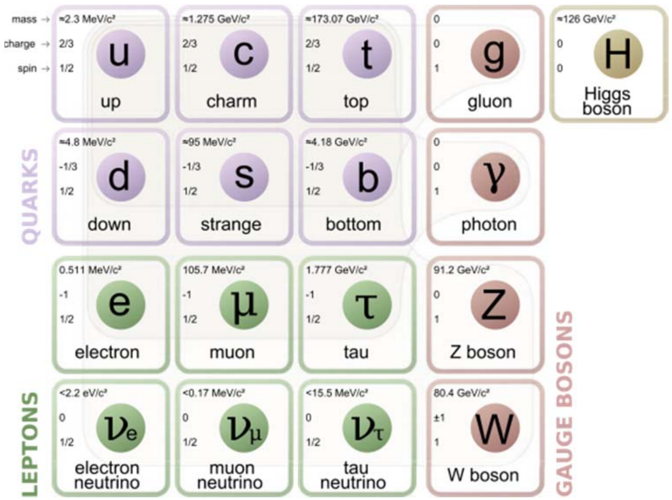
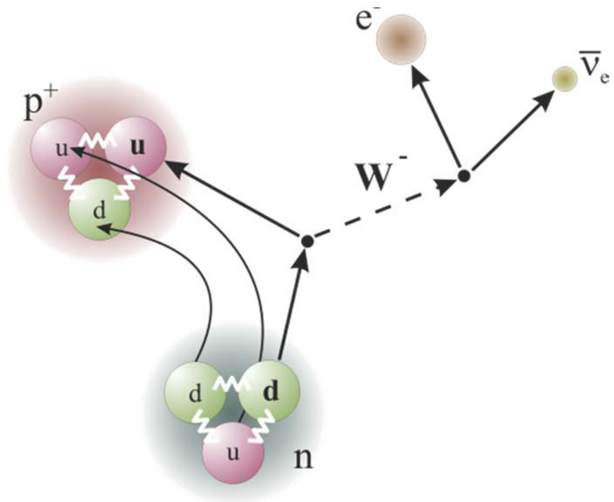
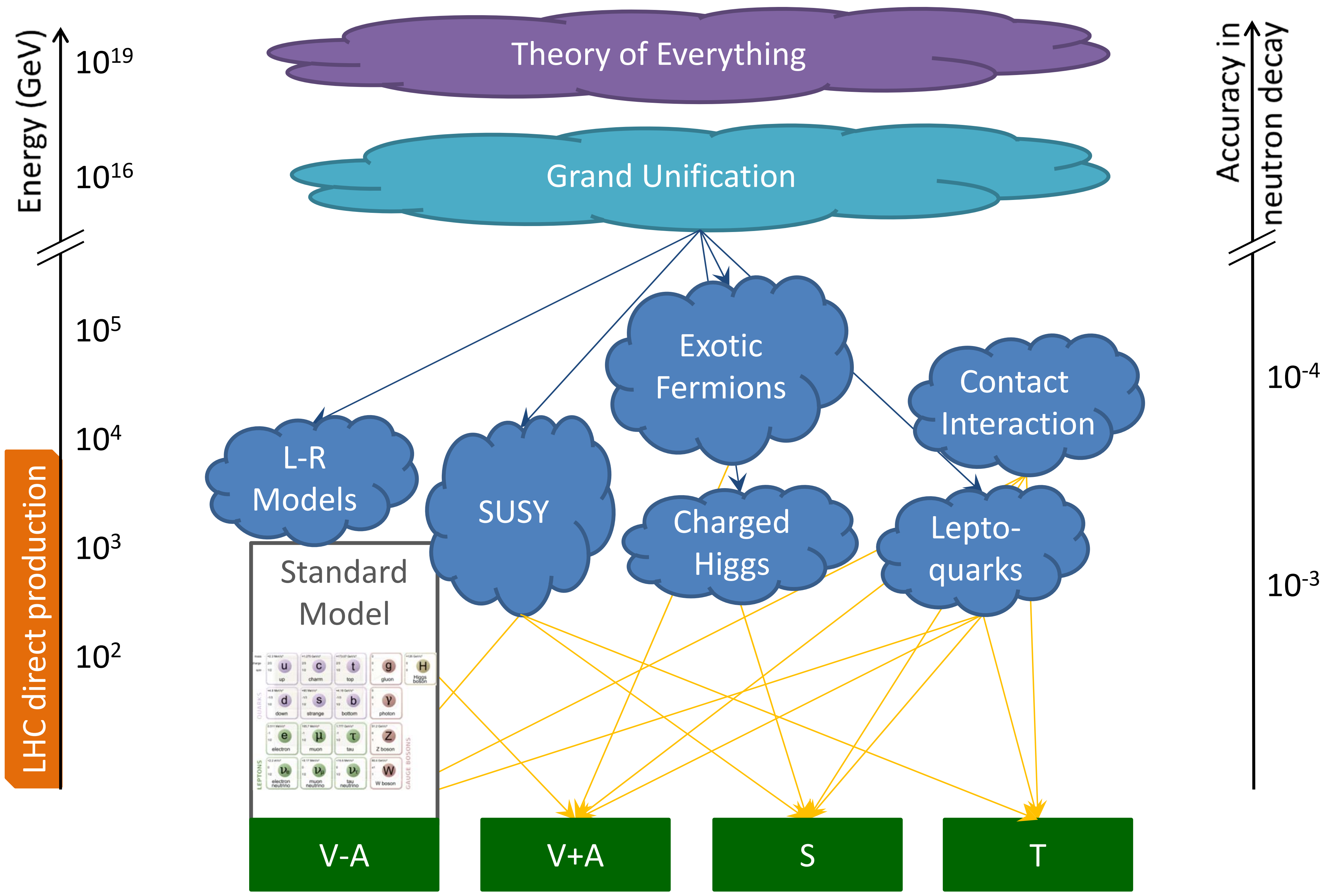




NoMoS

Beyond the Standard Model Physics in Neutron Decay

Gertrud Konrad
Stefan-Meyer-Institut Wien, ÖAW, Austria
Atominstitut, TU Wien, Austria


Energy (GeV)
10^{19}
10^{16}
10^{5}
10^{4}
10^{3}
10^{2}
LHC direct production
Theory of Everything
Grand Unification
Exotic Fermions
Contact Interaction
L-R Models
SUSY
Charged Higgs
Lepto-quarks
Standard Model
V-A
V+A
S
T
Accuracy in neutron decay
10^{-4}
10^{-3}

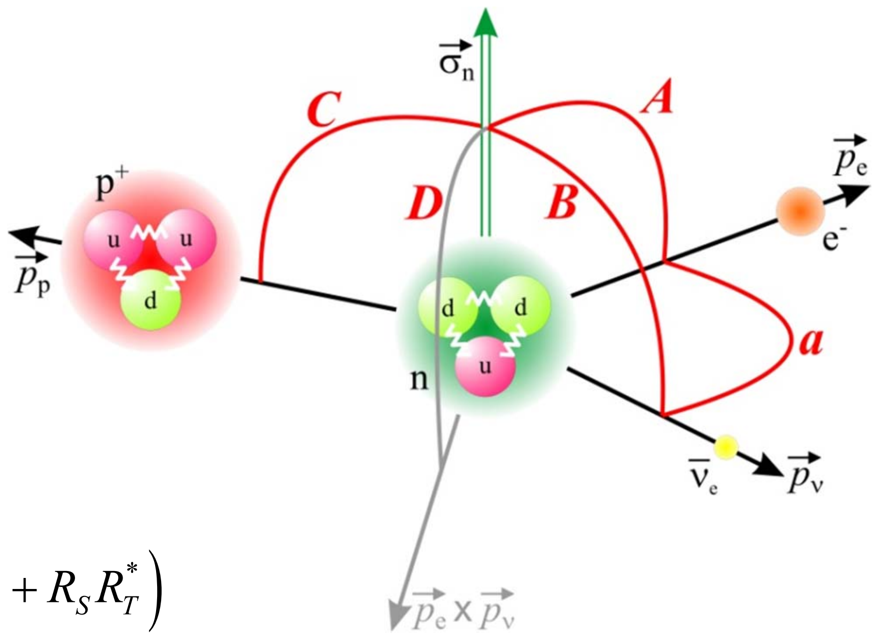
Neutron decay correlations

$$\frac{d^3\Gamma}{dE_e d\Omega_e d\Omega_\nu} = \frac{1}{2(2\pi)^5} \overbrace{G_F^2 |V_{ud}|^2 \left(1+3|\lambda|^2\right)}^{\propto \tau_n^{-1}} p_e E_e (E_0 - E_e)^2$$

$$\times\left[1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \frac{\langle\vec{\sigma}_n\rangle}{\vec{\sigma}_n}\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right)\right]$$

J.D. Jackson *et al.*, PR **106**, 517 (1957)

- 10 unknown parameters:
  G_F, V_{ud}, L_j, R_j, $j=V, A, S, T$
- 20 or more observables:
  τ_n, a, b, A, B, C, D, …



$$\xi a = |L_V|^2 - |L_A|^2 - |L_S|^2 + |L_T|^2 + |R_V|^2 - |R_A|^2 - |R_S|^2 + |R_T|^2$$

$$\xi A = -2\Re\left(|L_A|^2 + L_V L_A^* - |L_T|^2 - L_S L_T^* - |R_A|^2 - R_V R_A^* + |R_T|^2 + R_S R_T^*\right)$$

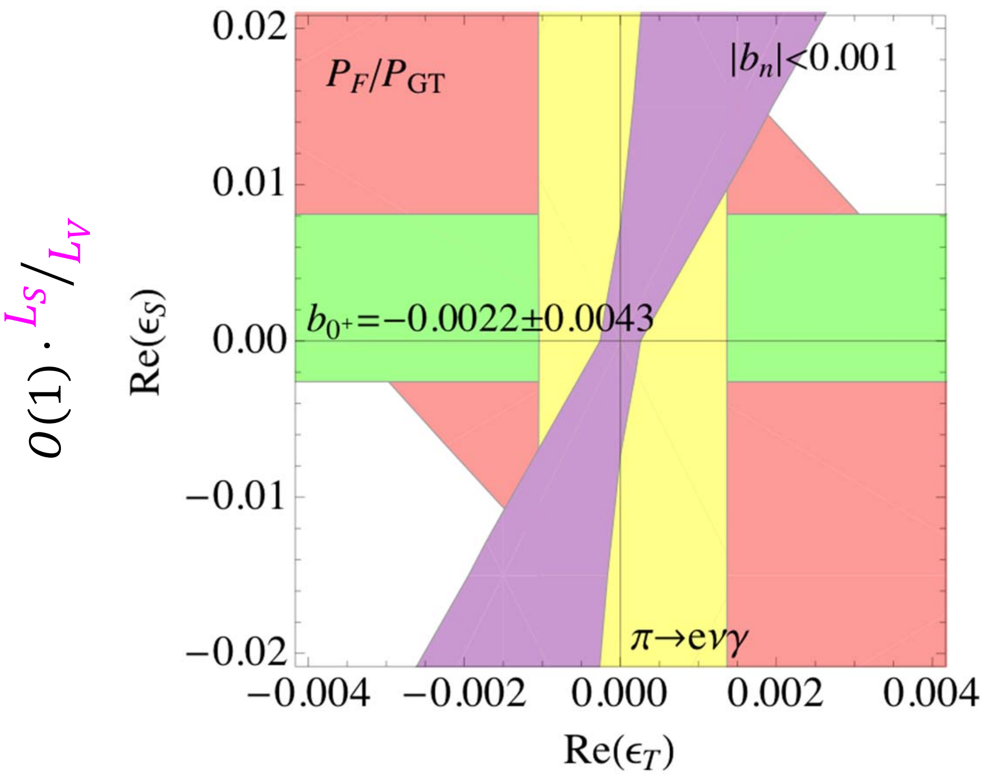
$$\xi b = 2\Re\left(L_S L_V^* + 3L_A L_T^* + R_S R_V^* + 3R_A R_T^*\right)$$ yet unmeasured

$$\xi = |L_V|^2 + 3|L_A|^2 + |L_S|^2 + 3|L_T|^2 + |R_V|^2 + 3|R_A|^2 + |R_S|^2 + 3|R_T|^2$$

F. Glück *et al.*, NP A **593**, 125 (1995)

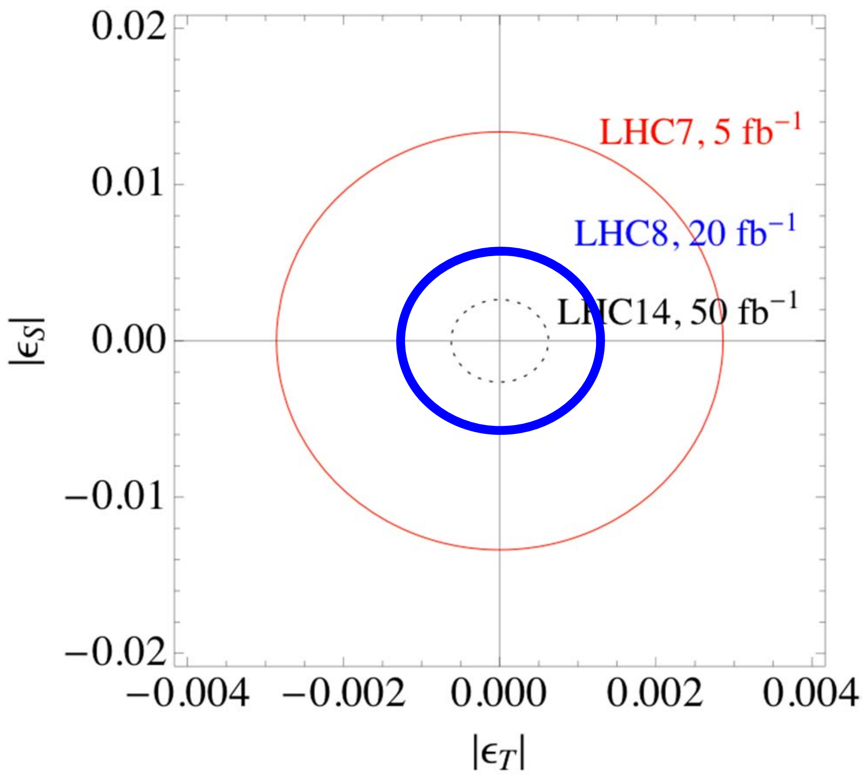
Prospects for scalar and tensor interactions

b at 10^{-3} level precision



$O(1) \cdot L_T/L_A$

LHC limits



CMS search for $pp \to e + \nu + X$

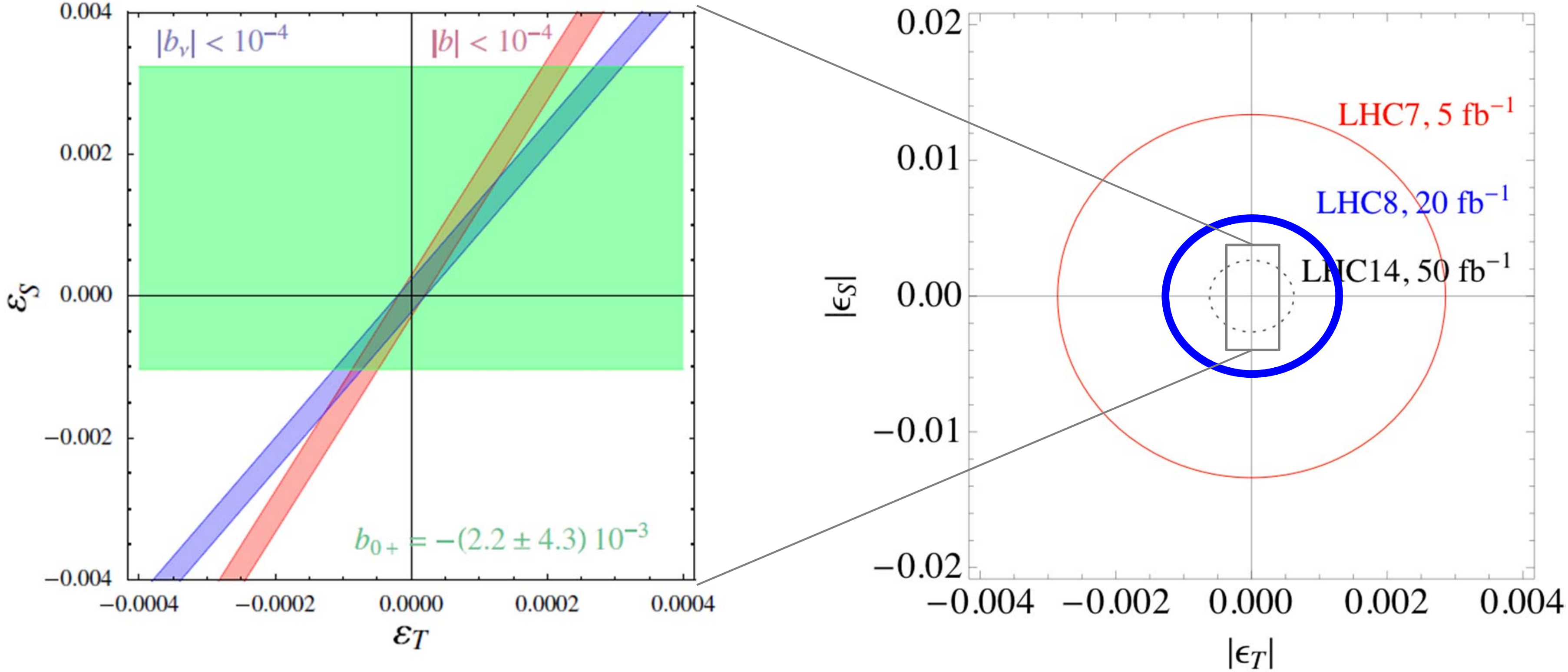
O. Naviliat-Cuncic, M. González-Alonso, Ann. Phys. (Berlin) **525**, 600 (2013); see also: NPAC-13-03; arXiv:1304.1759
see also: G. Konrad *et al.,* in: Proc. 5th BEYOND 2010, World Scientific, 660, 2011, arXiv: 1007.3027v2 (2010)

Prospects for scalar and tensor interactions

b at 10^{-4} level precision

LHC limits

$O(1) \cdot L_S / L_V$



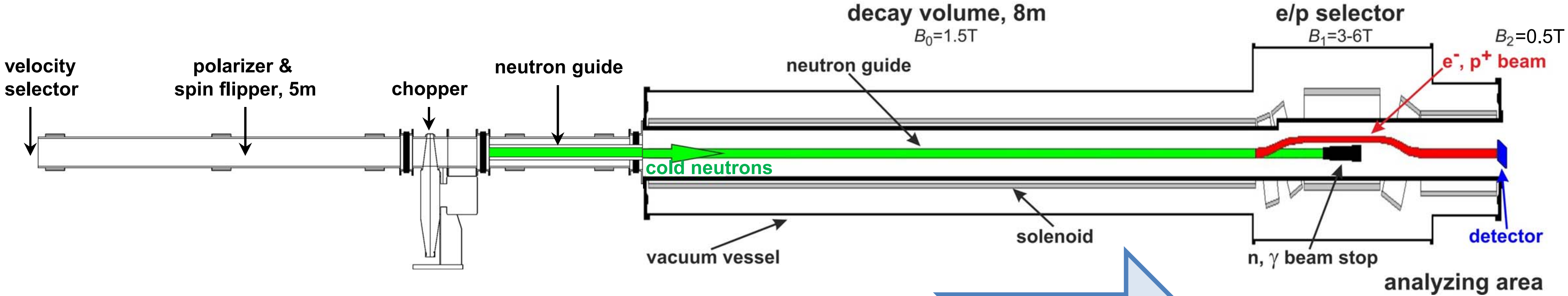
$O(1) \cdot L_T / L_A$

CMS search for $pp \rightarrow e + \nu + X$

T. Bhattacharya *et al.*, PR D **85**,054512 (2012)
O. Naviliat-Cuncic, M. González-Alonso, Ann. Phys. (Berlin) 525, 600 (2013); see also: NPAC-13-03; arXiv:1304.1759

The new Facility PERC

Proton Electron Radiation Channel



D. Dubbers *et al.*, NIM A **596**, 238 (2008)
G. K. *et al.*, J. Phys.: Conf. Ser. **340**, 012048 (2012)

see talk by B. Märkisch

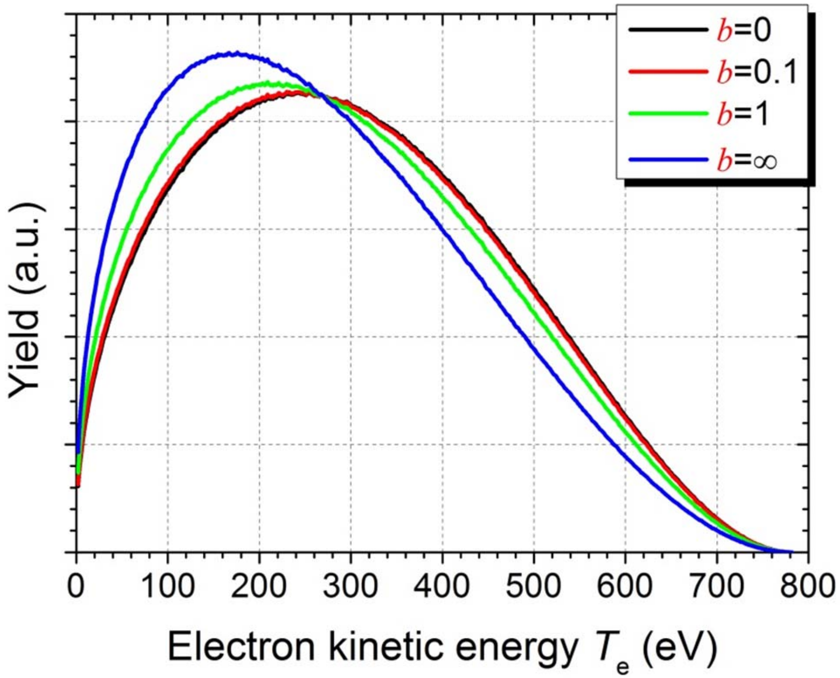
- Statistics: high flux $\phi=2\times10^{10}$ cm^{-2}s^{-1} and high decay rate $=1\times10^{6}$ m^{-1}s^{-1}
- Sensitivity:
  - improved by up to 2 orders of magnitude to sub-10^{-4}-level
  - highest phase space $d\Omega_e$, $d\Omega_p$ densities
- Systematics:
  - precise cuts in $d\Omega_e$, $d\Omega_p$: $\frac{\sin\theta_1}{\sin\theta_0}=\sqrt{\frac{B_1}{B_0}}$
  - $\leq 10^{-4}$ (for e⁻), especially $\Delta P/P=10^{-4}$

C. Klauser, PhD thesis, TU Wien, 2013
C. Klauser *et al.*, J. Phys.: Conf. Ser. **340**, 012011 (2012)

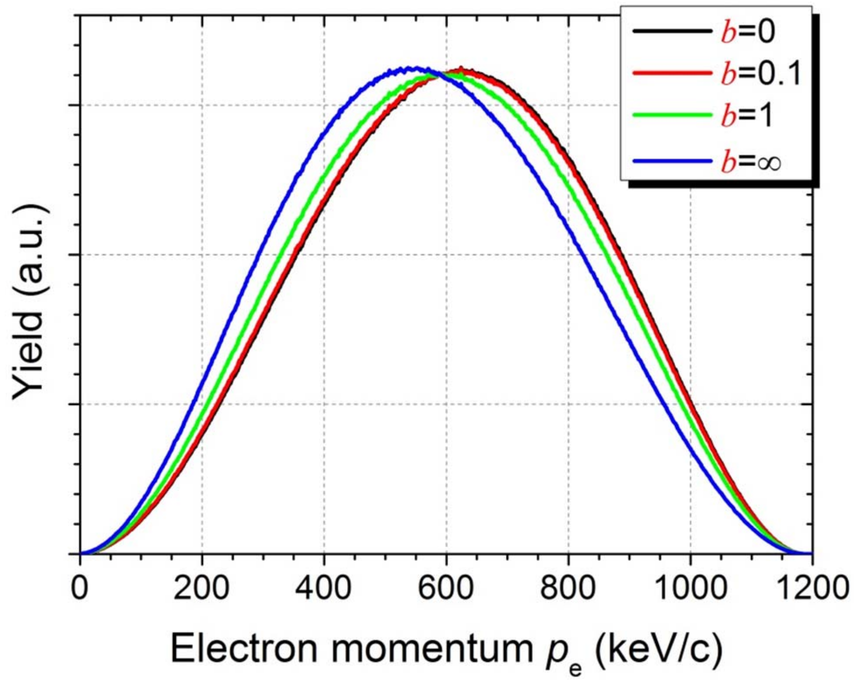
- Versatility: $a, b, A, B, C, f_2, \ldots$

Prospects for Fierz term *b* @ PERC

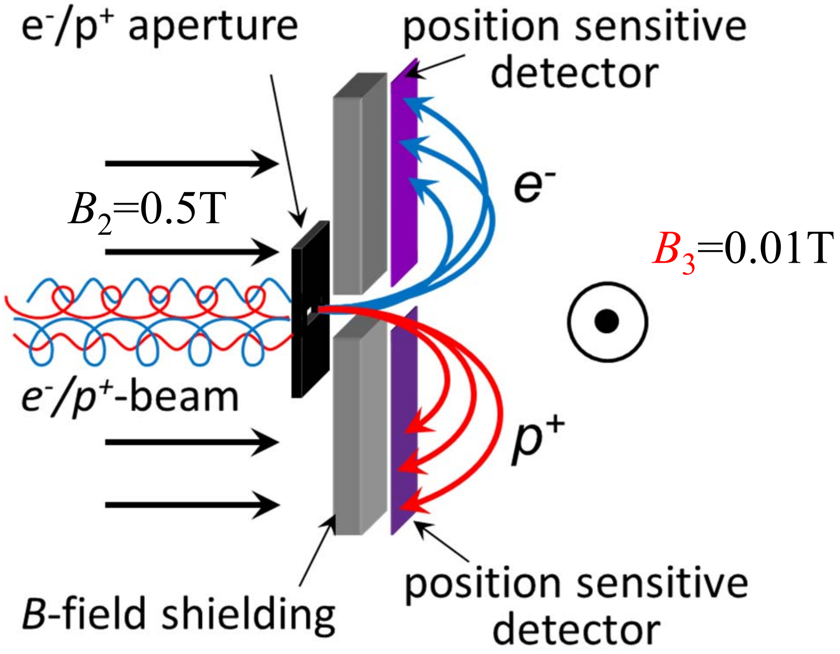
Electron energy spectrum



Electron momentum spectrum

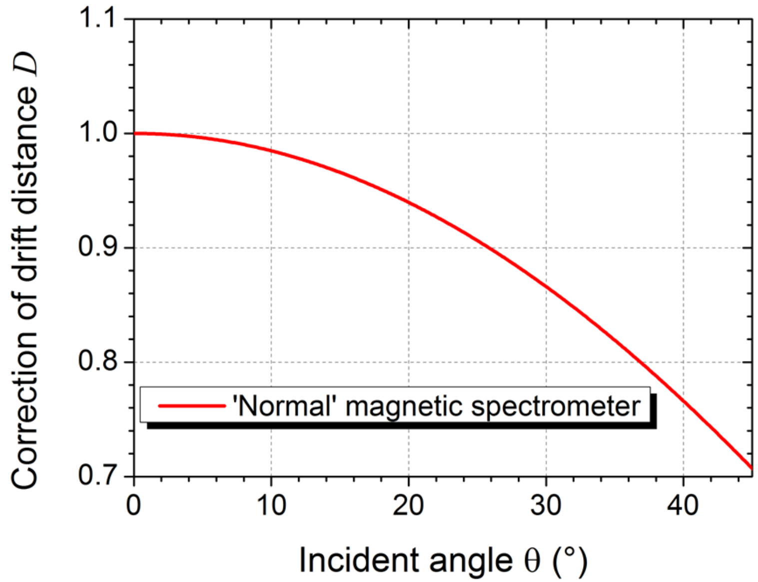


Magnetic spectrometer @ PERC



Radius of gyration:

$$r(p,\theta) = \frac{p_\perp}{|q| B_3} = \frac{p}{|q| B_3} \cos\theta$$



+ large drift distances $\mathcal{O}$(dm)

– no low momentum measurements
– large corrections for θ
– non-adiabatic transport of particles
– B_2-field coupled with B_3-field
– pitch angles easily distorted

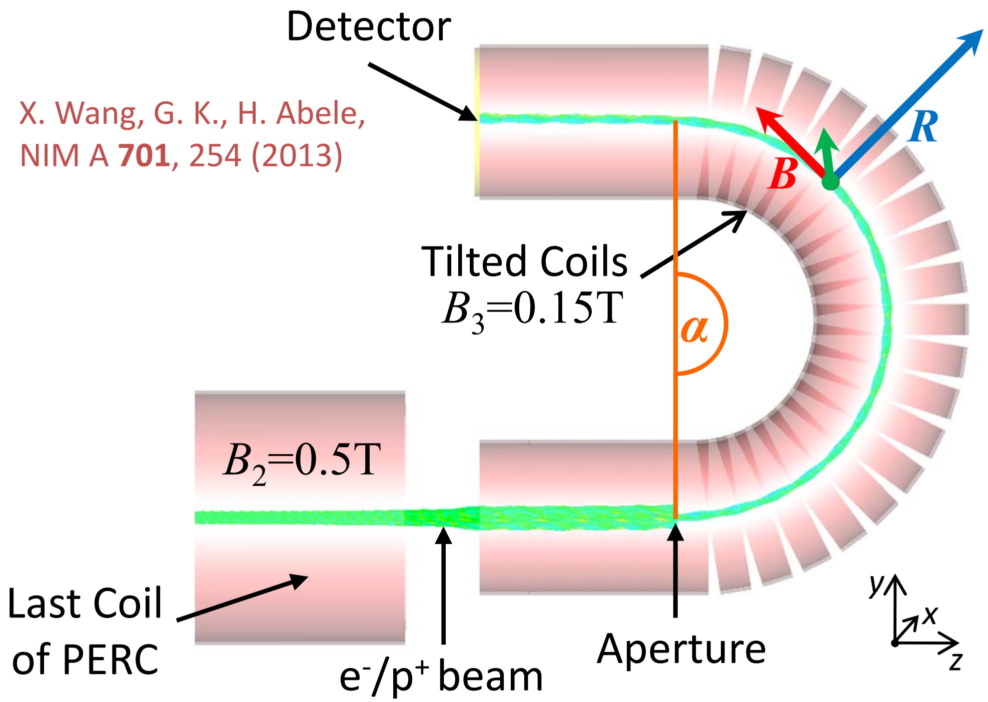
NoMoS

Neutron Decay Products Momentum Spectrometer

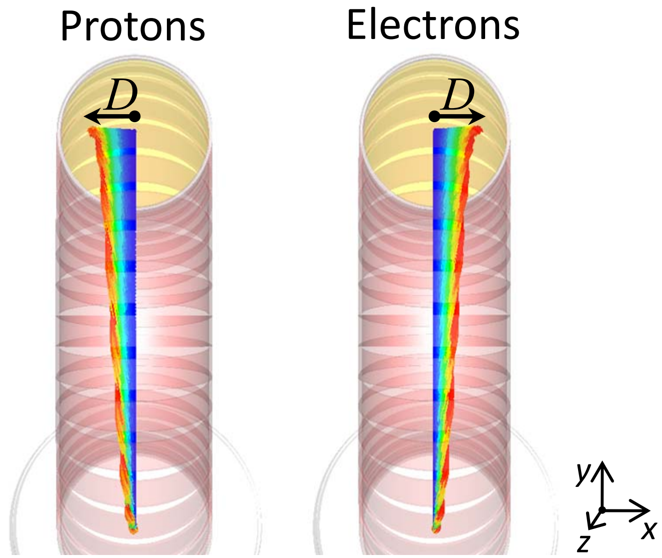
ÖAW New Frontiers Group at SMI

R×B drift momentum spectrometer

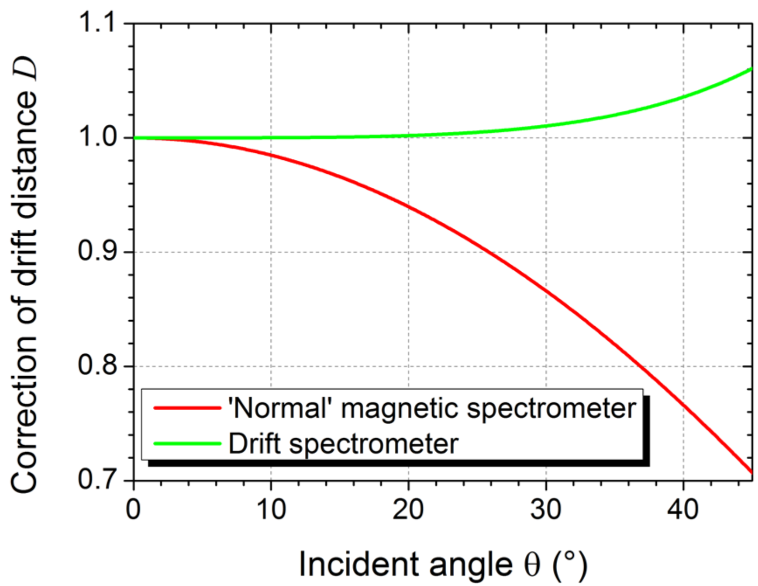
X. Wang, G. K., H. Abele, NIM A **701**, 254 (2013)



$$v_d \propto \frac{R \times B}{qR^2B^2}$$



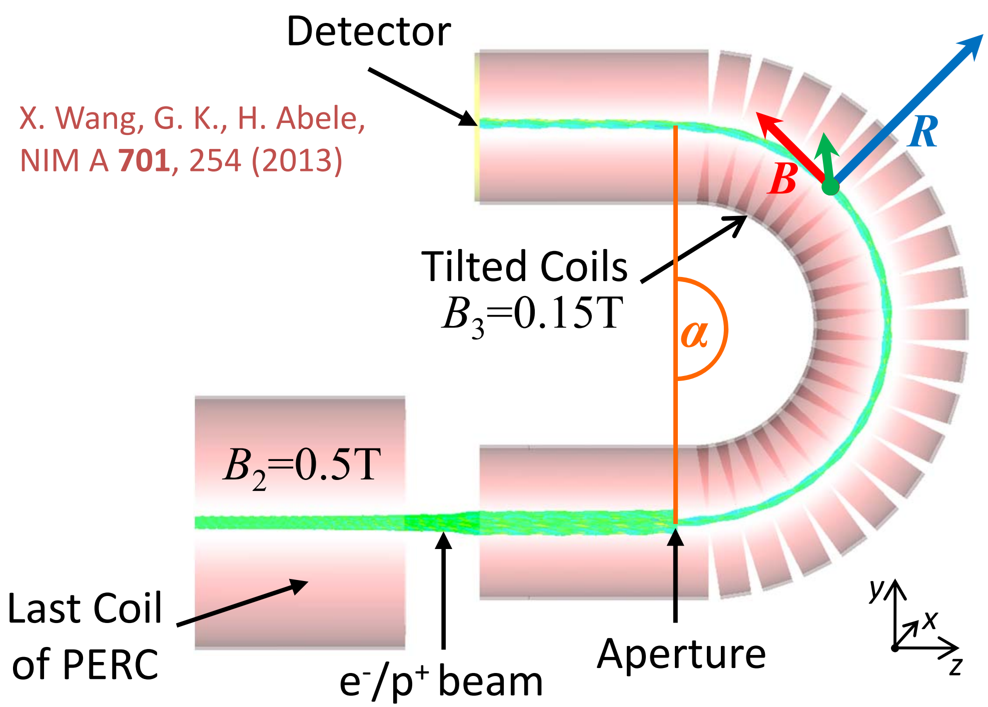
$$D(p,\theta) = \int_T v_d \mathrm{d}t = \frac{p}{qB_3} \cdot \alpha \cdot \frac{1}{2}(\cos\theta + \frac{1}{\cos\theta})$$



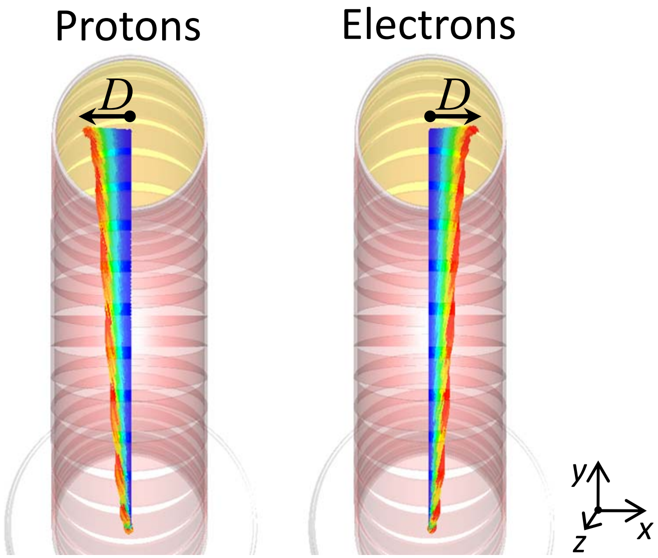
- + extremely versatile
- + adiabatic transport of particles
- + low momentum measurements
- + small corrections for θ
- + large acceptance of θ

R×B drift momentum spectrometer

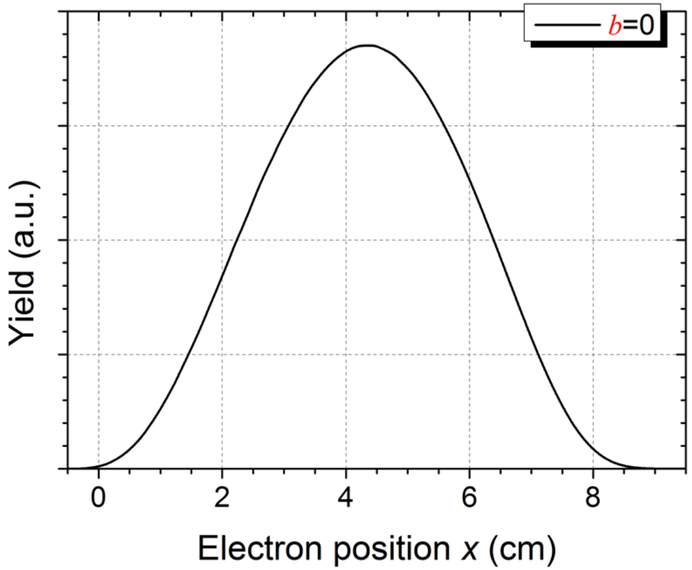
X. Wang, G. K., H. Abele, NIM A **701**, 254 (2013)



$$v_d \propto \frac{\boldsymbol{R}\times\boldsymbol{B}}{qR^2B^2}$$



$$D(p,\theta) = \int_T v_d \, \mathrm{d}t = \frac{p}{qB_3}\cdot\alpha\cdot\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$



+ extremely versatile
+ adiabatic transport of particles
+ low momentum measurements
+ small corrections for θ
+ high resolution: $\Delta p/p = 14.4\ \mathrm{keVc^{-1}mm^{-1}}$

1.2%mm⁻¹

− small drift distances $\mathcal{O}$(cm)

NoMoS Physics Programme

Research focus:

- Weak magnetism form factor f_2
  - study the structure of the weak interaction
- β-asymmetry parameter A, electron-antineutrino correlation coefficient a
  - determine weak coupling constants ratio $\lambda = g_A / g_V$
  - test CKM unitarity
- Fierz interference term b
  - non-zero value indicates existence of scalar or tensor interactions
  - caused by, e.g., yet unknown charged Higgs bosons or leptoquarks
- Oscillatory, sidereal effects in the case of Lorentz invariance violation

Goal:

electron and proton spectroscopy on the sub-10^{-4}- respectively 10^{-3}-level

Theoretical prerequisite:

- analyse standard correlation coefficients to order 10^{-5}
- ✓ comprehensive analysis of standard correlation coefficients to order 10^{-4}

A. Ivanov *et al.*, Phys. Rev. D**88**, 073002 (2013)

Summary & Outlook

- Neutron alphabet
  - deciphers the Standard Model of particle physics
  - observables in neutron β-decay are abundant
- Precision measurements of neutron β-decay
  - address important open questions of particle physics and cosmology
  - can continue to probe for SUSY in regions where it is not accessible to LHC
  - 10^{-3} level b measurements complementary to improved LHC results
- New facility PERC:
  - clean and bright source of neutron decay products
  - sensitivity improved to sub-10^{-4}-level
  - systematics $\leq 10^{-4}$
- ÖAW New Frontiers Group NoMoS at SMI:
  - novel **R**×**B** drift spectrometer for momentum spectroscopy
  - comprehensive physics programme

see talk by B. Märkisch