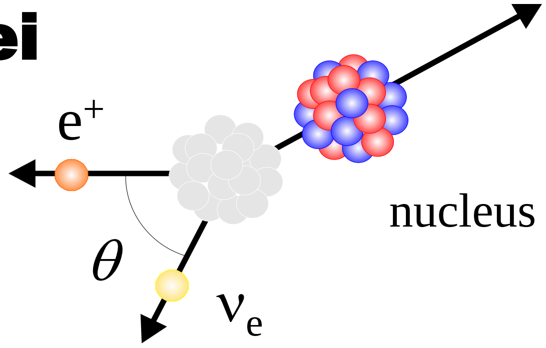
Limits on scalar currents using the positron-neutrino correlation from β-p decay of T_z = - 2 nuclei



N. Severijns et al.
KU Leuven

Bertram Blank et al.
CEN Bordeaux-Gradignan

D. Zakoucky et al.
NPI Řež

E. Liénard et al.
LPC Caen

- Physics case
- Experiment
- Needs

ISCC meeting, June 28, 2016

Scaler currents in weak decays

The e-ν correlation depends strongly on the nature of the current
e.g. $0^+ \rightarrow 0^+$ transition (Fermi transition → vector + scalar currents):

spins have to couple to zero

e^+

ν

spins

Standard Model
Vector Currents

New Physics?
Scalar Currents

momenta

e^+

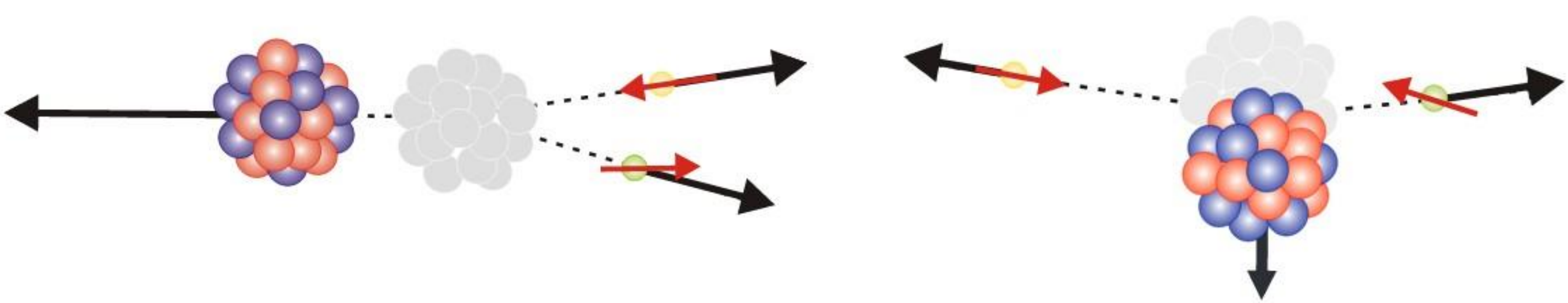
ν_e

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

e^+

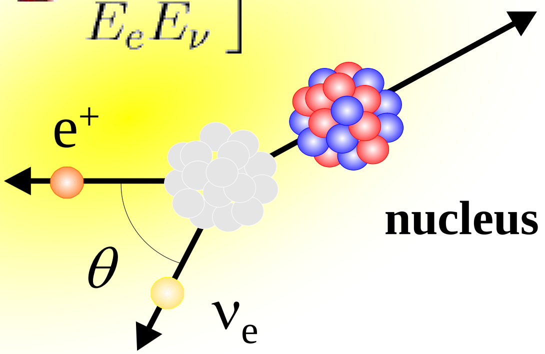
ν_e

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



Beta-neutrino correlations

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



Beta-neutrino correlation coefficient:

$$a_{\beta\nu}\xi = |M_F|^2\left[|C_V|^2 + |C_V'|^2 - |C_S|^2 - |C_S'|^2 \mp 2\frac{\alpha Z m}{p_e}\mathrm{Im}(C_S C_V^* + C_S' C_V'^*)\right]$$
$$+\frac{|M_{GT}|^2}{3}\left[|C_T|^2 + |C_T'|^2 - |C_A|^2 - |C_A'|^2 \pm 2\frac{\alpha Z m}{p_e}\mathrm{Im}(C_T C_A^* + C_T' C_A'^*)\right]$$

Fierz coefficient:

$$b = \pm 2\sqrt{1-\alpha^2 Z^2}\,\mathrm{Re}\left[|M_F|^2(C_S C_V^* + C_S' C_V'^*) + |M_{GT}|^2(C_T C_A^* + C_T' C_A'^*)\right]\xi^{-1}$$

Search for physics beyond the standard model

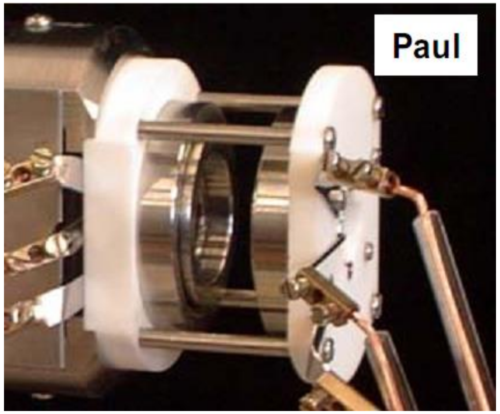
TRAPS:

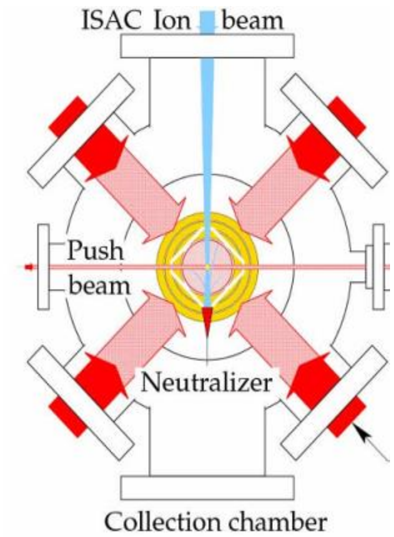
- Paul trap : **LPC-GANIL**
  ^{6}He

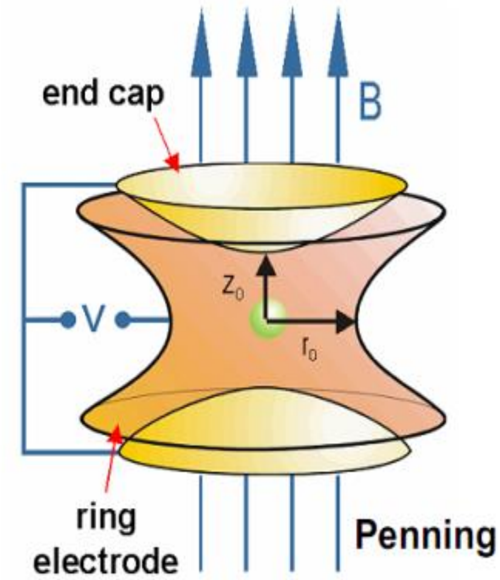
- Penning trap : **WITCH-ISOLDE**
  ^{35}Ar

- MOT trap : **TRIUMF, Berkeley**
  ^{37}K, ^{80}Rb

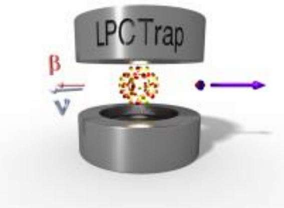
Alternative:
measurements in refrigerators:
Leuven, NICOLE, POLAREX
^{60}Co, ^{114}In, ^{12}N, ^{107}In

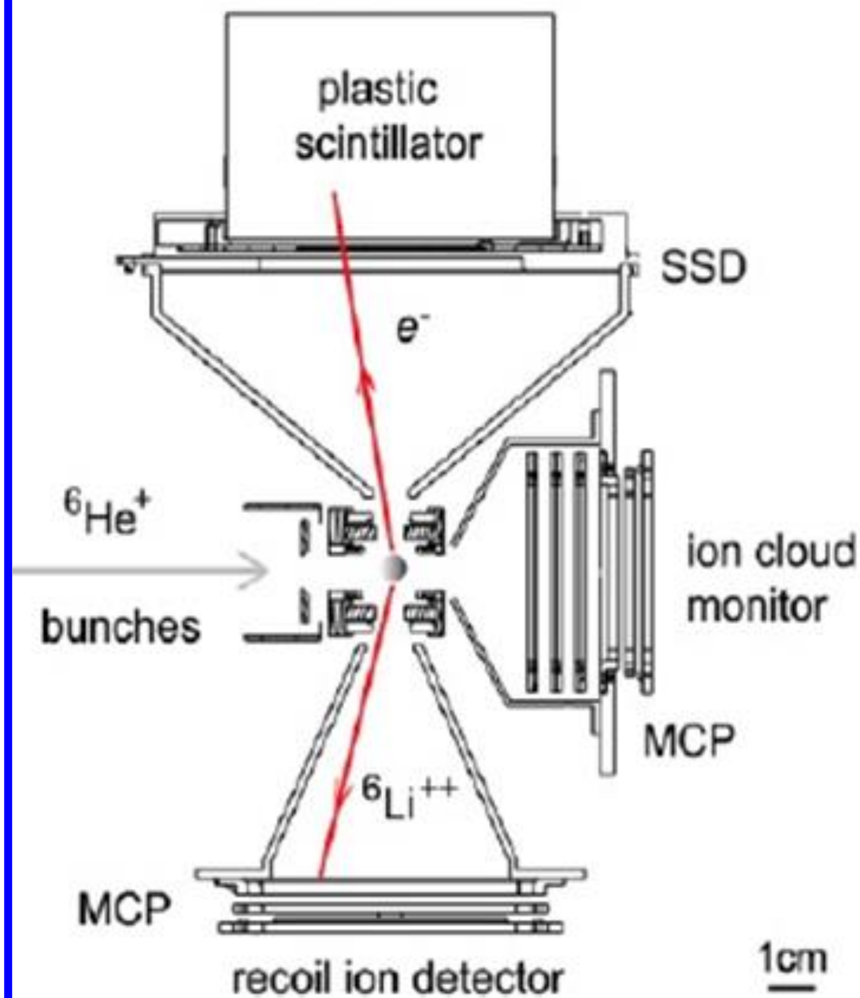






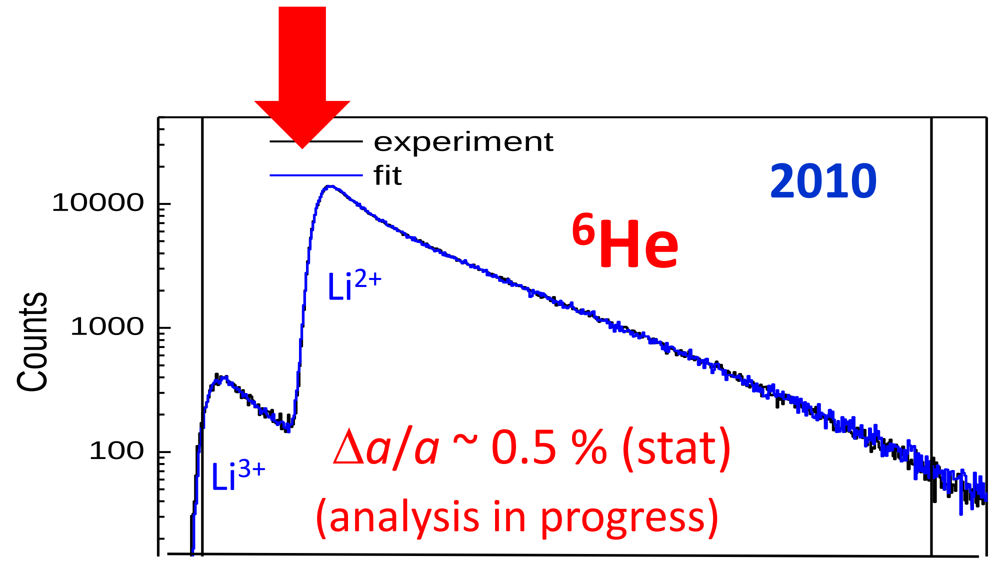
Tensor currents with LPCTrap at GANIL: ^{6}He





2006 (^{6}He): $a_{\beta\nu} = -0.3335(73)_{stat}(75)_{syst}$

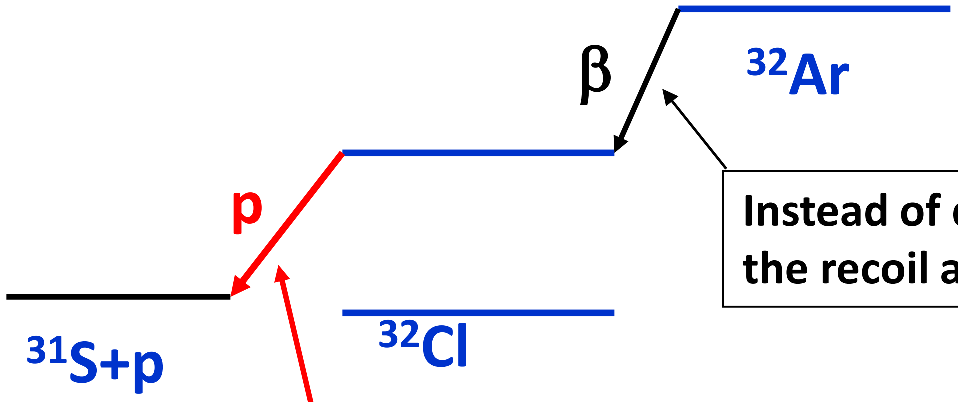
X. Fléchard et al., J. Phys. G 38 (2011) 055101



charge-state distribution and comparison to atomic theory:

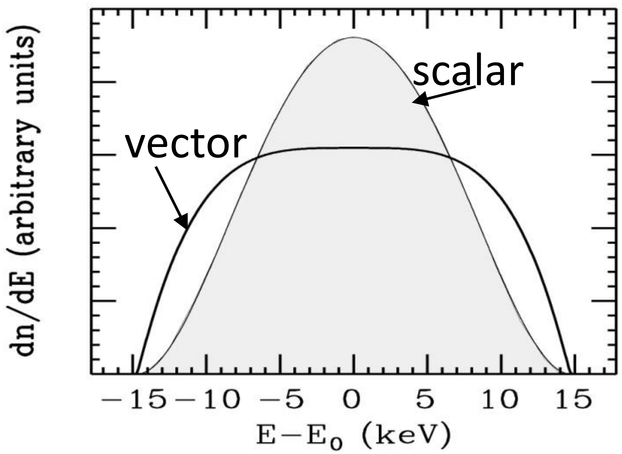
C. Couratin et al., PRL 108 (2012) 243201

A different approach…



Instead of detecting the recoil and the beta

Detection of the proton that contains the information about the ^{32}Cl recoil (Doppler effect…)



Proton peak shape

First experiment: ISOLDE II

Beta-neutrino recoil broadening in β-delayed proton emission of ^{32}Ar and ^{33}Ar

D. Schardt[1], K. Riisager[2]

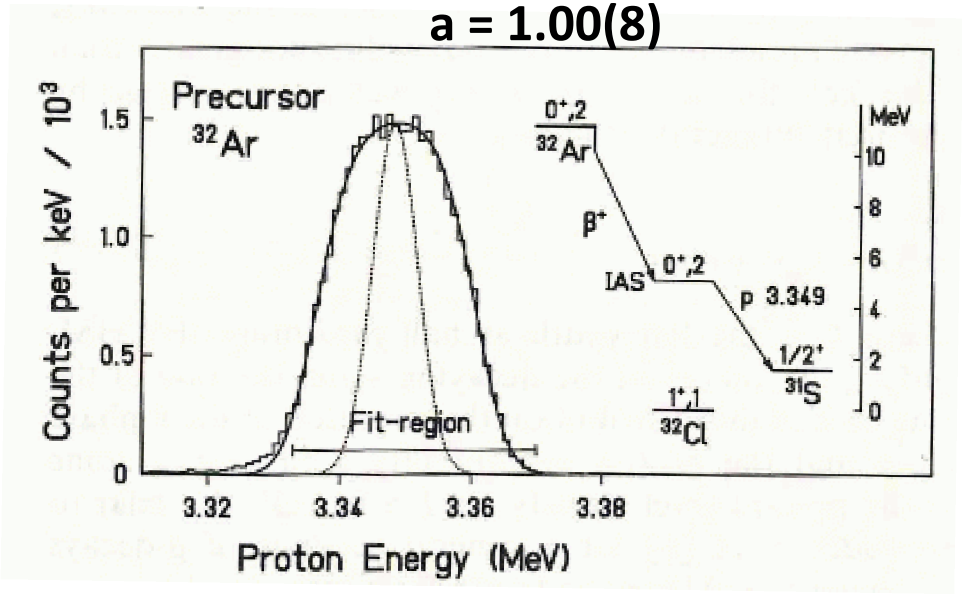
[1] GSI, Postfach 110552, W-6100 Darmstadt 11, Germany
[2] Institute of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark

ZPA 345 (1993) 265

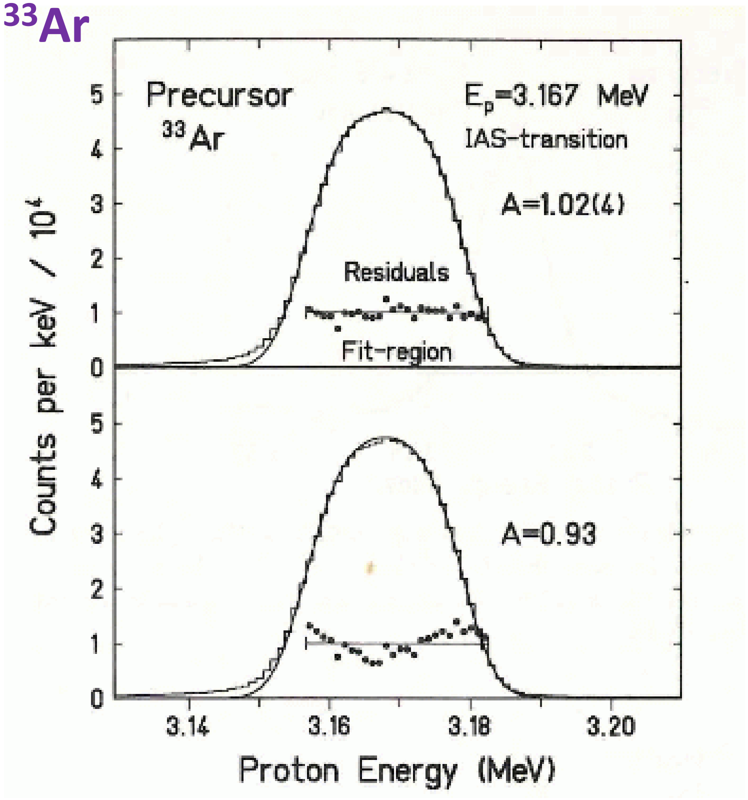
Set-up: cooled silicon detector

^{32}Ar

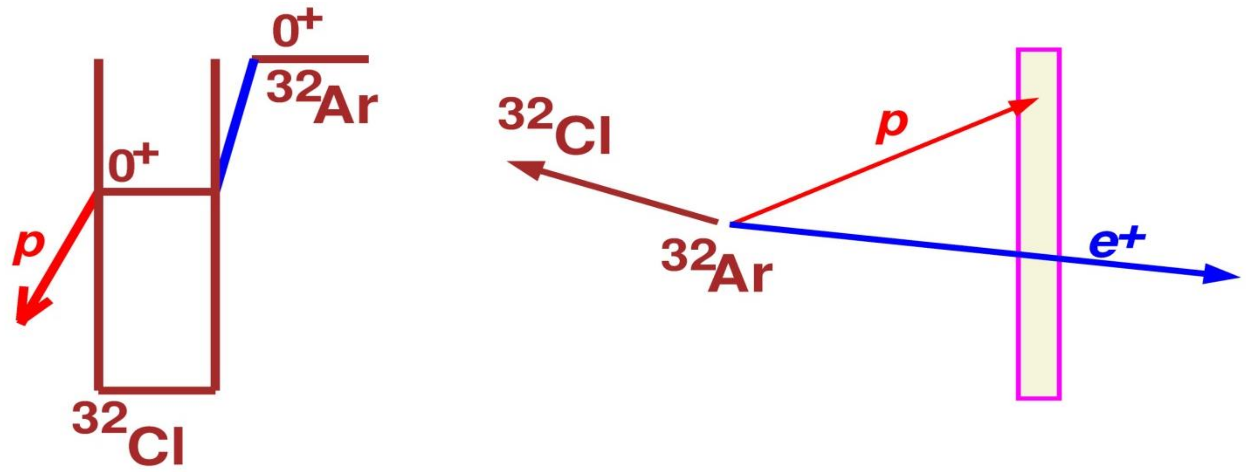
a = 1.00(8)

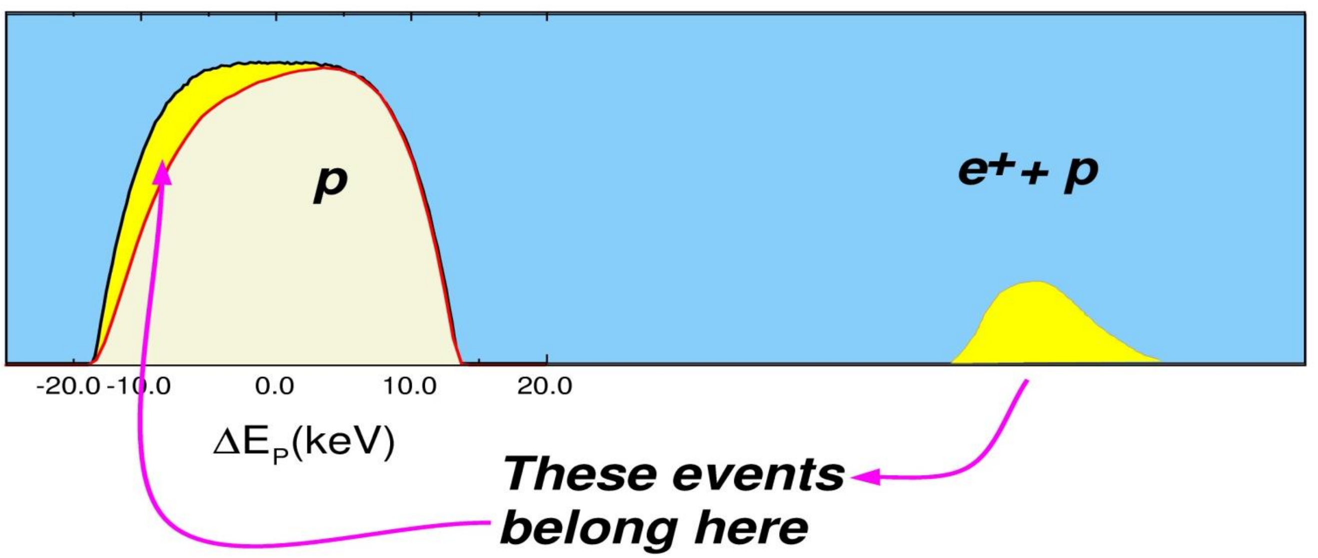


^{33}Ar



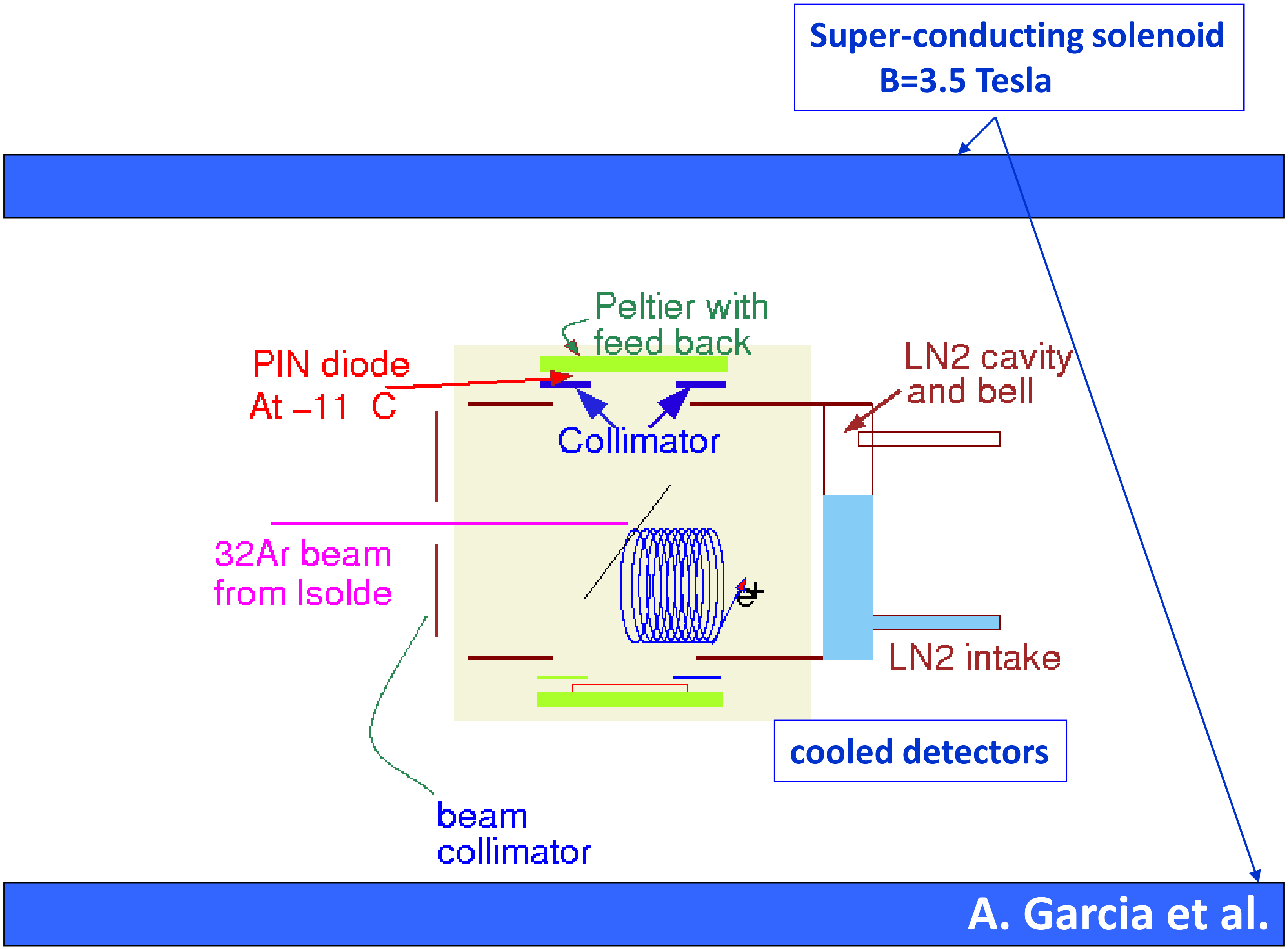
Problem: Summing of protons and electrons



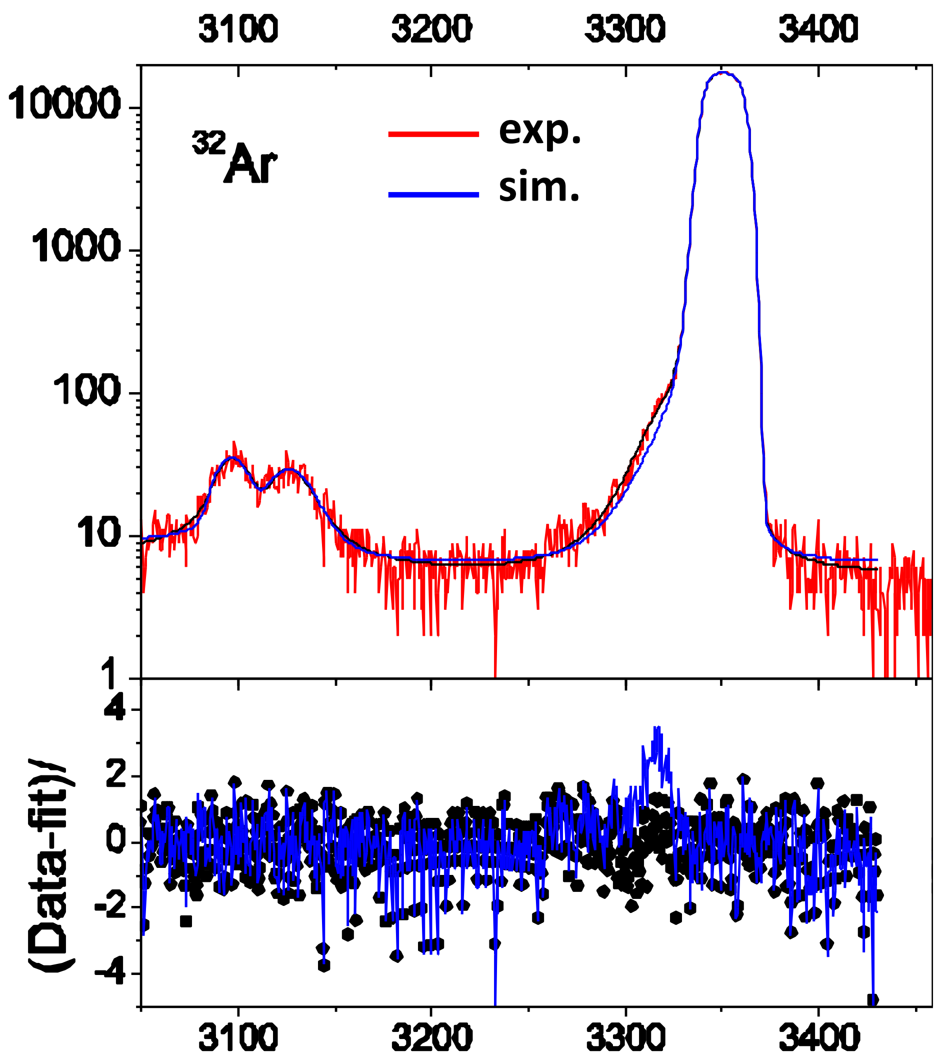


A. Garcia et al.

Second experiment at ISOLDE



Results for 32Ar



Result:

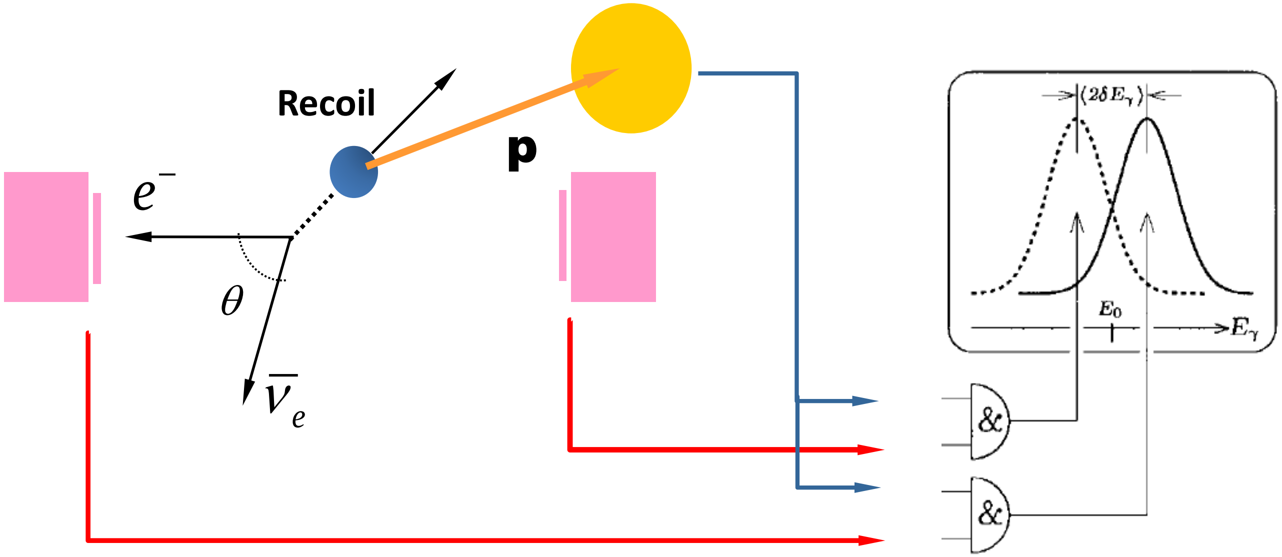
$\tilde{a}$=0.998(5)

E. G. Adelberger et al., PRL 83 (1999) 1299

A. Garcia et al., Hyperfine Interact. 129 (2000) 237

Improved detection: +90° or -90°

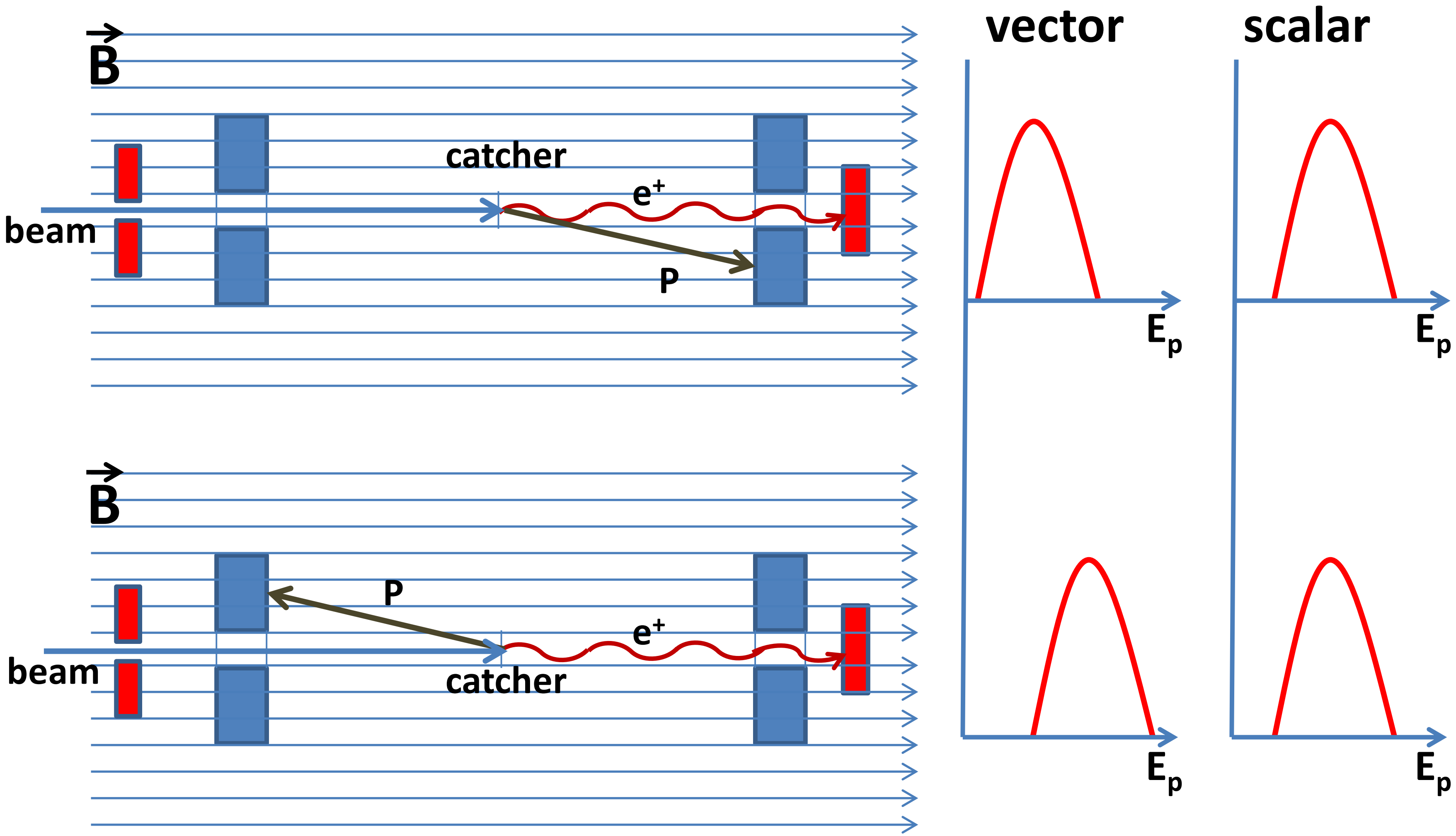
$$W(E,\theta) = W(E)\,[1 + \frac{v_e}{c}\cos(\theta) + b\,\frac{m}{E}]$$



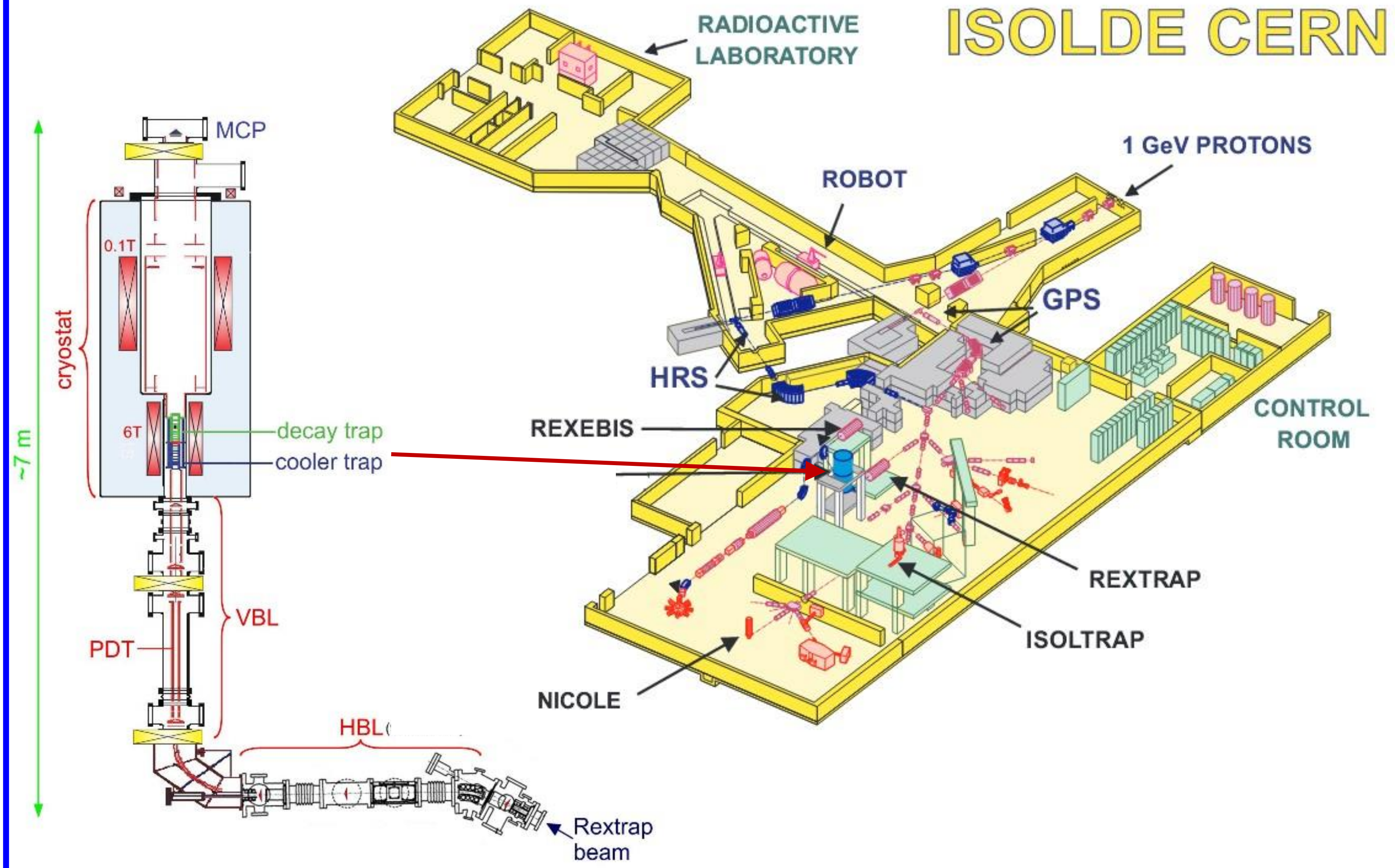
Detection of shift rather than width ➔ ➔ improved sensitivity

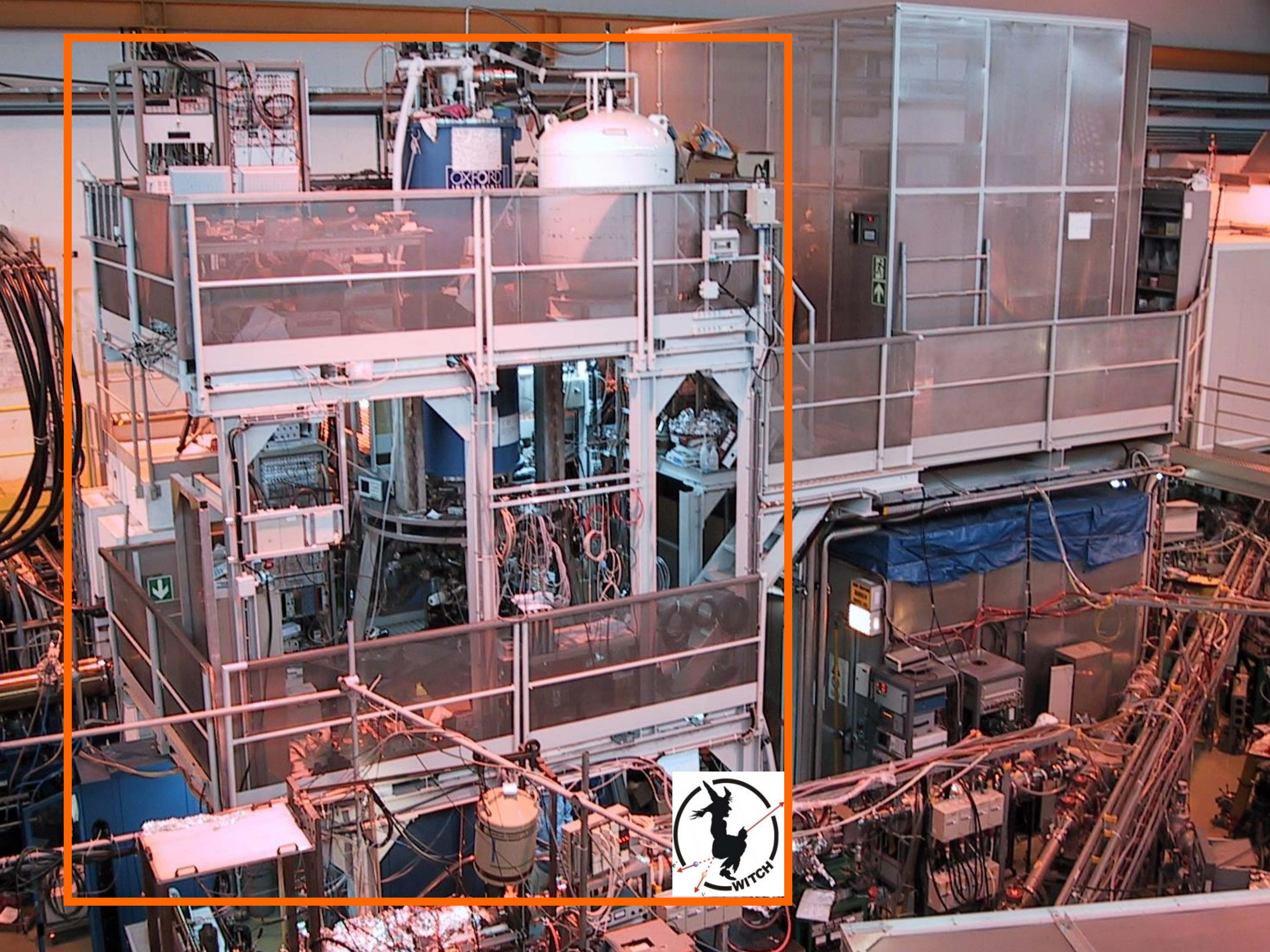
However, we have to avoid electrons in the proton detector….

Positron – proton pile-up: Penning-trap magnet



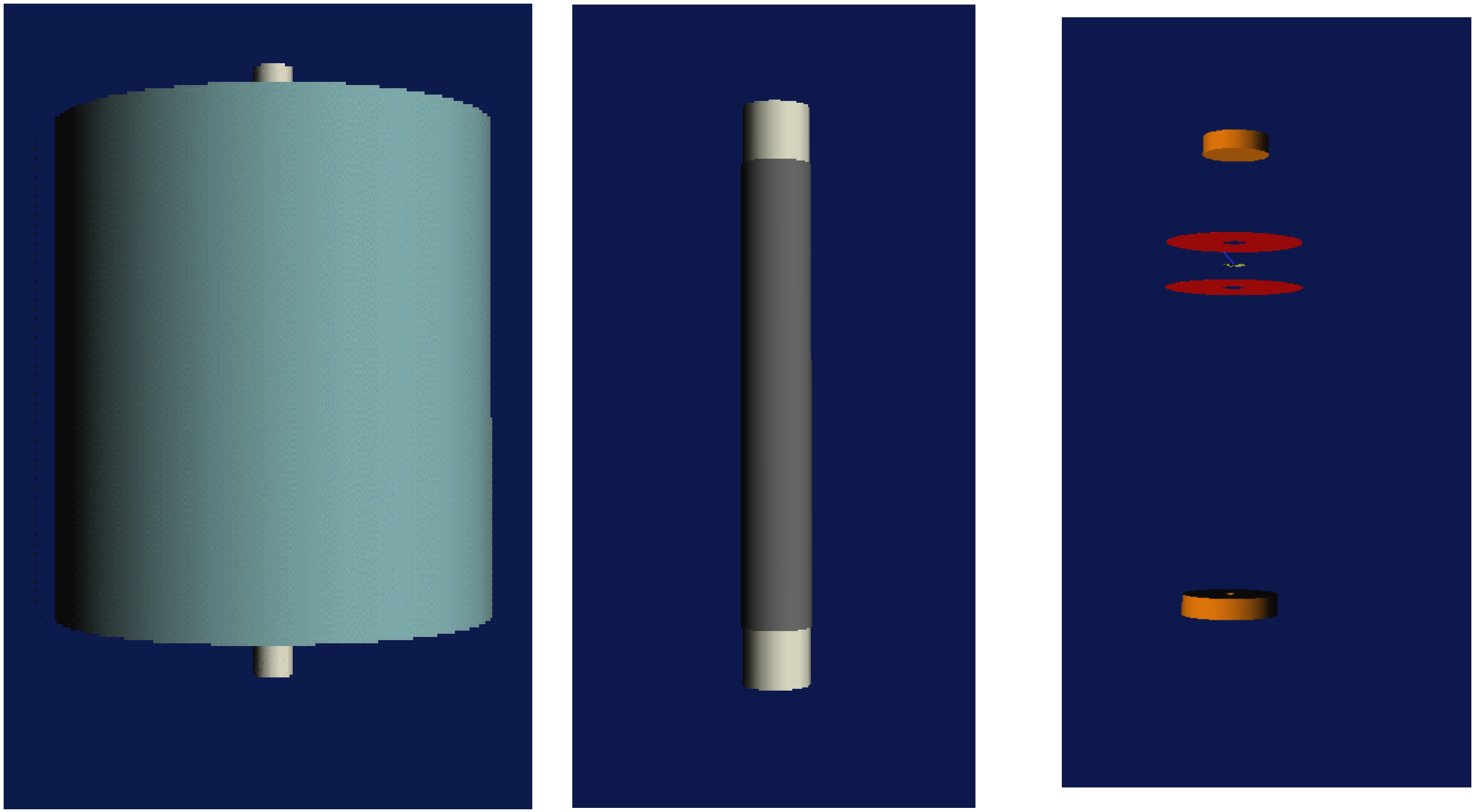
WITCH at ISOLDE




OXFORD
WITCH

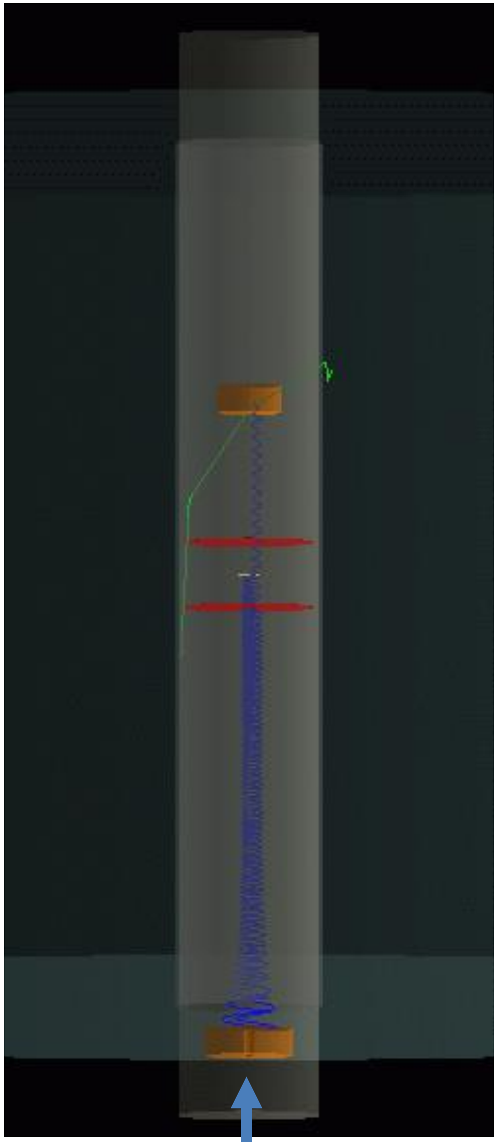
New measurement with WITCH at ISOLDE

Schematically, for first simulations…



magnet and cryostat **vacuum tube** **detectors and catcher**

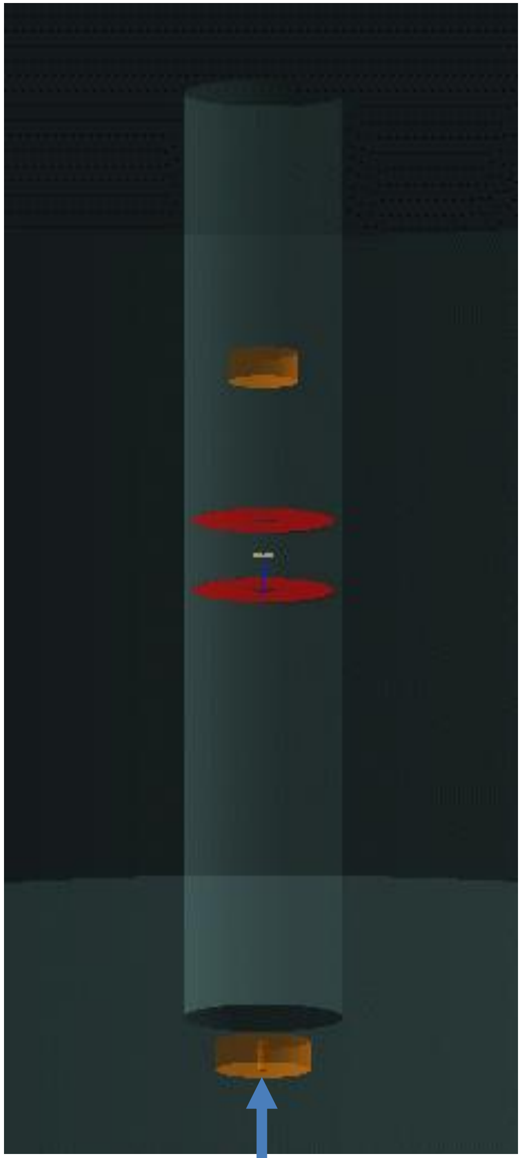
New measurement with WITCH at ISOLDE



← electrons

protons →

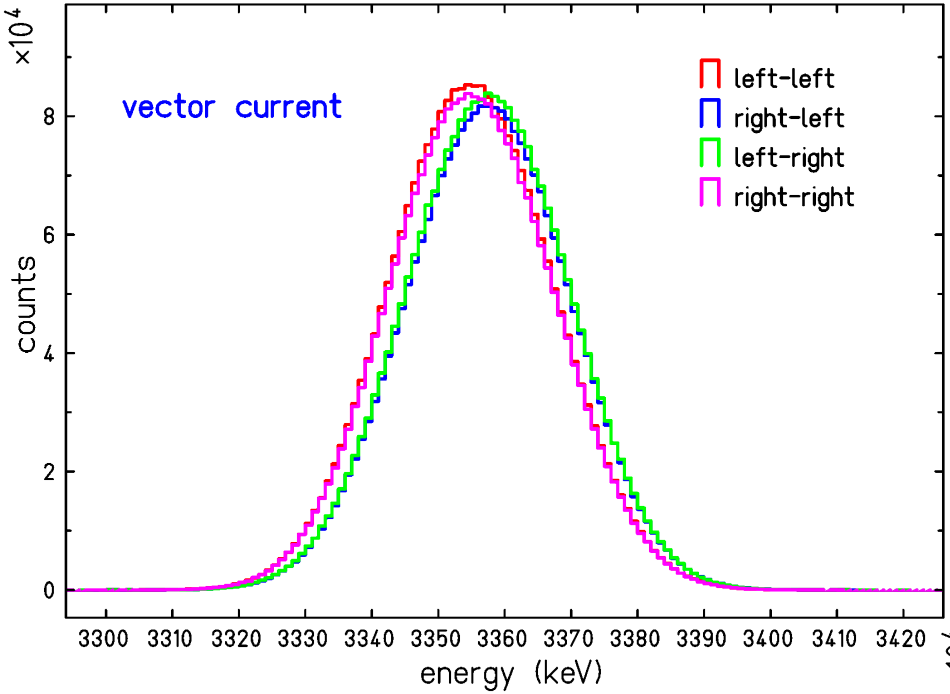
first problem:
backscattering
of electrons
→ fast timing
with plastic
scintillators?



beam

beam

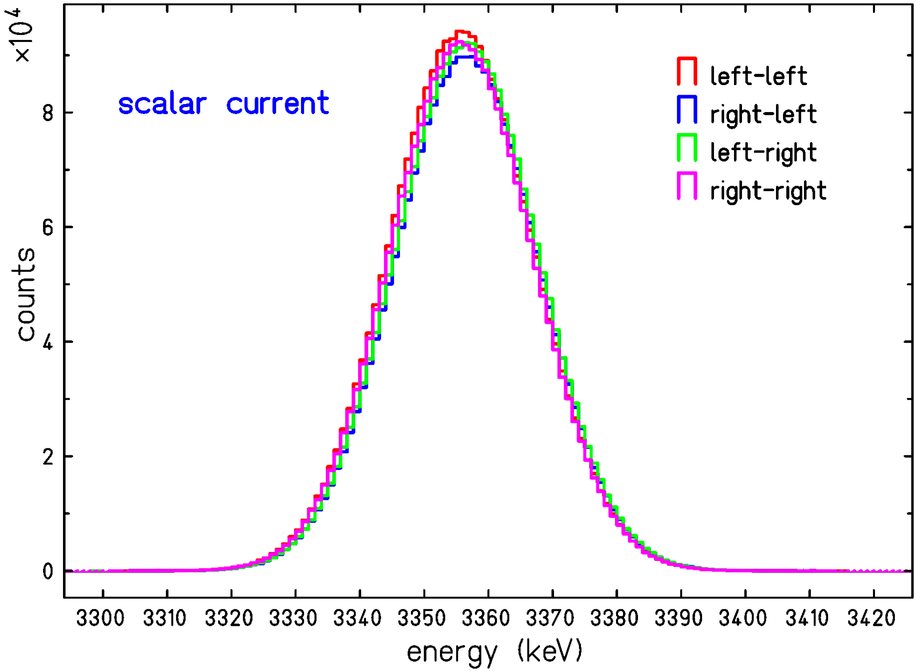
First simulations:



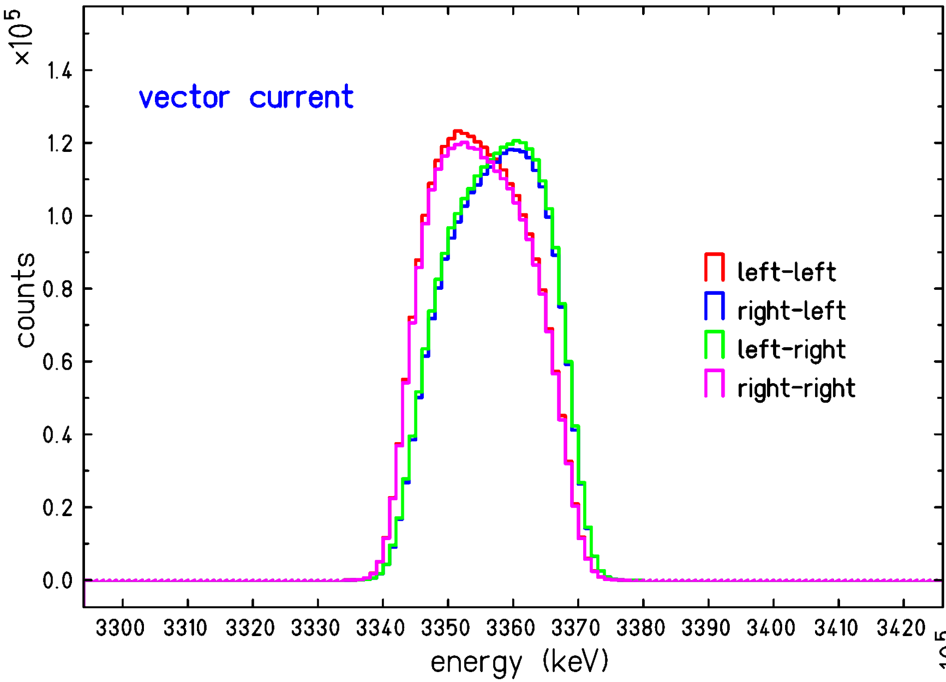
not yet a complete GEANT4 simulation!

- **event generator**
- **angular cuts**

Resolution: σ = 10 keV



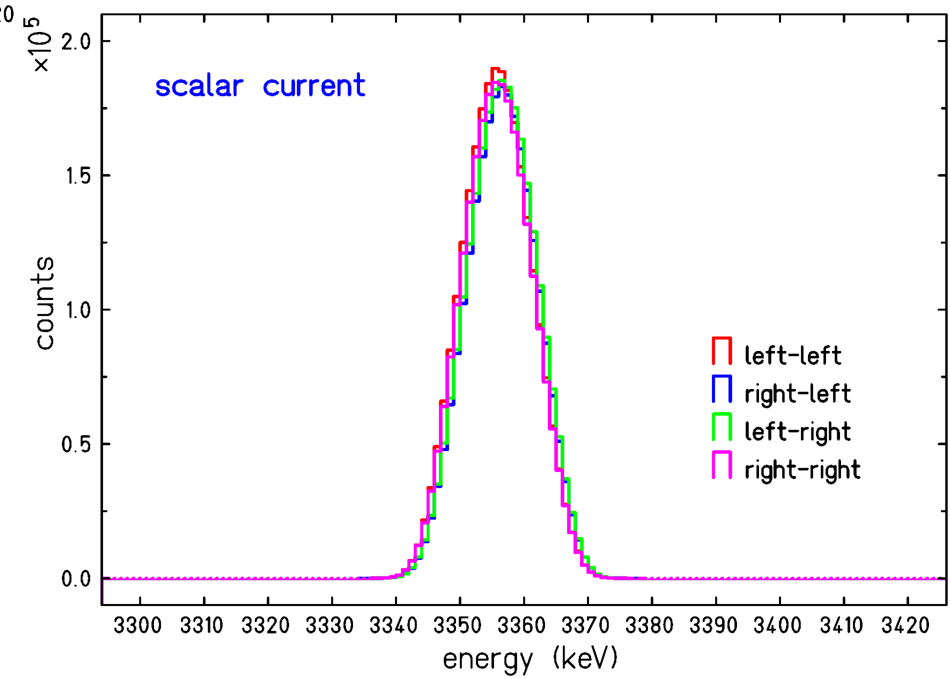
First simulations:



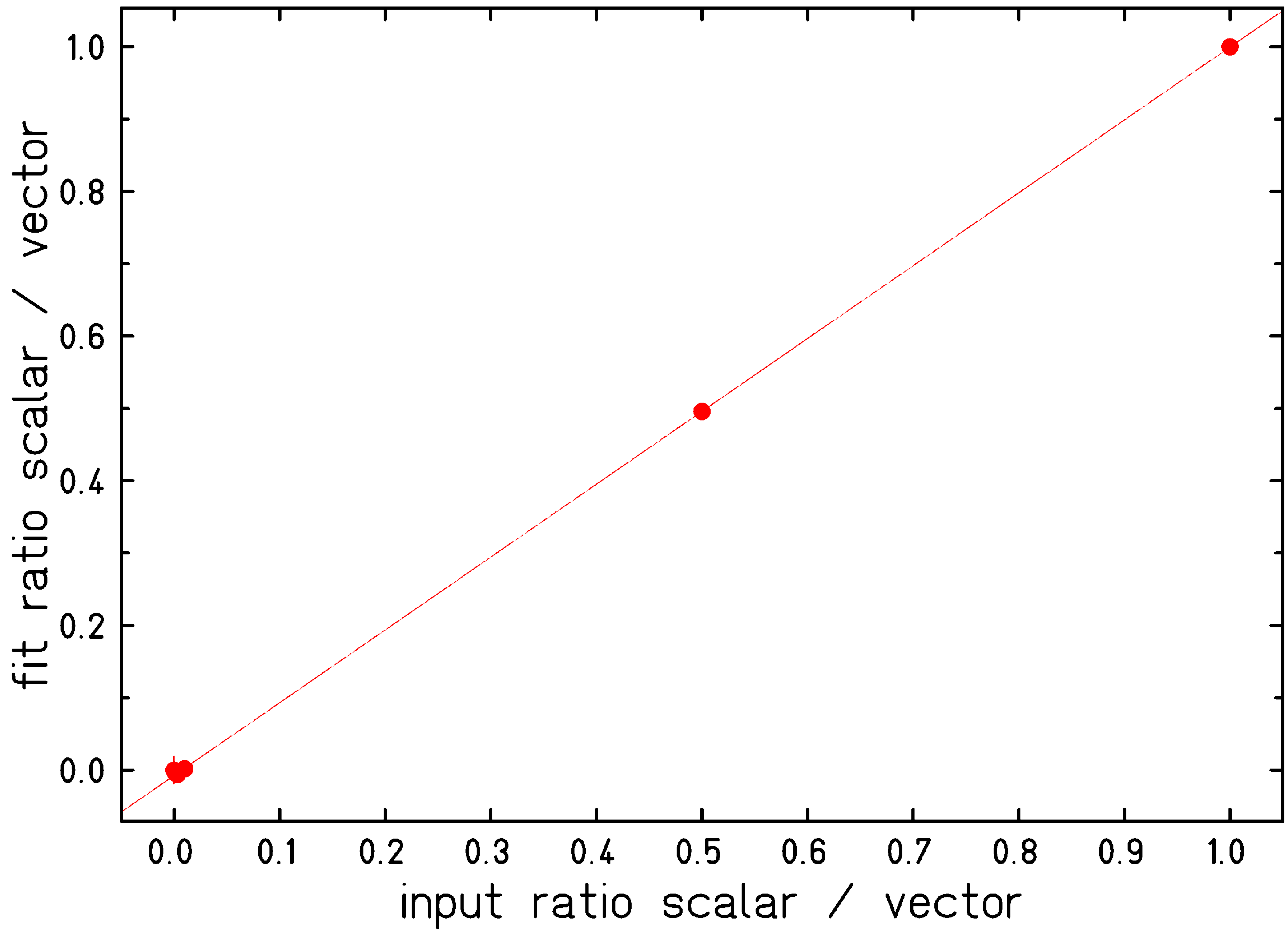
not yet a complete GEANT4 simulation!

- event generator
- angular cuts

Resolution: σ = 2keV



First simulations:



Remarks

= = > > from measurement of width to energy shift

- past attempts:
  - ^{18}Ne: V. Egorov et al., NP A621 (1997) 745)

    ➔ limited statitics
  - ^{14}O: V. Vorobel, Eur. Phys. J A 16 (2003) 139

    ➔ molecular effect

- new project: TAMUTRAP (Dan Melconian et al.)

  ➔ we are in touch…

Remarks

- cooling of detectors to improve resolution
- aim: with a FWHM = 5 keV ➔ $\Delta a \approx 0.1\%$
  ➔ competitive with LHC
- but also understand other effect: e.g. weak magnetism

- use of solid catcher or trapping?
- use of scintillators or silicon detectors for positrons?

- typical intensity: >1000 pps
- nuclei: ^{20}Mg, ^{24}Si, ^{28}S, <u>^{32}Ar</u>, ^{36}Ca…
  ➔ only ^{32}Ar feasible today, maybe ^{20}Mg

- possibility to search also for tensor currents in GT transitions

Thanks for your attention

distribution in
- **electron and neutrino directions** and in
- **electron energy**

from **polarized nuclei :**

Correlation measurements

$$\omega\left(\langle\vec{J}\rangle \mid E_e,\Omega_e,\Omega_\nu\right) dE_e\, d\Omega_e\, d\Omega_\nu$$

$$\propto \underbrace{F(\pm Z,\, E_e)}_{\text{Fermi function}} \quad \underbrace{p_e\, E_e\, (E_0 - E_e)^2\, dE_e\, d\Omega_e\, d\Omega_\nu}_{\text{phase space}}$$

Fermi function — **phase space**

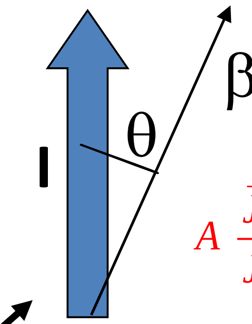
$$\text{x}\quad \xi \left\{ 1 + a\,\frac{\vec{p}_e\cdot\vec{q}}{E_e E_\nu} + b\,\frac{\gamma m_e}{E_e} + A\,\frac{\vec{J}}{J}\cdot\frac{\vec{p}_e}{E_e} + R\,\vec{\sigma}\cdot\frac{\vec{J}}{J}\,\text{x}\,\frac{\vec{p}_e}{E_e} + \ldots \right\}$$

β-ν correlation

Fierz interference term (b ≡ 0 in standard model)

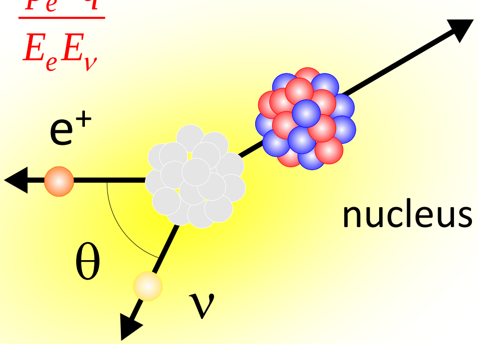
β-asymmetr

R-correlation



$$A\,\frac{\vec{J}}{J}\cdot\frac{\vec{p}_e}{E_e}$$

$$a\,\frac{\vec{p}_e\cdot\vec{q}}{E_e E_\nu}$$



$$\tilde{X} = \frac{X}{1 + b\,\dfrac{\gamma m_e}{E_e}}$$

J,D, Jackson, S.B. Treiman, H.W. Wyld, Nucl. Phys. 4 (1957) 206

3. Exotic weak currents (scalar, tensor, V+A)

1. βν correlation

$$a\,\frac{\vec{p}_e\cdot\vec{q}}{E_e E_\nu} \xrightarrow{\text{exp.}} \tilde{a} = \frac{a}{1 + b\,\dfrac{\gamma m_e}{E_e}}$$

with $\gamma = \sqrt{1-(\alpha Z)^2}$

$$a_F \cong 1 - \frac{|C_S|^2 + |C_S^{'}|^2}{|C_V|^2}$$

$$a_{GT} \cong -\frac{1}{3}\left[1 - \frac{|C_T|^2 + |C_T^{'}|^2}{|C_A|^2}\right]$$

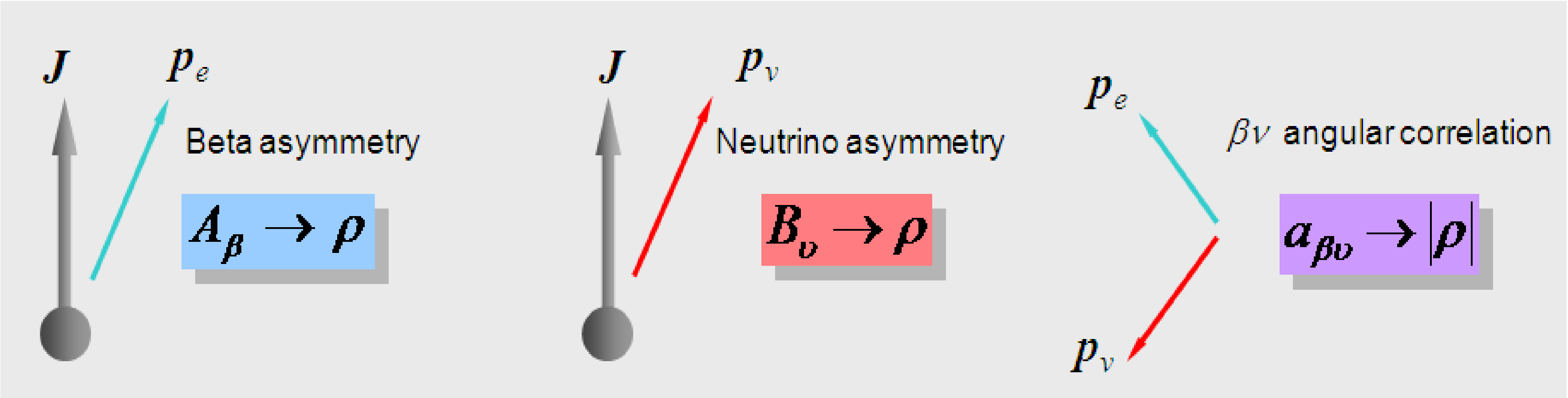
$$b_F \cong Re\,\frac{C_S + C_S^{'}}{C_V}$$

Fierz term

$$b_{GT} \cong Re\,\frac{C_T + C_T^{'}}{C_A}$$

!!! for pure transitions weak interaction results are independent of nuclear matrix elements !!!

- extract mixing ratio $\rho = C_A M_{GT} / C_V M_F$ from correlation measurements:



- there are 35 candidates between ^{3}H and ^{83}Mo, near the N = Z line

(best are the ones with A < 45 about)

- correlation measurements have been carried out for:

^{17}F, ^{19}Ne, ^{21}Na, ^{29}P, ^{35}Ar and ^{37}K