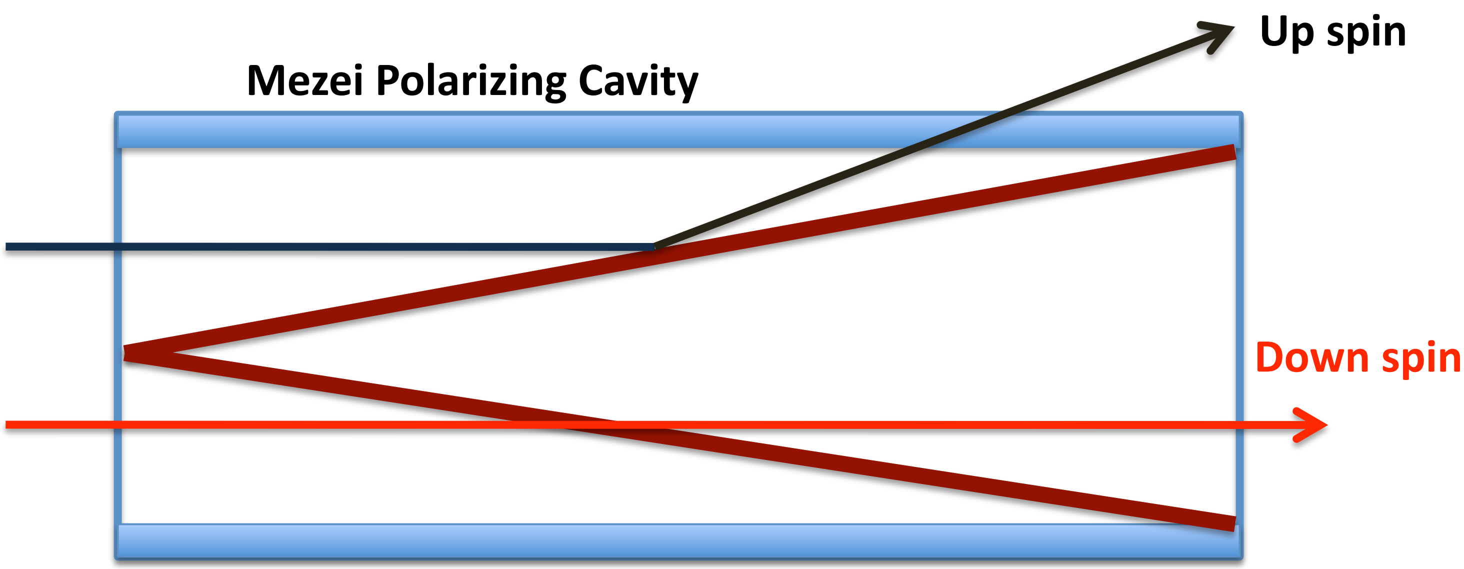
Options for a polarizing device for NG7-SANS and NG6-vSANS

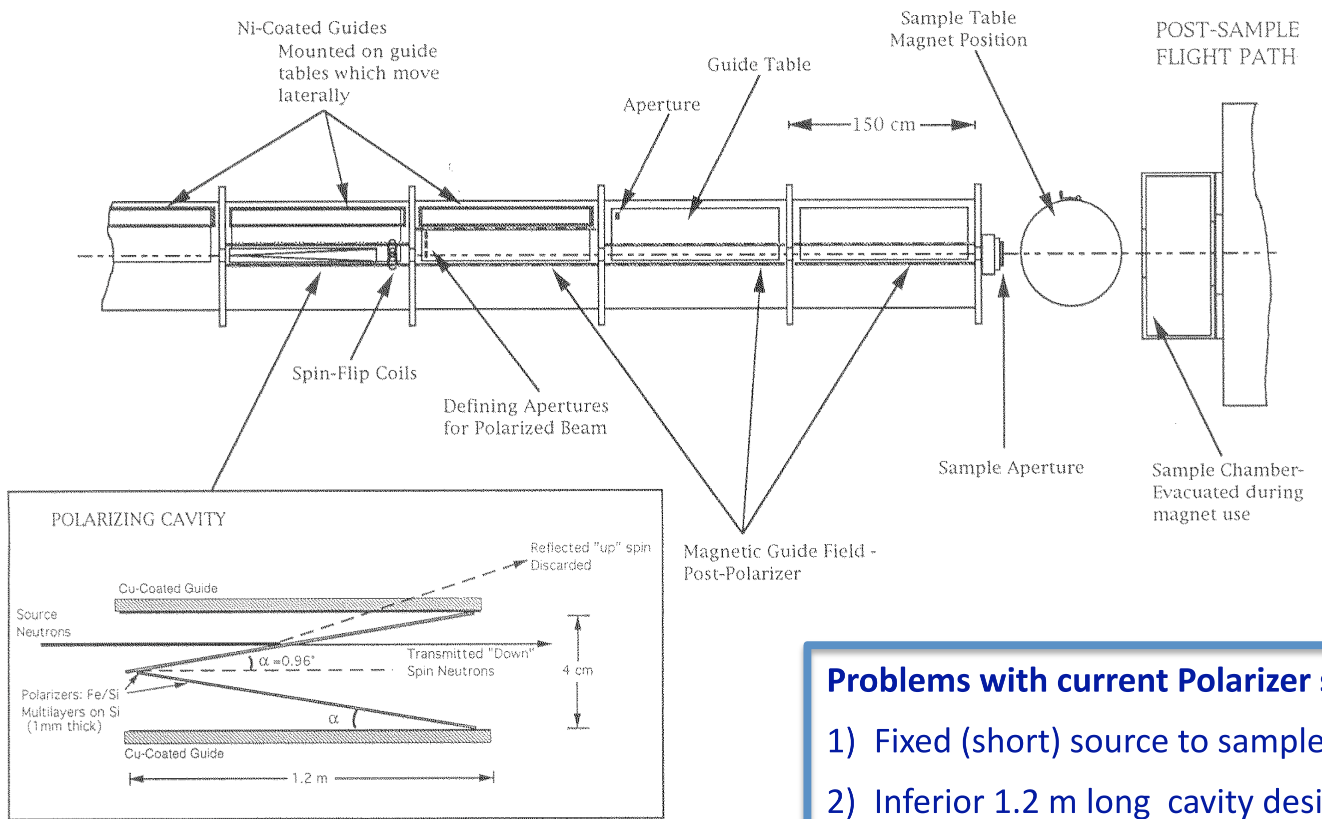
John Barker
SANS seminar
11/18/2009



Talk Outline

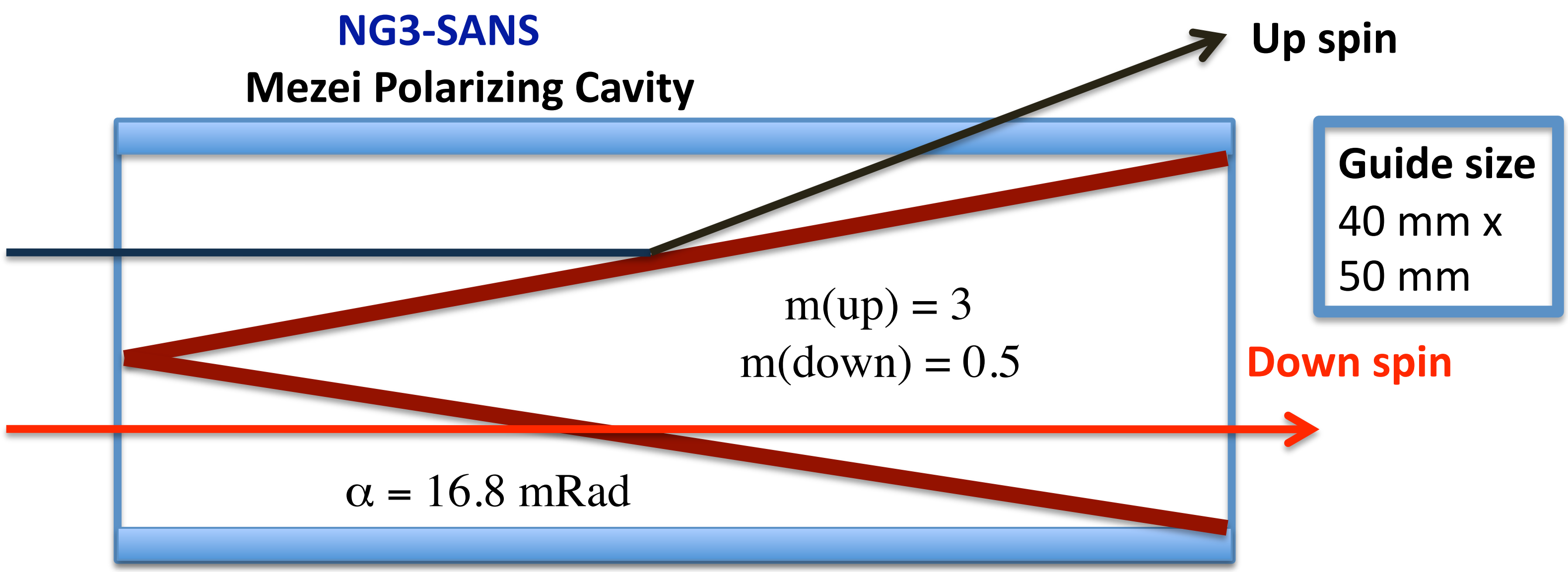
1) Current Polarizing Instrumentation on NG3-30m-SANS
2) SANS Polarizing Instrumentation at HZB (Berlin) and PSI
3) He(3) Cell performance as a Polarizer or Analyzer
4) Possible improvements to performance on NG7-30m-SANS
    a. Double coated mirrors for cavity
    b. Relocate to increase source to sample distance → lower Q_{min}
    c. Replace precession coil flipper with RF flipper
    d. Expand sample area (room for insitu He(3) analyzer)
5) Statistical Optimization of Cavity and Analyzer Polarizations
    a. Ratio of non-spin-flip to spin-flip (1, 10, and 100)
    b. Improve Cavity Polarization (P = 0.9, 0.99 and 0.999)
    c. Improve He(3) Analyzer Polarization P_{he}= 60%, 75%, 90%, + 95%
6) Summary

NG3-SANS: Polarizing Neutron Guide Arrangement



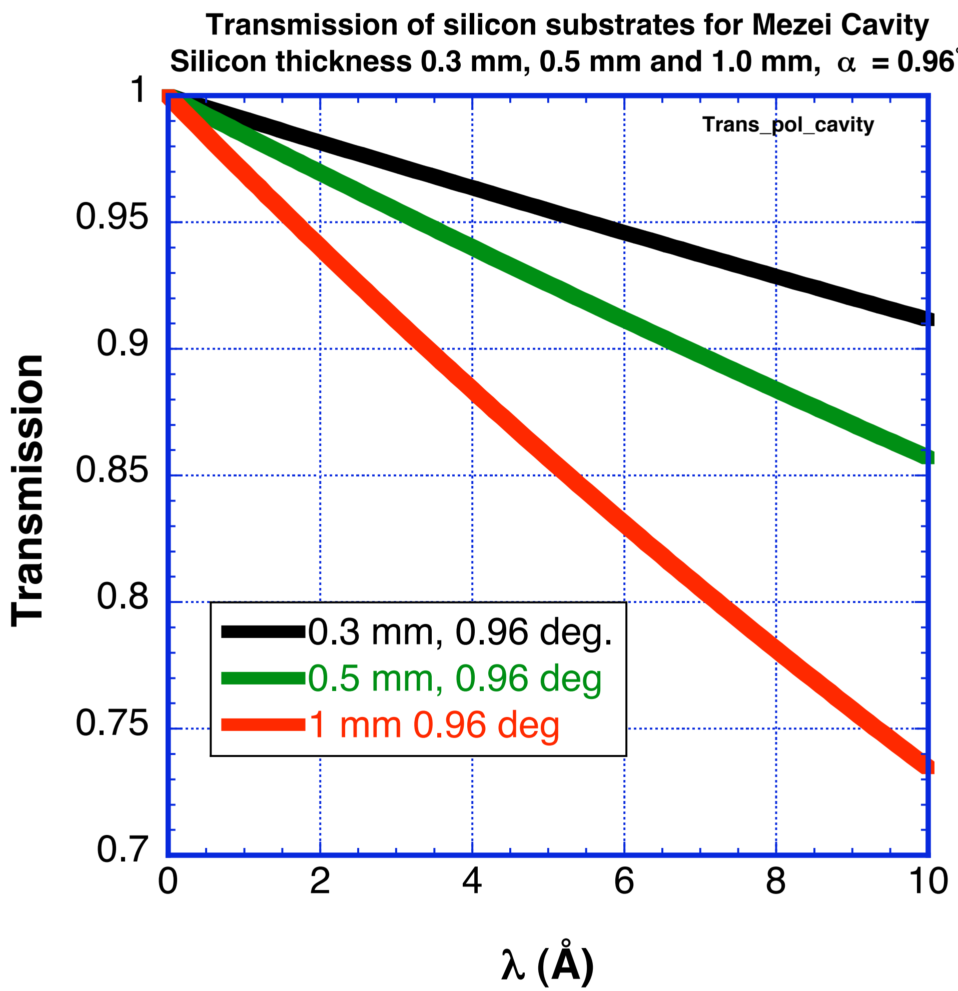
Problems with current Polarizer system design:

1) Fixed (short) source to sample distance
2) Inferior 1.2 m long cavity design (P = 94%)
    a) Inside coating only: 2 mm gap
    b) Small (40 mm x 50 mm)
    c) Thick (1 mm) Si substrate
3) Low efficiency precession spin flipper (P=95%)

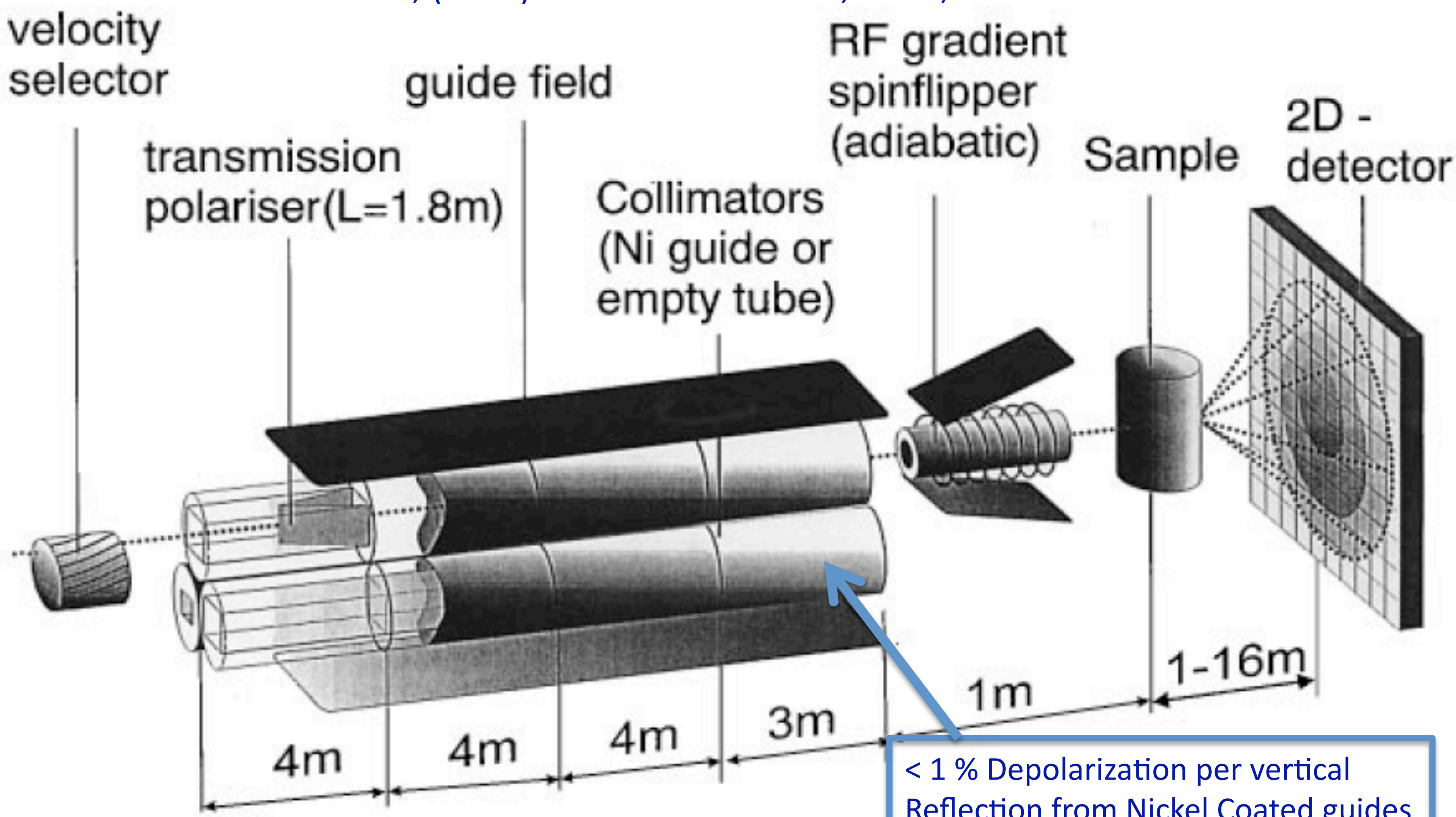


Potential changes for NG7 location:

1) Increase length from 1.2 m to 1.5 m (40 mm to **50 mm** width)
2) Super mirror both sides of substrate (eliminates 2 mm gap)
3) Thinner Si substrate (0.5 mm versus 1.0 mm)
4) Move from 7^{th} to 2^{nd} box, 7.5 m farther from sample.
5) Extras: External magnetic guide field, RF flipper.


Transmission of silicon substrates for Mezei Cavity
Silicon thickness 0.3 mm, 0.5 mm and 1.0 mm, α = 0.96°
Trans_pol_cavity
Transmission
λ (Å)
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2
4
6
8
10
0.3 mm, 0.96 deg.
0.5 mm, 0.96 deg
1 mm 0.96 deg

Keller et al, (2000) *Nuc. Instr. Methods*, **A451**, 474-479



< 1 % Depolarization per vertical
Reflection from Nickel Coated guides
With 10 Gauss guide field

Fig. 1. SANS instrument V4 at BENSC Berlin.

Aswal et al, (2008) *Nucl. Instr. Methods,* **A586**, 86-89.

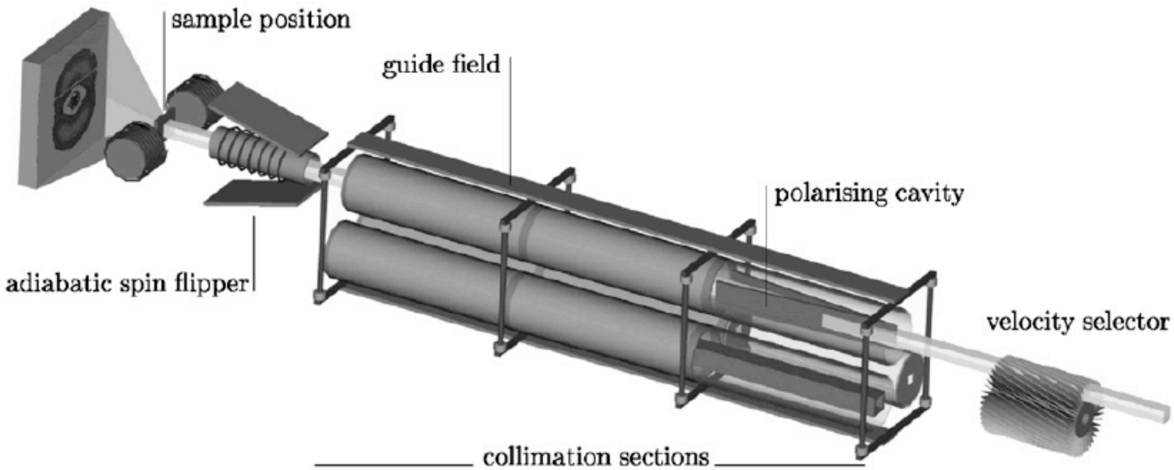


Fig. 1. Sketch of the polarisation option at SANS-I. The polarising cavity is located inside a neutron guide (not shown) within the first exchangeable segment of the collimator.

Keller et al, (2000) *Nuc. Instr. Methods*, **A451**, 474-479

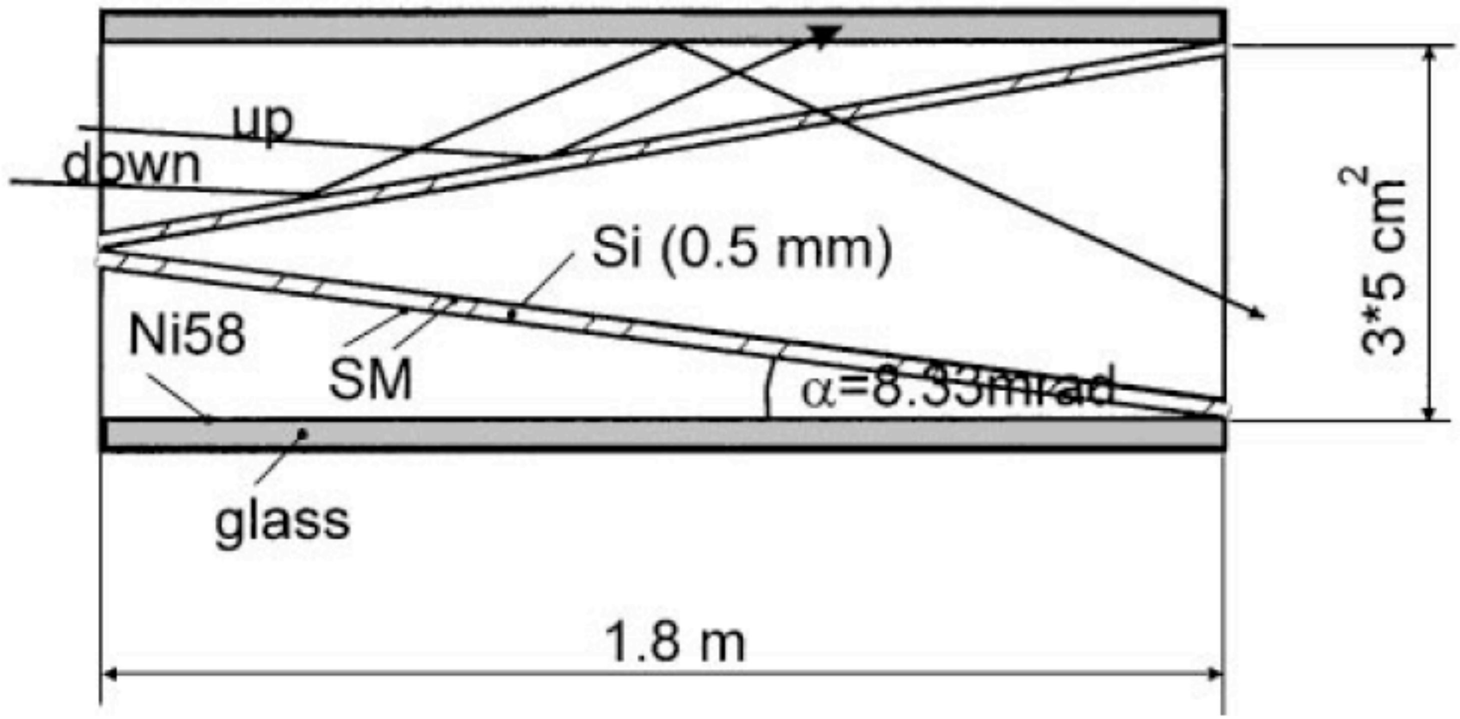


Fig. 2. Transmission polarizer (top view). Si-wavers with supermirrors on both sides are arranged in a V-shape inside a neutron guide. Spin-down neutrons are transmitted, spin-up neutrons are absorbed in the glass walls.

> 93 % Polarization

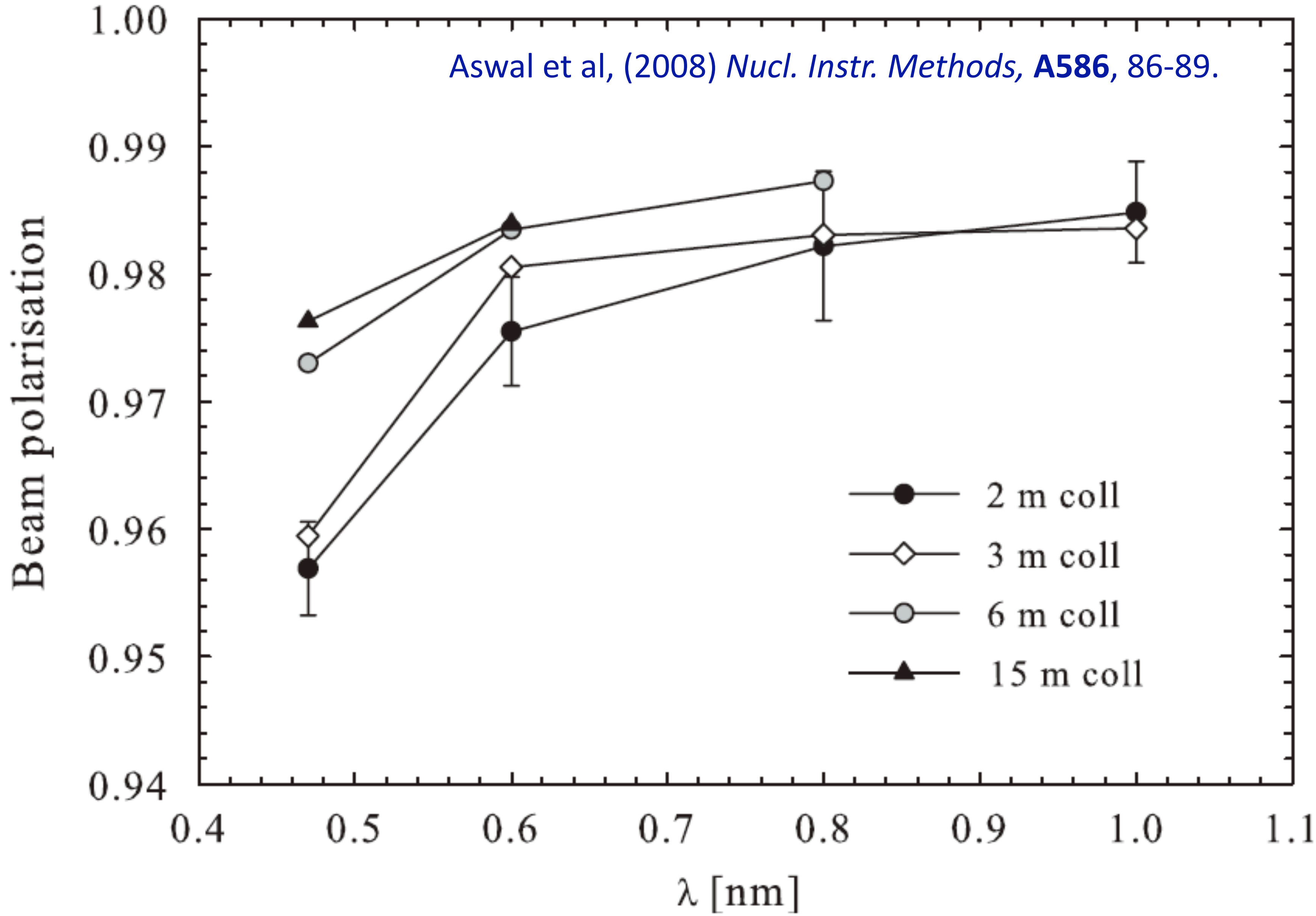
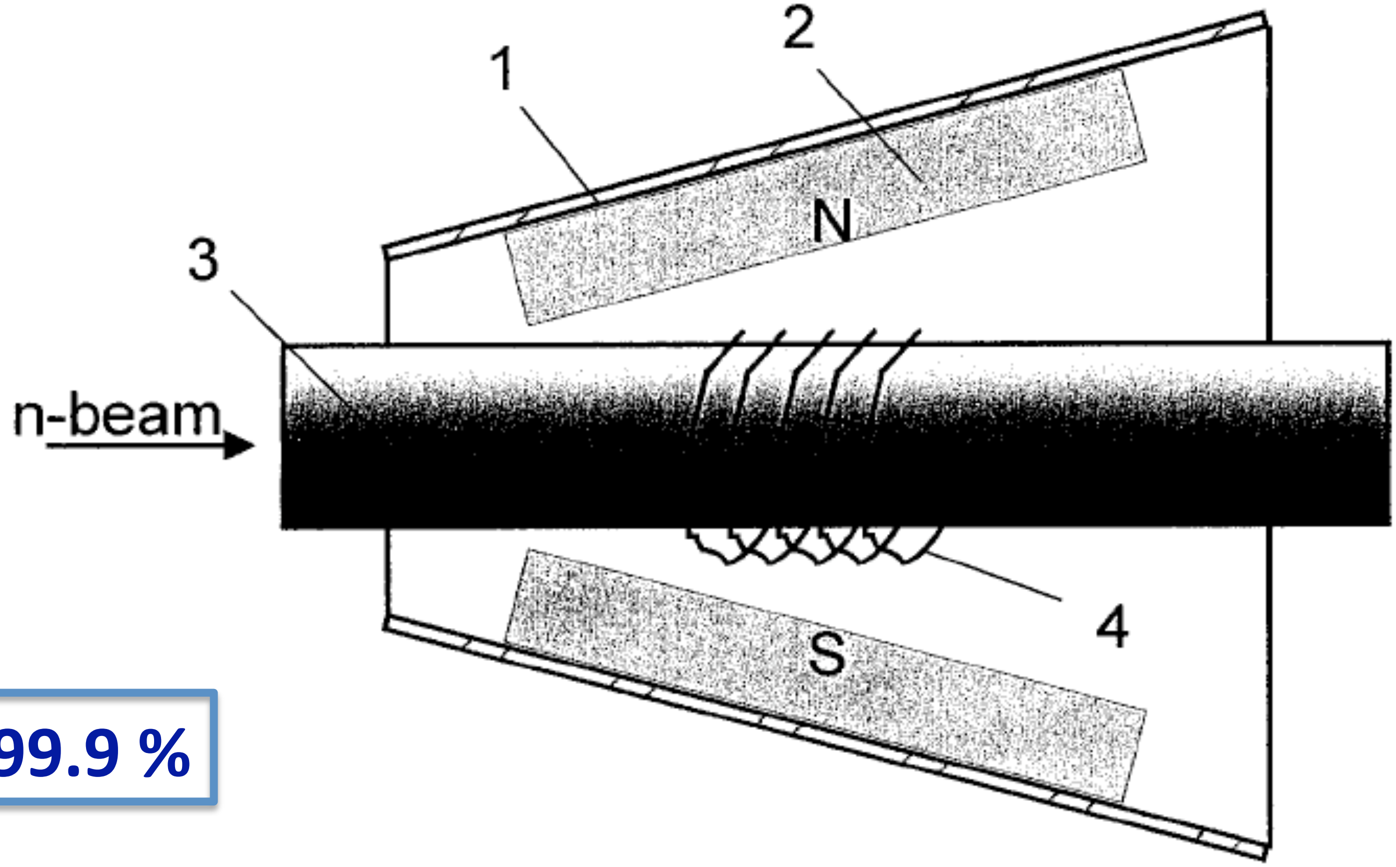


Fig. 4. Polarisation of the neutron beam at SANS-I at SINQ for different collimation lengths. For clarity the measurement error is shown for one

Keller et al, (2000) *Nuc. Instr. Methods*, **A451**, 474-479



P > 99.9 %

Fig. 3. RF gradient spin flipper. (1) Iron yoke (length 21 cm, width 22 cm/37 cm at left/right side); (2) Ferrite permanent magnets $20 \times 10 \times 2\ cm^3$; (3) Beam tube (ceramic, ∅ 11 cm); (4) RF coil.

Aswal et al, (2008) *Nucl. Instr. Methods,* **A586**, 86-89.

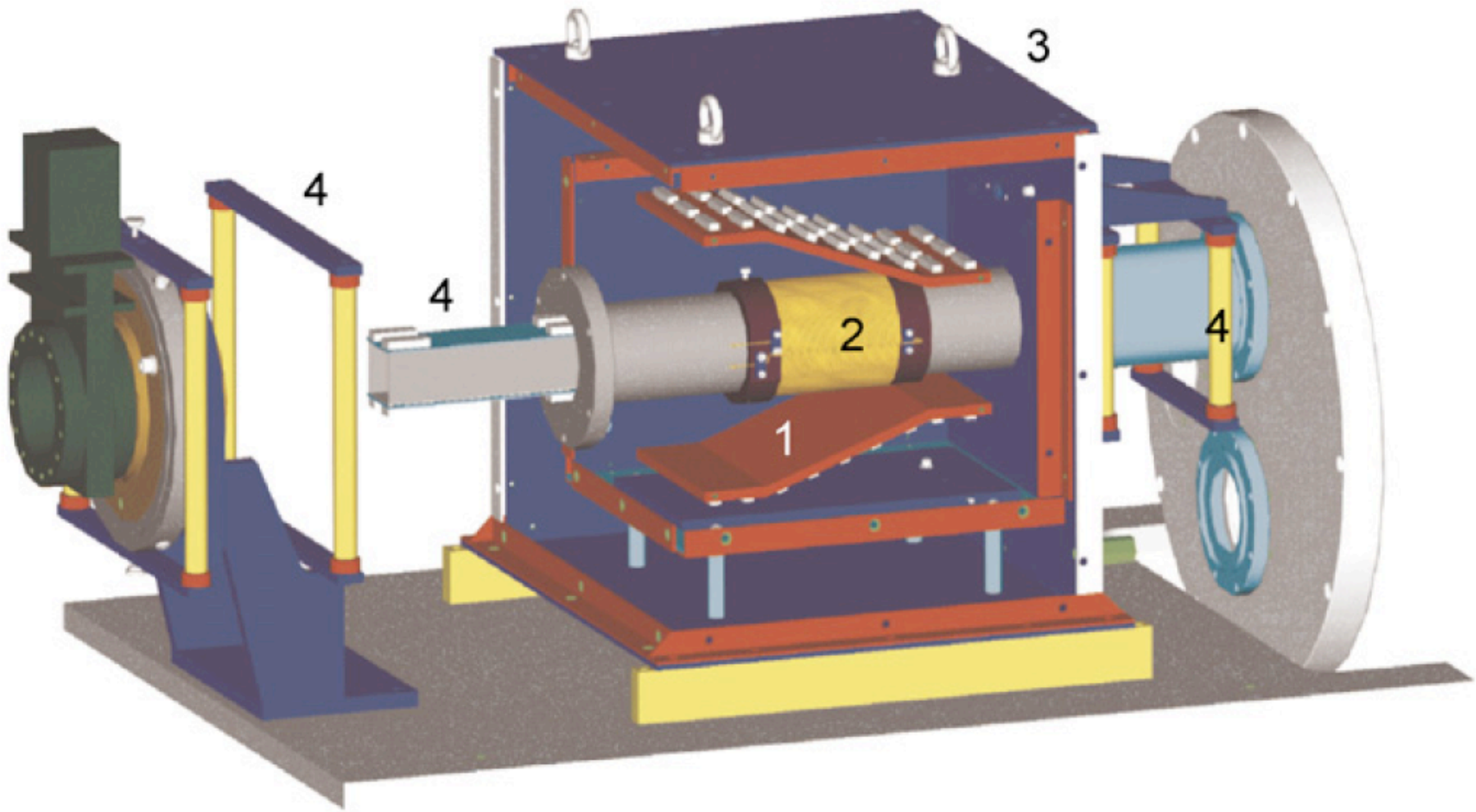
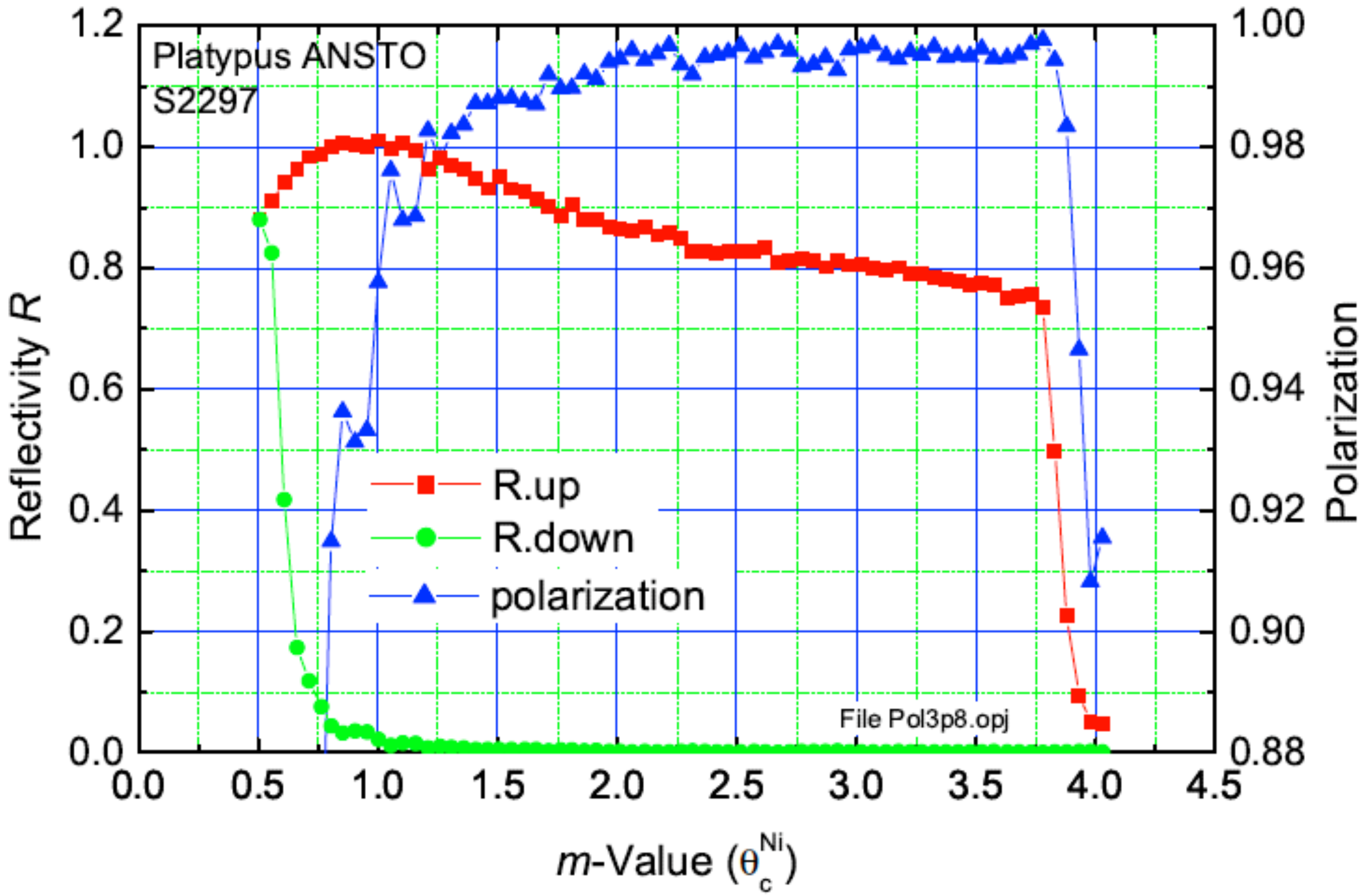


Fig. 3. Schematic drawing of the spin flipper setup with (1) the gradient field, (2) the radio-frequency solenoid, (3) the magnetic shielding box and (4) the magnetic guiding field.



Boni et al, (2009) *Physica B*, **404**, 2620-2623.

Fig. 1. Neutron reflectivity for spin up and down from a polarizing supermirror for Platypus [8] showing an excellent reflectivity and polarization. The solid lines are guides to the eye.

Boni et al, (2009) *Physica B*, **404**, 2620-2623.

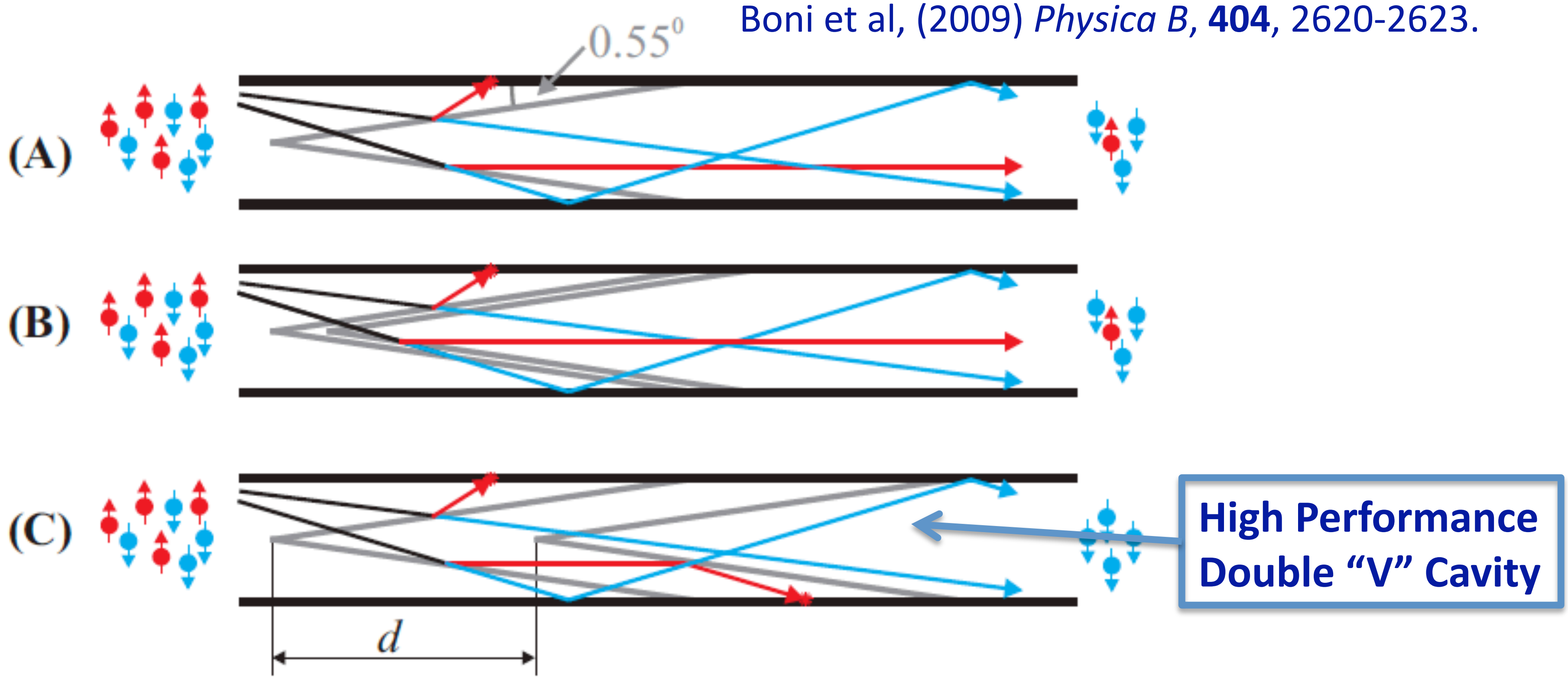
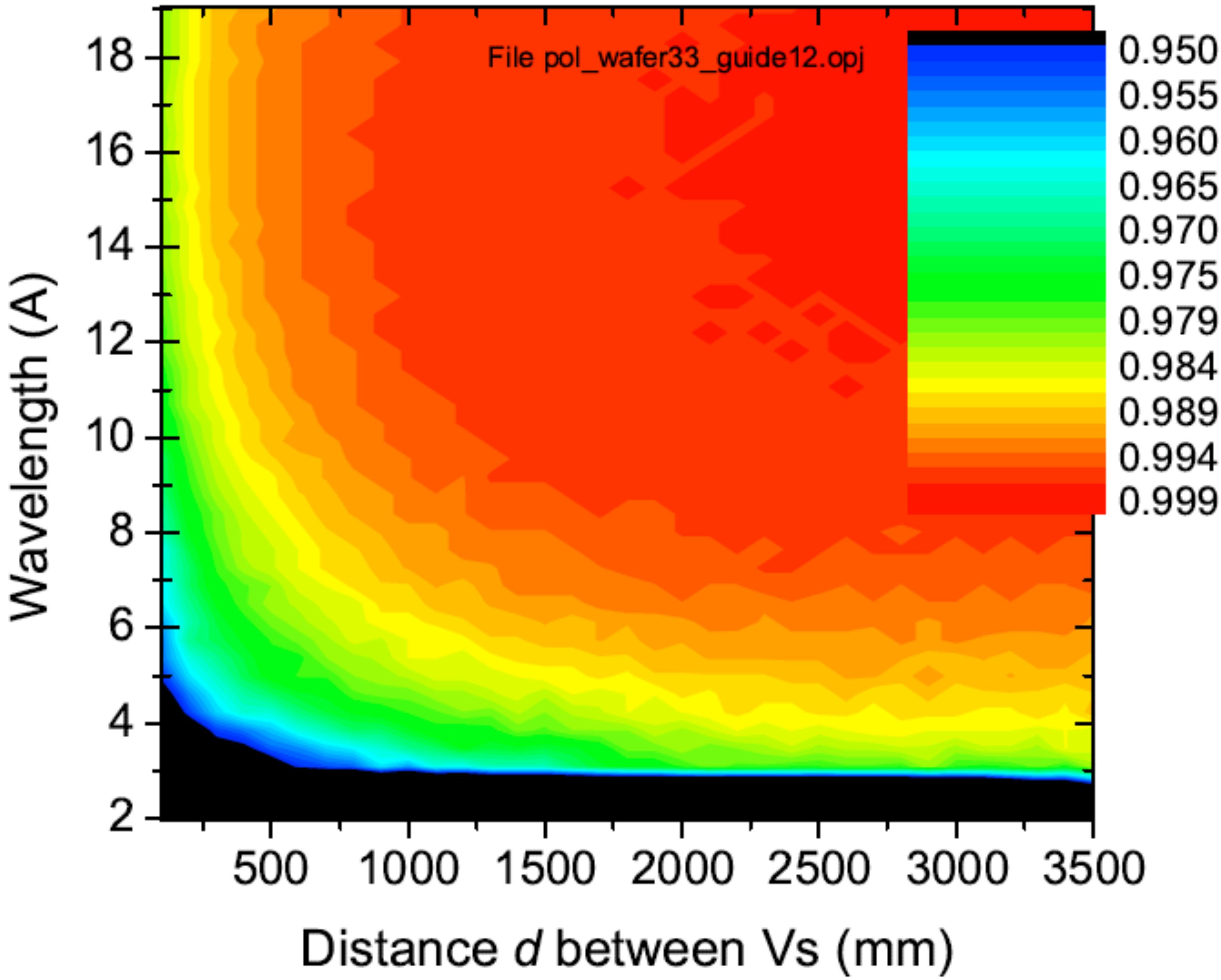


Fig. 4. Top view of polarizing cavities. If a single V-cavity is used (A), there is a possibility that neutrons with the up-polarization are transmitted. If the two Vs are displaced by a significant distance d (C), the wrongly polarized neutrons are removed and the polarization of the transmitted beam is increased. If the Vs are too close (B), P does not improve.

Double Cavity Performance: Boni et al, (2009) *Physica B*, **404**, 2620-2623.

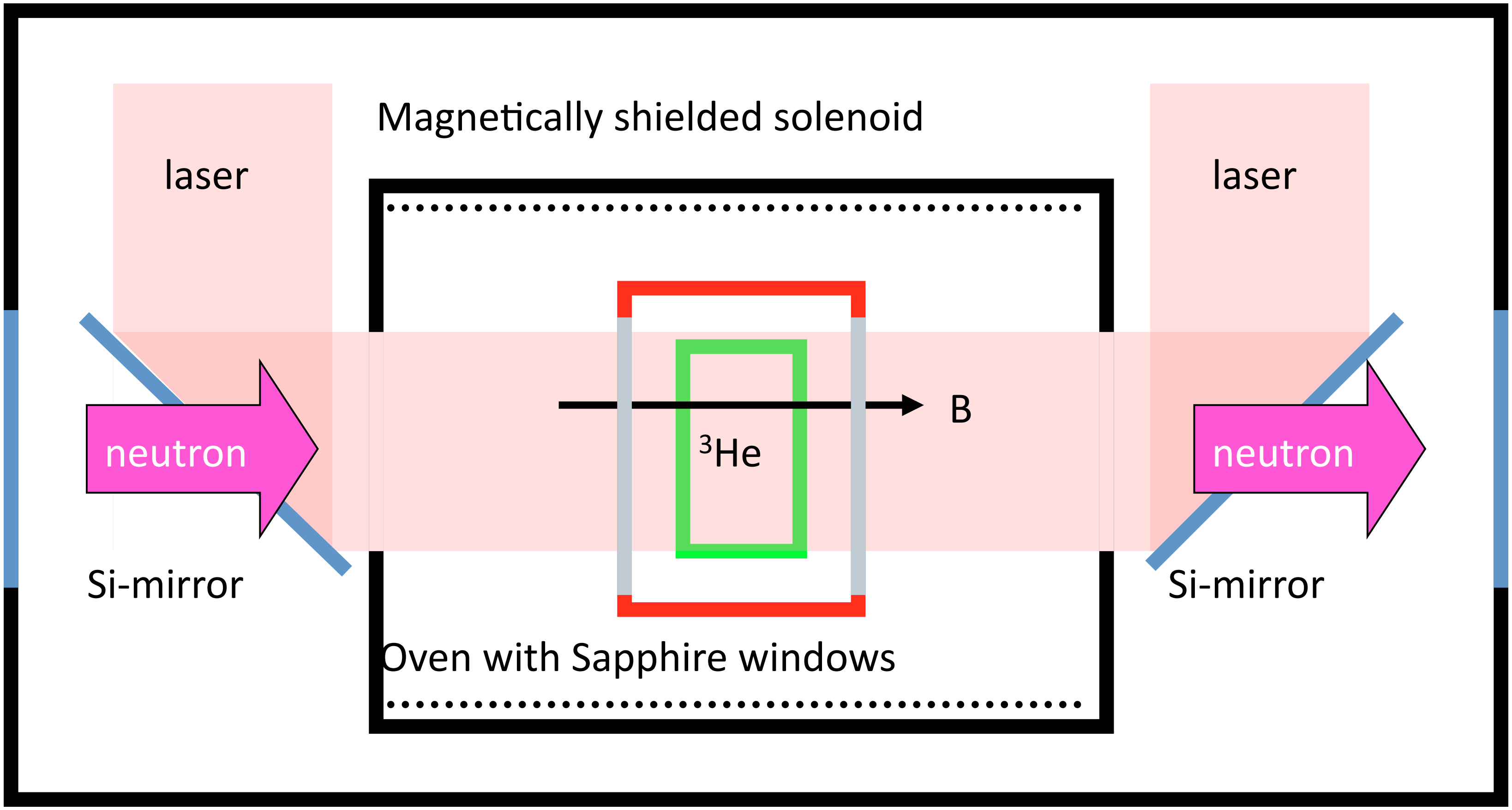


In-situ ^{3}He analyzer for V-SANS (solenoid)

{ Wangchun Chen, 2009 }

Conceptual design

~25” x 18” x 25”



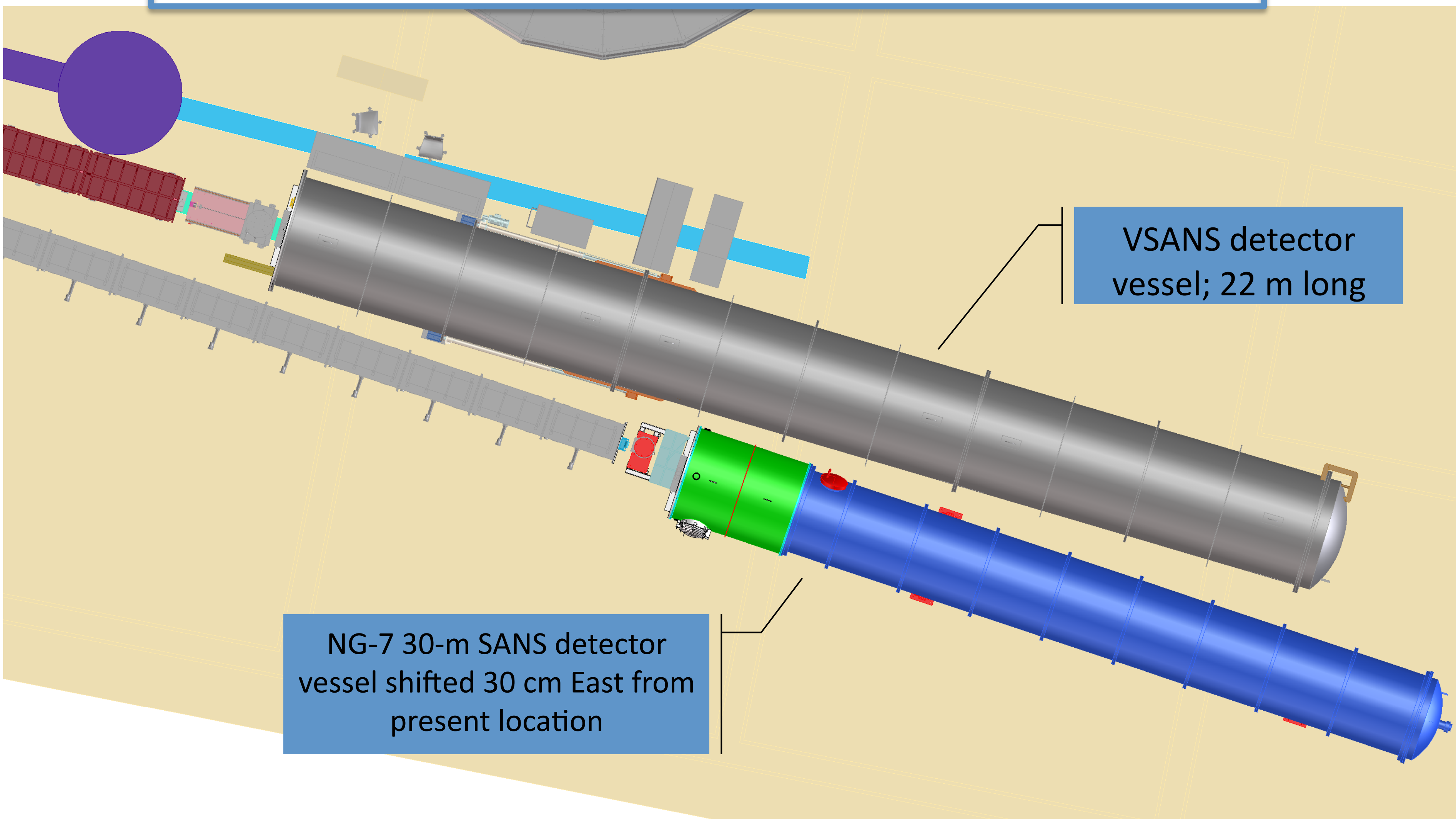
Laser shielding with Si-windows

Budget

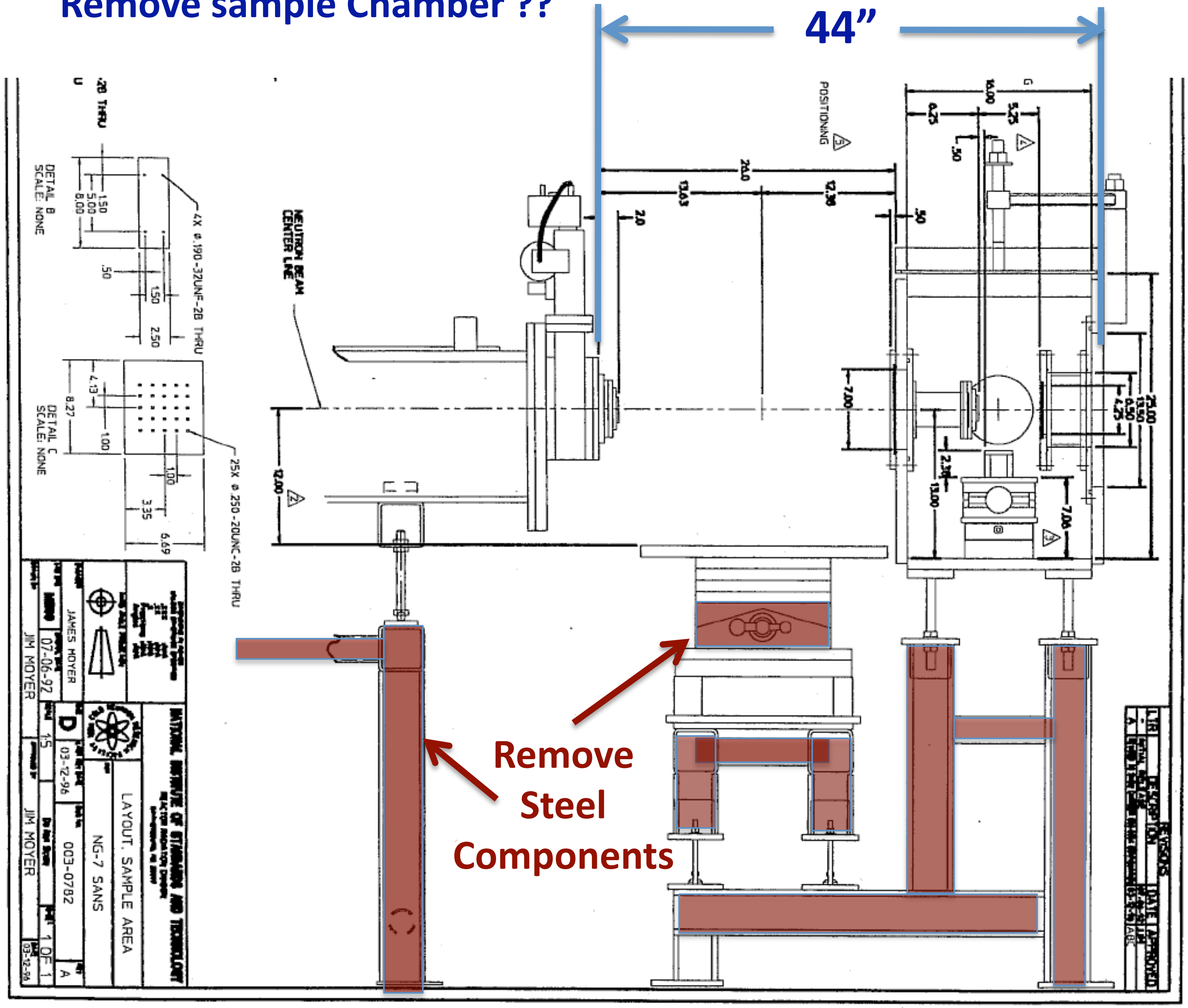
{ Wangchun Chen, 2009 }

Item	Description	Cost/each, $	#	Total, $
cell	12 cm ID, 7 cm long, including ^{3}He gas, Rb/K	5,000	2	10,000
Holding field	Magnetically shielded solenoid, power supply	8,000	1	8,000
Oven and temp. controller	Home-made non-magnetic oven, heating elements, temp. controller	6,000	1	6,000
Laser and optics	100 W diode bar + laser driver + optics High pressure chiller	11,000 7,000	2 1	22,000 7,000
Laser misc.	Power meter, laser safety goggles	3,000	1	3,000
Spectrum analyzer		5,000	1	5,000
NMR hardware	Lock-in, function generators, RF amplifier	12,000	1	12,000
Data acquisition	DAQ, BNC connector, GPIP, computer	4,000	1	4,000
Laser shielding		2,000	1	2,000
Misc.	Silicon window, sapphire window, etc	8,000	1	8,000
				87,000

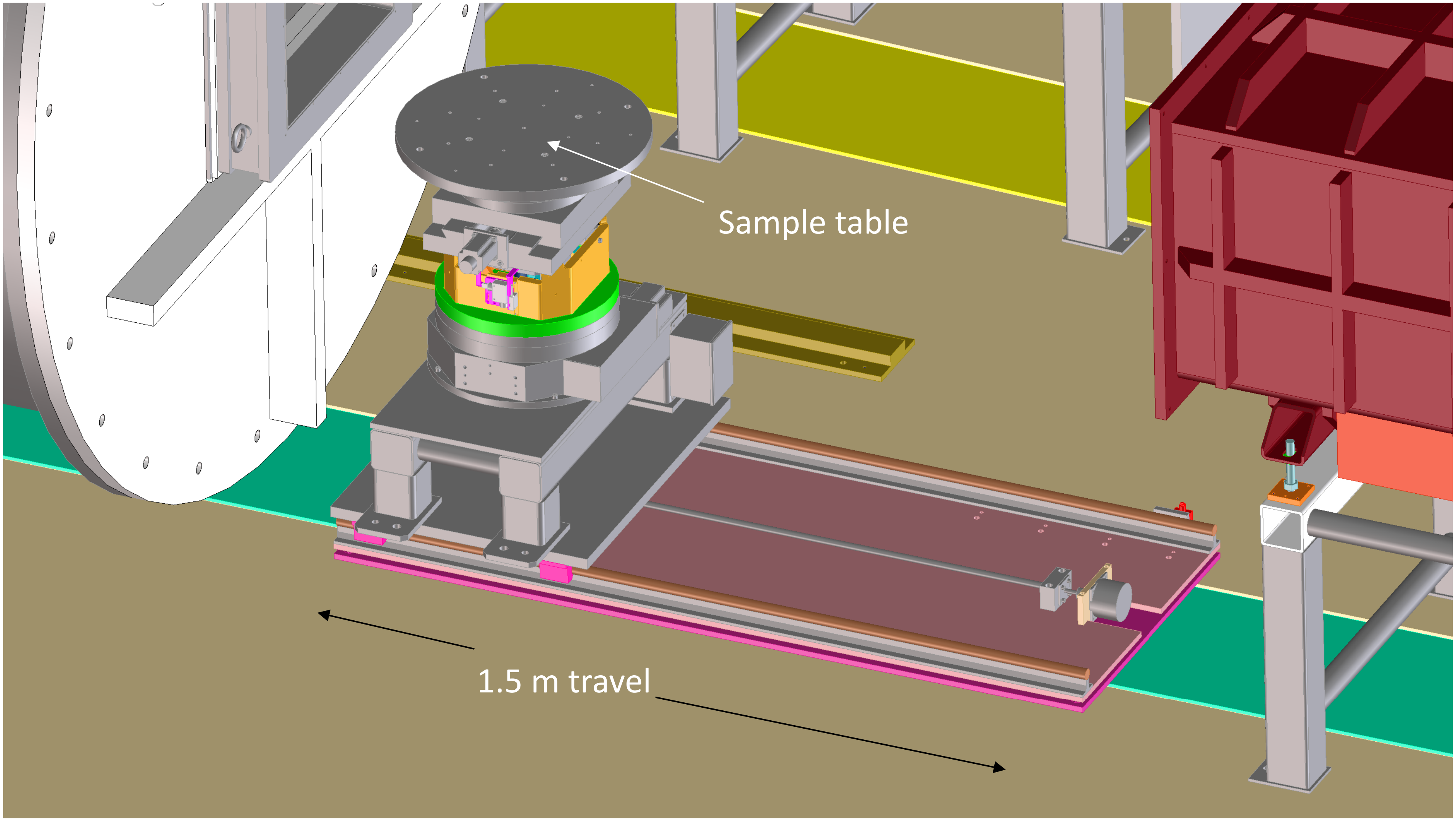
To offset detector tank, need to remake sample chamber and end plate For new beam center position.



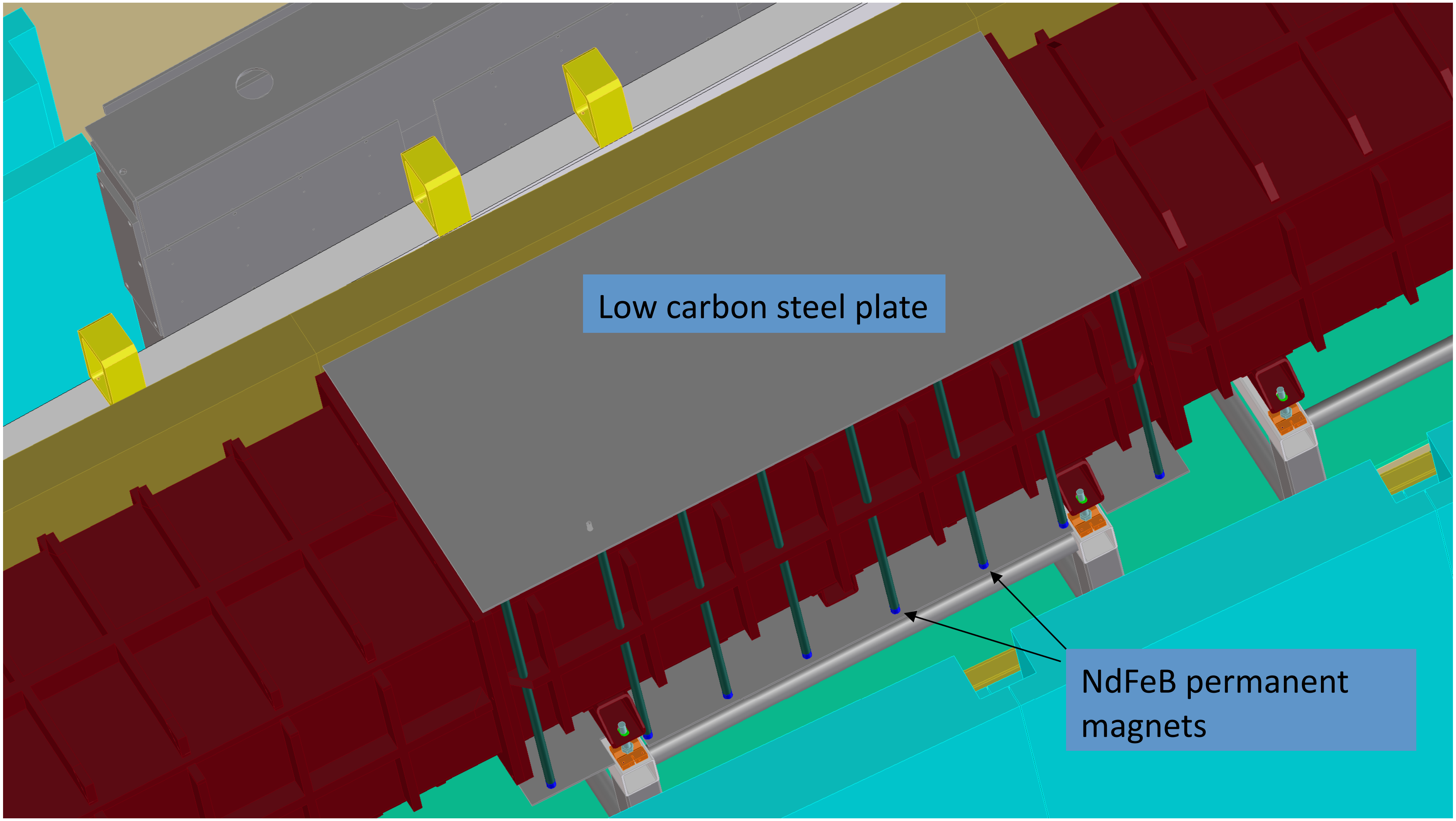
Remove sample Chamber ??



vSANS sample area: up to 2 m long… Could copy sample table for NG7

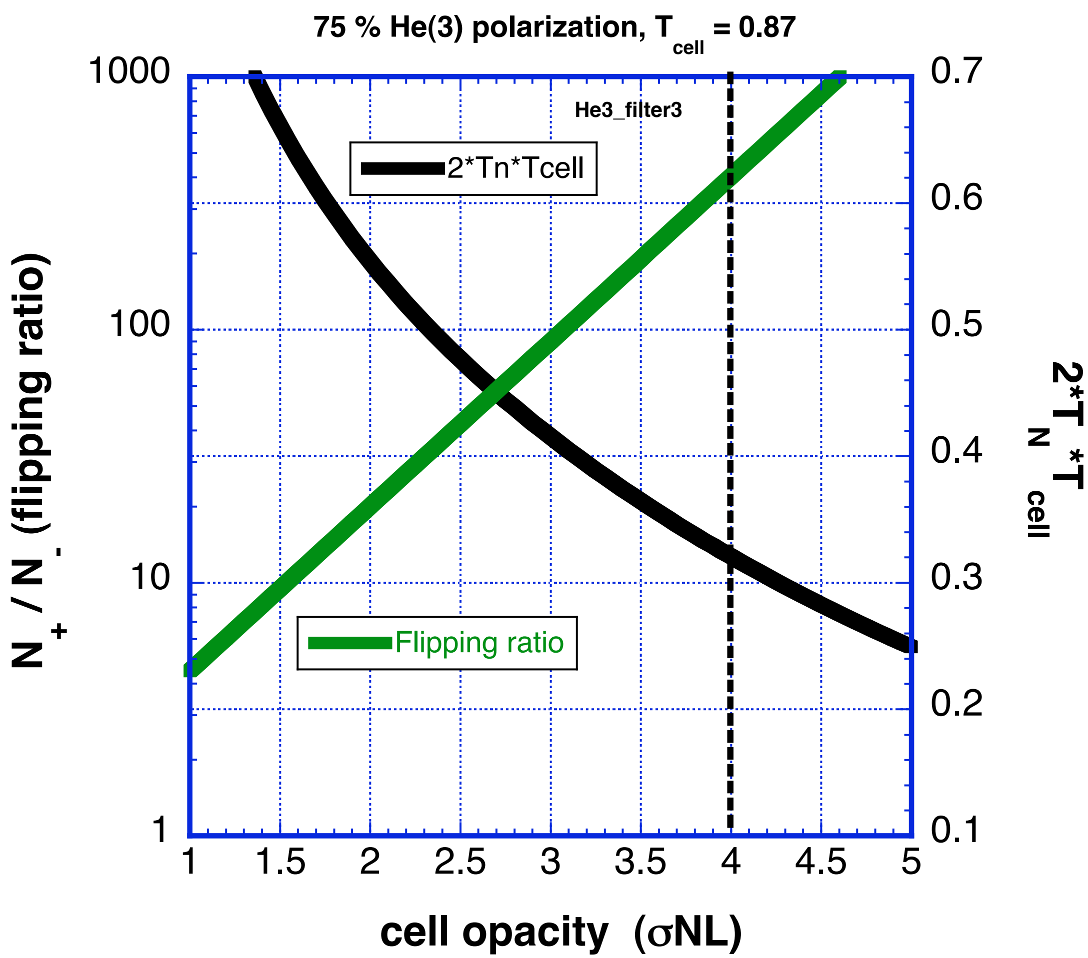


Entire pre-sample vessel is in a magnetic guide field constructed with permanent magnets and soft iron top and bottom plates

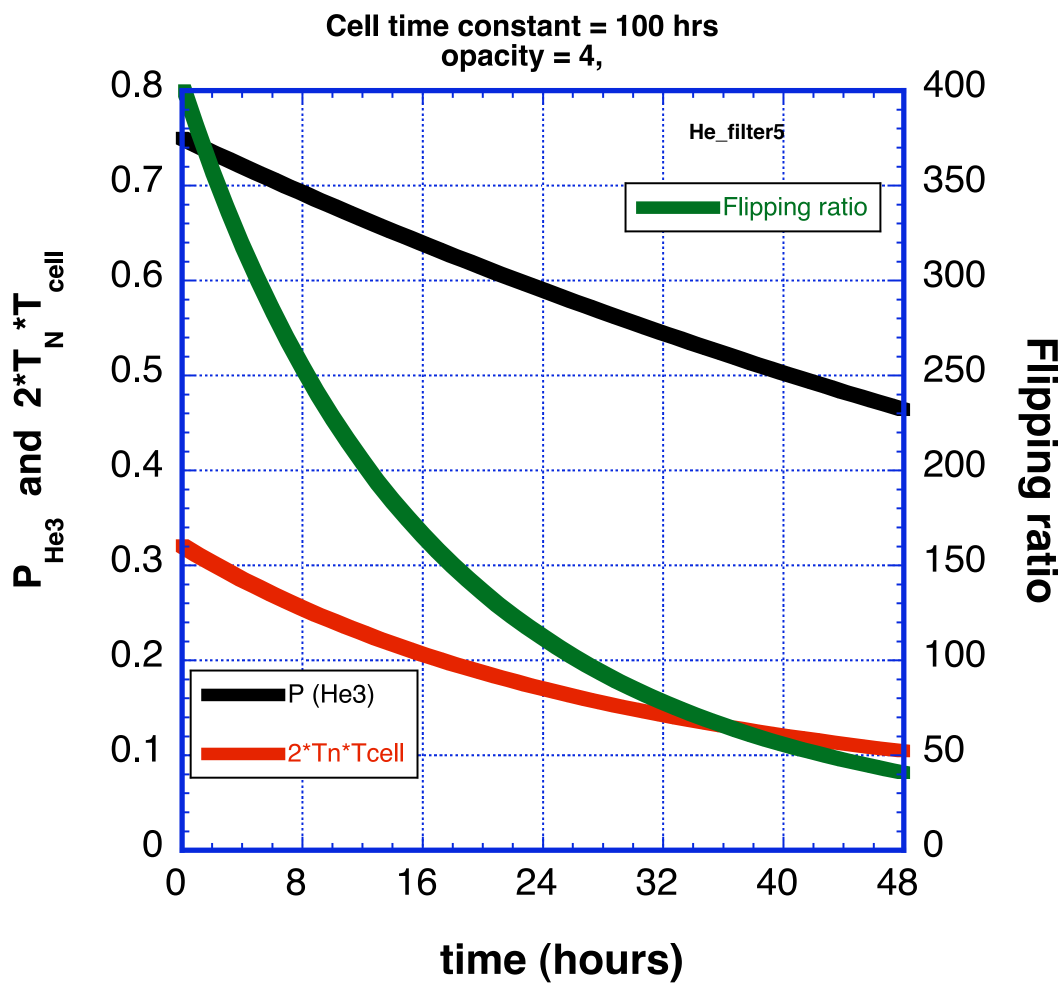


He(3) Cell for beam Polarization ??

With a factor of three
Loss in intensity, can
achieve **99.5%** polarization



Need Insitu He(3) cell to maintain high flipping ratios!



Insitu He(3) Cell for Polarizer:

Pros:

1) Cheaper… (w/o guide field and RF flipper).
2) No guide field eases optics maintenance.
3) Easy to adjust polarization: just change opacity.
4) Can share system with other instruments.

Cons:

1 Expensive (labor, parts) to maintain operation
(lasers, furnace, cooling system, etc.).
2) P sensitive to fringe magnetic field from sample environment.
3) Factor of **2 to 4** reduction in beam intensity.
4) Requires 0.6 m or more of additional sample space.

A matrix format is often more convenient where inversion of the square matrix allows the four unknown scattering cross sections to be uniquely extracted.

$$\underbrace{\begin{bmatrix} N_{\text{off}}^{\uparrow}T_{\text{norm}(\uparrow)}^{\uparrow} & N_{\text{off}}^{\uparrow}T_{\text{norm}(\uparrow)}^{\downarrow} & N_{\text{off}}^{\downarrow}T_{\text{norm}(\uparrow)}^{\downarrow} & N_{\text{off}}^{\downarrow}T_{\text{norm}(\uparrow)}^{\uparrow} \\ N_{\text{off}}^{\uparrow}T_{\text{rev}(\downarrow)}^{\uparrow} & N_{\text{off}}^{\uparrow}T_{\text{rev}(\downarrow)}^{\downarrow} & N_{\text{off}}^{\downarrow}T_{\text{rev}(\downarrow)}^{\downarrow} & N_{\text{off}}^{\downarrow}T_{\text{rev}(\downarrow)}^{\uparrow} \\ N_{\text{on}}^{\uparrow}T_{\text{norm}(\uparrow)}^{\uparrow} & N_{\text{on}}^{\uparrow}T_{\text{norm}(\uparrow)}^{\downarrow} & N_{\text{on}}^{\downarrow}T_{\text{norm}(\uparrow)}^{\downarrow} & N_{\text{on}}^{\downarrow}T_{\text{norm}(\uparrow)}^{\uparrow} \\ N_{\text{on}}^{\uparrow}T_{\text{rev}(\downarrow)}^{\uparrow} & N_{\text{on}}^{\uparrow}T_{\text{rev}(\downarrow)}^{\downarrow} & N_{\text{on}}^{\downarrow}T_{\text{rev}(\downarrow)}^{\downarrow} & N_{\text{on}}^{\downarrow}T_{\text{rev}(\downarrow)}^{\uparrow} \end{bmatrix}}_{Time\ Dependent\ Coefficients} \underbrace{\begin{bmatrix} \sigma^{\uparrow\uparrow} \\ \sigma^{\uparrow\downarrow} \\ \sigma^{\downarrow\downarrow} \\ \sigma^{\downarrow\uparrow} \end{bmatrix}}_{To\ Solve} = \underbrace{\begin{bmatrix} I_{\text{off,norm}} \\ I_{\text{off,rev}} \\ I_{\text{on,norm}} \\ I_{\text{on,rev}} \end{bmatrix}}_{Measured} \tag{1.2}$$

$$N_{\text{off}}^{\uparrow} = (\frac{1+P_{SM}}{2})(1-\chi_D) + (\frac{1-P_{SM}}{2})(\chi_D)$$

$$N_{\text{off}}^{\downarrow} = (\frac{1+P_{SM}}{2})(\chi_D) + (\frac{1-P_{SM}}{2})(1-\chi_D)$$

$$\begin{aligned} N_{\text{on}}^{\uparrow} = [(\frac{1+P_{SM}}{2})(1-\chi_F) + (\frac{1-P_{SM}}{2})(\chi_F)] * (1-\chi_D) + \\ [(\frac{1+P_{SM}}{2})(\chi_F) + (\frac{1-P_{SM}}{2})(1-\chi_F)] * (\chi_D) \end{aligned} \tag{1.3}$$

$$\begin{aligned} N_{\text{on}}^{\downarrow} = [(\frac{1+P_{SM}}{2})(1-\chi_F) + (\frac{1-P_{SM}}{2})(\chi_F)] * (\chi_D) + \\ [(\frac{1+P_{SM}}{2})(\chi_F) + (\frac{1-P_{SM}}{2})(1-\chi_F)] * (1-\chi_D) \end{aligned}$$

Simplifying Assumptions:

1) spin-flip xsections are equal:
2) Non-spin-flip xsections are equal:
3) Flipper efficiency is 100% (use RF flipper)

Changes in notation:

Cavity Polarization: S = P_{SM} (includes any sample depolarization)

Analyzer Polarization:

$$A = \frac{T_{Norm}^{\uparrow} - T_{Norm}^{\downarrow}}{T_{Norm}^{\uparrow} + T_{Norm}^{\downarrow}}$$

$$T_{Norm}^{\uparrow} = T_0 \exp\left(-(1 - P_{He})\tau\right)$$

$$T_{Norm}^{\downarrow} = T_0 \exp\left(-(1 + P_{He})\tau\right)$$

Normalize Scattering Intensity Measurements by Analyzer transmission

$$I' = \frac{I}{T_{Norm}^{\uparrow} + T_{Norm}^{\downarrow}}$$

Minimize error in spin flip xsection: optimize S, A, opacity and counting times:

Total counting time: $t_{tot} = t_{off,Rev} + t_{off,Norm}$

$$I'^{off}_{Norm} = \frac{\sigma_{\uparrow\uparrow}}{4}\left[(1+S)(1+A)+(1-S)(1-A)\right] + \frac{\sigma_{\uparrow\downarrow}}{4}\left[(1+S)(1-A)+(1-S)(1+A)\right]$$

$$I'^{off}_{Rev} = \frac{\sigma_{\uparrow\uparrow}}{4}\left[(1+S)(1-A)+(1-S)(1+A)\right] + \frac{\sigma_{\uparrow\downarrow}}{4}\left[(1+S)(1+A)+(1-S)(1-A)\right]$$

$$\sigma_{\uparrow\downarrow} = \frac{I'^{off}_{Rev}(1+SA) - I'^{off}_{Norm}(1-SA)}{2SA}$$

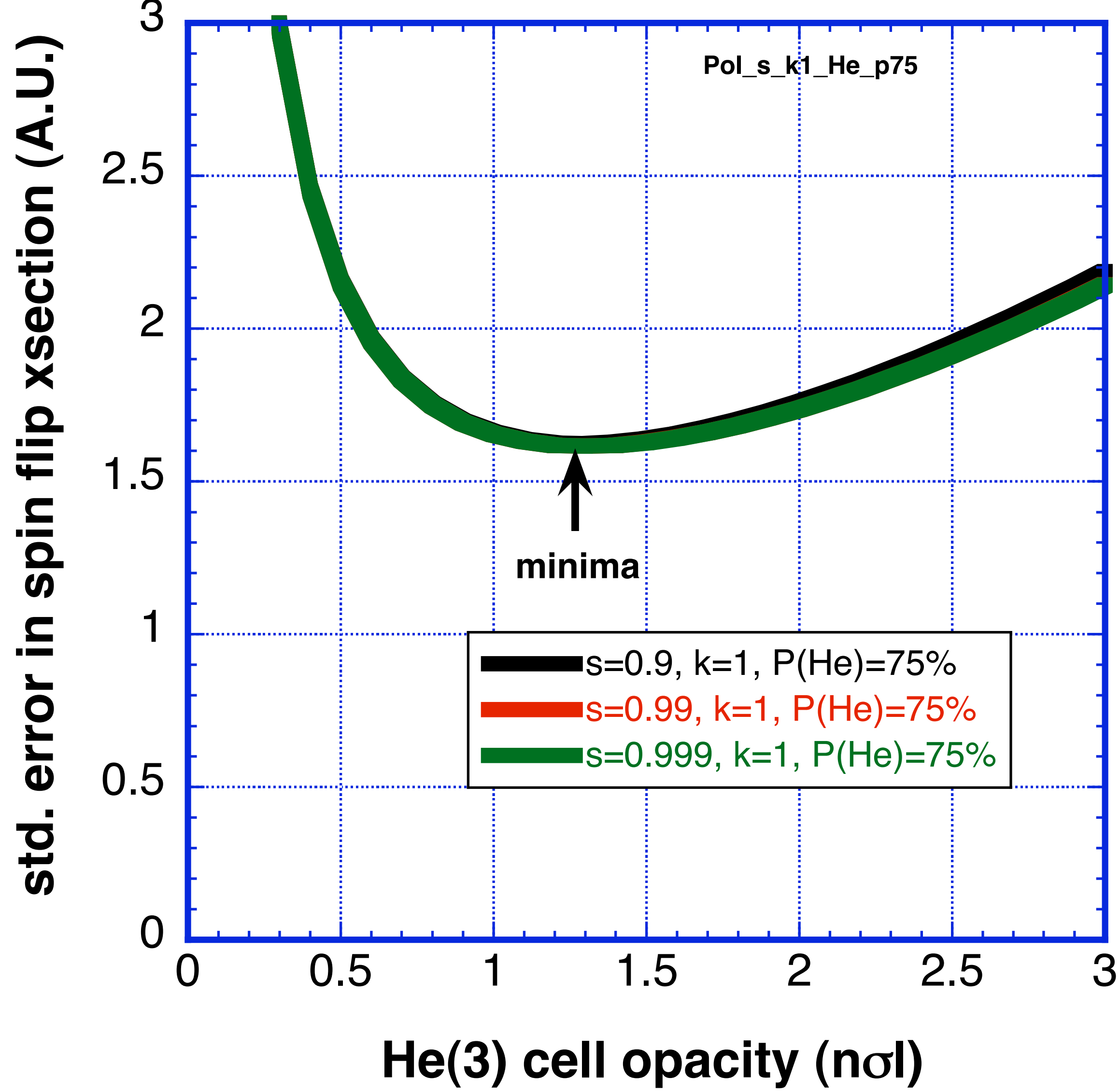
$$K \equiv \sigma_{\uparrow\uparrow} / \sigma_{\uparrow\downarrow}$$

$$Var(\sigma_{\uparrow\downarrow}) = \frac{1}{\left(2SA(T^{\uparrow}_{Norm}+T^{\downarrow}_{Norm})\right)^2}\left[\frac{I^{off}_{Rev}(1+SA)^2}{t_{off,rev}} + \frac{I^{off}_{Norm}(1-SA)^2}{t_{off,Norm}}\right] =$$

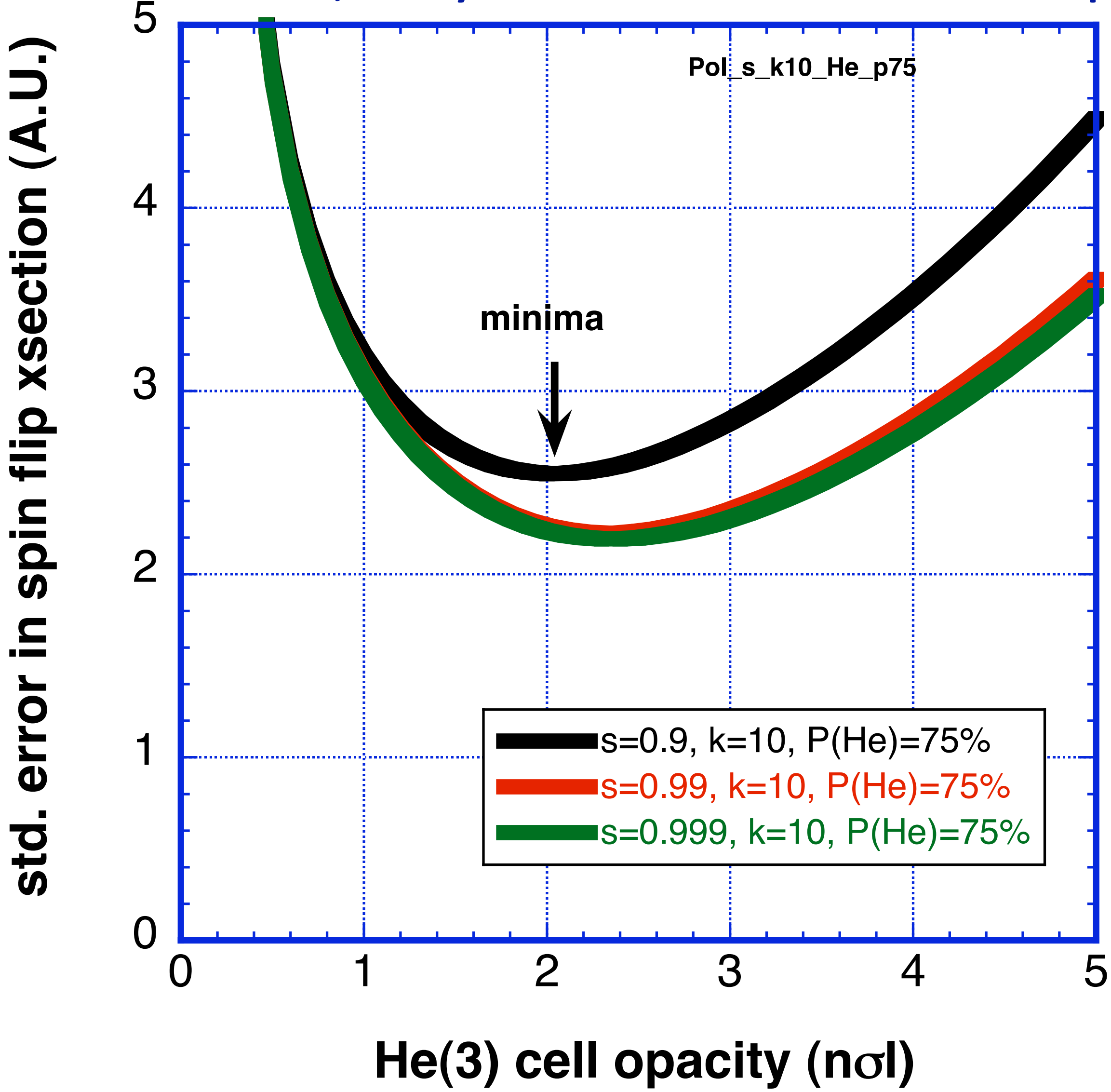
$$Var(\sigma_{\uparrow\downarrow}) = \frac{1}{t_{tot}\left(2SA(T^{\uparrow}_{Norm}+T^{\downarrow}_{Norm})\right)^2}\left[I^{off}_{Rev}(1+SA)^2\left(1+\frac{t_{off,Norm}}{t_{off,rev}}\right) + I^{off}_{Norm}(1-SA)^2\left(1+\frac{t_{off,Rev}}{t_{off,Norm}}\right)\right]$$

$$\frac{t_{off,Rev}}{t_{off,Norm}} = \frac{1+SA}{1-SA}\sqrt{\frac{I'^{off}_{Rev}}{I'^{off}_{Norm}}}$$

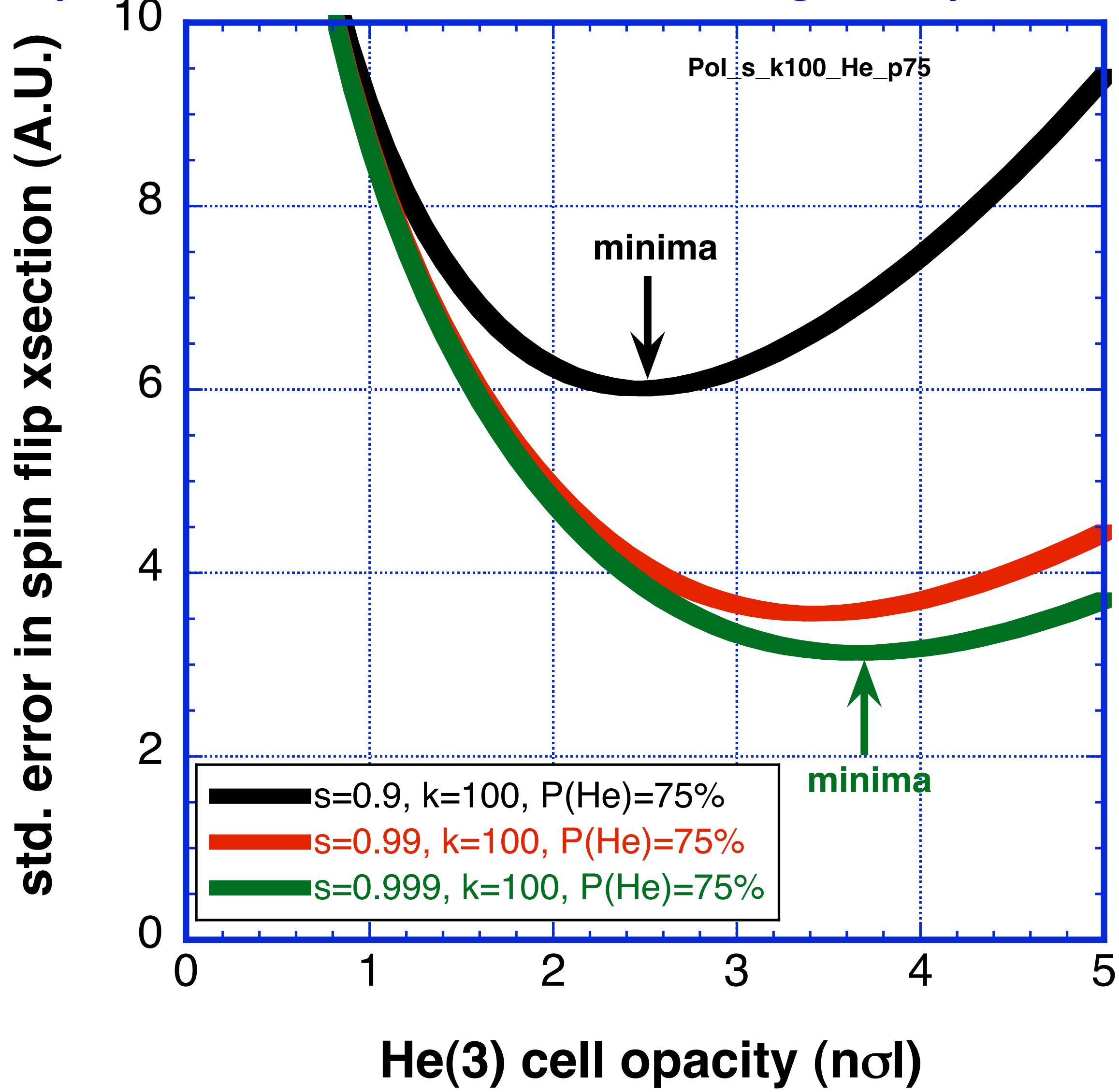
For K=1, Cavity Polarization S = 90 % is adequate

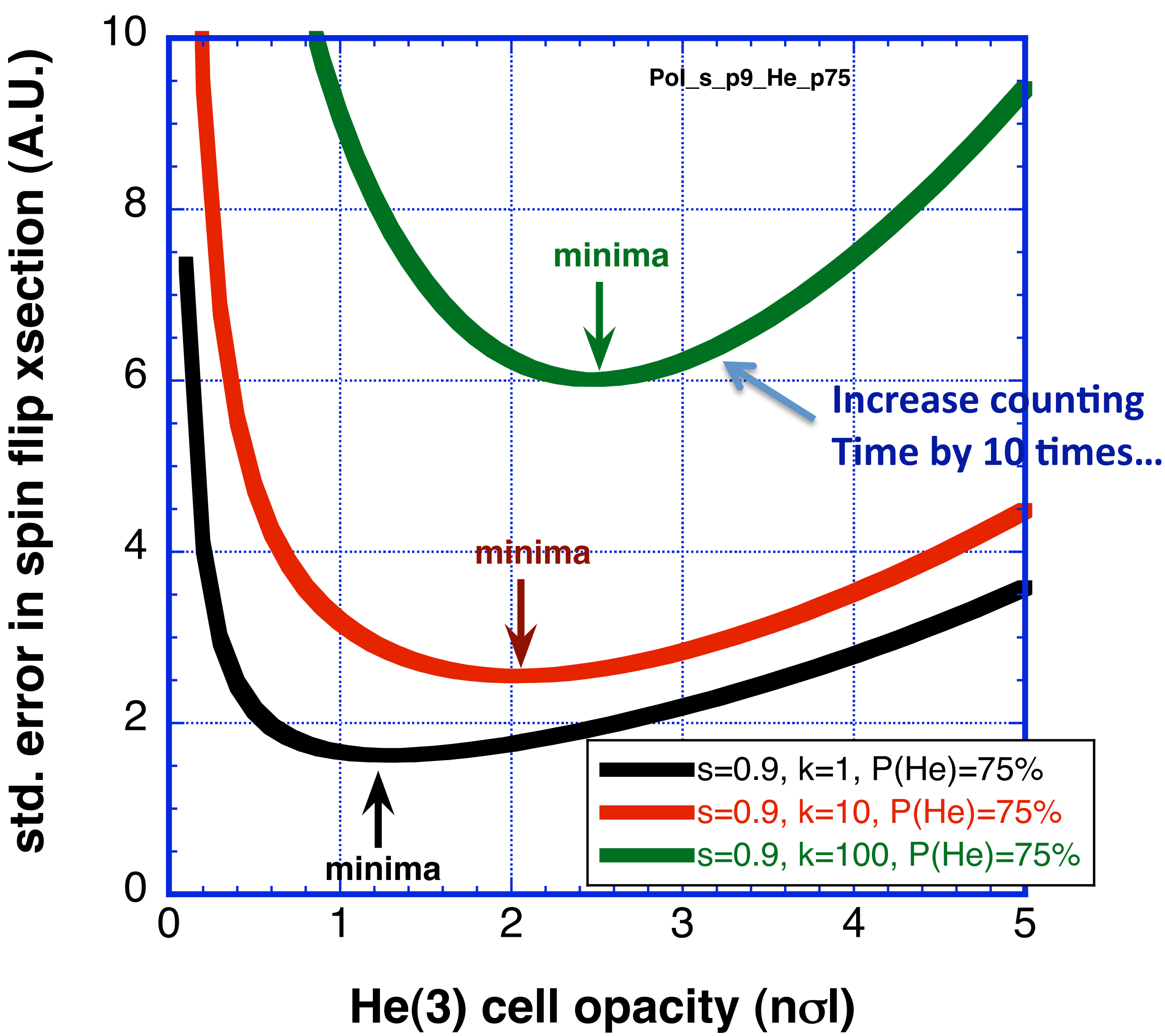


For K=10, Cavity Polarization S = 90 % is still adequate!!

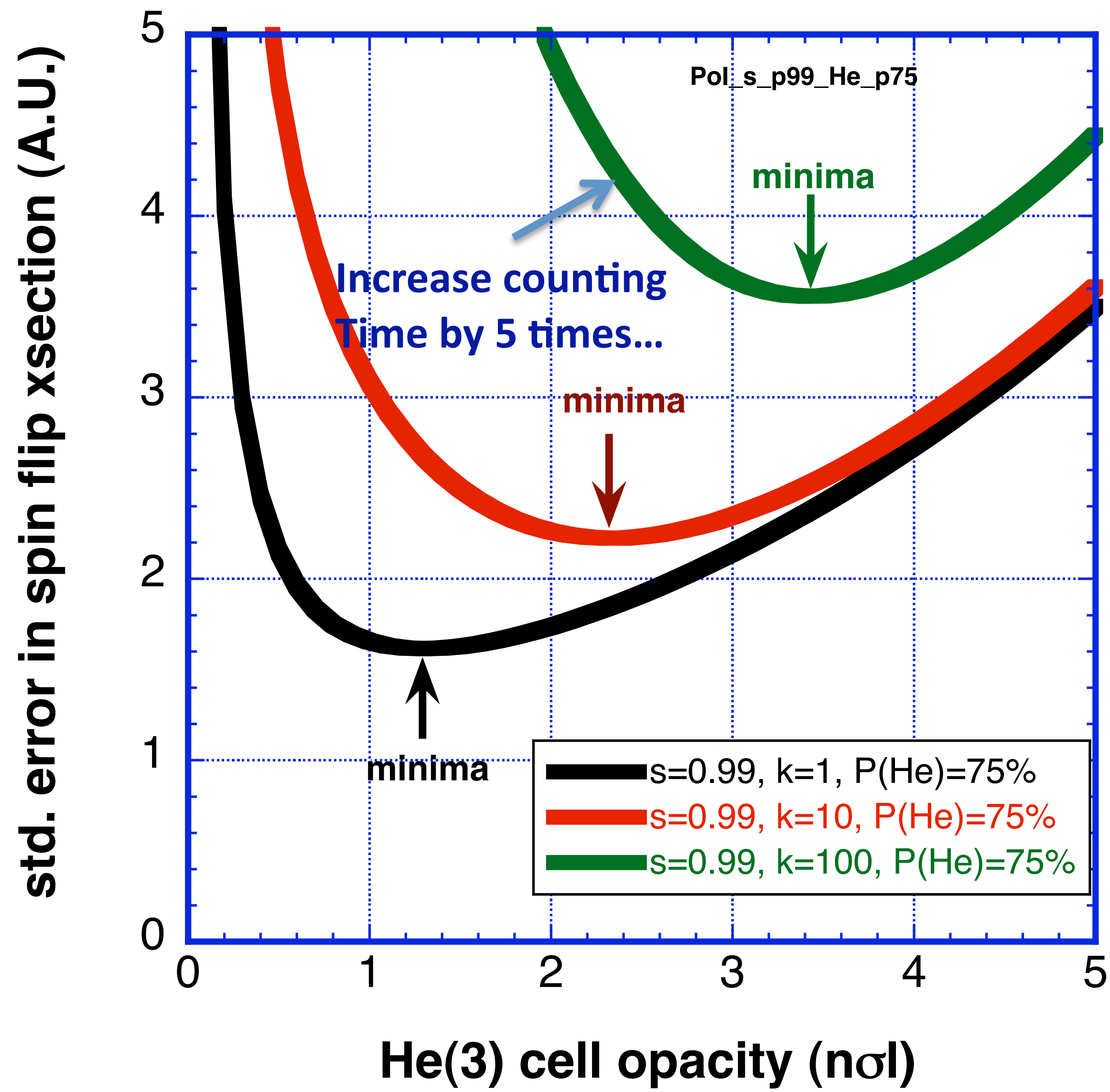


For K=100, Cavity Polarization S = 99 % reduces counting time by factor of three.

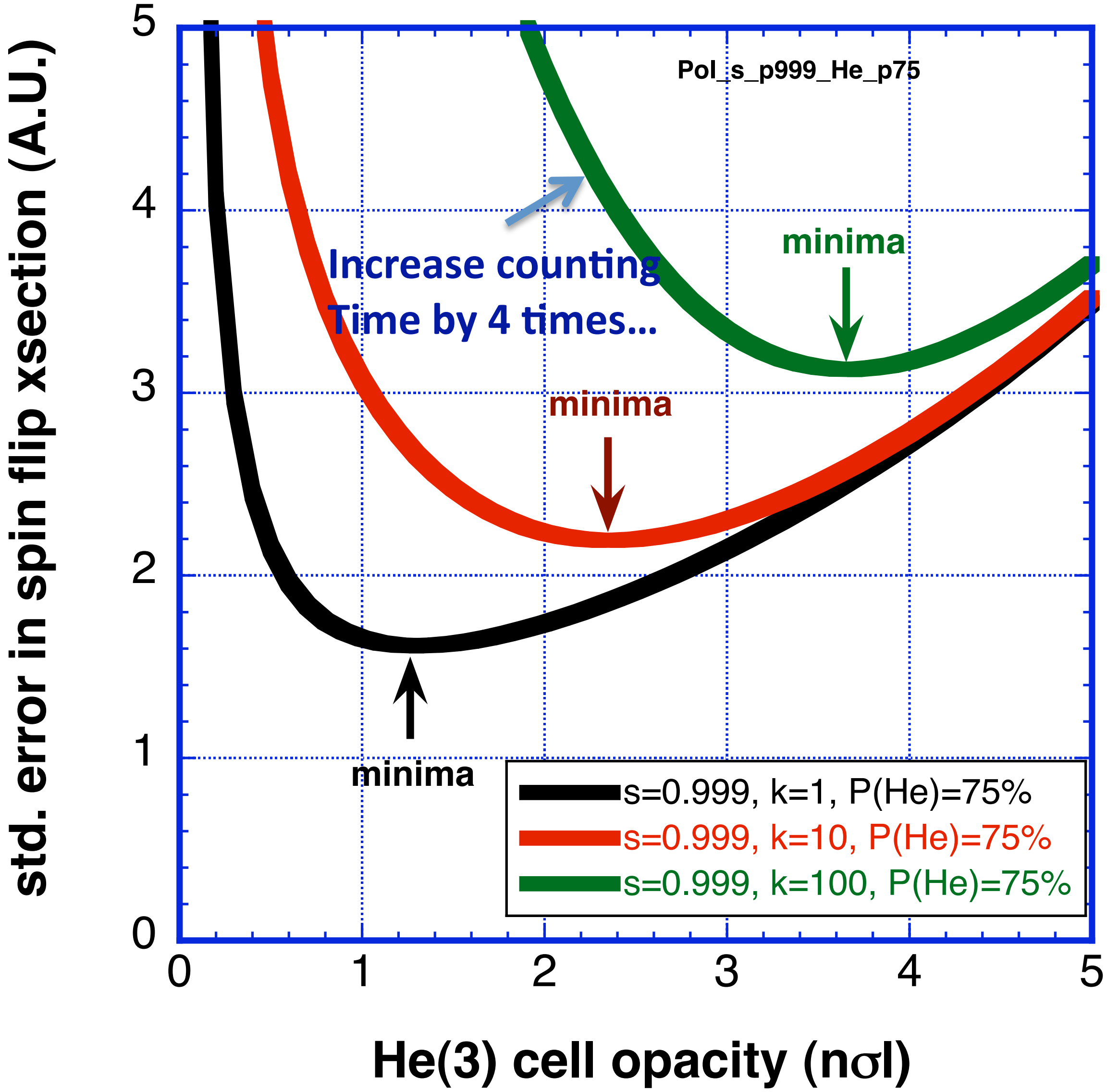




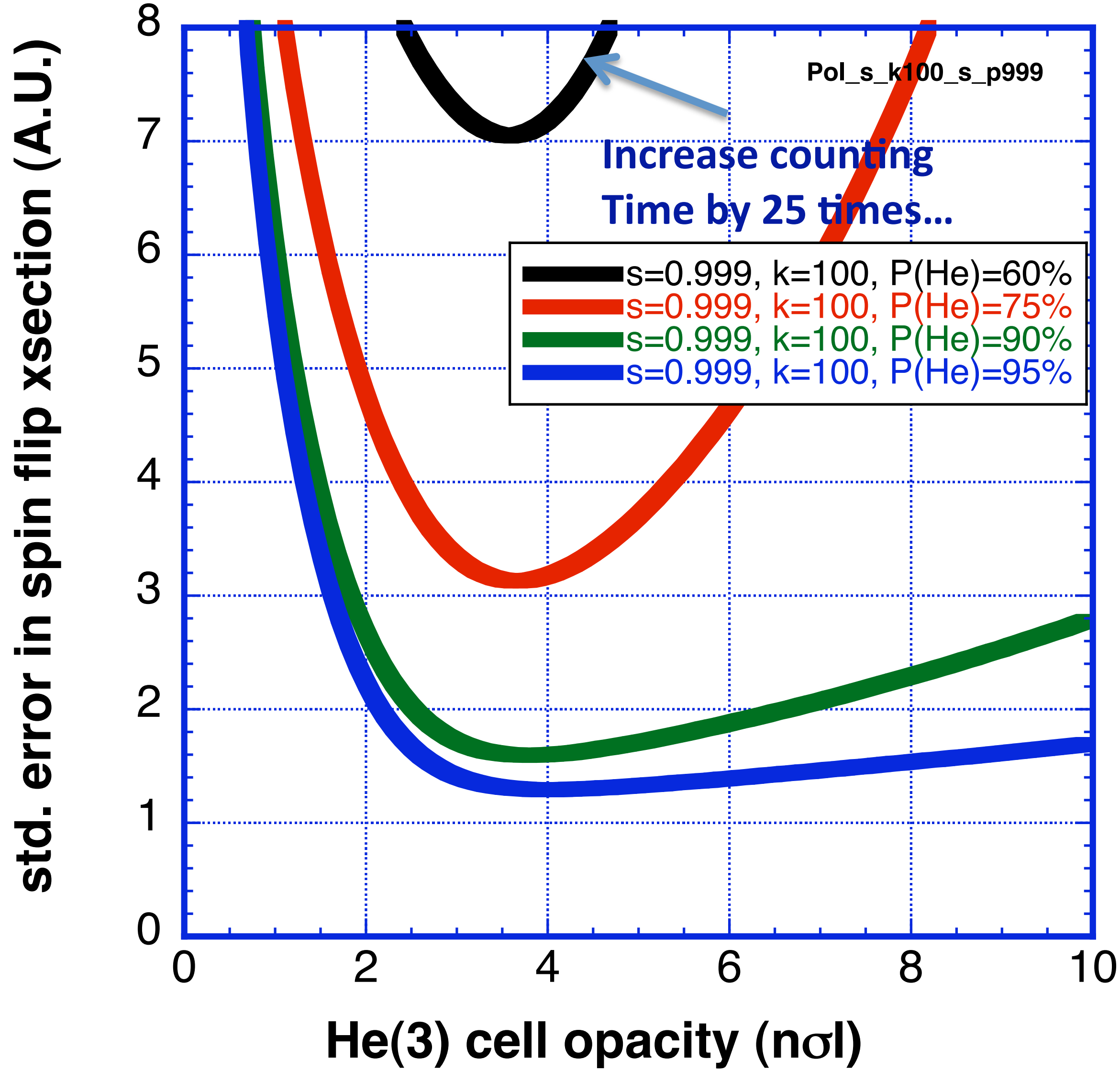
Pol_s_p9_He_p75
std. error in spin flip xsection (A.U.)
He(3) cell opacity (nσl)
minima
minima
minima
Increase counting
Time by 10 times…
s=0.9, k=1, P(He)=75%
s=0.9, k=10, P(He)=75%
s=0.9, k=100, P(He)=75%



Pol_s_p99_He_p75
minima
Increase counting
Time by 5 times...
minima
minima
s=0.99, k=1, P(He)=75%
s=0.99, k=10, P(He)=75%
s=0.99, k=100, P(He)=75%
std. error in spin flip xsection (A.U.)
He(3) cell opacity (nσl)
0
1
2
3
4
5



Pol_s_p999_He_p75
Increase counting
Time by 4 times...
minima
minima
minima
s=0.999, k=1, P(He)=75%
s=0.999, k=10, P(He)=75%
s=0.999, k=100, P(He)=75%
std. error in spin flip xsection (A.U.)
He(3) cell opacity (nσl)
0
1
2
3
4
5
0
1
2
3
4
5



Pol_s_k100_s_p999
Increase counting
Time by 25 times...
s=0.999, k=100, P(He)=60%
s=0.999, k=100, P(He)=75%
s=0.999, k=100, P(He)=90%
s=0.999, k=100, P(He)=95%
std. error in spin flip xsection (A.U.)
He(3) cell opacity (nσl)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10

Summary:

General

1) For P = 98% use **single** V cavity; for P = 99.9 % use **double** V cavity.
2) For He(3) analyzer, need to vary opacity: $1.3 \le \tau \le 4.0$.

Changes to NG7 SANS:

1) New **single** V cavity P=98%, m=3 supermirror, 1.5 m long, 50 mm x 50 mm.
2) Add magnetic guide field to outside vacuum vessel (boxes).
3) Use > 99.9% efficiency radio frequency (RF) flipper.
4) Remove sample chamber and steel components from sample area.
5) Insitu He(3) analyzer.

Design for NG6 vSANS:

1) **Double** V cavity P=99.9 %, m=3 supermirror, 3 m long, 60 mm x 150 mm. **($145k)**
2) Non magnetic Nickel (doped with Mo) guides.
3) Magnetic guide field to outside vacuum vessel (boxes).
4) Use > 99.9% efficiency radio frequency (RF) flipper.
5) Large (2 m) sample area.
6) Insitu He(3) analyzer.