Polarized Targets for Spin Filtering Experiments

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Requirements

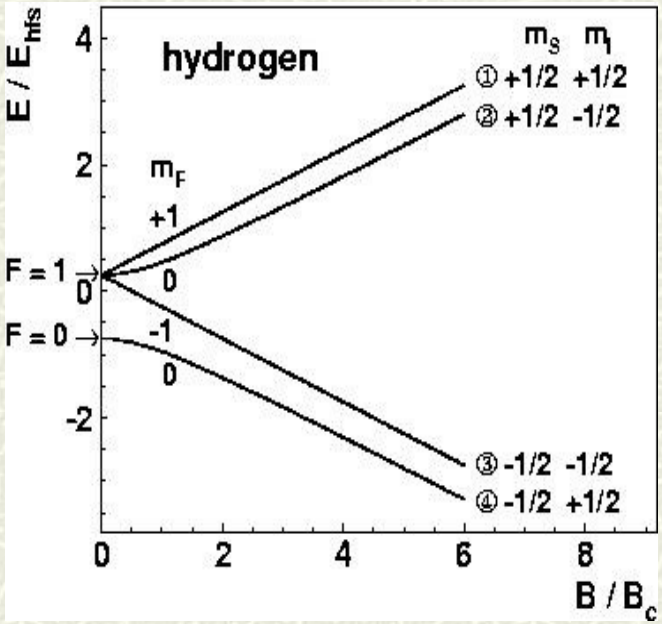
- High polarization of the target
- Density up to 10^{15} atoms/cm^2
- Variability of the direction of the spin axis
- Implementation into storage rings
- Ability to produce electron and nuclear polarization separately
- Ability to measure the polarization independently

Polarization of the Target Gas

- Hydrogen states are defined as ($|a\rangle = |m_S, m_I\rangle$:

$|1\rangle = |\,½, ½\rangle$
$|2\rangle = \cos\boldsymbol{\theta}\,|\,½, -½\rangle + \sin\boldsymbol{\theta}\,|\,-½, ½\rangle$
$|3\rangle = |\,-½, -½\rangle$
$|4\rangle = -\sin\boldsymbol{\theta}\,|\,½, -½\rangle + \cos\boldsymbol{\theta}\,|\,-½, ½\rangle$

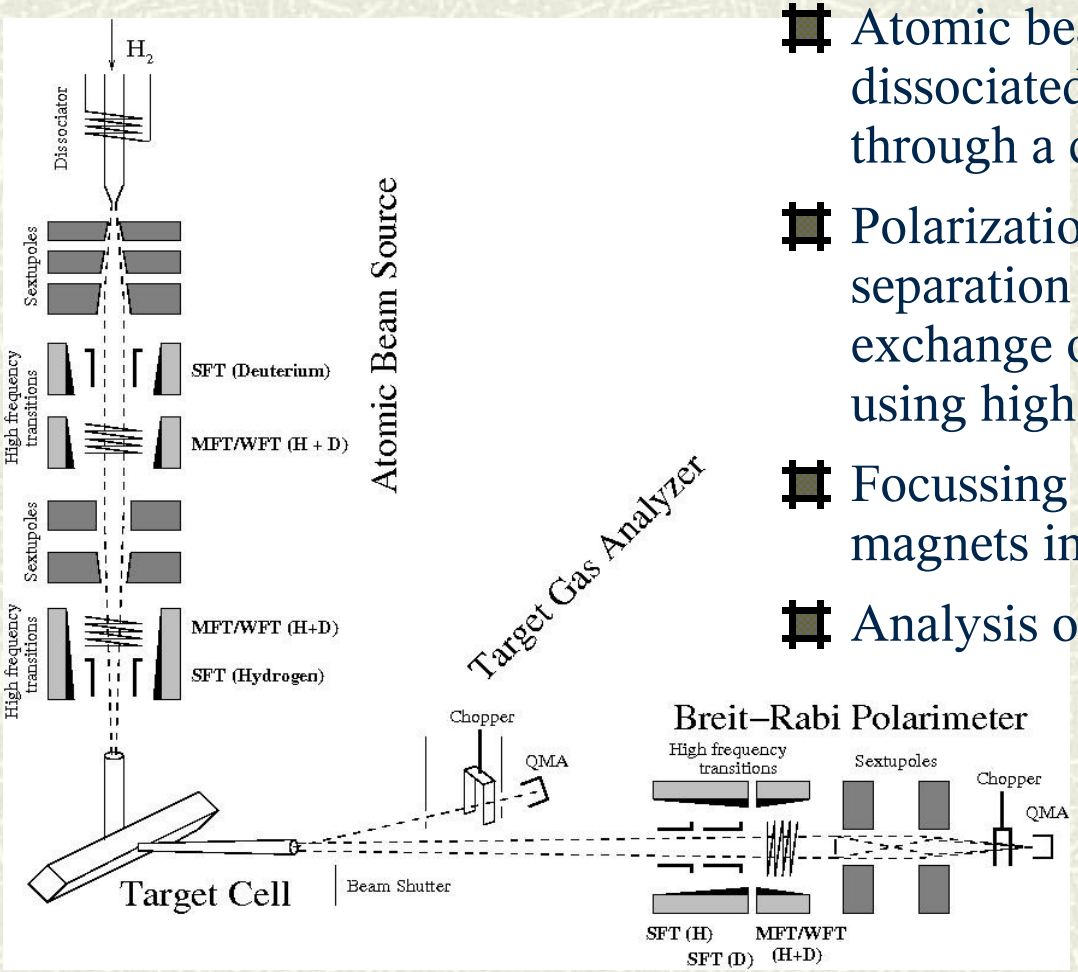
with $\boldsymbol{\theta} = ½ \arctan(B_C/B)$



- Polarization:

$P_e = n_1 - n_3 + (n_2 - n_4)\cos 2\boldsymbol{\theta}$
$P_z = n_1 - n_3 - (n_2 - n_4)\cos 2\boldsymbol{\theta}$

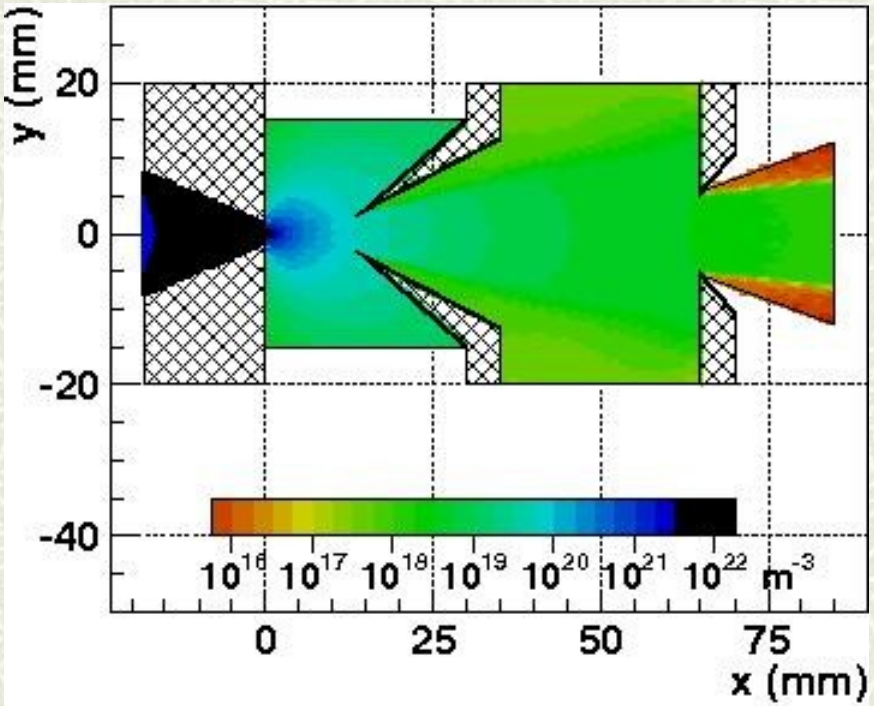
Setup of a Polarized Target



- Atomic beam produced by expansion of dissociated hydrogen gas into vacuum through a cooled nozzle
- Polarization achieved by Stern-Gerlach separation in sextupole magnets and exchange of populations of hyperfine states using high frequency transitions
- Focussing of the beam by sextupole magnets into storage cell
- Analysis of target polarization by BRP and TGA

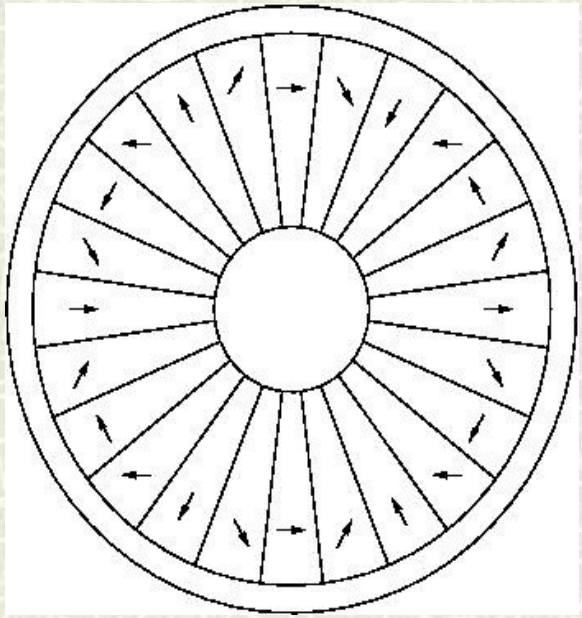
Producing an Atomic Beam

- H dissociated via electron impact in a cold plasma provided by a RF (MW) dissociator
- Expansion of the gas through a cooled nozzle (~ 100K) into the vacuum
- Beam formation using skimmer and collimator in front of the entrance of the first sextupole magnet

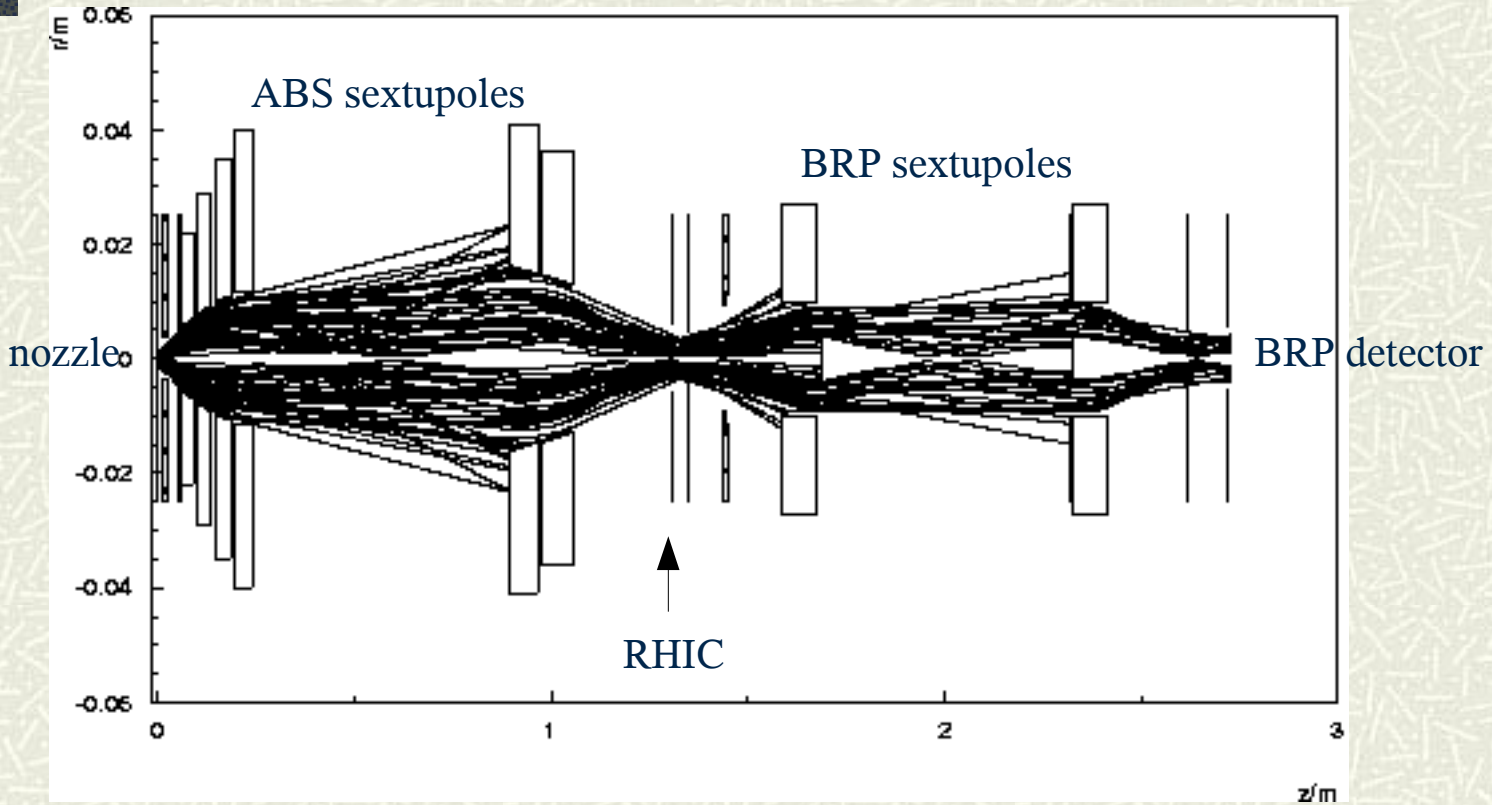


The Sextupole System

- Permanent magnet with high gradient field consisting of 24 segments with a pole tip field of ~1.5 T
- Magnets focus states with $m_e = ½$
- Defocussing of states with $m_e = - ½$
- Atomic beam electron polarized after sextupole magnets
- Magnets also used to focus the beam into the entrance tube of the storage cell (ABS) and into QMA-analyzer (BRP)



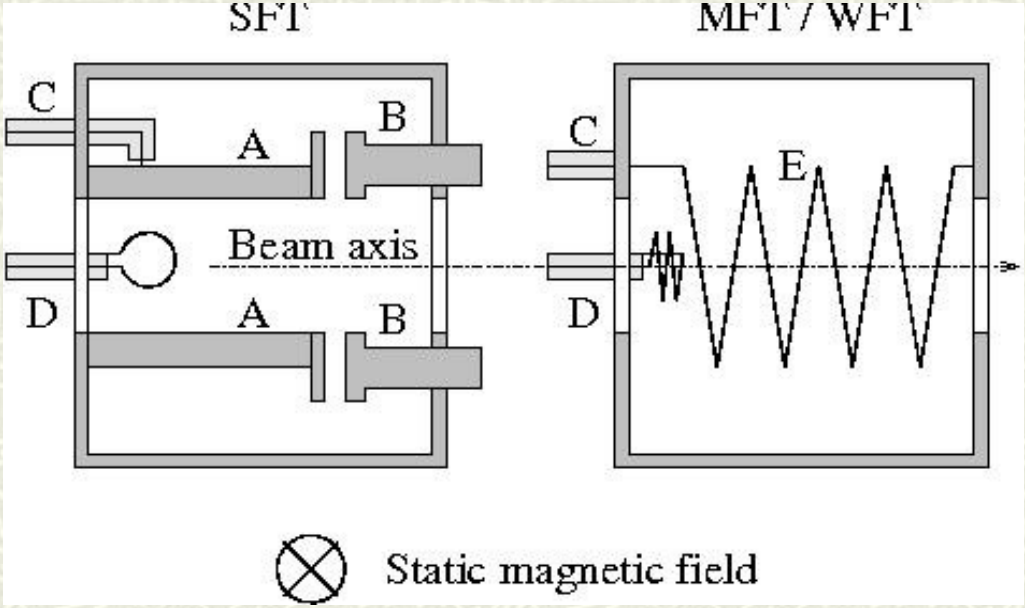
The Sextupole system



Tracking calculations for the H-Jet polarimeter at BNL (thanks to T.Wise, University of Wisconsin)

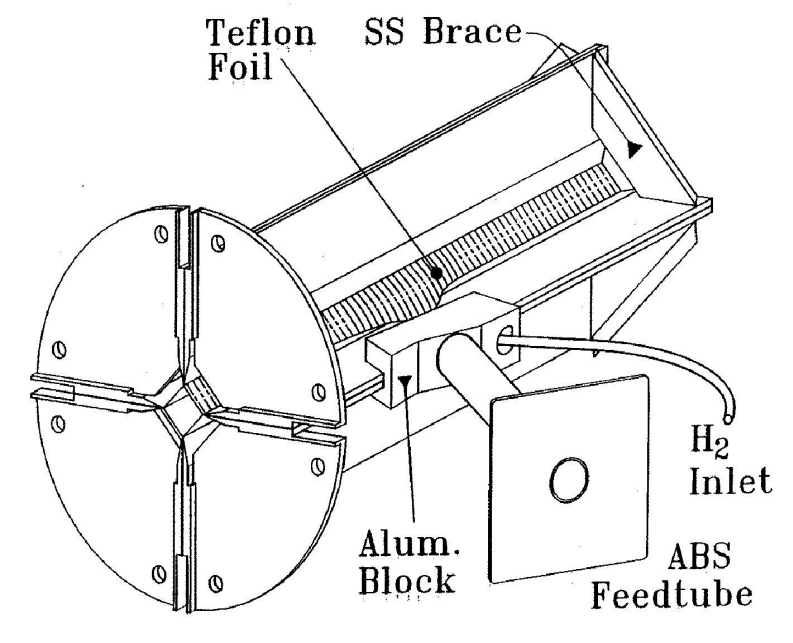
The High Frequency Transitions

- HFT's exchange populations of hyperfine states and are therefore used to create the nuclear polarization of the atomic beam (ABS) and to analyze the polarization (BRP)
- The efficiencies ~ 100%
- 3 types:
  Strong **F**ield **T**rans. (**Δ**F=1)
  Medium **F**ield **T**rans. (single photon and **Δ**F=0)
  Weak **F**ield **T**rans. (multi photon and **Δ**F=0)



Storage Cell and Holding field

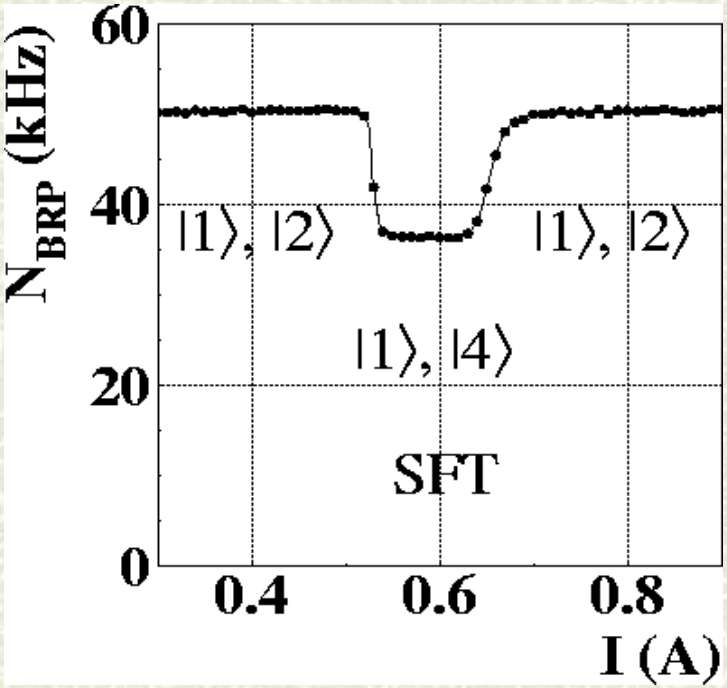
- Pure Jet Target has a density of about 10^{12} cm^{-2} (H-Jet BNL)
- Filtering requires 10^{15} $atoms/cm^{-2}$ therefore use of storage cell (first proposed by W.Haeberli)
- To suppress wall depolarization coating with teflon/drifilm or use of teflon foil as cell
- Holding field defines polarization of mixed states (|2> and |4>) and spin axis



PINTEX storage cell

Polarization analysis

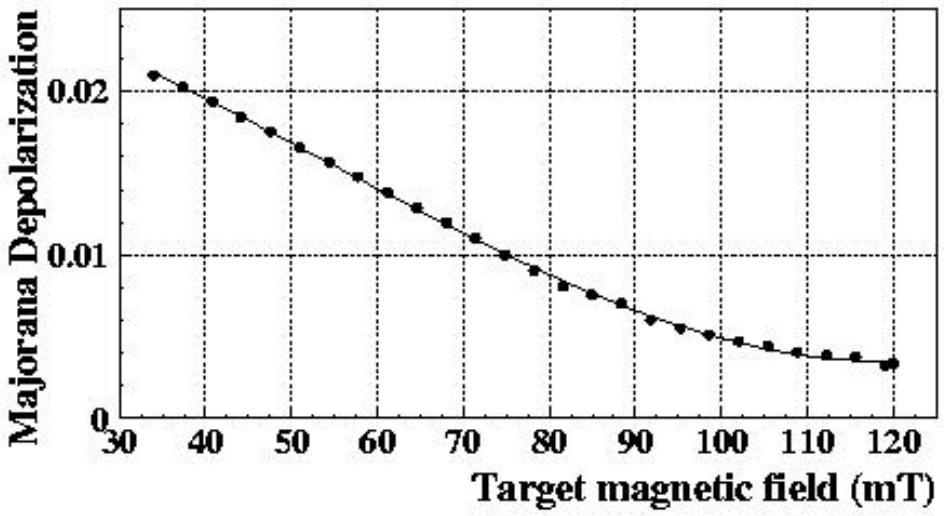
- TGA is used to determine atomic fraction of the target gas
- BRP measures the polarization of the target gas using combinations of high frequency transitions in ABS and BRP
- Determination of the polarization using these measurements and the strenght of the holding field



Measurement at HERMES

Depolarizing effects

- Majorana depolarization if change of direction of magnetic fields in rest frame of the atoms along atomic beam path is too rapid
- No depolarization if field changes are adiabatic, i.e. slow compared to Larmor time $t_L \sim 1/B$

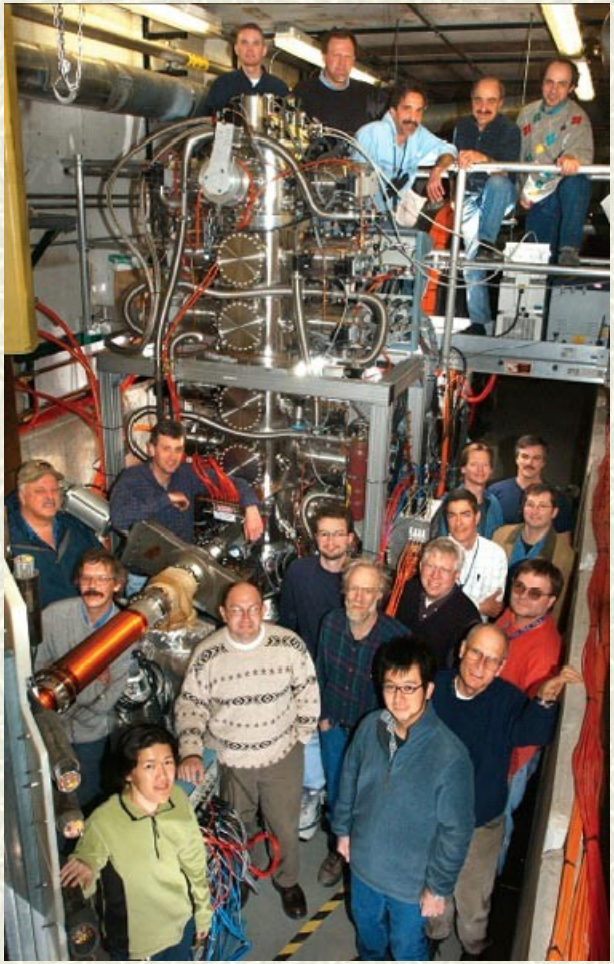


Measurement at the H-Jet at BNL

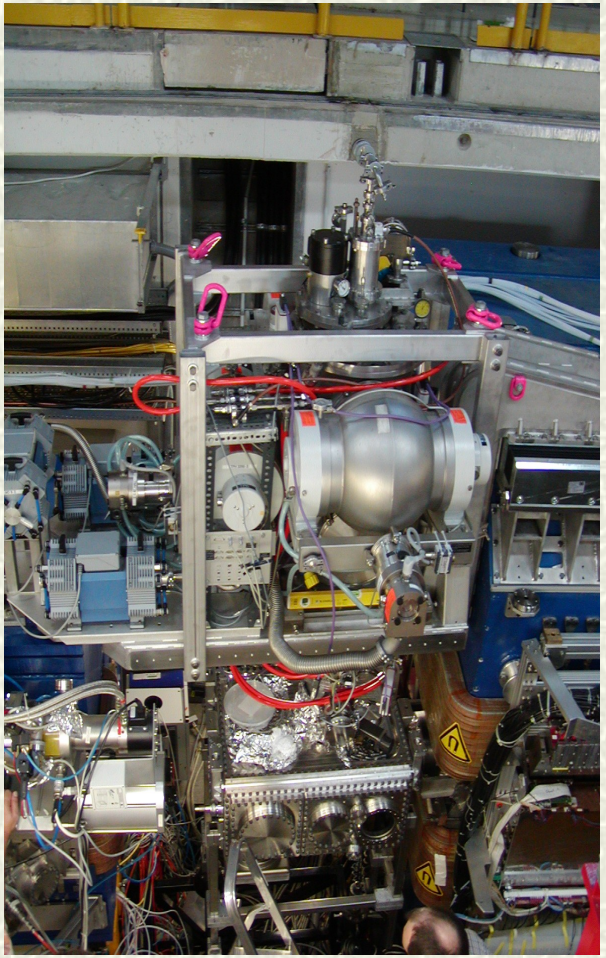
Summary

- Polarized gas target meets the requirements for the filtering tests
- Ability to provide highly polarized H and D
- Storage cell will increase density to the values needed but thin wall will allow to detect recoils
- Change of spin direction can be achieved by switching the target holding field from vertical to longitudinal
- BRP will be able to measure the target polarization with the accuracy needed (calibration using pp scattering)

Some Polarized Targets used so far



H-Jet at BNL



ANKE at COSY

Some Polarized Targets used so far

HERMES at HERA