

# Status & prospects of the KATRIN experiment

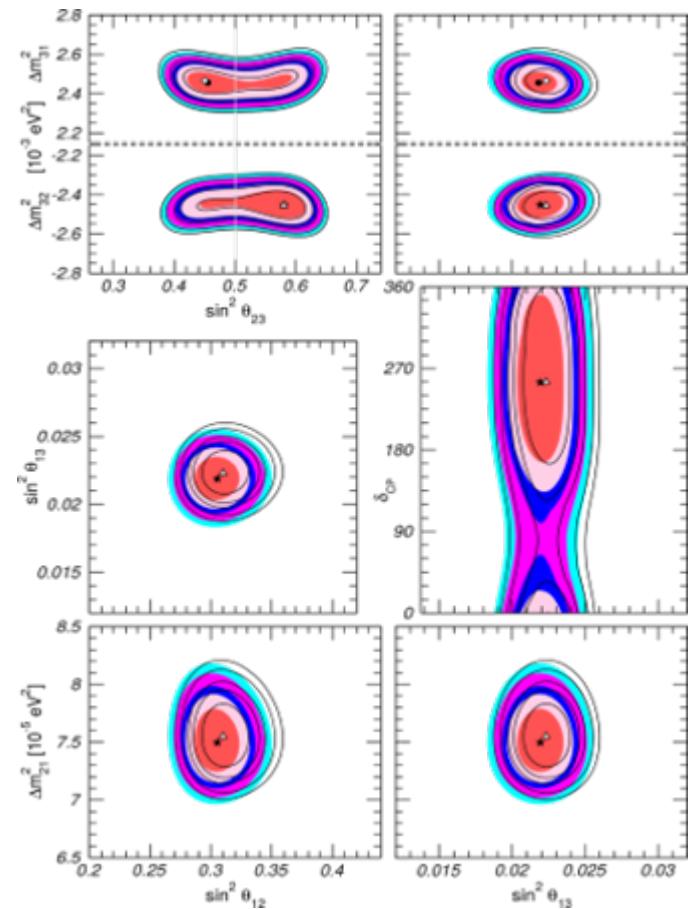
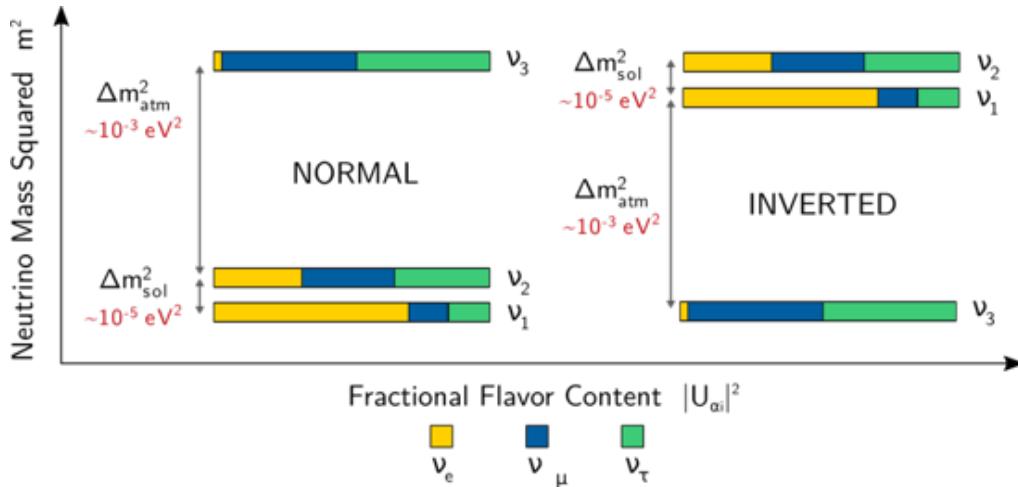
ICNFP 2016, Κολυμβαρί<sup>1</sup>  
Nikolaus Trost (IKP)

Karlsruhe Institute of Technology (KIT) – Institute for Nuclear Physics (IKP)



# Neutrino mass

- Oscillation Experiments show  $m_\nu > 0$
- Nobel Prize 2015: Takaaki Kajita, Arthur McDonald
- $m_\nu$  inaccessible to oscillation experiments, sensitive only to  $\Delta m_\nu^2$



Gonzalez-Garcia, Maltoni, Schwetz (2014)

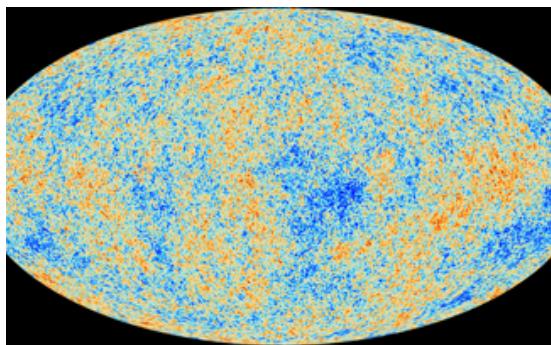
# Ways towards an old frontier

- the neutrino is the only SM particle with unknown mass.
- Very important for structure formation in cosmology
- neutrino mass hints towards new physics: LNV, new possible source of CP violation, right handed neutrinos (steriles), new mass generation mechanism?

## Cosmology

$$M_\nu = \sum_i m_i$$

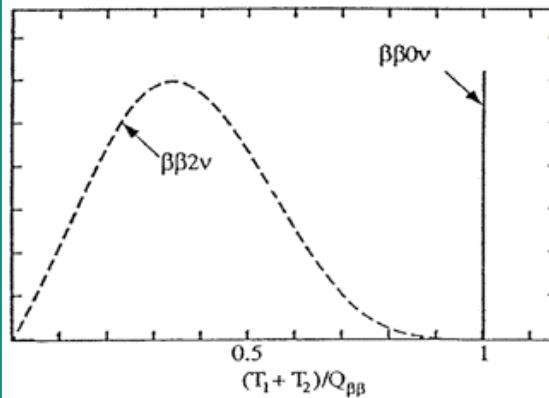
Upper limit 0.2-1 eV  
 Model Dependence:  
 Multiparameter  $\Lambda$ CDM



## $0\nu\beta\beta$

$$m_{\beta\beta}^2 = \left| \sum_i U_{ei}^2 m_i \right|^2$$

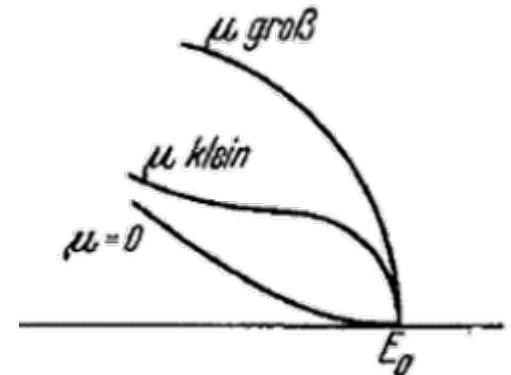
Upper limit: 0.2-0.4 eV  
 LNV, Majorana  $\nu$ , nuclear  
 ME, Cancelling CP Phases



## ( $\beta$ decay) kinematics

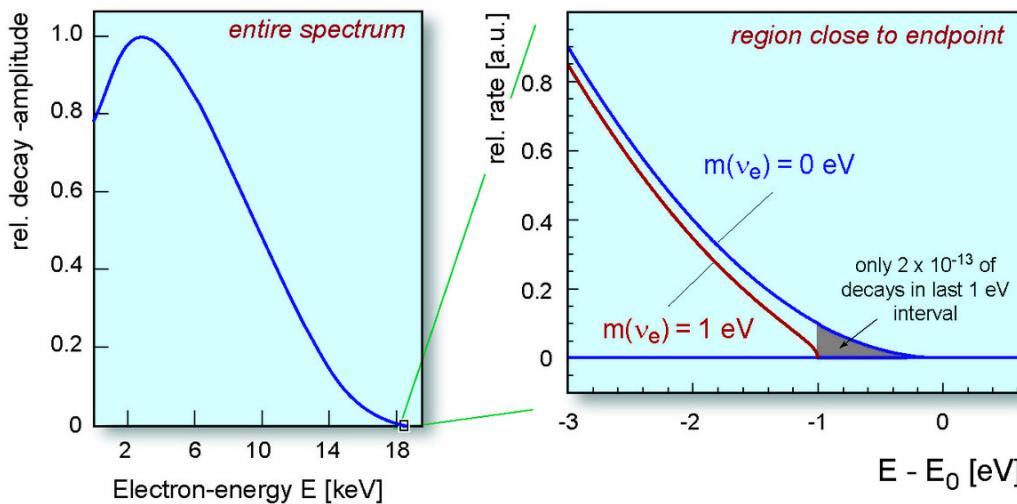
$$m_\beta^2 = \sum_i |U_{ei}|^2 m_i^2$$

Upper limit: 2 eV  
**Model Independent**



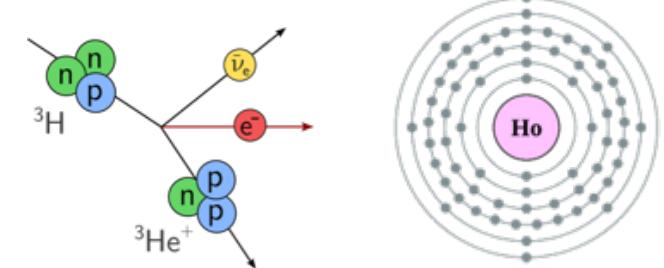
# Direct measurement of $m_\nu$ – what is needed?

$$\frac{d\Gamma}{dE} = C F(Z, E) p(E + m_e) (E_0 - E) \sum_i |U_{ei}|^2 \sqrt{(E_0 - E)^2 - m^2(\nu_i)}$$



The neutrino mass is extracted  
from the spectral distortion!  
(see later slide)

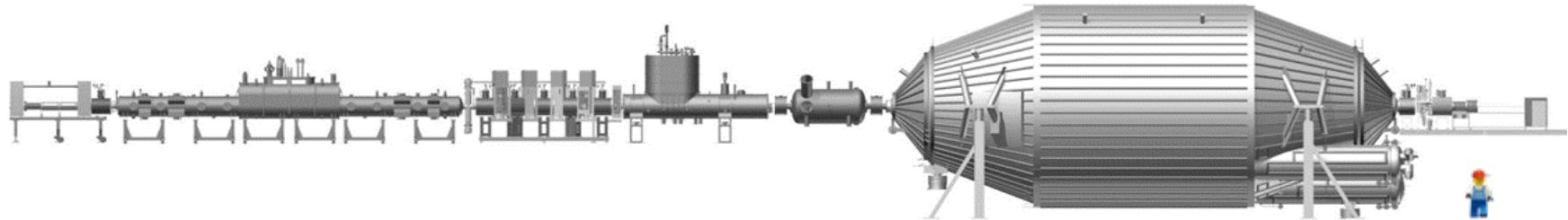
- high luminosity source
- low energy endpoint
- low background
- extremely good energy resolution, calibration and stability



KATRIN  
Project8

EcHO  
Holmes  
Numecs

# The Karlsruhe Tritium Neutrino Experiment



Calibration&  
Monitoring

Windowless  
Gaseous Tritium  
Source

electron  
Transport &  
Tritium Pumping

Spectrometer

Detector

- Design goal: 200 meV 90% C.L Sensitivity on  $m_{\nu}$
- Improvement by factor 10
- Reduce systematic and statistic uncertainties by factor 100
- 70m long setup, situated in Karlsruhe near the Tritium Laboratory
- ~120 Collaborators from 17 Institutions in 6 Countries



Fachhochschule Fulda  
*University of Applied Sciences*



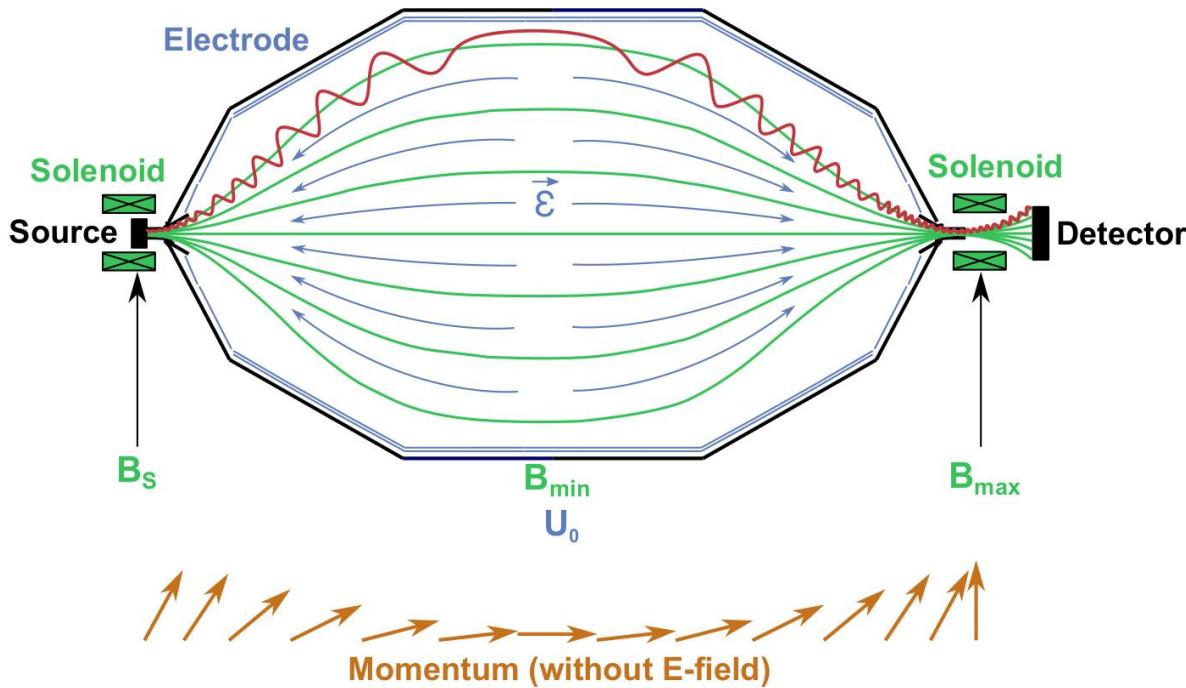
THE UNIVERSITY  
of NORTH CAROLINA  
at CHAPEL HILL



AKADEMIE VĚD  
ČESKÉ REPUBLIKY

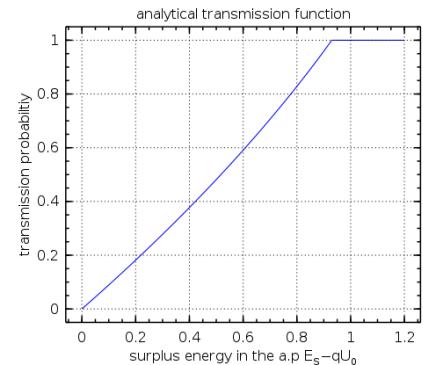
# a high resolution $\beta$ spectrometer

Magnetic Adiabatic Collimation with Electrostatic Filter

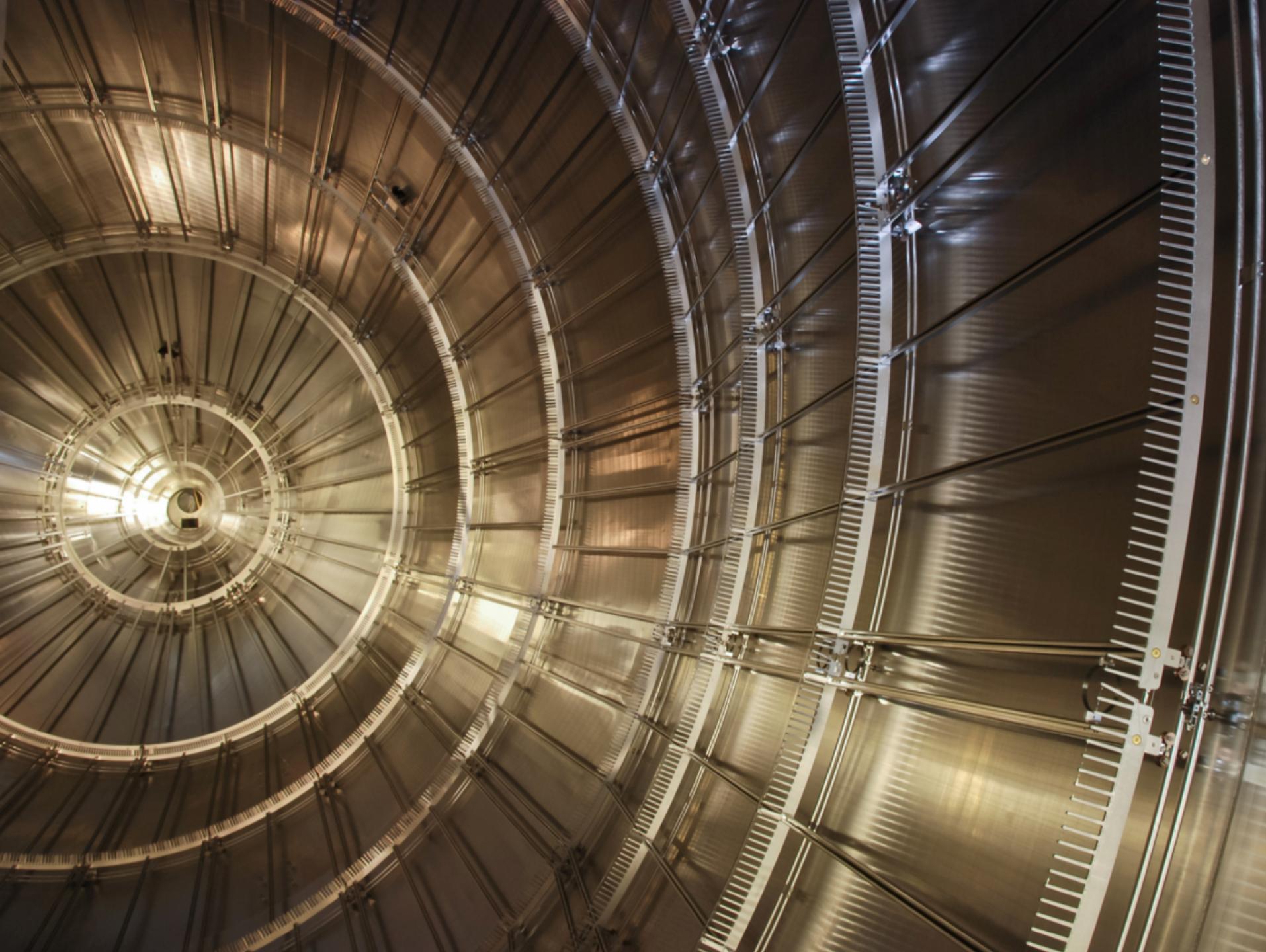


$$\frac{\Delta E}{E} = \frac{B_{\min}}{B_{\max}} \approx \frac{1}{20000}$$

$$\Delta E = 0.93 \text{ eV}$$



- Integrating high pass filter
- Up to  $2\pi$  acceptance angle
- Challenge:  $1200\text{m}^3$  UHV  $1.\text{e}-10 \text{ mbar}$
- 10 mcps Background

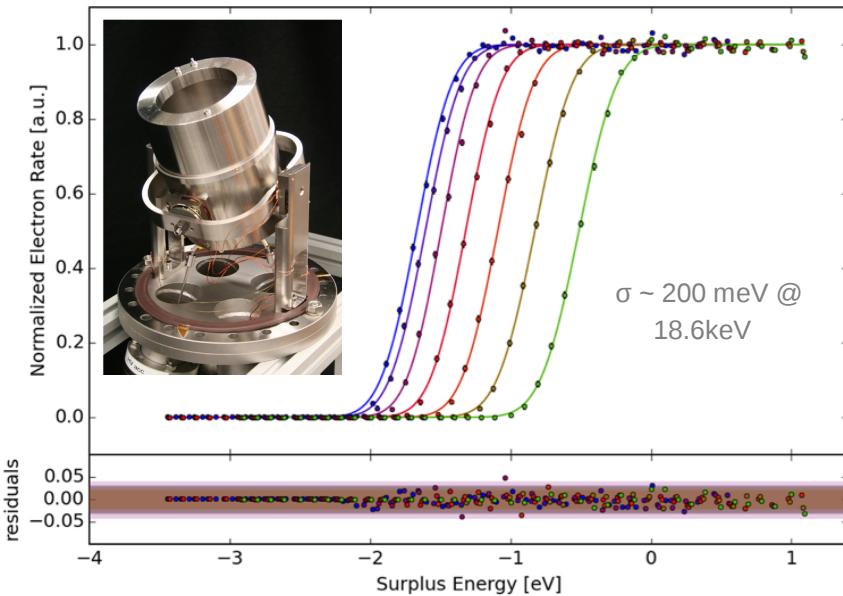


# spectrometer & detector commissioning

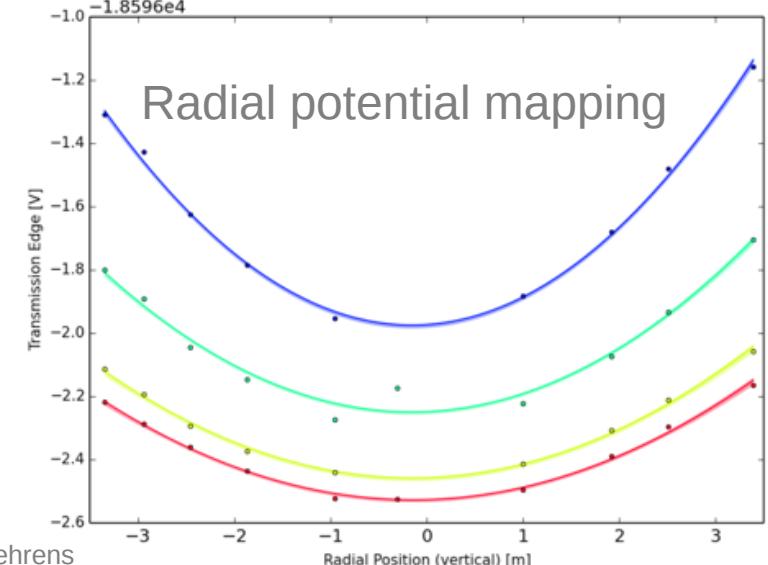
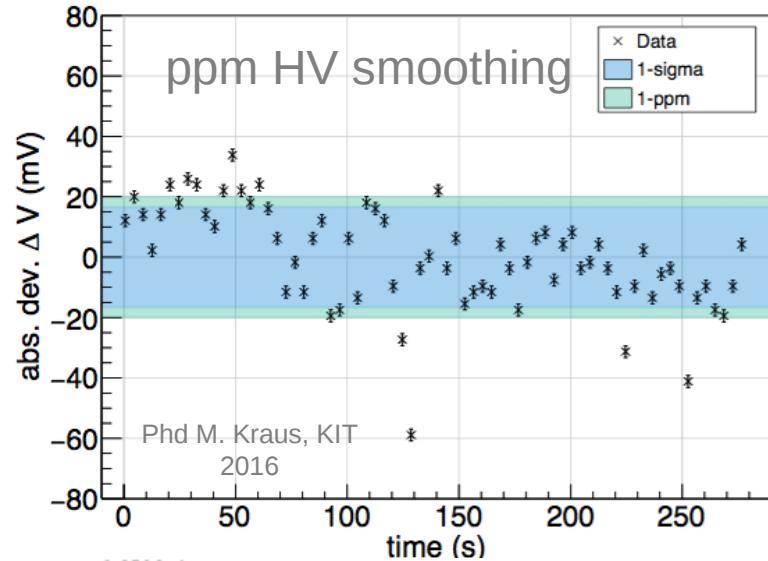
2013-2015



- precision e-gun
- pitch angle selective
- small beam spot
- Tool for characterizing the main spectrometer
- filter works like expected

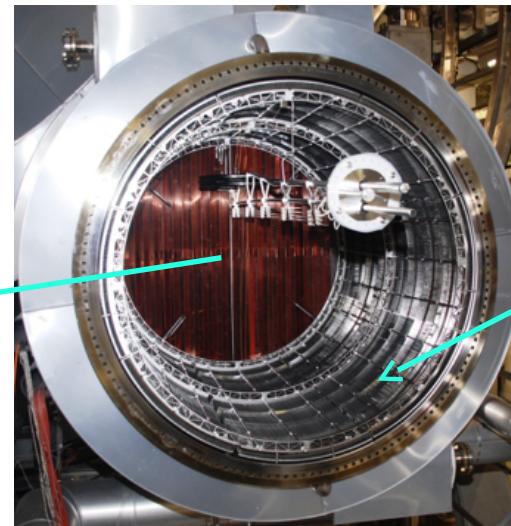
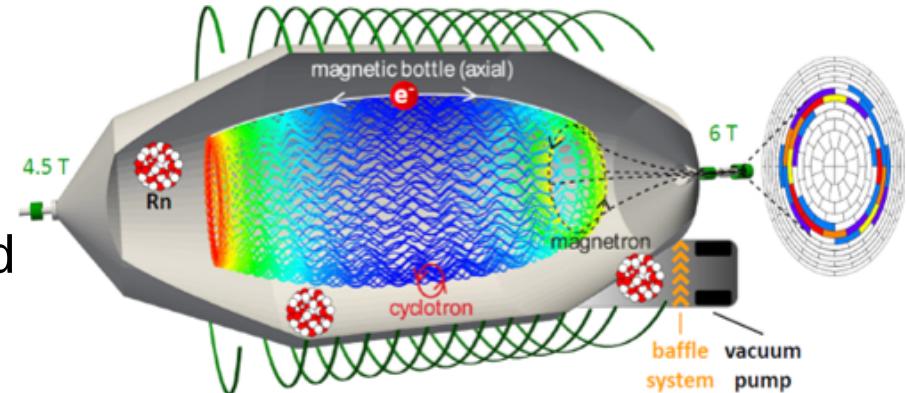
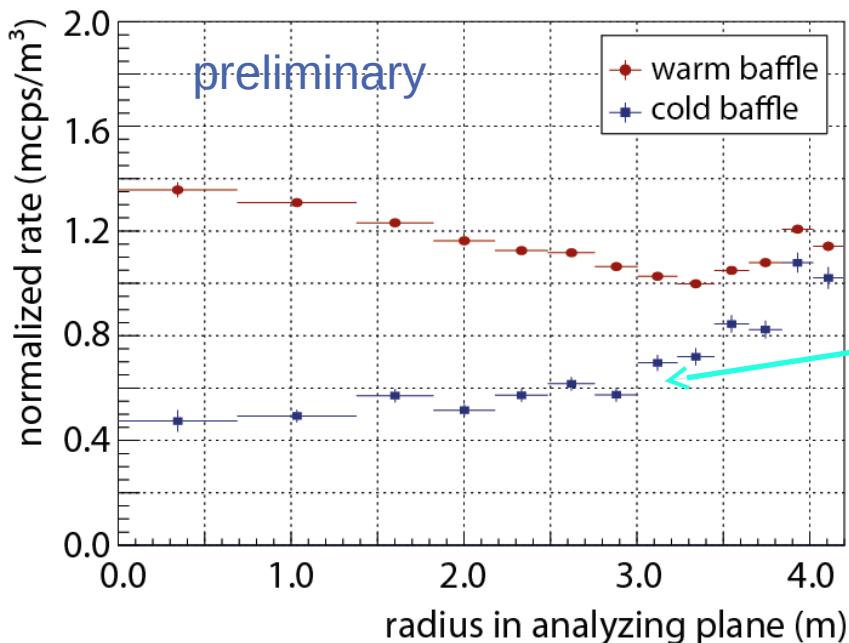


S.Groh, J. Behrens

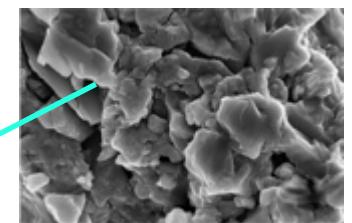


# Background

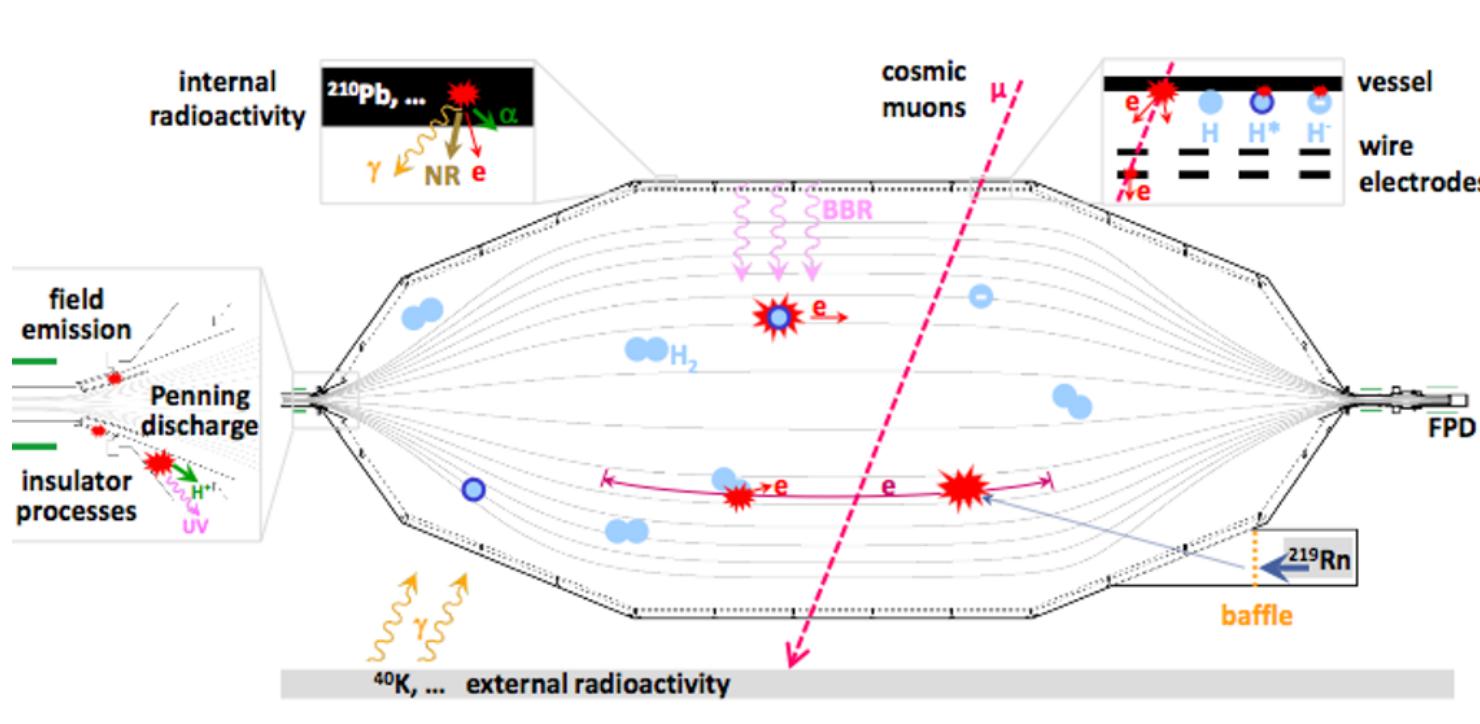
- Known Bg Source: Rn from NEG pump
- Shielded by LN cooled Baffles
- Highly effective, other Background source remains



non evaporable  
getter pump



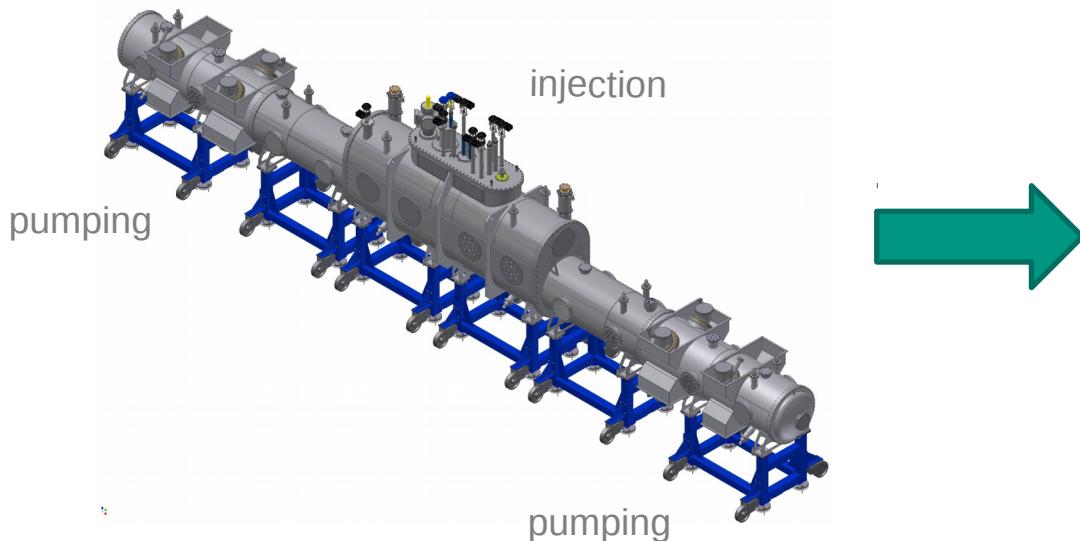
# Background Investigation



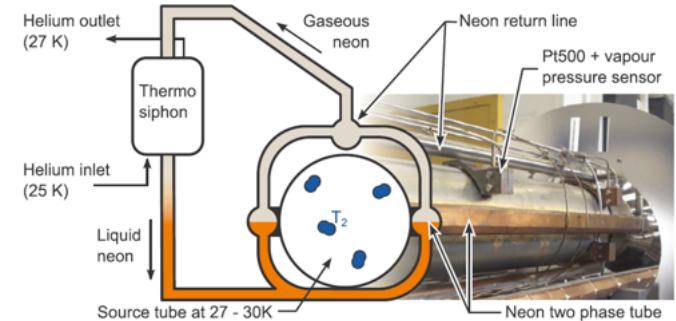
- Many scenarios excluded with dedicated measurements
- Magnetic shielding prevents charged particles from entering the fluxtube
- Excited neutral particles ( $\text{Rn}, \text{H}^*?$ ) can enter the sensitive volume and decay

# Windowless Gaseous Tritium Source

- 100 GBq molecular gaseous tritium
- 1.e-3 stability of column density and all related parameters: temperature, pressure, tritium purity...
- closed loop processing for tritium purification
- cooldown in the next weeks



2 phase neon cooling @ 30K

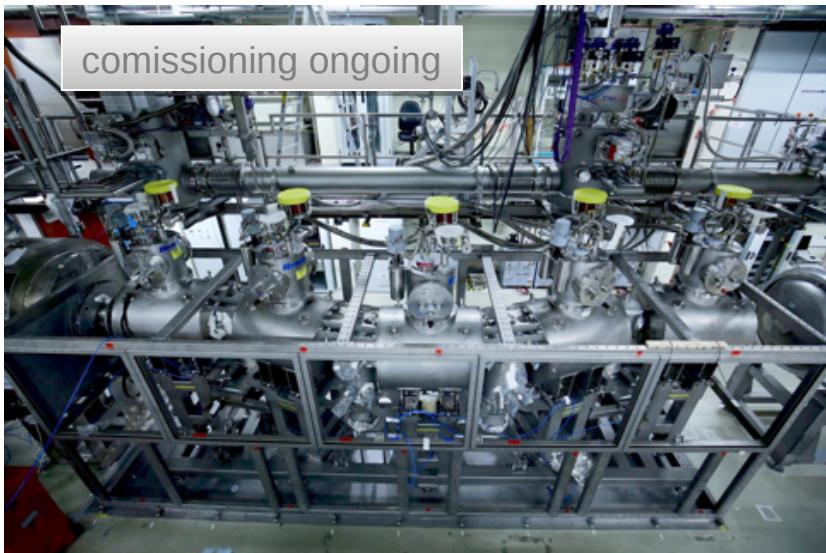
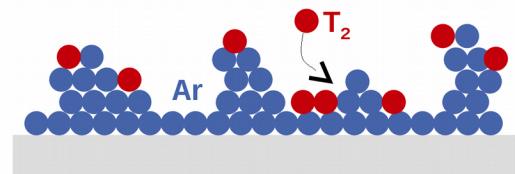


10m long, Ø 90 mm beamtube,  
3.6T nominal field, 22T



# Transport and pumping sections

- Adiabatic electron transport in up to 5.6T magnetic field
- Tritium retention  $1.e14$
- Beamlime bent to prevent direct line of sight
- Active (TMP) and passive tritium pumping
- Ion diagnostic and electrostatic blocking



passive cryo pumping with 3-4K Ar frost



# Measurements ahead



## Source and transport section

- Mech. & Cryo Infrastructure ready 100%
- Test of > 800 sensors
- Cold tests (cryogenics & s.c. magnets) 50%
- Inactive commissioning (D2) then active (T2)

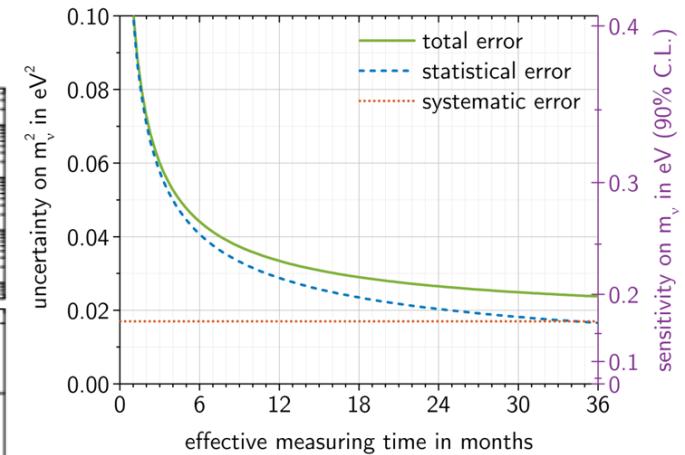
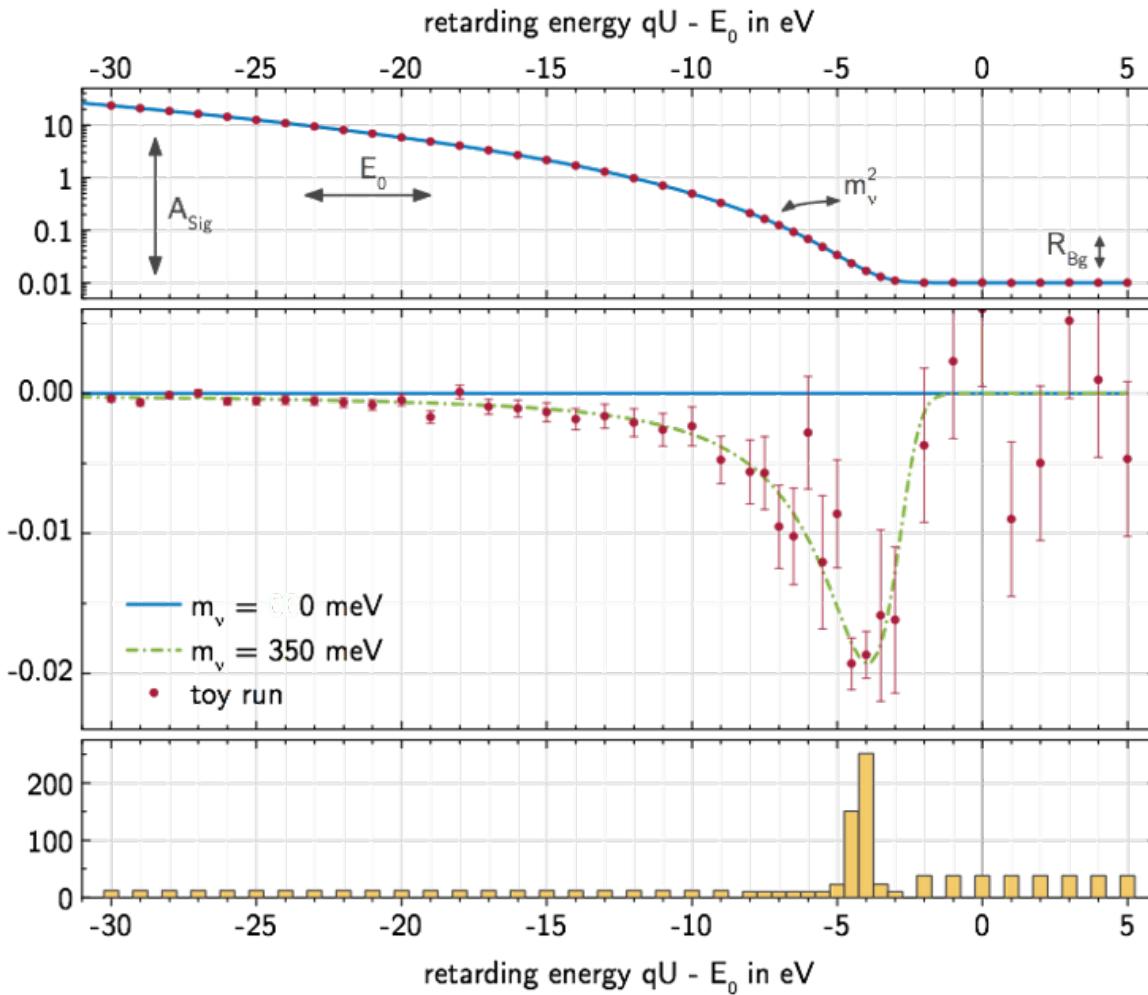
## Spectrometer and detector section

- 2 Sucessfull comissioning phases
- Integrate pre spectrometer

## Full system integration

- "First light" autumn 2016
- Tritium data 2017

# neutrino mass sensitivity



- 4 fit parameters:  
 $A_{\text{Sig}}, R_{\text{Bg}}, E_0, m_\nu^2$
- Spectral shape is sensitive
- 3.net (5 cal.) years to balance statistic and systematic uncertainty

# Beyond neutrino mass: more frontiers

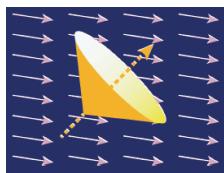
in standard operation

## RH Currents

Bonn et al. (2011)

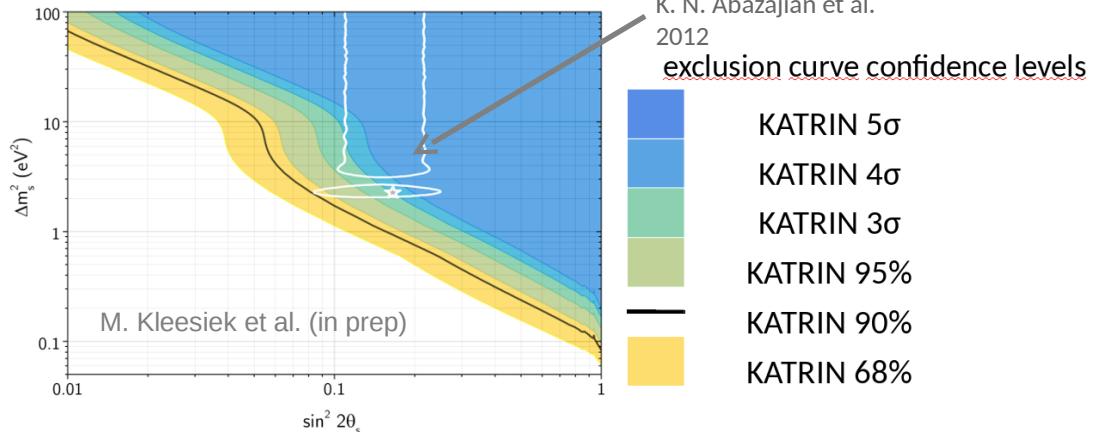
## Lorentz Symmetry Violation

Blasone et al. (2005),  
Diaz, Kostelecky & Lehnert (2013)



## Light sterile neutrino search

e.g Fromaggio & Barret (2011)



far from the tritium endpoint  
– R&D required

## Search for keV sterile neutrinos (WDM candidate)

Susanne Mertens et al. (2015) - Tristan Group  
Barry, Heek, Rodejohann (2014)

# Thank you – Questions?



# Cosmology – Model dependence with multiple data sets

	Planck	Planck + R16	Planck +R16+BAO	Planck +R16+JLA	Planck +R16+ WL	Planck +R16+lensing
$\Omega_b h^2$	$0.02239 \pm 0.00030$	$0.02239 \pm 0.00029$	$0.02258^{+0.00026}_{-0.00032}$	$0.02270 \pm 0.00025$	$0.02252 \pm 0.00029$	$0.02214 \pm 0.00027$
$\Omega_c h^2$	$0.1186 \pm 0.0035$	$0.1187 \pm 0.0036$	$0.1209^{+0.0032}_{-0.0036}$	$0.1218 \pm 0.0034$	$0.1189^{+0.0035}_{-0.0041}$	$0.1176 \pm 0.0035$
$\tau$	$0.058 \pm 0.021$	$0.058^{+0.021}_{-0.023}$	$0.058 \pm 0.021$	$0.059 \pm 0.021$	$0.050 \pm 0.020$	$0.057 \pm 0.021$
$n_S$	$0.967 \pm 0.013$	$0.967 \pm 0.013$	$0.976 \pm 0.12$	$0.981 \pm 0.011$	$0.973 \pm 0.013$	$0.959 \pm 0.012$
$\log(10^{10} A_S)$	$3.048 \pm 0.043$	$3.048^{+0.043}_{-0.048}$	$3.053 \pm 0.043$	$3.056 \pm 0.043$	$3.030 \pm 0.040$	$3.042 \pm 0.044$
$H_0$	$> 67.1$	$73.5 \pm 1.9$	$71.3 \pm 1.6$	$70.9 \pm 1.5$	$73.4 \pm 2.0$	$73.7 \pm 1.9$
$\sigma_8$	$0.81^{+0.16}_{-0.12}$	$0.804^{+0.056}_{-0.044}$	$0.788 \pm 0.036$	$0.785^{+0.056}_{-0.037}$	$0.788^{+0.050}_{-0.044}$	$0.826 \pm 0.039$
$\sum m_\nu$ [eV]	$< 0.53$	$< 0.512$	$0.35^{+0.16}_{-0.25}$	$< 0.384$	$0.41^{+0.13}_{-0.39}$	$0.32^{+0.14}_{-0.24}$
$w$	$-1.32^{+0.47}_{-0.67}$	$-1.29^{+0.15}_{-0.12}$	$-1.14^{+0.12}_{-0.10}$	$-1.079^{+0.072}_{-0.057}$	$-1.25^{+0.14}_{-0.11}$	$-1.33^{+0.14}_{-0.12}$
$N_{\text{eff}}$	$3.08^{+0.26}_{-0.30}$	$3.09^{+0.26}_{-0.31}$	$3.26^{+0.24}_{-0.28}$	$3.37^{+0.24}_{-0.28}$	$3.17^{+0.25}_{-0.33}$	$2.94 \pm 0.25$
$A_{\text{lens}}$	$1.21^{+0.09}_{-0.14}$	$1.18^{+0.09}_{-0.11}$	$1.210 \pm 0.095$	$1.22^{+0.09}_{-0.11}$	$1.23^{+0.09}_{-0.10}$	$1.034^{+0.060}_{-0.067}$
$\frac{dn_S}{d \ln k}$	$-0.0034 \pm 0.0098$	$-0.003^{+0.010}_{-0.011}$	$-0.0003 \pm 0.0091$	$0.001^{+0.009}_{-0.011}$	$-0.0001 \pm 0.0099$	$-0.0055 \pm 0.0091$
$r$	$< 0.0911$	$< 0.0934$	$< 0.0974$	$< 0.0943$	$< 0.103$	$< 0.0843$

Table I. 68% c.l. constraints on cosmological parameters in our extended 12 parameters scenario from different combinations of datasets.

[Eleonora Di Valentino](#), [Alessandro Melchiorri](#),  
[Joseph Silk](#) (2016 1606.00634)

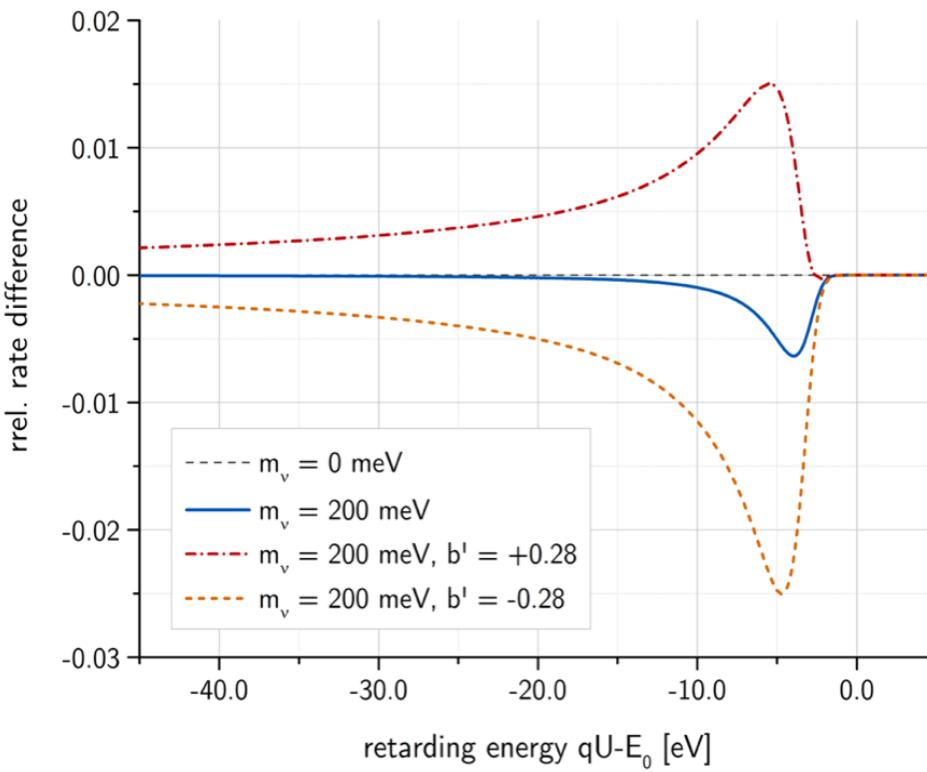
General understanding about relaxation of  
 cosmologic neutrino mass bounds:  
 Steen Hannestad (2005)

# Effect of RH current contributions

$$\frac{d\Gamma}{dE dt} \propto E_\nu \sqrt{E_\nu^2 - m_\nu^2} \left(1 + b' \frac{m_\nu}{E_\nu}\right) \quad [\text{J. Bonn et al., Phys. Lett. B 703 (2011) 310}]$$

Fierz-like parameter  $b'$   
enters differential rate

$$b' \approx -2 \frac{\Re(L_V R_V^* + L_V R_S^*) |\mathcal{M}_F|^2 + \Re(L_A R_A^* + L_A R_T^*) |\mathcal{M}_{GT}|^2}{|L_V|^2 |\mathcal{M}_F|^2 + |L_A|^2 |\mathcal{M}_{GT}|^2}$$



## Imprint on integrated spectrum:

- Only small sensitivity on  $b'$  if endpoint  $E_0$  left free in fit  
→ good for determination of  $m^2(v_e)$
- Improvement of present bounds on  $b'$  with KATRIN for small  $m(v_e)$  if
  - external  $E_0$  value with accuracy < 50 meV as input\*
  - absolute energy scale in KATRIN  $U_{\text{spec}} - U_{\text{source}}$  known to same accuracy of < 50 meV

\*) 70 meV accuracy:

E. G. Myers et al., PRL 114 (2015) 013003

# Probing Lorentz invariance in $\beta$ decay

## Standard Model Extension (SME) framework:

Neutrinos satisfy Dirac-like equation

$$(i\Gamma^\alpha \partial_\alpha - \mathbf{M}) \psi = 0$$

with  $\Gamma$ ,  $\mathbf{M}$  including momentum-dependent coefficients

[Kostelecky & Mewes (2004, 2009)]

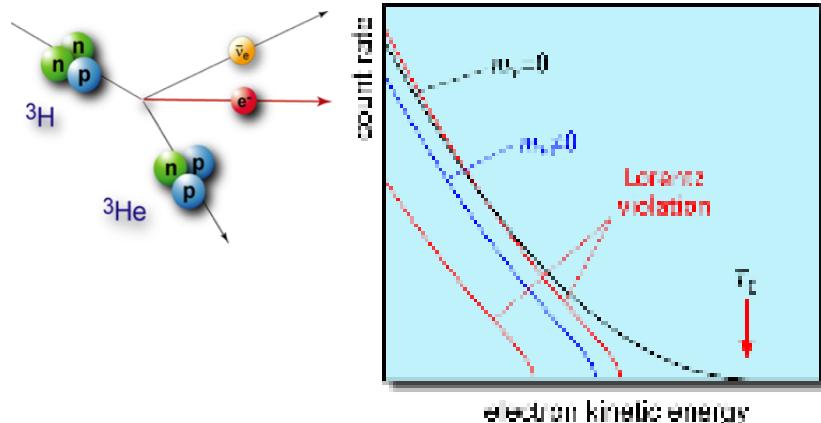
## Experimental searches:

- Neutrino oscillations
- Neutrino velocity (ToF)
- Weak decays

probe oscillation-free parameters

[review: Diaz (2014)]

## Tritium $\beta$ decay:



- Modified energy dependence of decay rate
- Spectral shape dependent on sidereal time and experiment orientation
- Effective dim-3 coefficient:  
osc. shift of endpoint  $T_{0,\text{eff}}$  with  $\omega_{\text{sidereal}}$
- Effective dim-2 coefficient:  
osc. of  $m^2$  parameter (can mimic tachyonic  $v$ )

[Diaz, Kostelecky, & Lehnert (2013)]