Measurement of beta-neutrino correlation coefficient in neutron and nuclear decay.

Hitesh Rahangdale
University of Tennessee
Nab Collaboration

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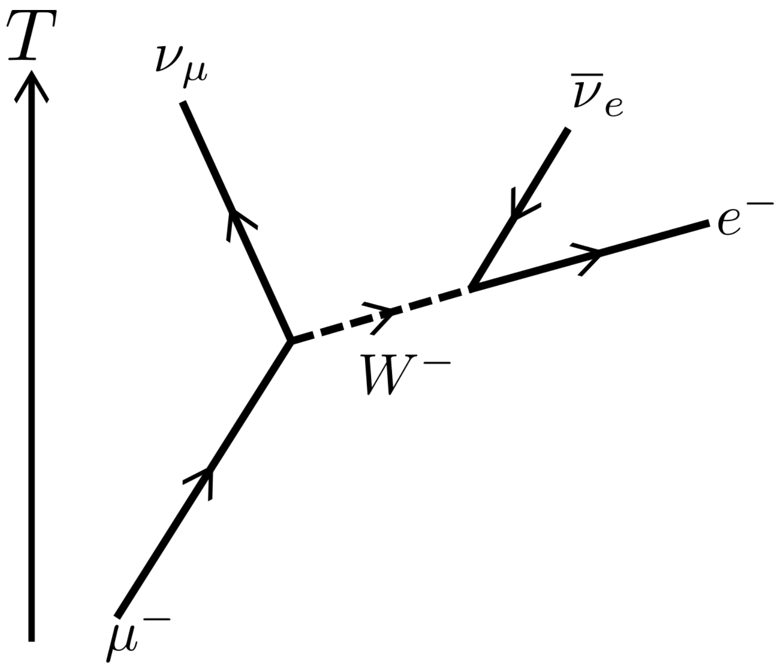
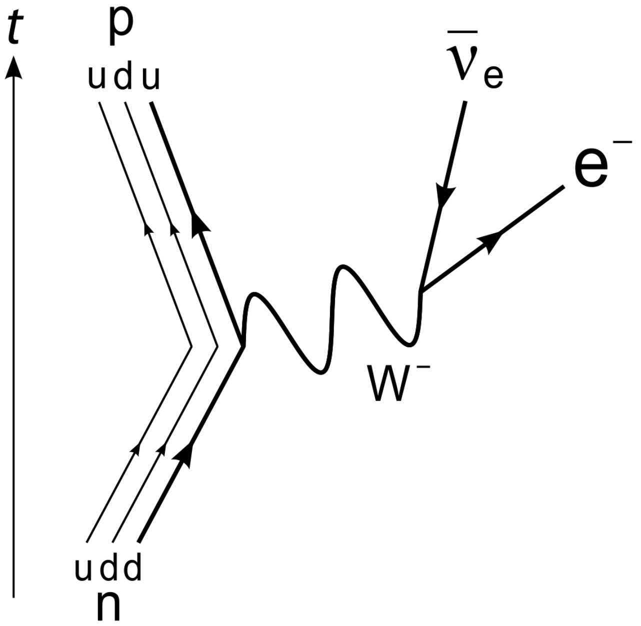
Beta Decay

In Simplest Form, Muon decay



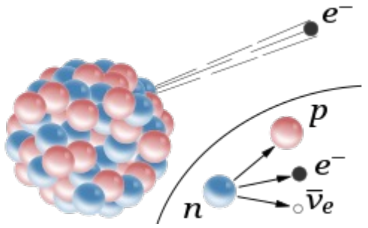
Measurement of Fermi Constant

Neutron Decay



Access to quark mixing element V_{ud}

Nuclear Beta decay



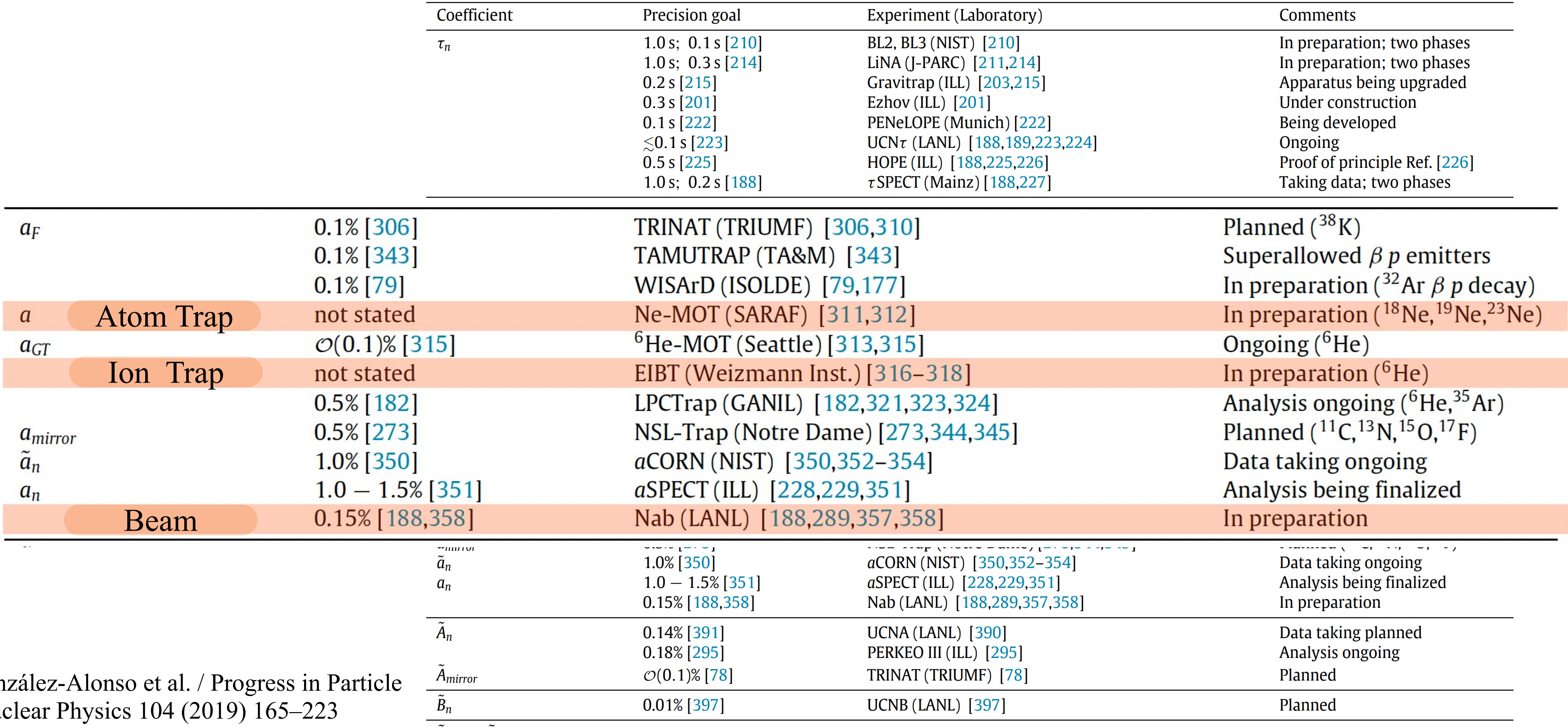
$${}^{A}_{Z}X \to {}^{\;\;A}_{Z\mp1}Y + e^{\mp} + \overline{\nu_e}(\nu_e)$$

Fermi: $\nu + \beta$ do not carry total angular momentum $\Rightarrow$ $J_i = J_f$

Gammow-Teller: $\nu + \beta$ carry unit total angular momentum $\Rightarrow J_i = J_f, J_f \pm 1$

Many Systems available experimentally

Efforts, Worldwide



Coefficient	Precision goal	Experiment (Laboratory)	Comments
τ_n	1.0 s; 0.1 s [210]	BL2, BL3 (NIST) [210]	In preparation; two phases
	1.0 s; 0.3 s [214]	LiNA (J-PARC) [211,214]	In preparation; two phases
	0.2 s [215]	Gravitrap (ILL) [203,215]	Apparatus being upgraded
	0.3 s [201]	Ezhov (ILL) [201]	Under construction
	0.1 s [222]	PENeLOPE (Munich) [222]	Being developed
	$\lesssim$0.1 s [223]	UCNτ (LANL) [188,189,223,224]	Ongoing
	0.5 s [225]	HOPE (ILL) [188,225,226]	Proof of principle Ref. [226]
	1.0 s; 0.2 s [188]	τSPECT (Mainz) [188,227]	Taking data; two phases

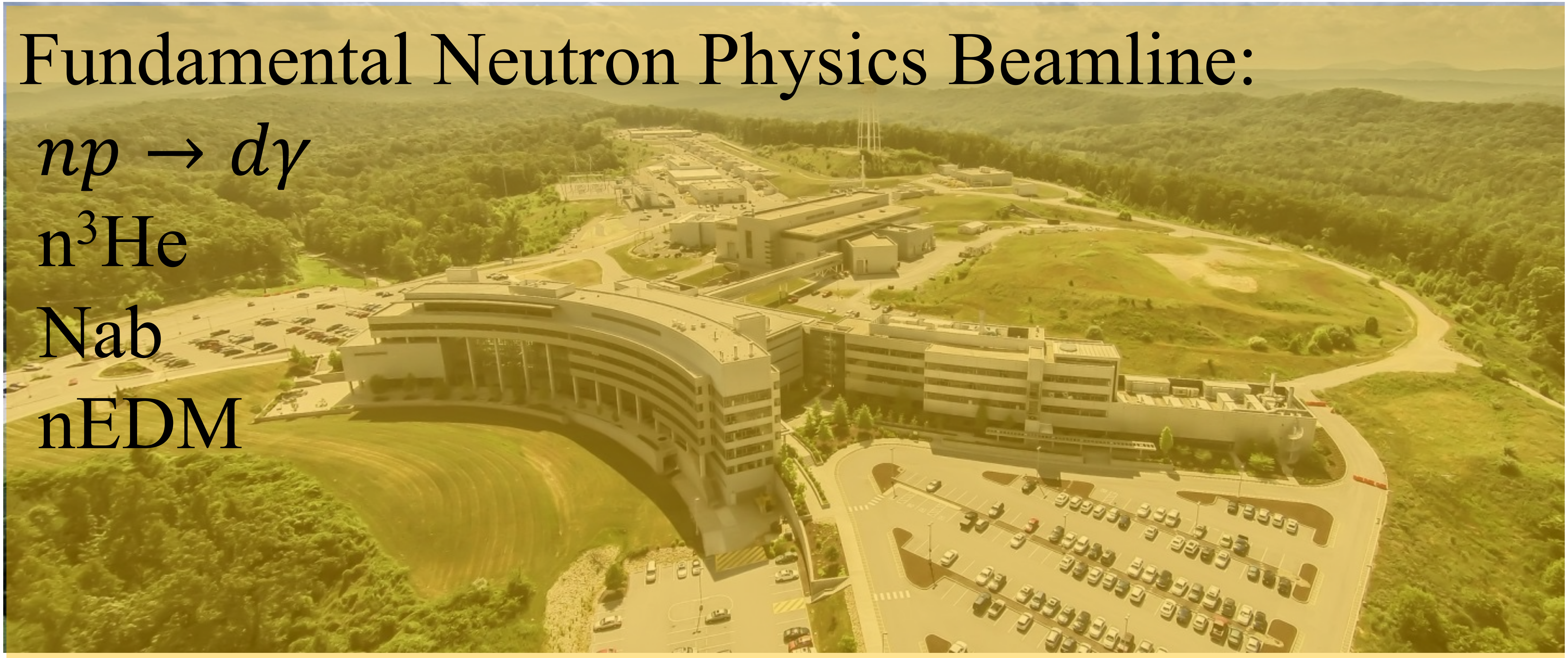
a_F		0.1% [306]	TRINAT (TRIUMF) [306,310]	Planned (^{38}K)
		0.1% [343]	TAMUTRAP (TA&M) [343]	Superallowed $\beta\, p$ emitters
		0.1% [79]	WISArD (ISOLDE) [79,177]	In preparation (^{32}Ar $\beta\, p$ decay)
a	Atom Trap	not stated	Ne-MOT (SARAF) [311,312]	In preparation (^{18}Ne,^{19}Ne,^{23}Ne)
a_{GT}		$\mathcal{O}$(0.1)% [315]	^{6}He-MOT (Seattle) [313,315]	Ongoing (^{6}He)
	Ion Trap	not stated	EIBT (Weizmann Inst.) [316–318]	In preparation (^{6}He)
		0.5% [182]	LPCTrap (GANIL) [182,321,323,324]	Analysis ongoing (^{6}He,^{35}Ar)
a_{mirror}		0.5% [273]	NSL-Trap (Notre Dame) [273,344,345]	Planned (^{11}C,^{13}N,^{15}O,^{17}F)
$\tilde{a}_n$		1.0% [350]	*a*CORN (NIST) [350,352–354]	Data taking ongoing
a_n		1.0 – 1.5% [351]	*a*SPECT (ILL) [228,229,351]	Analysis being finalized
	Beam	0.15% [188,358]	Nab (LANL) [188,289,357,358]	In preparation

$\tilde{a}_n$	1.0% [350]	*a*CORN (NIST) [350,352–354]	Data taking ongoing
a_n	1.0 – 1.5% [351]	*a*SPECT (ILL) [228,229,351]	Analysis being finalized
	0.15% [188,358]	Nab (LANL) [188,289,357,358]	In preparation

$\tilde{A}_n$	0.14% [391]	UCNA (LANL) [390]	Data taking planned
	0.18% [295]	PERKEO III (ILL) [295]	Analysis ongoing
$\tilde{A}_{mirror}$	$\mathcal{O}$(0.1)% [78]	TRINAT (TRIUMF) [78]	Planned
$\tilde{B}_n$	0.01% [397]	UCNB (LANL) [397]	Planned

M. González-Alonso et al. / Progress in Particle and Nuclear Physics 104 (2019) 165–223

Nab @SNS



Fundamental Neutron Physics Beamline:

$np \rightarrow d\gamma$

n^3He

Nab

nEDM

Neutron Beta Decay

$$\frac{dw}{dE_e d\Omega_e d\Omega_\nu} \propto p_e E_e (E_0 - E_e)^2 \left[1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \langle \vec{\sigma}_n \rangle \cdot \left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + \cdots \right)\right]$$

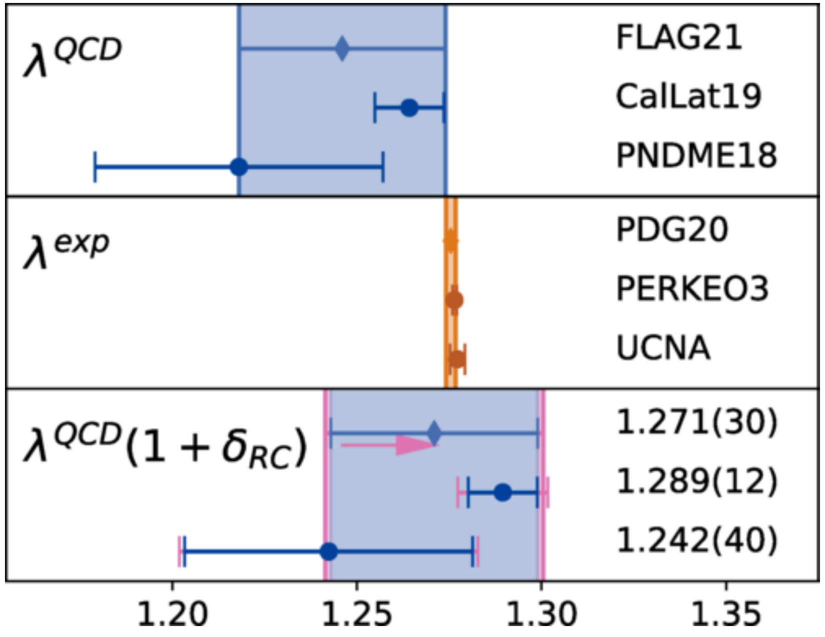
J. Jackson[Phys. Rev. 106, 517 (1957)]

Beta-neutrino correlation

$$a = \frac{1 - |\lambda|^2}{1 + 3|\lambda|^2}$$

$\lambda = g_A/g_V$

Neutron lifetime $\Gamma = \tau_n^{-1} = \frac{2\pi}{\hbar} G_F^2 V_{ud}^2 (1 + 3|\lambda|^2) \int \rho(E_e) dE_e,$

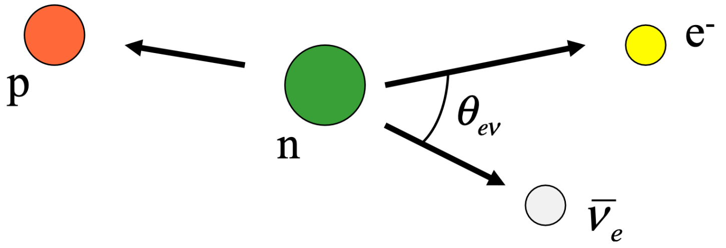


Nab Goal: $\frac{\Delta a}{a} = 0.1\%$ $\Delta b = 3\times 10^{-3}$

PDG20 $a = -0.1059 \pm 0.0028$ $b = 0.017 \pm 0.020$

Vincenzo [Phys. Rev. Lett. 129, 121801(2022)]

$a_{\beta\nu}$measurement in Nab



Momentum conservation kinematics for beta decay,

$$\overrightarrow{p_p} + \overrightarrow{p_e} + \overrightarrow{p_{\overline{\nu}_e}} = 0 \qquad p_p^2 = p_p^2 + p_{\overline{\nu}_e}^2 + 2p_e p_{\overline{\nu}_e} cos\theta_{e\nu}$$

Neglecting proton recoil energy, $E_0 = E_{\overline{\nu}_e} + E_e$

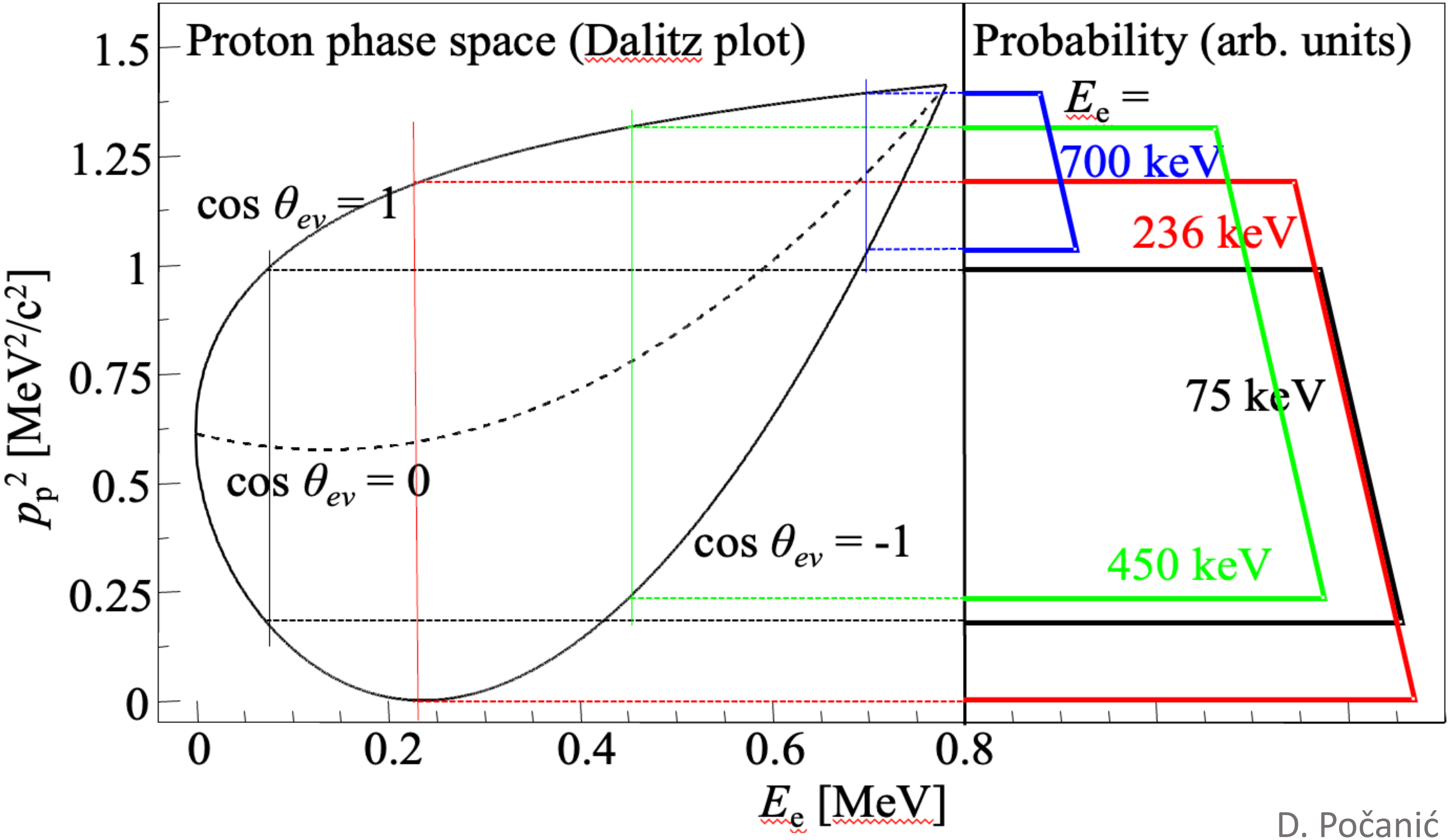
$$cos\theta_{e\nu} = \frac{1}{2}\left(\frac{p_p^2 - (2E_e^2 + E_0^2 - eE_0E_e)}{E_e(E_0 \ - E_e)}\right)$$

So, the neutron decay rate,

$$d\omega \ \propto 1 + a\beta cos\theta_{e\nu}$$

$$1 + a\beta \frac{p_p^2 - (2E_e^2 + E_0^2 - eE_0E_e)}{2\ E_e(E_0 \ -E_e)}$$

$a_{\beta\nu}$ measurement in Nab



For given E_e,

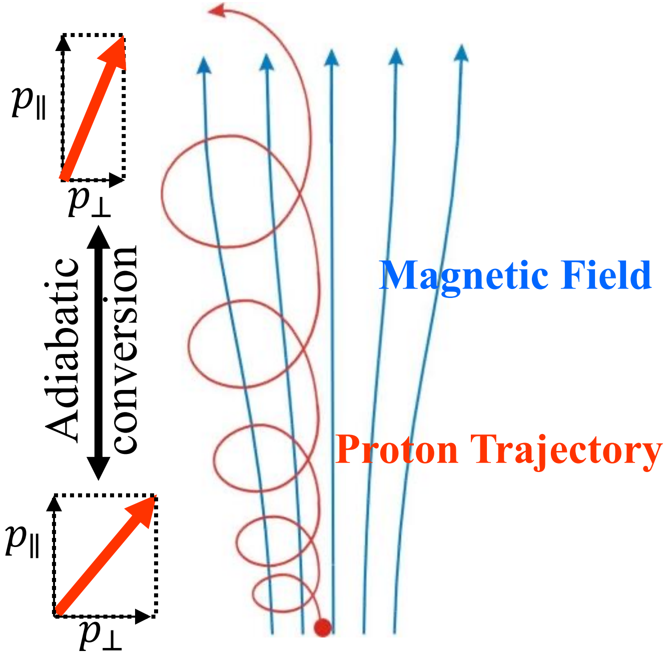
- $cos\theta_{e\bar{\nu}}$ is a function of p^2
- Multiple measurement of a for different energy cut

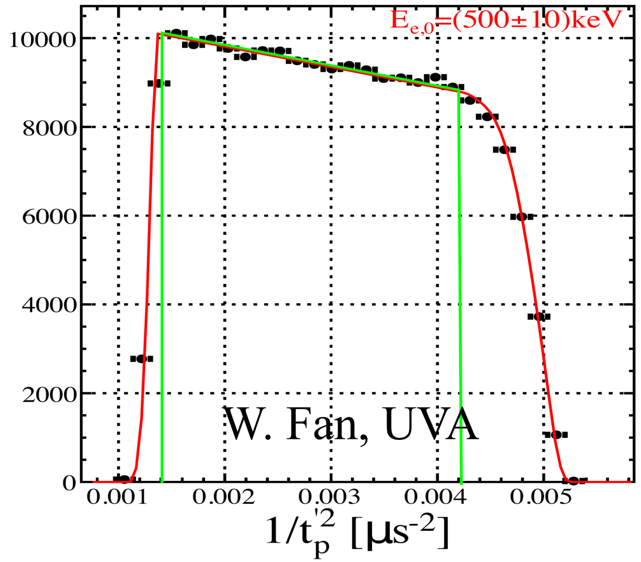
D. Počanić et al., NIM A 611, 211 (2009)

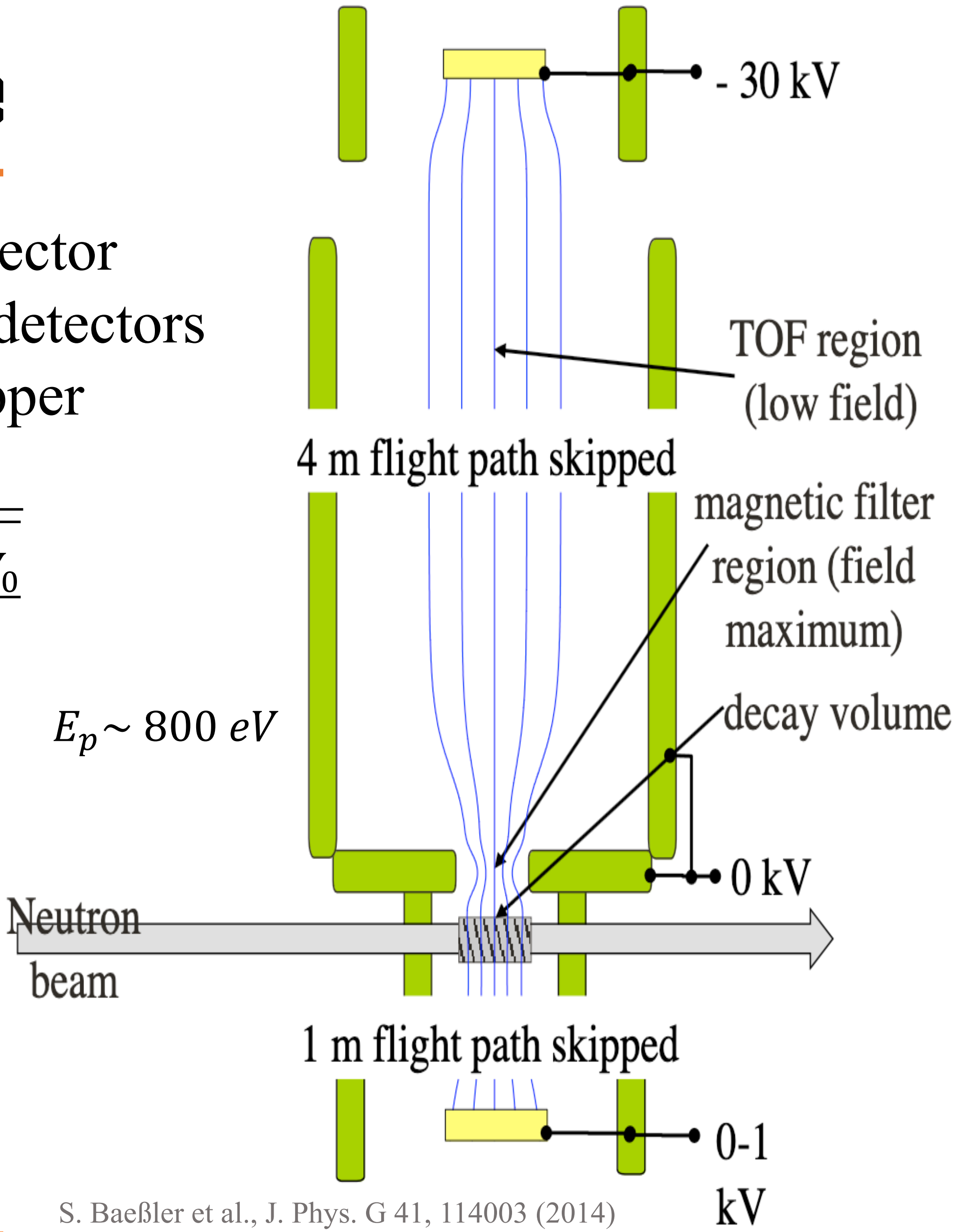
Nab Measurement Scheme

- Employ E x B field to guide, proton to the upper detector
- Measure Electron energy via upper & lower silicon detectors
- Measure proton momentum via Time-of-Flight in upper detector

$$t_p = \frac{m_p}{p_p} \int_{z_0}^{l} \frac{\partial z}{\sqrt{1 - \frac{B(z)}{B_0} \sin^2 \theta_{p,0} + \frac{q(V(z) - V_0}{E_{p,0}}}}$$



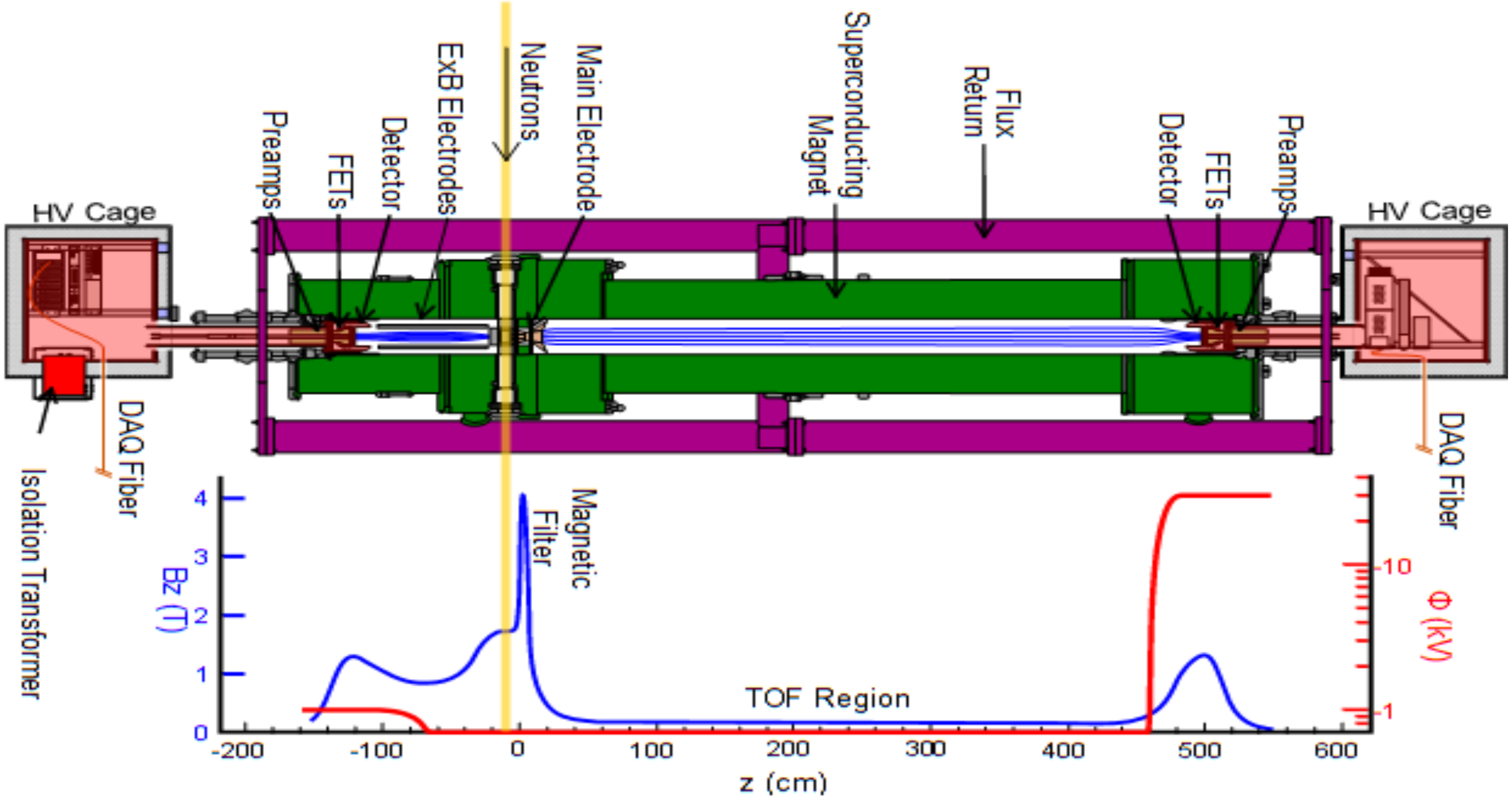




$E_p \sim 800\ eV$

S. Baeßler et al., J. Phys. G 41, 114003 (2014)

Nab Spectrometer



General Idea: J.D. Bowman, Journ. Res. NIST 110, 40 (2005)
Original configuration: D. Počanić et al., NIM A 611, 211 (2009)
Asymmetric configuration: S. Baeßler et al., J. Phys. G 41, 114003 (2014)

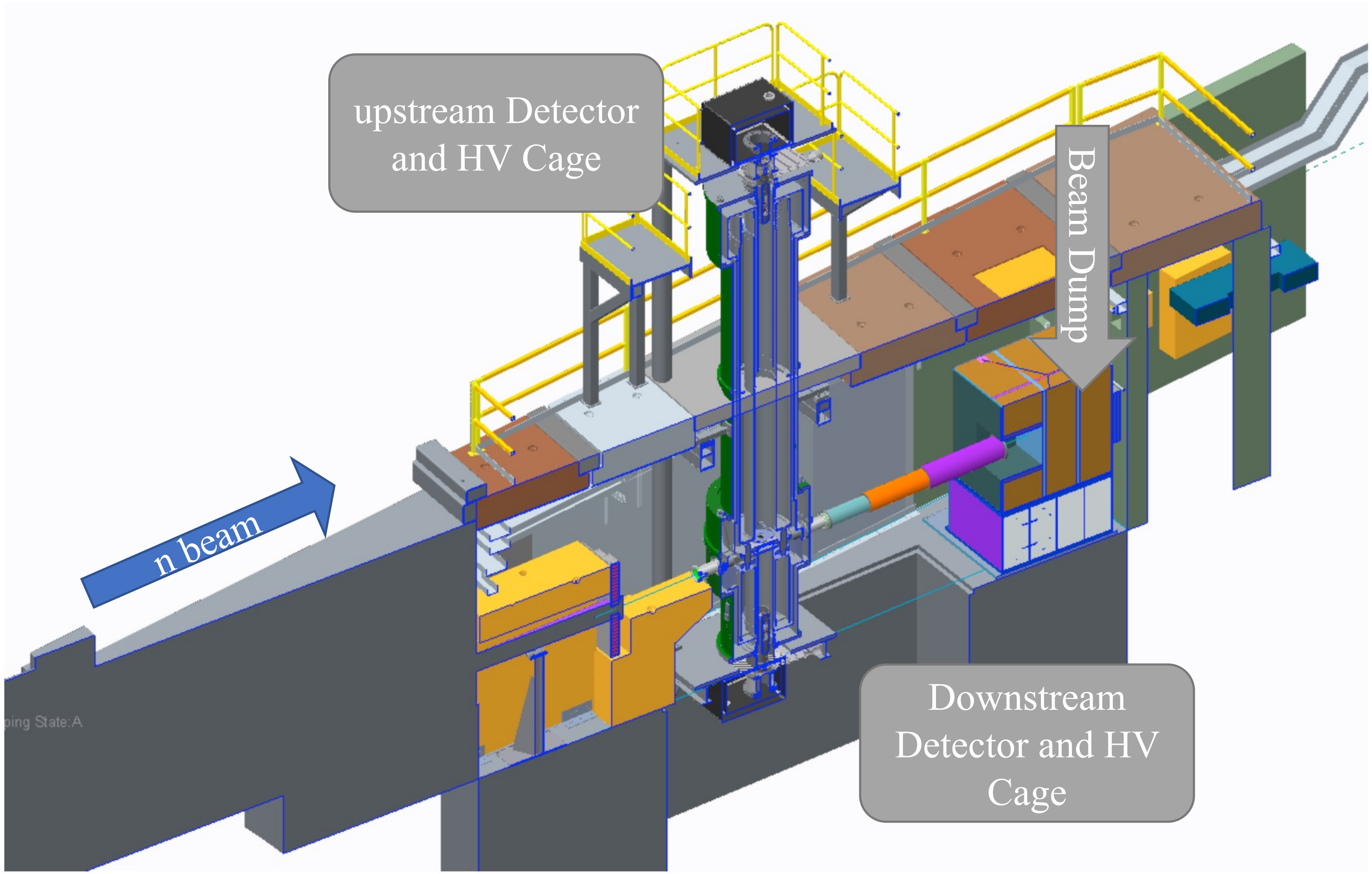
Images: J.Fry, A. Jezghani

Uncertainty Budget

- Expect 1600 decay/s in decay Volume.
- ~200 proton/sec
- 3.8×10^{8} events in 6 weeks
  - $\left(\frac{\Delta a}{a}\right)_{stat} \sim 2\times10^{-3}$
- Over two years dedicated
  - 4.4×10^{9} protons(in det.)
  - $\left(\frac{\Delta a}{a}\right)_{stat} \sim 7\times10^{-4}$

Experimental parameter	**Main specification**	$(\boldsymbol{\Delta a/a})_{syst}$
Magnetic field		
... curvature at pinch	$\Delta\gamma/\gamma = 2\%$ with $\gamma = d^2\,B_z(z)/dz^2/B_z(0)$	**$5.3\cdot10^{-4}$**
… ratio $r_B = B_{TOF}/B_0$	$(\Delta r_B)/r_B\ = 1\%$	$2.2\cdot10^{-4}$
… ratio $r_{B,DV} = B_{DV}/B_0$	$(\Delta r_{B,DV})/r_{B,DV}\ = 1\%$	$1.8\cdot10^{-4}$
Length of the TOF region		none
Electric potential inhomogeneity:		
… in decay volume / filter region	$\lvert U_F - U_{DV}\rvert < 10$ mV	**$5\cdot10^{-4}$**
… in TOF region	$\lvert U_F - U_{TOF}\rvert < 200$ mV	$2.2\cdot10^{-4}$
Neutron beam:		
… position	$\Delta\overline{z_{DV}} < 2$ mm	$1.7\cdot10^{-4}$
… profile (including edge effect)	Slope at edges < 10%/cm	$2.5\cdot10^{-4}$
… Doppler effect		small
… Unwanted beam polarization	$\lvert\overline{P_n}\rvert \ll 10^{-4}$	$1\cdot10^{-4}$
Adiabaticity of proton motion		$1\cdot10^{-4}$
Detector effects:		
… Electron energy calibration	$\Delta E < 0.2$ keV	$2\cdot10^{-4}$
… Shape of electron energy response	fraction of events in tail to 1%	**$4.4\cdot10^{-4}$**
… Proton trigger efficiency	$\epsilon_p < 100$ ppm/keV	$3.4\cdot10^{-4}$
… TOF shift due to detector/electronics	$\Delta t_p < 0.3$ ns	$3.9\cdot10^{-4}$
Electron TOF		small
Residual gas	$p < 2\cdot10^{-9}$ torr	$3.8\cdot10^{-4}$ (prelim.)
TOF in acceleration region	$\Delta r_{ground\ el.} < 0.5$ mm	$3\cdot10^{-4}$ (prelim.)
Background / Accidental coincidences		small
Sum		**$1.2\cdot10^{-3}$**

Nab Spectrometer and Magnet



upstream Detector and HV Cage

Beam Dump

n beam

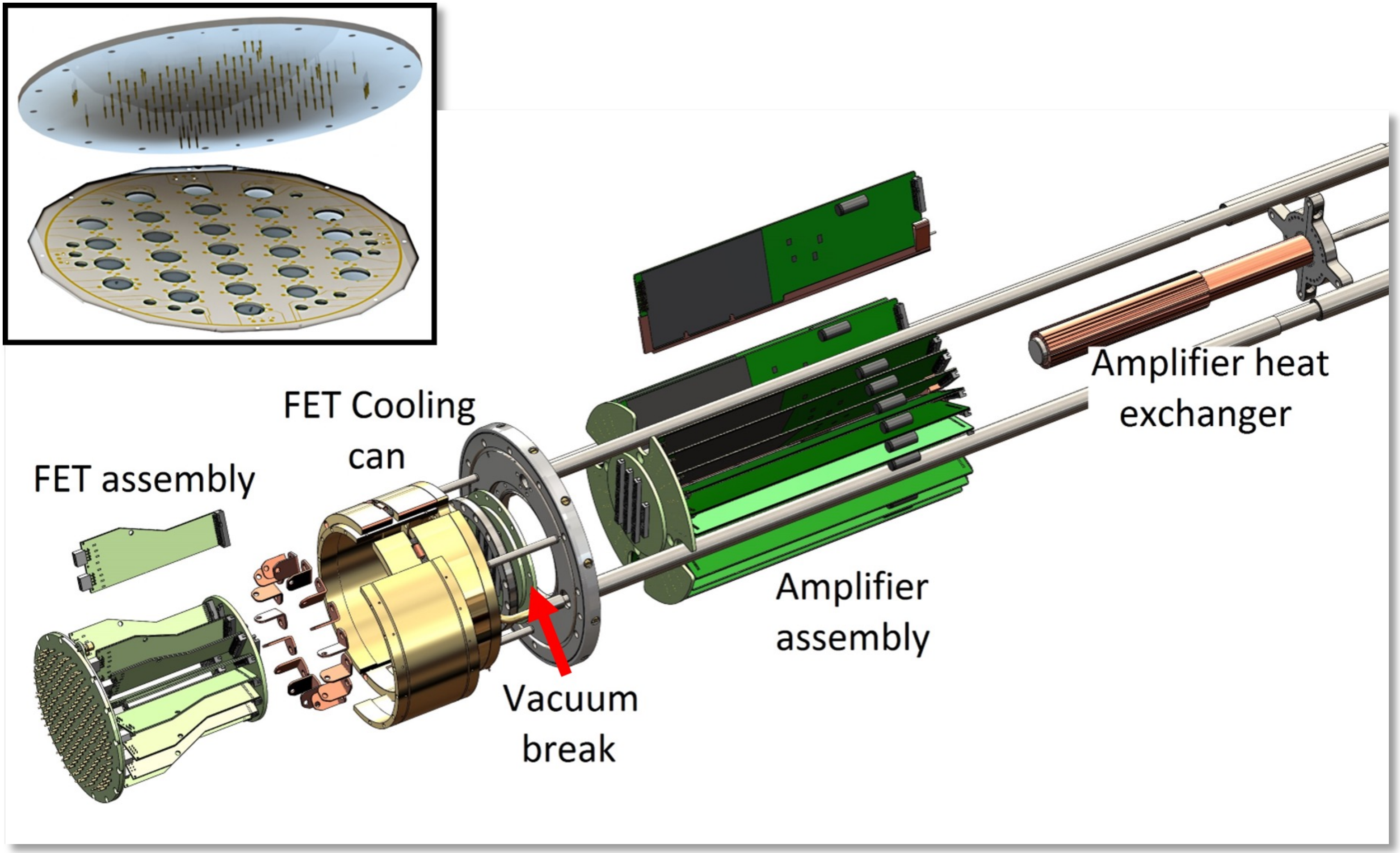
Downstream Detector and HV Cage

Magnet first installed in 2018

Detector System

Detector

- 15 cm diameter, full thickness: 2mm
- 127 pixels, dead layer < 100nm
- Energy resolution ~ few keV, proton threshold: 10keV
- Detector testing at Manitoba and ORNL
- Detailed pulse shape analysis by L. Hayen arXiv:2212.03438v1



Detector Cooling

- The cooling system must run continuously for extended periods.

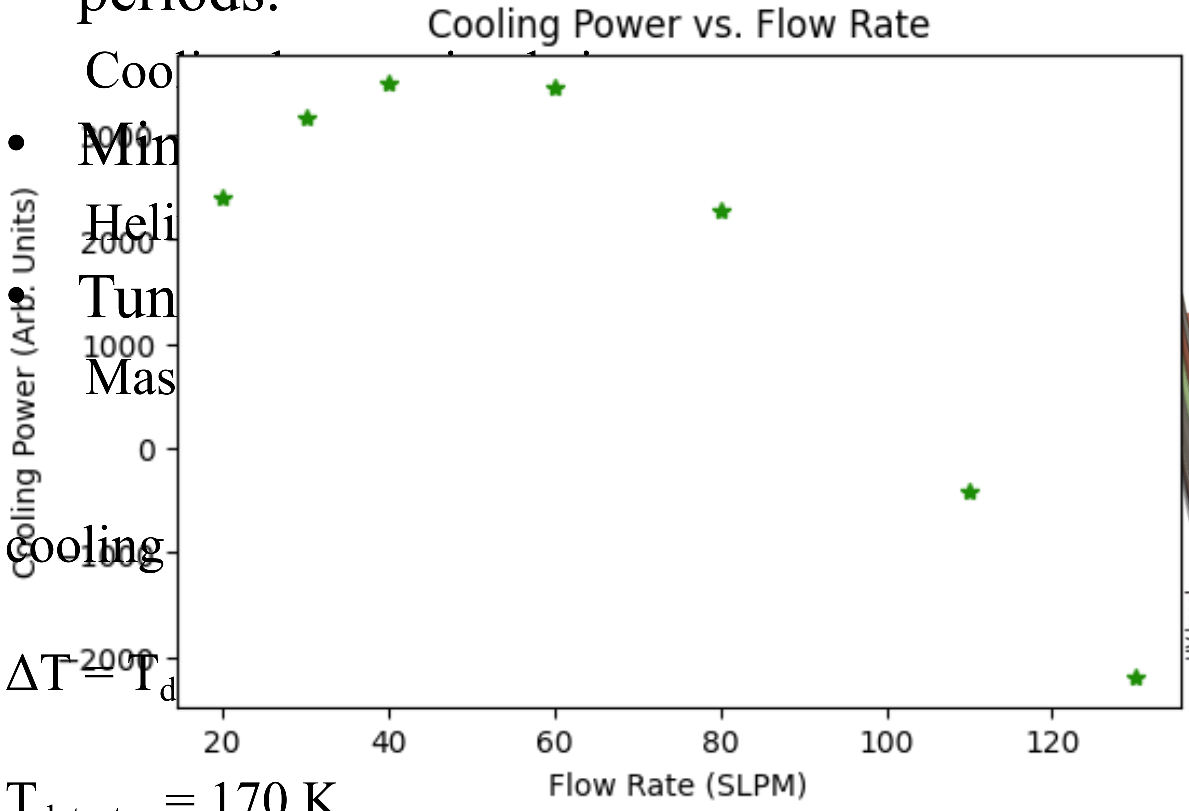
Coo

- Min

Heli

- Tun

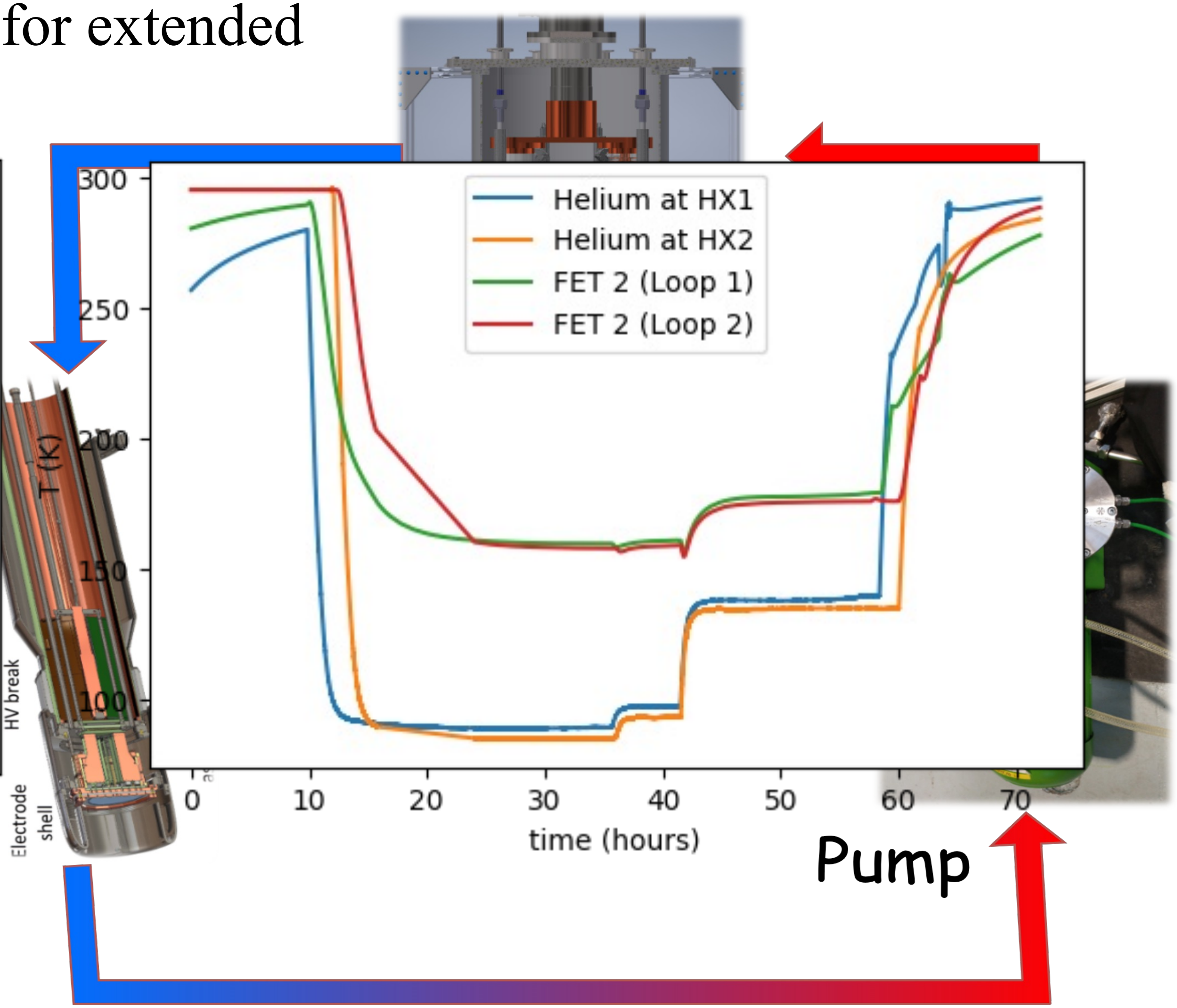
Mas



cooling

$\Delta T = T_d$

$T_{detector} = 170$ K



courtesy: Love Christie

Detector Cooling

Use of Counterflow heat exchanger.

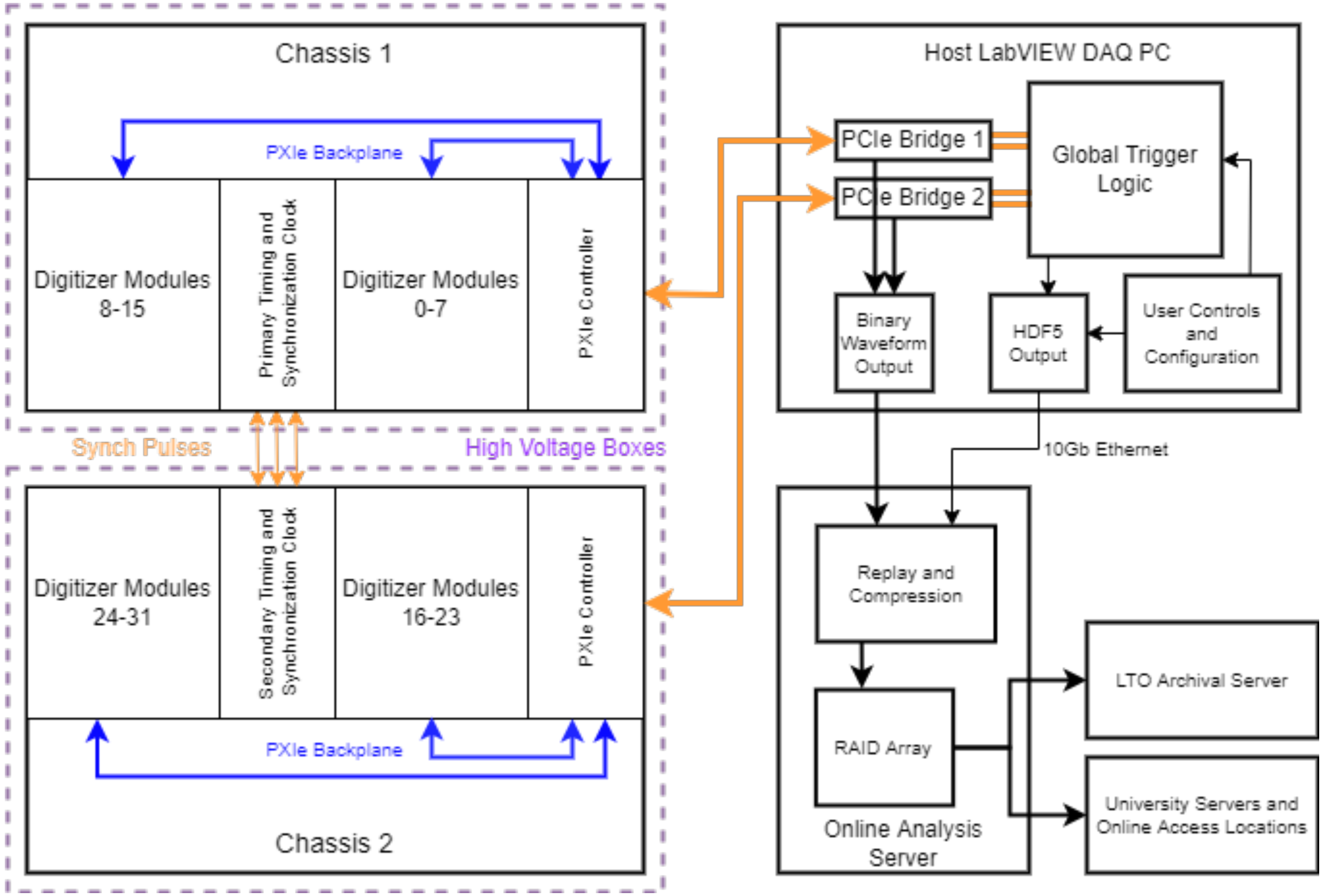
Separate cryocooler for each detector.

Projected $T_{det.} = 120\text{-}130$ K

courtesy: Love Christie

DAQ

1. Can identify signals at a rate of 50kHz
2. Parse through triggers to identify coincident protons and electrons
3. Data is replayed and compressed into HDF5
4. Exported to RAID and offline servers
   1. LTO tapes for archival



Expect, post compression, around 50 MB/s or ~25 TB/week in total!

courtesy: David Mathews

Neutron beam polarization

$$\frac{dw}{dE_e d\Omega_e d\Omega_\nu} \propto p_e E_e (E_0 - E_e)^2 \left[1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \langle \vec{\sigma}_n \rangle \cdot \left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + \cdots \right) \right]$$

For Unpolarized Target

$$d\Gamma^3 \propto 1 + a \cdot \frac{|\overrightarrow{p_e}||\overrightarrow{p_\nu}|}{E_e E_\nu} cos(\theta_{e\nu}) + b \cdot \frac{m_e}{E_e}$$

If net polarization in the beam

$$| \langle \sigma_n \rangle |(A \cdot \beta_e \langle \cos\theta_e \rangle + B \langle \cos\theta_e \rangle \cdot \cos\theta_{e\nu})$$

$$\frac{\Delta a}{a} \sim 10^{-4} \qquad | \langle \sigma_n \rangle | < 2 \times 10^{-5}$$

To reach Nab goal

- Completely unpolarized beam
- Flip the neutron spin and average over time

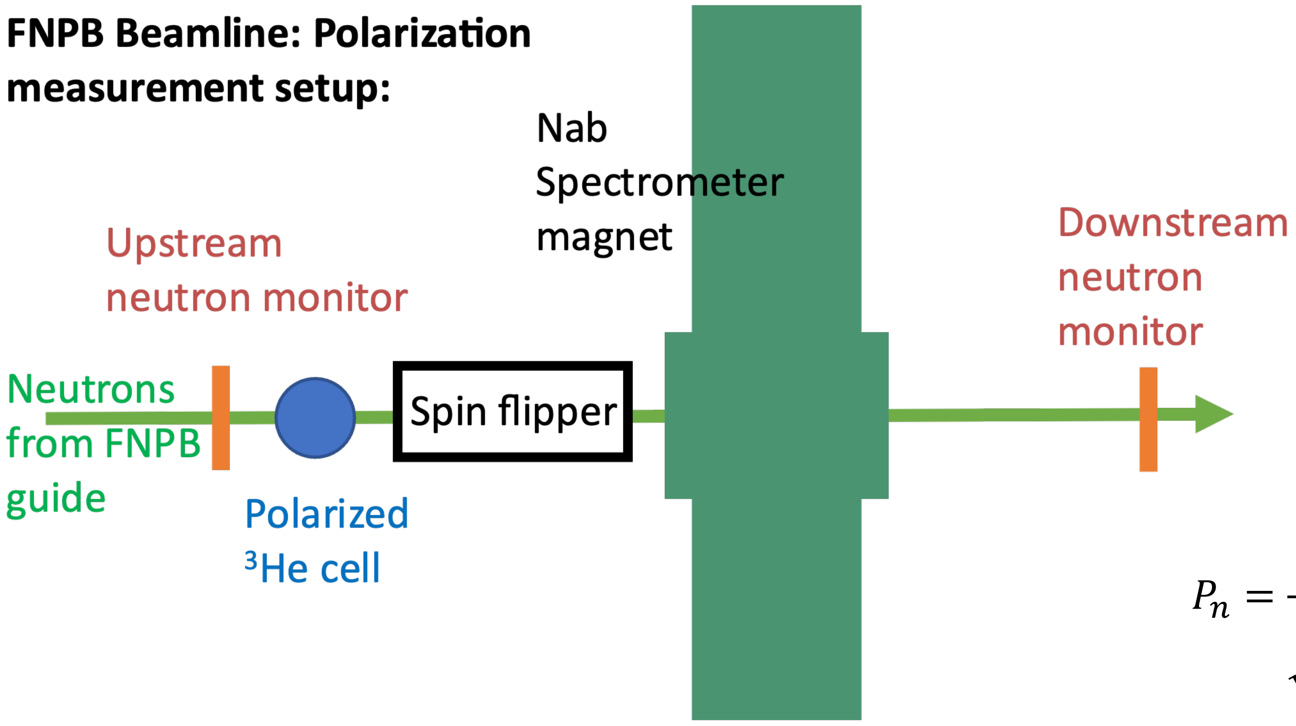
Neutron Polarization: Measurement

The capture Cross section for reaction :

$^{3}\mathrm{He} + \mathrm{n} \rightarrow \mathrm{p} + {}^{3}\mathrm{H}$ highly spin dependent.

It is minimum when the spins are aligned and maximum with spins anti-aligned.

FNPB Beamline: Polarization measurement setup:



For unpolarized He cell.

$$T_0 = Ne^{-\kappa} \qquad \kappa = nl\sigma_0 \frac{\lambda}{\lambda_0}$$

For polarized cell. aligned spin

$$T_{up} = N(1 - P_n \tanh(\kappa P_{He}))e^{-\kappa} \cosh(\kappa P_{He})$$

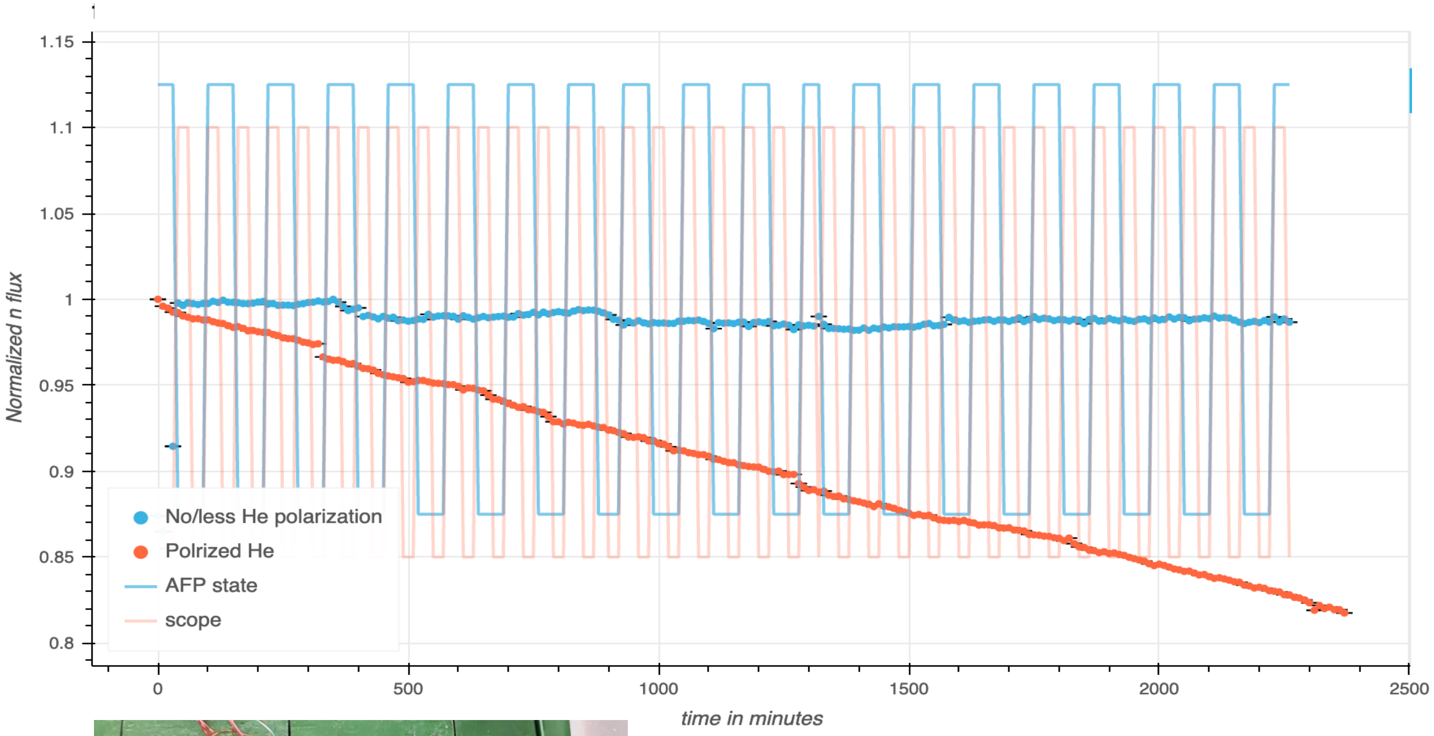
For polarized cell. anti-aligned spin

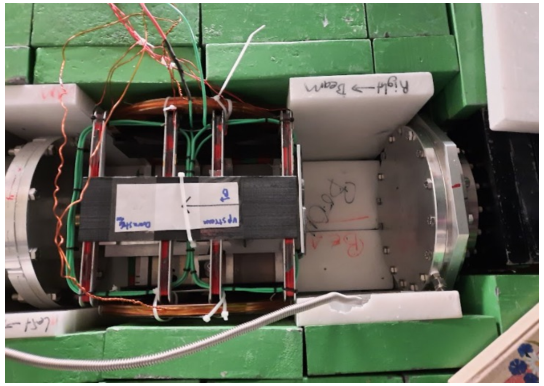
$$T_{up} = N(1 + P_n \tanh(\kappa P_{He}))e^{-\kappa} \cosh(\kappa P_{He})$$

$$P_n = \frac{R_{dn} - R_{up}}{\sqrt{(R_{up} + R_{dn})^2 - 4}} \qquad R_{up} = \frac{T_{up}}{T_0}, R_{dn} = \frac{T_{dn}}{T_0}$$

Neutron Polarization: Measurement

- First measurements last year.
  - Used ^{3}He cell upstream.
  - Neutron spin flipper not used.
  - Flipped He spin via AFP
  - Flux measurement upstream & downstream.
- Measurements
  - ~3 days of data
  - He cell lifetime: 81.6 ± 2.1 *hrs*
  - AFP efficiency: 99.93%
  - Data taken with and without choppers.
  - Holding field gradient: ~10^{-6}(sim)
  - npol 0 ± 0.01 *preliminary*
- Problems
  - Nab magnet was off
  - Det. Efficiency drift by 20%



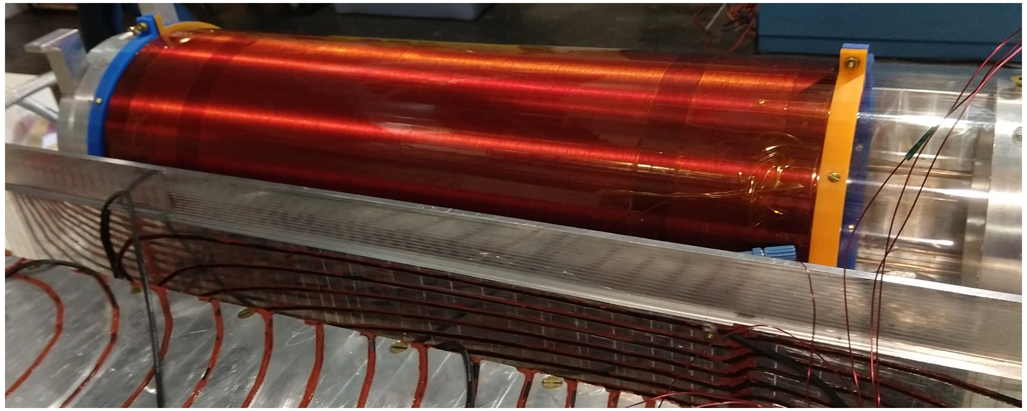


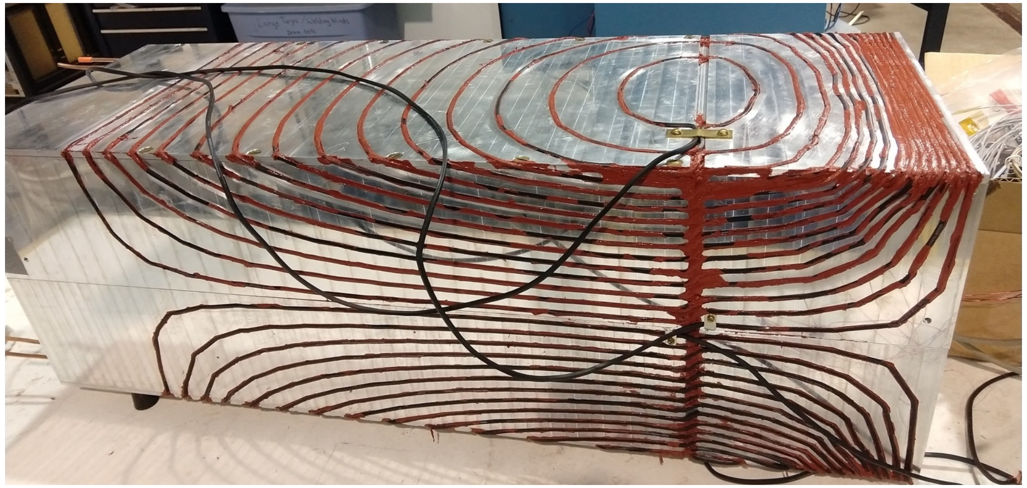
^{3}He cell is placed in Merritt coils

Chelsea Hendrus, Sepehr Samiei, S.Baeßler, Jason Pioquinto

Neutron Polarization: Spin Flipper

- Why we need spin flipper:
  - $\Delta p_n \sim 10^{-5}$ measurement is long shot.
  - Alternating n-flip will average out the net flip
- Adiabatic Fast Passage Spin Flipper
  - RF Solenoid
  - Static Gradient Field
- Characterization
  - Field Measurements.
  - Testing at HFIR

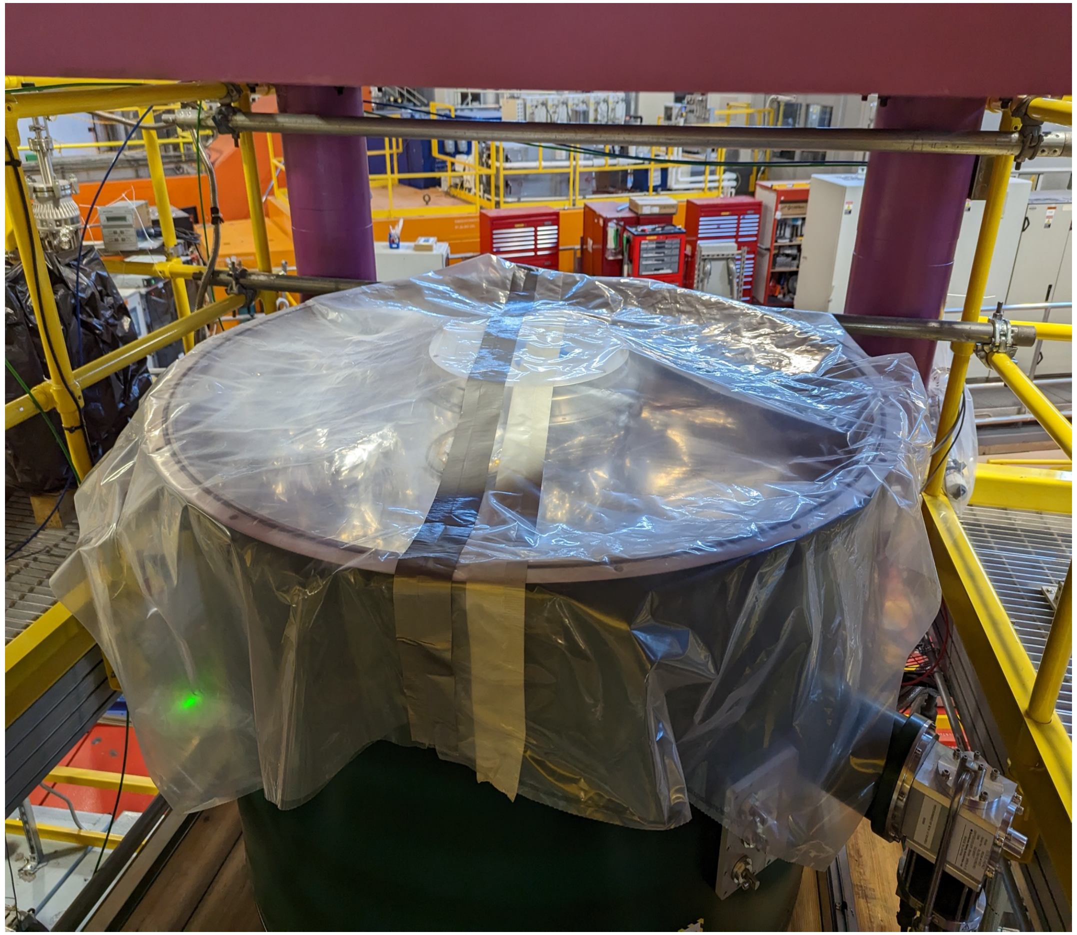




Magnet

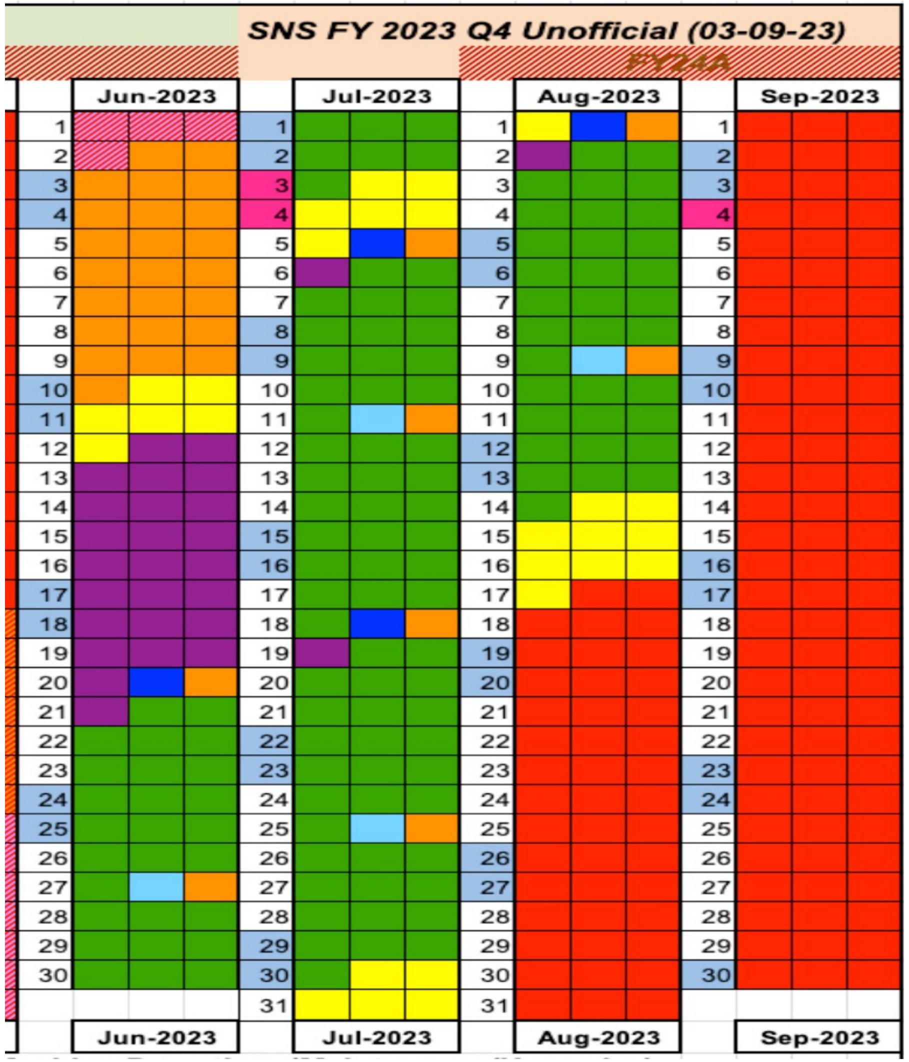
Magnet stopped cooling in July 2022

Repair Started Early this year



Current Status and Outlook

- Magnet:
    - Successful cooldown two weeks ago.
    - Successfully energized to specifications
- Electrodes:
    - Installed
- Detectors:
    - Getting ready to install.
    - Currently cooling in test stand and debugging.
- Detector Cooling:
    - Separate cryocooler for both the detectors
- DAQ:
    - Ability to simultaneously read data from two DAQs
- Polarization:
    - Spin flipper out of beamline.
    - Planned tests at HFIR
    - Neutron monitor efficiency measurements at HFIR



SNS FY 2023 Q4 Unofficial (03-09-23)

FY24A

Jun-2023				Jul-2023				Aug-2023				Sep-2023			
1	▨	▨	▨	1	🟩	🟩	🟩	1	🟨	🟦	🟧	1	🟥	🟥	🟥
2	▨	🟧	🟧	2	🟩	🟩	🟩	2	🟪	🟩	🟩	2	🟥	🟥	🟥
3	🟧	🟧	🟧	3	🟩	🟨	🟨	3	🟩	🟩	🟩	3	🟥	🟥	🟥
4	🟧	🟧	🟧	4	🟨	🟨	🟨	4	🟩	🟩	🟩	4	🟥	🟥	🟥
5	🟧	🟧	🟧	5	🟨	🟦	🟧	5	🟩	🟩	🟩	5	🟥	🟥	🟥
6	🟧	🟧	🟧	6	🟪	🟩	🟩	6	🟩	🟩	🟩	6	🟥	🟥	🟥
7	🟧	🟧	🟧	7	🟩	🟩	🟩	7	🟩	🟩	🟩	7	🟥	🟥	🟥
8	🟧	🟧	🟧	8	🟩	🟩	🟩	8	🟩	🟩	🟩	8	🟥	🟥	🟥
9	🟧	🟧	🟧	9	🟩	🟩	🟩	9	🟩	🩵	🟧	9	🟥	🟥	🟥
10	🟧	🟨	🟨	10	🟩	🟩	🟩	10	🟩	🟩	🟩	10	🟥	🟥	🟥
11	🟨	🟨	🟨	11	🟩	🩵	🟧	11	🟩	🟩	🟩	11	🟥	🟥	🟥
12	🟨	🟪	🟪	12	🟩	🟩	🟩	12	🟩	🟩	🟩	12	🟥	🟥	🟥
13	🟪	🟪	🟪	13	🟩	🟩	🟩	13	🟩	🟩	🟩	13	🟥	🟥	🟥
14	🟪	🟪	🟪	14	🟩	🟩	🟩	14	🟩	🟨	🟨	14	🟥	🟥	🟥
15	🟪	🟪	🟪	15	🟩	🟩	🟩	15	🟨	🟨	🟨	15	🟥	🟥	🟥
16	🟪	🟪	🟪	16	🟩	🟩	🟩	16	🟨	🟨	🟨	16	🟥	🟥	🟥
17	🟪	🟪	🟪	17	🟩	🟩	🟩	17	🟨	🟥	🟥	17	🟥	🟥	🟥
18	🟪	🟪	🟪	18	🟩	🟦	🟧	18	🟥	🟥	🟥	18	🟥	🟥	🟥
19	🟪	🟪	🟪	19	🟪	🟩	🟩	19	🟥	🟥	🟥	19	🟥	🟥	🟥
20	🟪	🟦	🟧	20	🟩	🟩	🟩	20	🟥	🟥	🟥	20	🟥	🟥	🟥
21	🟪	🟩	🟩	21	🟩	🟩	🟩	21	🟥	🟥	🟥	21	🟥	🟥	🟥
22	🟩	🟩	🟩	22	🟩	🟩	🟩	22	🟥	🟥	🟥	22	🟥	🟥	🟥
23	🟩	🟩	🟩	23	🟩	🟩	🟩	23	🟥	🟥	🟥	23	🟥	🟥	🟥
24	🟩	🟩	🟩	24	🟩	🟩	🟩	24	🟥	🟥	🟥	24	🟥	🟥	🟥
25	🟩	🟩	🟩	25	🟩	🩵	🟧	25	🟥	🟥	🟥	25	🟥	🟥	🟥
26	🟩	🟩	🟩	26	🟩	🟩	🟩	26	🟥	🟥	🟥	26	🟥	🟥	🟥
27	🟩	🩵	🟧	27	🟩	🟩	🟩	27	🟥	🟥	🟥	27	🟥	🟥	🟥
28	🟩	🟩	🟩	28	🟩	🟩	🟩	28	🟥	🟥	🟥	28	🟥	🟥	🟥
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				31	🟨	🟨	🟨	31	🟥	🟥	🟥				
Jun-2023				Jul-2023				Aug-2023				Sep-2023			

The Nab Collaboration

Oak Ridge National Laboratory

University of Virginia

NC STATE UNIVERSITY

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Los Alamos NATIONAL LABORATORY

ASU Arizona State University

EKU EASTERN KENTUCKY UNIVERSITY

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WKU

Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

UNIVERSITY OF South Carolina

Main project funding:

NSF

U.S. DEPARTMENT OF ENERGY
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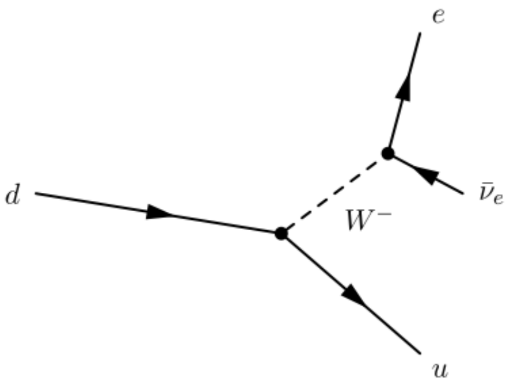
University of Virginia

Nuclear Beta Decay



$$
\begin{aligned}
H_{\text{int}} = & (\bar{\psi}_p \psi_n)(C_S \bar{\psi}_e \psi_\nu + C_S{}' \bar{\psi}_e \gamma_5 \psi_\nu) \\
& + (\bar{\psi}_p \gamma_\mu \psi_n)(C_V \bar{\psi}_e \gamma_\mu \psi_\nu + C_V{}' \bar{\psi}_e \gamma_\mu \gamma_5 \psi_\nu) \\
& + \tfrac{1}{2}(\bar{\psi}_p \sigma_{\lambda\mu} \psi_n)(C_T \bar{\psi}_e \sigma_{\lambda\mu} \psi_\nu + C_T{}' \bar{\psi}_e \sigma_{\lambda\mu} \gamma_5 \psi_\nu) \\
& - (\bar{\psi}_p \gamma_\mu \gamma_5 \psi_n)(C_A \bar{\psi}_e \gamma_\mu \gamma_5 \psi_\nu + C_A{}' \bar{\psi}_e \gamma_\mu \psi_\nu) \\
& + (\bar{\psi}_p \gamma_5 \psi_n)(C_P \bar{\psi}_e \gamma_5 \psi_\nu + C_P{}' \bar{\psi}_e \psi_\nu) \qquad (1)
\end{aligned}
$$

Beta decay rate for polarized target:

$$
\frac{d^3\Gamma}{dE_e d\Omega_e d\Omega_\nu} \propto \xi \left\{ 1 + a_{\beta\nu} \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b_{Fierz} \frac{m_e}{E_e} + \frac{\langle \vec{I} \rangle}{I} \cdot \left[A_\beta \frac{\vec{p}_e}{E_e} + B_\nu \frac{\vec{p}_\nu}{E_\nu} + D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu} \right] \right\}
$$

$a_{\beta\nu}$ in nuclear decays

$$\frac{d^3\Gamma}{dE_e\,d\Omega_e\,d\Omega_\nu} \propto \xi\left\{1+\boxed{a_{\beta\nu}}\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu}+\boxed{b_{Fierz}}\frac{m_e}{E_e}+\cancel{\frac{\langle\vec{I}\rangle}{I}\cdot\left[\boxed{A_\beta}\frac{\vec{p}_e}{E_e}+\boxed{B_\nu}\frac{\vec{p}_\nu}{E_\nu}+\boxed{D}\frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu}\right]}\right\}$$

When using unpolarized target.

The Beta Nu correlation coefficient:

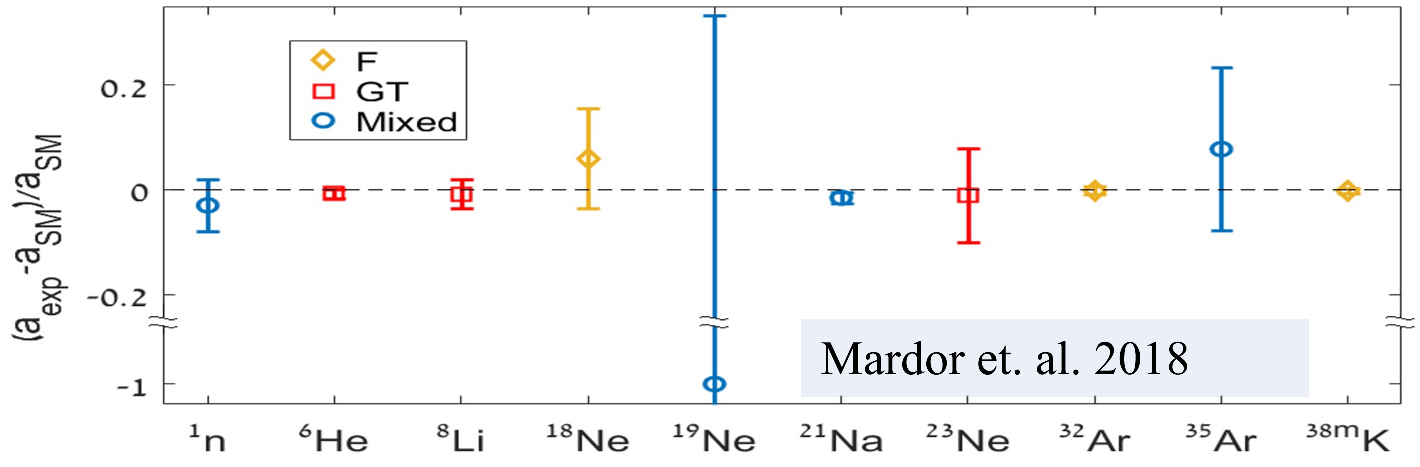
$$a_{\beta\nu}\propto|M_F|^2\left(|C_V|^2+|C'_V|^2-\cancelto{0}{|C_S|^2}-\cancelto{0}{|C'_S|^2}\right)-\frac{1}{3}|M_{GT}|^2\left(|C_A|^2+|C'_A|^2-\cancelto{0}{|C_T|^2}-\cancelto{0}{|C'_T|^2}\right)$$

SM predictions:

$a_{\beta\nu} = 1$ for pure Fermi Transition

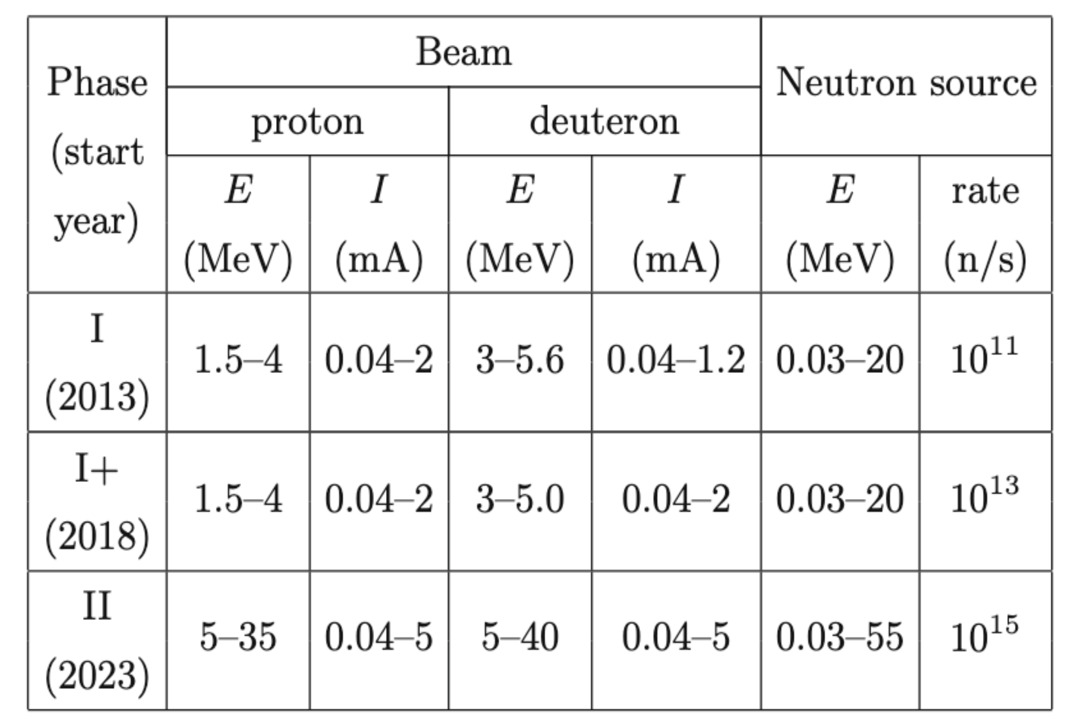
$= -\frac{1}{3}$ for pure GT

or combination for mixed transition

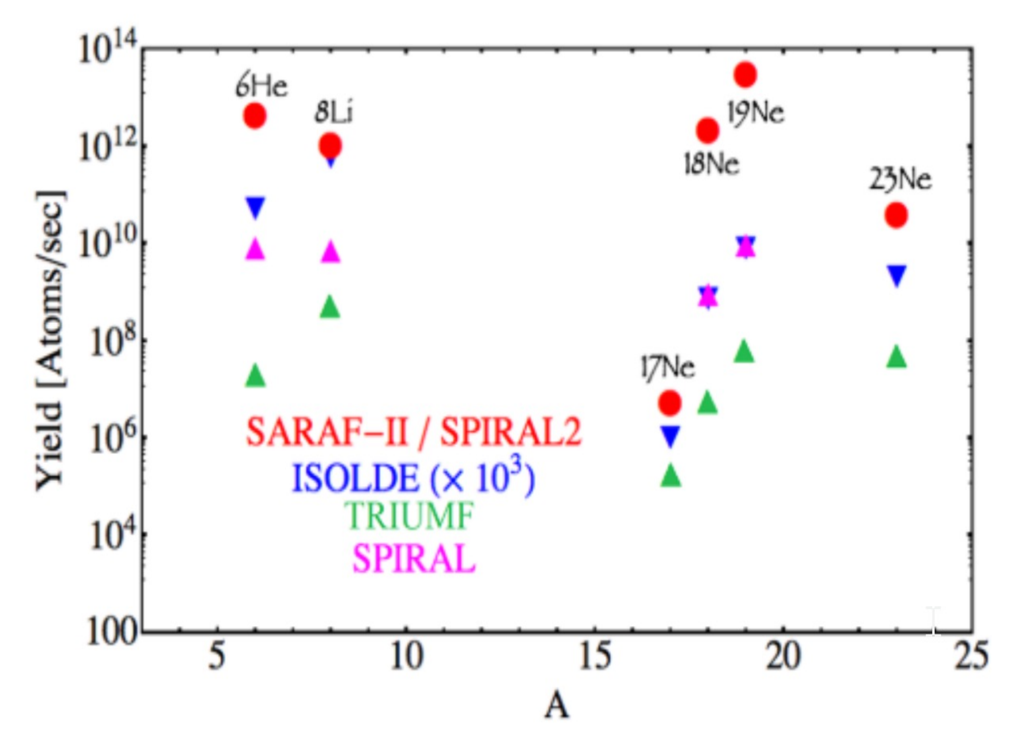


Mardor et. al. 2018

Soreq Applied Research Accelerator Facility



Phase (start year)	Beam				Neutron source	
	proton		deuteron			
	E (MeV)	*I* (mA)	*E* (MeV)	*I* (mA)	*E* (MeV)	rate (n/s)
I (2013)	1.5–4	0.04–2	3–5.6	0.04–1.2	0.03–20	10^{11}
I+ (2018)	1.5–4	0.04–2	3–5.0	0.04–2	0.03–20	10^{13}
II (2023)	5–35	0.04–5	5–40	0.04–5	0.03–55	10^{15}



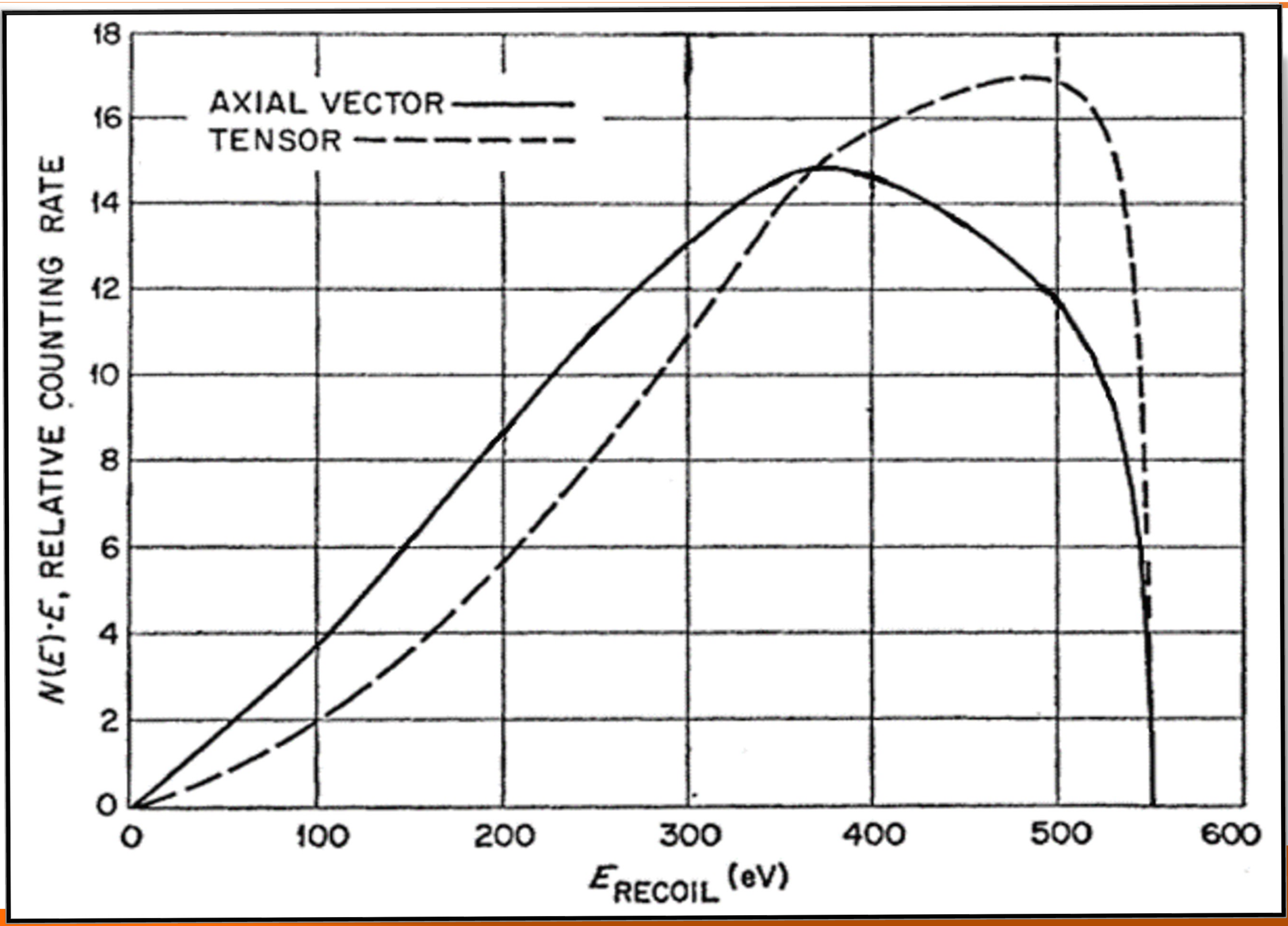
$a_{\beta\nu}$ measurement in ^{23}Ne Roadmap

- Produce ^{23}Ne by n,p reaction

- Measure Branching Ratio, (to reduce unc in $a_{\beta\nu}$ meas.)

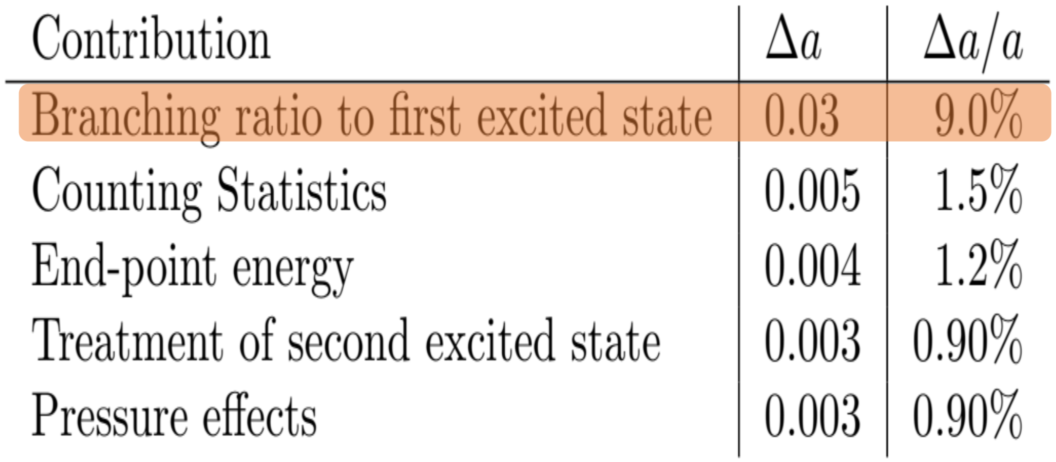
- Trap in MOT, to precisely measure recoil ion energy distribution

- Compute recoil energy dist. for each transition, for various $a_{\beta\nu}$ and compare to exp.



Branching Ratio and Reanalysis:

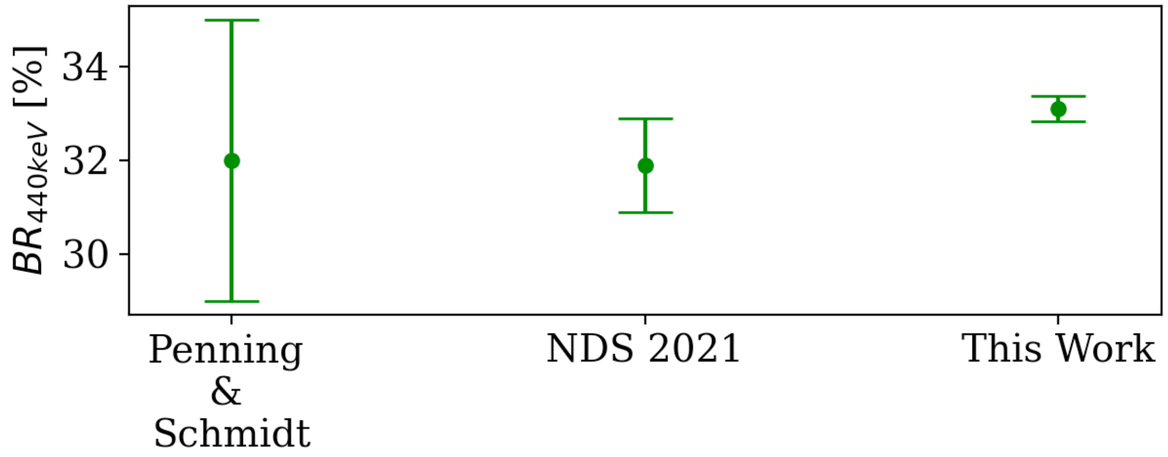
First Measurement of $a_{\beta\nu}$ in ^{23}Ne was done by Carlson in 1960 at Oak Ridge National Lab reactor

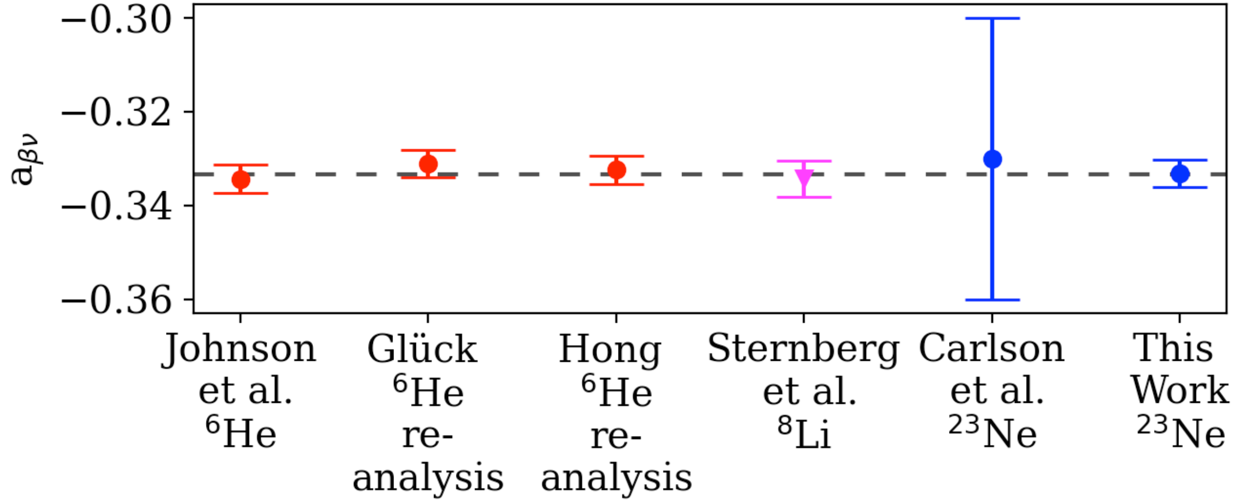


Contribution	Δa	$\Delta a/a$
Branching ratio to first excited state	0.03	9.0%
Counting Statistics	0.005	1.5%
End-point energy	0.004	1.2%
Treatment of second excited state	0.003	0.90%
Pressure effects	0.003	0.90%

Carlson, Physical Review, 132(5):2239, 1963.

Penning, Physical Review, 105:647–651,1957.

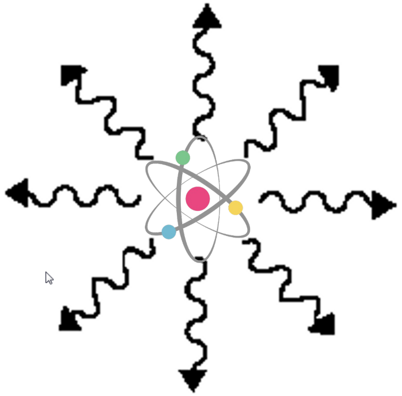




Mishnayot, Glick-Magid, **HR**, et al., arXiv:2107.14355

Neutral Atom Trapping

At Rest $\Delta \mathrm{E} = h/\lambda$



$\Delta\vec{p} = 0$

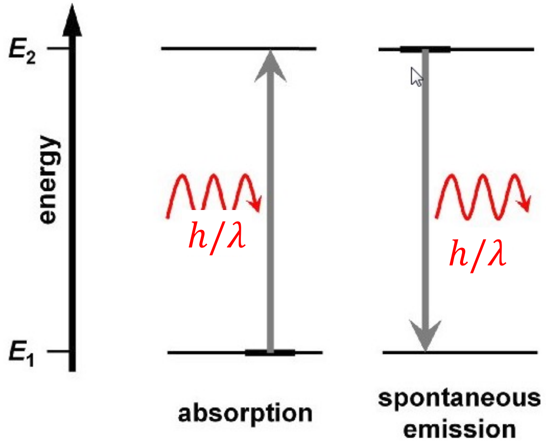
Emission

In Motion $\Delta \mathrm{E} = h/\lambda'$

Red/Blue Doppler shift

$\Delta\vec{p} = N\hbar k\ \hat{z}$

Absorption



Two level Atom

Cooling Force.

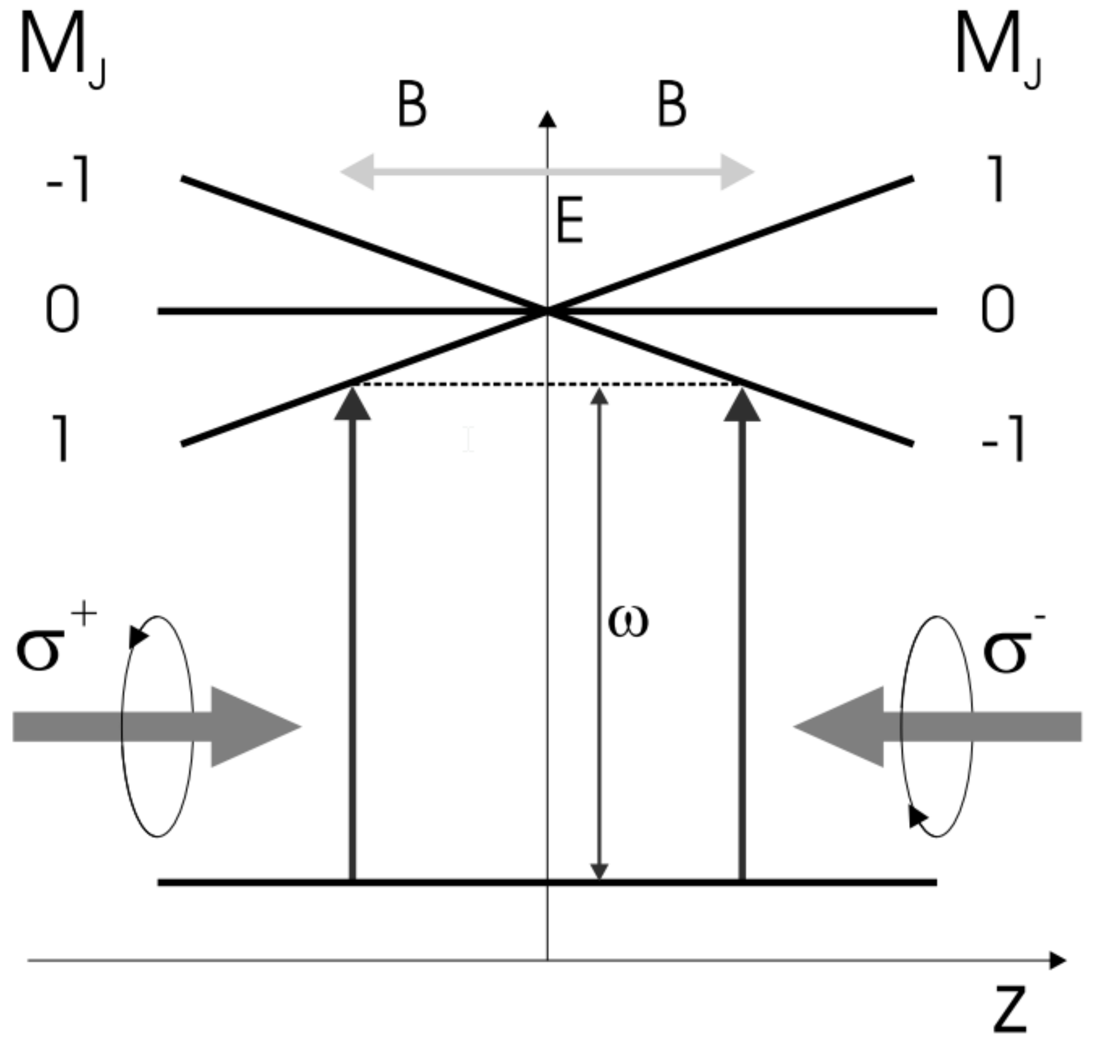
$$\mathbf{F} = \hbar\mathbf{k}\frac{\Gamma}{2}\frac{s}{1+s+(2\delta/\Gamma)^2}$$

$s\ -\frac{I}{I_o} saturation\ parameter$

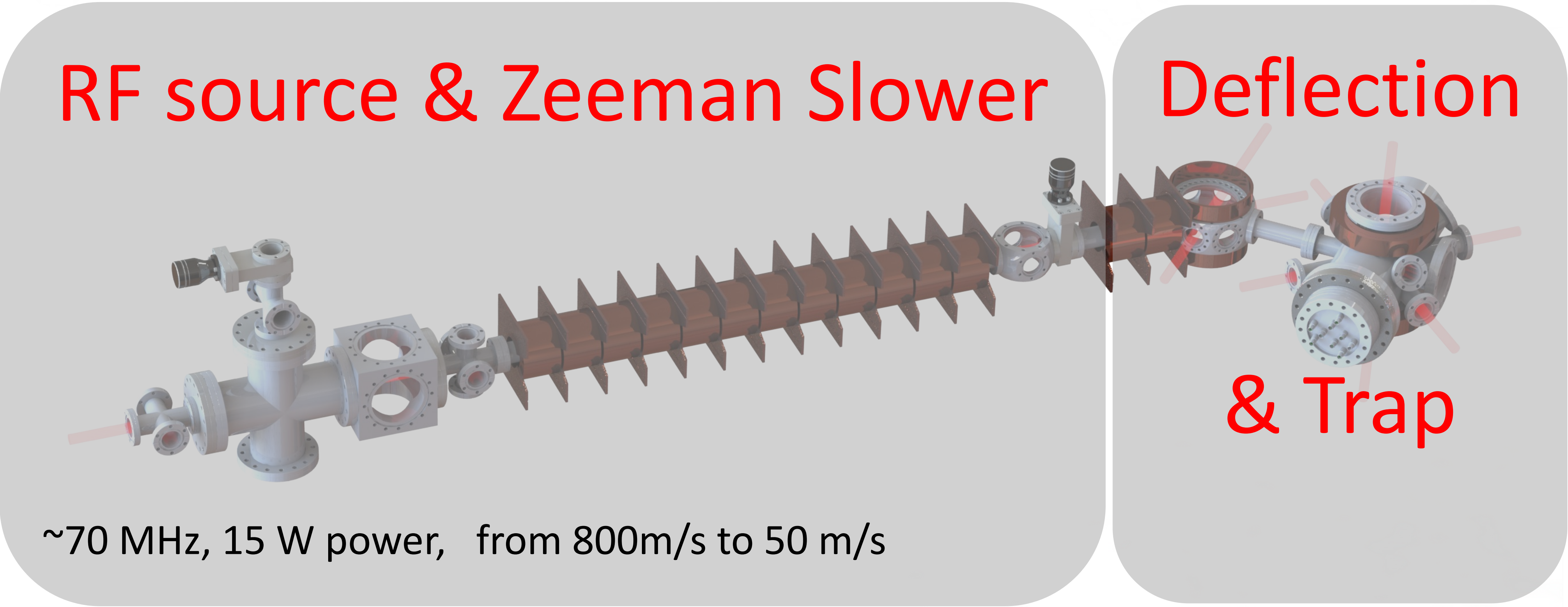
$\delta = \omega\ -\omega_o\ -detuning, \Gamma\ -Linewidth$

Neutral Atom Trapping

- Doppler cooling alone cannot do the trapping
- For that we need position dependent force.
- Inhomogeneous magnetic field & circularly polarized beams
- $\Delta\mathrm{E} = -\vec{\mu} \cdot \vec{B} \ = \mu_B B g m_i$
- $\sigma \pm \ \ derives\ \delta M_j = \ \pm$
- For 3D trap we need 6 such beams



Magneto Optical Trap

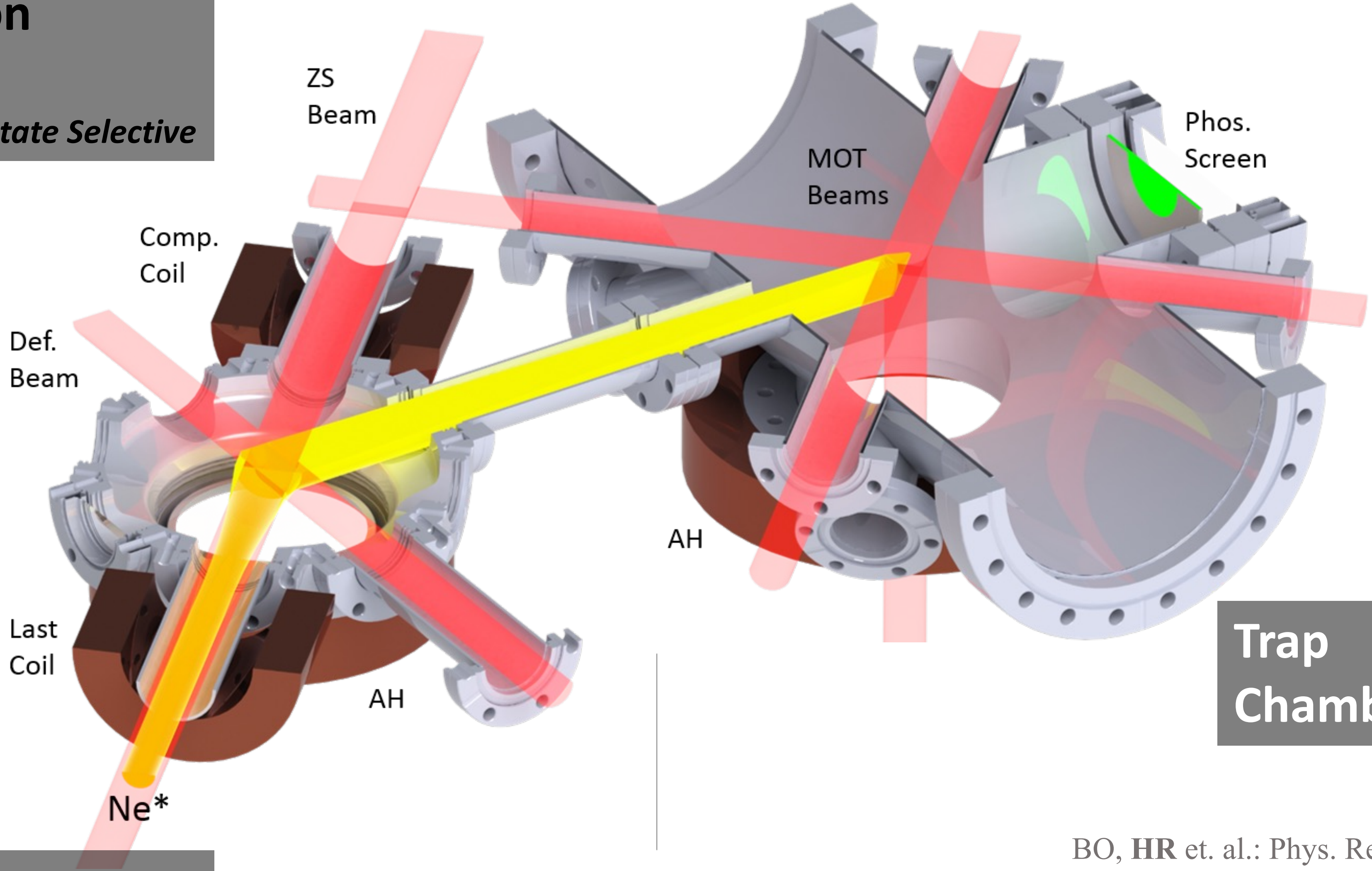


~70 MHz, 15 W power,   from 800m/s to 50 m/s

MOT

Deflection Stage

Isotope and state Selective



- 3 Retroreflective Beams
  + Anti-Helmholtz coils
- ~5Γ Detuning
- Trapped both stable isotopes of Neon
- ~20 sec trap lifetime
- Efficiency ~ 10^{-10}

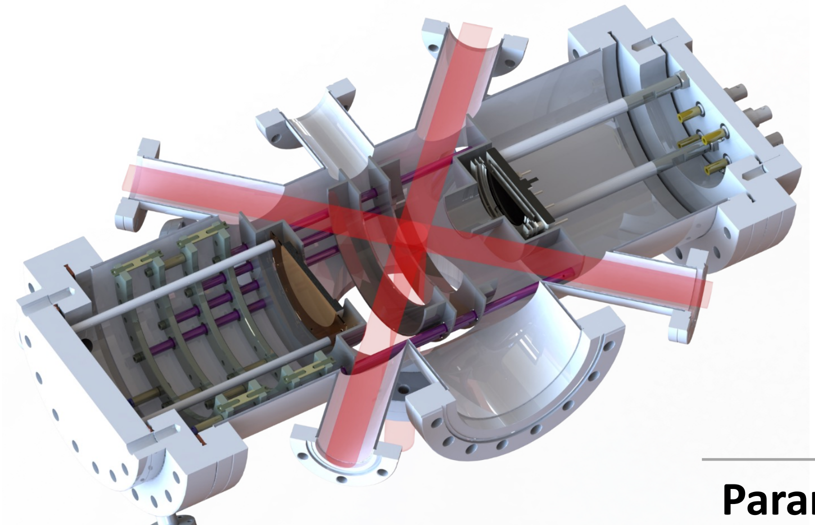
Trap Chamber

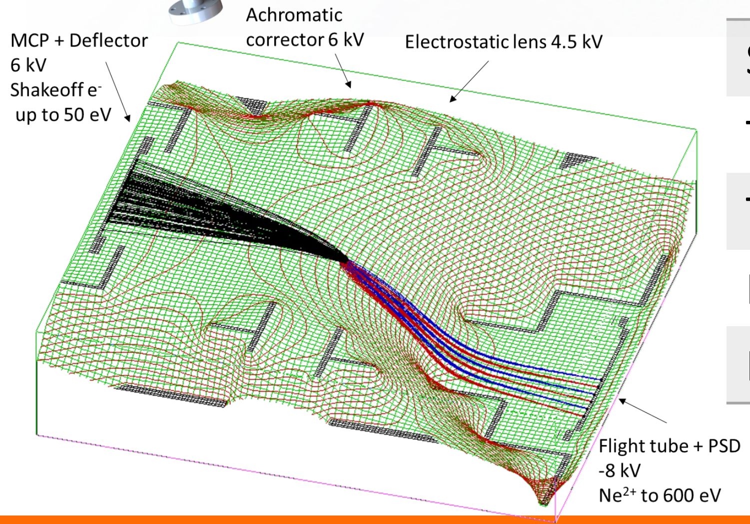
From Zeeman Slower

BO, **HR** et. al.: Phys. Rev. Lett. 123, 063401 (2019)

Detector for recoils:

(Magneto-optical-trap with High energy Velocity Map Imaging)





- ○ Trigger on **Shakeoff-e**
- ○ Direct detection of **recoil ion** energy (100% collection)

Parameter	**Effect on $a_{\beta\nu}$(%)**
Shift along detection axis(0.2mm)	< 0.3
Trap Radial shift(0.2mm)	< 0.1
Trap volume(x 1.5)	< 0.1
Lens Voltage(0.1%)	<0.2
Lens Diameter(0.4mm)	0.4

BO, **HR** et. al.: Phys. Rev. C 101, 035501 (2020)

Conclusions:

- Made the MOT.
- Loaded ^{20}Ne, ^{22}Ne stable isotopes.
- Successfully produced ~10^8 ^{23}Ne.(More in SARAF Phase II)
- Measured branching Ratio for ^{23}Ne.
- Reanalysis of Carlson data allows for 1.02% measurement of $a_{\beta\nu}$

^{23}Ne Collaboration:

Hebrew University of Jerusalem Israel
Prof. Guy Ron(PI)
Ben Ohayon
Vishal Srivastava
Doron Gazit
Ayala Glick-Magid

Soreq
Tsviki Hirsh
Sergey Vaintraub

LLNL
Jason Burke
Nick Scielzo
Aaron Gallant
Yonatan Mishnayot

Weizmann Institute
Oded Heber

The Nab Collaboration

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National Laboratory

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UNIVERSITY OF
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Main project funding:

NSF

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UNIVERSITY of VIRGINIA

Beam Flux measurement

Upstream Monitor

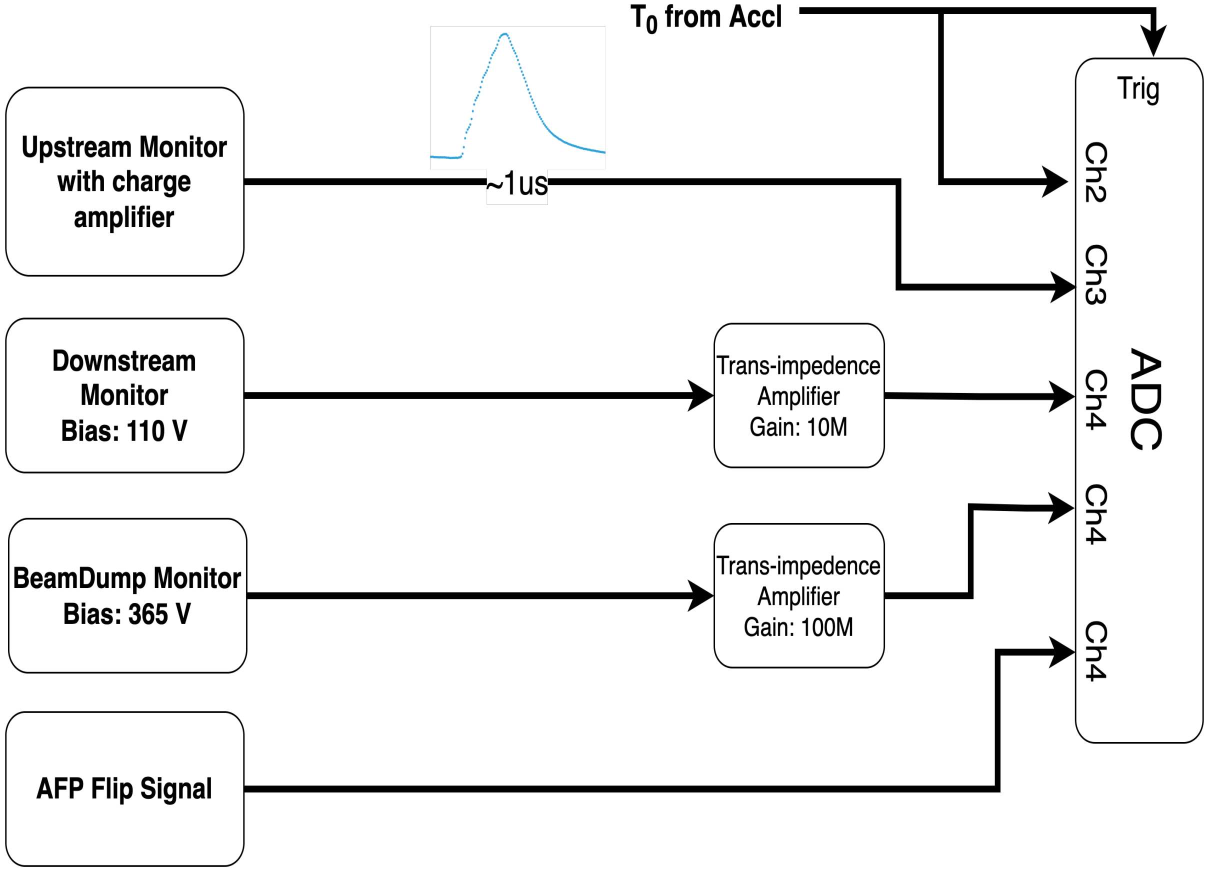
- Counting type detector with ^{14}N + CF$_4$ gas mixture
- Able to detect individual neutrons.
- Used with preamp to get single neutron event.
- Produces narrow signals. ~500ns width

Downstream Monitor:

- Thick Monitor filled with ^{3}He.
- Does not detect individual neutrons and needs high flux.
- Produces current proportional to neutron flux.

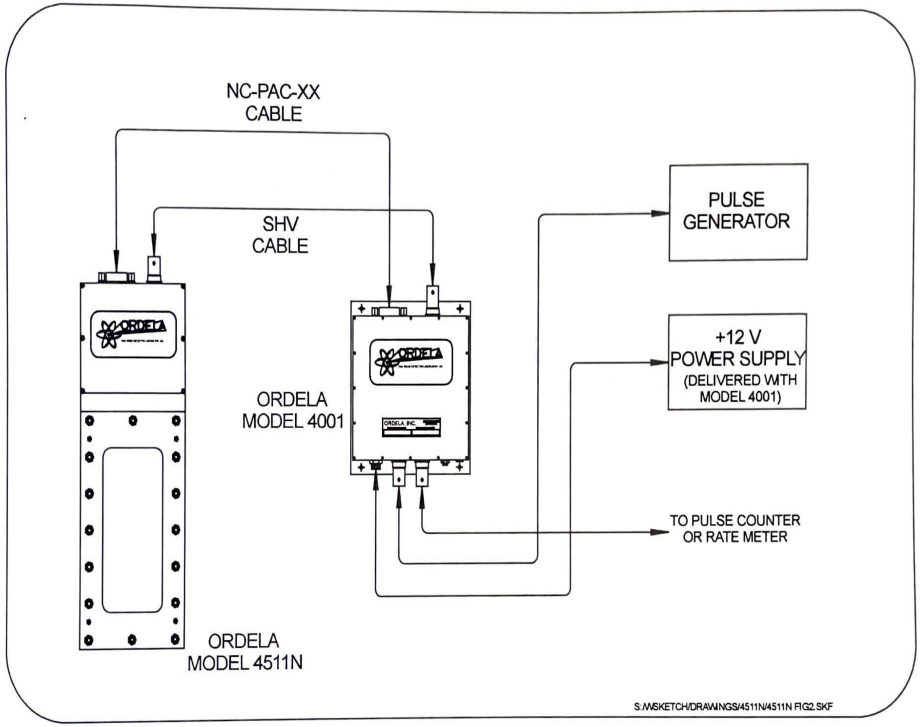
DAQ:

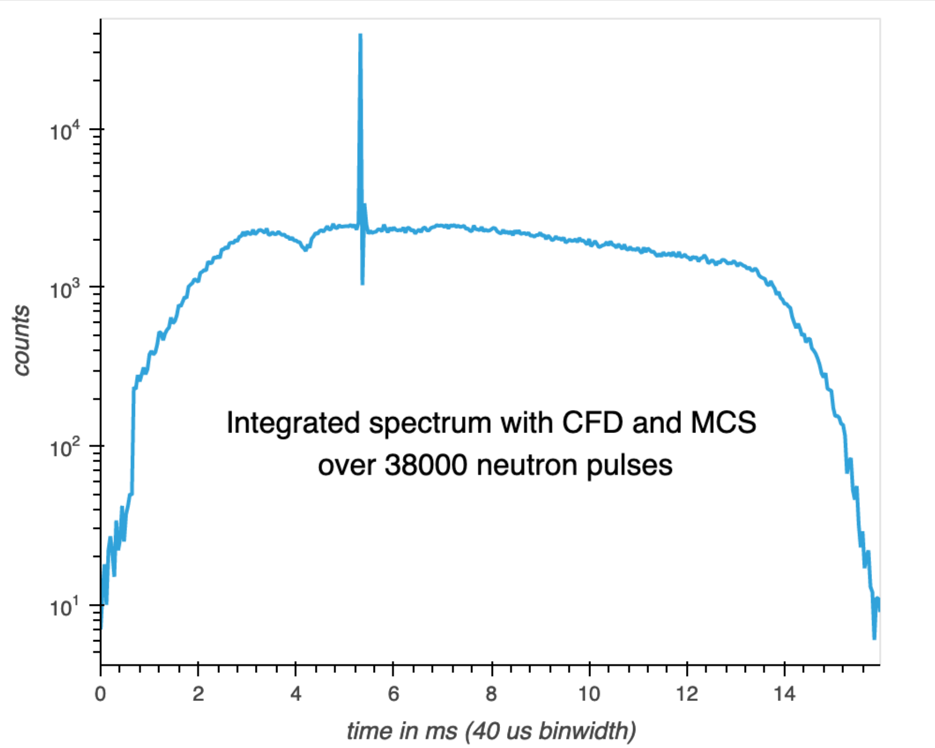
- Our DAQ contains voltage ADC, with 48 channels.
- It works in triggered mode
- Triggered by signal form SNS at 60Hz.
- For each trigger, data is sampled at 400us, for ~16ms, i.e, 40 time bins



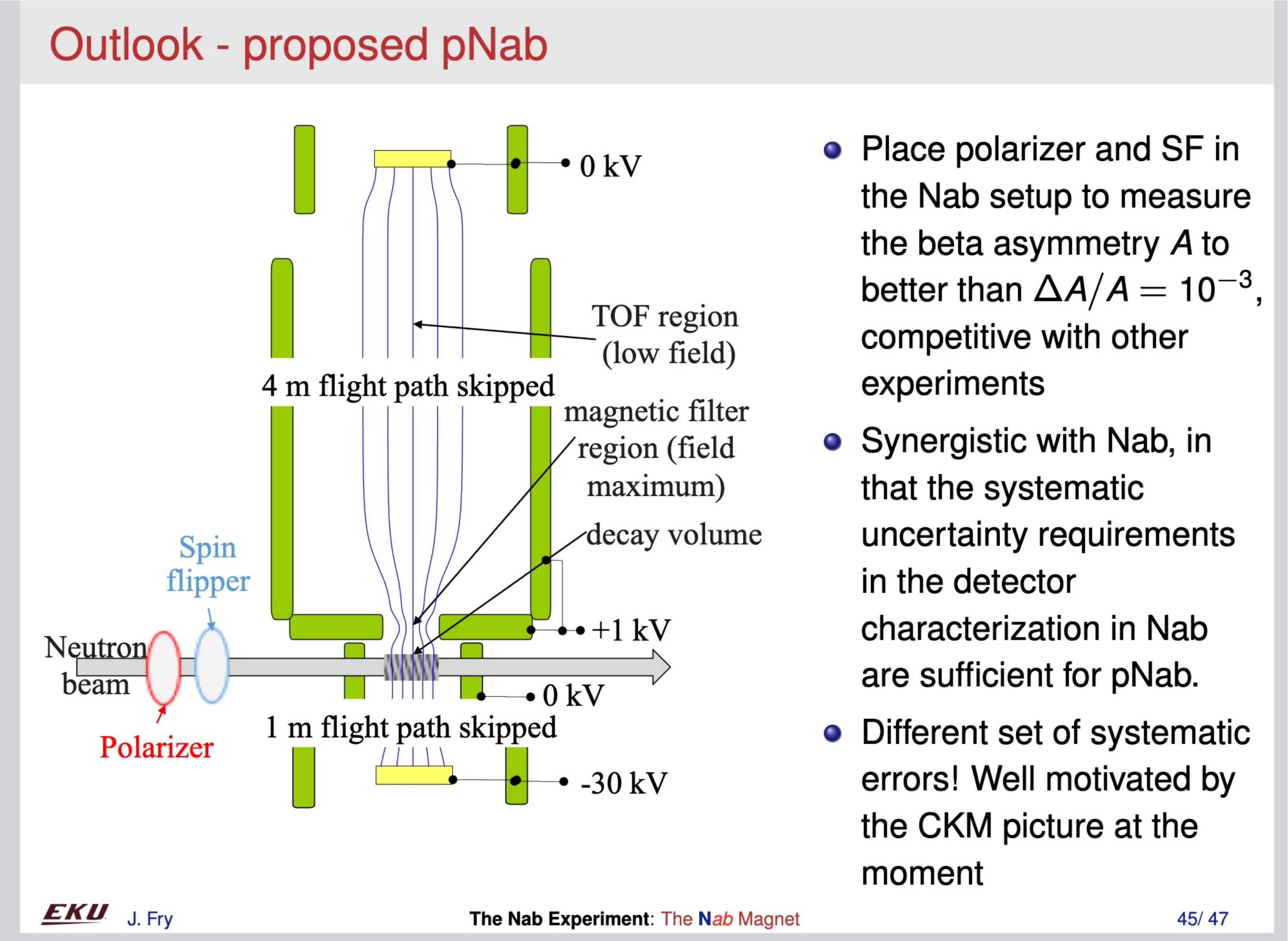
Beam Flux Measurement

Can’t directly incorporate, current upstream monitor in DAQ





- dynamic range
- Large integration time



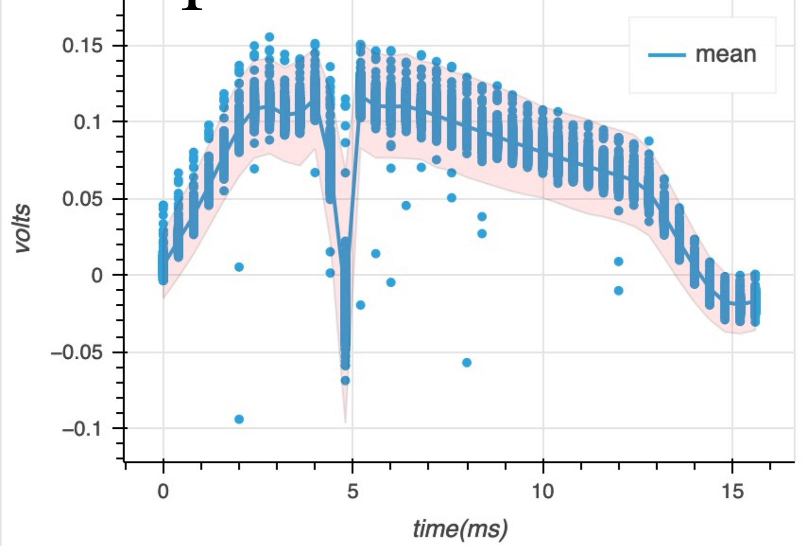
Outlook - proposed pNab

- Place polarizer and SF in the Nab setup to measure the beta asymmetry A to better than $\Delta A/A = 10^{-3}$, competitive with other experiments
- Synergistic with Nab, in that the systematic uncertainty requirements in the detector characterization in Nab are sufficient for pNab.
- Different set of systematic errors! Well motivated by the CKM picture at the moment

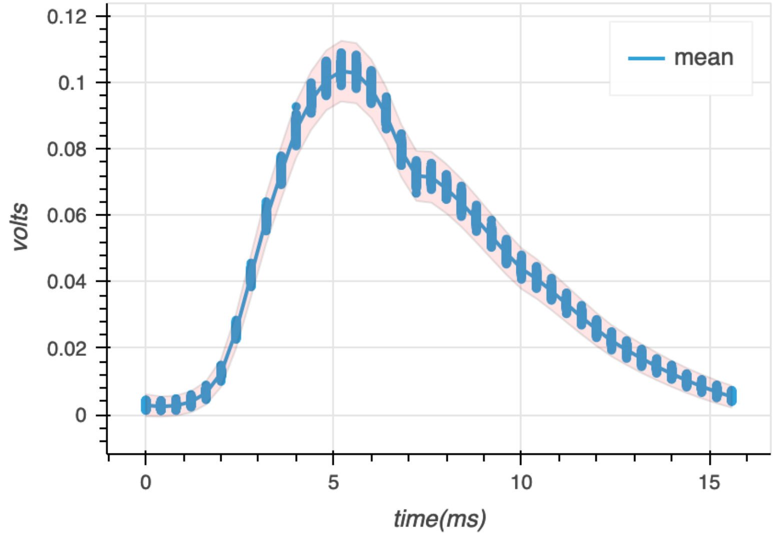
EKU J. Fry **The Nab Experiment**: The **N***ab* Magnet 45/ 47

Beam Flux Measurement

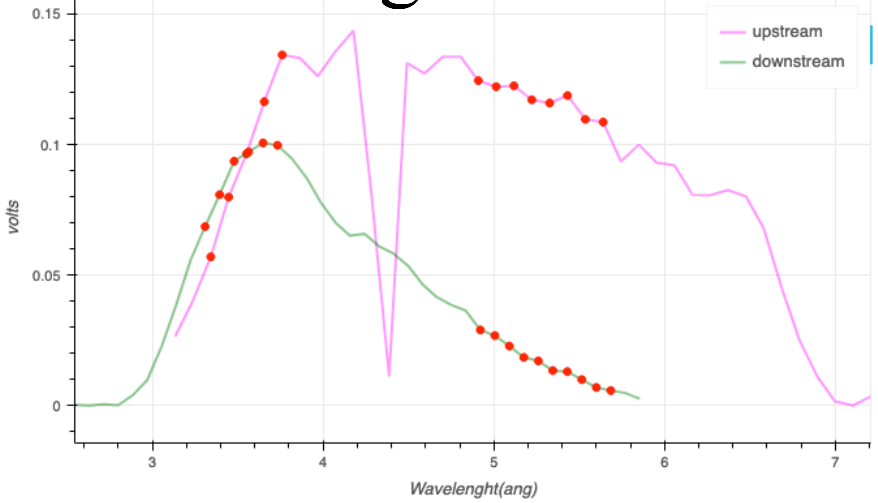
Upstream Monitor



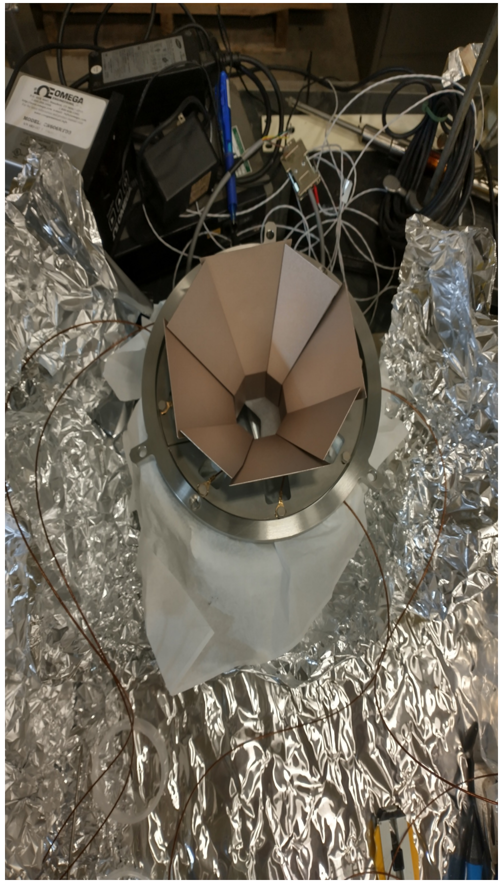
Downstream Monitor

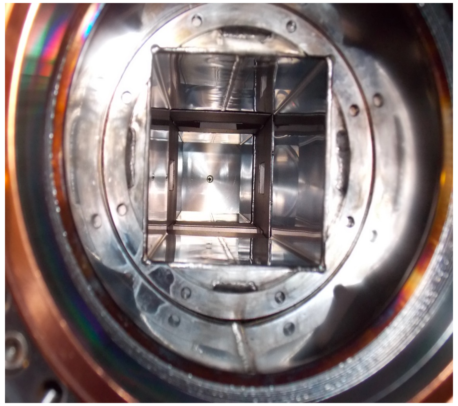


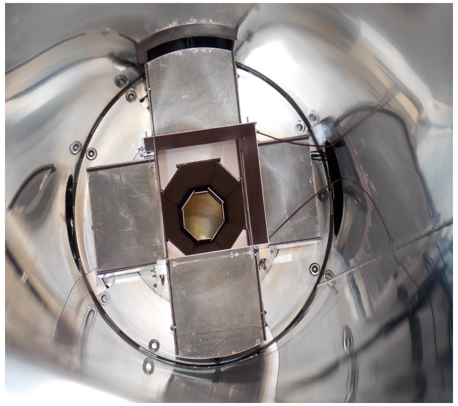
Wavelength calibrated

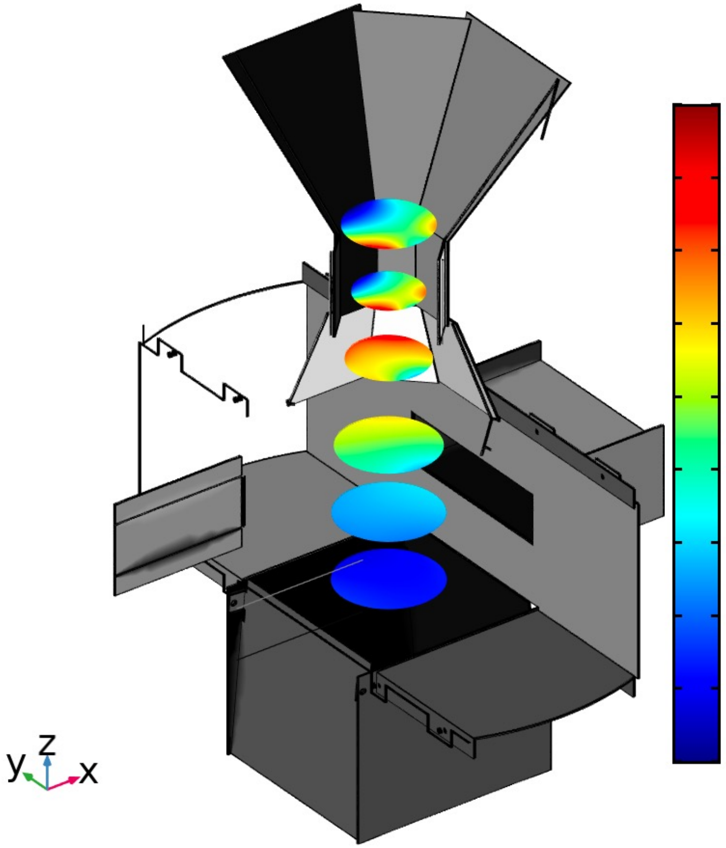


Electrode System:

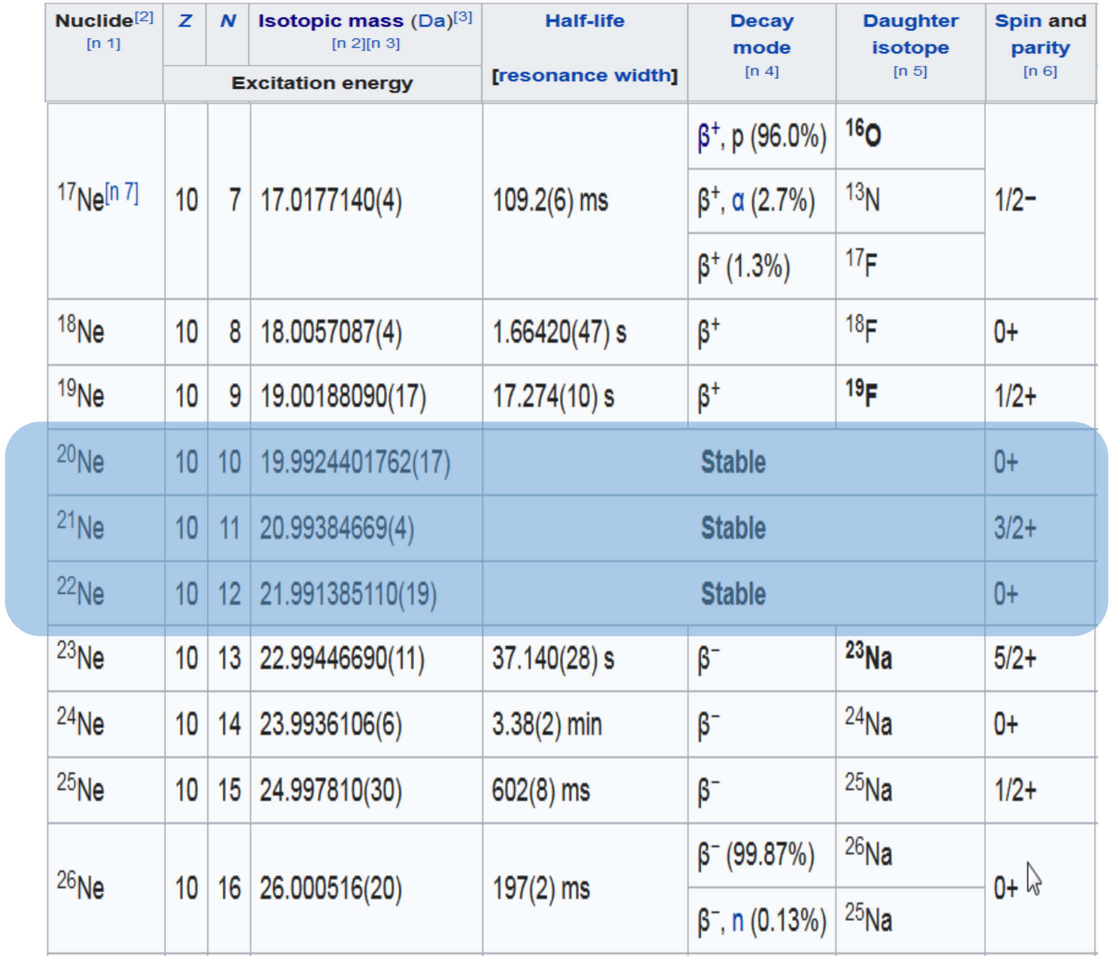






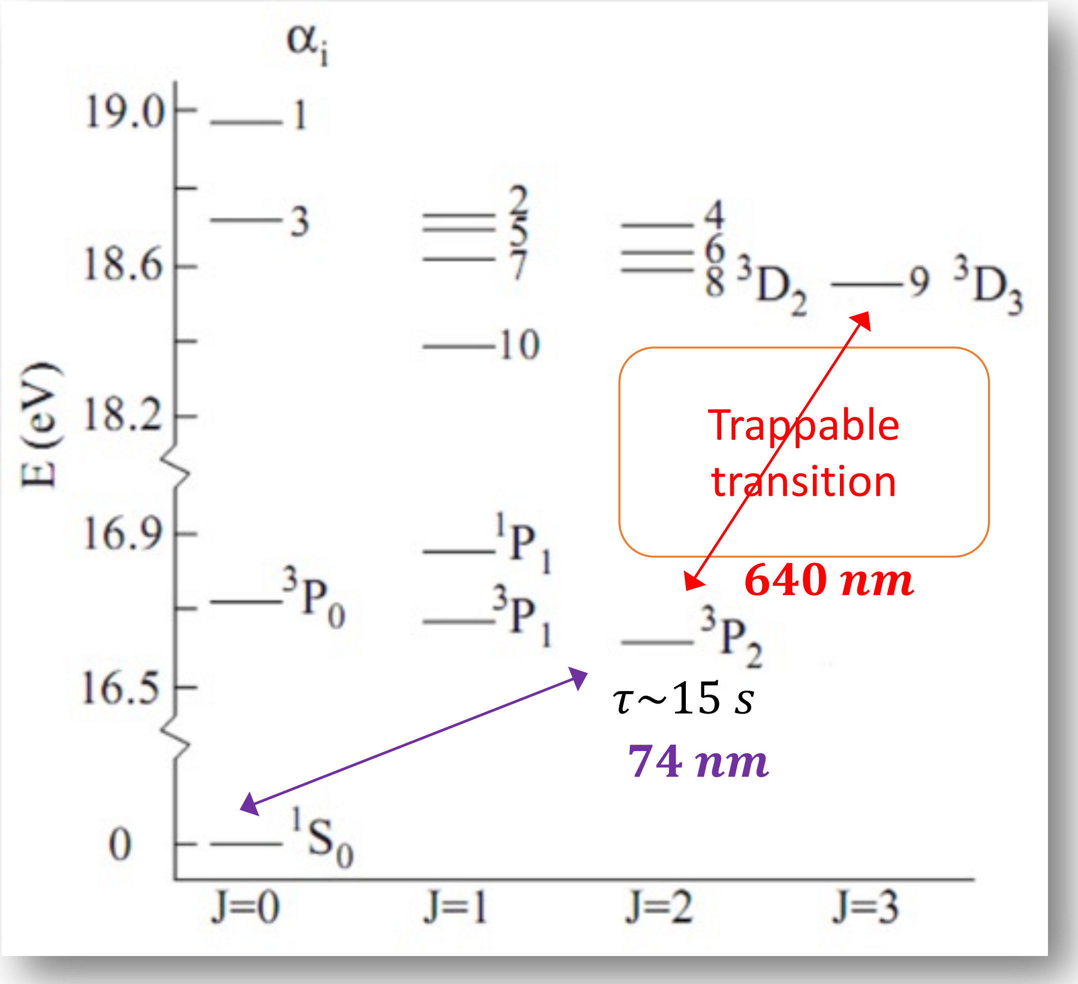


Neon scheme & isotopes



Nuclide[2] [n 1]	Z	N	Isotopic mass (Da)[3] [n 2][n 3]	Half-life	Decay mode [n 4]	Daughter isotope [n 5]	Spin and parity [n 6]
	Excitation energy			[resonance width]			
^{17}Ne[n 7]	10	7	17.0177140(4)	109.2(6) ms	β$^+$, p (96.0%)	^{16}O	1/2−
					β$^+$, α (2.7%)	^{13}N	
					β$^+$ (1.3%)	^{17}F	
^{18}Ne	10	8	18.0057087(4)	1.66420(47) s	β$^+$	^{18}F	0+
^{19}Ne	10	9	19.00188090(17)	17.274(10) s	β$^+$	^{19}F	1/2+
^{20}Ne	10	10	19.9924401762(17)	Stable			0+
^{21}Ne	10	11	20.99384669(4)	Stable			3/2+
^{22}Ne	10	12	21.991385110(19)	Stable			0+
^{23}Ne	10	13	22.99446690(11)	37.140(28) s	β$^-$	^{23}Na	5/2+
^{24}Ne	10	14	23.9936106(6)	3.38(2) min	β$^-$	^{24}Na	0+
^{25}Ne	10	15	24.997810(30)	602(8) ms	β$^-$	^{25}Na	1/2+
^{26}Ne	10	16	26.000516(20)	197(2) ms	β$^-$ (99.87%)	^{26}Na	0+
					β$^-$, n (0.13%)	^{25}Na	

Ne Even isotope energy Scheme:



Detection System:

Neon Cell:

- hollow cavity of 10mm diameter, 6 mm height
- 75 micron Be for β transmission

Electron Detection:

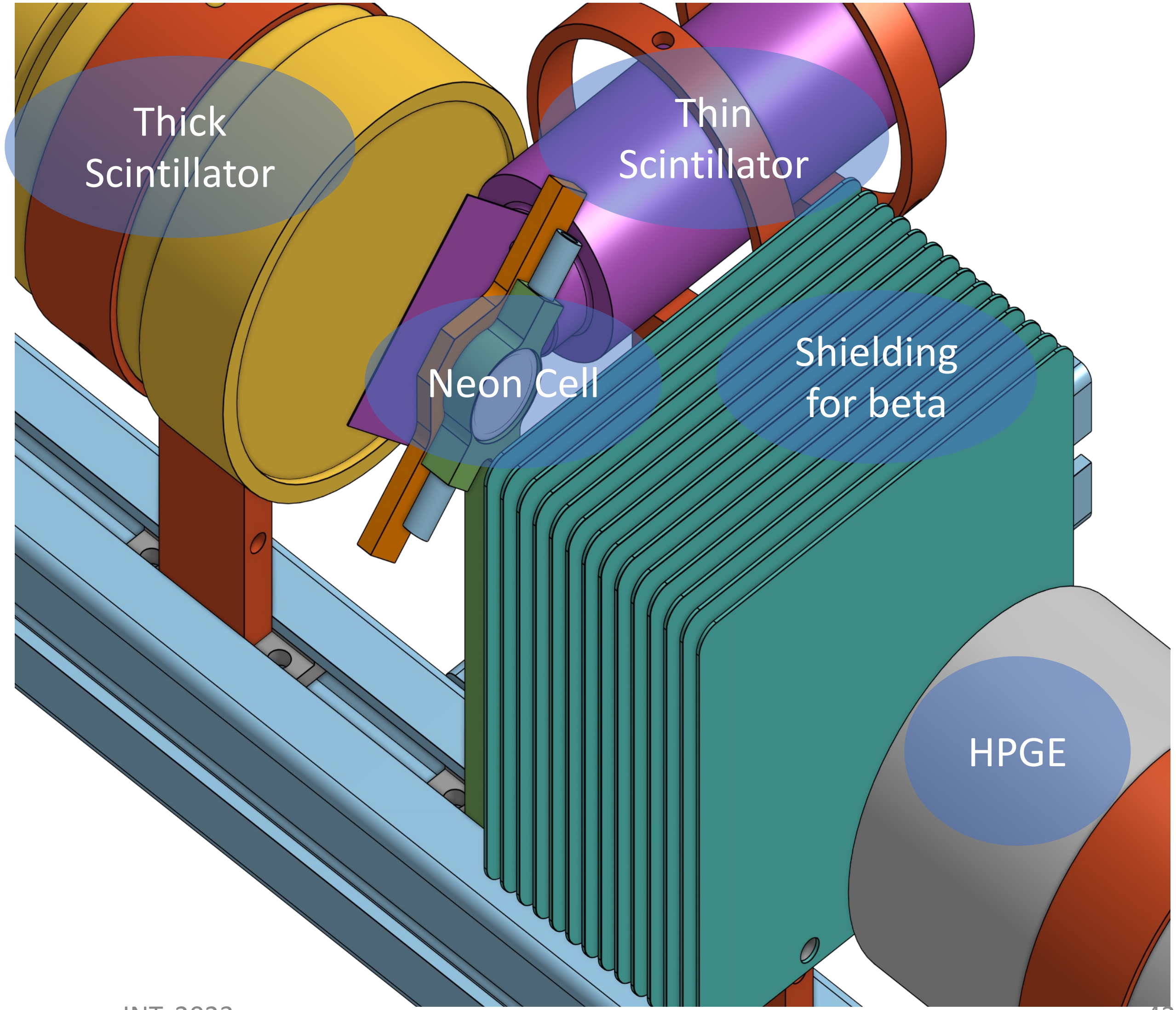
- Thin and Thick scintillation detectors
- make electron telescope to identify β.

Gamma Detection:

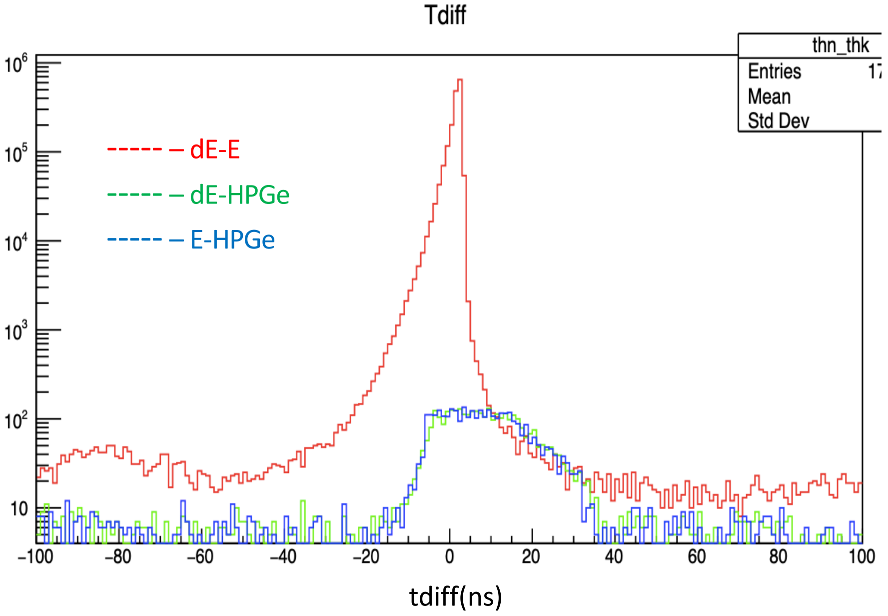
- Gammas are detected with highly pure Germanium Detector
- p-Type 40%

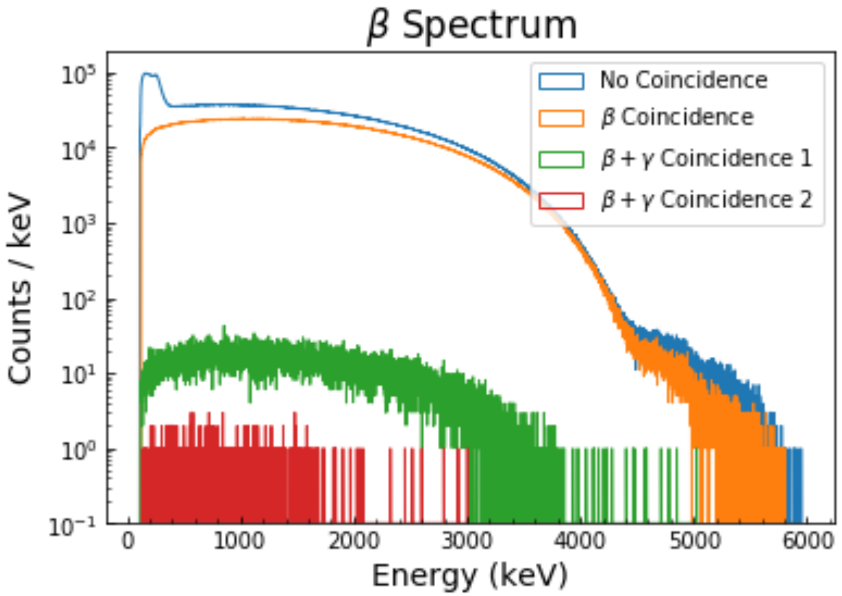
Data Acquisition

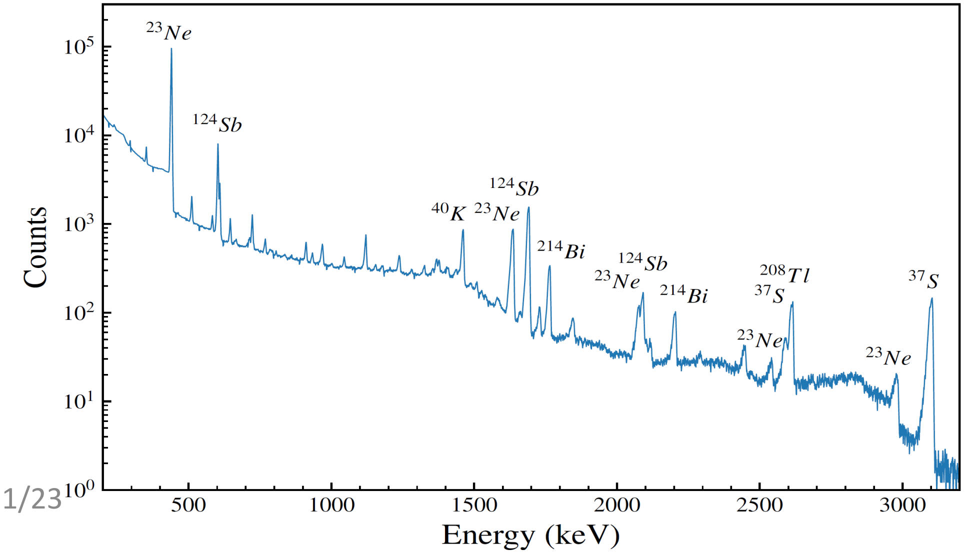
- Preamplifiers + CAEN N6780 digital MCA module.
- Data collection in list mode we searched for triple coincidence event.

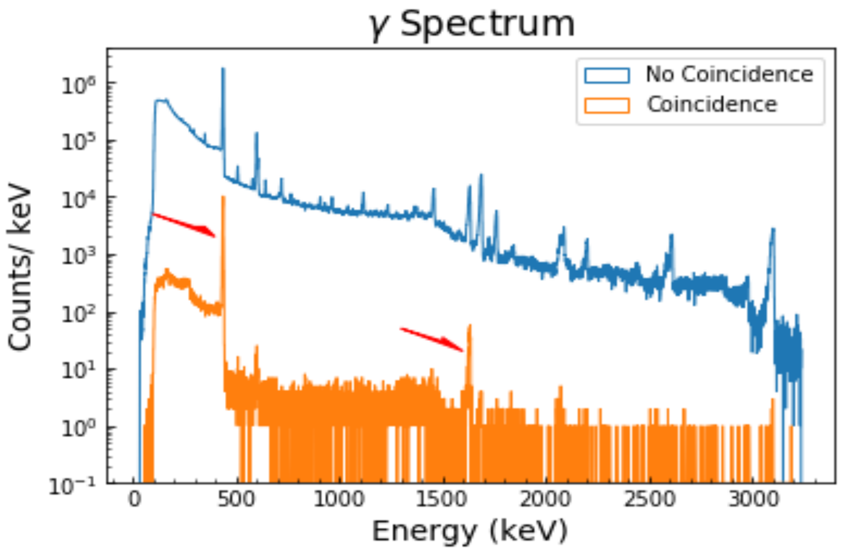


Data Analysis/Preliminary



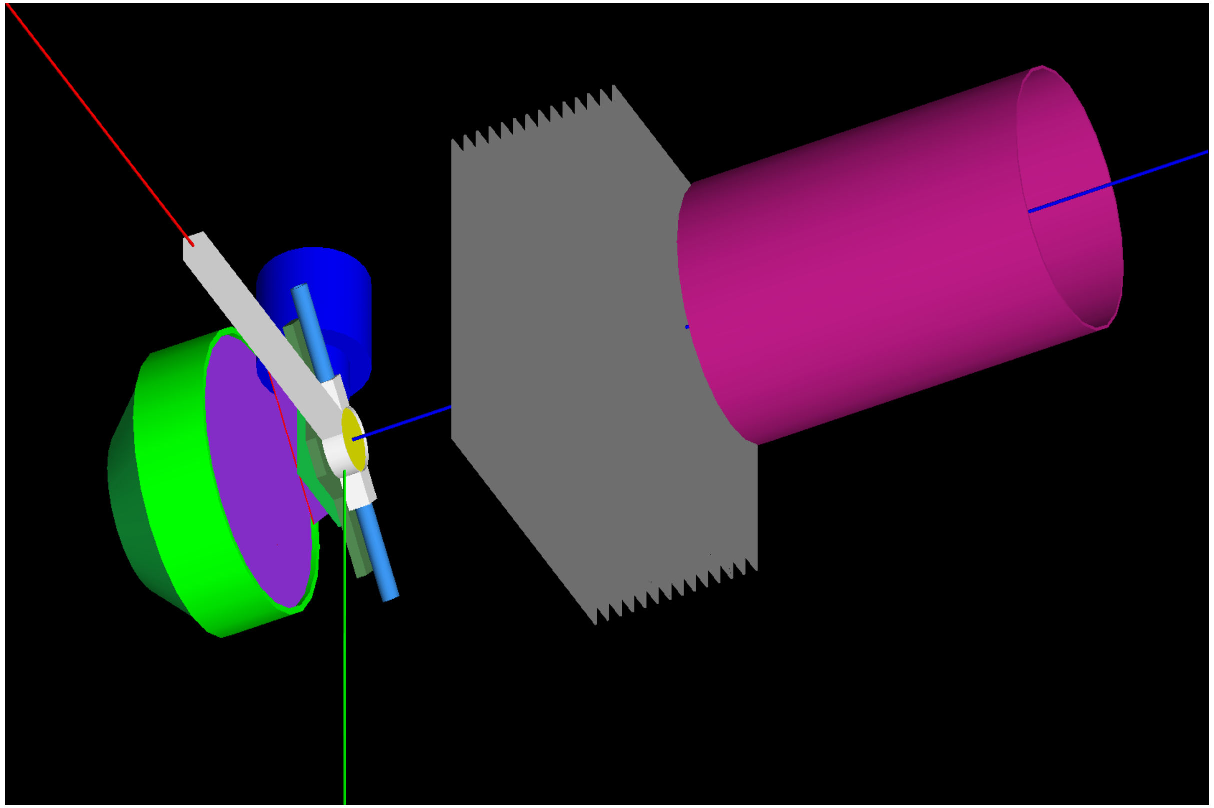






Background Correction- Geant4 Simulation

- Neon 23 is flowing Through pipes/ Turbo etc.
- Possibility of lots of β background
- Thick Ta Foils Between β detector & cell during expt.(no. β expected in detector)
- Still β events observed.
- Could be β from background/bremsstrahlung
- Using G4 to discriminate between background/Bremsstrahlung.



Preliminary