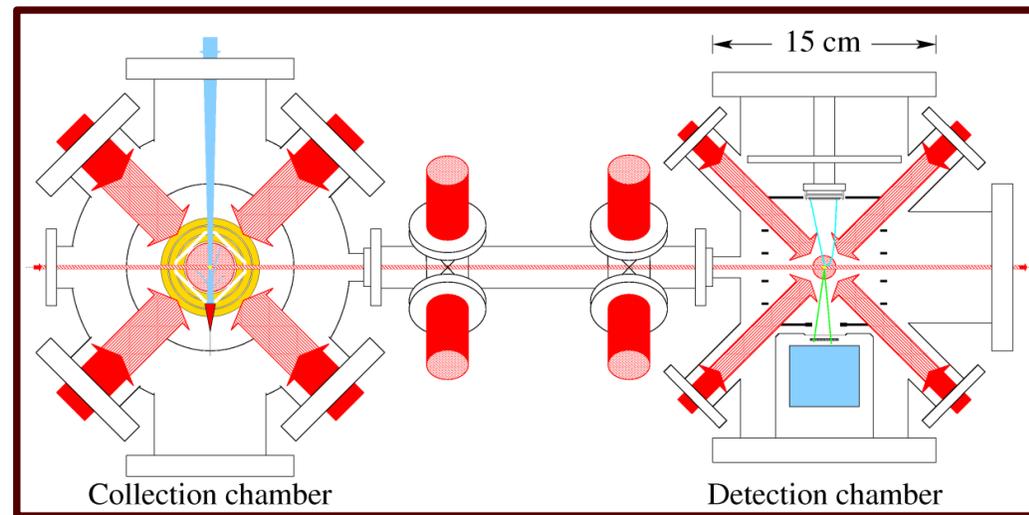
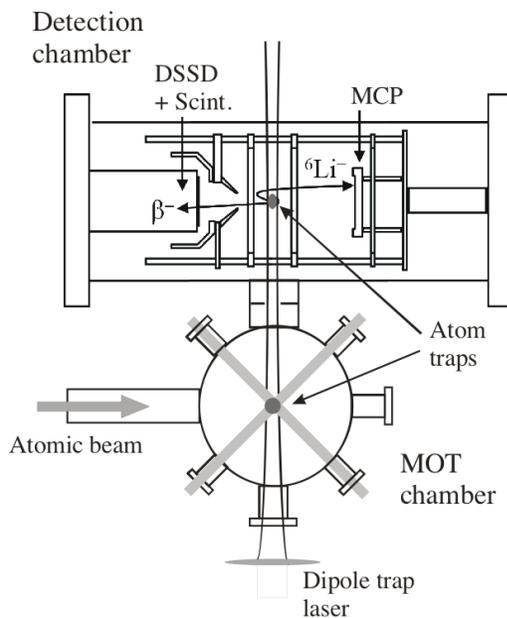
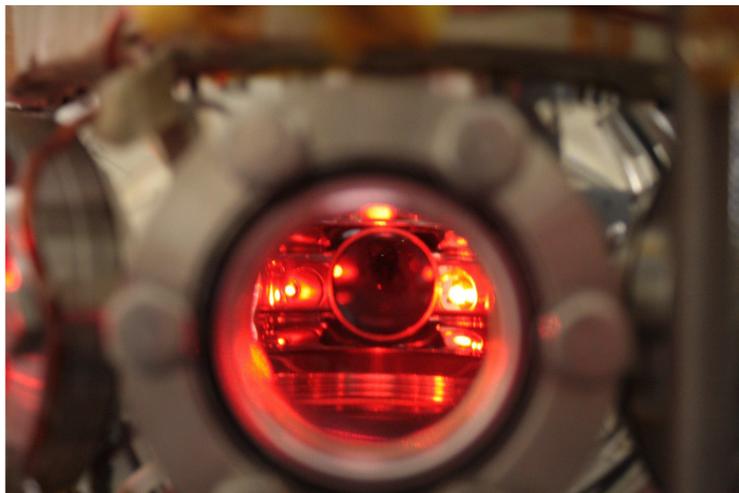
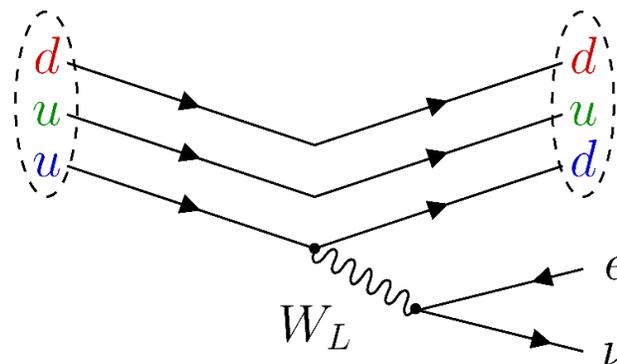
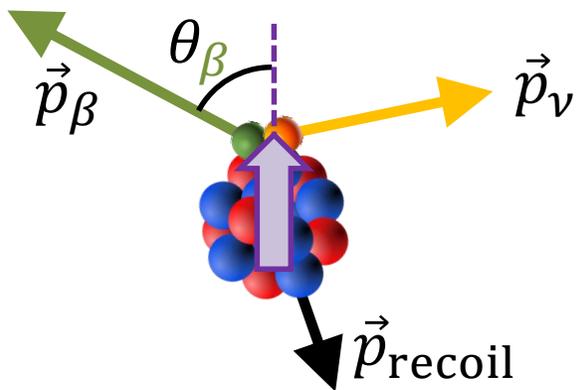
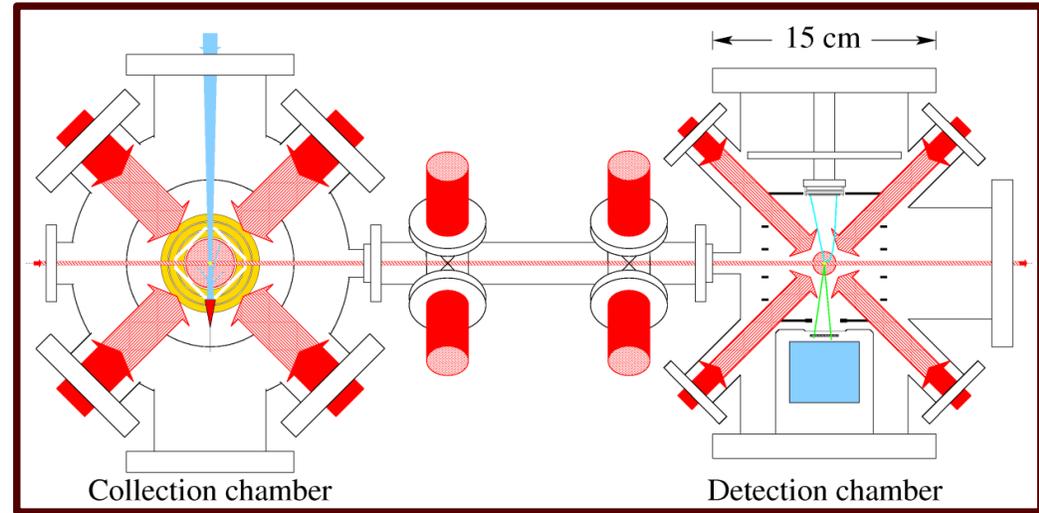
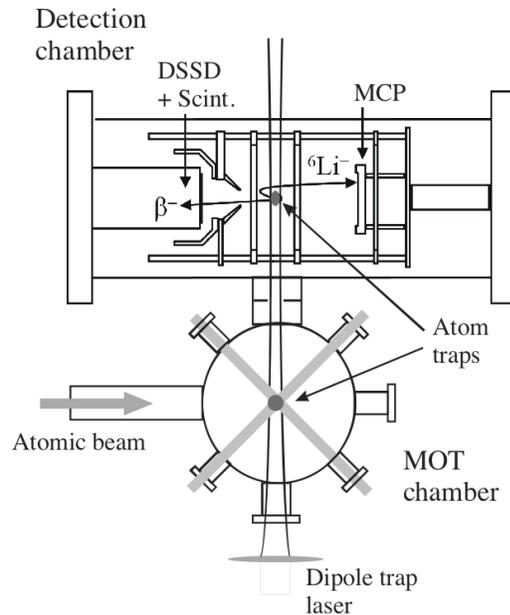
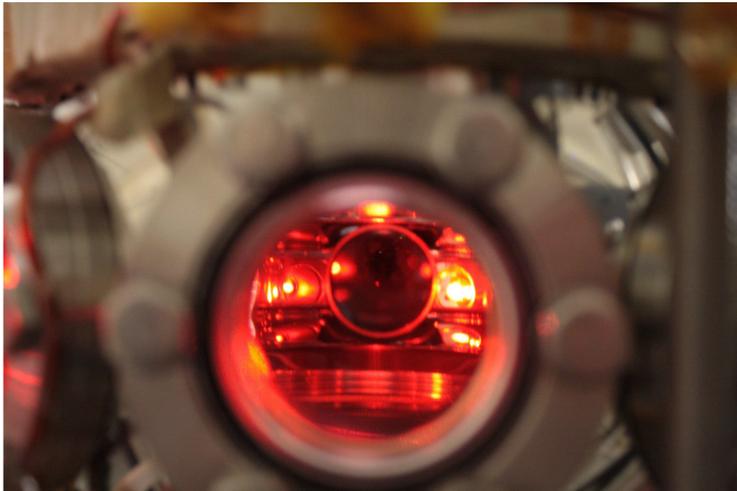
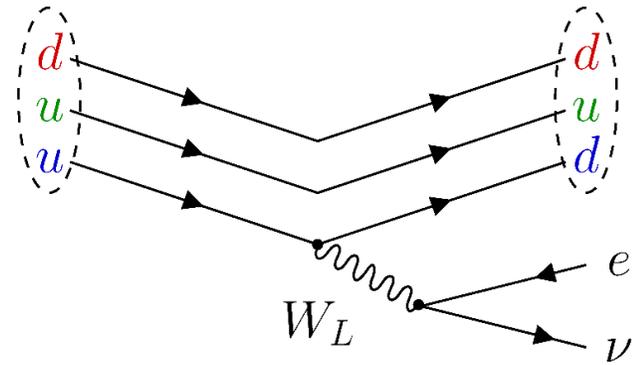
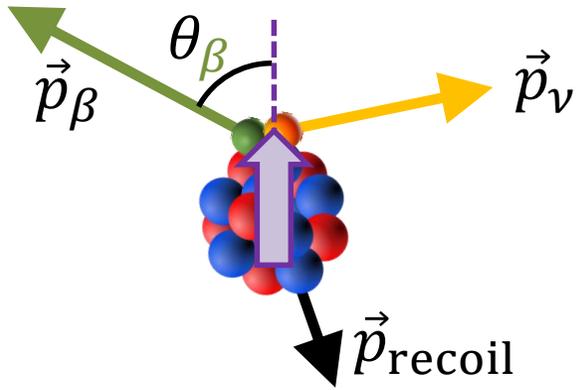


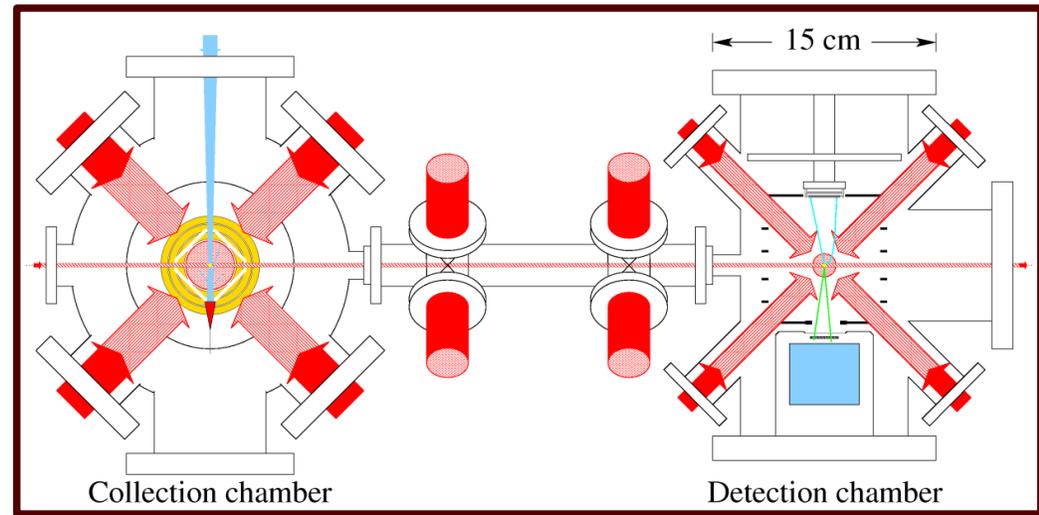
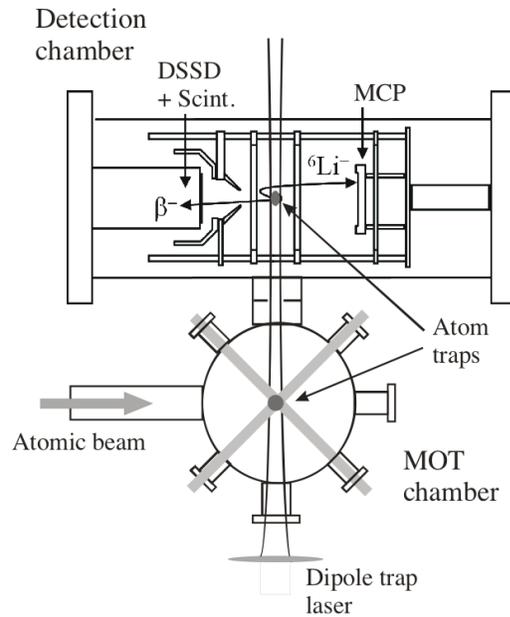
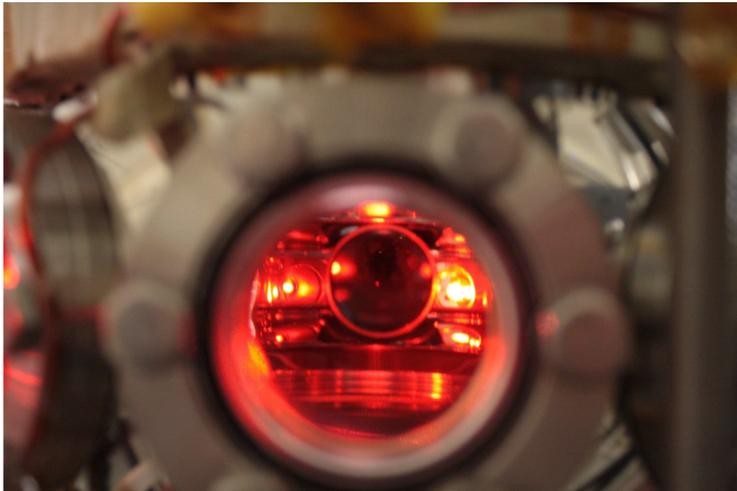
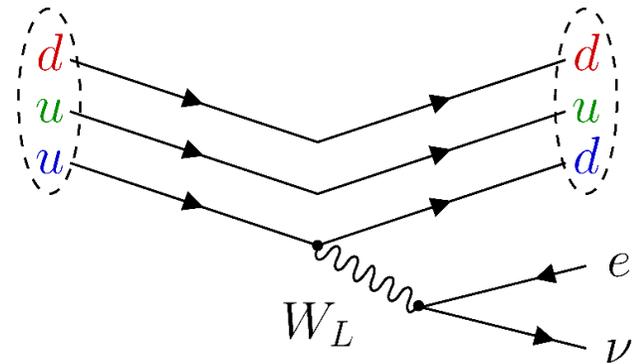
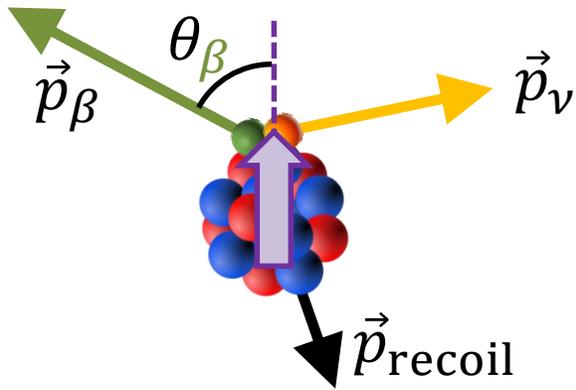
β decay asymmetry measurements with trapped atoms



β decay ~~asymmetry~~ correlation measurements with trapped atoms

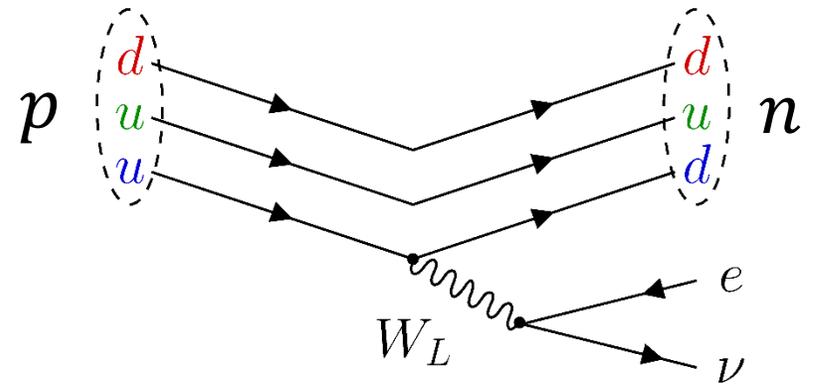


Precision β decay ~~correlation~~ ~~asymmetry~~ measurements with trapped atoms



The standard model and beyond

• This is the standard model:



pure $V - A$ interaction

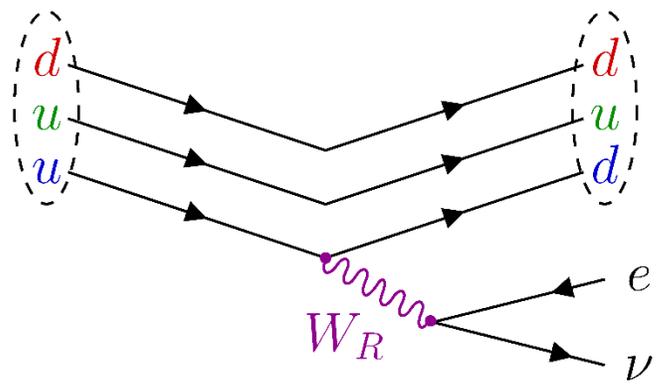
$$H_\beta = \bar{p}\gamma_\mu n(C_V \bar{e}\gamma^\mu \nu + C'_V \bar{e}\gamma^\mu \gamma_5 \nu) - \bar{p}\gamma_\mu \gamma_5 n(C_A \bar{e}\gamma^\mu \gamma_5 \nu + C'_A \bar{e}\gamma^\mu \nu)$$

$$C_V = C'_V = 1$$

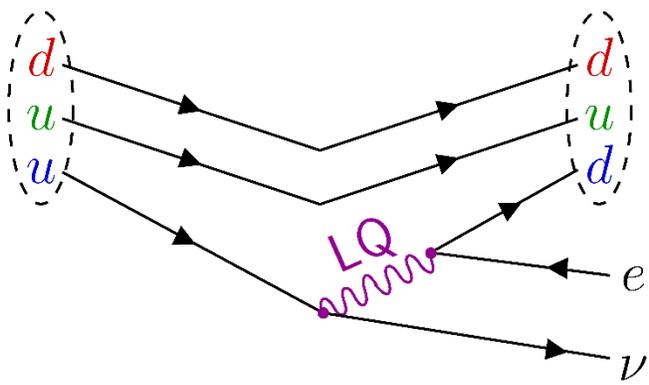
$$C_A = C'_A \approx 1.27$$

• These are not:

Right-handed bosons, or scalar/tensor leptoquarks, or SUSY, or...



$$C_i \neq C'_i$$



$$C_S, C_T \neq 0$$

- Profumo, Ramsey-Musolf, Tulin, Phys. Rev. D **75**, 075017 (2007)
- Vos, Wilschut, Timmermans, Rev. Mod. Phys. **87**, 1483 (2015)
- Bhattacharya *et al.*, Phys. Rev. D **94**, 054508 (2016)

The precision frontier

Goal:

✱ To complement high-energy experiments by pushing the precision frontier

✱ Angular correlations in β decay: values sensitive to new physics

(Hopefully you saw the nice talk by González-Alonso this morning)

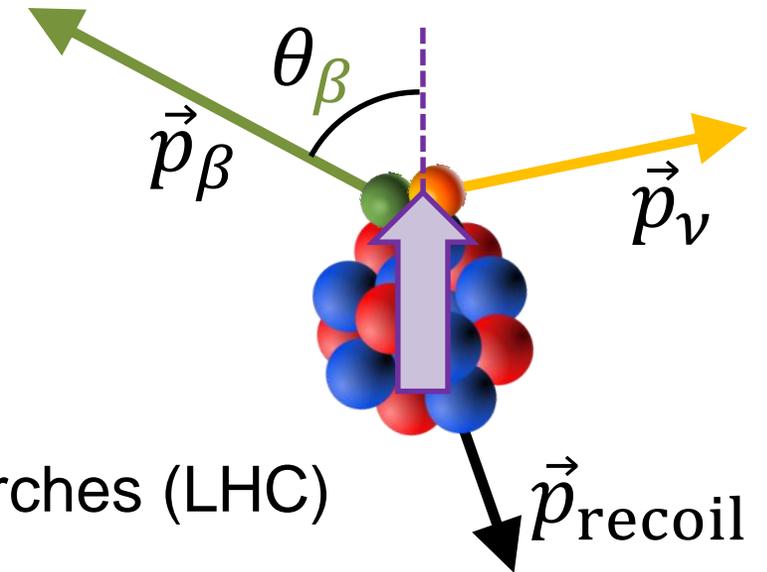
Global gameplan:

✱ Measure the 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)

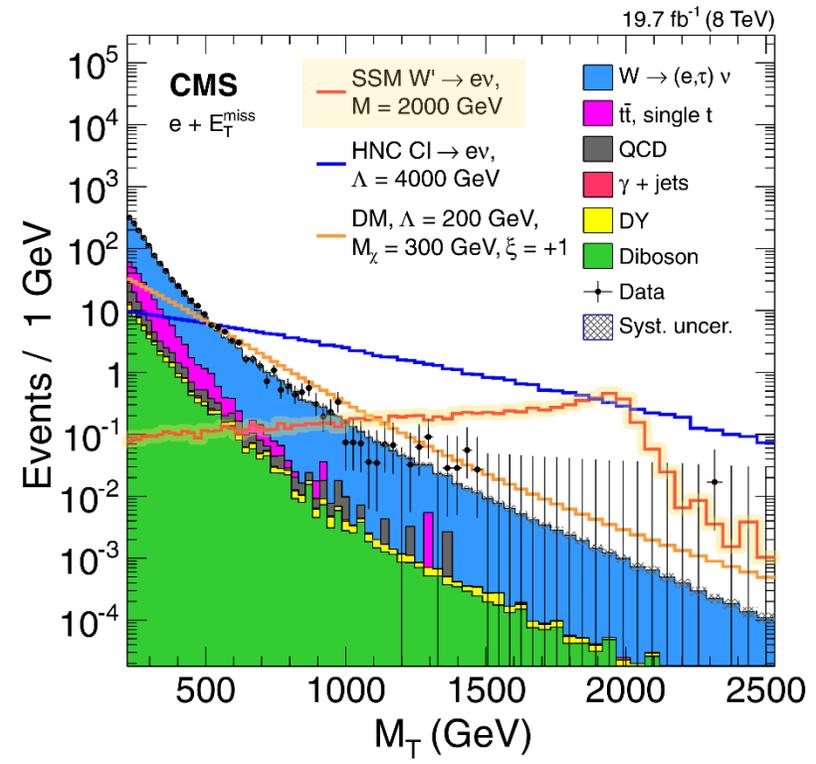
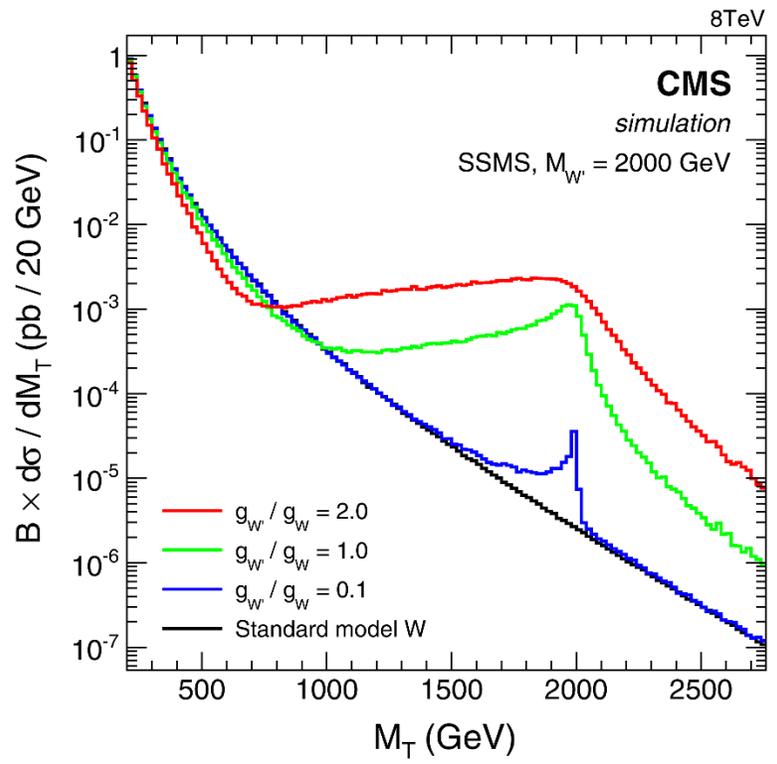
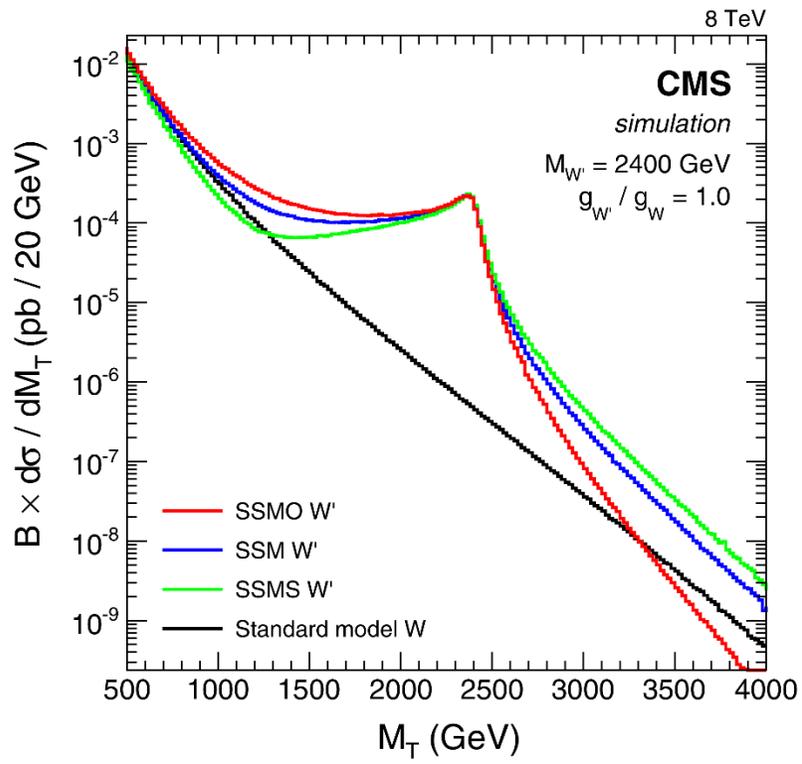
Vos, Wilschut and Timmermans, RMP **87**, 1483 (2015)

González-Alonso, Naviliat-Čunčić and Severijns, arXiv:1803.08732

The energy frontier

• CMS collaboration, Phys. Rev. D **91**, 092005 (2015)

- Look for direct production \Rightarrow excess of events in the missing transverse energy
- $\sigma(pp \rightarrow e + \text{MET} + X)$ channel with $\int L = 20 \text{ fb}^{-1}$ at $\sqrt{s} = 8 \text{ TeV}$



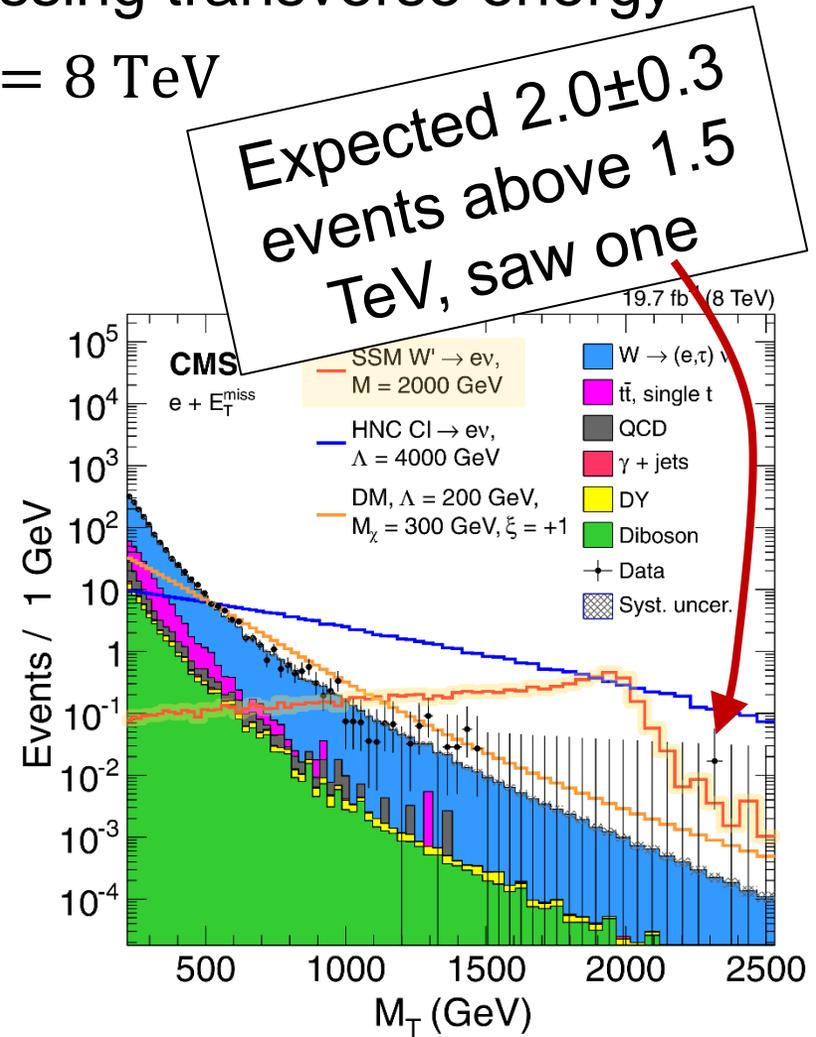
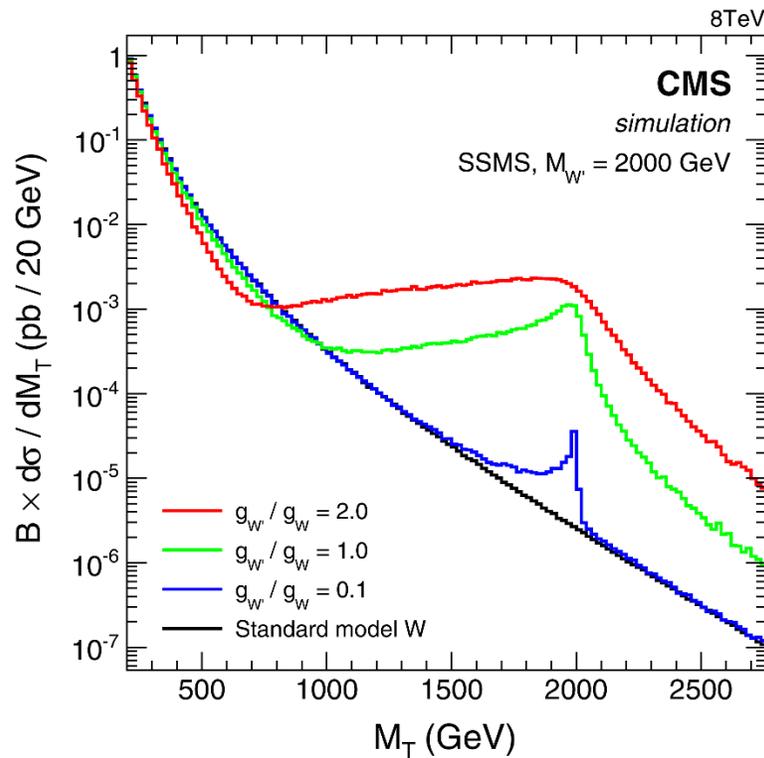
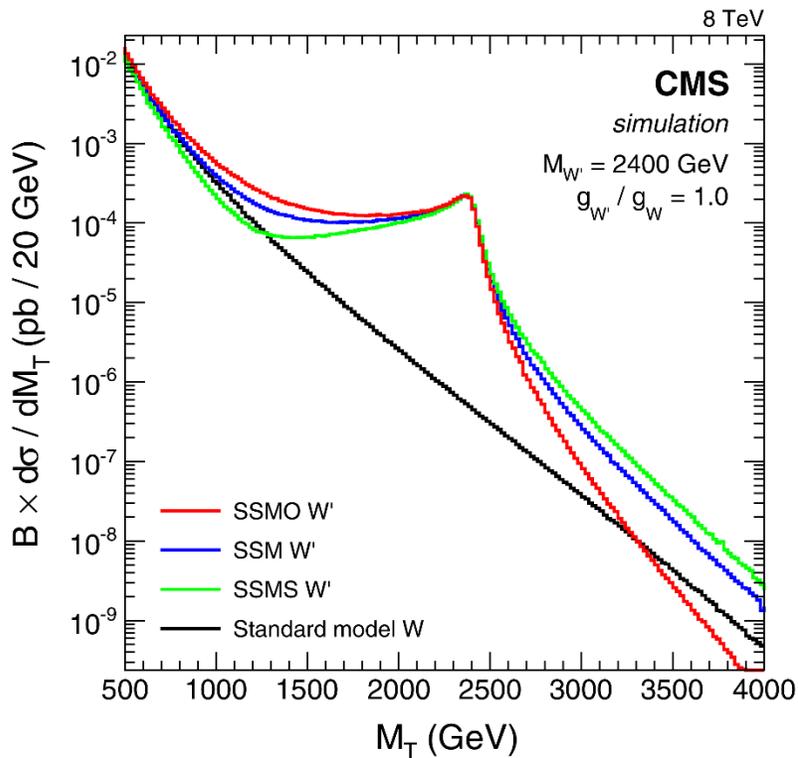
The energy frontier

• CMS collaboration, Phys. Rev. D **91**, 092005 (2015)

✳ Look for direct production \Rightarrow excess of events in the missing transverse energy

✳ $\sigma(pp \rightarrow e + \text{MET} + X)$ channel with $\int L = 20 \text{ fb}^{-1}$ at $\sqrt{s} = 8 \text{ TeV}$

✳ No excess observed \rightsquigarrow place limits
(see Gonzalez-Alonzo, arXiv:1803.08732 for EFT interpretation)



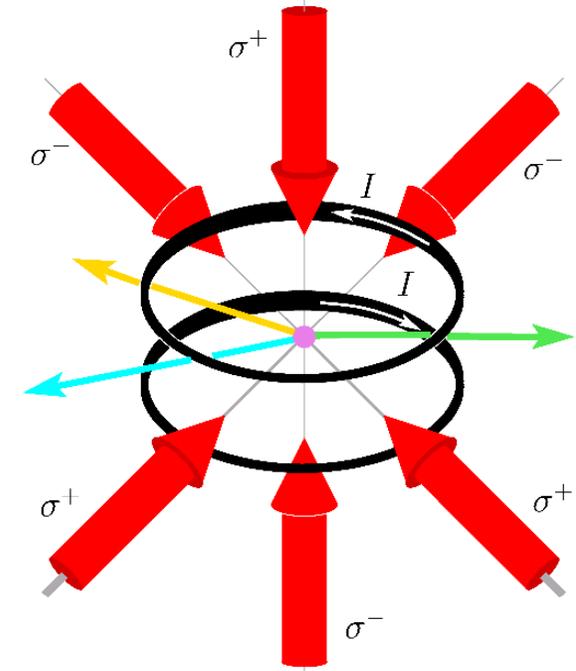
0.1% is a tall order...how to reach that precision?

Ion traps

- ✱ Can trap any ion
- ✱ Well-known for mass measurements (ISOLTRAP, JYFLTRAP, LEBIT, TITAN,...)
- ✱ Beta-Decay Paul Trap @ ANL
 - β - ν correlation of ${}^8\text{Li}$ to 1%; poised to reach 0.1% precision
- ✱ No other correlation experiments completed yet, but a number are planned:
 - TAMUTRAP @ Texas A&M (${}^{32}\text{Ar}$; ${}^{20}\text{Mg}$, ${}^{24}\text{Si}$, ${}^{28}\text{S}$, ${}^{36}\text{Ca}$, ${}^{40}\text{Ti}$)
 - LPCTrap @ GANIL (${}^6\text{He}$)
 - EIBT @ Weizmann Institute → SARAF (${}^6\text{He}$ to start)
 - NSLTrap @ Notre Dame (${}^{11}\text{C}$, ${}^{13}\text{N}$, ${}^{15}\text{O}$, ${}^{17}\text{F}$)

Magneto-optical traps

- ✱ Atoms are cold and confined to a small volume
- ✱ Isomerically selective; low backgrounds
- ✱ Very shallow trap, minimal volumes to scatter off

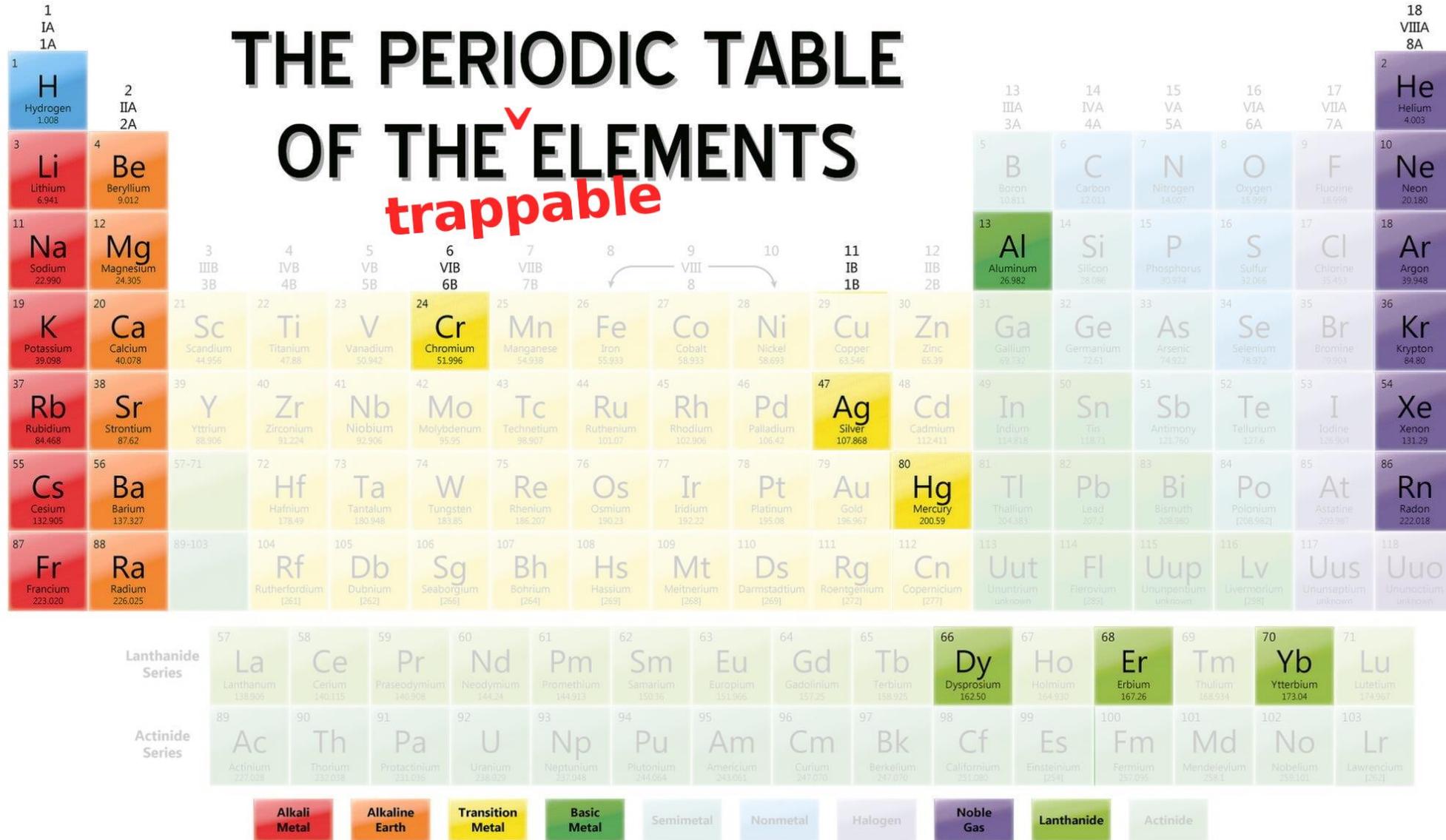


Difficulty with MOTs: not all atoms can be trapped

THE PERIODIC TABLE OF THE ELEMENTS

1 IA 1A H Hydrogen 1.008	2 IIA 2A Be Beryllium 9.012											13 IIIA 3A B Boron 10.811	14 IVA 4A C Carbon 12.011	15 VA 5A N Nitrogen 14.007	16 VIA 6A O Oxygen 15.999	17 VIIA 7A F Fluorine 18.998	18 VIIIA 8A He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 Al Aluminum 26.982	6 Si Silicon 28.086	7 P Phosphorus 30.974	8 S Sulfur 32.066	9 Cl Chlorine 35.453	10 Ar Argon 39.948
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIIB 3B Sc Scandium 44.956	4 IVB 4B Ti Titanium 47.88	5 VB 5B V Vanadium 50.942	6 VIB 6B Cr Chromium 51.996	7 VIIB 7B Mn Manganese 54.938	8 VIII 8 Fe Iron 55.933	9 VIII 8 Co Cobalt 58.933	10 VIII 8 Ni Nickel 58.693	11 IB 1B Cu Copper 63.546	12 IIB 2B Zn Zinc 65.39	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown
Lanthanide Series			57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide Series			89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]
Alkali Metal	Alkaline Earth	Transition Metal	Basic Metal	Semimetal	Nonmetal	Halogen	Noble Gas	Lanthanide	Actinide								

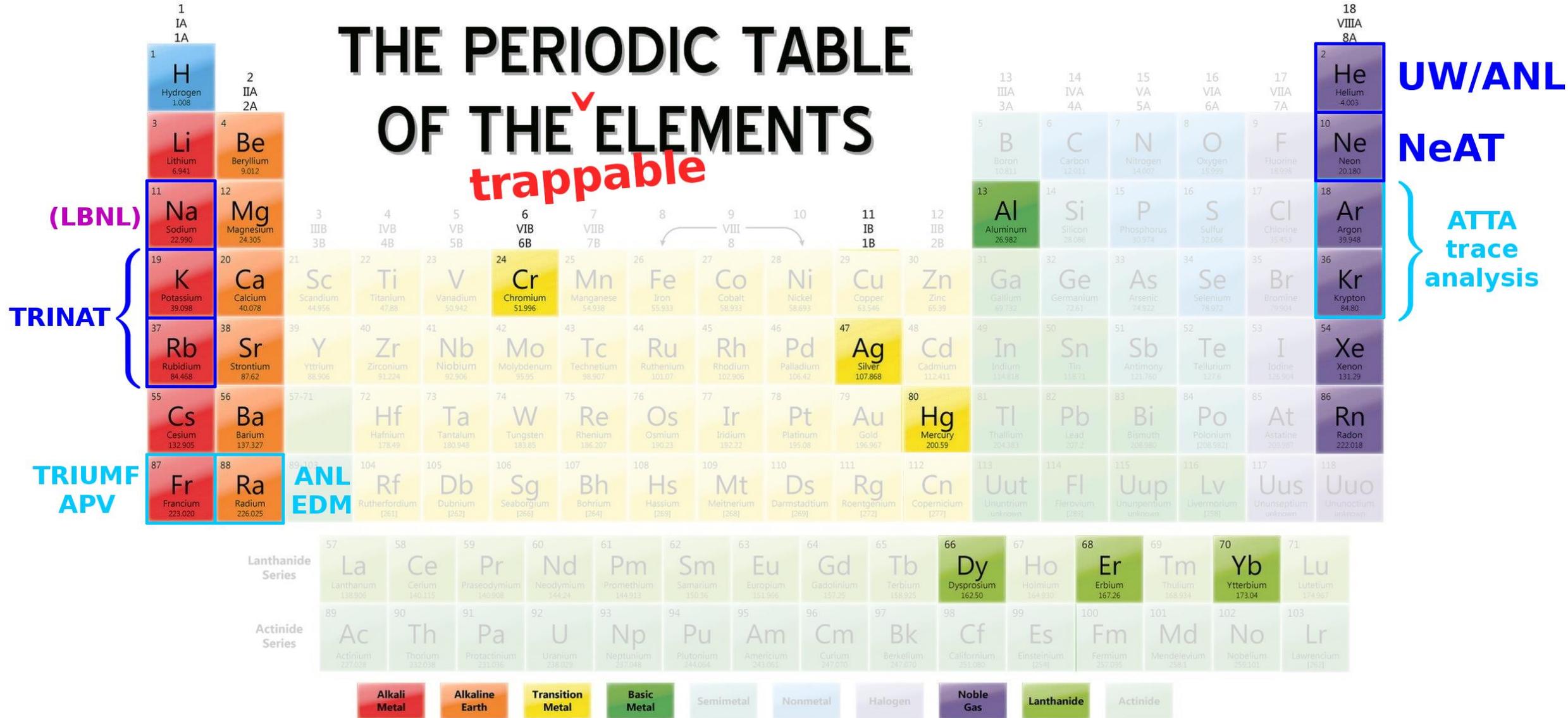
Difficulty with MOTs: not all atoms can be trapped



Difficulty with MOTs: not all atoms can be trapped

THE PERIODIC TABLE OF THE ELEMENTS

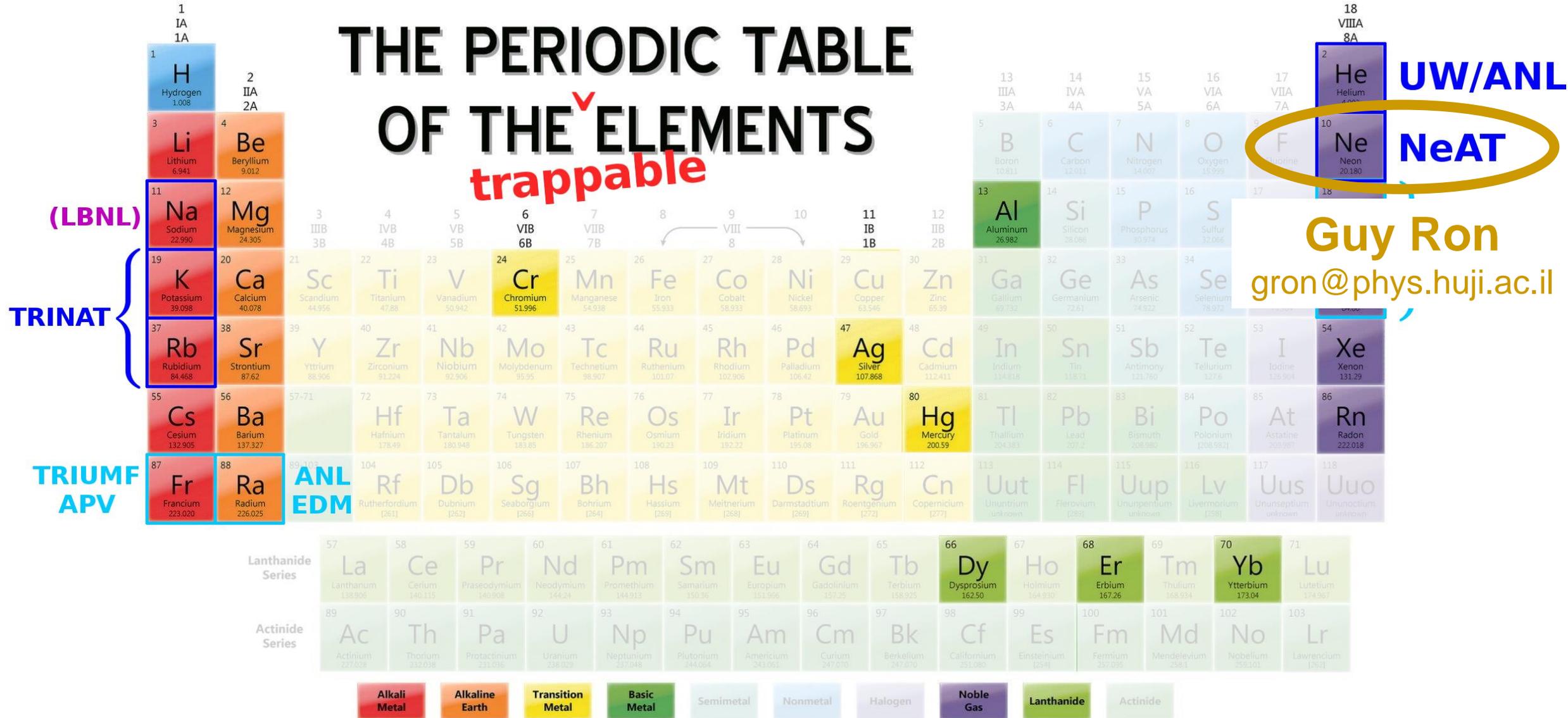
trappable



Difficulty with MOTs: not all atoms can be trapped

THE PERIODIC TABLE OF THE ELEMENTS

trappable



Neon isotopes to be studied, and why

^{18}Ne

- ✳ Pure GT to ground state (**tensor** interaction)
- ✳ Pure F to 1st excited state (V_{ud})
- ✳ **PNC** via mixing of 0^- with 0^+

^{19}Ne

- ✳ Mirror transition to ground state (V_{ud} , and if polarized esp. sensitive to **RHC**)

^{23}Ne

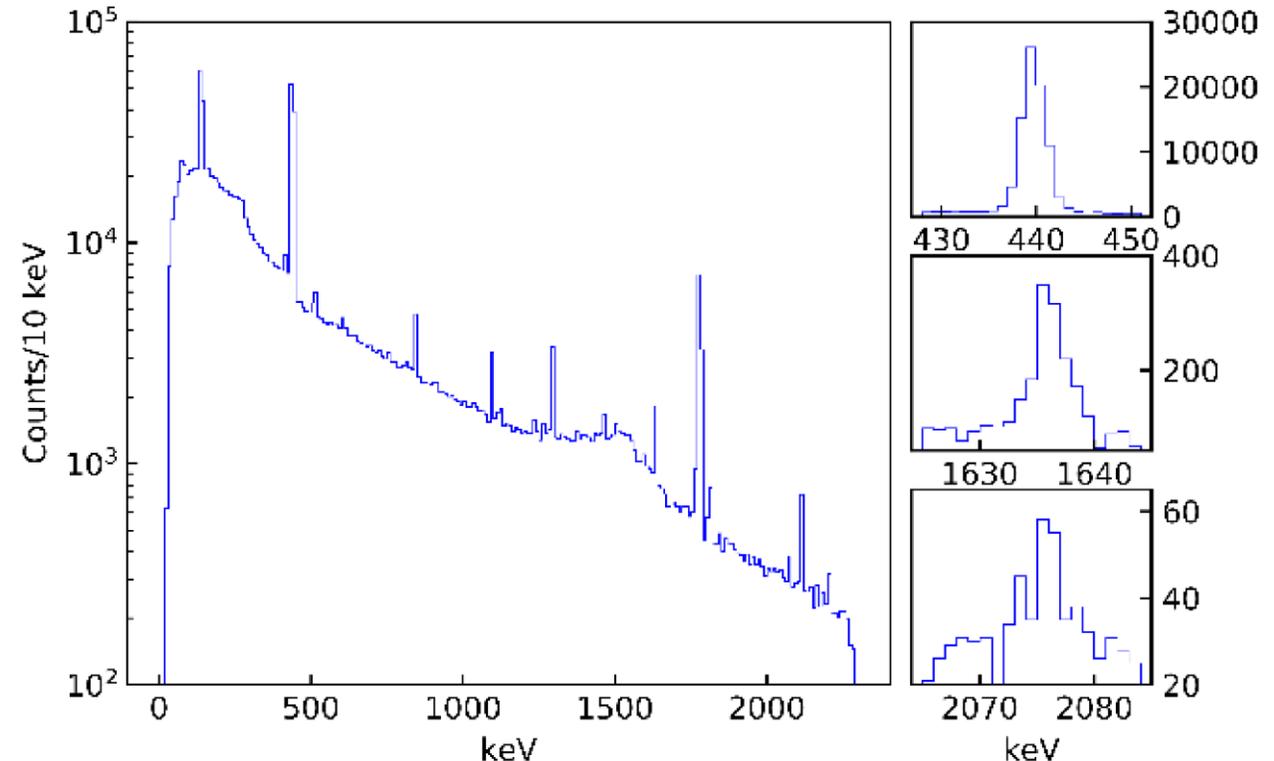
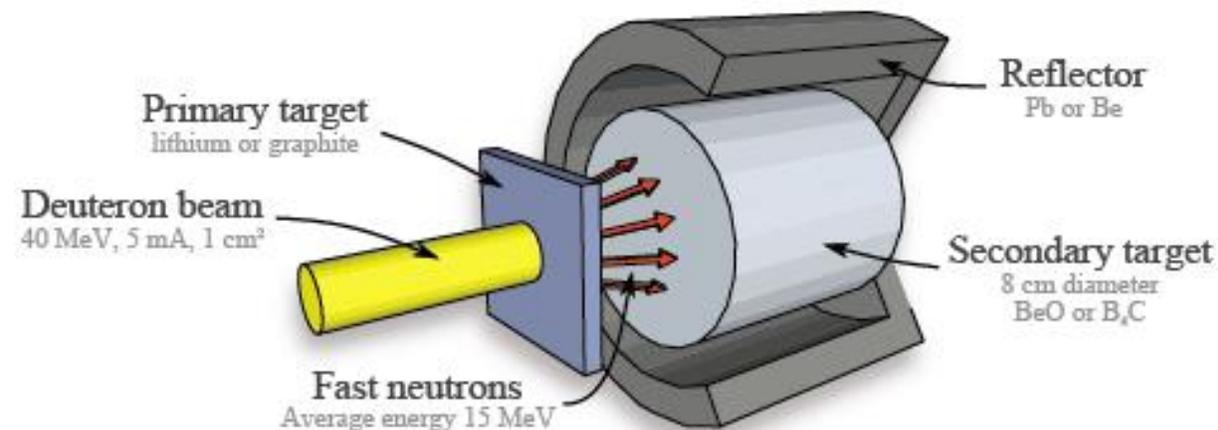
- ✳ Easiest to produce (reaction threshold only 3.8 MeV)
- ✳ Pure GT to ground state; almost pure GT to 1st excited (**tensor** interaction)

^{17}Ne

- ✳ Large Q -value \Rightarrow **Fierz?**
- ✳ Interesting **spectroscopy** (Borromean halo \rightarrow halo ^{17}F)

Production of Ne isotopes @ SARAF

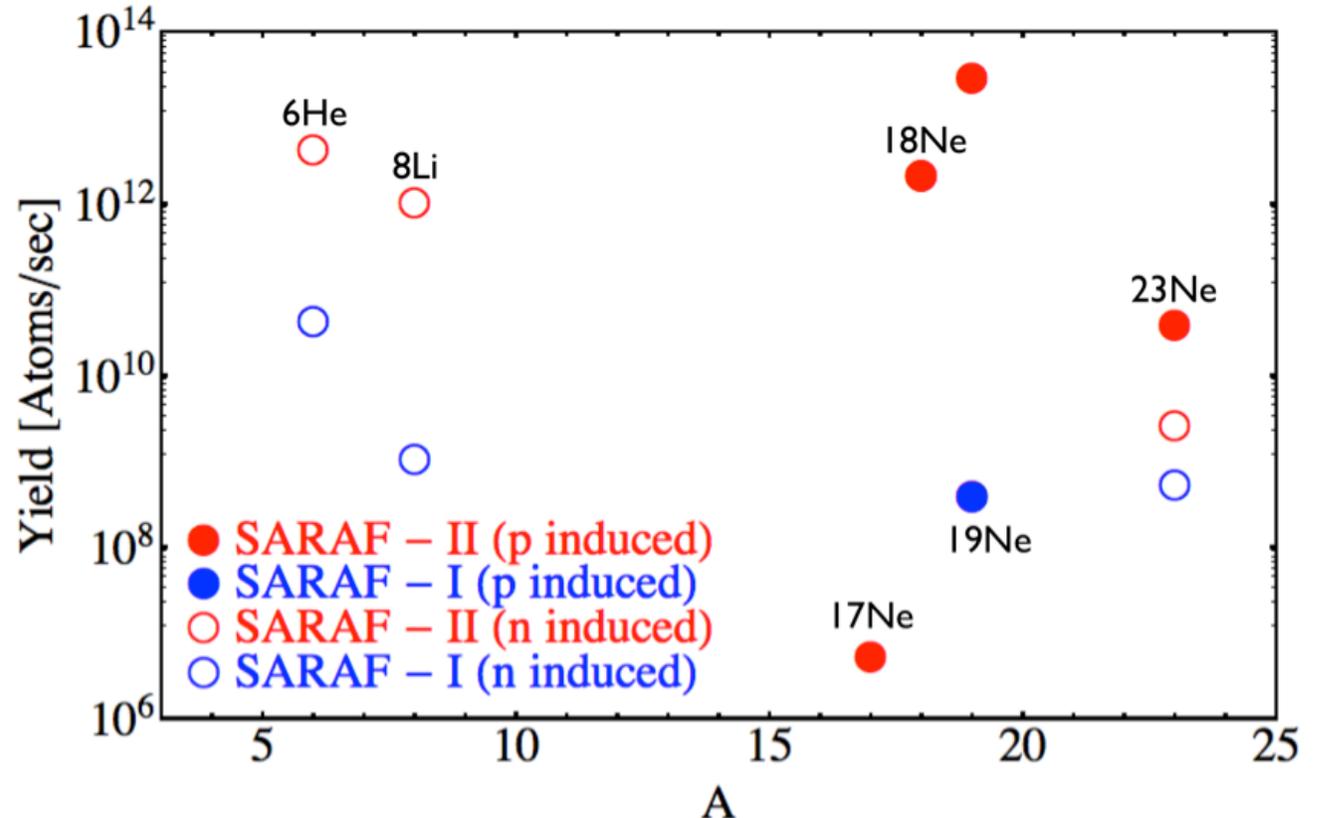
- Initial test @ WI successful \Rightarrow able to produce and move ^{23}Ne
- SARAF: New, (very) high current p/d accelerator (5 mA/up to 40 MeV) under construction at SOREQ
- Currently running d beams on LiF target for neutron beam production with SARAF-I



Production of Ne isotopes @ SARAF

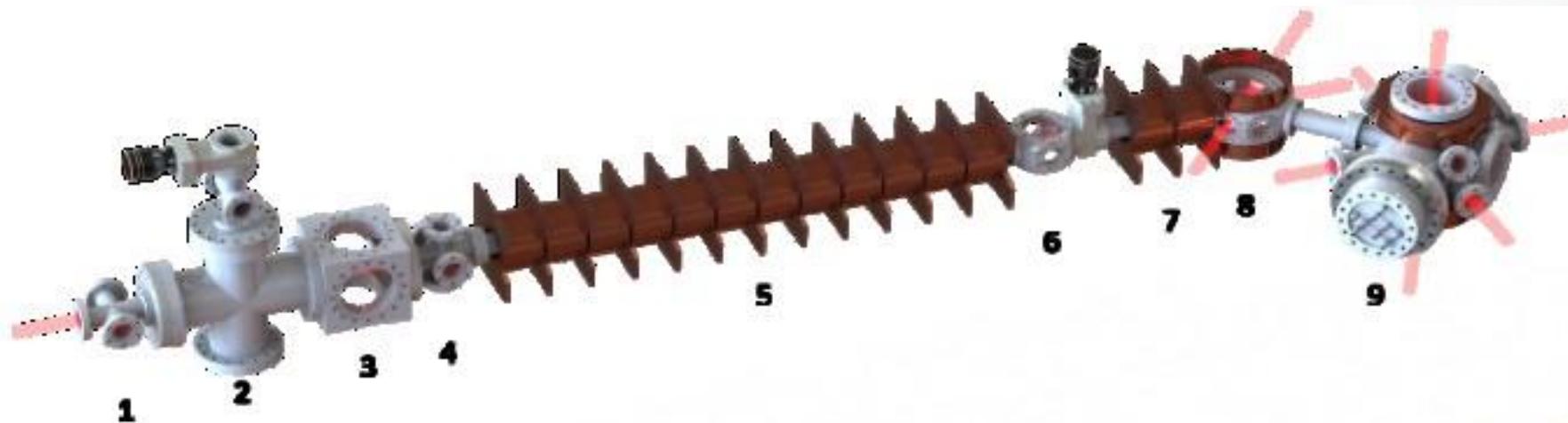
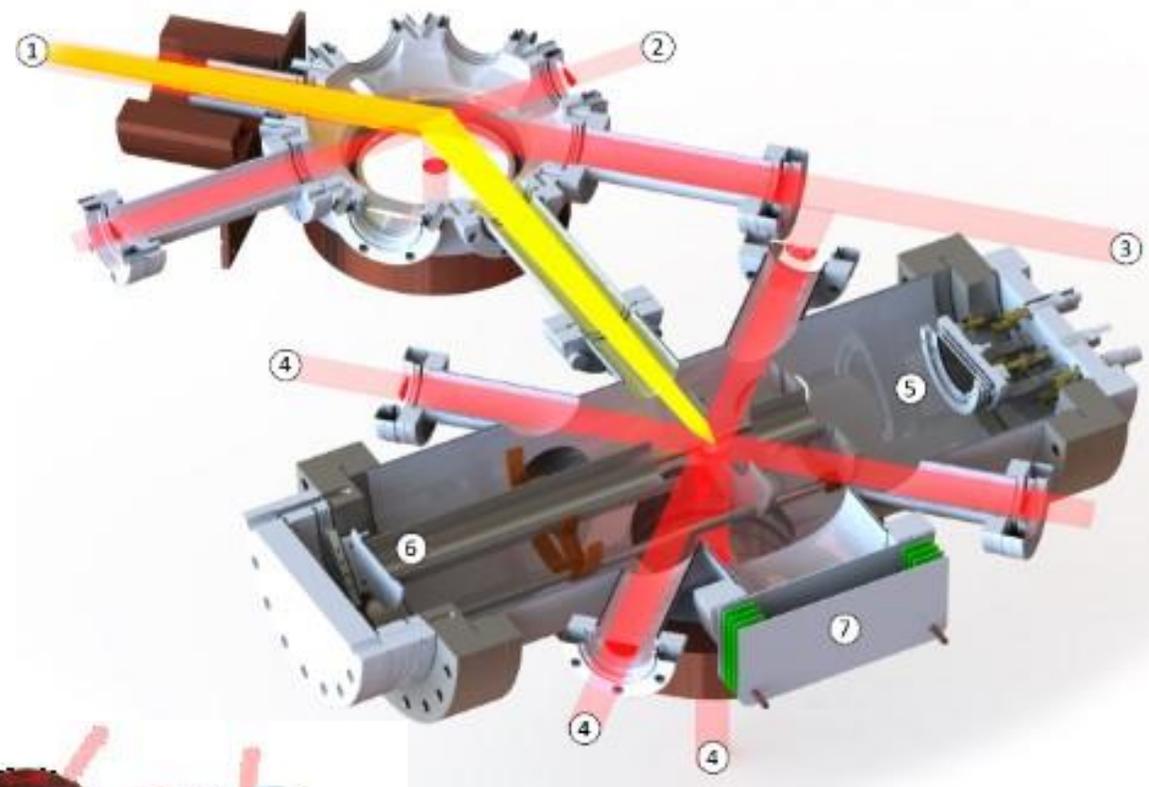
- Initial test @ WI successful \Rightarrow able to produce and move ^{23}Ne
- SARAF: New, (very) high current p/d accelerator (5 mA/up to 40 MeV) under construction at SOREQ
- Currently running d beams on LiF target for neutron beam production with SARAF-I
- Neutron production also possible with liquid-Li (under construction)

High yields expected!



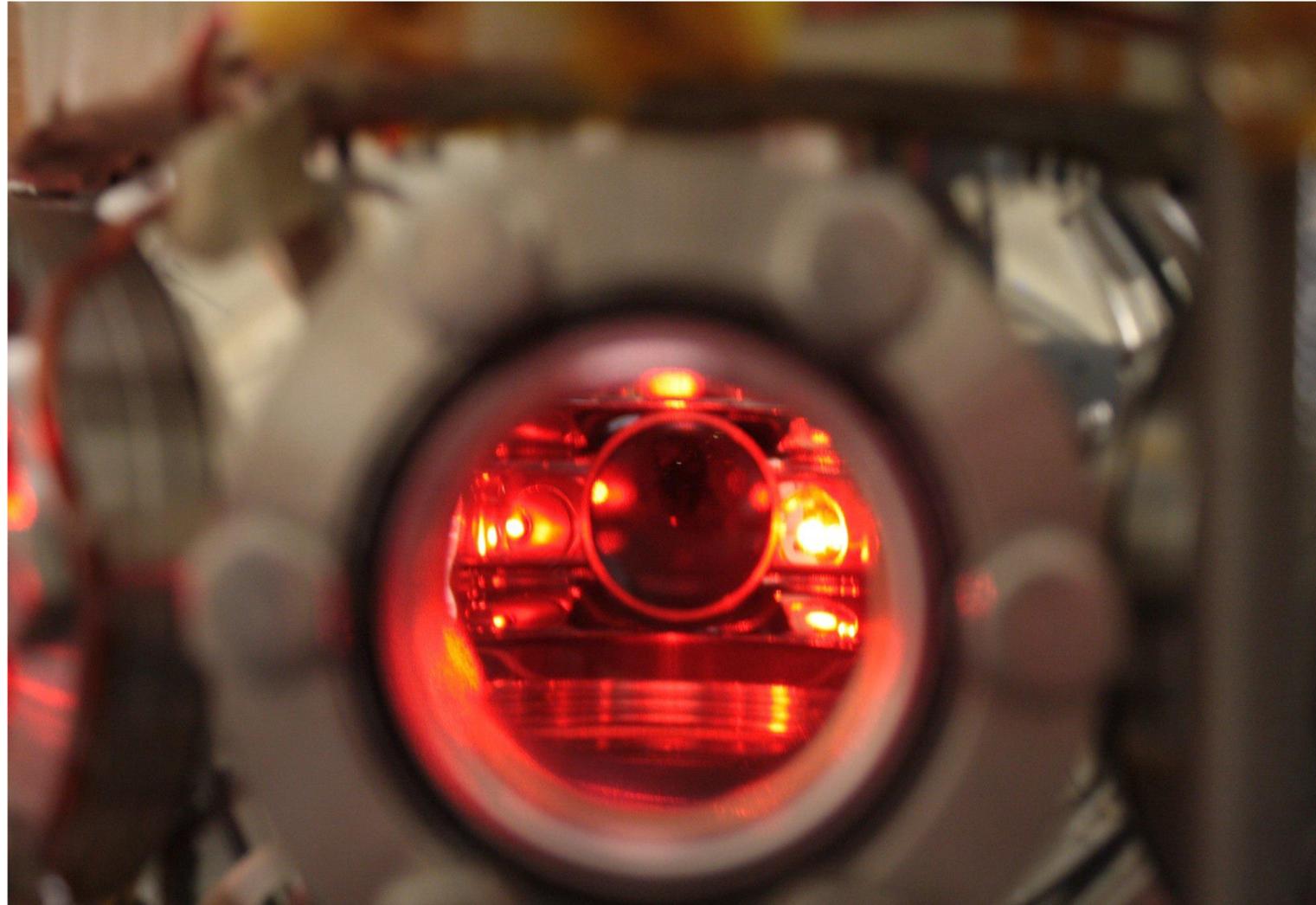
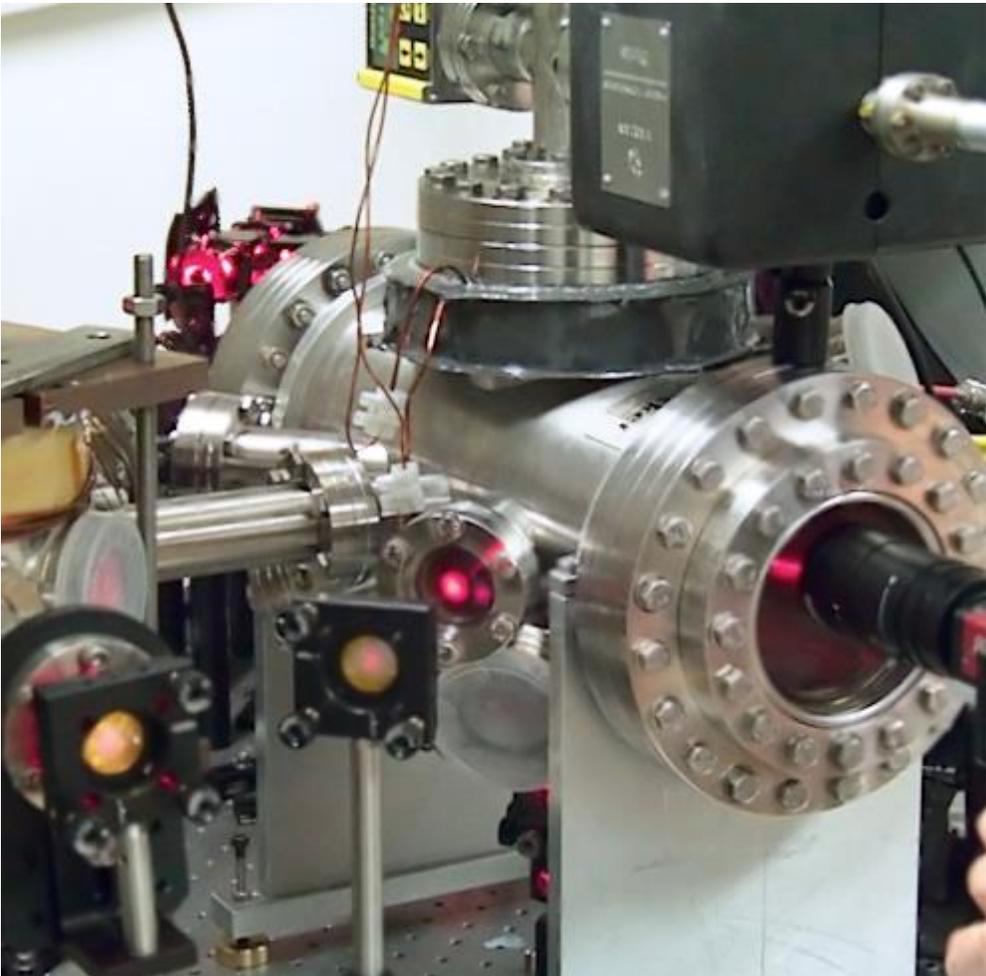
Trapping Ne isotopes with NeAT

- Produce and transport to NeAT
- Excite to metastable state ($\epsilon \sim 10^{-5}$)
- Zeeman slower and deflector to reduce backgrounds
- Trap in science chamber, observe β and recoil



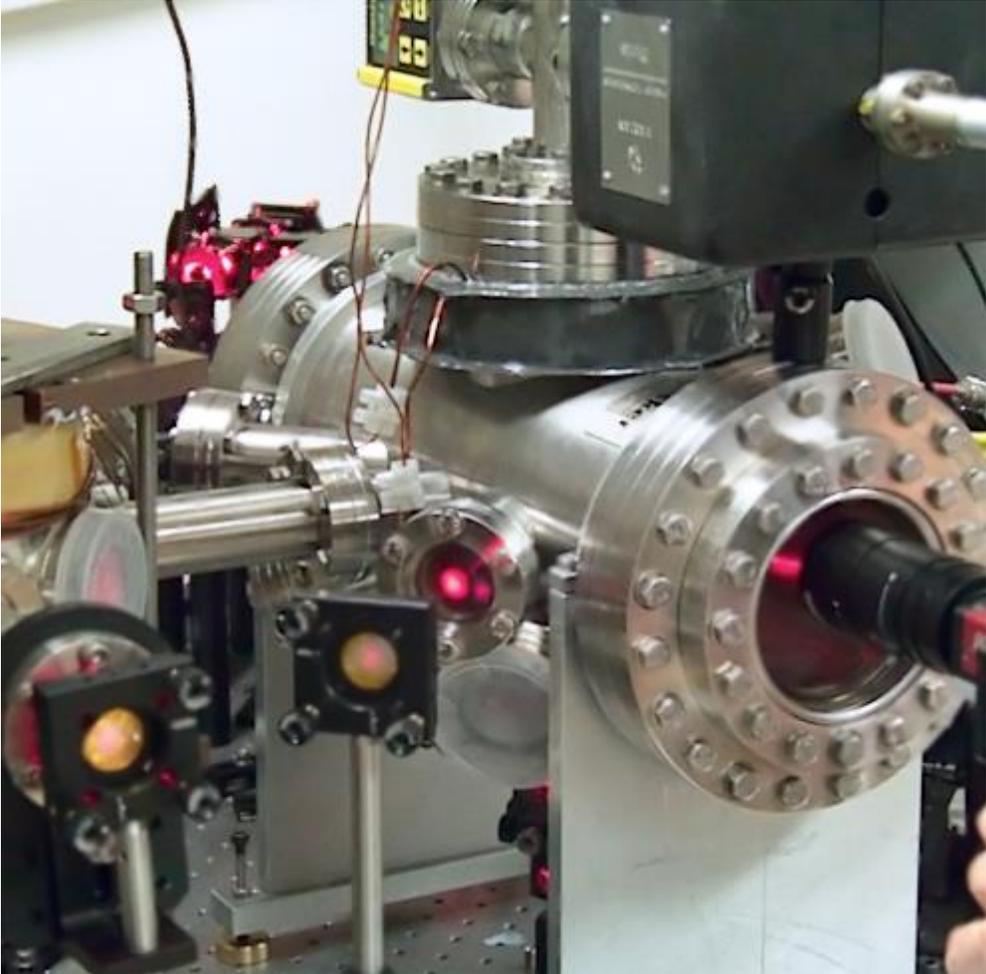
Status of NeAT

- Demonstrated ability to trap $\sim 10,000$ Ne atoms



Status of NeAT

- Demonstrated ability to trap $\sim 10,000$ Ne atoms
- Recently moved to SARAF



Most sensitive probe is the Fierz interference:

Decay rate is:
$$dw = dw_0 \left[1 + a_{\beta\nu} \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b \frac{\Gamma m_e}{E_e} \right]$$

${}^6\text{He}$ is a **great** case!

Large endpoint (3.5 MeV)

Nuclear structure under control

Simple decay

Sensitive to tensor interactions

$$a_{\beta\nu} \approx -\frac{1}{3} \left(1 - \frac{C_T^2 + C_T'^2}{2C_A^2} \right)$$

$\beta - \nu$ correlation

$$b \approx \pm \frac{(C_T + C_T')}{C_A}$$

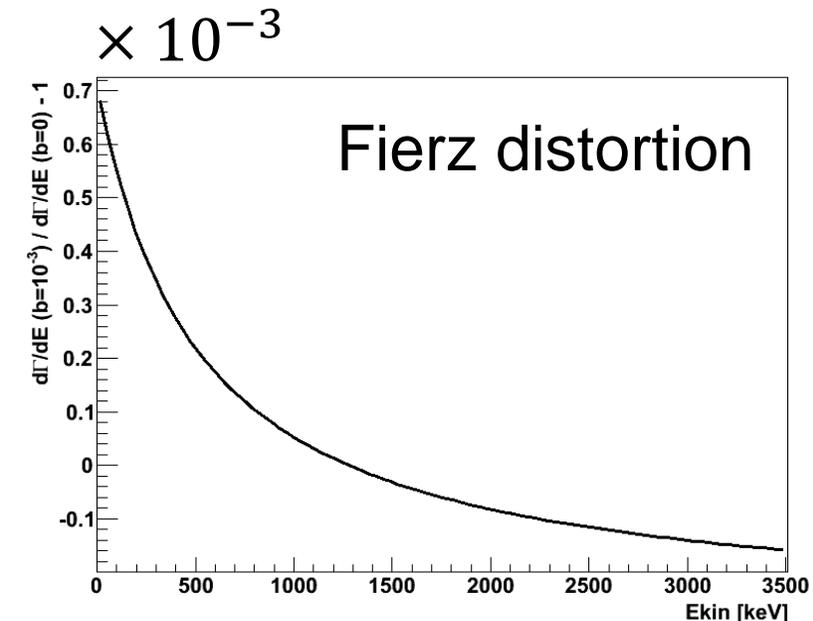
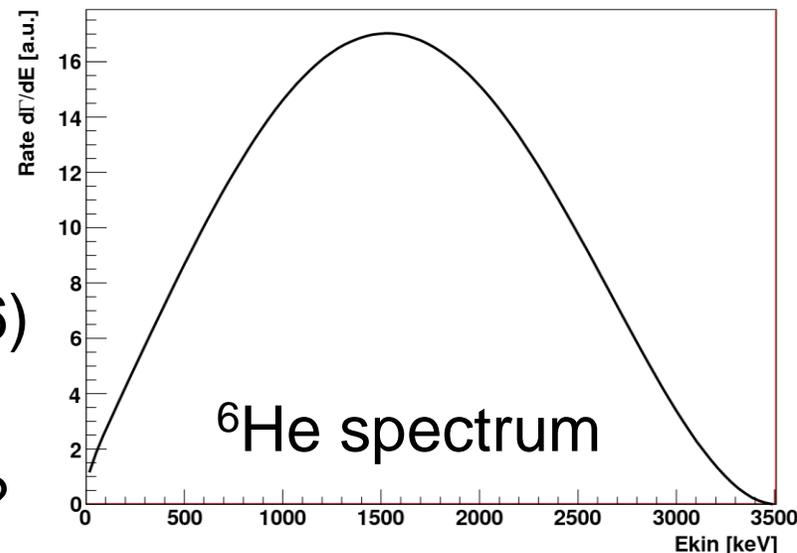
Fierz interference

Status:

Lifetime (PRC **86**, 035506)

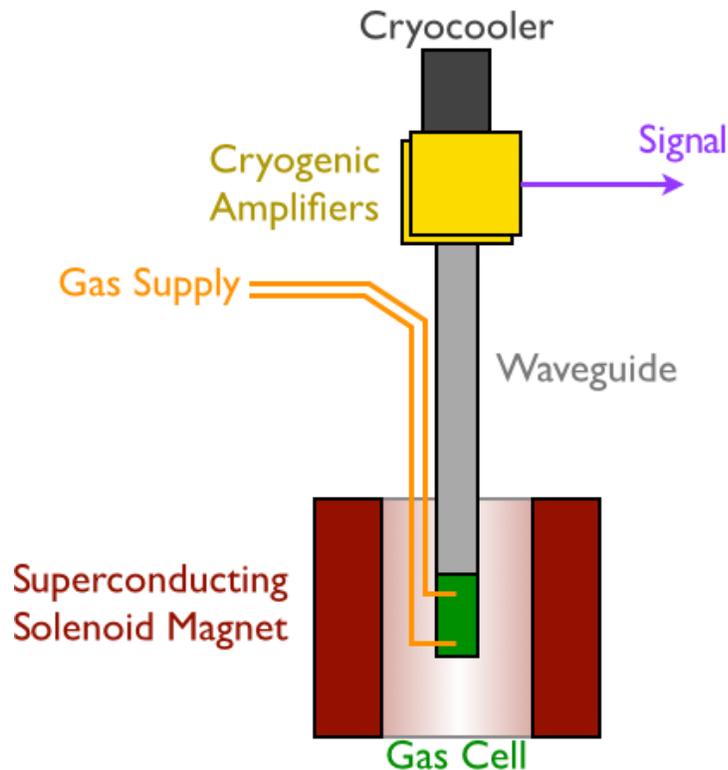
Charge state fractions

$a_{\beta\nu}$: stats for 0.2%; systs?



New idea: use the Cyclotron Radiation Emission Spectroscopy (CRES) technique

Project 8 collaboration gets $\frac{FWHM}{E} \approx 10^{-3}$ resolution for conversion electrons of 18 – 32 keV

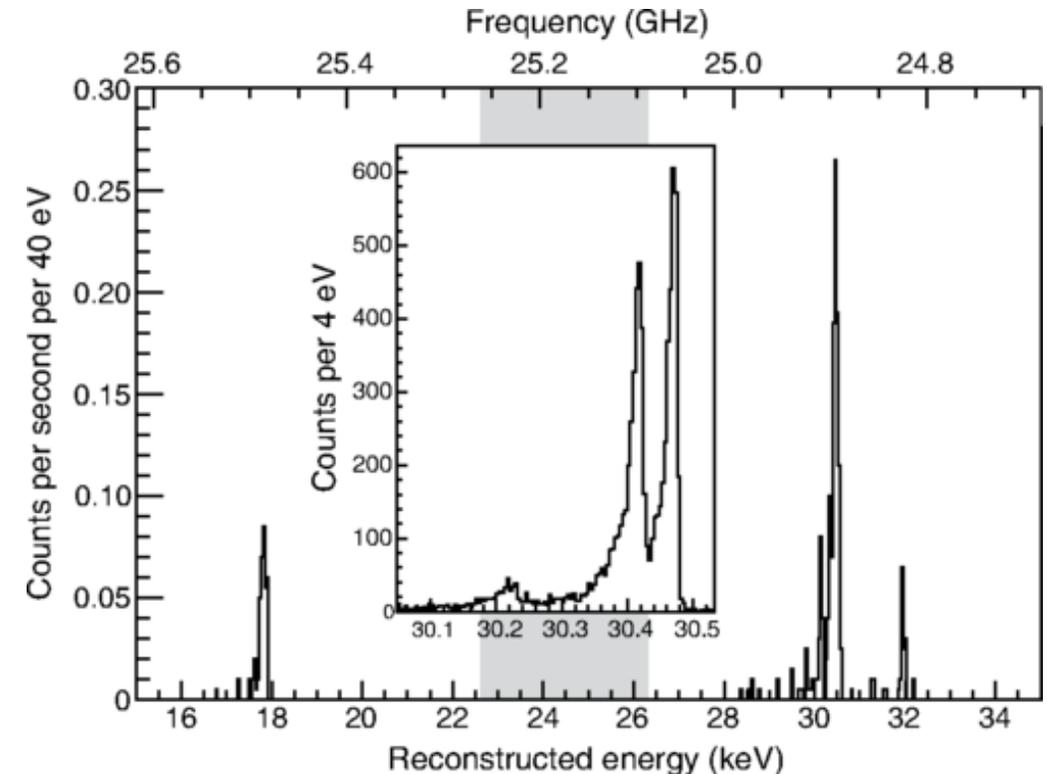


PRL 114, 162501 (2015) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 24 APRIL 2015

Single-Electron Detection and Spectroscopy via Relativistic Cyclotron Radiation

D. M. Asner,¹ R. F. Bradley,² L. de Viveiros,³ P. J. Doe,⁴ J. L. Fernandes,¹ M. Fertl,⁴ E. C. Finn,¹ J. A. Formaggio,⁵ D. Furse,⁵ A. M. Jones,¹ J. N. Kofron,⁴ B. H. LaRoque,³ M. Leber,³ E. L. McBride,⁴ M. L. Miller,⁴ P. Mohanmurthy,⁵ B. Monreal,³ N. S. Oblath,⁵ R. G. H. Robertson,⁴ L. J. Rosenberg,⁴ G. Rybka,⁴ D. Rysewyk,⁵ M. G. Stemberg,⁴ J. R. Tedeschi,¹ T. Thümmel,⁶ B. A. VanDevender,¹ and N. L. Woods⁴

(Project 8 Collaboration)



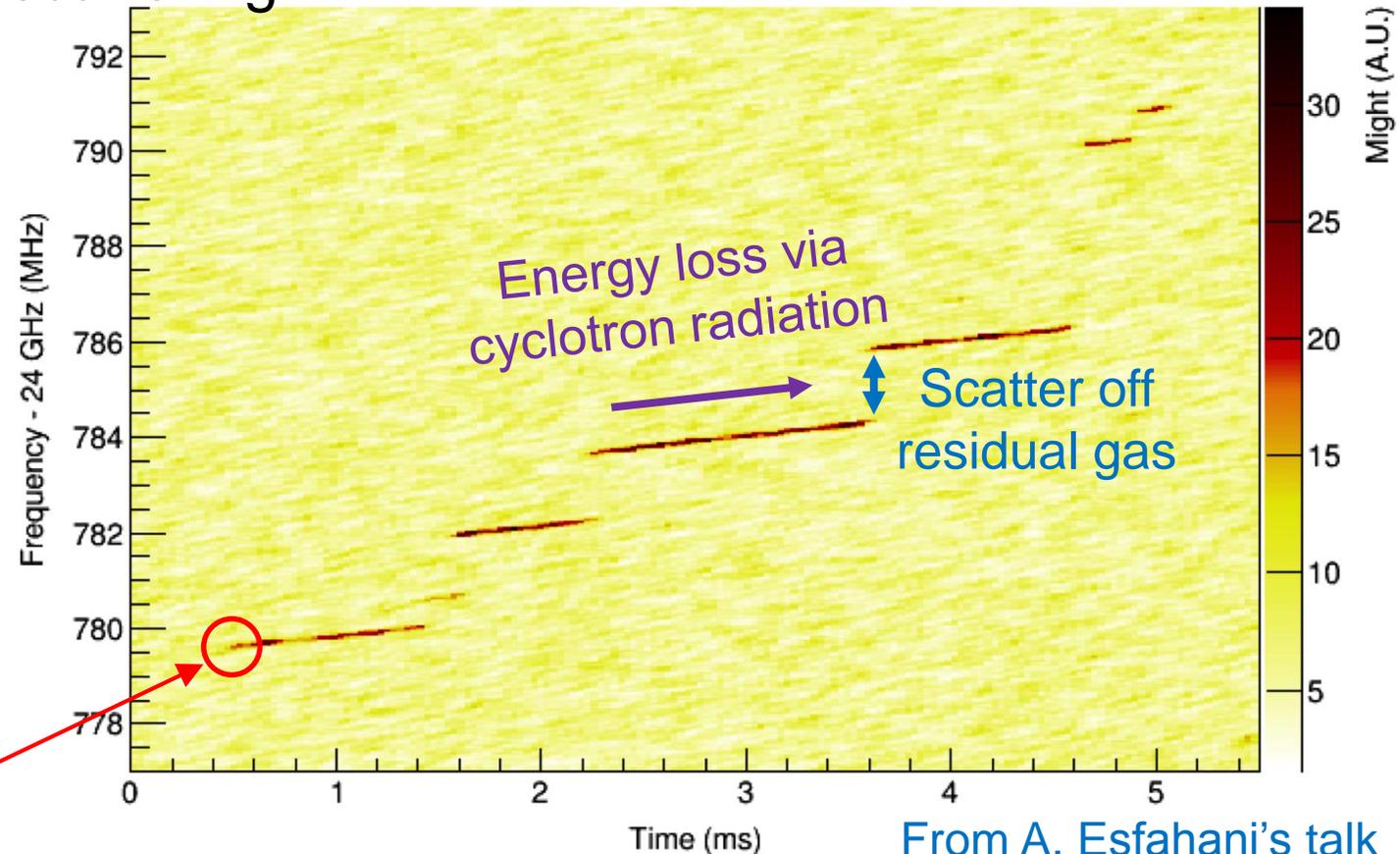
${}^6\text{He}$ at UW – CRES technique

Why CRES for ${}^6\text{He}$?

- Measures β energy at creation, before complicated energy-loss mechanisms
- High resolution allows debugging of systematic uncertainties
- No background from photon or e scattering
- ${}^6\text{He}$ in gaseous form works well with the technique
- ${}^6\text{He}$ ion trap allows sensitivity higher than any other proposed
- Counts needed not a big demand on running time

$$2\pi f = \frac{qB}{m + E_{\text{kin}}}$$

Initial frequency $\rightarrow E$



Emerging ${}^6\text{He}$ little- b collaboration

W. Byron¹, M. Fertil¹, A. Garcia¹, B. Graner¹, G. Garvey¹, M. Guigue⁴, K.S. Khaw¹, A. Leredde², D. Melconian³, P. Mueller², N. Oblath⁴, R.G.H. Robertson¹, G. Rybka¹, G. Savard², D. Stancil⁵, H.E. Swanson¹, B.A. Vandevender⁴, F. Wietfeldt⁶, A. Young⁵

¹University of Washington, ²Argonne National Lab, ³Texas A&M, ⁴North Carolina State University, ⁵Pacific Northwest National Laboratory, ⁶Tulane University

Phase I: proof of principle (next 3 yrs)

-  2 GHz bandwidth
-  Show detection of cyclotron radiation from ${}^6\text{He}$
-  Study power distribution

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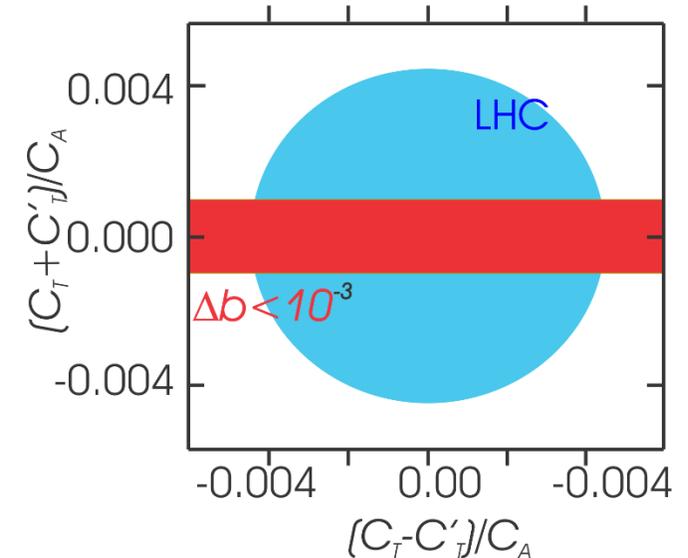
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- ✳ Show detection of cyclotron radiation from ${}^6\text{He}$
- ✳ Study power distribution

Phase II: first measurement ($b < 10^{-3}$)

- ✳ 6 GHz bandwidth
- ✳ ${}^6\text{He}$ and ${}^{19}\text{Ne}$ measurements

Effect	Δb	
	No trap	Ion trap
Magnetic field uncertainties	10^{-4}	$< 10^{-4}$
Wall effect uncertainties	10^{-3}	
RF pickup uncertainties	10^{-4}	10^{-5}
Misidentification of events	10^{-4}	5×10^{-5}



Emerging ${}^6\text{He}$ little- b collaboration

W. Byron¹, M. Ferti¹, A. Garcia¹, B. Graner¹, G. Garvey¹, M. Guigue⁴, K.S. Khaw¹, A. Leredde², D. Melconian³, P. Mueller², N. Oblath⁴, R.G.H. Robertson¹, G. Rybka¹, G. Savard², D. Stancil⁵, H.E. Swanson¹, B.A. Vandevender⁴, F. Wietfeldt⁶, A. Young⁵

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Phase I: proof of principle (next 3 yrs)

- 2 GHz bandwidth
- Show detection of cyclotron radiation from ${}^6\text{He}$
- Study power distribution

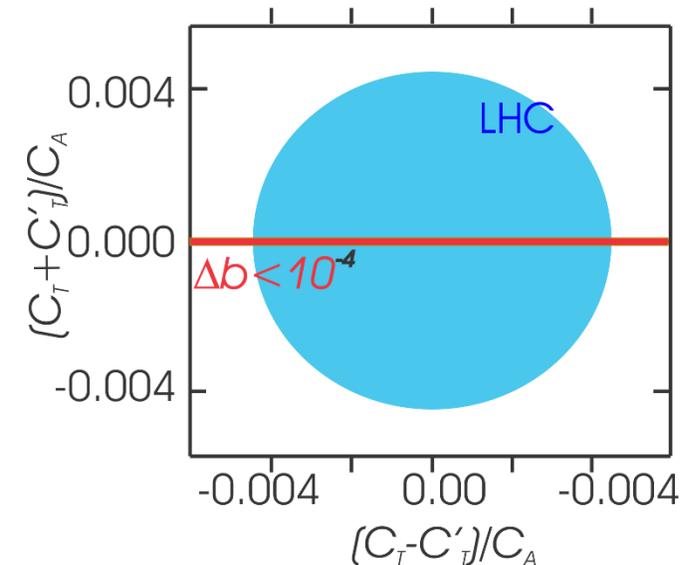
Phase II: first measurement ($b < 10^{-3}$)

- 6 GHz bandwidth
- ${}^6\text{He}$ and ${}^{19}\text{Ne}$ measurements

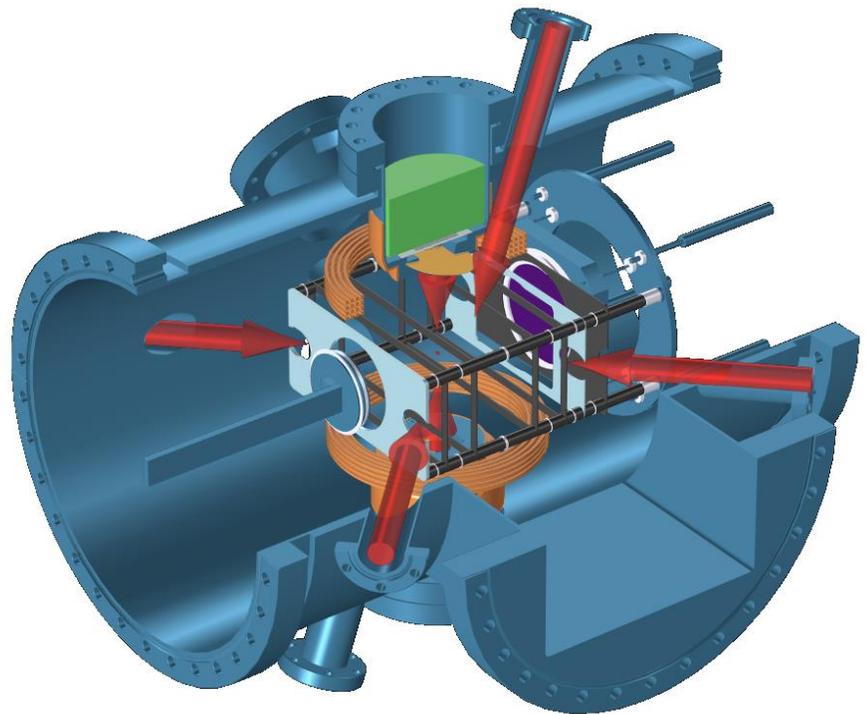
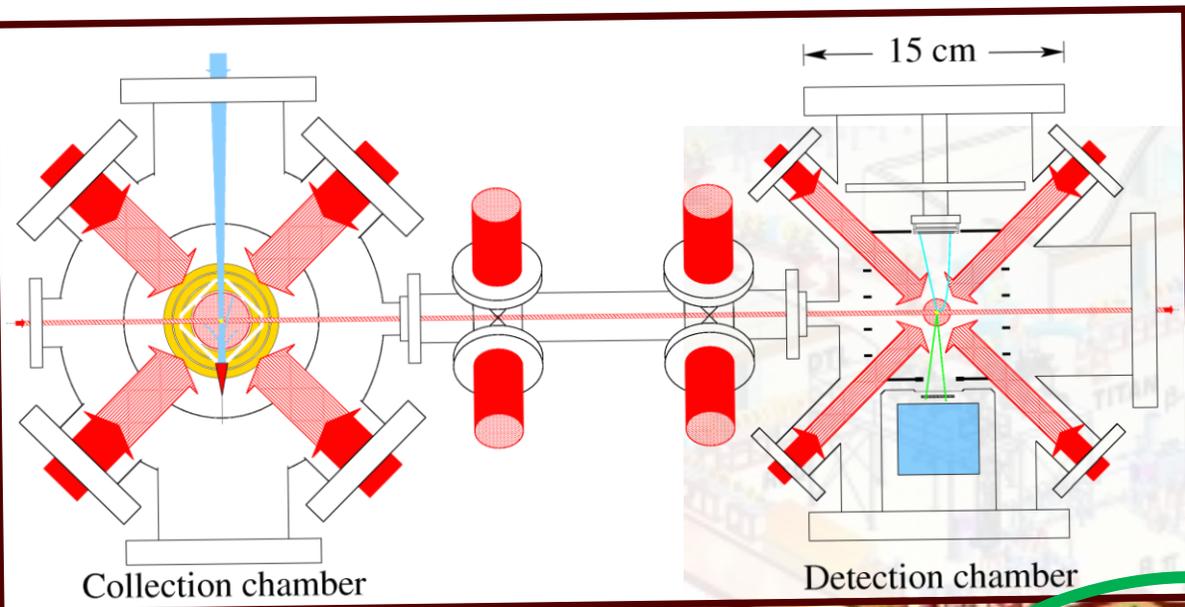
Phase III: ultimate measurement ($b < 10^{-4}$)

- Ion trap for no limitation from geometric effect

Effect	Δb	
	No trap	Ion trap
Magnetic field uncertainties	10^{-4}	$< 10^{-4}$
Wall effect uncertainties	10^{-3}	
RF pickup uncertainties	10^{-4}	10^{-5}
Misidentification of events	10^{-4}	5×10^{-5}



The TRIUMF Neutral Atom Trap



up to 8×10^7 $^{37}\text{K}/\text{s}$

• Angular correlations of K and Rb isotopes

• Recent result: A_β of ^{37}K

TiC target
1750 °C

70 μA
protons

p
Cyclotron

Isobaric analogue decay of ^{37}K

Beautiful nucleus to test the standard model:

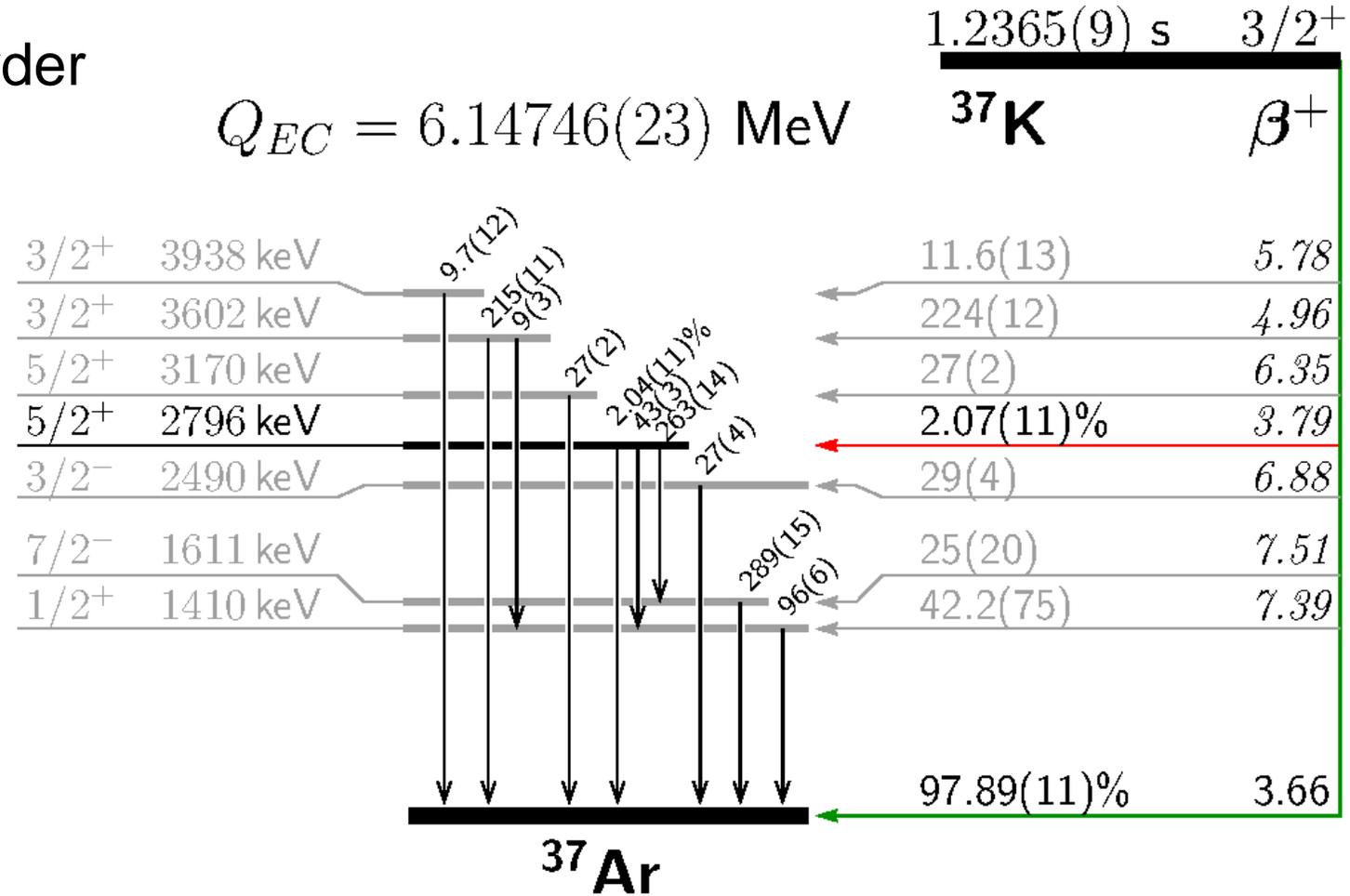
✱ Alkali atom \Rightarrow “easy” to trap with a MOT and polarize with optical pumping

✱ Isobaric analogue decay

\Rightarrow 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.



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

$$a_{\beta\nu} = 0.6648(18)$$

Fierz interference

$$b = 0 \quad (\text{sensitive to scalars \& tensors})$$

β asymmetry

$$A_\beta = -0.5706(7)$$

ν asymmetry

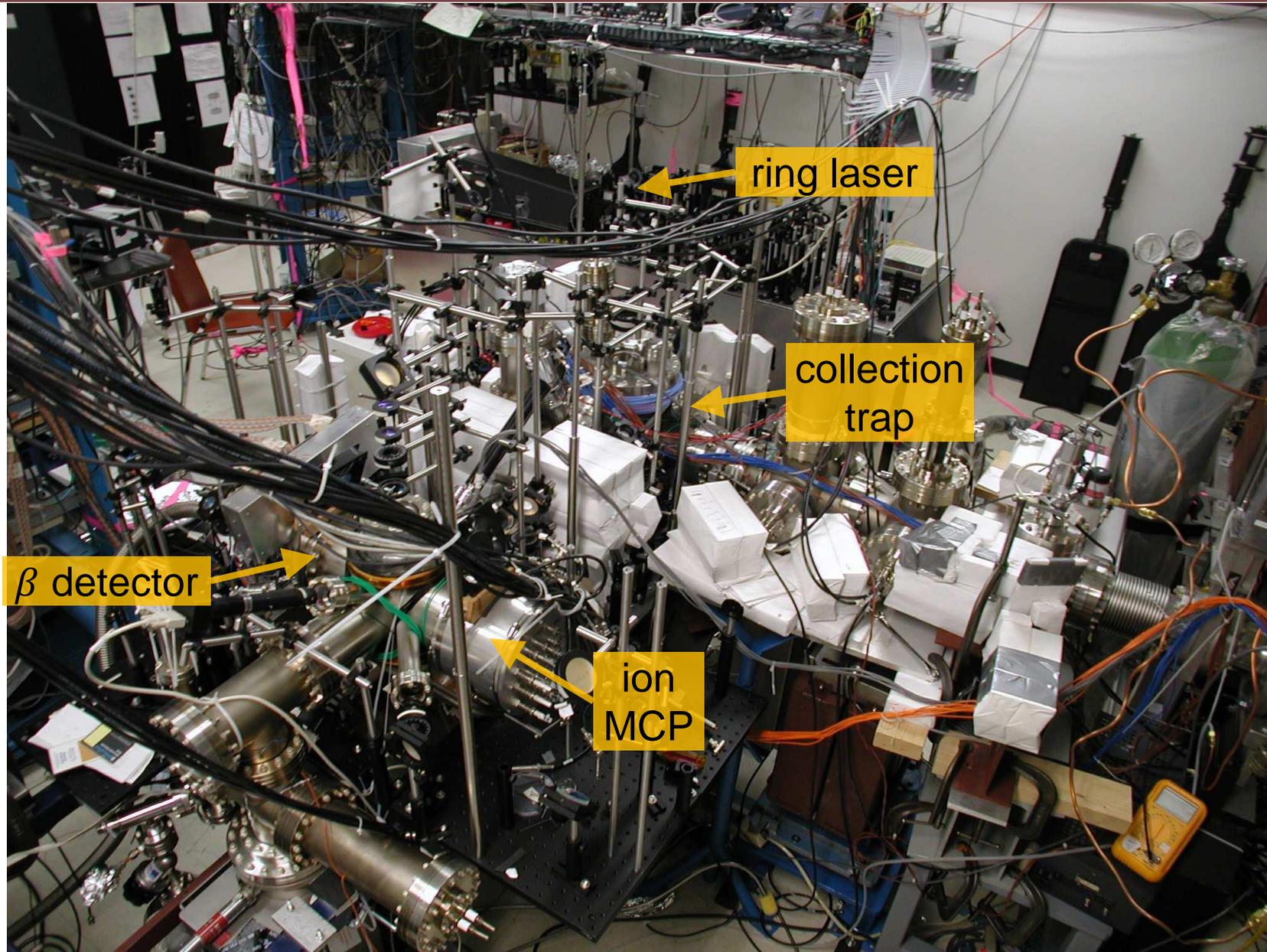
$$B_\nu = -0.7702(18)$$

Time-violating correlation

$$D = 0 \quad (\text{sensitive to imaginary couplings})$$

→ Data is in hand for improved branching ratio (currently limits predictions)

The TRINAT lab (an older picture)



ring laser

collection trap

β detector

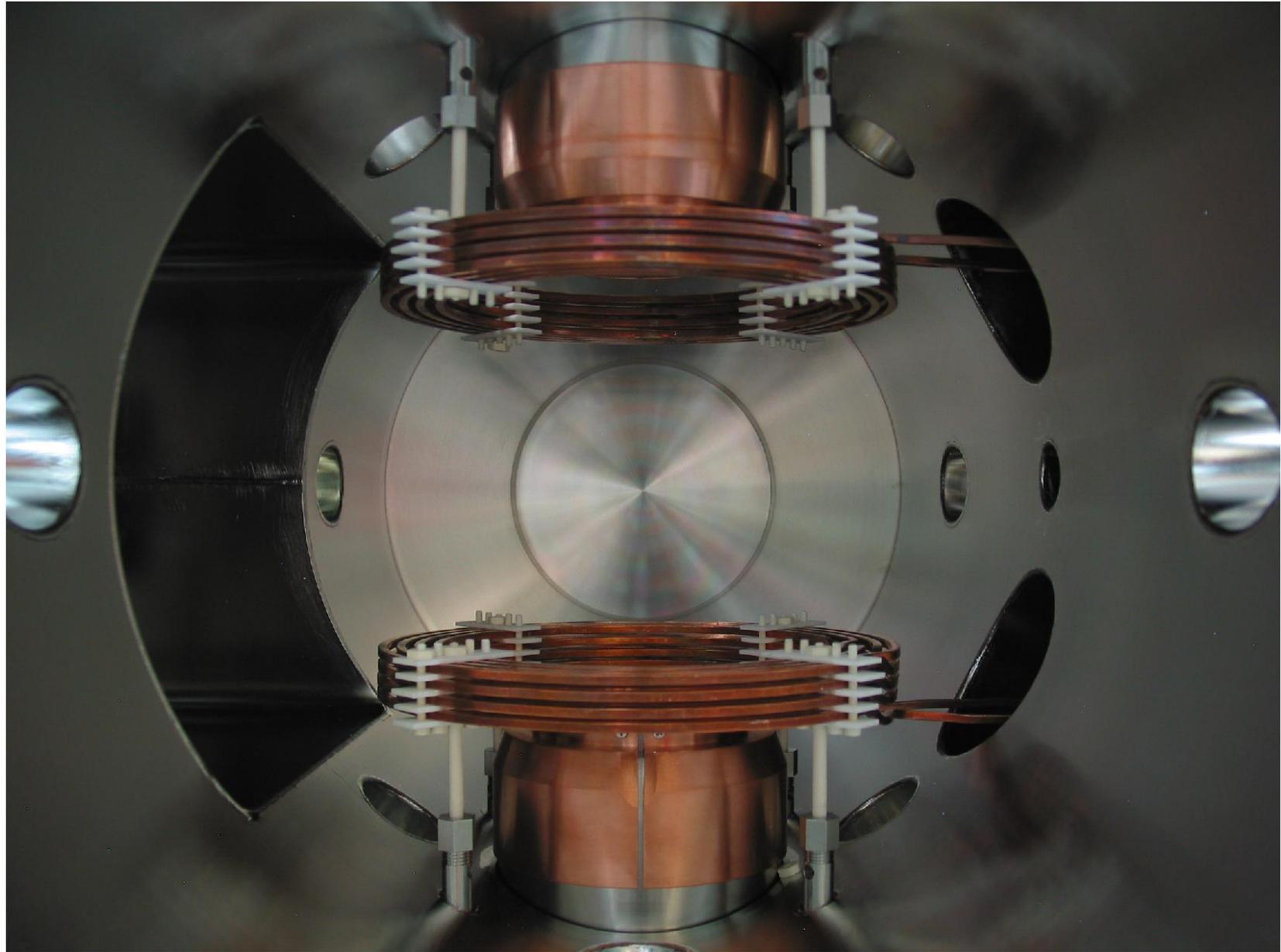
ion MCP

RIB from ISAC

Outline of β asym & polarization measurements

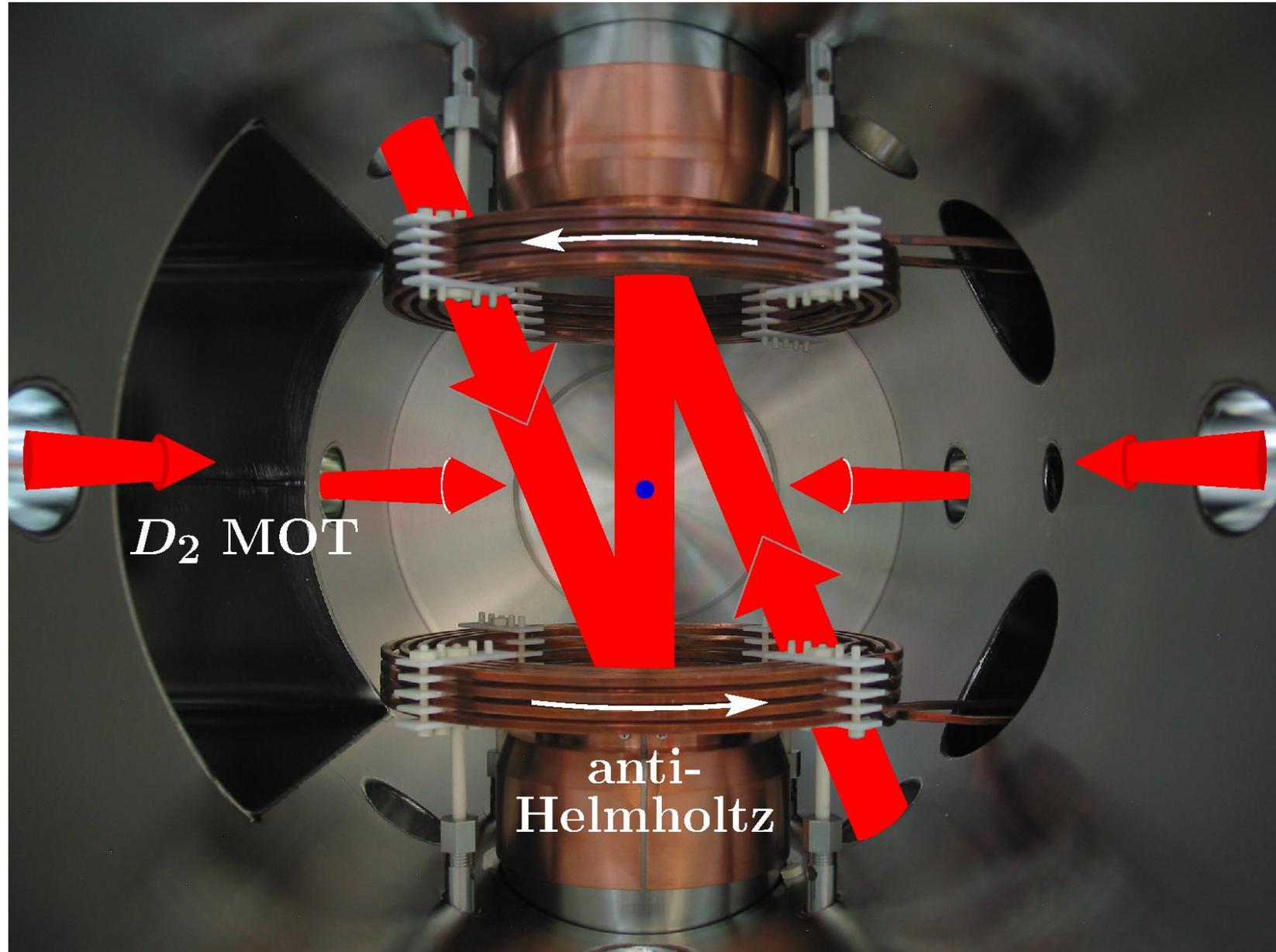
Not shown:

- ✱ Recoil MCP detector into page
- ✱ Shake-off e^- MCP out of page
- ✱ Hoops for electric field to collect recoil and shake-off e^-
- ✱ The β telescopes within the re-entrant flanges (top *and* bottom)



Outline of β asym & polarization measurements

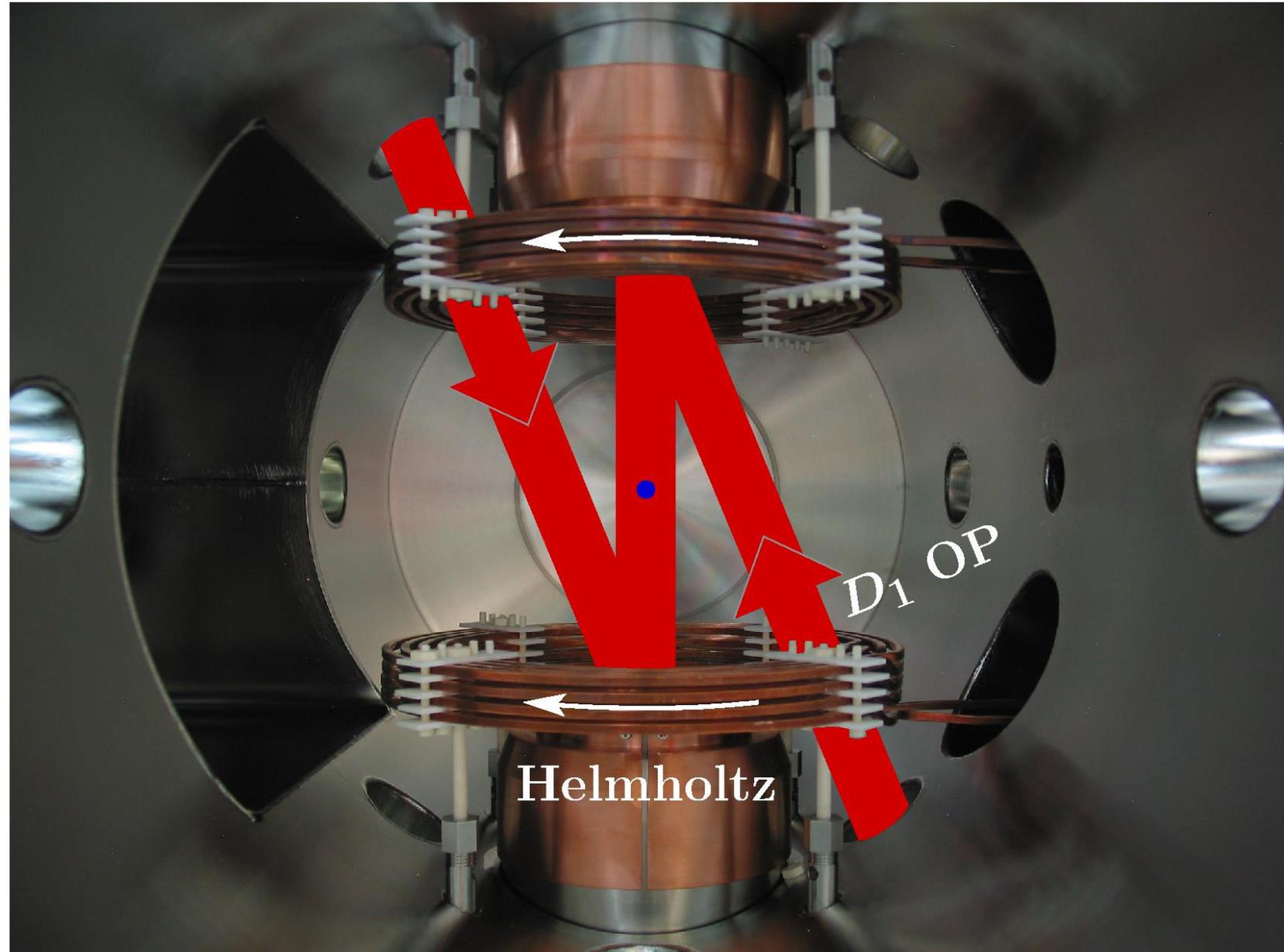
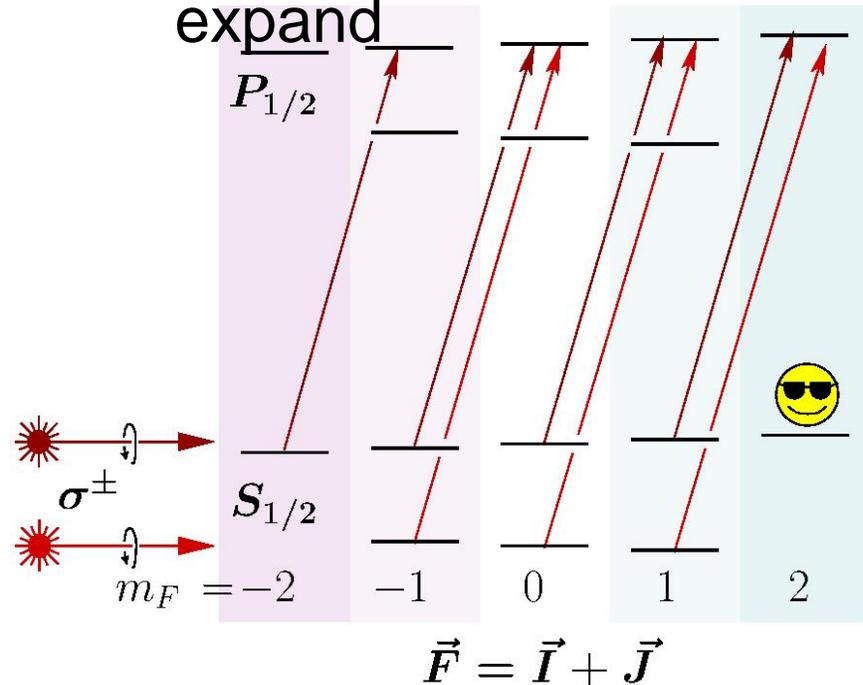
- MOTs provide a source that is:
 - Cold (~ 1 mK)
 - Localized (~ 1 mm³)
 - In an open, backing-free geometry
- Allows us to detect \vec{p}_β and \vec{p}_{rec}
 \Rightarrow deduce \vec{p}_ν
event-by-event



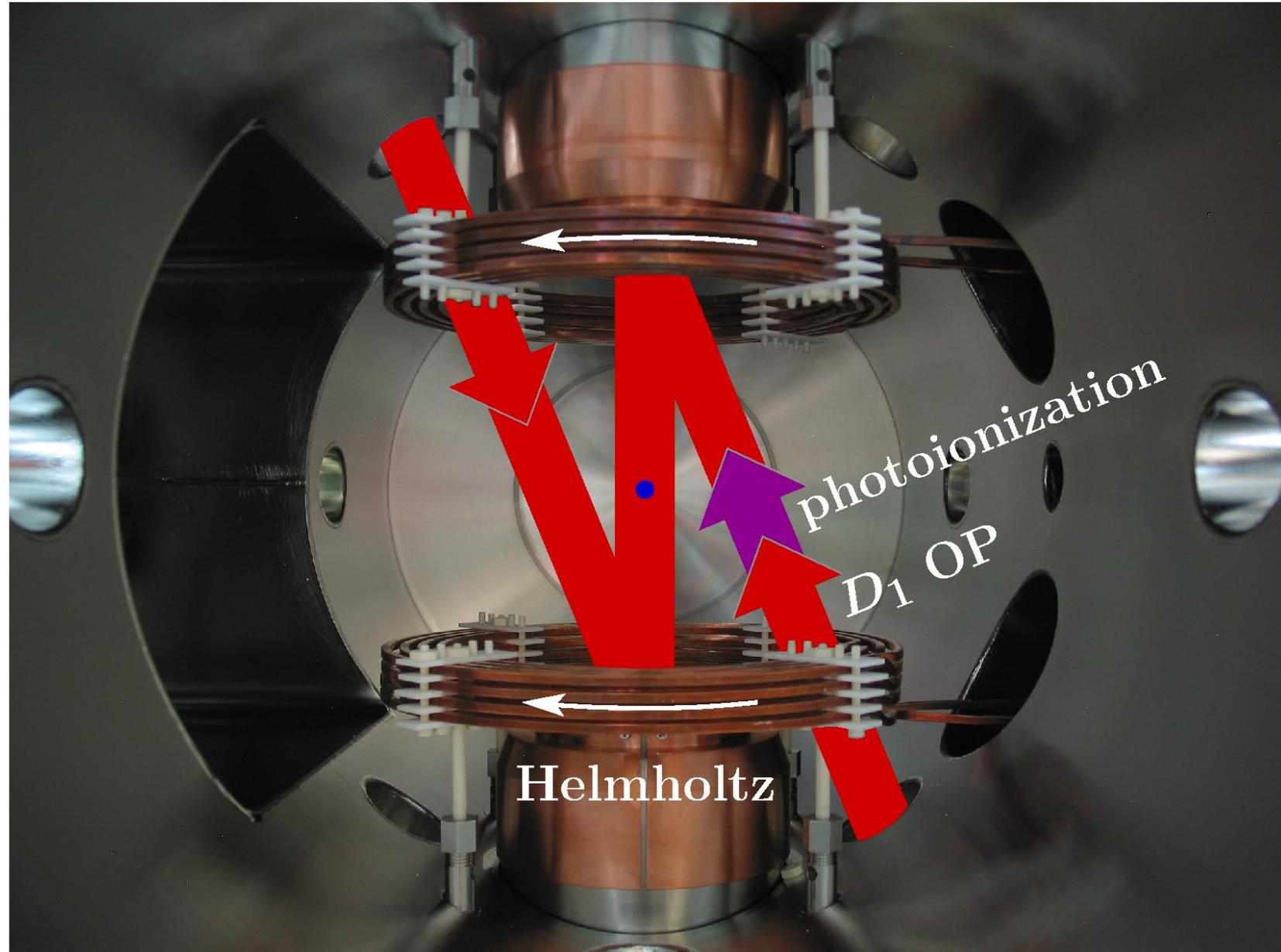
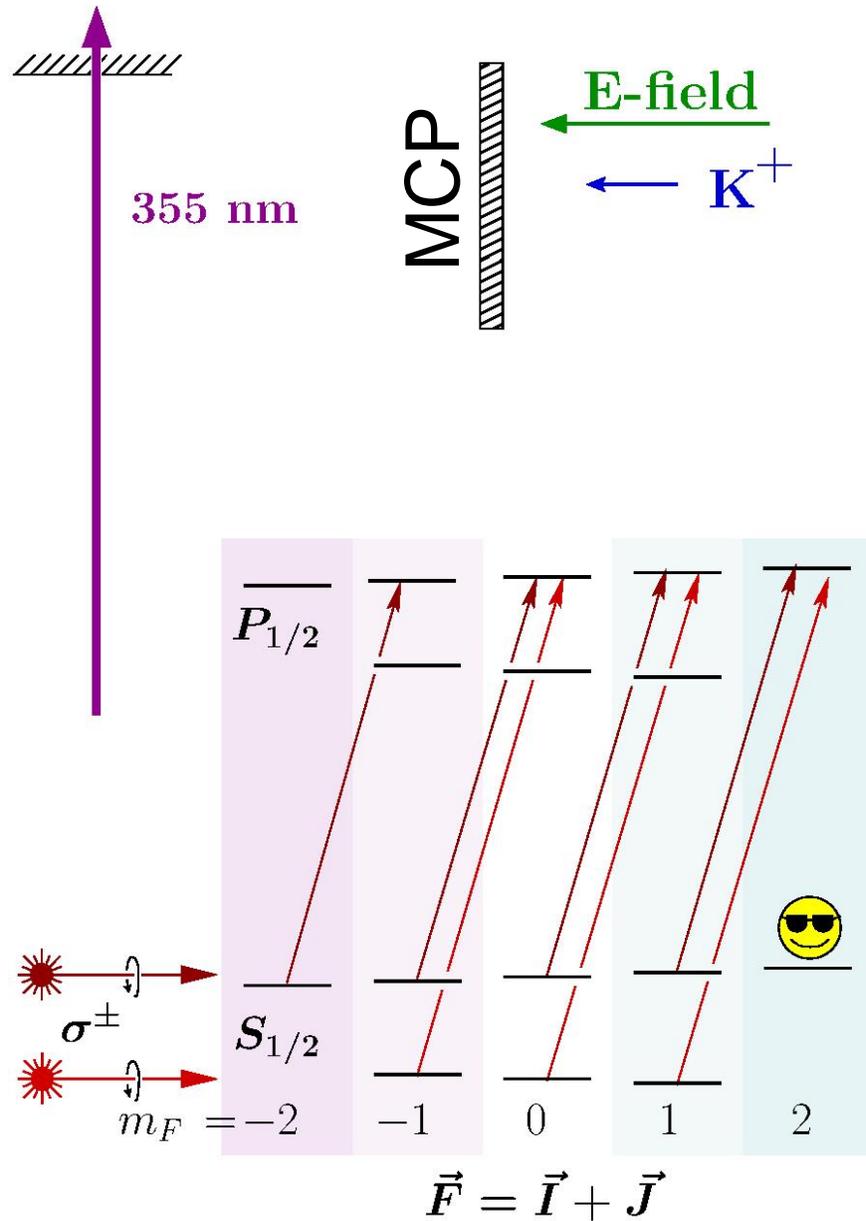
Outline of β asym & polarization measurements

Optical pumping:

- ✱ Polarized light transfers ang momentum to atom
- ✱ Nuclear and atomic spins are coupled
- ✱ Polarize as (cold) atoms expand



Outline of β asym & polarization measurements

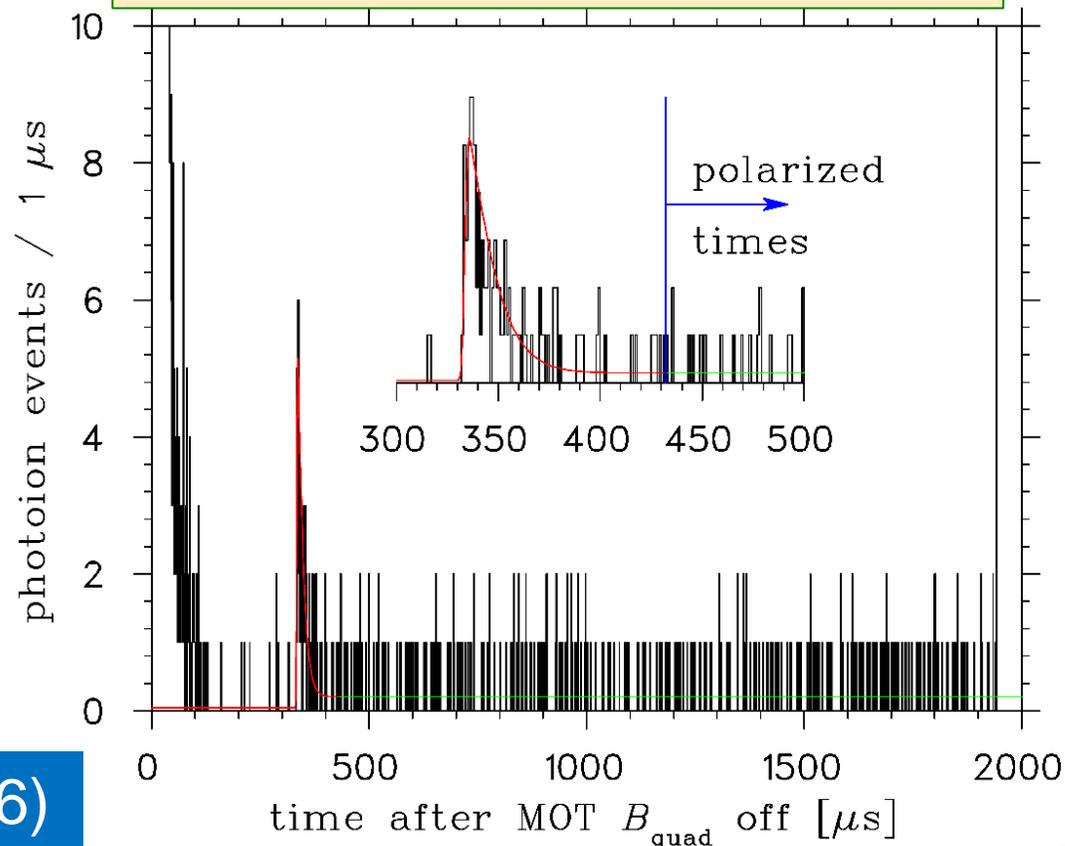
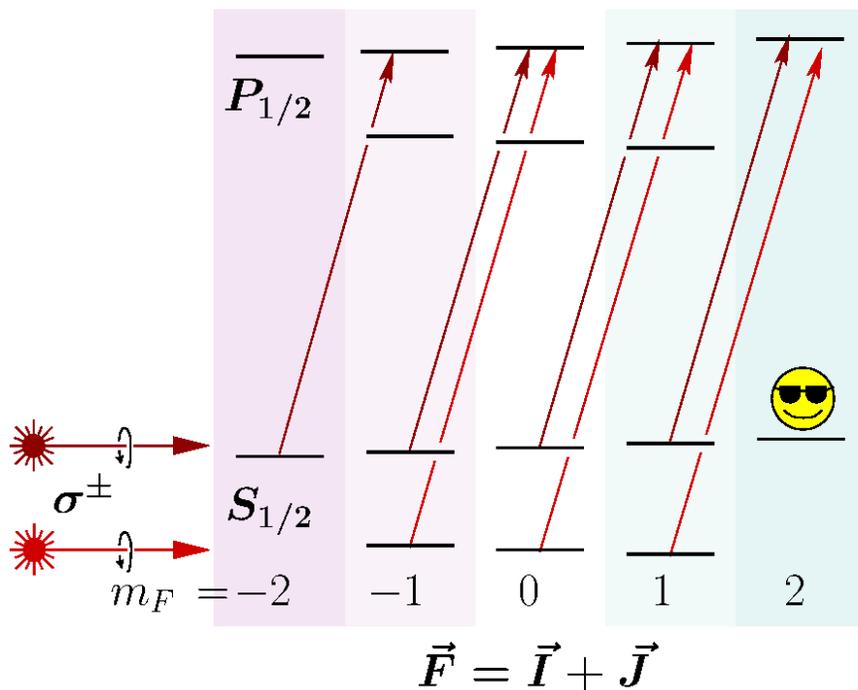


Optical pumping is fast and *efficient!*

• No time to go into details, but basically

- Measure the rate of photons (\Leftrightarrow fluorescence) as a function of time
- Model sublevel populations using the optical Bloch equations
- Determine the average nuclear polarization:

$$\langle |P_{\text{nuc}}| \rangle = 0.9913(9)$$



B.Fenker *et al*, New J. Phys. 18, 073028 (2016)

The β asymmetry measurement

E_β detectors:

Plastic scintillator

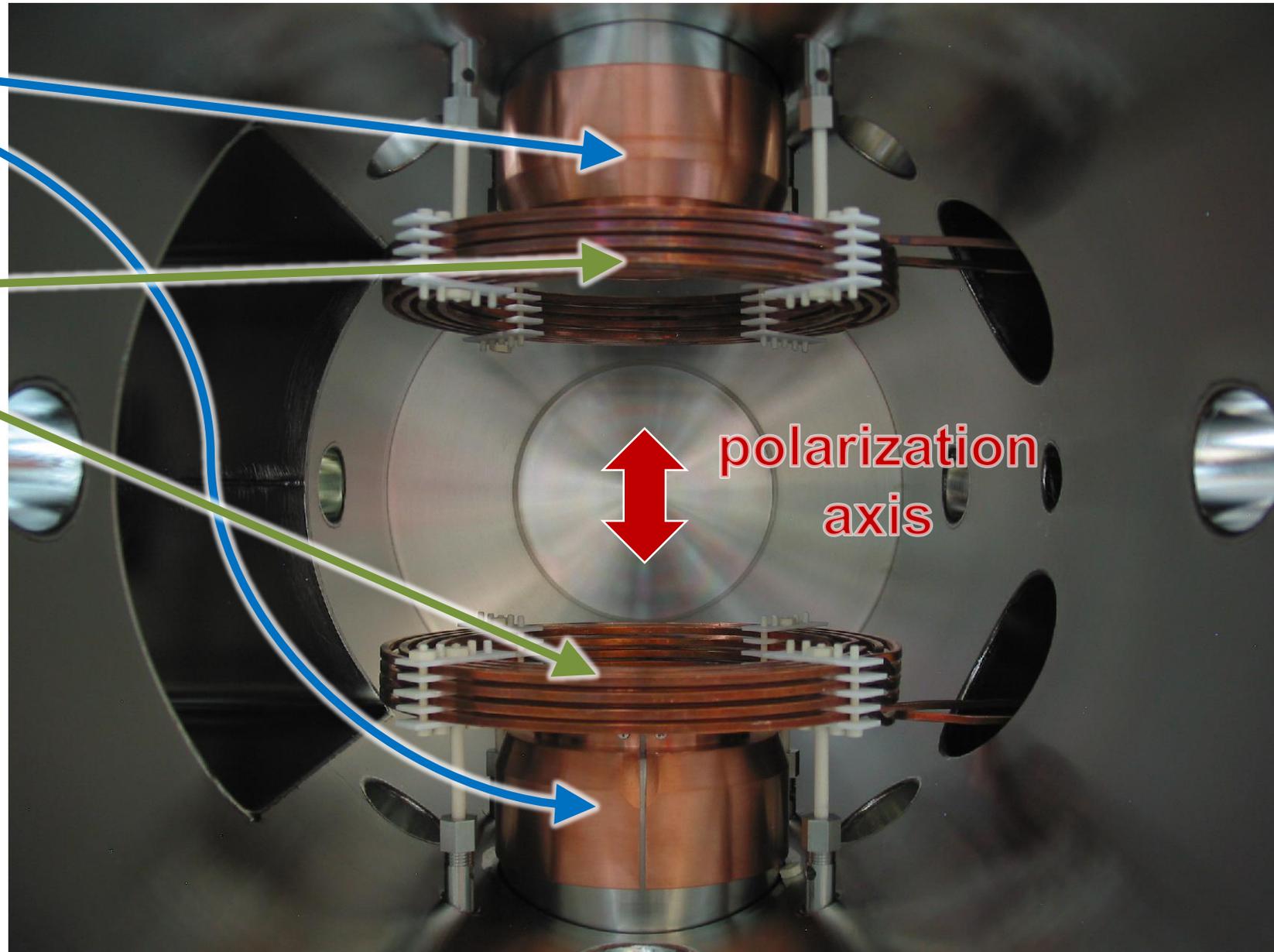
ΔE_β detectors:

Double-sided Si-strip

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

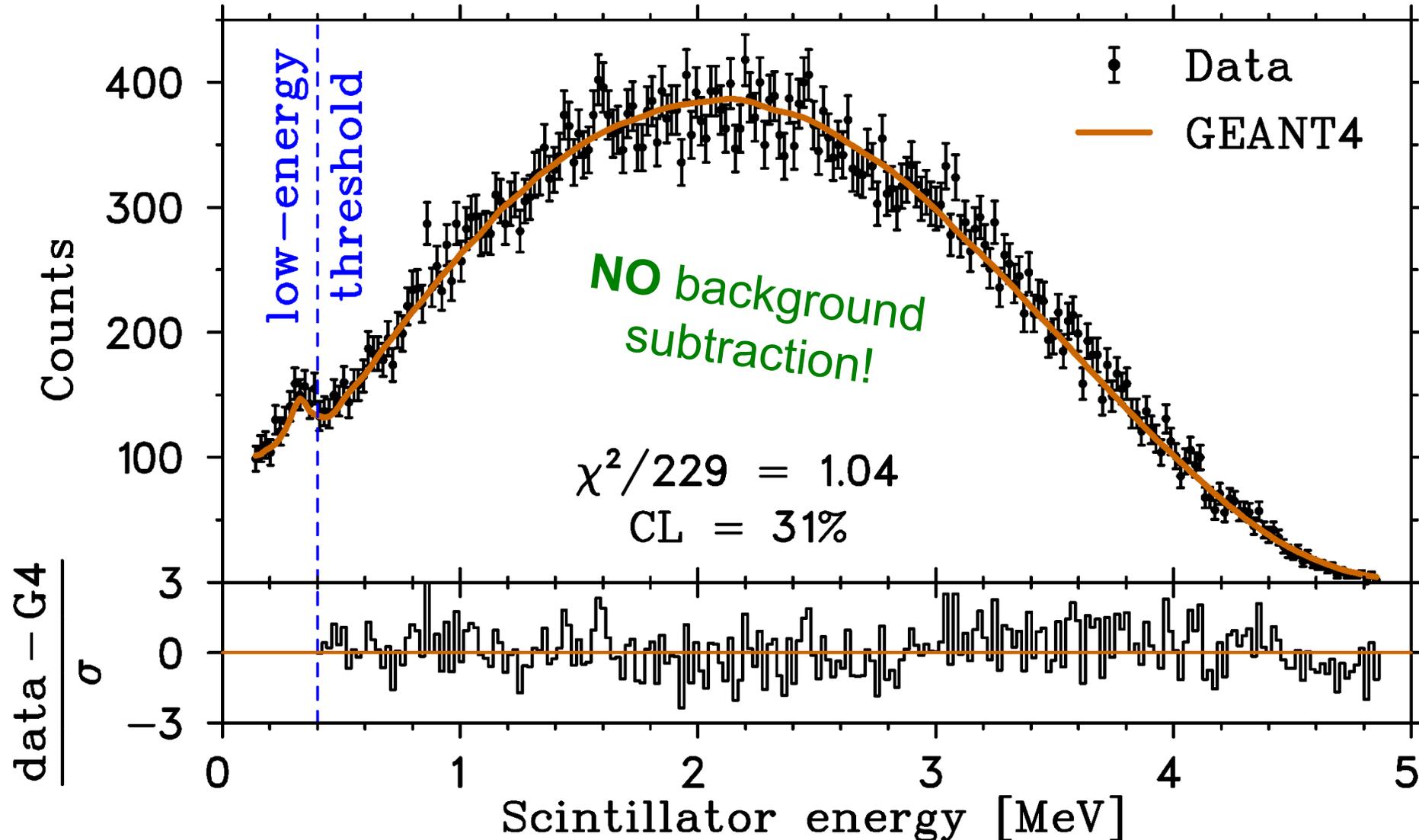
$$A_{\text{obs}}(E_e) = \frac{1 - S(E_e)}{1 + S(E_e)}$$

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



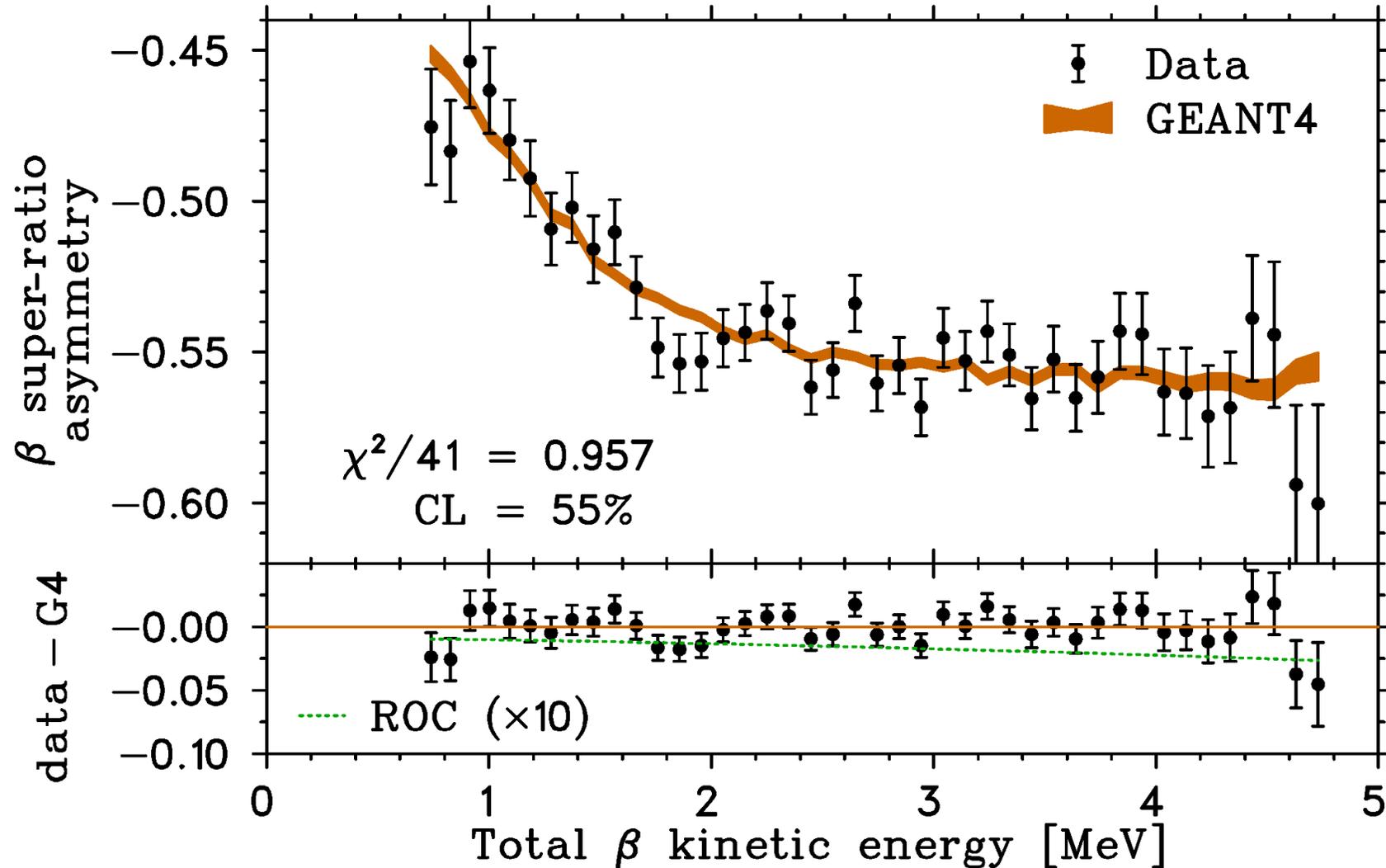
^{37}K β asymmetry measurement

Energy spectrum – great agreement with GEANT4 simulations:



^{37}K β asymmetry measurement

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

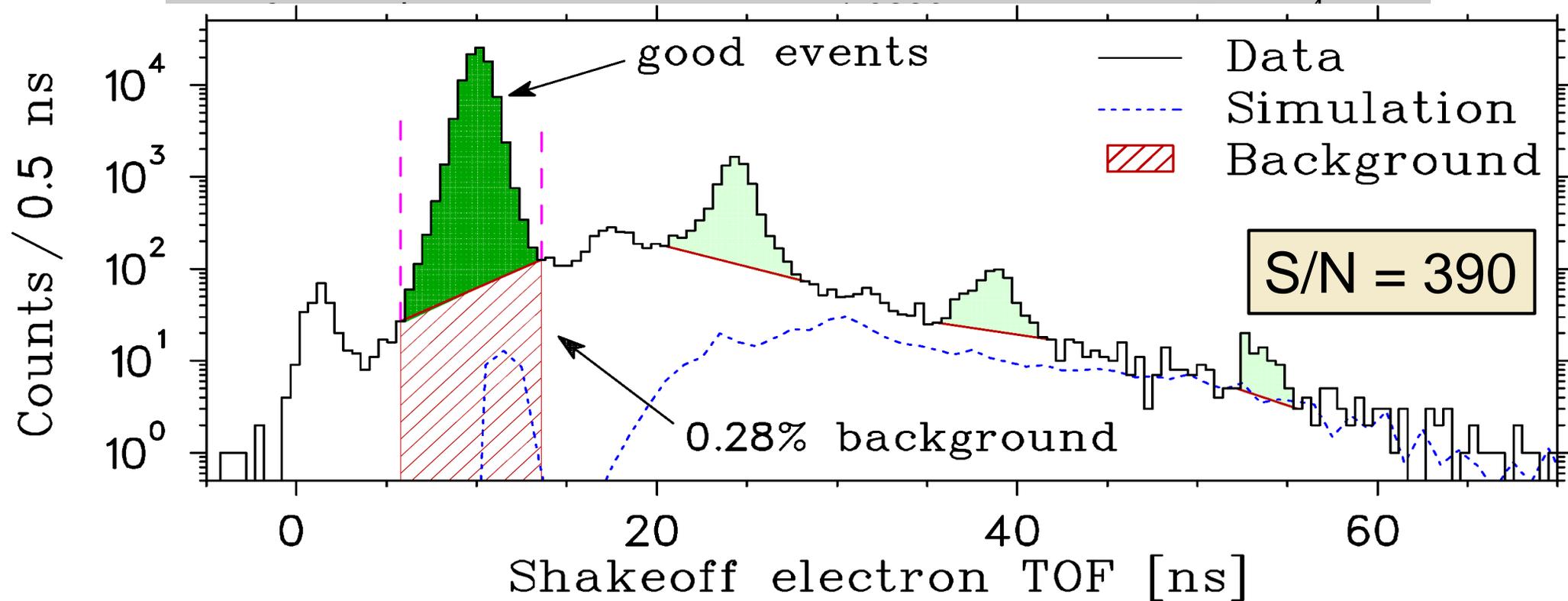


(Dominant) Error budget

Source	Correction	Uncertainty, ΔA_β
Systematics		
Background	1.0014	8×10^{-4}
β scattering	1.0230	7×10^{-4}
Trap position		4×10^{-4}
Trap movement		5×10^{-4}
ΔE position cut		4×10^{-4}
Shake-off e^- TOF region		3×10^{-4}
TOTAL SYSTEMATICS		13×10^{-4}
STATISTICS		13×10^{-4}
POLARIZATION		5×10^{-4}
TOTAL UNCERTAINTY		19×10^{-4}

(Dominant) Error budget and A_β result

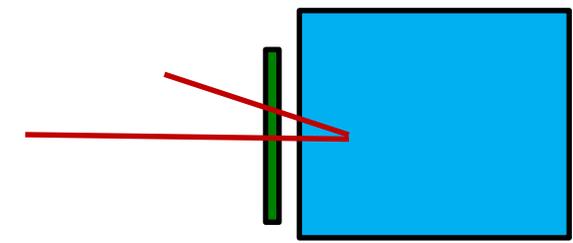
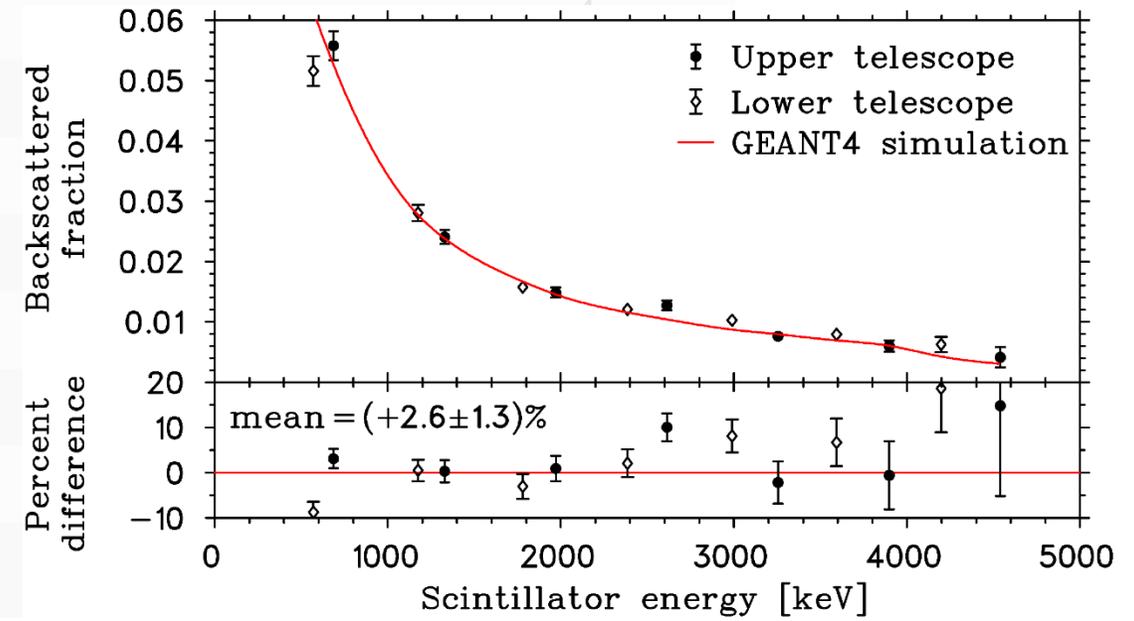
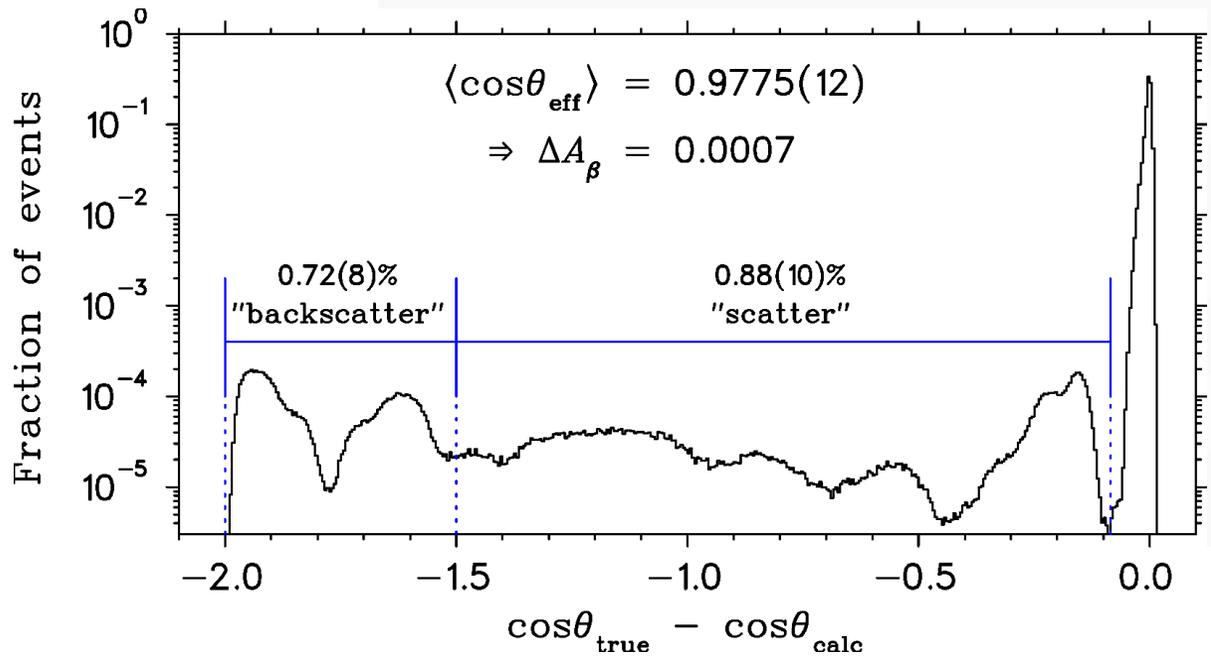
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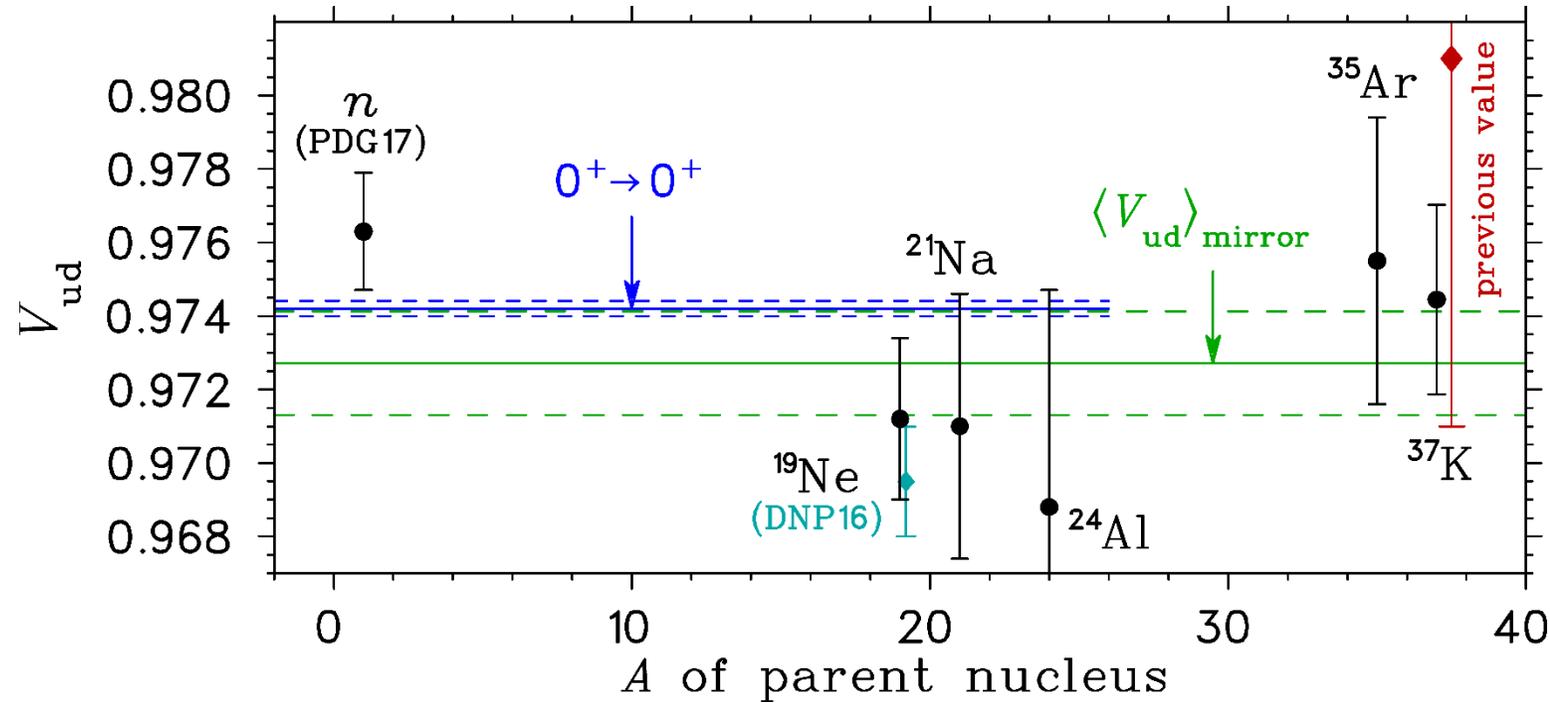
$$A_\beta^{\text{meas}} = -0.5707(19) \text{ cf } A_\beta^{\text{SM}} = -0.5706(7) \quad \left(\text{includes recoil-order corrections, } \Delta A_\beta \approx -0.0028 \frac{E_\beta}{E_0} \right)$$

B.Fenker *et al*, PRL 120, 062502 (2018)

Interpretation and future prospects

Comparison of V_{ud} from:

- ✱ Mirror nuclei (including ^{37}K)
- ✱ The neutron
- ✱ Pure Fermi decays



B.Fenker *et al*, PRL 120, 062502 (2018)

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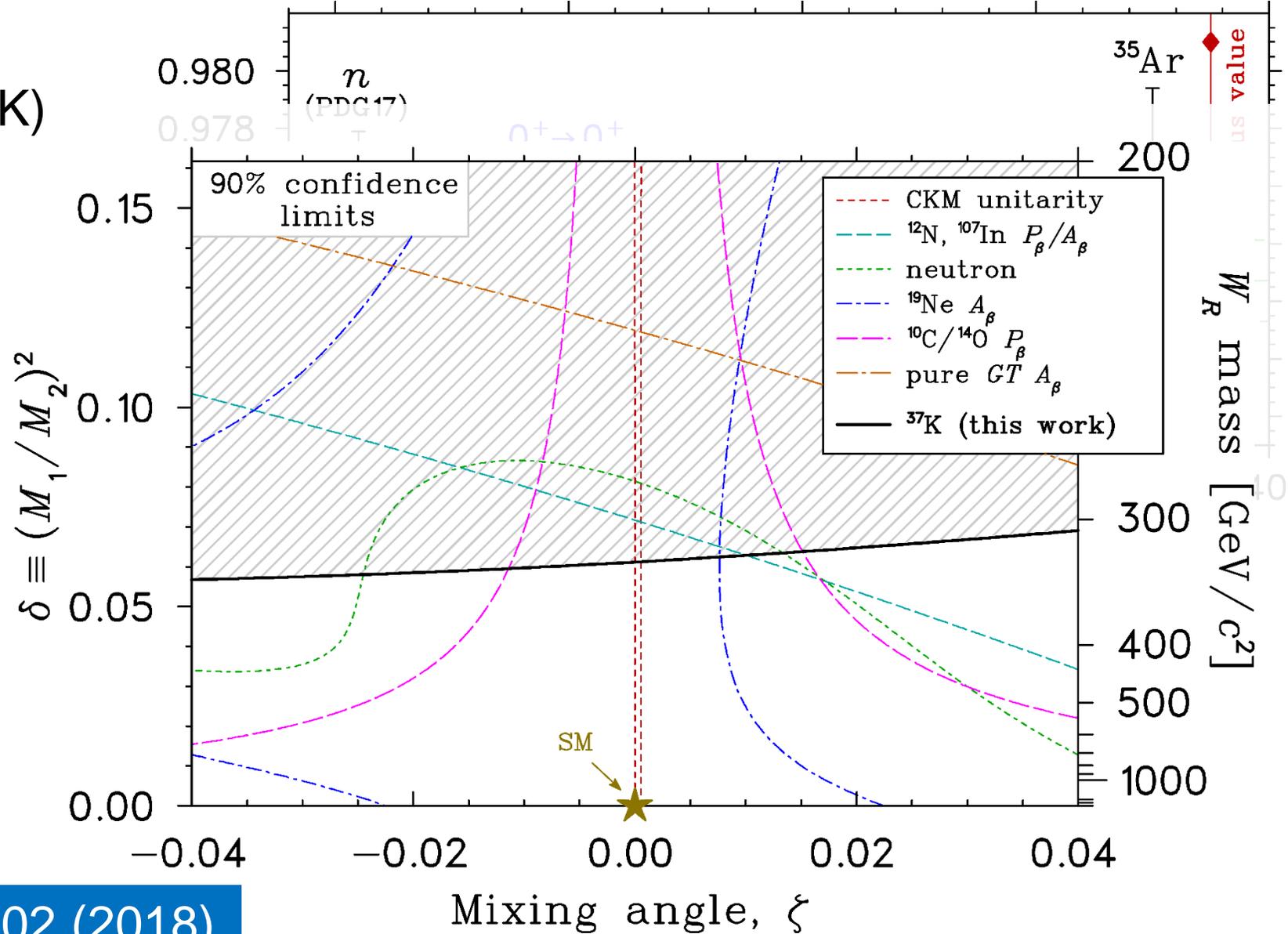
✱ Pure Fermi decays

Also other physics to probe:

✱ Right-handed currents

✱ 2nd class currents

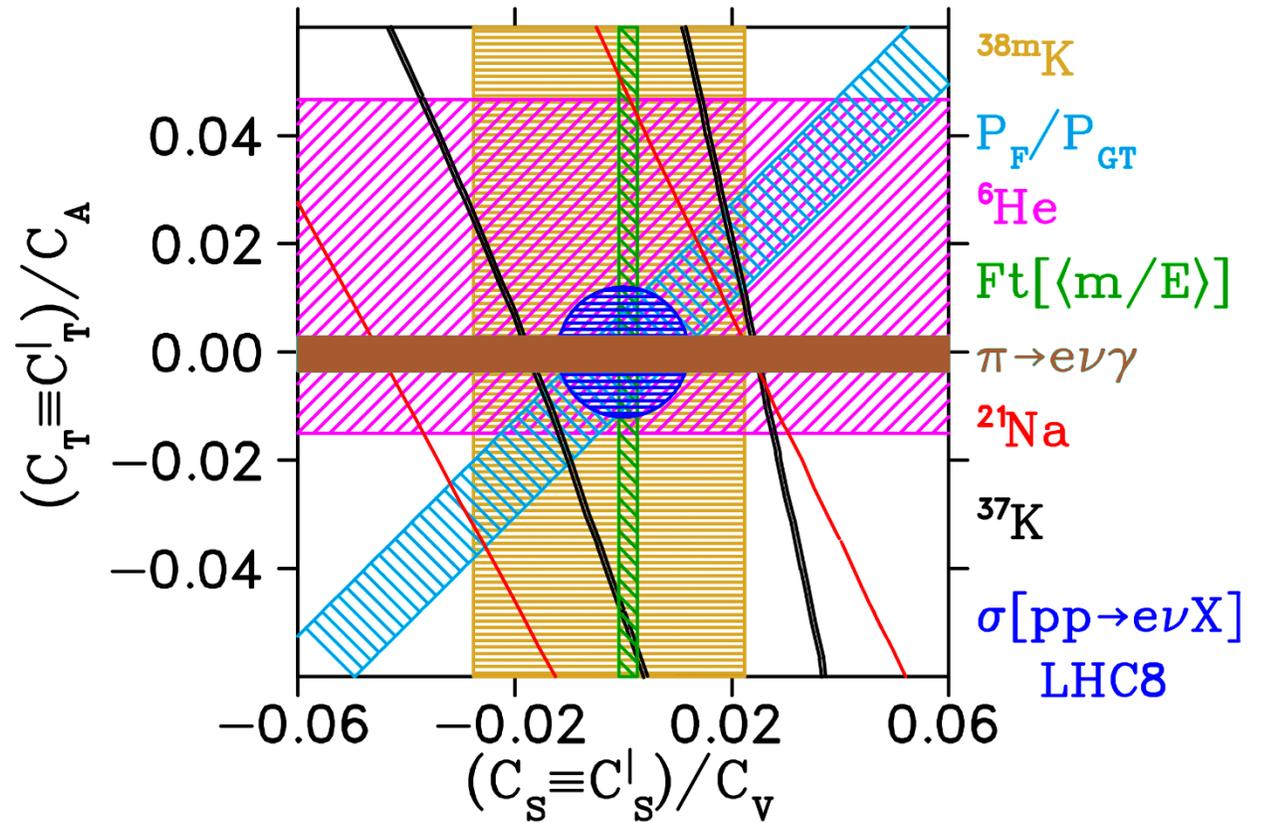
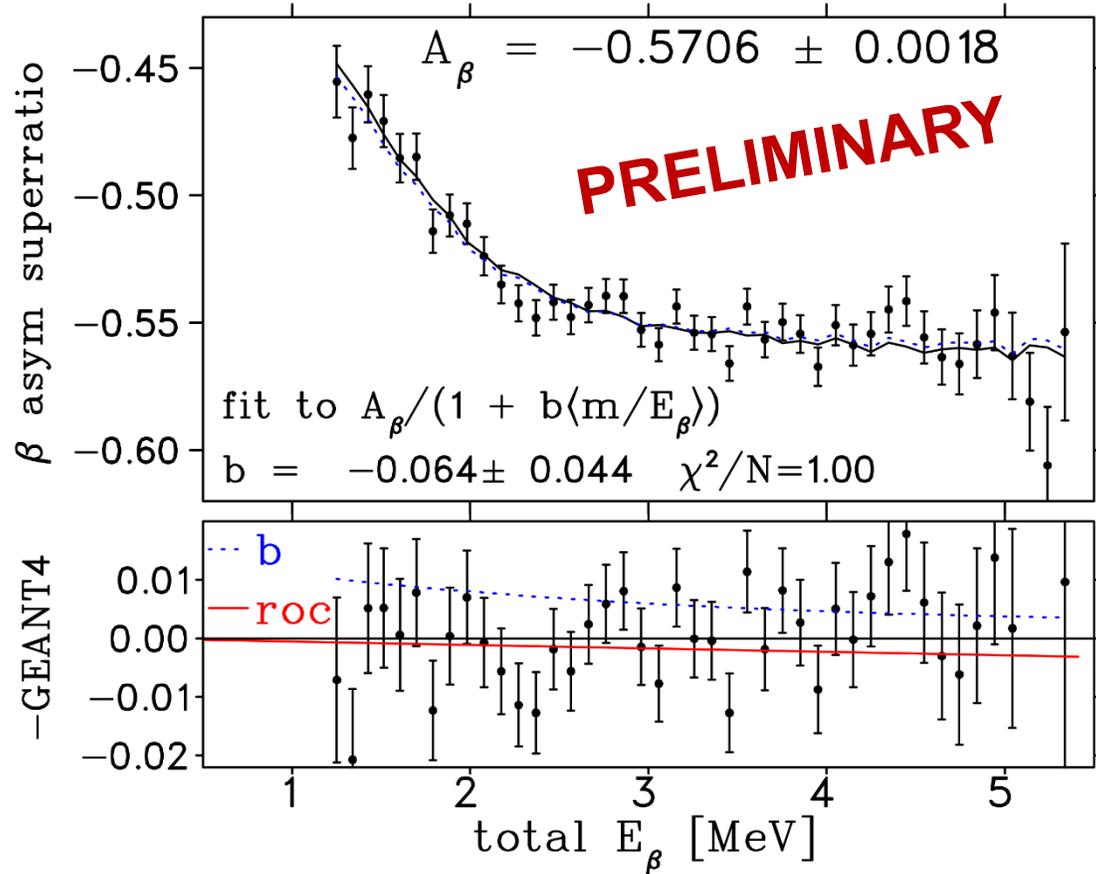
✱ Scalar & tensor currents



B.Fenker *et al*, PRL 120, 062502 (2018)

Future plans

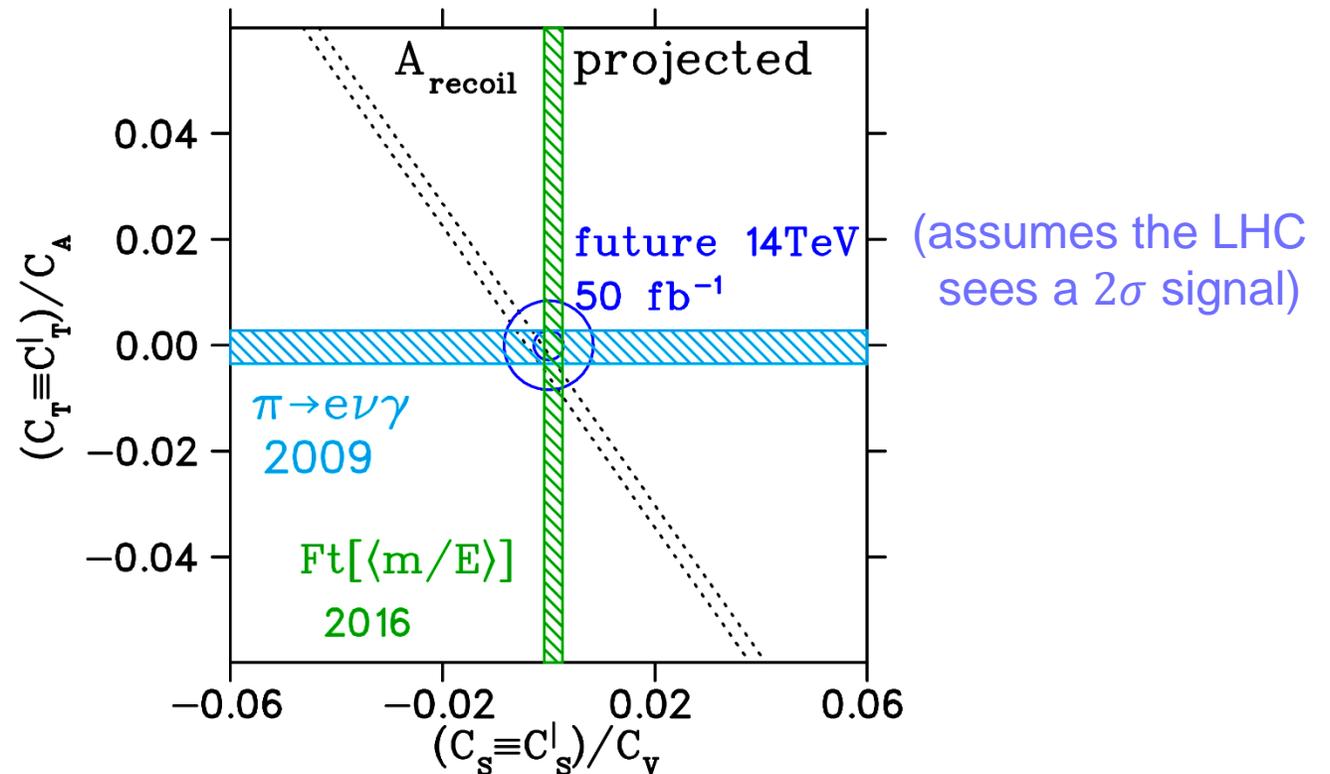
- Complete analysis as a function of $E_\beta \Rightarrow$ Fierz, 2nd class currents
- Improve A_β measurement by 3 – 5 \times



PRELIMINARY

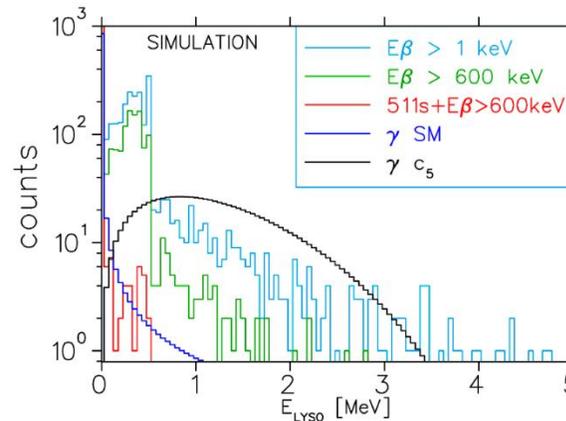
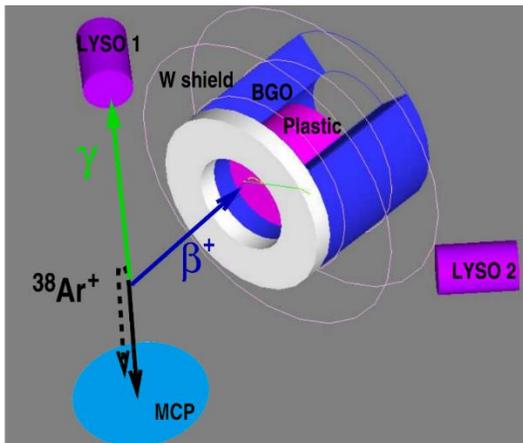
Future plans

- Complete analysis as a function of $E_\beta \Rightarrow$ Fierz, 2nd class currents
- Improve A_β measurement by 3 – 5 \times
- Measure $A_{\text{recoil}} \propto A_\beta + B_\nu$
 - ✱ Technique demonstrated in ^{80}Rb (Pitcairn *et al.*, PRC **79**, 015501 (2009))
 - ✱ High statistics measurement



Future plans

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 - ✳️ High statistics measurement
- Measure triple-vector $(\vec{p}_e \times \vec{k}_\gamma) \cdot \vec{p}_\nu$ (T -violating) correlation in $^{38\text{m}}\text{K}$
 - ✳️ Motivated by Gardner and He, PRD **87**, 116012 (2013)



- Effect 250x larger than for the neutron
- Fake final state effect small: 8×10^{-4}
- unique measurement in 1st generation
- $\sigma \sim 0.02$ in 1 week

Future plans

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 - ✱ Motivated by Gardner and He, PRD **87**, 116012 (2013)
- E_ν spectrum in $0^- \rightarrow 0^+$ decay of ^{92}Rb
 - ✱ Important for modeling nuclear reactors (sterile ν ?) and non-proliferation

⋮

Final thought and thanks

- MOTs helping pave the way for the precision frontier
- NeAT about to get going, ${}^6\text{He}$ with CRES super-exciting, and more good things to come from TRINAT

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