Development of a Polarized H^+/D^+ Ion Source at IMP

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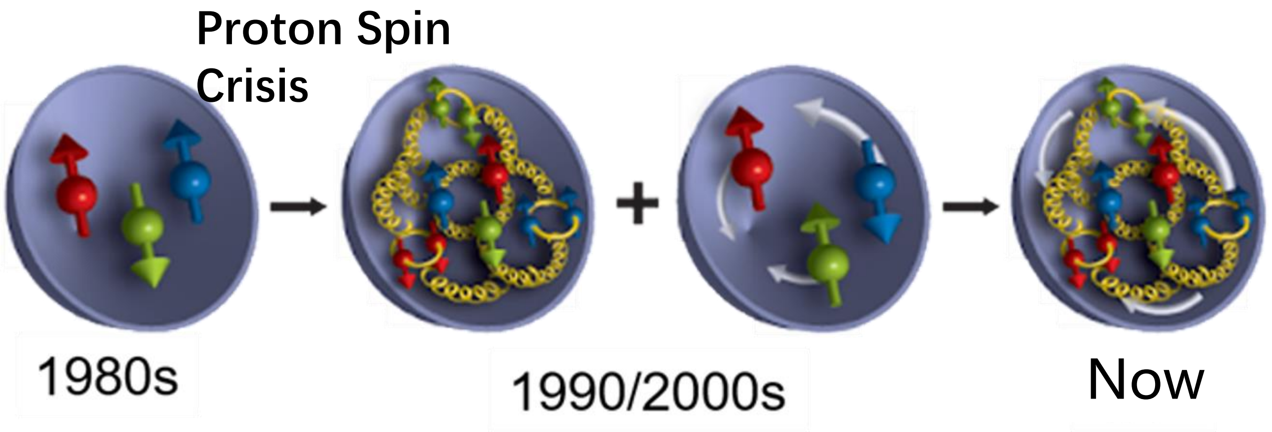
Outline

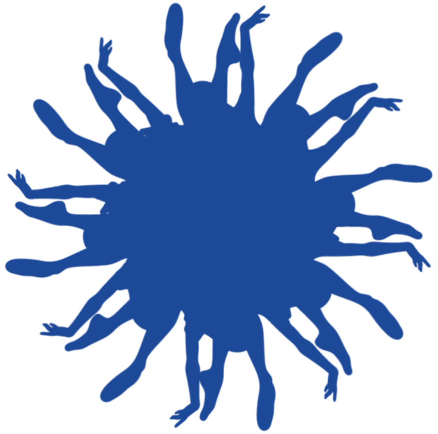
- Introduction: Polarized ion beams and EicC
- SPIS plan at IMP and status
- Polarized proton beam acceleration with HIAF-BRing

Introduction

"It (SPIN) is a mysterious beast, and yet its practical effect prevails over the whole of science. The existence of spin, and the statistics associated with it, is the most subtle and ingenious design of Nature—without it the whole universe would collapse"

--Shin'ichiro Tomonaga, the story of spin, 1997

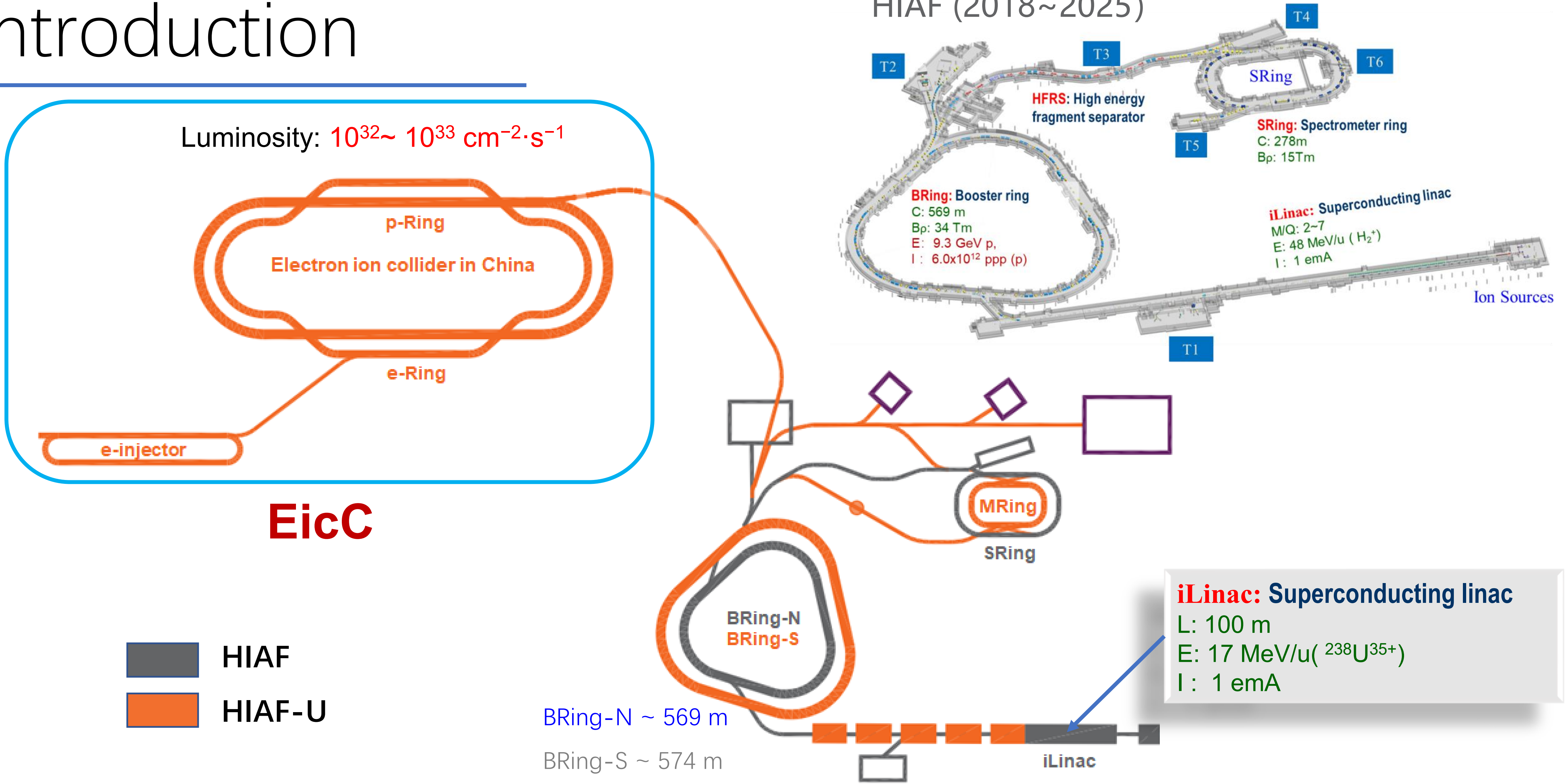




- **Spins of particles in polarized beam favor a particular direction.**
- Polarized ion beams are indispensable to spin physics research
- Polarized ion beams can enhance experiment sensitivity and precision.

Introduction

HIAF (2018~2025)



Polarized p(d), 1 mA, 80%

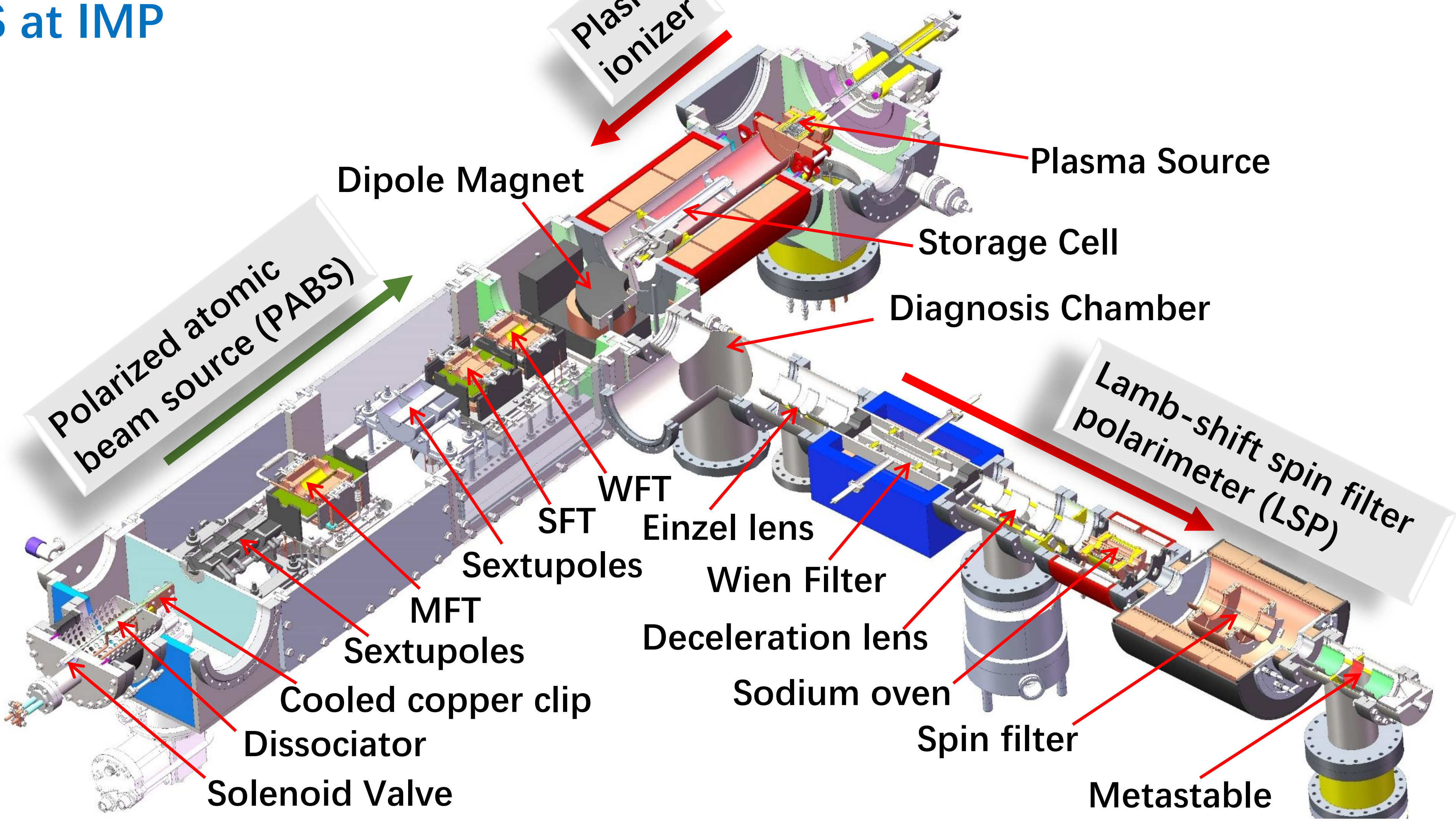
More information in Jiancheng Yang's report, Friday morning

SPIS plan at IMP and status

Layout of the SPIS at IMP

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

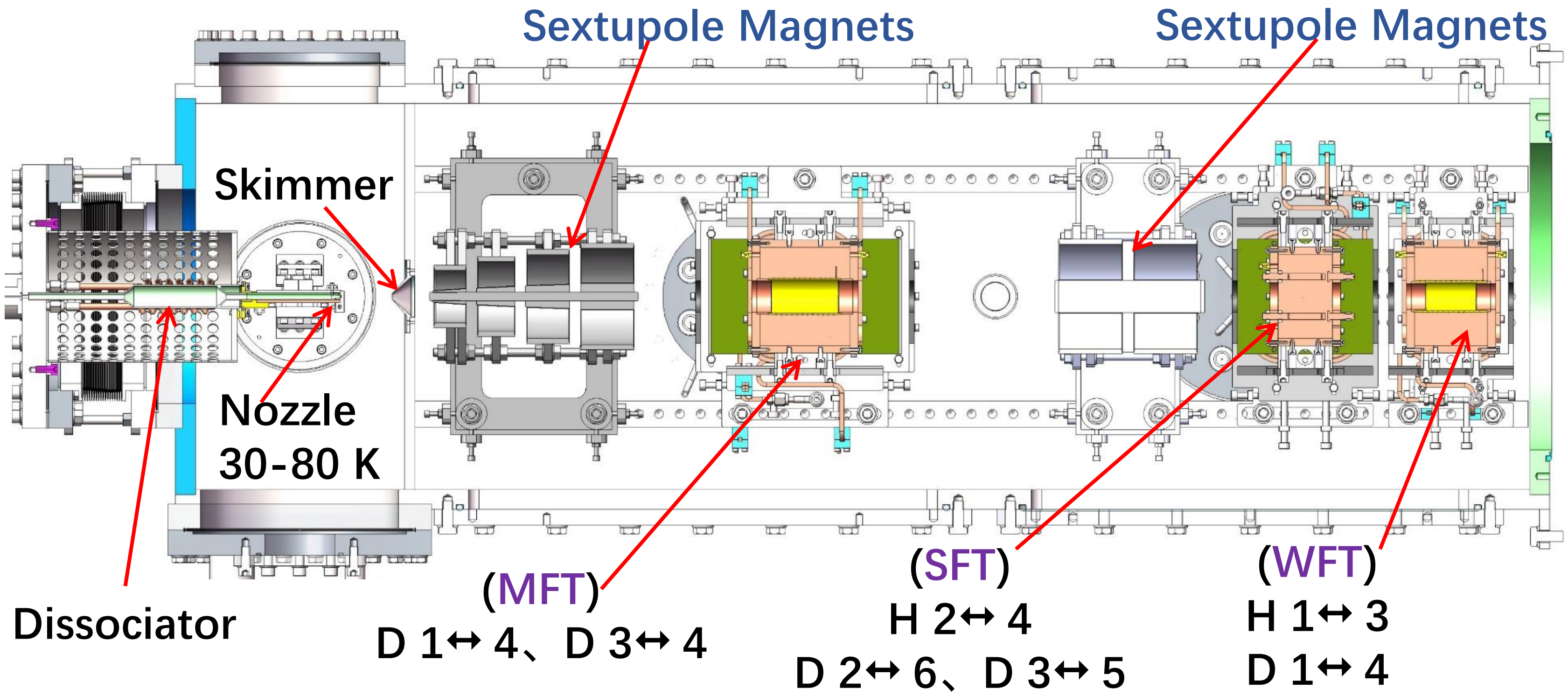
$$H^0\uparrow + D^+ \rightarrow H^+\uparrow + D^0$$
$$D^0\uparrow + H^+ \rightarrow D^+\uparrow + H^0$$

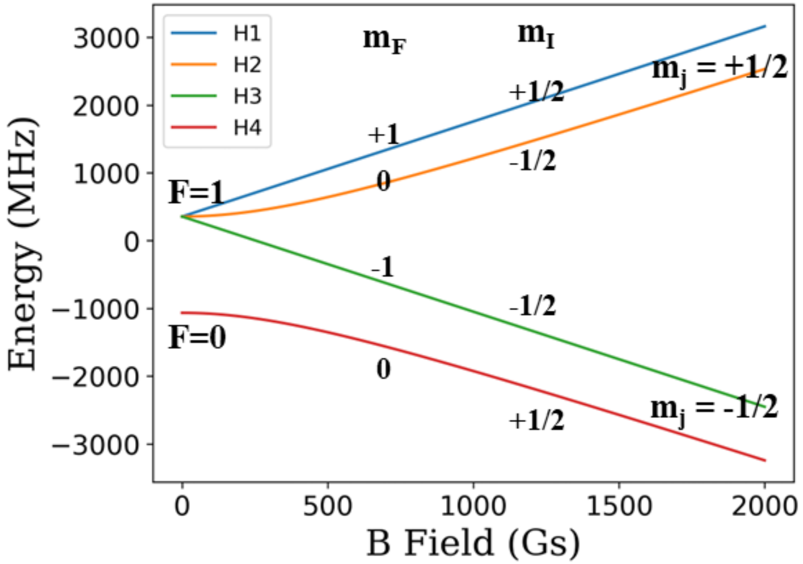


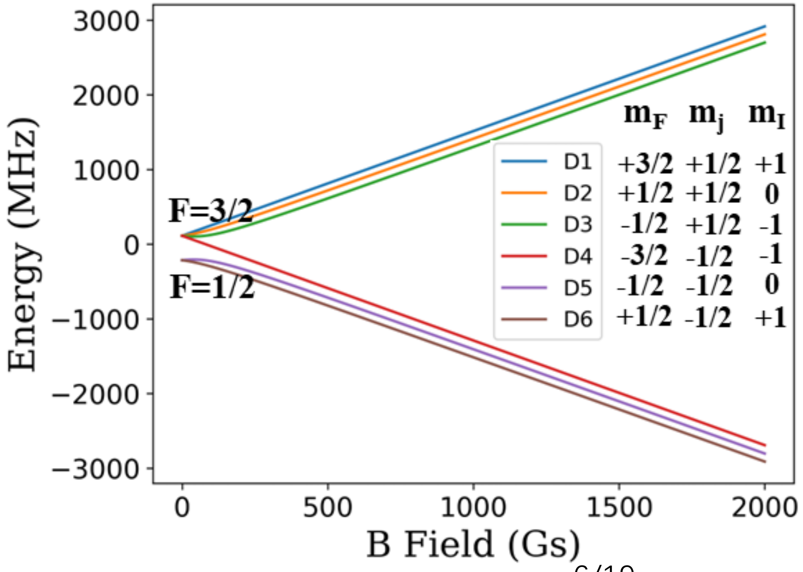
SPIS plan at IMP and status

Principles for PABS
More information in Sheng Zhang's report

- **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

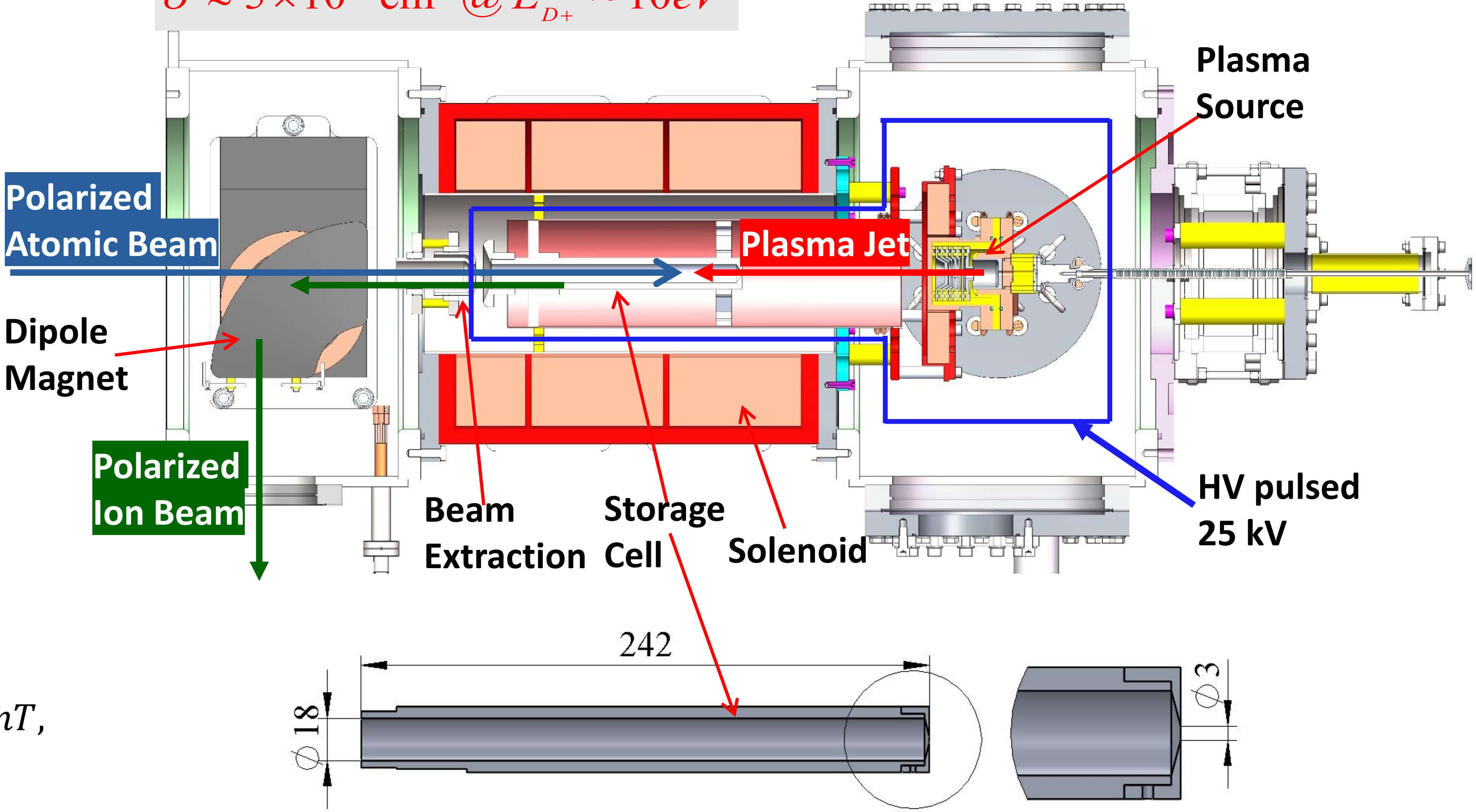
$$H^0 \uparrow + D^+ \rightarrow H^+ \uparrow + D^0$$

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

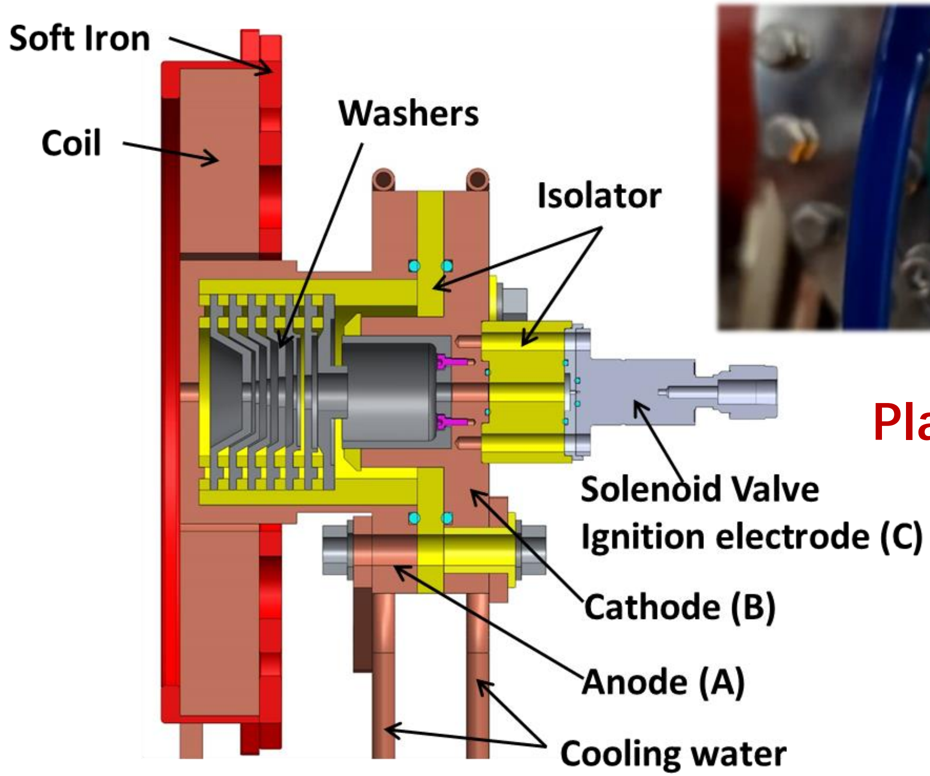
Quasi-resonant charge exchange

- 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

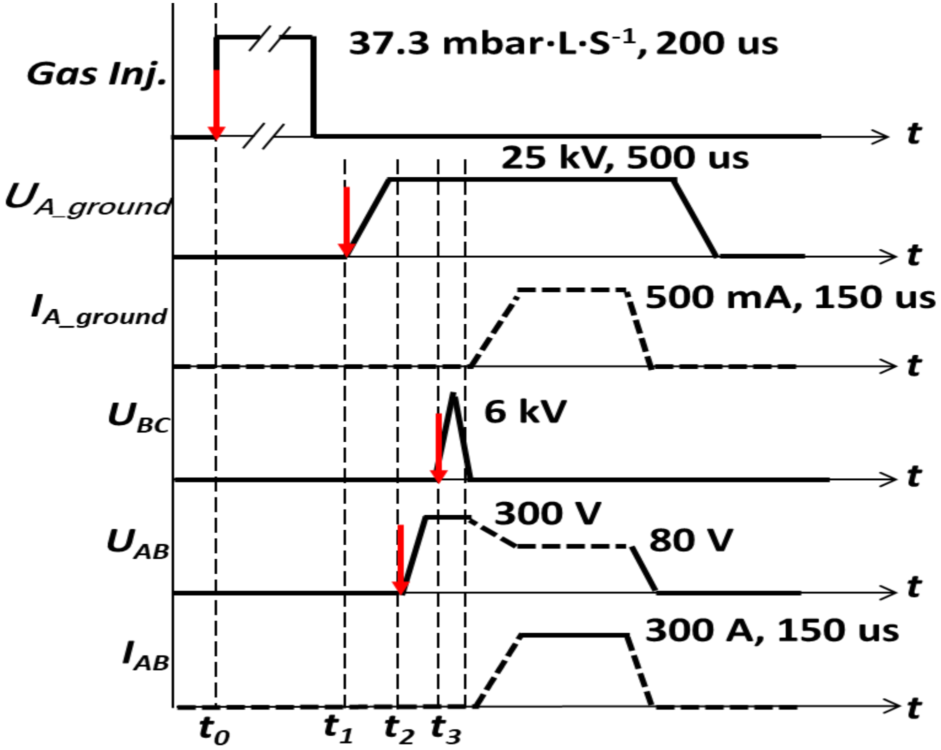
$B_{c,H}^{1S} = 50.7\ mT, B_{c,D}^{1S} = 11.7\ mT,$

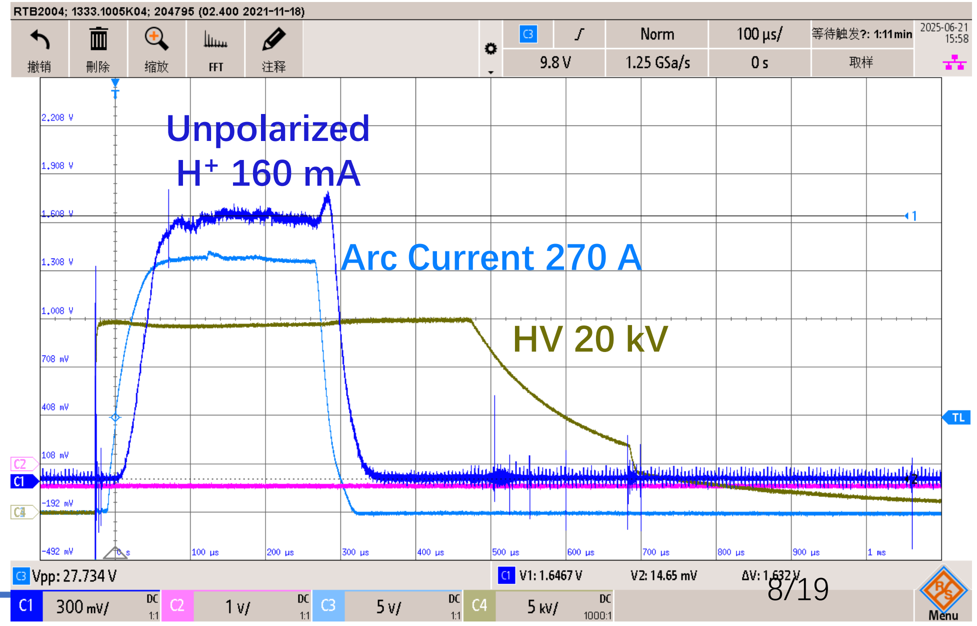


SPIS plan at IMP and status



Plasma generator



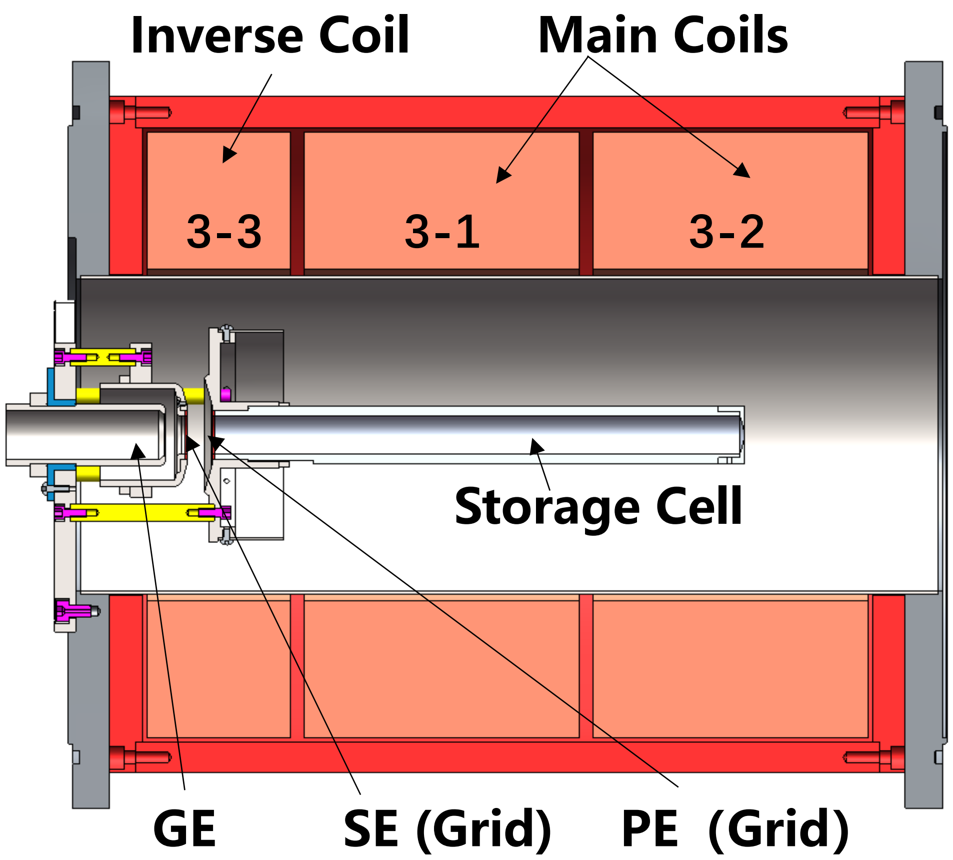


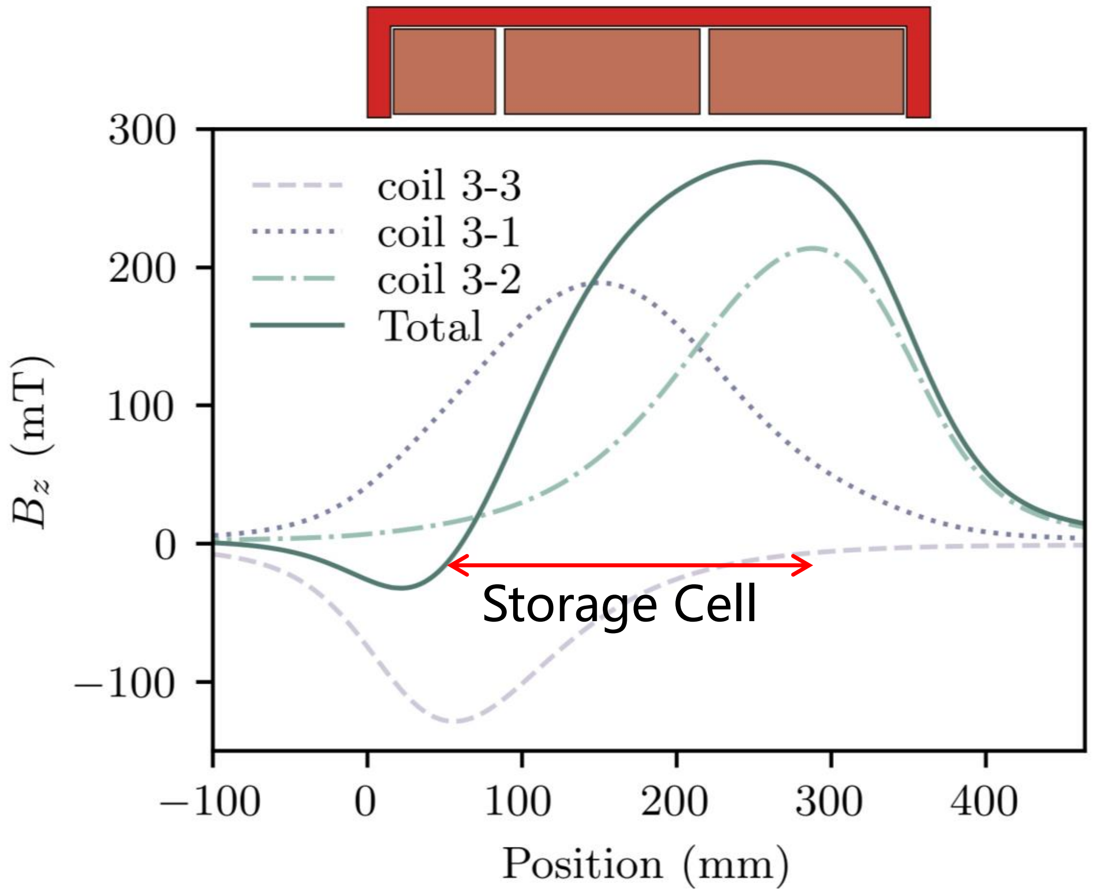
- **Pulsed gas injection**
- **Ignition with a HV spark**
- **Arc discharge at the narrow washers canal**
- **proton percentage 90%**

SPIS plan at IMP and status

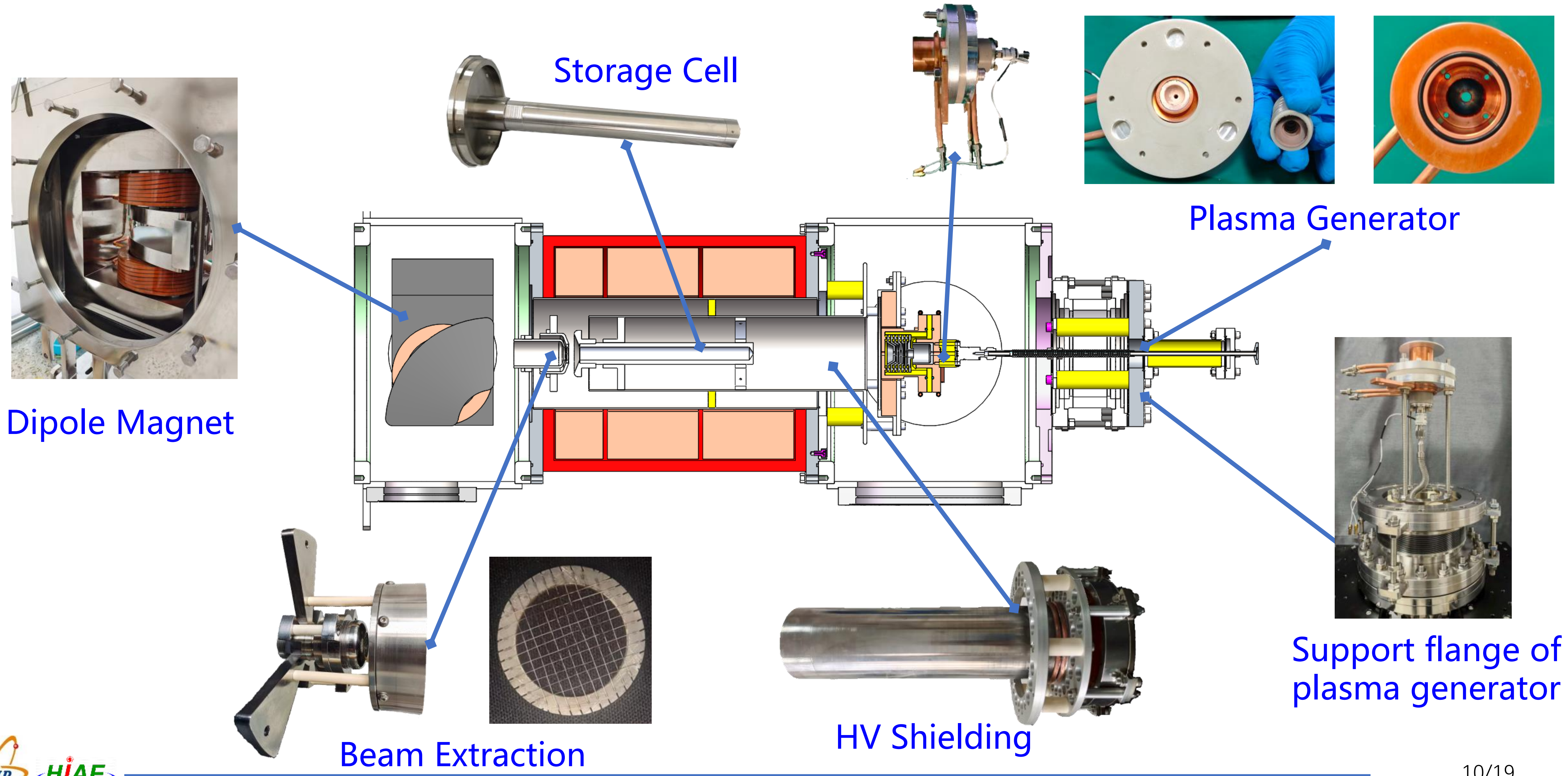
B-Field in ionization region

- **Strong B-Field 280 mT at the small diaphragm end of the storage cell**
- **Near-zero B-Field at the beam extraction system**



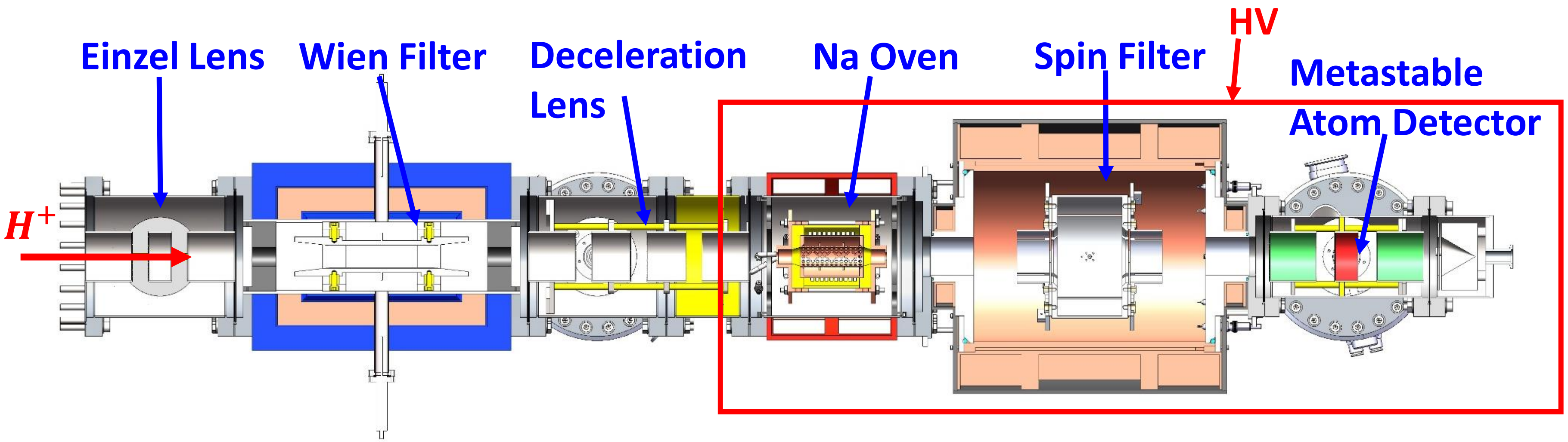


SPIS plan at IMP and status

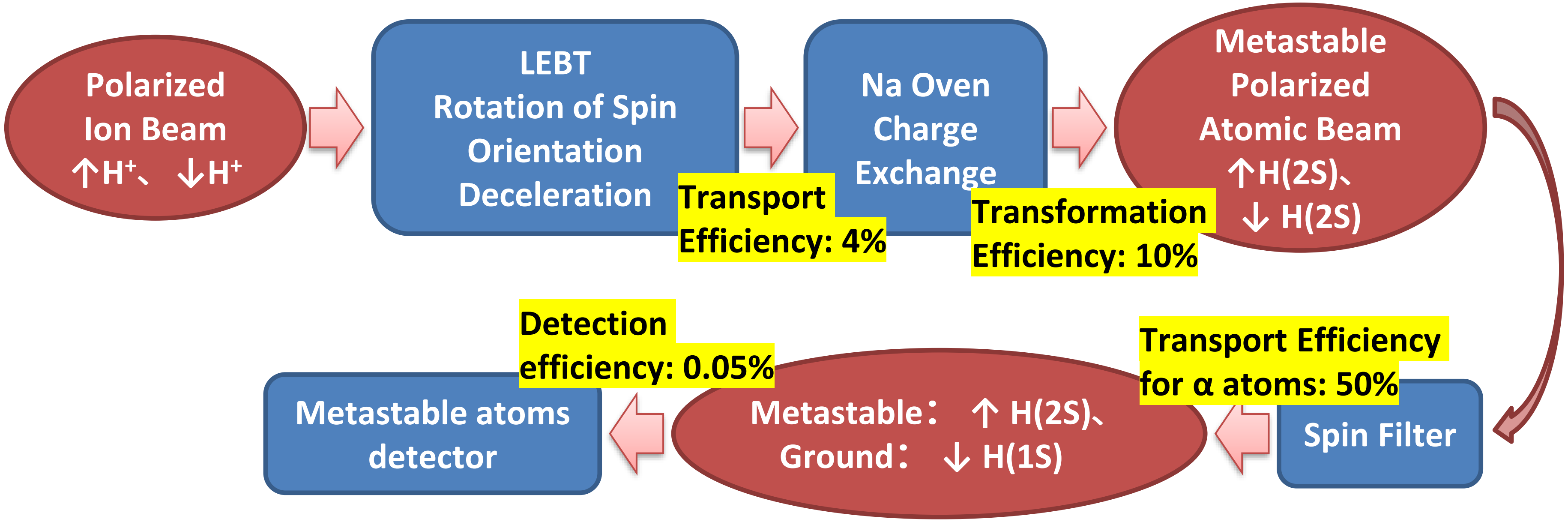


SPIS plan at IMP and status

Principles for Lamb shift polarimeter

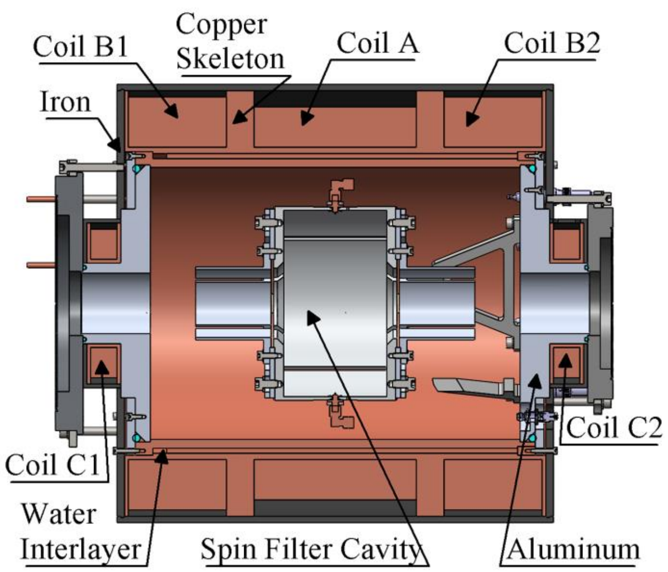


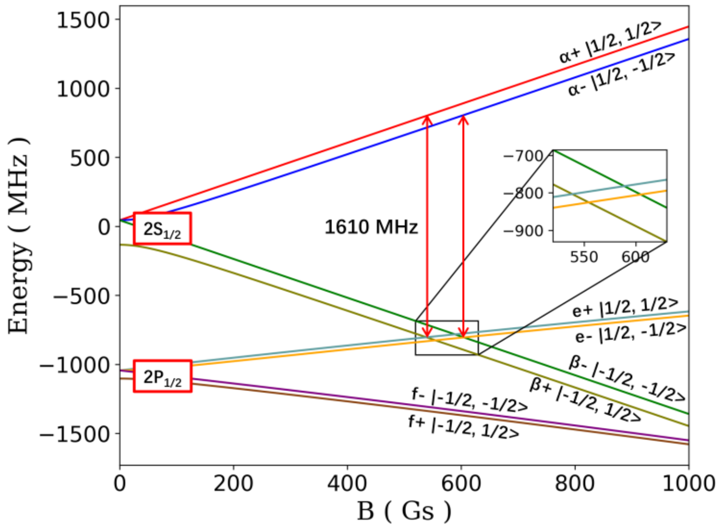
- Directed measurement downstream of SPIS
- No need for further acceleration
- Immunity to mixed H_2^+ in polarization measurement for D^+
- More sensitive and intuitive



SPIS plan at IMP and status

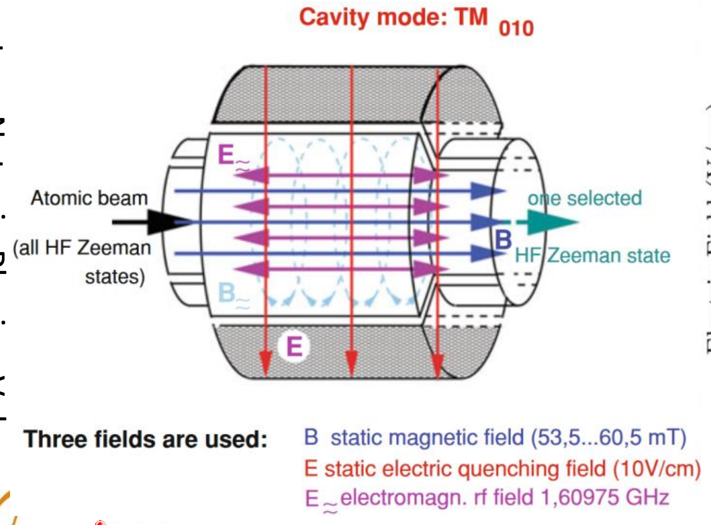
Spin Filter

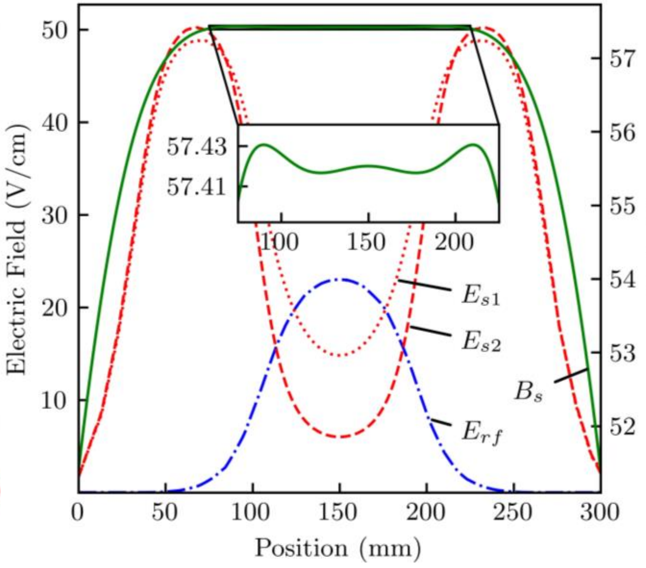


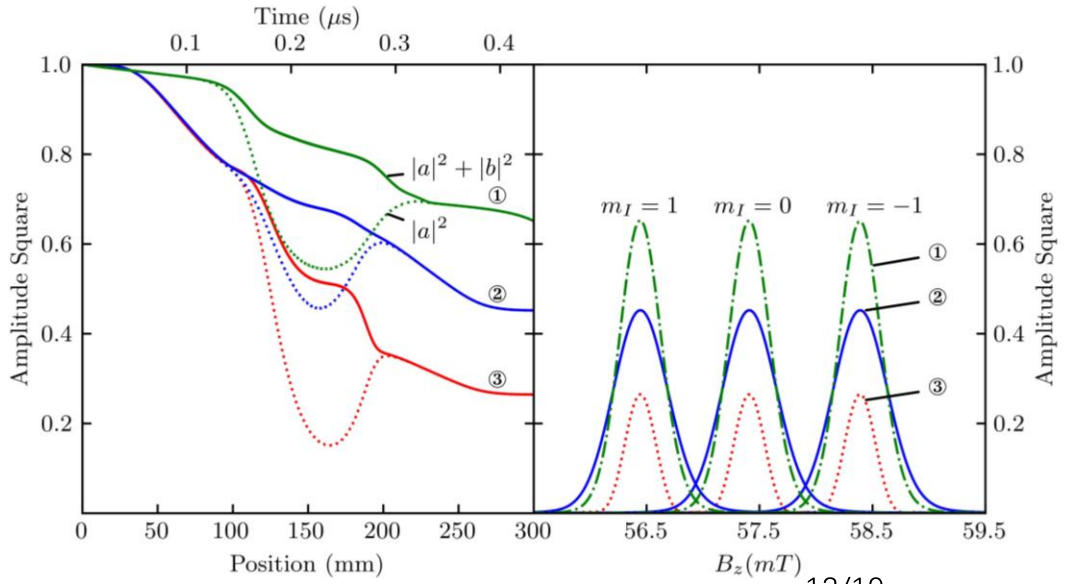


- **All H/D(2S) atoms are quenched by these electro-magnetic fields**
- **H/D(2S) atoms with specified m_I are preserved by α-β-e three level resonance**

Lecture Notes in Physics, Volume 842, Spring, 2012

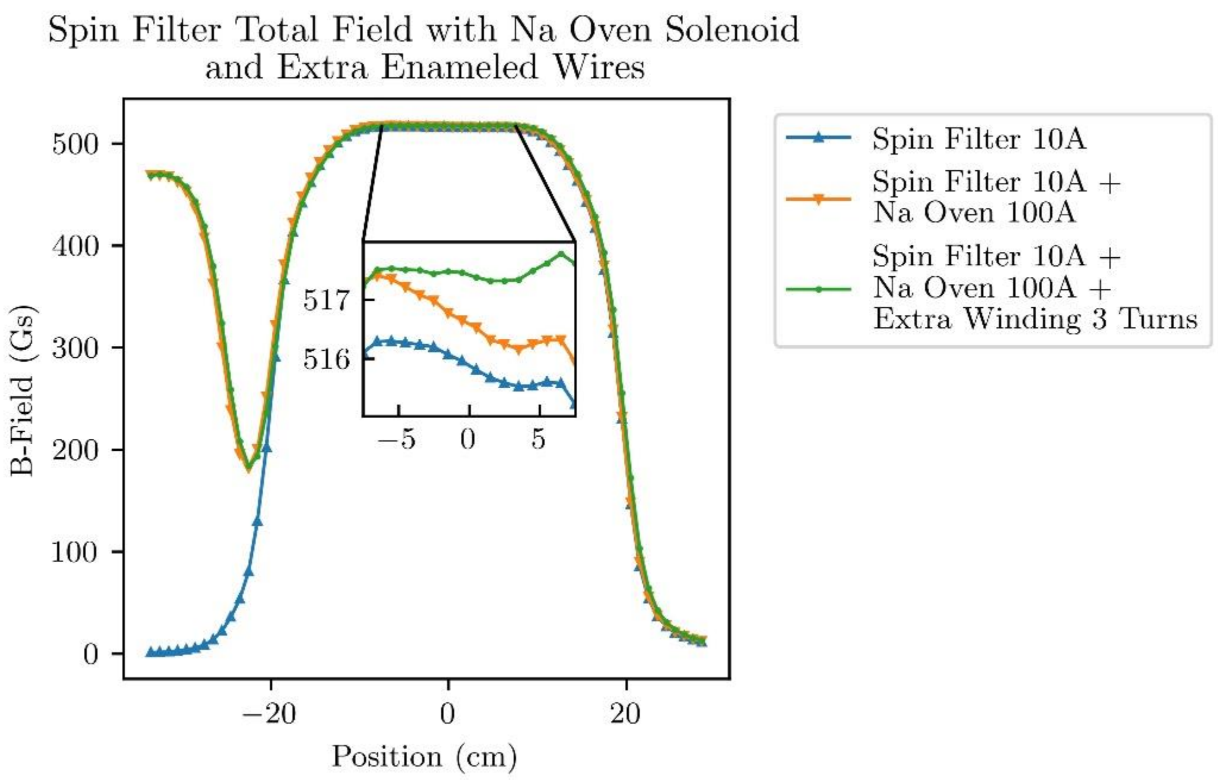


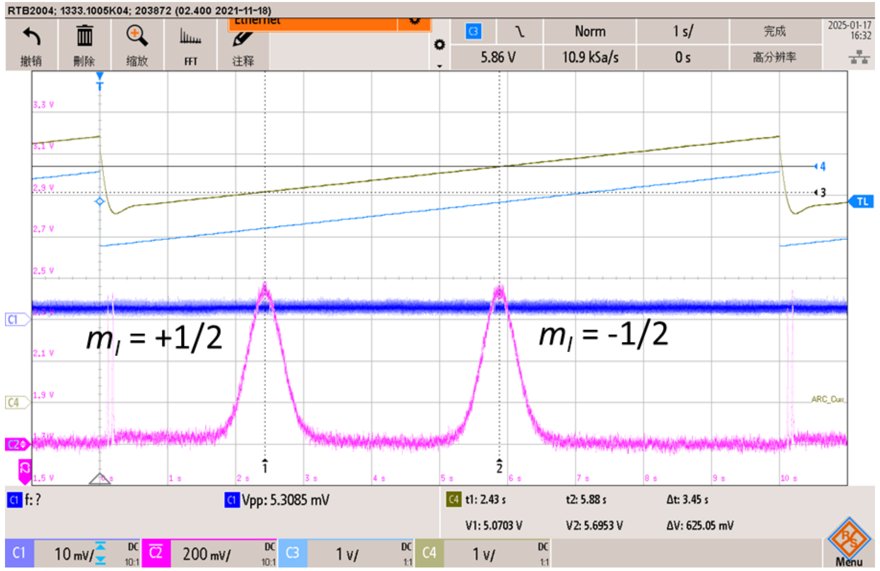


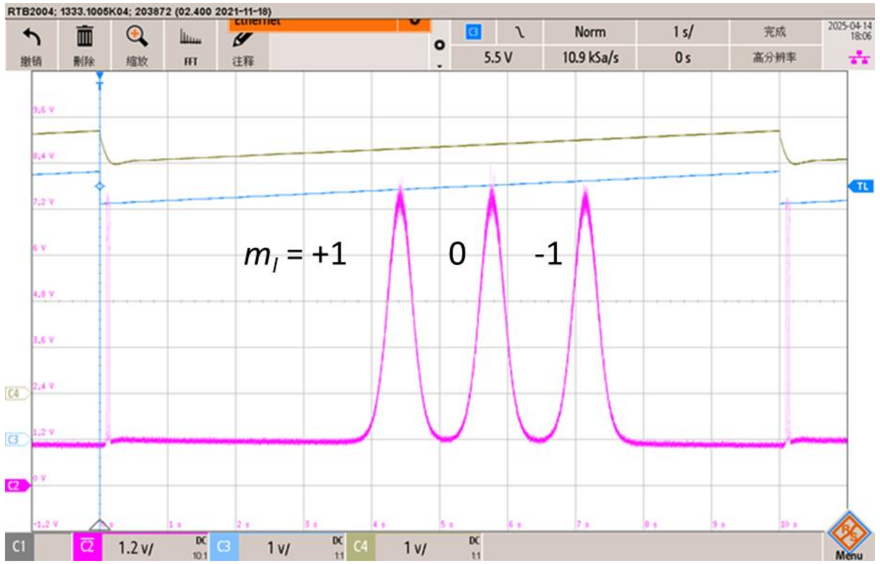


SPIS plan at IMP and status

LSP Tests

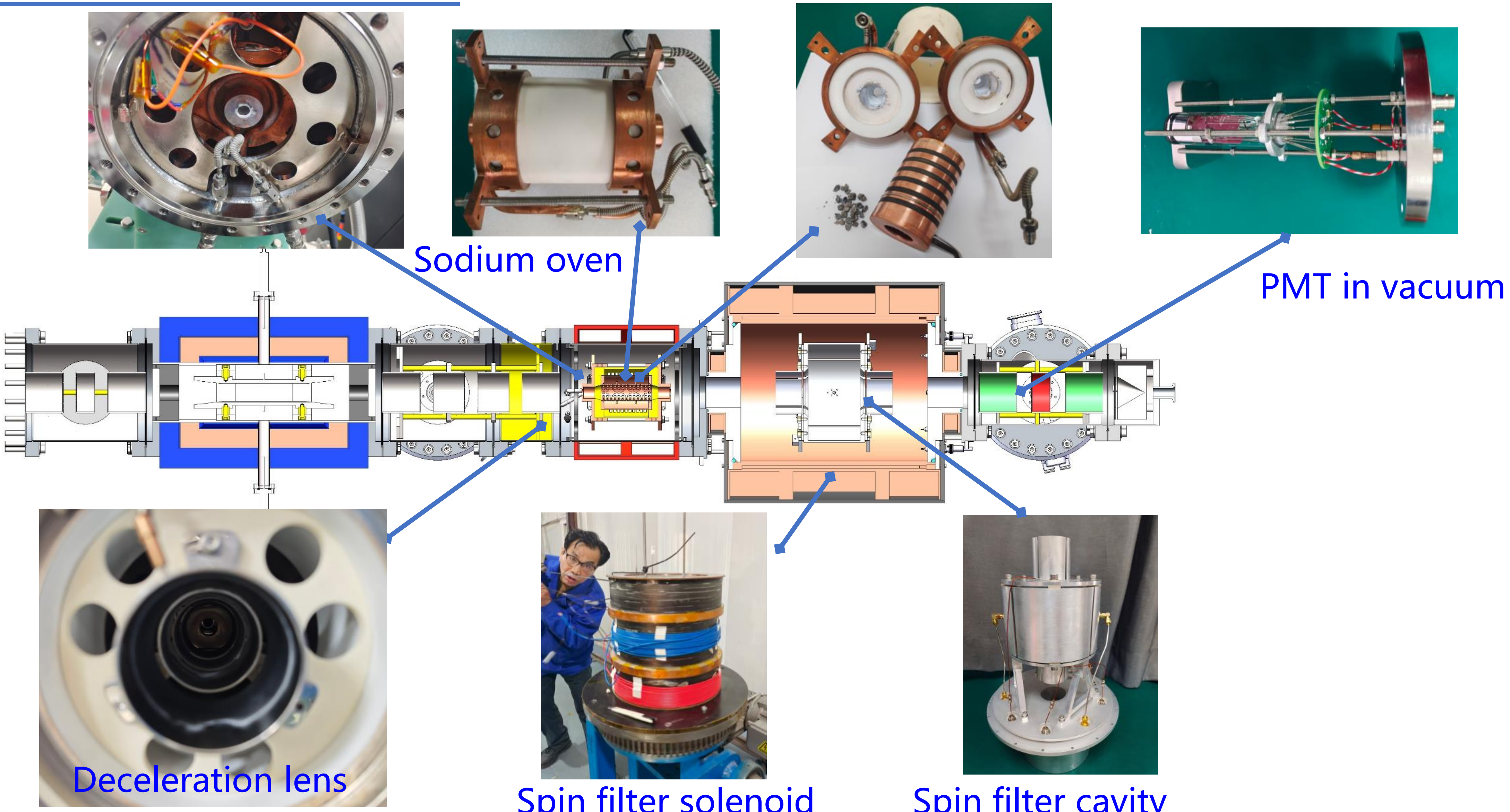






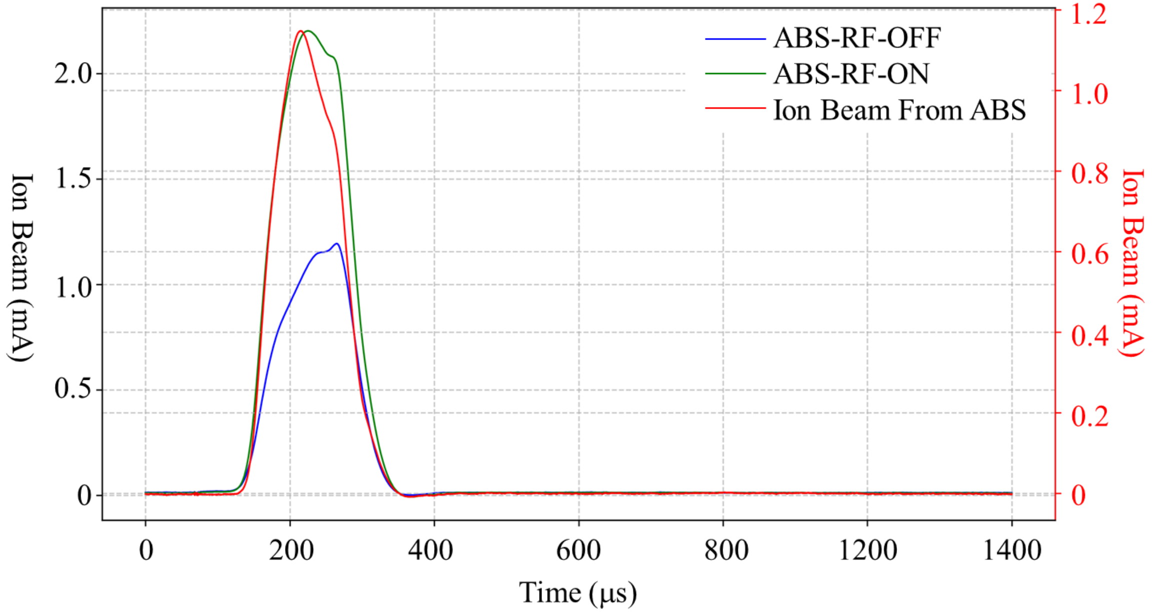
- **Spin filter B-Field fluctuation smaller than 0.1 mT**
- **Lyman spectrums measured with unpolarized H^+/D^+ beams (DC)**

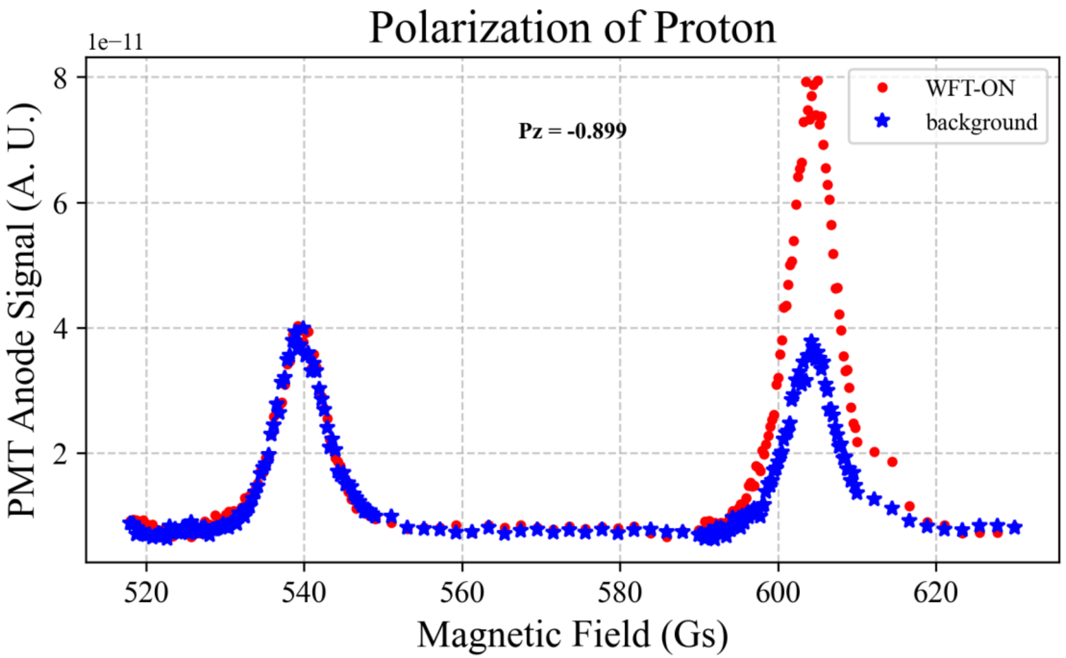
SPIS plan at IMP and status



SPIS plan at IMP and status

Joint testing of PABS, plasma ionizer and LSP (proton beam)



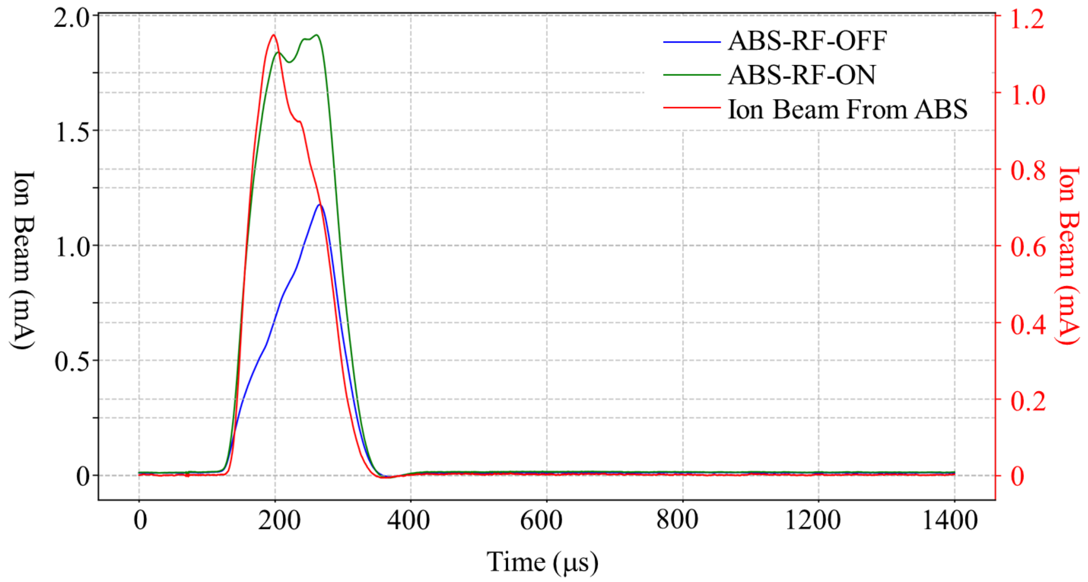


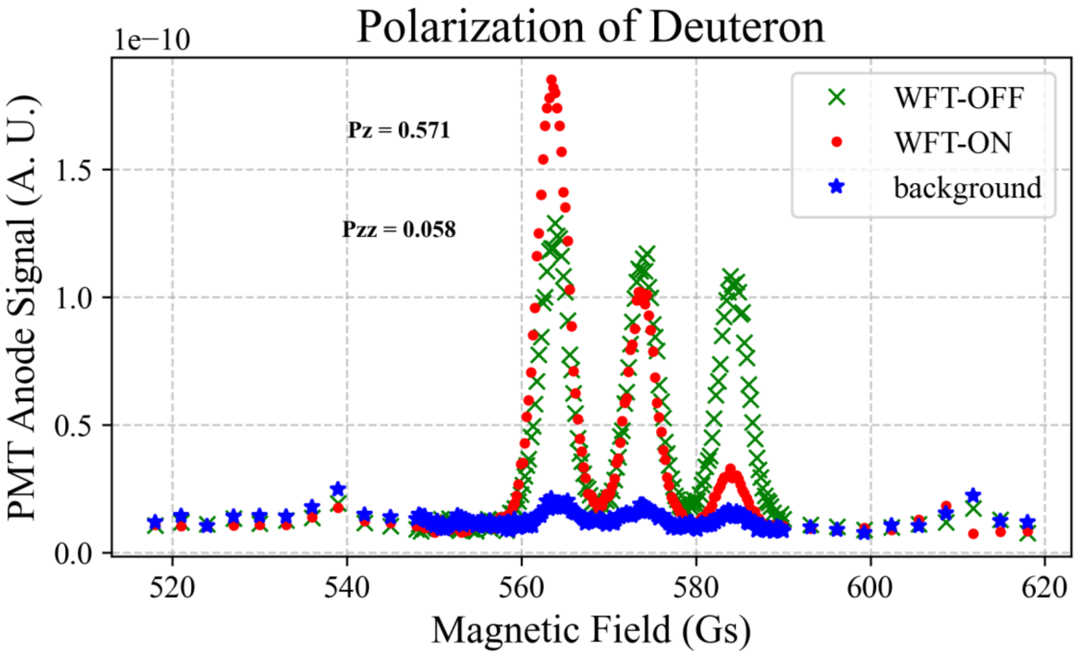
- Background H^+ from ionizer residual gas
- Injected atomic beam in flux of 3E16 atoms/s
- Ionization efficiency 20%

- Atomic beam polarization 90%
- Overall proton beam polarization 40%

SPIS plan at IMP and status

Joint testing of PABS, plasma ionizer and LSP (deuteron beam)

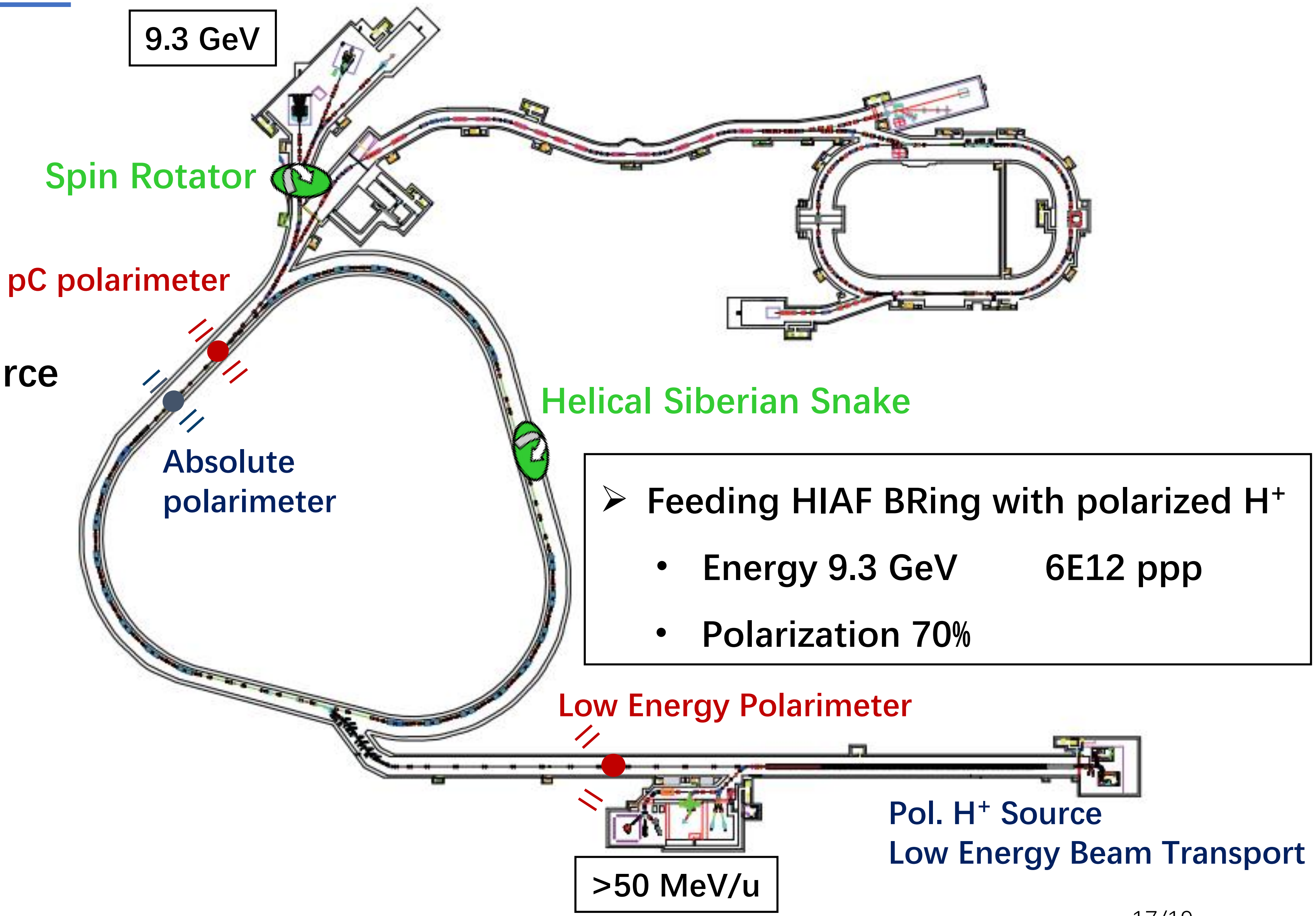




- Polarized D^+ mixed with H_2^+
- Mixed H_2^+ has no effect on D^+ beam polarization measurement
- Vector polarized D^+ beam with a polarization of 86%

Polarized proton beam acceleration with HIAF-BRing

- ➢ Production
  - Polarized H^+ (H^- or H_2^+) Source
- ➢ Acceleration
  - Siberian Snake
    [M. X. Li, NIMA, 2022]
- ➢ Diagnosis
  - Polarimeters



- ➢ Feeding HIAF BRing with polarized H^+
  - Energy 9.3 GeV 6E12 ppp
  - Polarization 70%

Summary

- $H^+/D^+\uparrow$ beams extracted from the SPIS up to **1 mA** with polarization more than **80%**
- Beam **polarization measurement with a LSP directly downstream the SPIS**
- SPIS operating improvements will be continued
- **Polarized proton beam acceleration in HIAF-BRing** is being discussed

Acknowledge

Thanks to A.S. Belov, JINR’s SPI Group and R. Engels for valuable discussions and suggestions.

Thanks for your attention!!

Backup

Status of worldwide SPIS development

- **High performance polarized ion beams can only be generated by spin polarized ion sources (SPIS)**
- **SPIS originated in the 1960s.**
- **Two steps for producing polarized ion beam: 1) nuclear spin polarized atoms; 2) ionization**

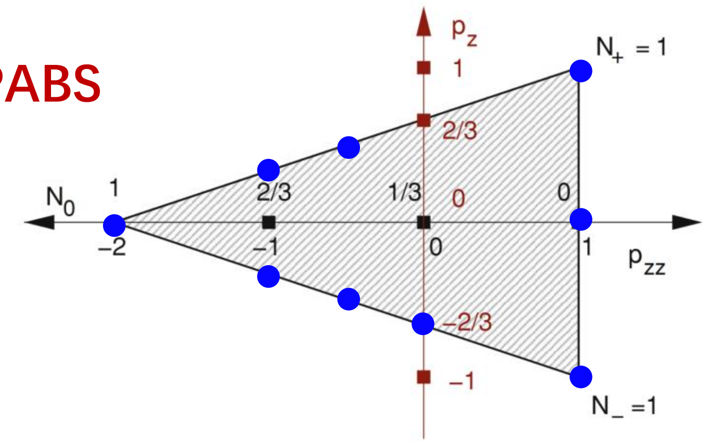
Year	Institute	Particle	Intensity	Polarization	Polarization Acquisition	Ionization
2008	INR	H^+, H^-	11 mA, 4 mA, 200 μs, 10 Hz	90%	ABPIS	Plasma ionizer
2019	JINR	D^+	6 mA, 150 μs, 1 Hz	88%	ABPIS	Plasma ionizer
2003	IUCF	H^-, D^-	1.8 mA, 2 mA, 300 μs, 2 Hz	90%	ABPIS	Plasma ionizer
2005	FZJ	H^-	50 μA, 20 ms, 0.5 Hz	90%	ABPIS	Cs beam
2016	BNL	H^-	4 mA, 300 μs	85%	OPPIS	Na cell

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

IMP HIAF

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.**

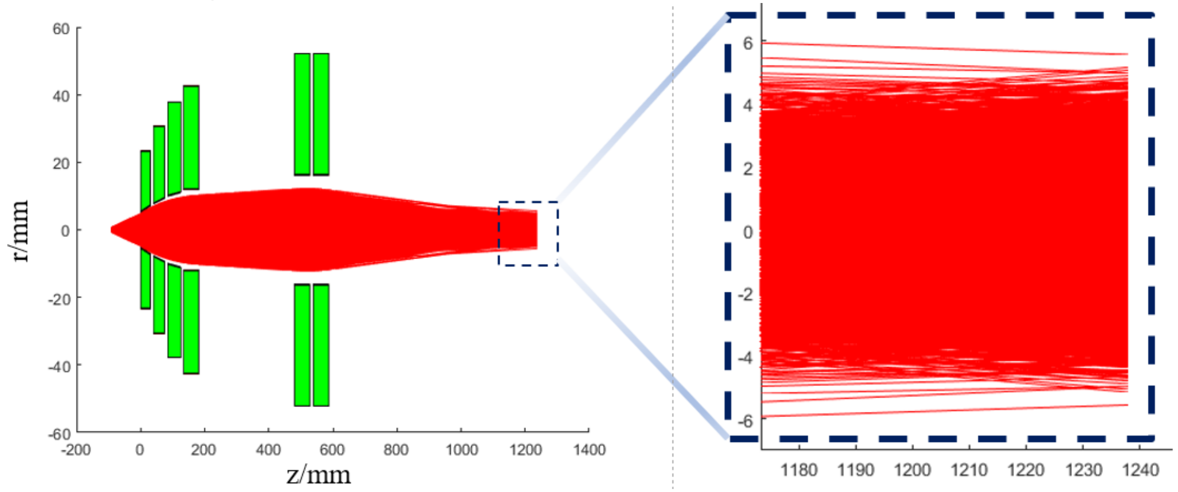
1	2	Polarization mode	3	4	5	6	7	8	9	10	11
H			D								
1+2+3+4		Atomic beam state	1+2+3+4+5+6								
1+2		After the 1st sextupole	1+2+3								
-	-	Transition in MFT	-	1↔4	1↔4	3↔4	3↔4	3↔4	1↔4	-	-
1+2	1+2	Statse after MFT	1+2+3	2+3+4	2+3+4	1+2+4	1+2+4	1+2+4	2+3+4	1+2+3	1+2+3
-	-	After the 2ed sextupole	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

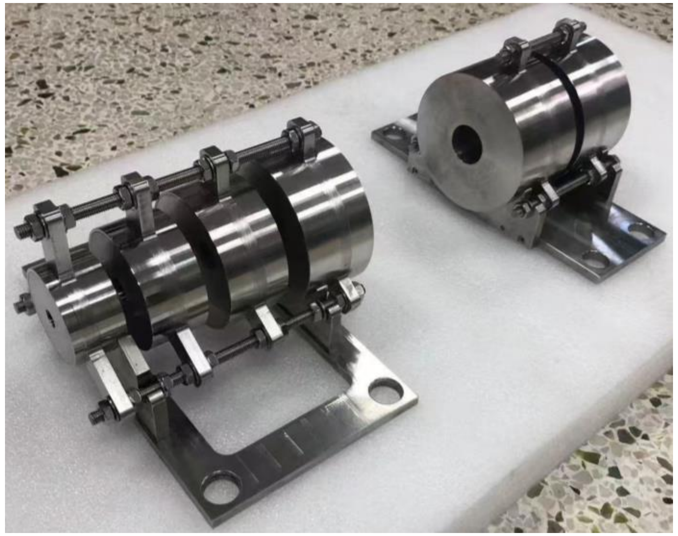
IMP HIAF

SPIS plan at IMP and status

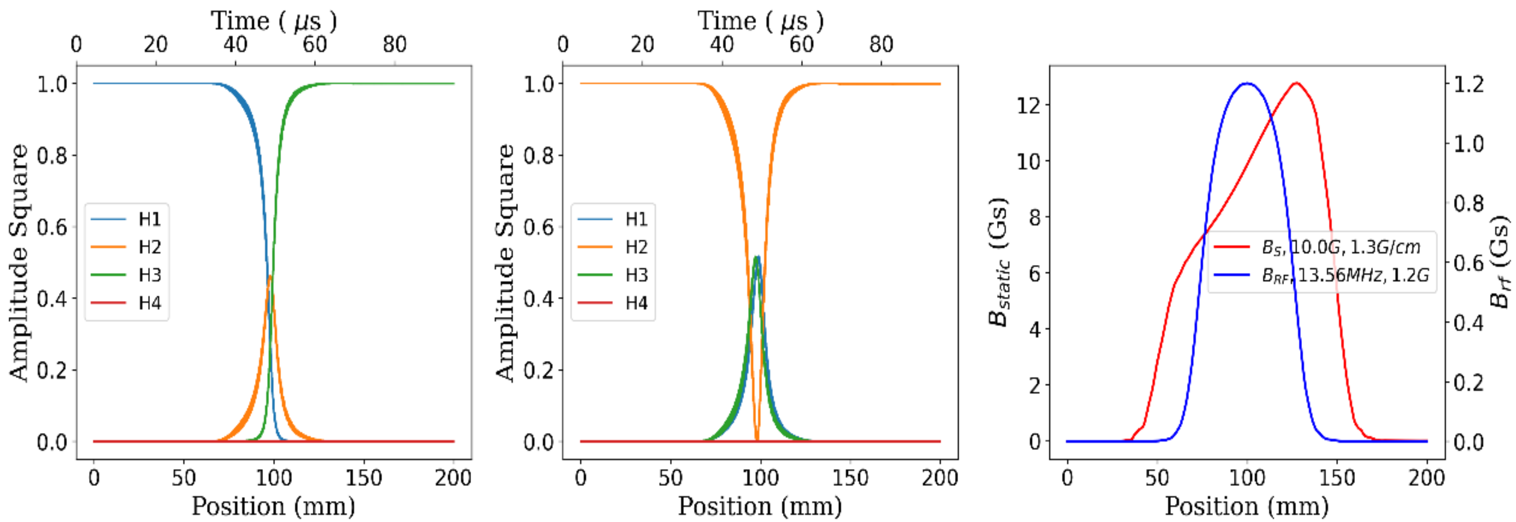
Principles for PABS

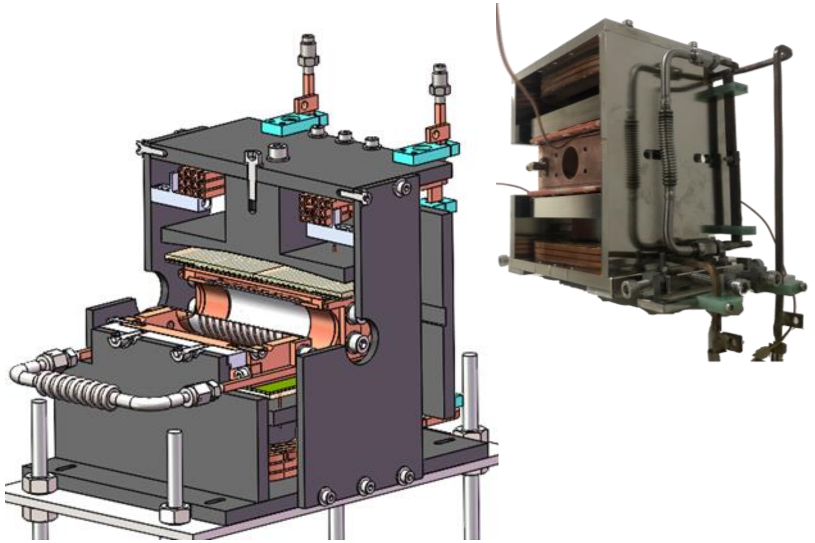
- **Atoms with m_j = 1/2 are focused by sextupole magnets**



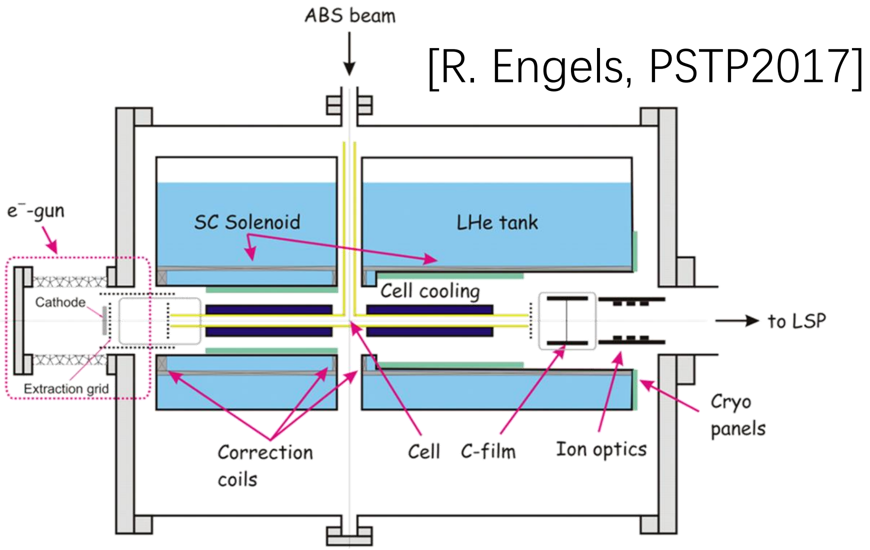


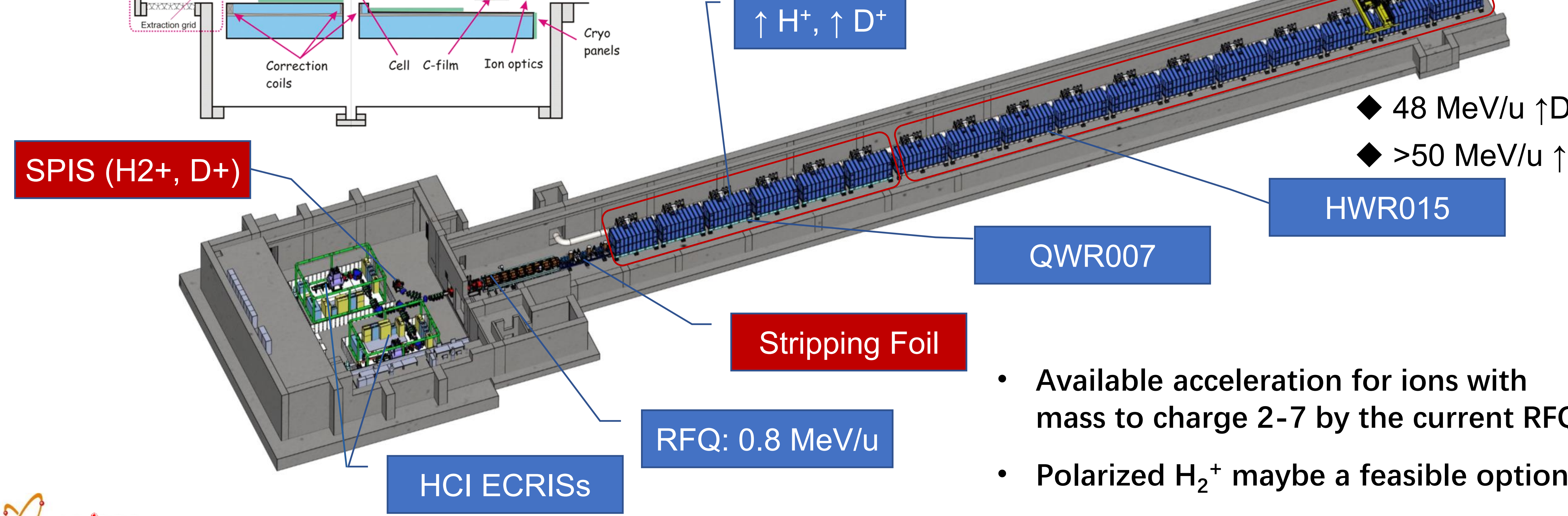
- **Atoms staying in H1 state transition to H3**





Strategy of feeding HIAF-BRing with polarized protons





- 48 MeV/u ↑D^+
- >50 MeV/u ↑H^+

- **Available acceleration for ions with mass to charge 2-7 by the current RFQ**
- **Polarized H_2^+ maybe a feasible option**