Lorentz invariance on trial in the weak decay of polarized atoms

Stefan E. Müller

KVI, University of Groningen
the Netherlands

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Lorentz Symmetry

Lorentz symmetry is the invariance of the laws of physics under

- **rotations**
- **boosts**

It underlies

- **the theory of Special Relativity**
- **the Standard Model of Particle Physics**

Also essential component of **General Relativity**, and closely connected to **CPT symmetry**

Observation of Lorentz Symmetry Breaking would highly affect our current understanding of nature

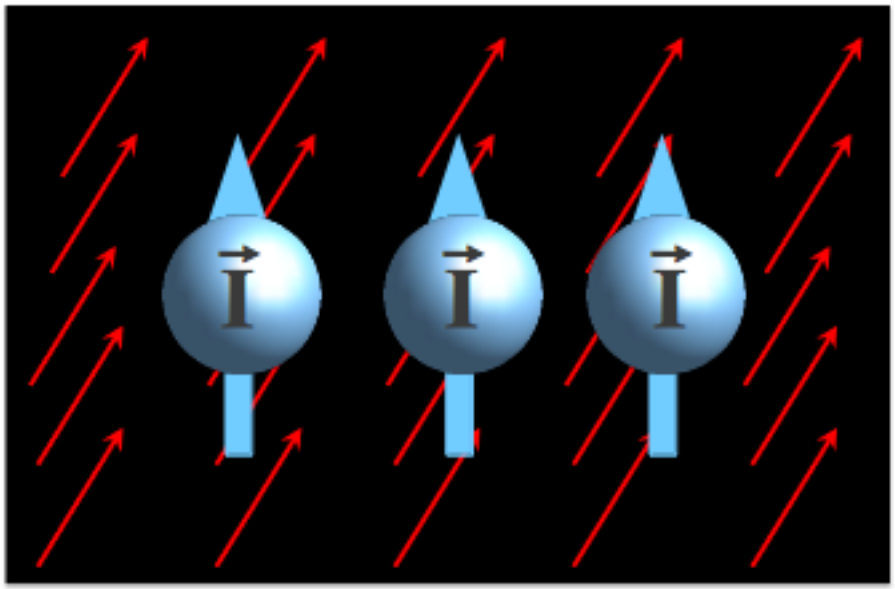
Status of Lorentz Symmetry Breaking

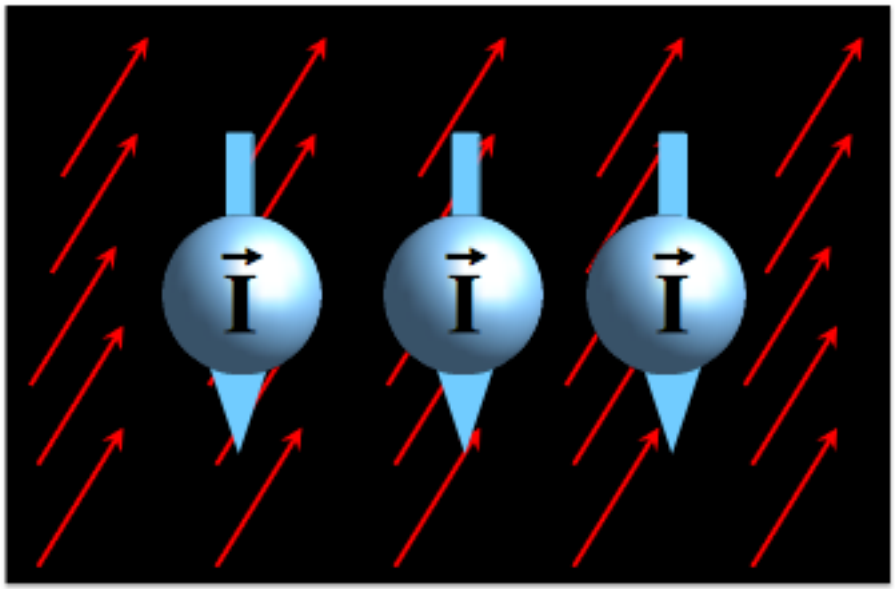
- LSB as low-energy signature of Quantum Gravity models
- Kostelecký *et al.*: **Standard Model Extension (SME)** hidden background fields connected to vacuum
- Many experimental searches, no evidence of LSB
- Tests mainly QED and gravity experiments, astrophysical observations
- Weak interaction tested in neutral meson and neutrino oscillations

Weak decay sector essentially unexplored

Lorentz Symmetry Breaking

- spin-polarized nuclei interact with hypothetical background fields





What is the change in the decay rate if the orientation of the nuclear spin changes with respect to background fields?

- search for variations induced by daily, yearly or "deliberate" reorientation of the nuclear spin

Lorentz Symmetry Breaking

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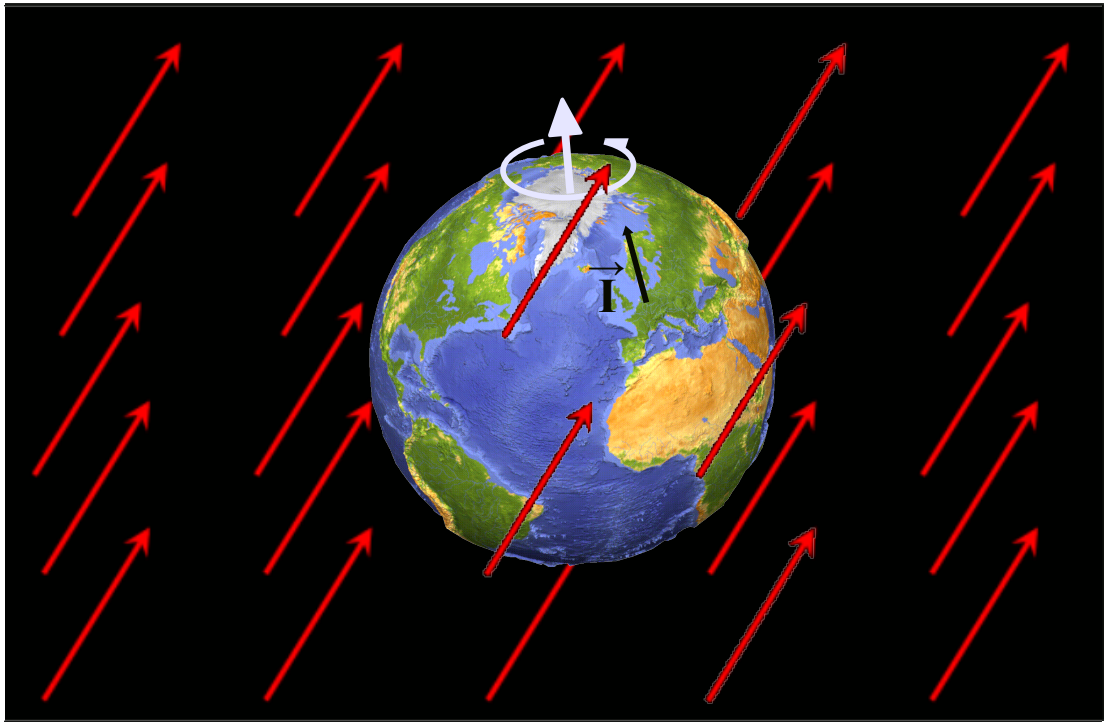

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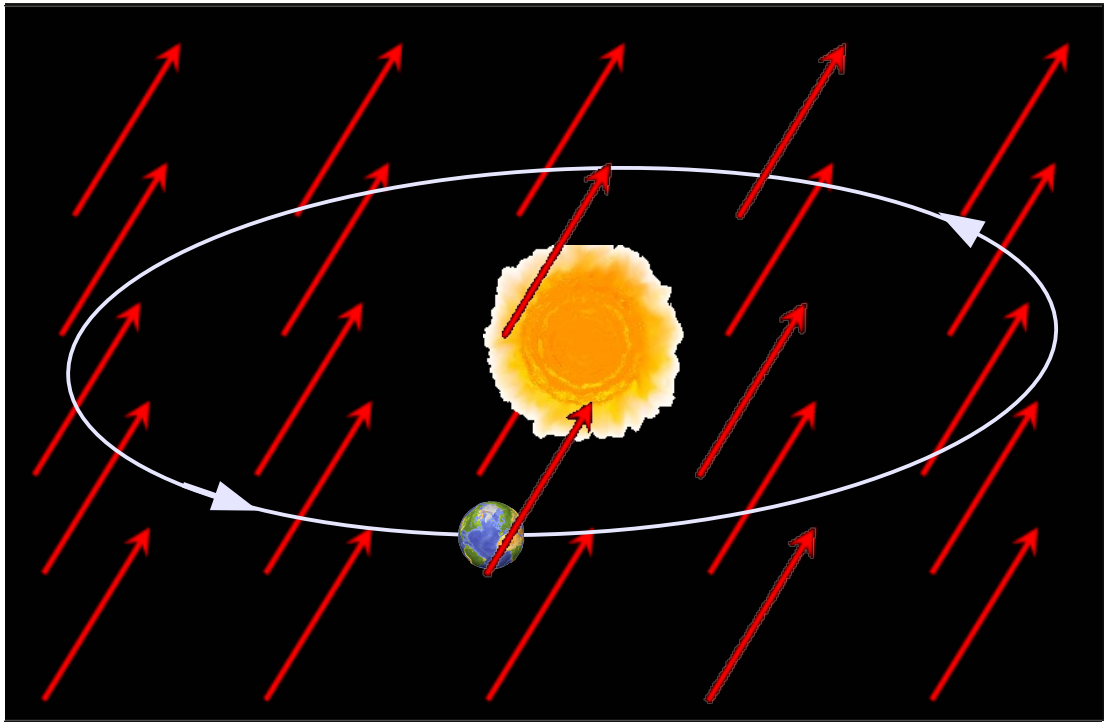

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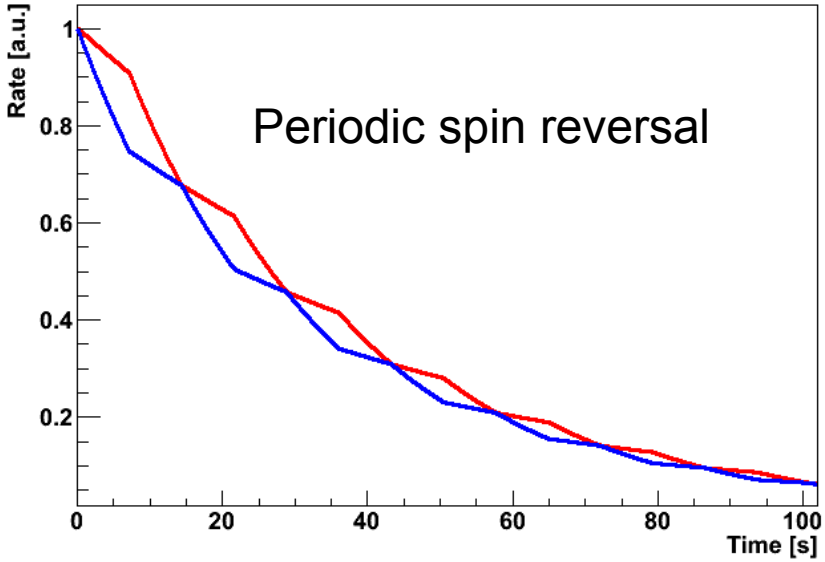
General approach:

- **Produce** short-lived isotopes with AGOR facility at KVI
- **Transport** atoms to provide cleaner experimental conditions
- **Polarize** nuclei via optical pumping of atoms into “stretched” state
- **Measure** change in decay rate while flipping polarization of nuclei

Detect

- β or annihilation γ's (β^+)
- γ's from decay of daughter nuclei
- fluorescence



Production:

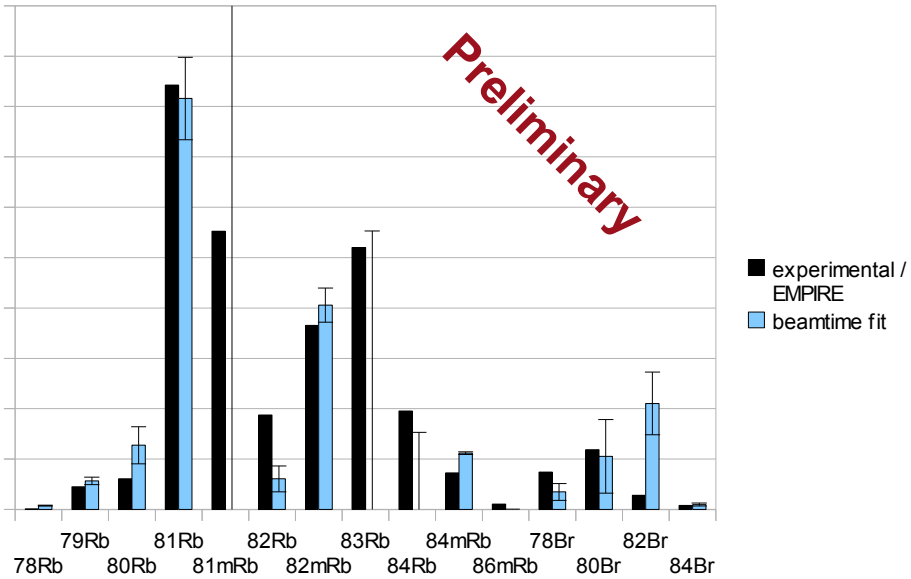
Production of ^{80}Rb:

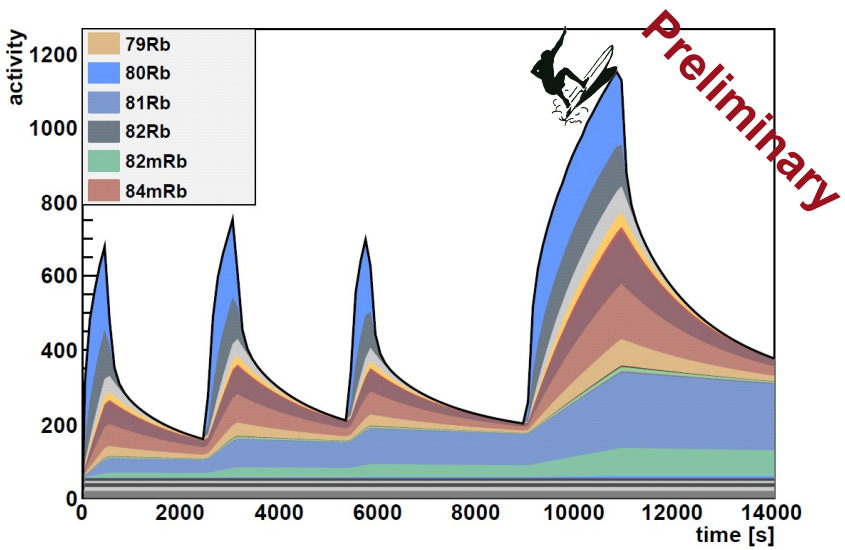
- **Produce** in situ via ^{82}Kr(p,3n)^{80}Rb reaction using 10 bar **Krypton target**

  - 10^9 decays/s feasible

- **Properties** : $1^+ \rightarrow 0^+$ (GT), β^+, $\tau_{1/2}$ = 34s

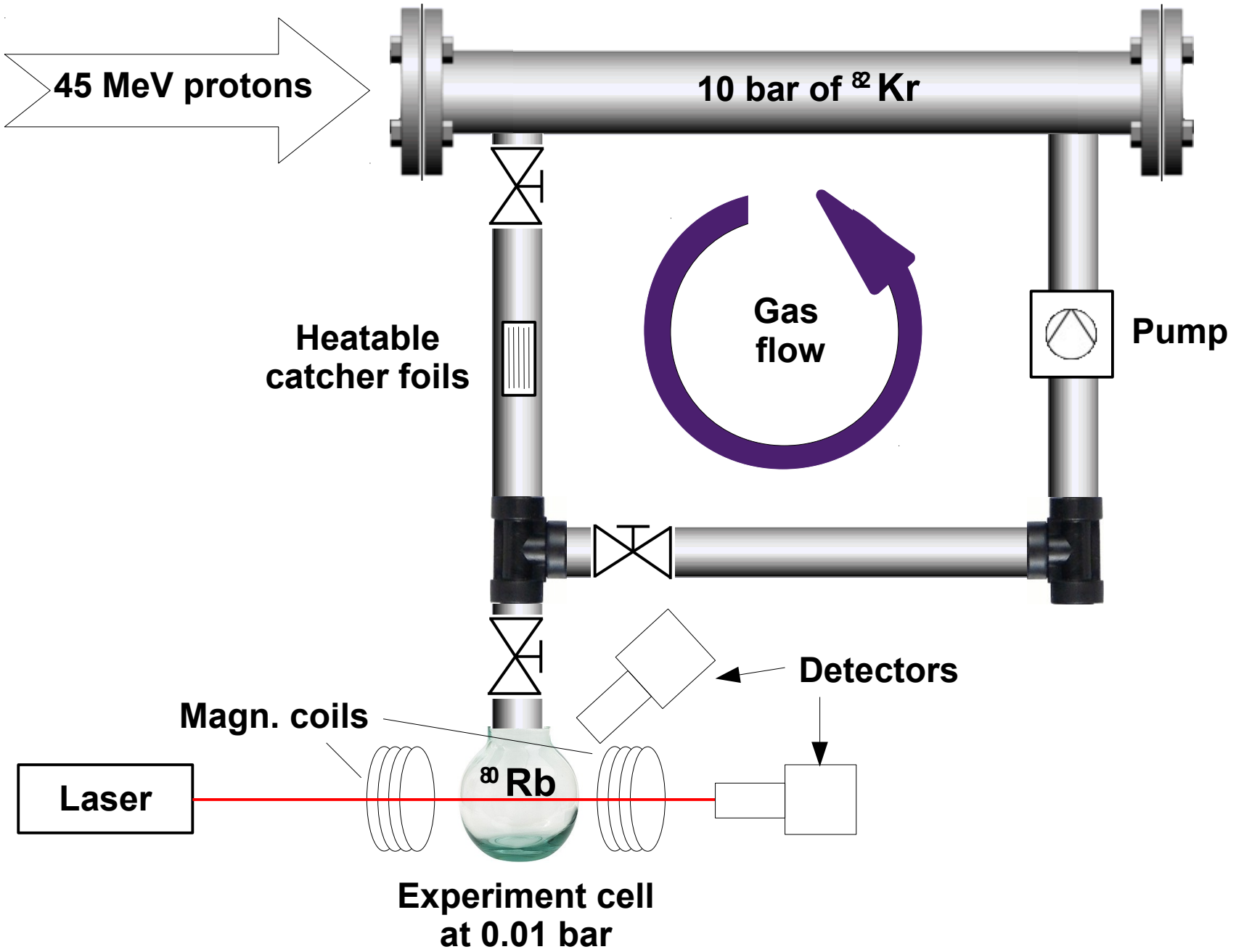
Production rates (arbitrary scaling)





Total activity breakdown

Production and Transport:

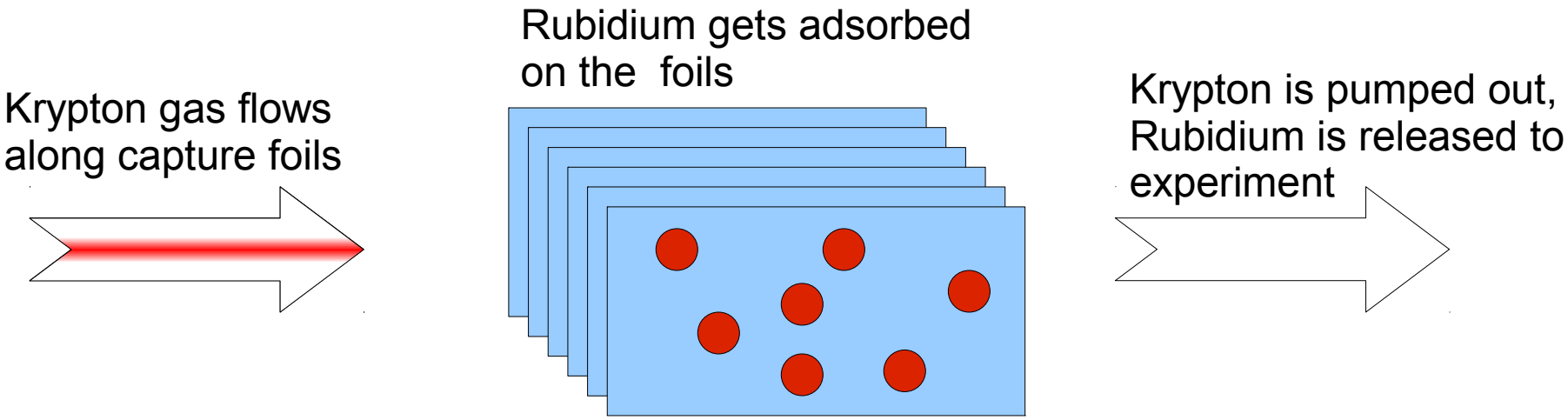


Transport:

- **Experimental challenge** :

Optimal polarization needs buffer gas pressure reduced to 10 mbar
- extract Rubidium from Krypton and store it

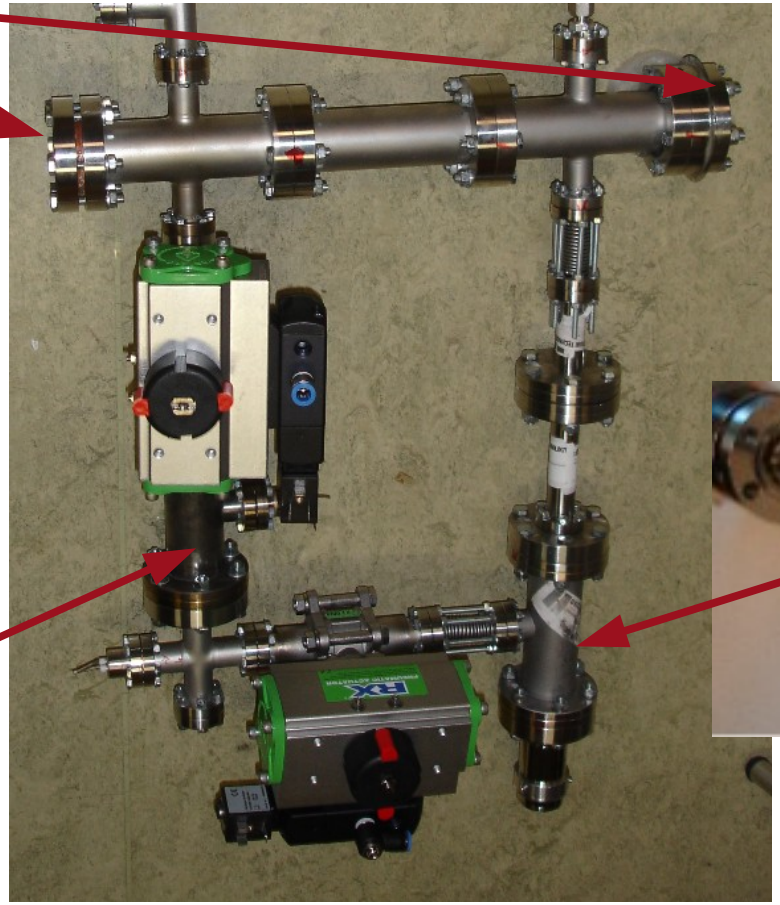
Accumulate the Rubidium via adsorption on a cold surface, then release it by heating the surface



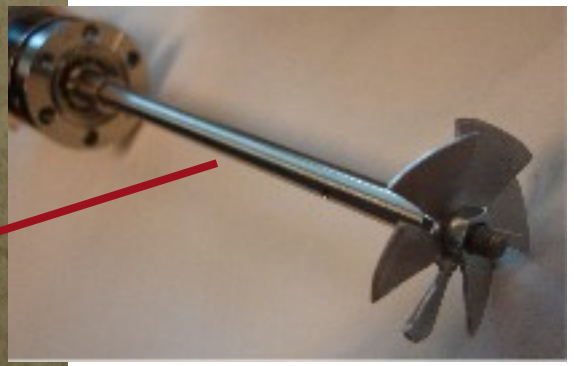
Titanium foils: high capture rate for Rubidium at room temperature, release at about 650 K.

Experimental setup:

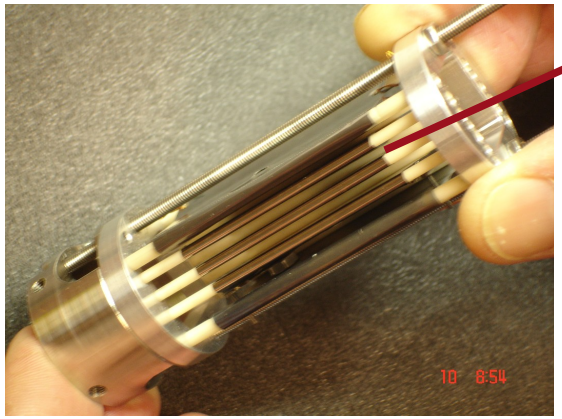
Beam windows of
100µm HAVAR foil



Propeller on
rotatable feedthrough



Stack of 4µm Ti-foils



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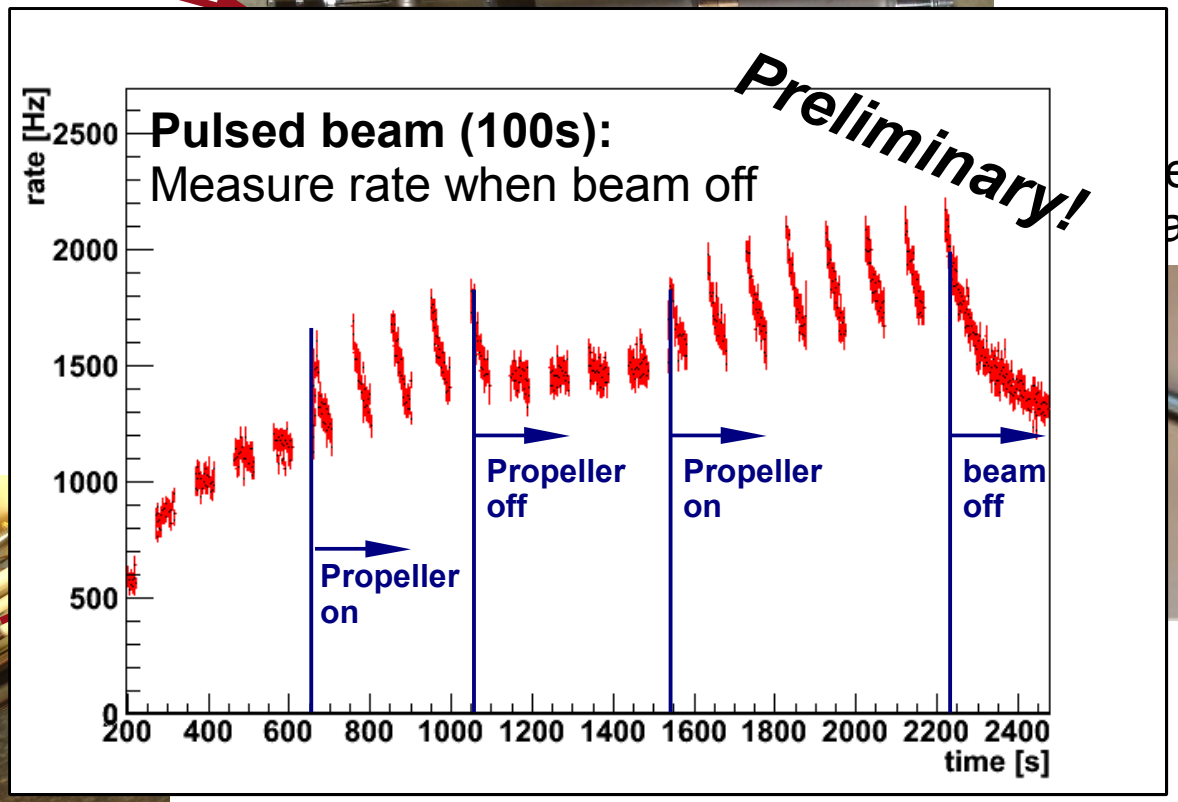

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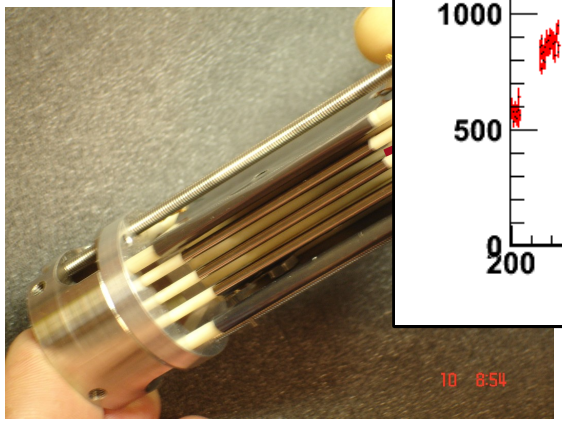


Polarization by optical pumping

Use weak magnetic field & circularly polarized $\sigma^{\pm}$ light to pump atoms into "stretched" state

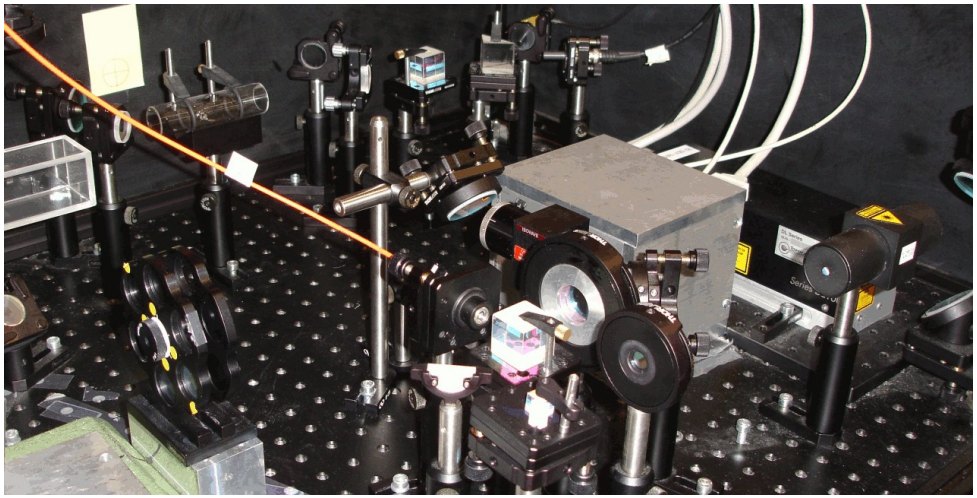
- **Stabilized laser beams**

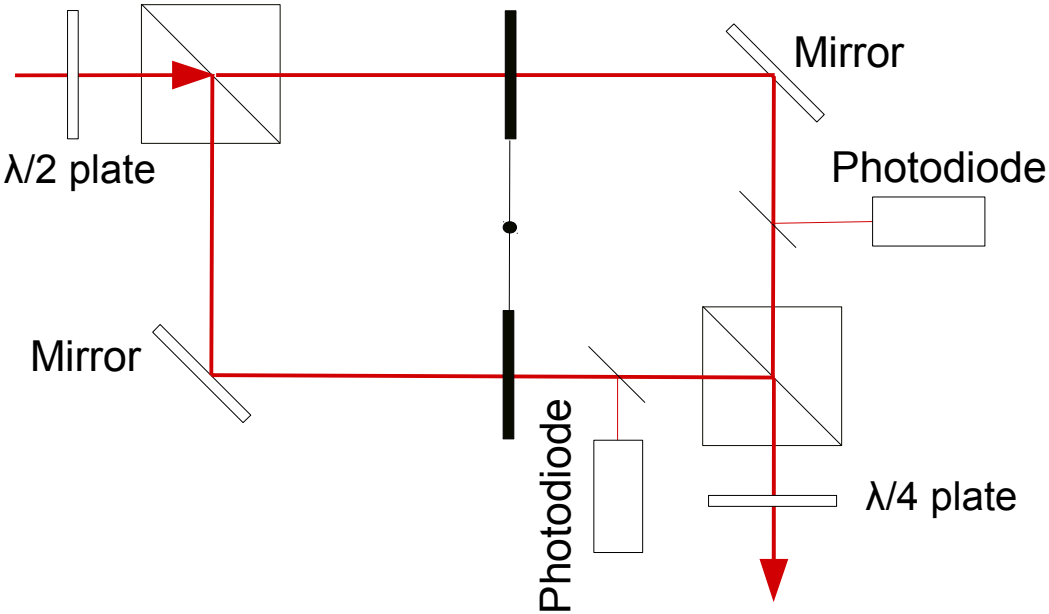
  - i.e. lock laser to hyperfine structure transitions from vapor cell

- **"Polarization switch" to change between $\sigma^{\pm}$ polarized light**

  - split beam in σ^{+} and σ^{-} part and use chopper wheel to block beam

- **Coils for magnetic field** (few Gauss sufficient)





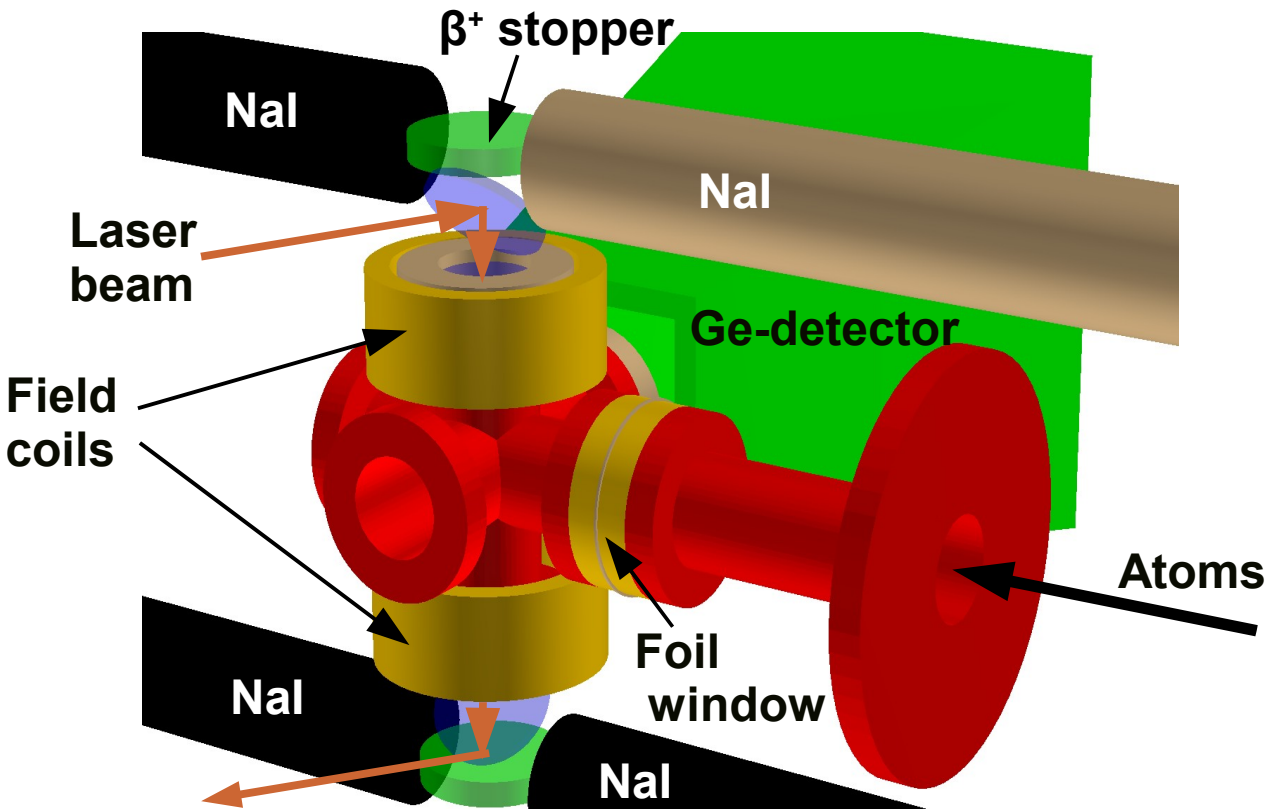
Detection:

- **Two pairs of NaI detectors** to measure 511 keV coincidences

  - *use parity violating asymmetry to extract nuclear polarization*

- **Ge-detector** for daughter nuclei decay photons or 511 keV γ's

  - *measurement of decay lifetime*



Conclusions

- Lorentz symmetry is a keystone of modern physics
- No compelling evidence for its violation has been found to date
- Unique test of Lorentz Symmetry breaking using weak decay of spin-polarized atoms
- Theoretical development for interpreting the observables within SME framework underway
- Production and transport of rubidium tested
- Lasers set up and stabilized, setting up of detectors under way
- Next step: Test of detector setup using ^{20}Na from TRIμP separator

People:

Extra slides

Decay rate:

Decay rate including LSB terms:

$$\frac{d\Gamma}{dE\,d\Omega} \sim \left(1 + A_0 \frac{\langle \vec{I} \rangle}{I} \cdot \frac{\vec{p}}{E}\right) + \xi_1 \left(1 + \xi_A \left(\hat{p} \cdot \frac{\langle \vec{I} \rangle}{I}\right)\right) \hat{p}\,\hat{n} + \\ + \xi_2 \frac{\langle \vec{I} \rangle}{I} \hat{n} + \xi_3 \hat{p}_i \left(\frac{\langle \vec{I} \rangle}{I}\right)_j \rho^{ij}$$

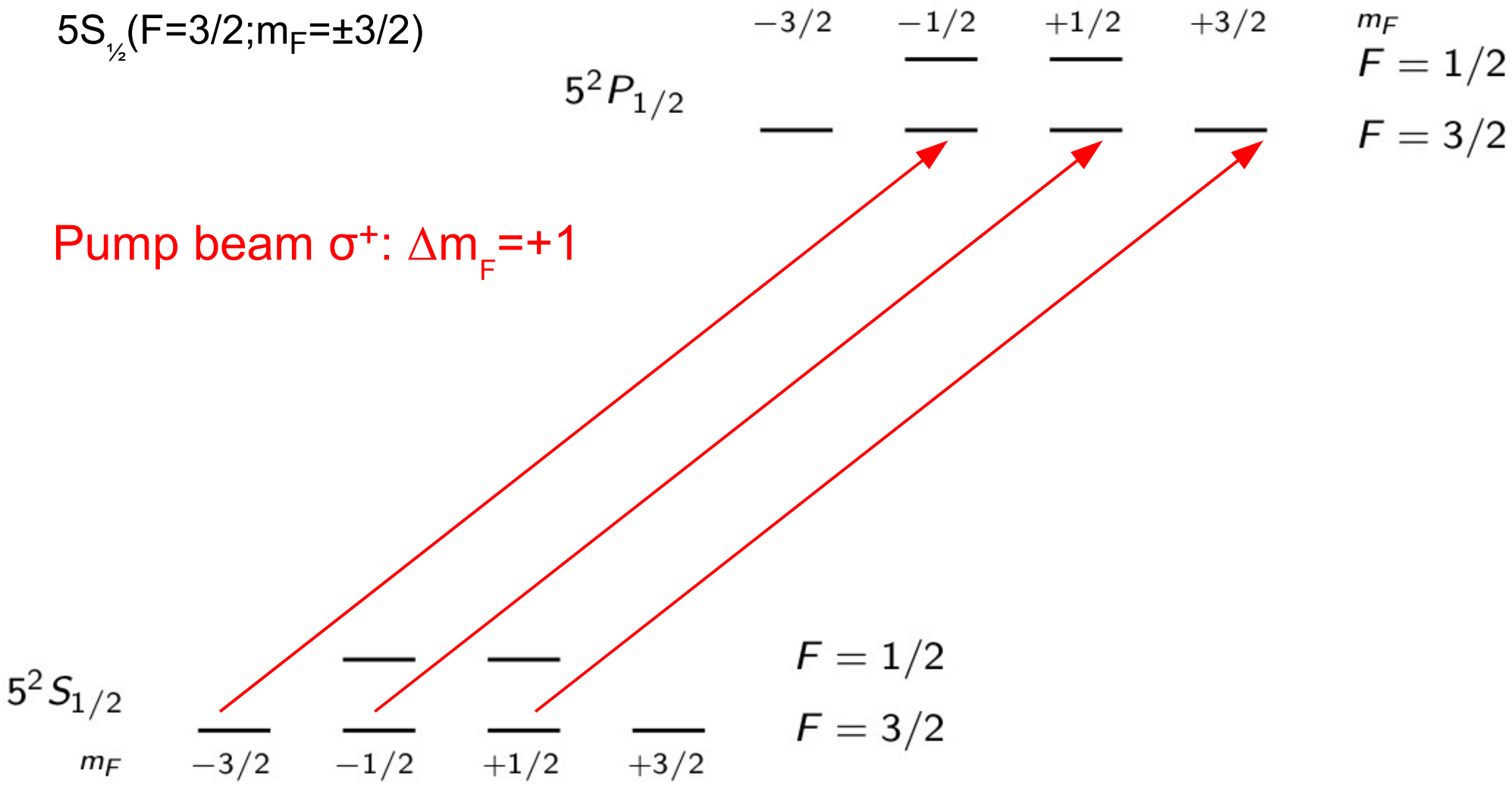
I = nuclear spin; p, E = electron momentum and energy

$\xi_{1,2,3,A}$ = coupling strength to LIV fields $\hat{n}, \rho^{ij}$

Polarization by optical pumping

Use weak magnetic field & circularly polarized σ± light with 795nm (D1 transition) to pump the Rb atoms into the “stretched” state

$5S_{1/2}(F=3/2;m_F=\pm 3/2)$



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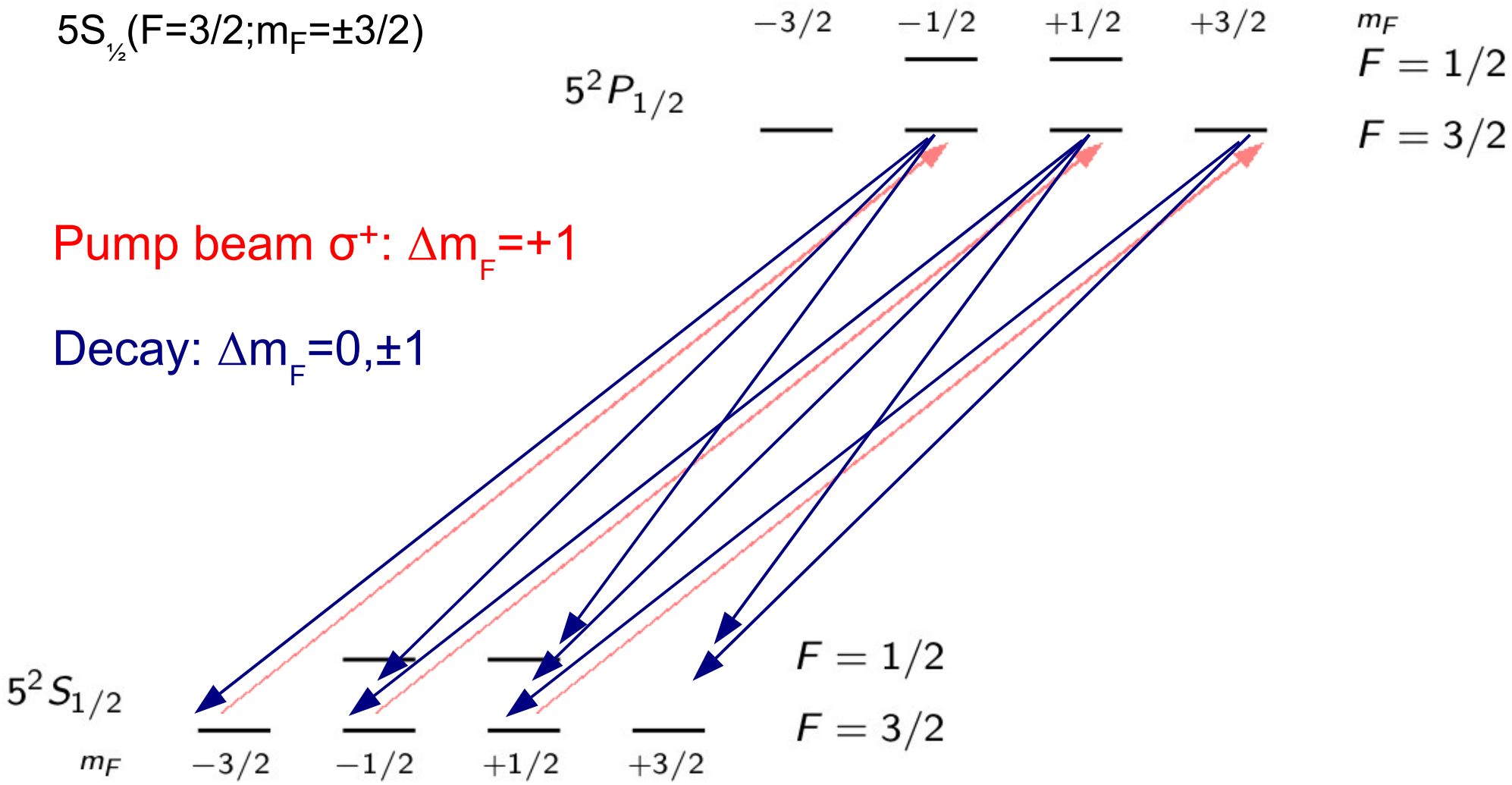

Pump beam σ^+: $\Delta m_F=+1$

Decay: $\Delta m_F=0,\pm 1$

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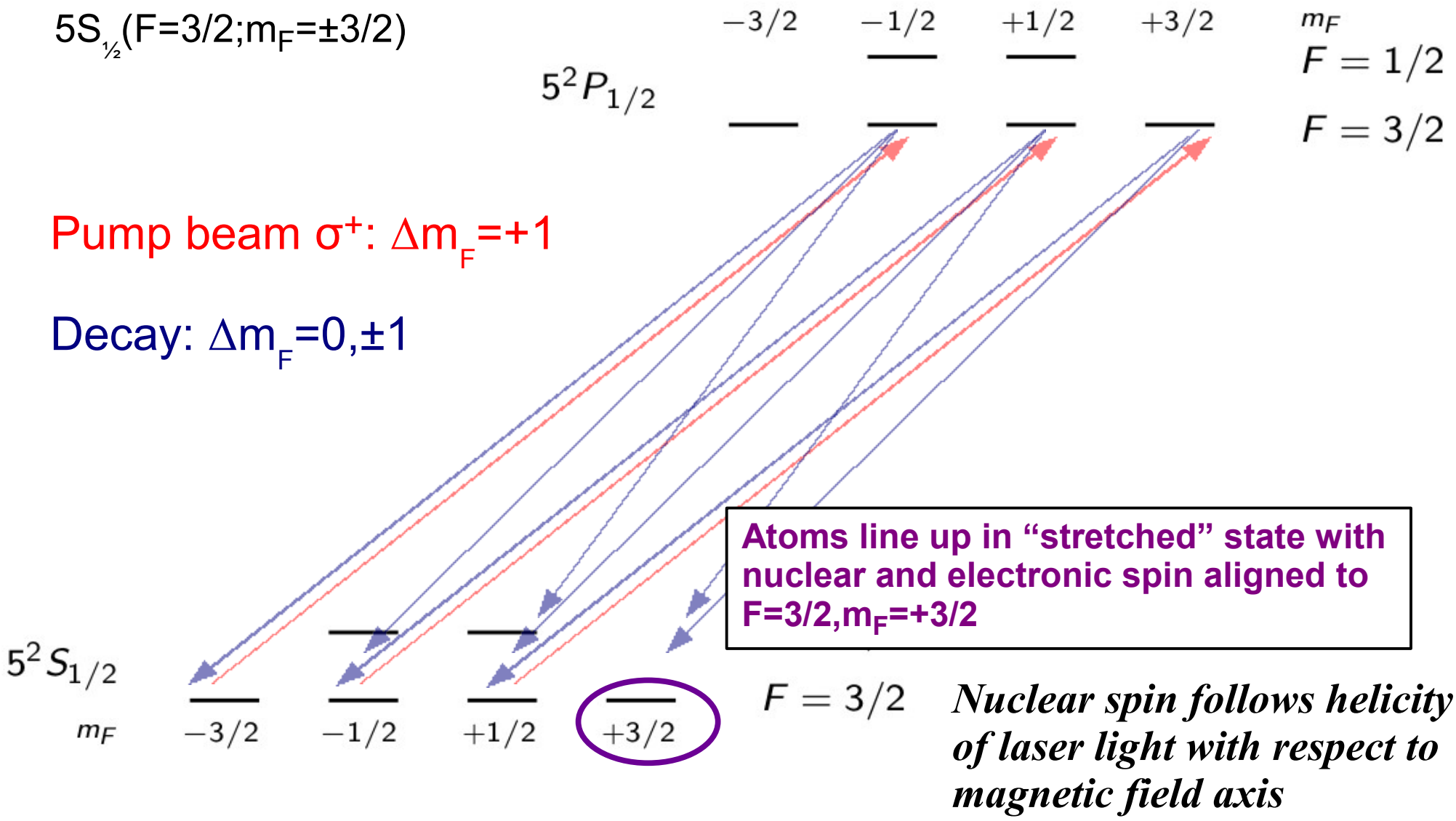

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Atoms line up in "stretched" state with nuclear and electronic spin aligned to $F=3/2, m_F=+3/2$

Nuclear spin follows helicity of laser light with respect to magnetic field axis