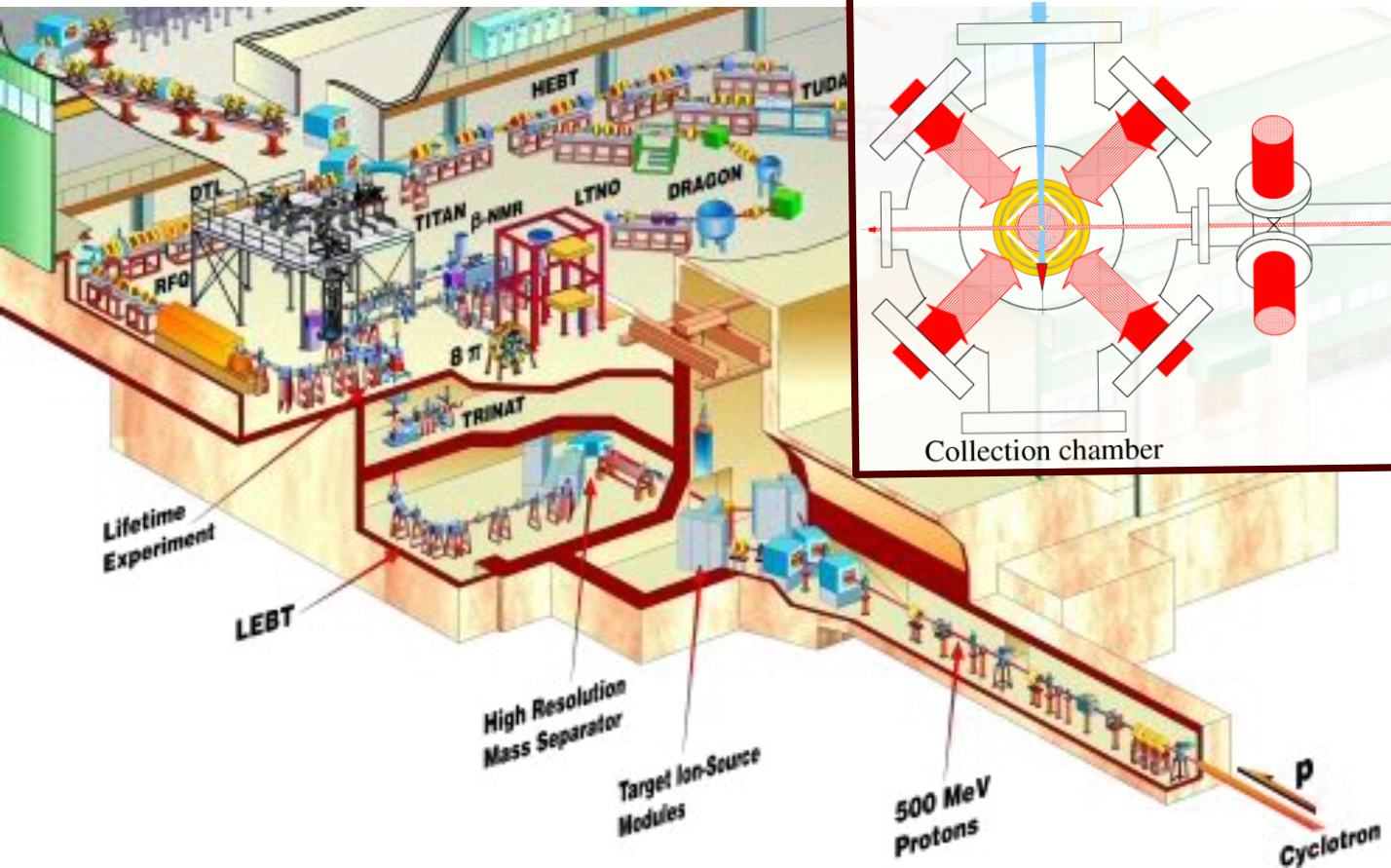
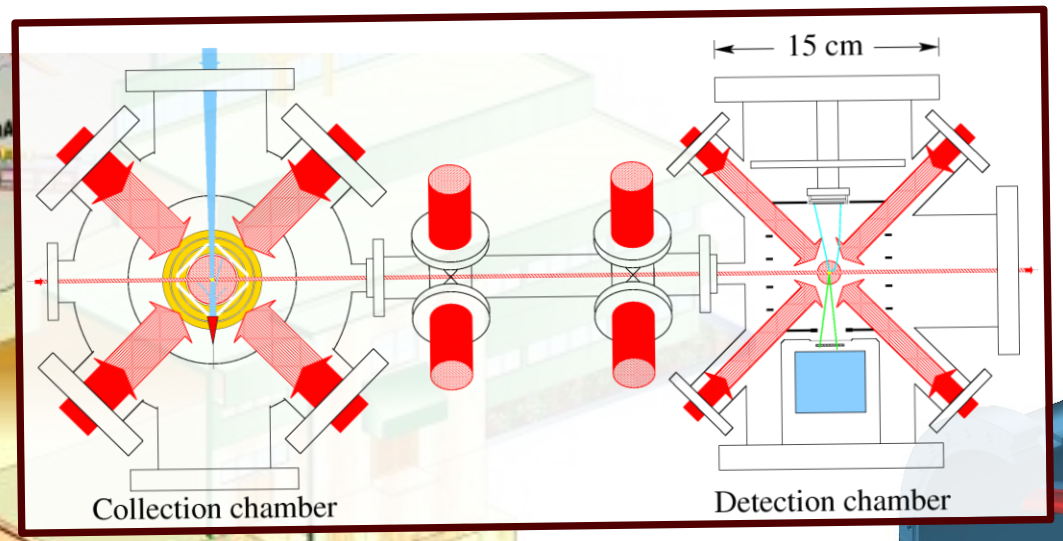
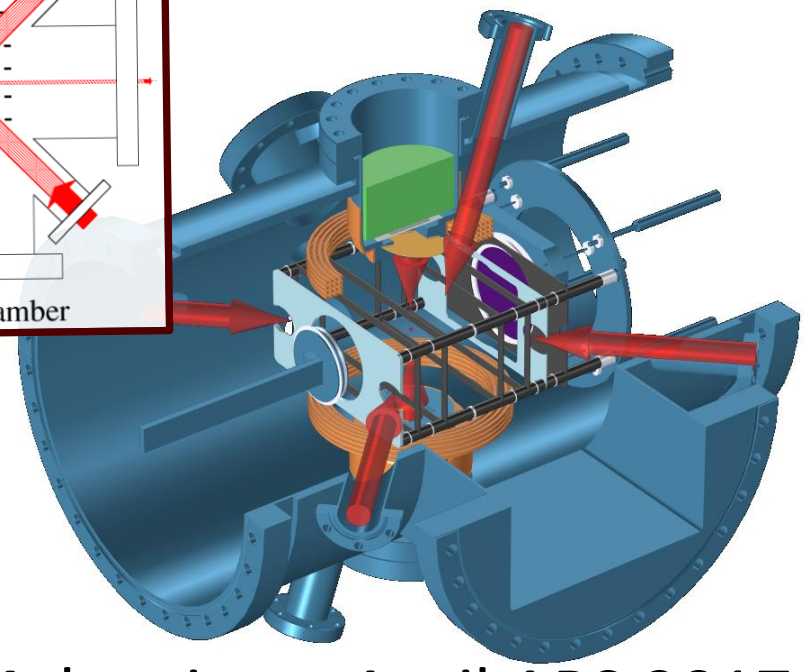
Precision measurement of the positron asymmetry of laser-cooled, spin-polarized ^{37}K



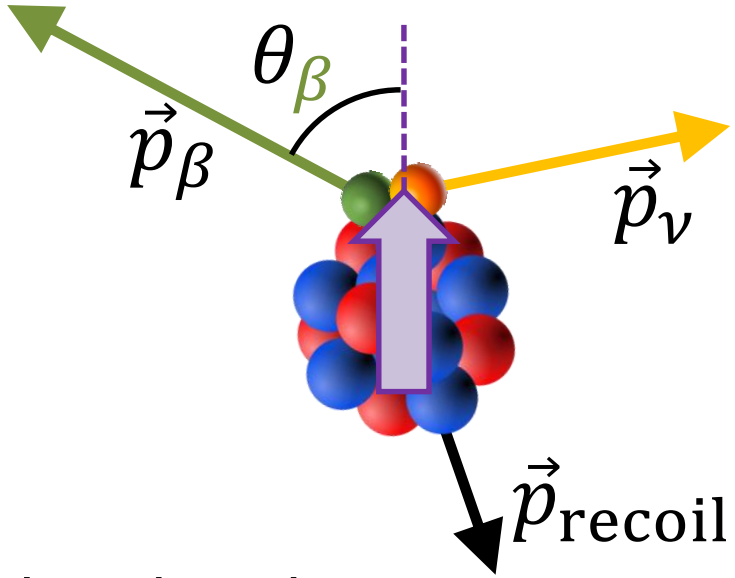




D. Melconian – April APS 2017

Introduction

- Goal:
  - To complement high-energy experiments by pushing the precision frontier
  - Angular correlations in β decay: values sensitive to new physics

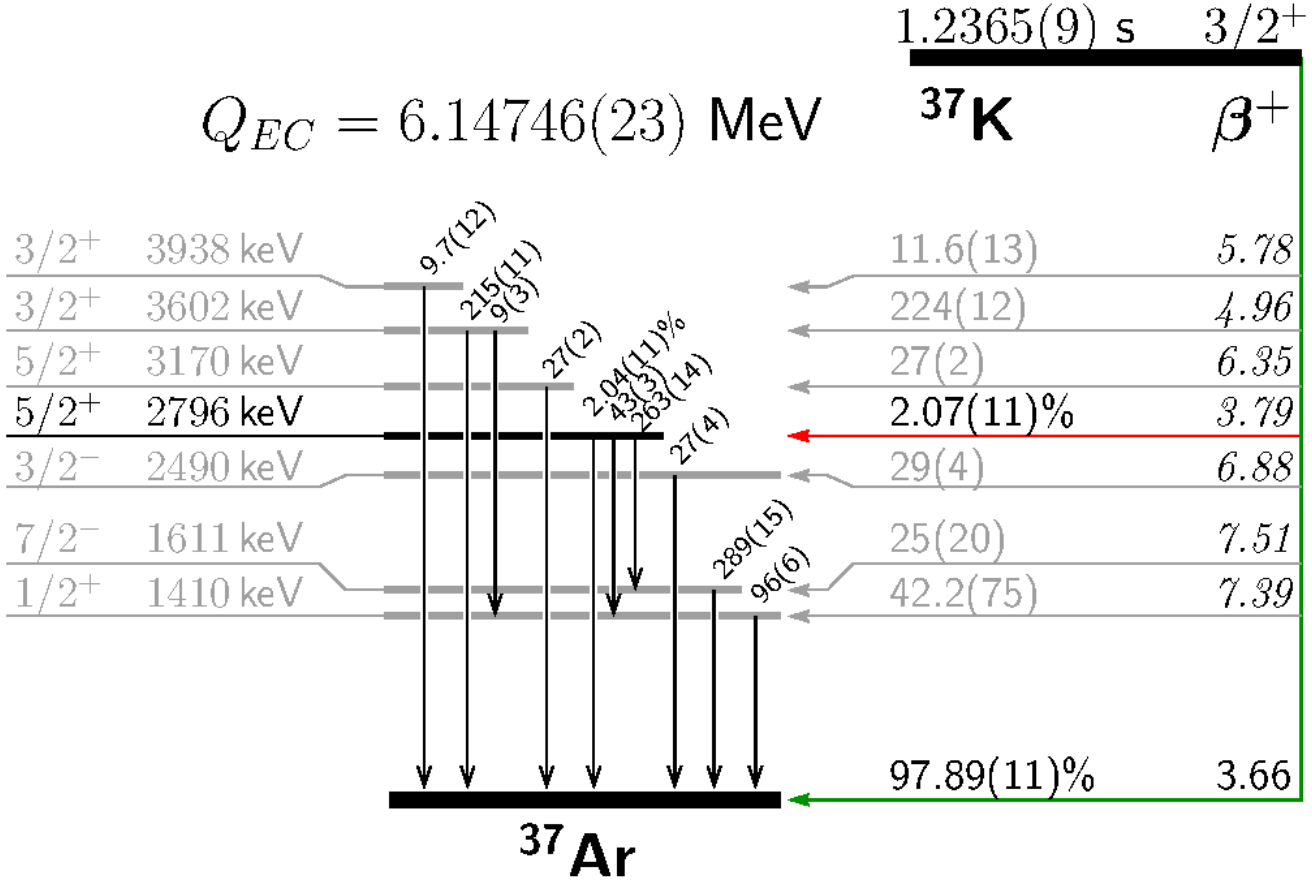


- Global gameplan:
  - Measure the β-decay parameters
  - Compare to SM predictions
  - Look for deviations $\Leftrightarrow$ new physics
  - Precision of $\leq \mathbf{0.1\%}$ needed to complement other searches (LHC)

Naviliat-Cuncic and Gonzalez-Alonso, Ann Phys **525**, 600 (2013), Cirigliano, Gonzalez-Alonso and Graesser, JHEP **1302**, 046 (2013), Vos, Wilschut and Timmermans, RMP **87**, 1483 (2015)

Isobaric analogue decay of ^{37}K

- Beautiful nucleus to test the standard model:
  - Alkali atom ⇒ "easy" to trap with an atom trap and polarize with optical pumping
  - Isobaric analogue decay
    ⇒ theoretically clean; recoil-order corrections under control
  - Lifetime, Q-value and branches (*i.e.* the Ft value) well known
  - Strong branch to the g.s.
- But there are challenges…
  - Can't calculate M_{GT} or even C_A
    ⇒ need to measure $\rho \equiv C_A M_{GT}/C_V M_F$
  - Nuclear spin 3/2 ⇒ need to polarize the atoms, and especially know how polarized they are (also alignment)



The Ft is measured well enough (for now)

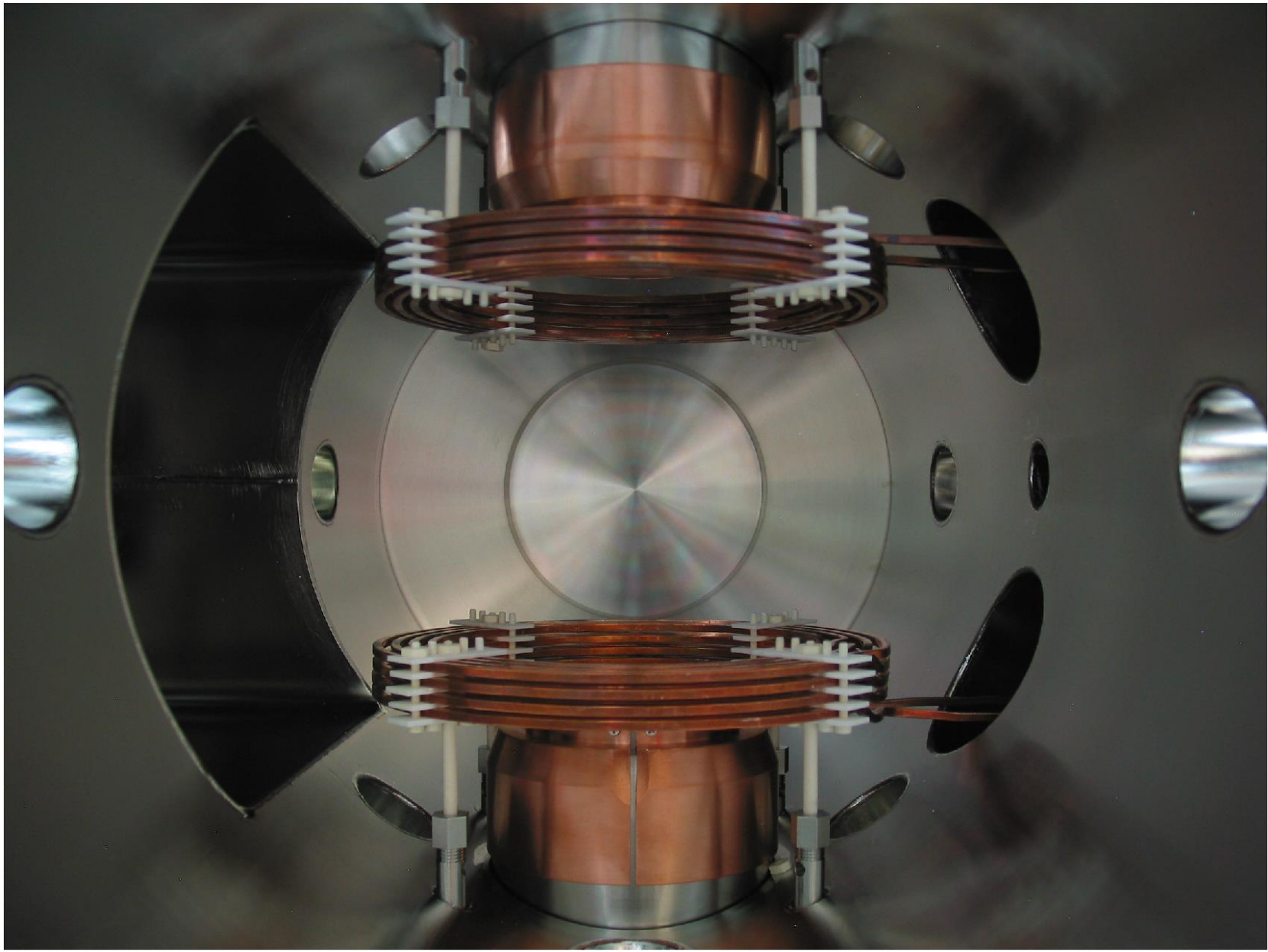
$$dW = dW_0 \left[1 + a\frac{\vec{p}_\beta \cdot \vec{p}_\nu}{E_\beta E_\nu} + b\frac{\Gamma m_e}{E_\beta} + \frac{\langle \vec{I} \rangle}{I} \cdot \left(A_\beta \frac{\vec{p}_\beta}{E_\beta} + B_\nu \frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_\beta \times \vec{p}_\nu}{E_\beta E_\nu} \right) + \text{alignment term} \right]$$

Correlation	SM expectation
$\beta - \nu$ correlation	$a_{\beta\nu} = 0.6668(18)$
Fierz interference	$b = 0$ (sensitive to scalars & tensors)
β asymmetry	$\boldsymbol{A_\beta = -0.5719(7)}$
ν asymmetry	$B_\nu = -0.7703(18)$
Time-violating correlation	$D = 0$ (sensitive to imaginary couplings)

⇝ Data is in hand for improved branching ratio (currently limits Ft)

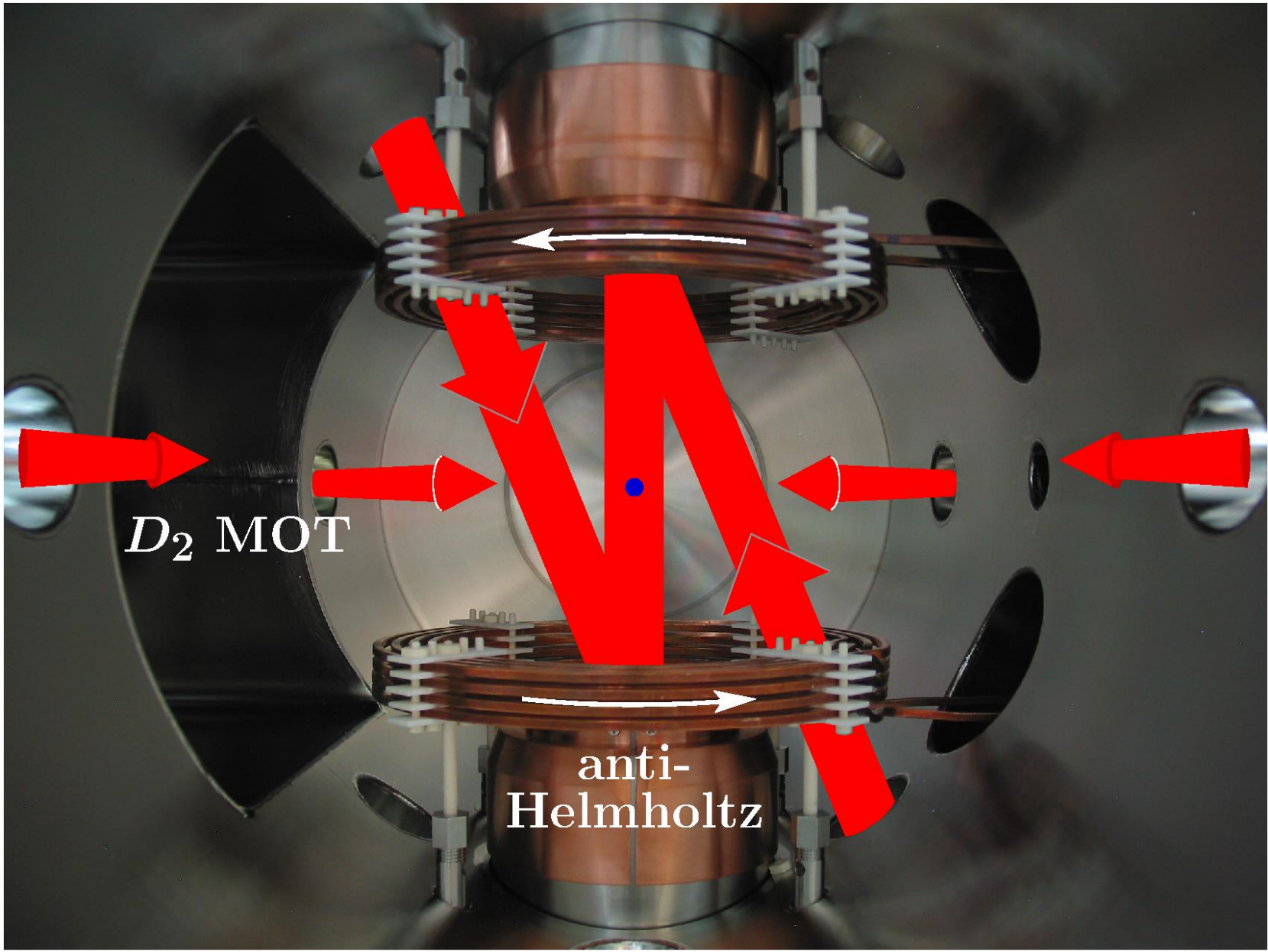
Outline of β asym & polarization measurements

- Not shown:
  - Recoil MCP detector into page
  - Shake-off e^- MCP out of page
  - The β telescopes within the re-entrant flanges (top *and* bottom)



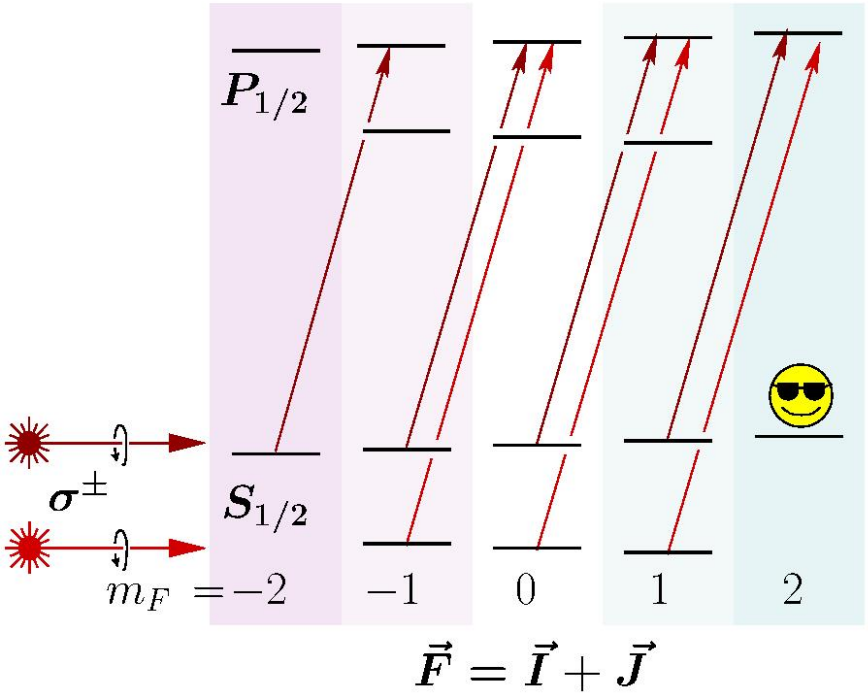
Outline of β asym & polarization measurements

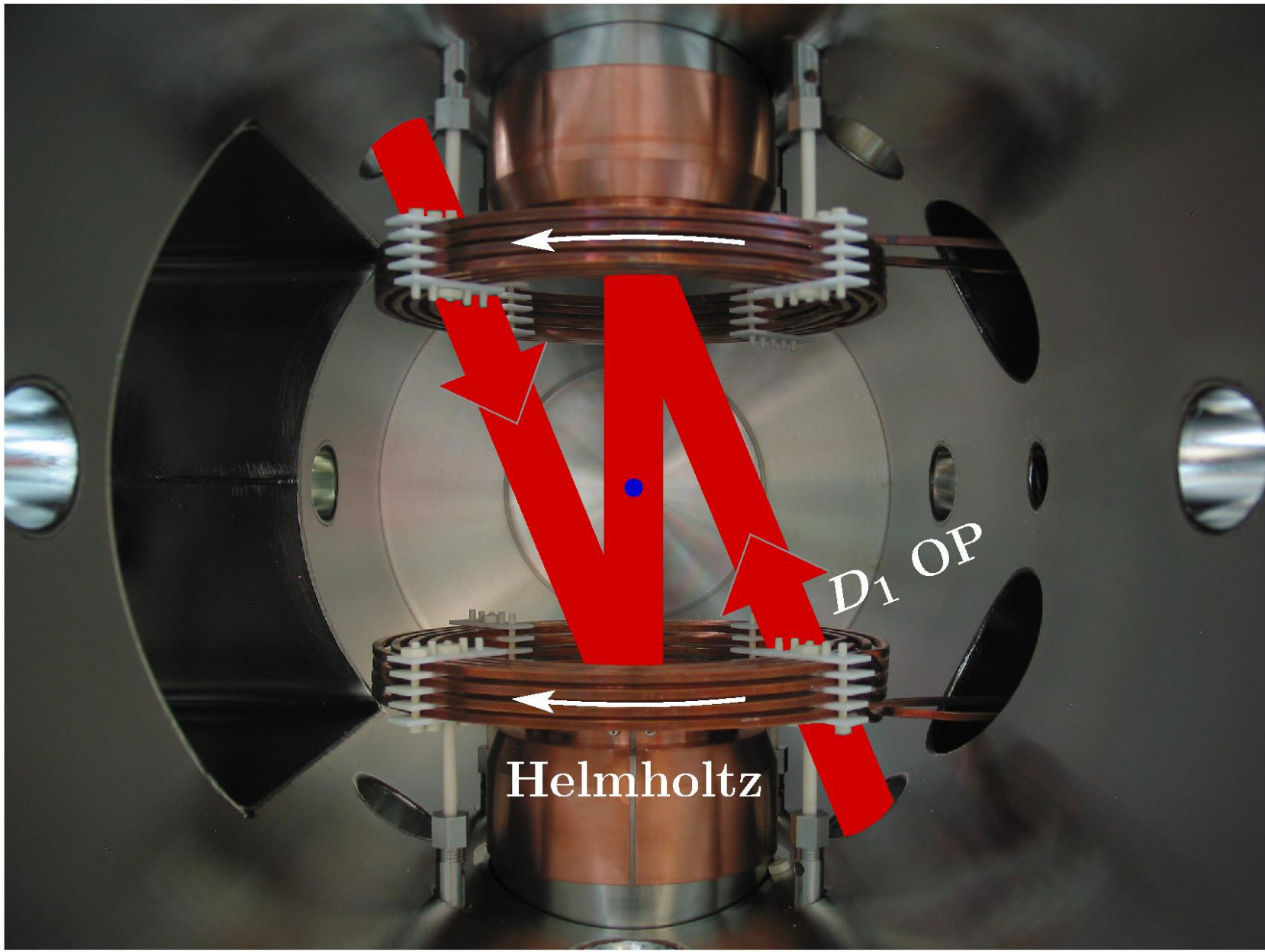
- MOTs provide a source that is:
  - Cold ($\sim 1\ \mathrm{mK}$)
  - Localized ($\sim 1\ \mathrm{mm}^3$)
  - In an open, backing-free geometry
- Allows us to detect $\vec{p}_\beta$ and $\vec{p}_{\mathrm{rec}}$
  $\Rightarrow$ deduce $\vec{p}_\nu$ event-by-event!



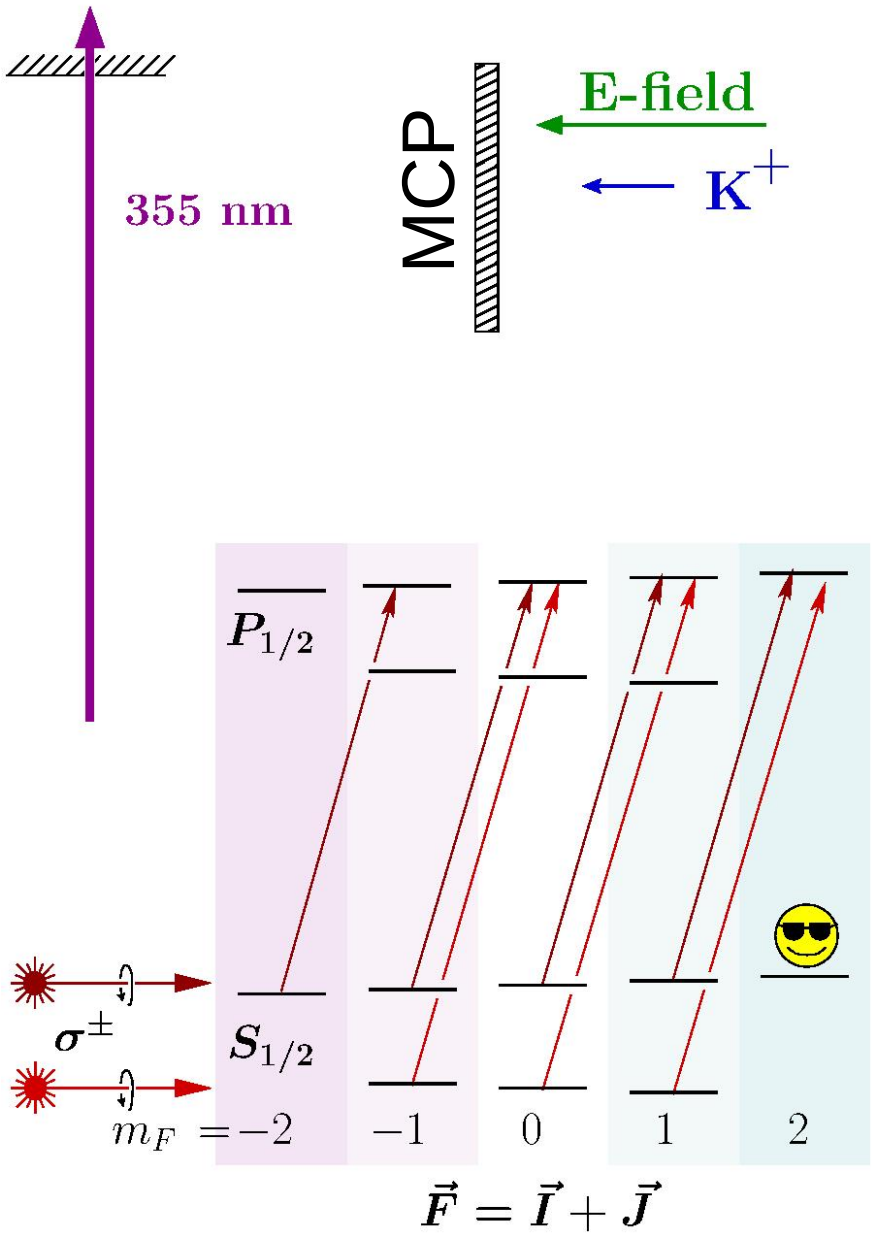
Outline of β asym & polarization measurements

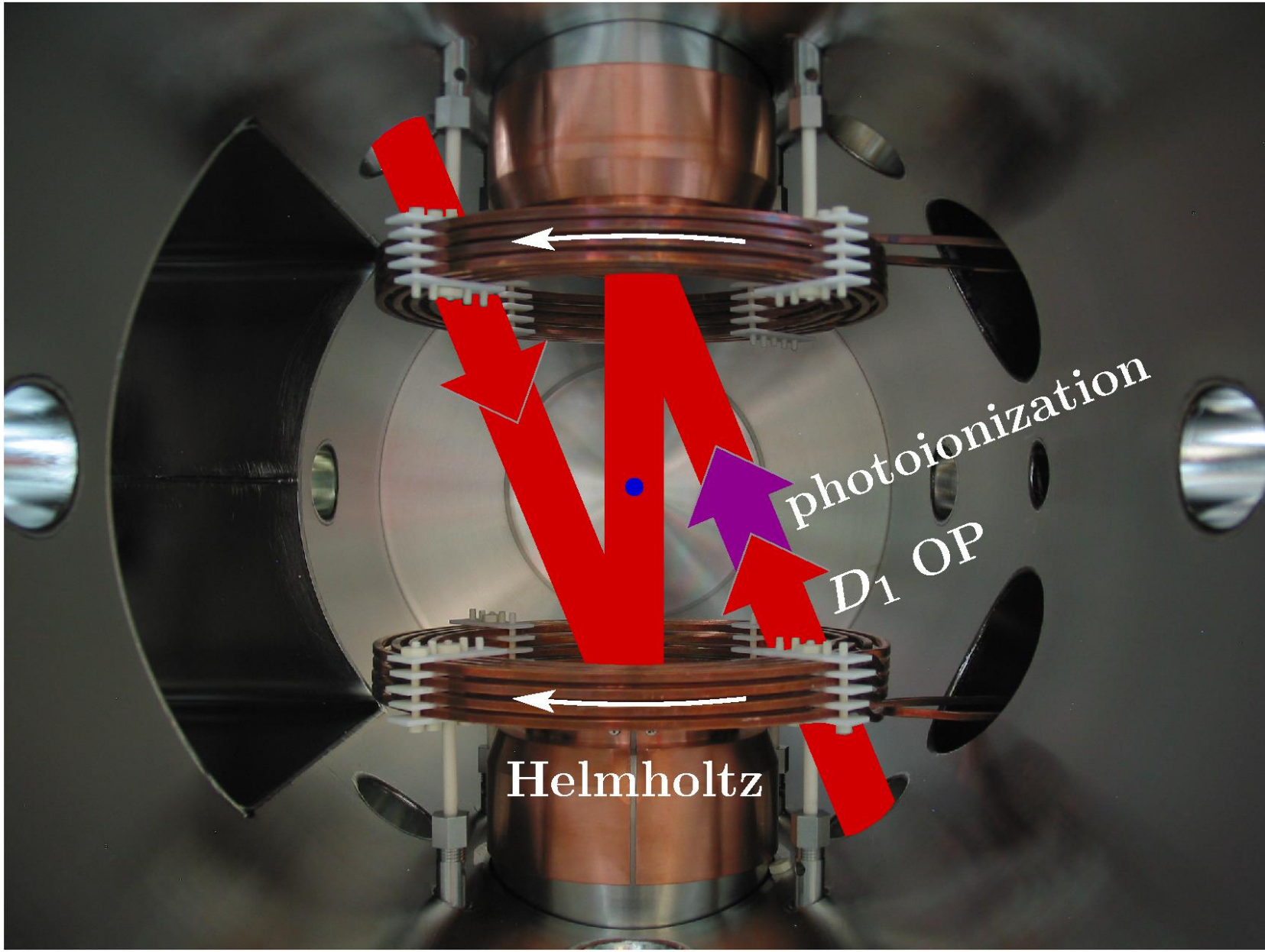
- Optical pumping:
  - Polarized light transfers ang momentum to atom
  - Nuclear and atomic spins are coupled





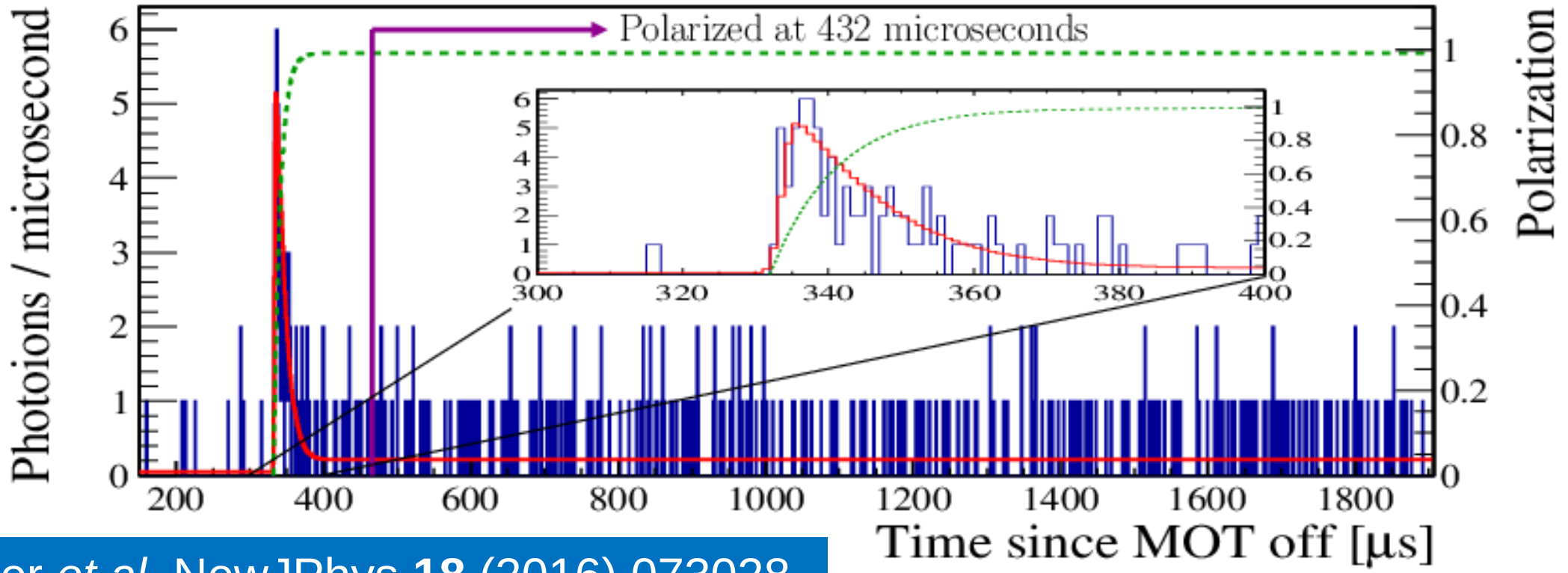
Outline of β asym & polarization measurements





Optical pumping is fast and *efficient*!

- No time to go into details, but basically
  - Measure the rate of photons (⇔ fluorescence) as a function of time
  - Model sublevel populations using the optical Bloch equations
  - Determine the average nuclear polarization: $\langle |P_{\mathrm{nucl}}| \rangle = 0.9913(9)$



B.Fenker *et al*, NewJPhys **18** (2016) 073028

The β asymmetry measurement

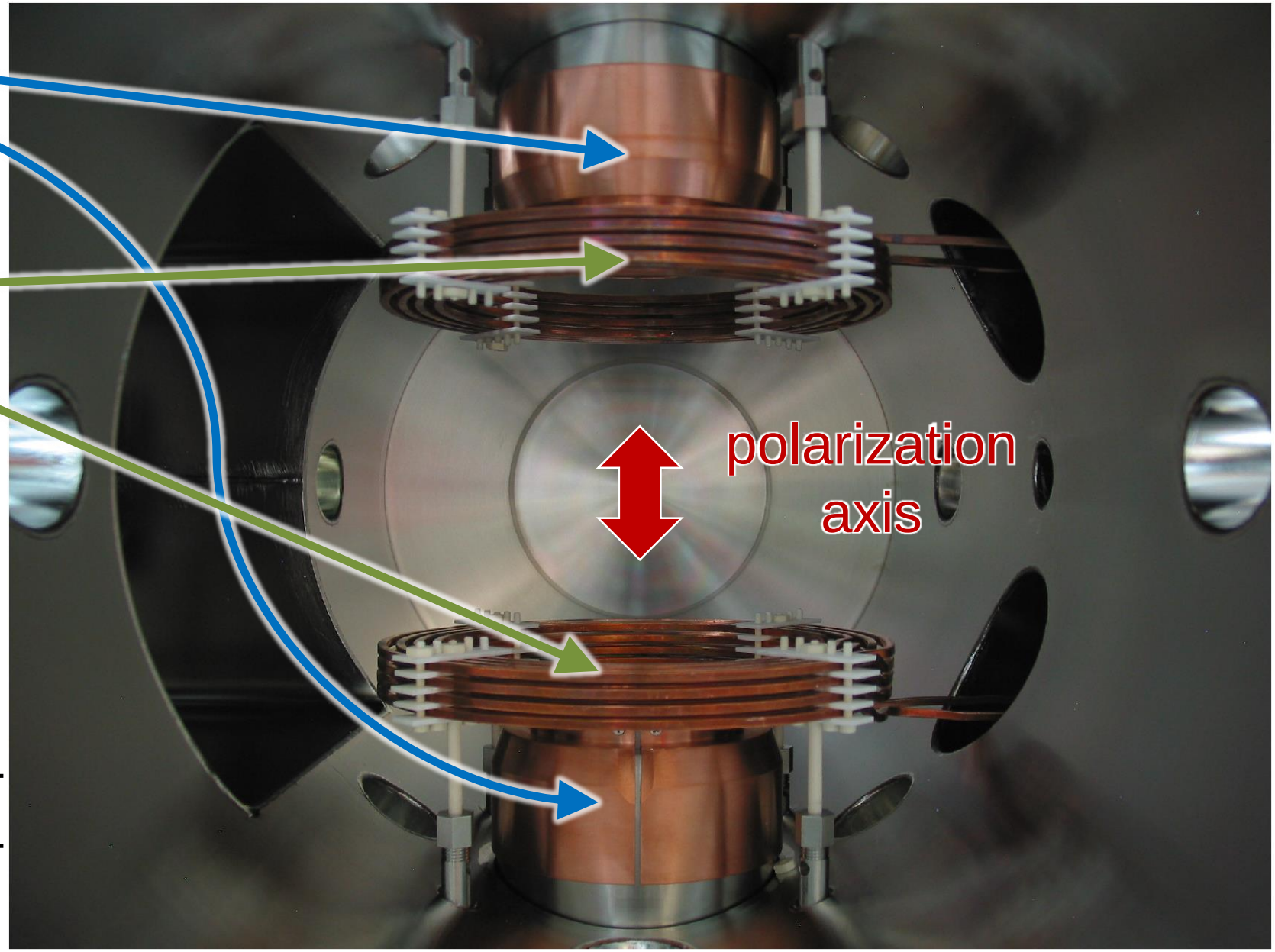
E_β detectors:
Plastic scintillator

ΔE_β detectors:
Double-sided Si-strip

Use **all** information via the super-ratio:

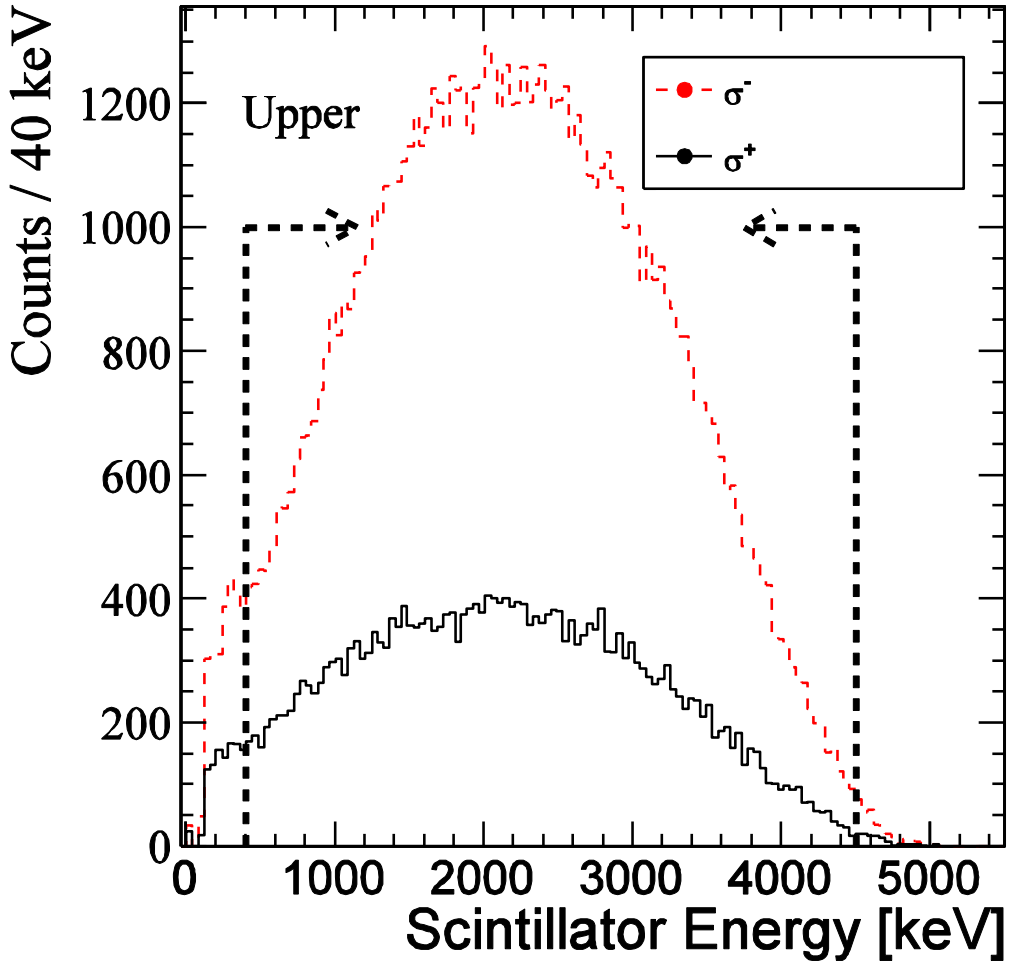
$$A_{\text{obs}}(E_e) = \frac{1-s(E_e)}{1+s(E_e)}$$

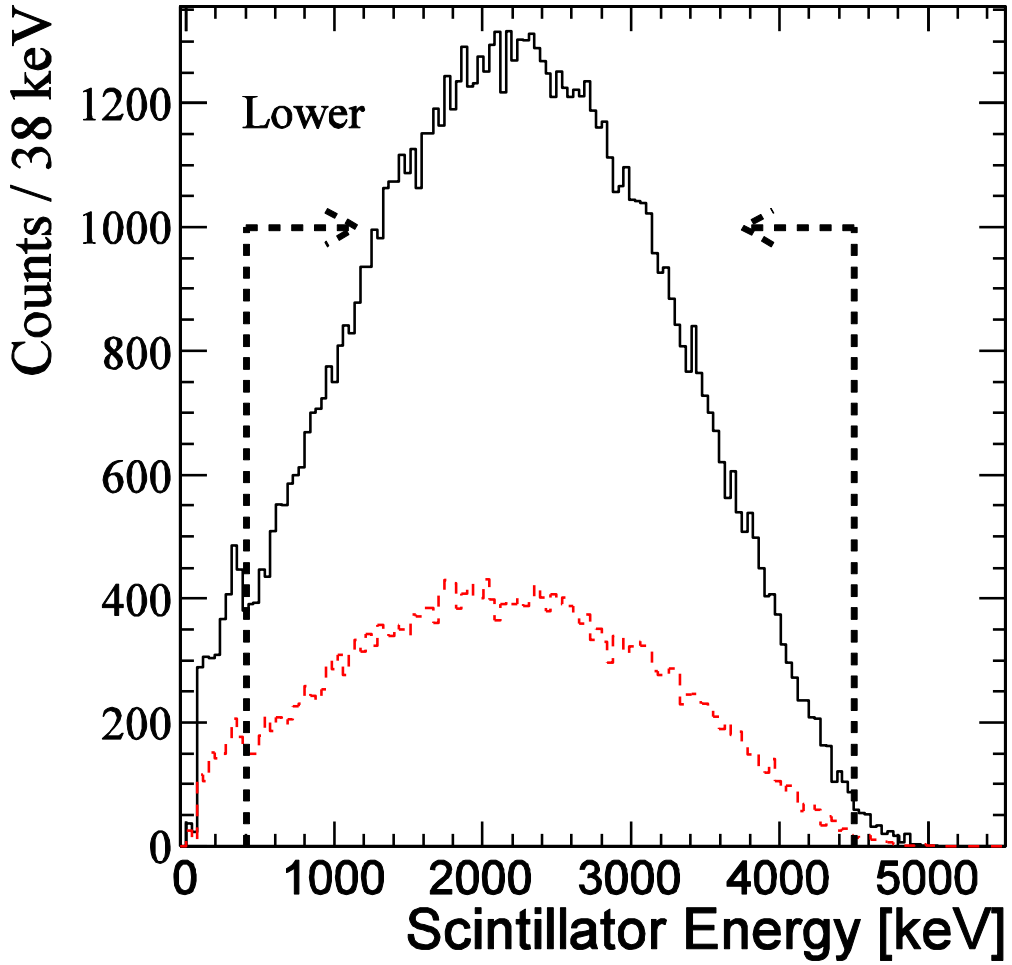
with $s(E_e) = \sqrt{\frac{r_1^{\uparrow}(E_e)\, r_2^{\downarrow}(E_e)}{r_1^{\downarrow}(E_e)\, r_2^{\uparrow}(E_e)}}$



^{37}K β Asymmetry

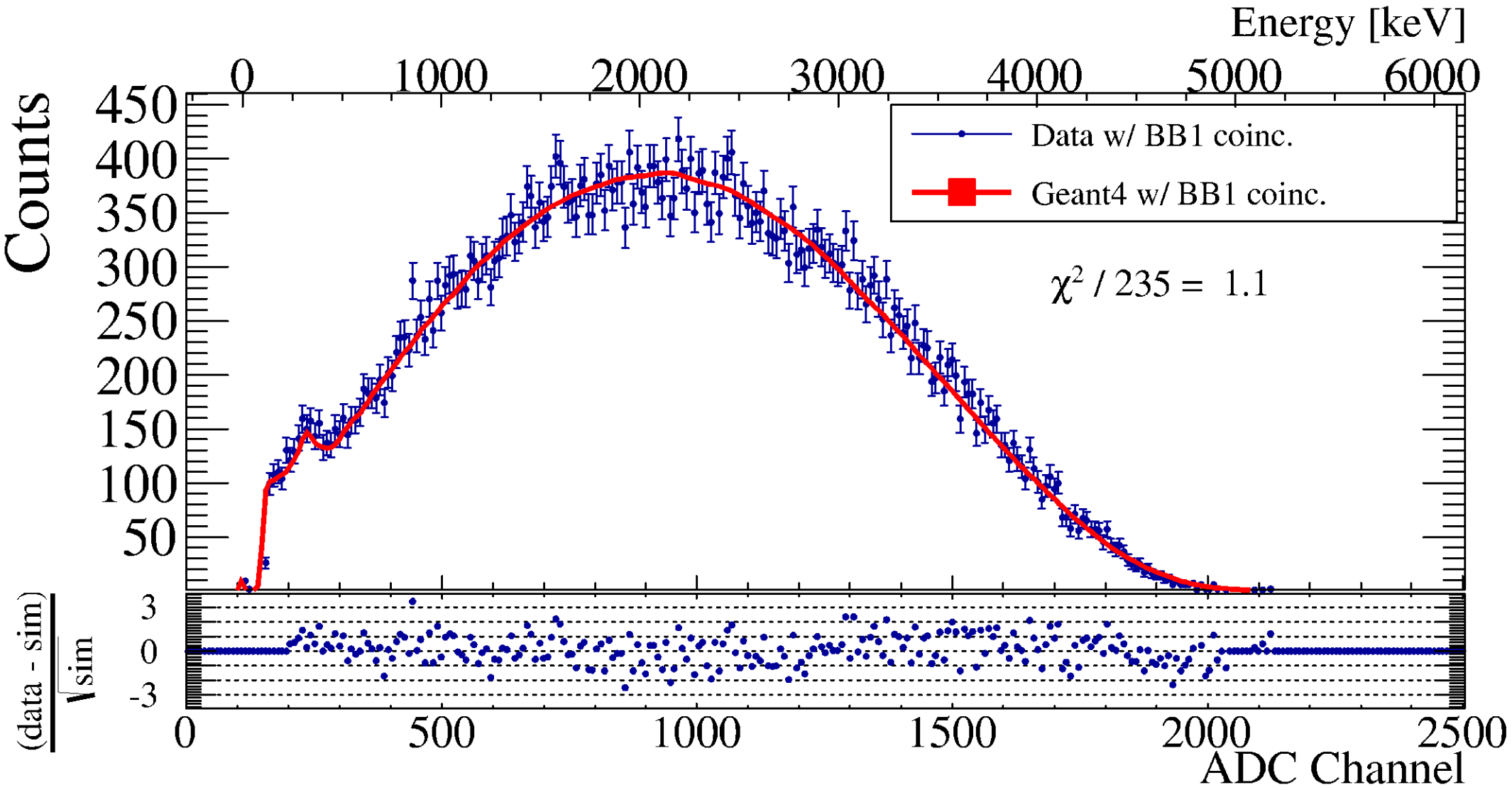
- **Two detectors** and **polarization states**: reduce systematics
- **Blind analysis**: remove small subset of one data set until all cuts defined





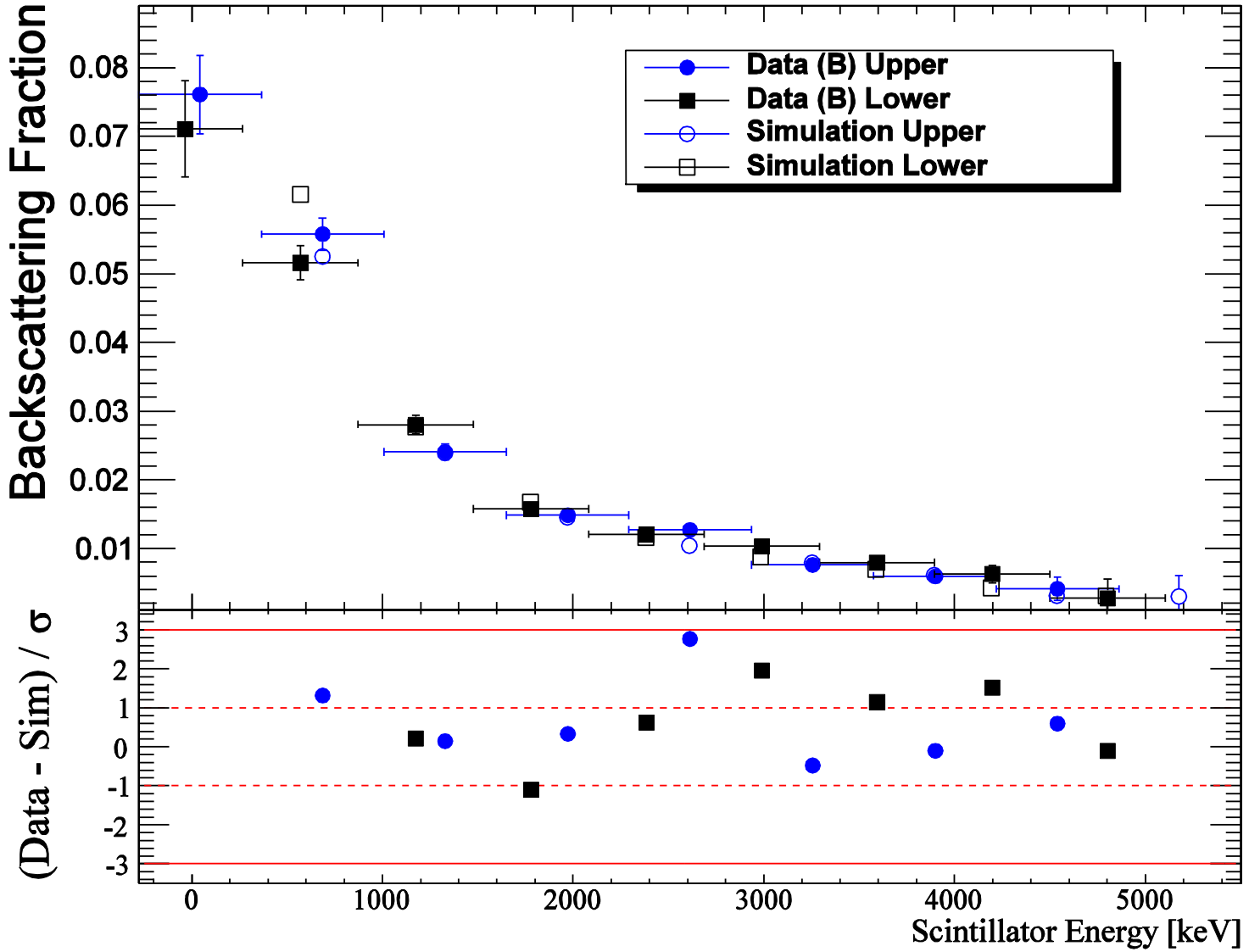
^{37}K β Asymmetry

- Energy spectrum – ***great agreement*** with GEANT4 simulations:



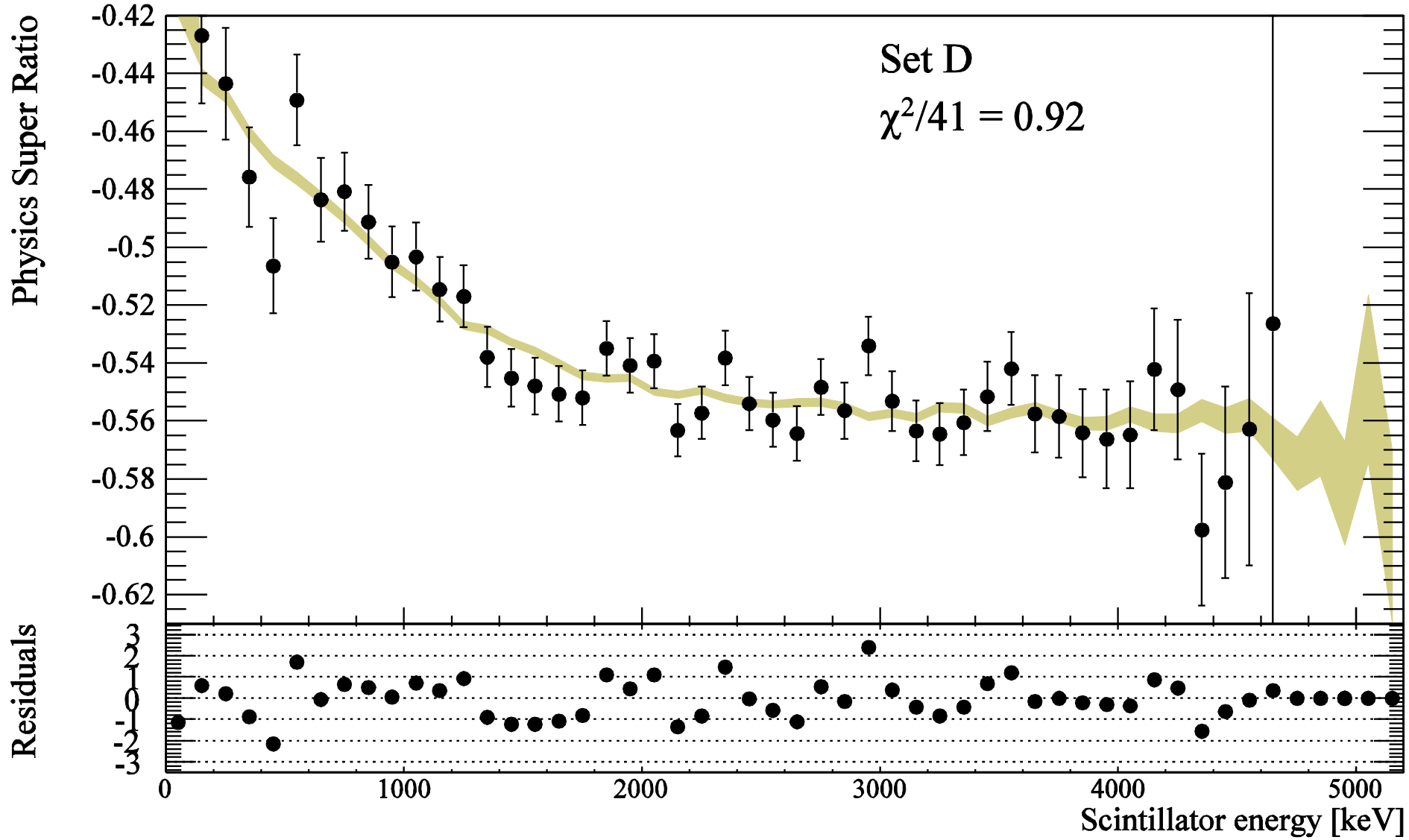
^{37}K β Asymmetry

- Energy spectrum – ***great agreement*** with GEANT4 simulations:
  - Backscattering too!



^{37}K β Asymmetry

- Asymmetry as a function of β energy (*no* background subtraction!)*:*



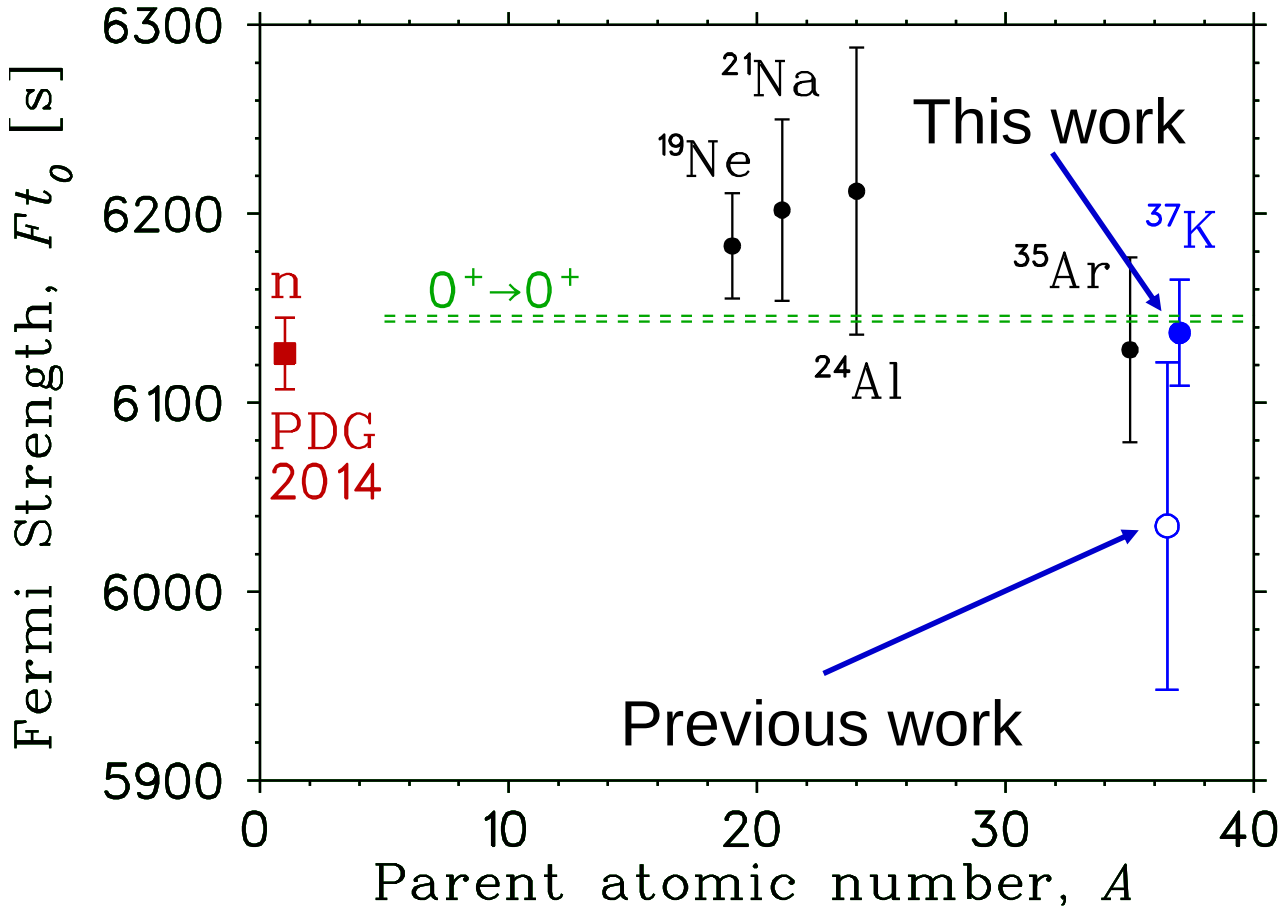
(Dominant) Error budget and A_β result

Source	Correction	Uncertainty, ΔA_β
Systematics		
Background	– 0.0007	7×10^{-4}
Trap position		4×10^{-4}
Trap movement		5×10^{-4}
ΔE position cut		4×10^{-4}
GEANT4 physics list		4×10^{-4}
Shake-off e^- TOF region		3×10^{-4}
TOTAL SYSTEMATICS		**12**$\times 10^{-4}$
STATISTICS		**13**$\times 10^{-4}$
POLARIZATION		5×10^{-4}
TOTAL UNCERTAINTY		**18**$\times 10^{-4}$

$$A_\beta^{meas} = -\mathbf{0.5707(18)} \;\; cf \;\; A_\beta^{\mathrm{SM}} = -0.5706(7) \xrightarrow[\text{corrections}]{\text{recoil-order}} \mathbf{-0.5715(7)}$$

Interpretation and future prospects

- Comparison of Ft values of:
  - Mirror nuclei (including ^{37}K)
  - The neutron
  - Pure Fermi decays
- Also other physics to probe:
  - Right-handed currents
  - 2nd class currents
  - Scalar and tensor currents



- Recently awarded 16 additional shifts at high priority by TRIUMF's EEC
- 0.1% is in sight… Stay tuned!

Collaboration and support

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