Preliminary Studies of Polarized beams at HIAF

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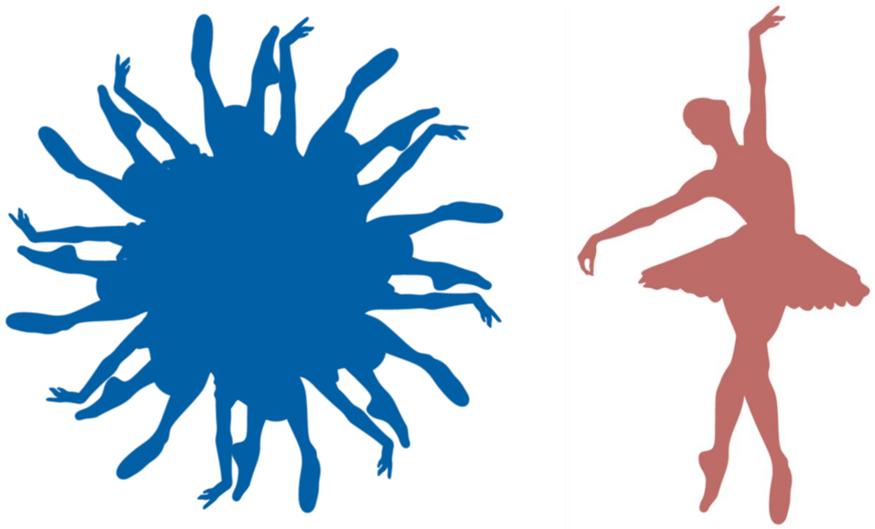
on behalf of the HIAF spin team

2025.11.29

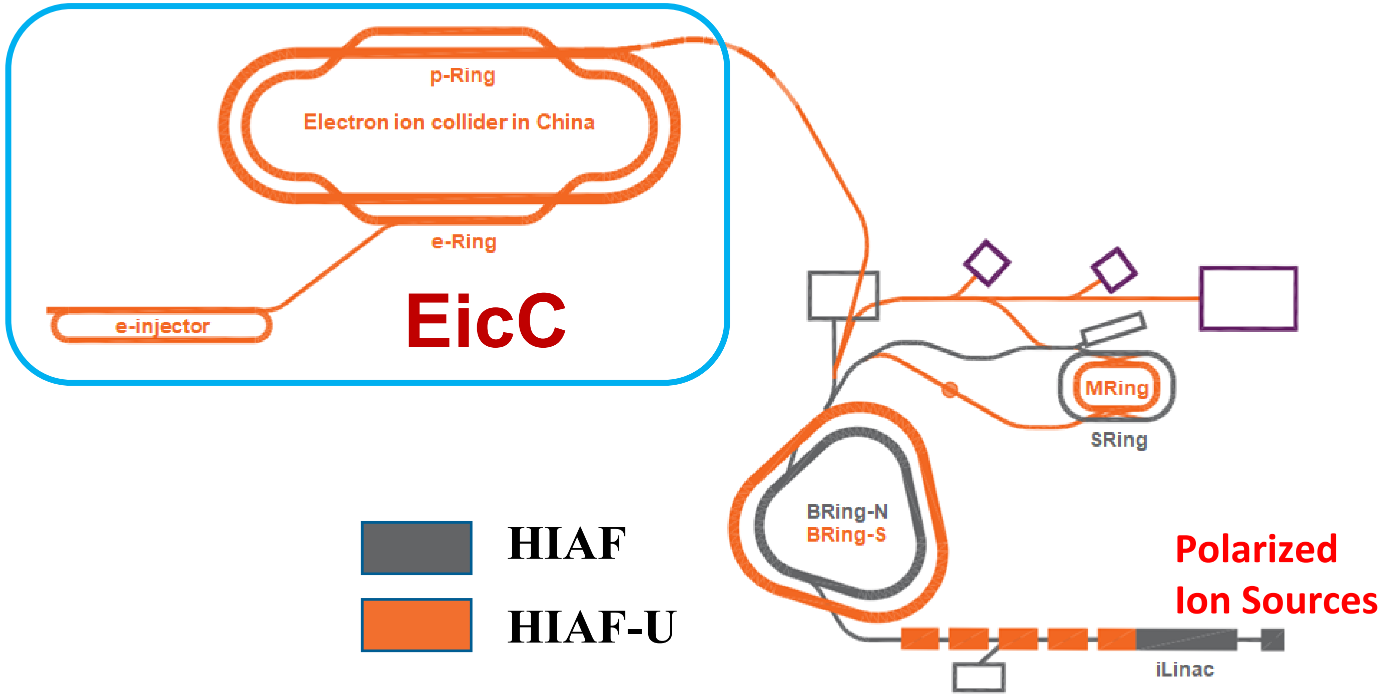
Outline

- Background & Overview
- Polarized Ion Source
- Depolarization Resonance & Siberian Snake
- Polarimeters

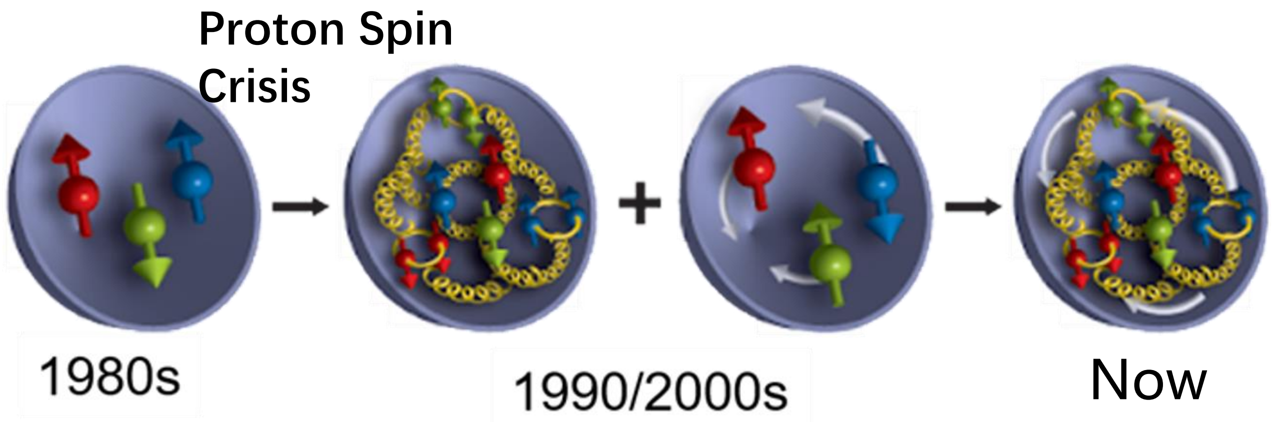
Background



Ordinary & Polarized Ion Beam

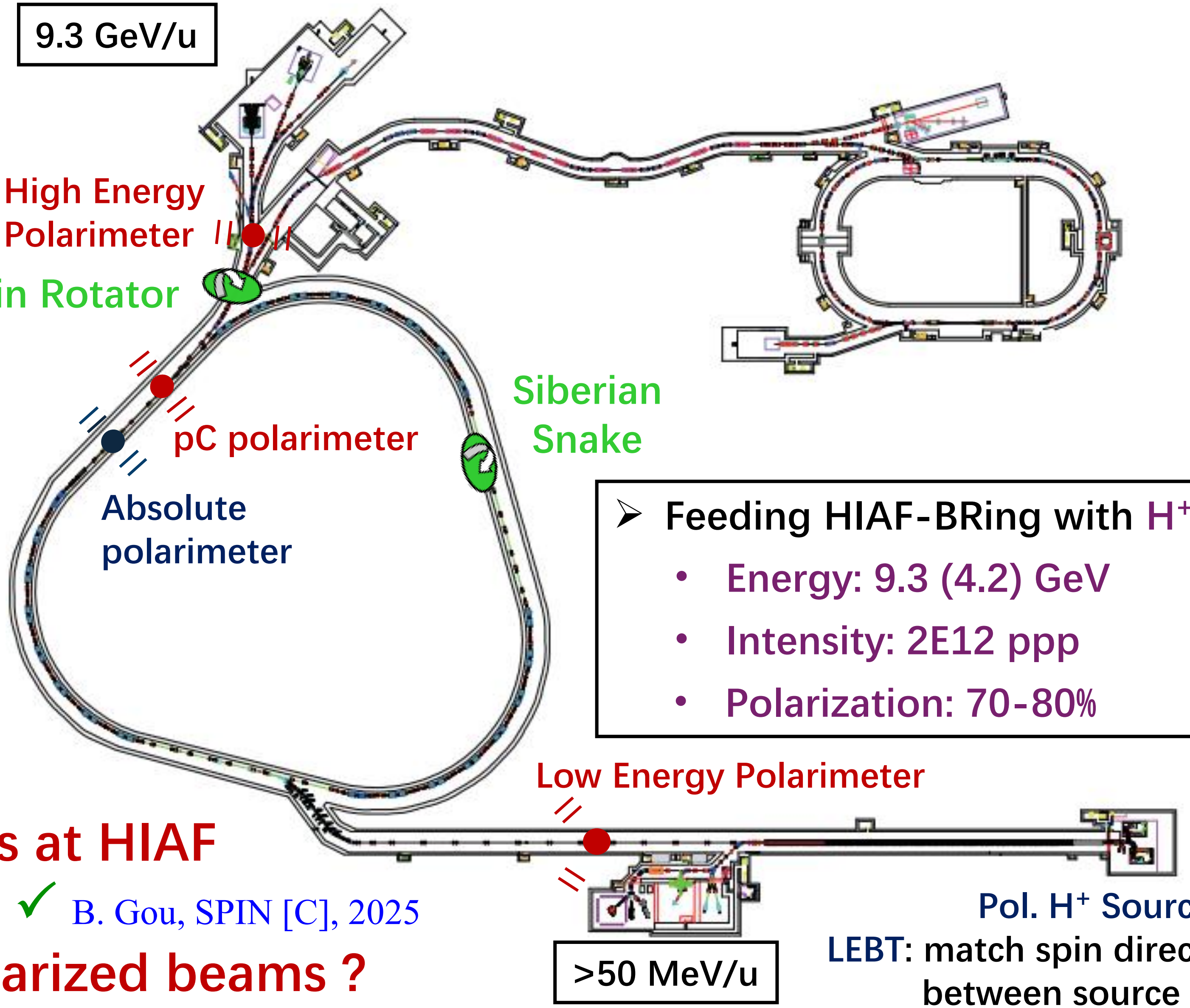


- ➢ **Polarized Ion beams: Spin utilized as an additional degree of freedom**
  - **More information, more sensitive**
- ➢ **A must-do for EicC: polarized beams**
  - **Production, acceleration, diagnostics**



Overview for Acceleration of Polarized Ions with HIAF

- **Polarized Ion Source**
- **Siberian Snake**
  - Avoid depolarization during acceleration
- **Polarimeters**
  - Linac
  - BRing
  - External station
- **Spin Rotator**
  - Transversal / longitudinal



- Feeding HIAF-BRing with $H^+/D^+\uparrow$
  - Energy: 9.3 (4.2) GeV
  - Intensity: 2E12 ppp
  - Polarization: 70-80%

- **Spin-polarized experiments at HIAF**
  - Polarized Internal target ✓ B. Gou, SPIN [C], 2025
  - External station with polarized beams ?

Background – A List of Polarized Ion Beam Milestones

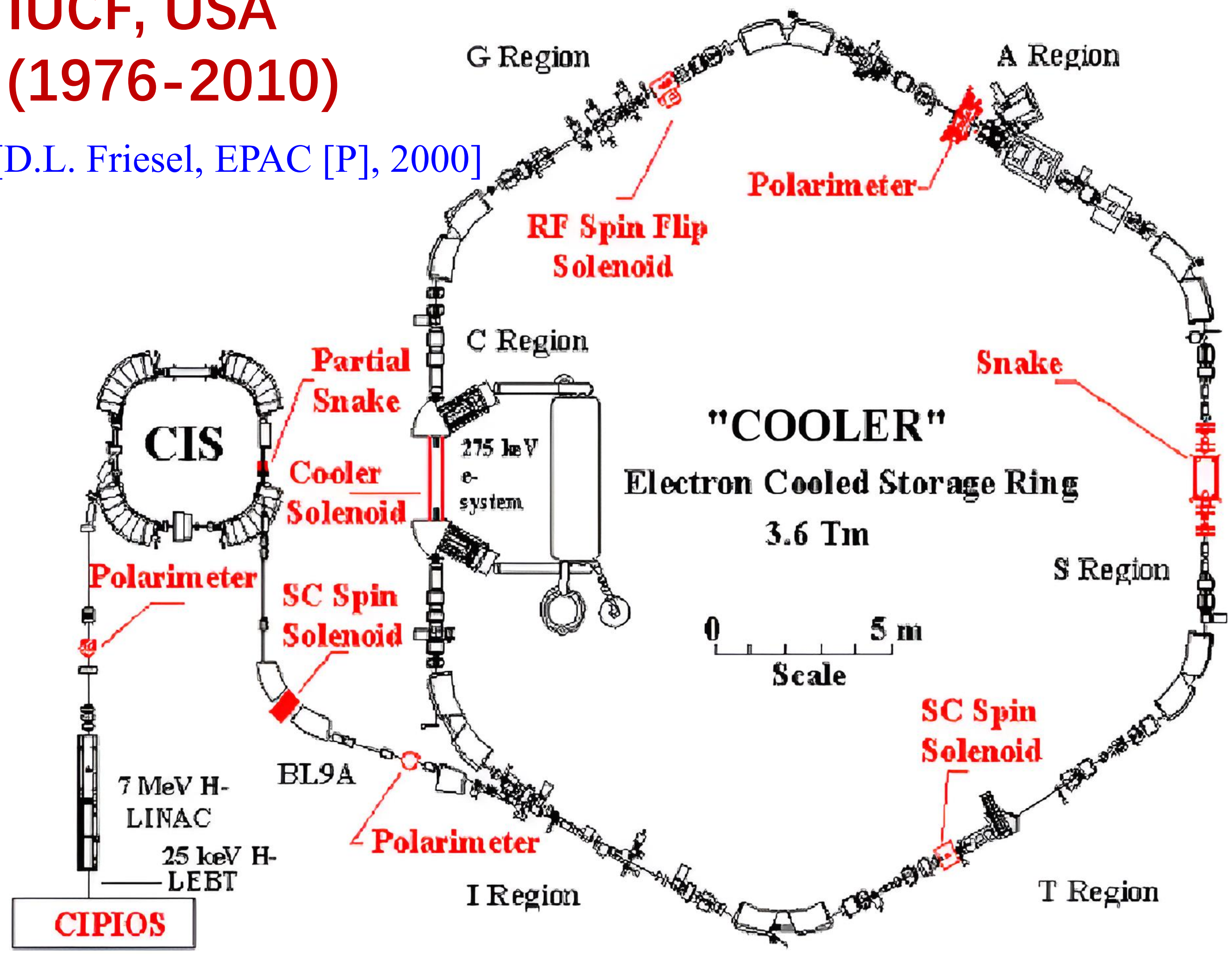
[T. Roser, Past, present, and future of polarized hardon beams, 2021]

Facility	Years	Species	Beam Momentum [GeV/c]	P [%]	
Cyclotrons Synchro-cyclo.	1960	p, ions	0.01~0.6	80%	Follows development of source and targets
ZGS	1973	p	12	70%	First synchrotron, weak focusing
Saturne	1981	p, ions	4	80%	First strong focusing synchrotron
AGS	1984	p	24	75%	Two partial snakes added, 2004-2005
RHIC	2000	p	255	60%	100 GeV pp collisions in 2001, 250 GeV in 2009. Full snakes, spin rotators
EIC-HSR	2030	p, D, $^3He^{2+}$	275	70%	Under design

Background – Several Polarized Ion Facilities

IUCF, USA (1976-2010)

[D.L. Friesel, EPAC [P], 2000]



H^+/D^+, 0.5-0.7E10 ppp, 203/240 MeV, Polarization 80%

COSY, Germany (1989-2023)

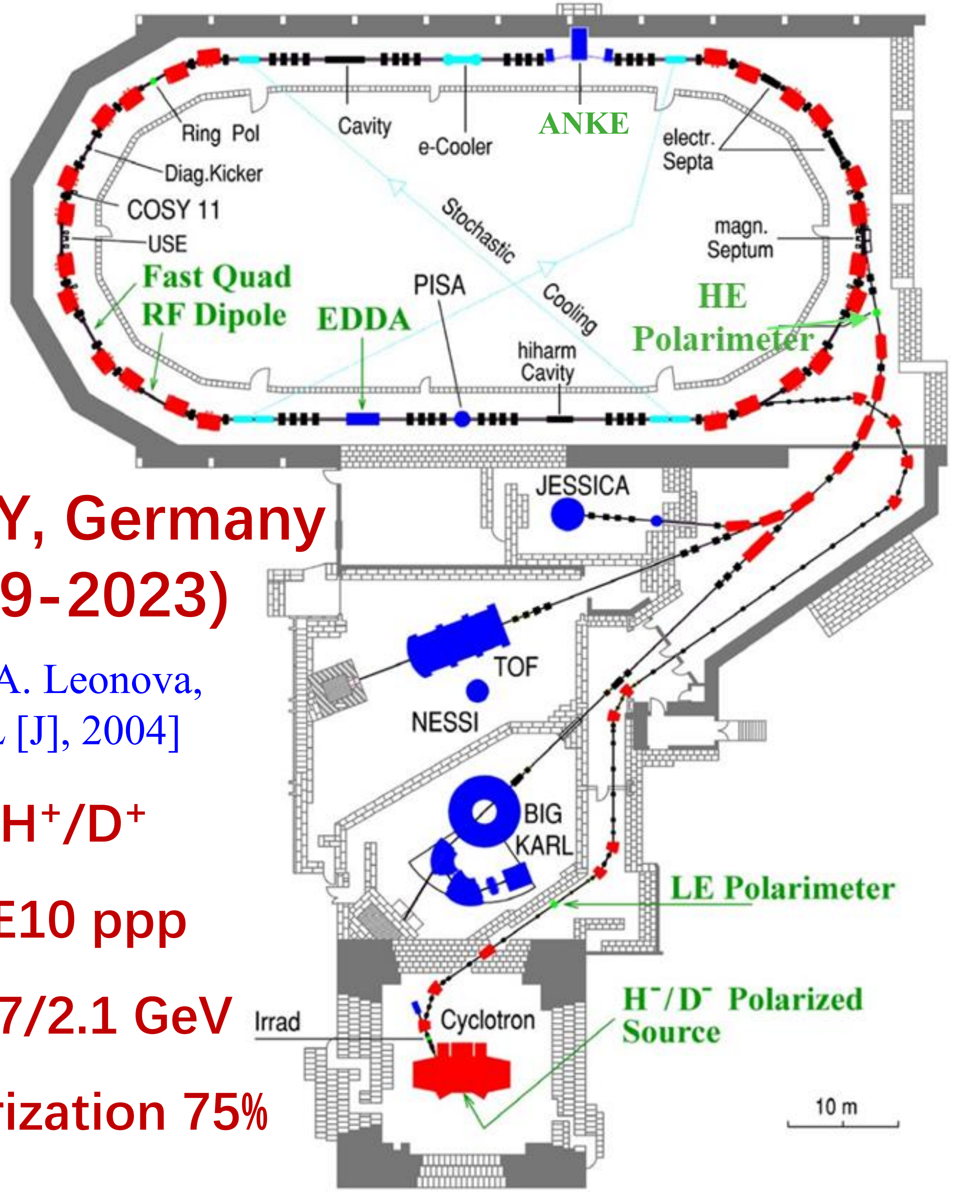
[M.A. Leonova, PRL [J], 2004]

H^+/D^+

6E10 ppp

~2.7/2.1 GeV

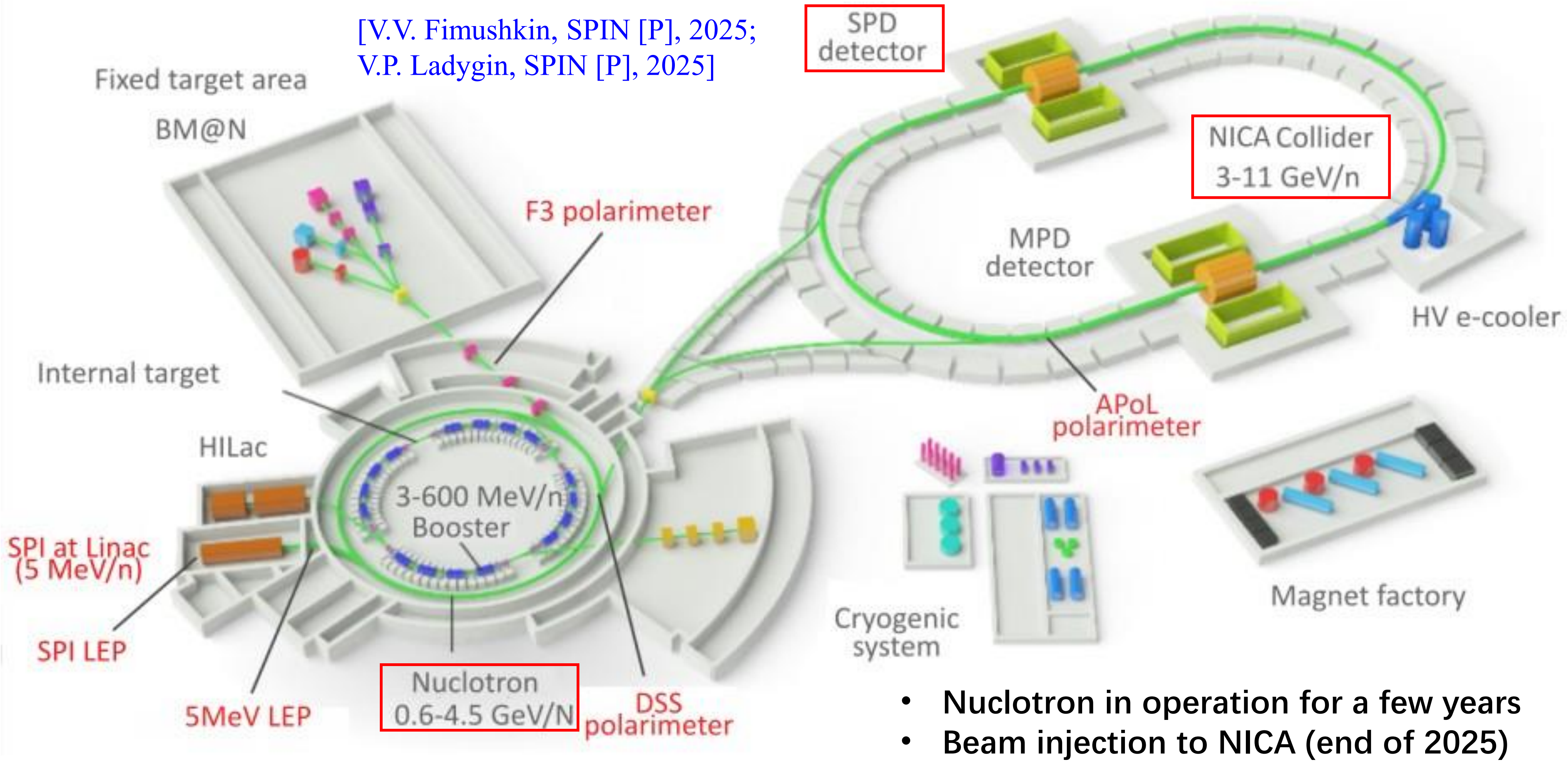
Polarization 75%



Background – Several Polarized Ion Facilities

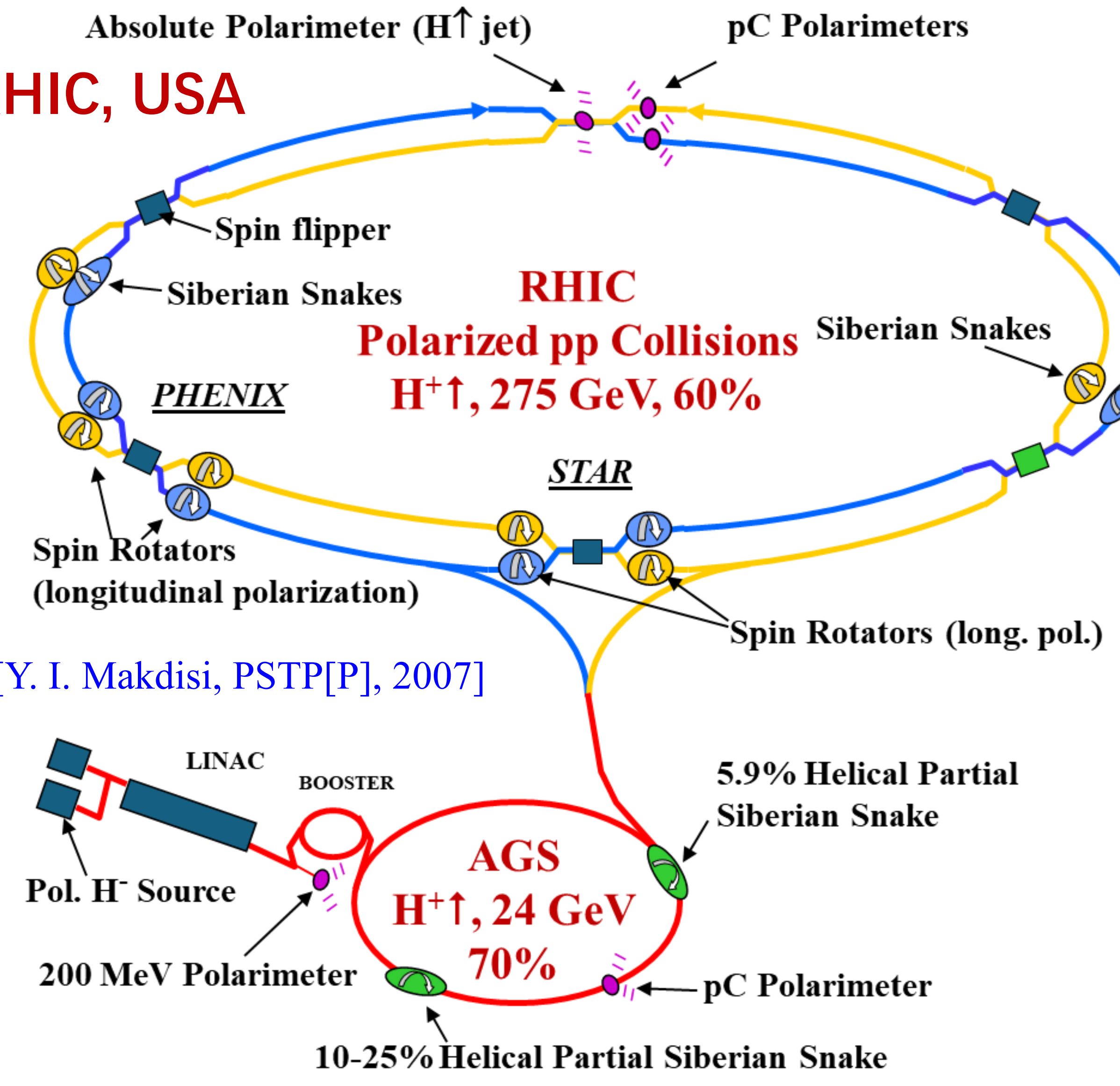
NICA, Russia, On Progress, $H^+/D^+\uparrow$, Ion Collider

[V.V. Fimushkin, SPIN [P], 2025;
V.P. Ladygin, SPIN [P], 2025]



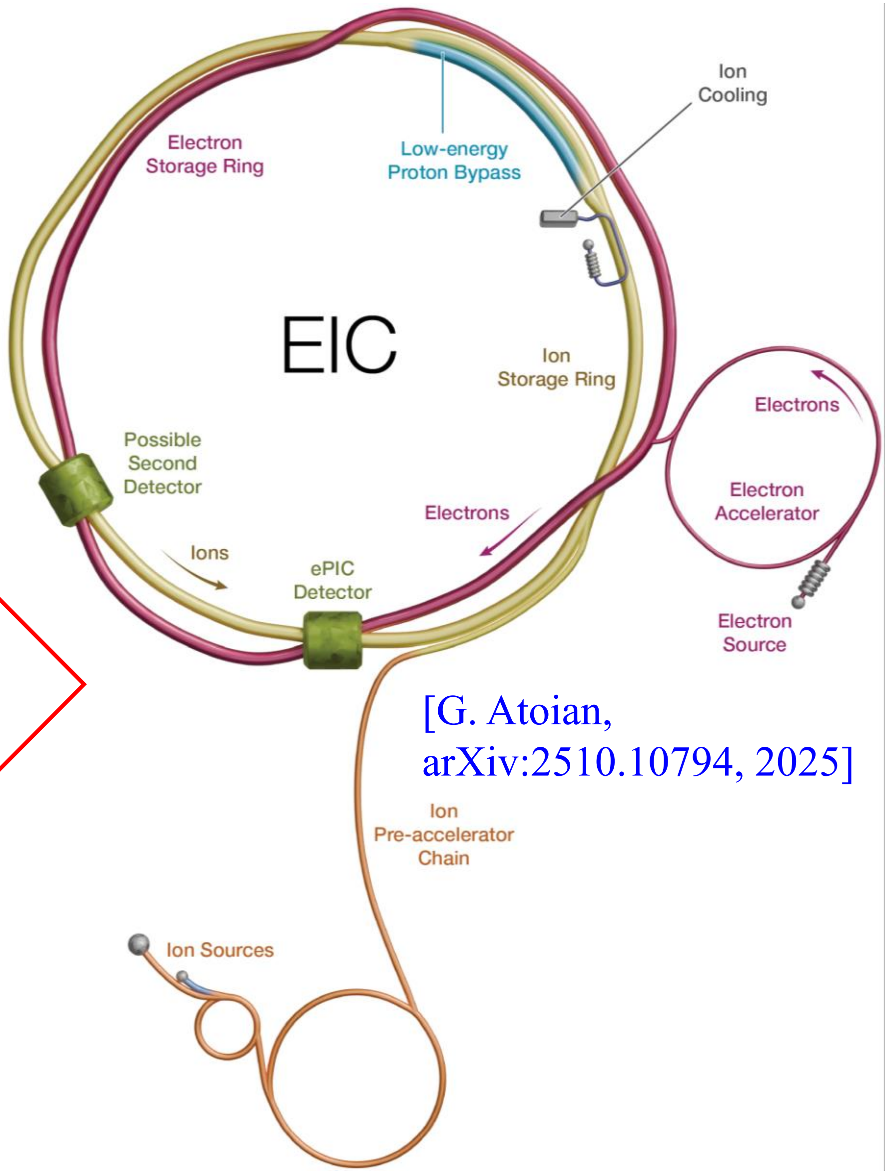
- **Nuclotron in operation for a few years**
- **Beam injection to NICA (end of 2025)**

RHIC, USA



[Y. I. Makdisi, PSTP[P], 2007]

To be upgraded to EIC



[G. Atoian, arXiv:2510.10794, 2025]

Polarized Ion Source

- SPIS originated in the 1960s.
- Two steps for producing polarized ion beam: 1) nuclear spin polarized atoms; 2) ionization

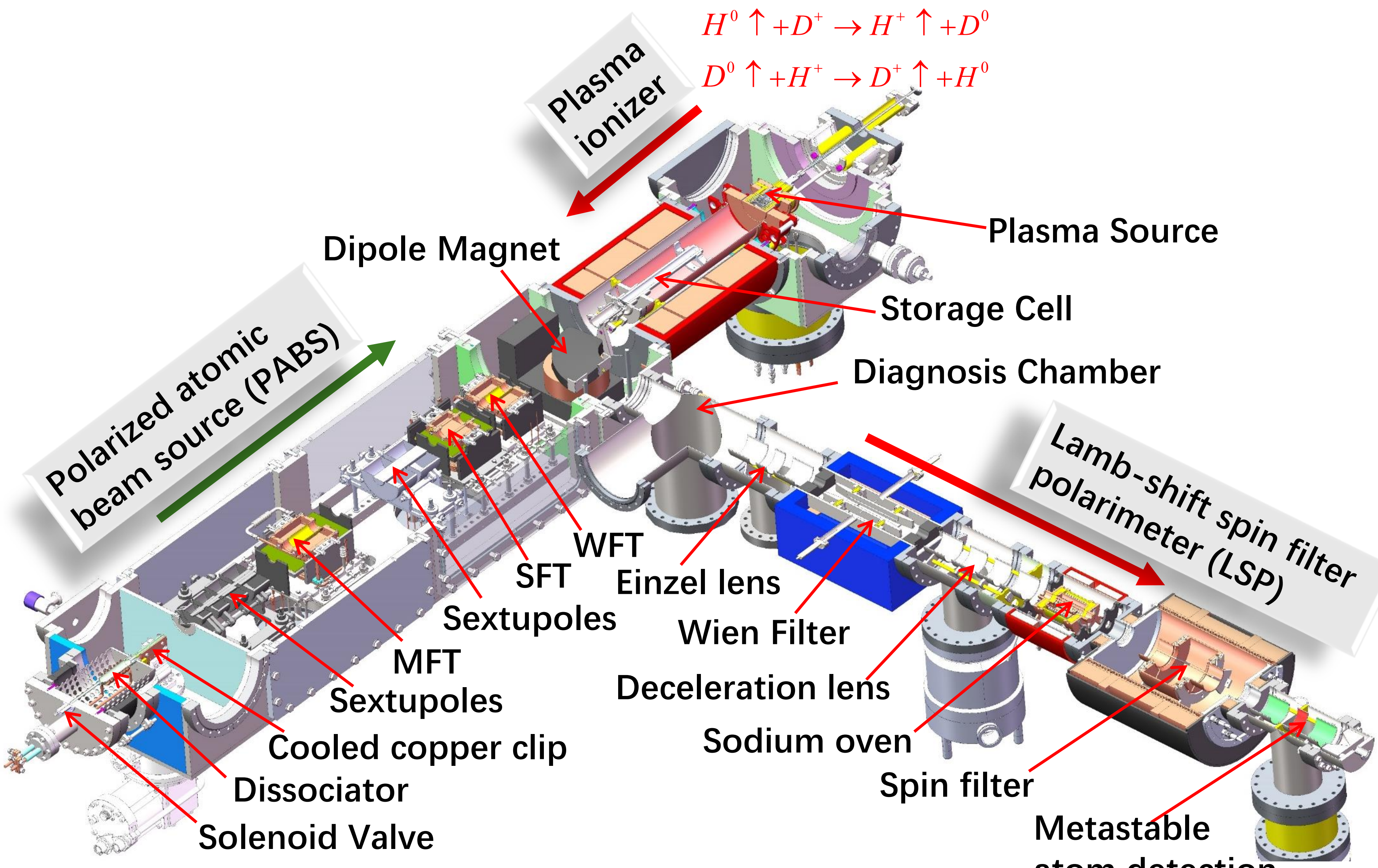
years	Institute	Species	Intensity	Polarization	Polarization Acquisition	Ionization	Reference
2007	INR, RUS	H^+, H^-	11 mA, 4 mA, 200 μs, 10 Hz	90%	ABPIS	Plasma ionizer	A.S. Belov, PSTP [C], 2007
2018	JINR, RUS	D^+	6 mA, 150 μs, 1 Hz	88%	ABPIS	Plasma ionizer	V.V. Fimushkin, SPIN [C], 2018
2002	IUCF, USA	H^-, D^-	1.8 mA, 2 mA, 300 μs, 2 Hz	90%	ABPIS	Plasma ionizer	V.P. Derenchuk, SPIN [C], 2002
2007	FZJ, DEU	H^-	50 μA, 20 ms, 0.5 Hz	90%	ABPIS	Cs beam	R. Gebel, PSTP [C], 2007
2016	BNL, USA	H^-	4 mA, 300 μs	85%	OPPIS	Na cell	A. Zelenski, RSI [J], 2016
2023	BNL, USA	$^3He^{++}$	Goal: 2 mA	70%	OPPIS	EBIS	A. Zelenski, NIMA [j], 2023

ABPIS: Atomic Beam Polarized Ion Source   OPPIS: Optical Pumping Polarized Ion Source

SPIS at IMP

- Start from 2020.06
- Design Goals
- Polarized H^+/D^+
- Intensity: > 1 mA
- Polarization: > 80%
- 2-5 Hz, > 100 μs

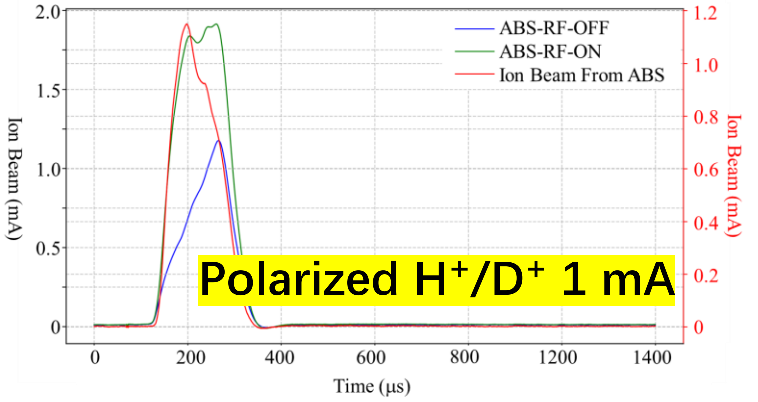
$$H^0\uparrow + D^+ \rightarrow H^+\uparrow + D^0$$
$$D^0\uparrow + H^+ \rightarrow D^+\uparrow + H^0$$

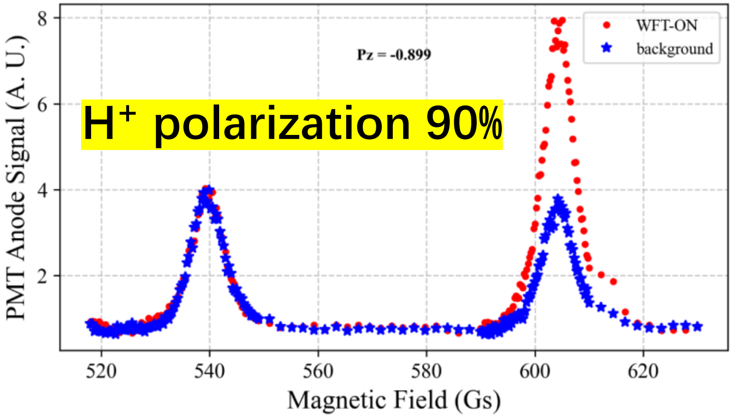


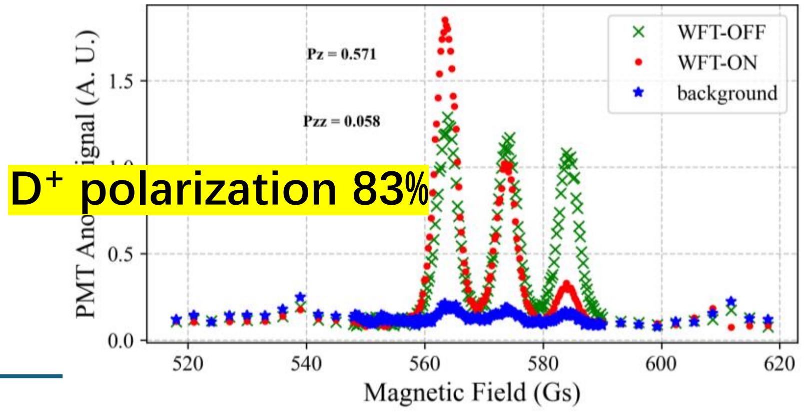
Polarized Ion Source

✓ Design goals achieved

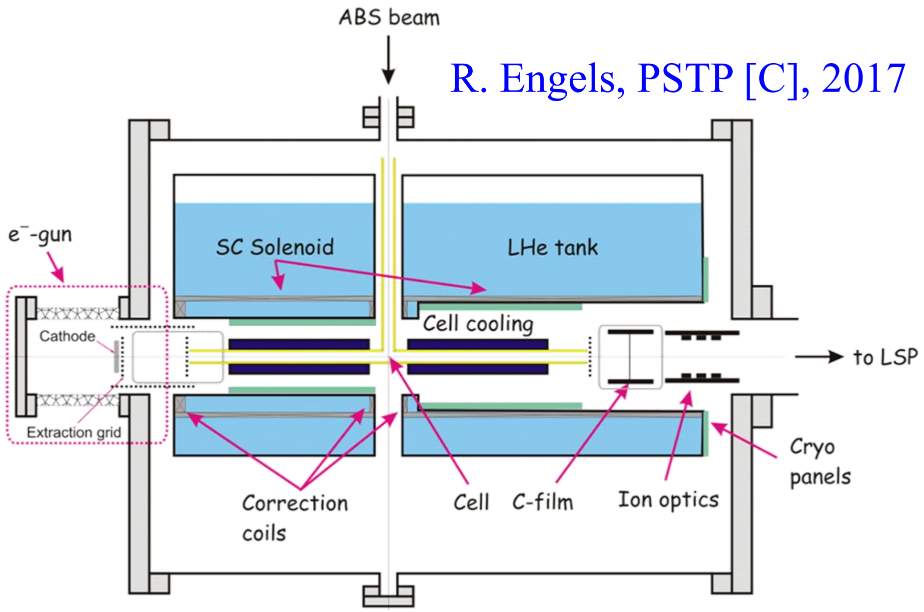
➢ Optimization ongoing





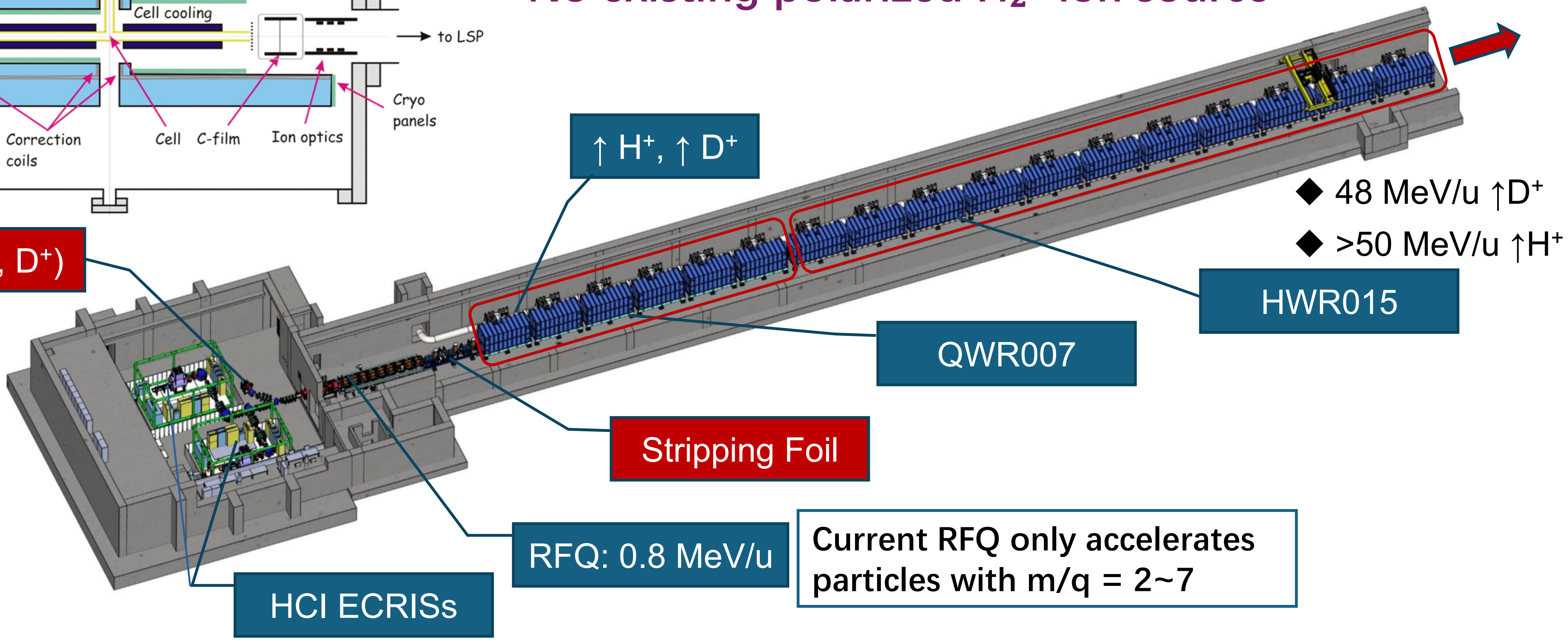


Polarized Ion Source



- **Polarized H_2^+ ion source & Stripper**

Challenge!!!
No existing polarized H_2^+ ion source



- 48 MeV/u $\uparrow D^+$
- >50 MeV/u $\uparrow H^+$

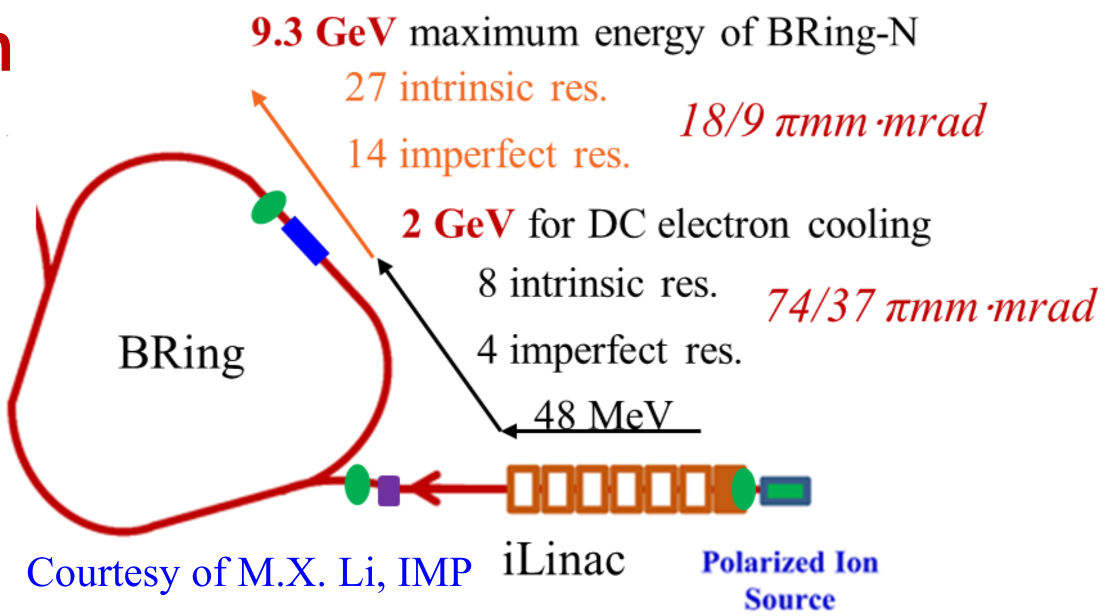
Current RFQ only accelerates particles with m/q = 2~7

Polarized Beam Acceleration

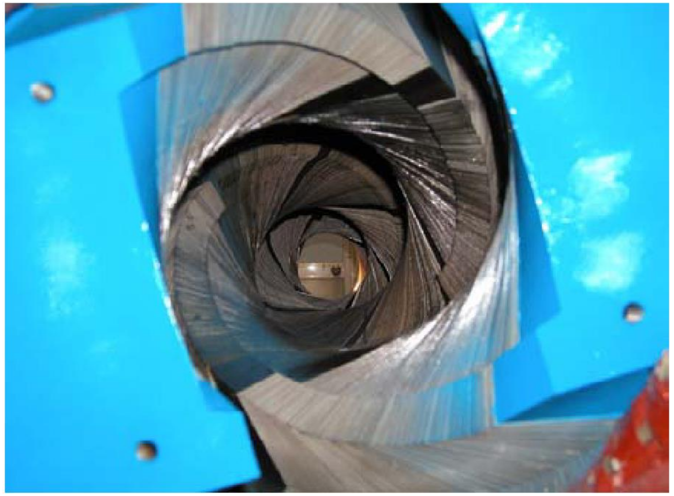
➢Siberian snakes to avoid depolarization

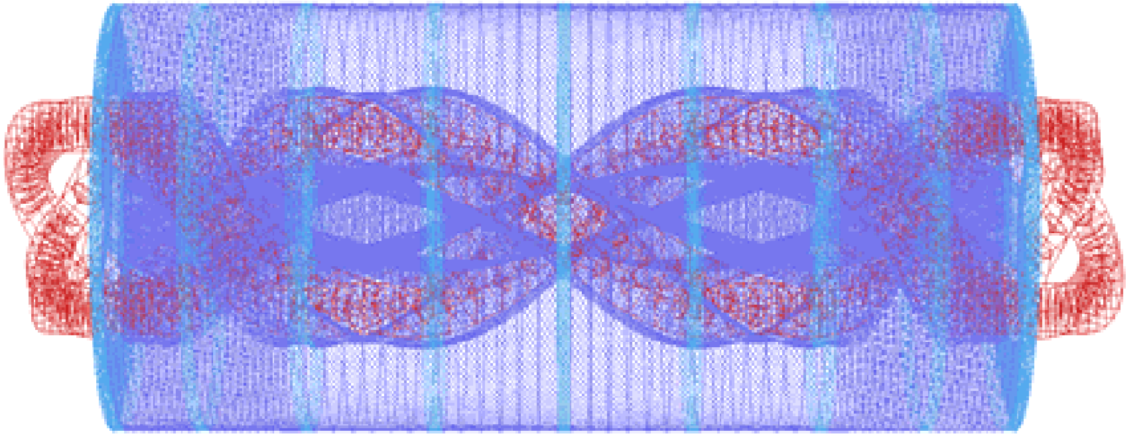
HIAF-BRing

- Protons (9.3 GeV): Many depolarization resonances
- Deuterons (4.2 GeV): No significant depolarization



Courtesy of M.X. Li, IMP



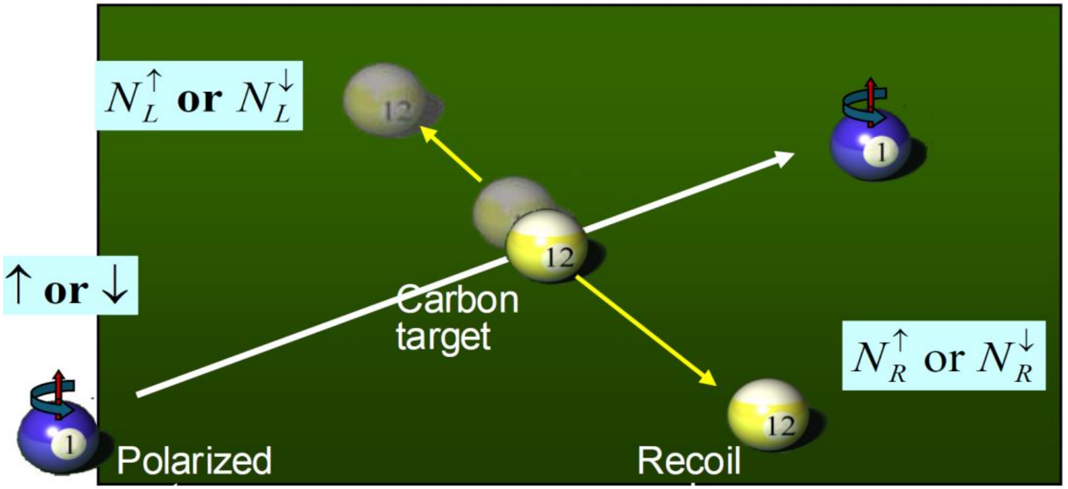


[J. Takano, PAC [C], 2005]

More information about the polarization preservation for HIAF and EicC can be found in
M.X. Li, NIMA [J], 2022
M.X. Li, PRAB [J], 2025

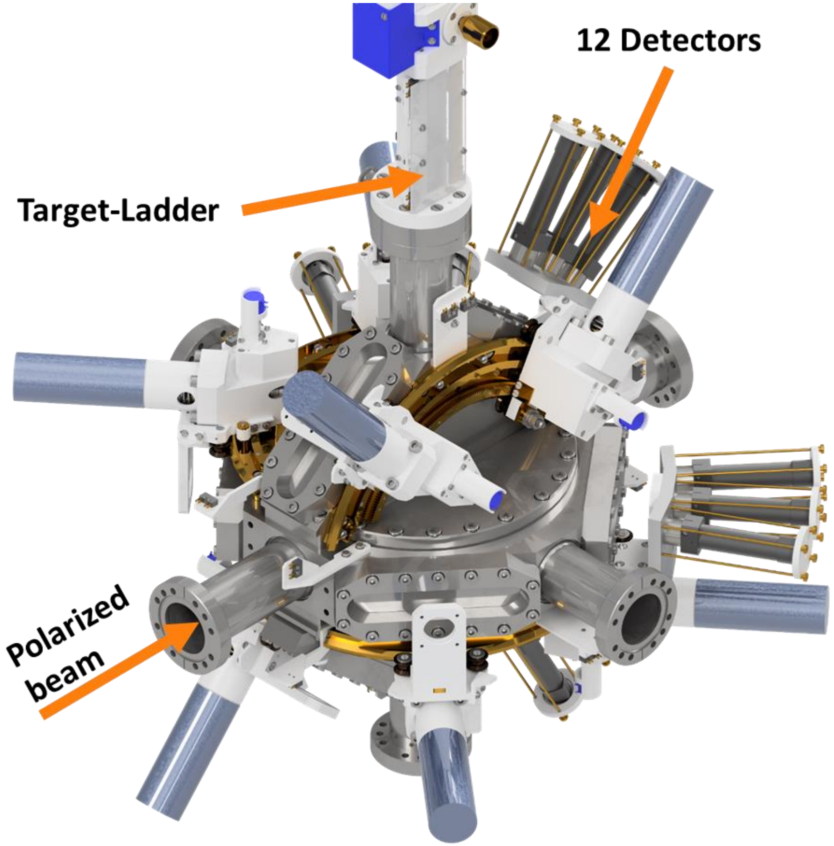
- Spin dependent reactions
  - $\vec{p}$p → pp
  - $\vec{p}$C → pC
- Angular asymmetry → Beam polarization

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}, \qquad P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$



H.X. Huang, workshop on polarized ion source and beams at EIC, 2025

Low-energy polarimeter at COSY

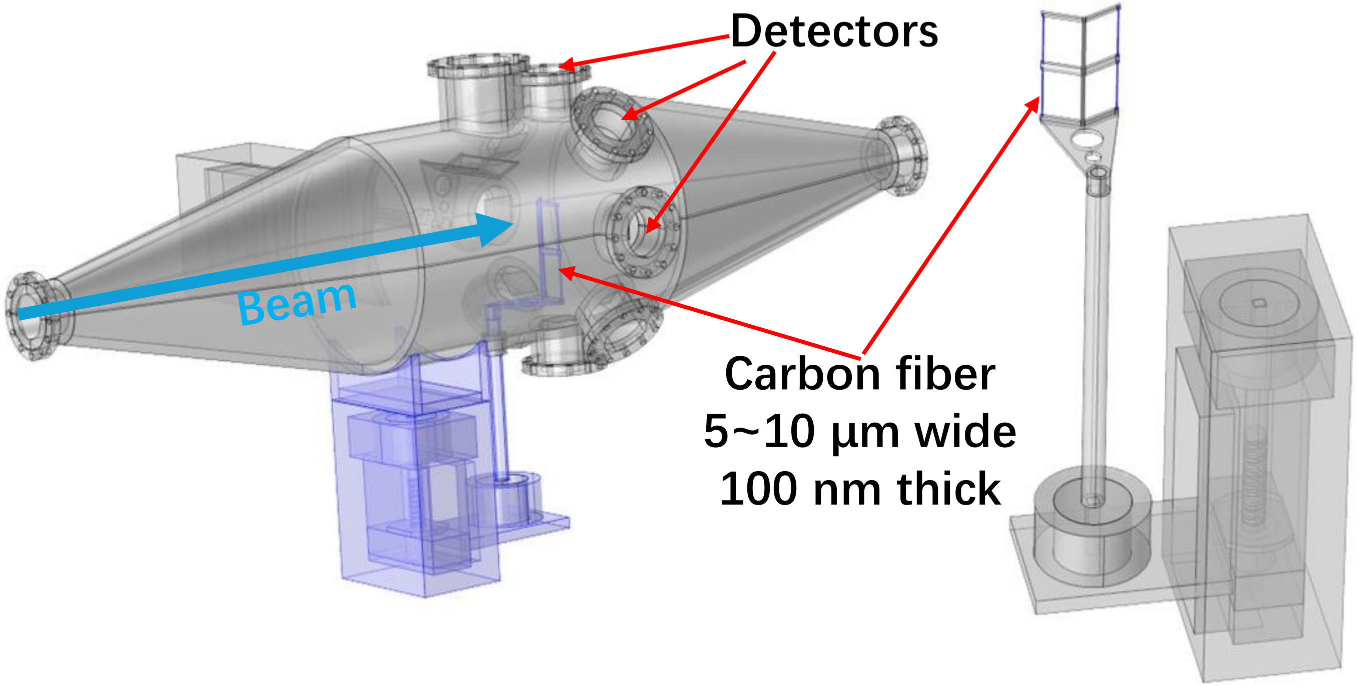


J. Wirtz, master thesis, RWTH Aachen University, 2024

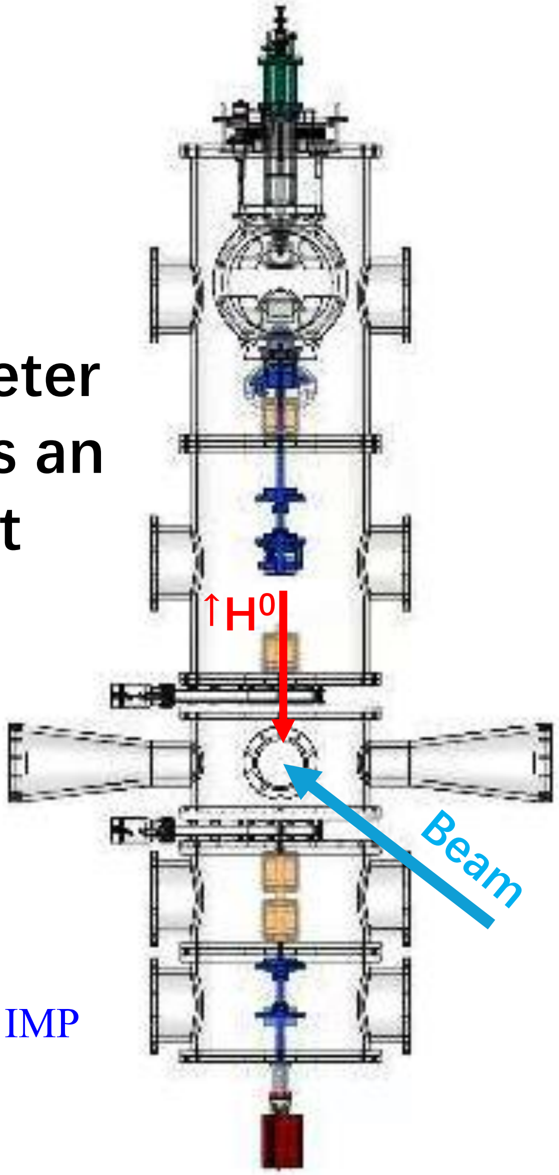
High-energy Polarimeters

➢ **At BRing**

- pC polarimeter: fast, relative
- H-jet polarimeter: absolute, slow
- pC polarimeter calibrated by H-jet



H-jet polarimeter can be used as an internal-target



Courtesy of B. Gou, IMP

Summary

A passionate team is working toward spin-polarized beams at HIAF (IMP and SDU)

Collaborations are welcome!

Production	Acceleration	Diagnostics
✓ Polarized H^+/D^+ ion source developed at IMP ■ Existing RFQ cannot acc. H^+ □ A polarized H_2^+ ion source □ Another RFQ	• Siberian snakes needed for polarization preservation • Theory and simulation done for HIAF and EicC	• Polarimeters needed at different energies • H-jet polarimeter can be used as an internal-target
¥ 10 million	¥ 5 million	¥ 8 million

Acceleration of polarized deuterons with HIAF is much easier than proton

Thanks

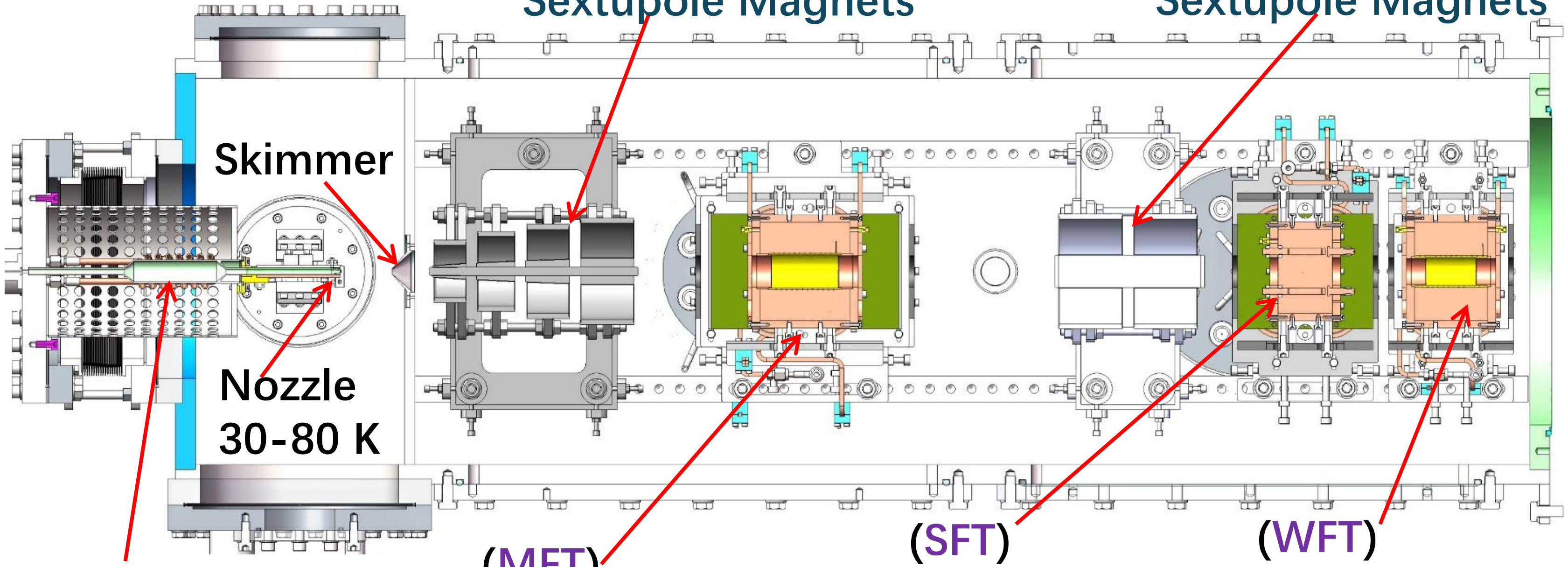
Thank you for Listening

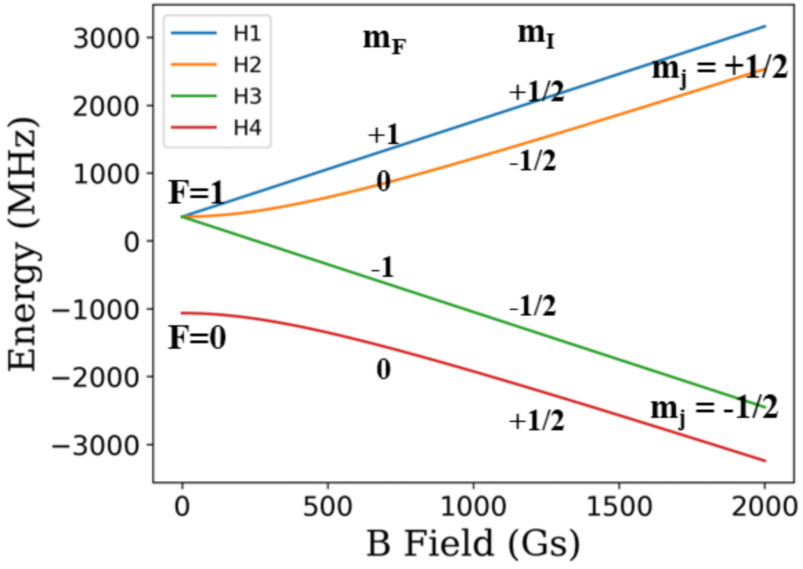
Questions & Discussions Welcome

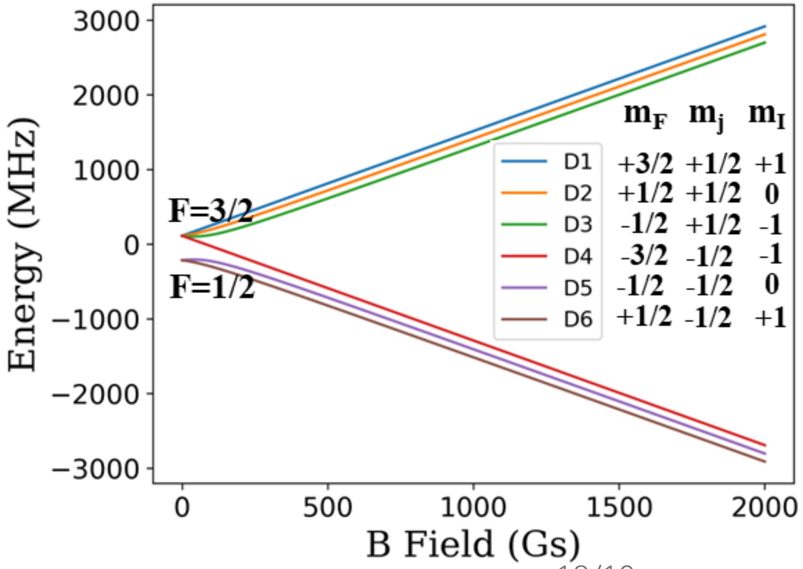
SPIS plan at IMP and status

Principles for PABS

- **Sextupole magnets:**
  - focus the atoms $m_j = 1/2$; defocus others $m_j = -1/2$
  - Electron spin polarized atomic beam







- **Medium (Strong, Weak) Field Transition**
  - Transfer the polarization from electron to nucleus
  - Nuclear spin polarized atomic beam

SPIS plan at IMP and status

Principles for Plasma Ionizer

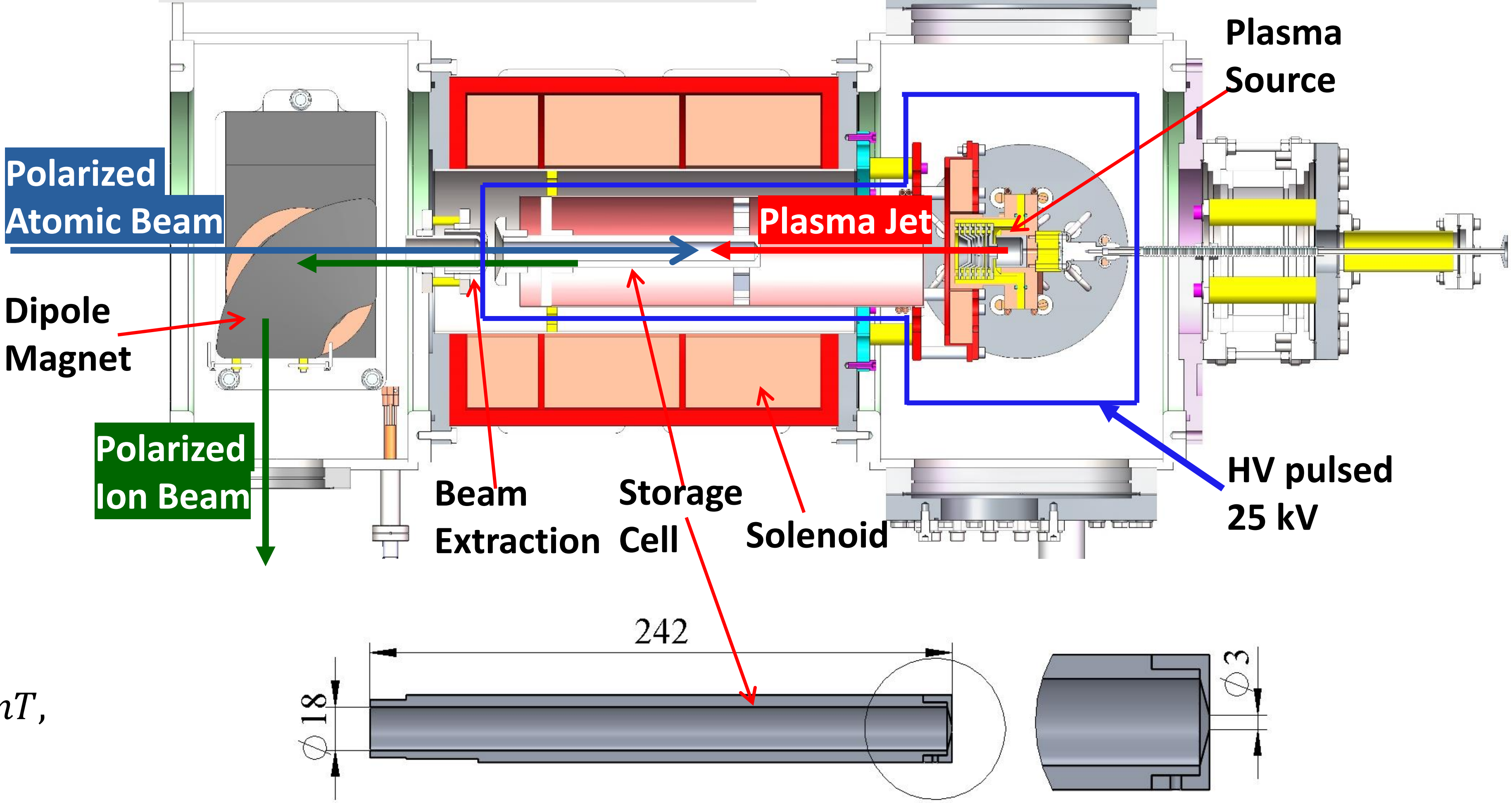
$$H^0 \uparrow + D^+ \rightarrow H^+ \uparrow + D^0$$

$$\sigma \approx 5\times10^{-15}\,\mathrm{cm}^2 \;@\; E_{D+} \sim 10eV$$

Quasi-resonant charge exchange

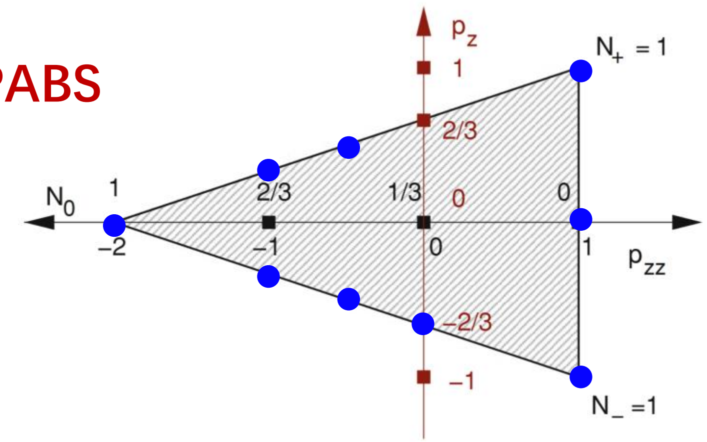
- Arc source produces plasma jet with high density
- Storage cell to increase the density of polarized atoms
- Strong magnetic field ($\gg \boldsymbol{B}_c$) avoid depolarization during the charge exchange

$B_{c,H}^{1S} = 50.7\ mT, B_{c,D}^{1S} = 11.7\ mT,$



SPIS plan at IMP and status

Principles for PABS



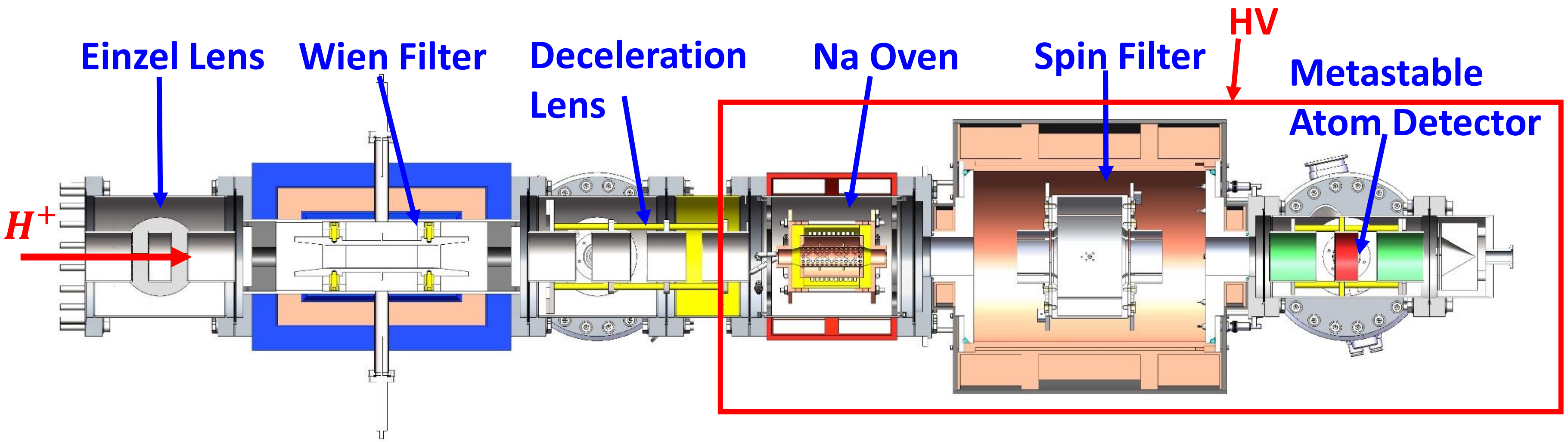
- **Switching on one or two transitions, polarized atomic beams in distinct polarization modes can be obtained.**

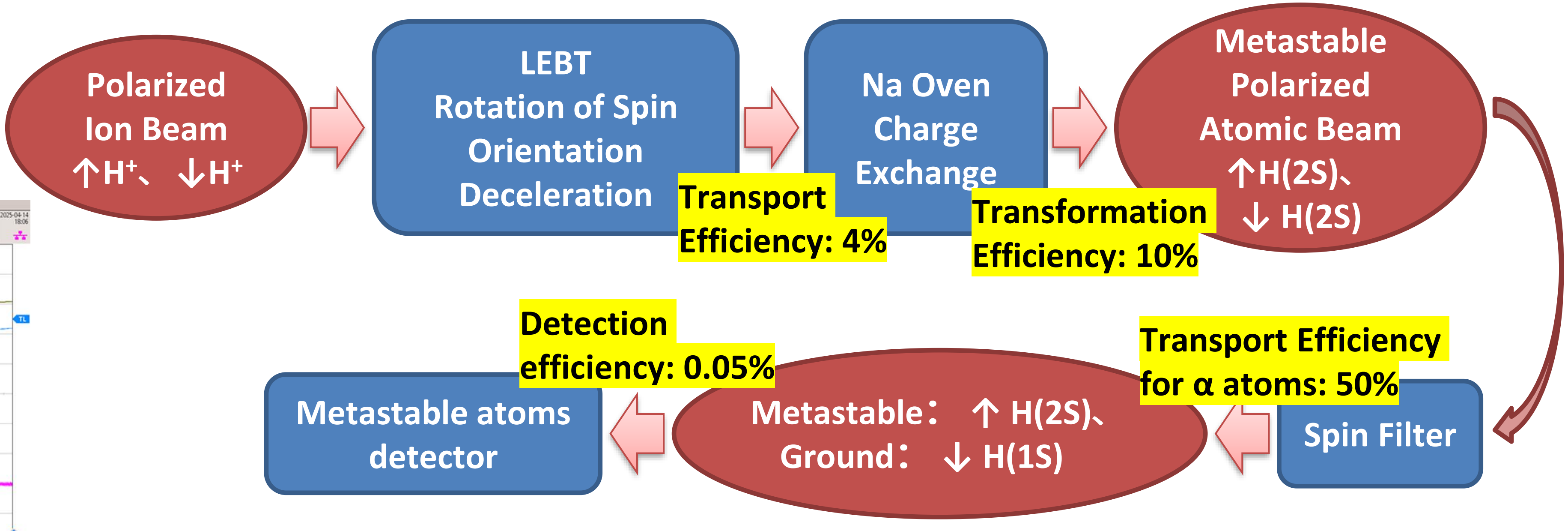
1	2	Polarization mode	3	4	5	6	7	8	9	10	11
H			D								
1+2+3+4		Atomic beam state	1+2+3+4+5+6								
1+2		After the 1st sextupole	1+2+3								
-	-	Transition in MFT	-	1↔4	1↔4	3↔4	3↔4	3↔4	1↔4	-	-
1+2	1+2	Statse after MFT	1+2+3	2+3+4	2+3+4	1+2+4	1+2+4	1+2+4	2+3+4	1+2+3	1+2+3
-	-	After the 2ed sextupole	1+2+3	2+3	2+3	1+2	1+2	1+2	2+3	1+2+3	1+2+3
2↔4	-	Transition in SFT	-	2↔6	3↔5	2↔6	-	-	-	2↔6	3↔5
1+4	1+2	States after SFT	1+2+3	3+6	2+5	1+6	1+2	1+2	2+3	1+3+6	1+2+5
-	1↔3	Transition in WFT	1↔4 2↔3	-	-	-	1↔4 2↔3	-	-	1↔4 3↔2 6↔5	-
1+4	2+3	States after WFT	2+3+4	3+6	2+5	1+6	3+4	1+2	2+3	2+4+5	1+2+5
1+4	2+3	Final states in ionizer	2+3+4	3+6	2+5	1+6	3+4	1+2	2+3	2+4+5	1+2+5
1	-1	Vector polarization	- 2/3	0	0	1	-1	1/2	- 1/2	- 1/3	1/3
-	-	Tensor polarizationz	0	1	-2	1	1	- 1/2	- 1/2	-1	-1

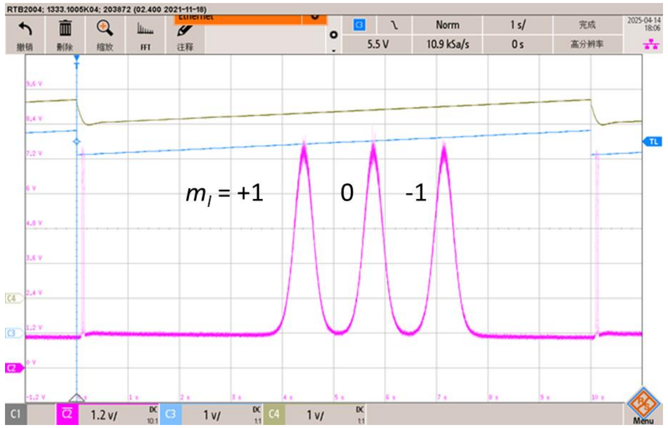
SPIS plan at IMP and status

Principles for Lamb shift polarimeter

- Directed measurement downstream of SPIS
- No need for further acceleration
- Immunity to mixed H_2^+ in polarization measurement for D^+
- More sensitive and intuitive

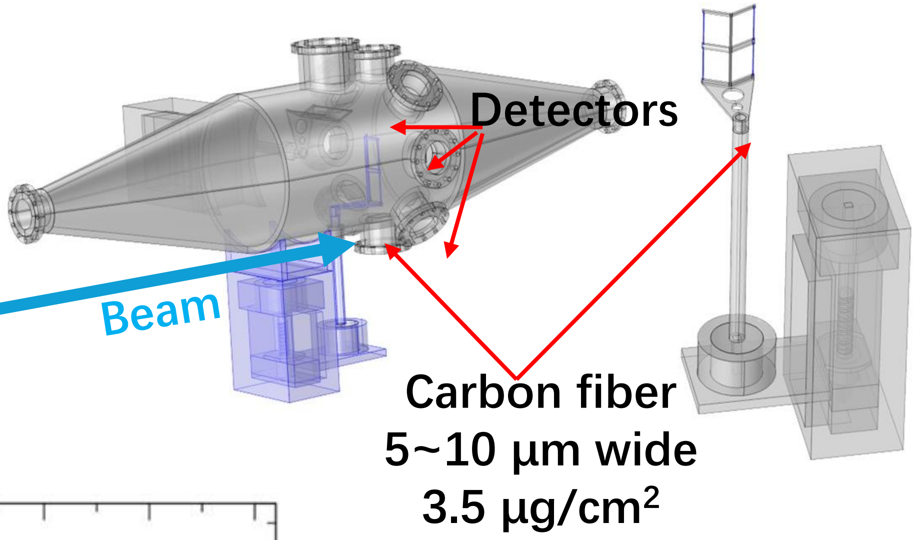




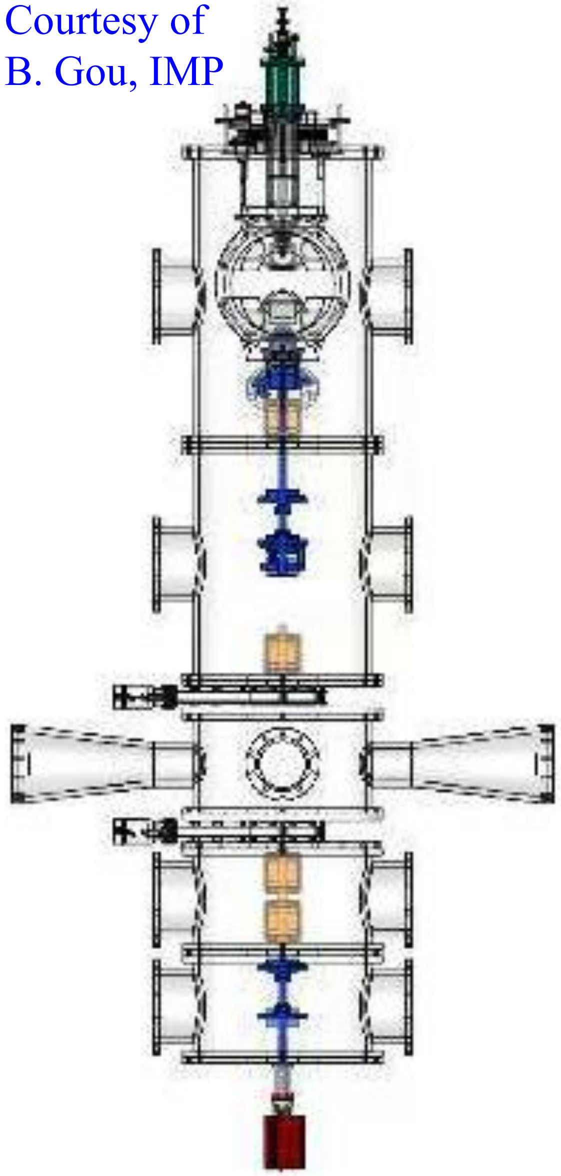


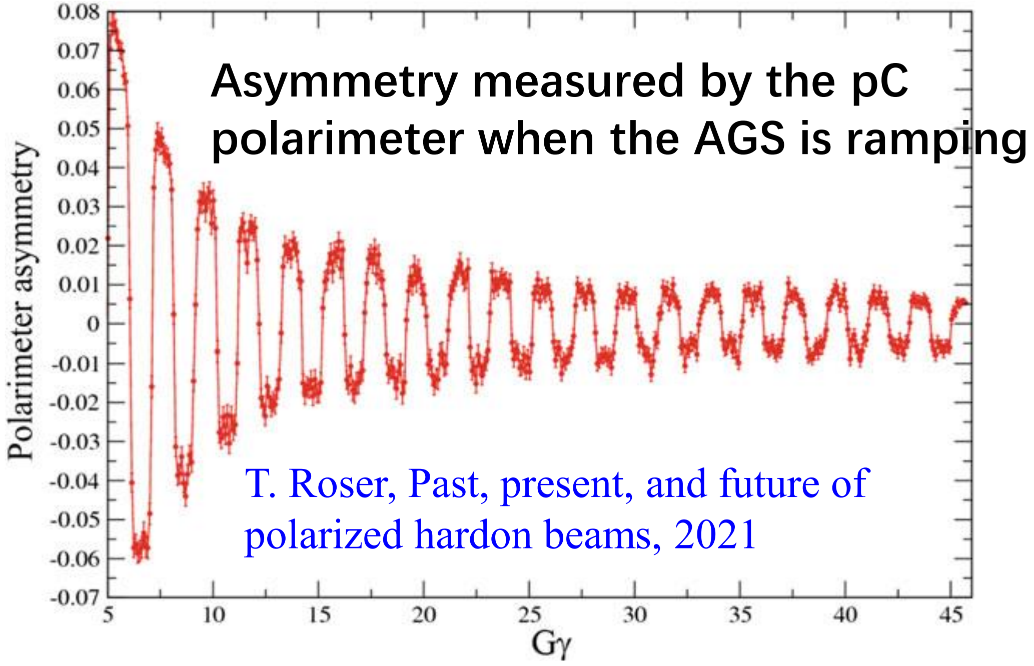
High-energy Polarimeters

- At BRing
- pC polarimeter: fast, relative
- H-jet polarimeter: absolute, slow
- pC polarimeter calibrated by H-jet



Courtesy of
B. Gou, IMP





T. Roser, Past, present, and future of polarized hardon beams, 2021