e + $\vec{H}\vec{D}$ice target in Hall B

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- challenges with transverse polarization in a $\sim 4\pi$ detector
- the basics of polarizing solid hydrogen
- characteristics with photon beams
- equipment development and schedule for Hall B
- prospects for electron experiments

Electron experiments with transversely polarized $\vec{H}$ and $\vec{D}$ in Hall B

- ***DVCS, DVMP* :**
  $\Rightarrow$ ***$\tilde{E}$ GPD*** $\rightarrow$ ***2+1 dimensional tomography***
  $\rightarrow$ ***quark orbital angular momentum***

- ***Semi-inclusive-DIS* :**
  $\Rightarrow$ ***Collins function*** $\rightarrow$ ***transverse $\vec{q}q \rightarrow$ Asy in hadron fragmentation***
  $\rightarrow$ ***transverse quark orbital angular momentum***

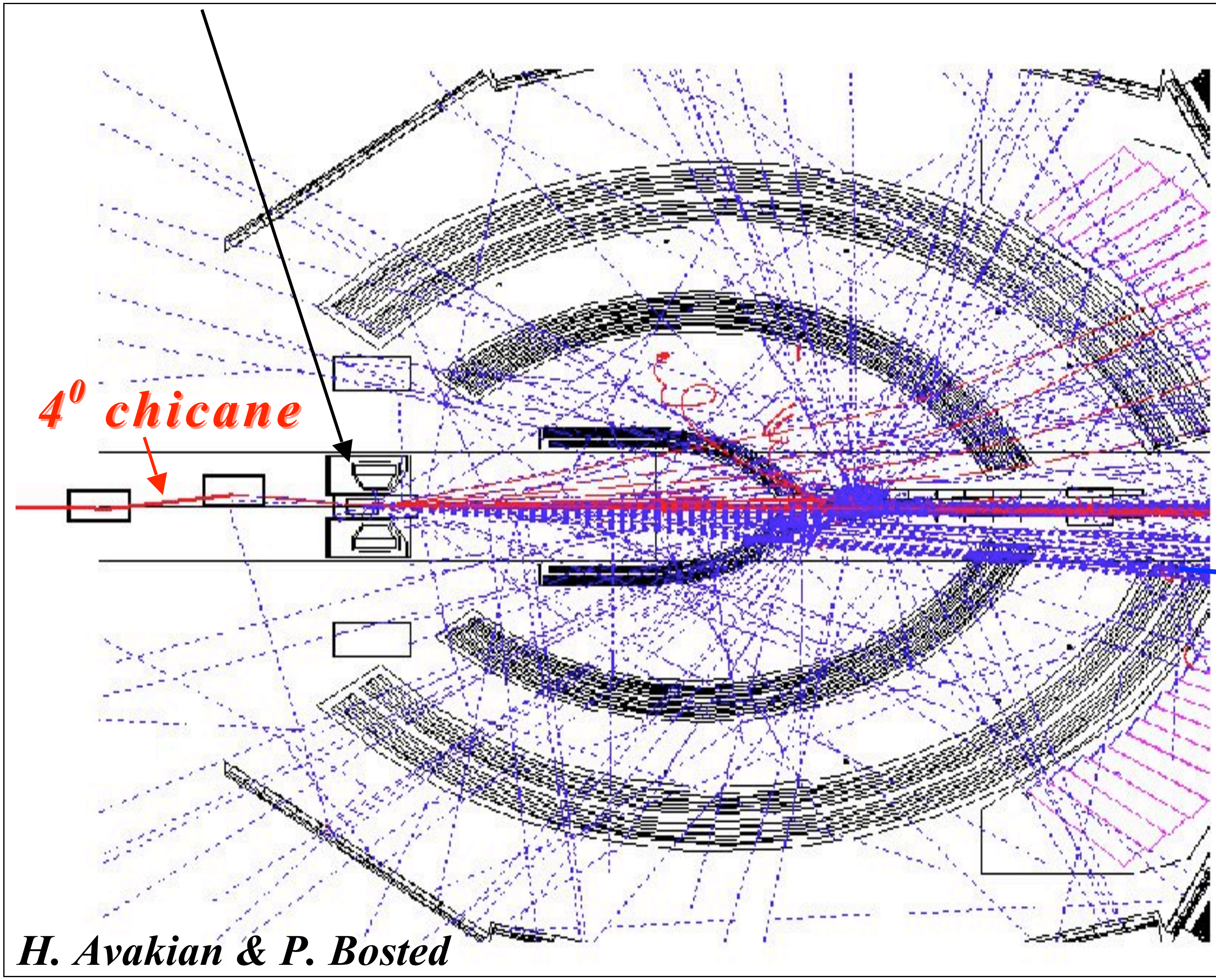
  $\Rightarrow$ ***Sivers function*** $\rightarrow$ ***u-d separation in $\vec{N}^{\perp} \rightarrow$ single-spin Asy***

- ***Inclusive-DIS* :**
  $\Rightarrow$ ***g_2, A_2 PDF*** $\rightarrow$ ***color-polarizability of the gluon field***

- ***N* transition form factors* :**
  $\rightarrow$ ***constraining structure of baryons***

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

BdL ≈ 4.2 T × 0.3 m



- *large transverse field compensated by chicane*
- *brem γ's peaked along incoming e at ~4^0*

⇒"Sheet of flame" 4^0

⇒large background

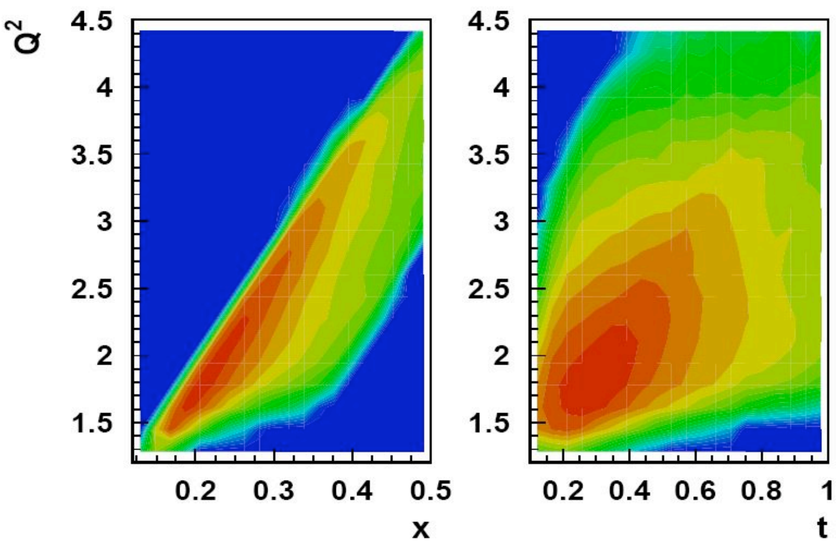
- *limited acceptance in θ and Q^2*

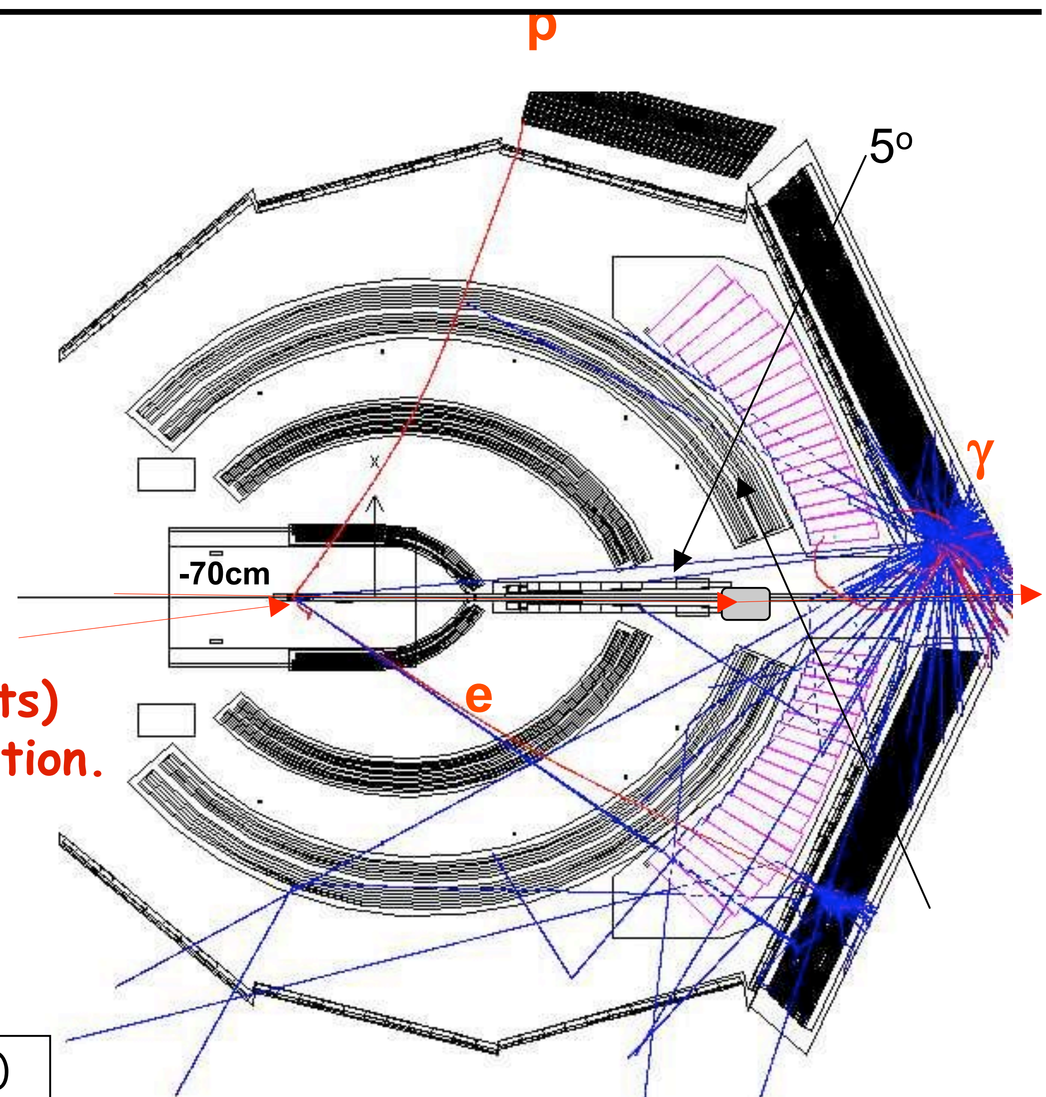
Expected $\vec{H}$ and $\vec{D}$ spin-relaxation times with γ beams:

	measured (γ)		projected (γ)	
B	0.90 tesla	0.01 tesla	0.40 tesla	0.04 tesla
$B \times dL$ (for L=0.12m)	0.108 tesla-m	0.001 tesla-m	0.048 tesla-m	0.005 tesla-m
orientation	solenoid	solenoid	saddle	saddle
$T_1(H)$	> 300 d	8 d	>200 d	~ 30 d
$T_1(D)$	> 500 d	55 d	>300d	~200 d

compare to 1.4 T-m with NH_3/ND_3

E08-021 simulation with transversely polarized HD in CLAS





- Beam on target at ~0.2°, parallel at center (use small steering magnets)
- HD holding field corrects e deflection.

Run conditions

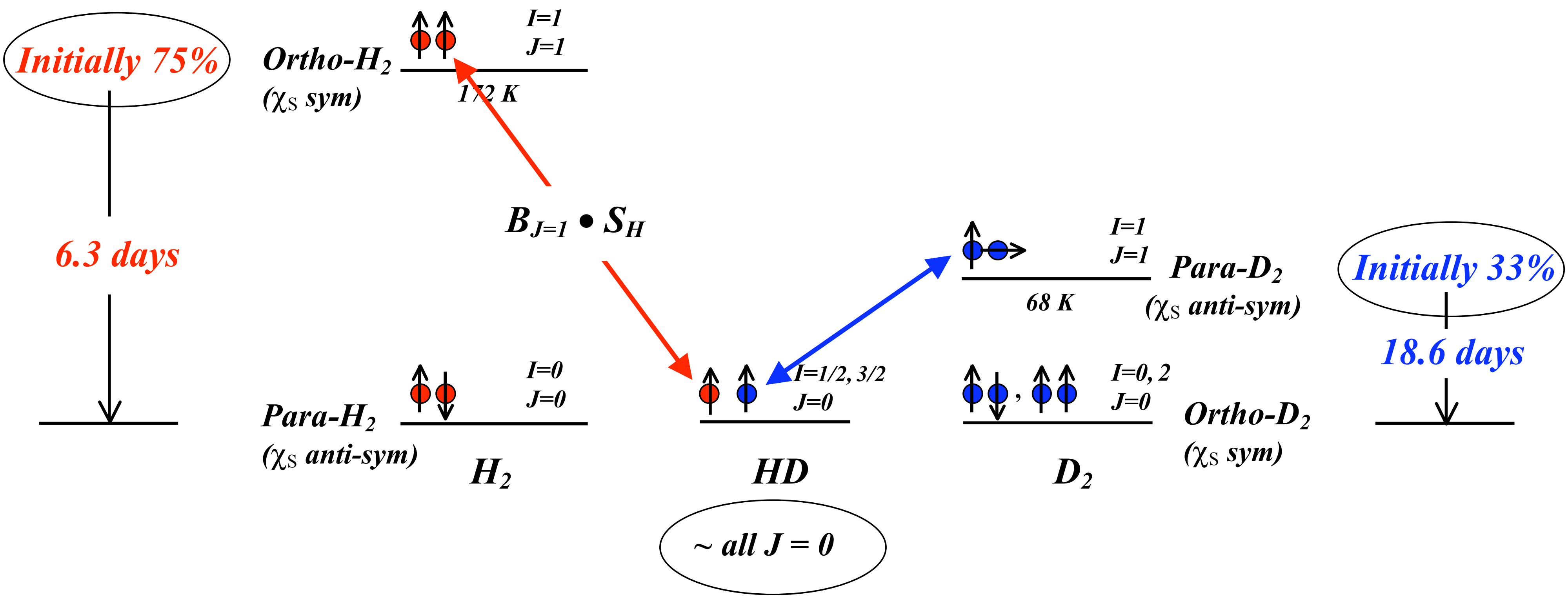
- 25 days of HD (+5 days of H, D, empty target)
- 4cm HD, 2 nA
- beam polarization 80%
- HD-Ice target polarization (H-75%,D-25%)

Solid Deuterium-Hydride (HD) – a new class of polarized target

- a quantum crystal: zero-point motion big fraction of lattice spacing
- polarized at high field (15-17 tesla) and low temperature (~10 mK), in a few days;
- frozen-spin state reached in a few months;
  can then be moved to "warm" (½ K), low field (0.01 – 0.5 tesla)
- spin can be moved between H and D with RF transitions
- all of the material can be polarized, with almost no background, and the spins last for years !

External Magnetic field rapidly aligns Ortho-H_2 and Para-D_2

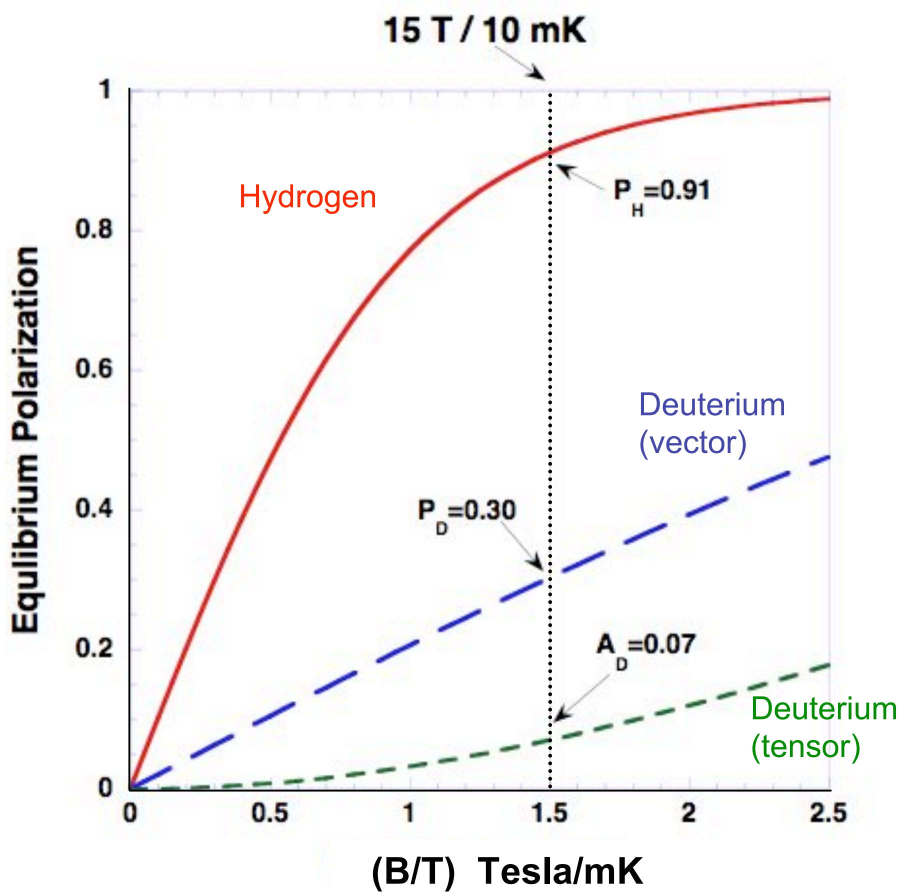
then spin-exchanges with H and D in HD



- *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_2 and D_2
- o-H_2 and p-D_2 spin-exchanges and polarizes HD
- wait for J=1 H_2 and D_2 to decay



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- **the adventure:**
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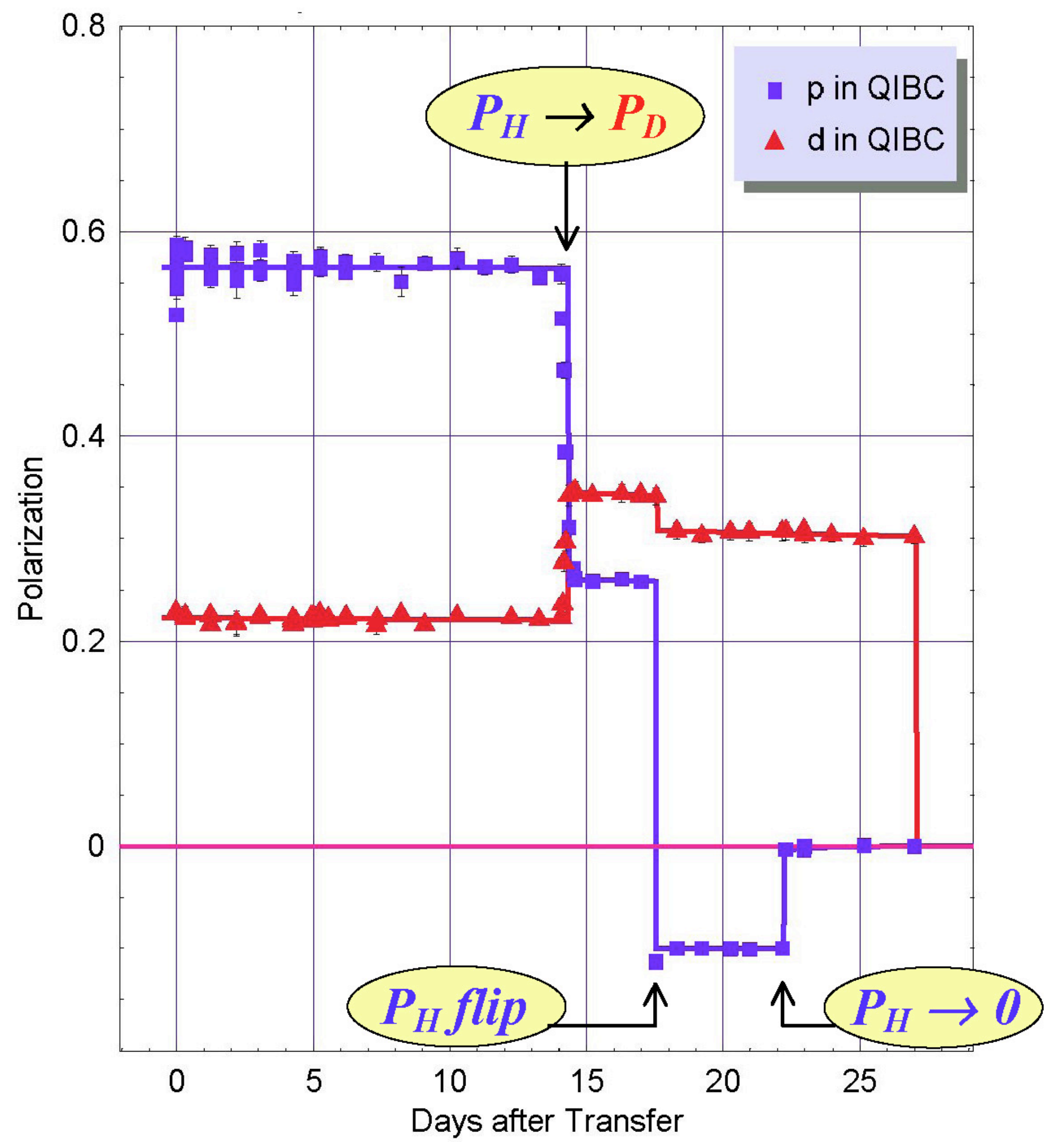
  ⇒ in principle, this is an advantage (accumulate stock; open in-beam)

  ⇒ in practice, there are many ways to make a mistake when moving macroscopic chunks of solid polarized hydrogen !

HD in-beam polarization:

LEGS/BNL - Fall'06

- T_1(1/e dacay) ~ 1-2 yr
- RF forbidden (mol-mol) $\vec{H} \Rightarrow \vec{D}$ transfer
- RF allowed (inter-mol) $\vec{H}$ flip
- BNL polarizations: P(H) = 62%; P(D) = 35%
- projected JLab targets P(H) > 75%; P(D) > 40%



Simultaneous measurements of reactions on both $\vec{H}$ and $\vec{D}$

- *polarized reactions on H and D can be separated by*

  - moving target spins between H and D;

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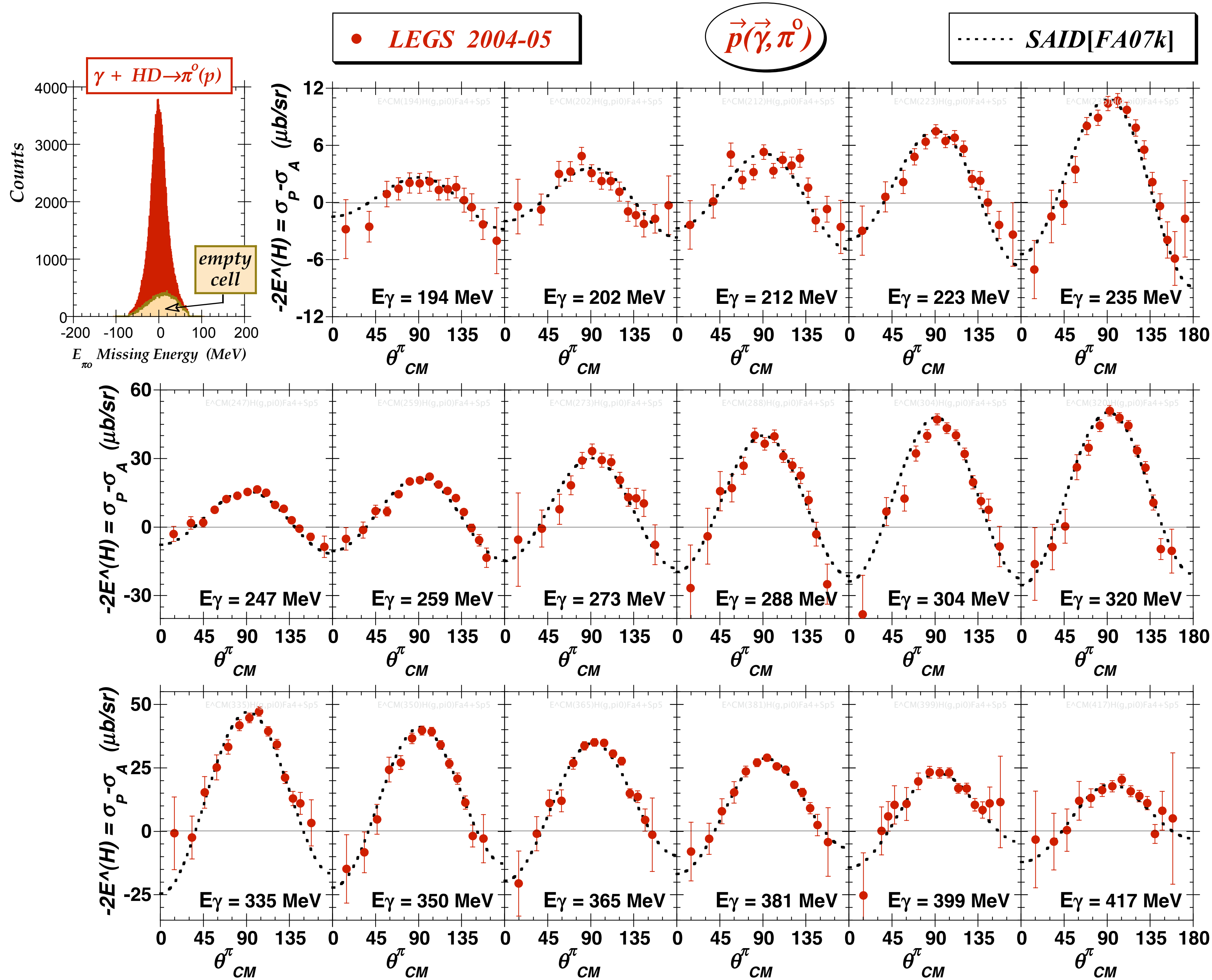
- *eg.* $\int {}^{d\sigma}\!/_{d\Omega}\, d\phi$ in meson production :

$$d\sigma(\theta, E_\gamma) = d\sigma_0^{HD} - P_\gamma^c P_H \hat{E}_H - P_\gamma^c P_D^V \hat{E}_D + \sqrt{1/2}\; P_D^T \hat{T}_{20}^0$$

- 4 unknowns with different coefficients;

- straight forward to collect data under 8 different conditions, over-determining the unknowns

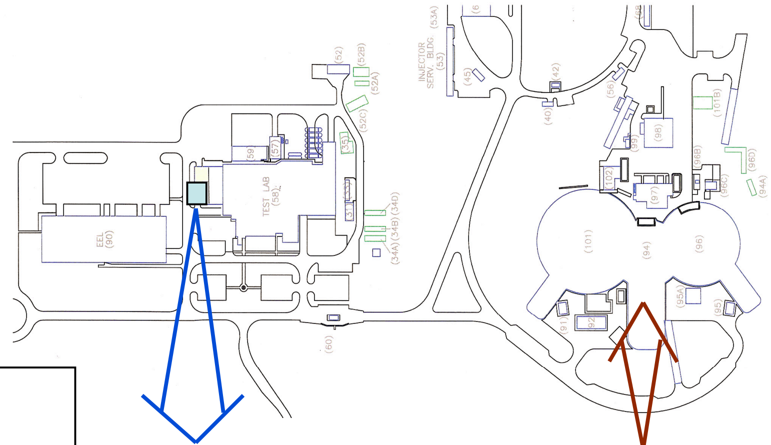


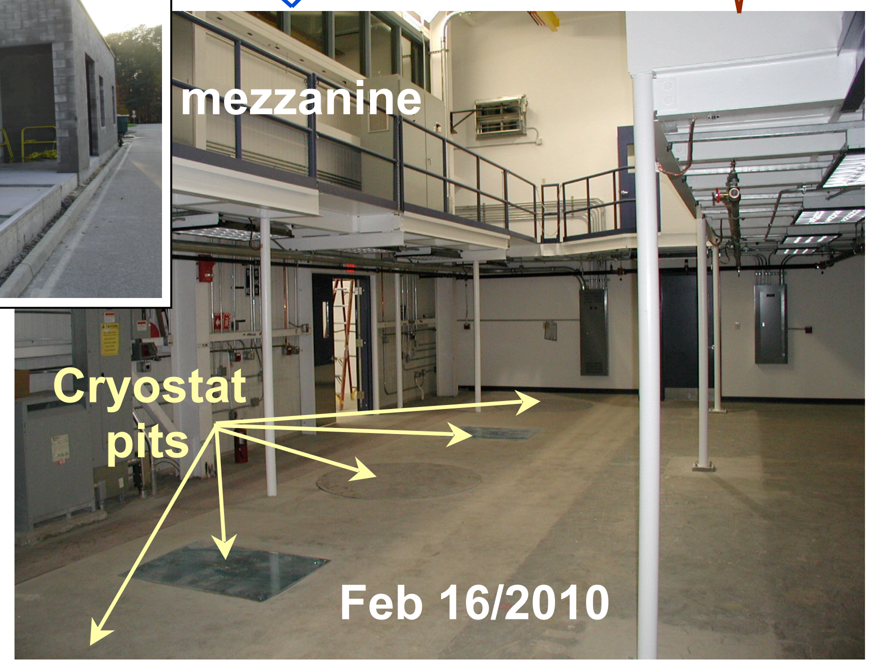
LEGS 2004-05
$\vec{p}(\vec{\gamma},\pi^o)$
SAID[FA07k]
γ + HD→π^o(p)
Counts
empty cell
$E_{\pi o}$ Missing Energy (MeV)
-2E^(H) = σ_P-σ_A (μb/sr)
θ^π_{CM}
Eγ = 194 MeV
Eγ = 202 MeV
Eγ = 212 MeV
Eγ = 223 MeV
Eγ = 235 MeV
Eγ = 247 MeV
Eγ = 259 MeV
Eγ = 273 MeV
Eγ = 288 MeV
Eγ = 304 MeV
Eγ = 320 MeV
Eγ = 335 MeV
Eγ = 350 MeV
Eγ = 365 MeV
Eγ = 381 MeV
Eγ = 399 MeV
Eγ = 417 MeV

$\vec{H}\vec{D}$ice program at Jefferson Lab

- BNL HD staff from LEGS
  transfer to Jefferson Lab - 2008

  - Renovation of building space to
    create HD polarizing Lab - Feb/2010





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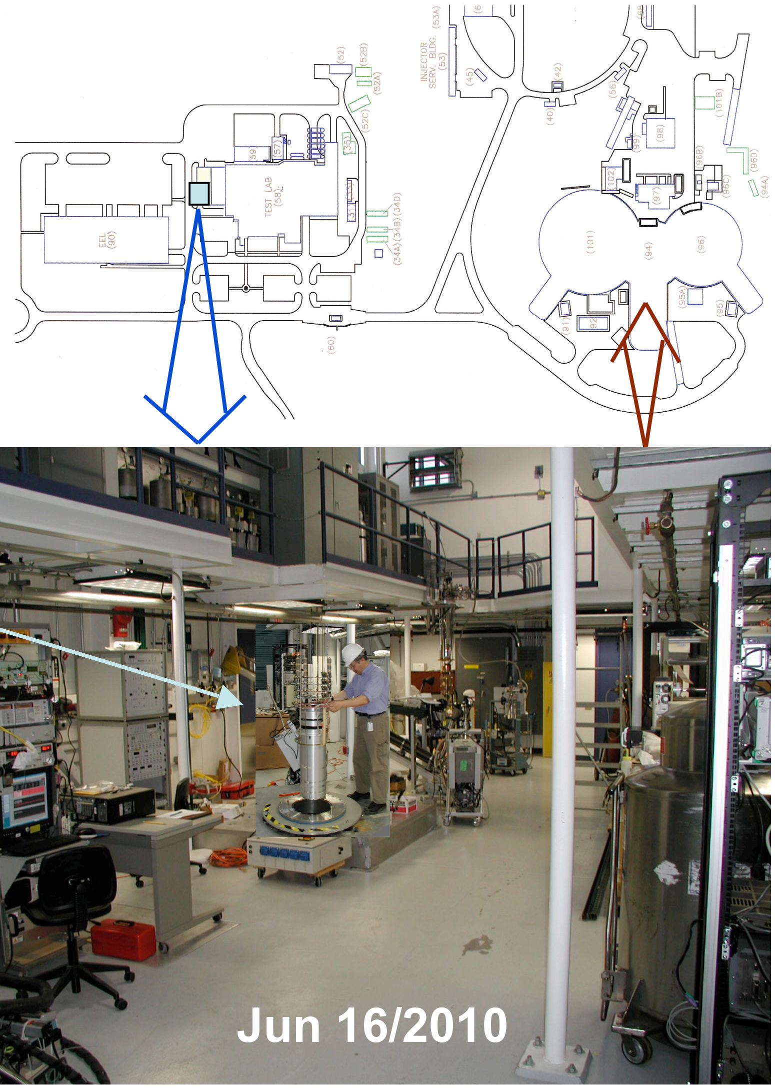
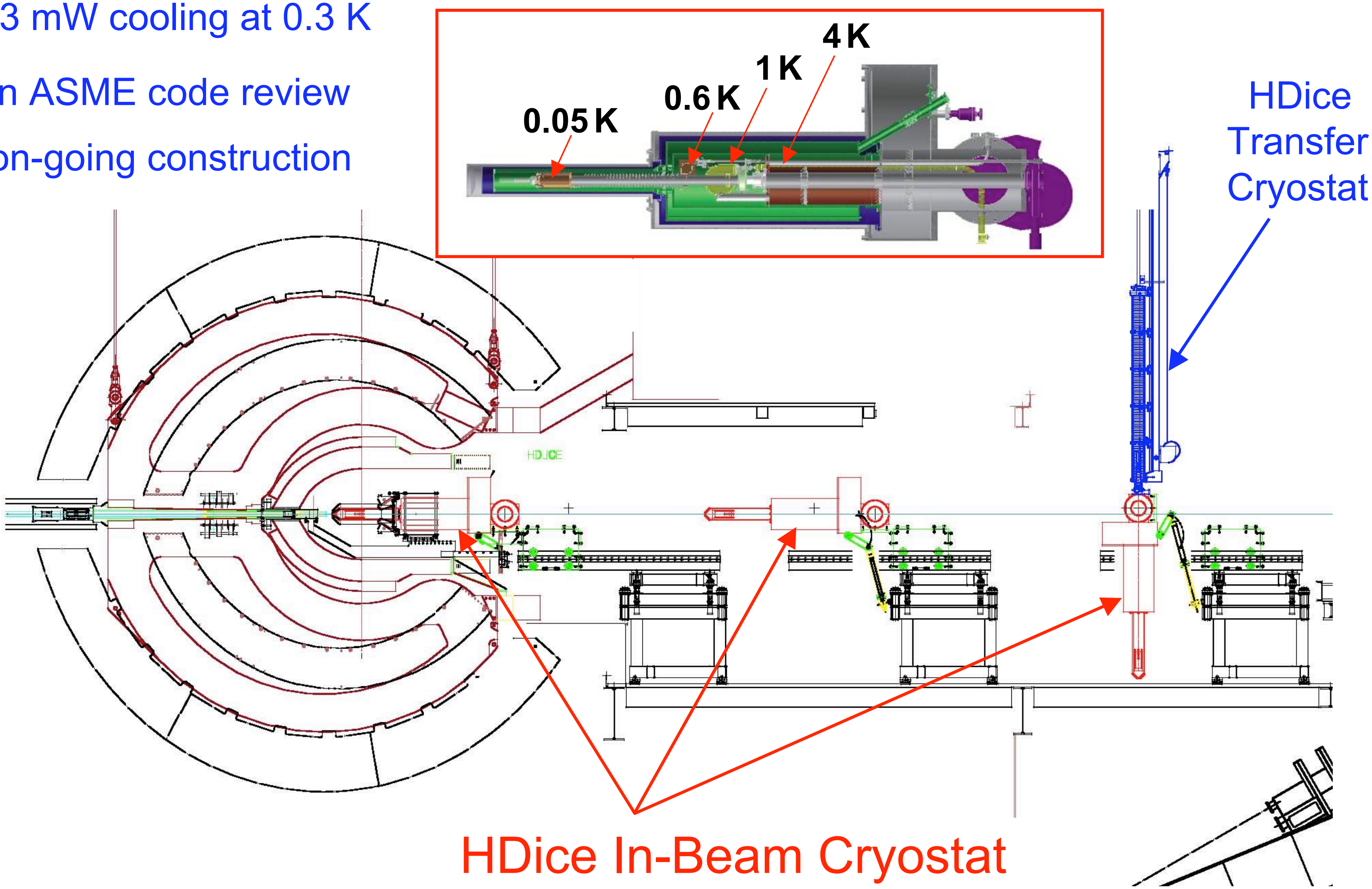


HDice In-Beam Cryostat for CLAS

- designed for both γ (w Start Counter) and e^- (w mini-Torus) running
- 13 mW cooling at 0.3 K
- in ASME code review
- on-going construction



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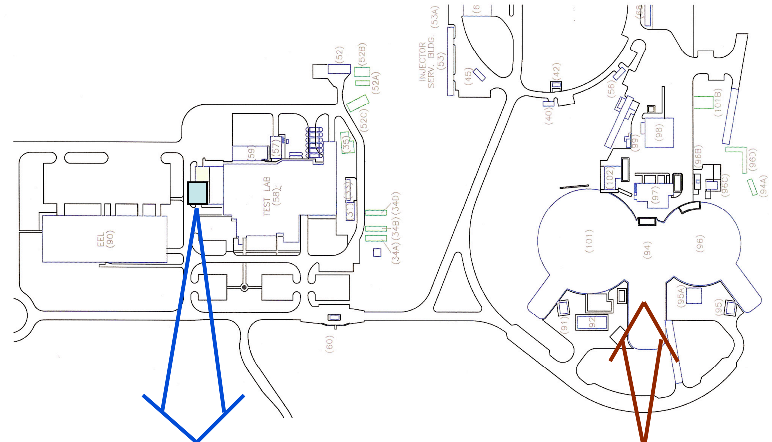
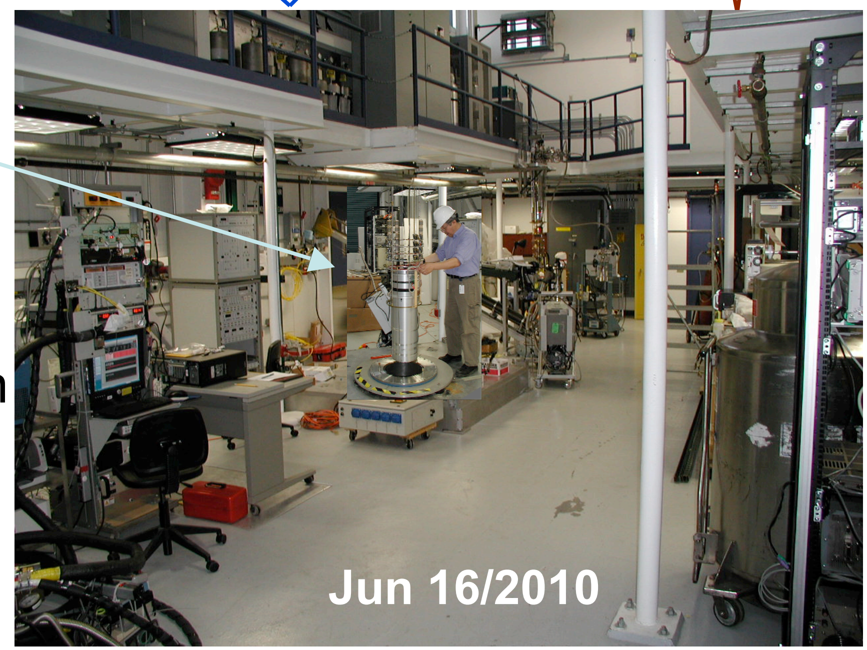
  - schedule: “*complete”* γ-K/π production
    installation $\rightarrow$ ~ Jan/2011

  - test with electrons $\rightarrow$ ~ Apr/2011





Depolarization of frozen-spin $\vec{H}\vec{D}$ with electrons

- ***beam heating***

  - 1 nA of 10 GeV electrons ⇒ 1 mW heat in 2 cm of HD (*GEANT*);
  - much lower heating than complex targets (NH_3, Butanol) due to lower Z
  - very low temperatures are *not* needed to hold HD spins (T_1 ~ a year at ½ K)

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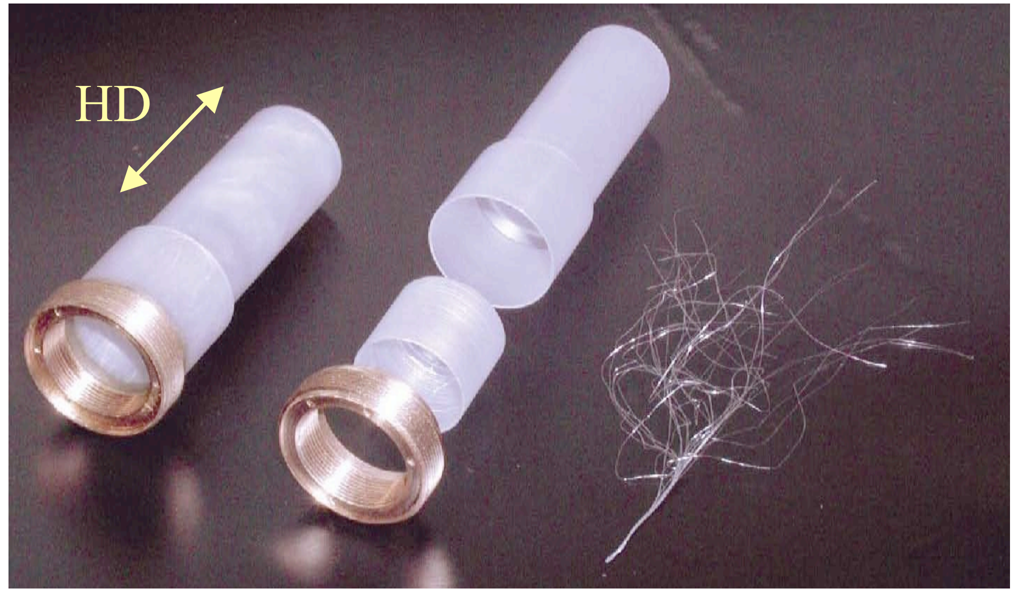
⇒ ***very hopeful signs; study of (B,T) parameter space with direct tests next year***

extras

Ortho ⇔ para decays generate heat, which must be removed to polarize

- ***HD condensed into target cell with ~ 2000 50 μm 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^2	mass fraction
HD	0.735	77%
Al	0.155	16%
CTFE (C_2ClF_3)	0.065	7 %

Development work to optimize polarization:

	JLab	BNL conditions
Target volume (smaller ∅), ⇒ reduced heat in polarizing	15mm ∅ × 50mm ⇒ 0.17 μW /tgt	25mm ∅ × 50mm ⇒ 0.50 μW /tgt
Aluminum purity to improve thermal conductivity	99.9998%	99.99%
Copper purity to improve thermal conductivity • new tgt cells/rings • new *cold finger* for DF	99.99998%	99.9%
Solenoid: field homogeneity to improve H ⇒ D spin transfer	2×10^{-4}	few $\times 10^{-3}$
RF coil: field variation with "*bird-cage" design* improve H ⇒ D spin transfer	~13%	~ 100%