# *Testing Lorentz Invariance in weak decay of $^{20}$Na atoms*

Katsunori Yai, Elwin Dijck,
Stefan Müller, Gerco Onderwater,
Hans Wilschut, Rob Timmermans

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KVI, University of Groningen
The Netherlands

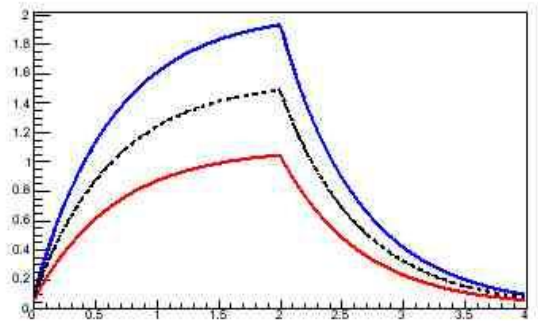
# Outline

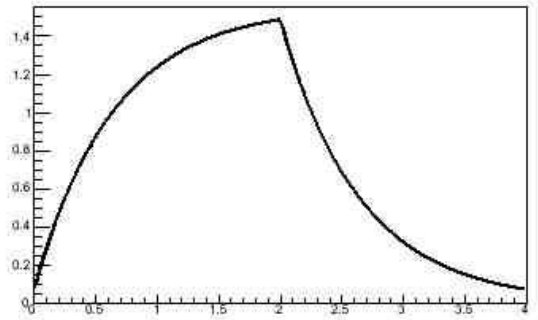
- Ideal Form
- Theory
  - What is the Lorentz Symmetry?
  - Lorentz Invariance Violation
- Experiment
  - Approach

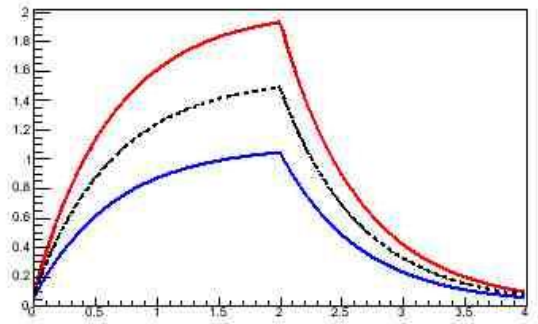
1. Production : $^{20}Ne(p,n)^{20}Na$
2. Stopping : Al foil & HAVAR foil & ~2atm of Ne gas
3. Polarization : optical pumping
4. Detection : $^{20}Na \rightarrow {}^{20}Ne + e^{+} + \nu_e$
   NaI-detectors ($e^{+}$) and Ge-detector ($\gamma$-ray)

  - Conclusion : beam-time 14-19/11/2011
- For Next Beam-time

# Ideal Form







- Standard Model Extension
- Hope to unite quantum mechanics and gravity
  → Lorentz Invariance Violation (LIV)
- Weak decay sector is essentially unexplored

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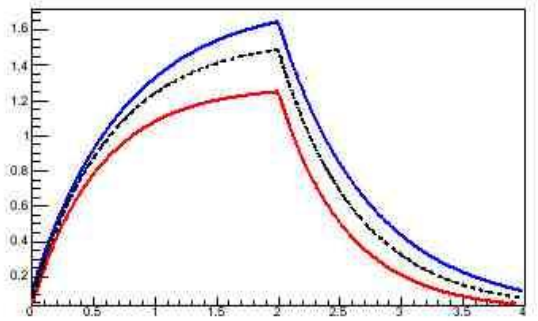
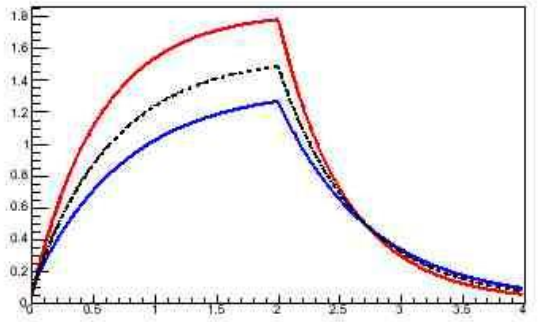
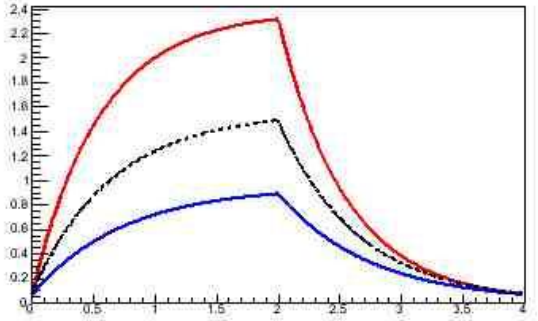
- Figure on the left : Only Parity violation
- Counting rate of β-particle
- Center : Normal signal (**black**)
- Top : polarized up (**blue**: forward spin direction,
  **red**: opposite spin direction)
- Bottom : polarized down
- Lifetimes are all the same. (LI is hold)

# Ideal Form







- Standard Model Extension
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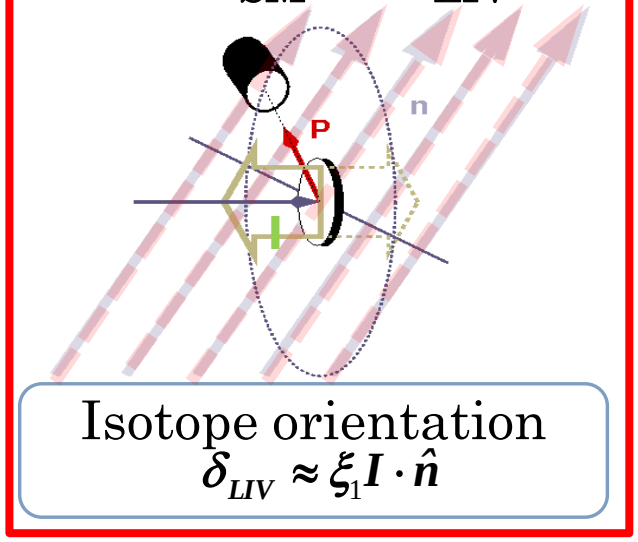
- Figure on the left : **LIV**
- Counting rate of β-particle
- Center : unpolarized LIV
- Top & Bottom : polarized LIV

- Lifetimes change with regard to nuclear spin direction if the orientation of the polarization changes.

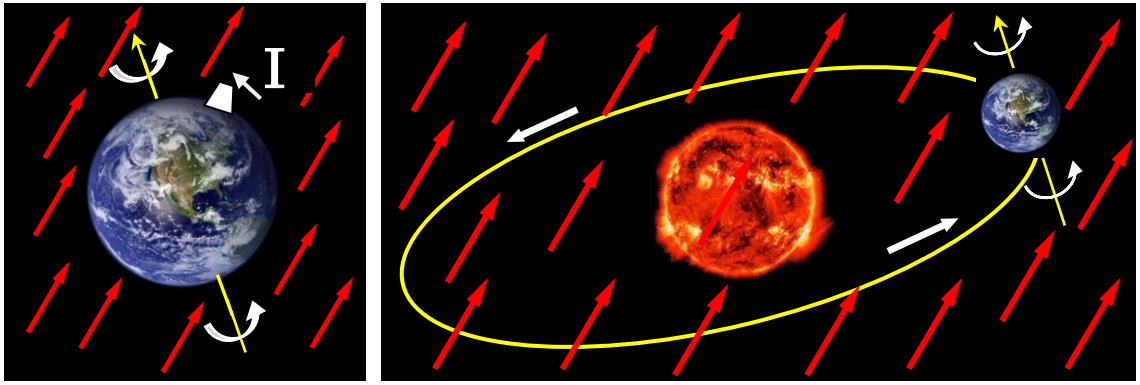
# Lorentz Invariance Violation

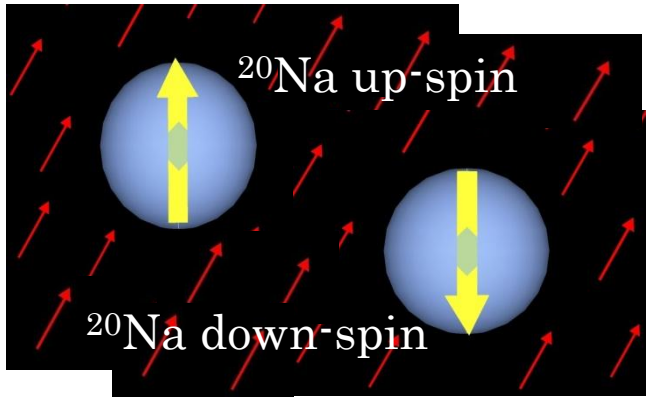
- LI : No dependence on reference frame
  - Orientation in laboratory frame
  - Earth rotation (day-night)
  - Earth revolution
    (relation to the solar system)
- LIV : made by special direction $\hat{n}$ (red arrow)

$\Gamma \sim \Gamma_{SM}(1+\delta_{LIV})$




Isotope orientation
$\delta_{LIV} \approx \xi_1 \boldsymbol{I} \cdot \hat{\boldsymbol{n}}$

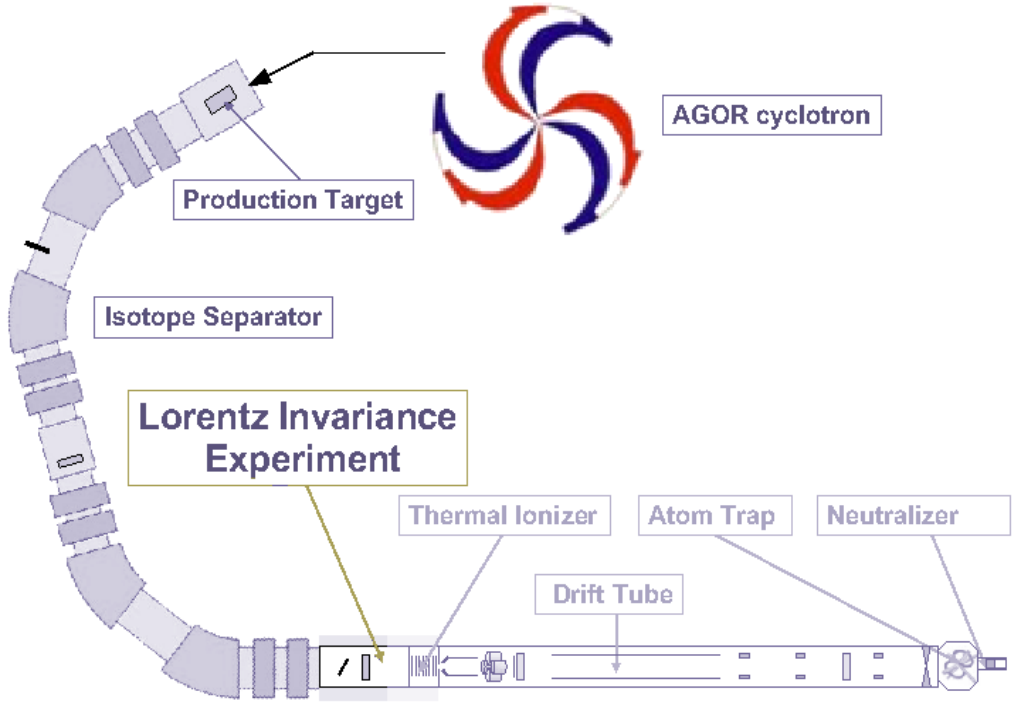


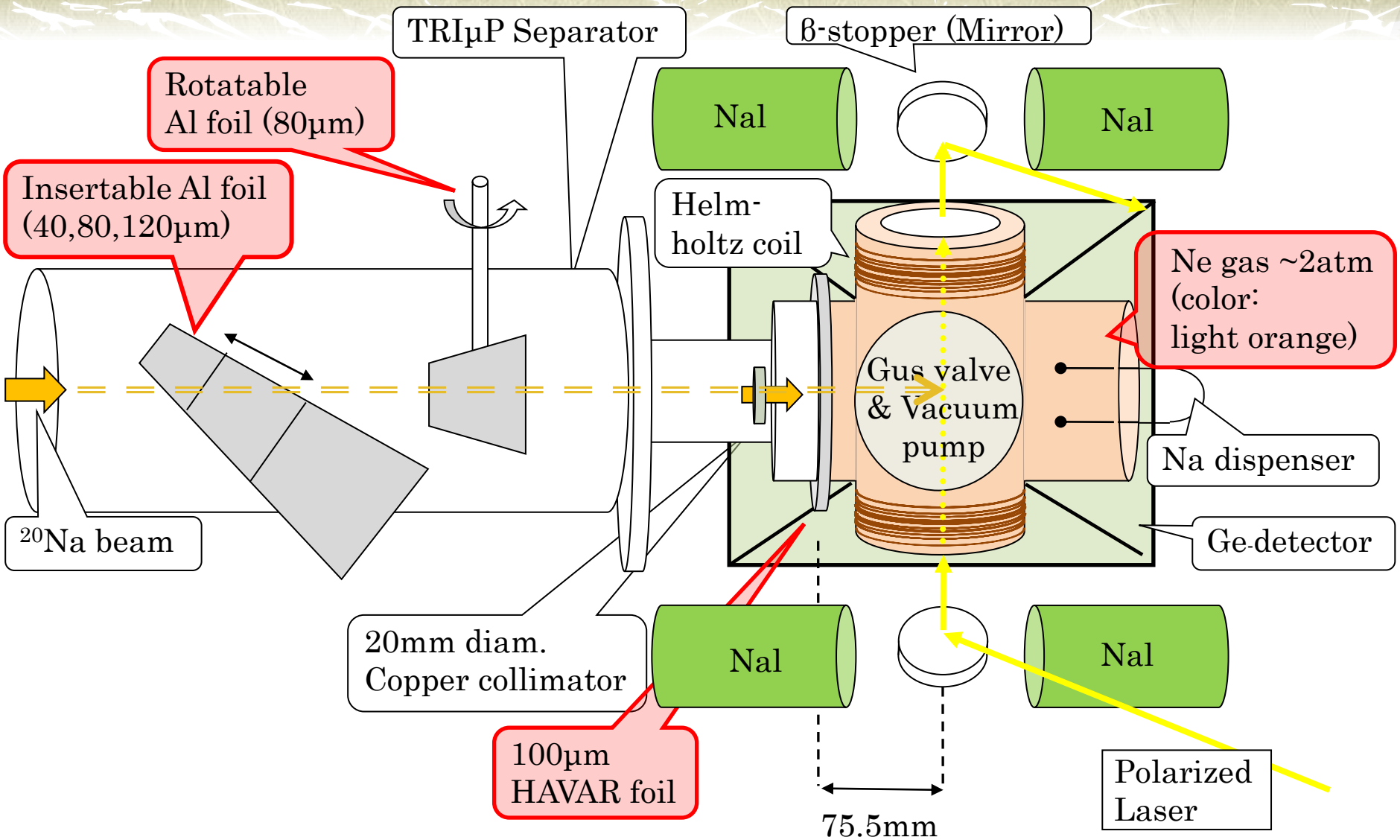

- Search for violations
  induced by various frames
  "deliberate" reorientation= **weak decays of spin-polarized $^{20}$Na**

# <Approach> 1. Production

- $^{20}Ne+p \rightarrow {}^{21}Na^{*}$ (or $^{22}Na^{*}$) $\rightarrow {}^{20}Na+n$ (or $^{20}Na+2n$)
- $t_{1/2}(^{20}Na)=0.448s$
- Junks : $^{19}Ne(t_{1/2}=17s)$, $^{18}Ne(t_{1/2}=1.67s)$
- $^{20}Na$ ~$10^{6}$/s (~$10^{4}$/s/pnA, ~100pnA)

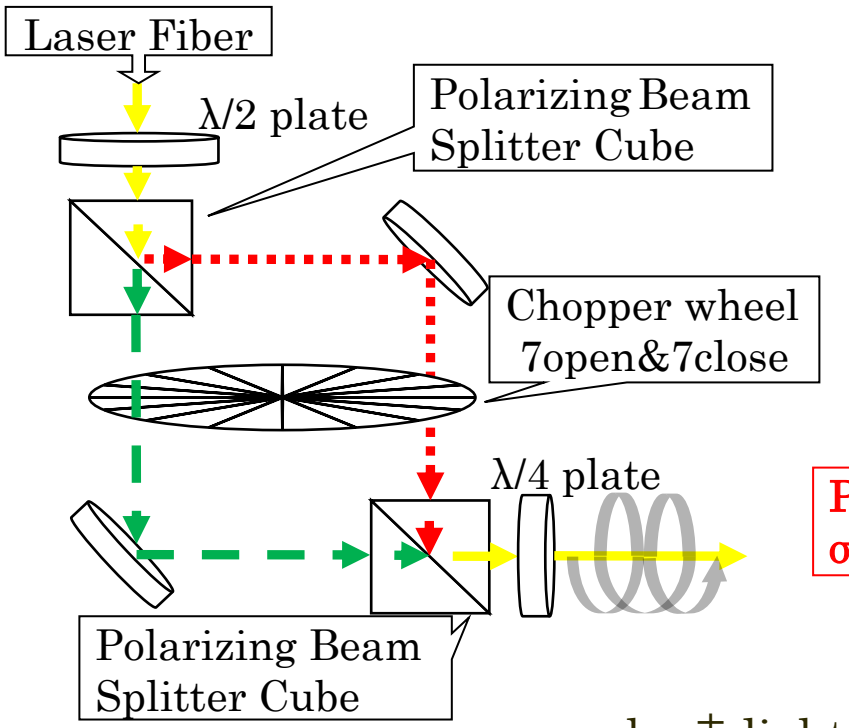



# 2. Stopping & Schematic Setup



# 3. Polarization →Optical pumping

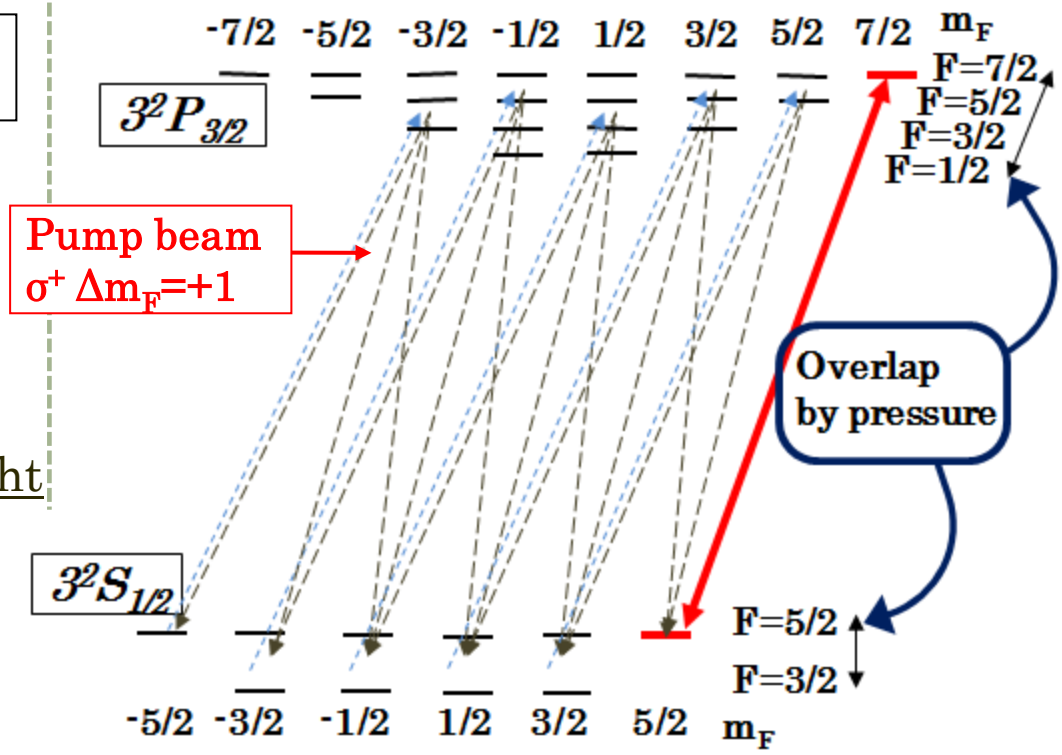
**To make polarized nuclei**




each $\sigma^{\pm}$ light

- ✓Red→vertical light
- ✓Green→horizontal light
- ✓incidents in the detector cell Alternately

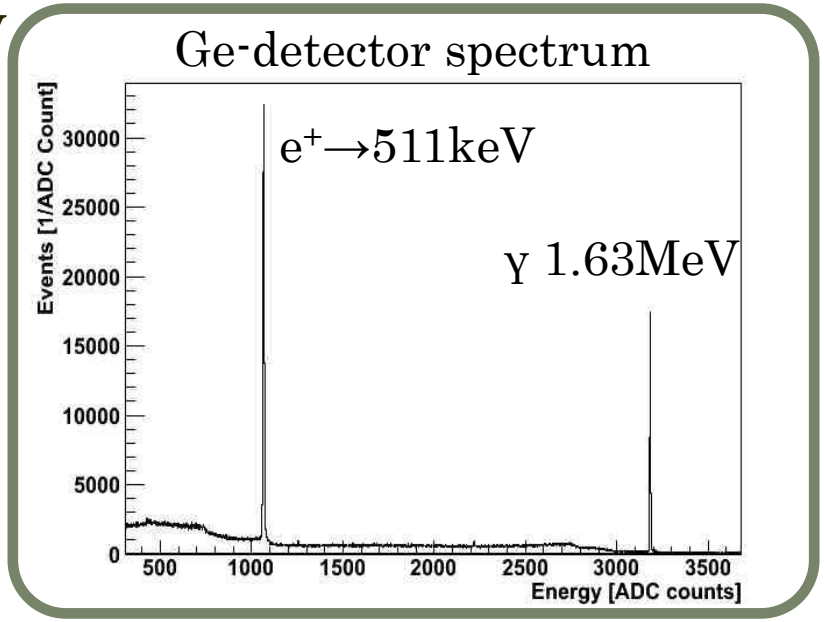
- ✓**circularly polarized $\sigma^{\pm}$ light** with 589.1nm (D2 transition)
- ✓Each laser ~200mW
- ✓Pumping rate ~75%
- ✓Required time ~several ms



# 4. Detection

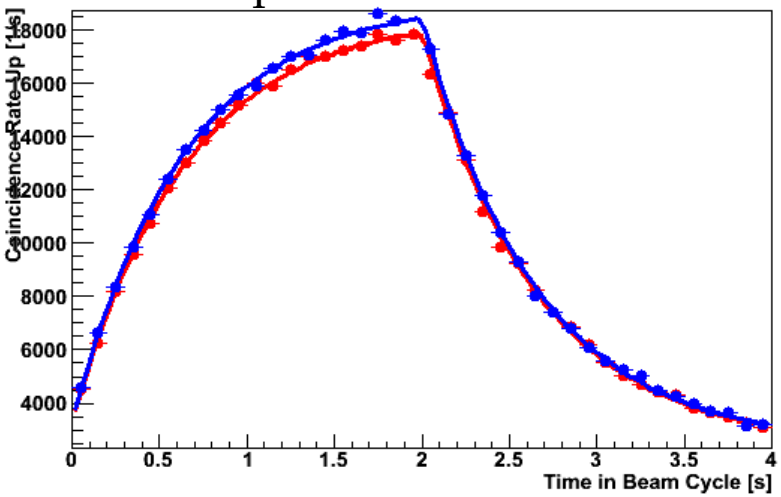
$^{20}Na \rightarrow {}^{20}Ne + e^{+} + \nu_e + \gamma\text{-ray (1.63MeV)}$

- NaI-detectors to measure 511keV γ-ray coincidences (electron-positron pair annihilation)
  - Observing Parity violating asymmetry with polarized nuclei
  - Observing further asymmetry
- Ge-detector to measure → 1.63MeV (or 511keV) γ-rays
  - Daughter nuclei decay γ-rays

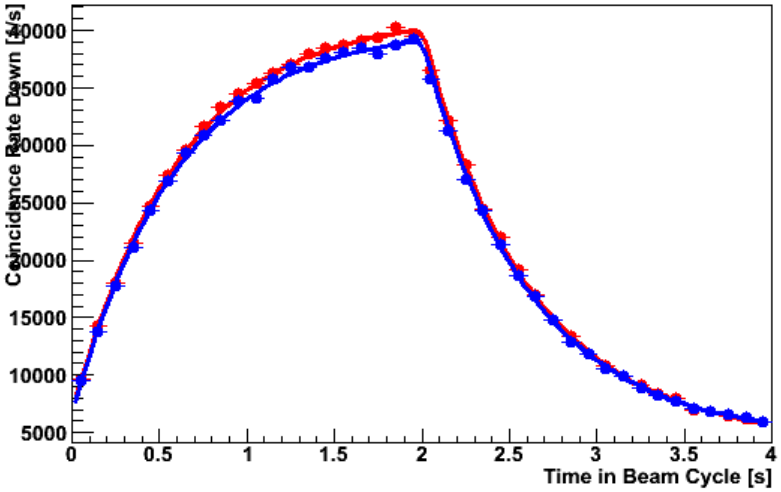


# Preliminary Beam Test & Analysis

Top NaI coincidences



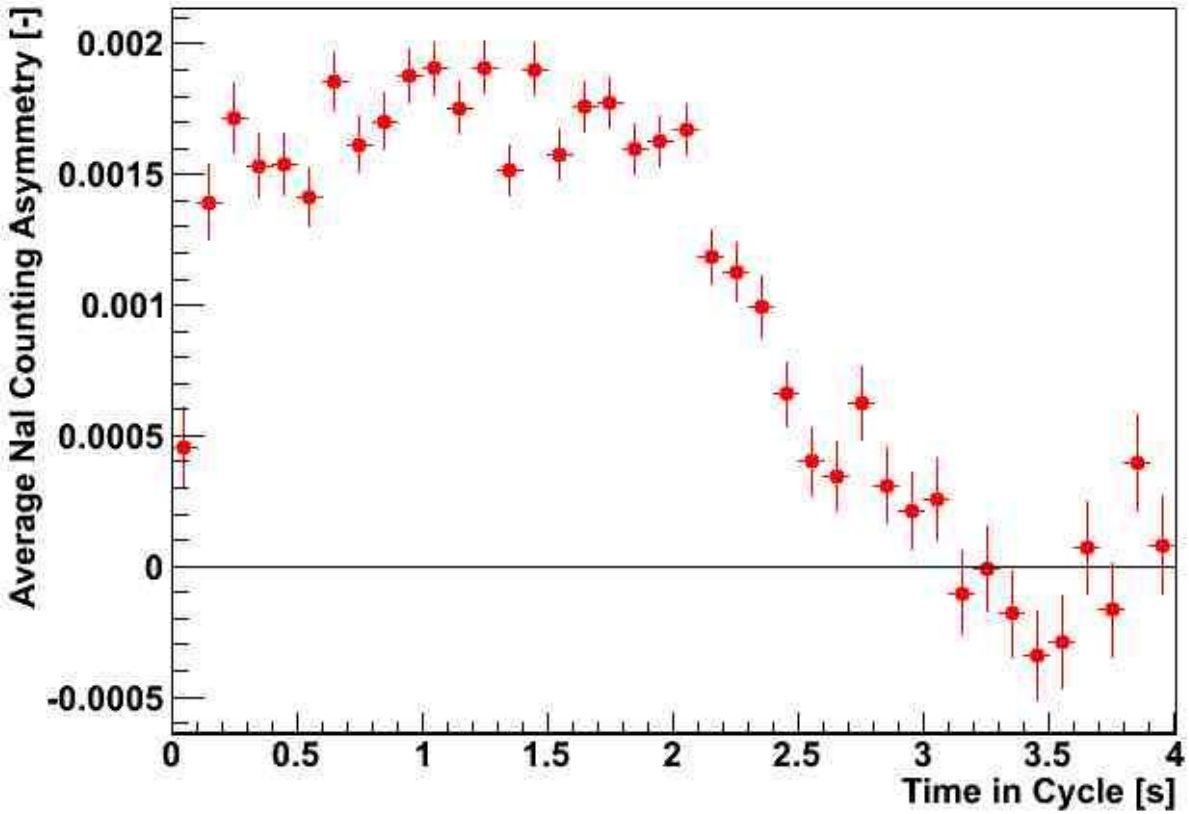

Bottom NaI coincidences




- Comparing coincidences of 511keV γ-rays
  (e$^+$annihilations from $\sigma^+$ or $\sigma^-$ polarized Na atoms' weak decay)
- Na beam: 2s ON & 2s OFF
- Most of the junks have little effect
  (because they have long half-life)

# Preliminary Beam Test & Analysis

- The average of NaI coincidences asymmetry rate ~0.15%
  (red−blue of previous slide)



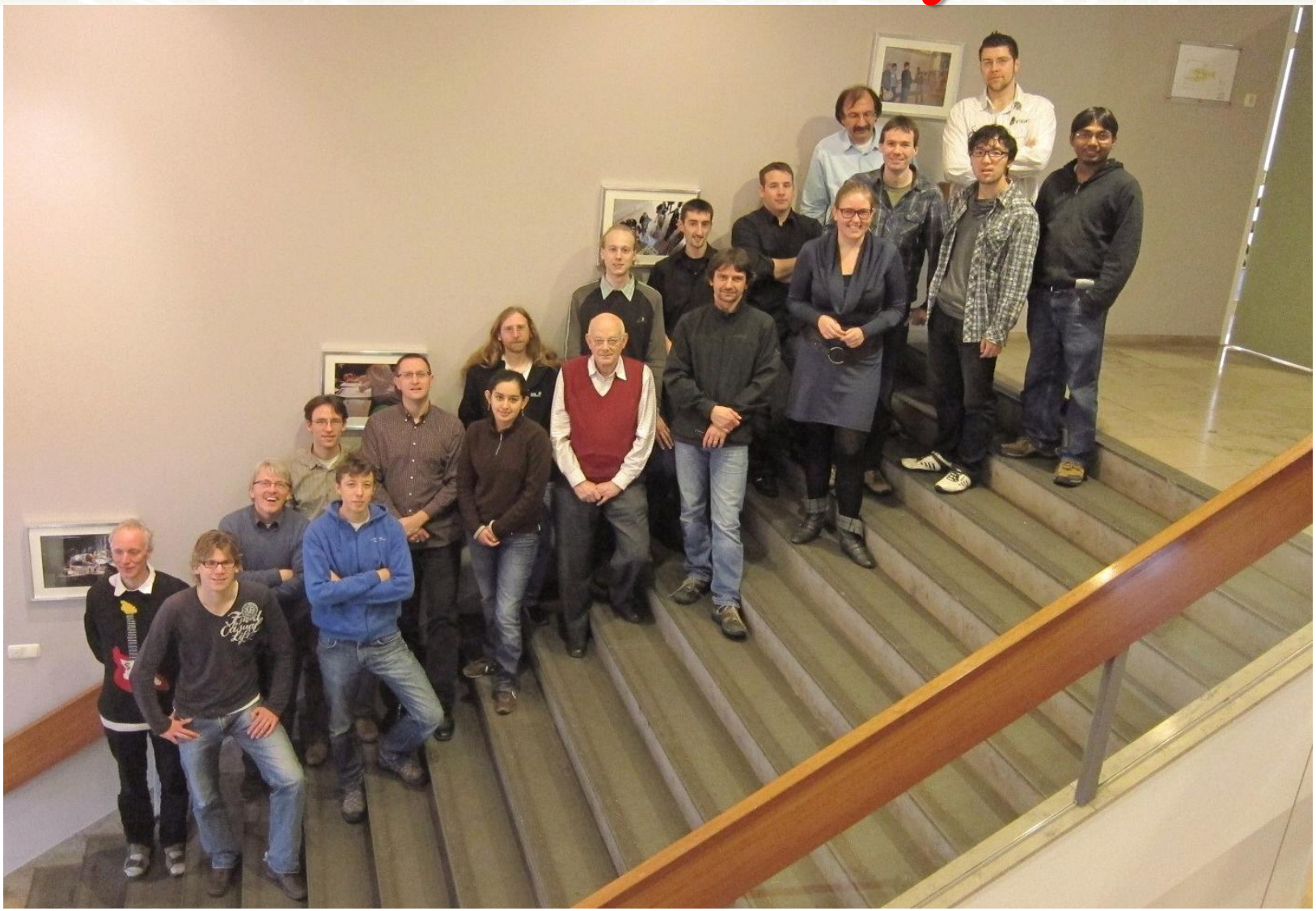

- Too small to detect LIV!

# For next beam-time

- Efficiently collecting $^{20}$Na
  - More neutralization
  - Strictly simulation to stop in the very center of Cell

  (This calculation is my work by using SRIM and Geant4)
- Efficiently polarizing $^{20}$Na
  - Adjusting wavelength (or using D1 probe laser)
  - Increasing intensity of pumping laser
- Efficiently collecting γ-ray 511keV
  - Increasing NaI-coincidences
- Purify Ne buffer gas

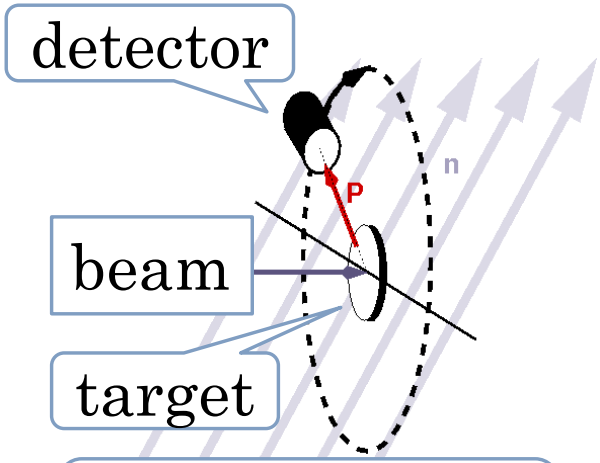
# Revenge in the next beam-time (End of January?)



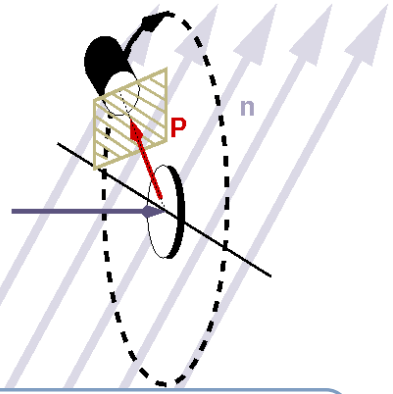
# extra

# Three generic experiments

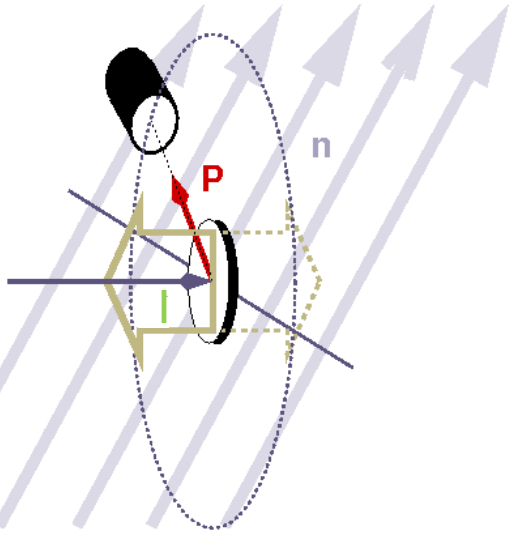
- dependence on the frame $\hat{\boldsymbol{n}}$ fixed at cosmological scale




Emission direction
$\Delta\Gamma_1 \approx \xi_1 \boldsymbol{p}\cdot\hat{\boldsymbol{n}}$




β-polarization
$\Delta\Gamma_2 \approx \xi_2 \boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$




Isotope orientation
$\Delta\Gamma_3 \approx \xi_3 \boldsymbol{I}\cdot\hat{\boldsymbol{n}}$

detect the β-decay distribution for polarized nuclei