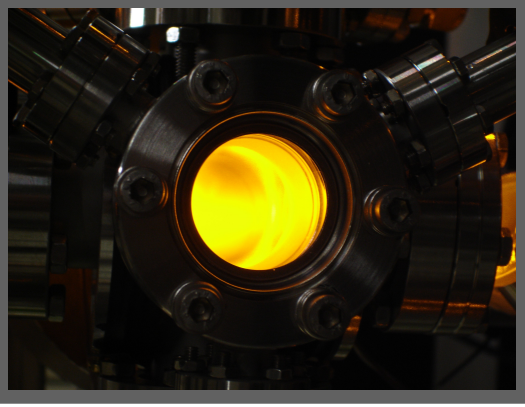
Testing Lorentz Invariance in Weak Decays

using polarized sodium atoms



Auke Sytema

J.E. van den Berg, O. Böll, D. Chernowitz, E.A. Dijck, J.O. Grasdijk, S. Hoekstra, K. Jungmann, S.C. Mathavan, C. Meinema, A. Mohanty, S.E. Müller, J.P. Noordmans, M. Nuñez Portela, C.J.G. Onderwater, C. Pijpker, R.G.E. Timmermans, K.K. Vos, L. Willmann, H.W. Wilschut

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FOM

Lorentz Invariance Violation (LIV)

- Tested by many experiments
  [V.A. Kostelecky and N. Russel, Rev.Mod.Phys.**83**(2011)11]

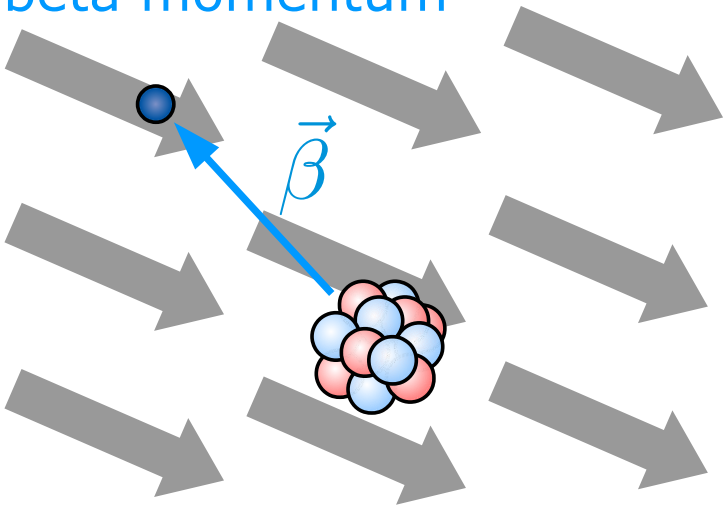
- In weak decay: very few tests and theory
  → **Experimental and theoretical program started**

- Lorentz invariance
  → Rotational invariance
  → Angular momentum conservation

Rotational invariance violation

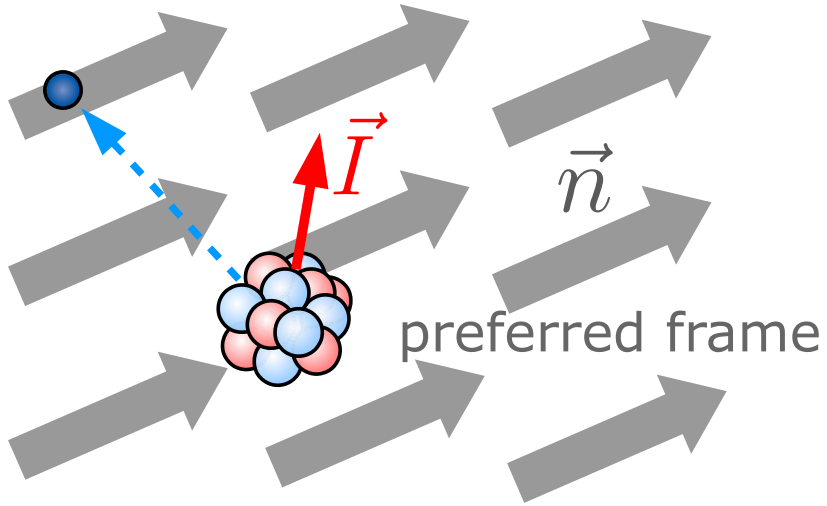
possible dependence on vector orientation

beta momentum



Measured in '70s
R. Newman and S. Wiesner, PRD**14**(1976)1
J.D. Ullman, PRD**17**(1978)1750
Reanalyzed by theory
J.P Noordmans *et. al.*, PRL**111**(2013)171601

nuclear polarization



First test performed
S.E. Müller *et al.*, PRD**88**(2013)071901R
Second experiment
New limits

Principle

polarization degree

nuclear polarization direction

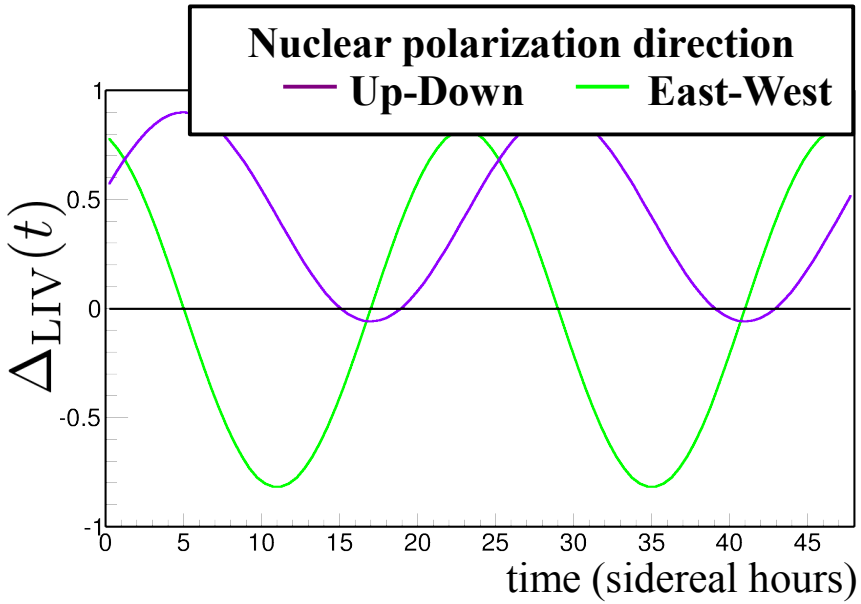
$$\frac{d\Gamma}{\Gamma_0} = \underbrace{1 + A\vec{\beta}\cdot P\hat{I}}_{d\Gamma_{\rm SM}/\Gamma_0} + \underbrace{\vec{n}\cdot P\hat{I}}_{d\Gamma_{\rm LIV}/\Gamma_0} \rightarrow \text{Measure } \Delta_{\rm LIV}(t) \equiv \frac{\Delta\tau(t)}{\tau^{\rm lit.}}\frac{1}{P(t)}$$

Measure polarization

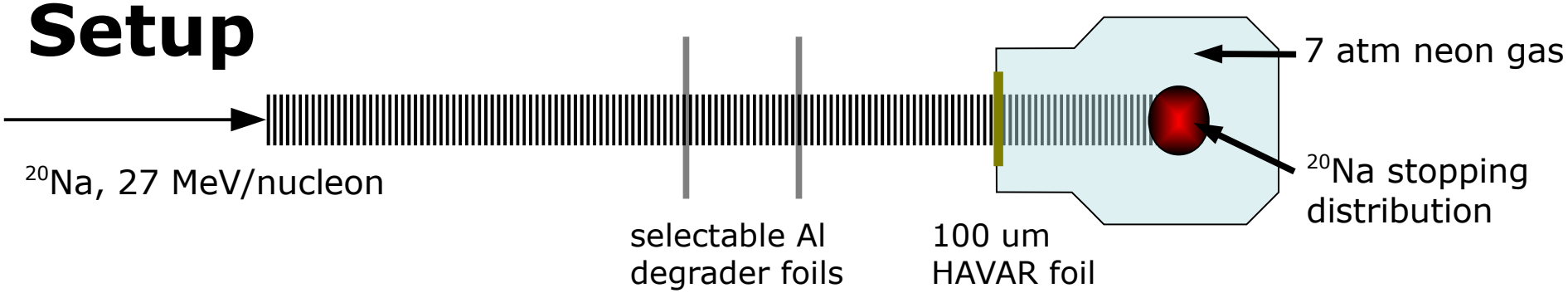
χ **tensor framework**

- $n_k = A\epsilon_{ijk}\Im(\chi^{ij})$
- transform to Sun-centered frame

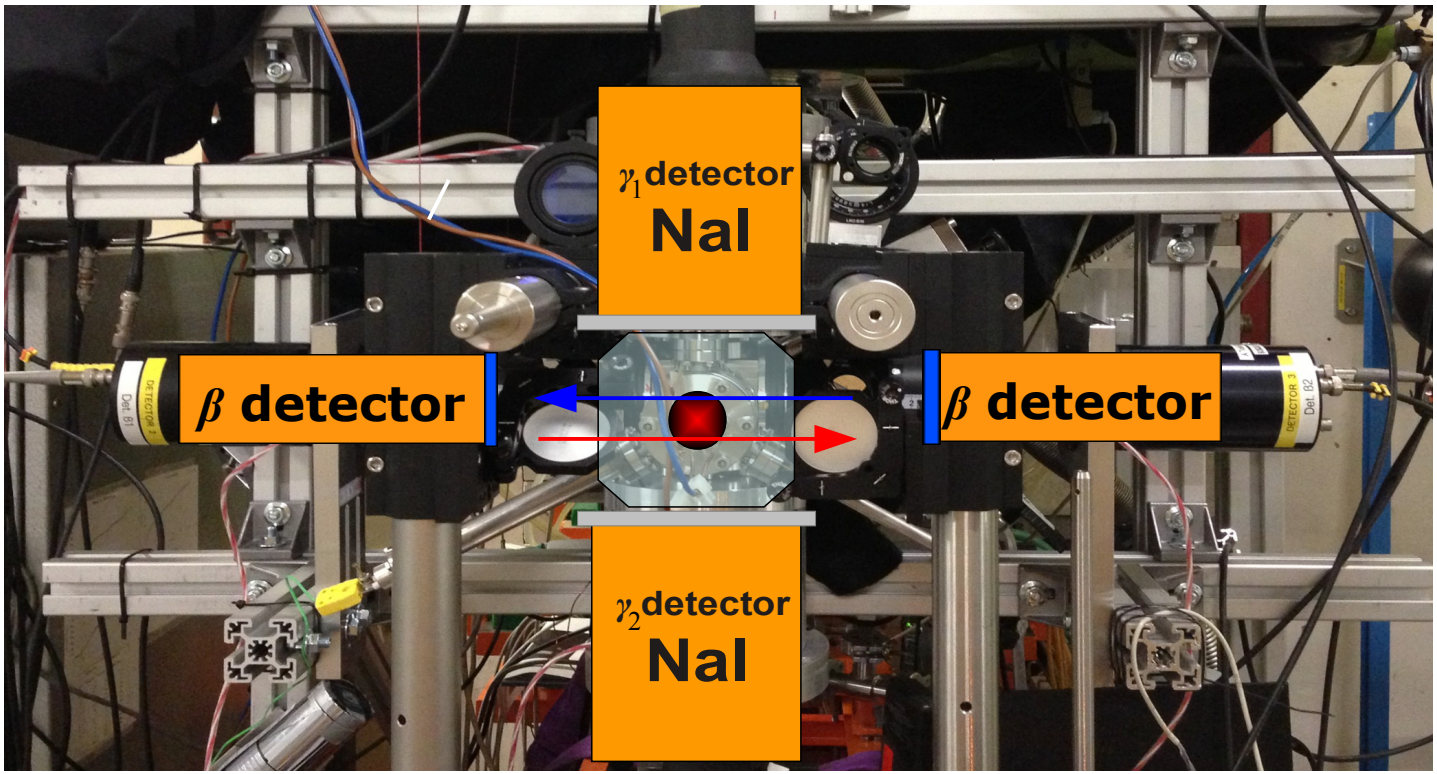
Example for galactic direction ($l = 83^o$, $b = 34^o$)



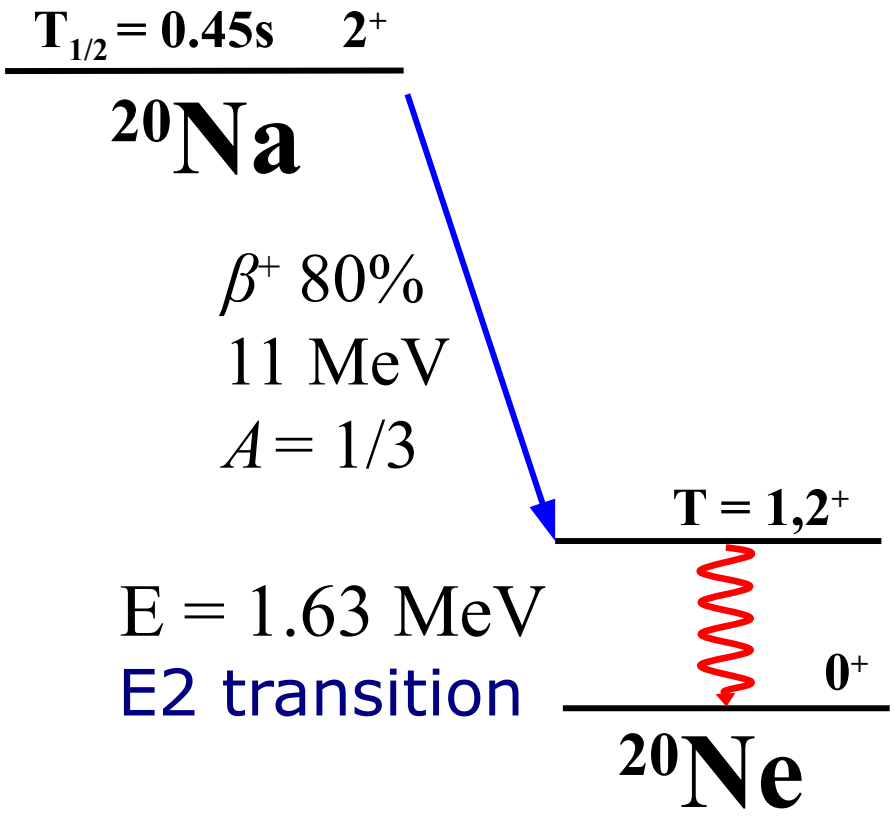
Setup



both particle beam and laser helicity are switched



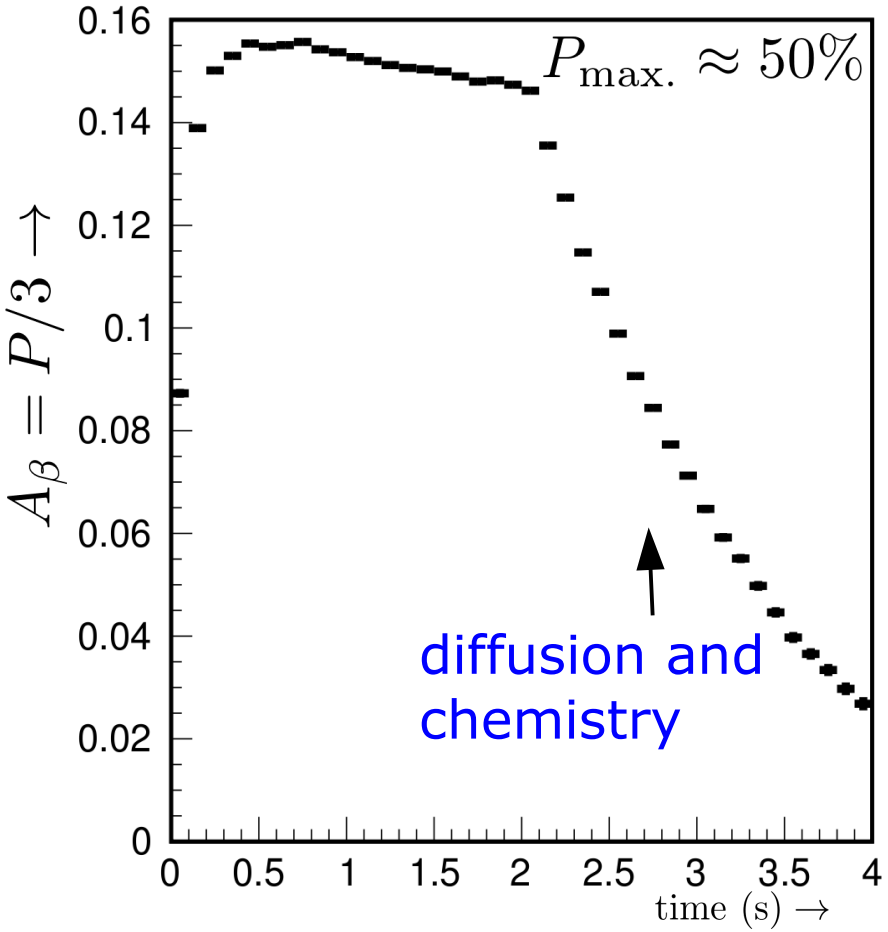
^{20}Na decay



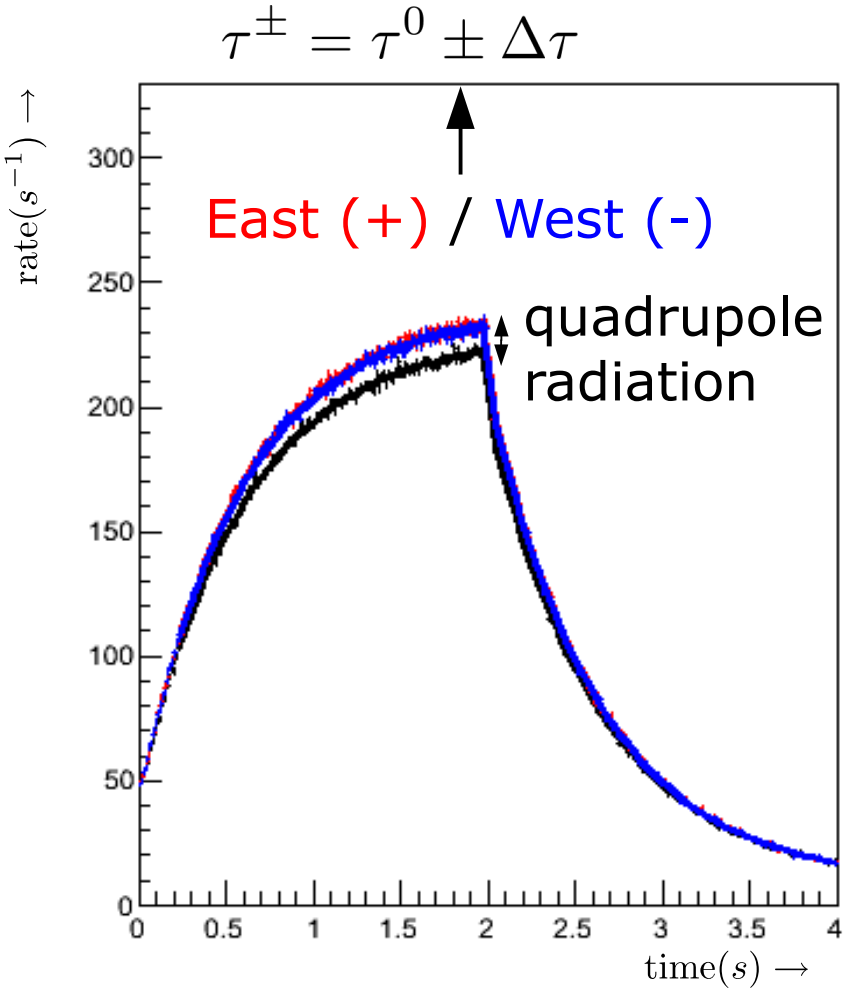
Measure high energy
$\beta^+ \,//\, P\hat{I}$
→ **Measures polarization**

Gammas measure **rate variation due to** $\vec{n} \cdot \hat{I}$
(assumes LI in EM decay)
→ **Measures LIV**

Polarization from β asymmetry



$\Delta_{\mathrm{LIV}}(t)$ from $\Delta\tau$



Systematic shifts and uncertanties

Driven by temperature fluctuations

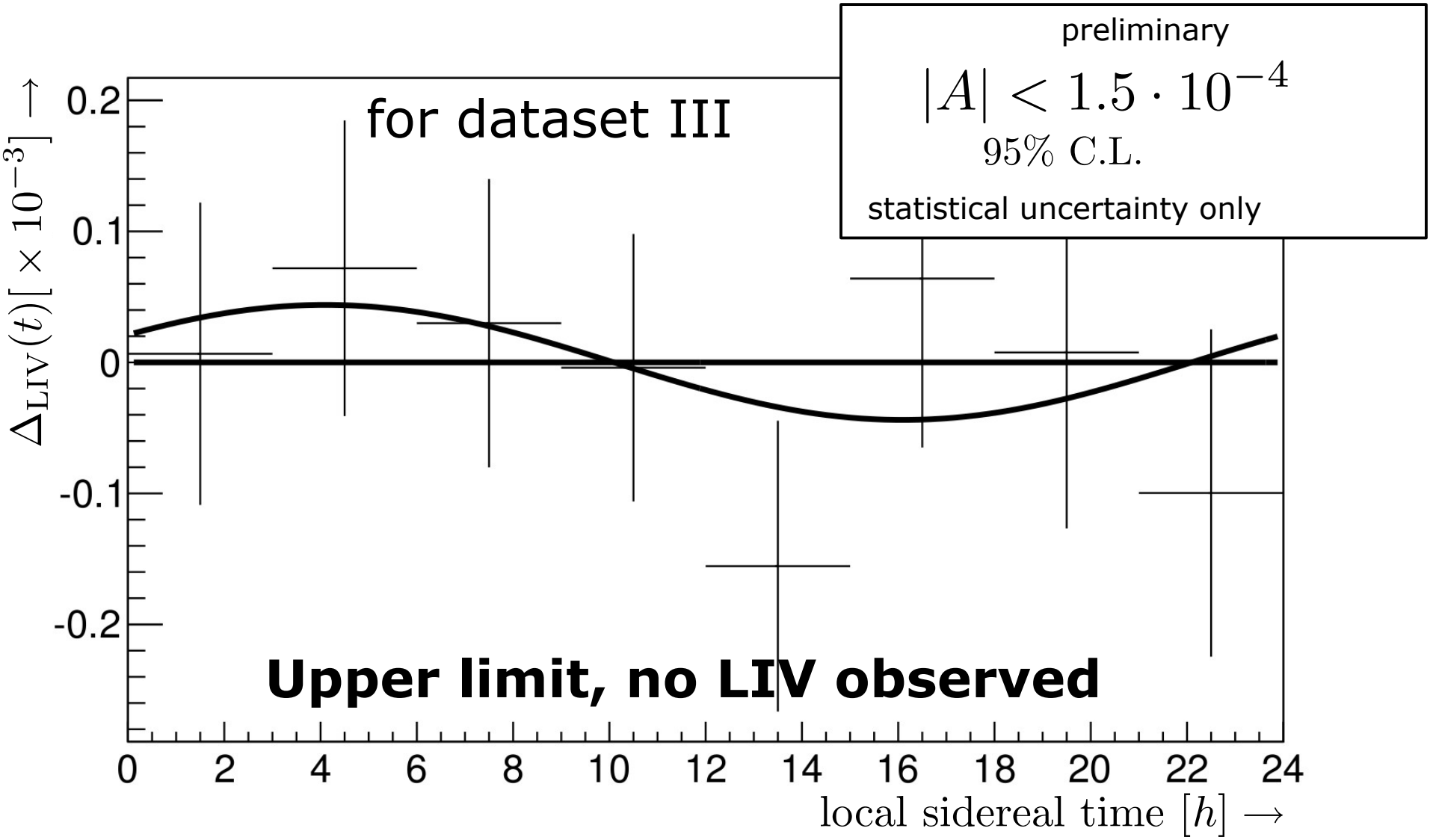
- ^{20}Na diffusion, detectors, laser, electronics
- systematics correlated → corrected for

Temperature and pressure during experiment measured

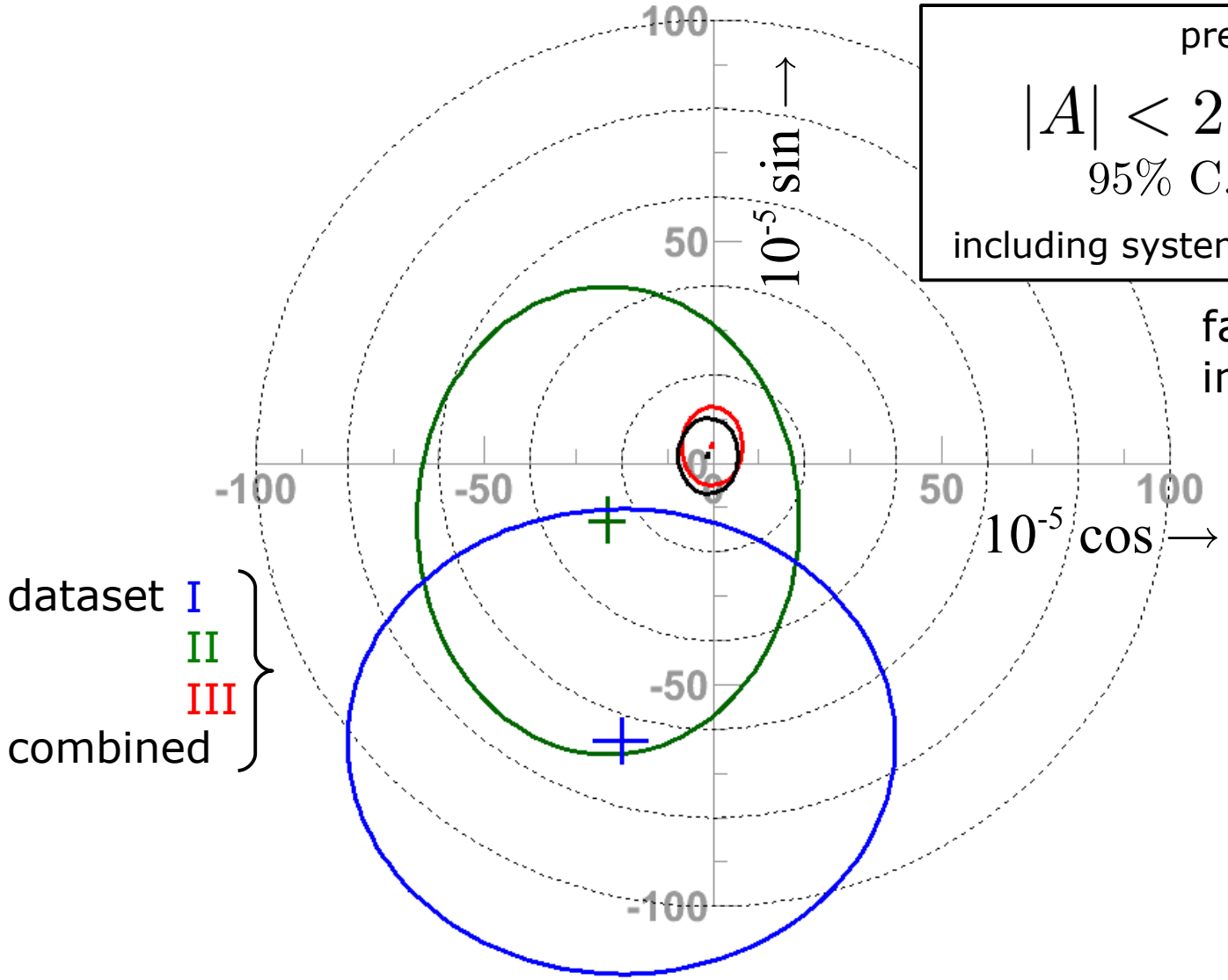
- $A_{\text{temp.}}^{\text{peak-peak}} < 2^\circ\,\text{C}$
- $A_{\text{temp.}}^{\text{sid.}} = O(10^{-2})^\circ\,\text{C}$

amplitude of temperature variations
at sidereal frequency

Results after unblinding



LIV bounds



preliminary

$$|A| < 2 \cdot 10^{-4}$$

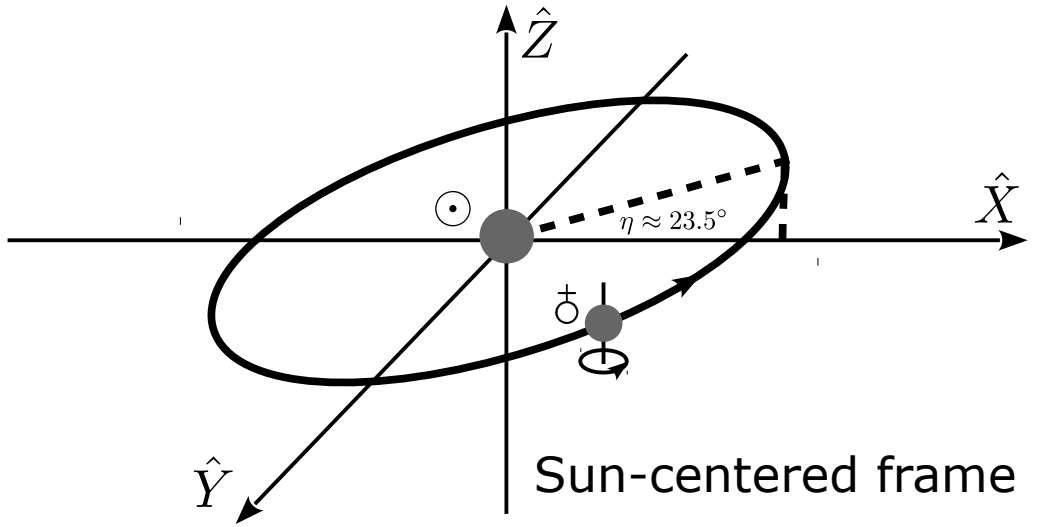
95% C.L.

including systematic uncertainties

factor 15 improvement!

LIV limits

Description	Coefficient	90% C.L.
sidereal variation $\frac{\Delta\tau}{\tau}\frac{1}{P_{\rm eff}}$	$\lvert A_{\rm LIV}\rvert$	
	this work	$< 2\times10^{-4}$
	previous work	$< 3\times10^{-3}$
χ tensor and SME	$\lvert(X_i)^X\rvert = \lvert(k^A_{\phi\phi})^{YZ} + \frac{1}{2g}(k_{\phi W})^{YZ}\rvert$	$< 3\times10^{-4}$
	$\lvert(X_i)^Y\rvert = \lvert(k^A_{\phi\phi})^{XZ} + \frac{1}{2g}(k_{\phi W})^{XZ}\rvert$	



Conclusion

- **Unique test of LIV in the weak decay**
- Improvements over first experiment, systematic errors eliminated or reduced
- New limit on nuclear polarization dependent LIV in beta decay
  → O(10) sensitivity increase
- Publication in preparation