



山东大学
SHANDONG UNIVERSITY

Optically Polarized ^3He and Polarized ^3He Ion Beams

Xiaqing Li (Shandong Univ.)

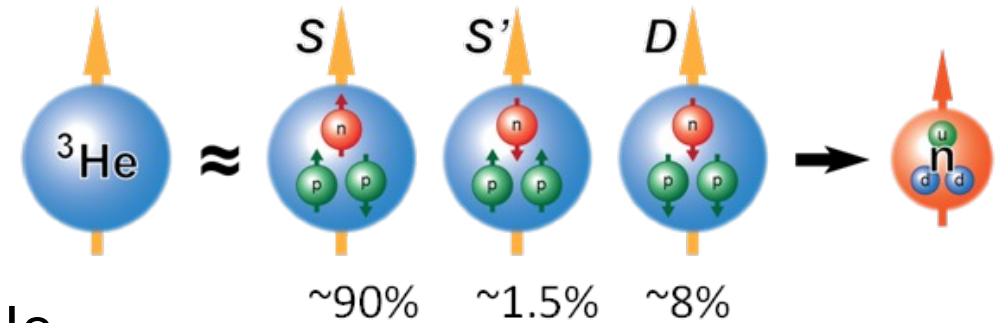
The 1st Annual Conference on Electron-Ion Collider
Physics in China

Qingdao

April 20, 2026

Polarized ^3He : Effective Polarized Neutron

- ^3He nucleus: S state $\sim 90\%$
 - 2 proton spins anti-parallel
 - Neutron carries most of the nuclear spin
- Two **optical pumping** methods to polarize ^3He
 - **Metastability-exchange (MEOP)** and **Spin-exchange (SEOP)**
- Polarized ^3He targets for lepton scattering experiments

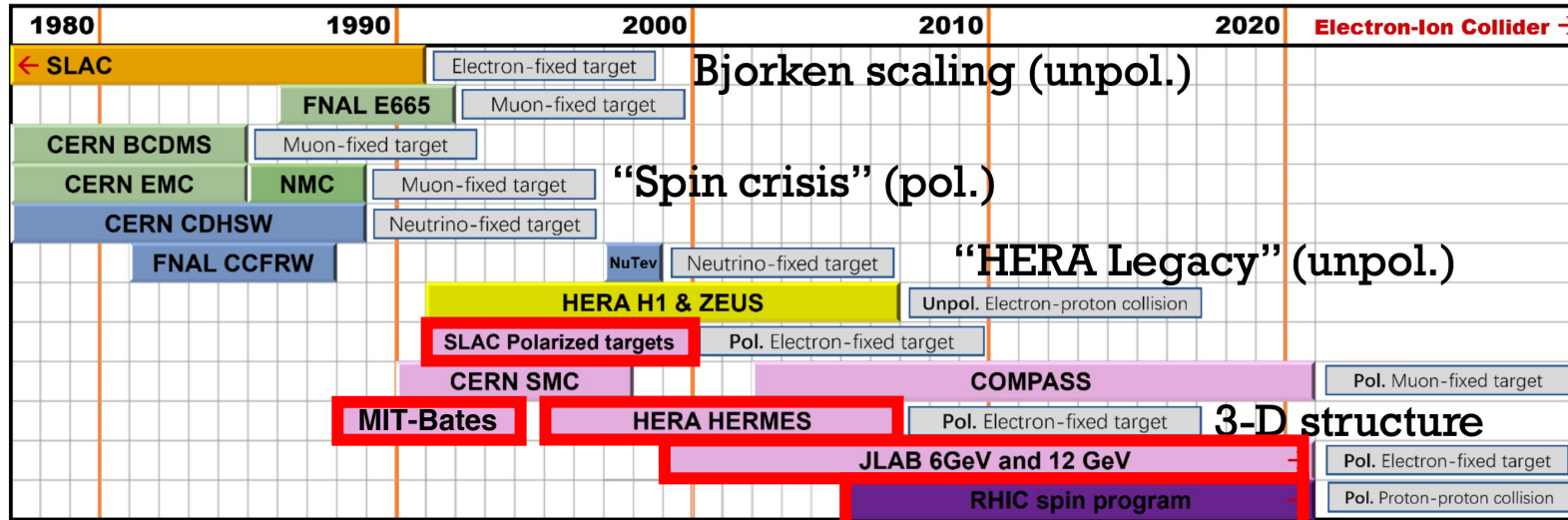


➤ SEOP

- MIT-Bates
- SLAC
- JLab
- TUNL

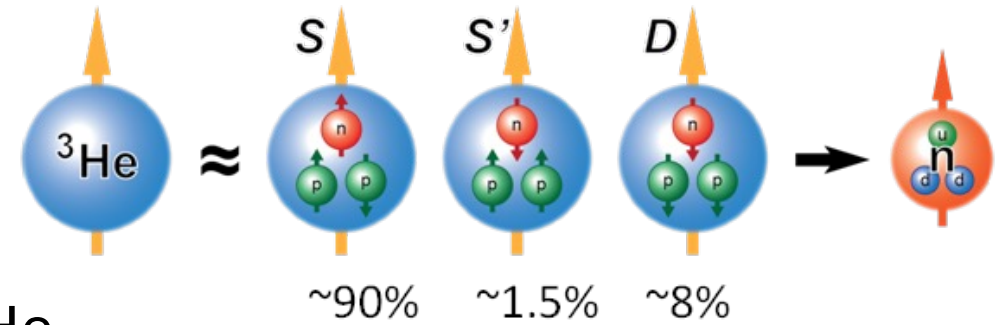
➤ MEOP

- MIT-Bates
- HERMES
- MAMI
- (JLab)
- (RHIC)



Polarized ^3He : Effective Polarized Neutron

- ^3He nucleus: S state $\sim 90\%$
 - 2 proton spins anti-parallel
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- Two **optical pumping** methods to polarize ^3He
 - Metastability-exchange (MEOP)** and **Spin-exchange (SEOP)**
- Few polarized ^3He ion sources realized in history

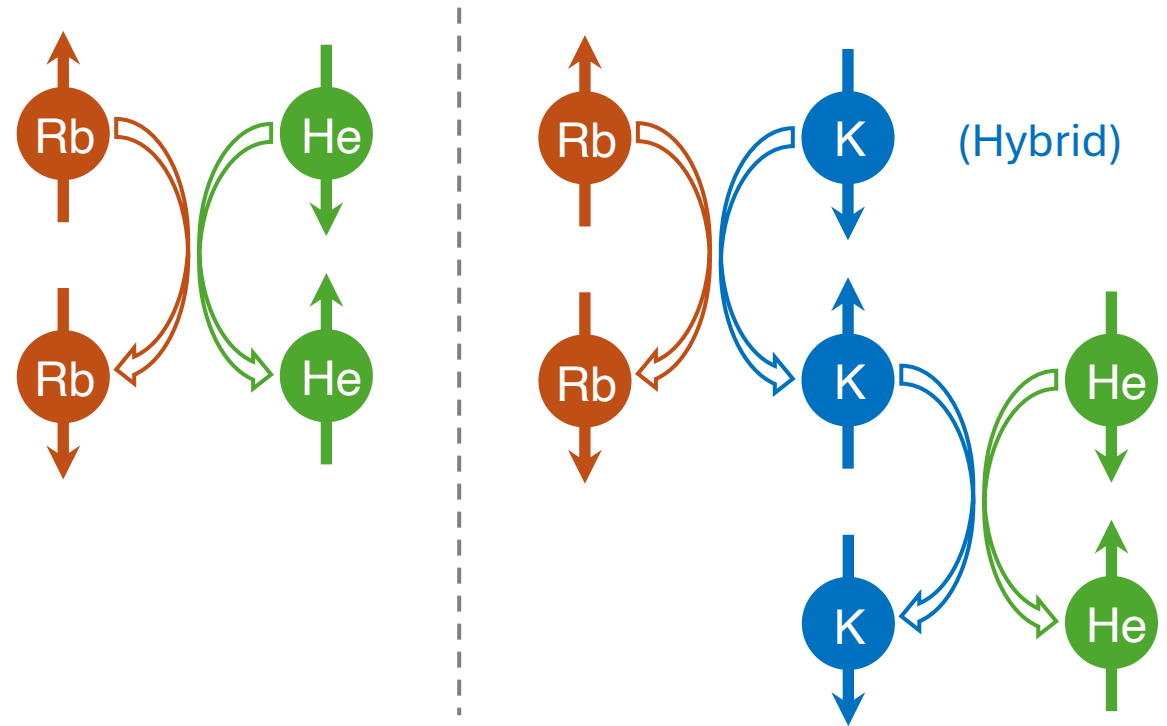
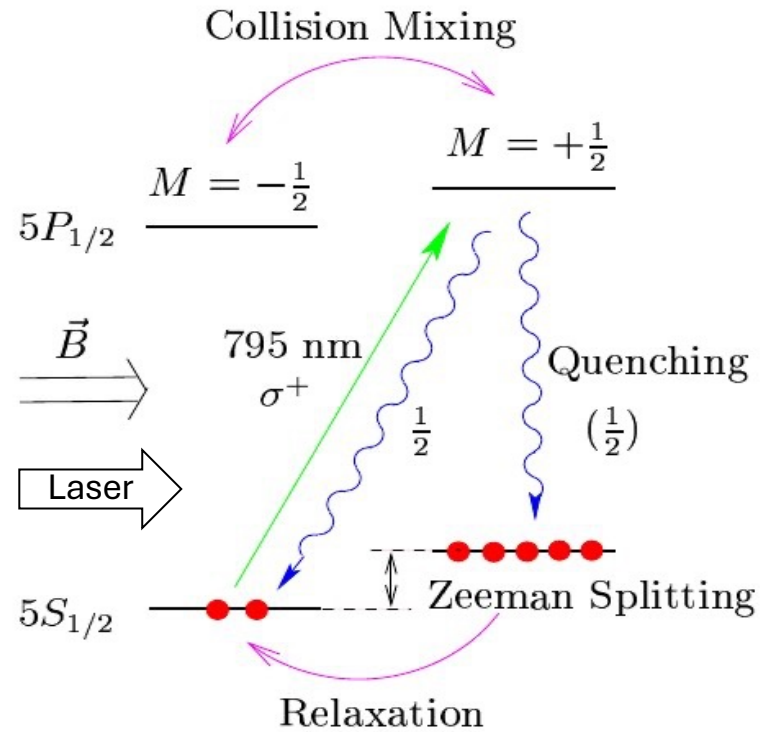


Source	Year	Polarizer	Polarization	Current
Rice (US)	1969	MEOP	< 10%	$\sim 4 \mu\text{A}$
Birmingham (UK)	1974	Lambshift	< 65%	$\sim 0.1 \text{ nA}$
Laval (CA)	1983	ABS	$\sim 90\%$	$\sim 300 \text{ nA}$
BNL (US)	Ongoing	MEOP	70-80% expected	$\sim 1 \text{ mA}$ (bunched)

Spin-Exchange Optical Pumping (SEOP)

- I. Optically pump alkali-metal atoms in ^3He gas mixture
- II. Spin exchange between alkali electrons and ^3He nuclei

Bouchiat, Carver, and Varnum, PRL 5, 373 (1960)

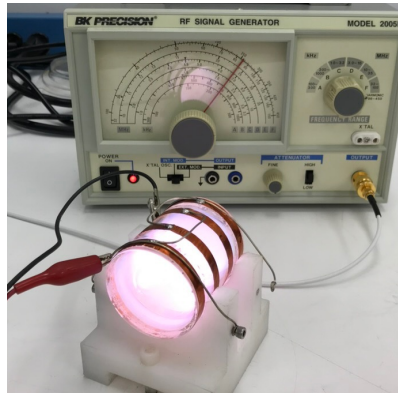


Spin-exchange collisions

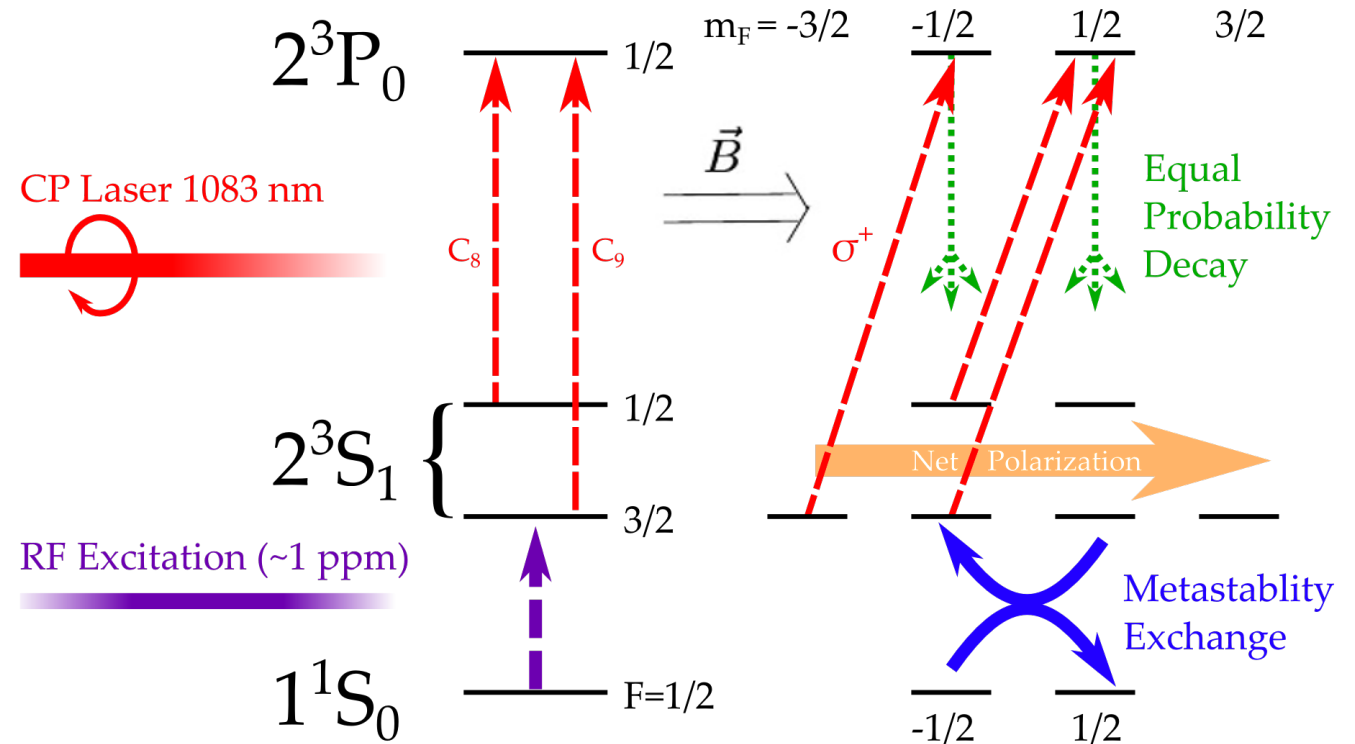
Metastability-Exchange Optical Pumping (MEOP)

- I. RF excitation: promote a small portion of ^3He atoms to 2^3S_1 metastable state

Colegrove, Schearer, Walters, PRL 132, 2561 (1963)



- II. Optical pumping: laser driven polarization of 2^3S_1 atoms
- III. Metastability exchange collisions between 2^3S_1 and ground state polarize ^3He nuclei

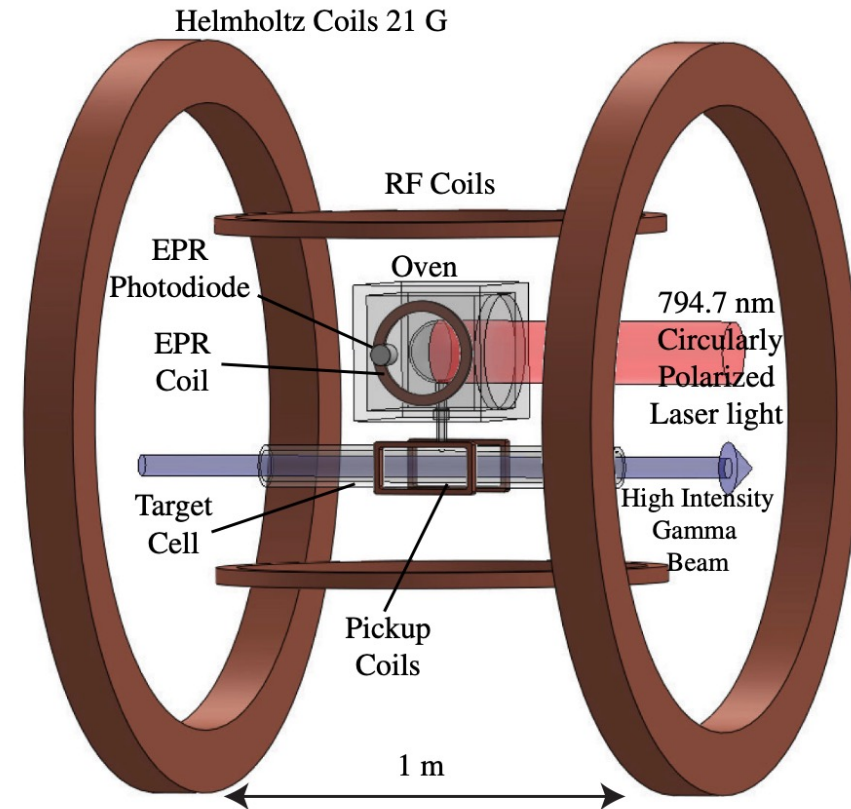


Polarimetry for SEOP

➤ Nuclear Magnetic Resonance (NMR)

- Adiabatic Fast Passage
 - transverse RF signal with swept frequency
 - ^3He spin flipped at Larmor frequency
 - pick up the spin precessing signal
- Free Induction Decay
 - transverse RF pulse at Larmor frequency
 - ^3He spin tilted by a small angle
 - measure the transverse relaxation time of FID

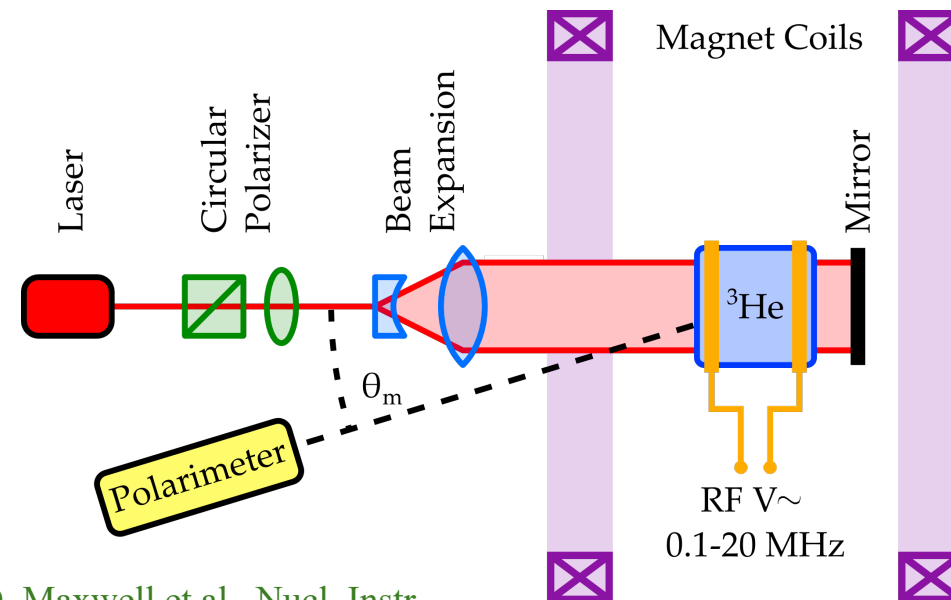
➤ Electron Paramagnetic Resonance (EPR)



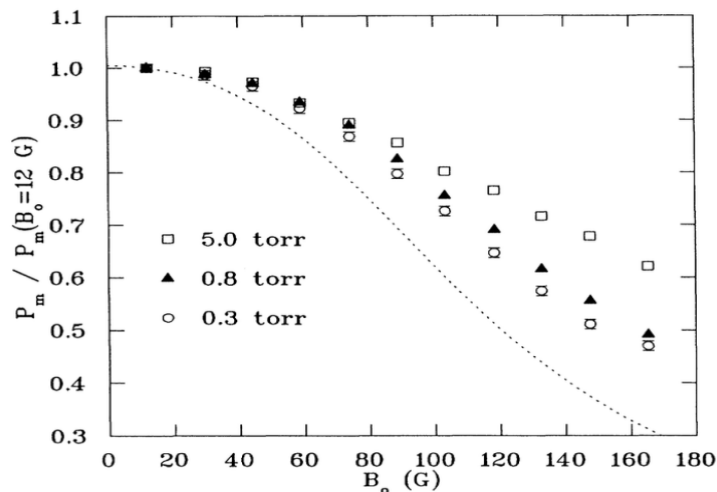
T.R. Gentile *et al.*, Rev. Modern Phys. 89, 045004 (2017)

Polarimetry for MEOP (Low Field)

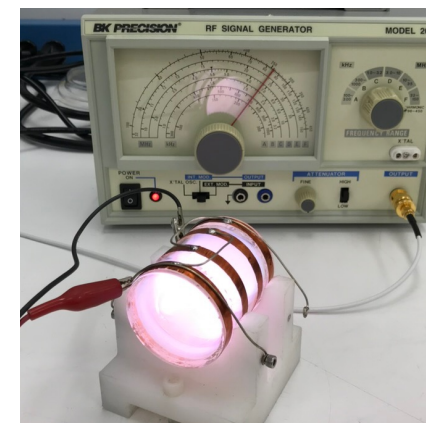
- Measure the degree of circular polarization of the 668 nm fluorescence light emitted by the metastable ^3He
- Directly obtain the electron polarization
- Infer nuclear polarization by NMR calibration
- Only work in low magnetic fields



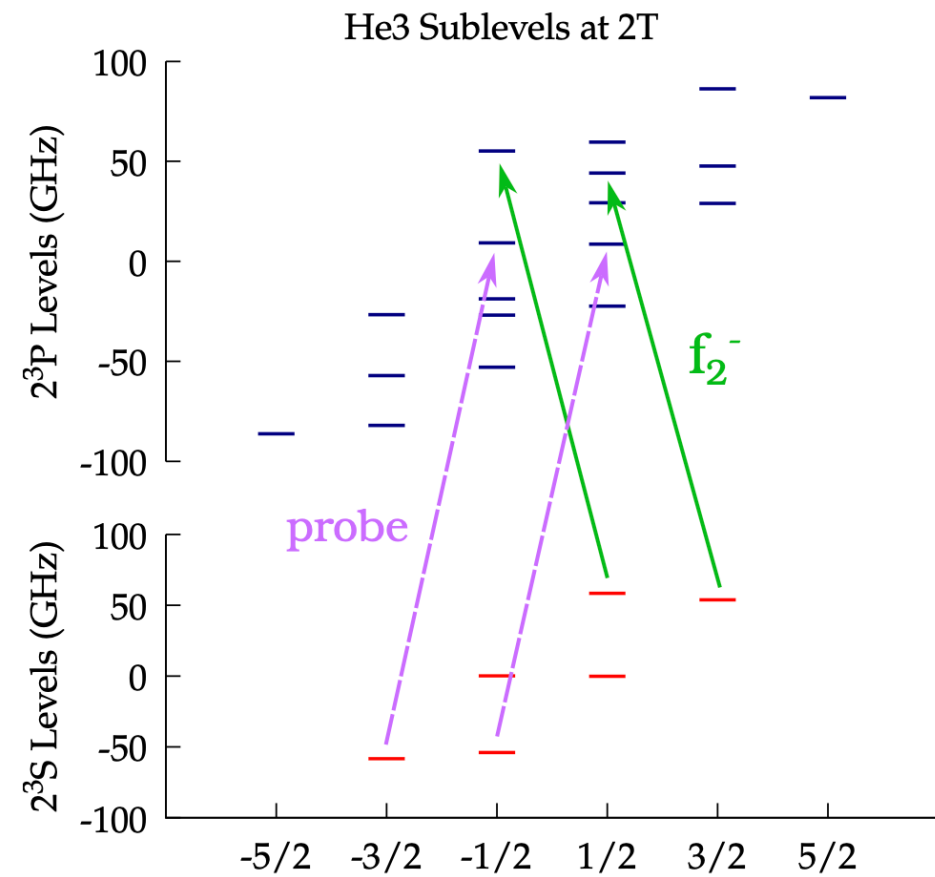
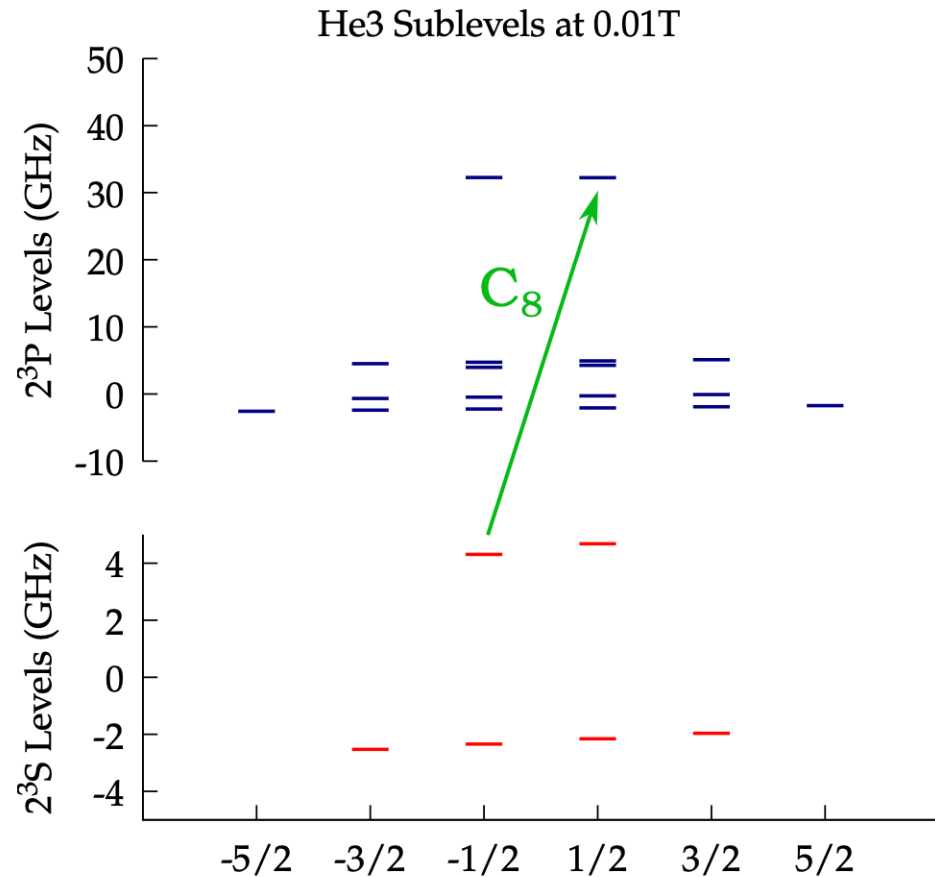
J.D. Maxwell et al., Nucl. Instr. and Meth. A 764, 215 (2014)



W. Lorenzon et al., Phys. Rev. A 47, 468 (1993)

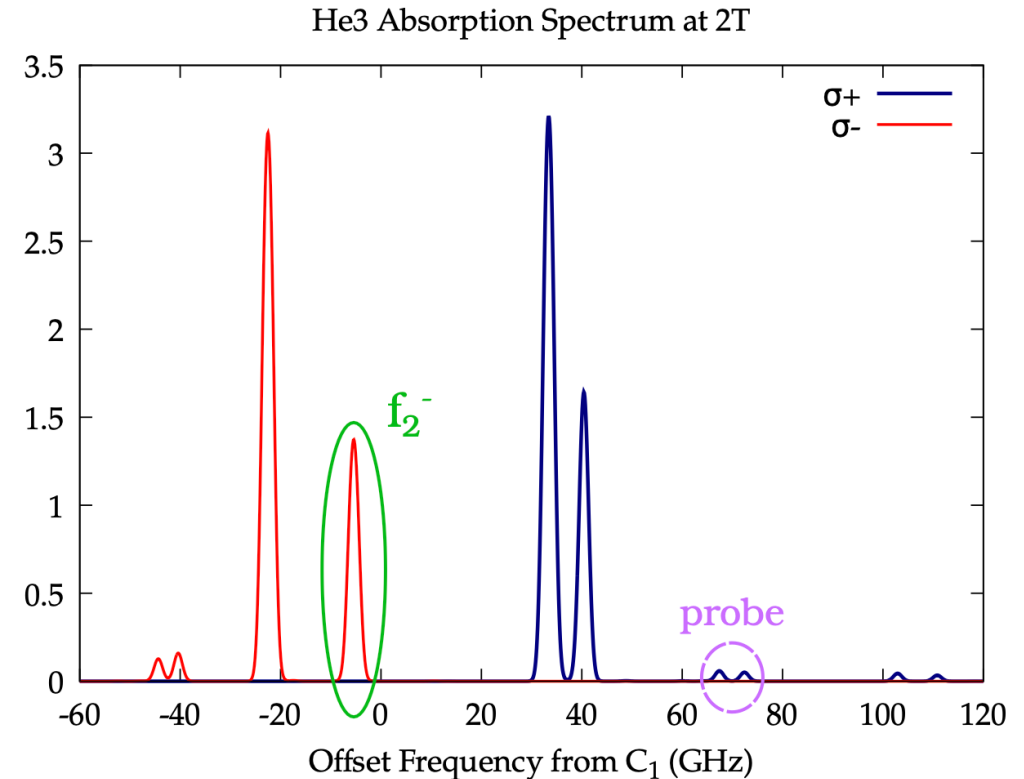
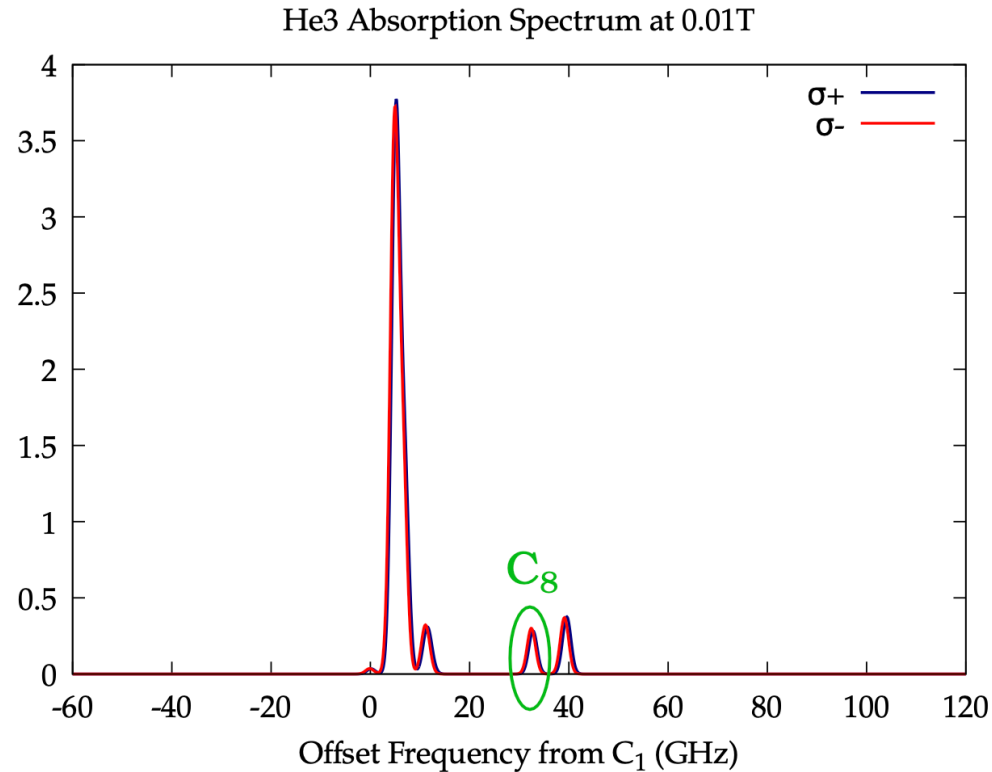


Zeeman Sublevels Significantly Modified in High Magnetic Fields



Figures based on Courtade (2002), Nikiel (2013), from calculation by Nacher.

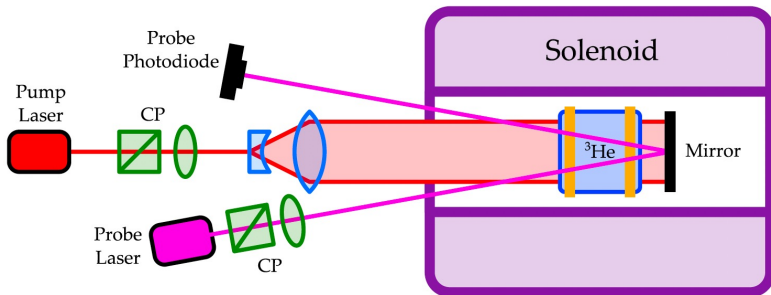
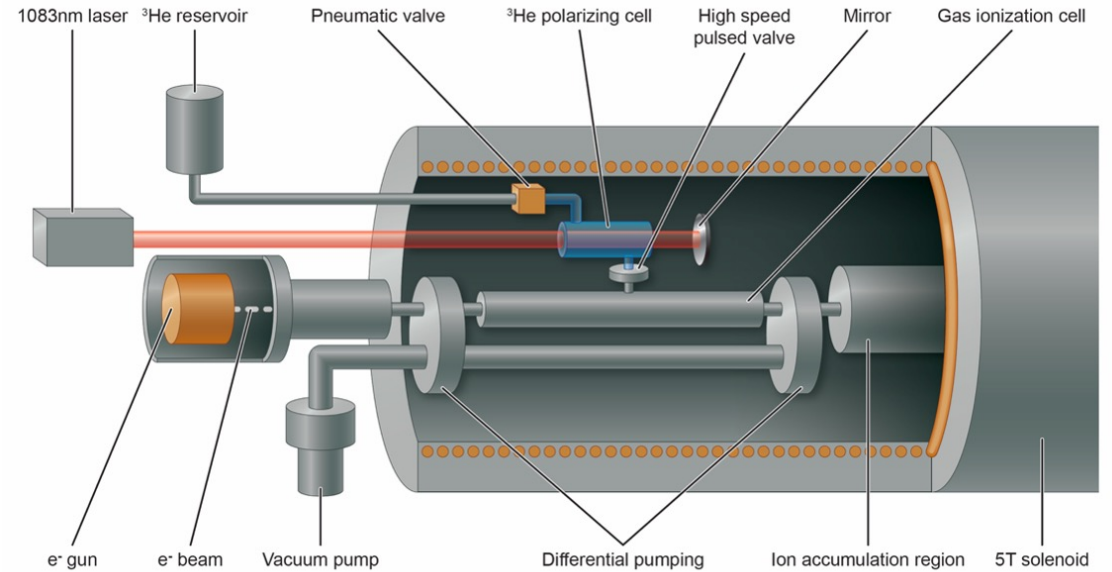
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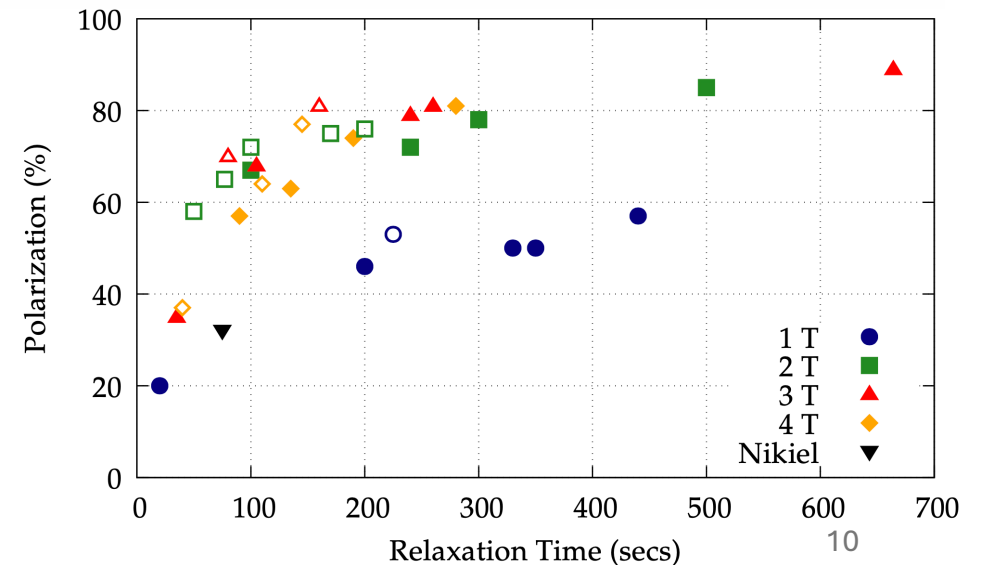
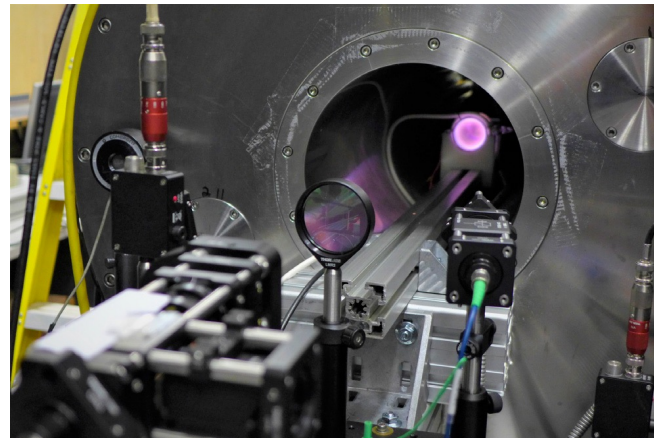
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BNL-MIT Development on Polarized $^3\text{He}^{++}$ Source for the Future EIC at BNL

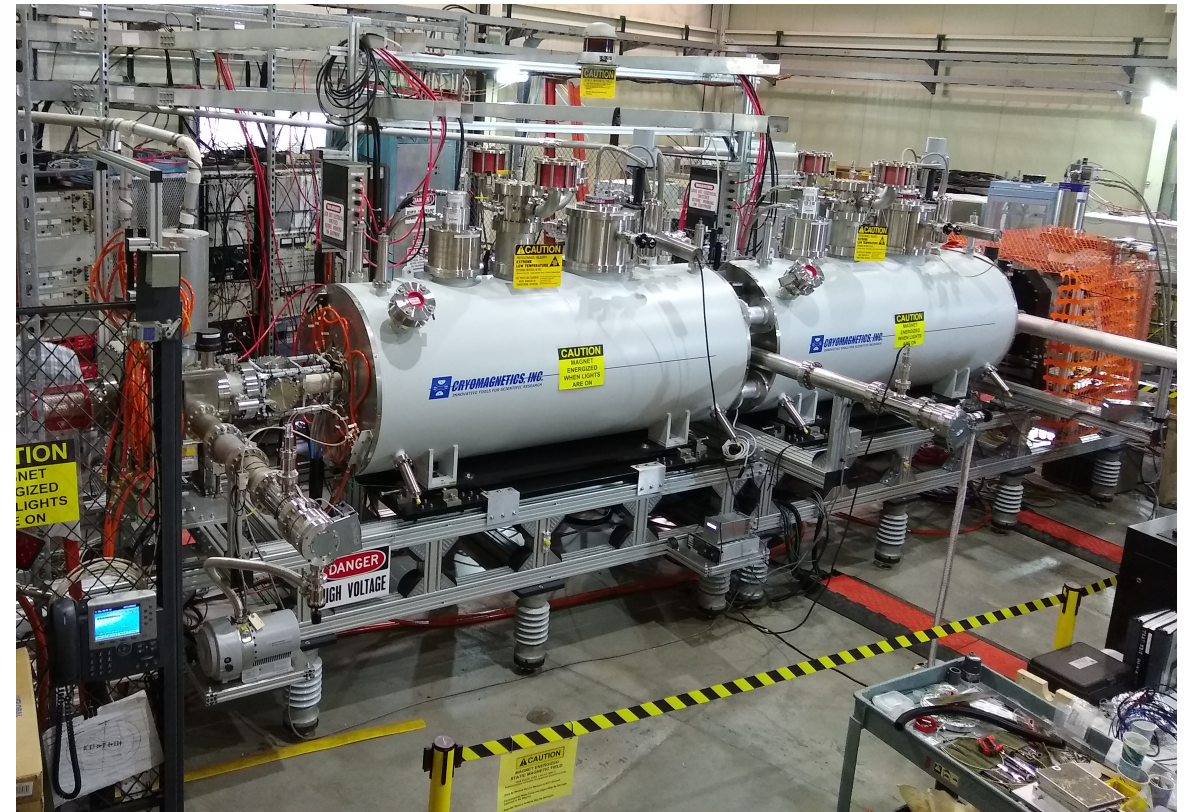
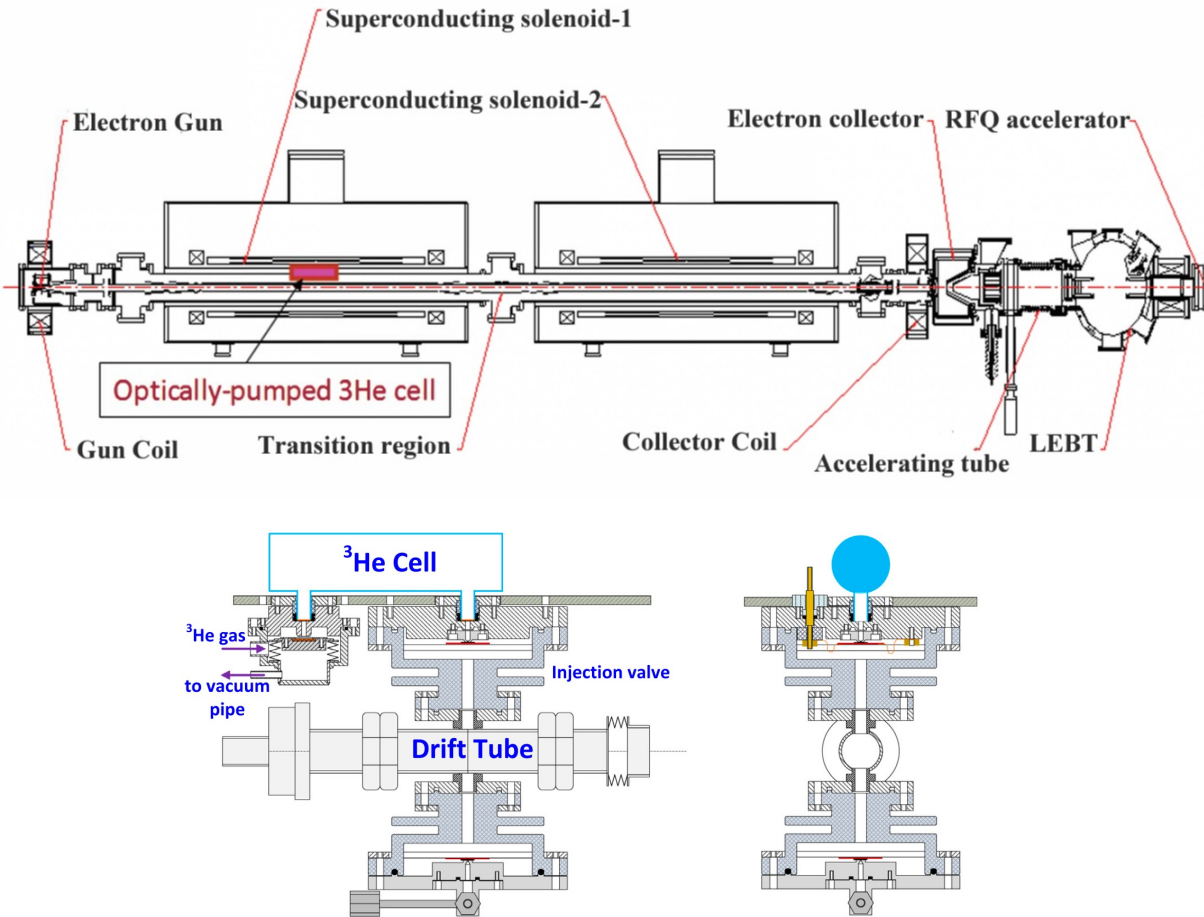
- RHIC produced polarized proton beams from an optical pumping polarized ion source (OPPIS)
- Electron Beam Ion Source (EBIS) operates at 5 T
- MEOP within 5 T field, transfer into EBIS for ionization and extraction



J.D. Maxwell et al., Nucl. Instr. and Meth. A 959, 161892 (2020)

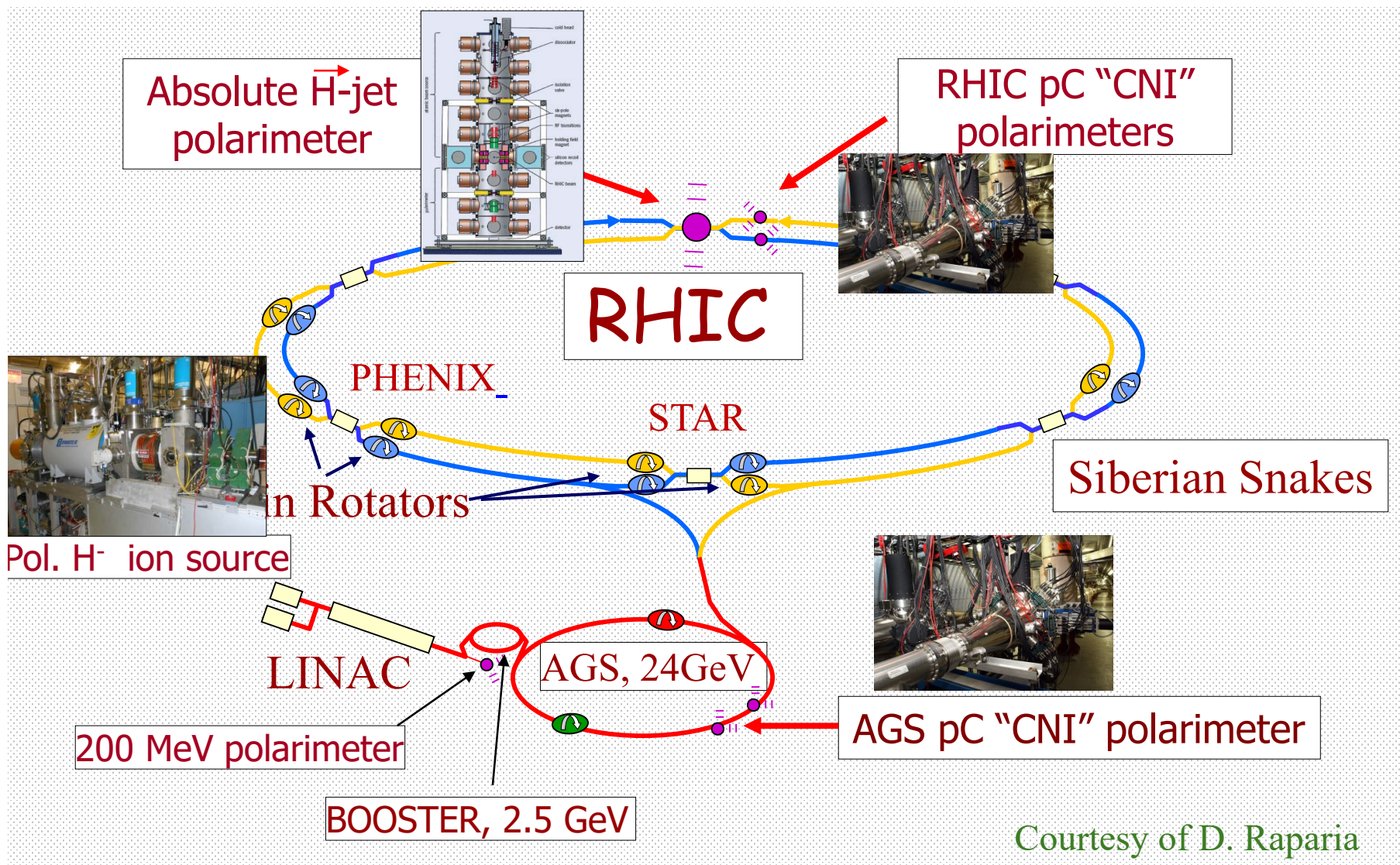


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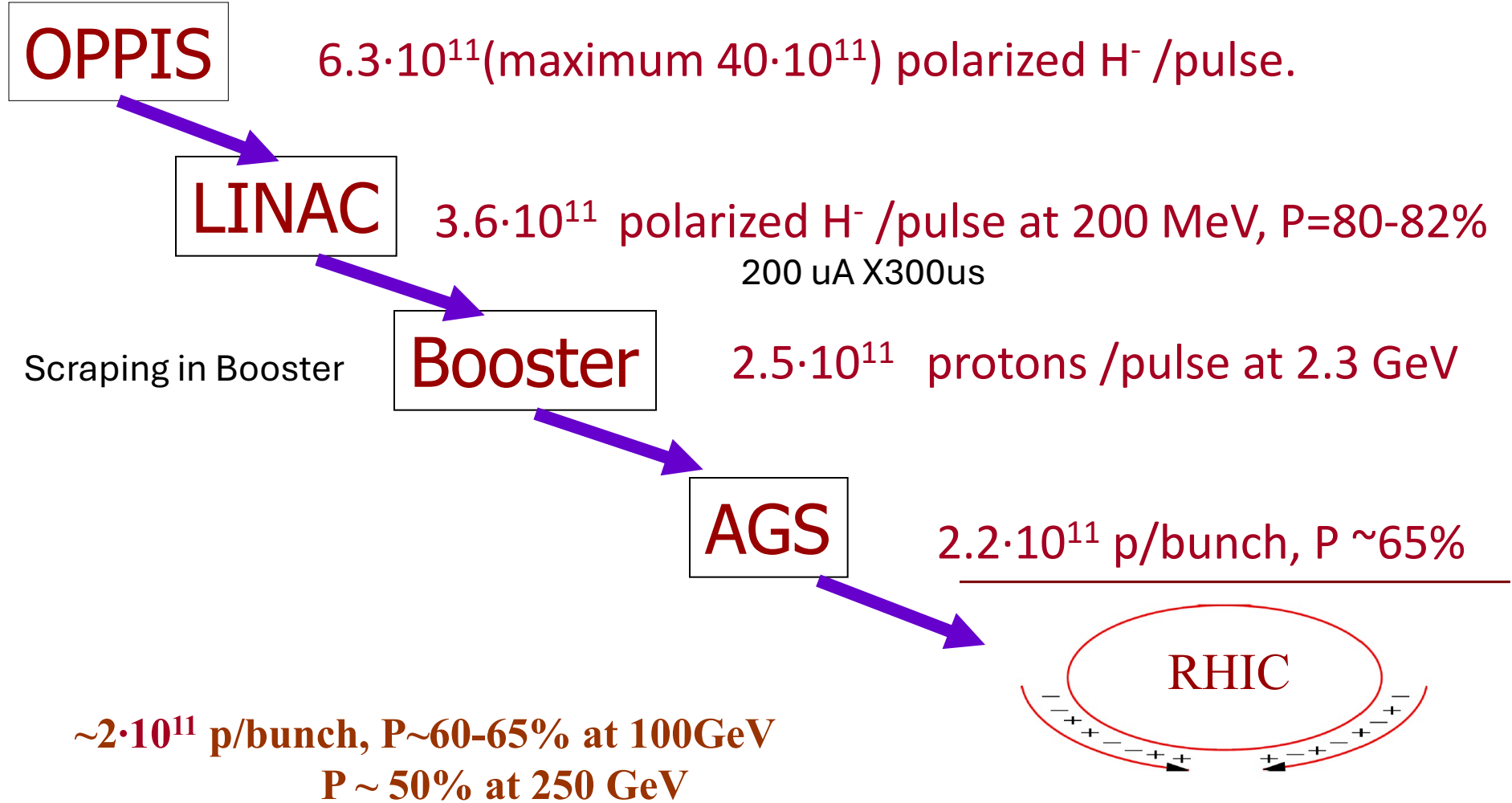


A. Zelenski *et al.*, Nucl. Instr. and Meth. A 1055, 168494 (2023)

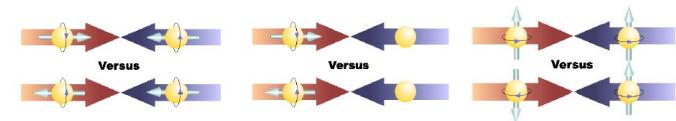
Polarized Proton Beams at RHIC



Polarized Proton Beams at RHIC



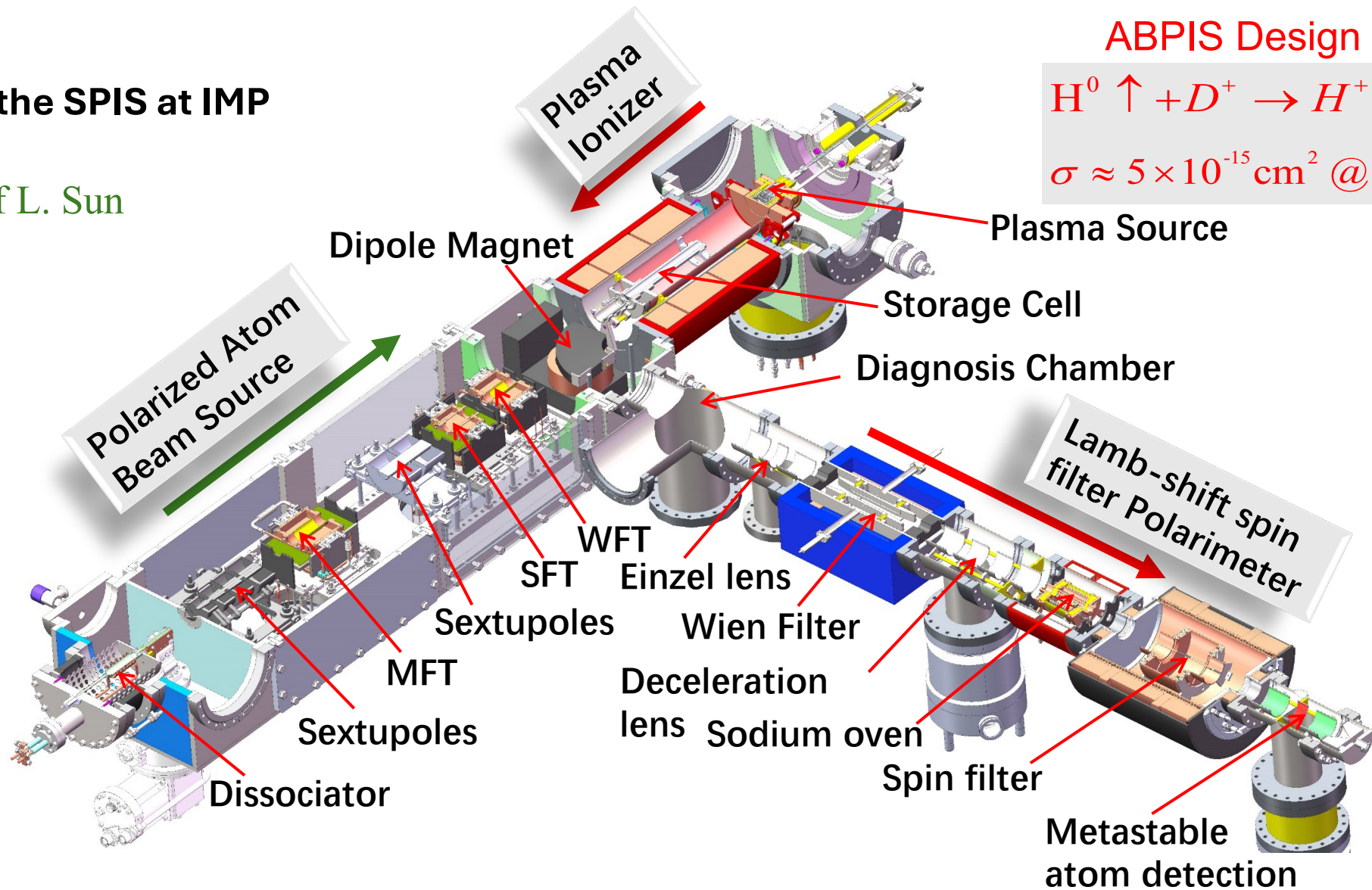
Courtesy of D. Raparia



Polarized Proton/Deuteron Sources at IMP

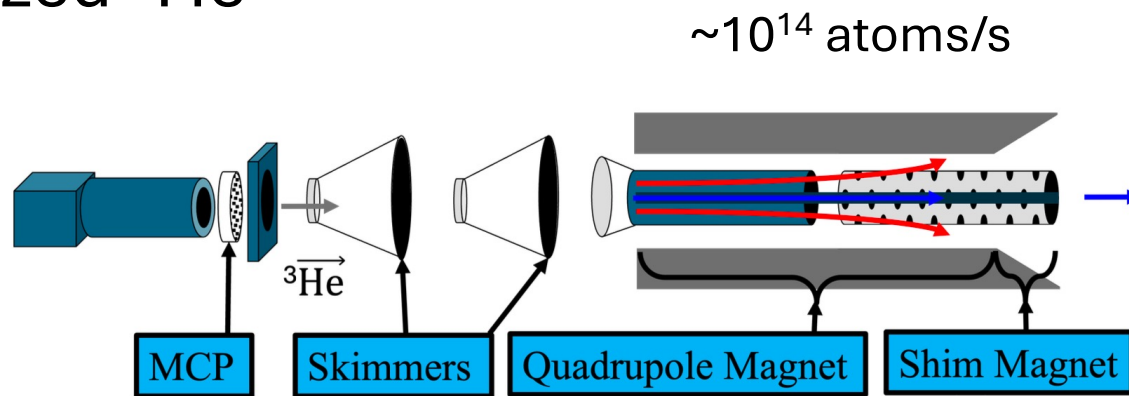
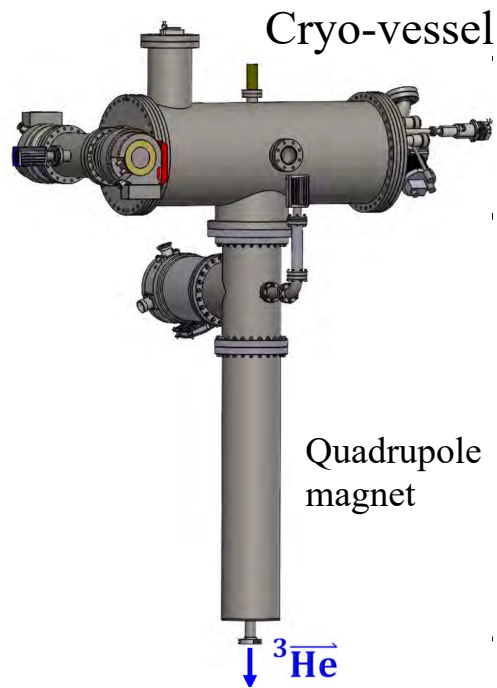
Layout of the SPIS at IMP

Courtesy of L. Sun



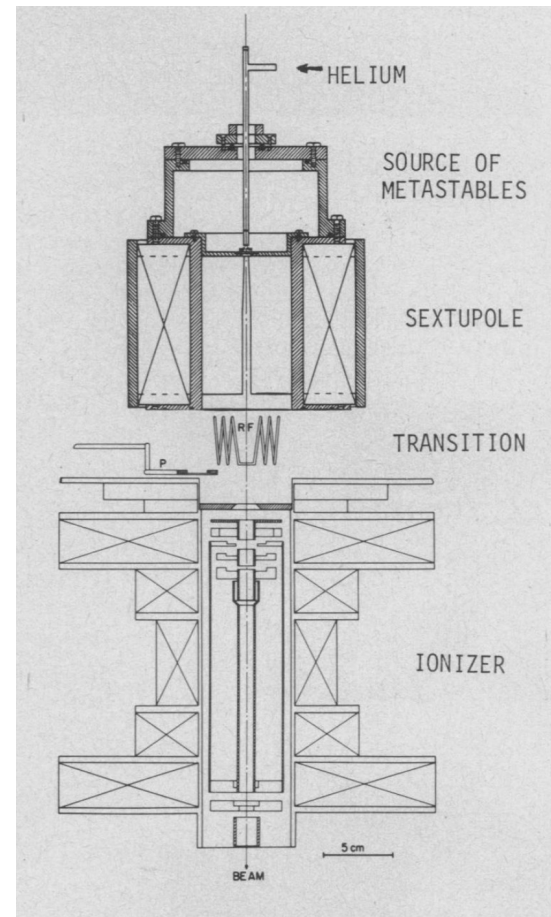
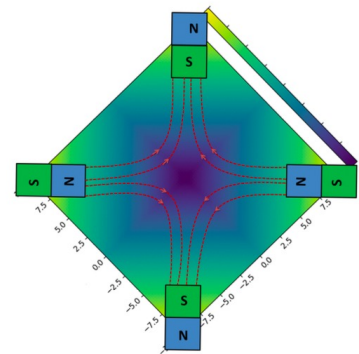
Path towards Polarized $^3\text{He}^{++}$ Source in China

- ABS polarized ^3He



^3He : quadrupole magnet selects spins

- **1.3 K \approx 86 μeV**
- $\Delta E = \mu_m \approx 67 \text{ neV/T}$
- initial angle very important



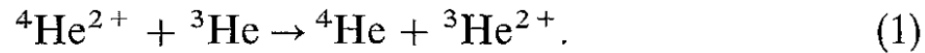
P. Murthy, PSTP2024

F. Rathmann, PSTP2024

IEEE Transactions on Nuclear Science 32 (5), 1835-1837 (1985)

Path towards Polarized ${}^3\text{He}^{2+}$ Source in China

Unpolarized ${}^4\text{He}^{2+}$ ions are formed in a separate ion source. An ECR ion source could be used for efficient dc ${}^4\text{He}^{2+}$ ions production.



A cross-section of this reaction at relative energy of 50 eV is $\sigma_1 = 4 \times 10^{-16} \text{ cm}^2$ [9]. In Ref. [9] a total cross-section for the reaction ${}^4\text{He}^{2+} + {}^4\text{He}$ has been measured. A conclusion has been made

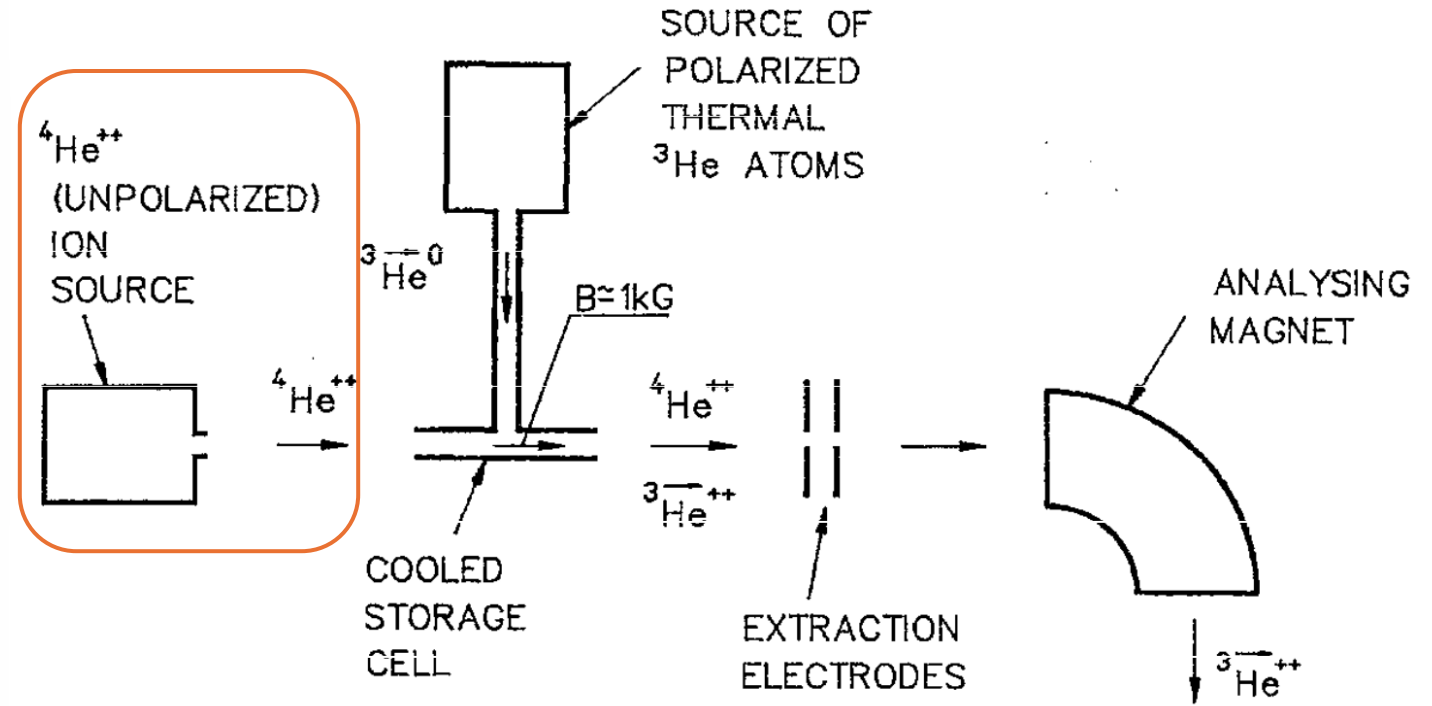
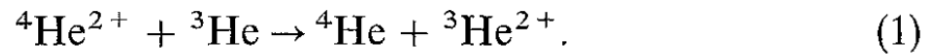


Fig. 1. A schematic diagram of the polarized ${}^3\text{He}^{2+}$ ion source.

A.S. Belov, NIMA 402, 205 (1998)

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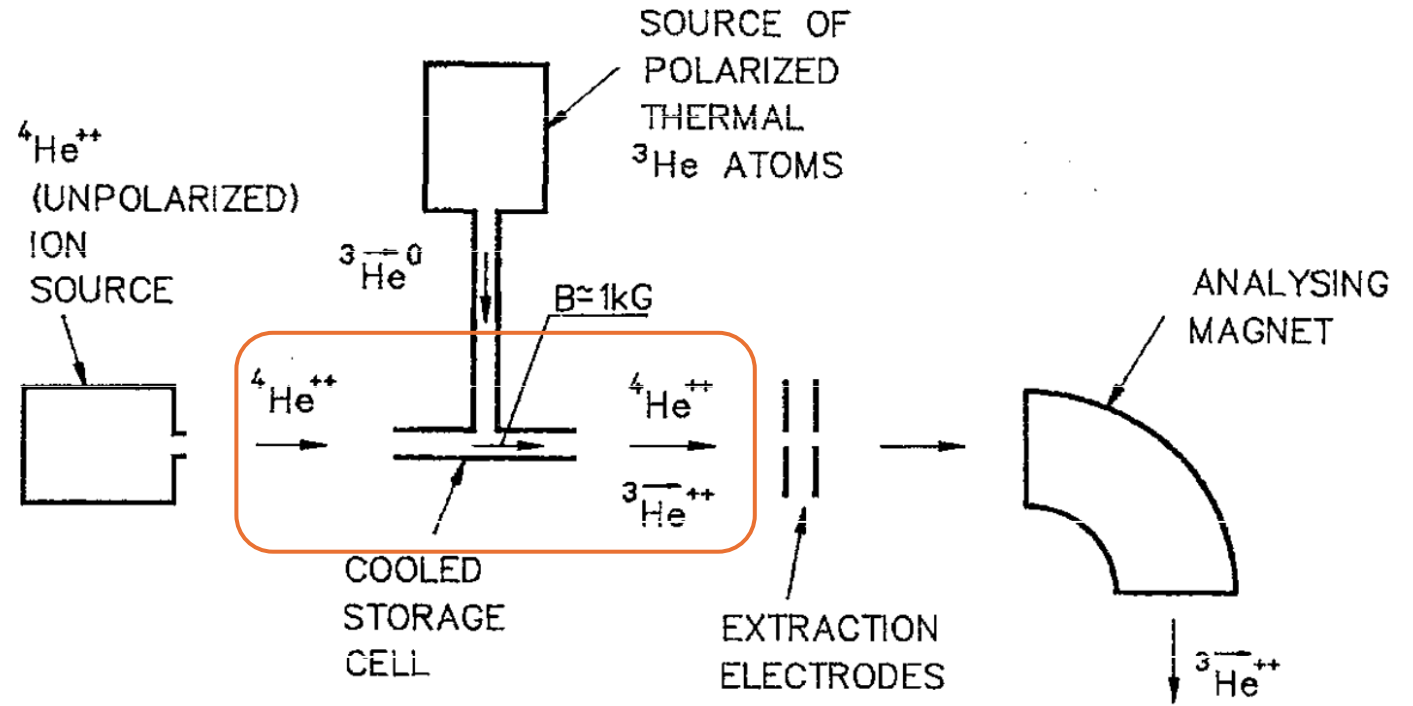
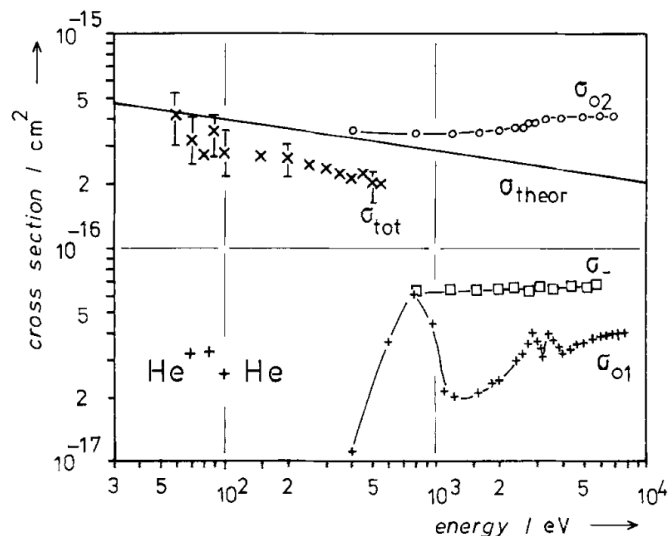


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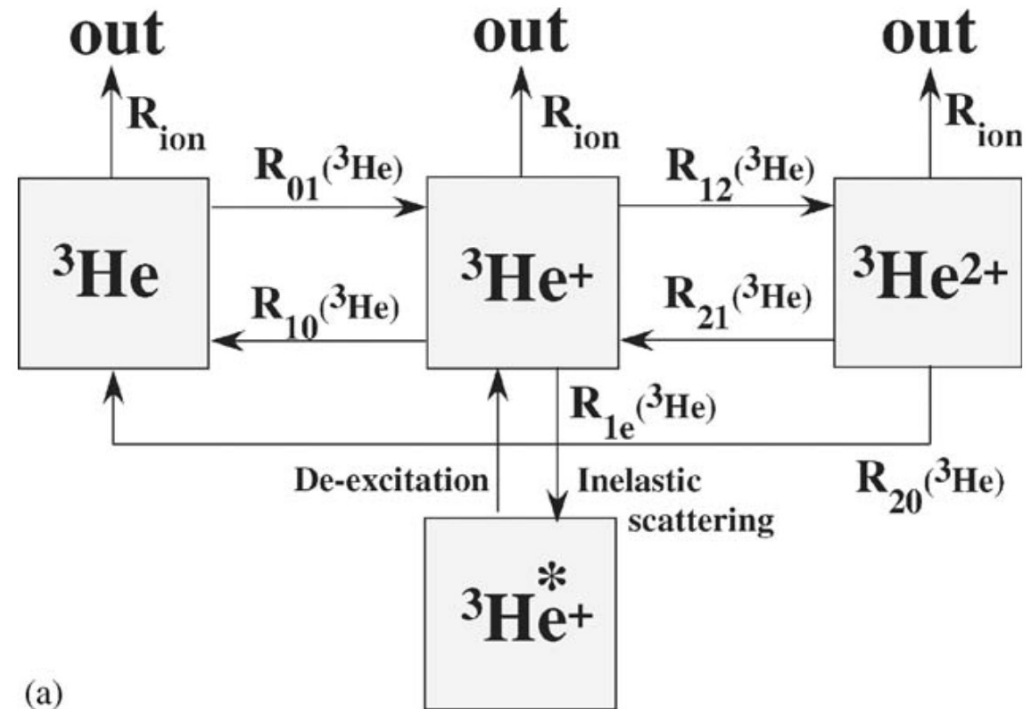
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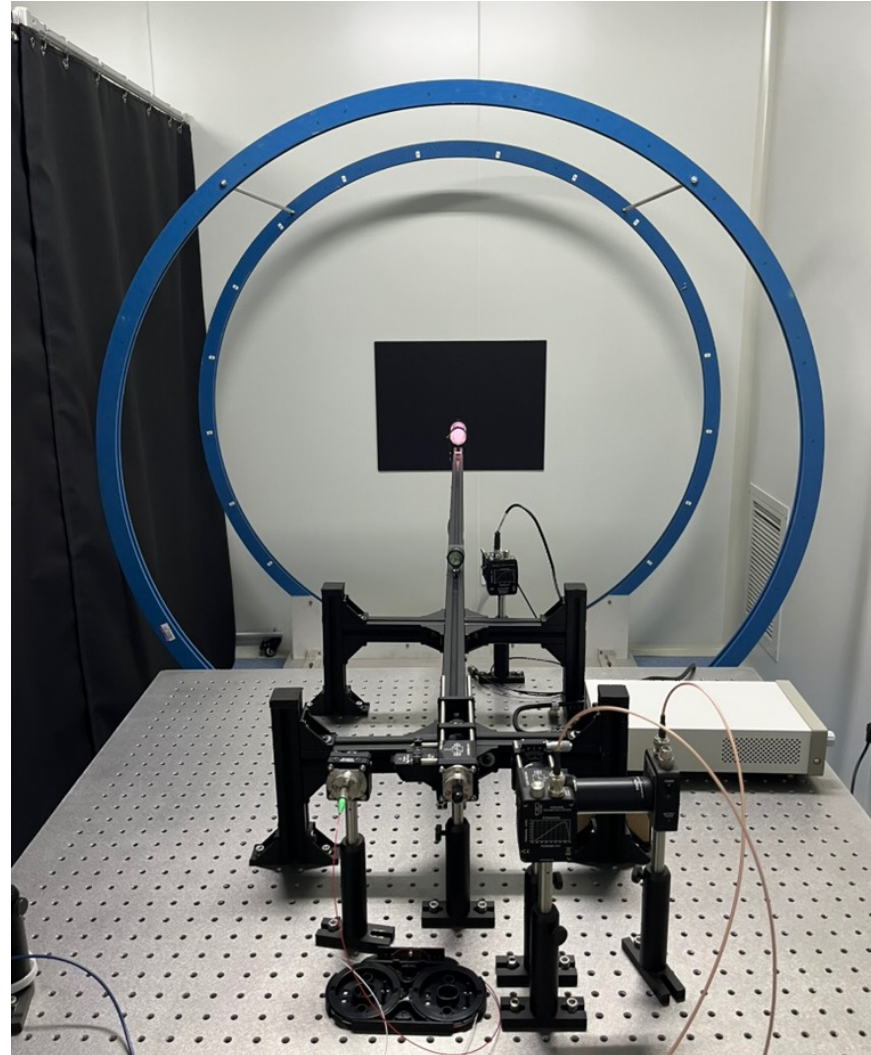
ECR ionizer

- Monte Carlo simulation for multiple ionization, inelastic scattering and de-ionization processes for ${}^3\text{He}$, ${}^3\text{He}^+$ and ${}^3\text{He}^{++}$ in ECR plasma
- Polarization 10-20% expected in the 2004 work
- New simulation to be performed for the latest 4th generation ECR

M. Tanaka et al. / Nuclear Instruments and Methods in Physics Research A 524 (2004) 46–59



New Polarized ^3He Lab at Shandong U. (Qingdao)



^3He gas cell (1 Torr)

- Low field system established
- To be upgraded to high field tests

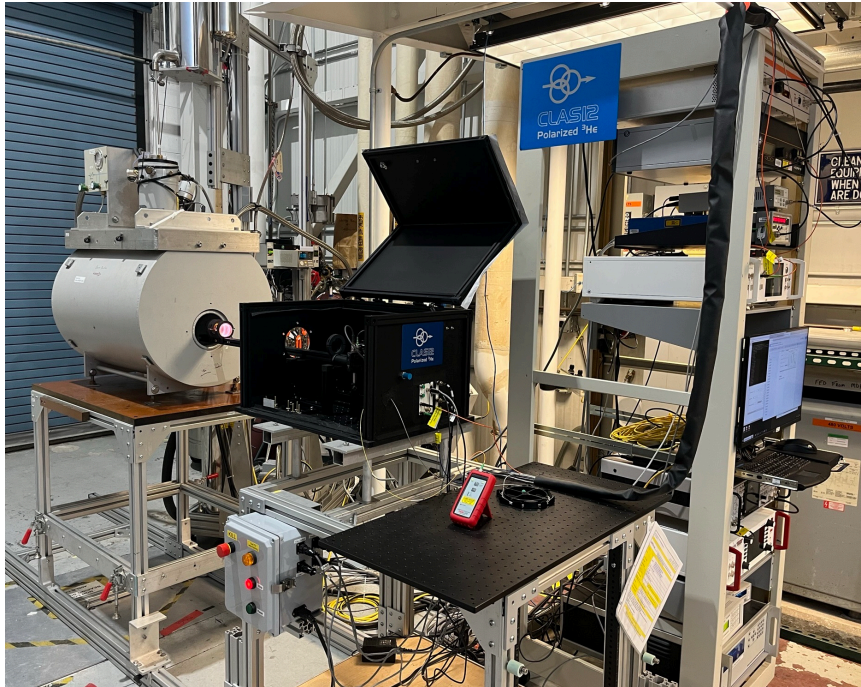
Summary

- Spin polarized ^3He is a powerful effective polarized neutron
- New techniques for polarized ^3He in high magnetic fields will provide new opportunities for spin studies at the state-of-the-art nuclear and particle experimental facilities
- Development on novel polarized ^3He target and ion source is underway and expected to provide unprecedented improvement in understanding nucleon spin structures

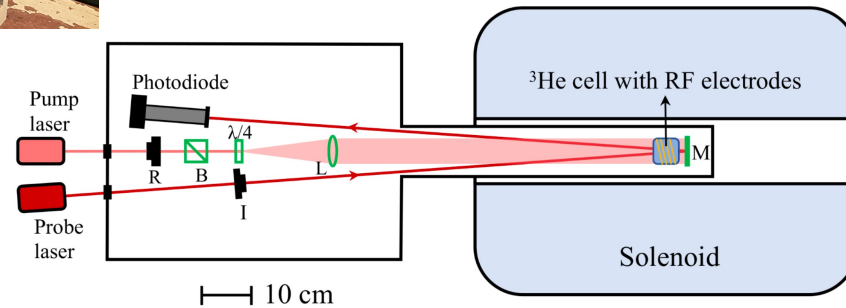
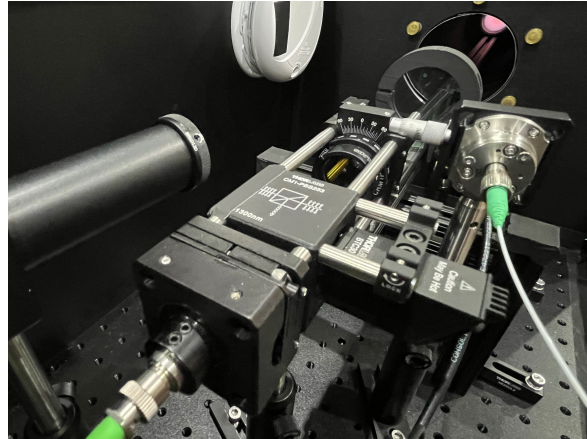
Thanks for your attention!

Backup

JLab-MIT Development on Polarized ^3He Target in High Fields



X. Li et al., NIMA 168, 792 (2023)



Systematic studies of high-field MEOP on pumping rate and max polarization

