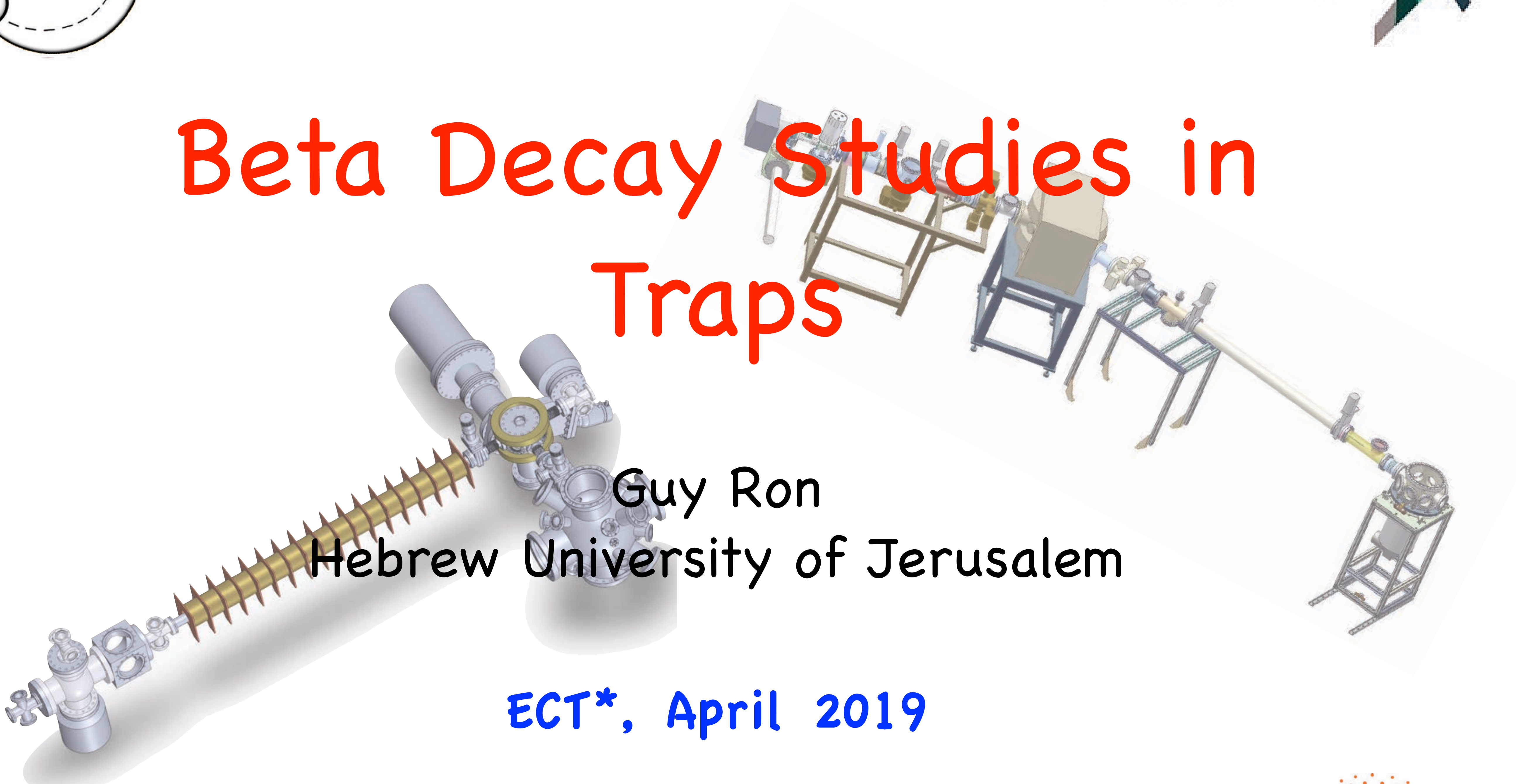
Beta Decay Studies in Traps



Guy Ron
Hebrew University of Jerusalem

ECT*, April 2019

β decay RATE

Total decay rate (Oriented Nuclei)

$$\frac{d\Gamma}{dE_\beta d\Omega_\beta d\Omega_\nu} \propto \xi \left\{ 1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m}{E_e} + c\left[\frac{1}{3}\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} - \frac{(\vec{p}_e \cdot \vec{j})(\vec{p}_\nu \cdot \vec{j})}{E_e E_\nu}\right]\right.$$

$$\left.\left[\frac{J(J+1) - 3 < (\vec{J} \cdot \vec{j})^2 >}{J(2J-1)}\right] + \frac{< \vec{J} >}{J} \cdot \left[A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu}\right]\right\}$$

J.D. Jackson, S.B. Treiman, & H.W. Wyld, Phys. Rev. 106, 517 (1957)

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Electron-neutrino correlation

$$\begin{aligned} \xi a &= |M_F|^2 \left(-|C_S|^2 + |C_V|^2 - |C_S'|^2 + |C_V'|^2\right) + \\ &\quad \frac{|M_{GT}|^2}{3}\left(|C_T|^2 - |C_A|^2 + |C_T'|^2 - |C_A'|^2\right) \\ \xi &= |M_F|^2 \left(|C_S|^2 + |C_V|^2 + |C_S'|^2 + |C_V'|^2\right) + \\ &\quad |M_{GT}|^2 \left(|C_T|^2 + |C_A|^2 + |C_T'|^2 + |C_A'|^2\right) \end{aligned}$$

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β decay RATE

$$\omega(\boldsymbol{\sigma}|E_e,\Omega_e,\Omega_\nu)dE_e d\Omega_e d\Omega_\nu = \frac{1}{(2\pi)^5}p_e E_e(E^0-E_e)^2 dE_e d\Omega_e d\Omega_\nu \times \tfrac{1}{2}\xi\left\{1+a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}+b\frac{m}{E_e}+\boldsymbol{\sigma}\cdot\left[G\frac{\mathbf{p}_e}{E_e}+H\frac{\mathbf{p}_\nu}{E_\nu} + K\frac{\mathbf{p}_e}{E_e+m}\left(\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}\right)+L\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_eE_\nu}\right]\right\}.$$

$$\omega(\langle\mathbf{J}\rangle,\boldsymbol{\sigma}|E_e,\Omega_e)dE_e d\Omega_e = \frac{1}{(2\pi)^4}p_e E_e(E^0-E_e)^2 dE_e d\Omega_e \times\xi\left\{1+b\frac{m}{E_e}+\left(A\frac{\langle\mathbf{J}\rangle}{J}+G\boldsymbol{\sigma}\right)\cdot\frac{\mathbf{p}_e}{E_e}+\boldsymbol{\sigma}\cdot\left[N\frac{\langle\mathbf{J}\rangle}{J} + Q\frac{\mathbf{p}_e}{E_e+m}\left(\frac{\langle\mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_e}{E_e}\right)+R\frac{\langle\mathbf{J}\rangle}{J}\times\frac{\mathbf{p}_e}{E_e}\right]\right\}.$$

$$\omega(\langle J\rangle|E_e,\Omega_e,\Omega_\nu)dE_e d\Omega_e d\Omega_\nu = \frac{1}{(2\pi)^5}p_e E_e(E^0-E_e)^2 dE_e d\Omega_e d\Omega_\nu \xi\left\{1+a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}+b\frac{m}{E_e} + c\left[\frac{1}{3}\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu}-\frac{(\mathbf{p}_e\cdot\mathbf{j})(\mathbf{p}_\nu\cdot\mathbf{j})}{E_eE_\nu}\right]\left[\frac{J(J+1)-3\langle(\mathbf{J}\cdot\mathbf{j})^2\rangle}{J(2J-1)}\right] + \frac{\langle\mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e}+B\frac{\mathbf{p}_\nu}{E_\nu}+D\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_eE_\nu}\right]\right\}. \quad ($$

Problem - Most of the easy ones are quadratic in BSM terms

e.g.

$$a\xi = |M_F|^2(-|C_S|^2+|C_V|^2-|C_S'|^2+|C_V'|^2)+\frac{|M_{GT}|^2}{3}(|C_T|^2-|C_A|^2+|C_T'|^2-|C_A'|^2),$$

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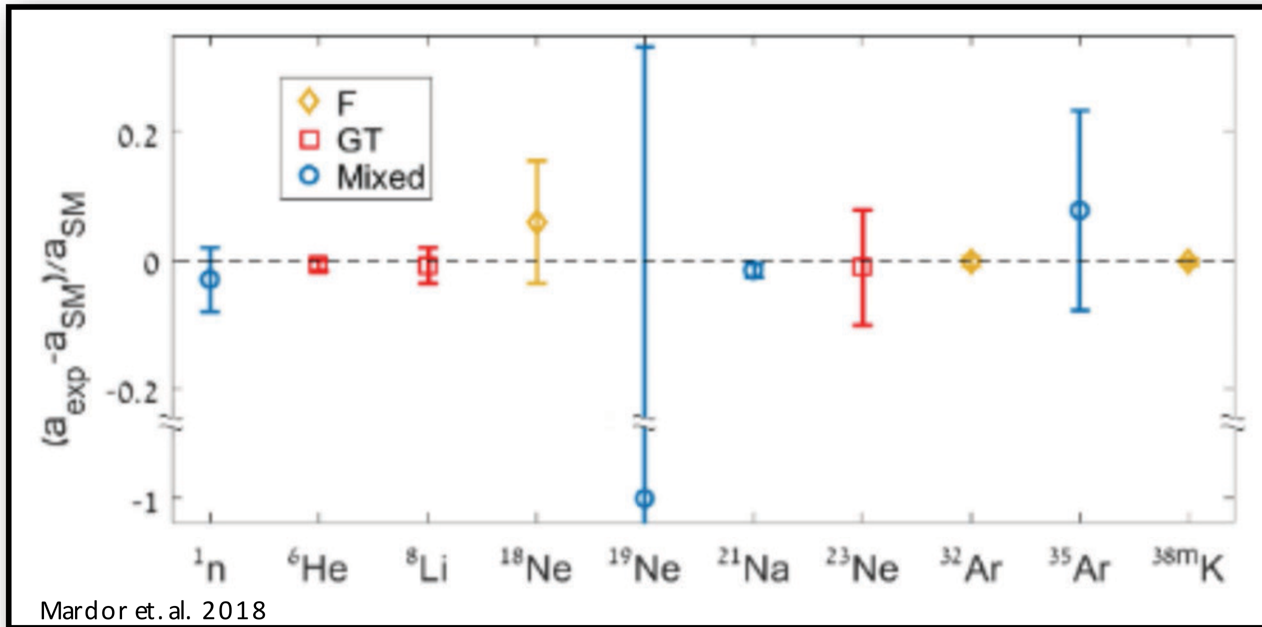
$$\omega(\langle J\rangle|E_e,\Omega_e,\Omega_\nu)dE_e d\Omega_e d\Omega_\nu = \frac{1}{(2\pi)^5} p_e E_e (E^0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu \xi\left\{1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} + b\frac{m}{E_e} + c\left[\frac{1}{3}\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} - \frac{(\mathbf{p}_e\cdot\mathbf{j})(\mathbf{p}_\nu\cdot\mathbf{j})}{E_e E_\nu}\right]\left[\frac{J(J+1) - 3\langle(\mathbf{J}\cdot\mathbf{j})^2\rangle}{J(2J-1)}\right] + \frac{\langle\mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_\nu}{E_\nu} + D\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_e E_\nu}\right]\right\}. \quad ($$

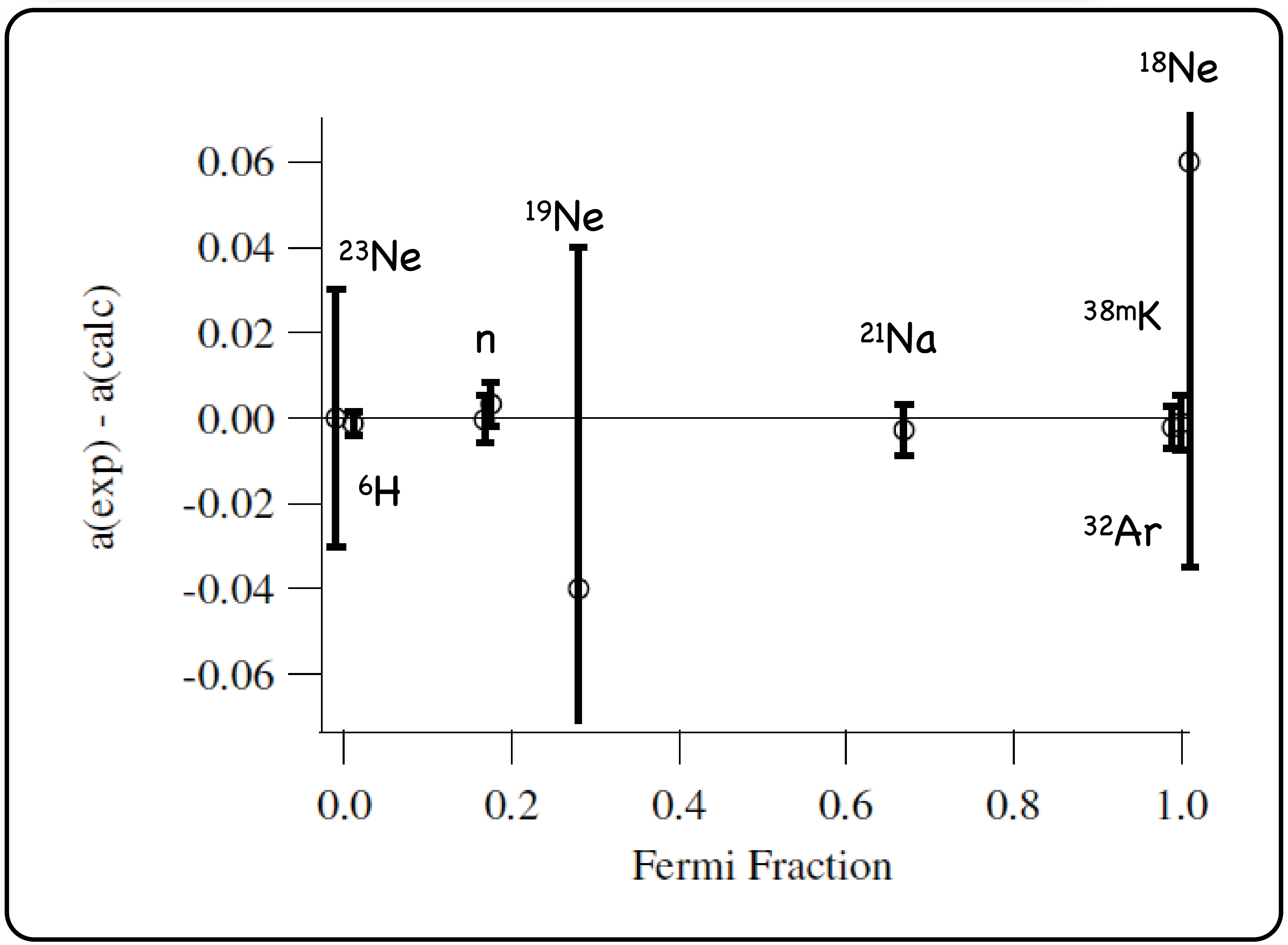
To access the ones linear in the BSM terms one needs (some of):

- Polarized nucleus (somewhat easy)
- Electron energy (harder)
- Neutrino energy (impossible, but can use recoil energy instead)
- Electron polarization (hard)

J.D. Jackson, S.B. Treiman, & H.W. Wyld, Phys. Rev. 106, 517 (1957)

State of the Art in $a_{\beta\nu}$





Anatomy of an Experiment

Produce Radioactive Atoms

(Produce, Transport, Neutralize)

↓

Trap/Contain

(MOT, Dipole, Ion, Electrostatic)

↓

Wait...

↓

Detect decay products (β, Ion)

(Scintillators, MCPs,...)

↓

Analyze and compare to SM

Coefficient	Experiment (Laboratory)	Comments
τ_n	BL2, BL3 (NIST)	In preparation; two phases
	LiNA (J-PARC)	In preparation; two phases
	Gravitrap (ILL)	Apparatus being upgraded
	Ezhov (ILL)	Under construction
	PENeLOPE (Munich)	Being developed
	UCNτ (LANL)	Ongoing
	HOPE (ILL)	Proof of principle
	τSPECT (Mainz)	Taking data
β-spectrum	Supercond. spectr. (Madison)	Ongoing
β-spectrum	Si-det. spectr. (Saclay)	Ongoing
b_{GT}	Scintill. detectors (NSCL)	Analysis ongoing (^{6}He, ^{20}F)
	miniBETA (Krakow-Leuven)	Being commissioned
	UCNA-Nab-Leuven (LANL)	Analysis ongoing (^{45}Ca)
b_n	Nab (LANL)	In preparation
	PERKEO III (ILL)	Possible with A_n data
	PERC (Munich)	Planned
a_F	TRINAT (TRIUMF)	Planned (^{38}K)
	TAMUTRAP (TA&M)	Superallowed $\beta\,p$ emitters
	WISArD (ISOLDE)	In preparation (^{32}Ar $\beta\,p$ decay)
a	Ne-MOT (SARAF)	In preparation (^{18}Ne, ^{19}Ne, ^{23}Ne)
a_{GT}	^{6}He-MOT (Seattle)	Ongoing with ^{6}He
	EIBT (SARAF)	In preparation (^{6}He)
	LPCTrap (GANIL)	Analysis ongoing (^{6}He, ^{35}Ar)
a_{mirror}	NSL-Trap (Notre Dame)	Planned (^{11}C, ^{13}N, ^{15}O, ^{17}F)
$\tilde{a}_n$	aCORN (NIST)	Data taking ongoing
a_n	aSPECT (ILL)	Analysis being finalized
	Nab (LANL)	In preparation
$\tilde{A}_n$	UCNA (LANL)	Data taking planned
	PERKEO III (ILL)	Analysis ongoing
$\tilde{A}_{mirror}$	TRINAT (TRIUMF)	Planned
$\tilde{B}_n$	UCNB (LANL)	Planned
$\tilde{A}_n$ (a_n, B_n, C_n)	PERC (Munich)	In preparation
$\tilde{A}_n$ (a_n, B_n)	BRAND (ILL)	Proposal
D	MORA (GANIL / JYFL)	In preparation (^{23}Mg)
R	MTV (TRIUMF)	Data taking (^{8}Li) ongoing
D, R	BRAND (ILL)	Proposal

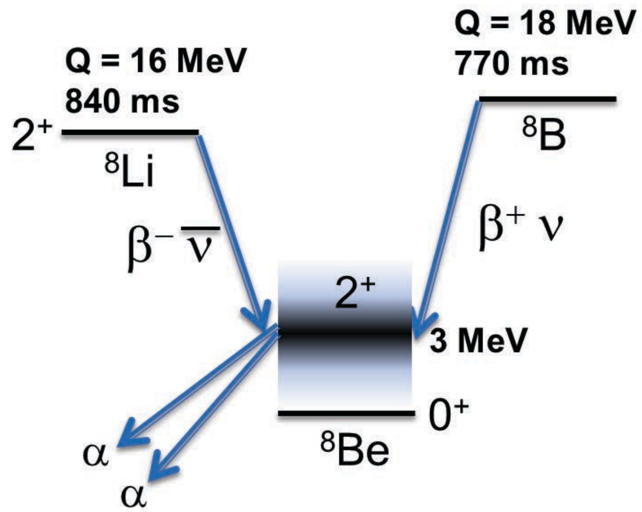
2018 Review, Naviliat-Cuncic, Severins

A small and biased sample of efforts
^{8}Li @ Argonne

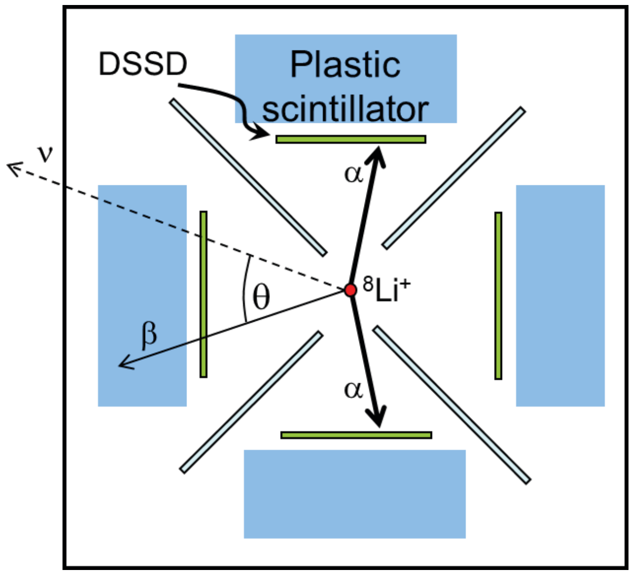
Courtesy Nick Scielzo

Detailed studies of β-decay angular correlations in ^{8}Li and ^{8}B using the Beta-decay Paul Trap

^{8}Li/^{8}B have many advantages

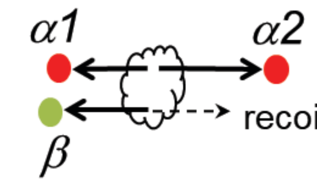


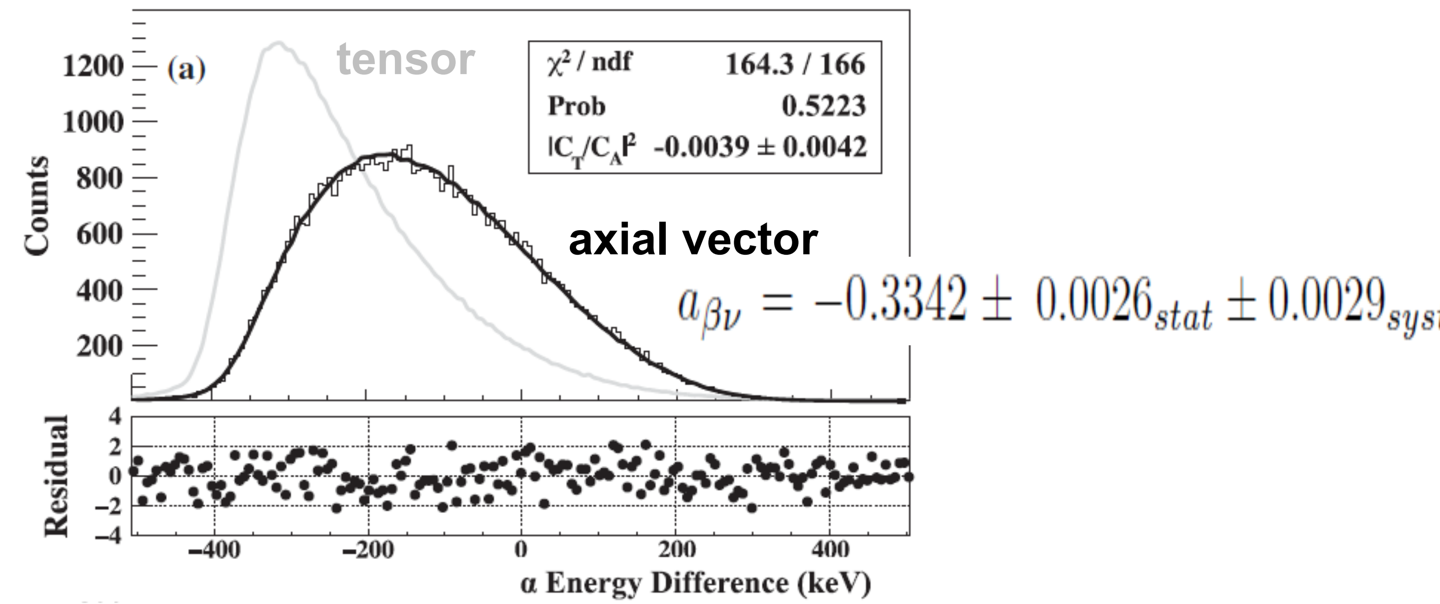
- β and 2α measurement allows complete reconstruction of each decay
- Nearly pure Gamow-Teller transitions
- Large kinematic shifts imparted to α particles from leptons
- β-ν-α correlation gives ×3 enhancement



Symmetries in decay and detector array suppress systematic effects

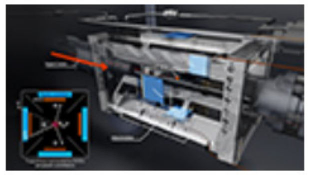
Most sensitive measure of β-ν correlation from ΔE_{α} when β parallel to α





$$a_{\beta\nu} = -0.3342 \pm 0.0026_{stat} \pm 0.0029_{syst}$$

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



08.19.16 | SCIENCE HIGHLIGHT

Improved Tests of the Weak Nuclear Force from Beta Decay

Studies of the neutrinos emitted in the radioactive decay of nuclei held in an ion trap allow sensitive searches for new interactions.

Read More »

Argonne NATIONAL LABORATORY

McGill

The University of Chicago

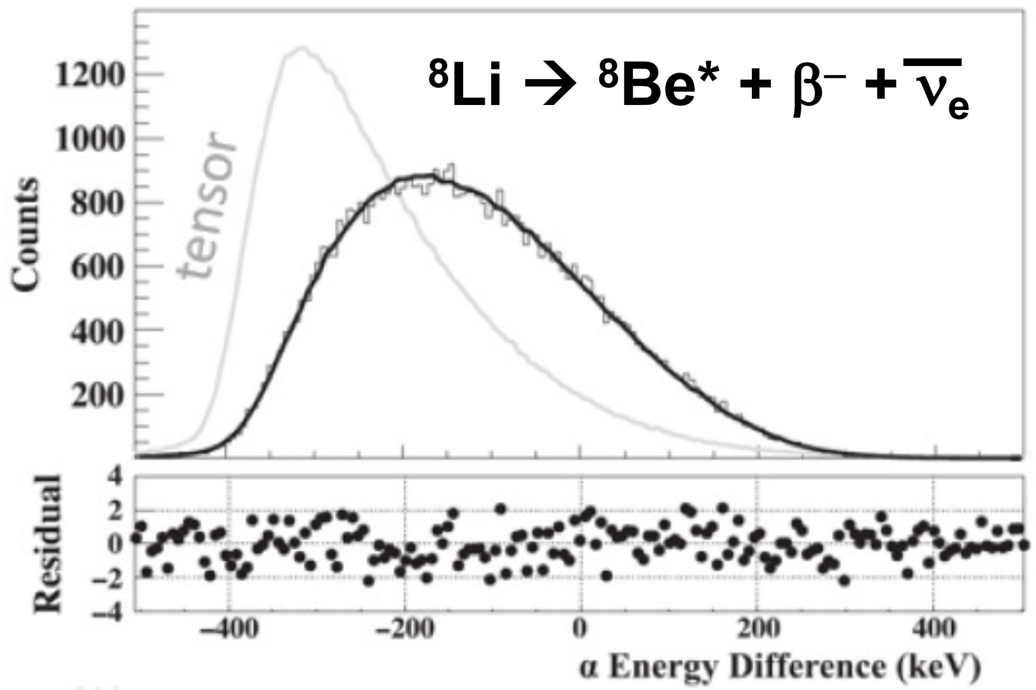
Berkeley UNIVERSITY OF CALIFORNIA

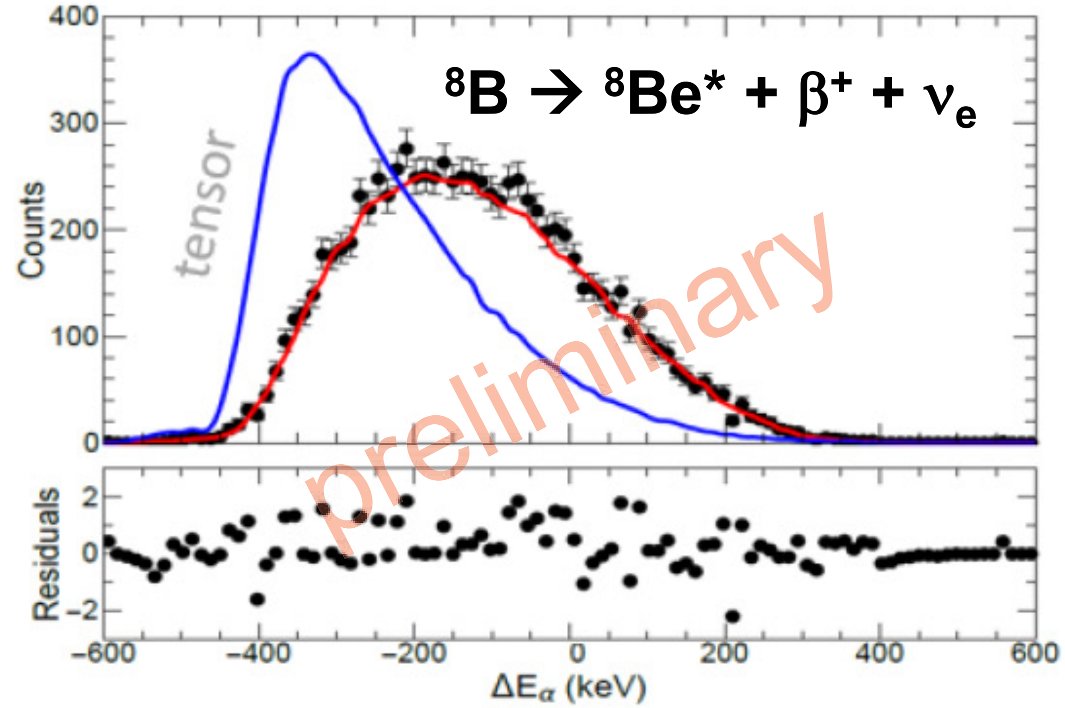
UNIVERSITY OF MANITOBA

SOREQ

LSU

Future plans – increased precision on ^{8}Li and ^{8}B





- New β-ν results in hand for ^{8}B
- Precise ^{8}B neutrino spectrum for solar neutrinos
- Higher-precision β-ν results for ^{8}Li under analysis
- Search for Fierz interference term
- Determine recoil-order terms through comparisons between ^{8}Li vs. ^{8}B
  - Weak magnetism (change sign with $\beta^{\pm}$)
  - Second-class currents (independent of $\beta^{\pm}$)

Complicated phase space and higher-order terms need to be well understood or will limit reach

d_I/Ac	5.5 ± 1.7
j_2/A^2c	-490 ± 70
j_3/A^2c	-980 ± 280

T. Sumikama *et al.*, PRC 83, 065501 (2011)

$$
\begin{aligned}
d^7\Gamma = {}& F_{\mp}(Z,E)\,\frac{G_v^2\cos^2\theta_c}{2(2\pi)^6}\,(E_0-E)^2 pE\, dE\, d\Omega_e\, d\Omega_\nu\, d\Omega_n \\
&\times\Big(g_1(E) + g_2(E)\,\frac{\mathbf{p}}{E}\cdot\hat{k} + g_3(E)\Big[\Big(\frac{\mathbf{p}}{E}\cdot\hat{k}\Big)^2 - \frac{1}{3}\frac{\mathbf{p}^2}{E^2}\Big] \\
&+ \delta_1(E, v^*, \tau_{J'J''}(L))\,\frac{\hat{n}\cdot\mathbf{p}}{E} \\
&+ \delta_2(E, v^*, \tau_{J'J''}(L))\,\hat{n}\cdot\frac{\mathbf{p}}{E}\,\frac{\mathbf{p}}{E}\cdot\hat{k} \\
&+ \delta_3(E, v^*, \tau_{J'J''}(L))\,\hat{n}\cdot\hat{k} \\
&+ \delta_4(E, v^*, \tau_{J'J''}(L))\,\hat{n}\cdot\hat{k}\,\frac{\mathbf{p}}{E}\cdot\hat{k} \\
&+ \tfrac{1}{10}\tau_{J'J''}(L)\,T^{(2)}(\hat{n}):\Big\{ g_{10}(E)[\mathbf{p}/E, \mathbf{p}/E] \\
&+ g_{11}(E)[\mathbf{p}/E, \mathbf{p}/E]\,\frac{\mathbf{p}}{E}\cdot\hat{k} + g_{11}(E)[\mathbf{p}/E, \hat{k}] \\
&+ g_{12}(E)[\mathbf{p}/E, \hat{k}]\,\frac{\mathbf{p}}{E}\cdot\hat{k} + g_{13}(E)[\hat{k}, \hat{k}] \\
&+ g_{15}(E)[\hat{k}, \hat{k}]\,\frac{\mathbf{p}}{E}\cdot\hat{k} + g_{16}(E)\Big[\frac{\mathbf{p}}{E}, \frac{\mathbf{p}}{E}\times\hat{k}\Big] \\
&+ g_{17}(E)\Big[\hat{k}, \frac{\mathbf{p}}{E}\times\hat{k}\Big]\Big\} \\
&+ \delta_8(E, v^*, \tau_{J'J''}(L))\,T^{(3)}(\hat{n}):[\mathbf{p}/E, \mathbf{p}/E, \hat{k}] \\
&+ \delta_9(E, v^*, \tau_{J'J''}(L))\,T^{(3)}(\hat{n}):[\mathbf{p}/E, \hat{k}, \hat{k}] \\
&+ \tfrac{1}{10}\omega_{J'J''}(L)\,T^{(4)}(\hat{n}):\{ g_{25}(E)[\mathbf{p}/E, \mathbf{p}/E, \mathbf{p}/E, \hat{k}] \\
&+ g_{26}(E)[\mathbf{p}/E, \mathbf{p}/E, \hat{k}, \hat{k}] \\
&+ g_{27}(E)[\mathbf{p}/E, \hat{k}, \hat{k}, \hat{k}]\}\Big). \qquad (53)
\end{aligned}
$$

B.R. Holstein, RMP 46, 789 (1974)

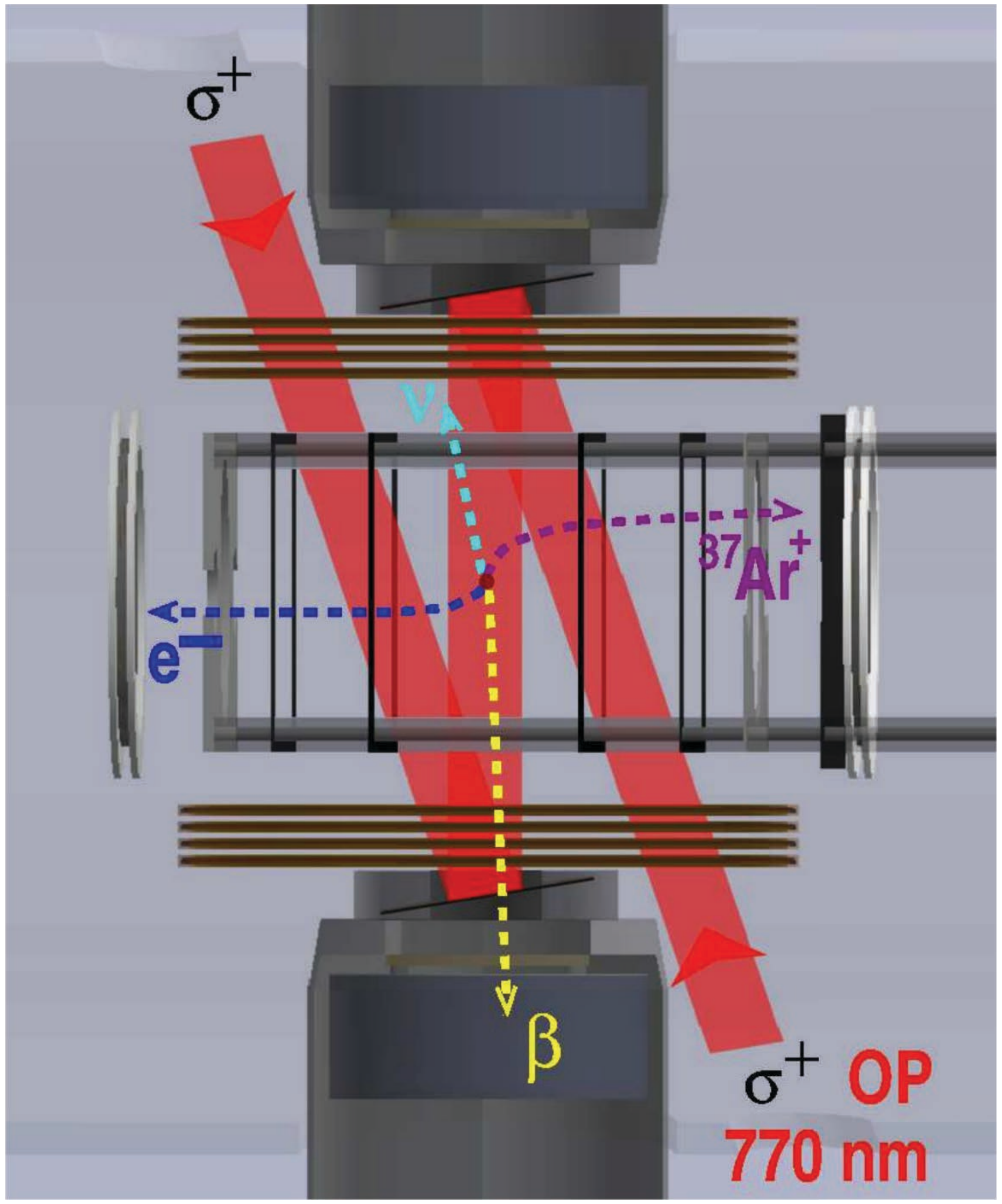
A small and biased sample of efforts
TRINAT @ TRIUMF

Courtesy John Behr and Dan Melconian

TRIUMF Neutral Atom Trap for decay

J.A. Behr

D. Melconian



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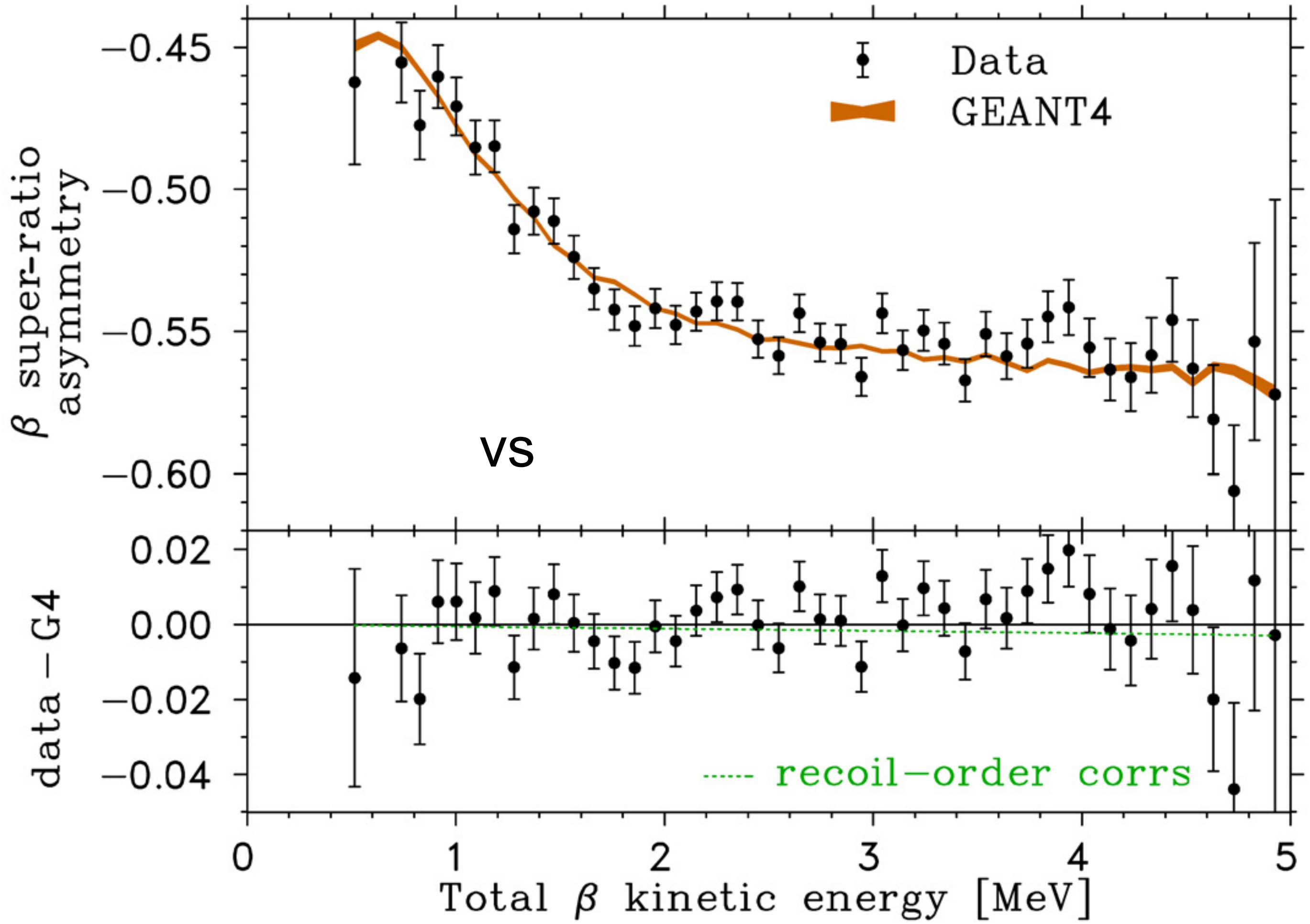
D. Melconian

Most accurate asymmetry
Fenker PRL **120** 062502 (2018)



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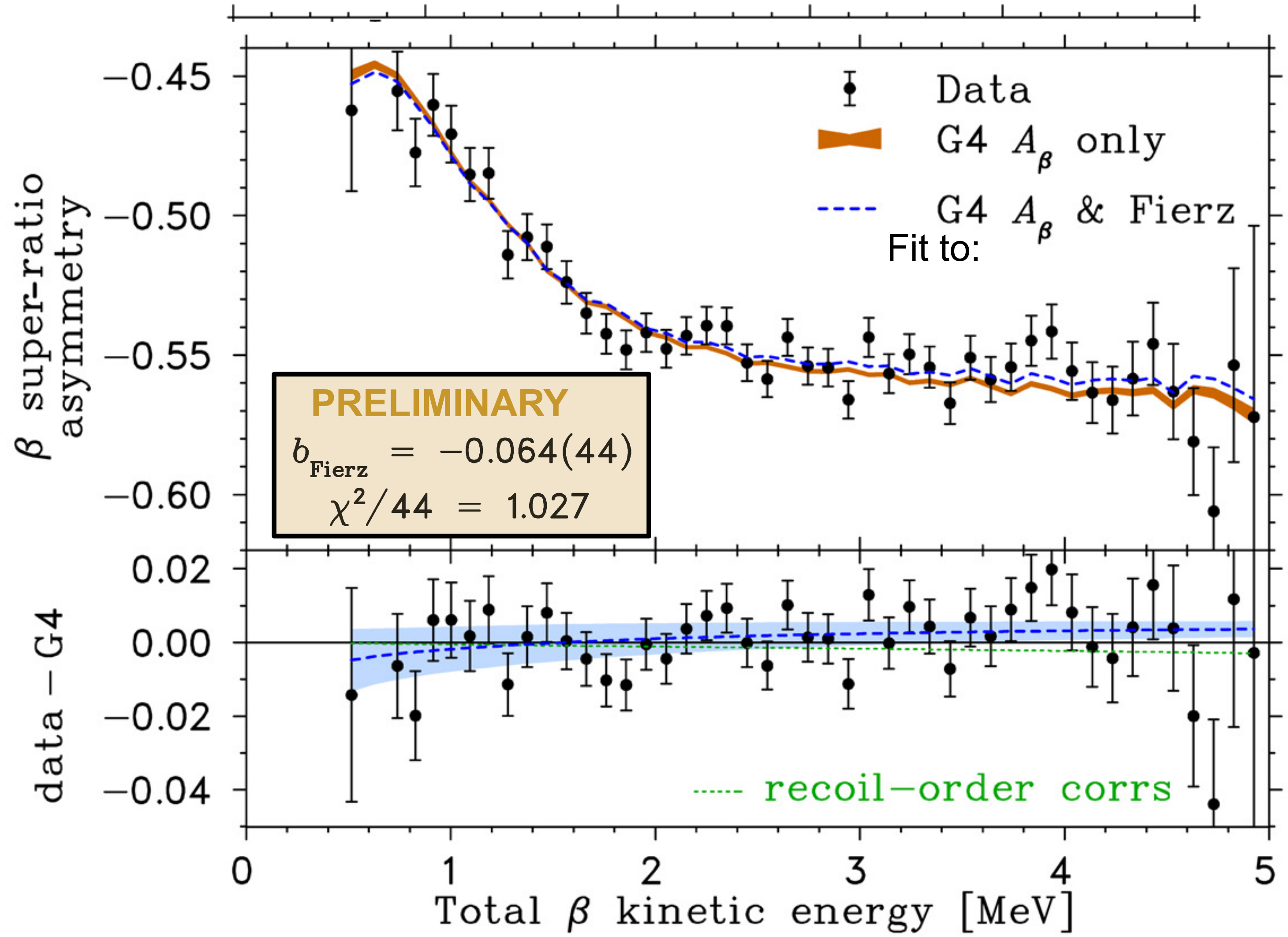

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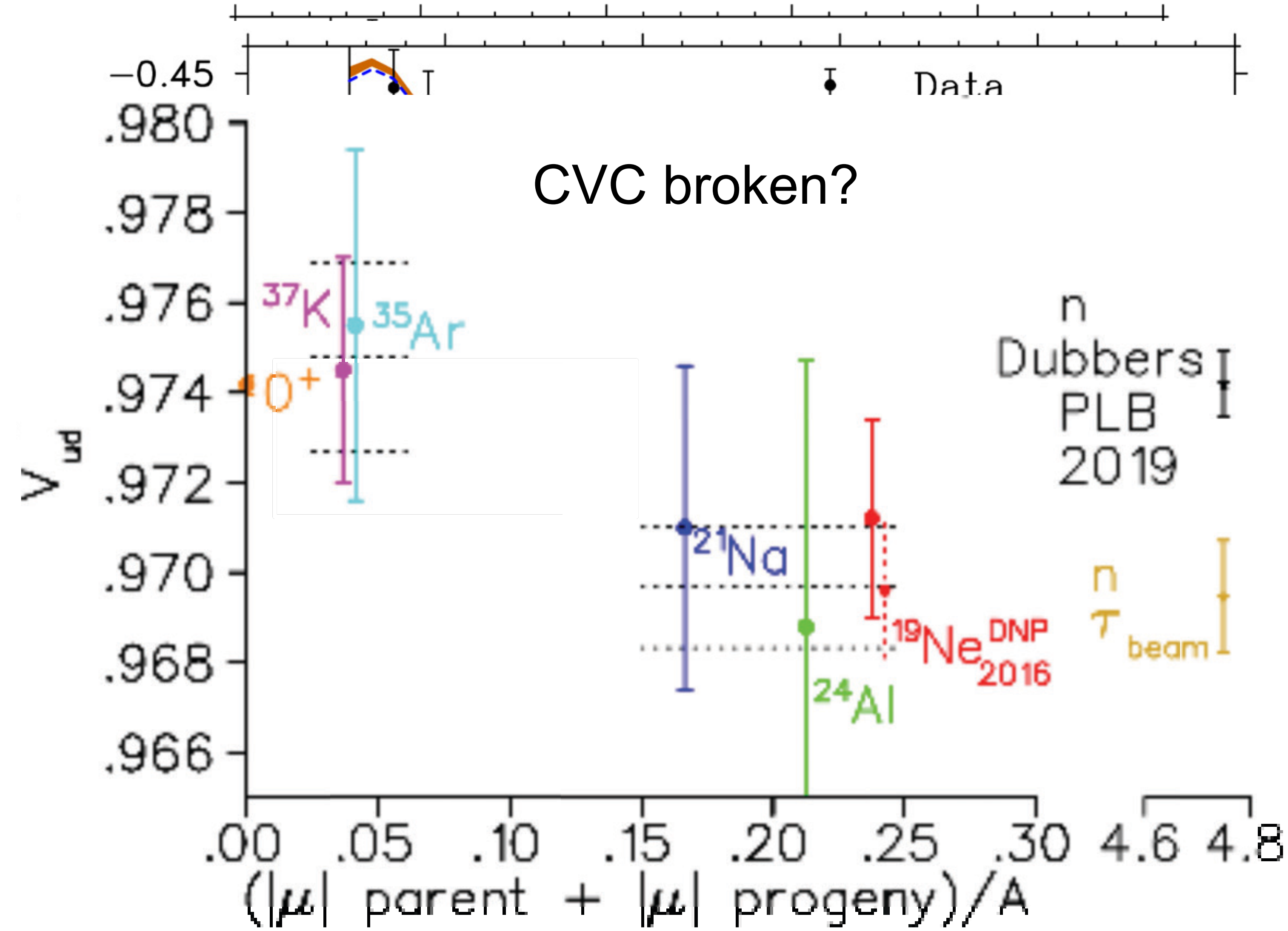

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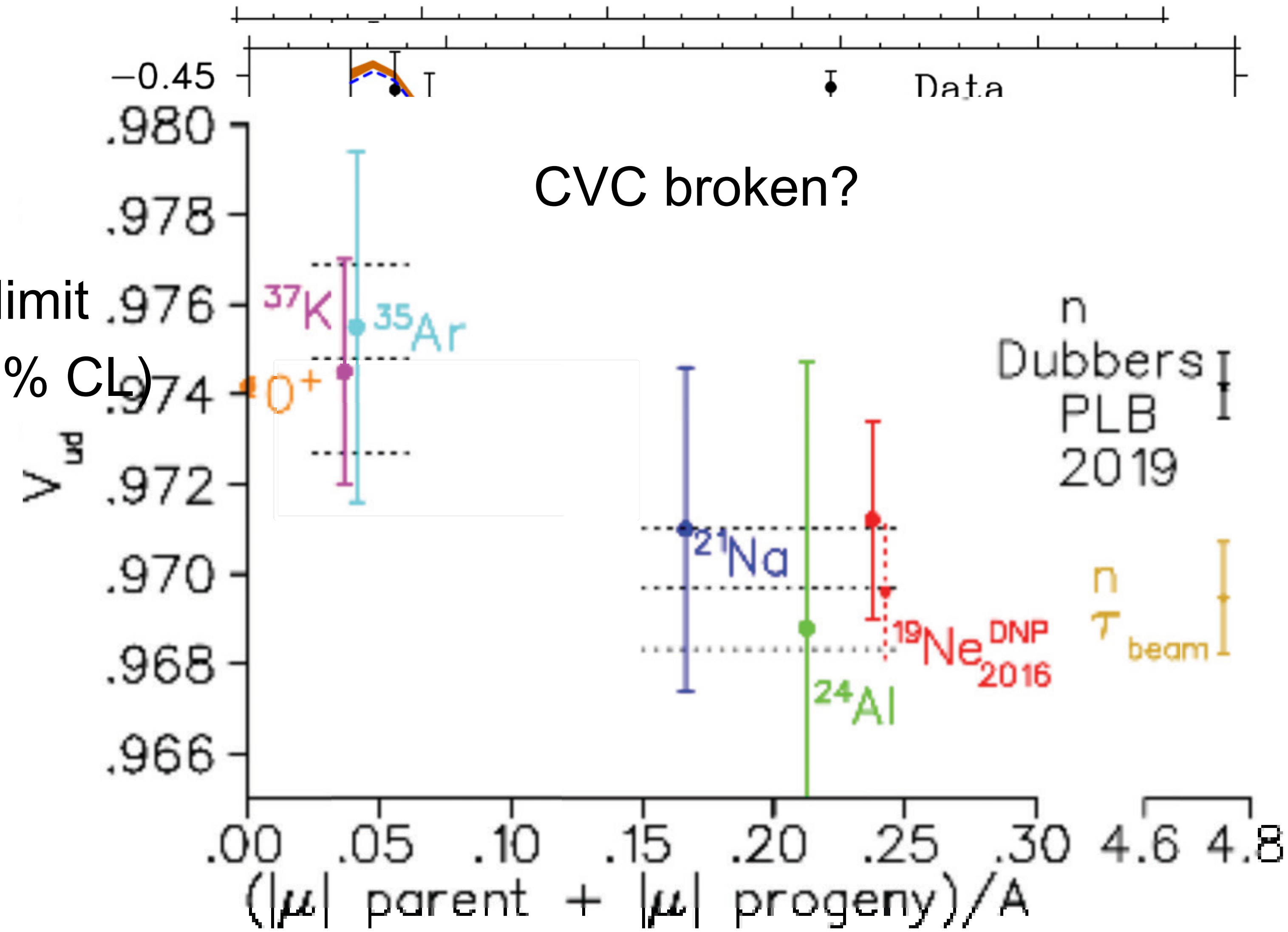
; RHC: best -decay limit

Mw > 352 GeV (90% CL)



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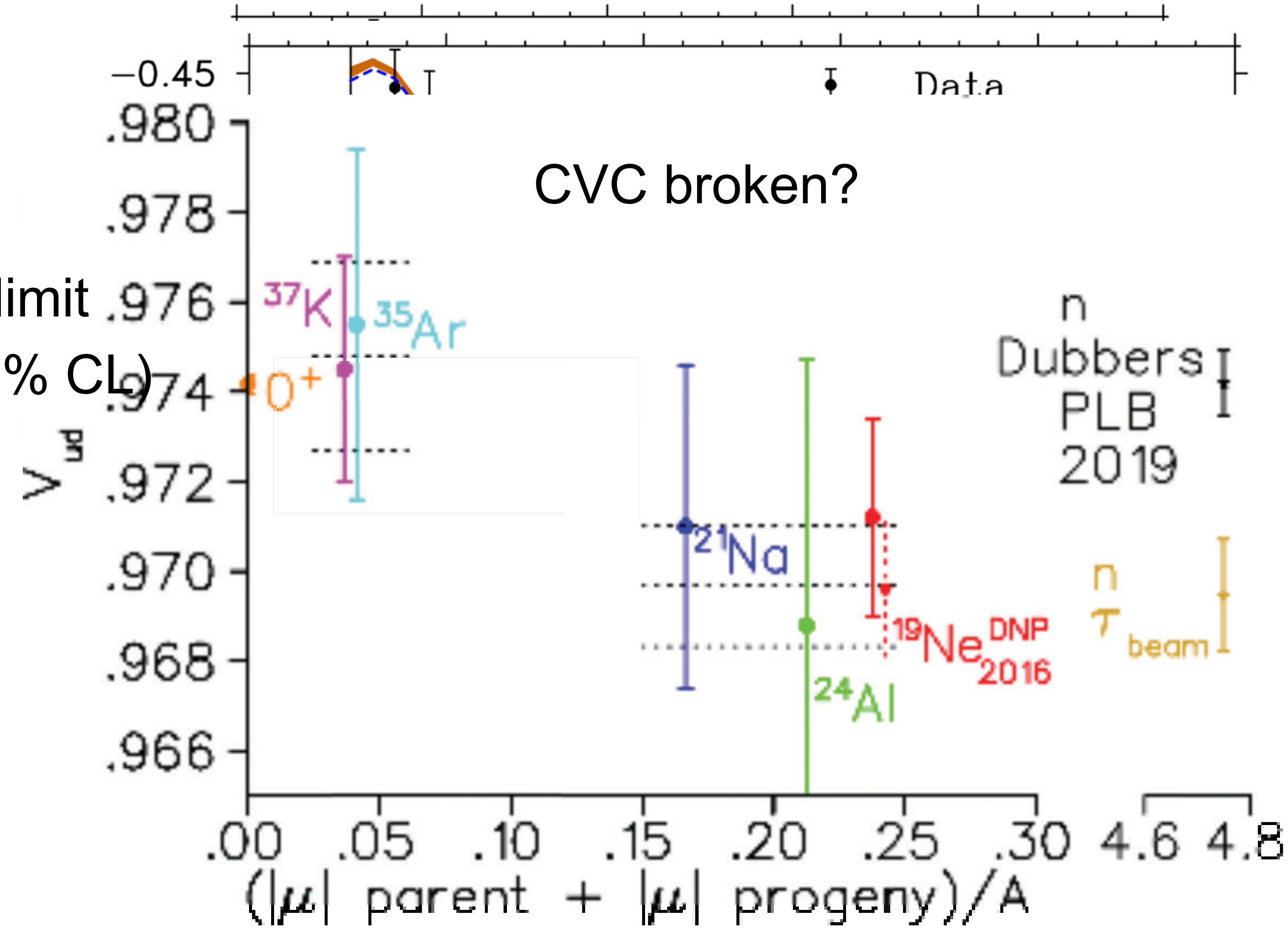
Future:

- Finalize and improve



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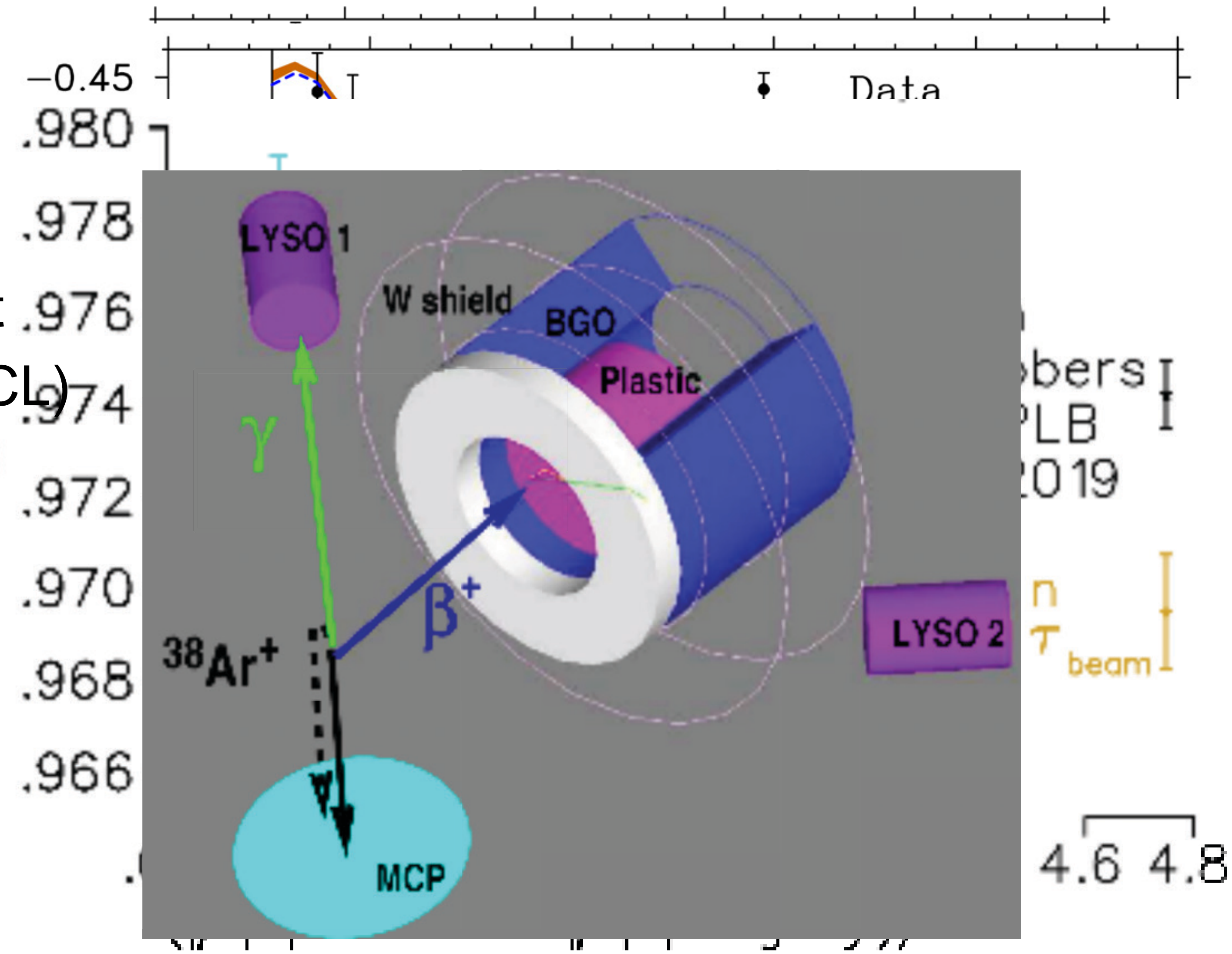

TRIUMF Neutral Atom Trap for decay

TRIUMF — J.A. Behr
TEXAS A&M UNIVERSITY — D. Melconian

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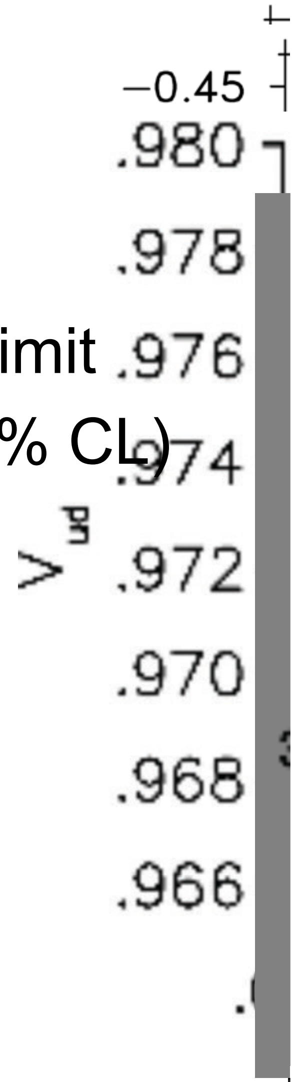
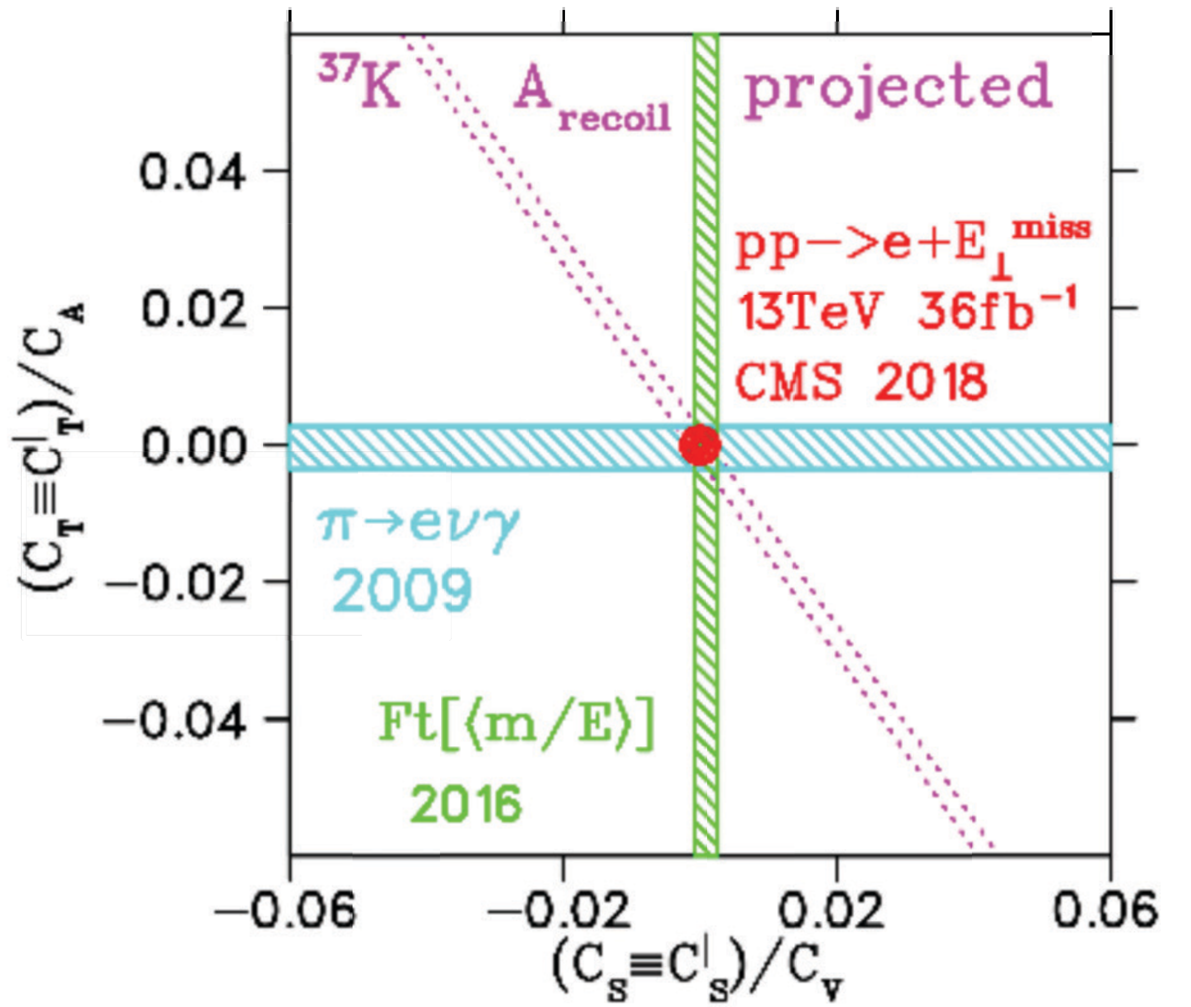
Future:

- Finalize and improve
- T-violation in ^{37}K -> ^{37}Ar
  unique for 1st generation
- Spin asymmetry of nuclear recoils
  similar sensitivity to 4-fermion
  contact interaction as LHC!

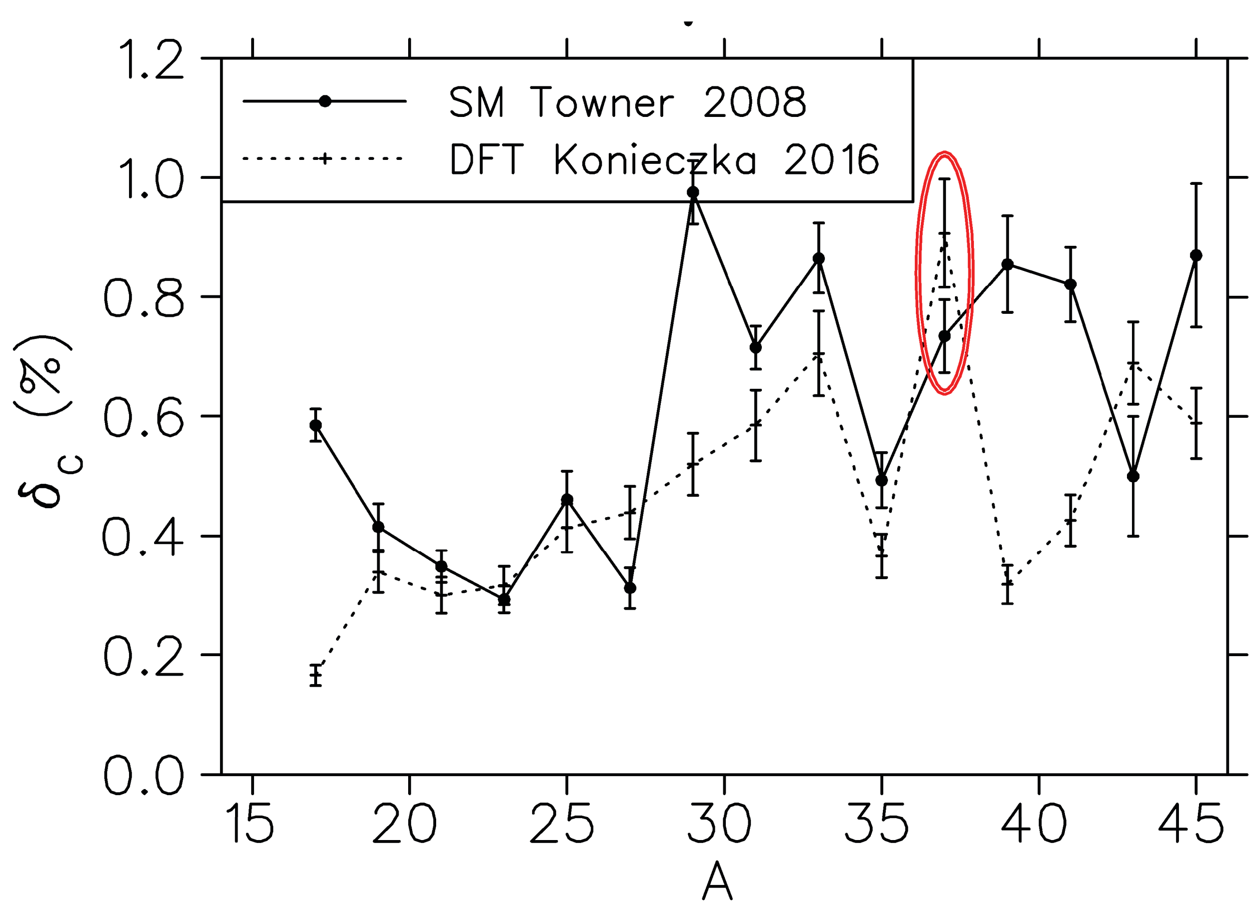




JHEP06 128 expected 2.5 events, saw 2;
using Oscar+Gonzalez−Alonso AnnPhys 2013

TRINAT theory needs:

- Isospin symmetry breaking correction in ^{37}K
  - SW-SM vs DFT vs …
  - Needed for interpreting results as we push < 0.1% to precision



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  - Limitations of Holstein's *approximations*? *Uncertainty??*
  - Aligned with need for δ_c for 0^+ -> 0^+

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  - Aligned with need for δ_c for $0^+ \to 0^+$
- Radiative corrections
  - Not only δ'_R, δ_{NS} but hard bremsstrahlung as, e.g., F. Glück calculated for ^{38m}K and the neutron

Is this loop already bigger than nEDM limits?

TRINAT theory needs:

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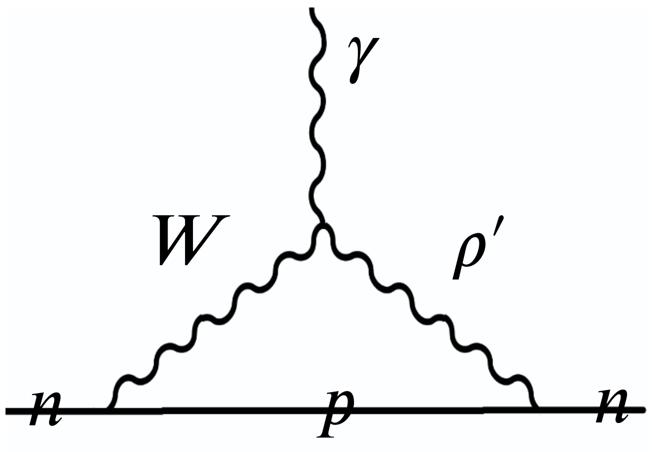
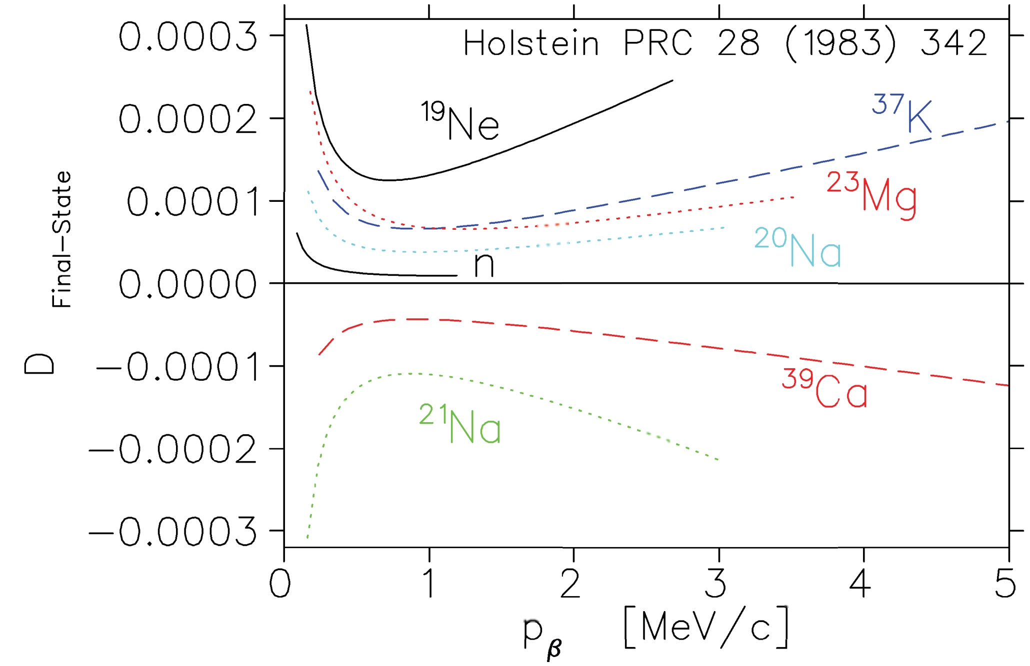
  - Aligned with need for δ_c for $0^+ \to 0^+$
- Radiative corrections
  - Not only δ'_R, δ_{NS} but hard bremsstrahlung as, e.g., F. Glück calculated for ^{38m}K and the neutron
- EDMs and T-violating radiative decay
  - Gardner and He PRD 2013 constrained by nEDM or not? 1-100 MeV scale leptoquarks?

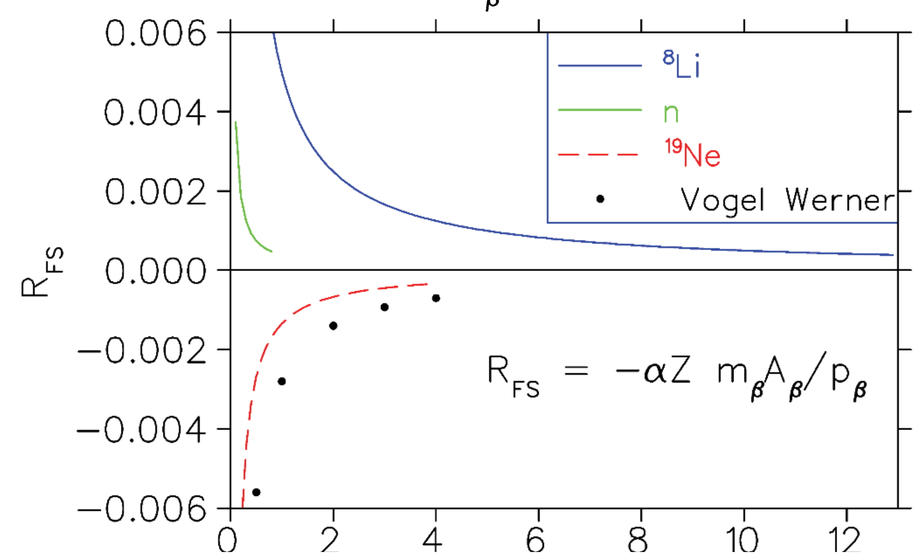


TRINAT theory needs:

- **Isospin symmetry breaking** correction in ^{37}K
  - SW-SM vs DFT vs …
  - Needed for interpreting results as we push < 0.1% to precision
- **Recoil-order effects**
  - Limitations of Holstein's *approximations*? *Uncertainty*??
  - Aligned with need for δ_c for $0^+ \to 0^+$
- **Radiative corrections**
  - Not only δ'_R, δ_{NS} but hard bremsstrahlung as, e.g., F. Glück calculated for ^{38m}K and the neutron
- **EDMs and T-violating radiative decay**
  - Gardner and He PRD 2013 constrained by nEDM or not? 1-100 MeV scale leptoquarks?
- **Final state effects**, and correlations
  - $D\vec{J}\cdot(\vec{p}_\beta \times \hat{p}_\nu)/E_\beta; R\sigma_\beta \cdot \left(\vec{J}\times\vec{p}_\beta/E_\beta\right) \; vs \; R_{fs} = -\frac{\alpha Z m_\beta}{p_\beta}A_\beta$

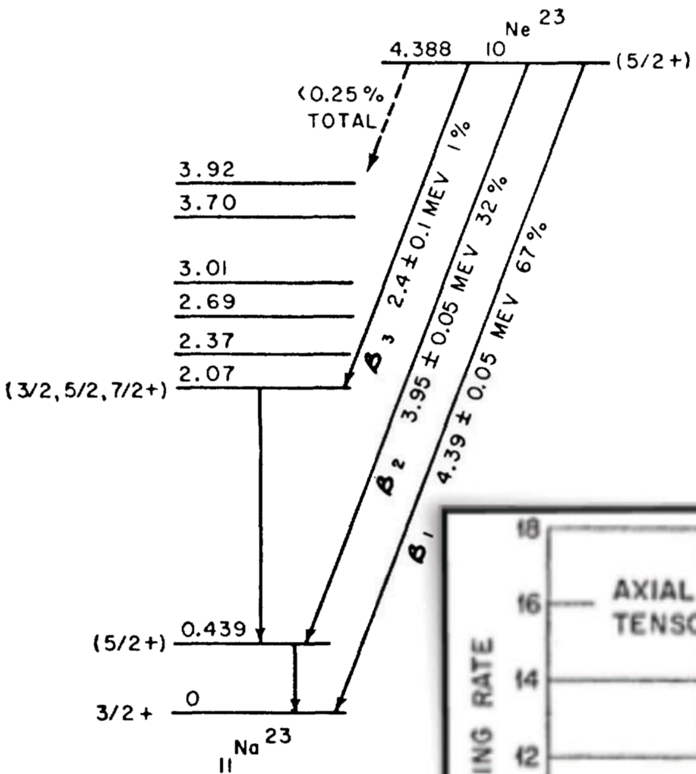
Is this loop already bigger than nEDM limits?



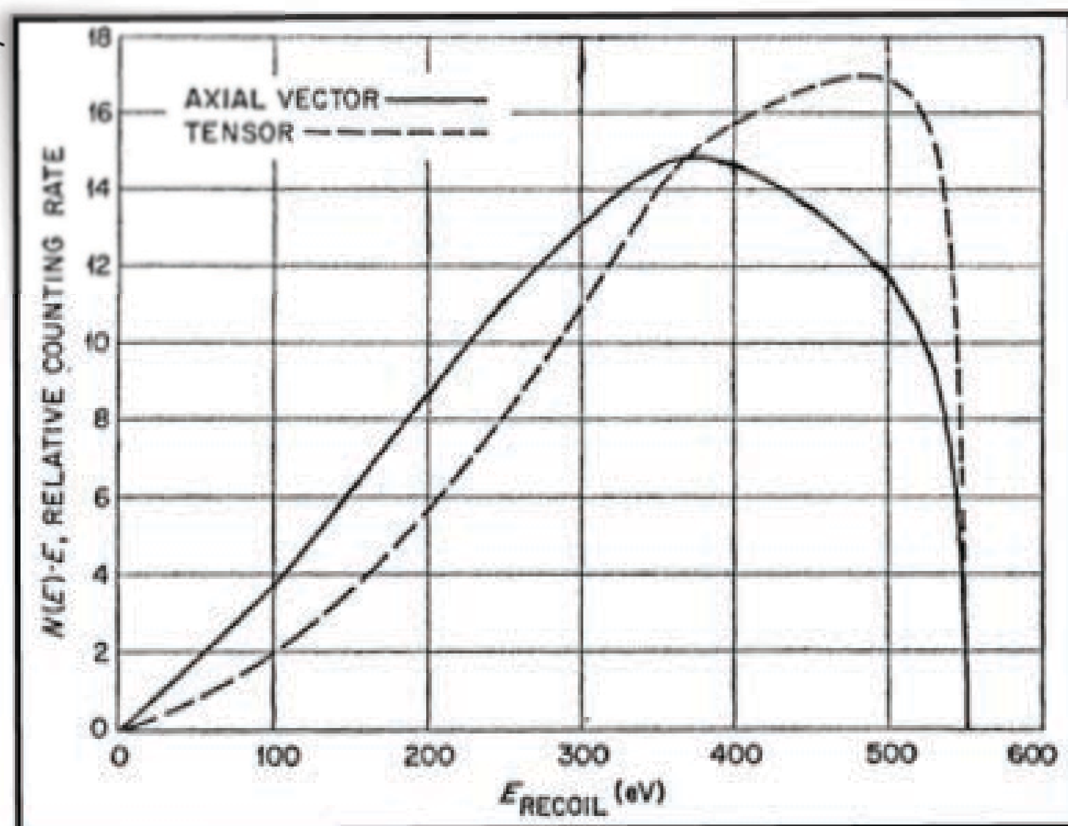


A small and biased sample of efforts
NEAT @ HUJI

$a_{\beta\nu}$ from recoil ion



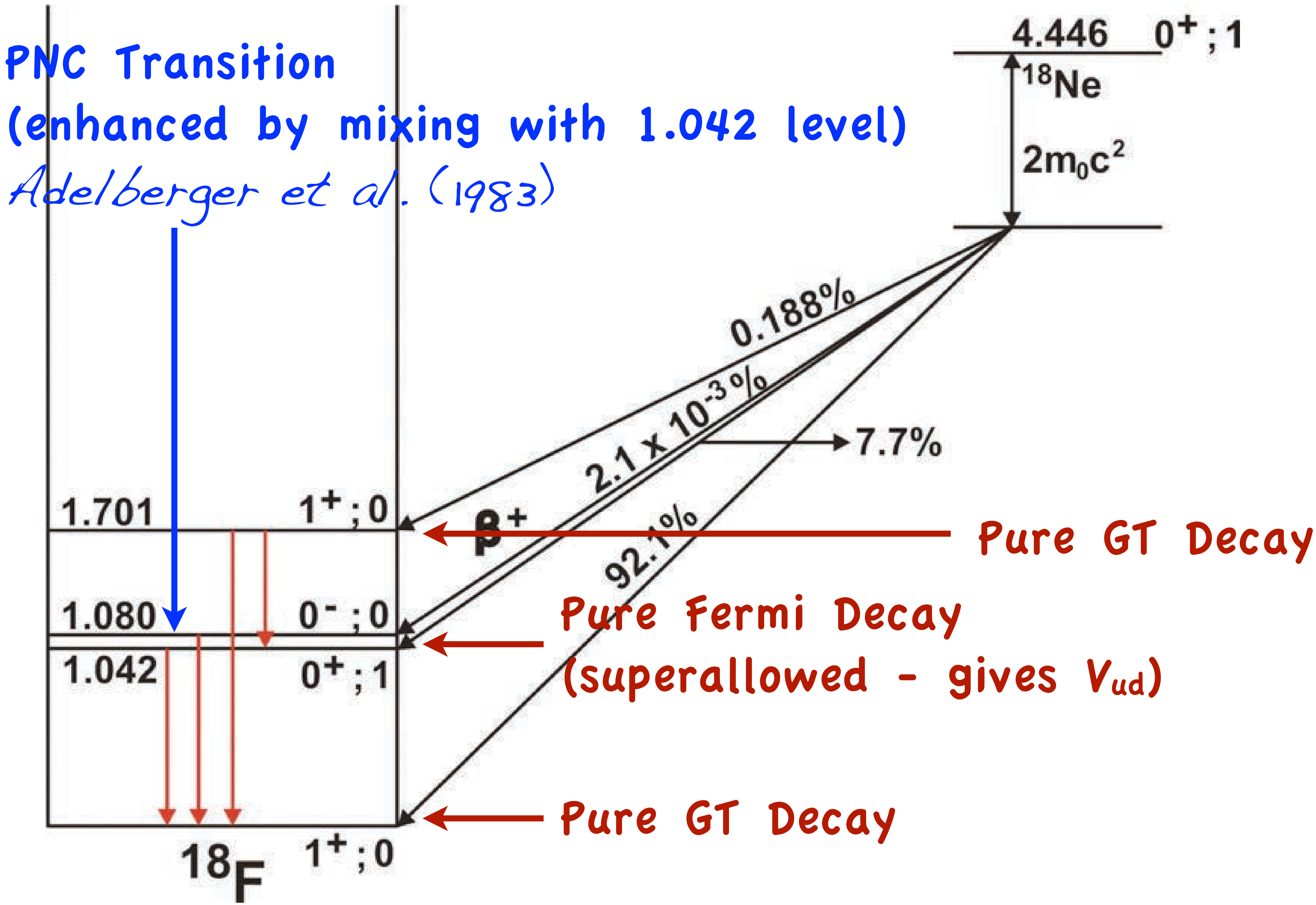
Know your branching ratios.



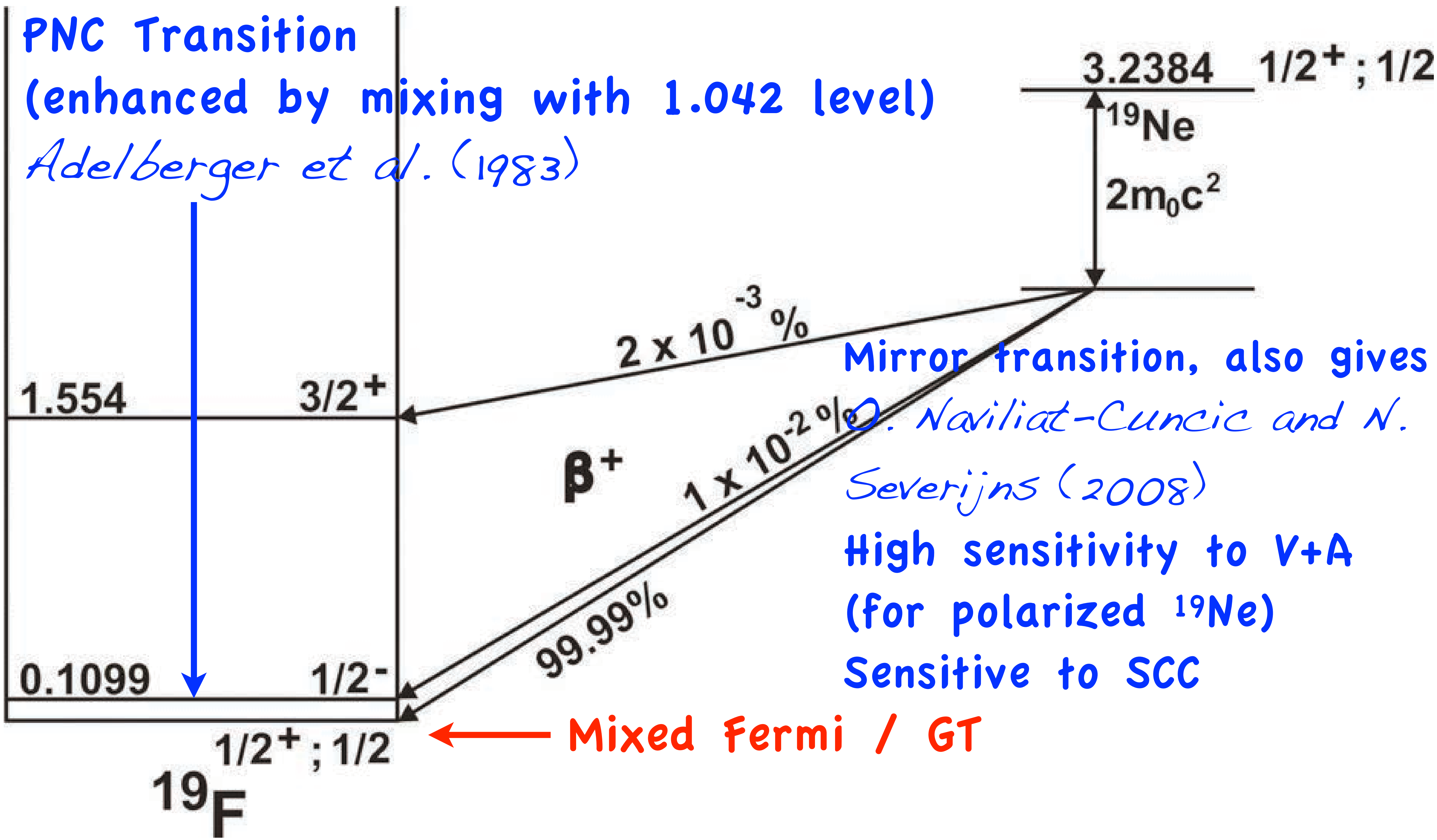
Compute recoil energy dist. for each transition, for various $a_{\beta\nu}$ and compare to experiment.

Some complicated math

Higher order corrections


PNC Transition
(enhanced by mixing with 1.042 level)
Adelberger et al. (1983)
4.446 0+ ; 1
18Ne
2m0c2
0.188%
2.1 x 10-3 %
7.7%
92.1%
β+
1.701 1+ ; 0
1.080 0- ; 0
1.042 0+ ; 1
18F 1+ ; 0
Pure GT Decay
Pure Fermi Decay
(superallowed - gives Vud)
Pure GT Decay

PNC Transition
(enhanced by mixing with 1.042 level)
Adelberger et al. (1983)

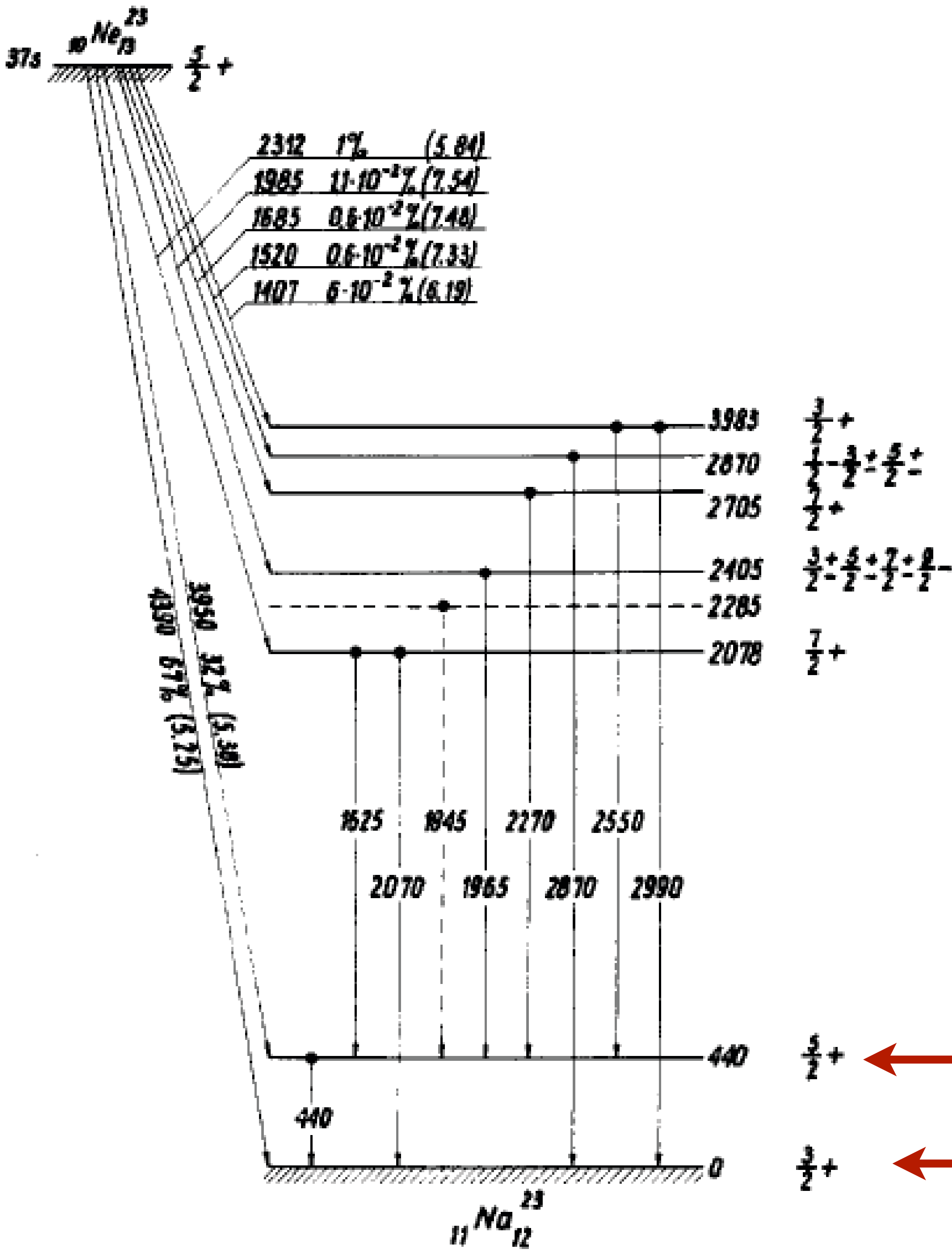


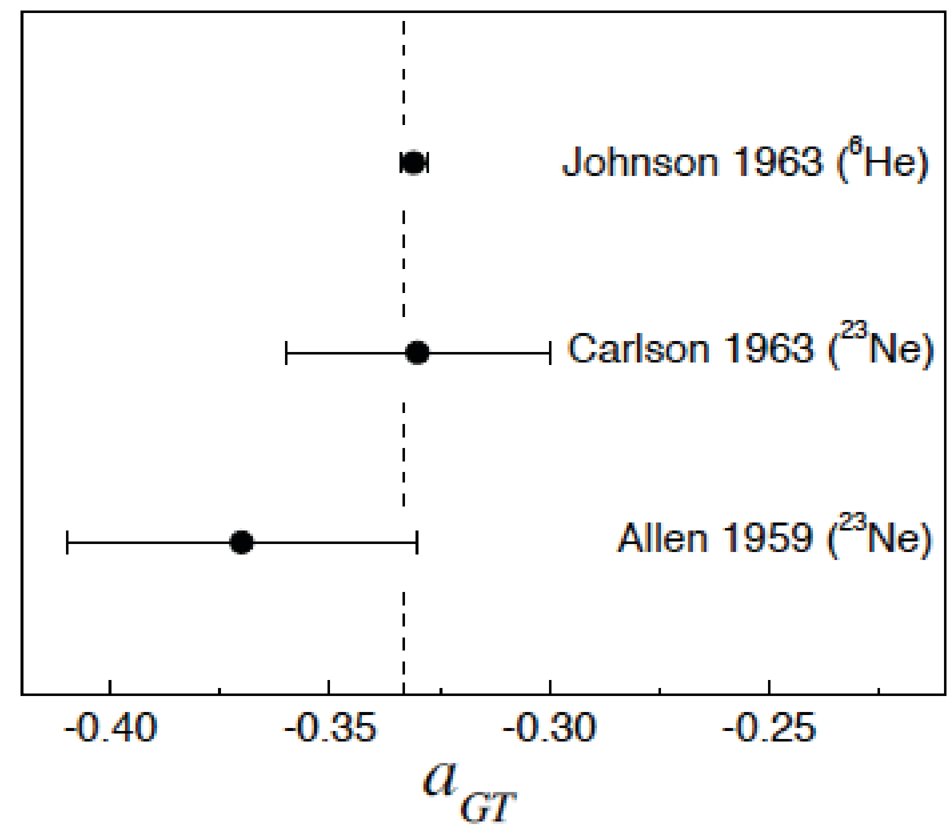
Mirror transition, also gives V_{ud}
O. Naviliat-Cuncic and N. Severijns (2008)

High sensitivity to V+A
(for polarized ^{19}Ne)

Sensitive to SCC

Mixed Fermi / GT

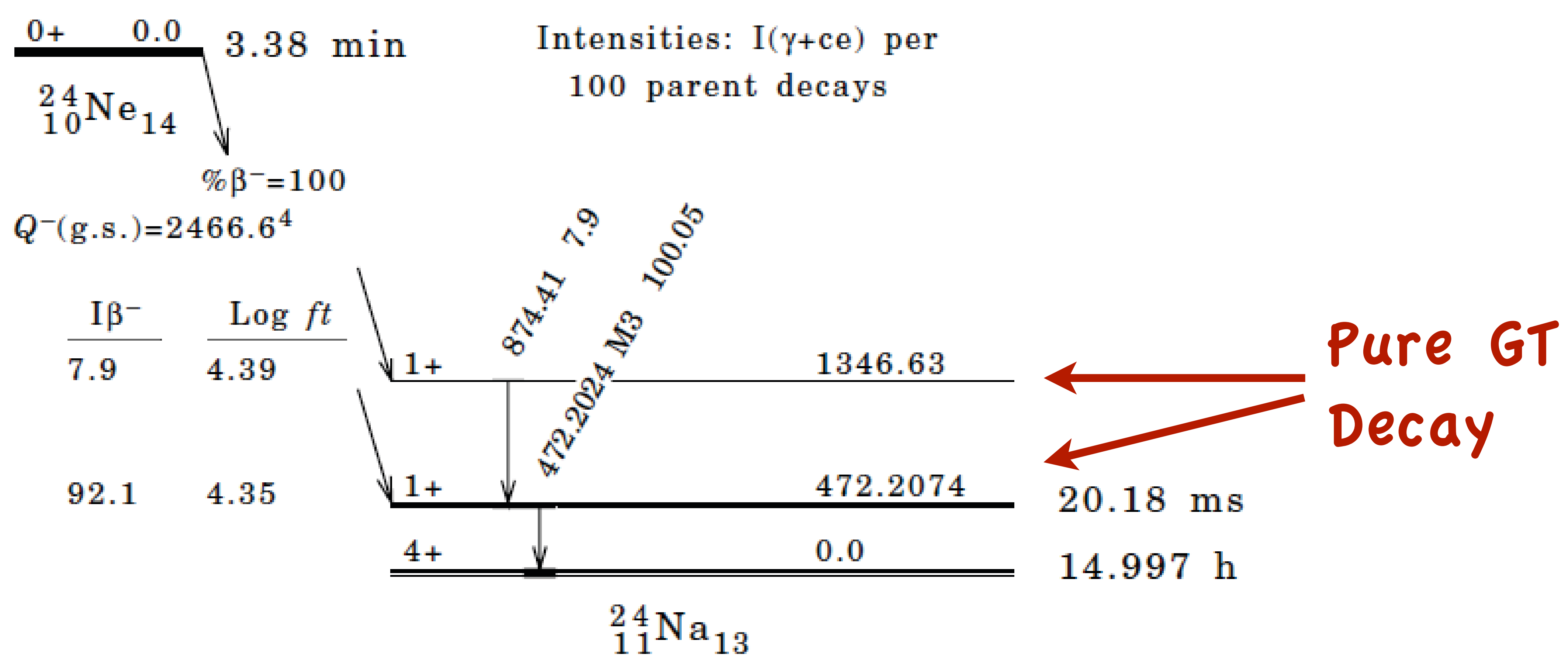




Almost Pure GT Decay

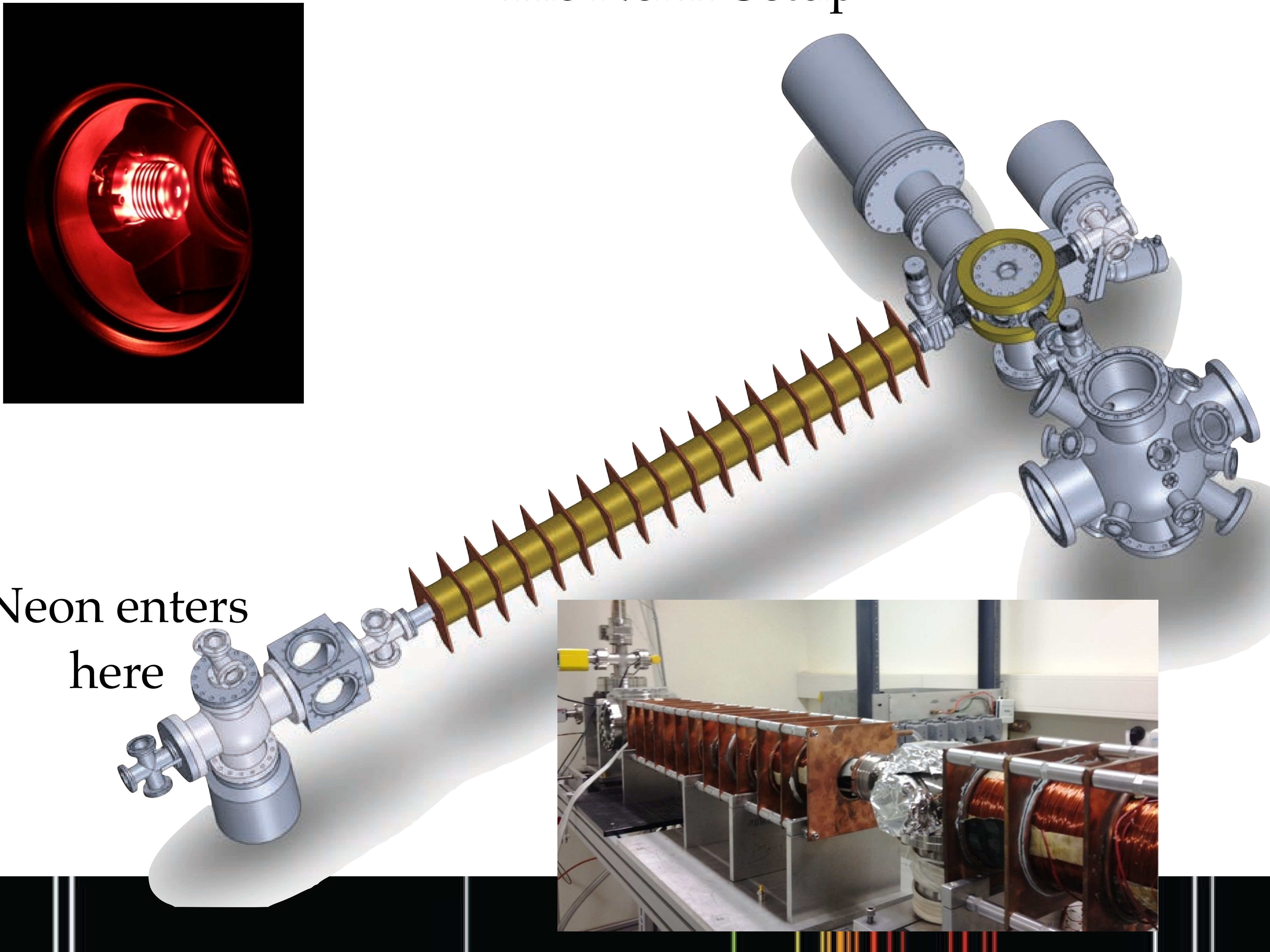
Pure GT Decay

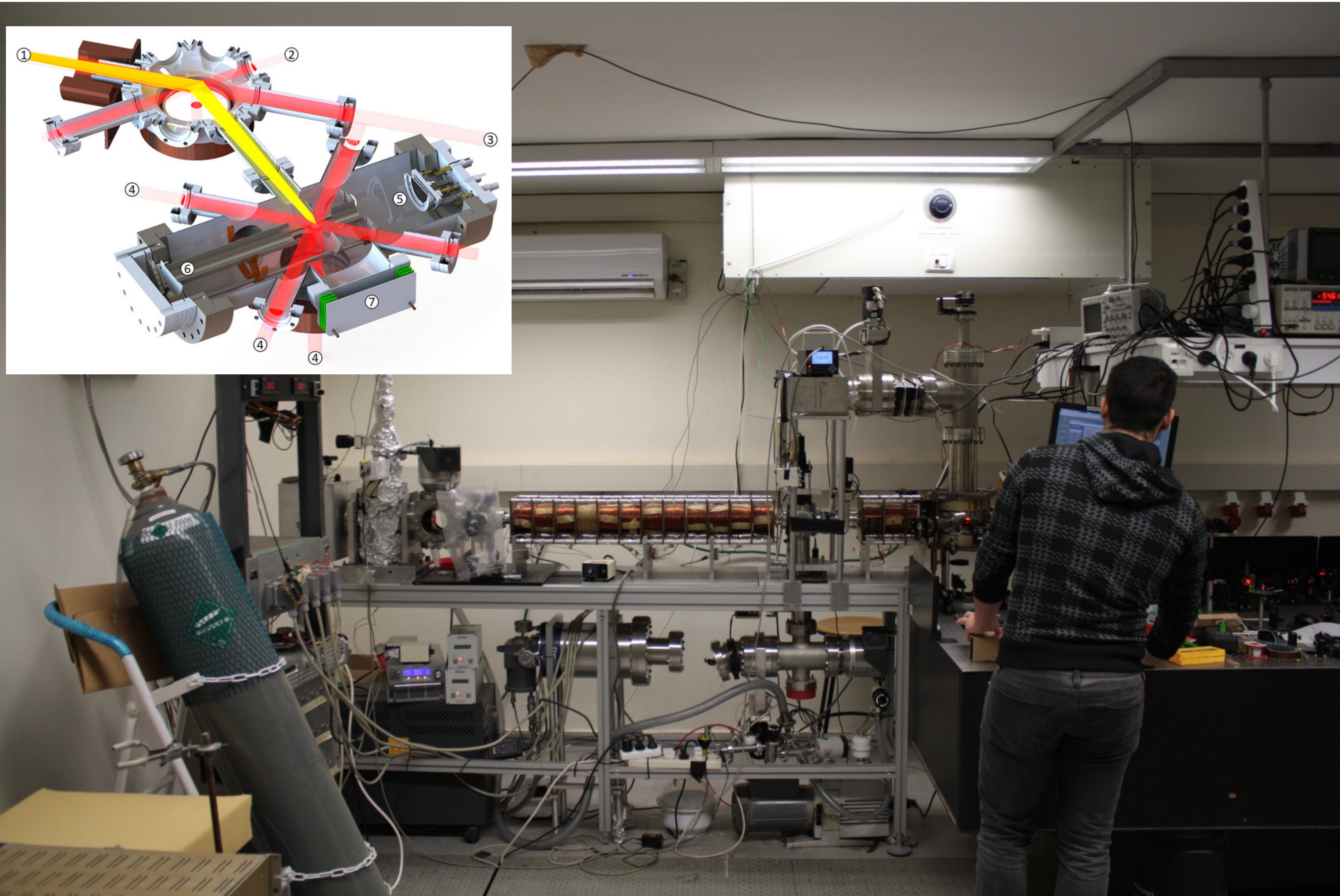
^{24}Ne



0+ 0.0
3.38 min
$^{24}_{10}Ne_{14}$
%β⁻=100
Q⁻(g.s.)=2466.6 4
Intensities: I(γ+ce) per
100 parent decays
Iβ⁻
Log ft
7.9
4.39
92.1
4.35
874.41 7.9
472.2024 M3 100.05
1+ 1346.63
1+ 472.2074
20.18 ms
4+ 0.0
14.997 h
$^{24}_{11}Na_{13}$
Pure GT
Decay

The NeAT Setup

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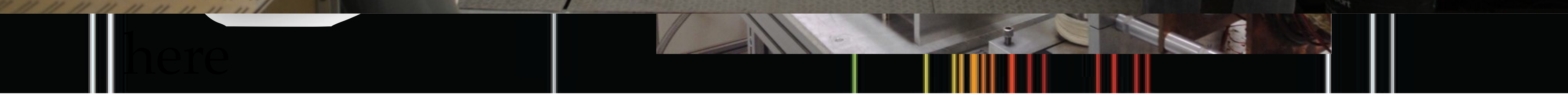
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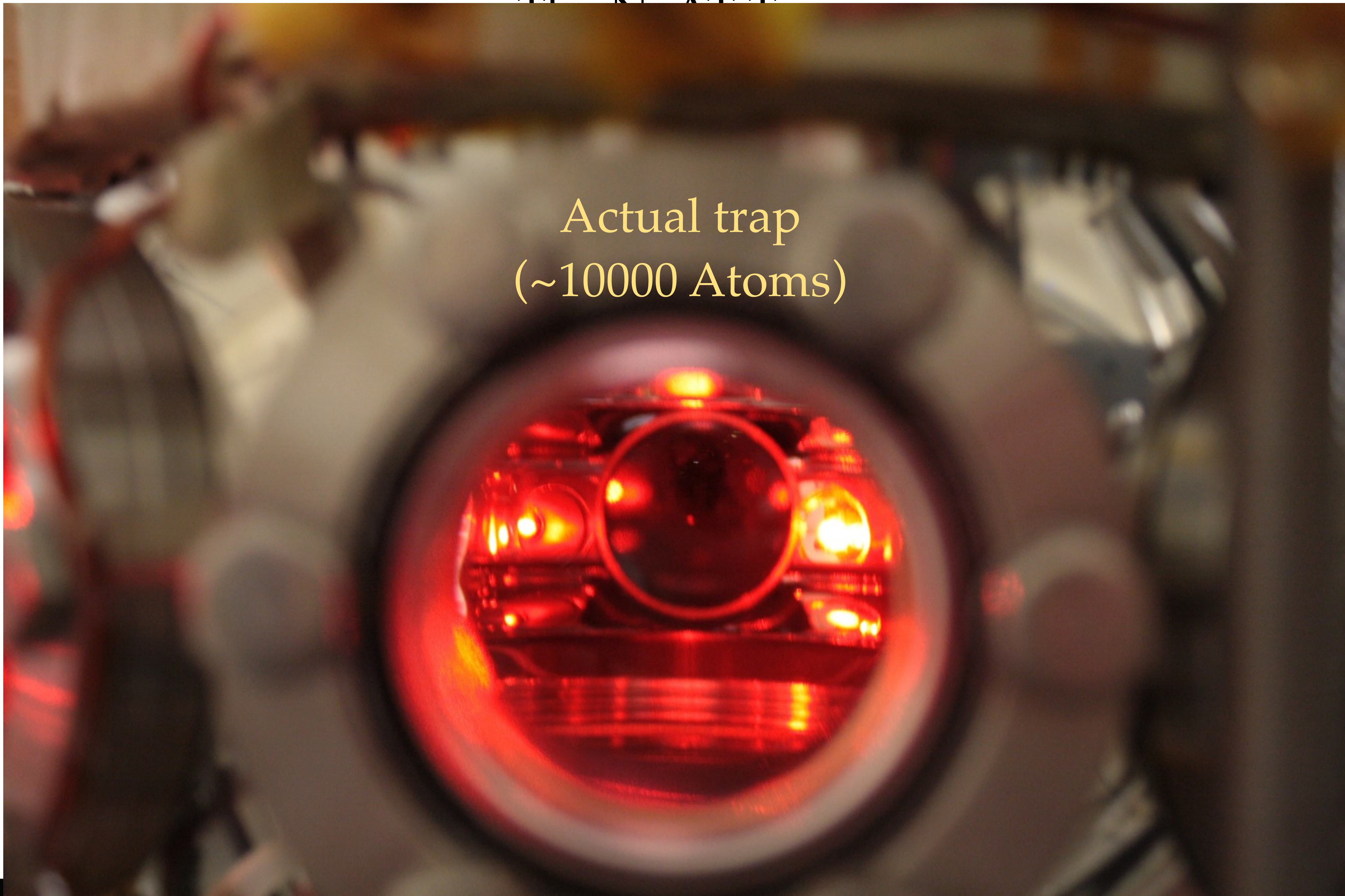


here

A Brief Aside

Optical traps

- Once cooled and trapped by the MOT, atoms can be trapped by the purely dipole force.

Interaction of laser E field and induced dipole moment:

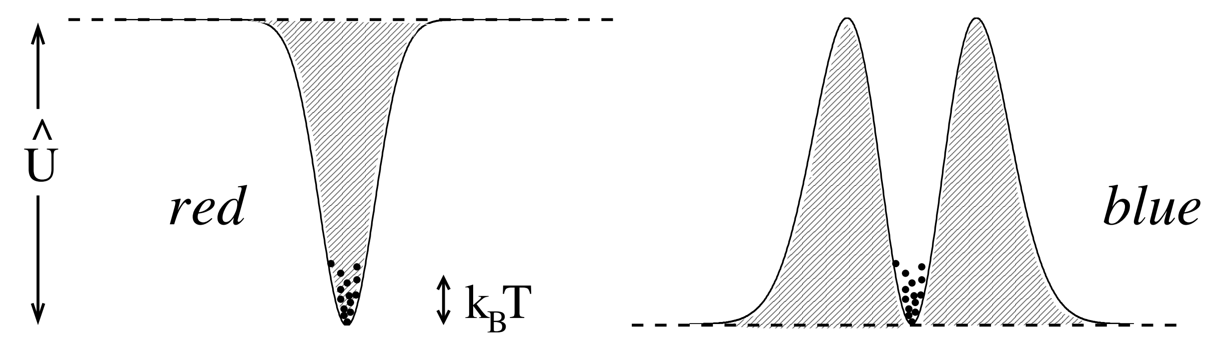
$$\tilde{p} = \alpha \tilde{E}$$

$$U_{dip} = -\frac{1}{2} \langle \mathbf{pE} \rangle$$

$$U_{dip}(\vec{r}) = \frac{3\pi c^2}{2w_0^3} \frac{\Gamma}{\Delta} I(\vec{r})$$

$$\gamma_{sc}(\vec{r}) = \frac{3\pi c^2}{2\hbar w_0^3} \left(\frac{\Gamma}{\Delta} \right)^2 I(\vec{r})$$

$$\Delta = w_{laser} - w_0$$



Red detuned traps are attractive

Blue detuned traps are repulsive

Looking Ahead (Tech IV)

Dark Blue Traps

- Currently testing two optical traps (dark cavities surrounded by blue detuned light). Based on designs by Davidson *et al.* (slightly modified).

Friedman, N., Kaplan, A., and Davidson, N. Adv. At. Mol. Opt. Phys., 48:99 (2002).

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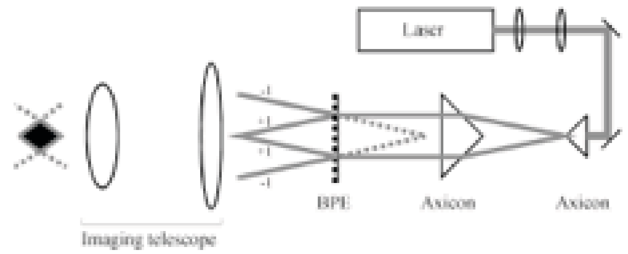
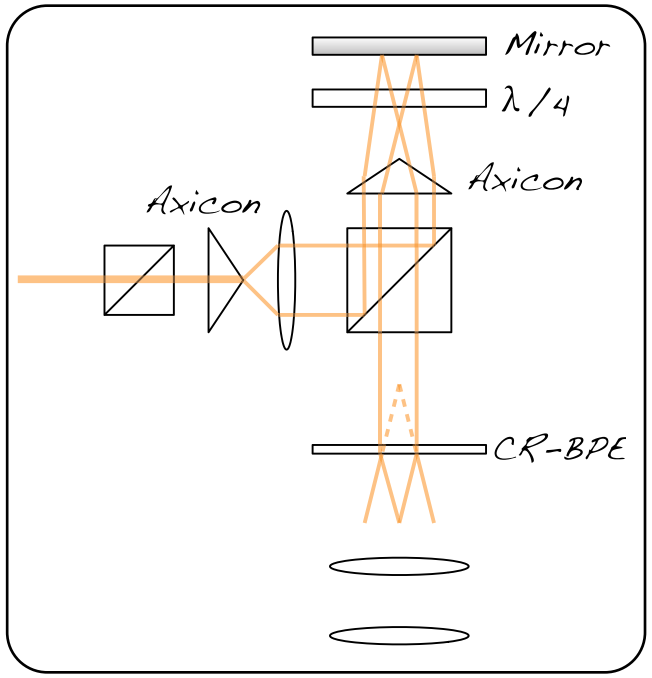
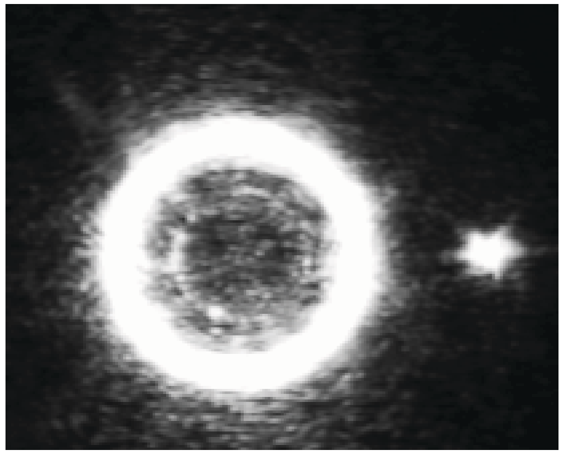
Single beam "axicon" trap







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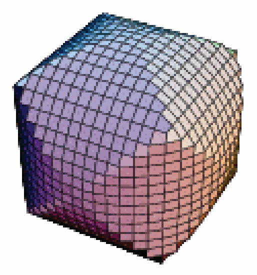

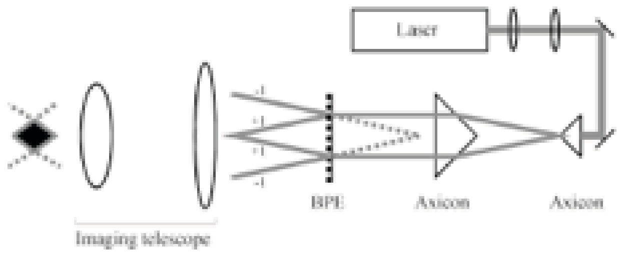

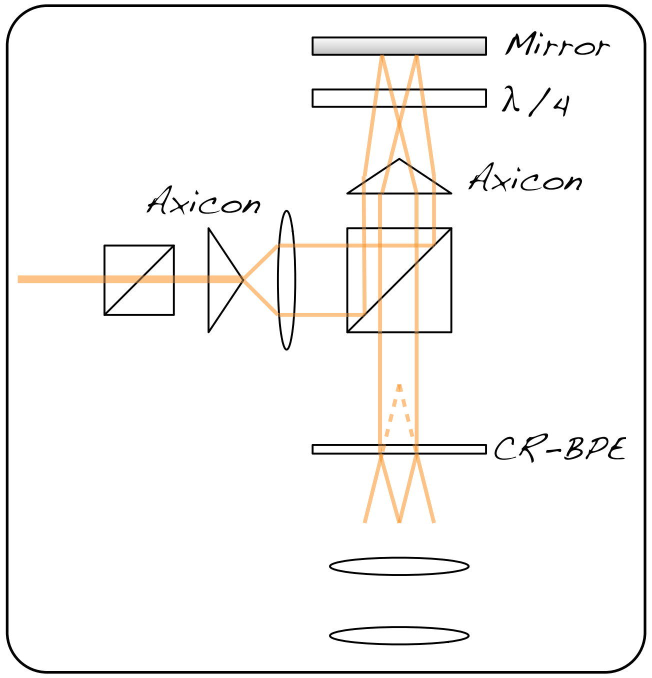

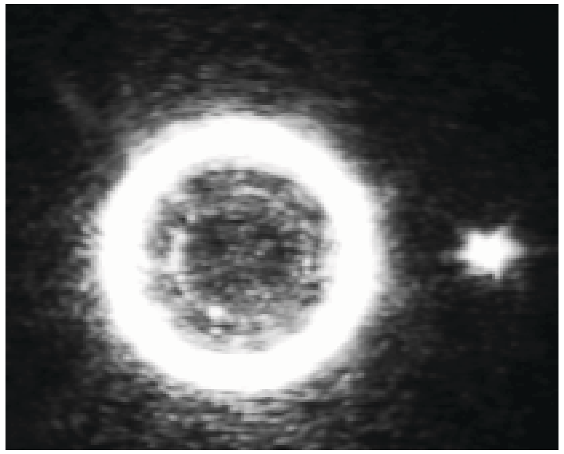

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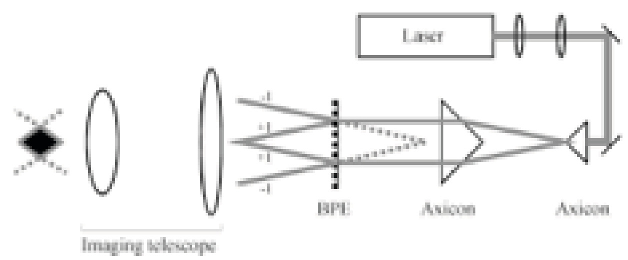
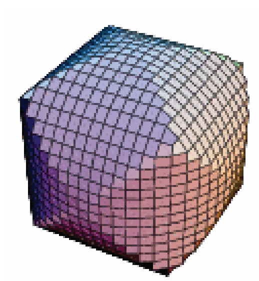
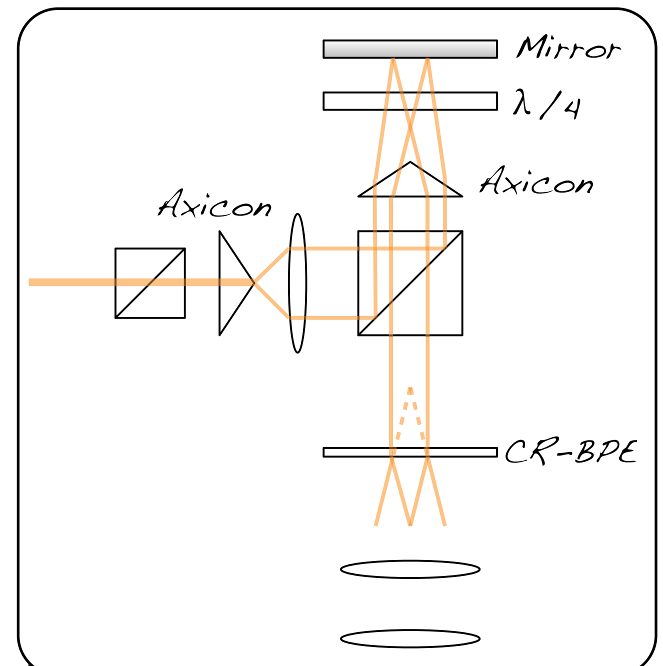
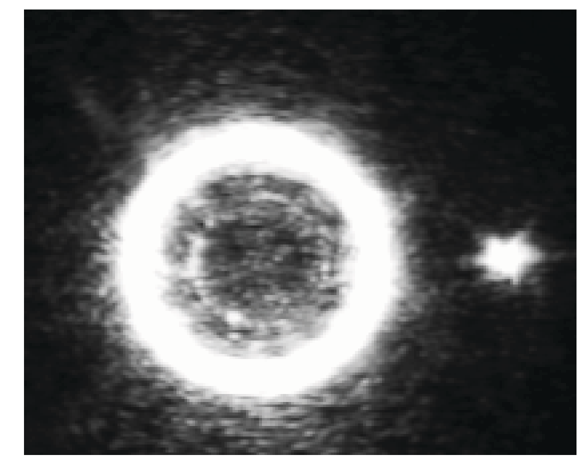
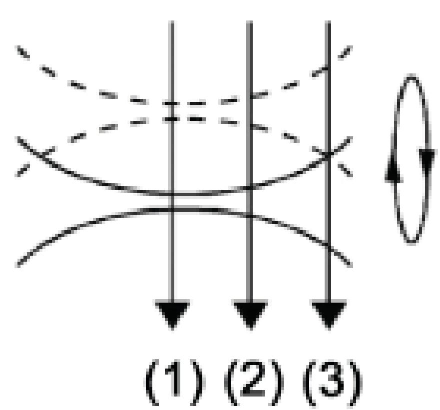


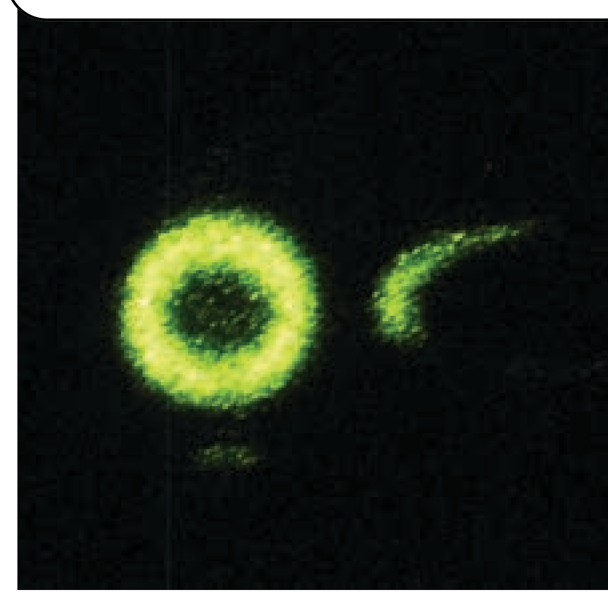


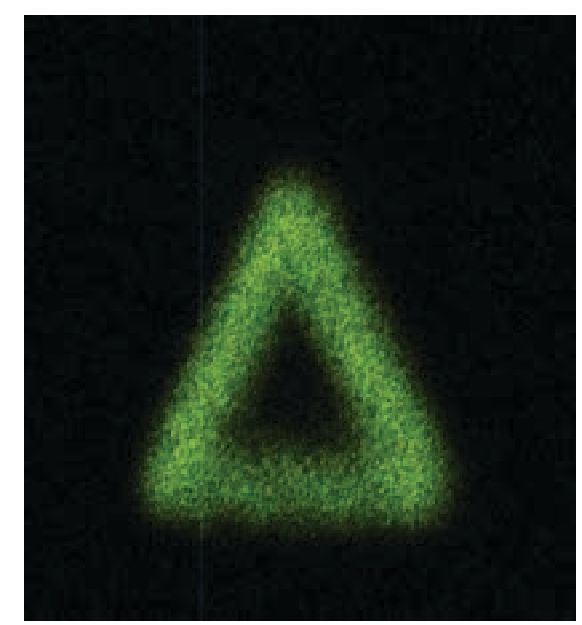




ROtating Beam Optical Trap (but in 2 orthogonal directions)





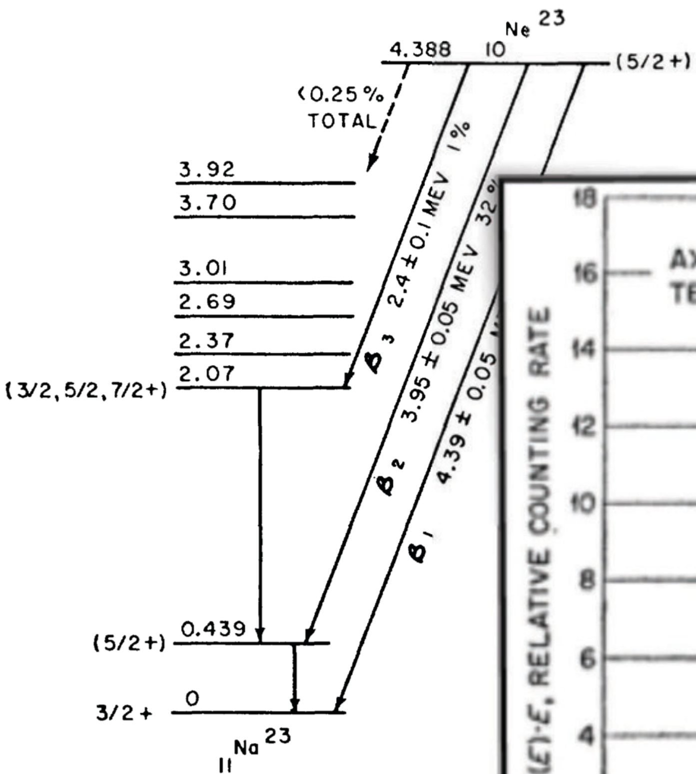


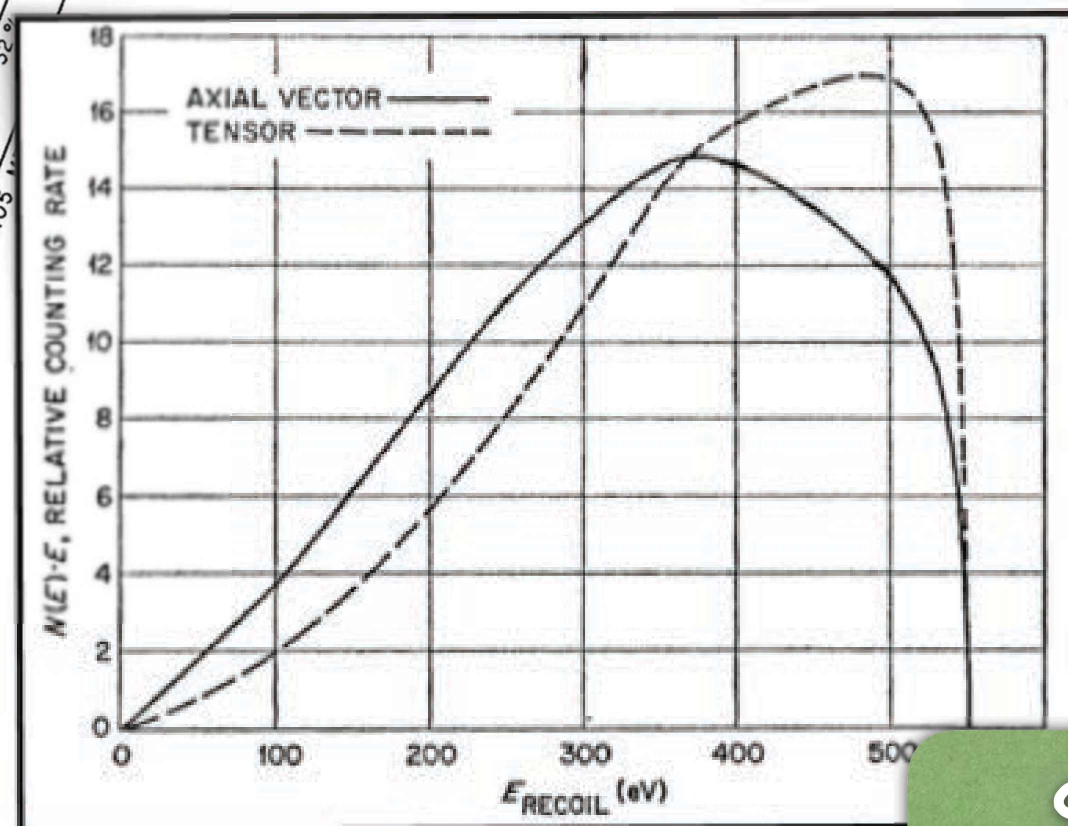
Digitally controlled

Friedman, N., Kaplan, A., and Davidson, N. Adv. At. Mol. Opt. Phys., 48:99 (2002).

$a_{\beta\nu}$ from recoil ion

Know your branching ratios.





Compute recoil energy dist. for each transition, for various $a_{\beta\nu}$ and compare to experiment.

Some complicated math

$$Q(r)dr = \frac{r}{12}[Q_0(r) + b\,Q_1(r) + a\,Q_2(r)]dr,$$

where

$$Q_i(r) = [W F_i(W,r)]_{W_{\min}(r)}^{W_{\max}(r)},$$

and

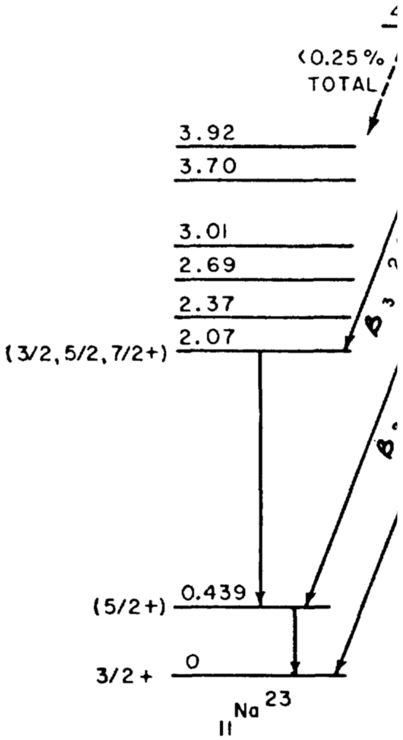
$$F_0(W,r) = W(3W_0 - 2W),$$
$$F_1(W,r) = 3m(2W_0 - W),$$
$$F_2(W,r) = 3\left(r^2 + m^2 - W_0^2 + W_0 W - \frac{2}{3}W^2\right).$$

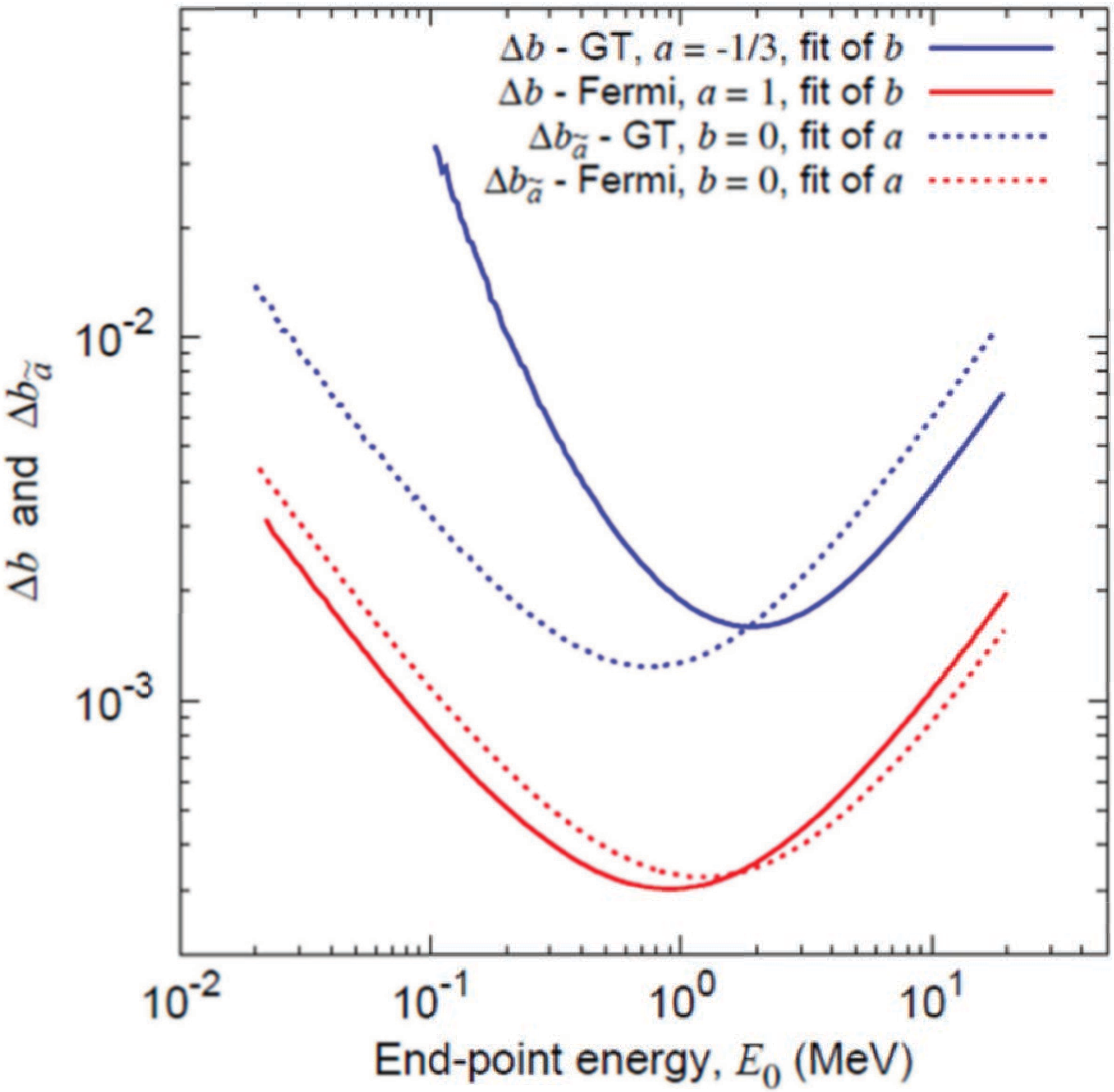
PHYSICAL REVIEW C **94**, 035503 (2016)

Kinematic sensitivity to the Fierz term of β-decay differential spectra

M. González-Alonso[1,*] and O. Naviliat-Cuncic[2,†]

$a_{\beta\nu}$ from recoil ion





ecoil energy
ıch transition,
; $a_{\beta\nu}$ and
ɔ experiment.

nplicated
th

$$Q(r)dr = \frac{r}{12}[Q_0$$

where

$$Q_i(r) =$$

and

$$F_0(W,r) = W(3W$$

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PHYSICAL REVIEW C 94, 035503 (2016)

Kinematic sensitivity to the Fierz term of β-decay differential spectra

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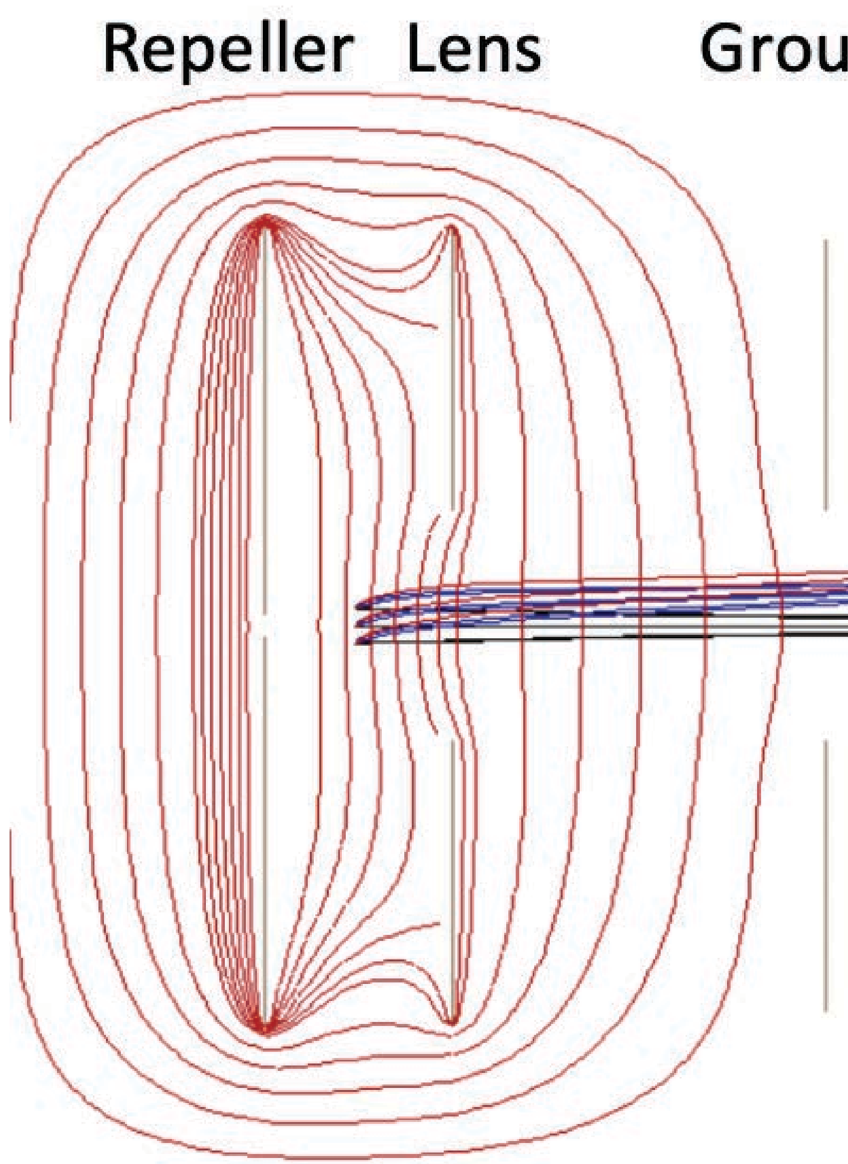
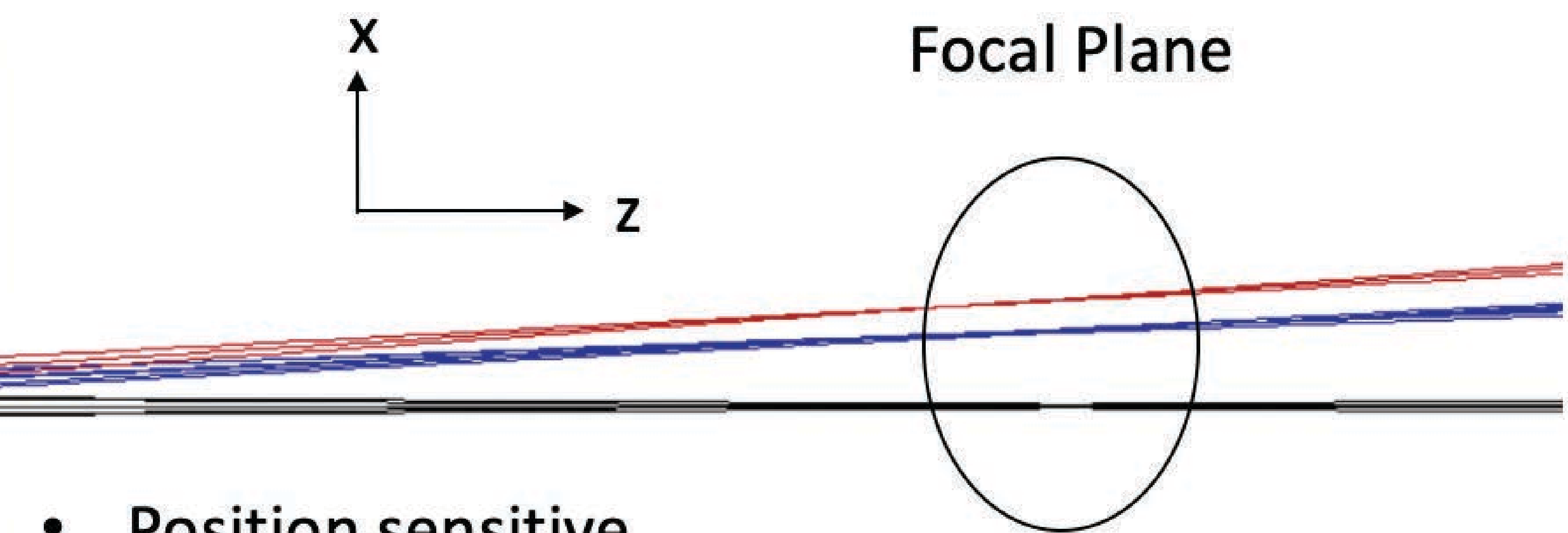
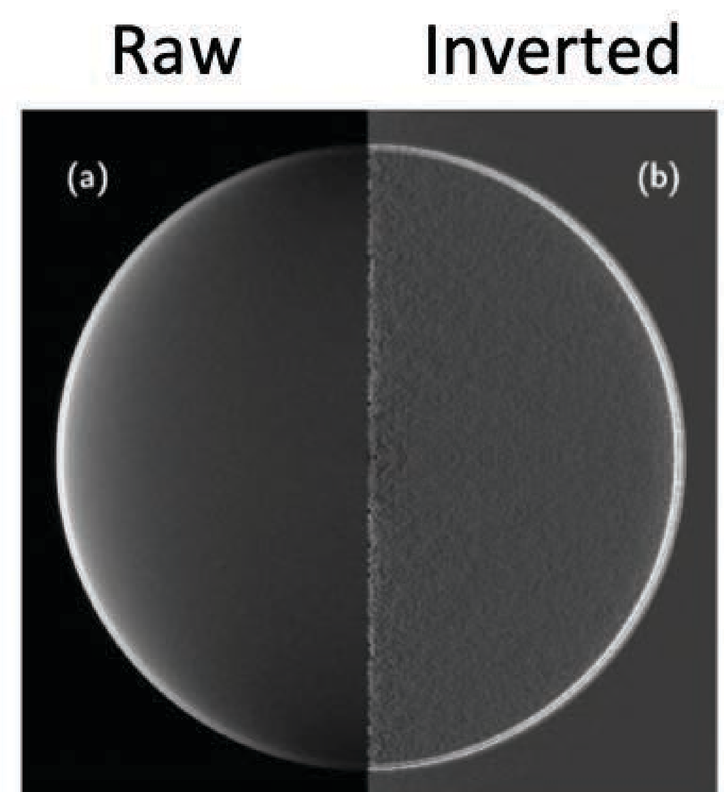
Velocity Map Imaging (VMI) (Eppink & Parker 1997)

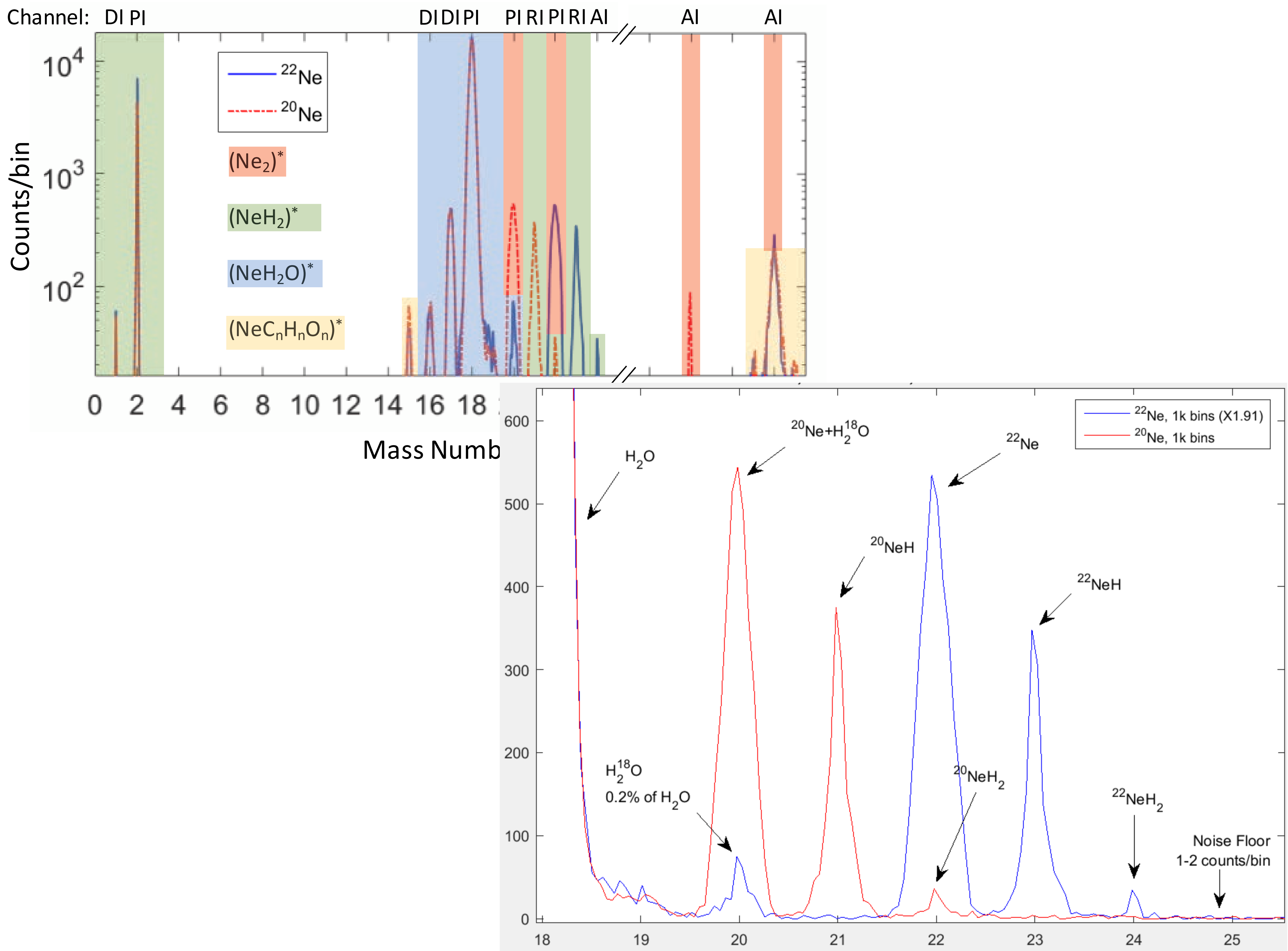




- Position sensitive detector at focal plane.
- Energy from position ($E_x \propto R^2$)
- Position focusing with Einzel lens.
- Abel inversion from 2D to 3D.

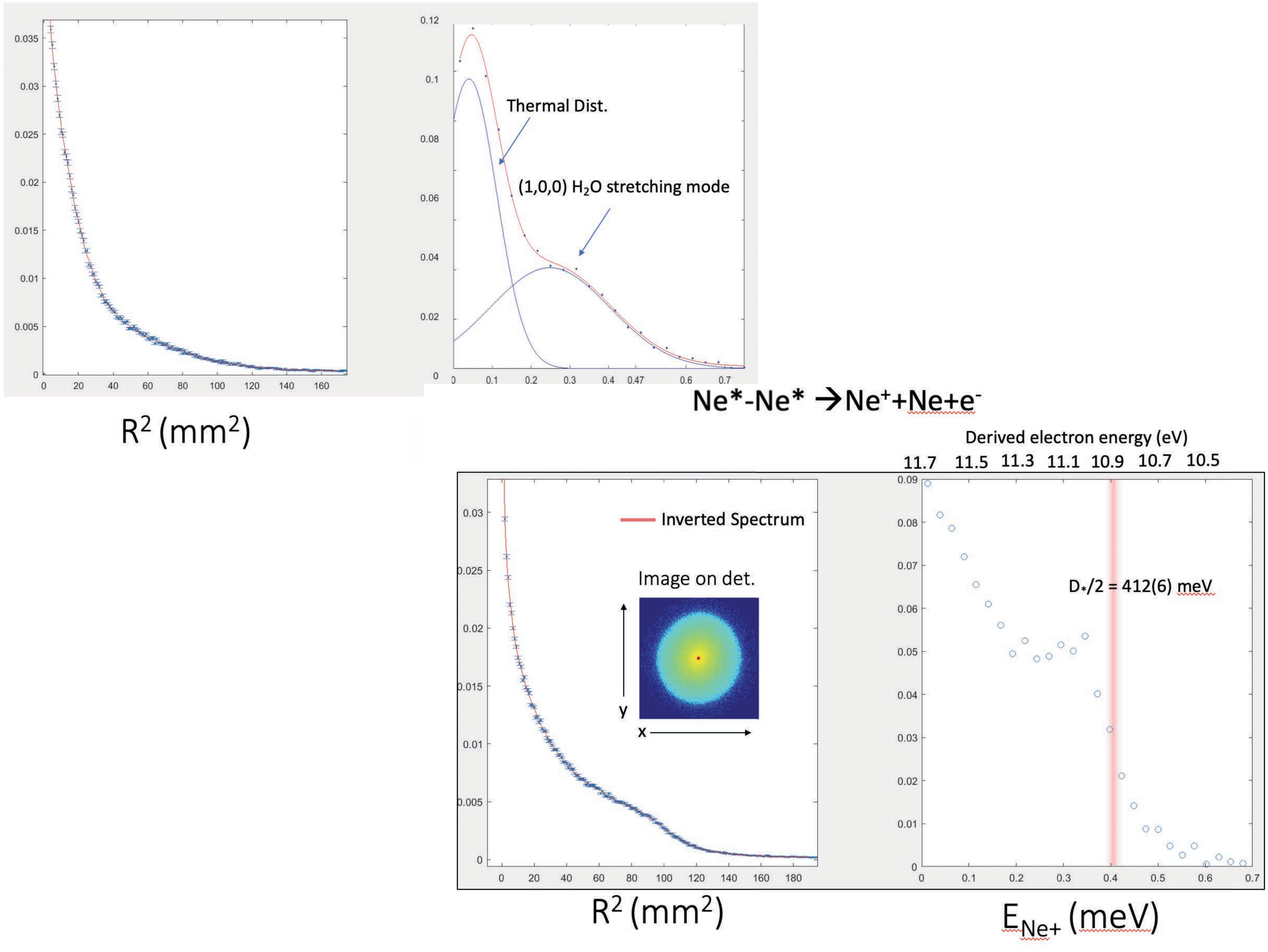


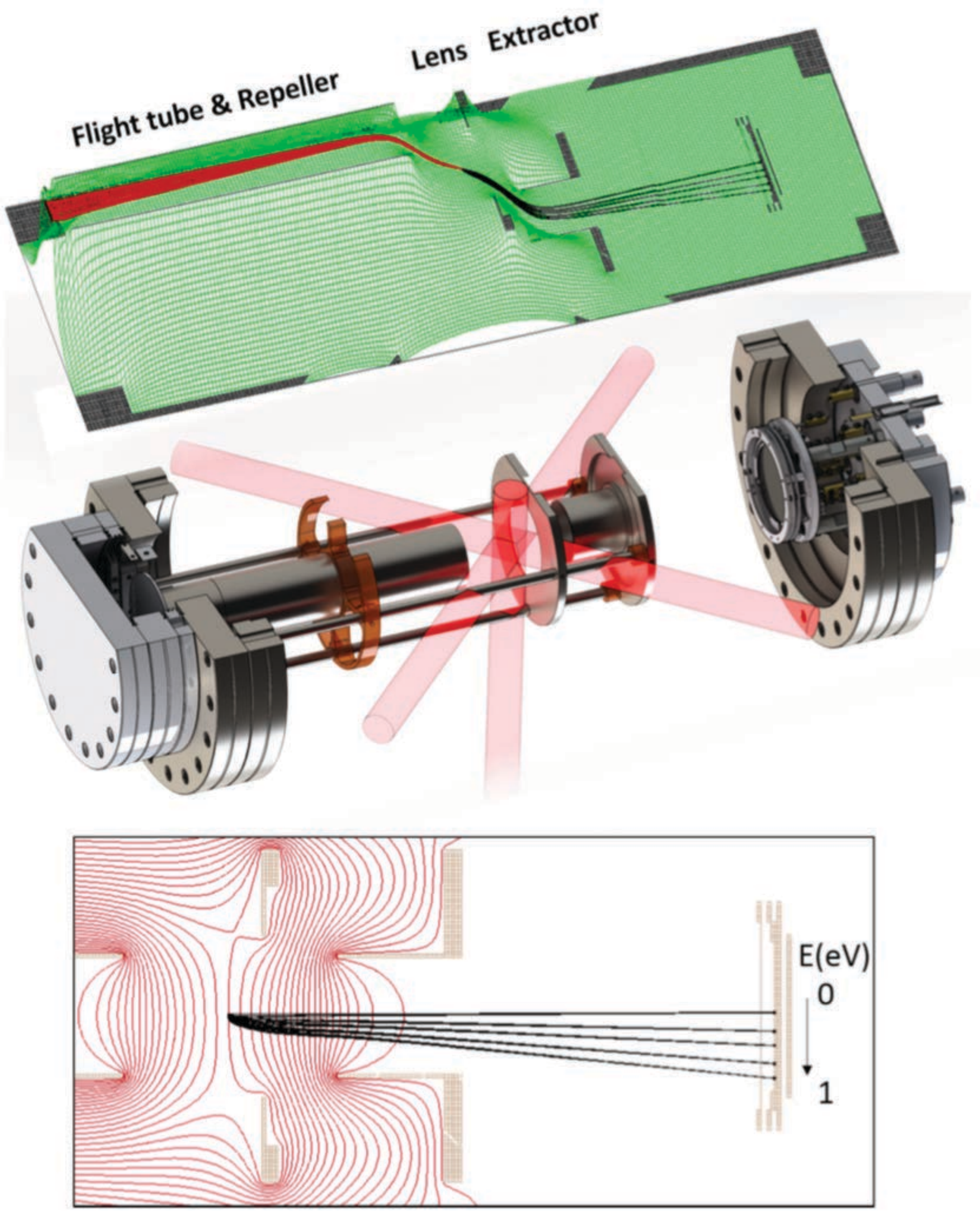
CAVANAGH *et al.*

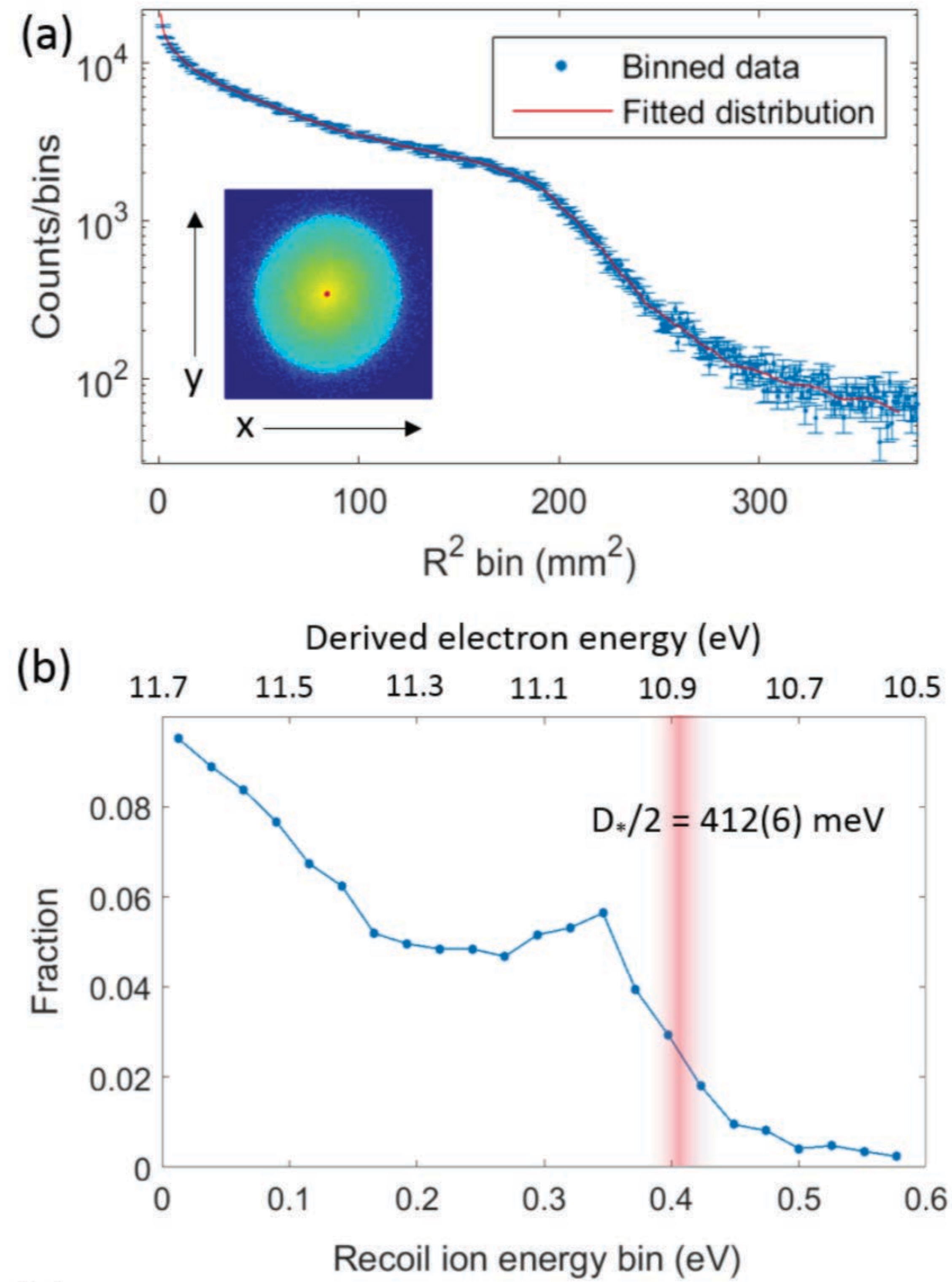


Channel: DI PI
DI DI PI
PI RI PI RI AI
AI
AI
22Ne
20Ne
(Ne2)*
(NeH2)*
(NeH2O)*
(NeCnHnOn)*
Counts/bin
10^4
10^3
10^2
0 2 4 6 8 10 12 14 16 18
Mass Numb
22Ne, 1k bins (X1.91)
20Ne, 1k bins
H2O
20Ne+H2 18O
22Ne
20NeH
22NeH
H2 18O
0.2% of H2O
20NeH2
22NeH2
Noise Floor
1-2 counts/bin
600
500
400
300
200
100
0
18 19 20 21 22 23 24 25

Thermal collisions: $Ne^*-H_2O \rightarrow H_2O^+$

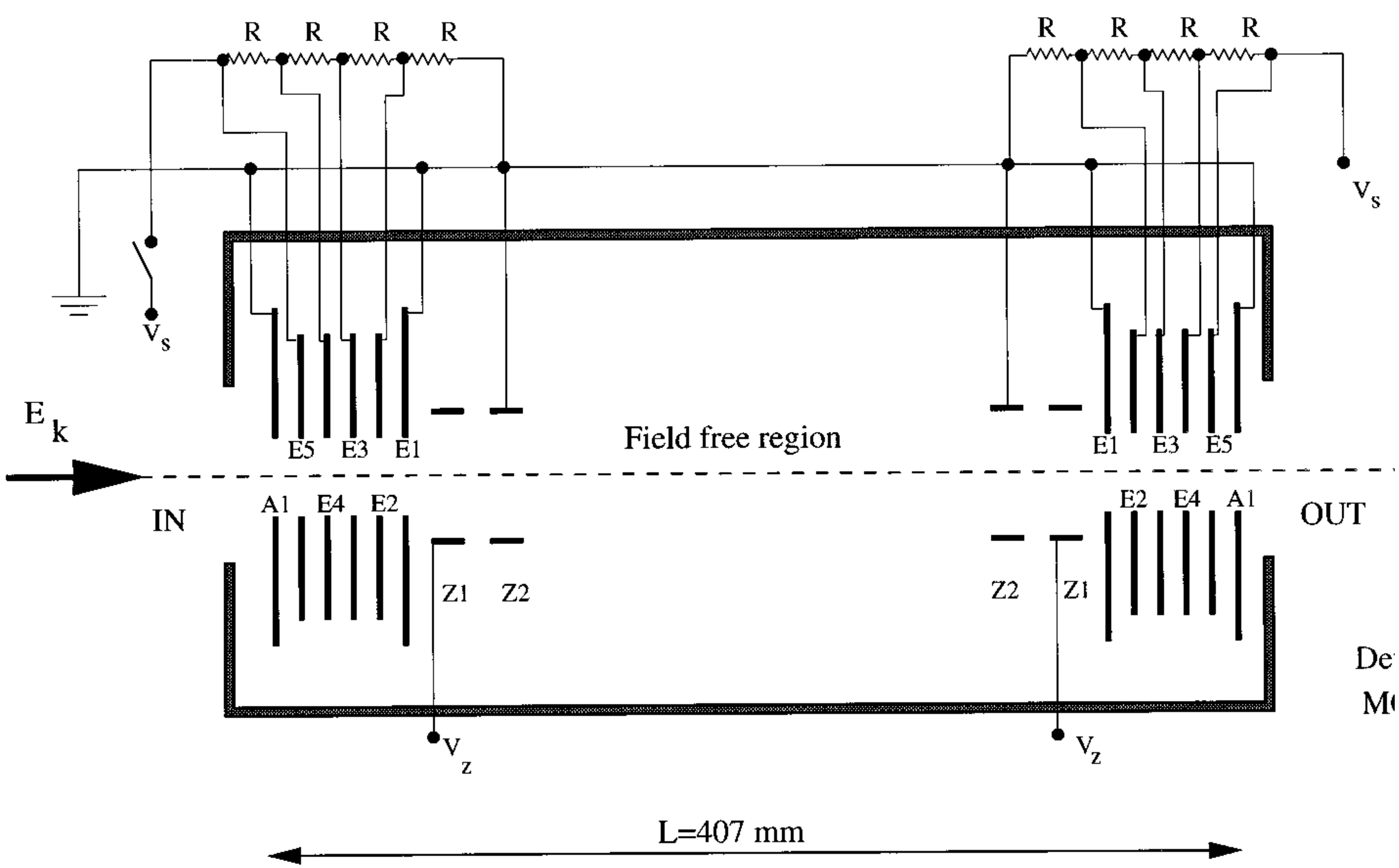


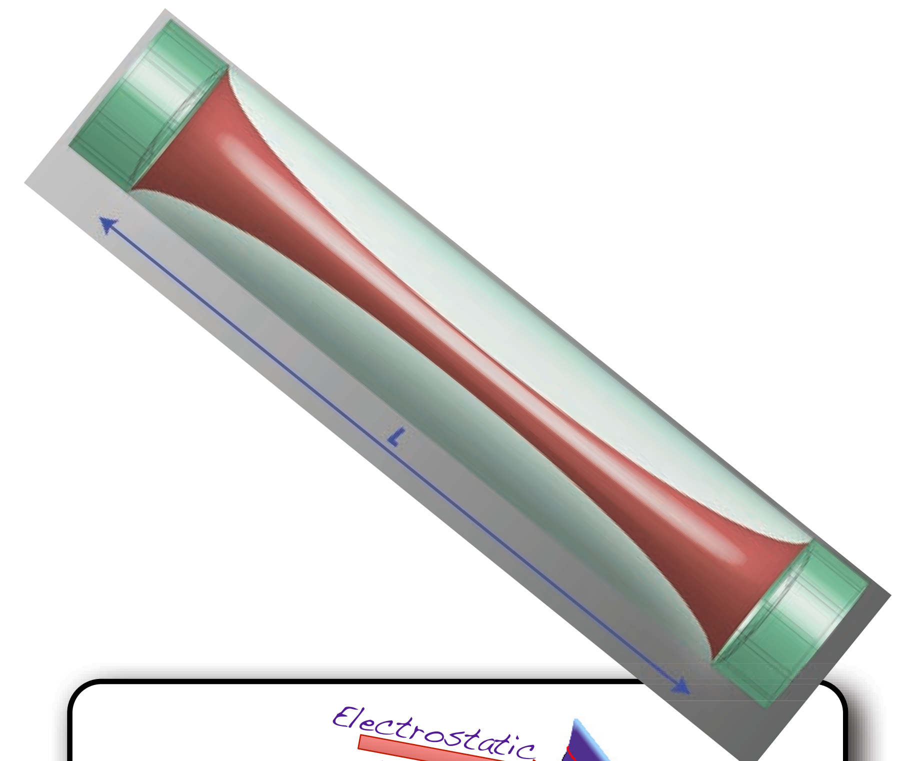

Flight tube & Repeller
Lens
Extractor
E(eV)
0
1

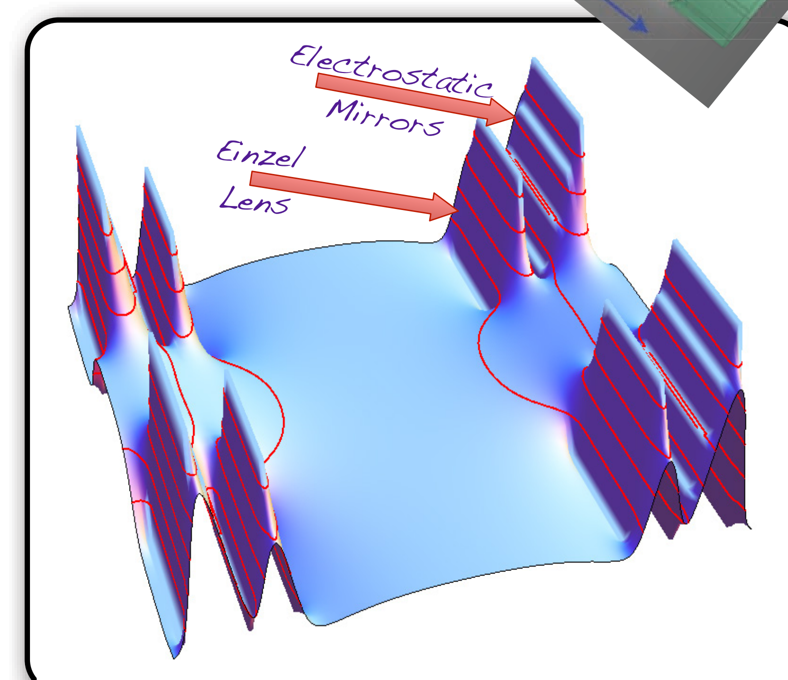

(a)
Binned data
Fitted distribution
Counts/bins
10^4
10^3
10^2
y
x
0
100
200
300
R^2 bin (mm^2)
(b)
Derived electron energy (eV)
11.7
11.5
11.3
11.1
10.9
10.7
10.5
$D_*/2$ = 412(6) meV
Fraction
0.08
0.06
0.04
0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
Recoil ion energy bin (eV)

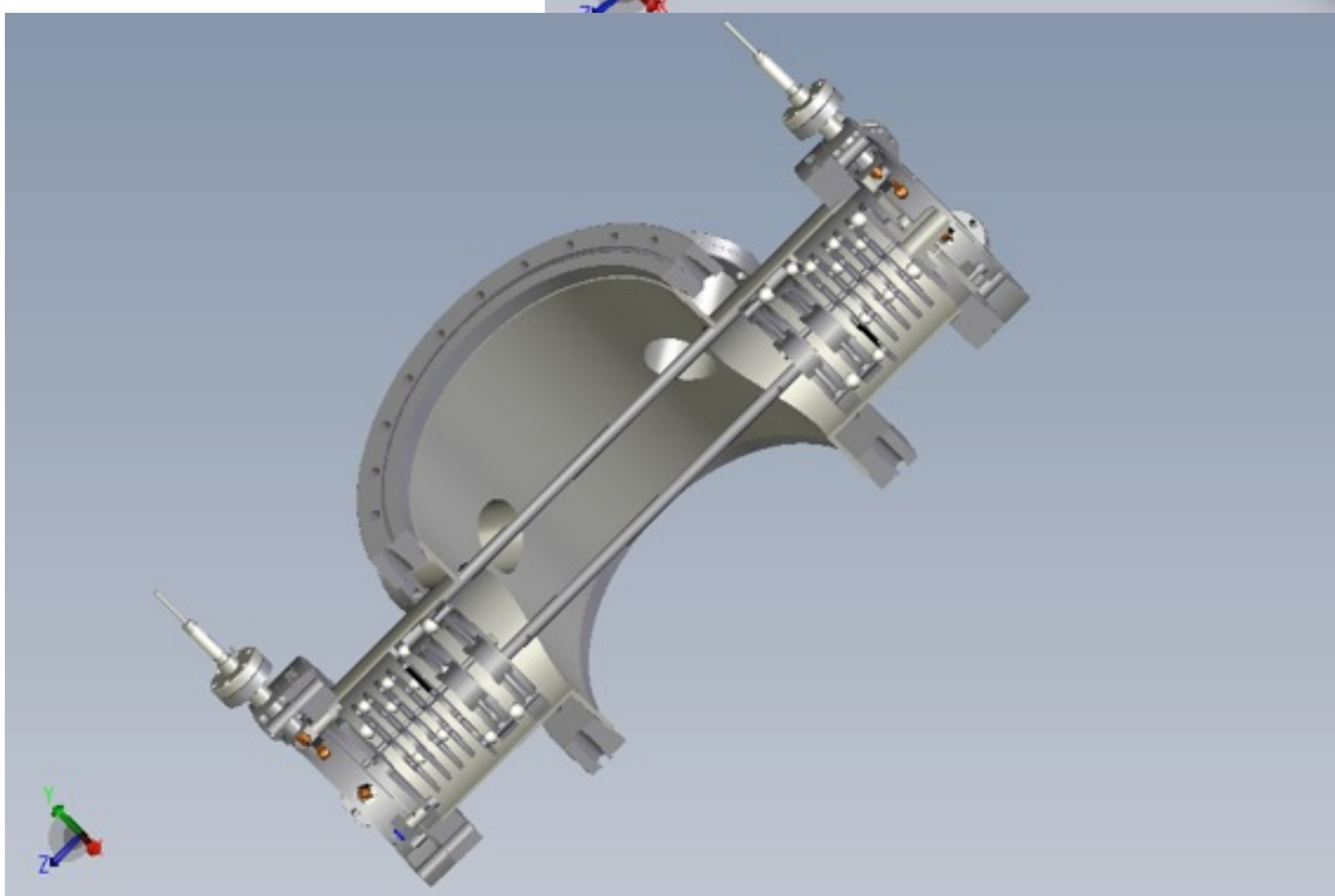
A small and biased sample of efforts
WIRED @ HUJI

Ernshaw's theorem talks about stationary charges.
Moving charges in an electrostatic field actually "see" changing fields.
Trap design very similar to a resonant cavity for laser light.

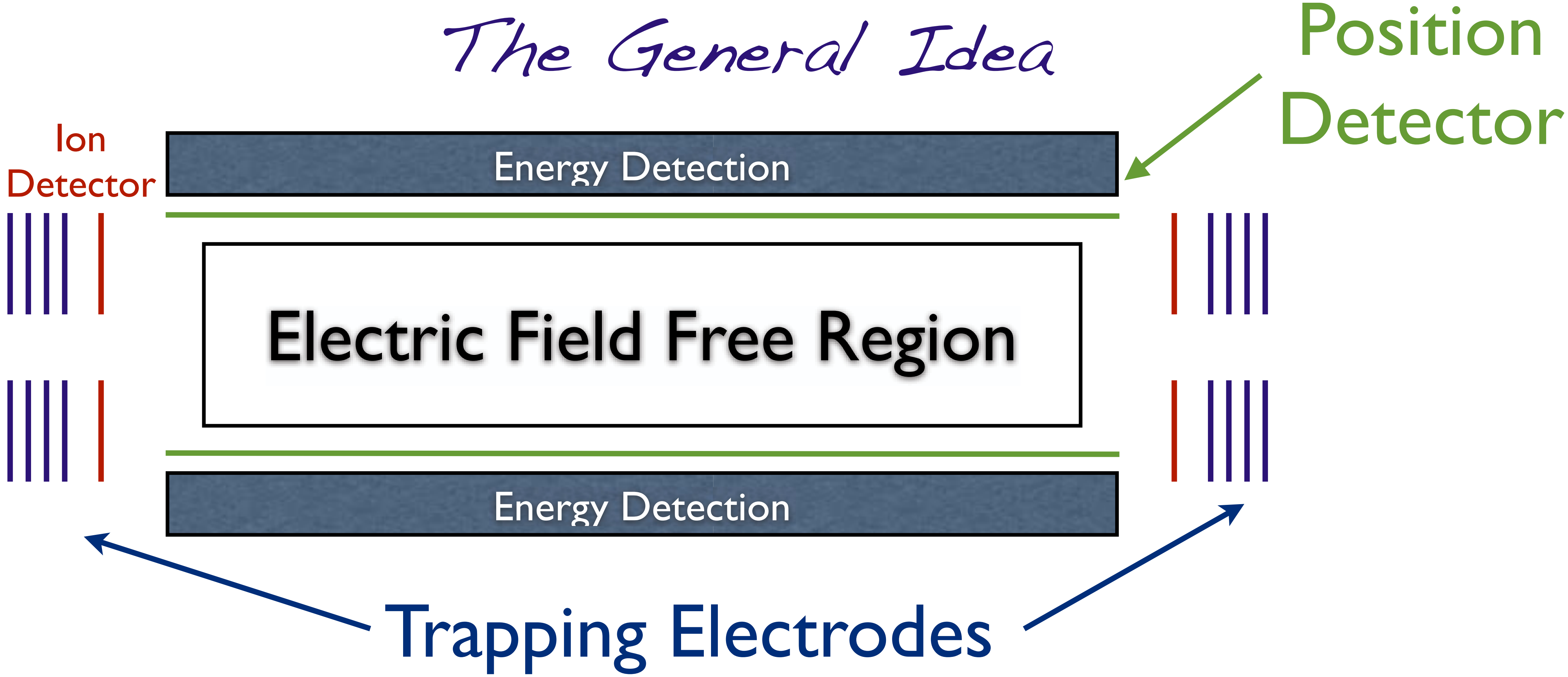






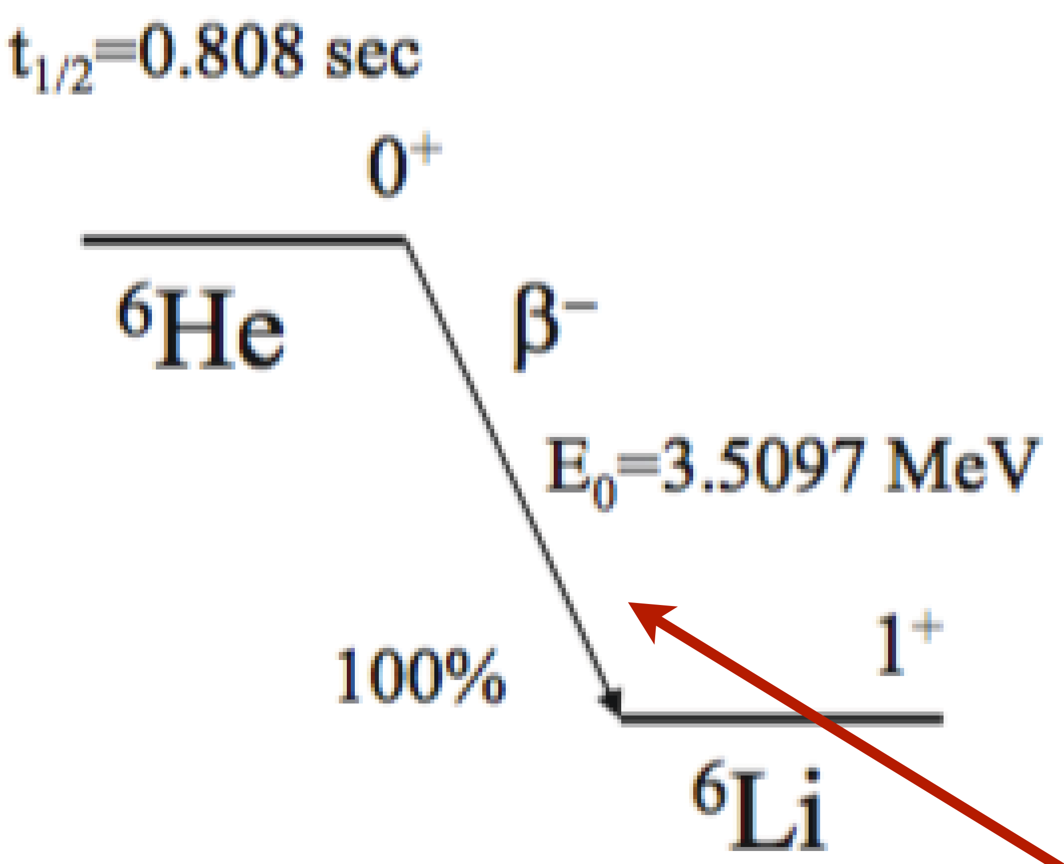


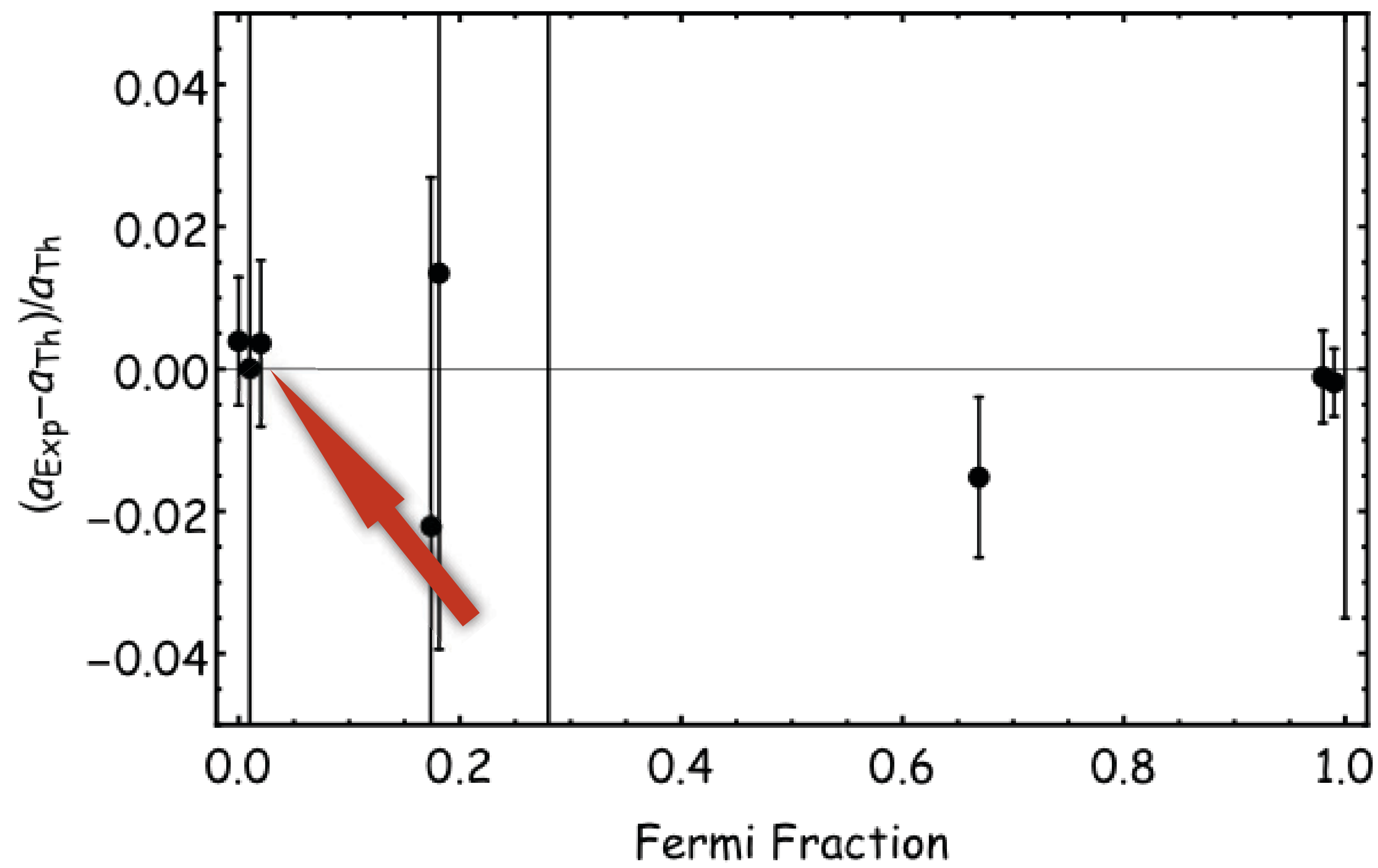
β-Decay Studies



- Recoil ion detected in MCP.
- β detected in position detectors.
- Need bunch position for full reconstruction (multiple scattering of β in detectors).
- Large solid angle + kinematic focussing → detection efficiency > 50%.
- No need for electrostatic acceleration (ions at ~keV). Decay in field free region.

^{6}He





Best experimental limit:

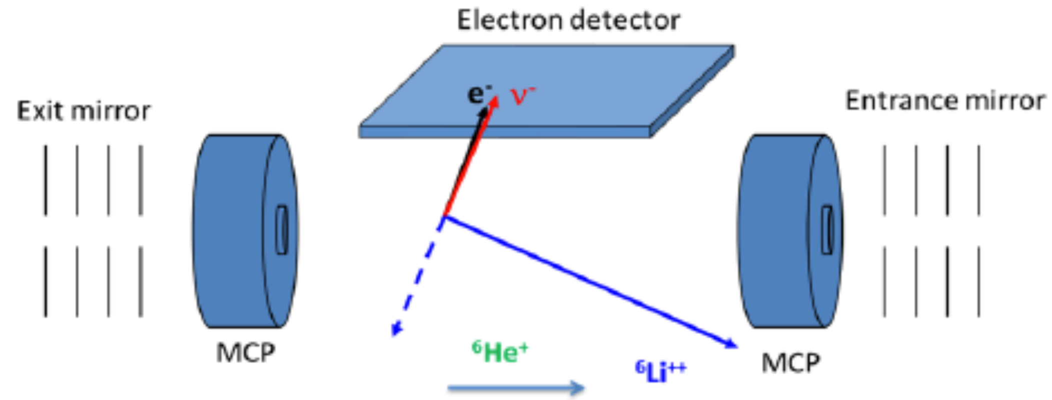
$$a = -0.3343 \pm 0.0030$$

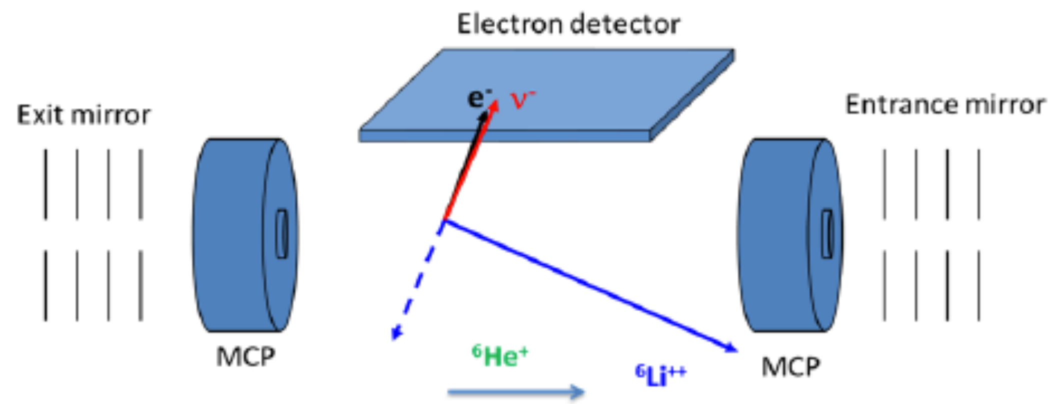
$$\frac{|C_T|^2 + |C'_T|^2}{|C_A|^2 + |C'_A|^2} \leq 0.4\%$$

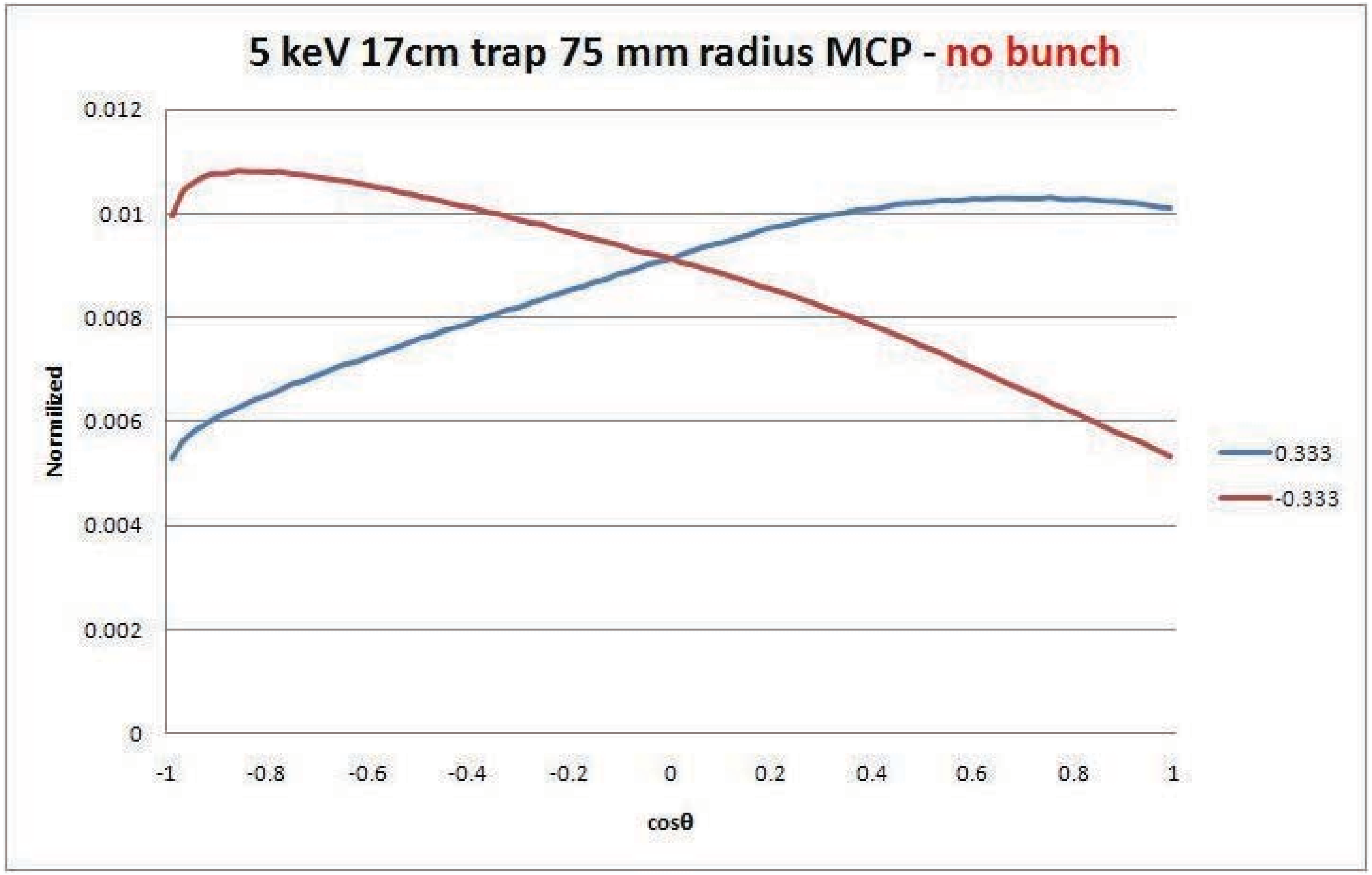
Johnson et al., Phys. Rev. (1963)

Pure GT Decay

Recoil order corrections well under control







1e6 events gives 0.6% stat. uncertainty

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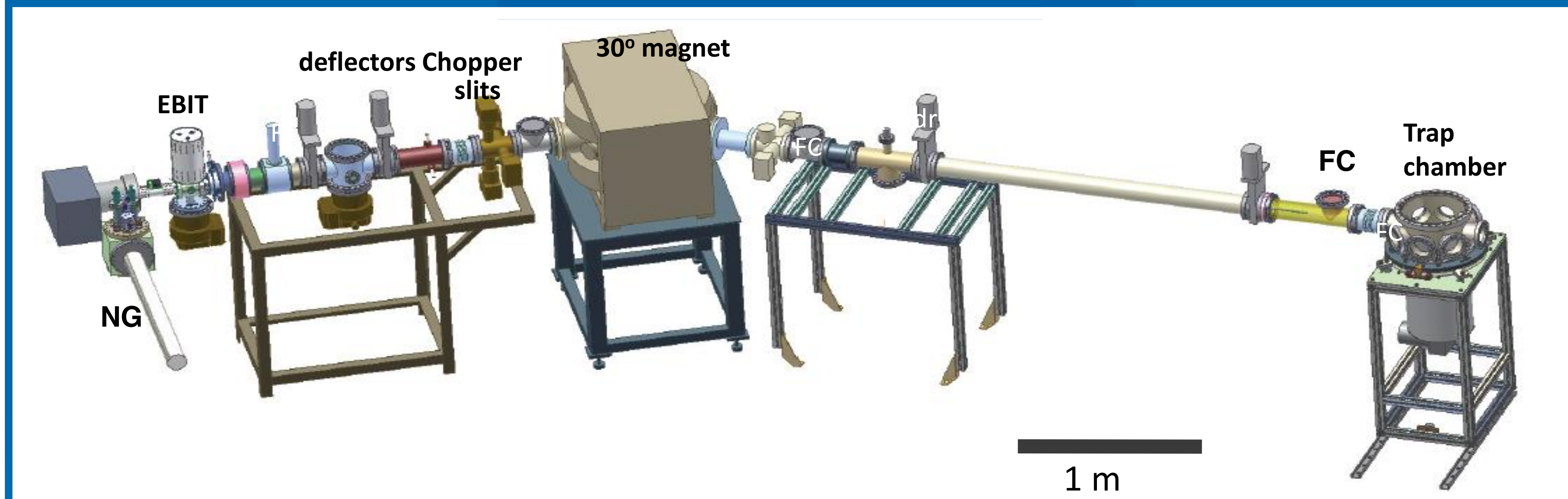
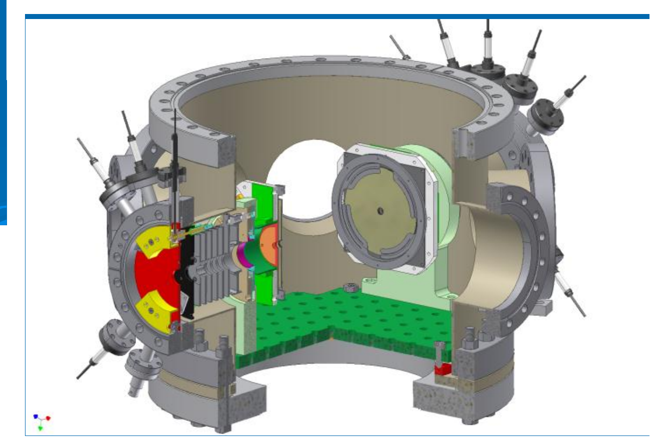
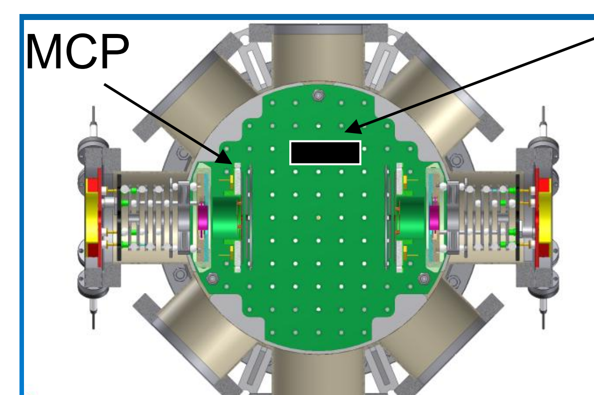
WIRED

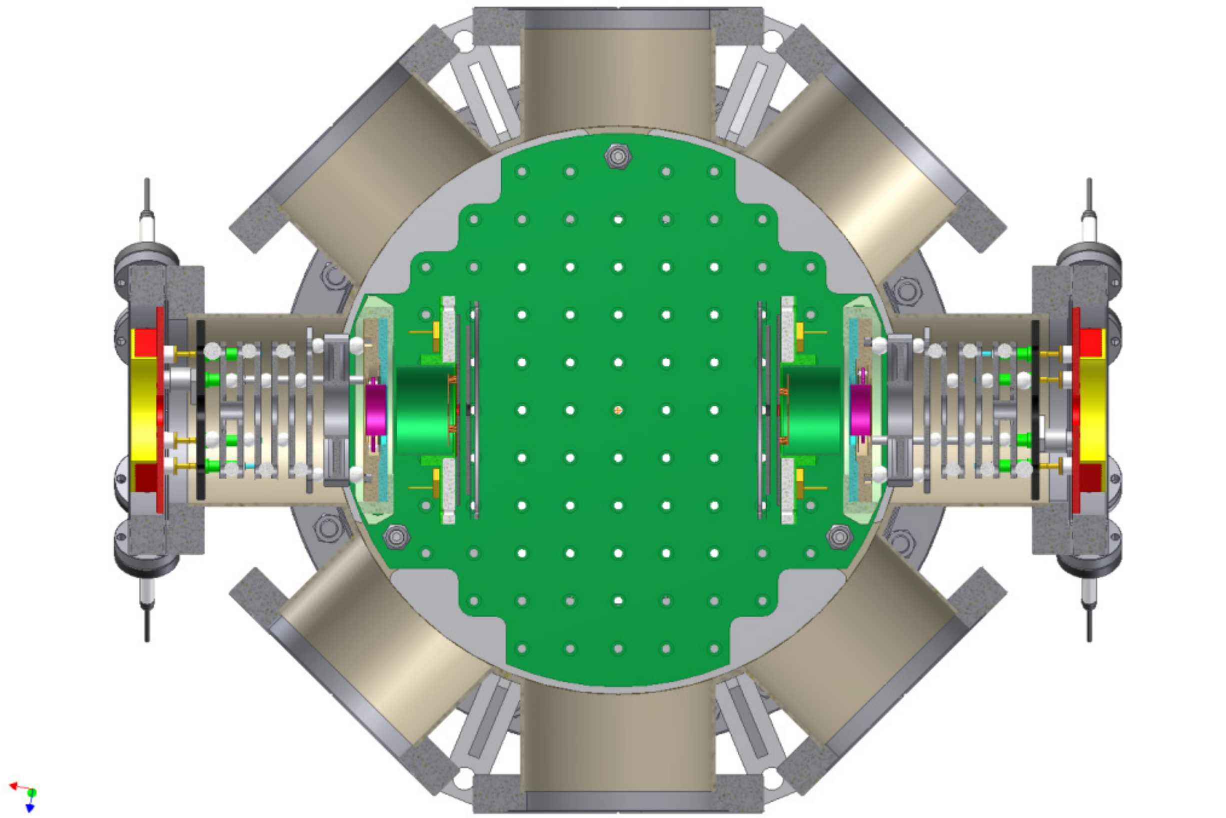
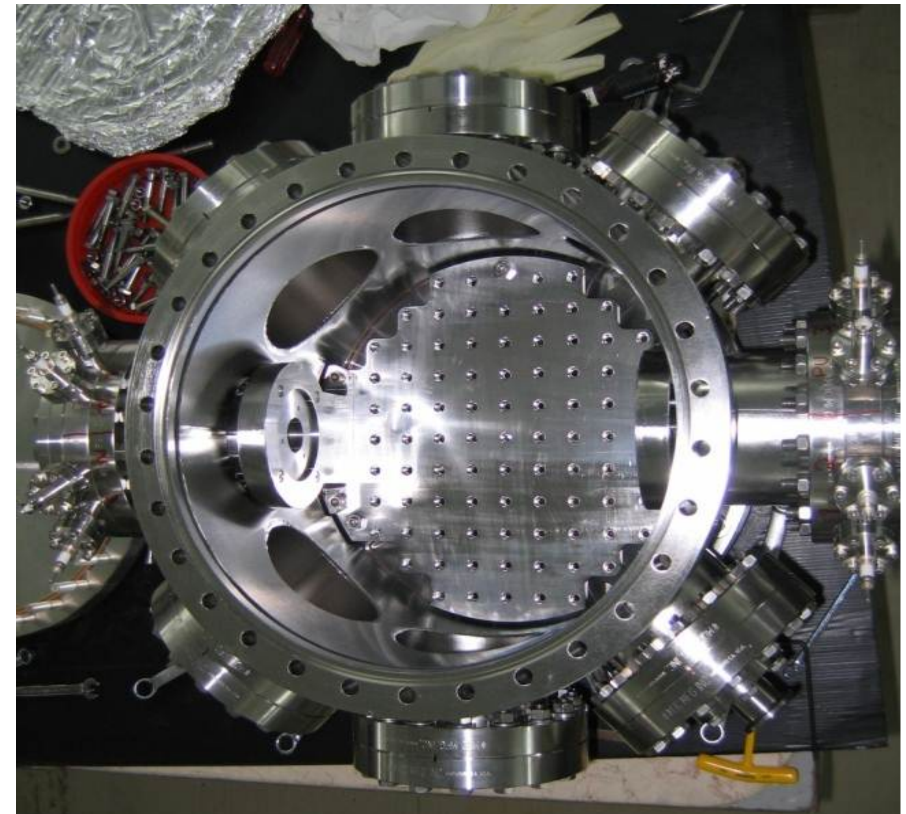
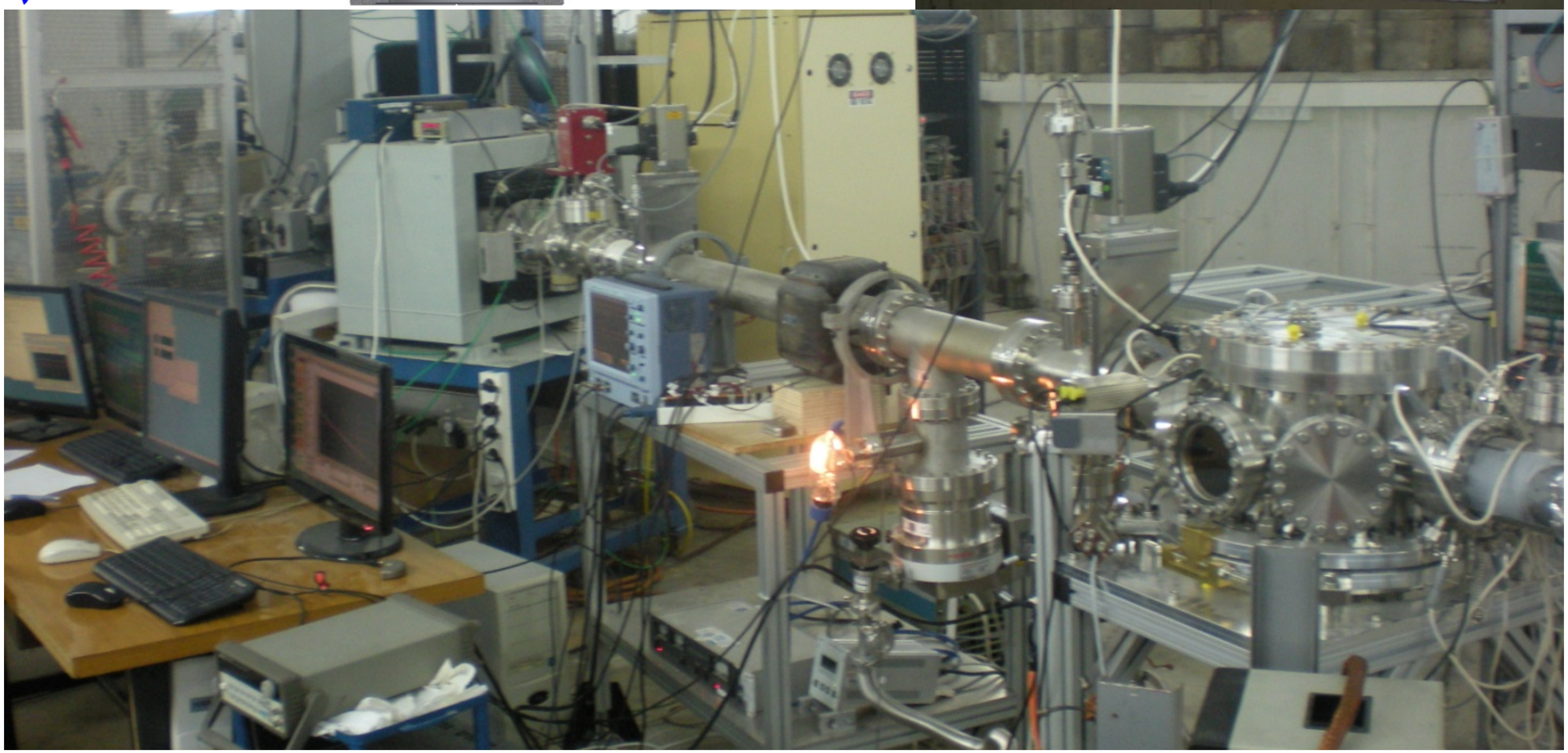
Weizmann Institute Radioactive Electrostatic Device

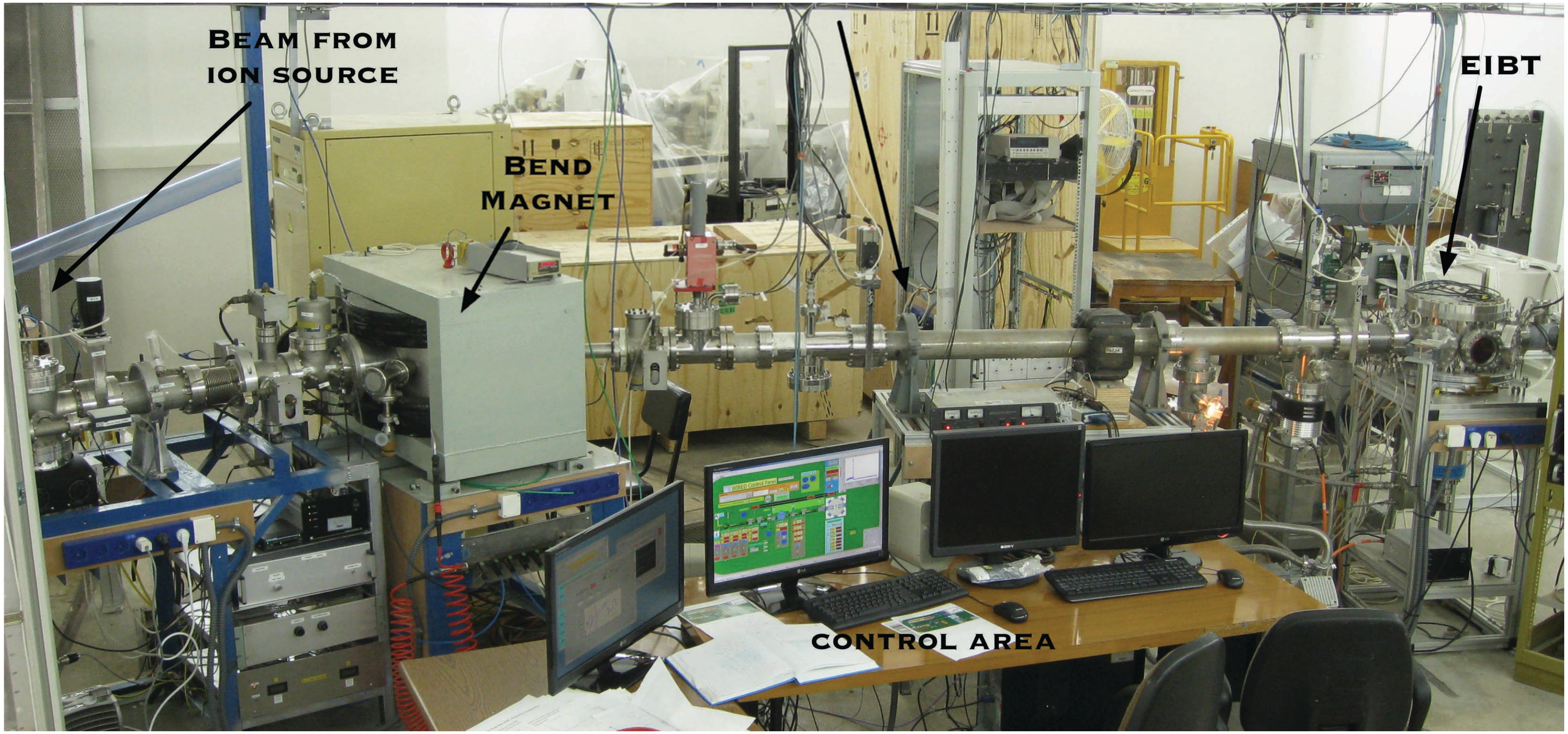
Experimental scheme

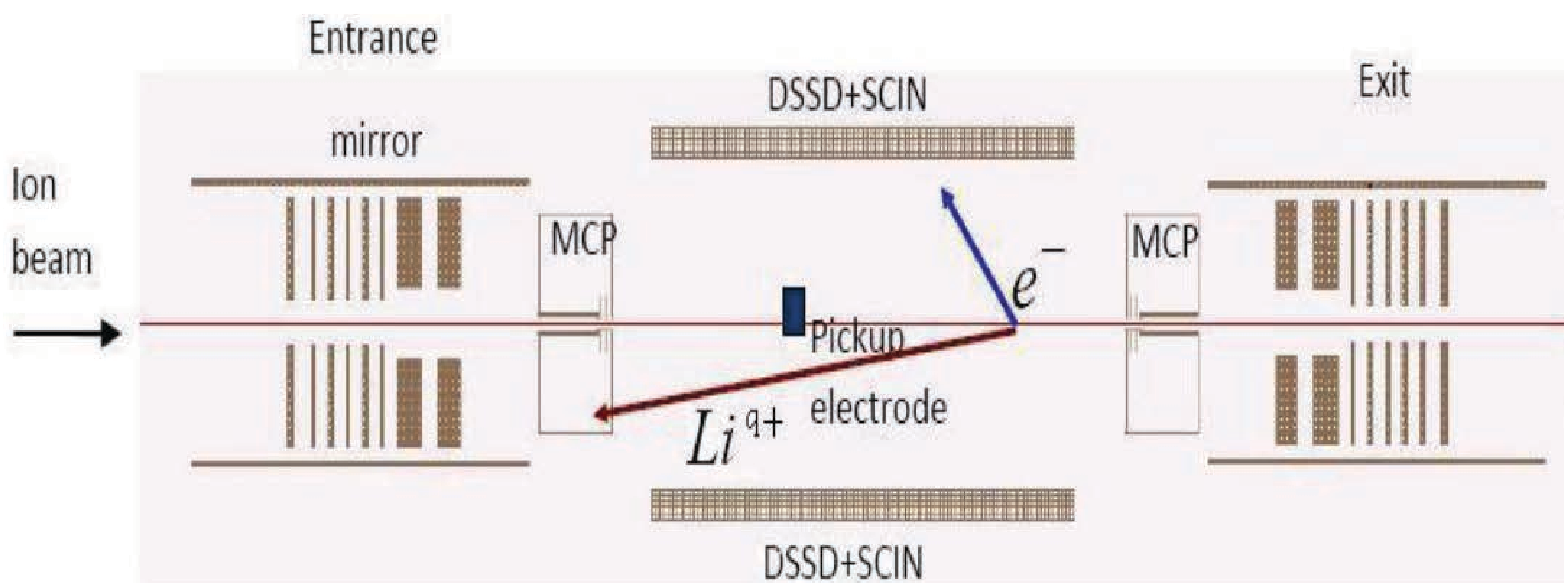




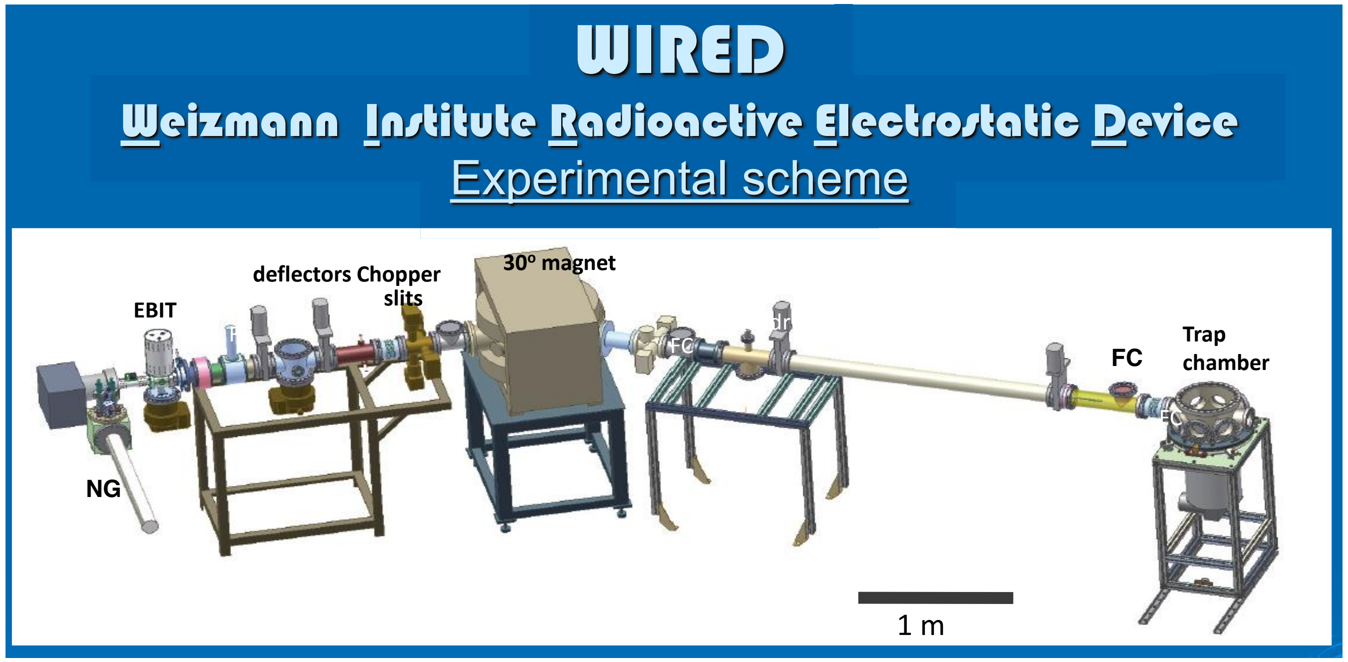



Beam from
ion source
Bend
Magnet
EIBT
control area


Entrance
mirror
DSSD+SCIN
Exit
Ion
beam
MCP
MCP
e−
Pickup
electrode
Li q+
DSSD+SCIN

Trap

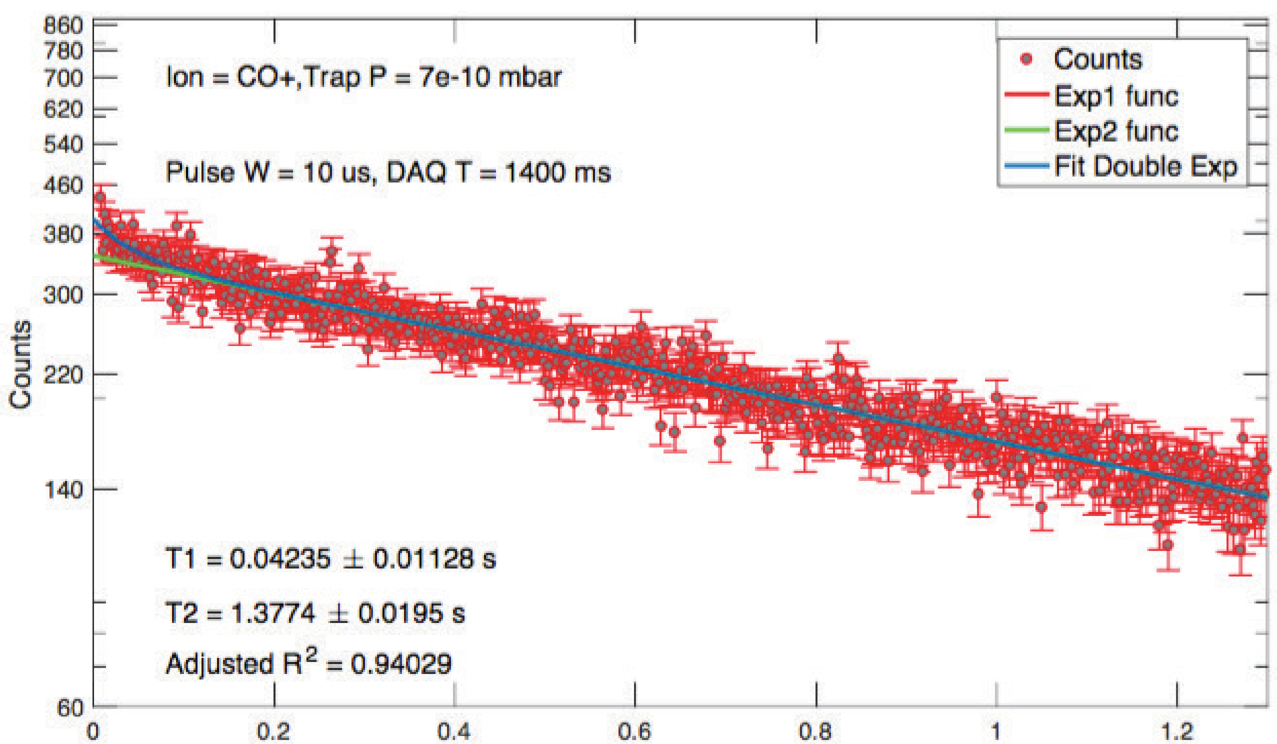


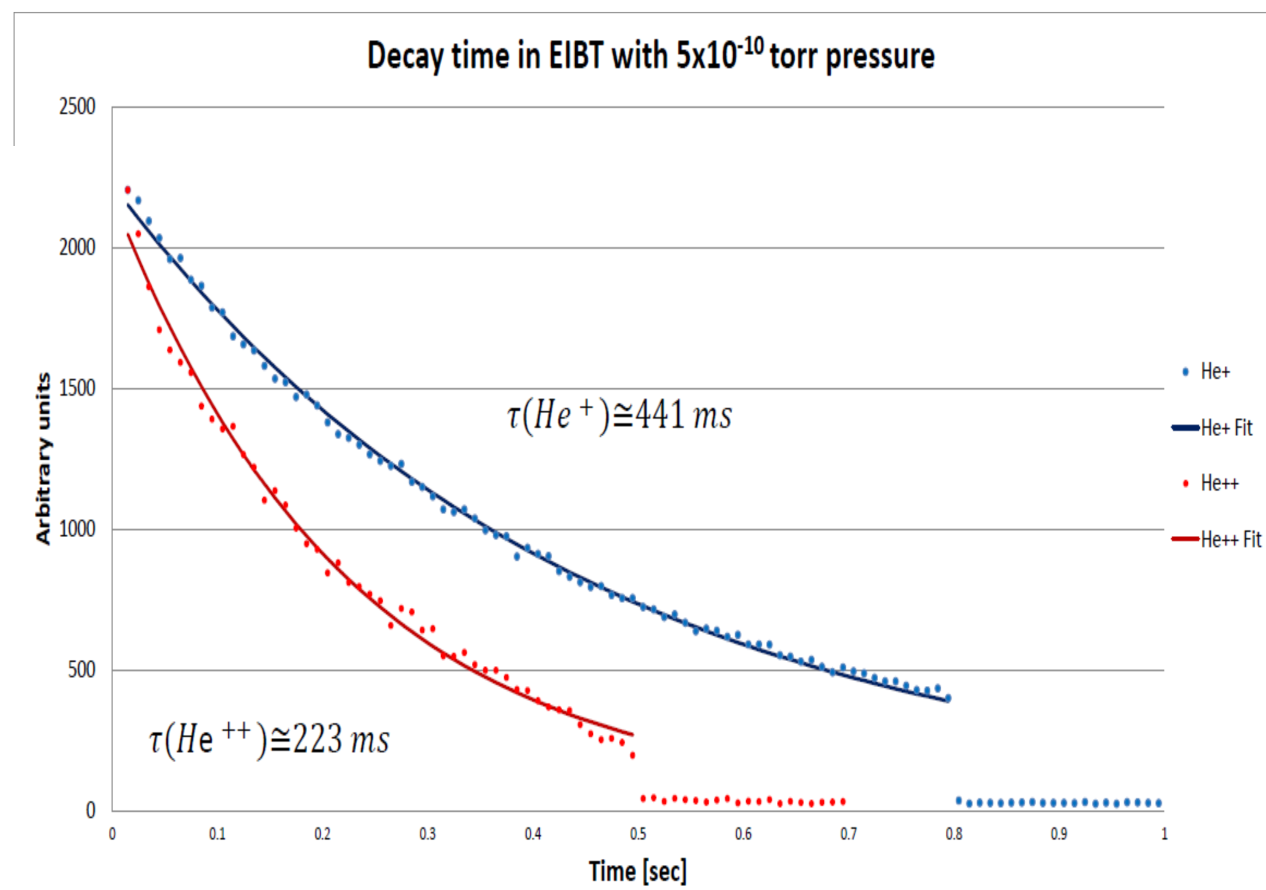
Stable isotopes trapped

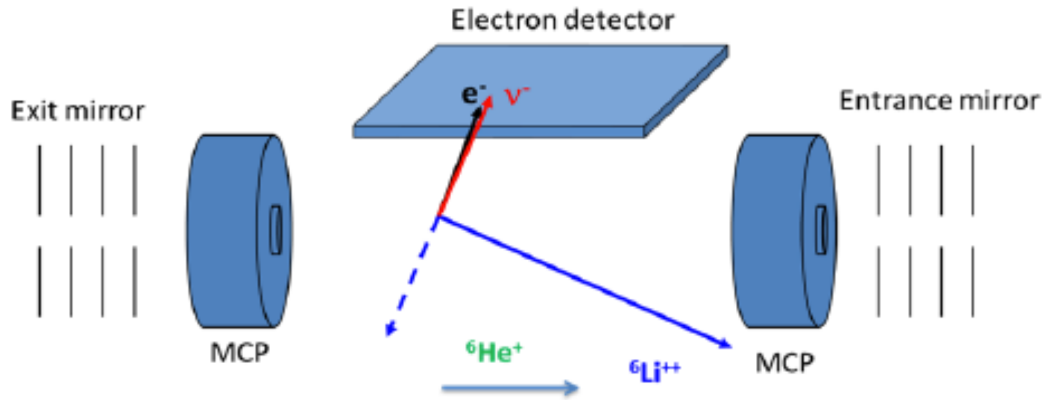
Detectors:

- MCP's
- Plastic Scintillator with multiple photomultipliers

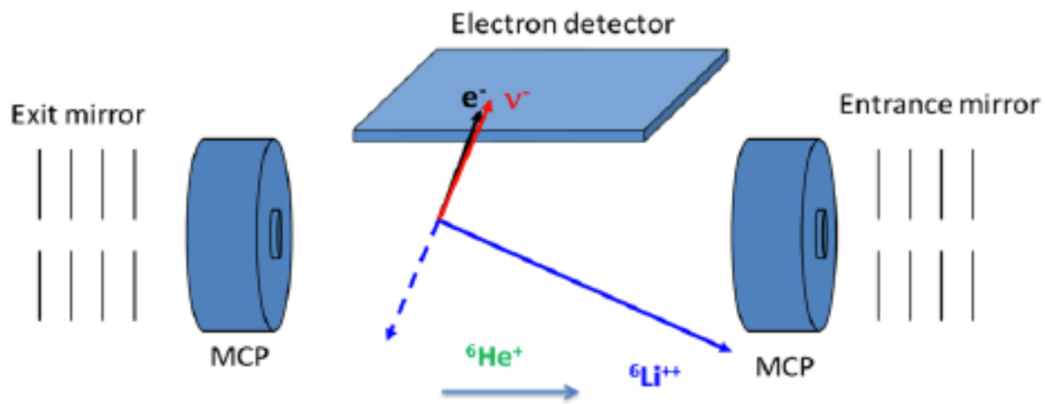
Electronics – ADC, TDC,…

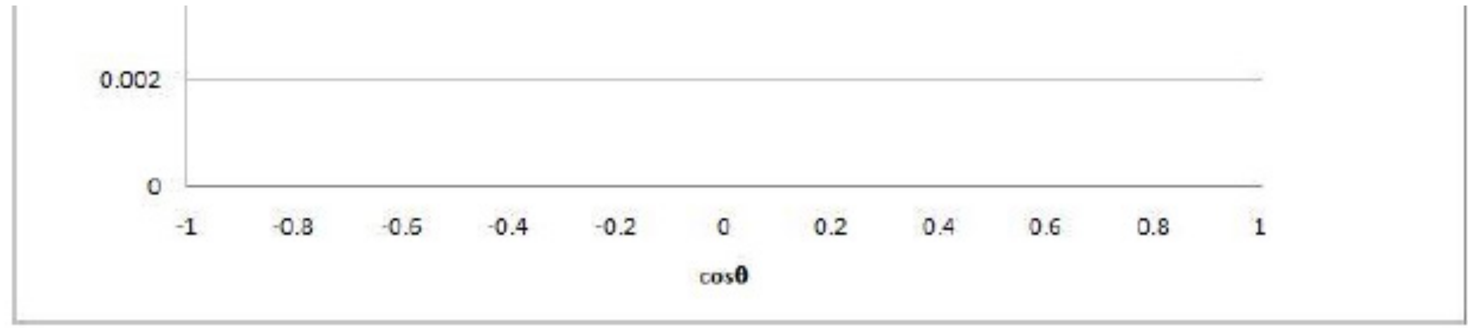






Source	Uncertainty	$\Delta a_{\beta\nu}$ ($\times 10^{-3}$)
LAPS Energy	5 %	0.86
LAPS Position	5 mm	0.71
MCP Position	1 mm	0.22
^{6}Li TOF	5 ns	0.23
Bunch size	1 cm	1.38
Total		1.80





- Recoil ion detected in MCP.
- β detected in position detectors.
- Need bunch position for full reconstruction (multiple scattering of β in detectors).
- Large solid angle + kinematic focussing → detection efficiency > 50%.
- No need for electrostatic acceleration (ions at ~keV). Decay in field free region.

Summary

- Lots of new experiments coming on and finalizing measurements.
- The "standard" $a_{\beta\upsilon}$ experiments are being augmented by other correlation measurements, some of which will be linearly sensitive to the BSM terms.
- All experiments are aiming for $O(10^{-3/4})$
- What we need (as experimentalists):
  - Branching ratios (eg. for ^{23}Ne the largest uncertainty is the BR).
  - Decent calculations of radiative corrections for the heavier nuclei.
  - Recoil order corrections (Doron/Ayala/et al.)
  - To agree on a standard notation!!!!