

PREX AT-puzzle: nuclear dependence of beam normal single spin asymmetry



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Hall A & C Collaboration meeting
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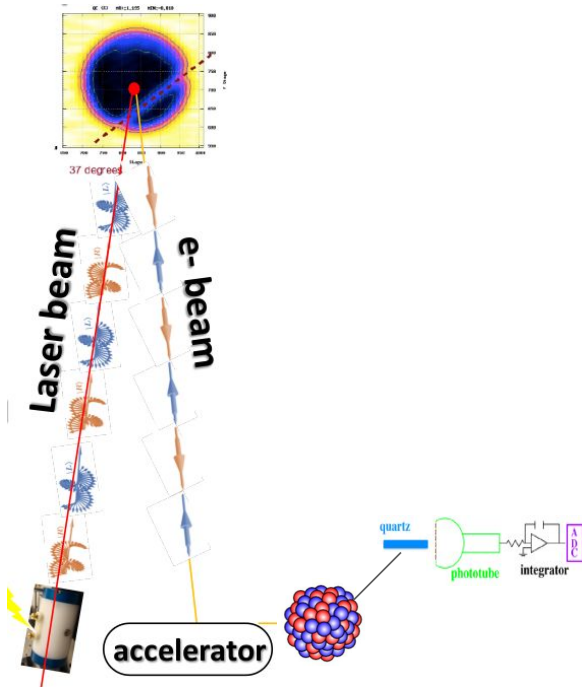
 Jefferson Lab

Outline

- What is PREX AT puzzle?
- Status of AT measurements
- Approved proposal on Nuclear dependence of AT
 - Experimental details
 - Status
- New proposal for studying kinematic dependence of AT
- Summary

PREX AT Puzzle

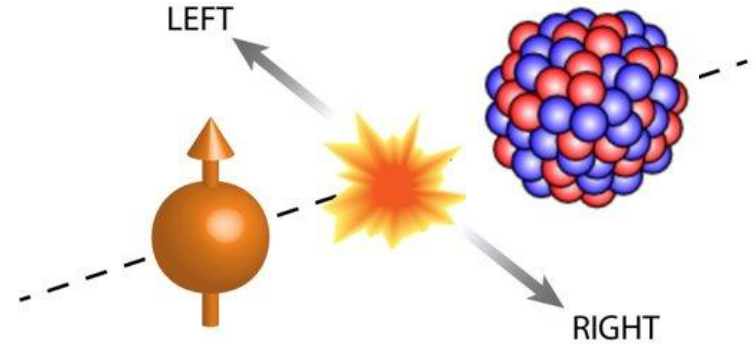
Parity Experiment



- Prex asymmetry - Parity violating \sim sub ppm.
- Due to weak interaction

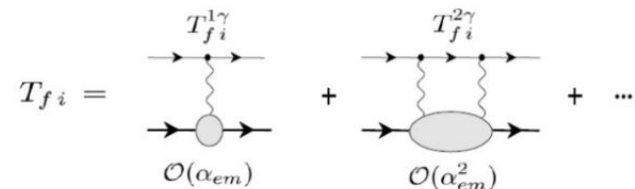
$$A_{pv} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

Major Systematic for Parity Experiment



- Transverse asymmetry - Parity conserving \sim few ppm.
- Interference term amongst one- and multi-photon exchange.

$$B_n = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} = \frac{2\Im(T^{1\gamma*} \cdot \text{Abs}T^{2\gamma})}{|T^{1\gamma}|^2} \approx \mathcal{O}(\alpha \frac{m}{E}) \approx \text{ppm}$$



Different nomenclature: BNSSA, AT, A_n , B_n , vector analyzing power

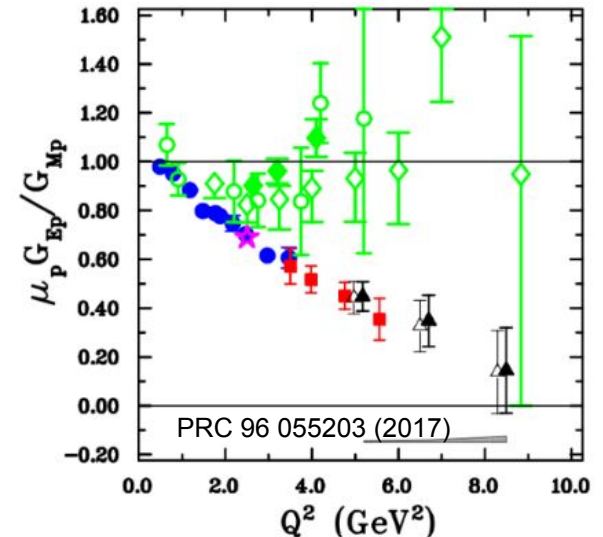
Why AT is of interest?

- **Going beyond single-boson exchange:** In precision electroweak experiments, we now need to go beyond Born approximation and consider multi-boson exchange box diagrams (etc.):

- **$\gamma\gamma$ -box diagrams** - real part of the two-photon exchange contribution - Rosenbluth vs Recoil Polarization: (Nucl. Phys. A741 234 (2004)).
- AT depends on the **imaginary part** of two-photon exchange contribution

-models can be tested by both kinds of observables

- **γZ - box diagrams in weak charge measurements:** Important for precision test of standard models - push for extreme precision (MOLLER)

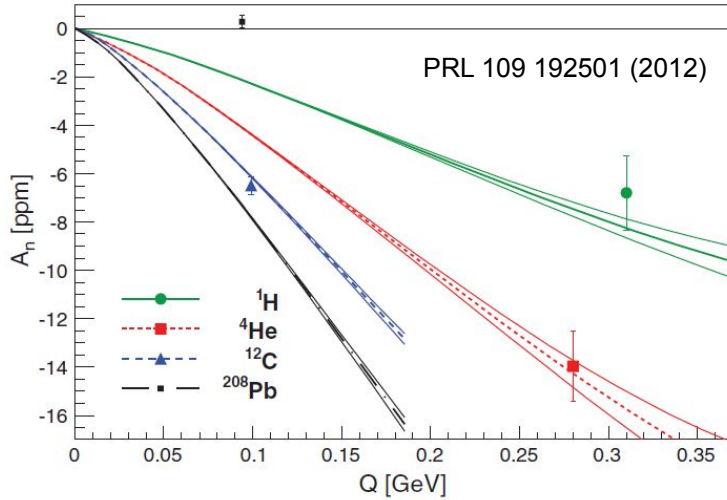


- **False asymmetry for Parity-violating electron scattering experiment:**

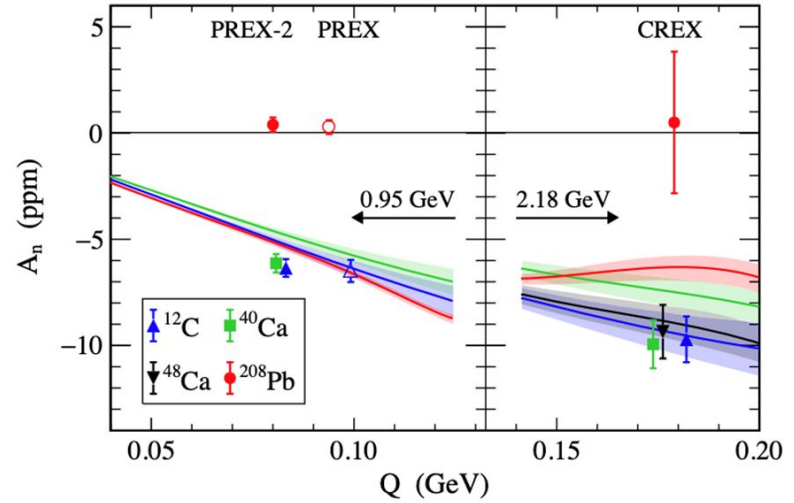
- Can cause false asymmetry in precision parity violating electron scattering measurements if apparatus doesn't have perfect symmetry and if beam polarization is not perfectly longitudinal

PREX AT Puzzle: Previous AT measurements

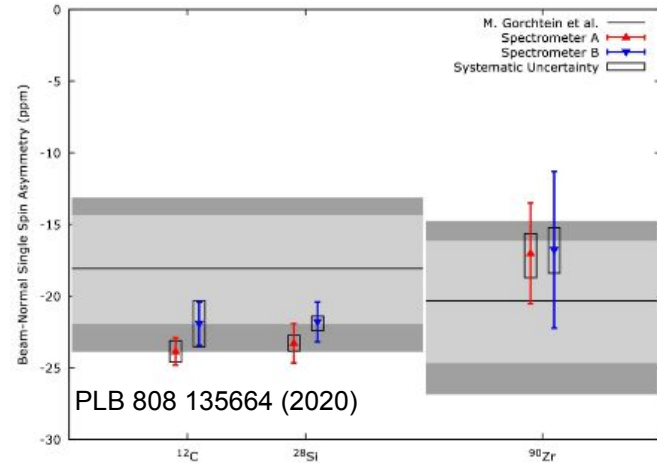
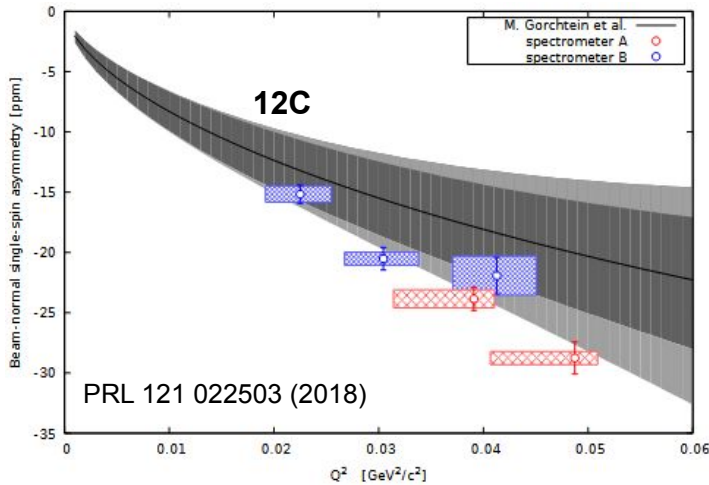
JLab measurements:



PRL 128, 142501 (2022)



Mainz measurements:

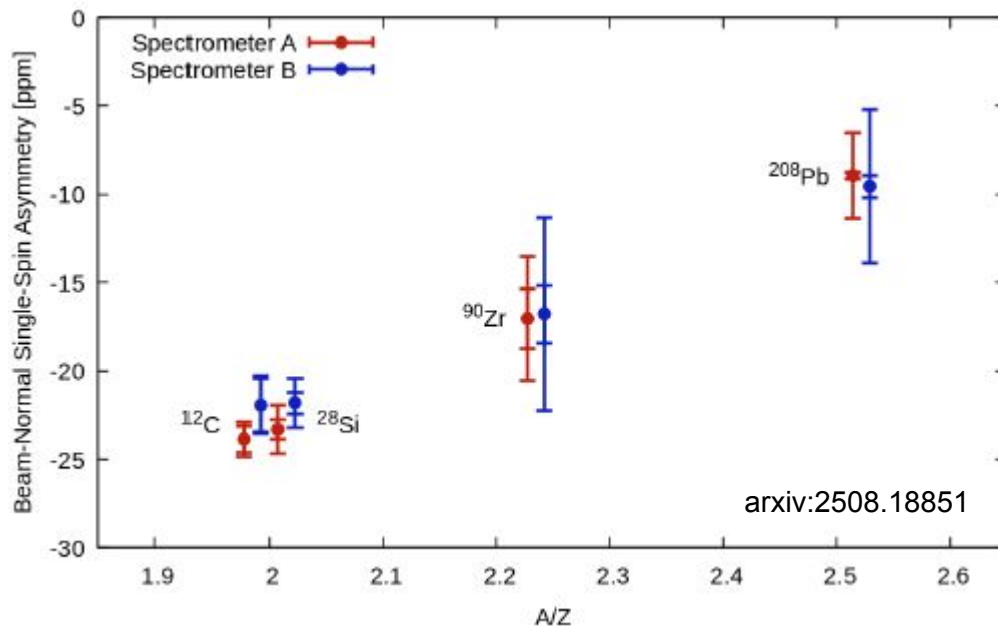
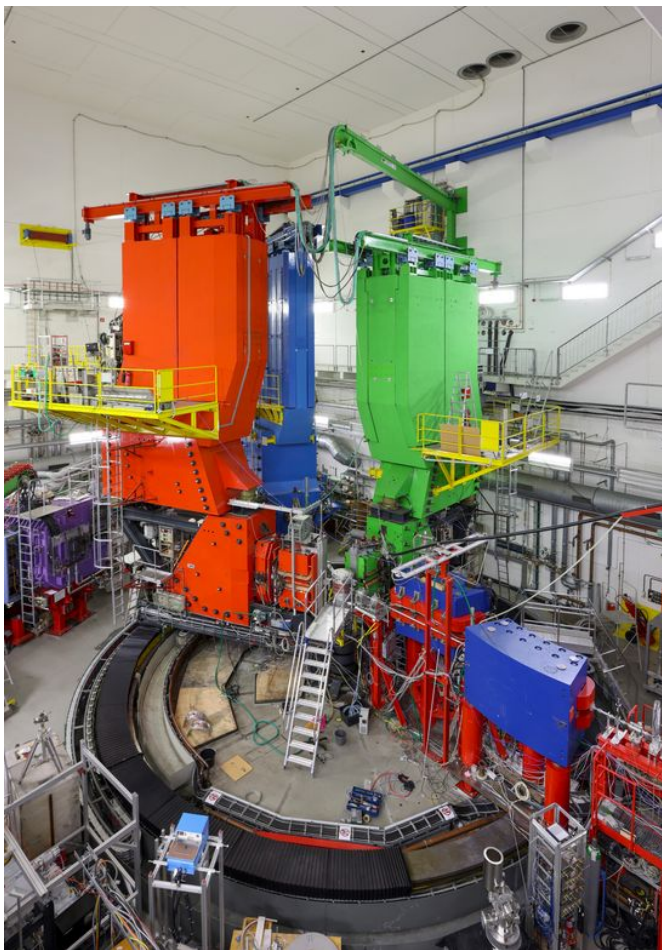


Are there some nuclear dependence of AT!!??

$$A_n \approx A_0(Q)(1 - C \cdot Z^2 \alpha)$$

$$C = 0.02$$

^{208}Pb AT Puzzle: Previous AT measurements



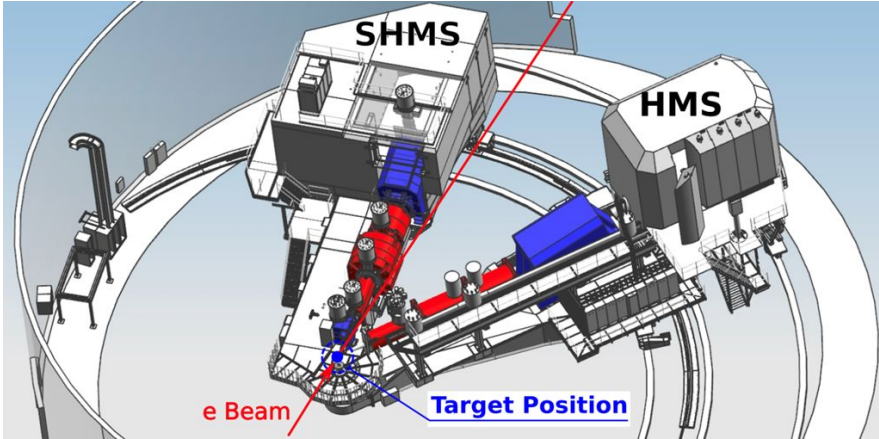
$\text{BNSSA} (^{208}\text{Pb}) = (-9.1 \pm 2.1 \text{ (stat)} \pm 0.7 \text{ (syst)}) \text{ ppm}$
 @ $Q^2 = 0.04 \text{ (GeV/C)}^2$

Experiment	Target	E_{beam} (GeV)	Angle (deg)	Q^2 (GeV^2)	A_n (ppm)
PREX-II & CREX [14]	^{12}C	0.95	4.87	0.0066	-6.3 ± 0.4
	^{40}Ca	0.95	4.81	0.0065	-6.1 ± 0.3
	^{208}Pb	0.95	4.69	0.0062	0.4 ± 0.2
	^{12}C	2.18	4.77	0.033	-9.7 ± 1.1
	^{40}Ca	2.18	4.55	0.030	-10.0 ± 1.1
HAPPEX & PREX-I [15]	^{48}Ca	2.18	4.53	0.030	-9.4 ± 1.1
	^{208}Pb	2.18	4.60	0.031	0.6 ± 3.2
	^4He	2.750	6	0.0773	-13.97 ± 1.45
	^{12}C	1.063	6	0.00984	-6.49 ± 0.38
	^{208}Pb	1.063	6	0.00881	0.28 ± 0.25

Are there some strong kinematic dependence!!??

Proposed experiment (E12-24-007) : Nuclear dependence of BNSSA

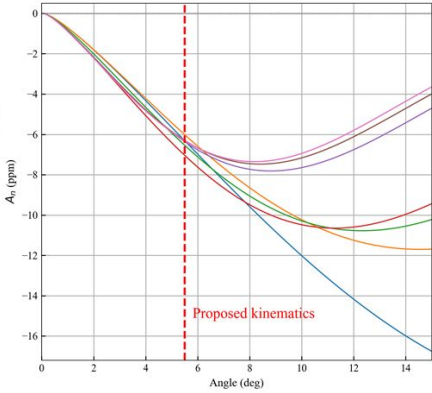
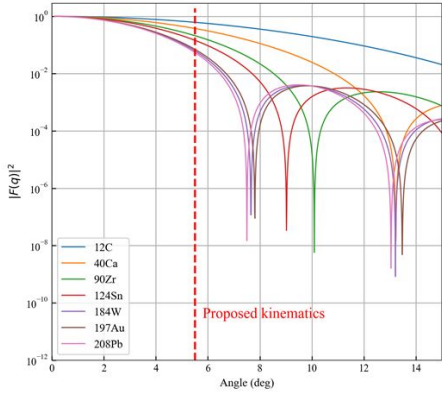
- The standard Hall C SHMS spectrometer will be used at a scattering angle of 5.5 deg with ~1 GeV transversely polarized electron beam: +/- 0.5 ppm (stat) and +/- 0.2 ppm (syst).
- The small scattering angle is chosen: 1) to maximize FoM and 2) to facilitate data interpretation with existing theories.



This will run early 2027!!

	SHMS	HMS
Scattering angle (deg)	5.5-40	10.5-80
Solid Angle (msr)	~4	~6
Central Momentum (GeV/c)	1-11	0.5-7

Target	Proton number	Thickness (mg/cm ²)	Beam current (μA)	Rate (MHz)	Beam time (hours)	Position scan (hours)
¹² C	6	1280.9	30	494	1.76	20
⁴⁰ Ca	20	483.13	30	411	2.11	-
⁹⁰ Zr	40	301.6	30	306	2.84	-
¹²⁴ Sn	50	276.1	30	261	3.32	20
¹⁴⁰ Ce	58	238.3	30	247	3.51	-
¹⁴² Nd	60	227.5	30	246	3.52	-
¹⁴⁴ Sm	62	217.7	30	245	3.54	-
¹⁸² W	74	200.8	30	216	4.02	-
¹⁹⁷ Au	79	193.8	30	207	4.20	20
²⁰⁸ Pb	82	191.1	30	200	4.34	20
²³² Th	90	182.2	30	189	4.60	-
Total production beam time						5.1 days



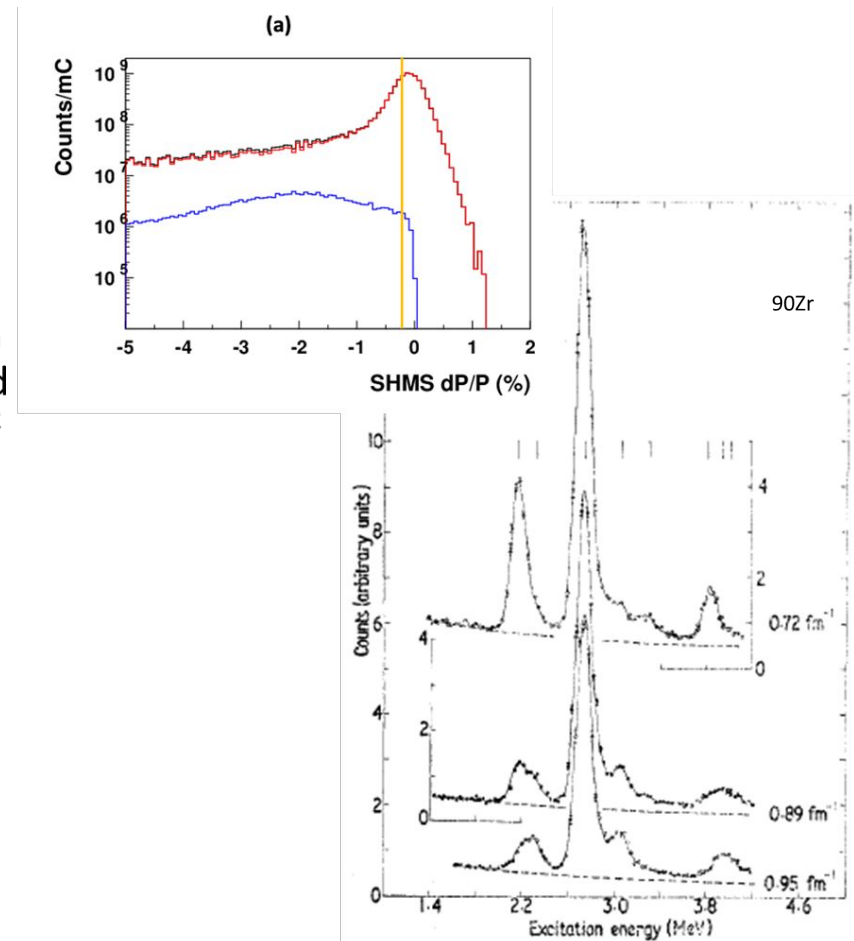
List of proposed targets

Target	Proton number	Thickness (mg/cm^2)	Beam current (μA)	Rate (MHz)	Beam time (hours)	Position scan (hours)
^{12}C	6	1280.9	30	494	1.76	20
^{40}Ca	20	483.13	30	411	2.11	-
^{90}Zr	40	301.6	30	306	2.84	-
^{124}Sn	50	276.1	30	261	3.32	20
^{140}Ce	58	238.3	30	247	3.51	-
^{142}Nd	60	227.5	30	246	3.52	-
^{144}Sm	62	217.7	30	245	3.54	-
^{182}W	74	200.8	30	216	4.02	-
^{197}Au	79	193.8	30	207	4.20	20
^{208}Pb	82	191.1	30	200	4.34	20
^{232}Th	90	182.2	30	189	4.60	-
Total production beam time						5.1 days

- The ^{12}C target provides baseline measurements
- Important consistency check for ^{40}Ca and ^{208}Pb measurements from the previous JLab measurements with different experimental setup and approach
- **Intermediate to heavy Z-targets** will provide important new inputs for studying nuclear dependence of the asymmetry
- Water-cell target was proposed in the original proposal for precise spectrometer angle measurement.
- Instead of that we are planning to use C-elastic and C-first excited state scattered electrons and CH₂ target for angle measurement
- We wish to have **^{13}C target** for quantify changes due to the extra neutron in ^{12}C and to justify using chemically pure targets

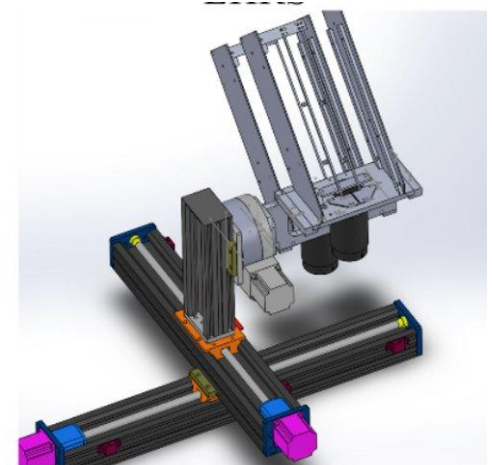
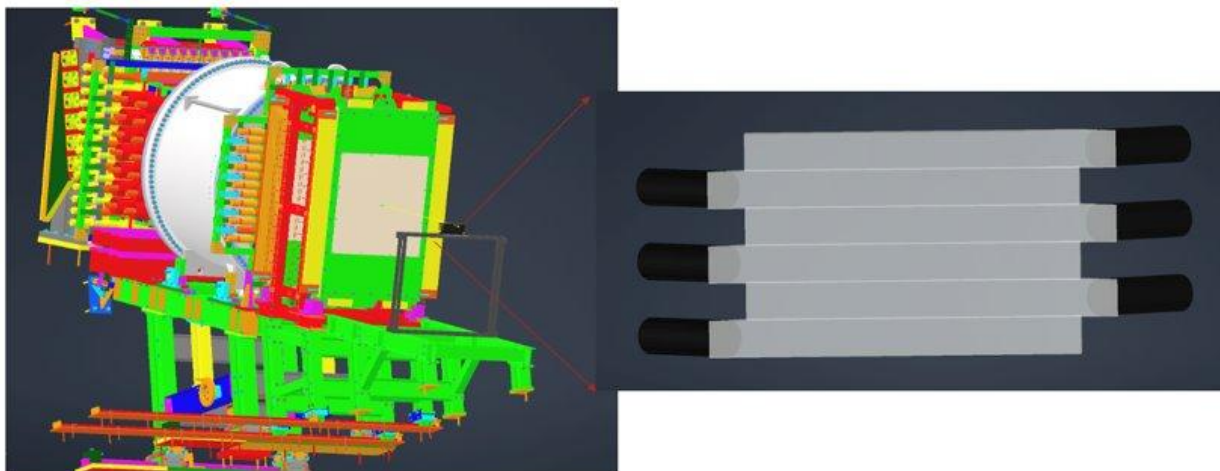
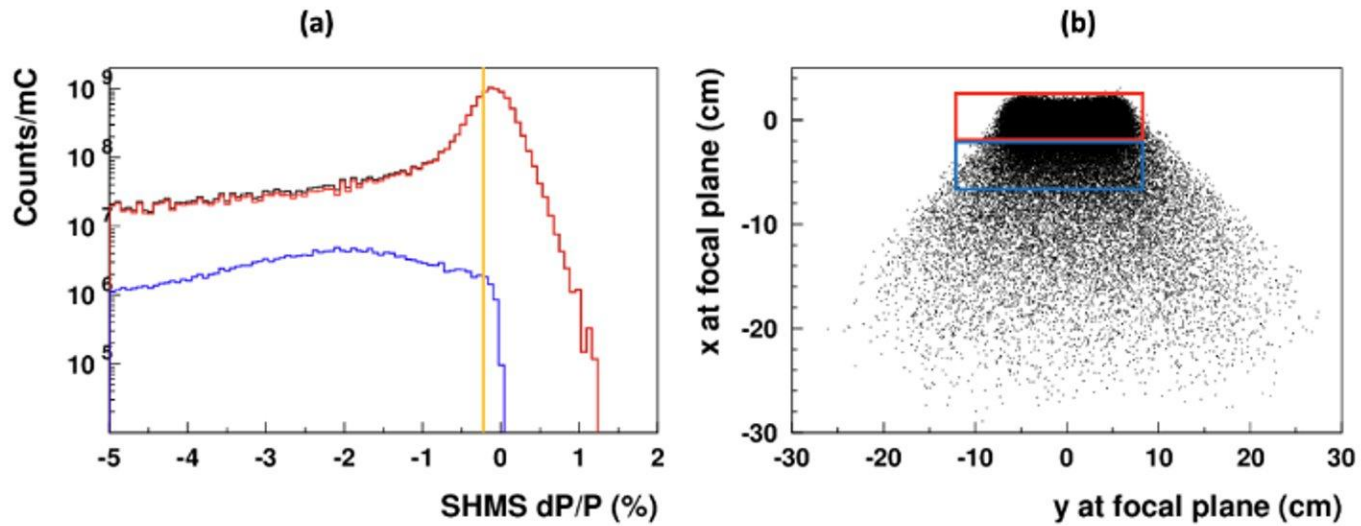
Inelastic nuclear states

- Some of the targets have low lying inelastic nuclear states that could have a sizeable asymmetry
 - The rate contributions of each of these states can be estimated from existing experimental data and are much smaller than the elastic signal at this Q^2
 - Our systematic budget includes a conservative estimation of these possible asymmetries and their subtraction from the result
 - This analysis procedure was established by the Qweak A127 A_T publication
- The scans will allow for multiple measurements that will empirically test this approach (possibly even determining the combined asymmetry of these nuclear excited states)



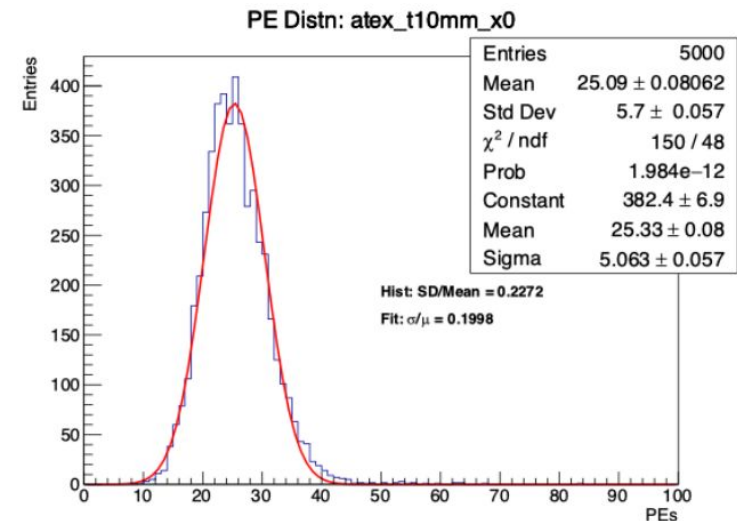
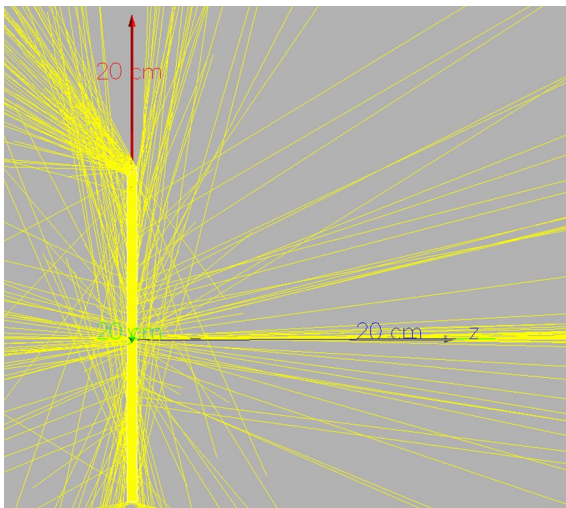
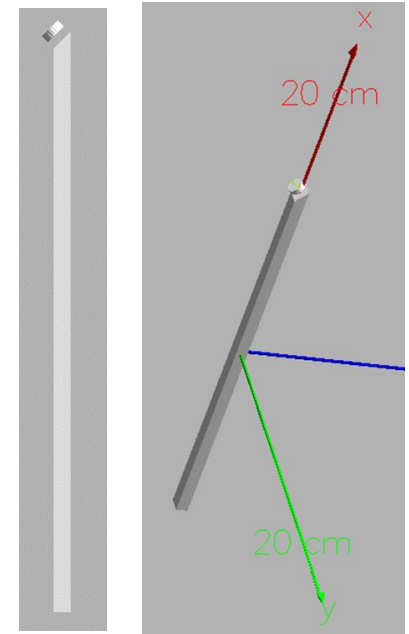
J. Phys. G: Nucl. Phys., Vol. 1, No. 5, 1975

Focal plane detectors



Optical simulations for the detector

- Quartz:
 - Dimension: 200 mm x 8 mm x 10 mm
 - Glisur surface, ground finish, polish level 0.98
- PMT:
 - Hamamatsu R2496
 - Quartz window: 10 mm radius, 3mm thick, positioned 0.5 mm from the bevel
 - Bialkali photocathode, 8 mm active diameter
 - Quantum efficiency used from factory data sheet
- Qsim:
 - E-beam : 1 GeV



Optics setup, DAQs, beam modulations, beamline elements etc

- **Optics:**
 - We will use sieve collimator and 12C target to set up the spectrometer optics
 - CH2 target will be used for accurate measurement of Spectrometer angle

- **Beamline elements for Parity experiments:**
 - All the hardware for beam modulation exists, need to re-establish connection and test their functionality. Working with the I&C for that.

- **DAQ:**
 - A new parity DAQ is set up. That will be used for production
 - Standard SHMS DAQ for the commissioning and Q2 measurements

- **Analysis:**
 - Production data - The PREX/CREX framework
 - Hall C analyzer for the commissioning and Q2 measurements

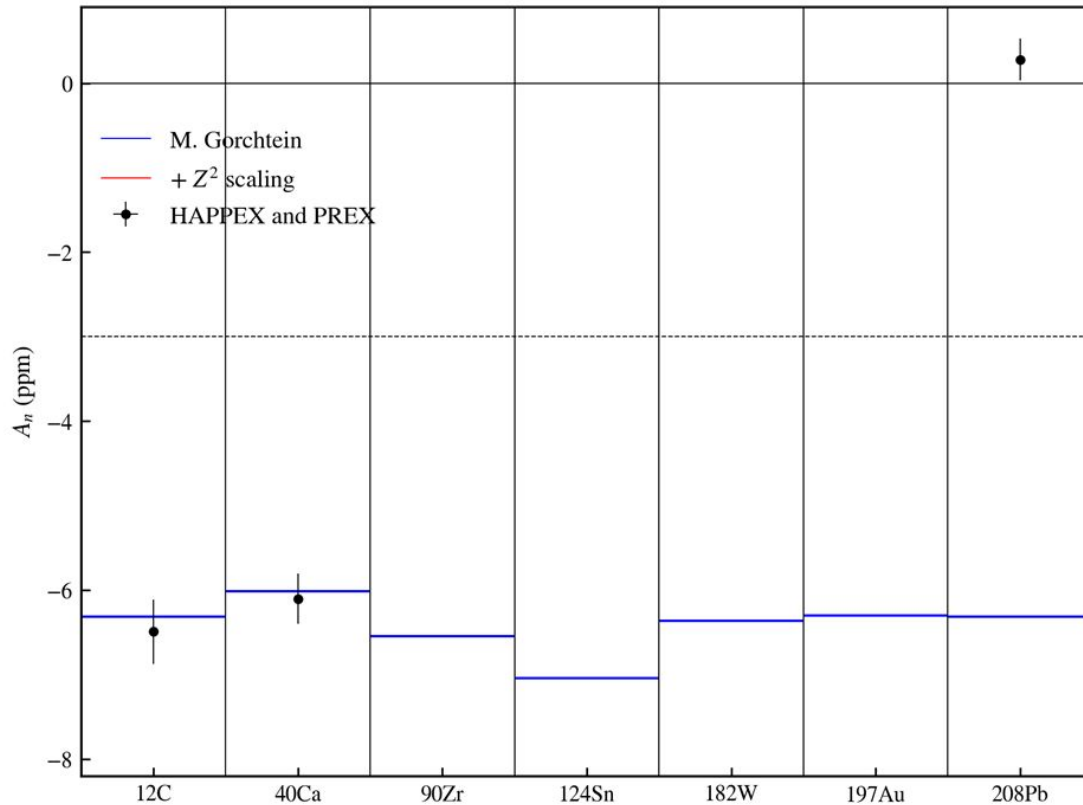
Systematic uncertainties

Effect	Uncertainty [ppb/percent]	PREX-2 A_n achieved [ppb]
Inelastic contributions	130 / 2.2%	≤ 10
A_{false}	100 / 1.6%	≤ 80
Polarization	70 / 1.1%	≤ 60
Detector non-linearity	50 / 0.8%	≤ 30
Target impurities	50 / 0.8%	≤ 40
Total	192 / 3.2%	≤ 113
Statistical precision	500 / 8.3%	-

The experiment takes advantage of recent progress made in the setup of the parity quality beam and analysis techniques used for parity experiments.

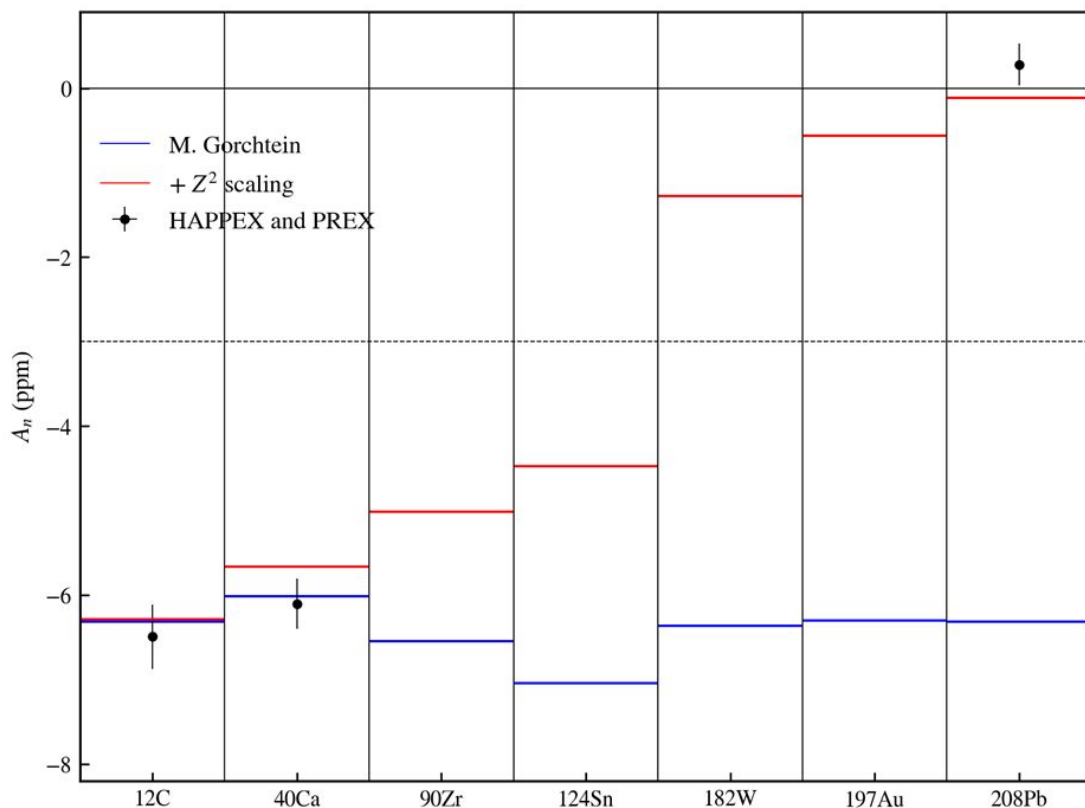
The systematic budget is more conservative than what was obtained just a few years ago with PREX-2 and CREX.

Projected Results



- TPE calculations suggest 6-7 ppm asymmetries for all targets at the proposed kinematics

Projected Results



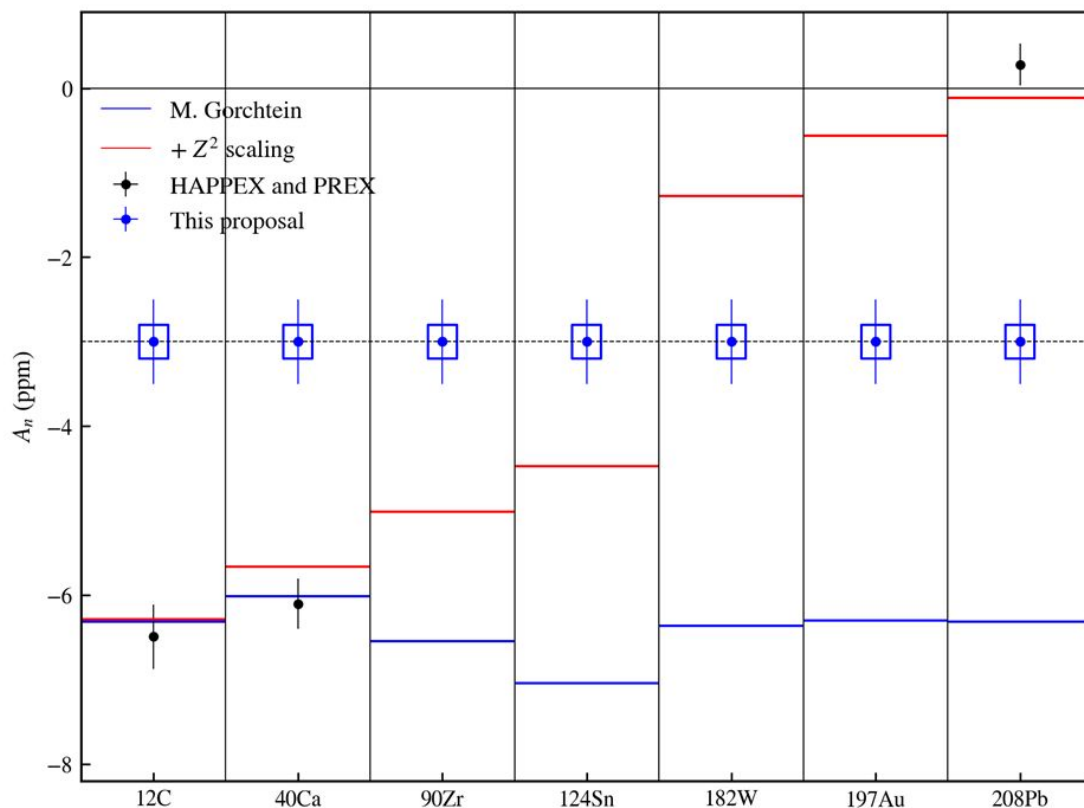
- TPE calculations suggest 6-7 ppm asymmetries for all targets at the proposed kinematics

- Empirical determination of asymmetry suppression assuming correction:

$$A_n \approx A_0(Q)(1 - C \cdot Z^2 \alpha)$$

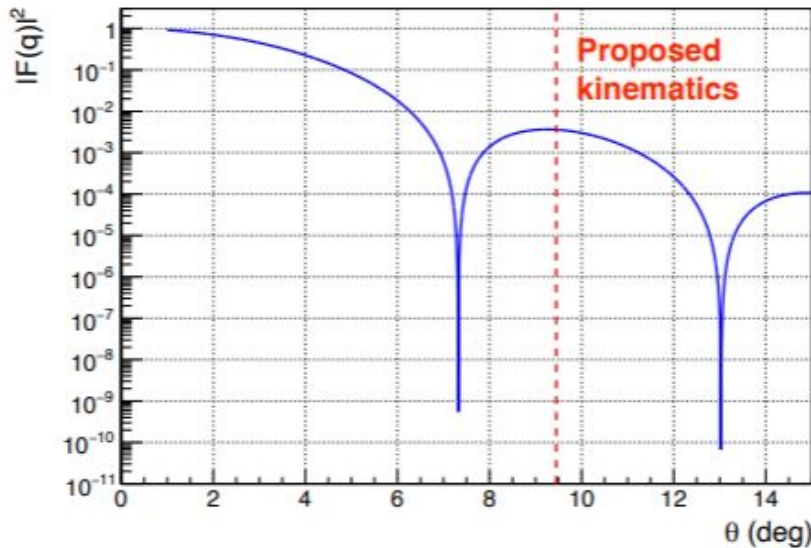
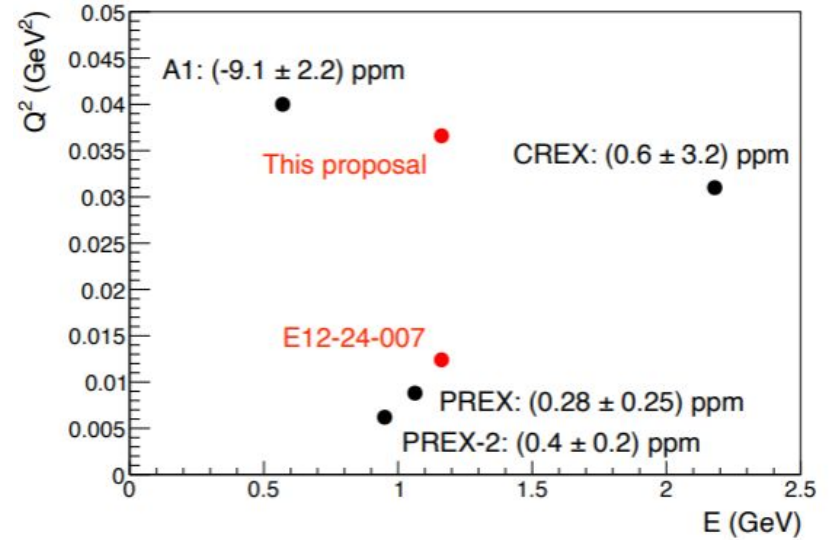
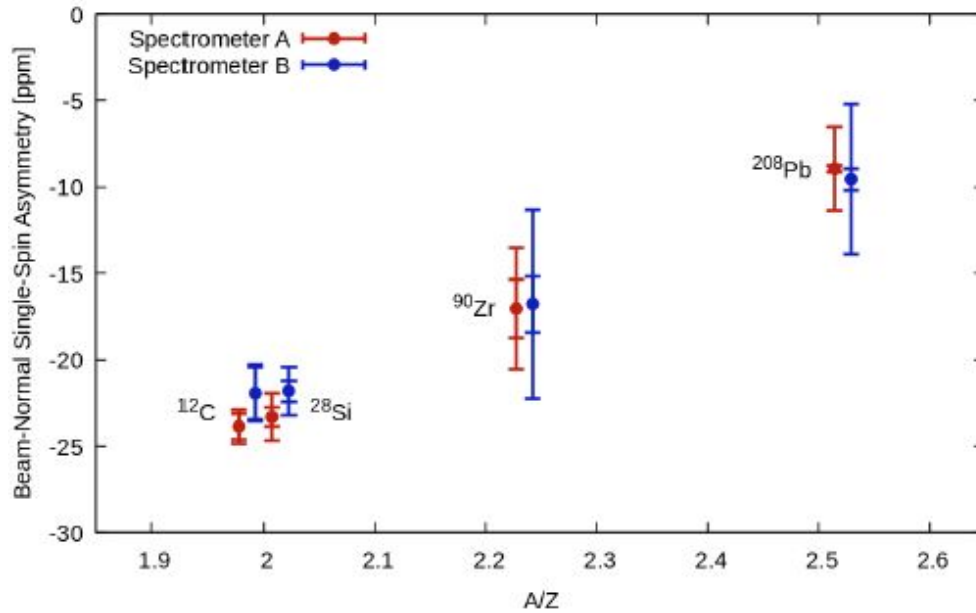
$$C = 0.02$$

Projected Results



- TPE calculations suggest 6-7 ppm asymmetries for all targets at the proposed kinematics
- Empirical determination of asymmetry suppression assuming correction:
$$A_n \approx A_0(Q)(1 - C \cdot Z^2 \alpha)$$
$$C = 0.02$$
- The precision proposed in this experiment will allow studying the nuclear dependence of the asymmetry

New proposal (PR12-26-002) in the PAC54



- ~1 GeV beam on a ^{208}Pb target for 10 days
- SHMS @ 9.45 deg.
- Beam current ~ 60 μA .
- Asymmetry goal ~ ± 1.5 ppm.

Summary

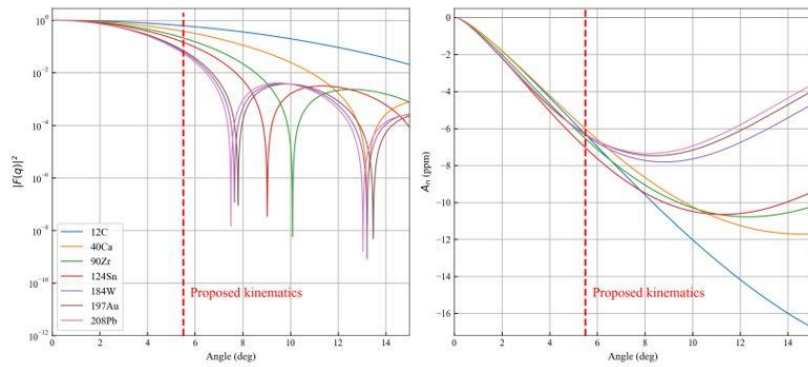
- **Presented a picture of our current understanding of the beam-normal single spin asymmetry (BNSSA)**
 - Gave an introduction of BNSSA
 - Existing data of AT on nuclear targets
 - Current puzzle for the 208Pb data

- **Approved proposal (E12-24-007): Nuclear dependence of BNSSA**
 - Motivation and goal of this proposal
 - Experimental details

- **New proposal (PR12-26-002): Nuclear dependence of BNSSA**
 - Motivation of the new proposal -
 - We are hoping this will get approved and we will run this along with E12-24-007.

We are excited to run next year. Please join our effort

Thanks for the invitation and for your attention



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	^{12}C	1.063	6	0.00984	-6.49 ± 0.38
	^{208}Pb	1.063	6	0.00881	0.28 ± 0.25
Mainz [16, 17]	^{12}C	0.570	15.10	0.023	-15.984 ± 1.252
	^{12}C	0.570	23.50	0.039	-23.877 ± 1.225
	^{28}Si	0.570	23.51	0.038	-23.302 ± 1.470
	^{28}Si	0.570	19.40	0.036	-21.807 ± 1.480
	^{90}Zr	0.570	23.51	0.042	-17.033 ± 3.848
	^{90}Zr	0.570	20.67	0.042	-16.787 ± 5.688
Qweak [18]	^{12}C	1.158	7.7	0.02528	-10.68 ± 1.07
	^{27}Al	1.158	7.7	0.02372	-12.16 ± 0.85

