Westfälische Wilhelms-Universität Münster

The KATRIN experiment

Launch Workshop, Heidelberg, November 9-12, 2009

Christian Weinheimer for the KATRIN collaboration

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- **Introduction**
- **Status of the different KATRIN components**
- **Background suppression**
- **Systematics and sensitivity**
- **Conclusion**

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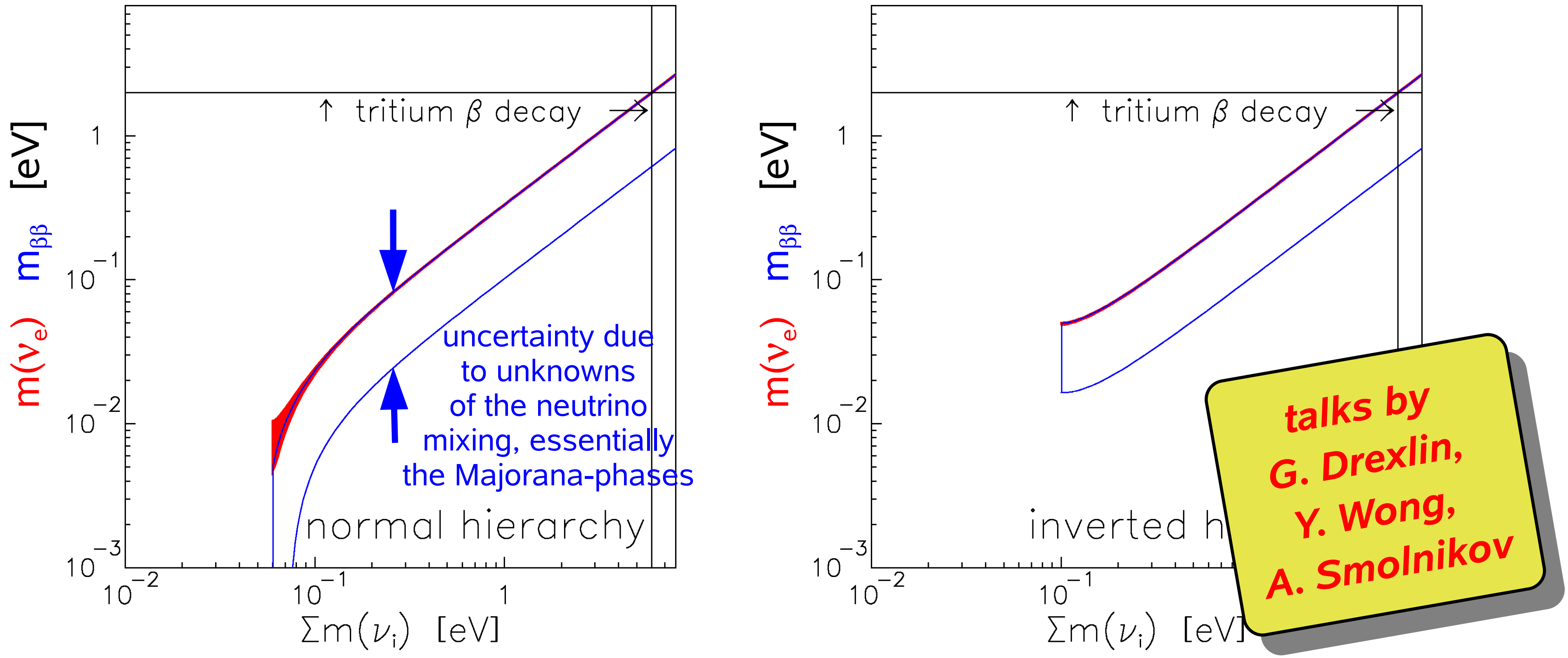
Comparison of the different approaches to the neutrino mass

Direct kinematic measurement: $m^2(\nu_e) = \Sigma |U_{ei}^2| m^2(\nu_i)$ (incoherent)

Neutrinolesss double β decay: $m_{\beta\beta}(\nu) = | \Sigma |U_{ei}^2| e^{i\alpha(i)} m(\nu_i)|$ (coherent)

- if no other particle is exchanged (e.g. R-violating SUSY)
- problems with uncertainty of nuclear matrix elements



⇒ absolute scale/cosmological relevant neutrino mass in the lab by single β decay

Direct determination of $m(\nu_e)$ from β decay

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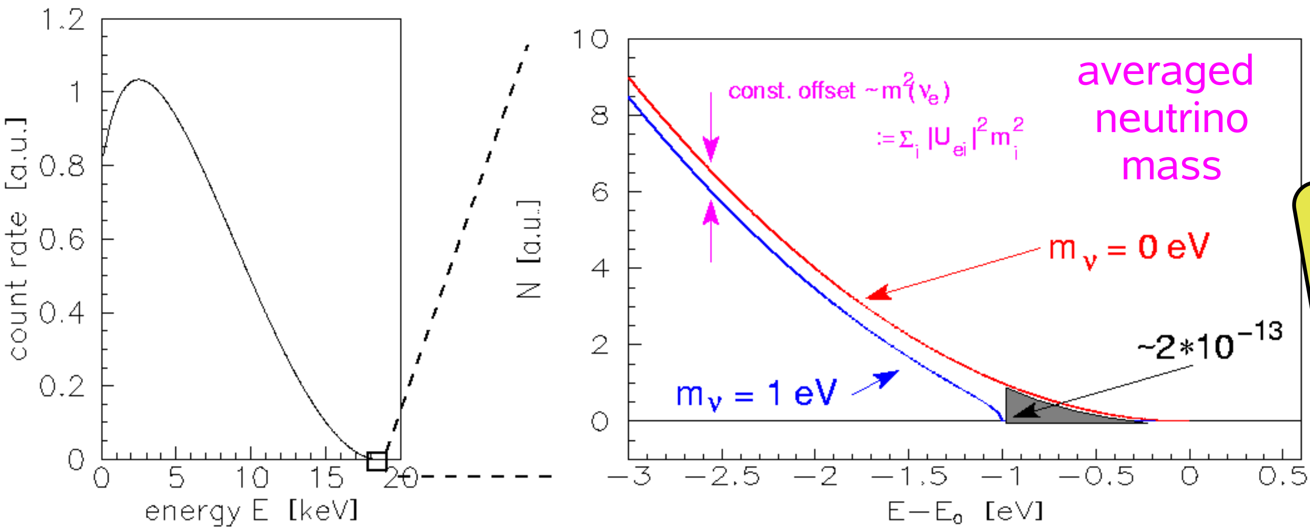
KATRIN – Karlsruhe Tritium Neutrino Experiment

β decay: $(A,Z) \rightarrow (A,Z+1)^+ + e^- + \bar{\nu}_e$

β electron energy spectrum:

$$dN/dE = K\ F(E,Z)\ p\ E_{tot}\ (E_0-E_e)\ \Sigma\,|U_{ei}|^2\ \sqrt{(E_0-E_e)^2 - m(\nu_i)^2}$$

(modified by electronic final states, recoil corrections, radiative corrections)

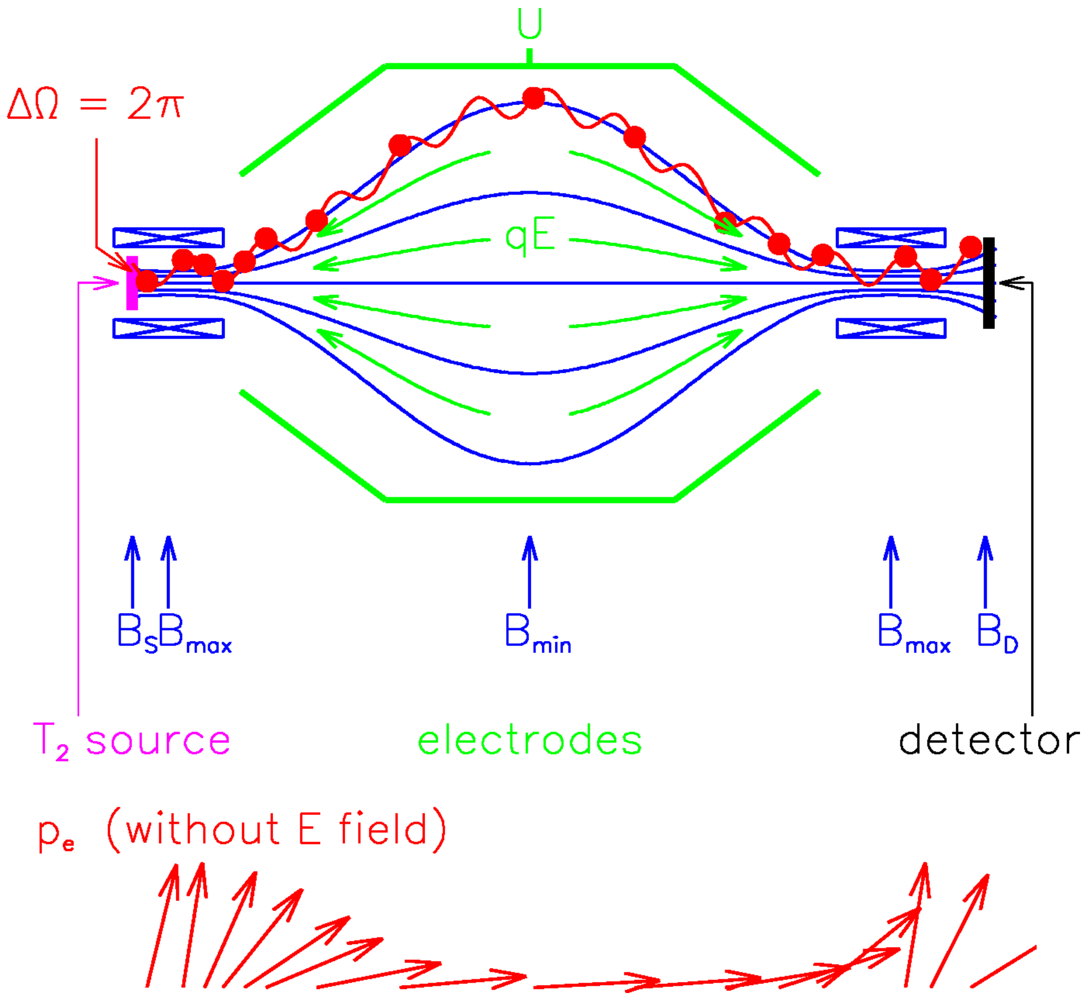


E.W. Otten & C. Weinheimer
Rep. Prog. Phys.
71 (2008) 086201

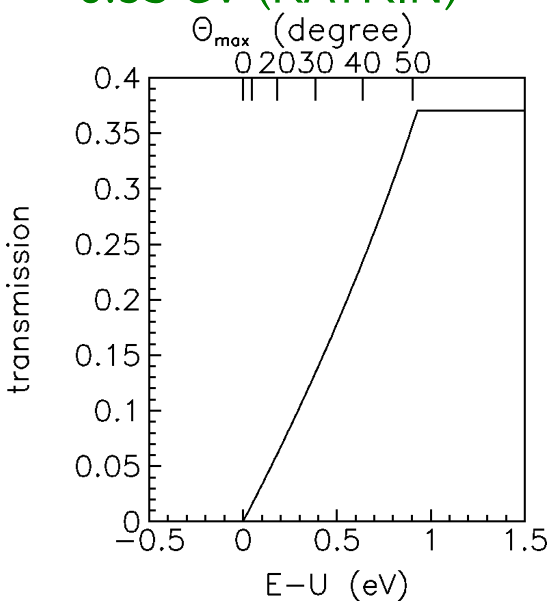
Need: **low endpoint energy** ⇒ **Tritium ^3H, (^{187}Re)**

very high energy resolution &
very high luminosity &
very low background
⇒ **MAC-E-Filter**
(or bolometer for ^{187}Re)

Tritium experiments: source ≠ spectrometer MAC-E-Filter



- Two supercond. solenoids compose magnetic guiding field
- adiabatic transformation:
  $\mu = E_{\perp}/B = \text{const.}$
  ⇒ parallel e^- beam
- Energy analysis by electrostat. retarding field
  $\Delta E = E \cdot B_{min}/B_{max}$
  $= 0.93$ eV (KATRIN)



⇒ sharp integrating transmission function without tails →

Magnetic Adiabatic Collimation + Electrostatic Filter
(A. Picard et al., Nucl. Instr. Meth. 63 (1992) 345)

The Karlsruhe Tritium Neutrino experiment KATRIN

is being set up at the Forschungszentrum Karlsruhe

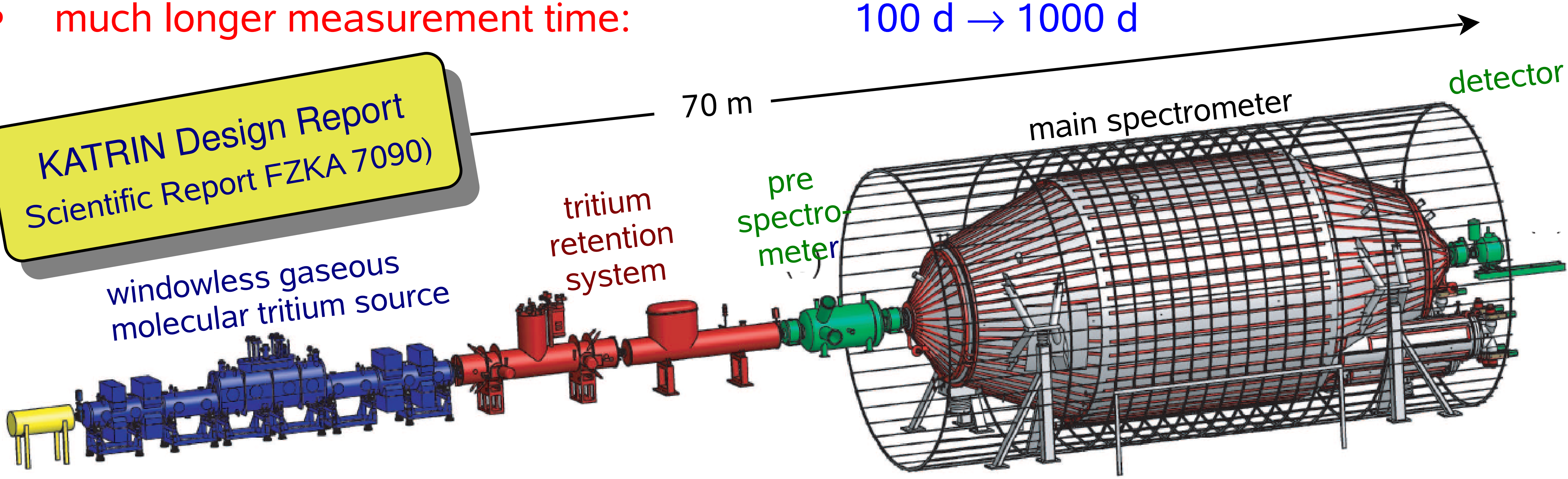
Physics Aim: m(ν_e) sensitivity of 0.2 eV (currently 2 eV)

- higher energy resolution: $\Delta E \approx$ 1eV
  since $E/\Delta E \sim A_{spectrometer}$ ⇒ larger spectrometer
- relevant region below endpoint becomes smaller
  even less rate $dN/dt \sim A_{source} \sim A_{spectrometer}$ ⇒ larger spectrometer

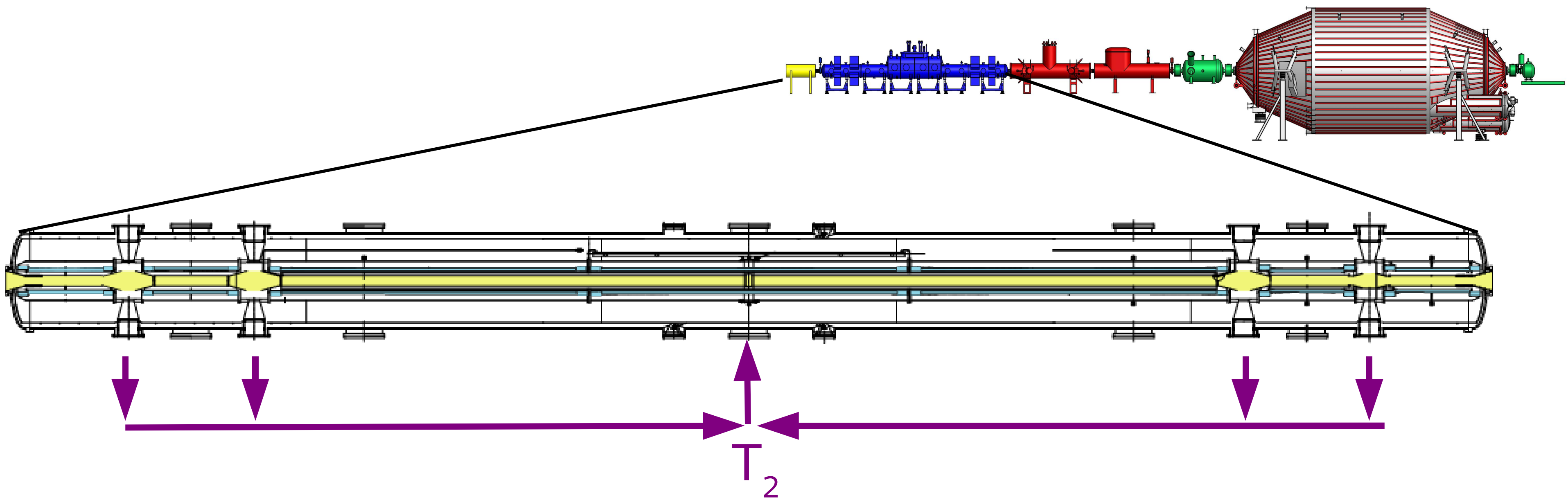
} ∅10m

- small systematics ⇒ windowless gaseous tritium source
- much longer measurement time: 100 d → 1000 d

KATRIN Design Report
Scientific Report FZKA 7090)



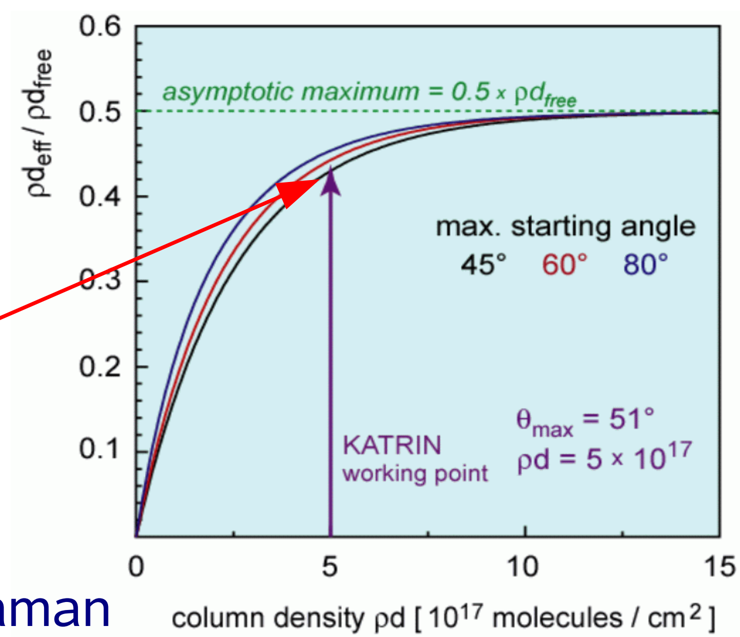
Molecular Windowless Gaseous Tritium Source WGTS



WGTS: tub in long superconducting solenoids
∅ 9cm, length: 10m, T = 30 K

Tritium recirculation (and purification)
p_{inj} = 0.003 mbar, q_{inj} = 4.7Ci/s

allows to measure with near to maximum count rate using
$\rho d = 5 \cdot 10^{17}/cm^2$
with small systematics



check column density by e-gun, T_2 purity by laser Raman

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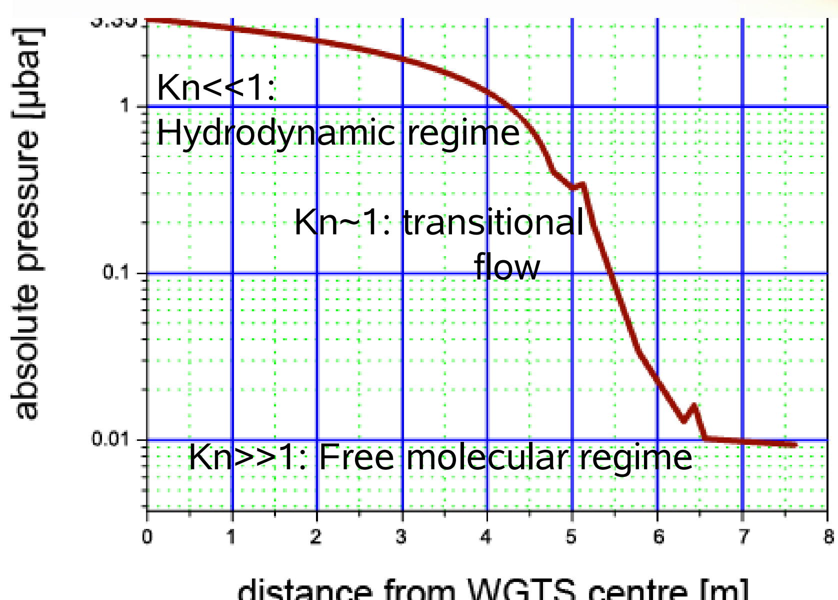
Molecular Windowless Gaseous Tritium Source WGTS

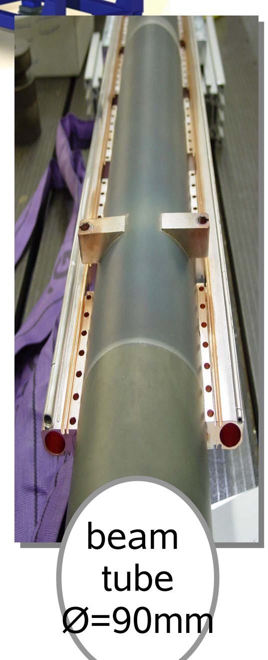
KATRIN Karlsruhe Tritium Neutrino Experiment

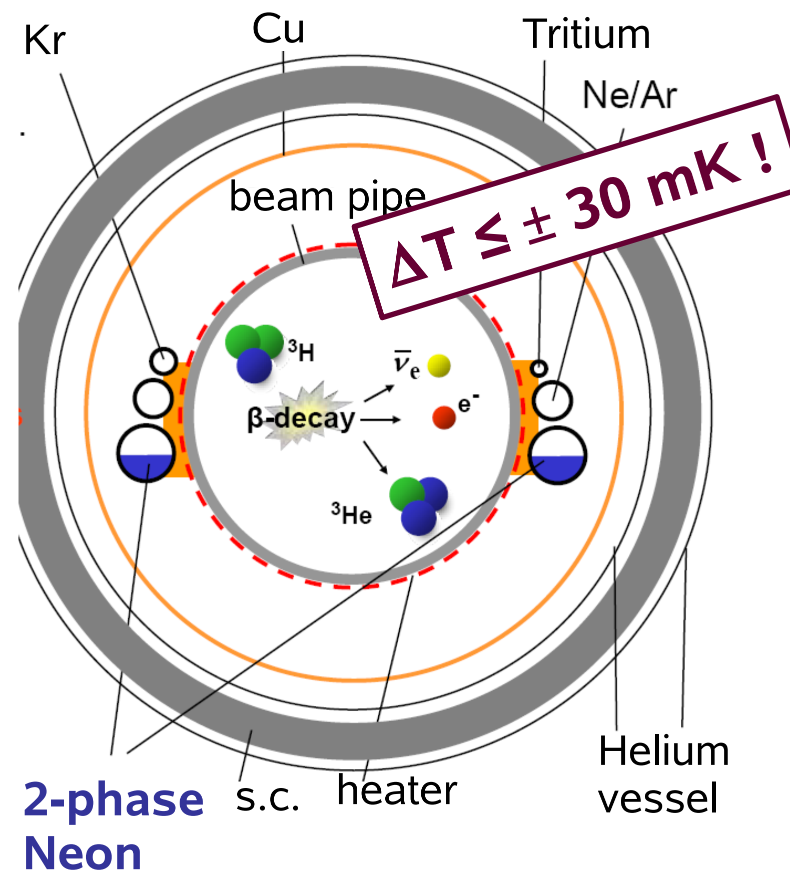
Conceptional design

Neon cooling with
g temperature: 27–28 K
l (homogeneity): ± **0.1%**
(stability/hour): ± **0.1%**

S. Grohmann, Cryogenics 49, No. 8 (2009) 413







WGTS under construction

WGTS-demonatrator
will arrive early 2010

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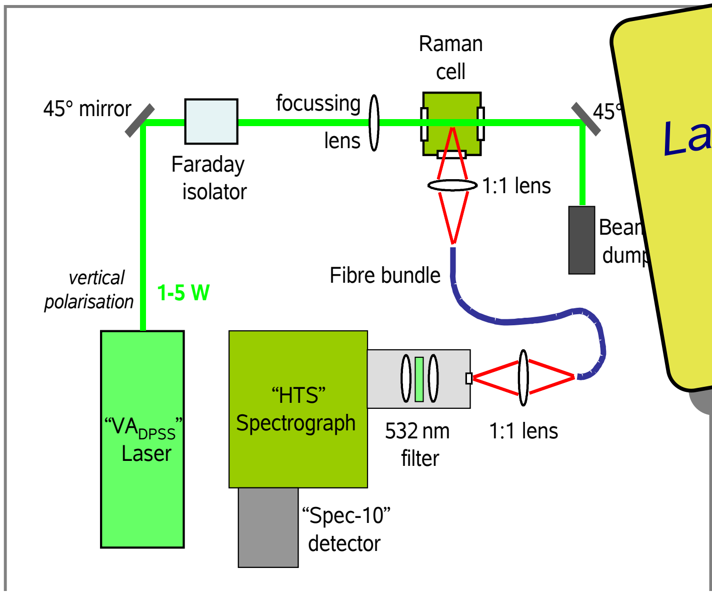
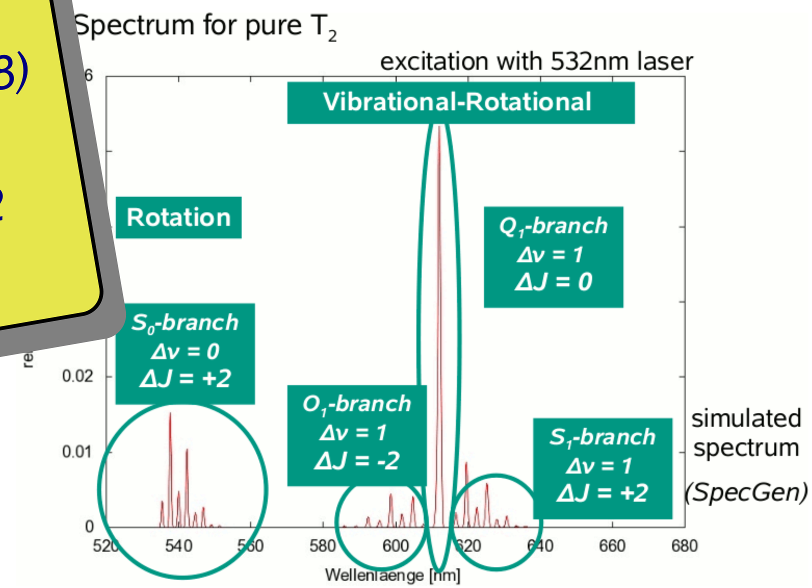
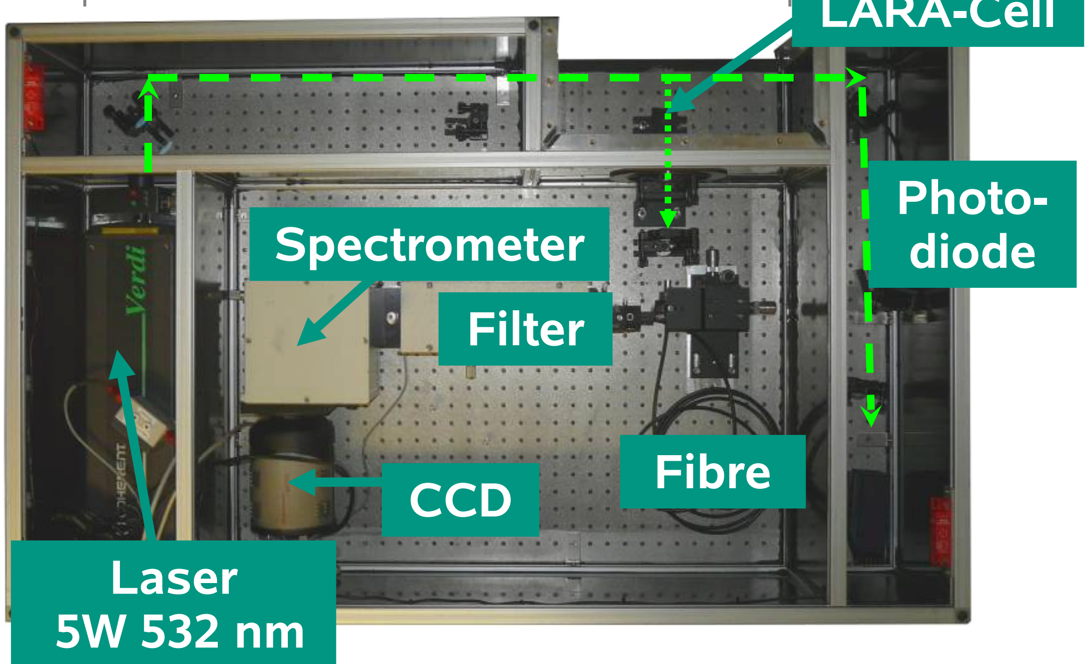
Measurement of tritium concentration by laser Raman spectroscopy

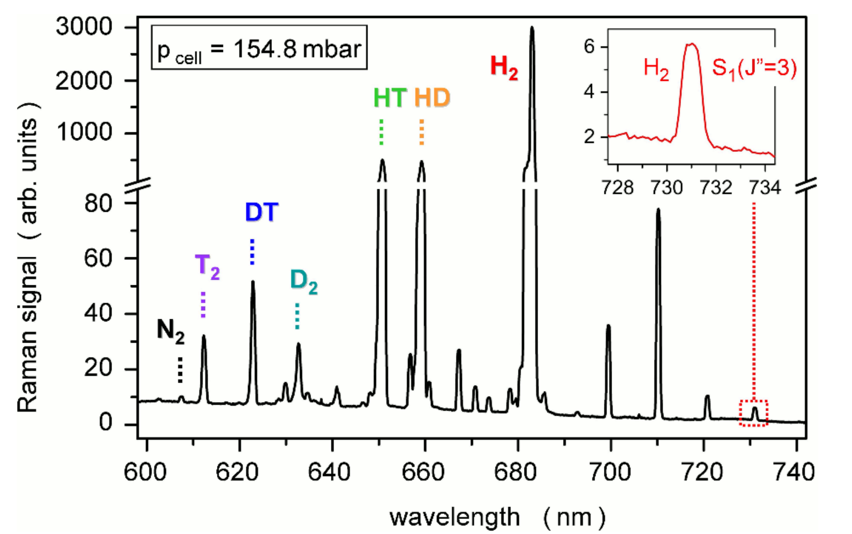
R.J. Lewis et al.,
Las. Phys. Lett.1-10 (2008)
M.Sturm et al,
Las. Phys. 20 (2010) 2
(to be published)







H_2 / HD / T_2 / DT / HT
= 0.820 / 0.083 / 0.003 / 0.005 / 0.085



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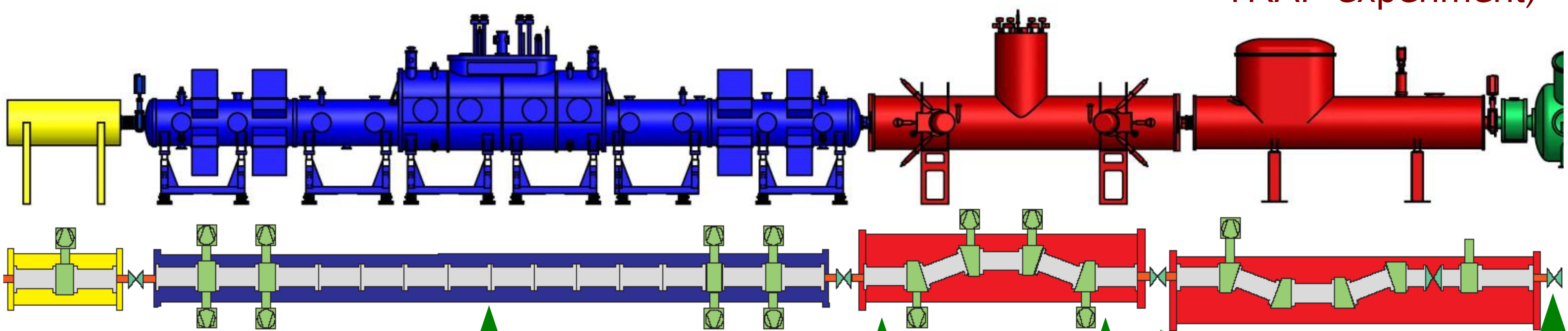
Transport and differential & cryo pumping sections

Molecular windowless gaseous tritium source

Differential pumping

Cryogenic pumping
with Argon snow
at LHe temperatures
(successfully tested with the TRAP experiment)



T_2-injection 1.8 mbar l/s (STP)
= 1.7*10^{11} Bq/s = 40 g/d

FT-ICR Penning traps to measure ions from WGTS

≈ 10^{-7} mbar l/s

< 2.5 10^{-14} mbar l/s

⇒ adiabatic electron guiding & T_2 reduction factor of ~10^{14}

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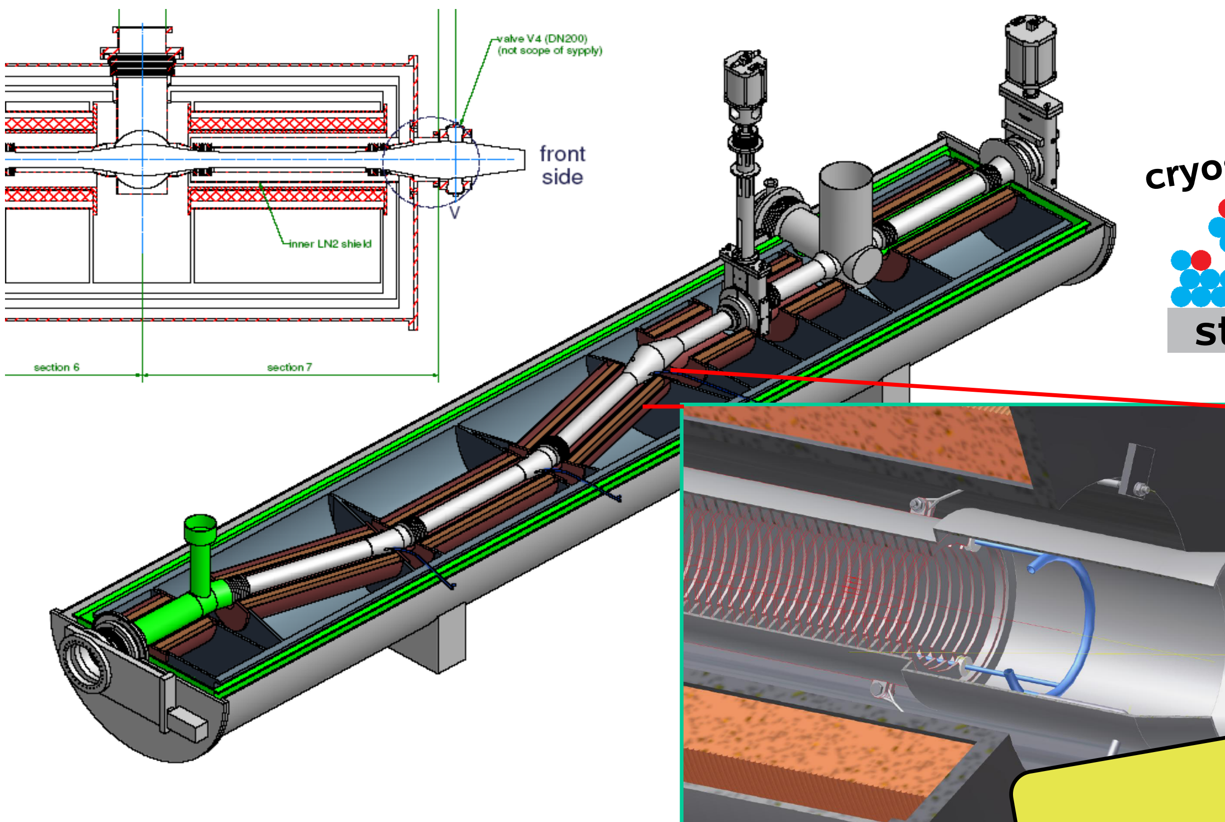
Arrival of DPS2-F at Karlsruhe: July 15, 2009

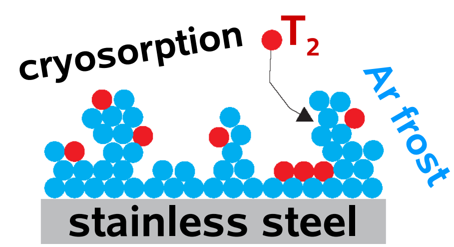
FT-ICR Penning traps:
M. Ubieto-Diaz et al.,
Int. J. Mass. Spectrom.
288 (2009) 1-5

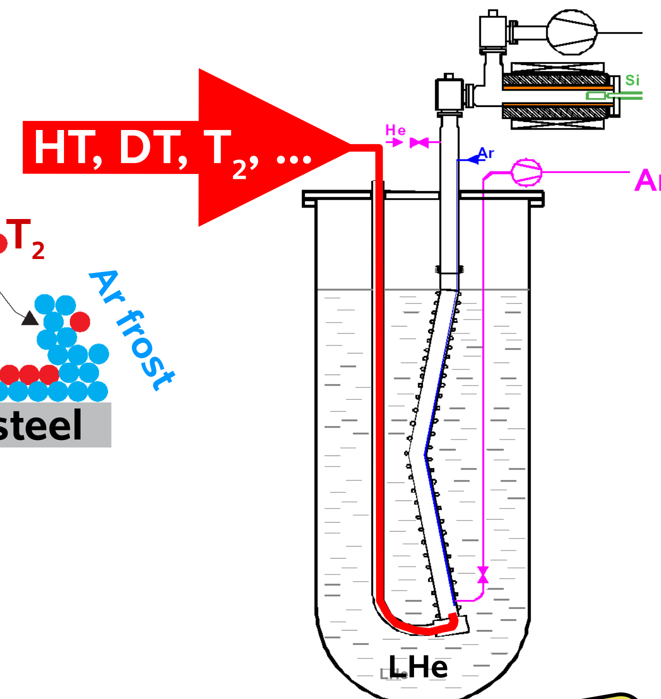
Cryogenic pumping section and test of principle

TRAP: TRitium Argon frost Pump

CPS: cryogenic pumping section







- cryosorption of T_2 by Ar frost
- magnetic guiding field B = 5.6 T
- specification finished
- estimated delivery 2010

O. Kazachenko et al., Nucl. Instr. Meth. A 587 (2008) 136
F. Eichelhardt et al., Fusion Science and Technology 54 (2008) 615

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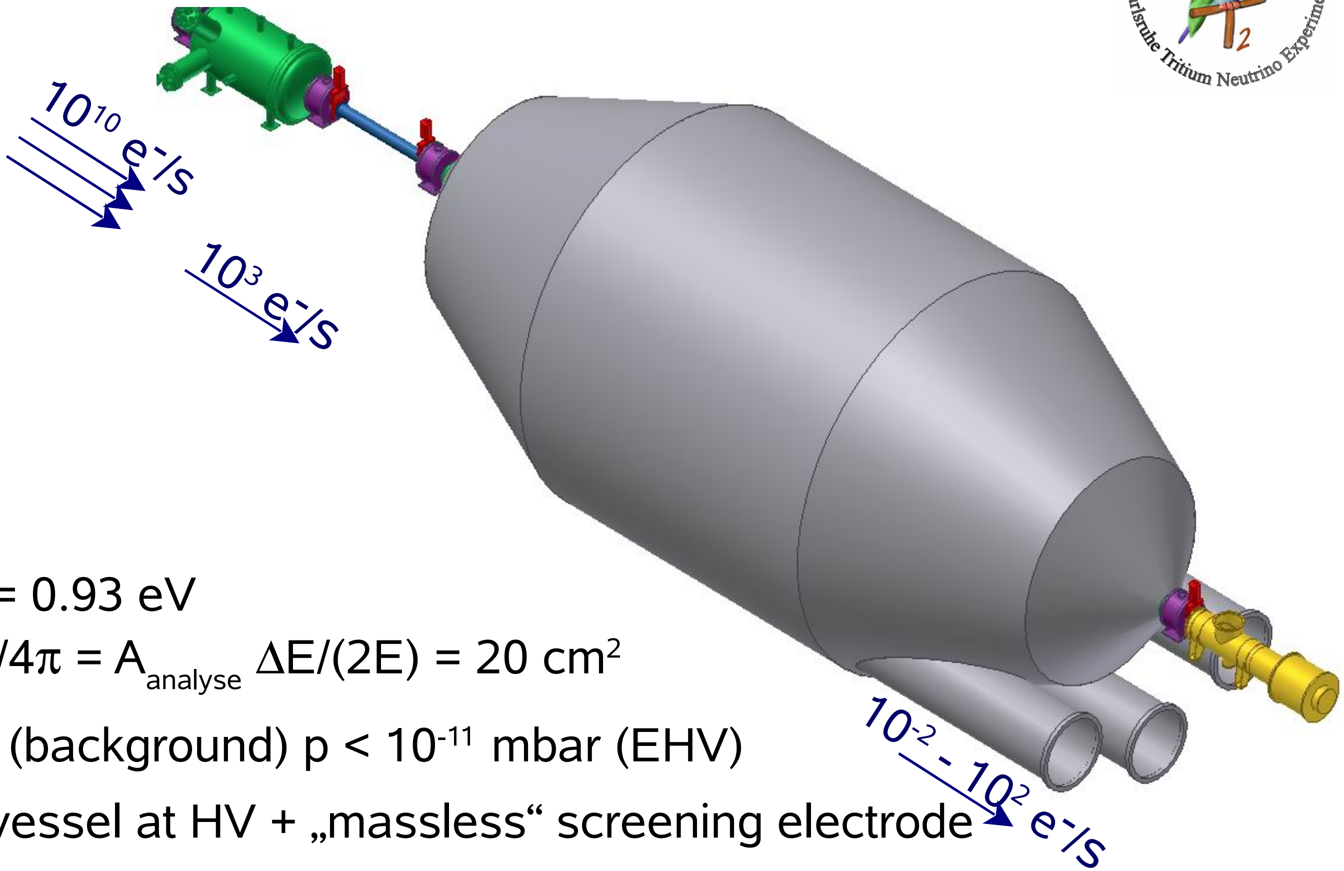
Pre and main spectrometer



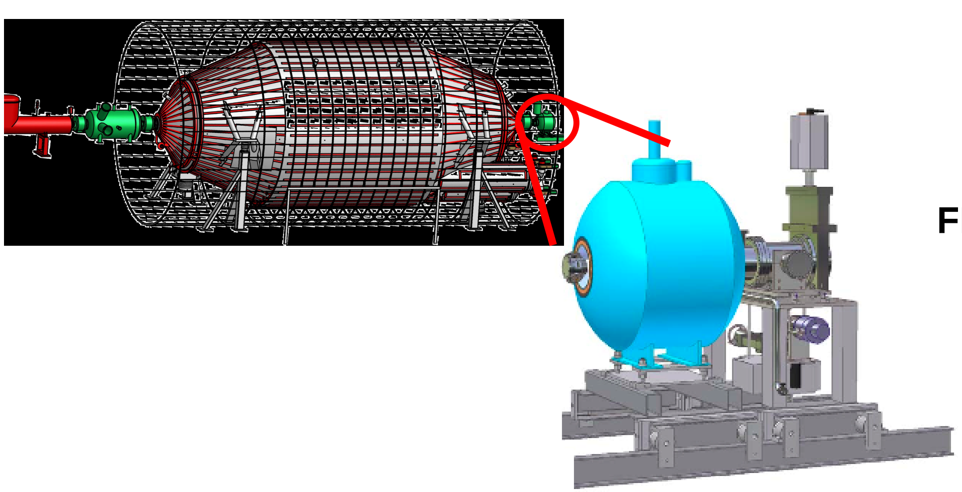
Main spectrometer:

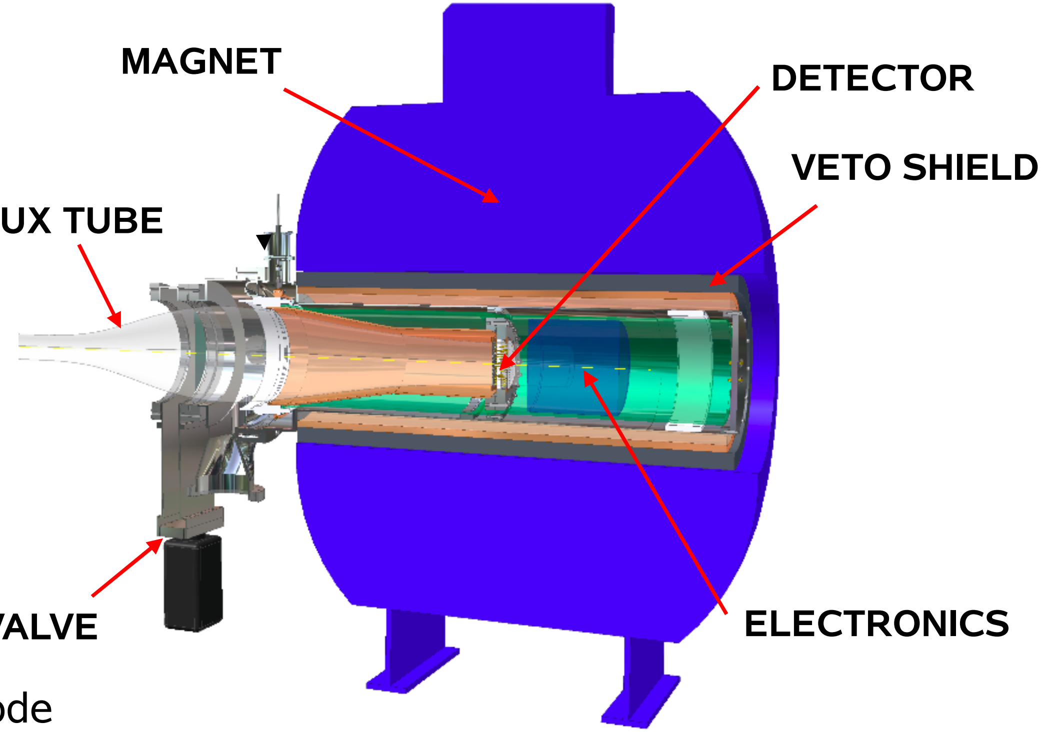
- ∅10m, length 24m
  ⇒ large energy resolution: $\Delta E = 0.93$ eV
  ⇒ high luminosity: $L = A_{Seff}\ \Delta\Omega/4\pi = A_{analyse}\ \Delta E/(2E) = 20\ cm^2$
- ultrahigh vacuum requirements (background) $p < 10^{-11}$ mbar (EHV)
- „simple“ construction: vacuum vessel at HV + „massless“ screening electrode

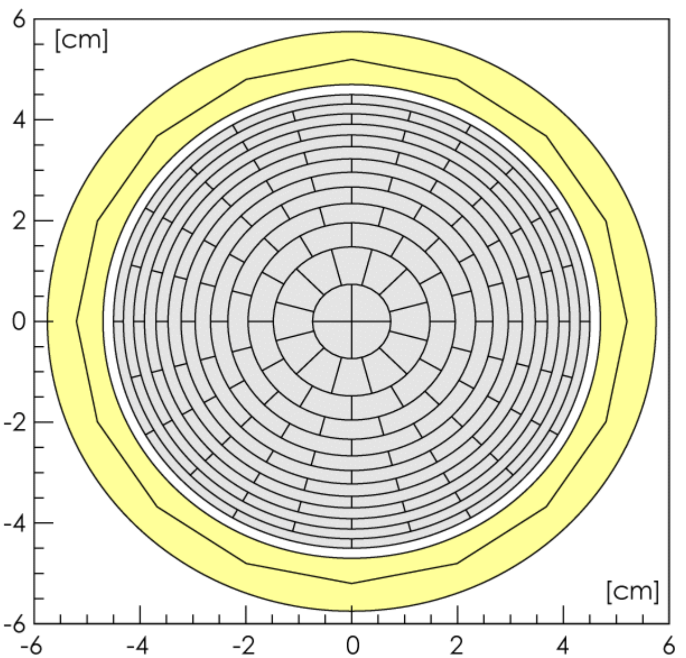
Pre spectrometer

- Transmission of electron with highest energy only
  (10^{-7} part in last 100 eV)
  ⇒ Reduction of scattering probaility in main spectrometer
  ⇒ Reduction of background
- only moderate energy resolution required: $\Delta E = 80$ eV
- test of new ideas (EHV, shape of electrodes, avoid and remove of trapped particles, ...)

Detector Setup







- Si-Pin diode
- Detection of transmitted β-decay electrons (mHz to kHz)
- **Low background for endpoint investigation**
- High energy resolution ΔE < 1 keV
- 12 rings with 30° segmentation + 4 fold center = **148 pixels**
  - record azimuthal and radial profile of flux tube
    - minimize background
    - investigate systematic effects
    - compensate field inhomogeneity in analyzing plane

(magn. field of 3 - 6 T, active veto shield, post-accel. mode)

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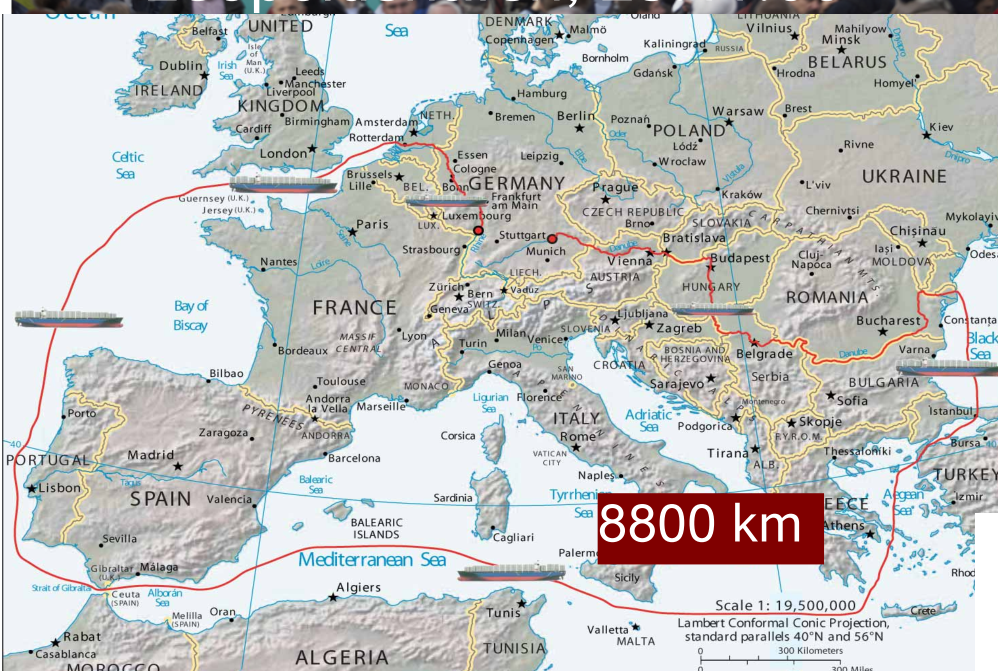
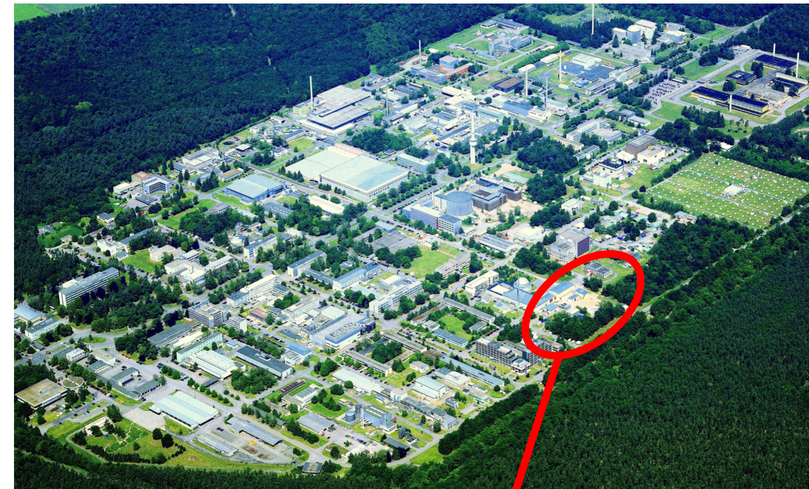
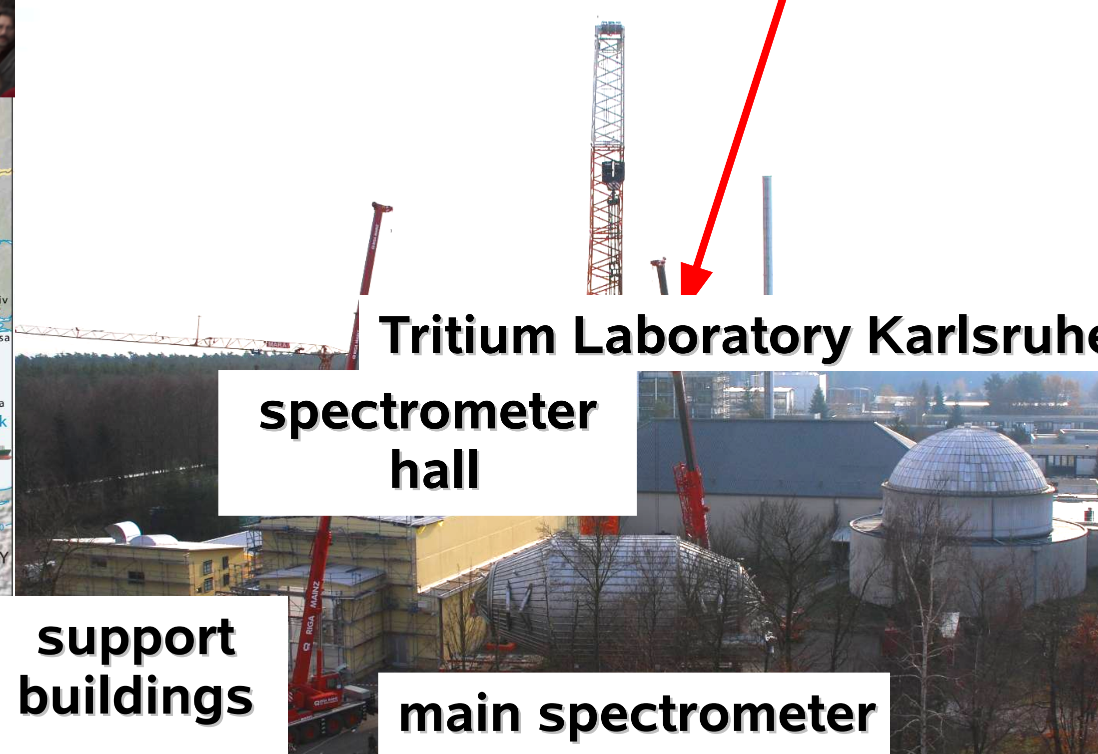
Main Spectrometer – Transport to Forschungszentrum Karlsruhe

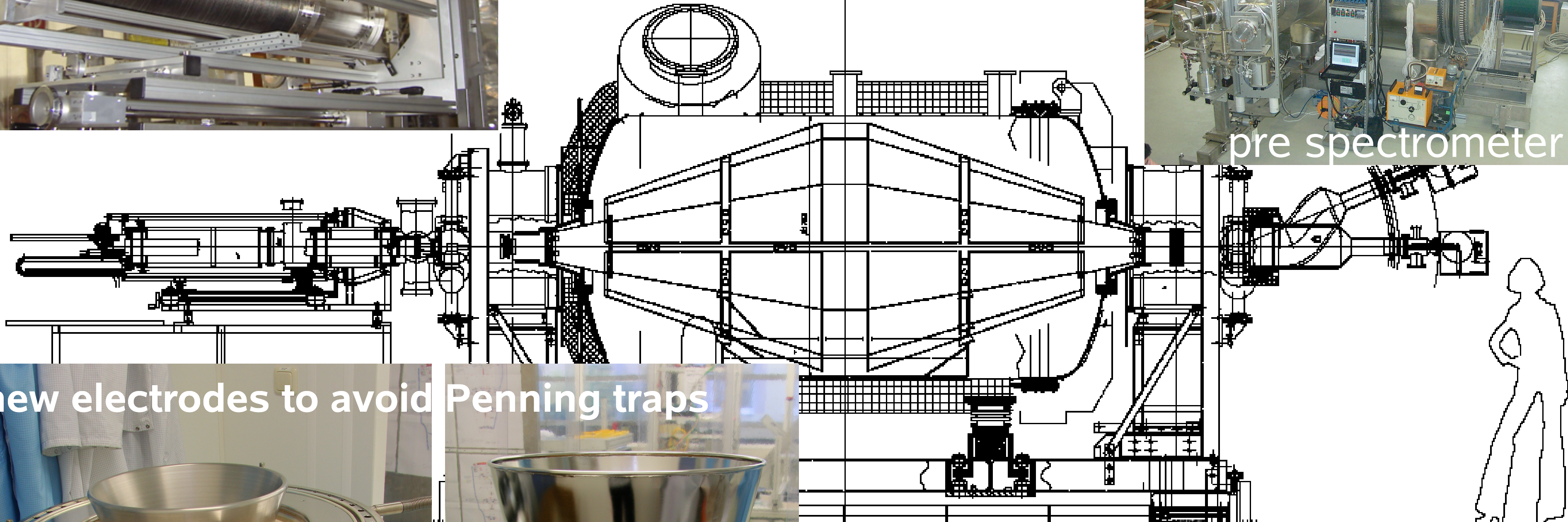
KATRIN Karlsruhe Tritium Neutrino Experiment

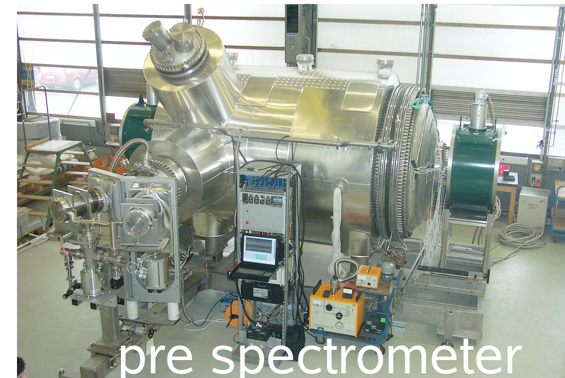




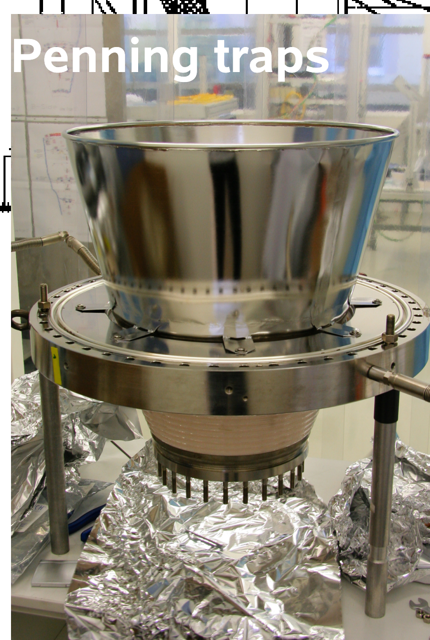


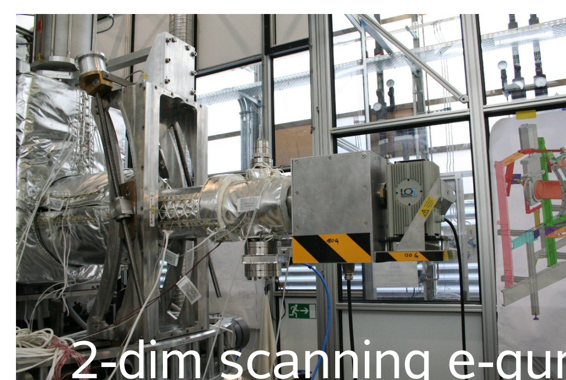
Electromagnetic design tests at the pre spectrometer



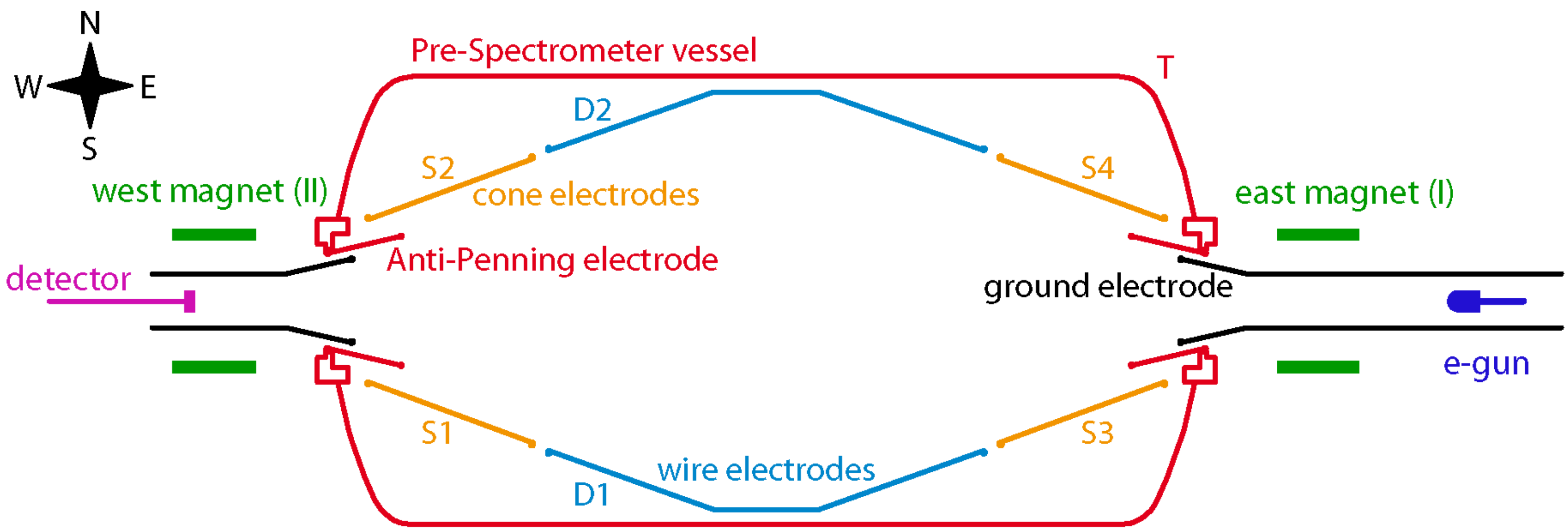


new electrodes to avoid Penning traps



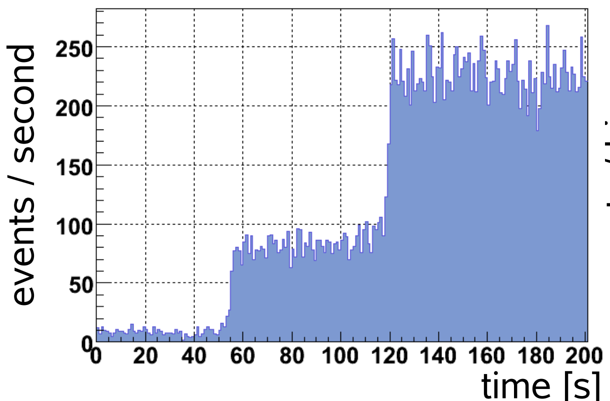


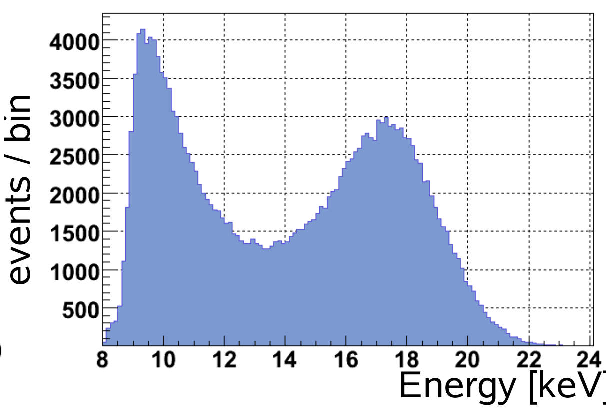
Pre spectrometer background studies I



Background at high B-fields (B_{max} > 2T)

- strong dependence on B (threshold)
- delayed ignition
- background strongly correlated with p
- strong dependence on voltage





⇒ background caused by trapped particles

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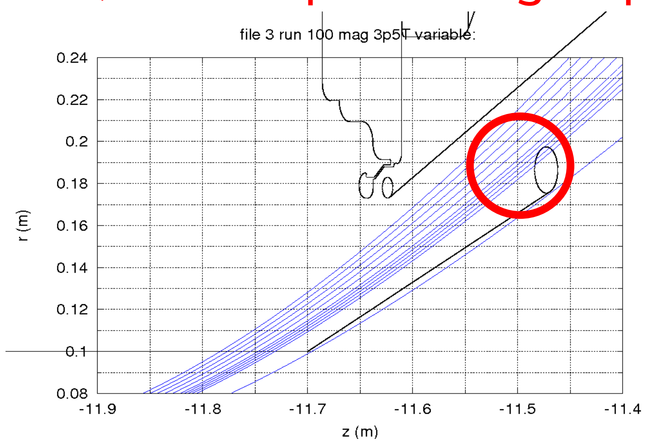
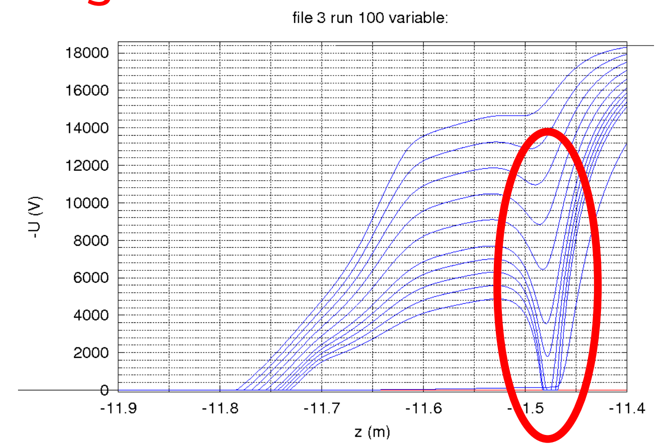
Pre spectrometer background studies II

Problem: very small, but deep Penning traps near geometrical corners



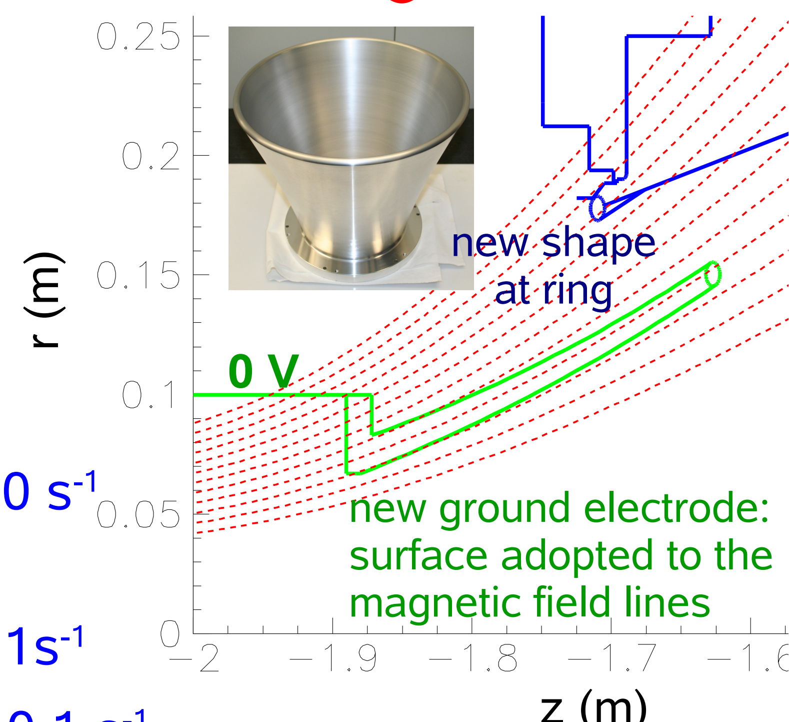


Solution: - very precise and very detailed electromagnetic calculations (special codes developed by KATRIN)

- avoid Penning trap by optimally shaped electrodes

Result: Background reduction by 10^4:

- with small Penning traps: bg ≈ 1000 s^{-1}
- optimally shaped electrodes with residual shallow Penning trap bg ≈ 1 s^{-1}
- no residual Penning trap bg ≈ 0.1 s^{-1}

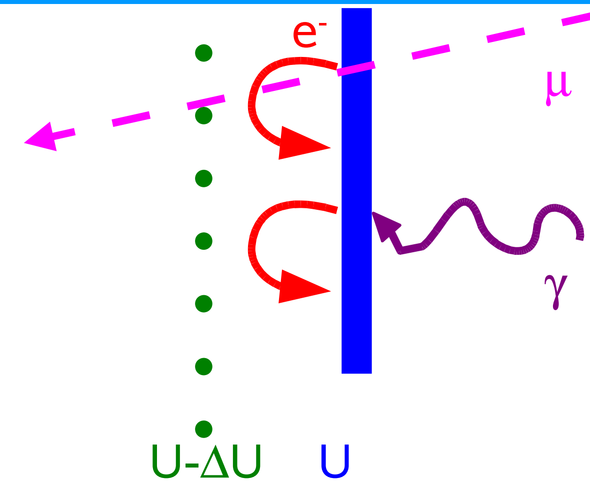


Background reduction: shielding by „massless“ wire electrode

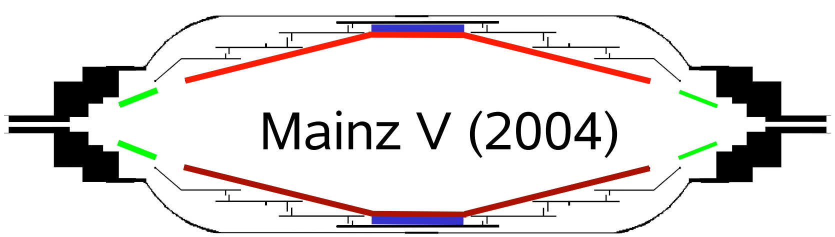
Secondary electrons from wall/electrode

by cosmic rays, environmental radioactivity, ...

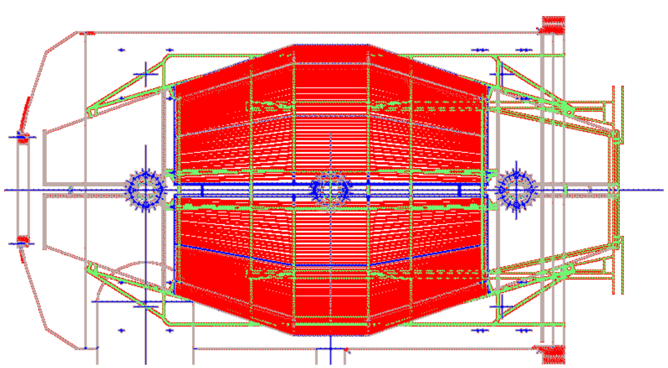
wire electrode on slightly more negative potential



First realisation: Mainz III

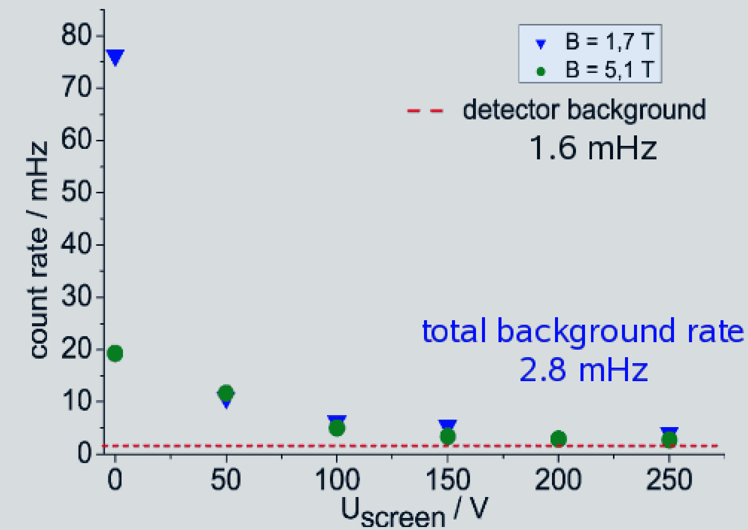


New record ! April 04



KATRIN pre spectrometer

Background suppression successfully tested at the Mainz MAC-E filter:



Dipl. thesis B. Ostrick (U Mainz, 2002), PhD thesis B. Flatt (U Mainz, 2004)

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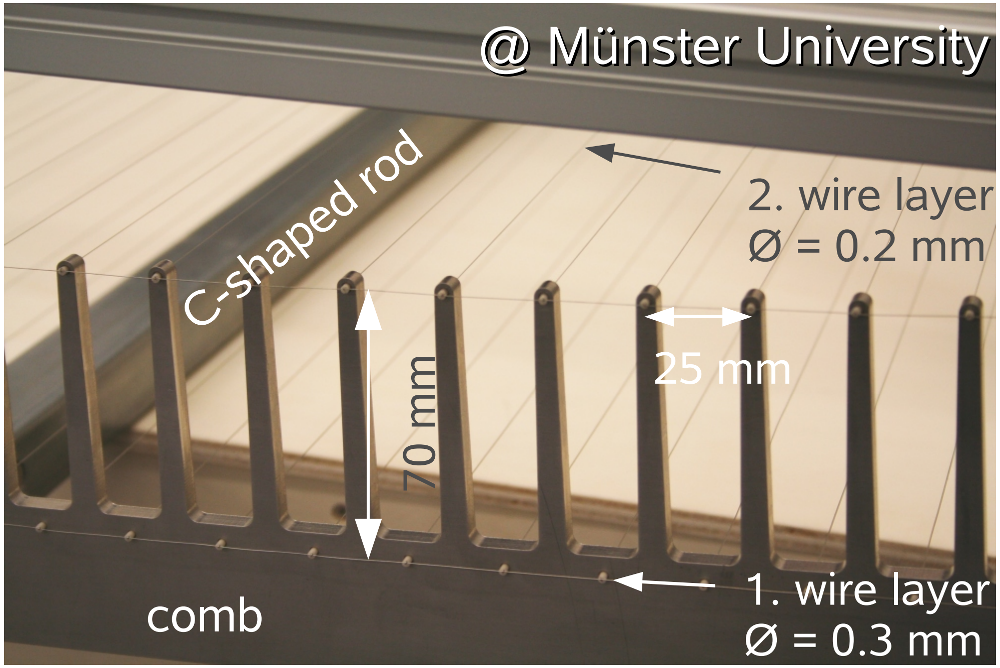
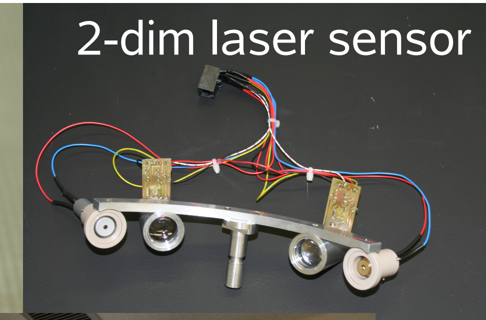
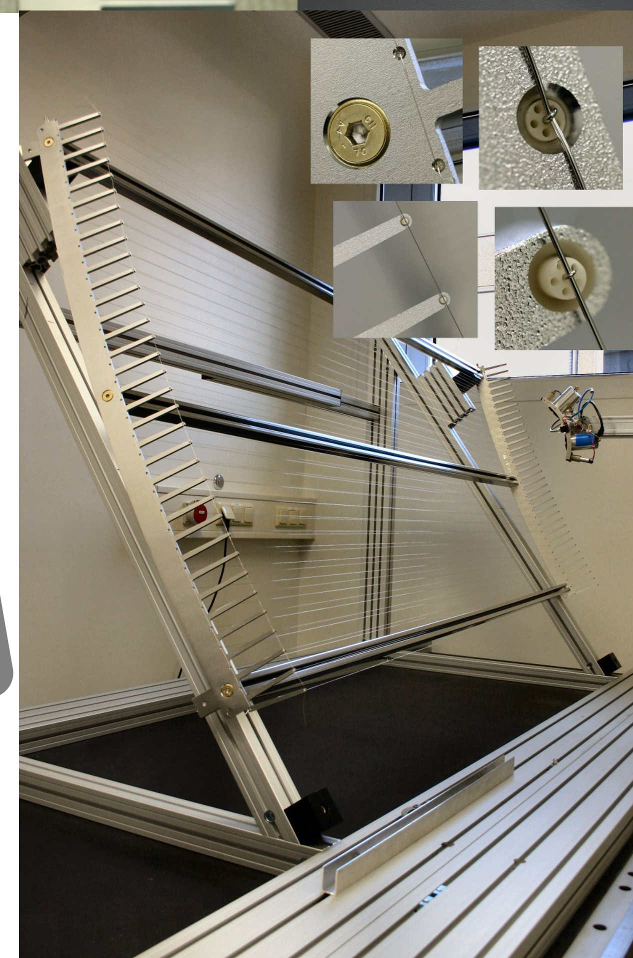
Double-wire layer electrode (690m²) production and quality assurance

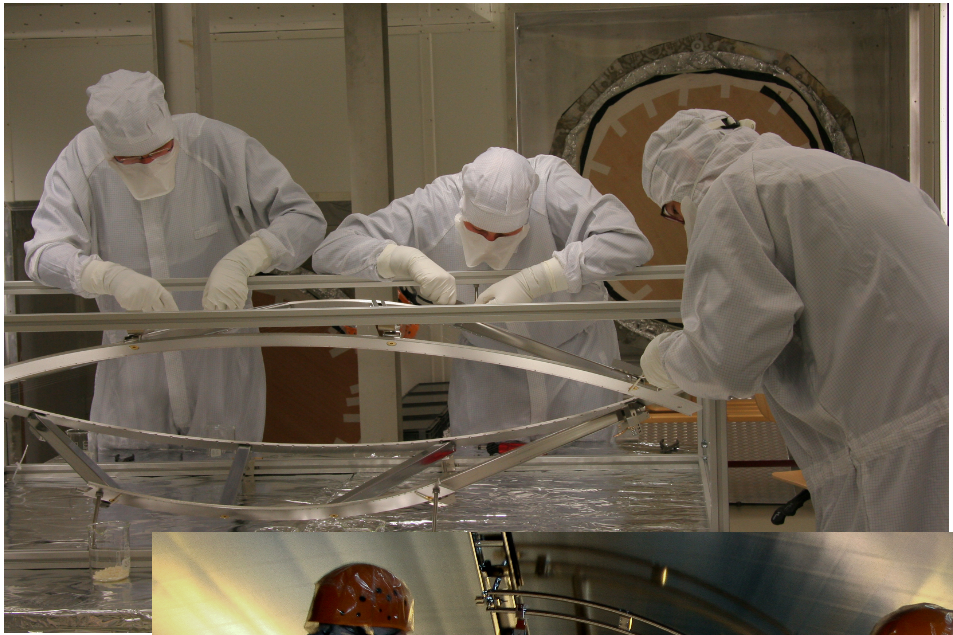


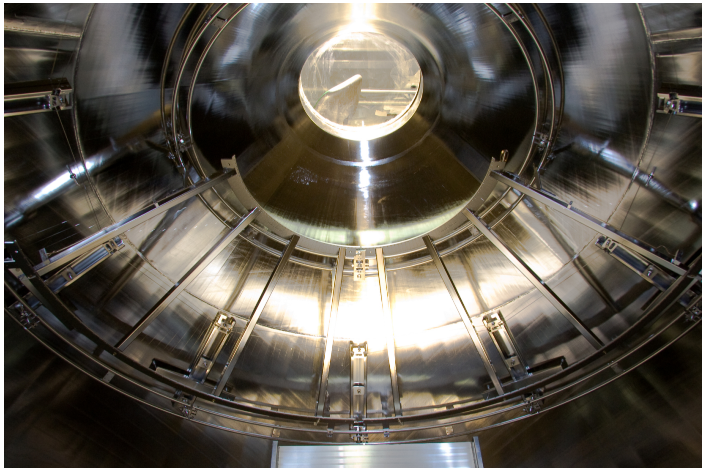


Electrode production finished in Oct. 2009



Electrode module installation at the main spectrometer has started





Systematic uncertainties

A) As smaller m(ν) as smaller the region of interest below endpoint E_0

B) Any unaccounted variance σ^2 leads to negative shift of m_ν^2: $\Delta m_\nu^2 = -2\sigma^2$

1. inelastic scatterings of ß´s inside WGTS
   - **dedicated e-gun measurements**, unfolding of response fct.

2. fluctuations of WGTS column density (required < 0.1%)
   - rear detector, Laser-Raman spectroscopy, T=30K stabilisation, **e-gun measurements**

3. transmission function
   - **spatial resolved e-gun measurements**

4. WGTS charging due to remaining ions (MC: ϕ < 20mV)
   - inject low energy meV electrons from rear side, diagnostic tools available

5. final state distribution
   - reliable quantum chem. calculations

6. HV stability of retarding potential on ~3ppm level required
   - **precision HV divider (PTB), monitor spectrometer beamline**

} a few contributions with $\Delta m_\nu^2 \leq 0.007\ \mathrm{eV}^2$ each

Stability of retarding potential / energy calibration: ppm at 18.6 kV

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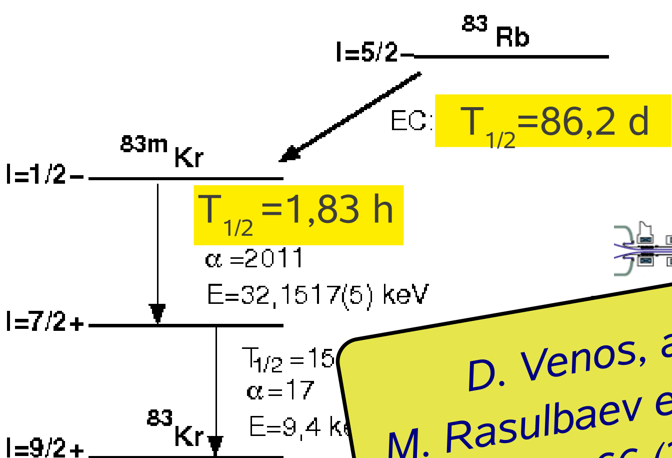
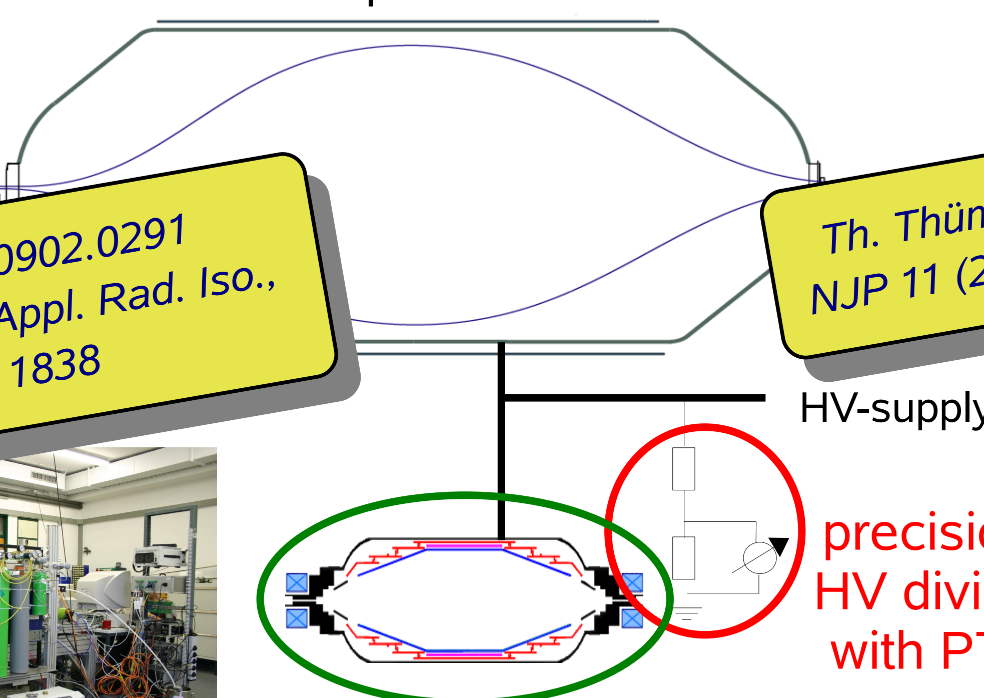
- Measure HV by precision HV divider
- Lock retarding HV by measuring energetically well-defined electron line with monitor spectrometer



^{83m}Kr conversion electron sources:

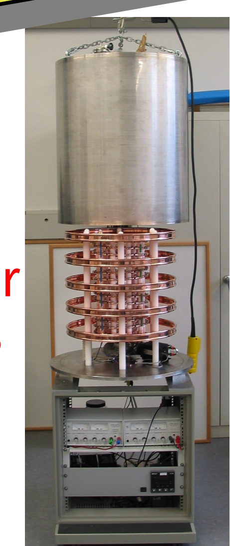
- condensed ^{83m}Kr: Münster/Mainz
- ^{83}Rb/^{83m}Kr: Rez/Mainz/Münster/Karlsruhe
- ^{83}Rb production: Bonn, Rez

D. Venos, arXiv 0902.0291
M. Rasulbaev et al., Appl. Rad. Iso., 66 (2008) 1838



Th. Thümmler et al., NJP 11 (2009) 103007

precision HV divider with PTB



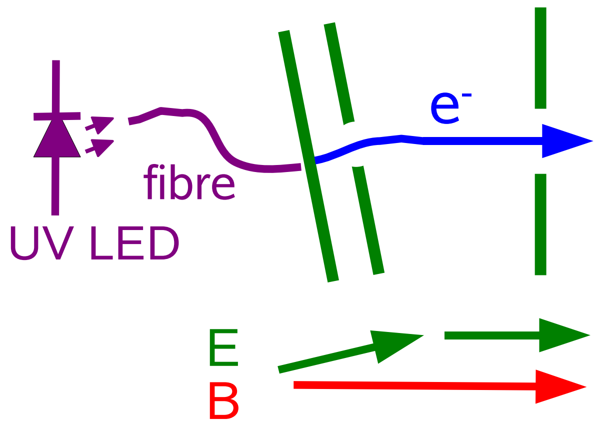
monitor spectrometer
= modified Mainz spec.:
ΔE=5eV → 1 eV

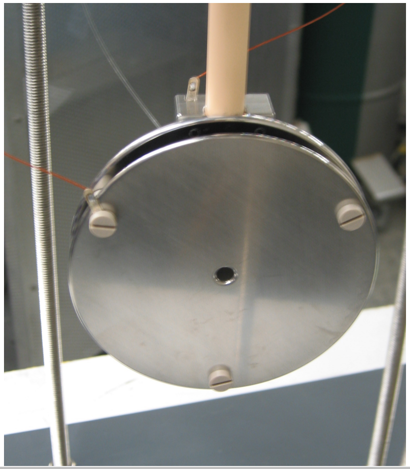
A new pulsed angular-defined UV LED photoelectron source

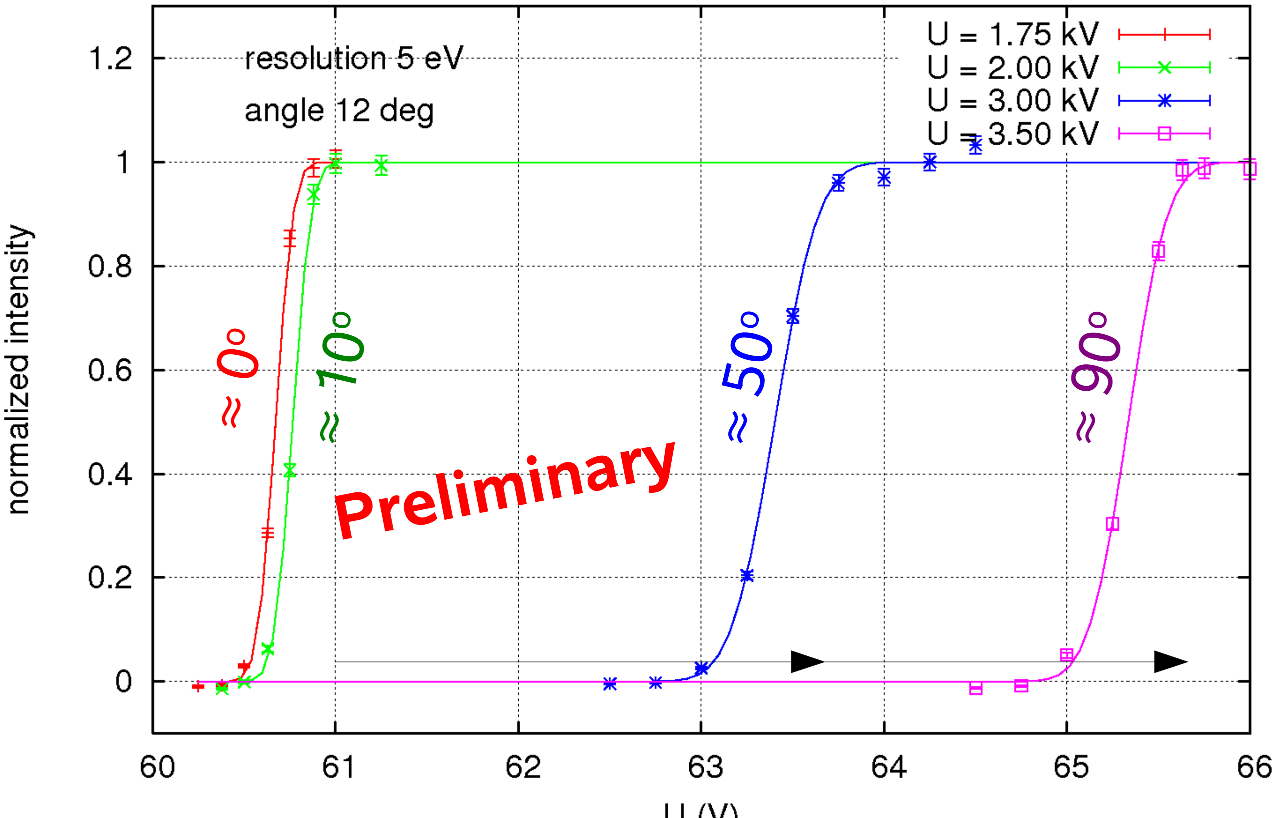
K. Valerius et al.,
NJP 11 (2009) 063018
(without angular-definition)

Idea:
fast non-adiabatic acceleration with adjustable non-parallel E and B fields

Angle at
electron source: 0° … 3.3°
pinch magnet: 0° … 90°

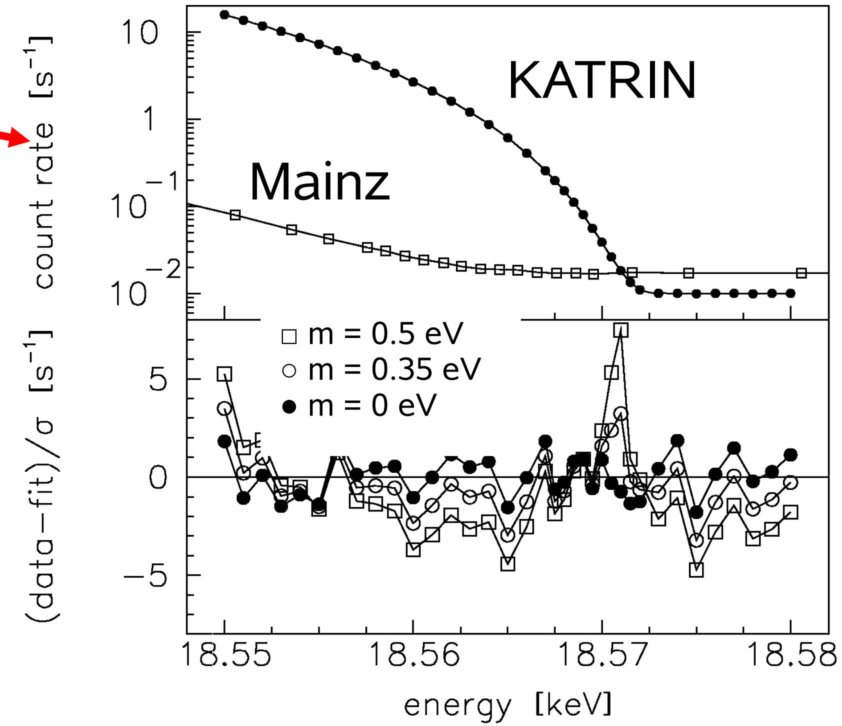




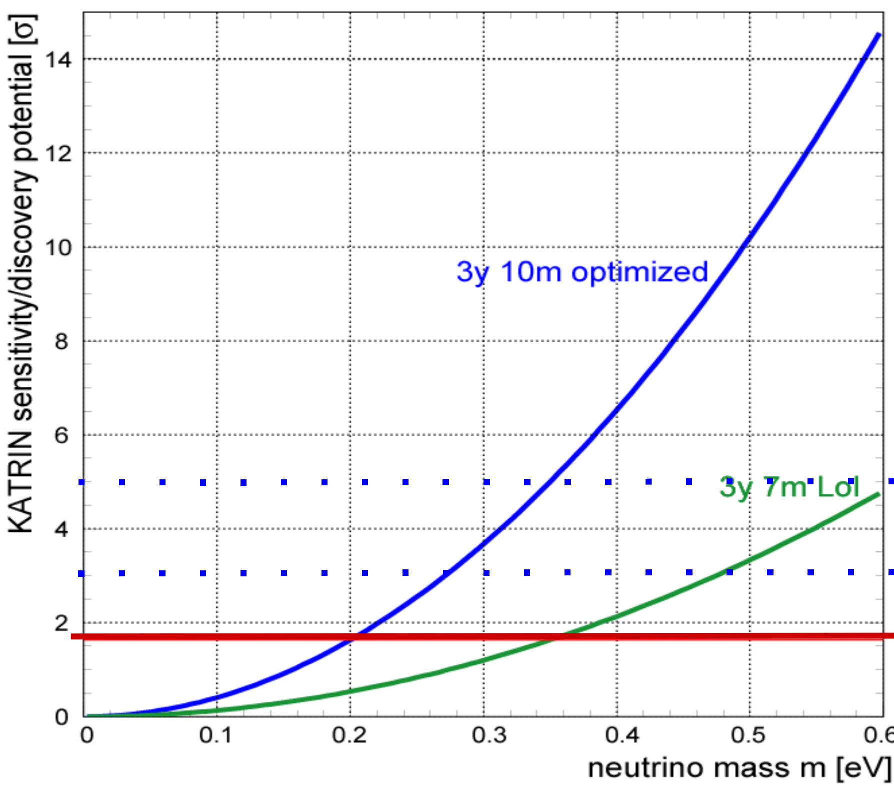


KATRIN´s sensitivity

Example of KATRIN simulation & fit
(last 25eV below endpoint, reference):



Expectation for 3 full beam years: $\sigma_{syst} \sim \sigma_{stat}$



discovery potential:

m_ν = 0.35eV (5σ)

m_ν = 0.3eV (3σ)

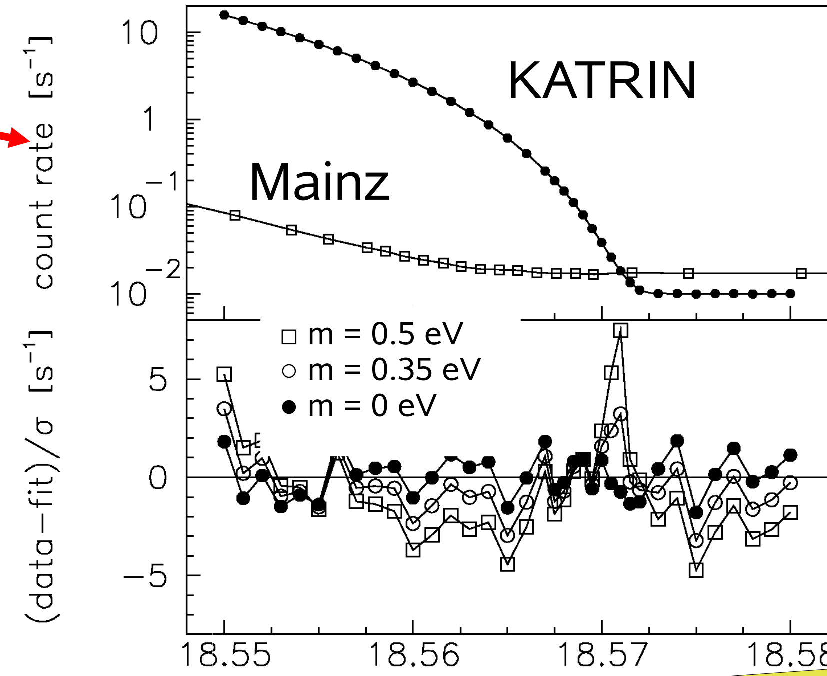
sensitivity:

m_ν < 0.2eV (90%CL)

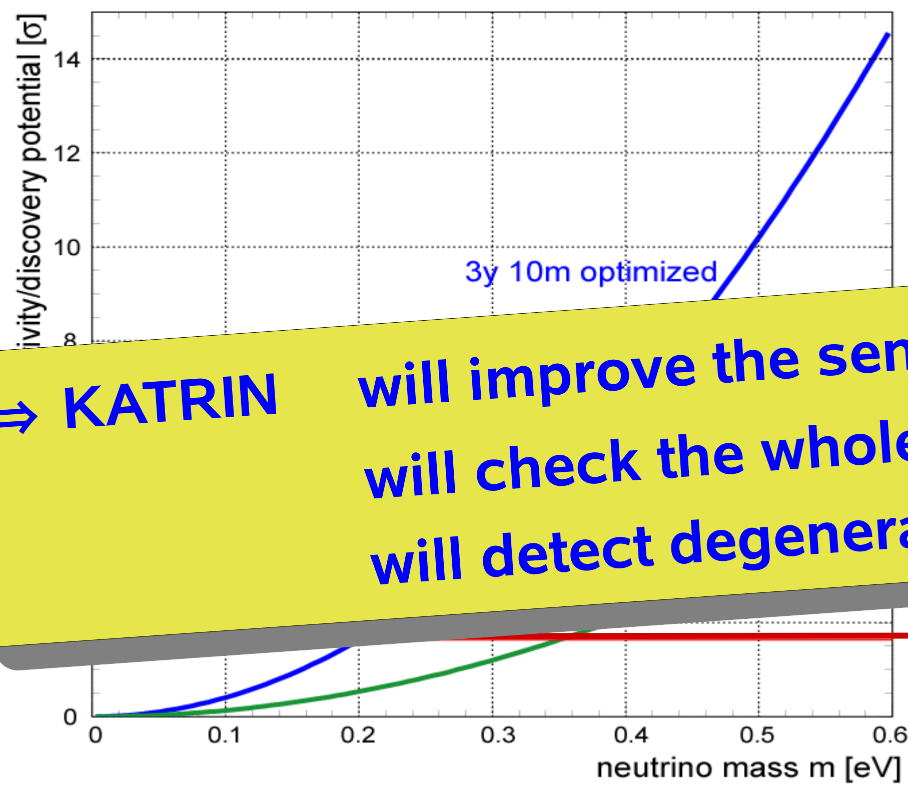
KATRIN´s statistical uncertainty

Westfälische Wilhelms-Universität Münster

Example of KATRIN simulation & fit
(last 25eV below endpoint, reference):



Expectation for 3 full beam years: $\sigma_{syst} \sim \sigma_{stat}$



⇒ **KATRIN** **will improve the sensitivity by 1 order of magnitude**
will check the whole cosmological relevant mass range
will detect degenerate neutrinos (if they are degen.)

m_ν = 0.3eV (3σ)

sensitivity:
m_ν < 0.2eV (90%CL)

Conclusion

Some of the KATRIN highlights in 2009:

WGTS:	Laser Raman spectroscopy per mille sensitivity demonstrated
DPS2-F:	arrived, commissioning has started
Pre spectrometer:	background has been reduced by 4 orders
Main spectrometer:	Air coil system completed
	Inner electrode installation has started
Calibration:	Monitor spectrometer is being installed
	Implanted ^{83}Rb sources are very stable (ppm)
	New angular-defined e-gun demonstrated

KATRIN: 0.2 eV sensitivity:

2009-11 commissioning of main spectrometer and detector

2009-12 commissioning of tritium source and tritium elimination lines

2012- regular data taking for 5-6 years (3 full-beam-years)

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