Center for Experimental Nuclear and Particle Astrophysics

Faculty:

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Themes:

Searches for Axions, Gravity, Neutrinos, NuclearAstro, Tests of symmetries in β decay,

Reltivst. Heavy Ion Colls.

General thread: precision experiments to search for signatures of new physics

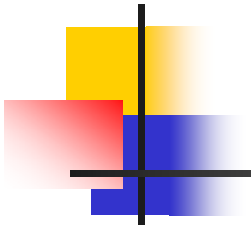
Example 1: Breaking of CPT symmetry and searching for extra dimens. using torsion pendula.

Example 2: Are Neutrinos identical to Anti-neutrinos? Majorana

Example 3: Searching for axions in an electromagnetic cavity

Example 4: Cooking of elements in stars: Nuclear astrophysics.

Example 5: Using Ultra-Cold Neutrons to search for new physics



How good is CPT symmetry?

Kostelecky's et al.'s preferred-frame approach

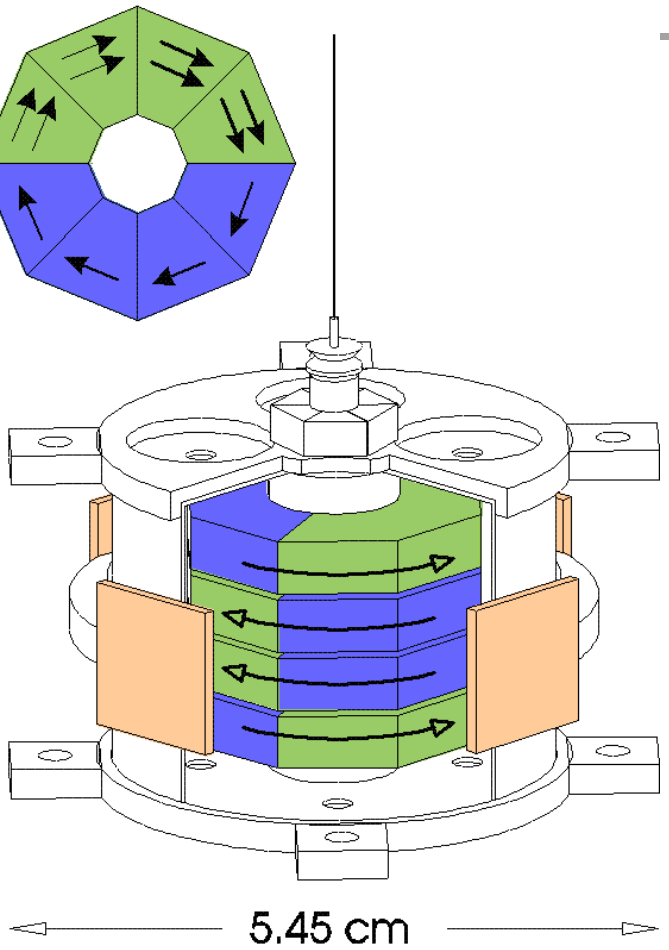
•imagine that vector and axial-vector fields were spontaneously generated in the early universe and then inflated to large extents.

•particles couple to these preferred-frame fields in Lorentz-invariant manners.

•this "Standard Model Extension" predicts new observables many of which violate CPT. One observable is $E = \sigma_e \cdot \tilde{b}_e$ where $\tilde{b}_e$ is fixed in inertial space - its benchmark value is $m_e^2 / M_{Planck} \approx 2 \times 10^{-17}$ eV.

•the spin pendulum can test if electrons tend to precess about an arbitrary direction in inertial space.

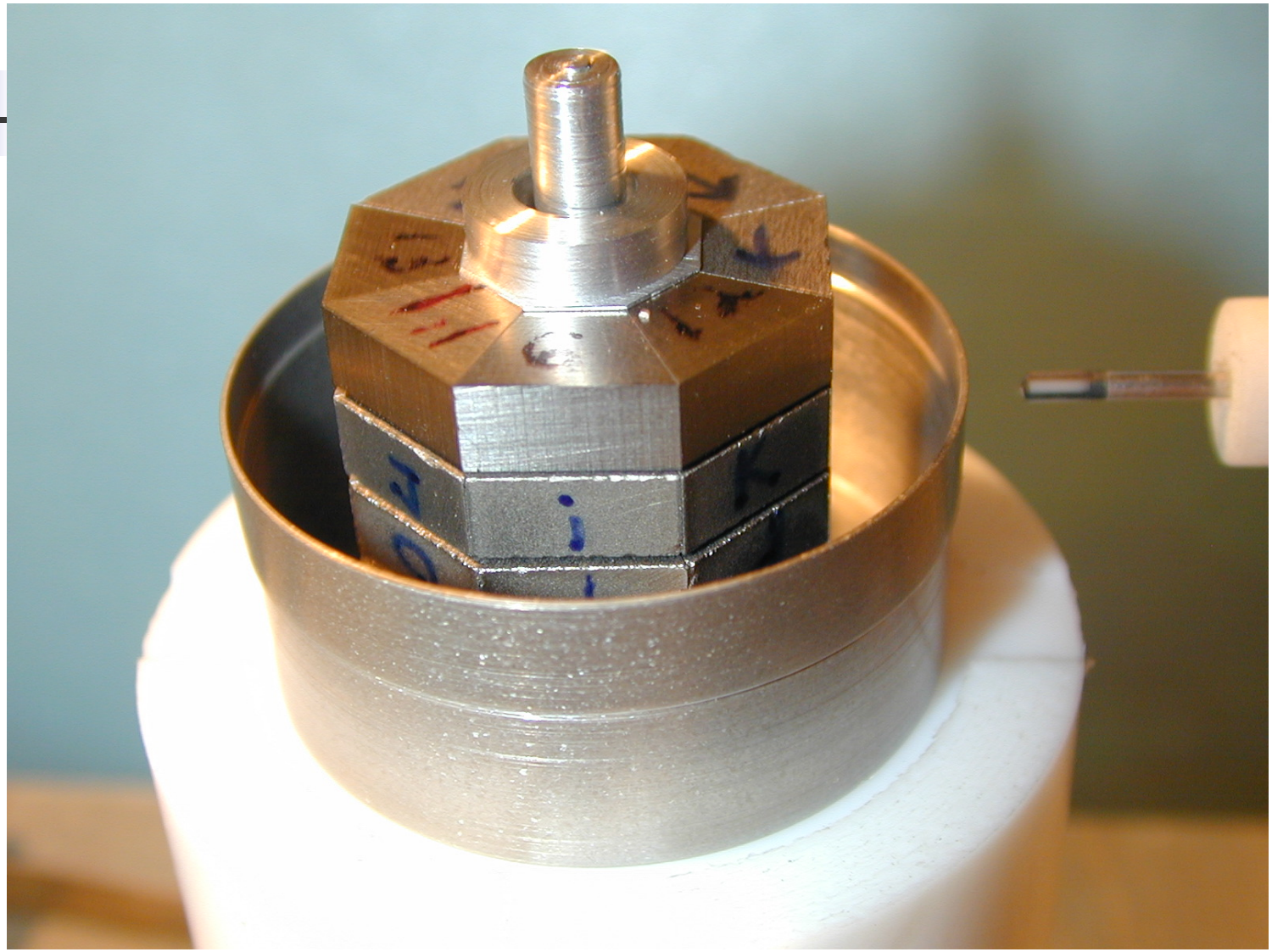
the Eöt-Wash spin pendulum



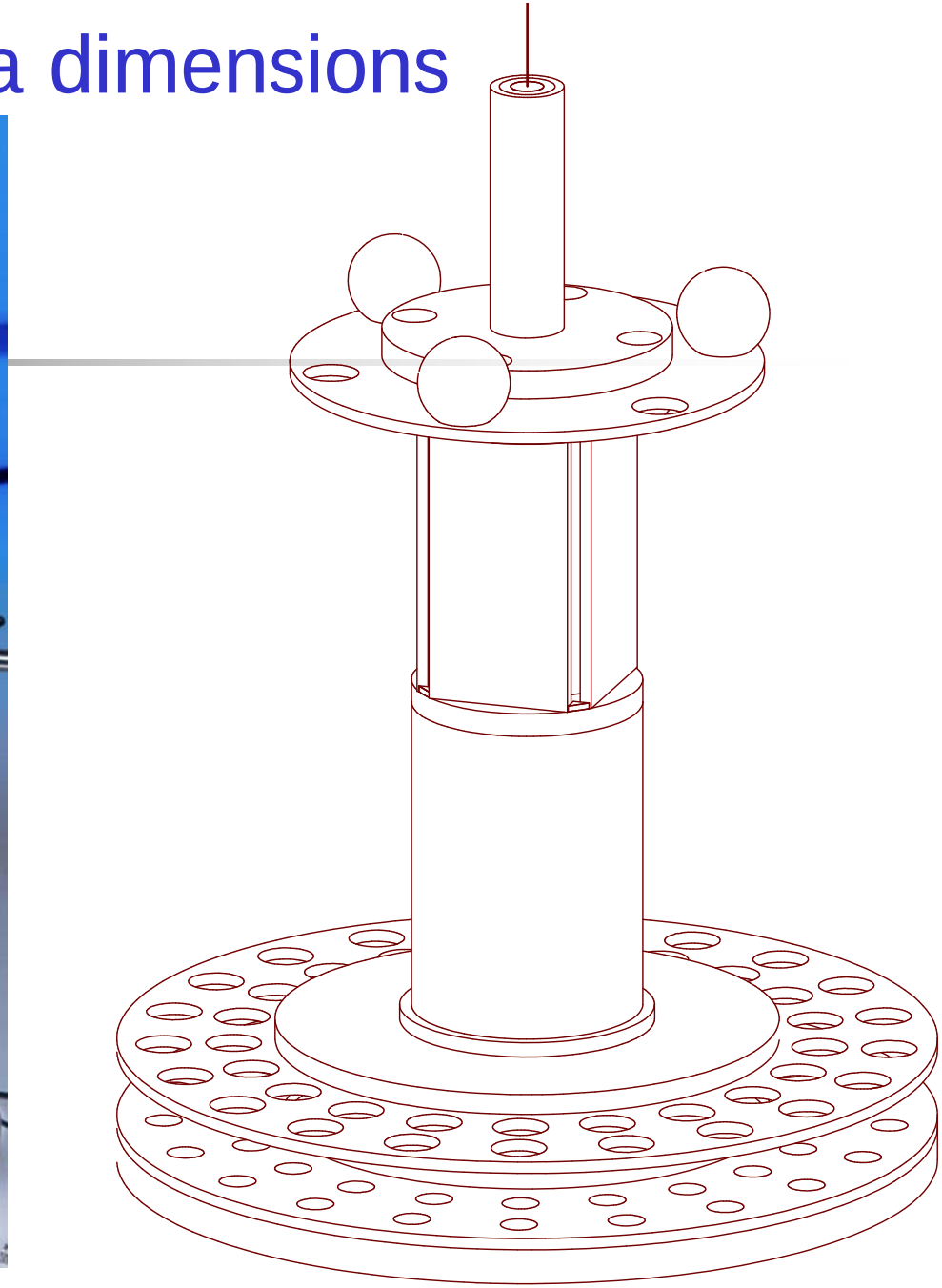
- 10^{23} polarized electrons
- negligible mass asymmetry
- negligible composition asymmetry
- flux of B confined within octagons
- negligible external B field

- Alnico: all B comes from electron spin: spins point opposite to B
- $SmCo_5$: Sm 3^+ ion has spin pointing along total B and its spin B field is nearly canceled by its orbital B field--so B of $SmCo_5$ comes almost entirely from the Co's electron spins
- Therefore the spins of Alnico and Co cancel and pendulum's net spin comes from the Sm and
- $J = -S$

measuring the stray magnetic field of the spin pendulum



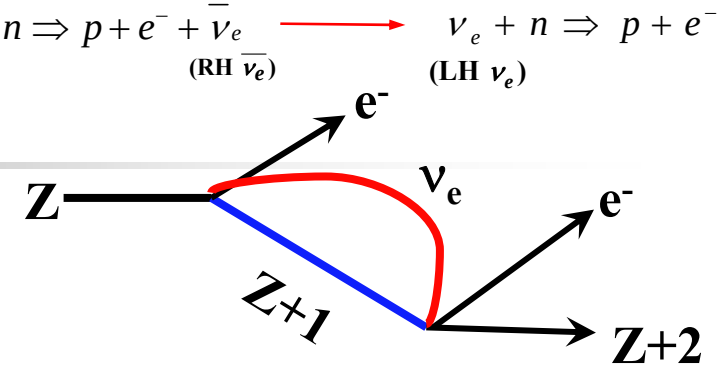
Searches from extra dimensions



some “gee-whiz” numbers

- typical torque in our 42-hole experiments is ~ 1fN-m with statistical uncertainty of ~0.006 fN-m
- corresponds to a force ~(40±0.24) fN
- get an idea how small this is by cutting postage stamp into 10^{12} equal pieces
- typical force is 60 times the weight of 1 of those pieces
- typical statistical error is ~1/3 the weight of 1 piece

Double- beta decay: Majorana experiment



0νββ-decay probes fundamental physics:

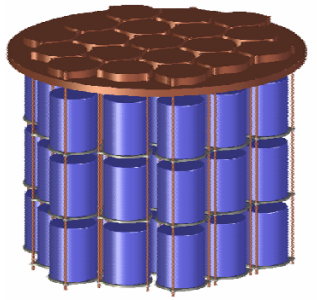
- Only technique to determine if ν = anti-ν
- If so, 0νββ offers the most promising method for determining the overall absolute neutrino mass scale.
- Tests one of nature's most fundamental symmetries, lepton number conservation.

Majorana Collaboration is proposing to build a next-generation, 76Ge based experiment.

Based on 60 kg modules, each containing 57 segmented, n-type, 86% enriched 76Ge crystals

Scalable, with independent, ultra-clean, electroformed Cu cryostat modules

Expected Sensitivity (0.46 t-y of 76Ge exposure)

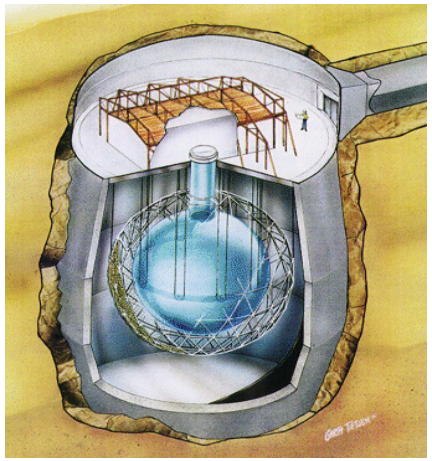


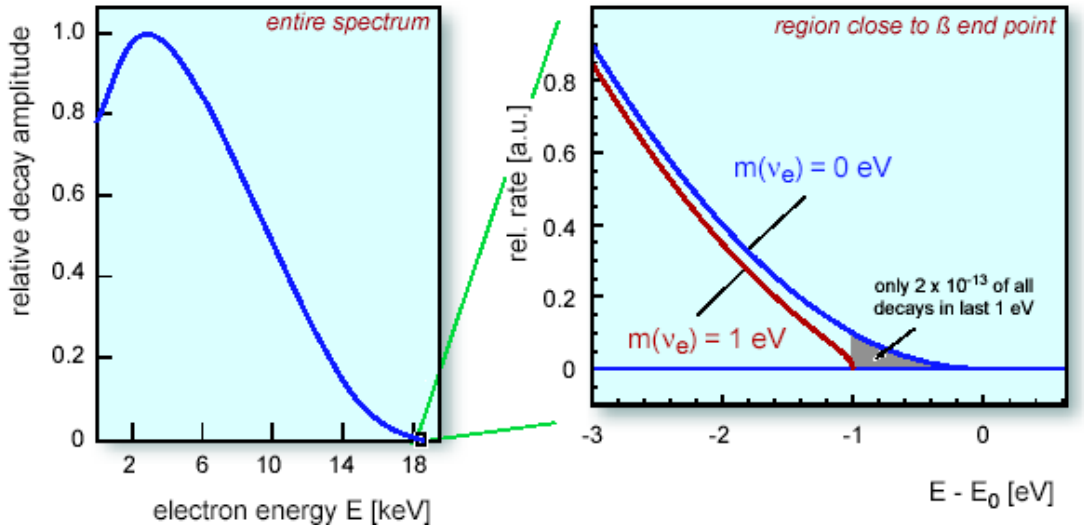
T1/2 >= 5.5 x 1026 y (90% CL) corresponding to <mν> < 100 meV

Other ν experiments at CENPA

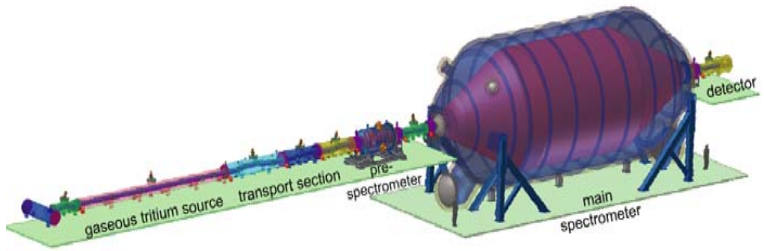
- SNO (solar neutrinos)
- Katrin (ν mass)

SNO

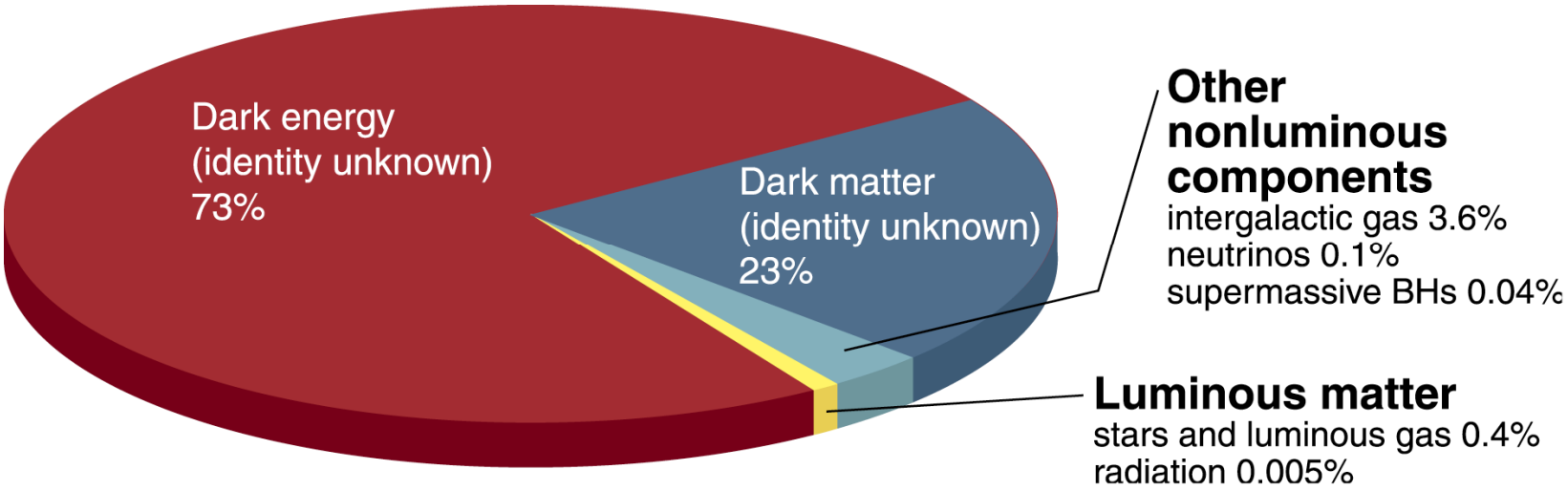




KATRIN



Searches for Axions

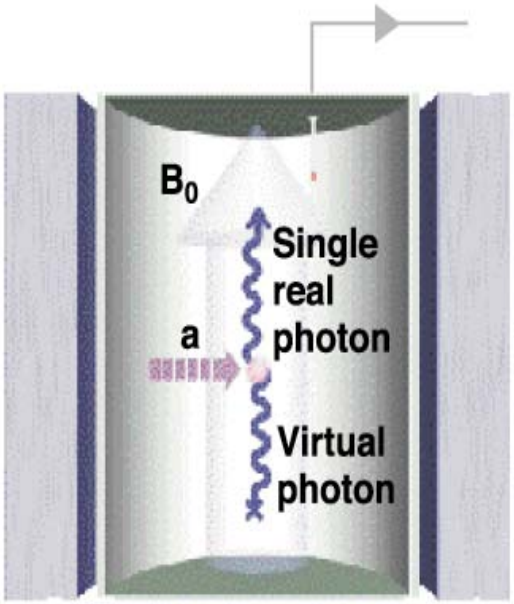


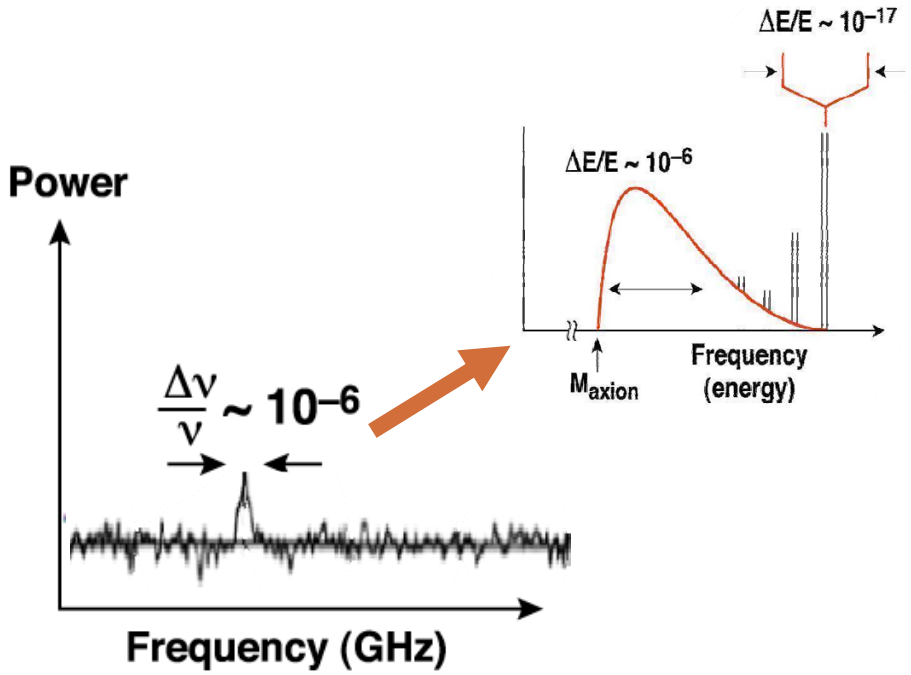
The axion mass range is scanned by tuning the cavity

Resonance condition: $h\nu = m_a c^2[1 + O(\beta^2 \sim 10^{-6})]$

Signal power: $P \propto (B^2 V Q_{cav})(g^2 m_a \rho_a) \sim 10^{-23}$ watts

There may be fine structure in the axion signal



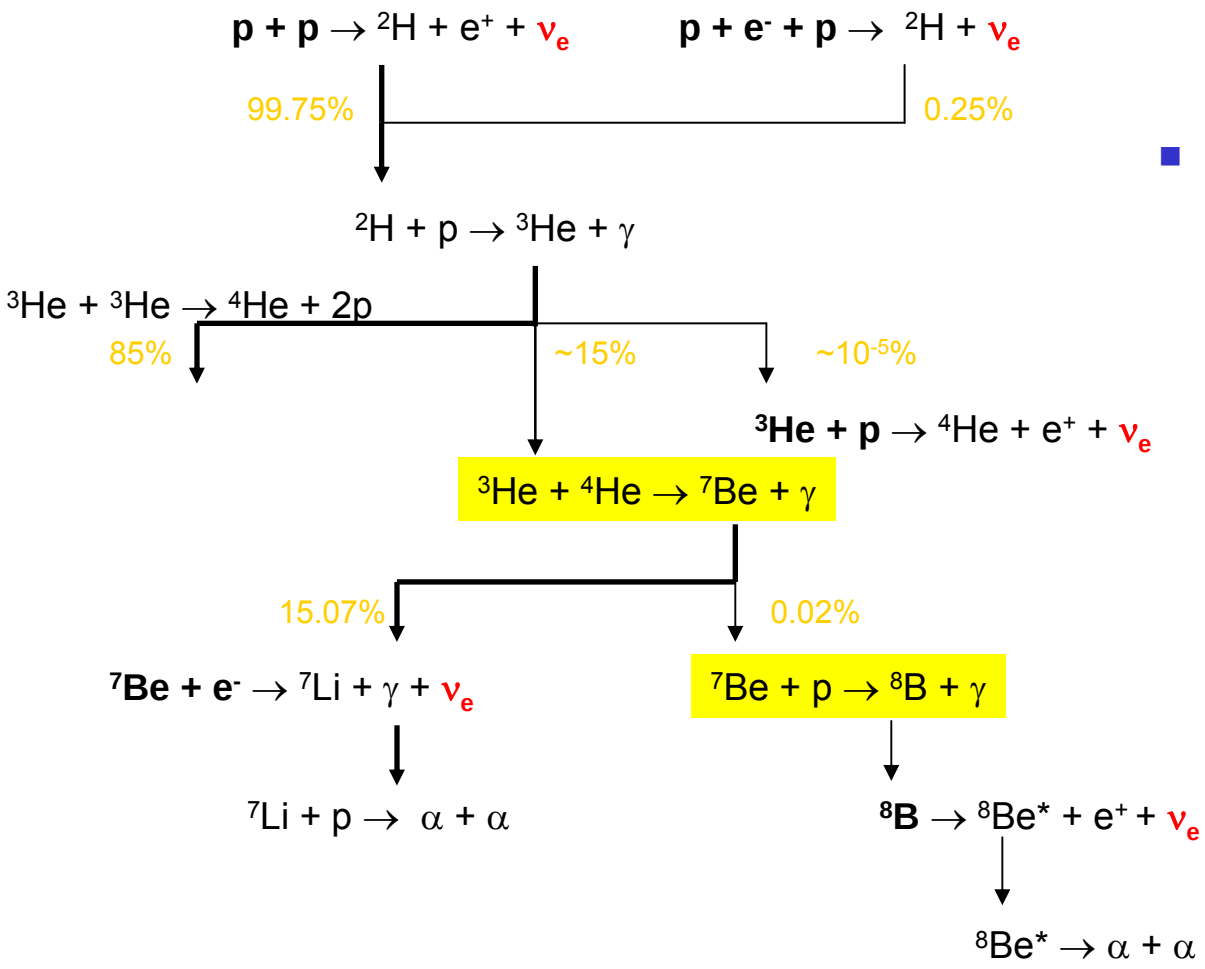


Nuclear Astrophysics at CENPA

1) Precision measurements of key reactions in the solar p-p chain that produce solar neutrinos.

2) Why isn't ^{22}Na a good tracer of novae explosions? Is it destroyed by fusion with protons?

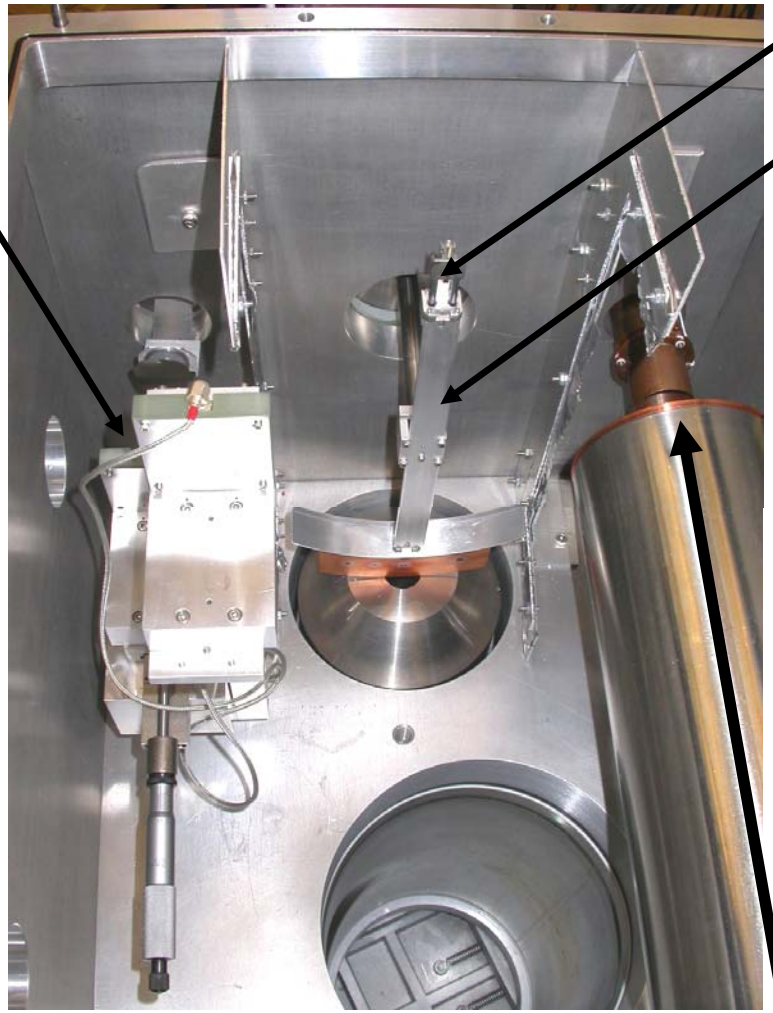
The solar pp chain



- Sun burns hydrogen to helium in its core.
- $4p \rightarrow {}^4He + 2\nu_e + 26$ MeV

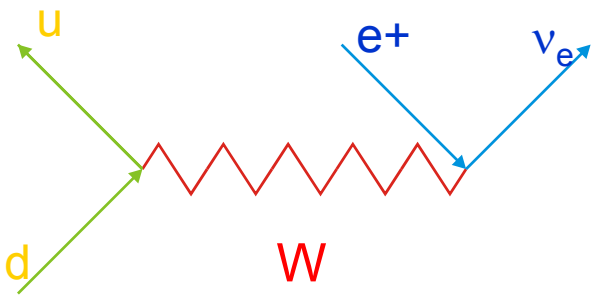
•Fusion reactions in yellow are measured here at CENPA

Chamber view for p + ^{7}Be fusion



Weak decays in the Standard Model

			Q	I
$\begin{pmatrix} \nu_e \\ e \end{pmatrix}$	$\begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}$	$\begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$	0 -1	1/2
$\begin{pmatrix} u \\ d' \end{pmatrix}$	$\begin{pmatrix} c \\ s' \end{pmatrix}$	$\begin{pmatrix} t \\ b' \end{pmatrix}$	+2/3 -1/3	1/2



From nuclear 0.974

Ke3 0.225

$b \to u l \nu$ 0.035

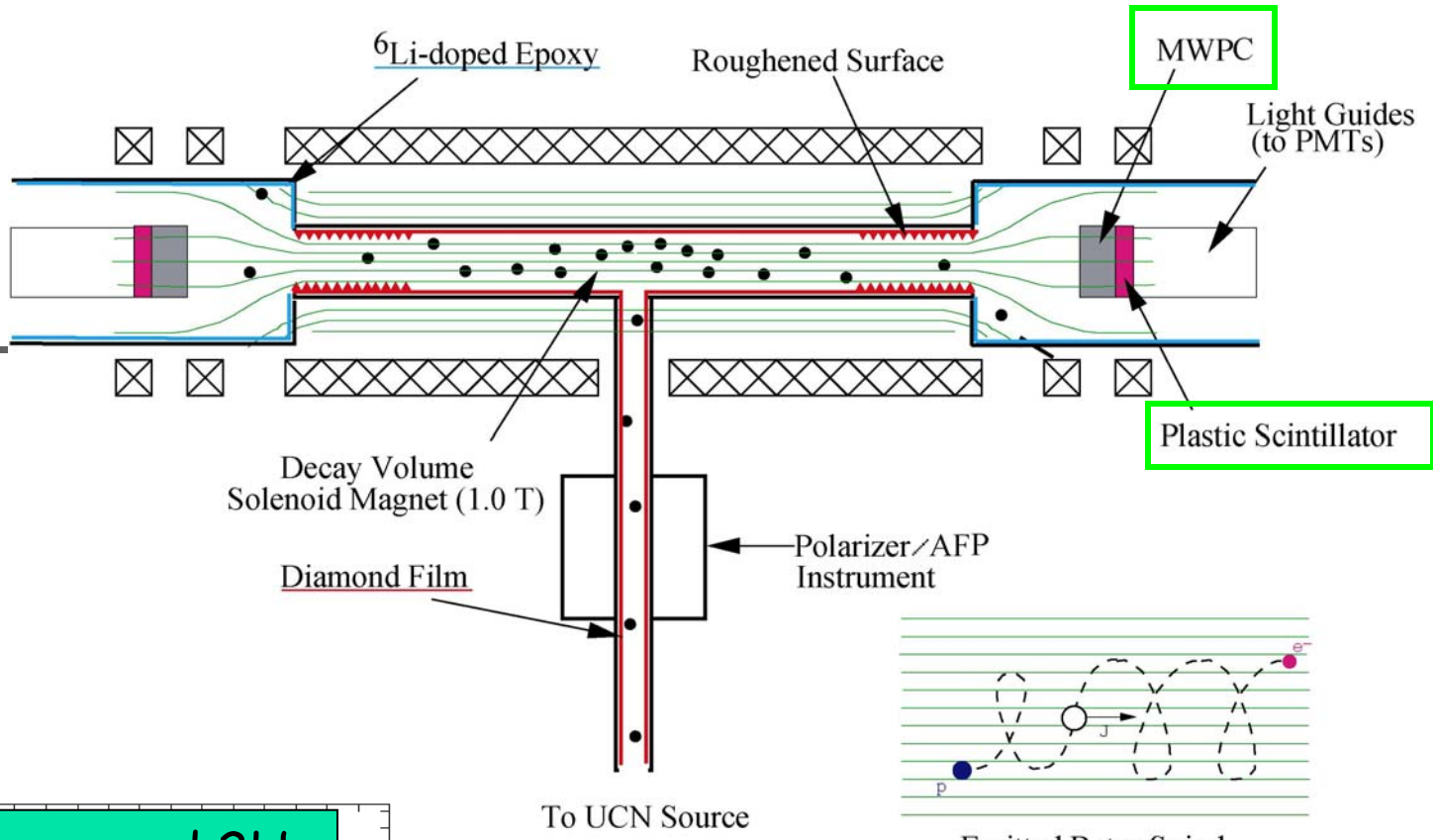
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} Vud & Vus & Vub \\ Vcd & Vcs & Vcb \\ Vtd & Vts & Vtb \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix: Is it really Unitary?

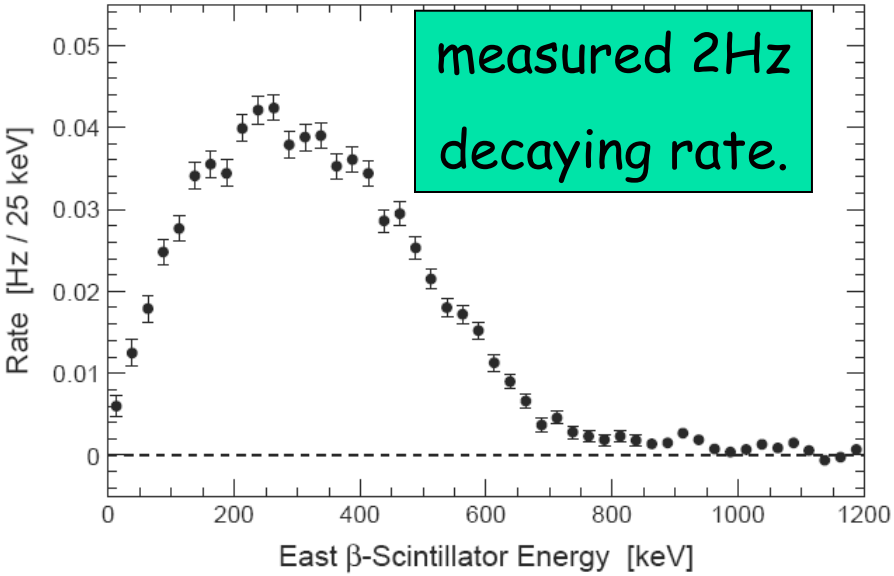
$$|Vud|^2 + |Vus|^2 + |Vub|^2 = 1?$$

UCNA:

Beta Asymm.

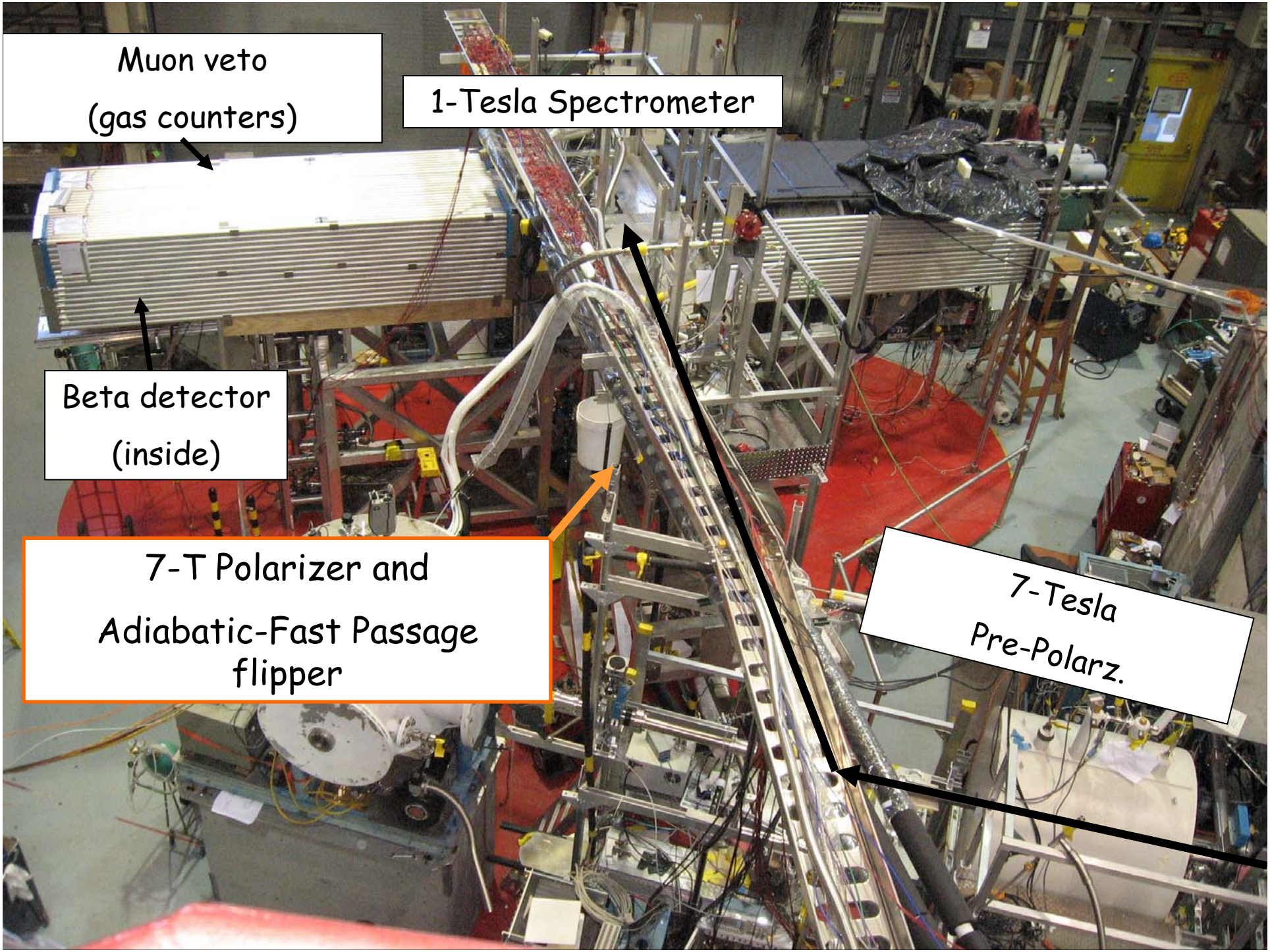


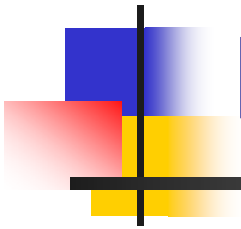
Emitted Betas Spiral
Along Magnetic Field Lines



2007: Measure A to 1%
R&D for 0.2% measurement

2008: Measure A to 0.2%


Muon veto
(gas counters)
1-Tesla Spectrometer
Beta detector
(inside)
7-T Polarizer and
Adiabatic-Fast Passage
flipper
7-Tesla
Pre-Polarz.

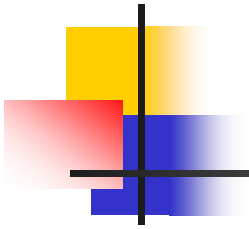


Weak Interactions in the Nucleus ("the 0.7% problem")

Presentation to

REU Students

July 2010



Using the nucleus to search for new physics

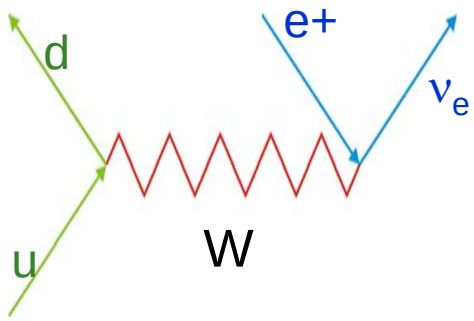
Summary

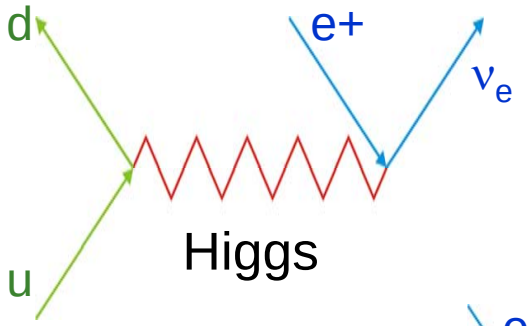
Non-VA forces in weak decays

→Measure e-ν correlation
→Searches for scalar currents in 32Ar
→Searches for tensor currents in 6He

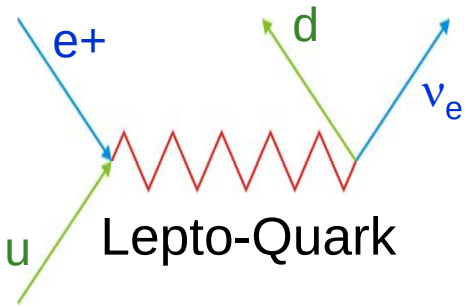
Non-VA currents in Weak decays

Are weak decays carried only by W's?





Or is there something new?



Non-VA currents in Weak decays

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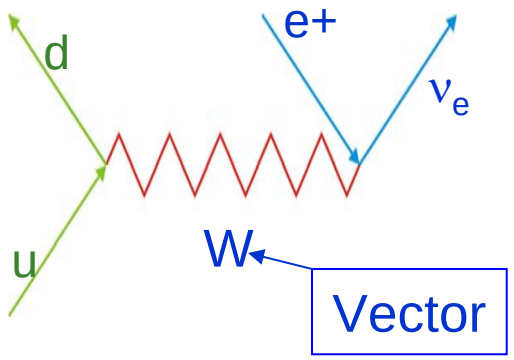

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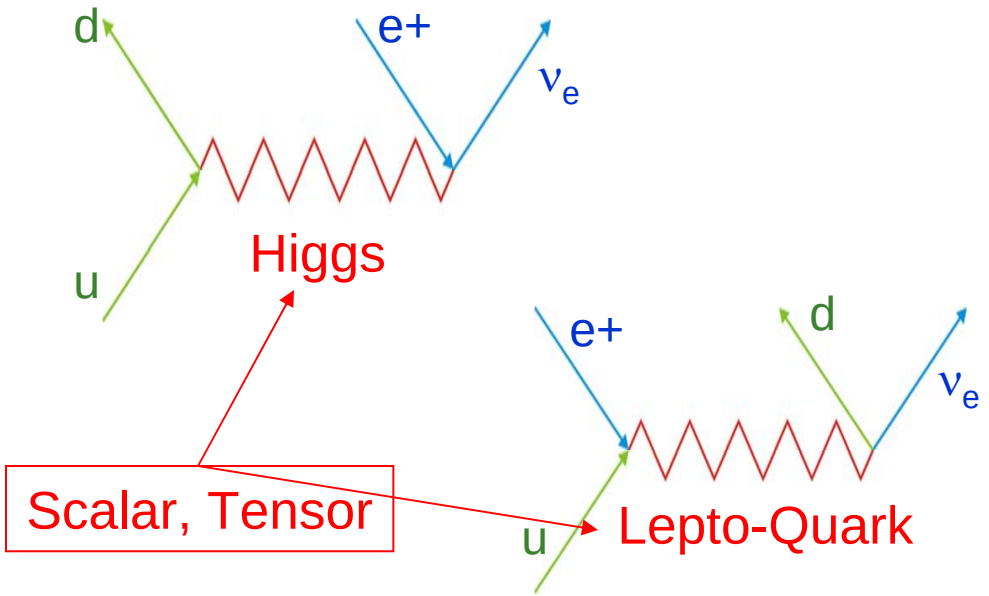
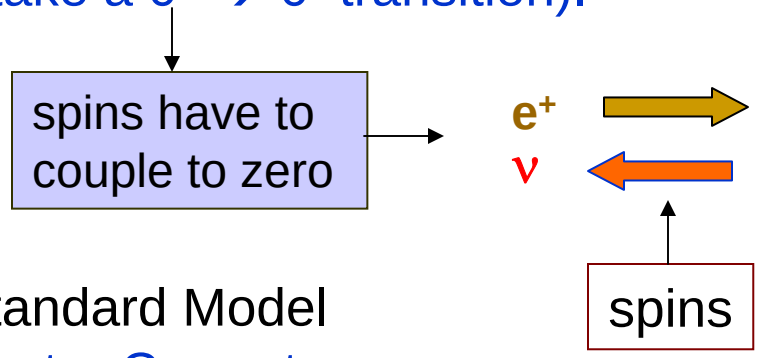


Detecting Scalar currents in weak decays

The e-ν correlation depends strongly on the nature of the carrier (we take a $0^+ \rightarrow 0^+$ transition).



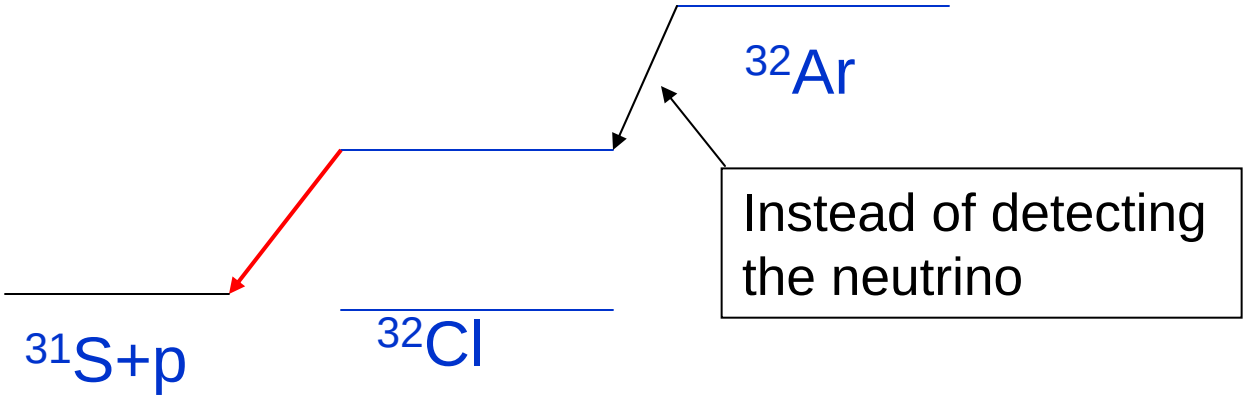
Standard Model
Vector Currents

New Physics?
Scalar Currents

$dW/d\Omega = 1 + p_e.p_\nu/E_e\ E_\nu$

$dW/d\Omega = 1 - p_e.p_\nu/E_e\ E_\nu$

A trick to avoid detecting the neutrino



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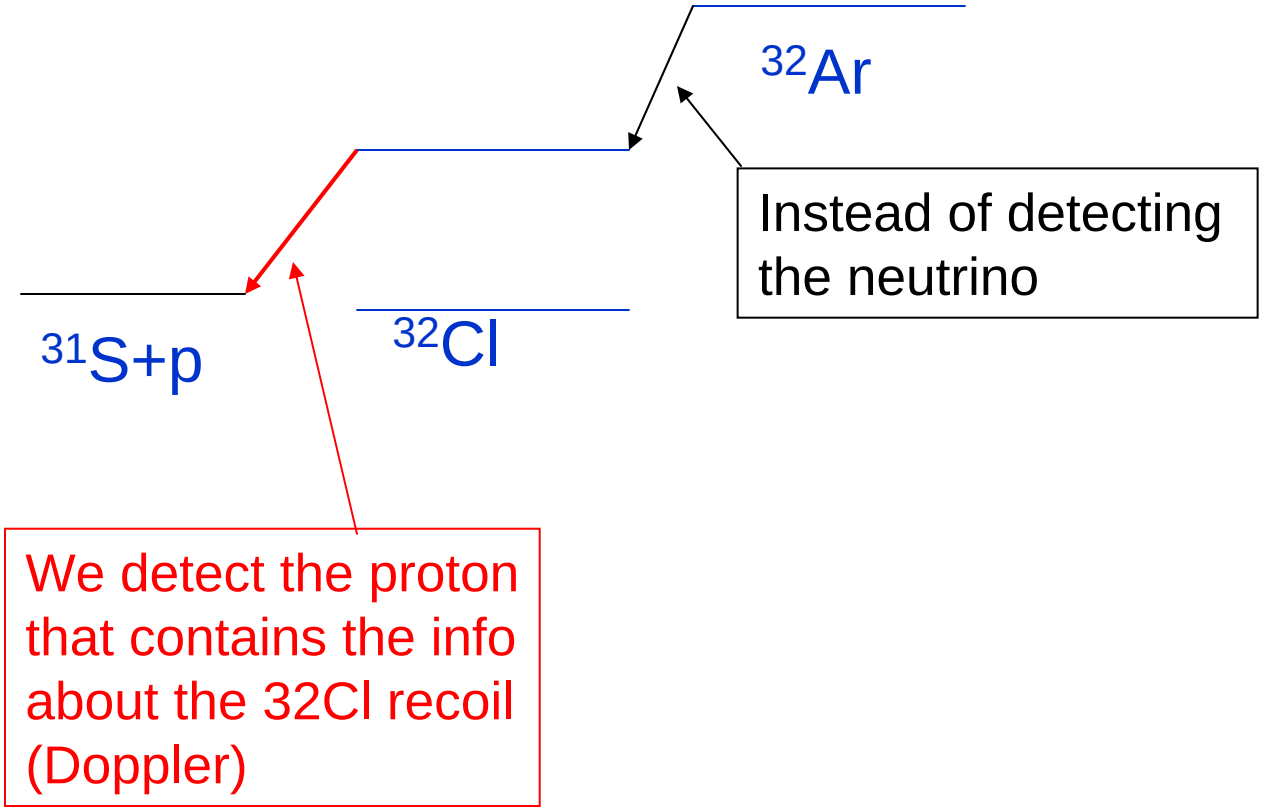

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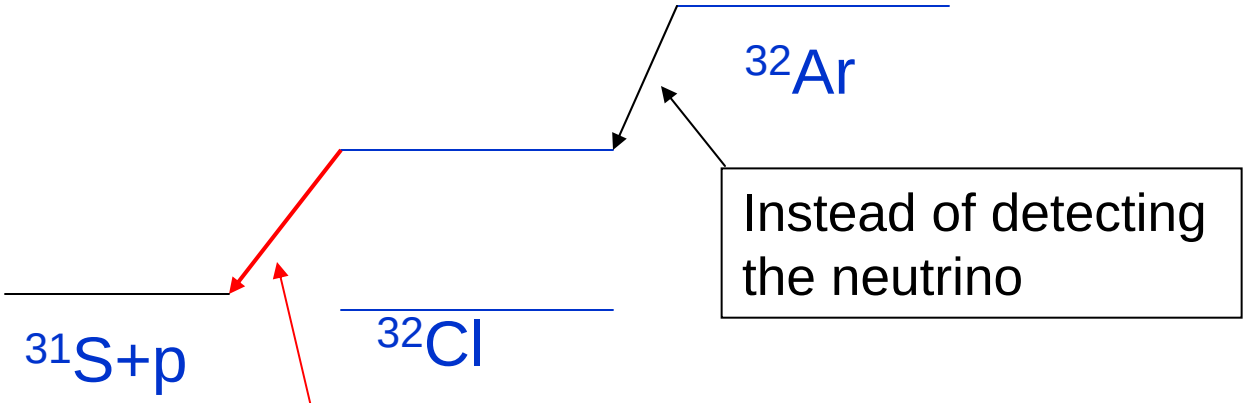
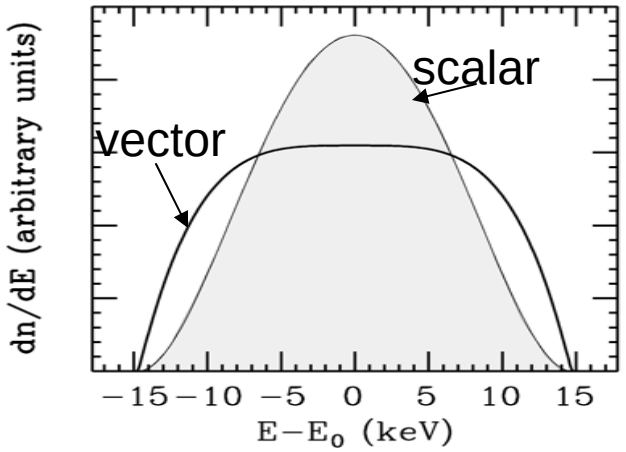
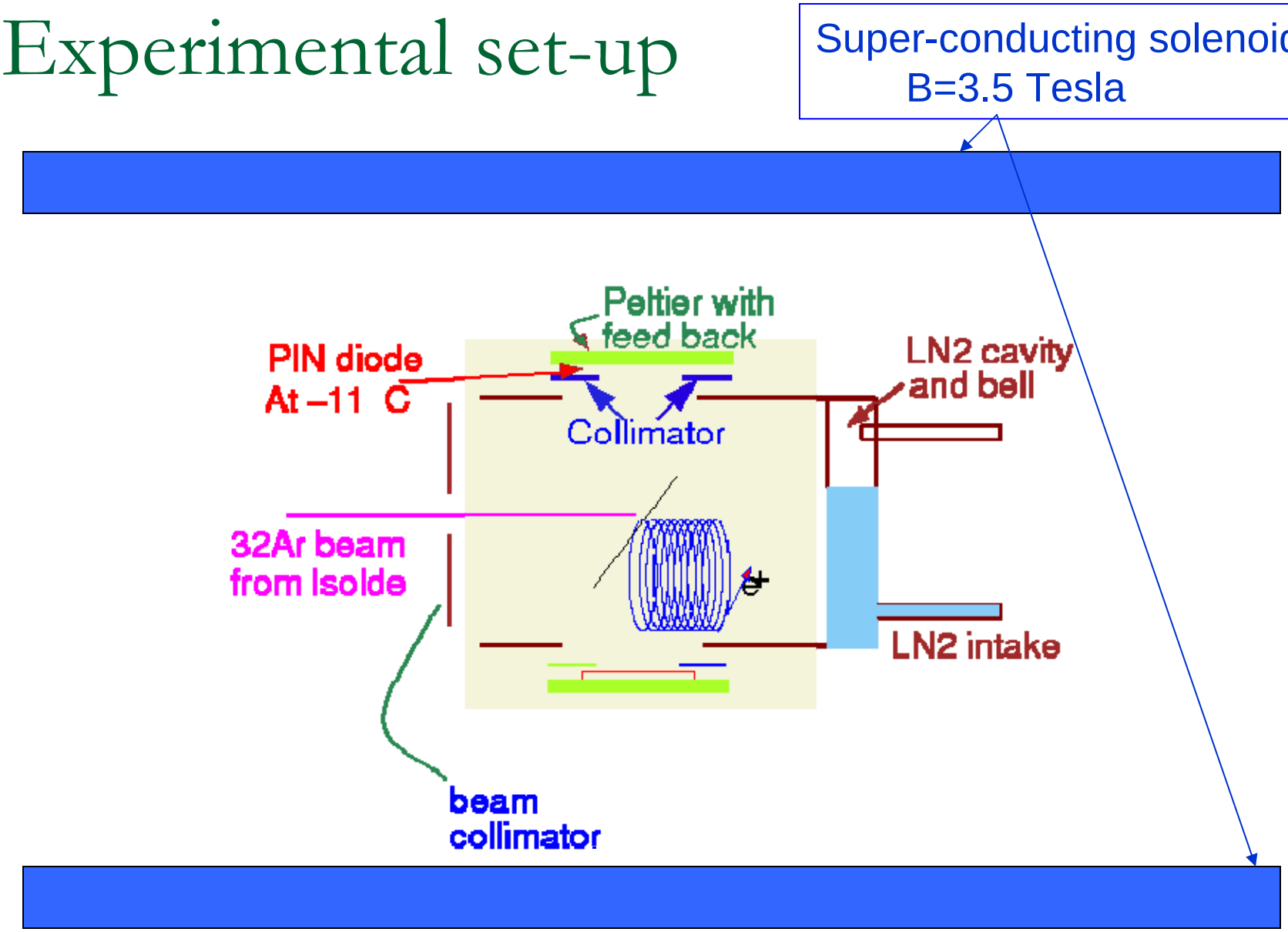


We detect the proton that contains the info about the 32Cl recoil (Doppler)

Monte-Carlo calculation of proton energy



Experimental set-up



In $0^+ \rightarrow 0^+$ nuclear β decay:

$H = G_W/\sqrt{2}\,(H_S + H_V)$

$H_S = (\bar{\Psi}_p \Psi_n)\ (\bar{\Psi}_e (C_S + \gamma_5 C'_S)\ \Psi_\nu)$

$H_V = (\bar{\Psi}_p \gamma^\mu \Psi_n)\ (\bar{\Psi}_e (C_V \gamma_\mu + C'_V \gamma_\mu \gamma_5)\ \Psi_\nu)$

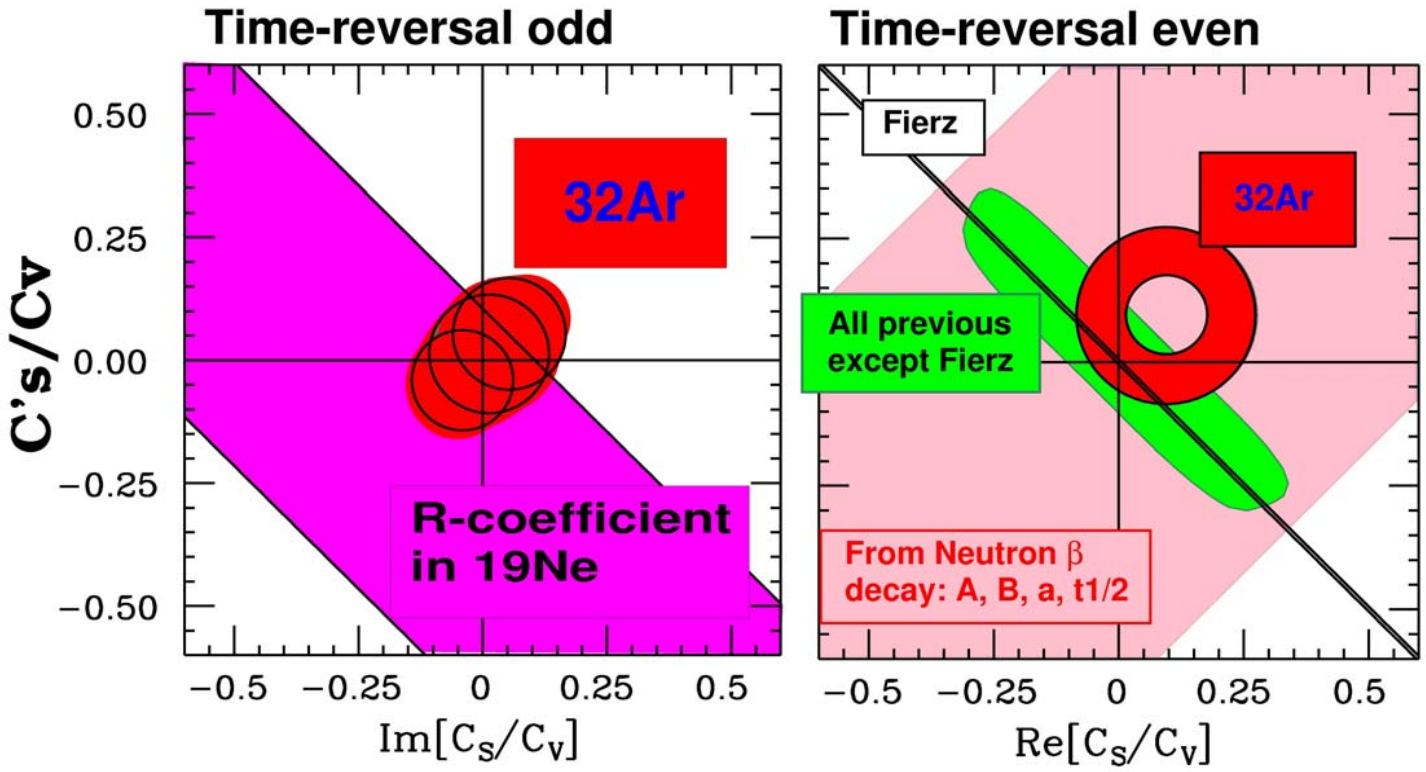
Consequence: decay rate for $0^+ \rightarrow 0^+$ decays

$$dW = dW_0\left(1 + a\,\frac{\vec{p}_e \cdot \vec{R}_\nu}{E_e E_\nu} + b\,\frac{\Gamma m_e}{E_e} + \langle \vec{J} \rangle . \ldots\right)$$

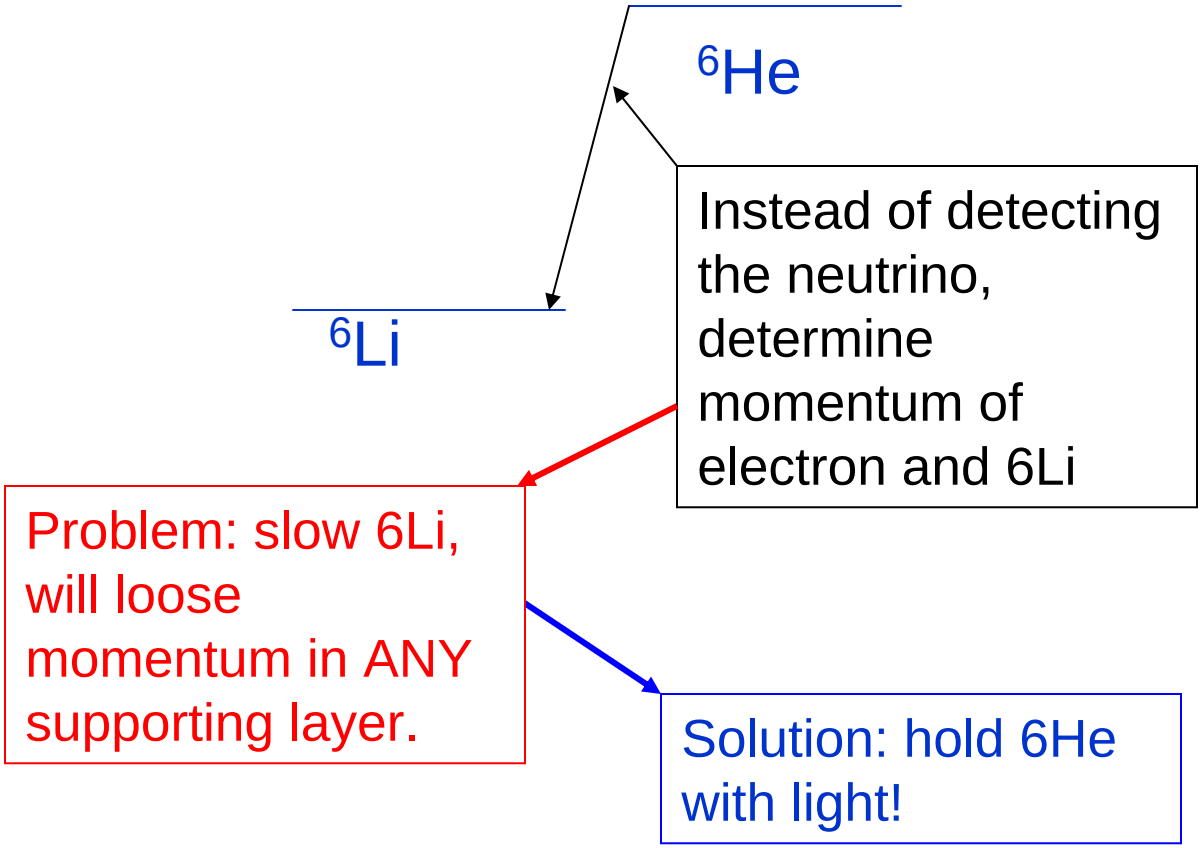
$$a = \frac{C_V^2 + C_V'^2 - C_S^2 - C_S'^2}{C_V^2 + C_V'^2 + C_S^2 + C_S'^2}$$

$$b = \frac{-2\mathrm{Re}(C_S C_V^* + C'_S C'^*_V)}{C_V^2 + C_V'^2 + C_S^2 + C_S'^2}$$

Consequences for couplings

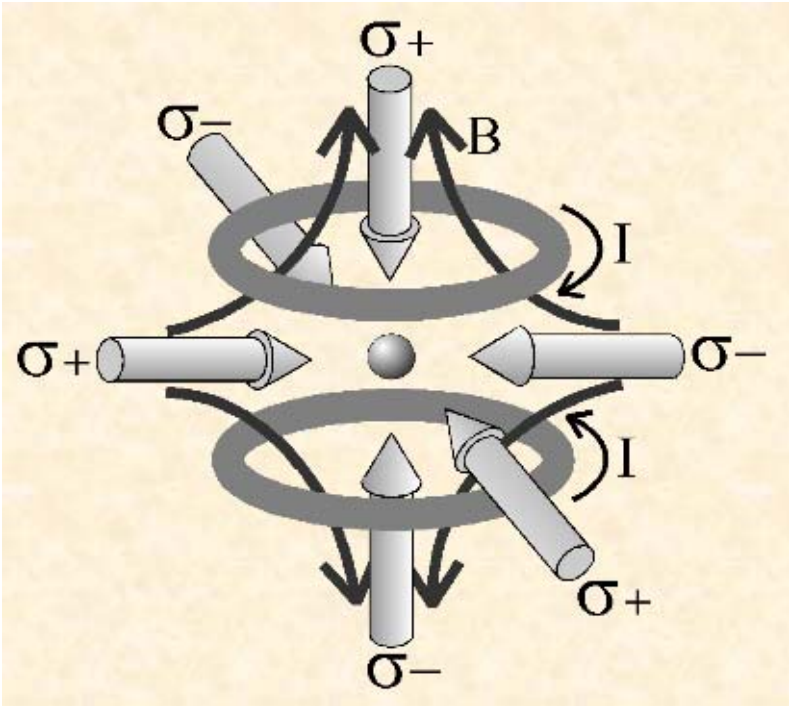


Searching for tensor currents in 6He

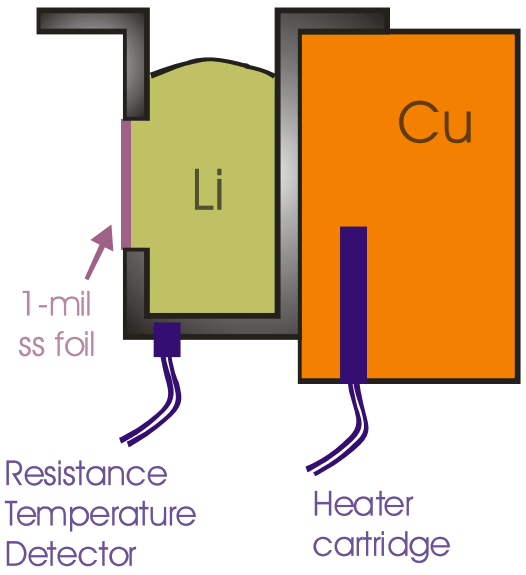


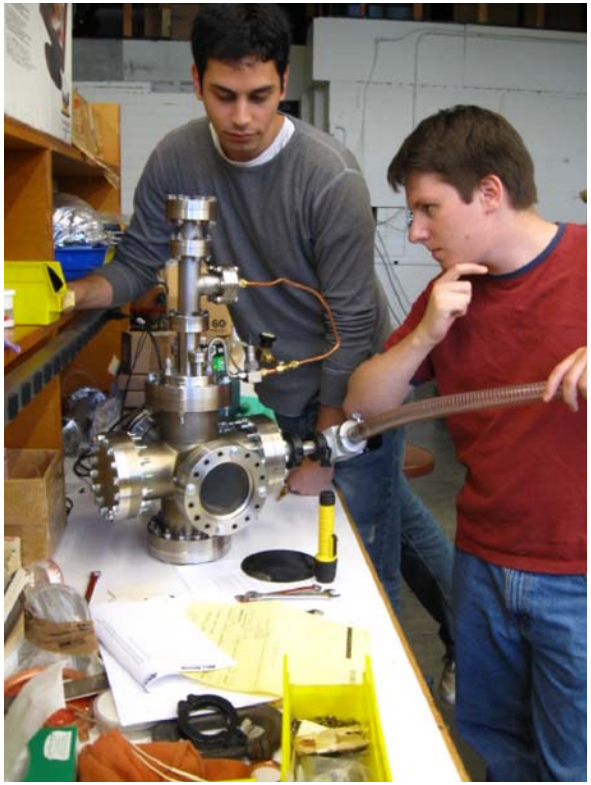
Magneto-Optical Trap

- Six orthogonal, counter-propagating beams of opposite circular polarization are red-detuned as in the Doppler cooling configuration
- Anti-Helmholtz coils introduce a quadrupole field with zero magnetic field at the center and linearly increasing field in the directions of the lasers



Production of 6He at CENPA





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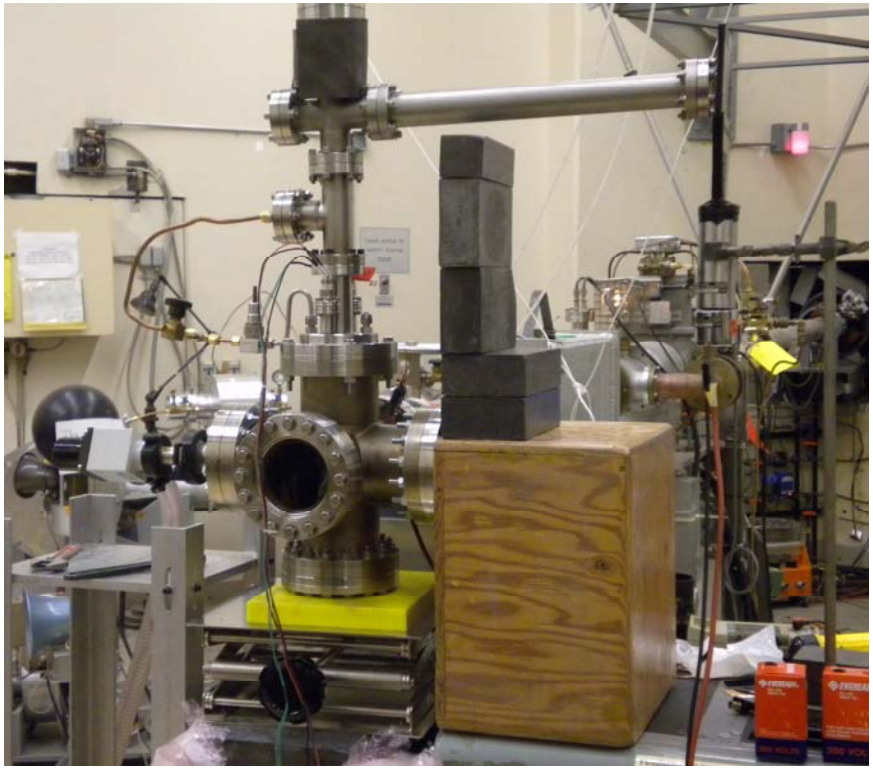

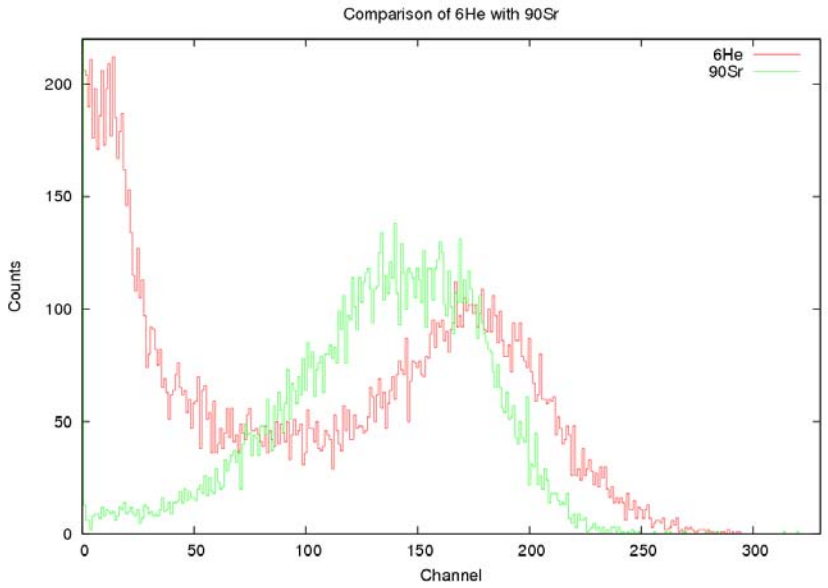

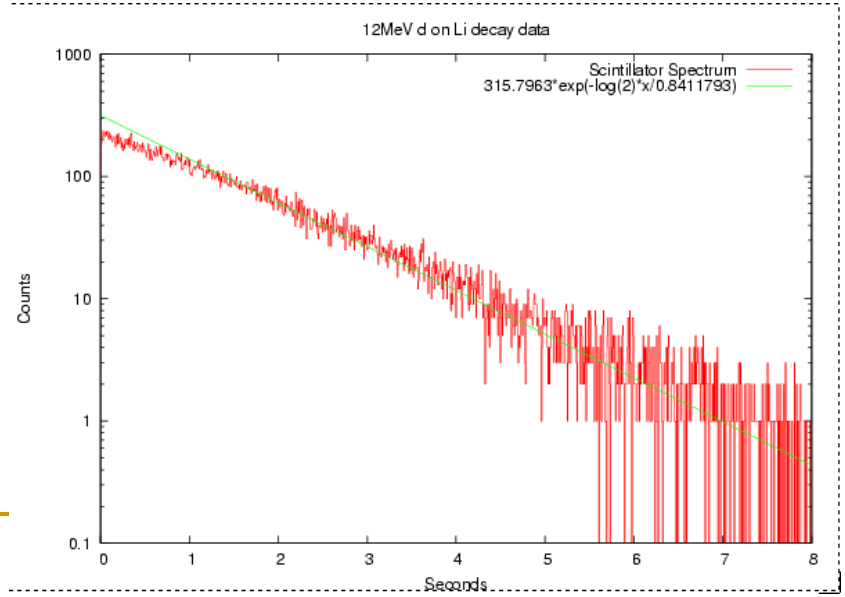

Works out very well!


The End