Precision neutron beta decay experiments as a probe of BSM physics

Dagmara Rozpędzik

Jagiellonian University

Nordic Conference on Particle Physics, SPAATIND 2020

Skeikampen, January 2 - 7, 2020

Content

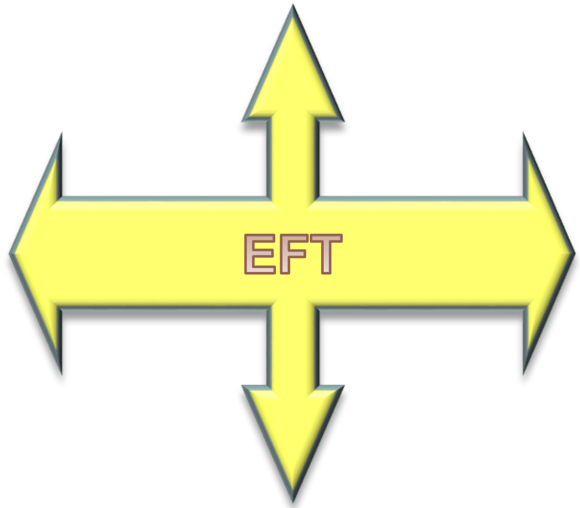
- ✓Theory approach
- ✓ Neutron decay correlation experiments
- ✓ BRAND project (idea & challenges)
- ✓BRAND plans for the future measurements
- ✓Conclusions and outlook

Searching for new physics beyond the Standard Model

High energy Frontier

- **HE accelerators** operate at TeV scale

study of 2nd and 3rd particle families)



Low energy Frontier

- **precision measurements** operates at neV scale

⇒ study of 1st particle family
⇒ good sensitivity for energy, momentum and spin polarization measurements)

➢ Beta Decay

Sensitivity to new physics in beta decay comes at the precision frontier via:

- ✓ tests of unitarity of the CKM matrix
- ✓ by precision measurements of beta spectrum shape
- ✓ by precision measurements of correlations sensitive to the chiral structure of the weak interactions, e.g. neutron correlation coefficient measurements

EFT and search for BSM

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum \frac{1}{\Lambda_i^2}\mathcal{L}_i \approx \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2}\sum \alpha_i \mathcal{O}_i^{(6)}$$

$\mathcal{O}_{\rm i}^{(6)}$ – dimension-6 operators

$\alpha_{\rm i}$ – *Wilson coefficients* $\alpha_i = \Lambda^2 f_i(g_{\text{BSM}}, M_{\text{BSM}})$

Observables for $E << \Lambda$: $\mathcal{R} = \mathcal{R}_0\left(1 + \frac{\mathcal{O}(M)}{\Lambda} + \frac{\mathcal{O}(M^2, E^2, ME)}{\Lambda^2} + \ldots\right.$

- BSM physics can generate additional contributions to the vector and axial-vector couplings of SM, with coupling strengths coupling constants ε_L and ε_R as well as chirality-flipping currents (scalar, pseudo-scalar and tensor) with coupling ε_S, ε_P, ε_T

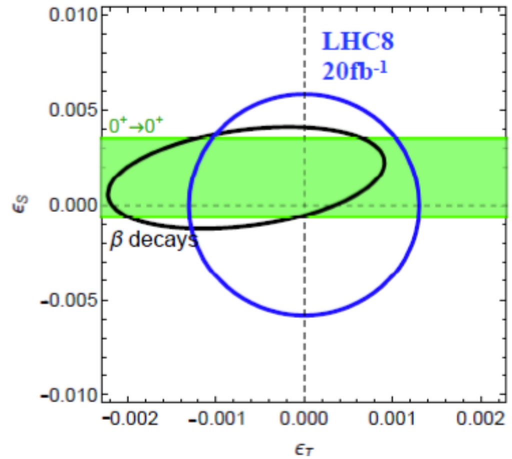
- the dimensionless couplings are related to the new physics scale via

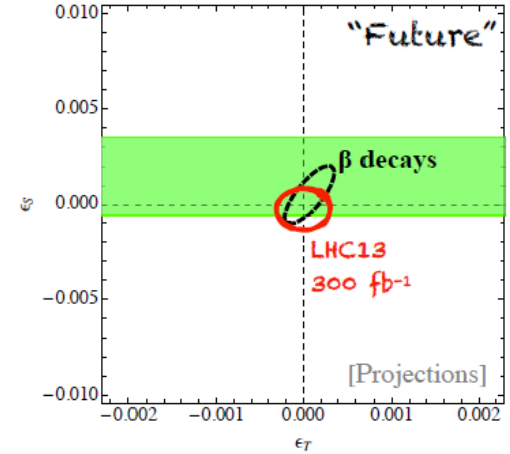
$$\epsilon_i \approx \left(\frac{v}{\Lambda}\right)^2$$

with υ = 174 GeV, vacuum expectation value.

- experiments reaching sensitivity $\varepsilon_i < 10^{-3}$ can explore λ = 5 -10 TeV range
=> not fully explored at the energy frontier, where many models for new physics provide observable effects

V. Cirigliano et al. arXiv:1907.02164v2 (2019)

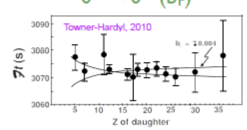




M. Gonzales-Alonso, Prog. in Part. and Nucl. Phys. Vol. 104, (2019) 165-223.
R. Gupta et al. , Phys. Rev. D 98, 034503 (2018).

ε_S and ε_T couplings

0+ →0+ (bF)



$-1.0\times10^{-3} < g_S\, \varepsilon_S < 3.2\times10^{-3}$

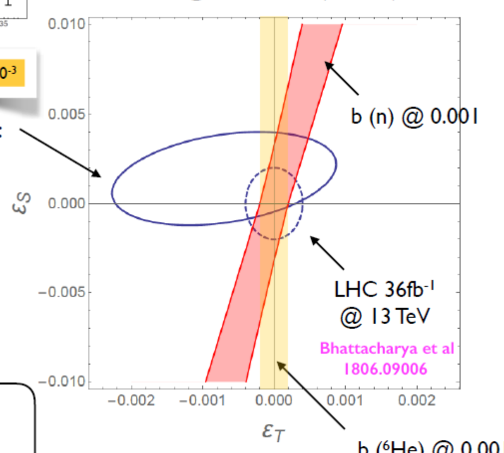
Current low-E data: dominated by 0+→ 0+, τ(n), A(n)

Gonzalez-Alonso, Naviliat-Cuncic, Severijns, 1803.08732

g_S =1.01(10)
g_T =0.99(4)
Bhattacharya et al (PNDME) 1806.09006

FUTURE

$\varepsilon_{S,T}$ @ μ= 2 GeV (MS-bar)



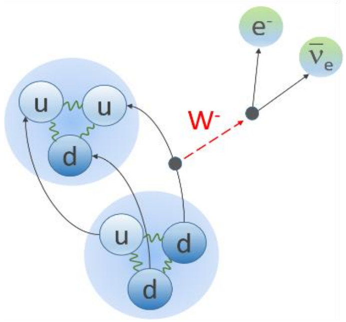
LHC puts very strong constraints on 4-fermion interactions

Prospective beta decay measurements competitive, probing $\Lambda_{S,T}$ ~ 5-10 TeV

V. Cirigliano - *talk on ACFI Workshop, Amherst (2018).*

Neutron β-decay in Standard Model

Semi-leptonic decay process



- In the Standard Model (SM) only two parameters survive (at tree level):

$$H = \frac{G_F}{\sqrt{2}} V_{ud} \;\; \bar{p}\left\{ \gamma_\mu \left(1+\lambda\gamma_5\right) + \frac{\mu_p - \mu_n}{2m_p} \sigma_{\mu\nu} q^\nu \right\} n \;\; \bar{e}\gamma^\mu \left(1-\gamma_5\right)\nu_e$$

V_{ud} – CKM matrix element $\quad \lambda \equiv \dfrac{g_A}{g_V}$ – axial-to-vector coupling constant ratio

two decay amplitudes (vector and axial-vector) need two measurements to specify SM values

- V_{ud}, λ can be extracted from:

f – phase space factor
δ_R – radiative correction (model independent)
Δ_R – radiative correction (model dependent)

- Neutron lifetime measurements:

$$\tau_n^{-1} = \frac{G_F^2 m_e^2}{2\pi^3} \left|V_{ud}\right|^2 f \left(1+\delta_R\right)\left(1+\Delta_R\right)\left(1+3\lambda^2\right) \Rightarrow \tau_n = \frac{(4908.7 \pm 1.9)\ \mathrm{s}}{\left|V_{ud}\right|^2 \left(1+3\lambda^2\right)}$$

- Differential decay rates: angular distribution of decay products (correlation coefficients)

e.g. neutron spin and electron-momentum angular correlation: parameter A

Neutron β-decay correlations

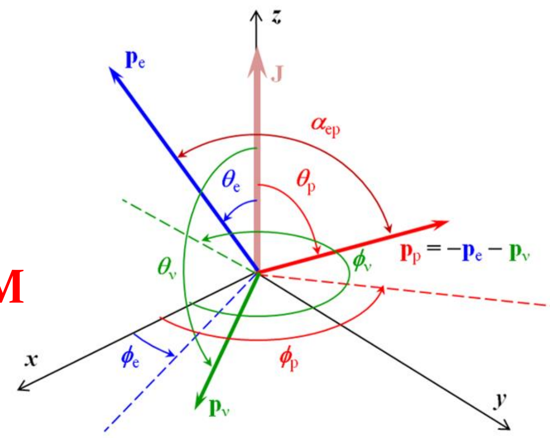
Observables in neutron beta decay can be expressed generally as a function of possible coupling constants (assuming only Lorentz-Invariance). Depending on the initial state and measured quantities for beta decay products it is possible to define various differential rates and split them into terms depending on momenta and spins of particles (C.F. v.Weizsäcker, Z. f. Phys. 102,572 (1936), M. Fierz, Z. f. Phys. 105, 553 (1937), J.D. Jackson et al., PR 106, 517 (1957))

$$d\Gamma \sim \boxed{1 + a\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + b\frac{m_e}{E_e} + \frac{\langle\mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + D\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\right]}$$

SM

$$\begin{aligned}
&+\boldsymbol{\sigma}\cdot\left[G\frac{\mathbf{p}_e}{E_e} + H\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + K\frac{\mathbf{p}_e}{E_e+m_e}\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + L\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + N\frac{\langle\mathbf{J}\rangle}{J}\right]\\
&+\boldsymbol{\sigma}\cdot\left[Q\frac{\mathbf{p}_e}{E_e+m_e}\frac{\langle\mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_e}{E_e} + R\frac{\langle\mathbf{J}\rangle}{J}\times\frac{\mathbf{p}_e}{E_e} + S\frac{\langle\mathbf{J}\rangle}{J}\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}} + T\frac{\mathbf{p}_e}{E_e}\frac{\langle\mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\right]\\
&+\boldsymbol{\sigma}\cdot\left[U\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\frac{\langle\mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_e}{E_e} + V\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\times\frac{\langle\mathbf{J}\rangle}{J} + W\frac{\mathbf{p}_e}{E_e+m_e}\frac{\langle\mathbf{J}\rangle}{J}\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\right]
\end{aligned}$$

BSM



$\mathbf{p}_e$ - electron momentum $\mathbf{p}_\nu$ - neutrino momentum

$\boldsymbol{\sigma}$ - electron spin sensing direction

- Electron spin related coefficients reveal sensitivity to SM and BSM physics
- Polarization of decay electrons can be analyze with required accurancy and statistical efficiency
- Expression for correlation coefficients a,b,...,W are function of $\lambda = g_A/g_V$

J.D. Jackson et al., Phys. Rev. 106, 517 (1957); J.D. Jackson et al., Nucl. Phys. 4, 206 (1957); M.E. Ebel et al., Nucl. Phys. 4, 213 (1957)

Measuring electron-momentum, proton-momentum and transverse electron polarization, the differential decay distribution can be expressed as

$$d\Gamma \sim 1+a\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}+b\frac{m_e}{E_e}+\frac{\langle\mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e}+B\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}+D\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\right]$$

$$+\boldsymbol{\sigma}_\perp\cdot\left[H\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}+L\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}+N\frac{\langle\mathbf{J}\rangle}{J}+R\frac{\langle\mathbf{J}\rangle}{J}\times\frac{\mathbf{p}_e}{E_e}\right]$$

$$+\boldsymbol{\sigma}_\perp\cdot\left[S\frac{\langle\mathbf{J}\rangle}{J}\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}+U\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\frac{\langle\mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_e}{E_e}+V\frac{\mathbf{p}_{\bar\nu}}{E_{\bar\nu}}\times\frac{\langle\mathbf{J}\rangle}{J}\right]$$

Neutron lifetime $\Gamma = \tau_n^{-1}$

neutrino-electron correlation Fierz interference term beta asymmetry neutrino asymmetry includes $b_\nu = 0$

$$\boxed{a=\frac{1-\lambda^2}{1+3\lambda^2},\quad b=0,\quad A=-2\frac{\lambda(1+\lambda)}{1+3\lambda^2},\quad B=-2\frac{\lambda(1-\lambda)}{1+3\lambda^2},\quad D=0}$$

- Experimental correlation coefficients related to p_e, p_ν and σ are deduced form rate asymmetries:

$$ASY=\frac{\Gamma_1-\Gamma_2}{\Gamma_1+\Gamma_2};\qquad \mathbf{p}_e\to-\mathbf{p}_e,\ \mathbf{p}_\nu\to-\mathbf{p}_\nu,\ \mathbf{J}\to-\mathbf{J},\ \boldsymbol{\sigma}_\perp\to-\boldsymbol{\sigma}_\perp$$

- All correlation coefficients can be expressed as linear combinations of real and imaginary parts of exotic (**scalar** and **tensor**) couplings:

$$\boxed{X=X_{V\text{-}A}+X_{\mathrm{FSI}}+c_{\mathrm{Re}\,S}\,\mathrm{Re}\boldsymbol{S}+c_{\mathrm{Re}\,T}\,\mathrm{Re}\boldsymbol{T}+c_{\mathrm{Im}\,S}\,\mathrm{Im}\boldsymbol{S}+c_{\mathrm{Im}\,T}\,\mathrm{Im}\boldsymbol{T}}$$

$\boldsymbol{S}=\frac{C_S+C_S'}{C_V}$, $\boldsymbol{T}=\frac{C_T+C_T'}{C_A}$, $c_{\mathrm{Re}\,S}, c_{\mathrm{Re}\,T}, c_{\mathrm{Im}\,S}, c_{\mathrm{Im}\,T}$ – functions of $\lambda = C_A/C_V$ and kinematical quantities

- Overdetermination is advantageous in suppressing systematic errors

Sensitivity factors for scalar and tensor couplings at leading order (no recoil terms and point charge)

K. Bodek – *talk on Fundamental Symmetries Research with Beta Decay Workshop, Seattle (2019)*

coefficient	SM (λ)	FSI (λ)	c(Re*S*)	c(Re*T*)	c(Im*S*)	c(Im*T*)
a	-0.104793	0	-0.171405[2]	0.171405[2]	-0.000727	+0.001171
b	0	0	+0.171405	+0.828595	0	0
A	-0.117233	0	0	0	-0.000923	+0.001420
B	+0.987560	0	-0.126422	+0.194539	0	0
D	0	0	0	0	+0.000923	-0.000923
H	0	+0.060888	-0.171405	+0.276198	0	0
L	0	-0.000444	0	0	+0.171405	-0.276198
N	0	+0.068116	-0.217582	+0.334815	0	0
R	0	+0.000497	0	0	-0.217582	+0.334815
S	0	-0.001845	+0.217582	-0.217582	0	0
U	0	0	-0.217582	+0.217582	0	0
V	0	0	0	0	-0.217582	+0.217582

* Kinematical factor averaged over electron kinetic energy E_k = (200,783) keV

† $(|C_S|^2+|C'_S|^2)/2$ instead of ReS and $(|C_T|^2+|C'_T|^2)/2$ instead of ReT, respectively

Cancellation effects are insignificant for transverse electron polarization related correlation coefficients

Fundamental neutron physics provides more than 20 observables reach in information which is difficult to achieve (or not achievable at all) in other fields of Particle Physics

Which neutrons should we use?

- **Cold neutrons:** $E_{kin}^{CN} \sim 5\,\text{meV},\ \upsilon^{CN} \sim 1\,\text{km/s}$
  - **CN production via moderation of thermal neurons:**
    - Cold sources: moderators made of liquid hydrogen or deuterium operated at 20 K
    - Cold moderators are typically inserted close to reactor core or to spallation target
- **Ultra-cold neutrons:** $E_{kin}^{UCN} \sim 300\,\text{neV},\ \upsilon^{UCN} < 8\,\text{m/s}$
  - **UCN production via moderation of CN**

Facility	Pulsed	
ANNI (ESS)	Yes	4
PF1B (ILL)	No	2
MEPHISTO (FRM II)	No	1.8
NG-6 (NIST)	No	
NG-C (NIST)	No	
FunSpin (PSI)	No	
FnPB (SNS)	Yes	
FP12 (LANSCE)	Yes	
NOP (J-PARC)	Yes	

The three most efficient CN sources

Time-averaged neutron capture flux in 10^{10} [n/cm²/s]

ANNI is a cold neutron beam facility for particle physics, it will make full use of the ESS pulse structure.

Scientific programme:

1) Neutron Beta Decay

The proposed instrument is optimized for measurements of correlation coefficients in neutron beta decay. It will improve the measurement by one order of magnitude, unlocking the accuracy range of 10-4 and providing broad band probes for physics beyond the standard model.

The achievable accuracy tests new physics on a mass scale of 1-100 TeV, this mass scale is far beyond the threshold for direct production at existing or planned particle colliders.

2) …

3) …

https://europeanspallationsource.se/science-using-neutrons/particle-physics

Neutron β-decay correlations worldwide

Measurable	Experiment	Lab	Method	Status	Sensitivity (projected)	Target Date
$\beta-\nu$	aCORN[1]	NIST	electron-proton coinc.	running complete	1%	N/A
$\beta-\nu$	aSPECT[2]	ILL	proton spectra	running complete	0.88%	N/A
$\beta-\nu$	Nab[3]	SNS	proton TOF	construction	0.12%	2022
β asymmetry	PERC[4]	FRMII	beta detection	construction	0.05%	commissioning 2020
11 correlations	BRAND[5]	ILL/ESS	various	R&D	0.1%	commissioning 2025

arXiv: 1907.02164v2 (2019)

- Review on the interrelations between decay coefficients can be found e.g. in D. Dubbers and M. G. Schmidt, Rev. Mod. Phys. 83 (2011) 1111-1171.
- Sensitivity analysis of new experiments can be also find in S. Baessler talk presented on NORDITA Workshop „Particle Physics with Neutrons at the ESS" (2018).

Experiment	Correlation and anticipated precision
aSPECT	a (3×10^{-4})
aCORN	a (5×10^{-4})
Nab/aBBa/PANDA	a ($\sim10^{-4}$), b (3×10^{-4}), A, B, C ($\sim10^{-4}$)
emiT [6]	D ($\sim10^{-4}$) – measured
PERC	a, b, A (3×10^{-5}), B, C, D (?)
PERKEO [8]	A (2×10^{-4}), B, C (2×10^{-3}) – measured
UCNA	A (2.5×10^{-3})
UCNB	B ($<10^{-3}$)
nTRV [7]	N, R ($\sim10^{-2}$) - measured

* included data up to 2018

[1] G. Darius, Physical Review Letters 119, 042502 (2017).
[2] M. Simson, Nucl. Instr. Meth. A 611, 203 (2009).
[3] D. Pocanic, et al., NIMA, 611, 211 (2009).
[4] D. Dubbers, NIMA, 596, 238 (2008).
[5] K. Bodek, EPJ Web Conf. 219 (2019) 04001.
[6] T. E. Chupp, et al., Phys. Rev. C, 86, 035505 (2012).
[7] A. Kozela, et al., Phys. Rev. C 85, 045501 (2012).
[8] H. Abele, et al., J Res Natl Inst Stand Technol. 110(4): 377–381 (2015).

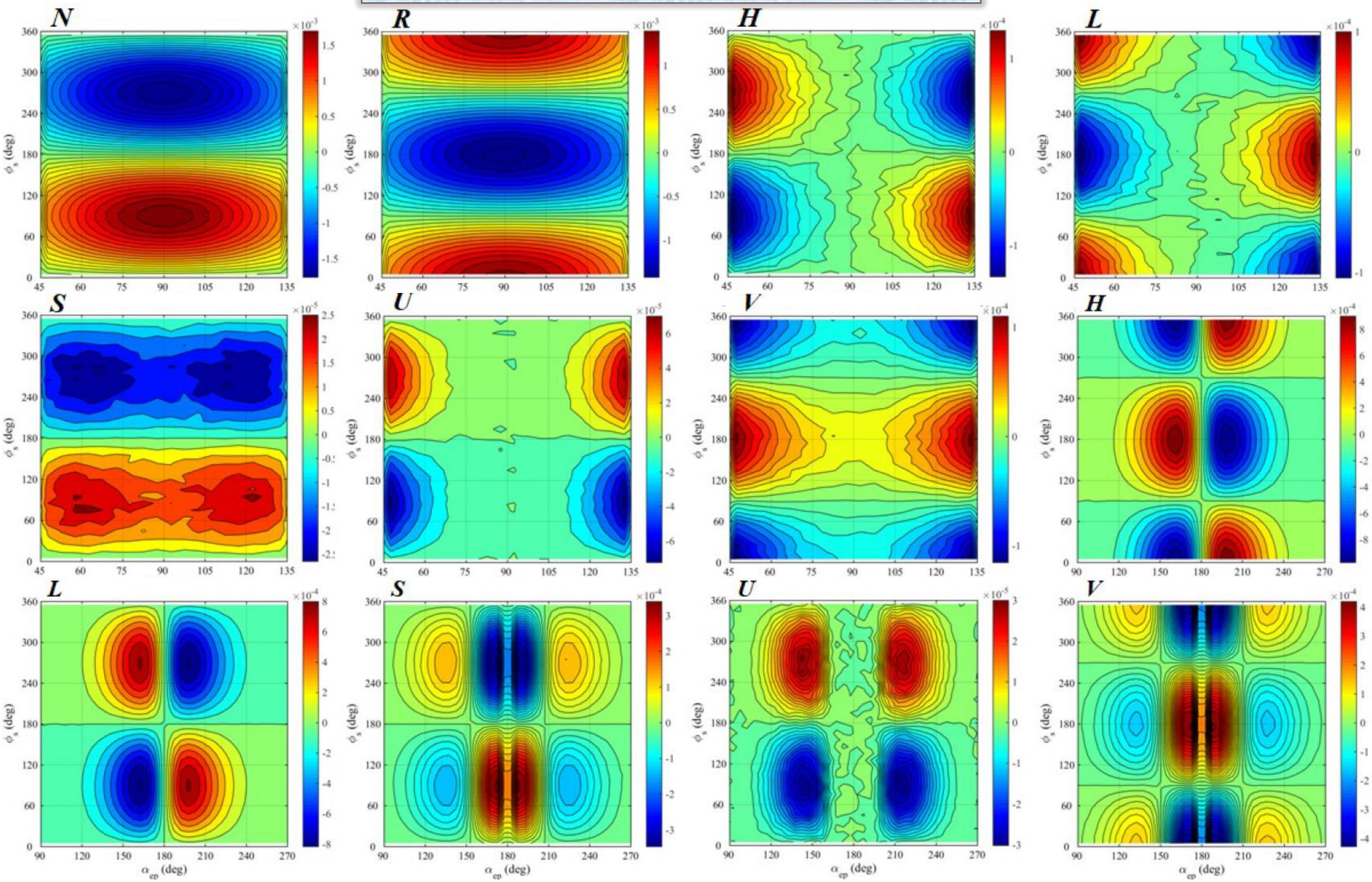
BRAND will be measured the 11 correlation coefficients

$$d\Gamma \sim 1 + a\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}} + b\frac{m_e}{E_e} + \frac{\langle \mathbf{J}\rangle}{J}\cdot\left[A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}} + D\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}}\right]$$

$$\boxed{\begin{aligned}&+ \boldsymbol{\sigma}_\perp\cdot\left[H\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}} + L\frac{\mathbf{p}_e}{E_e}\times\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}} + N\frac{\langle \mathbf{J}\rangle}{J} + R\frac{\langle \mathbf{J}\rangle}{J}\times\frac{\mathbf{p}_e}{E_e}\right]\\ &+ \boldsymbol{\sigma}_\perp\cdot\left[S\frac{\langle \mathbf{J}\rangle}{J}\frac{\mathbf{p}_e}{E_e}\cdot\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}} + U\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}}\frac{\langle \mathbf{J}\rangle}{J}\cdot\frac{\mathbf{p}_e}{E_e} + V\frac{\mathbf{p}_{\bar{\nu}}}{E_{\bar{\nu}}}\times\frac{\langle \mathbf{J}\rangle}{J}\right]\end{aligned}}$$

were never measured before

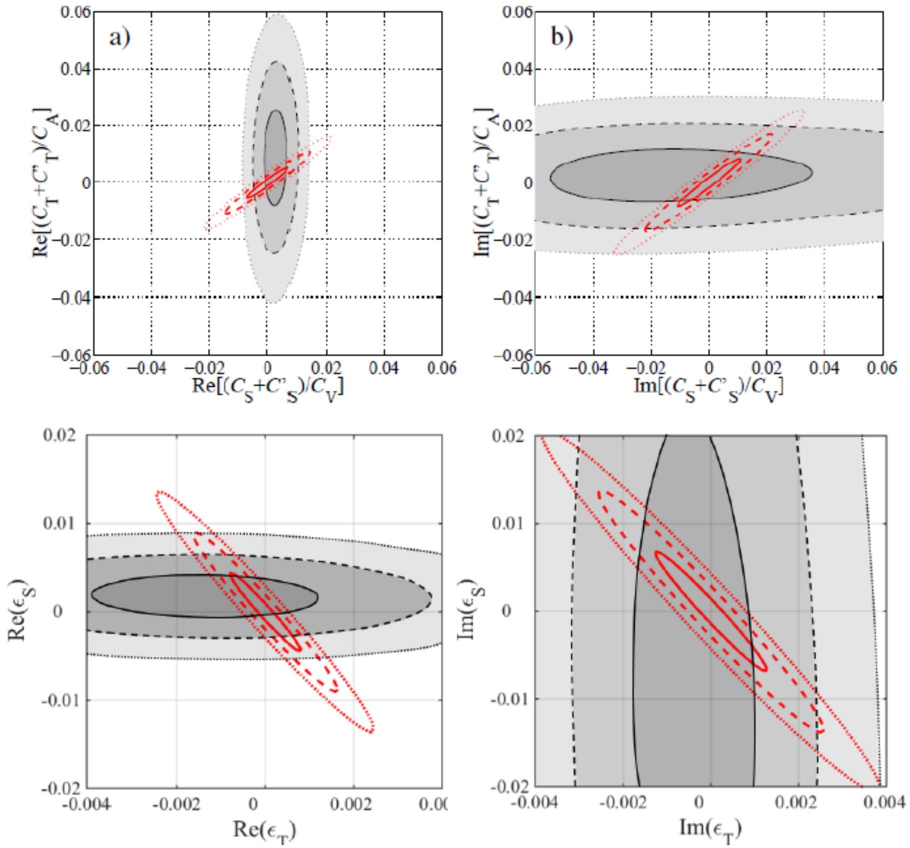
BRAND – kinematical sensitivity maps



Sensitivity maps for the *N, R, H, L, S, U* and *V* coefficient as a function of the polar electron angle θ_e or the relative electron-proton angle and the azimuthal spin projection angle ϕ_s (arbitrary units). Irregularities in contours are due to limited statistics in simulations. The kinematical acceptance is defined by

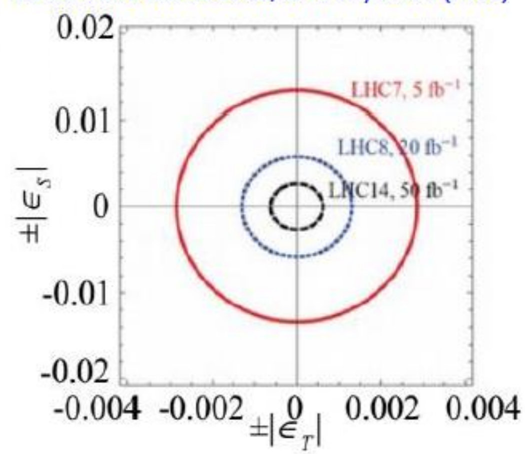
$$E_e^{kin} \in (200, 782)\,\text{keV},\ E_p^{kin} \in (50, 760)\,\text{eV},\ \theta_e \in (45^o, 135^o),\ \theta_p \in (30^o, 150^o).$$

Impact of H, L, N, R, S, U and V measurement with anticipated accuracy of 5 x 10^{-4} (in ultimate BRAND phase)



- ❑ In order to be competitive with HE searches, new n-decay correlation coefficient measurements should improve by 1 order of magnitude

M. Gonzalez-Alonso et al., Ann. Phys. 525 (2013)



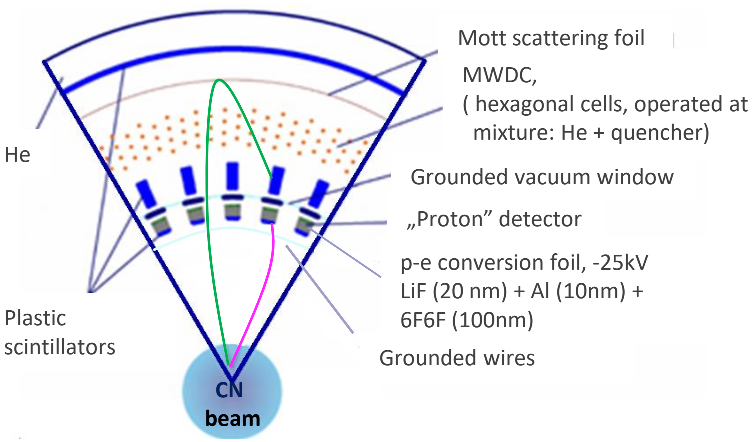
- ❑ Constraints on ReS and ReT contributions will be comparable to that obtained from Fierz term (spectrum shape) with $\Delta b < 10^{-3}$ but with completely different systematics

- ❑ Similar accuracy is expected for ImS and ImT contribution (TRV effects)

K. Bodek Acta Phys. Pol. B 47 (2016) 349

BRAND concept

One sector (1/6) of BRAND ultimate setup



Experimental methods:

- ❑ neutron beam in vacuum
- ❑ axial symmetry
- ❑ electron tracking in low Z and low pressure MWDC
- ❑ measure decay electrons and e-p coincidences
- ❑ p-e conversion followed by e detection in scintillator (ToF, position)
- ❑ decay vertex reconstruction
- ❑ electron spin analysis by Mott scattering (vertex reconstruction)

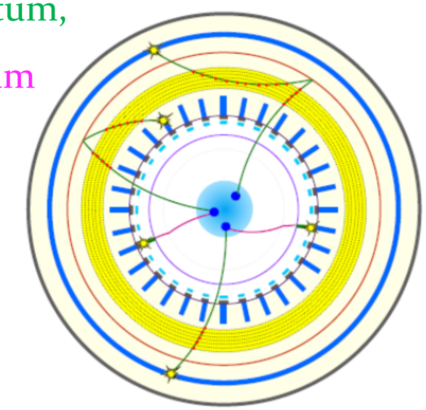
For reconstruction of decay kinematics

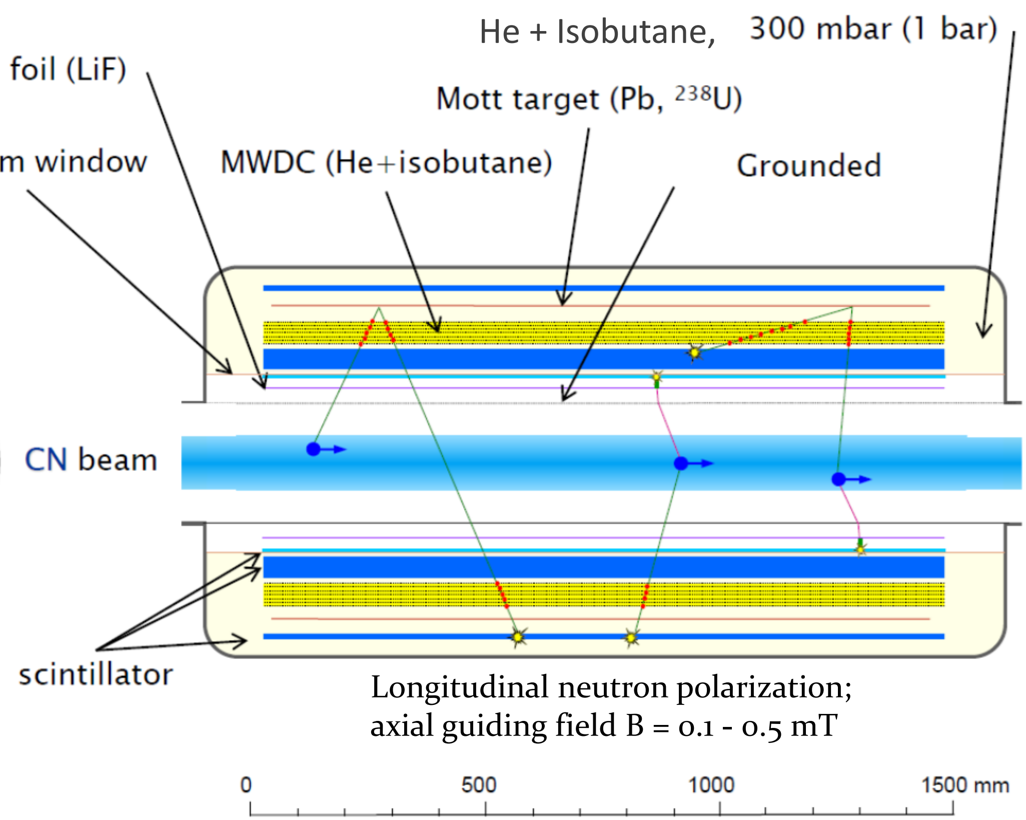
- ❑ electron 4-momentum,
- ❑ proton 4-momentum

and

- ❑ electron transverse polarization

will be measured

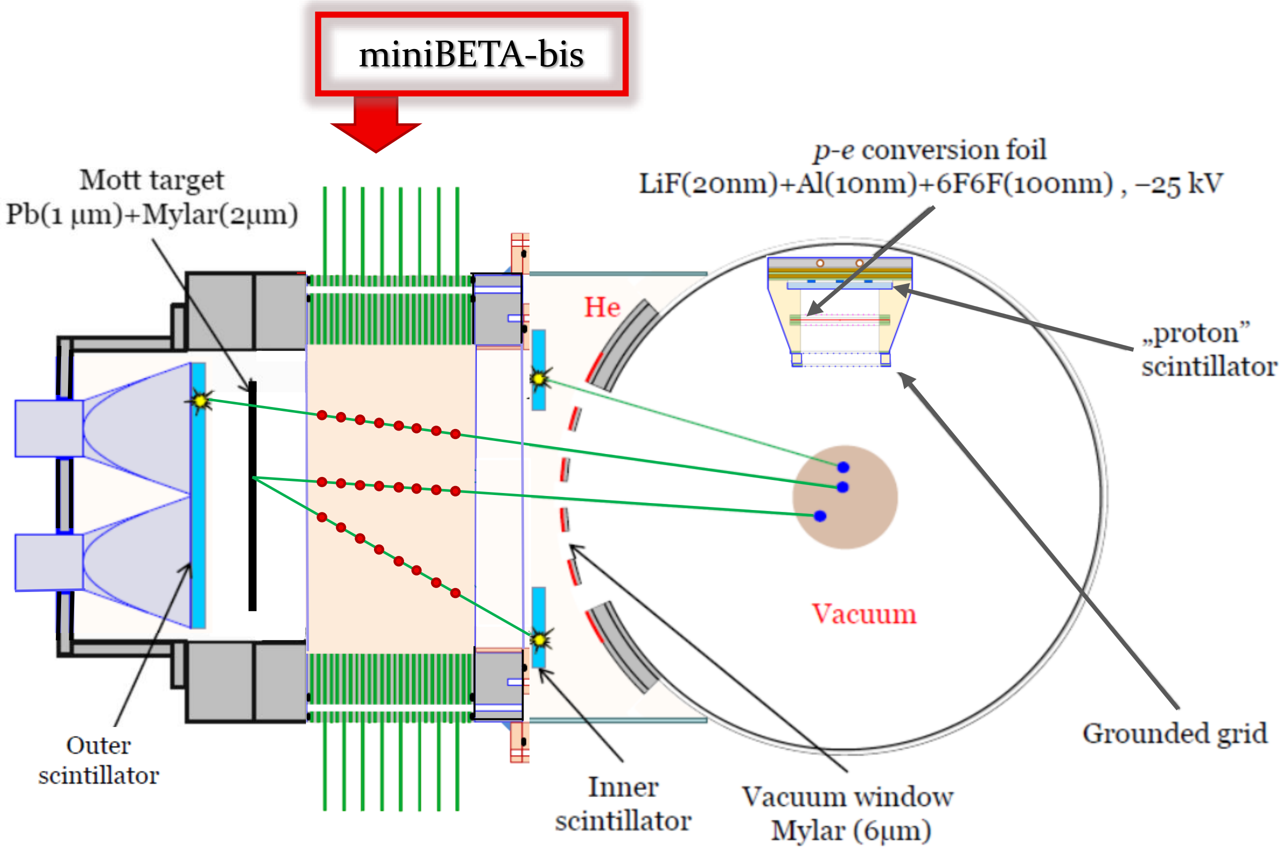




Longitudinal neutron polarization;
axial guiding field B = 0.1 - 0.5 mT

K. Bodek, et al. Acta Phys. Pol. B 47 (2016) 349.
K. Bodek, et al. EPJWeb of Conf. 04001 (2019).

Concept of test setup for the BRAND at ILL (1st run of 2020)



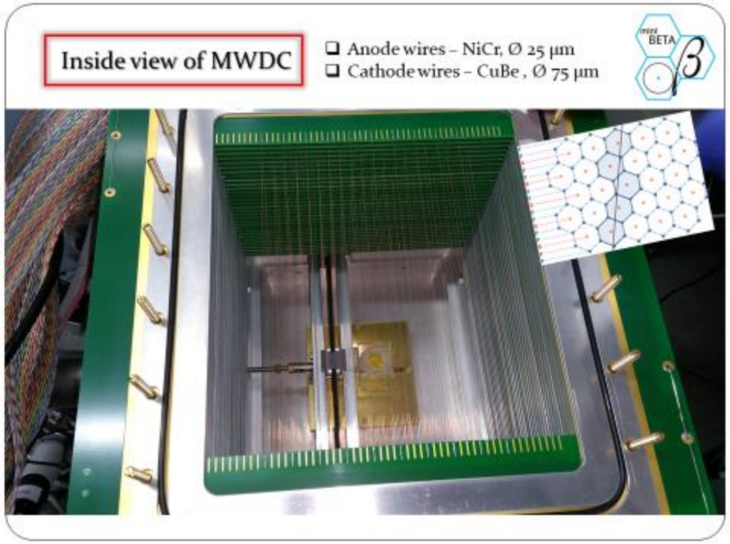
Electron tracking

- Decay electrons from free neutron decay
- Mott scattering for electron spin analysis
- adopted the MWDC technique of the miniBETA spectrometer*

* Acta Phys. Pol. A, 23, 2647 (2018); arXiv:1810.02785 (2018);

Detection of electrons

MWDC based on miniBETA spectrometer



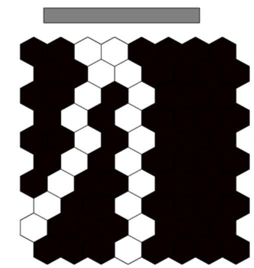
- ❑ Energy detector + wire chamber:

  energy readout from the scintillator + backscattering detection;
- ❑ XY positioning: drift time measurement: $t_{\mathrm{TDC}} = t_{\mathrm{Stop}} - t_{\mathrm{Start}}$

  - t_{Start} : scintillator

  - t_{Stop} : signal from a wire
- ❑ Z positioning: charge division;
- ❑ 80 hexagonal cells

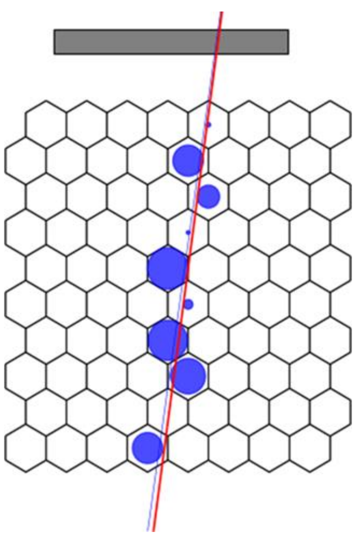
  (10 signal planes with 8 wires each);

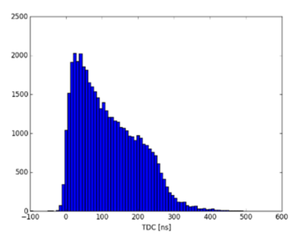


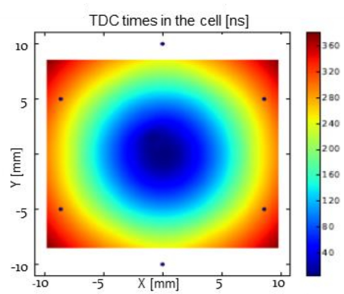
V-tracks

- ❑ Filled with He + quencher mixture with low pressure;
- ❑ Expected Mott vertex position uncertainty Δr= 2 mm,Δz= 2 cm,

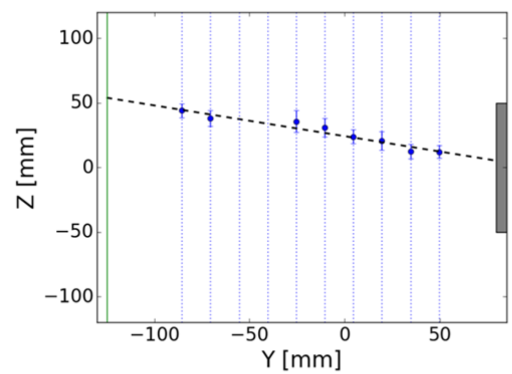
  $\theta_{\mathrm{Mott}} \in (100^{\circ} - 150^{\circ})$



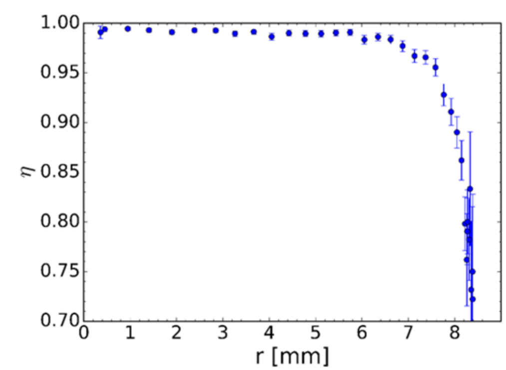




From drift time: $\Delta r = 0.5$ mm



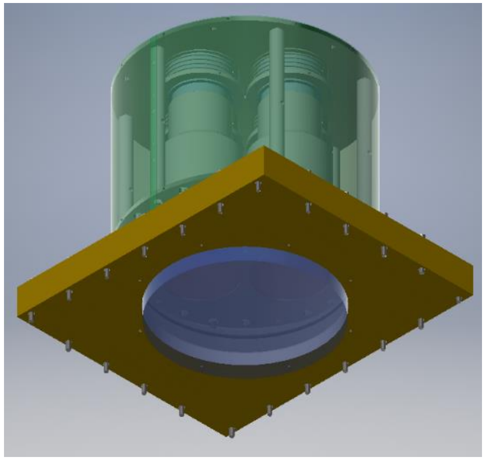
From charge division: $\Delta z/z = 0.02$

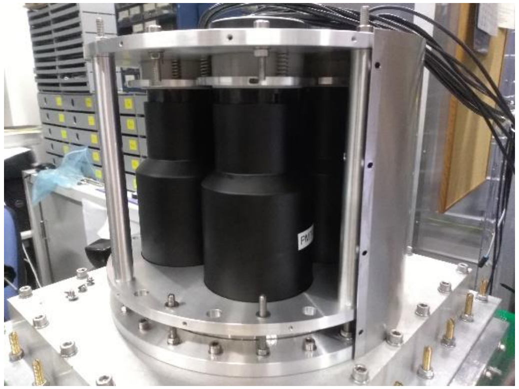


Efficiency = 99% $r \in (0,7)$ mm

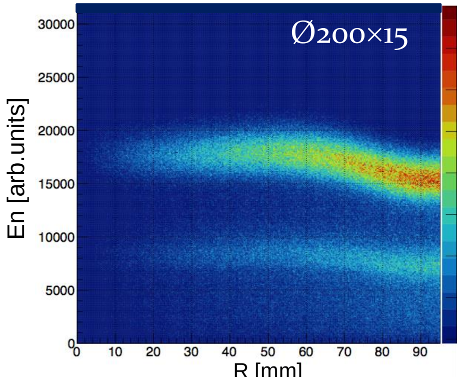
Electron energy measurements with the plastic scintillator

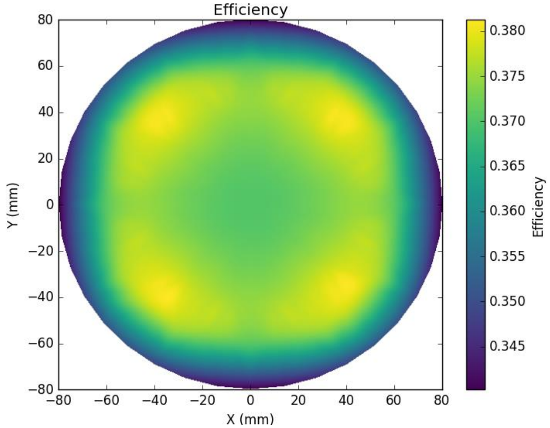
Primary electrons





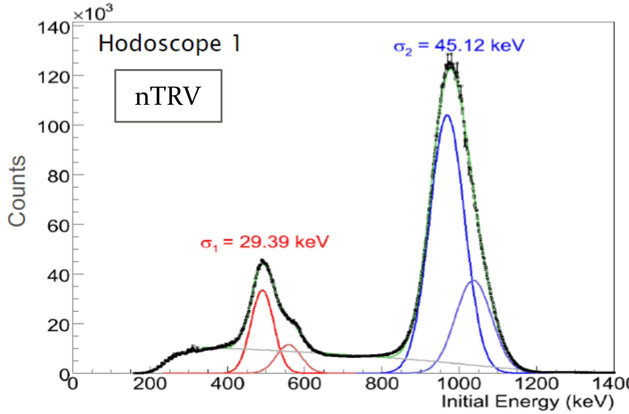
Simulated light collection versus radial distance

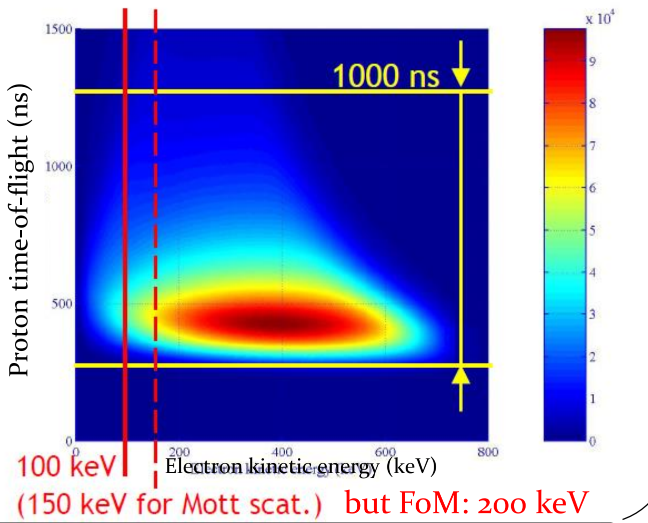




- Maximum gain and response uniformity across the scintillator surface
- Apply position dependent calibration
- Reduced gamma background
- Reached energy resolution σ = 28 keV for E_e = 482 keV (207Bi) [miniBETA]
- Feasible electron energy threshold for direct electrons: 150 keV

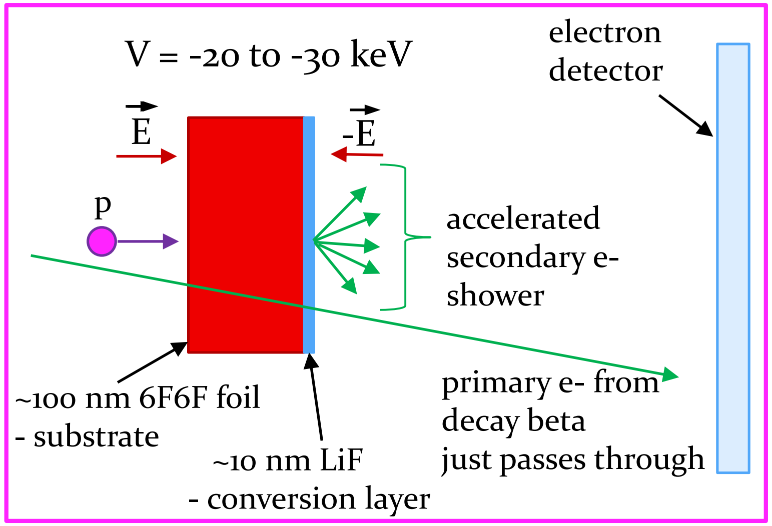
Mott electrons - detected by the inner scintillator



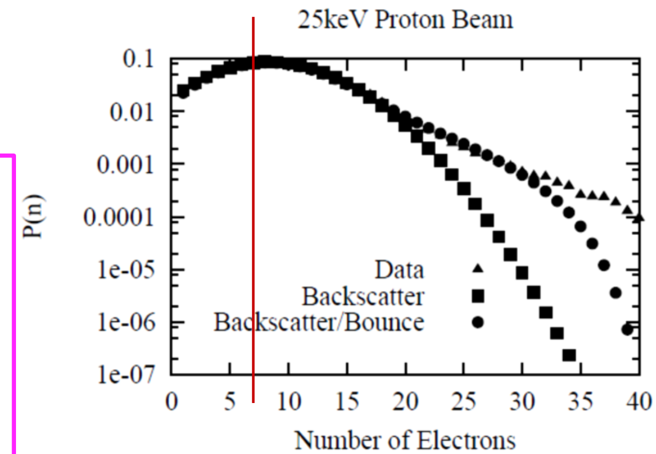


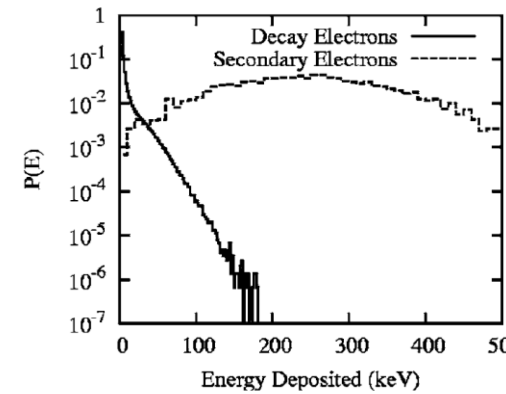
Proton detection principle

- Acceleration in electric field (~25 kV)
- The secondary electron conversion technique
- Energy information from hit position and TOF in plastic scintillator



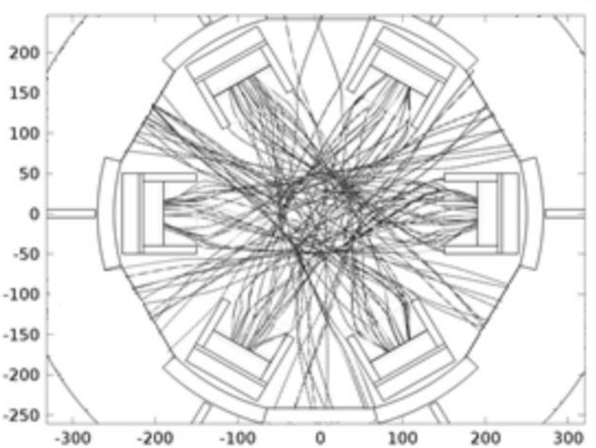
S. Hoedl, et al., Journal of App. Phys. 99, 084904 (2006)





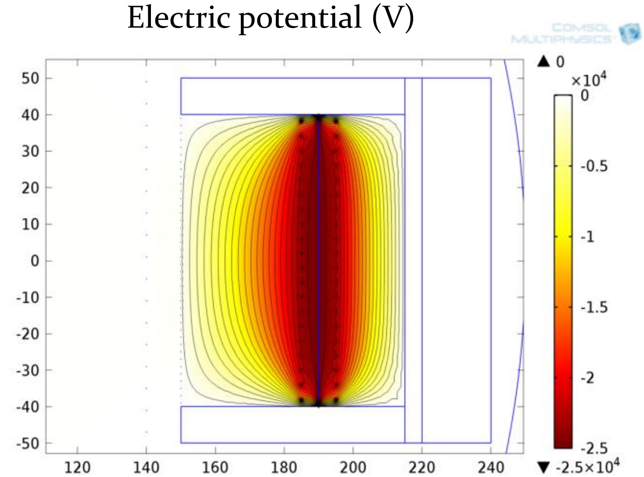
Influence of electric field on proton trajectories (COMSOL simulations)

Proton trajectories



After optimalization of the wire thickness and distance between wires: (geometrical) efficiency for proton detection ~ 63%

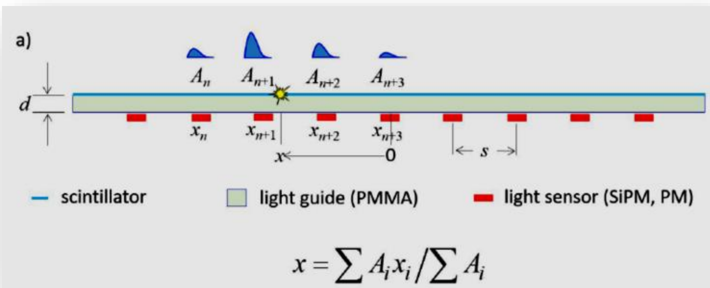
Electric potential (V)



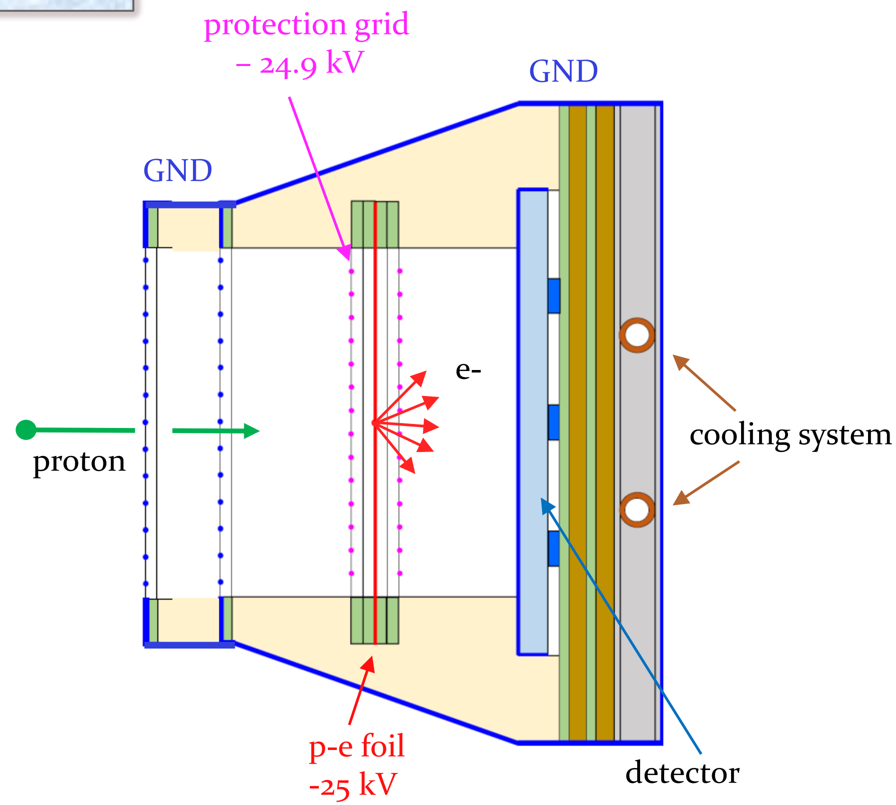
„Proton” detector

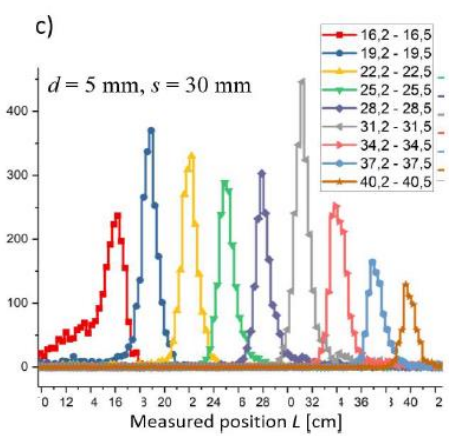
Proton (electron) detector (R&D):

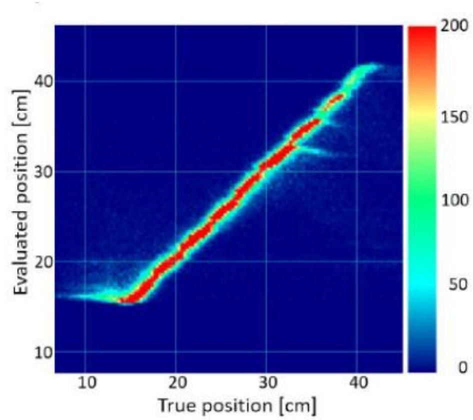
- 25 µm thick plastic scintillator
- MPPC light readout
- current preamplifiers with cooling system
- hit position resolution reached ~5 mm



Light readout principle of proton detector







Three project phases are foreseen

	BRAND I	BRAND II	BRAND III
Site	ILL Grenoble	ILL Grenoble	ESS Lund
Time	3 - 4 years	3 - 4 years	5-6 years
Pressure	Ambient	Ambient	300 mbar
Mott target	Pb (Au)	Pb (Au)	Depleted U
Coverage of azimuthal angle	1/6	Full	Full
Statistical precision (goal)			
A	0.0008	0.00008	0.000016
a, B, D	0.005	0.0005	0.0001
R, N	0.01	0.001	0.0002
H, L, S, U, V	0.02	0.002	0.0004
Systematic errors			
R, N, H, L, S, U, V	2×10^{-3} BRAND I (ILL)	$\rightarrow$ 1×10^{-3} BRAND II (ILL)	$\rightarrow$ 5×10^{-4} BRAND III (ESS)

BRAND is one of the experiments proposed for the ANNI beamline – the pulsed cold neutron beam facility dedicated for particle physics at the European Spallation Source (ESS) which is currently being constructed in Lund, Sweden

Conclusions

- **BRAND** project offers systematic exploration of the transverse electron polarization correlation coefficients *R, N, H, L, S, U, V* in neutron beta decay (the last five were never measured before)

- Combined impact of *R, N, H, L, S, U, V* on new physics is comparable (or better) to Fierz term *b* and reveals completely different systematics

- „HE approach" (tracking, vertex reconstruction) allows to measure in low magnetic field which is necessary for transverse electron polarization

- Simultaneous measurement of standard coefficients *a, A, B* and *D* will provide consistency check and comparison of systematic effects specific to high- and low- magnetic field techniques

Summary and outlook

- Fundamental neutron physics gives strong input to Particle Physics
- Neutron observables allow to test directly SM and search for TeV scale physics BSM
- HE accelerators can find BSM particles on-shell, while β-decay experiments can confirm it in observables (off-shell corrections)
- BRAND project, devoted to measure 7 electron spin related coefficients (5 of them were not measured before), is taking off at ILL
- In future, BRAND could efficiently exploit the pulsed structure of ANNI beamline at the ESS

BRAND Collaboration

- JU Krakow: K. Bodek[1)], D. Rozpedzik, J. Zejma[1)], K. Lojek:
  e- and *p*-detectors, front end electronics and DAQ, simulations
- INP PAS Krakow: A. Kozela[1)], K. Pysz & Co.:
  mechanical structure, vacuum window, MWDC tracker, Mott target, Slow Control
- ILL Grenoble: T. Soldner:
  polarized CN beam and infrastructure, vacuum
- KU Leuven: N. Severijns[1)], L. De Keukeleere:
  guiding magnetic field
- NCSU Raleigh: A. Young, J. Choi:
  pe-converter film

[1)] Members of nTRV@PSI

Two PhD open positions at JU for BRAND!


Thank you for your attention!