WISArD - Probing beyond SM with beta delayed protons

Marcin Pomorski
CENBG, IN2P3, CNRS

Seminarium ZFJ FUW
25th March 2021

Outline

- What and why? Physics motivation behind the experiment
- How? The setup of WISArD
- When and where? Proof of principle experiment.
- What do we do now…
- ... and what will we do soon.

WISArD?

- WISArD stands for Weak-Interaction Studies with Ar^{32} Decay
- The aim of the experiment is to put stringent (rivaling those of LHC experiments) limits on exotic currents in β-decay by measuring correlations between β particle and proton in β-delayed proton emissions...

Theoretical basis

- Let us consider pure Fermi and Gamov-Teller β decays.
- In framework of effective field theory those are vector scalar and axial-vector tensor transitions, respectively

$$\begin{aligned}\mathcal{L}_{\text{Lee-Yang}} = & -\bar{p}\gamma^{\mu}n\left(C_V\bar{e}\gamma_{\mu}\nu - C'_V\bar{e}\gamma_{\mu}\gamma_5\nu\right) + \bar{p}\gamma^{\mu}\gamma_5 n\left(C_A\bar{e}\gamma_{\mu}\gamma_5\nu - C'_A\bar{e}\gamma_{\mu}\nu\right) \\ & - \bar{p}n\left(C_S\bar{e}\nu - C'_S\bar{e}\gamma_5\nu\right) - \frac{1}{2}\bar{p}\sigma^{\mu\nu}n\left(C_T\bar{e}\sigma_{\mu\nu}\nu - C'_T\bar{e}\sigma_{\mu\nu}\gamma_5\nu\right) \\ & - \bar{p}\gamma_5 n\left(C_P\bar{e}\gamma_5\nu - C'_P\bar{e}\nu\right) + \text{h.c.}\end{aligned}$$

- According to SM there are no contributions to β-decays from scalar and tensor currents

Angular correlations

- The nature of the β-decays affects the angular distribution between β particle and neutrino in β-decays.

$$w(E_e, \Omega_e, \Omega_\nu) \propto w_0(Z, E_e)\left(1 + \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} a_{\beta\nu} + \frac{m_e}{E_e} b\right)$$

- Both α angular-correlation coefficient and b Fierz term depend on the C_n coefficients

Correlations, correlation..

- Fermi decays:

$$a_{\beta\nu_F} \approx 1 - \frac{|C_S|^2 + |C_S'|^2}{|C_V|^2},$$

$$b_F \approx \pm Re\left(\frac{C_S + C_S'}{C_V}\right)$$

- Gamov-Teller decays:

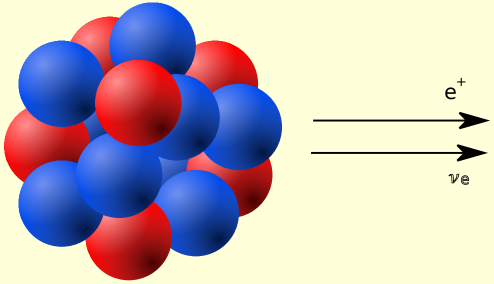
$$a_{\beta\nu_{GT}} \approx -\frac{1}{3}\left[1 - \frac{|C_T|^2 + |C_T'|^2}{|C_A|^2}\right]$$

$$b_{GT} \approx \pm Re\left(\frac{C_T + C_T'}{C_A}\right)$$

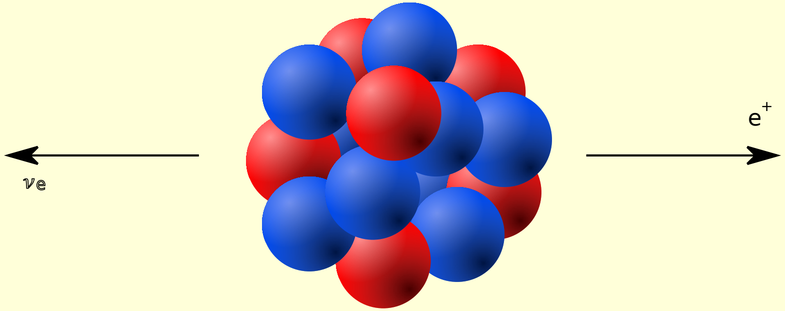
$$\tilde{a}_{\beta\nu} \approx a_{\beta\nu}/(1 + \alpha b),$$

Let’s take a step back

- One can not measure angular distribution of neutrino…
- But one can observe daughter nucleus recoil...
- Let’s consider Fermi transition:



vector

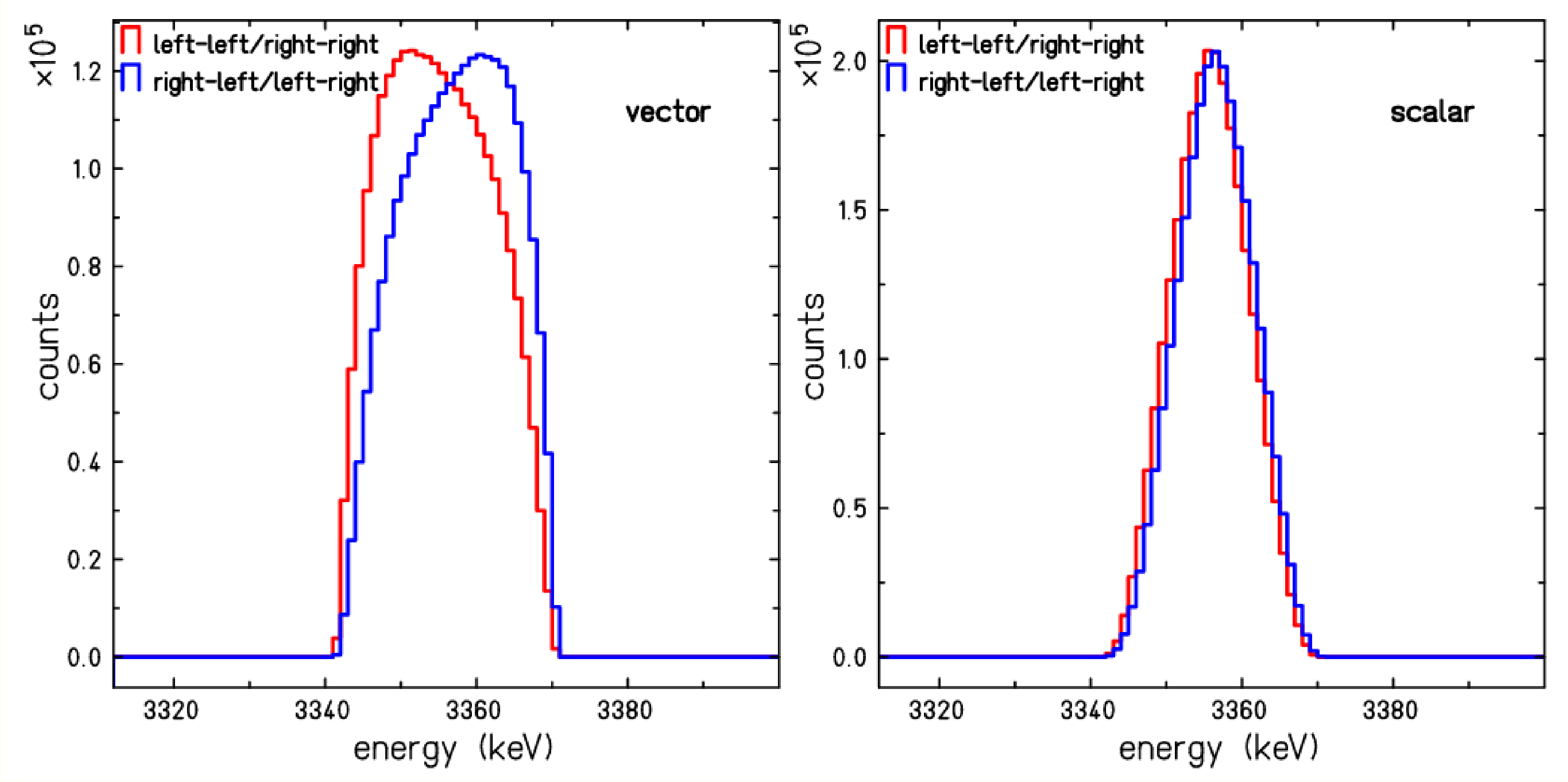


scalar

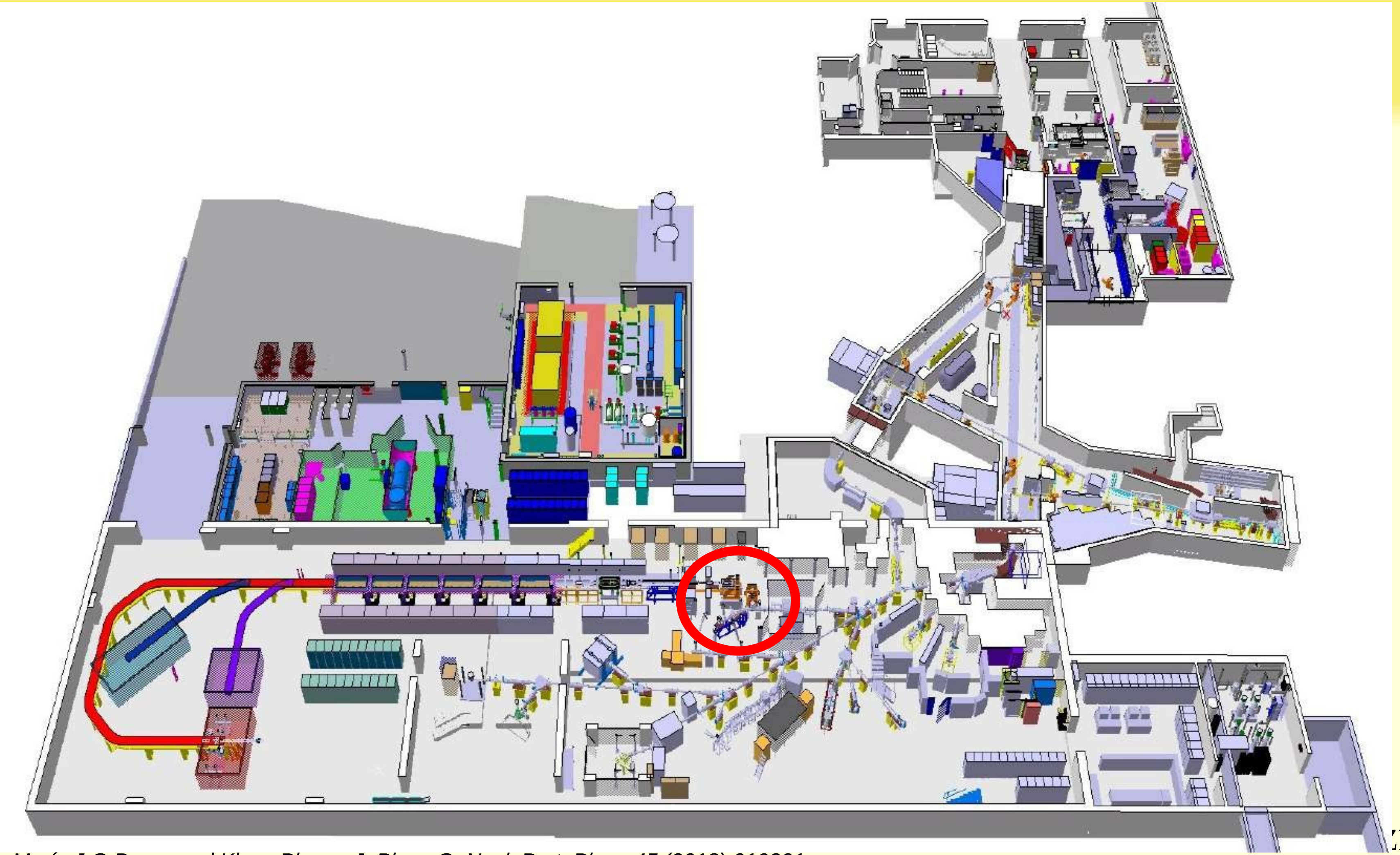
How to measure recoil and β?

- We may use β-delayed proton emission.
- When the proton is emitted, it’s energy in LAB will depend on the recoil energy in CM.
- Bonus: one can use proton energy to gate pure Fermi transitions!

Let’s take another step back



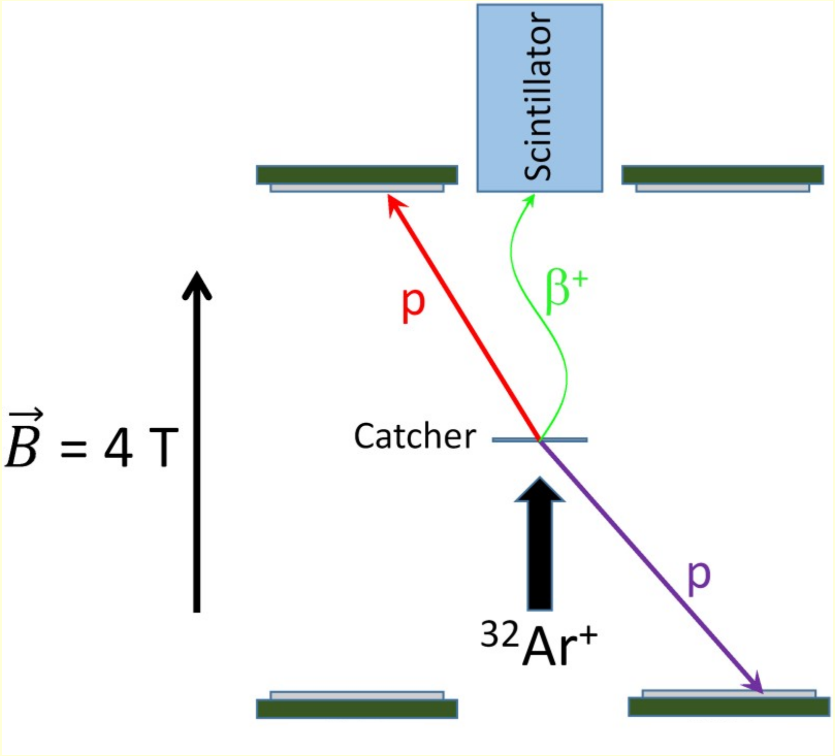
N Severijns and B Blank
J. Phys. G: Nucl. Part. Phys.44(2017)074002



María J G Borge and Klaus Blaum, J. Phys. G: Nucl. Part. Phys. 45 (2018) 010301

The setup (schematic)

- Instead of large β detector, the measurement is done in strong magnetic field
- This field gives us effective 2π coverage for electrons
- Notice only one scintillator



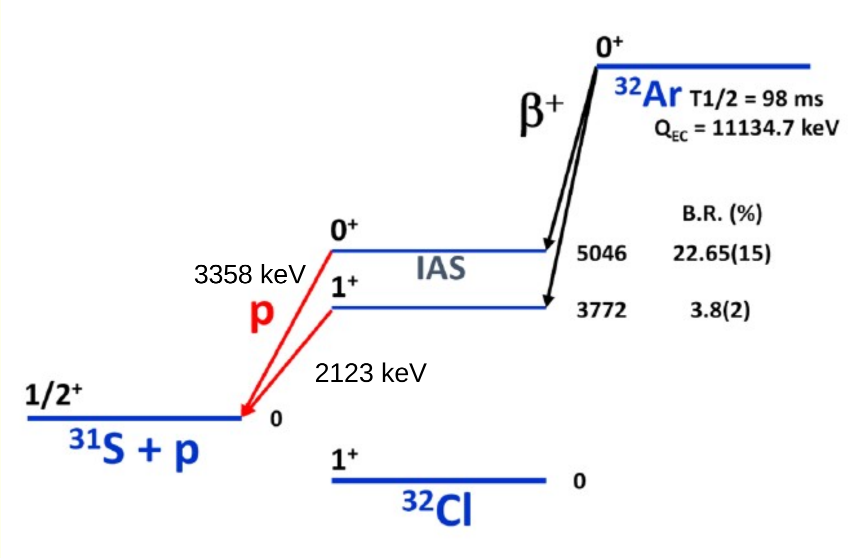
V. ARAUJO-ESCALONA et al. PHYSICAL REVIEW C 101, 055501 (2020)

What’s the catch?

- When you want to achieve 10^{-3} precision, every part of the setup is a catch
- Now that we simplified physics we need to complicate the design...

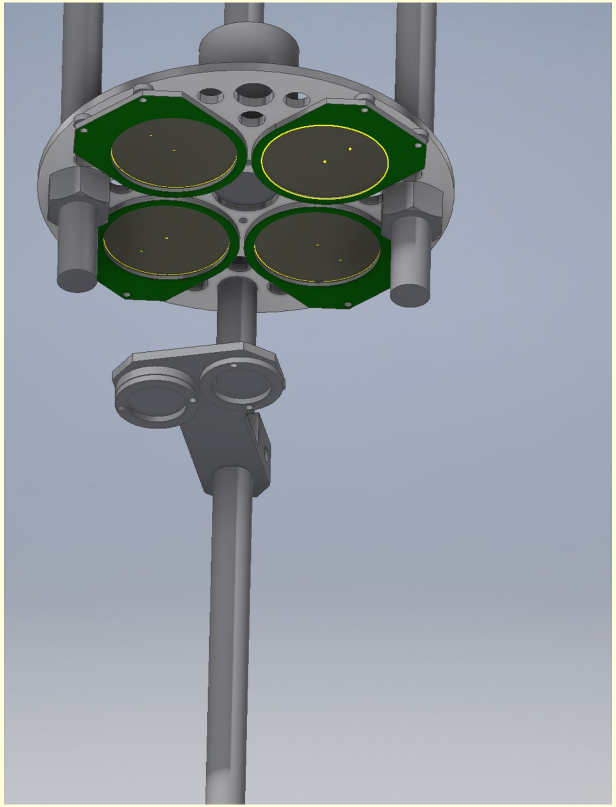
Case of Ar^{32}

- Well known structure
- Good production with ISOL technique
- Possible to measure both pure Fermi and pure GT transitions in single experiment.



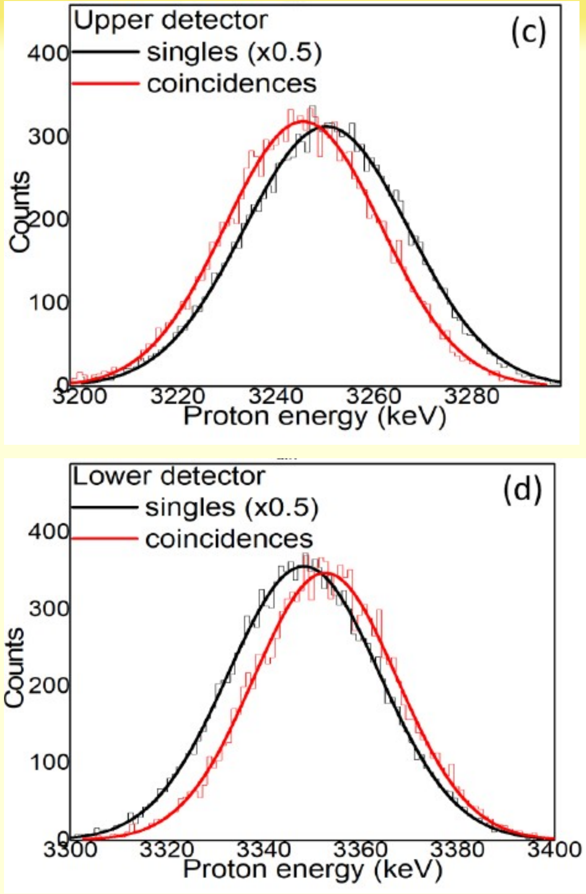
Proof of principle experiment

- Performed soon before LS2
- Used whatever hardware was on the shelf
- Only around 35h of beam
- Results published:
  V. Araujo-Escalona et al.
  PHYSICAL REVIEW C 101, 055501 (2020)

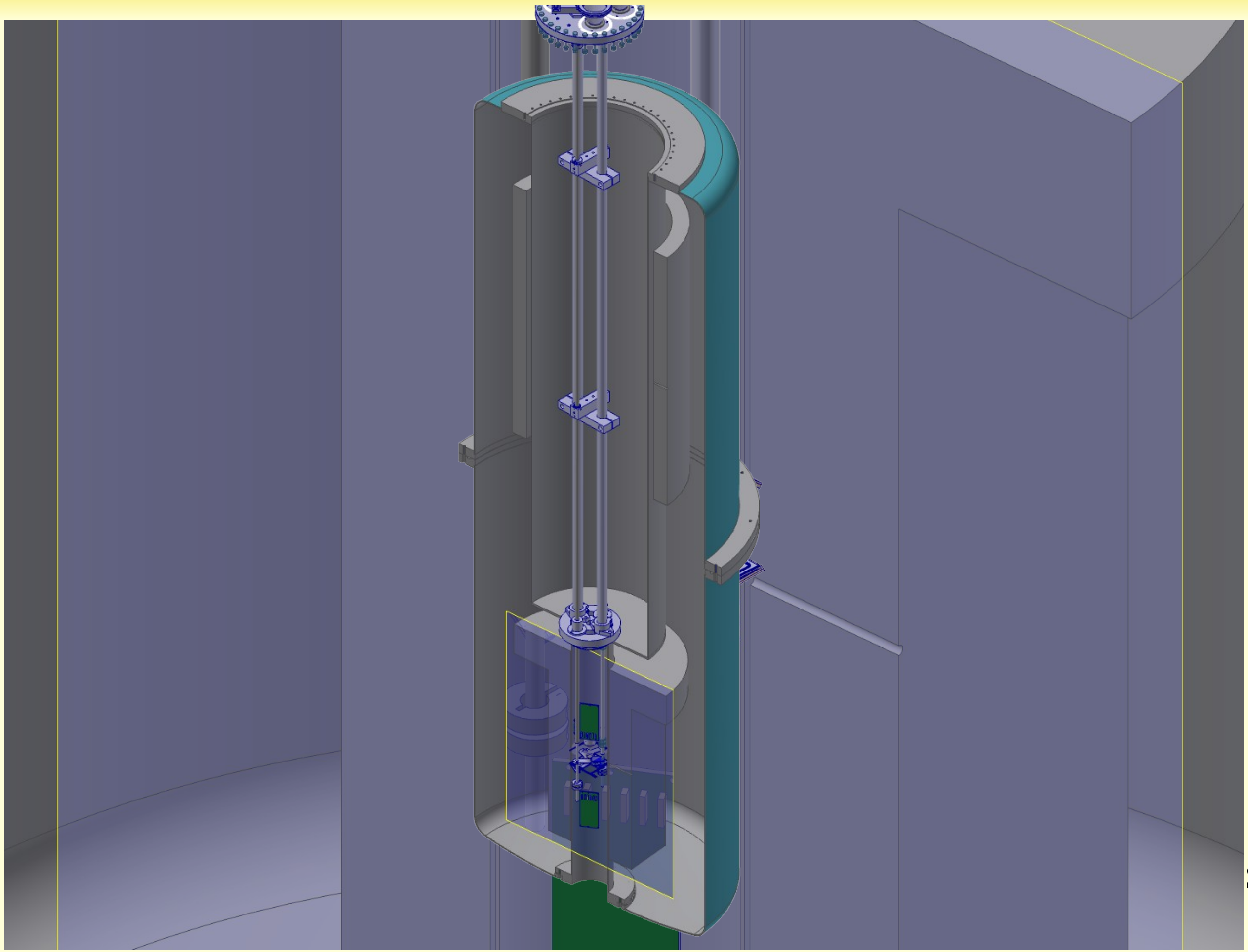


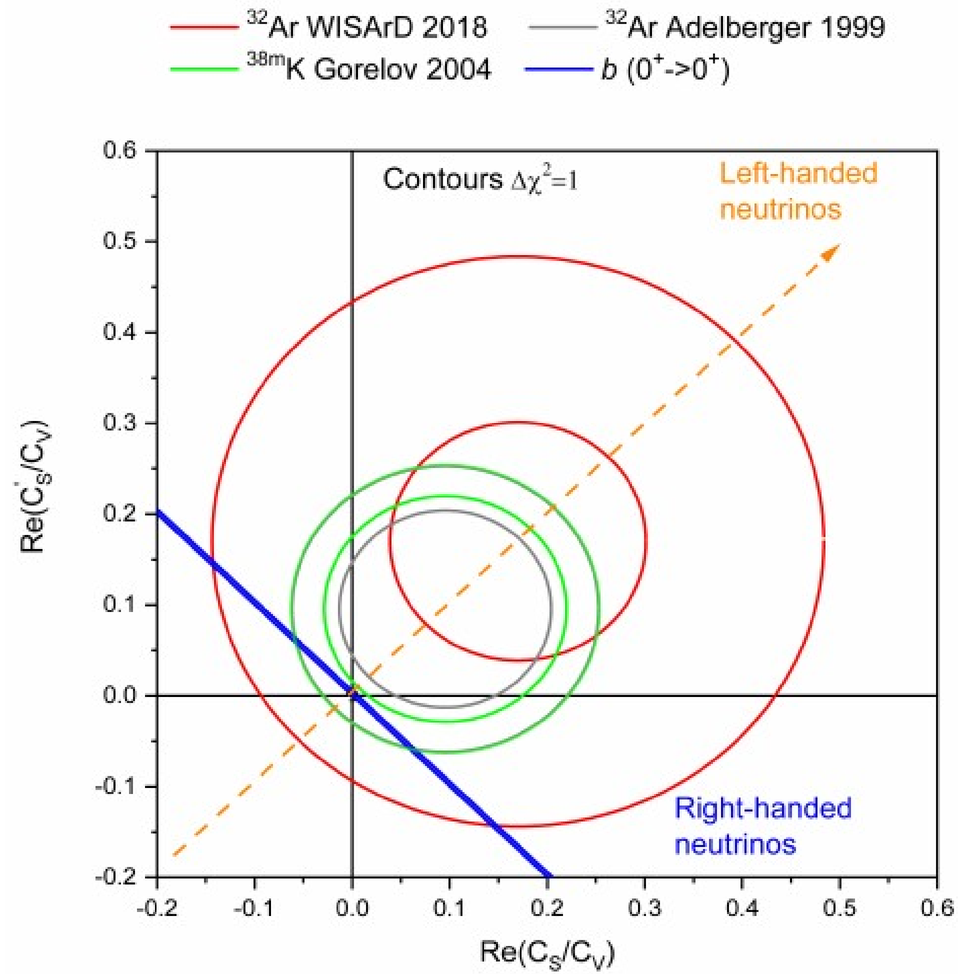
Proof of principle results

- $\tilde{a}_{\beta\nu\ \mathrm{Fermi}} = 1.007(32)_{\mathrm{stat}}\ (25)_{\mathrm{syst}}$
- $\tilde{a}_{\beta\nu\ \mathrm{GT}} = -0.222(86)_{\mathrm{stat}}\ (16)_{\mathrm{syst}}$
- This is in agreement with expected values of 1 and -1/3
- Interestingly - this is 3rd most precise measurement of $\tilde{a}_{\beta\nu}$ in pure Fermi transition so far

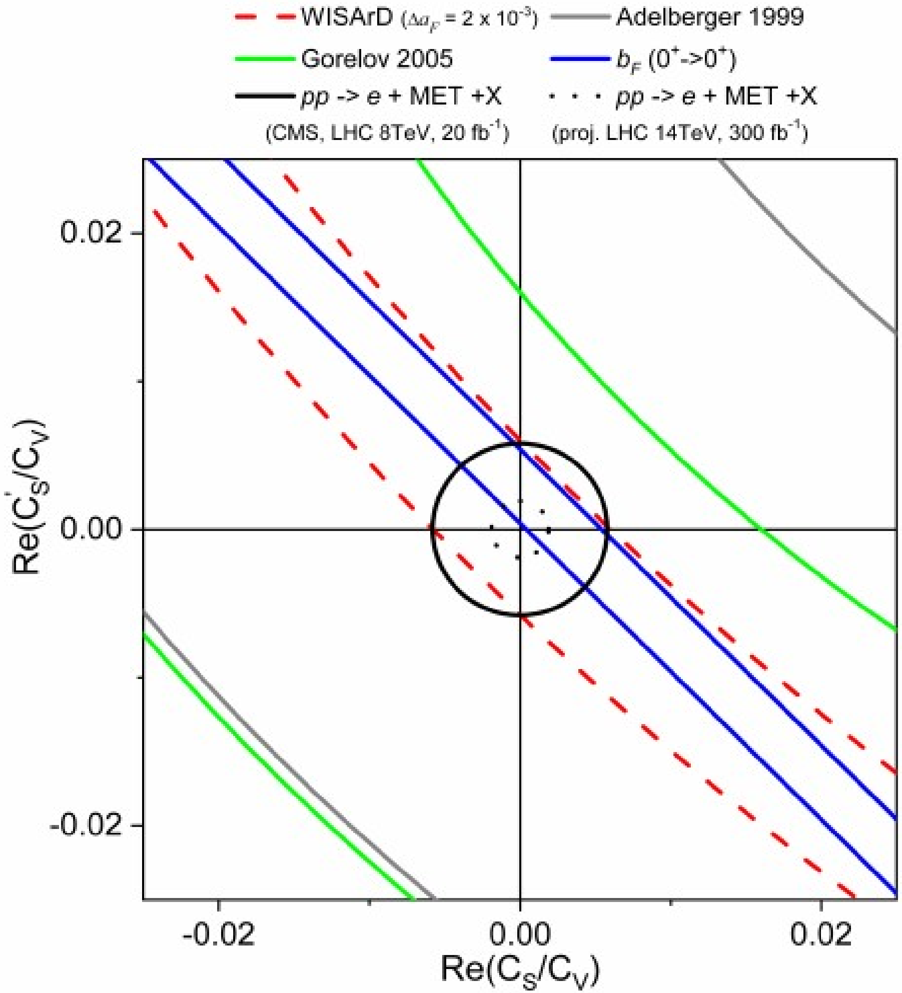


Final setup is a bit more complicated...





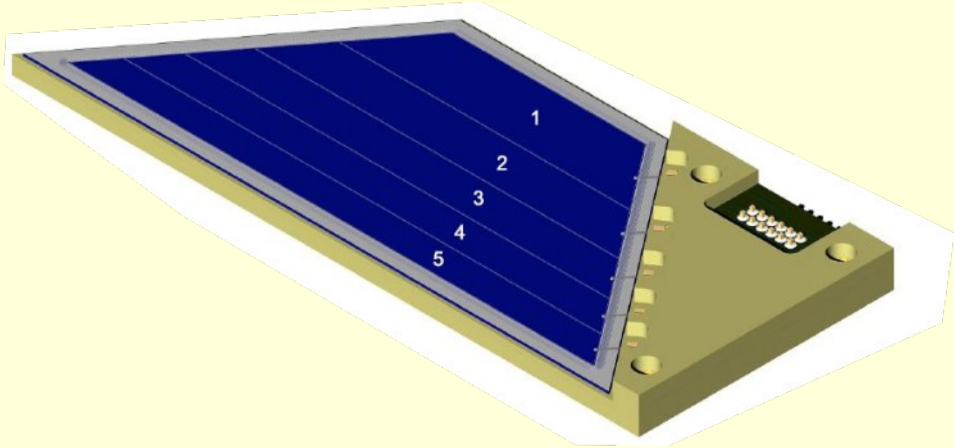
32Ar WISArD 2018
32Ar Adelberger 1999
38mK Gorelov 2004
b (0+->0+)
Contours Δχ2=1
Left-handed neutrinos
Right-handed neutrinos
Re(C'S/CV)
Re(CS/CV)

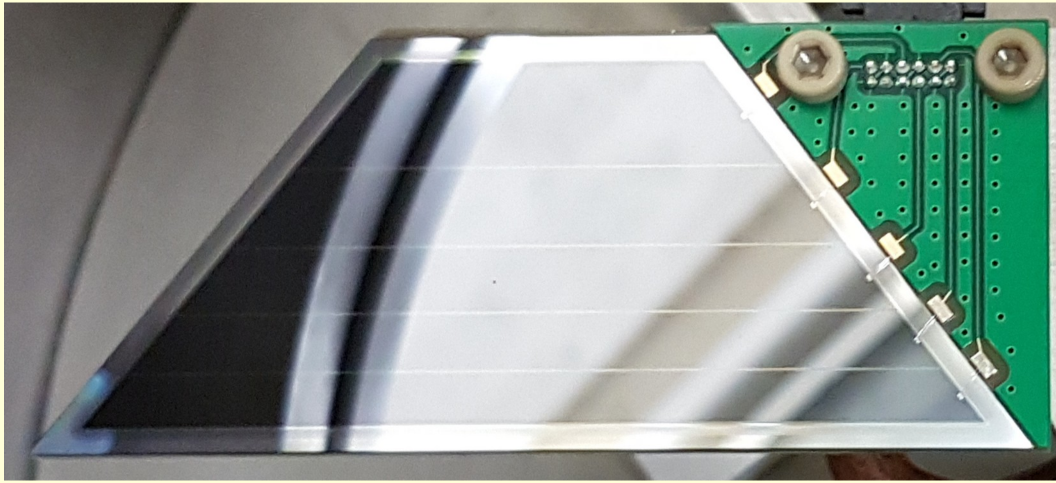


WISArD (ΔaF = 2 x 10-3)
Adelberger 1999
Gorelov 2005
bF (0+->0+)
pp -> e + MET +X (CMS, LHC 8TeV, 20 fb-1)
pp -> e + MET +X (proj. LHC 14TeV, 300 fb-1)
Re(C'S/CV)
Re(CS/CV)

My part - Silicon detectors

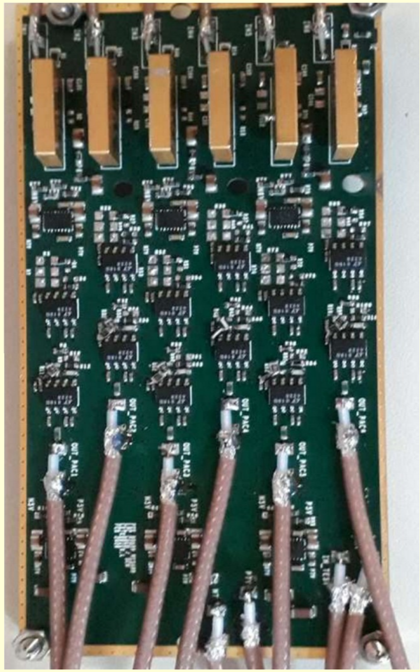
- Custom made
- 5 strips with almost the same area each
- Dead layer under 100nm
- Expected resolution under 10 keV FWHM





Comes in set with pre-amp

- High resolution, high density
- Made at LPC Caen

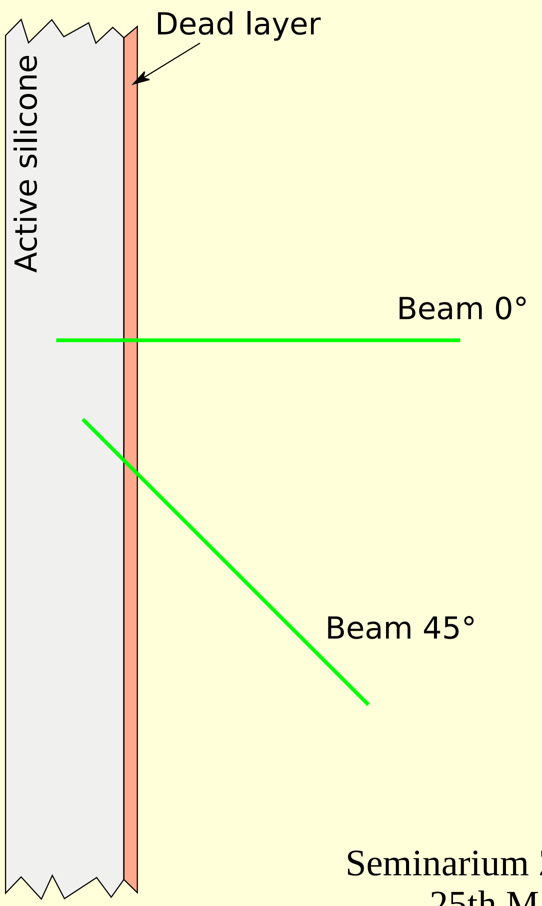


Things to check

- Temperature study - find the point of diminishing returns
- Test entire set ACQ - preamp – detector
- Measure dead layer
- Confirm resolution

Measuring dead layer

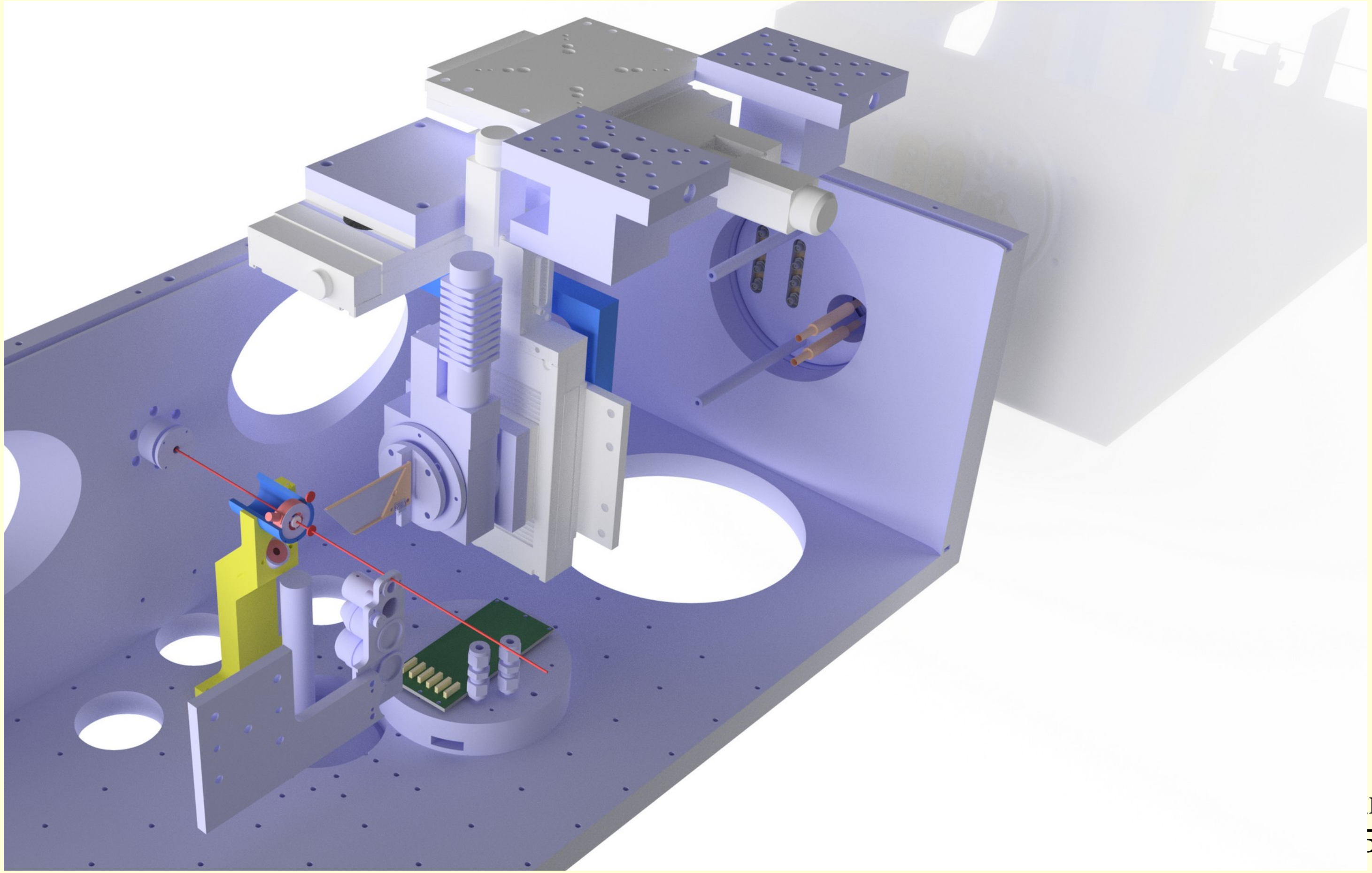
- Deal layer results in energy shift when changing angle
- AIFIRA excellent energy stability is ideal for this.



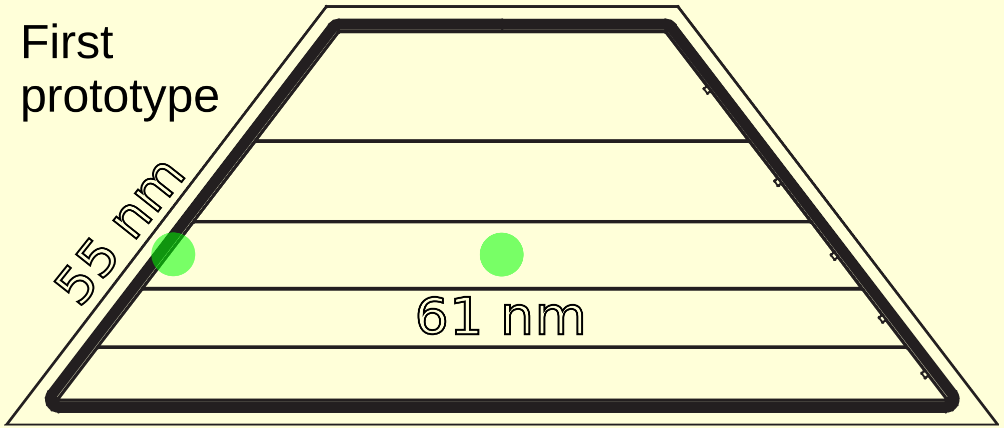
AIFIRA accelerator

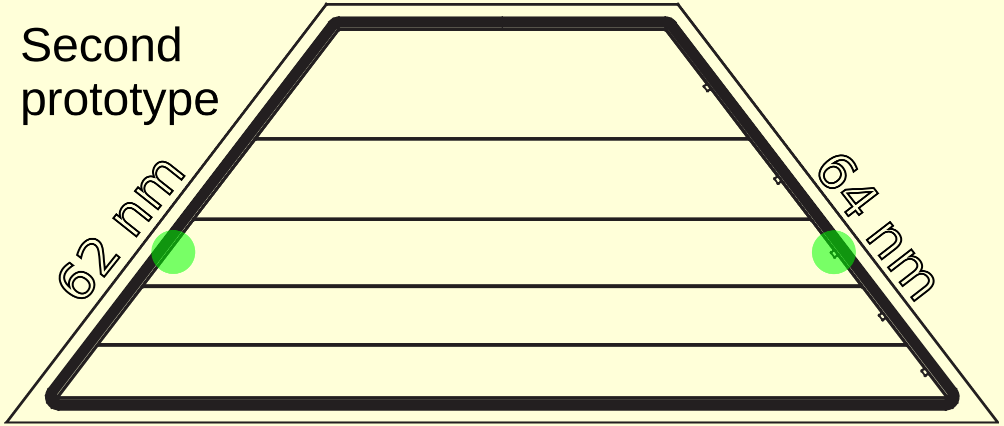
- Electrostatic accelerator here in CENBG
- Good energy stability and intensity control

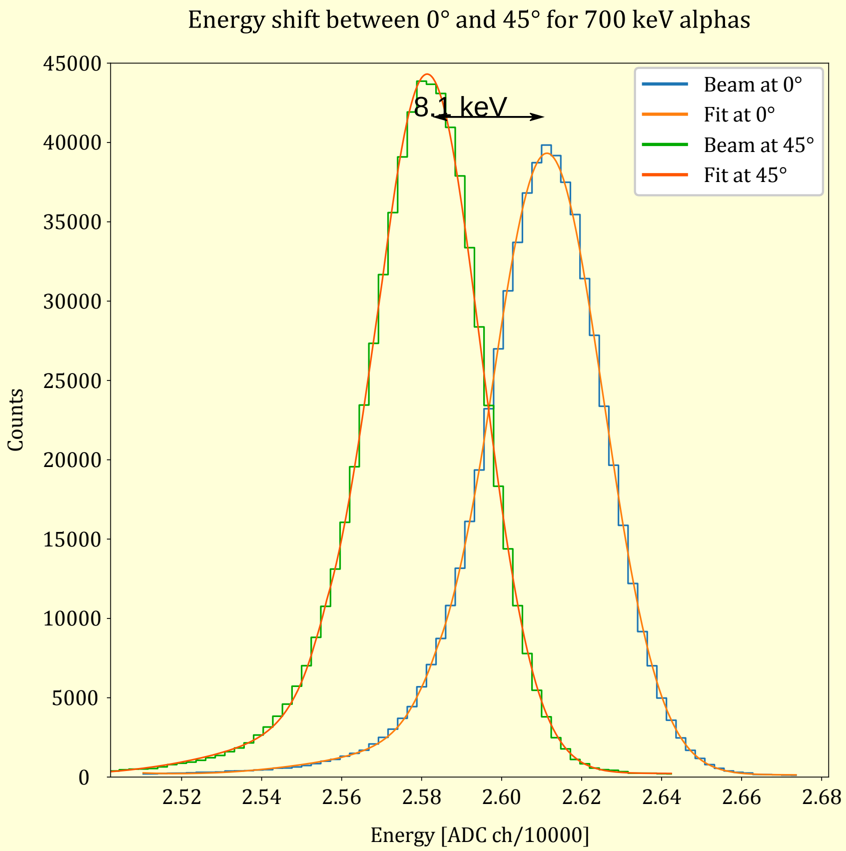
AIFIRA nano chamber



Energy shift and dead layer estimation







Is 60nm thin enough?

- On average we observed thickness of 61 ± 4nm
- This corresponds to shift of ~1 keV for protons in actual experiment
- Resolution of the detector also looks good.

σ values in keV

Run \ Strip	2	3	4	5
2	3.79 ± 0.02	3.78 ± 0.01	-	-
3.1	-	3.64 ± 0.02	4.29 ± 0.05**	5.21 ± 0.02
3.2	-	3.56 ± 0.02	4.20 ± 0.06**	$5.20 \pm 0.03\%$
4	-	3.59 ± 0.02	4.40 ± 0.07**	5.56 ± 0.04
5	3.81 ± 0.02	3.70 ± 0.02	-	-
6	-	3.95 ± 0.01	-	-
7	-	$3.46 \pm 0.04\%$	3.61 ± 0.04	4.44 ± 0.03
8*	-	3.36 ± 0.05	3.67 ± 0.05	4.25 ± 0.04
9*	-	3.50 ± 0.03	-	-
10*	3.87 ± 0.04	3.61 ± 0.05	-	-
11*	-	3.38 ± 0.04	3.54 ± 0.04	3.98 ± 0.06

Outlook

- Most of design is final, we are ordering the hardware
- 7 more Si detectors are coming
- Detectors measurements are progressing
- Magnetic field verified
- Assembly late this year?

Thank you for your attention