Improving the AGS Polarization with 80 Tune Jumps

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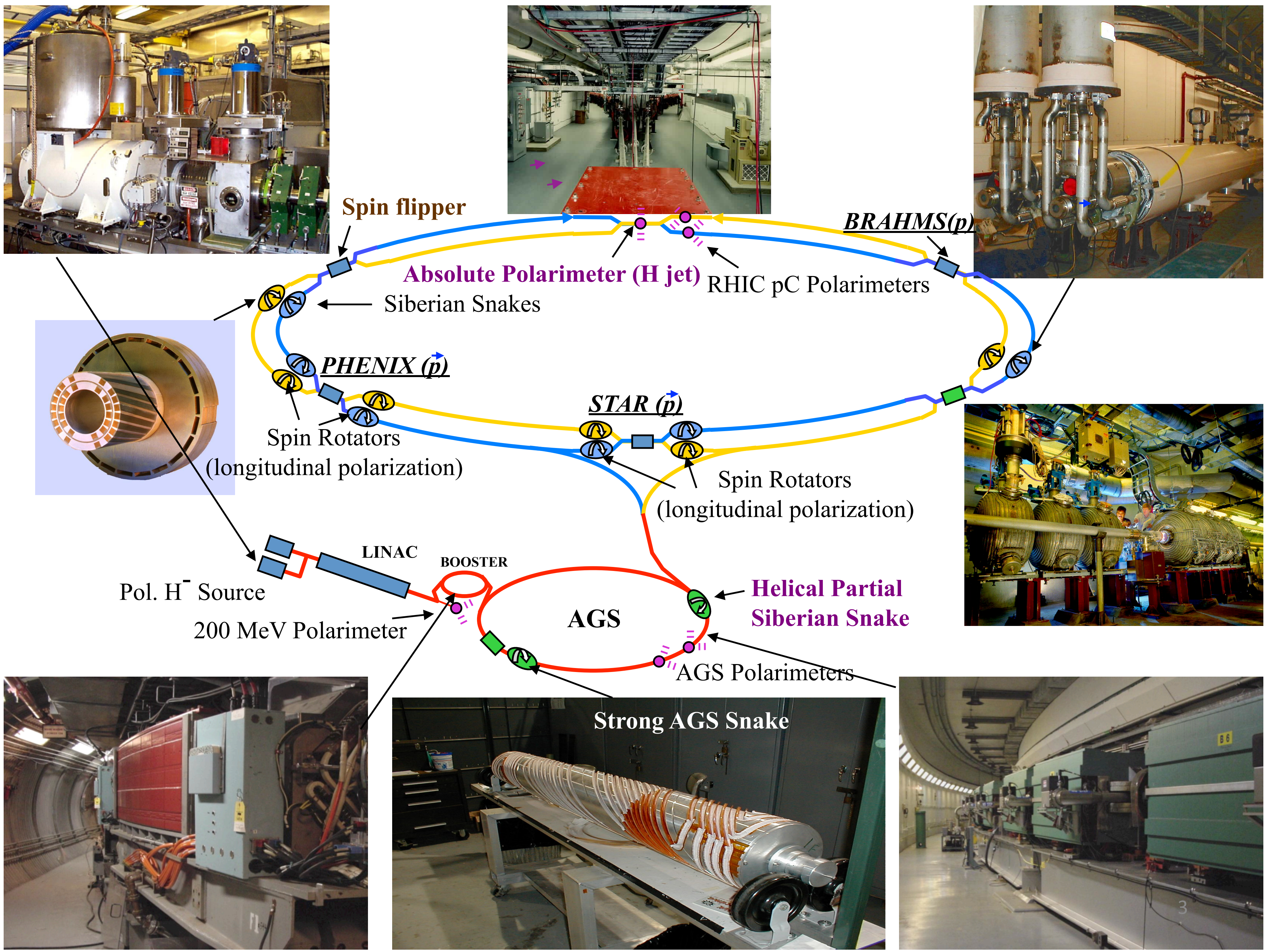
Overview

- Overview of recent improvements to RHIC polarized proton performance

- Why do we need a tune jump?
  - Depolarization mechanisms in the AGS

- AGS Horizontal Tune Jump system
  - Principle and implementation
  - Operational experience


Spin flipper
Absolute Polarimeter (H jet)
RHIC pC Polarimeters
BRAHMS(p)
Siberian Snakes
PHENIX (p)
STAR (p)
Spin Rotators
(longitudinal polarization)
Spin Rotators
(longitudinal polarization)
LINAC
BOOSTER
Pol. H⁻ Source
200 MeV Polarimeter
AGS
Helical Partial
Siberian Snake
AGS Polarimeters
Strong AGS Snake

RHIC Polarized Protons: Run 12

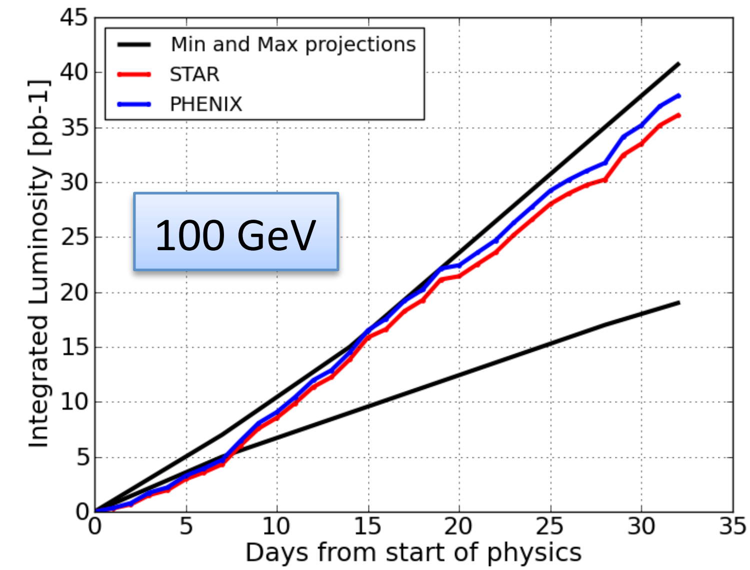
Run 12 was very successful

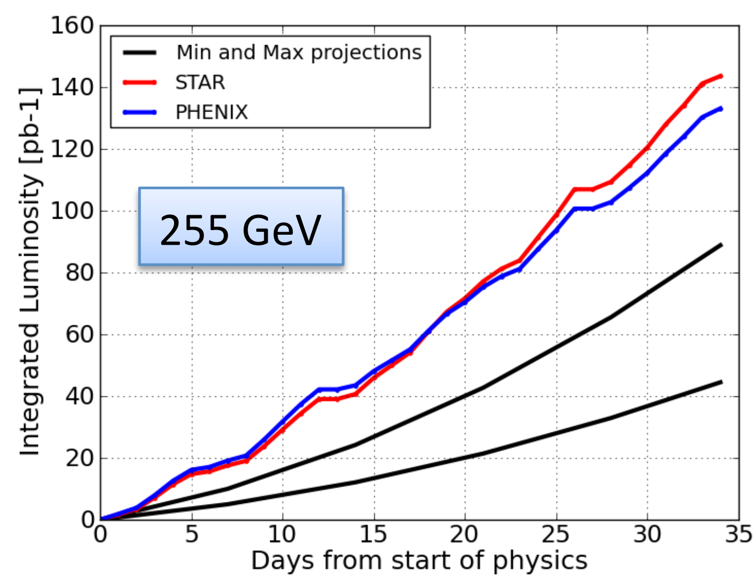
Operation at both 100 and 255 GeV programs (5 weeks each)

Met or exceeded all luminosity goals

The increase to 255 GeV is a new record for polarized proton collisions

The increase was motivated by an attemp to improve polarization decay at store (see MOPPC025)

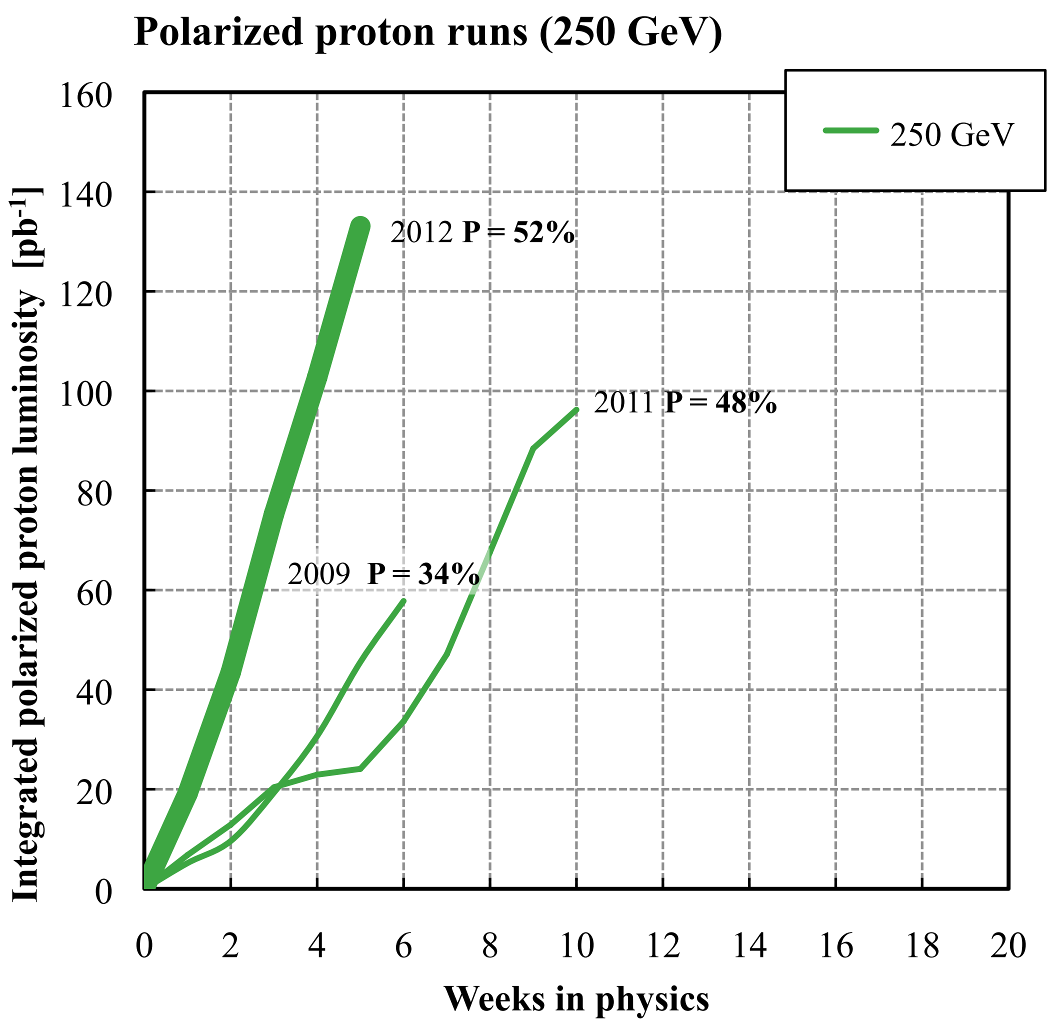




Luminosity Developments

- 9 MHz RF system
  - Longer bunches
  - Higher intensity with no e-cloud
- Polarized proton source improvements
- Feedback control of orbit, tune and coupling

	Intensity [10^{11}/ bunch]	Peak Lumi [10^{30} $cm^{-2}s^{-1}$]	Avg Lumi [10^{30} $cm^{-2}s^{-1}$]
Run-9	1.1	85	55
Run-11	1.65	145	90
Run-12	1.7	165	105



Polarization Developments

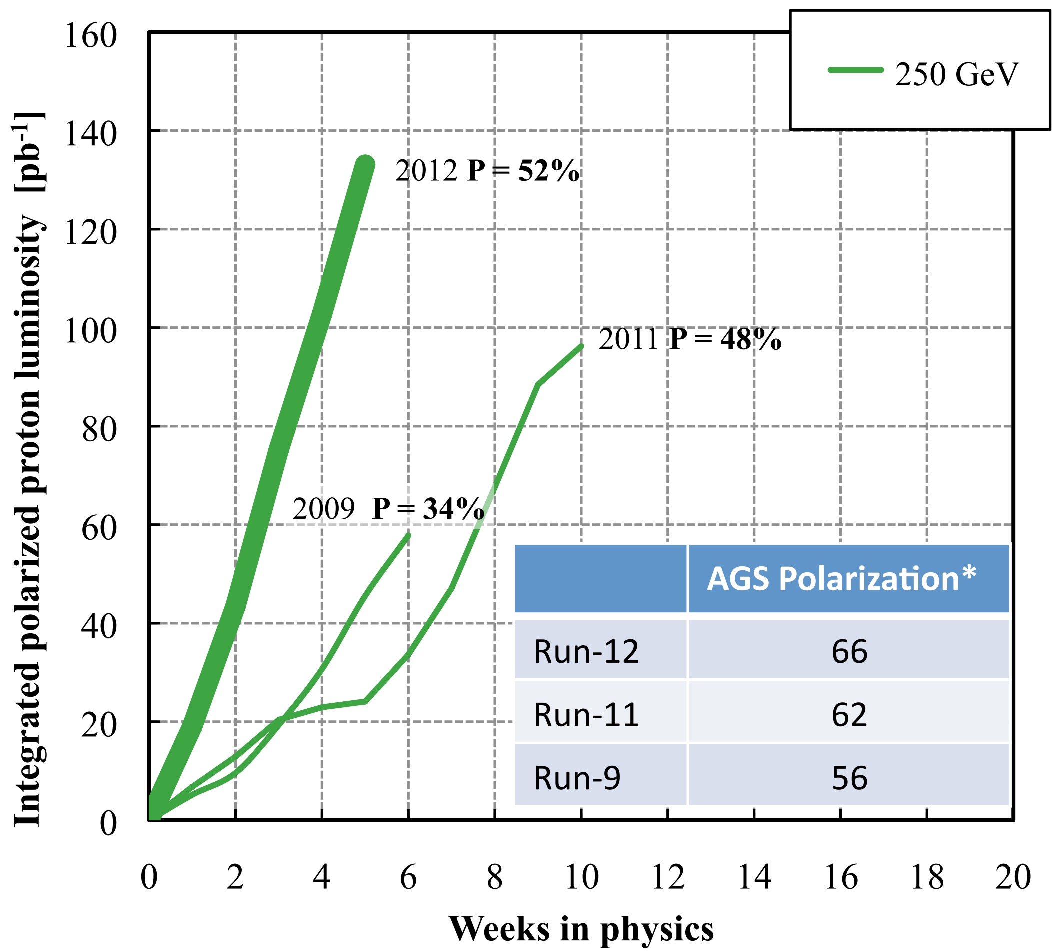
- 2011 → 2012
  - Incremental improvements
    - Lower emittance (source)
    - RHIC snake adjustments
    - Precise resonance correction in Booster

- 2009 → 2011
  - RHIC ramp vertical tune of 0.672 (avoids 0.7 snake resonance)
    - Enabled by feedback

AGS Horizontal Tune Jump

Polarization at AGS extraction +10% (relative)

Polarized proton runs (250 GeV)



	AGS Polarization*
Run-12	66
Run-11	62
Run-9	56

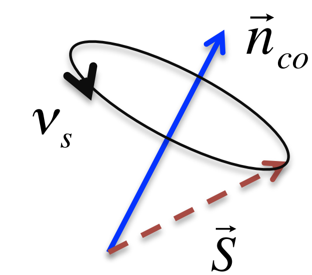
* At an intensity of 2.0×10^{11}

Spin Resonances

Thomas-BMT
(No E-fields)

$$\frac{d\vec{S}}{dt} = \frac{e}{\gamma m}\vec{S} \times \left[(1+G\gamma)\vec{B}_{\perp} + (1+G)\vec{B}_{\parallel}\right]$$

In a periodic lattice, can define a one turn map on the closed orbit: $e^{-i\pi\nu_s \hat{n}_{co} \cdot \vec{\sigma}}$



In a planar, ideal synchrotron:

Stable spin direction = n_{co} = vertical
Spin tune = ν_s = Gγ (energy dependent)

For vertical stable spin direction, it is horizontal magnetic fields that drive depolarization via resonant kicks away from vertical:

Particles sample horizontal B fields from:

- Non-zero vertical closed orbit in quadrupoles → Imperfection Resonance: $\nu_s = G\gamma = n$
- Vertical betatron motion in quadrupoles → Intrinsic Resonance: $\nu_s = G\gamma = n \pm Q_Y$

n is any integer

Avoiding Spin Resonances in the AGS

A Siberian snake rotates the spin of the proton by an angle χ in one pass through the device

‘full’ snakes:
$\chi = 180°$

$\nu_s = ½$
n_{co} = vertical

Not enough room in the AGS!

‘partial’ snakes:
$X < 180°$

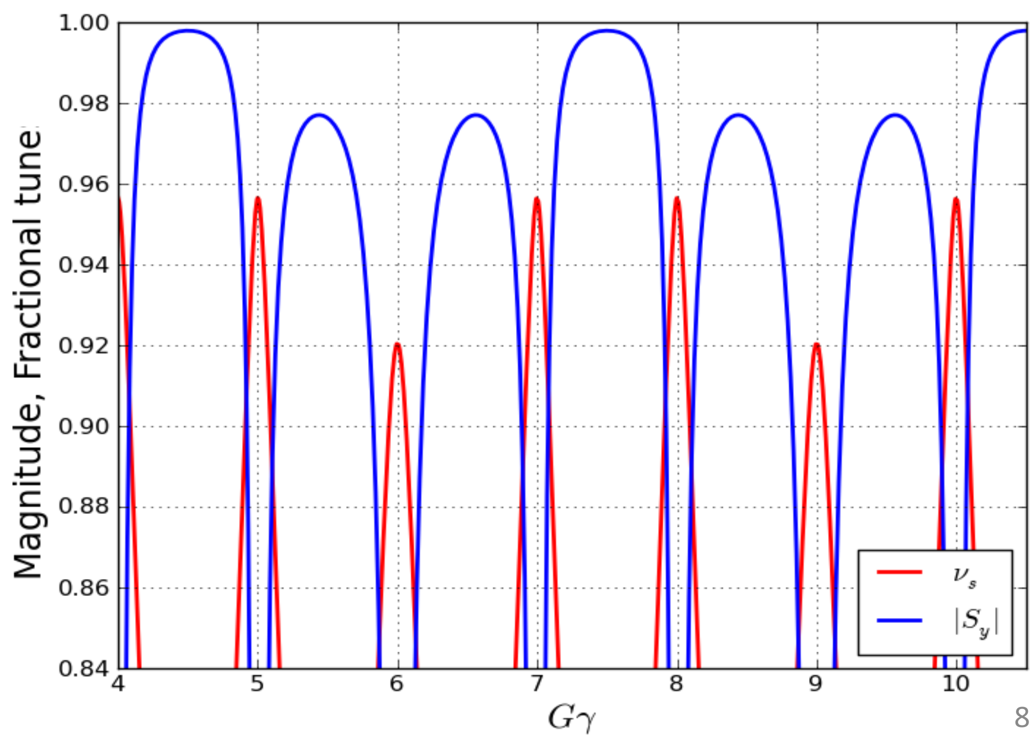
$\nu_s \neq G\gamma$
n_{co} NOT vertical

AGS has two partial snakes (helical dipoles)
$X = 6°, 10°$

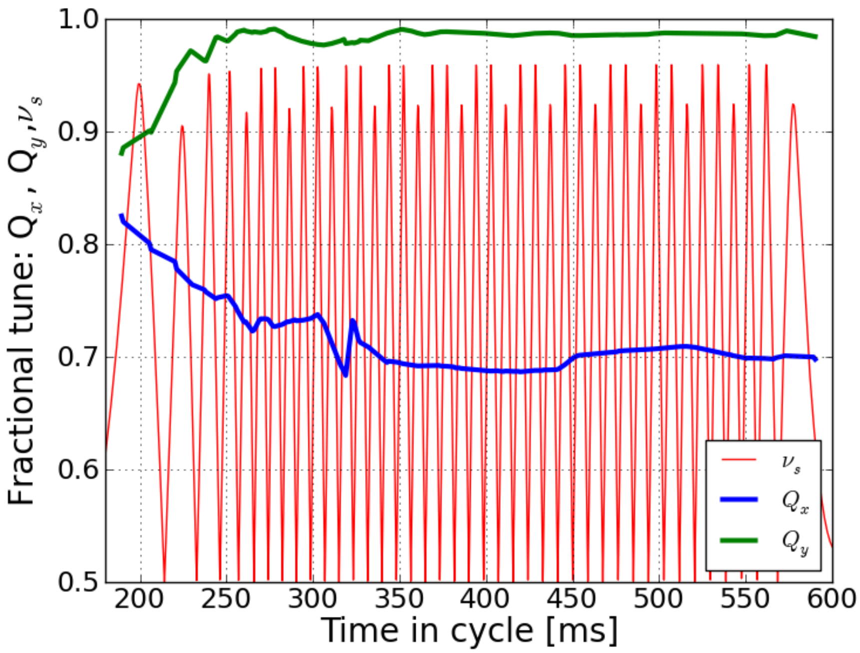
$\nu_s \neq n$
No imperfection resonance!

If Q_y near integer
$\nu_s \neq n +/- Q_y$
No vertical intrinsic resonance!

BUT:
The stable spin vector has a horizontal component
Excites horizontal resonances
$\nu_s = n +/- \mathbf{Q_x}$



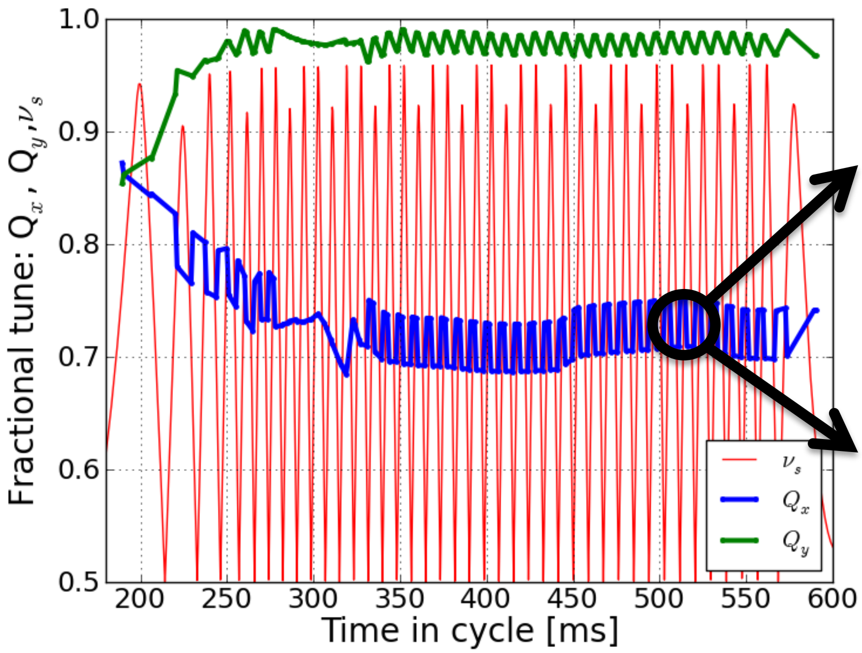
Horizontal Tune Jump

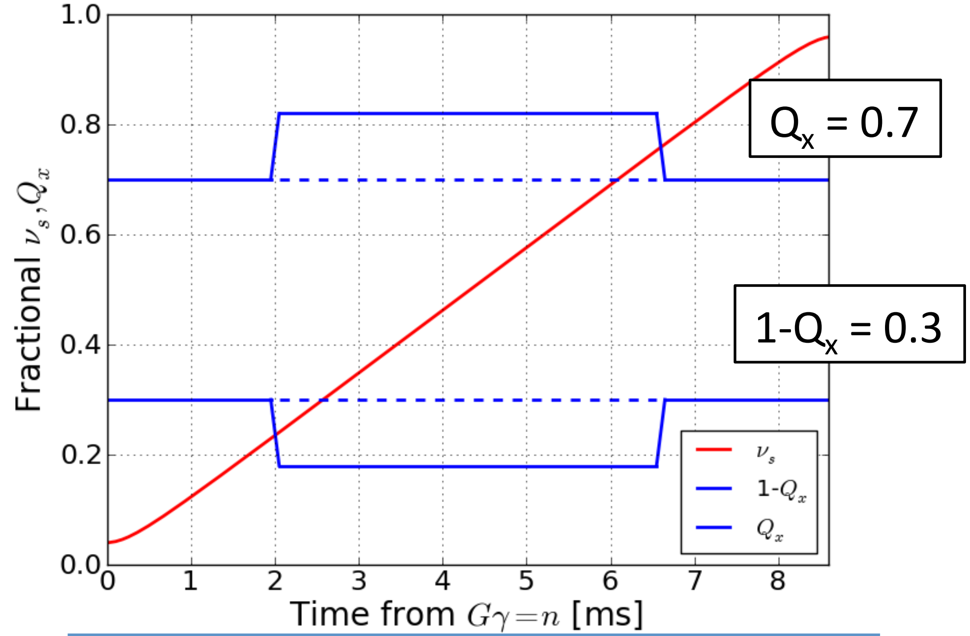


Intensity suffers too much at high Q_x, so the resonances must be crossed

With a tune jump, they can be crossed quickly

Horizontal Tune Jump





Intensity suffers too much at high Q_x, so the resonances must be crossed

With a tune jump, they can be crossed quickly

$$\frac{P_f}{P_i} = 2\exp\left[-\frac{\pi|\varepsilon|^2}{2\alpha}\right] - 1$$

Froissart-Stora

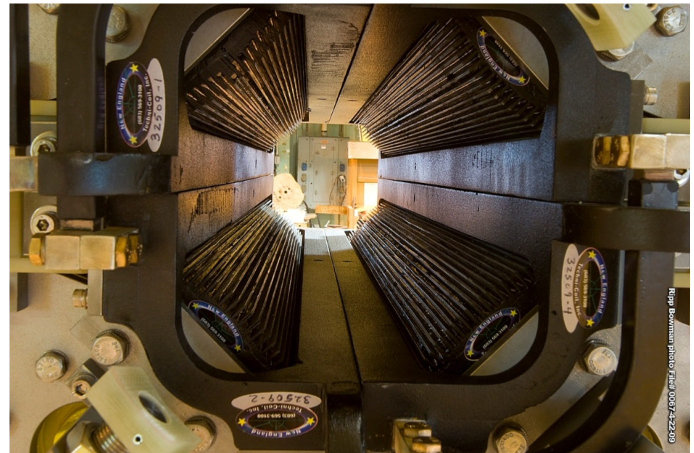
P_i, P_f = initial and final polarization

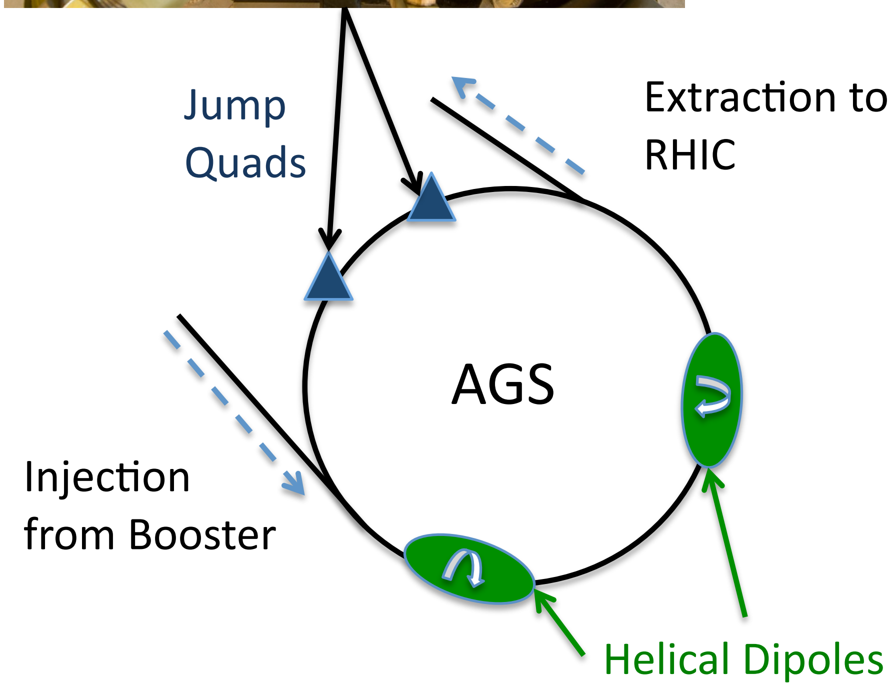
α = crossing rate

ε = resonance strength

Tune Jump Implementation

- Two identical pulsed quads, one AGS superperiod apart at β_x maxima provide the jumps
- Q_x is jumped 0.04 in 100 μs
- AGS acceleration range is $G\gamma = 4.5 – 45.5$
- 82 Horizontal resonances must be jumped



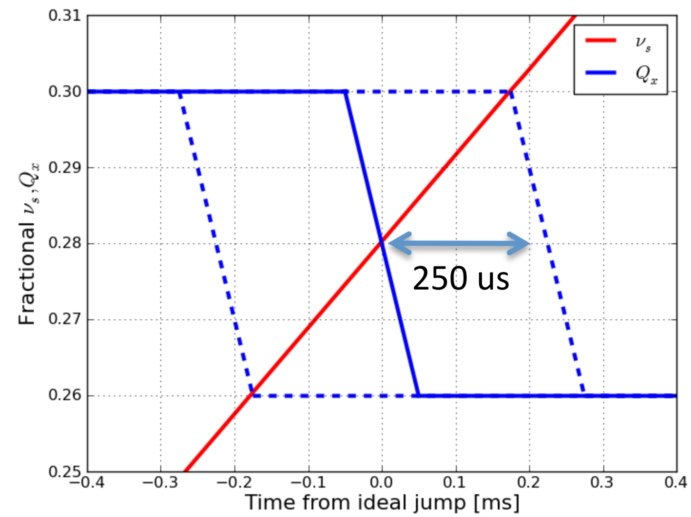


Tune Jump Implementation: Timing

Horizontal resonances result in an accumulated relative polarization loss of ~10%, distributed over all 82 jumps.

Polarization loss from a single loss cannot be measured: No empirical scans to optimize timing

Correct jump timing requires precise knowledge of Q_x and beam energy



Energy information comes from:

RF frequency	*Magnetic Field*
High precision at injection energy when $\beta \approx 0.9$ Loses sensitivity as β->1	AGS reference magnet Limited by the precision of the instrumentation

Jump timing has to be determined to < 250 μs (set by jump height and acceleration rate)
250 μs ≈ 0.02 units of Gγ

Maximum disagreement between the two energy measurements is just about 200 μs

Polarization Improvement

Depolarization from intrinsic resonances is amplitude dependent

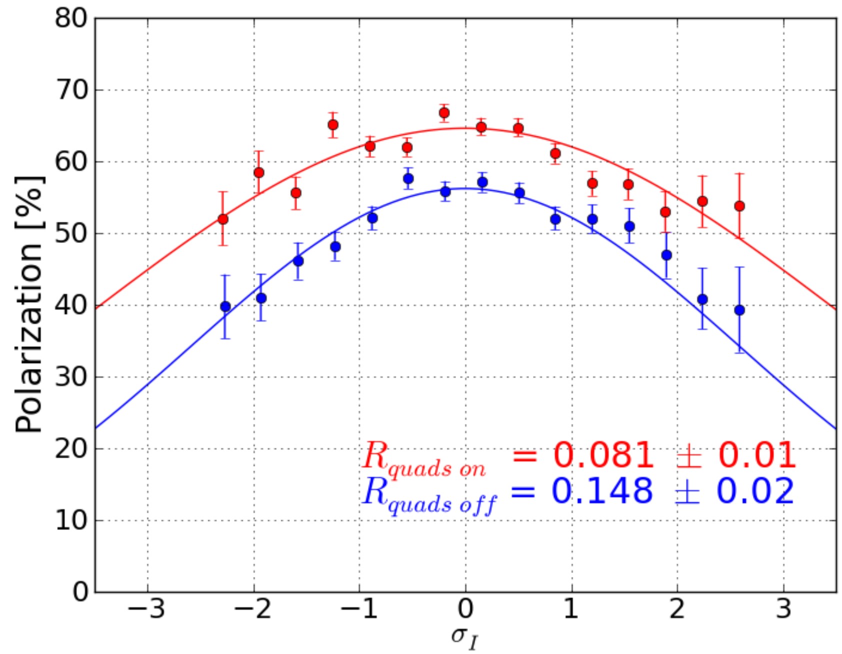
Resonance jumping improves the horizontal 'polarization profile'

The R parameter quantifies the steepness of the polarization drop-off relative to the intensity distributions:

$$R = \frac{\sigma_I^2}{\sigma_P^2}$$

σ_p, σ_I are the sigmas of the polarization and intensity profiles (fitted as Gaussian)

Ideally σ_p is large, R→0



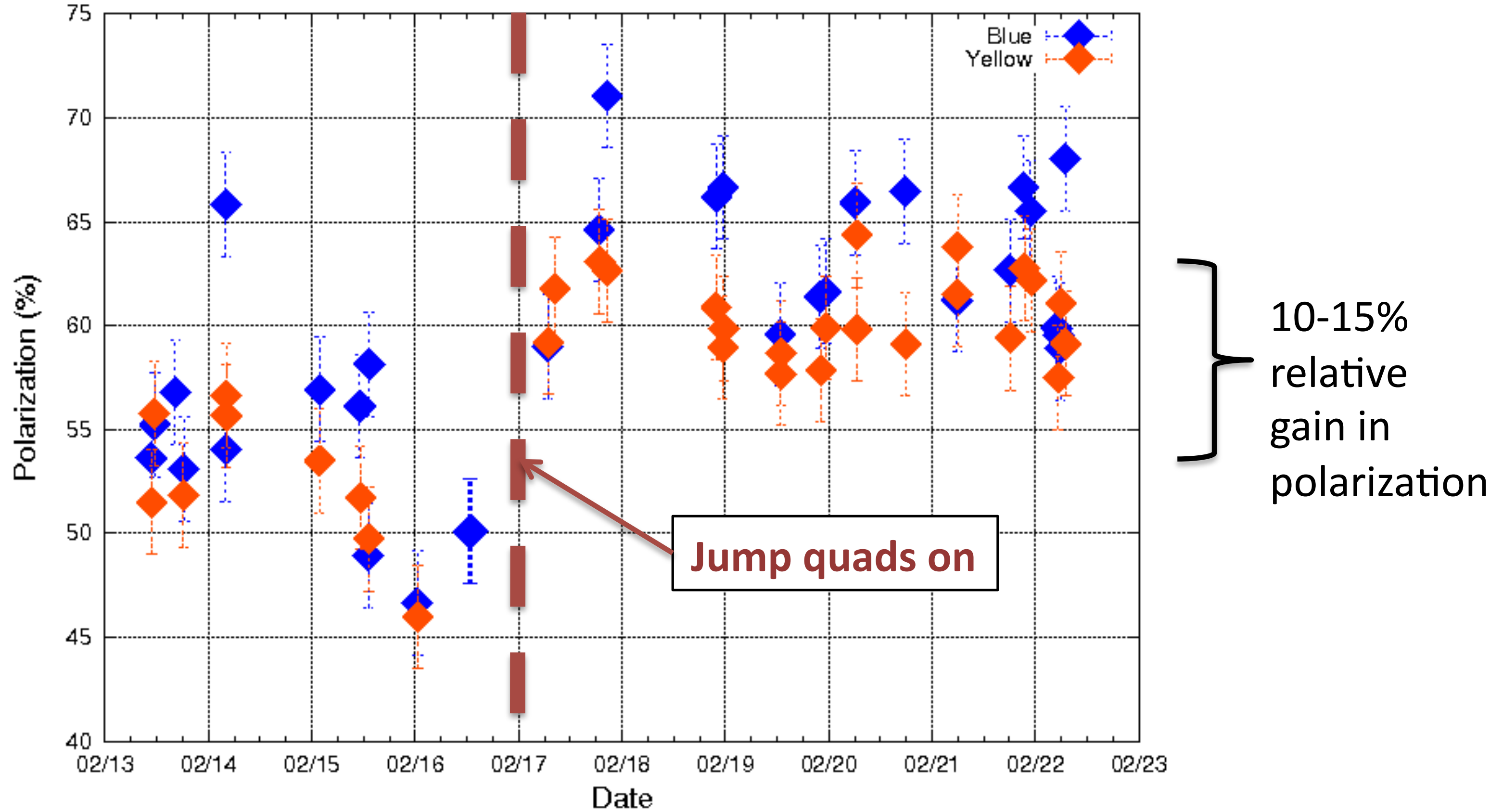
Measured at AGS extraction with a p-carbon internal polarimeter

Vertical carbon target swept horizontally across the beam.

Polarization binned by position in beam distribution

Polarization Improvement: RHIC Injection

Jump quads used routinely for RHIC physics fills starting in Run-11 (Feb. 2012)



Measured in RHIC at injection energy with a p-carbon internal polarimeter

Polarization as shown here is averaged over the entire distribution

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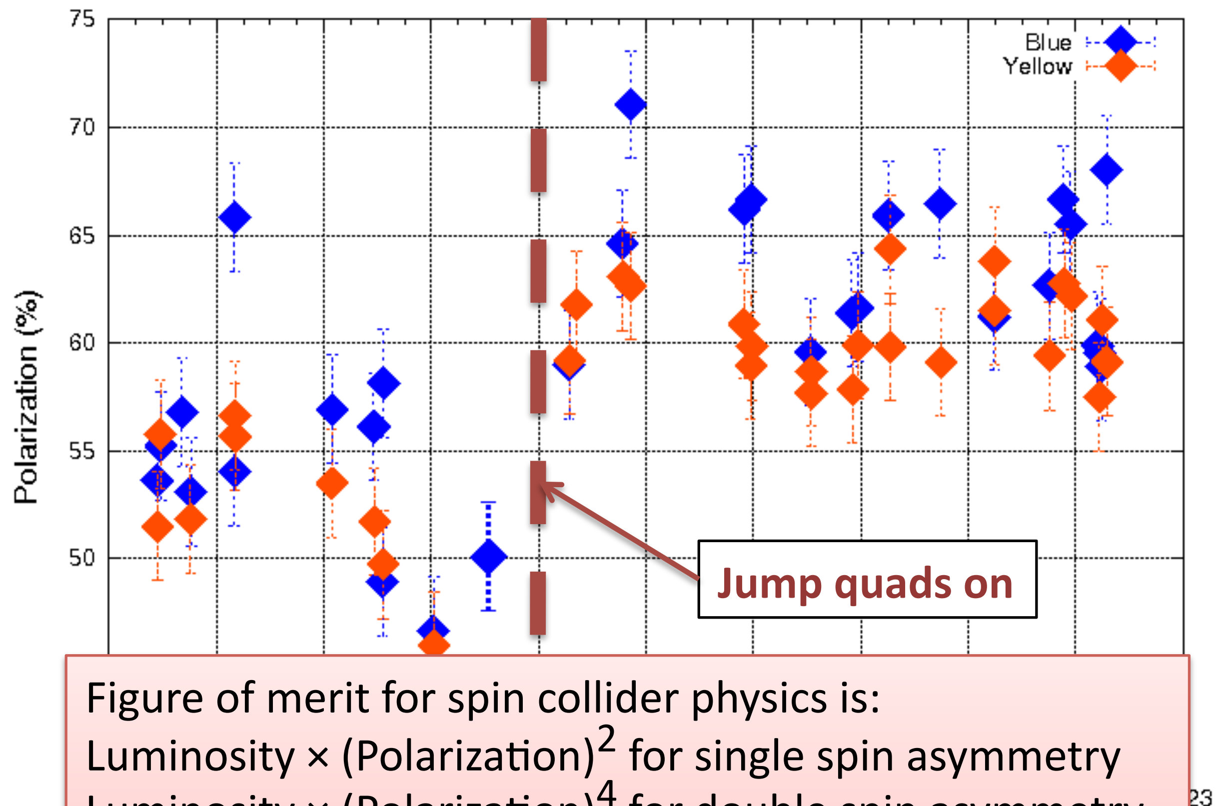


10-15% relative gain in polarization

Figure of merit for spin collider physics is:
Luminosity × $(\text{Polarization})^2$ for single spin asymmetry
Luminosity × $(\text{Polarization})^4$ for double spin asymmetry

A 10% relative gain in polarization is then a 20 or 50% increase in figure of merit!

Measure … rimeter

Pola … ion

Vertical Emittance

The *vertical* tune jump caused by the quads is non-adiabatic!

Jump is ~30 turns, vertical betatron period is 60-100 turns.

Potential sources of emittance growth:

<u>Orbit</u>

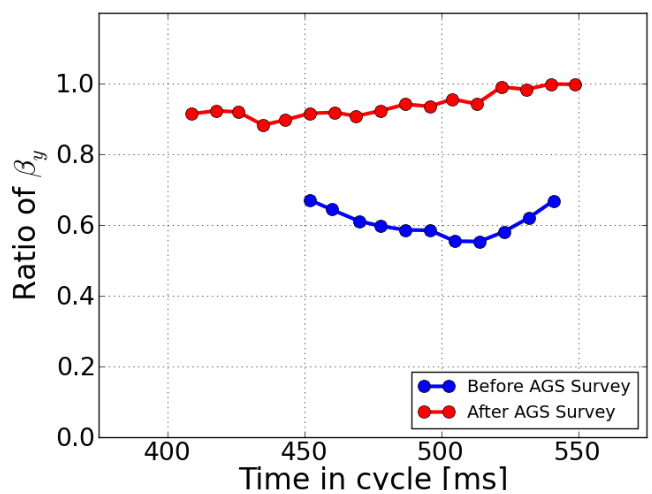
Orbit not centered in jump quads

Improved our orbit harmonic controls and software to allow easy correction of beam position in the quads

Vertical dipole damper reduces sensitivity to drift.

<u>Optical mismatch</u>

Quads are separated by 90° vertical betatron phase advance, beta-beating from gradient errors can break the matching



<u>Unsynchronized jumps</u>

The two quadrupoles must pulse simultaneously

Remote readout of an inductive pickup coil in the field region of each quad allows precise synchronization (~1 us)

The above efforts limit the emittance growth from the 82 jump to <10% (the precision of the AGS IPM) < ~0.1% per jump!

Open Questions

- Can the timing be further optimized?
  - Beam-based calibrations of the energy measurement?
  - E.g. Jumping a single artificially excited strong vertical intrinsic?
- Are all 82 jumps necessary?
  - Simulation and some experimental evidence suggest that the last few resonances dominate
  - Experimental verification would be a good benchmark for the simulations
  - Three or four resonances are operationally simpler to handle.

Summary

- RHIC polarized proton operation has achieved record luminosity and polarization in recent runs owing to improvements throughout the accelerator chain.
- Polarization in the AGS has improved due to the successful commissioning of the AGS horizontal tune jump system.
- The tune jump has been in operation for all RHIC polarized proton fills since February, 2011.
- Work continues to reduce systematic errors in the timing of the tune jumps