Beta spectrum shape measurements using backscatter recognition

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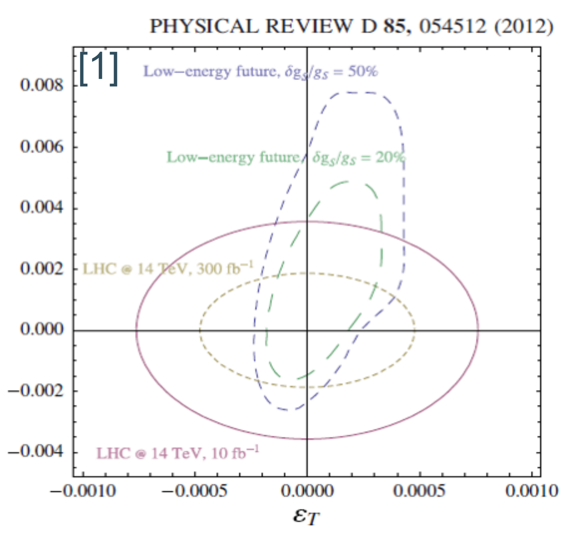
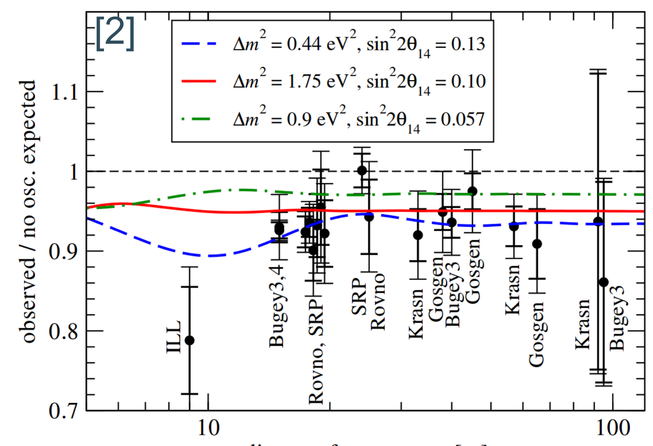
Why?

Probing Beyond SM

- **High**-energy frontier
  $pp \rightarrow e + MET + X$
- **Low**-energy frontier
  small effects on the WI

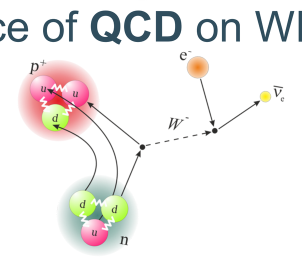
→ Complementary constraints on **Scalar(S)** and **Tensor(T)** currents through *Effective Field Theory* (***EFT***)





Probing SM

- Influence of **QCD** on WI?

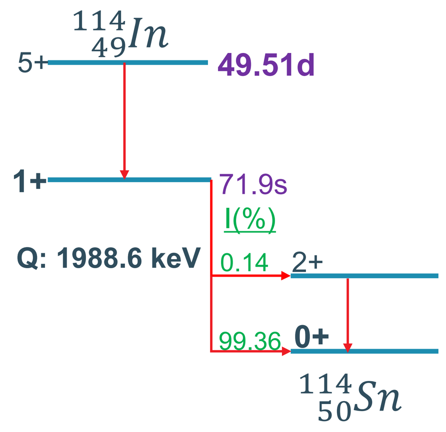


→ *Weak Magnetism (WM)*
Reactor anti-neutrino anomaly

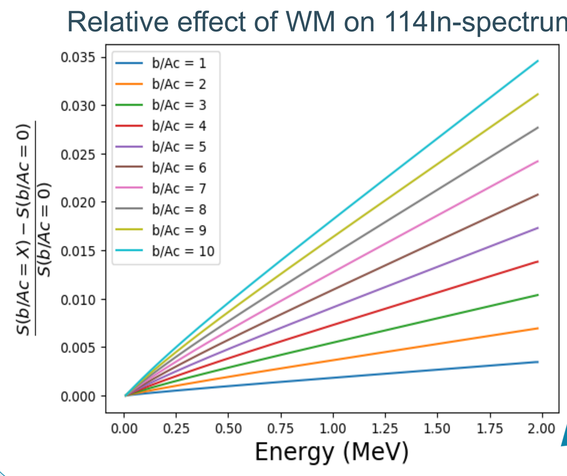
What?

β-spectrum shape

- Sensitive to **S currents for Fermi** decay and **T currents for Gamow-Teller** decay: *Fierz term*
- Required experimental precision: *~10^{-3}*
- Other effects: *radiative corrections, nuclear, atomic, molecular,...* [3]



Relative effect of WM on 114In-spectrum



^{114}In → ^{114}Sn

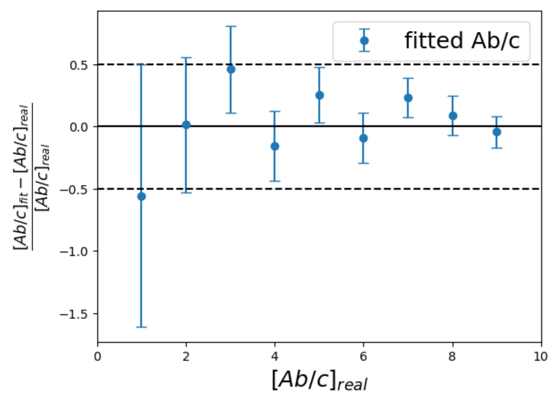
- **Pure GT**-decay
- Favorable end-point energy
- Isomeric state with a $t_{1/2}$ of 50 days
- **Unexplored mass range with respect to WM**

Challenges?

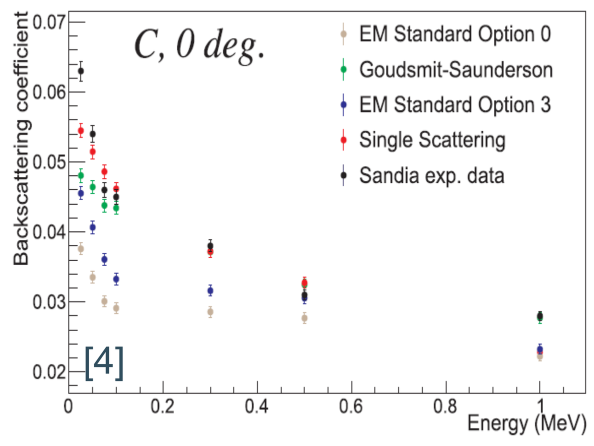
Statistical

- **~10^8 decays** required to extract a value for the WM form factor
  → For a 20 kBq source:~ 12h
- **Stability** in time is crucial:
  e.g. electronic drifts

Relative error on the WM form factor



Backscattering on Carbon at normal incidence

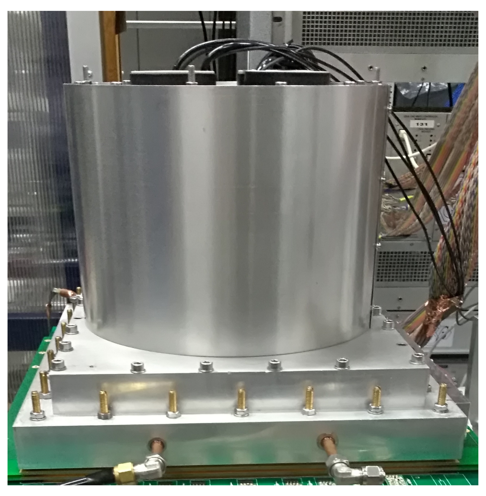


Systematic

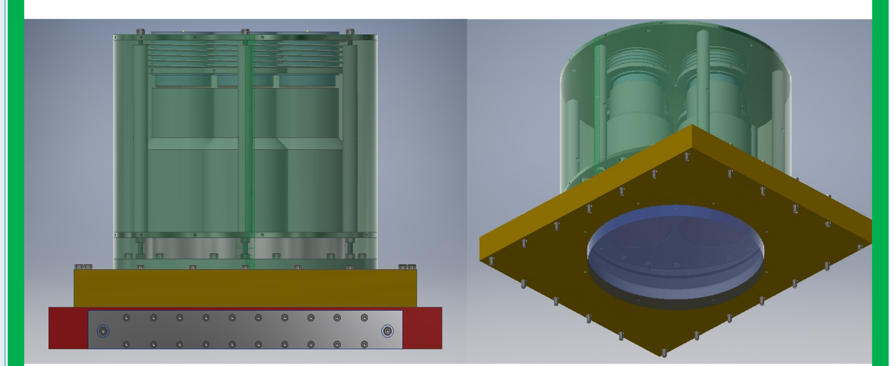
- **Back scattering** is the main source of systematic uncertainty
  → Partial energy deposition
- Increasing accuracy in **Geant4** scattering models

How?

Scintillator



Plastic: EJ-204 (Eljen technology)
Cylinder: h=30mm, r=100mm
4 PMTs: XP3330 (Photonis)



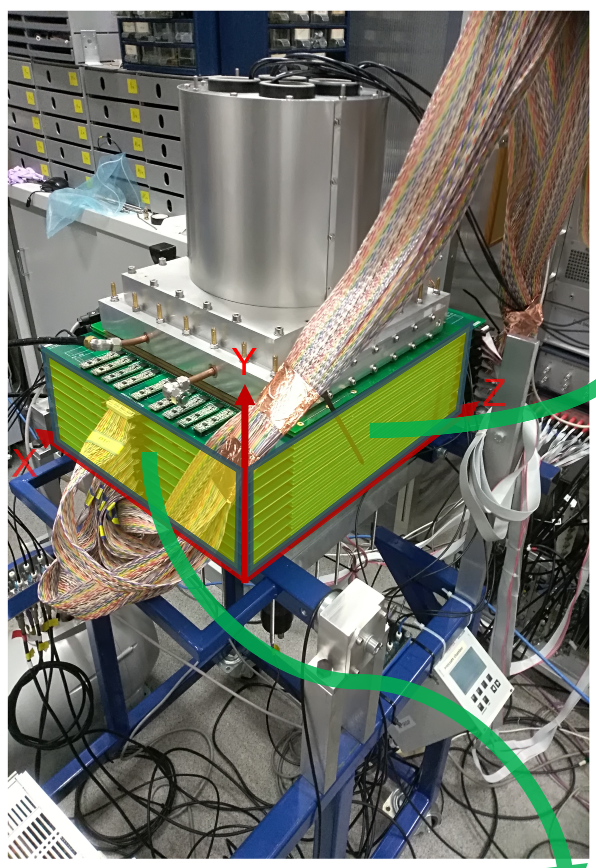
Advantages

- Low **backscattering coefficient** (~2–7%)
- Low amount of **brehmsstrahlung** (<10%) [5]

Disadvantages

- Low **energy resolution** (~5-20%)
- High **non-uniformity** in light collection efficiency (~15-20%)

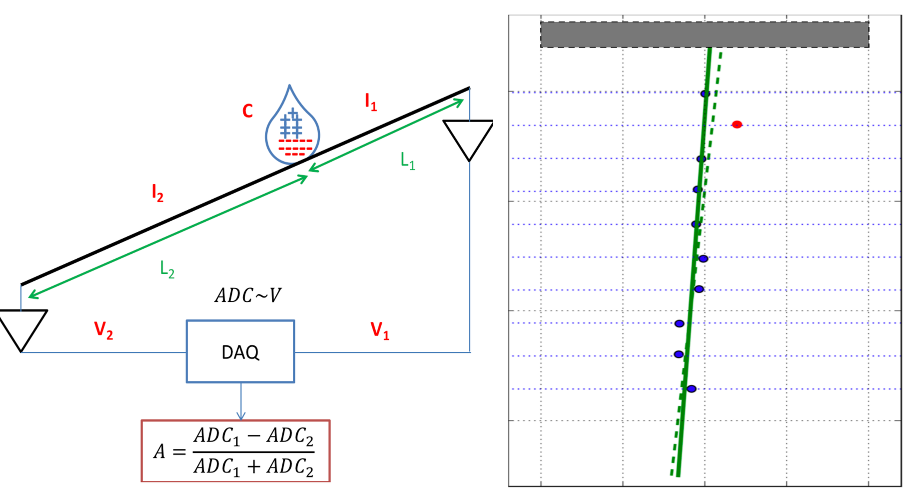
miniBETA



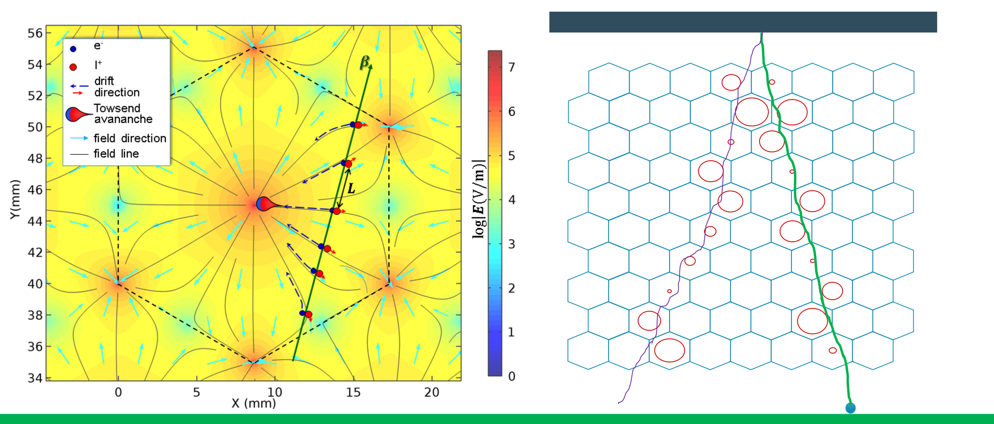
Multi-Wire Drift Chamber (MWDC)

- **Recognize back-scattered** electrons as *V-tracks*
- **Reduce background** from *gamma's and cosmic muons*
- **Correct for gain non-uniformity** by reconstructing the scintillator hit position

Tracking in ZY-plane



Tracking in XY-plane



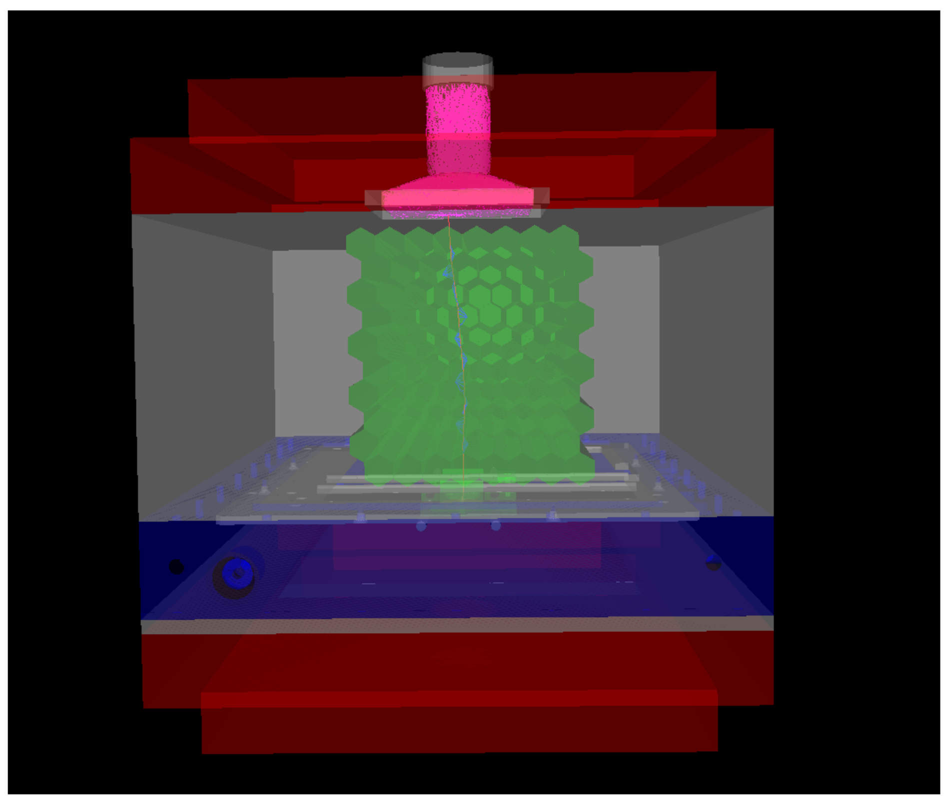
MWDC properties

- Mixture of **Helium** and **Isobutane** (20-50%)
- **Low pressure** (*300-600mbar*)
- **Signal wires** at *~2000V*
- **Field wires** at *ground-level*

Monte-Carlo simulations

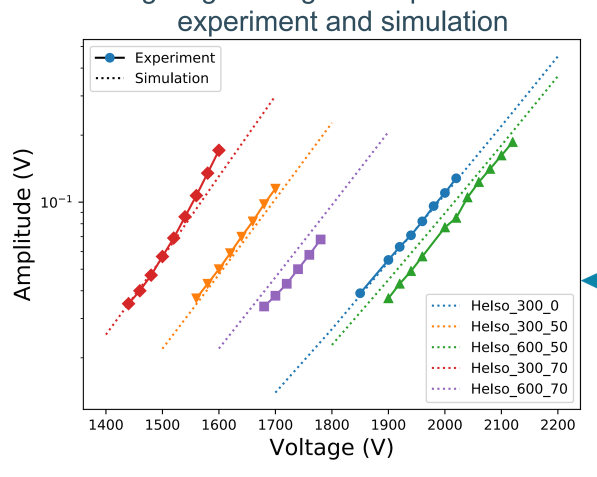
- **Geant4**
  - Detector geometry
  - Particle tracking
- **Garfield++**
  - Ionization and electron drift
  - Signal readout

*→Goal: **Interface Geant4 and Garfield++** and fully simulate events in order to support the measurements* [6]



Results

Average signal height: comparison between experiment and simulation



Signal height versus voltage

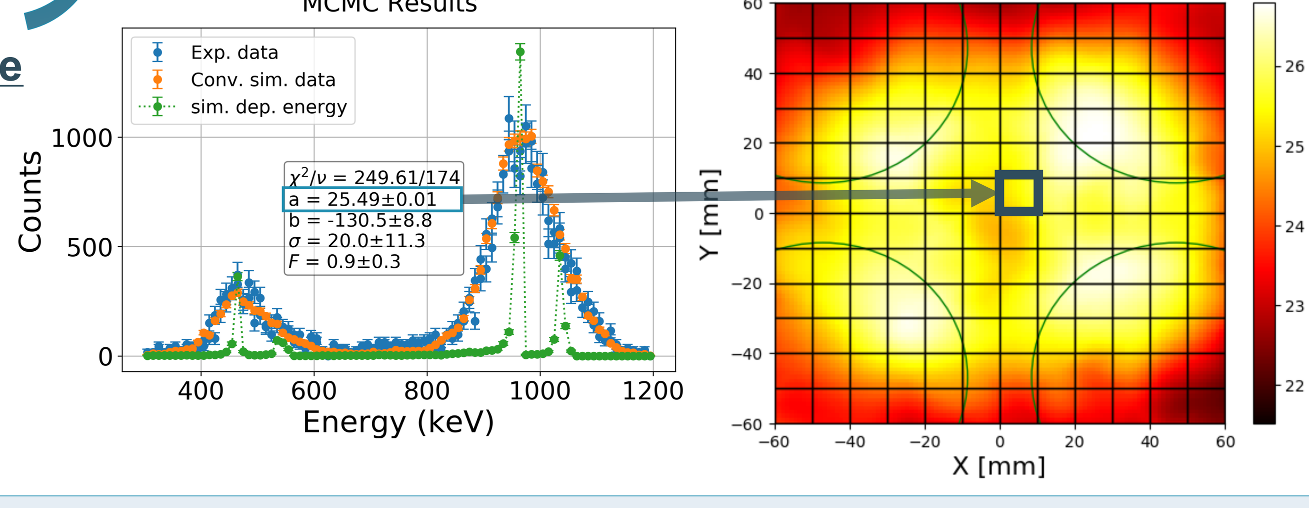
- Average signal height from muonic data for:
  → Different gas mixtures
  → Increasing Voltage
- Very **good agreement** with simulation
- Remaining discrepancy due to inaccuracies in **Penning effect**

2D-gain map

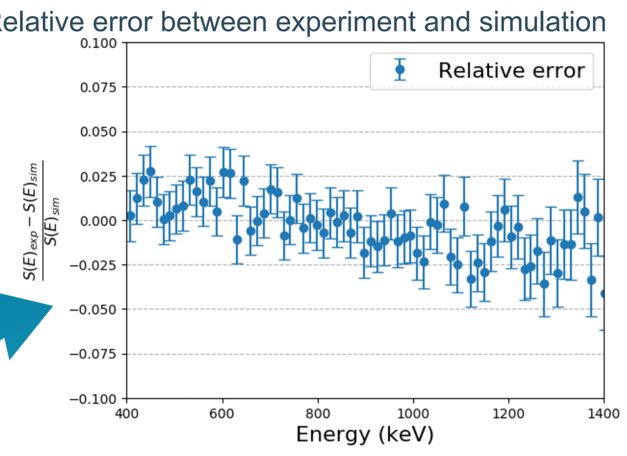
- Scintillator calibration with **Bizmuth-207**:
  → *2 e⁻ conversion peaks at ~500 keV and 2 peaks at ~1 MeV*
- Model of the detector response includes a **linear** term with **offset**, a **noise** resolution and a **Fano** factor:

$$ADC = aE + b \quad \& \quad \sigma_E = \sigma_n + F\sqrt{E}$$

- Divide scintillator surface in a **grid of squares**
- Fit experimental spectrum with simulated spectrum using a **Markov Chain Monte Carlo (MCMC)** method
- **Extract gain** for each location and **map** the detector surface



Relative error between experiment and simulation



Preliminary ^{114}In results

Fairly good agreement between experiment and simulation but **systematic effects arise at the % level**

→ Origin: the track reconstruction algorithm is energy dependent!!!

Work in progress…

Conclusions

- The beta spectrum shape is sensitive to both **BSM physics** → *Fierz* and **uncharted SM physics** → *Weak Magnetism*
- **^{114}In → ^{114}Sn** is a good candidate to probe WM
- **Back-scattering** and **non-uniform light collection efficiency** are monitored by a **MWDC**
- Proof of principle: **2D gain map** of the scintillator surface
- Preliminary comparison of the ^{114}In spectrum with simulation: **systematics at the % percent level due to the track reconstruction algorithm** *→ requires further analysis!*

References

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[2] A. Hayes and P. Vogel, Reactor neutrino spectra. Annu. Rev. Nucl. Part. Sci. 66(2016) 219-244
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[4] P. Dondero et al., Electron backscattering simulation in Geant4. Nucl. Instr. and Meth. A 425(2018)
[5] G. Soti, Search for a tensor component in the weak interaction Hamiltonian. PhD thesis (2013)
[6] D. Pfeiffer and L. De Keukeleere, Interfacing Geant4, Garfield++ and Degrad for the simulation of gaseous Detectors. Nucl. Instr. and Meth. A 935(2019)