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Kinematics of proton and deuteron beam polarization in the transparent spin mode of the NICA collider

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Outline

1. Manipulation of the beam polarization in the Transparent Spin Mode of NICA

2. Kinematics of proton and deuteron polarization in the Transparent Spin Mode of NICA

3. The direction of polarization at the injection place and at the location of the polarimeter.

4. Summary

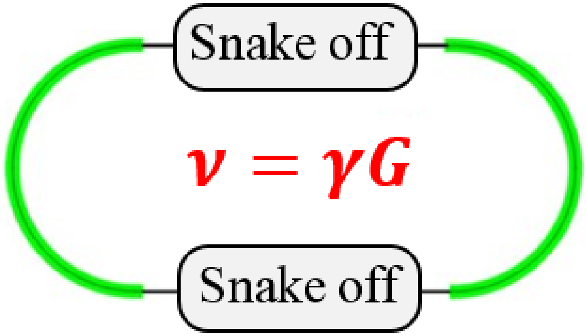
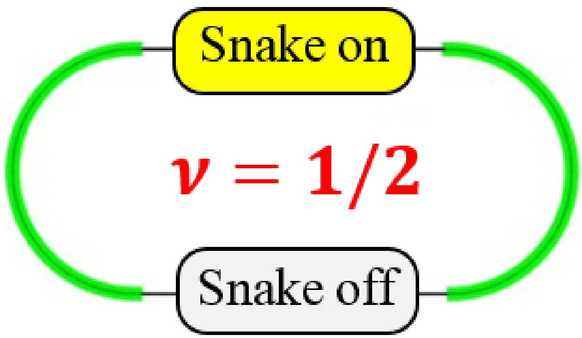
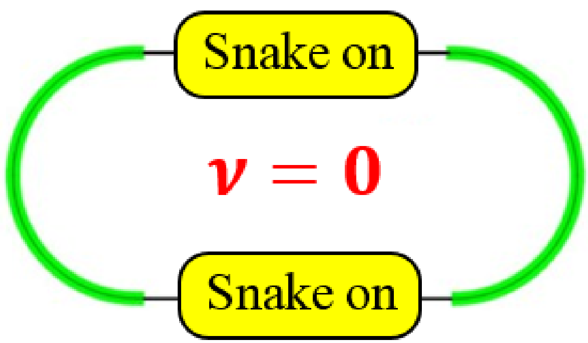
Distinct Spin mode (DS mode)

Periodic spin motion along
the closed orbit is **unique**

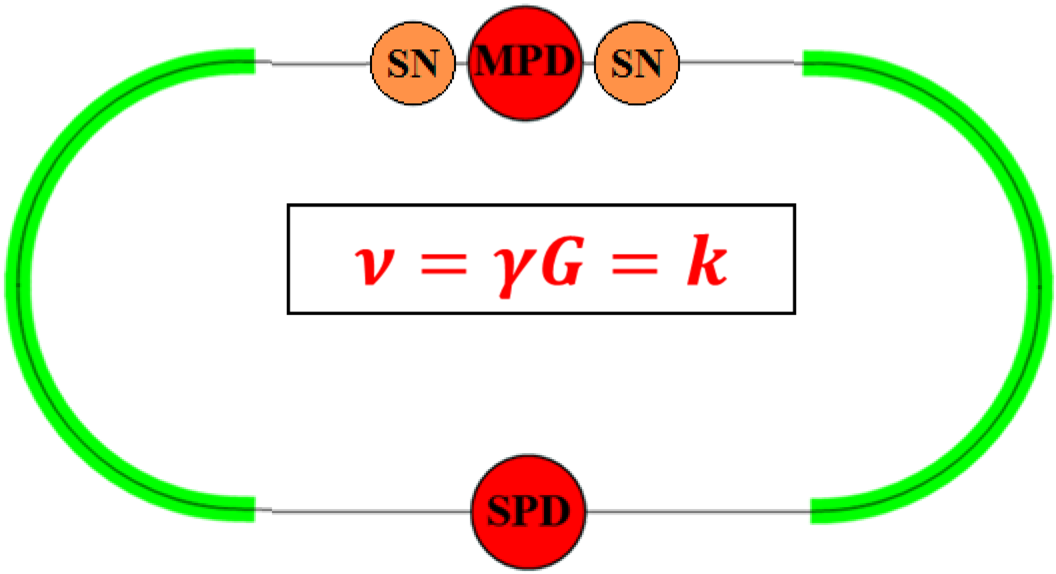
Transparent Spin mode (TS mode)

Any spin direction **repeats**
every particle turn

TS and DS modes at the NICA collider with two snakes

Collider's configuration	Spin mode
Without snakes 	**($\gamma G \neq k$) Distinct Spin (unique spin direction)** **($\gamma G = k$) Transparent Spin (any spin direction)**
With one snakes 	**Distinct Spin mode (unique spin direction)**
With two snakes 	**Transparent Spin mode (any spin direction)**

Transparent Spin Mode in NICA Collider at integer spin resonances (discrete values of energy).



Polarized beam is injected from Nuclotron to the NICA collider at energy which correspond to integer spin resonance

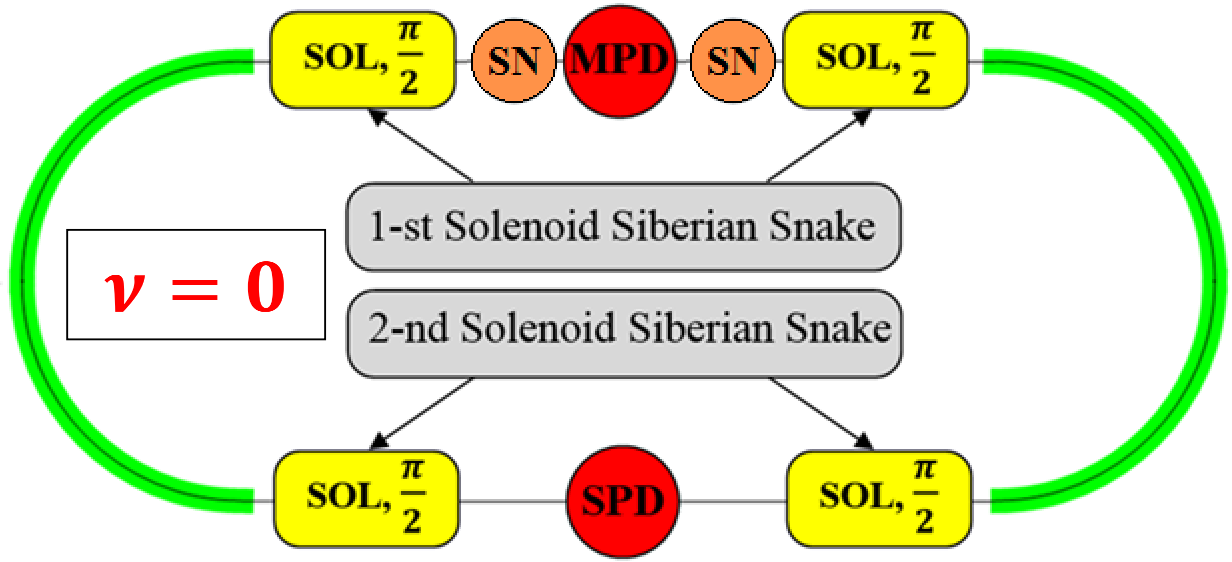
Spin Navigators based on "weak" solenoids with maximum field integral ***BL* < 0.6 T·m** (***protons, deuterons***)

Polarization direction in **SPD** or **MPD** — **any** direction **in vertical plane** (*z*-*y*)

Protons: $E_{kin}^{min} = 108$ MeV, $\Delta E = 523$ MeV (25 energy points)

Deuterons: $E_{kin} = 5.63$ GeV/u, $pc = 13$ GeV (1 energy point)

Transparent Spin Mode in NICA Collider at zero-spin tune (continuous values of energy).



Solenoids for spin transparency mode:

BL = 1÷25 T·m (***protons***), BL = 3÷80 T·m (***deuterons***)

Orbital parameters do not depend on the beam energy

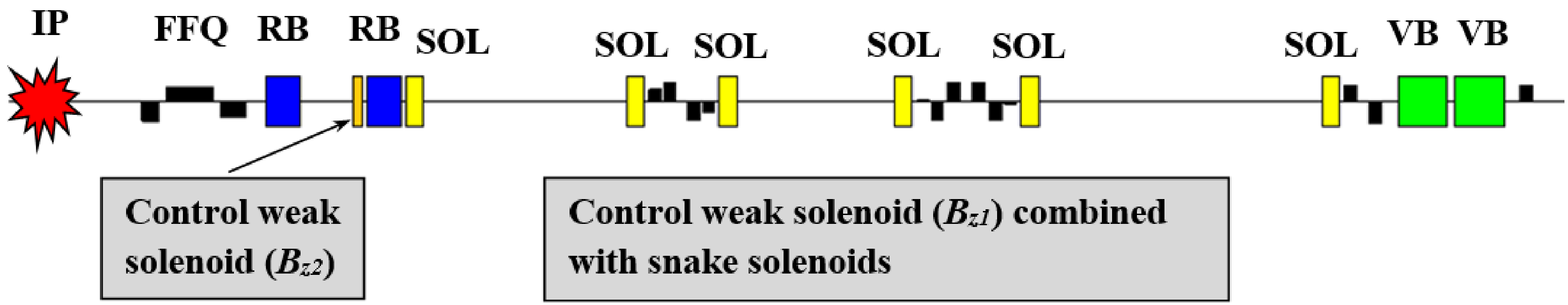
Spin Navigators based on "weak" solenoids with maximum field integral BL < 0.6 T·m (***protons, deuterons***)

Polarization direction (*p, d, ^{3}He, …*) :

in **SPD** or **MPD** — **any** direction **in vertical plane** (*z-y*);

in **arcs** — **any** direction **in orbit plane** (*z-x*).

Schematic layout of the half experimental straight section



SOL – **6T Solenoid of 0.7 m** (One Siberian Snake = 12×SOL)

VB – arc's Vertical-field Bending magnets,

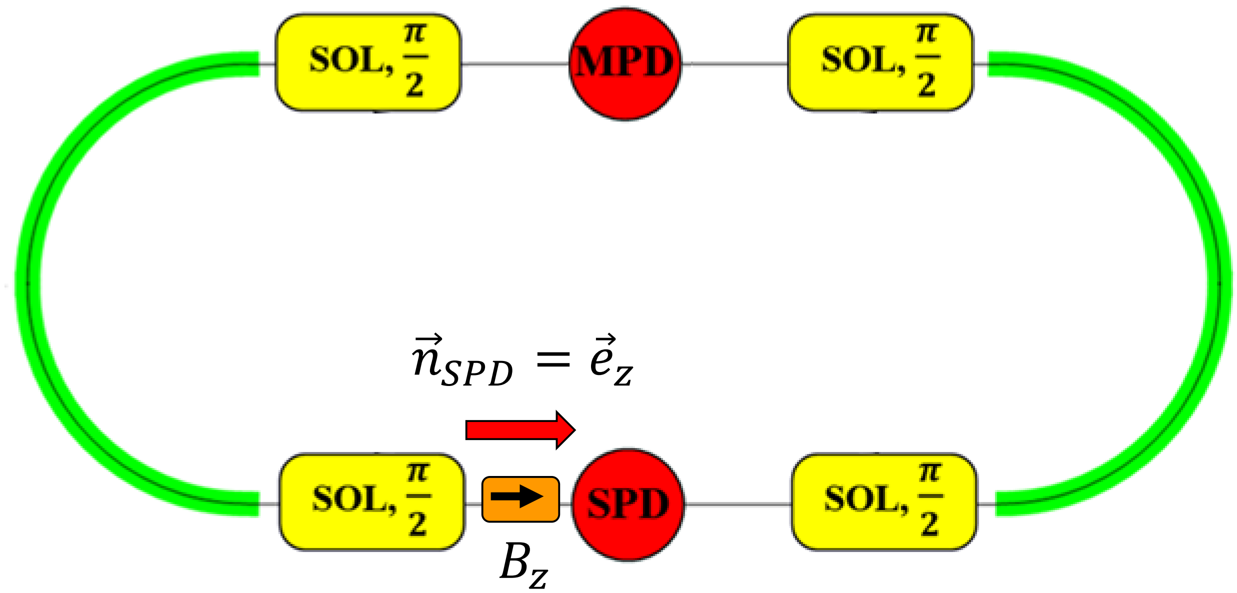
RB – Radial-field Bending magnets ,

FFQ – Final Focus Quadrupoles

p **up to momentum of 13.5 GeV/c**

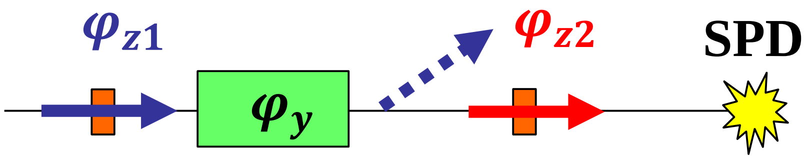
d **up to momentum of 4.12 GeV/c**

Longitudinal polarization at SPD



The direction of the stable polarization $\vec{n}$ coincides with the navigator solenoid axis $\vec{e}_z$ at the solenoid's location. Outside of the navigator, the direction of $\vec{n}(z)$ is determined by magnetic fields of the lattice

Ion polarization control in NICA by means of spin navigators



φ_{z1} stabilizes the longitudinal polarization before the dipole ($\varphi_y = \gamma G \alpha_{orb}$)

φ_{z2} stabilizes the longitudinal polarization after the dipole

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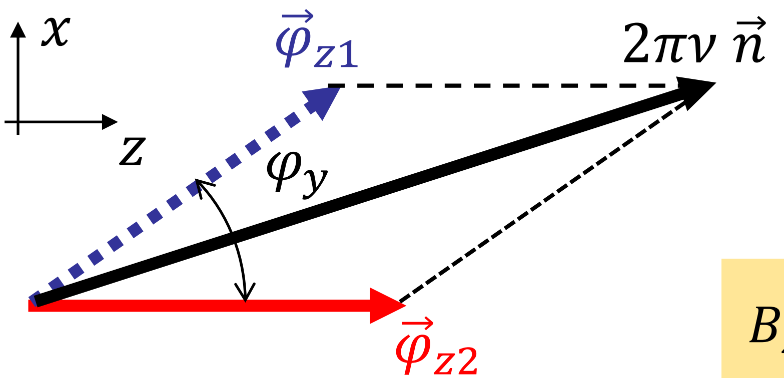
Vector diagram for calculation of navigator's solenoid field integrals (SPD)



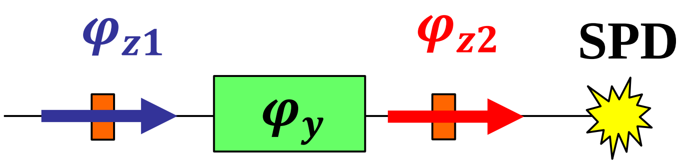
$$\varphi_{z2} = 2\pi\nu\left(n_z - \frac{n_x}{\tan\varphi_y}\right)$$

$$\varphi_{z1} = 2\pi\nu\frac{n_x}{\sin\varphi_y}$$

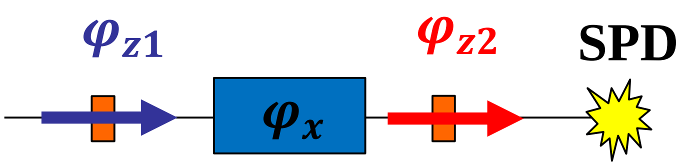
$$B_{zi}L_z = \frac{\varphi_{zi}}{1+G}B\rho$$

$$\varphi_y = \gamma_{max}G\,\alpha_{orb} < \pi$$

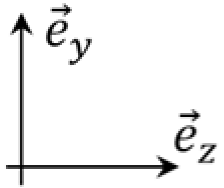
Control in horizontal plane (*xz*) of SPD



Control in vertical plane (*yz*) of SPD

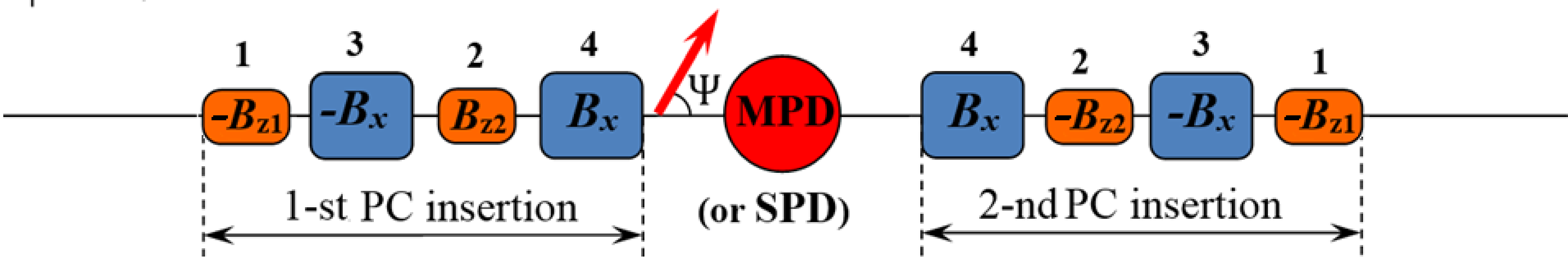


Ion polarization control in NICA collider by means of "weak" solenoids

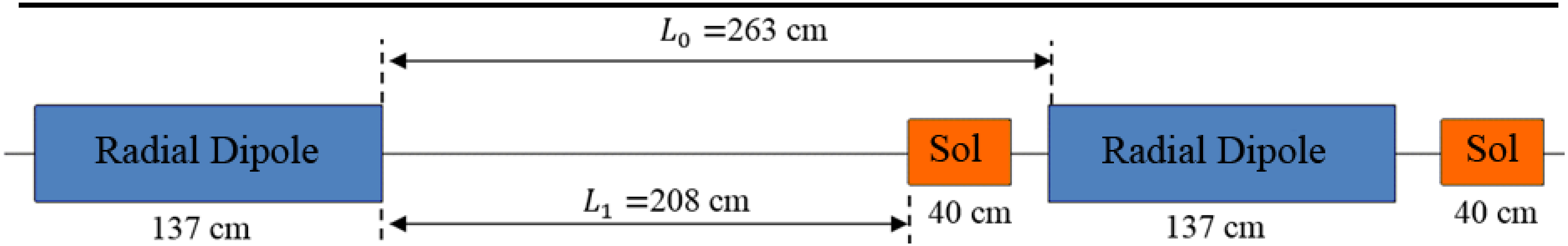


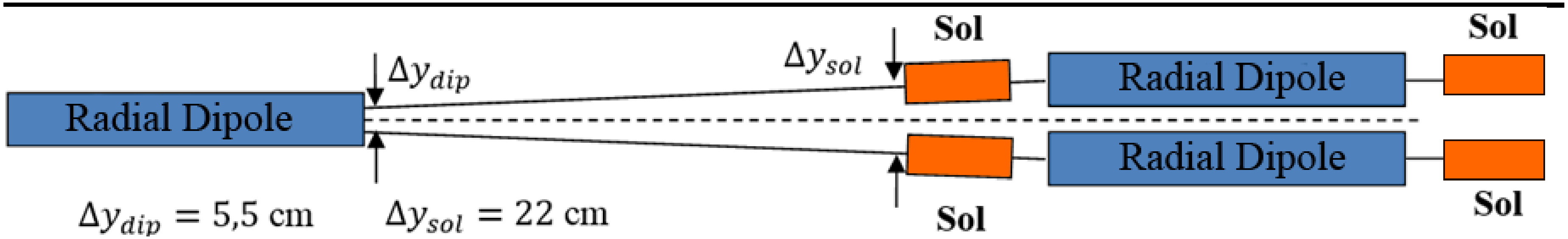
$$\vec{S}_{MPD} = \vec{e}_y \sin\Psi + \vec{e}_z \cos\Psi$$

1,2 – weak solenoids
3,4 – radial dipoles



Ψ is the angle between the polarization and velocity directions





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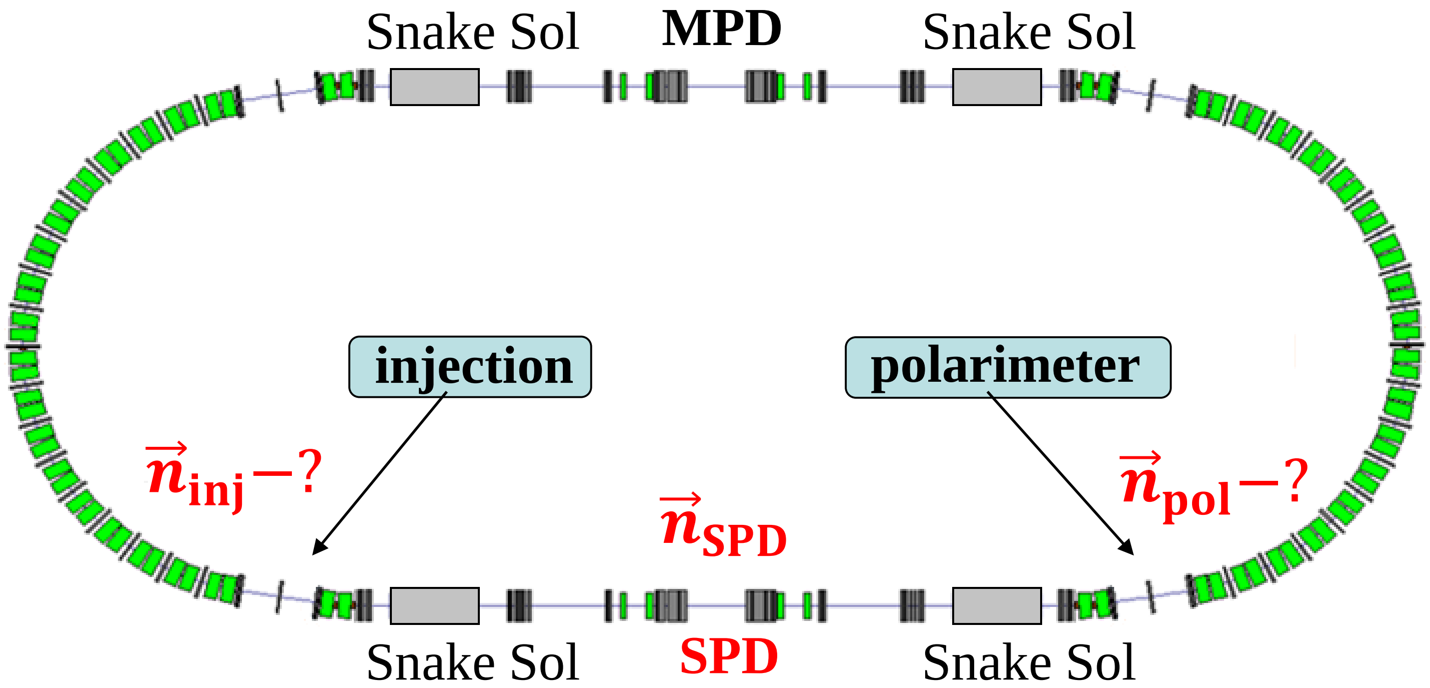
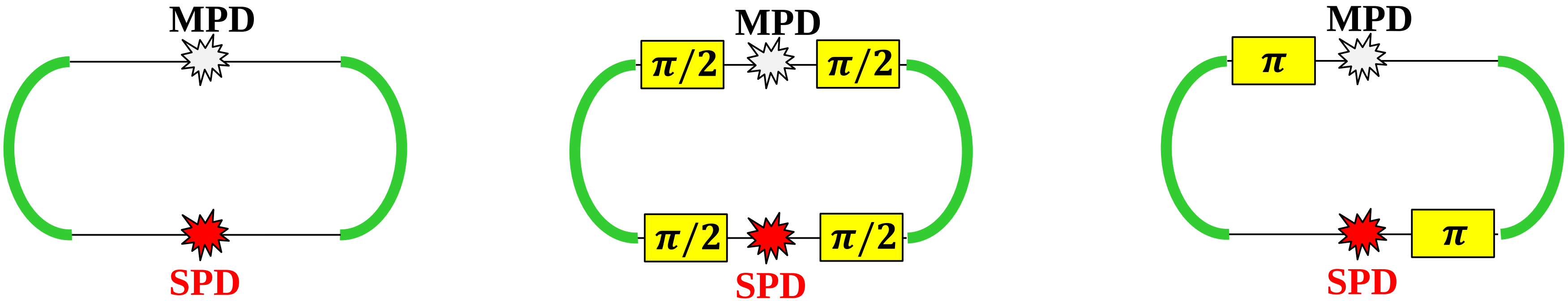
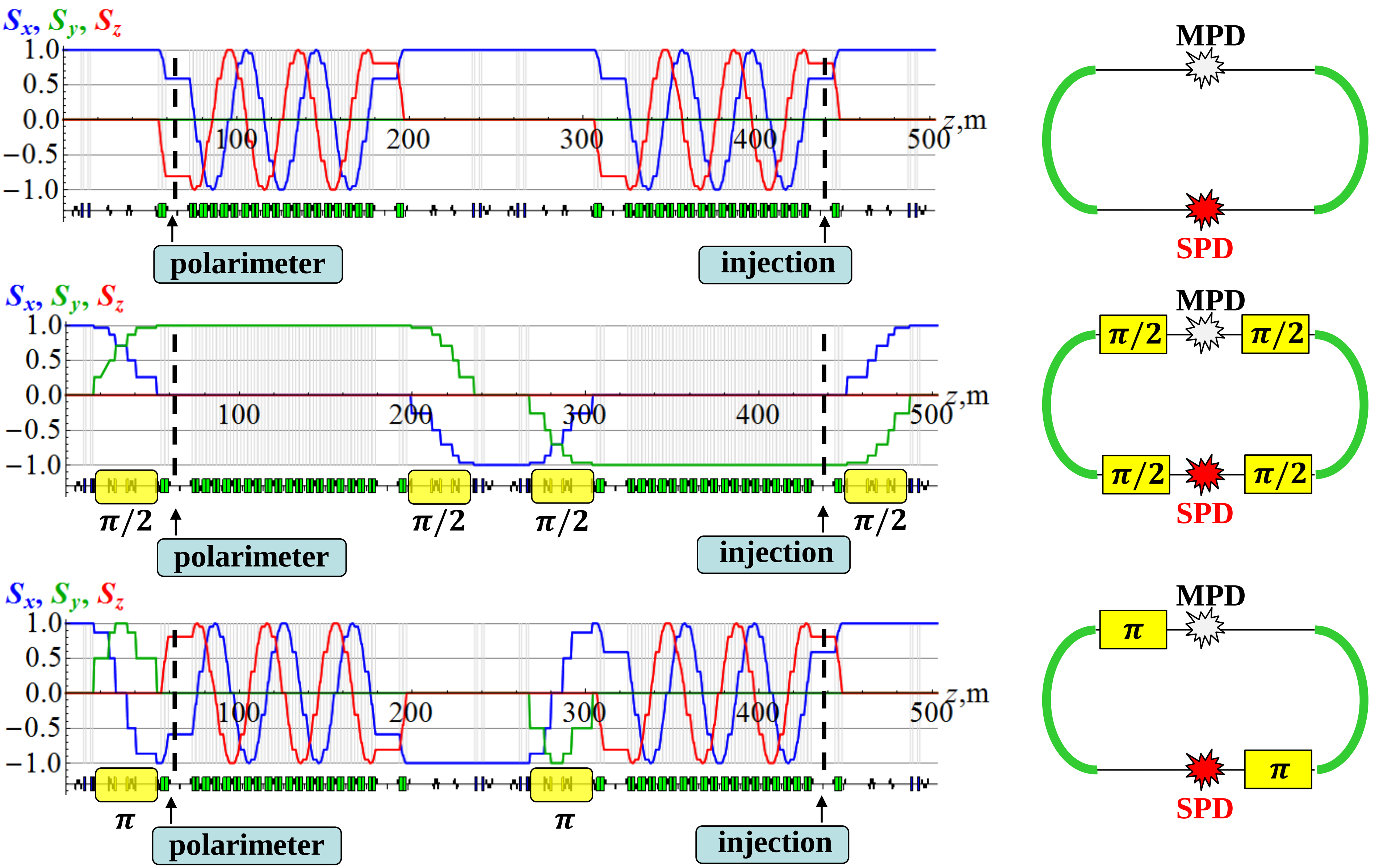
Polarization at the injection place and the location of the polarimeter



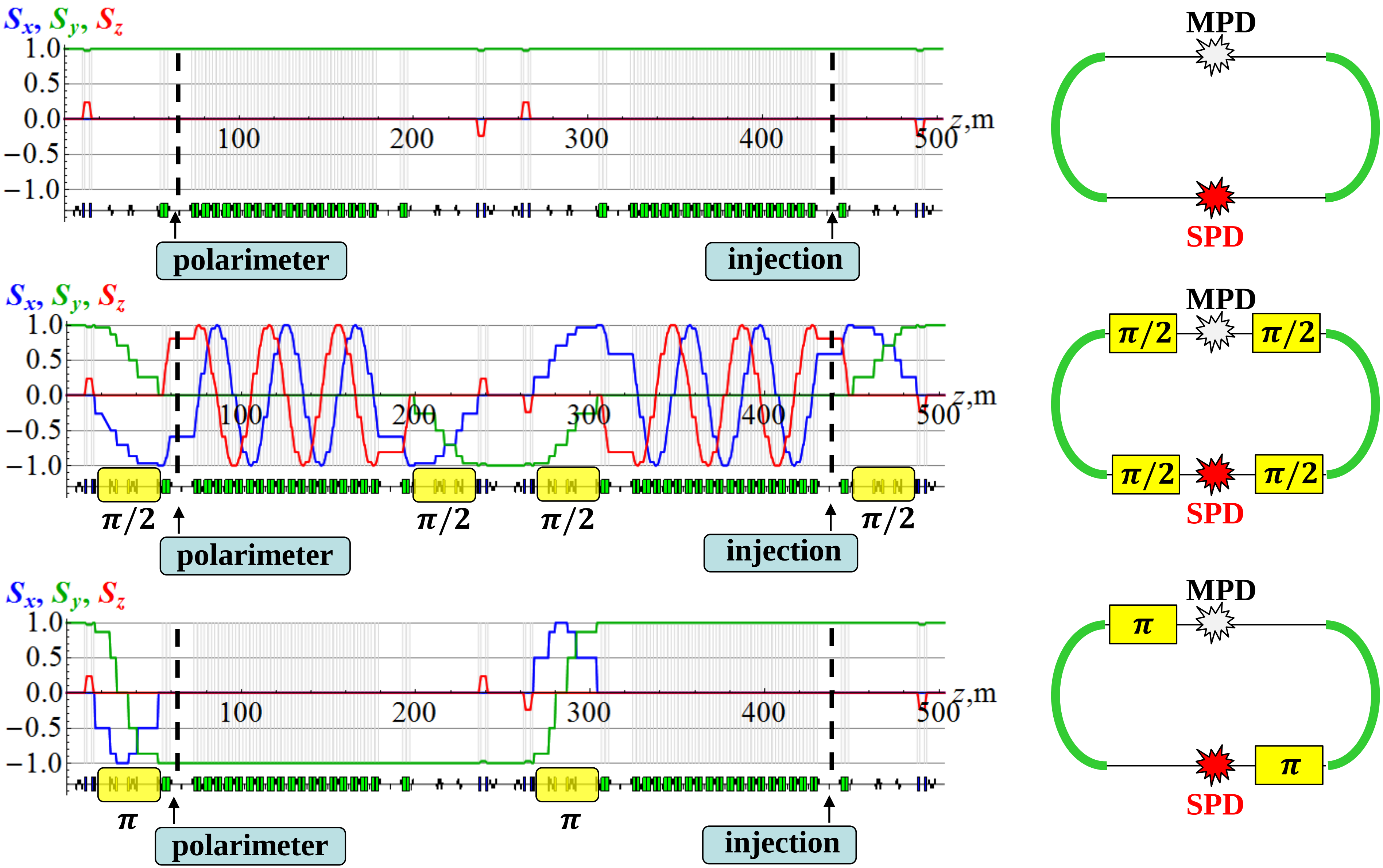
Three TS-mode schemes for comparison of spin kinematics



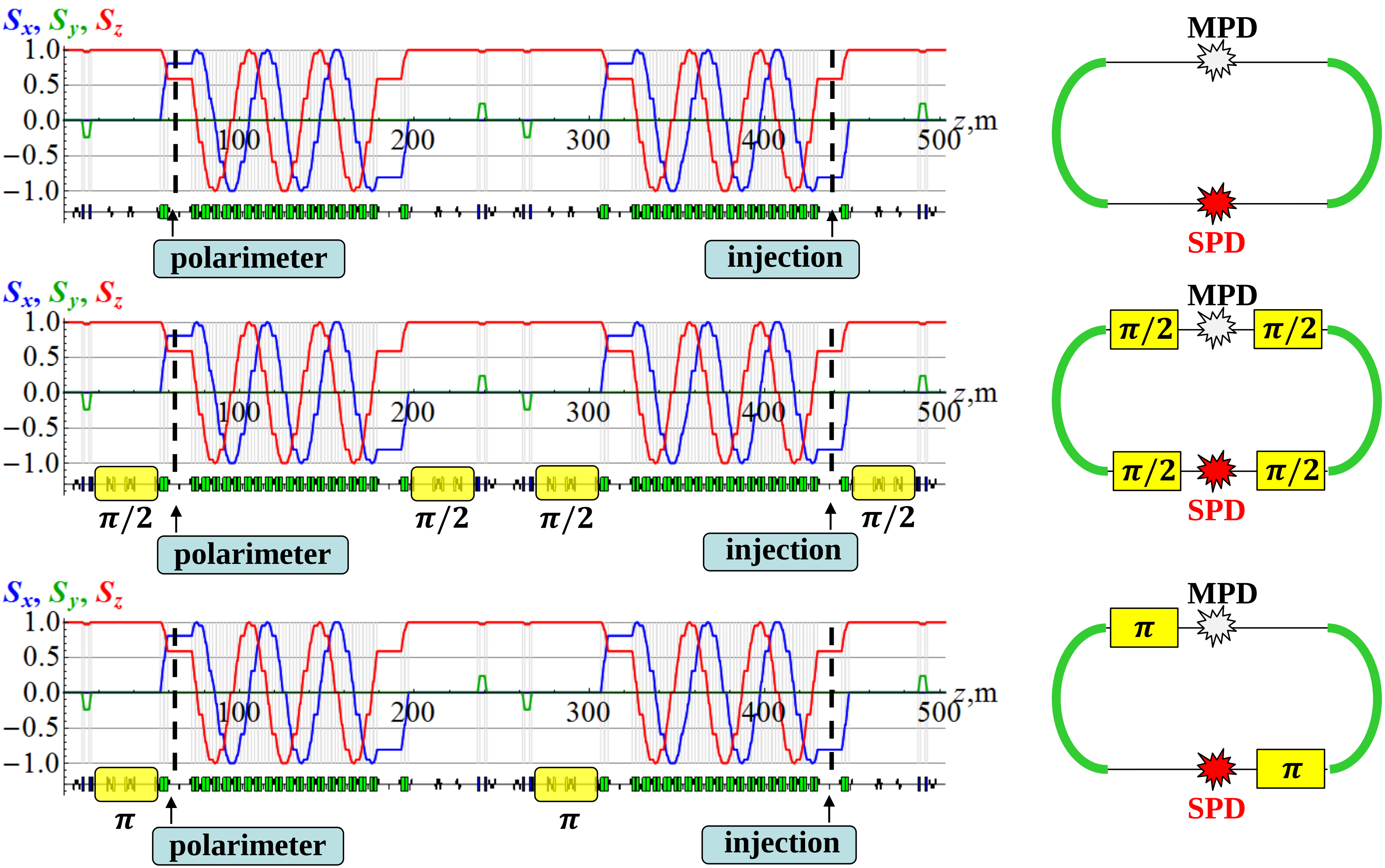
Radial Proton Polarization at SPD ($\gamma G = 6$)



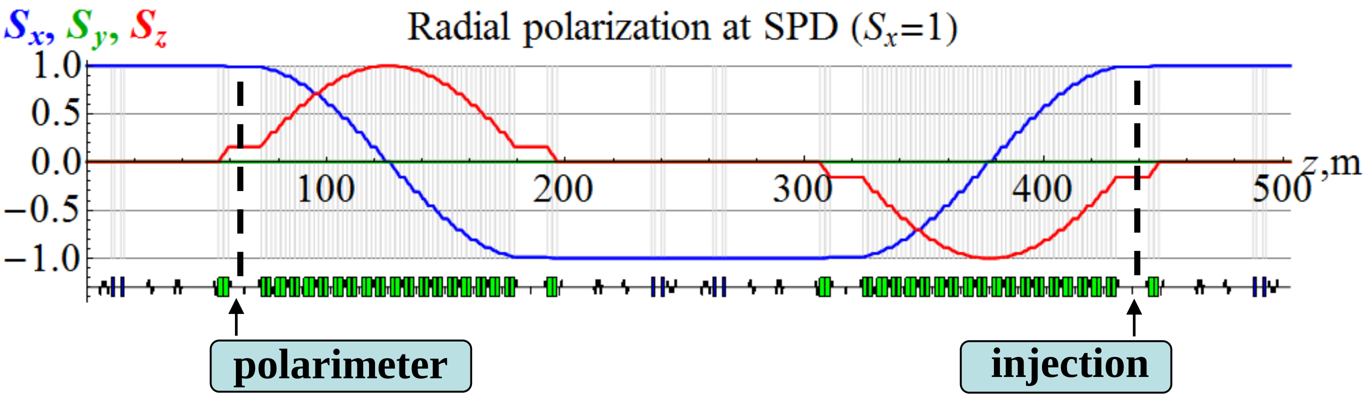
Vertical Proton Polarization at SPD ($\gamma G = 6$)

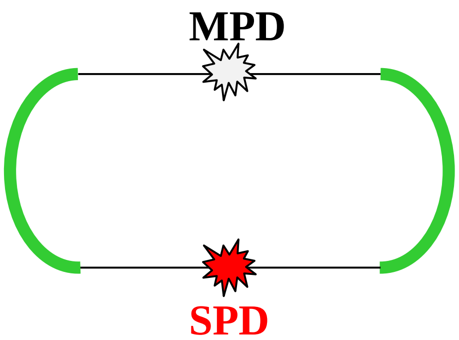


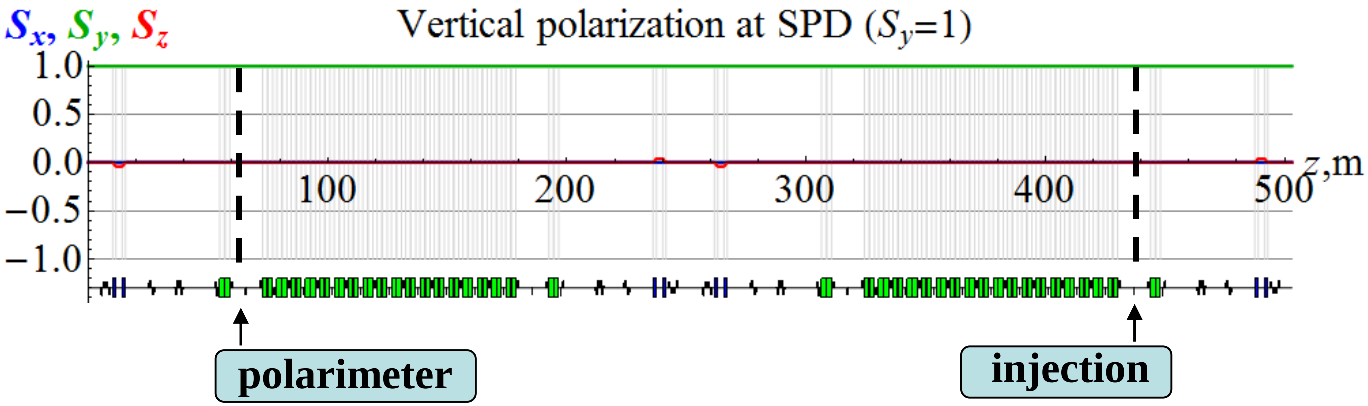
Longitudinal Proton Polarization at SPD ($\gamma G = 6$)

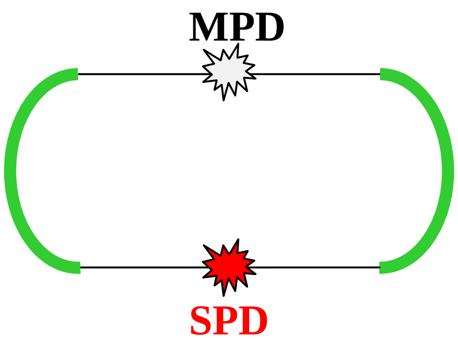


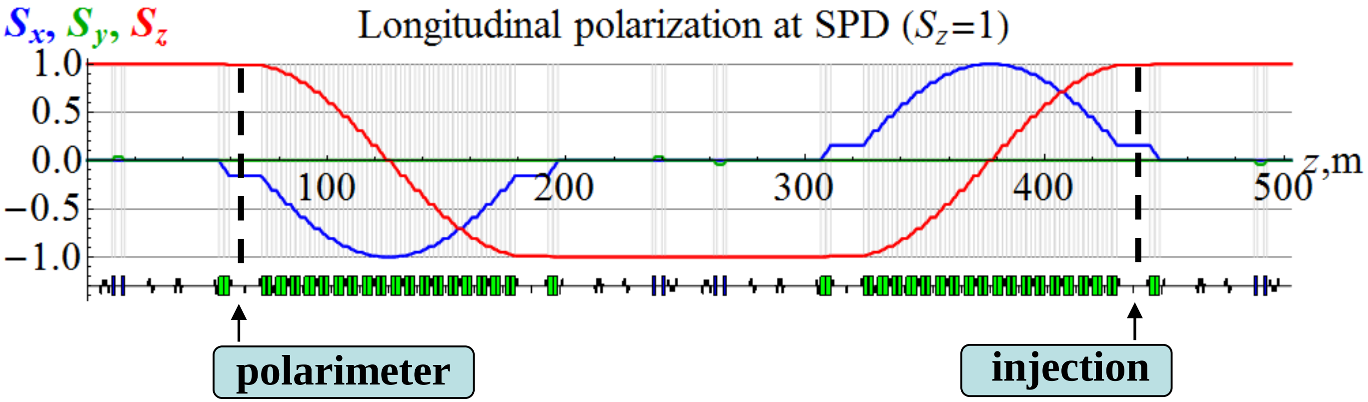
Deuteron Polarization at SPD $(\gamma G = -1)$

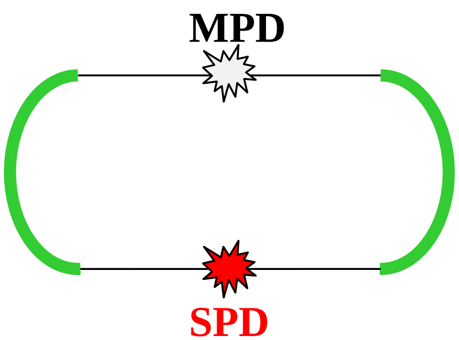












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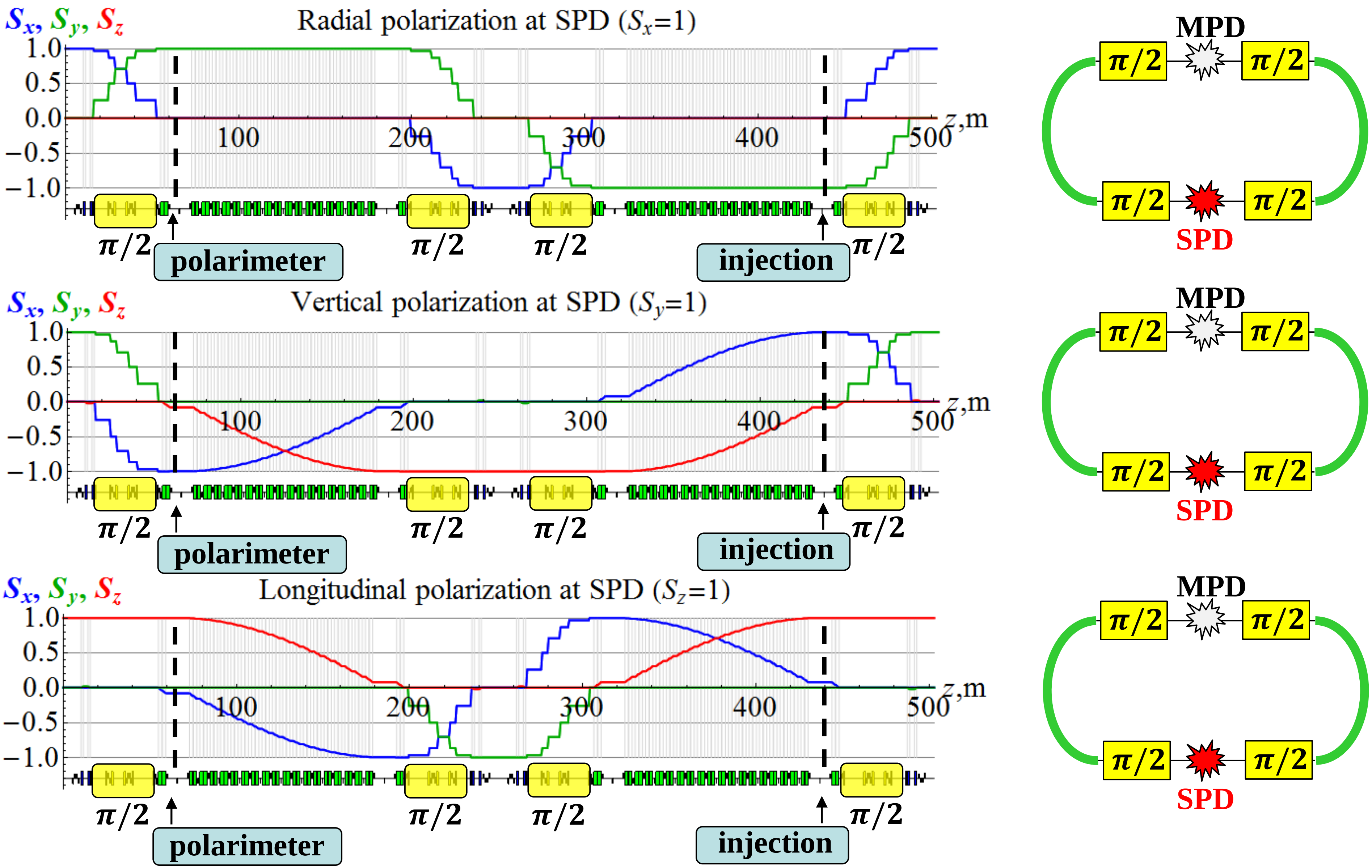
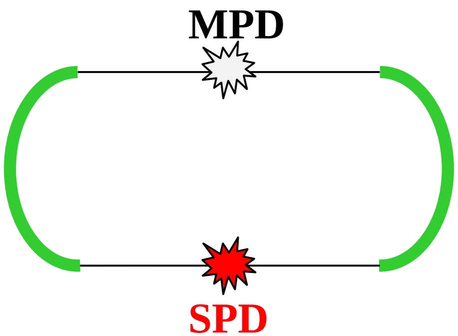
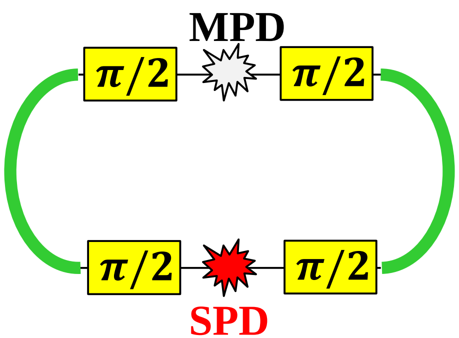
Deuteron Polarization at SPD $(\gamma G = -0.5, \mathrm{BL}_{snake} \approx 56\ T \cdot m)$



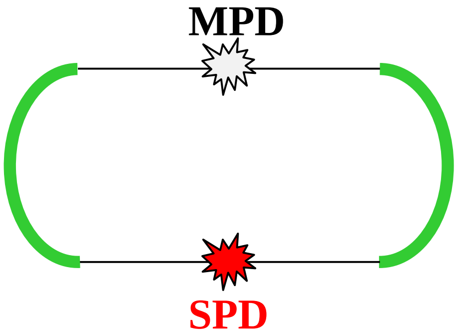
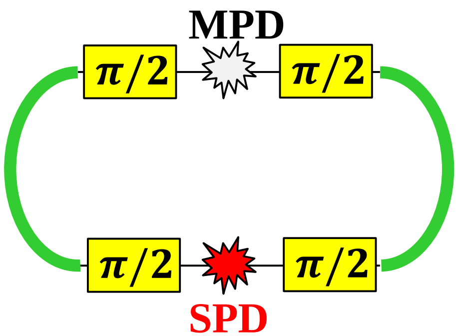
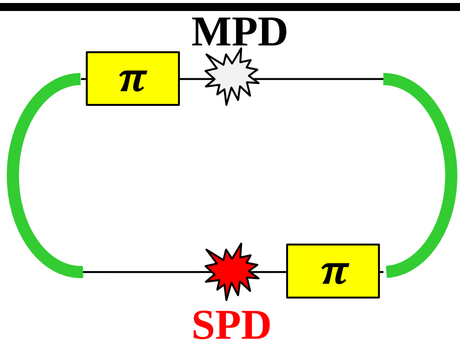
Deuteron Polarization Direction in the NICA TS-mode

TS-mode scheme	SPD	Injection	Polarimeter
	$\vec{e}_x$	$\approx \vec{e}_x$	$\approx \vec{e}_x$
	$\vec{e}_y$	$\vec{e}_y$	$\vec{e}_y$
	$\vec{e}_z$	$\approx \vec{e}_z$	$\approx \vec{e}_z$
	$\vec{e}_x$	$\vec{e}_y$	$-\vec{e}_y$
	$\vec{e}_y$	$\approx \vec{e}_x$	$\approx -\vec{e}_x$
	$\vec{e}_z$	$\approx \vec{e}_z$	$\approx \vec{e}_z$

(yz) is the vertical plane

(xz) is the collider plane

Proton Polarization Direction in the NICA TS-mode

TS-mode scheme	SPD	Injection	Polarimeter
	$\vec{e}_x$	(xz)	(xz)
	$\vec{e}_y$	$\vec{e}_y$	$\vec{e}_y$
	$\vec{e}_z$	(xz)	(xz)
	$\vec{e}_x$	$-\vec{e}_y$	$\vec{e}_y$
	$\vec{e}_y$	(xz)	(xz)
	$\vec{e}_z$	(xz)	(xz)
	$\vec{e}_x$	(xz)	(xz)
	$\vec{e}_y$	$\vec{e}_y$	$-\vec{e}_y$
	$\vec{e}_z$	(xz)	(xz)

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Summary

The kinematics of beam polarization is calculated when vertical, longitudinal or radial polarization is set in the SPD detector for different schemes of placement of snake solenoids.

The results are relevant to solve the tasks of injection and polarimetry for conducting experiments with polarized beams in the spin transparency mode.

Thank you for your attention!