

# Transverse Polarized Target Options for CLAS12

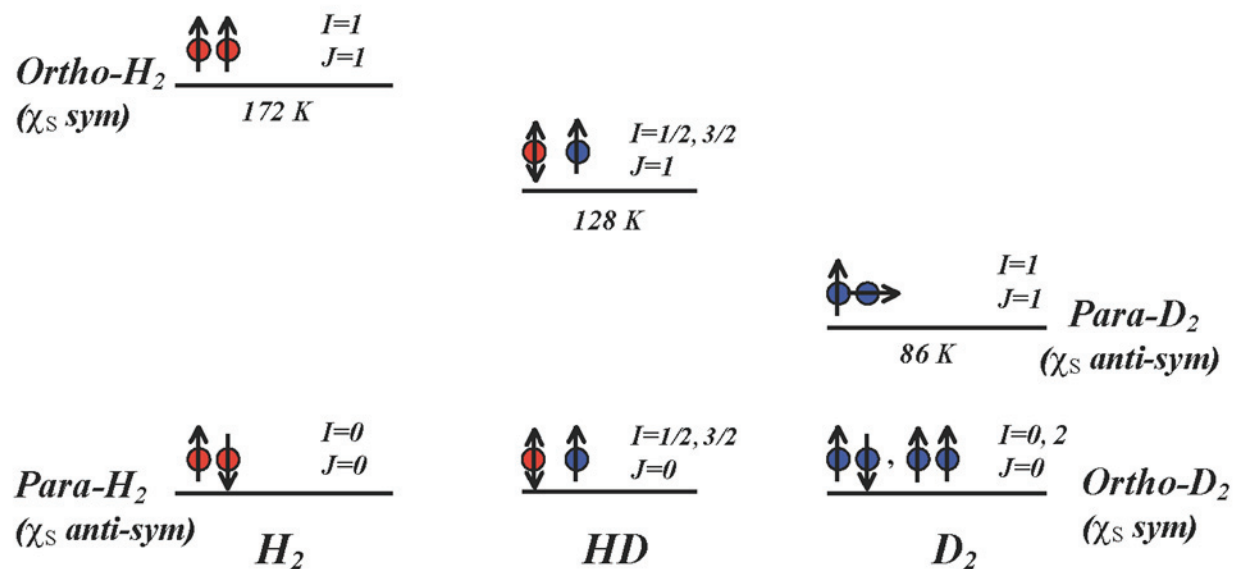
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*Jefferson Laboratory*

- *Frozen-spin HD and performance with photon beams*
- *Advantages for transverse polarized H and D*
- *Heating and radiation damage with electron beams*
- *Comparison with transverse polarized  $\text{NH}_3/\text{ND}_3$  target*

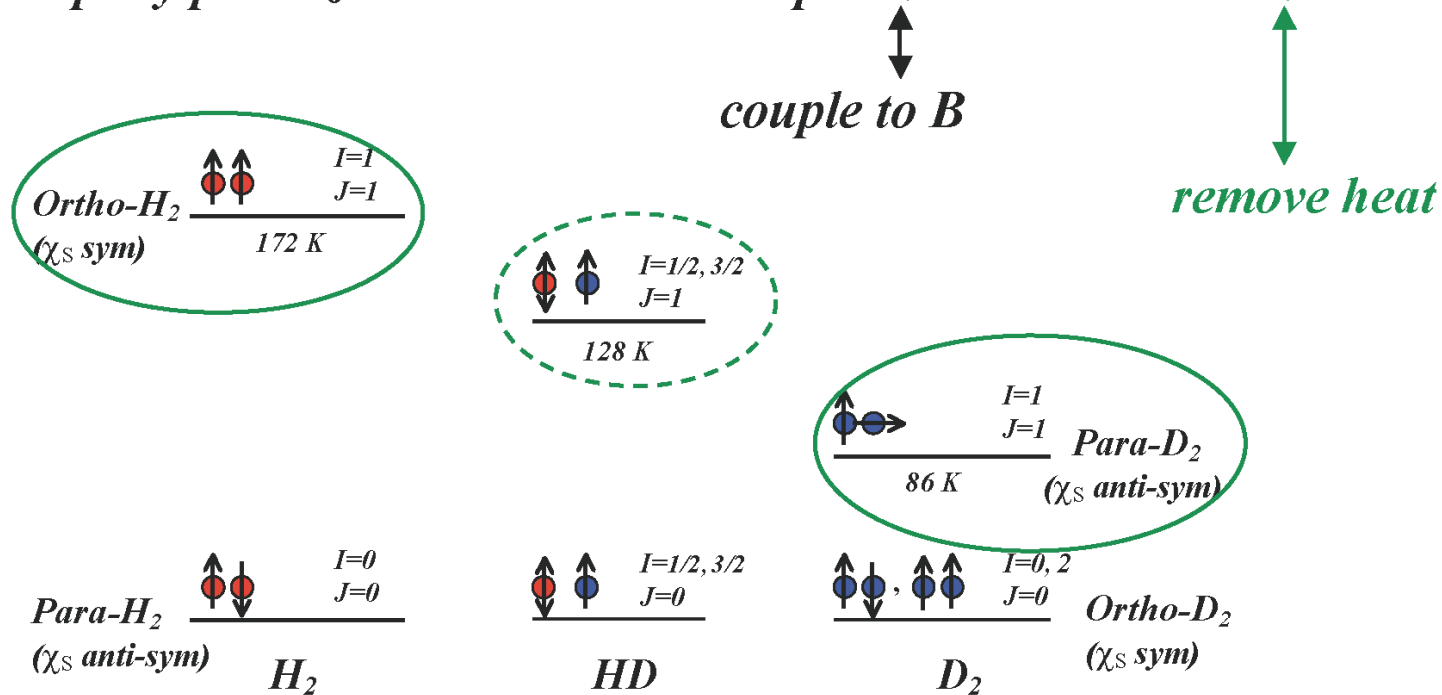
## Polarizing HD: the rotational levels of the solid hydrogens



**Figure.** The relative energy spacing of the low-lying nuclear spin ( $I$ ) and molecular orbital angular momentum ( $J$ ) levels in  $H_2$ ,  $HD$  and  $D_2$ . The symmetries of the nuclear spin wavefunction ( $\chi_s$ ) are indicated.

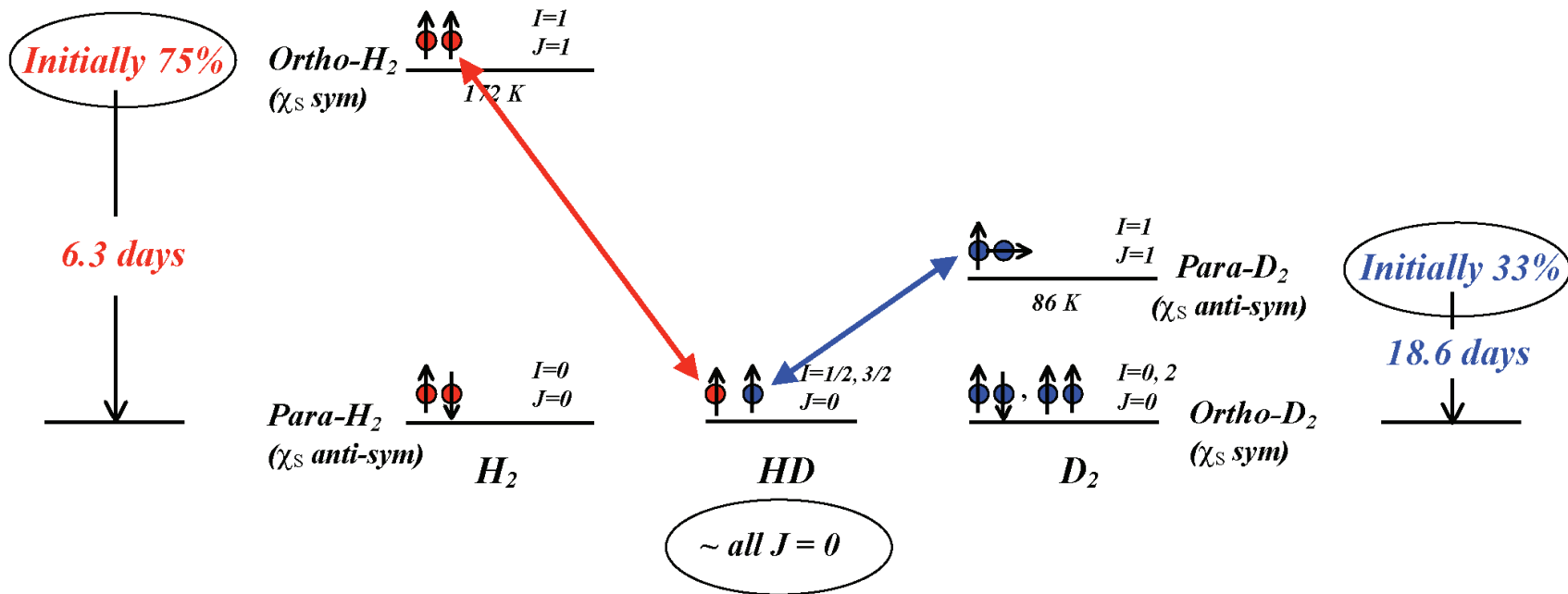
## Polarizing HD: the rotational levels of the solid hydrogens

- *Rapidly polarizable levels: nuclear spin  $I \neq 0$  AND orbital  $J \neq 0$*



**Figure.** The relative energy spacing of the low-lying nuclear spin ( $I$ ) and molecular orbital angular momentum ( $J$ ) levels in  $H_2$ , HD and  $D_2$ . The symmetries of the nuclear spin wavefunction ( $\chi_s$ ) are indicated.

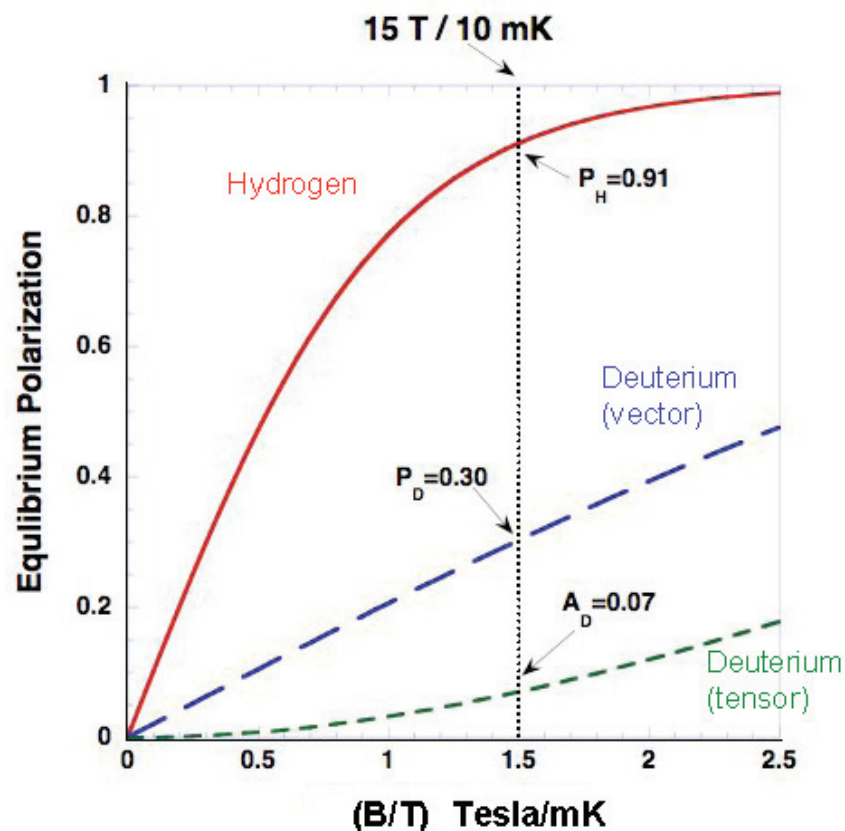
*External Magnetic field rapidly aligns **Ortho-H<sub>2</sub>** and **Para-D<sub>2</sub>**  
then spin-exchanges with **H** and **D** in **HD***



- relaxation switch – A. Honig, *Phys. Rev. Lett.* **19** (1967).

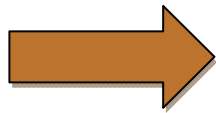
# HD field/low-temp Polarization

- align spins with high B (15 Tesla) and low T (~12 mK)
- polarize small concentrations of J=1 H<sub>2</sub> and D<sub>2</sub>
- o-H<sub>2</sub> and p-D<sub>2</sub> spin-exchanges and polarizes HD
- wait for J=1 H<sub>2</sub> and D<sub>2</sub> to decay



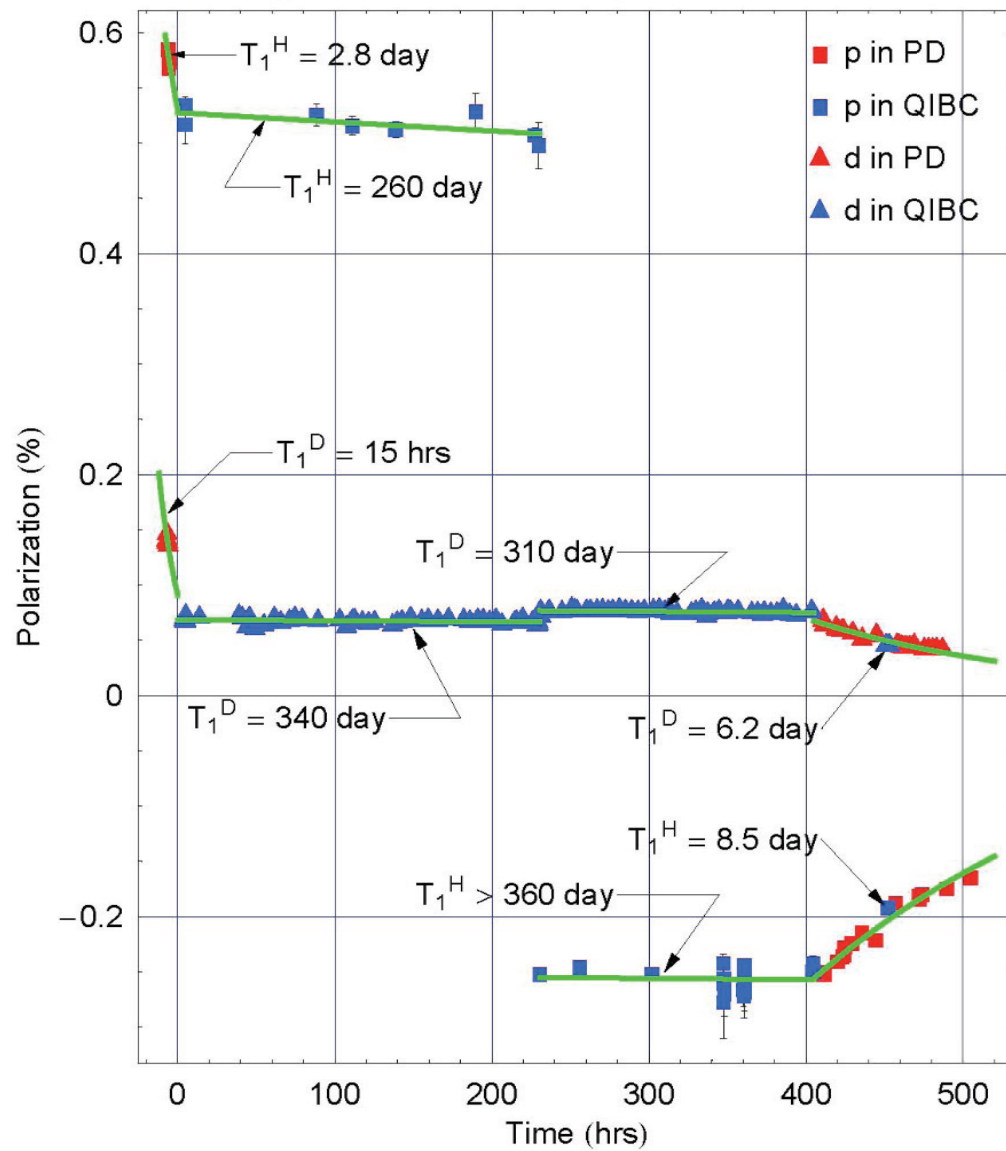
## HD polarize/run sequence:

- *Condense HD gas → liquid → solid in 2-4 K cryostat; calibrate NMR*
- *Transfer to dilution refrigerator*
- *Polarize at 15 Tesla and 12-16 mK*
- *Hold 2-6 months for ortho-H<sub>2</sub> and para-D<sub>2</sub> to decay away*
- *Transfer to 2-4 K cryostat; make NMR polarization measurement*
- *Transfer to In-Beam-Cryostat*
- *Hold target for experiment at 0.2-0.7 K and ~0.1 to 0.9 Tesla*



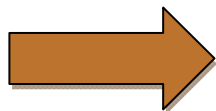
*Spin-relaxation times ( $T_1$ ) ~ a year*

Target #3 Polarization during Fall 2004 data run



## Alternate HD polarize/run sequence:

- *Condense HD gas  $\rightarrow$  liquid  $\rightarrow$  solid in 2-4 K cryostat; calibrate NMR*
- *Transfer to dilution refrigerator*
- *Polarize at 15 Tesla and 12-16 mK*
- *Hold 2-6 months for ortho- $H_2$  and para- $D_2$  to decay away*
- *Transfer to 2-4 K cryostat; make NMR polarization measurement*
- *Transfer to In-Beam-Cryostat*
- *Hold target for experiment at 0.2-0.7 K and  $\sim$ 0.1 to 0.9 Tesla*



*Spin-relaxation times ( $T_1$ )  $\sim$  a year*

- *RF transfer  $P_H \rightarrow P_D$  at 0.2 K and 0.05 Tesla*
- *RF flip spins as needed*



## Increasing D polarization:

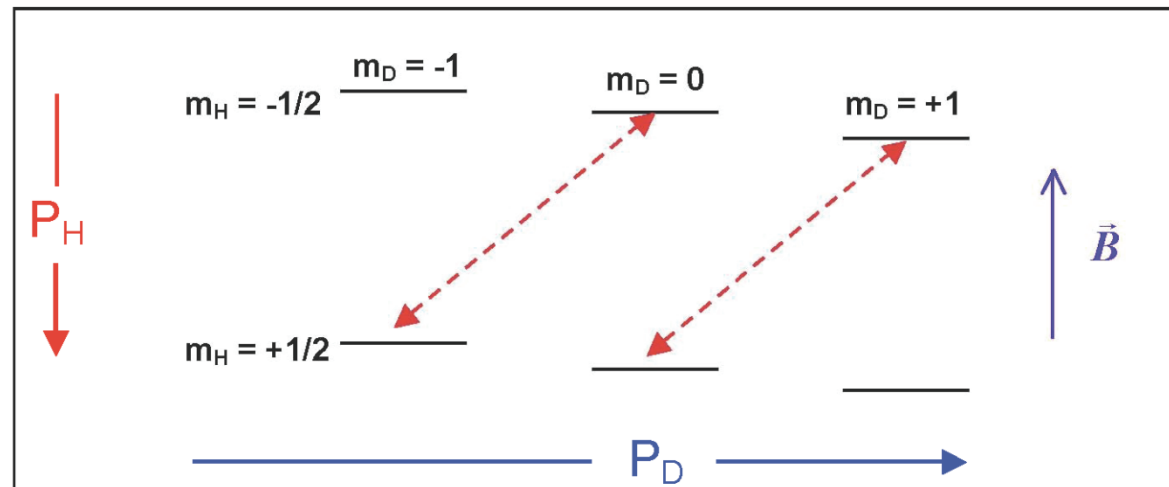
- Brute force (high B/low T)  $\longrightarrow P_D \sim 15\% - 25\%$  ( $\mu_D / \mu_H \sim 1/3$ )
- Forbidden adiabatic fast passage (FAFP) inverts state populations

- Polarize H
- RF transfer

$$P_H \longrightarrow P_D$$

- $P_D$  should reach 50% but limited by NMR field  $\leftarrow$  requires R&D

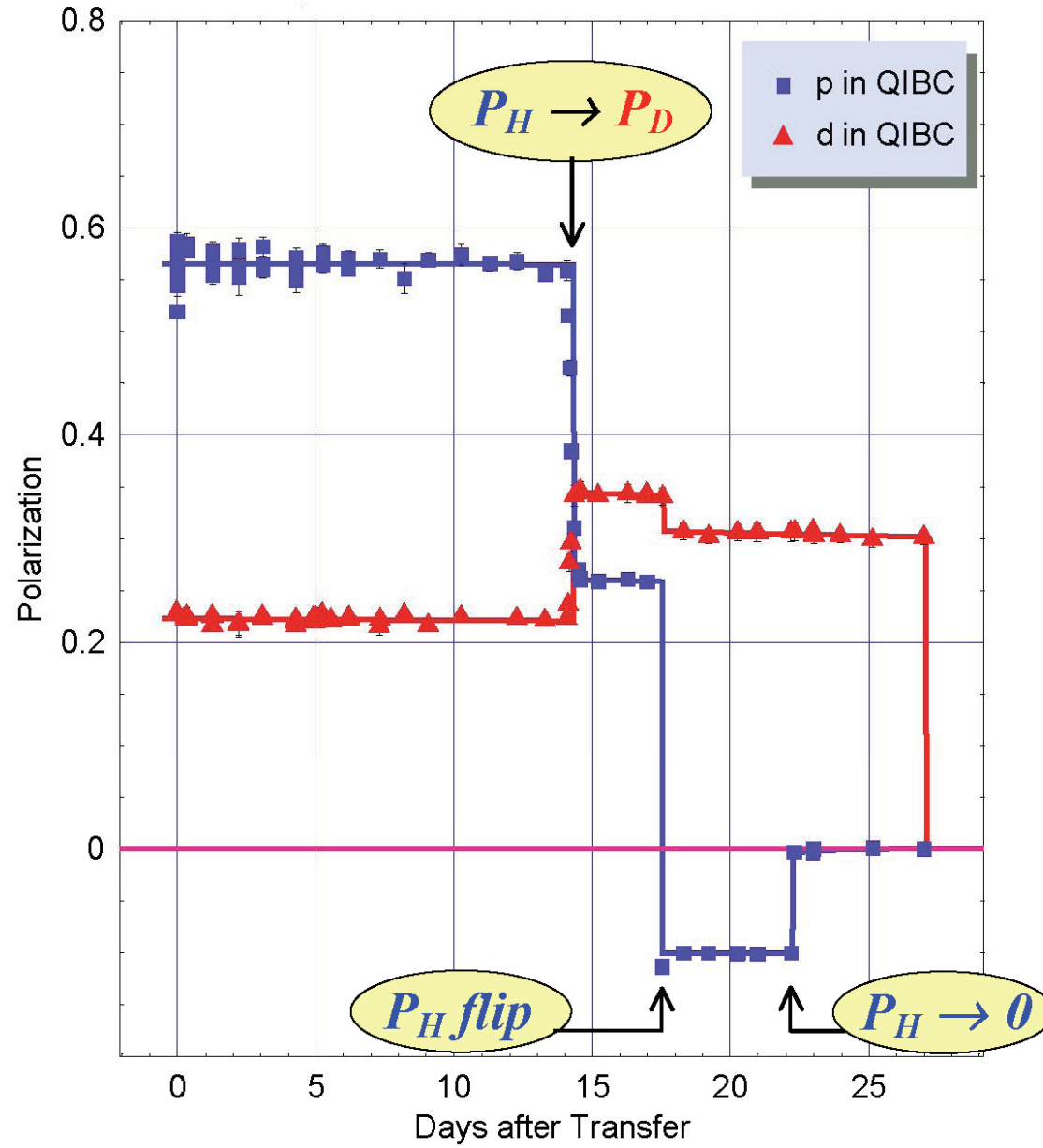
Zeeman levels of HD



- Saturating FAFP  $\rightarrow$  equalize sub-state populations for both transitions

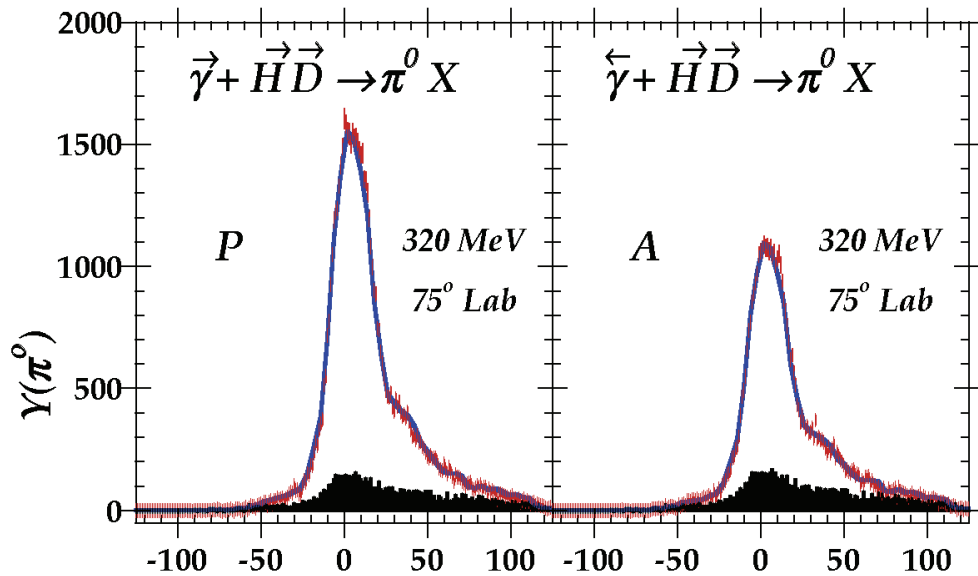
$$P_D = 37\% \leftarrow \text{achieved}$$

*BNL – Fall'2006*

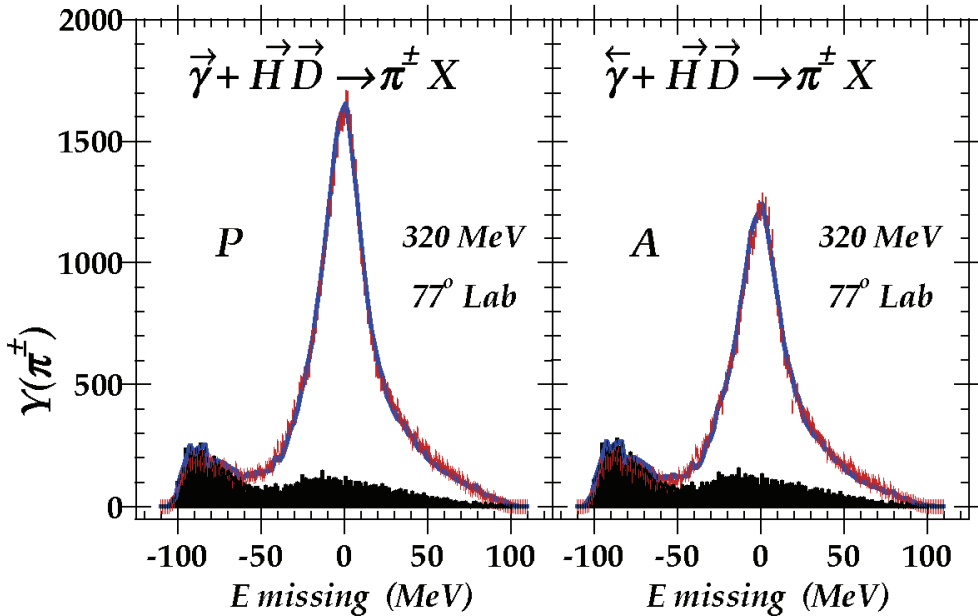


## Advantages of a transverse polarized HD target:

- *Adequate polarization – **demonstrated** ( more may be possible)*
- *Long frozen-spin lifetimes at 0.3 K – **demonstrated***
- *Dilution factor very low, residual can be removed with empty target subtraction*



↯ *HD data*  
 — *MC simulation*  
 ↯ *empty cell data*



*1 of 17 Eγ bins*  
*X 4 target pol groups*  
*X 10 θ bins*  
*(integrated over φ)*

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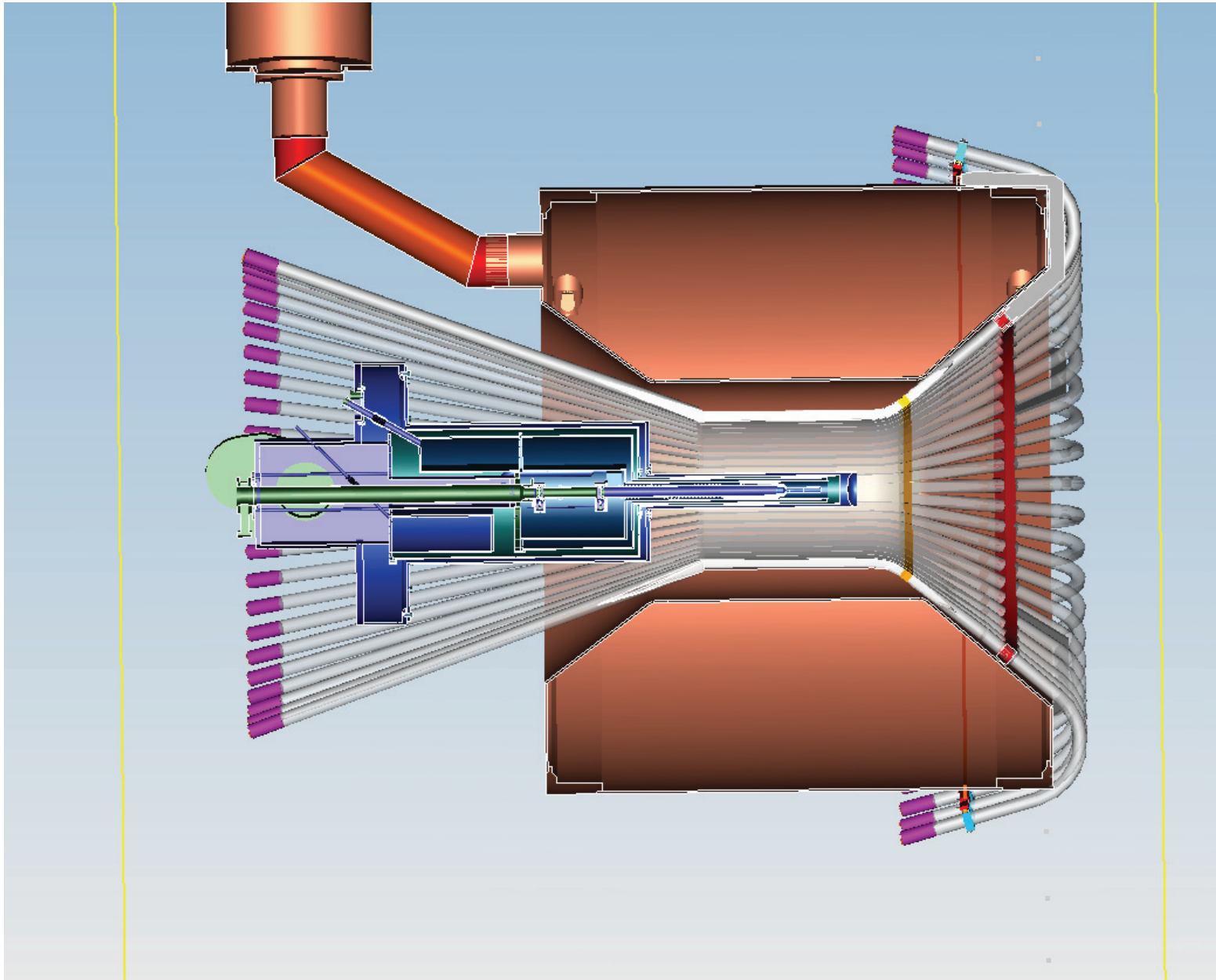
- *Adequate polarization – **demonstrated** ( more may be possible)*
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- *Dilution factor very low, residual can be removed with empty target subtraction – **demonstrated***
- *Low holding field required*

*Expected spin-relaxation times for appropriately prepared targets*

	<i>measured (<math>\gamma</math>)</i>		<i>projected</i>	
<i>B</i>	<i>0.89 tesla</i>	<i>0.01 tesla</i>	<i>0.40 tesla</i>	<i>0.04 tesla</i>
<i>B × dL</i> <i>(for L=0.12m)</i>	<i>0.108 tesla-m</i>	<i>0.001 tesla-m</i>	<i>0.048 tesla-m</i>	<i>0.005 tesla-m</i>
<i>orientation</i>	<i>solenoid</i>	<i>solenoid</i>	<i>saddle</i>	<i>saddle</i>
<i>T<sub>1</sub>(H)</i>	<i>&gt; 300 d</i>	<i>8 d</i>	<i>&gt;200 d</i>	<i>~ 30 d</i>
<i>T<sub>1</sub>(D)</i>	<i>&gt; 500 d</i>	<i>55 d</i>	<i>&gt;300d</i>	<i>~200 d</i>

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- *Low holding field required – **demonstrated***
- *Small cryostat required*





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- *Dilution factor very low, residual can be removed with empty target subtraction – **demonstrated***
- *Low holding field required – **demonstrated***
- *Small cryostat required – conflicts with SVT but otherwise okay*
- *Low Z means less bremsstrahlung.*

**So what's the problem?**

## Beam Heating

- *5 nA of 10 GeV electrons produce 5 mW heat in 2 cm of HD (Geant)*
- *This is roughly the cooling power of the BNL In-Beam Cryostat at 0.5 K.*
- *The new JLab In-Beam Cryostat is calculated to be capable of a cooling power of 13.8 mW at 0.3 K.*
- *Note: This is 1/4 the heating FROST (Butanol) would see, due to lower Z.*

**Beam heating seems to be under control**

## Radiation Damage – Degraded $T_1$

- *Mano and Honig, NIM 124(1975)1, placed HD ice sample in de-focused 10.38 GeV electron beam from Cornell Synchrotron. Saw degraded  $T_{1H}$ .*
  - *$T_{1H}$  @ 4.2K, 0.28T, went from  $3 \times 10^4$  s to 930 s after exposure of  $8.5 \times 10^{12} e/cm^2 = 1.4 \mu C/cm^2 = 280$  s @  $5 nA/cm^2$ .*
  - *28 GeV proton damage implied damaged  $T_{1H}$  @ 1.7K is  $10 \times$  longer*
- *Photon results not helpful because dose too small*
  - *$5 \times 10^6$  photons/s, 2% R.L.,  $3 cm^2$ , 400 hr, results in  $4.8 \times 10^{10} e/cm^2$  and a contribution to  $T_{1H}$  @ 1.7K of 20 days, too small to see.*

## Radiation Damage – continued

- *Dynamically polarized targets see the effect as well. In fact, some targets use irradiation instead of chemical doping. Scaling from their data:*
  - *At Bonn,  $10^{16}$  20-MeV-electrons/cm<sup>2</sup> dose to Butanol generated  $2 \times 10^{19}$  paramagnetic impurities/g.*
  - *For HD and a dose of  $10^{13}$ /cm<sup>2</sup>, this is  $6 \times 10^{16}$  /mole =  $10^{-7}$  mole/mole.*
  - *Roughly same concentration as para -D<sub>2</sub> after 3 months aging. That gave  $T_{1H}$  of 2.8 days @2K versus the 2.7 hours M&H observed. Not surprising that radiation induced impurities are 24 times better at relaxing H.*
- *Everything is consistent within an order of magnitude or so. 5minutes at 5 nA/cm<sup>2</sup> will produce a  $T_{1H}$  of less than 3 hours at 1.7 K. But what happens at lower temperatures?*

## ***This is the major unknown with electrons on HD.***

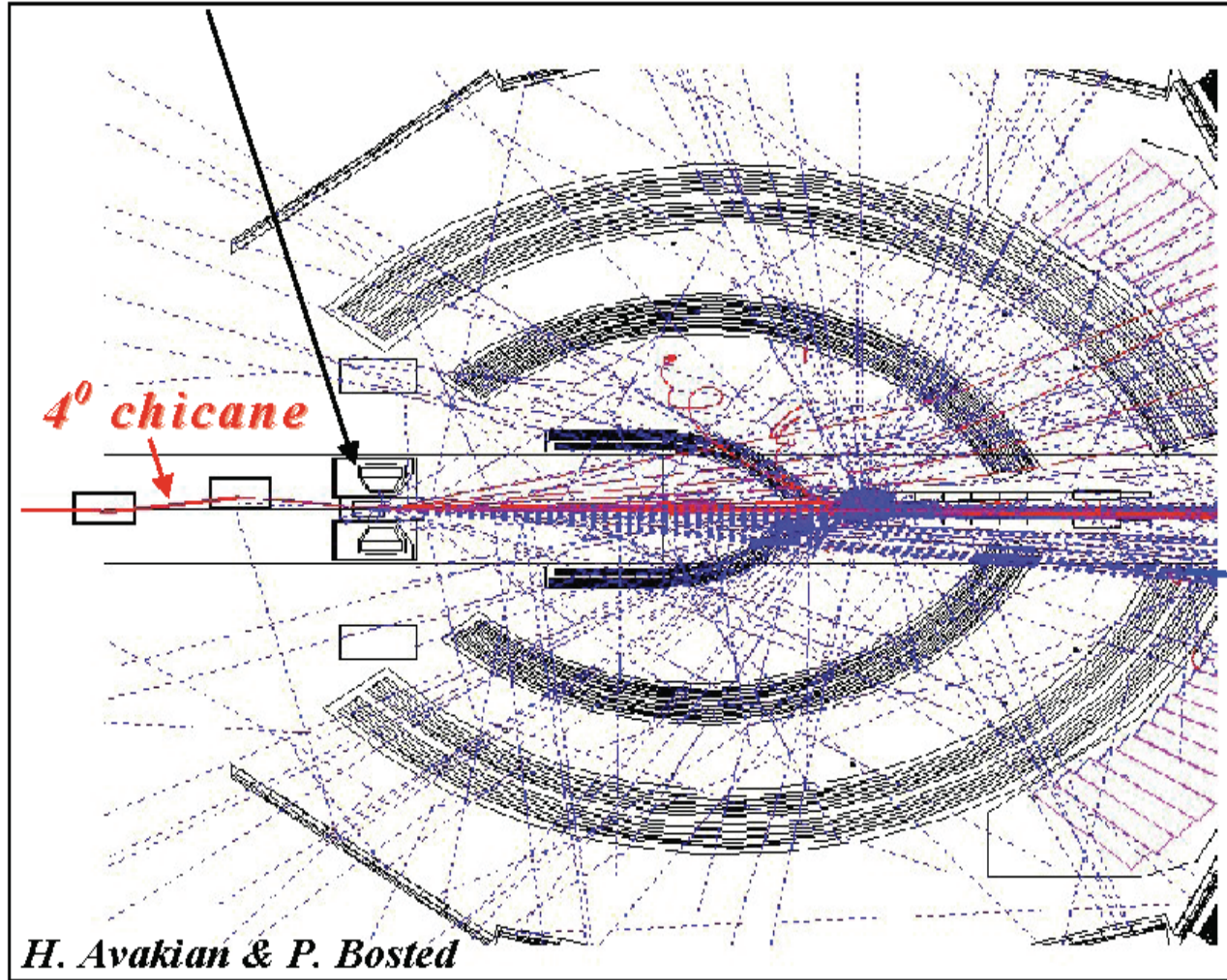
- *The hope is that the de-polarization by the paramagnetic impurities will have strong temperature dependence and freeze out.*
  - *If impurities couple to lattice via induced phonon emission they will have a  $T^3$  dependence which will give a factor of  $10^3$  longer  $T_1$  at 0.17 K.*
  - *This is roughly consistent with the polarization lifetime enhancements of the frozen spin Butanol targets at low temperatures.*
- *There must be a beam test with electrons! Just such a test is planned for Spring 2011.*

## Comparison with transverse polarized NH<sub>3</sub>/ND<sub>3</sub> target

- *Well studied technique with proven electron capability*
- *Adequate polarization – **H higher, D about the same***
- *Dilution factor poor, large background*
- *Large magnet cryostat required – **conflicts with solenoid***
- *High polarizing field required*
  - ***4.2 T×0.3 m=1.3 T·m, (compare to HD 0.048 or 0.005T·m)***
  - ***Requires chicane to compensate for beam***
  - ***Leaves bremsstrahlung  $\gamma$ 's at 4 degrees***

*UVa (Oxford) Transverse  $N\vec{H}_3 / N\vec{D}_3$  target with CLAS*

*BdL  $\approx 4.2 T \times 0.3 m$*



- *large transverse field compensated by chicane*
- *brem  $\gamma$ 's peaked along incoming  $e$  at  $\sim 4^\circ$*
- $\Rightarrow$  "Sheet of flame"*
- $4^\circ$*
- $\Rightarrow$  large background*
- *limited acceptance in  $\theta$  and  $Q^2$*

*H. Avakian & P. Bosted*

## Summary:

- *HD offers several advantages over  $\text{NH}_3/\text{ND}_3$* 
  - *Lower holding field – no “Sheet of flame”*
  - *Smaller cryostat – solenoid can stay, only SVT has to go*
  - *Lower background, smaller Dilution Factor*
- *HD has a major unknown, Radiation Damage.*
  - **Test required! Spring 2011**



## ***Extras***

## Contributions to systematic errors on target polarization:

Source	$\delta P(H)$	$\delta P(D)$
thermal equilibrium calibration - noise, temperature, bkg, ...	0.9%	1.0%
frozen-spin measurement - white noise - holding field noise - non-linearities, homogeneity, ...	0.4% 0.5% 1.0%	2.0% 0.5% 1.0%
calibration transfer - circuit drift, differential ramp - Lock-in gain differential error - cold-transfer loss	1.6% 2.8% 1.0%	1.6% 2.8% 1.0%
Total fractional error:	3.7%	4.2%

## Target wires:

*Ortho  $\leftrightarrow$  para decays generate heat, which must be removed to polarize*

- *HD condensed into target cell with  $\sim 2000$   $50 \mu\text{m}$  Al cooling wires soldered into 60 holes in copper cooling ring*



- *Composition of a standard target cell with 4 cm of HD (0.9 moles):*

Material	gm/cm <sup>2</sup>	mass fraction
HD	0.735	77%
Al	0.155	16%
CTFE (C <sub>2</sub> ClF <sub>3</sub> )	0.065	7 %

## HDice Timeline

HDice Lab – complete design of building modifications – Jan'09 ✓

Building construction – April – Sept'09

Install Cryogenic equipment into HDice Lab – beginning late Sept'09

Polarize sets of targets for E06-101 – Mar-June'10; Aug-Dec'10

Design/construct new In-Beam Cryostat for CLAS – May'08-July'10

Installation in Hall B – July-Sept'10

E06-101 run:  $\vec{\gamma} + \vec{H} \cdot \vec{D}$  – Sept'10-April'11

e+HD test: – April'11

polarized targets for e+HD DVCS – June-Oct'11

E08-021 run:  $\vec{e} + \vec{H} \cdot \vec{D}$  – Nov-Dec'11

