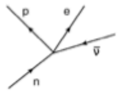
Search for S and T currents with ^{32}Ar

M.Versteegen
P.Alfaurt, D.Atanasov, P.Ascher, B.Blank, F.Cresto, L.Daudin, X.Fléchard, A.Husson, A.Garcia, M.Gerbaux, J.Giovinazzo, S.Grévy, J.Ha, R.Lica, E.Liénard, D.Melconian, C.Mihai, M.Nasser, C.Neacsu, A.Ortega-Moral, M.Pomorski, M.Roche, N.Severijns, S.Vanlangendonck, D.Zakoucky

PhyNuBE
26-31 March 2023

Weak exotic couplings

- **Lee-Yang Lagrangian : n beta decay**



$$\begin{aligned}
-\mathcal{L}_{LY} &= C_V \left(\bar{p}\gamma^{\mu} n + \frac{C_A}{C_V}\bar{p}\gamma^{\mu}\gamma_5 n\right) \times \bar{e}\gamma_{\mu}(1-\gamma_5)\nu_e \\
&+ C_S\,\bar{p}n \times \bar{e}(1-\gamma_5)\nu_e + \frac{1}{2}\,C_T\,\bar{p}\sigma^{\mu\nu}n \times \bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e + hc \\
&+ \mathit{right\text{-}handed\ \ neutrinos}
\end{aligned}$$

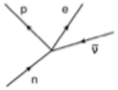
SM “V-A” structure

Exotic couplings : S and T
P omitted

M. González-Alonso, Colloque GANIL (2019)
T.Lee, C-N Yang Phys. Rev. 104 (1956)

Weak exotic couplings

- **Lee-Yang Lagrangian : n beta decay**



$$-\mathcal{L}_{LY} = C_V\left(\bar{p}\gamma^{\mu}n + \frac{C_A}{C_V}\bar{p}\gamma^{\mu}\gamma_5 n\right) \times \bar{e}\gamma_{\mu}(1-\gamma_5)\nu_e$$

$$+ C_S\,\bar{p}n \times \bar{e}(1-\gamma_5)\nu_e + \frac{1}{2}\,C_T\,\bar{p}\sigma^{\mu\nu}n \times \bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e + hc$$

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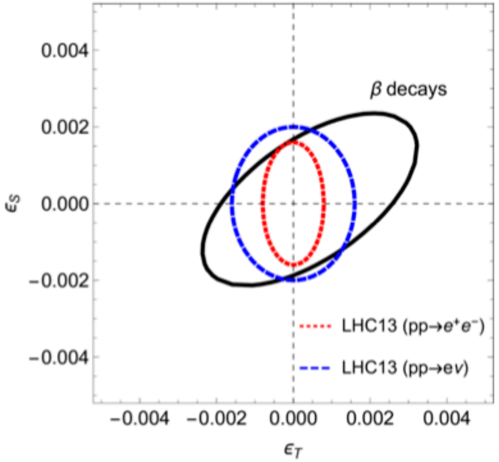


- **Effective Field Theory**

Model independent approach : no assumption on NP origin

Wilson coefficients at quark level :

$$\epsilon_i \propto \left(\frac{m_W}{\Lambda}\right)^2 \quad \sim 10^{-3}$$

TeV NP scale

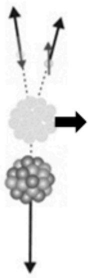
EFT

$$\overline{C}_V + \overline{C}'_V = 2\,g_V\,(1+\epsilon_L+\epsilon_R)$$
$$\overline{C}_A + \overline{C}'_A = -2\,g_A\,(1+\epsilon_L-\epsilon_R)$$
$$\overline{C}_S + \overline{C}'_S = 2\,g_S\,\epsilon_S$$
$$\overline{C}_P + \overline{C}'_P = 2\,g_P\,\epsilon_P$$
$$\overline{C}_T + \overline{C}'_T = 8\,g_T\,\epsilon_T$$

M. González-Alonso, Colloque GANIL (2019)
T.Lee, C-N Yang Phys. Rev. 104 (1956)
M. González-Alonso, O. Naviliat-Cuncic, N. Severijns Prog. Part. Nucl. Phys. (2019)
A. Falkowski, M. González-Alonso, O. Naviliat-Cuncic JHEP04 (2021)

Nuclear beta decay

- **Decay rate distribution for polarized nuclei**



$$\frac{dW(\mathbf{J})}{dE_e d\Omega_e d\Omega_\nu} = dW_0 \times \xi \left\{ 1 + a \frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \frac{< \mathbf{J} >}{J} \cdot \left(A \frac{\mathbf{p}_e}{E_e} + B \frac{\mathbf{p}_\nu}{E_\nu} + D \frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu} \right) \right\}$$

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

Nuclear beta decay

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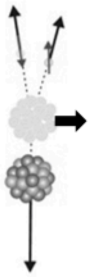

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β–ν correlation coefficient
CP conserving
Access to C_S and C_T quadratically

Fierz interference term
CP conserving
Access to C_S and C_T linearly

« D » coefficient
CP violating
Access to C_A, C_A', C_V, C_V' linearly

Correlation measurements
Beta spectrum shape measurements

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

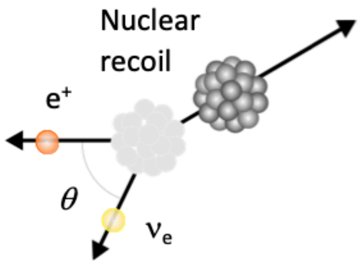
Angular correlation measurement

- **Decay rate for non polarized nuclei**

$$\frac{dW(\mathbf{J})}{dE_e d\Omega_e d\Omega_\nu} = dW_0 \times \xi \left\{1 + a\,\frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b\,\frac{m_e}{E_e} + \frac{<\mathbf{J}>}{J} \cdot \left(A\,\frac{\mathbf{p}_e}{E_e} + B\,\frac{\mathbf{p}_\nu}{E_\nu} + D\,\frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu}\right)\right\}$$

$$dW = dW_0 \times \xi \left(1 + a\,\frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b\,\frac{m}{E_e}\right)$$

$a > 0$: $\theta = 0°$ favored and large recoil
$a < 0$: $\theta = 180°$ favored and small recoil



Angular correlation measurement

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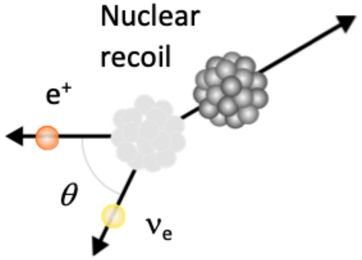


- **Correlation measurement = recoil measurement**

access to :

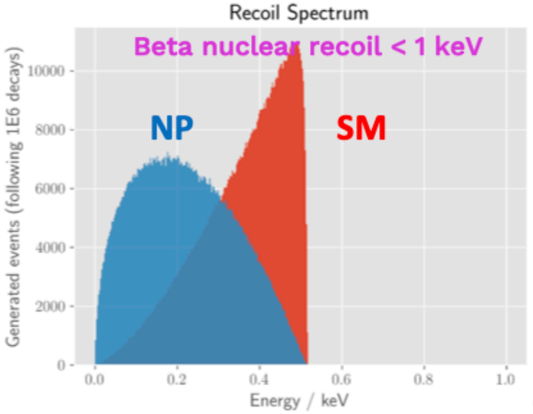
$$\tilde{a} \sim \frac{a}{1 + b < \frac{m_e}{E_e} >}$$

Pure Fermi transition ΔJ=0 S=0

Vector Coupling

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

$$b_F \approx \pm Re\left(\frac{C_S + C_S'}{C_V}\right)$$ **= 0**


Recoil Spectrum

Many Projects

$$\frac{dW(\mathbf{J})}{dE_e d\Omega_e d\Omega_\nu} = dW_0 \times \xi \left\{1 + a\,\frac{\mathbf{p}_e \cdot \mathbf{p}_\nu}{E_e E_\nu} + b\,\frac{m_e}{E_e} + \frac{<\mathbf{J}>}{J} \cdot \left(A\,\frac{\mathbf{p}_e}{E_e} + B\,\frac{\mathbf{p}_\nu}{E_\nu} + D\,\frac{\mathbf{p}_e \times \mathbf{p}_\nu}{E_e E_\nu}\right)\right\}$$

^{6}He @ LPC (Paul trap)
^{8}Li @ ANL (Paul trap)
^{6}He @ ANL (MOT)
^{32}Ar @ Texas A&M (Penning)
^{38m}K @ TRIUMF (MOT)
n @ aSPECT
n @ nab
...

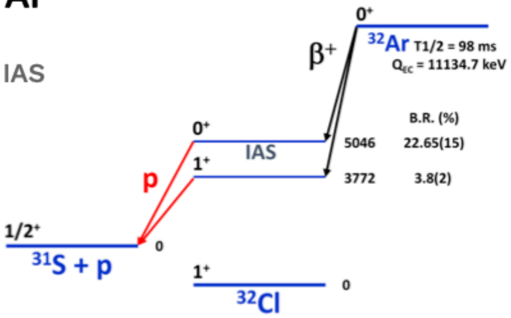
^{114}In @ ISOLDE
^{6}He @ LPC (bSTILED)
^{6}He @ NSCL
...

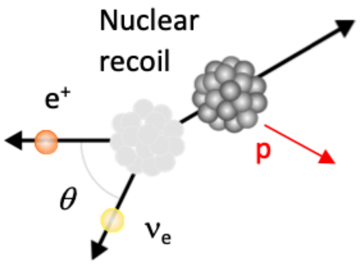
THE MORA PROJECT
MATTER'S ORIGIN FROM RADIOACTIVITY

The case of ^{32}Ar

- **β-delayed proton emission in ^{32}Ar**
  - ☐ Fermi $0^+ \longrightarrow 0^+$ transition from GS to IAS
  - ☐ Recoil energy ~640 eV
  - ☐ Beta delayed p emission ~3.3 MeV
  - ☐ IAS : Γ ~ 20 eV ⇔ $T_{1/2}$ ~ 10^{-17} s

➪ p emission in flight from the recoil





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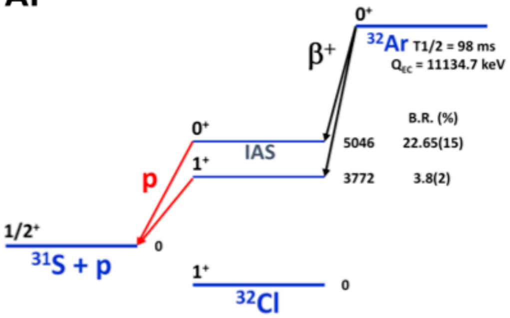

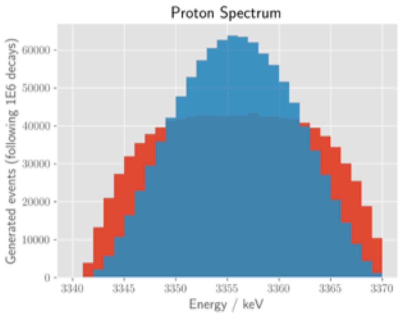

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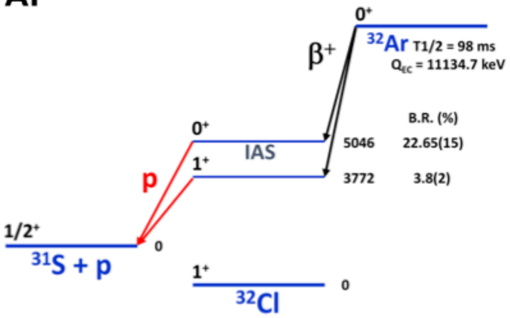
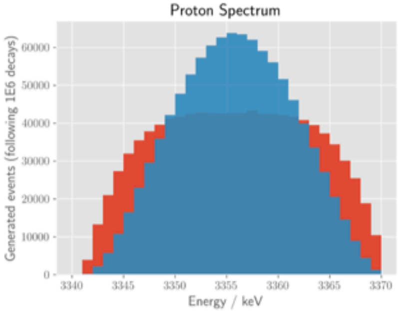
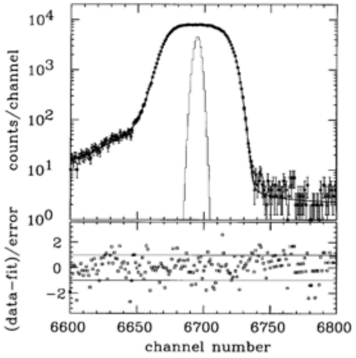




- **Broadening measurement**
  - ☐ ^{32}Ar beam at ISOLDE (60 keV)
  - ☐ 9x9 mm^2 cooled p-i-n diodes
    high resolution ~ 3 keV FWHM (pulser)
  - ☐ 3.5 T magnetic field

$$\tilde{a} = 0.9989(52)_{stat}(39)_{syst}$$

➯ precision level : 0.65%

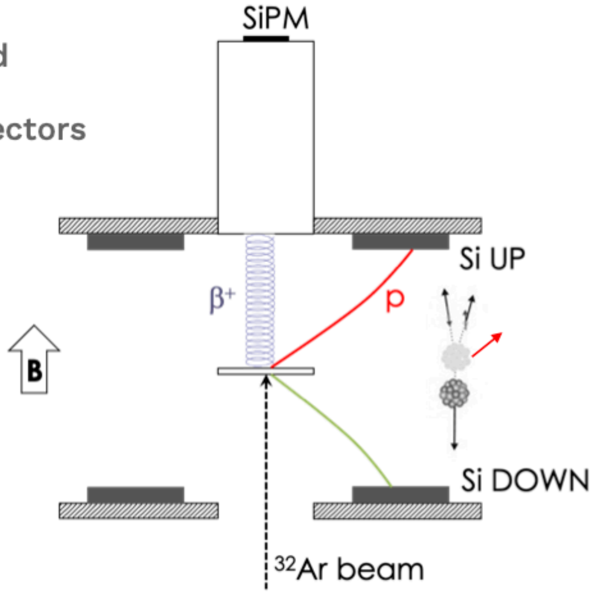


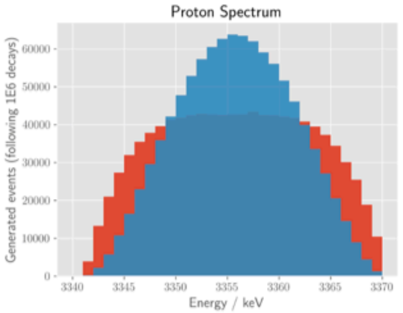
E. G. Adelberger et al. Phys. Rev. Lett. 83 (1999)

WISArD Weak Interaction Studies with ^{32}Ar Decay

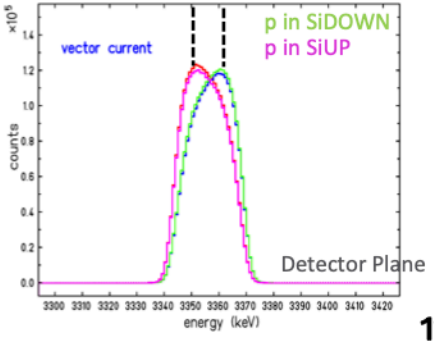
- **β-p coincidence measurement**
  - ☐ Strong magnetic field
  - ☐ 2 symmetrical p detectors
    high resolution
    high solid angle
  - ☐ Beta detector
    low detection threshold

➪ precision level : 0.1%

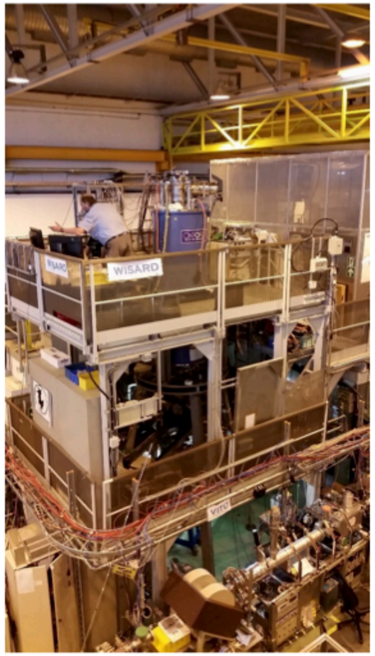


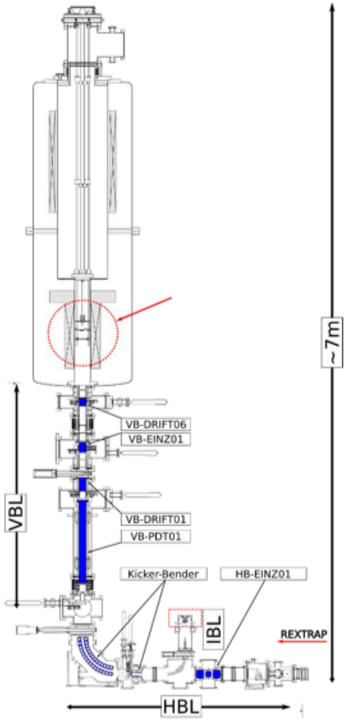


ΔE : linear with ã



WISArD setup @ISOLDE





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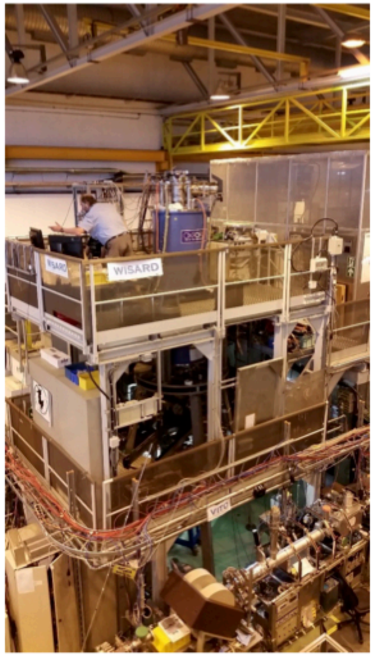
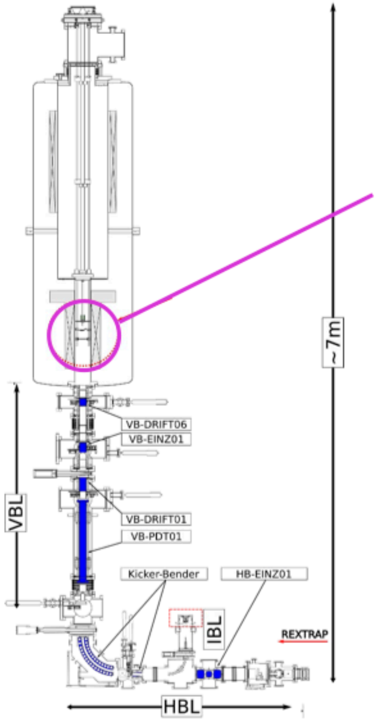
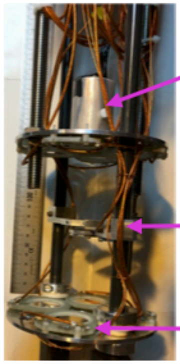




- **Proof-of-Principle Setup 2018**



β detector
plastic scintillator + 1 SiPM 6x6 mm^2
Hammamatsu

catcher
Al-mylar 6.7(1) µm

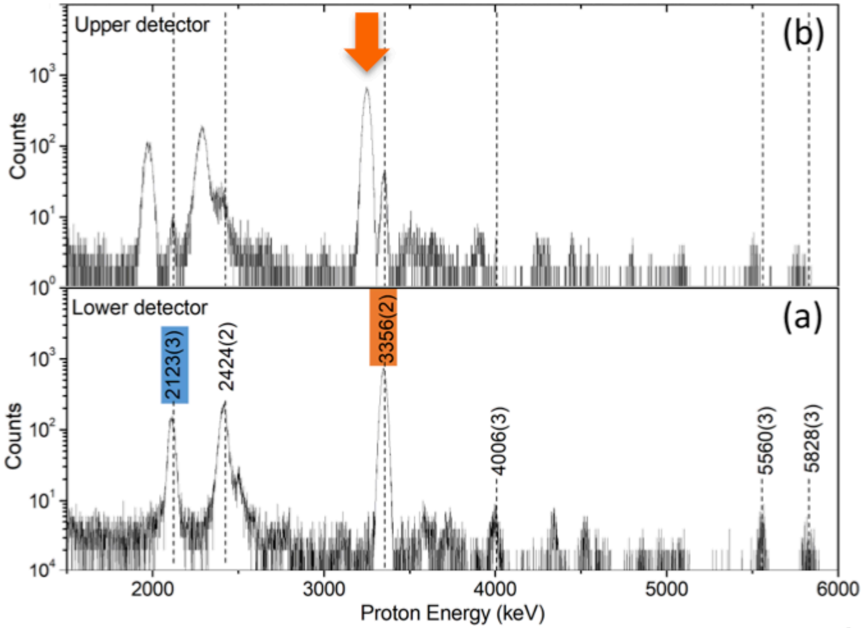
p detectors
2 x 4 Si surface barrier 300 µm
Dead layer ~ 430 (300) nm
Resolution ~ 35 keV

in B = 4 T
(WITCH magnet)

+ FASTER DAQ

Proof-of-Principle Experiment – 2018

- **Single p spectra calibration**
  - ☐ Si UP
    Catcher thickness
    dead layer
  - ☐ Si DOWN
    dead layer



V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

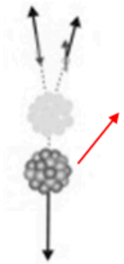
Proof-of-Principle Experiment - 2018

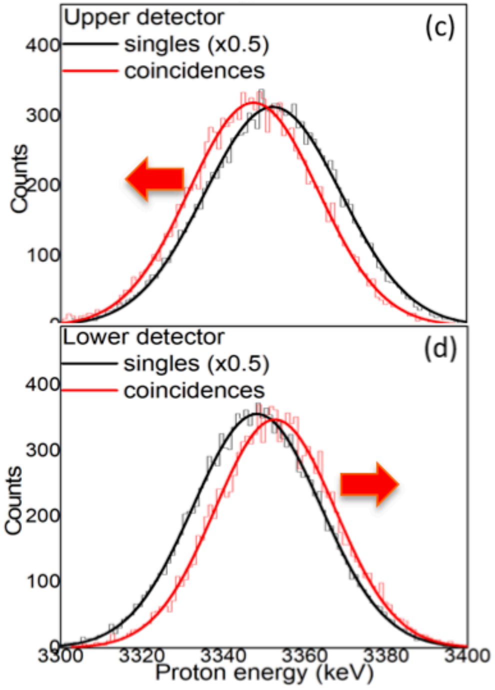
- **Single p spectra calibration**
  - ☐ Si UP
    Catcher thickness
    dead layer
  - ☐ Si DOWN
    dead layer
- **β-p coïncidence**

$$\Delta E = \left|\bar{E}_{coinc} - \bar{E}_{single}\right|$$

$$\Delta E_F = 4.49(3)\ keV$$

Mean value over 8 detectors





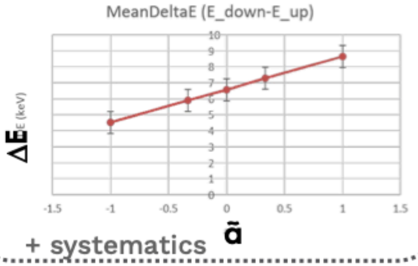
V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

Proof-of-Principle Experiment - 2018

- **Extraction of ã**

$\Delta E_F = 4.49(3)\ keV$

Monte Carlo simulations



+ systematics

$\tilde{a}_F = 1.007(32)_{stat}(25)_{syst}$

35h of beam
Ion transmission 12%
N_{coinc} ~ 10^5

➪ precision level : 4%

V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

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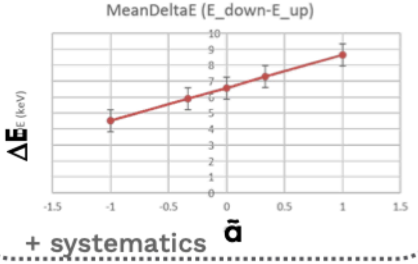

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V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

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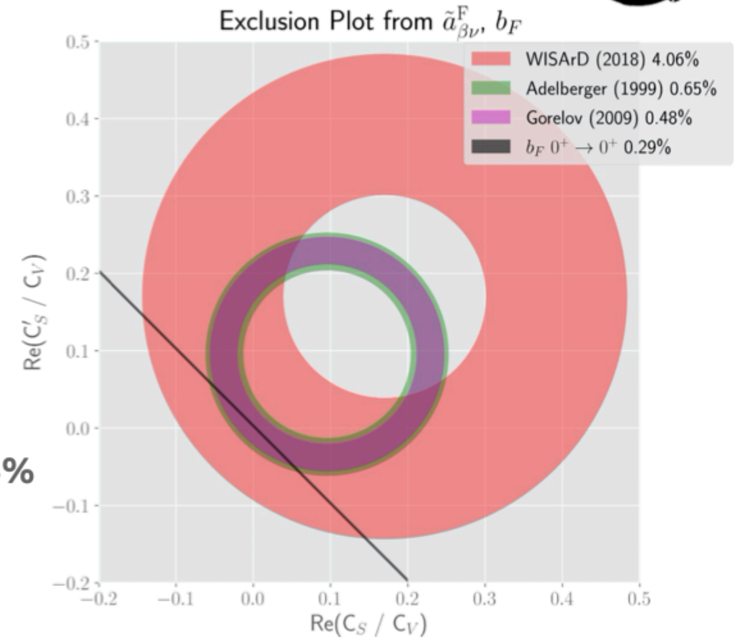

Exclusion plot from D. Atanasov

Proof-of-Principle Experiment – 2018

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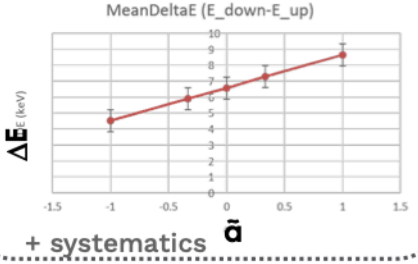

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V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

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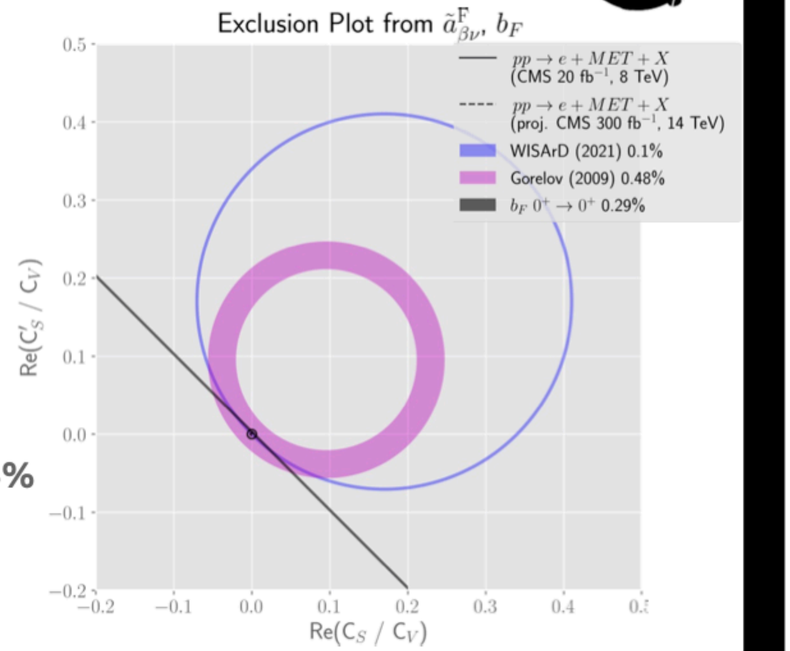

Exclusion plot from D. Atanasov

Proof-of-Principle Experiment - 2018

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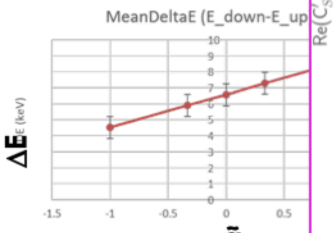
$\Delta E_F = 4.49(3)\ ke$

Monte Carlo simul



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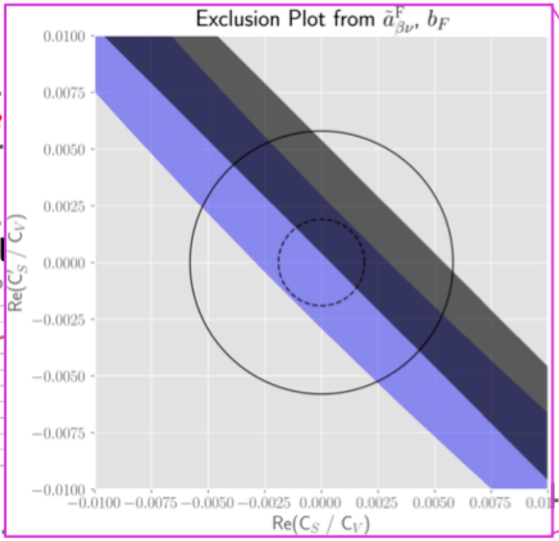
V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)



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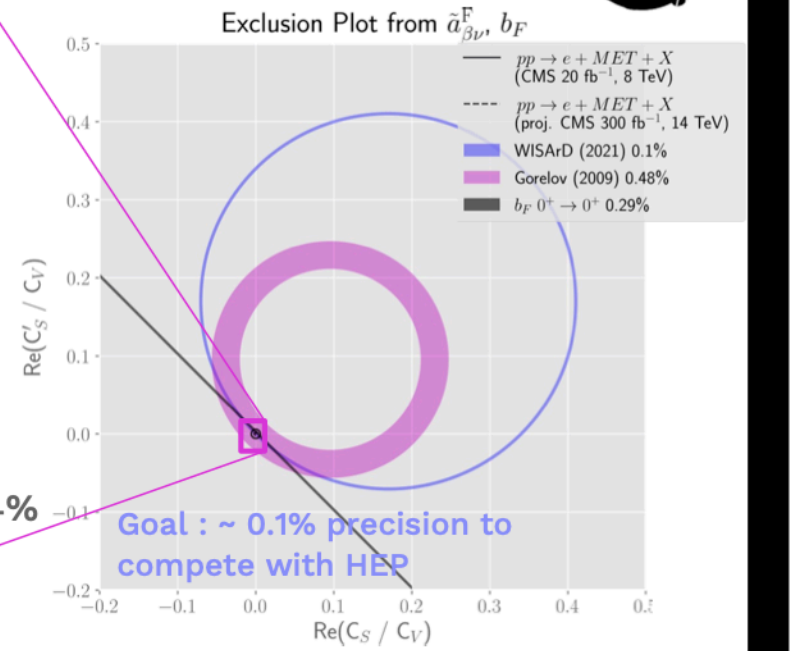
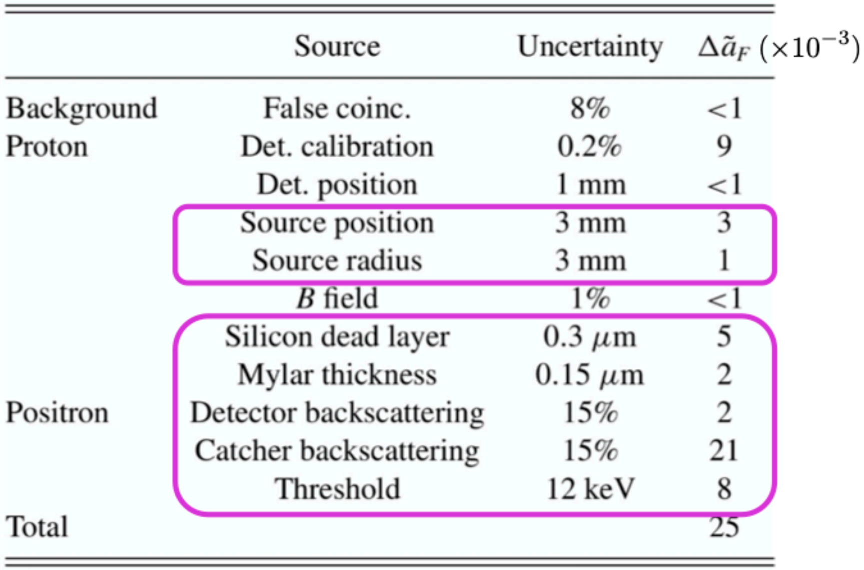


Goal : ~ 0.1% precision to compete with HEP

Exclusion plot from D. Atanasov

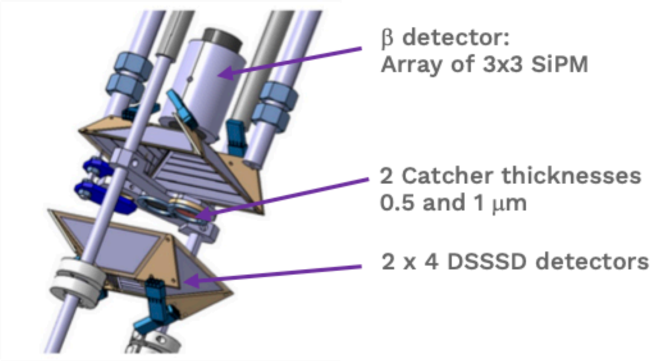
Proof-of-Principle Experiment - 2018



	Source	Uncertainty	$\Delta\tilde{a}_F$ ($\times 10^{-3}$)
Background	False coinc.	8%	<1
Proton	Det. calibration	0.2%	9
	Det. position	1 mm	<1
	Source position	3 mm	3
	Source radius	3 mm	1
	B field	1%	<1
Positron	Silicon dead layer	0.3 μm	5
	Mylar thickness	0.15 μm	2
	Detector backscattering	15%	2
	Catcher backscattering	15%	21
	Threshold	12 keV	8
Total			25

Upgrade 2019 - 2022

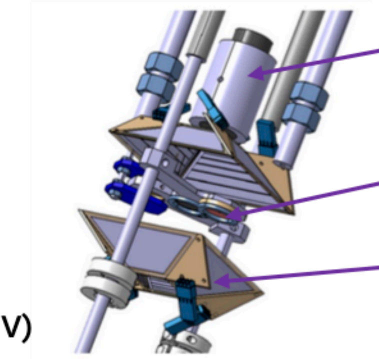
- **Setup geometry**
  - 57% maximum solid angle
  - 90° p incident angle



D. Atanasov et al. NIM A 1050 168159 (2023)

Upgrade 2019 - 2022

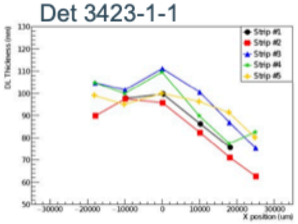
- **Setup geometry**
    - 57% maximum solid angle
    - 90° p incident angle
- **p detectors**
    - Cooled -23°
    - < 100 nm dead layer
      α 700 keV
    - 15-20 keV FWHM (α 5.3 MeV)

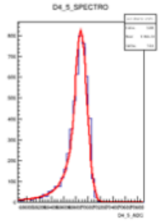


β detector:
Array of 3x3 SiPM

2 Catcher thicknesses
0.5 and 1 μm

2 x 4 DSSSD detectors

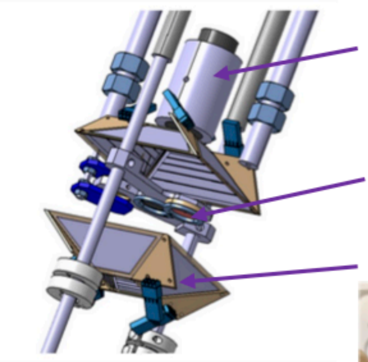




D. Atanasov et al. NIM A 1050 168159 (2023)

Upgrade 2019 - 2022

- **Setup geometry**
  - ☐ 57% maximum solid angle
  - ☐ 90° p incident angle
- **p detectors**
  - ☐ Cooled -23°
  - ☐ < 100 nm dead layer
    α 700 keV
  - ☐ 15-20 keV FWHM (α 5.3 MeV)
- **β detector**
  - ☐ 130 keV FWHM @ 1 MeV
  - ☐ Dual gain output
  - ☐ Mult 3 threshold < 23 keV



β detector:
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2 Catcher thicknesses
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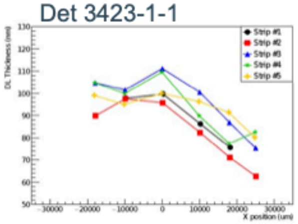

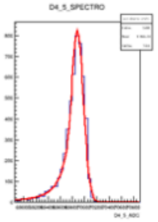

D. Atanasov et al. NIM A 1050 168159 (2023)

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- **p detectors**
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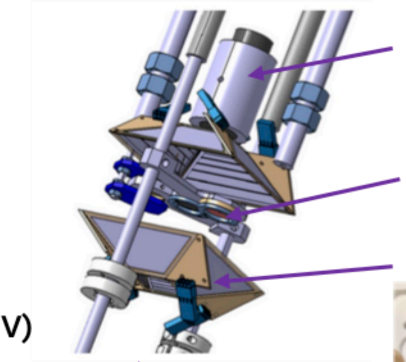
  - < 100 nm dead layer
    α 700 keV
  - 15-20 keV FWHM (α 5.3 MeV)
- **β detector**
  - 130 keV FWHM @ 1 MeV
  - Dual gain output
  - Mult 3 threshold < 23 keV
- **MCP + segmented FC**
  - Resolution < 300 μm FWHM
- **Beam line transmission : 90%**



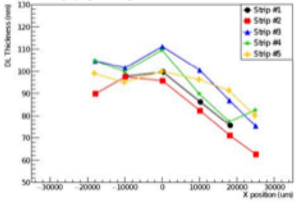
β detector:
Array of 3x3 SiPM

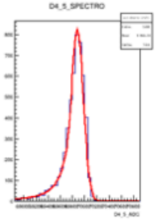
2 Catcher thicknesses
0.5 and 1 μm

2 x 4 DSSSD detectors

MCP

Det 3423-1-1

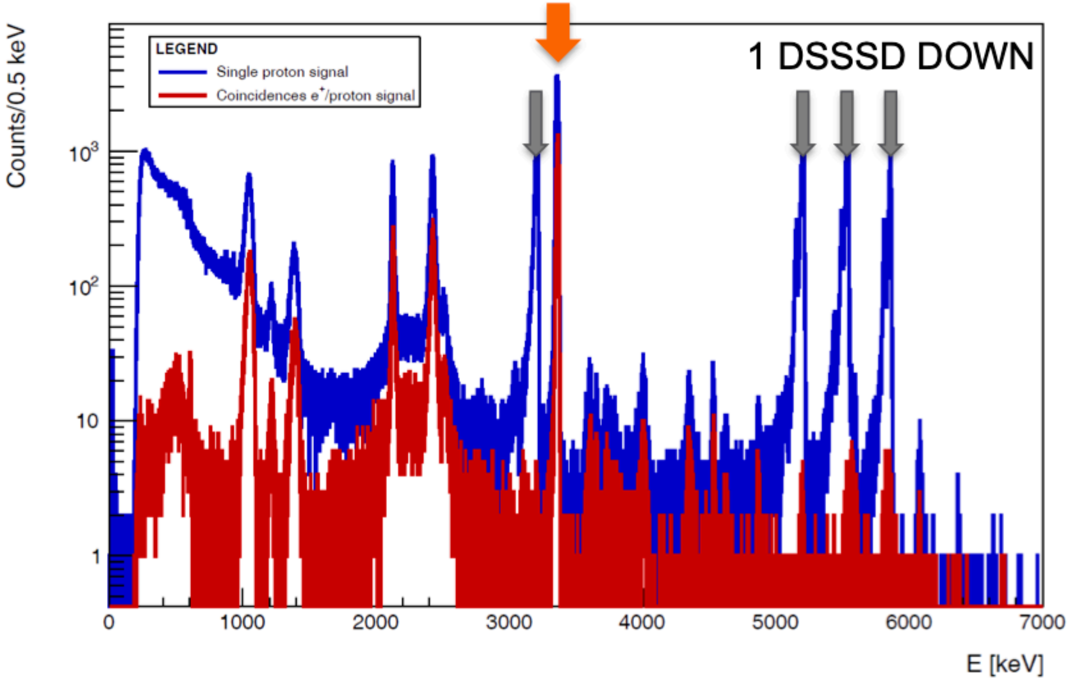




D. Atanasov et al. NIM A 1050 168159 (2023)

Test run - 2021

- 43h of ^{32}Ar beam time
  - ☐ 4-α source pollution
  - ☐ Resolution 7-10 keV FWHM
  - ☐ F + GT transitions



Analysis F. Cresto

Test run - 2021

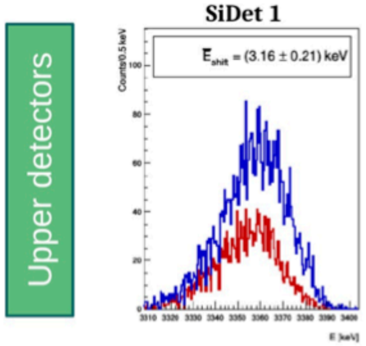
- 43h of ^{32}Ar beam time
  - ☐ 4-α source pollution
  - ☐ F + GT transitions
- Kinematic broadening visible
  - ☐ IAS peak 19 keV FWHM
- Kinematic shift (down)

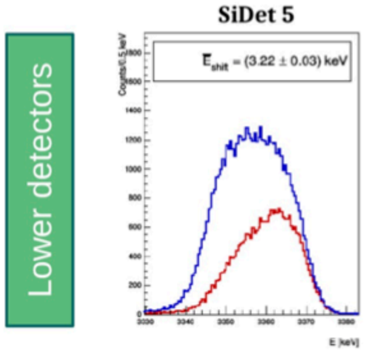
$$\Delta E_F = 3.97(8) - 2.66(6)$$

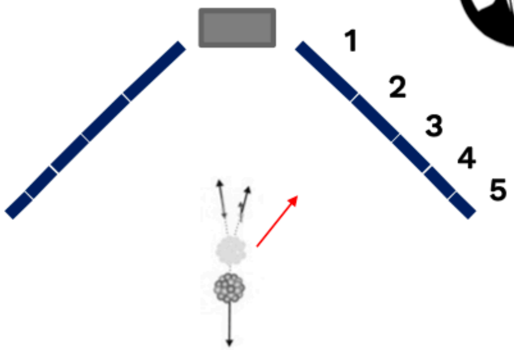
- Preliminary value of ã

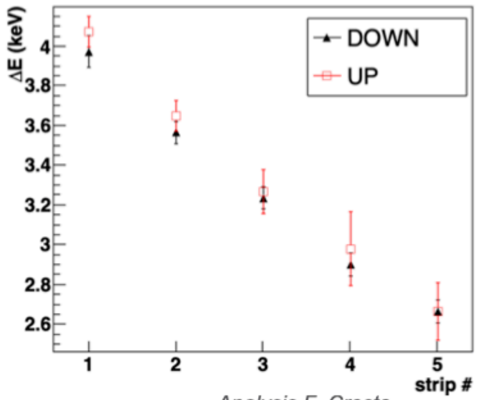
$$1.002 \pm 0.017 \text{ (stat.)}$$

➩ stat. precision level : 2%







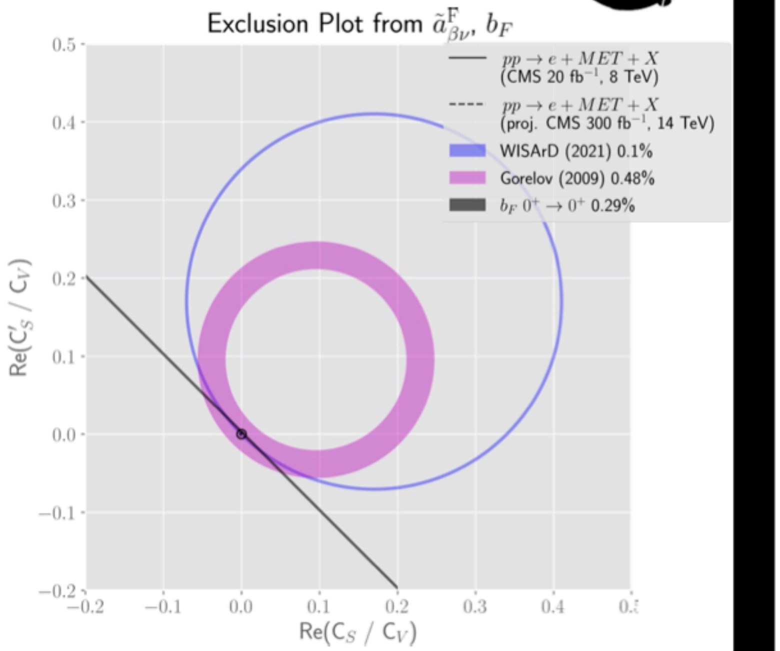


Analysis F. Cresto

Next data taking : 2023

- 24 shifts
  - ~150h ^{32}Ar : 3x10^{7} β-p events
  - 2 shifts ^{33}Ar for calibration
  - 3 shifts for beam tuning

	Source	Uncertainty	$\Delta\tilde{a}_F$	
Background	False coinc.	8%	<1	
Proton	Det. calibration	0.2%	9	🟩
	Det. position	1 mm	<1	🟩
	Source position	3 mm	3	🟩
	Source radius	3 mm	1	🟧
	B field	1%	<1	🟩
	Silicon dead layer	0.3 μm	5	🟩
	Mylar thickness	0.15 μm	2	🟩
Positron	Detector backscattering	15%	2	🟧
	Catcher backscattering	15%	21	🟧
	Threshold	12 keV	8	🟧
Total			25	

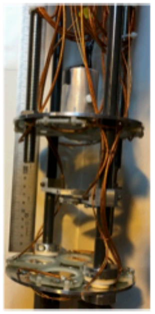


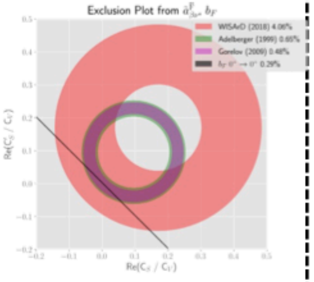
Exclusion plot from D. Atanasov

Conclusion

2018 2021 2023

Proof-of-Principle



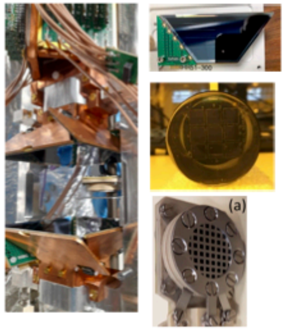


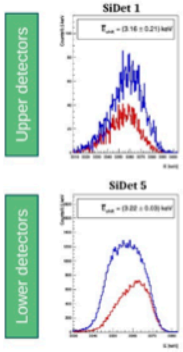
$\Delta E_F = 4.49(3)\ keV$

$\tilde{a}_F = 1.007(32)_{stat}(25)_{syst}$

V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

Upgrade

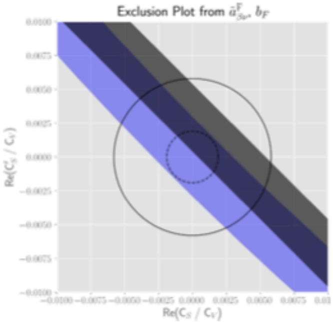




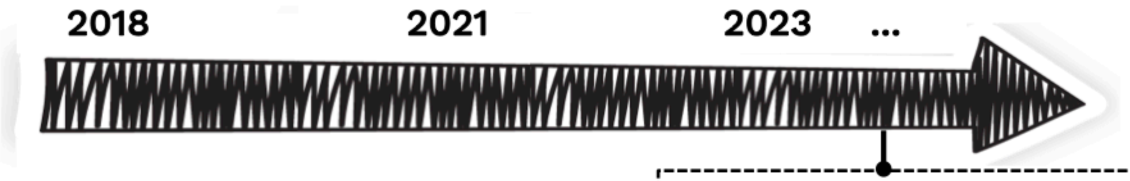
1.002 ± 0.017 (stat.)

D. Atanasov et al. NIM A 1050 168159 (2023)

Next data taking ^{32}Ar



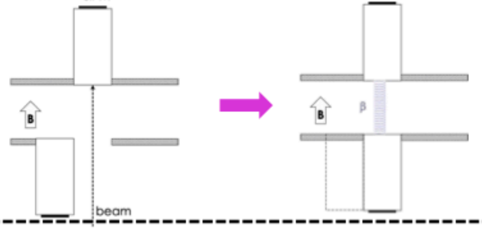
Outlook



- **β spectrum shape measurement**

$$dW = dW_0 \times \xi \left(1 + b\frac{m}{E_e}\right)$$

  - ☐ **Challenges :**
    backscattering, dead layer, energy loss in source...



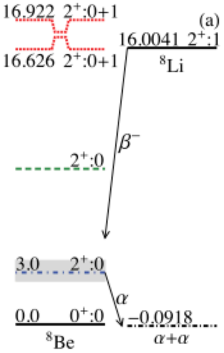
Outlook

- **β-2α emitter : ^{8}Li**
  - ☐ GT transition : T current?
  - ☐ Best limit to date in trap (BPL)

$$a_{\beta\nu} = -0.3325 \pm 0.0013_{\text{stat}} \pm 0.0019_{\text{syst}}$$

$$|C_T/C_A| < 0.087 \text{ at the } 95.5\% \text{ C.L.}$$

M.T. Burkey et al. Phys. Rev. Lett. 128 (2022)



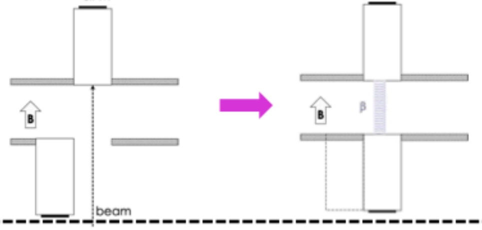
- **Other β-p candidates**
  - ☐ ^{20}Mg : sensitivity to b x2
  - ☐ ^{24}Si, ^{28}S

- **β spectrum shape measurement**

$$dW = dW_0 \times \xi \left(1 + b\frac{m}{E_e}\right)$$

  - ☐ **Challenges :**

    backscattering, dead layer, energy loss in source...



Thank you for your attention

P.Alfaurt, D.Atanasov, P.Ascher, B.Blank, F.Cresto, L.Daudin, X.Fléchard, A.Husson, A.Garcia, M.Gerbaux, J.Giovinazzo, S.Grévy, J.Ha, R.Lica, E.Liénard, D.Melconian, C.Mihai, M.Nasser, C.Neacsu, A.Ortega-Moral, M.Pomorski, M.Roche, N.Severijns, S.Vanlangendonck, M.Versteegen, D.Zakoucky

Back up

Test run 2021 : preliminary systematics

- **Evaluated**
  - Catcher thickness
  - β detection threshold

For mylar (down) : 5 ‰

- **To be evaluated**
  - Backscattering in catcher and at the surface of the β detector
  - p spectrum calibration
  - Implantation point position

HE vs HP

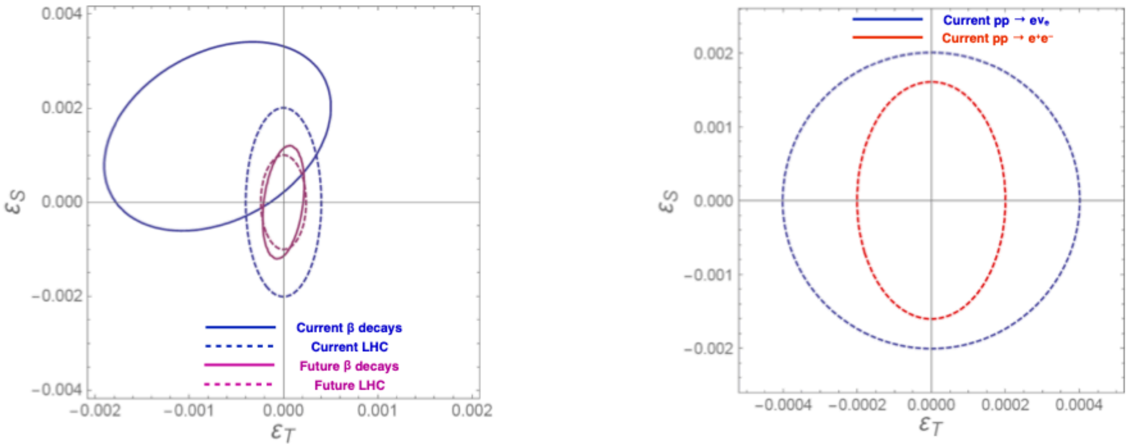
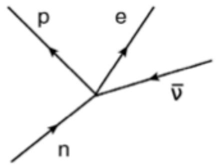


FIG. 8. Current and projected 90% C.L. constraints on ϵ_S and ϵ_T defined at 2 GeV in the $\overline{\text{MS}}$ scheme. (Left) The beta-decay constraints are obtained from the recent review article, Ref. [81]. The current and future LHC bounds are obtained from the analysis of the $pp \to e + MET + X$. We have used the ATLAS results [82], at $\sqrt{s} = 13$ TeV and integrated luminosity of 36 fb^{-1}. We find that the strongest bound comes from the cumulative distribution with a cut on the transverse mass at 2 TeV. The projected future LHC bounds are obtained by assuming that no events are observed at transverse mass greater than 3 TeV with an integrated luminosity of 300 fb^{-1}. (Right) Comparison of current LHC bounds from $pp \to e + MET + X$ versus $pp \to e^+e^- + X$.

R. Gupta et al Phys. Rev. D 98 (2018)

Beta decay



- **n beta decay Lagrangian**

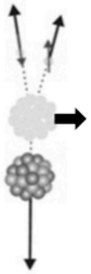
$$-\mathcal{L}_{LY} = C_V\left(\bar{p}\gamma^\mu n + \frac{C_A}{C_V}\bar{p}\gamma^\mu\gamma_5 n\right)\times\bar{e}\gamma_\mu(1-\gamma_5)\nu_e$$

$$+\,C_S\,\bar{p}n\times\bar{e}(1-\gamma_5)\nu_e + \frac{1}{2}C_T\,\bar{p}\sigma^{\mu\nu}n\times\bar{e}\sigma_{\mu\nu}(1-\gamma_5)\nu_e + hc$$

SM "V-A" structure

Exotic currents : S and T
P omitted

- **Decay rate distribution for polarized nuclei**

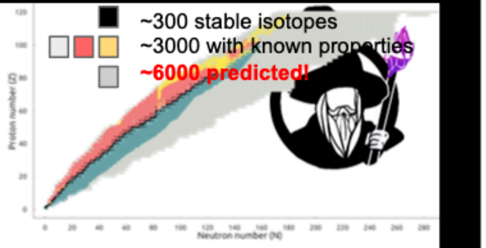


$$\frac{dW(\mathbf{J})}{dE_e d\Omega_e d\Omega_\nu} = dW_0 \times \xi\left\{1 + a\,\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_e E_\nu} + b\,\frac{m_e}{E_e} + \frac{<\mathbf{J}>}{J}\cdot\left(A\,\frac{\mathbf{p}_e}{E_e} + B\,\frac{\mathbf{p}_\nu}{E_\nu} + D\,\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_e E_\nu}\right)\right\}$$

☐ **Ft values : V_{ud}, b**
☐ **Beta spectrum shape : b**
☐ **Correlation measurements : a, b, D**

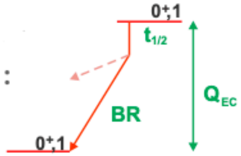
T.Lee, C-N Yang Phys. Rev. 104 (1956)
M. González-Alonso, Colloque GANIL (2019)
J.D Jackson, S.B Treiman, H.W Wyld Nuclear Phys 4 (1957)

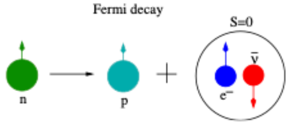
Ft values : total decay rates



- **Unitarity test of the CKM matrix 1st row :** $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \mathbf{NP}$

$0^+ \longrightarrow 0^+$ superallowed Fermi transition :





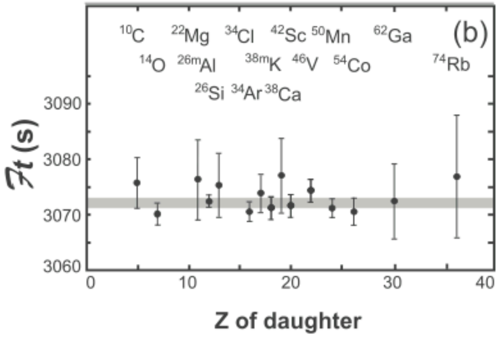
Statistical rate function $f \propto \int dW_0$ $\times$ **Partial half-life** $t = \frac{t_{1/2}}{BR}(1 + P_{EC})$ $\times$ **Corrections: Radiative < 1% Structure < 1%** $=$ $\mathcal{F}t = \dfrac{K}{2G_F^2\, V_{ud}^2\, (1 + \Delta_R^V)}$

Trap : Q_{EC}
$\Delta m \sim 10^{-8}$

Beta counting and Ge with calibrated ε :
$t_{1/2}$ and BR
$\Delta\varepsilon \sim 0.2\%$

Theoretical Calculations
uncertainties < 0.1%
(except ^{62}Ga&^{74}Rb)

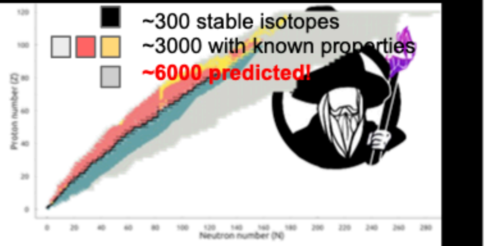
15 transitions with
uncertainties < 0.3%



222 individual measurements from 23 decays : $|\mathbf{V_{ud}}| = \mathbf{0.97373 \pm 0.00031}$

JC. Hardy & IS. Towner Phys.Rev.C 102 (2020)

Ft values : total decay rates



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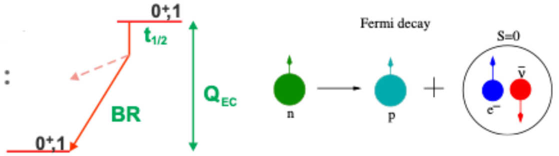
0+ ⟶ 0+ superallowed Fermi transition :

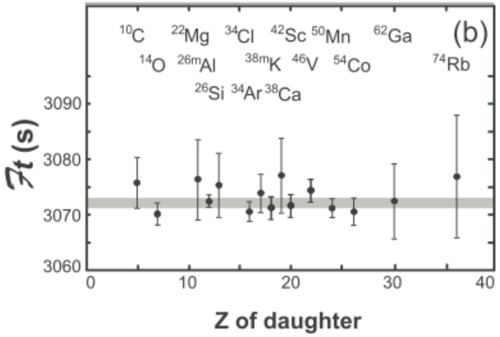


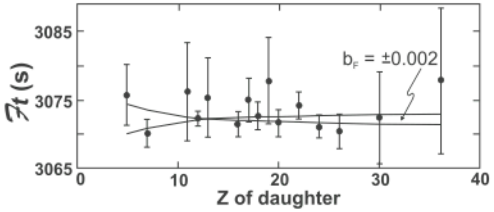
Statistical rate function $f \propto \int dW_0$	×	Partial half-life $t = \frac{t_{1/2}}{BR}(1+P_{EC})$	×	Corrections: Radiative < 1% Structure < 1%	=	$\mathcal{F}t = \frac{K}{2G_F^2\, V_{ud}^2\,(1+\Delta_R^V)}$
Trap : Q_{EC} $\Delta m \sim 10^{-8}$		Beta counting and Ge with calibrated ε : $t_{1/2}$ and BR Δε ~ 0.2%		Theoretical Calculations uncertainties < 0.1% (except ^{62}Ga&^{74}Rb)		15 transitions with uncertainties < 0.3%

222 individual measurements from 23 decays : $|\mathbf{V_{ud}}| = \mathbf{0.97373 \pm 0.00031}$

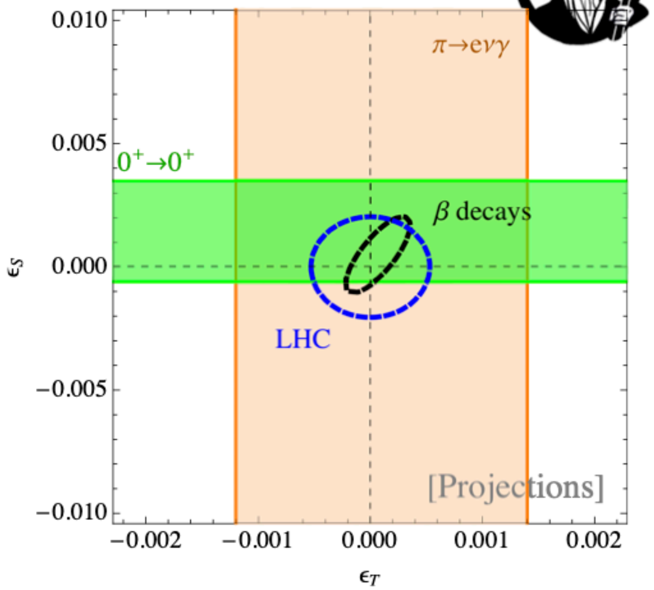
- **Sensitivity to exotic scalar currents : b = ± 0.002**

If b≠0 then f is affected : $ft' = ft \times \frac{1}{1 + b < \frac{m_e}{E_e} >}$

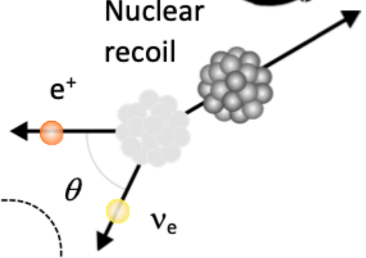




JC. Hardy & IS. Towner Phys.Rev.C 102 (2020)


0.010
0.005
0.000
−0.005
−0.010
ϵ_S
−0.002
−0.001
0.000
0.001
0.002
ϵ_T
$\pi \to e\nu\gamma$
$0^+ \to 0^+$
β decays
LHC
[Projections]

Correlation measurements : WISArD



- **Decay rate for non polarized nuclei :**

$$dW = dW_0\left(1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu} + b\frac{m_e}{E_e}\right)$$

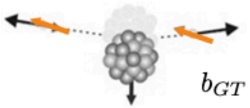
Pure F transition ΔJ=0 S=0

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

$$b_F \approx \pm Re\left(\frac{C_S+C'_S}{C_V}\right) \quad = 0$$

⇨Best measurement a_F at 0.45%

Pure GT transition ΔJ=0 or 1 S=1



$$a_{GT} \cong -\frac{1}{3}\left(1 - \frac{|C_T|^2+|C'_T|^2}{|C_A|^2}\right) \quad = -1/3$$

$$b_{GT} \approx \pm Re\left(\frac{C_T+C'_T}{C_A}\right) \quad = 0$$

⇨Best measurement a_{GT} at < ~1%

Gorelov, A. et al, Phys. Rev. Lett. 94, 1425 (2005)
Johnson, C.H. et al, Phys. Rev. 132, 1149 (1963)