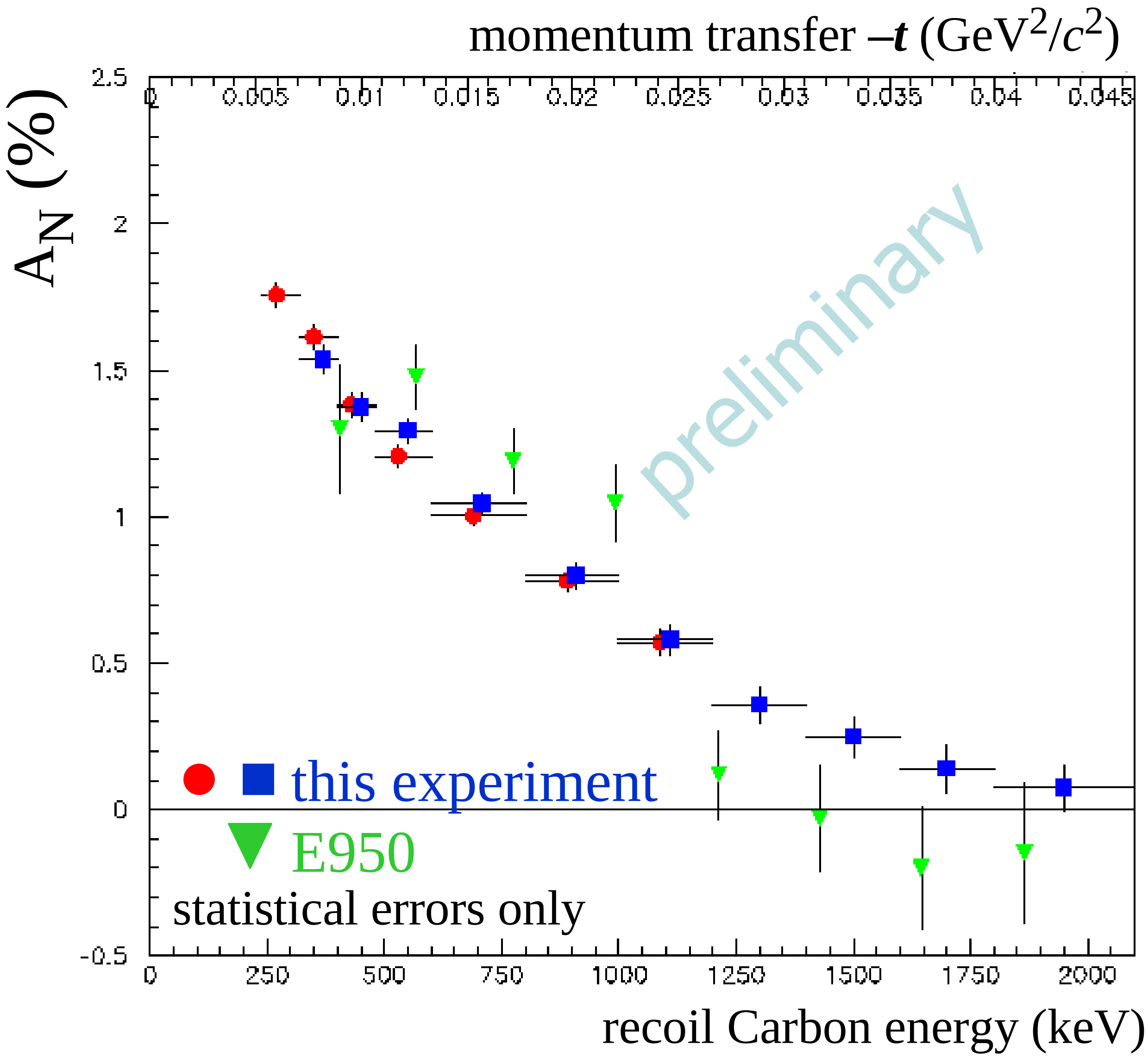
Asymmetry and A_N at 24.3 GeV

$P_B \sim 37 - 42\ \%$



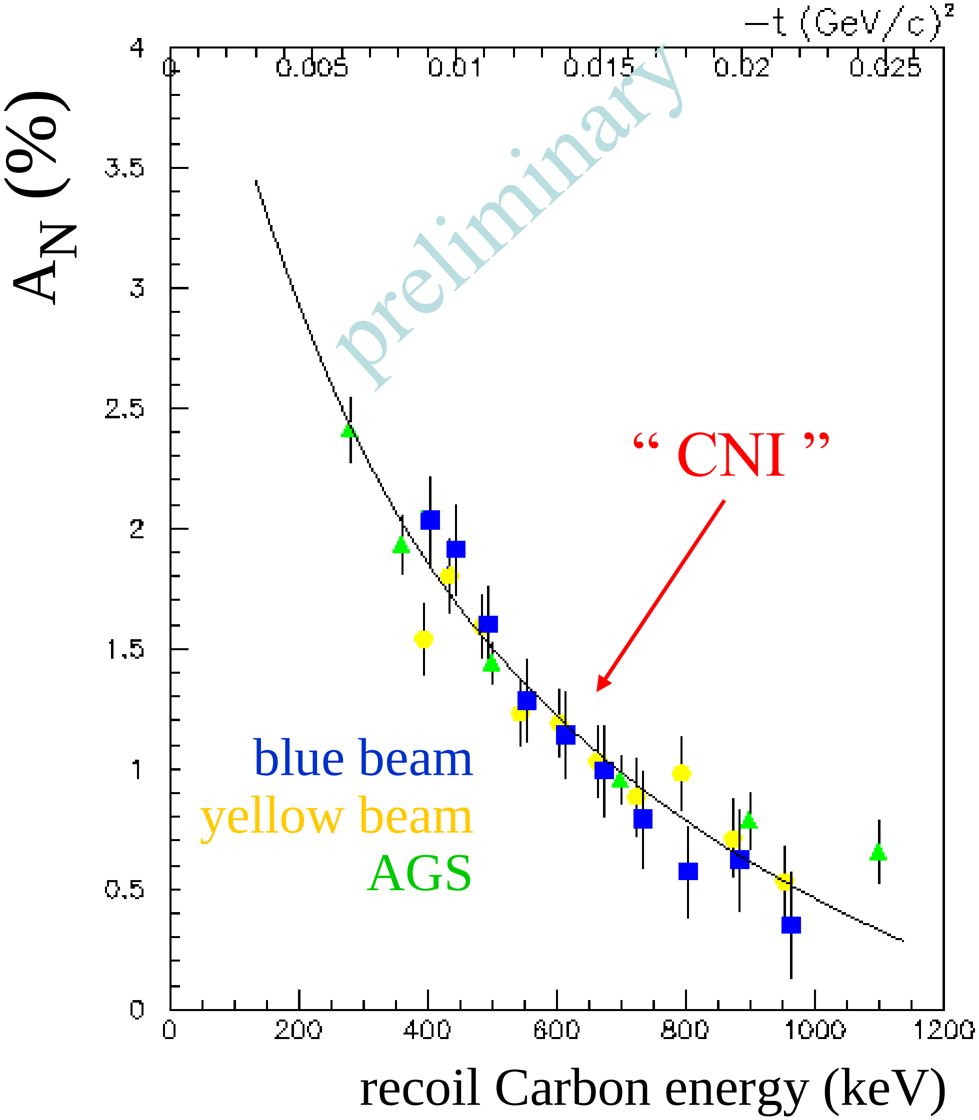


A_N at 21.7 GeV



momentum transfer –t (GeV²/c²)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
A_N (%)
2.5
2
1.5
1
0.5
0
-0.5
preliminary
this experiment
E950
statistical errors only
0
250
500
750
1000
1250
1500
1750
2000
recoil Carbon energy (keV)

A_N at RHIC energy (100 GeV)



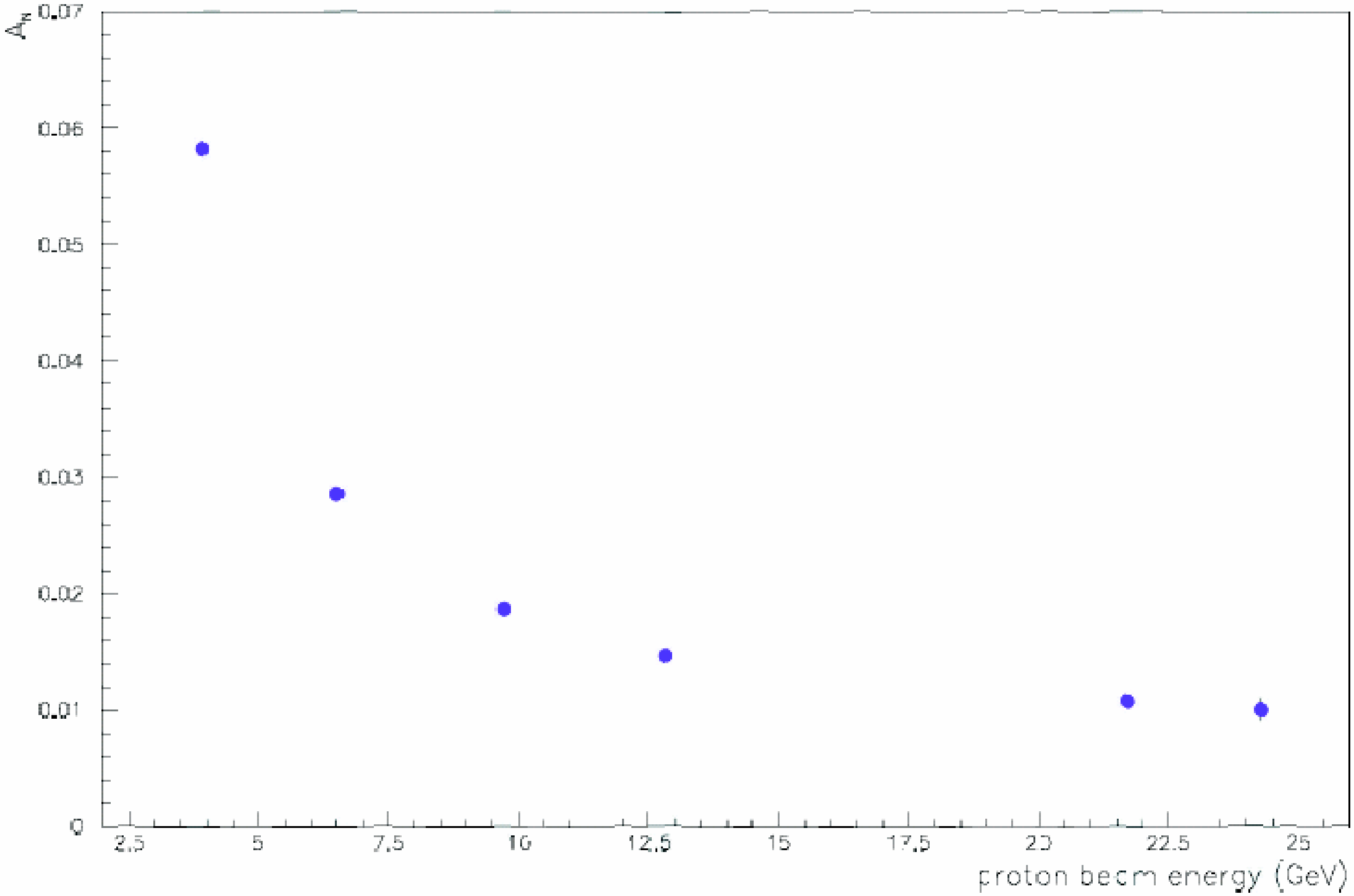
for normalization assume
A_N (24.3 GeV) = A_N (100 GeV)
i.e. no energy dependence
[$0.009 < |t| < 0.022$ $(\text{GeV}/c)^2$]

very similar shape of the ***t*** dependence at 24 and 100 GeV

⇒ suggestive of very small energy dependence for A_N between 24 and 100 GeV

systematic error for RHIC data < 30 %

A_N vs. Beam Energy



A_N –t dependence