KU LEUVEN

NUCLEAR AND RADIATION PHYSICS

^{32}Ar data analysis 2018

- Experimental technique
- WISArD setup
- Data analysis & results
- Conclusion & perspectives

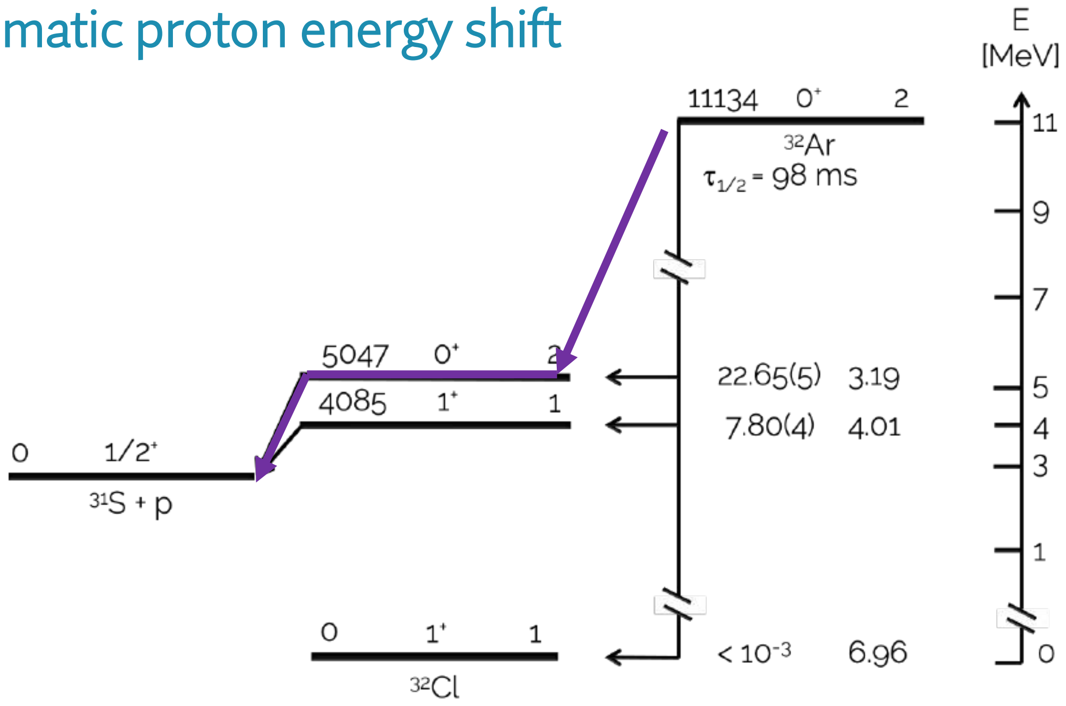
WISArD Collaboration Meeting (March 21st, 2021)

Victoria Araujo-Escalona

PhD student KU Leuven (currently based at CENBG)

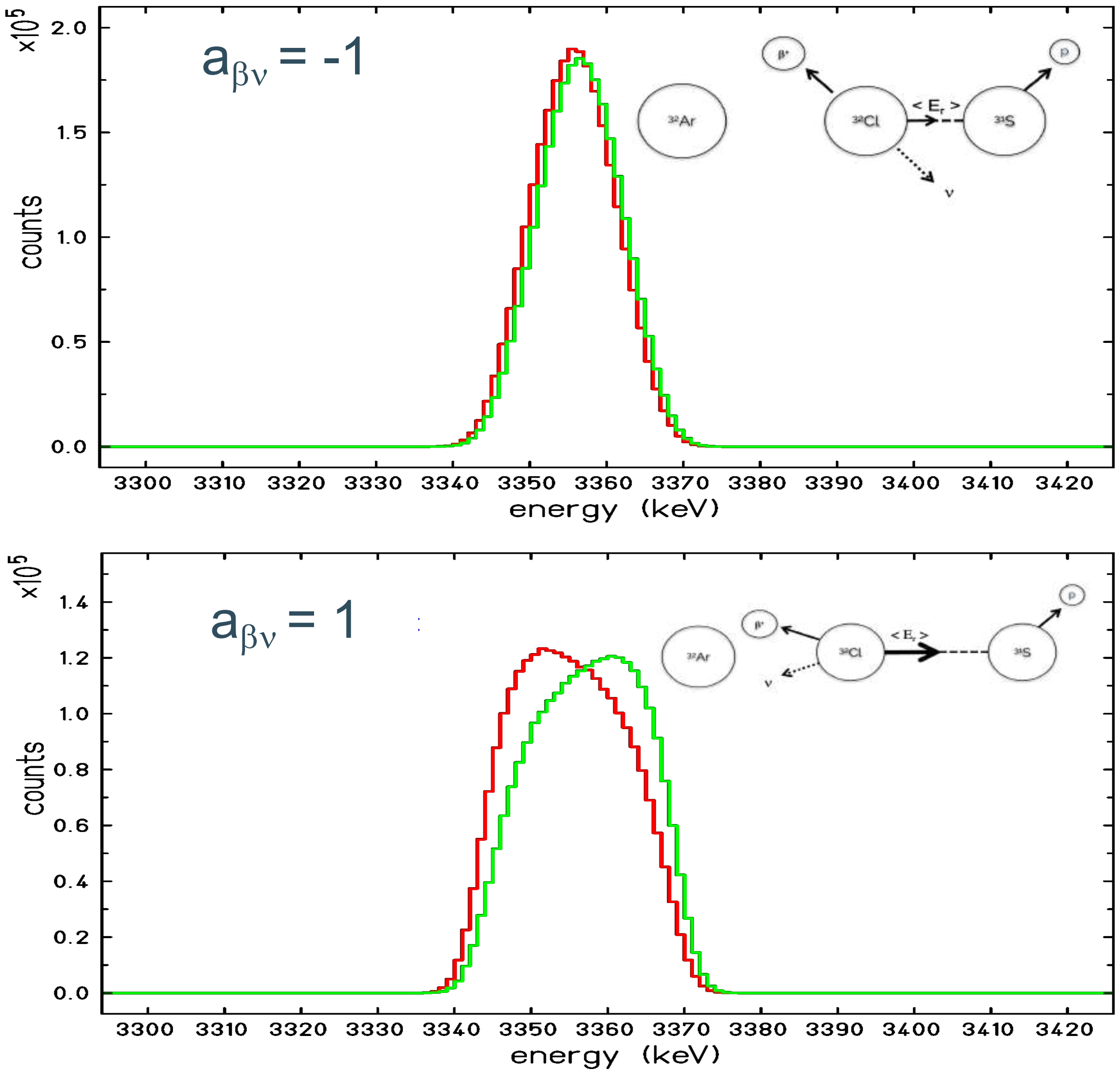
How do we measure?

Kinematic proton energy shift



Experimental objective

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



Proton energy distribution

Red: parallel direction Green: antiparallel

KU LEUVEN

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]
  β–$\bar{\nu}$–α 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

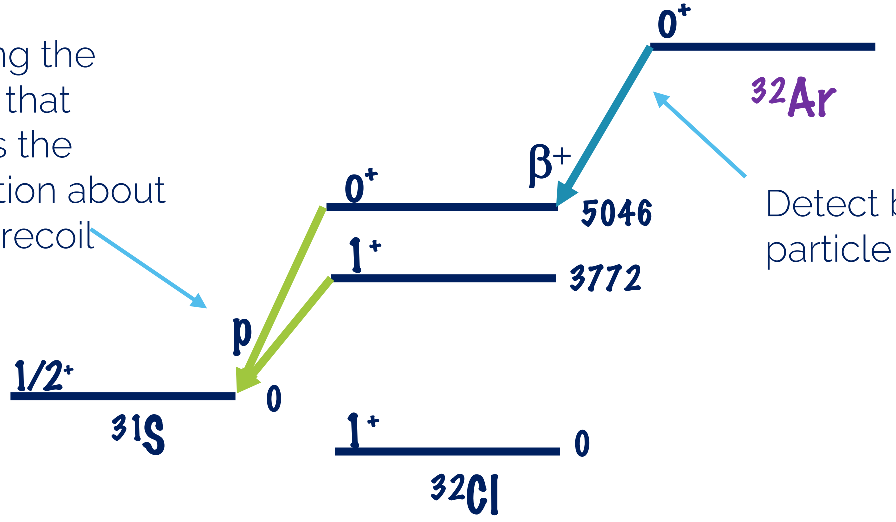
$$\Delta a_{\beta\nu}^{F} \sim 5.10^{-3}$$

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

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

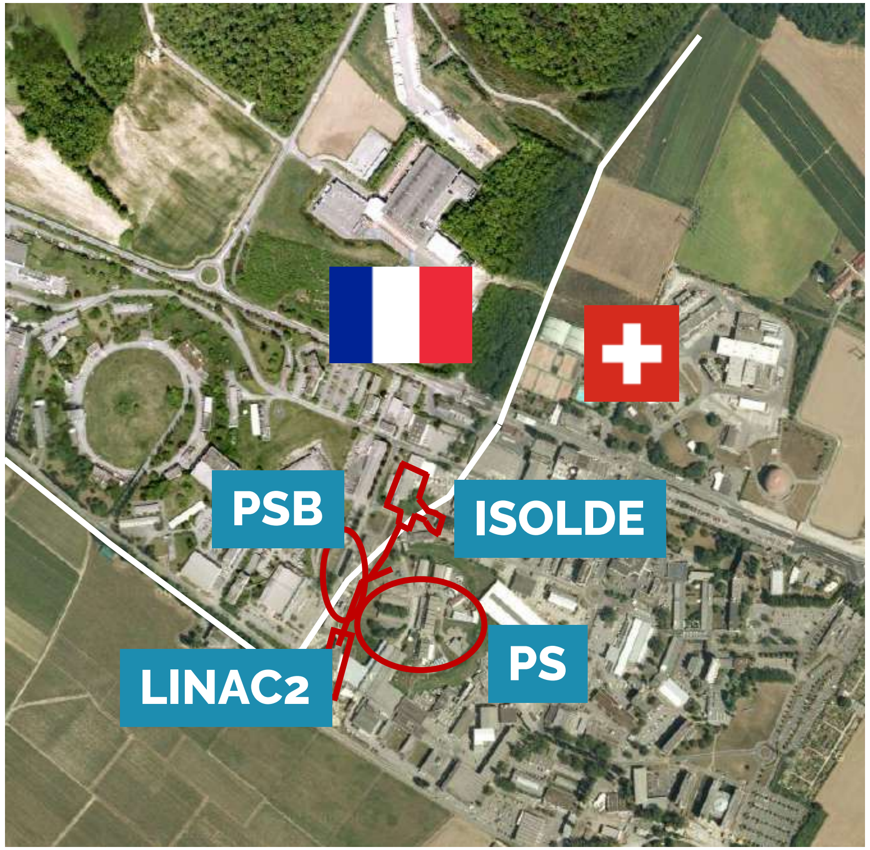
Weak **I**nteraction **S**tudies with ^{32}**Ar**gon **D**ecay: The 0.1% challenge!

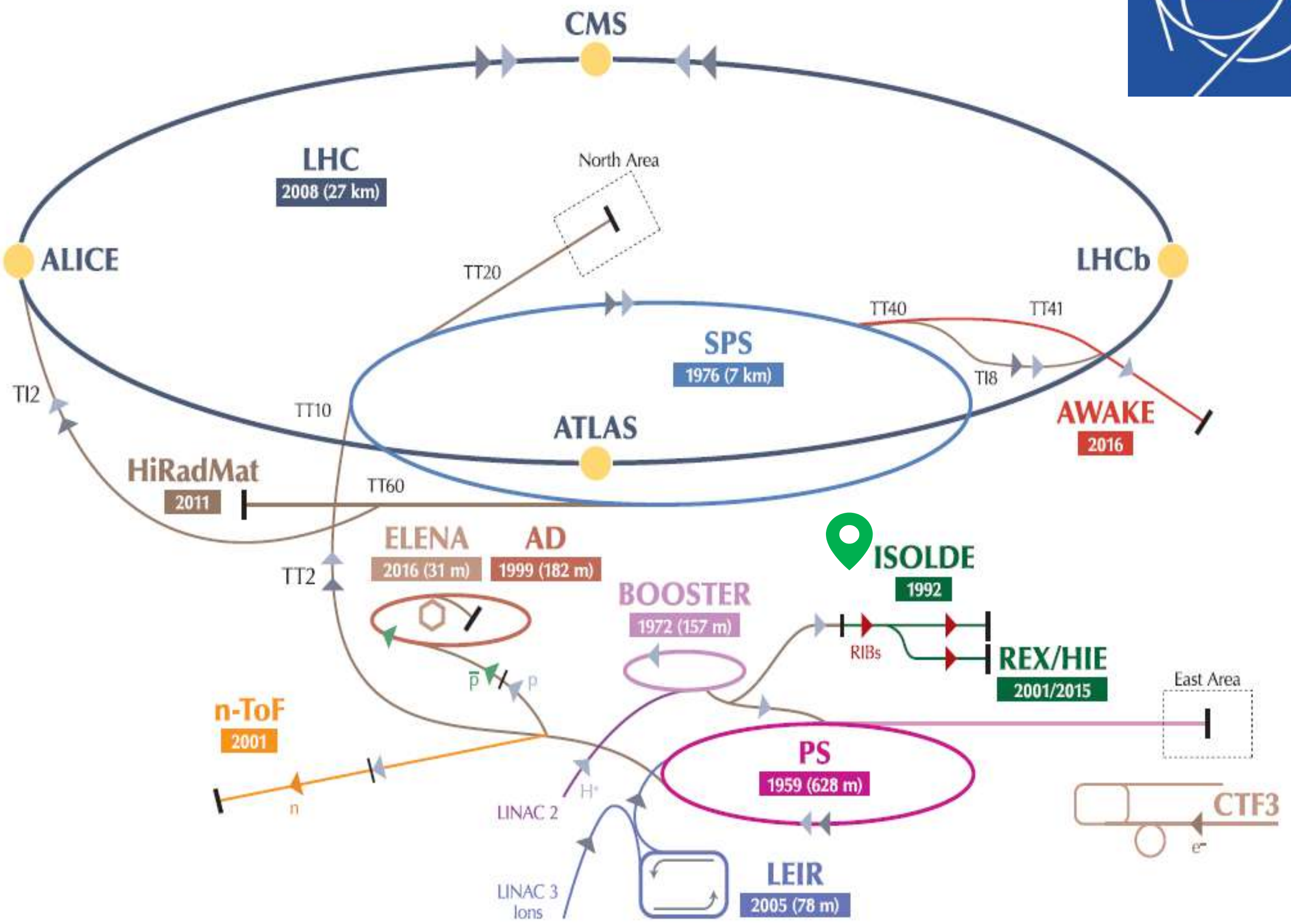
Detecting the protons that contains the information about the ^{32}Cl recoil



Detect beta particle

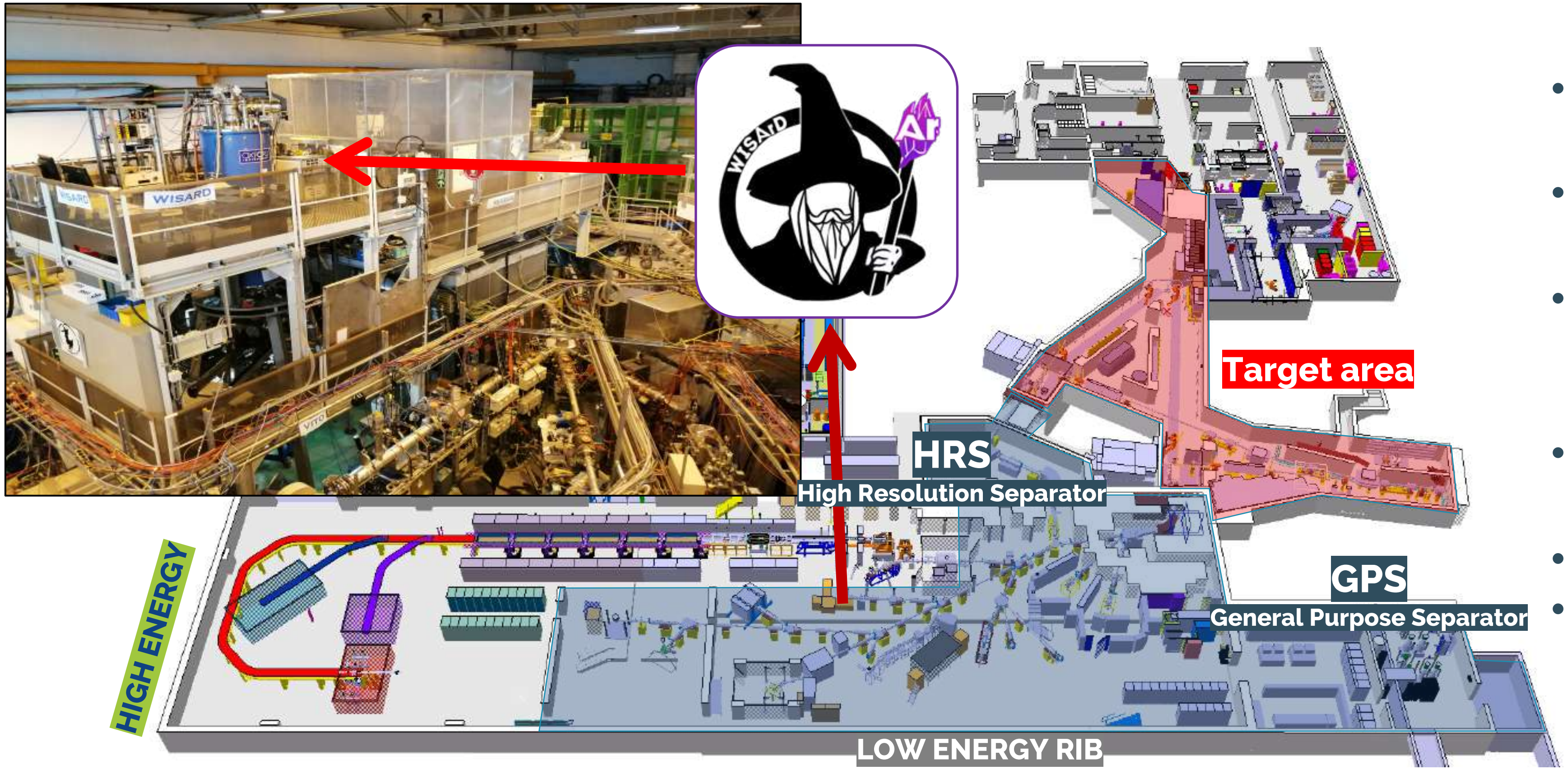
ISOLDE @ CERN





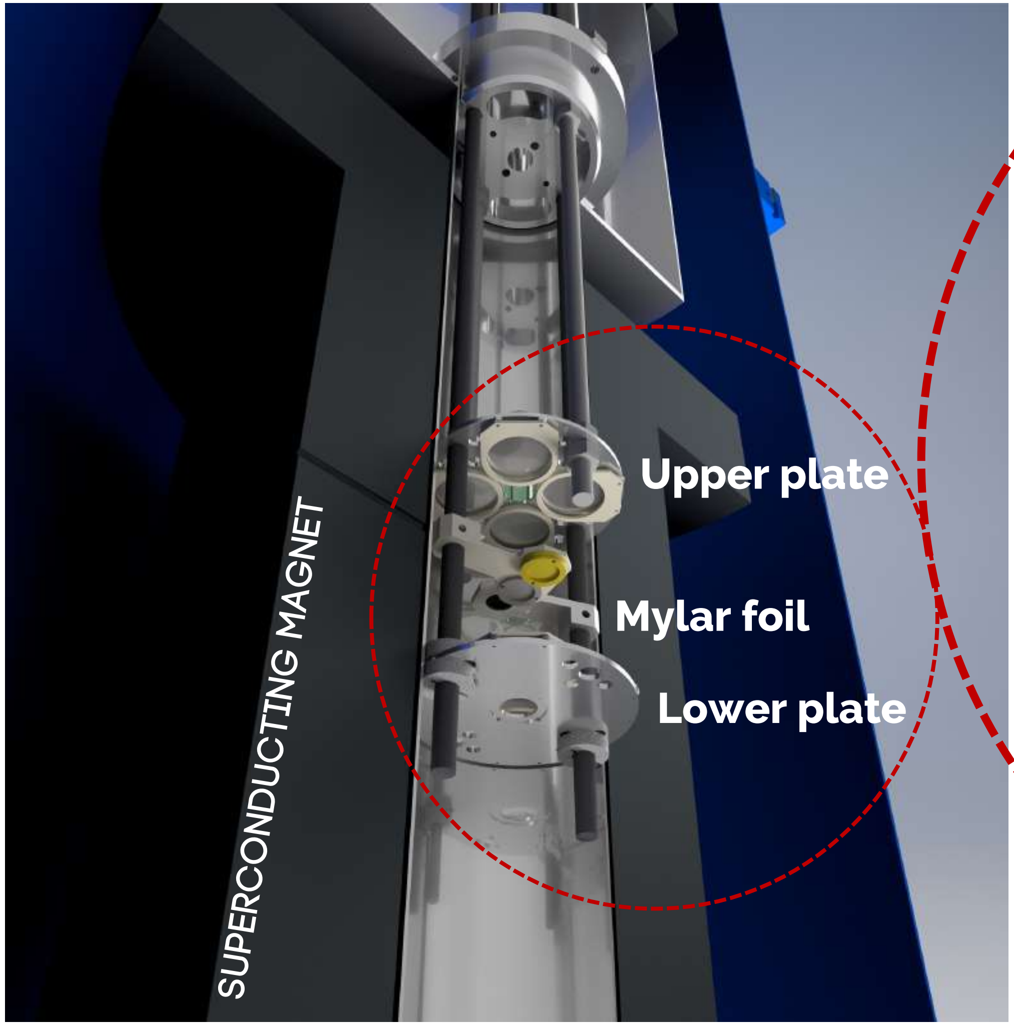
Isotope On-Line Device at CERN's Accelerators Complex

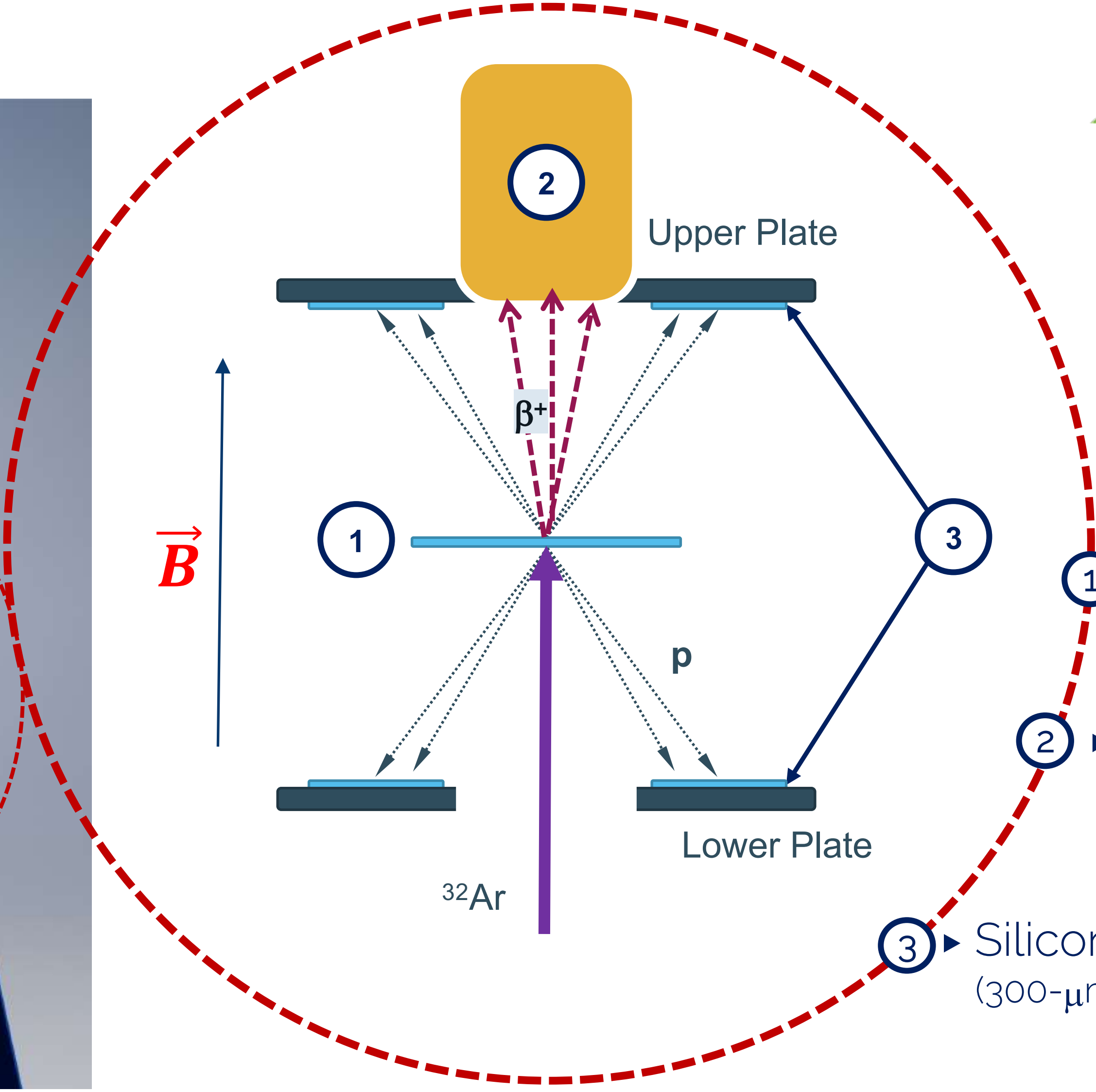
Experimental Setup



- 1.4 GeV protons → CaO target
- Effective beam time of 35 hrs
- 1700 pps production yield (ISOLDE capability 3640 pps)
- approx. 10^5 proton-positron coincidences (Fermi)
- Implantation rate of 90 pps
- Ion transmission in the beamline was 12% (inadequate existing beam optics $^{32}Ar^{+}$ beam 30 keV)

Inside the WISArD





1. Mylar foil (7-μm-thick Ø= 15mm)
2. Plastic scintillator +SiPM (50mm / Ø=20mm)
3. Silicon detectors (300-μm-thick / Ø= 30mm)

Data Analysis

Experimental data

1. Energy calibration
   - SiDW → Dead layer thickness
   - SiUP → Mylar thickness
2. Coincidence measurement.
   short time window between p and β
3. Kinematic energy shift, ΔE_p

Monte Carlo simulations

1. Event generator (CRADLE++)
2. GEANT4 simulations
   - $\tilde{a}_{\beta\nu}$ vs ΔE_p
3. Systematic uncertainties

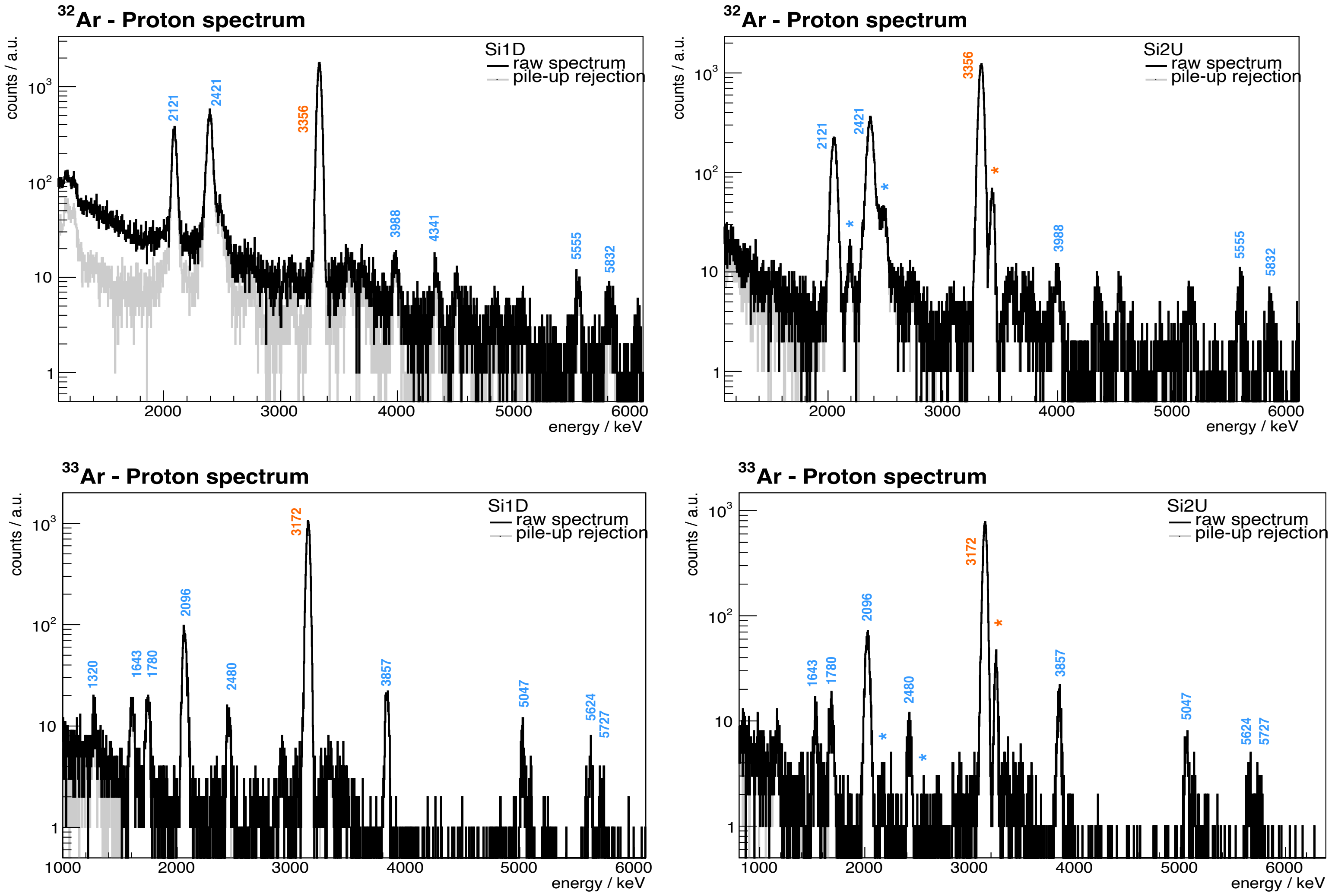
Data Analysis

Experimental data

1. Energy calibration
   - SiDW → Dead layer thickness
   - SiUP → Mylar thickness
2. Coincidence measurement.
   short time window between p and β
3. Kinematic energy shift, ΔE_p

Monte Carlo simulations

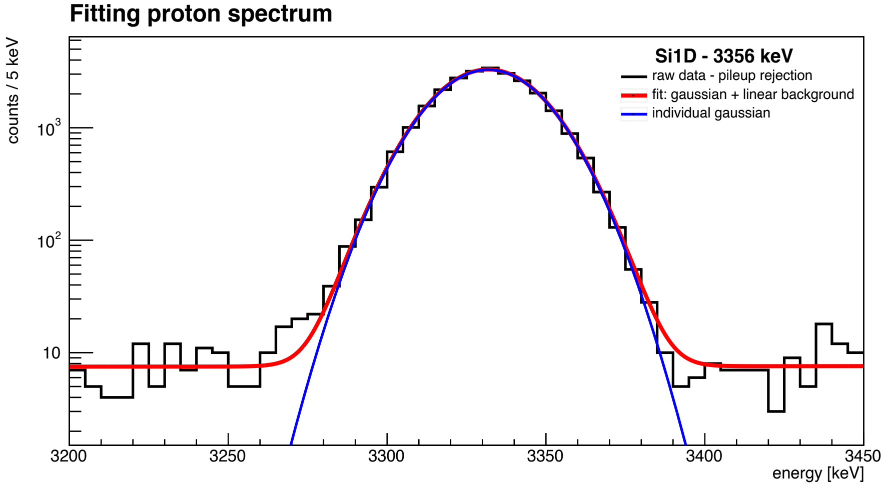
1. Event generator (CRADLE++)
2. GEANT4 simulations
   - $\tilde{a}_{\beta\nu}$ vs ΔE_p
3. Systematic uncertainties

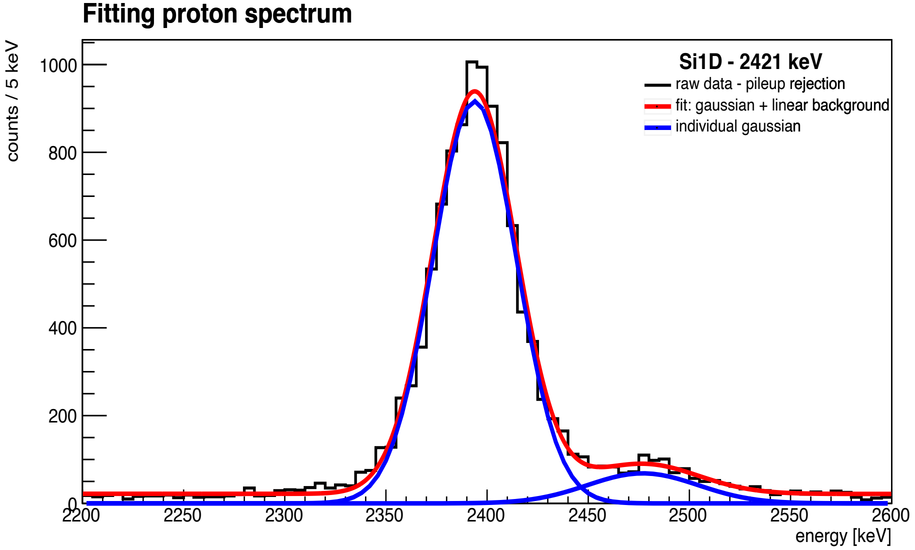


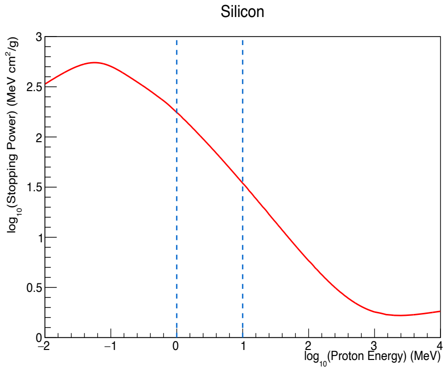
Data Analysis

Experimental data

1. Energy calibration
   - SiDW → Dead layer thickness
   - SiUP → Mylar thickness







Fitting procedure

- ✓ Blank et al (proton energy literature, E_{lit})
- ✓ SiDW: determine calibration parameters & dead layer thickness
- ✓ Gaussian function plus a linear background fit

$$E_{cal} = Cx + y + E_{loss}\Big|_{DL}$$

- ✓ Chi2 minimization function

$$\chi^2 = \frac{(E_{lit} - E_{cal})^2}{\delta E_{lit}{}^2 + \delta E_{cal}{}^2}$$

Dead Layer thickness 1290(120) nm

- Silicon detectors (300-μm-thick / Ø= 30mm)

Data Analysis

Experimental data

1. Energy calibration
   - SIDW → Dead layer thickness
   - SiUP → Mylar thickness

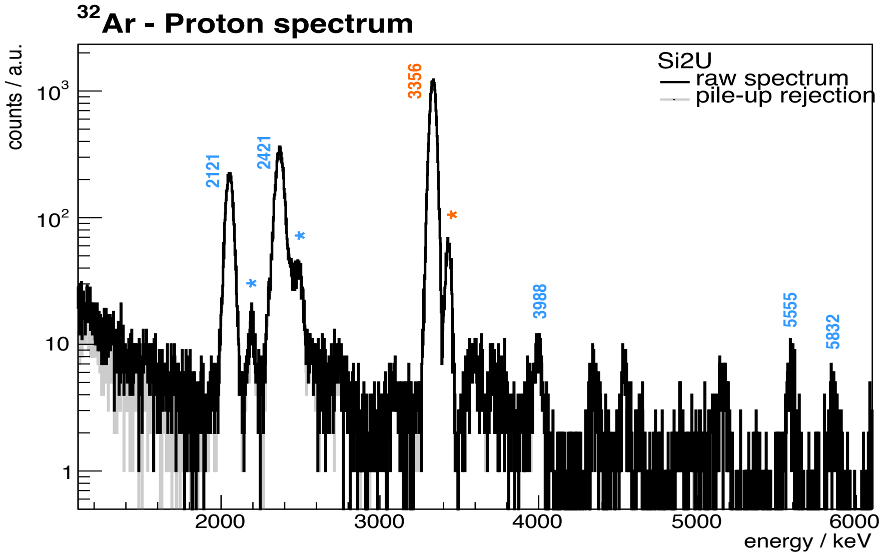
Fitting procedure

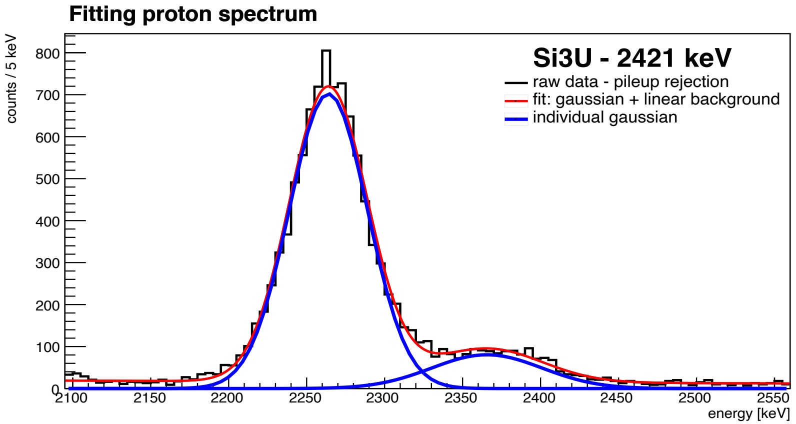
- ✓ Blank et al (proton energy literature, E_{lit})
- ✓ SiUP: determine calibration parameters & mylar thickness
- ✓ Gaussian function plus a linear background fit

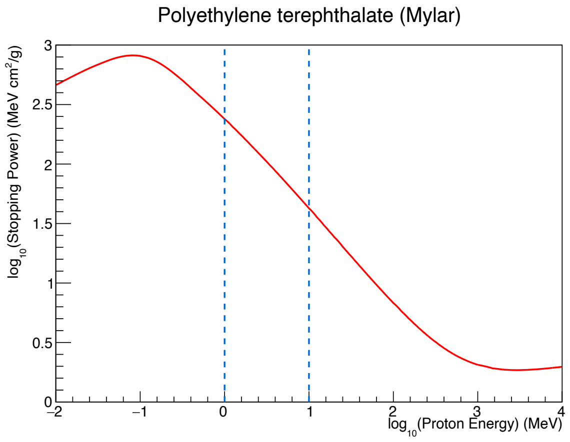
$$E_{cal} = Cx + y + E_{loss}\Big|_{DL} + E_{loss}\Big|_{mylar}$$

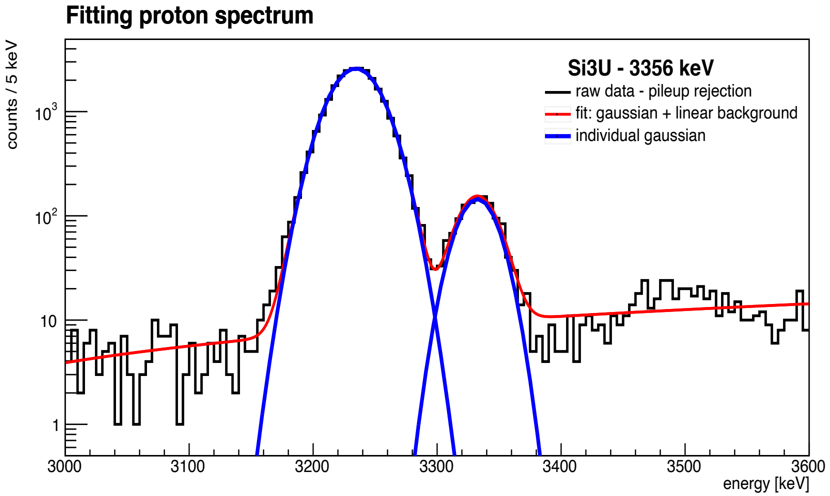
- ✓ Chi2 minimization function

$$\chi^2 = \frac{(E_{lit} - E_{cal})^2}{\delta E_{lit}{}^2 + \delta E_{cal}{}^2}$$







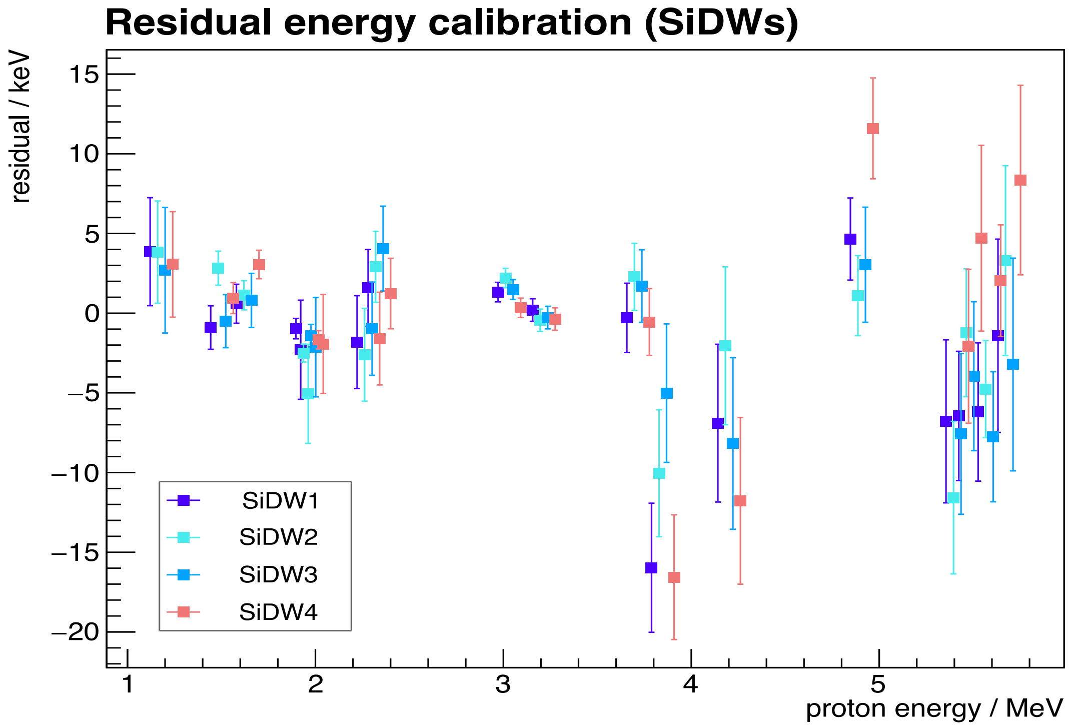


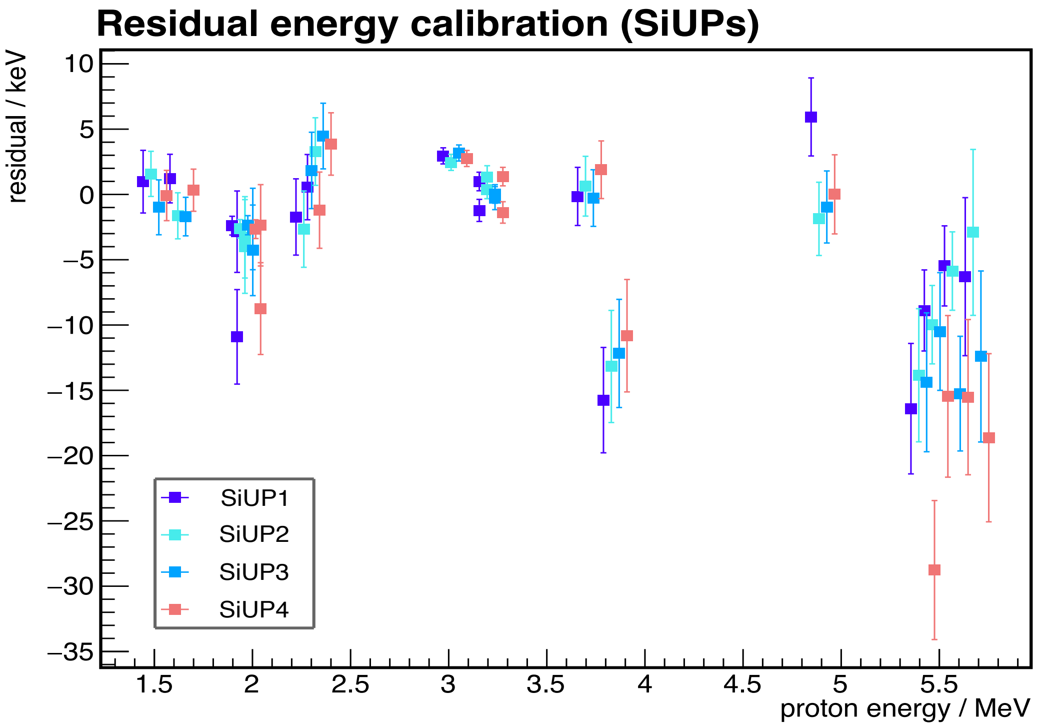
Mylar thickness 6937(700) nm

Data Analysis

Experimental data

1. Energy calibration
   - SIDW → Dead layer thickness
   - SiUP → Mylar thickness





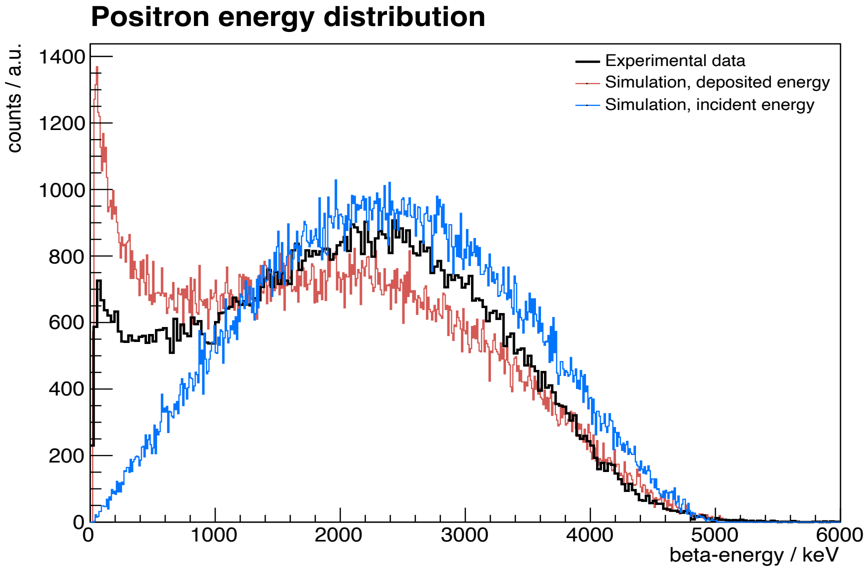
Data Analysis

Experimental data

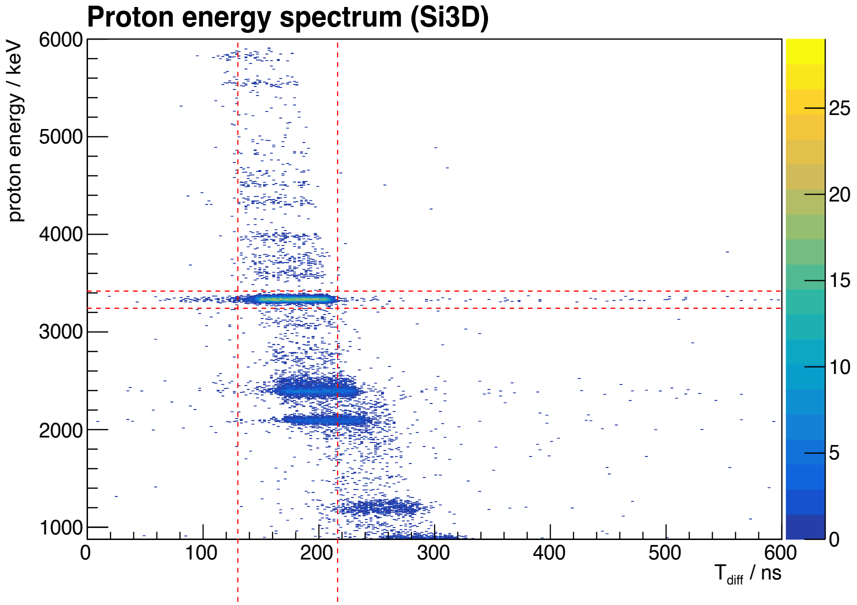
1. Energy calibration
   - SIDW → Dead layer thickness
   - SiUP → Mylar thickness
2. **Coincidence measurement**
   short time window between p and β
3. Kinematic energy shift, ΔE_p

Monte Carlo simulations

1. Event generator (CRADLE++)
2. GEANT4 simulations
   - $\tilde{a}_{\beta\nu}$ vs ΔE_p
3. Systematic uncertainties



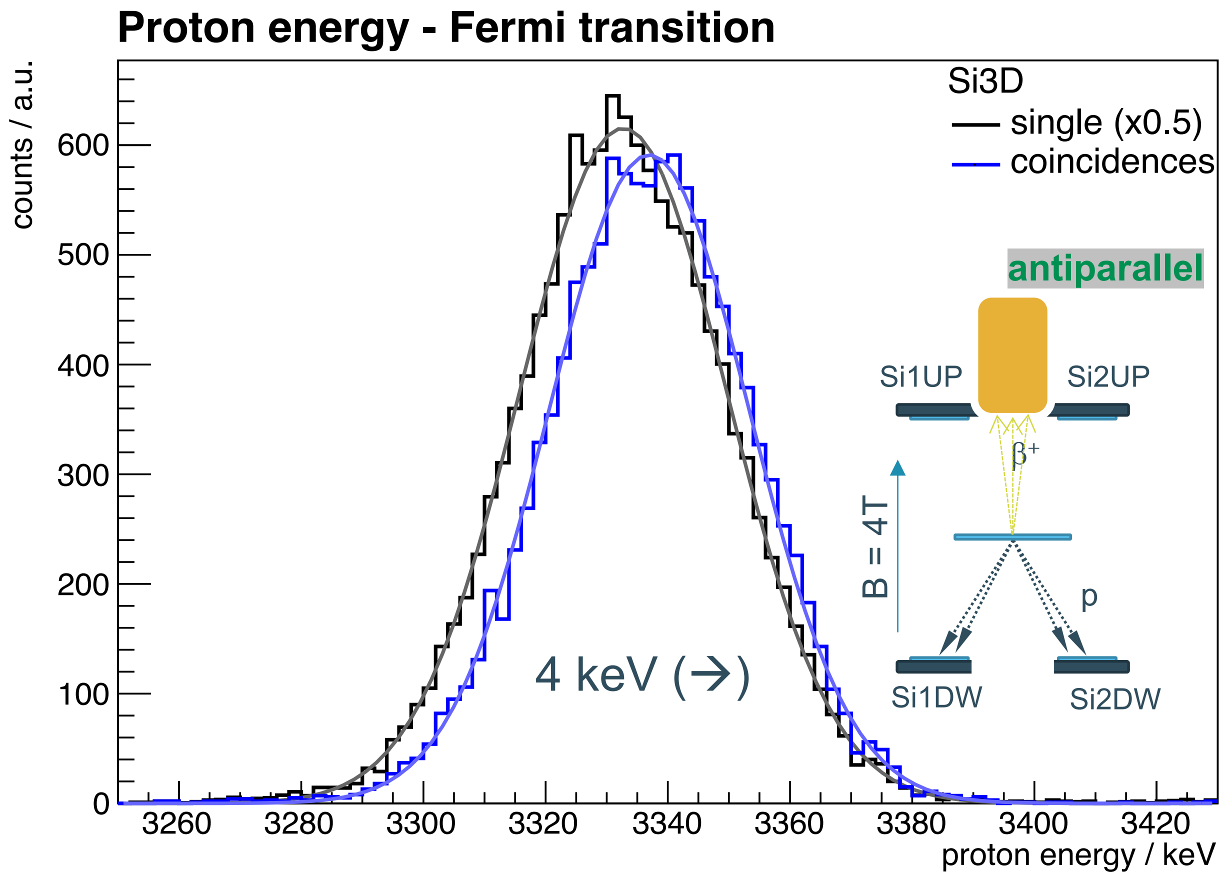
beta threshold =25(12)keV

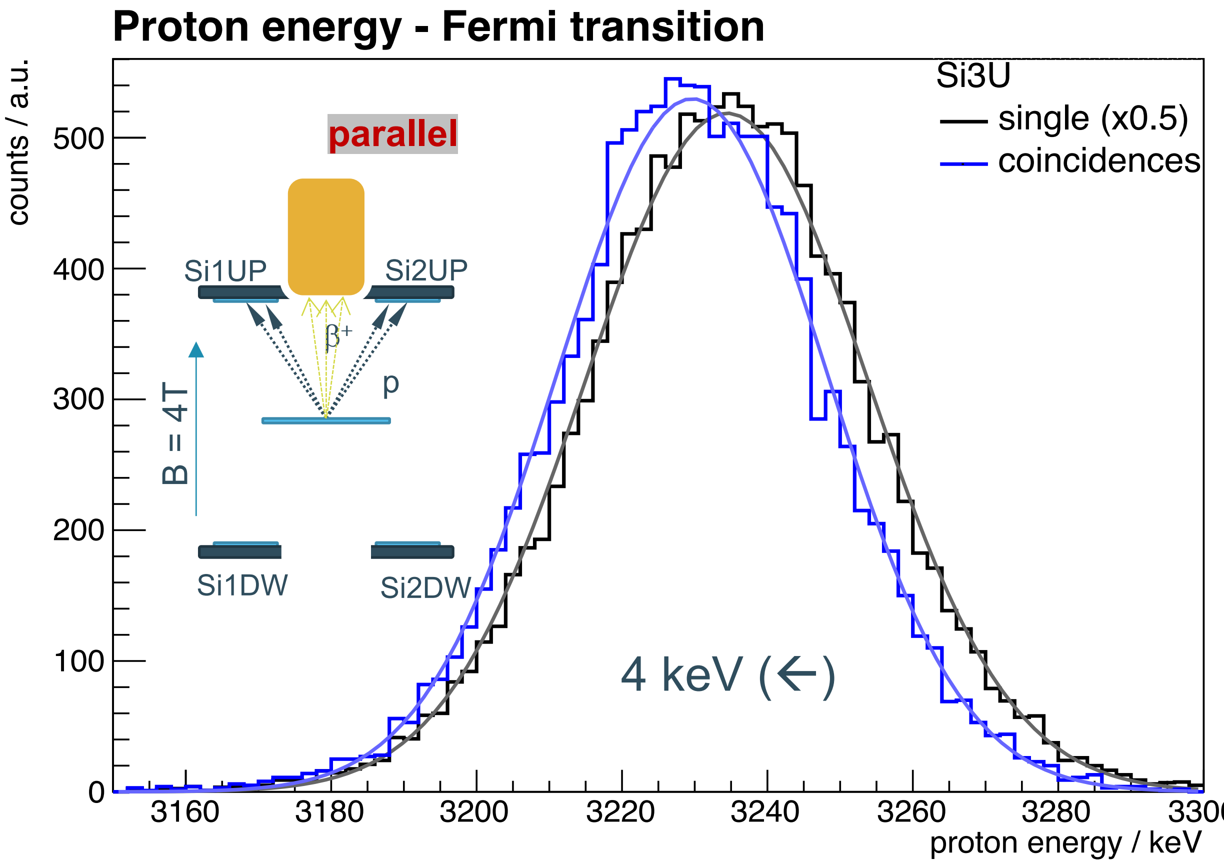


Tdiff = narrow range (individually)
Fermi

KU LEUVEN

Kinematic proton energy shift
β-p coincidence measurements



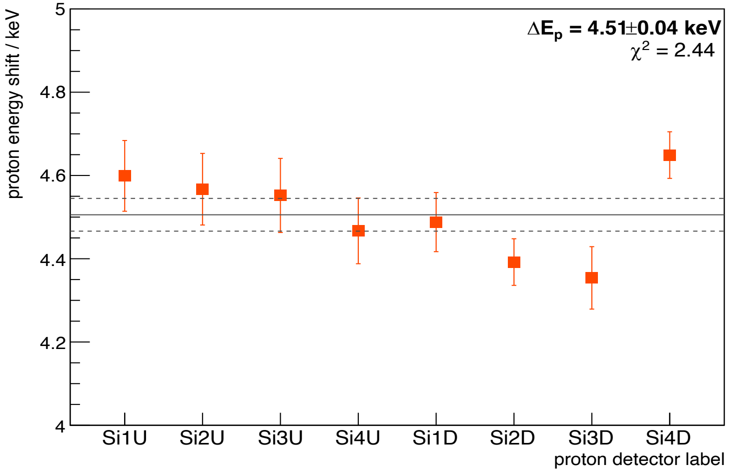


Clear energy shifts observed in the dominant vector contribution

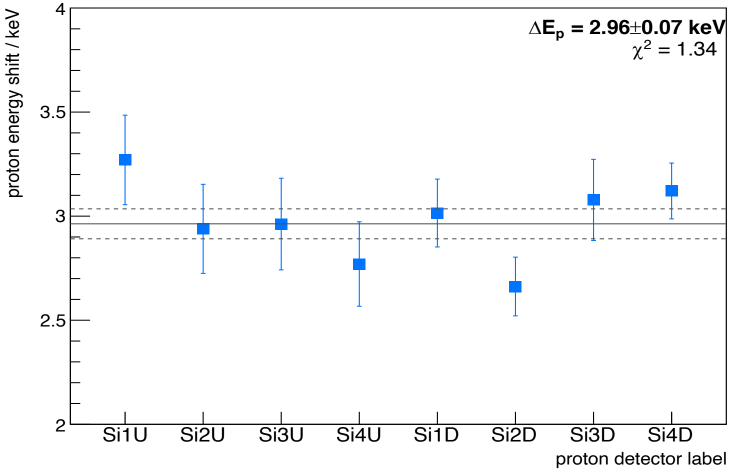
Data Analysis

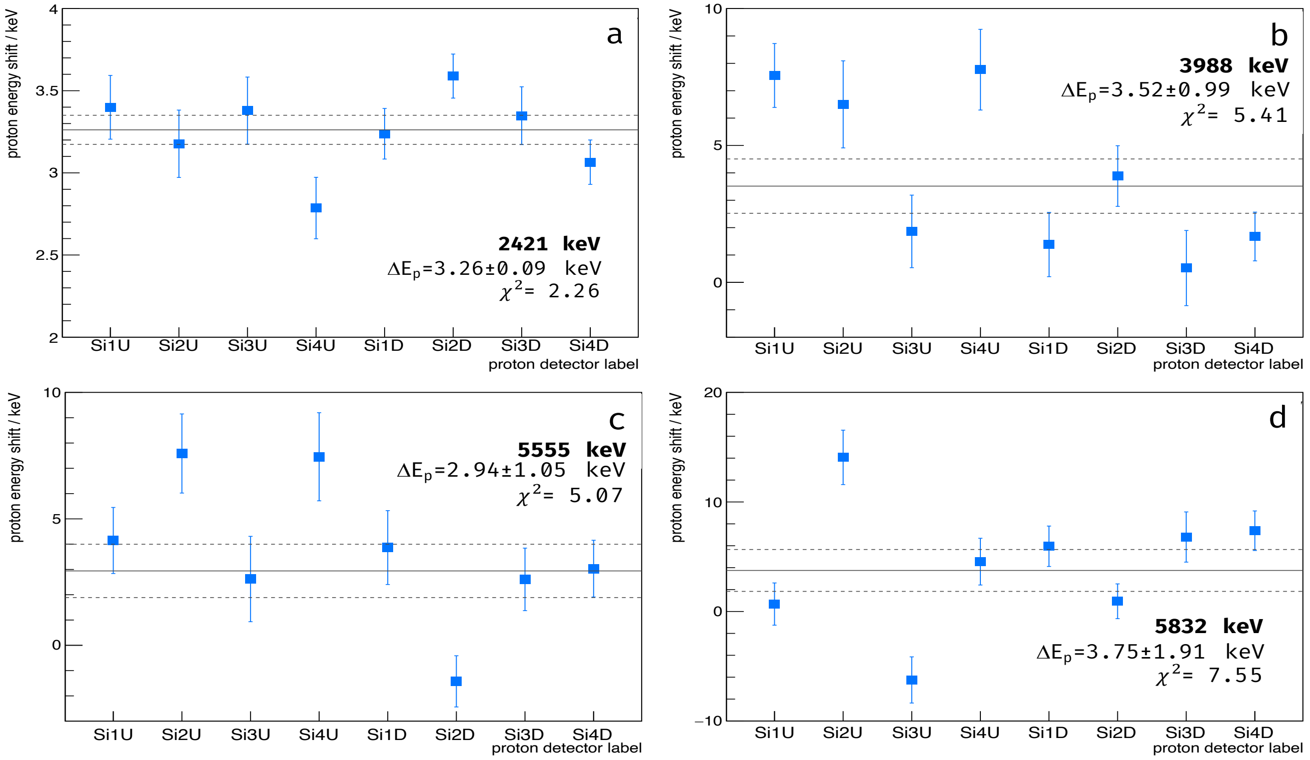
weighted average energy shift

Fermi transition - 3356 keV



GT transition - 2121 keV



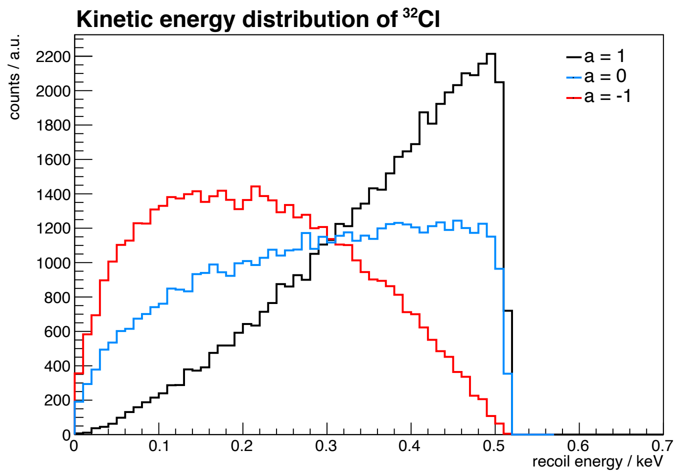


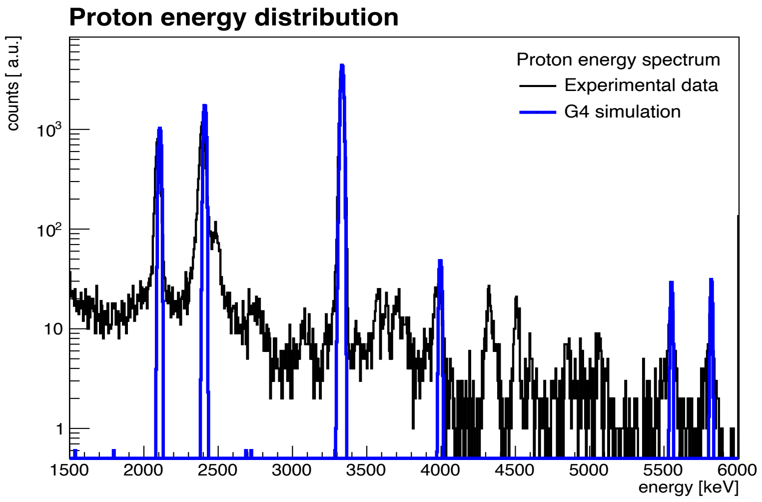
Extended study of the proton energy shift for proton groups followed by a pure GT transition. (a) 2421 keV, (b) 3988 keV, (c) 5555 keV and (d) 5832 keV

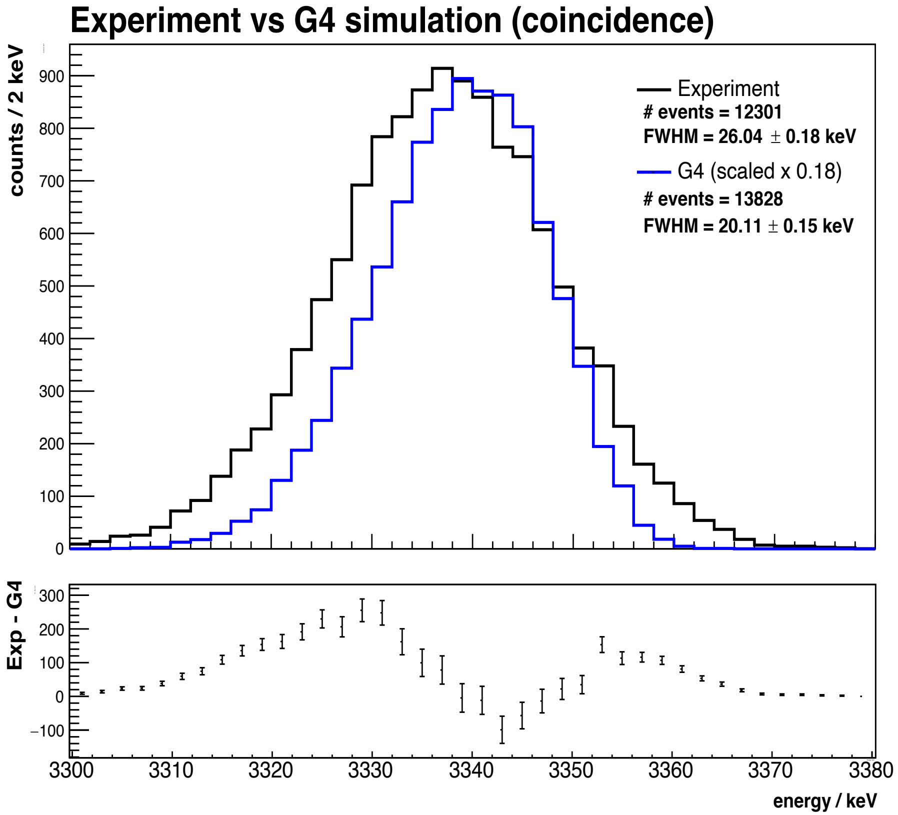
$$\Delta \mathbf{E} = \left|\bar{\mathbf{E}}_{\mathbf{coinc}} - \bar{\mathbf{E}}_{\mathbf{single}}\right| \qquad \delta \bar{E}_{shift} = \sqrt{\left(\bar{E}^2_{shift} / N_s + \bar{E}^2_{shift} / \frac{N_s}{N_c} \right)}$$

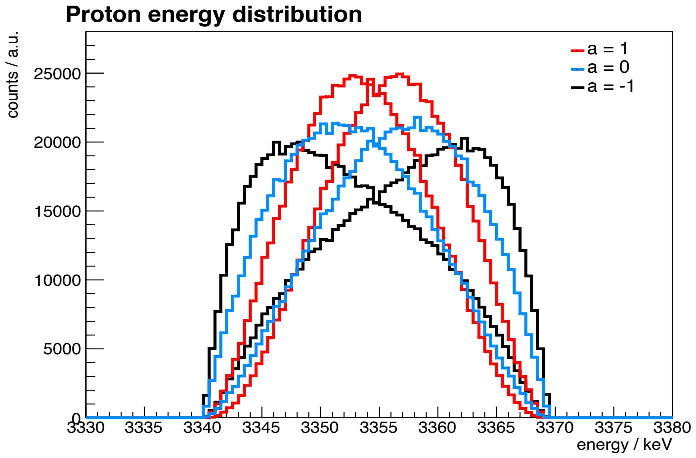
KU LEUVEN

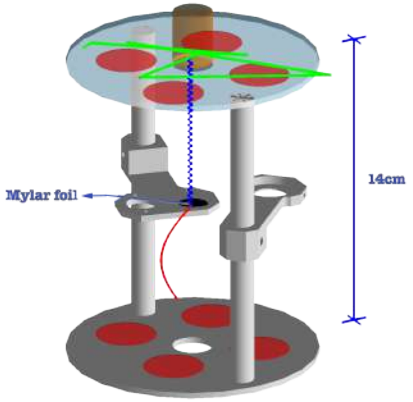
Monte Carlo simulations
CRADLE ++ and GEANT4







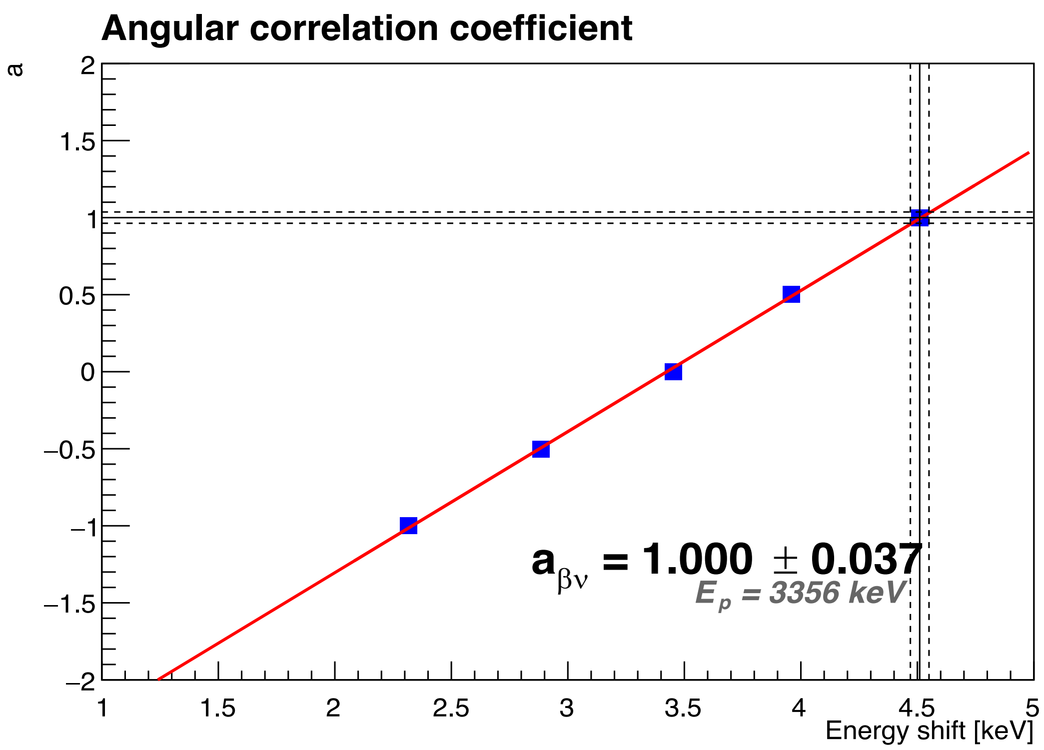


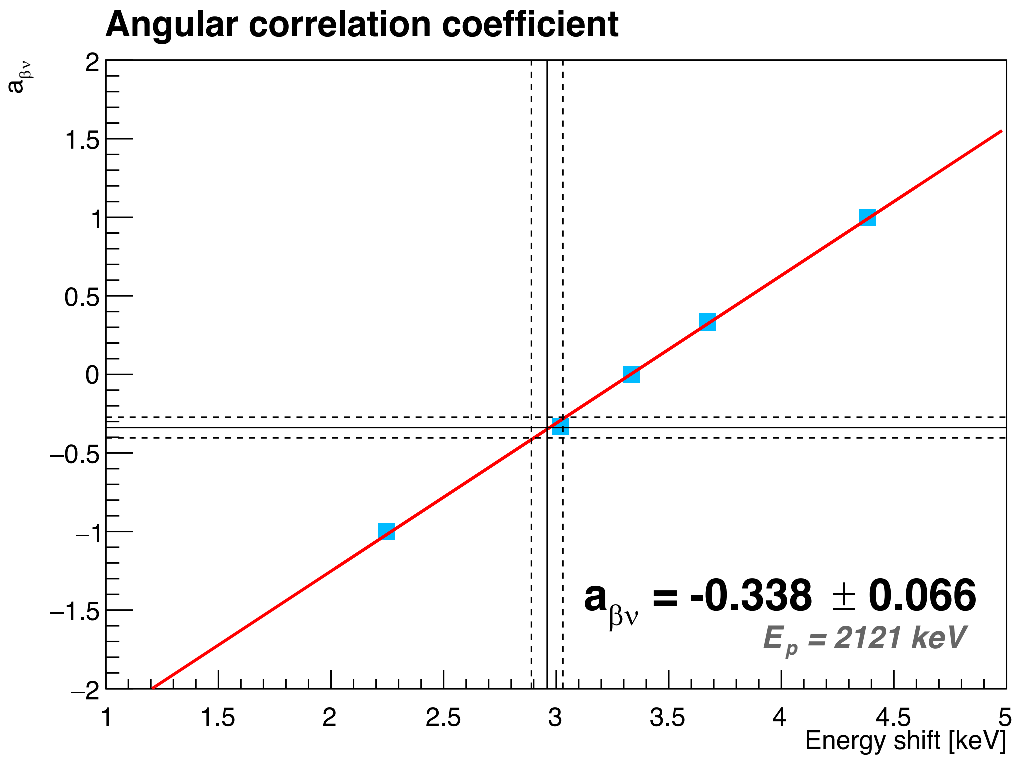


G4: no distinction between active volume and dead layer in silicon detectors

Angular correlation coefficient

Energy shift from G4 with a given a-parameter





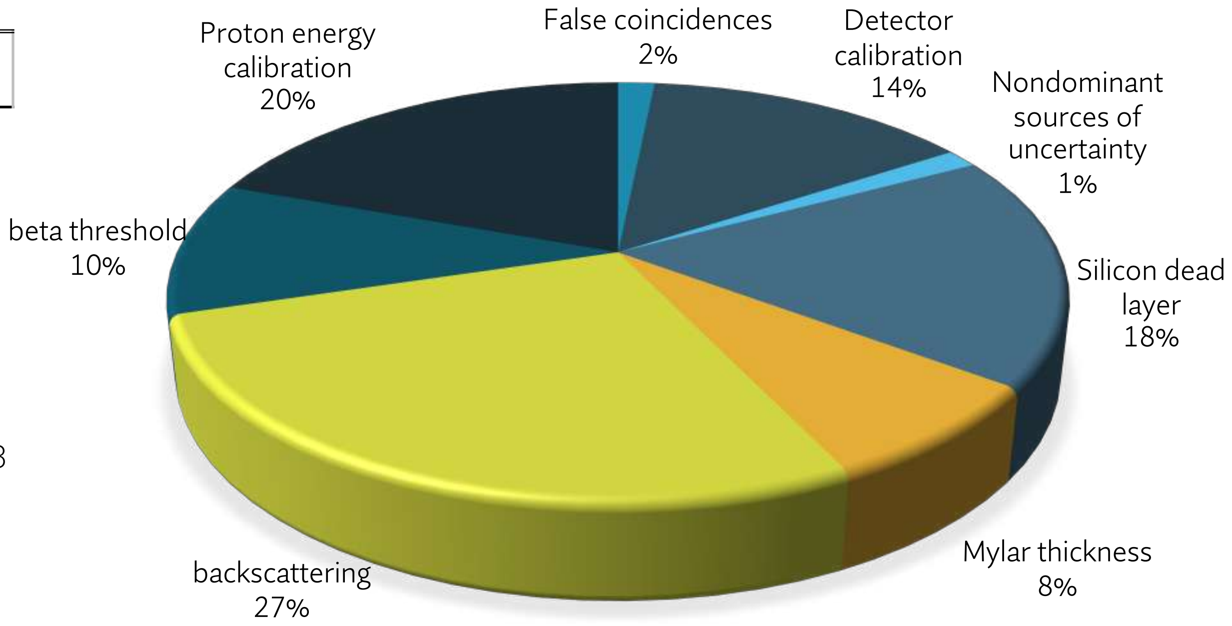
superallowed Fermi transition

KU LEUVEN

Systematic uncertainties
Monte Carlo simulations

	Source	uncertainty	$\delta\tilde{a}_F$	$\delta\tilde{a}_{GT}$
background	False coincidence	0.3%	1E-03	2E-03
proton	Linear slope uncertainty	0.3%	9E-03	6E-03
	Proton energy from literature	1 keV	1.23E-02	2.59E-03
	Silicon dead layer thickness	120 nm	1.15E-02	1.50E-02
	Mylar thickness	700 nm	4.87E-03	6.60E-03
positron	β backscattering	15%	1.74E-02	2.78E-02
	β energy threshold	12 keV	6.53E-03	8.27E-04
Nondominant	Detector position	1 mm	3.21E-04	1.86E-04
	Source position	1 mm	7.86E-04	2.78E-04
	Source radius	1 mm	1.67E-04	1.77E-04
	Magnetic field	1%	2.41E-05	4.64E-04
	Fierz interference term, b_F	0.1%	2.12E-04	2.83E-05
Total			0.027	0.033

Systematic uncertainties



$$\frac{da_{\beta\nu}}{d\kappa} = \frac{da_{\beta\nu}}{dE_p}\frac{dE_p}{d\kappa}$$

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)	Gamow-Teller transition	$a_{GT} = -0.33(3)$ Carlson et al. (^{23}Na)
			$a_{GT} = -0.3343(30)$ Johnson et al. (^{6}He)
	$a_F = 0.9981(30)$ Gorelov et al. (^{38}K^{m})		$a_{GT} = -0.3342(38)$ Sternberg et al. (^{8}Li)
	$a_F = 1.000(37)_{stat}(27)_{syst}$ Araujo et al. (^{32}Ar)		$a_{GT} = -0.338(66)_{stat}(34)_{syst}$ Araujo et al. (^{32}Ar)

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

Conclusions

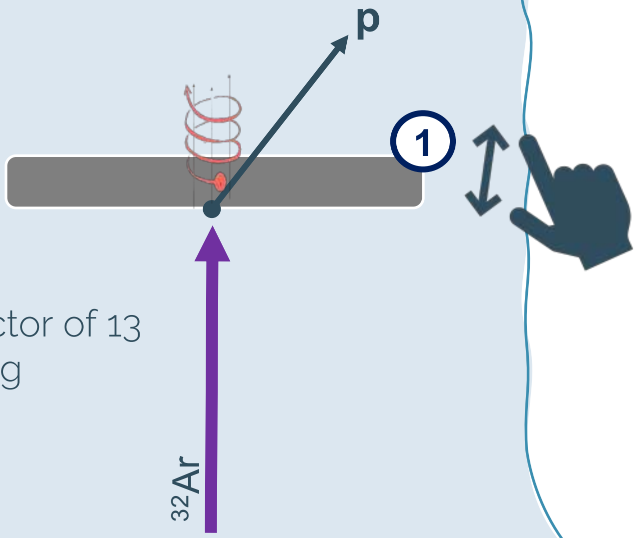
- ✓ Successful proof-of-principle experiment, expected kinematic energy shifts of proton peaks is observed, providing the third most precise measurement of $\boldsymbol{a_{\beta\nu}}$ in a pure Fermi transition.
- ✓ Simultaneous measurements of $a_{\beta\nu}$for different transitions (Fermi and Gamow-Teller) 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 $\boldsymbol{\sigma}$ and 1.5σ for F and GT, respectively.
- ✓ statistical uncertainty is reduced by a factor 2.5 using this technique instead broadening

Outlook

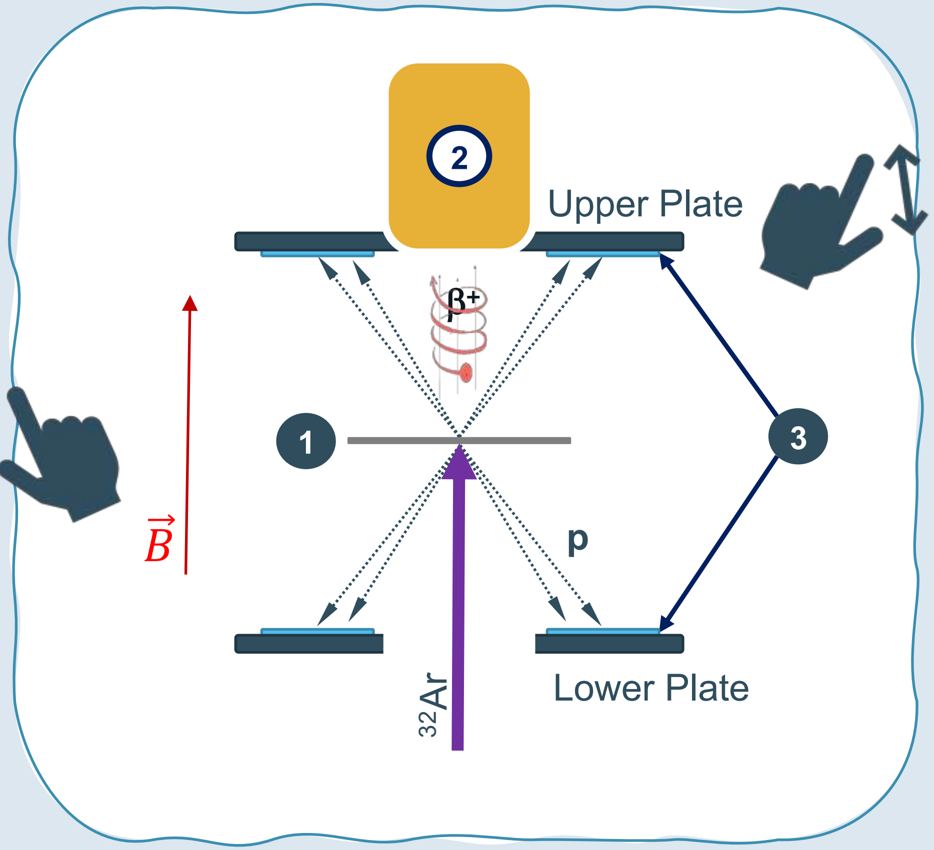
- ❑ ^{32}Ar production, transmission and longer beamtime
- ❑ New setup geometry and improve proton energy resolution. Segmented silicon detectors with well known and thinner dead layer.
- ❑ Reduce thickness of the mylar foil
- ❑ Full characterization of the plastic scintillator. Lower the positron energy threshold below 10keV to reduce the uncertainty.

Looking ahead

Mylar foil
(7-μm-thick)
500nm-thick
reduce by a factor of 13
β backscattering



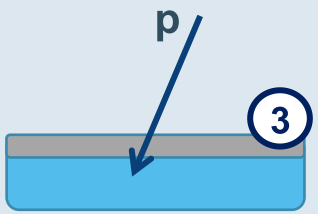
32Ar beam:
production yield > 1700pps
beam transmission 12%→70%



1 Mylar foil

2 Plastic Scintillator (BC-408)

3 Silicon detector



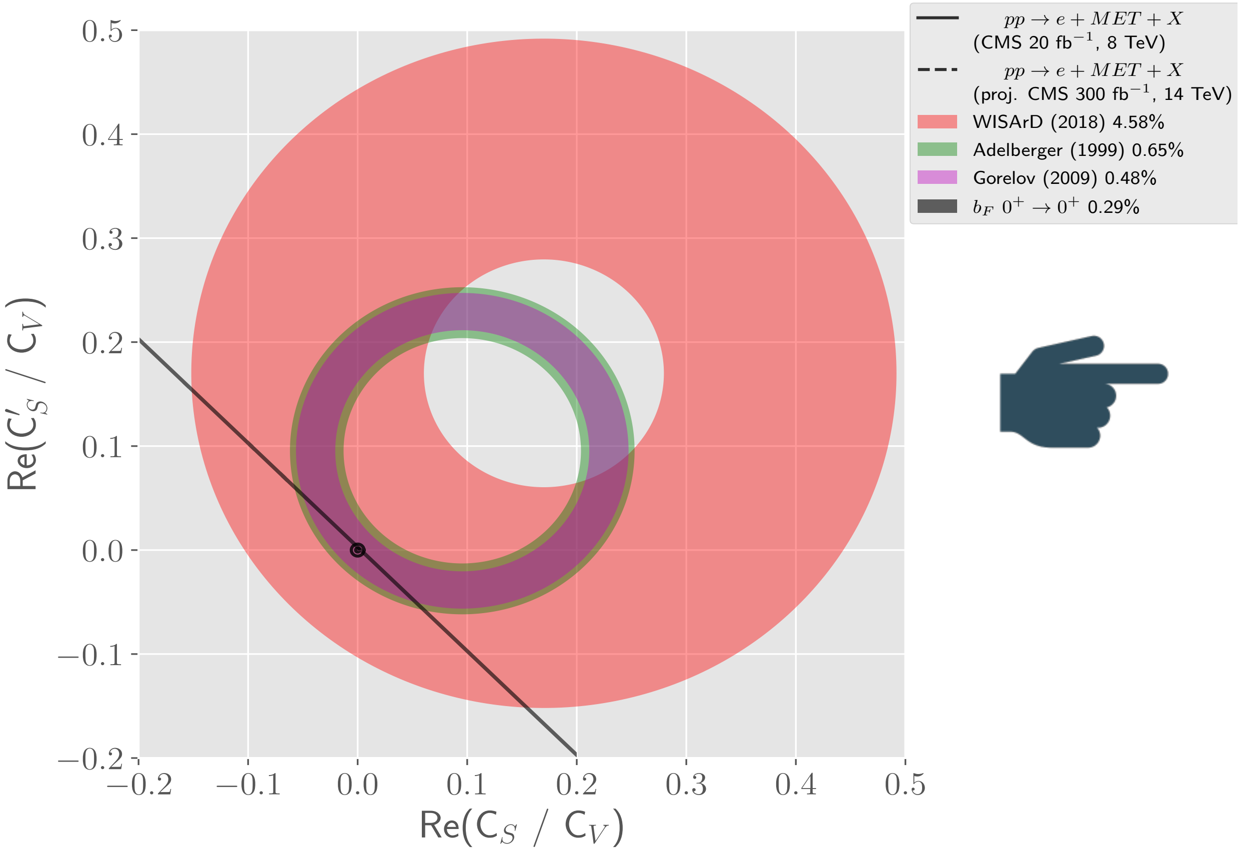
Thick 300 μm
Diameter 30 mm
* DL thickness 1290(120) nm

detection solid angle 8%→30%
energy resolution 30kev→ 5-10 keV
thinner dead layer <80nm

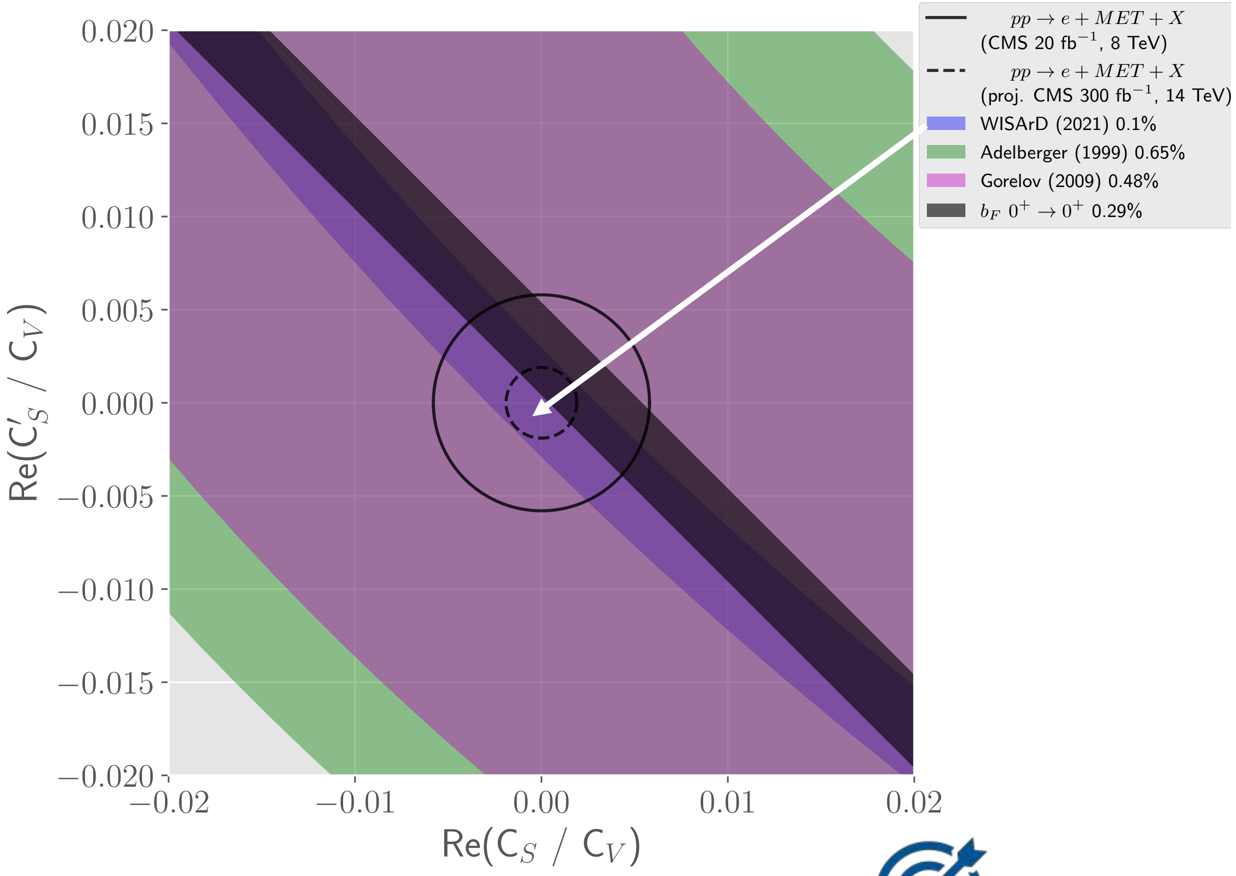
nondominant reduced by a factor 5

- Detector position
- Magnetic Field
- Source radius
- Source position

Conclusion and outlook
Exclusion plot



Current situation



Perspective

Thank you!

victoria.araujoescalona@kuleuven.be

V. Araujo-Escalona, N. Severijns, S. Vanlangendonck.
KU Leuven, Belgium

P. Alfaurt, P. Ascher, **B. Blank**, L. Daudin, M. Gerbaux, J. Giovinazzo, S. Grévy, T. Kurtukian Nieto, M. Roche, M. Versteegen
CENB Gradignan, France

X. Fléchard, E. Liénard, G. Quéméner.
LPC Caen, France

D. Zakoucky.
Rez, Czech Republic

D. Atanasov.
CERN, Switzerland