Ion Polarization in RHIC/eRHIC

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Polarized Ion Sources (reporting for Anatoly Zelenski)

Polarized proton beams in RHIC/eRHIC

Polarized He3 for eRHIC (reporting for Waldo MacKay)

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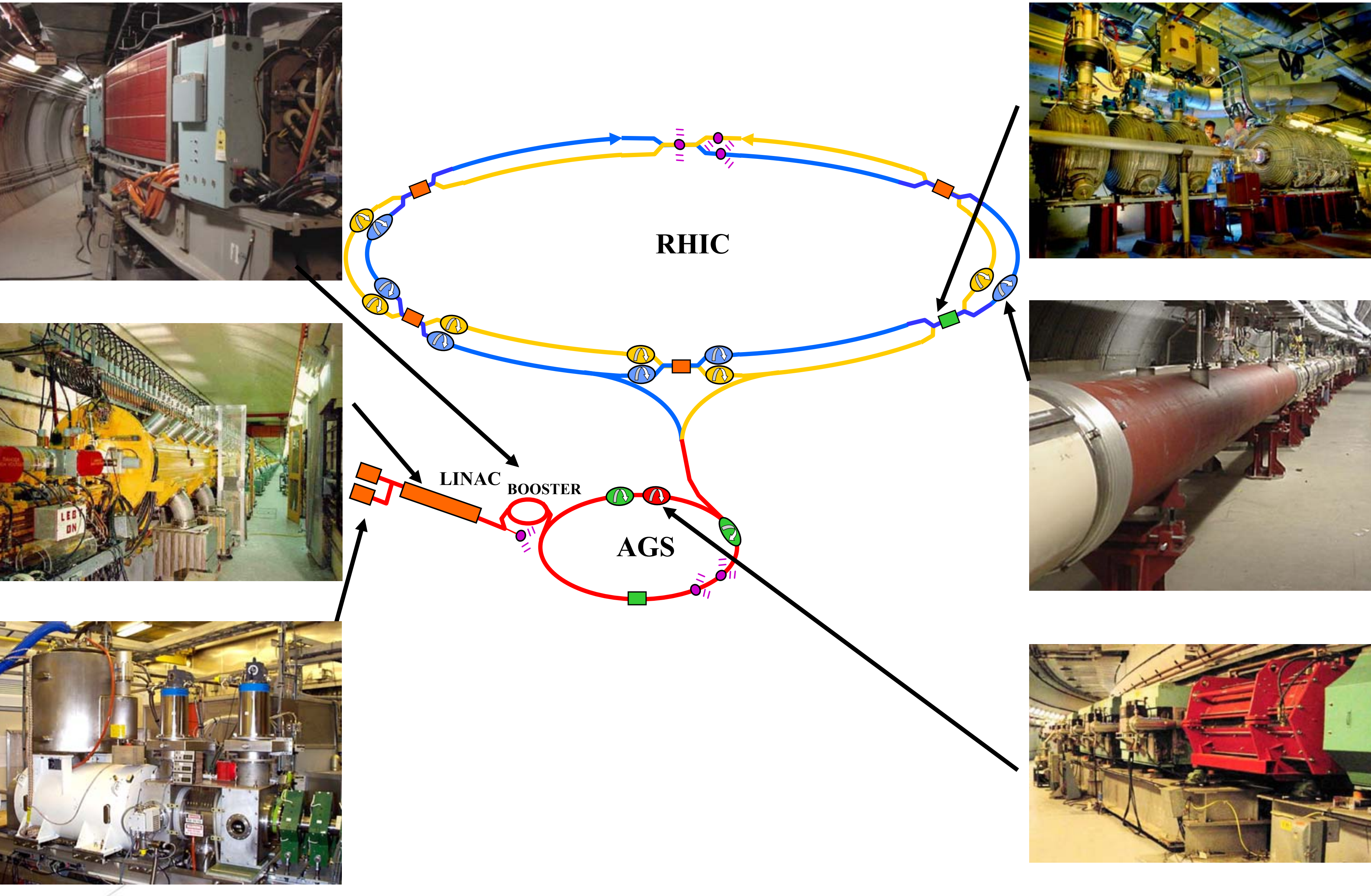
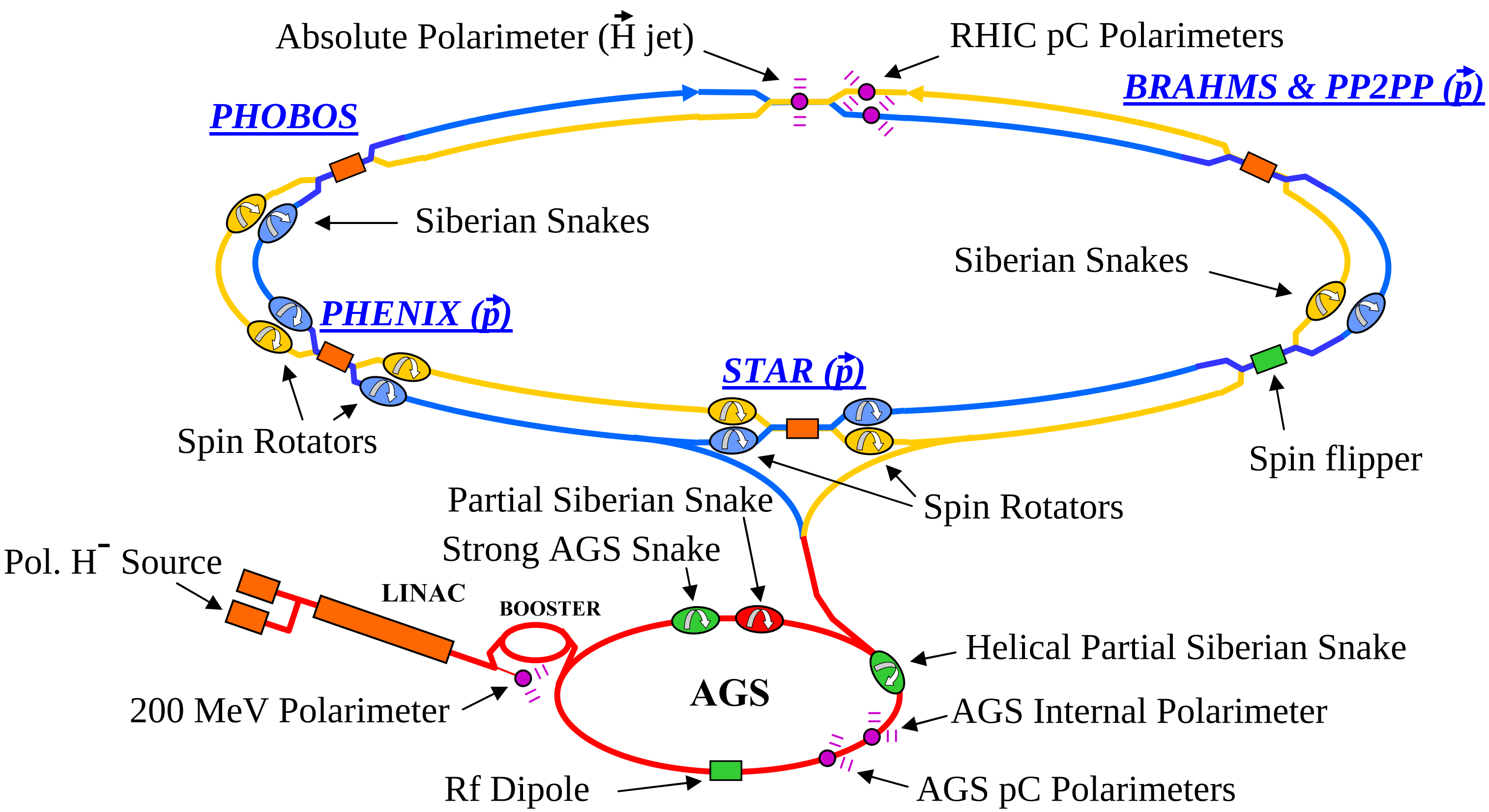
Thomas Roser
2nd Electron-Ion Collider Workshop
March 15-17, 2004

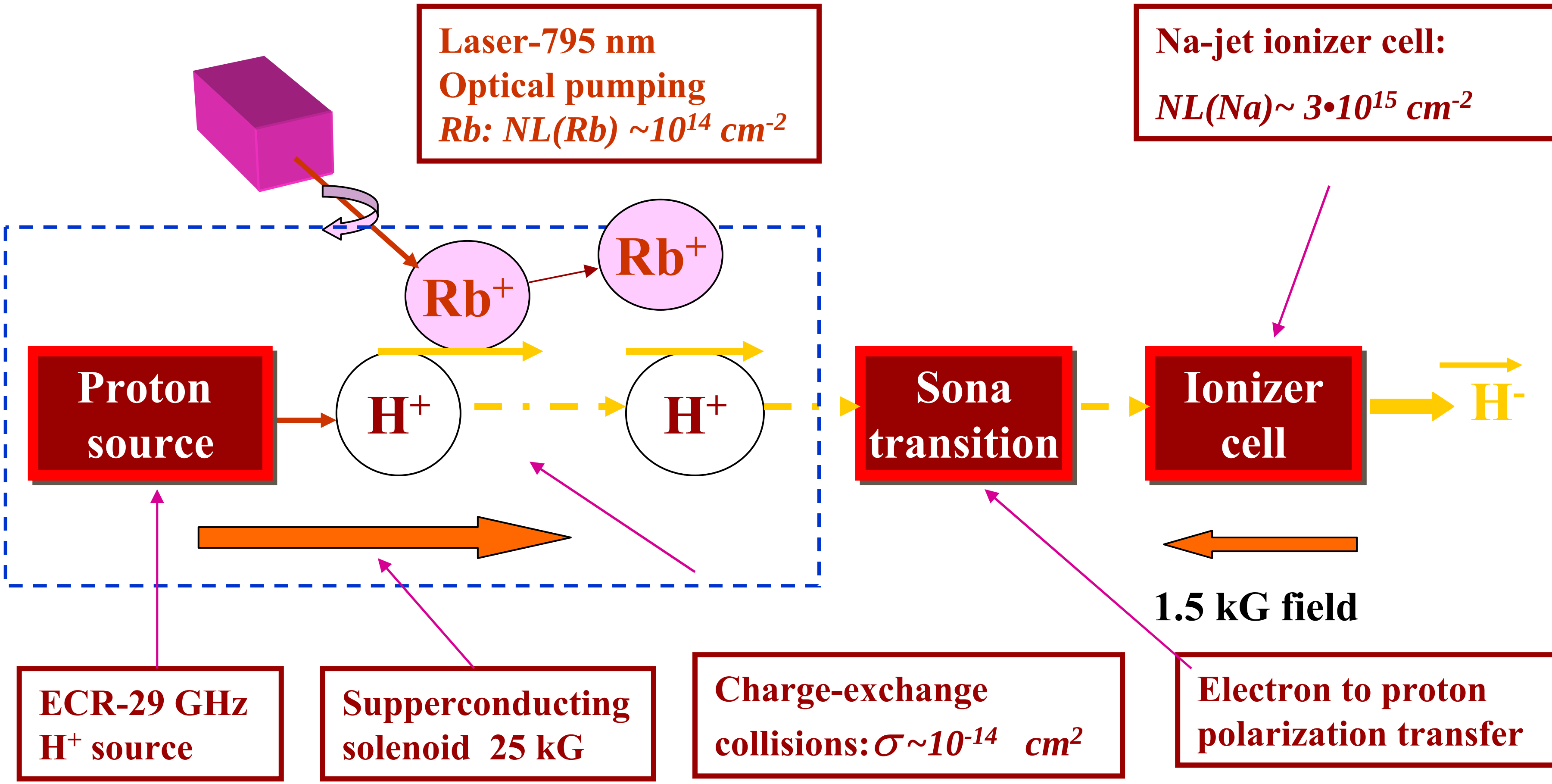
Polarized Protons at RHIC



Polarized Proton Collisions in RHIC



SPIN-EXCHANGE POLARIZATION IN PROTON-Rb COLLISIONS



Laser beam is a primary source of angular momentum:

10 W (795 nm) ⇒ $4 \cdot 10^{19}$ hν/sec ⇒ **2 A, $\vec{H}^0$ equivalent intensity.**

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Polarized H- for RHIC

Polarized source for RHIC was developed in collaboration: BNL – KEK – TRIUMF – INR, Moscow(1998-2002)

- **Source intensity 12· 10^{11} H^{-}/pulse.**
- **Pulse duration 300-500 us, repetition rate up to 7 Hz .**
- **85% polarization was obtained with the TRIUMF solenoid.**
- **75-80% with KEK solenoid.**

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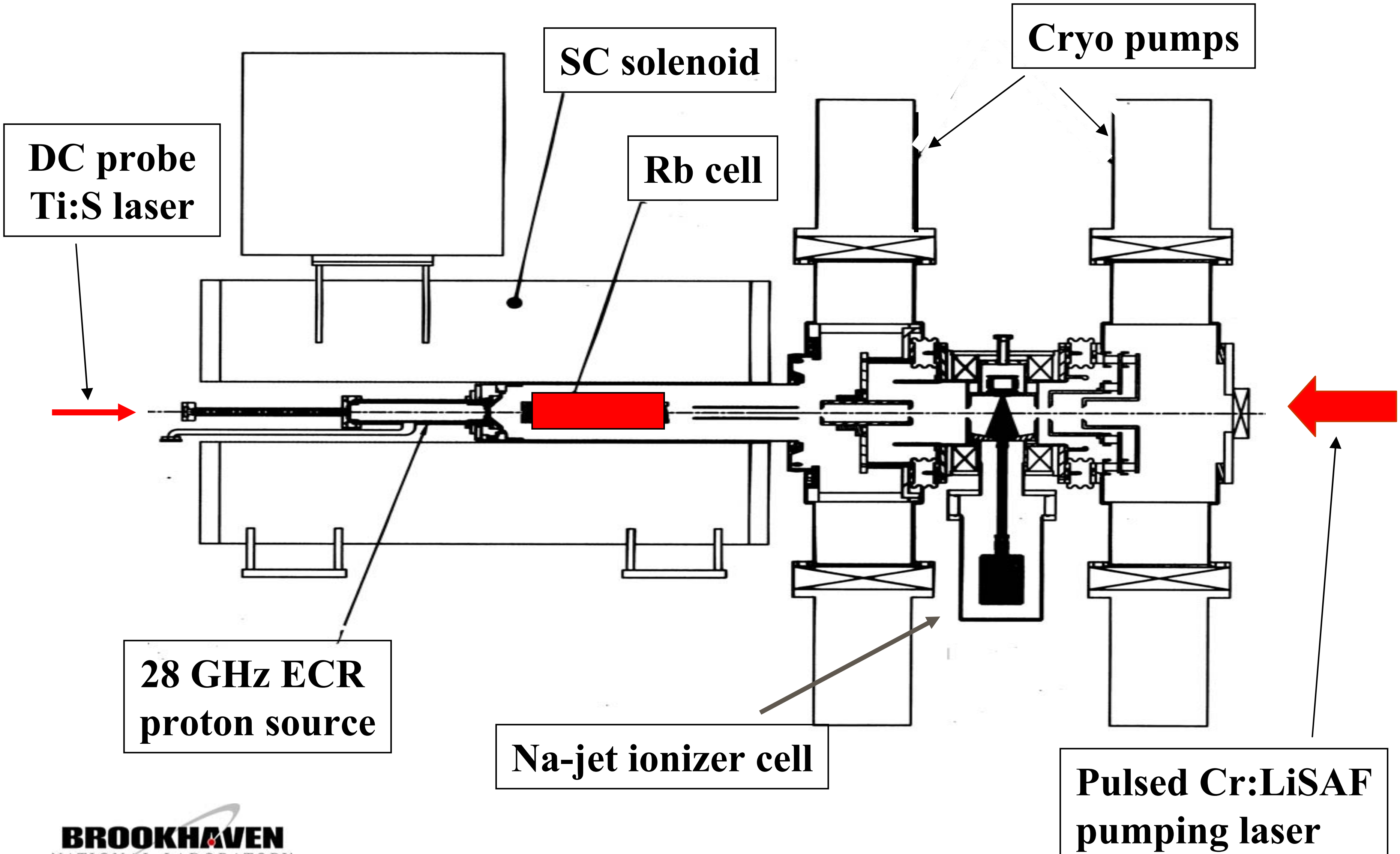
Schematic Layout for the RHIC OPPIS



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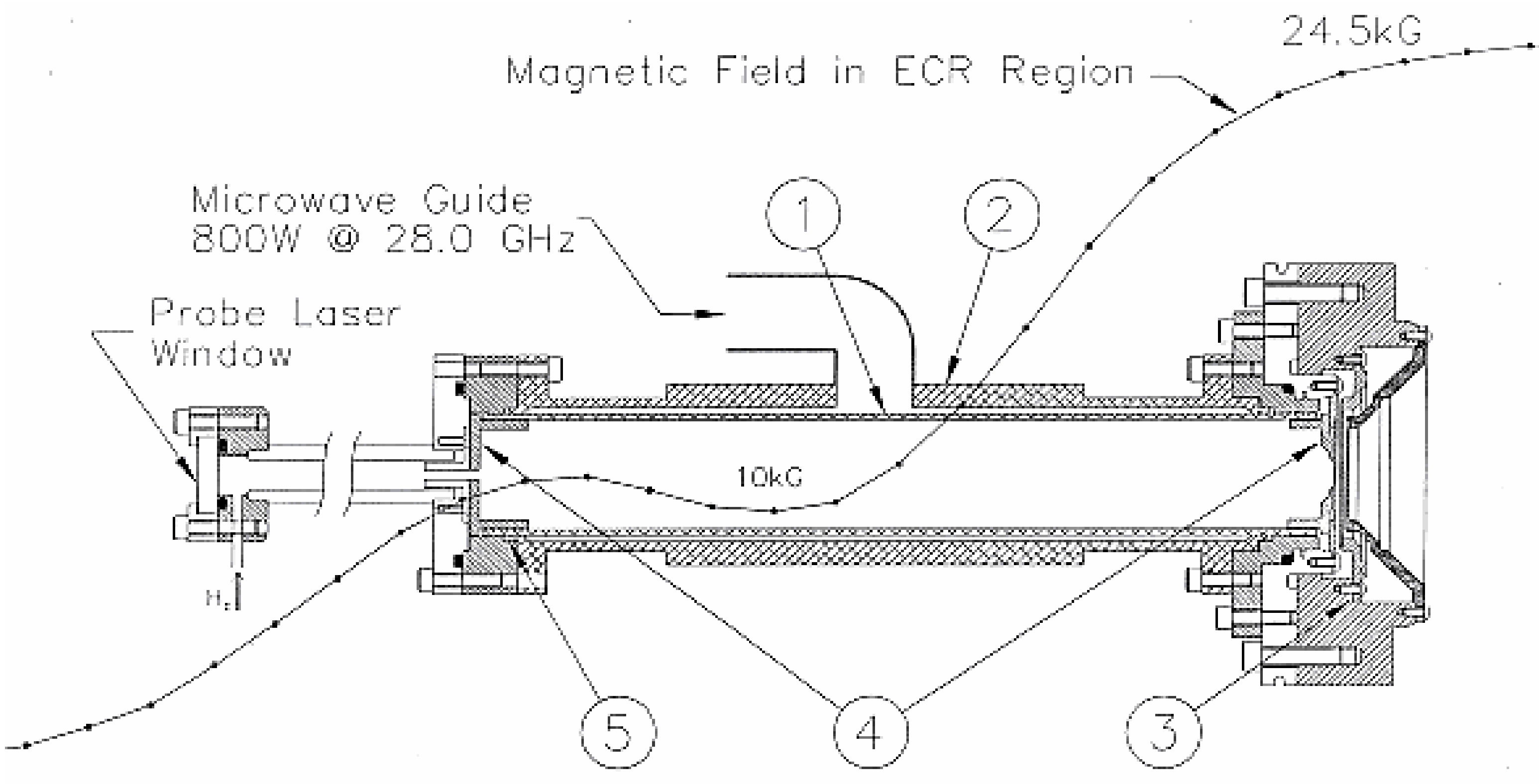
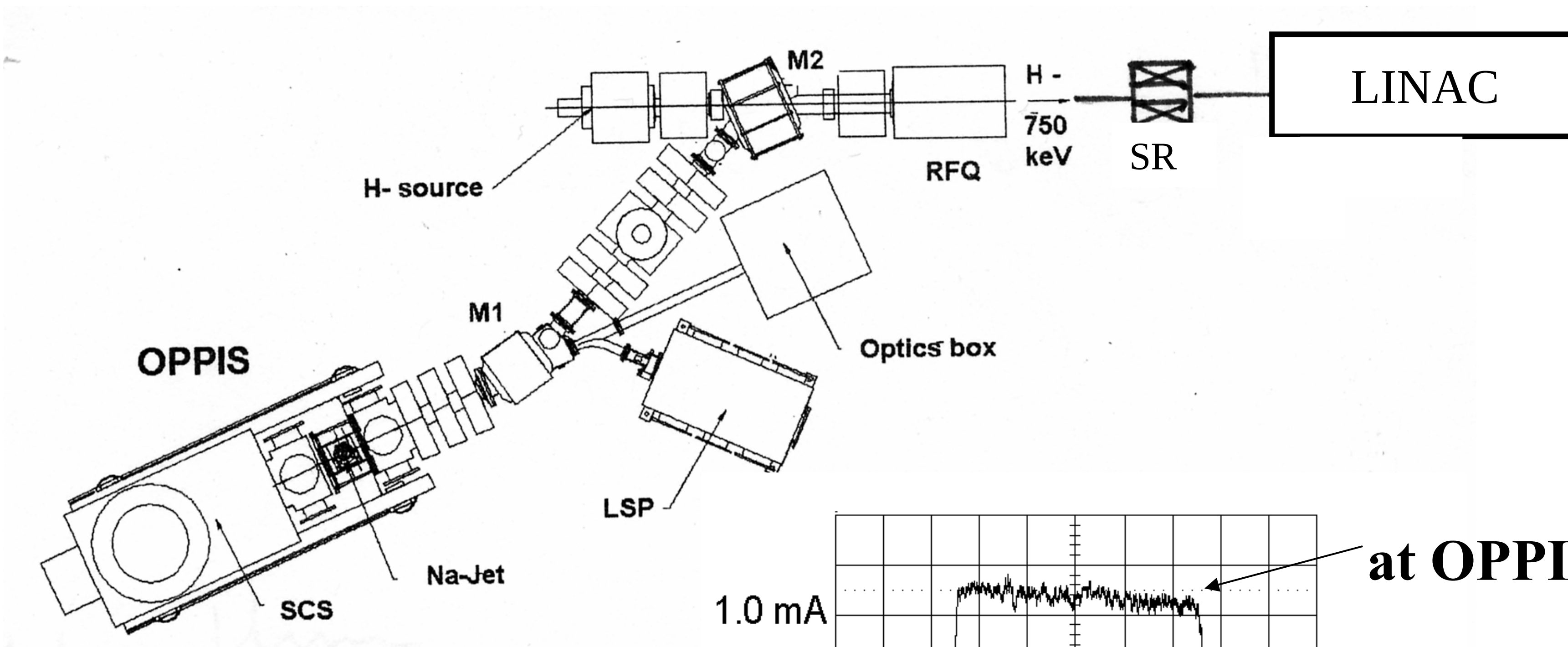
ECR Primary Proton Source

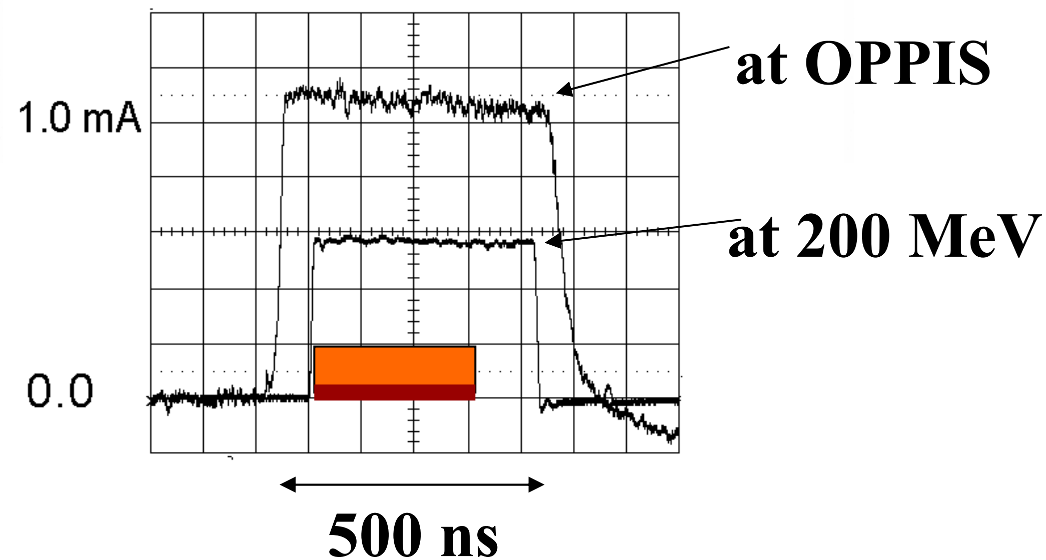


1-quartz liner Ø40 мм; 2- ECR-cavity; 3-three-grid multi-hole proton extraction system; 4- boron-nitride cups; 5-"Kalrez" O-rings. Longitudinal magnetic field distribution for optimal OPPIS operation.

Polarized Injector Layout



OPPIS	optically-pumped polarized H- ion source
M_1M_2	bending magnets
LSP	Lamb-shift polarimeter
SR	spin-rotator

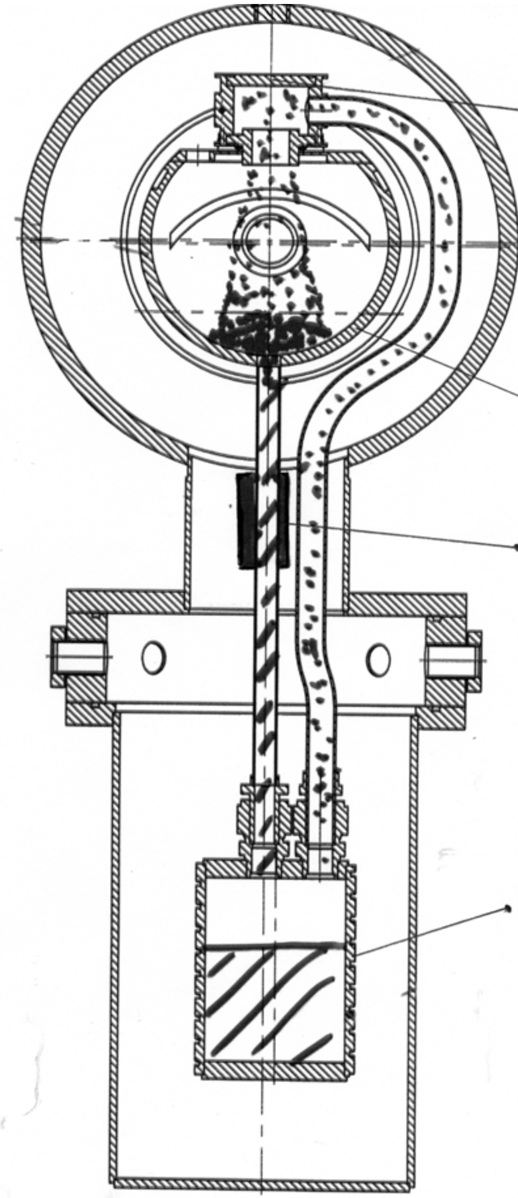


Sodium Jet Ionizer Cell

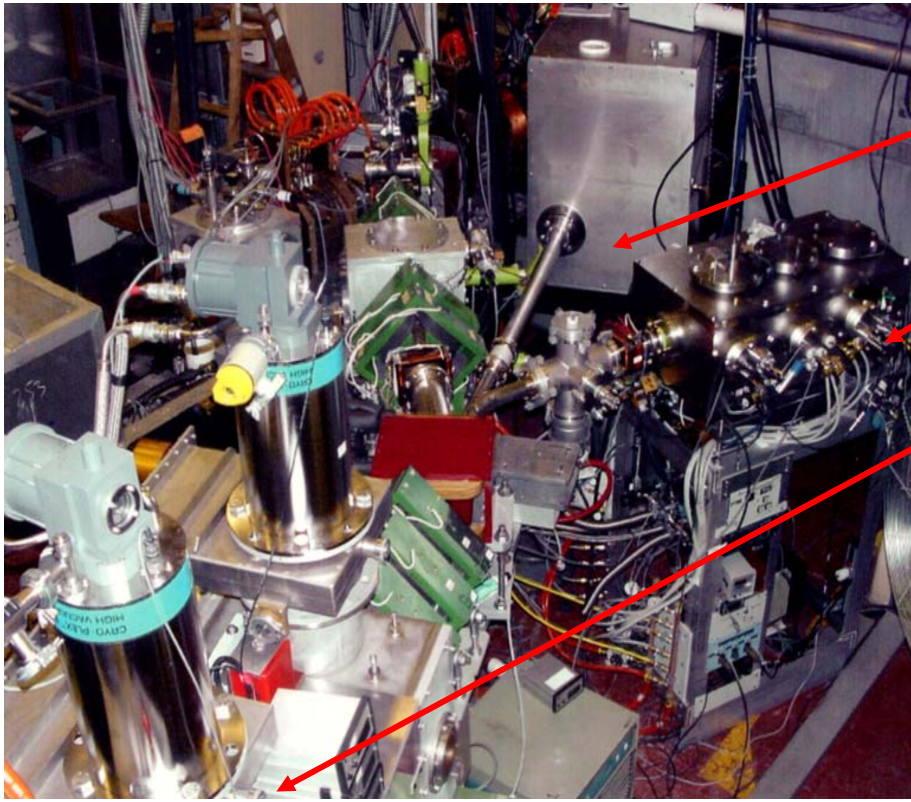
Transverse vapor flow in the N-jet cell: Reduces sodium vapor losses by 3-4 orders of magnitude, which allows the cell aperture to be increased to 3.0 cm .

Reservoir - operational temperature: ~ 500 °C.
Nozzle temperature: ~ 500 °C.
Collector - Na-vapor condensation: ~ 120 °C
Trap - return line: ~ 120 – 180 °C.

Na-jet cell is isolated and biased to –32 keV to accelerate H- beam to 35 keV without HV platform .



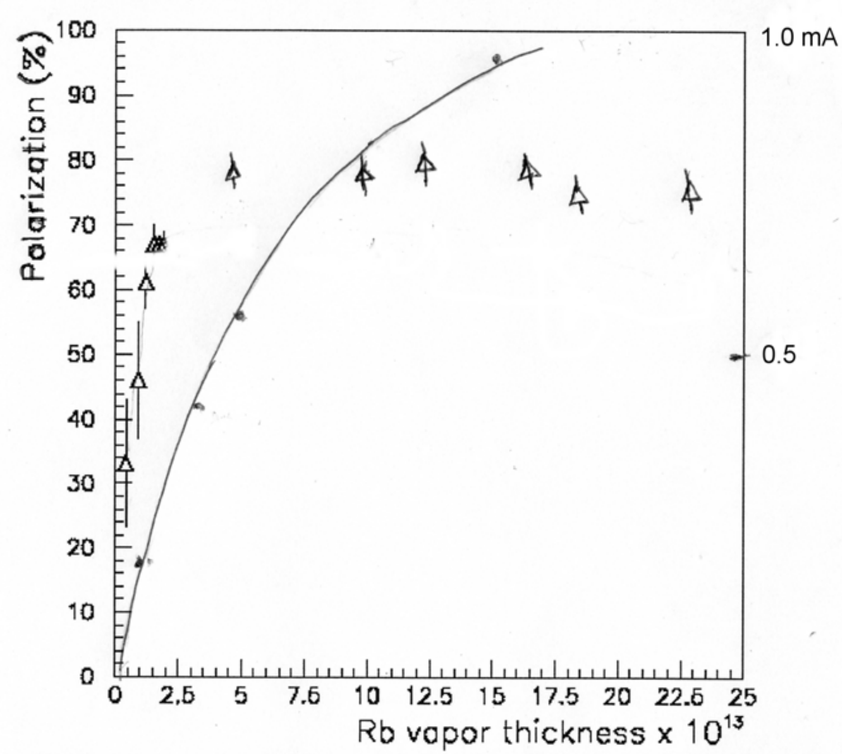
Lamb-shift OPPIS polarimeter at 2-35 keV beam energy



Optics box

Lamb-shift Polarimeter

OPPIS

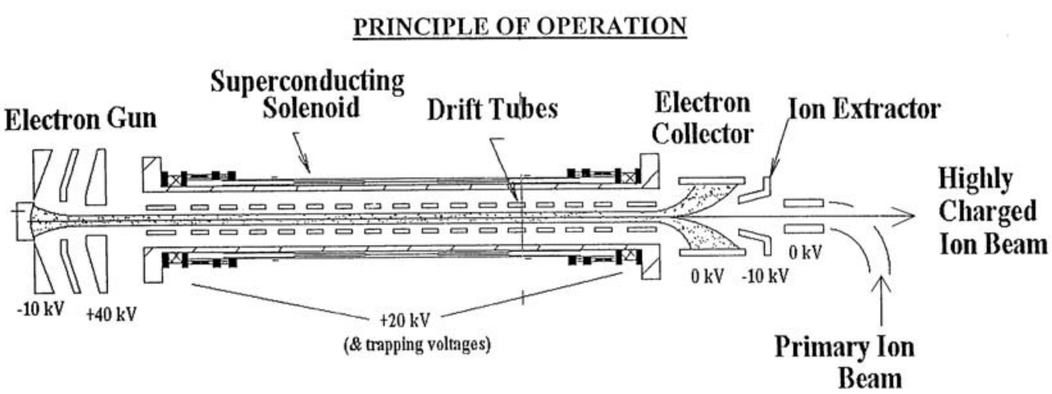


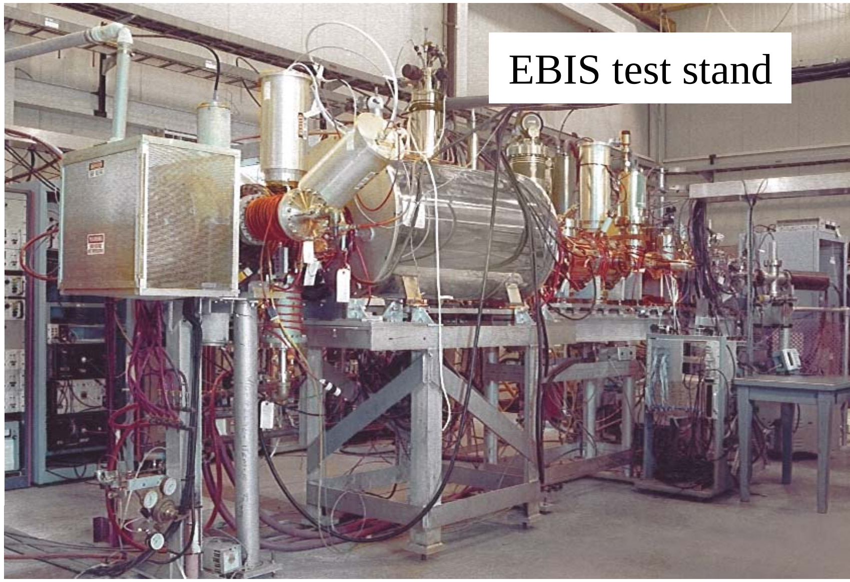
Proton polarization vs. Rb vapor thickness, as measured in the Lamb-shift polarimeter.

Polarized D^- and He^{++} ion sources

Vector spin polarized D^- ion beam in excess of 1.0 mA can be produced in the OPPIS, as well as in the atomic beam source with resonant plasma ionizer.

J.Alessi and A.Zelenski proposed to use an EBIS (Electron Beam Ion Source under development at BNL) for nuclear polarized 3He gas ionization to $3He^{++}$ ions. The polarized 3He will be produced by conventional technique of optical pumping in metastable states. The expected beam intensity is about $2 \cdot 10^{11}$ $3He^{++}$ ions/pulse, polarization 70-75%.





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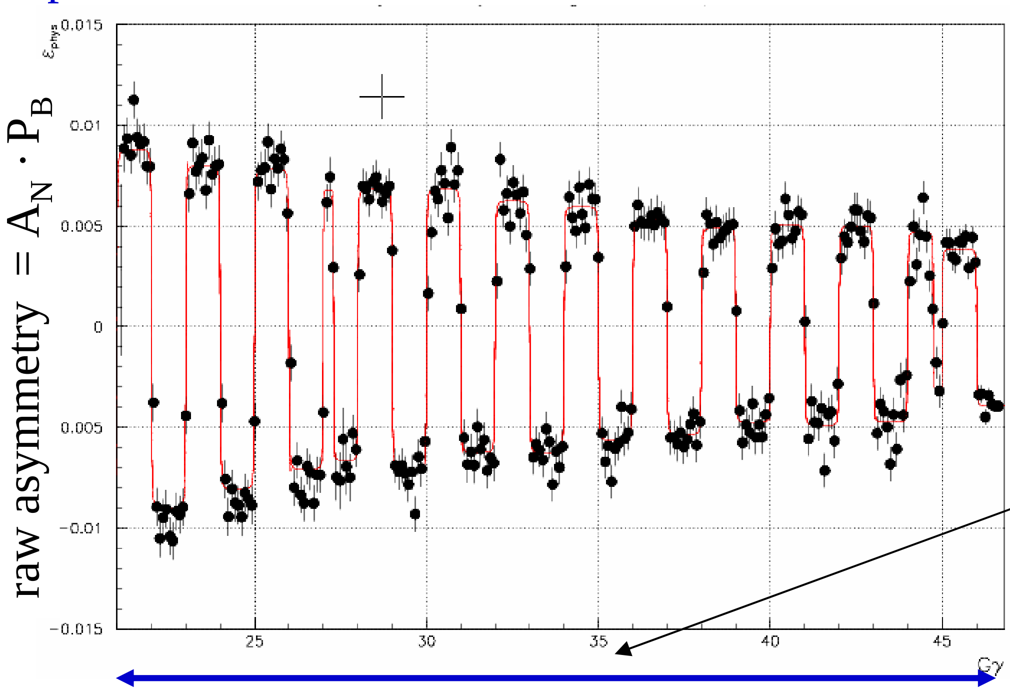
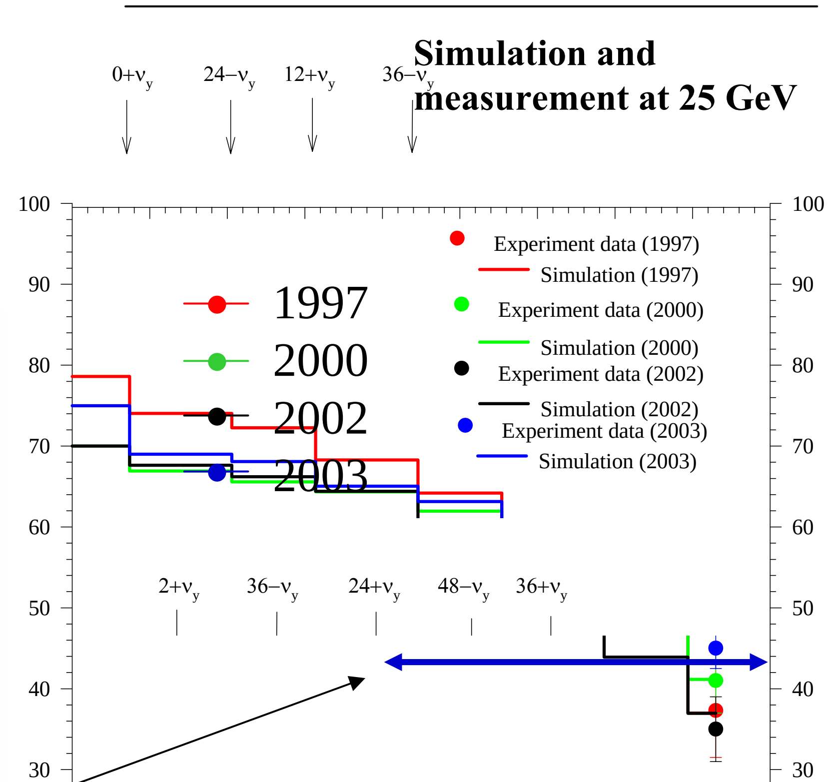
Proton polarization at the AGS

- Full spin flip at all imperfection and strong intrinsic resonances using partial Siberian snake and rf dipole
- Ramp measurement with new AGS pC CNI polarimeter:





- Remaining polarization loss from coupling and weak intrinsic resonances
- New helical partial snake (RIKEN funded) will eliminate coupling res. (Install. 1/04)
- To avoid all depolarization in AGS build strong AGS helical Siberian snake! (Installation: 10/04)

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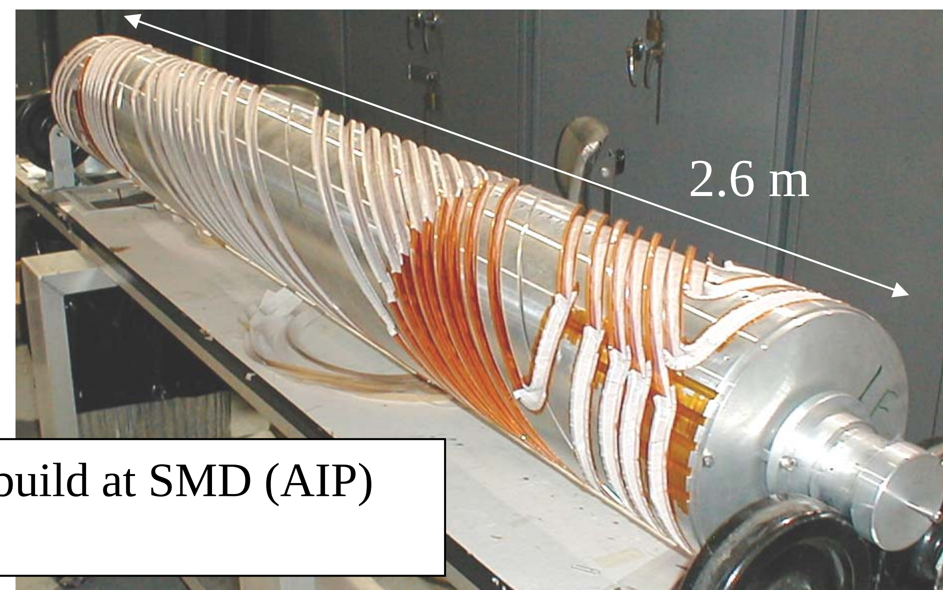
New AGS helical snakes

5 % helical snake build at Tokana Industries funded by RIKEN. Installation: Jan. 2004.

- Cold strong snake eliminates all depolarizing resonances in AGS.
- Warm snake avoids polarization mismatch at AGS injection and extraction.



30% s.c. helical snake build at SMD (AIP) Installation: Oct. 2004

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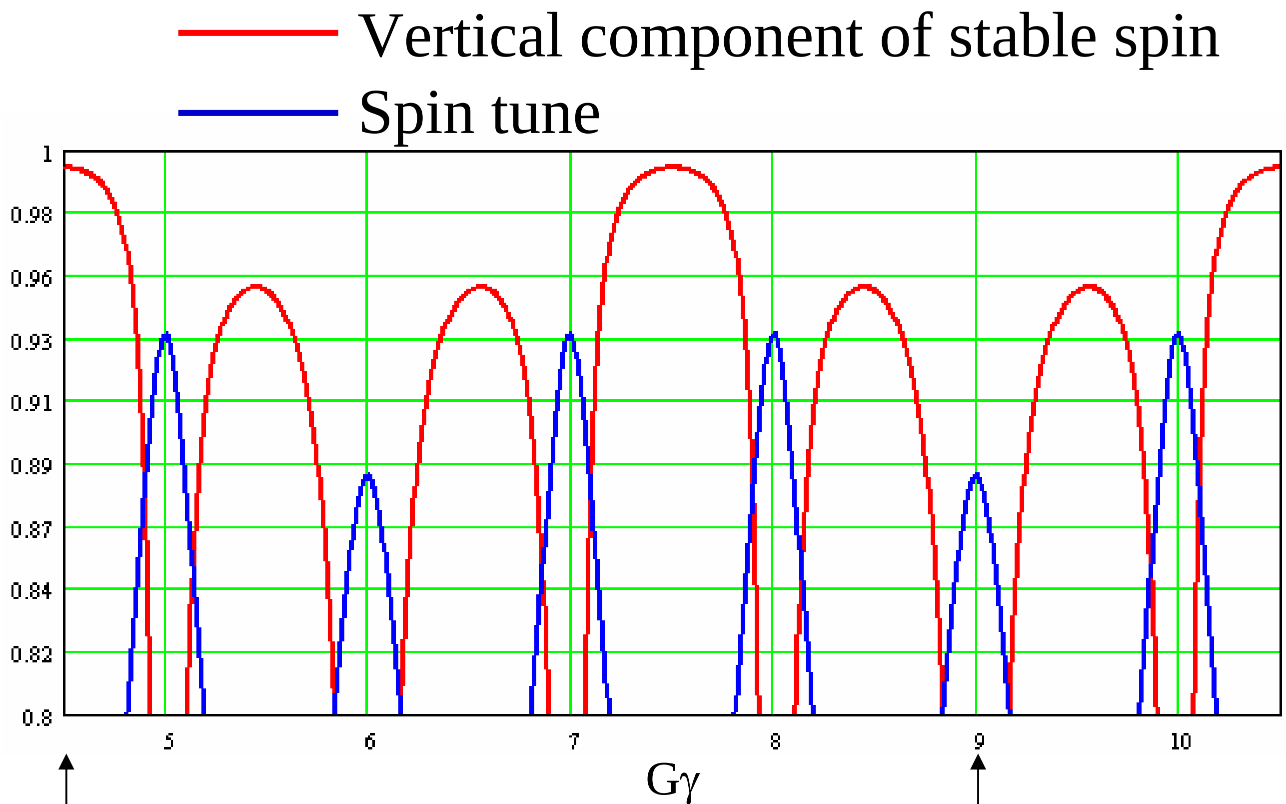
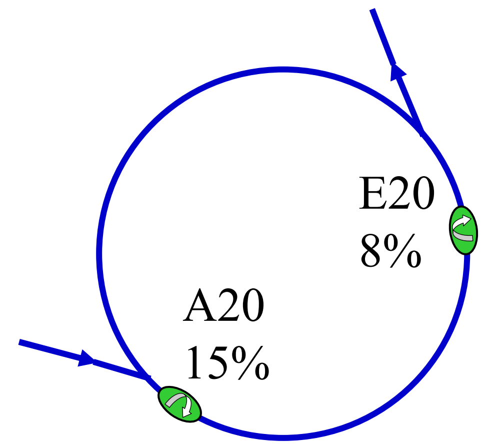
2 Partial Siberian Snakes in AGS





Injection

First intrinsic resonance (0+ν)

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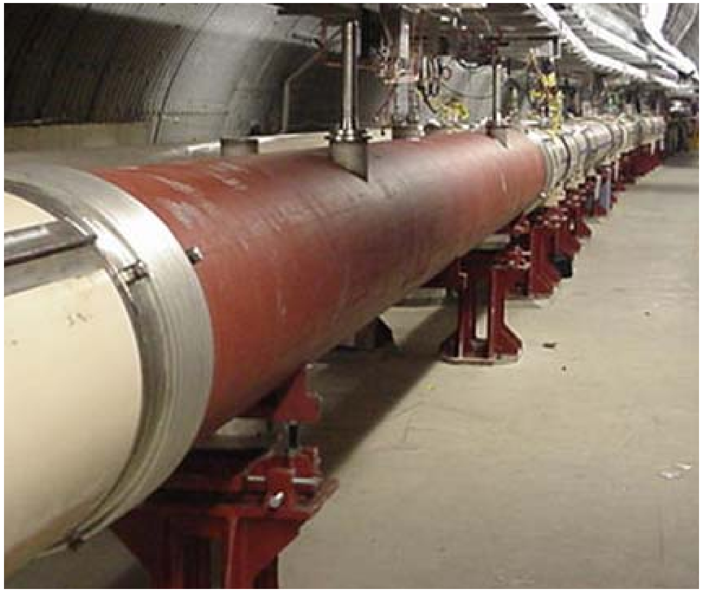
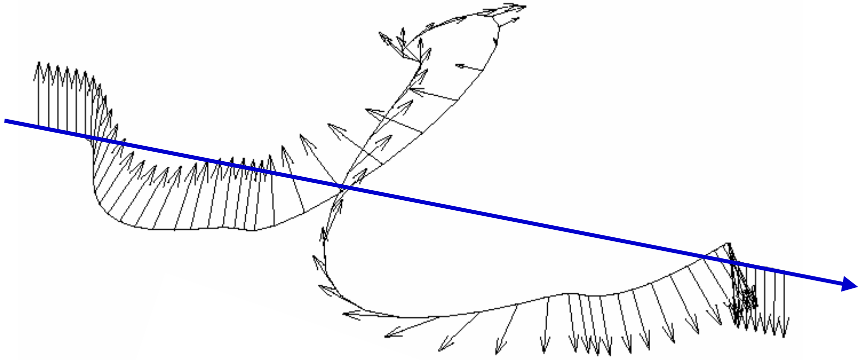
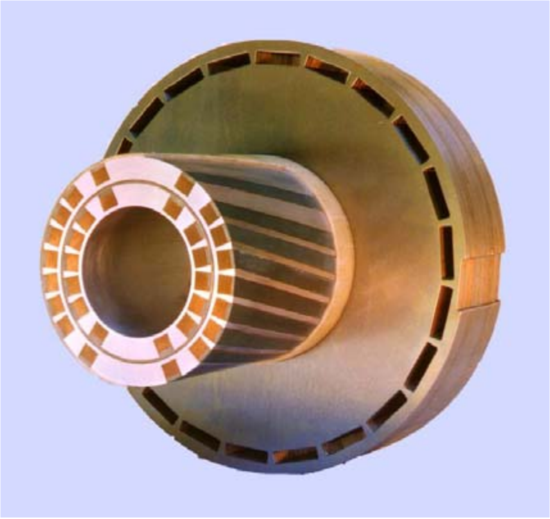
Siberian Snake in RHIC Tunnel

Siberian Snake: 4 superconducting helical dipoles, 4Tesla,
2.4 m long with full 360° twist





Funded by RIKEN, Japan
Designed and constructed at BNL



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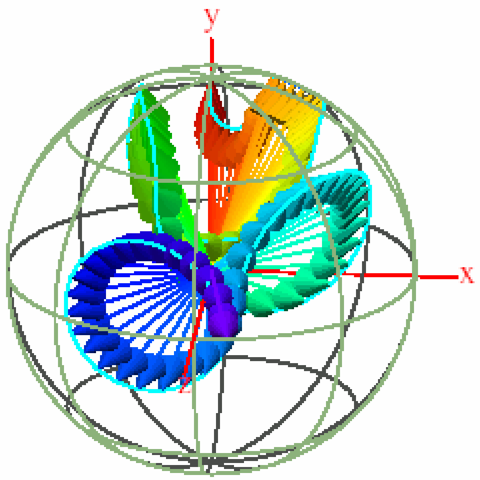
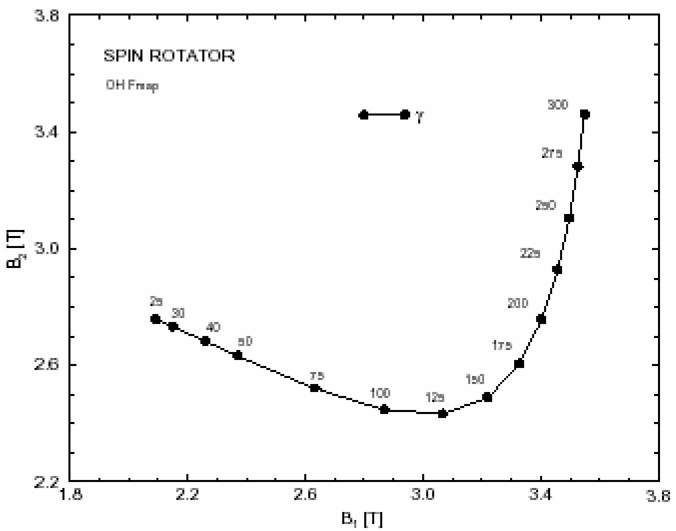
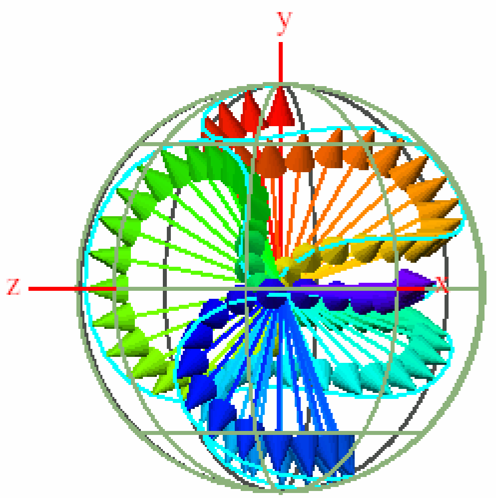
Spin Rotators and Compensation for D0-DX Bends



$E = 25$ GeV

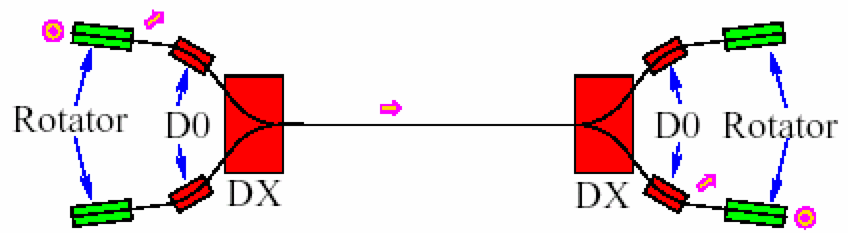
D0DX: 10° precession





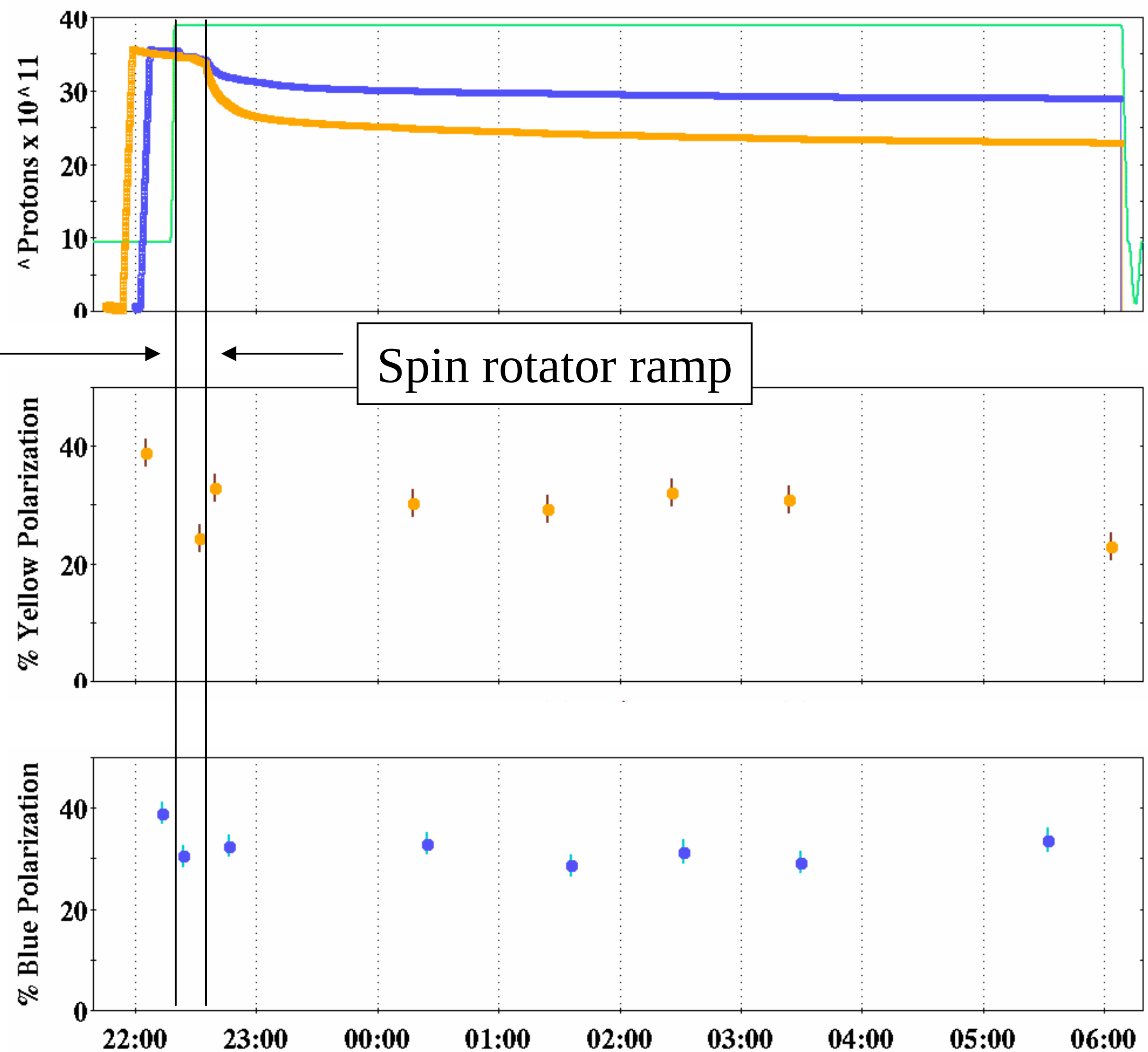
$E = 250$ GeV

D0DX: 100° precession



Polarization survival in RHIC (store # 3713)

Acceleration and squeeze ramp



Some loss during accel/squeeze ramp (Tune too close to ¼)

No loss during spin rotator ramp and during store

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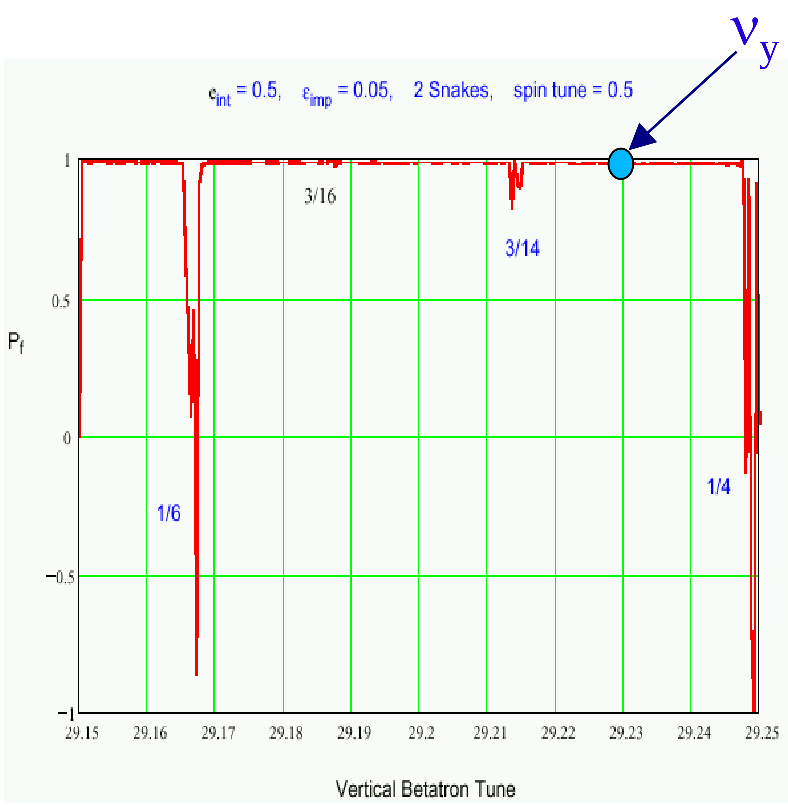
RHIC Polarization Set-up

2 Siberian Snakes per ring hold the spin tune at ½ during acceleration.

The vertical tune was chosen at 0.23, between 2 high-order spin resonances:

- 1/4=0.25 ; depends on vertical orbit
- 3/14=0.2143; exists even without orbit errors

Need excellent tune control; eventually need tune feed-back.



The special vertical orbit, "really" flat was used as the ideal orbit

- 2002 survey showed up to 5 mm misalignment. Partially realigned for Run-3
- The goal number for vertical orbit correction is 0.5mm rms
- Development of beam based orbit “flattening”

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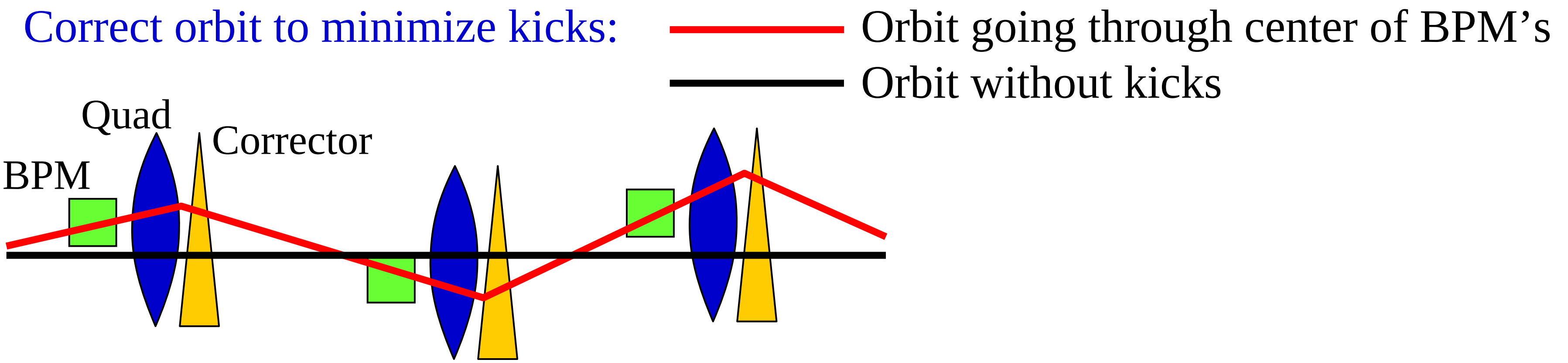
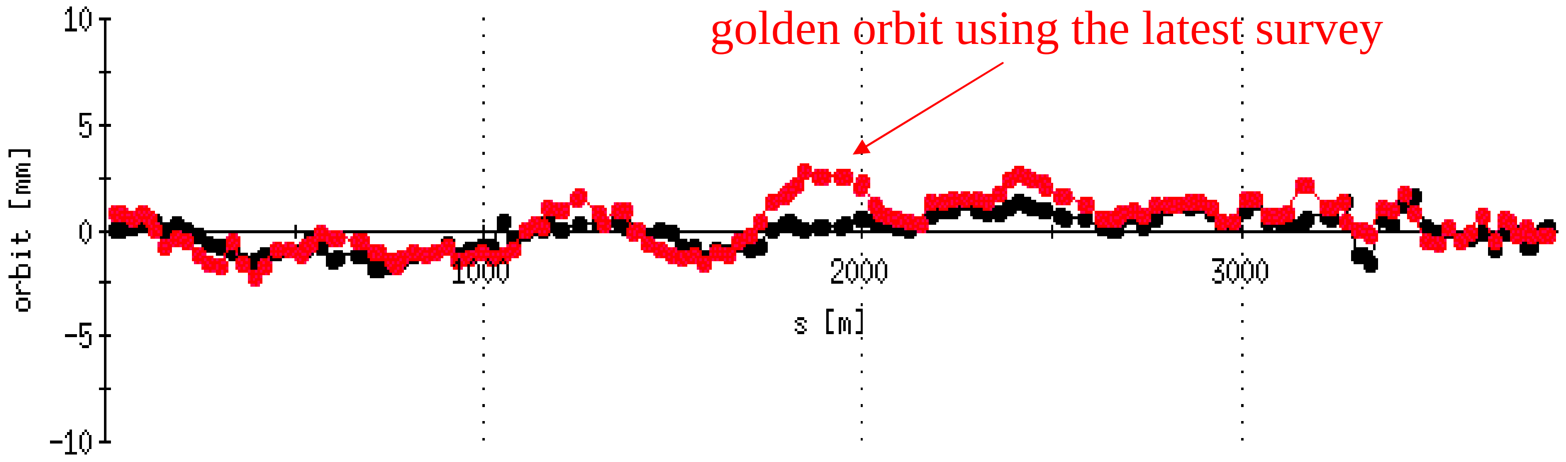
Ideal Orbit for Polarization

Correct orbit to minimize kicks:



Yellow vertical orbit flattened based on survey:



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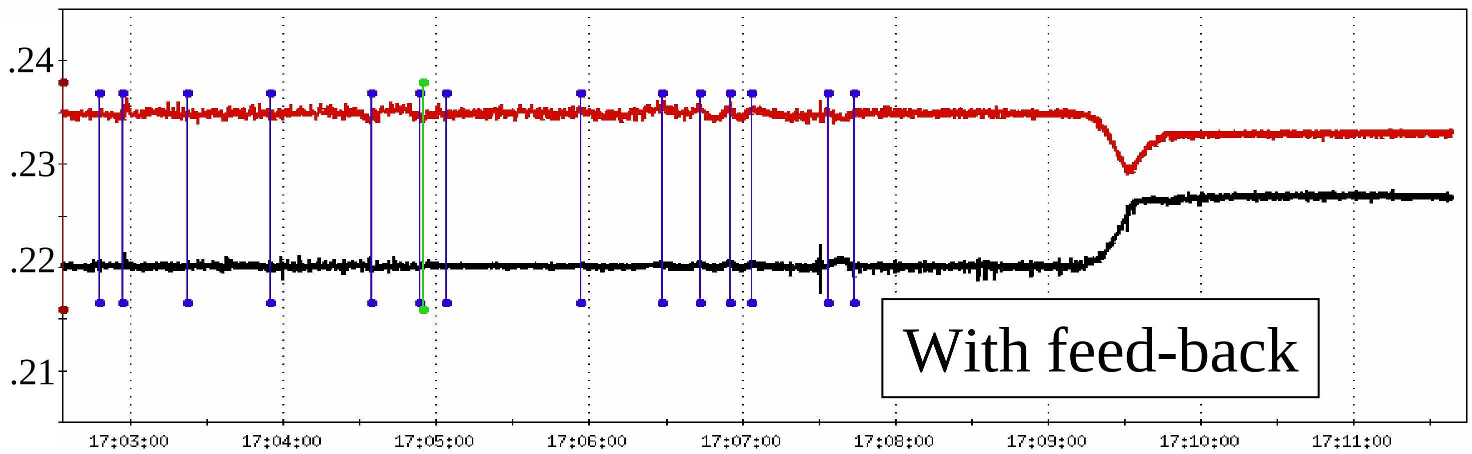
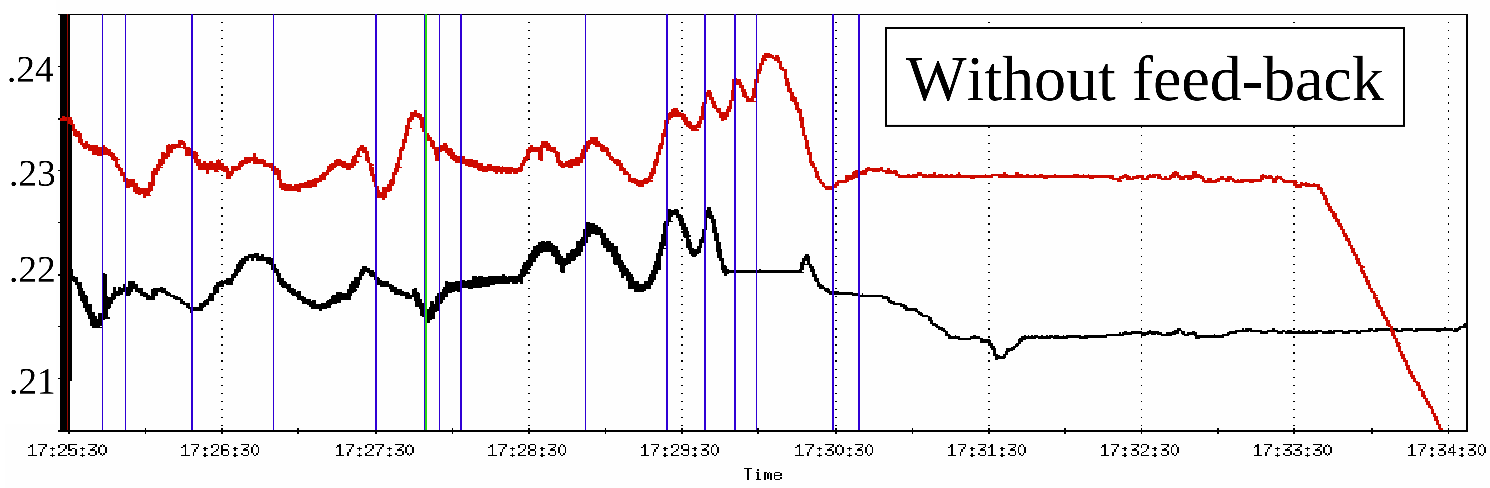
Proton Ramp with Tune Feedback





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RHIC Spin Parameters for Different Species

	p	$^{2}H^{+}$	$^{3}He^{+2}$	e^{-}
m [GeV/c^2]	0.9382720	1.8756127	2.8083912	0.0005109989
$G = (g-2)/2$	1.79284734	-0.1426177	-4.184	0.001159652
mc^2/G [MeV]	523.3418	13156.49	671.2216	440.6485
$(p/q)_{\mathrm{inj}}$ [Tm]	81.113	81.113	81.027	
U_{inj} [GeV]	24.335	24.364	48.664	
U_{inj}/n [GeV]	24.335	12.182	16.221	
γ_{inj}	25.9362	13.0034	17.3280	
$G\gamma_{\mathrm{inj}}$	46.500	-1.854	-72.500	
$(p/q)_{\mathrm{store}}$ [Tm]	833.904	833.904	833.904	33.356
U_{store} [GeV]	250.000	250.005	500.004	10
U_{store}/n [GeV]	250.000	125.003	166.668	10
γ_{store}	266.4473	133.2926	178.0394	19569.54
$G\gamma_{\mathrm{store}}$	477.699	19.062	744.917	22.6938

Formula for a Single Helical Dipole

Parameters for a single RHIC rotator helix

Pitch: $k = \frac{2\pi}{\lambda}$, $\quad \lambda = 2.41$ m $\qquad$ [+(−) for right(left)-handed]

$\kappa = \frac{q}{p}(1 + G\gamma)B$

Rotation axis: $\hat{n} = \dfrac{k\hat{z} + \kappa\hat{x}}{\sqrt{\kappa^2 + k^2}}$

Precession angle: $\alpha = 2\pi\left(\sqrt{1 + \left(\frac{\kappa}{k}\right)^2} - 1\right)$

Transverse offset: $\Delta x = \dfrac{q}{p}\dfrac{B\ell}{k} = \dfrac{q}{p}\dfrac{\lambda^2}{2\pi}B$

Scaling Snakes and Spin Rotators to He3

Scaling of the field at maximum energy:

The maximum rigidity of the beams must the same: $r_{\rm max} = \frac{p}{q} = 834$ Tm

$$\gamma_{\rm He^3} \simeq \frac{Z}{A}\gamma_{\rm p}$$

Want the same precession, so κ must be the same.

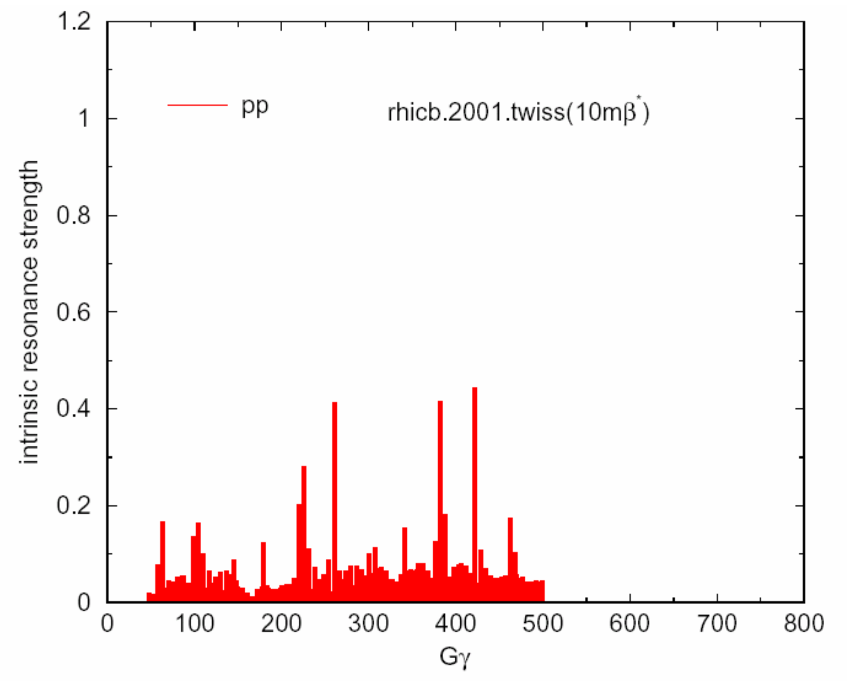
$$B_{\rm He^3} \simeq \frac{1 + G_{\rm p}\gamma_{\rm p}}{1 + G_{\rm He^3}\gamma_{\rm He^3}} B_{\rm p}$$

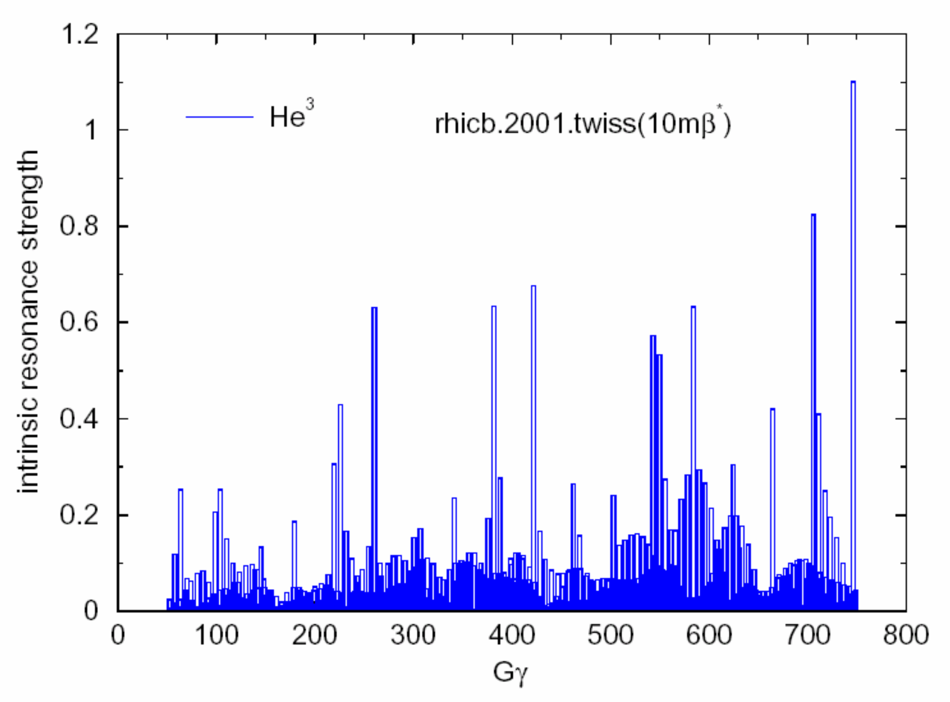
$$\simeq \frac{AG_{\rm p}}{ZG_{\rm He^3}} \simeq -0.643$$

Snake excursion at injection $r_{\rm inj} = 81.1$ Tm (for protons):

$$\Delta y = \begin{cases} 3.2\ \text{cm}, & \text{for protons} \\ -2.1\ \text{cm}, & \text{for He}^3 \end{cases}$$

Depolarizing Resonances for Protons and He3





$(G\gamma)_{max}$ = 477 (protons); 743 (He3)

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Summary

- BNL OPPIS reliably delivers polarized H^- ion beam for the RHIC spin program.
  - Intensity exceeds RHIC limit
  - A new superconducting solenoid for OPPIS would improve beam intensity and increase polarization to 85% value.
  - A higher intensity (in excess of 10 mA) polarized H^- ion beam can be produced in a pulsed OPPIS
- A feasibility study of high intensity polarized He3 source was proposed to be carried out at the EBIS test-stand.
- Spin precession and orbit excursions in snakes and rotators should work for protons eRHIC.
  - Snakes are the same as for RHIC Spin.
  - If no "D0DX" bends for IR, then fields in rotators are essentially constant for all energies (like the snakes).
- He3 requires less field in snakes and rotators.
  - Injection orbit excursions reduced.
- Maximum $G\gamma$ is higher for He3
  - This needs to be investigated.

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