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NUCLEAR AND RADIATION PHYSICS

Searching for physics beyond the Standard Model using β decay of ^{32}Ar.

- Physics case
- Experimental setup
- Results & discussion
- Conclusion & perspective

ISOL France meeting (March 17-19, 2021)

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Physics Case

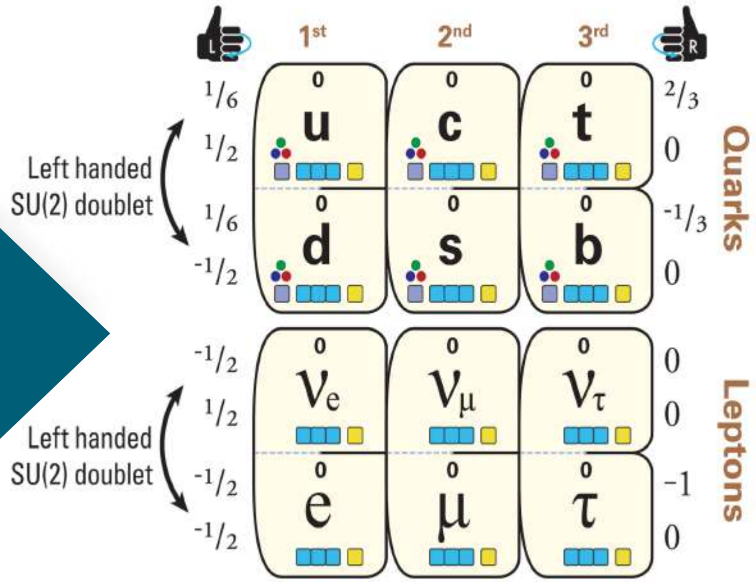
High energy experiments

01 Collider experiments at high energies.

02 New particles or new gauge bosons

A Weak Interaction in the SM: Vector-Axial-vector (V-A) theory.

B Angular correlation measurements of the emitted particles in a beta decay



Look for deviations from Standard Model predictions

High precision measurements

01 Low energy experiments: **nuclear beta decay**

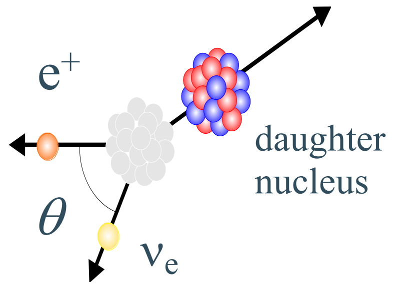
02 Improve the precision on decay observables

Nuclear Observables:

β–ν Angular Correlation Coefficient

$$d\Gamma \propto d\Gamma_0 \left(1 + a_{\beta\nu} \frac{\bar{p}_e \cdot \bar{p}_\nu}{E_e E_\nu} + b \frac{\gamma m_e}{E_e} + \cdots \right)$$ [1]

Decay rate | Phase space factor & Fermi function | Angular correlation coefficient | Fierz interference term



New Physics (NP) through beta decay!

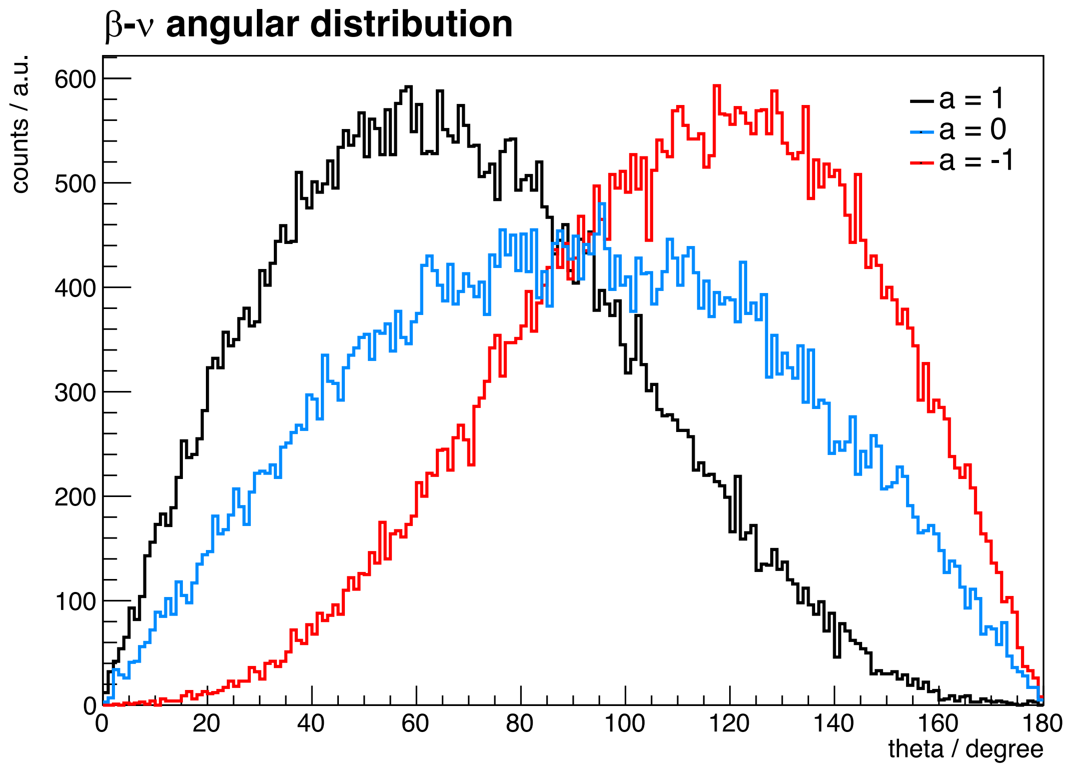
SM → Vector currents
Preferred emission angle: $\theta = 0°$

$$a^F_{\beta\nu} \cong 1 - \frac{|C_S|^2 + |C'_S|^2}{|C_V|^2}$$

NP → Scalar currents
Preferred emission angle: $\theta = 180°$

$$b_F \cong \pm Re\left(\frac{C_S + C'_S}{C_V}\right)$$

Left-handed neutrino

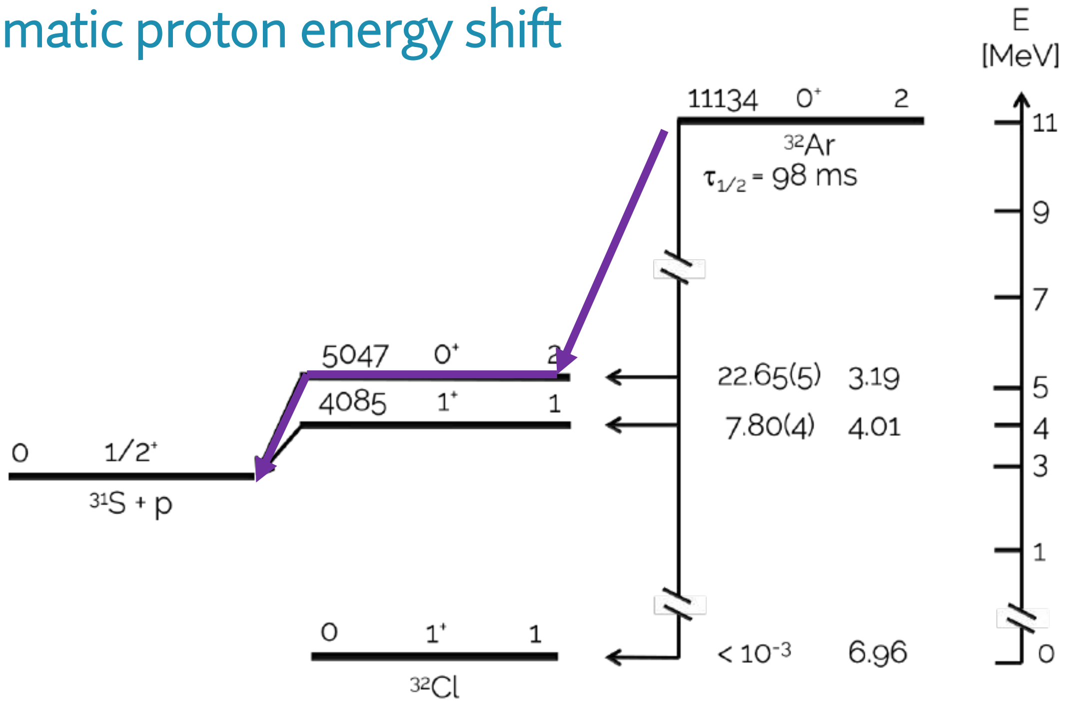


[1] J.D. Jackson et al Phys. Rev. 106, 517 (1957)

(!) Measure goes like an average over the β spectrum

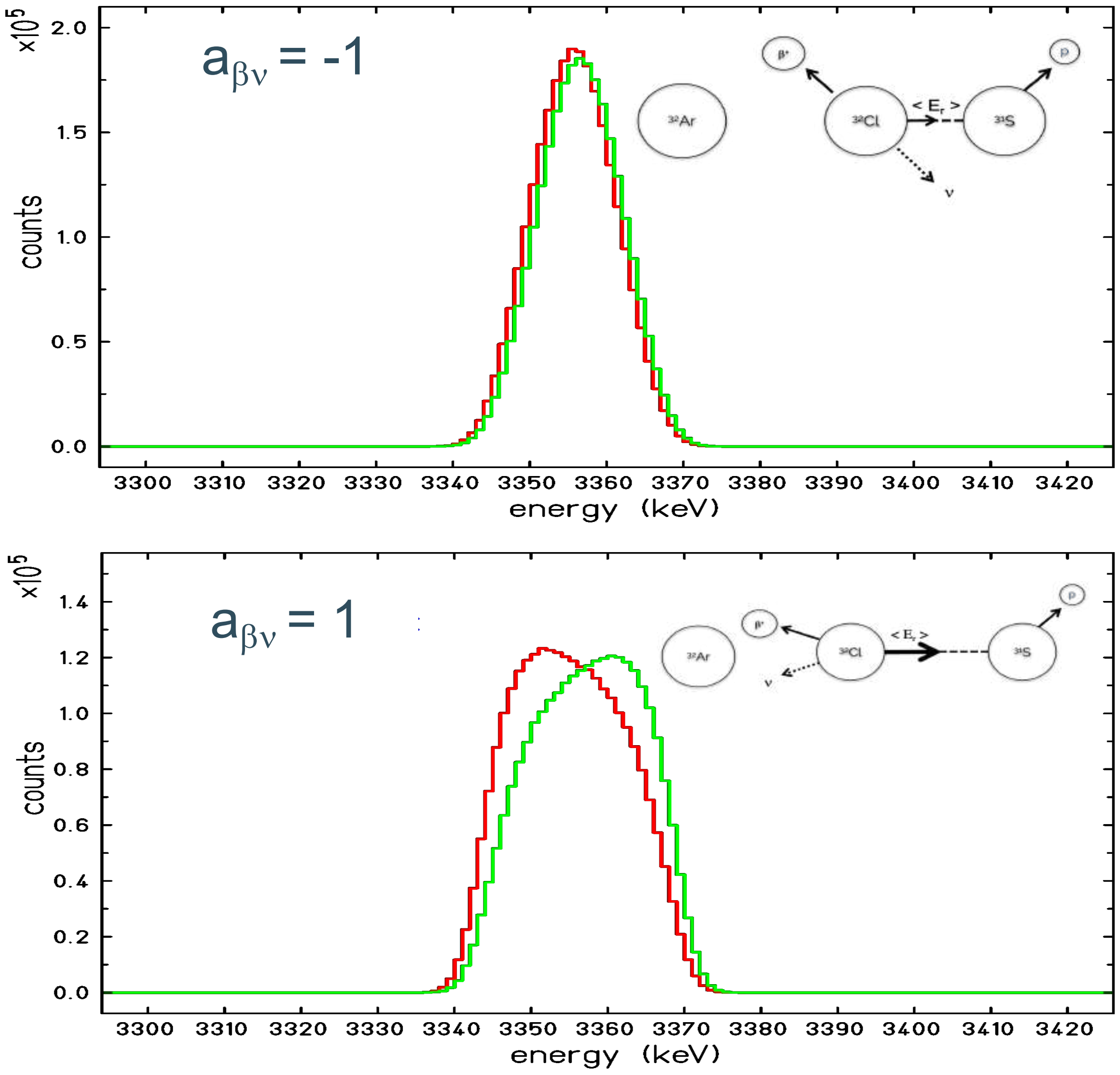
What do we measure?

Kinematic proton energy shift



Technique advantages

- Recoil energy ~hundreds eV
- Proton energies ~several MeV
- The energy of the emitted protons is subject to kinematic shift due to the recoiling daughter nucleus

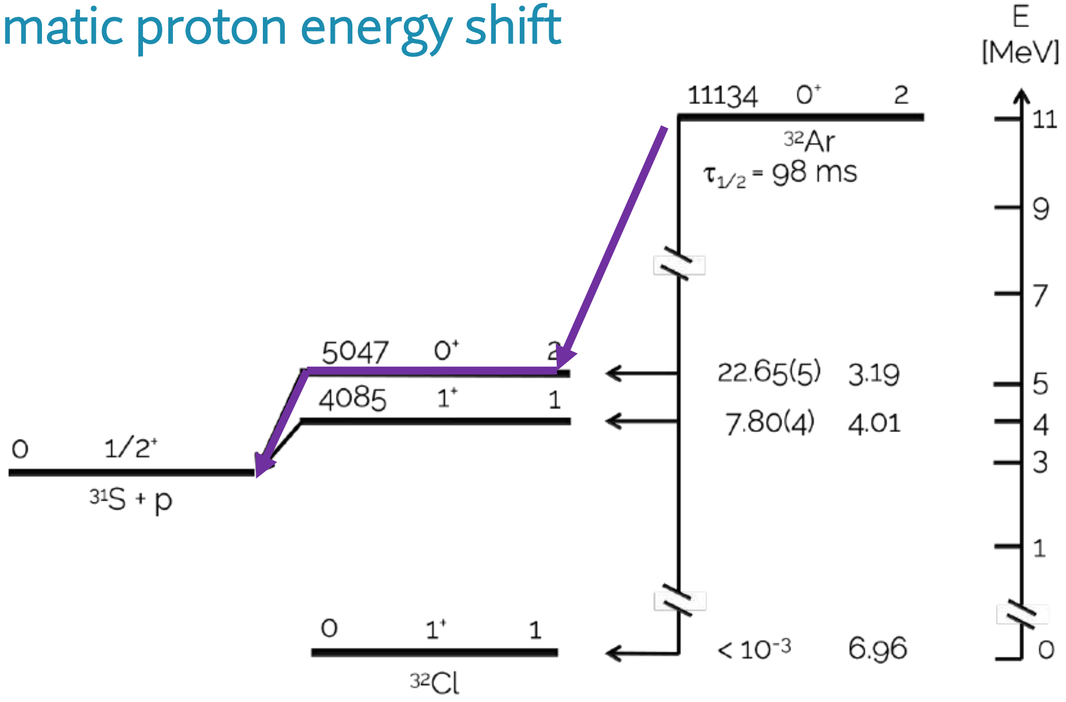


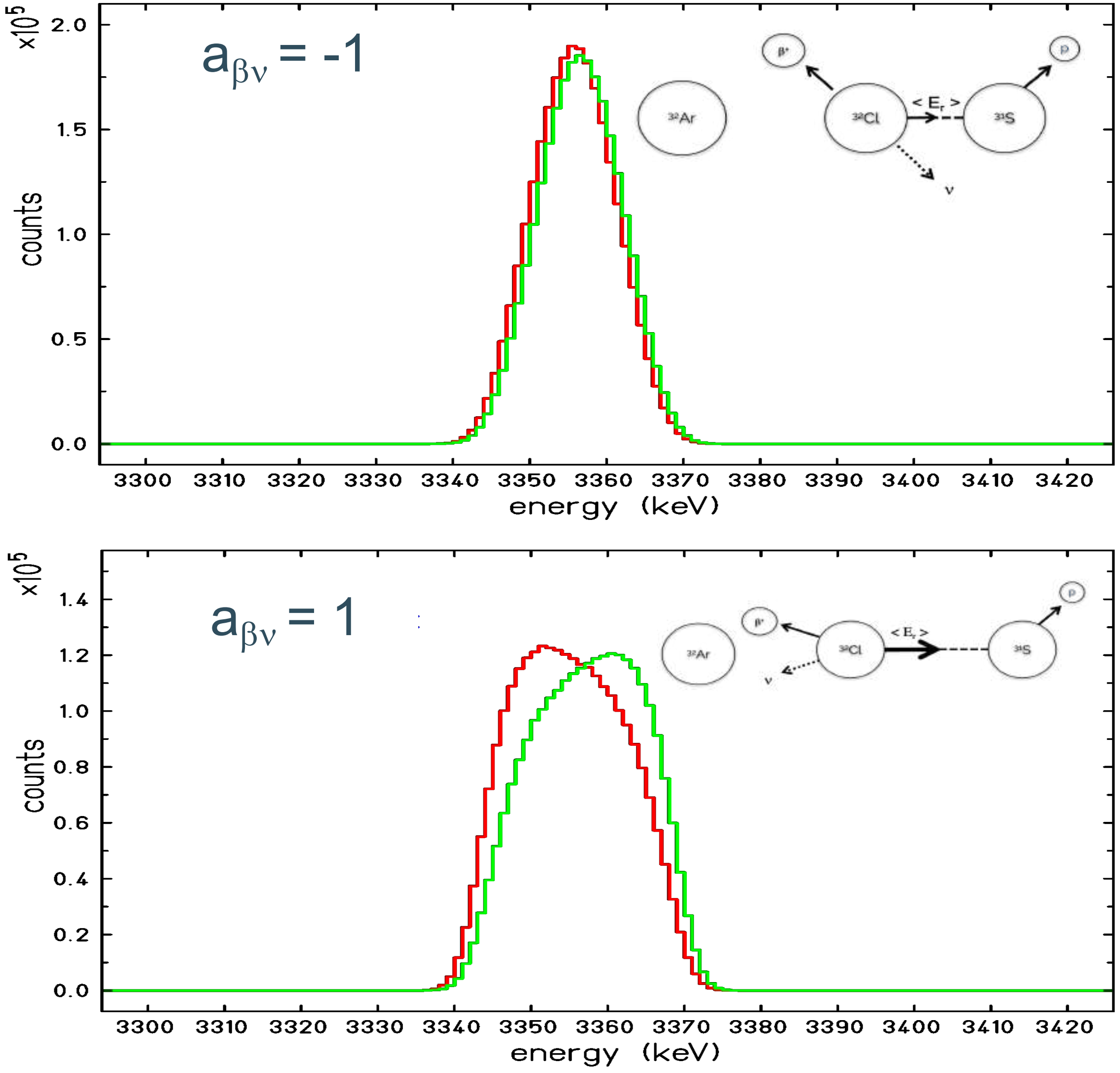
Proton energy distribution

Red: parallel direction Green: antiparallel

What do we measure?

Kinematic proton energy shift





Proton energy distribution

Red: parallel direction Green: antiparallel

Experimental objective

- ☞ Measuring proton energy and momentum from ^{32}Cl with high resolution
- ☞ Extract $a_{\beta\nu}$ from beta decay of the $^{32}Ar \rightarrow {}^{32}Cl$

Experimental technique

Kinematic proton energy shift

- Clifford, 1989.
  β–ν–α correlation measurement (^{20}Na)
- Egorov, 1997; Vorobel, 2003.
  β–ν–γ correlation measurement (^{18}Ne)
  β–ν–γ correlation measurement (^{14}O)
  Adelberger, 1999 [F]
  β–ν–p correlation measurement (^{32}Ar)
- Sternberg, 2015 [GT]
  $\beta-\bar{\nu}-\alpha$ correlation measurement (^{8}Li)

Secondary particles emitted after the decay

Kinematic energy shift

- **Measure the centroid of the proton energy distribution instead the broadening of the proton spectra, WISArD.**

SCALAR
Fermi transition
- Preferred emission angle: θ = 180°
- Minimum recoil energy

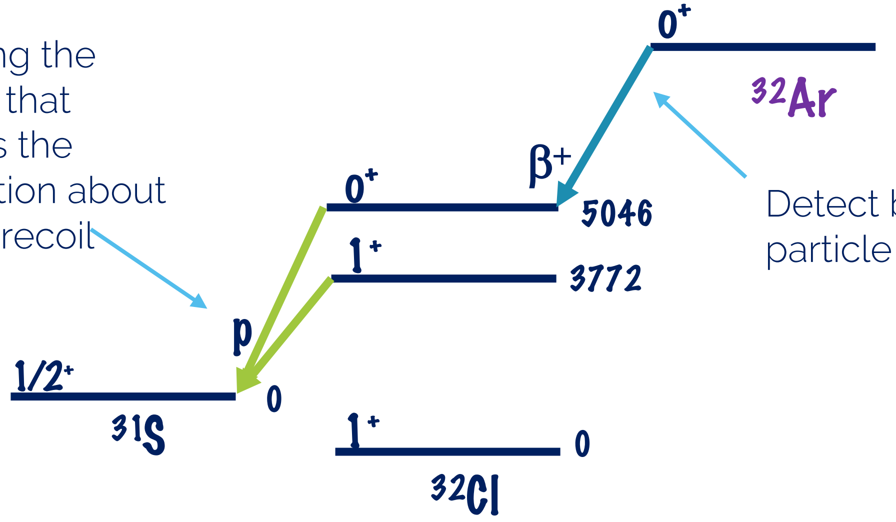
$$\Delta a_{\beta\nu}^{F} \sim 5.10^{-3}$$

TENSOR
GT Transition
- Preferred emission angle: θ = 0°
- Maximum recoil energy

$$\Delta a_{\beta\nu}^{GT} \sim 3.10^{-3}$$

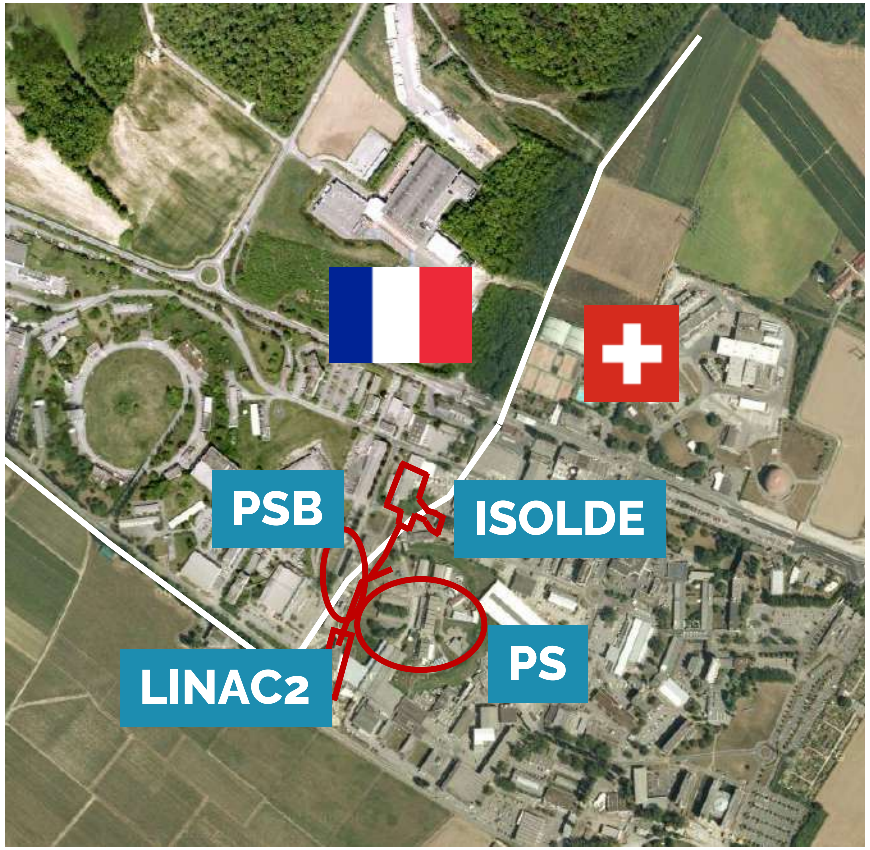
The 0.1% challenge!

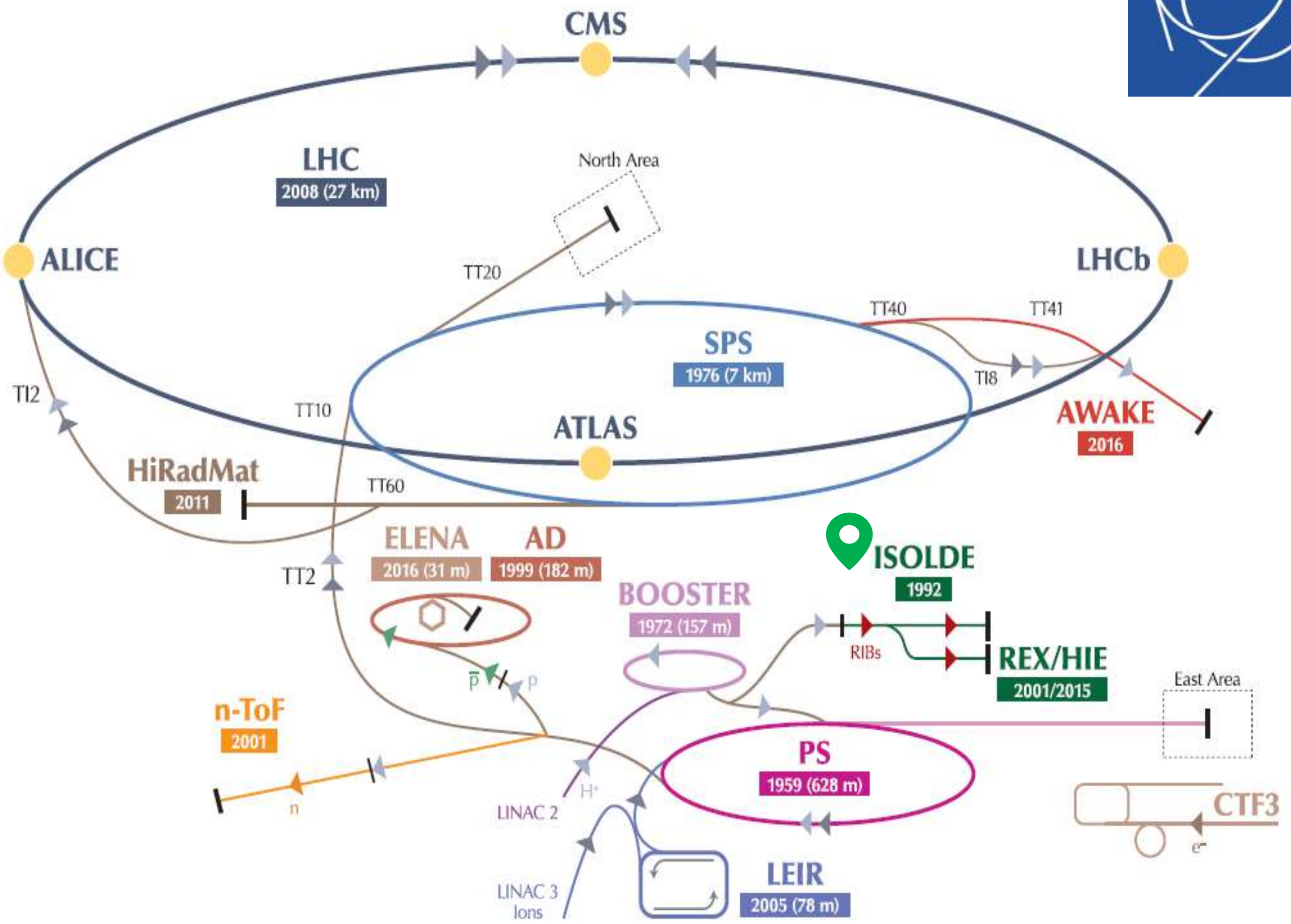
Detecting the protons that contains the information about the ^{32}Cl recoil



Detect beta particle

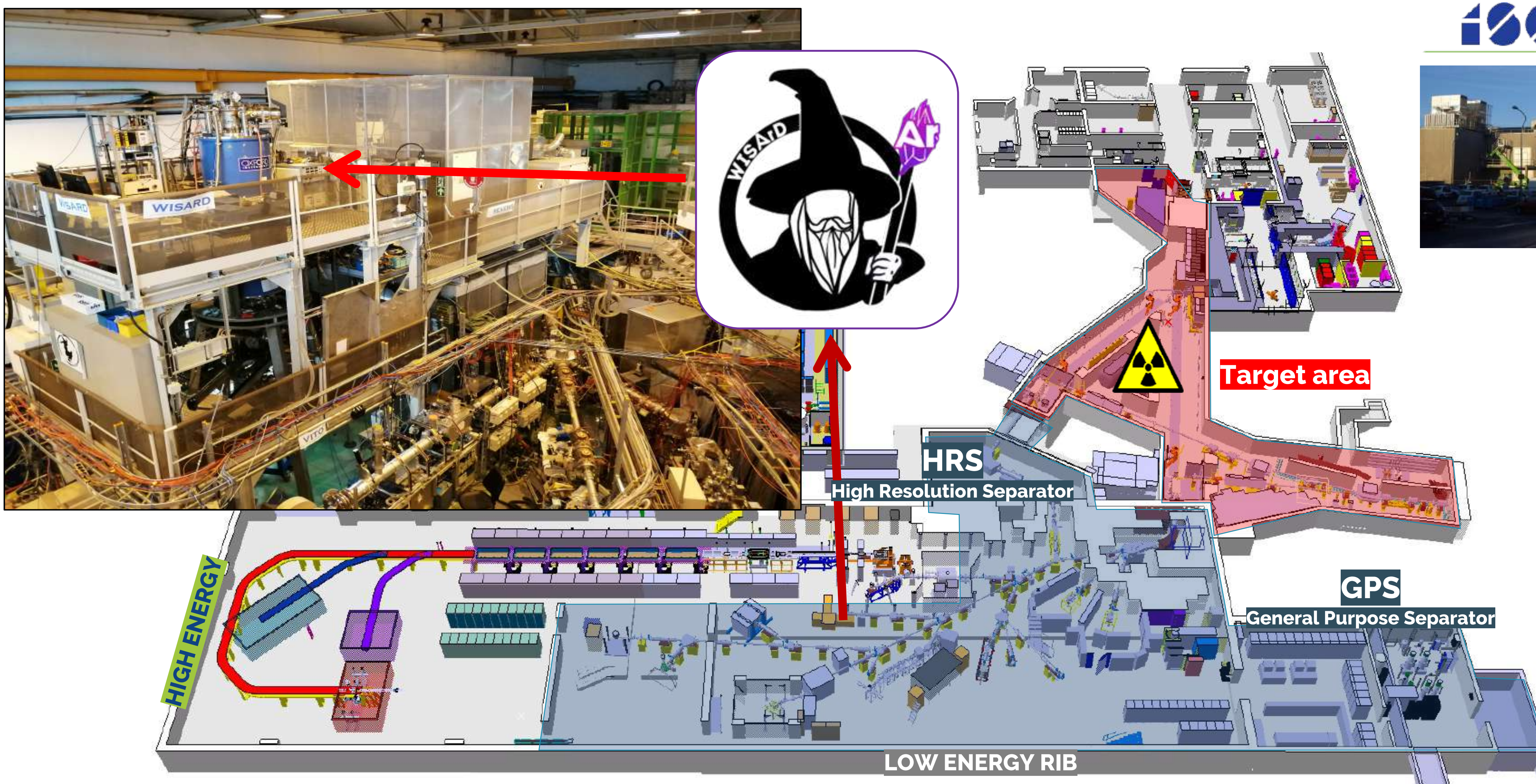
ISOLDE @ CERN



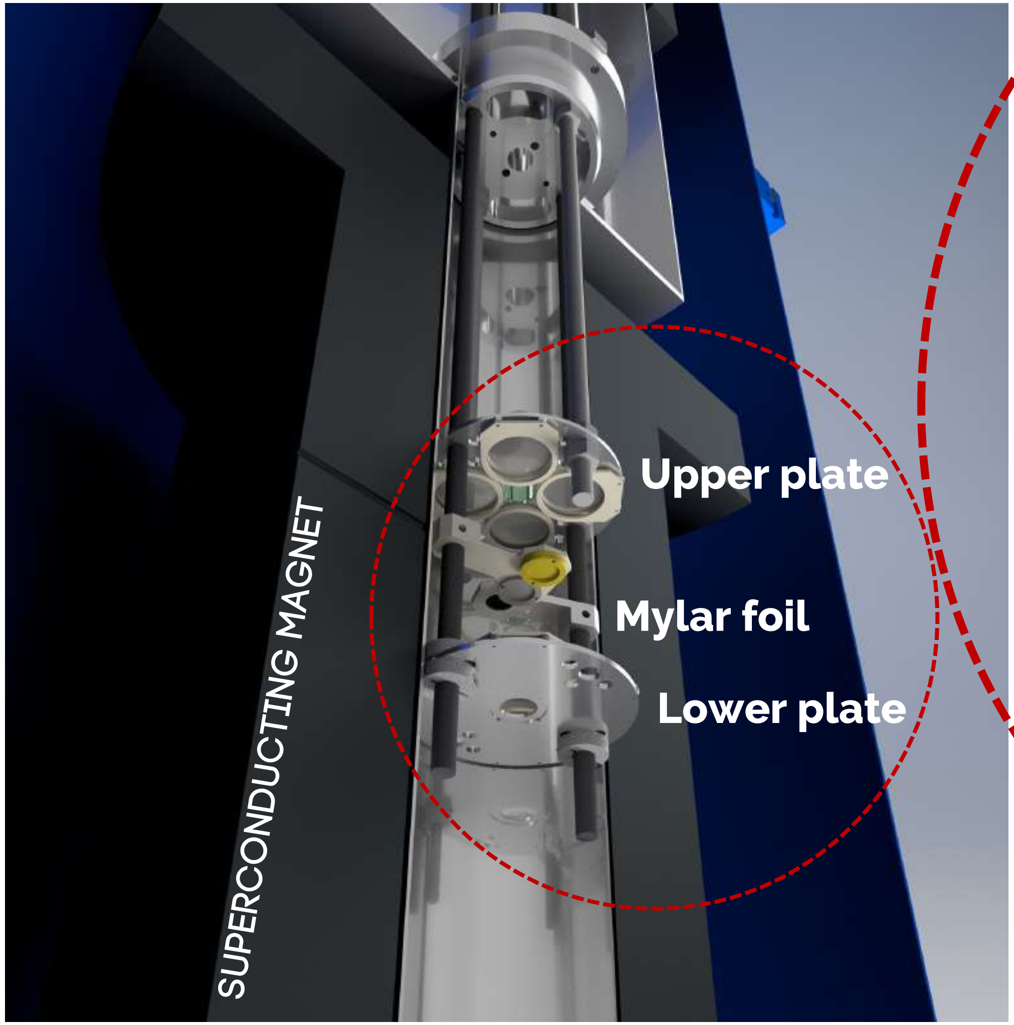


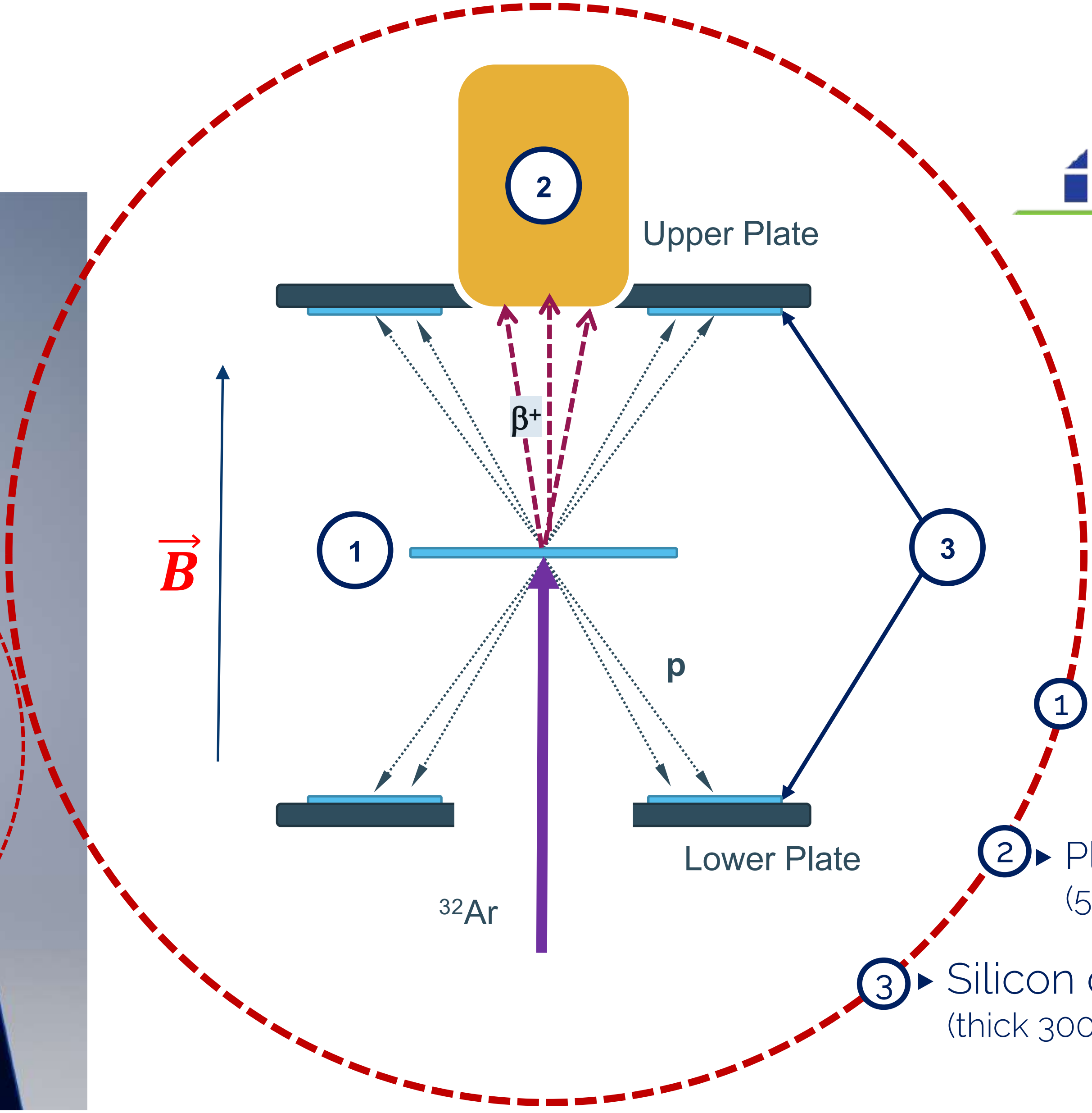
Isotope On-Line Device at CERN's Accelerators Complex

Experimental Setup



Inside the WISArD



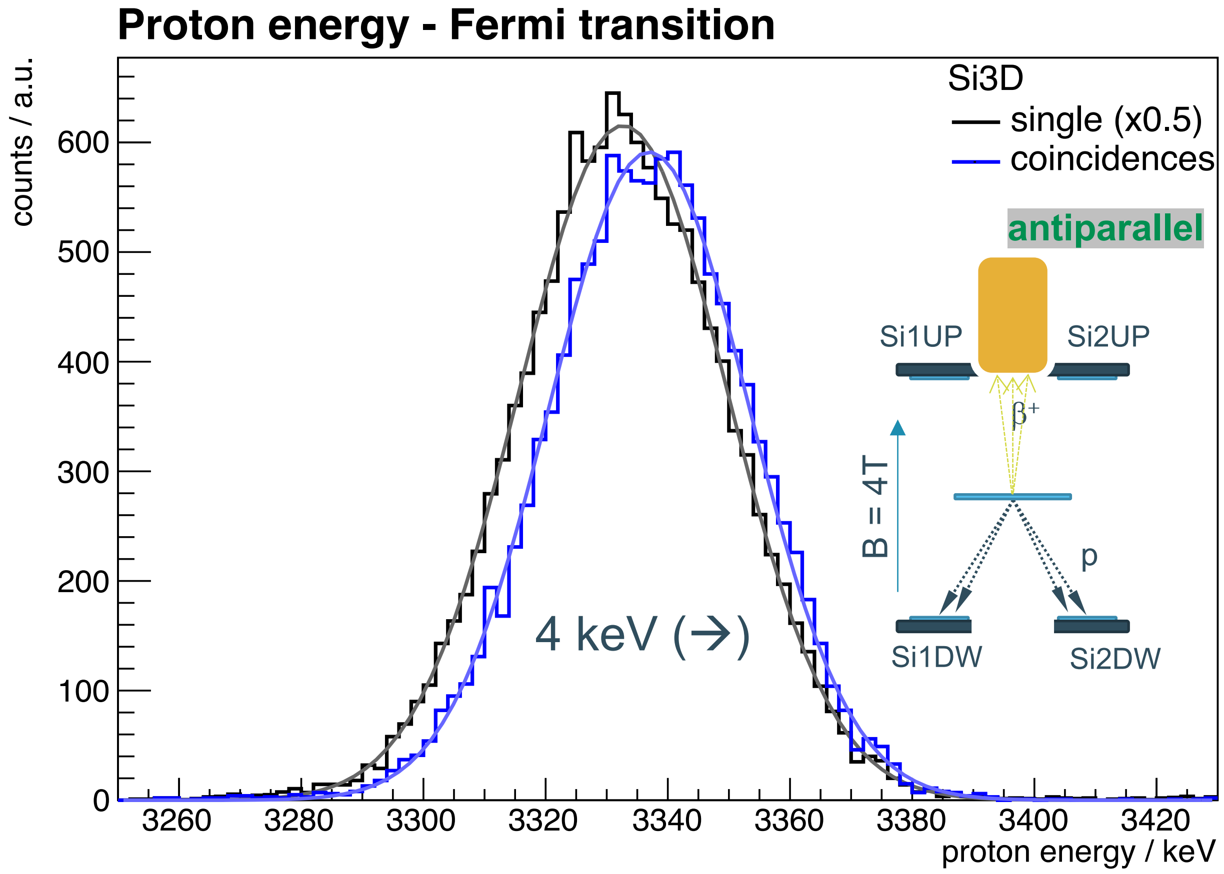


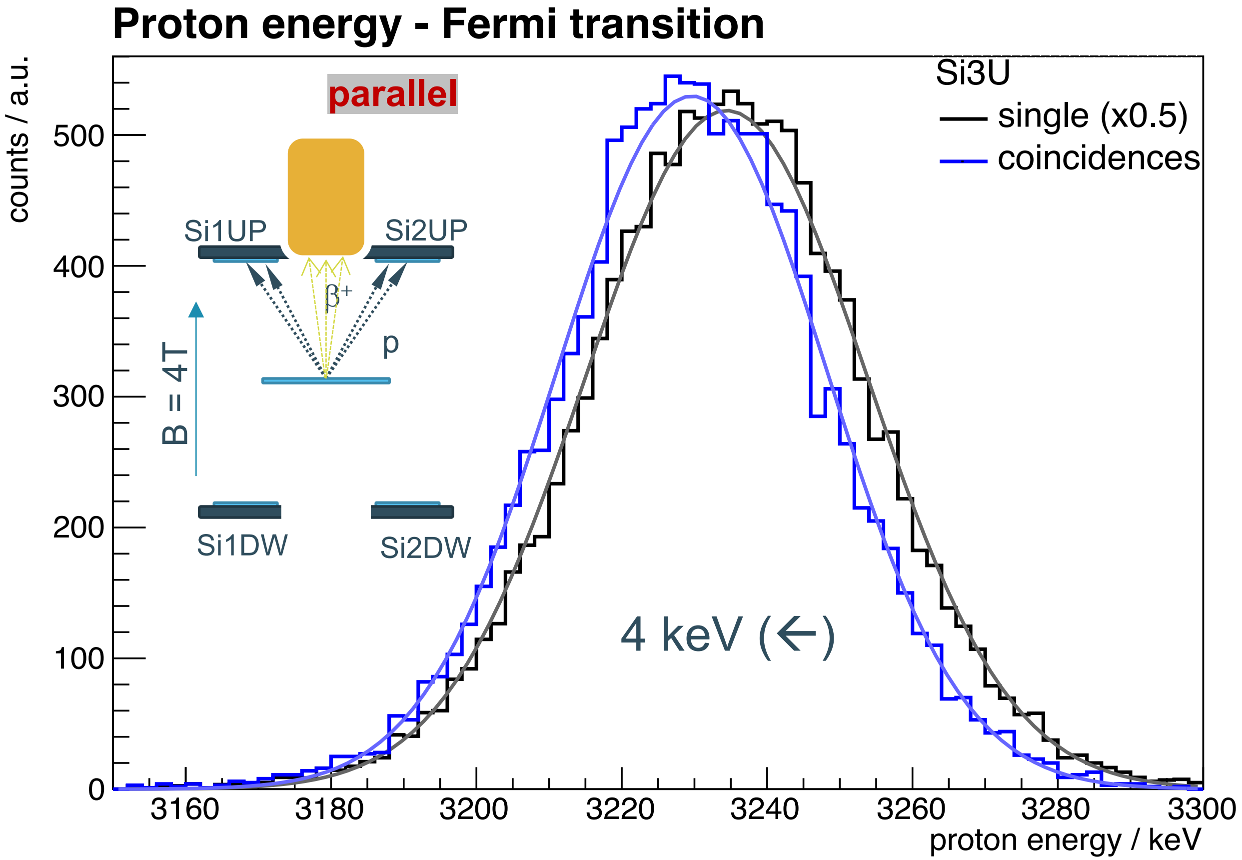
1. Mylar foil (7 μm)
2. Plastic scintillator (5cm / Ø=20mm)
3. Silicon detectors (thick 300 μm / Ø= 30mm)

Kinematic proton energy shift
β-p coincidence measurements

Weighted average energy shift

$$\Delta E = \left|\bar{E}_{coinc} - \bar{E}_{single}\right| = 4.51 \pm 0.04 \text{ keV}$$





Clear energy shifts observed in the dominant vector contribution

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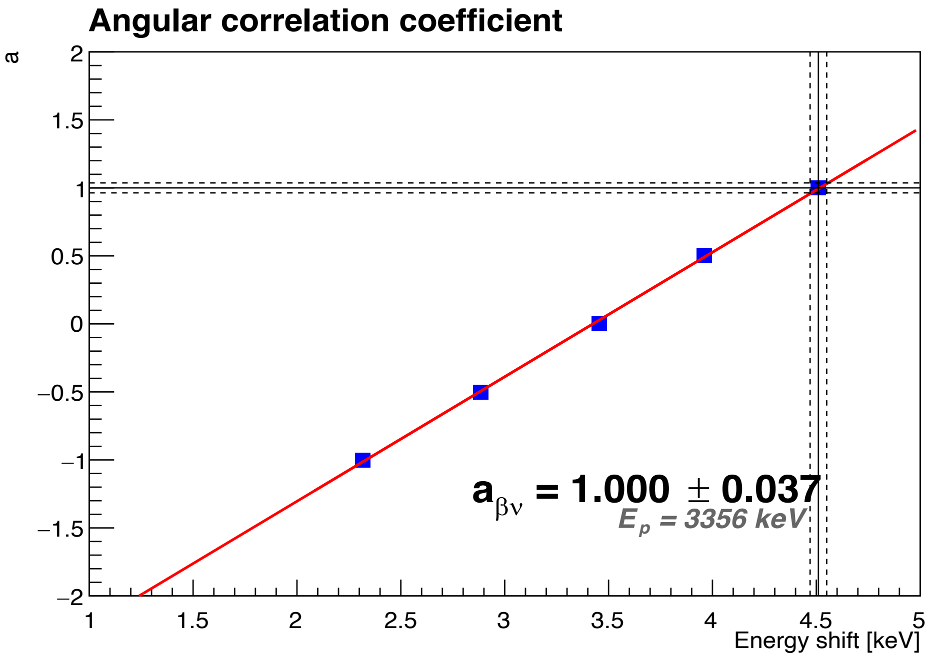
Angular correlation coefficient
Monte Carlo simulations

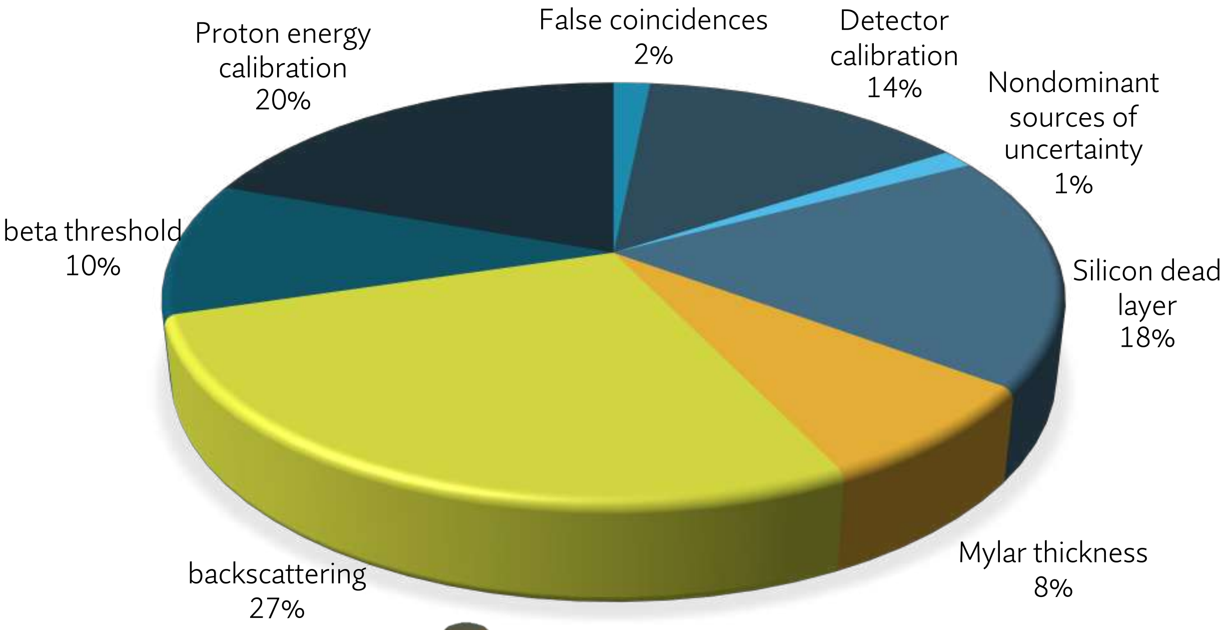


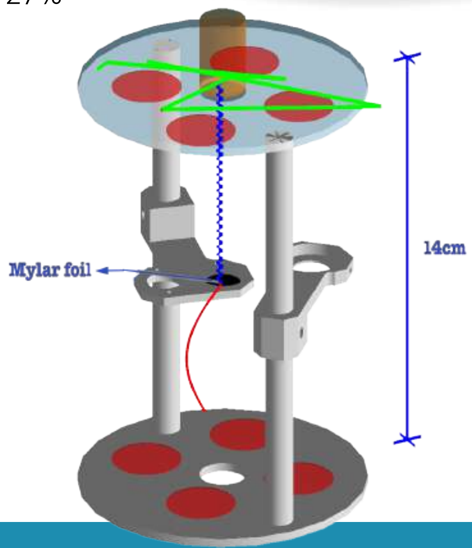
$$\tilde{a}^{F}_{\beta\nu} = 1.000(37)_{stat}(27)_{syst}$$

$$\tilde{a}^{GT}_{\beta\nu} = -0.338(66)_{stat}(34)_{syst}$$

V. Araujo-Escalona et al., PRC 101, 055501(2020)

Systematic uncertainties





Non-dominant sources of uncertainty:
- Detector position
- Magnetic Field
- Source radius
- Source position

Angular correlation coefficient, $a_{\beta\nu}$

The 3rd best measurement!

Fermi transition	
	$a_F = 0.9989(52)$ Adelberger et al. (^{32}Ar)
	$a_F = 0.9981(30)$ Gorelov et al. (^{38}K^{m})
	$a_F = 1.000(37)_{stat}(27)_{syst}$ Araujo et al. (^{32}Ar)

Gamow-Teller transition	
	$a_{GT} = -0.33(3)$ Carlson et al. (^{23}Na)
	$a_{GT} = -0.3343(30)$ Johnson et al. (^{6}He)
	$a_{GT} = -0.3342(38)$ Sternberg et al. (^{8}Li)
	$a_{GT} = -0.338(66)_{stat}(34)_{syst}$ Araujo et al. (^{32}Ar)

V. Araujo-Escalona et al., PRC 101, 05501(2020)

Conclusions

- ✓ Successful proof-of-principle experiment, expected kinematic energy shifts of proton peaks is observed, providing the third most precise measurement of $\boldsymbol{a_{\beta\nu}}$ in a pure Fermi transition.
- ✓ Simultaneous measurements of $a_{\beta\nu}$ for different transitions (Fermi and Gamow-Teller) in a single experiment can be performed with same isotope.
- ✓ Setup that allows to get a better control of systematic errors.
- ✓ Agreement with the SM with deviation σ and 1σ for F and GT, respectively.

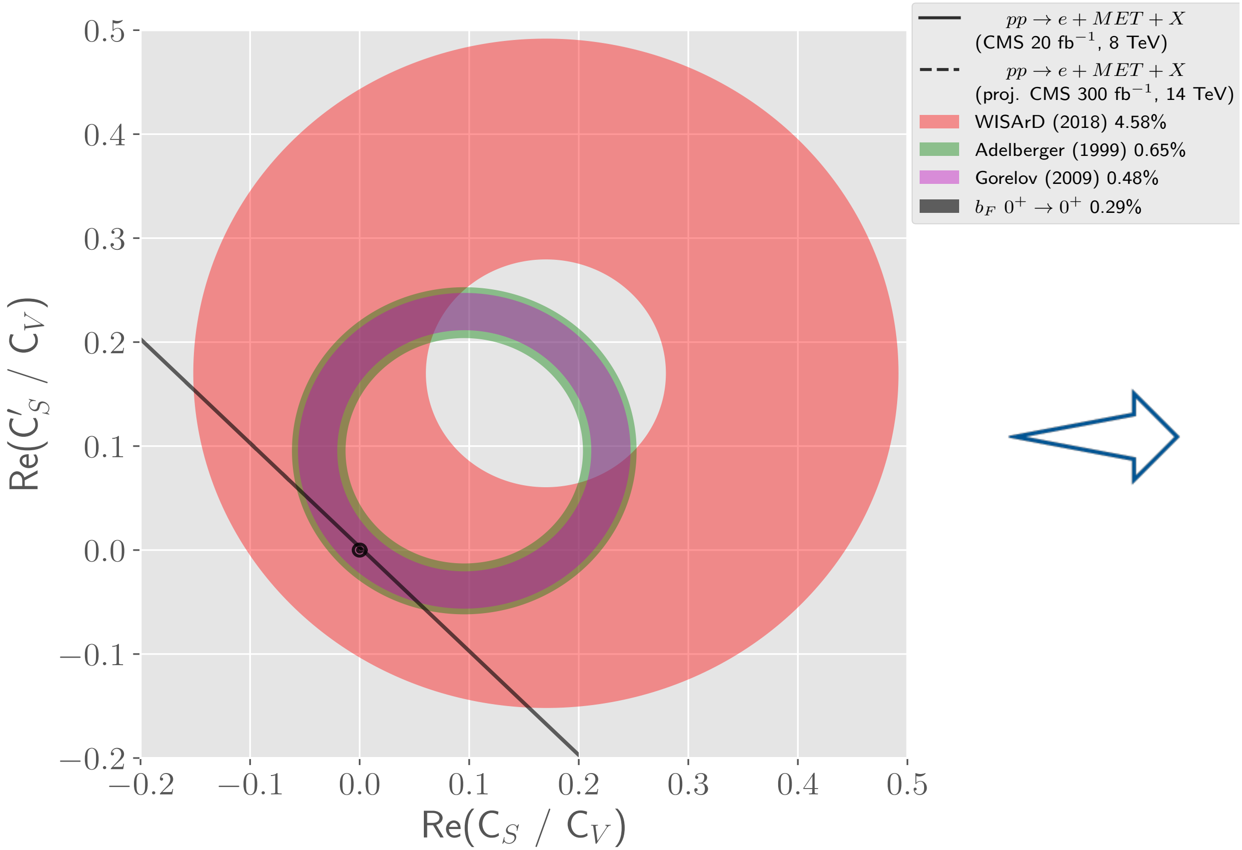
Outlook

- ❑ ^{32}Ar production, transmission and longer beamtime
- ❑ New setup geometry and improve proton energy resolution. Segmented silicon detectors with well known and thinner dead layer.
- ❑ Reduce thickness of the mylar foil
- ❑ Full characterization of the plastic scintillator. Lower the positron energy threshold below 10keV to reduce the uncertainty.
- ❑ Simultaneous measurement on $a_{\beta\nu}$ with the intense proton lines followed a GT transition and the superallowed F transition

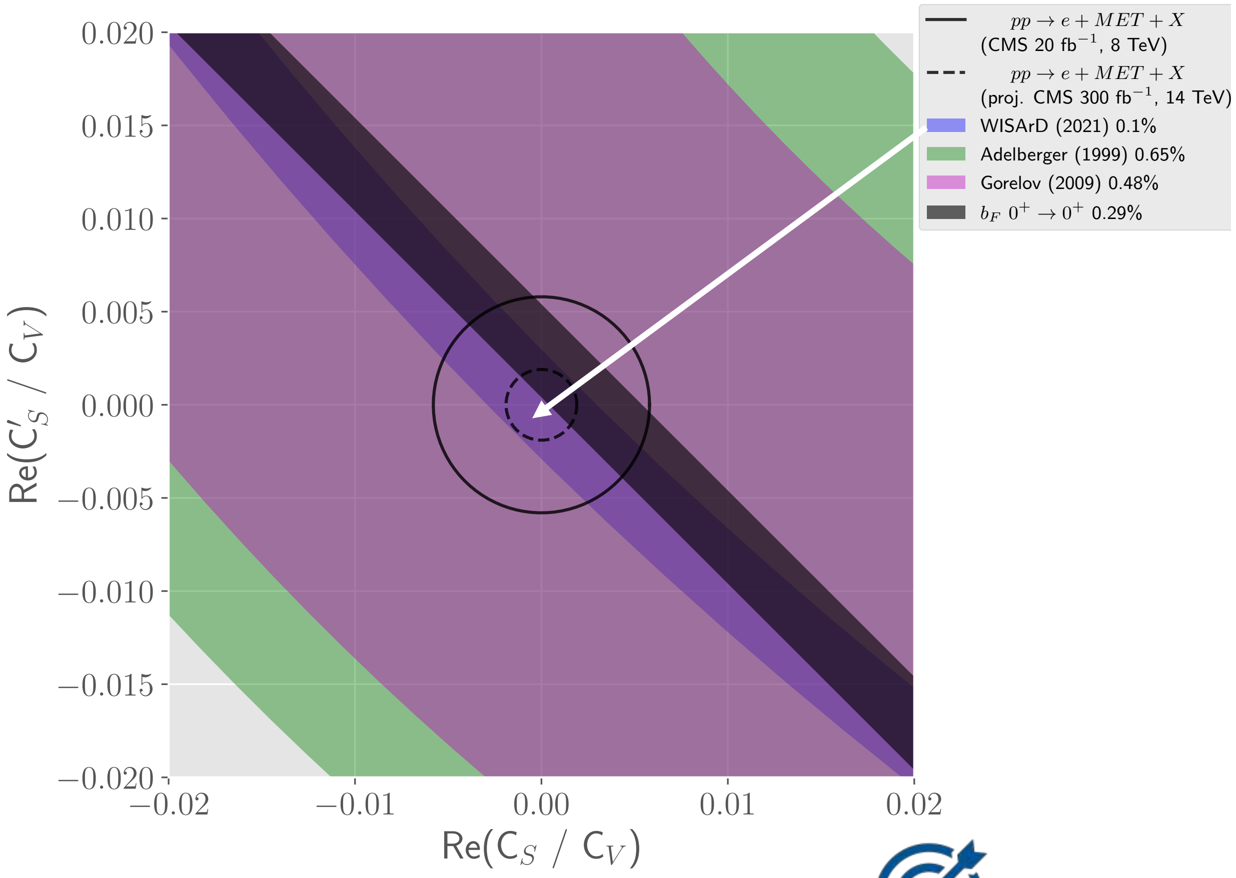
Talk: M. Pomorski 18/03 @ 14:45

Conclusion and outlook

Exclusion plot



Current situation



Perspective

Thank you!

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