Performances of frozen-spin polarized HD targets for Nucleon spin experiments.

@ PST05, Nov.14-17, 2005

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on behalf of LEGS Spin Collaboration

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Motivation

Nucleon Spin Sum Rules

- Gerasimov−Drell−Hearn

$$-\frac{\alpha}{2m^2}\kappa^2 = \frac{1}{4\pi^2}\int_{m_\pi}^{\infty}\frac{\sigma_{1/2}-\sigma_{3/2}}{E_\gamma}\,dE_\gamma$$

  - Nucleon spin strucure at $Q^2=0$
  - LEGS covers ~65%
  - Measurement down to pion threshold is important

- Forward Spin−Polarizability

$$\gamma_0 = \frac{1}{4\pi^2}\int_{m_\pi}^{\infty}\frac{\sigma_{1/2}-\sigma_{3/2}}{E_\gamma^3}\,dE_\gamma$$

  - Test of chiral perturbation theories
  - LEGS covers ~90%
  - Measurement down to pion threshold is important

Multipole Amplitudes

- Double polarization observables
  - Asymmetries E and G
  - Neutron channels $\pi^0 n$ and $\pi^- p$

Attractive Features Polarized HD Target

1. **Pure Solid Targets**

* Only unpolarizable nucleons associated with target cell which can be measured separately and subtracted in coventional way

2. **Long Spin-Relaxation time**

~ 1 year in beam

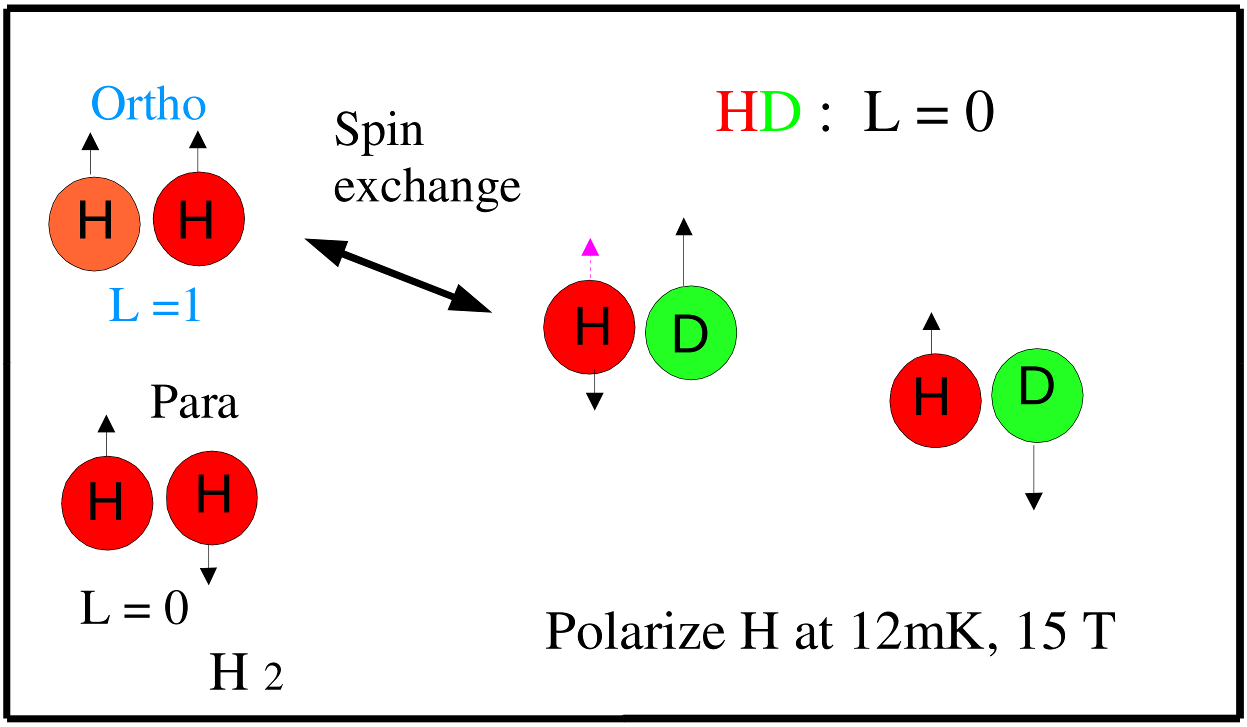
3. $\vec{H} \longrightarrow \vec{D}$: **Higher D polarization**

4.

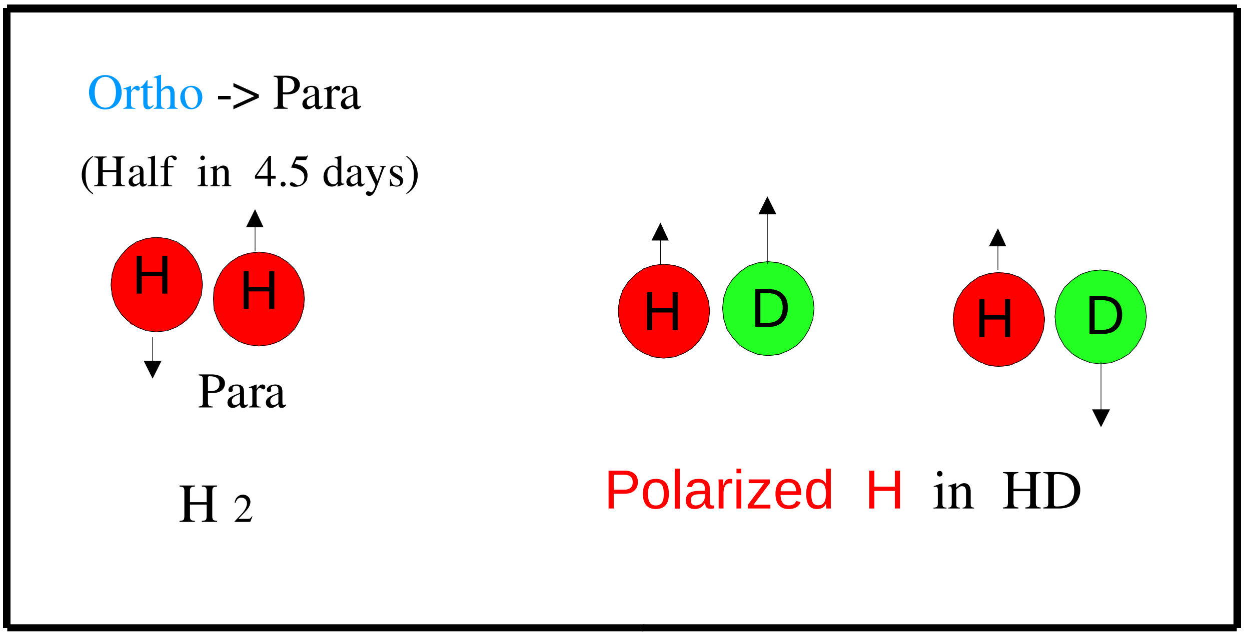
Can Select

- **H↑ D↑**
- **H↑ D**
- **H D↑**

Polarize H in HD using polarized ortho -H_2

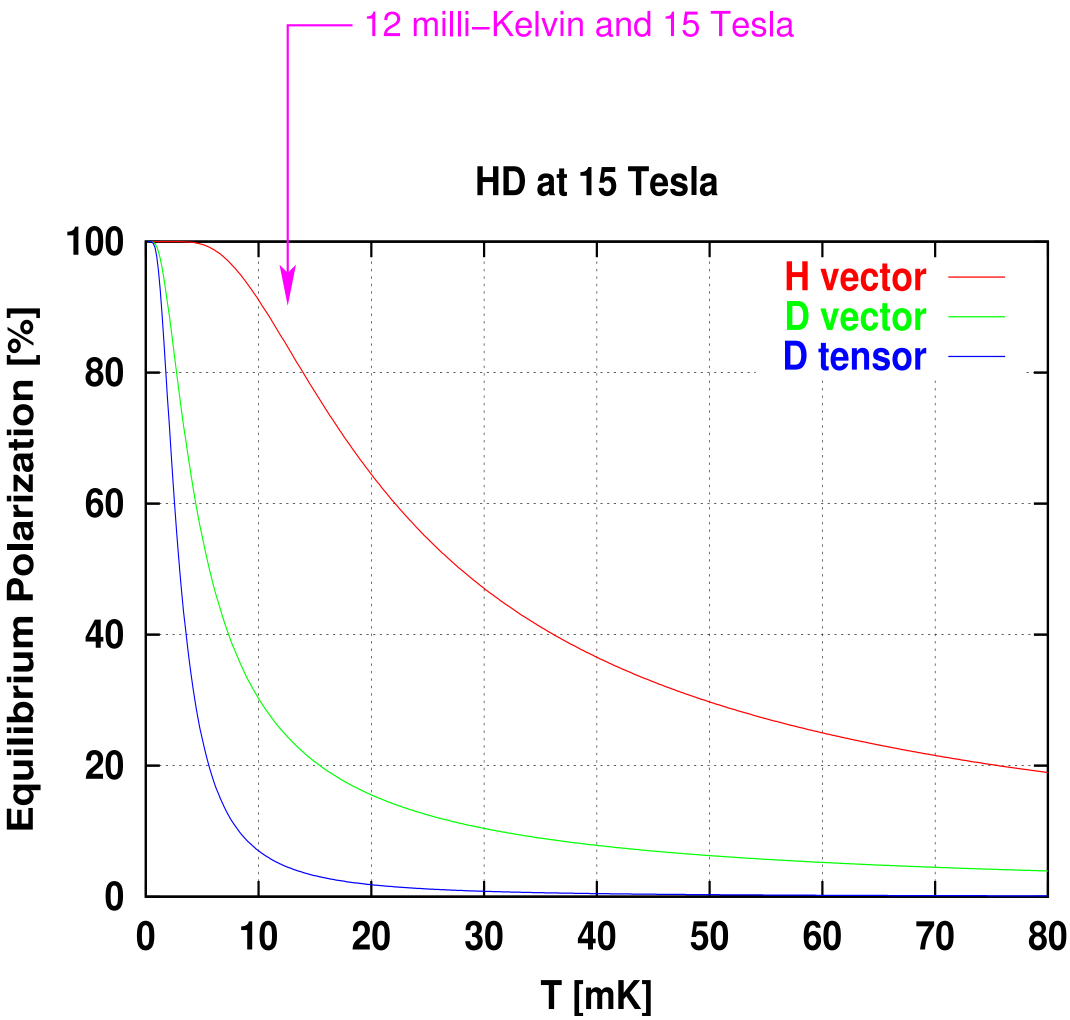


12 mK, 15 T ↓ Age: ~ 3 months

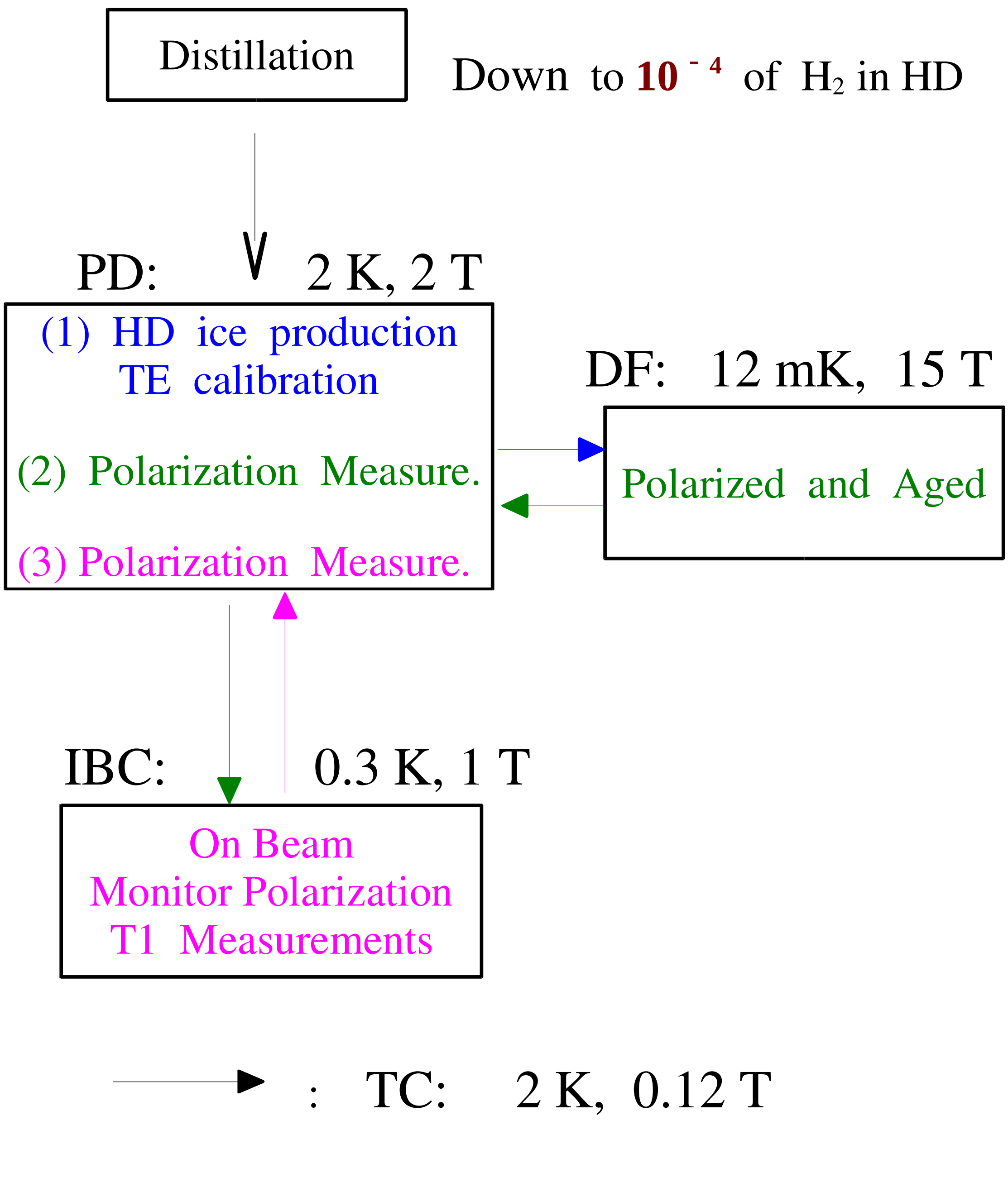


No spin exchange to HD (Frozen Spin)

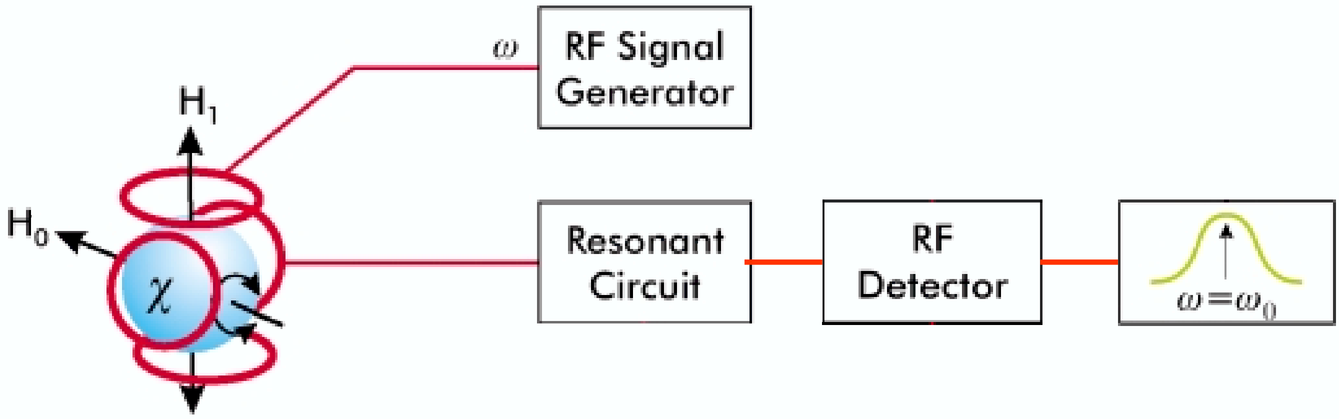
Expected Polarizations



HD target Produced, Calibrated, Polarized and On the beam



Cross-Coil NMR for Measuring Target Polarization

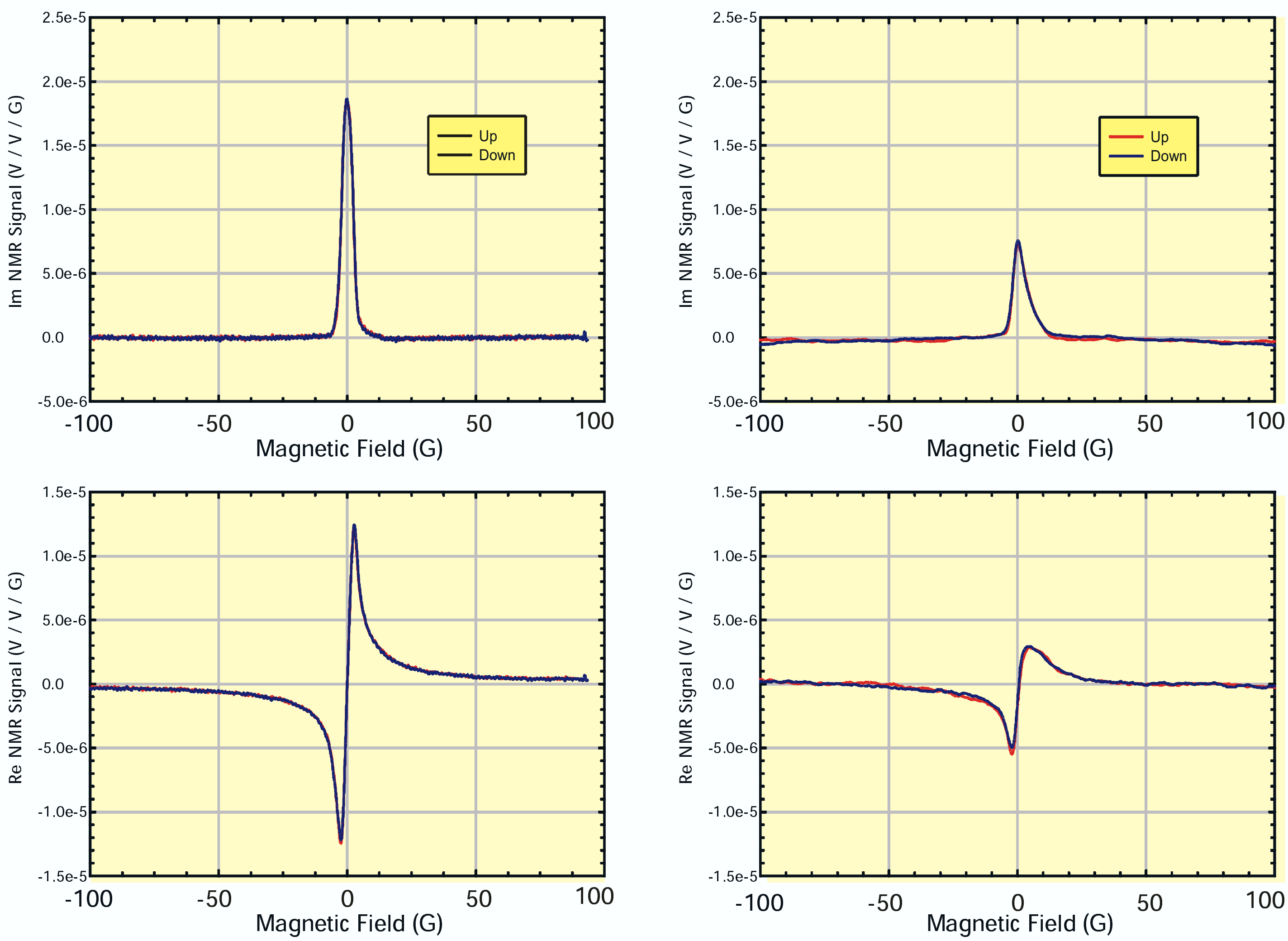


Typical NMR Scans for the SPHICE Target at TE

Hydrogen

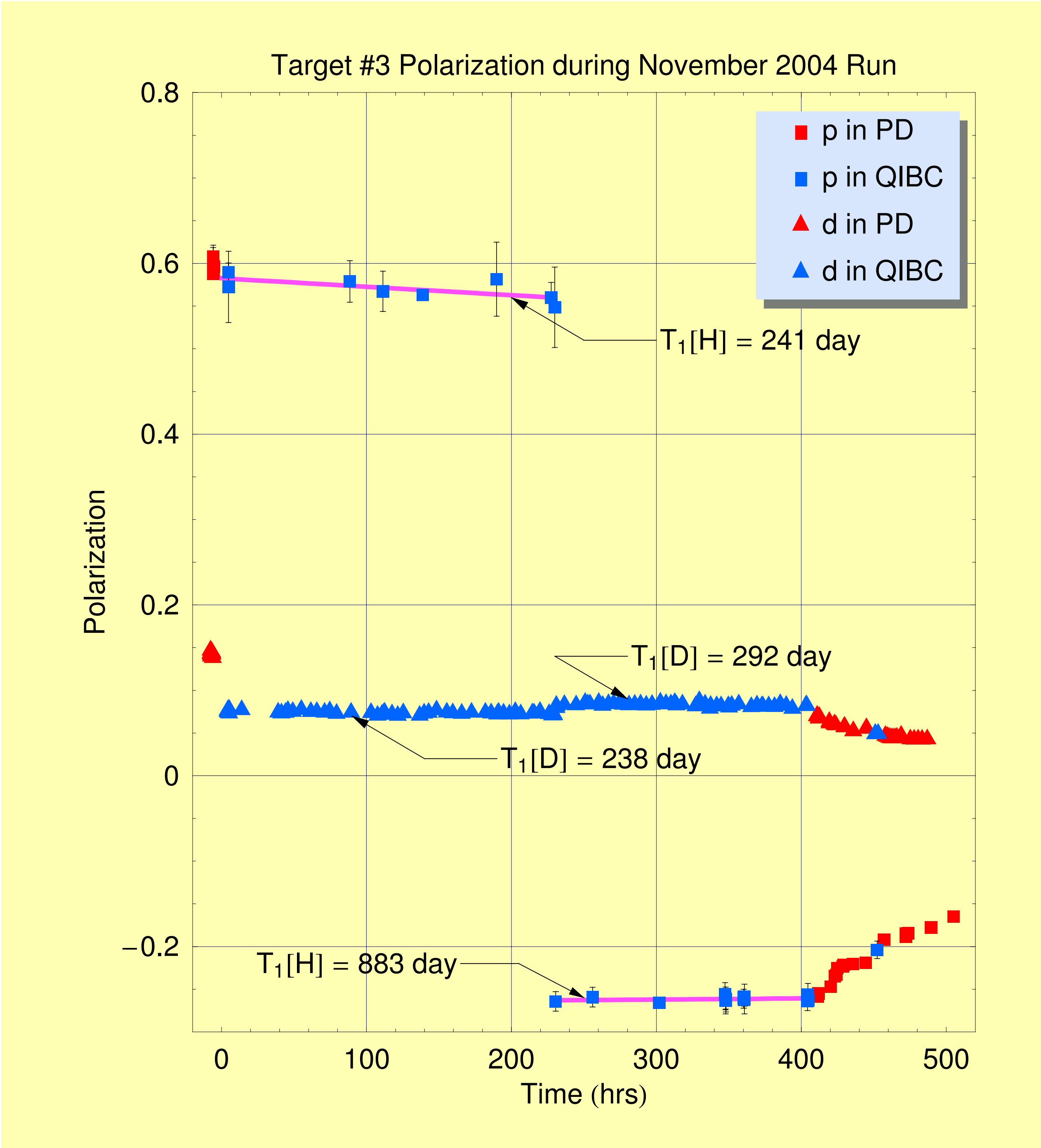
$$\text{NMR Signal} = \frac{2\,V_{out}}{\pi\,\mu_0\,L_0\,V_m\,\mu\,V_{in}\,\eta\,G_1}$$

Deuterium

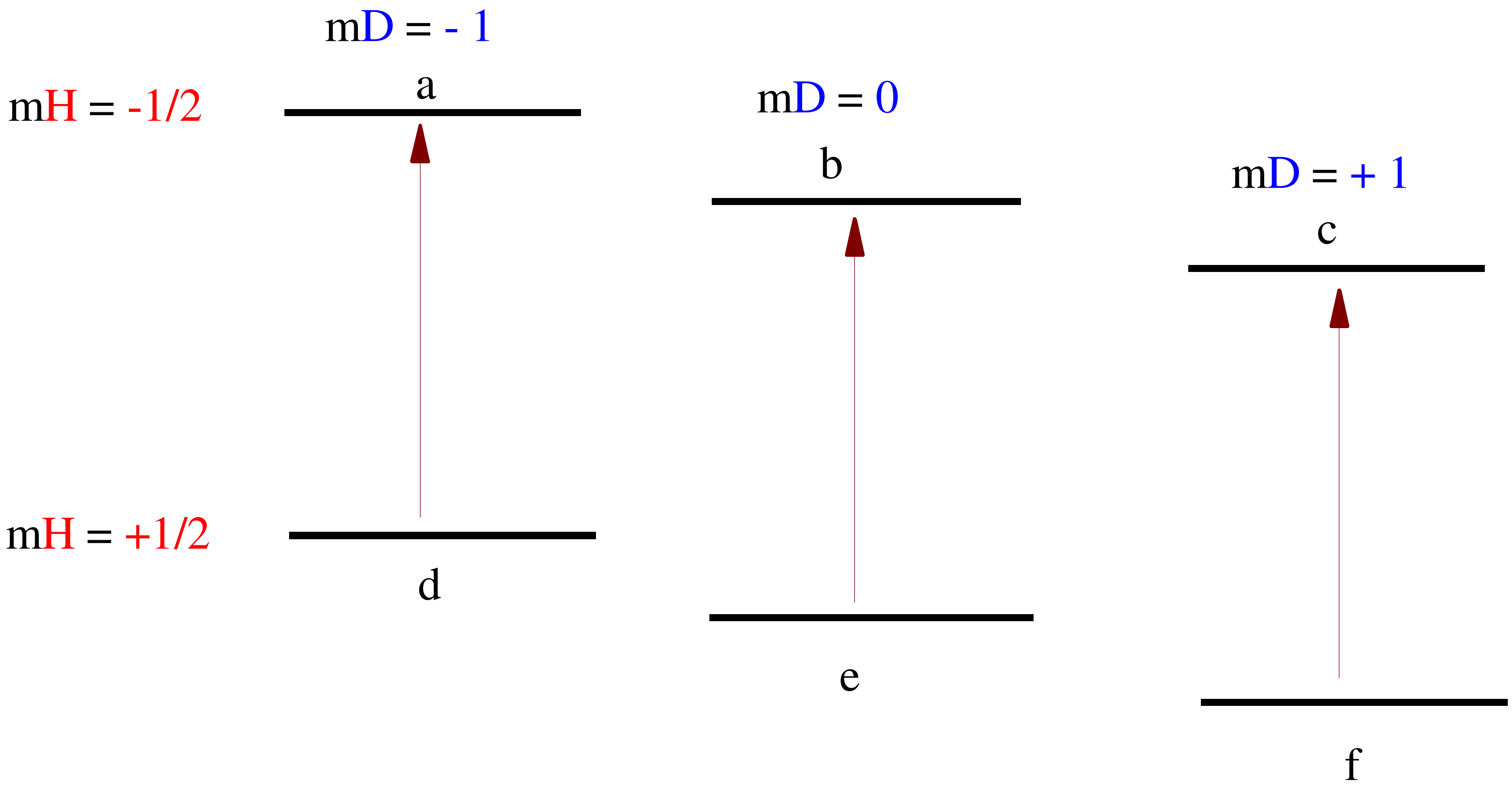


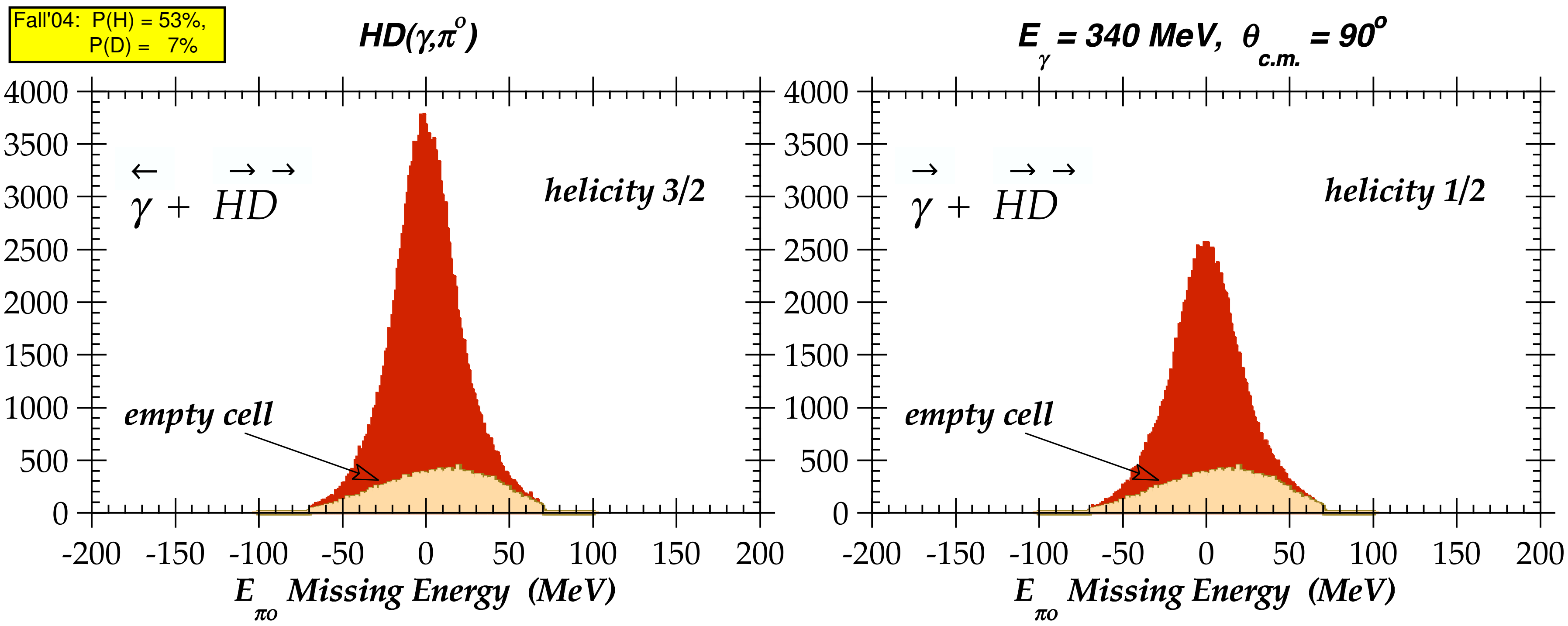
Summary of HD target polarizations during recent runs at LEGS

Year	Duration	$\bar{P}(D)$	$\bar{P}(H)$
Fall 2004	17 days	+ 7 %	+ 53 %, - 26 %
Spring 2005	32 days	+ 31 %	+ 30 %, -7 %


Target #3 Polarization during November 2004 Run
Polarization
Time (hrs)
0.8
0.6
0.4
0.2
0
−0.2
0
100
200
300
400
500
p in PD
p in QIBC
d in PD
d in QIBC
T1[H] = 241 day
T1[D] = 292 day
T1[D] = 238 day
T1[H] = 883 day

Spin transition: H ↑ → H ↓
Allowed fast passage RF transition

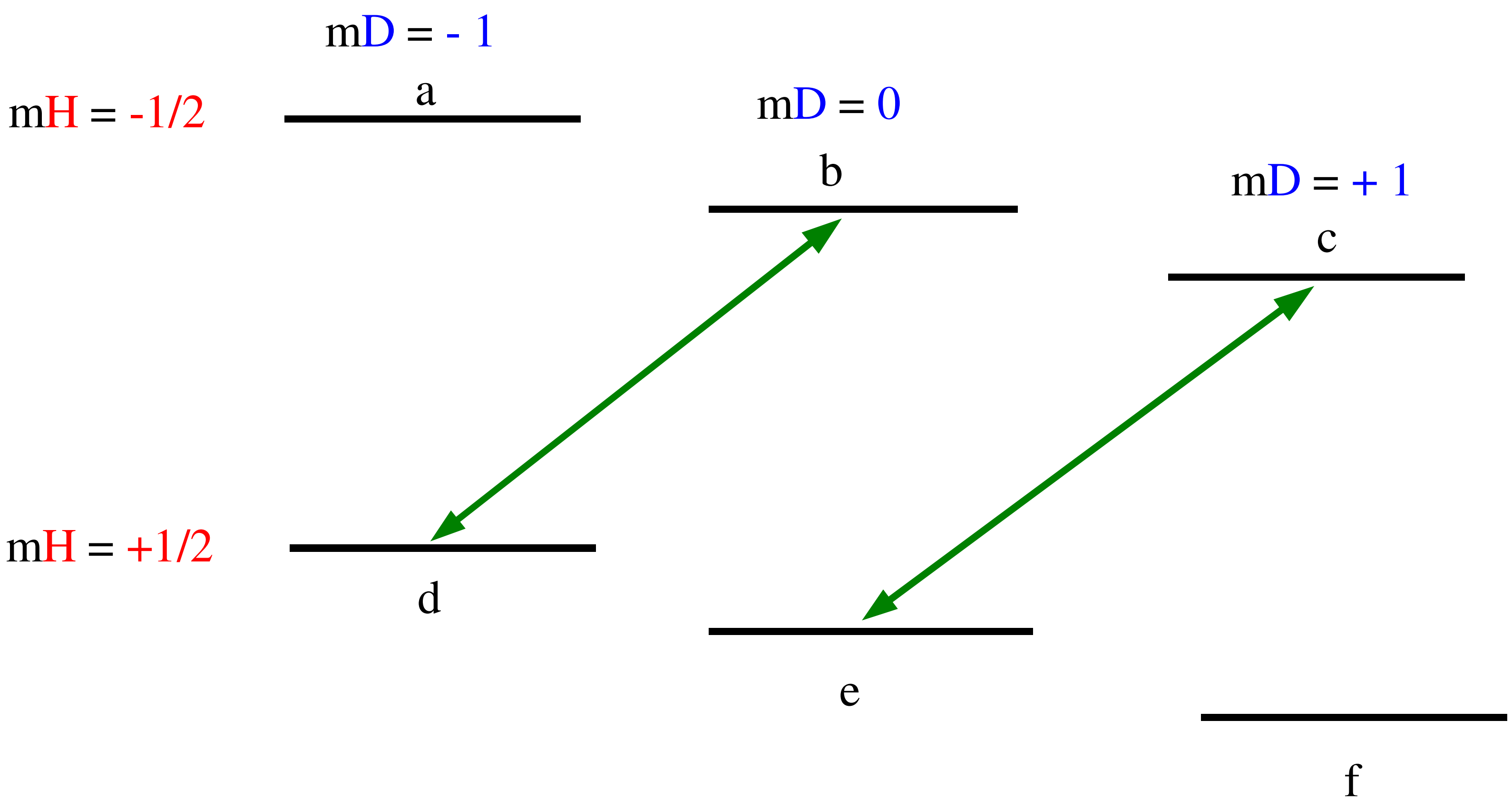




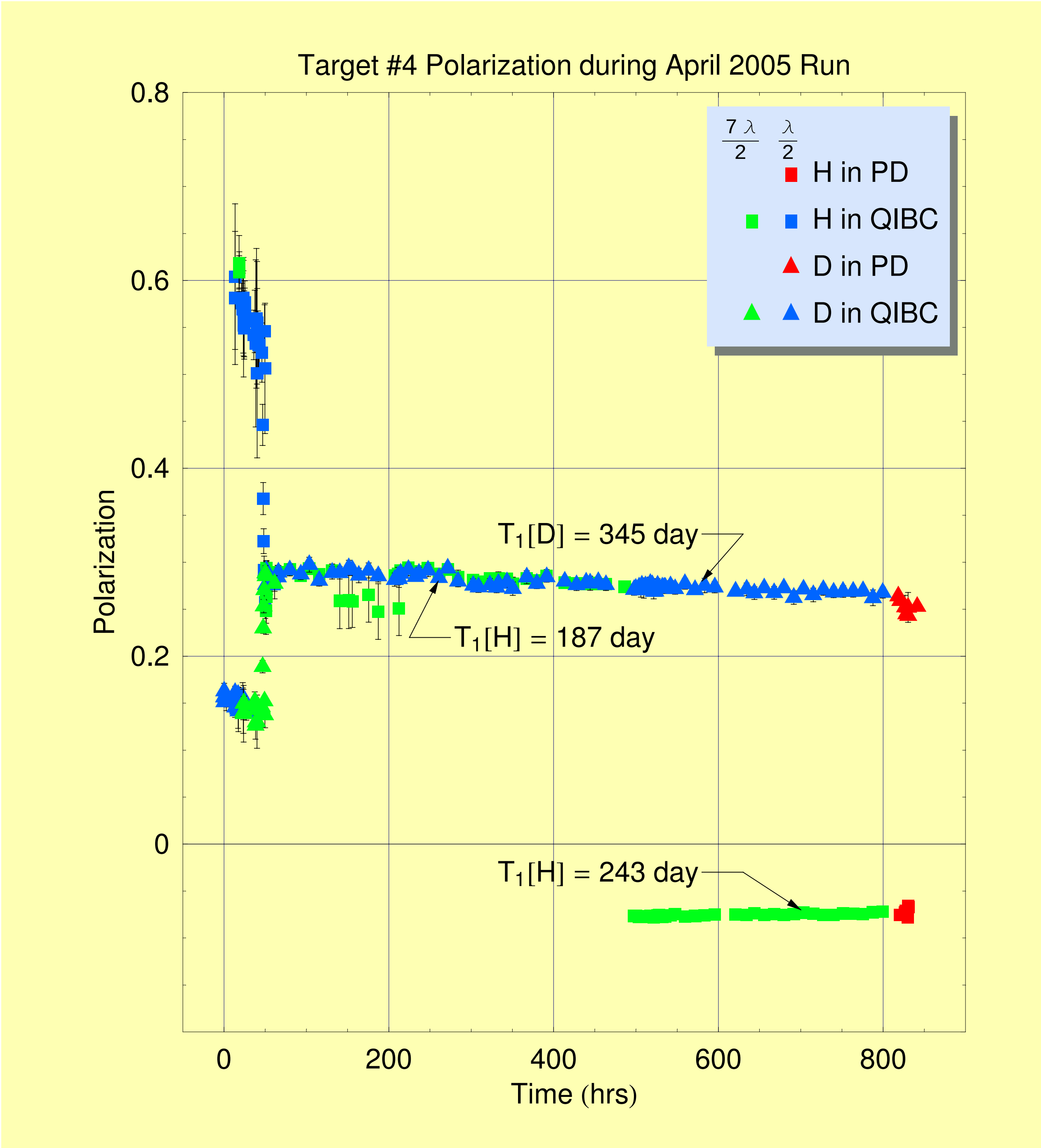
Fall'04: P(H) = 53%,
P(D) = 7%
HD(γ,π^o)
E_γ = 340 MeV, θ_c.m. = 90^o
γ + HD
helicity 3/2
helicity 1/2
empty cell
E_πo Missing Energy (MeV)

Spin transition: $\vec{H} \rightarrow \vec{D}$

Saturated Forbidden RF Transition



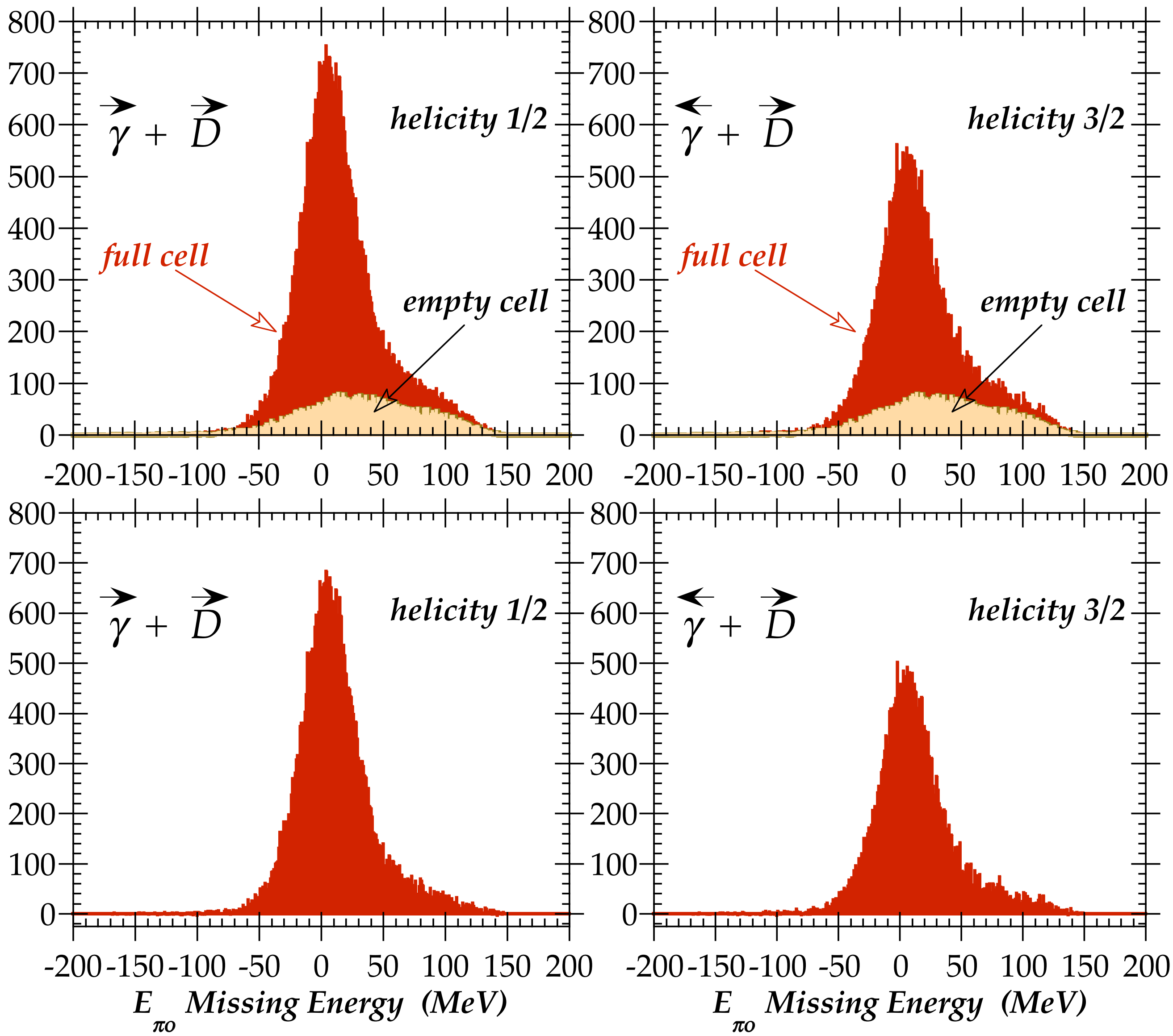
Nd > Nb, Ne > Nc $\longrightarrow$ Nd = Nb, Ne = Nc


Target #4 Polarization during April 2005 Run
0.8
0.6
0.4
0.2
0
Polarization
0
200
400
600
800
Time (hrs)
7 λ / 2
λ / 2
H in PD
H in QIBC
D in PD
D in QIBC
T1[D] = 345 day
T1[H] = 187 day
T1[H] = 243 day

LEGS production run #2, deepUV-1 (Spring'05)

$D(\gamma,\pi^o n)$ $P_\gamma = 92\%$ $P_D = 31\%$

$E\gamma = 341$ MeV $\theta_{cm}(\pi^o n) = 105^o$

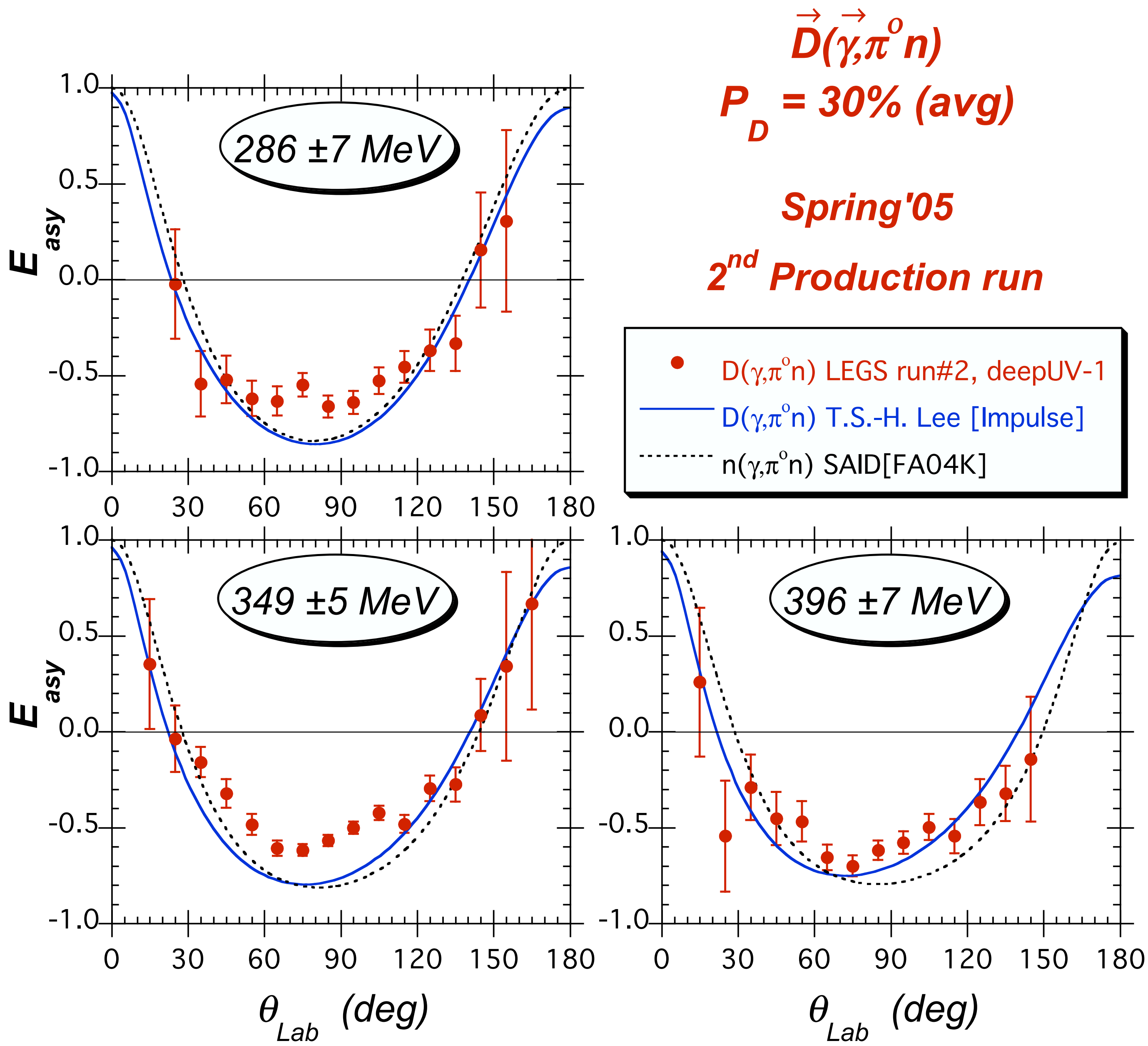


- target cell and Al wires contain the only unpolarizable nucleons;

- background is sampled in runs with an empty cell

D(g,pi0n)341MeV105 full&empty_FS

- very preliminary -



Experiment schedule - through 2006 :

- ✓ Fall'04: $\vec{H}\cdot\vec{D}(\vec{\gamma},\pi^o)$ to extract $\vec{H}(\vec{\gamma},\pi^o)$ and $\vec{H}(\vec{\gamma},\pi^+)$
- ✓ FY'05: $\vec{H}\cdot\vec{D}(\vec{\gamma},\pi^o)$ to extract $\vec{D}(\vec{\gamma},\pi^o)$
- Sept'05-Jan'06: install Time-Projection-Chamber
- Feb'06 -Apr'06: $H_2(\gamma,\pi^+)$, $D_2(\gamma,\pi^\pm)$ calibrations
- May'06 -June'06: $\vec{H}\cdot\vec{D}(\vec{\gamma},\pi^\pm)$ - run 1
- Aug'06 -Sept'06: $\vec{H}\cdot\vec{D}(\vec{\gamma},\pi^\pm)$ - run 2

extract: $\vec{D}(\vec{\gamma},\pi^-)$, $\vec{D}(\vec{\gamma},\pi^+)$, $\vec{H}(\vec{\gamma},\pi^+)$

- Oct'06: expected end of LEGS experiments

Figures of merit for Butanol and HD

target	Low-resolution and Low-Intensity γ-beam (a)	high-resolution Low-Intensity γ-beam (b)	High Intensity γ-beam (c)	Nuclear-background-limited High Intensity γ-beam (d)	Atomic-background-limited High Intensity γ-beam (e)
Figure of merit	$\rho_{eff}\ (P_{eff})^2$	$1.4\ \rho_{eff}\ (P'_{eff})^2$	$(P_{eff})^2$	$(P_{eff})^2/A$	$(P_{eff})^2/Z^2$
p in C_4H_9OH	0.017	0.110	0.23	0.0031	0.0069
n in C_4D_9OD	0.010	0.010	0.18	0.0021	0.0070
p in HD	0.019	0.067	0.45	0.1500	0.4500
n in HD	0.010	0.014	0.46	0.1500	0.4500

(a) count rate is beam-limited; reactions on *p*, *n* distinguished; *bound* vs *free* not distinguished; $P_{eff} = P \bullet f$

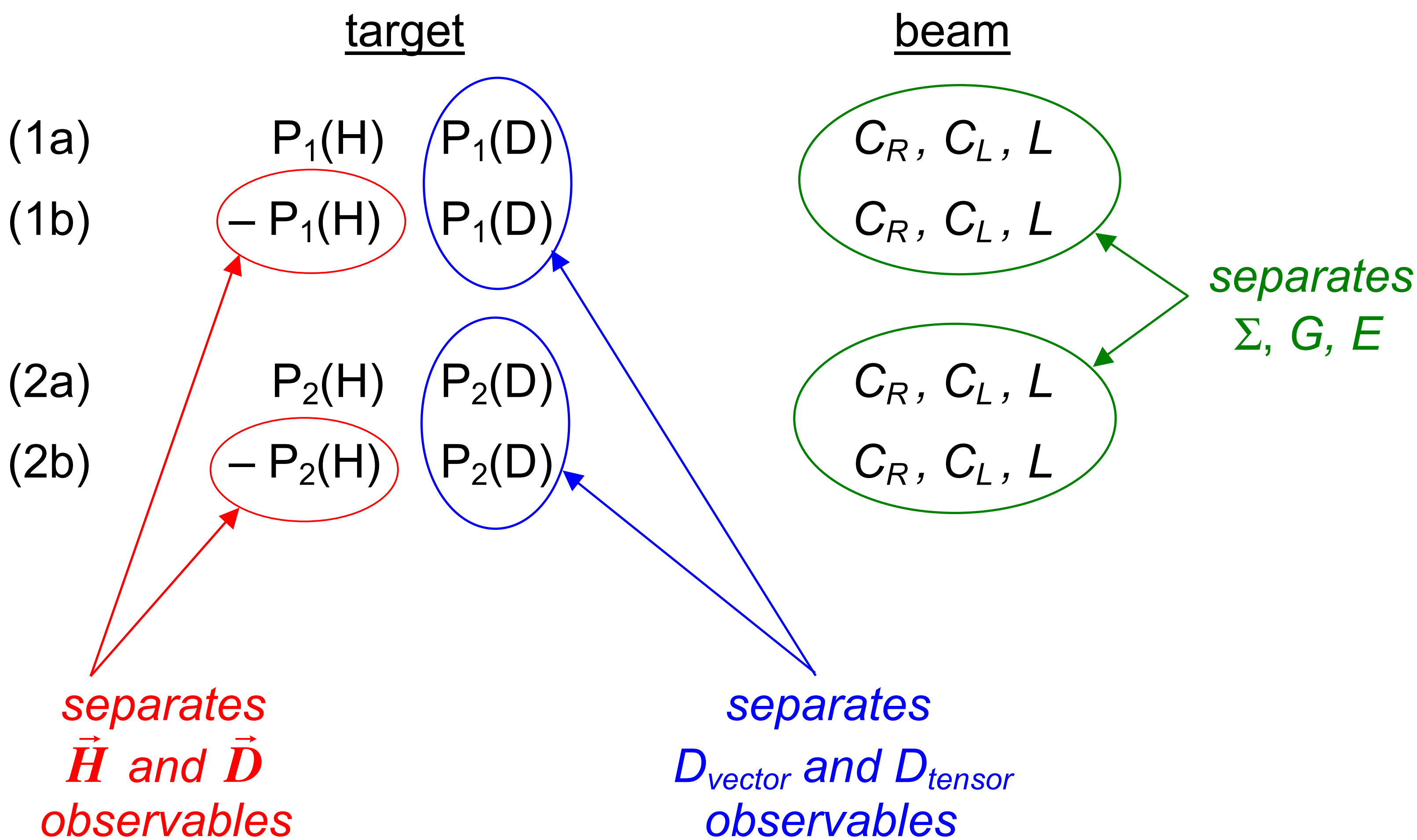
(b) count rate is beam-limited; reactions on *p*, *n* distinguished; *bound* vs *free* distinguished with cut; $P_{eff} = P \bullet [\ P_{free} / (P_{free} + 0.2 \bullet P_{bound})\ ]$

(c) beam flux can be increased as needed; count rate is limited by accidentals; $P_{eff} = P \bullet f$

(d) beam flux can be increased as needed; count rate is limited by dead time from nuclear events; $P_{eff} = P \bullet f$

(e) beam flux can be increased as needed; count rate is limited by dead time from atomic electrons; $P_{eff} = P \bullet f$

Complete set of measurements with longitudinal target polarization:



- example: $\gamma + HD \rightarrow \pi^o$ (from LEGS/BNL)

Separate reactions to n from p with TPC

$$\gamma + n \rightarrow p + \pi^{--}$$

$$\rightarrow n + \pi^{0}$$

Separate !

$$\gamma + p \rightarrow n + \pi^{+}$$

$$\rightarrow p + \pi^{0}$$

Central tracking with magnetic analysis in a Time-Projection Chamber

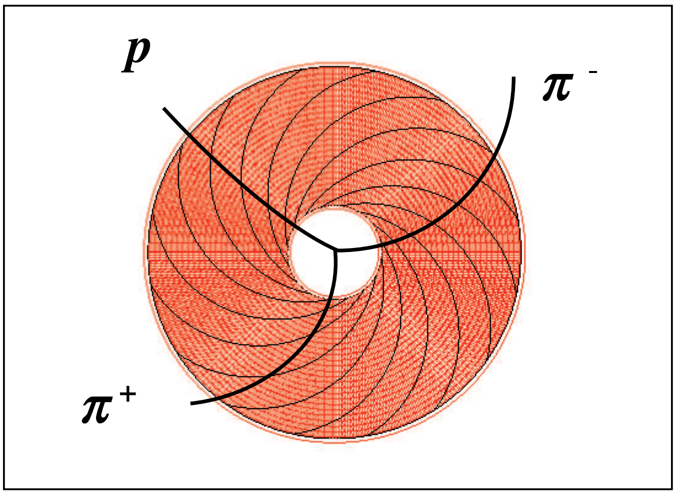
- isolate *neutron* reactions:

$$\gamma + n \rightarrow \pi^- p$$

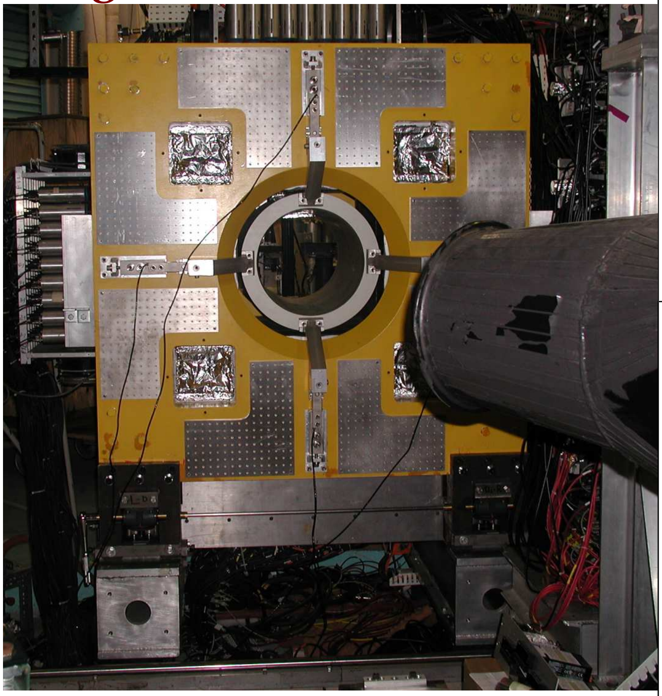
separate

$D(\gamma, \pi^- p)$ from $D(\gamma, \pi^+ n)$

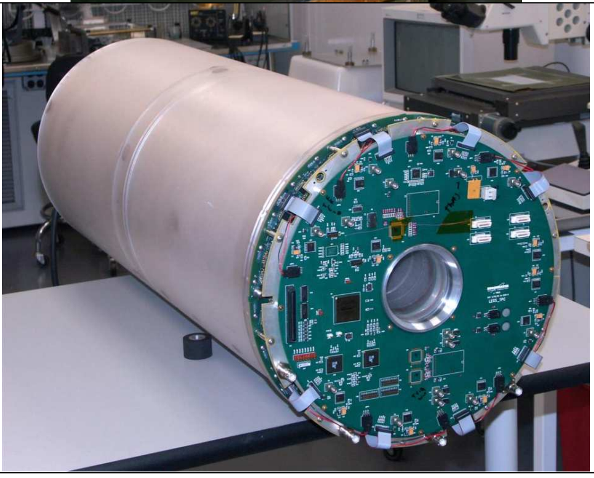
measure the $\pi^\pm$ *charge*



Large-bore 2 tesla solenoid



TPC



LEGS spin experiments

1. Compton backward-scattered polarzied γ beam

$0.17 < E\gamma < 0.42$ GeV

$< P\gamma > \sim 90\ \%$

2. 4 π detector

$(\sigma_{1/2} - \sigma_{3/2})/ E\gamma$;

Total cross sections

3. Polarized HD solid target

The LEGS-Spin Collaboration

- Brookhaven National Laboratory
  A. Caracappa, S. Hoblit, O. Kistner, F. Lincoln, L. Miceli, M. Lowry, **A.M. Sandorfi** *, C. Thorn, X. Wei
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- James Madison University
  C. S. Whisnant
- Norfolk State University
  M. Khandakar
- Ohio University
  C. Bade, **K. Hicks** *, M. Lucas, J. Mahon, S. Kizigul
- Syracuse University
  A. Honig
- University di Roma - Tor Vergata
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- University of South Carolina
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- University of Virginia
  S. Kucuker, R. Lindgren, B. Norum, K. Wang
- Virginia Polytechnic Institute & State University
  M. Blecher, T. Kageya

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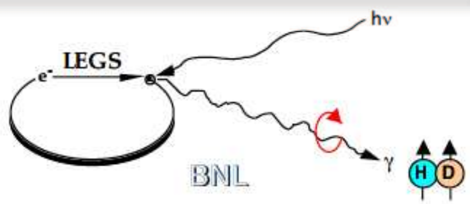
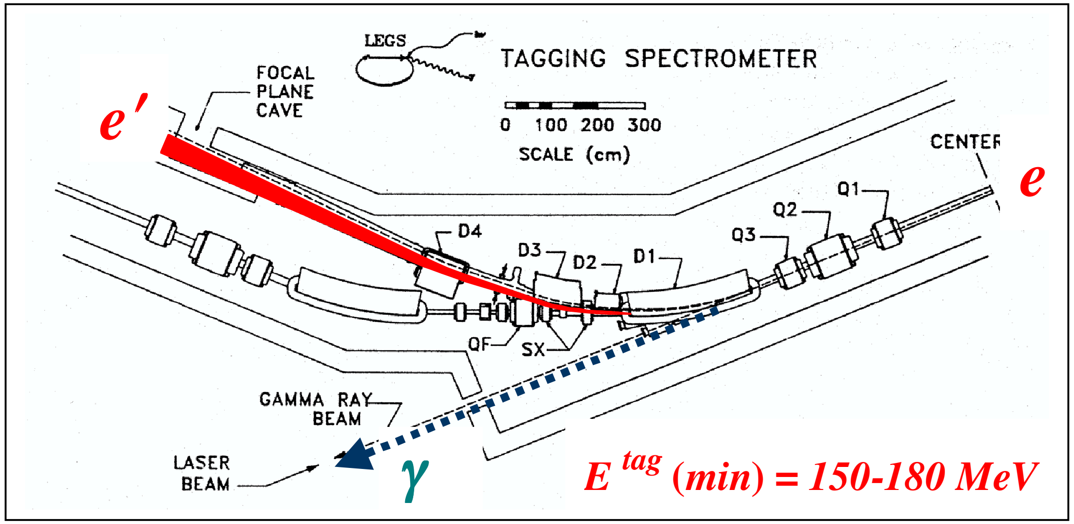
10 institutions in

3 countries

Post-Docs (NSF)
Grad Students
* LSC Executive com



Laser-Electron-Gamma-Source (LEGS)

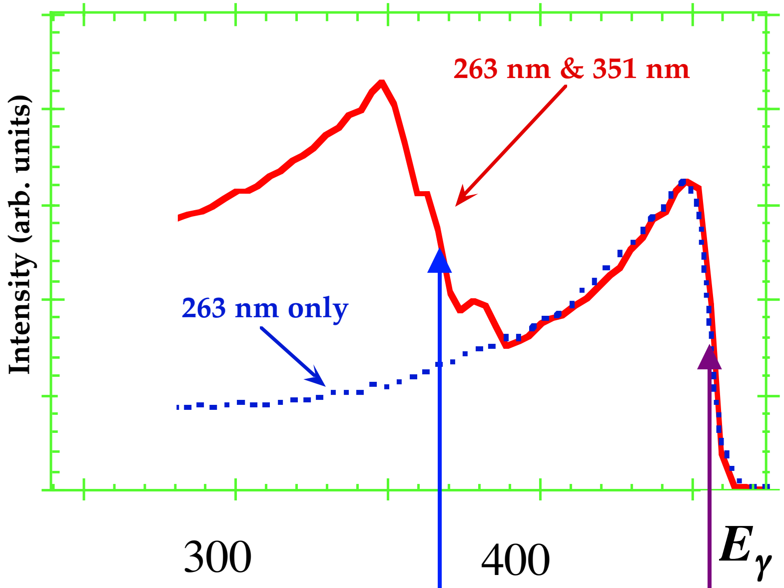


NSLS $E_e = 2.8$ ***GeV***

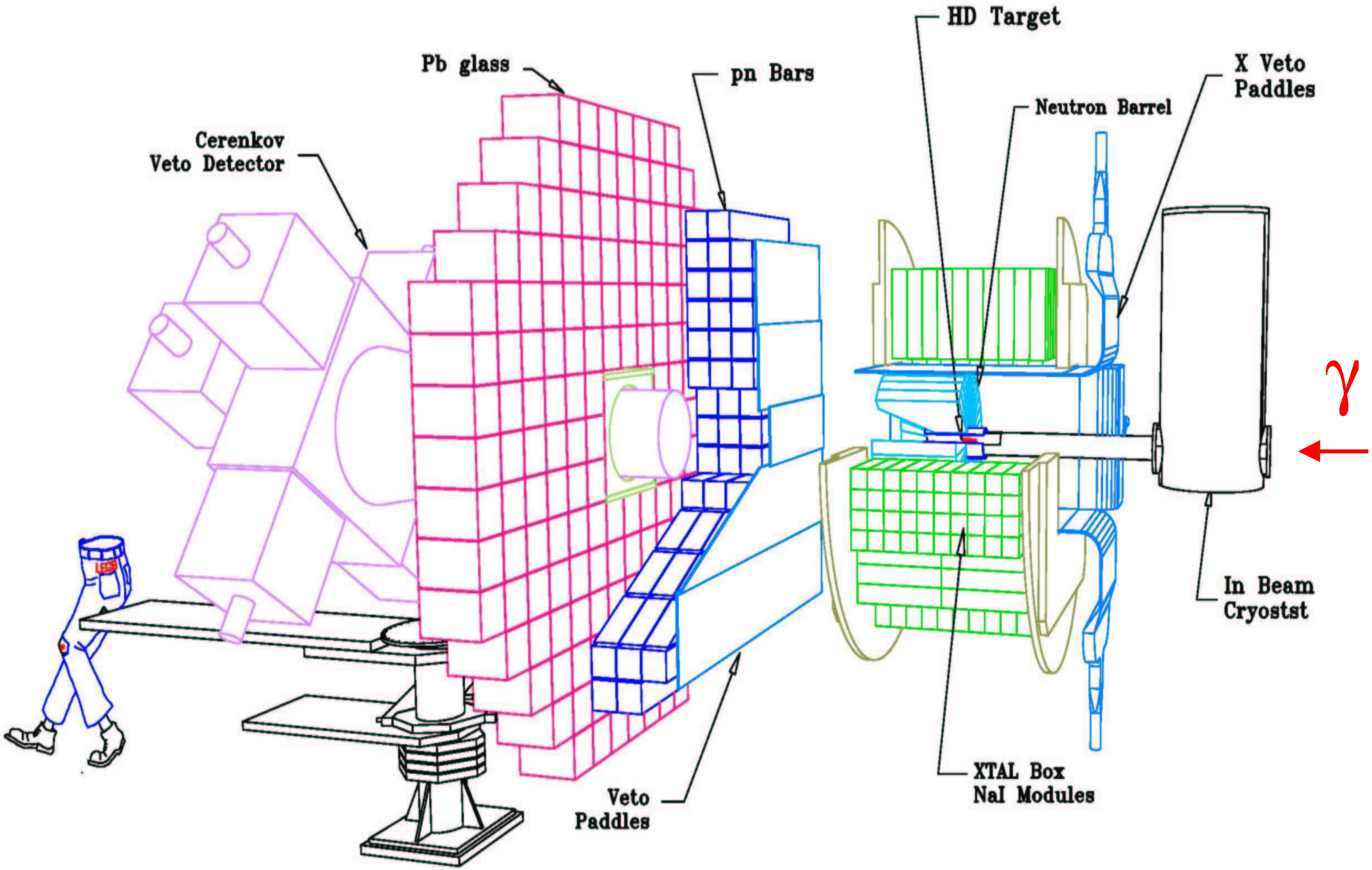
γ beam energy determined by e′ tagging

$$E_\gamma = E_e - E_{e'}\ , \quad \Delta E_\gamma = 3\ \text{MeV}$$

	4ω Nd-YLF ring laser	Ar-Ion laser			
λ(nm)	263	300	351	488	515
E_γ *(max)*	*471 MeV*	*421 MeV*	*368 MeV*	*275 MeV*	*262 MeV*



SASY Current Setup



Separating $\vec{H}$ and $\vec{D}$ data with spin flip - *example, π^o production*

Run A: $\vec{H}\cdot\vec{D}$ **with parallel spins**

$$\sigma^{A}_{\vec{\gamma}_L} = \sigma\left[\vec{p}(\overleftarrow{\gamma},\pi^{o})\right] + \sigma\left[\vec{D}(\overleftarrow{\gamma},\pi^{o})\right]$$

$$\sigma^{A}_{\vec{\gamma}_R} = \sigma\left[\vec{p}(\vec{\gamma},\pi^{o})\right] + \sigma\left[\vec{D}(\vec{\gamma},\pi^{o})\right]$$

Run B: $\overleftarrow{H}\cdot\vec{D}$ **with anti-parallel spins**

$$\sigma^{B}_{\vec{\gamma}_L} = \sigma\left[\overleftarrow{p}(\overleftarrow{\gamma},\pi^{o})\right] + \sigma\left[\vec{D}(\overleftarrow{\gamma},\pi^{o})\right]$$

$$\sigma^{B}_{\vec{\gamma}_R} = \sigma\left[\overleftarrow{p}(\vec{\gamma},\pi^{o})\right] + \sigma\left[\vec{D}(\vec{\gamma},\pi^{o})\right]$$

$$\Delta\sigma(p) = \left(\sigma_{3/2} - \sigma_{1/2}\right)_p = \left[\sigma^{B}_{\vec{\gamma}_R} - \sigma^{A}_{\vec{\gamma}_R}\right] + \left[\sigma^{A}_{\vec{\gamma}_L} - \sigma^{B}_{\vec{\gamma}_L}\right] \quad \textit{from } \gamma p \rightarrow \pi^{o} p$$

$\Rightarrow$

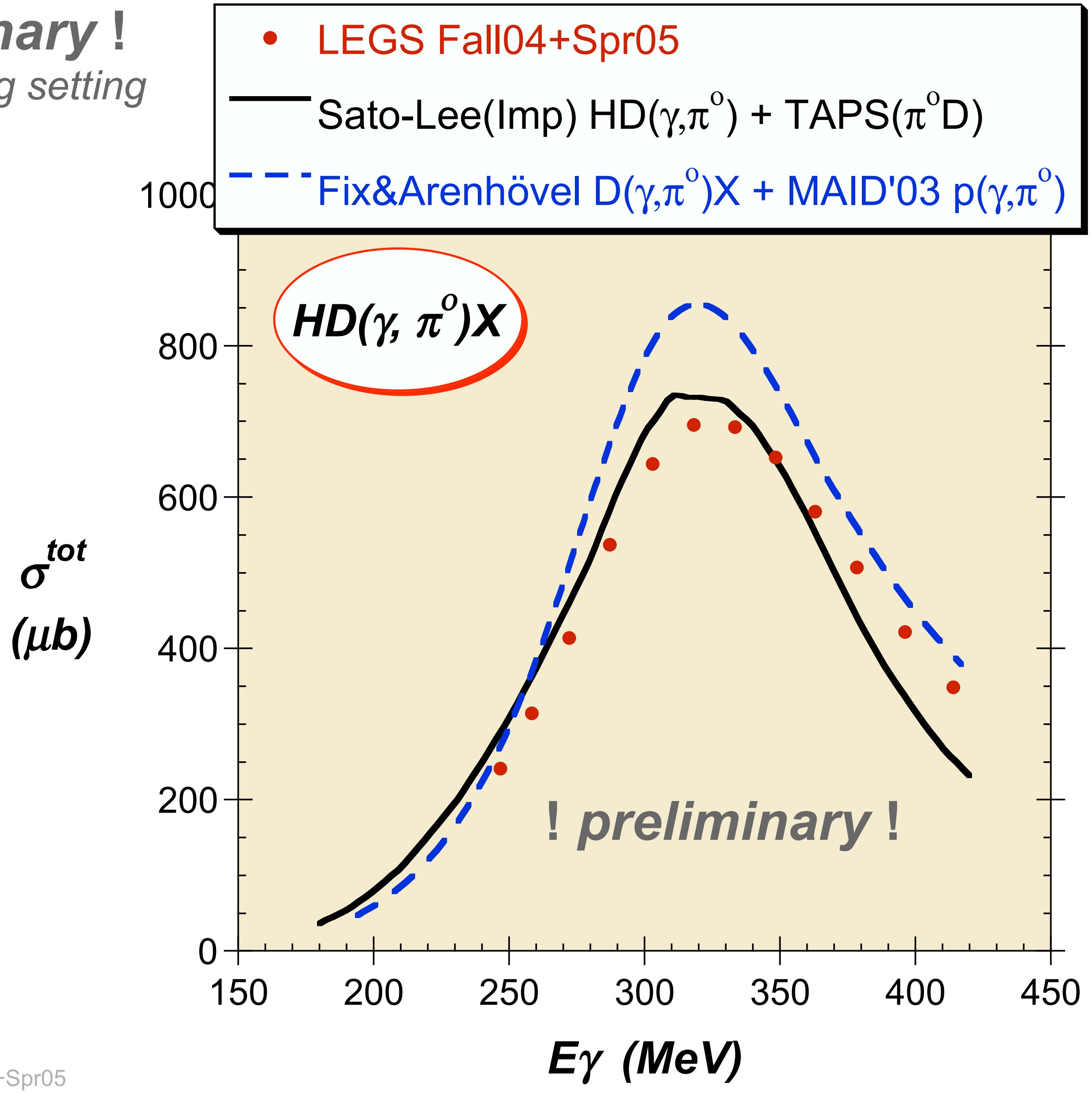
$$\Delta\sigma(D) = \left(\sigma_{3/2} - \sigma_{1/2}\right)_D = \left[\sigma^{A}_{\vec{\gamma}_L} - \sigma^{B}_{\vec{\gamma}_R}\right] + \left[\sigma^{B}_{\vec{\gamma}_L} - \sigma^{A}_{\vec{\gamma}_R}\right] \quad \textit{from } \gamma D \rightarrow \pi^{o} X$$

- similarily, runs with different P_D separate Vector and Tensor D-observables

- in general, one fits out different observables from runs with different polarizations

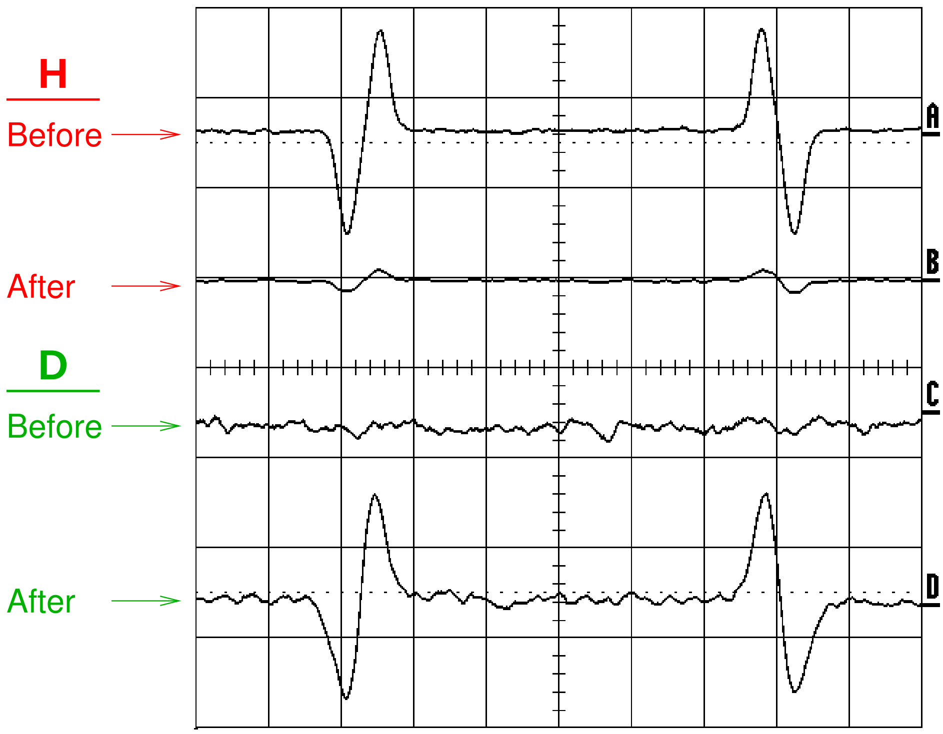
! *preliminary* !

3/4 of High tag setting



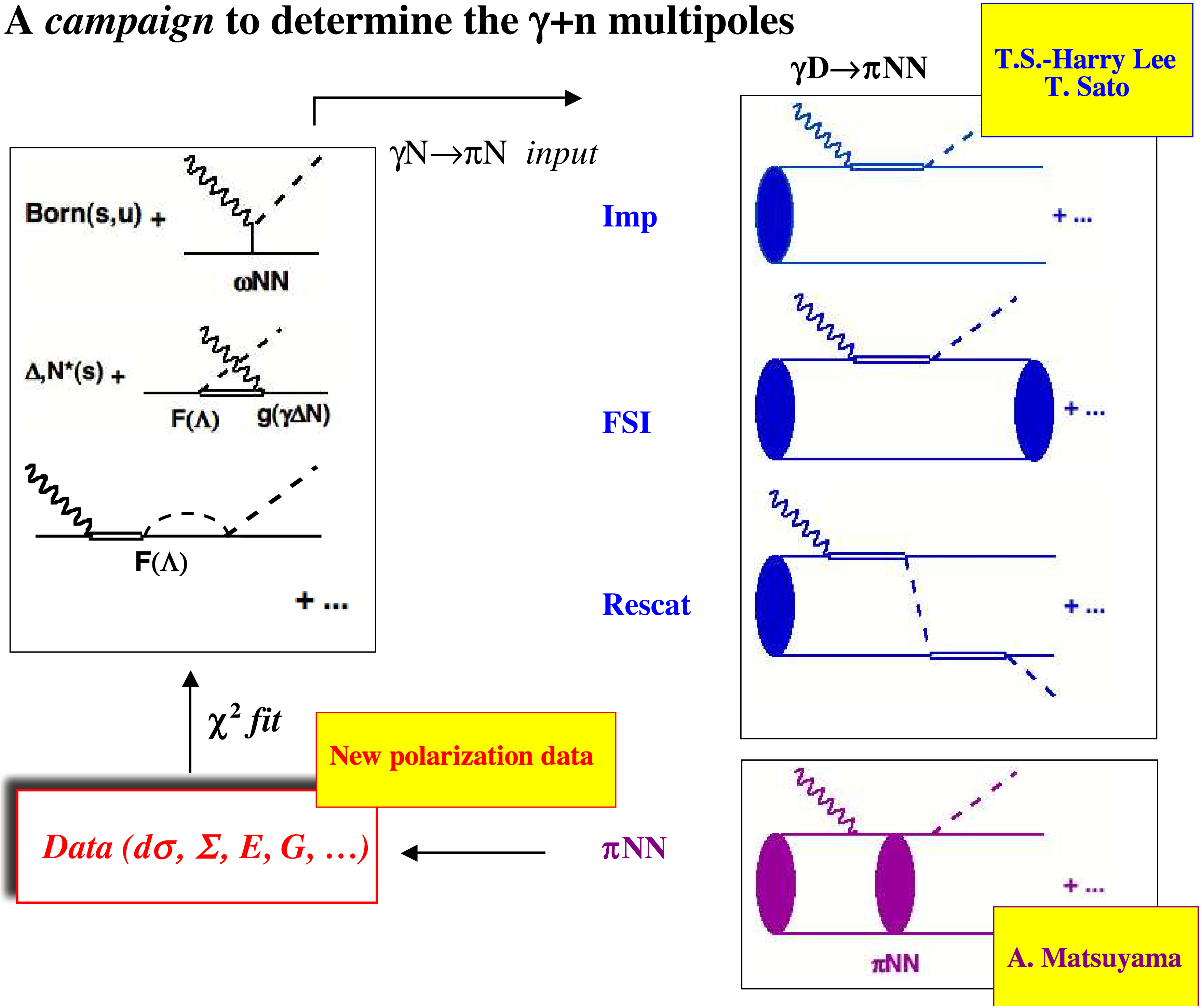
XSC HD(g,pi0)X Fall04+Spr05

Forbidden Adiabatic Fast Passage

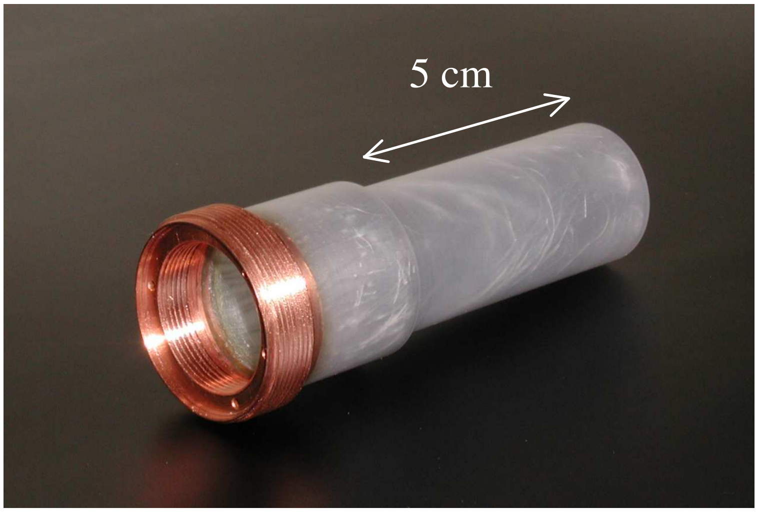


Efficiency of transfer = 67%

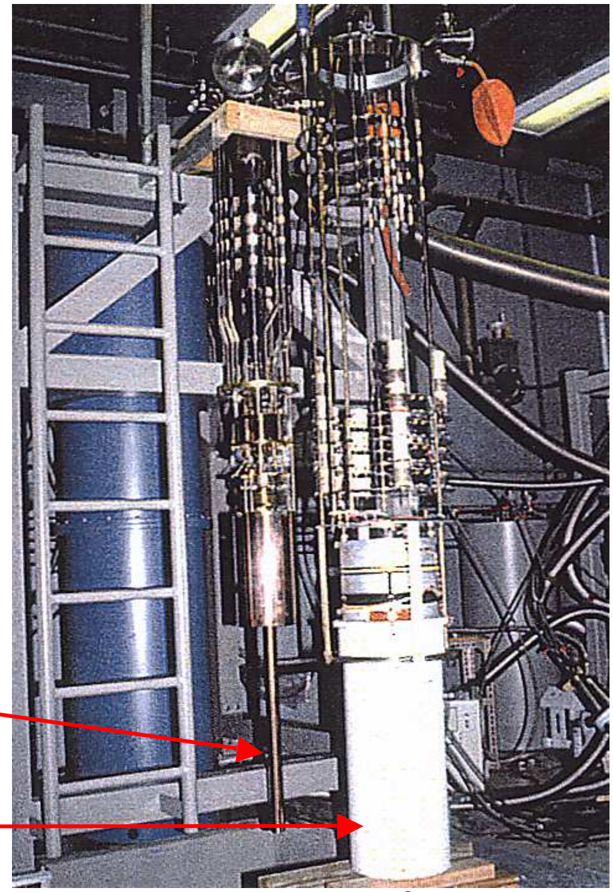
A *campaign* to determine the γ+n multipoles



HD target cycle:

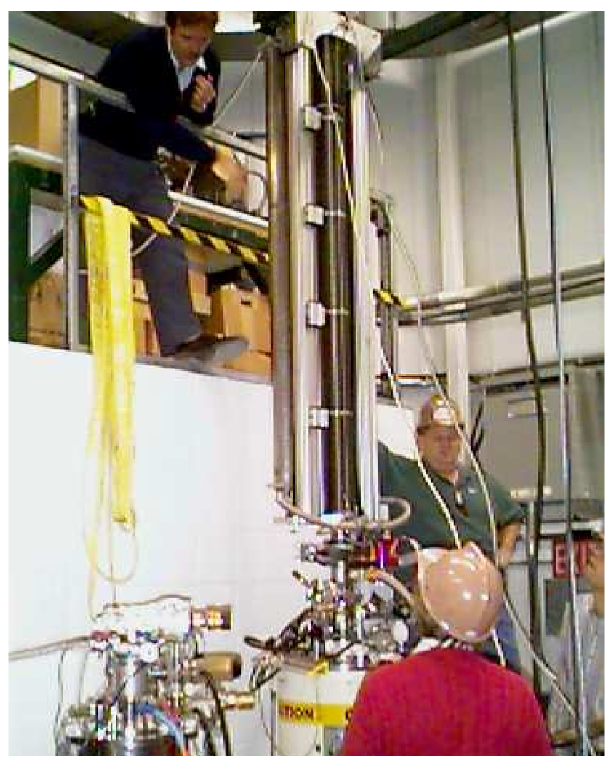


target injection into dilution fridge;
~min 45 days at 15 Tesla / 12 mK



extraction with Transfer-Cryostat

- **2.5°K and 0.120 T**



loading In-Beam-Cryostat

- **0.25°K and 1.00 Tesla**