Neutron Polarization and polarimetry for precision neutron decay measurments

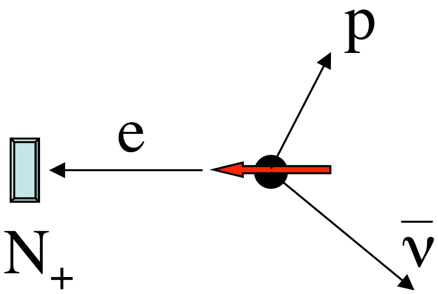
Tim Chupp
University of Michigan
For the Nab/abBA/PANDA collaboration

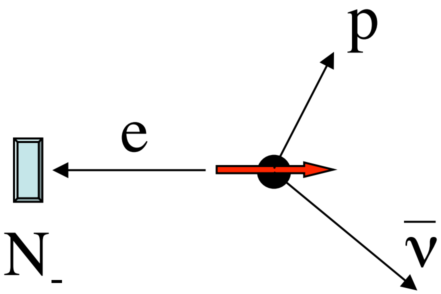
Outline:

The goal: control **<J>** and measure to <0.1%
Polarization techniques (PSM, ^{3}He)
Spin flipping
Polarimetry
Outlook

Polarization

$$\frac{d^5\Gamma}{dE_e d\Omega_e d\Omega_\nu} = G(E_e)\left(1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + A\frac{\langle\vec{\sigma}_n\rangle \cdot \vec{p}_e}{E_e} + B\frac{\langle\vec{\sigma}_n\rangle \cdot \vec{p}_\nu}{E_\nu} + D\frac{\langle\vec{\sigma}_n\rangle \cdot (\vec{p}_e \times \vec{p}_\nu)}{E_e E_\nu}\right)$$



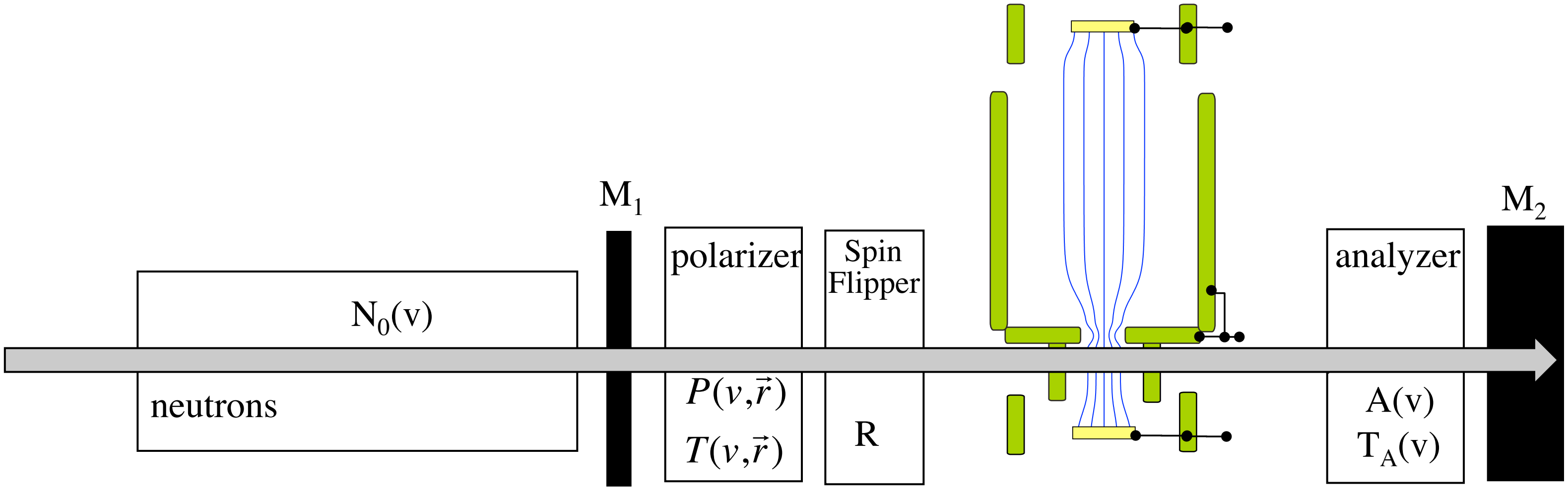


$$\text{Asymmetry:} \quad \frac{N_+ - N_-}{N_+ + N_-} = \mathbf{k(E)A}\, P_n\, \mathcal{A}\, \mathcal{F}\, (1-f) + A_{\text{false}}$$

background
spin flip efficacy
analyzing power
neutron polarization–Averaged appropriately

A 0.1% measurement of A requires a 0.1% measurment of P_n

Polarization

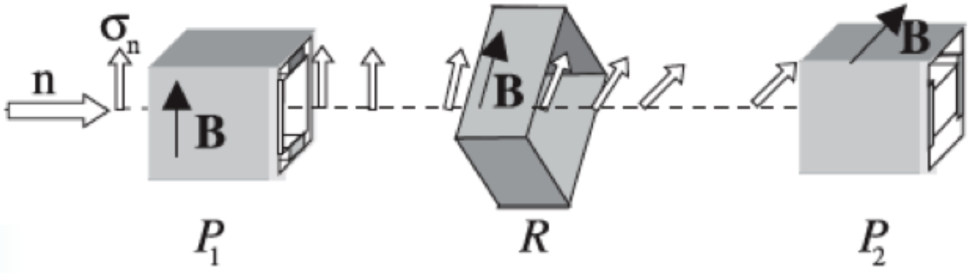


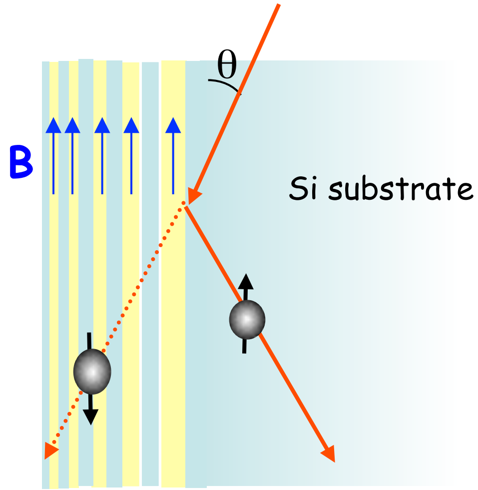
P/A	P_n (5Å)	T_n	$P^2\rho$	features
PSM(XSM)	99.x%	10%	0.1	Pn~ 1; static
He (60%)	80%	30%	0.2	**flip** P_3; P_3 varies

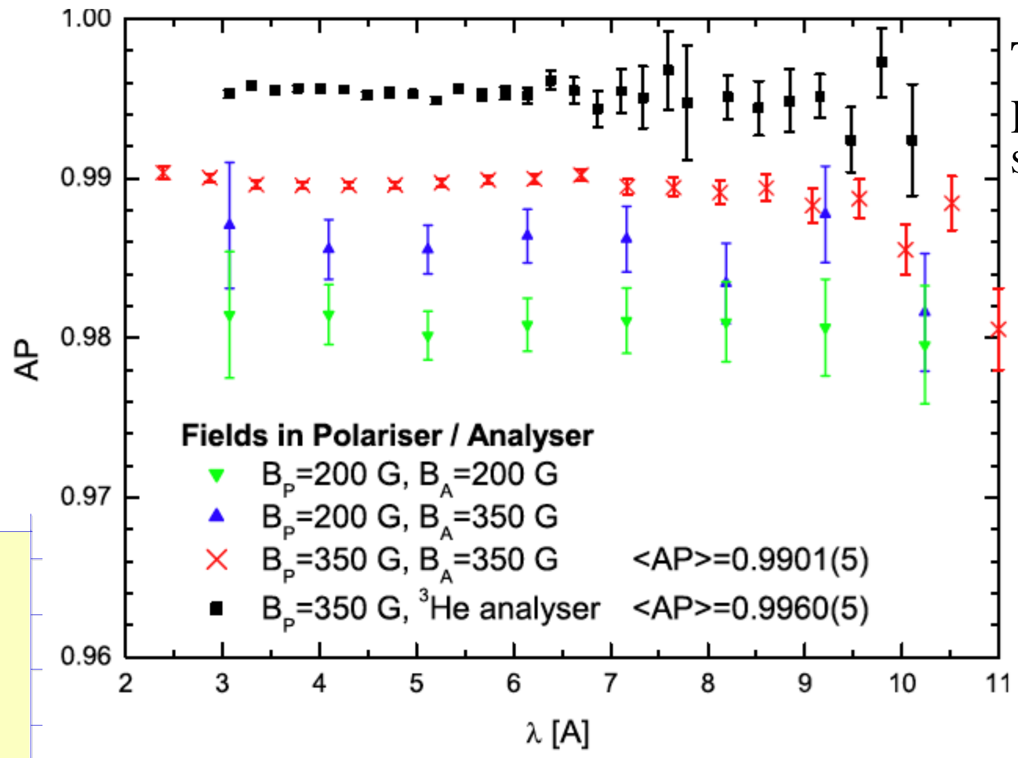
A 0.1% measurement of A requires a 0.1% measurment of $\langle P_n \rangle$

Crossed Supermirror (XSM)

Kreuz et al.



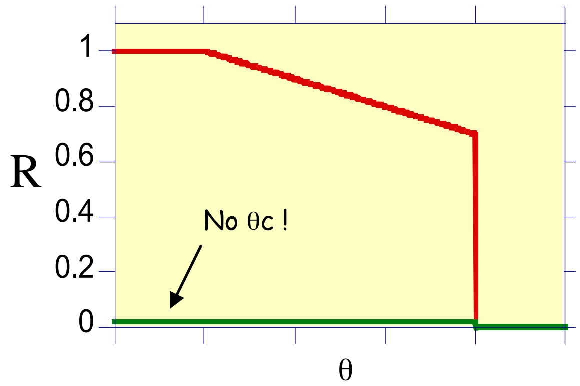




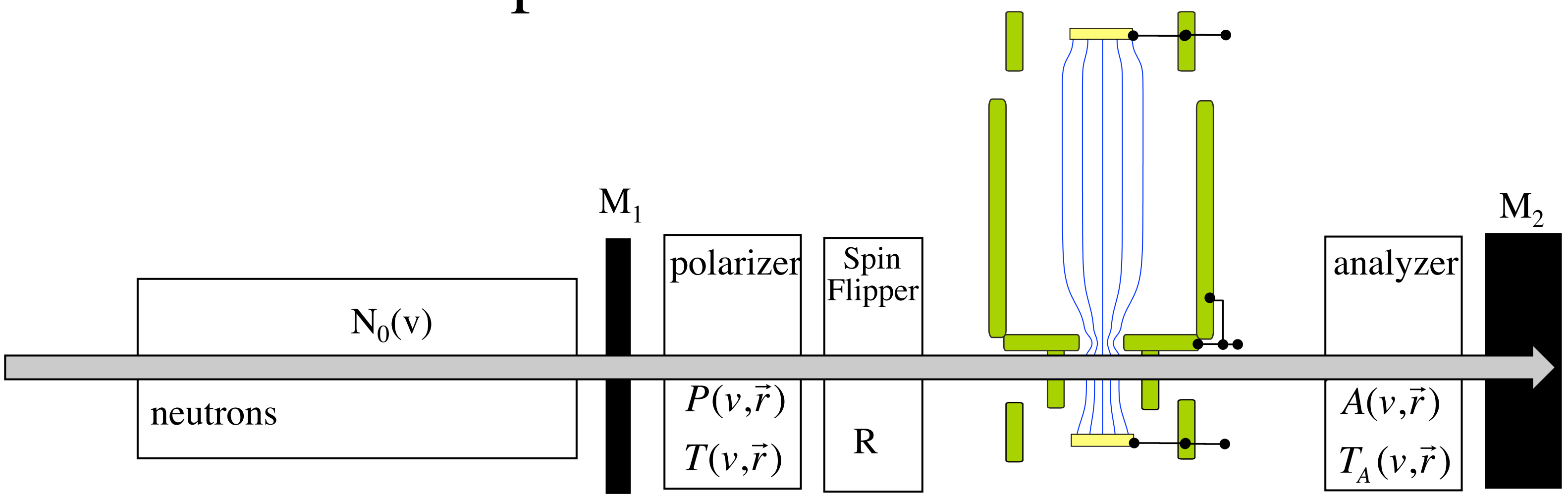
Thick ^{3}He analyser

P_n=0.997±0.001

Schuman PRL **99, 191803** (2007)

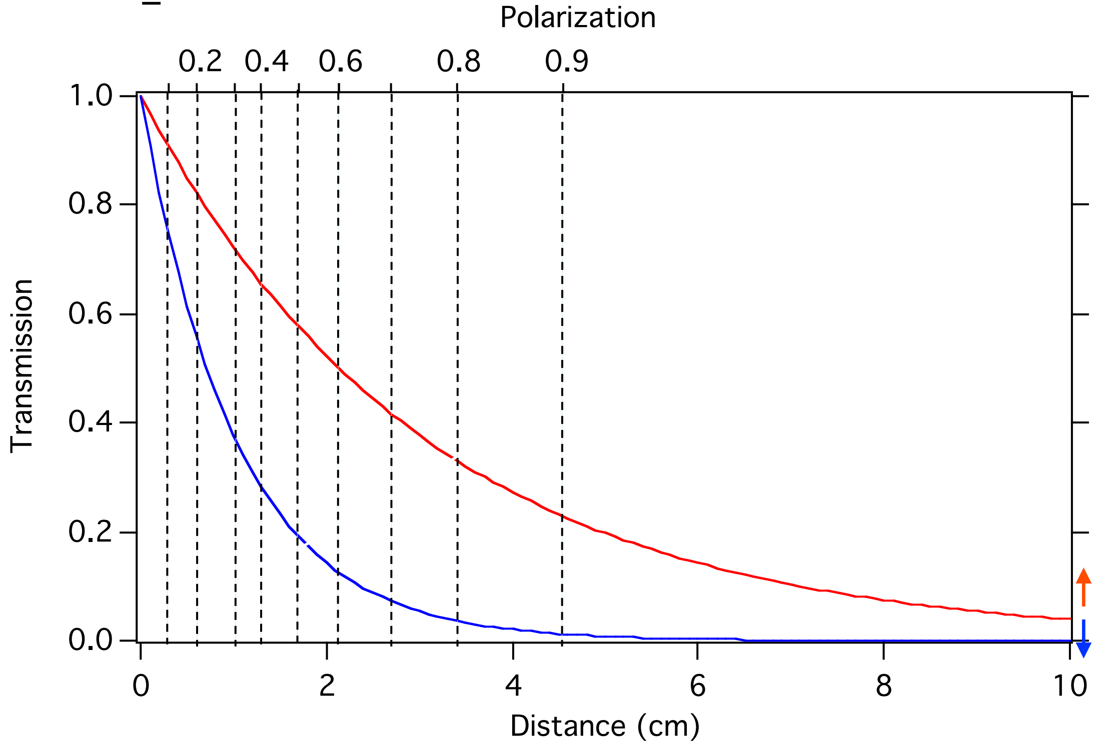


^{3}He spin filter: n +^{3}He -> ^{1}H + ^{3}H



$$T_{\pm} = e^{-n_3\sigma_0 t \frac{v_0}{v}(1\mp P_3\,)}$$

σ_0=5333 b

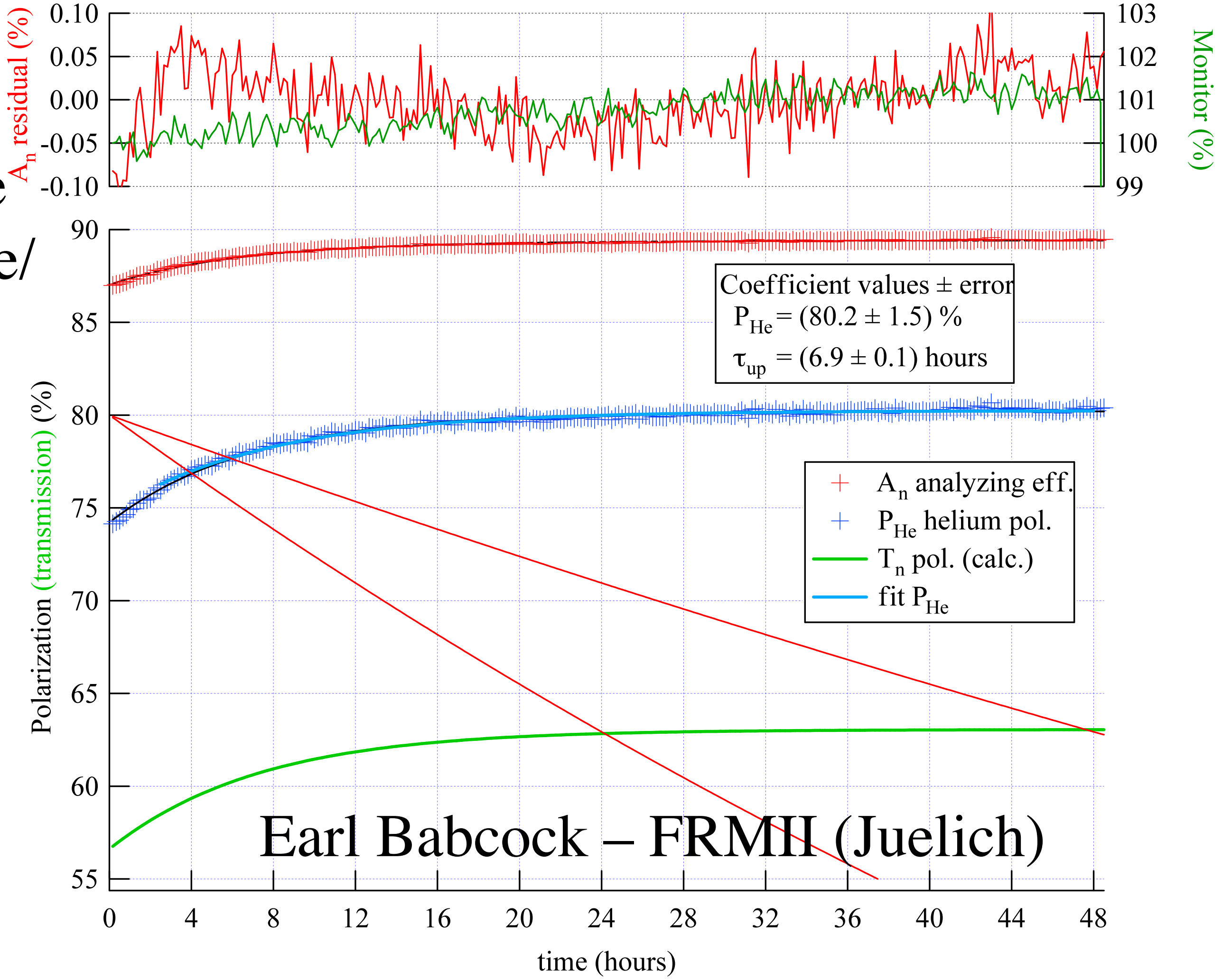


^{3}He: continuous polarization by Spin Exchange

Huge Progress with ^{3}He (NIST-Wisc/ILL/UVa/Jlab…)

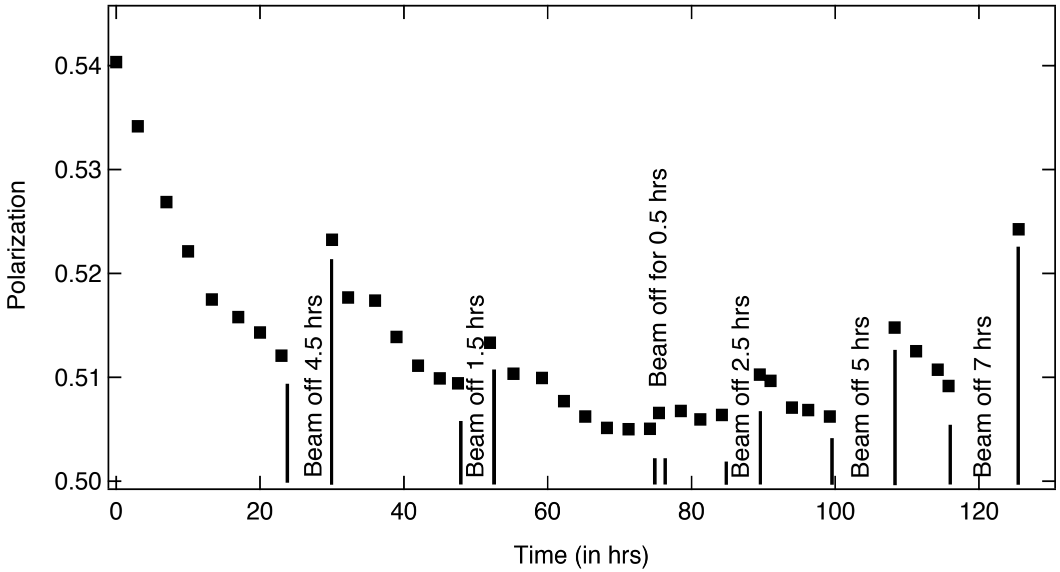
- Glass/cell technology (GE180)
- Hybrid Spin Exchange
- Metastability exchange/ compressors
- Lasers
- Magnetic boxes

…



Earl Babcock – FRMII (Juelich)

^{3}He Polarizer Neutron-flux Limitations?

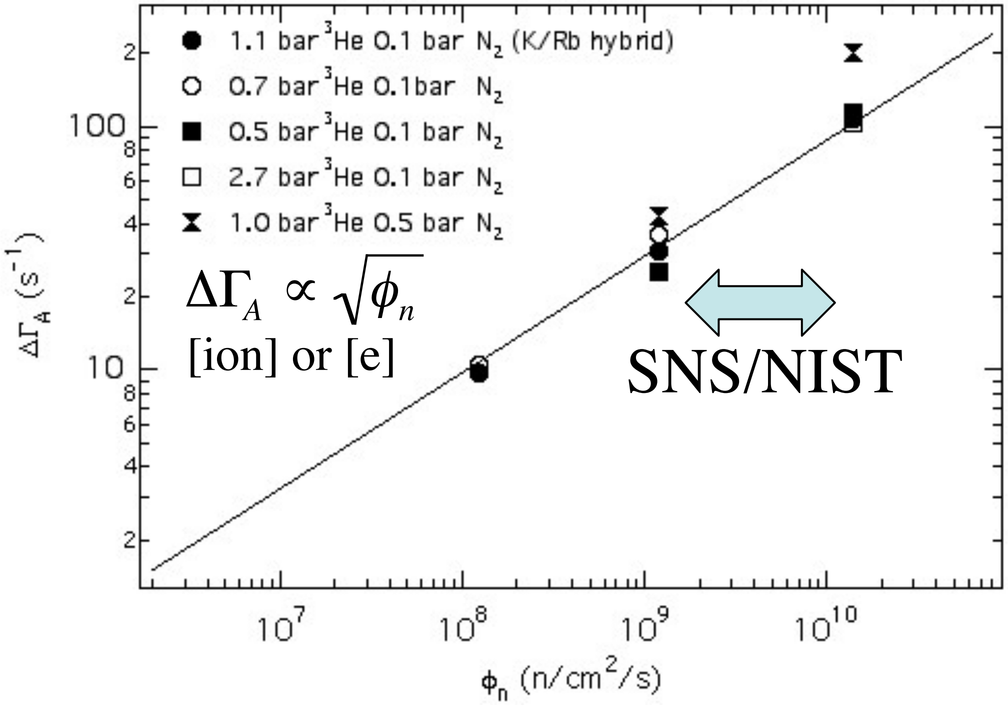


Lansce data
shows effect on P_{Rb}

$$P_{Rb} = \frac{\gamma_{opt}}{\gamma_{opt} + S\Gamma_A}$$

$S_{Rb} = 10.8$
$S_K = 6$

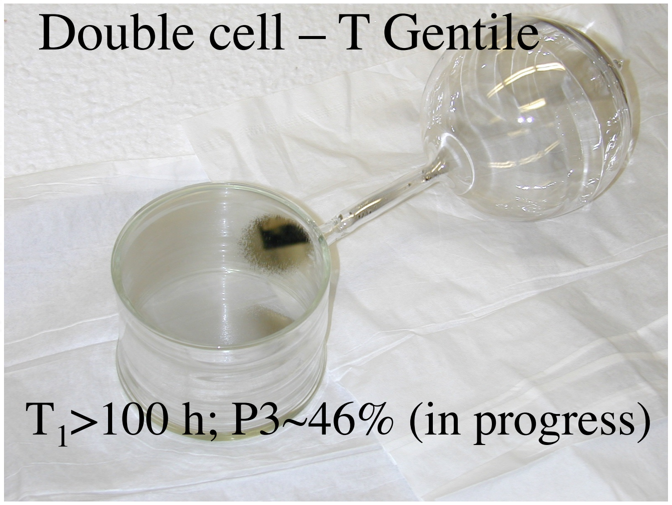
Rb relaxation rate increase



$\Delta\Gamma_A \propto \sqrt{\phi_n}$
[ion] or [e]

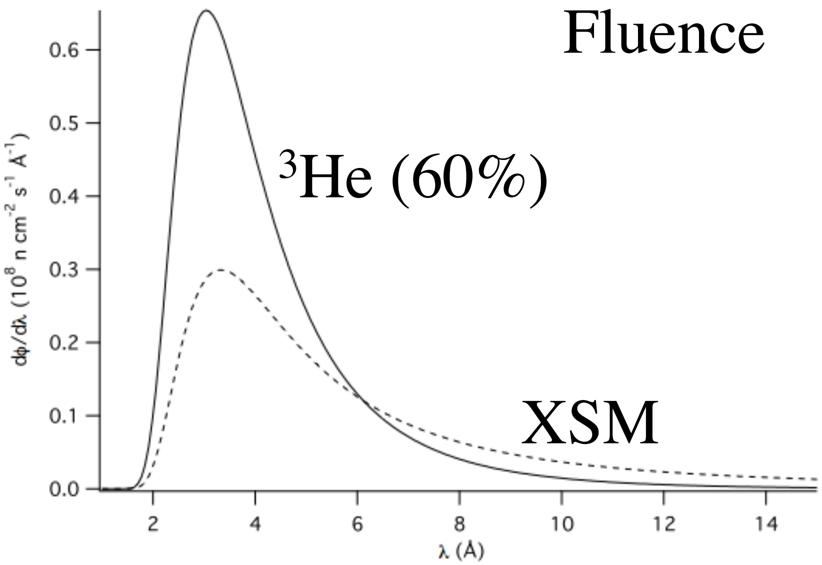
SNS/NIST

Also a slow (100s) increase
Not fully understood
Requires increased laser power (e.g. few times)
Double cell – T Gentile



T_1>100 h; P3~46% (in progress)

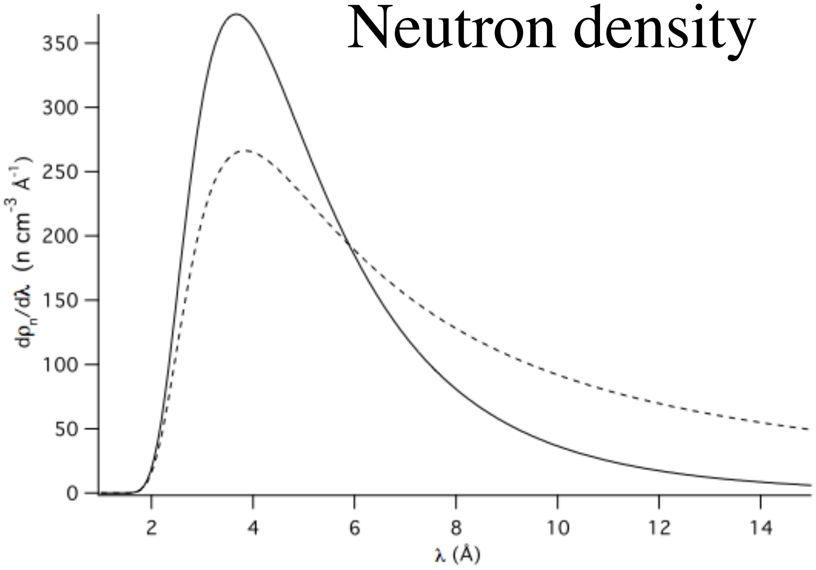
Neutron Beam



Fluence

^{3}He (60%)

XSM



Neutron density

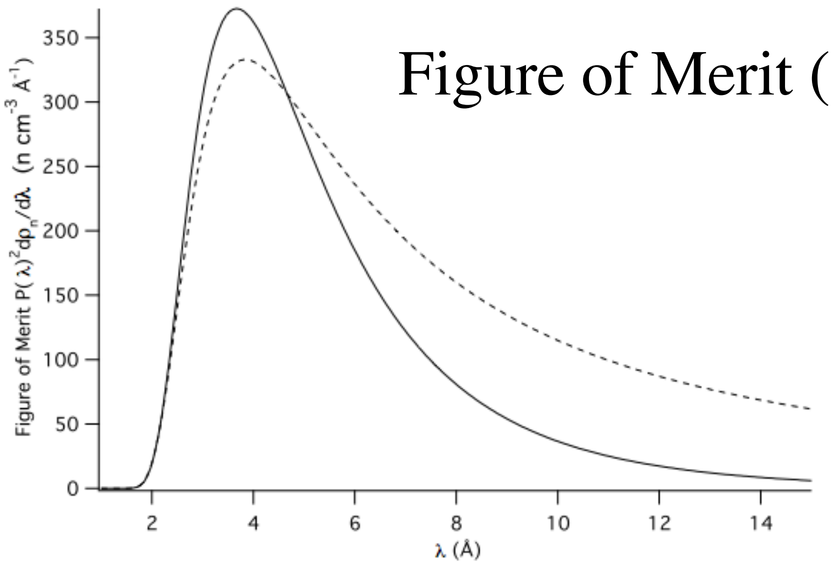


Figure of Merit ($P^2 d\rho_n / d\lambda$)

Polarization Summary

- Both approaches can be perfected for abBA/PANDA
- ^{3}He provides $P\overset{\text{asymmetry}}{\alpha}$(tof) (Bowman and Pentilla)
- Supermirror design for m=3+ guides required
- Magnetic field accomodations for spin transport
- Rate estimates based on 0.1 of Nab flux (XSM):

  75 live days for 0.1% measurement of *A*

The fast adiabatic spin flipper

$$i\hbar\frac{d\psi}{dt} = \left(-\vec{\mu}\cdot\vec{B}\right)\psi = -\left(\frac{\mu_+B_- + \mu_-B_+}{2} + \mu_zB_z\right)\psi$$

RF

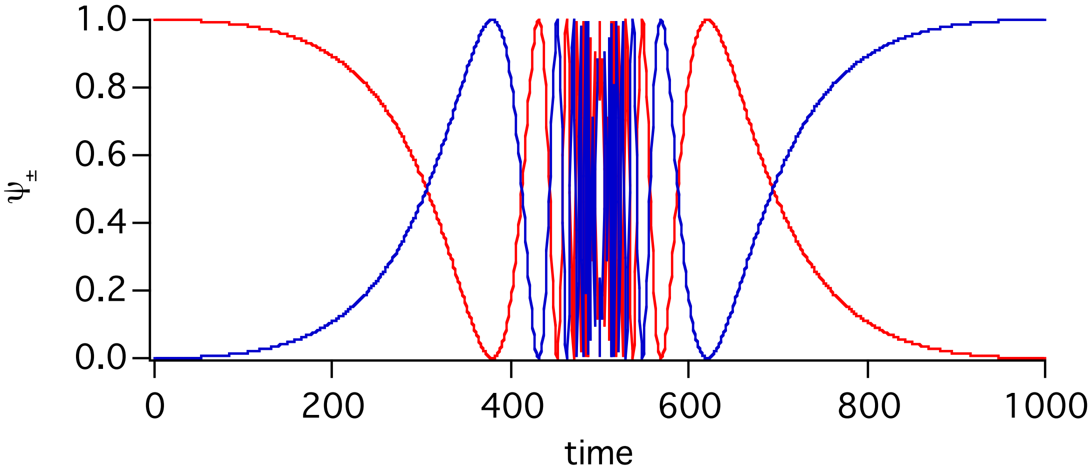
$$B_\pm = \frac{B_1}{2}e^{\pm i\omega_0 t}$$

Spatial gradient

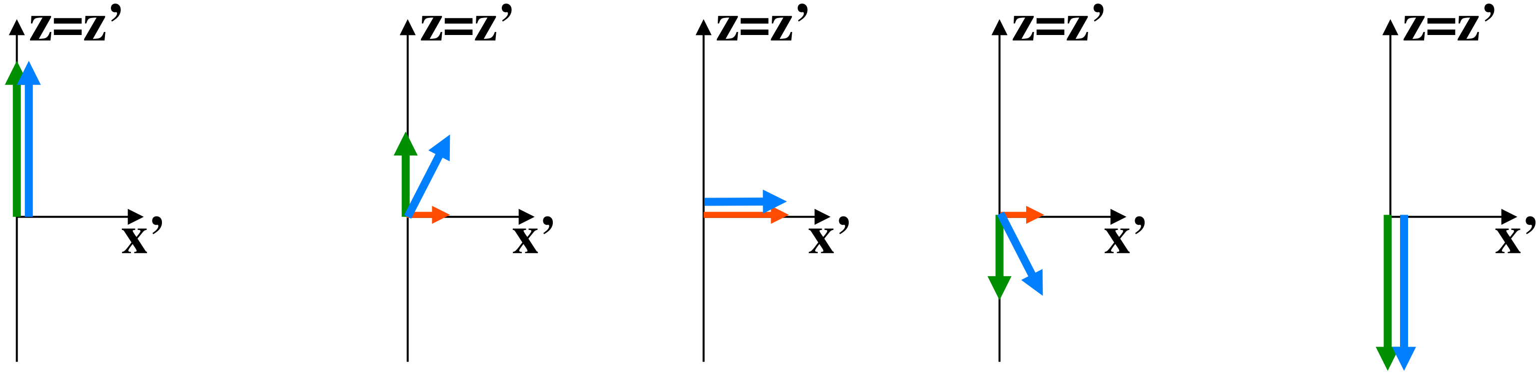
$$B_z = \beta_0 t = \beta_0\frac{z}{t}$$

$$i\hbar\frac{d}{dt}\begin{bmatrix}\psi_+\\ \psi_-\end{bmatrix} = \begin{bmatrix}\mu_z\beta_0 t & \frac{B_1}{2}e^{i\omega_0 t}\\ \frac{B_1}{2}e^{-i\omega_0 t} & \mu_z\beta_0 t\end{bmatrix}\begin{bmatrix}\psi_+\\ \psi_-\end{bmatrix}$$

$$\psi = \begin{bmatrix}\psi_+\\ \psi_-\end{bmatrix}$$

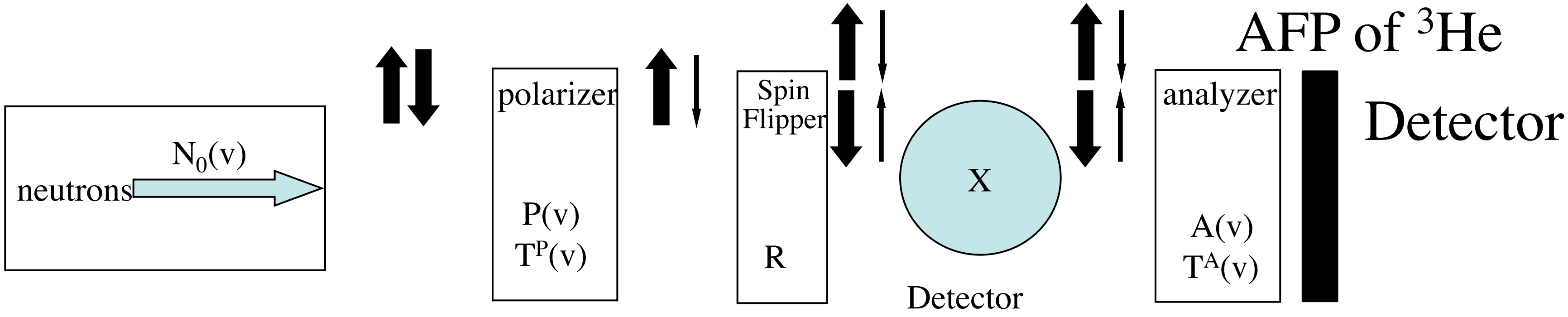


RF ON

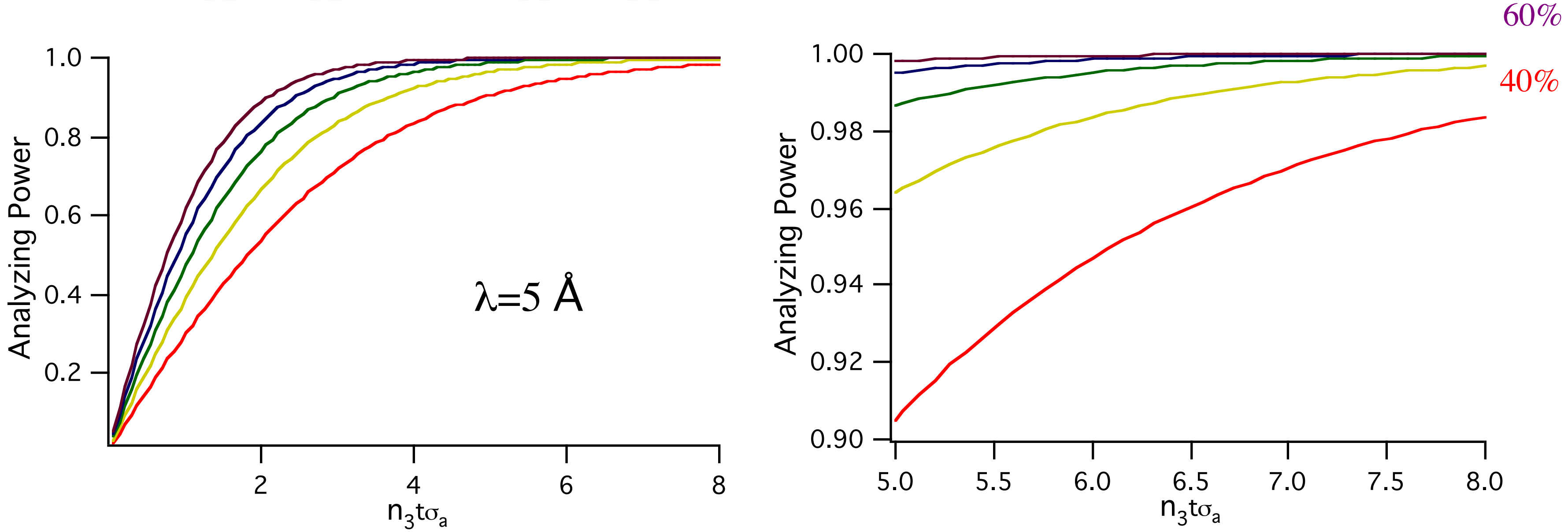


99.9x% “efficient” AND we can measure it!

Neutron Polarimetry – thick ^{3}He



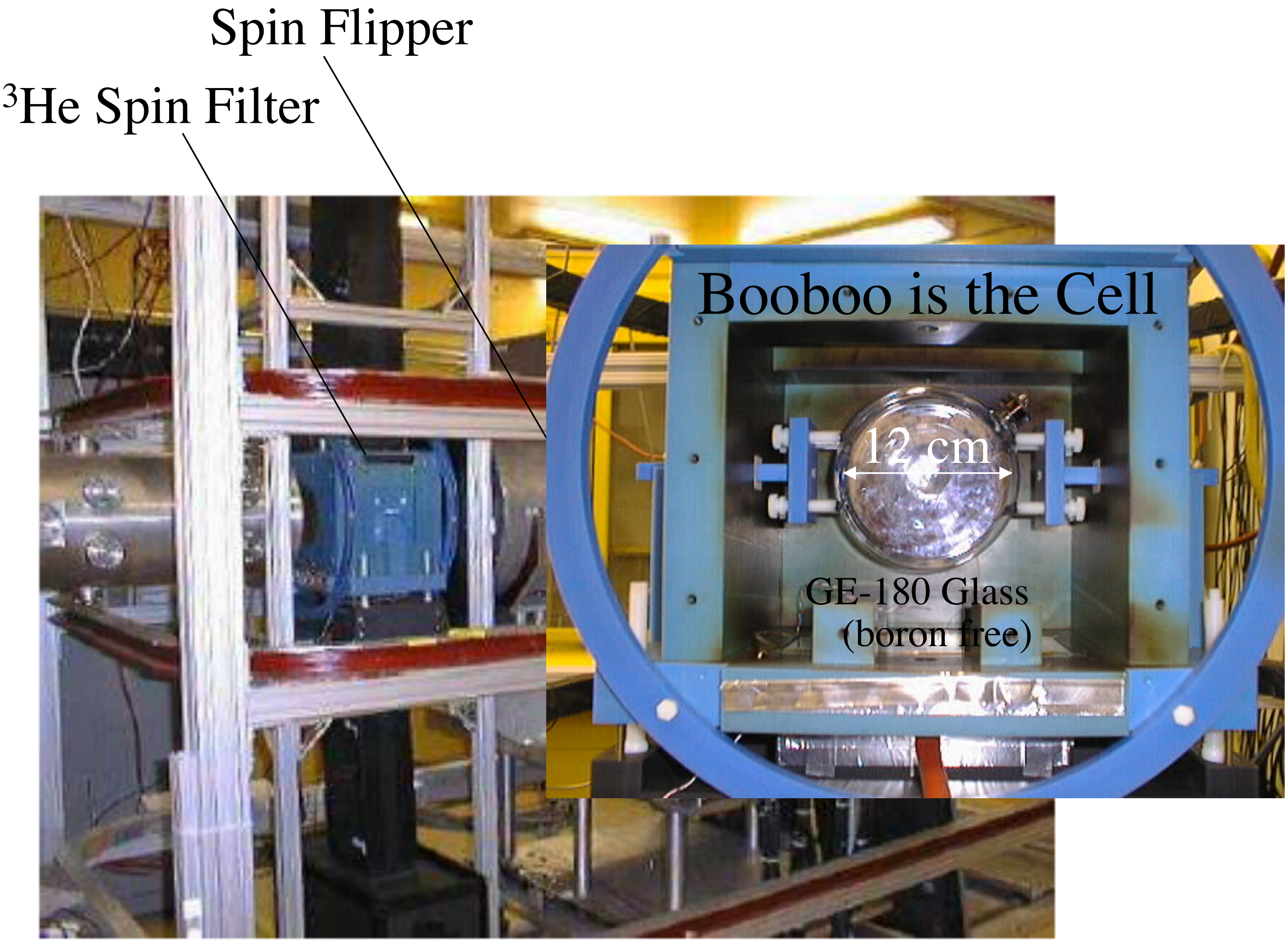
$$\frac{[T_A^P/T_A^0]^+ - [T_A^P/T_A^0]^-}{[T_A^P/T_A^0]^+ + [T_A^P/T_A^0]^-} = P_n(\lambda)\tanh(P_A\sigma_0 t_A\frac{\lambda}{\lambda_0}).$$



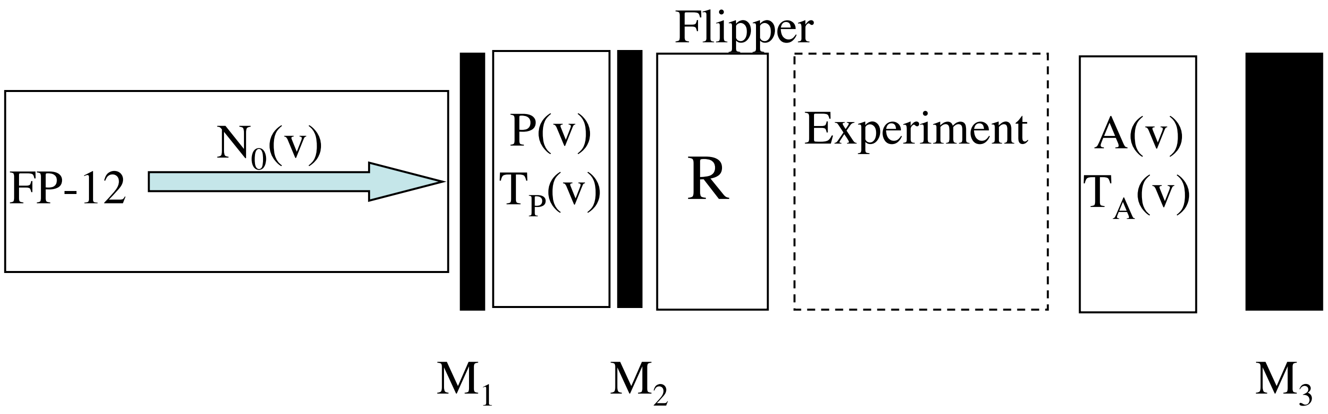
Opaque Analyzer: For $n_3t\sigma_a$ large enough (1-A) small enough (Zimmer)

Characterize Polarizer AND Flipper

^{3}He and P_n test: n+p —> d + γ (@LANSCE)



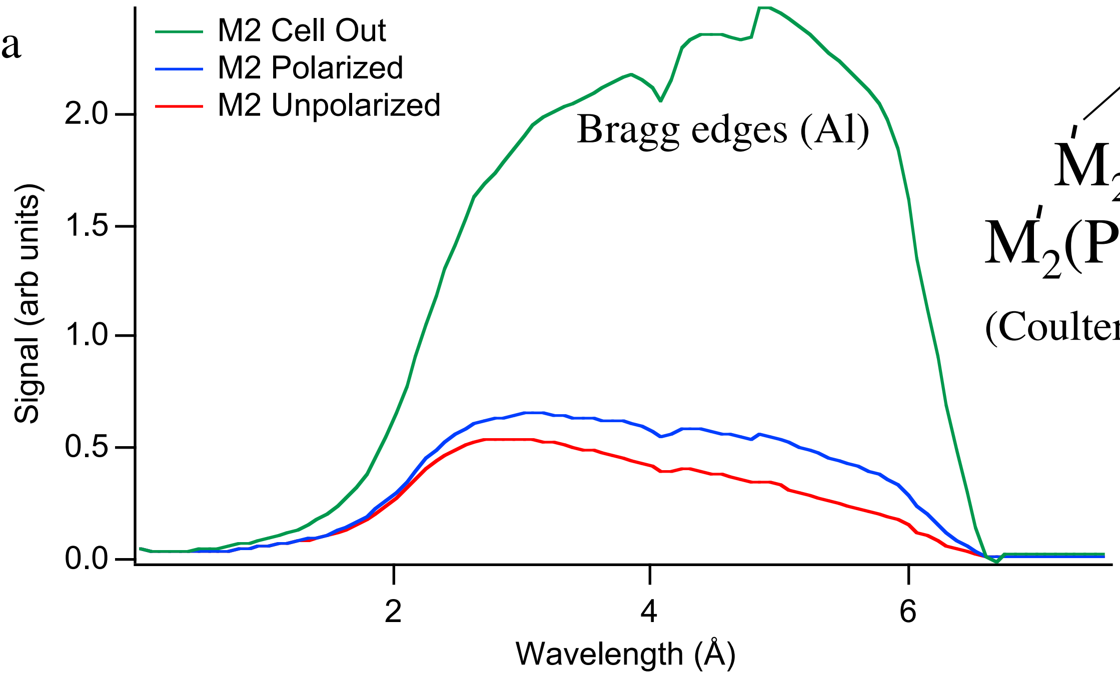
Pulsed Beam Neutron Polarimetry



$$T_{A/P}=T_0\cosh\alpha_{A/P}P_{A/P}$$
$$T_0=\exp(-\alpha_{A/P}-\alpha_{gl}-\ldots)$$
$$P/A=\tanh\alpha_{A/P}P_{A/P}$$

$$M_1=N_0\varepsilon_1+B_1 \qquad M_2=N_0T_1T_P\varepsilon_2+B_2$$

npdgamma
FP12

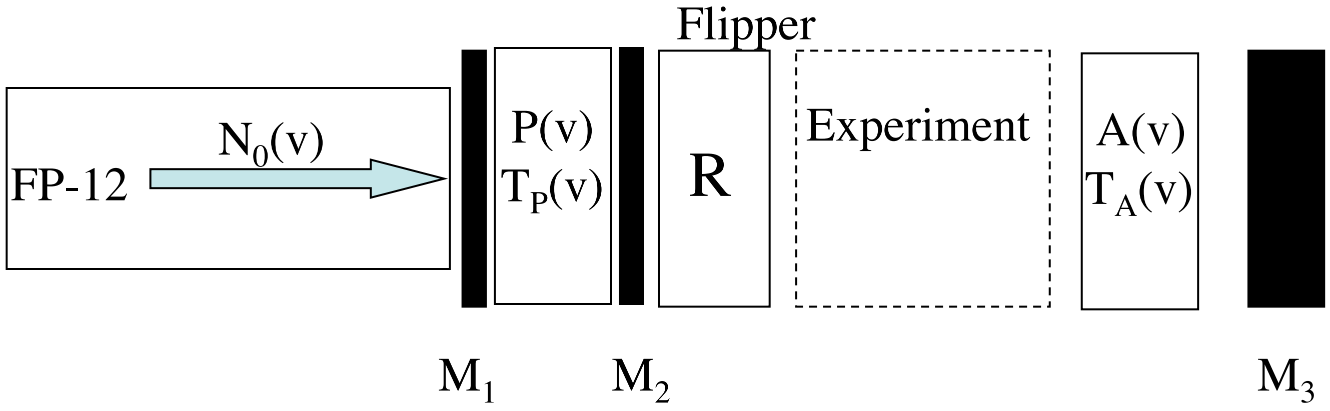


normalized to M1

$$M_2'(0)/M_2'(\text{out}) = T_0$$
$$M_2'(P)/M_2'(0) = \cosh\alpha_P P_P$$

(Coulter et al. NIMA ***288***, 463 (1989)

Pulsed Beam Neutron Polarimetry



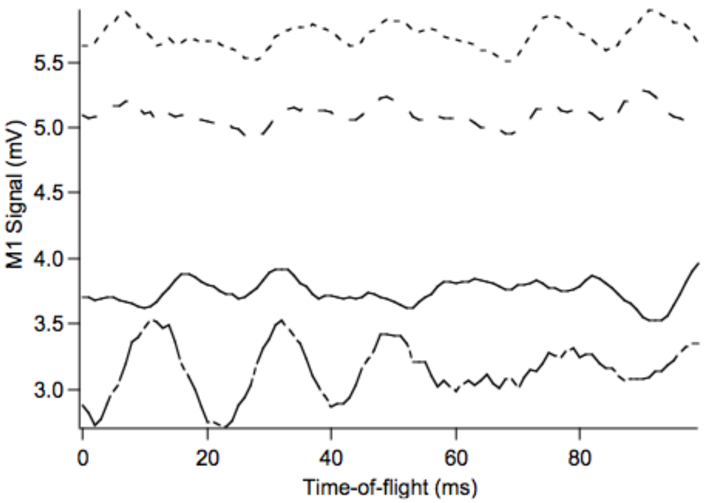
$$T_{A/P}=T_0\cosh \alpha_{A/P}P_{A/P}$$

$$T_0=\exp(-\alpha_{A/P}- \alpha_{gl}-\ldots)$$

$$P/A=\tanh \alpha_{A/P}P_{A/P}$$

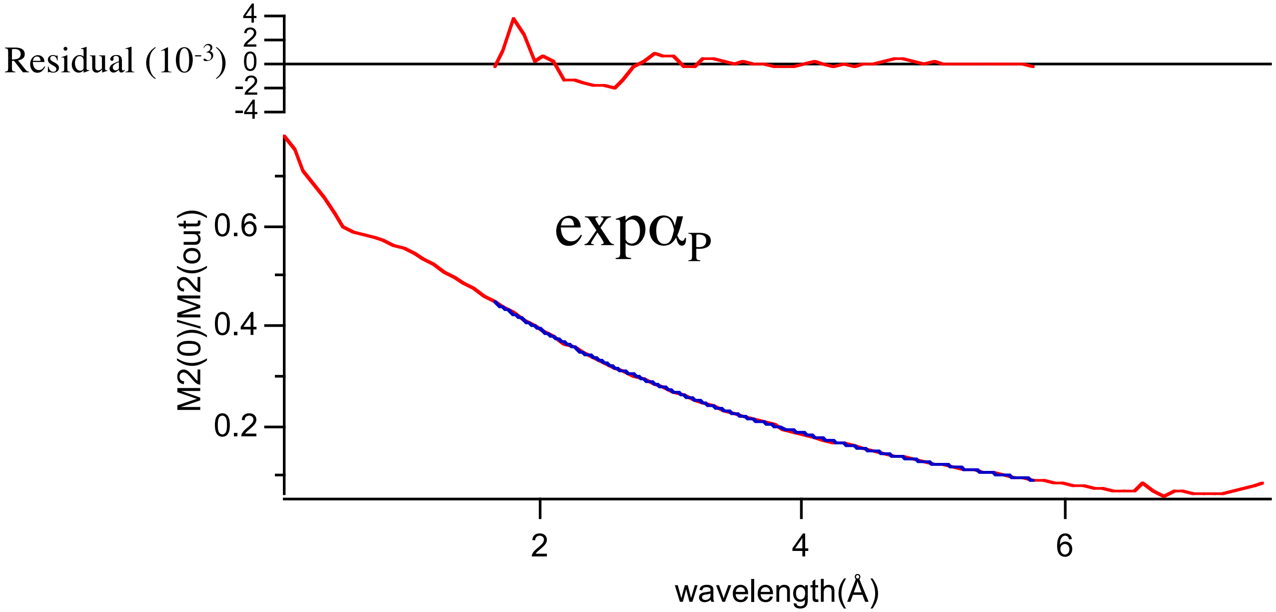
$$M_1= N_0\varepsilon_1+B_1 \qquad M_2= N_0T_1T_P\,\varepsilon_2+B_2$$

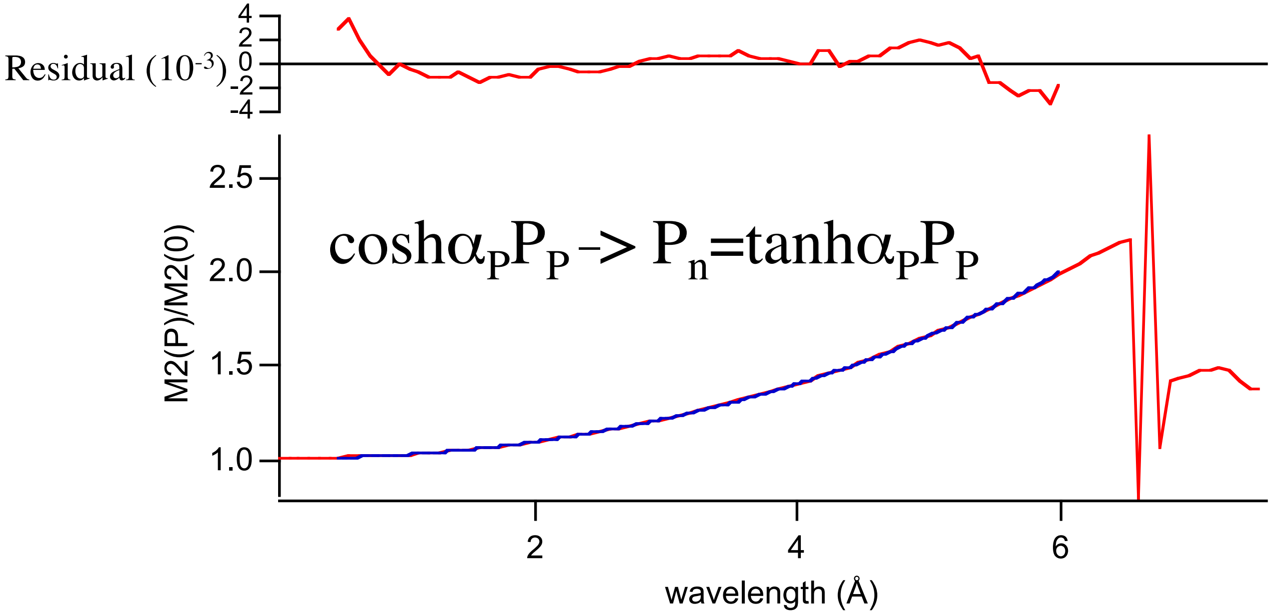
npdgamma
FP12



Offsets/Backgrounds

Demonstrates understanding at 10^{-3} level; also LANSCE FP12 available

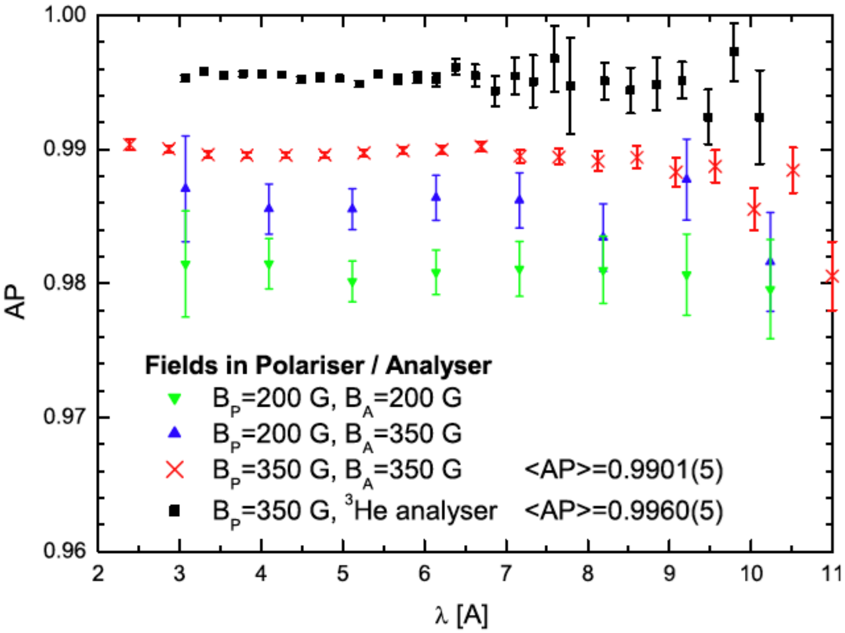




Polarimetry Summary

- Use opaque 3He and pulsed/chopped beam: measure $P(v,\vec{r})\,,R(v,\vec{r})$
- Pulsed beam (SNS): measure continuously
- Chopped beam (NIST): monitor continuously – calibrate monitor
- Neutron flux-^{3}He issues not limiting
- Statistics not limiting
- Systematics: backgrounds (beta delayed neutrons), ^{3}He AFP losses

  ~10^{-4} at LANSCE Should be ~constant vs tof at SNS
- LANSCE FP12 test beam available



Thick ^{3}He analyser

$P_{n=}0.997\pm0.001$

(0.0005 reasonable)

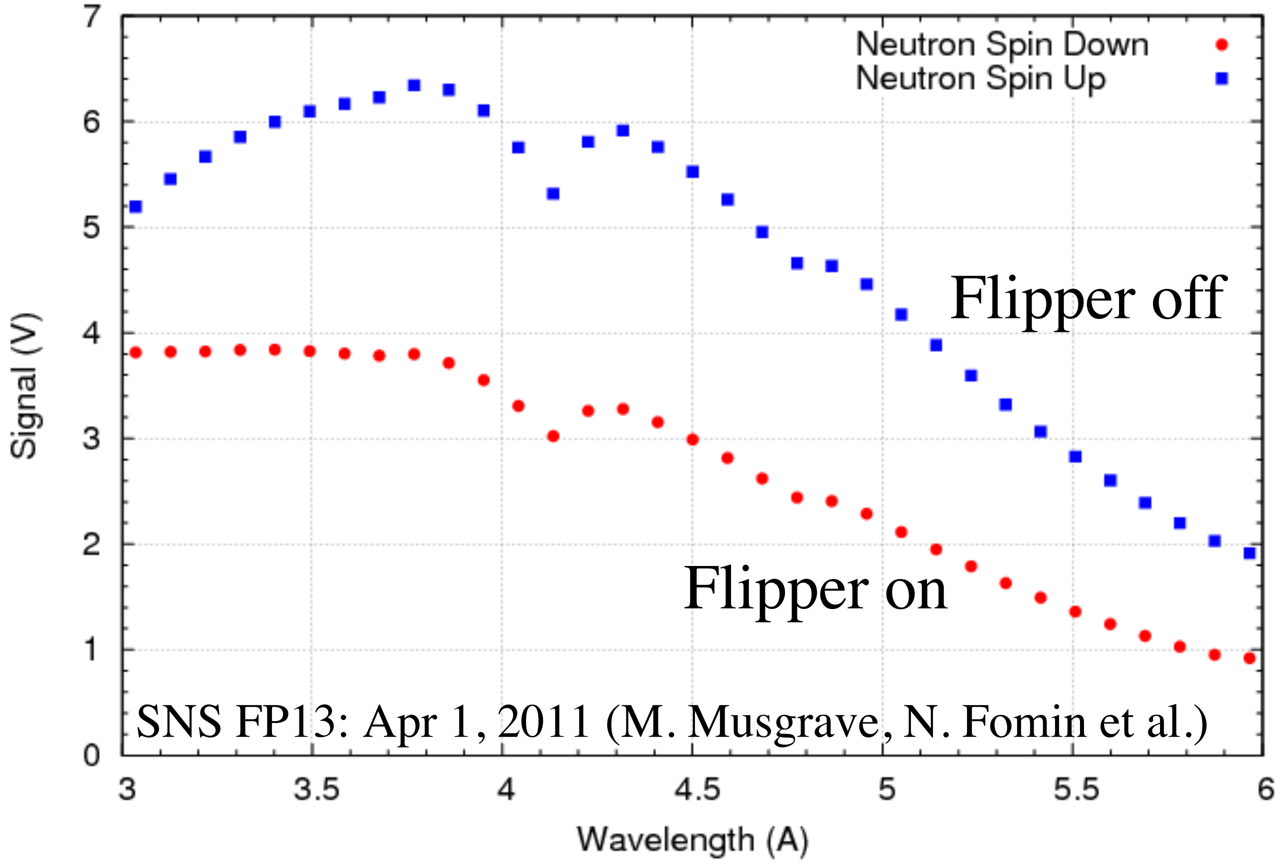
T. Soldner

Community ^{3}He resources

- NIST/Wisconsin/MunichORNL/SNS/LANL/Mich/ Indiana/Hamilton: Gentile, Walker, Babcock, Tong…
- PLUS neutron scattering AND electron scattering communities

Cell production, lasers, optical pumping research, ^{3}He in beam

Transmission through a ^{3}He analyzer



Flipper off

Flipper on

SNS FP13: Apr 1, 2011 (M. Musgrave, N. Fomin et al.)

Summary

- Polarizer: 99.xx % polarization; 10% transmission
- Flipper: 99.xx % effiecient
- 0.1% measurement of $\langle P_n \rangle$, spin flipper: CONSERVATIVE
- Community has expertise and resources