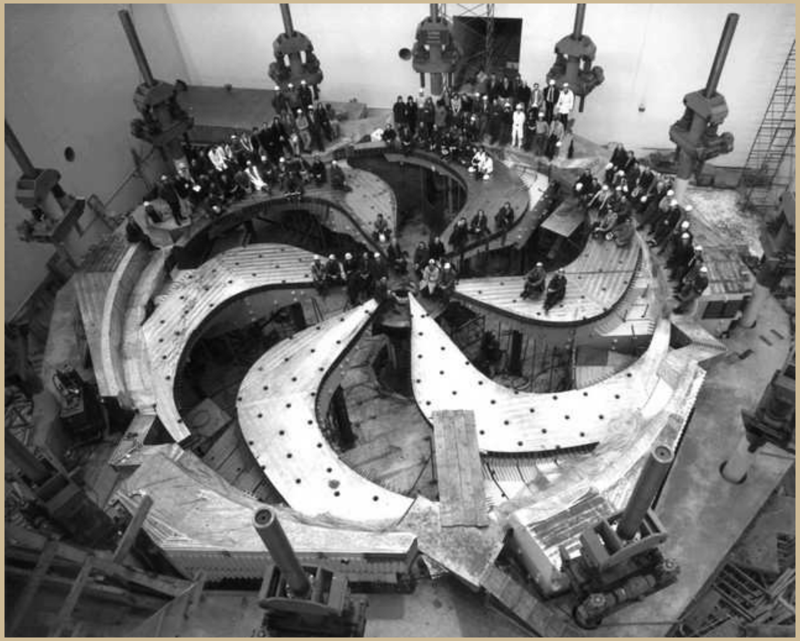
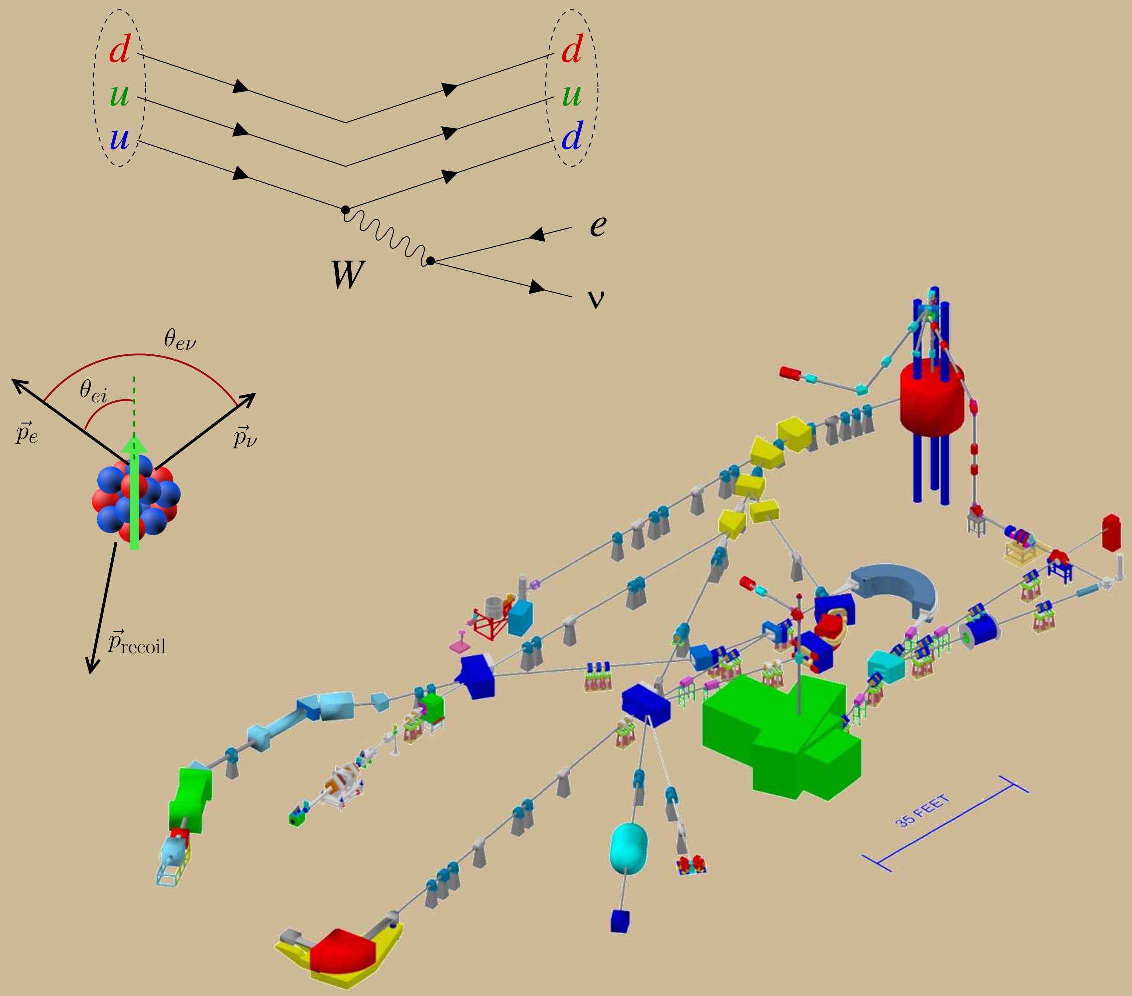
Probing Fundamental Symmetries via Precision Correlation measurements of β Decay





Dan Melconian

HSEBSM, Quy Nhởn, Aug 5, 2016

Overview

1. **Introduction**
    - I think we all know why we want to test the SM. . .
    - One precision frontier: correlation parameters of β decay
2. **Ion Traps**
    - LPC Trap
    - Beta-decay Paul Trap
    - TAMUTRAP
3. **Neutral Atom Traps**
    - CENPA/ANL
    - TRINAT
4. **Elegant vs. brute-force tests**
    - *very* short summary

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- *very* short summary [thanks Oscar!]

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How β-decay can test the SM?

- Begin by looking at the rate for β decay

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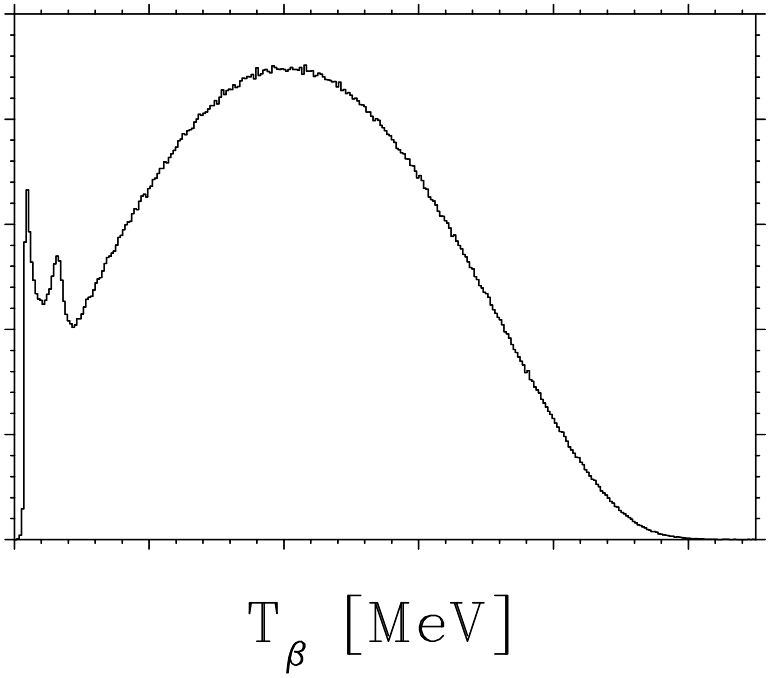

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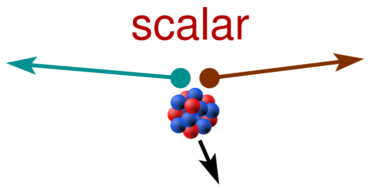
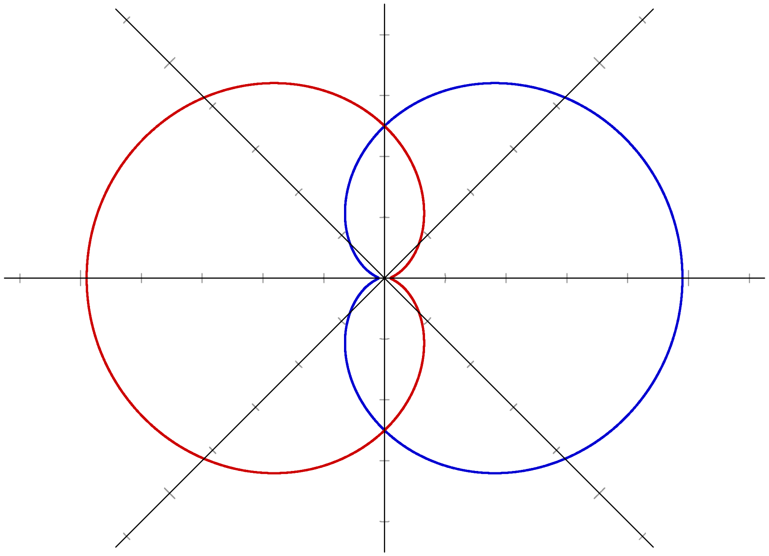
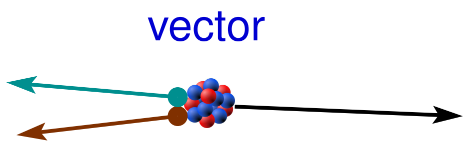


$$a_{\beta\nu} = \frac{-|C_S|^2 - |C'_S|^2}{|C_S|^2+|C'_S|^2}$$





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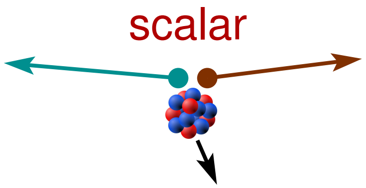

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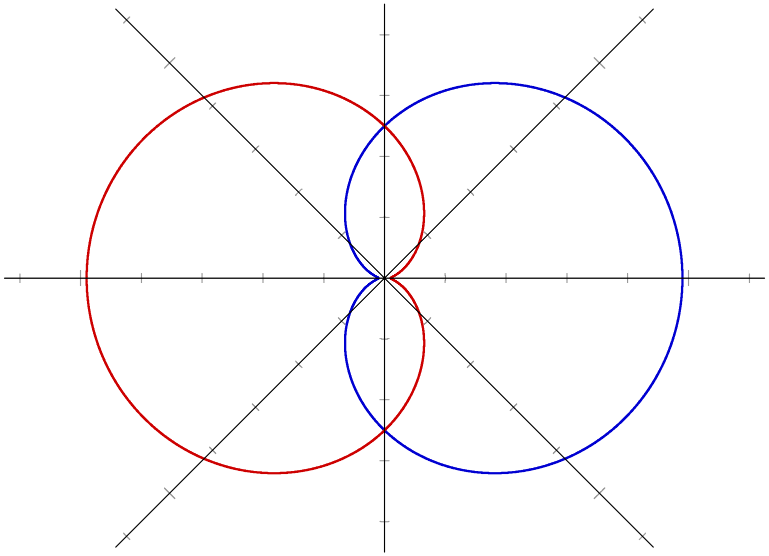

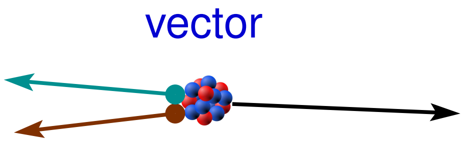

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This correlation is quadratic in the couplings. . . not as sensitive as the Fierz parameter, which is linear:

$$b_F = \frac{-2\Re e(C_S^* C_V + C_S'^* C_V')}{|C_V|^2 + |C_V'|^2 + |C_S|^2 + |C_S'|^2} = 0??$$

see González-Alonso and Naviliat-Čunčić, arXiv:1607.08347!

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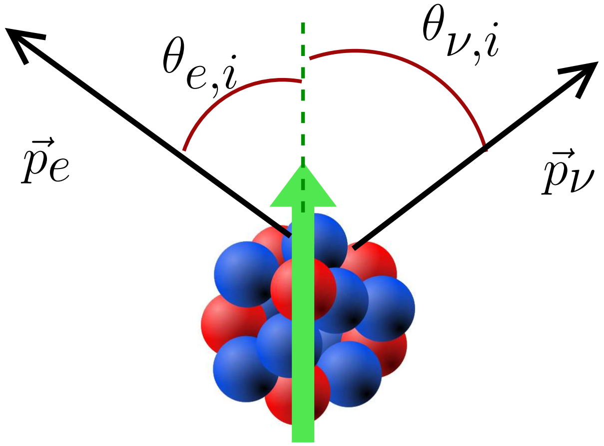
$$\left. + \frac{\langle \vec{I} \rangle}{I} \cdot \left[\underbrace{\boldsymbol{A}_\beta \frac{\vec{p}_e}{E_e}}_{\beta \text{ asym}} + \underbrace{\boldsymbol{B}_\nu \frac{\vec{p}_\nu}{E_\nu}}_{\nu \text{ asym}} + \underbrace{\boldsymbol{D} \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}}_{T-\text{violating}} \right] + \ldots \right)$$



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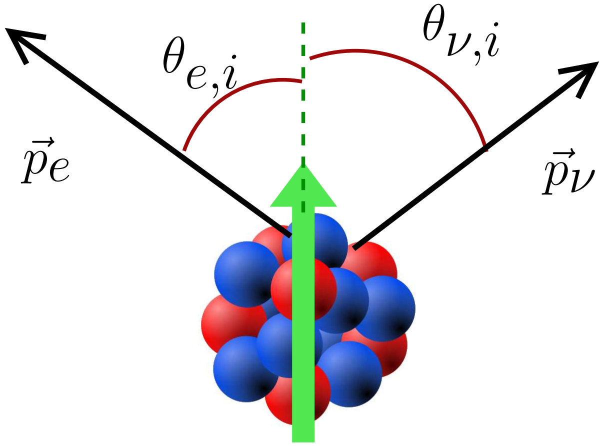

$$A_\beta = \frac{-2\rho}{1+\rho^2}\left[(1-xy)\sqrt{\frac{3(1+x^2)}{5(1+y^2)}} - \frac{\rho(1-y^2)}{5(1+y^2)}\right]$$

where $x \approx (M_L/M_R)^2 - \zeta$

and $y \approx (M_L/M_R)^2 + \zeta$

are right-handed current parameters
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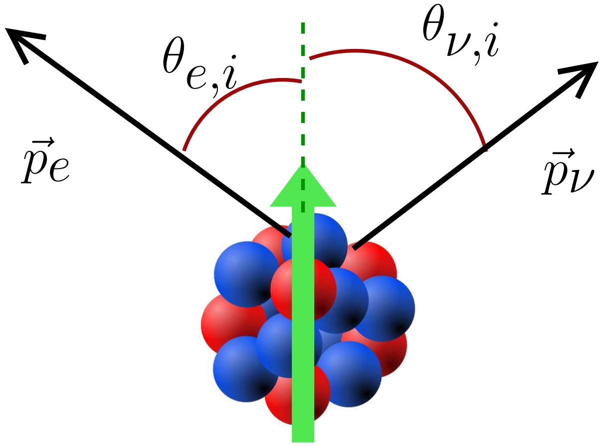
β-decay parameters depend on the currents mediating the weak interaction

$\Rightarrow$ sensitive to **new physics** $\Leftarrow$



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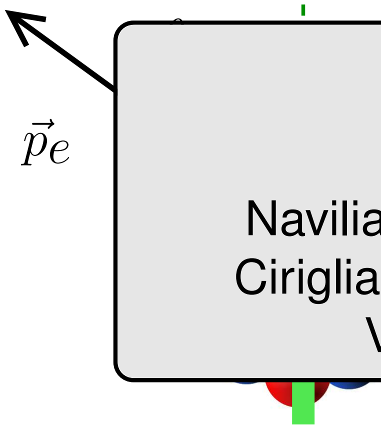
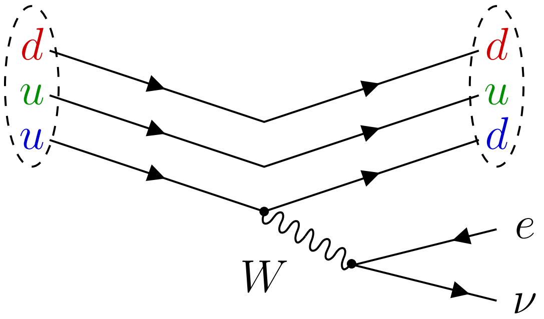
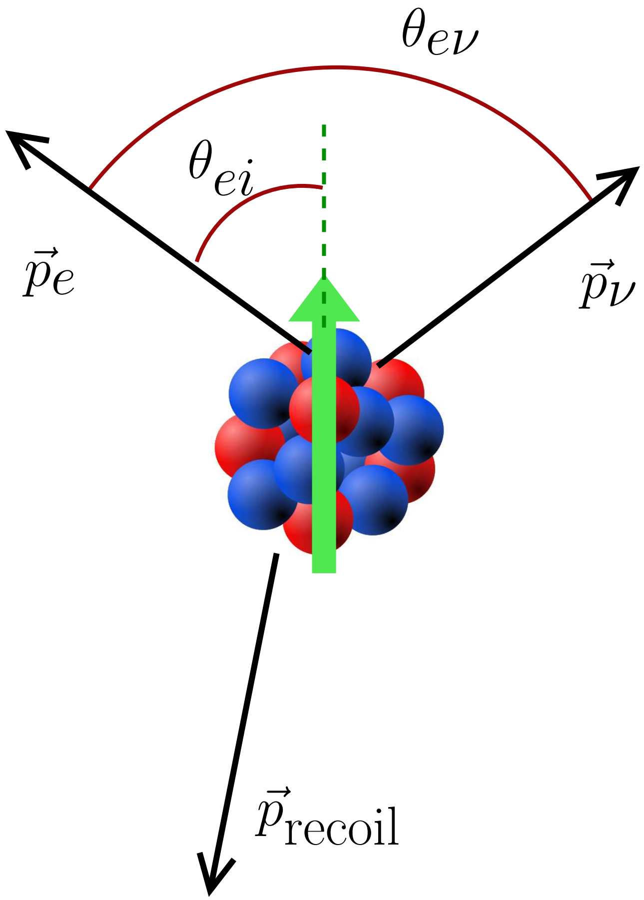


Goal must be $\lesssim$ **0.1%** to complement LHC

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

How to acheive our goal?





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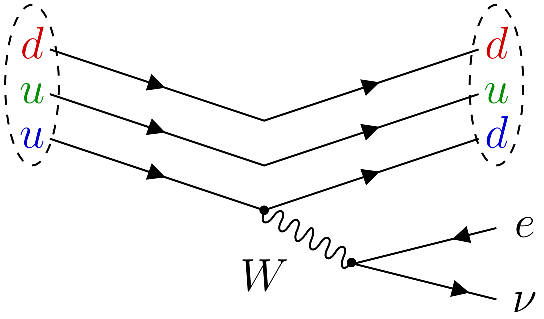

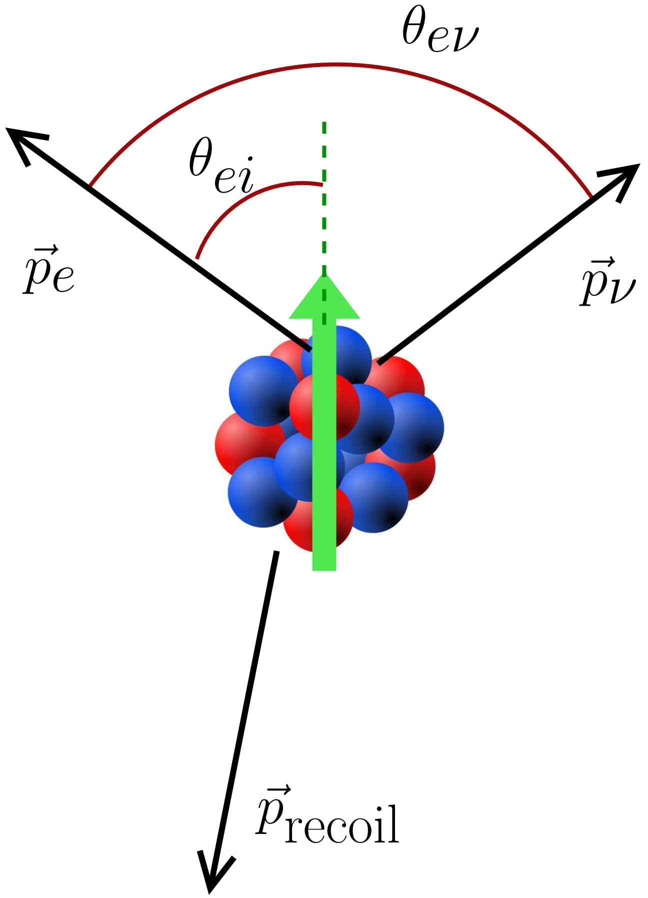

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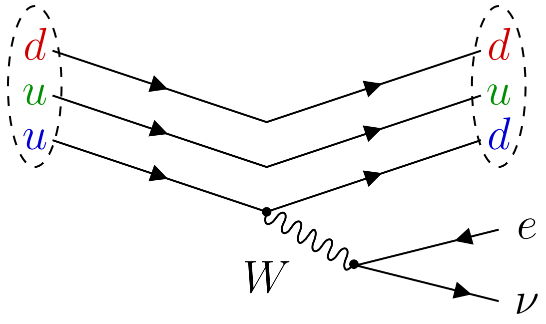

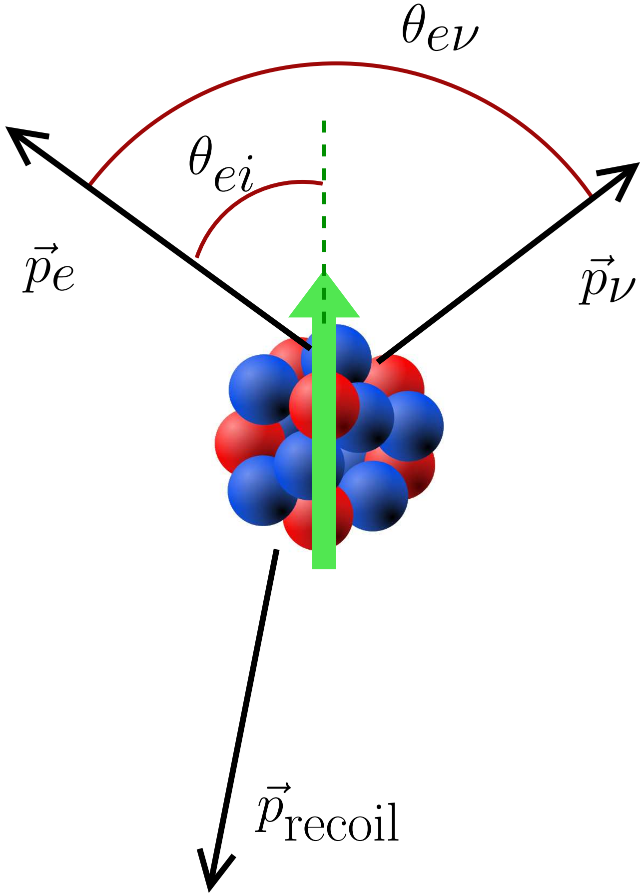

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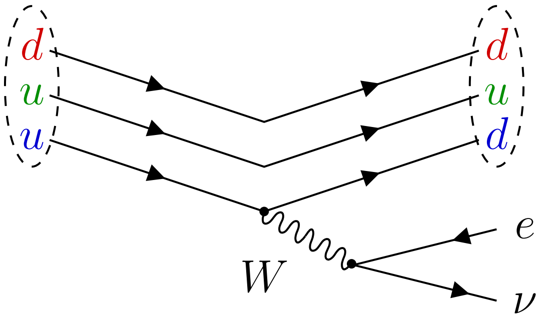

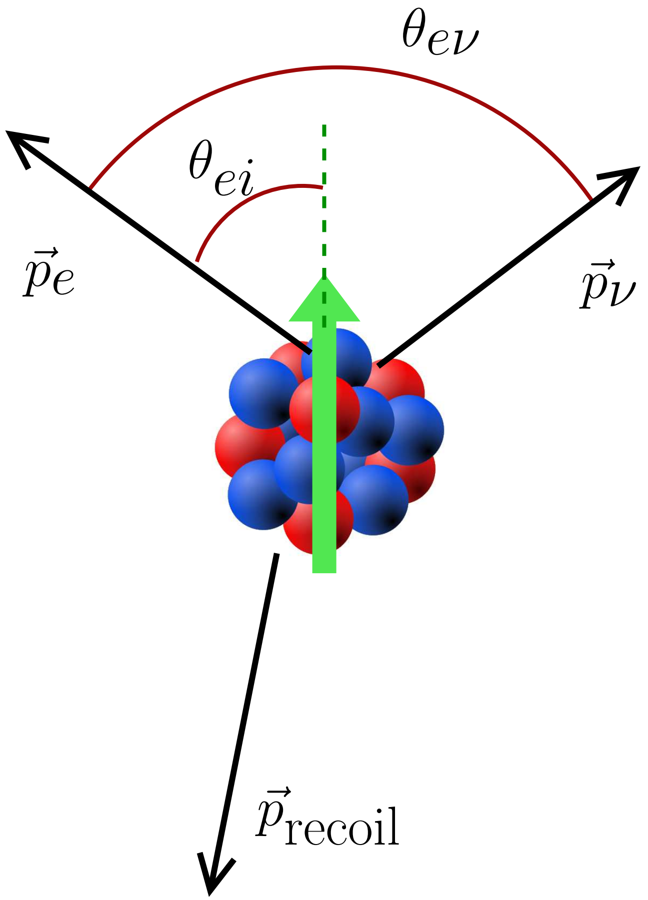

- perform a β decay experiment on **short-lived** isotopes
- make a **precision measurement** of the angular correlation parameters
- **compare** the SM predictions to observations
- look for **deviations** as an indication of **new physics**

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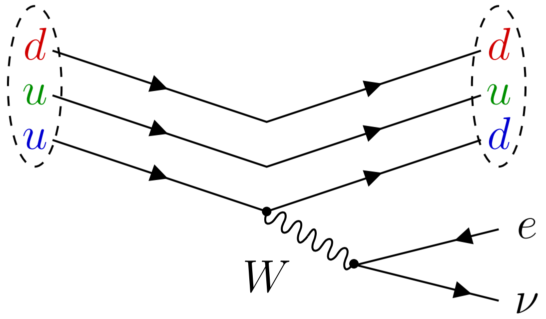

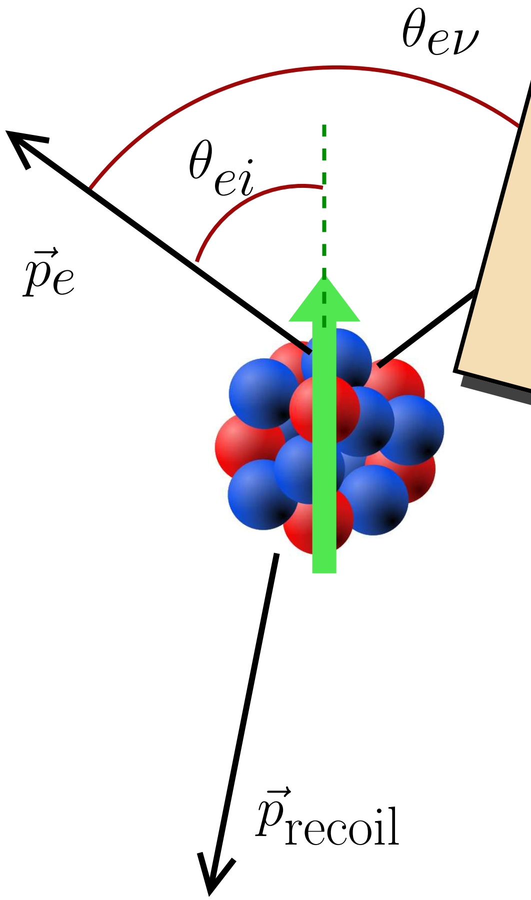

- perform a β decay experiment on **short-lived** isotopes
- make a **precision measurement** of the angular correlation parameters
- the SM predictions to obser-
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perform a nuclear measurement – often using atomic techniques – to test high-energy theories

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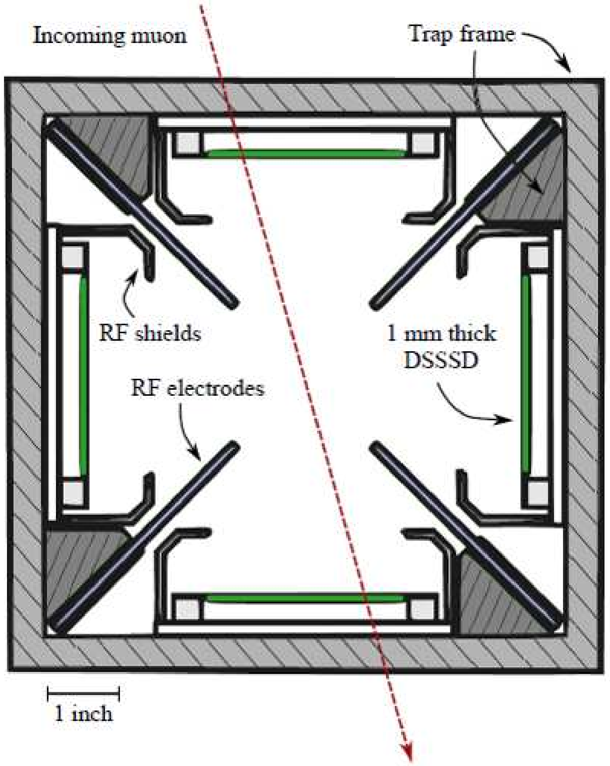
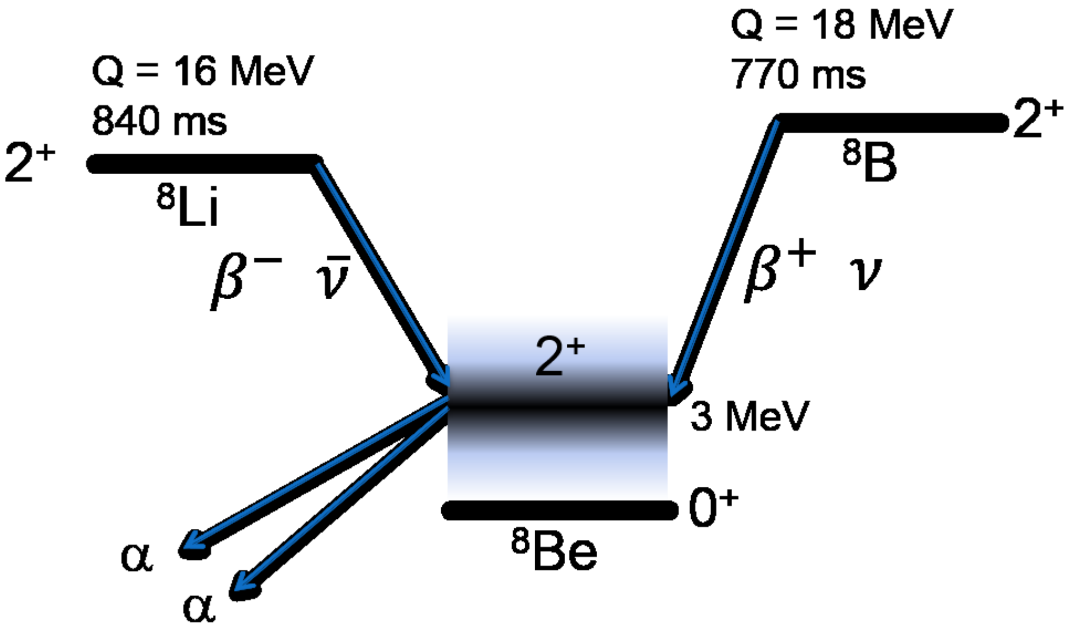
The Beta-decay Paul Trap (BPT) @ ANL



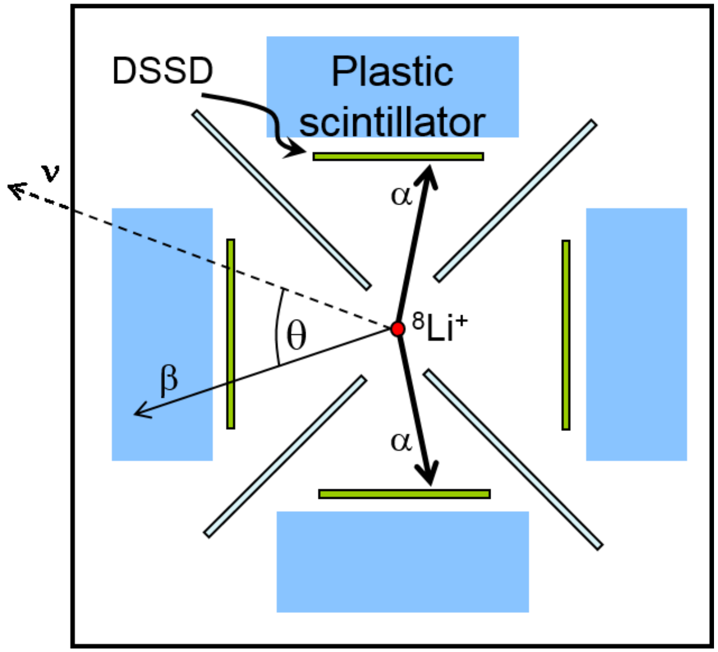
- Ions confined with electric fields (RF radially, DC axially)
- Ions cooled with buffer gas ($\sim 10^{-5}$ Torr)
- Up to 10^6 ions stored in trap

- Large ($\sim$ 30%) solid angle for detectors
- Currently DSSSD + scintillators; past used MCPs and HPGes

^{8}Li/^{8}B in the BPT



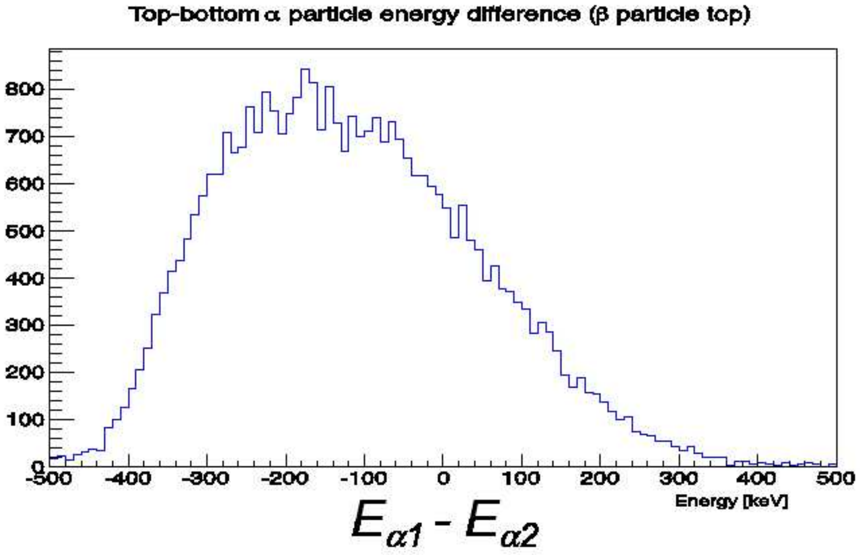
trapped ions surrounded by DSSDs and plastic scintillators



- Nearly pure Gamow-Teller ⇔ sensitive to A, T
- MeV charged particles ⇒ easier to measure
- Large kinematic shifts on 1.5 MeV α's (± 400 keV)
- $3\times$ enhancement using $\beta - \nu - \alpha$ correlation

BPT Results

$^{8}\mathrm{B} \rightarrow {}^{8}\mathrm{Be}^{*} + \beta^{+} + \nu_{e}$



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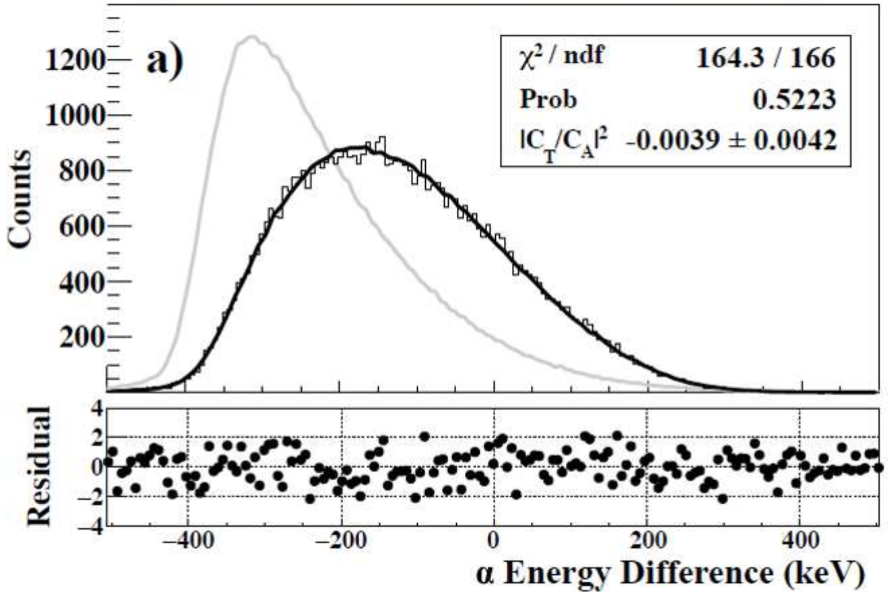
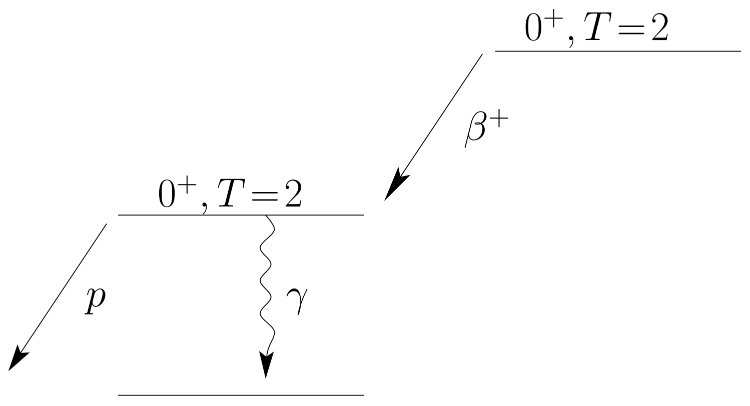
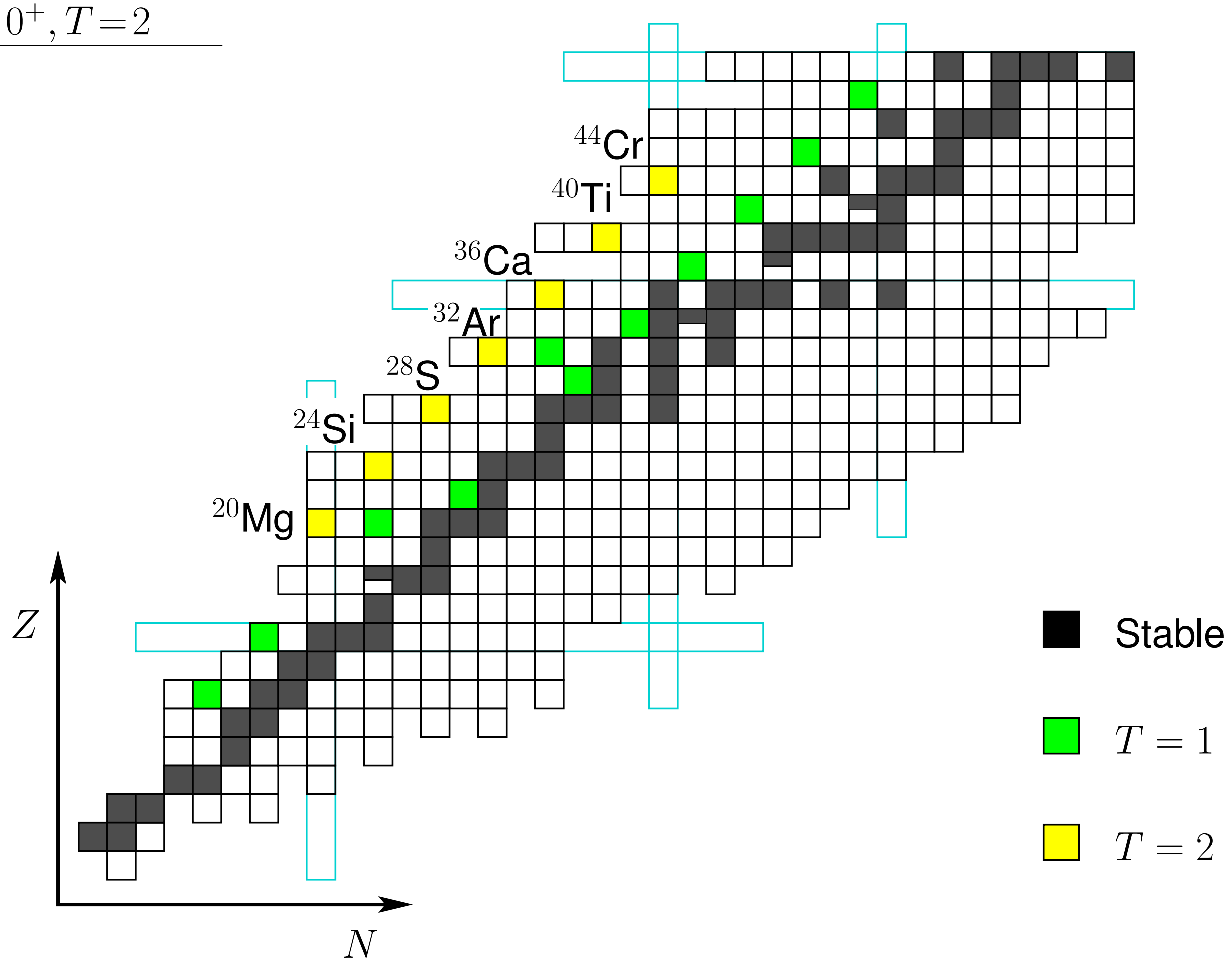


Sternberg *et al.*, PRL **115**, 182501 (2015)

- Mature program with $a_{\beta\nu}$ measured to 0.4% in ^{8}Li
- Similar stats for ^{8}B collected
- "0.1% within sight. . . "

TAMUTRAP: $T = 2$ Superallowed Decays





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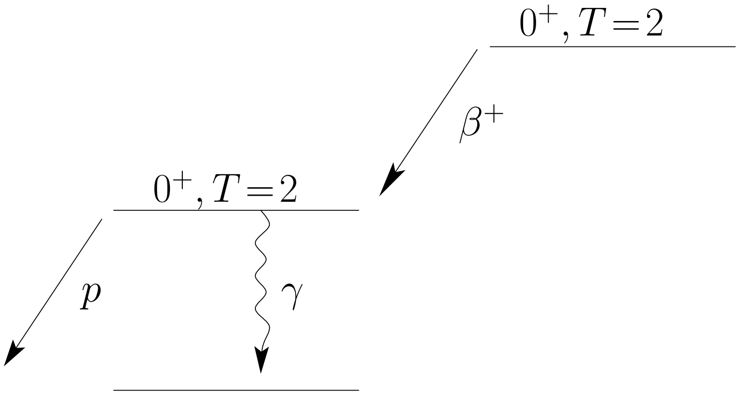

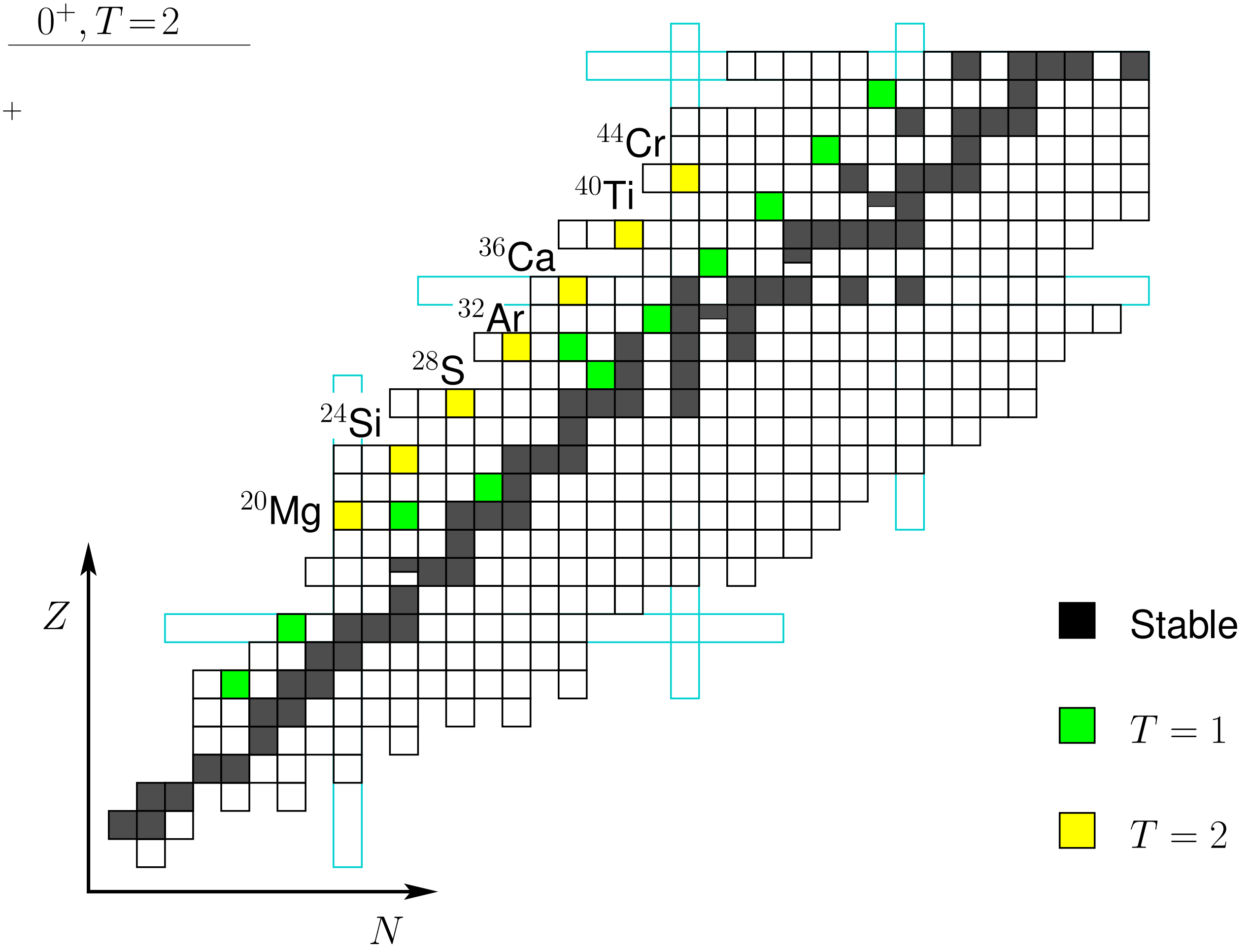

- $\beta - \nu$ correlations
- model-dependence of δ_C calcs seem to depend on T . . .
- new cases for V_{ud} (?)

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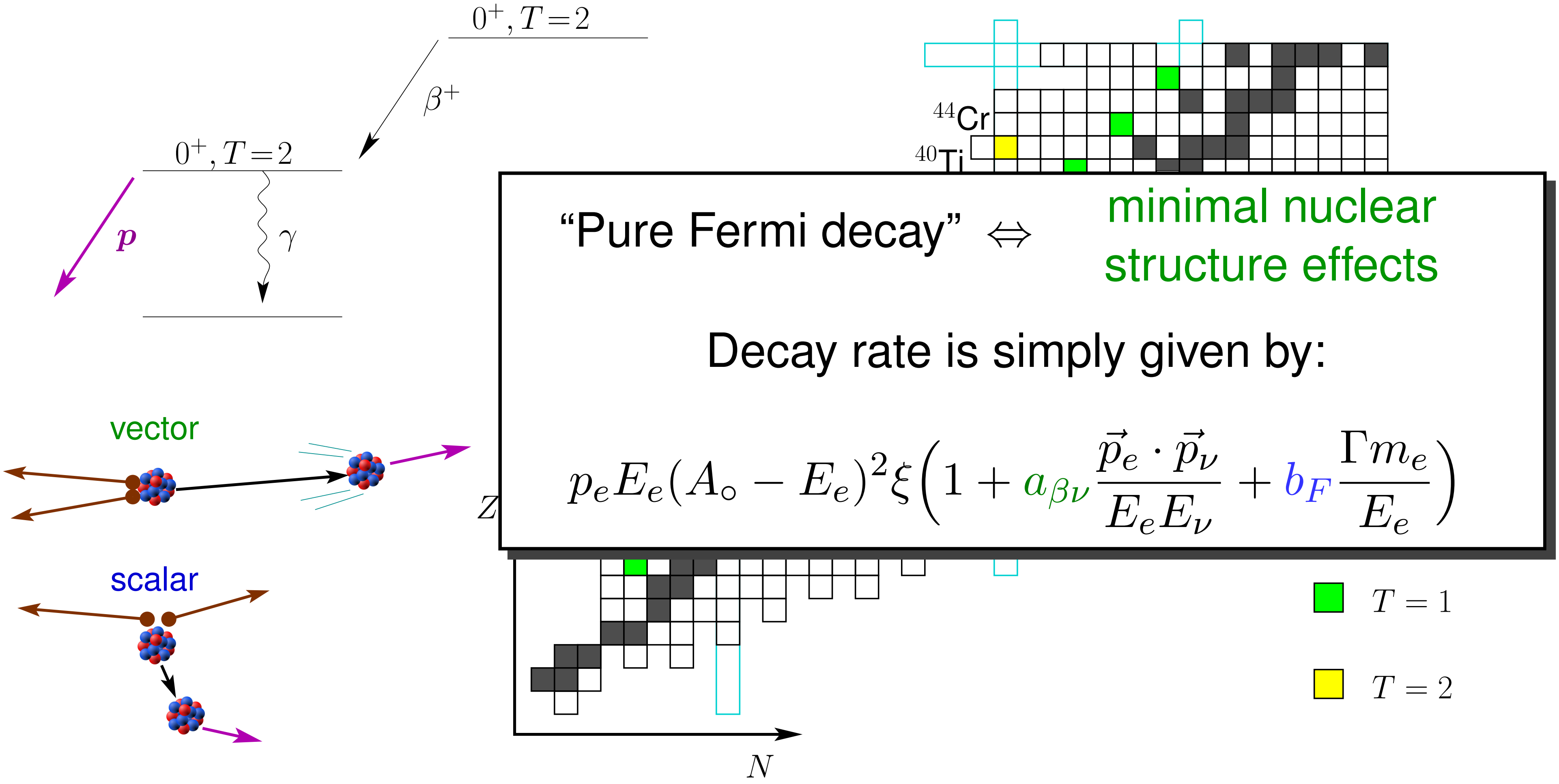

"Pure Fermi decay" ⇔ minimal nuclear structure effects

Decay rate is simply given by:

$$p_e E_e (A_\circ - E_e)^2 \xi \left(1 + a_{\beta\nu}\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b_F \frac{\Gamma m_e}{E_e}\right)$$

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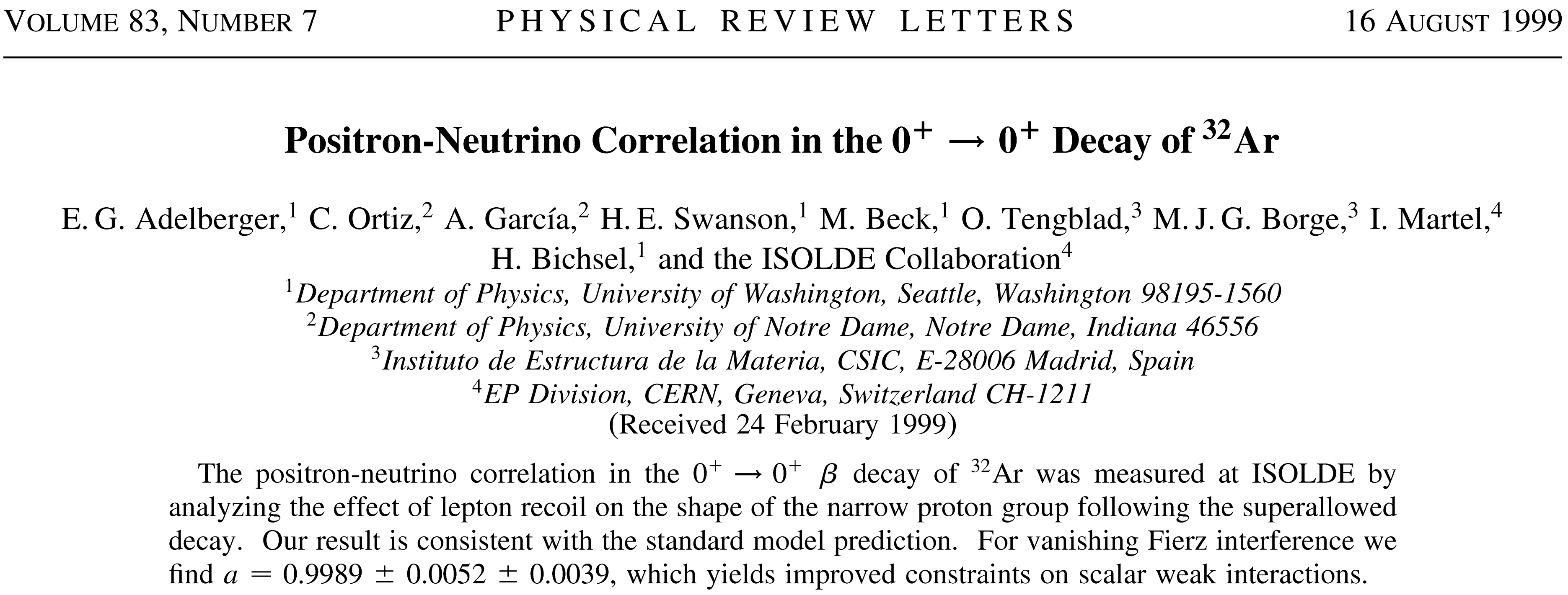
$\beta - \nu$ correlation from ^{32}Ar



VOLUME 83, NUMBER 7 PHYSICAL REVIEW LETTERS 16 AUGUST 1999

Positron-Neutrino Correlation in the $0^+ \rightarrow 0^+$ Decay of ^{32}Ar

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H. Bichsel,[1] and the ISOLDE Collaboration[4]
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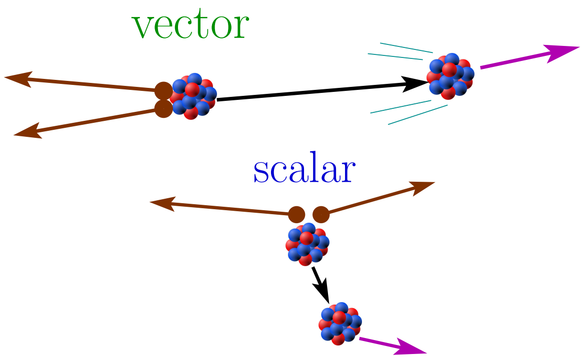
[2]*Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556*
[3]*Instituto de Estructura de la Materia, CSIC, E-28006 Madrid, Spain*
[4]*EP Division, CERN, Geneva, Switzerland CH-1211*

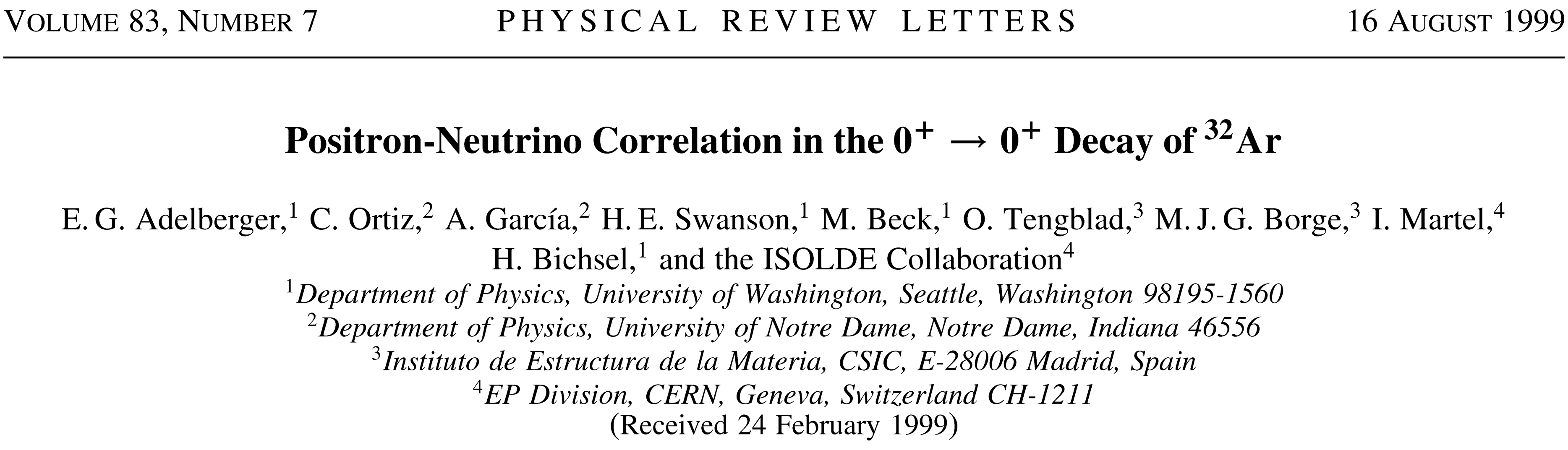
(Received 24 February 1999)

The positron-neutrino correlation in the $0^+ \rightarrow 0^+$ β decay of ^{32}Ar was measured at ISOLDE by analyzing the effect of lepton recoil on the shape of the narrow proton group following the superallowed decay. Our result is consistent with the standard model prediction. For vanishing Fierz interference we find $a = 0.9989 \pm 0.0052 \pm 0.0039$, which yields improved constraints on scalar weak interactions.

Doppler shape of delayed proton
depends on $\vec{p}_e \cdot \vec{p}_\nu$!



$\beta - \nu$ correlation from ^{32}Ar



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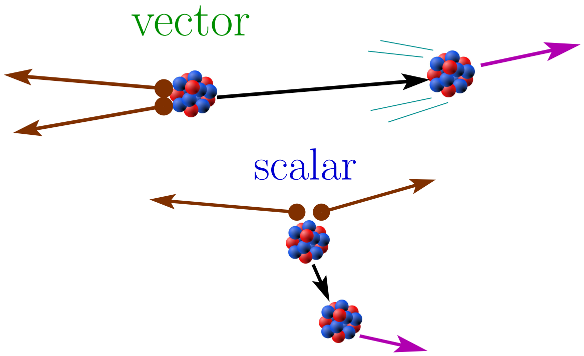

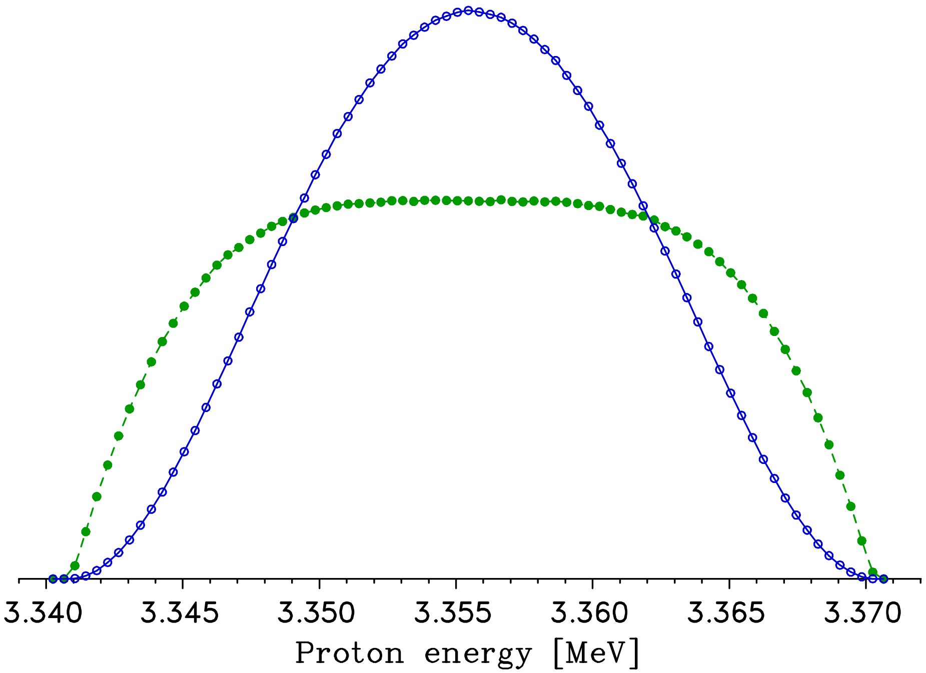

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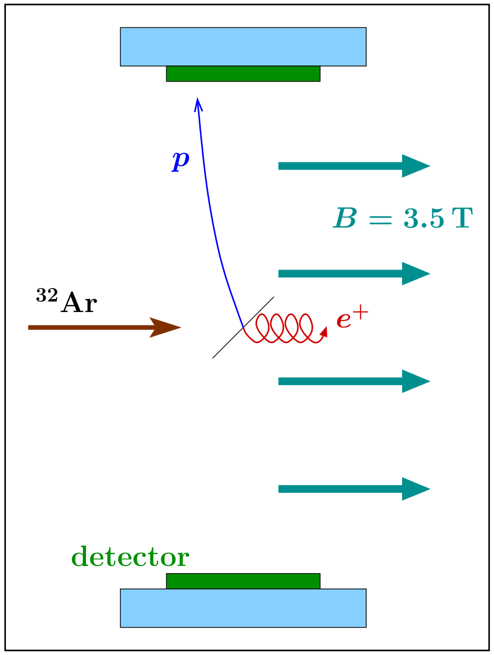

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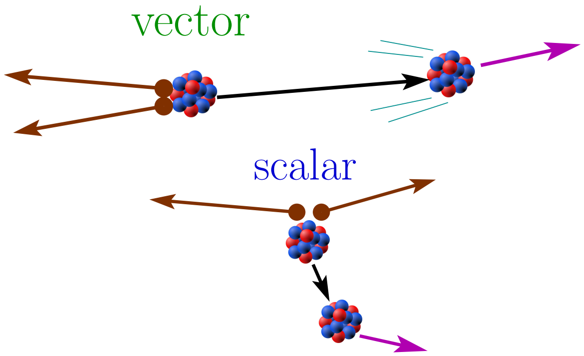

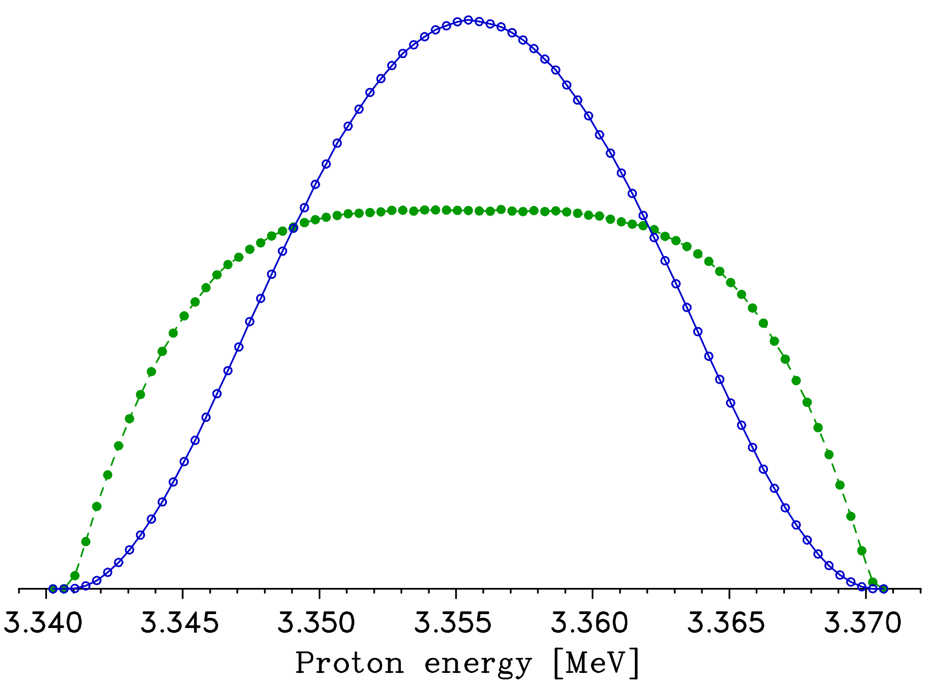

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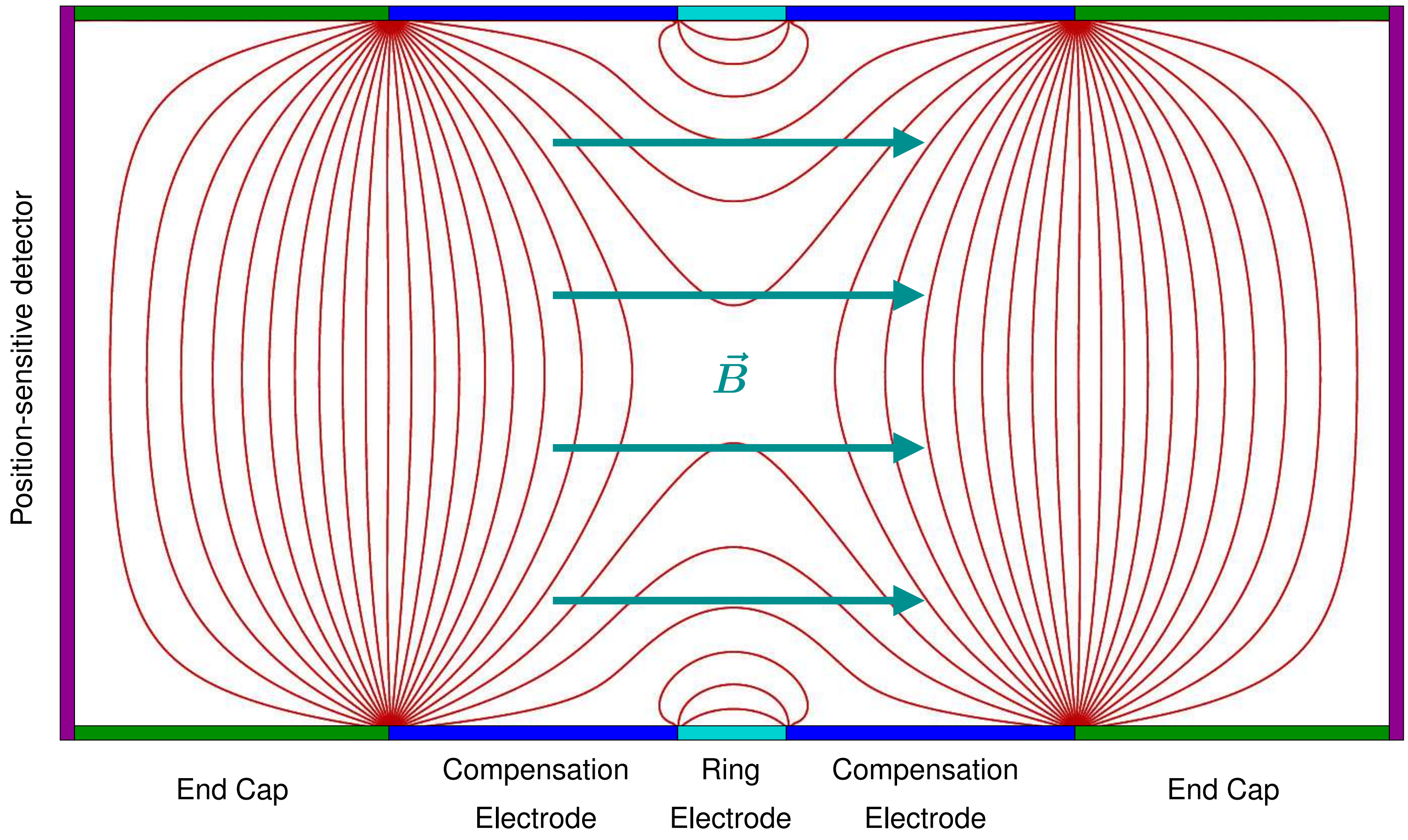
utilize technology of Penning traps to provide a **backing-free** source of localized radioactive ions!!



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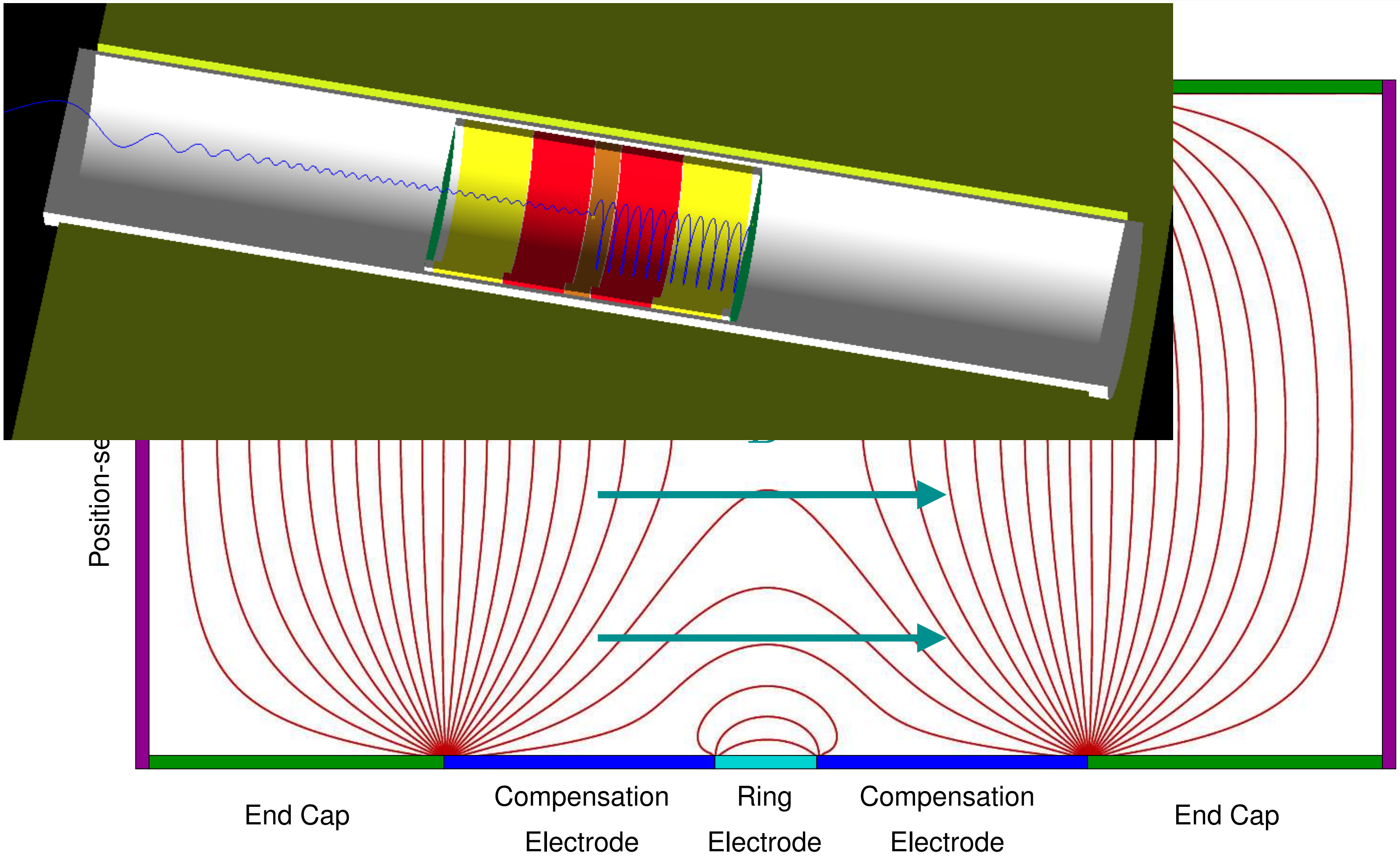

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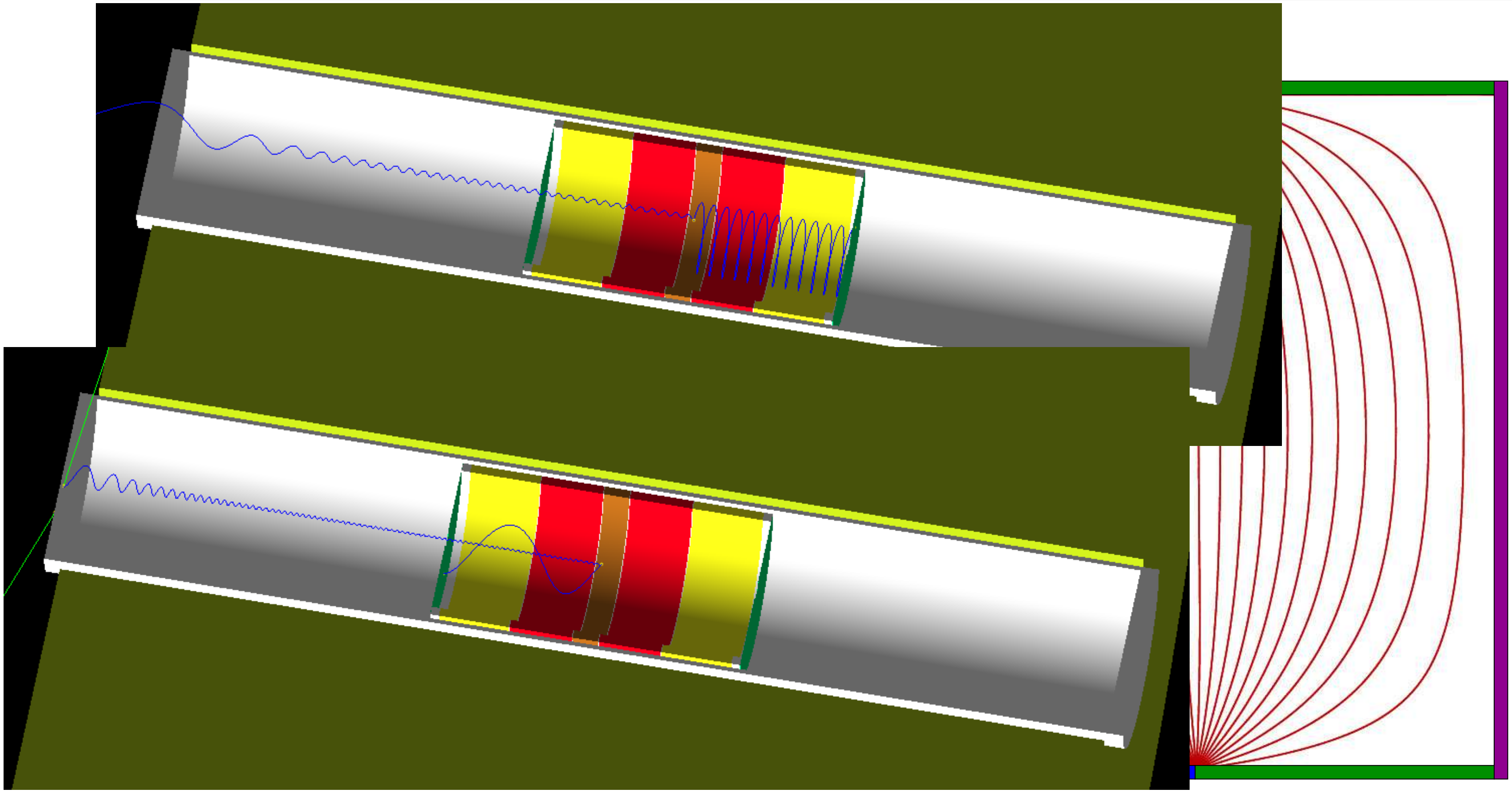

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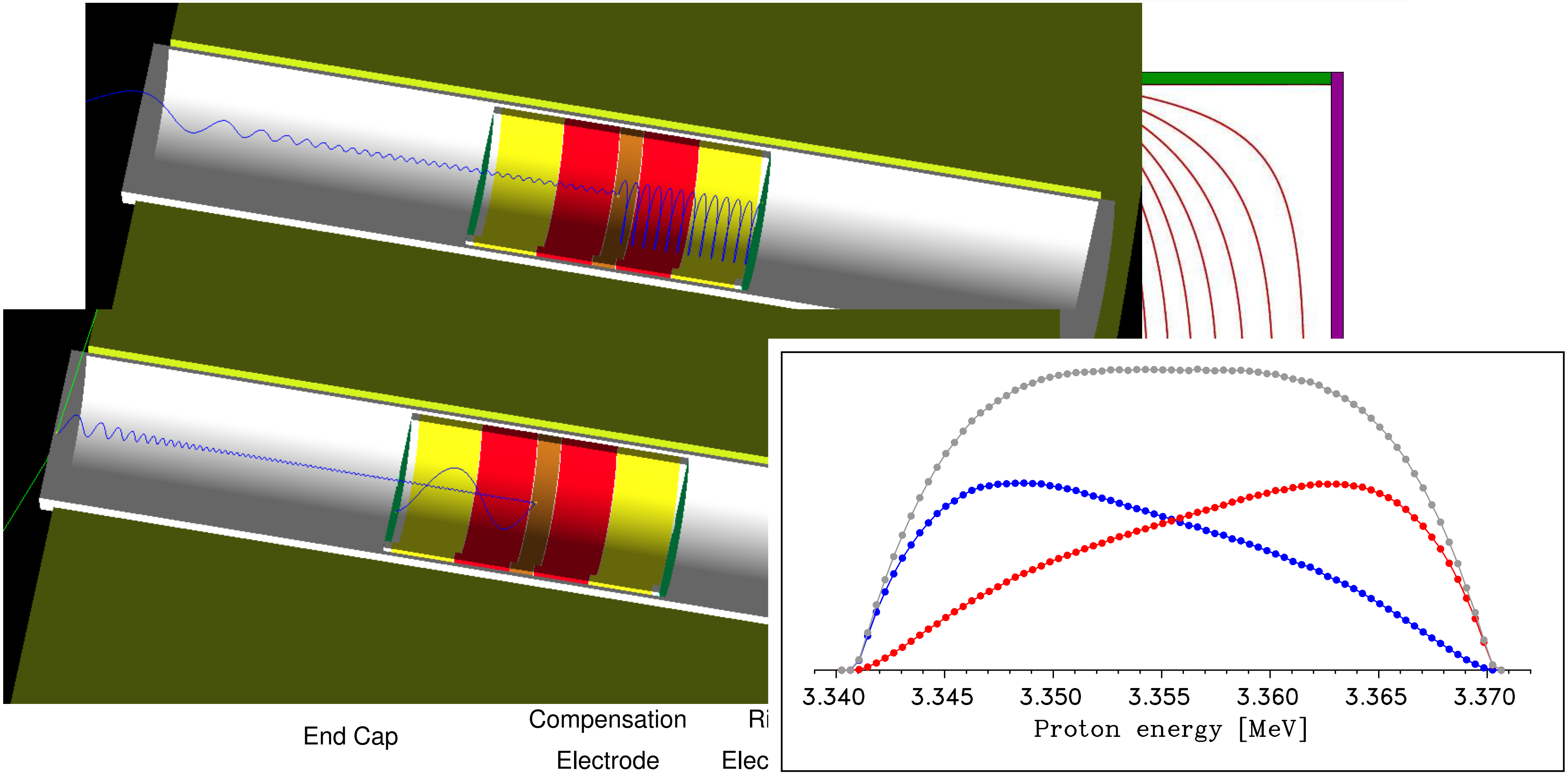
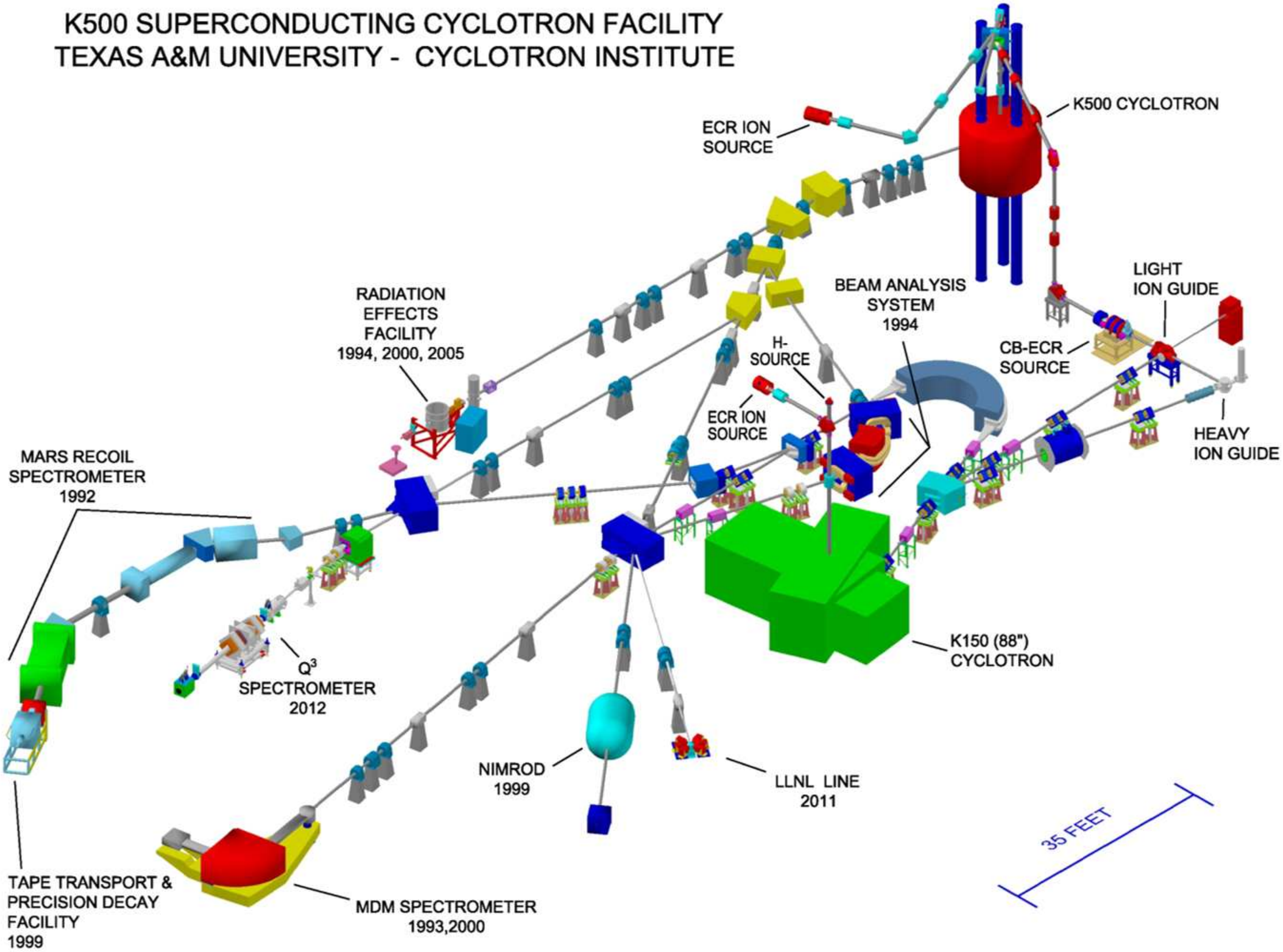


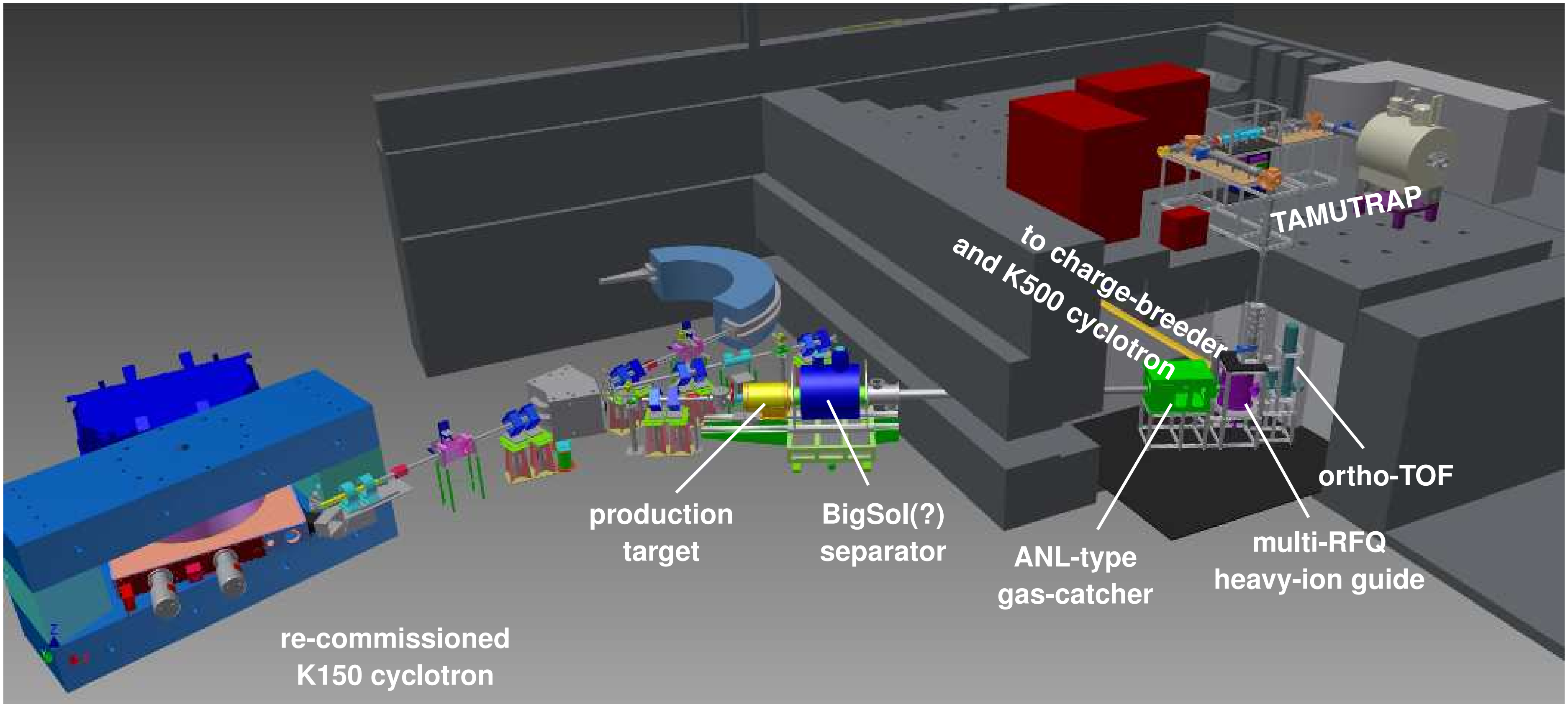
A Penning trap at T-REX CI/TAMU



The Texas A&M University Penning Trap

- will be the **world's most open-geometry** Penning trap!
- uniquely suited for studying β-delayed proton decays:

  $\beta - \nu$ correlations, ft values/V_{ud}
- mass measurements, EC studies, laser spectroscopy, . . .



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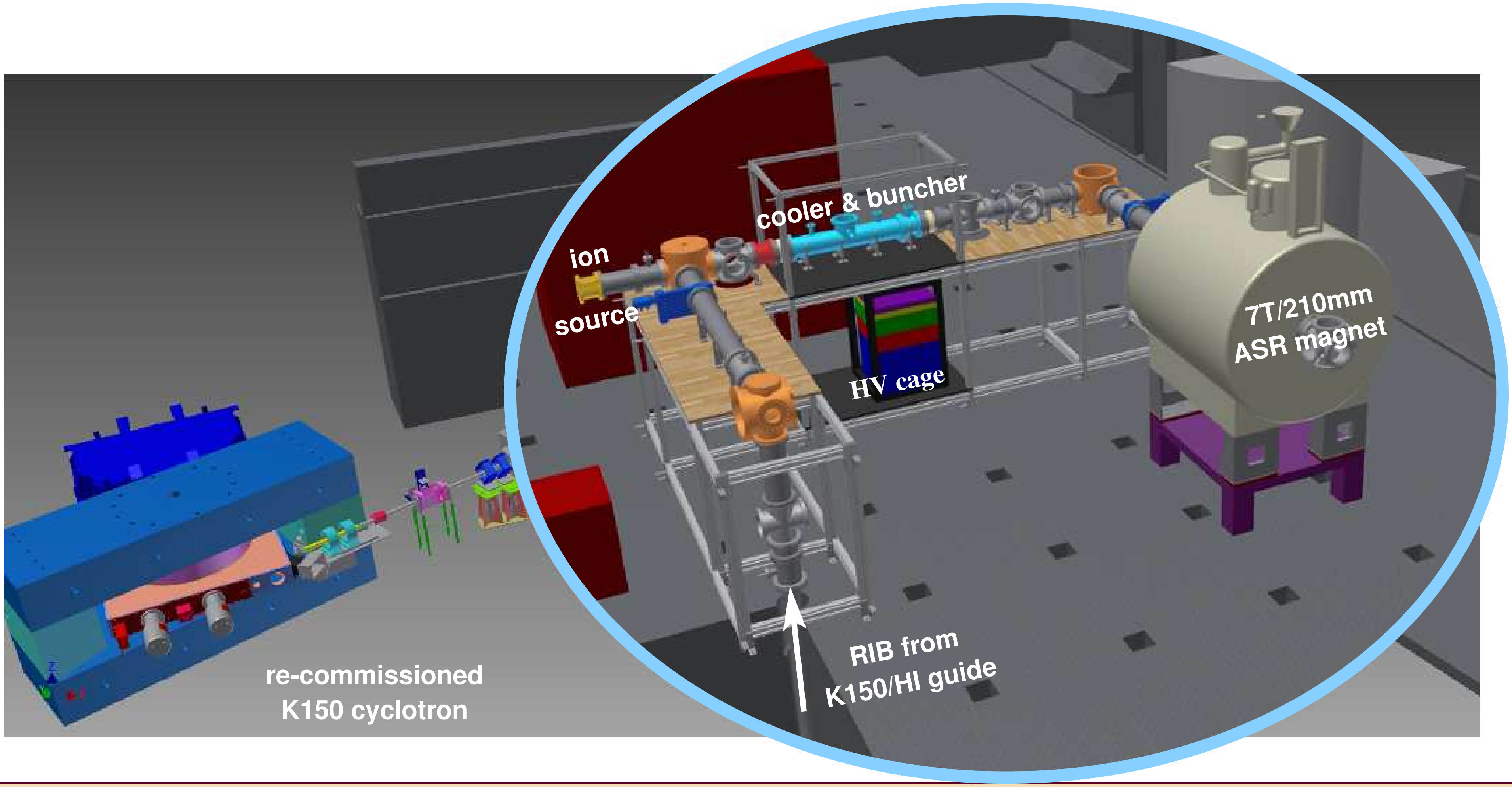
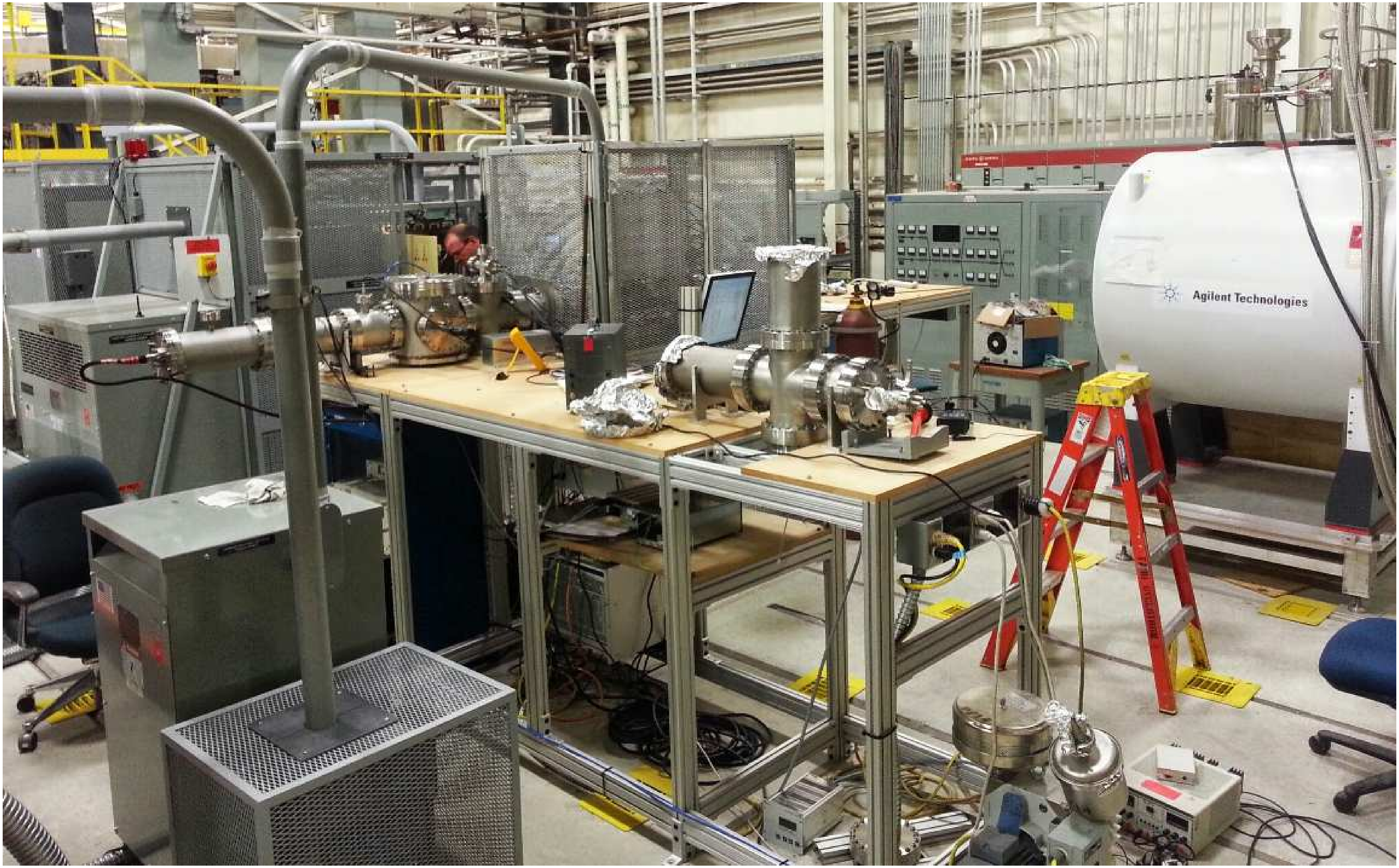


Status in 2013



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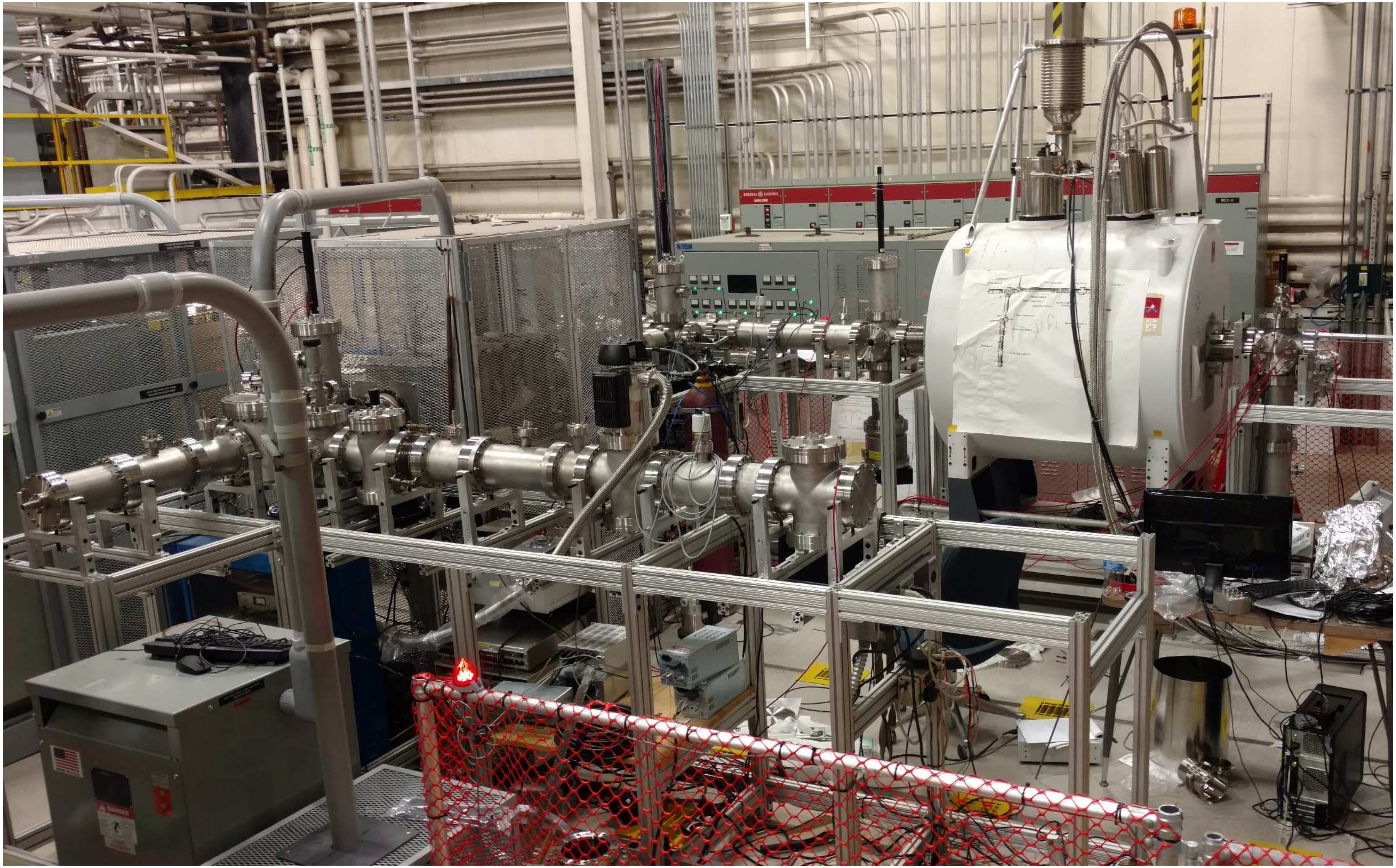

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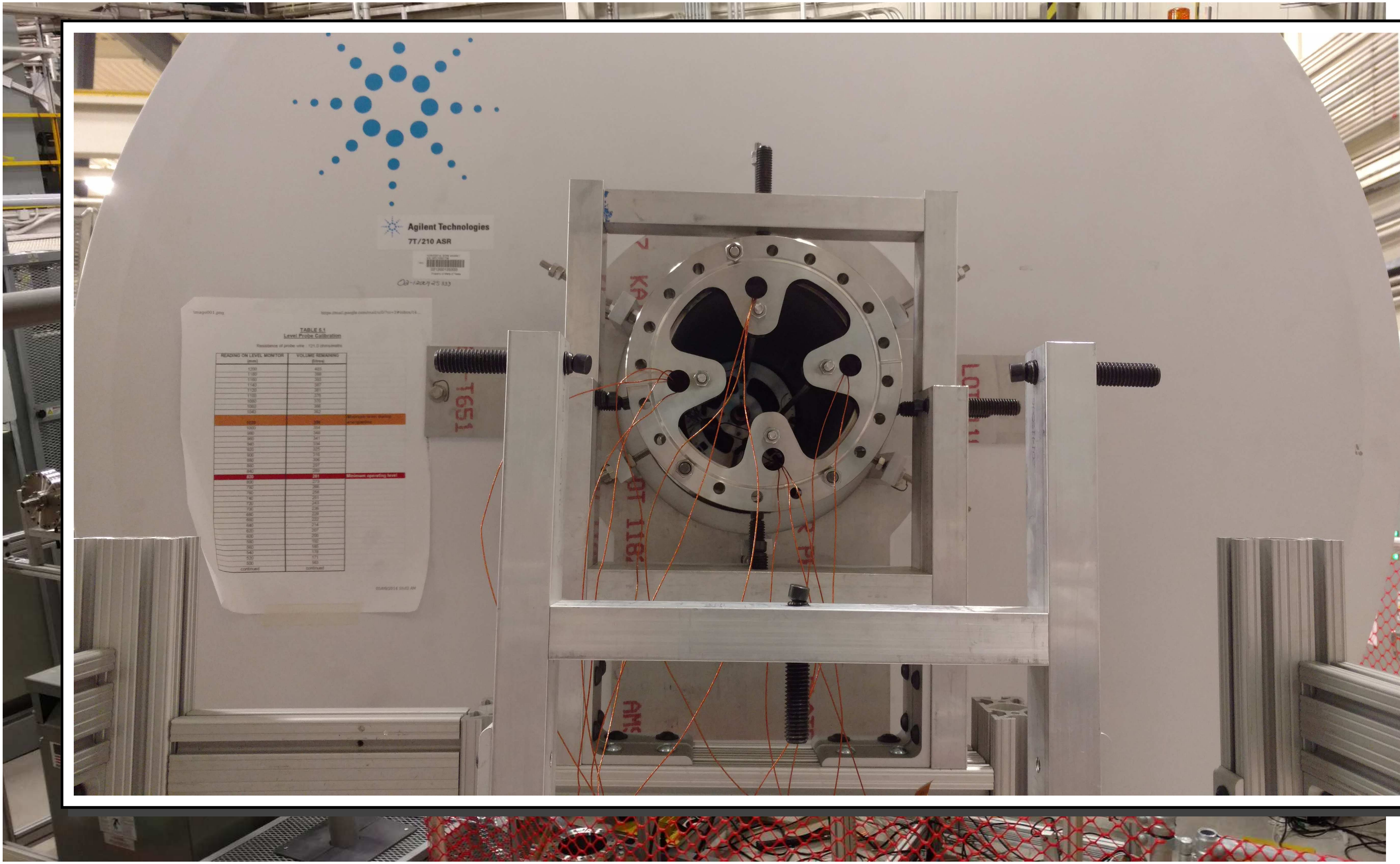

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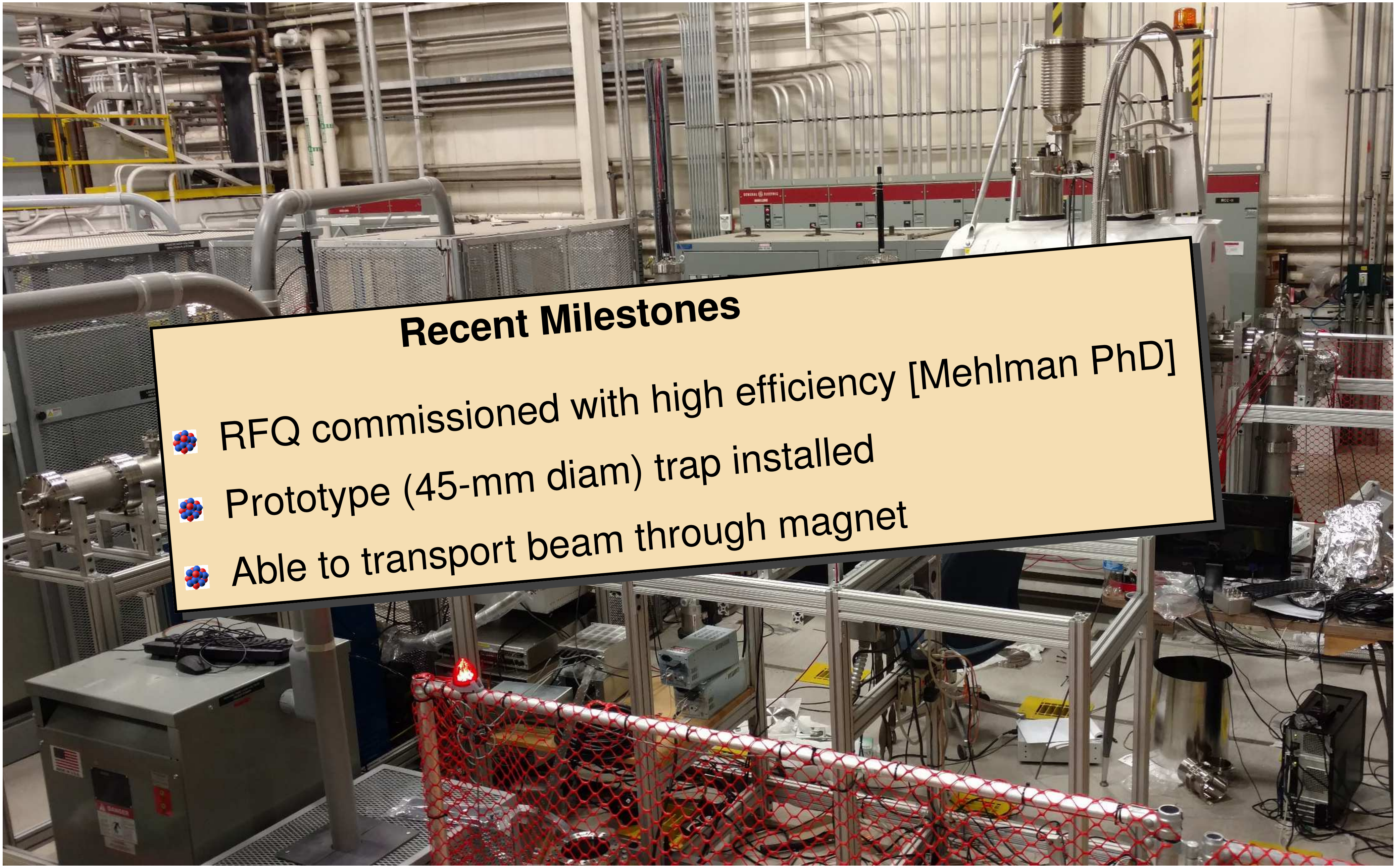

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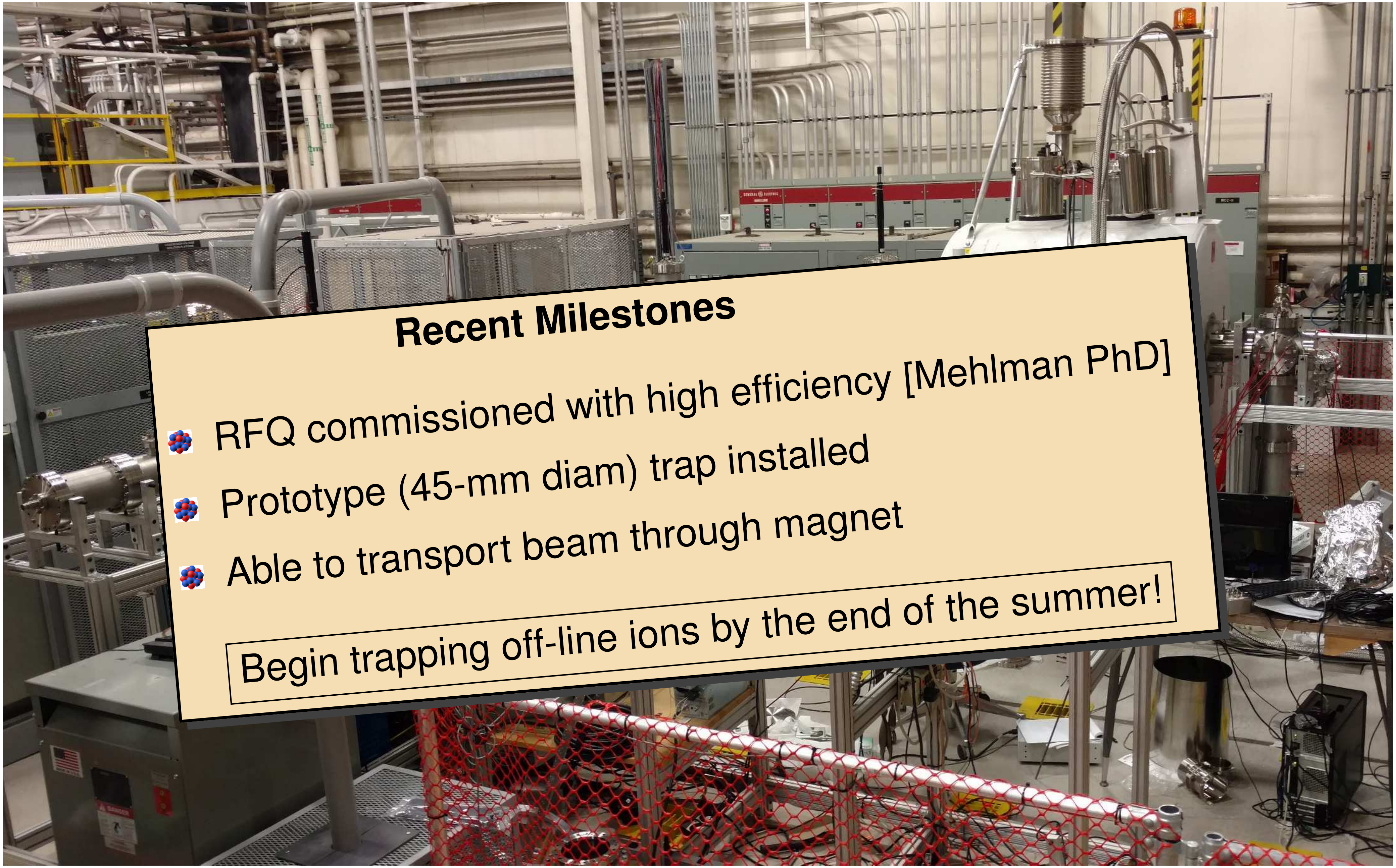

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Begin trapping off-line ions by the end of the summer!

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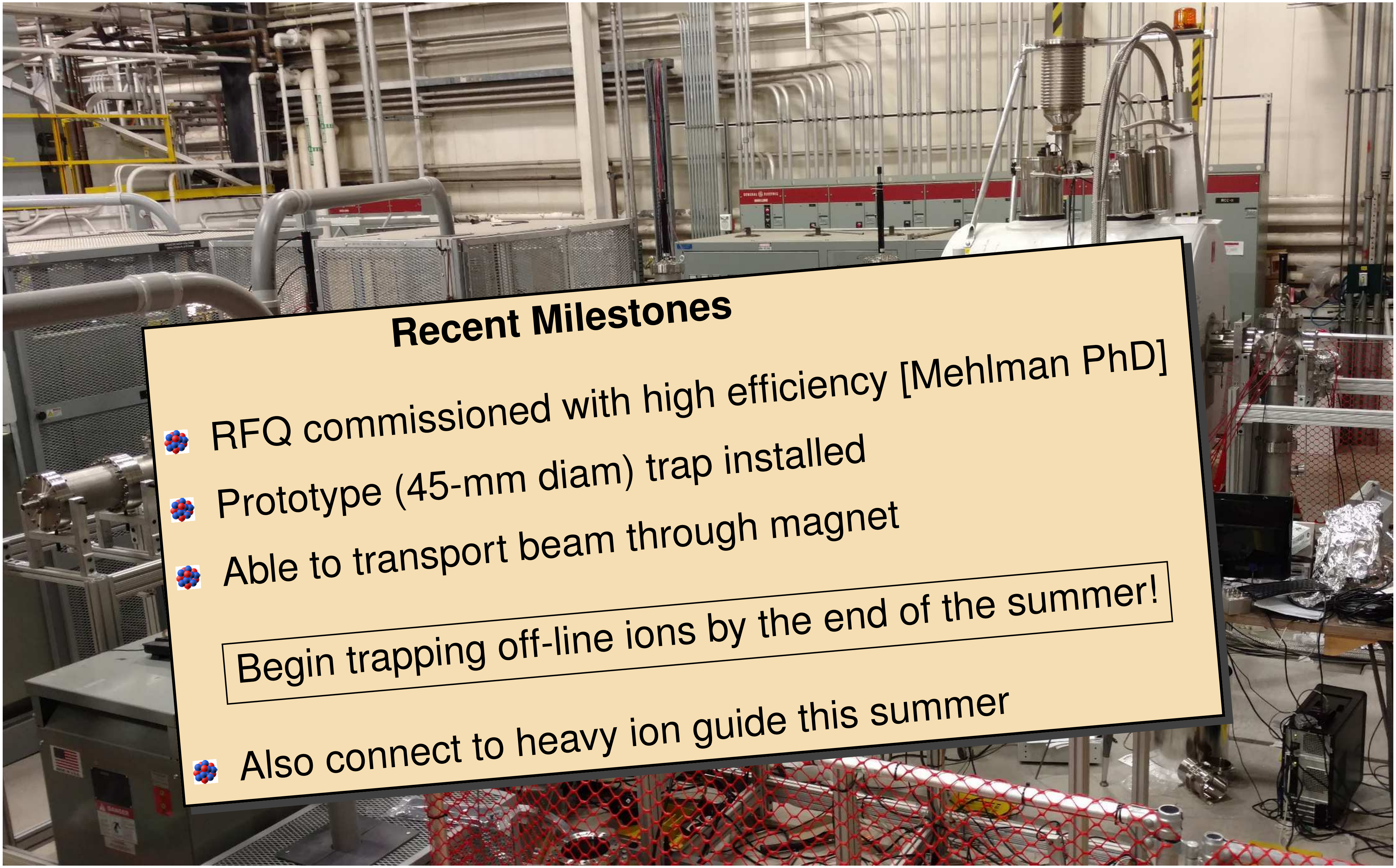

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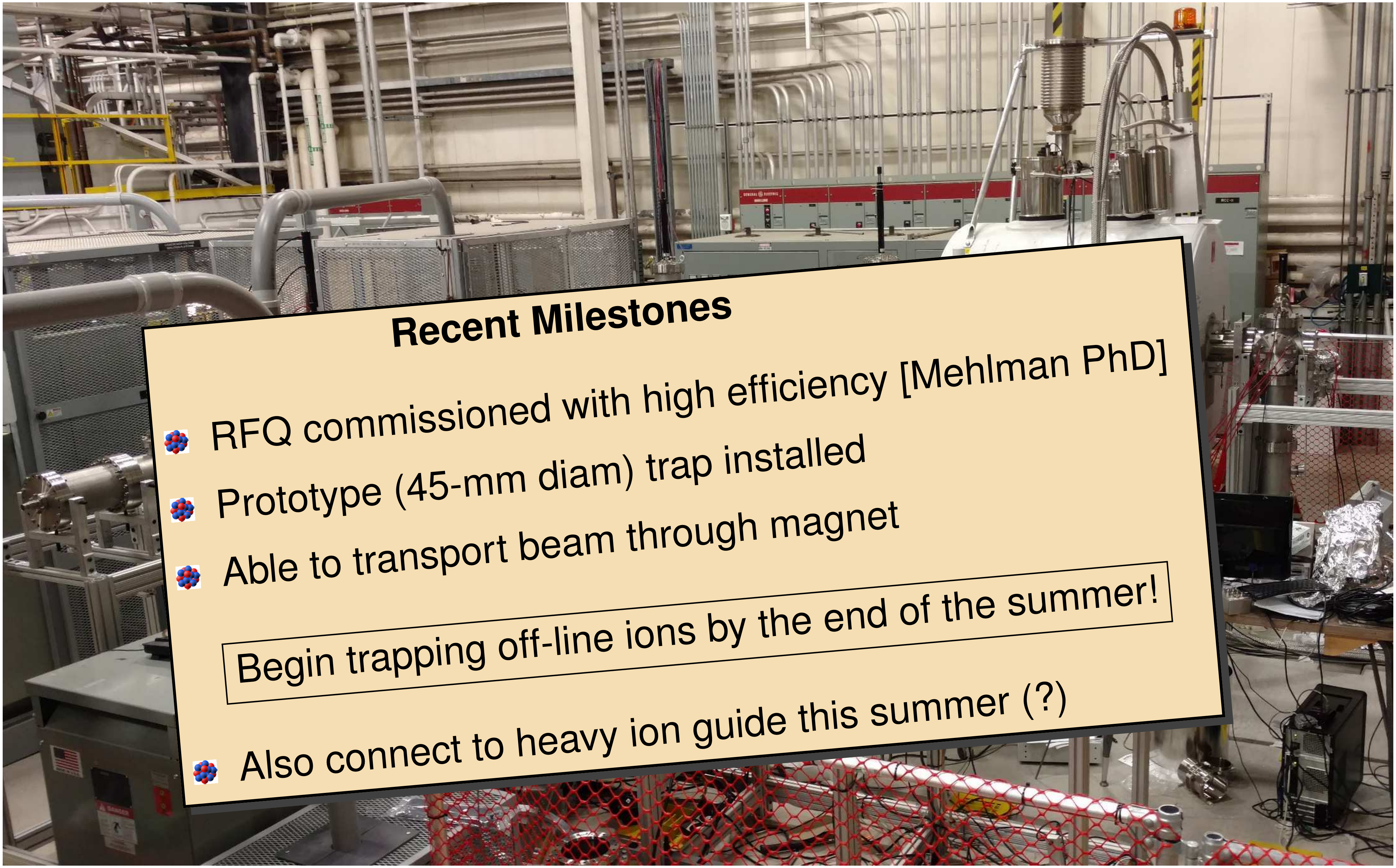

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Overview

1. Introduction

- I think we all know why we want to test the SM. . .
- One precision frontier: correlation parameters of β decay

2. Ion Traps

- LPC Trap
- Beta-decay Paul Trap
- TAMUTRAP

3. Neutral Atom Traps

- CENPA/ANL
- TRINAT

4. Elegant vs. brute-force tests

- *very* short summary

^{6}He $\beta - \nu$ Angular Correlations @ UW

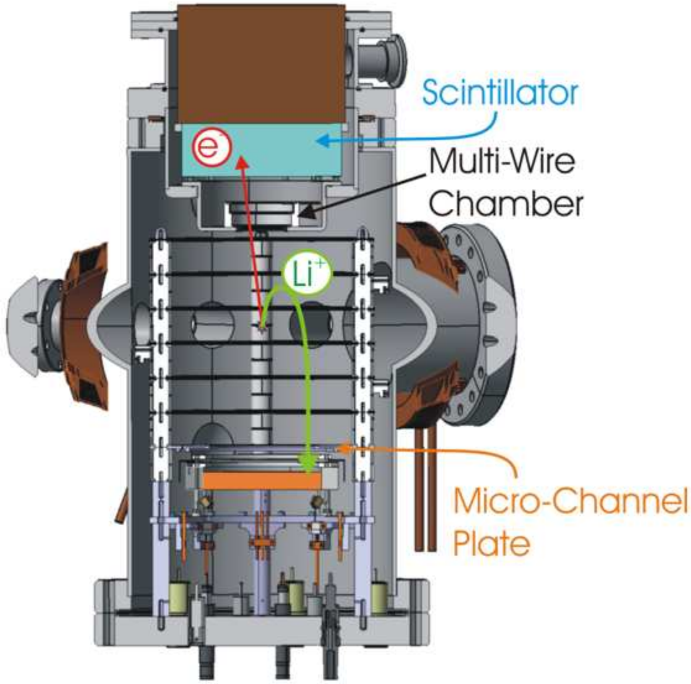
Y. Bagdasarova[1], K. Bailey[2], X. Fléchard[3], A. Garcia[1,*], R. Hong[1], A. Knecht[4], A. Leredde[2], E. Liennard[3], P. Mueller[2,*], O. Naviliat-Cuncic[5], T. O'Connor[2], M. Sternberg[1], H.E. Swanson[1], F. Wauters[1]

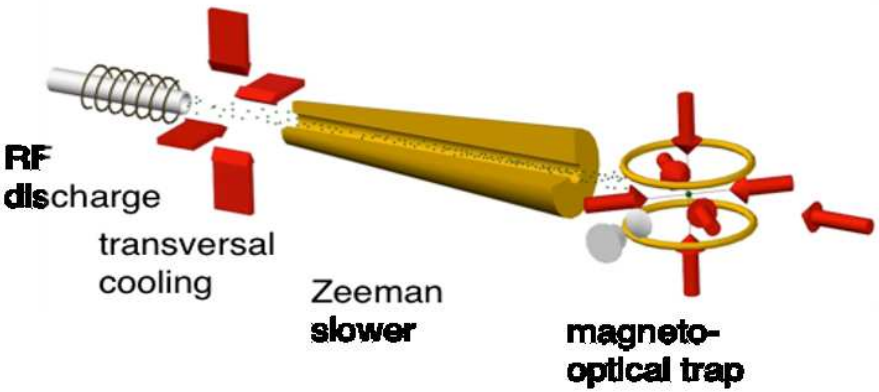
[1]*University of Washington,* [2]*Argonne National Lab,* [3]*LPC, CAEN, France*
[4]*PSI,* [5]*NSCL, Michigan State University*

[*]Spokepersons

- Goal: measure "little a" to 0.1% in ^{6}He
  - pure Gamow-Teller decay
  - sensitive to tensor couplings
  - simple nuclear and atomic structure
- Laser cooling and trapping to prepare ^{6}He source
- Detect electron and ^{6}Li in coincidence
- ΔE-E scintillator system for electron detection (energy, start of time-of-flight)
- Micro-channel plate detector for ^{6}Li detection (position, time-of-flight)

^{6}He Trap/Detector Chamber





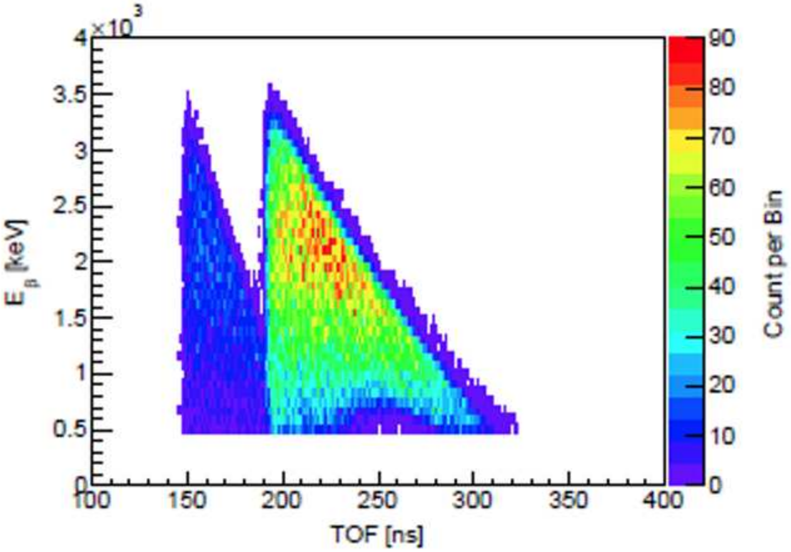
^{6}He $\beta - \nu$ Angular Correlations @ UW

Laser trapping:
All systems working and efficiencies enough for a determination of little-a at the 1% within 3 days (including calibrations)!

Status:
Presently working on systematic uncertainties.
Aiming for $\Delta a/a$ <1% in near future.
Ultimate goal: 0.1% uncertainty.

6He Source:
Reliable source of ~10^{10} ^{6}He's/s in low-background environment
A High-Intensity Source of 6He Atoms for Fundamental Research
A. Knecht et al. NIM A. **660**, 43 (2011)

Example of data taken recently:
E_β versus TOF which yields $\Delta a/a$ ≤1%.



(a) Experiment

^{6}He b Measurement @ UW

M. Fertl[1], A. Garcia[1], M. Guigue[4], P. Kammel[1], A. Leredde[2], P. Mueller[2], R.G.H. Robertson[1], G. Rybka[1], G. Savard[2], D. Stancil[3], M. Sternberg[1], H.E. Swanson[1], B.A. Vandeevender[4], A. Young[3]

[1]University of Washington, [2]Argonne National Lab, [3]North Carolina State University, [4]Pacific Northwest National Laboratory

- Goal: measure "little b" to 10^{-3} or better in ^{6}He
  - Highest sensitivity to tensor couplings
- Determine shape of beta spectrum in search for tensor couplings.
- Use Cyclotron Radiation Electron Spectroscopy. Similar to Project 8 setup for tritium decay but need to extend the technique to higher energy betas and to a precision determination of a continuum spectrum. Non trivial: under development.
- **In 1 day of running would determine *b* one order of magnitude better than any previous experiment.**

Decay rate: C_T and C_T' represent the new physics. C_A is the usual axial coupling constant for Weak Int.

$$dw = dw_0 \left[1 + a \frac{\vec{p}_e}{E_e} \cdot \frac{\vec{p}_\nu}{E_\nu} + b \frac{\Gamma m_e}{E_e} \right]$$

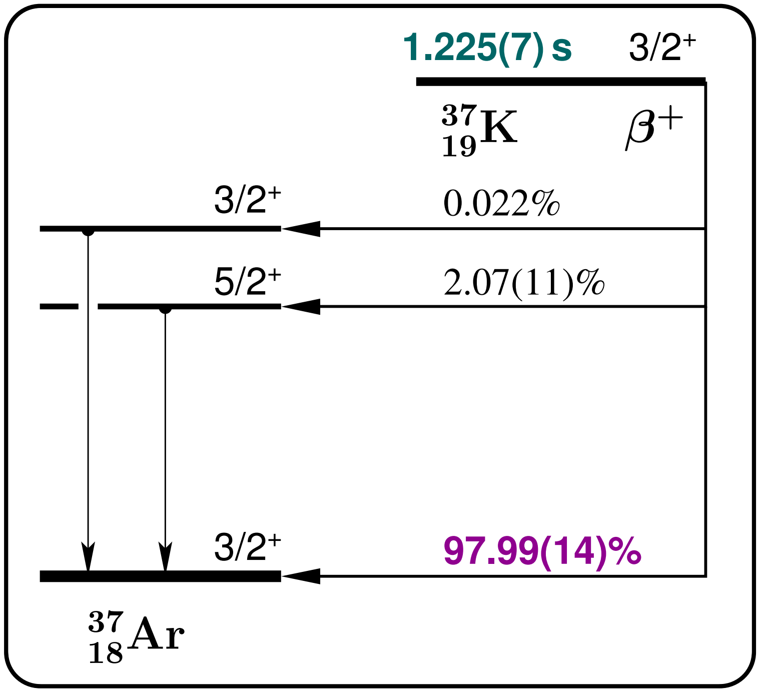
$$a \approx -\frac{1}{3} \frac{2|C_A|^2 - |C_T|^2 + |C_T'|^2}{2|C_A|^2 + |C_T|^2 + |C_T'|^2}$$

$$b \approx \frac{\mathrm{Re}\left[2C_A\left(C_T + C_T'\right)\right]}{2|C_A|^2 + |C_T|^2 + |C_T'|^2}$$

Little-*b* is called "Fierz interference" and depends linearly on the new couplings. This makes it a more sensitive probe of the new physics.

The β^+-decay of ^{37}K

Almost as simple as $0^+ \rightarrow 0^+$:



- **isobaric analogue** decay
- **strong** branch to g.s.

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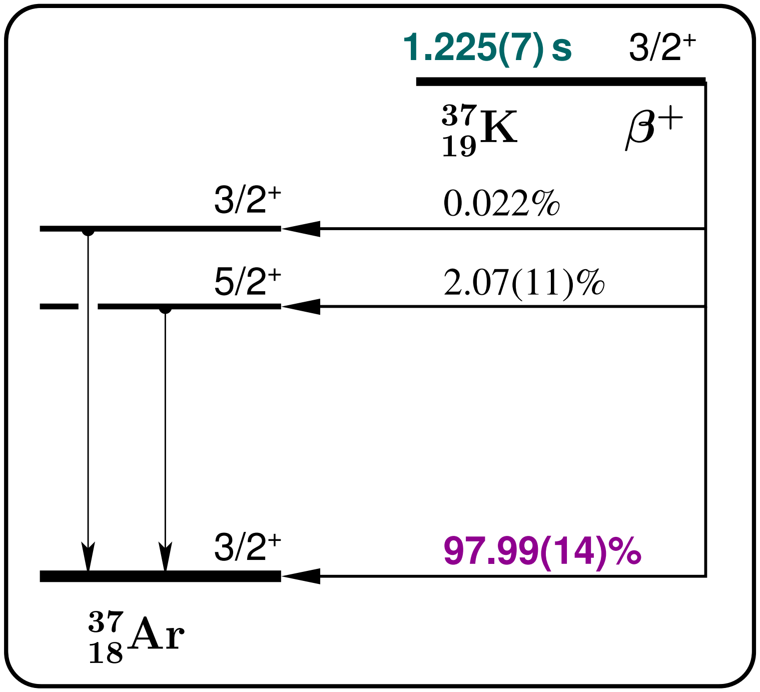

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- **polarization/alignment**
- **mixed** Fermi/Gamow-Teller

$\Rightarrow$ need $\rho \equiv C_A M_{GT} / C_V M_F$ to get predictions for correlation parameters

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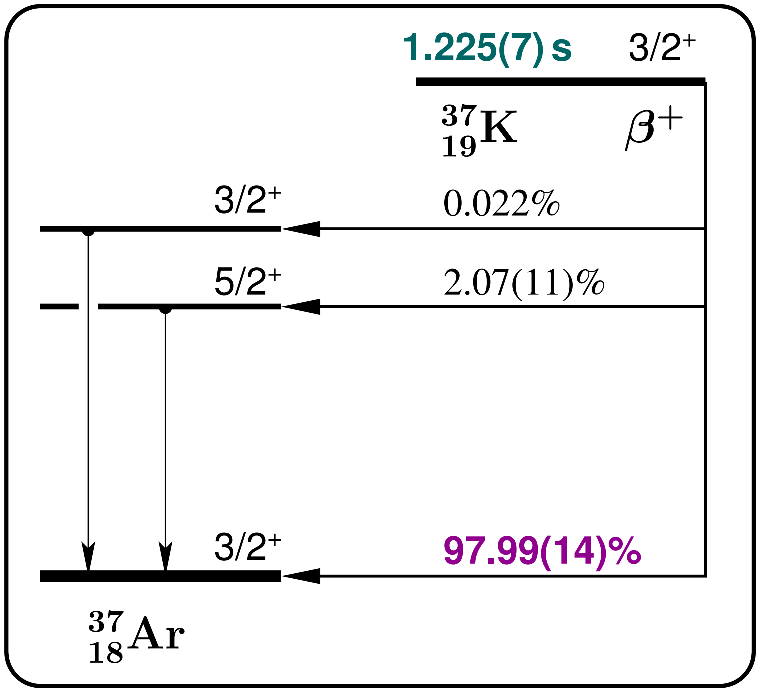

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get ρ from the comparative half-life:

$$\boxed{\rho^2 = \frac{2\mathcal{F}t^{0^+\rightarrow 0^+}}{\mathcal{F}t} - 1}$$

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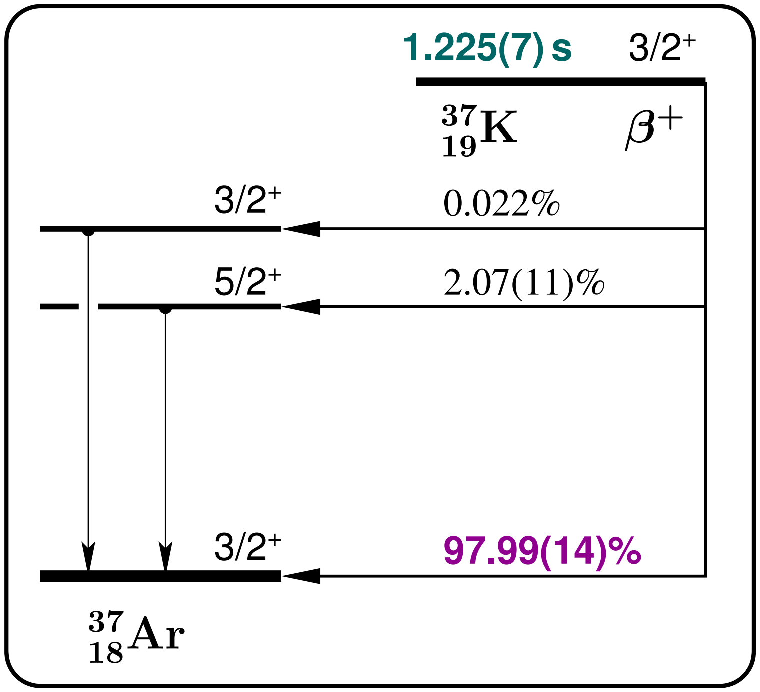

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$$\left.\begin{array}{r l} Q_{EC}: & \pm 0.003\% \\ BR: & \pm 0.14\% \\ t_{1/2}: & \pm \mathbf{0.57\%} \end{array}\right\} \boldsymbol{\mathcal{F}t} = 4562(28) \;\Rightarrow\; \boxed{\boldsymbol{\rho} = 0.5874(\mathbf{71})}$$

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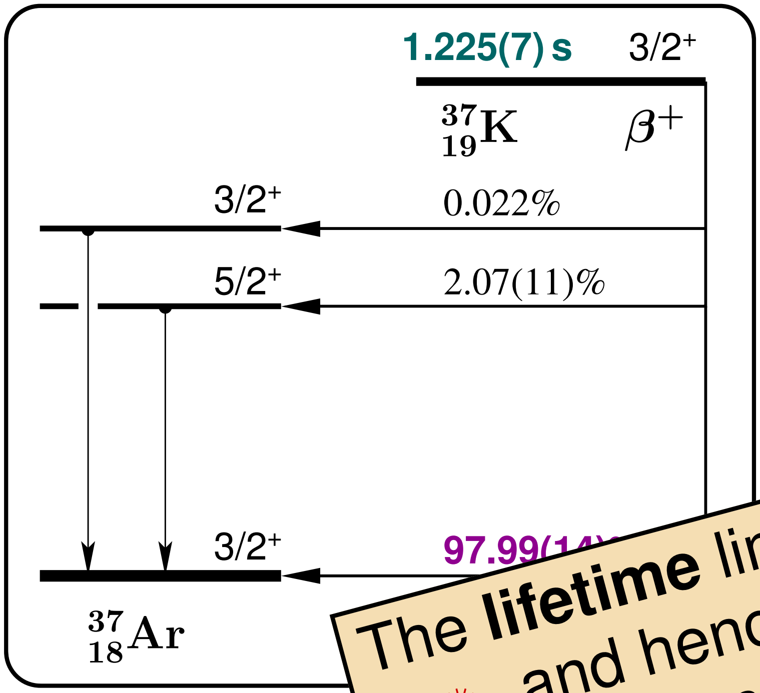

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$M_{GT}/C_V M_F$

r correlation pa-

The **lifetime** limited the $\mathcal{F}t$ value
- and hence precision of ρ
- and hence the predictions of the correlation parameters

get ρ fro lf-life:

$$\boxed{\rho^2 = \frac{2\mathcal{F}t^{0^+\rightarrow 0^+}}{\mathcal{F}t} - 1}$$

Q_{EC}: ±0.003%

BR: ±0.14%

$t_{1/2}$: **±0.57%**

$$\mathcal{F}t = 4562(28) \quad \Rightarrow \quad \boxed{\rho = 0.5874(\mathbf{71})}$$

Angular distribution of a $\frac{3}{2}^{+} \rightarrow \frac{3}{2}^{+}$ *decay*

$$dW \sim 1 + a_{\beta\nu}\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu} + b\Gamma\frac{m}{E_e} + \frac{\vec{I}}{I}\cdot\left[\boldsymbol{A_\beta}\frac{\vec{p}_e}{E_e} + \boldsymbol{B_\nu}\frac{\vec{p}_\nu}{E_\nu} + \boldsymbol{D}\frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu}\right]$$

Correlation	Expectation
$\beta-\nu$ correlation:	$a_{\beta\nu} = 0.6580(\mathbf{61})$
Fierz interference parameter:	$b_{\text{Fierz}} = 0$ (sensitive to scalars and tensors)
β asymmetry:	$A_\beta = -0.5739(\mathbf{21})$
ν asymmetry:	$B_\nu = -0.7791(\mathbf{58})$
Time-violating D coefficient:	$D = 0$ (sensitive to imaginary couplings)
	$\vdots$
a $\beta-$recoil observable specific to our geometry	$R_{\text{slow}} \sim \frac{1-a_{\beta\nu}-2c_{\text{align}}/3\,-\,(A_\beta-B_\nu)}{1-a_{\beta\nu}-2c_{\text{align}}/3\,+\,(A_\beta-B_\nu)} = 0$

Recall: measurements of these correlations to $\lesssim \mathbf{0.1\%}$
complement collider experiments and test the SM

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Correlation	Expectation
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β asymmetry:	$A_\beta = -0.5739(\mathbf{21}) \quad\to\quad -0.5719(\mathbf{7})$
ν asymmetry:	$B_\nu = -0.7791(\mathbf{58}) \quad\to\quad -0.7703(\mathbf{18})$
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Recall: measurements of these correlations to $\lesssim \mathbf{0.1\%}$ complement collider experiments and test the SM

(data in hand for improved branching ratios)

Thank you, AMO physicists!!

Atomic methods have opened up a new vista in precision work and provide the ability to push β decay measurements to $\lesssim 0.1\%$

- laser-cooling and trapping (magneto-optical traps)
- sub-level state manipulation (optical pumping)
- characterization/diagnostics (photoionization)

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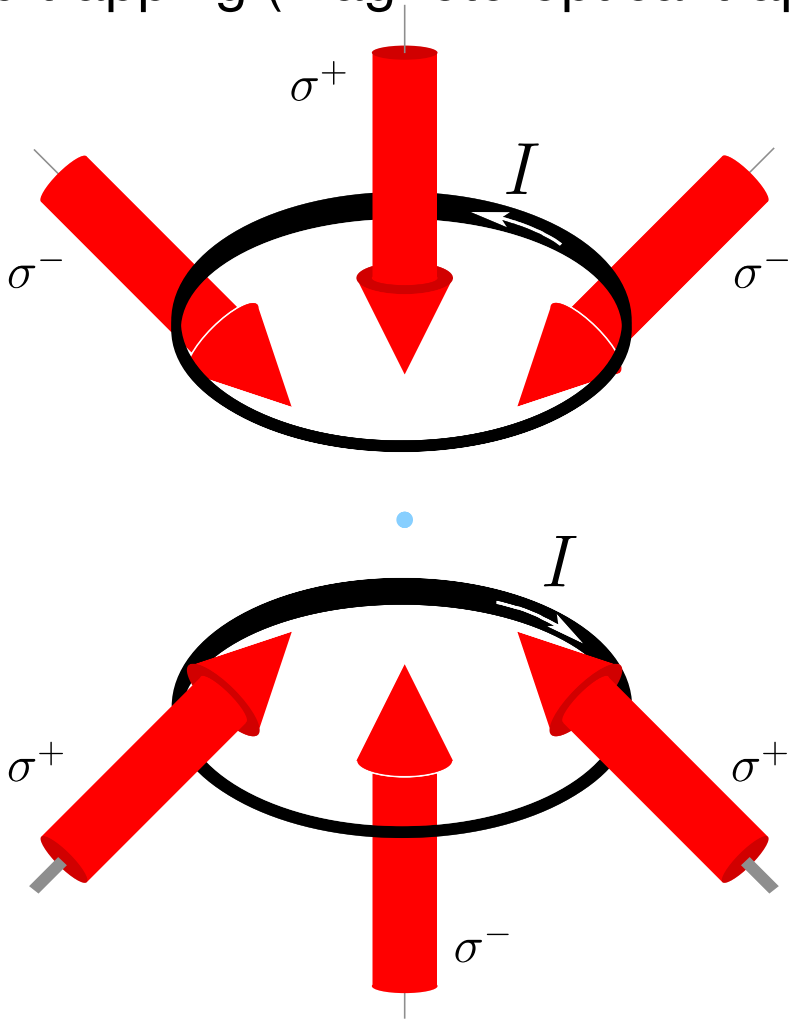

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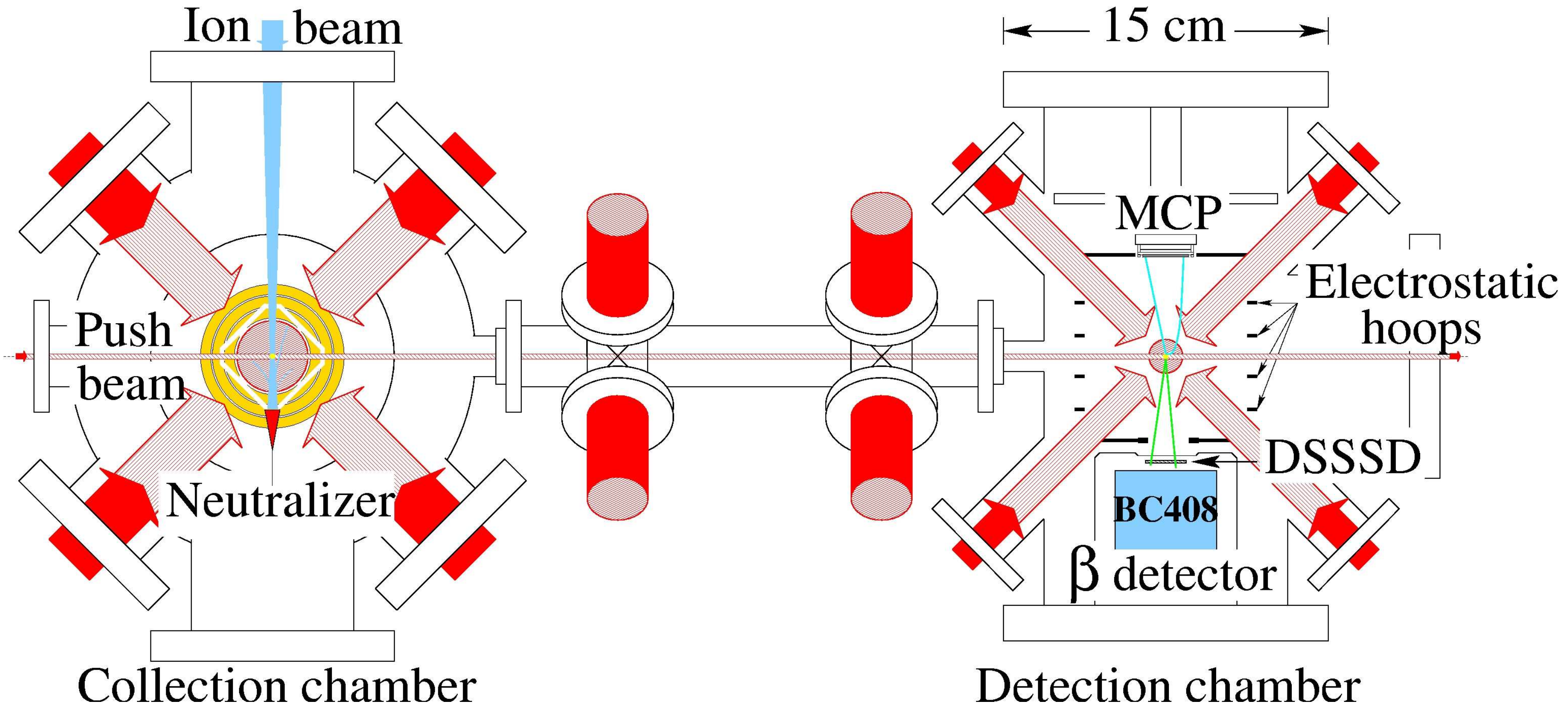

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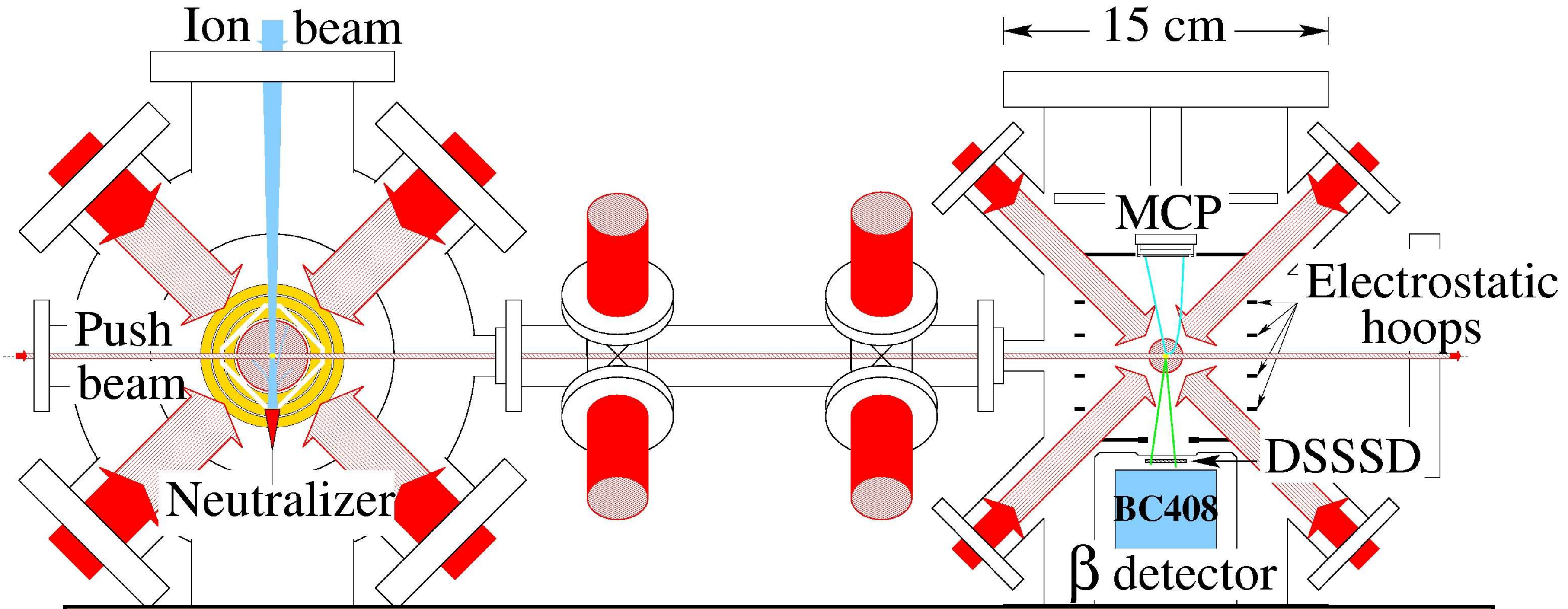

Traps provide a **backing-free**, very **cold** ($\lesssim 1$ mK), **localized** ($\sim 1\ \mathrm{mm}^3$) source of **isomerically-selective**, **short-lived** radioactive atoms

Thank you, AMO physicists!!

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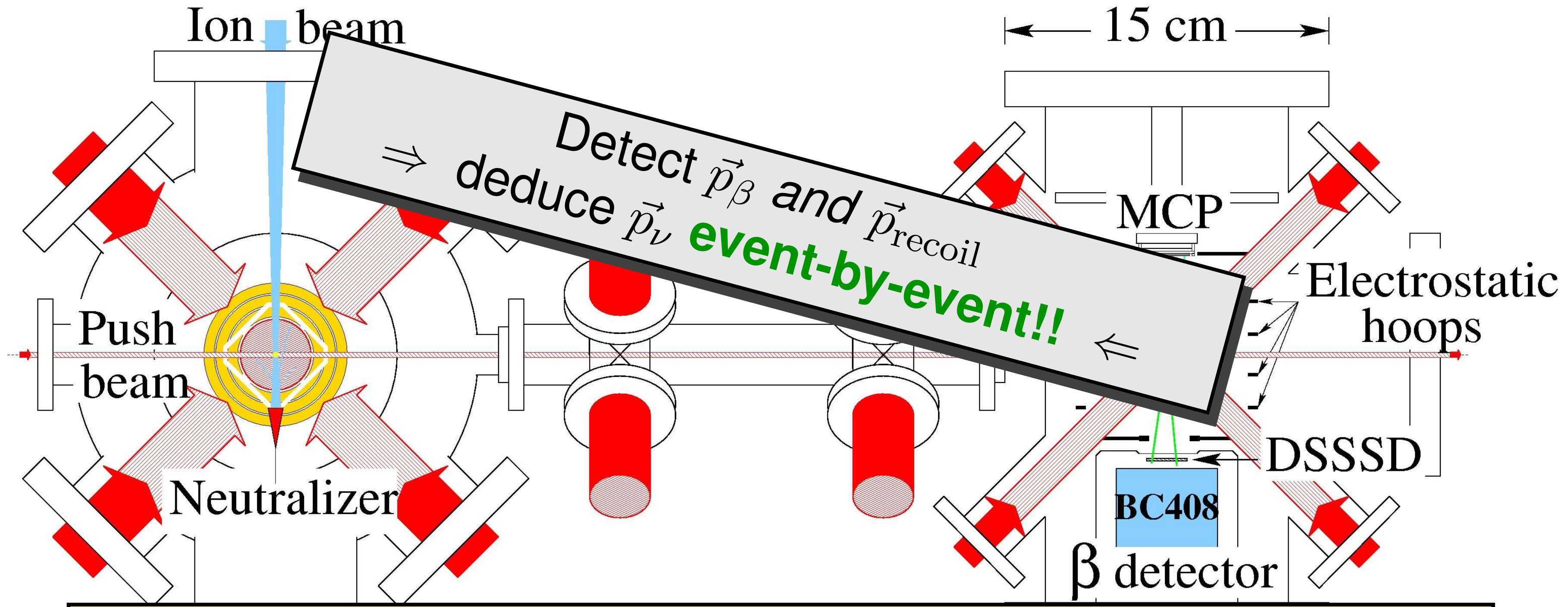
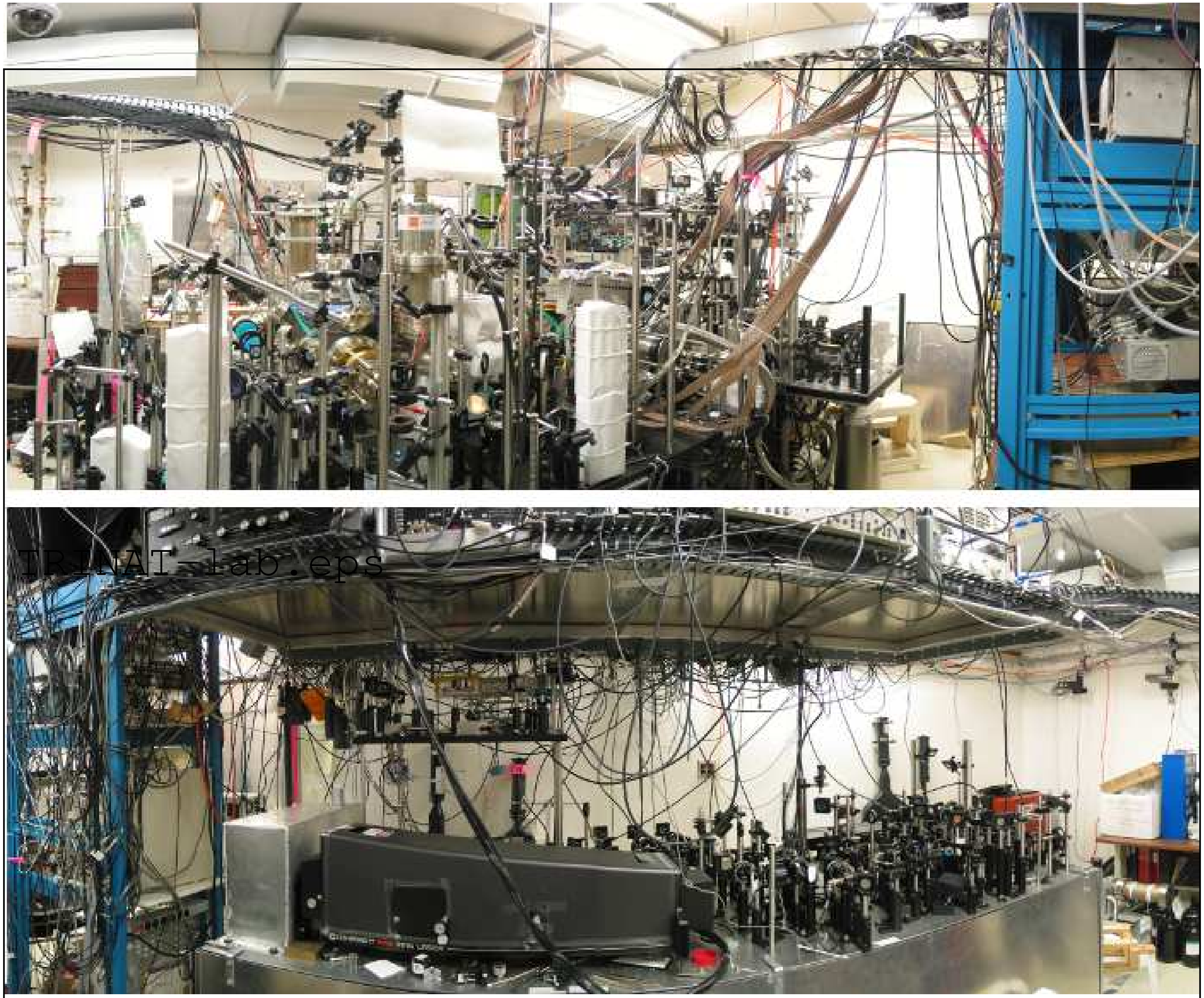


Detect $\vec{p}_\beta$ and $\vec{p}_{\rm recoil}$

⇒ deduce $\vec{p}_\nu$ **event-by-event!!** ⇐

Traps provide a **backing-free**, very **cold** ($\lesssim 1$ mK), **localized** ($\sim 1\ \mathrm{mm}^3$) source of **isomerically-selective**, **short-lived** radioactive atoms

The TRINAT lab

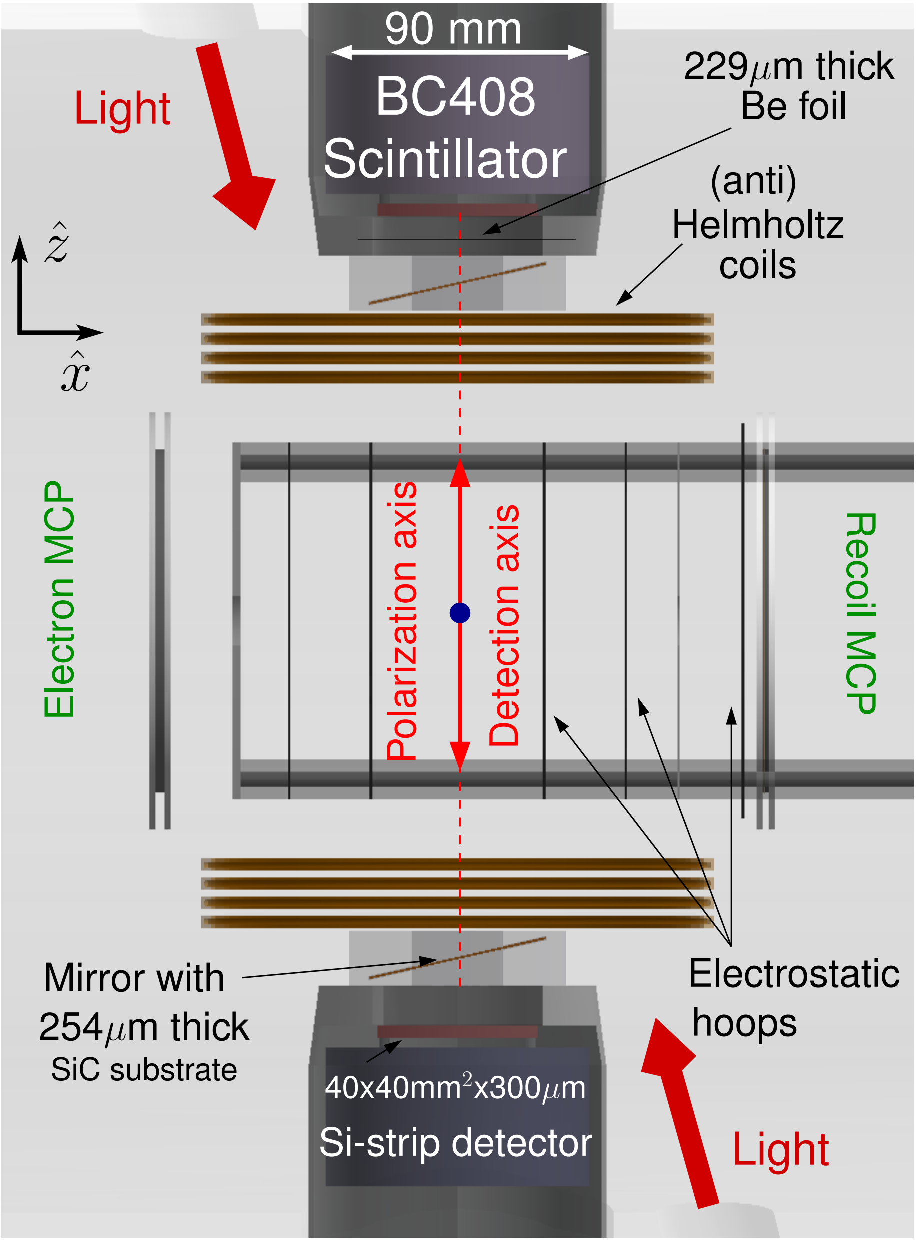


TRINAT_lab.eps

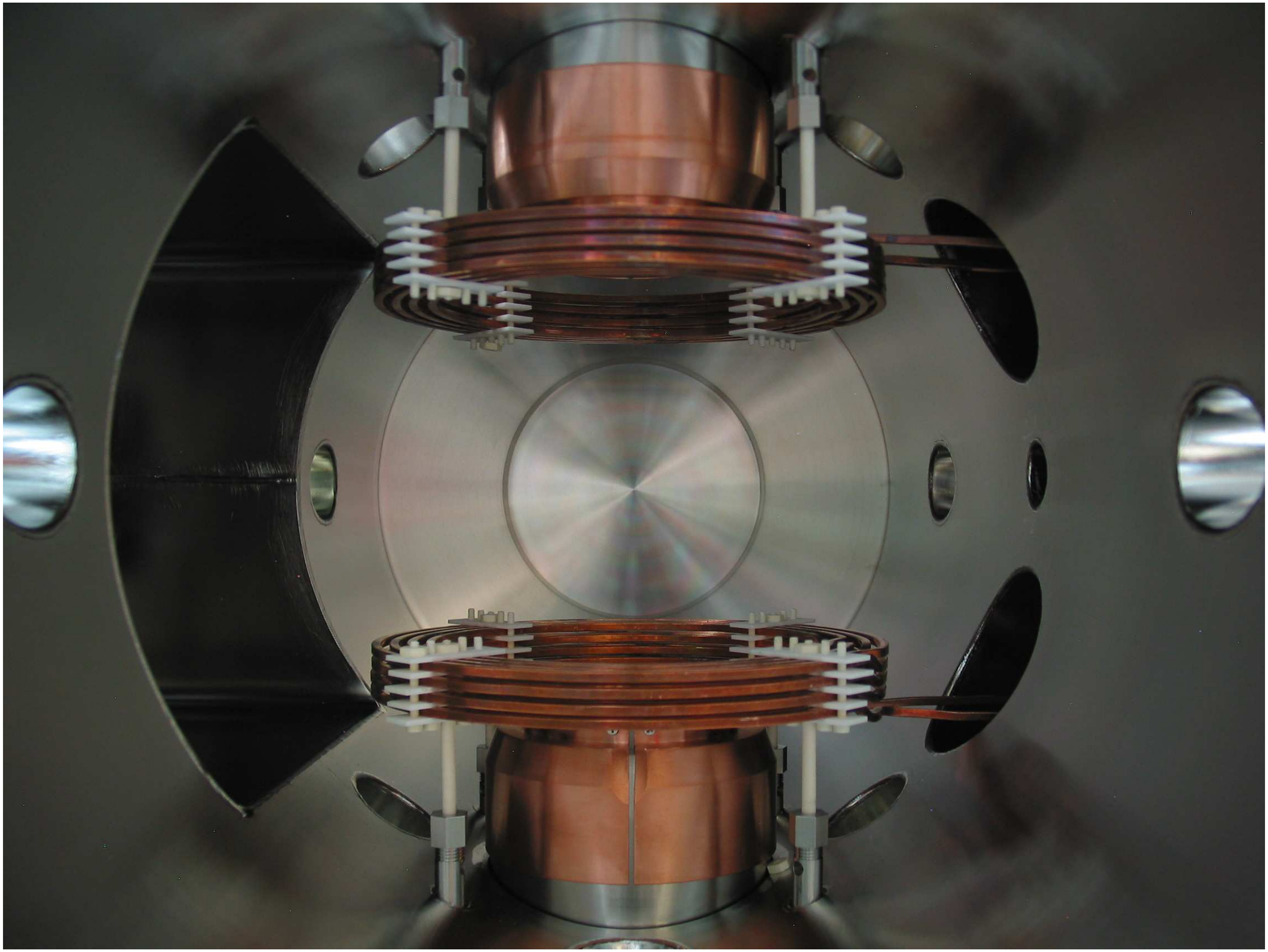
The measurement chamber

- Shake-off e^- detection
  $\rightsquigarrow$ know decay occured from trap
- Better control of OP beams
  $\rightsquigarrow$ less heating, higher P
- $B_{\rm quad} \rightarrow B_{\rm OP}$ quickly: AC-MOT
  $\rightsquigarrow$ better duty cycle, higher polarization
- Increased β/recoil solid angles
  $\rightsquigarrow$ better statistics
- Stronger E-field (one day…)
  $\rightsquigarrow$ better separation of charge states, higher statistics

⋮



Outline of polarized experiment



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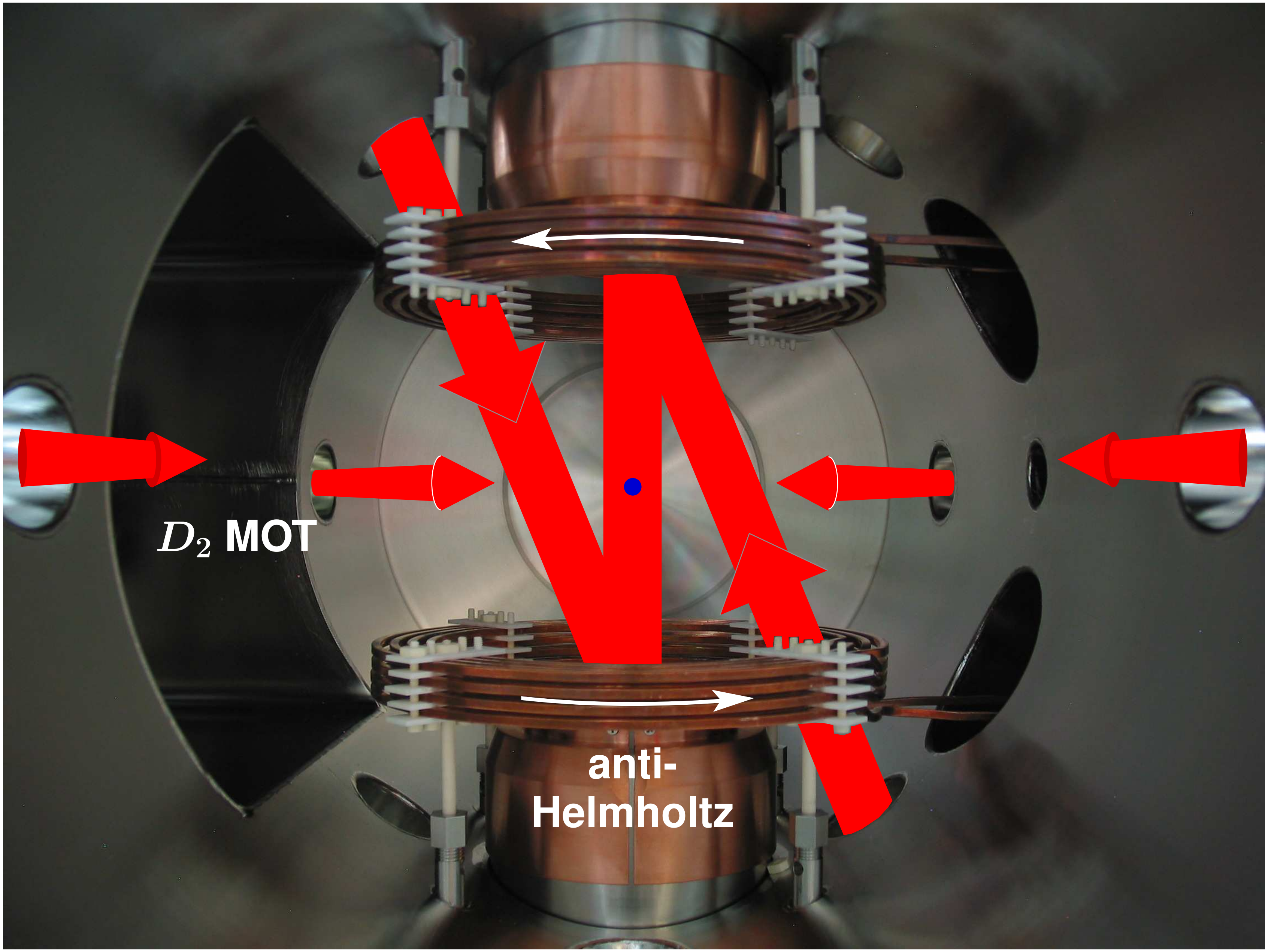

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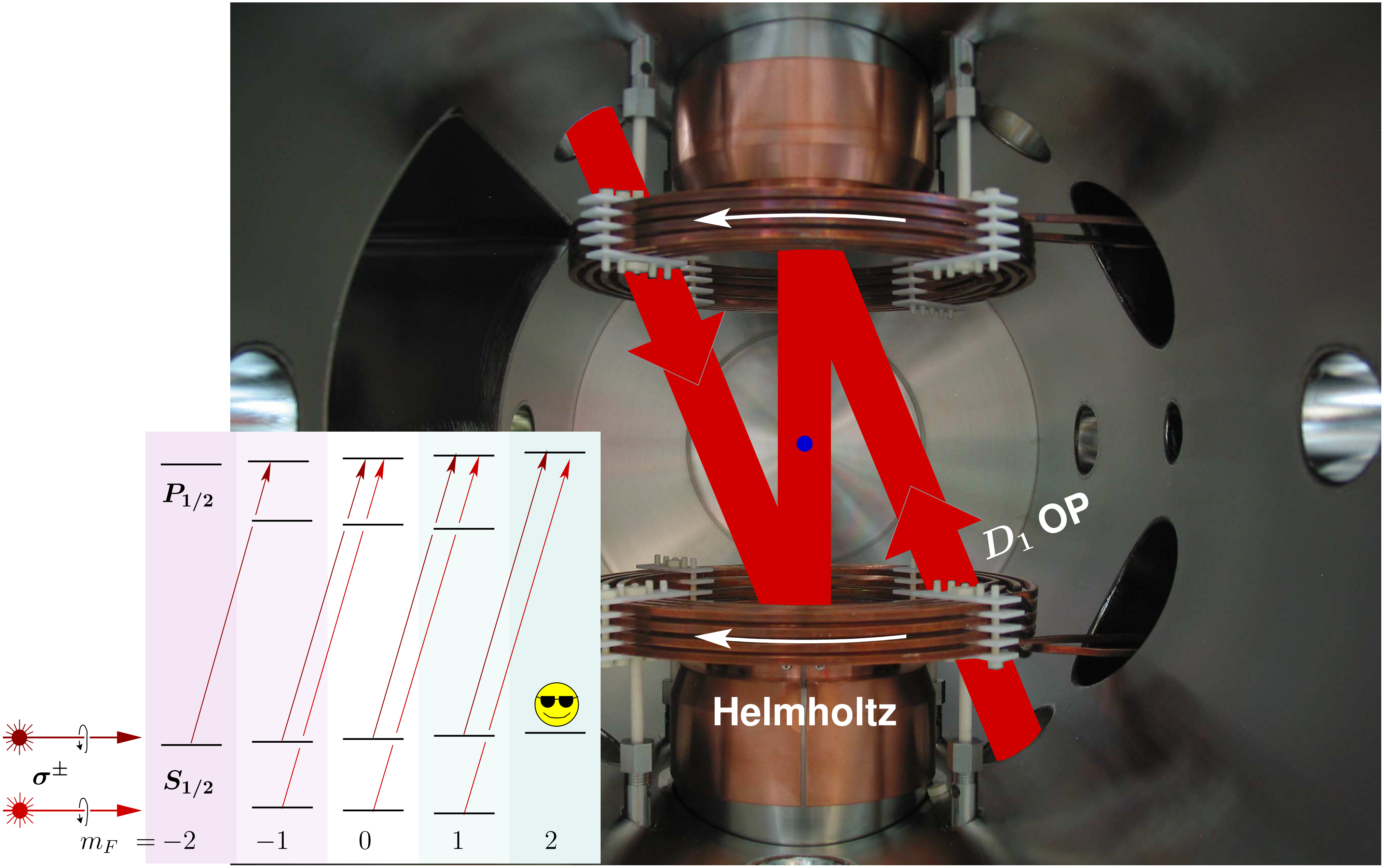

$\vec{F} = \vec{I} + \vec{J}$

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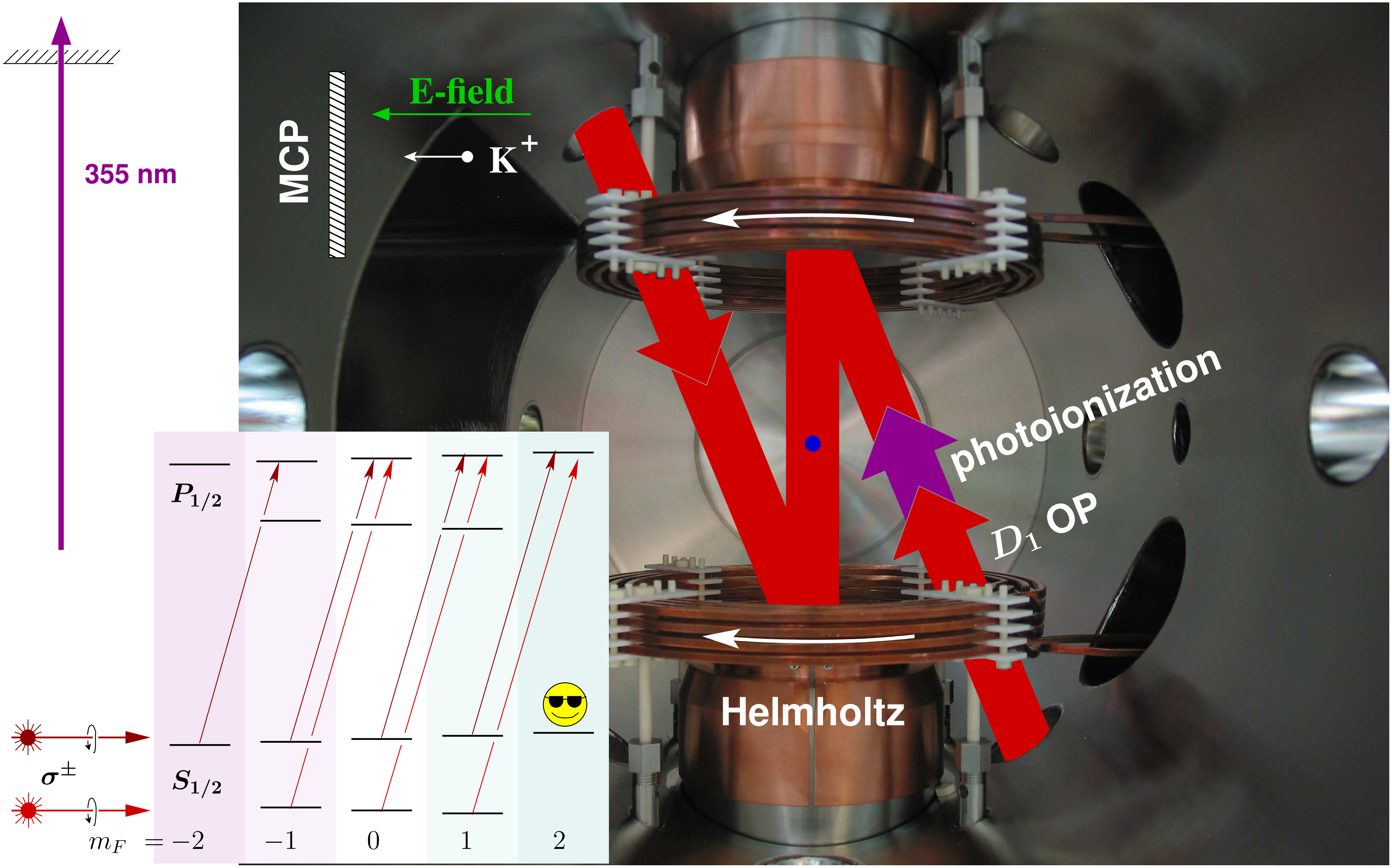
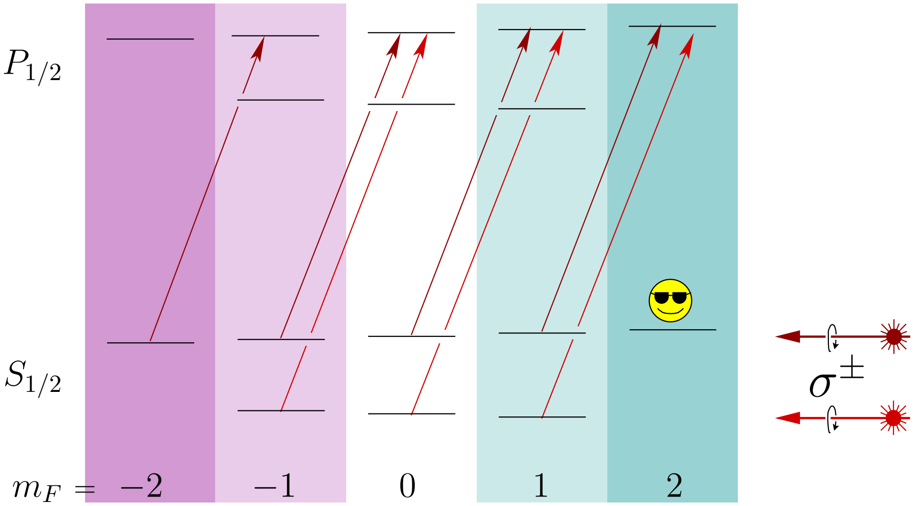
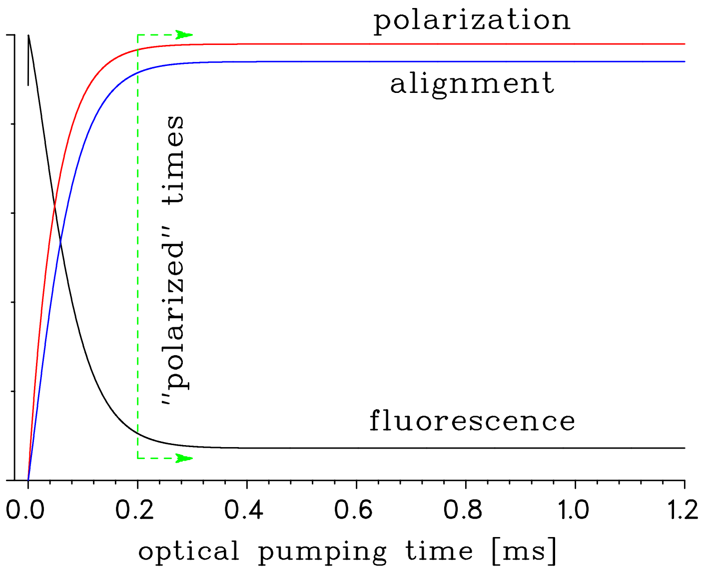


$$\vec{F} = \vec{I} + \vec{J}$$

Atomic measurement of P

Deduce P based on a model of the excited state populations





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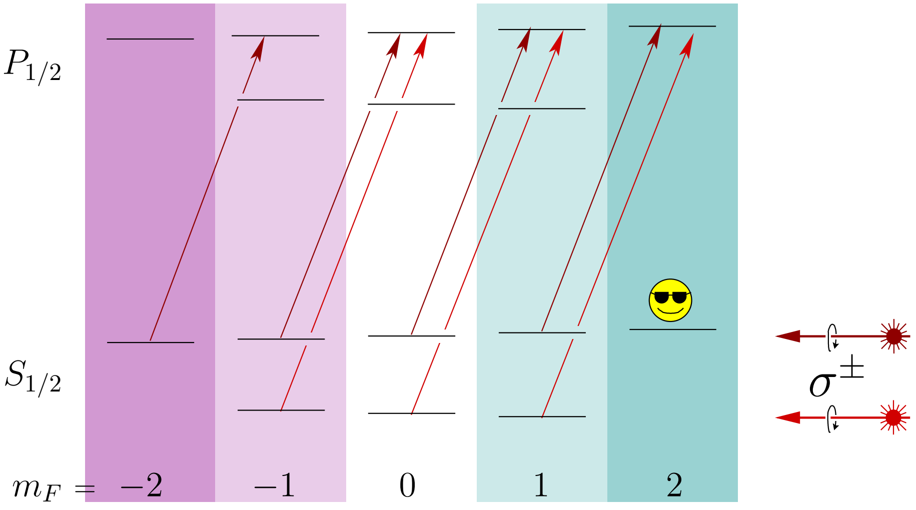
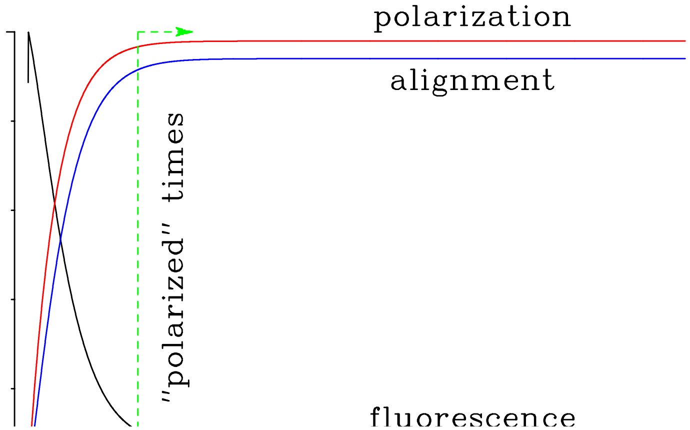
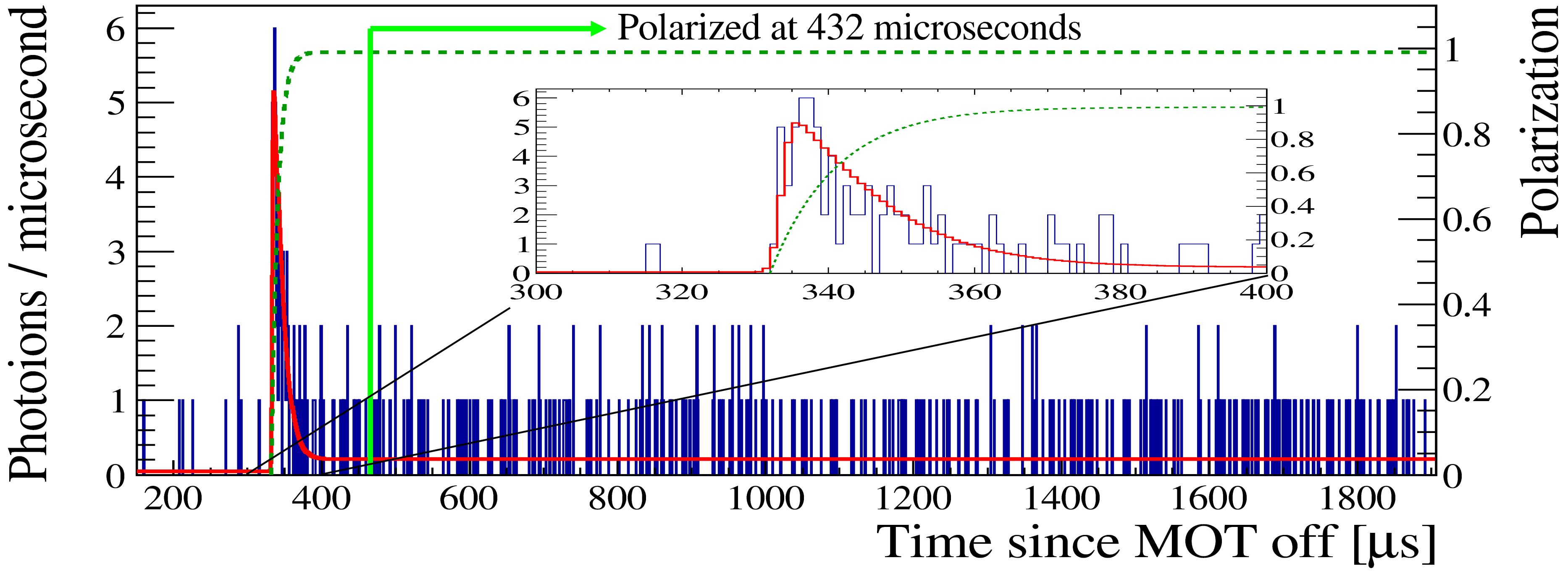




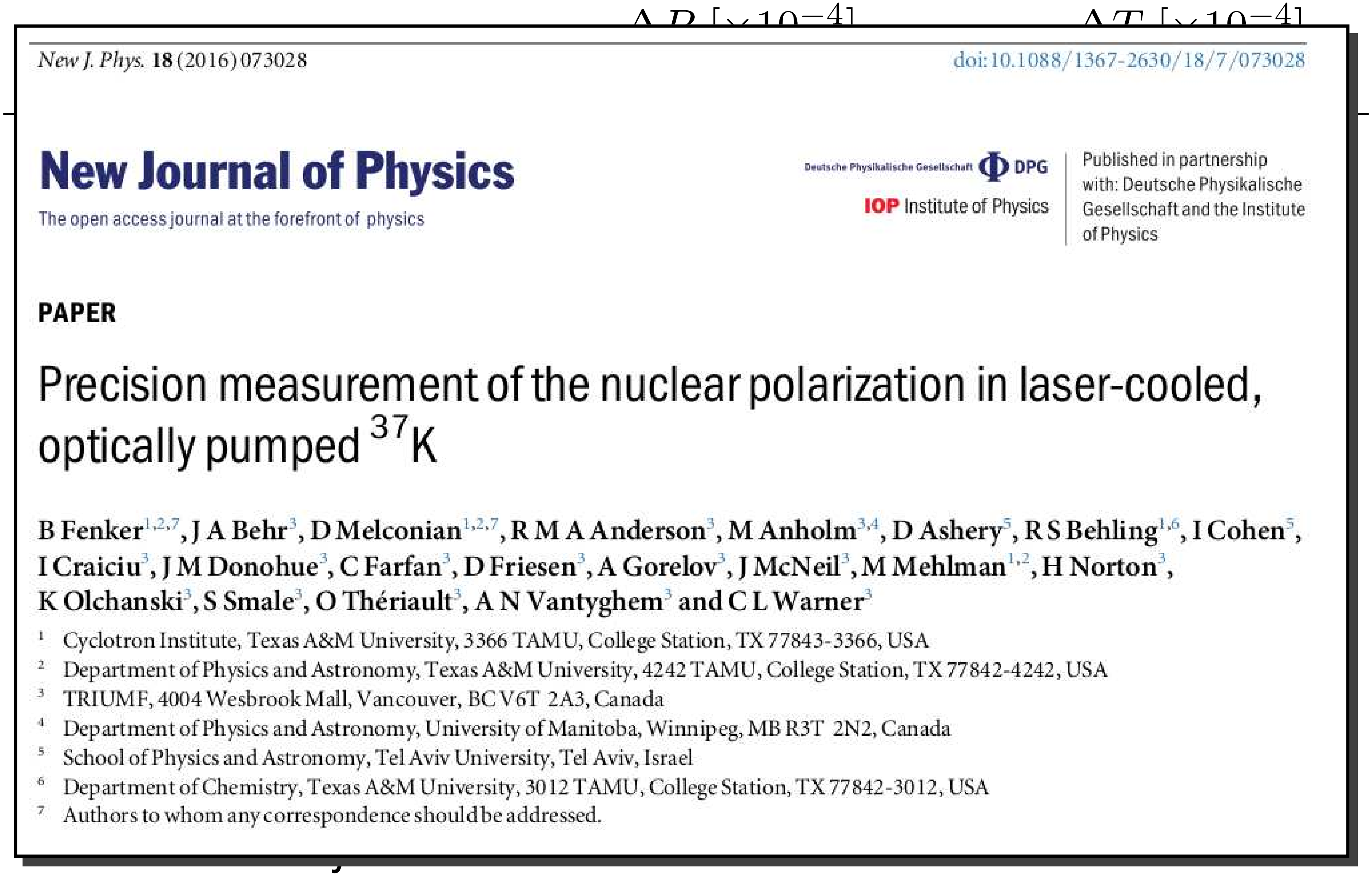


Polarization error budget

Source	ΔP $[\times 10^{-4}]$ σ^-	σ^+	ΔT $[\times 10^{-4}]$ σ^-	σ^+
Systematics				
Initial alignment	3	3	10	8
Global fit vs. average	2	2	7	6
Uncertainty on s_3^{out}	1	2	11	5
Cloud temperature	2	0.5	3	2
Binning	1	1	4	3
Uncertainty in B_z	0.5	3	2	7
Initial polarization	0.1	0.1	0.4	0.4
Require $\mathcal{I}_+ = \mathcal{I}_-$	0.1	0.1	0.1	0.2
Total systematic	5	5	17	14
Statistics	7	6	21	17
Total uncertainty	9	8	27	22

Polarization error budget

ΔP [$\times 10^{-4}$] ΔT [$\times 10^{-4}$]



New J. Phys. **18** (2016) 073028 doi:10.1088/1367-2630/18/7/073028

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PAPER

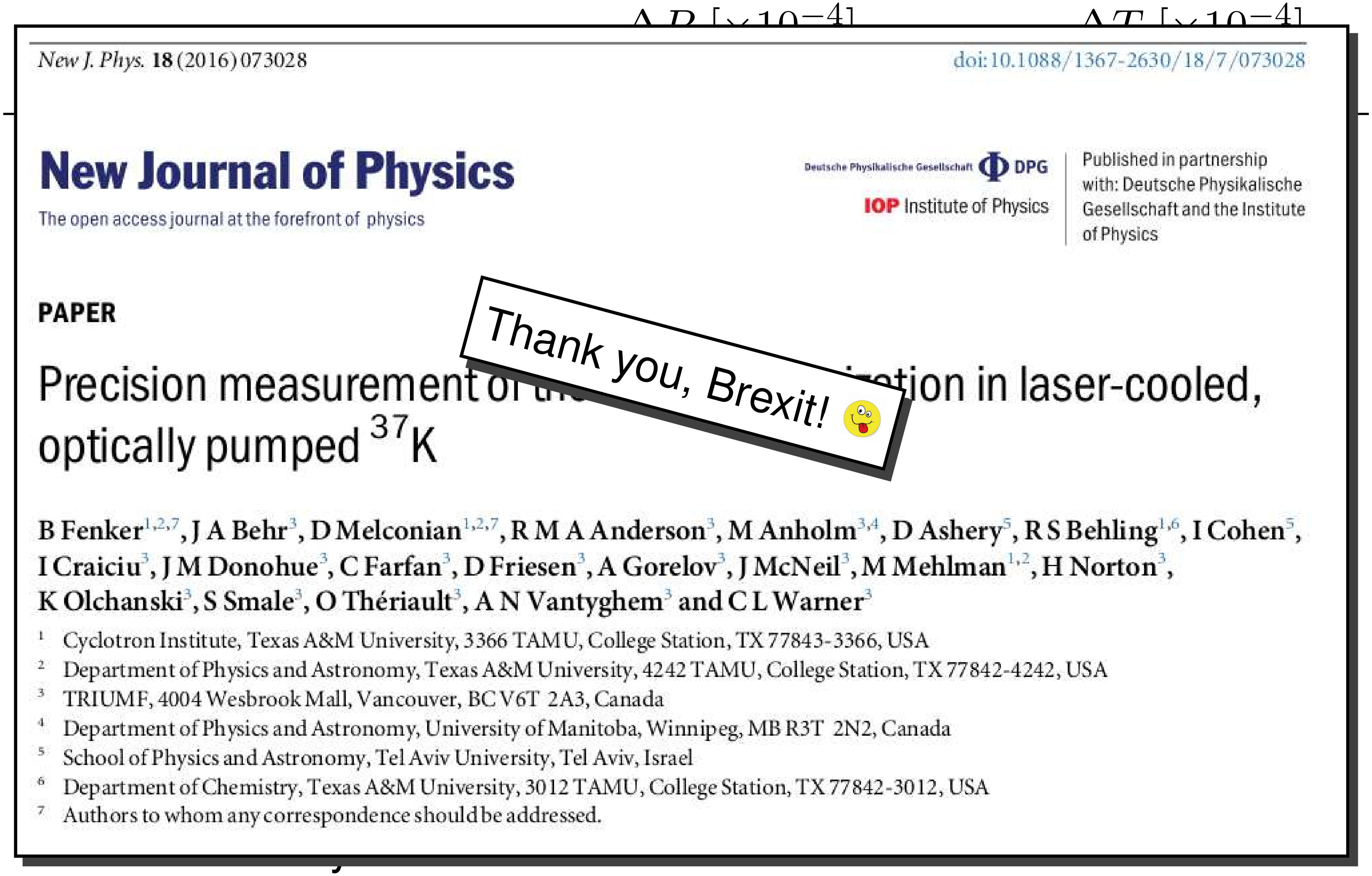
Precision measurement of the nuclear polarization in laser-cooled, optically pumped ^{37}K

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]

[1] Cyclotron Institute, Texas A&M University, 3366 TAMU, College Station, TX 77843-3366, USA
[2] Department of Physics and Astronomy, Texas A&M University, 4242 TAMU, College Station, TX 77842-4242, USA
[3] TRIUMF, 4004 Wesbrook Mall, Vancouver, BC V6T 2A3, Canada
[4] Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB R3T 2N2, Canada
[5] School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[6] Department of Chemistry, Texas A&M University, 3012 TAMU, College Station, TX 77842-3012, USA
[7] Authors to whom any correspondence should be addressed.

Polarization error budget

ΔP [$\times 10^{-4}$] ΔT [$\times 10^{-4}$]



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Thank you, Brexit! 😜

Polarization error budget

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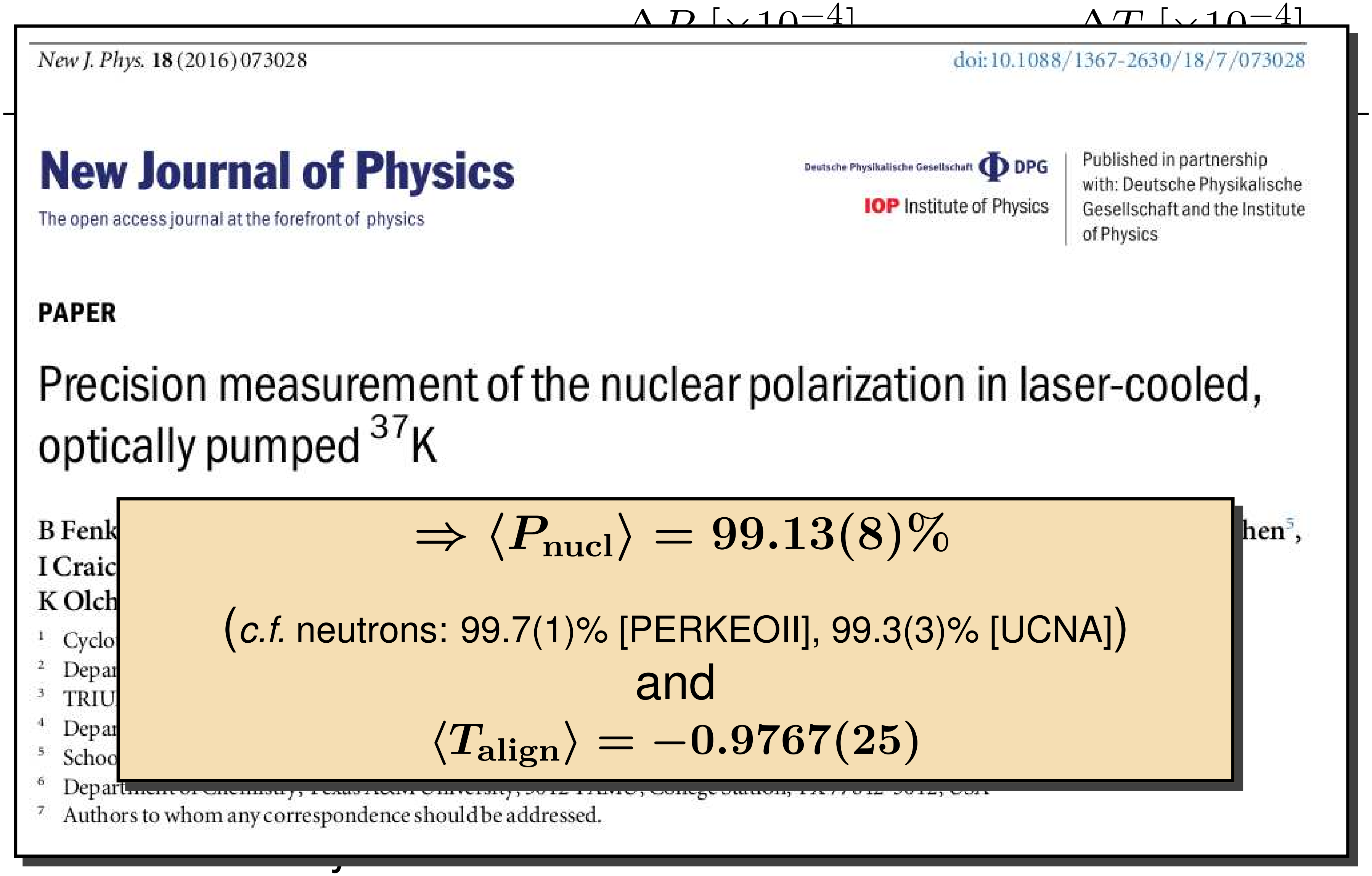

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$$\Rightarrow \langle P_{\text{nucl}} \rangle = \mathbf{99.13(8)\%}$$

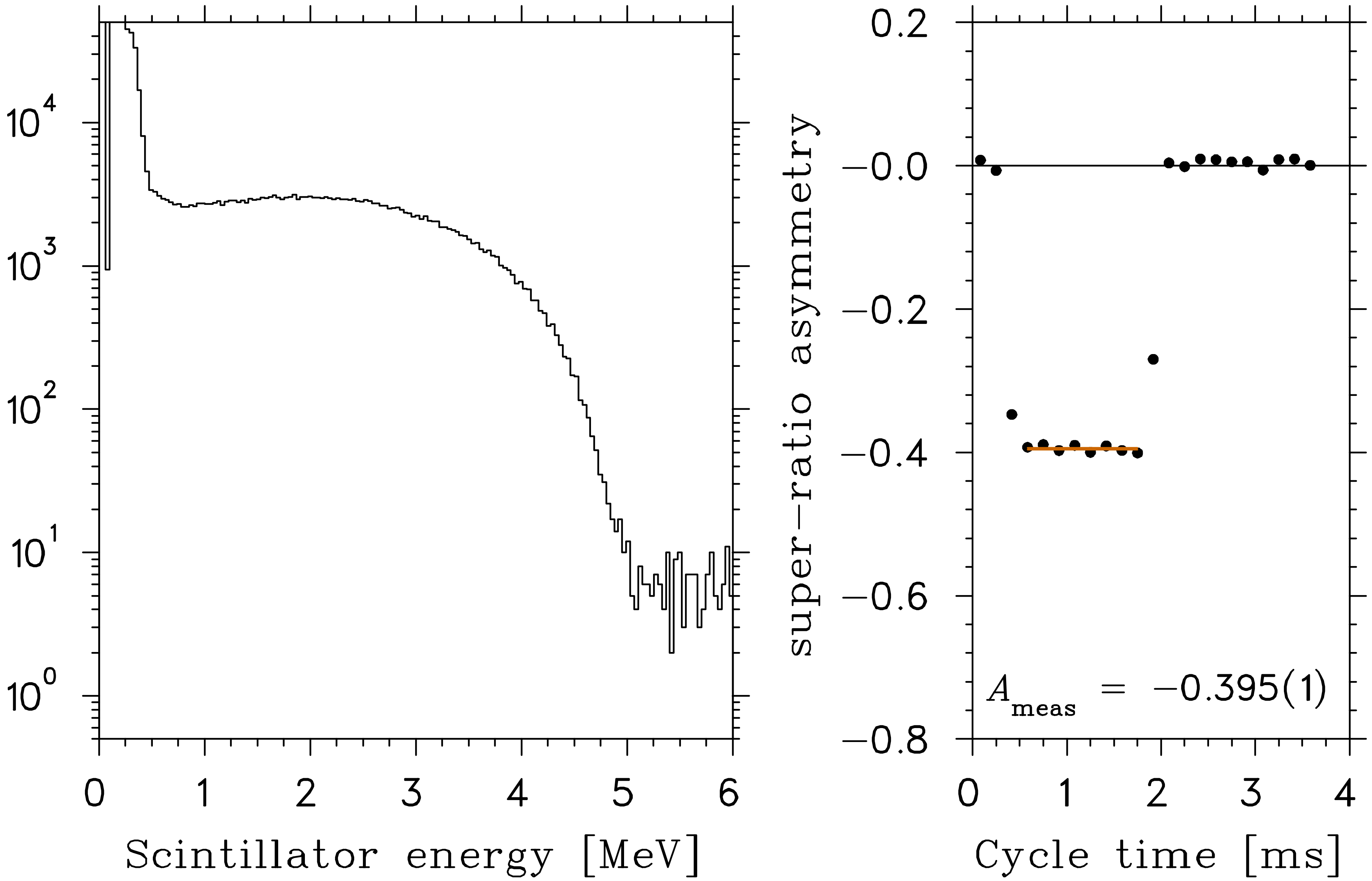
(*c.f.* neutrons: 99.7(1)% [PERKEOII], 99.3(3)% [UCNA])

and

$$\langle T_{\text{align}} \rangle = \mathbf{-0.9767(25)}$$

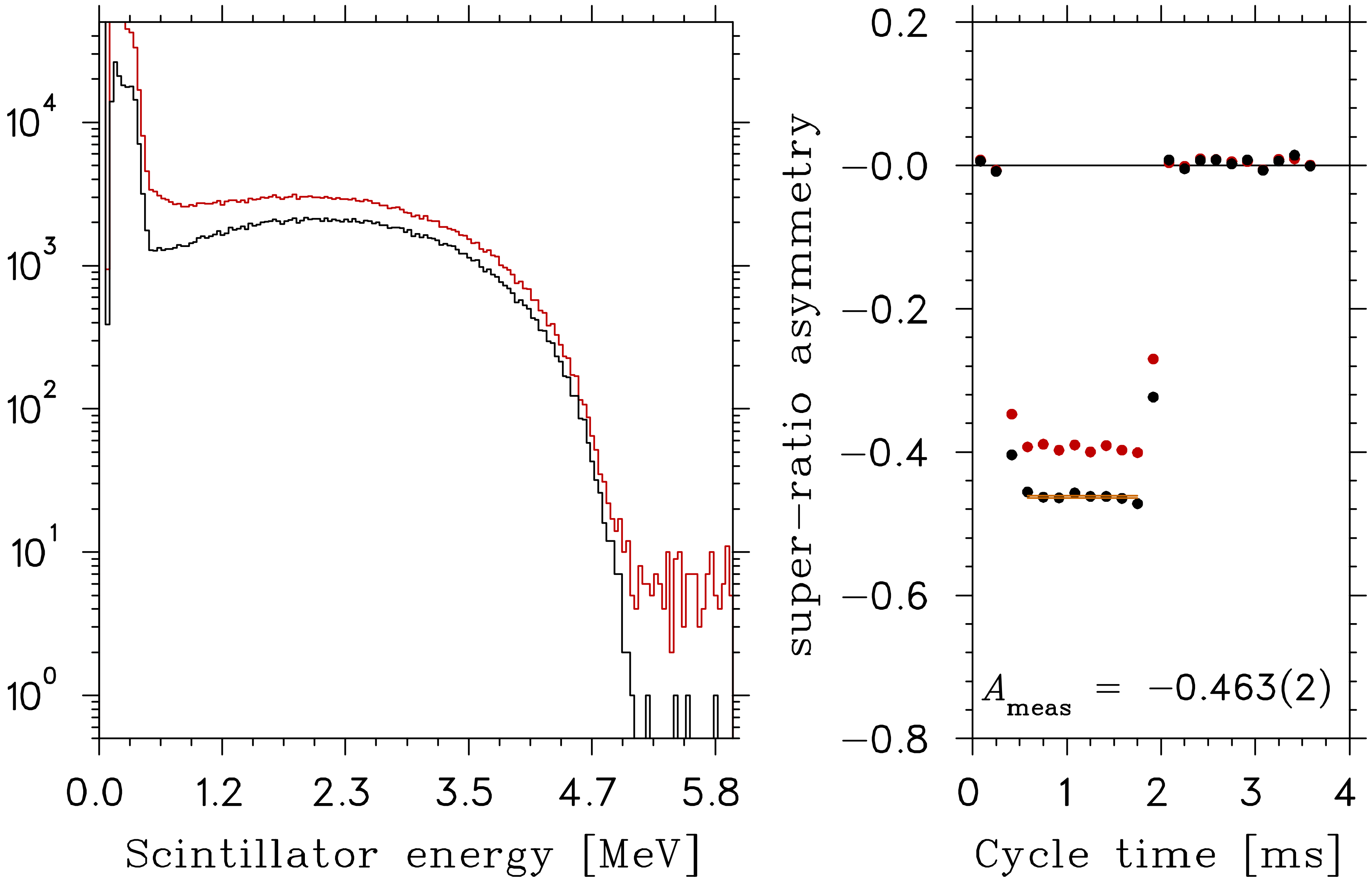
Scintillator spectra — June 2014

Just the raw data; a slight lower-energy cut to get rid of 511s



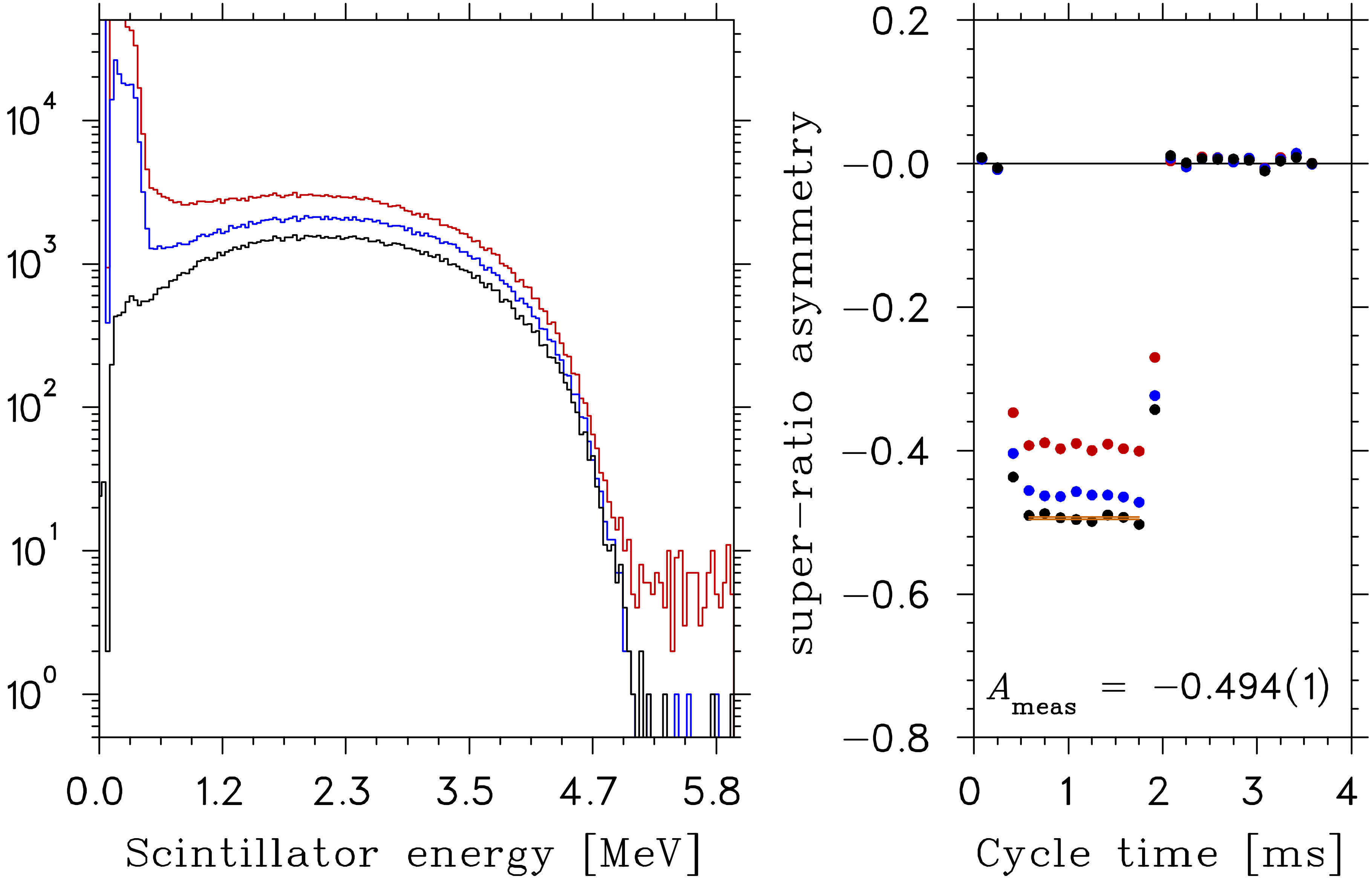
Scintillator spectra — June 2014

Requiring a shake-off e^- ⇒ decay occured from trap!



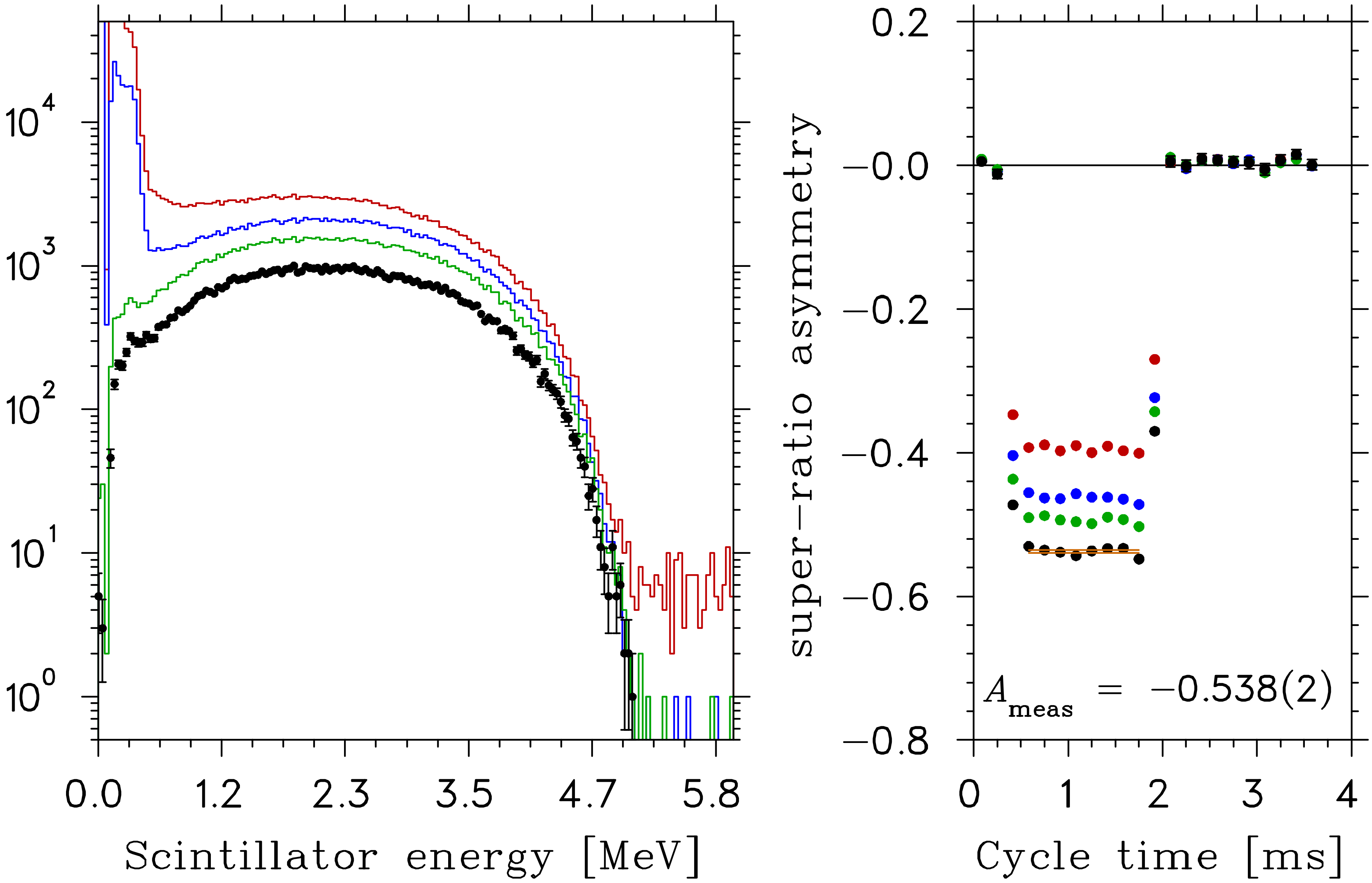
Scintillator spectra — June 2014

Requiring a ΔE coincidence $\Rightarrow$ remove γs

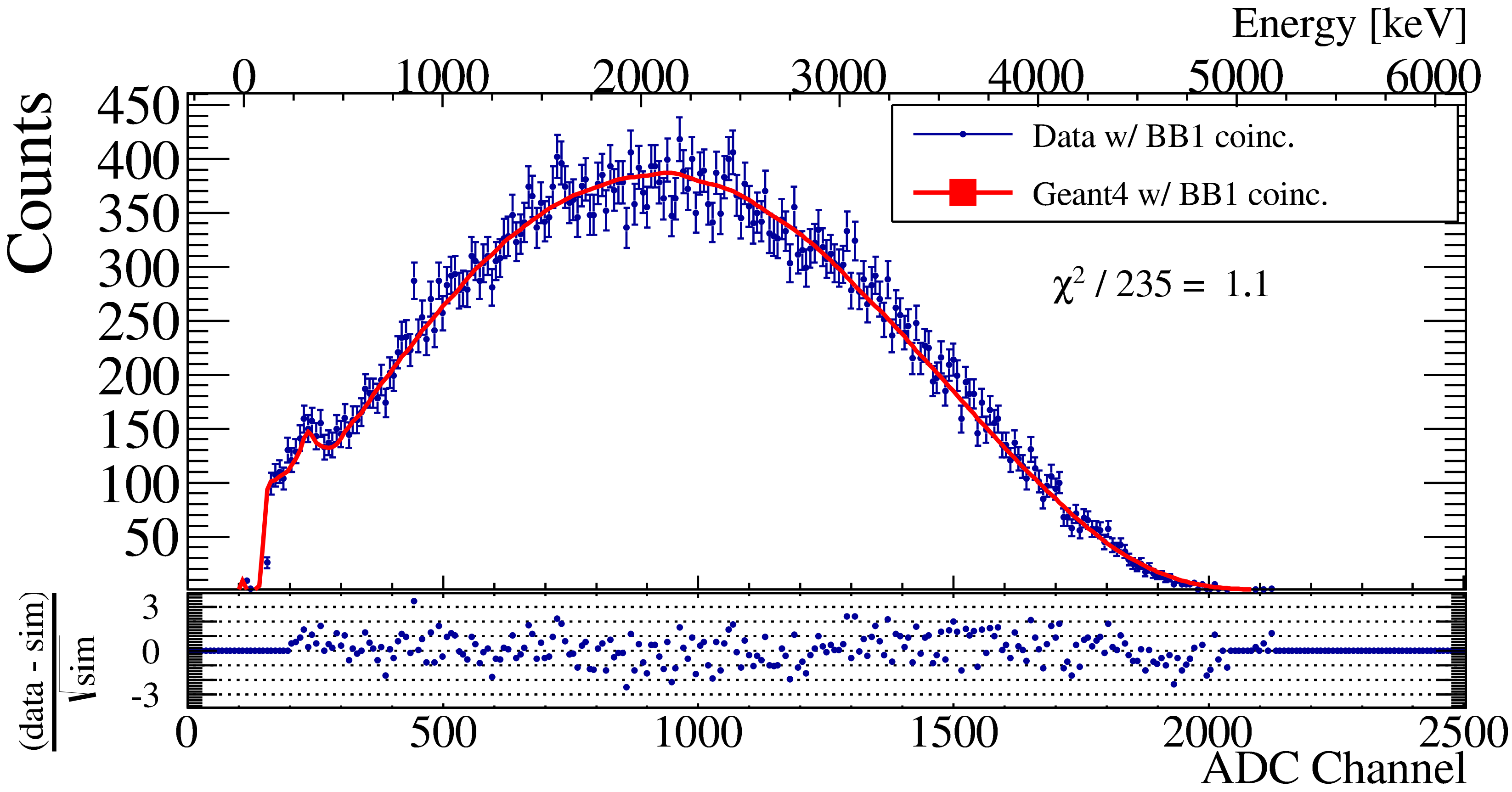


Scintillator spectra — June 2014

Put in all the basic analysis cuts ⇒ clean spectrum!!

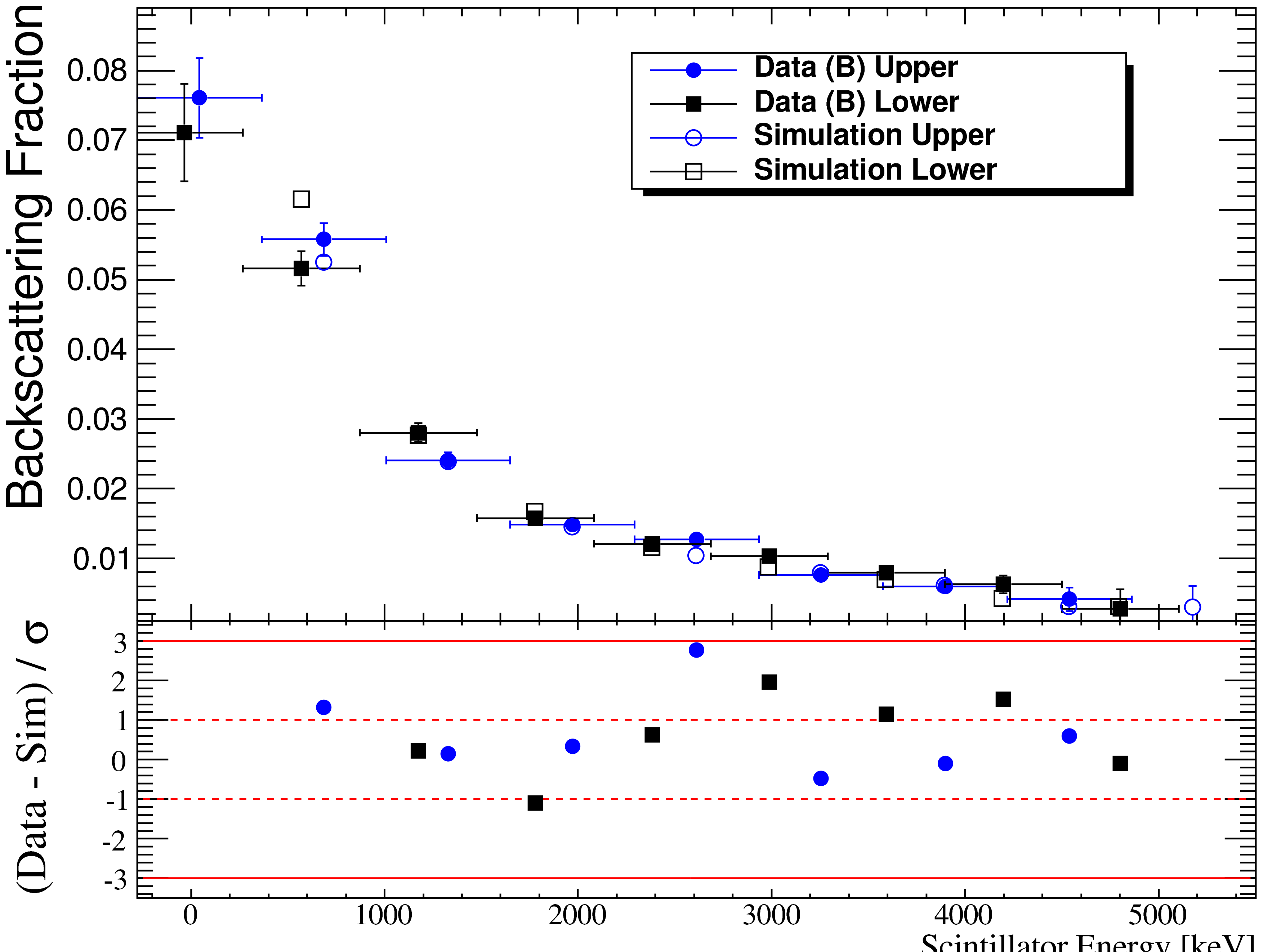


Energy Spectrum Compared to GEANT4

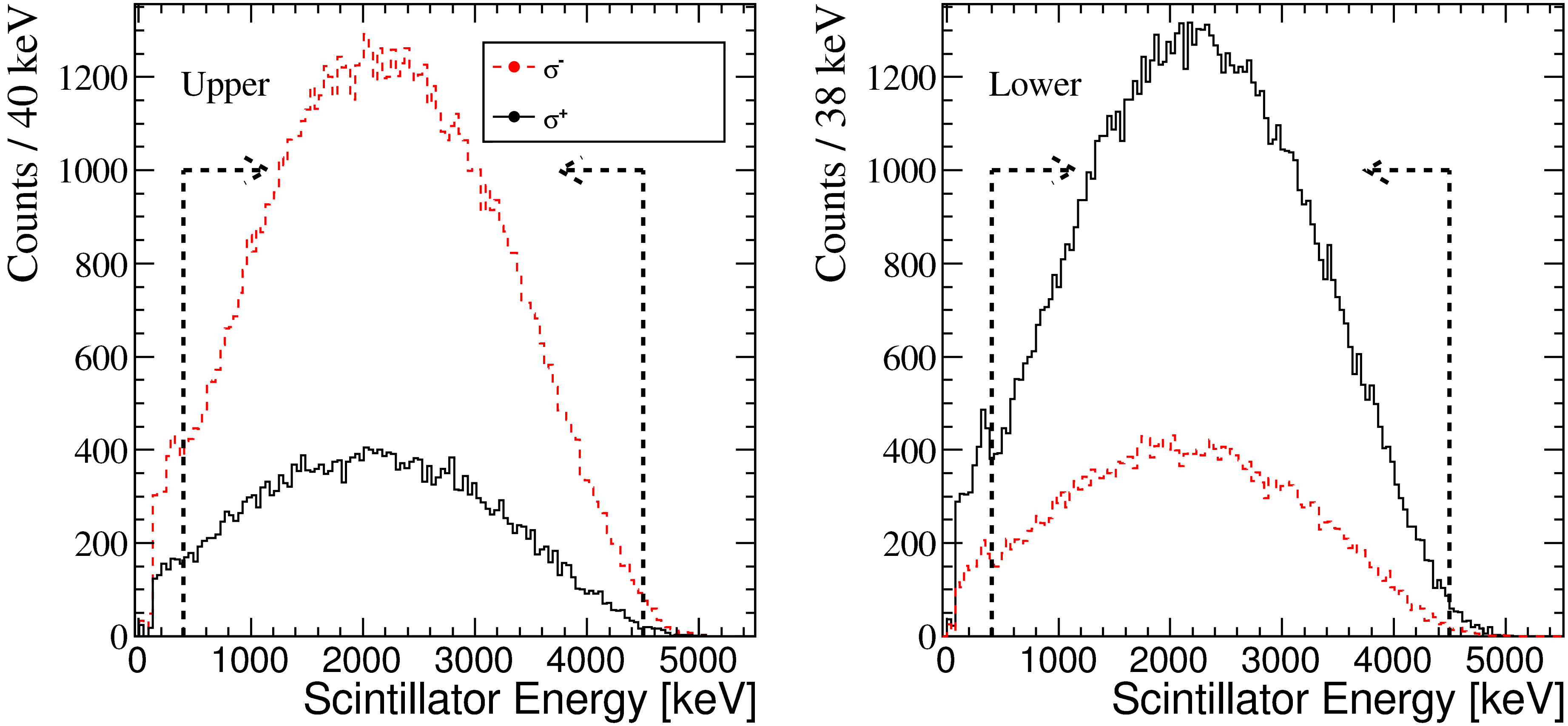


A Test of Backscattering

Although we're not very sensitive to backscattering (relatively speaking)...



Asymmetry Measurement (briefly)



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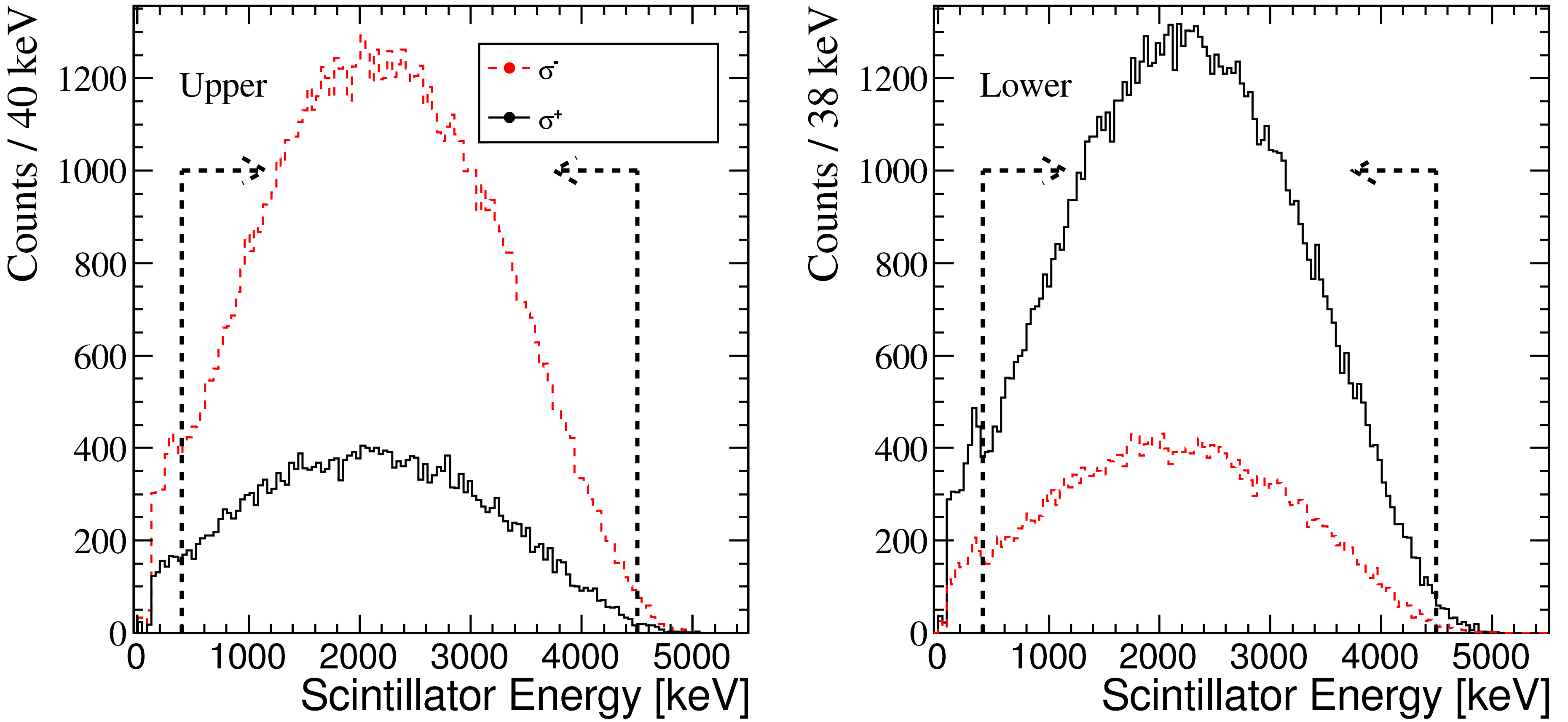

$$A_{\mathrm{obs}}(E_e) = \frac{1 - S(E_e)}{1 + S(E_e)}, \quad \text{where } S(E_e) \equiv \sqrt{\frac{r_1^-(E_e) r_2^+(E_e)}{r_1^+(E_e) r_2^-(E_e)}}$$

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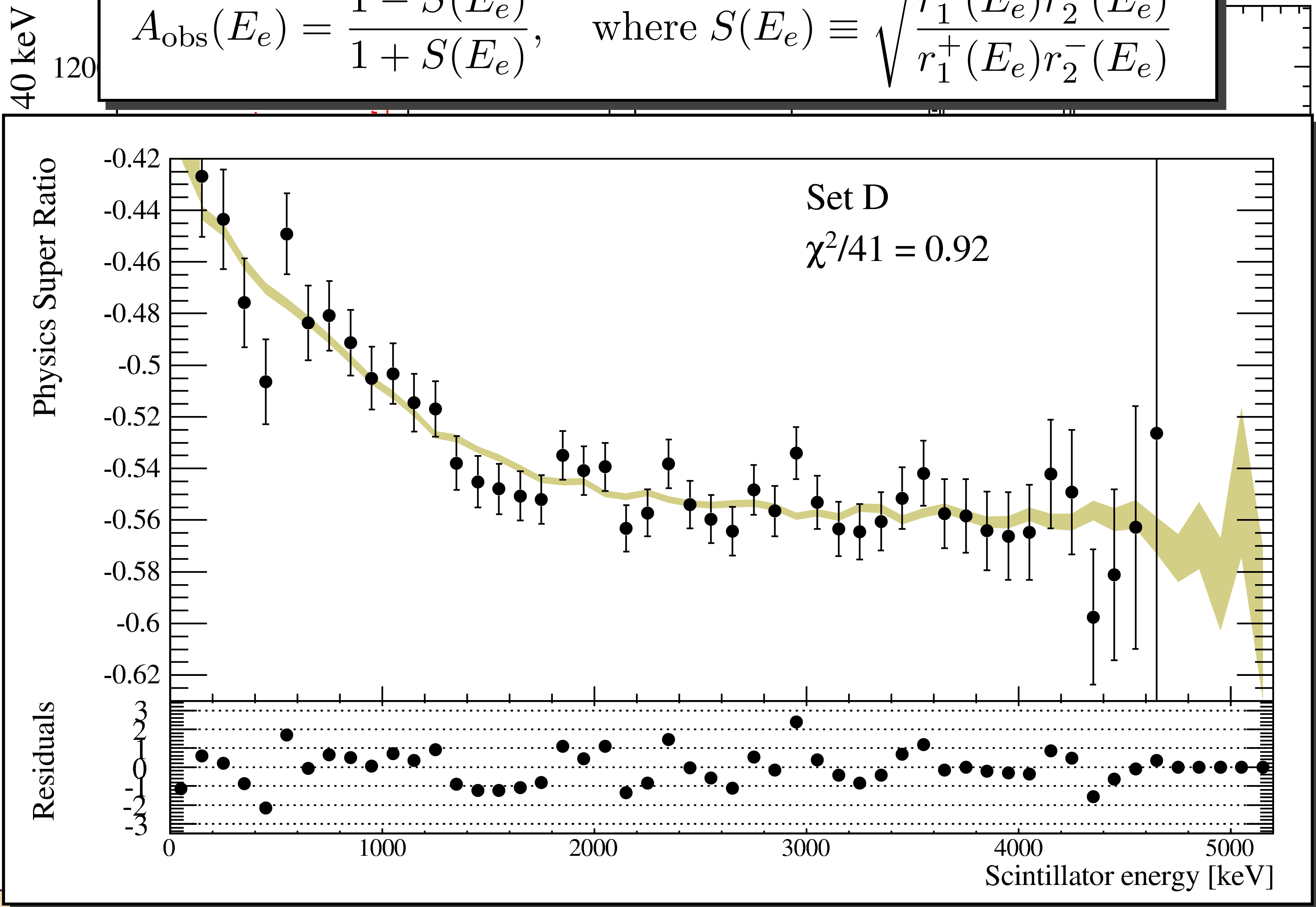

A_β Error Budget

Source		Corr	Uncert [$\times 10^{-4}$]
Backgrounds		1.0013	7
Trap parameters	position		4
	velocity		5
	temp, width		1
Thresholds/cuts	ΔE pos		5
	ΔE energy agreement		2
	ΔE threshold		1
	E threshold		0.3
G4 phys list			4
Shake-off e^- TOF			3
$E + \Delta E$			1
E calibration			0.1
Total systematics			12
Statistical			13
Polarization			9
Total uncertainty			20

Impact of A_β Measurement

- B. Fenker is completing interpretation (just unblinded 1.5 weeks ago!)

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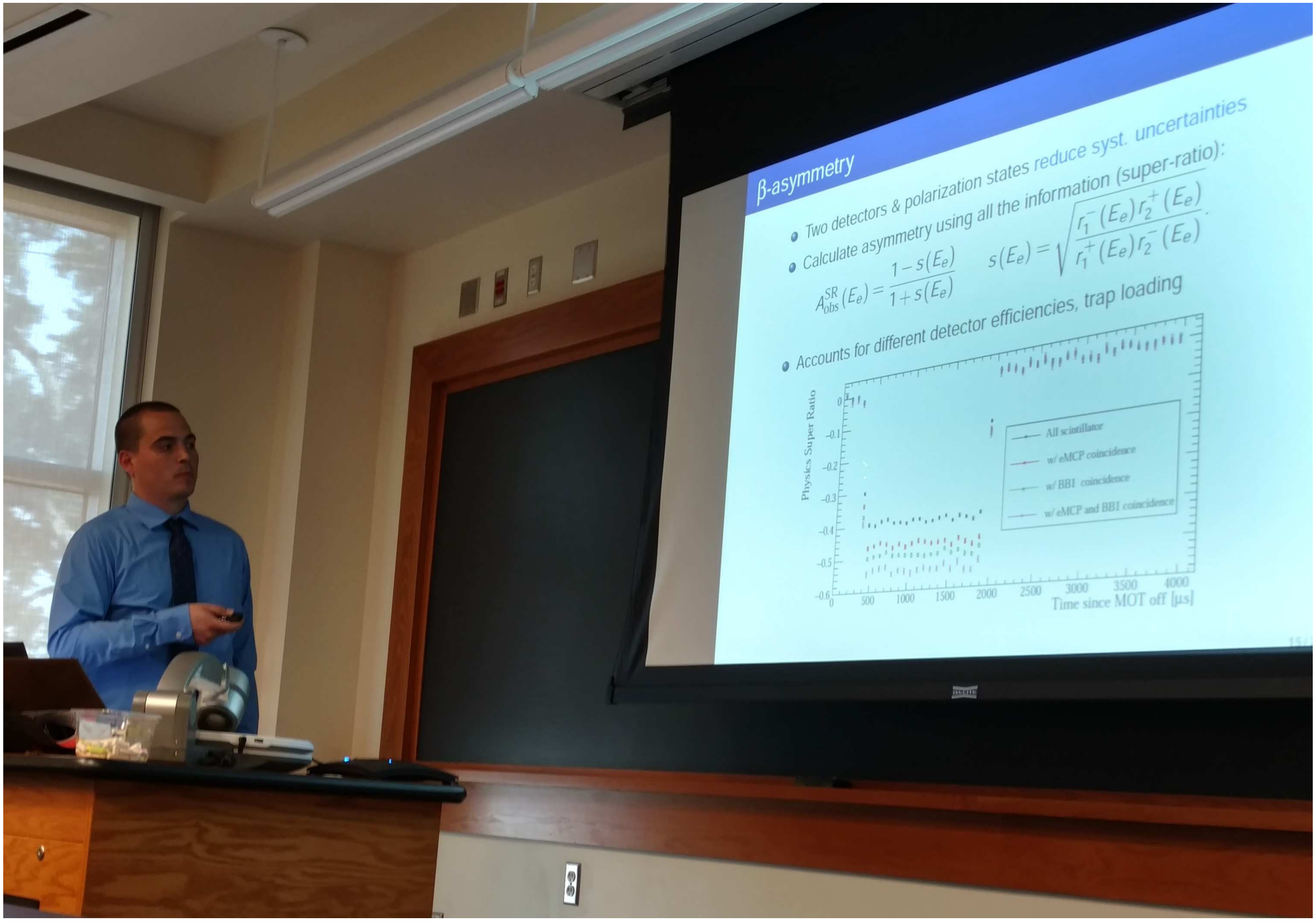

β-asymmetry

- Two detectors & polarization states reduce syst. uncertainties
- Calculate asymmetry using all the information (super-ratio):

$$A_{\mathrm{obs}}^{SR}(E_e) = \frac{1-s(E_e)}{1+s(E_e)} \qquad s(E_e) = \sqrt{\frac{r_1^-(E_e)\,r_2^+(E_e)}{r_1^+(E_e)\,r_2^-(E_e)}}.$$

- Accounts for different detector efficiencies, trap loading

Impact of A_β Measurement

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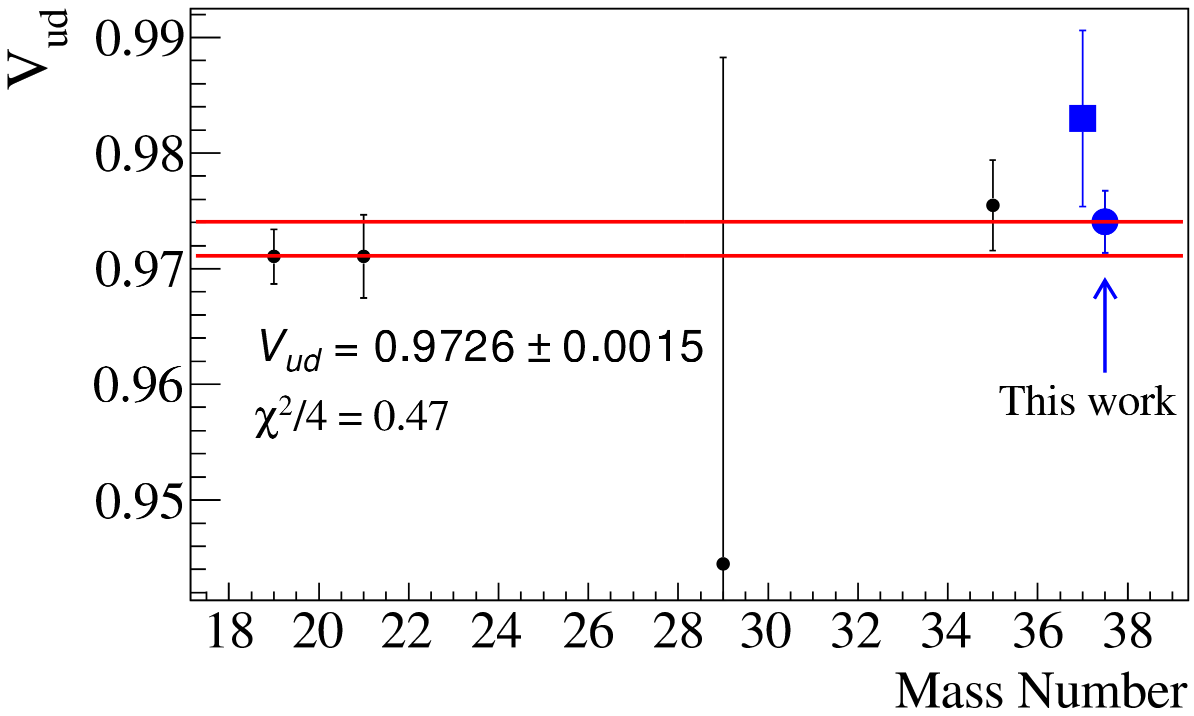

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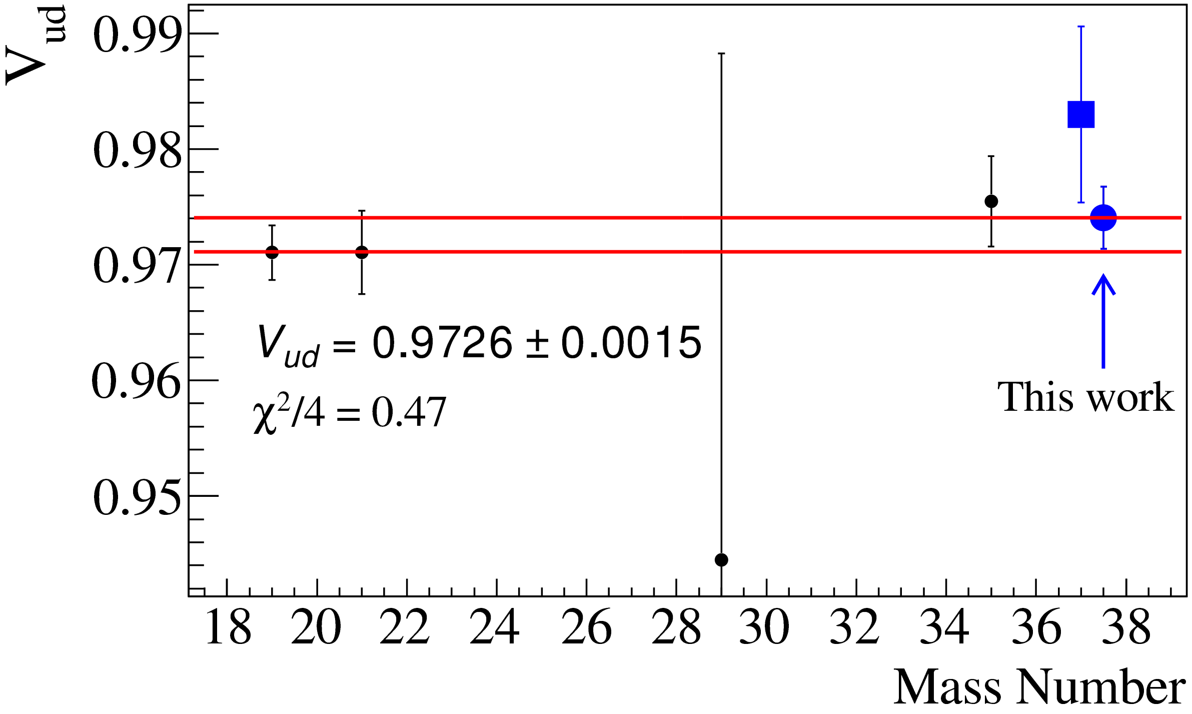


- We will publish soon and present at DNP – hope to see you in Vancouver!

Overview

1. Introduction

- I think we all know why we want to test the SM. . .
- One precision frontier: correlation parameters of β decay

2. Ion Traps

- LPC Trap
- Beta-decay Paul Trap
- TAMUTRAP

3. Neutral Atom Traps

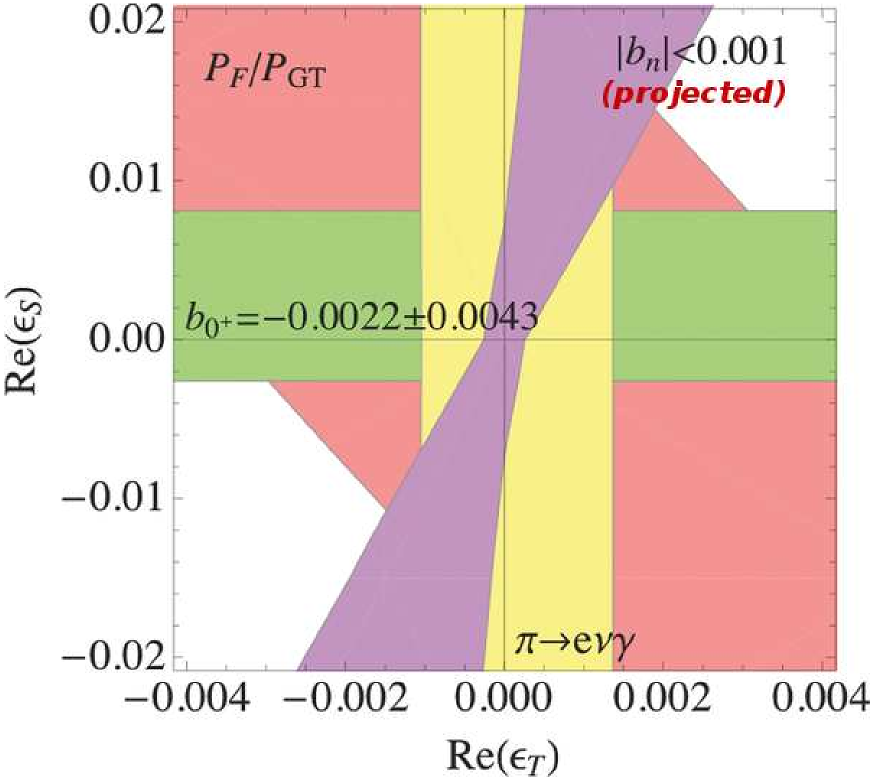
- CENPA/ANL
- TRINAT

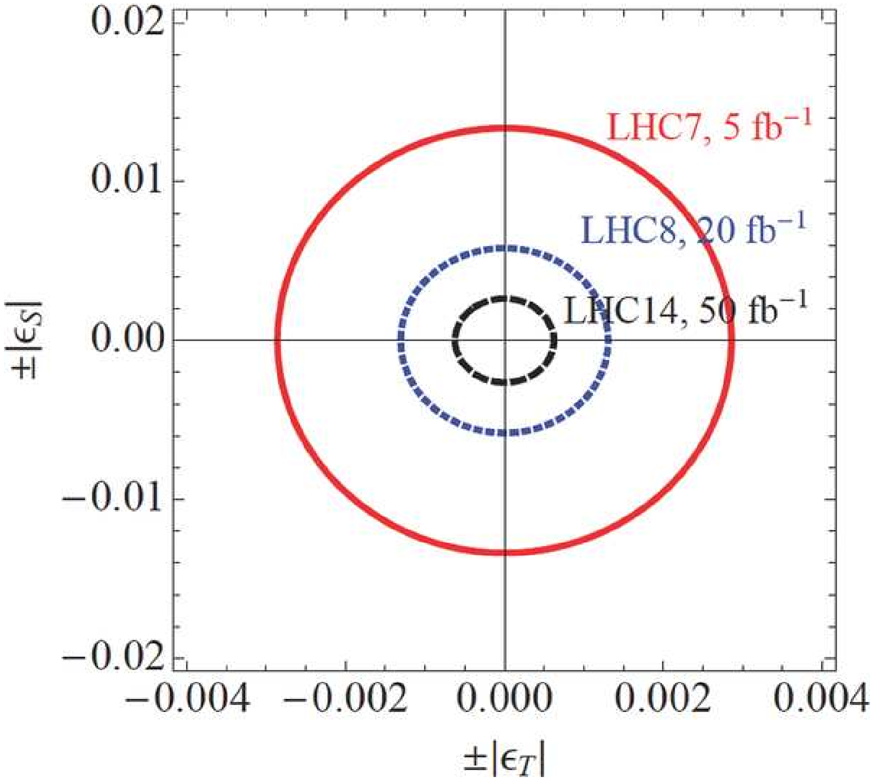
4. Elegant vs. brute-force tests

- *very* short summary

Low-energy Work Complements the LHC

Naviliat-Čunčić and González-Alonso, Ann. Phys. **525**, 600 (2013)





	$\lvert\tilde\epsilon_L\rvert$	$\lvert\tilde\epsilon_R\rvert$	$\lvert\tilde\epsilon_P\rvert$	$\lvert\tilde\epsilon_S\rvert$	$\lvert\tilde\epsilon_T\rvert$
Low energy	0.06	0.06	0.0003	0.14	0.030
LHC (CMS)	–	0.002	0.006	0.006	0.001

Summary

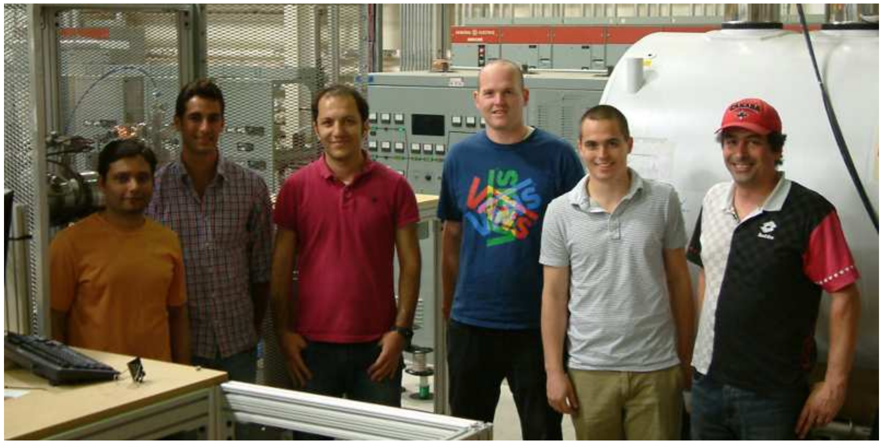
- As we all know, SM is fantastic, but **not** our “ultimate” theory
- Many exciting avenues to find more a complete model

- One of the **low-energy approaches:** precision measurement of correlation parameters

- Ion traps + RIB = ***cool*** physics
- Atom traps + RIB [+ opt. pumping] = ***cool*** physics
- Fun (but demanding) stuff that complements the “brute force” approach

The Mad Trappers/Thanks

TAMU: S. Behling, E. Bennett, M. Mehlman, B. Fenker, P. Shidling + TAMU/REU undergrads + ENSICAEN interns



The ICISE and HSEBSM organizers and for a wonderful workshop

and *all* the friendly Vietnamese people

TRINAT: TRIUMF J.A. Behr, A. Gorelov, L. Kurchananov, K. Olchanski, K.P. Jackson, . . .

D. Ashery, I. Cohen

M. Anholm, G. Gwinner

Funding/Support:

DE-FG02-93ER40773, ECA ER41747

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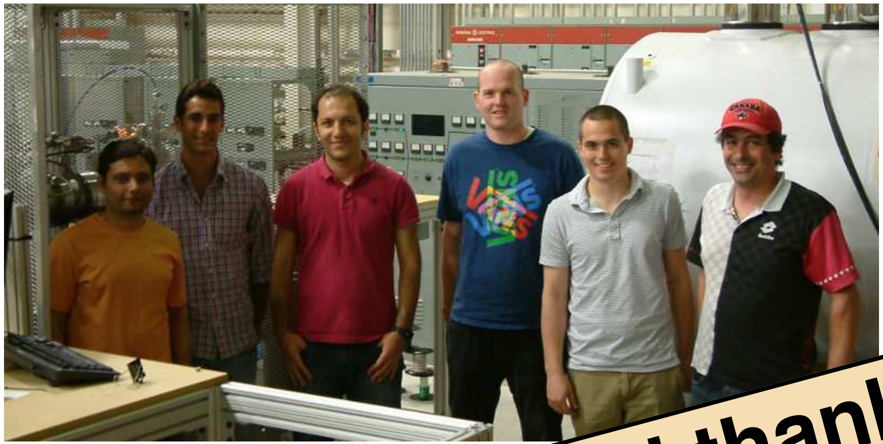

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And thank you for your attention!

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