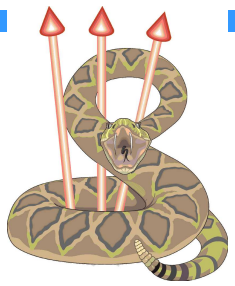


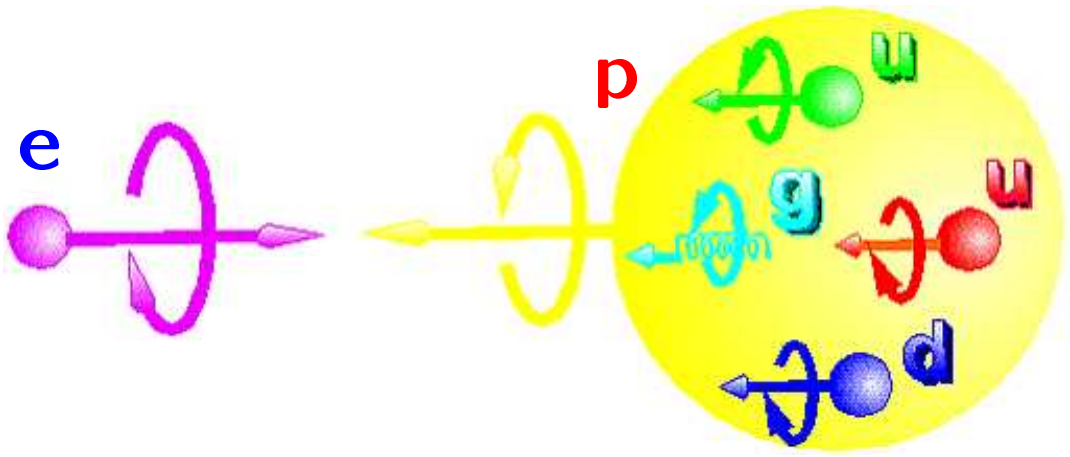
Polarized Protons at High Energies - Accelerator Challenges

and Physics Opportunities, May 17, 1999

Polarized protons at HERA: the accelerator issues

G. H. Hoffstätter

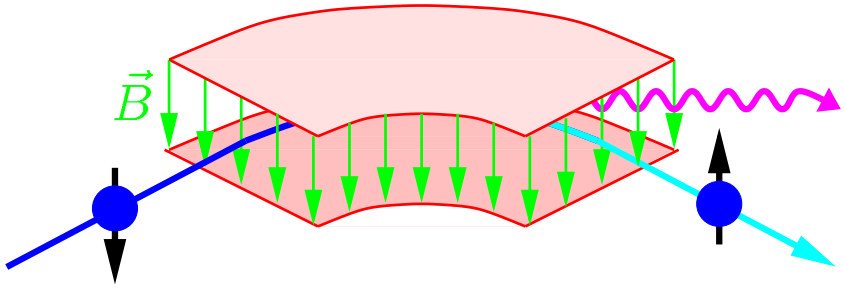
DESY, Hamburg



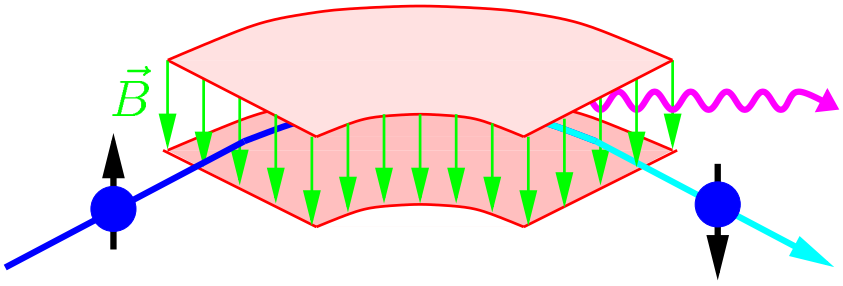
Logo of DESY 97-200

Selfpolarization of electrons

Every 10^{10}–th photon flips the spin of the electron.



in HERA every 38,5 minutes



in HERA every 16,2 hours

Idealized ring: Equilibrium polarization $\approx$ 92,38%.

HERA : routine running 60% polarization.

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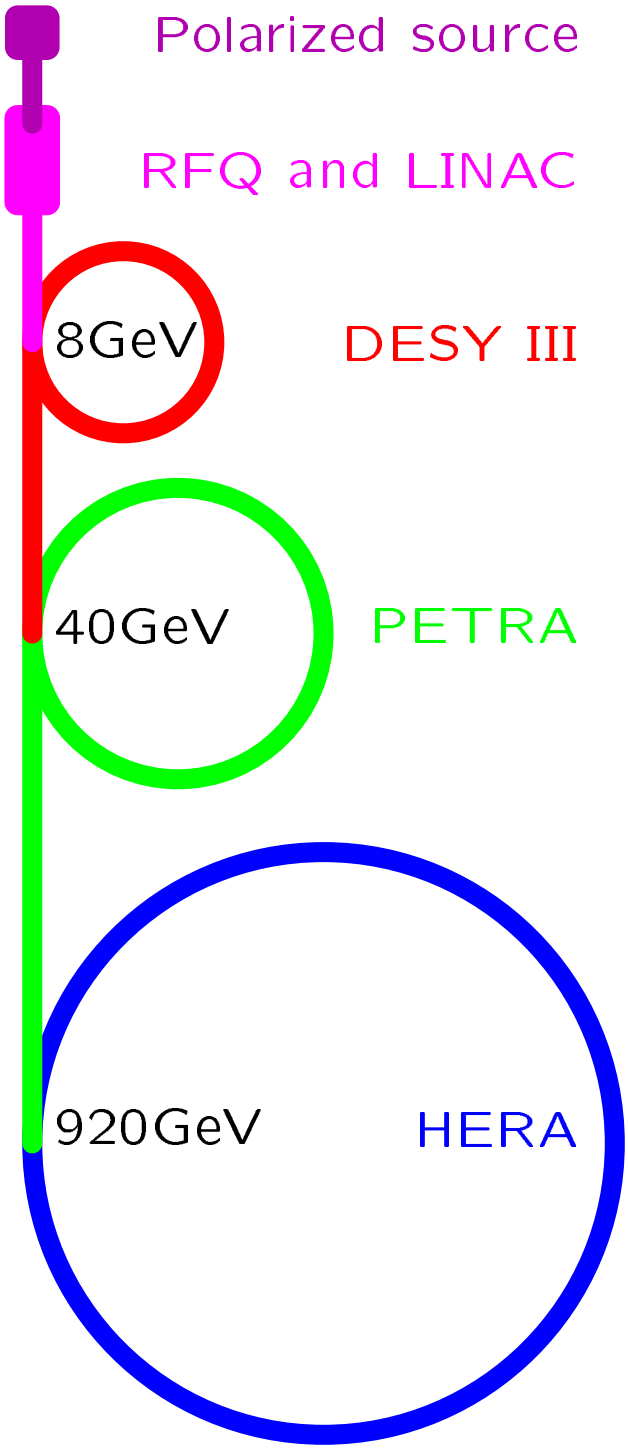
Polarized protons at DESY



Challenges:

- Polarized 20mA H^- source
- Acceleration
- Storage at 920 GeV
- Polarimetry

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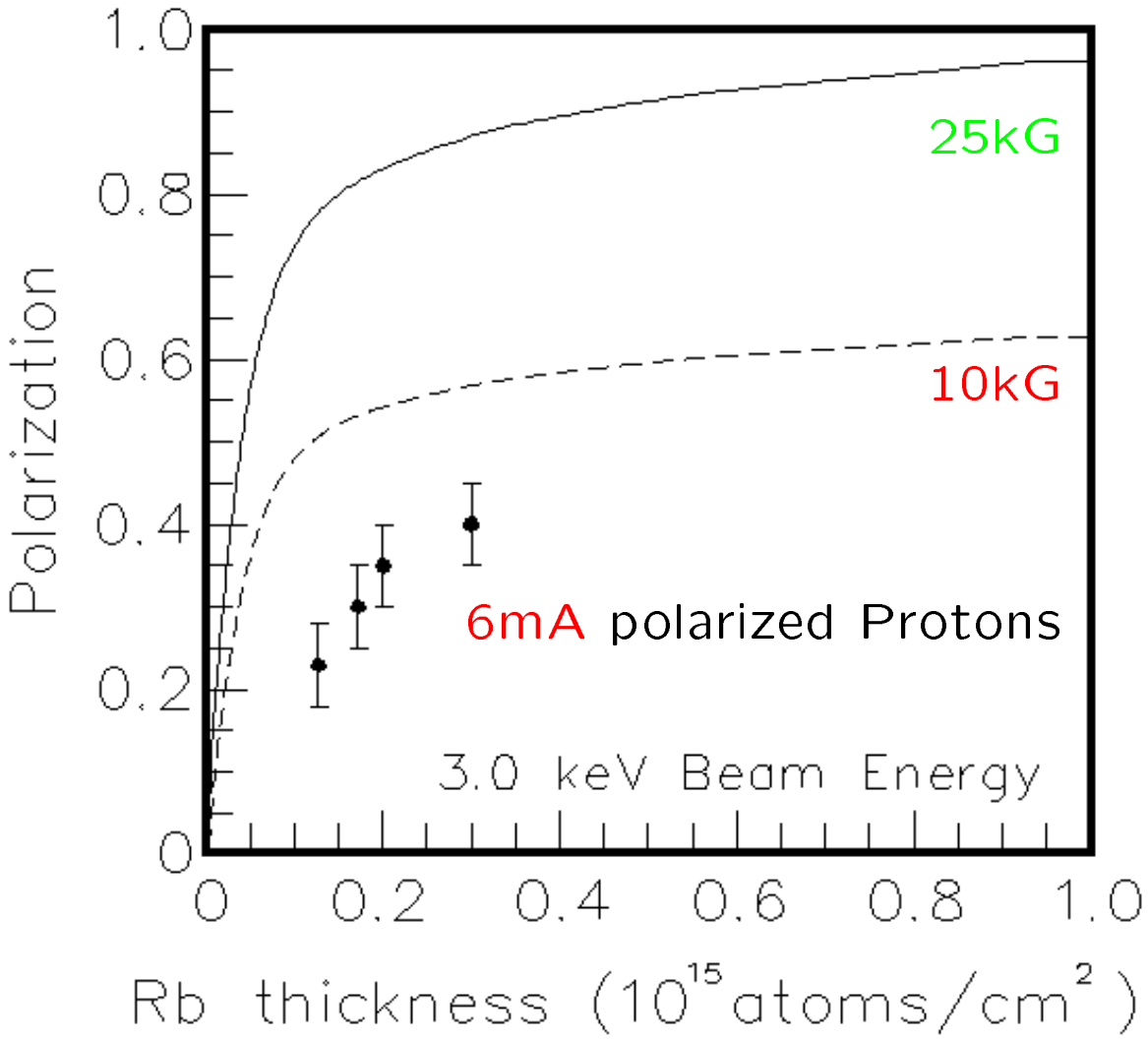
Polarized H^- source



Potential for higher polarization and for higher current.

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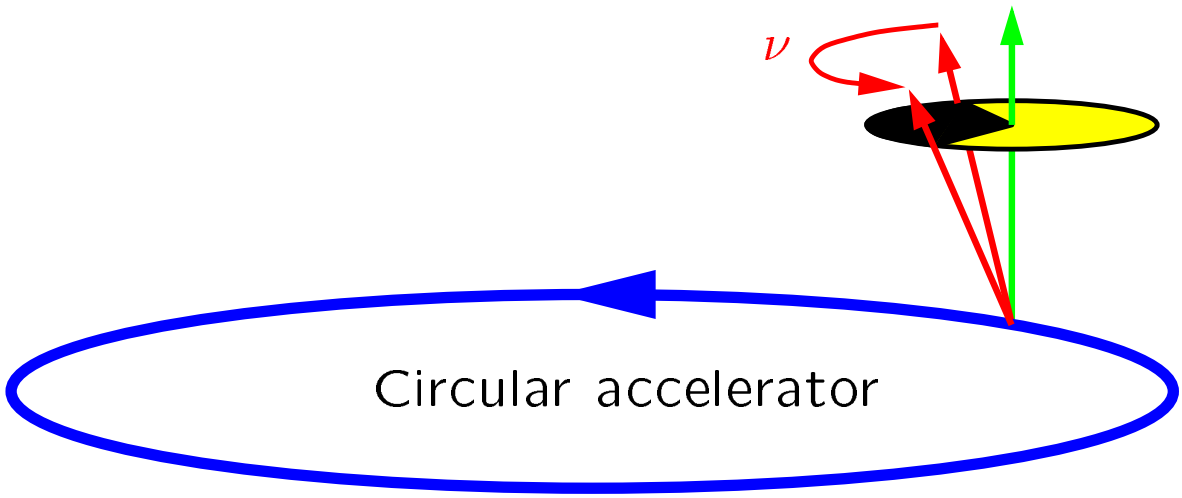
Spintune and spinkick

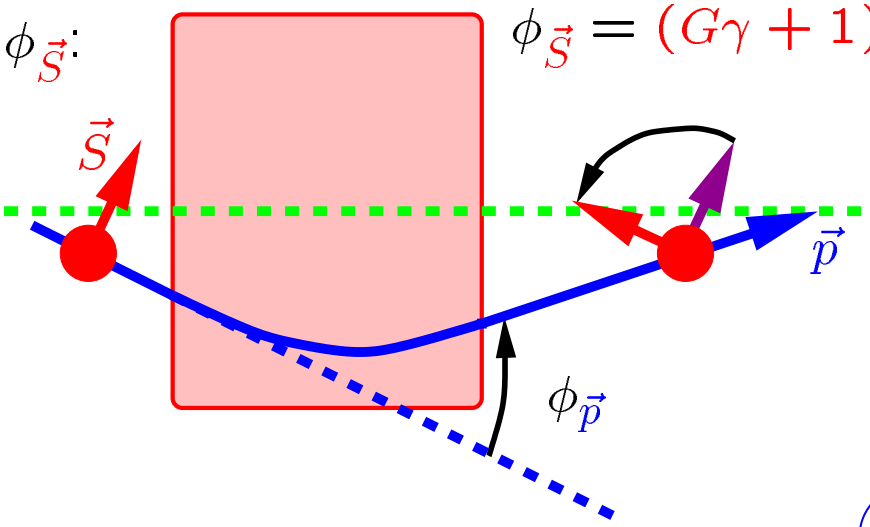
$$\frac{d\vec{p}}{dt} = (\frac{-q}{m\gamma})\{\qquad \vec{B}_\perp \qquad\}\times\vec{p}$$

$$\frac{d\vec{S}}{dt} = (\frac{-q}{m\gamma})\{(G\gamma+1)\vec{B}_\perp + (1+G)\vec{B}_\parallel\}\times\vec{S}$$



Spintune ν: Number or spin rotations per turn, 1758 at 920GeV.

Spinkick $\phi_{\vec{S}}$: $\phi_{\vec{S}} = (G\gamma+1)\phi_{\vec{p}}$



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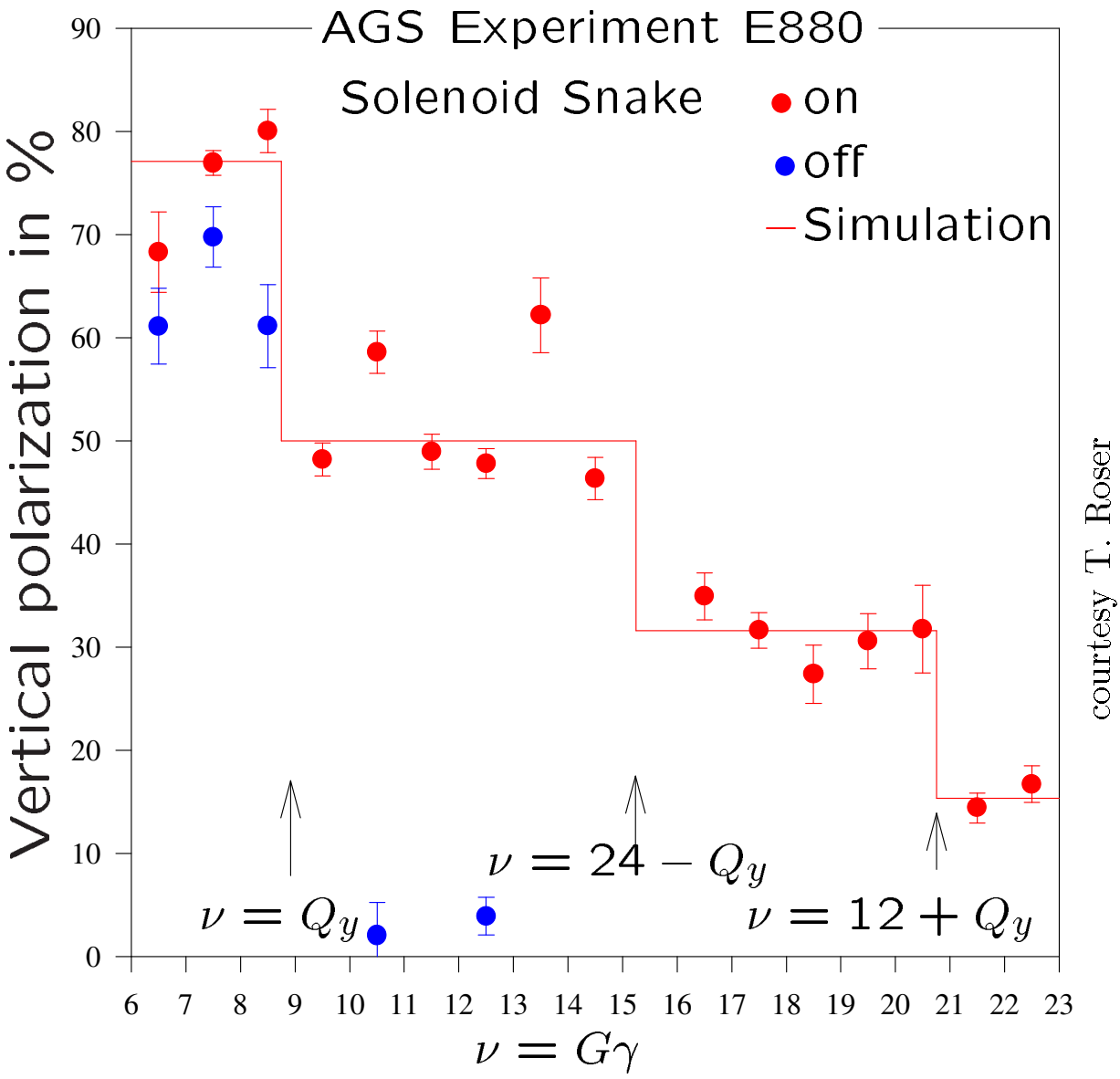
Imperfection Resonances

Integer spin tune: Spins have the same orientation every turn - disturbances accumulate.

Remedy: Controlled spin disturbance (Snake)



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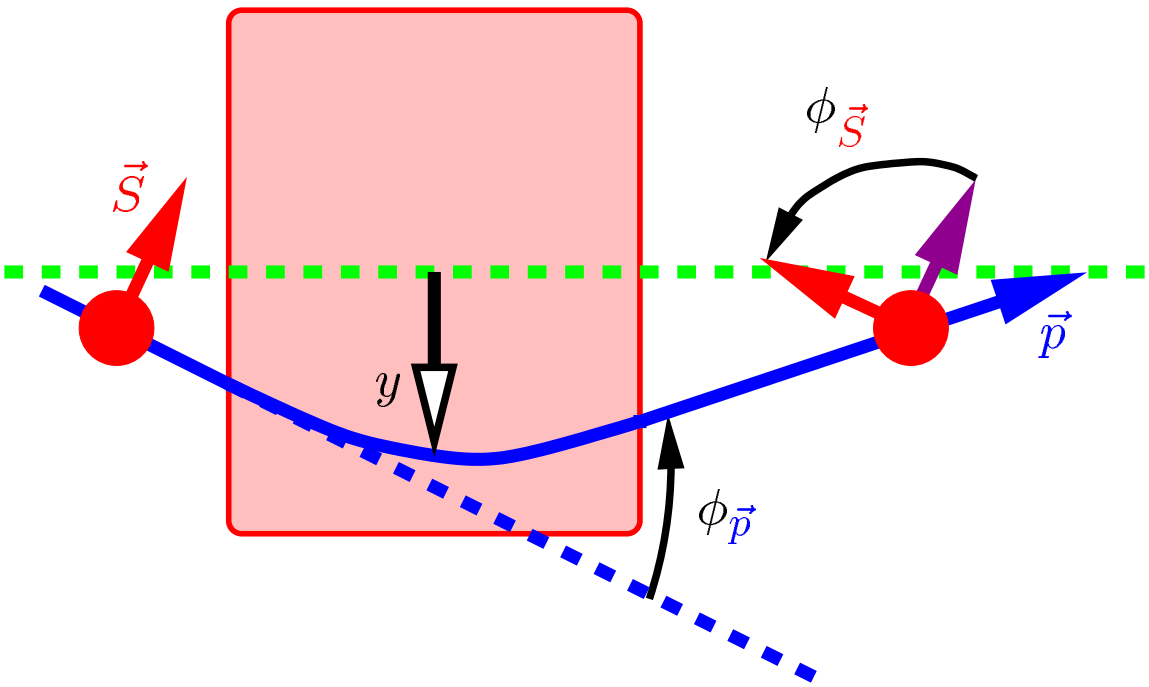
Periodic spin disturbance



$$\phi_{\vec{S}} \propto \phi_{\vec{p}} \propto y = y_0 \sin(\psi_0 + nQ_y)$$

Integer value of spin tune ν±Tune Q_y:

resonant disturbance of spin motion.

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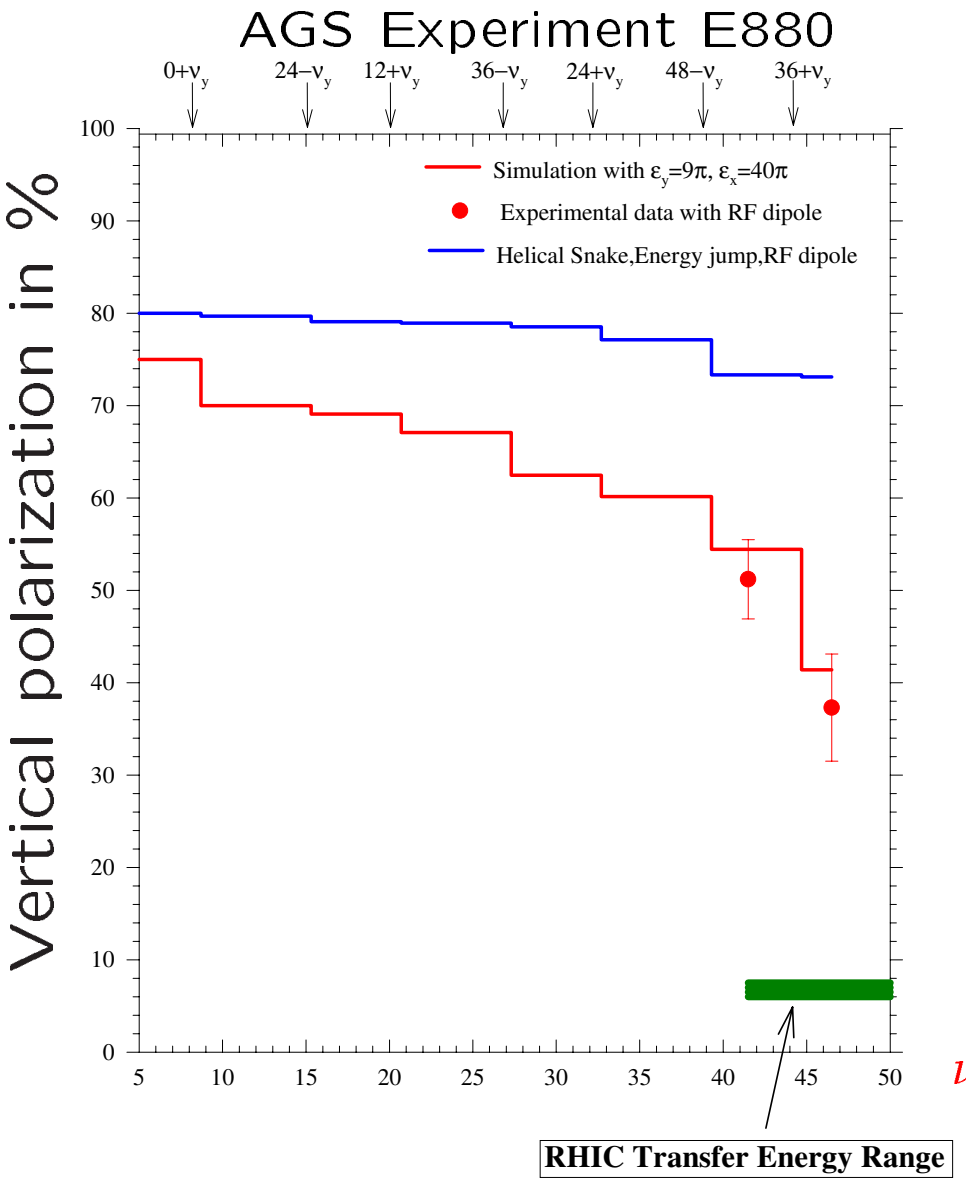
DESY

Crossing resonances

Remedy for DESY III: Tune jump, Energy jump, and RF dipole excitation



$\nu = G\gamma$

Remedy for PETRA and HERA: Fixing the spin tune $\nu = \frac{1}{2}$ by Siberian Snakes.

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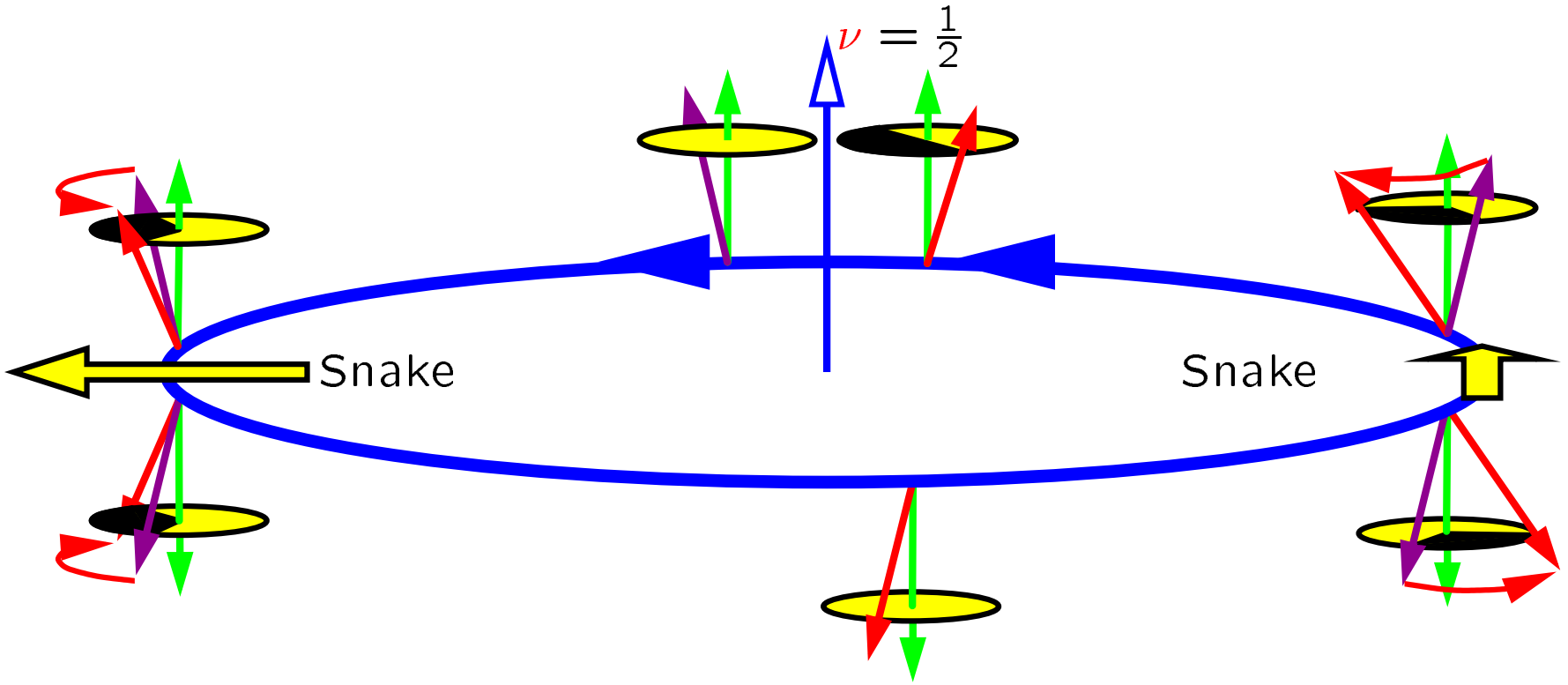
Siberian Snakes

Siberian Snakes rotate spins at all energies by $\frac{1}{2}$.



Freedom: Direction of rotation axis in the horizontal plane

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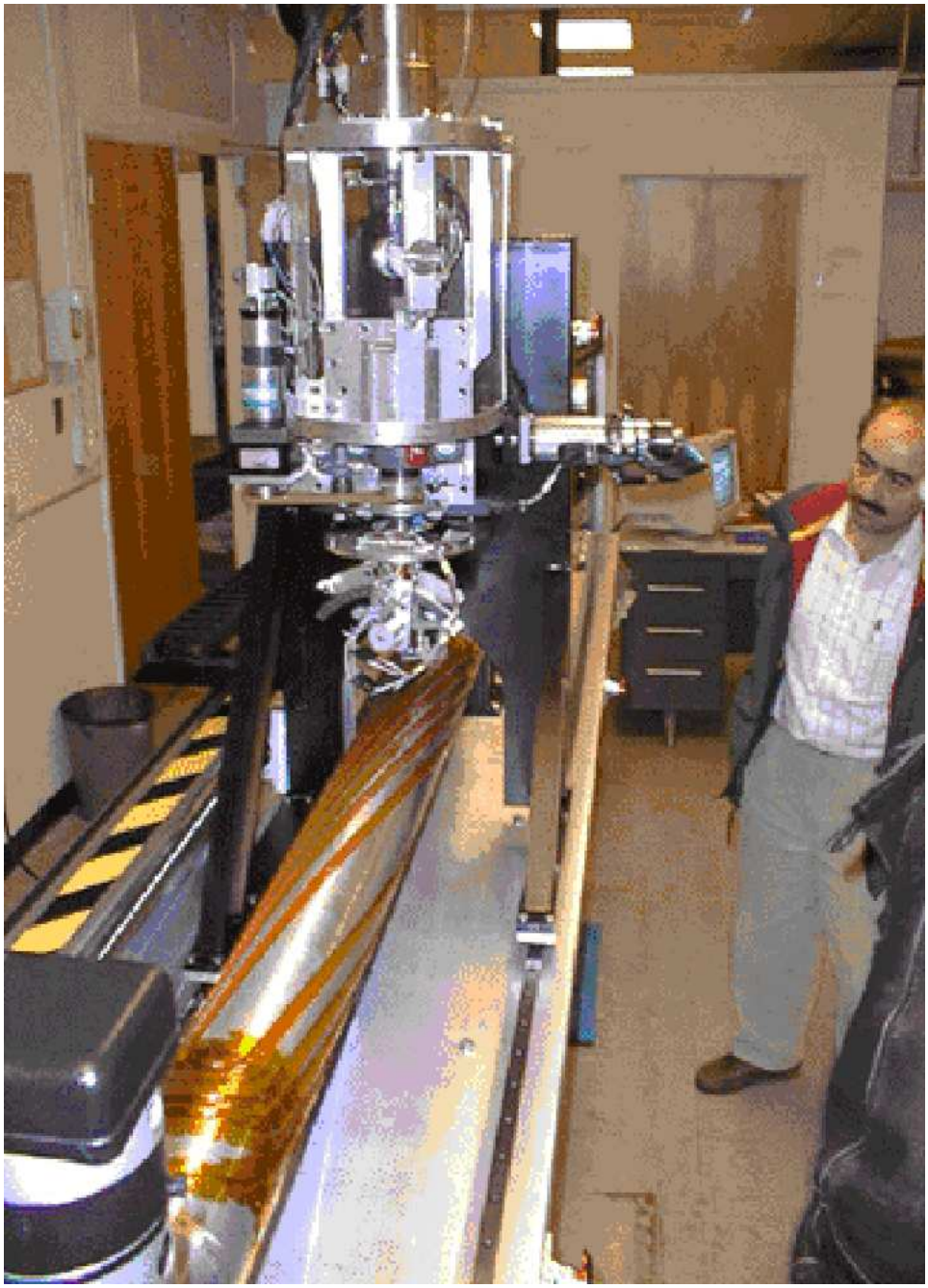
Helical Siberian Snakes

$$\frac{d\vec{p}}{dt} = (\frac{-q}{m\gamma})\{ \quad \vec{B}_{\perp} \quad \} \times \vec{p}$$

$$\frac{d\vec{S}}{dt} = (\frac{-q}{m\gamma})\{(G\gamma + 1)\vec{B}_{\perp} + (1+G)\vec{B}_{\parallel}\} \times \vec{S}$$



http://ad1.ags.bnl.gov/ rhicspin/images/Winder.jpg

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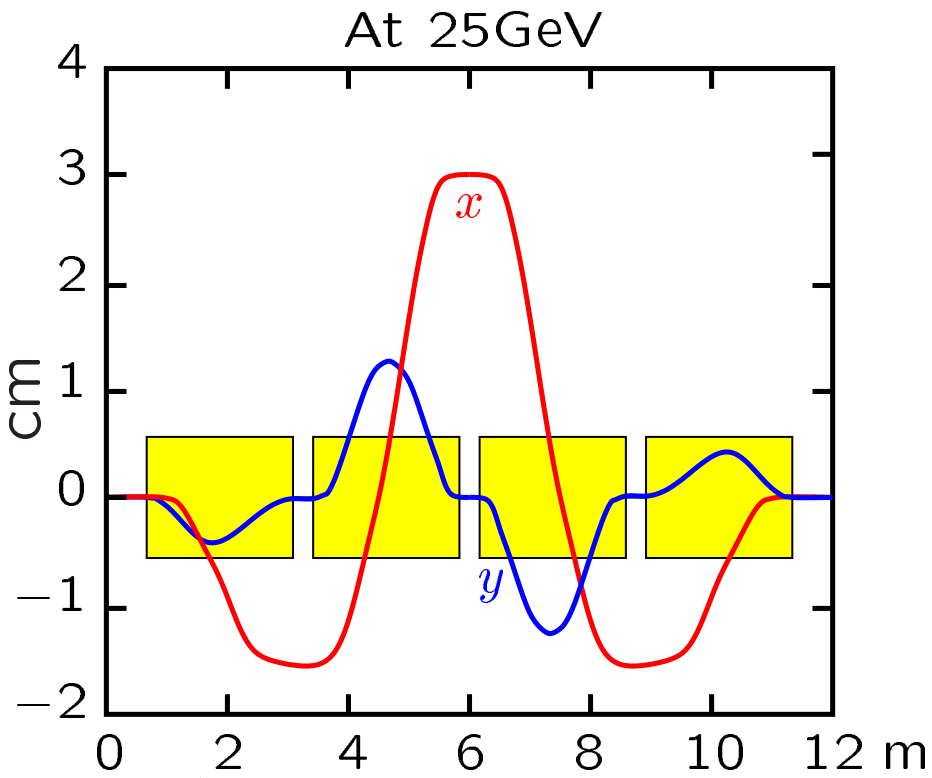
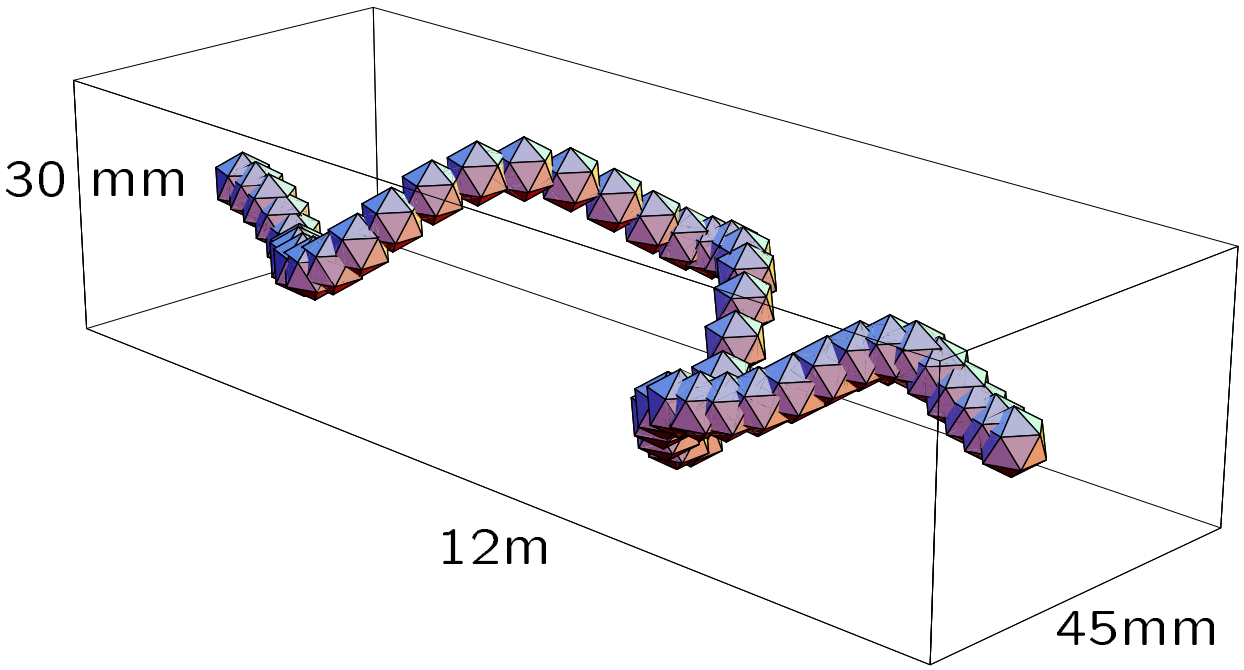
Orbit motion in RHIC type Siberian Snakes





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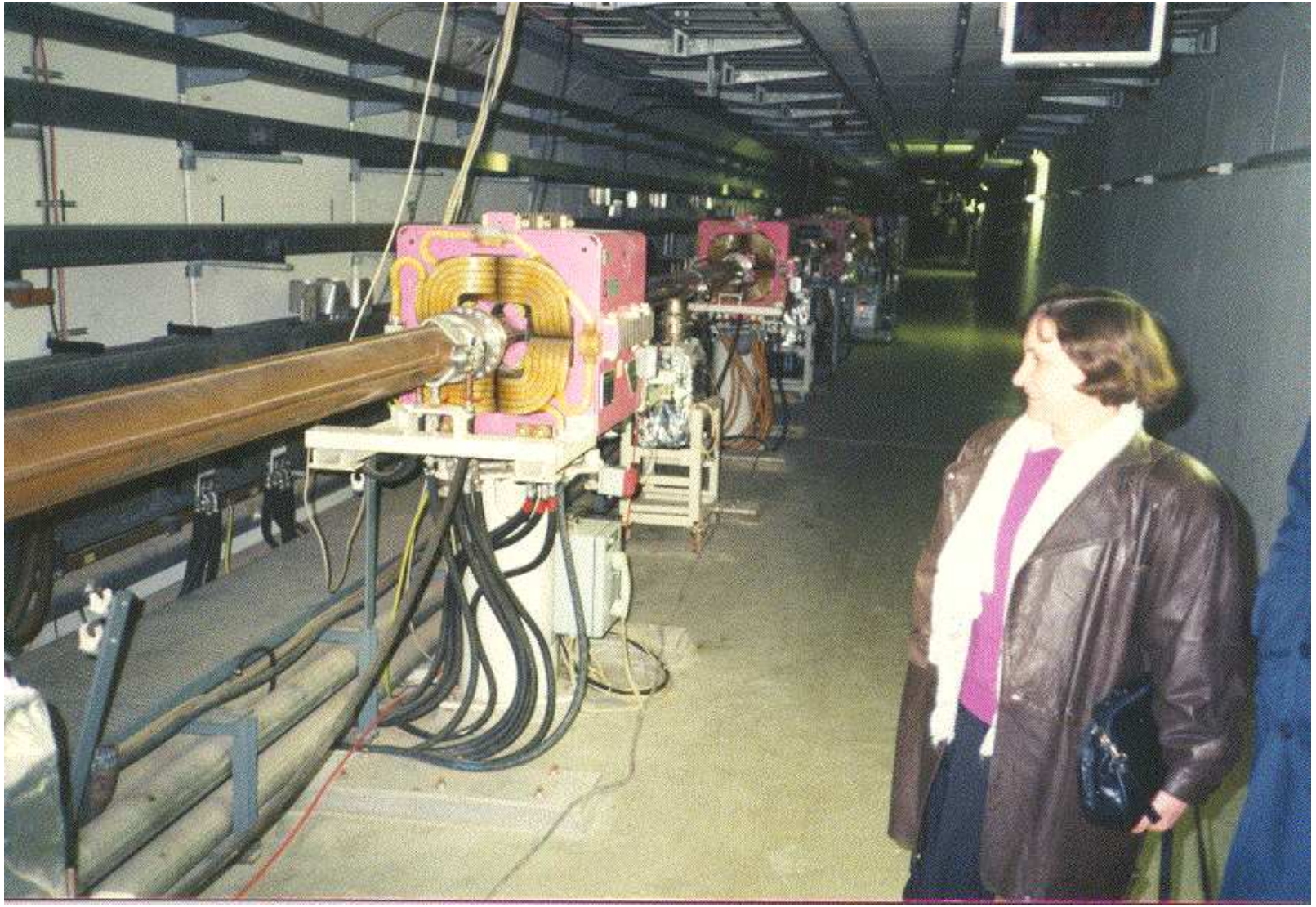
Space for Siberian Snakes in PETRA



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Space for Siberian Snakes in HERA

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Difficulties for polarized protons in HERA

- No perfect symmetry
- Vertical bends (Remedy: Flattening Snakes)
- Not build for polarization
- Hardly space for more than 4 Siberian Snakes
- Very high energy (920GeV) and spin tune (ν=1758)

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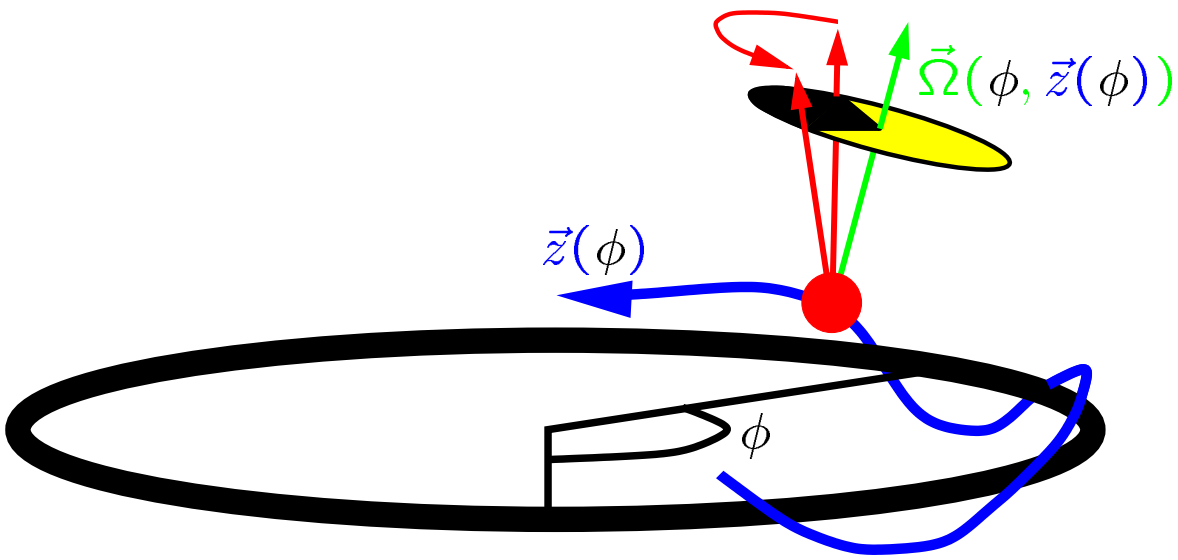
Isolated resonance model



$$\vec{S}' = \vec{\Omega}(\phi, \vec{z}(\phi)) \times \vec{S}$$

Approximation: all but one dominant Fourier component of $\vec{\Omega}(\phi, \vec{z}(\phi))$ are neglected.

Is this theory still applicable at

HERA	920GeV

???

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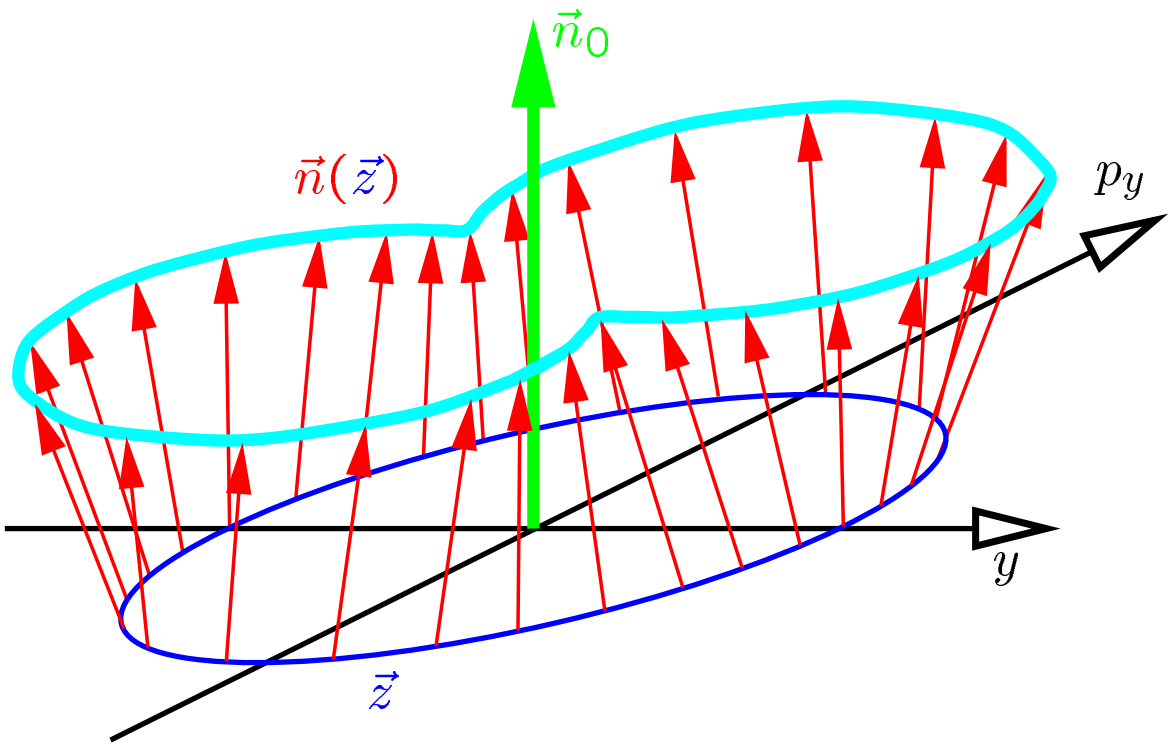
The invariant spin field



The spin transport matrix $\underline{A}(\vec{z}_n)$ with

$$\vec{S}_{n+1} = \underline{A}(\vec{z}_n)\vec{S}_n$$

defines the $\vec{n}$–axis

$$\vec{n}(\vec{z}_{n+1}) = \underline{A}(\vec{z}_n)\vec{n}(\vec{z}_n)$$

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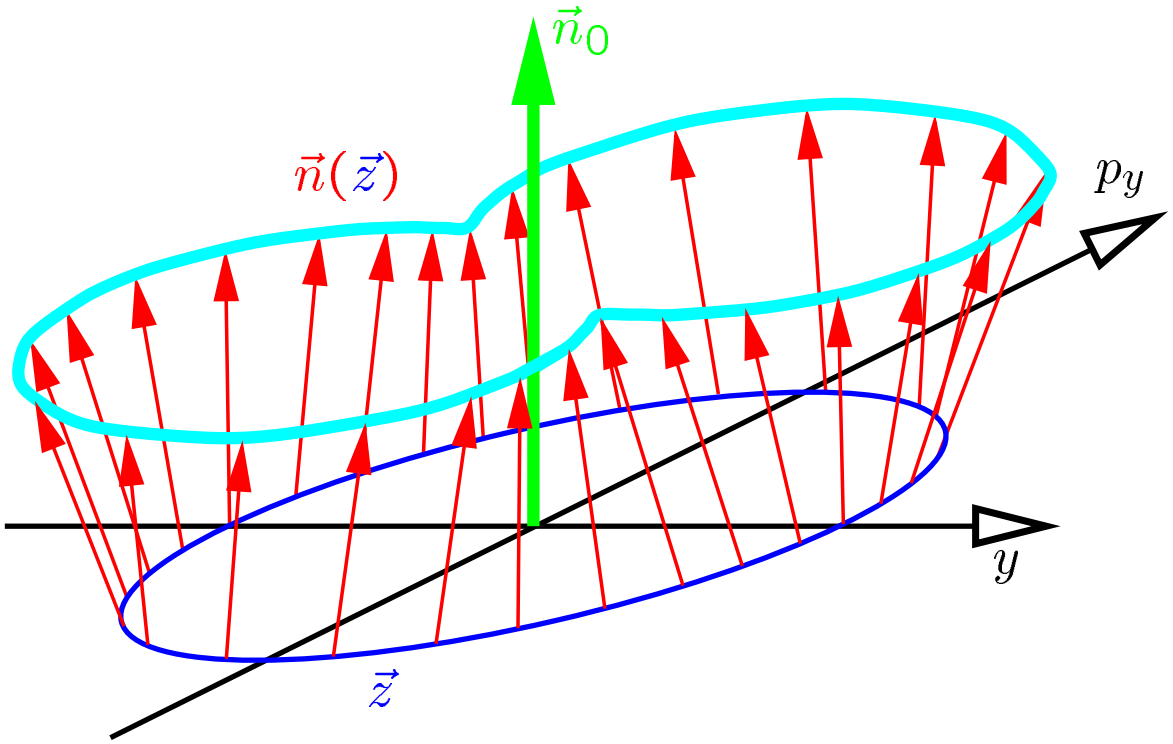
Significance of the $\vec{n}$–axis



Maximal polarization: $< \vec{n}(\vec{z}) >_{\text{phase space}}$

Divergence: $\sphericalangle\{\vec{n}(\vec{z}), \vec{n}_0\}_{\text{phase space}}$

At large divergence, the average polarization is small, even at 100% local polarization.

Linearized $\vec{n}(\vec{z})$ can easily be calculated.

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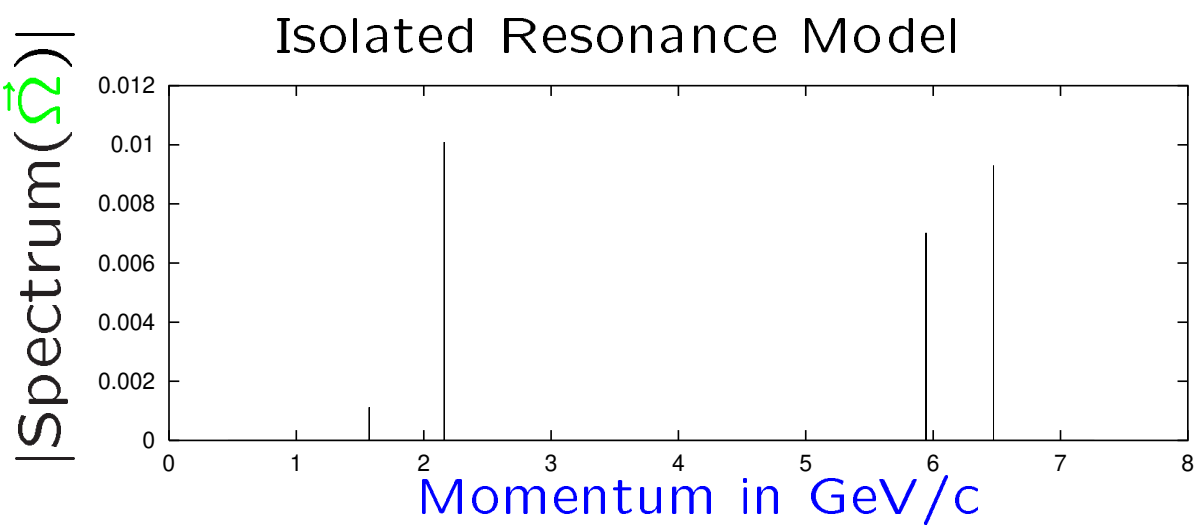
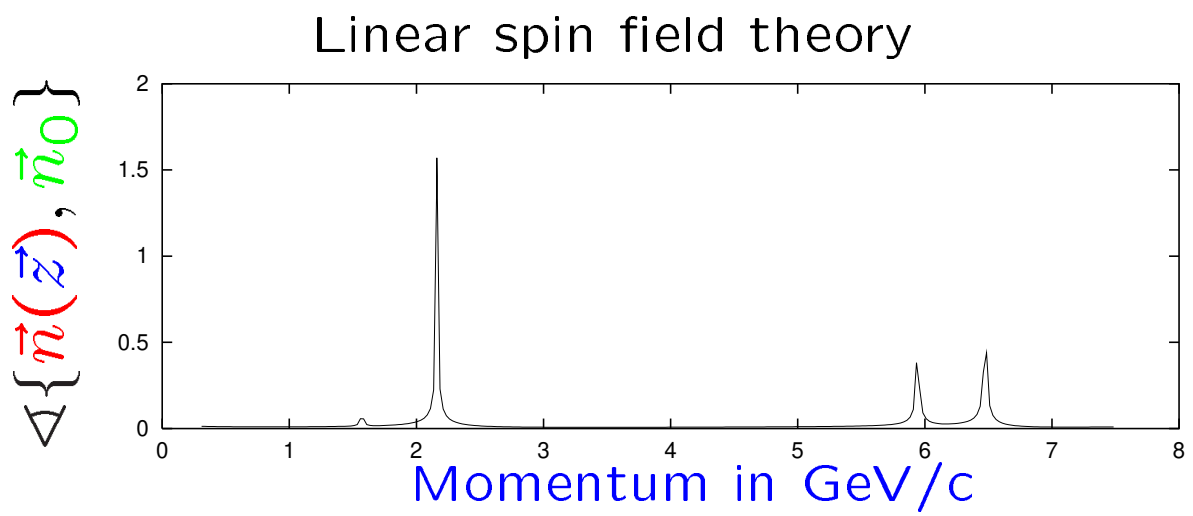
First order theory

A) DESY III





Low energy: First order theories agree.

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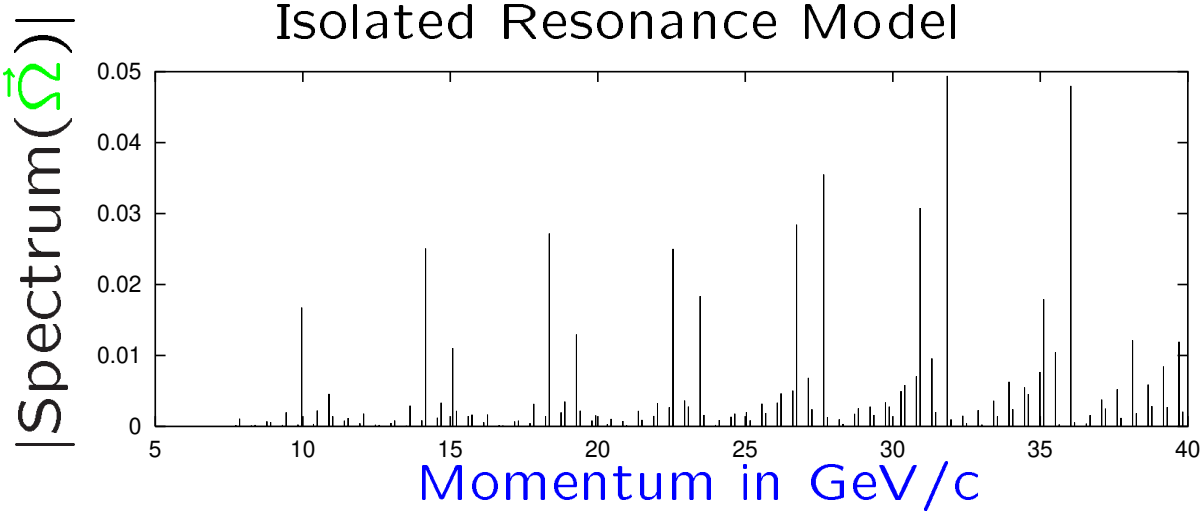
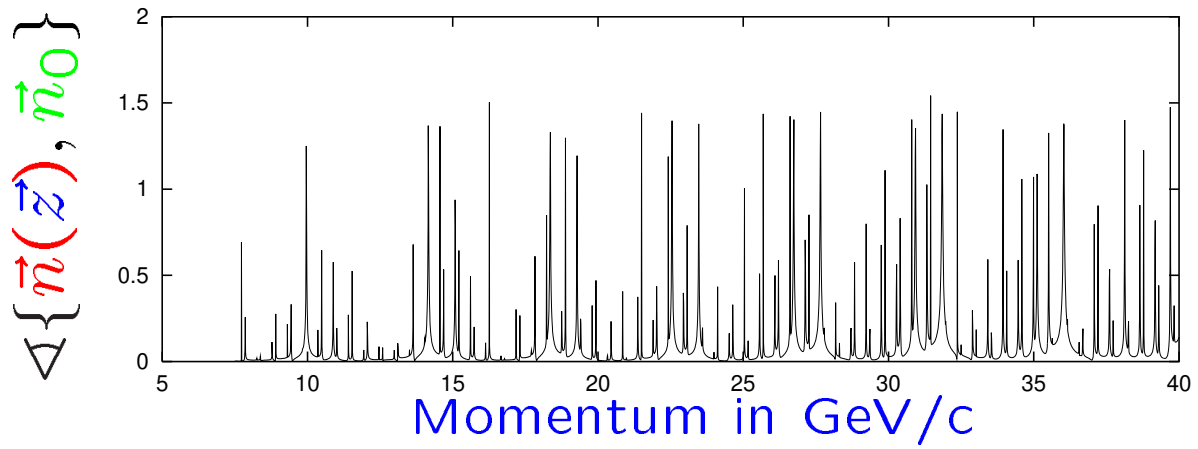
First order theory

B) PETRA

Isolated Resonance Model



Linear spin field theory



Medium energy: Resonances are barely isolated

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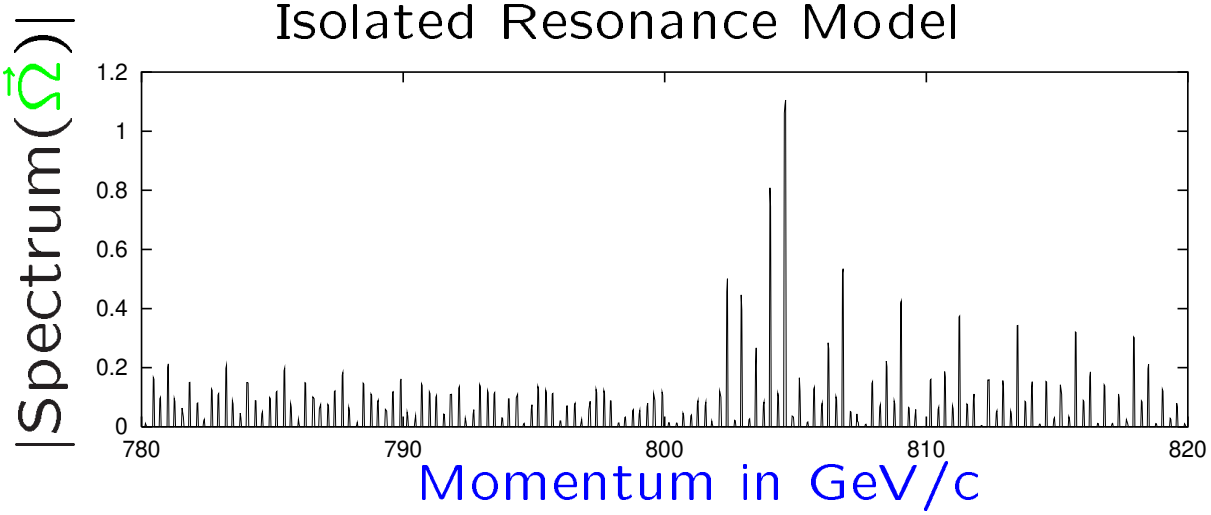
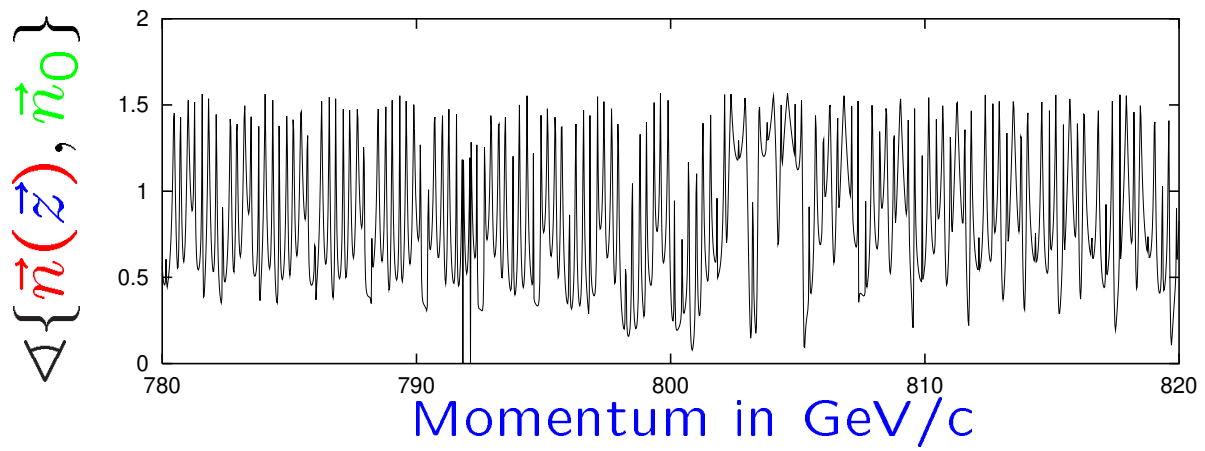
First order theory

C) HERA

Isolated Resonance Model



Linear spin field theory



High energy: Resonances are not isolated.

The Isolated Resonance Model looses applicability.

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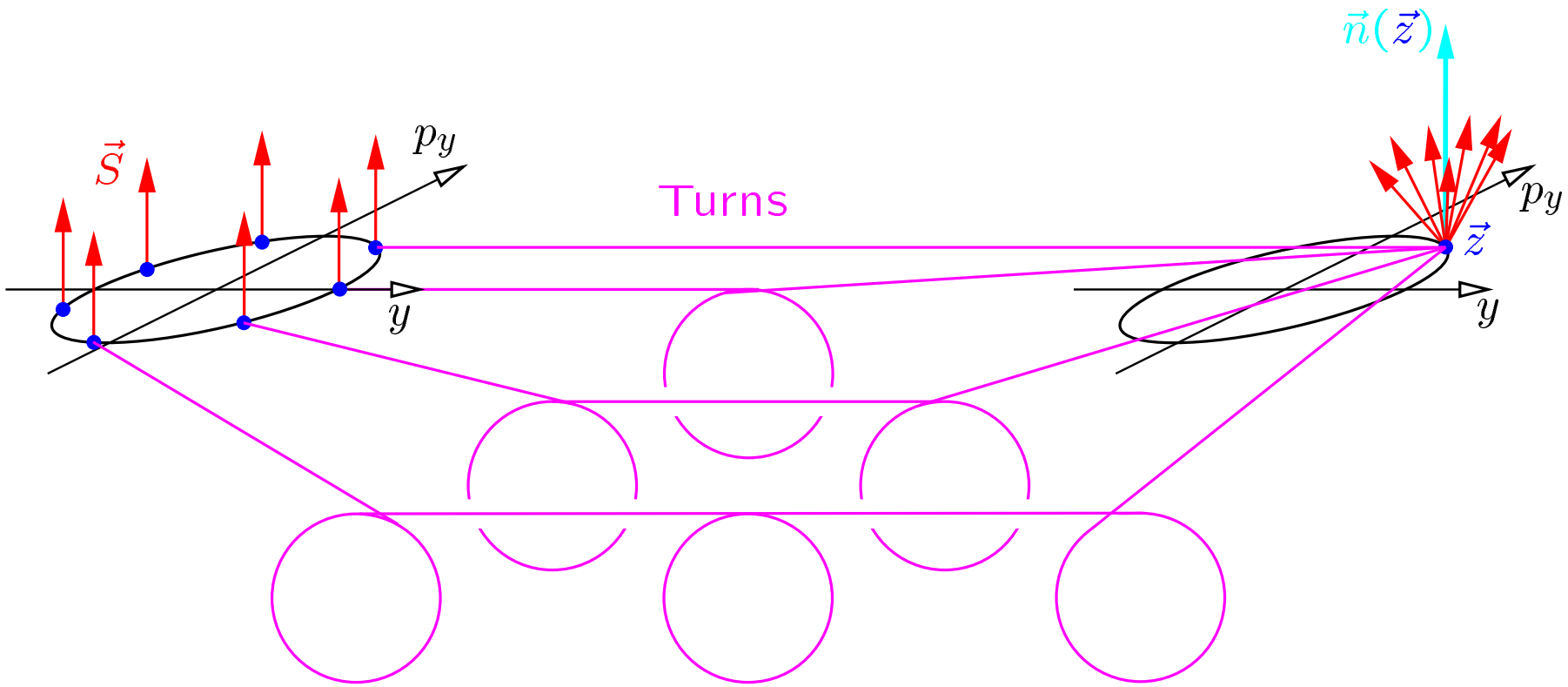
The stroboscopic average



The time average of the polarization at $\vec{z}$ is parallel to the $\vec{n}$–axis.

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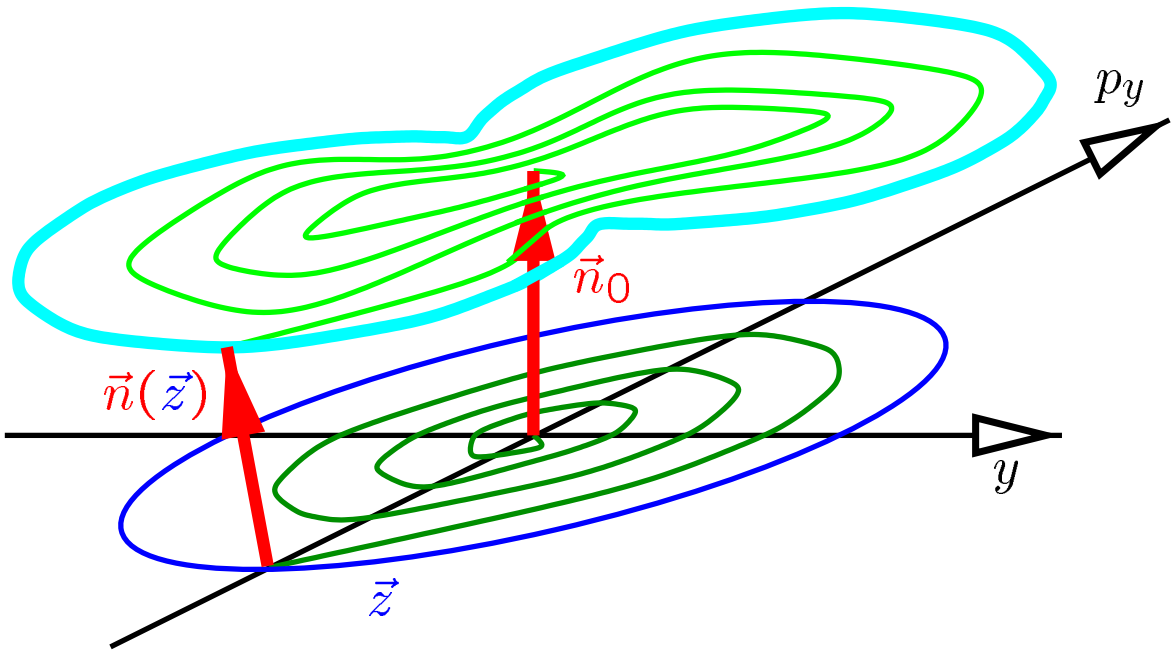
Anti-damping of the $\vec{n}$–axis



Other computational methods for the $\vec{n}$–axis:

- Fourier normal form (SODOM algorithm)
- Taylor normal form (COSY)

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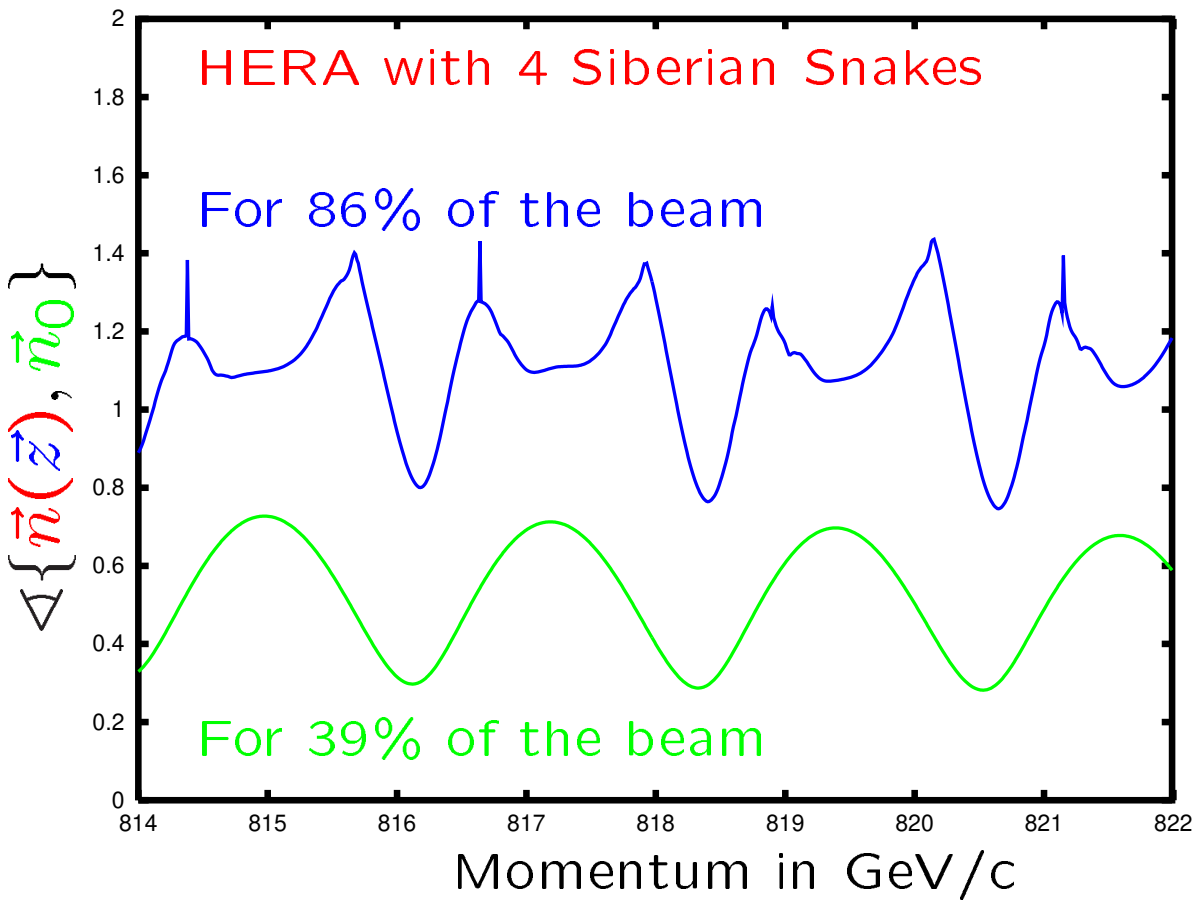
Higher order effects

- Overlapping resonances
- Amplitude dependent spin tune
- Nonlinear spin transport matrix $\vec{A}(\vec{z})$
- Deformation of the invariant spin field
- Higher order resonances



Siberian Snakes avoid first order resonances.
Higher order resonances become visible.

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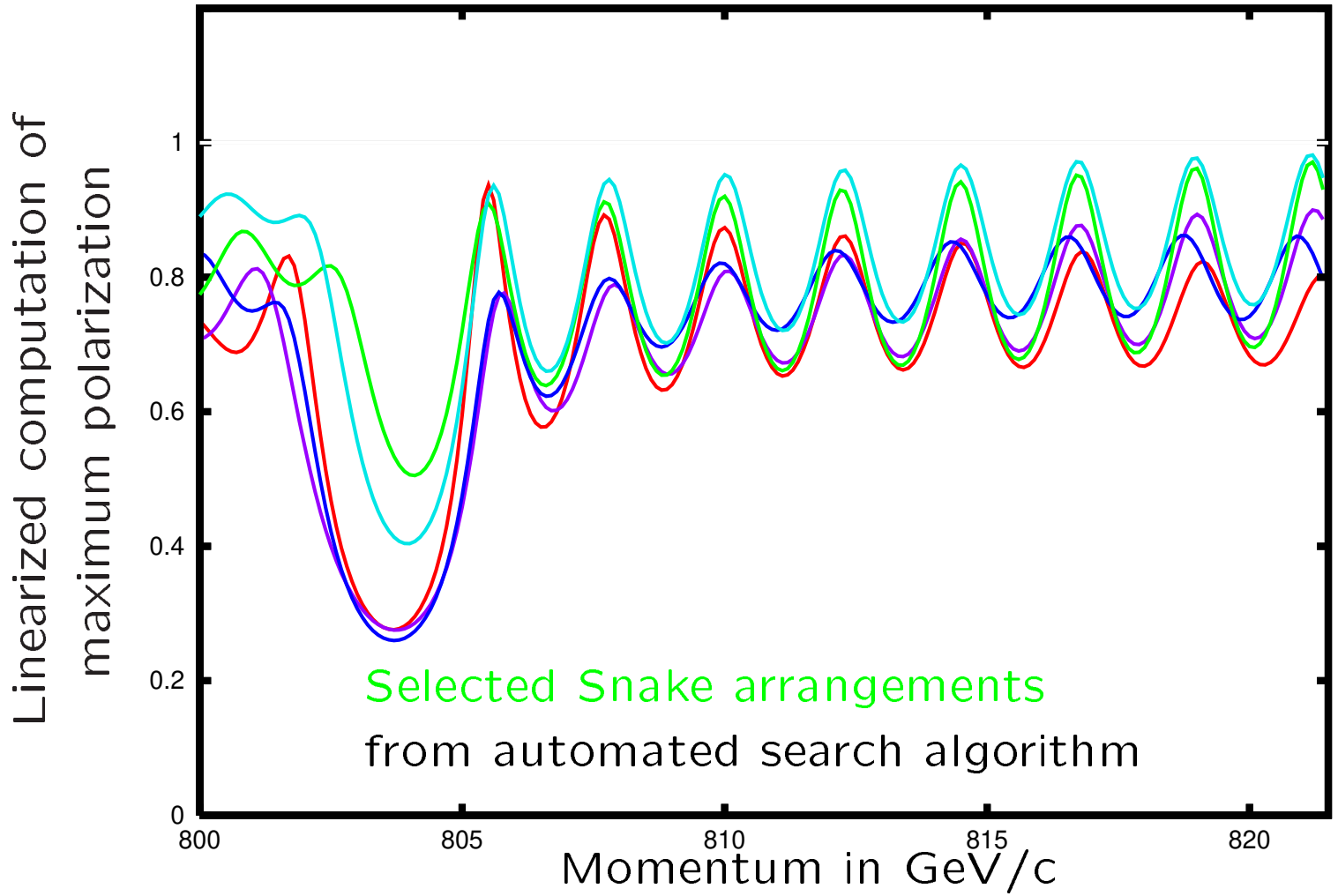
Filtering of Snake arrangements



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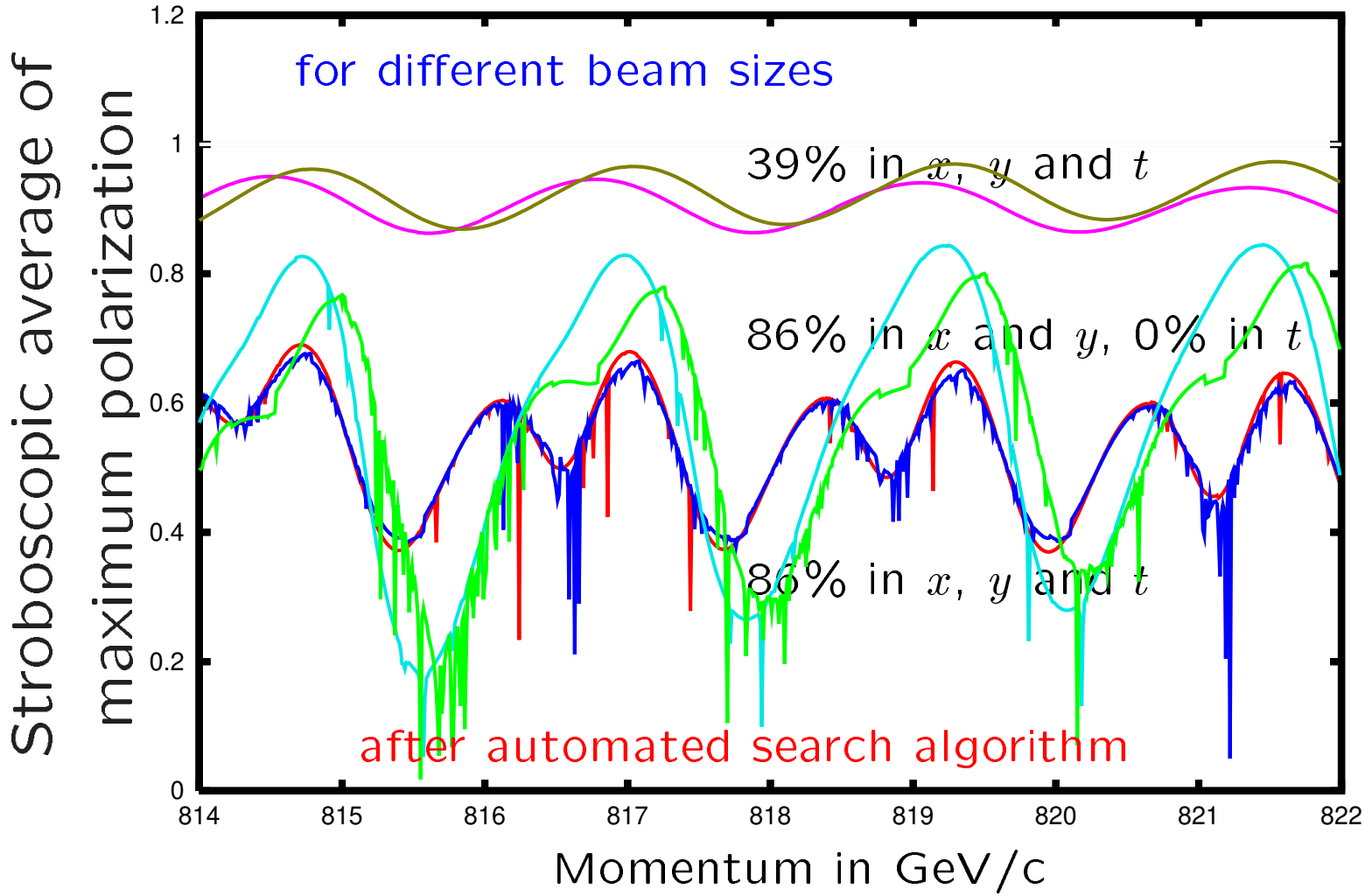
Maximum polarization



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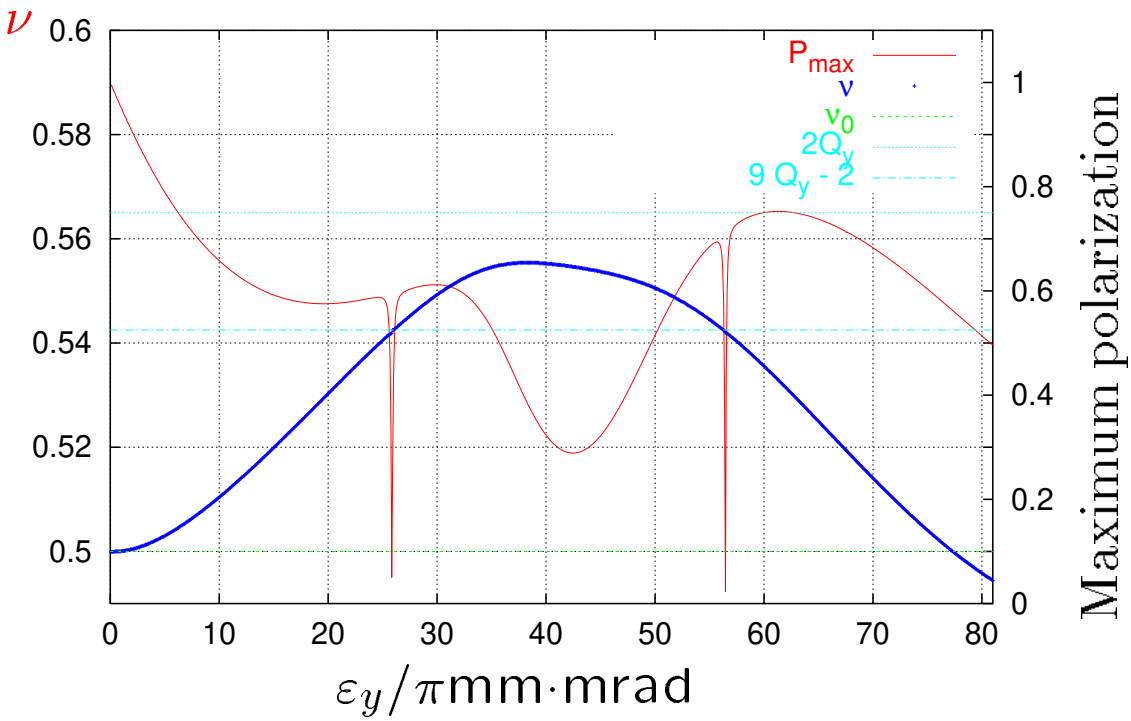
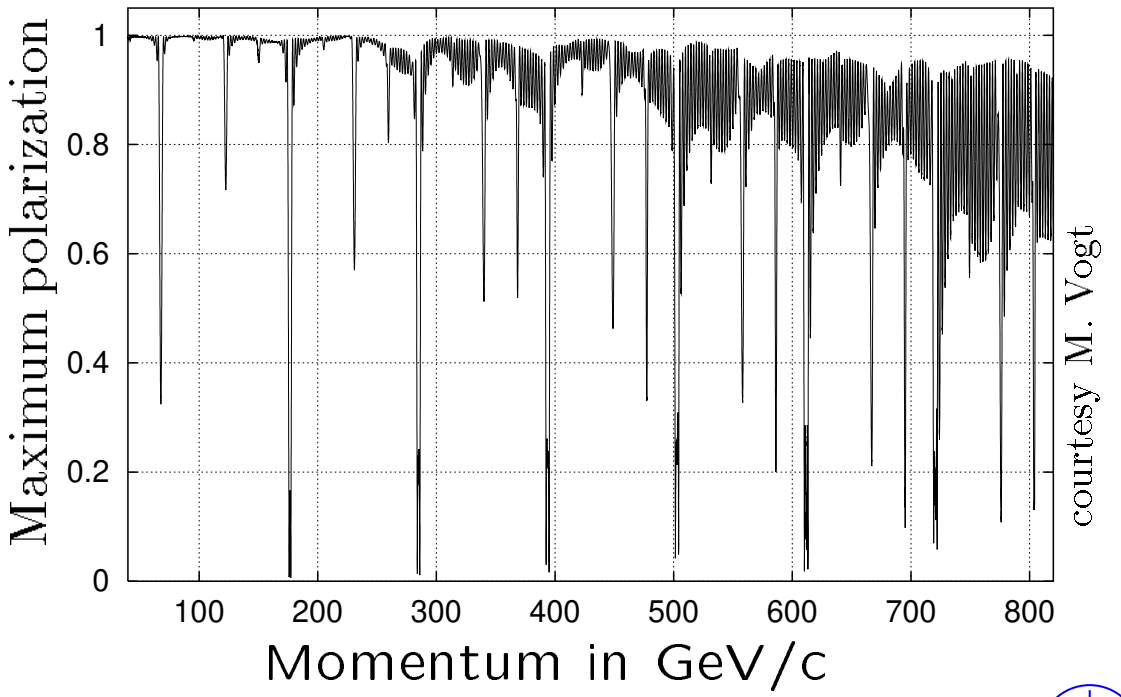
Amplitude dependend spin orbit resonances



Acceleration of $2\sigma_x/2\sigma_y/2\sigma_\tau$



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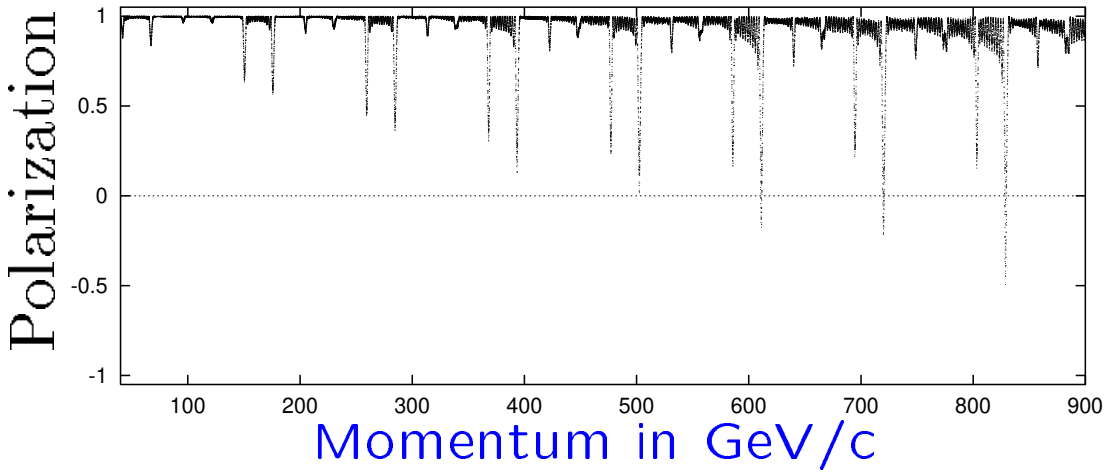
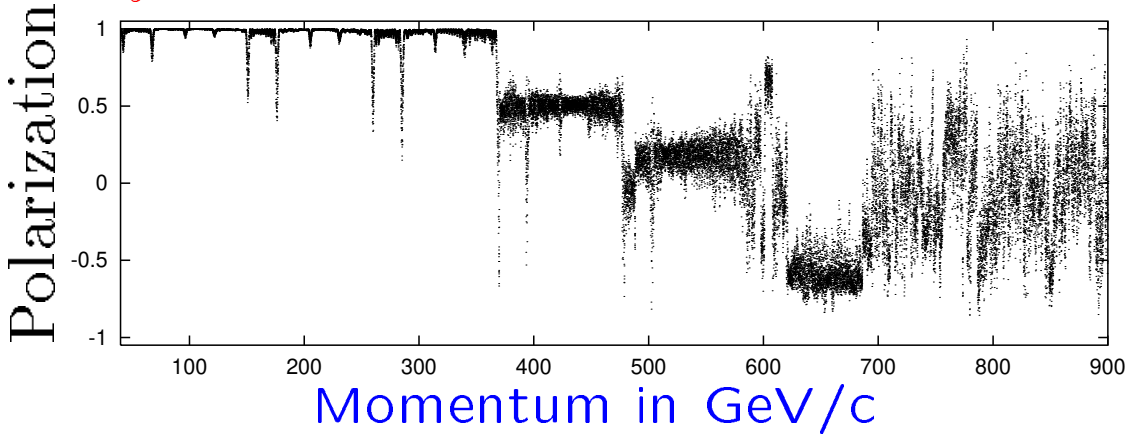
Misalignment errors

$1\sigma_y$ motion without misalignments

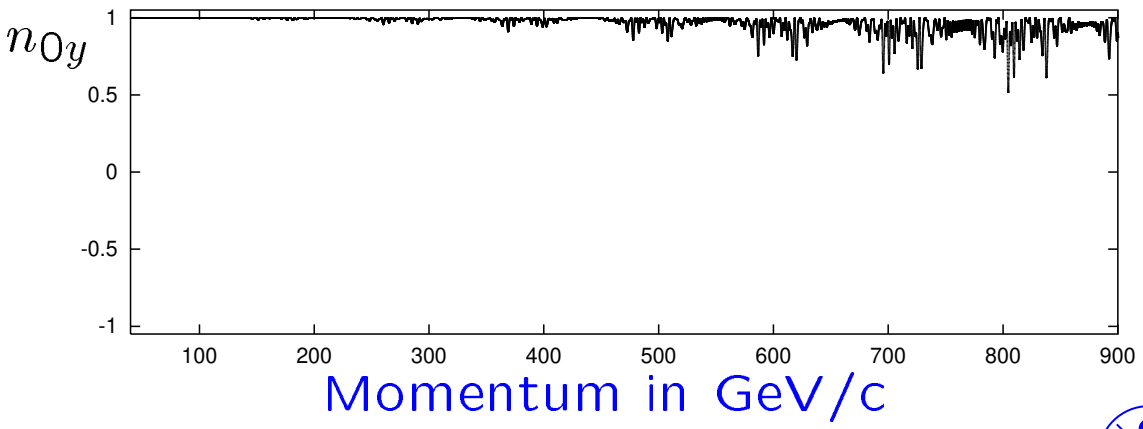


$1\sigma_y$ motion with $x_{rms} = y_{rms} = 0.5$mm



courtesy N. Golubeva / V. Balandin

closed orbit spin motion



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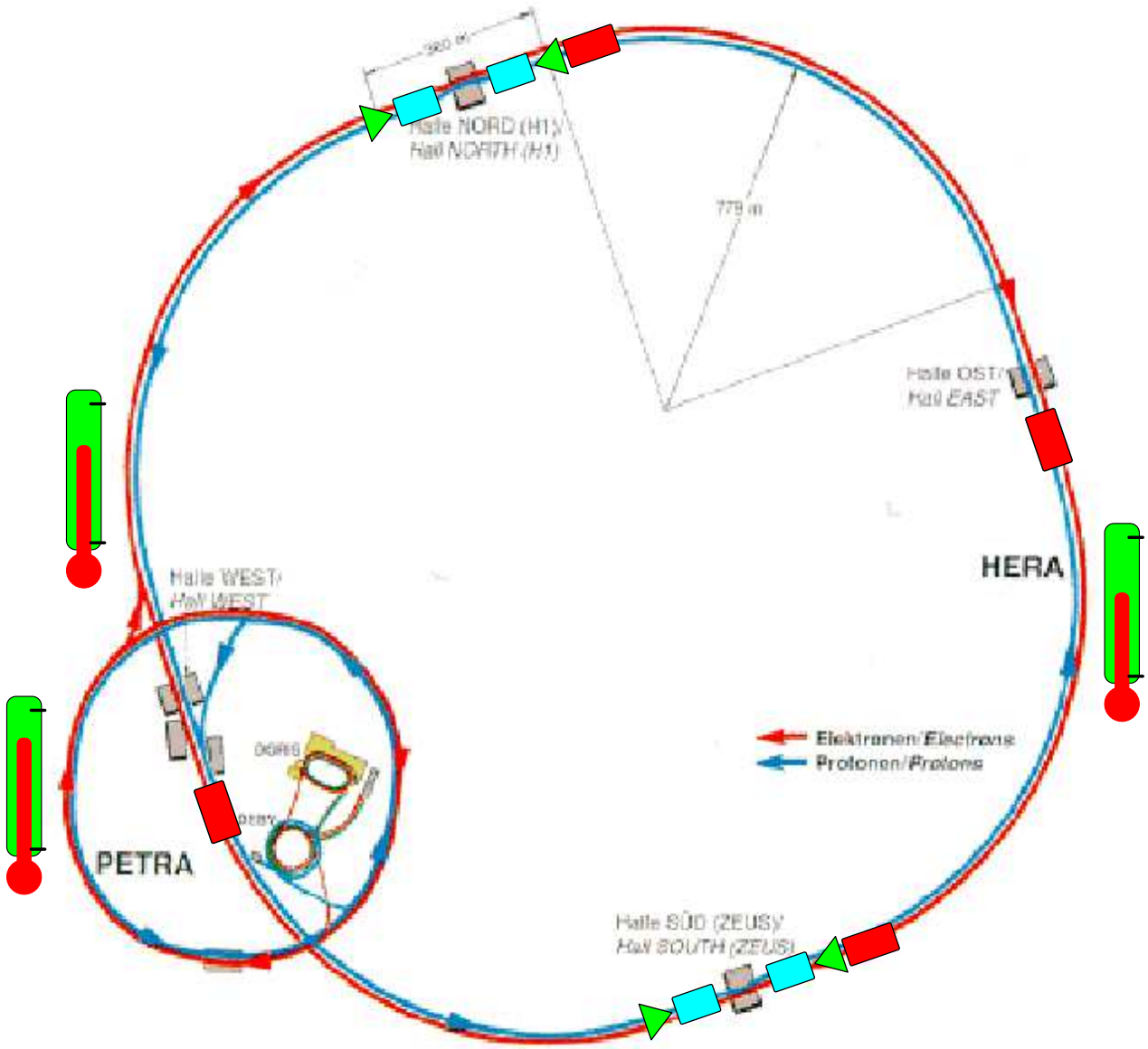
Required instalations in HERA



- Polarimeters
- Flattening Snakes
- Spin rotators
- At least 4 Siberian Snakes

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