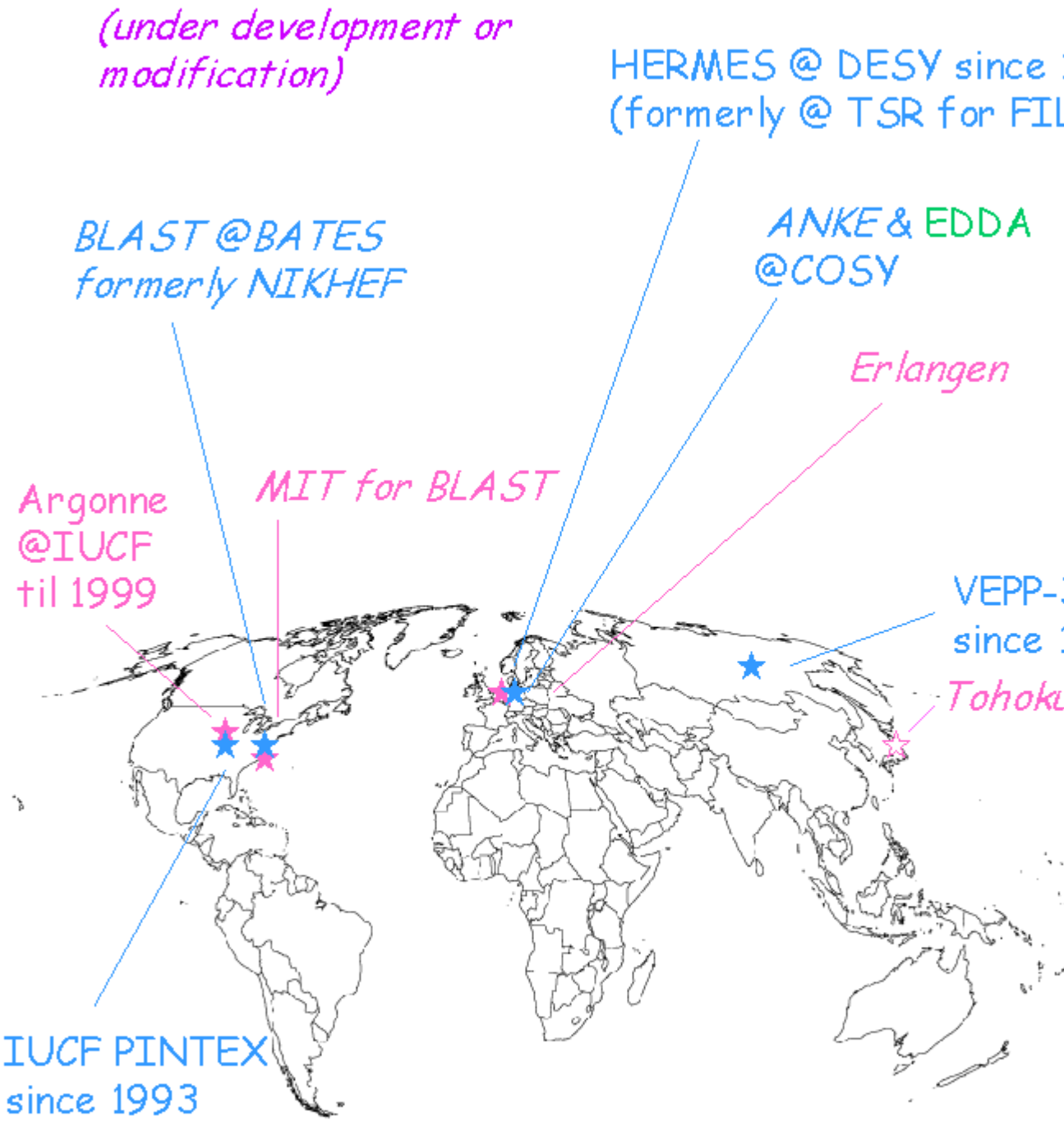
review of polarized, internal deuterium target

B. von Przewoski

Charlottesville

4/18/02

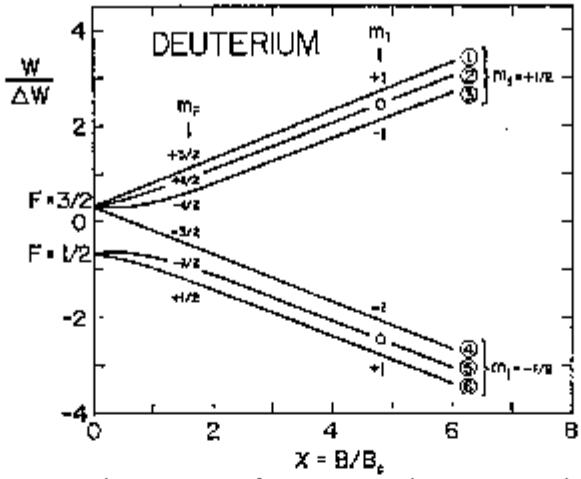

(under development or modification)
HERMES @ DESY since
(formerly @ TSR for FIL
BLAST @BATES formerly NIKHEF
ANKE & EDDA @COSY
Erlangen
MIT for BLAST
Argonne @IUCF til 1999
VEPP-
since
Tohoku
IUCF PINTEX since 1993
Atomic Beam Sources
Laser Driven Sources
only used for H free jet as planned for RHIC

vector polarization

$P_z = N_{m_I=+1} - N_{m_I=-1}$

tensor polarization

$P_{zz} = 1 - 3N_{m_I=0}$

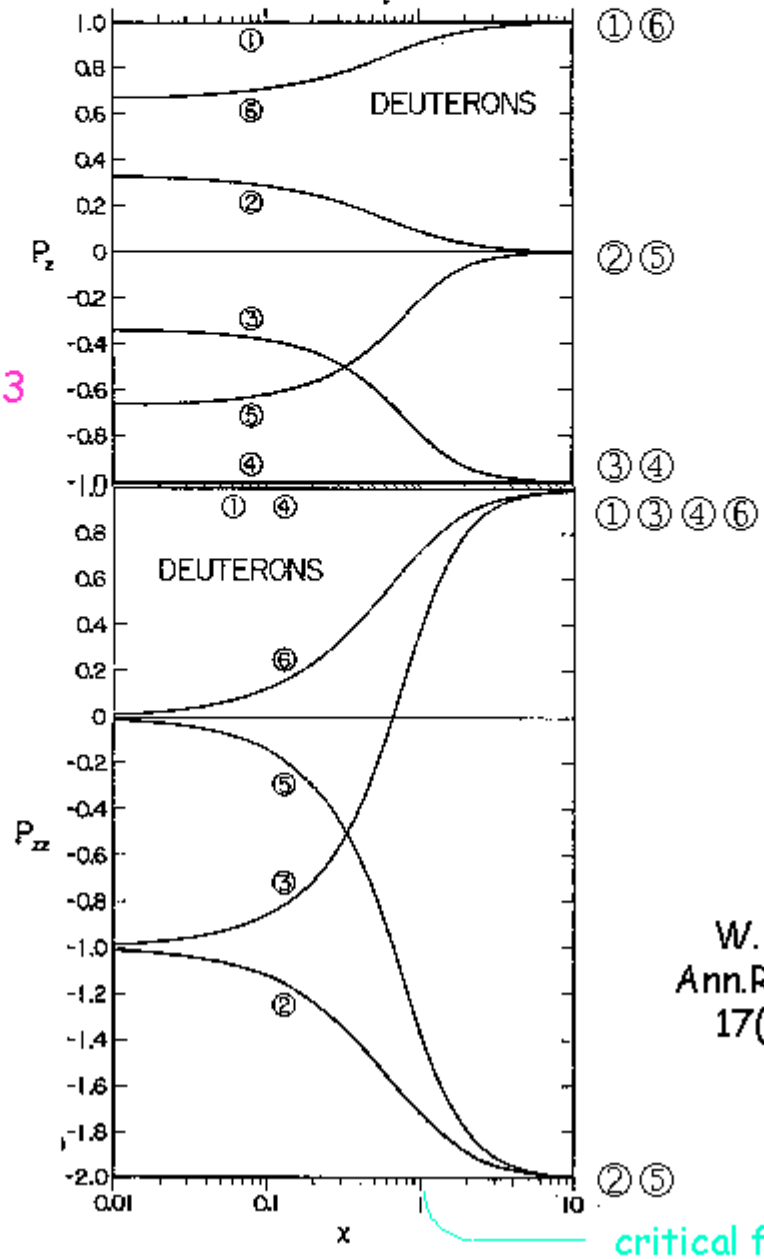


Stern-Ger
→states ①

example:
states ①②③
in a weak field

$P_z = \frac{1 + 1/3 - 1/3}{3} = 1/3$

$P_{zz} = \frac{1 - 1 - 1}{3} = -1/3$



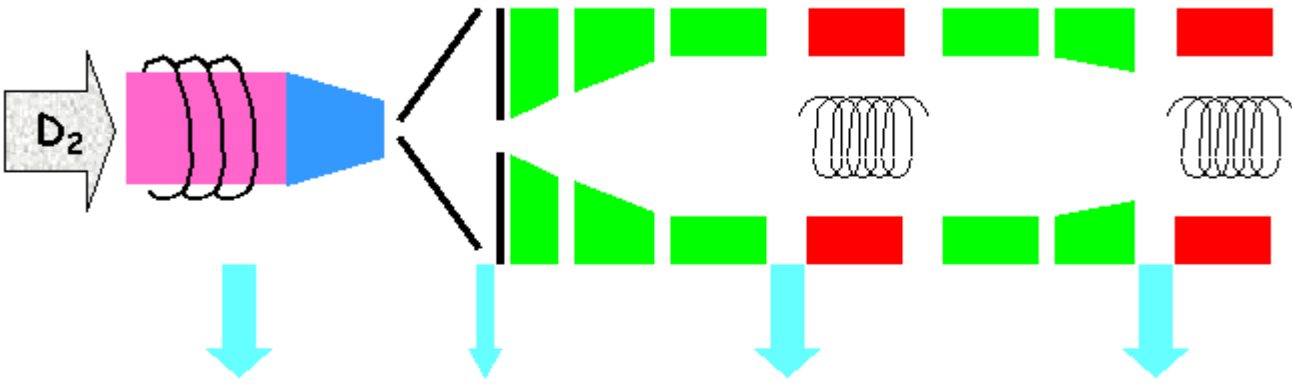
①⑥
②⑤
③④
①④
①③④⑥
②⑤

W. Haebe
Ann.Rev.Nuc
17(1967)3

no $P_{zz} = -2$ in
weak field

critical field = 1

Atomic Beam Source



~5000l/s ~2500l/s ~5000l/s ~2000l/s

Pumping: typically 4 stages

dissociator: 50 - 300 W, 10-30 MHz, ~80% dissociation fraction, 0.1% O_2 admixture

cooled nozzle: LN_2 or coldhead 80-100 K, 99.5% Alu

Skimmer, collimator

sextupole systems: Stern-Gerlach separation; newer sources have permanent magnets ~1.5 T Pole tip field

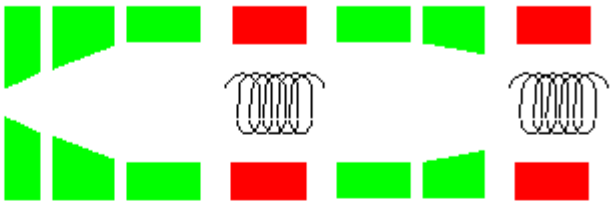
RF transition units: MF, WF oe SF, ~95 - 97% effic

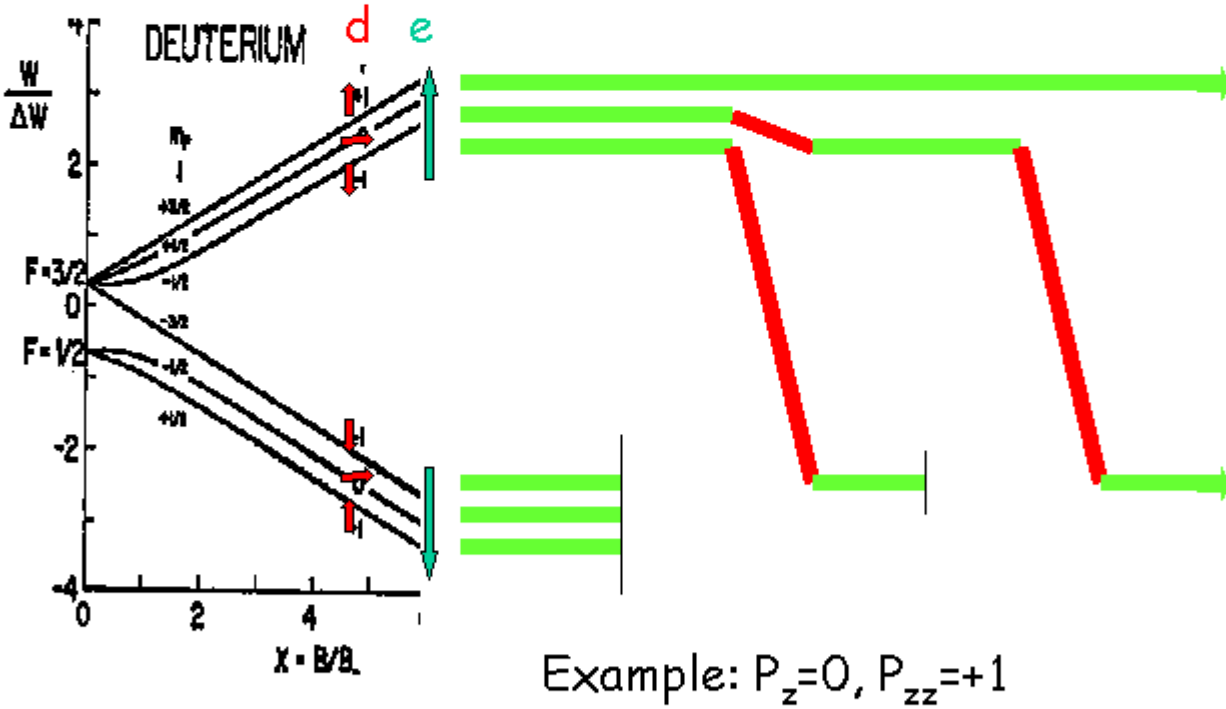
-> pure vector or tensor polarization possible

Wisconsin ABS at IUCF

T. Wise et al., NIM A336 (1993)

2MF transition units, 30 MHz, permanent magnets



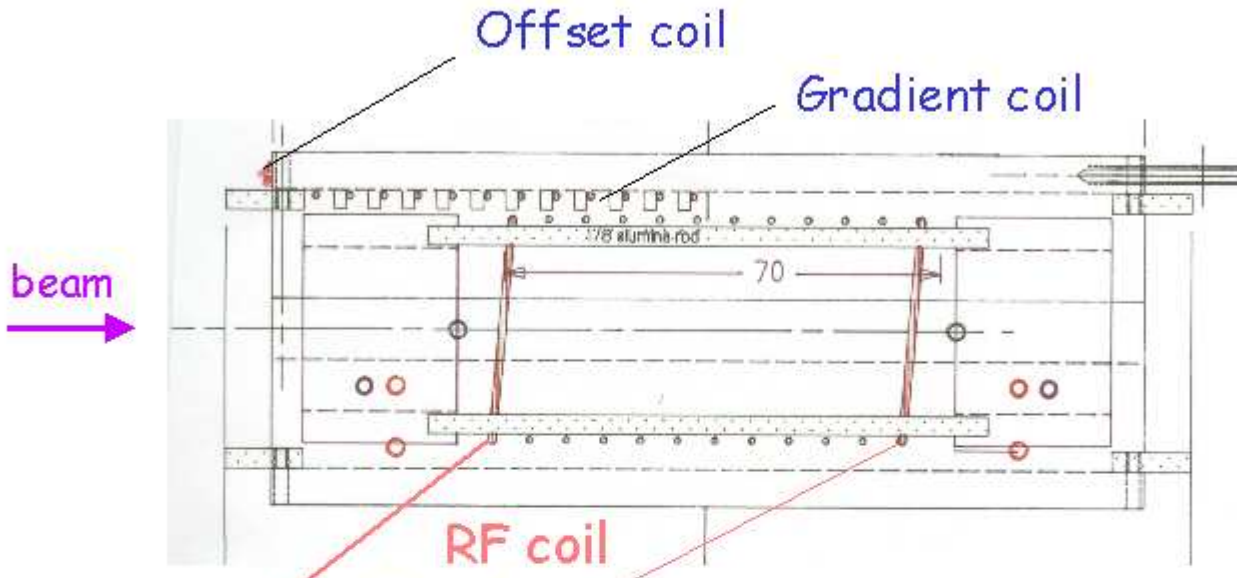


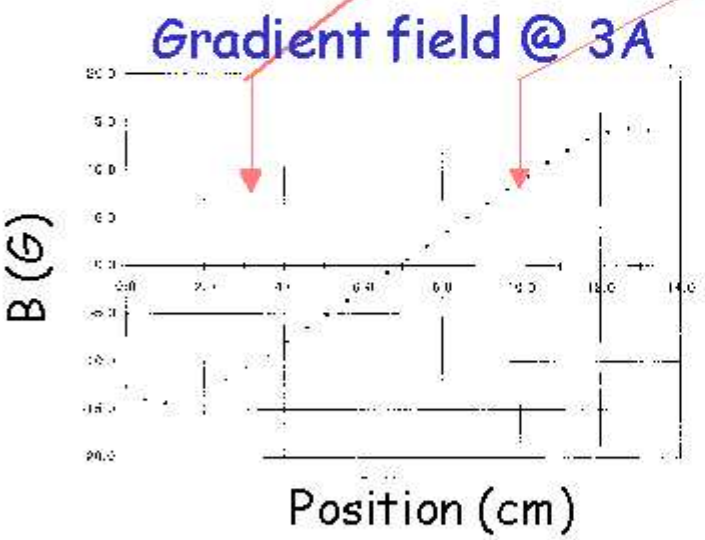
Example: $P_z=0$, $P_{zz}=+1$

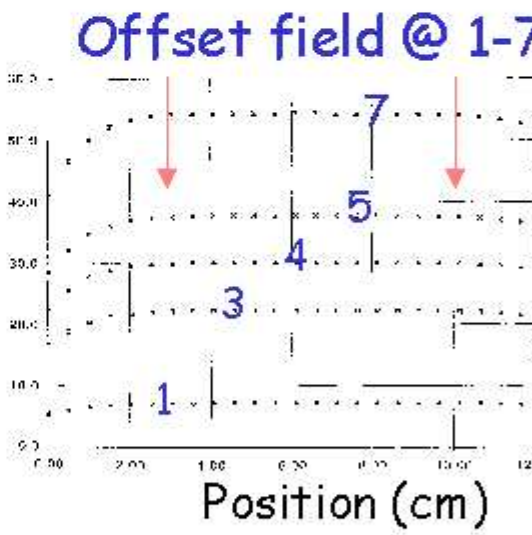
tensor: spin reversal with TUs

vector: spin reversal with holding field over target

computer controlled fields (PINTEX ABS @IUCF



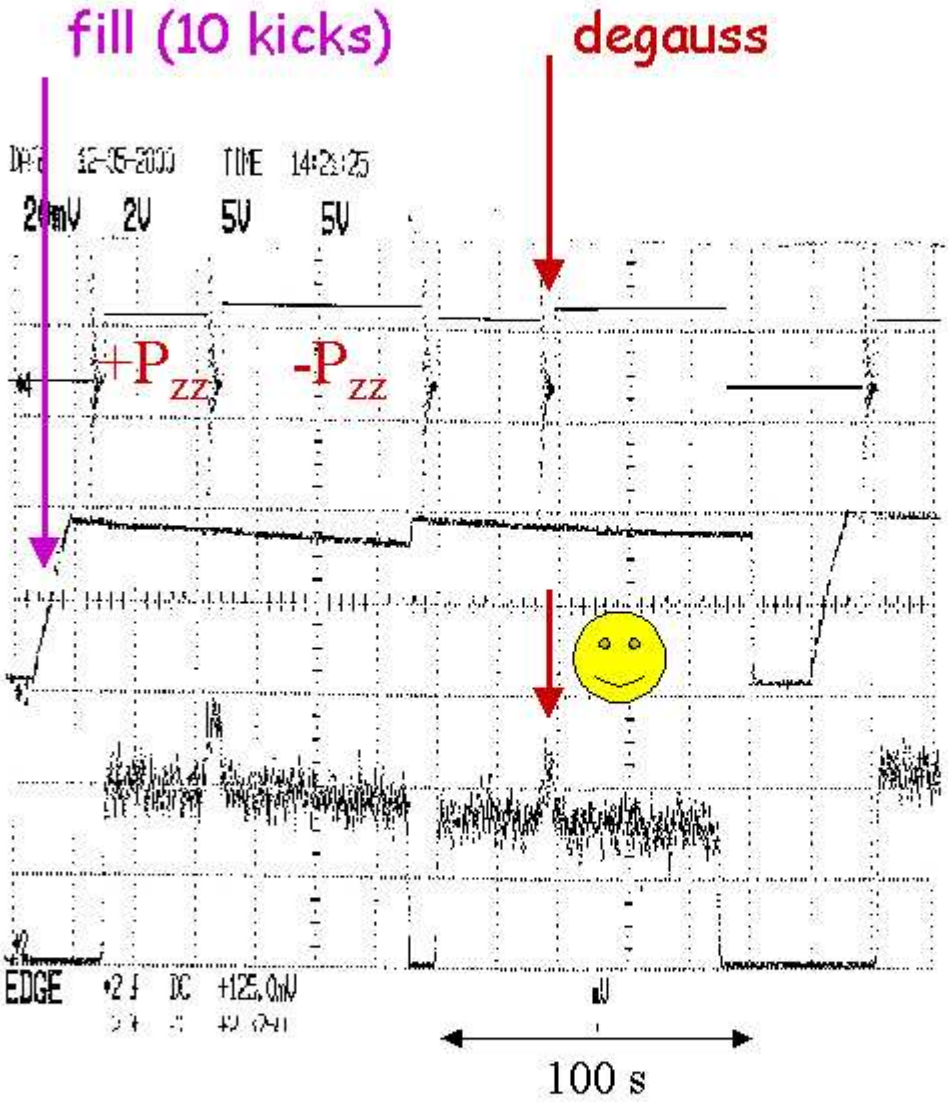




Alternate target polarization between

Tensor (+/-) and vector during Cooler cy

IUCF Cooler Cycle Scenario

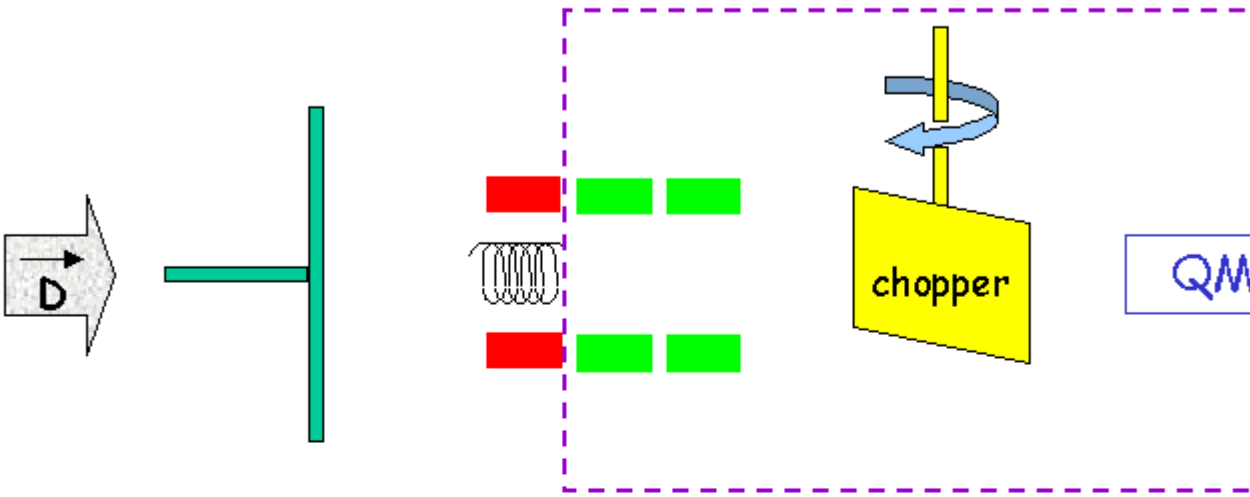


135 MeV

200 MeV

Next cycle

Breit-Rabi polarimeter (=inverted ABS)



need to know: atomic fraction, molecular polarizatio
samples central part of cell→ corrections

electron polarimeter → P_e

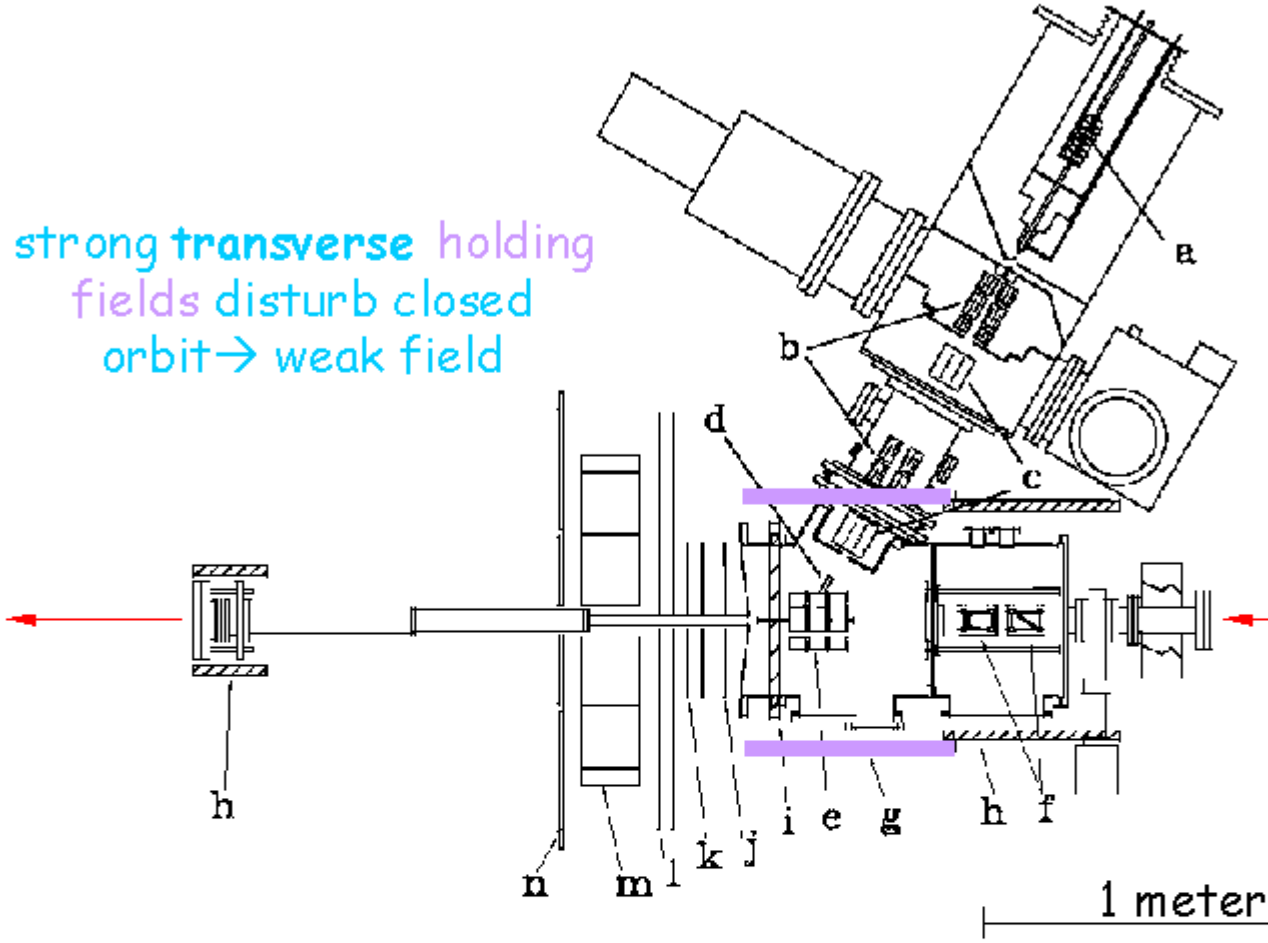
OR:

nuclear reaction, e.g. d(p,p)d, d(p,2p)n, t(d,n)α

need to know analyzing power

PINTEX ABS @ IUCF

strong **transverse** holding fields disturb closed orbit→ weak field



a: dissociator

b: sextupoles

c: transition units

d: storage cell

e: silicon barrel

f: beam position monitors

g: holding field coil

h: correction coils

i: holding field coil

j: start scintillator (ΔE

k: xy wire chamber

l: uv wire chamber

m: scintillator (E)

n: veto scintillator

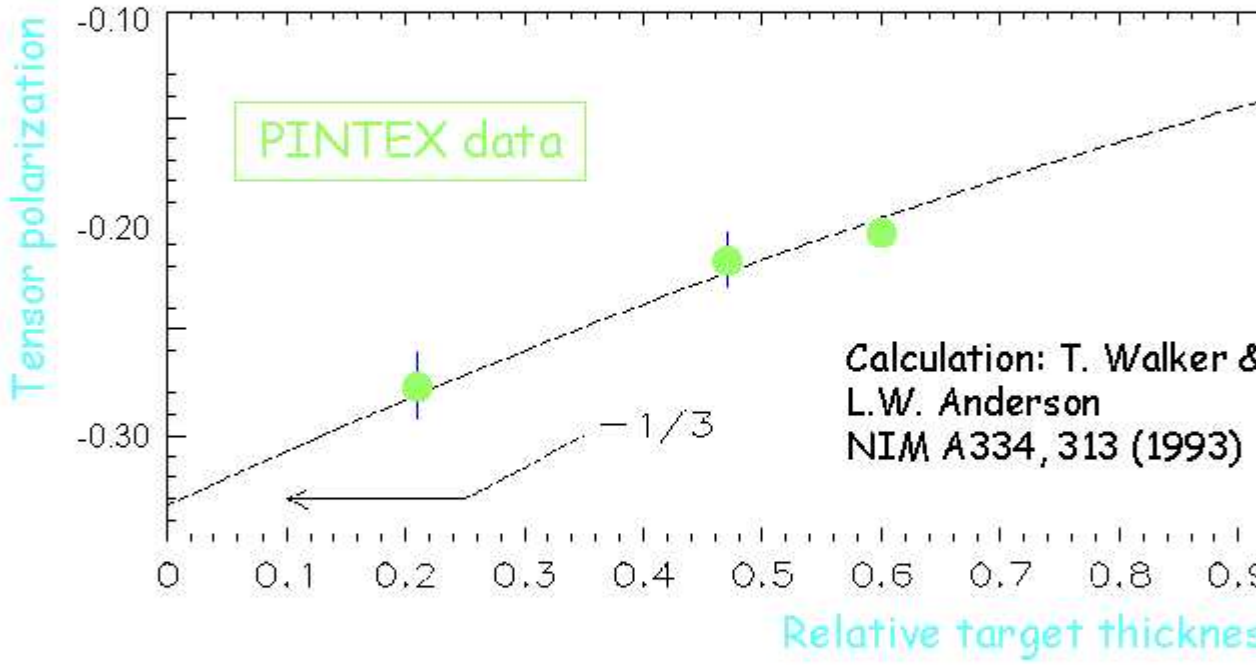
spin correlation coefficients and analyzing powers in p
elastic scattering (17 observables) and pion productio

Target tensor polarization without transition ani

(to exclude effects from inefficient transition

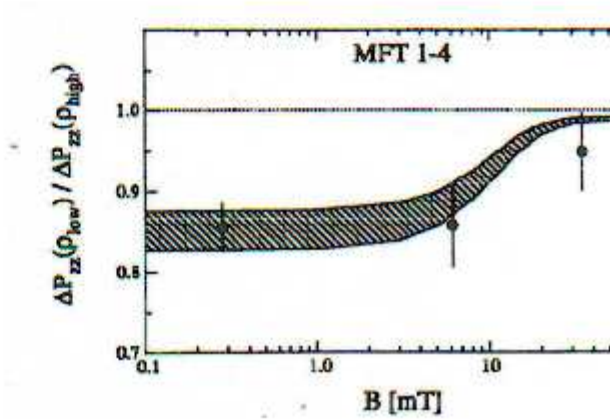
Maximum target polarization without MF transitions:

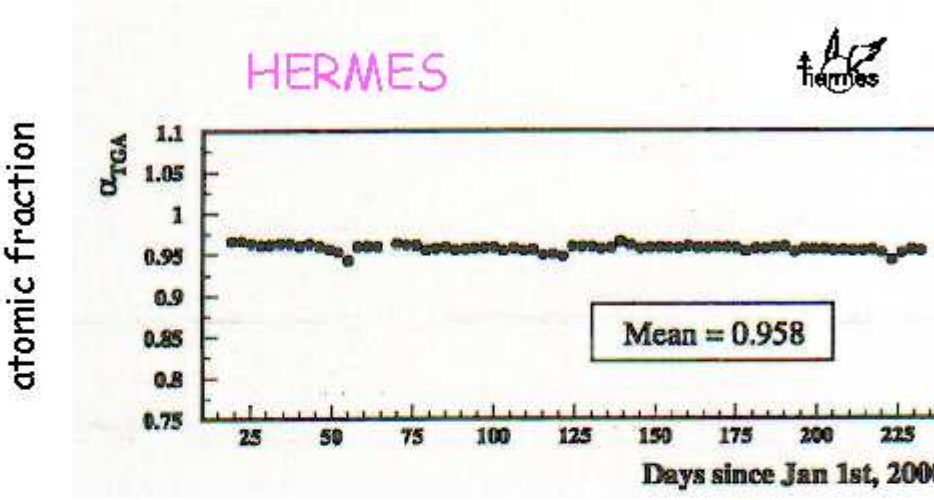
1/3 vector -1/3 tensor



Spin exchange significantly reduces the tensor polarizati

H.J. Bulten et al. Phys. Rev. A58 (1998) 1146





after corrections for recombination, depolarization.

→ P_{z+}= +0.851+/-0.031 P_{z-}= -0.840+/-0.028

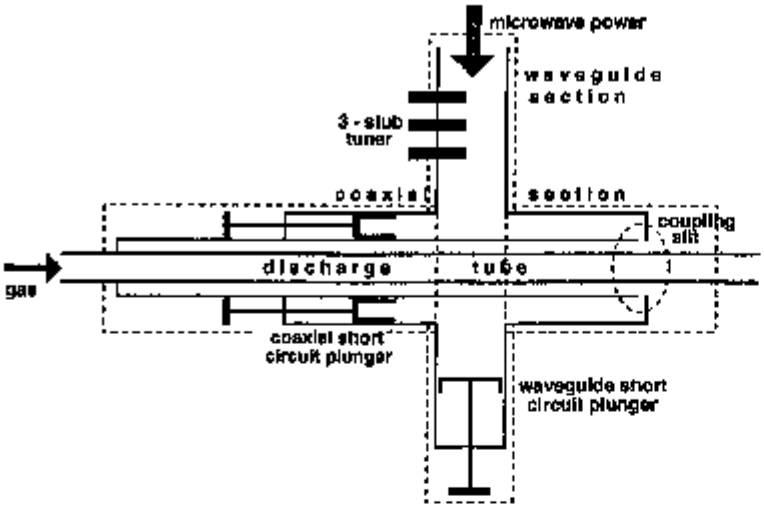
tensor polarization NIKHEF target:
J.F.J. van den Brand, PRL 78 (1997) 1235

P_{zz+}= +0.523+/-0.005 P_{zz-}= -1.037+/-0.007

(Only 80% rejection efficiency of 2nd sextupole)

wall depolarization and spin exchange worse for tens

possible increase
ABS intensity



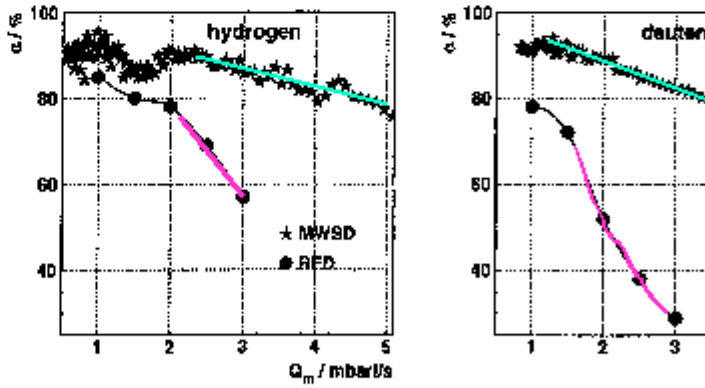
MWS operation shows: power transfer efficiency

$$\eta = \frac{\text{power transferred to discharge}}{\text{power delivered from magnetron}} \geq 92\ \%$$

- **Comparison with present HERMES RF-dissociat**

μ-wave dissociator

RF dissociator



MWSD operation:

P_{mw} = 800-1200 W, standing wave propagation ⇒ p_{pl} up to 70

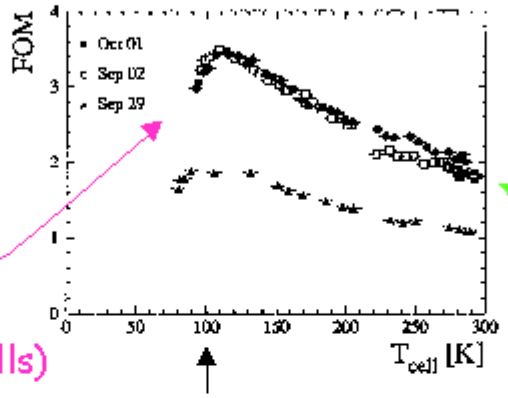
⟹ MWS based dissociator superior for high throughputs and deuterium operation

intra beam scattering ...

BUT: current high intensity ABS's limited $Q_m \approx$ 1-2 mbar l/s !

tailor cell to beam dimensions

coat cells with teflon or drifilm to minimize wall depolarization



P²I

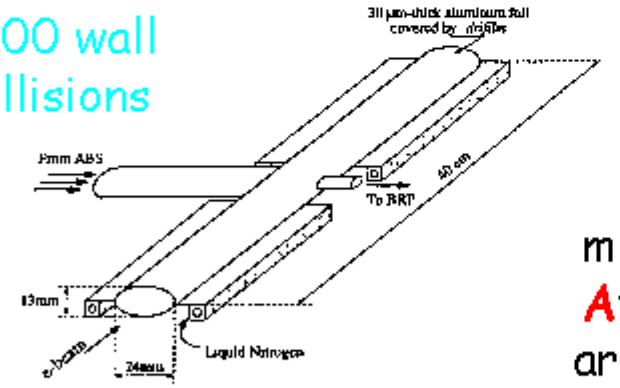
cold cell -> small P^2 (atoms stick longer to walls)

100 K

Zapfe et a
NIM A36
(1996) 29

warm c
-> small

~300 wall collisions

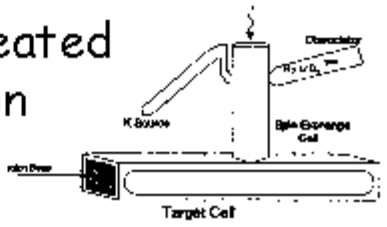


ABS: ~5x10¹³ atoms/cm²

many cells in use with **A**tomic **B**eam **S**ources are cooled, e.g. VEPP-3

cells for **L**aser **D**riven **T**argets are heated to prevent potassium condensation

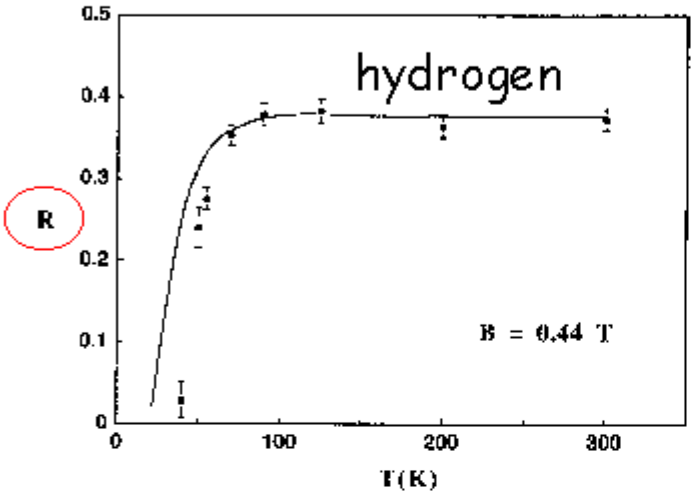
e.g. Argonne cell at IUCF

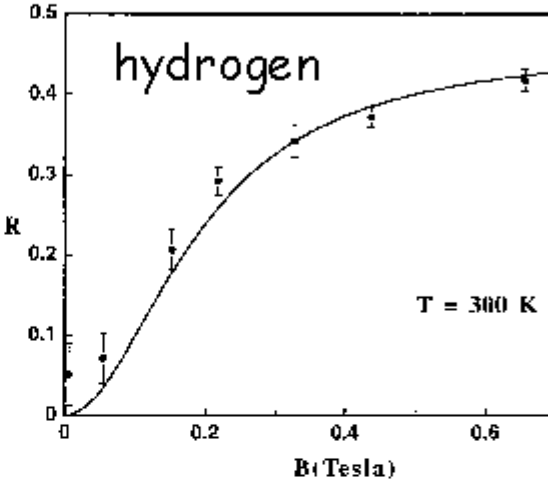


with this cell 4x10¹⁴ atoms/cm²

T. Wise et al. PRL 87 (2001) 042701-1

R=fraction of H polarization retained by molecules after recombination





→ ~ $\frac{1}{2}$ of the polarization is retained

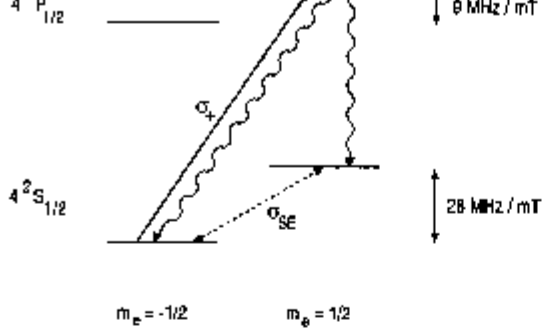
qualitatively: an unpolarized atom sticks to Cu surface and recombines with a polarized one

deuterium:

molecules retain the tensor polarization of the atom

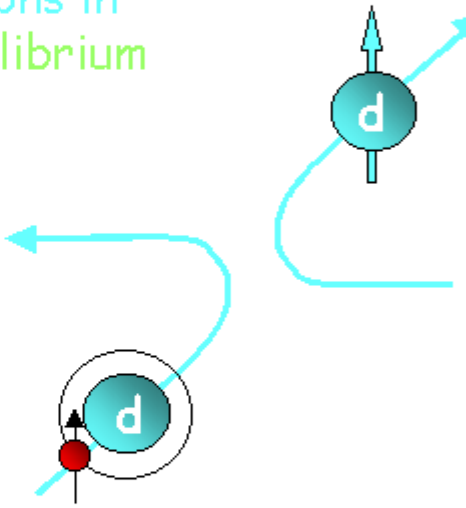
R= 0.81 +/- 0.31

J.F.J. van den Brand et al., PRL 78 (1997) 12

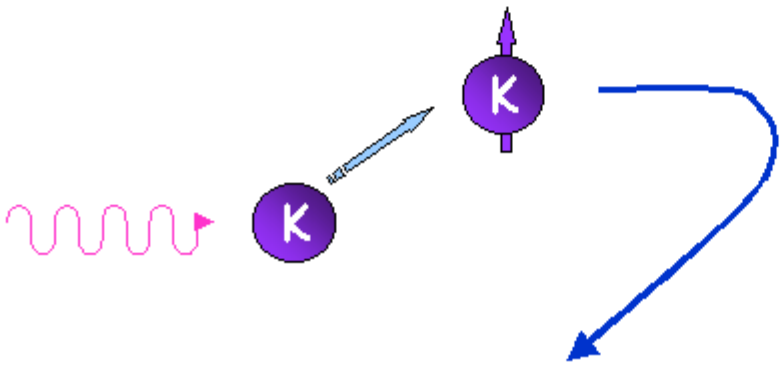


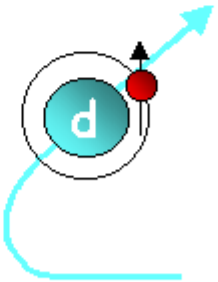
LDT

nuclear d polarization by dd spin exchange collisions in spin temperature equilibrium



circularly polarized laser light is used to pump potassium





Kd spin exchange collisions polarize e

weak magnetic field ($B \ll B_c$) : nucleon spin is coupled to electron spin, but efficient pumping fails due to radiatio trapping(= multiple scattering of laser light)

strong magnetic field ($B \gg B_c$) : needs many spin exchan collisions to reach spin temperature equilibrium (STE)

Walker & Anderson NIM A334 (1993) 31

STE= most probable relative substate population for a g total angular momentum

number of spin-exchange collisions needed to approach

$$\sim 1 + \left(\frac{B}{B_c}\right)^2$$

Argonne target:

holding field over cell = pumping field → gradient

high field region (~70 mT) → pumping

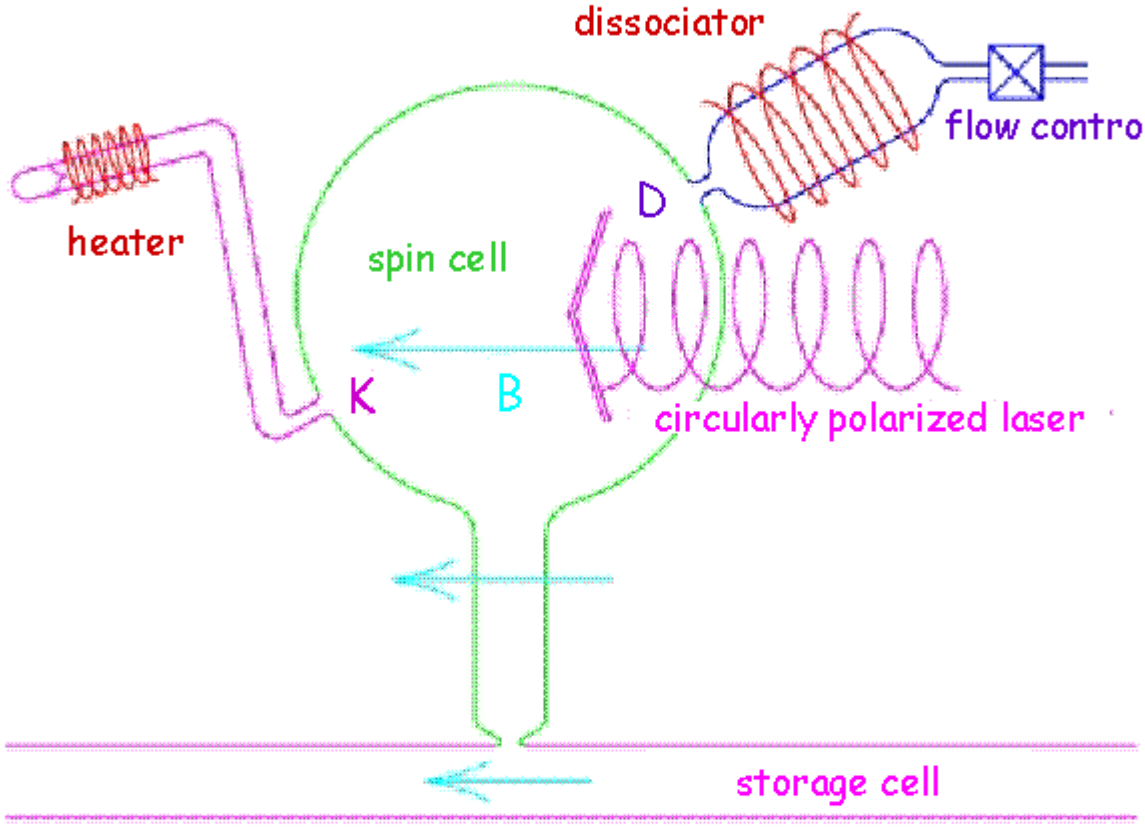
low field region (~20 mT) → fewer dd spin exchang collisions needed

population of a particular substate $\rho(m_F) = \frac{1}{N} e^{\beta m_F}$

β^{-1} is spin temperature and characteristic of systems angular momentum

Laser Driven Target

(Schematic: RpEX website: http://ldt.mit.edu/proton/target.html)



coating: drifilm

770.1 nmTi-Sapphire pump laser

polarization reversal: reverse helicity of laser light

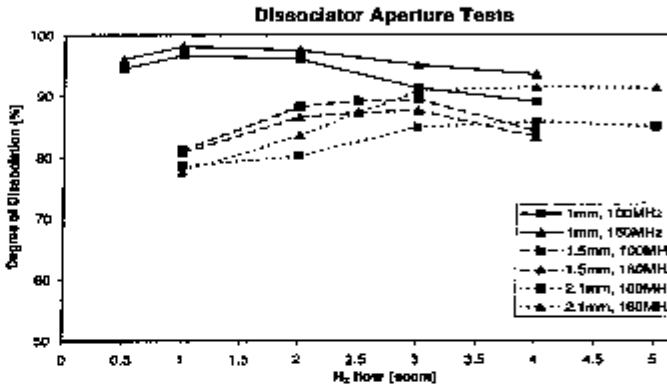
heat all surfaces to ~200° C to avoid K condensation

(Crawford et al., PST2001 Nashville, IN, Sep/30 - Oct/4 2001)

goal: 60% dissociation fraction and 50% polarization at 2×10^{18} atoms/s

90%

different geometries, 100 or 160 MHz

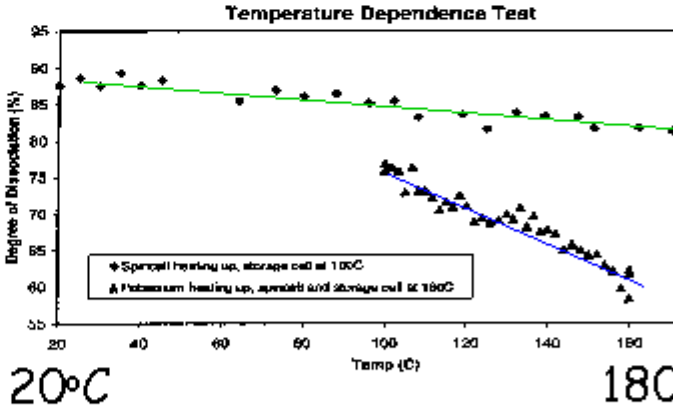


fl

90%

spincell, potassium heating

60%

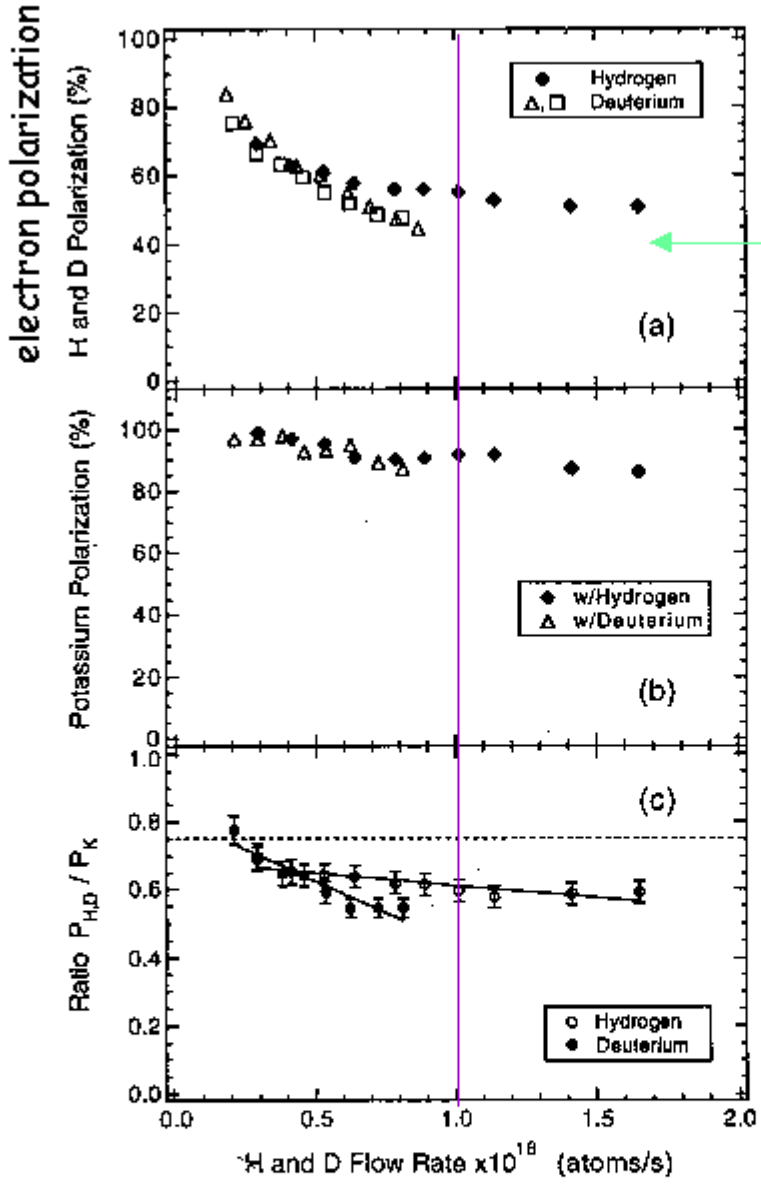


20°C

180

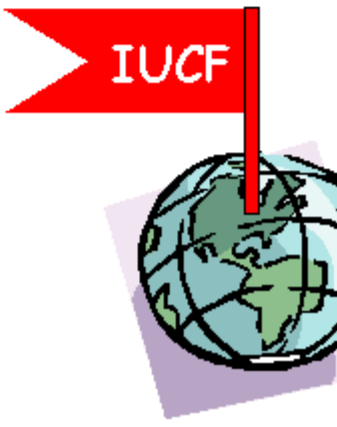
potassium influences dissociator performance

M. Poelker et al., NIM A364 (1995) 58



P_e = 40%

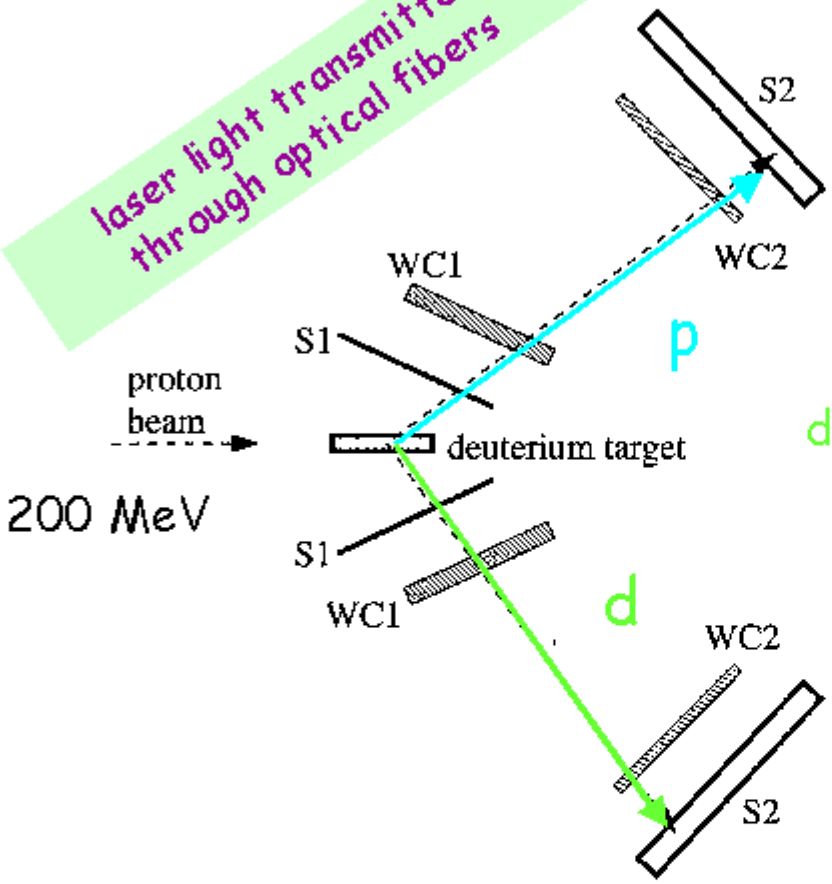
10^{18} atoms/s



Argonne target to IUCF in 1996

using the Argonne optically pumped target

laser light transmitted through optical fibers



~1x10^{18}atoms

detect proton and deuteron in coincider

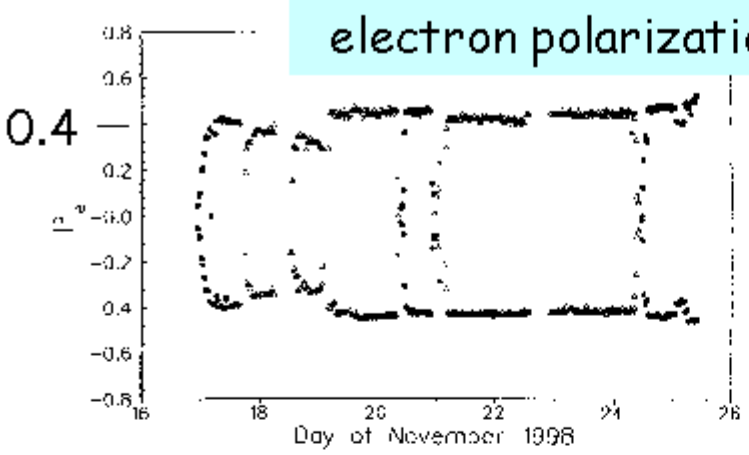
R.V. Cadman et al.
86 (2001) 0031-90

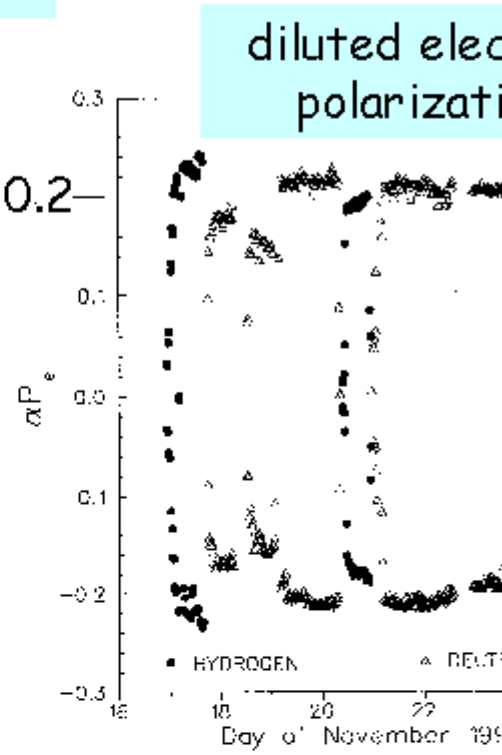
measured **nuclear** vector polarization P_z

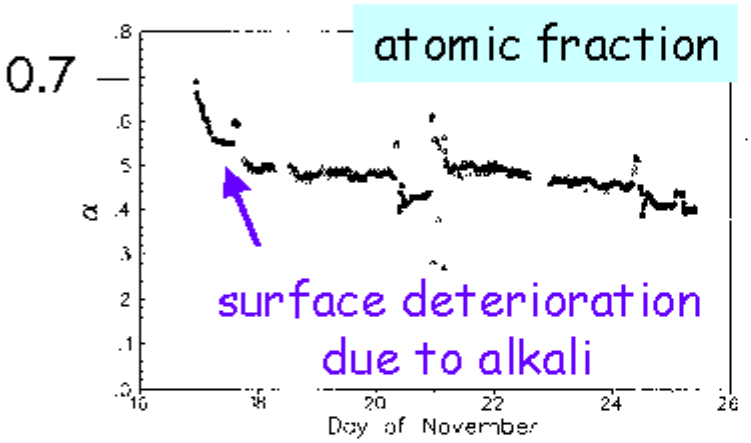
use analyzing power from pd breakup reaction

first nuclear physics experiment to use optically pumped deuterium target

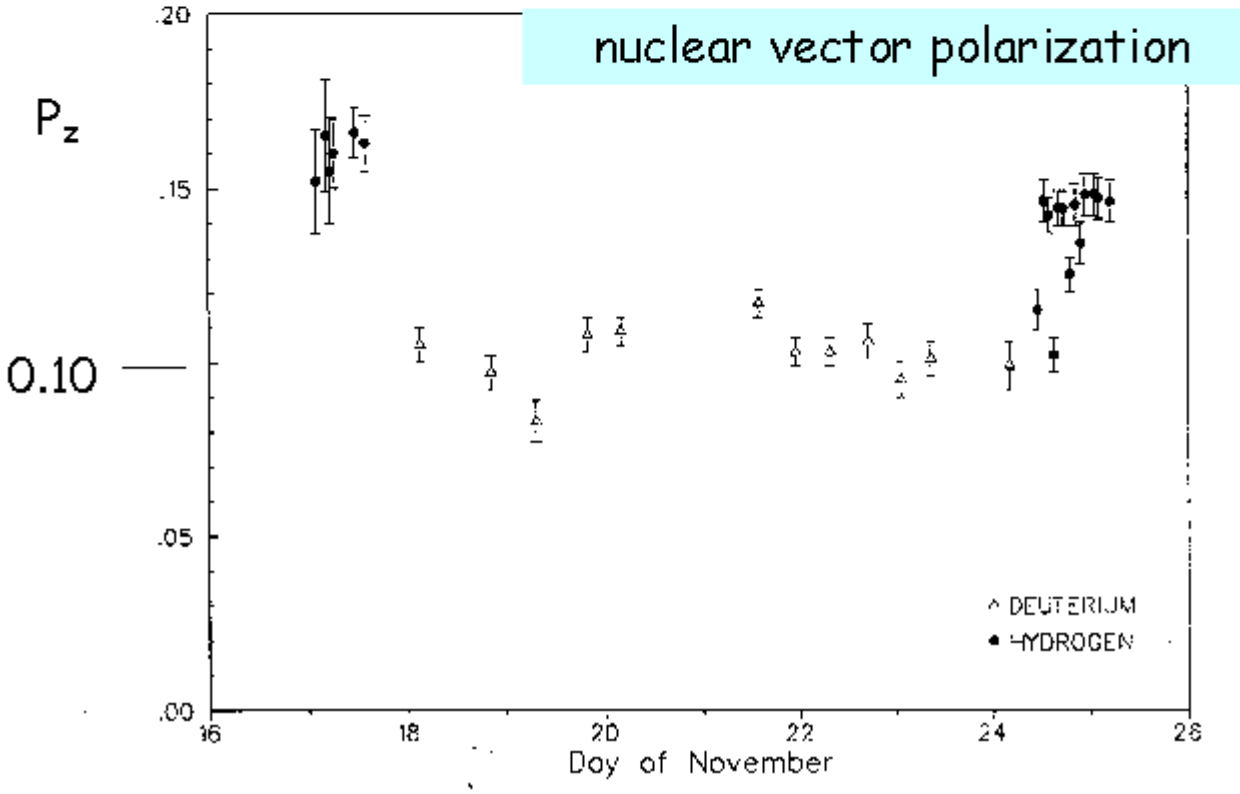
Spin correlation coefficient $C_{y,y}$ in pd elastic scattering



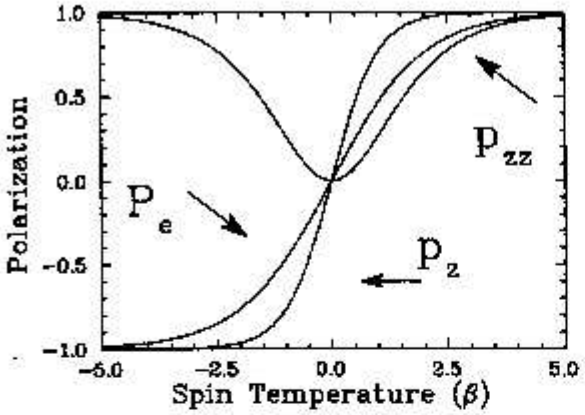




C.E. Jones et al., PST 99, Er



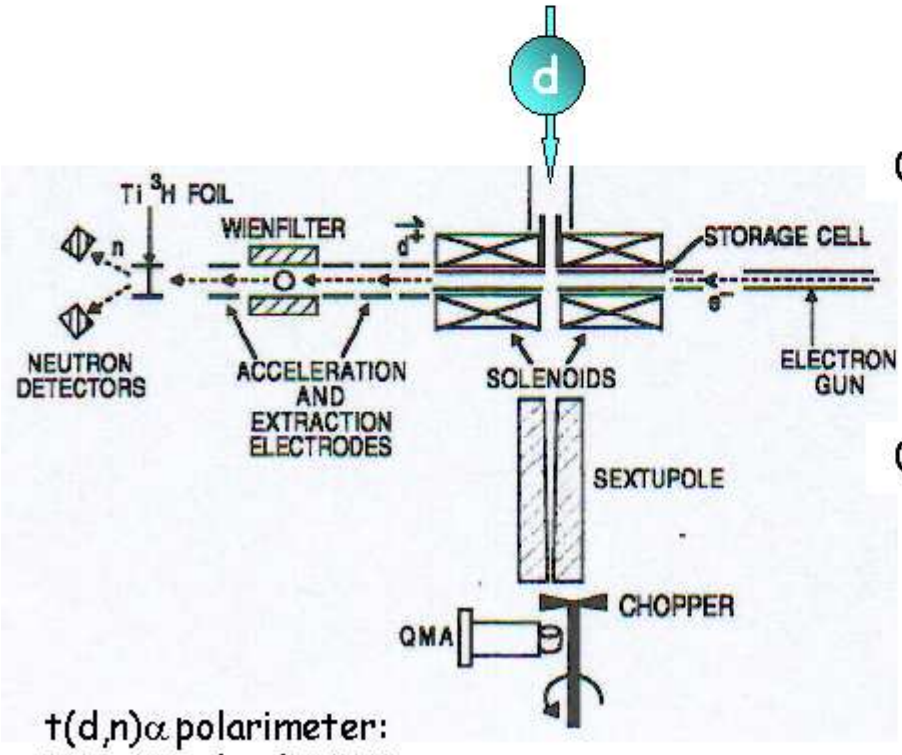
EDT Tensor polarization



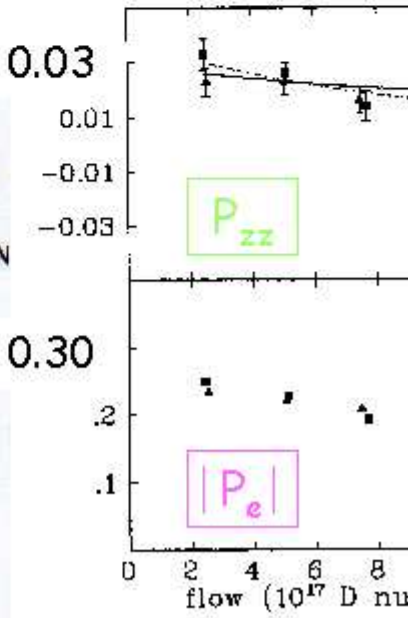
J.A. Fedchak et al. NIM A417 (199

spin temperature equilibr
for a given spin temperatu

only positive tensor polarization at spin temperatur
equilibrium, regardless of laser light helicity



t(d,n)α polarimeter:
Price, Haeberli NIM
A326 (1993) 416



10¹
nucle

established technology

pure spin states

flow ~3.5*10^{16} atoms/sec (at present, limit seems reached)

nuclear polarization P_z~85 %

without RF TU's P_z=1/3, P_{zz}=-1/3 in weak field

fast spin flip (vector) & not too slow spin flip (tensor)

P_z^2*I=2.8*10^{16}

relatively new technol

mixed spin states

flow ~10^{18} atoms/sec principle only limited laser power)

nuclear polarization P_z~

more compact near c really?

fast spin flip

P_z^2*I=1.0*10^{16}

ABS: works reliably with high polarization, but atomic beam intensity has hit a brick wall.

LDT: nuclear polarization is low, (necessary) potassium degrades surfaces