WISArD

Weak Interaction Studies with ^{32}Ar Decay

M.Versteegen

P.Alfaurt, P.Ascher, D.Atanasov, B.Blank, L.Daudin, X.Fléchard, A.Garcia, M.Gerbaux, J.Giovinazzo, S.Grévy, J.Ha, L. Hayen, C.Knapen, S.Lecanuet, R.Lica, E.Liénard, D.Melconian, C.Mihai, C.Neacsu, M.Pomorski, M.Roche, N.Severijns, S.Vanlangendonck, D.Zakoucky

Conseil Scientifique IN2P3
June 24-25 2024

Outline

- Search for Exotic Weak Scalar Couplings

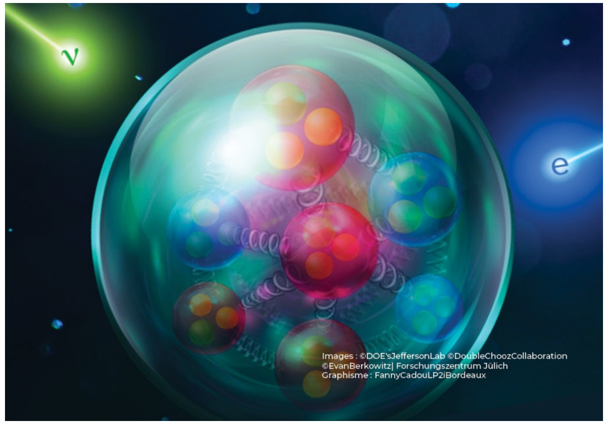
- Angular correlation measurement
  - Why ^{32}Ar ?
  - The WISArD set-up
  - Status and prospective

- Beta spectrum shape measurement
  - Fierz term and weak magnetism
  - Status and prospective at WISArD

2030 Roadmap Science Drivers

Pursue searches for unknown particles and interactions (New Phenomena)

Beta decay and the Standard Model



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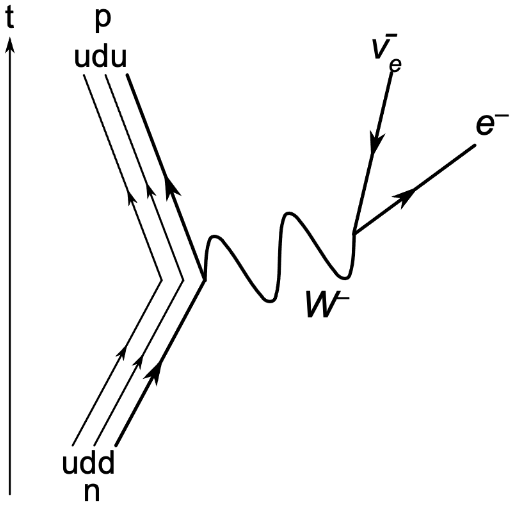
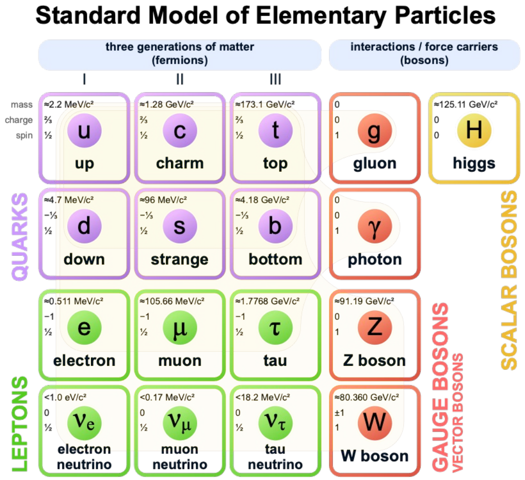
Graphisme : FannyCadouLP2iBordeaux





Nuclear β decay

- Ft values
- β spectrum shape
- Correlation coefficients

L. Hayen Annu. Rev. Nucl. Part Sci. (2024) arxiv:2403.08485

Weak interaction

- CVC hypothesis
- CKM matrix unitarity

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix} .$$

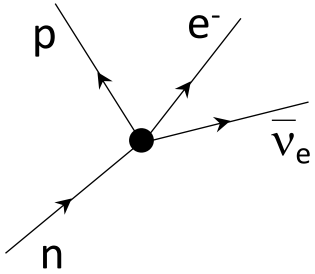
- **Exotic currents**
- CP violation
- …

Exotic currents in beta decay

- **Nucleon beta decay : Lee & Yang (1956)**

$$-\mathcal{L}_{n\to pe^-\bar{\nu}_e} = g \sum_{i=S,V,T,A,P} \boxed{\bar{p}\mathcal{O}_i n}\,\boxed{\bar{e}\mathcal{O}_i(C_i - C_i'\gamma_5)\nu} + h.c.$$

hadronic leptonic



T. Lee, C-N. Yang Phys. Rev. 104 (1956)
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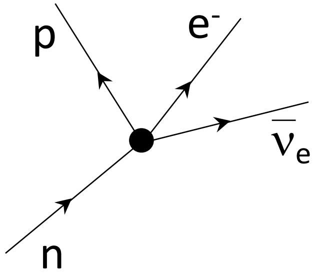
$$-\mathcal{L}_{n\to pe^-\bar{\nu}_e} = g \sum_{i=S,V,T,A,P} \underbrace{\boxed{\bar{p}\mathcal{O}_i n}}_{\text{hadronic}} \underbrace{\boxed{\bar{e}\mathcal{O}_i(C_i - C_i'\gamma_5)\nu}}_{\text{leptonic}} + h.c.$$



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

SM “V-A” structure

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

$$+ \,right\text{-}handed \;\; neutrinos$$

Exotic couplings : S and T
P omitted

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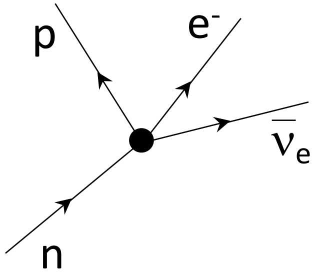

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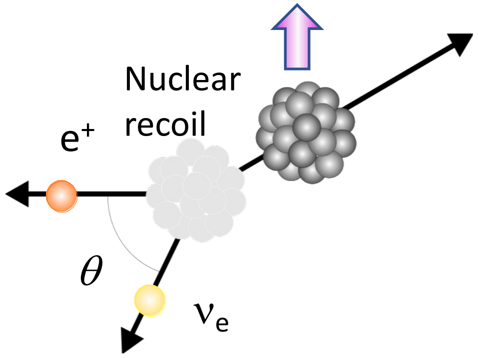
- **Beta decay distribution for allowed transition and polarized nuclei**



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

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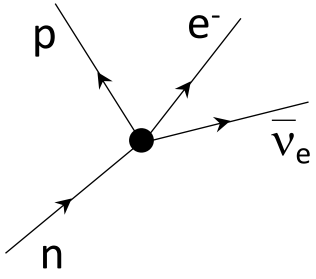

↳

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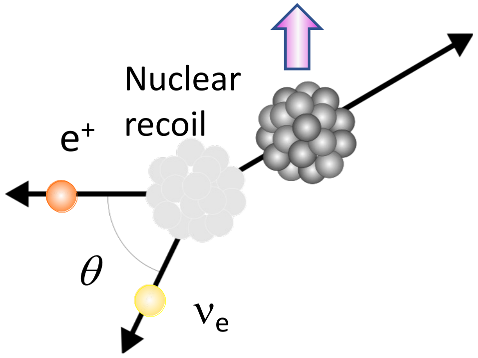

Nuclear polarization

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

Fermi Function
Phase space factor

β and
ν momenta

T. Lee, C-N. Yang Phys. Rev. 104 (1956)
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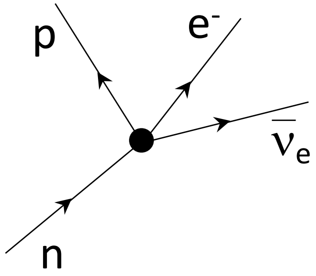
hadronic **leptonic**



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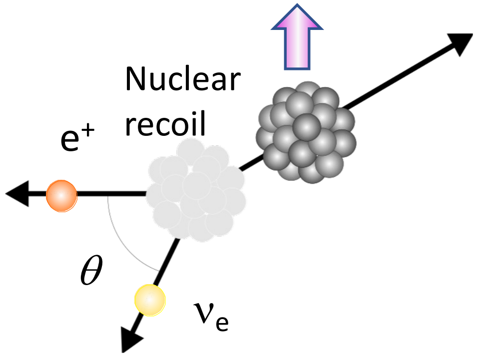

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β–ν correlation coefficient
CP conserving
Access to C_S and C_T quadratically

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

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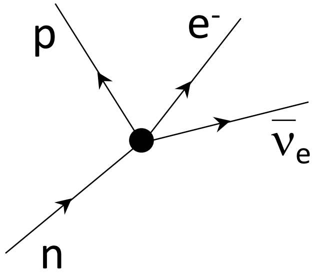

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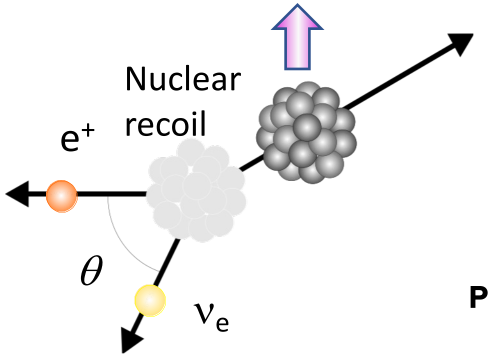

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Pure Fermi decay $a_F \cong 1 - \frac{|C_S|^2 + |C_S'|^2}{|C_V|^2}$ $b_F \approx \pm Re\left(\frac{C_S + C_S'}{C_V}\right)$

Pure Gamow-Teller decay $a_{GT} \cong -\frac{1}{3}\left(1 - \frac{|C_T|^2 + |C_T'|^2}{|C_A|^2}\right)$ $b_{GT} \approx \pm Re\left(\frac{C_T + C_T'}{C_A}\right)$

T. Lee, C-N. Yang Phys. Rev. 104 (1956)
M. González-Alonso, Colloque GANIL (2019)
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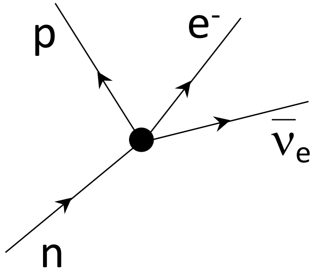
Bridging the gap between the HE and HP frontiers

- **Nucleon beta decay : Lee & Yang (1956)**



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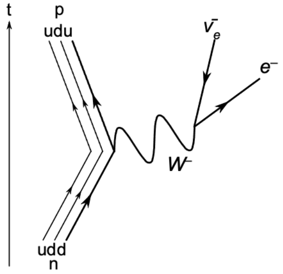
- **Parton beta decay : Effective Field Theory**



Linearized effective low energy Lagrangian without right-handed ν

$$\mathcal{L}_{\rm eff} = -\frac{G_F \tilde{V}_{ud}}{\sqrt{2}} \Big\{ \bar e \gamma_\mu (1-\gamma_5)\nu_e \cdot \bar u \gamma^\mu [1-(1-2\epsilon_R)\gamma_5] d$$
$$+ \epsilon_S \bar e (1-\gamma_5)\nu_e \cdot \bar u d$$
$$+ \epsilon_T \bar e \sigma_{\mu\nu}(1-\gamma_5)\nu_e \cdot \bar u \sigma^{\mu\nu}(1-\gamma_5) d \Big\} + h.c.$$

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

TeV NP scale ↵

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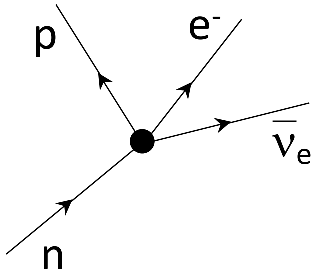

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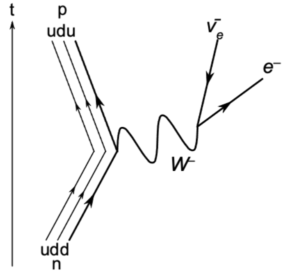

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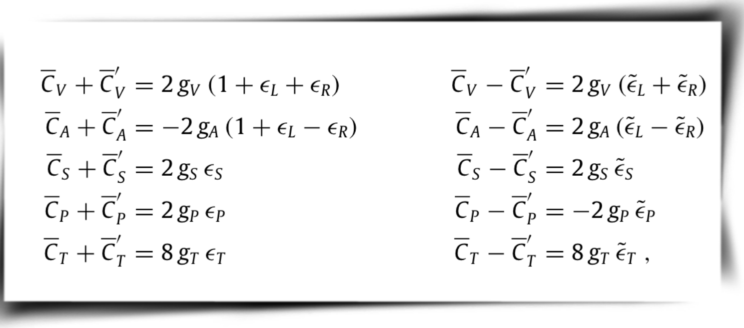
TeV NP scale : LHC ↵



$$\overline{C}_V + \overline{C}_V' = 2\,g_V\,(1+\epsilon_L+\epsilon_R) \qquad \overline{C}_V - \overline{C}_V' = 2\,g_V\,(\tilde{\epsilon}_L+\tilde{\epsilon}_R)$$
$$\overline{C}_A + \overline{C}_A' = -2\,g_A\,(1+\epsilon_L-\epsilon_R) \qquad \overline{C}_A - \overline{C}_A' = 2\,g_A\,(\tilde{\epsilon}_L-\tilde{\epsilon}_R)$$
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$$\overline{C}_T + \overline{C}_T' = 8\,g_T\,\epsilon_T \qquad \overline{C}_T - \overline{C}_T' = 8\,g_T\,\tilde{\epsilon}_T\,,$$

T.Lee, C-N Yang Phys. Rev. 104 (1956)
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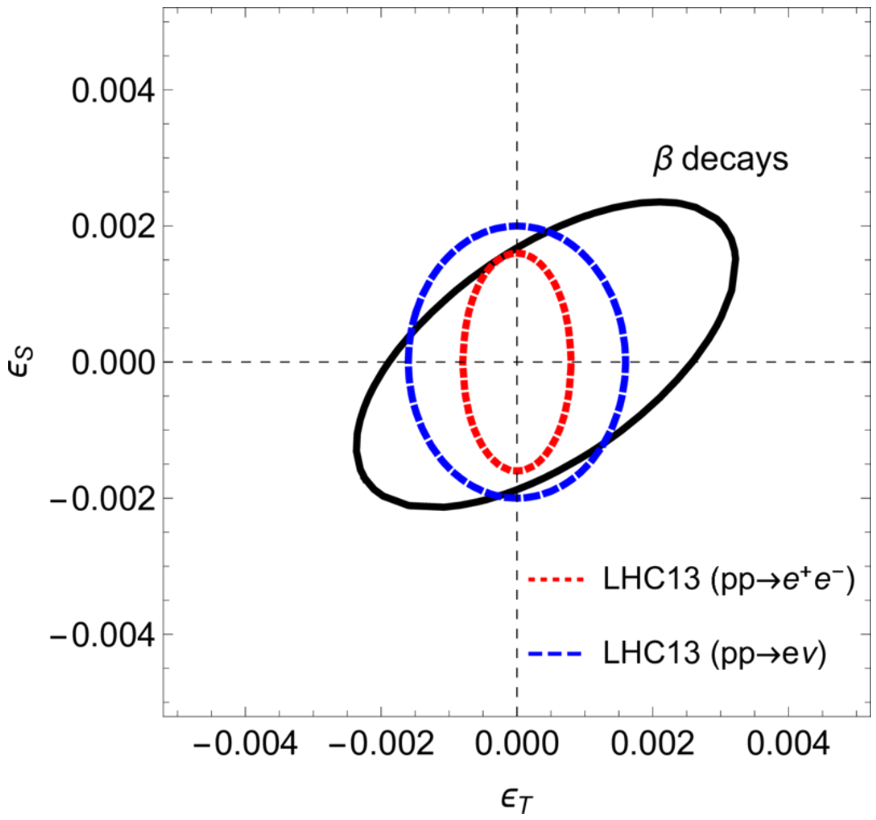
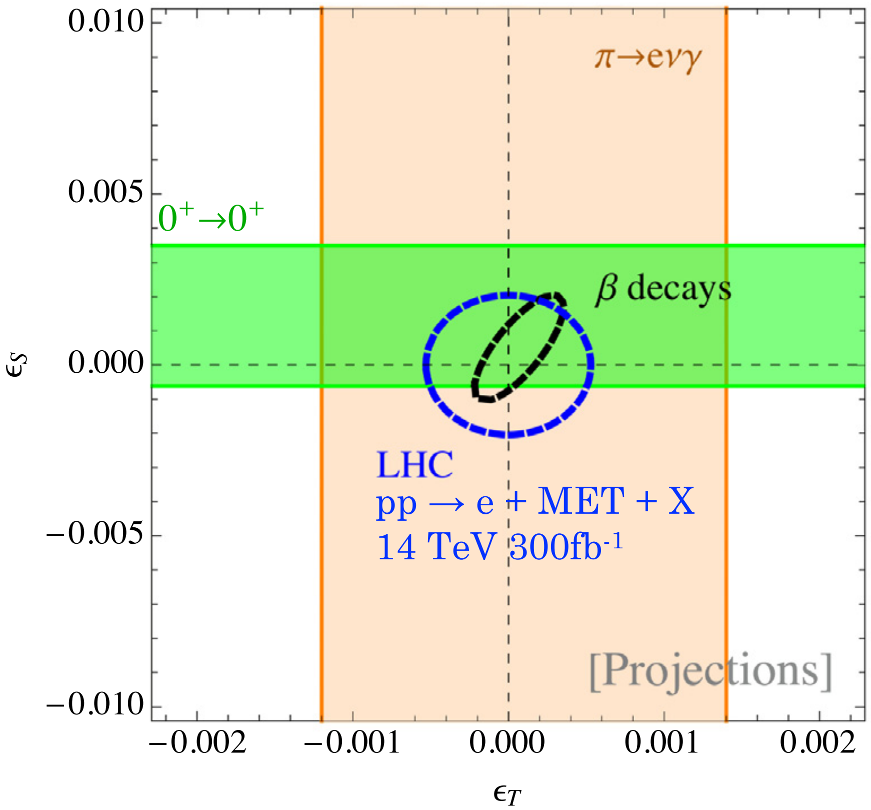
Bridging the gap between the HE and HP frontiers

- **Global analysis of nuclear beta decay observables**

  Ft values, correlation coefficients… of nuclear pure Fermi decays, mirror transitions and neutron decay





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Focus on exotic scalar currents

- **Sensitivity to non-Standard Scalar interaction**
  - **Left-handed : linear**

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

  - **Right-handed : quadratic**

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

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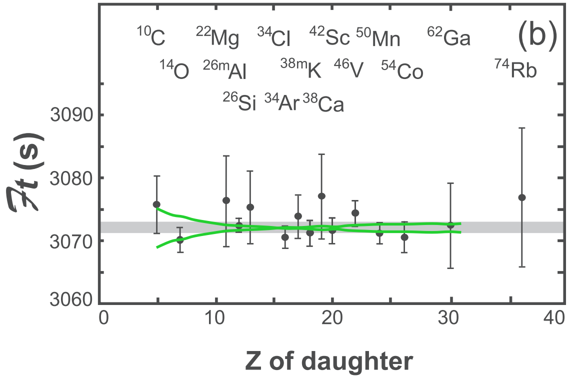
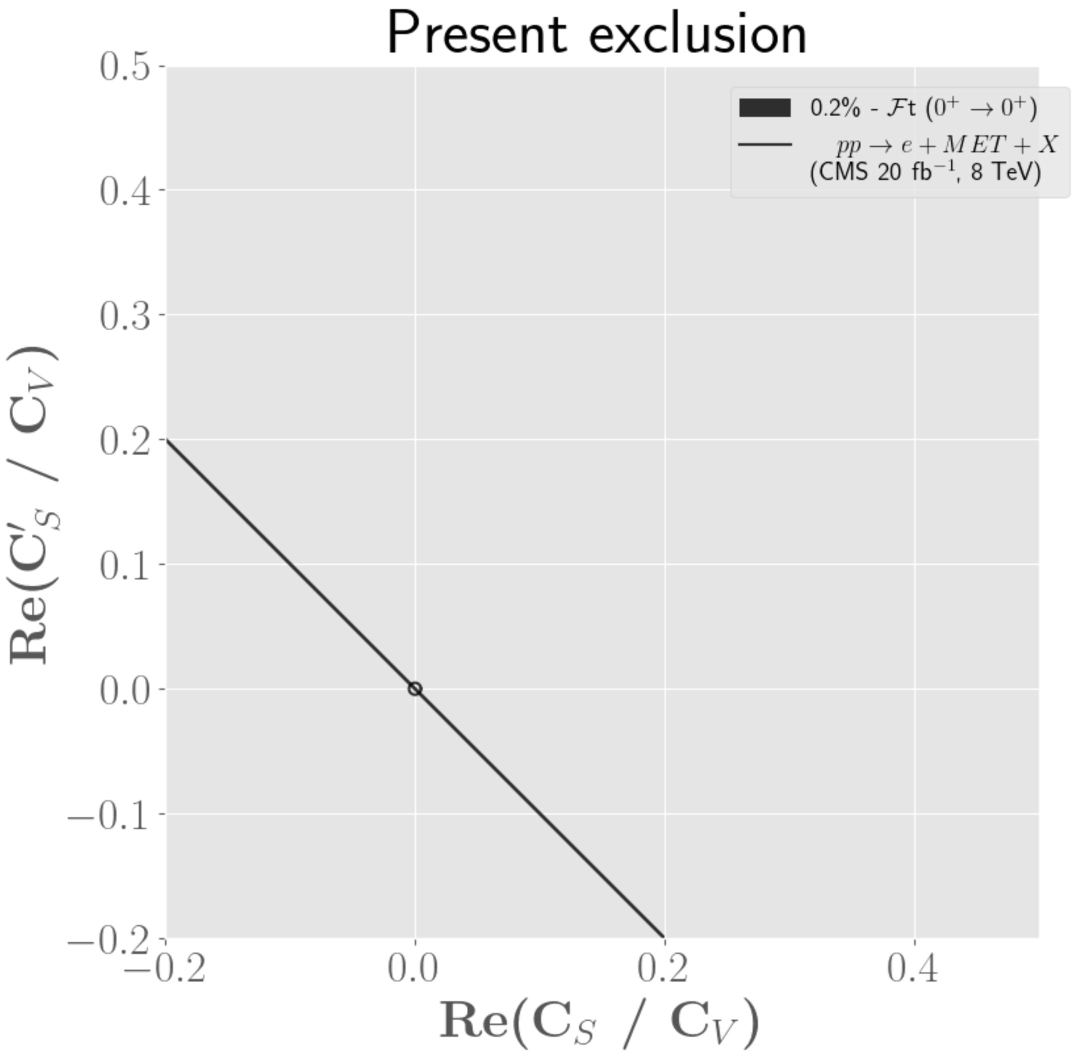
- **State of the art**
  - **Super-allowed $0^+ \rightarrow 0^+$ pure Fermi decay**

$$b_F \neq 0 \quad \Rightarrow \quad \mathcal{F}t(< 1/E_e >)$$



$$b_F = 0 \pm 0.002$$

J. Hardy, I. Towner, Phys. Rev. C 102 045501 (2020)



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  - Why ^{32}Ar ?
  - The WISArD set-up
  - Status and prospective
- Beta spectrum shape measurement
  - Fierz term and weak magnetism
  - Status and prospective at WISArD

2030 Roadmap Science Drivers

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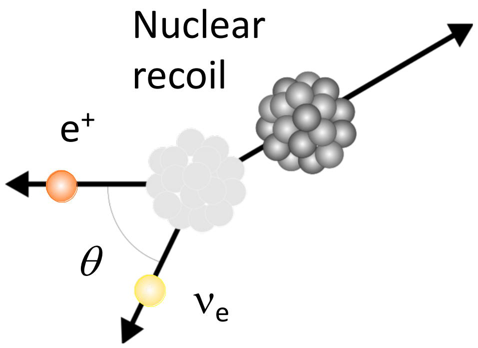
Angular correlation measurement

- **Beta decay distribution for unpolarized nuclei : integrating over J**

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

a > 0 : θ =0° favored and large recoil
a < 0 : θ =180° favored and small recoil



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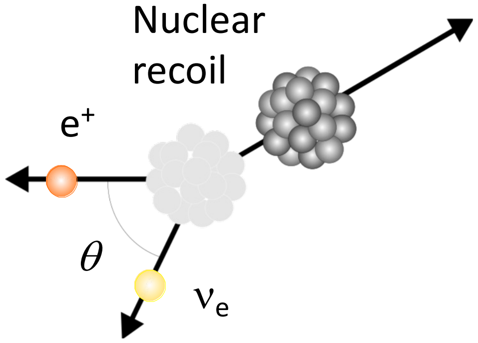
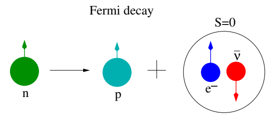


- **Angular correlation measurement = recoil measurement**

$$\tilde{a} = \frac{a}{1 + \alpha b_F}$$

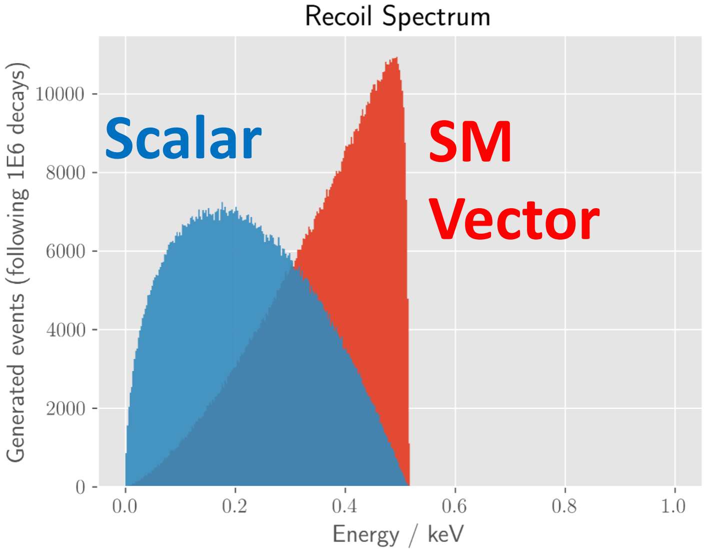
Pure Fermi transition ΔJ=0 S=0

Vector Coupling



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

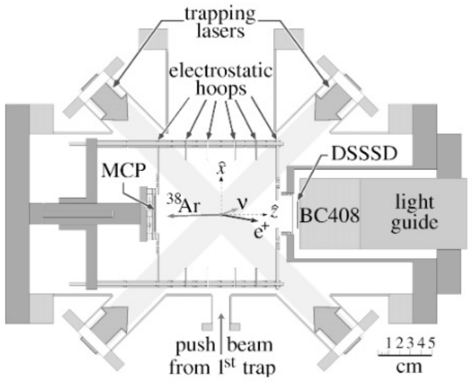
$$b_F \approx \pm Re\left(\frac{C_S + C'_S}{C_V}\right)$$ **= 0**

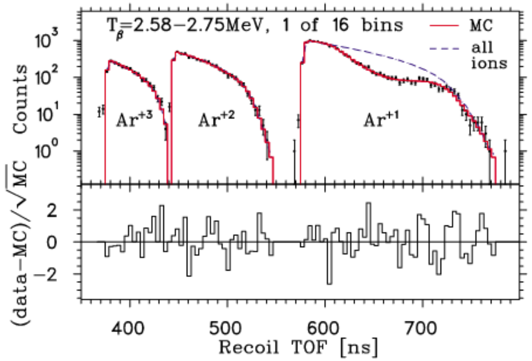


Beta nuclear recoil < few keV

Direct Recoil Measurements

- **TRINAT MOT @TRIUMF**

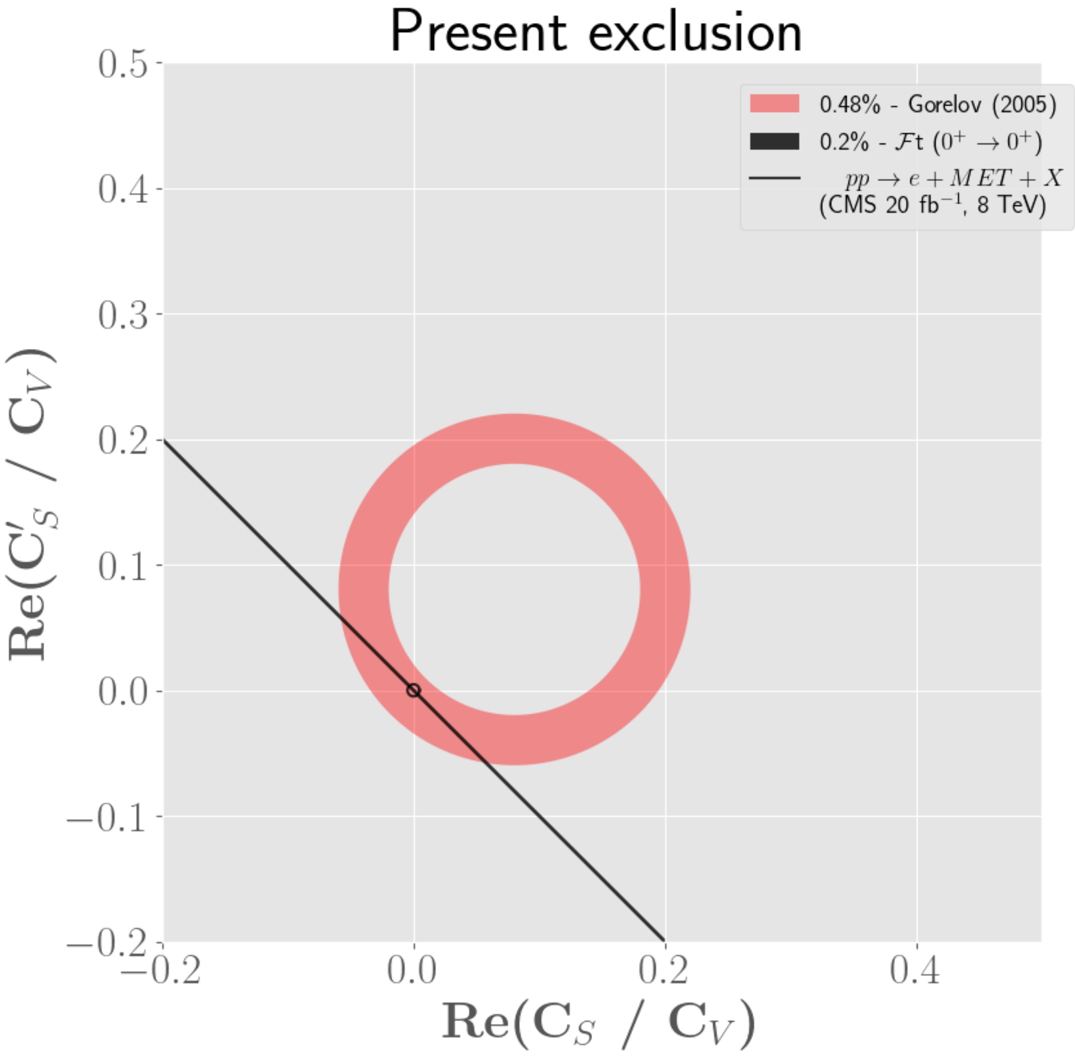




$$\tilde{a} = 0.9981(48) \qquad \alpha = 0.161$$

➪ precision level : 0.48%

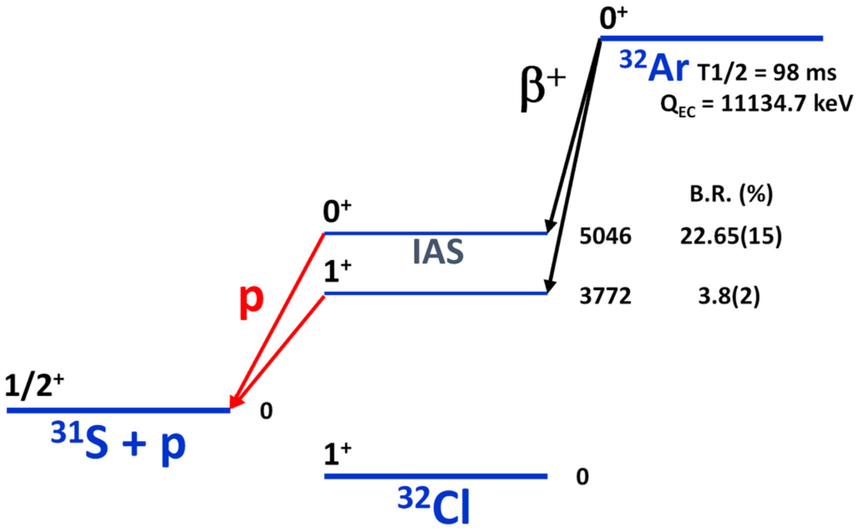
- **Paul Traps**
  - LPCTrap @GANIL ^{6}He
  - BPT @ANL 0.7% ^{8}Li $\alpha\sim0.09$
  - NSLTrap @Notre Dame U. – project 0.1% ^{11}C, ^{13}N, ^{15}O…
- **Penning Traps**
  - WITCH @ISOLDE ^{35}Ar
  - TAMUTRAP @Texas A&M– project 0.1% ^{32}Ar; ^{20}Mg, ^{24}Si…

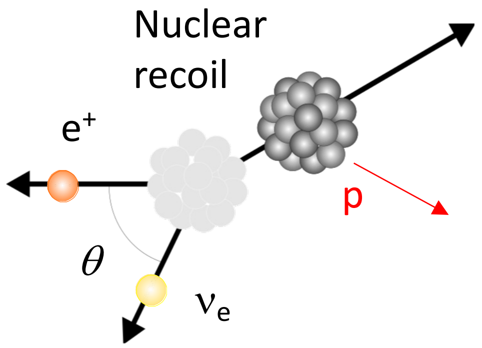


Why ^{32}Ar ?

- β-delayed proton emission in ^{32}Ar
    - Fermi $0^+ \longrightarrow 0^+$ transition from GS to IAS
    - Recoil ~640 eV
    - Beta delayed p emission IAS ~3.35 MeV
    - IAS : Γ ~ 20 eV ⇔ $T_{1/2}$ ~ 10^{-17} s

➪ p emission in flight from the recoil





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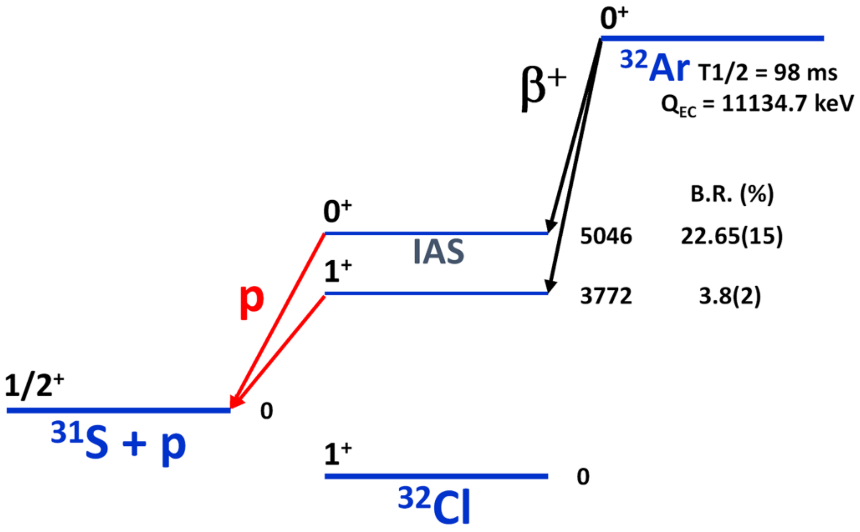
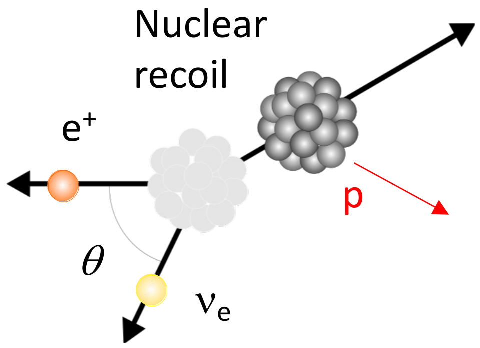
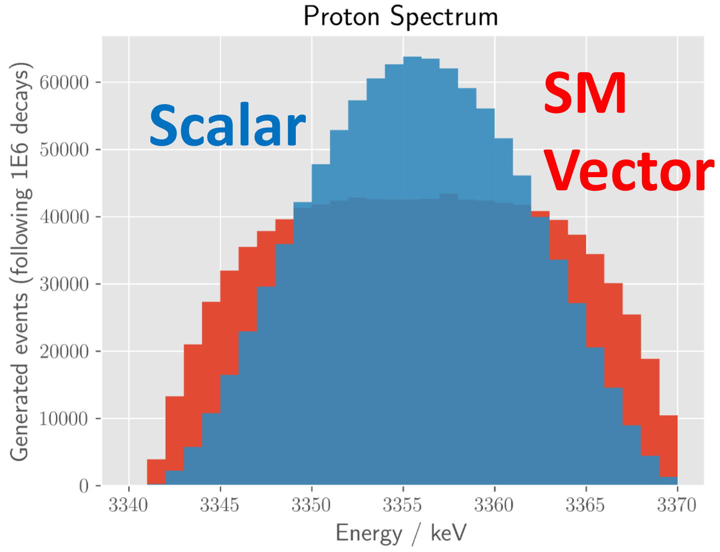


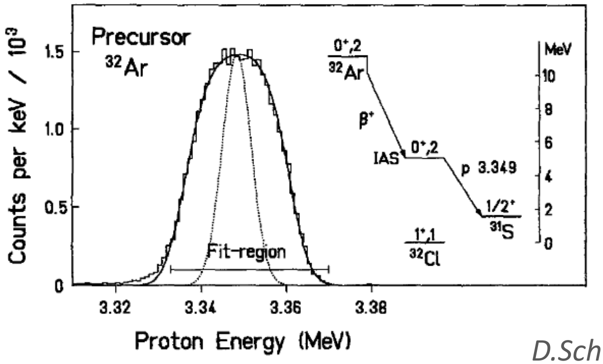


- kinematic broadening of the delayed proton spectrum
  - High resolution proton detectors
  - High statistics



Broadening Measurements

- **Cooled Si detectors**

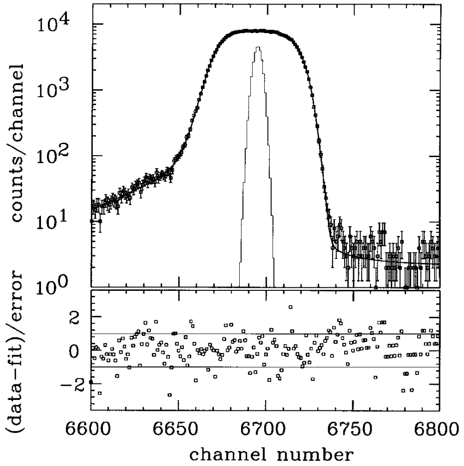


Sensitivity to b is not discussed

$$a = 1.00(8)$$

D.Schardt, K. Riisager ZPA 345 265 (1993)

- **Cooled p-i-n diodes**



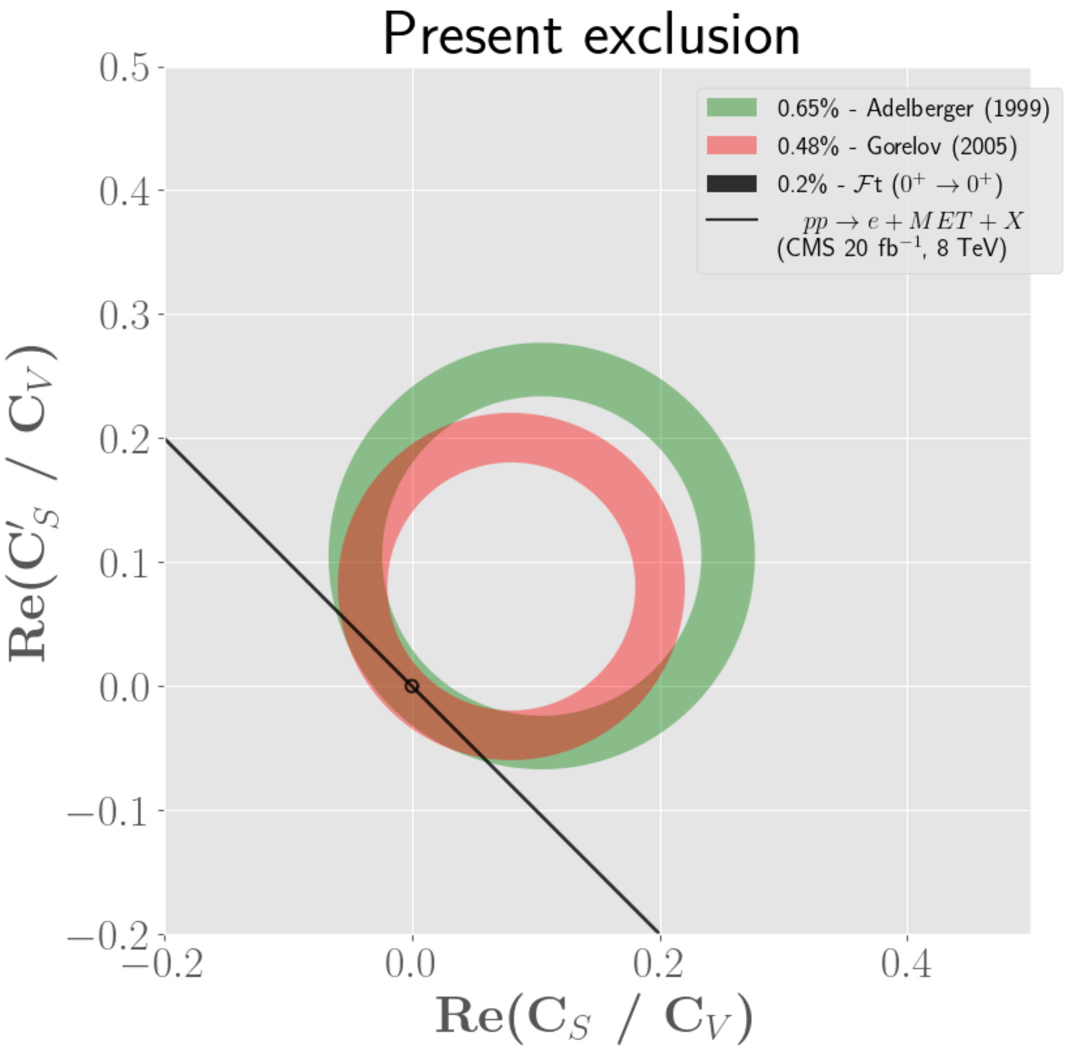
- ^{32}Ar beam at ISOLDE (60 keV)
- 9x9 mm^2 cooled p-i-n diodes
  - ~3 keV FWHM (pulser)
- 3.5 T magnetic field

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

$$\alpha = 0.210$$

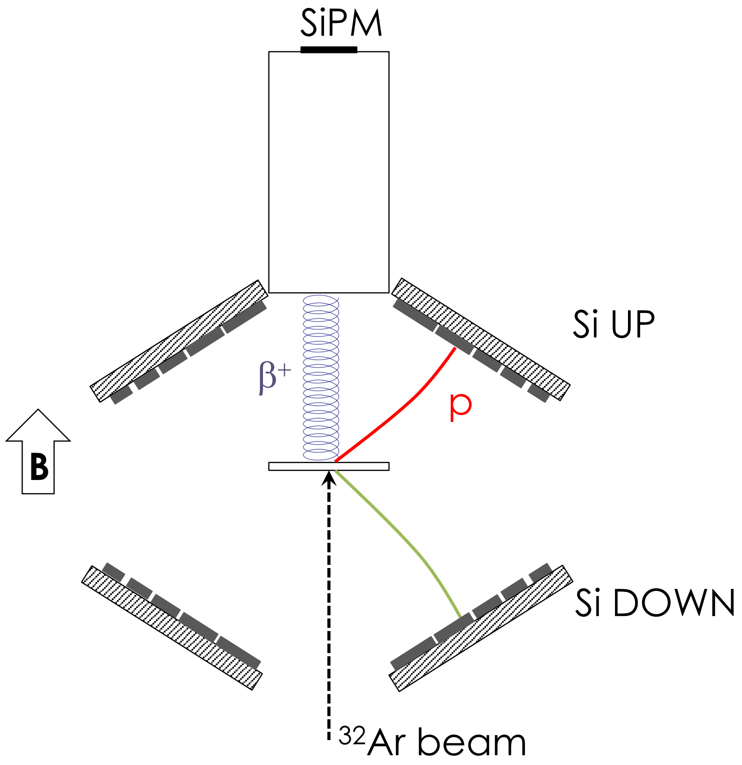
➩ precision level : 0.65%

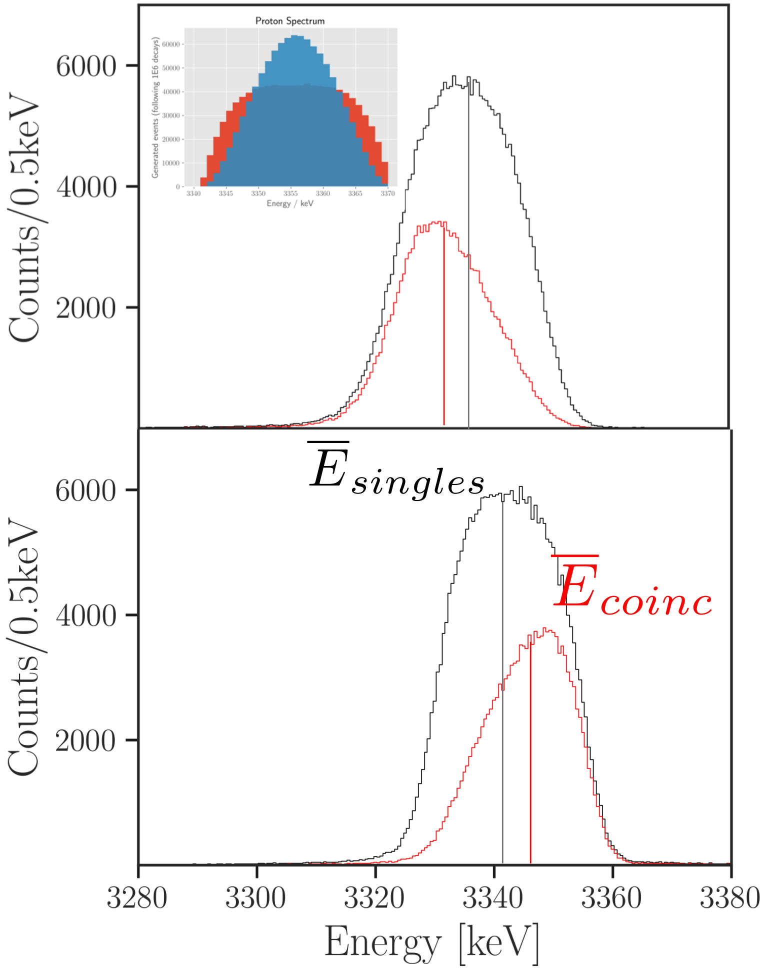
E. G. Adelberger et al. Phys. Rev. Lett. 83 (1999)
A. Garcia et al, Hyperfine Interact. 129 237 (2000)



Kinematic shift measurement : WISArD

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



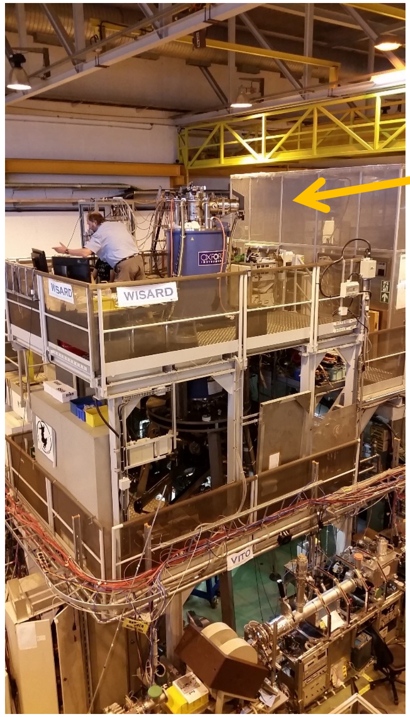


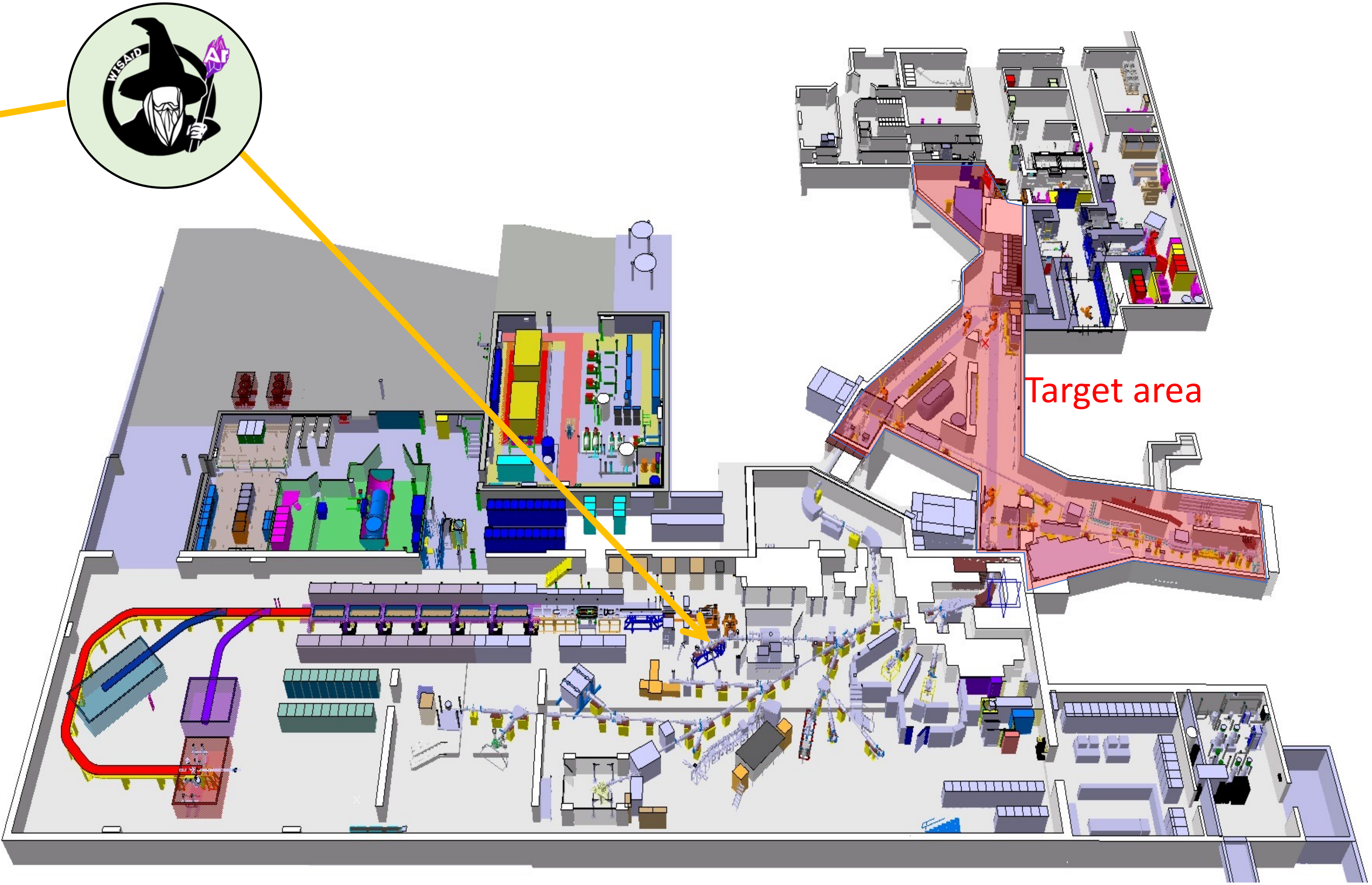
- **Kinematic shift**

$$\overline{E}_{shift} = \left|\overline{E}_{singles} - \overline{E}_{coinc}\right| \propto \tilde{a}$$

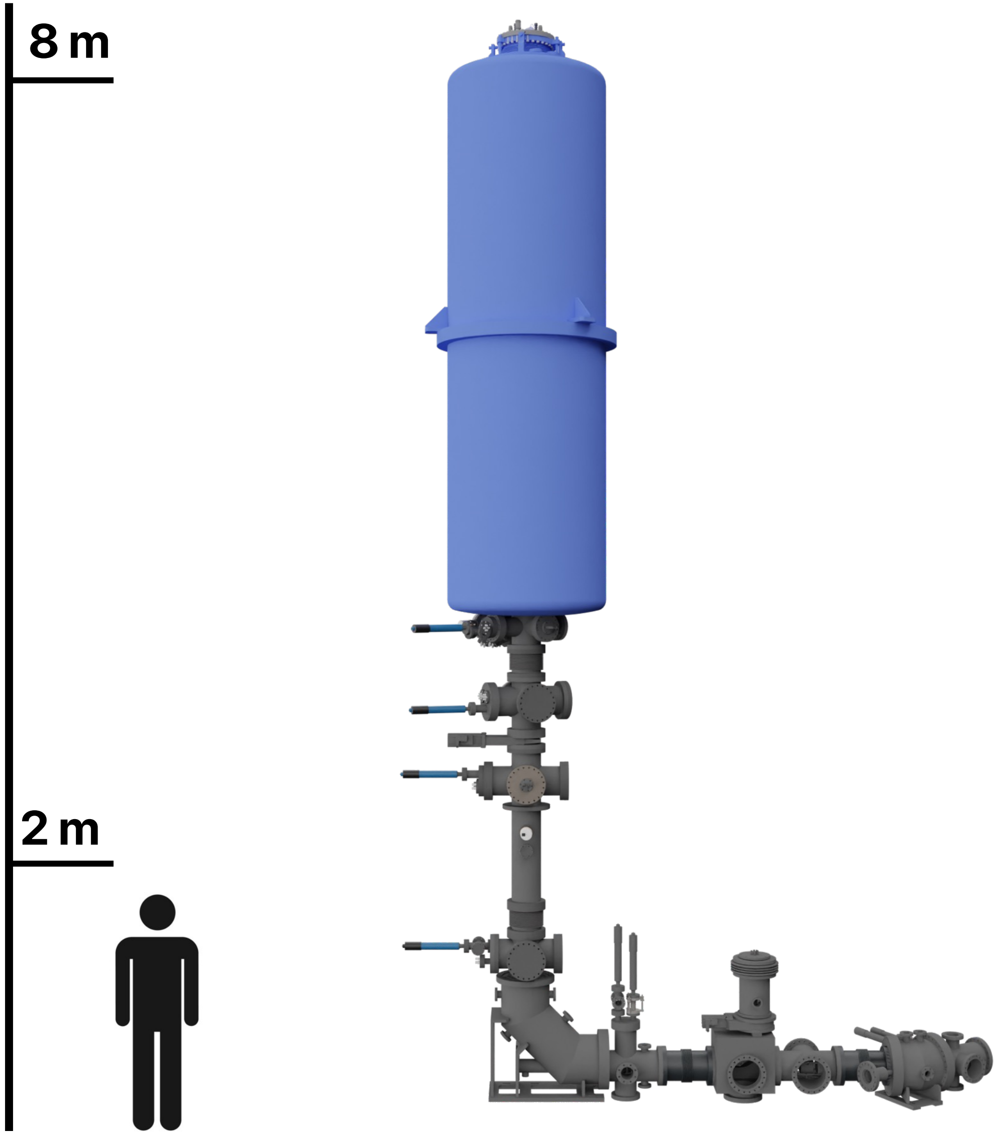
  - Differential measurement
  - Less sensitive to noise
  - Less sensitive to the detector response functions

WISArD at ISOLDE experimental hall





WISArD set-up



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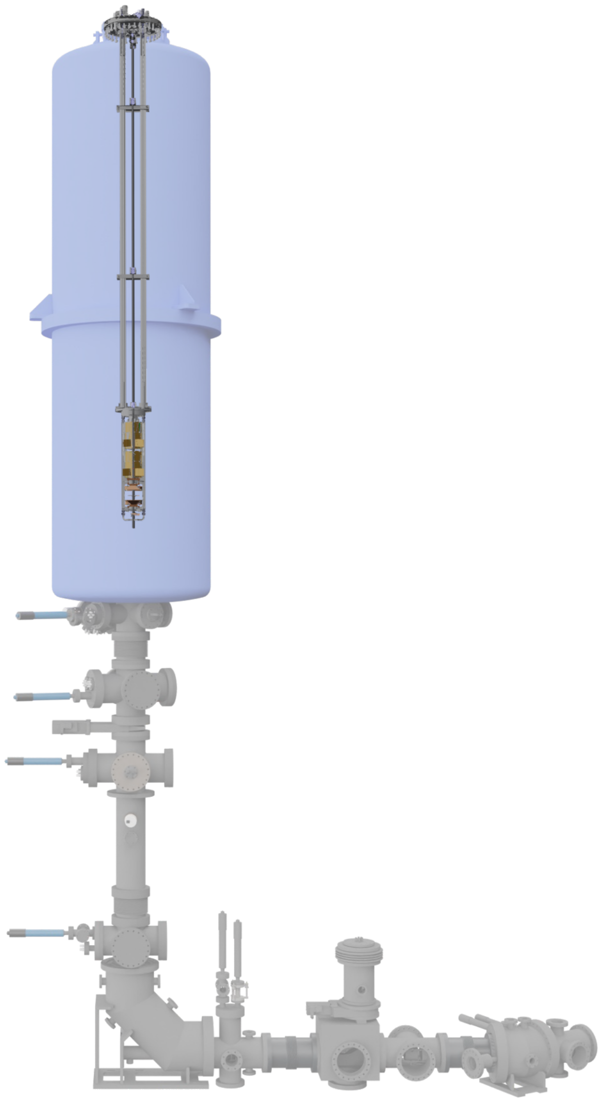
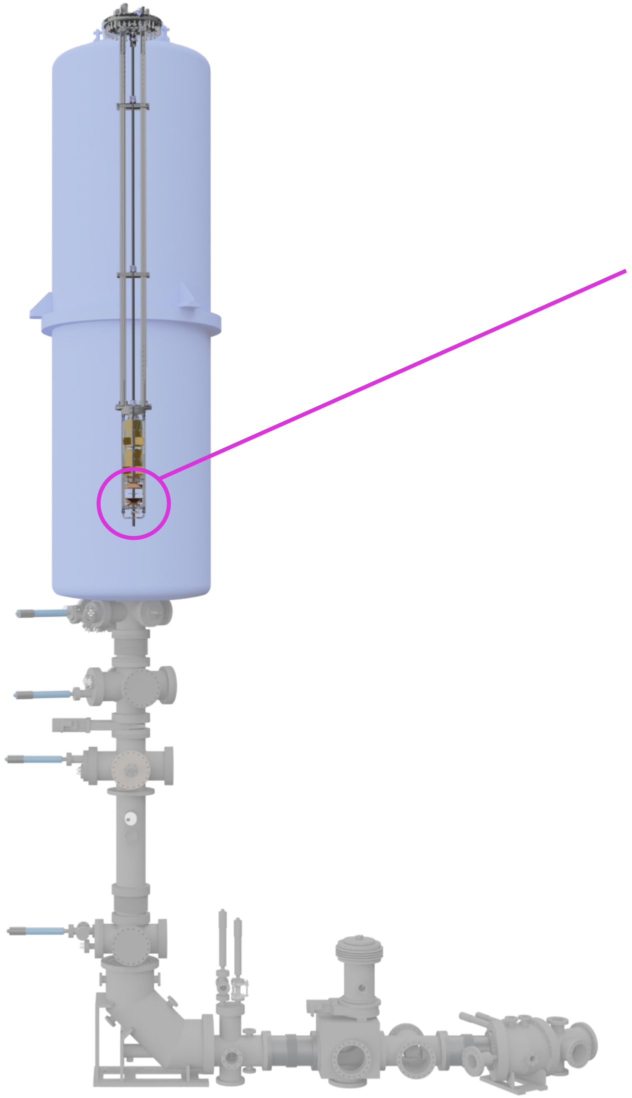
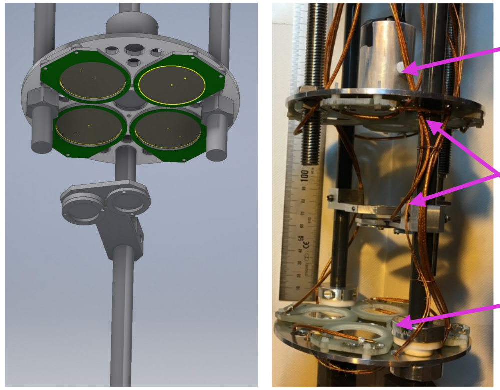


WISArD set-up

- Proof-of-Principle Experiment - 2018



in B = 4 T
(WITCH magnet)



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

catcher
Al-mylar 6.7(1) μm

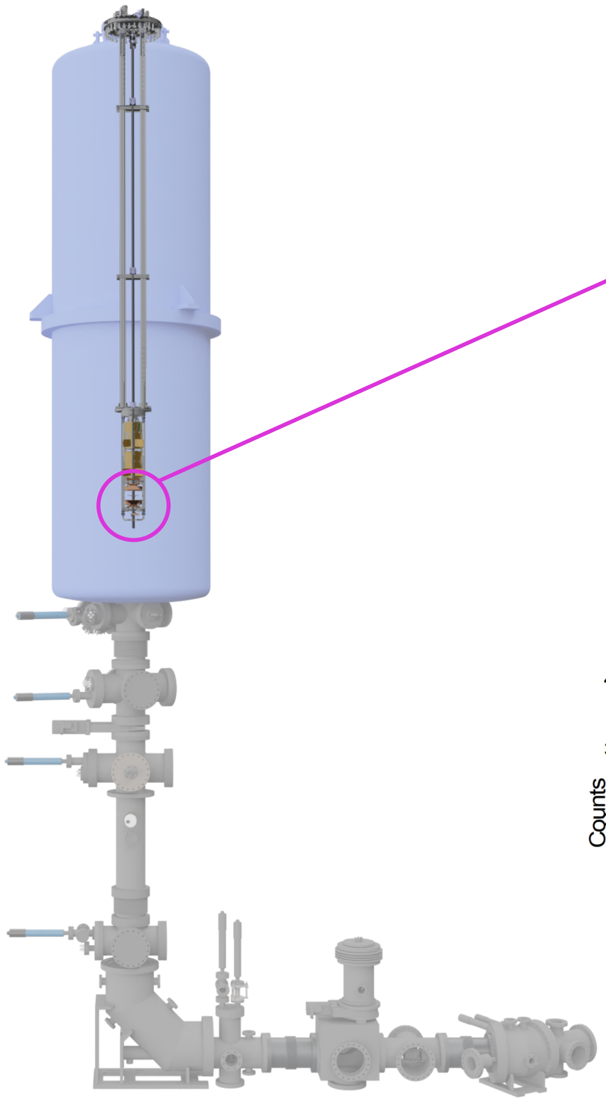
p detector planes
2 x 4 Si surface barrier 300 μm
Dead layer ~ 430 (300) nm
Resolution ~ 35 keV

+ FASTER DAQ

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

WISArD set-up

- Proof-of-Principle Experiment - 2018



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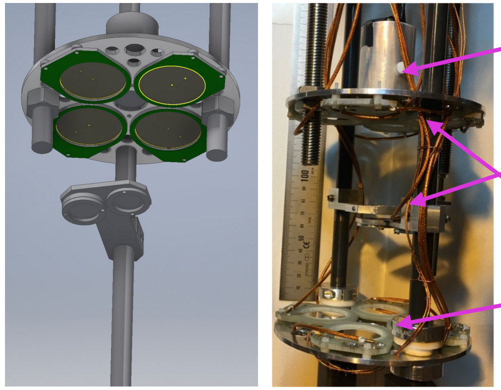

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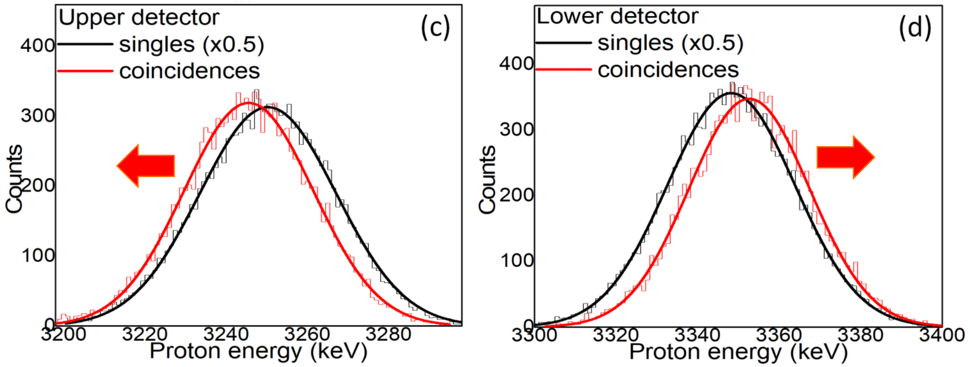


V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

35h beam time
N$_{coinc}$ ~ 10^5

$$\overline{E}_{shift} = 4.49(3)\ \text{keV}$$

$$\Downarrow$$

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

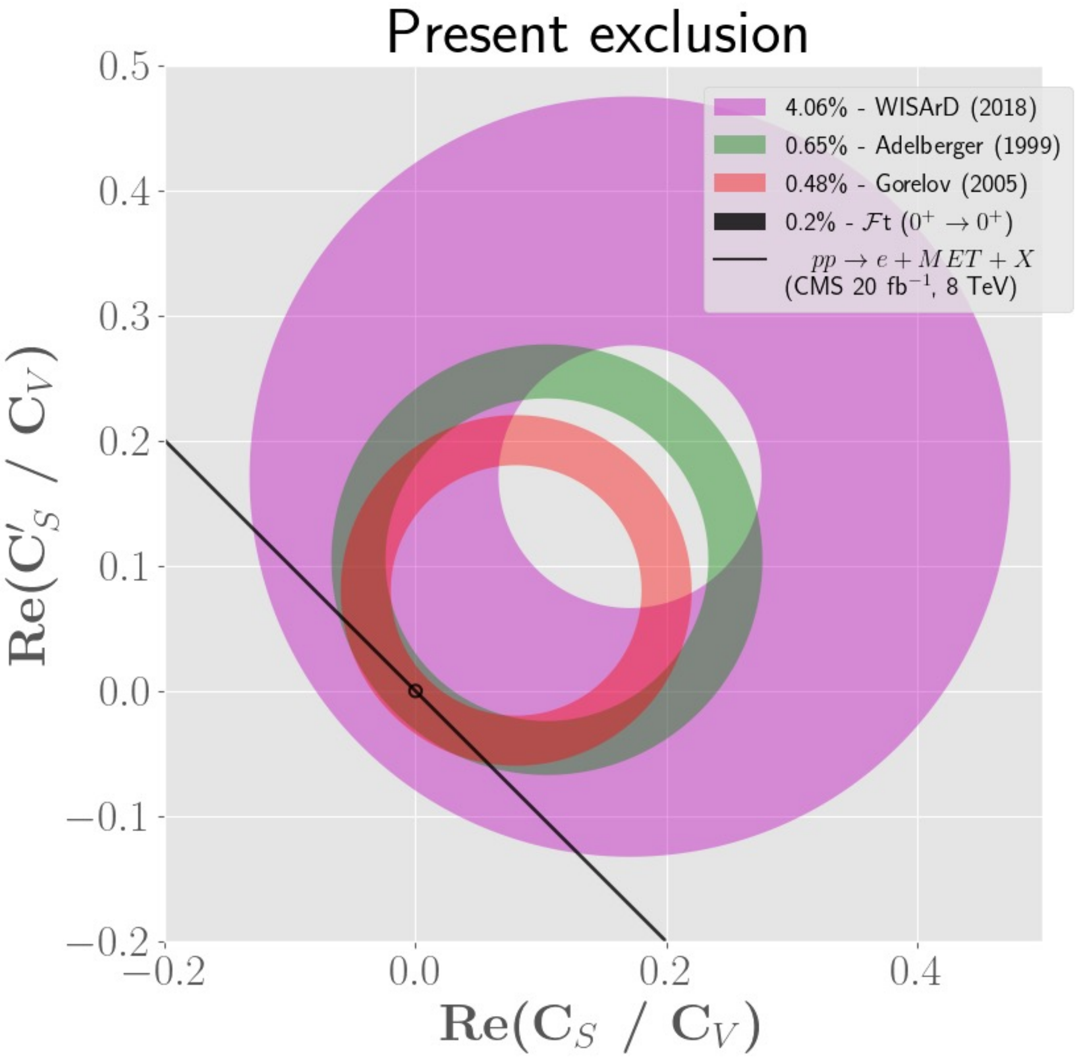
$$\alpha = 0.34$$

➪ precision level : 4%

First result

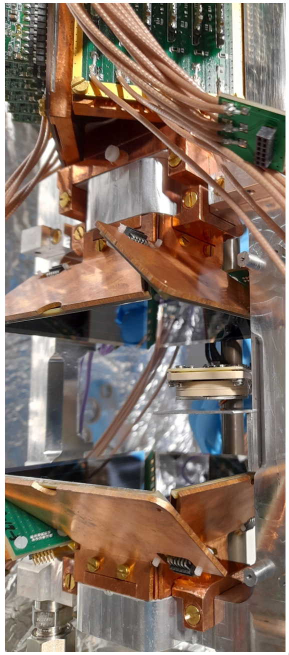
- **Full account of systematic uncertainties**
- **World's 3rd best result**

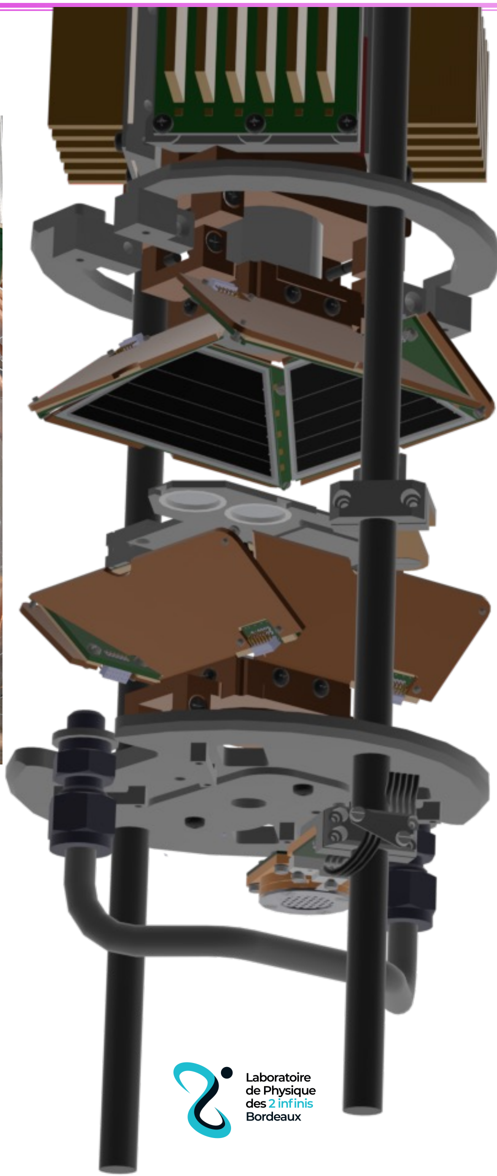
	Source	Uncertainty	$\Delta\tilde{a}_F$ ($\times 10^{-3}$)
Background	False coinc.	8%	<1
Proton	Det. calibration	0.2%	9
	Det. position	1 mm	<1
	Source position	3 mm	3
	Source radius	3 mm	1
	B field	1%	<1
	Silicon dead layer	0.3 μm	5
	Mylar thickness	0.15 μm	2
Positron	Detector backscattering	15%	2
	Catcher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



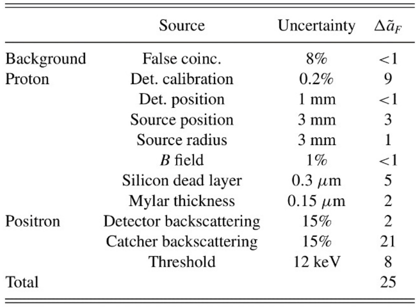
V. Araujo-Escalona et al. Phys. Rev. C 101 (2020)

Upgrade 2019-2021





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



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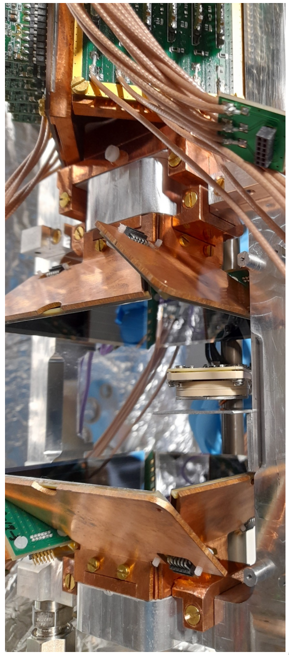
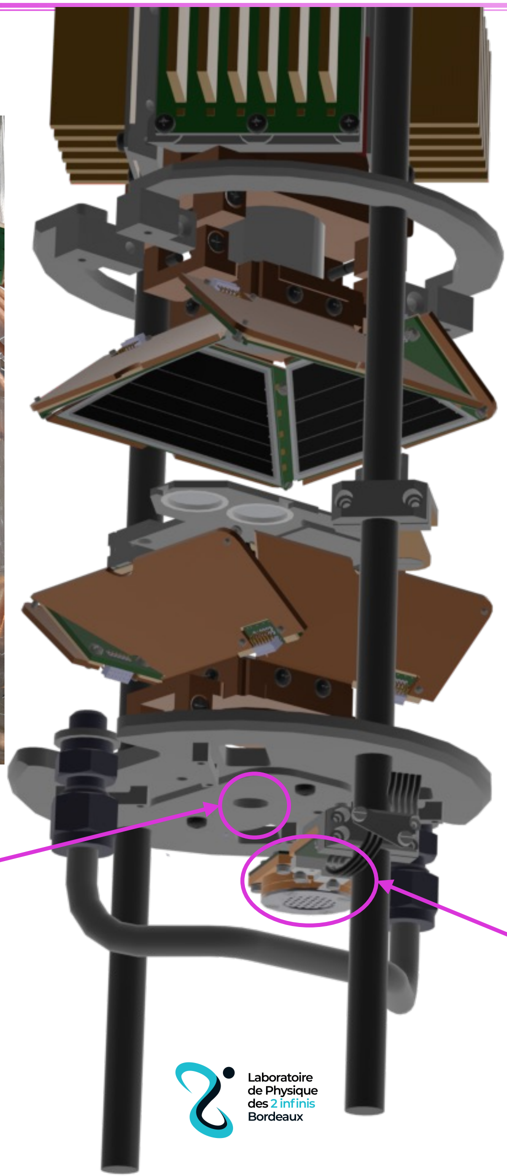
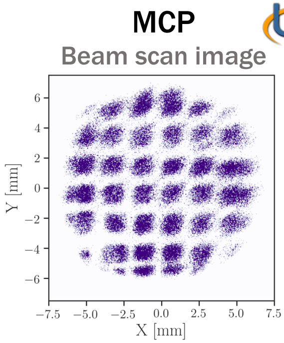
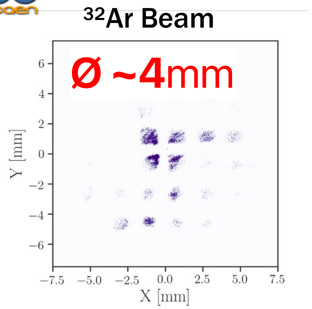


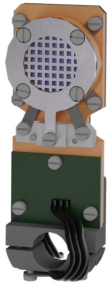


collimator
Φ ~ 6 mm

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







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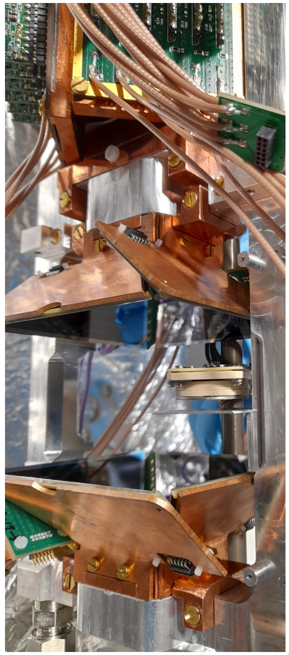
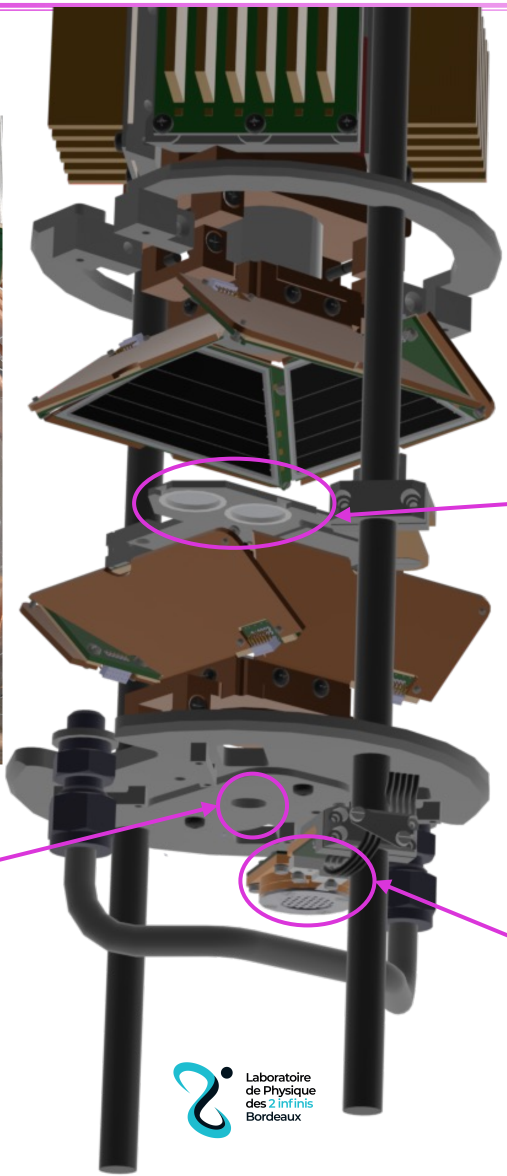
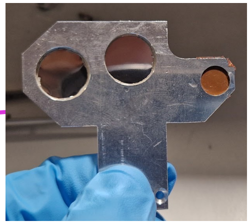




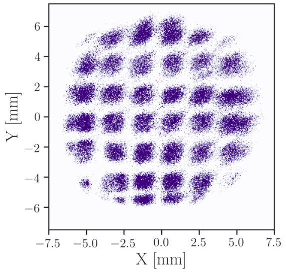
collimator
Φ ~ 6 mm



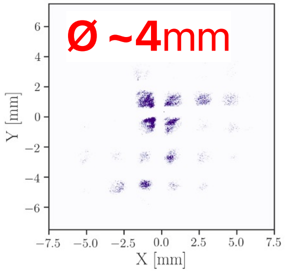
catcher
Al-Mylar 0.6 & 6 μm
α source ^{208}Po

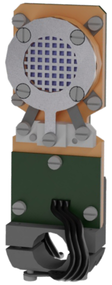
D. Atanasov et al. NIM A 1050 168159 (2023)

MCP
Beam scan image



^{32}Ar Beam





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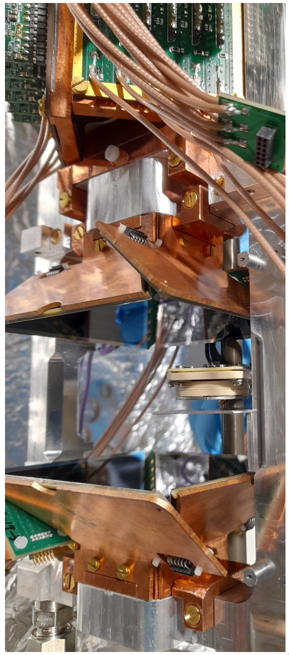
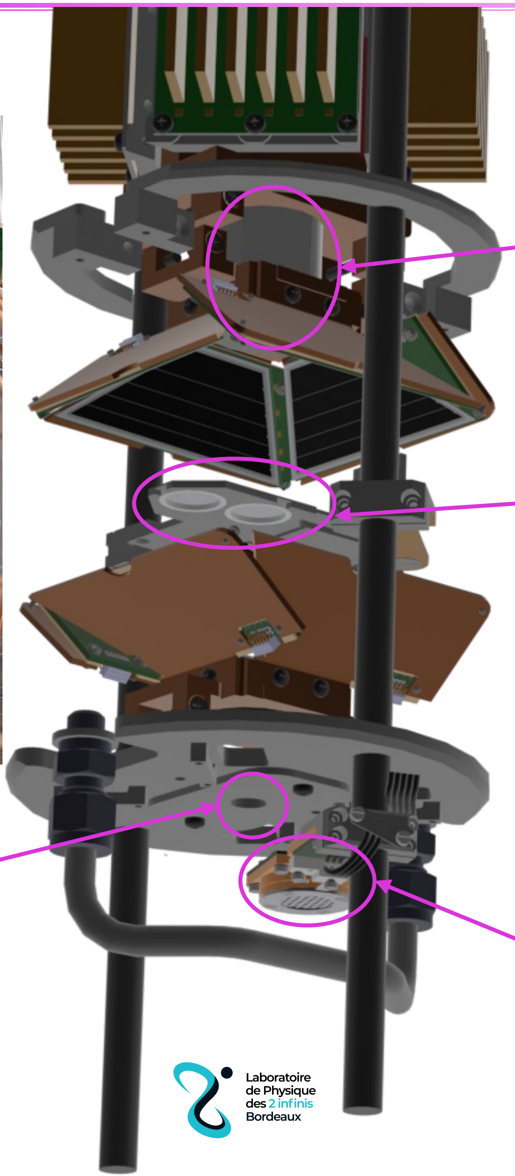
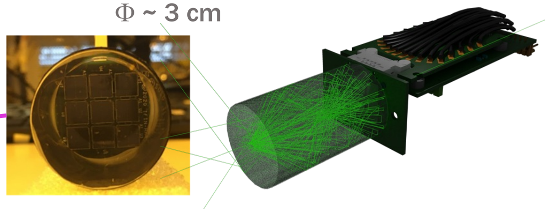
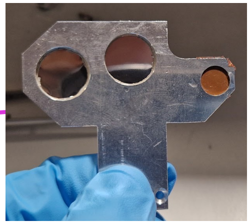




collimator
Φ ~ 6 mm

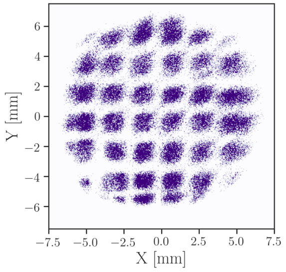
Beta detector
3x3 array of 6x6 mm^2 SiPM
Φ ~ 3 cm



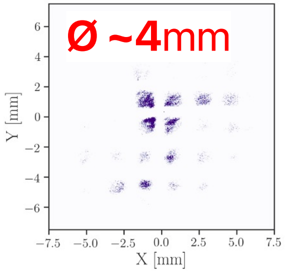


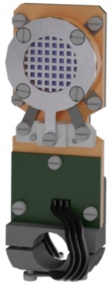
catcher
Al-Mylar 0.6 & 6 μm
α source ^{208}Po

MCP
Beam scan image



^{32}Ar Beam





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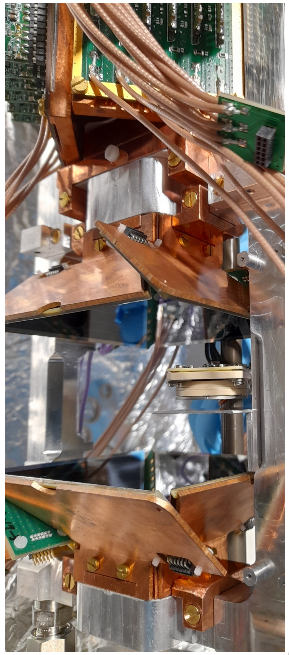
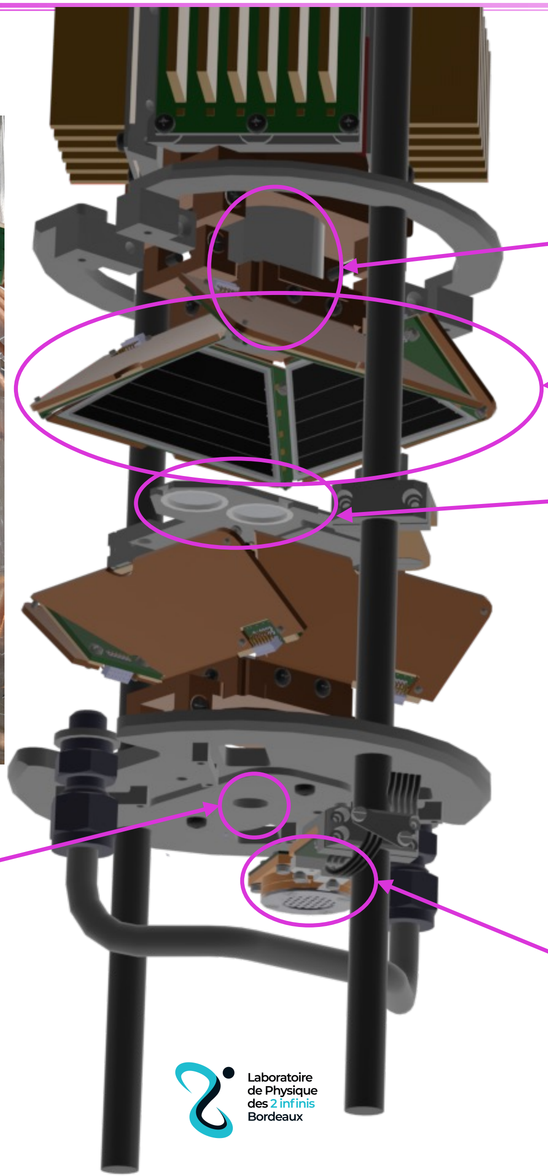
D. Atanasov et al. NIM A 1050 168159 (2023)

Upgrade 2019-2021

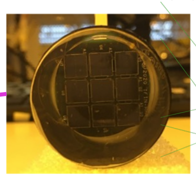


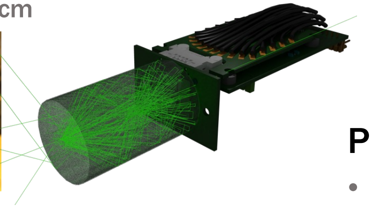


Beta detector

3x3 array of 6x6 mm^2 SiPM

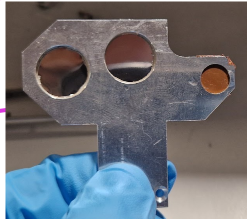
Φ ~ 3 cm





Proton detectors

- 2x4 300μm thick DSSD
- Dead layer ~ 100 nm (AIFIRA)
- Resolution ~ 10 keV FWHM (AIFIRA)
- 57% solid angle
- ~90° incident angle
- Copper cooling system -23°C

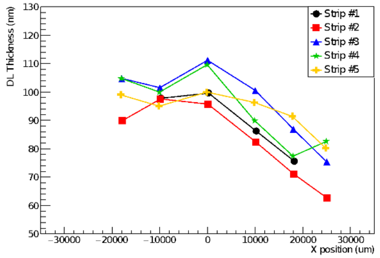


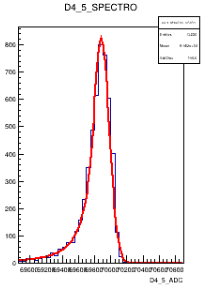
catcher

Al-Mylar 0.6 & 6 μm

α source ^{208}Po

Det 3423-1-1



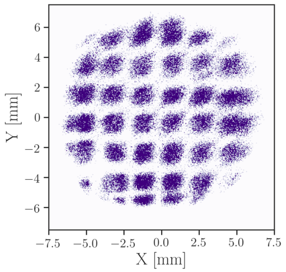


collimator

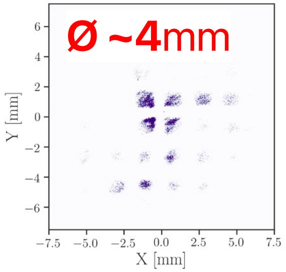
Φ ~ 6 mm

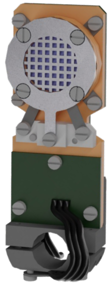
MCP

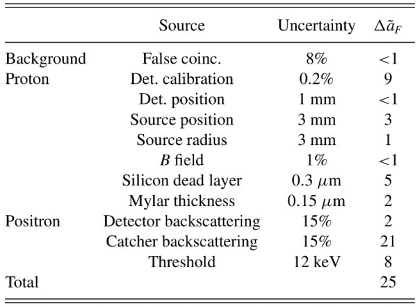
Beam scan image



^{32}Ar Beam







	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

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

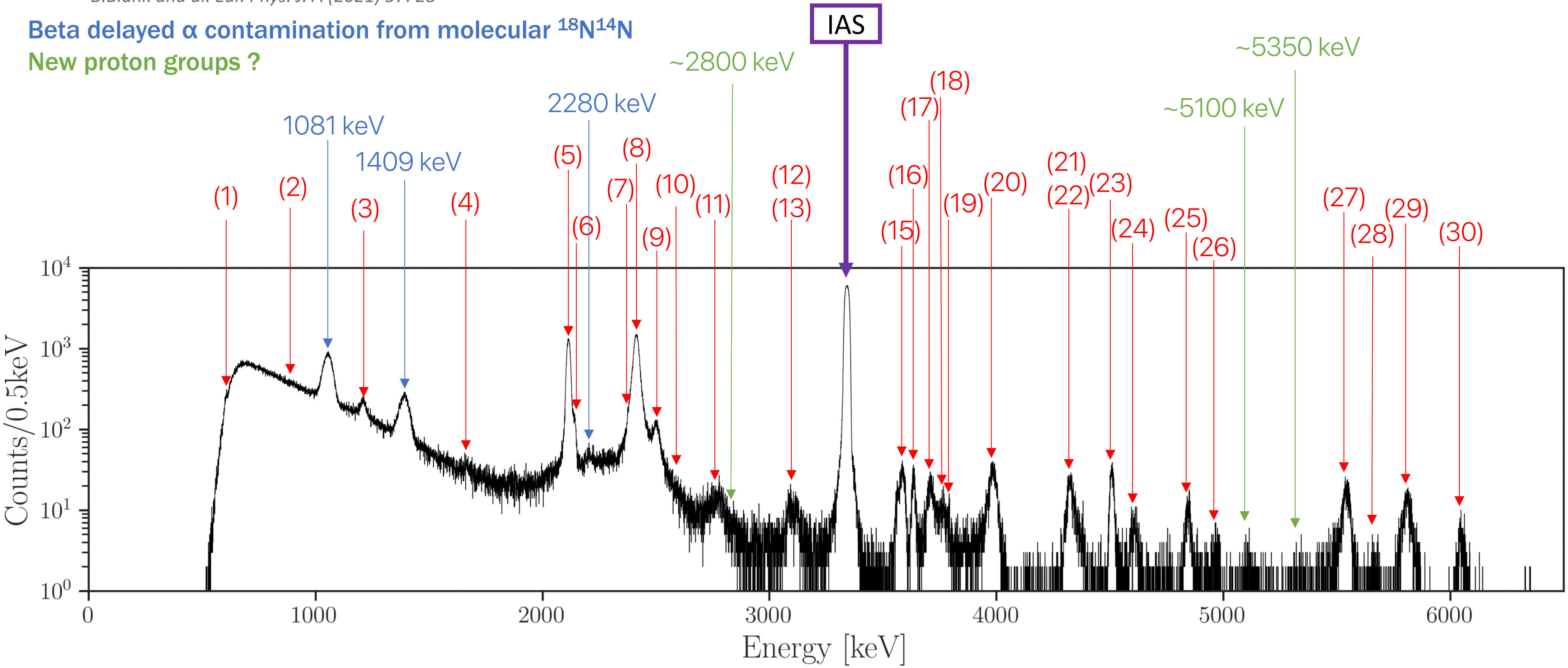
Latest Data Taking - May 2024

All known ^{32}Cl proton groups identified

B.Blank and al. Eur. Phys. J. A (2021) 57: 28

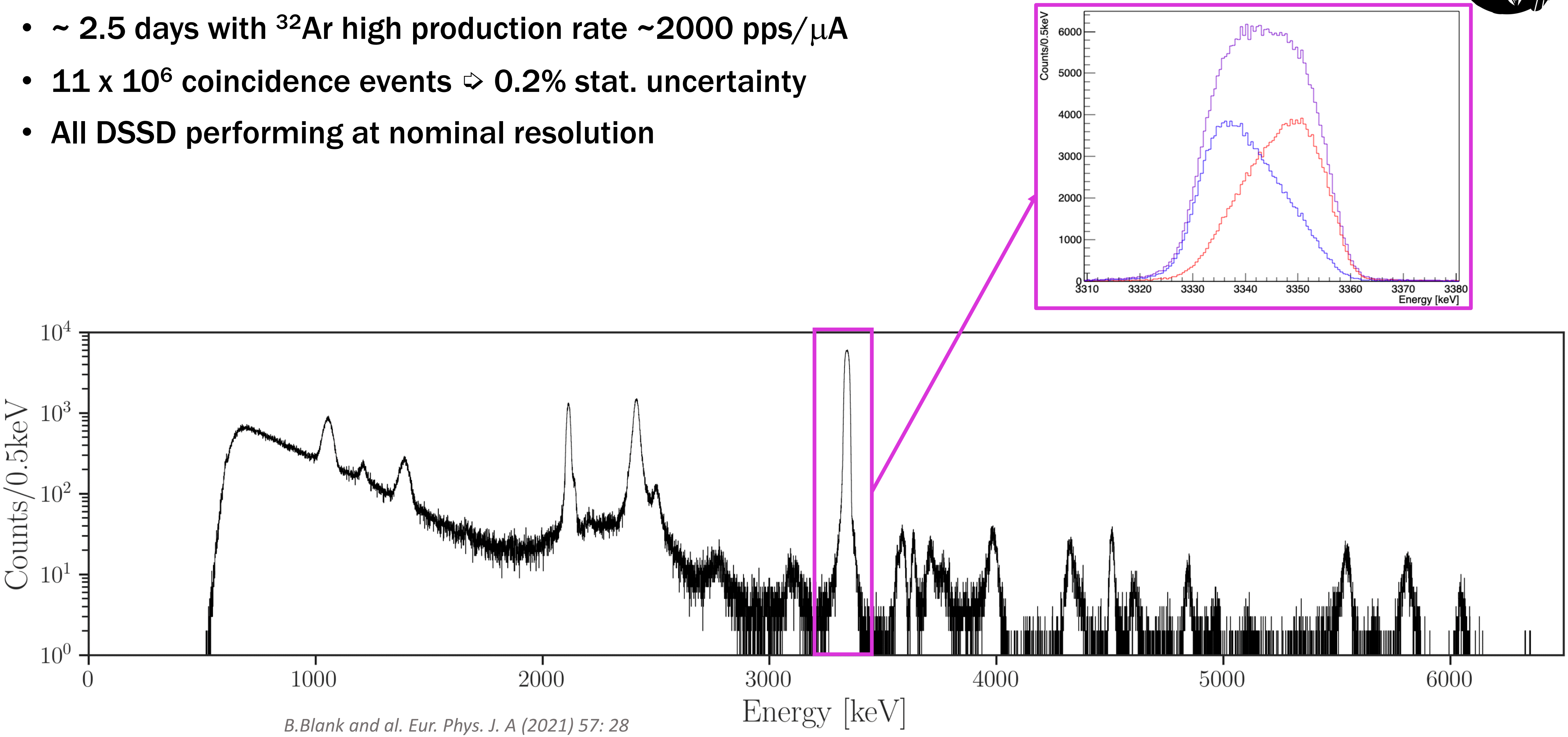
Beta delayed α contamination from molecular ^{18}N^{14}N

New proton groups ?



Latest Data Taking - May 2024

- ~ 2.5 days with ^{32}Ar high production rate ~2000 pps/μA
- 11 x 10^6 coincidence events ➪ 0.2% stat. uncertainty
- All DSSD performing at nominal resolution

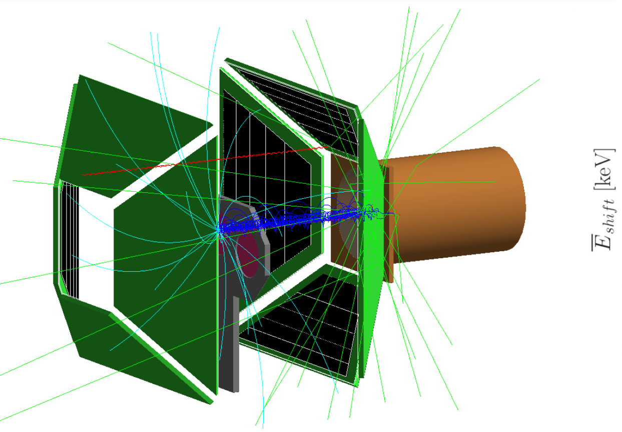


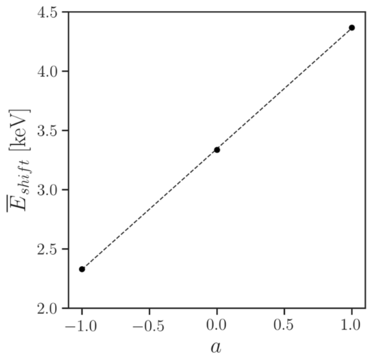
B.Blank and al. Eur. Phys. J. A (2021) 57: 28

Latest Data Taking - May 2024

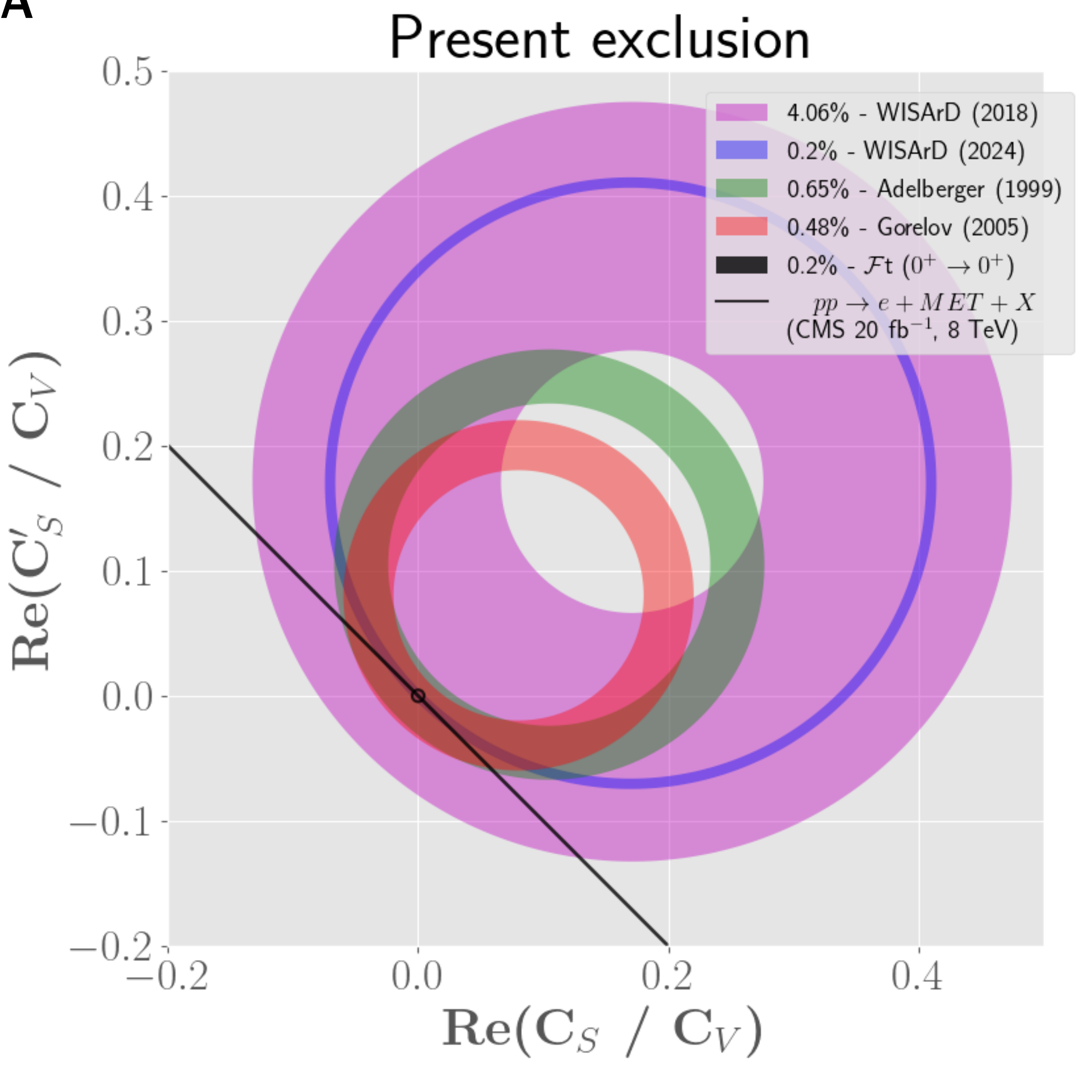
- ~ 2.5 days with ^{32}Ar high production rate ~2000 pps/μA
- 11 x 10^6 coincidence events ➪ 0.2% stat. uncertainty
- All DSSD performing at nominal resolution

- Analysis underway
  - Precise calibration of proton detectors
  - Extraction of $\overline{E}_{shift}$
  - GEANT4 simulation of the full geometry and data set
  - Precise assessment of systematic uncertainties





PhD S. Lecanuet



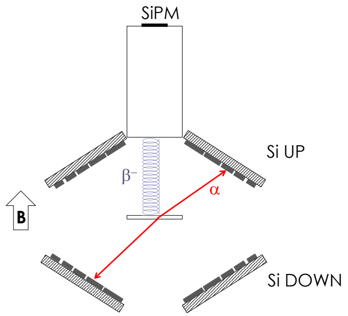
Perspectives

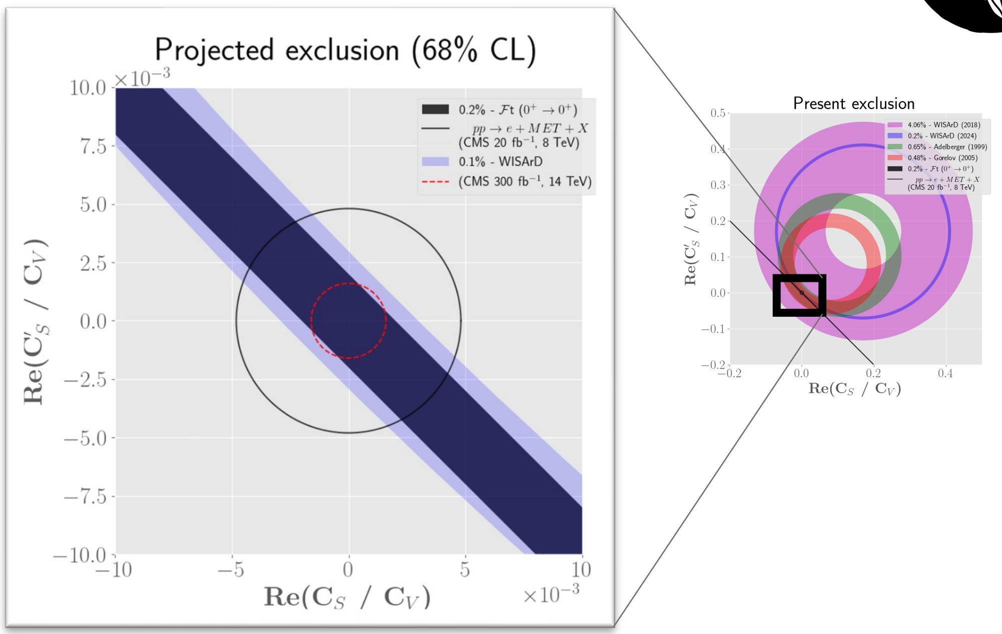
- Set-up fully operational

- 2025
  - New ^{32}Ar run depending on systematic uncertainty
  - ^{8}Li : beta-delayed α break-up

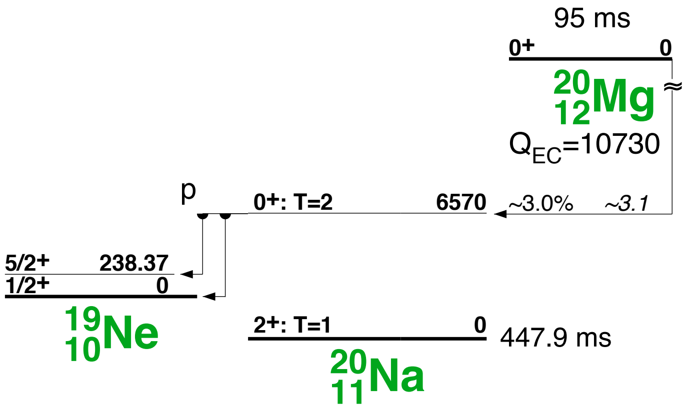
    Search for T currents

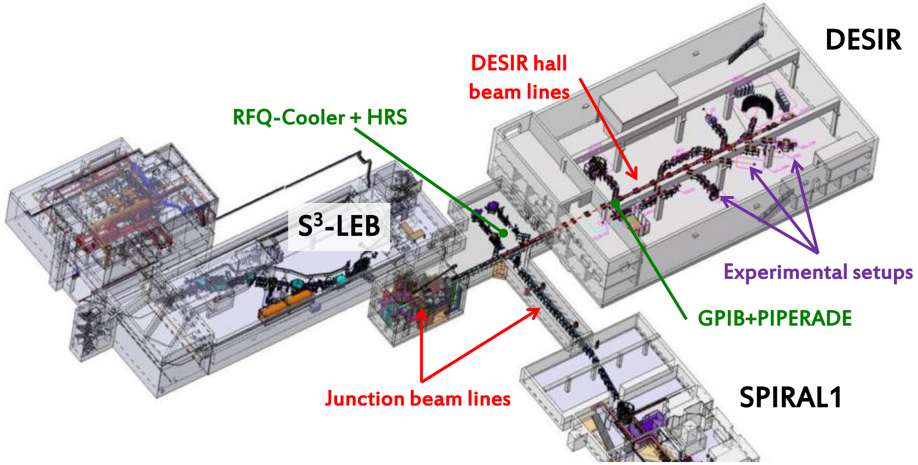
    WISArD sensitivity ?





- Long Term
  - New β-p candidates : ^{20}Mg @DESIR





Outline

- Search for Exotic Weak Scalar Couplings
- Angular correlation measurement
  - Why ^{32}Ar ?
  - The WISArD set-up
  - Status and prospective
- Beta spectrum shape measurement
  - Fierz term and weak magnetism
  - Status and prospective at WISArD

2030 Roadmap Science Drivers

Pursue searches for unknown particles and interactions (New Phenomena)

beta spectrum shape

- Decay distribution for unpolarized nuclei : integrating over all angles

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

Pure Fermi transition $b_{\text{Fierz},F} \simeq \pm\text{Re}\left(\frac{C_S + C'_S}{C_V}\right)$

Pure Gamow-Teller transition $b_{\text{Fierz},GT} \simeq \pm\text{Re}\left(\frac{C_T + C'_T}{C_A}\right)$

- Going down to 1‰ level of uncertainty
  - All corrections must be described at the 10^{-4} level or better
  - Nuclear effects : SM recoil order correction “Weak Magnetism”

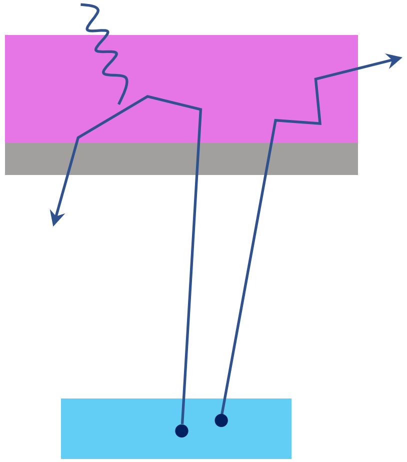
$$W(E_e)dE_e = dW_0 \times \xi \left(1 + b\frac{m}{E_e} \pm \frac{4}{3}\frac{E_e}{M}\frac{b_{\text{WM}}}{Ac}\right)$$

  - CVC hypothesis : beta decays within the same isospin multiplet (mirror decays) or where ΔT=1, $\Delta T_z=\pm1$
  - Theoretical calculations based on nuclear shel model in good agreement with experiment up to A~50

L. Hayen et al, Rev. Mod. Phys. 90 (2018)
N. Severijns et al Phys. Rev C 107, 015502 (2023)

Experimental challenges

- Partial energy deposit
  - Backscattering
  - Out-scattering
  - Bremsstrahlung
- Energy loss
  - Source localization
  - Detector dead layer
- Tracking simulations accuracy



G. Soti et al., NIMA 728 (2013)
*M. Kanafani, Phys. Rev. C **106**, 045502 2022*
D.Rozpedzik arXiv:2208.09971
S. Friedrich et al., Phys. Rev. Lett. 126, 021803 (2021)

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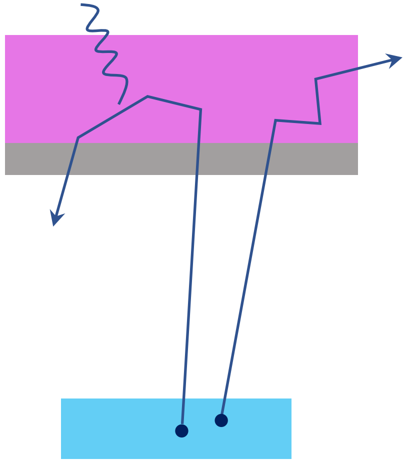
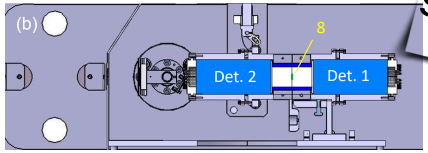
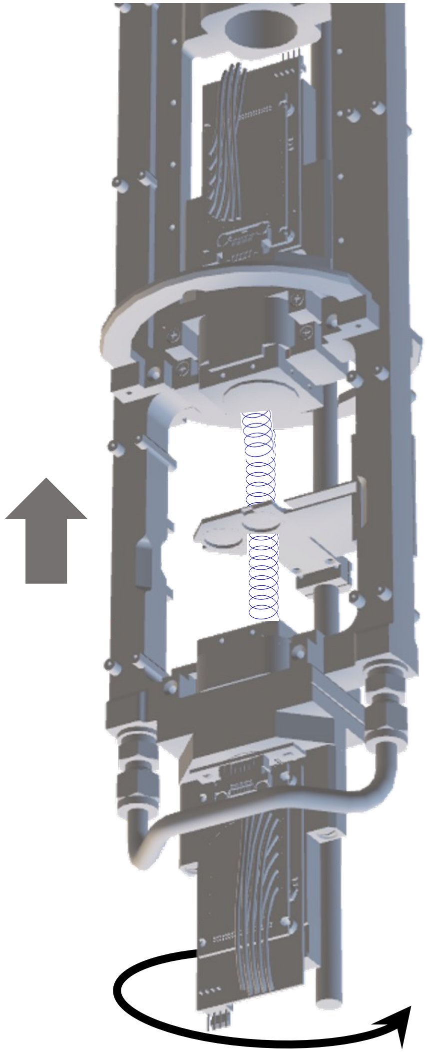


- Spectrometers
- 4π calorimetry
  - b-STILED, ^{20}F@MSU…
- Tracking with MWDC
  - MiniBETA
- New techniques
  - ^{6}He-CRES
  - superconducting tunnel-junctions …

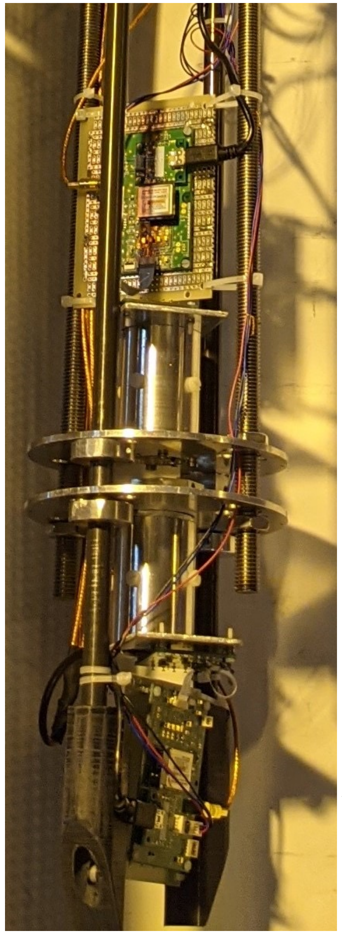


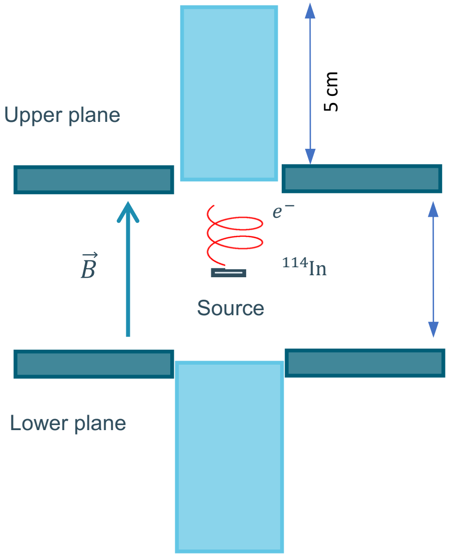
See talk X. Fléchard

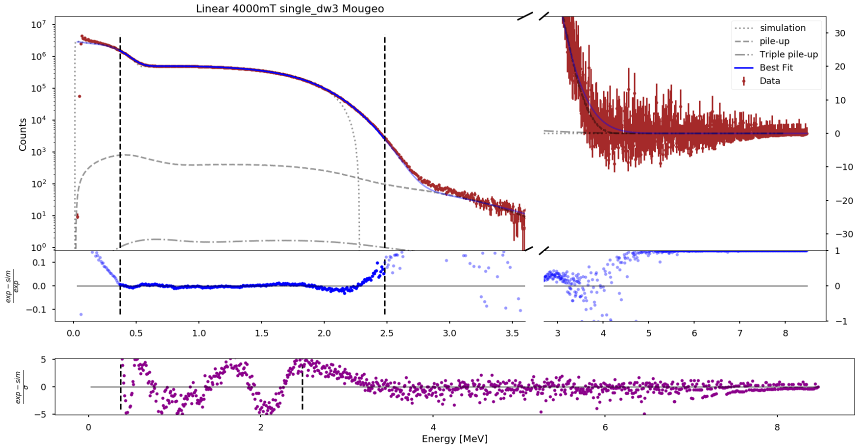


G. Soti et al., NIMA 728 (2013)
*M. Kanafani, Phys. Rev. C **106**, 045502 2022*
D.Rozpedzik arXiv:2208.09971
S. Friedrich et al., Phys. Rev. Lett. 126, 021803 (2021)

Beta-spectrum shape at WISArD







S. Vanlangendonck, PhD (2023)

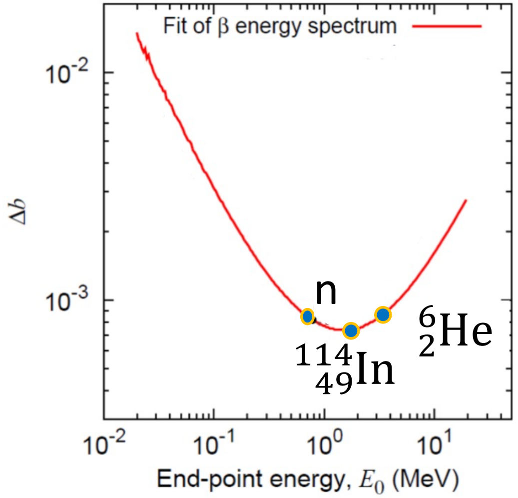
Proof-of-Principle : InESS – 2020

- ^{114}In source measurement

$$E_0 \sim 2\ \mathrm{MeV}$$

$$T_{1/2}(^{114m}\mathrm{In}) \sim 49\ \mathrm{d}$$

$$A > 70 \Rightarrow b_{WM}$$



- 2 PS scintillators with 6x6 mm^2 SiPM

Systematic uncertainty

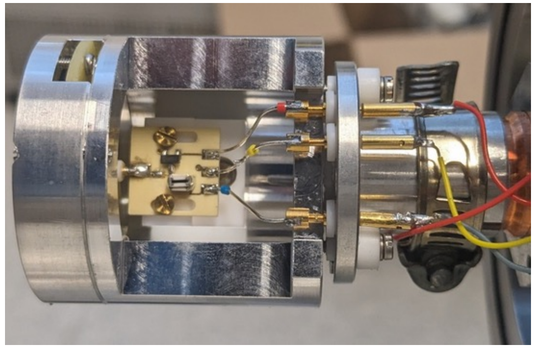
- Temperature sensitivity of the SiPM gain
- Calibration non-linearity
- Resolution ~200keV
- Threshold ~ 70 keV

New beta-shape measurements

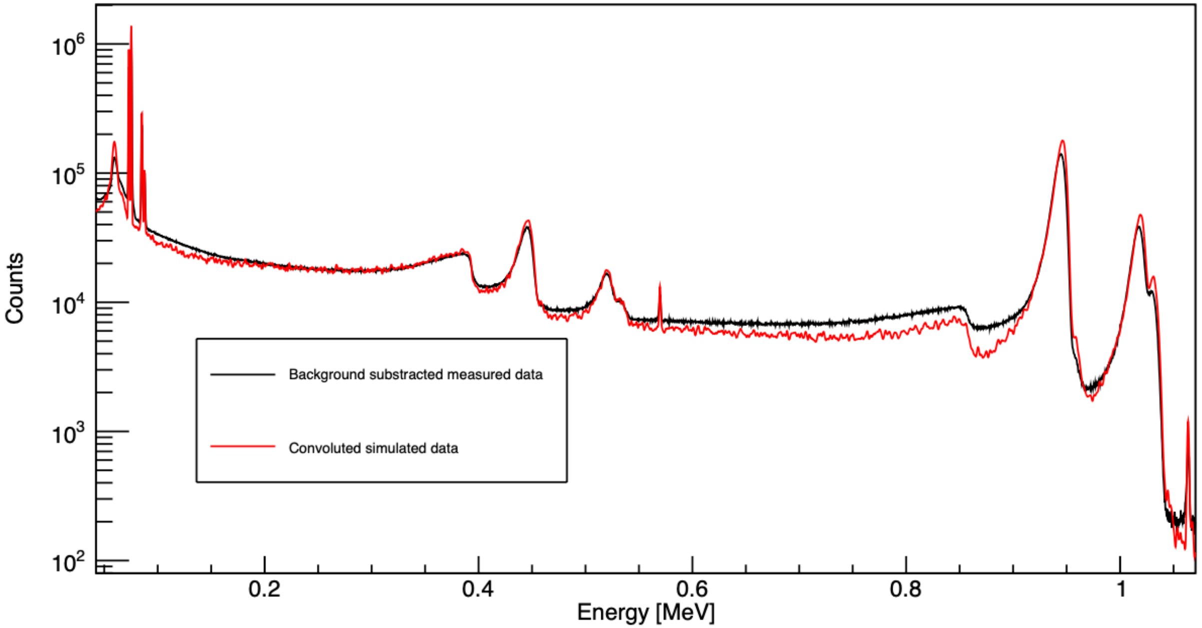
- Si(Li) detectors at T=77K
  - Lower threshold : < 5 keV
  - Higher resolution : 0.8 keV for γ @ 1MeV
  - GEANT4 model
- Ongoing
  - Higher backscattering probability to be assessed
  - Performances at -40 °C to be checked with glycol active cooling and Peltier elements
  - New detection tower under construction
- Perspective
  - Source measurements during LS3 2026-2028

    ^{114}In, ^{32}P, ^{22}Na
  - Beam measurements after 2028

    ^{14}O, ...



KU LEUVEN



C. Knapen, Master Thesis (2023)

The WISArD Project

Set-up developments and tests

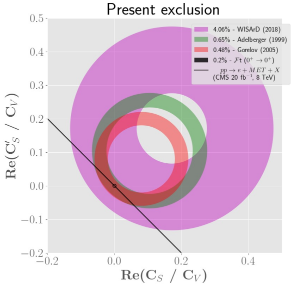
Data Analysis

Operation

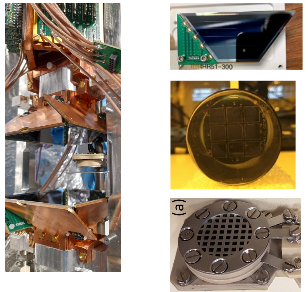
- ~ 20 collaborators from 8 institutions
- Total budget ~ 1.1 M€ from ANR and FWO ending 2024
- PhDs and Post-Doctorate Fellows :
  - V. Araujo-Escalona 2015-2017 KU Leuven
  - F. Cresto 2019-2023 ANR
  - M. Pomorski 2019-2022 ANR
  - D. Atanasov 2018-2023 KU Leuven, CERN Fellow, IN2P3
  - J. Ha 2022-2023 KU Leuven
  - S. Lecanuet 2023-2026 IN2P3
  - New PhD 2024-2027 Région Nouvelle Aquitaine – IN2P3
- IN2P3
  - **LP2i Bordeaux :** P.Alfaurt, P.Ascher, B.Blank, L.Daudin, M.Gerbaux, J.Giovinazzo, S.Grévy, S.Lecanuet, M.Roche, M. Versteegen
  - **LPC Caen :** X.Fléchard, L. Hayen, E.Liénard
  - **Future need for financial support : ~ 20k€ / year**

Conclusion and outlook

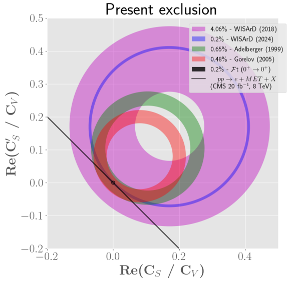
- Proof-of-Principle



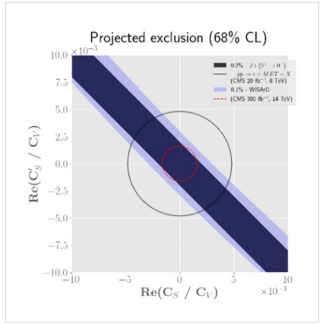
- Upgrade



- 0.2% uncertainty on $\tilde{a}$



- New Run : ^{32}Ar or ^{8}Li



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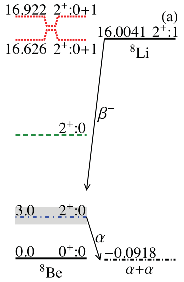
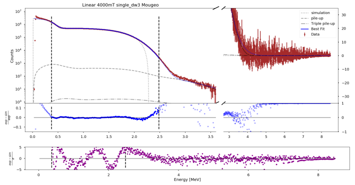
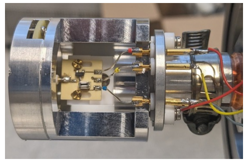


- InESS : ^{114}In



- Si(Li) @ISOLDE

Temperature tests



- Si(Li) @ISOLDE

Tests with B field

Calibration sources

^{207}Bi, ^{60}Co, ^{90}Sr…

- Shape meas.

Source

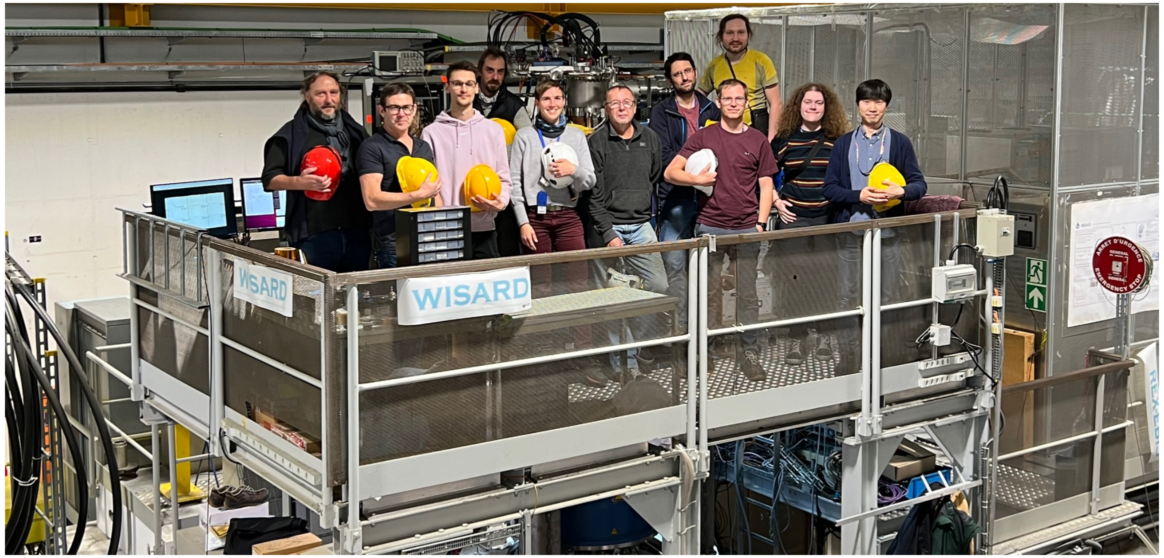
^{114}In, ^{90}Sr, ^{32}P,^{22}Na

- Shape meas.

RIB

^{14}O, mirror nuclei…

Thank you



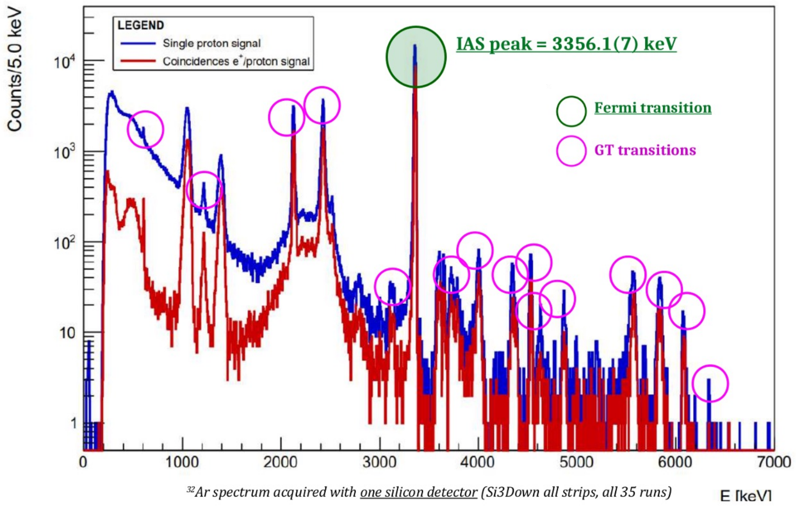
P.Alfaurt, P.Ascher, D.Atanasov, B.Blank, L.Daudin, X.Fléchard, A.Garcia, M.Gerbaux, J.Giovinazzo, S.Grévy, J.Ha, L. Hayen, C.Knapen, S.Lecanuet, R.Lica, E.Liénard, D.Melconian, C.Mihai, C.Neacsu, M.Pomorski, M.Roche, N.Severijns, S.Vanlangendonck, M. Versteegen, D.Zakoucky

Test Run 2021

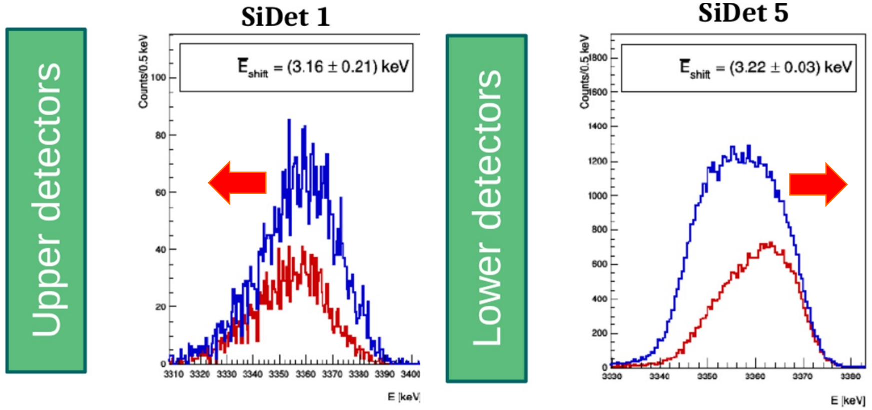
- 43h beam time
- Kinematic shift and broadening clearly visible

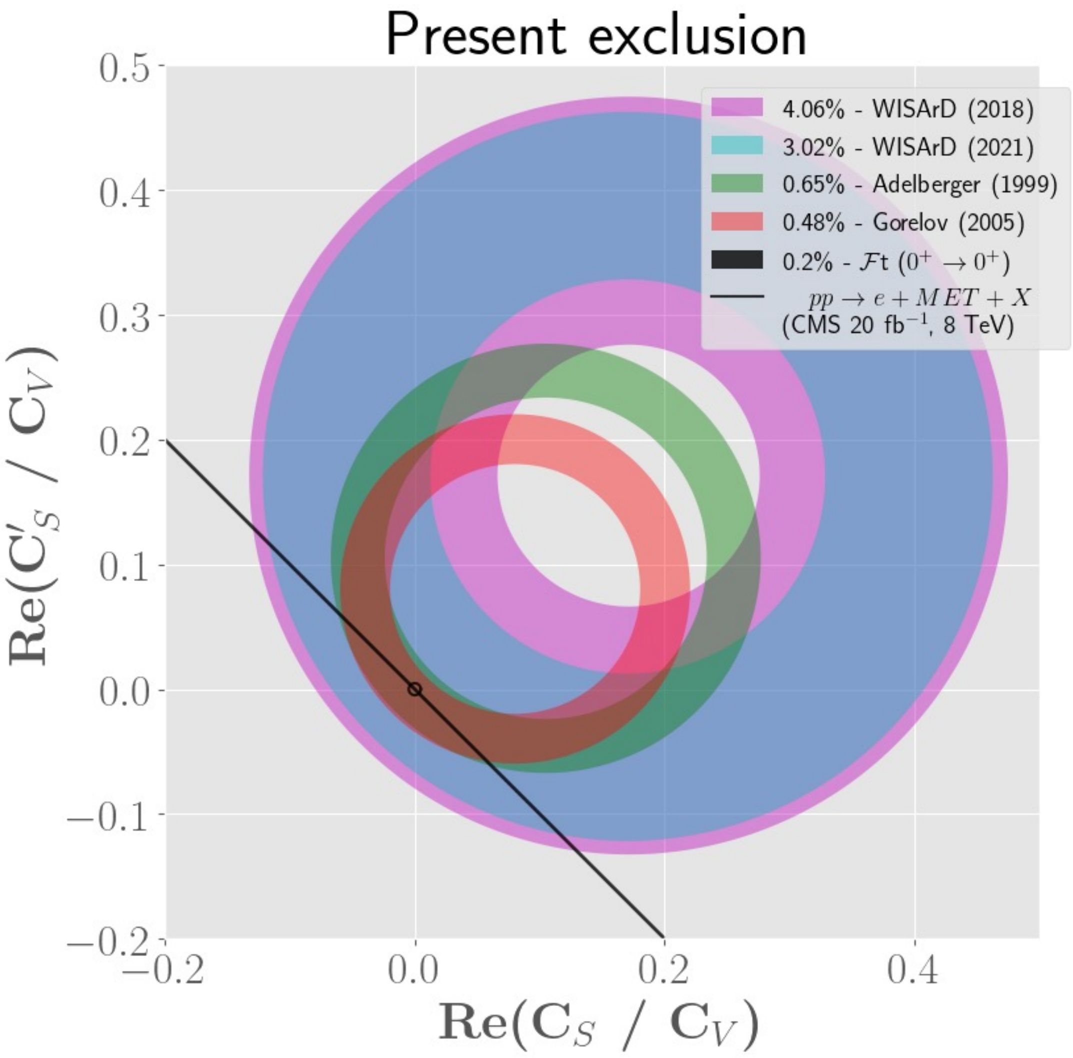
$$\tilde{a} = 1.002(17)_{stat}$$

➪ precision level : ~3%



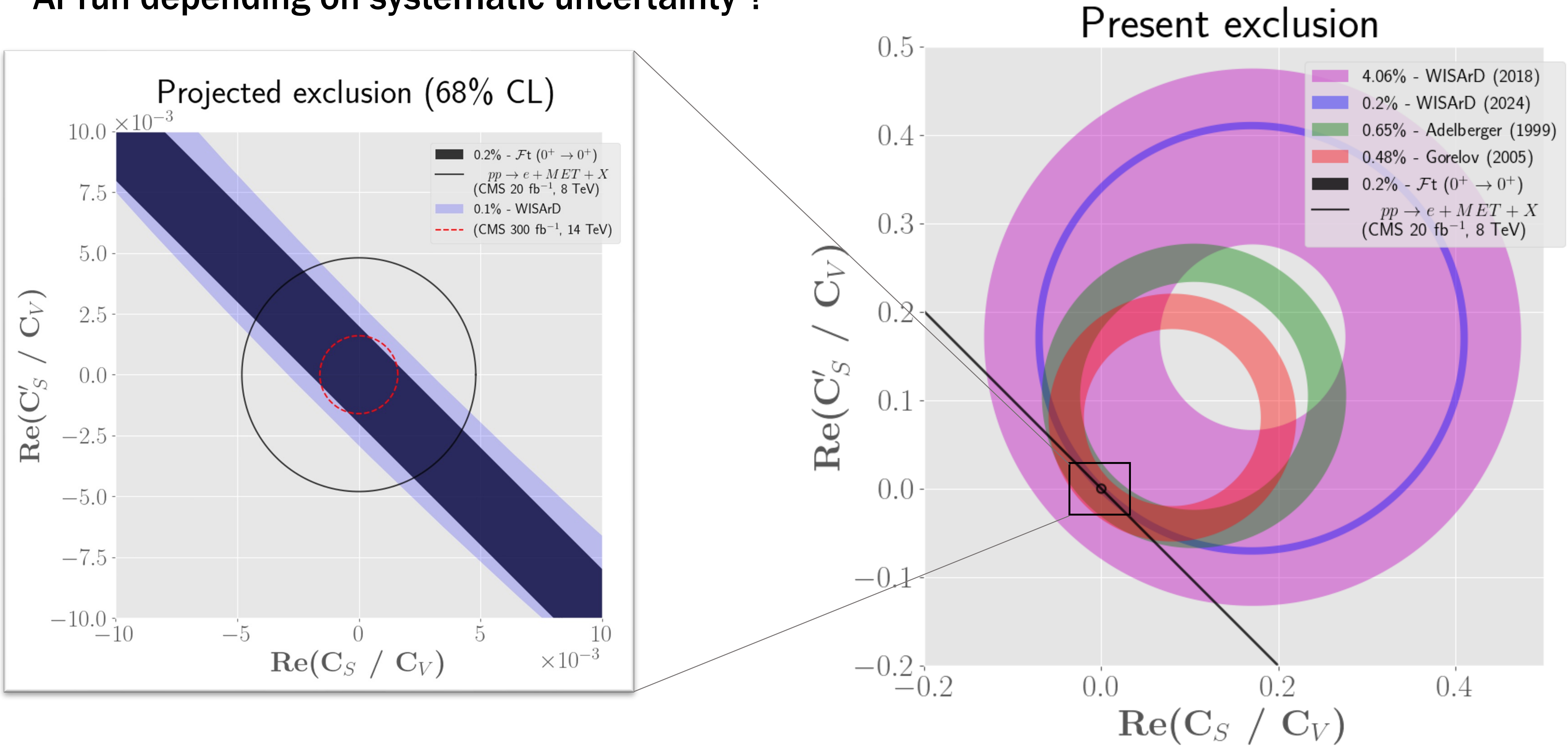
^{32}Ar spectrum acquired with one silicon detector (Si3Down all strips, all 35 runs)





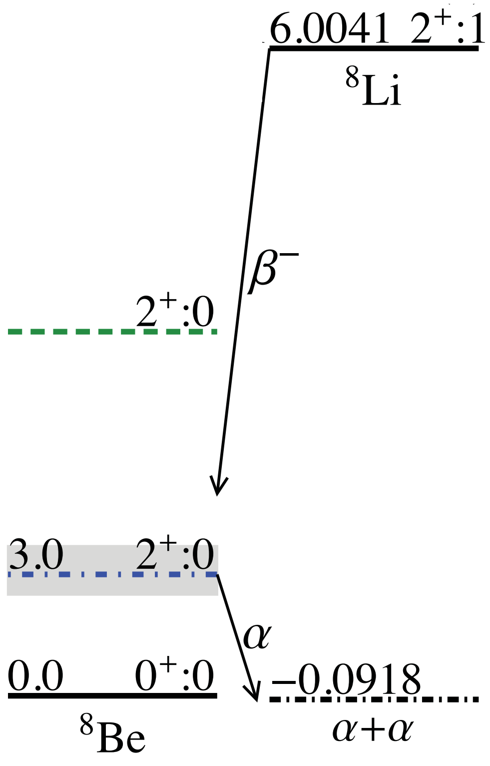
Short term perspectives - 2026

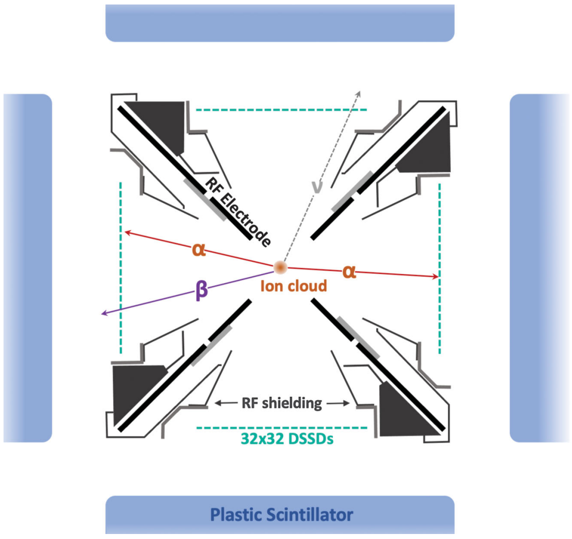
- New ^{32}Ar run depending on systematic uncertainty ?

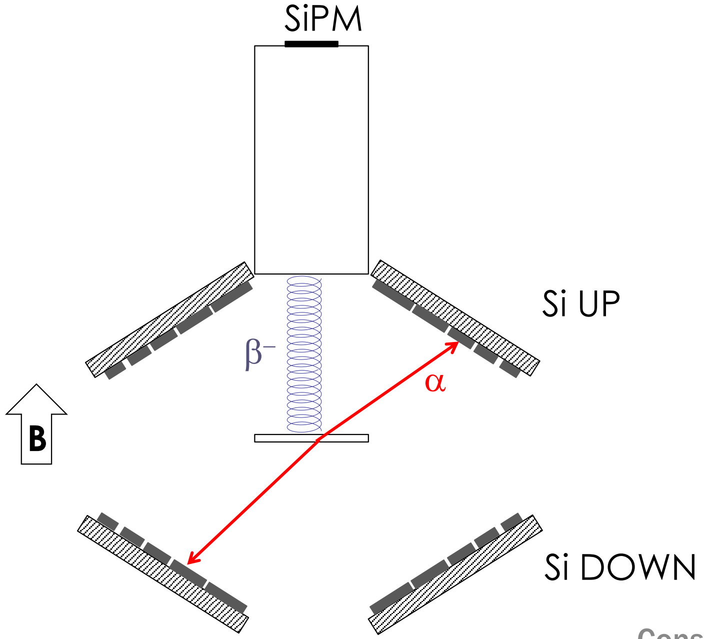


PhD S. Lecanuet

^{8}Li : β-delayed α break-up





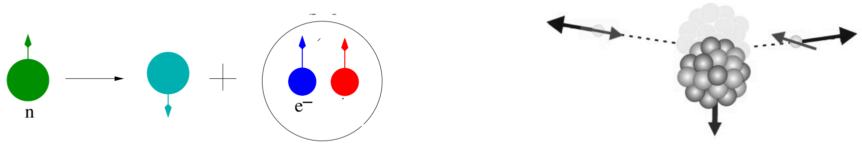


Pure Gamow-Teller transition **ΔJ=0 or 1 S=1**

Axial-Vector Coupling

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

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



- **Argonne : Paul Trap (BPT)**

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

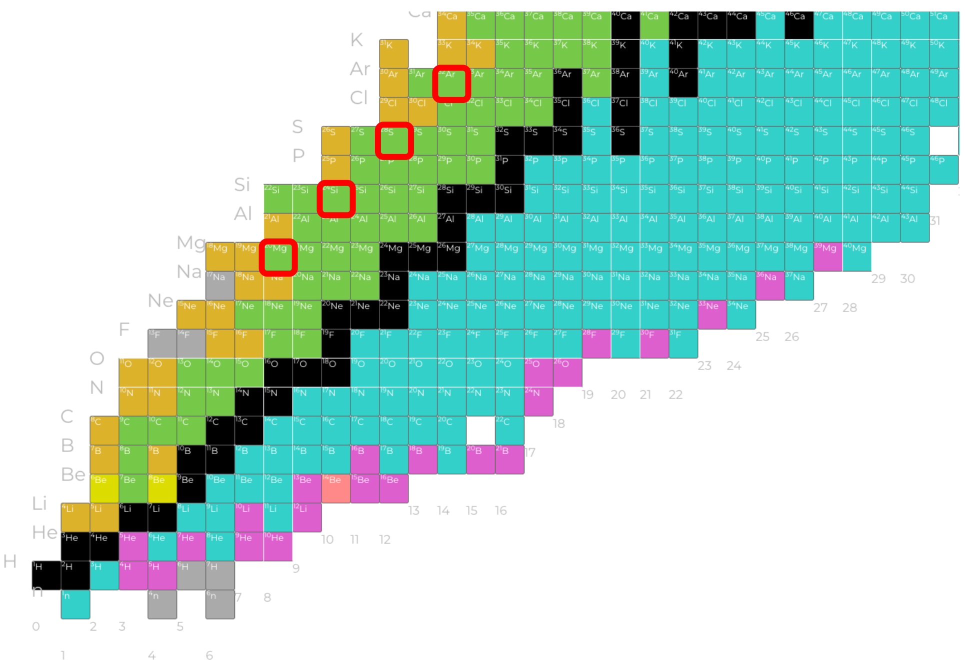
  $$|C_T/C_A| < 0.087 \text{ at the } 95.5\% \text{ C.L.}$$

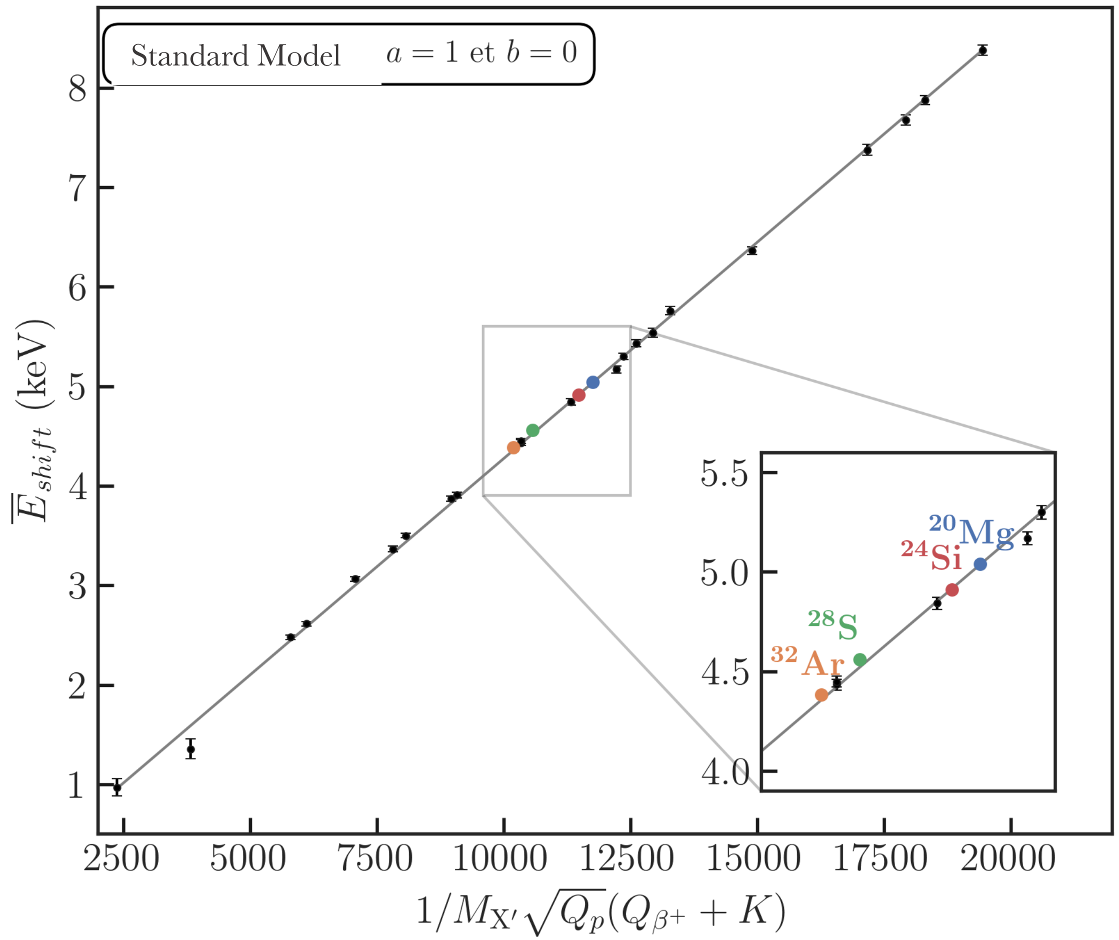
- **WISArD sensitivity ?**
  - **Geometry**
  - **Energy loss in the catcher and dead layers**

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

Longer term : other β-p candidates

- **14 β-p emitters with pure Fermi transition**
- **Kinematic shift :**
  - **∝ 1/M’ of daughter nucleus**
  - **∝ √Q_p proton kinetic energy**
  - **∝ Q_β endpoint**
- **3 exotic nuclei lighter than ^{32}Ar**

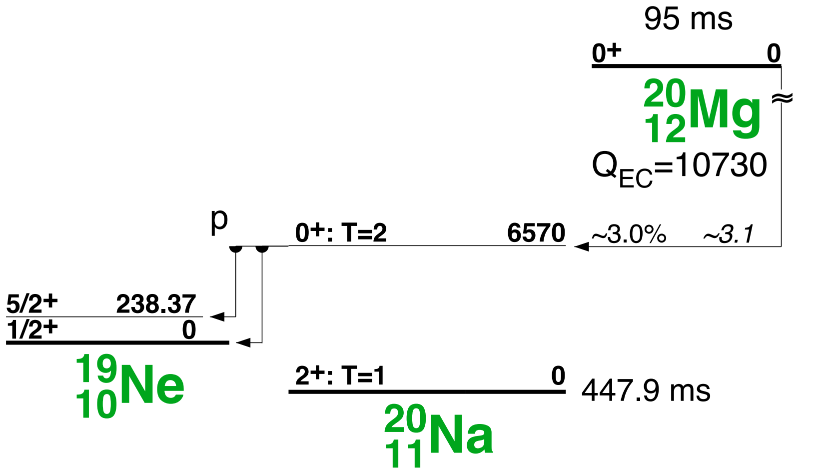




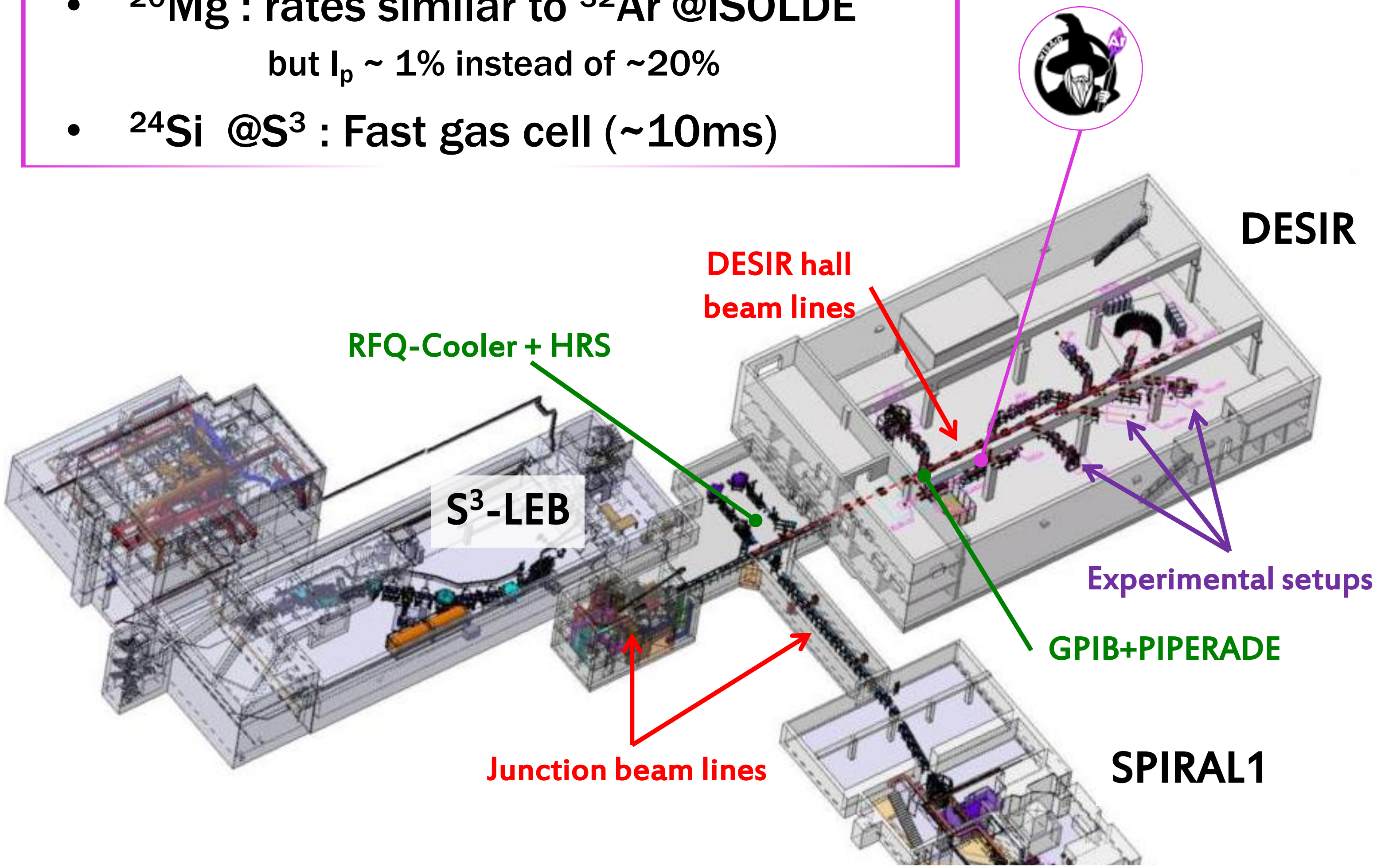
S. Lecanuet – M2 Internship

^{20}Mg at DESIR

- Contaminant : ^{20}Na ⇨ PIPERADE
- ^{20}Mg : rates similar to ^{32}Ar @ISOLDE
  but I_p ~ 1% instead of ~20%
- ^{24}Si @S^3 : Fast gas cell (~10ms)



M.V. Lund et al, Eur. Phys. J. A (2016) 52: 304

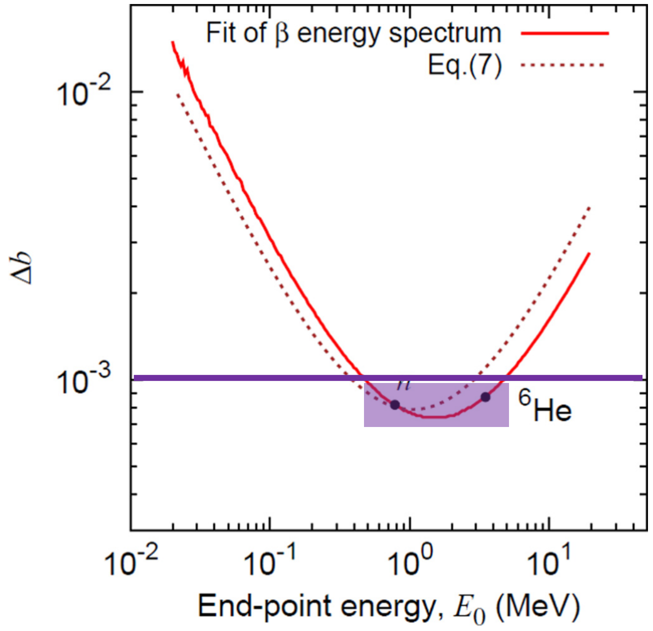


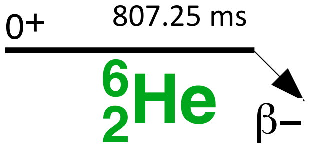
	$T_{1/2}$ (ms)	rate ISOLDE (ions/μC)	rate DESIR (pps)
^{20}Mg	90	-	1500-3600 (SP1) / 300-500 (S3)
^{24}Si	143	-	420 (S3)
^{28}S	125	-	?
^{32}Ar	100	~ 3000	2300 (SP1)

Choosing the best candidate

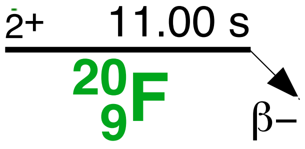
- **Theoretical constraints**
  - Radiative corrections under control
  - Recoil order corrections : b_{WM}
  - Simple shape : allowed transition
  - Simple decay scheme
- **Sensitivity**

E_0 between 1 and 3 MeV

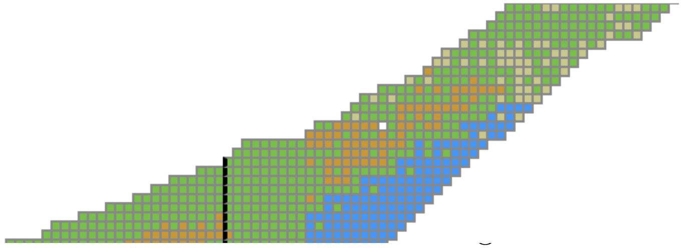


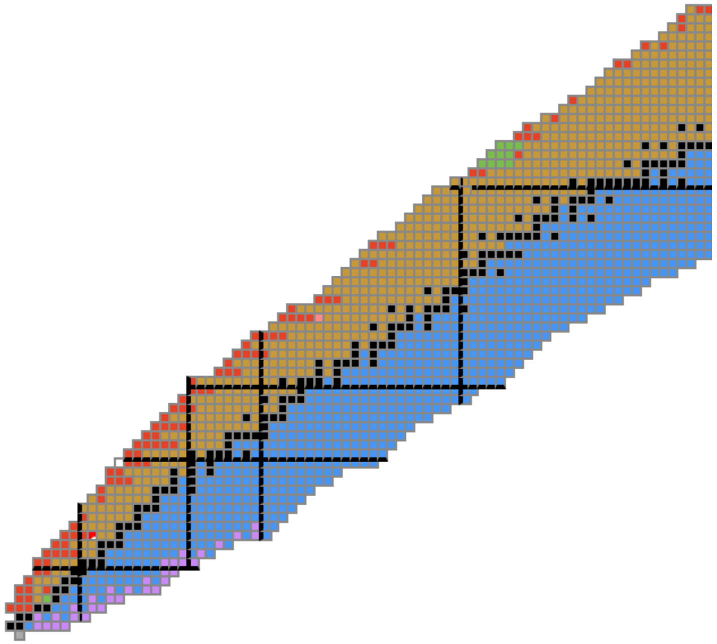


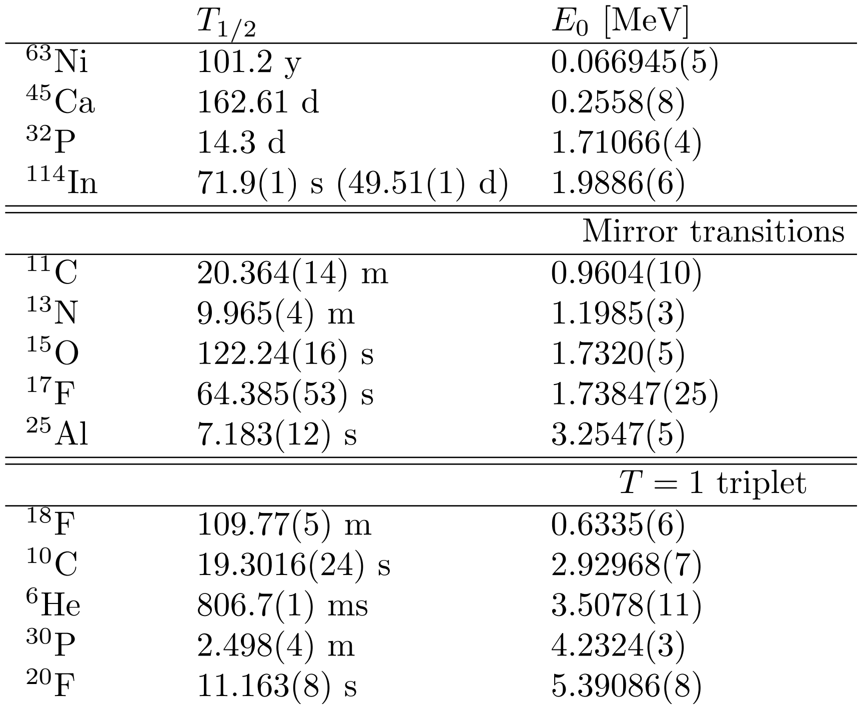
$Q_{\beta-}$ 3507.8



$Q_{\beta-}$ 5392



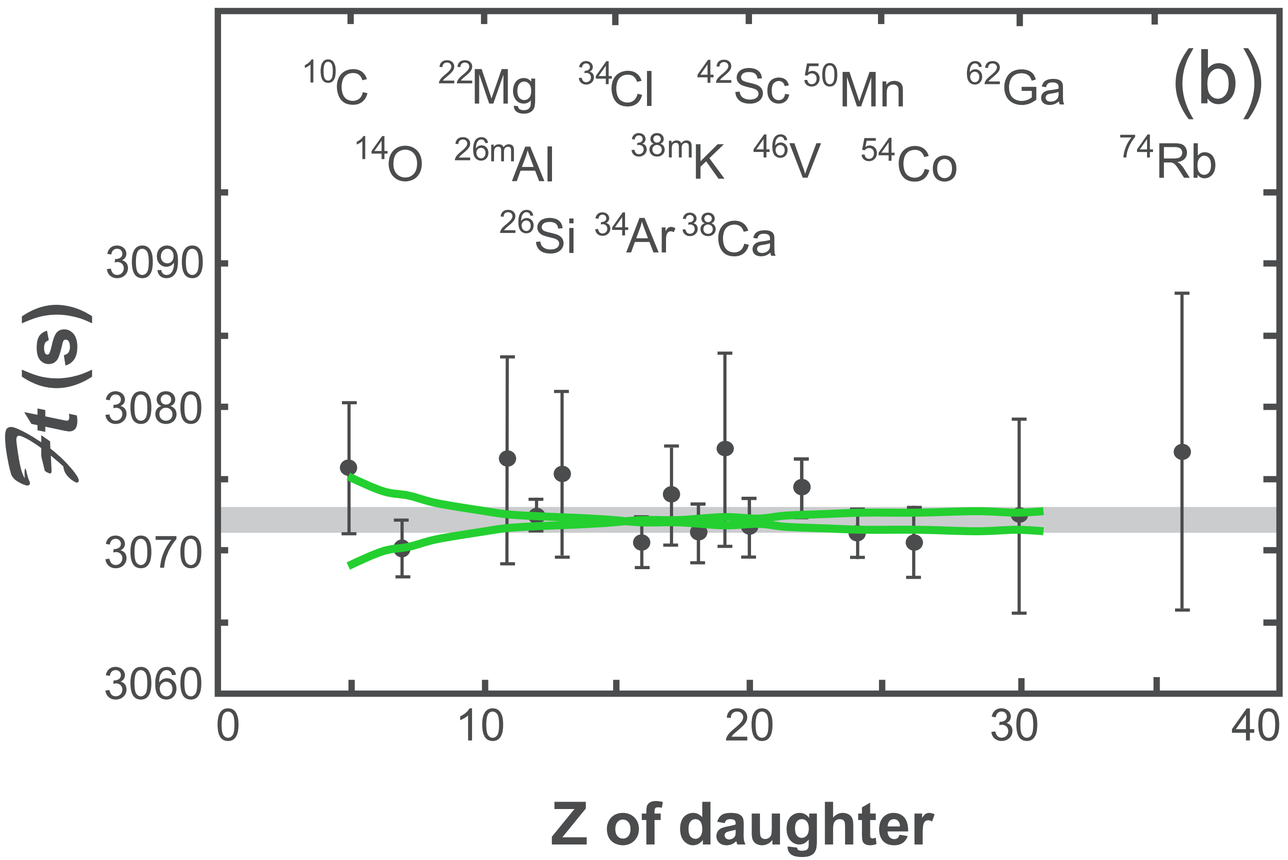




	$T_{1/2}$	E_0 [MeV]
^{63}Ni	101.2 y	0.066945(5)
^{45}Ca	162.61 d	0.2558(8)
^{32}P	14.3 d	1.71066(4)
^{114}In	71.9(1) s (49.51(1) d)	1.9886(6)
		Mirror transitions
^{11}C	20.364(14) m	0.9604(10)
^{13}N	9.965(4) m	1.1985(3)
^{15}O	122.24(16) s	1.7320(5)
^{17}F	64.385(53) s	1.73847(25)
^{25}Al	7.183(12) s	3.2547(5)
		$T = 1$ triplet
^{18}F	109.77(5) m	0.6335(6)
^{10}C	19.3016(24) s	2.92968(7)
^{6}He	806.7(1) ms	3.5078(11)
^{30}P	2.498(4) m	4.2324(3)
^{20}F	11.163(8) s	5.39086(8)

M. González-Alonso, O. Naviliat-Cuncic Phys. Rev. C 94 (2016)
L. Hayen et al, Rev. Mod. Phys. 90 (2018)

^{14}O : BR from beta spectrum shape



$\mathcal{F}t$

$=$

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%

Trap : Q_{EC}
Δm ~ 10^{-8}

Beta counting and Ge with calibrated ε :
$t_{1/2}$ and BR
Δε ~ 0.2%

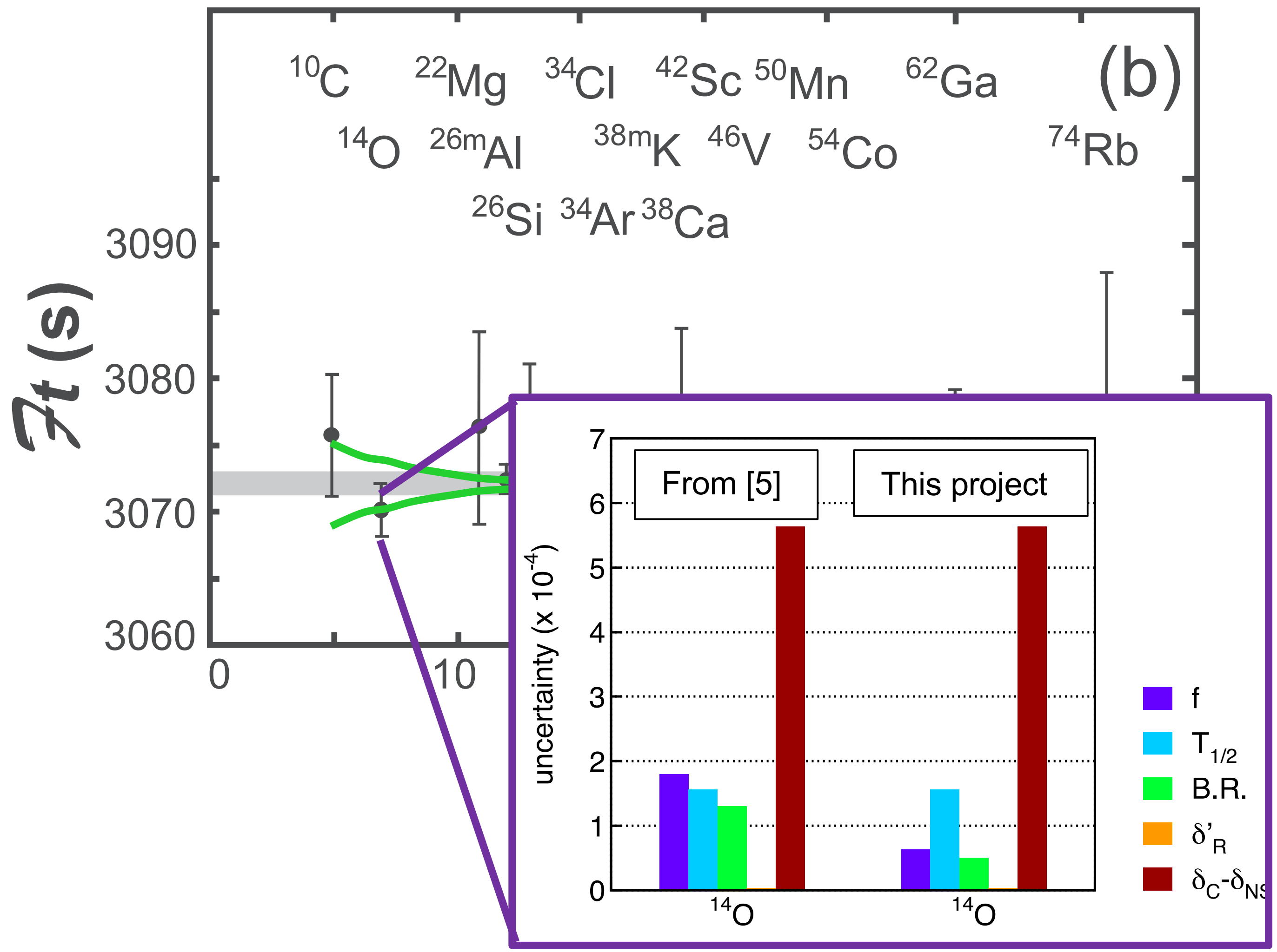
Theoretical Calculations
uncertainties < 0.1%
(except ^{62}Ga&^{74}Rb)

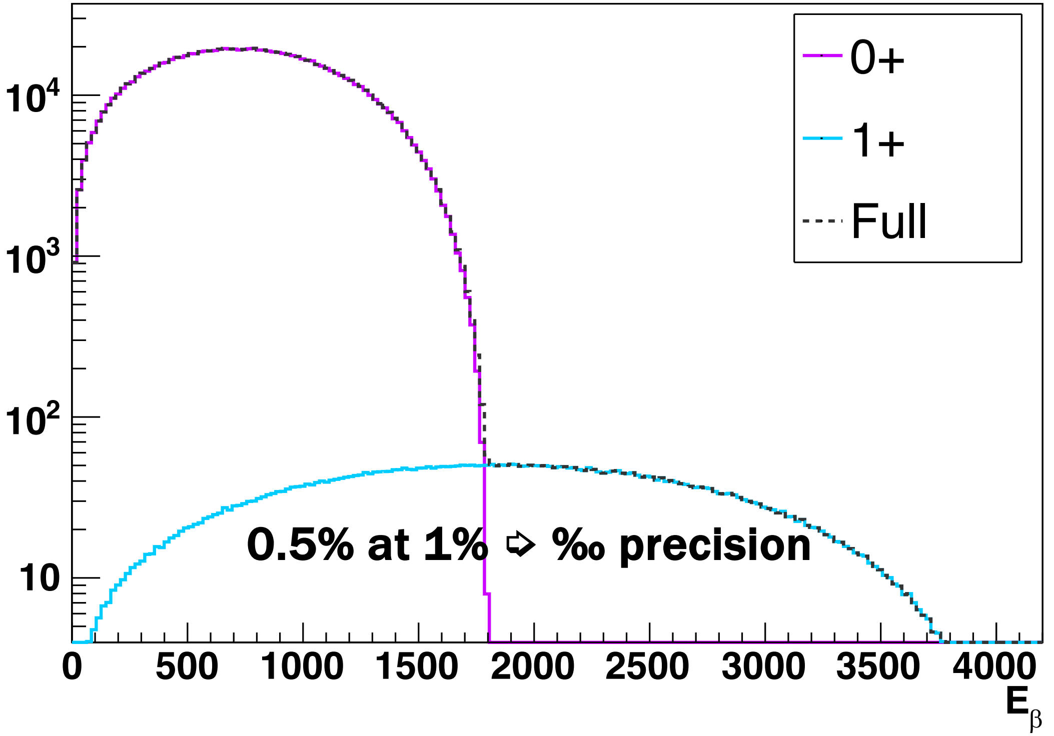
$$= \frac{K}{2G_F^2\, V_{ud}^2\,(1+\Delta_R^V)}$$

15 transitions with
uncertainties < 0.3%

$$b_F = -2\frac{C_S}{C_V} \neq 0 \Rightarrow \mathcal{F}t(< 1/W >)$$

^{14}O : BR from beta spectrum shape

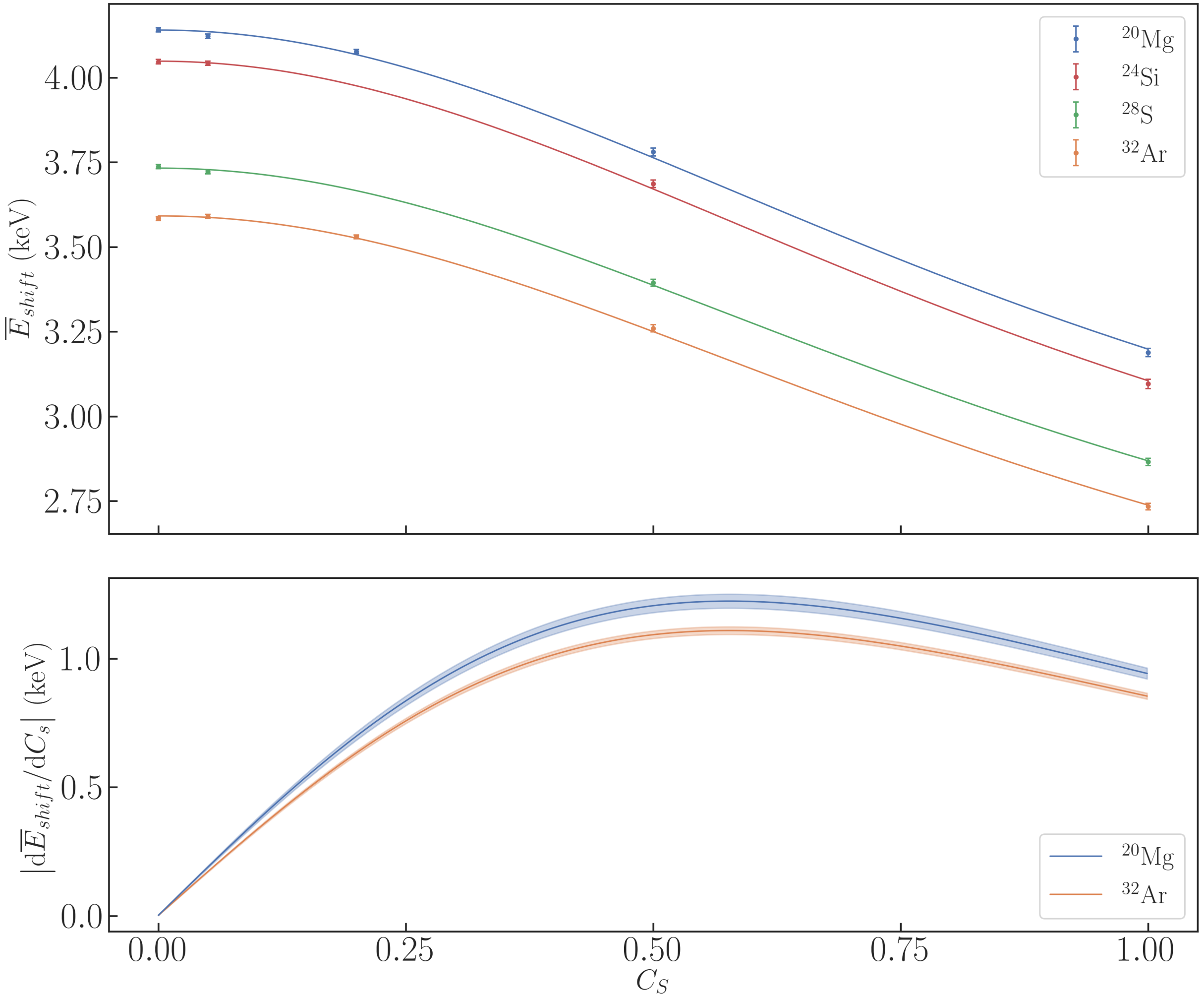




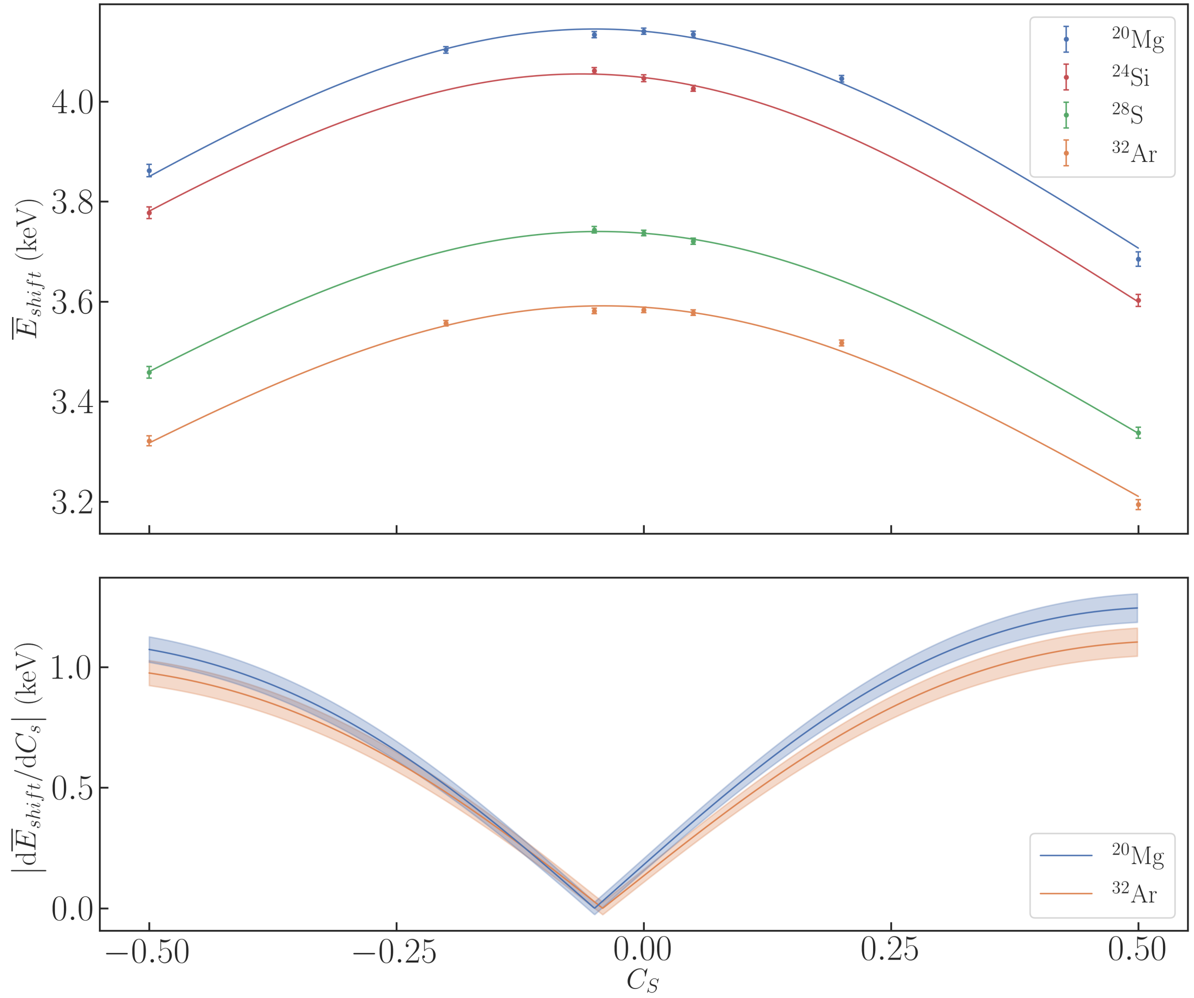
0.5% at 1% ➪ ‰ precision

Sensitivity to scalar currents

- Scalar right-handed currents : $b_F=0$



- Scalar left-handed currents : $b_F≠0$



HE vs HP frontiers

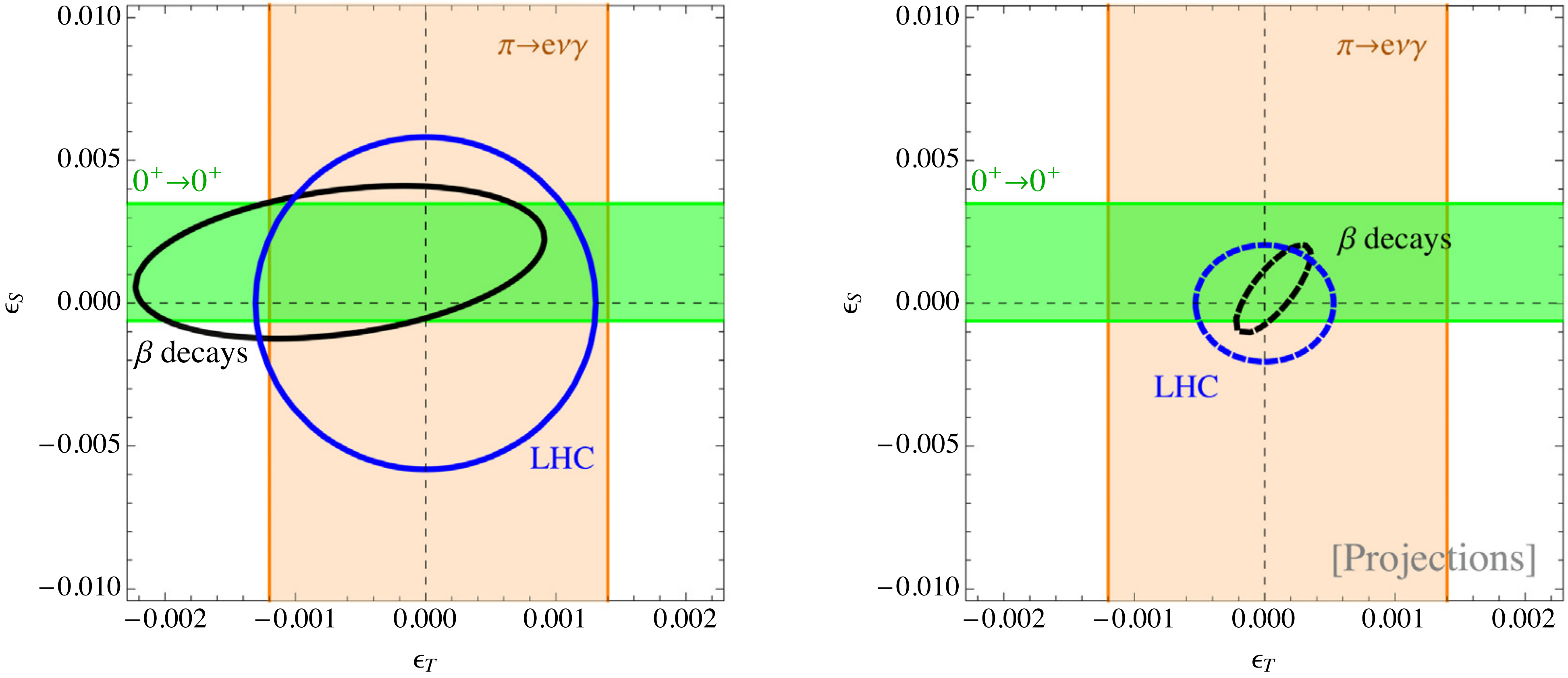
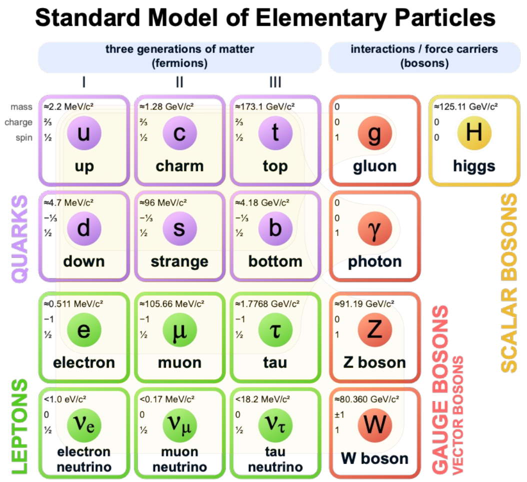


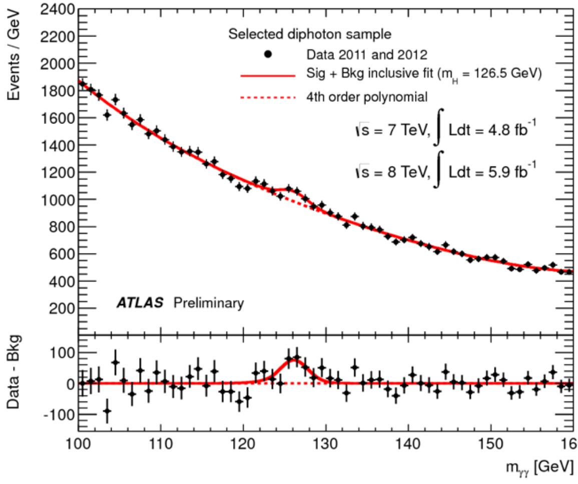
Fig. 14. (Left) 90% CL constraints on $\epsilon_{S,T}$ at $\mu = 2$ GeV from β-decay data, *cf.* Eq. (87), with $\Delta\chi^2 = 4.61$, (black ellipse), from the analysis of $pp \to e$+MET+X at the 8-TeV LHC (20 fb^{-1}) [12] (blue ellipse), and from radiative pion decay, *cf.* Eq. (118) [23] (orange band). The green band shows the 90% CL bound ($\Delta\chi^2 = 2.71$) using only superallowed Fermi decays. (Right) Same figure but using projected β-decay data, *cf.* Eq. (100) (black) and projected LHC bounds from $pp \to e +$ MET $+ X$ searches with 14 TeV and 300 fb^{-1} [23] (blue). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

M. González-Alonso, O. Naviliat-Cuncic, N. Severijns Prog. Part. Nucl. Phys. (2019)

Going Beyond the Standard Model

- The Standard Model of particle physics
  - Spectacular internal consistency





ATLAS (2012)