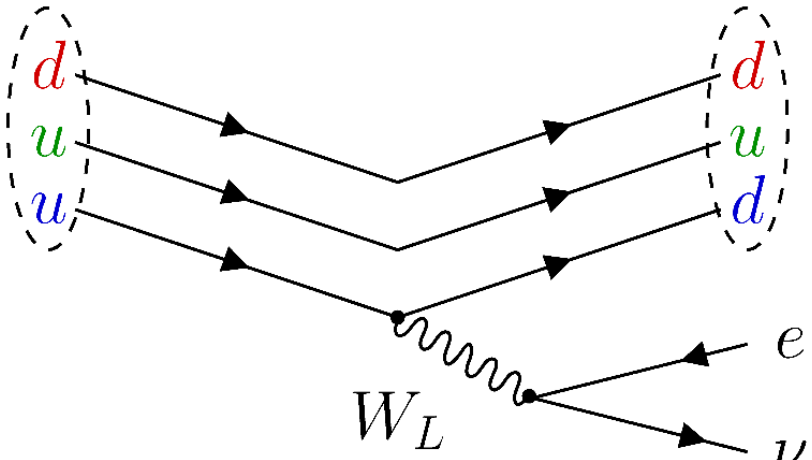
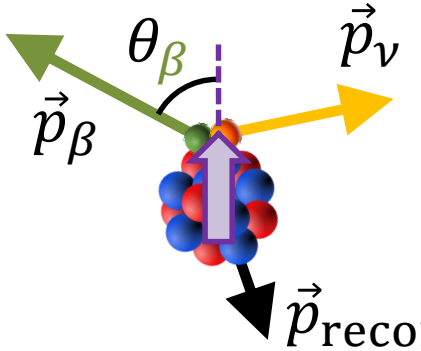
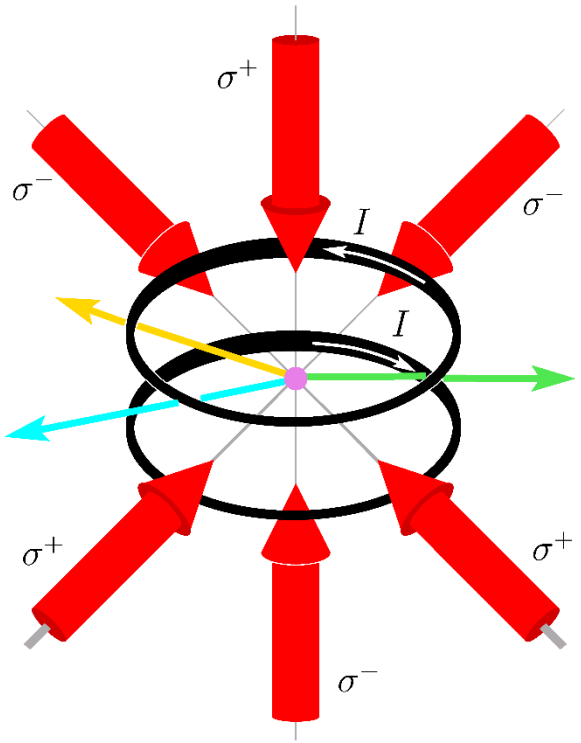
Angular correlation measurements at ISAC: using the atomic nucleus to search for BSM physics for 20 years



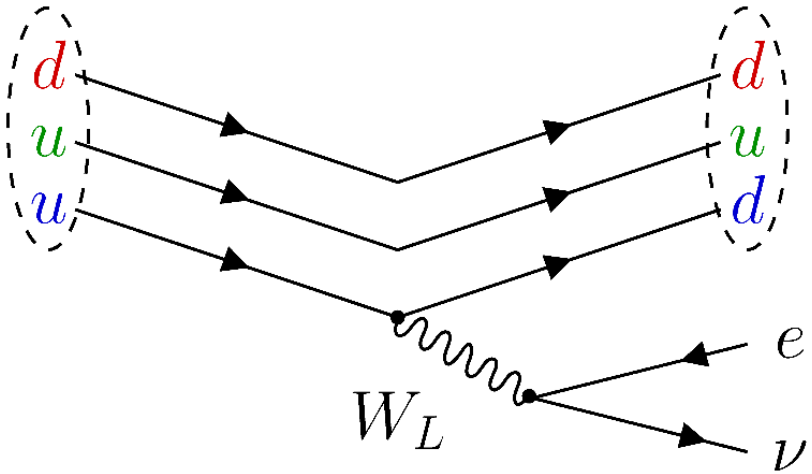


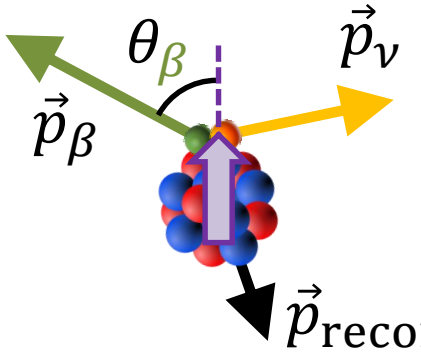


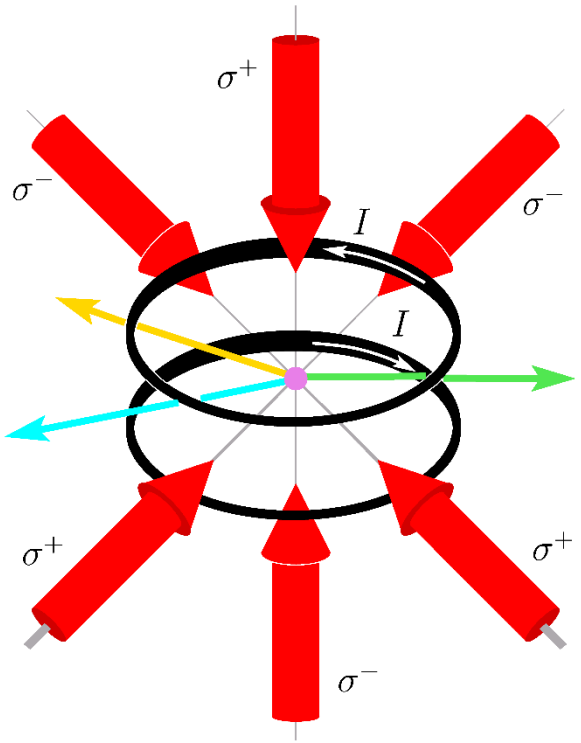
Dan Melconian, Texas A&M – ISAC20, Aug 2019

Angular correlation measure[illegible] physics for 20 years

Or: "JTW or bust: there's got to be a deviation SOMEWHERE"©
– G. Gwinner







Outline

- Introduction
  - How β decay probes BSM physics
- The TRIUMF Neutral Atom Trap
  - ^{38m}K – β-ν correlation, ν mass
  - ^{37}K – B_ν, D; A_β, b_{Fierz}
  - ^{92}Rb – $a_{\beta\nu}$, $\overline{\nu}_e$ energy spectrum
- Mott polarimetry T-violation experiment
  - ^{8}Li – R coefficient
- Summary

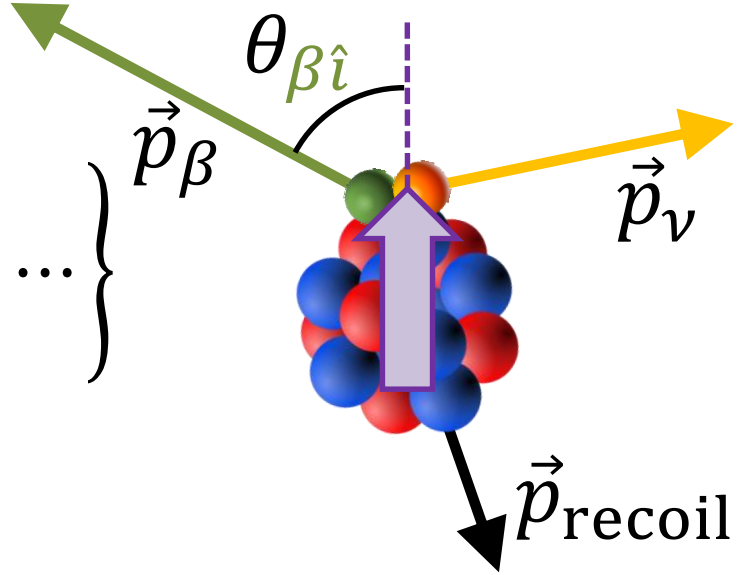
Introduction

- Goal:
  - To compliment high-energy experiments by pushing the precision frontier
  - Angular correlations: values sensitive to new physics

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

$$+ c\left[\frac{\vec{p}_\beta \cdot \vec{p}_\nu}{3E_\beta E_\nu} - \frac{(\vec{p}_\beta \cdot \hat{\imath})(\vec{p}_\nu \cdot \hat{\imath})}{E_\beta E_\nu} \right] \left[\frac{I(I+1) - 3\langle (\vec{I} \cdot \hat{\imath})^2 \rangle}{I(2I-1)} \right]$$

$$\left. + \vec{\sigma} \cdot \left[N\frac{\langle \vec{I} \rangle}{I} + Q\frac{\vec{p}_\beta}{E_\beta + m_e} \left(\frac{\langle \vec{I} \rangle}{I} \cdot \frac{\vec{p}_\nu}{E_\beta} \right) + R\frac{\langle \vec{I} \rangle}{I} \times \frac{\vec{p}_\beta}{E_\beta} \right] + \cdots \right\}$$



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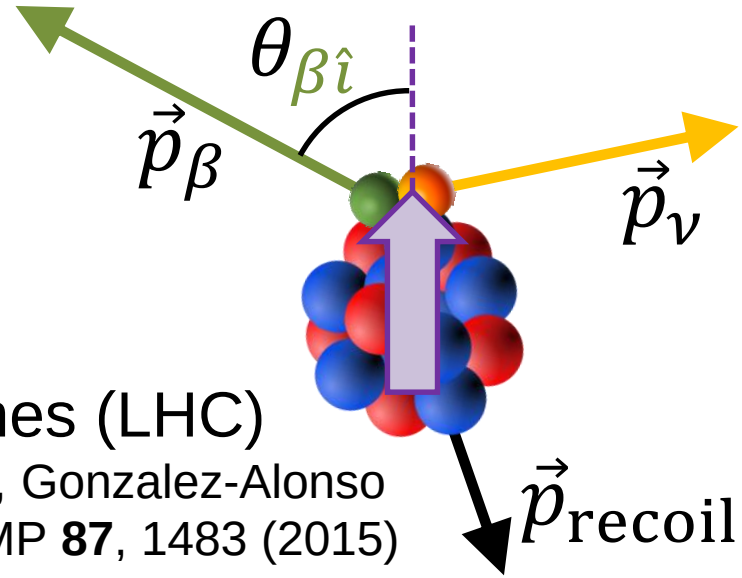
- Global gameplan:
  - Measure β-decay parameters
  - Compare to SM predictions
  - Look for deviations $\Leftrightarrow$ new physics
  - Precision of $\leq 0.1\%$ needed to complement other searches (LHC)

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)



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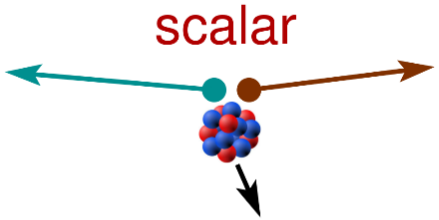
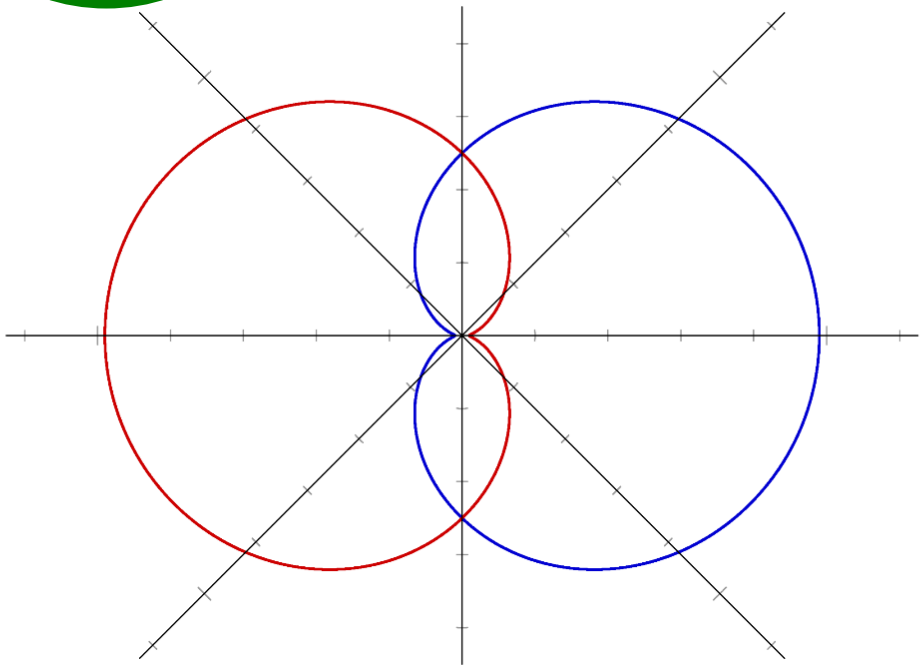
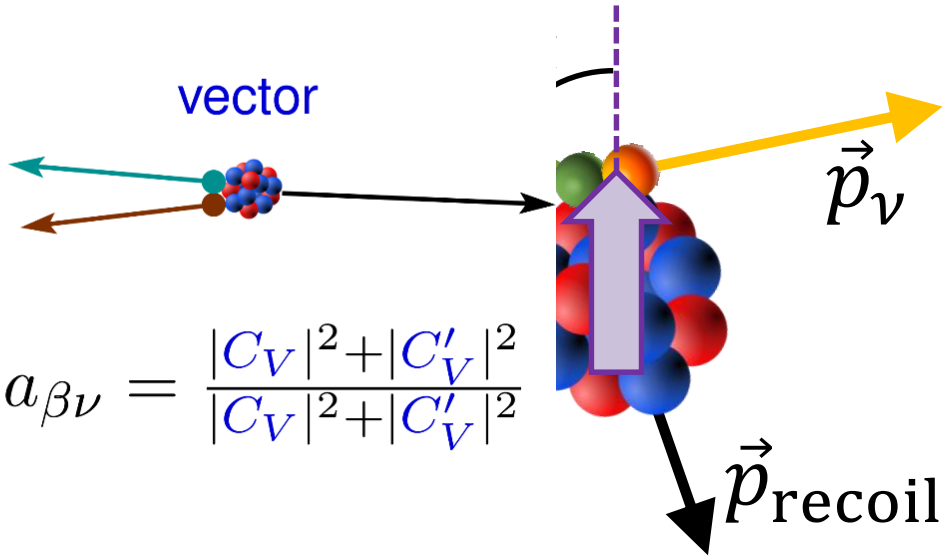


$$a_{\beta\nu} = \frac{-|C_S|^2 - |C'_S|^2}{|C_S|^2 + |C'_S|^2}$$



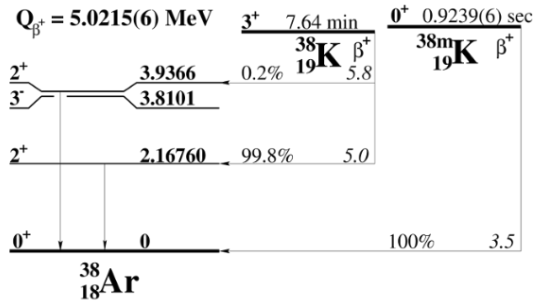


$$a_{\beta\nu} = \frac{|C_V|^2 + |C'_V|^2}{|C_V|^2 + |C'_V|^2}$$

My oldest slide

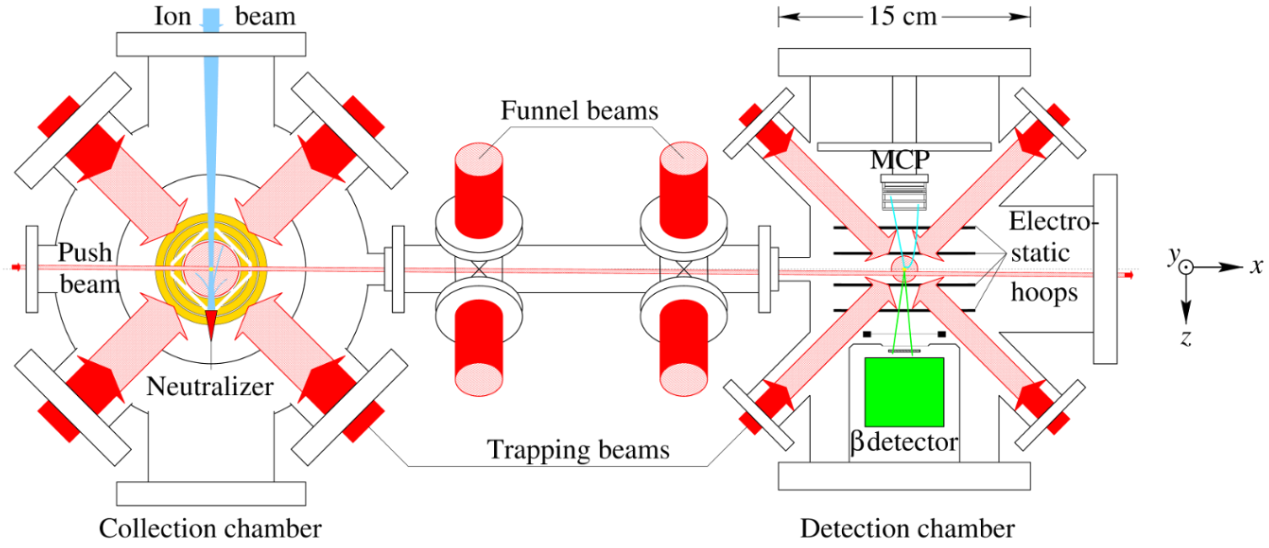
- TRINAT started with ^{38m}K
  - $0^+ \rightarrow 0^+$ decay
  - $a_{\beta\nu} = \frac{|C_V|^2+|C_V'|^2-|C_S|^2-|C_S'|^2}{|C_V|^2+|C_V'|^2+|C_S|^2+|C_S'|^2}$
  - Atom-trapping techniques
    ⇒ textbook source of short-lived nuclei

The $\beta - \nu$ correlation experiment



Pure Fermi decay of ^{38m}K
⇒ sensitive to scalar currents in the weak interaction

$$W(\theta_{\beta\nu}) = W_\circ(1 + a\frac{v}{c}\cos\theta_{\beta\nu})$$



March 16, 2000

My oldest slide

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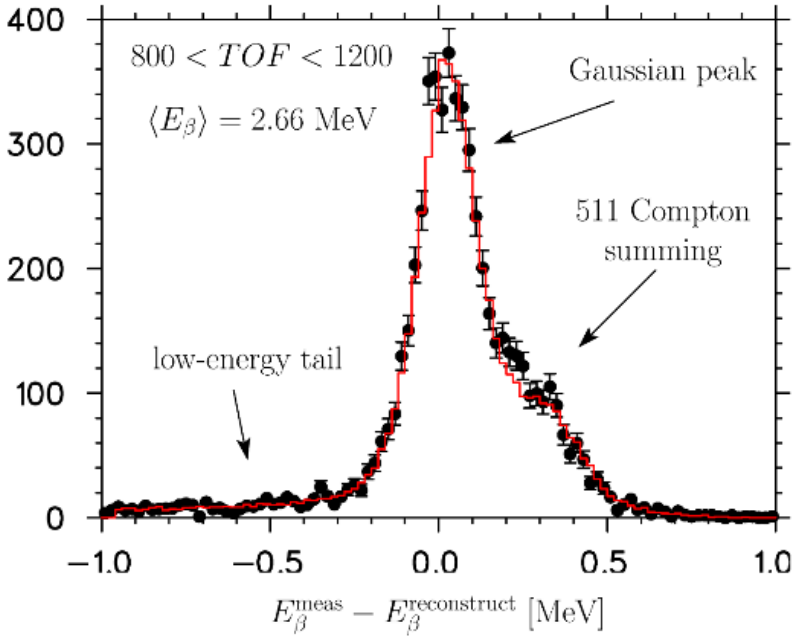

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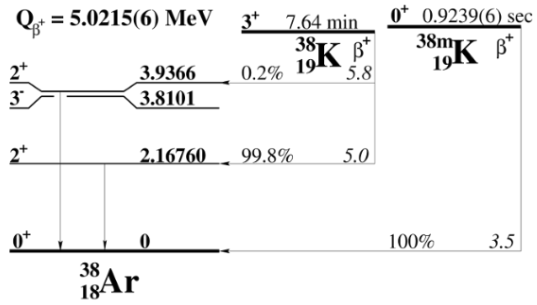

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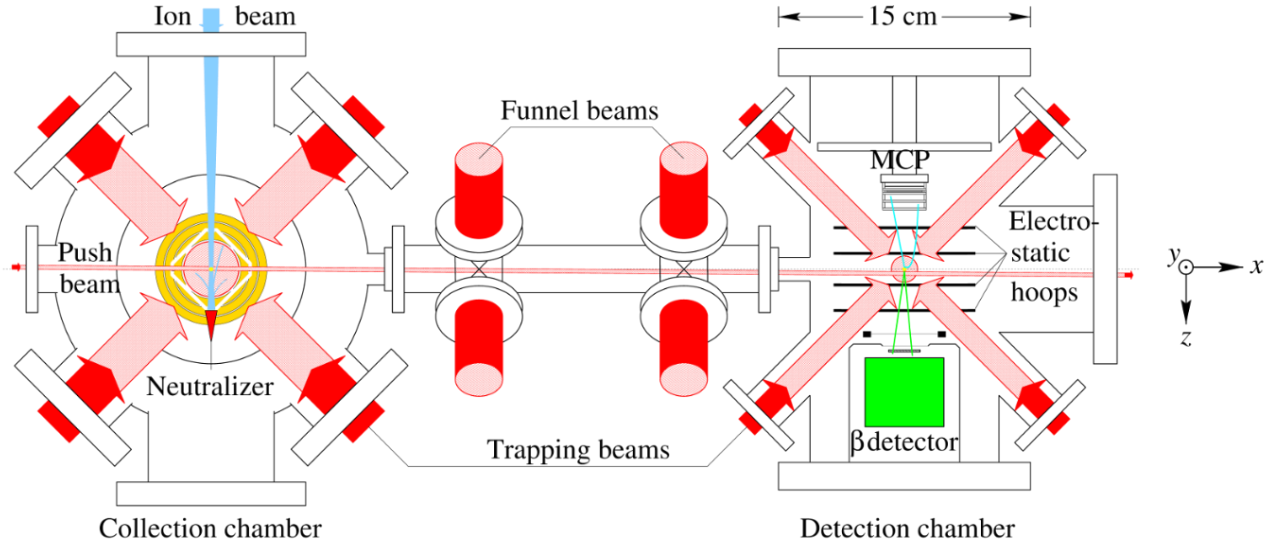


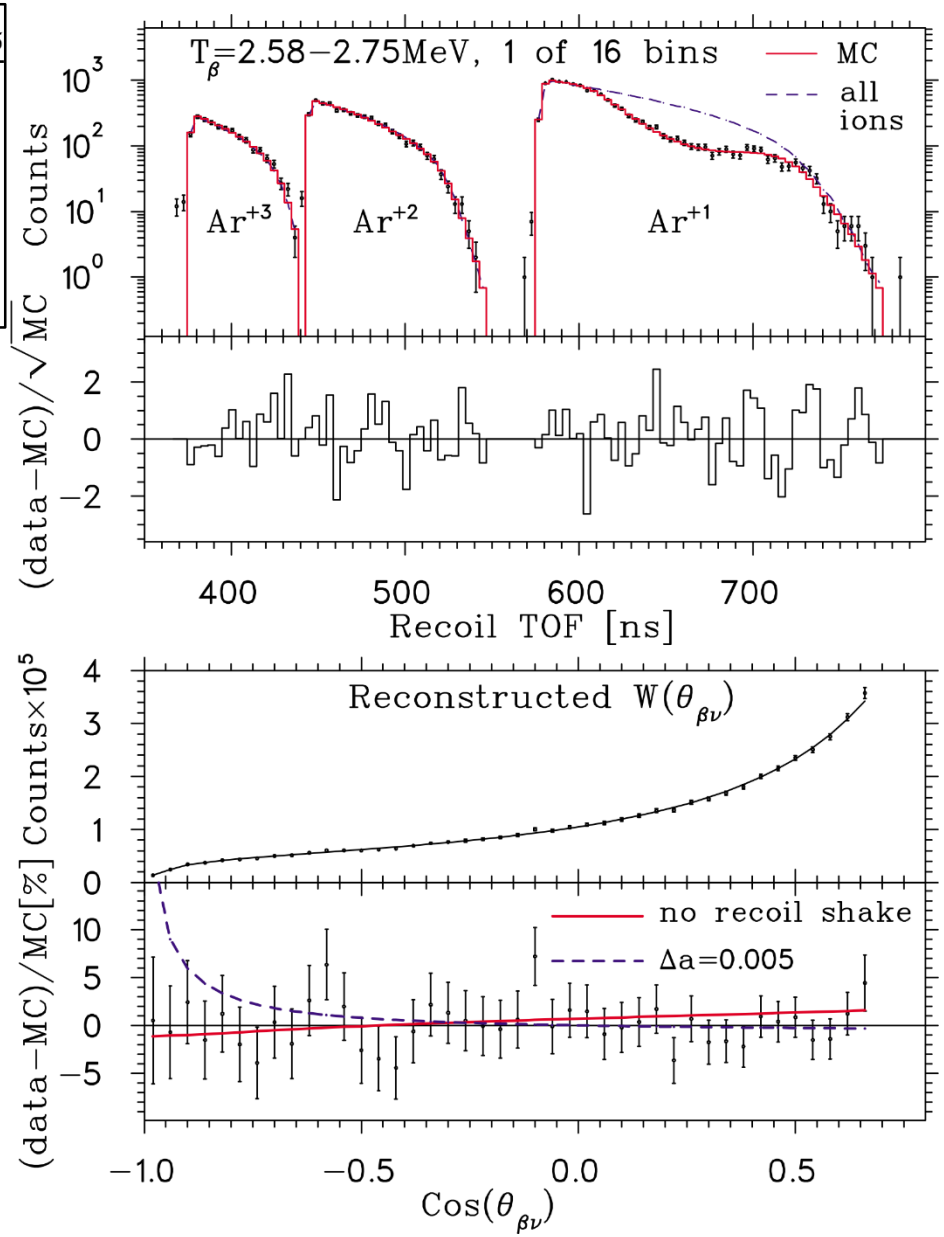
March 16, 2000

The world's best limits on scalar currents!

PRL **94,** 142501 (2005) PHYSICAL REVIEW LETTERS week ending 15 APRIL 2005

Scalar Interaction Limits from the β-ν Correlation of Trapped Radioactive Atoms

A. Gorelov,[1] D. Melconian,[1] W. P. Alford,[2] D. Ashery,[3] G. Ball,[4] J. A. Behr,[4] P. G. Bricault,[4] J. M. D'Auria,[5] J. Deutsch,[6] J. Dilling,[4] M. Dombsky,[4] P. Dubé,[1] J. Fingler,[4] U. Giesen,[4] F. Glück,[7] S. Gu,[4] O. Häusser,[1,*] K. P. Jackson,[4] B. K. Jennings,[4] M. R. Pearson,[4] T. J. Stocki,[1] T. B. Swanson,[5] and M. Trinczek[5]



- Kinematics overconstrained: measure $\vec{p}_\beta$ and $\vec{p}_{\text{recoil}} \Rightarrow$ deduce $\vec{p}_\nu$ event-by-event!

- $\tilde{a} \equiv \frac{a_{\beta\nu}}{1+b\frac{m_e}{\langle E_\beta \rangle}} = 0.9981 \pm 0.0030^{+0.0032}_{-0.0037}$

- (And we think we can do better…!)

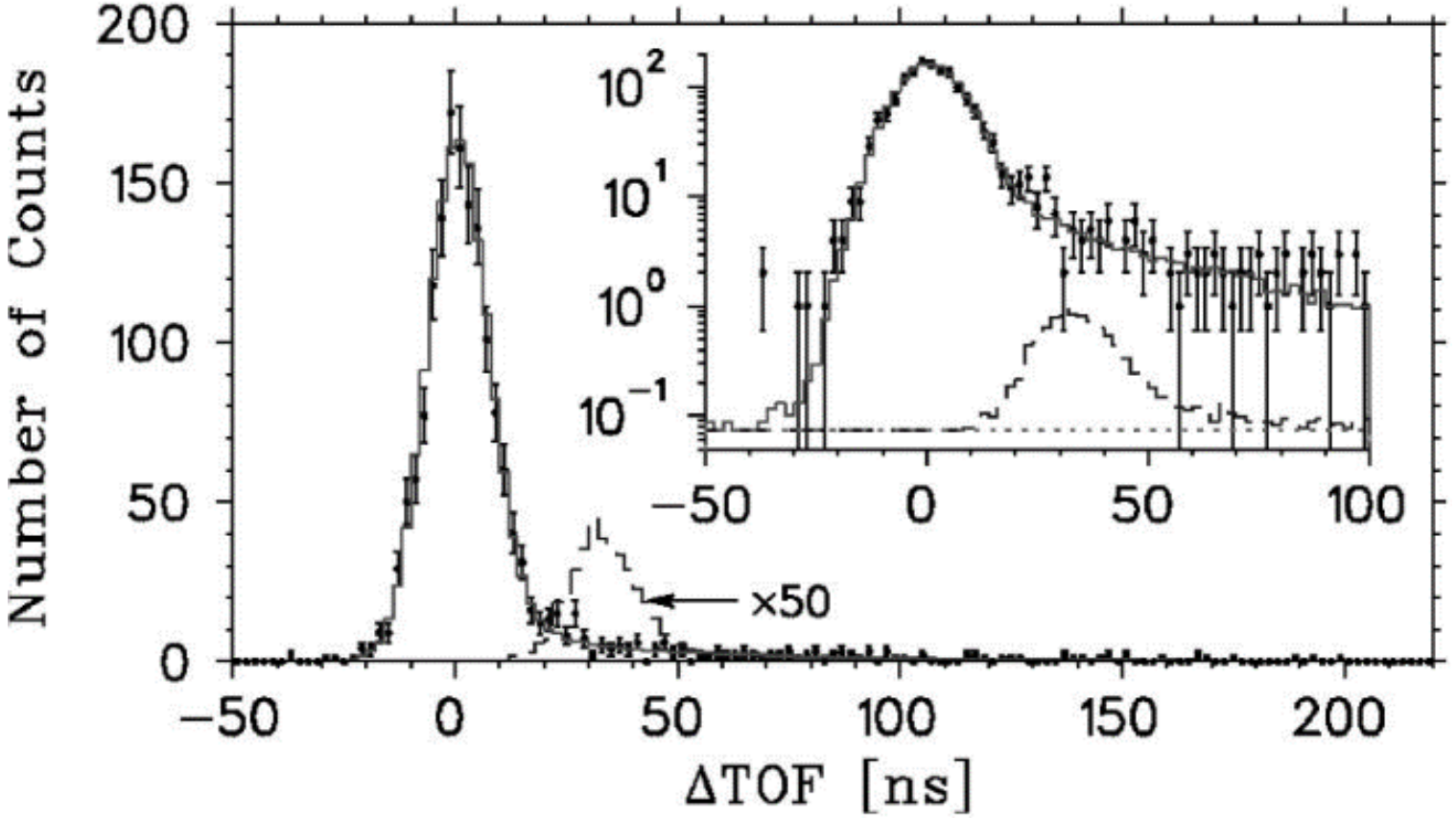
Able to place limits on heavy ν as well

VOLUME 90, NUMBER 1 PHYSICAL REVIEW LETTERS week ending 10 JANUARY 2003

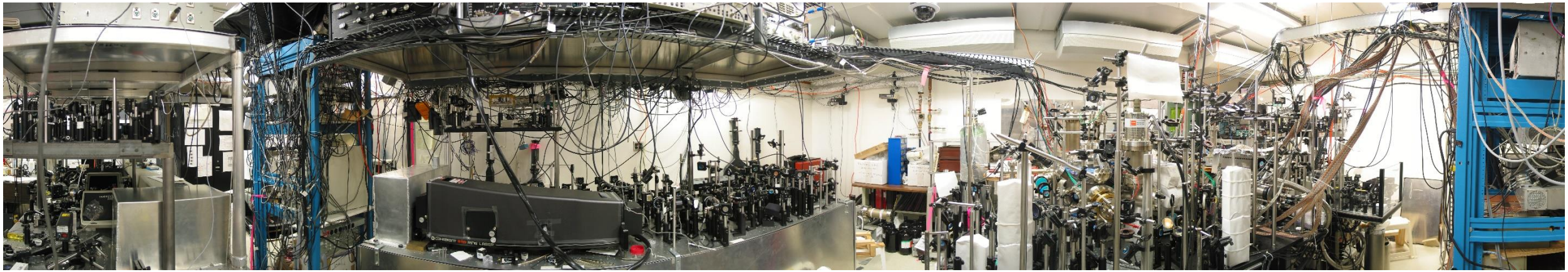
Novel Search for Heavy ν Mixing from the β^+ Decay of ^{38m}K Confined in an Atom Trap

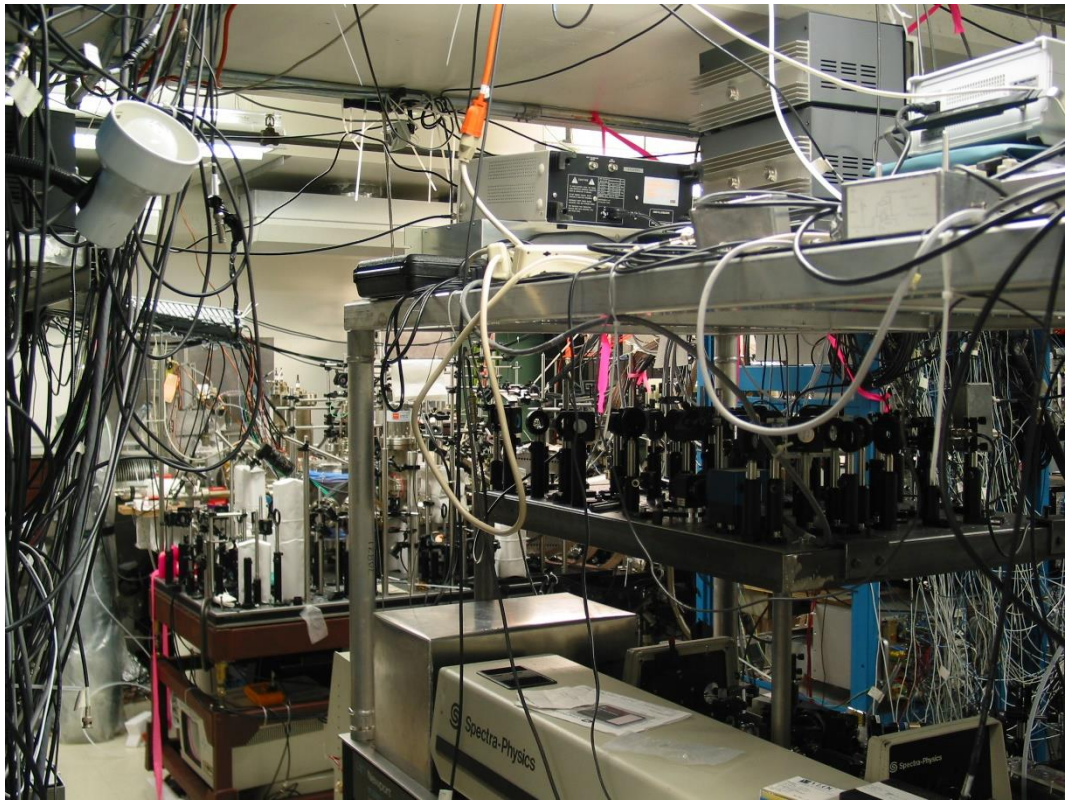
M. Trinczek,[1,*] A. Gorelov,[1] D. Melconian,[1] W. P. Alford,[2] D. Asgeirsson,[3] D. Ashery,[4] J. A. Behr,[3] P. G. Bricault,[3] J. M. D'Auria,[1] J. Deutsch,[5] J. Dilling,[6,3] M. Dombsky,[3] P. Dubé,[1] S. Eaton,[3] J. Fingler,[3] U. Giesen,[3] S. Gu,[3] O. Häusser,[1,†] K. P. Jackson,[3] B. Lee,[3] J. H. Schmid,[6] T. J. Stocki,[1] T. B. Swanson,[1] and W. Wong[3]

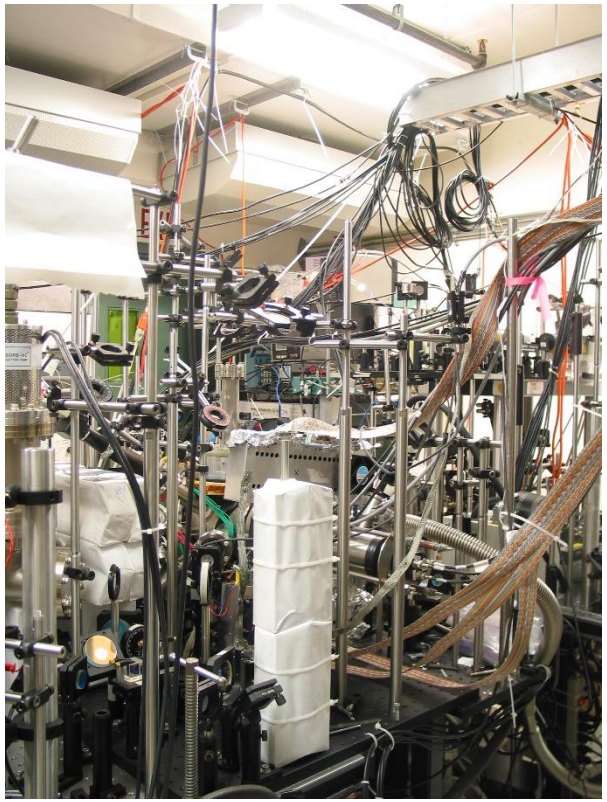
- Not a "correlation", but still a search for BSM physics
- HUNTER experiment is gearing up to do a similar (but more sensitive) expt using a similar approach

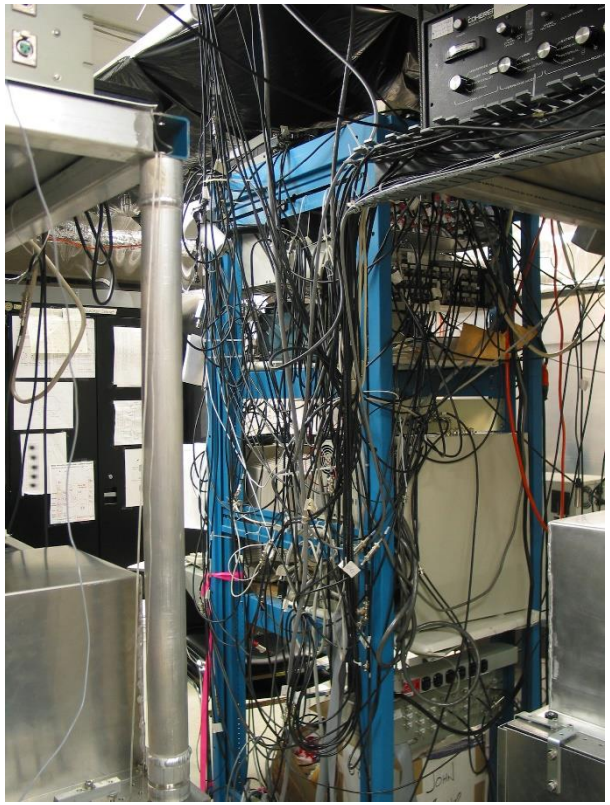


Just in case you thought it was simple…

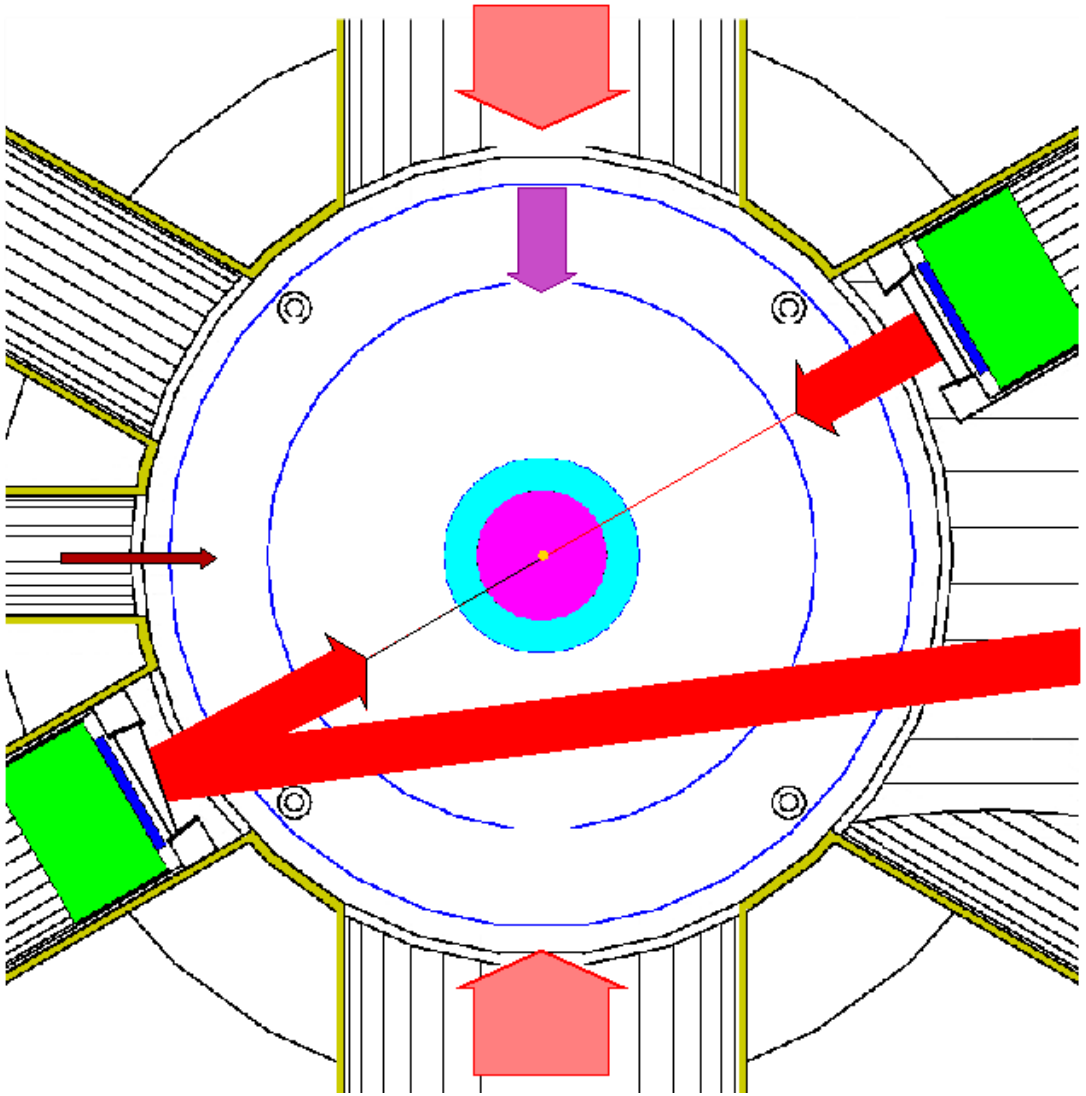


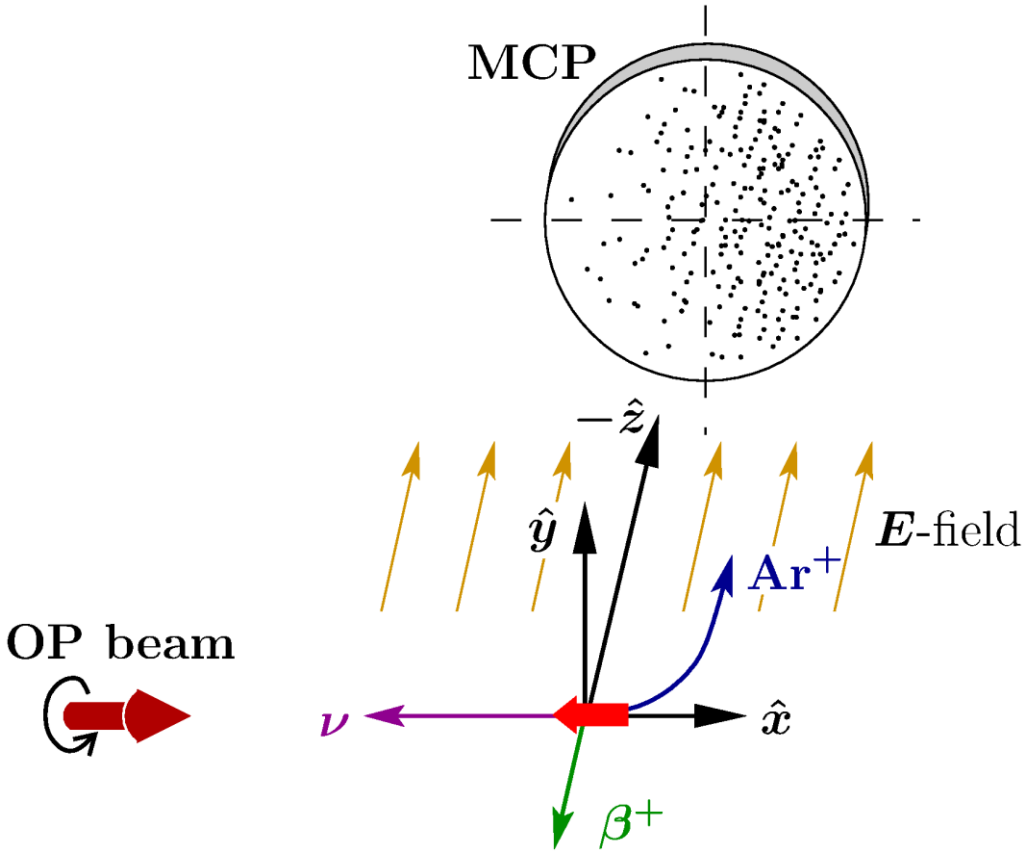






Polarized ^{37}K (v1): Measuring B_ν and D





$$\frac{\langle \vec{I} \rangle}{I} \cdot \left(B_\nu \frac{\vec{p}_\nu}{E_\nu} + D \frac{\vec{p}_\beta \times \vec{p}_\nu}{E_\beta E_\nu} \right)$$

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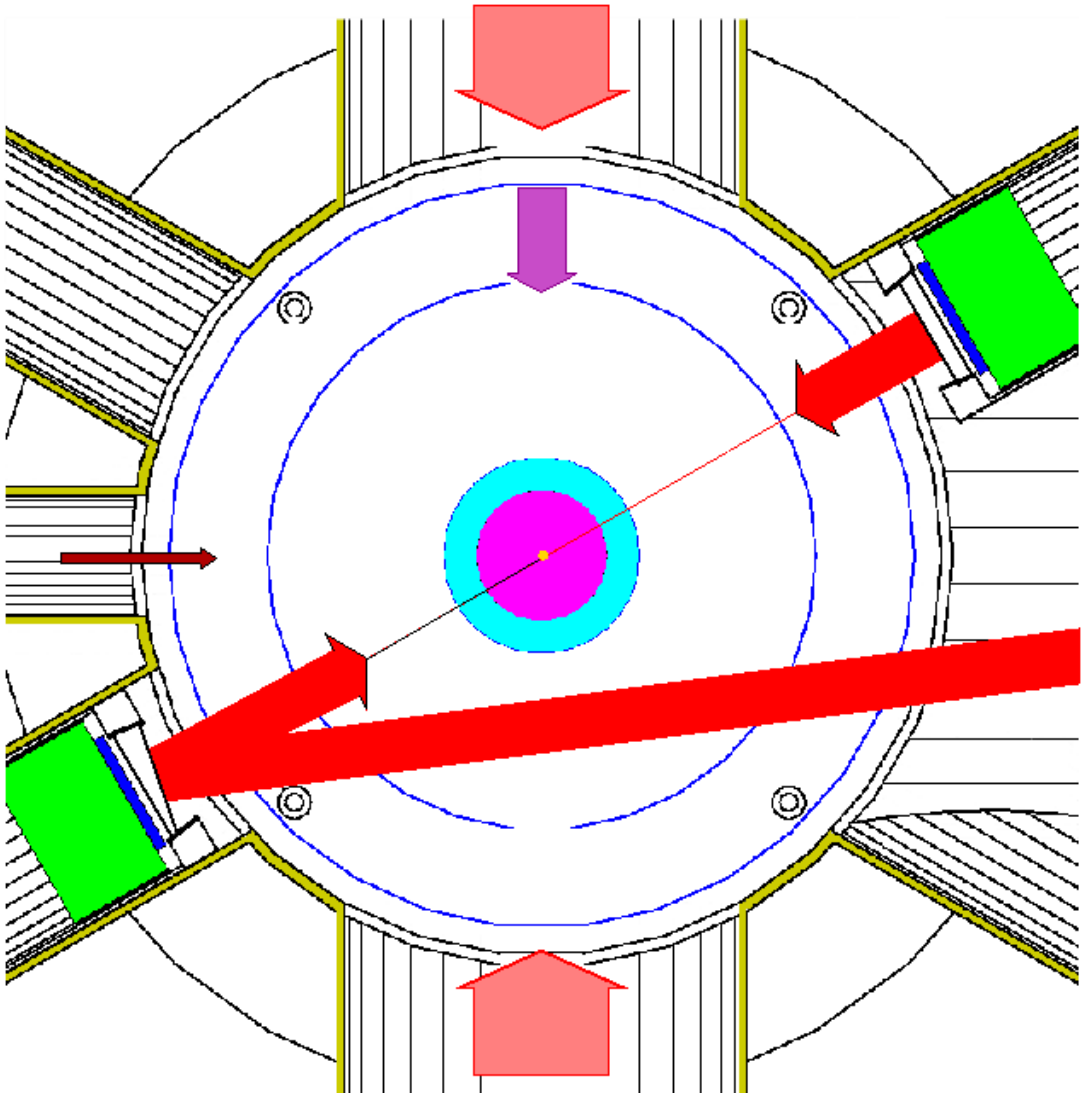

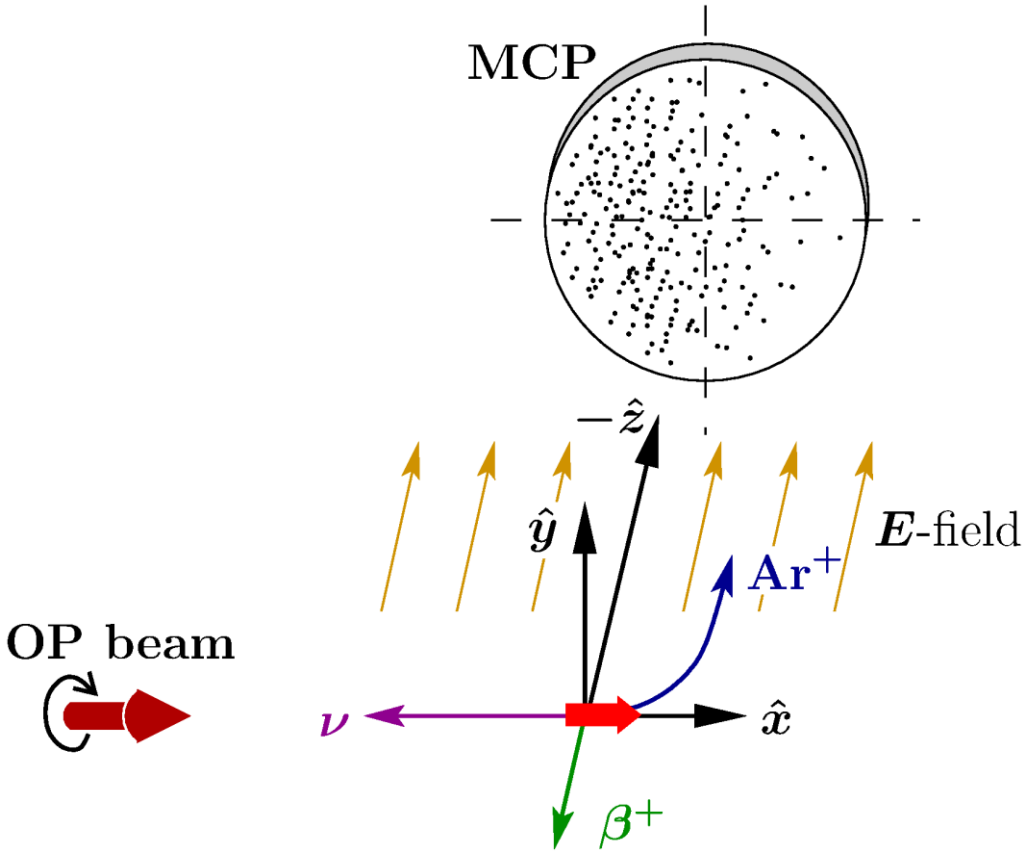

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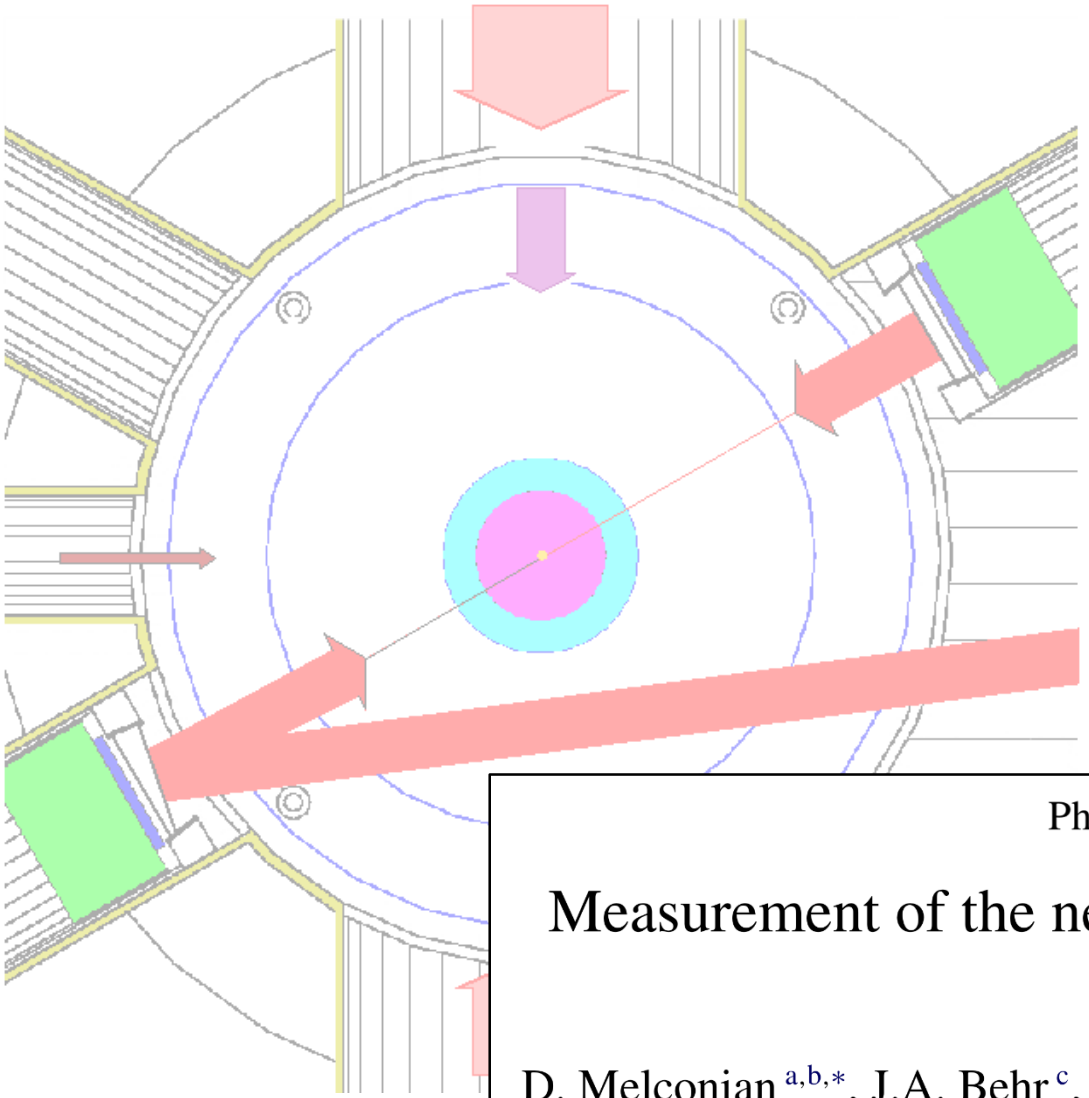
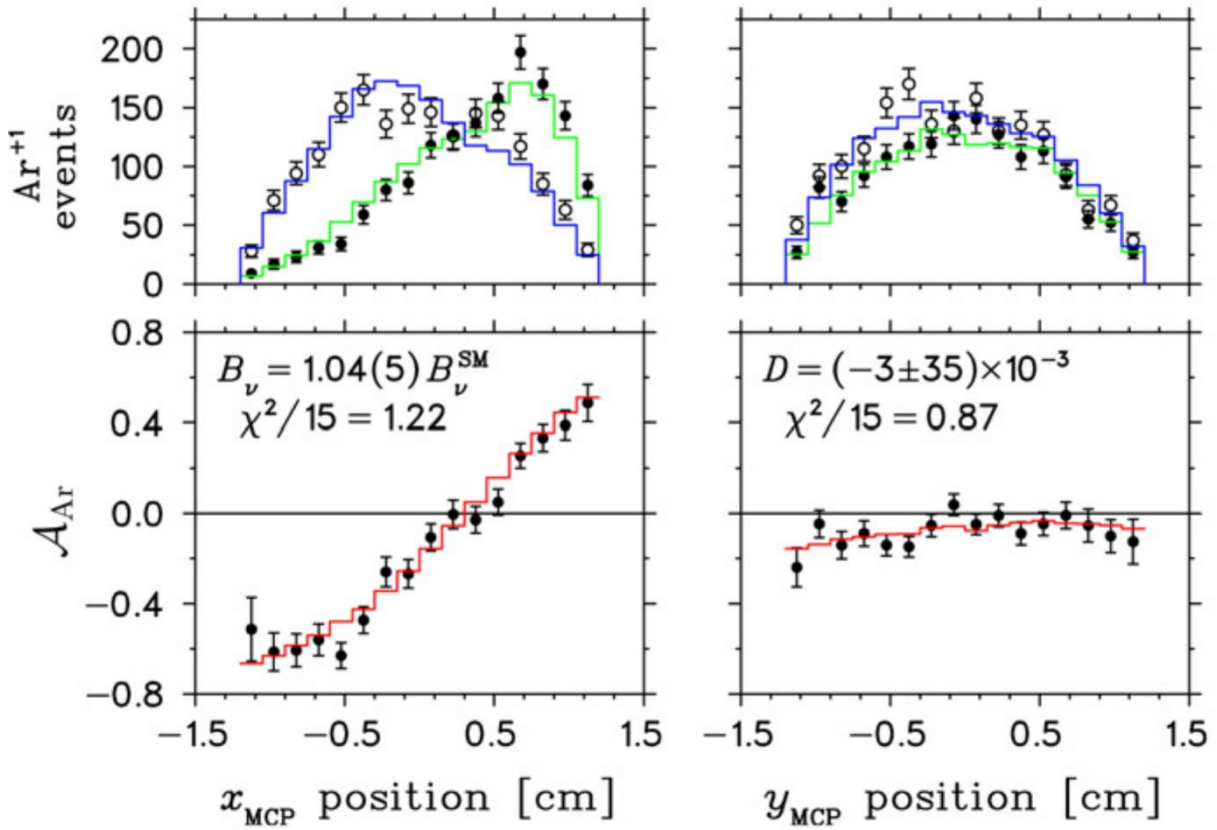


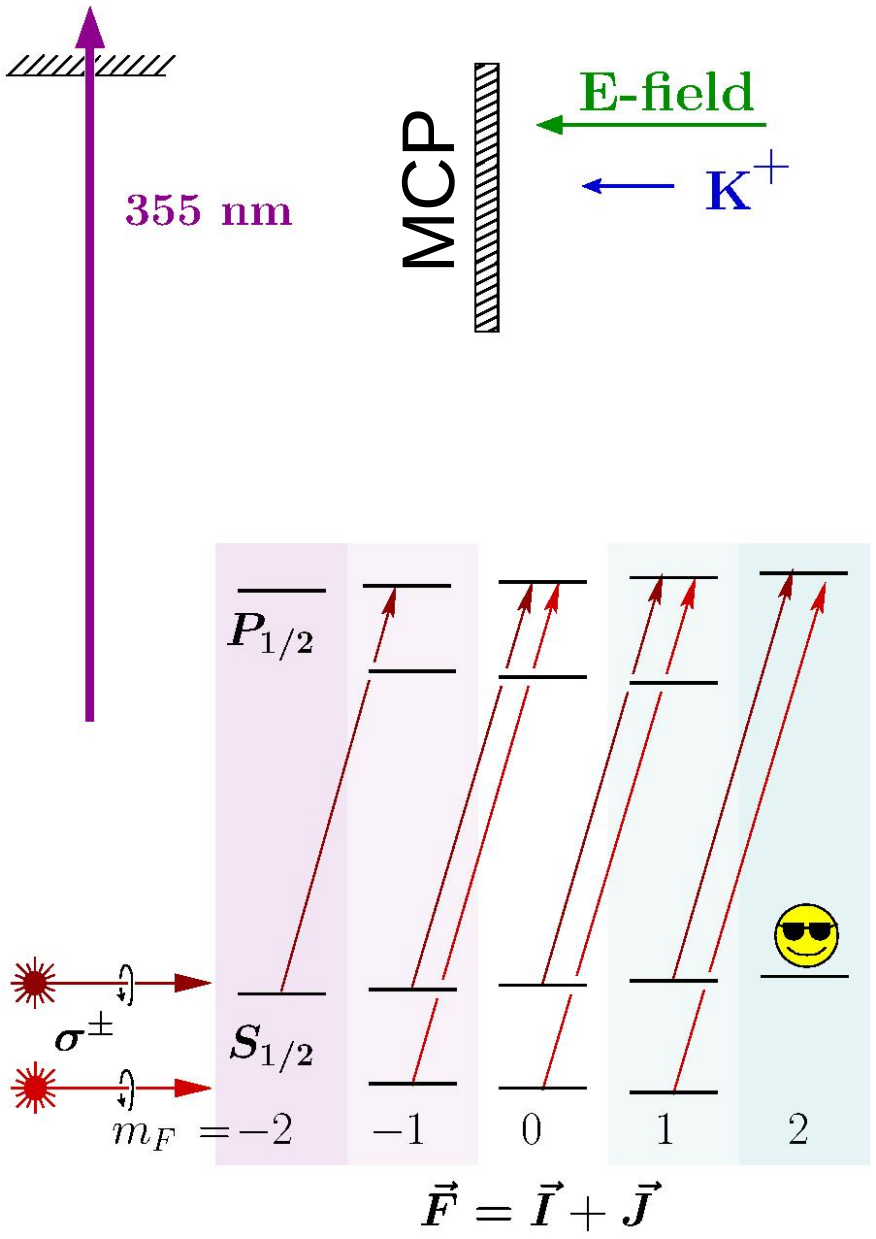


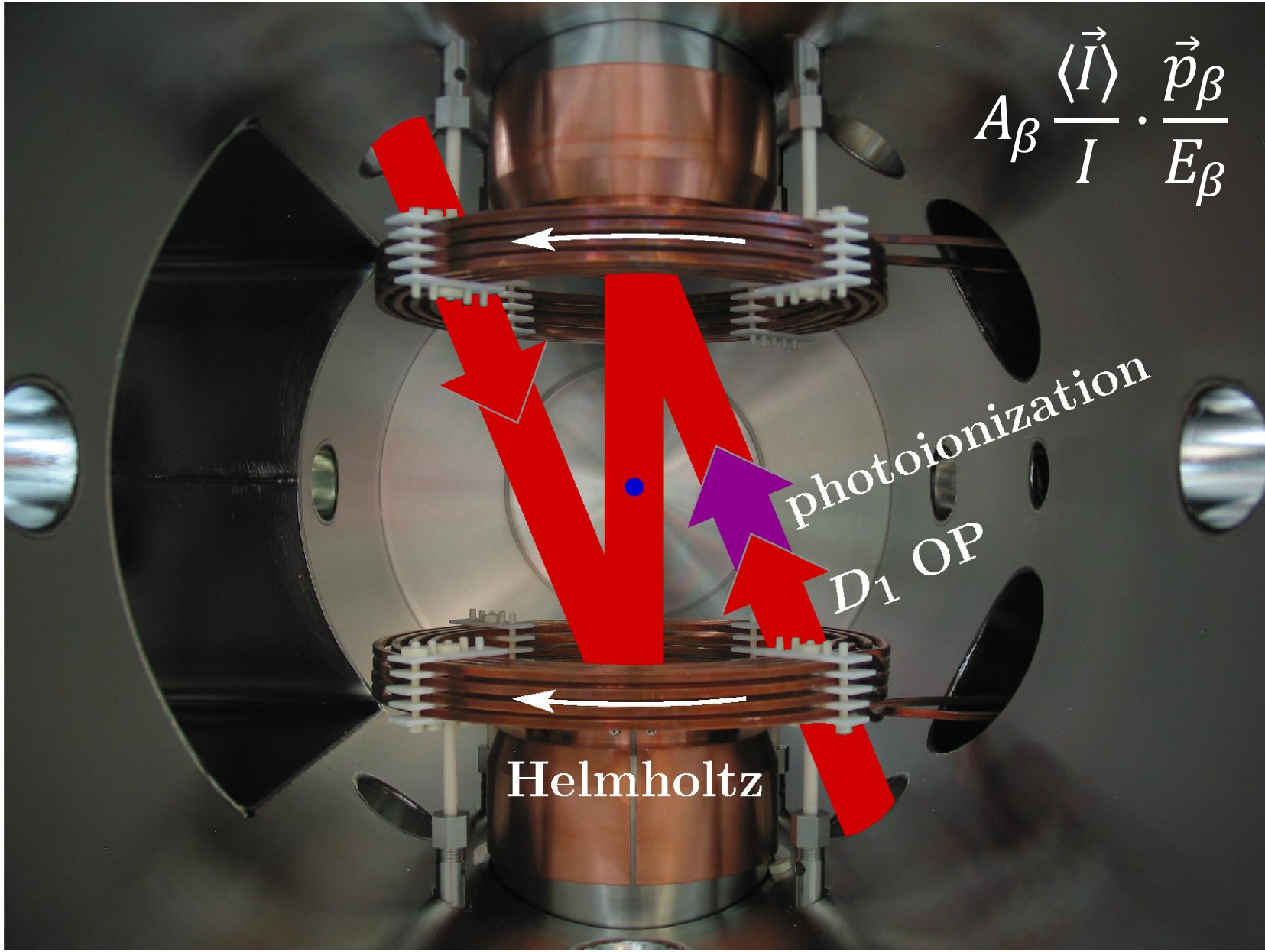
Physics Letters B 649 (2007) 370–375

Measurement of the neutrino asymmetry in the β decay of laser-cooled, polarized ^{37}K

D. Melconian [a,b,*], J.A. Behr [c], D. Ashery [d], O. Aviv [d], P.G. Bricault [c], M. Dombsky [c], S. Fostner [c], A. Gorelov [a], S. Gu [c], V. Hanemaayer [c], K.P. Jackson [c], M.R. Pearson [c], I. Vollrath [c]

Polarized ^{37}K (v2): Measuring A_β and b_{Fierz}





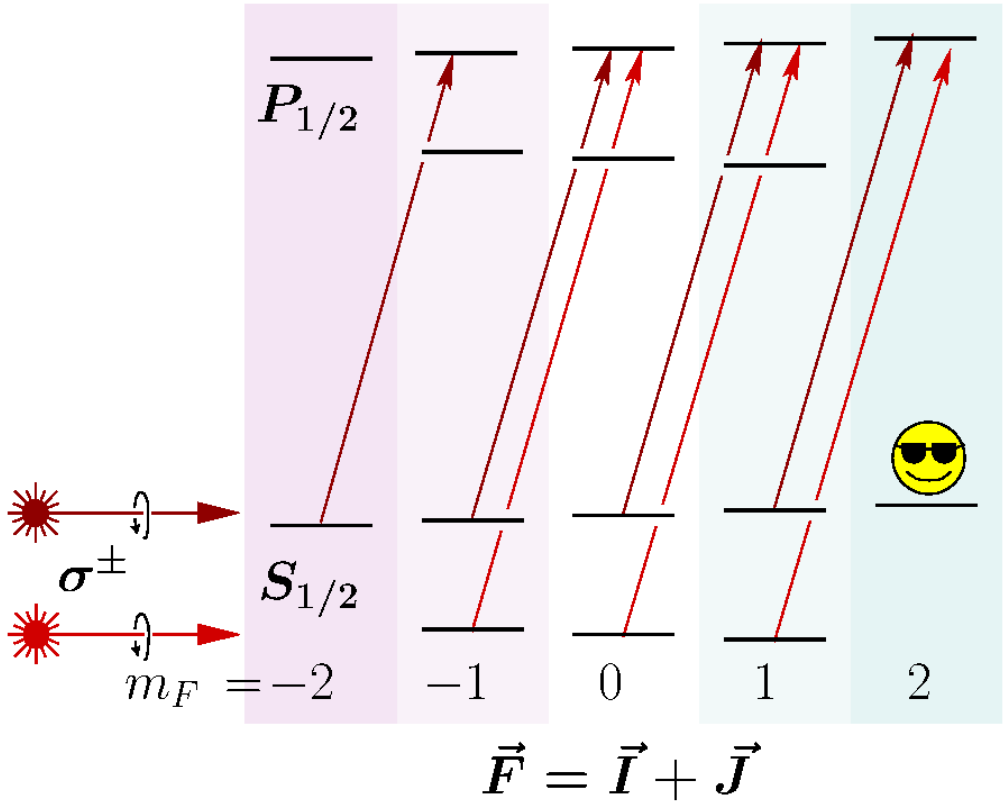
Very high and very precise polarization

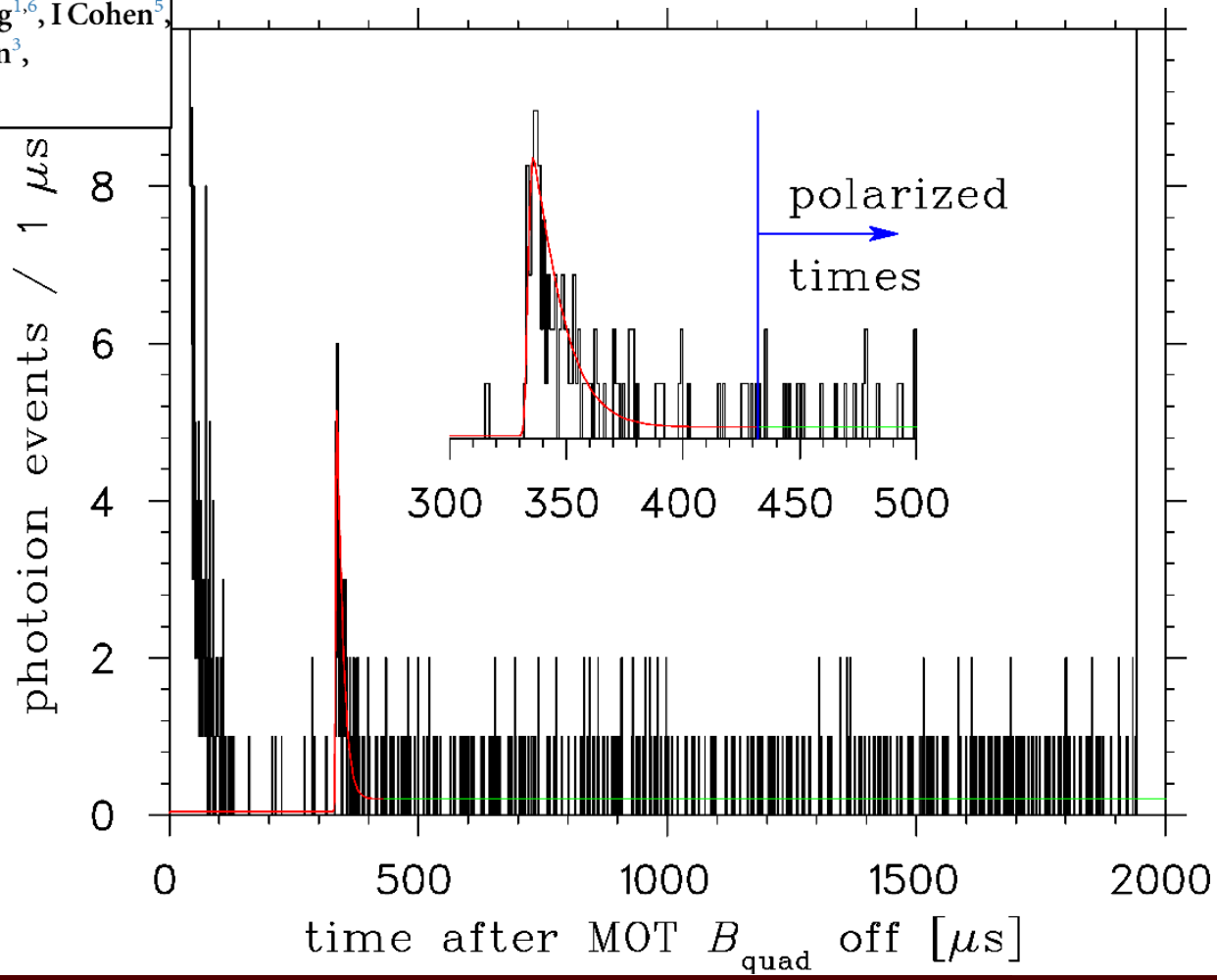
New Journal of Physics

Precision measurement of the nuclear polarization in laser-cooled, optically pumped ^{37}K

B Fenker[1,2,7], J A Behr[3], D Melconian[1,2,7], R M A Anderson[3], M Anholm[3,4], D Ashery[5], R S Behling[1,6], I Cohen[5], I Craiciu[3], J M Donohue[3], C Farfan[3], D Friesen[3], A Gorelov[3], J McNeil[3], M Mehlman[1,2], H Norton[3], K Olchanski[3], S Smale[3], O Thériault[3], A N Vantyghem[3] and C L Warner[3]

$$\langle |P_{\mathrm{nucl}}| \rangle = 0.9913(9)$$

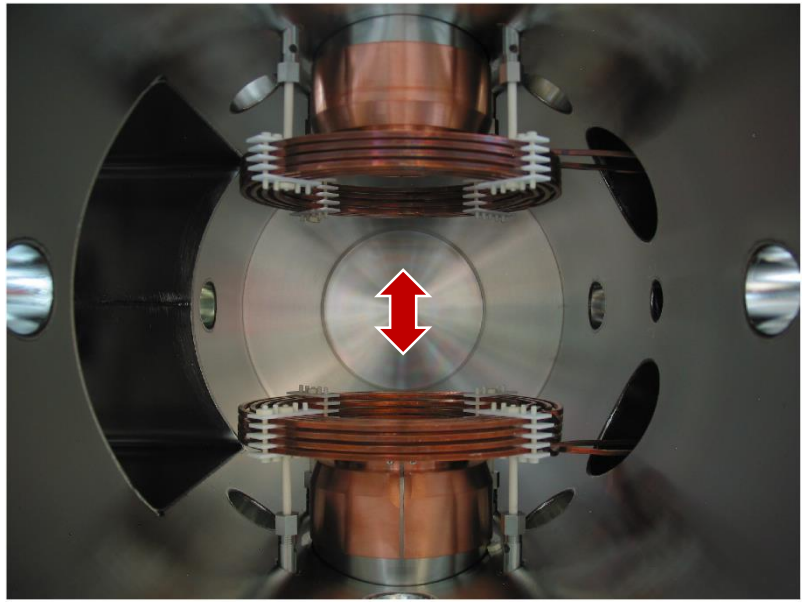




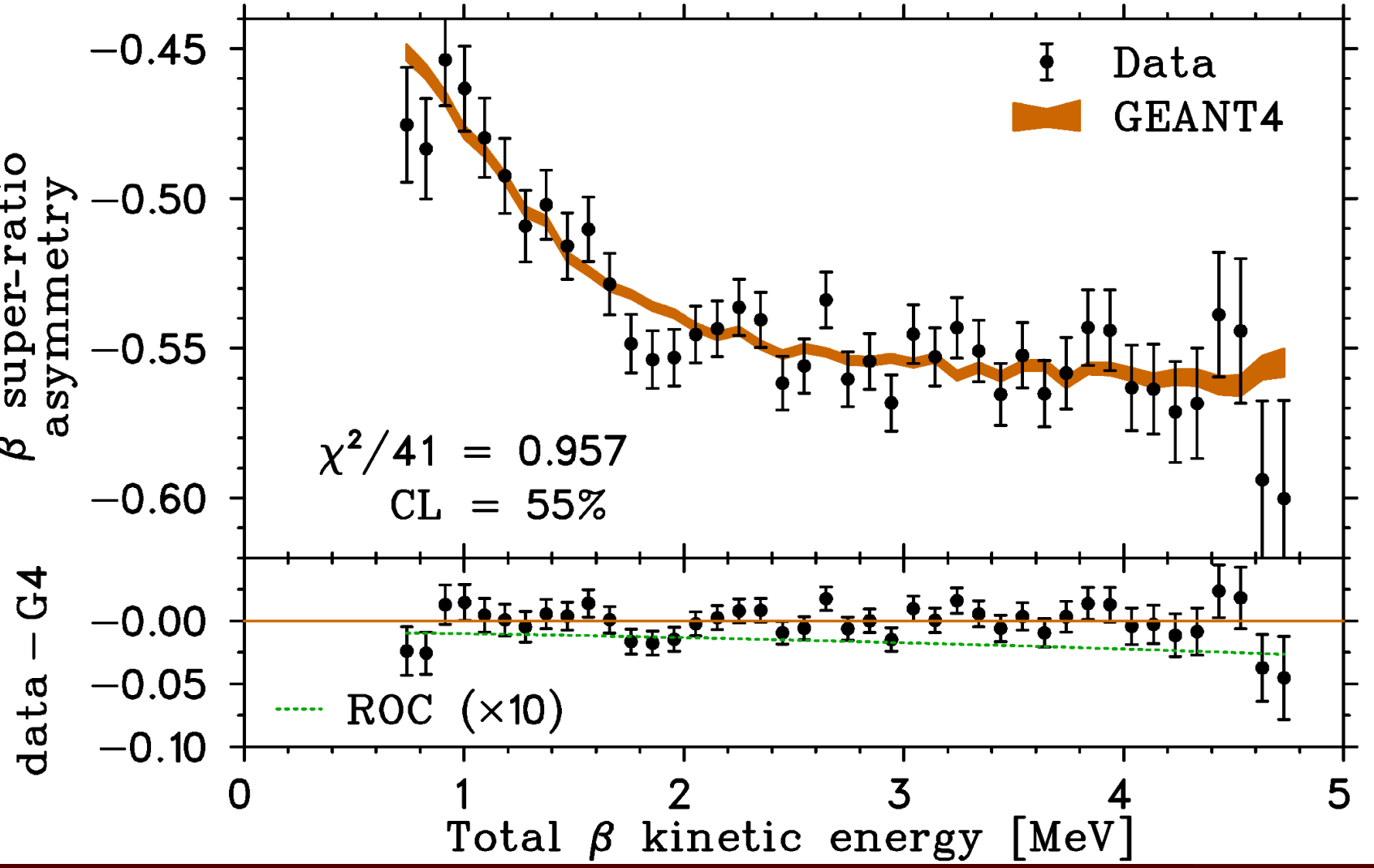
The β asymmetry from $\overrightarrow{^{37}\mathrm{K}}$

- Use **all** information via the super-ratio: $A_{\mathrm{obs}}(E_e) = \frac{1-S(E_e)}{1+S(E_e)}$ with

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



$$A_\beta \frac{\langle \vec{I} \rangle}{I} \cdot \frac{\vec{p}_\beta}{E_\beta}$$



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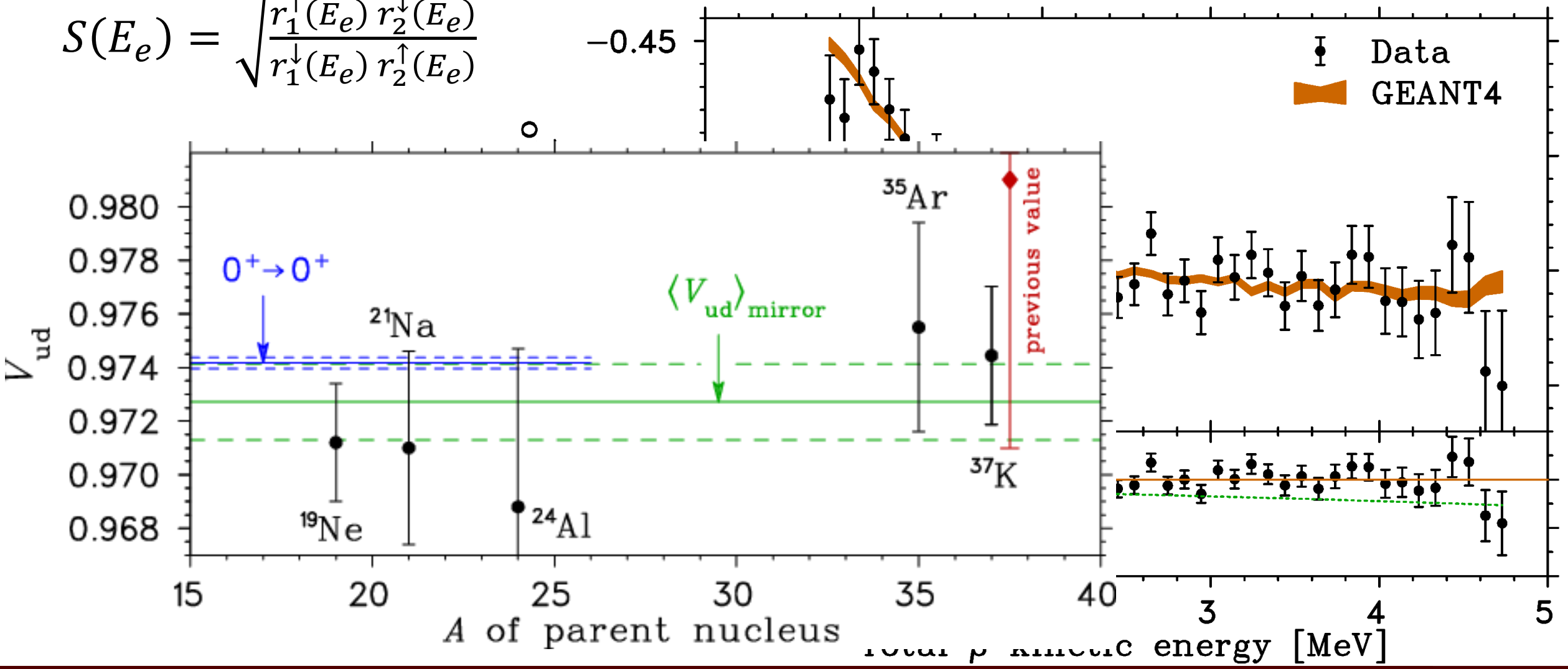
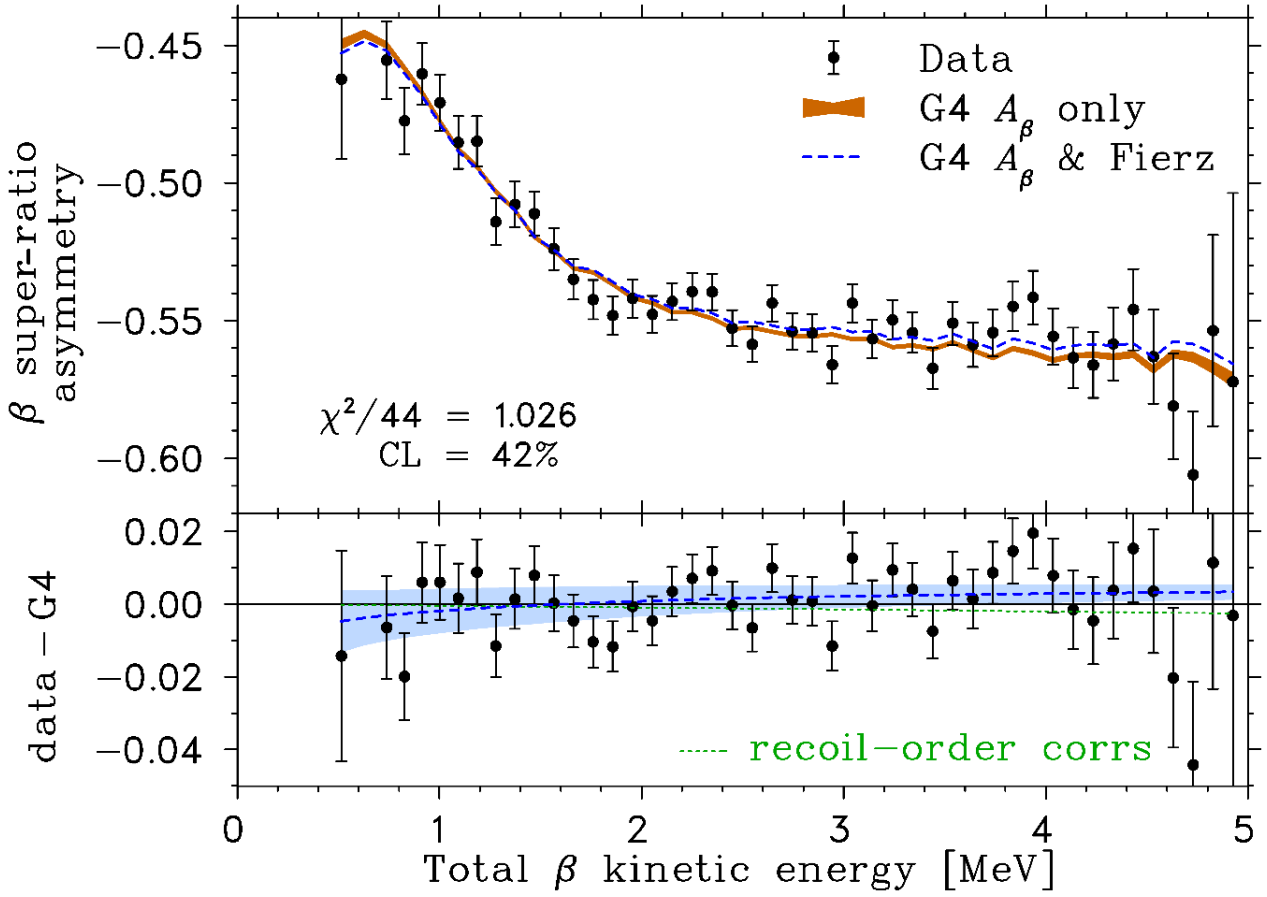
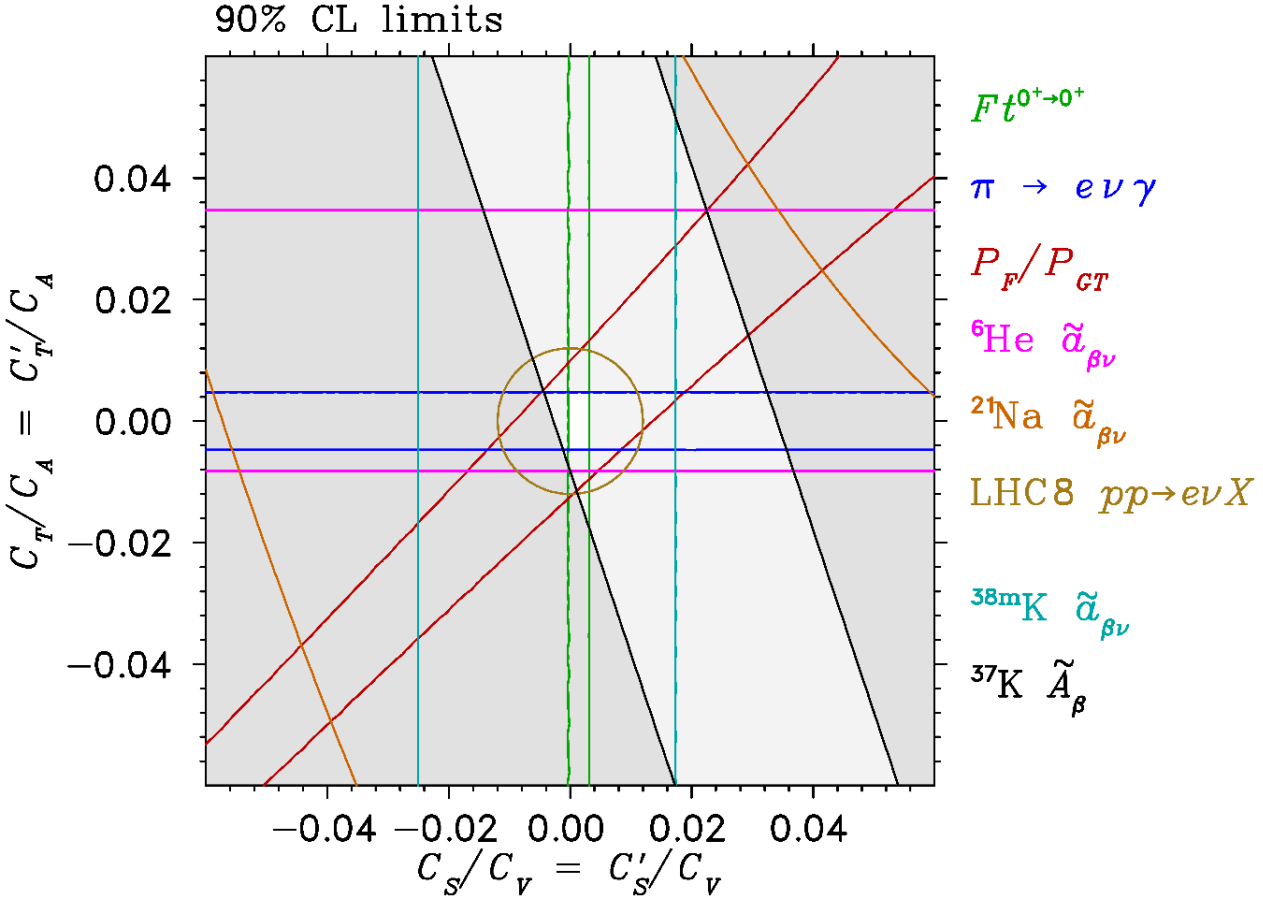


Status of b_{Fierz} from $\overrightarrow{^{37}\mathrm{K}}$

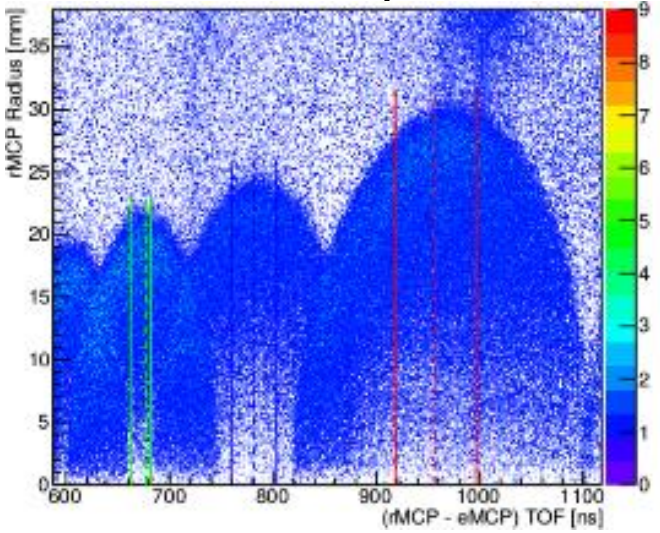
- Statistical uncertainty ~0.04, systs being evaluated; 2nd-class currents
- Next $\tilde{A}_\beta$ run should reach <0.1% precision, will complement other searches for BSM physics

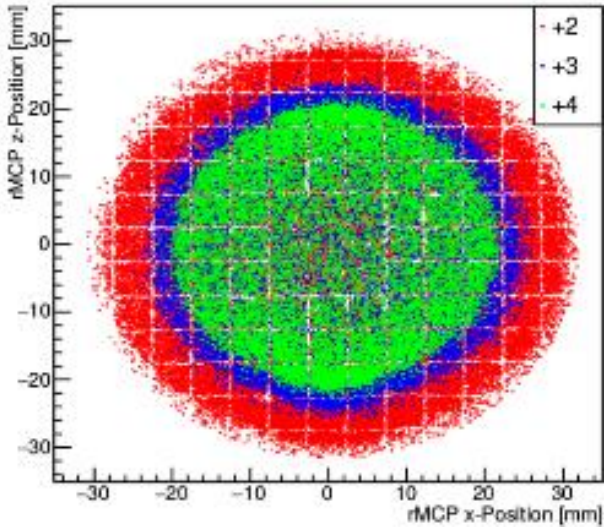


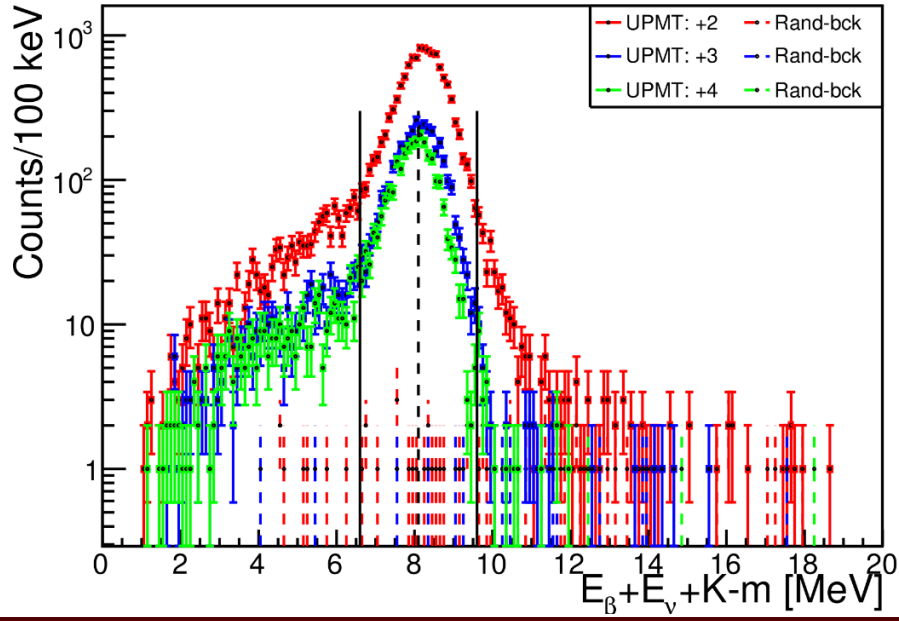


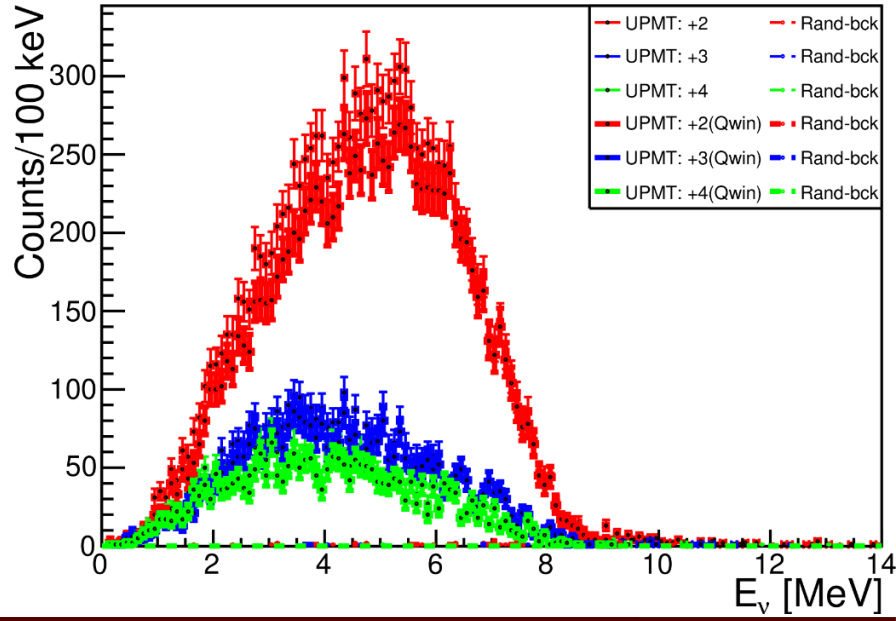
^{92}Rb 1st-forbidden $0^- \rightarrow 0^+$ decay

- MCP TOF + position ⇒ recoil kinetic energy ⇒ $a_{\beta\nu}$ (pseudoscalars?)
- β-telescope ⇒ β^- energy too
  - $E_{\bar{\nu}} = E_0 - E_\beta - E_{\text{recoil}}$ (reactor anomaly)
- Preliminary:
  - $a_{\beta\nu} = 0.322(11)(1)$ is much less than 1…
  - Reconstructed anti-neutrino spectrum looks promising!





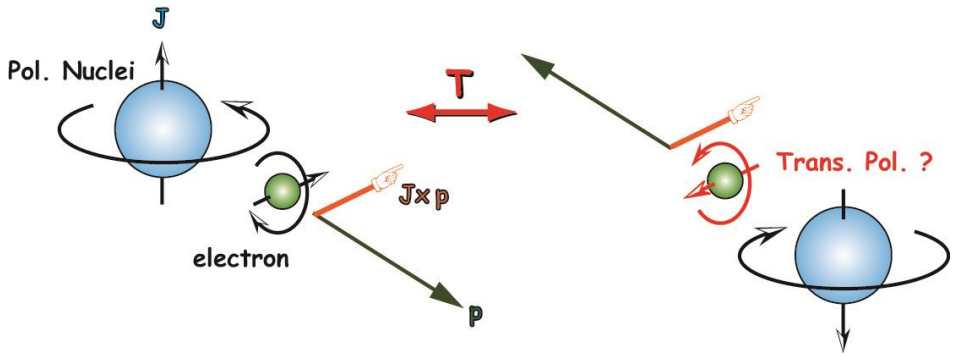


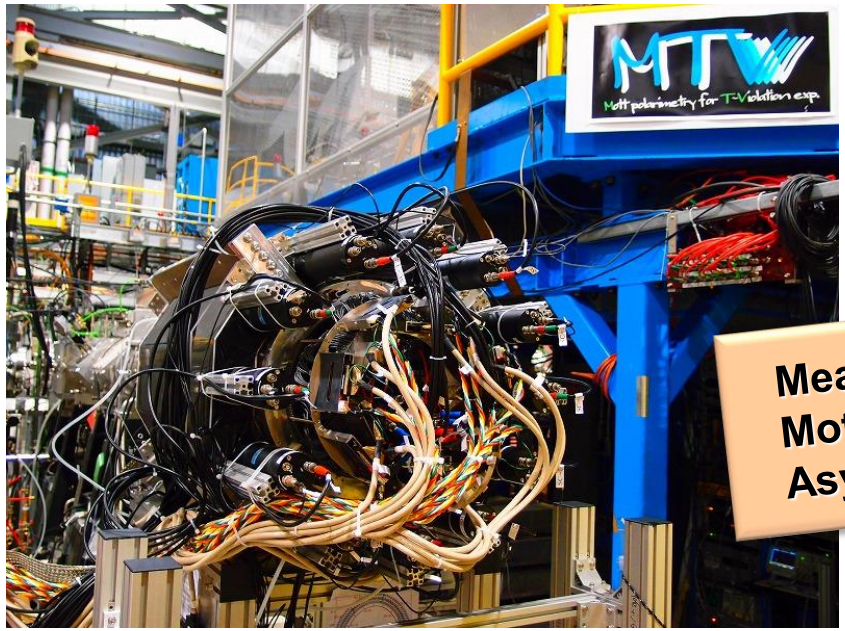


S1183-MTV : Test of time reversal symmetry using polarized unstable nuclei

Collaboration between Canada-Japan (Spokesperson : Jiro Murata, Rikkyo University, Japan)

Motivation : Searching T-Violating Transverse Electron Polarization in polarized Li-8 beta decay T & P violating (same as EDM, but in different system)





$$R\,\vec{\sigma}\cdot\frac{\langle\vec{I}\rangle}{I}\times\frac{\vec{p}_\beta}{E_\beta}$$

Measurement = Backward Mott Scattering Left-Right Asymmetry

TRIUMF (Canada)

Polarized Li-8 : TRIUMF-ISAC

10^7pps @ 80% polarization

MTV detector (Japan)

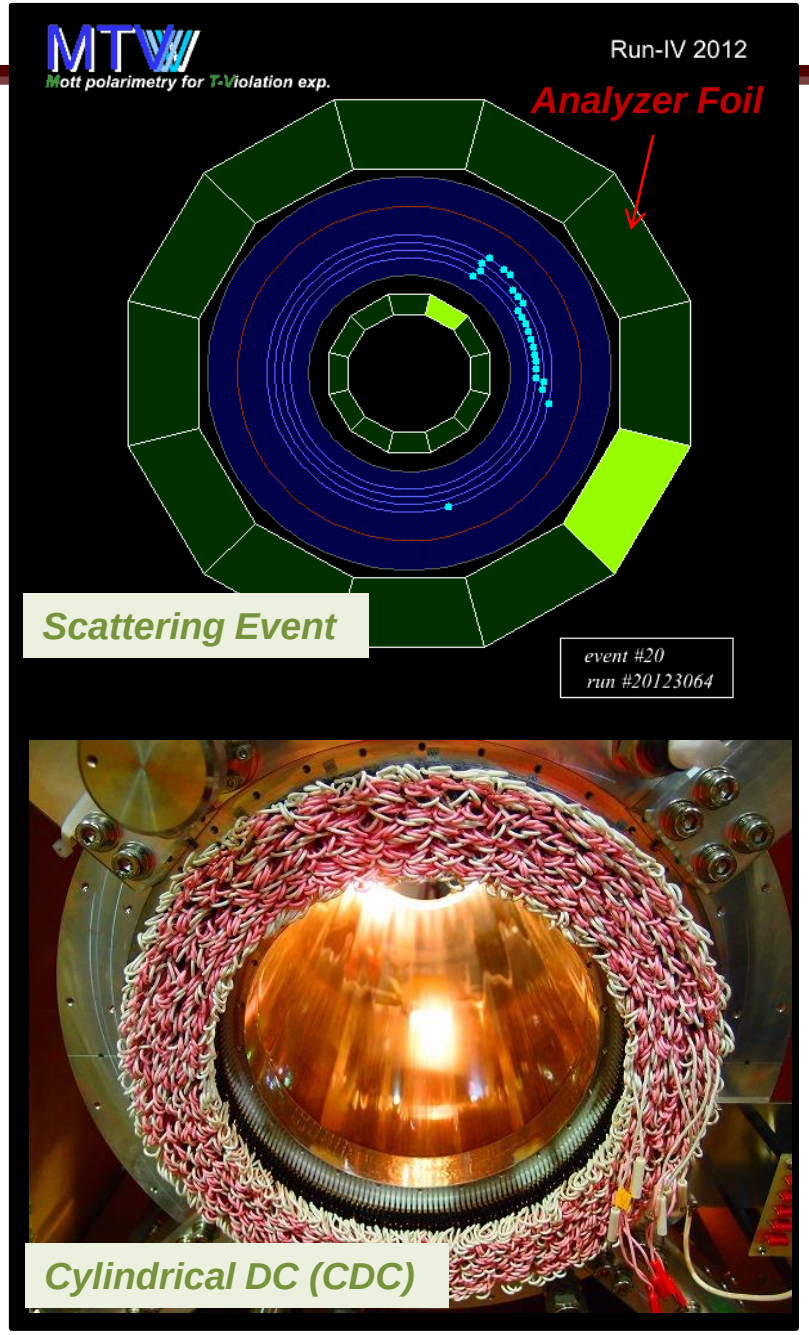
Transverse Electron Polarimeter : Mott Analyzer using Cylindrical Drift Chamber

50MHz Mott-Scattering Tracking Measurement

Highest Precision Test at $R \sim 10^{-4}$

Previous Test at PSI 2003 $R_{PSI} = (-0.9 \pm 2.2) \times 10^{-3}$

the only project testing R



2008 Test Experiment at KEK-TRIAC

KEK

***R*~40%** with 8% pol., 10^5pps

KEK to TRIUMF

TRIUMF

2011 – 2012 CDC Commissioning
2013 – 2015 Systematics Tests
2016 – 2017 Physics Production
Data Production Completed with ~10^{-4} precision!

Physics from Run 2016-17 (preliminary)

1. Test of ***R*** at the highest precision.
2. First measurement of nuclear ***N*** ***correlation*** ***(transverse polarization).***
3. Lorentz violation tests in weak interaction ***(half-life varying of pol. Li-8).***

MTV Collaboration
Japan : Rikkyo-U, Tohoku-U, Nagoya-U, RIKEN
Canada : TRIUMF

Summary

- These experiments are hard, and take time, effort and patience
- Lead to high-impact publications
  - ^{38m}K 1997 PRL – first trapping (TISOL)
  - ^{38m}K 2003 PRL – massive neutrinos
  - ^{38m}K 2005 PRL – β-ν correlation
  - ^{37}K 2007 PLB – ν asymmetry
  - ^{37}K 2016 NJP – nuclear polarization
  - ^{37}K 2018 PRL – β asymmetry
  - ^{37}K 2019/20 (PRL) – Fierz parameter
- TRIUMF is **uniquely suited** to mount these experiments
- None of this would have been possible without ISAC!

Incomplete list of (major) players

- TRIUMF
  - Otto Hausser, John D'Auria
  - John Behr, Alexandre Gorelov, Peter Jackson, Mike Trinczek, Melissa Anholm, James McNeil, Rob Pitcairn, Matt Pearson, Phil Levy
- Texas A&M Cyclotron Institute
  - Ben Fenker, Spencer Behling
- Tel Aviv University
  - Danny Ashery, Ofer Aviv, Iuliana Cohen
- Rikkyo University
  - Jiro Murata