Parity Violation in pp and np Experiments

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- Concentrate on polarized beam experiments

" Sometimes it is necessary to repeat what we know.

All mapmakers should place the Mississippi at the same

location, and avoid originality" -- *Saul Bellow*

For comprehensive reviews, see

- Adelberger and Haxton, Ann. Rev. Nucl. Part. Sci. <u>35</u>, 501 (1985)
- Haeberli and Holstein, in " Symmetries and Fundamental Interactions in Nuclei ", (1995) (nucl-th/951062)

Weak Interaction Examples:

Leptonic $\mu \to e^- + \nu_\mu \bar{\nu}_e$

Semi - Leptonic $n \to p + e^- + \bar{\nu}_e$ $\Lambda \to p + e^- + \bar{\nu}_e$

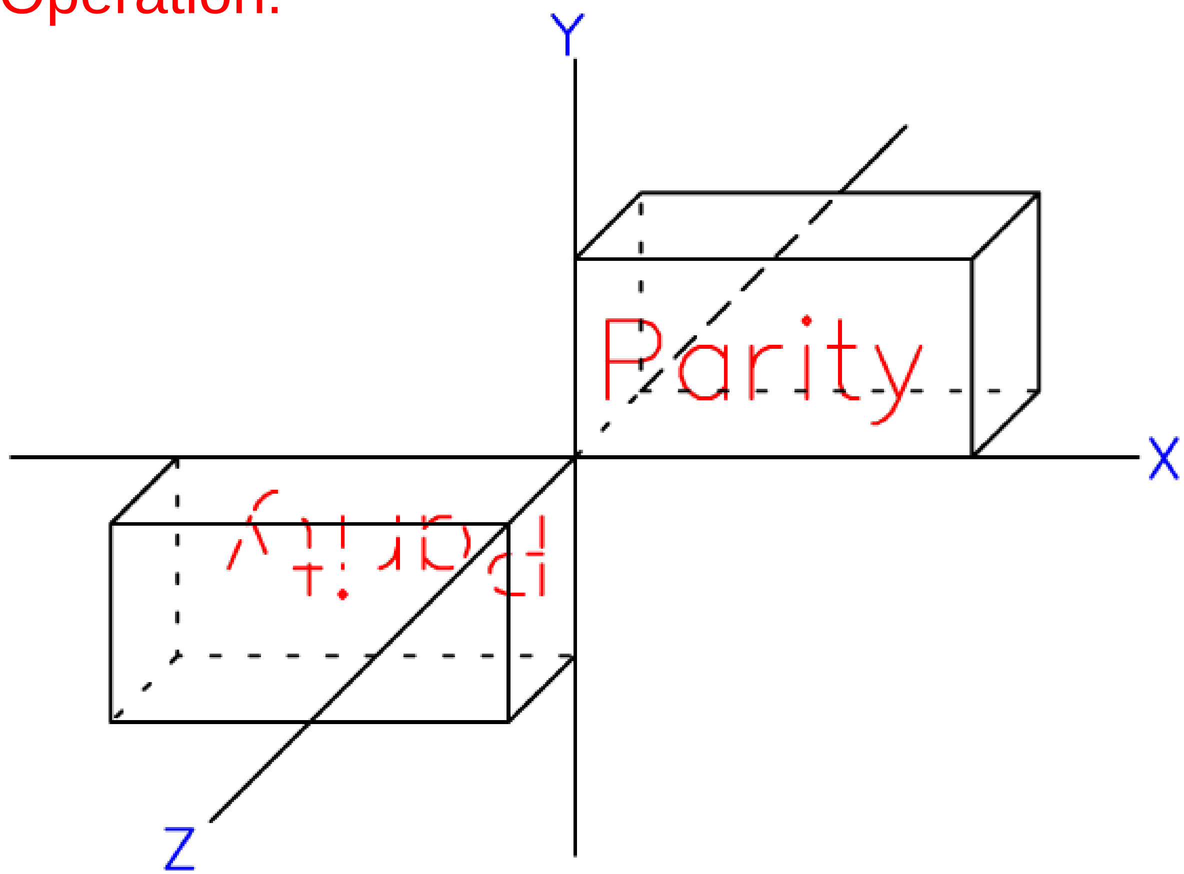
Hadronic $K^+ \to \pi^+ \pi^-$

Hadronic $\underbrace{p\,p \to p\,p}$

Dominated by strong NN force

- Use Parity to isolate weak part
- PV in NN interaction is only experimental signature of purely hadronic weak interaction
- pp and np experiments avoid many body and nuclear complications

The Parity Operation:

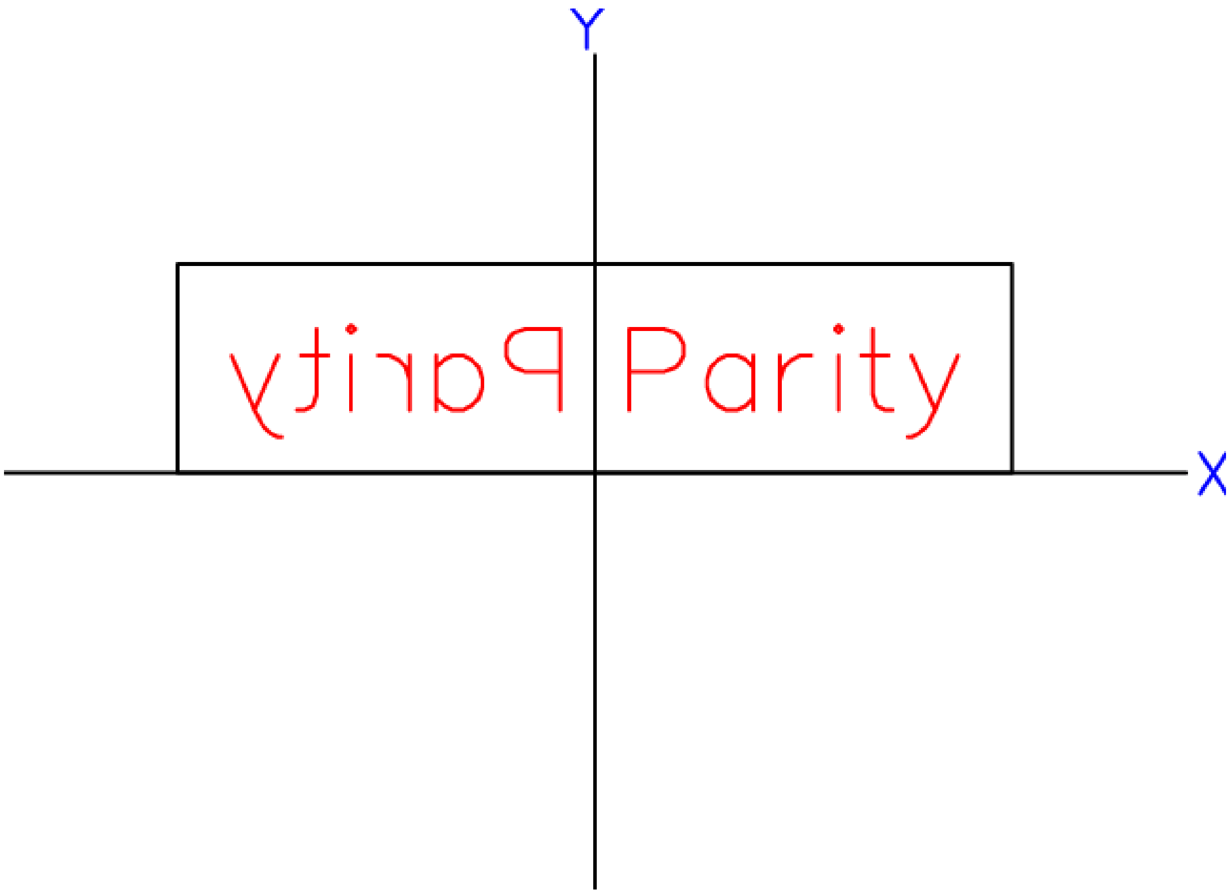


Simultaneous reflection of all space coordinates through the origin

Equivalent to reflection plus 180^{o} rotation

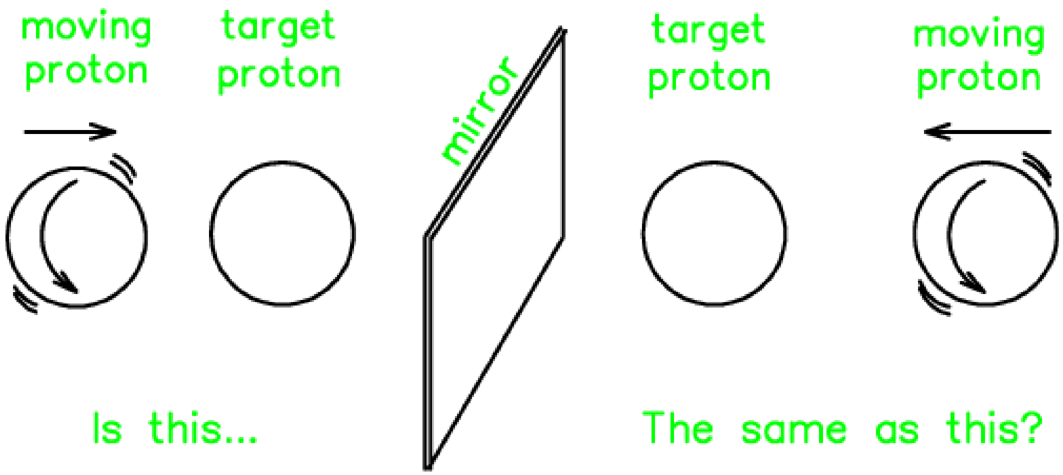
If we assume rotational invariance it is a mirror reflection

Parity operation plus 180 rotation:

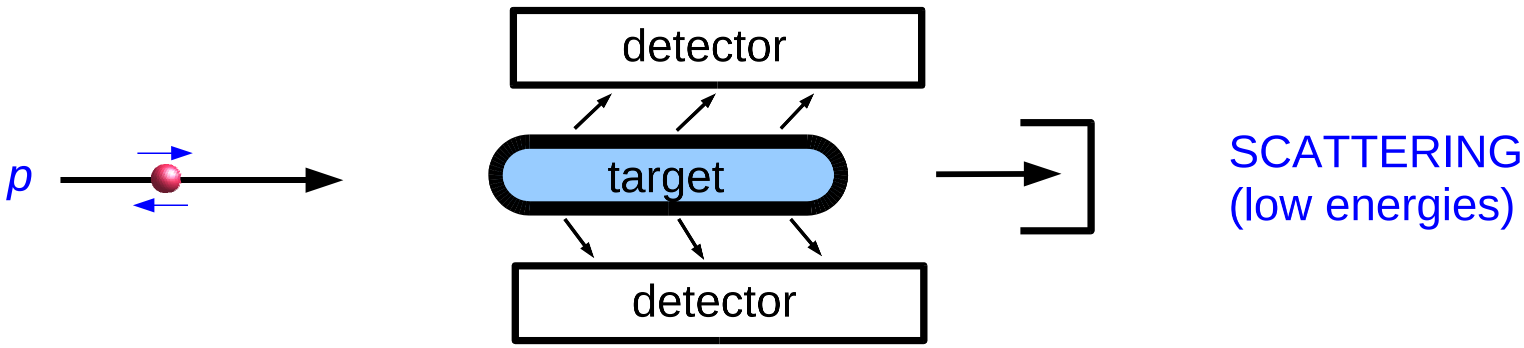


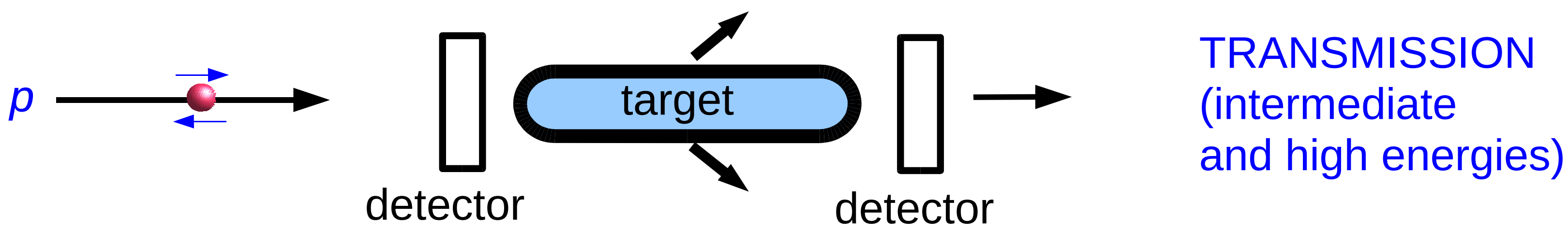
parity violation experiments involve SPIN

pp experiment:



Types of pp Experiments





Typically use current mode, not counting:

If $\frac{1}{\sqrt{N}} = 10^{-8}$ then $N = 10^{16}$ → 32 years at 10^{7} s^{-1}

Summary of $\vec{p}p$ Experiments

$$A_z = \frac{1}{P_z}\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

lab	technical details	result (10^{-7})	where reported
Los Alamos 15 MeV	scattering 3 atm x 38 cm hydrogen 4 liquid scintillators	$+1 \pm 4$	1974 Phys Rev Lett
	scattering 6.9 atm hydrogen 4 plastic scintillators	-1.7 ± 0.8	1978 Argonne Conference
Texas A&M 47 MeV	scattering 39 atm x 42 cm hydrogen 4 plastic scintillators	-4.6 ± 2.6	1983 Florence Conference
Berkeley 46 MeV	scattering 80 atm hydrogen He ion chamber around target	-1.3 ± 1.1	1980 Santa Fe Conference
		-1.63 ± 1.03	1985 Osaka Conference

Summary of $\vec{p}p$ Experiments

lab	technical details	result (10^{-7})	where reported
SIN (PSI) 45 MeV	scattering atomic beam source 100 atm hydrogen annular ion chamber	-3.2 ± 1.1 -2.32 ± 0.89 -1.50 ± 0.22	1974 Phys Rev Lett 1984 Phys Rev D 1987 Phys Rev Lett
Los Alamos 800 Mev	transmission 1 m liquid hydrogen 15% scattered ion chambers	$+2.4 \pm 1.1$	1986 Phys Rev Lett
Bonn 13.6 Mev	scattering 15 atm hydrogen surrounding hydrogen ion chambers	-1.5 ± 1.1 -0.93 ± 0.21	1991 Phys Lett B 1994 private communication

Summary of $\vec{p}p$ Experiments

lab	technical details	result (10^{-7})	where reported
TRIUMF 221 MeV	transmission optically pumped source 40 cm liquid hydrogen 4% scattered two ion chambers	$+0.84 \pm 0.34$	2001 Phys Rev Lett
Argonne ZGS 5130 MeV	transmission 81 cm distilled water 18% transmitted ion chambers and scintillators	$+26.5 \pm 7.0$	1986 Phys Rev Lett

Interpretation of NN Parity Violation Experiments

- Weak force carriers Z and W are heavy: M_z = 91 GeV; M_w = 80 GeV
- Range $$\frac{\hbar c}{m} \sim 0.002\ fm$$
- Meson description is often used:

π	140 MeV	$\Leftrightarrow$	1.4 fm
ρ	770 MeV		0.26 fm
ω	780 MeV		0.25 fm

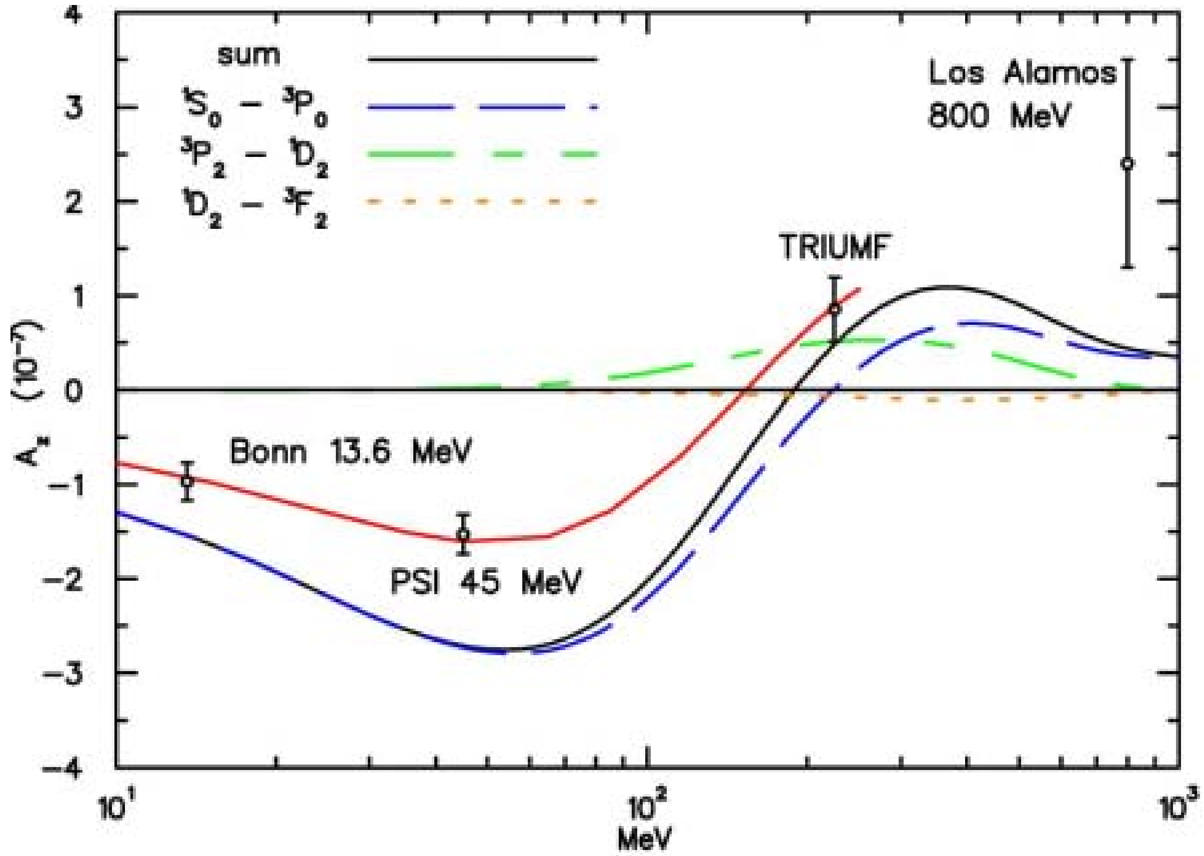
Nothing heavier because of ``hard core''

- 6 constants: $$f_\pi, h_\rho^{0,1,2}, h_\omega^{0,1}, h_\rho^{\prime 1}$$

For *pp* no π

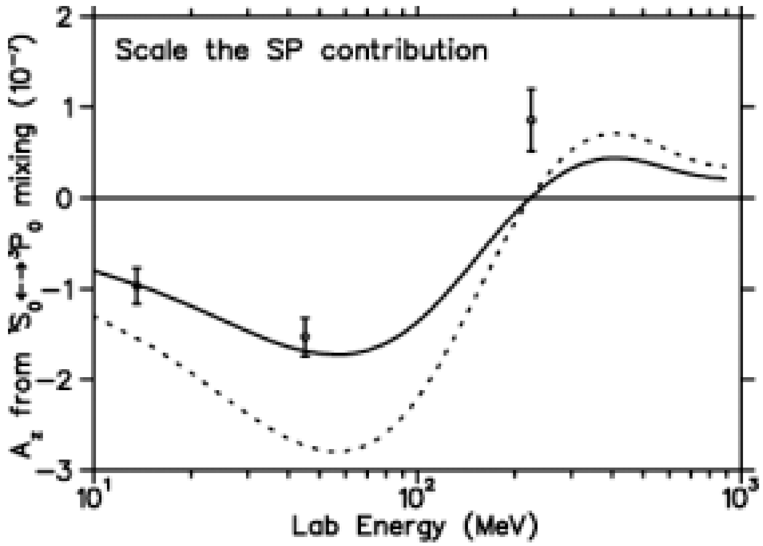
Usually ignored

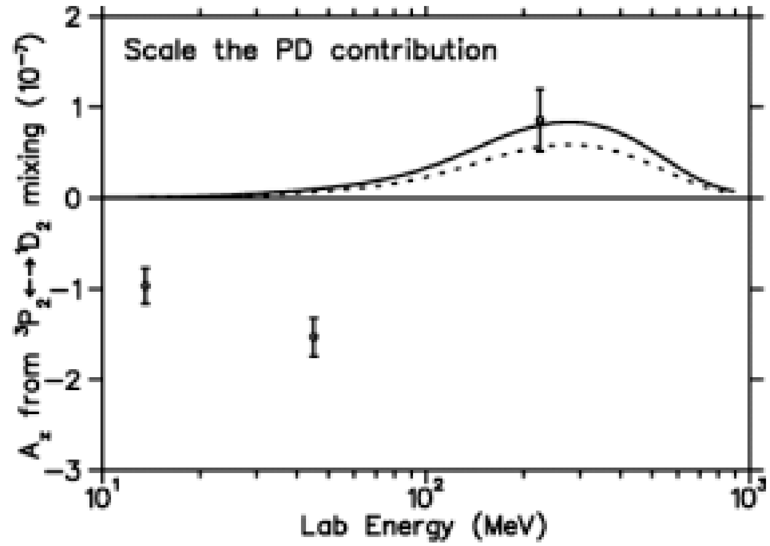
→Task of parity experiments is to find these constants



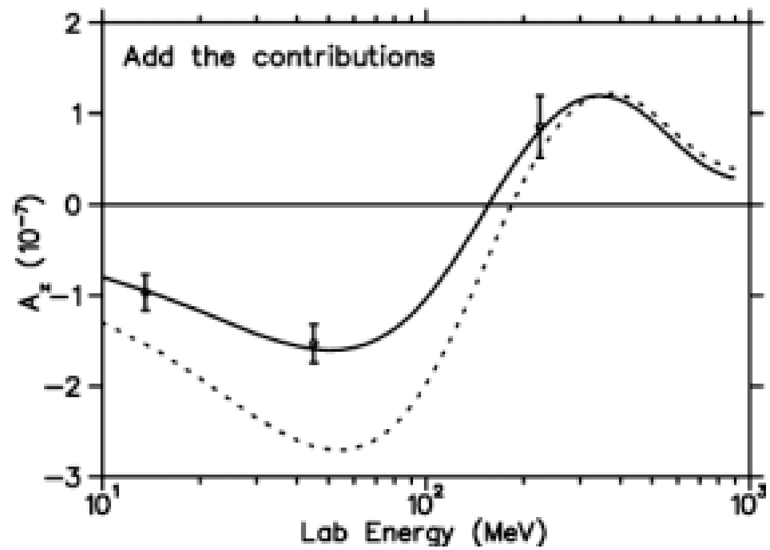
- Zero Crossing of $^1S_0 - {}^3P_0$ contribution determined by strong interaction phase shifts and experimental geometry
- Red Line is Carlson et al. calculation with AV18 strong potential and adjusted weak meson nucleon couplings
- Partial wave components from Driscoll and Miller

How to fit the data

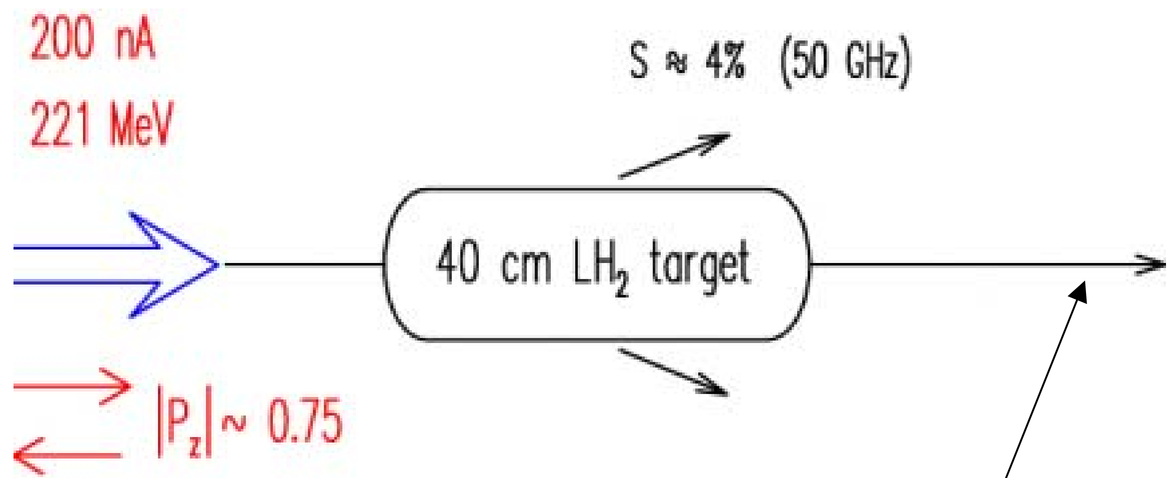




Data points are weighted means of existing data



The TRIUMF Parity Experiment

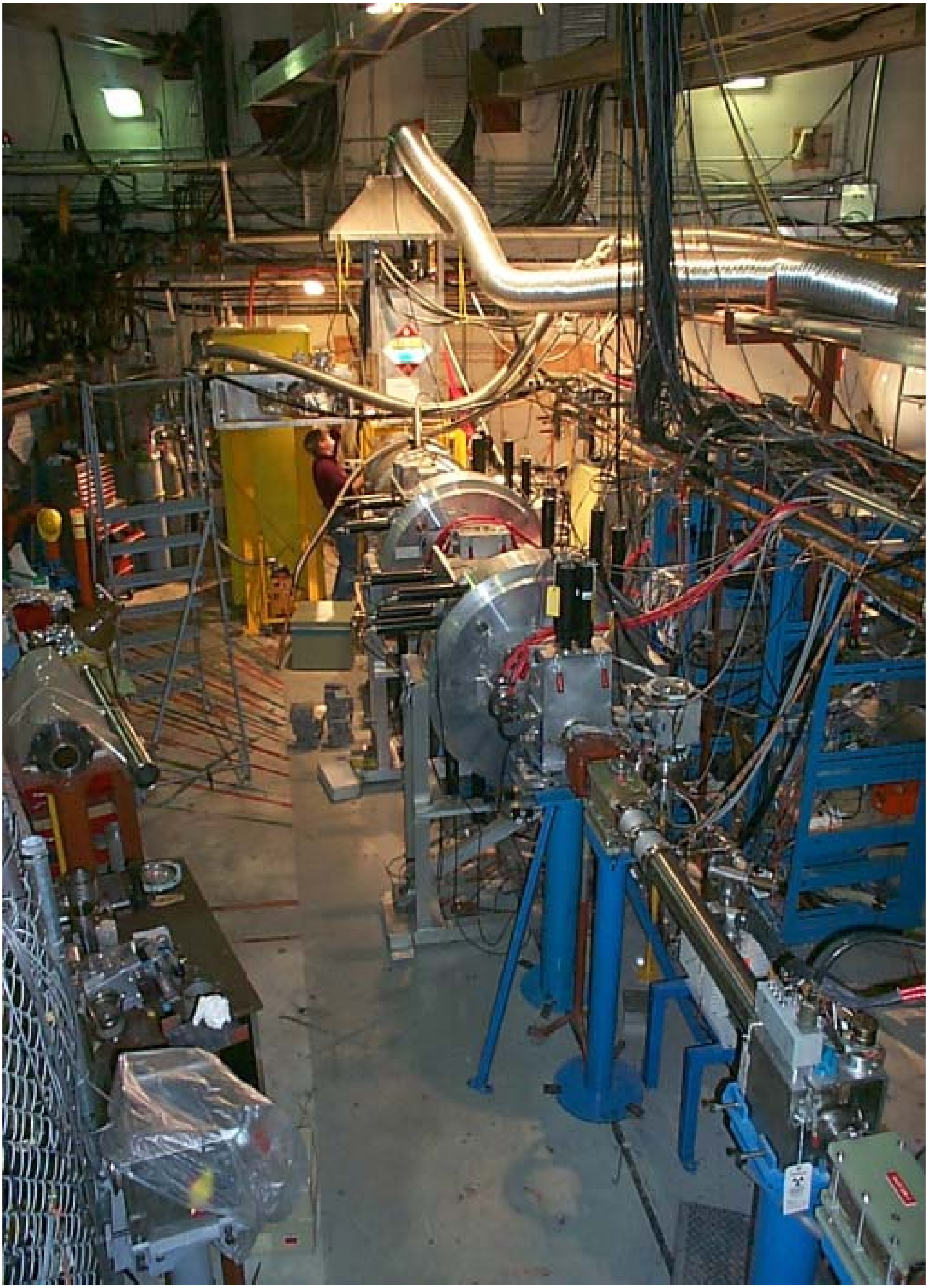


Flip beam helicity

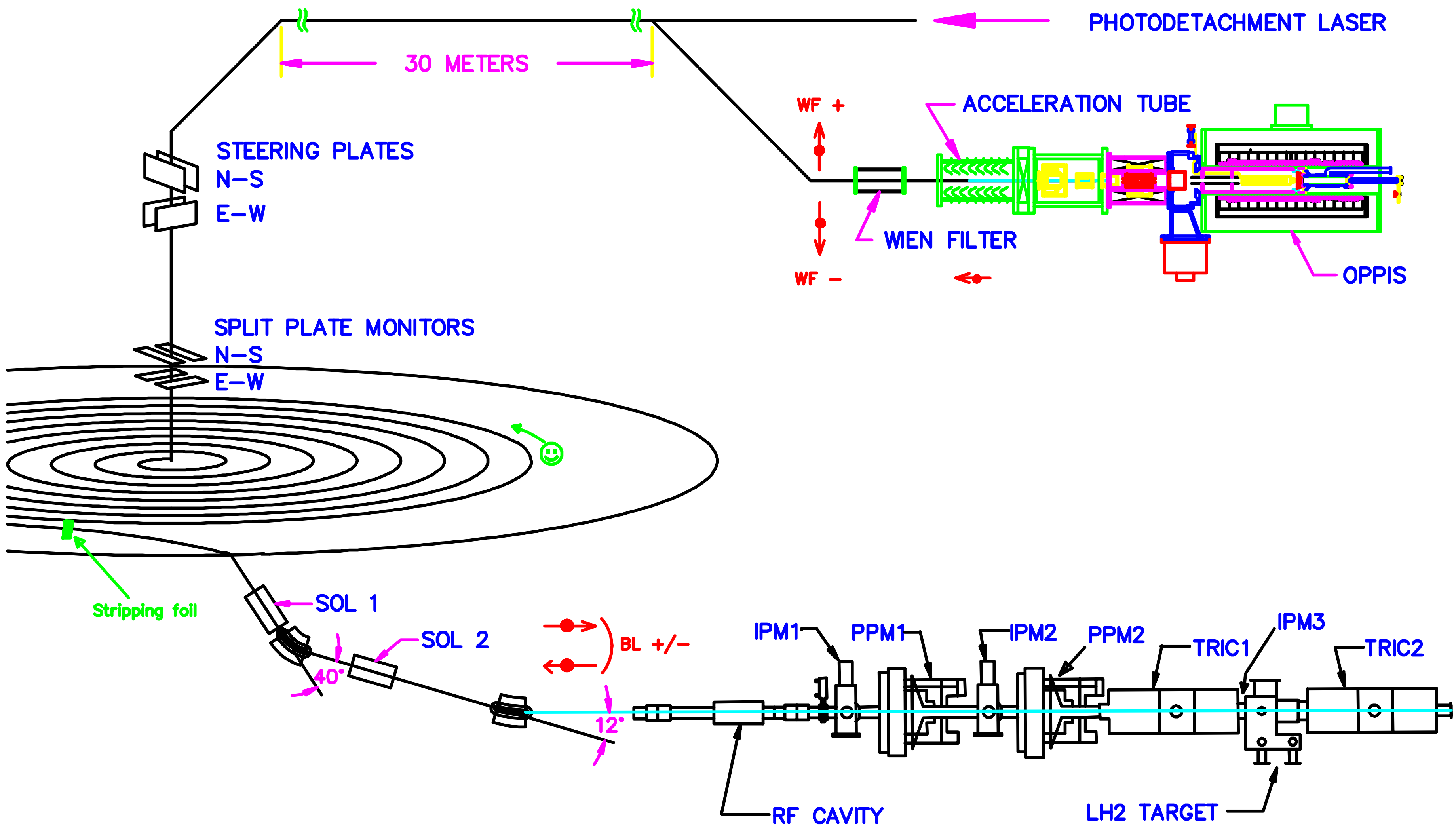
Look for small (2×10^{-9}) changes
In transmitted current

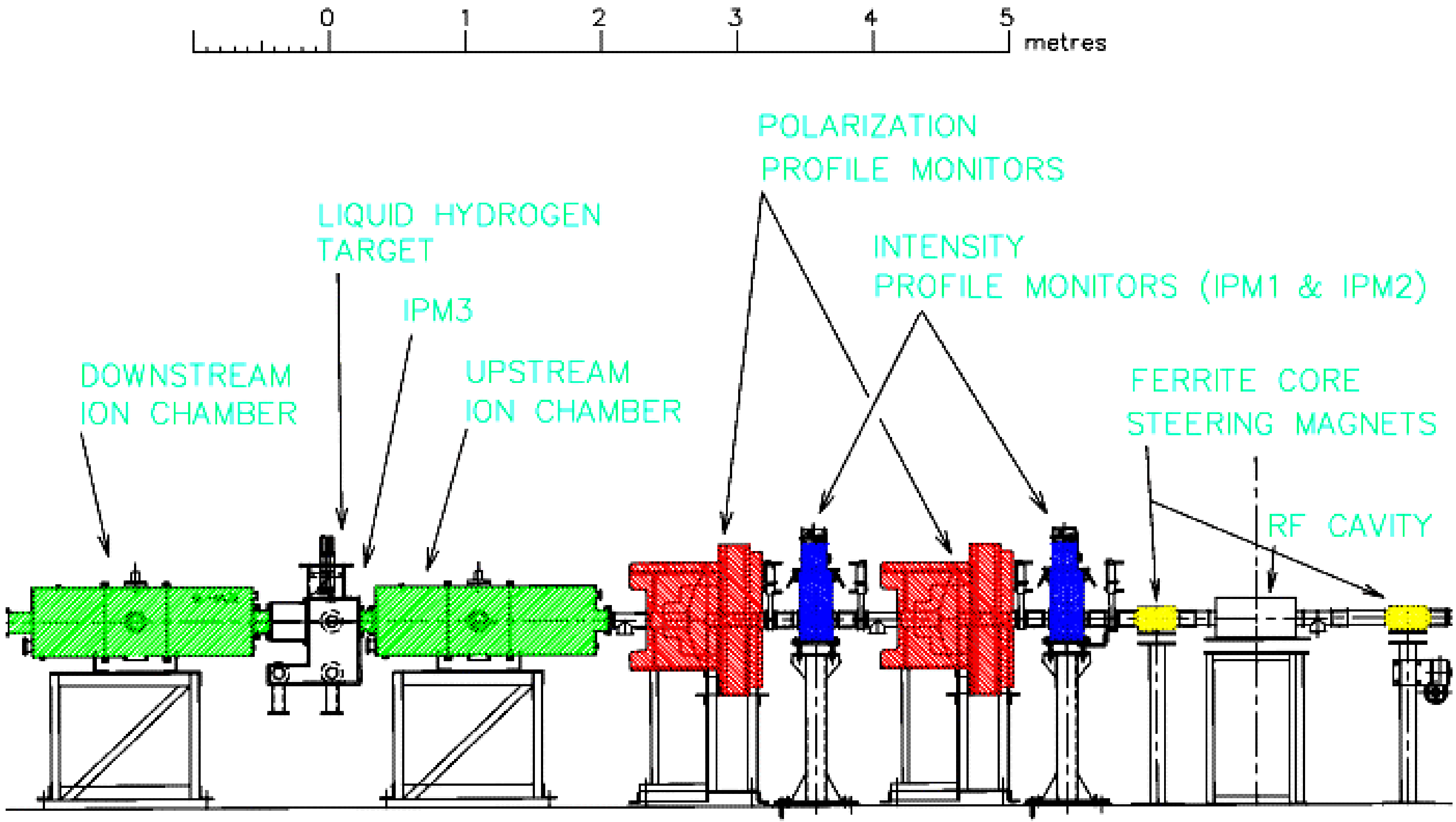
$$I_{scat} = I_i S(1 + P_z A_z)$$

$$A_z = \frac{1}{P_z} \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$



Experimental Layout





EXPERIMENT 497 EQUIPMENT

Systematic Errors

Parity non-conserving

$$\left(\frac{\partial A_z}{\partial x_i} \Delta x_i \right)$$

$$A_z(\text{measured}) = A_z(\text{PNC}) + \Delta A_z$$

from E497 transmission asymmetry

false effects arising from spin correlated modulations of

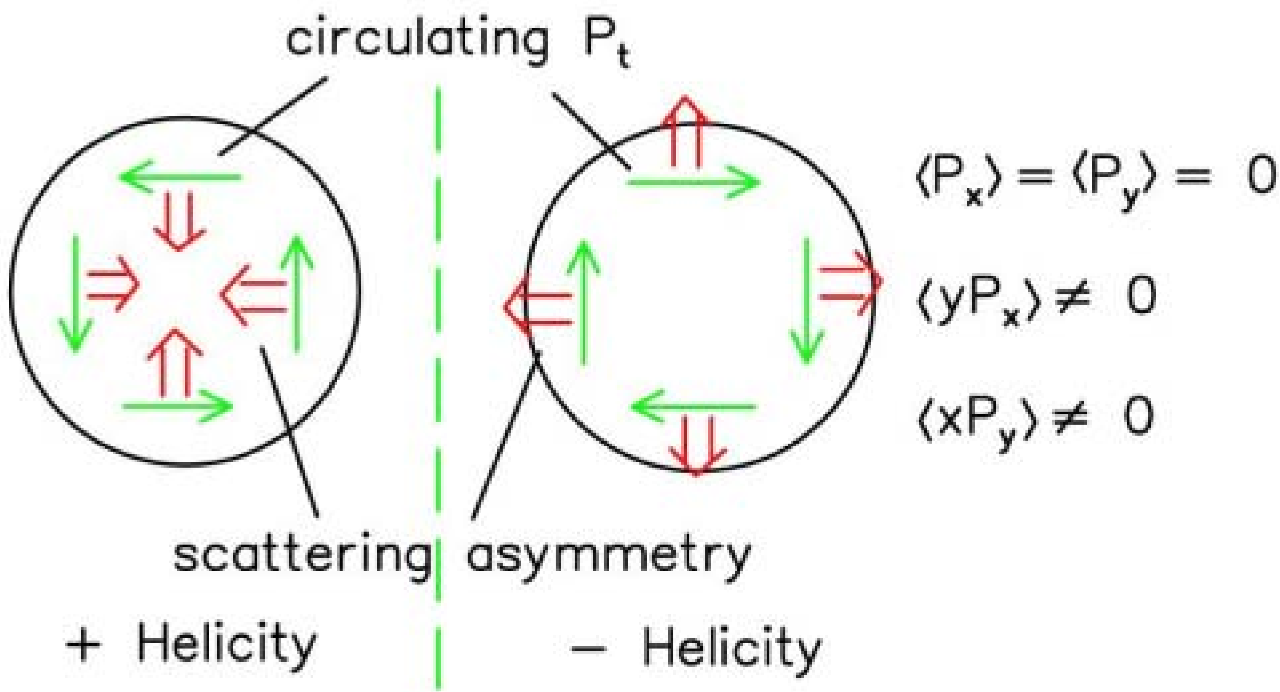
Measureable in Parity beamline

- beam size $(\Delta\sigma_x, \Delta\sigma_y)$
- position $(\Delta x, \Delta y)$
- transverse polarization (P_x, P_y)
- intensity $(\Delta I/I)$

Not measureable in Parity beamline

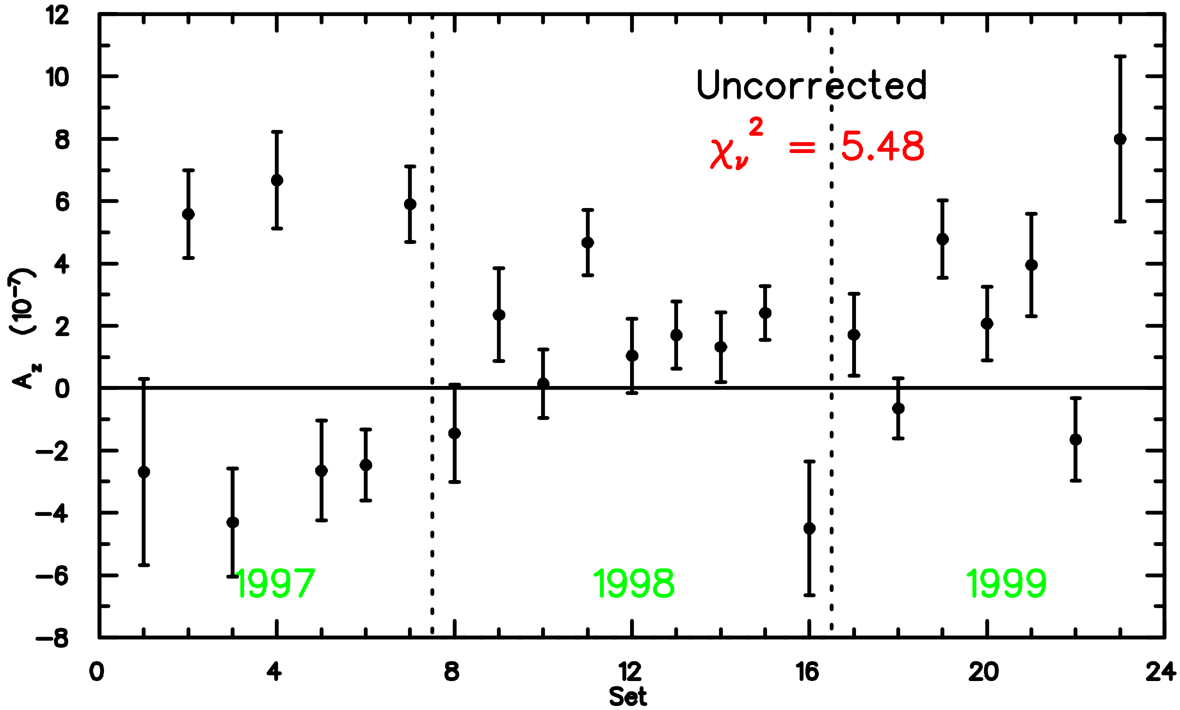
- energy (ΔE)

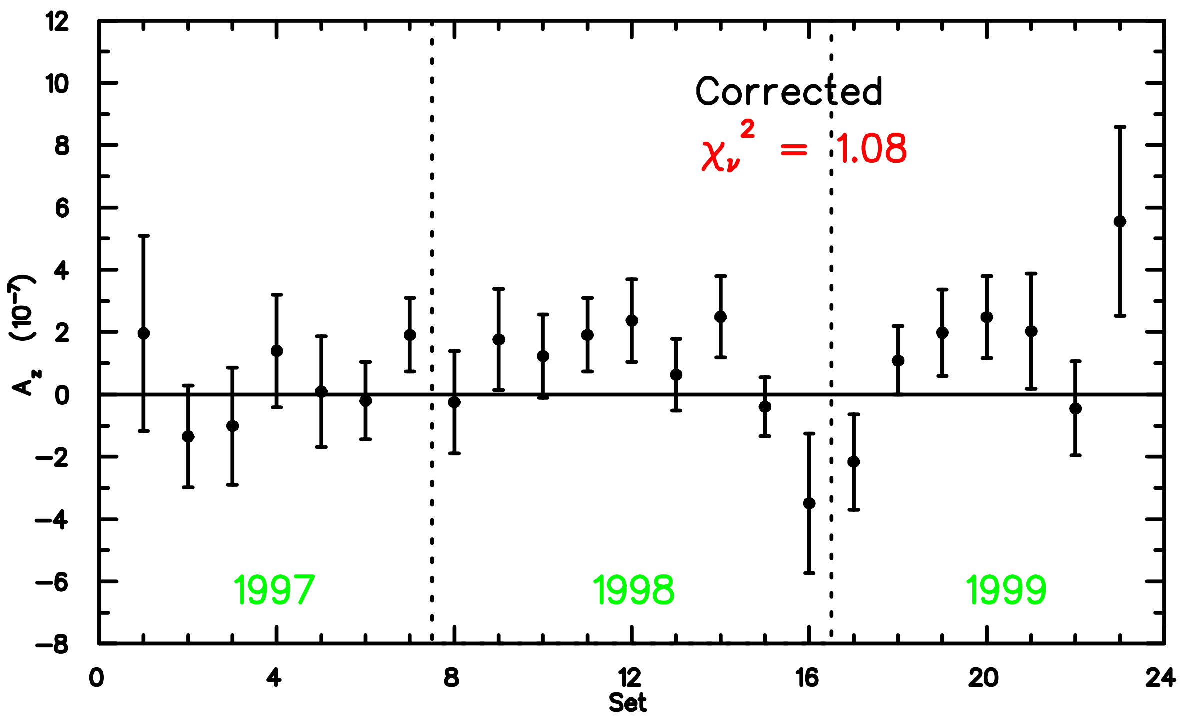
First Moments of Transverse Polarization



- Our PPMs measure $\langle yP_x \rangle$ and $\langle xP_y \rangle$
- Beam optics are set to reduce sensitivity to first moments

Correction of E497 Data





Corrections for Systematic Error

Property	Average Value	$10^7 \Delta A_z$
$A_z^{uncor.}(10^{-7})$	$1.68 \pm 0.29(stat.)$	
$y * P_x(\mu m)$	-0.1 ± 0.0	-0.01 ± 0.01
$x * P_y(\mu m)$	-0.1 ± 0.0	0.01 ± 0.03
$\langle yP_x \rangle(\mu m)$	1.1 ± 0.4	0.11 ± 0.01
$\langle xP_y \rangle(\mu m)$	-2.1 ± 0.4	0.54 ± 0.06
$\Delta I/I(ppm)$	15 ± 1	0.19 ± 0.02
$position{+}size$		0 ± 0.10
$\Delta E(meV)$	7–15	0.0 ± 0.12
Total		$0.84 \pm 0.17(syst.)$
$A_z^{corr}(10^{-7})$	$0.84 \pm 0.29(stat.) \pm 0.17(syst.)$	
$\chi^2_\nu(23sets)$	1.08	

Relation of A_z to couplings

pp Experiments measure the combinations:

$$h_\rho^{pp} = h_\rho^{(0)} + h_\rho^{(1)} + \tfrac{1}{\sqrt{6}} h_\rho^{(2)} \quad \text{and} \quad h_\omega^{pp} = h_\omega^{(0)} + h_\omega^{(1)}$$

In particular:

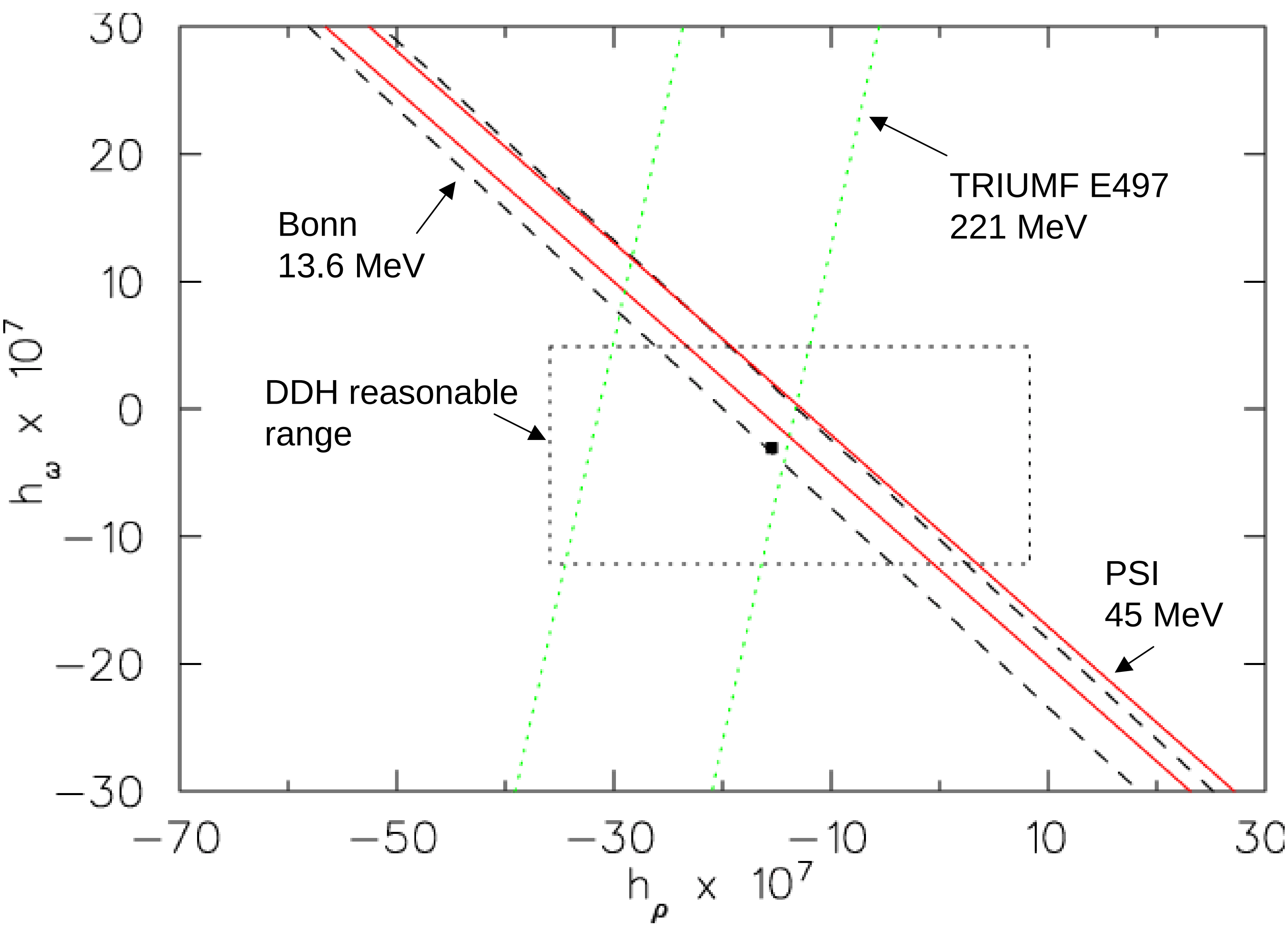
13.6 MeV $\quad A_z = 0.059 h_\rho^{pp} + 0.075 h_\omega^{pp}$

45 Mev $\quad A_z = 0.10 h_\rho^{pp} + 0.14 h_\omega^{pp}$

225 MeV $\quad A_z = -0.038 h_\rho^{pp} + 0.010 h_\omega^{pp}$

J.A. Carlson *et al.*, Phys. Rev. C **65**, 035505 (2002); R. Schiavilla, private communication (2001)

Constraints on Couplings

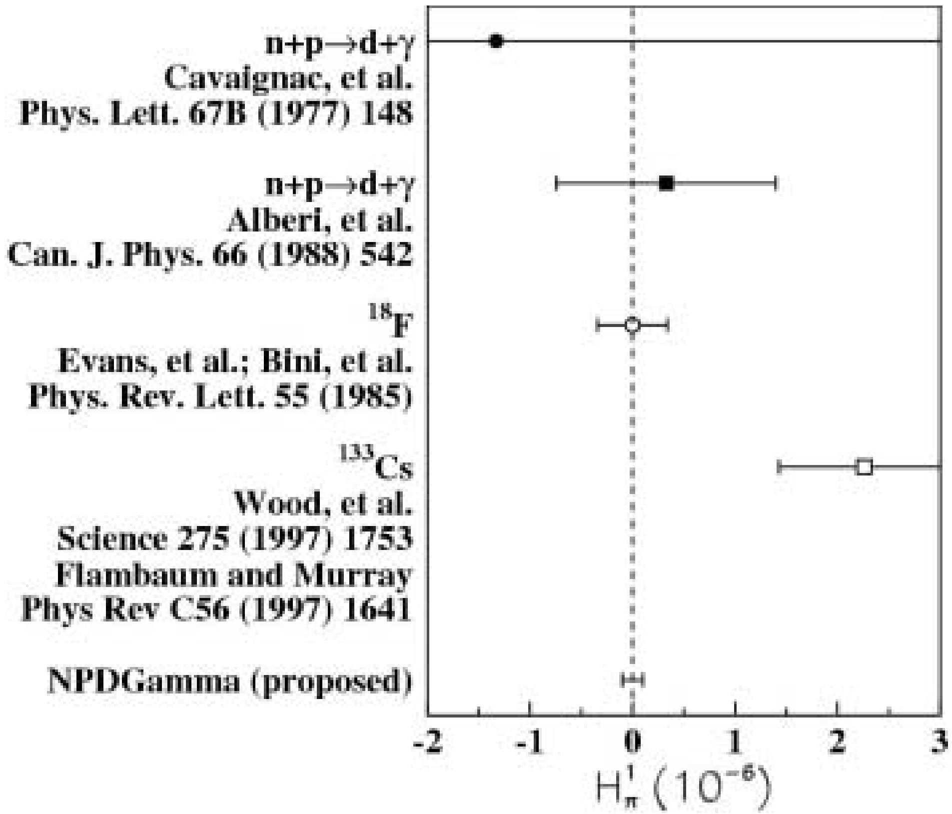


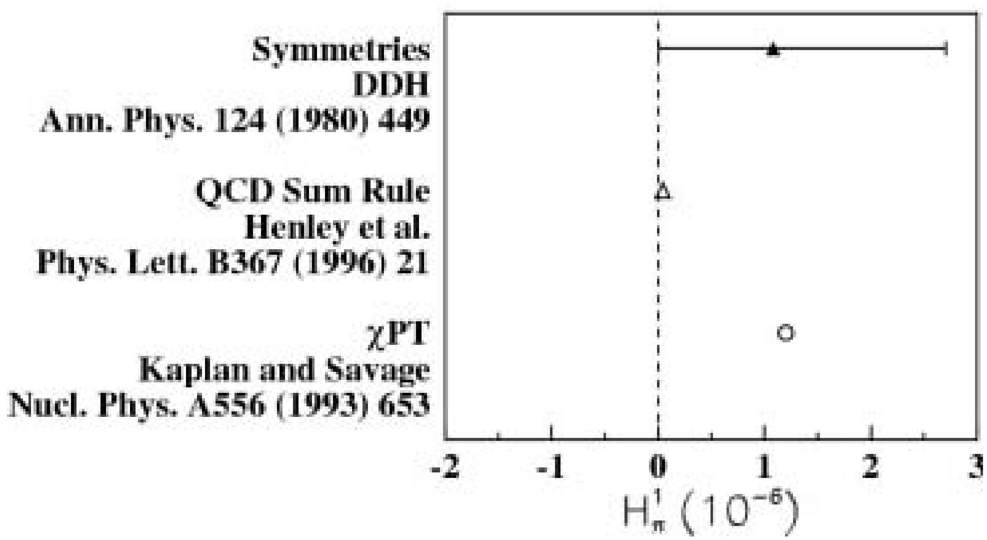
The NPDGamma Experiment at Los Alamos National Laboratory

NPDGamma is a nuclear physics experiment at

LANSCE

NPDGamma is under construction and will begin data collection in 2003.





$$A_\gamma \approx -0.045 H_\pi^1$$

A_γ is a clean measurement

of H_π^1

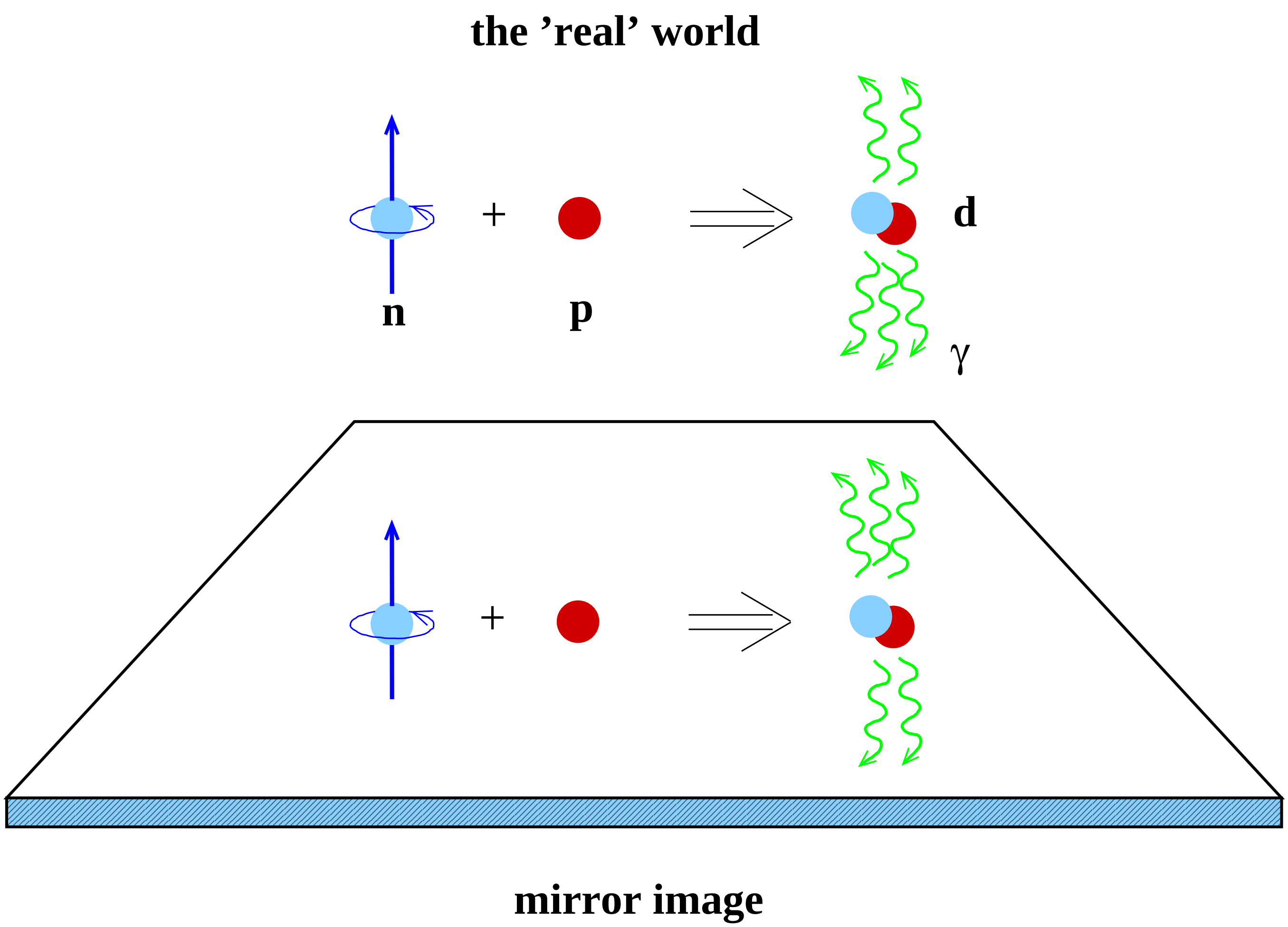
npdγ will provide better statistical precision than ^{18}F, and without many body and nuclear structure uncertainties

$np \rightarrow d\gamma$ Experiments

Lab	technical details	result (10^{-8})	reported
Leningrad	Unpolarized reactor neutrons on water. Measured P_γ	18 ± 18	Knyazkov 1984 Nuclear Physics A
ILL Grenoble	Polarized neutrons on liquid parahydrogen Liquid scintillator tanks Measured A_γ	6 ± 21 -1.5 ± 4.8	Cavaignac 1977 Phys Lett B Alberi 1988 Can. J. Phys
LANSCE Los Alamos	Polarized pulsed neutrons on liquid parahydrogen CsI(Tl) detectors will measure A_γ	$? \pm 0.5$ expect $\approx -5 \pm 0.5$	

$\vec{n} + p \rightarrow d + \gamma$ (2.2 MeV)

NPDGamma will measure A_γ, the parity-violating asymmetry in the distribution of emitted γ's



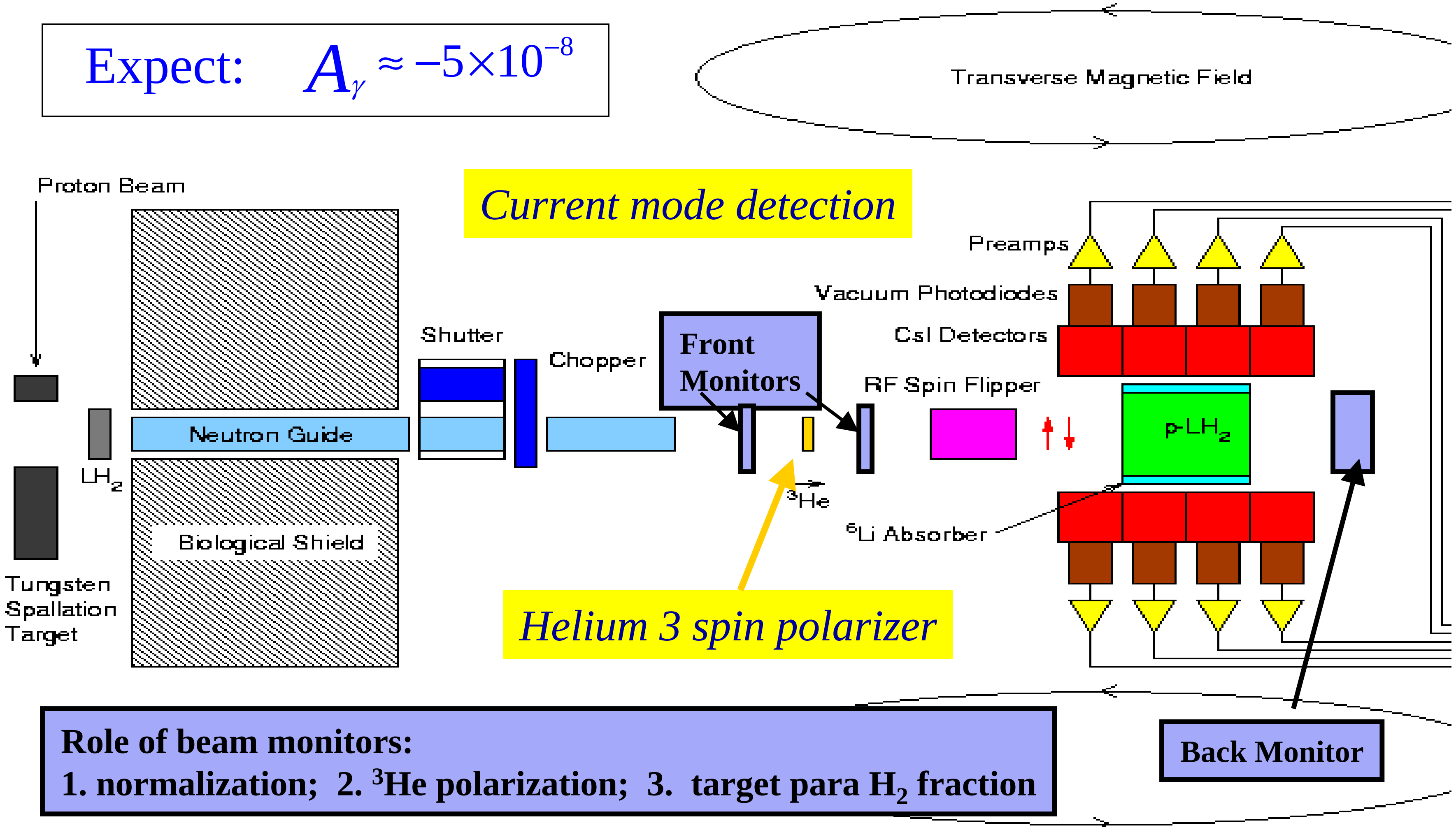
If the up/down γ rates differ, parity is violated (PV $\longrightarrow$ signature of the weak interaction)

Expected asymmetry $\approx 5 \times 10^{-8}$

Goal experimental error: 0.5×10^{-8}

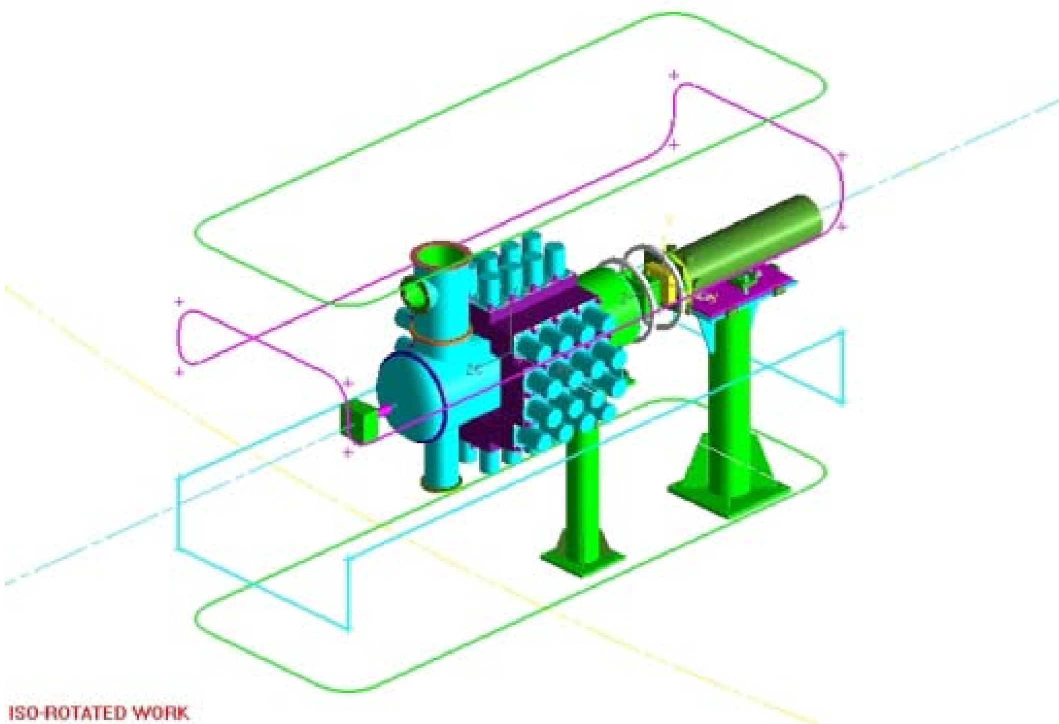
$\vec{n} + p \rightarrow d + \gamma$ Apparatus

Expect: $A_\gamma \approx -5\times10^{-8}$

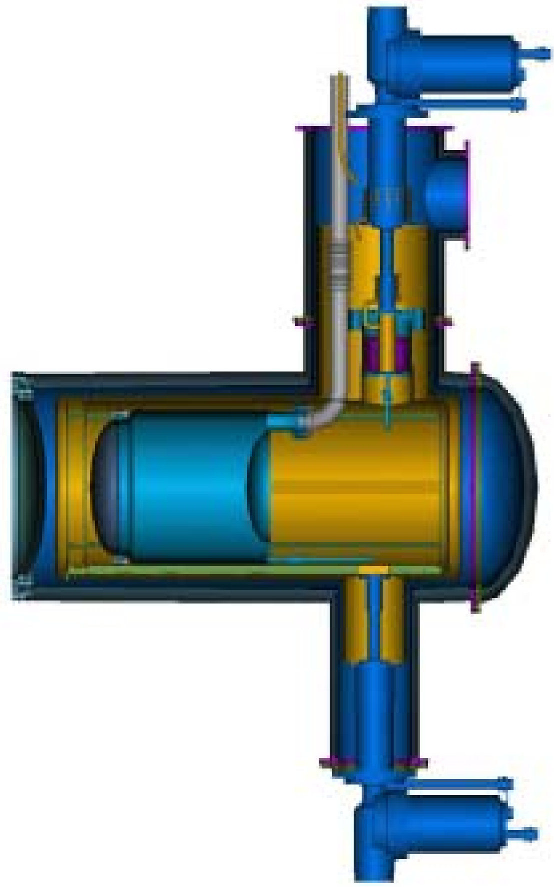


Role of beam monitors:
1. normalization; 2. ^{3}He polarization; 3. target para H_2 fraction

n+p->d+γ Experiment Layout

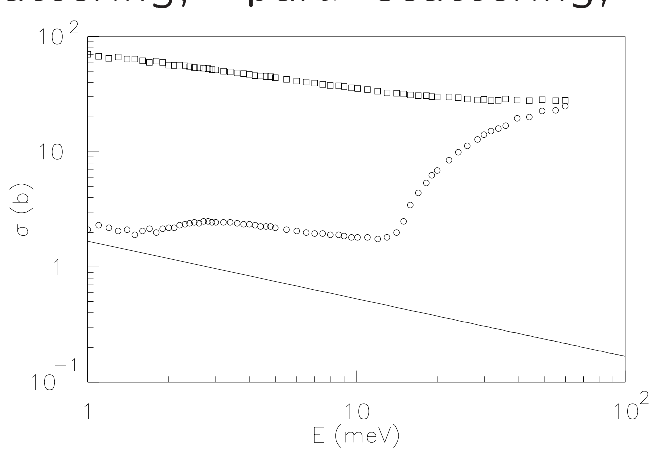


Liquid para-hydrogen target



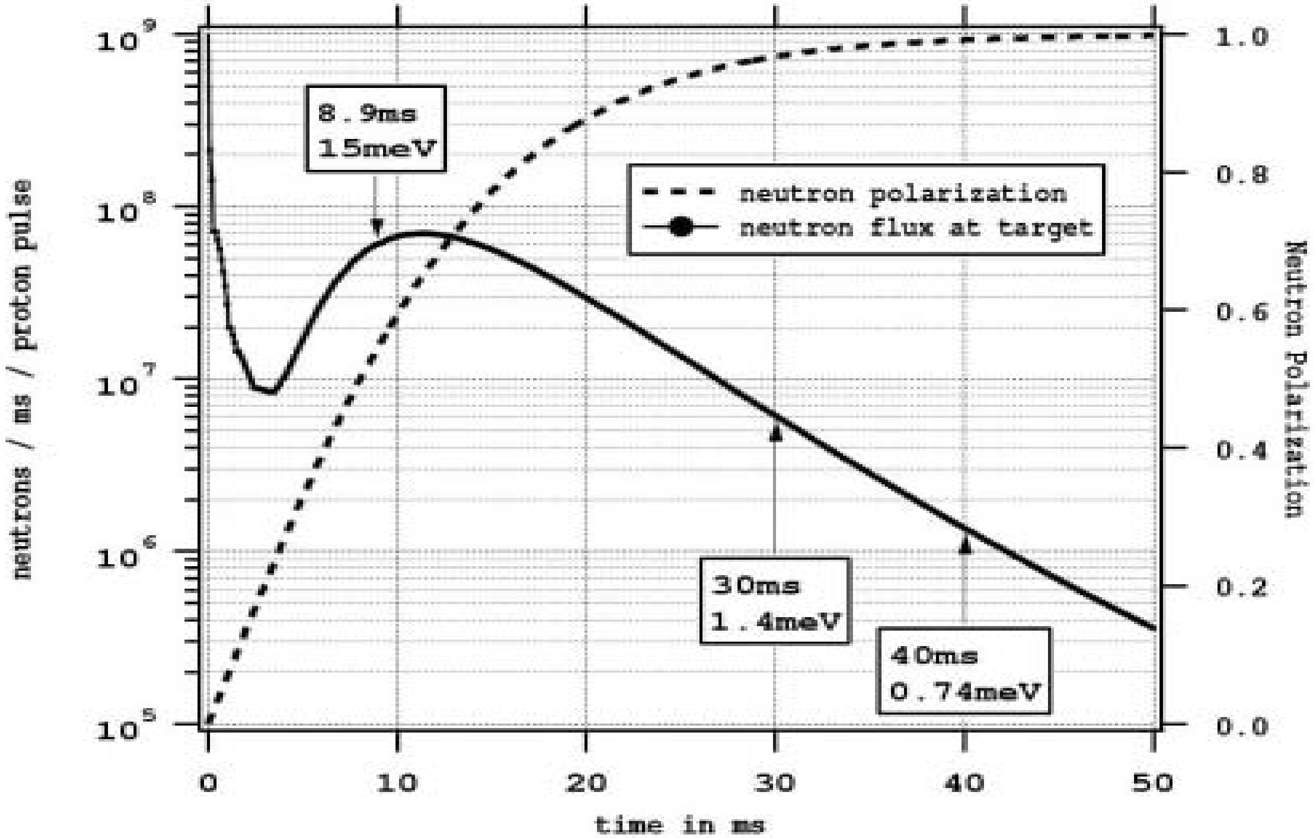
n cross-sections: ortho- ($\uparrow\uparrow$) and para- ($\downarrow\uparrow$) hydrogen

$\square$ ortho- scattering, $\circ$ para- scattering, $-$ np capture



at 17K, ortho- fraction is 0.03%

Pulsed neutron beam



- >15 meV – no asymmetry due to ortho/para spin flip – measure background
- <1.5 meV– chopper cuts off these *n* to prevent overlap – check noise
- A_γ is independent of energy

Flight Path 12 Construction Progress

in-pile
guide

shutter

frame
overlap
chopper

Test Run 2001 – Prototype Monitor

LND 27527

Sensitivity and intrinsic noise confirmed as predicted

^{3}He Spin Filter

Optical pumping of Rb vapor, which polarizes ^{3}He by hyperfine spin-exchange collisions.

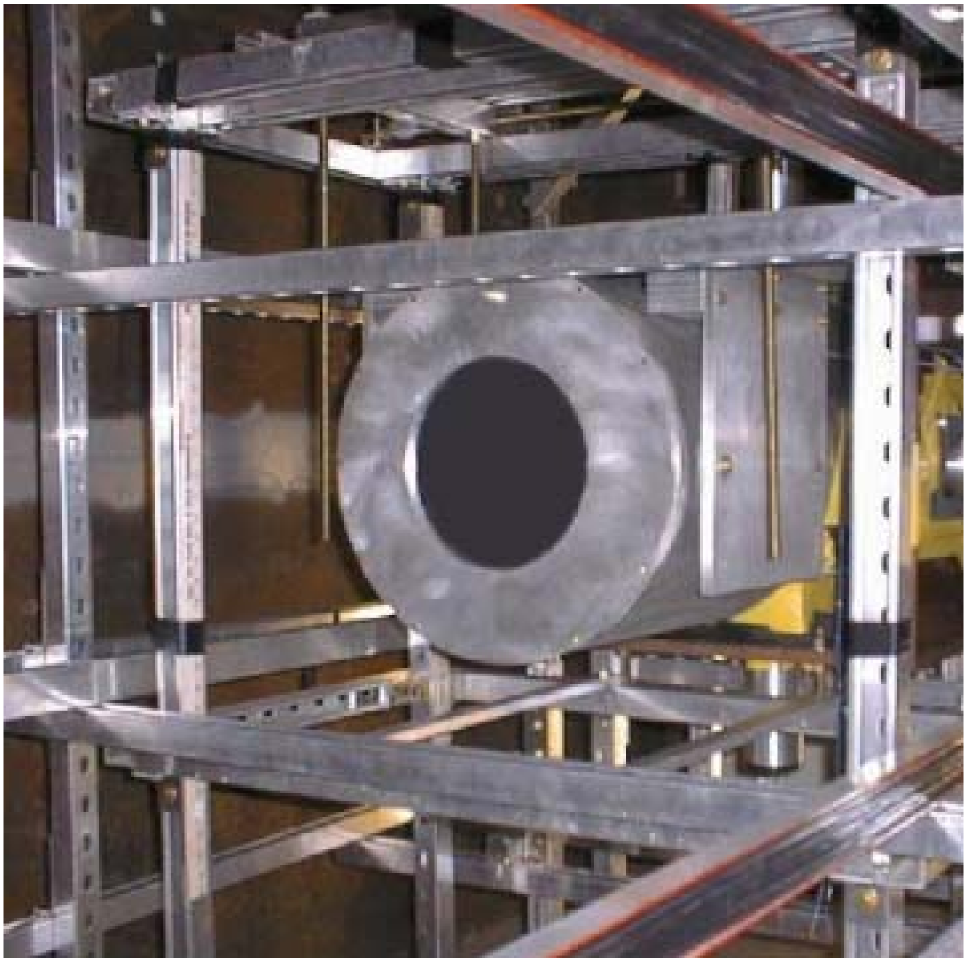
Neutron beam is polarized by passing through the cell. Antiparallel spin neutrons absorbed.

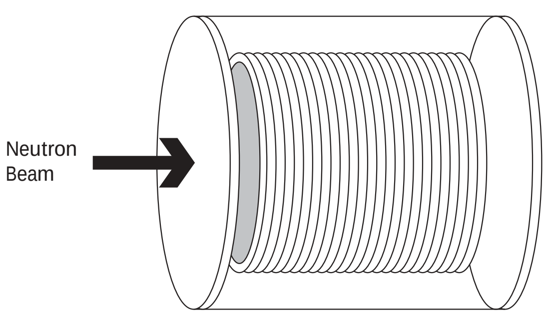
Fall 2000 Test Run: ^{3}He polarization of 26.5% $\longrightarrow n$ polarization of 30-70% for 2-10 meV

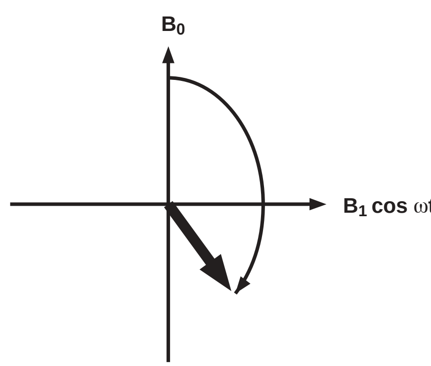
NIST group has fabricated large single cell: 12 cm dia., $T_1 > 500$ hr $\rightarrow$ 50% ^{3}He pol.

Radio Frequency Spin Flipper

In a DC magnetic field, apply a resonant RF magnetic field to precess the neutron spin by π



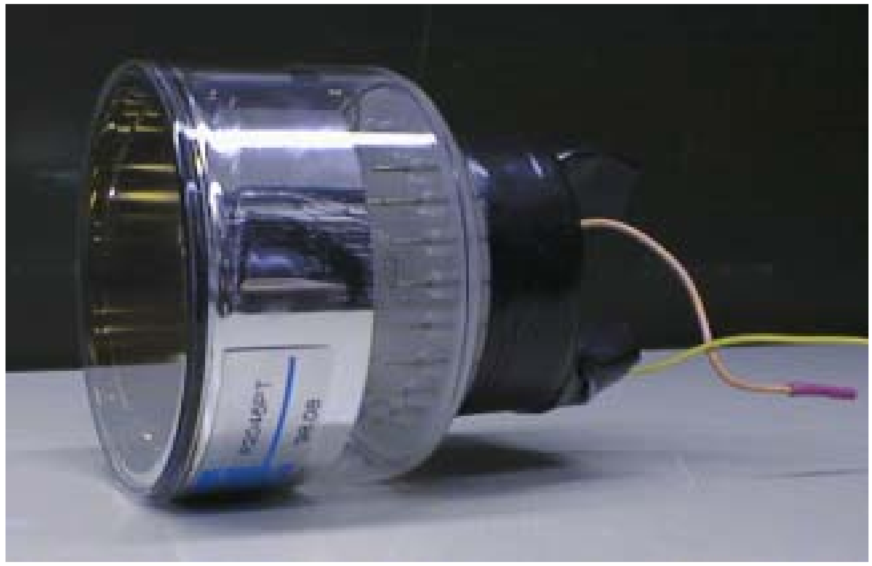


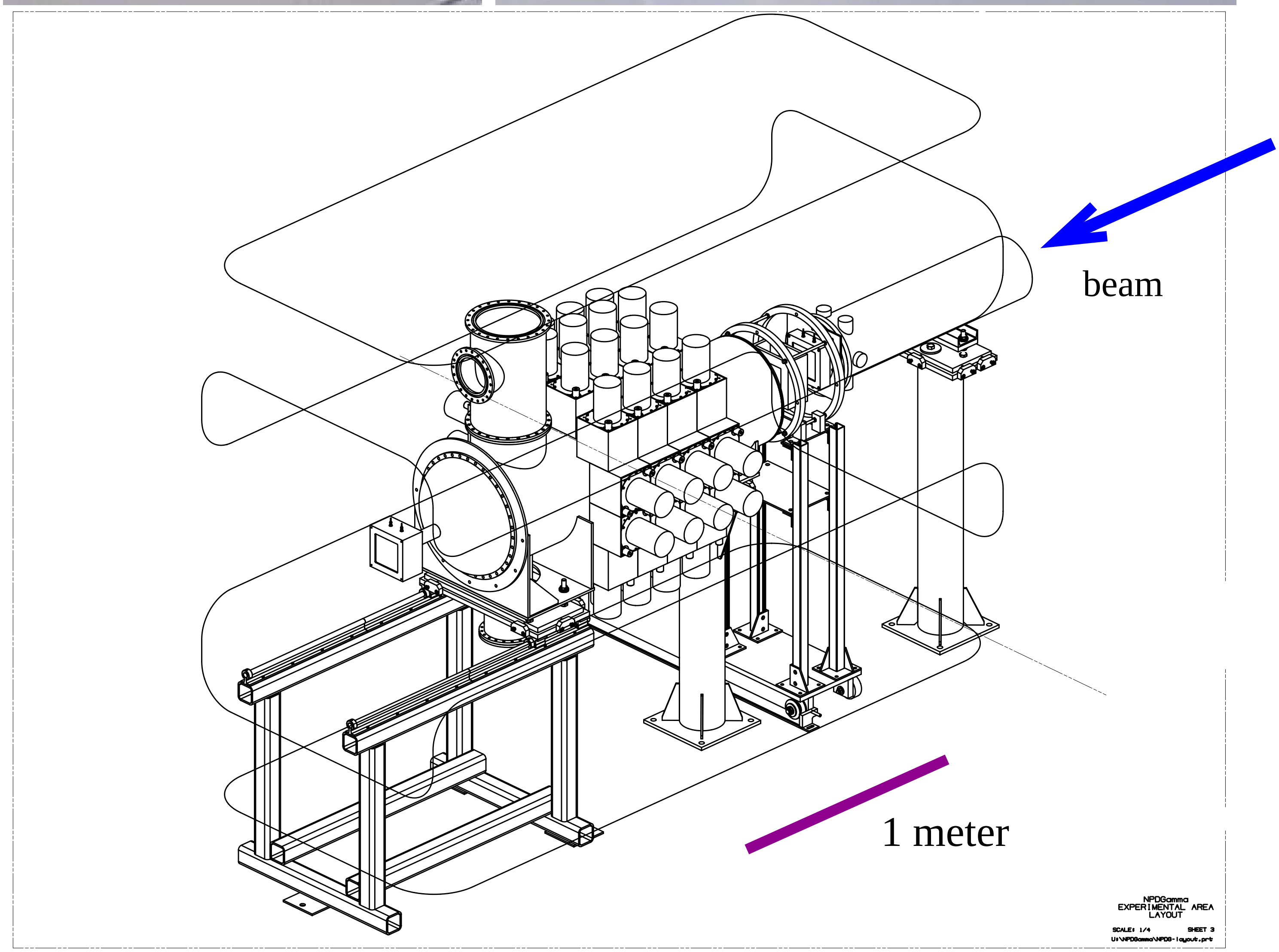


Spin flipper efficiency:
measured >95% on axis in Fall 2000

CsI(Tl) and Photodiode γ Detectors

48 detectors in the full array





(Neutron polarization direction up-down.)

Summary

- pp and np parity violation experiments permit study of the hadronic, $\Delta s = 0$ part of the weak interaction.

- np → dγ sensitive to long range part – measure f_π
  New precision experiment under construction at Los Alamos

- pp → pp sensitive to shorter range part – measure h_ρ^{pp} and h_ω^{pp}
  low energy measurements, plus the recent TRIUMF 221 MeV measurement have constrained h_ρ^{pp} and h_ω^{pp}

- The data so far are not enough to determine all the couplings.

"*errors using inadequate data are much less than those using no data at all*" -
-- *Charles Babbage.*