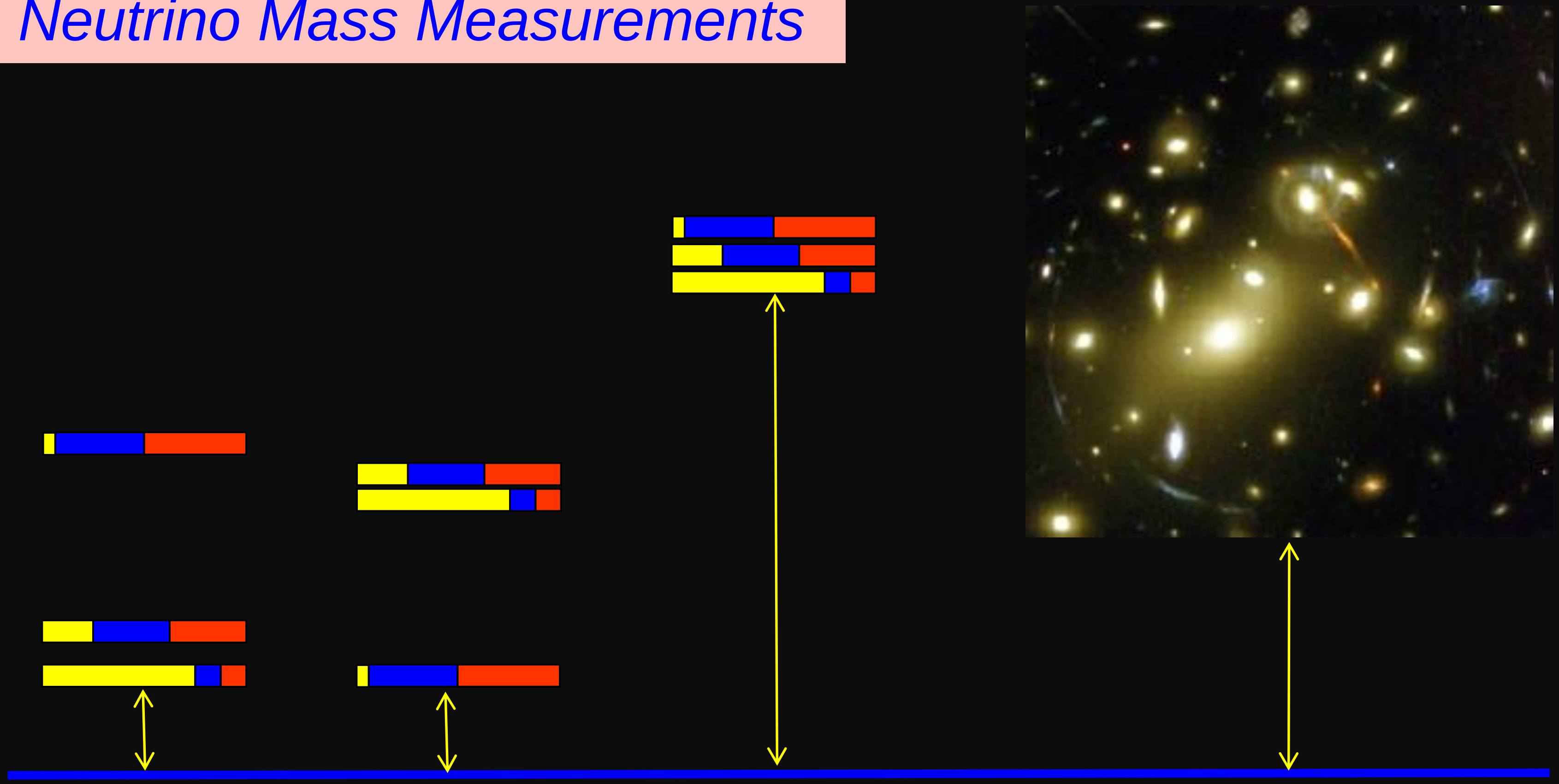
Neutrino Mass Measurements

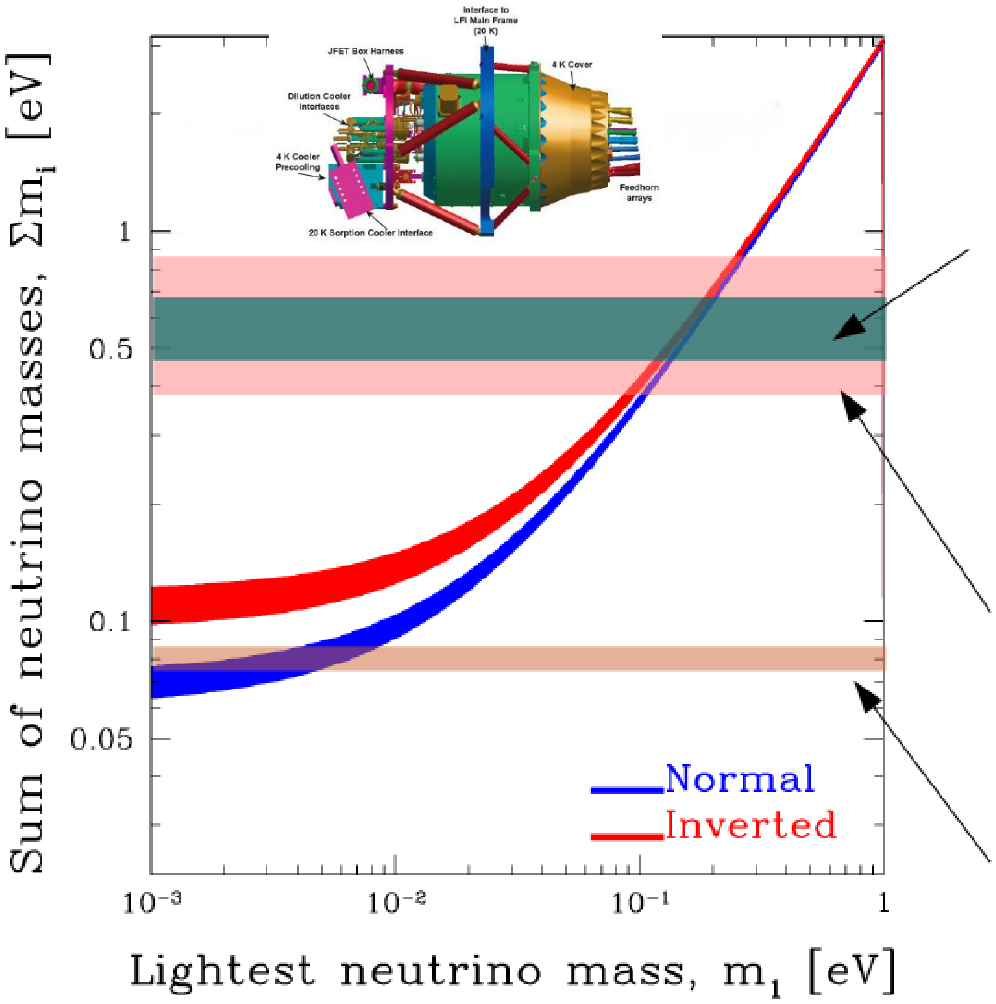


Particle Physics

Cosmology

What is the neutrino mass scale?

Present constraints and future sensitivities...



CMB (WMAP7+ACBAR+BICEP+QuaD)
+ LSS (SDSS-HPS)
+ HST+SNIa

$$\sum m_\nu < 0.44 \rightarrow 0.76\,\mathrm{eV} \quad (95\,\%\,\mathrm{CI})$$

depending on the model complexity

Hannestad, Mirizzi, Raffelt & Y^3W 2010
Gonzalez-Garcia et al. 2010, etc.

Planck alone (1 year)

$$\sum m_\nu < 0.38 \rightarrow 0.84\,\mathrm{eV} \quad (95\,\%\,\mathrm{CI})$$

Perotto et al. 2006

Planck+Weak lensing (LSST)

$$\sum m_\nu < 0.074 \rightarrow 0.086\,\mathrm{eV} \quad (95\,\%\,\mathrm{CI})$$

Hannestad, Tu & Y^3W 2006

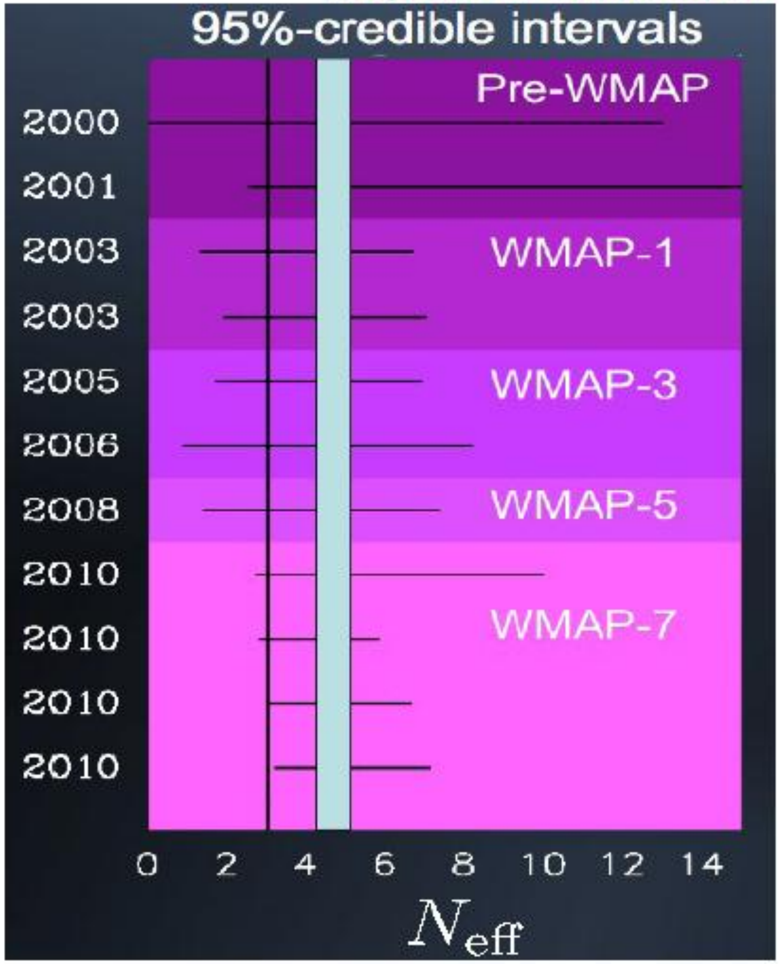
Recent hint for $N_{eff} > 3$ from precision cosmology...

- Parameterise excess relativistic energy density in terms of extra species of massless neutrinos.

$$\rho_\nu + \rho_X = \underline{N_{\text{eff}}} \left(\frac{7}{8} \frac{\pi^2}{15} T_\nu^4 \right)$$
$$= (3.046 + \Delta N_{\text{eff}}) \left(\frac{7}{8} \frac{\pi^2}{15} T_\nu^4 \right)$$

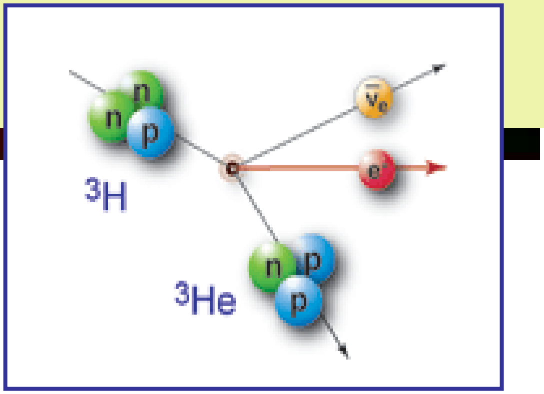
- **Evidence for $N_{eff} > 3$:**
  - @ 98.4% (CMB+LSS)
    Hou et al. 2011
  - @ 99.5% (CMB+LSS+BBN)
    Hamann et al. 2011

Adapted from S. Hannestad



Y.Y.Y. Wong

Neutrino mass from Beta Spectra



With flavor mixing:

$$\frac{dN}{dT} = \frac{G_F \cos\theta_C}{2\pi^3} |M_{\rm nuc}|^2 F(Z,T)(T+m)(T^2+2mT)^{1/2}(T_0-T)\sum_i |U_{ei}|^2 \left[(T_0-T)^2 - m_i^2\right]^{1/2}$$

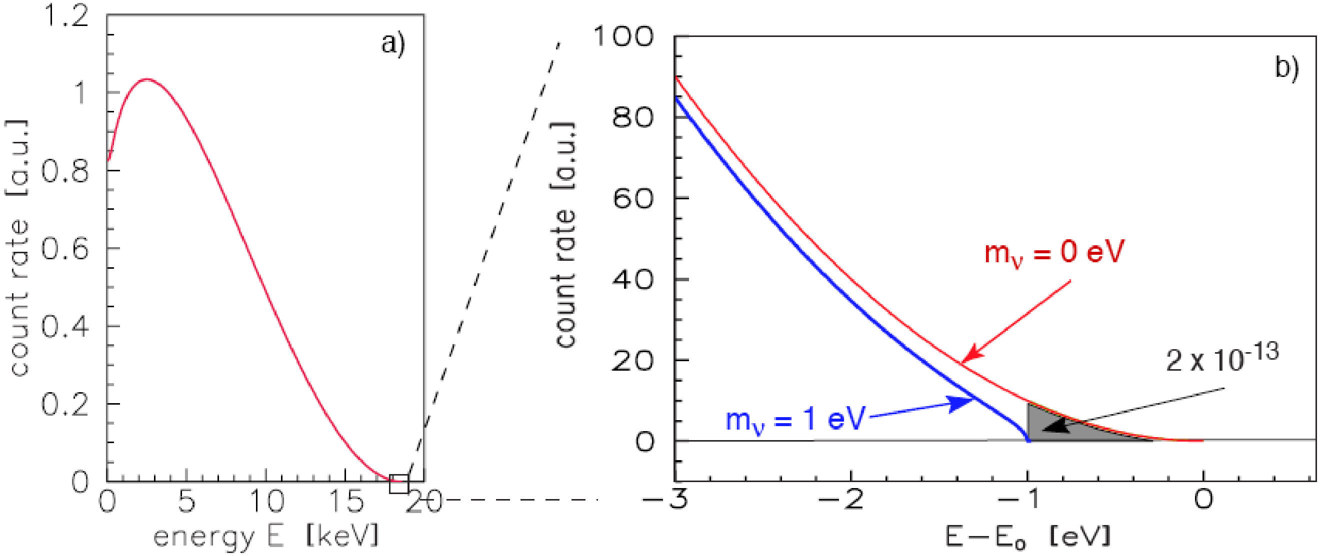
$$m_i^2 = \Delta m_{i0}^2 + m_0^2$$

mixing

neutrino masses

from oscillations

mass scale



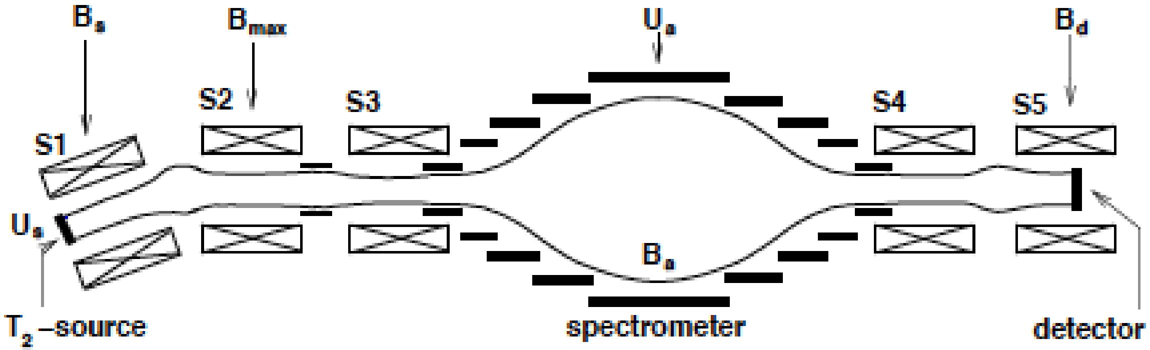
Current status of direct mass measurement

Mainz: solid T_2, MAC-E filter

C. Kraus et al., Eur. Phys. J. C40, 447 (2005)

$$m^2(\nu_e) = (-0.6 \pm 2.2_{\text{stat}} \pm 2.1_{\text{syst}})$$

$$m(\nu_e) < 2.3\ \text{eV}/c^2 \quad (95\%\ \text{C.L.})$$

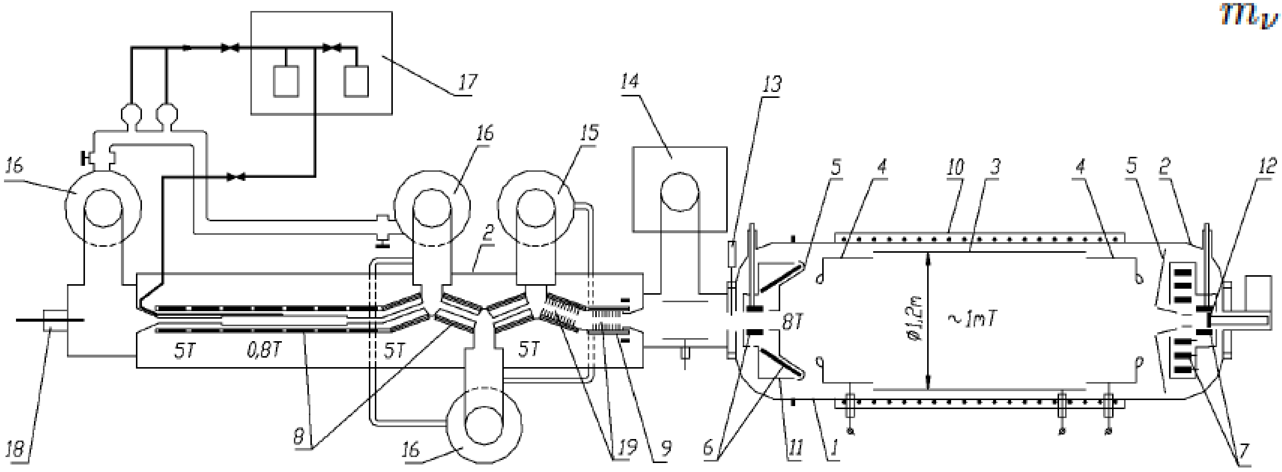


Troitsk: gaseousT$_2$, MAC-E filter

V. Aseev et al., PRD in press (2011)

$$m_\nu^2 = -0.67 \pm 1.89_{stat} \pm 1.68_{syst}$$

$$m_\nu < 2.05\ eV,\ 95\%\ C.L.$$



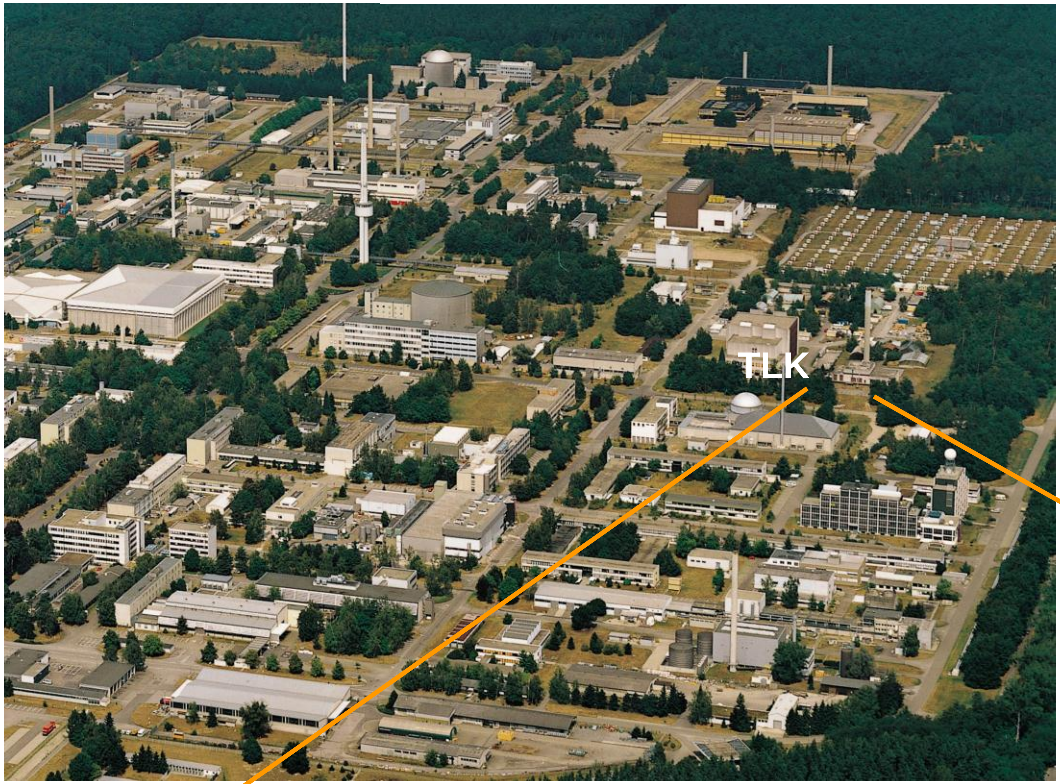
Together:…

$m_\nu < 1.8$ eV

(95% CL)

KATRIN

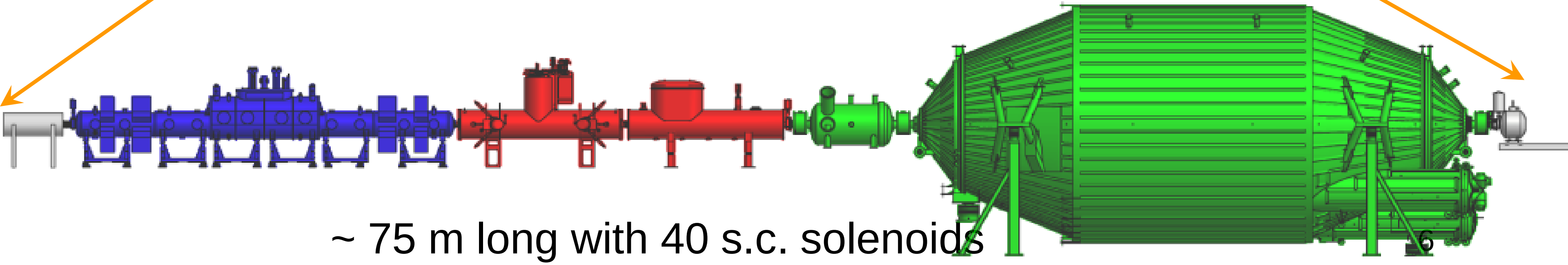
At Karlsruhe Institute of Technology
unique facility for closed T_2 cycle:
Tritium Laboratory Karlsruhe



Size of experiment now:
Diameter 10 m.

$$\sigma(m_\nu^2) = k\frac{b^{1/6}}{r^{2/3}t^{1/2}},$$

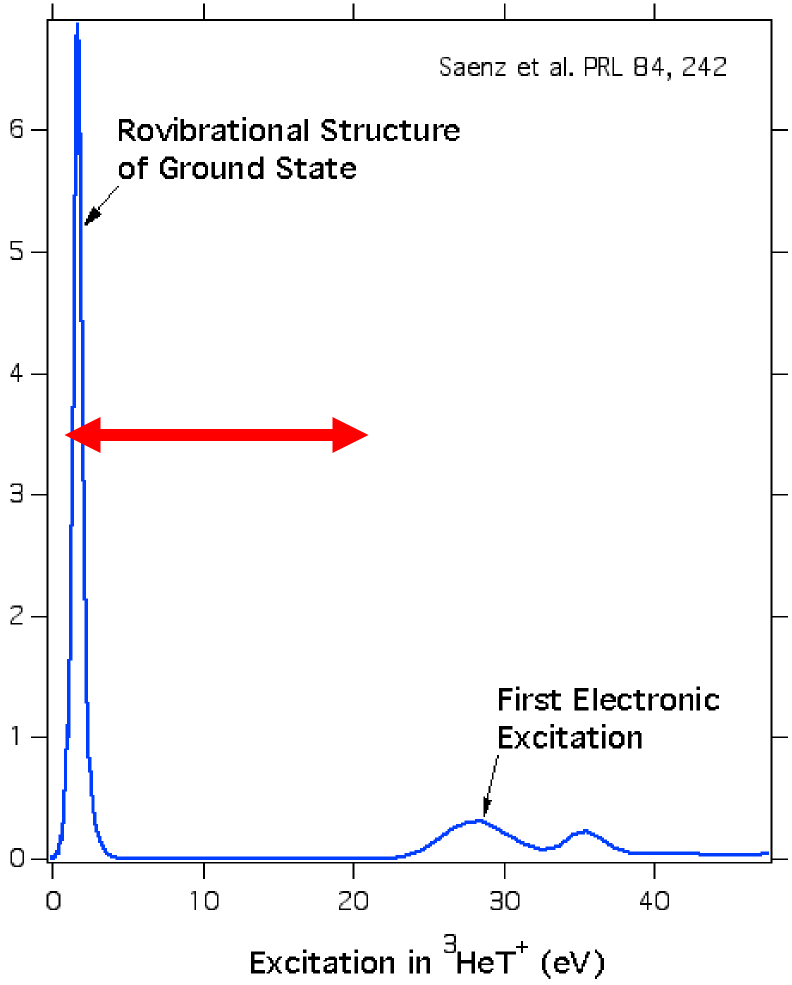
Next diameter: 300 m!



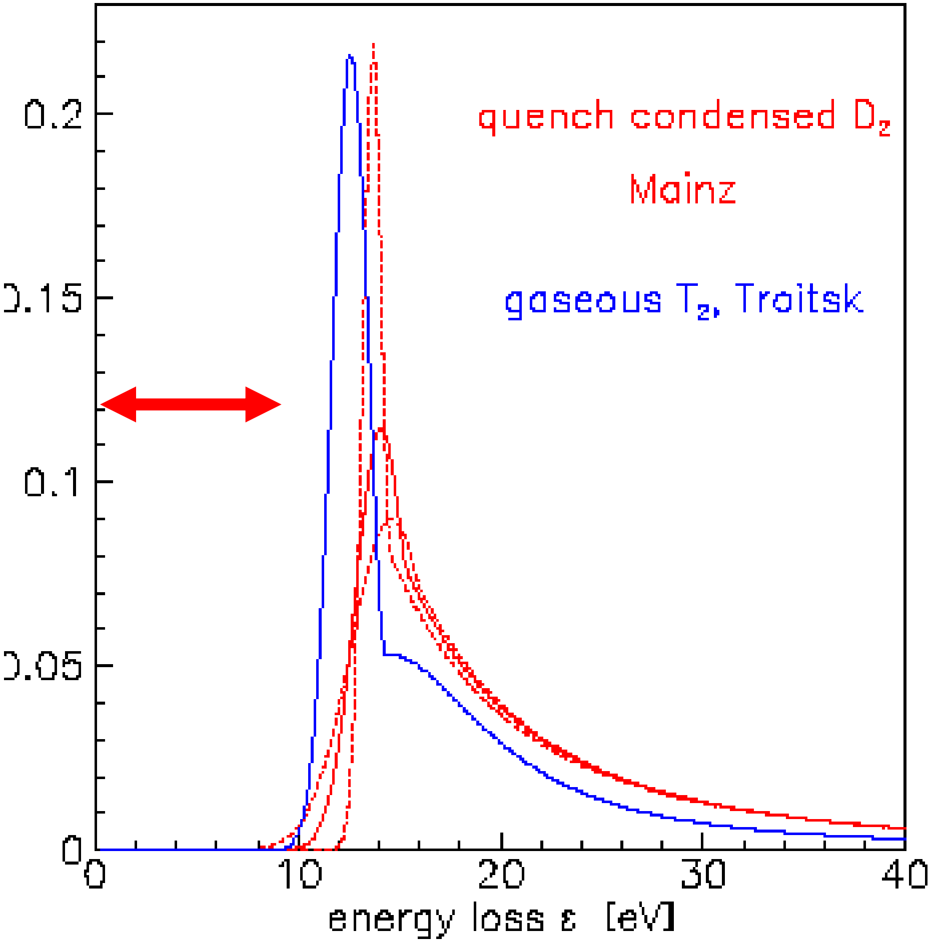
~ 75 m long with 40 s.c. solenoids

A window to work in

Molecular Excitations


Saenz et al. PRL 84, 242

Energy loss function



A window to work in

Molecular Excitations

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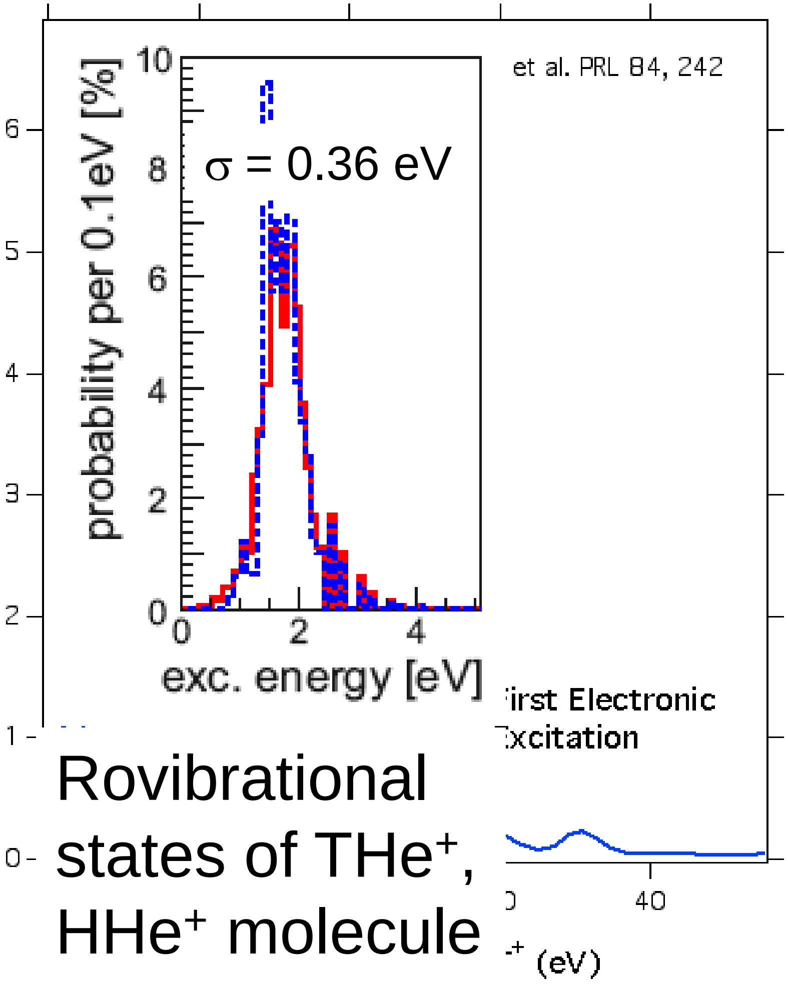
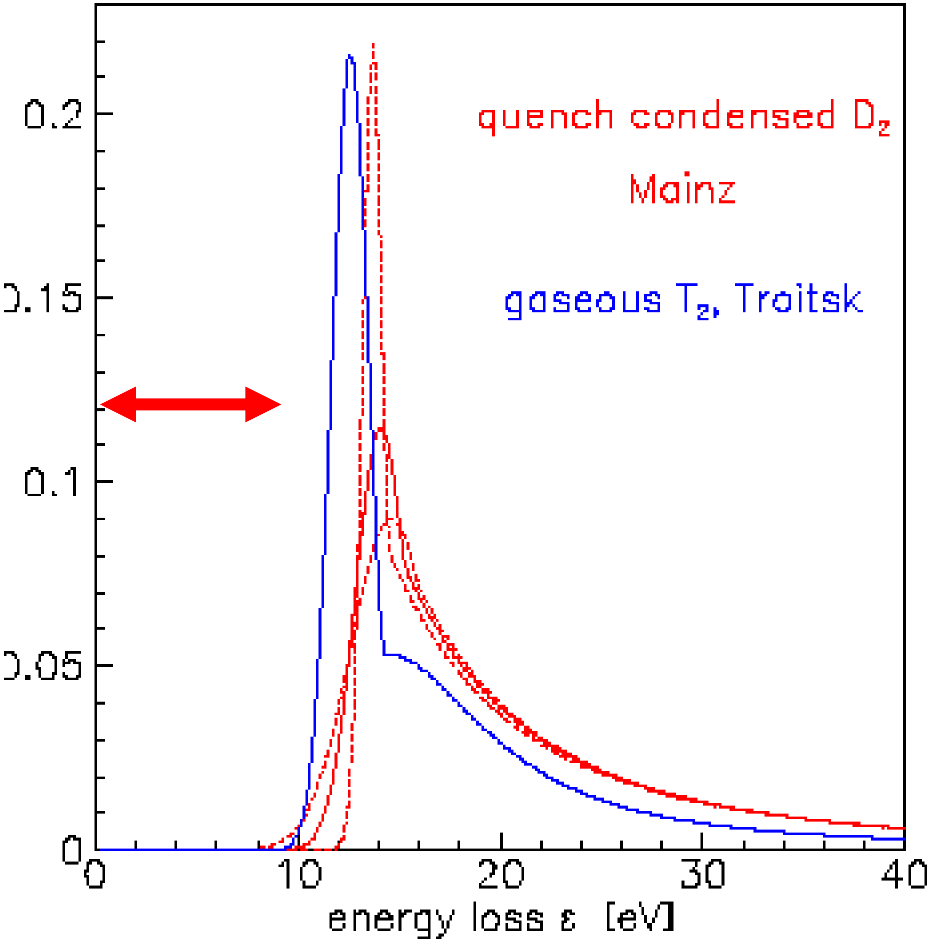
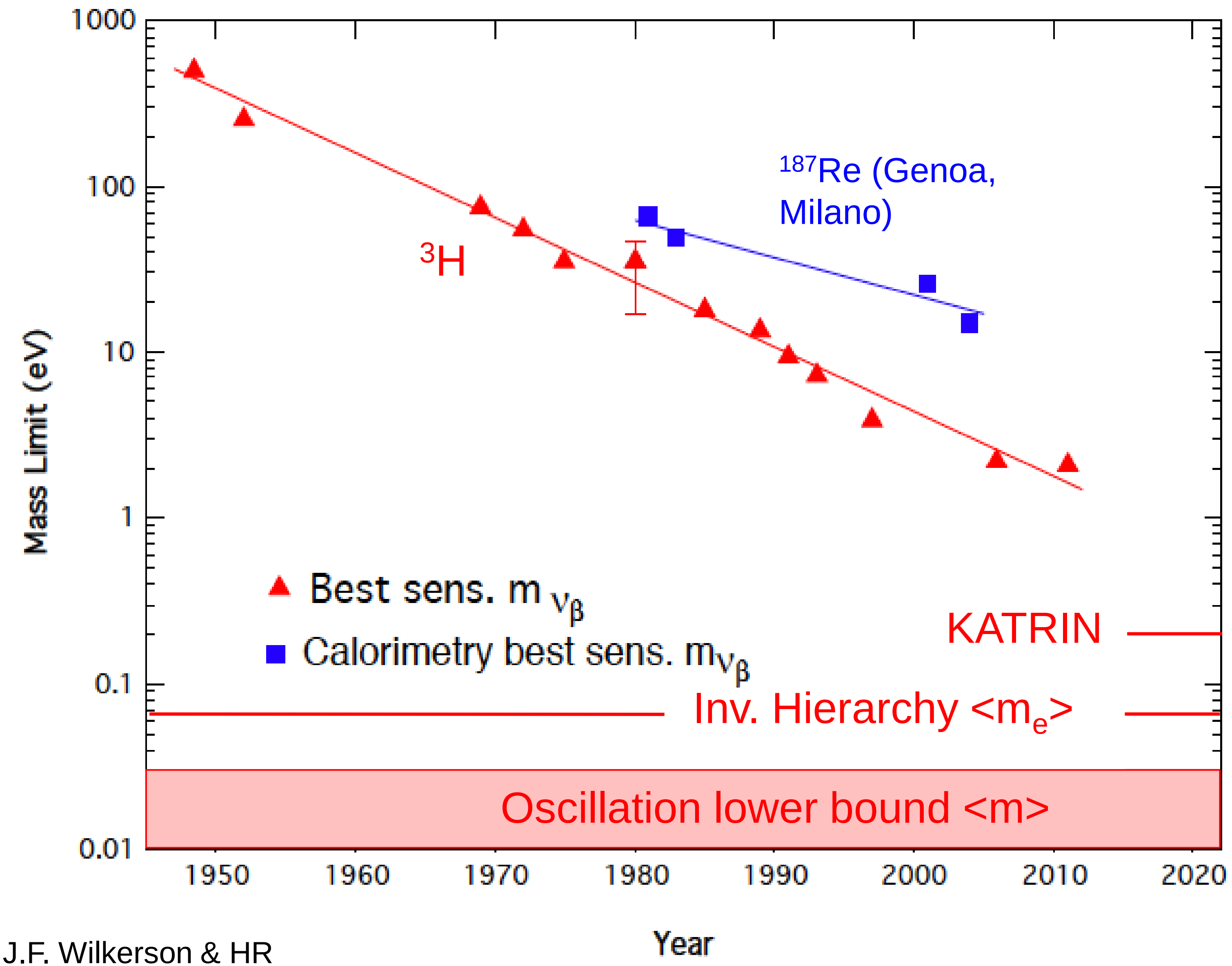


Rovibrational states of THe^+, HHe^+ molecule



Neutrino Mass Limits from β decay



J.F. Wilkerson & HR

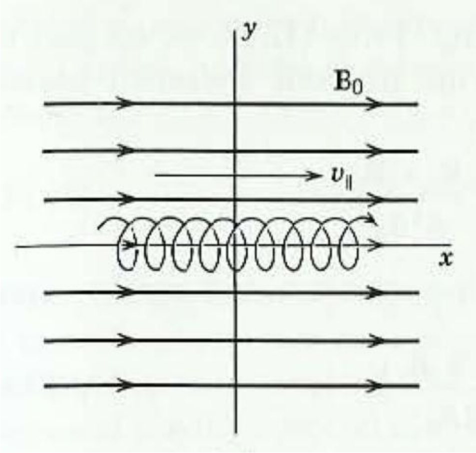
PROJECT 8

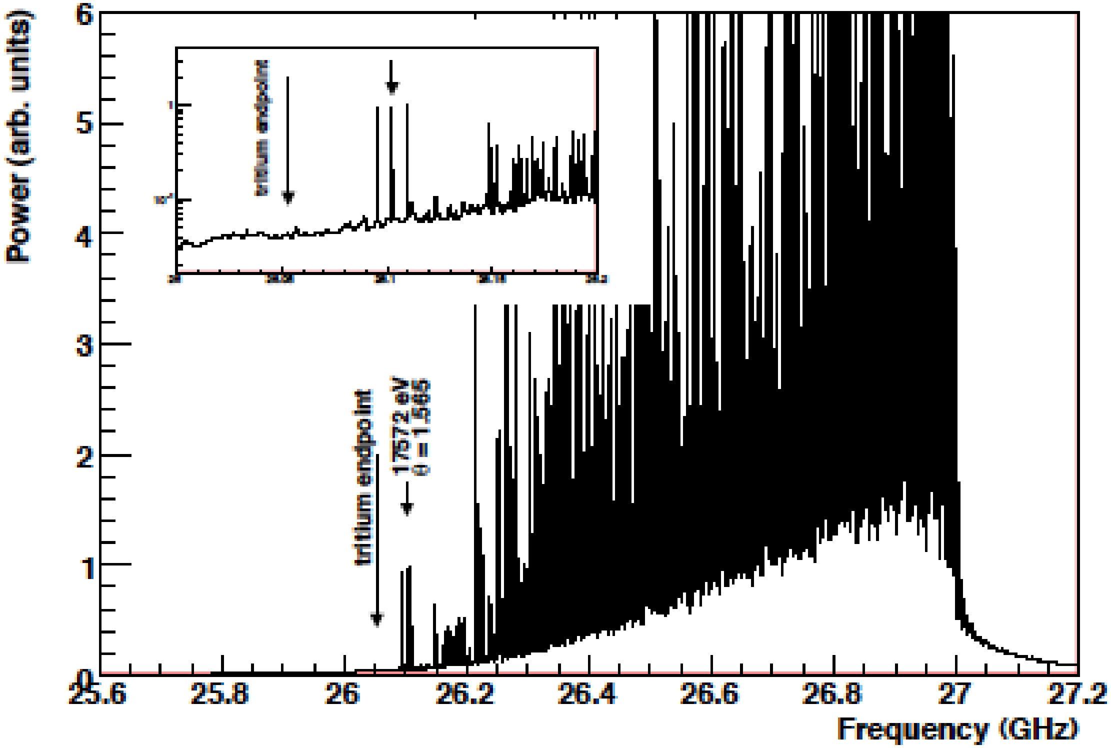
Cyclotron radiation from tritium beta decay

(B. Monreal and J. Formaggio, PRD 80:051301, 2009)

$$\omega = \frac{qB}{\gamma m} \equiv \frac{\omega_c}{\gamma}$$

$$\omega_c = 1.758820150(44) \times 10^{11}\ \mathrm{rad/s/T}$$

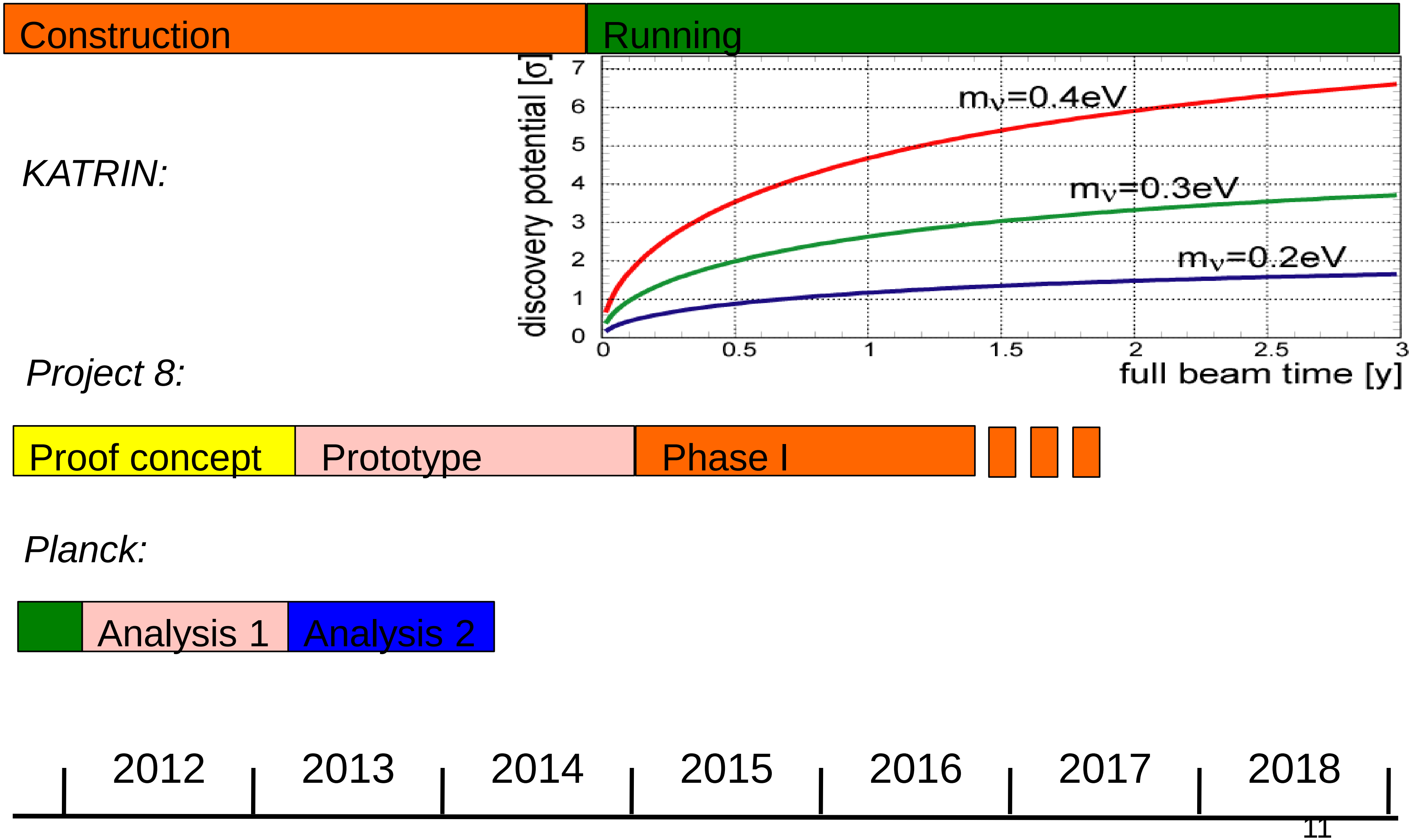




Radiated power ~ 1 fW

Parameter	Value	Unit
Electron energy	18.6	keV
β	0.2627	
γ	1.0364	
Field	1	T
ω_c	27.009	GHz

Neutrino mass: some milestones



KATRIN:

Construction

Running

Project 8:

Proof concept

Prototype

Phase I

Planck:

Analysis 1

Analysis 2