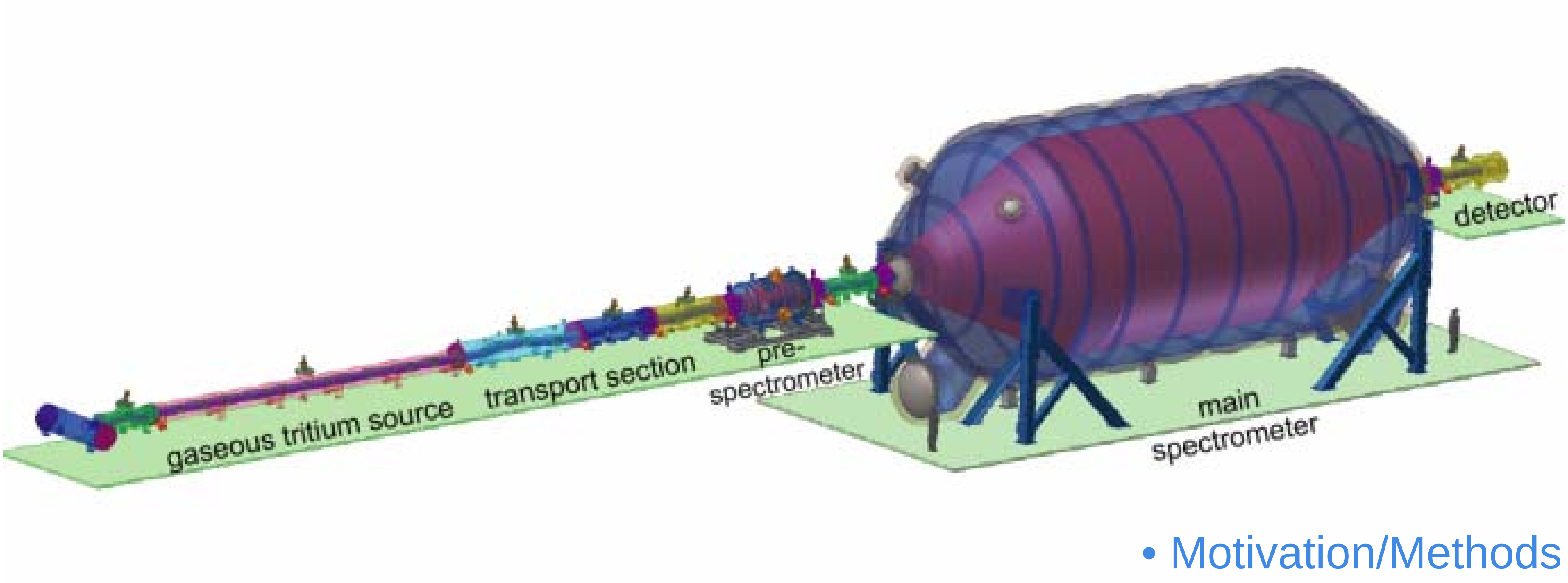
Direct Determination of Neutrino Mass with KATRIN

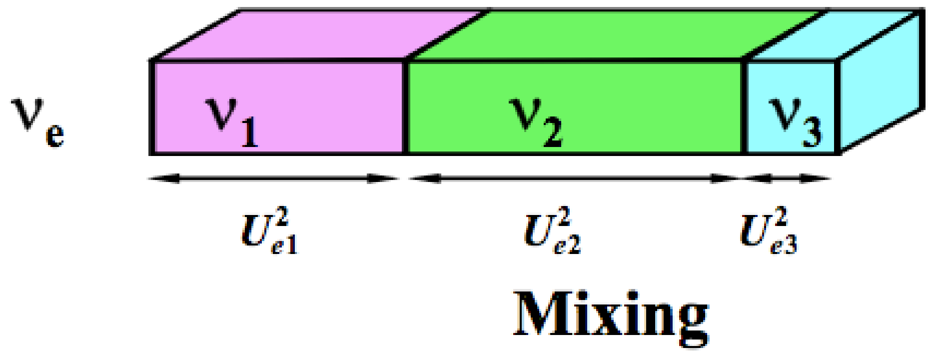


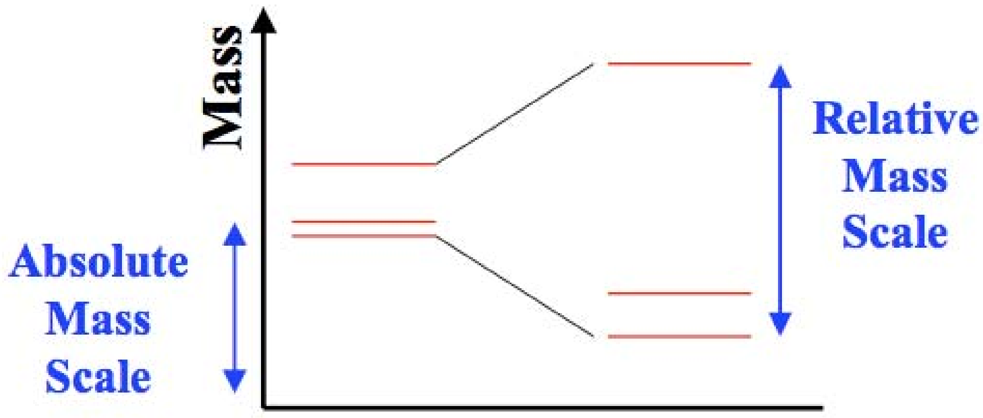
Keith Rielage, University of Washington, for the KATRIN Collaboration

- Motivation/Methods
- Previous β-decay exp.
- KATRIN
- Conclusions

Current Theory

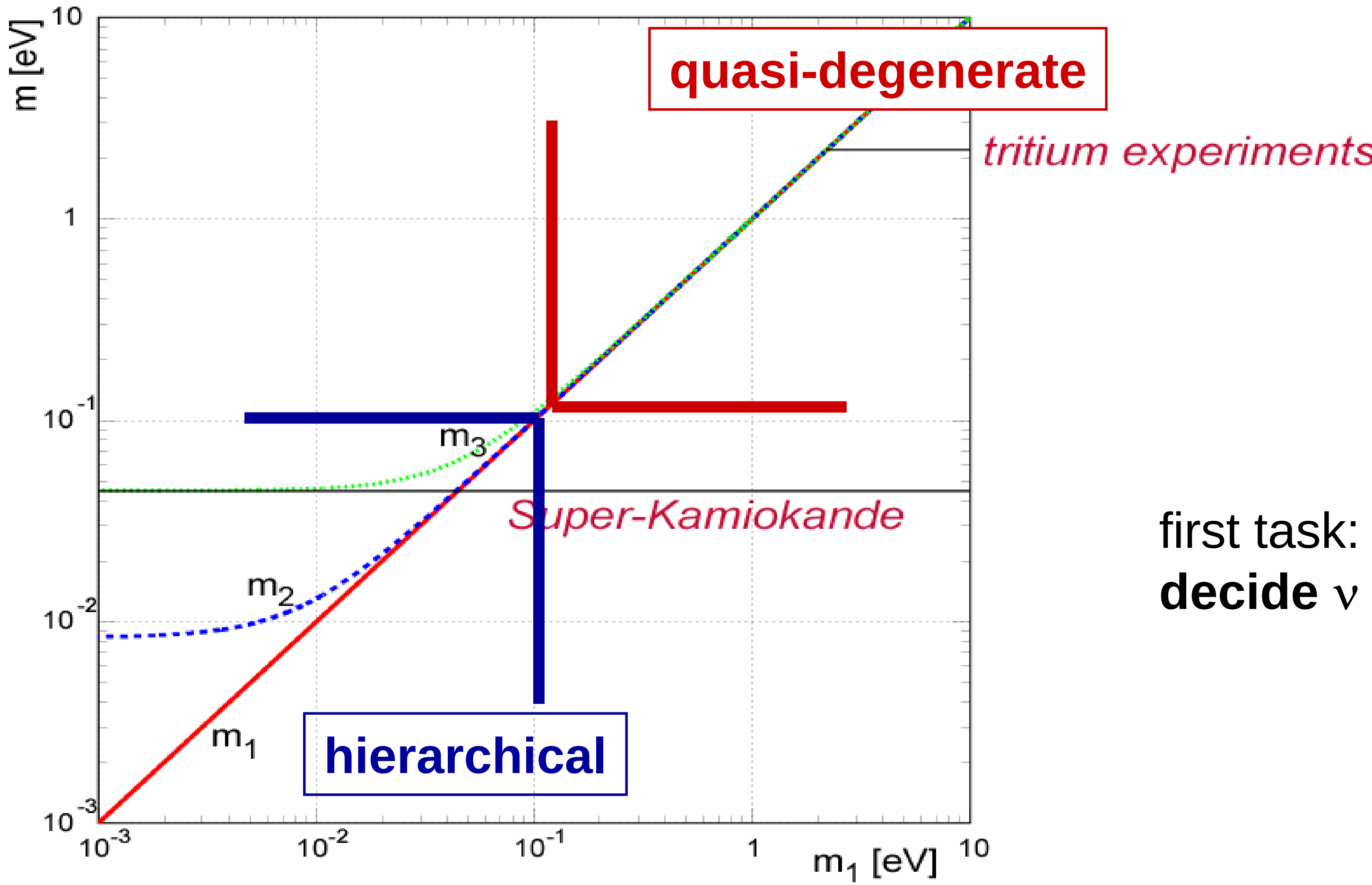
- Neutrino flavors a mix of three mass eigenstates
- Know the relative mass scale
- What is the absolute mass scale?
- What is the order of masses?





Neutrino Masses and Schemes

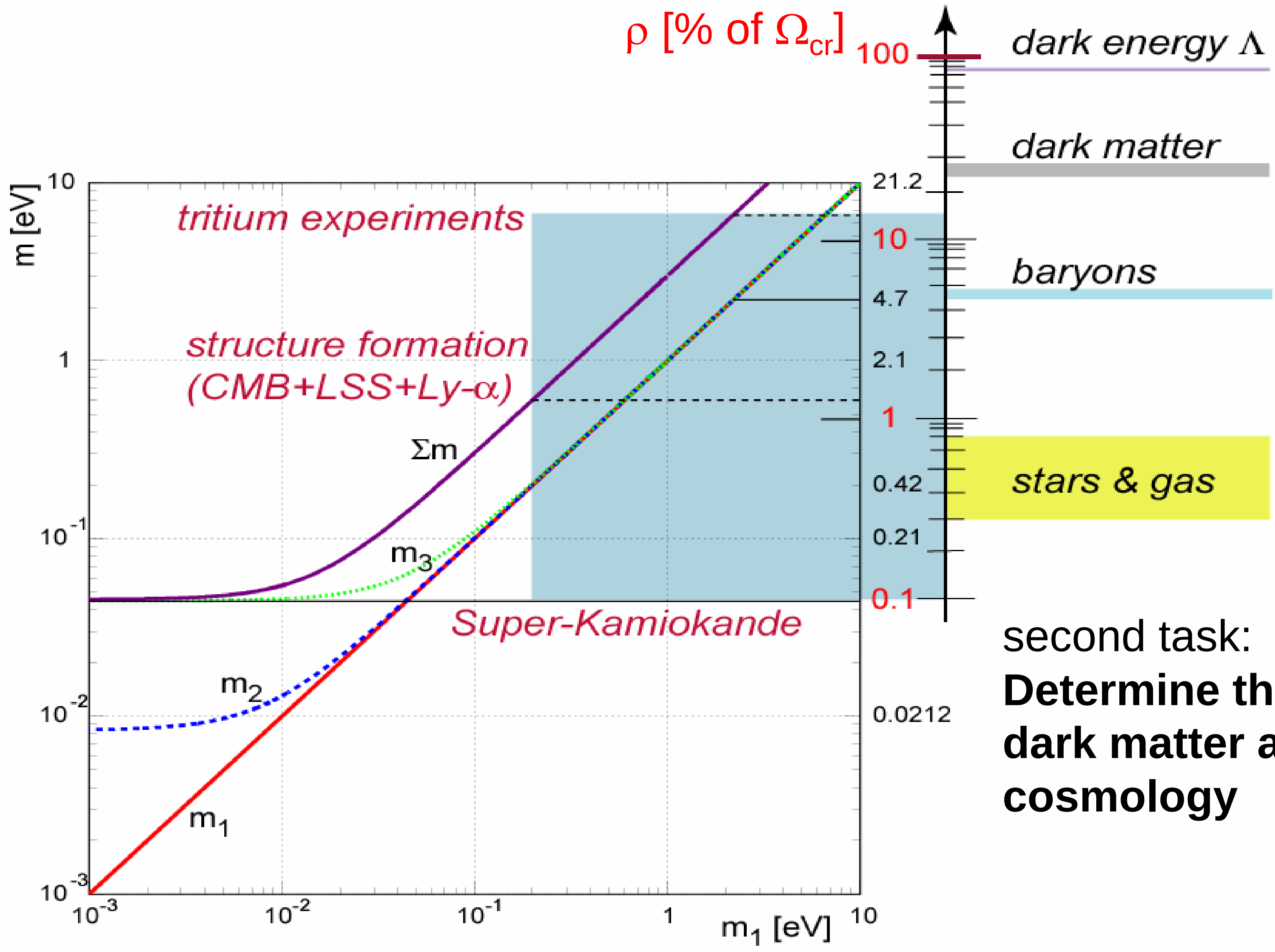
„normal“ mass hierarchy $m_1<m_2<m_3$



first task:

decide ν mass scenario

Neutrino Masses and Cosmology

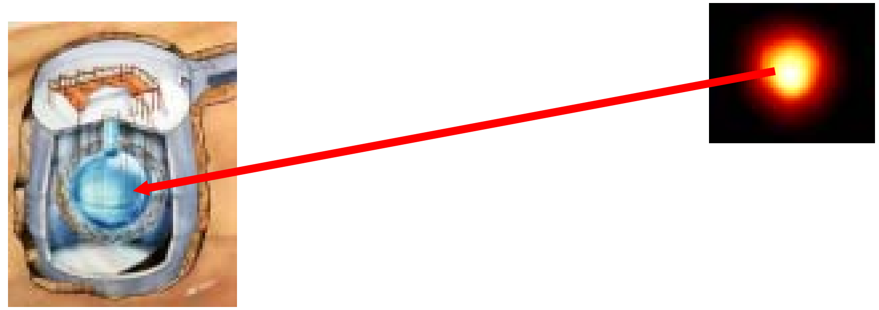


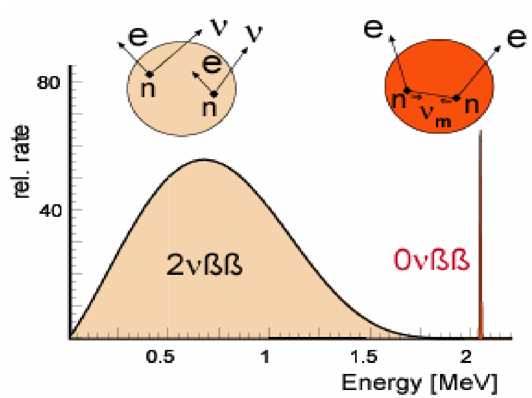
second task:

Determine the ν role as hot dark matter and impact on cosmology

Measurement Methods

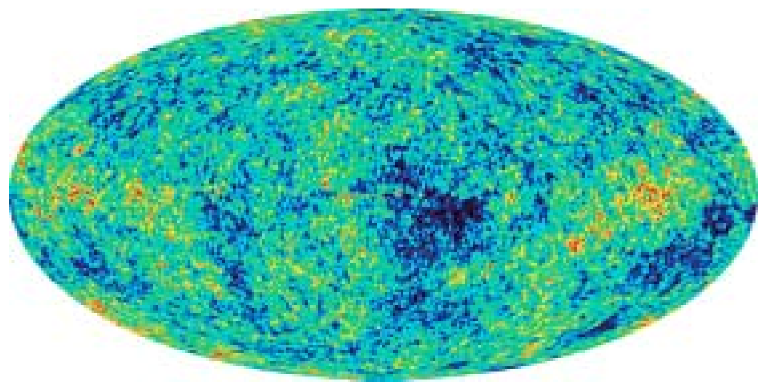
<u>Flavor change/oscillation</u>:
- Solar, atmospheric, reactor, supernova ν's
- ex. SNO, SuperK, KamLand



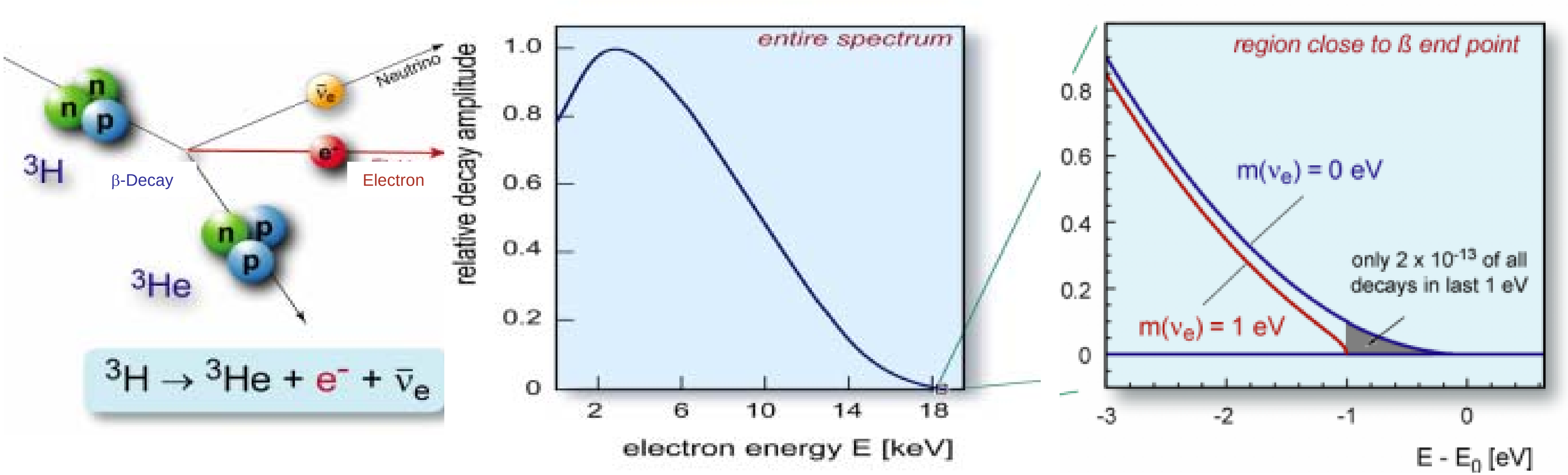


<u>0νββ-decay</u> → $<m_\nu>$:
- ex. Heidelberg-Moscow, Cuoricino
- Majorana particle

<u>Cosmology</u> → Σm_ν:
- CMBR + LSS
- Model dependent
- ex. WMAP, 2dF, SDSS



Direct Kinematics - Beta Decay



- Tritium provides:
  - "simple" structure
  - Low endpoint energy
  - Moderate half-life (12.3 years)
  - Super allowed transition
  - Availability

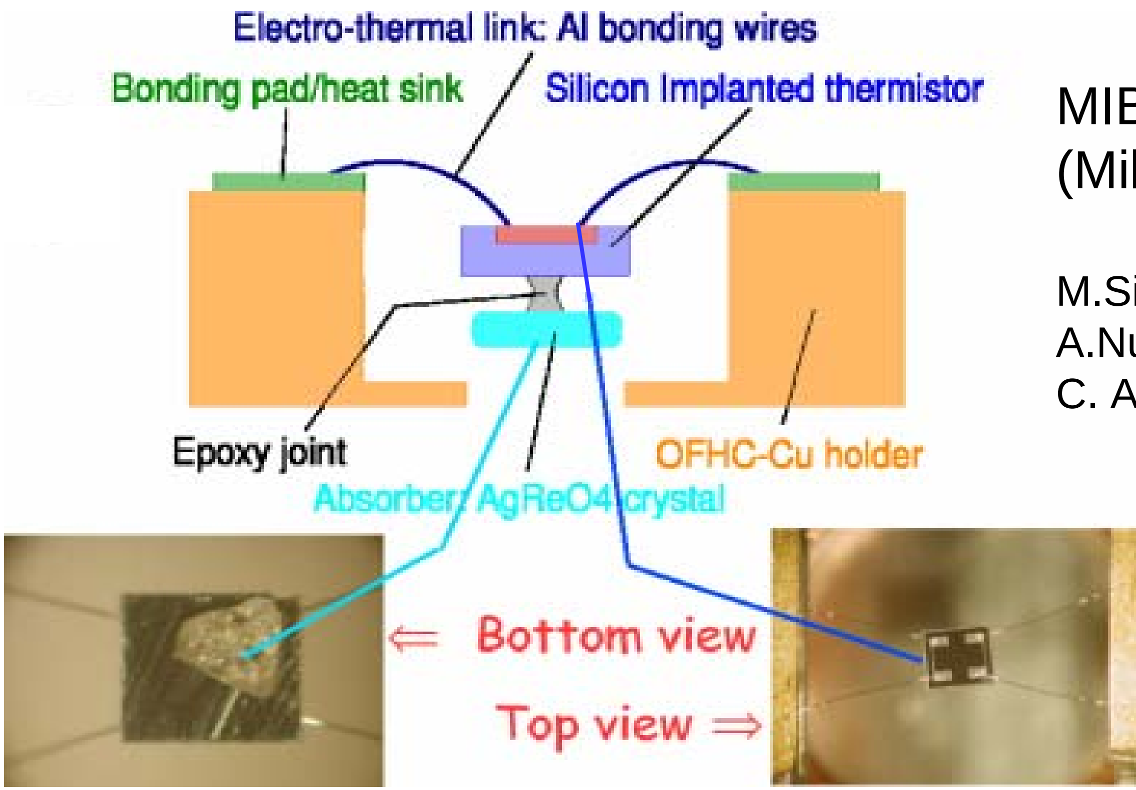
But also . . .

μ calorimeters for ^{187}Re β decay

$$^{187}\mathrm{Re} \longrightarrow {}^{187}\mathrm{Os} + e^- + \overline{\nu}_e$$

E_0 = 2.46 keV

neutrino mass measurement with array of 10 $AgReO_4$ crystals
→ lower pile up
→ higher statistics



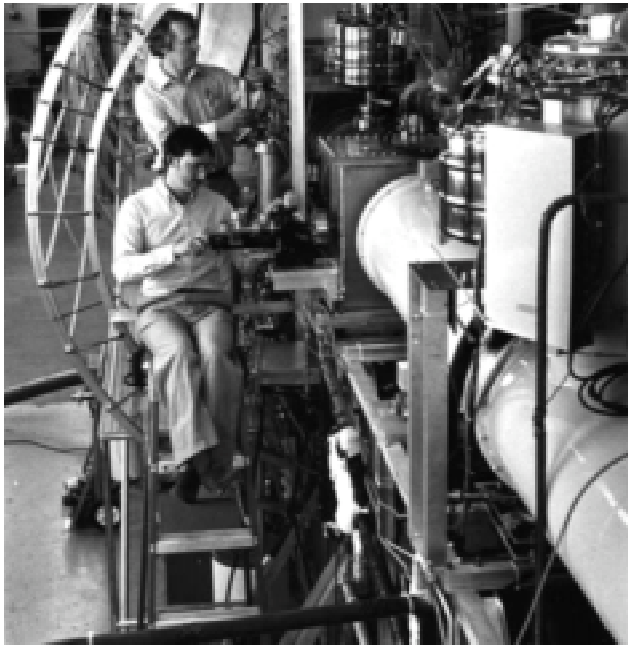
T_{op} ~ 70-100mK

MIBETA experiment
(Milano, Como, Trento)

M.Sisti *et al*, NIM A520(2004)125
A.Nucciotti *et al*, NIM A520(2004)148
C. Arnaboldi *et al*, PRL 91, 16802 (2003)

m_ν < 15eV

Tritium Beta Decay Lessons



- Los Alamos -- first to use T_2 gas
- Mainz & Troitsk -- used MAC-E spectrometer, improved systematics

Principle of MAC-E Filter

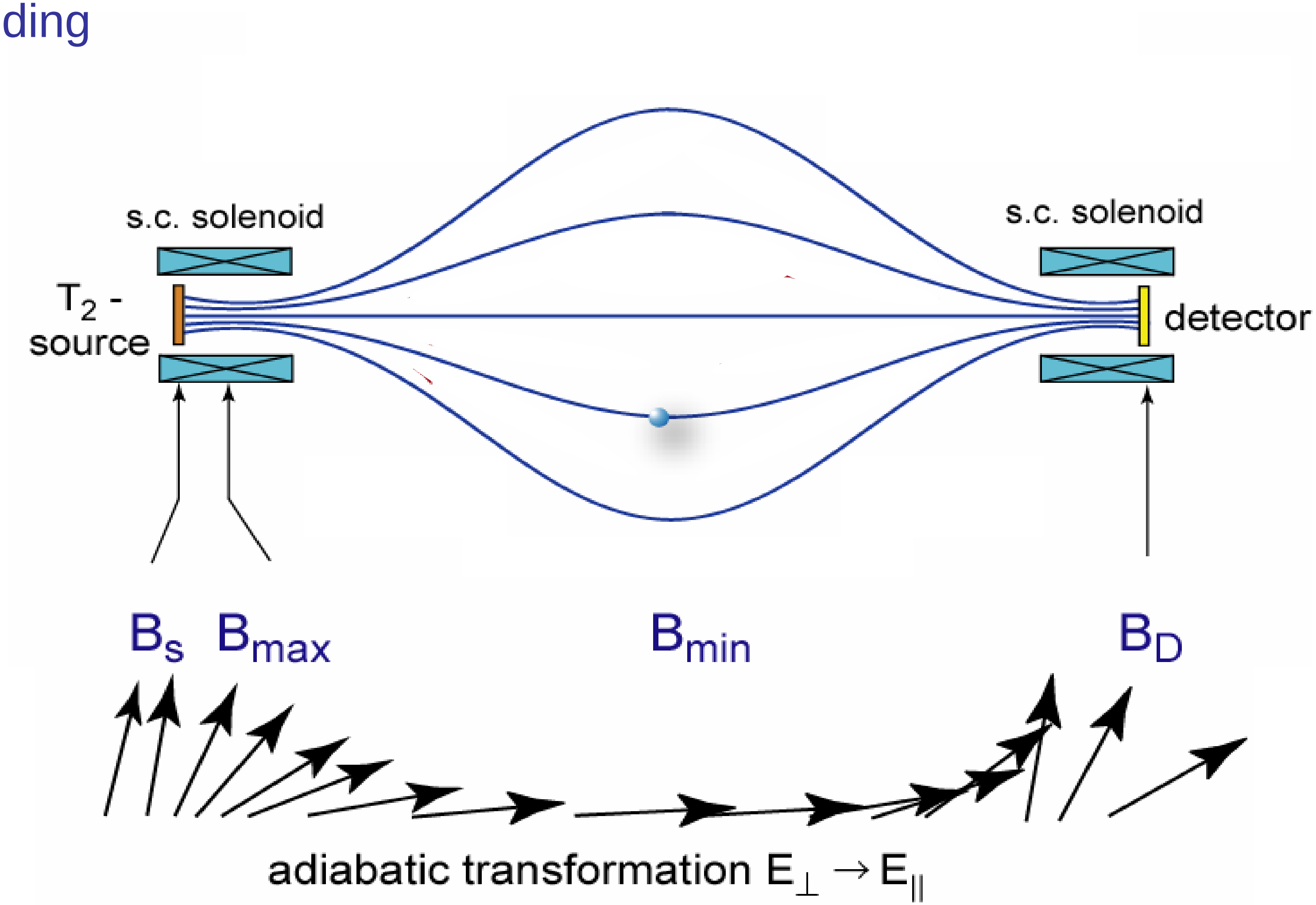
Adiabatic magnetic guiding of β´s along field lines in stray B-field of s.c. solenoids:

B_{max} = 6 T

B_{min} = 3×10^{-4} T

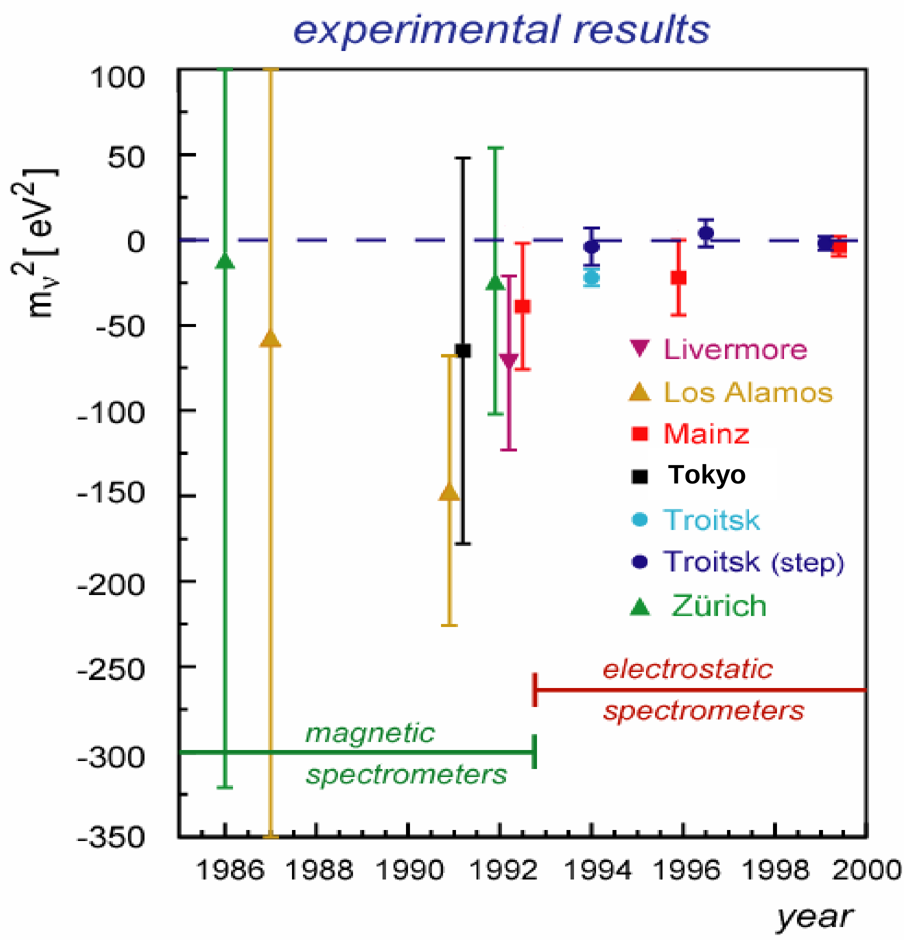
Energy analysis by static retarding E-field with varying strength:

High pass filter with integral β transmission for E>qU

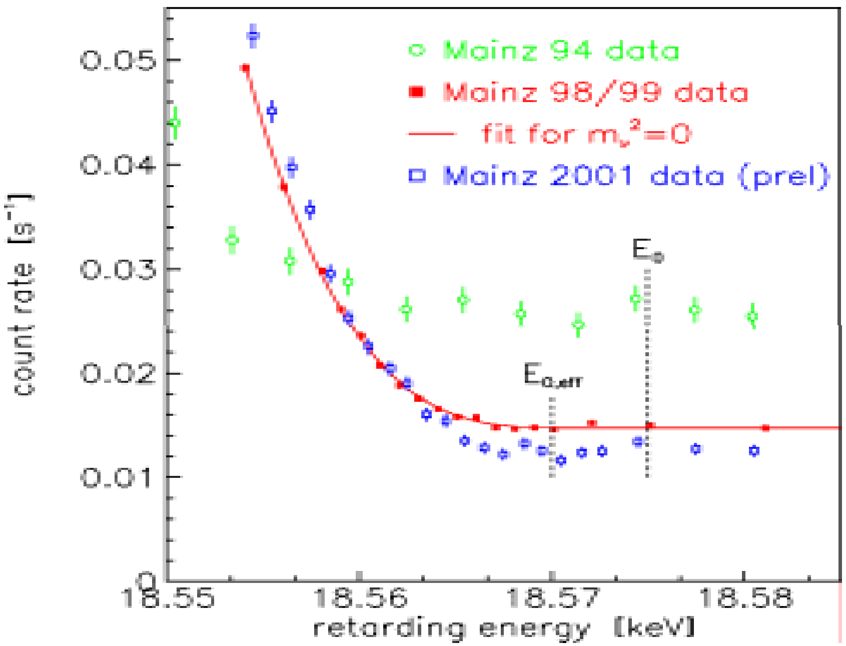


Previous Beta Decay Results

	m_ν
ITEP *T_2 in complex molecule* *magn. spectrometer (Tret'yakov)*	17-40 eV
Los Alamos *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 9.3 eV
Tokyo *T - source* *magn. spectrometer (Tret'yakov)*	< 13.1 eV
Livermore *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 7.0 eV
Zürich *T_2 - source impl. on carrier* *magn. spectrometer (Tret'yakov)*	< 11.7 eV
Troitsk (1994-today) *gaseous T_2 - source* *electrostat. spectrometer*	< 2.2 eV
Mainz (1994-today) *frozen T_2 - source* *electrostat. spectrometer*	< 2.2 eV



Results from MAINZ



- frozen T_2 on graphite
- T=1.86K
- A=2cm^2
- 20mCi activity
- spectr.: l=2m, Ø=0.9m
- ΔE=4.8eV

1994-2001 improvements in systematics:

- roughening of T_2 film
- inelastic scattering
- self charging of T_2 film

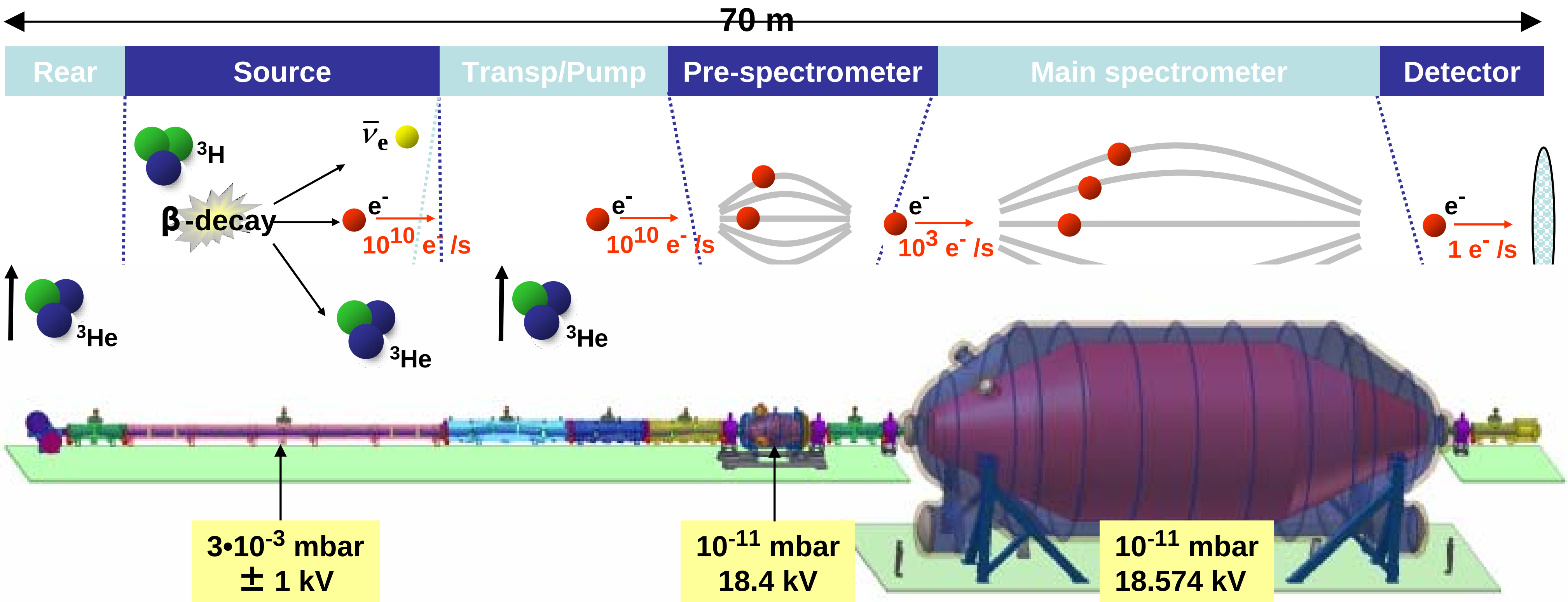
Goal: Improvement of 10x

- Strong source
  - 5×10^{17} molecules/cm^2 column density
- High source purity
  - 95%
- Long term stability
- Excellent energy resolution
  - $\Delta E < 1$ eV
- Low Background rate
  - < 10 mHz total in endpoint region

KATRIN Task:
Investigate Tritium endpoint with sub-eV precision!!

KATRIN Aim:
Improvement of m_ν by x 10 (2eV → 0.2eV)

Experimental Set-up



Rear System:
Monitor source parameters

Source:
Provide the required tritium column density

Transp. & Pump. system:
Transport the electrons, adibatically and reduce the tritium density significantly

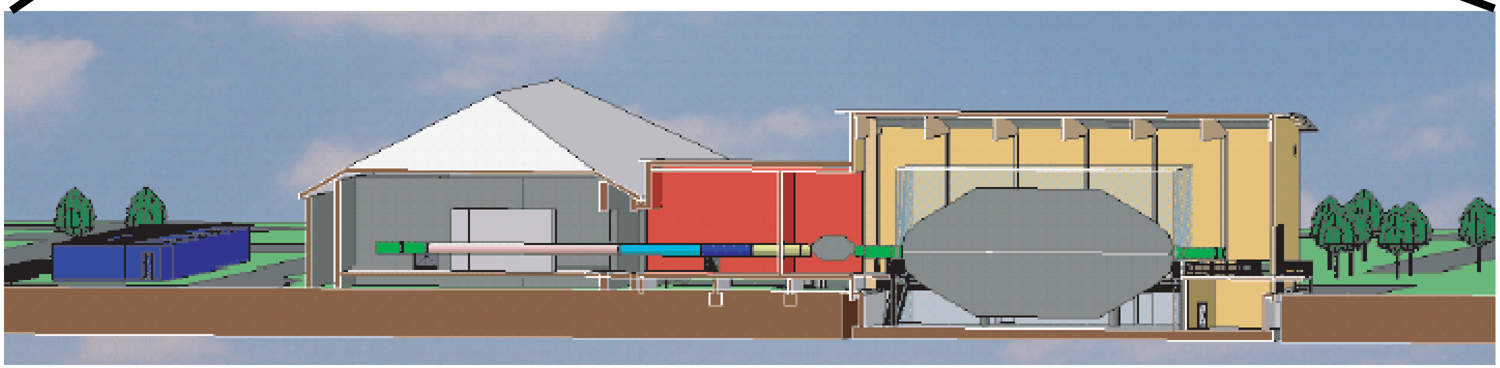
Pre-spectrometer:
Rejection of low energetic electrons and adiabatic guiding of electrons

Main-spectrometer:
Rejection of electrons below endpoint and adiabatic guiding of electrons

Detector:
Count electrons and measure their energy

KATRIN at Forschungszentrum Karlsruhe (FZK)

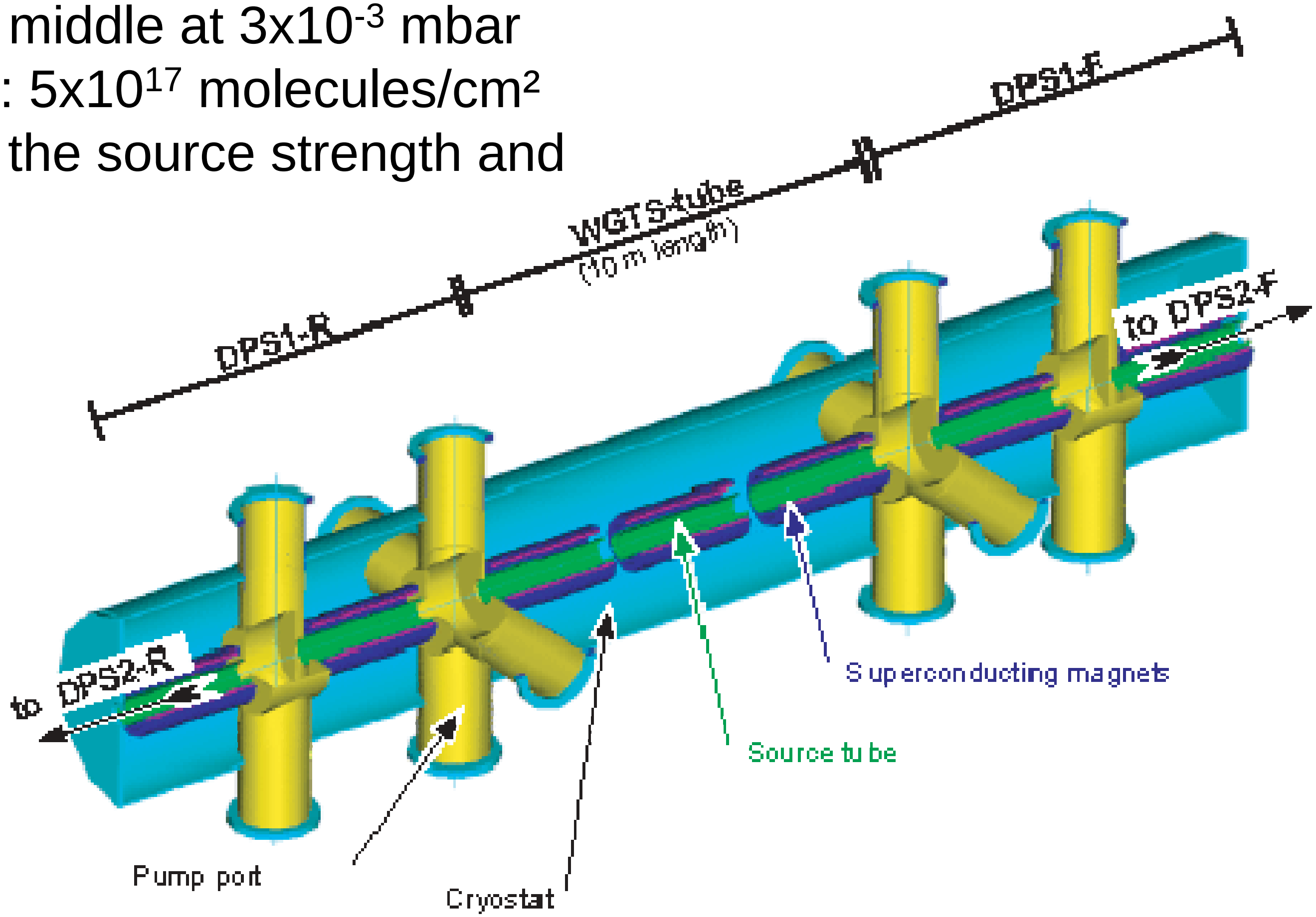
- TLK (part of FZK) is the only lab worldwide with a closed tritium cycle
- Built to demonstrate the fuel cycle for fusion (ITER)
- Provides all the necessary infrastructure for processing
- Licensed amount of 40 g, current inventory 25 g



Tritium Source

Windowless Gaseous Tritium Source (WGTS)

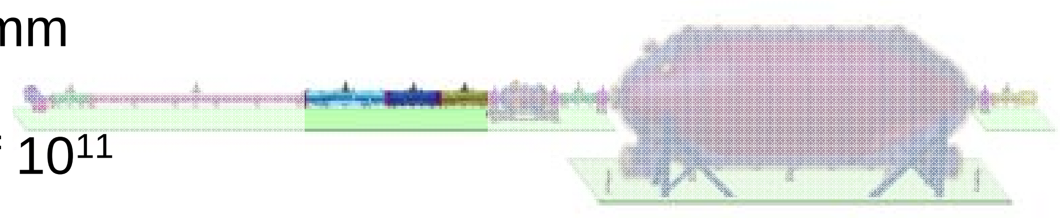
- Tritium injection in the middle at 3×10^{-3} mbar
- Target column density: 5×10^{17} molecules/cm²
- Rear system monitors the source strength and purity
- Contained within TLK

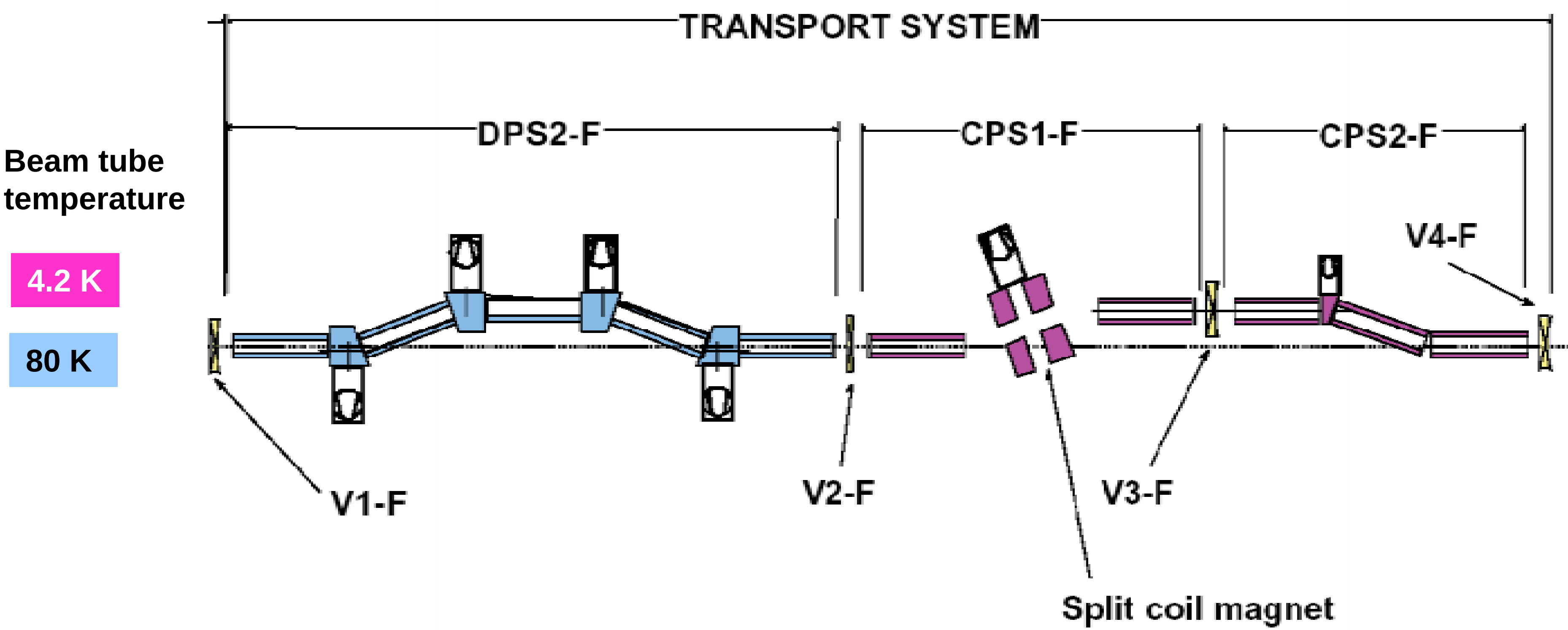


Transport Section

Transport Section:

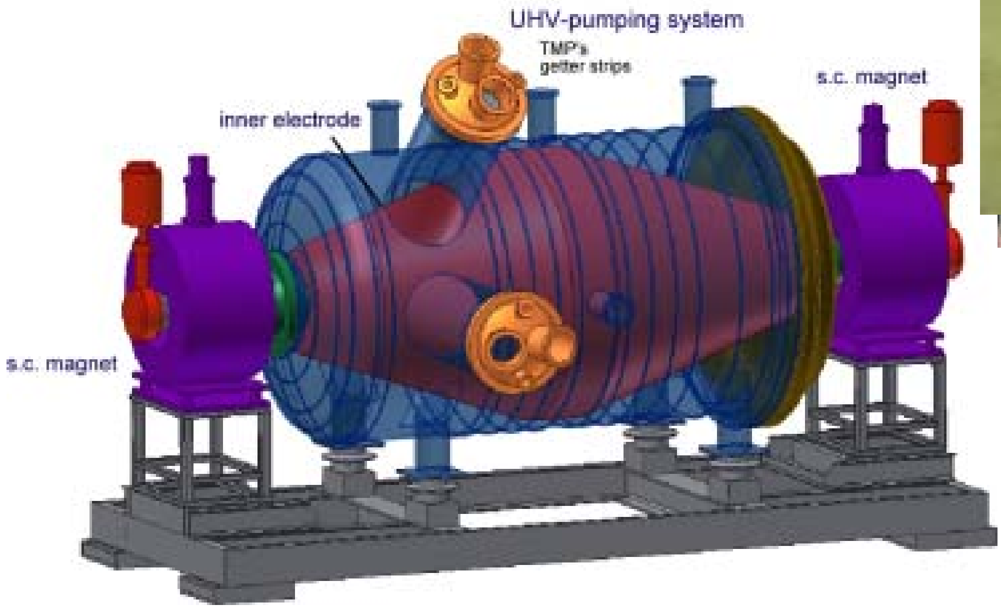
- Beam tube sections, L= 1 m, d=75 mm
- Differential Pumping Section (DPS)
- Total reduction in tritium by factor of 10^{11}
- Cryogenic Pumping Section (CPS)
- Cryotrapping at 4.2 K by charcoal or Argon frost





Pre-Spectrometer

Parameters:
- Length: 3.4 m (flange to flange)
- Diameter:1.7 m
- Vacuum: < 10^{-11} mbar
- Material: Stainless steel
- Magnets: 4.5 T



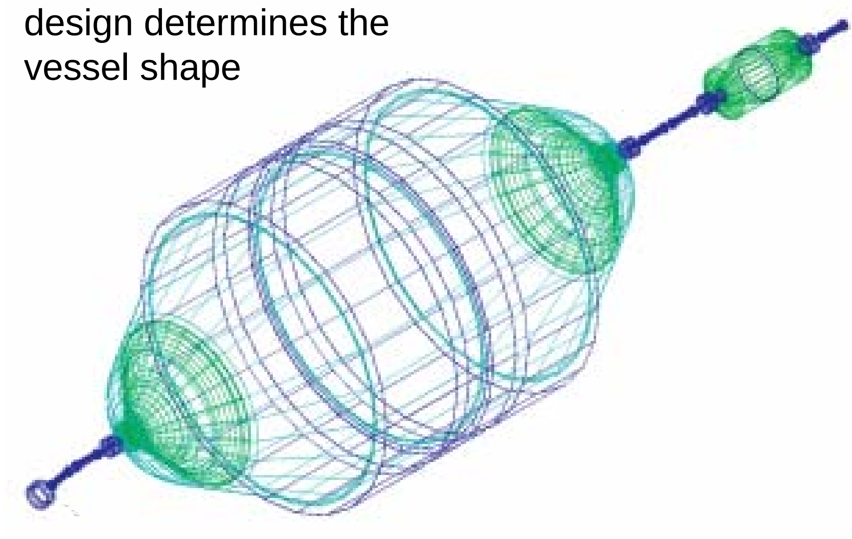
Status:
- Vacuum $7 \cdot 10^{-11}$ mbar (without getter)
- Outgassing $7 \cdot 10^{-14}$ mbar l/ s cm^2
- Measurements scheduled for Fall 2005

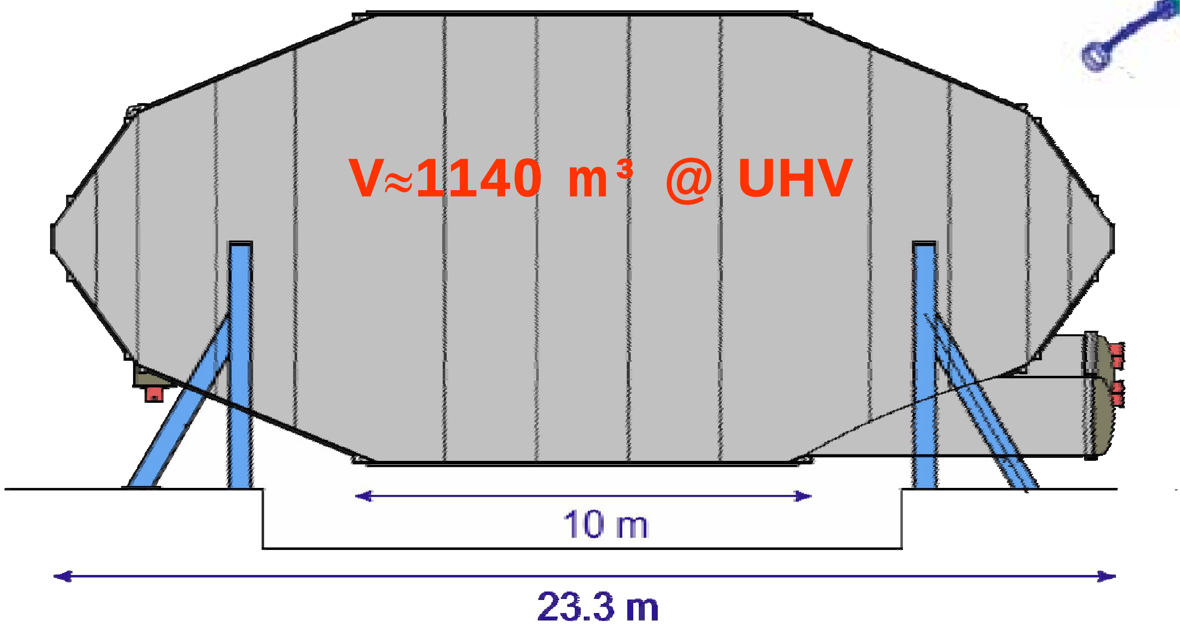
Main Spectrometer

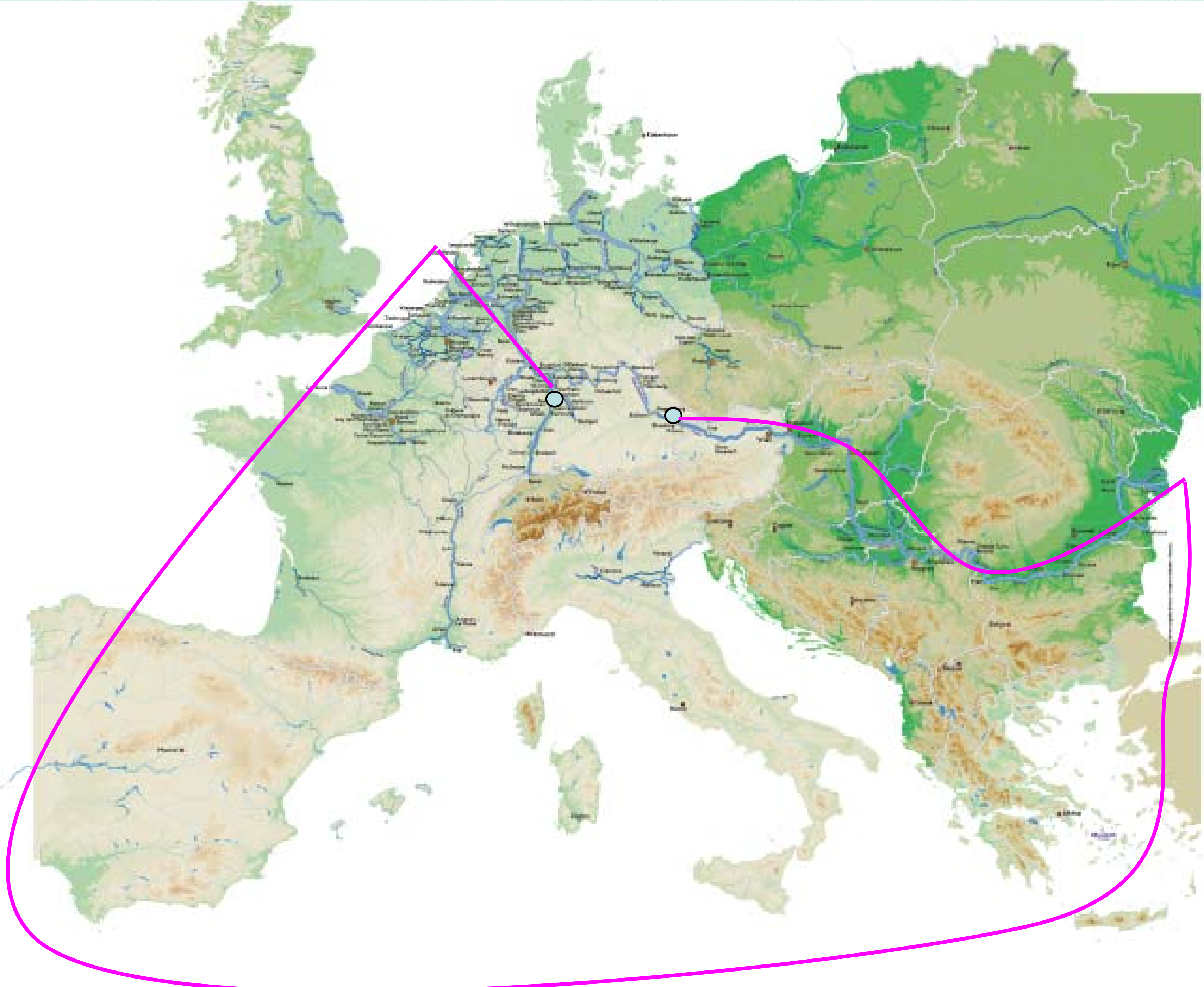
Requirements of main spectrometer:

- Length (from flange to flange): about 24 m.
- Inner Diameter (cylindrical part): 9.80 m.
- Wall outgassing rate < 10^{-12} (mbar·l/s·cm²).
- Ultimate pressure < 10^{-11} mbar .
- Temperatures between –20 °C and 350 °C.
- Voltage of 18.6 kV with 1 ppm accuracy

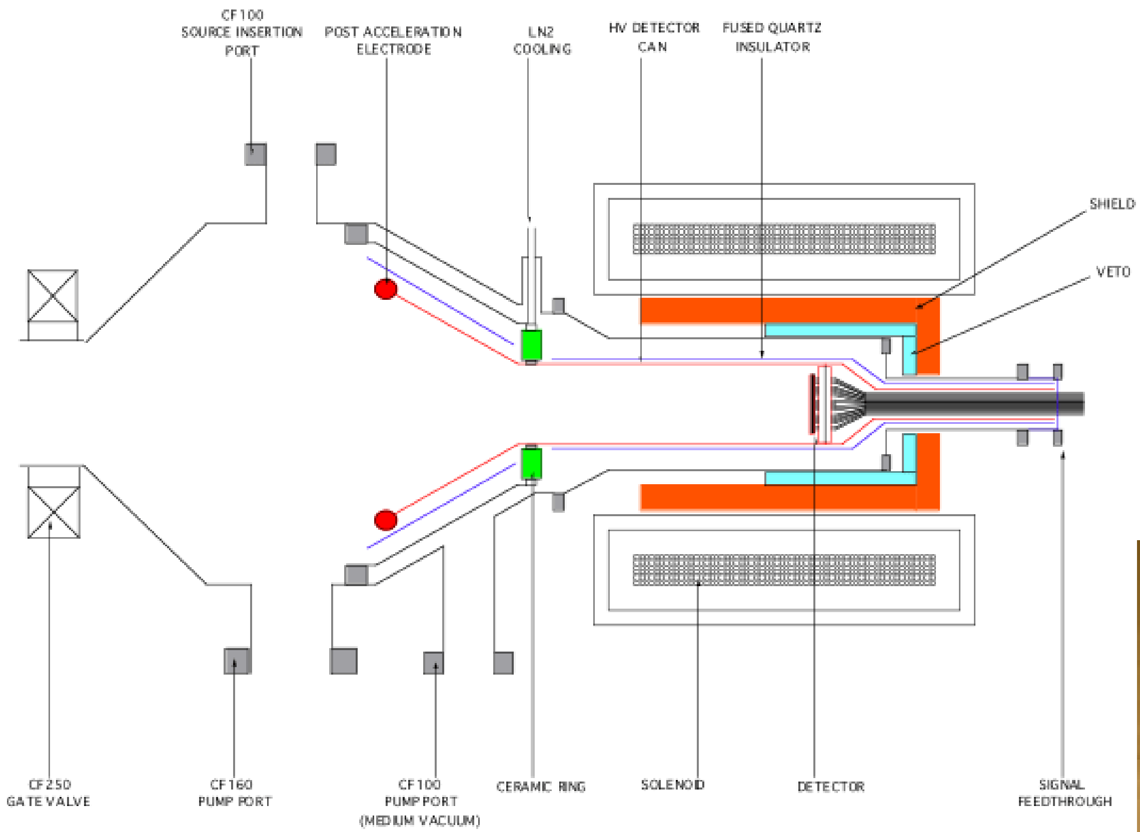
Electromagnetic design determines the vessel shape







Detector



Requirements for detector:

- Background: < 1 mHz
- Post acceleration option
- Segmented detection
- Sensitive to e^- < 100 keV
- Energy res. < 600 eV

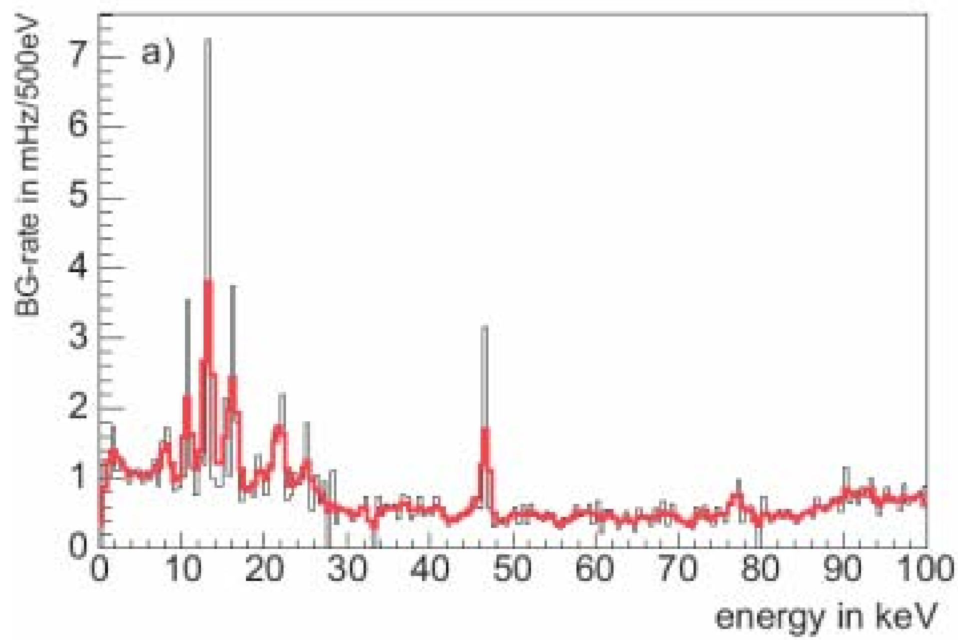
Prespectrometer detector

Status:

- Design phase
- Discussions with manufacturers

Backgrounds

- Backgrounds near detector from natural radioactivity, muons, neutrons
- Minimize by material selection and active/passive shielding
- Post acceleration
- Background from spectrometer -- position resolution of detector

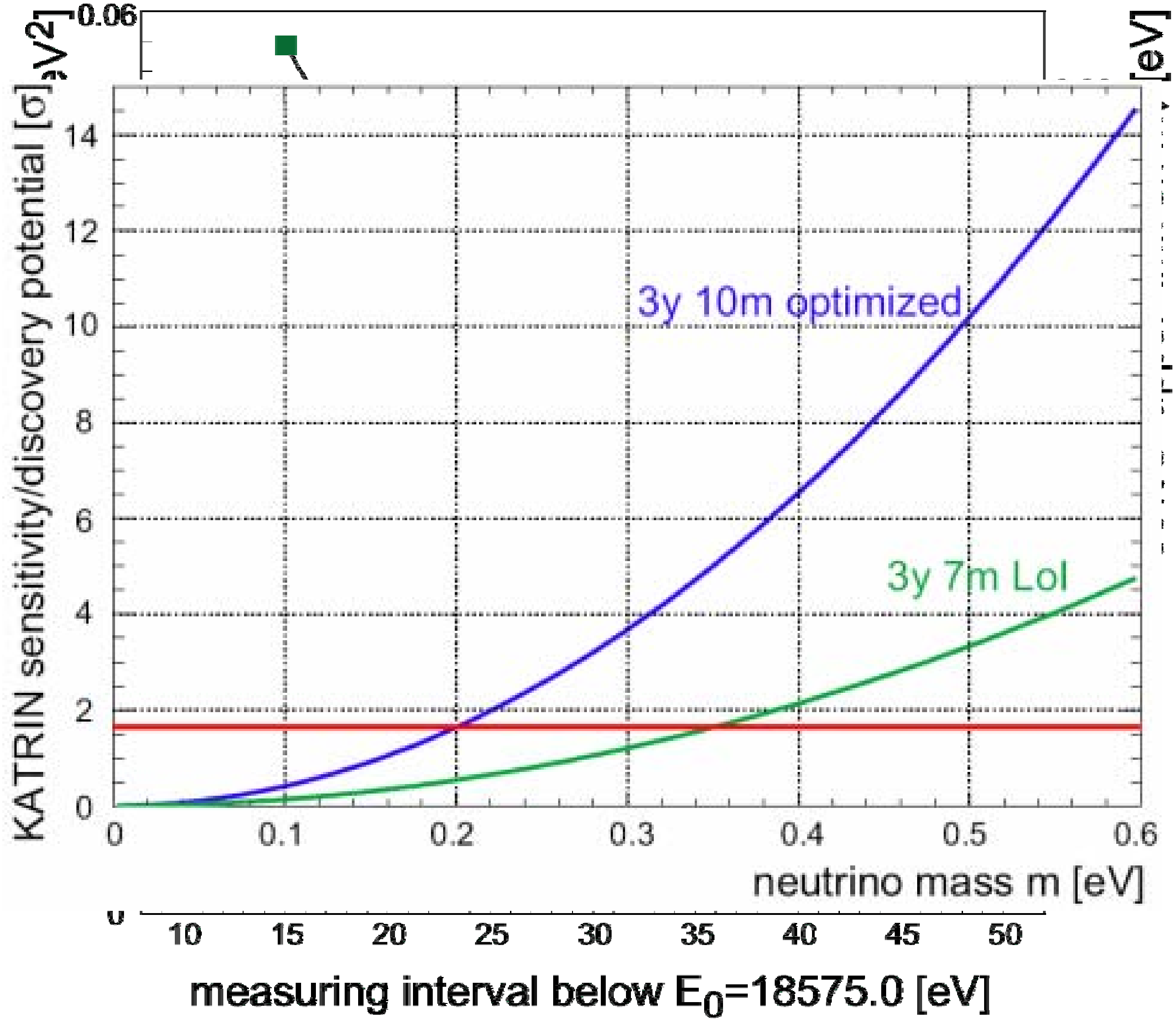


Monte Carlo of detector backgrounds

Challenges

- Vacuum of 10^{-11} mbar in the main spectrometer of over 1000 m^3
- Measuring tritium density to 0.1% precision
- Maintaining gradient of 10^{11} from WGTS to main spectrometer to avoid contamination
- Detector background of < 1 mHz
- Heating and cooling the set-up safely to reach vacuum

KATRIN Sensitivity



- Improved over original design (7 m diameter main spectrometer, source luminosity)
- Reduction in background
- Only shows statistical uncertainty

Status

- Pre-Spectrometer tests scheduled for Fall
- Most major components are ordered (main spectrometer, pumping sections, magnets, WGTS)
- Ground-breaking for building was Sept. 5
- German funding is in place
- Plan to submit a US proposal for the detector section to DOE in Fall '05
- On schedule for data collection beginning in 2009

Conclusions

- KATRIN can measure neutrino mass directly via kinematics of beta decay -- model independent
- Improvement of order of magnitude over previous best
- Goal of $m_\nu < 0.2$ eV (90% C.L.) achievable
- Technical challenges are in hand

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