aCORN Polarimetry

Tom Gentile
(Who very kindly volunteered to give this talk for…)

Gordon Jones
Hamilton College

Knoxville, 9/23/19

aCORN Polarimetry

- aCORN – new result
- Why Polarimetry?
- Polarimetry Apparatus
- Polarimetry Analysis
- aCORN Results

Neutron Decay Parameters

Recoil order ($\frac{1}{2}^+ \rightarrow \frac{1}{2}^+$) beta decay correlations (Jackson, Treiman, Wyld, 1957)

$$dW \propto \frac{1}{\tau} F(E_e)\left[1 + a\frac{\vec{p}_e \cdot \vec{p}_\upsilon}{E_e E_\upsilon} + A\frac{\vec{\sigma}_n \cdot \vec{p}_e}{E_e} + B\frac{\vec{\sigma}_n \cdot \vec{p}_\upsilon}{E_\upsilon} + D\frac{\vec{\sigma}_n \cdot (\vec{p}_e \times \vec{p}_\upsilon)}{E_e E_\upsilon} + b\frac{m_e}{E_e}\right]$$

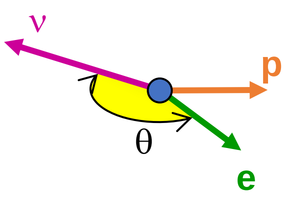
In the standard model we have

$$a \approx \frac{1-\lambda^2}{1+3\lambda^2} \qquad b = 0$$

$$A \approx -2\frac{\lambda^2 + \mathrm{Re}(\lambda)}{1+3\lambda^2} \qquad B \approx 2\frac{\lambda^2 - \mathrm{Re}(\lambda)}{1+3\lambda^2}$$

$$\tau \propto \frac{1}{g_V^2(1+3\lambda^2)} \qquad D \approx 2\frac{\mathrm{Im}(\lambda)}{1+3\lambda^2}$$

Where $\lambda \equiv \frac{g_A}{g_V}$



a ≈ -0.1

Why do we measure neutron decay parameters?

Within the Standard Model:

1) Determine G_A and G_V which govern important reactions:

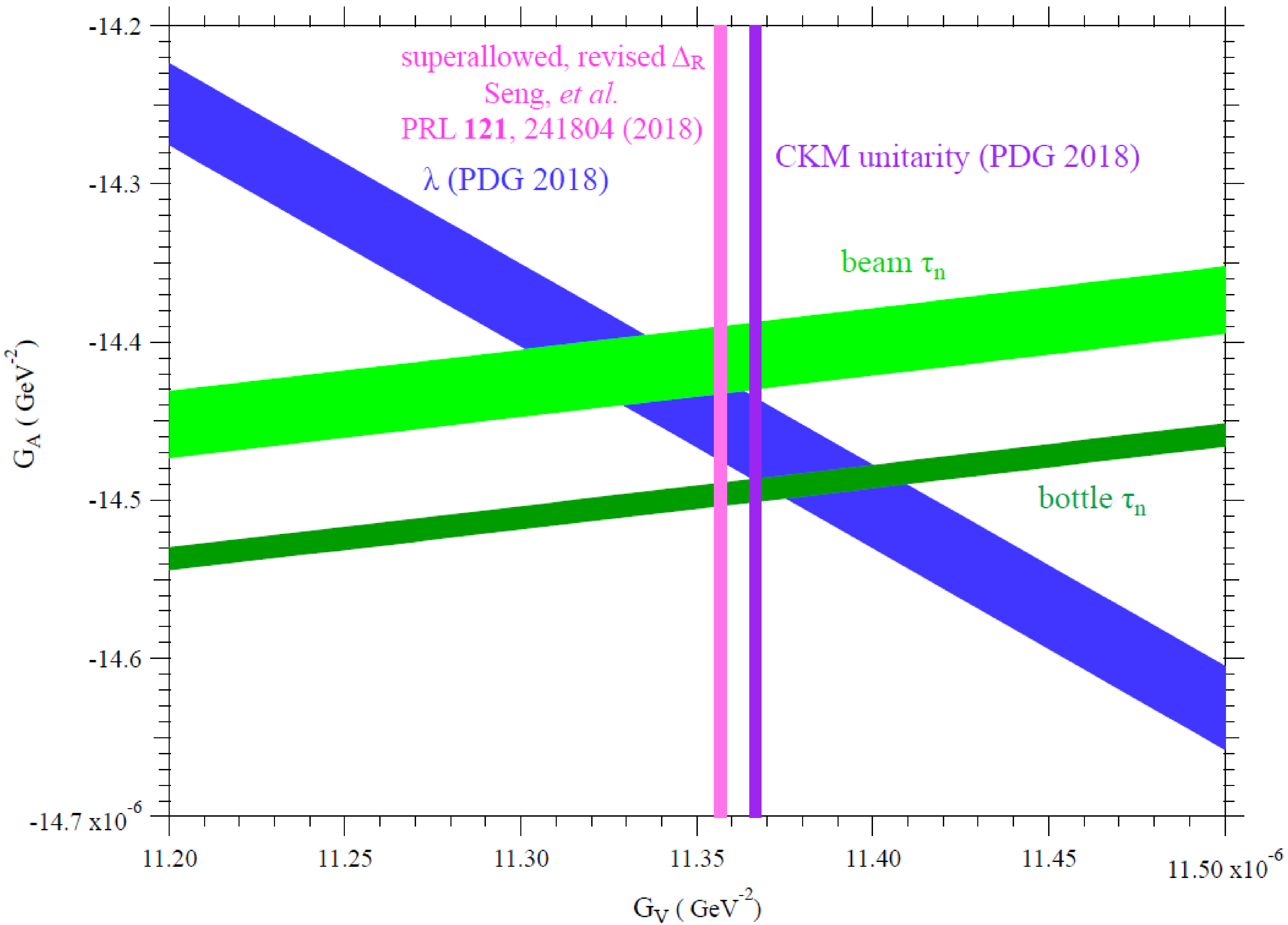
$n + e^+ \leftrightarrow p + \bar{\nu}$ (Big-Bang nucleosynthesis)
$p + e^- \leftrightarrow n + \nu$ (Big-Bang nucleosynthesis, neutron star formation)
$p + p \rightarrow D + e^+ + \nu$ (solar fusion)
$p + p + e^- \rightarrow D + \nu$ (solar fusion)
$\nu + n \rightarrow e^- + p$ (neutrino detection)
$\bar{\nu} + p \rightarrow e^+ + n$ (antineutrino detection).

2) Determine V_{ud}, test unitarity of the CKM matrix:

$$V_{ud} = \frac{G_V}{G_F}$$

$$\left|V_{ud}\right|^2 + \left|V_{us}\right|^2 + \left|V_{ub}\right|^2 = 1$$

unitarity condition



superallowed, revised Δ_R
Seng, *et al.*
PRL **121**, 241804 (2018)
CKM unitarity (PDG 2018)
λ (PDG 2018)
beam τ_n
bottle τ_n
-14.2
-14.3
-14.4
-14.5
-14.6
-14.7 x10^{-6}
G_A (GeV^{-2})
11.20
11.25
11.30
11.35
11.40
11.45
11.50 x10^{-6}
G_V (GeV^{-2})

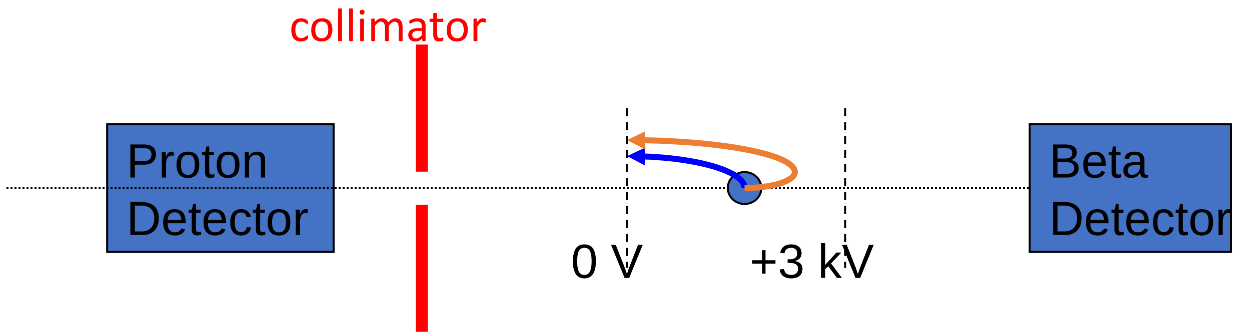
Method

1. For each beta momentum (green)
2. Confine proton momentum to axis (blue)

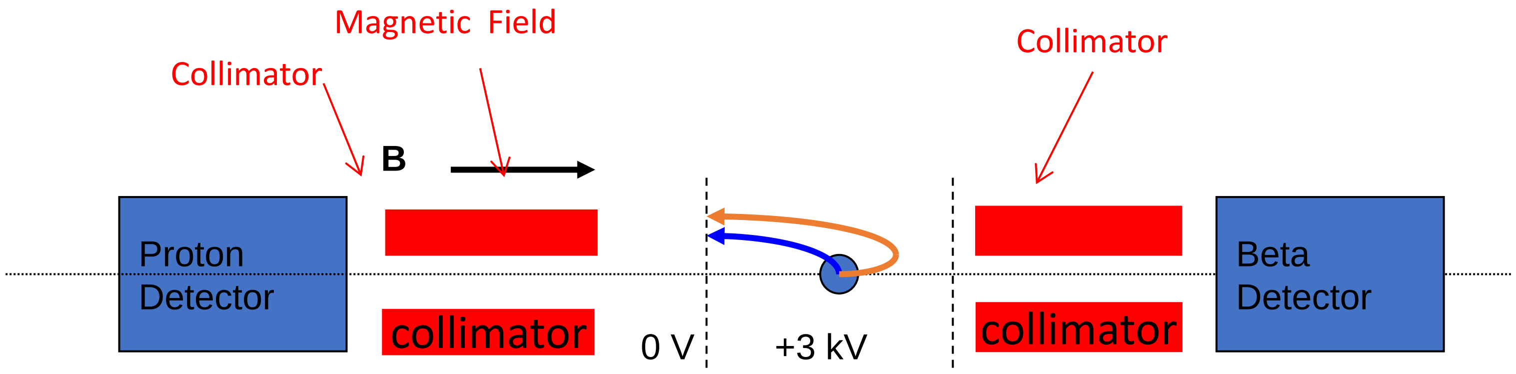
Two ways to satisfy transverse P conservation and E conservation

Number of small angle events vs. large angle events determines ‘a’ coefficient

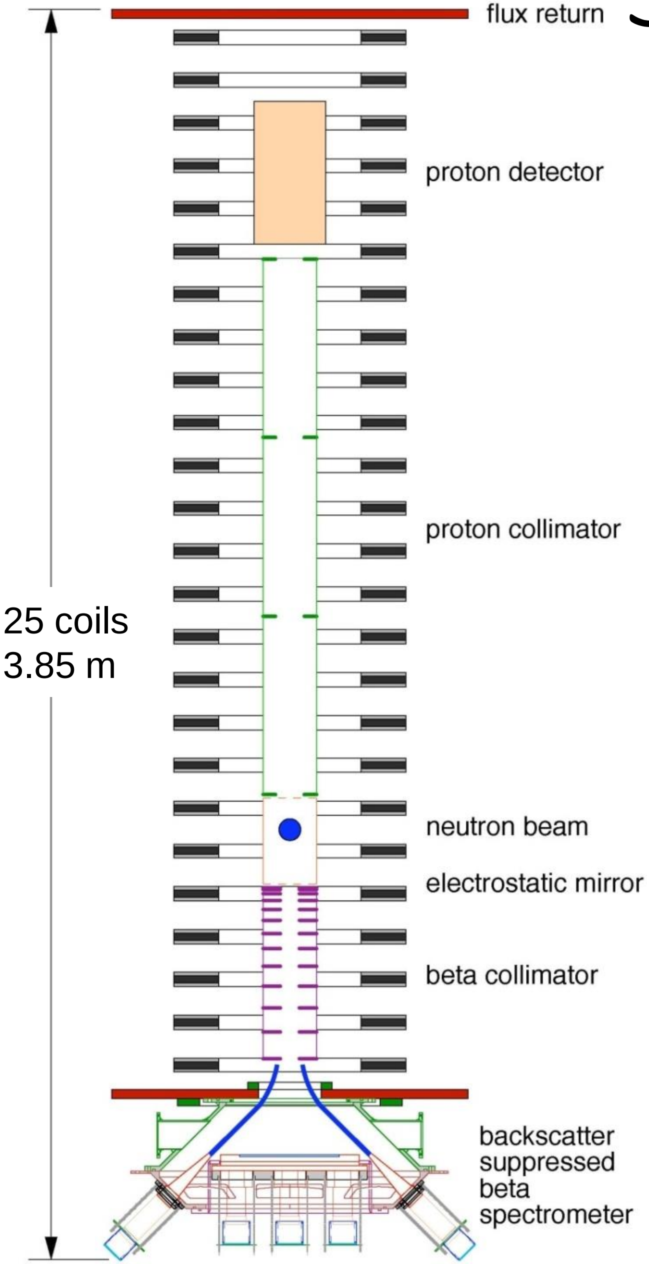
Distinguish two possible cases using timing



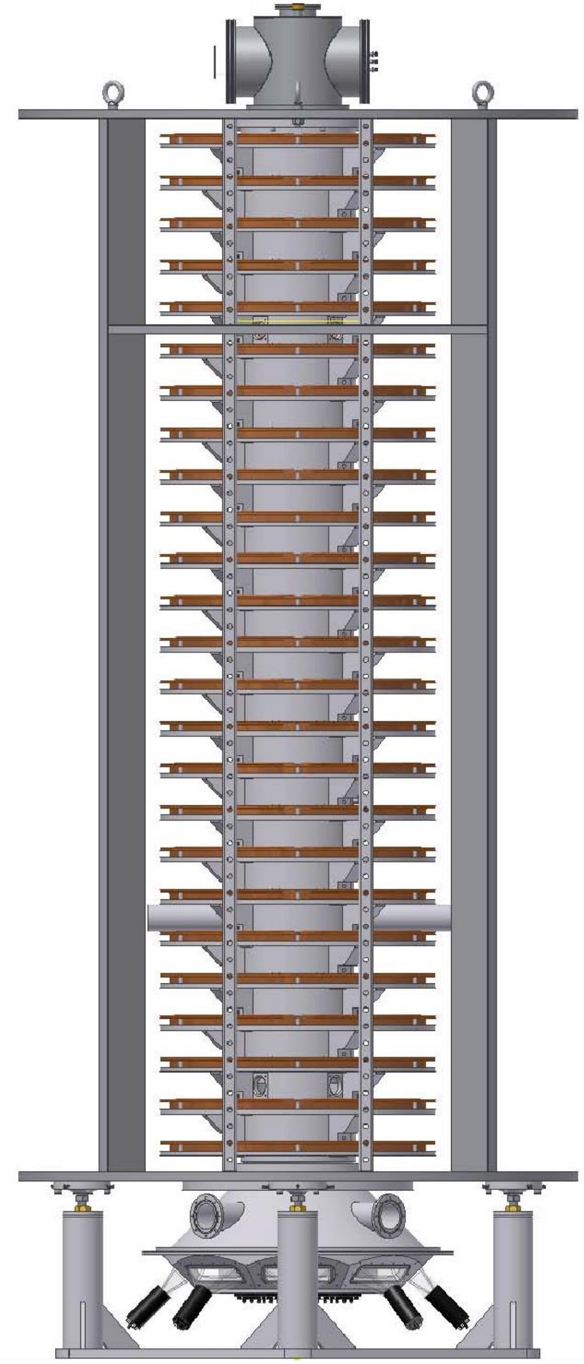
Magnetic Field to Increase Rate



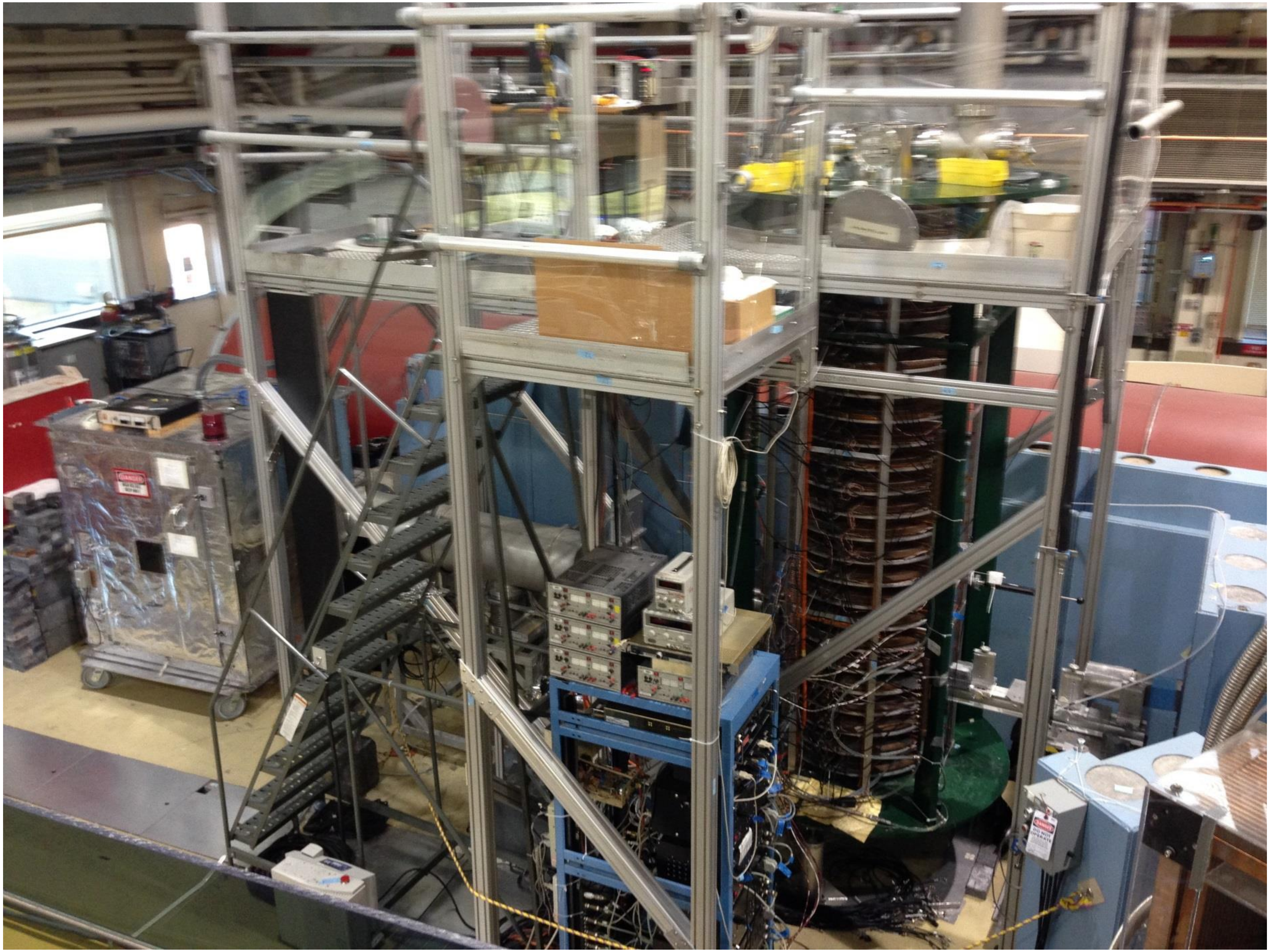
Schematic

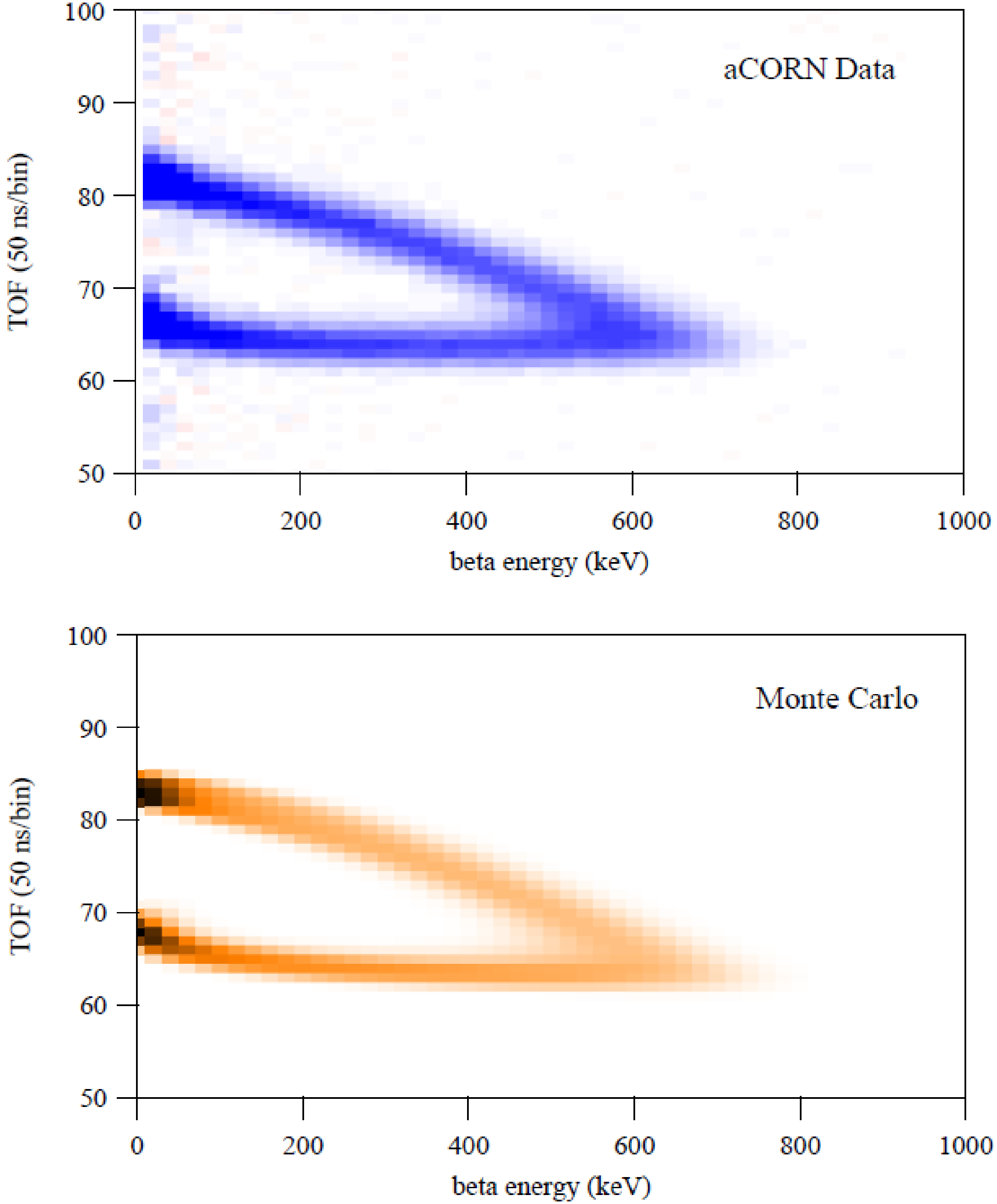


flux return
proton detector
proton collimator
25 coils
3.85 m
neutron beam
electrostatic mirror
beta collimator
backscatter
suppressed
beta
spectrometer



aCORN on NG-6

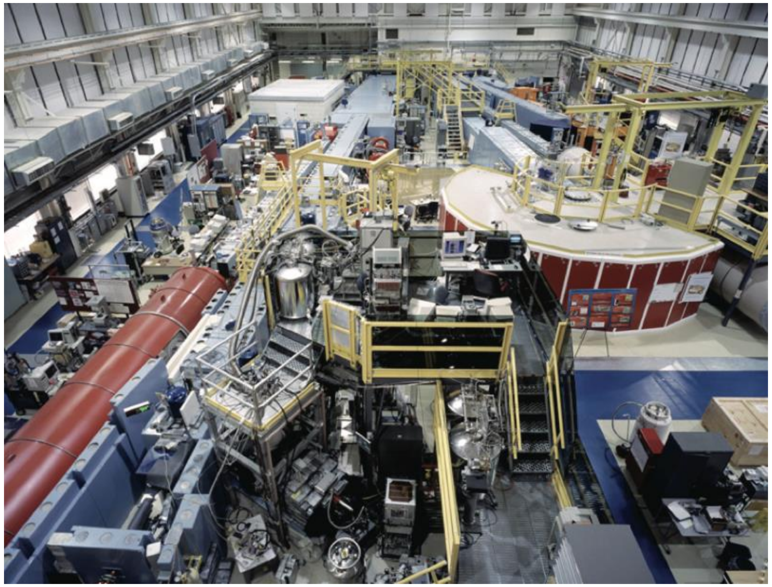




Background Subtracted “Wishbone” Data

Two Runs

NG-6



G. Darius, et al., Phys. Rev. Lett. 119, 042502 (2017)

B. Collet, et al., Rev. Sci. Instr. 88, 083503 (2017)

M.T. Hassan, et al., Nucl. Instr. Meth. A 867, 51 (2017)

$a = -0.1080 \pm 0.0030 \text{ (stat)} \pm 0.0028 \text{ (syst)}$

NG-C

- July 2015 – Sept. 2016
- Capture flux = 8×10^{9} cm^{-2} s^{-1}
- Compared to NG-6
  - 5x wishbone event rate
  - 10x counts
- Improved systematics
  - (electric field uniformity & smaller changes)
- Blinded Result: Neutron polarimetry

Why Polarimetry?

Neutron Decay Parameters

Recoil order (½⁺ → ½⁺) beta decay correlations

(Jackson, Treiman, Wyld, 1957)

$$dW \propto \frac{1}{\tau} F(E_e)\left[1 + a\frac{\vec{p}_e \cdot \vec{p}_\upsilon}{E_e E_\upsilon} + A\frac{\vec{\sigma}_n \cdot \vec{p}_e}{E_e} + B\frac{\vec{\sigma}_n \cdot \vec{p}_\upsilon}{E_\upsilon} + D\frac{\vec{\sigma}_n \cdot (\vec{p}_e \times \vec{p}_\upsilon)}{E_e E_\upsilon} + b\frac{m_e}{E_e}\right]$$

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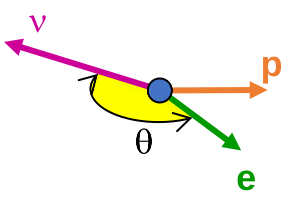

Where $\lambda \equiv \frac{g_A}{g_V}$

a ≈ -0.1

B ≈ 1

Neutron Decay Parameters

Recoil order (½⁺ → ½⁺) beta decay correlations
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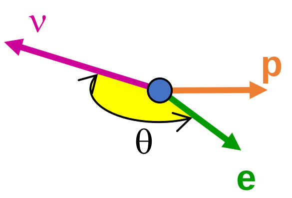


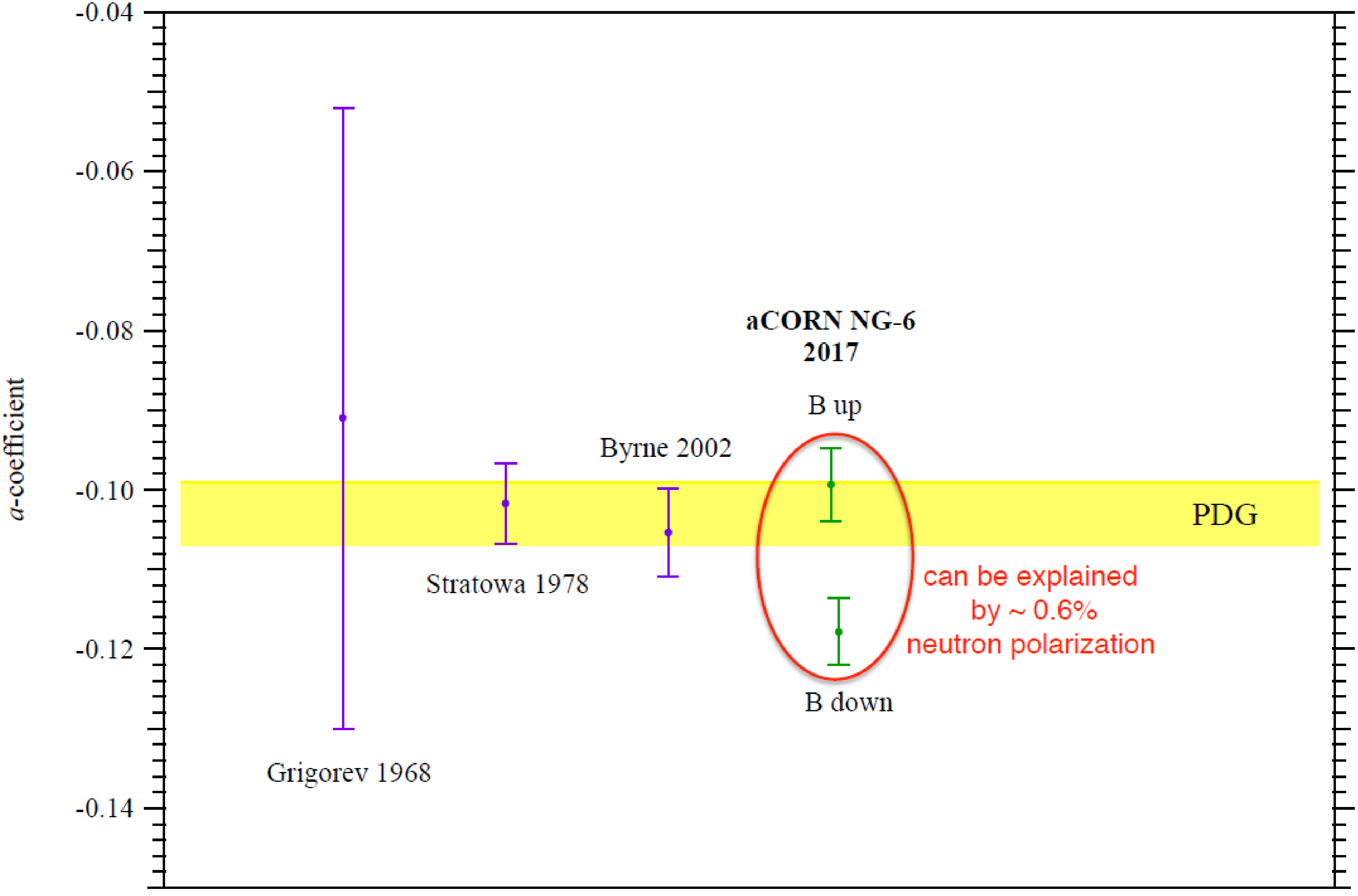
Where $\lambda \equiv \frac{g_A}{g_V}$

a ≈ -0.1

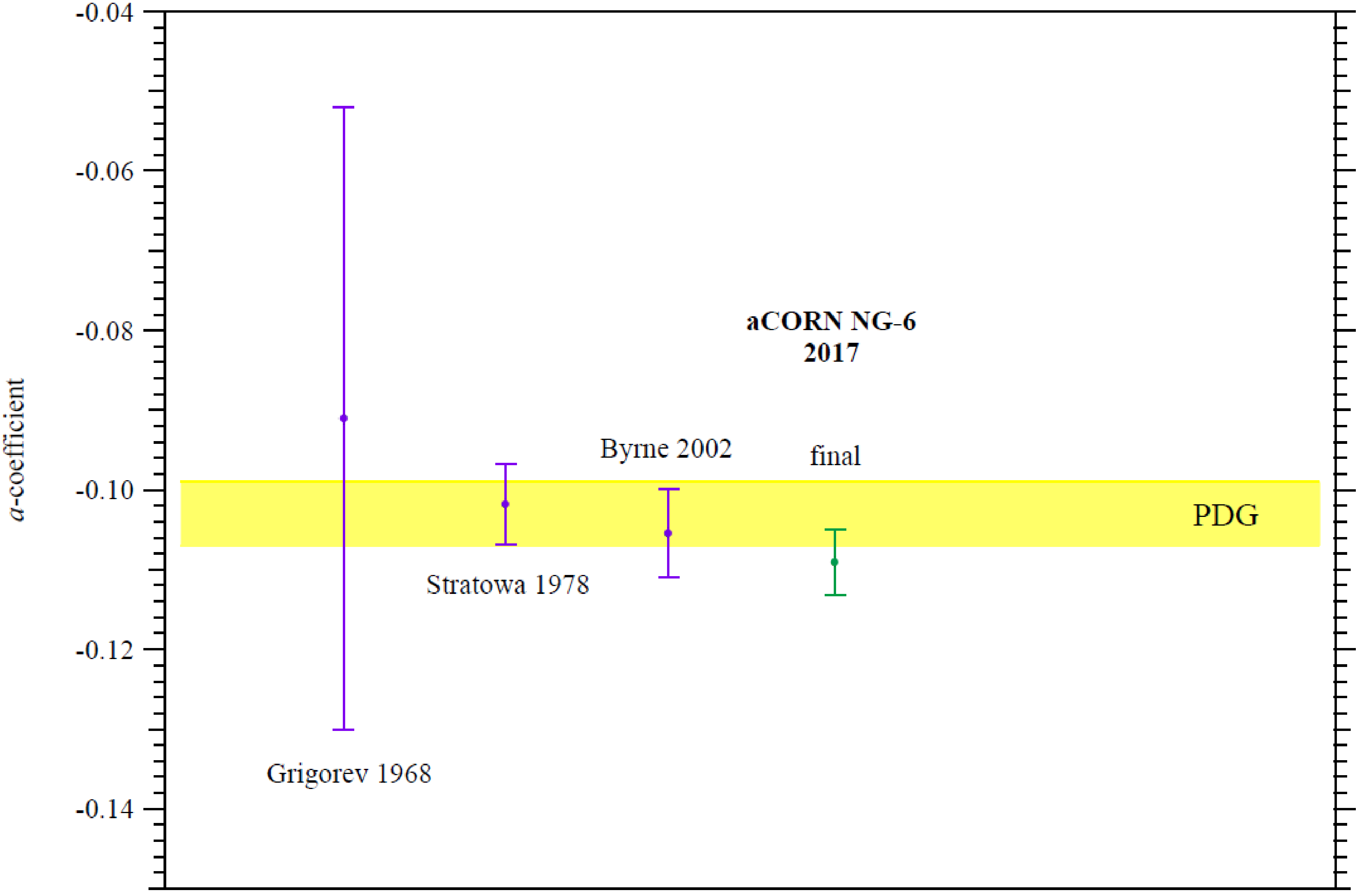
B ≈ 1

Asymmetry ≈ a $f_a(E_\beta)$ + PB $f_B(E_\beta)$

B $f_B(E_\beta) \approx 14 f_a(E_\beta)$



-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
a-coefficient
Grigorev 1968
Stratowa 1978
Byrne 2002
aCORN NG-6
2017
B up
B down
PDG
can be explained
by ~ 0.6%
neutron polarization


-0.04
-0.06
-0.08
-0.10
-0.12
-0.14
a-coefficient
aCORN NG-6
2017
Byrne 2002
final
PDG
Stratowa 1978
Grigorev 1968

Feature? Or Bug?

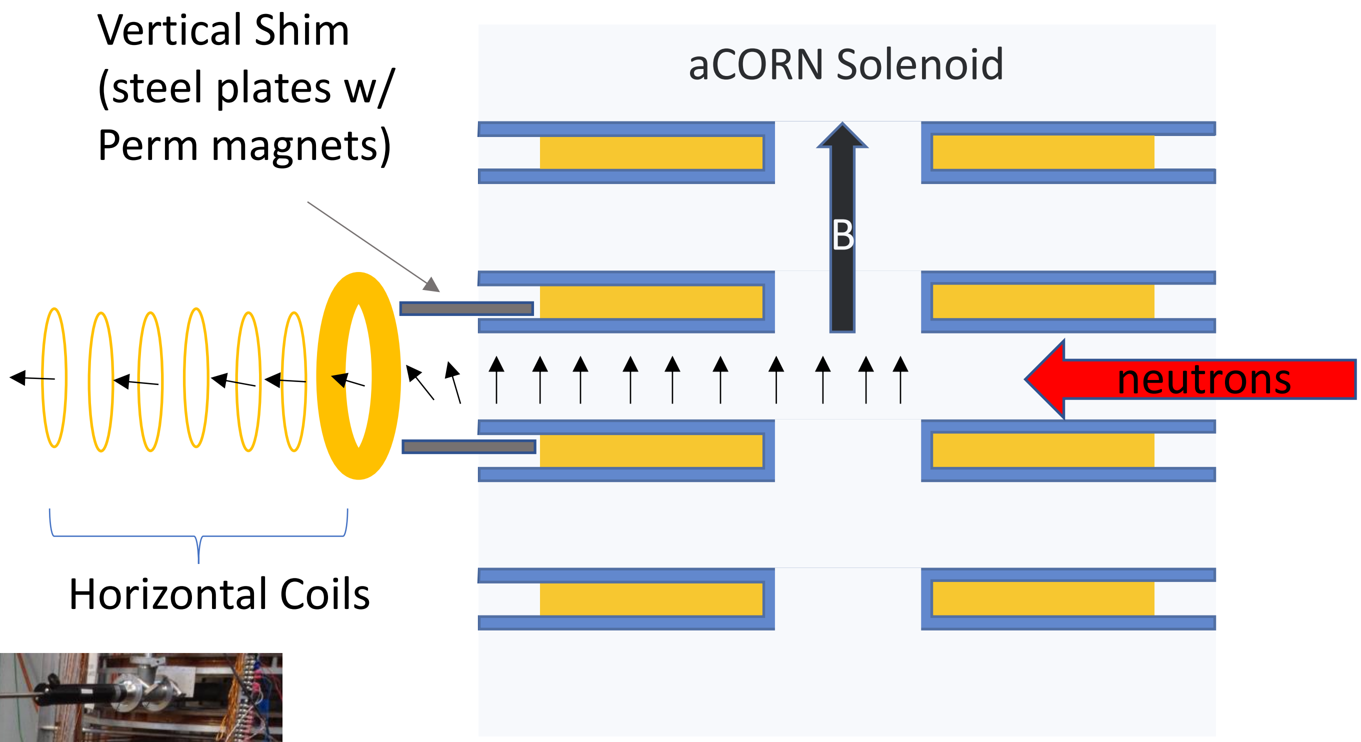
NG-C result used polarimetry as a blind.

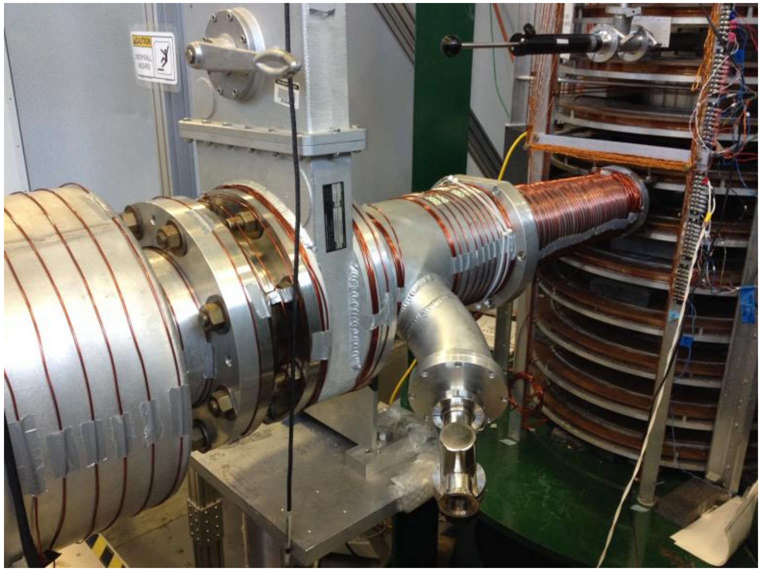
- Data cuts entirely determined using B field up
  (Effect of P_n unknown)
- B field down analyzed using same cuts
- Polarimetry result revealed must be consistent with both

aCORN Polarimetry

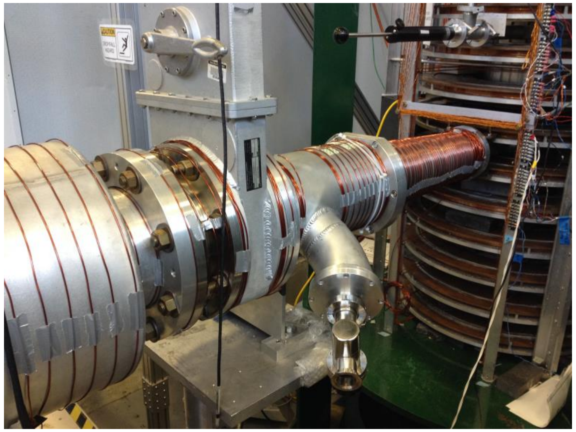
- aCORN – new result
- Why Polarimetry?
- Polarimetry Apparatus
  - Spin transport
  - ^{3}He-based neutron spin-filter
- Polarimetry Analysis
- aCORN Results

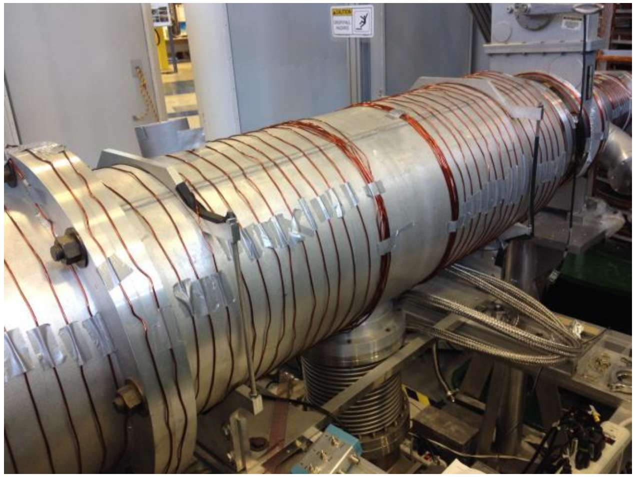
Spin Transport

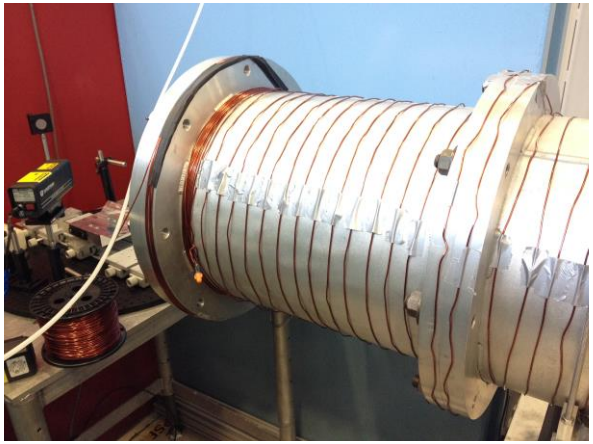




Spin Transport

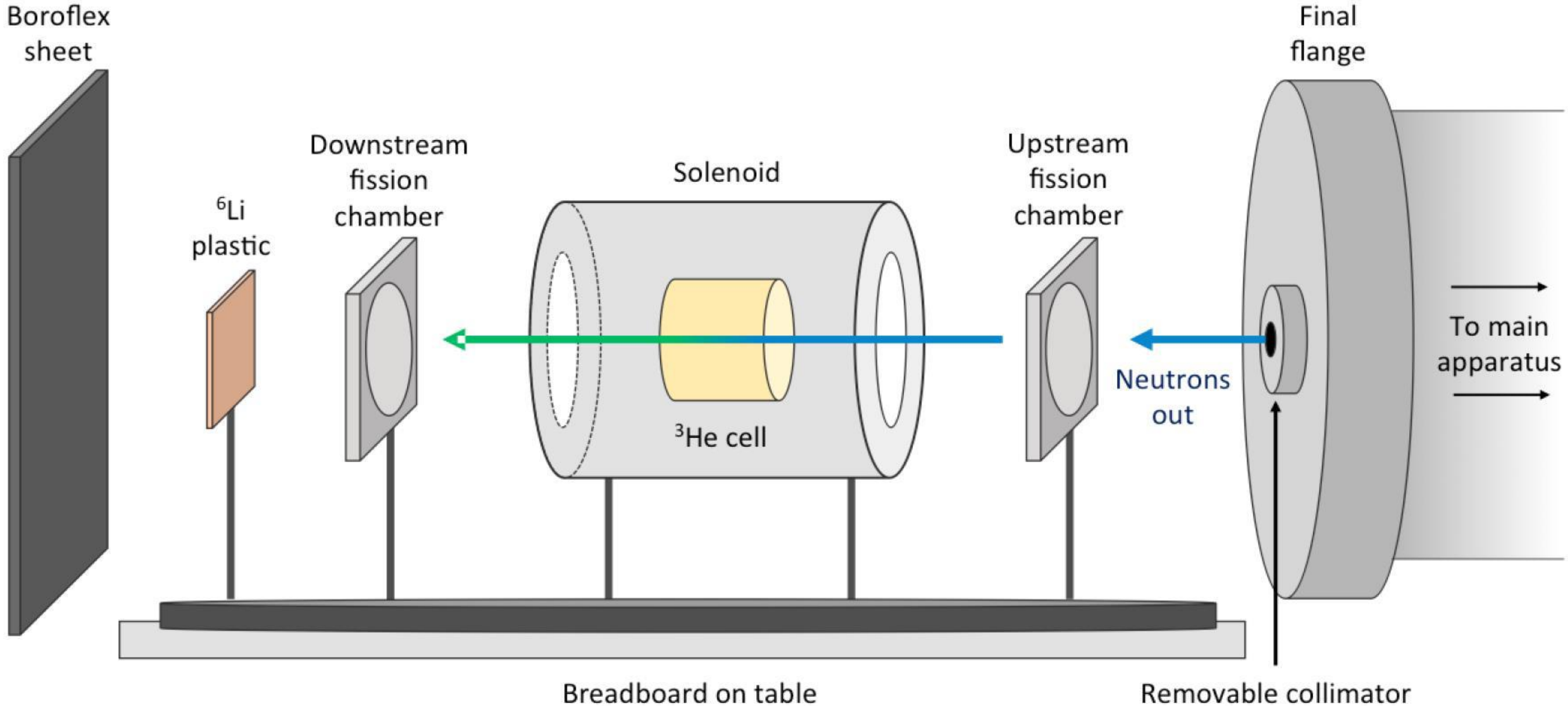




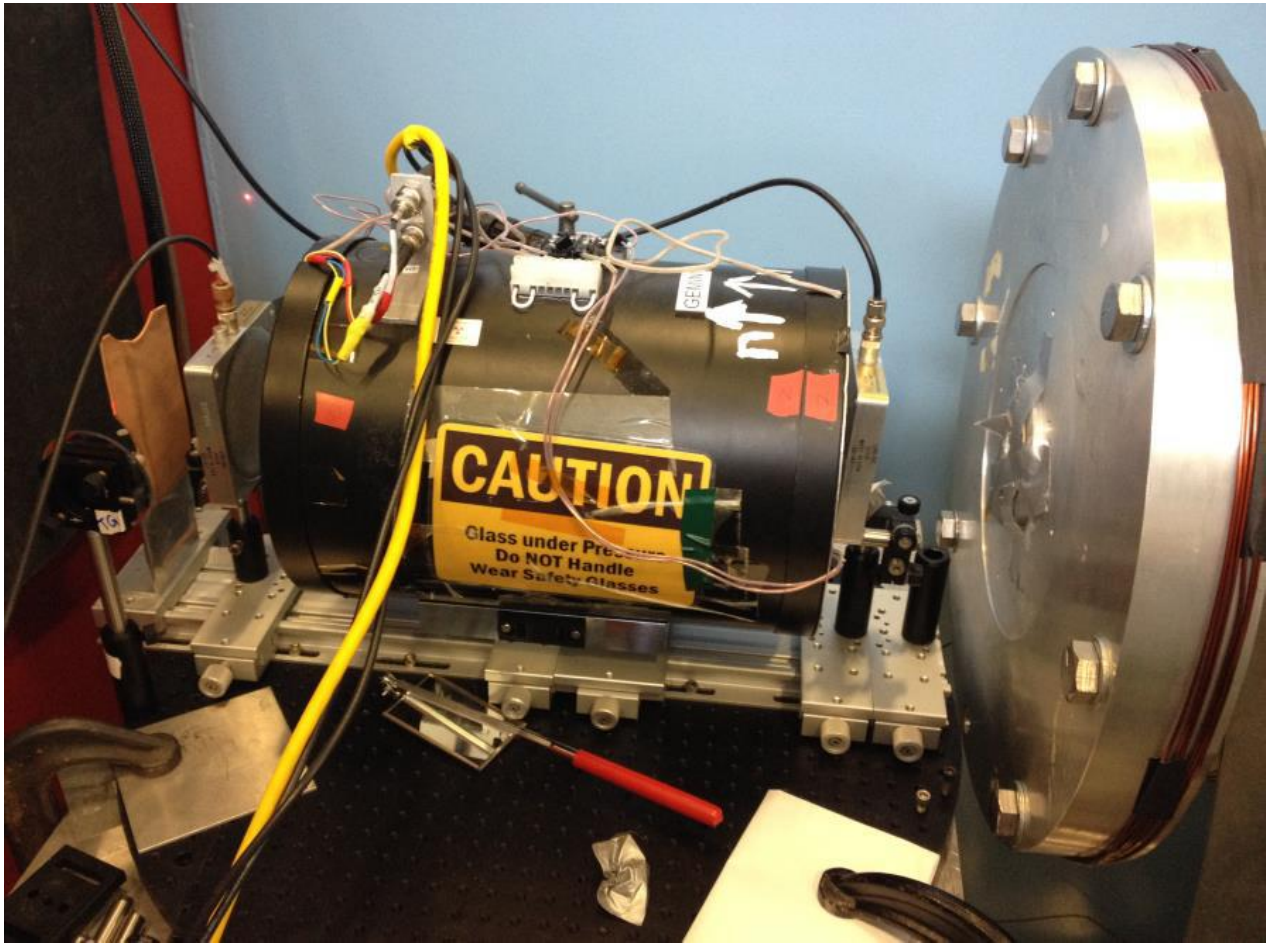


^{3}He-based Spin Filter

- Polarized offline using SEOP
- Transmission monitored by fission chambers
  - Aperture to limit rate
- ^{3}He flipped using frequency-sweep AFP NMR



Boroflex sheet
6Li plastic
Downstream fission chamber
Solenoid
3He cell
Upstream fission chamber
Final flange
Neutrons out
To main apparatus
Breadboard on table
Removable collimator


CAUTION
Glass under Pre
Do NOT Handle
Wear Safe
lasses

Procedure

Transmission monitored while ^{3}He polarization direction flipped

Transmission:

- Fission chamber recorded in 20 second intervals throughout runs
- 15 or 30 minute runs

AFP NMR fliped ^{3}He polarization between runs.

Sequence ↑↓↓↑↓↑↑↓ to reduce sensitivity to drift/decaying polarization

Discrete runs (June 21-27, July 28-August 1), and automated flips (August 1 and Aug 30)

^{3}He depolarized, then removed, after each run to measure ^{3}He thickness

Analysis

Transmission depends on:

Background:

T_0: Initial ^3He polarization

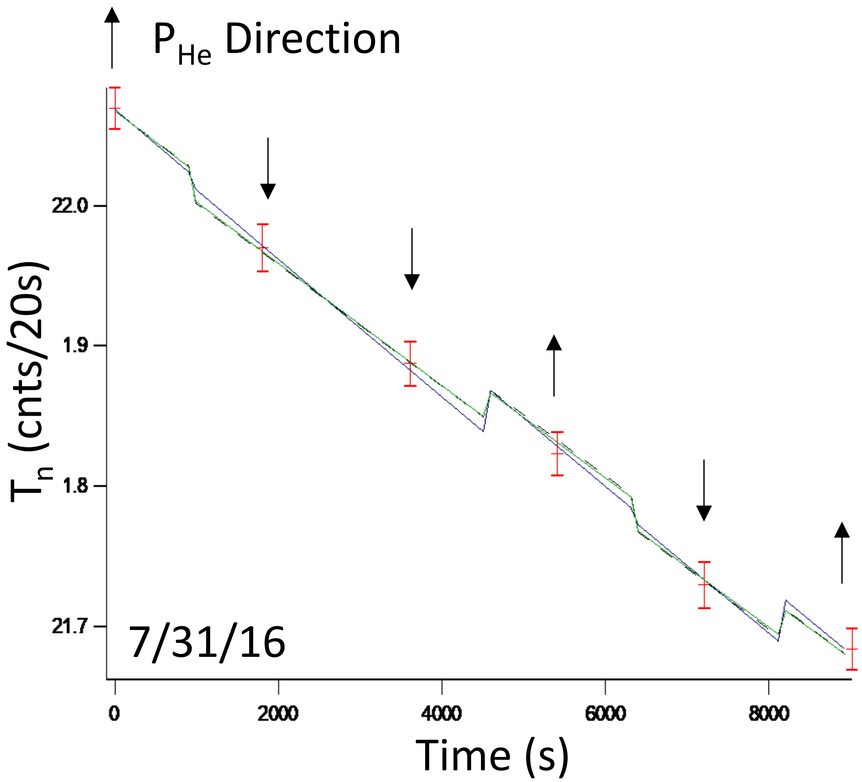
^3He polarization loss

T1: decaying ^3He polarization

AFP Loss:

Signal:

P_n: T_n depends on ^3He direction



Two fits shown:

MCNP white beam - J. Cook

Monochromatic beam

Fitting

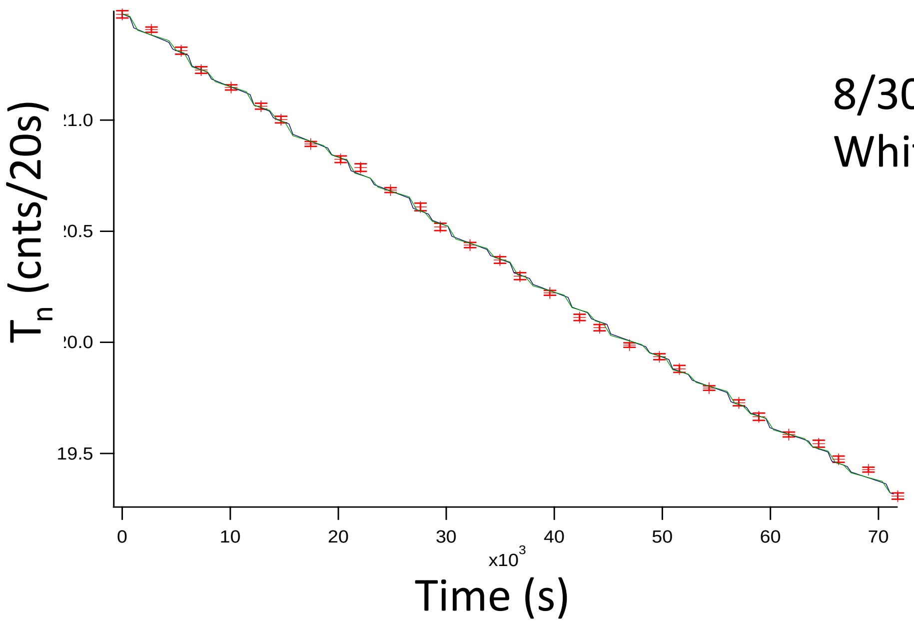
Variables: T1, AFP Loss, T_0, P_n

Fitting Function:

For each time, calculate P_{He} from T1 and number of AFP sweeps

Using P_n, calculate $T(\lambda)$ from T_0 and P_{he}

Integrate $T(\lambda)$ over the calculated neutron spectrum



8/30/16

White beam fit: P_n = -0.00023(13)

Fitting

Variables: T1, AFP Loss, T_0, P_n

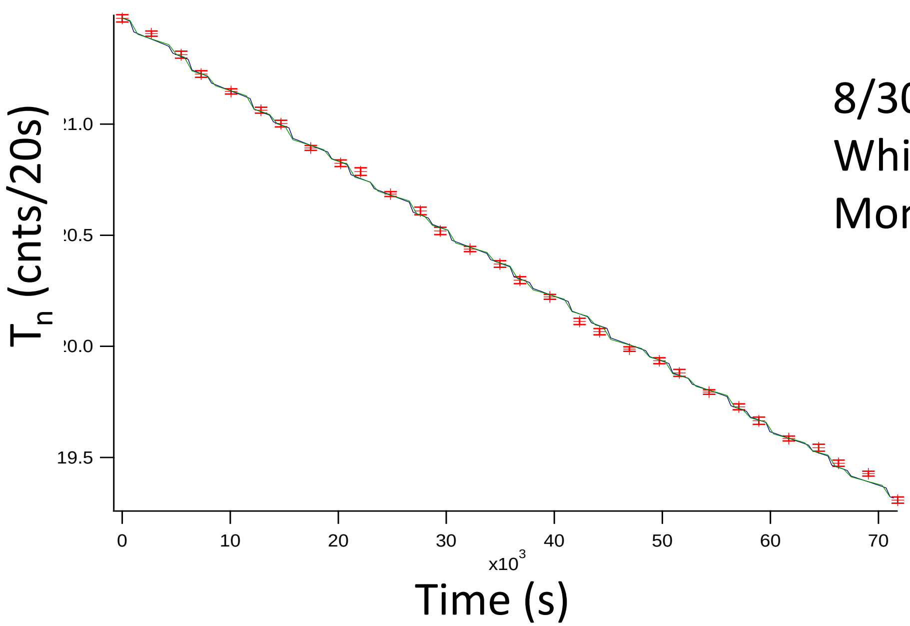
Fitting Function:

For each time, calculate P_{He} from T1 and number of AFP sweeps

Using P_n, calculate $T(\lambda)$ from T_0 and P_{he}

Integrate $T(\lambda)$ over the calculated neutron spectrum

For comparison, also fit assuming monochromatic beam



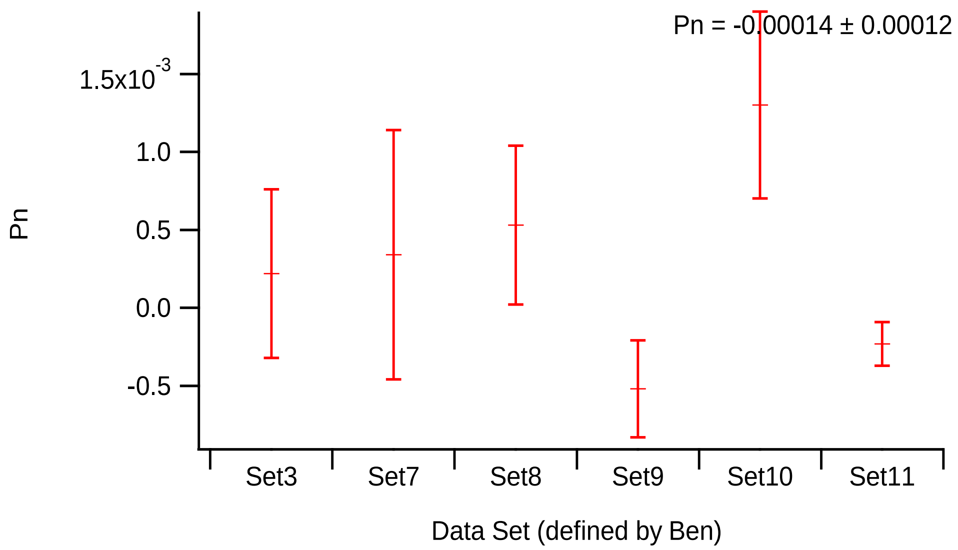
8/30/16

White beam fit: P_n = -0.00023(13)

Mono beam fit: P_n = -0.00022(14)

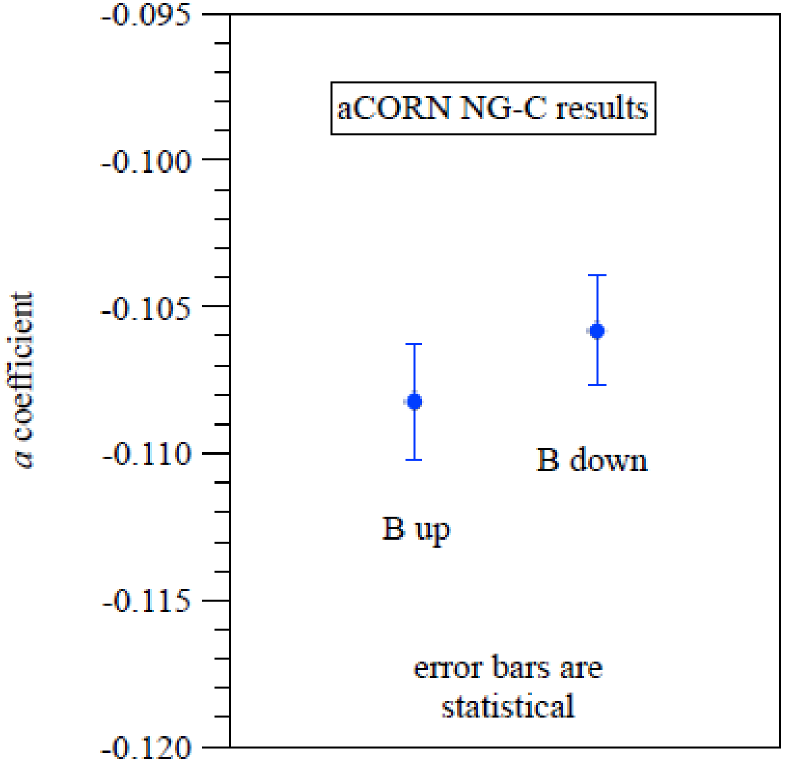
Preliminary Results

DataSet	Pn	Pn Err	PHe(%)	AFPloss	T1	Runs	date	time	ChiSqr
Data 3	0.00022	0.00054	46.0(1)	0.003(2)	100(111)	26-31	6/24	18:15	1.5
Data 7	0.00034	0.0008	30.0(1)	0.0027(4)	2000(big)	59b-65	6/25	12:07	1.6
Data 8	0.00053	0.00051	39%	0.0003	270	80	6/25	15:07	0
Data 9a	3.5E-5	0.00052	40	0.0018(2)	1600(big)	403-408	7/28	11:23	0.26
Data10a	0.0013	0.0006	39	0(fixed)	214(60)	416-418	8/29	12:51	0
Data 9	-0.00052	0.00031	50	0(.0006)	220(50)	409	7/31	13:24	0.13
Data11	-0.00023	0.00014	49.00(4)	0.0013(8)	580(400)	419	8/29	14:03	1.4



P_n = -0.014% ± 0.012%

aCORN NG-C Preliminary Result



Difference implies
$P_n = (0.8 \pm 1.0) \times 10^{-3}$

Preliminary
Polarimetry Result

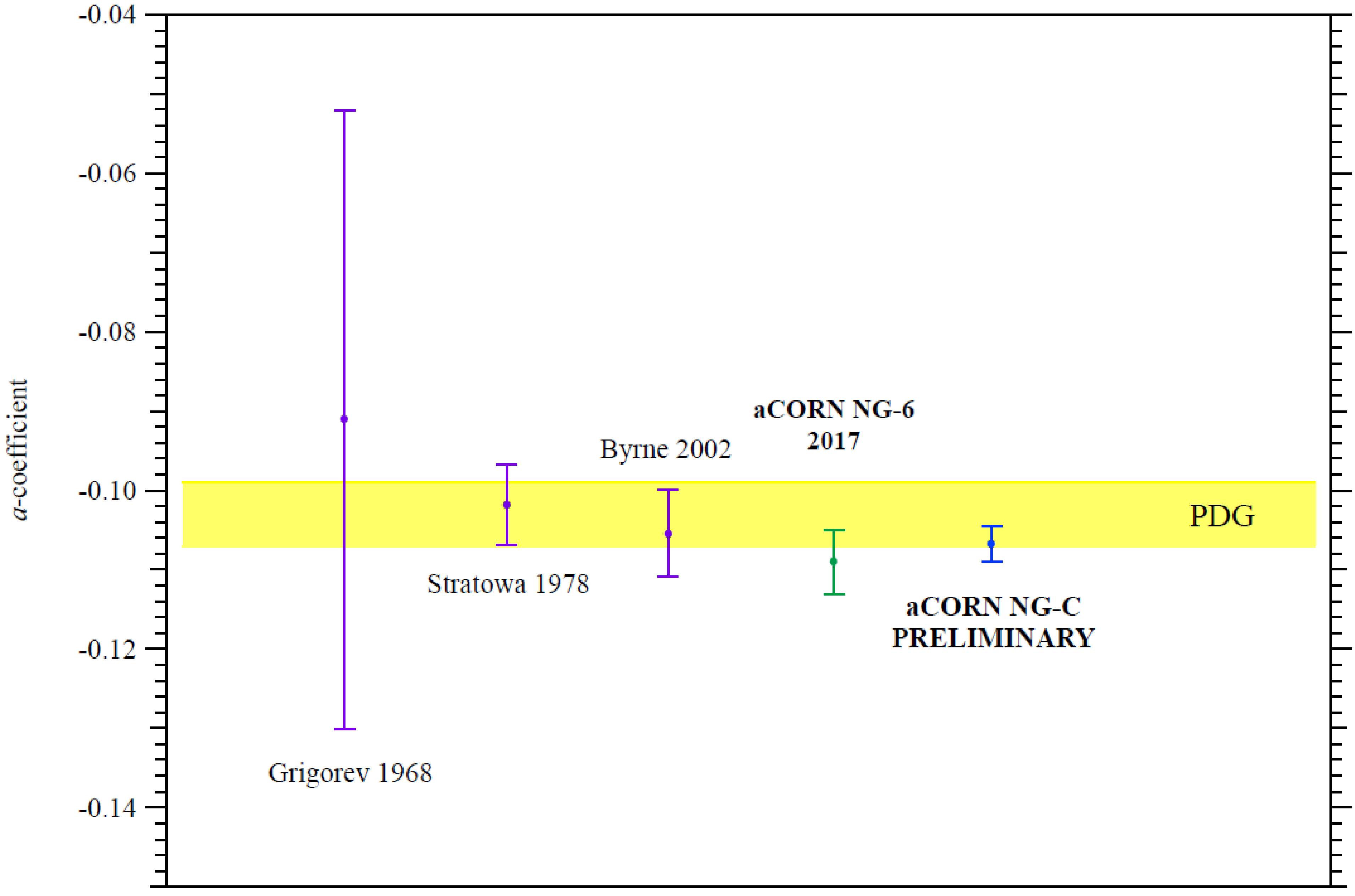
$P_n = (-0.14 \pm 0.12) \times 10^{-3}$

aCORN NG-C Preliminary Result

	correction	1 σ uncert.	relative
electrostatic mirror	0.00149	0.00030	0.0028
wishbone asymmetry		0.00048	0.0045
absolute B field	0.00043	0.00032	0.0030
B field shape	0.00051	0.00056	0.0053
residual gas		0.00049	0.0046
e scattering	-0.00076	0.00076	0.0072
energy loss in grid	-0.00111	0.00022	0.0020
beta energy calibration		0.00030	0.0028
proton collimator align.		0.00059	0.0055
electrostatic mirror align.		0.00043	0.0040
p scattering	0.00081	0.00065	0.0060
p focusing	0.00070	0.00050	0.0047
neutron beam density	-0.00045	0.00009	0.0008
total systematic	0.00162	0.0017	0.016
statistical		0.0014	0.013
total uncertainty		0.0022	0.021

a = -0.1067 ± 0.0014 (stat) ± 0.0017 (sys)

[PRELIMINARY]


-0.04
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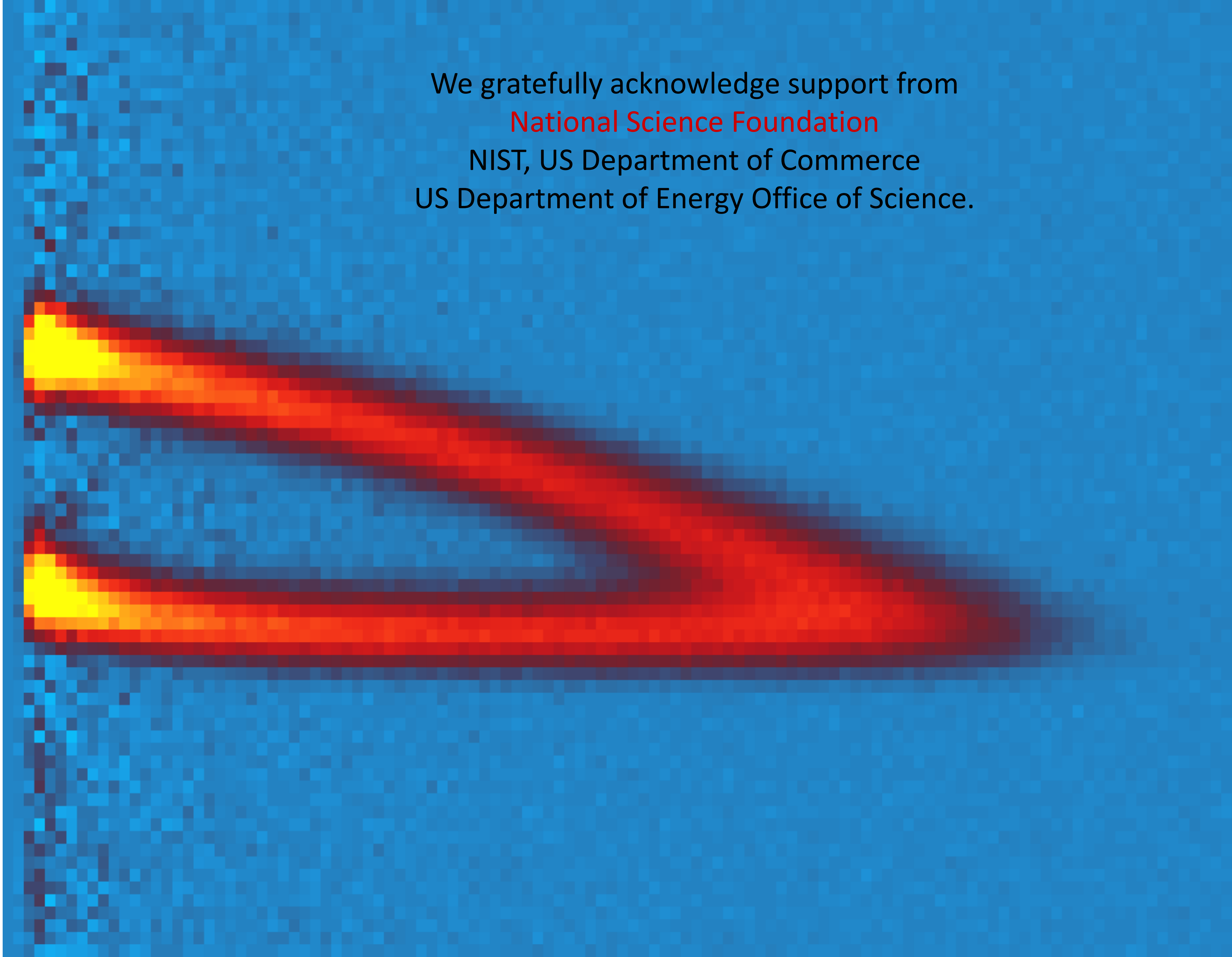
PRELIMINARY
PDG

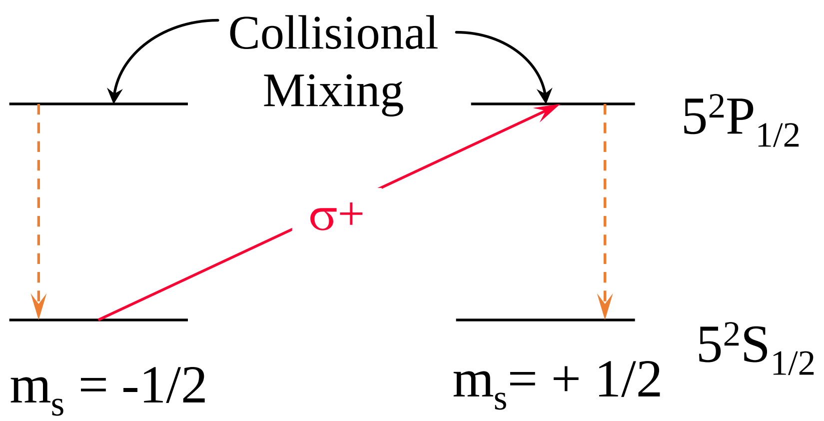


We gratefully acknowledge support from
National Science Foundation
NIST, US Department of Commerce
US Department of Energy Office of Science.

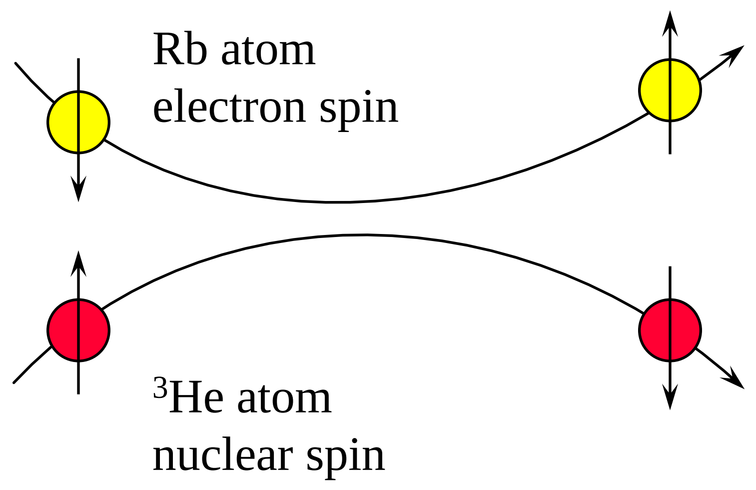
Thank You

Spin Exchange Optical Pumping

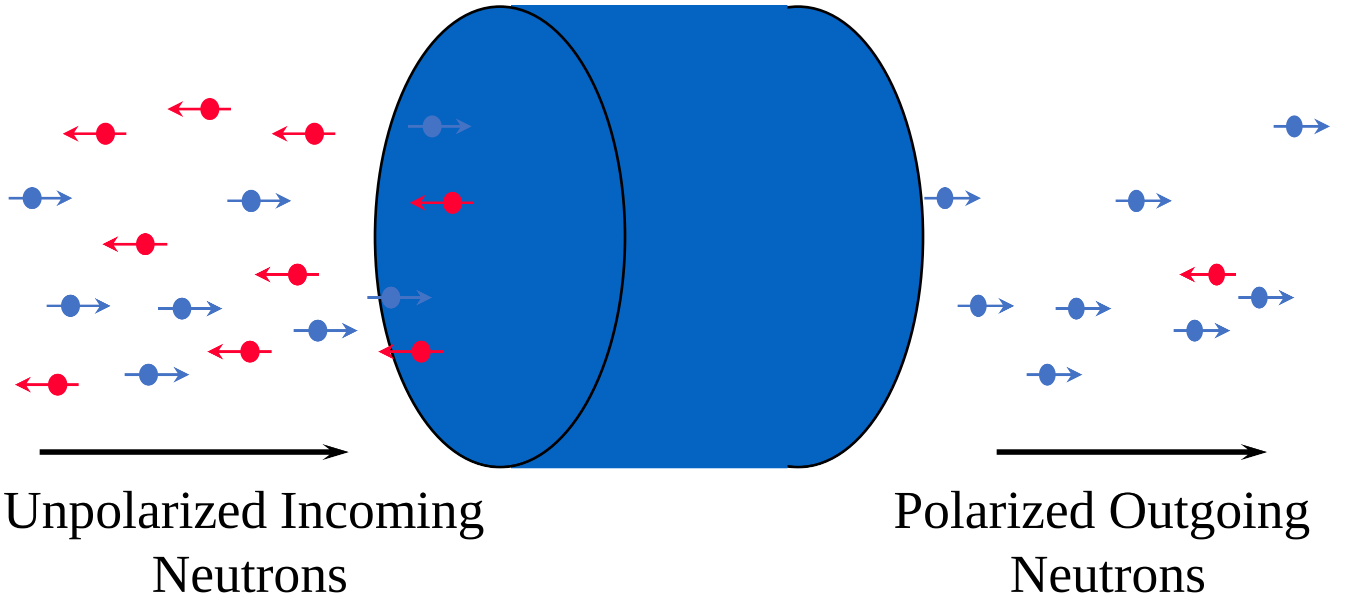
Optical Pumping of Rb

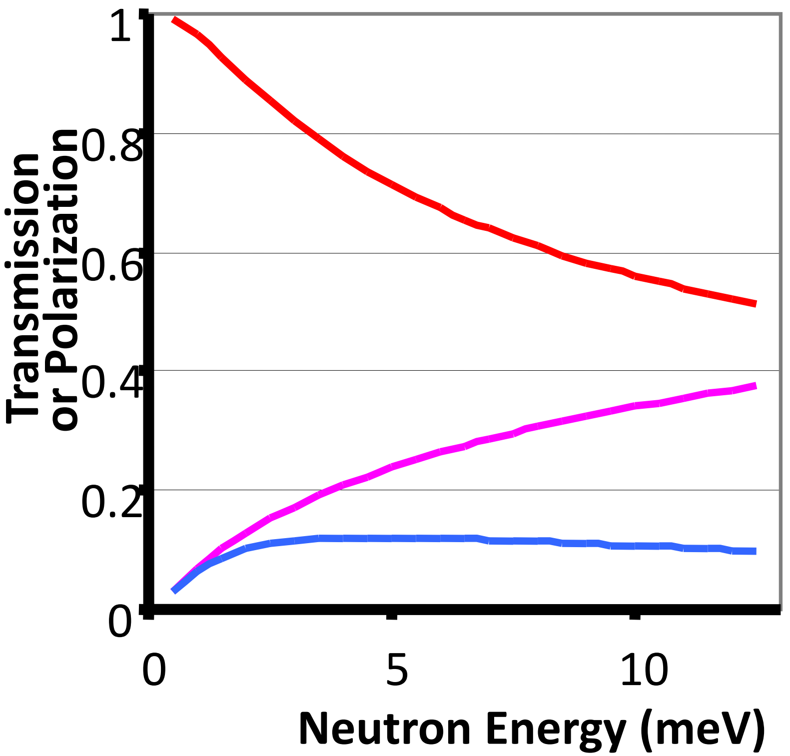


Spin-Exchange from Rb to ^{3}He



Spin Dependent Absorption Cross Section





$$\sigma \propto \frac{1}{v}$$