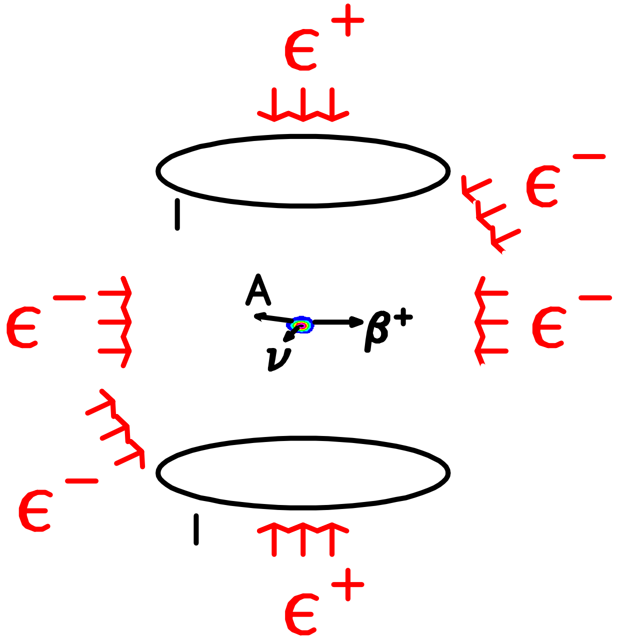
Search for scalars via β-ν correlations with atom traps +direct production

- $^{38\mathrm{m}}$K β-ν Gorelov PRL '05

$\tilde{a} = 0.9981 \pm 0.0030 \pm 0.0037$

General limits on 1st generation scalar couplings

Upgrade in progress



- Spin-polarized experiments:

Right-handed currents in $^{37}\vec{\mathrm{K}}$

$\mathrm{B}_\nu/\mathrm{B}_\nu^{\mathrm{SM}} = 0.982 \pm 0.026 \pm 0.017$

Melconian Phys. Lett. B '07

Upgrade in progress

Tensor interactions in $^{80}\vec{\mathrm{R}}$b:

statistics for <0.01 A_{recoil}

(observable 0 in lowest order)

- Planning 2-body decays: direct production of massive $0^\pm$, $1^\pm$ particles in $^{86\mathrm{m}}$Rb... isomer decay: 10^{-6} sensitivity/day

TRIUMF Neutral-Atom Trapping “TRINAT”

Simon Fraser U.
*__A.Gorelov__

U.W. (Texas A&M)
D.Melconian

U.British Columbia
** __R. Pitcairn__
** __T. Kong__

**__Grad Students__
*__Res. Assoc.__

TRIUMF
J.A.Behr
M.R.Pearson
K.P.Jackson
M. Dombsky
P. Bricault
*C.Höhr
J. Holt

Tel Aviv
D Ashery
Budapest
F.Glück
U.West.Ontario
W.P.Alford

Undergrad
J. Fung
U. Toronto

U. Manitoba
G. Gwinner
Stony Brook
G.Sprouse (Fr)
Maryland
L.Orozco (Fr)

Supported by Canadian NSERC, Canadian NRC through TRIUMF, WestGrid, Israel Science Foundation

Electroweak Interactions: what we "know"

- **E&M unified with Weak interactions**

$$\gamma \Longleftrightarrow \mathrm{Z}^0,\mathrm{W}^+,\mathrm{W}^-$$

1) Only spin-1 "vector" exchange bosons
2) Only left-handed ν's: "parity maximally violated" "V-A"
3) Z_0, W, γ couplings related and universal

- **What we can test with the trap techniques:**

1) Are there spin-0 <u>Scalar</u> Bosons ?
$I^\pi = 0^+ \rightarrow 0^+$ β^+-ν $\sigma \sim 0.5\%$ is useful
'Tensor' interactions? (spin-0 leptoquark)

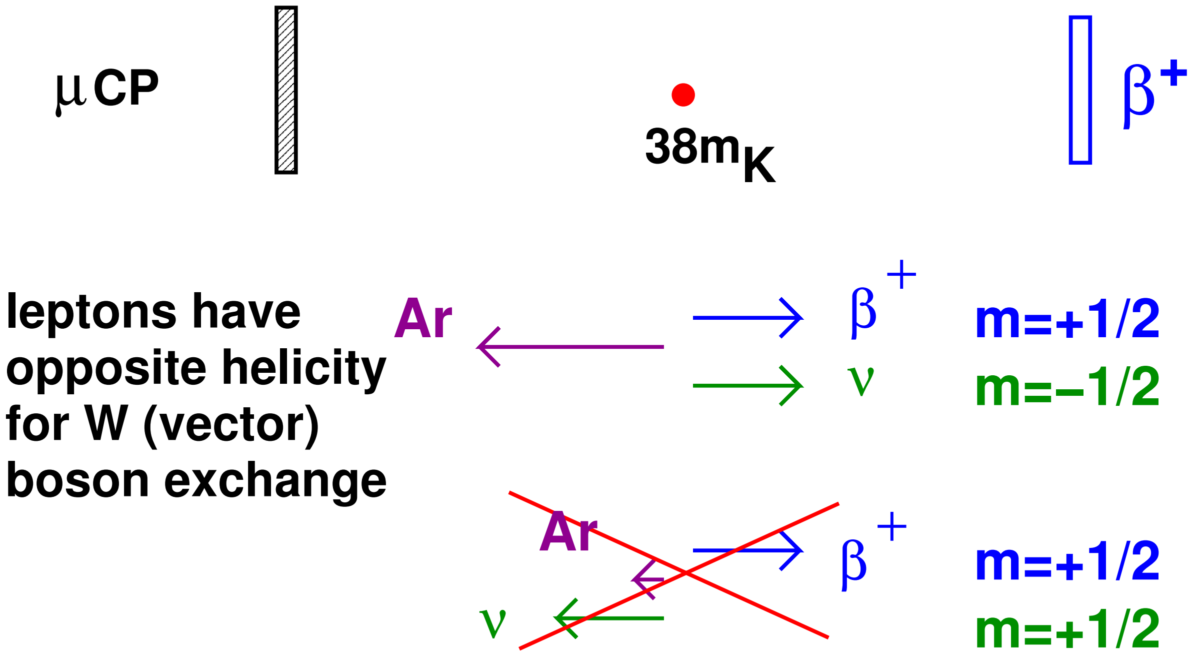
2) "V+A" producing right-handed ν's ?
Polarized observables with $\sigma \approx 0.1\%$ needed.

3) Additional Z's: Atomic parity violation

Time-Reversal violation: Electric Dipole Moments

Vector and Scalar bosons and the β-ν angular distribution

For $^{38\mathrm{m}}$K, $0^+ \rightarrow 0^+$ decay:



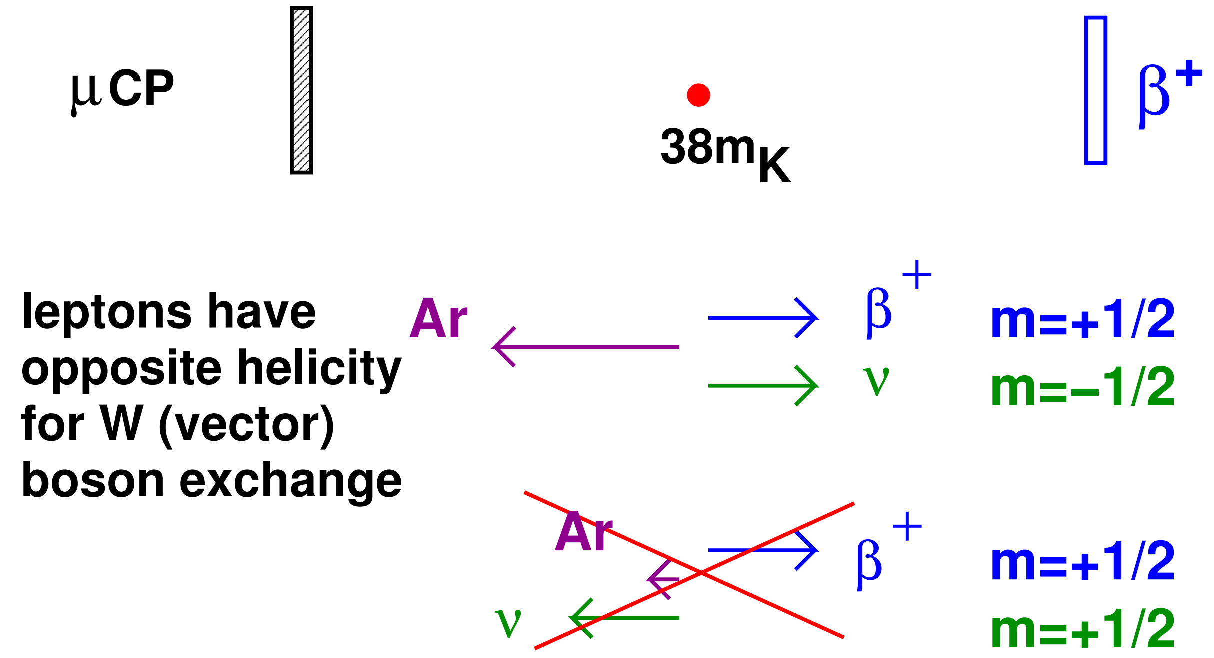
leptons have opposite helicity for W (vector) boson exchange

$$W[\theta_{\beta\nu}] = 1 \;+\; b\frac{m}{E} \;+\; a\,\frac{v_\beta}{c}\cos\theta_{\beta\nu} \qquad \Rightarrow \mathbf{a} = +1$$

For scalar exchange, lepton helicities are same: a= -1

Vector and Scalar bosons and the β-ν angular distribution

For $^{38\mathrm{m}}$K, $0^+ \rightarrow 0^+$ decay:



leptons have opposite helicity for W (vector) boson exchange

$$W[\theta_{\beta\nu}] = 1 \;+\; b\frac{m}{E} \;+\; a\,\frac{v_\beta}{c}\cos\theta_{\beta\nu} \qquad \Rightarrow a = +1$$

For scalar exchange, lepton helicities are same: a= -1

Corrections independent of nuclear structure to < 0.0002:

bremsstrahlung $\approx$ 0.002 (in M.C., F. Glück);

recoil order $\approx$ 0.0003

Deviation ⇒ non-standard model scalar interaction

Scalar Hamiltonian in ‘modern’ chirality notation

$$H_S = [(C_S + C'_S)\bar{e}(1-\gamma_5)\nu_e^{(L)} + (C_S - C'_S)\bar{e}(1+\gamma_5)\nu_e^{(R)}]\bar{u}d$$

$$W[\theta_{\beta\nu}] = 1 + bm_\beta/\langle E_\beta\rangle + \ a\ v/c\cos[\theta_{\beta\nu}]$$

$$a = \frac{|C_V|^2 + |C'_V|^2 - |C_S|^2 - |C'_S|^2 + (\frac{\alpha Z m}{p})2Im(C_S C_V^* + C'_S C'_V *}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}$$

$$b = \frac{-2\sqrt{1-\alpha^2 Z^2}\ Re(C_S C_V^* + C'_S C'_V *)}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}$$

$$a \approx 1 - (|C_S|^2 + |C'_S|^2)$$

$$b \approx -Re(C_S + C'_S)$$

Sources of Scalars: Are there any?

Charged Higgs: Required in SUSY

- 1st generation couplings unknown

$\Rightarrow$ most general limits on 1st generation couplings are from nuclear β decay

- Couplings in simplest MSSM:

like S.M. Higgs, couplings $\propto$ masses: (Not so in less simple Higgs models (Langacker hep-ph/0503068))

(Herczeg, Prog. Part. Nucl. Phys. 46/2 413 (2001), Haber et al. Nucl.Phys.B 161 493 (1979))

$$C_S + C_S' \approx 2 g_s \frac{m_e m_d}{m_H^2} \tan^2\beta \leq 5\text{x}10^{-6}$$

for tanβ $\leq$65 and $m_H \geq 69$ GeV, neglects squark family mixing

- R-parity violating sleptons

direct exchange constrained by $\pi \rightarrow e\nu$, $C_S + C_S'$ can be $\sim -2\text{x}10^{-3}$ (Herczeg)

Profumo, Ramsey-Musolf PRD 07 $C_S + C_S'$ can be 0.001 in SUSY in 1-loop order: test 'alignment' approximation

Other β-ν searches for scalars:

- **^{32}Ar β-delayed p emission Adelberger/Garcia U.W./ISOLDE**
  see below ...

- **WITCH ^{35}Ar^{+} Leuven/ISOLDE Severijns in progress**
  Penning ion trap + retardation spectrometer for recoil momentum

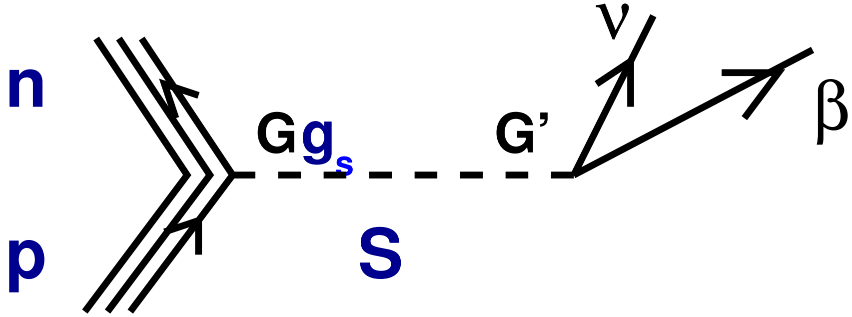
- **^{14}O^{+} Argonne Savard in progress**
  Transparent Paul ion trap: γ-ray Doppler shift

- **Superallowed $0^{+}\rightarrow 0^{+}$ ft Q-value dependence:**
  best limits on scalars coupling to left-handed ν

Limits from other experiments:

- **B. Campbell et al. NPB 709 419 (2005) limits from $\pi\rightarrow e\nu$** (see below)

Mass scale: Need hadronic matrix element for scalar interaction



Propagator+vertices: T $\propto g_S \frac{G_S^2}{M_S^2}$

Nucleon scalar form factor

$|g_S| = |\langle p|\bar{u}d|n\rangle| = ?$

Vector current is conserved (so $g_V = 1$), but Scalar current is not

Related by isospin rotation to $|\langle p|\bar{u}u - \bar{d}d|n\rangle|$, not directly related to experimentally measured quantity (unlike g_A or g_T)

$g_S \sim$ 0.25 to 1.0 (Herczeg ProgParNucPhys 46/2 413 (2001));

'but that's a factor of 16 in counting time'

0.6 (quark model Adler et al. PRD 11 3309 (1975));

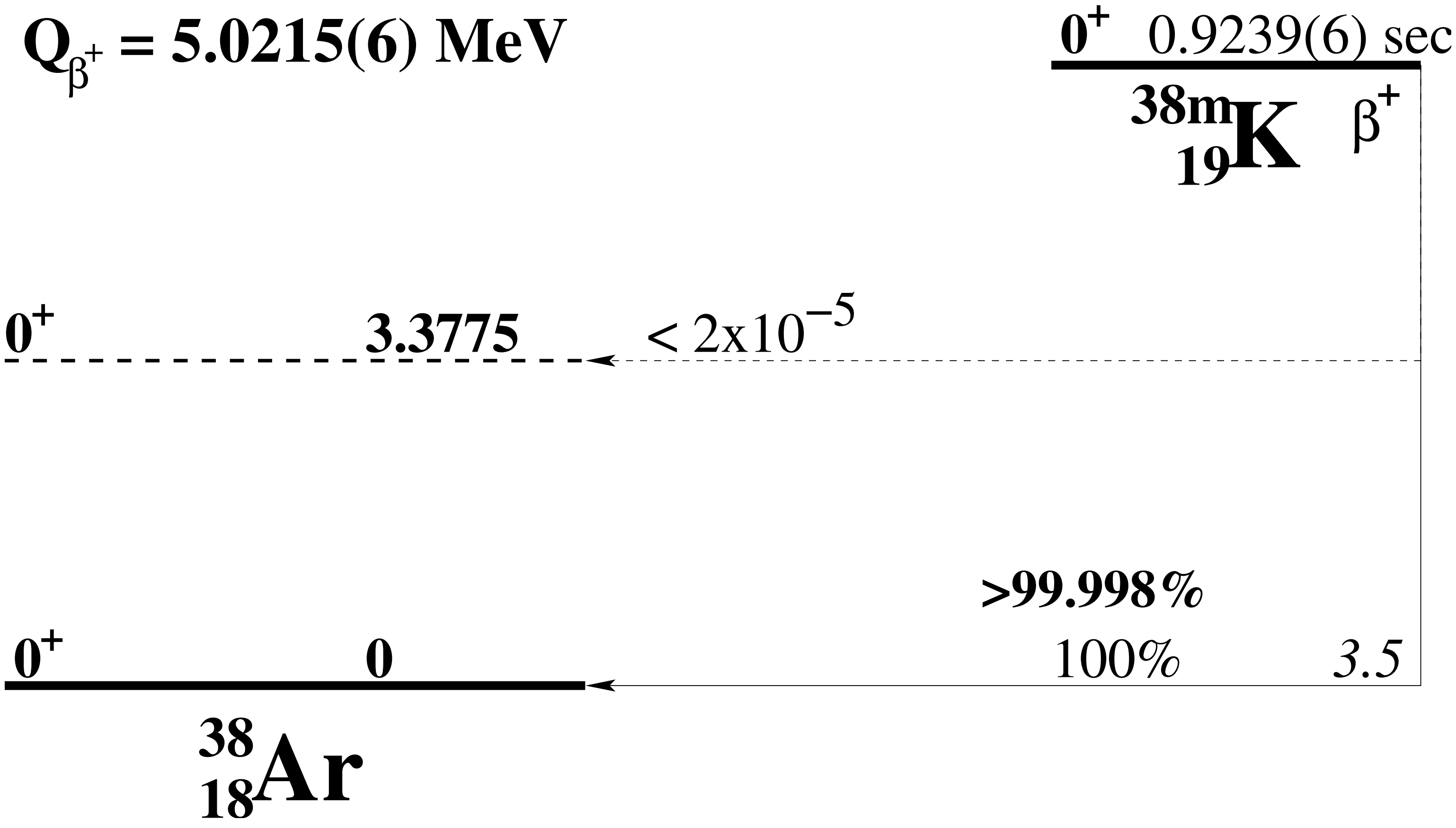
0.63(9) (Lattice gauge Liu et Woloshyn et al. PRD 59 (1999))

$$\frac{M_S}{(G_S/G_W)} > (.01)^{-\frac{1}{4}} \sqrt{g_S}\, M_W \approx 200 \text{ GeV}/\text{c}^2$$

'You also need a nucleon-nucleus form factor, about 1.1 or 1.2'

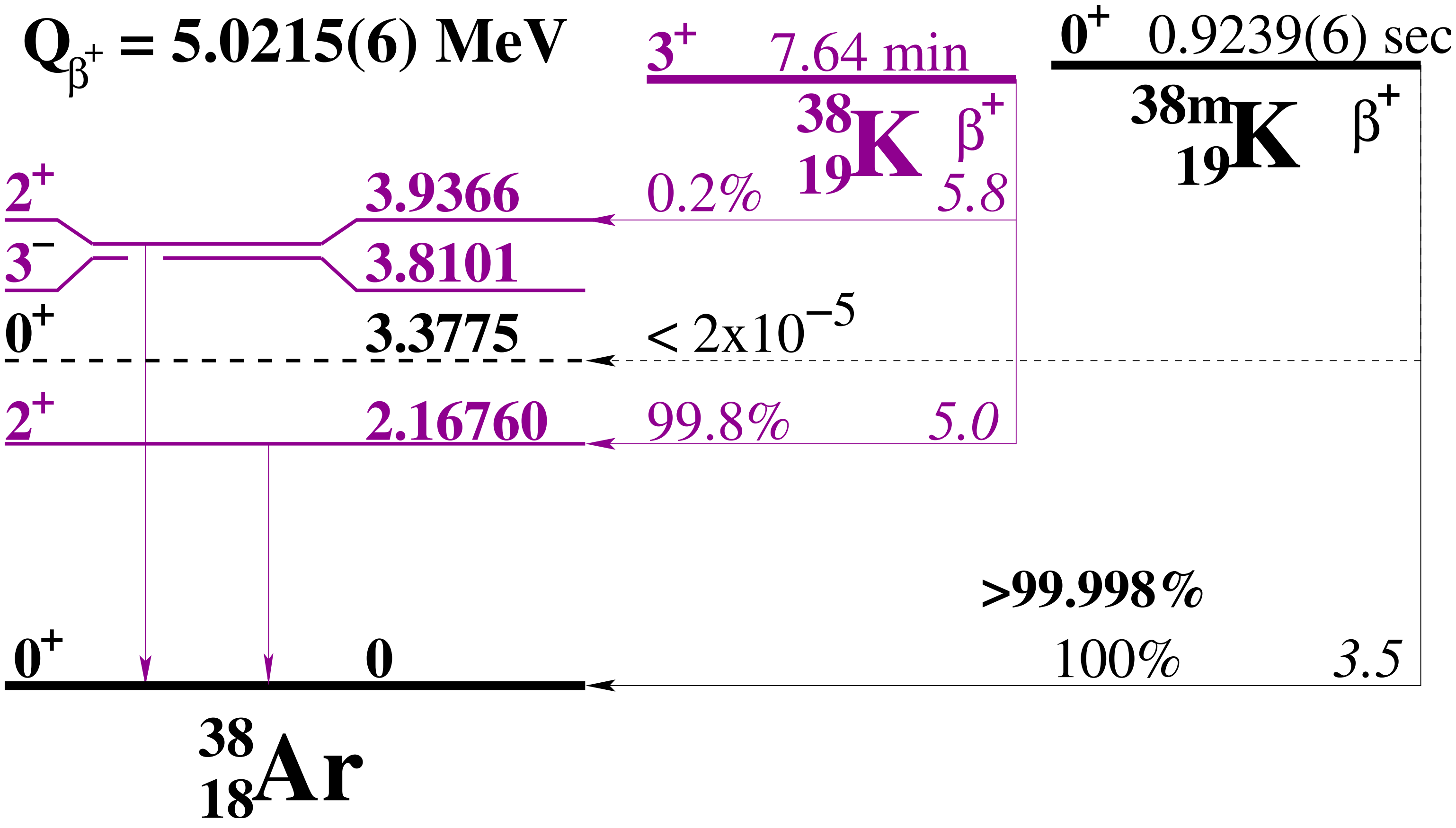
'g_S runs with p. You win over high-energy by 1.2.'

So we left this out of our PRL



Branches to excited states known to be negligible

Corrections independent of nuclear structure to < 0.0002:
bremsstrahlung ≈ 0.002 (in M.C., F. Glück),
recoil order ≈ 0.0003
For scalar exchange, lepton helicities are same: a= -1
Deviation ⇒ non-standard model scalar interaction



Branches to excited states known to be negligible

Corrections independent of nuclear structure to < 0.0002:

bremsstrahlung ≈ 0.002 (in M.C., F. Glück),

recoil order ≈ 0.0003

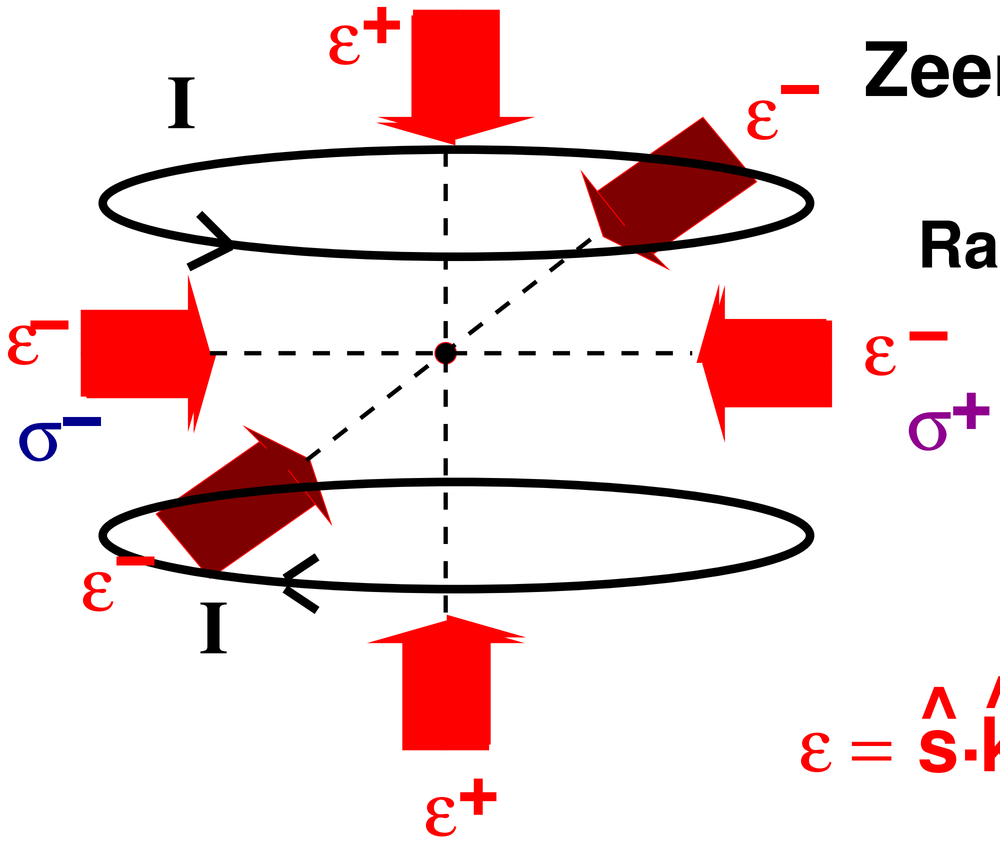
For scalar exchange, lepton helicities are same: a= -1

Deviation ⇒ non-standard model scalar interaction

(Ground state makes a background in β singles:
determines our E_β cut)

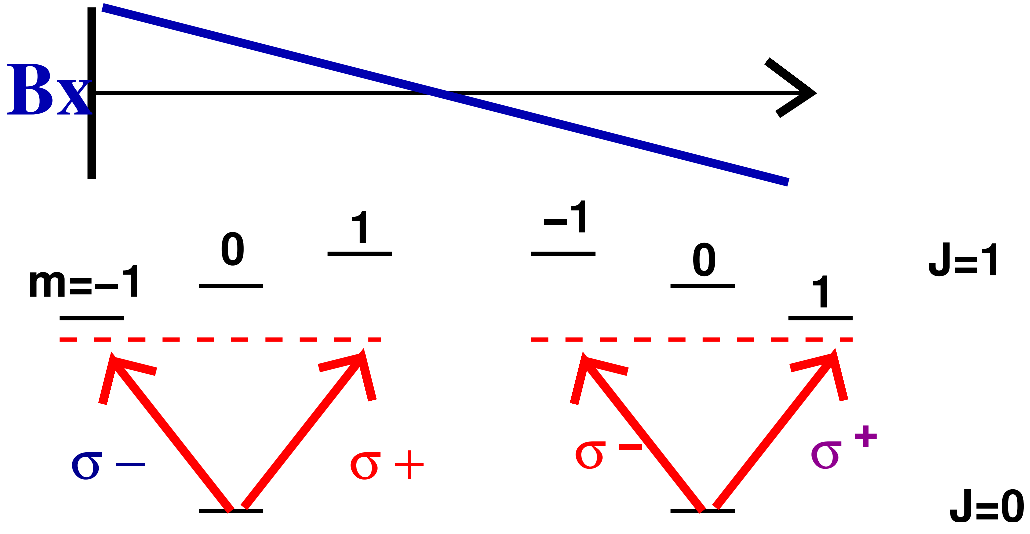
Zeeman Optical Trap (MOT)

Raab et al. PRL 59 2631 (1987)



Damped harmonic oscillator

$\varepsilon = \hat{s} \cdot \hat{k}$

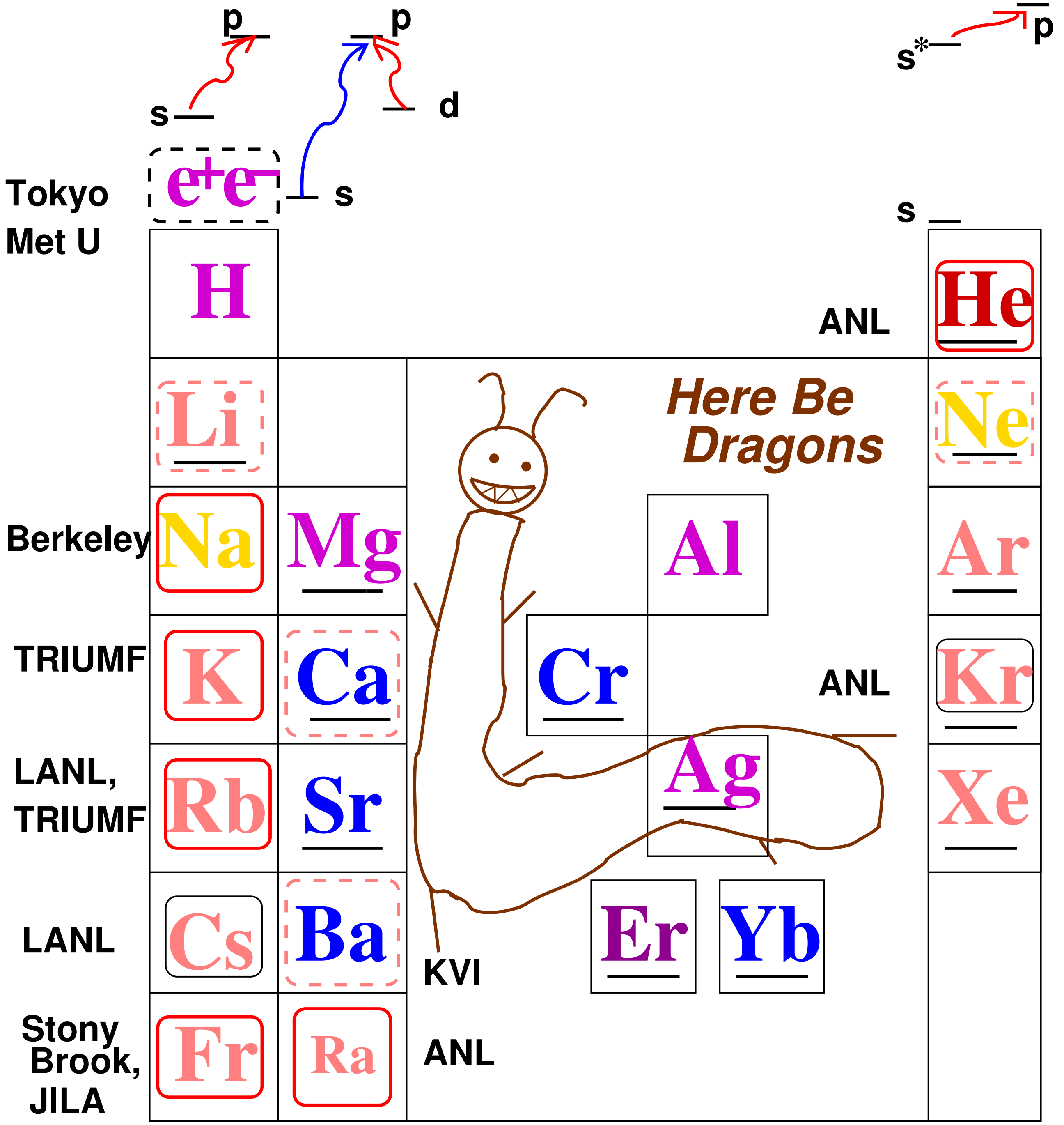


Bquad weak: recoils unperturbed

Velocities negligible

Vector polarization ~ 0
(Tensor alignment maybe)

Turn MOT off to polarize

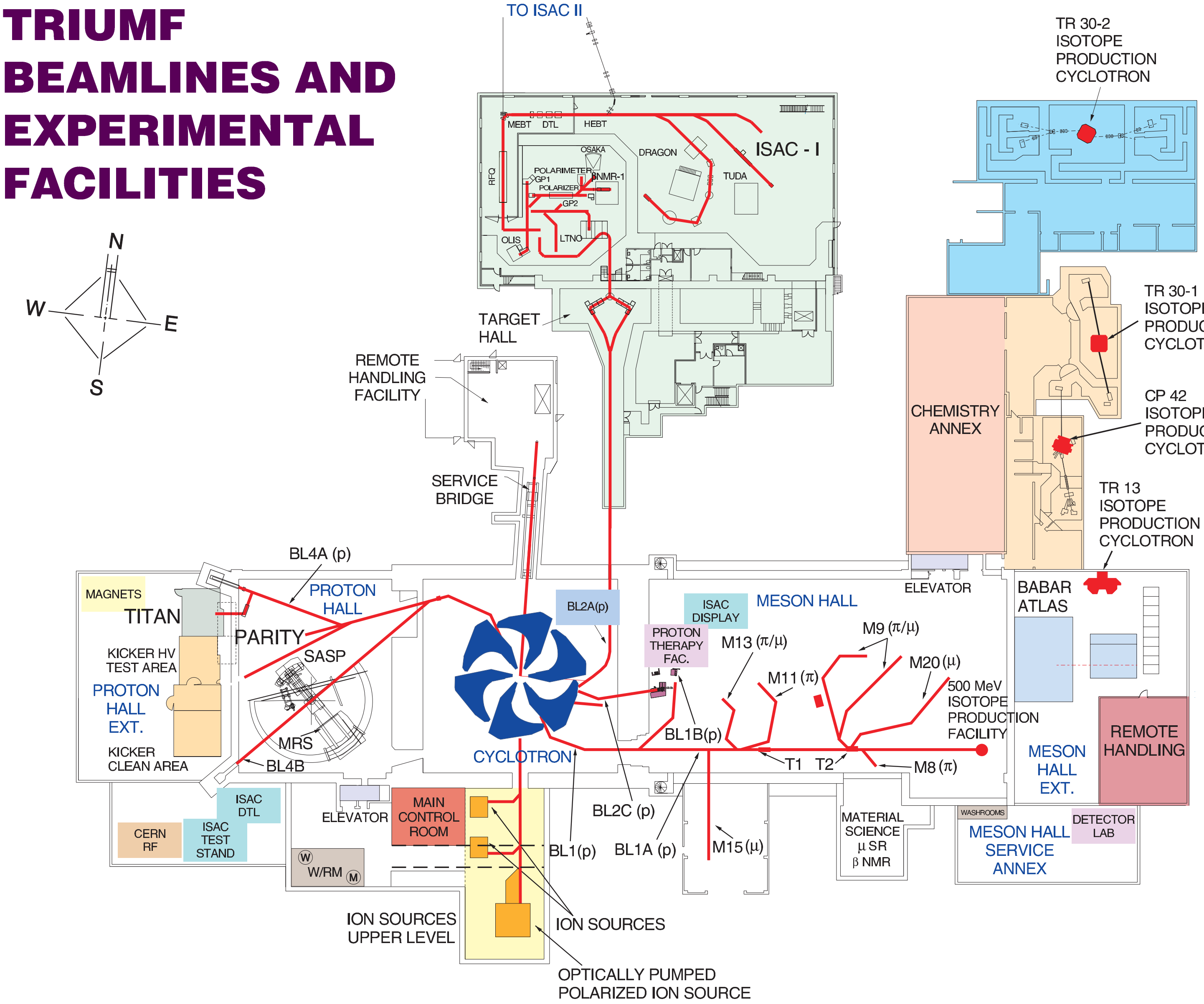


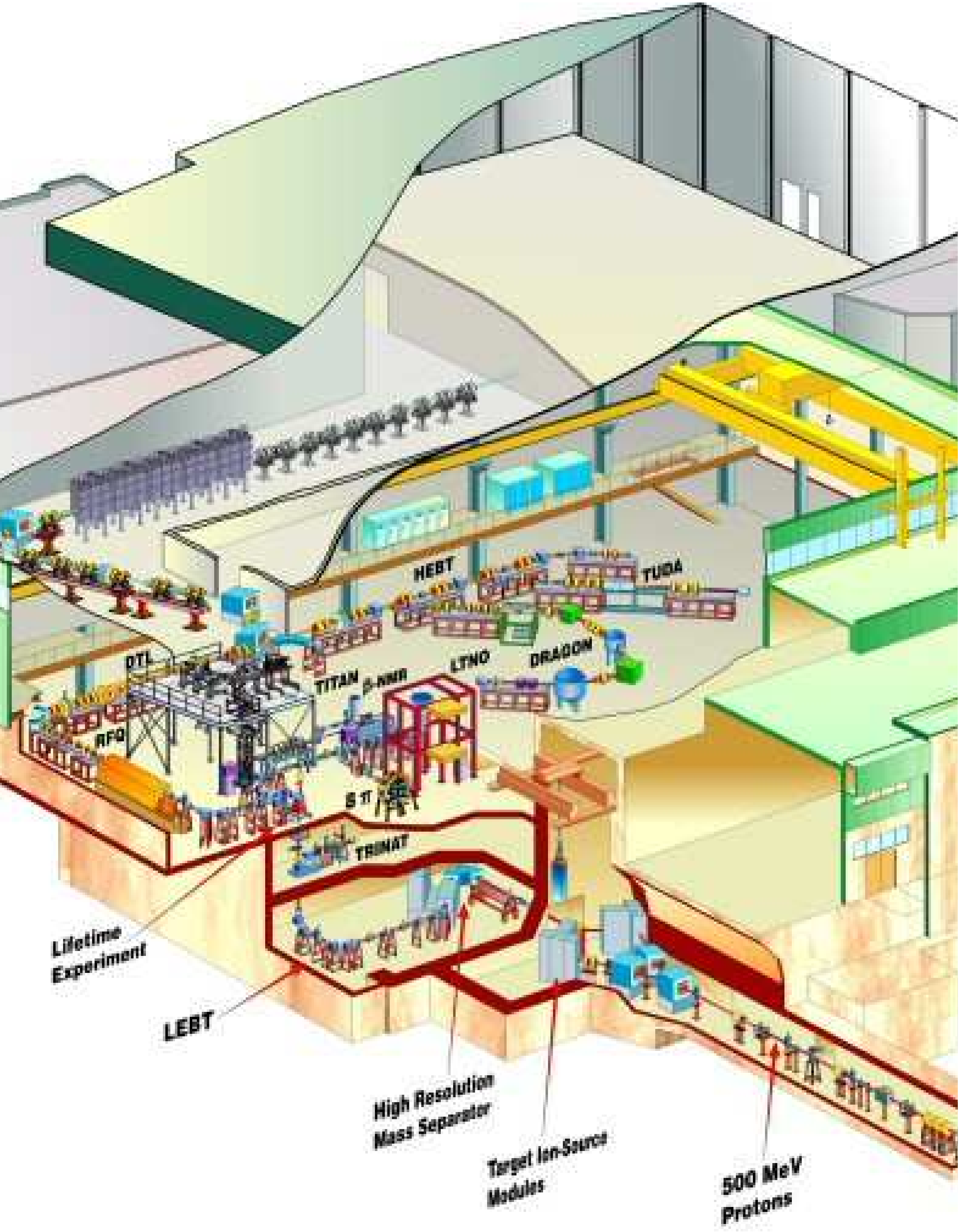
p
p
s
d
s*
p
e+e−
s
s
Tokyo Met U
H
ANL
He
Li
Here Be Dragons
Ne
Berkeley
Na
Mg
Al
Ar
TRIUMF
K
Ca
Cr
ANL
Kr
LANL, TRIUMF
Rb
Sr
Ag
Xe
LANL
Cs
Ba
KVI
Er
Yb
Stony Brook, JILA
Fr
Ra
ANL

—— Trapped in MOT ▢ Radioactives trapped

▢ Long–lived Rad. ⬚ Plans

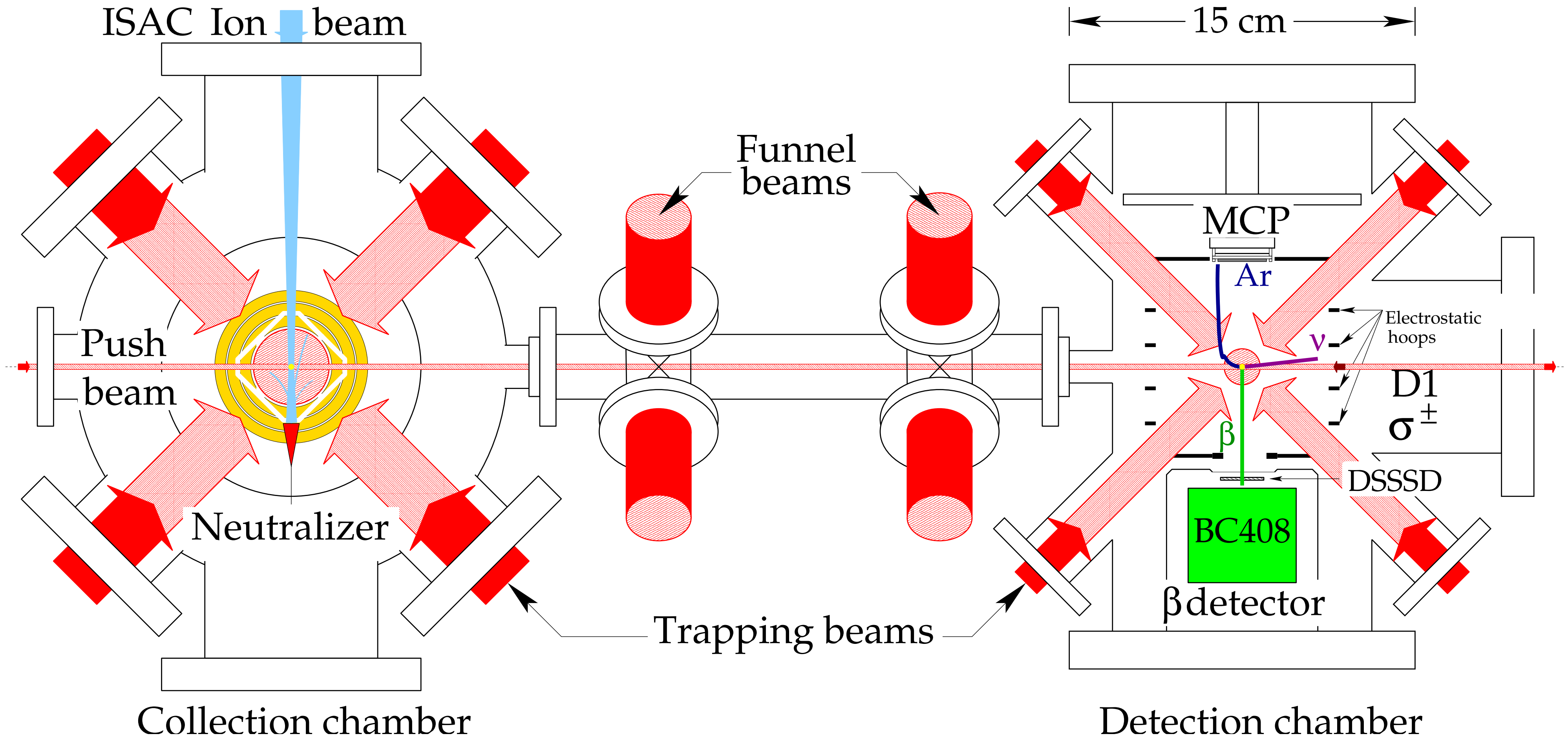
TRIUMF BEAMLINES AND EXPERIMENTAL FACILITIES

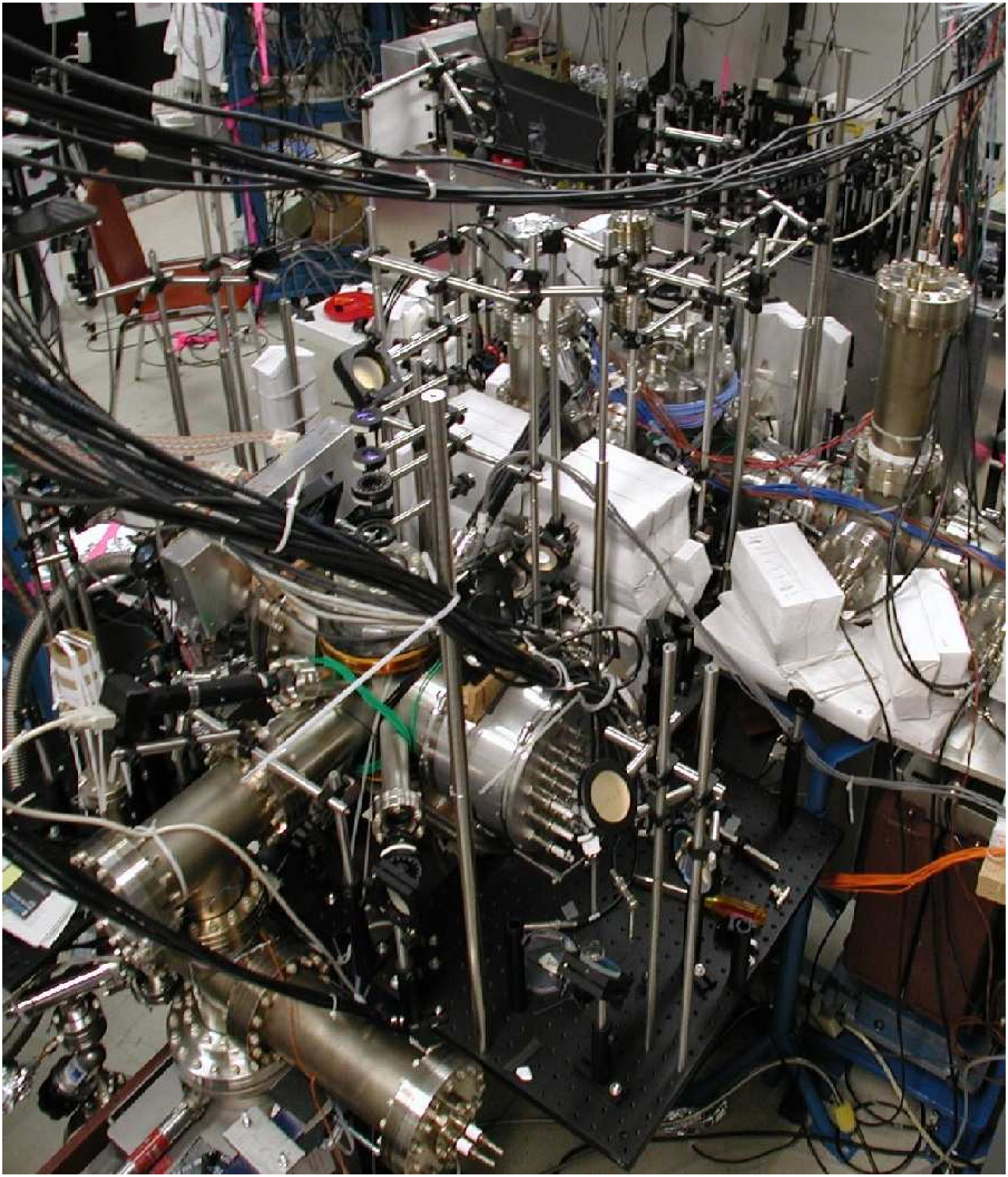



HEBT
TUDA
DTL
LTNO
DRAGON
TITAN
β-NMR
RFQ
8π
TRINAT
Lifetime Experiment
LEBT
High Resolution Mass Separator
Target Ion-Source Modules
500 MeV Protons

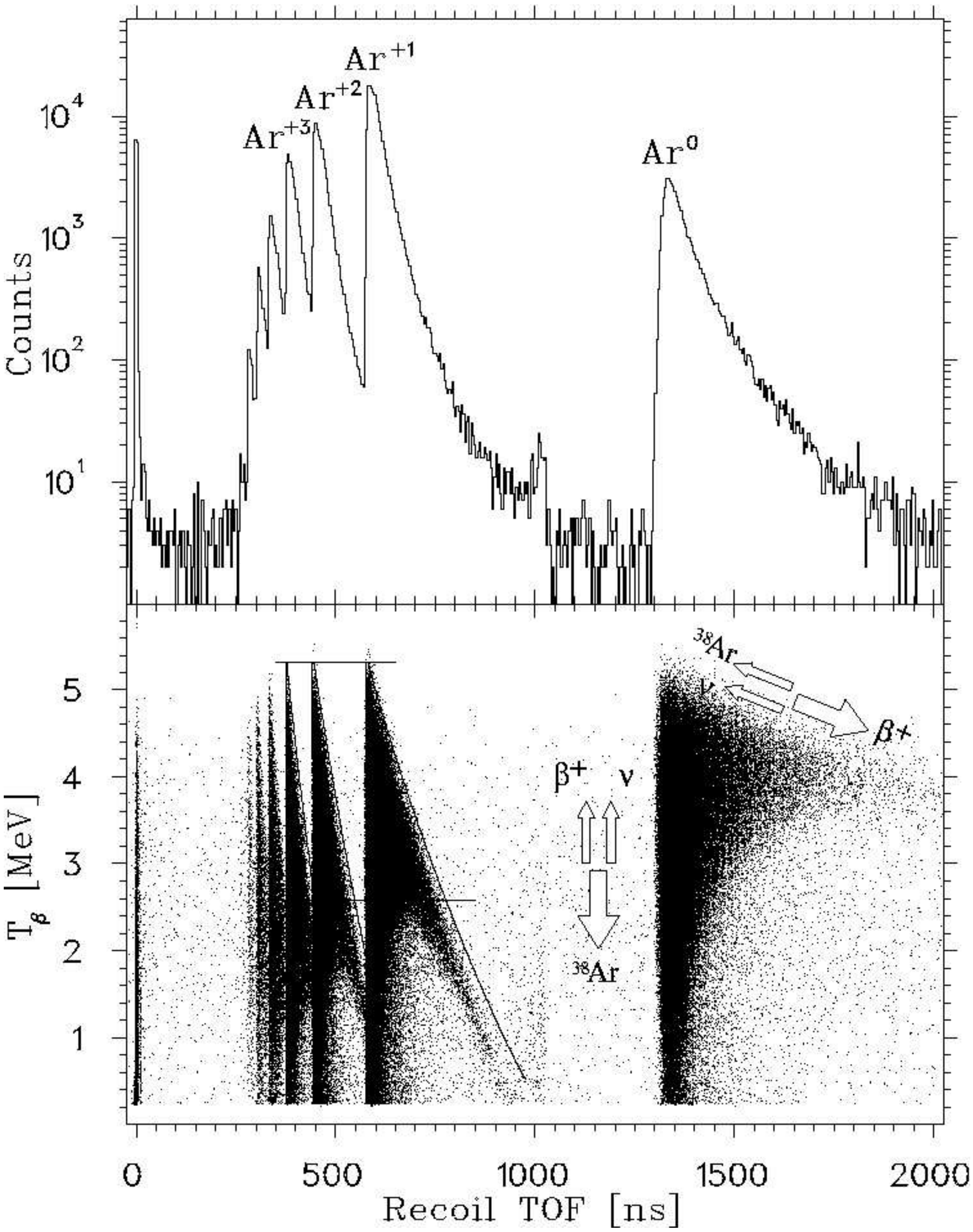
TRIUMF's Neutral Atom Trap

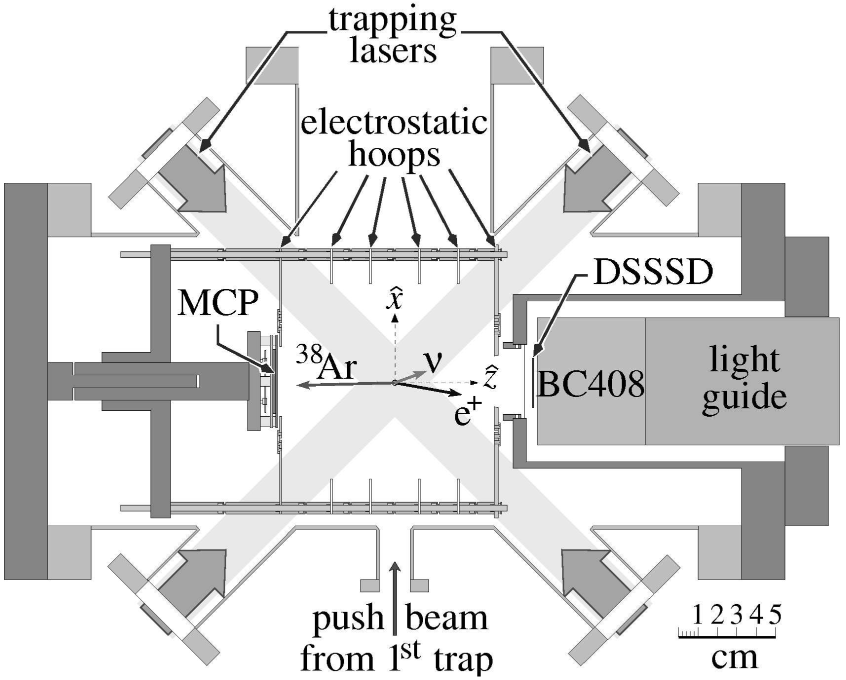
- **Isotope/Isomer selective**
- **Evade 1000x untrapped atom background by → 2nd MOT**
- **75% transfer (must avoid backgrounds!); 10^{-3} capture**
- **0.7 mm cloud for β-Ar^{+} → ν momentum → β-ν correlatio**
- **>97% polarized, known atomically**





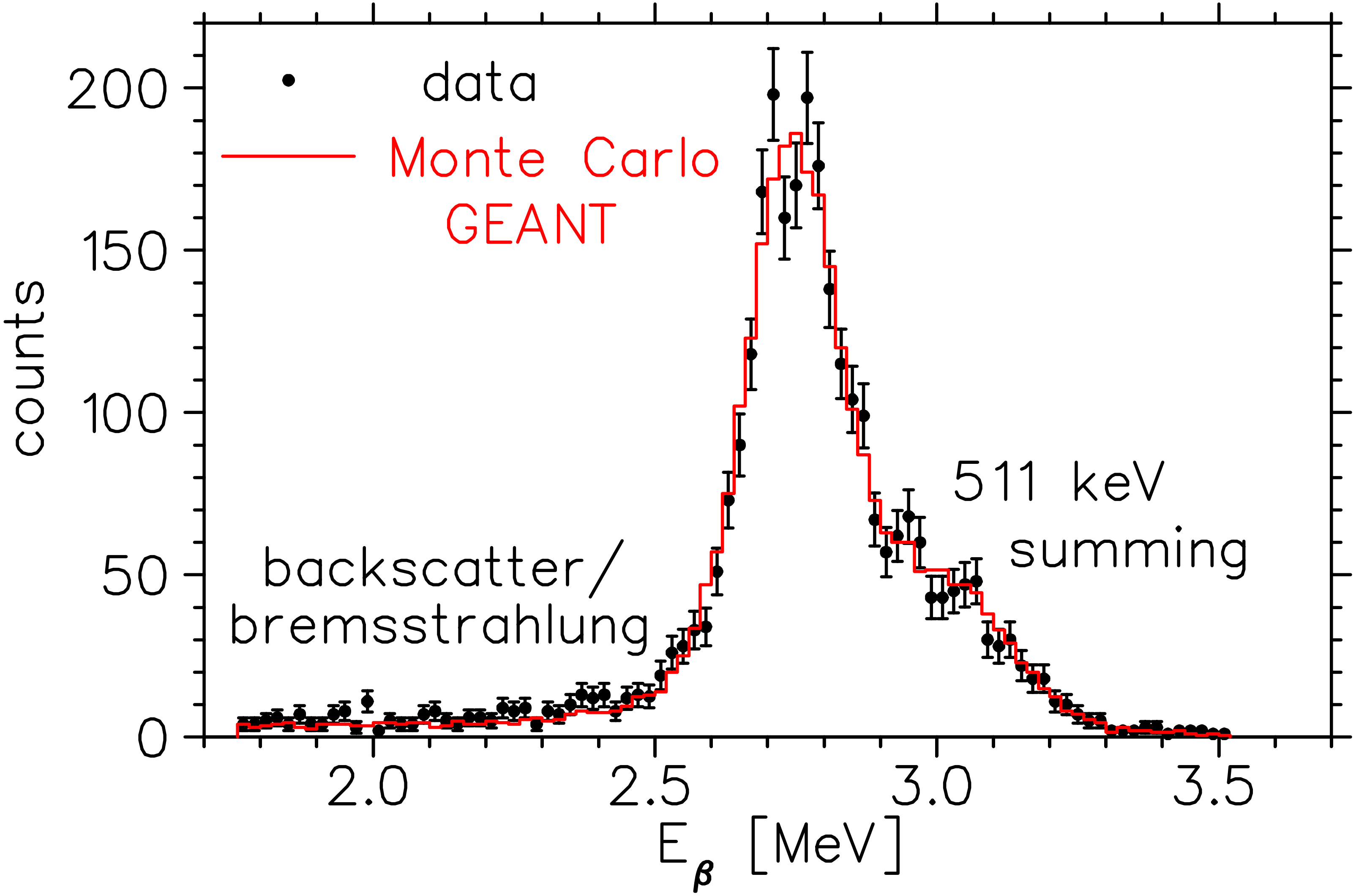
β-recoil coincidences   Raw data





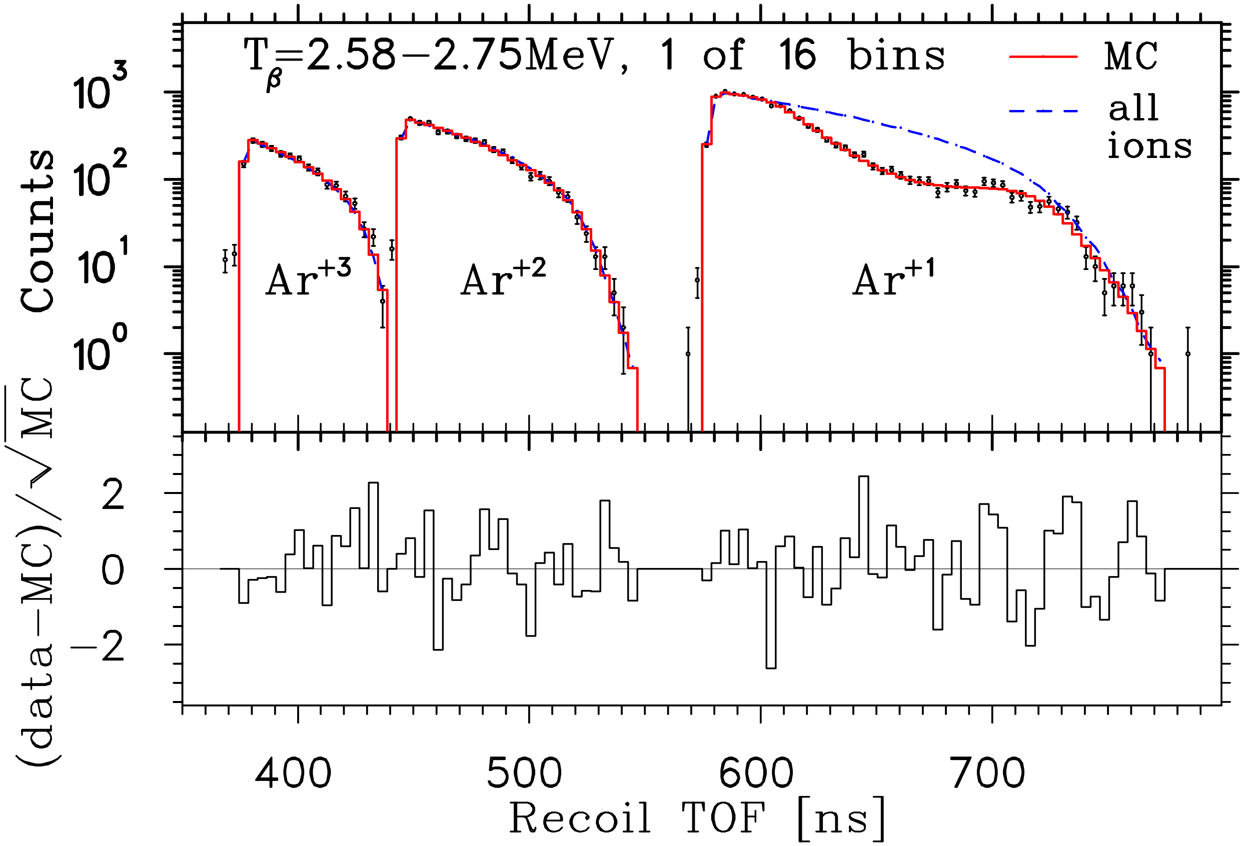
In-situ calibrations

E_β detector response for “monoenergetic” β’s from kinematics of other observables (β-recoil angle and recoil momentum)



^{38m}K $0^+ \rightarrow 0^+$
β-ν correlation

Recoil TOF[T_β],
C.L. of total fit 52%



Gorelov PRL Apr 2005
$\tilde{a}$=0.9981 ± 0.0030(stat) ± 0.0037(syst)
Best general constraints on scalars coupling to 1st generation
Upgrade approved: Goal 3x better
$\tilde{a}=a/(1+bm_\beta/\langle E_\beta\rangle)$

(Adelberger ^{32}Ar β-delayed proton emission PRL 1999
$\tilde{a}$=0.9989 ± 0.0052 ± 0.0039 under re-analysis)

Constraints on recoil shakeoff from W(θ) data

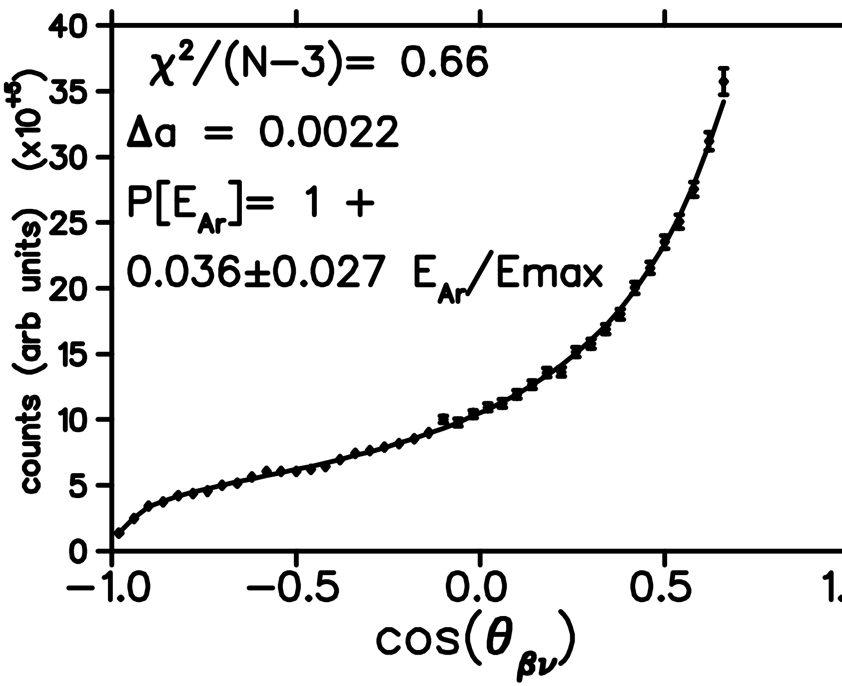
E_{rec} spectrum * (1 + c E_{rec})
Demonstrated ORNL ^{6}He β^-
(Carlson PR 129 (1963))

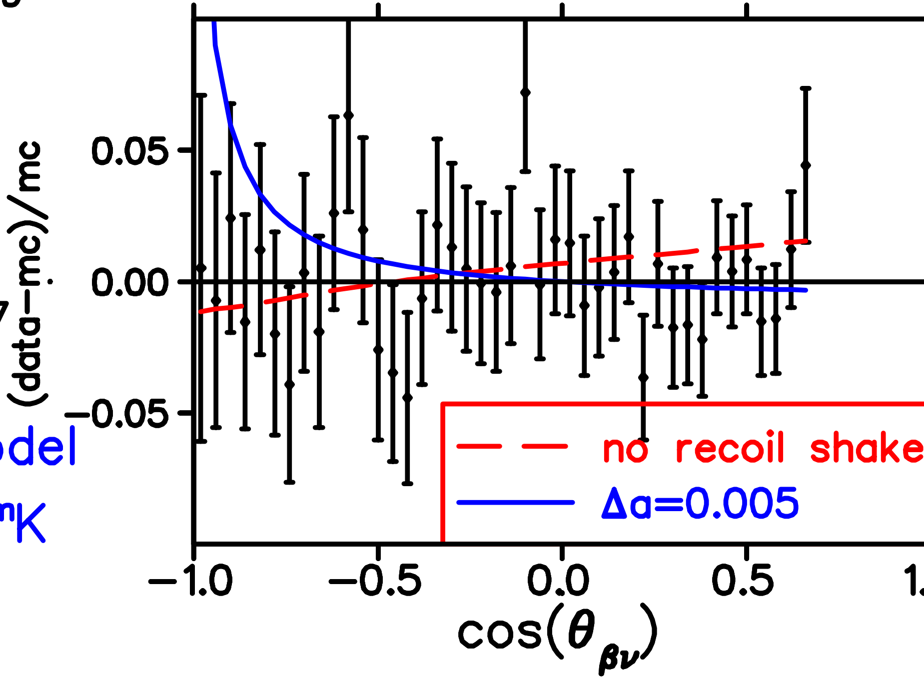
Estimated β^+ Scielzo PRA68 (2003) LBL
→ related to photoionization exps.
ignores ORNL term of opposite sign

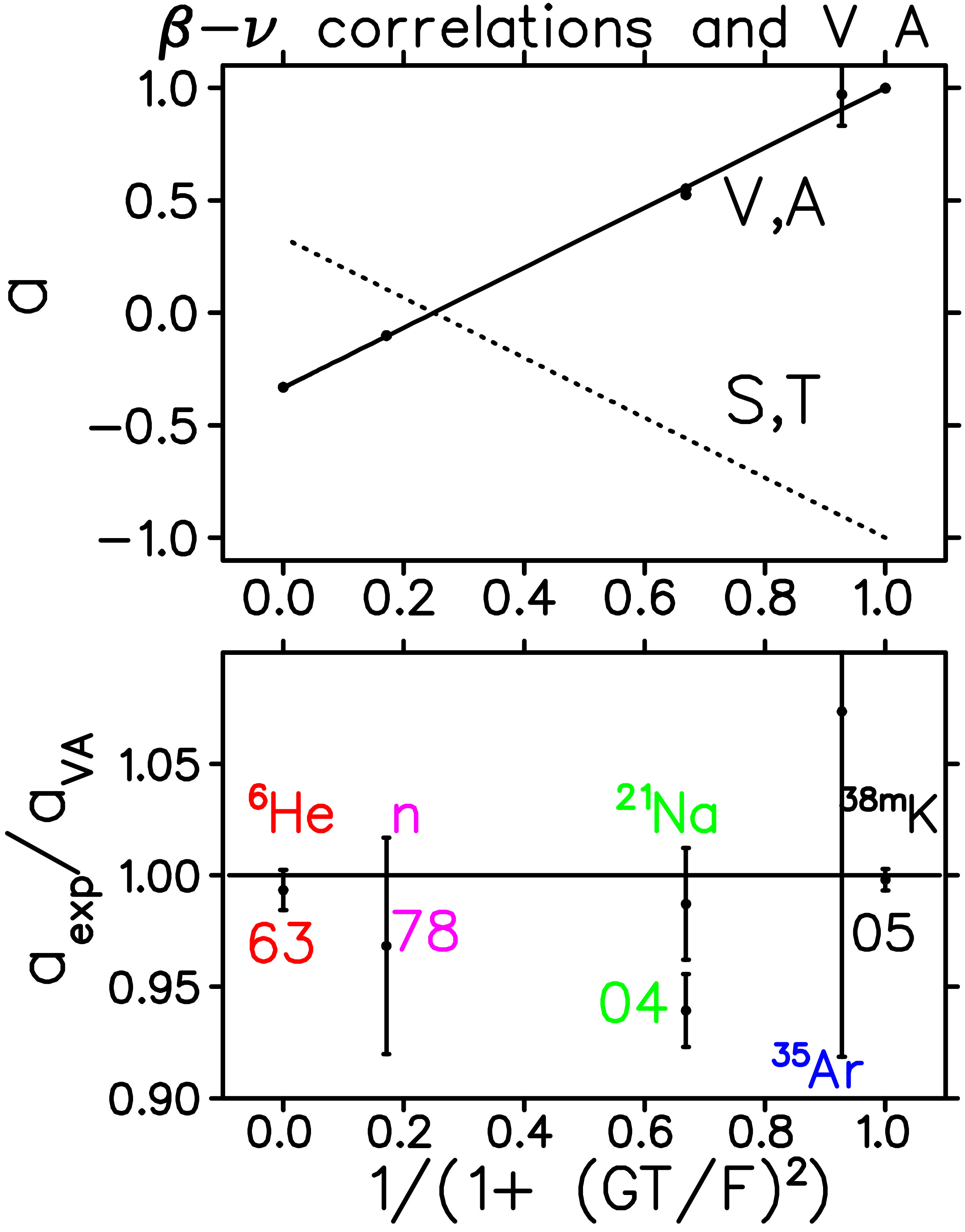
TRIUMF: can constrain from DATA:

- * Fit a and c to TOF[E_β] using $Ar^{+1,+2,+3}$
  c=.007 ± .070, Δa= .0002 ± .0020
- * Fit a and c to reconstructed W[θ]
  c=.036 ± .027, Δa= −.0022 ± .0017

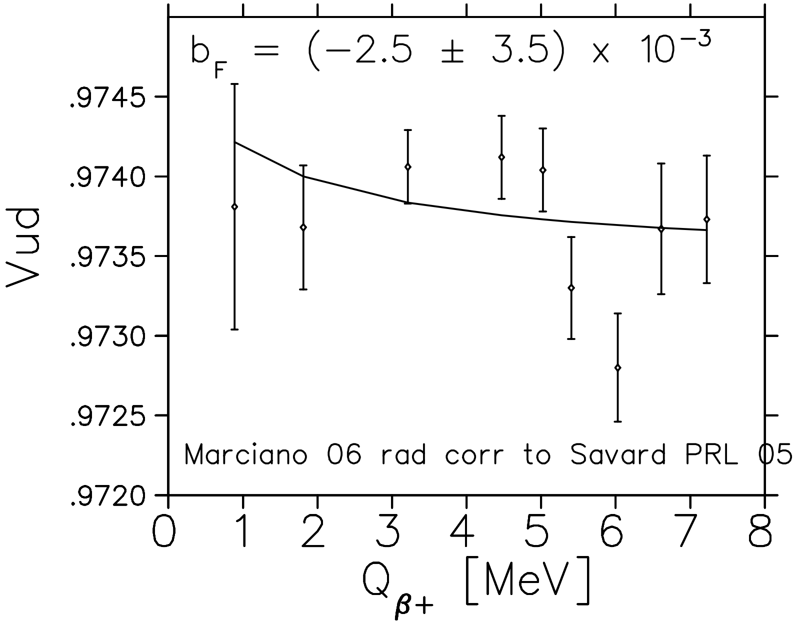
TRIUMF shake data consistent LBL model
Effects on a are much smaller in ^{38m}K






β−ν correlations and V A
a
1.0
0.5
0.0
−0.5
−1.0
V,A
S,T
0.0
0.2
0.4
0.6
0.8
1.0
a_{exp}/a_{VA}
1.05
1.00
0.95
0.90
^{6}He
63
n
78
^{21}Na
04
^{38m}K
05
^{35}Ar
0.0
0.2
0.4
0.6
0.8
1.0
$1/(1+ (GT/F)^2)$

Constraints on scalars from ‘Fierz interference term’ (Ormand Brown Holstein PRC 89)



- **Independent of V_{us} and CKM unitarity**
- **Scalar term $\propto m/E_\beta$ so low-Q (^{10}C and ^{14}O) are most sensitive**
- **High-Z needed to settle ‘base-line’**

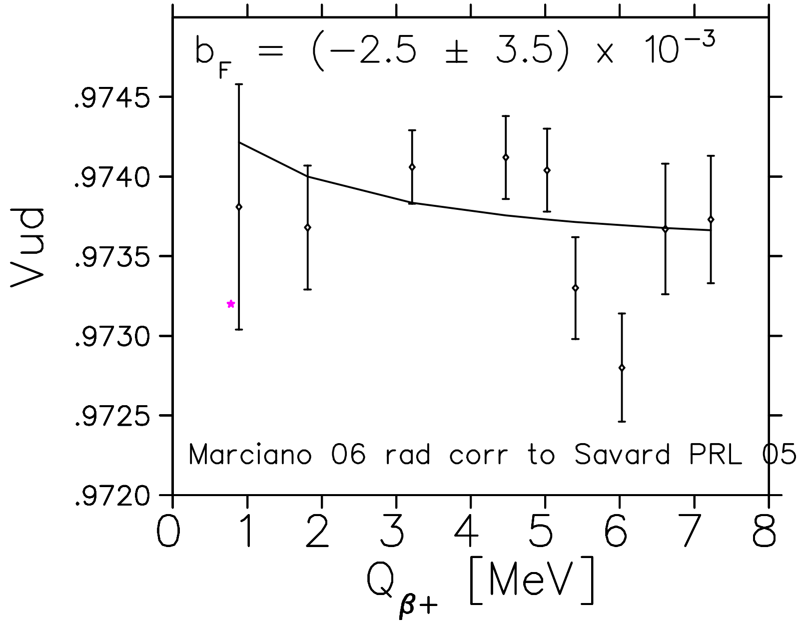
$b_F = -Re(C_S + C_S')$, **scalars that couple to left-handed ν only**

$$W[\theta_{\beta\nu}] = 1 + b_F m_\beta/\langle E_\beta\rangle + \ a\ v/c \cos[\theta_{\beta\nu}] \qquad a \approx 1 - |C_S|^2 + |C_S'|^2$$

- **TRINAT’s present statistical error is 4x bigger**
- **Would improve systematics by using kinematic info for E_β at $E_\beta < Q/2$**
- **Goal: achieve similar accuracy within one β-ν experiment (‘ambitious’)**
- **Goal: a window left open by $\pi \rightarrow e\nu$ for sleptons at 2×10^{-3} [Herczeg Prog. Part. Nucl. Phys. 46/2 413 (2001)]**

And reach SUSY contribution at 0.001 to test ‘alignment approximation’ [Profumo and Ramsey-Musolf PRD 07]

Constraints on scalars from ‘Fierz interference term’



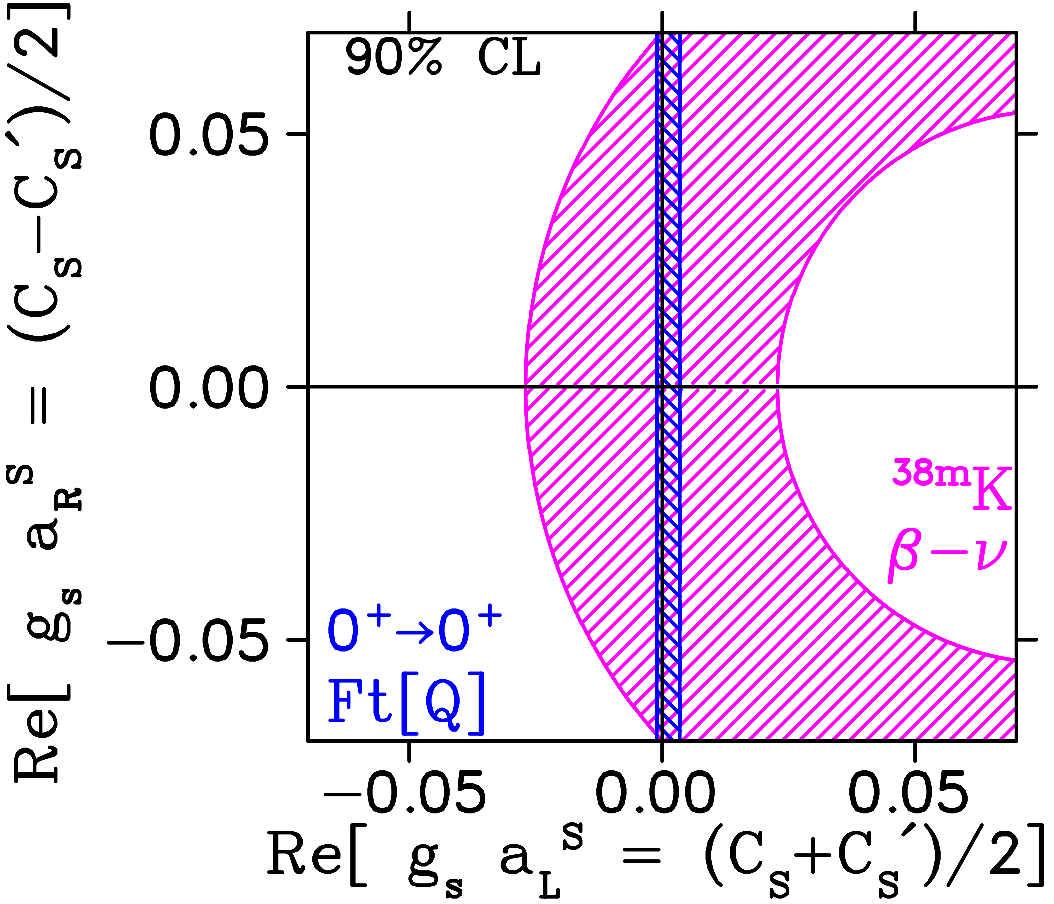
- Independent of V_{us} and CKM unitarity
- Scalar term $\propto m/E_\beta$ so low-Q (^{10}C and ^{14}O) are most sensitive
- High-Z needed to settle ‘base-line’
- neutron (β^- decay) would show opposite sign scalar: if it came in, say, here, that would be cool

$b_F = -Re(C_S + C'_S)$, scalars that couple to left-handed ν only

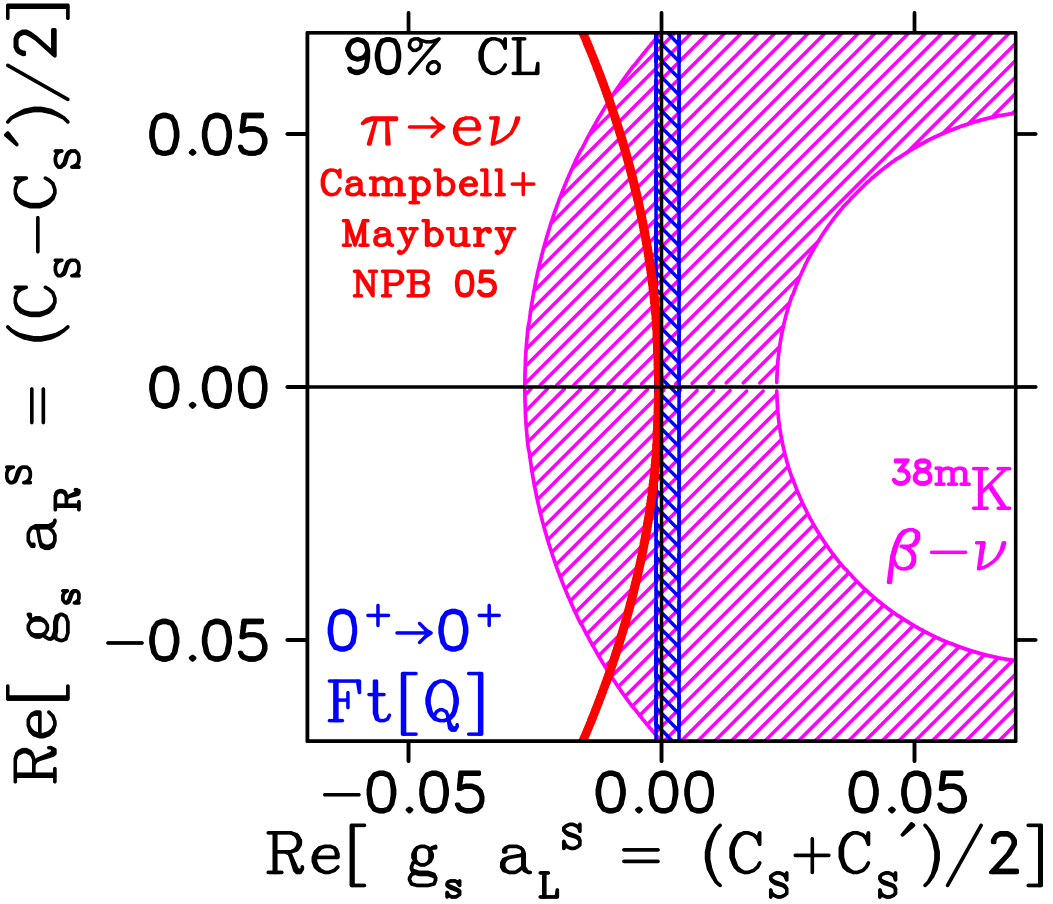
$$W[\theta_{\beta\nu}] = 1 + b_F m_\beta/\langle E_\beta \rangle + \ a\ v/c \cos[\theta_{\beta\nu}] \qquad a \approx 1 - |C_S|^2 + |C'_S|^2$$

- TRINAT’s present statistical error is 4x bigger
- Would improve systematics by using kinematic info for E_β at $E_\beta < Q/2$
- Goal: achieve similar accuracy within one β-ν experiment (‘ambitious’)
- Goal: a window left open by $\pi \rightarrow e\nu$ for sleptons at 2×10^{-3} [Herczeg Prog. Part. Nucl. Phys. 46/2 413 (2001)]

And reach SUSY contribution at 0.001 to test ‘alignment approximation’ [Profumo and Ramsey-Musolf PRD 07]

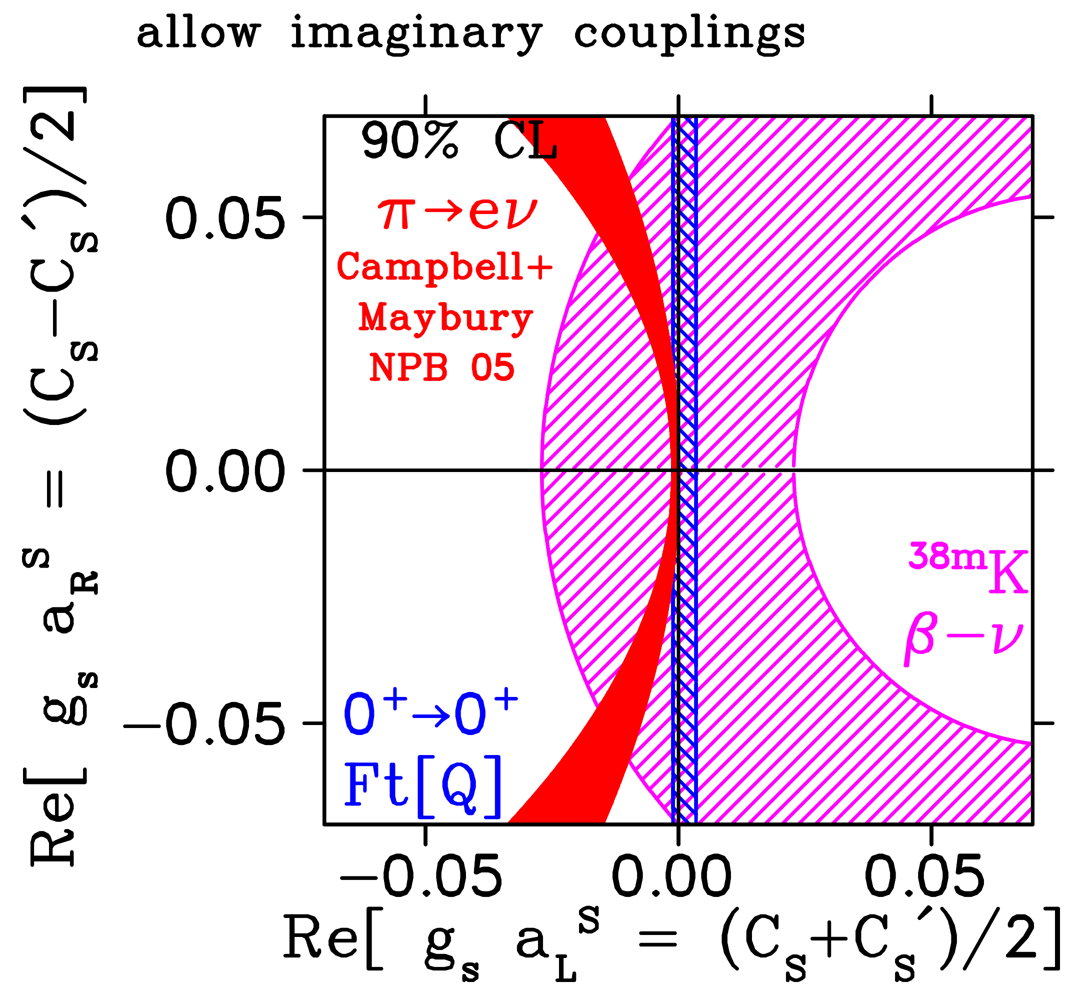


- 0^+ to 0^+ Ft tightly constrains scalars coupling to ν_L
- β-ν constraints lose on ν_L but are more general

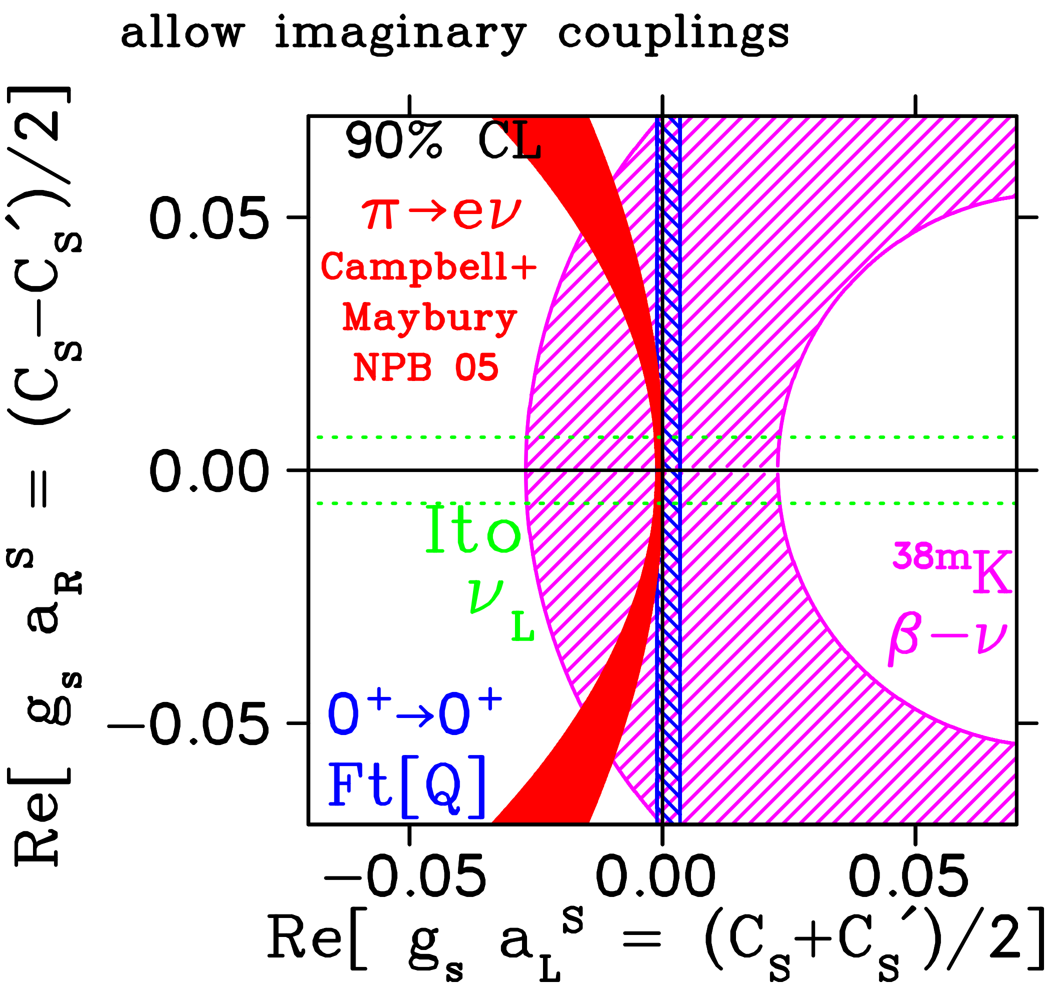


$(\pi \rightarrow e\nu)/(\pi \rightarrow \mu\nu)$:

- Scalar interaction produces effective pseudoscalar interaction after EW loop corrections
- Above limits assume:
  universal couplings and ‘$\Lambda = 200 GeV$’
- Limits relax to ∼ $0^+ \rightarrow 0^+$ if consider more general couplings (and use μ capture to help constrain)



An example of how constraints from $\pi \longrightarrow e\nu$ are more model-dependent



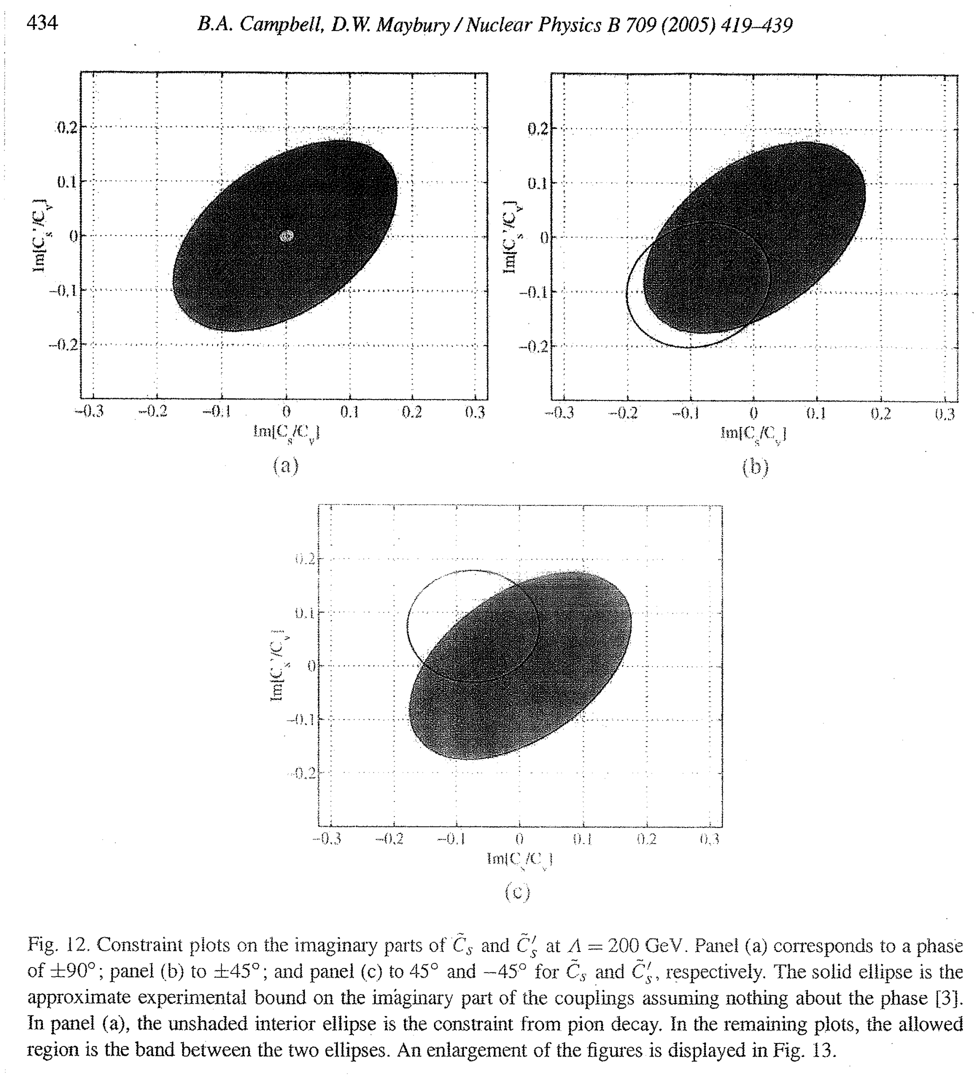
Ito and Prezeau PRL 05: Order-of-magnitude naturalness calculation:

Scalars (or tensors) coupling to ν_R contribute to the SM ν_L mass

Opportunity?: **We should constrain its size** to help understand ν mass?

I used $m_\nu <$ 3eV for "Ito", not 0.23 eV WMAP

Constraints on imaginary couplings:
If you know the relative phase, $\pi \longrightarrow e\nu$ constraints are tight



434 *B.A. Campbell, D.W. Maybury / Nuclear Physics B 709 (2005) 419–439*

Fig. 12. Constraint plots on the imaginary parts of $\tilde{C}_s$ and $\tilde{C}'_s$ at $\Lambda = 200$ GeV. Panel (a) corresponds to a phase of ±90°; panel (b) to ±45°; and panel (c) to 45° and −45° for $\tilde{C}_s$ and $\tilde{C}'_s$, respectively. The solid ellipse is the approximate experimental bound on the imaginary part of the couplings assuming nothing about the phase [3]. In panel (a), the unshaded interior ellipse is the constraint from pion decay. In the remaining plots, the allowed region is the band between the two ellipses. An enlargement of the figures is displayed in Fig. 13.

$^{38\mathrm{m}}$K β^+-ν Error Budget $\tilde{a}$=0.9981±0.0030(stat)

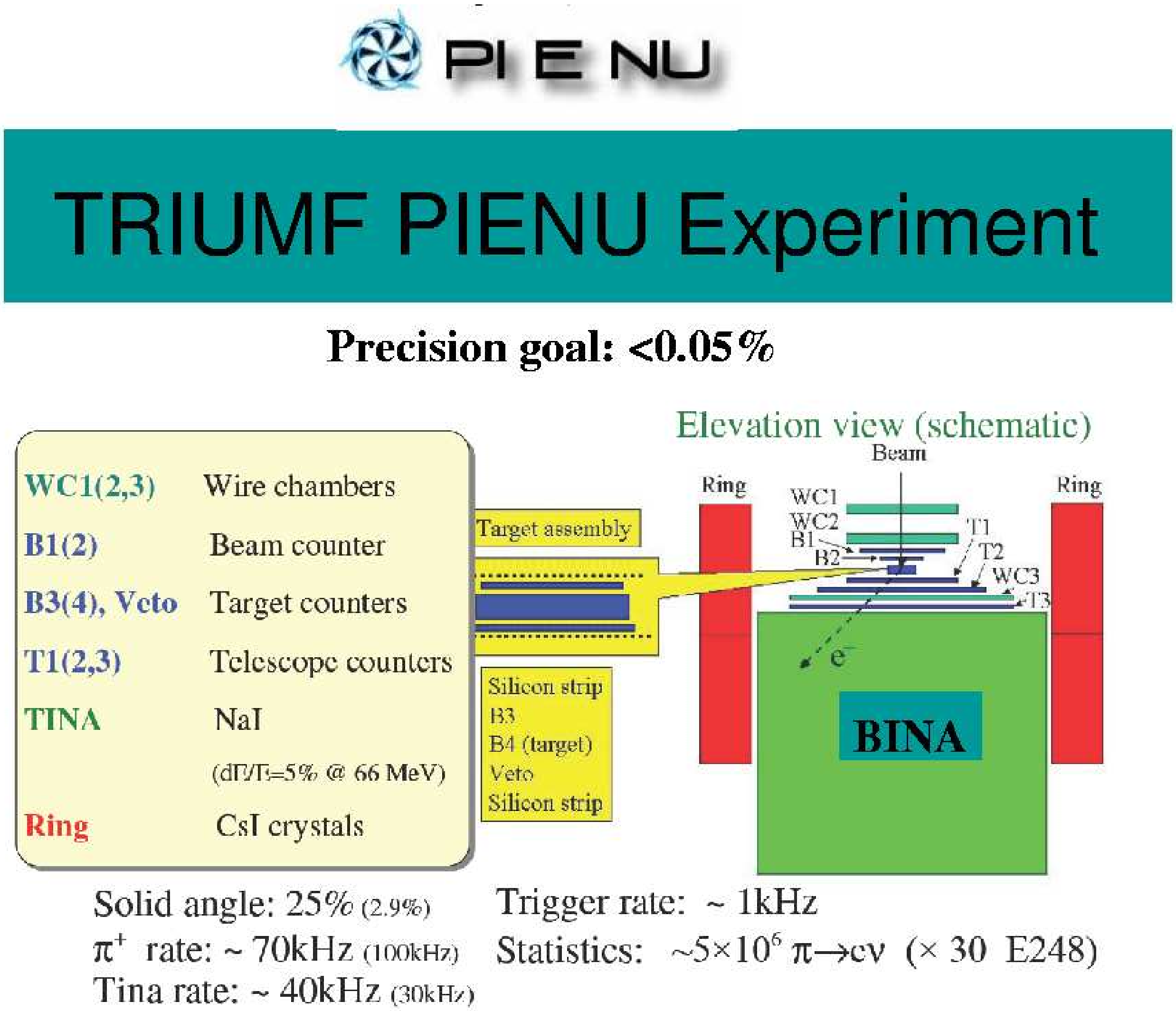
Error	PRL	Future
$\vec{E}$ field/trap width :	0.17%	0.04%
E field nonuniformity	0.14%	0.03%
β^+ backscattering bkgd	None	None
$E_{\beta+}$ Detector Response:		
Lineshape tail/total	0.06%	0.03%
511 keV Compton sum	0.09%	0.04%
Calibration, nonlinearity	0.17%	0.08%
MCP Eff[E_{Ar+}]	0.07%	0.03%
MCP Eff[θ]/XY position	0.08%	0.04%
e$^-$ shakeoff [E_{recoil}]	0.18%	0.08%
Sum systematics	0.37%	0.14%
Total error	0.48%	0.19%

Planned Improvements:

- Larger MCP
- E_β calibration from interwoven background-free ^{37}K
- $1/\sqrt{5}$ statistical error
  - (conservative)
  - larger ISAC yields
  - more laser power
- Permanent mask on MCP for position info test

- Most systematic errors determined by statistics-limited data evaluation.
- Further improvements possible: use all kinematic information.

TRIUMF has a new version of $\pi \longrightarrow e\nu$... so does PSI



PI E NU

TRIUMF PIENU Experiment

Precision goal: <0.05%

WC1(2,3)	Wire chambers
B1(2)	Beam counter
B3(4), Veto	Target counters
T1(2,3)	Telescope counters
TINA	NaI (dΓ/Γ=5% @ 66 MeV)
Ring	CsI crystals

Elevation view (schematic)

Solid angle: 25% (2.9%)

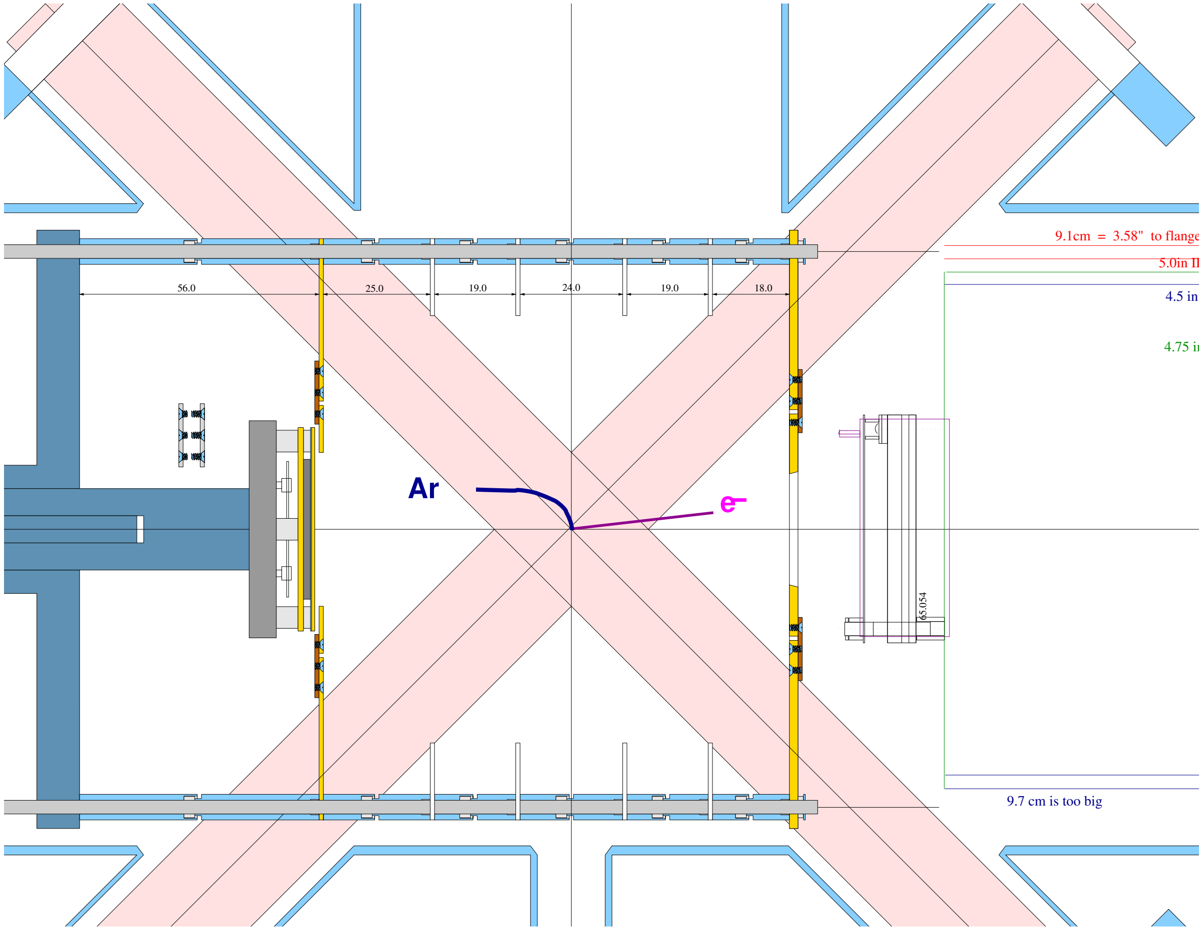
π^+ rate: ~ 70kHz (100kHz)

Tina rate: ~ 40kHz (30kHz)

Trigger rate: ~ 1kHz

Statistics: ~5×10^6 π→eν (× 30 E248)

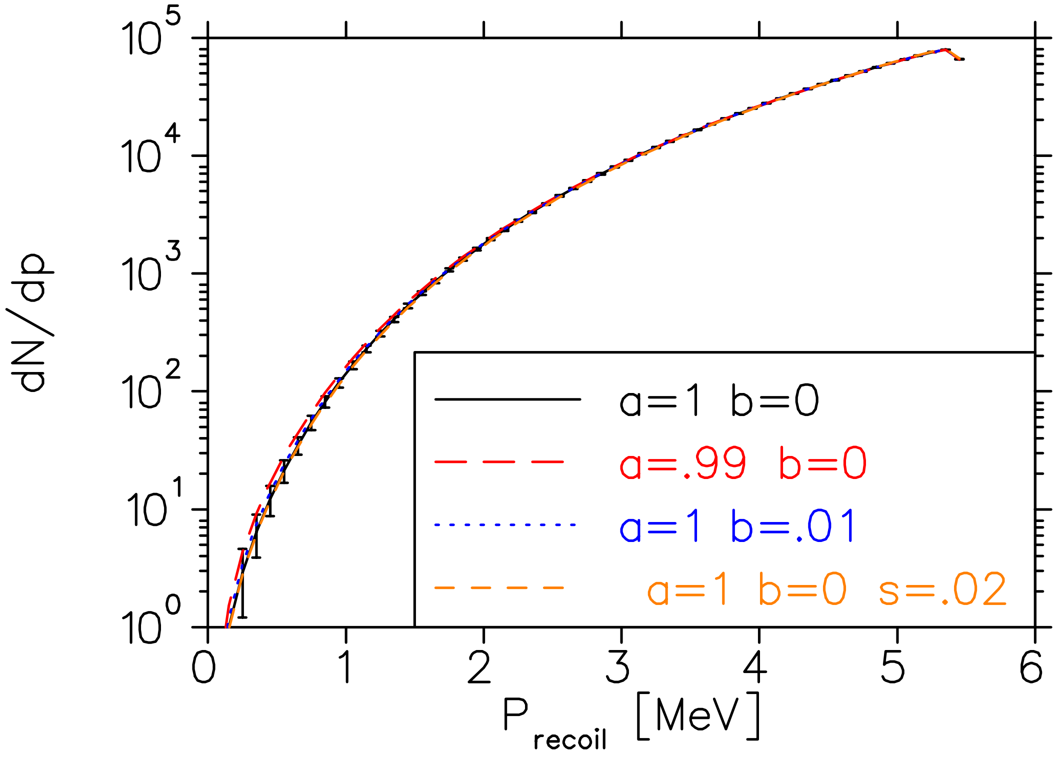
‘Method III’: New: Geometry with e$^-$ detector

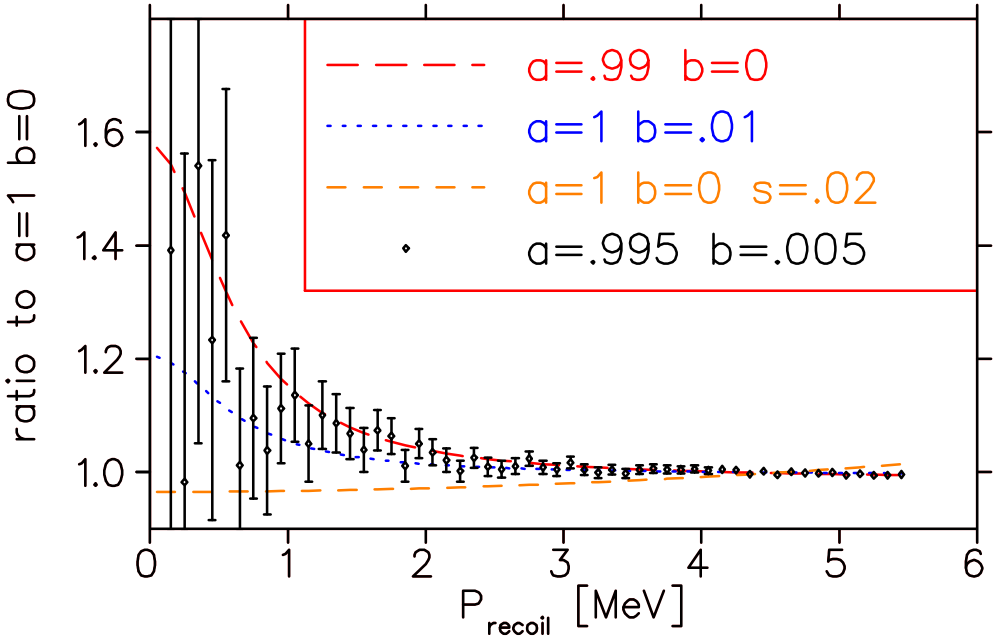


For ^{38m}K β-ν upgrade:

- High-statistics
- free of β bias
- expect collection for all e−’s < 100 eV

Other experiments are also made possible, e.g. ^{80}Rb tensor search by recoil singles





SIMULATION

Recoil momentum spectrum

Sensitive to a (a, b highly correlated)

Can extract momentum dependence of shakeoff separately

From 10^6 events $\sigma_a = 0.001$ (3 hours)

Superallowed Q-dependence of b error 0.003: 1 shift

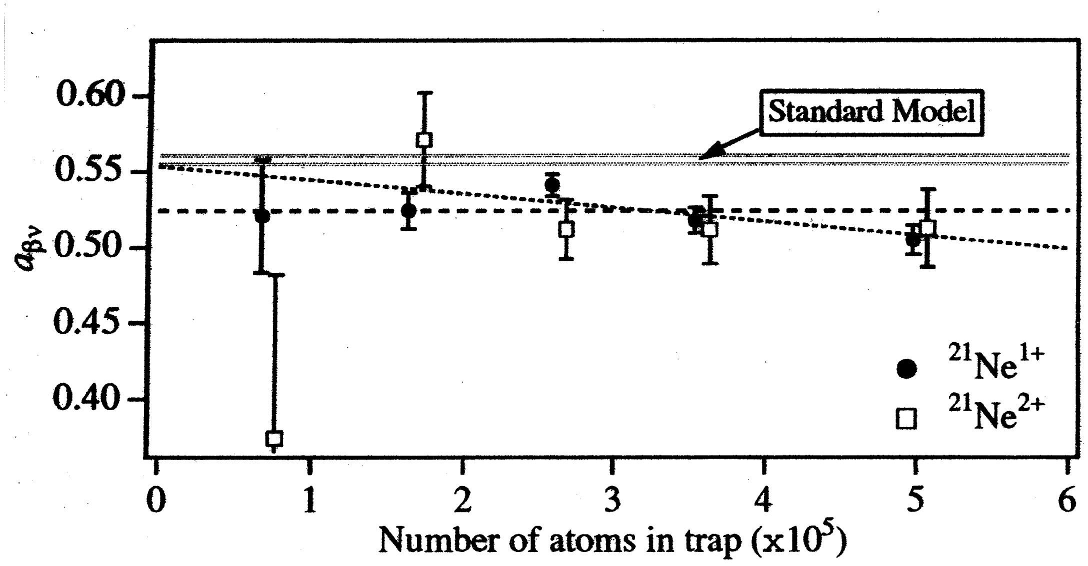
0.001 (sleptons) in 10 shifts

- **In reality will run under many conditions like other precision experiments**

A possible trap systematic: LBL measures ρ dependence

Molecular dimers form, perturb the recoil momentum direction

LBL has much better data since the publication (P. Vetter, private comm.)



Scielzo PRL 2004

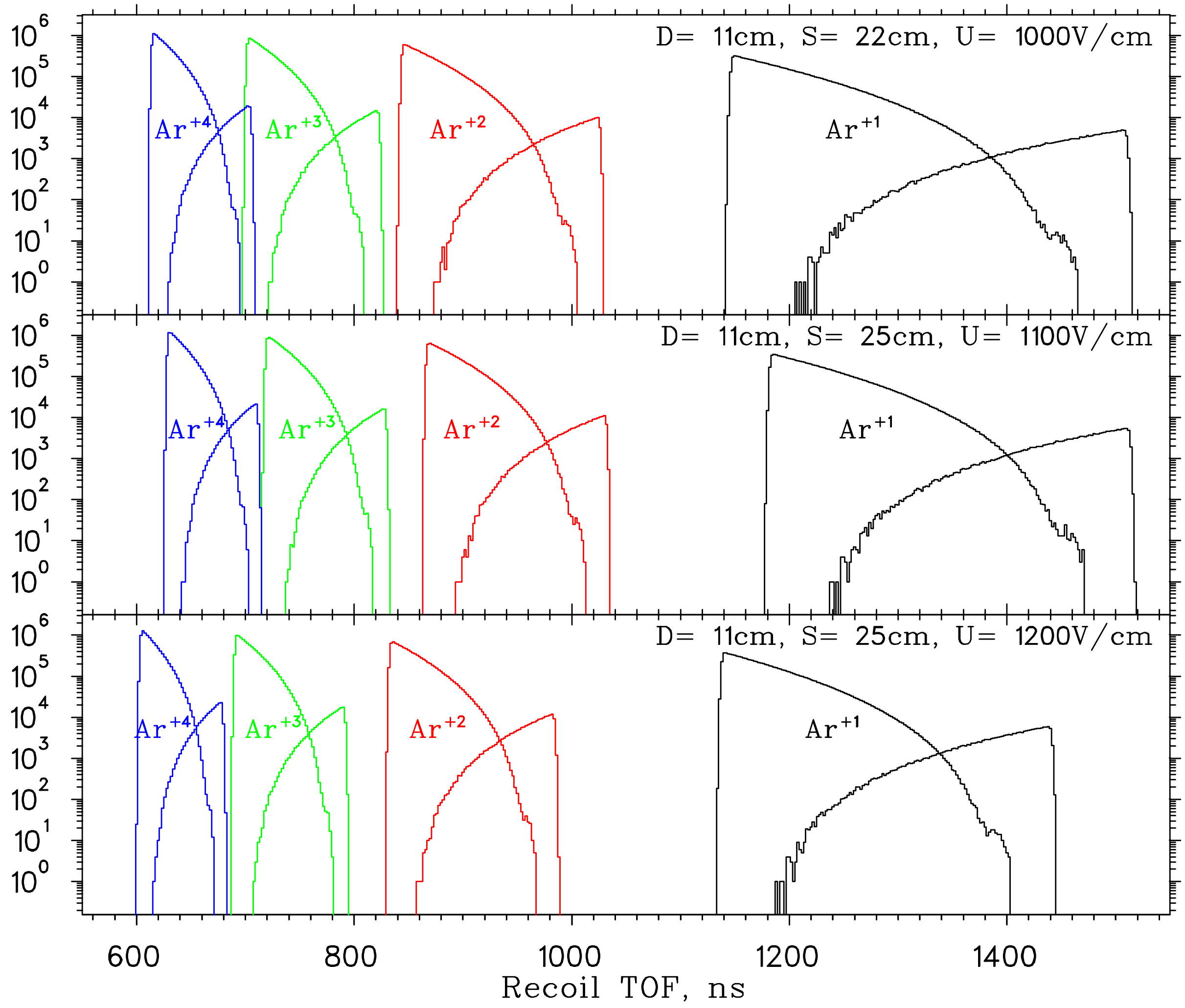
We ran ^{38m}K at 1/500 ρ, and it has 1/20 shorter $t_{1/2}$

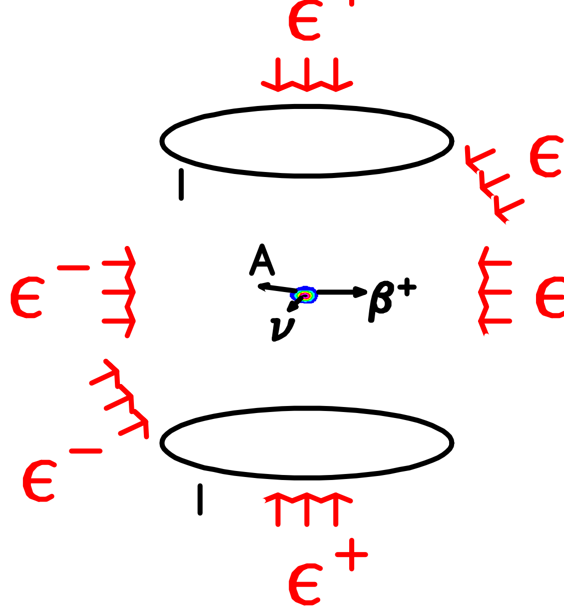
$\Rightarrow$ 10^{-4} of LBL's 5% effect

In principle we should measure $a[\rho]$; if necessary study it by photoion TOF and/or use a dark MOT to suppress it.

Upgrade: larger MCP with longer flight path (and larger field) to

- Collect all recoils (lessens systematic error)
- Fully separate charge states at all E_β to
  - Separate a, b
  - Deduce E_β from other observables
  - Measure and account for recoil momentum-dependent shakeoff





Summary of $^{38\mathrm{m}}$K β-ν correlation:

Pioneered trap techniques:
β^+–recoil coincidence $\Rightarrow \nu$ momentum
$\Rightarrow$ β-ν correlation in $^{38\mathrm{m}}$K
$\tilde{a}=0.9981\pm0.0030\pm0.0037$
Gorelov PRL 2005

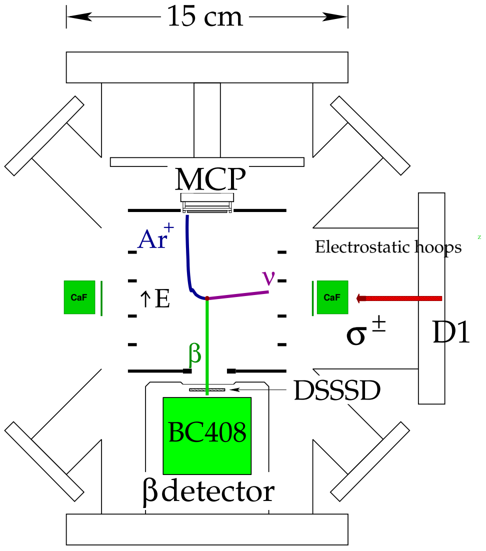
The limits on scalar interactions are model-independent
(TRV, chirality) and
free of nuclear structure-dependent corrections to ≈ 0.0002

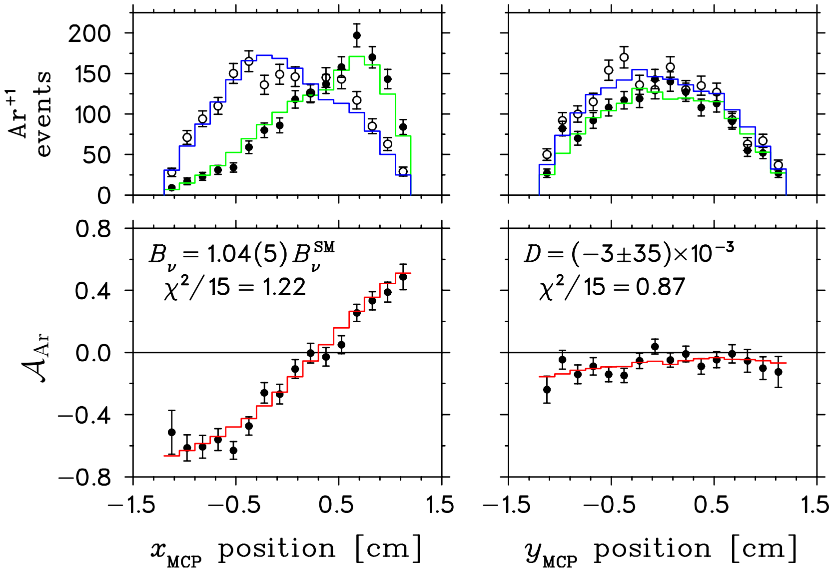
- Upgrade in progress to

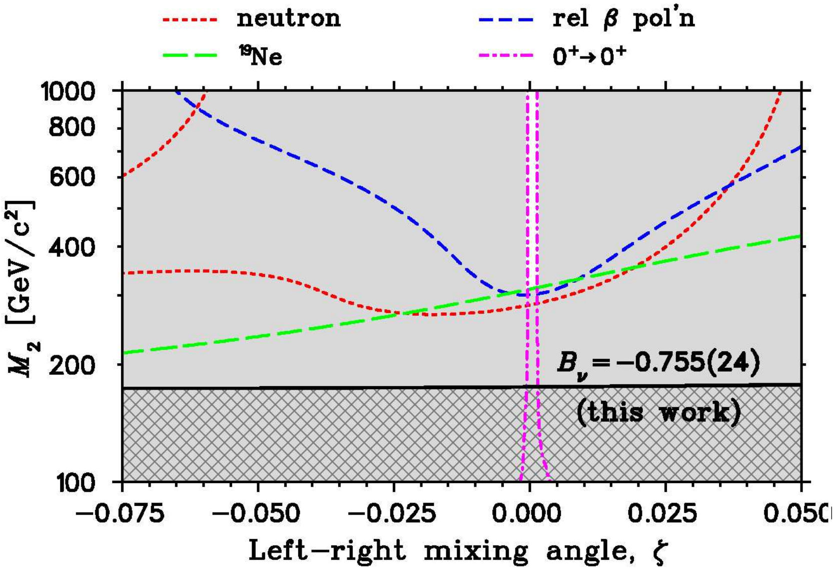
Improve accuracy by factors of 3 to 5
Separate a,b
Compete with $0^+ \rightarrow 0^+$ on Fierz term

In Progress: Spin asymmetries in $^{37}\vec{\mathrm{K}}$: a 'heavy neutron'

^{37}K decays to its isobaric mirror ^{37}Ar $\Rightarrow$
$\sim$ 0.002 corrections are given by CVC
Search for $SU(2)_L \times U(1) \longrightarrow SU(2)_L \times SU(2)_R \times U(1)$







ν asymmetry:
$P_x\, B_\nu\, \vec{I}\cdot\vec{p}_\nu$
$P_x = 0.97 \pm 0.01 \Rightarrow$
$B_\nu = -0.755 \pm 0.020 \pm 0.013$
$(B_\nu^{SM} = -0.769)$
D. Melconian *et al.*
Phys Lett B, in press
D is also possible
2nd-class current search

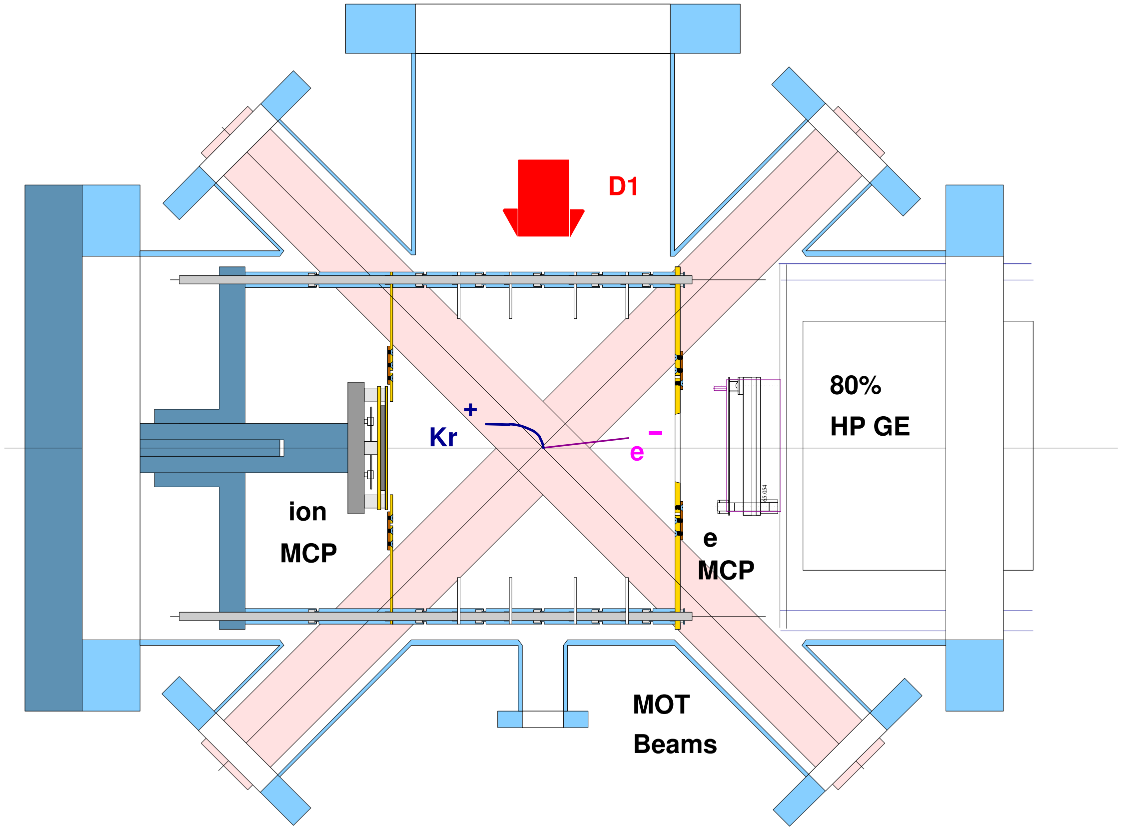
^{80}Rb decay: Search for Tensor Interactions

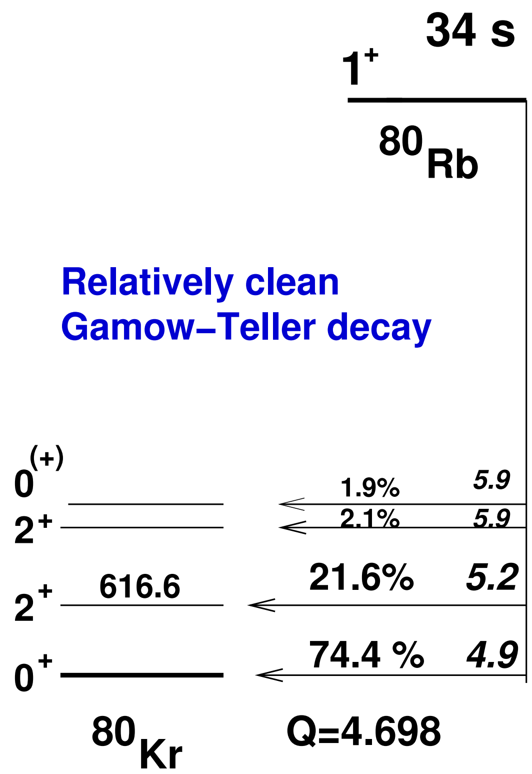
Spin asymmetry of recoils $A_{recoil} \xrightarrow{Q>>m} 5/8\ A_{\beta}+B_{\nu}$ (Treiman PR 1958)

- **For pure Gamow-Teller ^{80}Rb, $A_{recoil} = 0$**
- **non-SM results $\pi \rightarrow \nu e \gamma$ Bolotov 1992, PiBETA PRL 2004:**
  resolved by further PiBETA: E. Frlez hep-ex/0606023
  Would need accuracy $\sim$0.002 to contribute
- **or 0.01 constrains $C_T C_T'$, complements ^{6}He $\beta - \nu$**

We have statistical error $\approx$ 0.007:

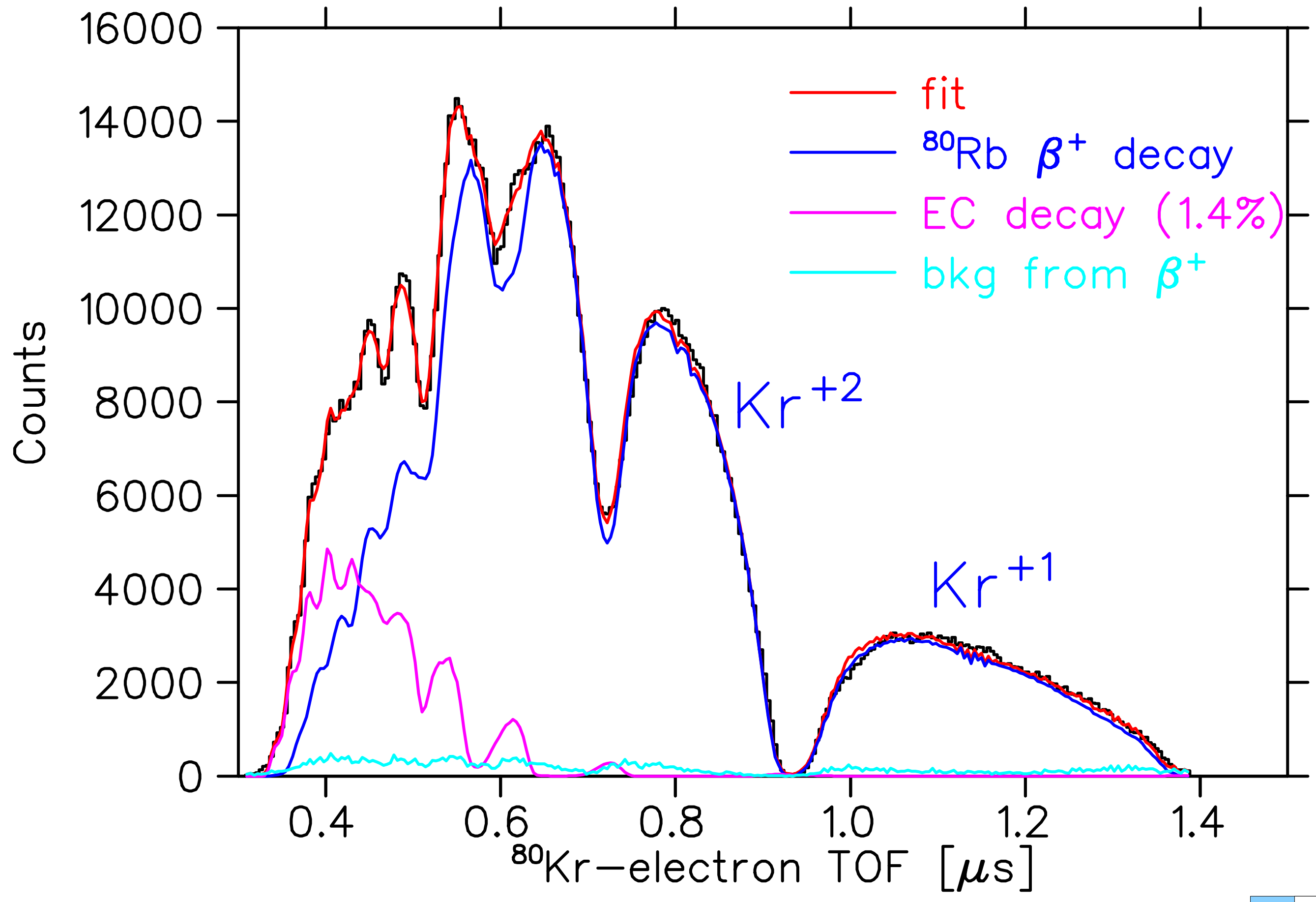
Need nuclear structure calculation of $\sim$ 0.02 correction





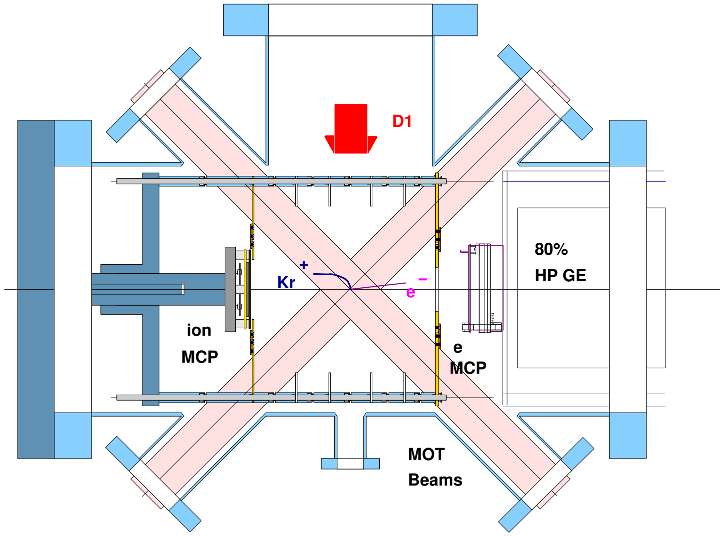
Relatively clean Gamow–Teller decay

^{80}Rb Data: TOF contributions:

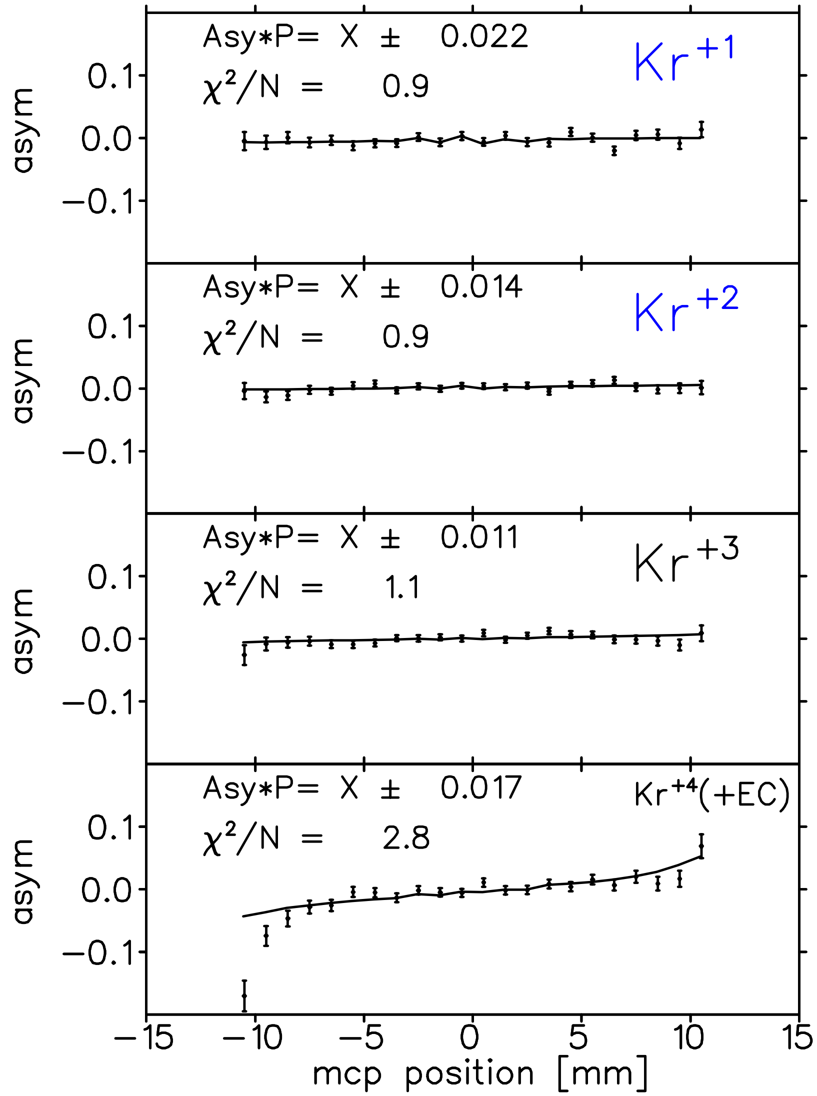


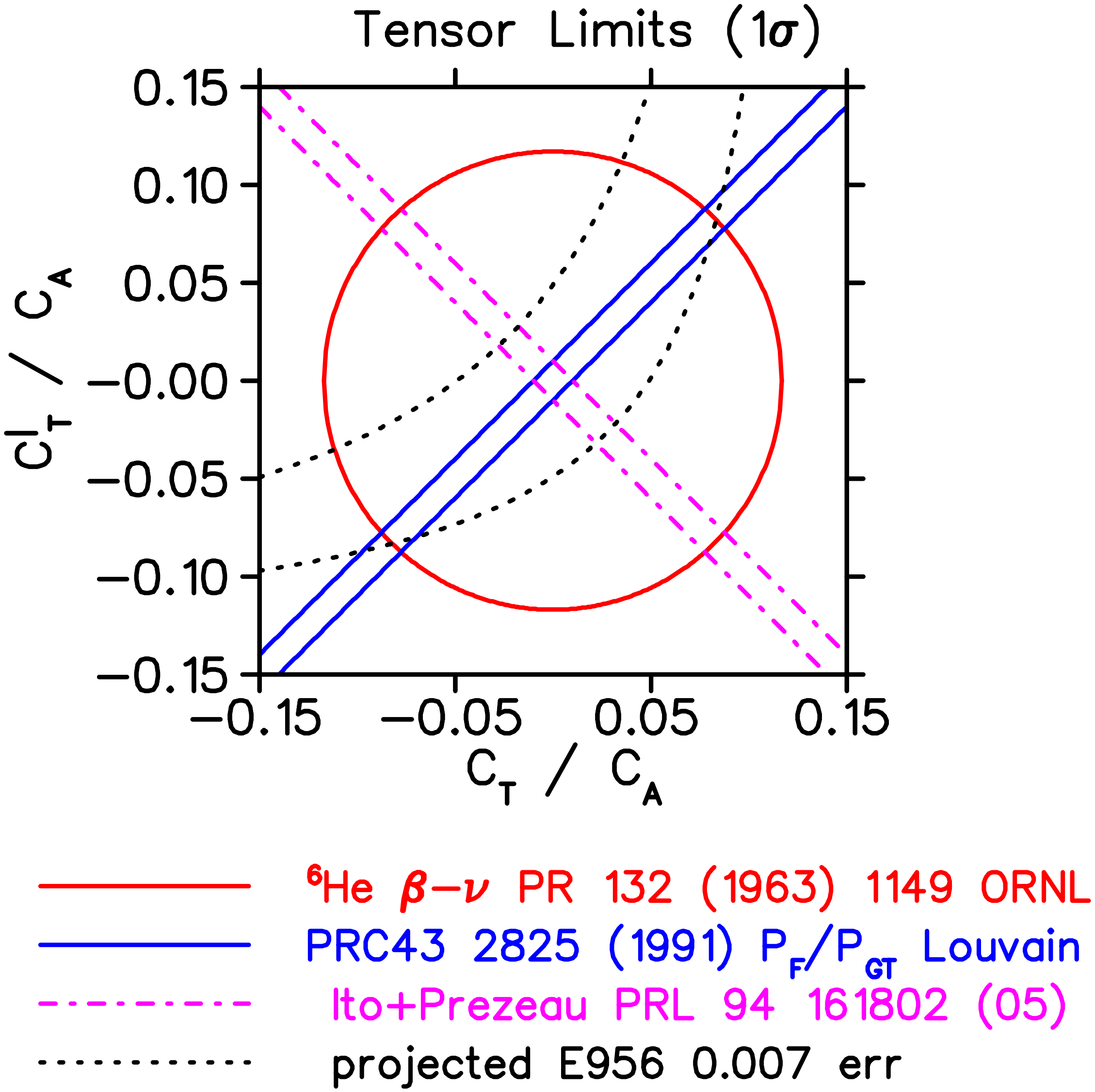
- **Kr^{+1}, Kr^{+2} clean**

- **recoil-shakeoff electron like Scielzo LBL NPA'04**

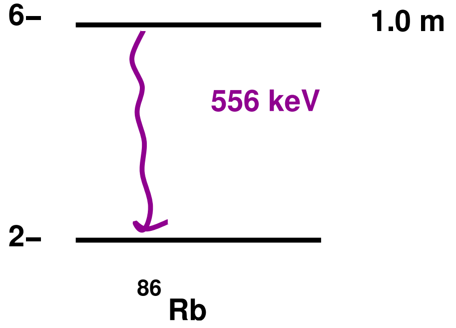


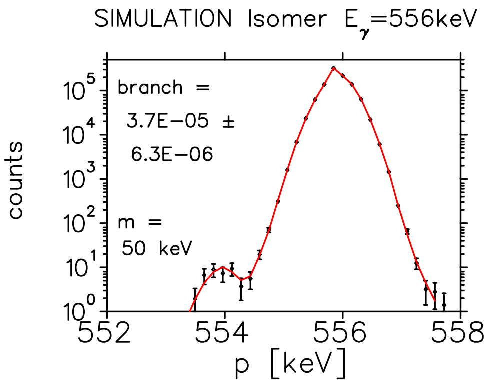
^{80}Rb Singles Recoil Asymmetry: statistics for ≈ 0.007



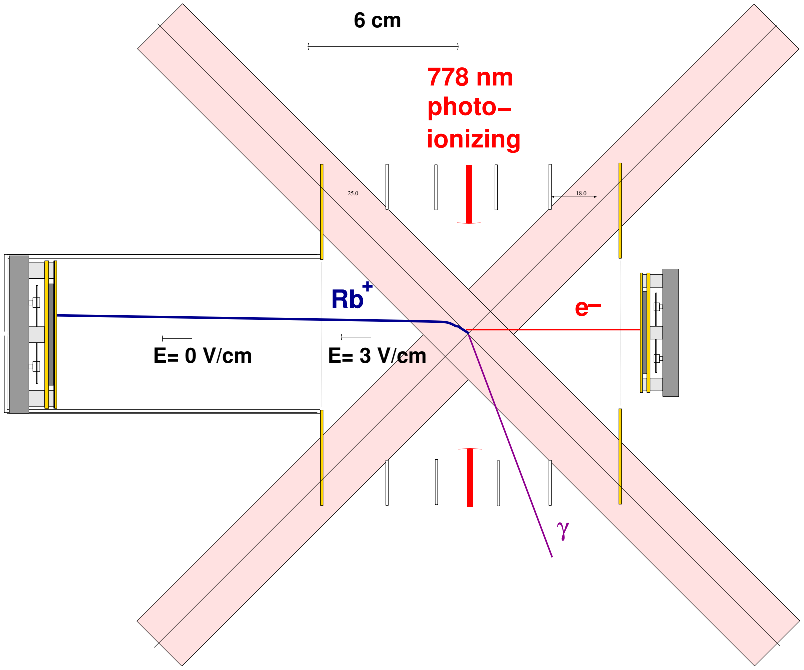


Search for massive particles in two-body decay
Basic idea:





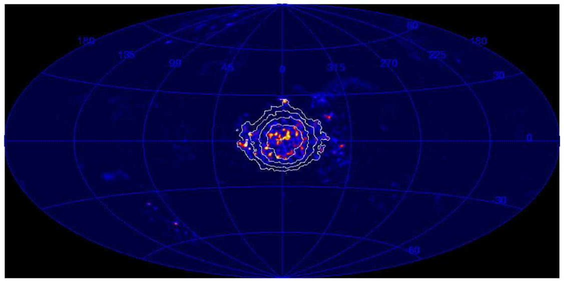
$$p=\sqrt{E_\gamma^2 - m_x^2}$$



- Limits on anything massive emitted from nuclear transition, independent of interaction in detector or lifetime
- Statistical sensitivity $\sim 10^{-6}$ branch per day of counting
- Could measure spin if see a signal (polarized angular distribution)

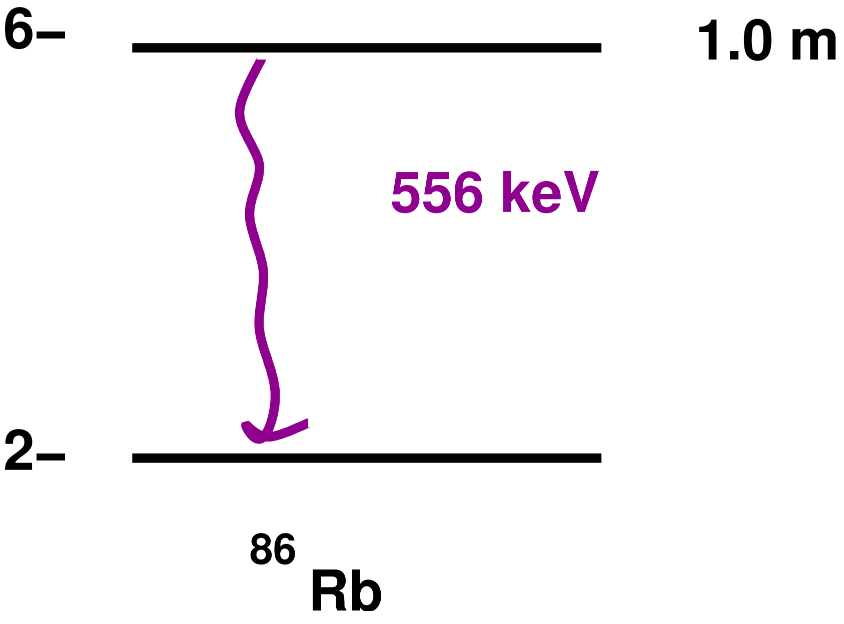
What particles can we look for? →

- Plan direct search for 20 to 800 keV-mass 0^+, 0^-, 1^+ ... particles



Knödlseder A&A '05

- Pairs of scalars with $511 \text{ keV} < m < 3 \text{ MeV}$ could $\rightarrow e^+ e^-$ to make the 511's at galaxy center (Beacom PRL 97 2006)
- Scenario needs extra spin-1 'U' boson: 10^{-6} sensitivity competitive with particle decays (Fayet 06)



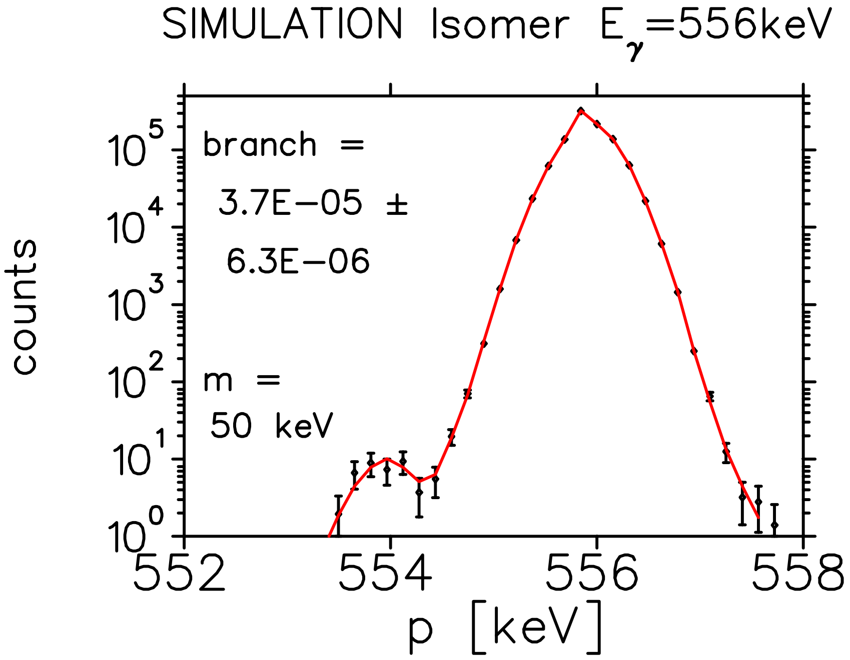
6–

1.0 m

556 keV

2–

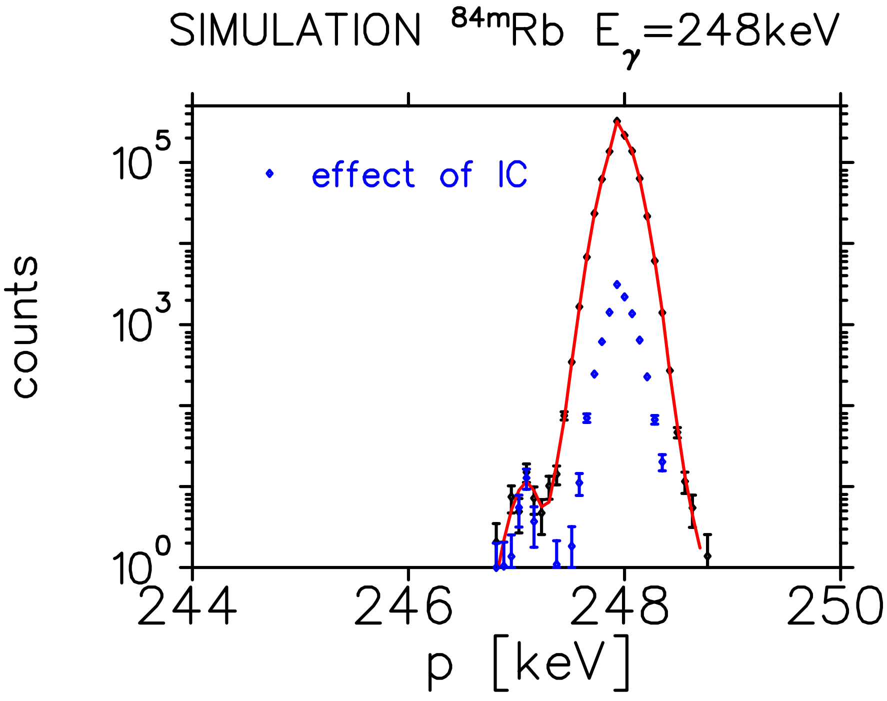
^{86}Rb



Isomer decay: ‘Are heavy 0^- searches still useful?’

- The original Peccei-Quinn axion solved the ‘strong CP problem’ with $m_{\text{axion}} \sim 100$’s keV. Couplings large enough to do so were ruled out long ago
(so people use μwave cavities now)
- There exist more exotic models that solve strong CP problem with arbitrarily small couplings. (e.g. ‘mirror universe’ Berezhiana PLB 500 286 (2001))
Other possible global U(1) symmetries for other problems produce axions with smaller couplings (Hall+Watari PRD 04, size of μ in SUSY).
- So improving direct limits is still useful

There are M1 transitions in Cs isotopes that are highly internally converted.
IC removes 99% of hard-to-resolve massless γ-ray and turns it to $> 1^+$ ions that we can separate completely by TOF.

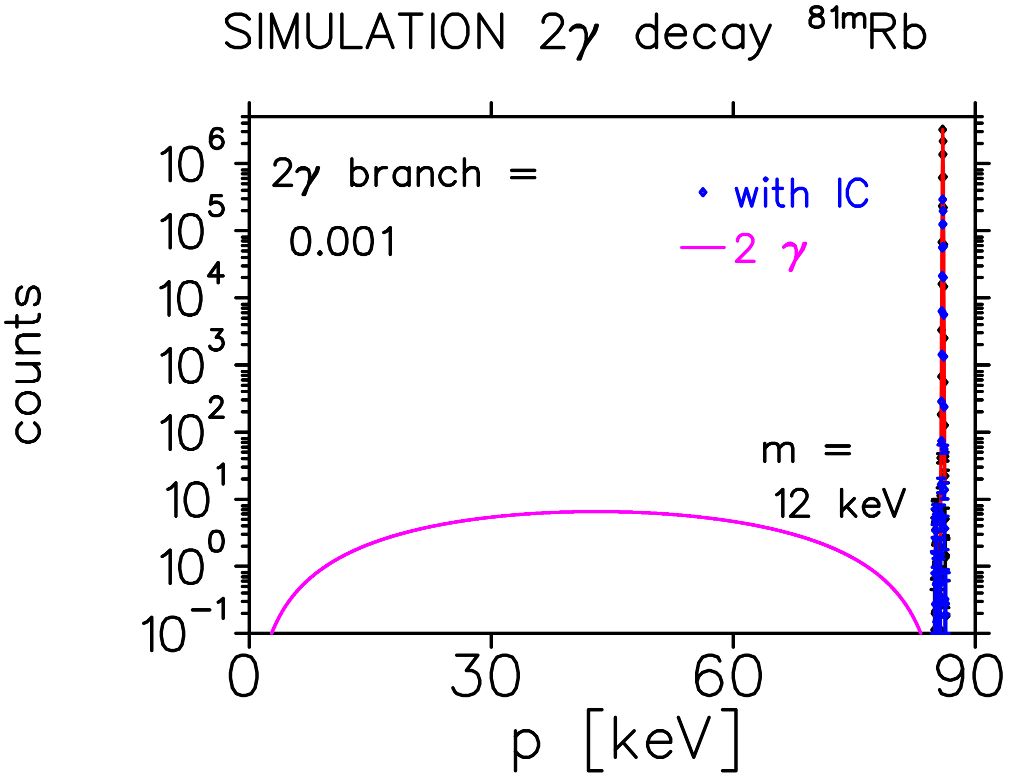


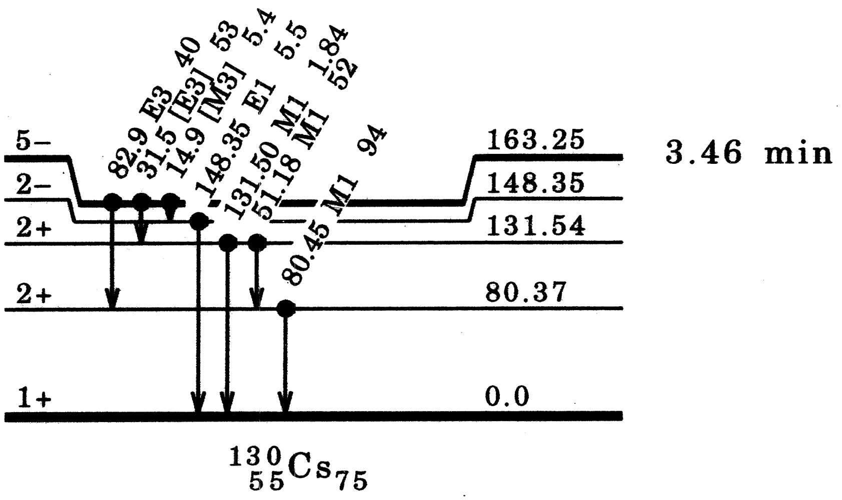
$\gamma\gamma$ emission for the single transitions: A ‘background’ that may be more interesting than the signal

E1E1 and M1M1 Observed in ^{40}Ca and ^{90}Zr 0^+ to 0^+ (MPI Heidelberg PRL 53 (1984) 1897)
Smooth 3-body spectrum: does not mimic axions

- **Intrinsically interesting as accessing virtual states**

Formally similar to $\beta\beta$ decay (but different operator, states)
(^{130}Cs $2^+ \rightarrow 1^+$ is intermediate state of geochemical ^{130}Ba is geochemically measured $\nu\nu\beta^+\beta^+$ decay (also ^{134,136}Cs for ^{134,136}Xe $0\nu\beta^-\beta^-$ decay)
Test of QRPA ?





$t_{1/2}$		# γ	M E	E_γ keV	IC α	m keV	Sens /day x10^{-6}	
20.3m	^{84m}Rb	2	M3	216	1.1	100-160	2.0	
4.3m	^{90m}Rb	1	M3	107	11	20-85	2.1	97% β^-
2.9m	^{138m}Cs	1	M3	80	218	15-60	2.8	20% β^-
3.5m	^{130m}Cs	2	M1	83	1.7	60-80	0.5	safe
		2	M3	15	2e6	10-13	0.2	safe
2.9h	^{134m}Cs	2	M1	11	91	6-8	0.6	
53m	^{135m}Cs	2	M4	846	.003	400-800	0.6	
		2	E2	787	.003	400-750	0.6	
1.0m	^{86m}Rb	1	E3	556	.04	40-400	0.05	
						>511	50	
31m	^{81m}Rb	1	E3	86	17	20-80	0.2	safe
19s	^{136m}Cs	1	E3?	?	?	?	1	short $t_{1/2}$

Minowa final sensitivity was $1.2\text{x}10^{-}6$ for 26 keV $< m_a <$ 166 keV

Harder: 20 KeV-mass sterile ν's $|\nu_e\rangle = \cos\theta\,|\nu_{m\approx 0}\rangle + \sin\theta\,|\nu_x\rangle$

- dark matter candidate... Dodelson PRL 1994
- $m_\nu \sim 10$ keV, $\sin^2 2\theta \sim 10^{-8}$ Abazajian PRD 2006 Need ∼0 background

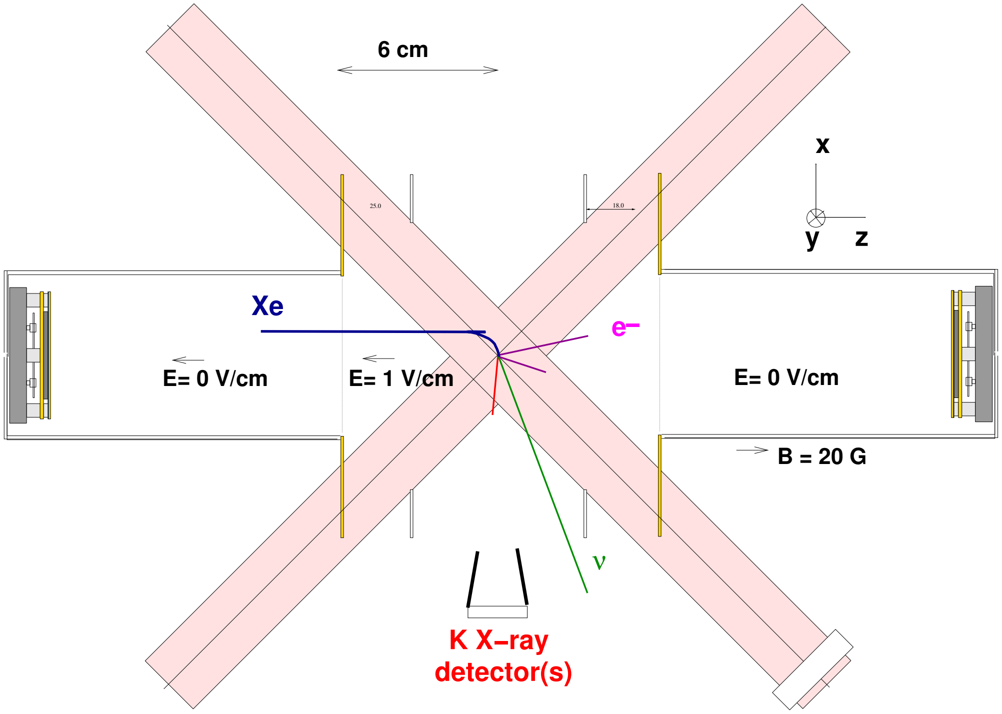
- 10^{-5} admixture possible at 40 keV: Useful for $T_{reheat} \approx 5$ MeV

Electron Capture Decay: ${}^{131}Cs + e^- \rightarrow \nu + {}^{131}Xe$

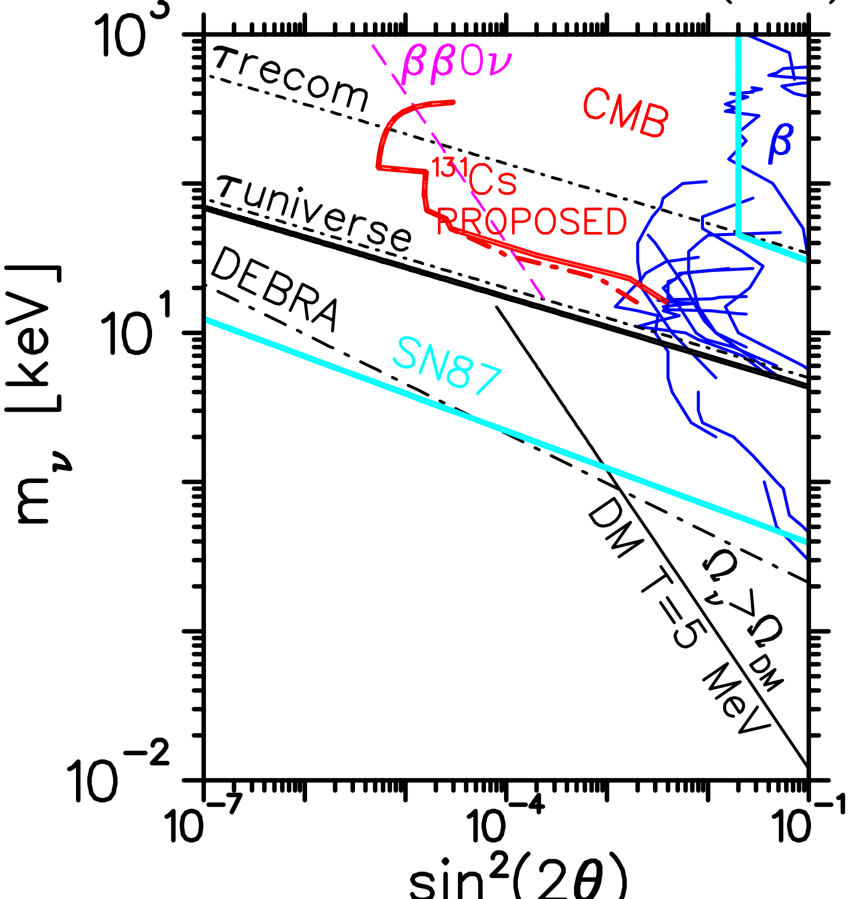
Tougher than isomer decay: To make this truly 'two-body',

Must measure momenta of all shakeoff e^-'s to 5% and K X-ray direction

SN87A timescale:but Hidaka Fuller Oct06 5 keV helps SN



after Gelmini PRL 93 81302 (2004)



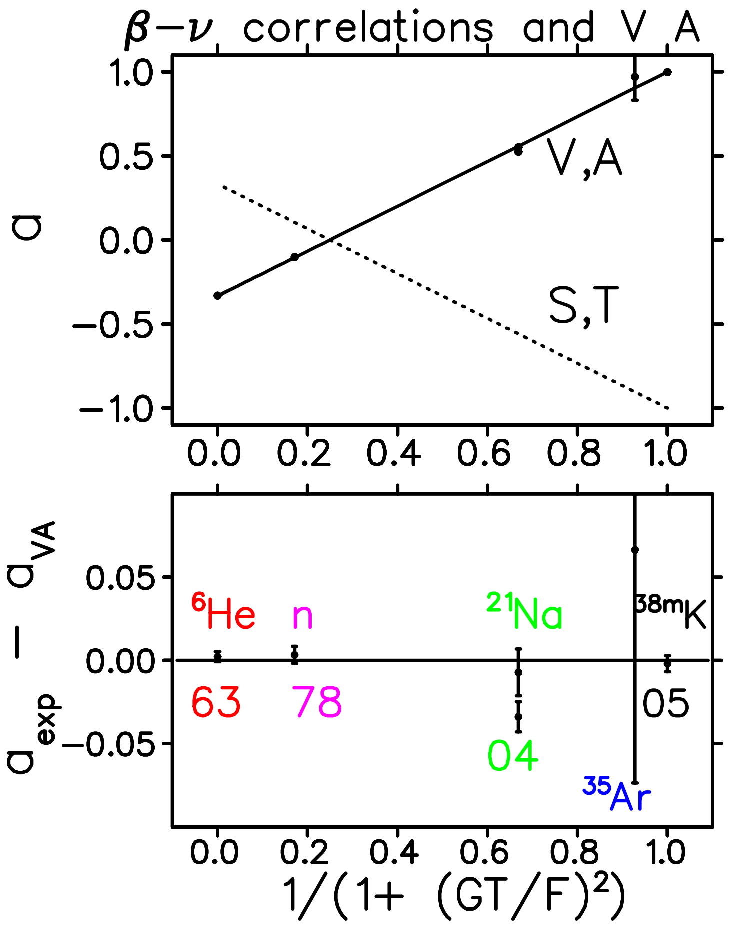
Search for scalar interactions via β-ν correlations with atom traps

- ^{38m}K β-ν Gorelov PRL '05

$\tilde{a} = 0.9981 \pm 0.0030 \pm 0.0037$

General limits on 1st generation scalar couplings

Goal: Improve 5X



- Spin-polarized experiments:

Right-handed currents in $^{37}\vec{\mathrm{K}}$

$B_\nu/B_\nu^{SM} = 0.982 \pm 0.026 \pm 0.017$

Melconian Phys. Lett. B '07

Goal: improve 10X

Tensor interactions in $^{80}\vec{\mathrm{R}}$b:

statistics for <0.01 A_{recoil}

(observable 0 in lowest order)

- Planning 2-body decays: direct production of massive $0^{\pm}$, $1^{\pm}$ particles in ^{86m}Rb... isomer decay: 10^{-6} sensitivity/day