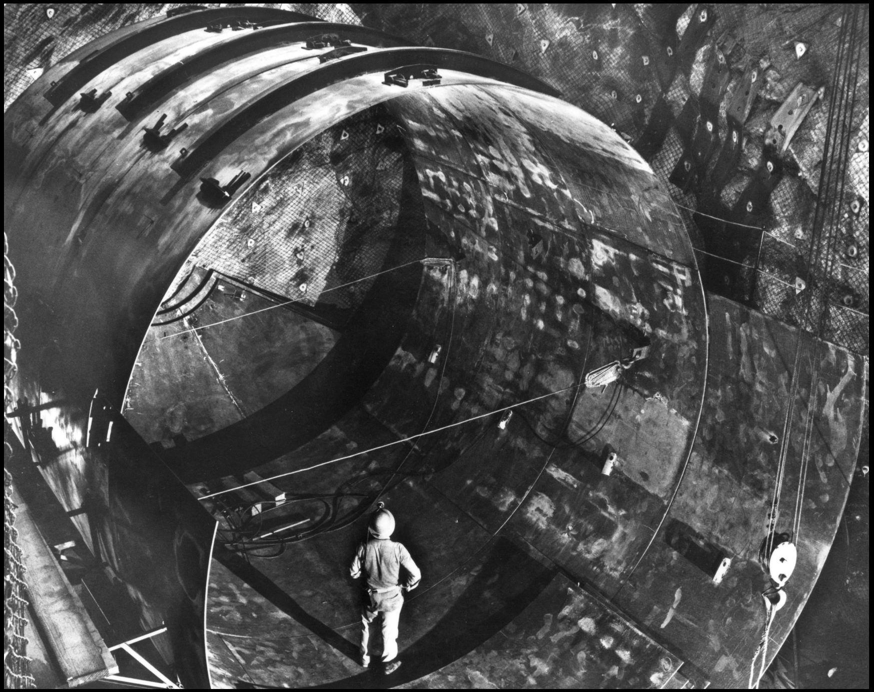
KATRIN:

Probing Nature's Smallest Mass Scale

Neutrino Mass in Context



1970: R Davis, Jr. and J Bahcall start counting Ar atoms produced by solar ν's in a tank of dry cleaning fluid, coming up short- B Pontecorvo and V Gribov think they might know why...

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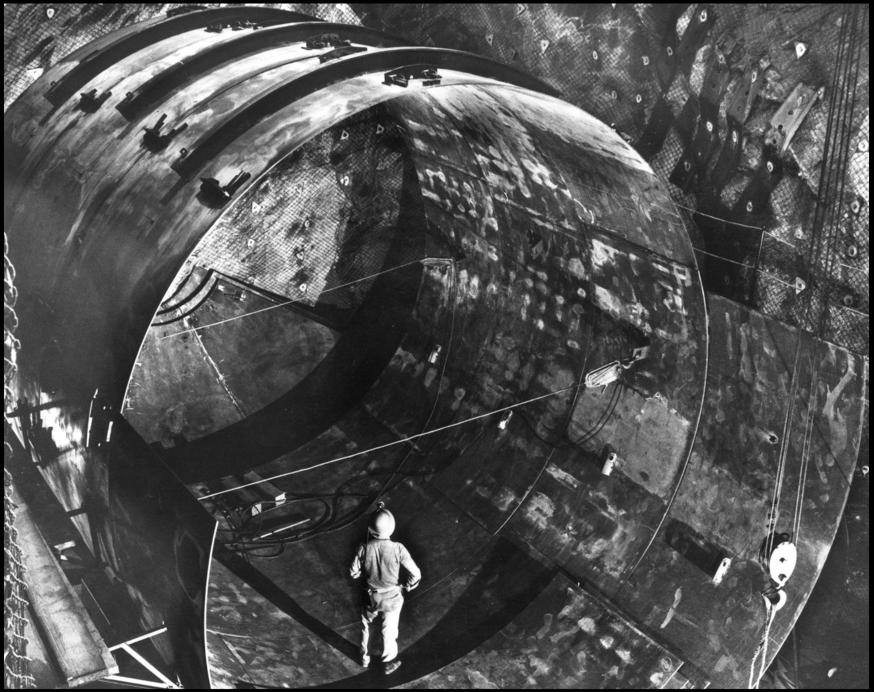

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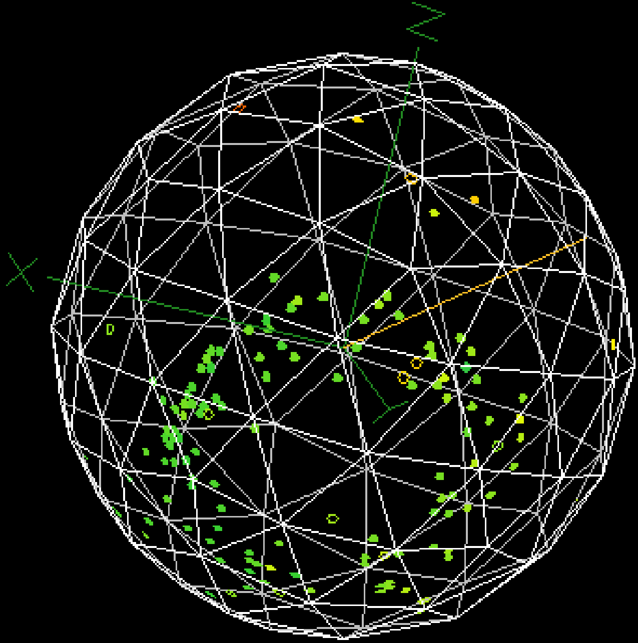
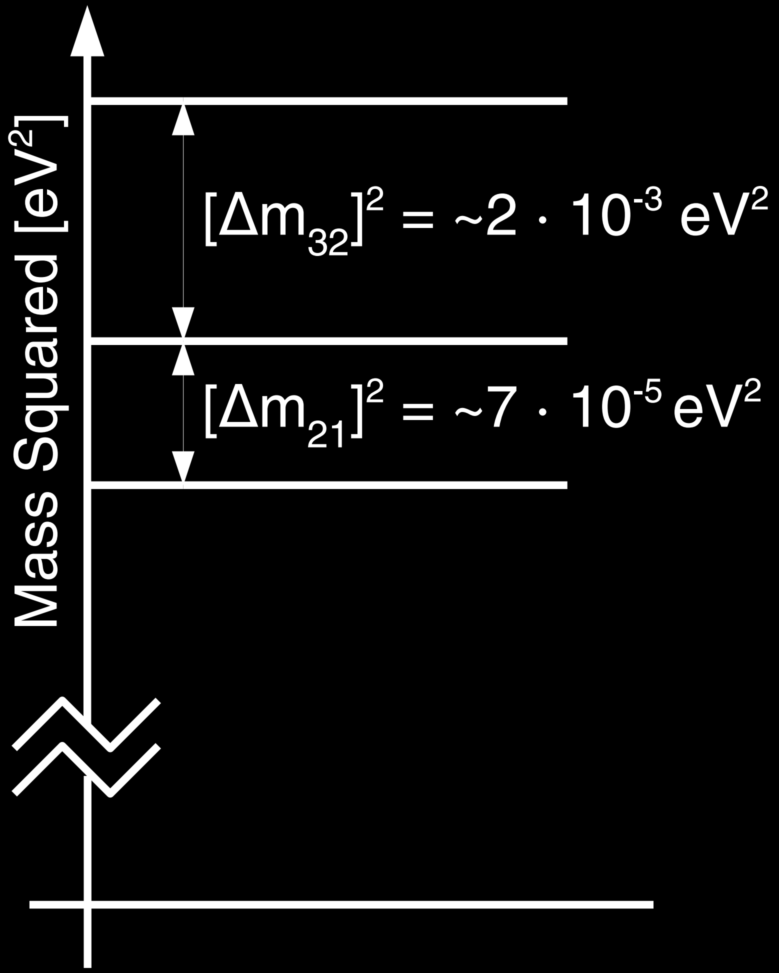


1998: The Super-Kamiokande experiment shows the mechanism that Pontecorvo and Gribov proposed is responsible: neutrino oscillations occur, implying neutrinos have mass

Neutrino Mass in Context

- neutrino flavor eigenstates are different from their mass eigenstates
- PNMS matrix for neutrinos is analogous to CKM matrix for quarks
- all mixing angles have been measured



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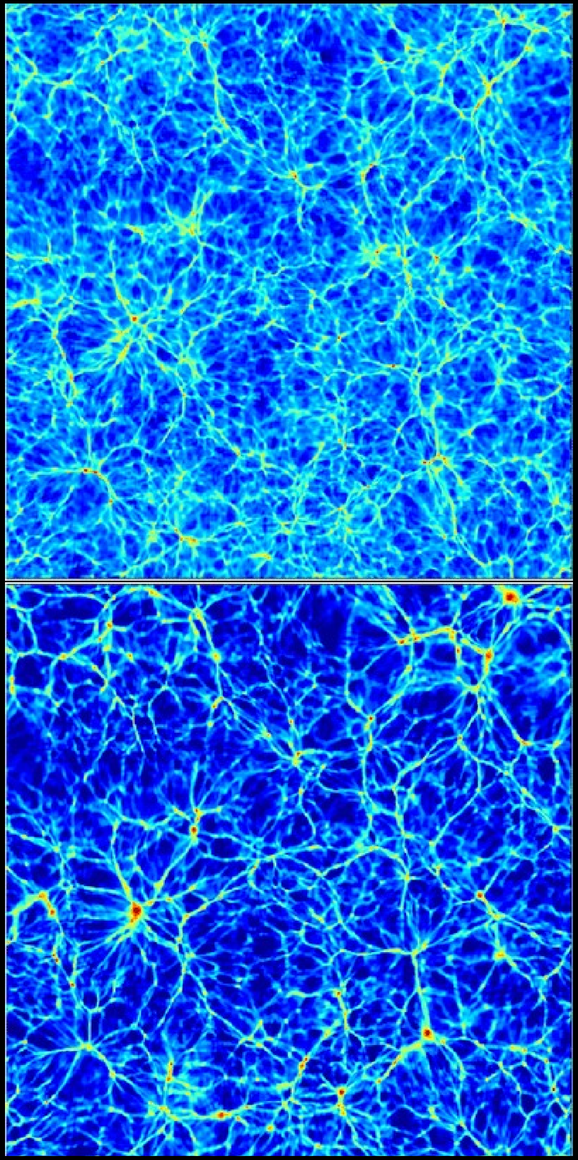

- most common fermion in the universe (336 cm^{-3})
- massive neutrinos act as hot dark matter and erase small scale structures

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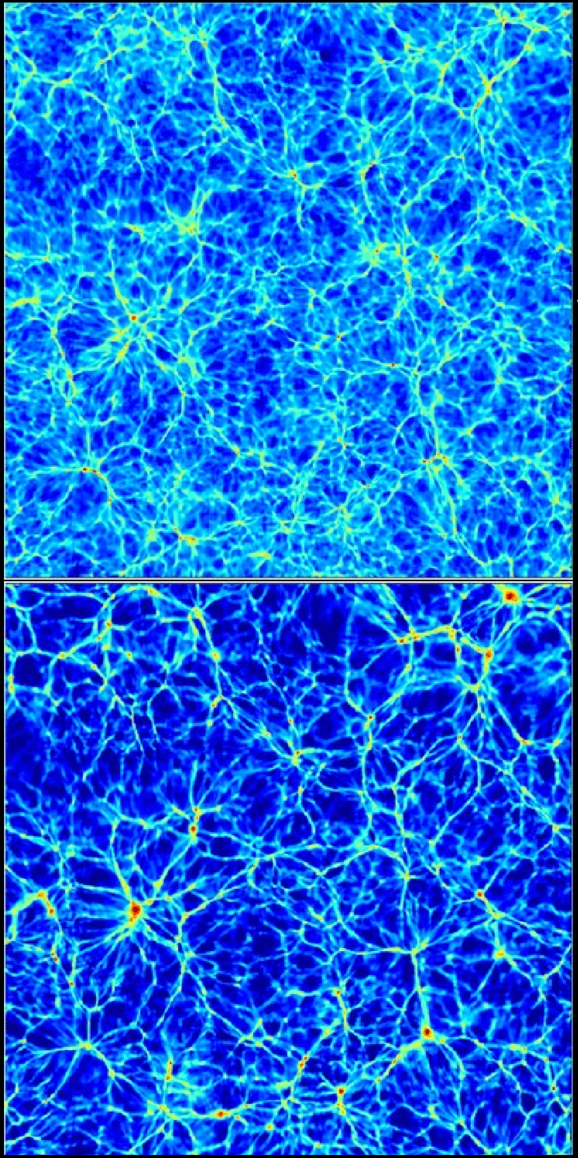

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numerical simulations of large scale structure in the universe with different neutrino masses

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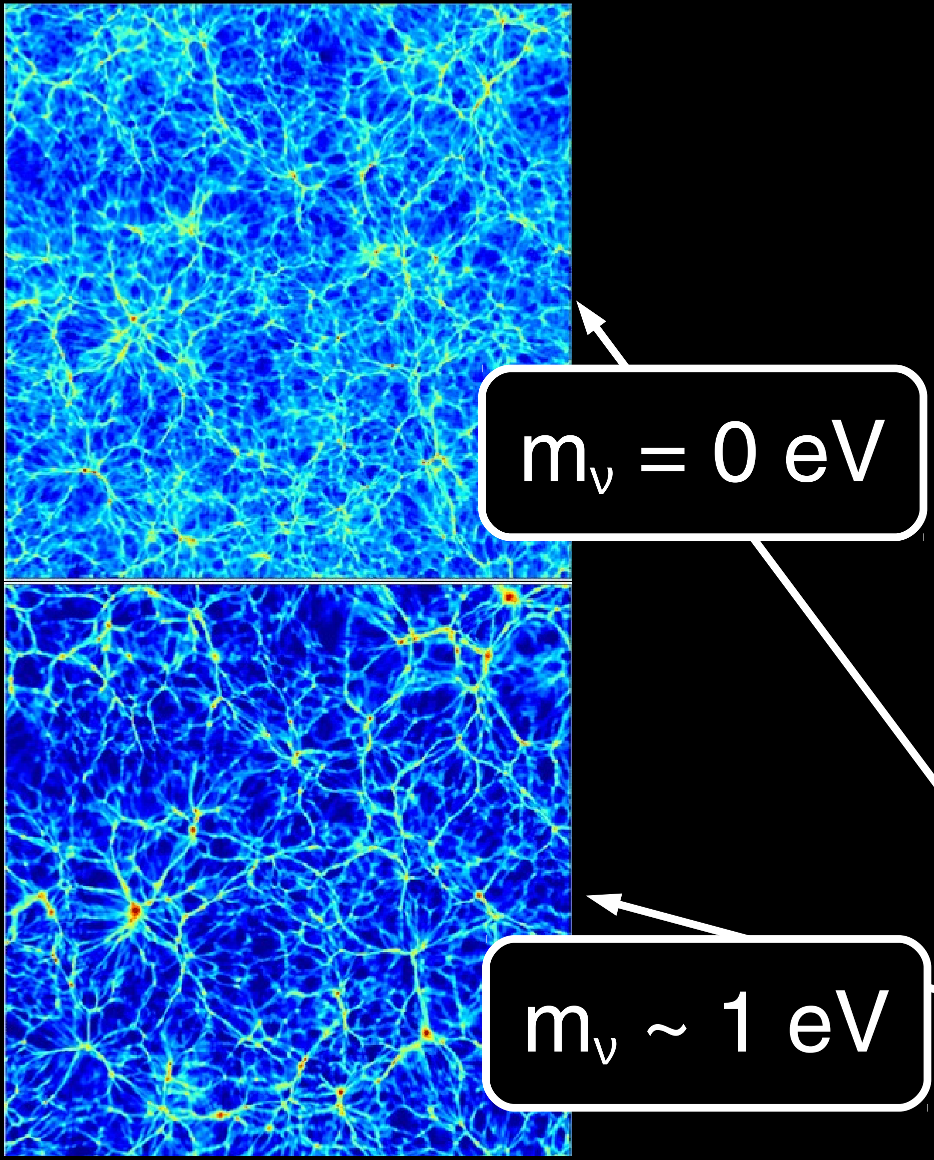

$m_\nu = 0$ eV

$m_\nu \sim 1$ eV

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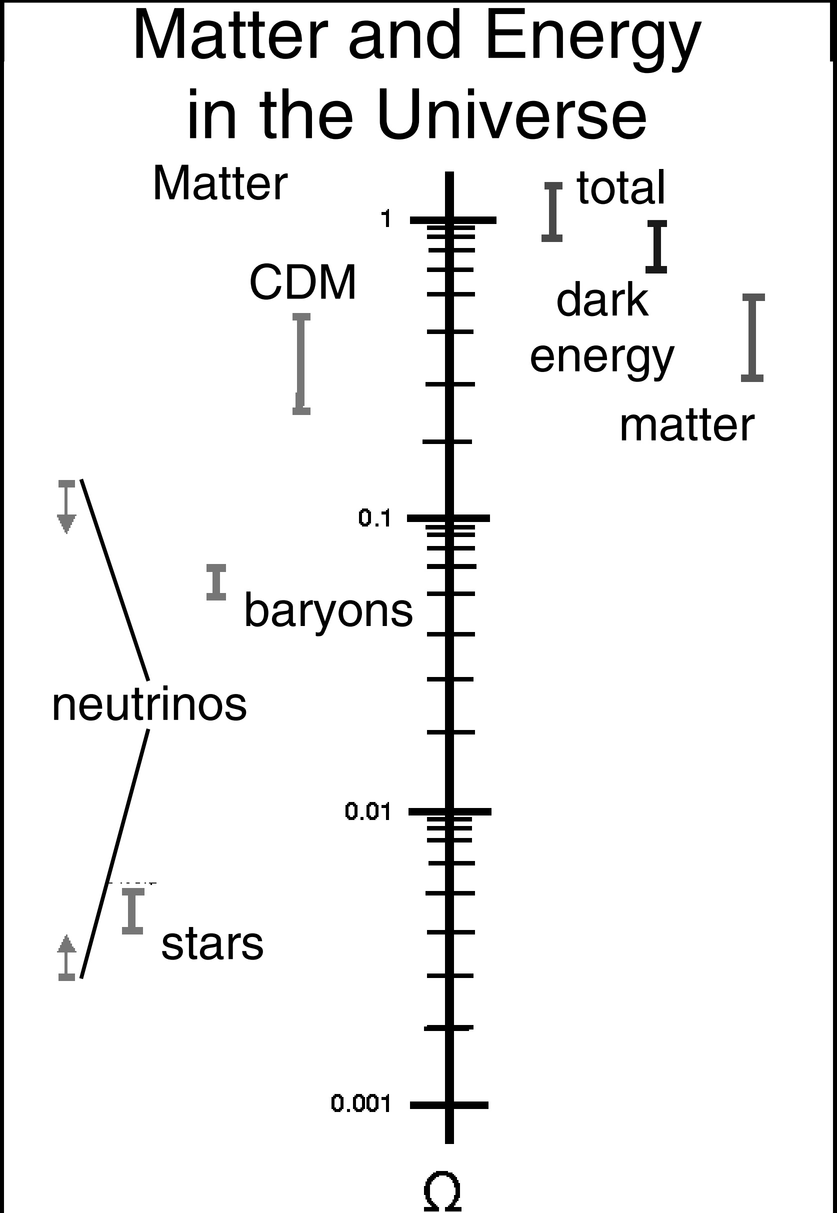
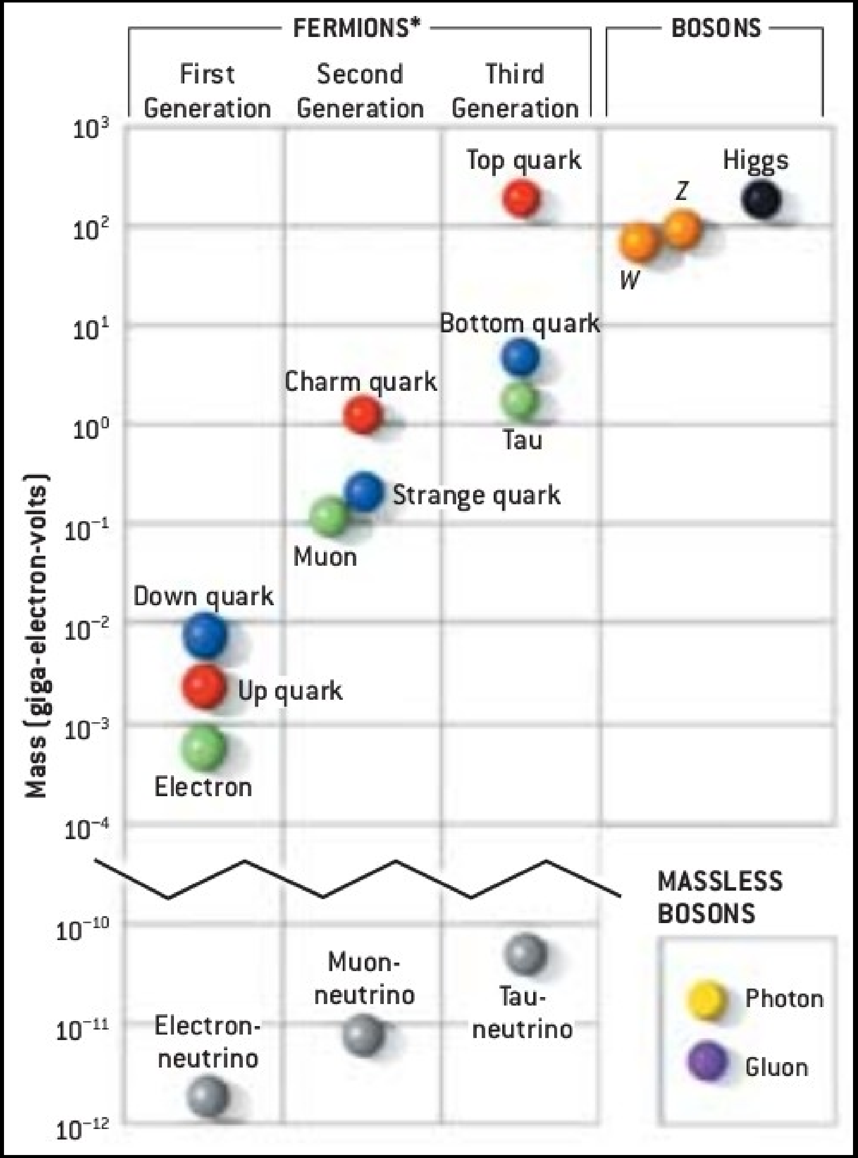


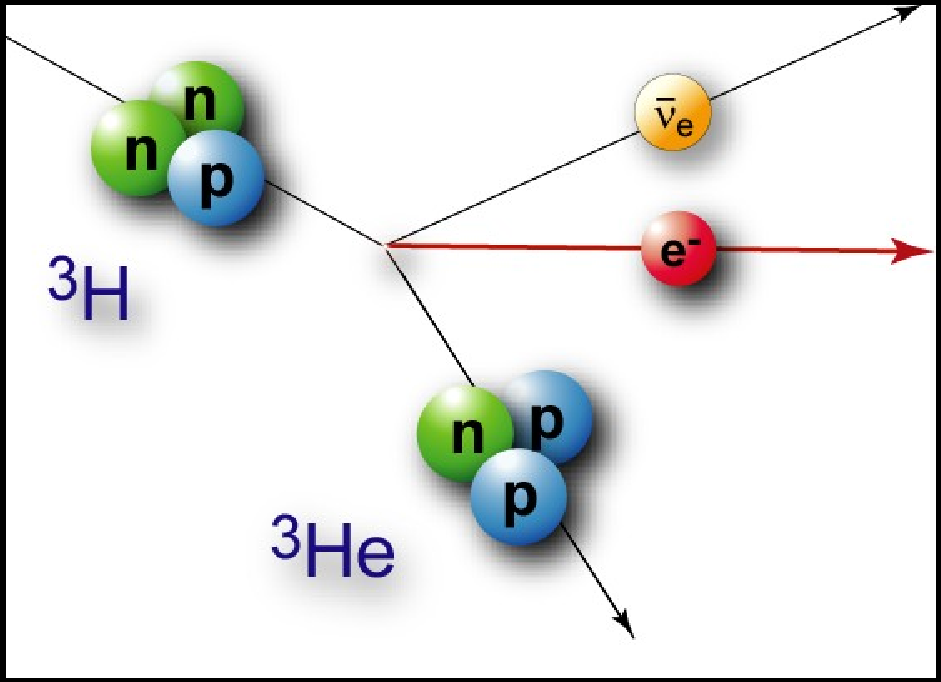
- most common fermion in the universe (336 cm^{-3})
- massive neutrinos act as hot dark matter and erase small scale structures
- neutrino contribution to matter density still only roughly known

Neutrino Mass in Context

- neutrinos are between five and six orders of magnitude lighter than the electron
- neutrinos may have majorana mass
- fine-tuning problem, new fundamental physics scale



Neutrino Mass from Tritium Decay

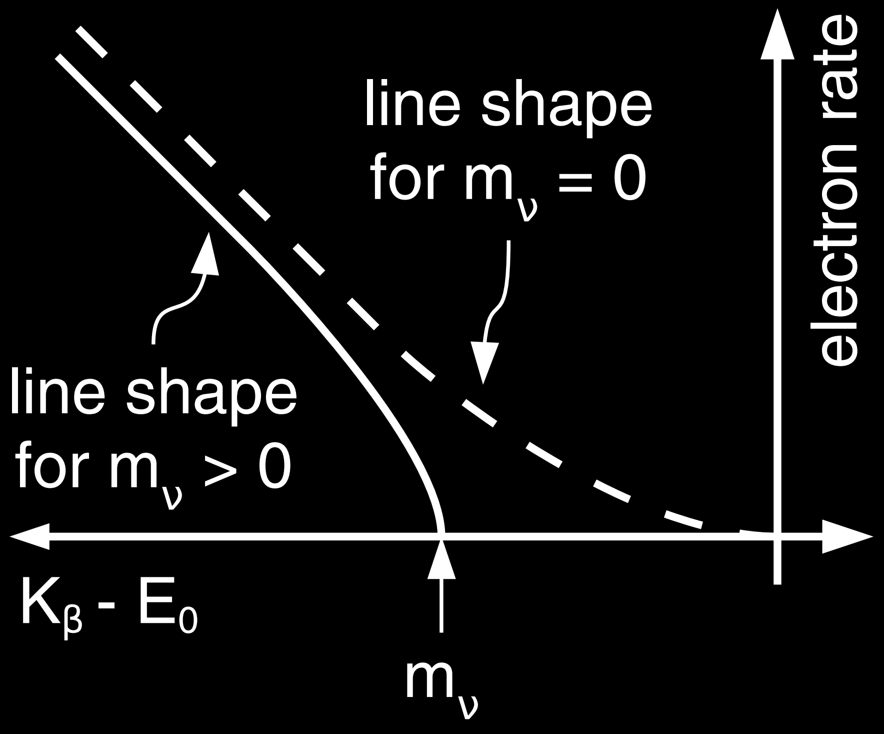


- half life of 12.3 years
- 18.6 keV of decay energy distributed among three products
- neutrino escapes undetected, but its mass affects the electron spectrum from kinematics alone

Neutrino Mass from Tritium Decay

- neutrino mass reduces endpoint electron energy
- spectrum tail acquires a characteristic curvature
- only one in $2 \cdot 10^{13}$ electrons falls in the relevant region of the spectrum

final eV of tritium beta spectrum



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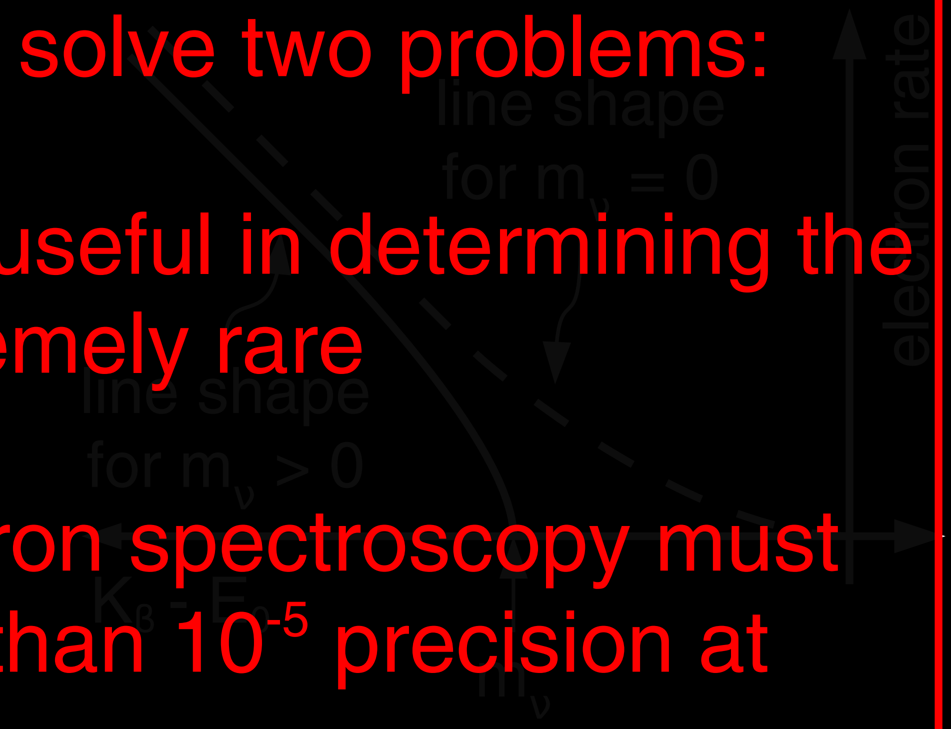
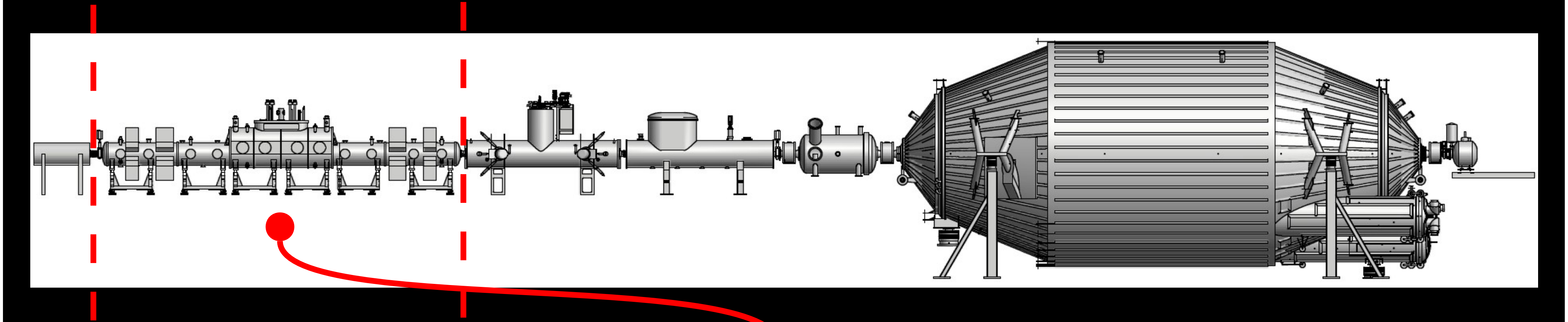


Any neutrino mass experiment exploiting the tritium endpoint must solve two problems:

- Luminosity – electrons useful in determining the neutrino mass are extremely rare
- Resolution – beta electron spectroscopy must be performed to better than 10^{-5} precision at nearly 20 keV

KATRIN: Overview



Source Section: gaseous tritium injected and removed under a high magnetic field which guides electrons

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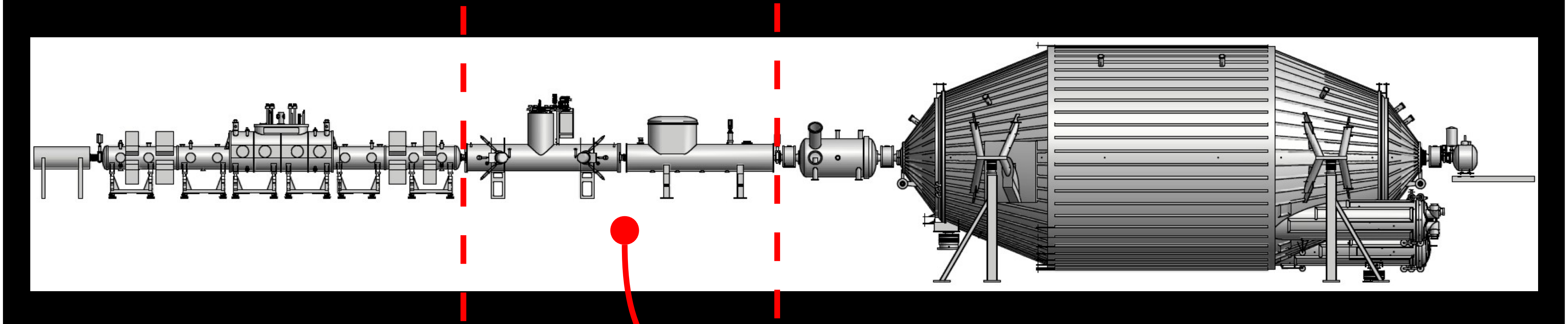

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Transport Section: residual tritium removed and remaining ions analyzed, high B-field transports electrons downstream

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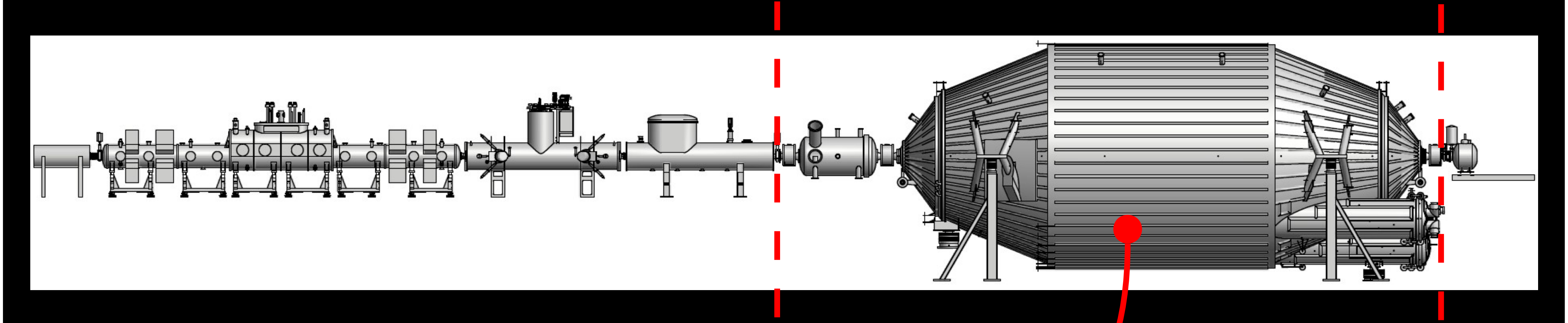

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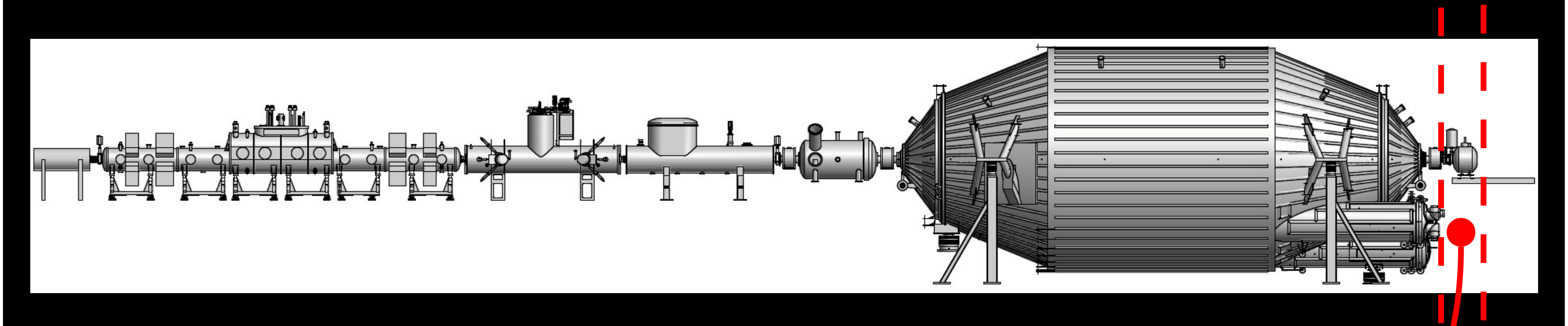

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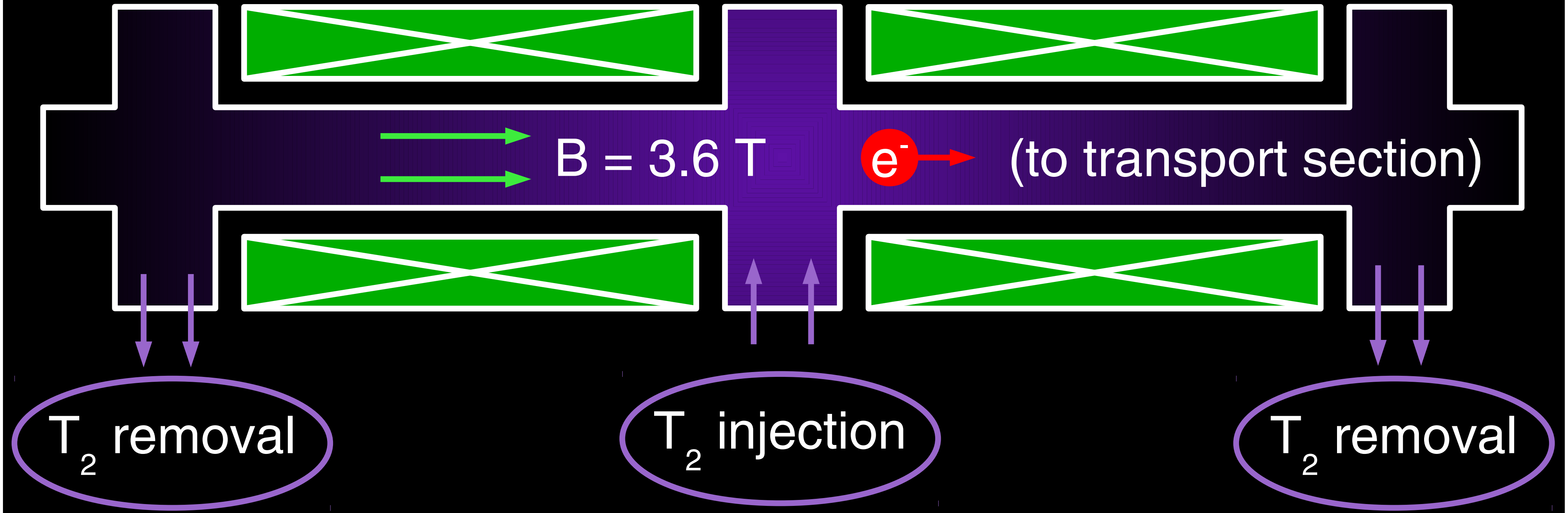
Detector Section: electrons undergo acceleration and are counted

Source: The WGTS



- pump tritium into beamline and then pump it all out again under high magnetic field
- electrons decaying in the beamline will be pinned to magnetic field lines, allowing them to be transported downstream

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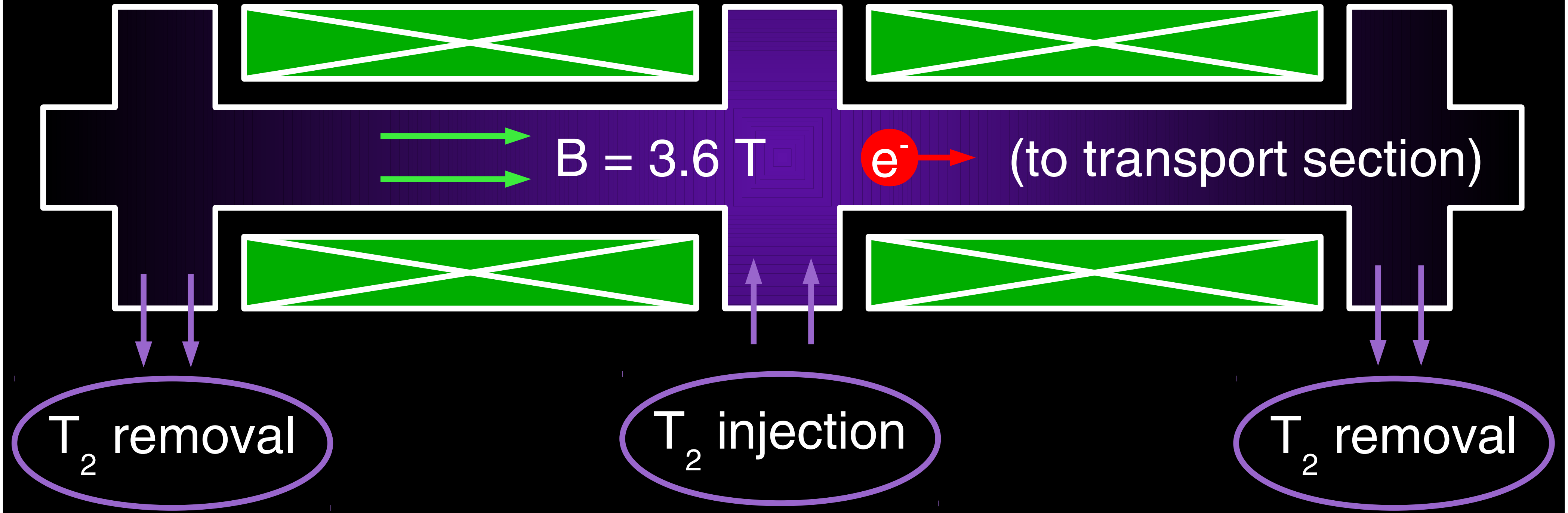

- removed tritium is recovered and re-injected with the help of a complex gaseous loop system
- column areal density must be extremely stable, which implies demanding pressure and temperature stability requirements

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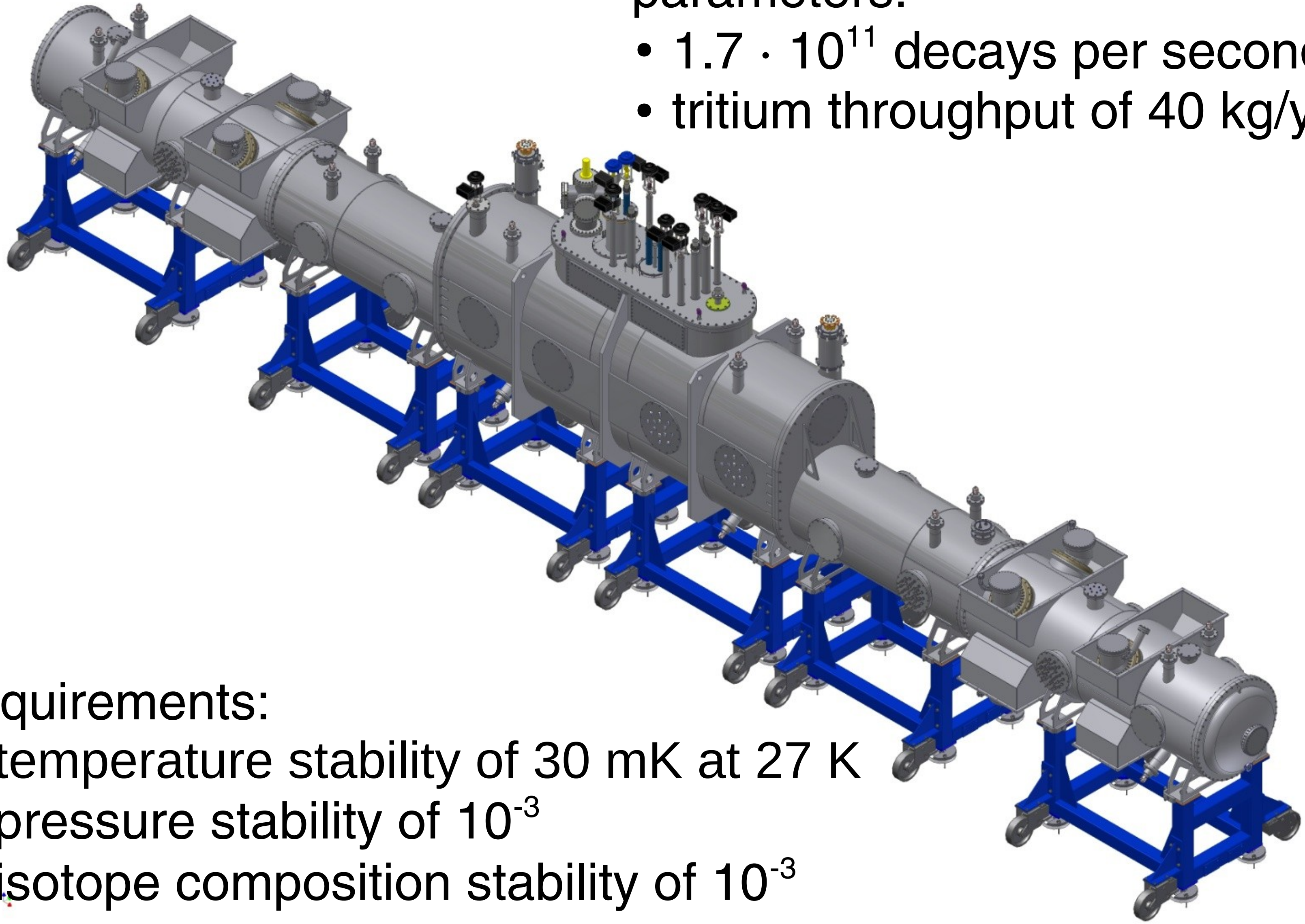
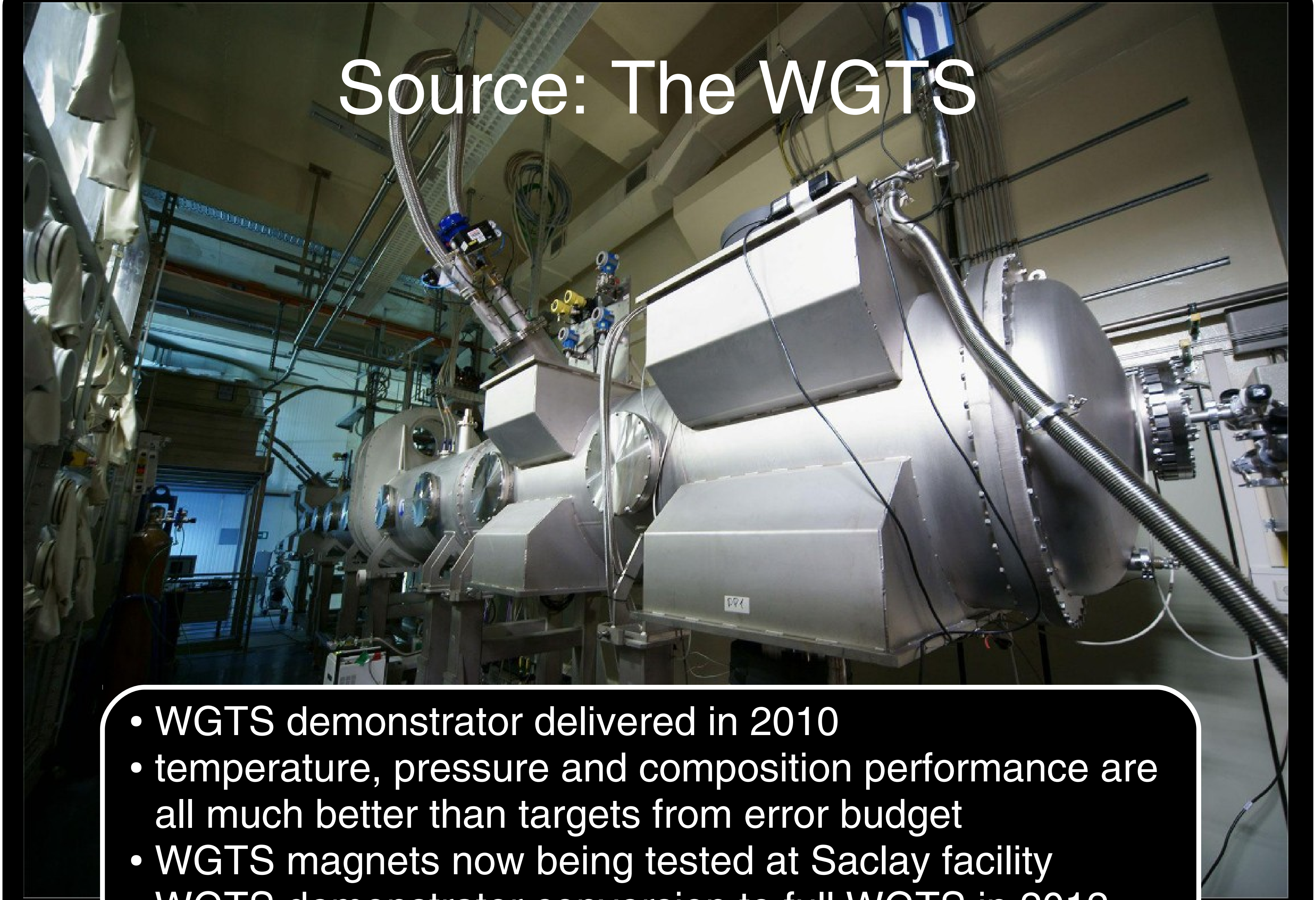


- parameters:
  - $1.7 \cdot 10^{11}$ decays per second
  - tritium throughput of 40 kg/year

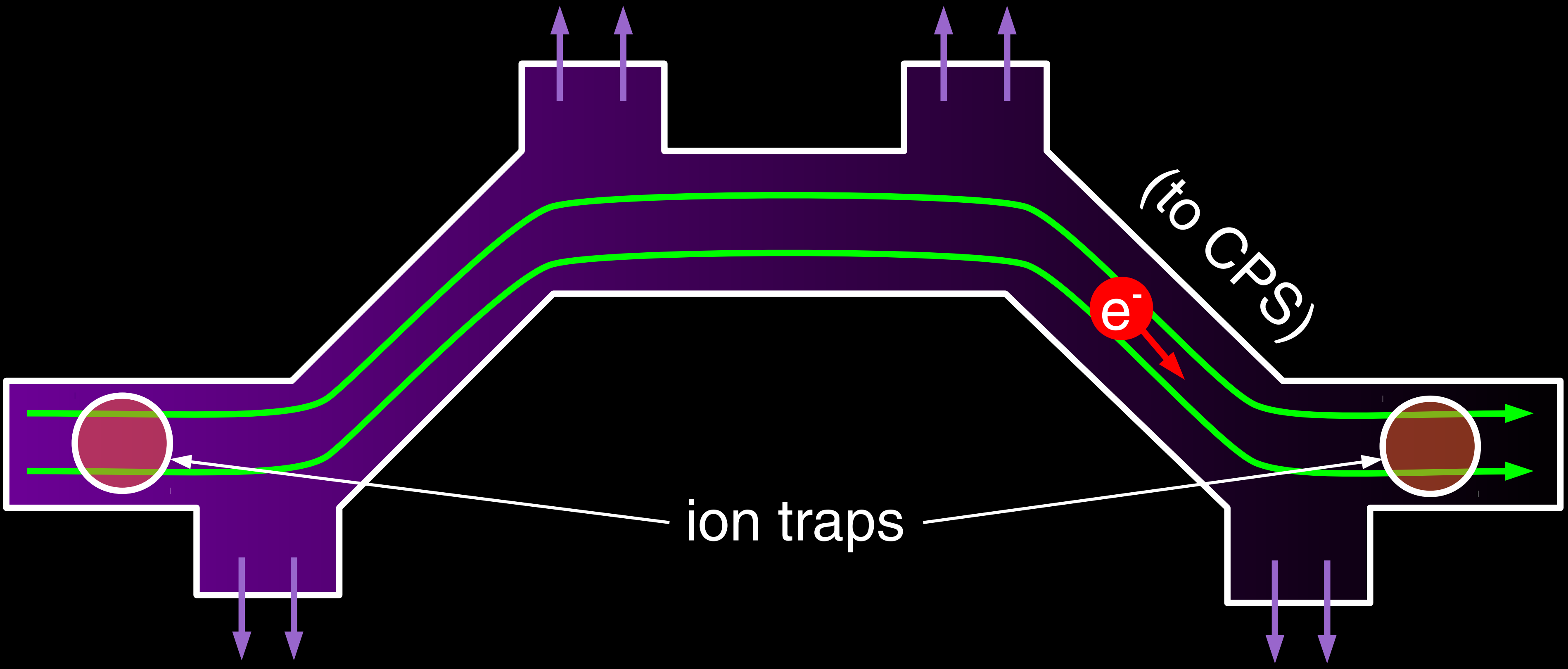
- requirements:
  - temperature stability of 30 mK at 27 K
  - pressure stability of 10^{-3}
  - isotope composition stability of 10^{-3}

Source: The WGTS



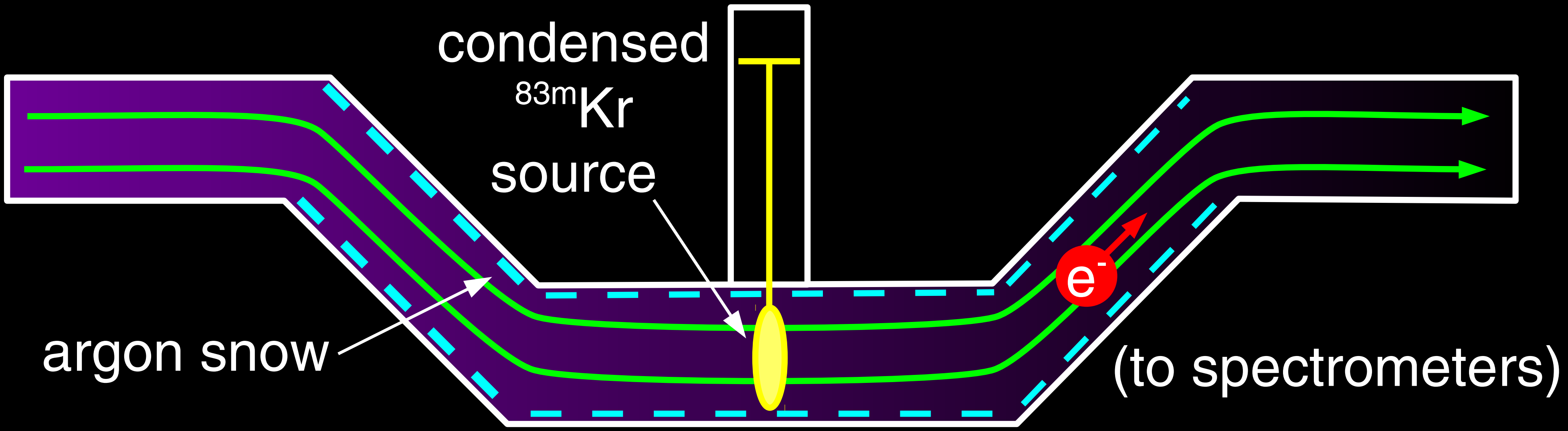
- WGTS demonstrator delivered in 2010
- temperature, pressure and composition performance are all much better than targets from error budget
- WGTS magnets now being tested at Saclay facility
- WGTS demonstrator conversion to full WGTS in 2012

Transport: The DPS



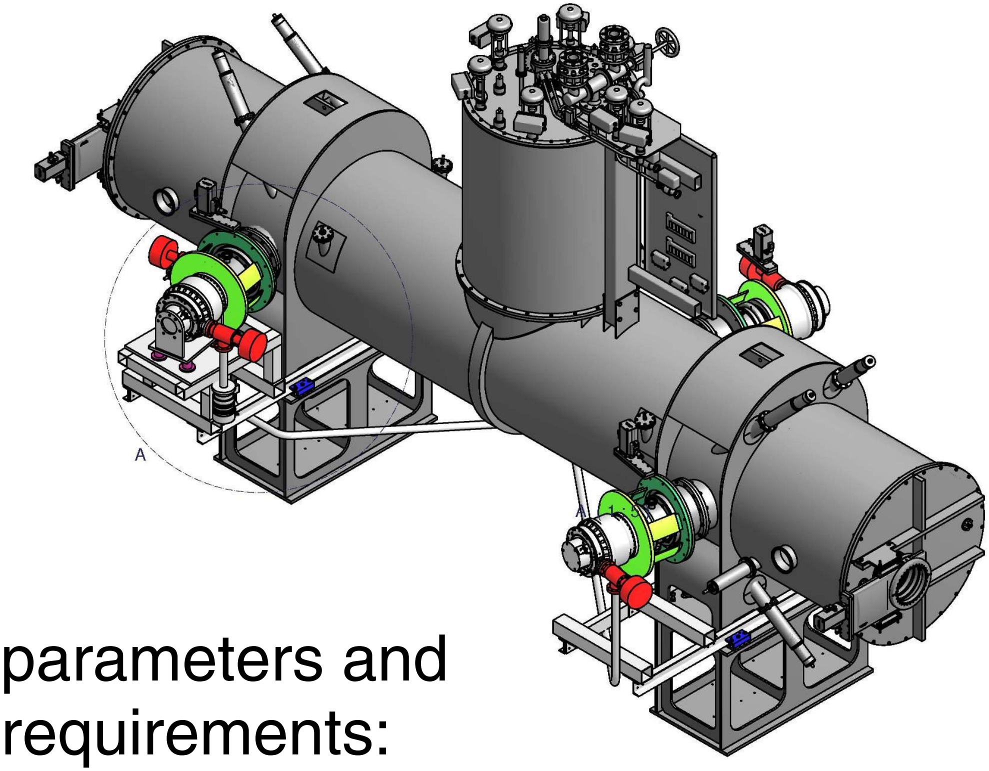
- four large turbopumps remove residual tritium from WGTS
- chicane prevents direct path from source to spectrometers
- two ion traps can be switched on to measure tritium reduction factor, dipoles eliminate residual ions
- strong, uniform magnetic field maintained for transport

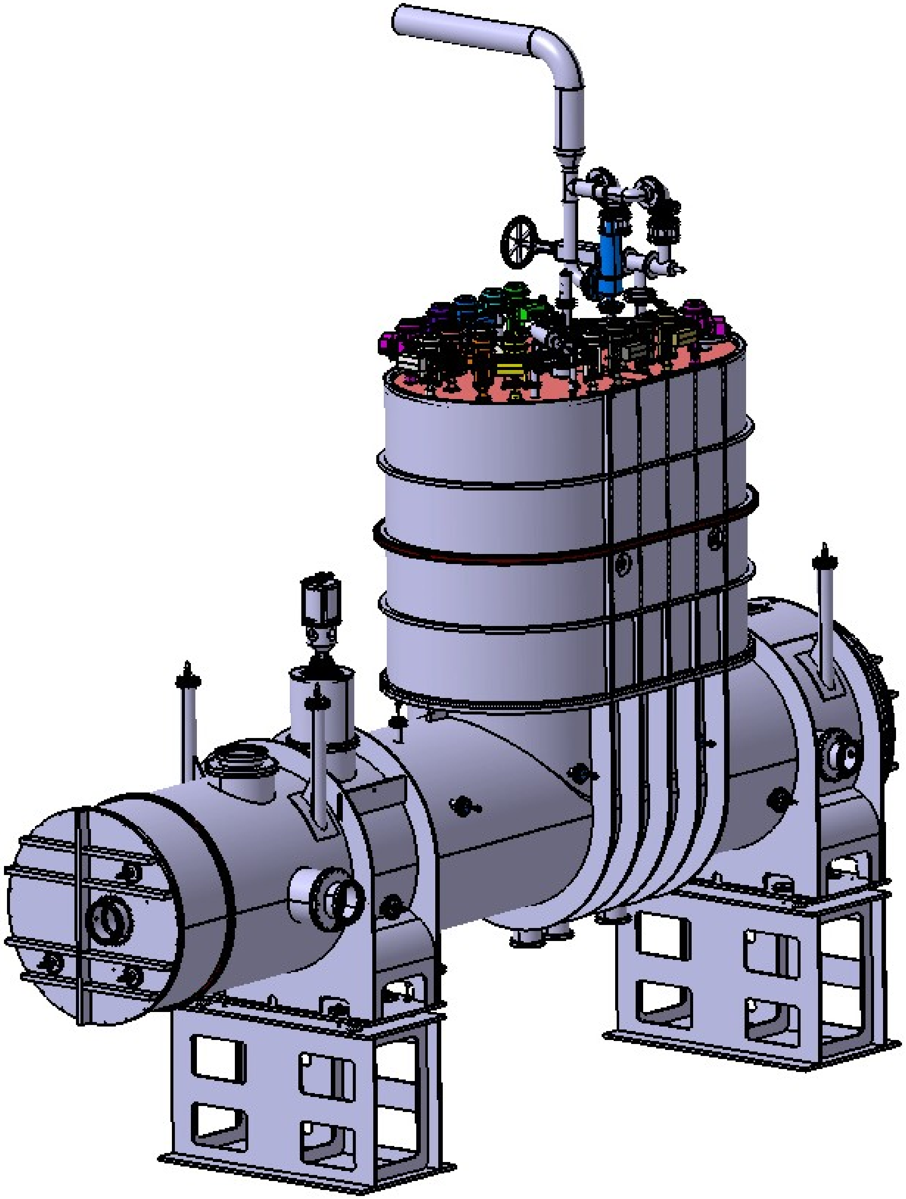
Transport: The CPS



- layer of argon snow removes final residual tritium inbound from the DPS
- second chicane to further shield spectrometer section
- condensed krypton source to provide calibration of transmission function in tritium-free conditions

Transport: The DPS and CPS





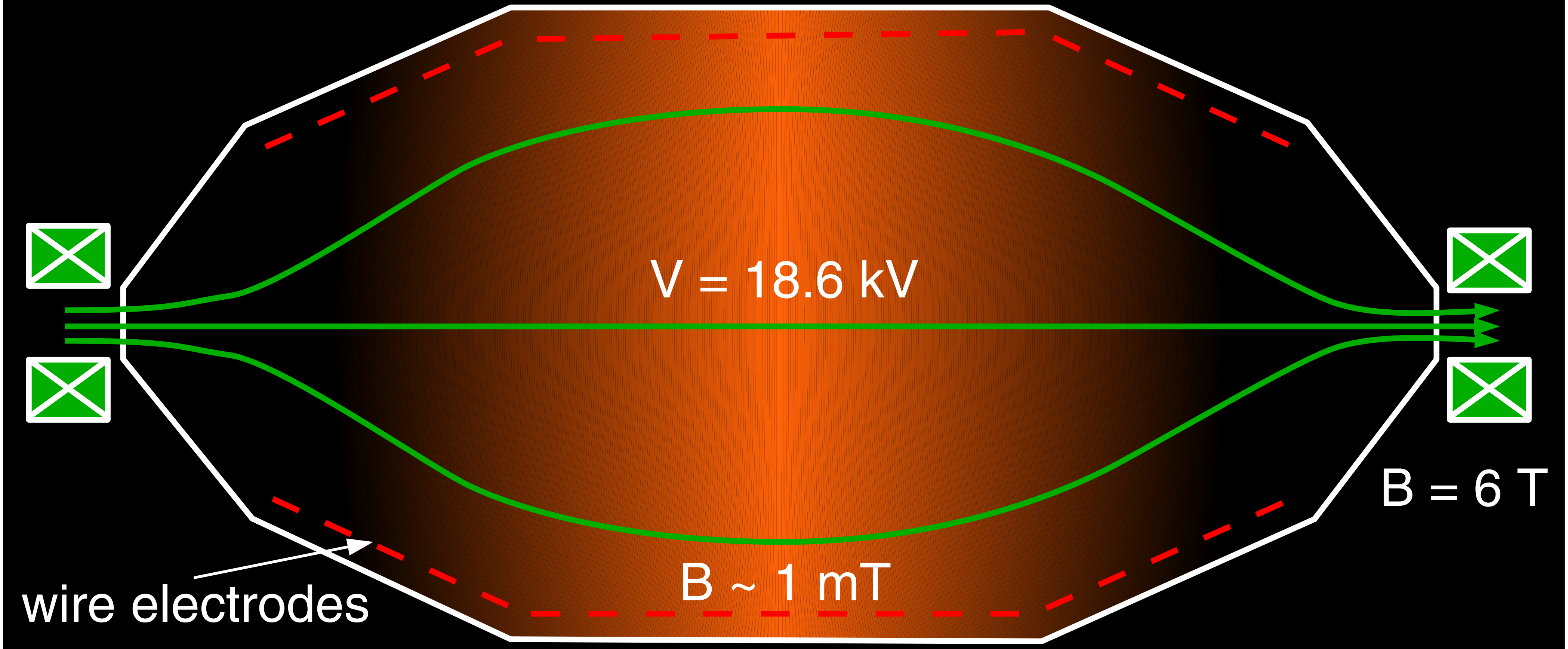
parameters and requirements:

- guiding field of 5.6 T
- reduction of ion flow by a factor of 10^5
- reduction of tritium flow by a factor of 10^{14}

Transport: The DPS and CPS

- DPS flow reduction without ion traps in agreement with simulations and within performance targets
- CPS diodes being refitted by ASG, delivery in 2014

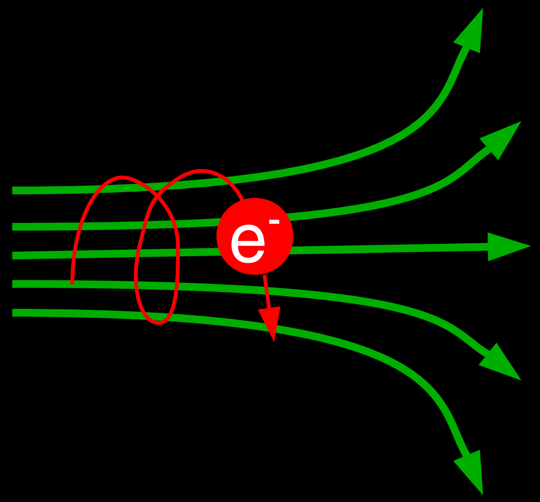
Analysis: The Spectrometers



- internal electrode system provides a potential smoothly ranging from 0 V to 18 kV
- magnetic field ranges from a maximum of 6 T at ports to about 1 mT in the central region

Interlude: The MAC-E Principle

if an electron is moving in a magnetic field that varies little over a single cyclotron gyration, the orbital magnetic moment of the electron is an adiabatic invariant of its motion



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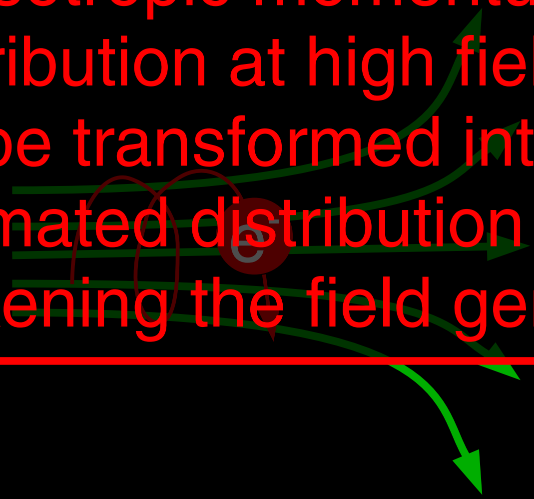

an isotropic momentum distribution at high field can be transformed into a collimated distribution by weakening the field gently

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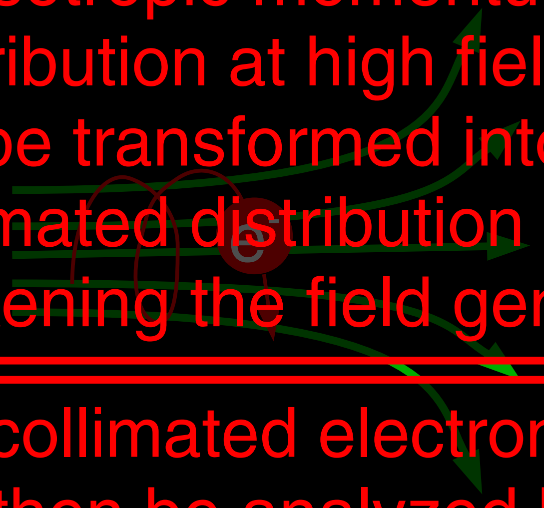

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the collimated electrons can then be analyzed by an electrostatic filter

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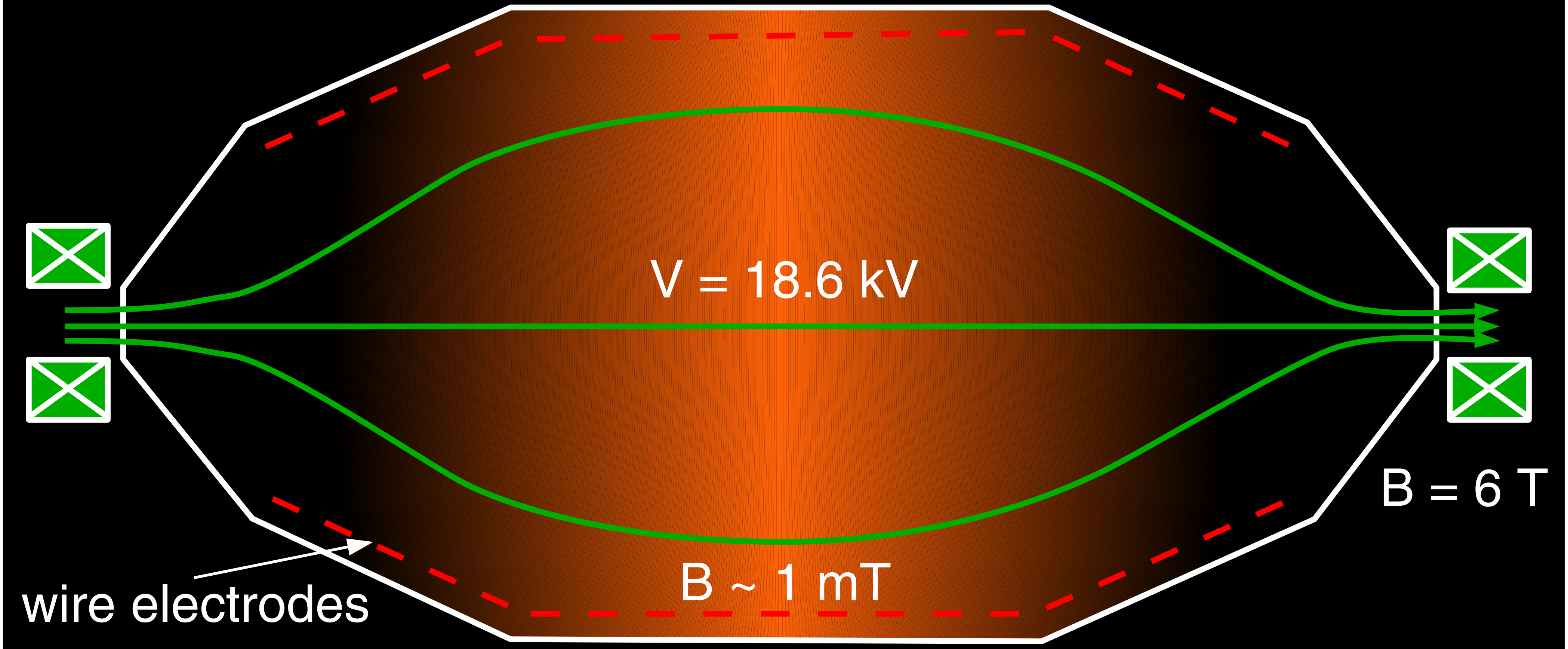
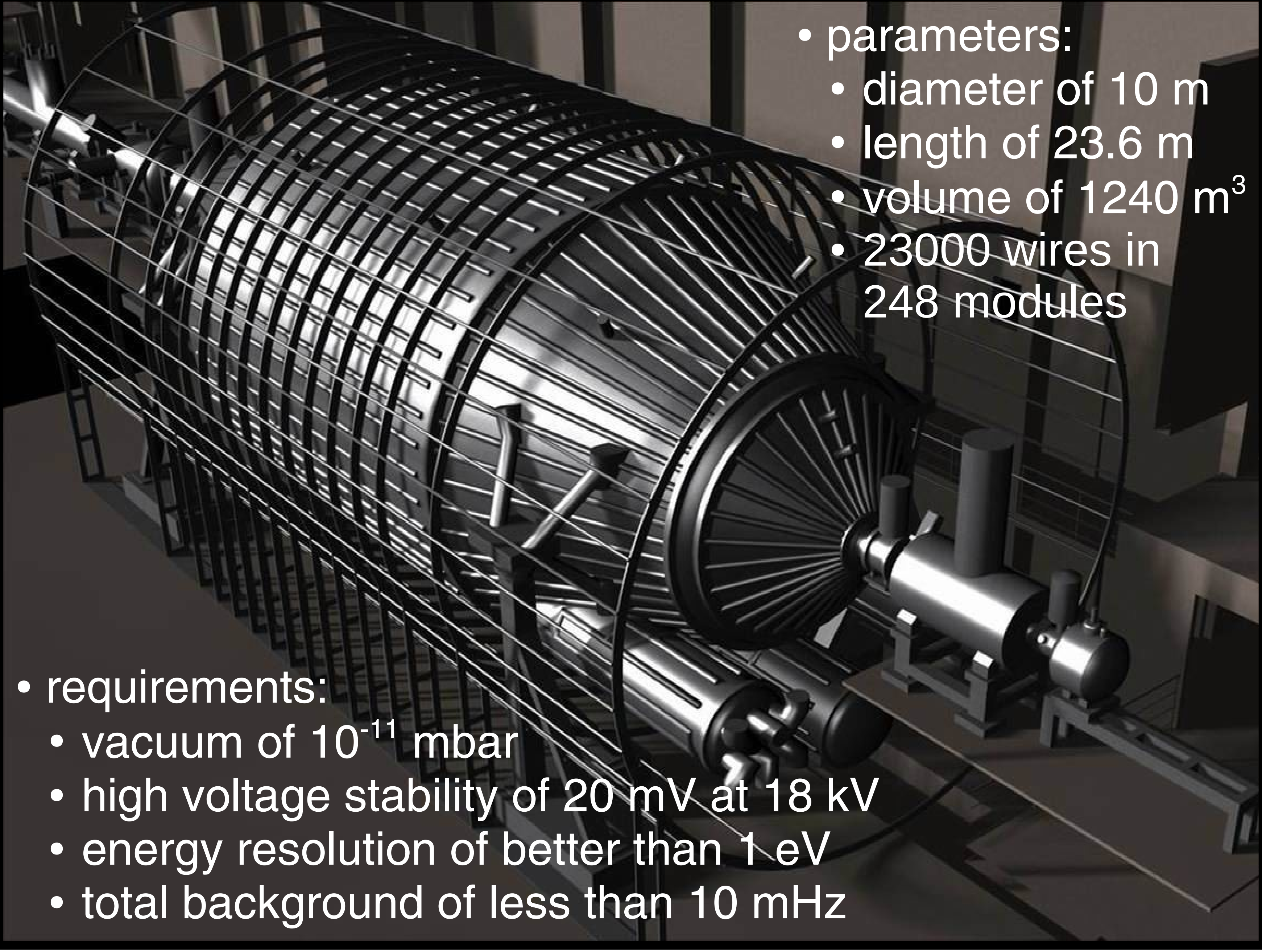


- resolution of MAC-E filter depends on the ratio B_{min}/B_{max}
- high resolution spectrometers are also excellent magnetic bottles
- electrons from nuclear decays in the spectrometer are trapped in the bottle causing backgrounds

Analysis: The Spectrometers



- parameters:
  - diameter of 10 m
  - length of 23.6 m
  - volume of 1240 m^3
  - 23000 wires in 248 modules

- requirements:
  - vacuum of 10^{-11} mbar
  - high voltage stability of 20 mV at 18 kV
  - energy resolution of better than 1 eV
  - total background of less than 10 mHz

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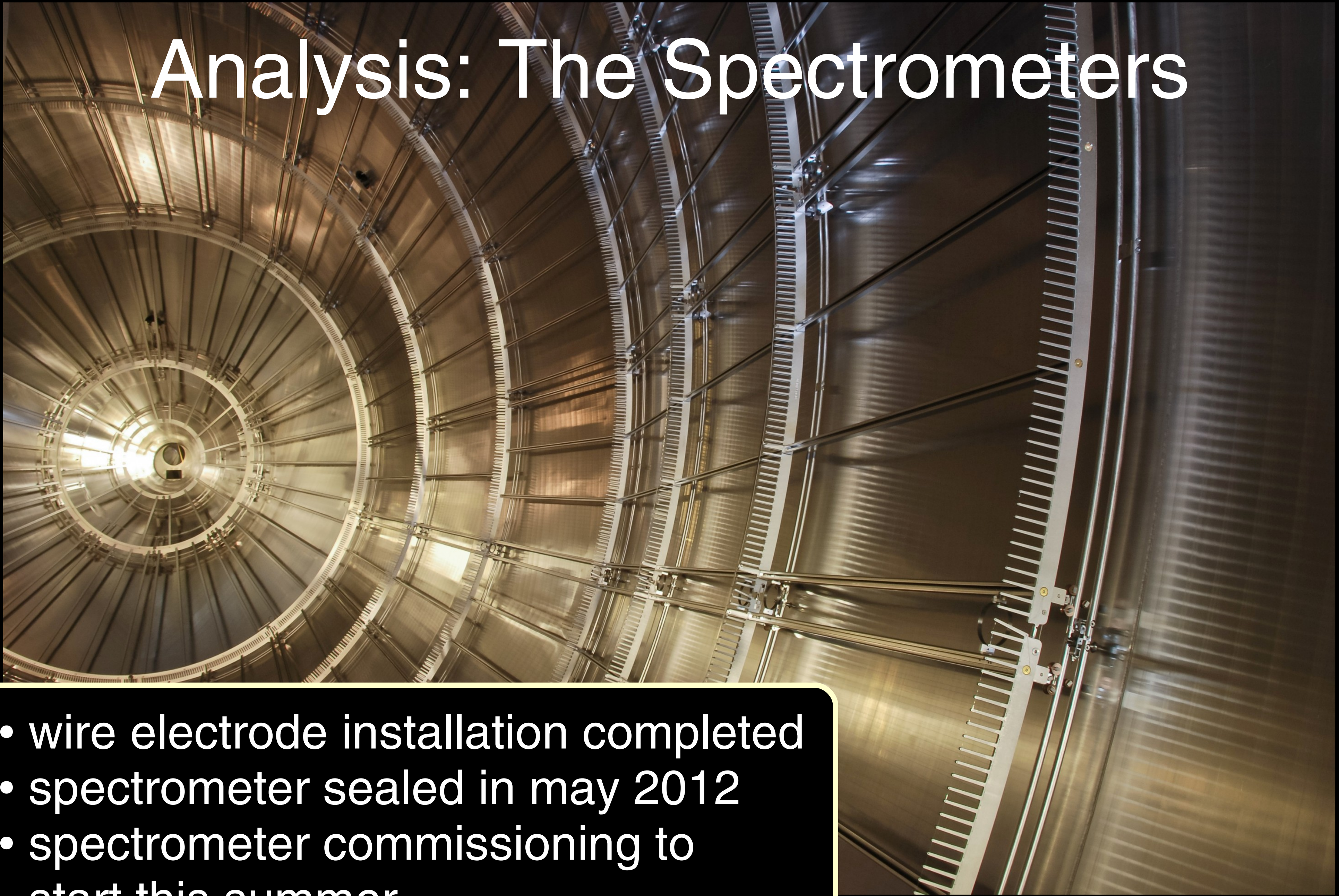
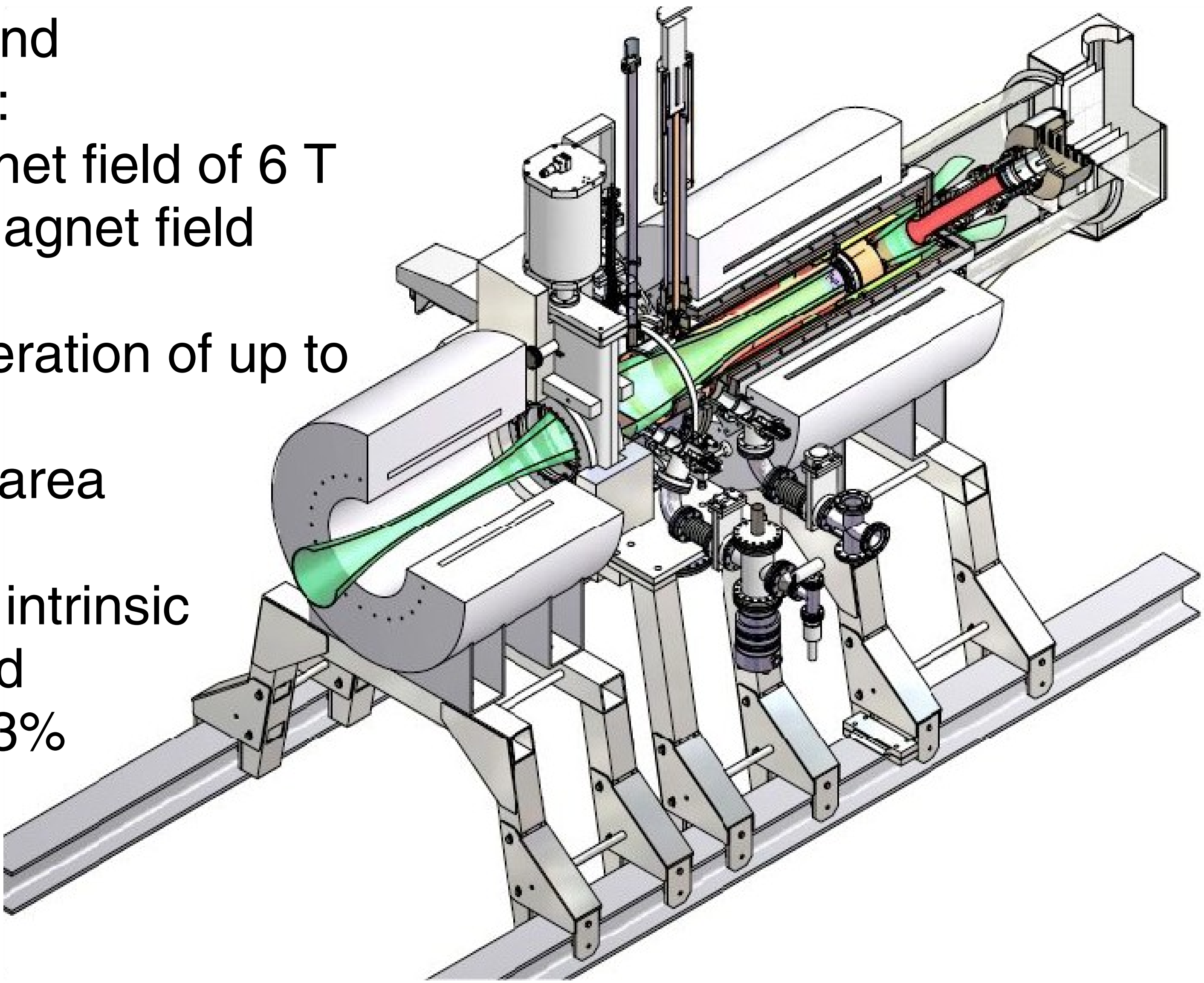


- wire electrode installation completed
- spectrometer sealed in may 2012
- spectrometer commissioning to start this summer

Signal: The FPD

parameters and requirements:

- pinch magnet field of 6 T
- focusing magnet field of 3 – 5 T
- post acceleration of up to 30 kV
- 148 equal-area pixels
- >1 mHz of intrinsic background
- ΔE/E of < 3%



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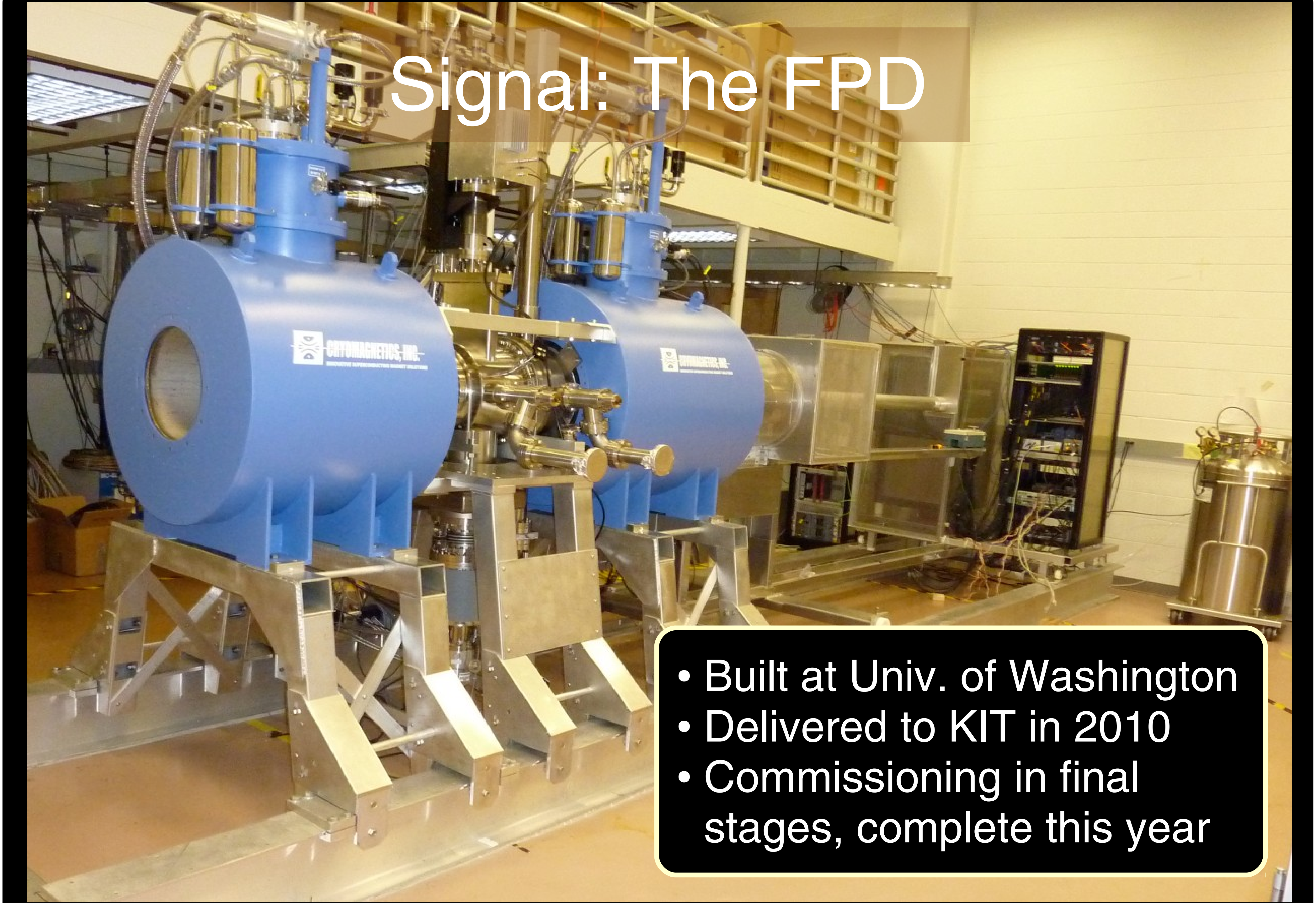

- Built at Univ. of Washington
- Delivered to KIT in 2010
- Commissioning in final stages, complete this year

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- all main KATRIN components are nearly complete
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Thanks for your attention...

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