The KATRIN Neutrino Mass Measurement: Experiment, Status, and Outlook

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(special thanks to Larisa Thorne and Prof. Diana Parno)

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CIPANP 2018

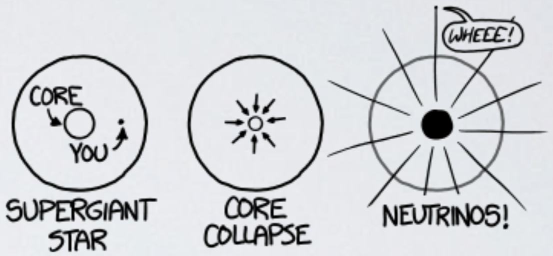
Outline

- Neutrino mass measurements
- KATRIN Apparatus
    - Components
    - MAC-E Spectrometer
- First Light and Krypton Measurements
- Status of First Tritium Running
- Summary and outlook

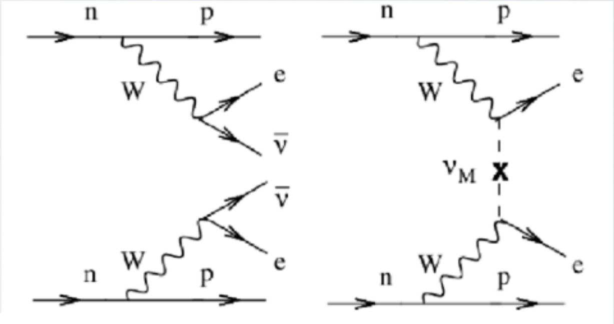
Neutrino Mass Measurements

- 4 approaches to neutrino mass scale:

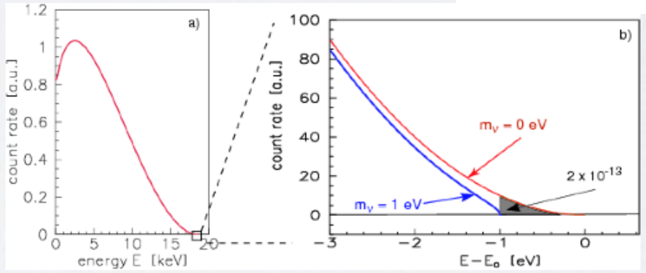
    1. (very) long baseline/ToF



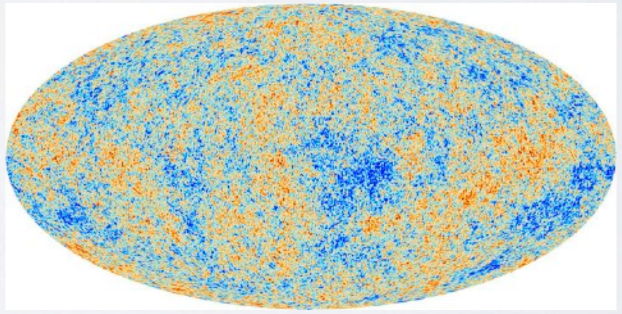
    2. Neutrinoless double β decay



    3. Kinematic methods



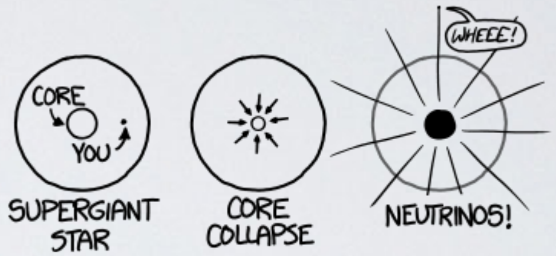
    4. Inferred from CMB/structure



Neutrino Mass Measurements

- 4 approaches to neutrino mass scale:

  1. (very) long baseline/ToF



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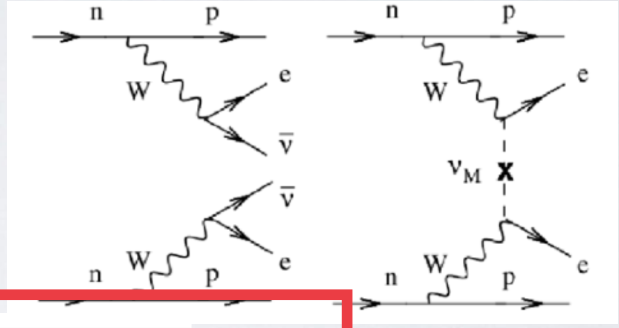

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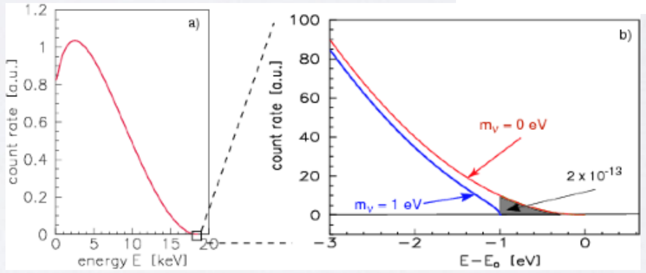

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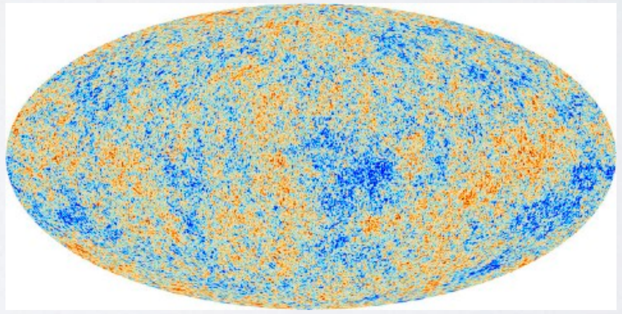
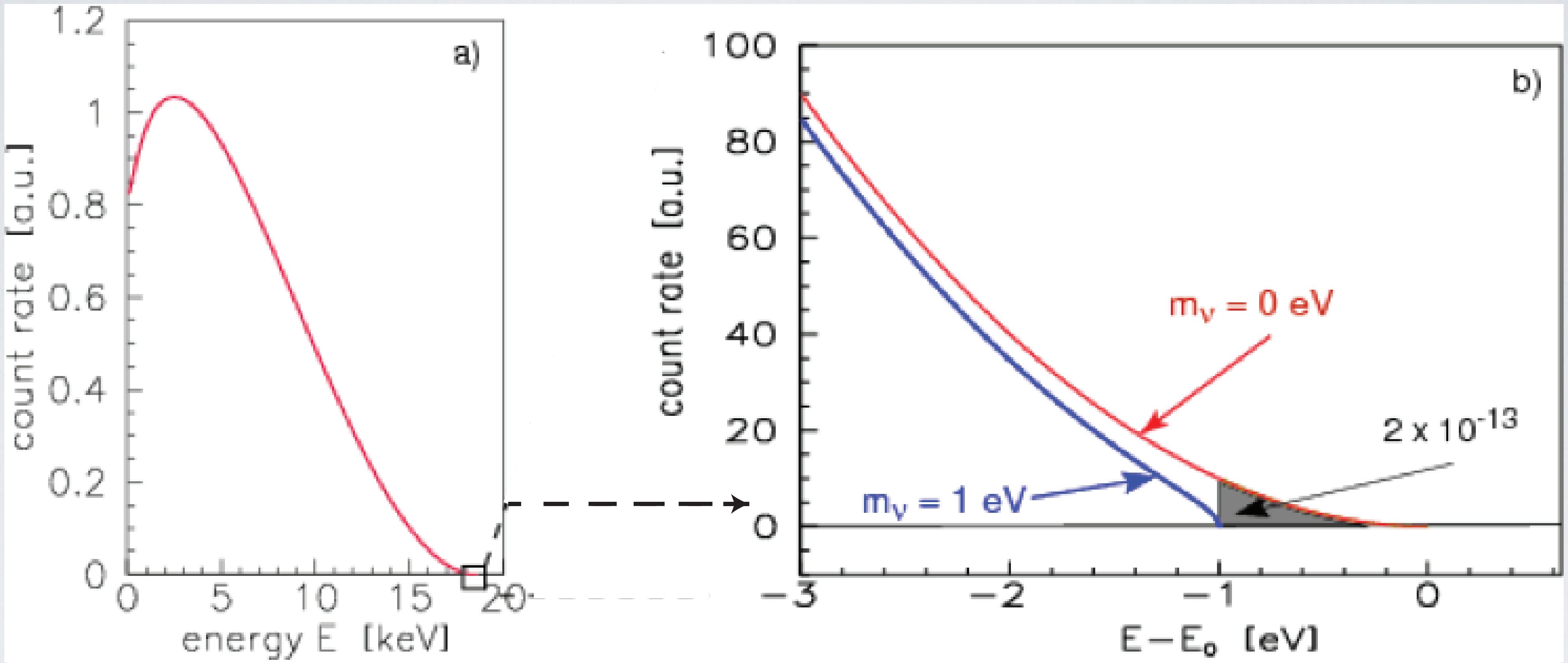


$$^{3}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \mathrm{e}^{-} + \bar{\nu}$$



Tritium decay β-spectrum

Spectrum shape sensitive to effective electron ν mass

$$m_{\nu}^{2} \equiv \sum_{j} \left| U_{ej} \right|^{2} m_{j}^{2}$$

KATRIN, in a nutshell

(**KA**rlsruhe **TRI**tium **N**eutrino)

- Goal: precision absolute neutrino mass measurement
- Design sensitivity: 0.2eV, at 90% C.L.
- Intense molecular Tritium source (T_2)
- High-resolution ($\Delta E \sim 0.93$eV) integrating spectrometer
- Detection of βs via segmented silicon pin diode
- Resolution via MAC-E Spectrometer

KATRIN Apparatus

Windowless Gaseous Tritium Source (WGTS)

10^{11} decay β's /second

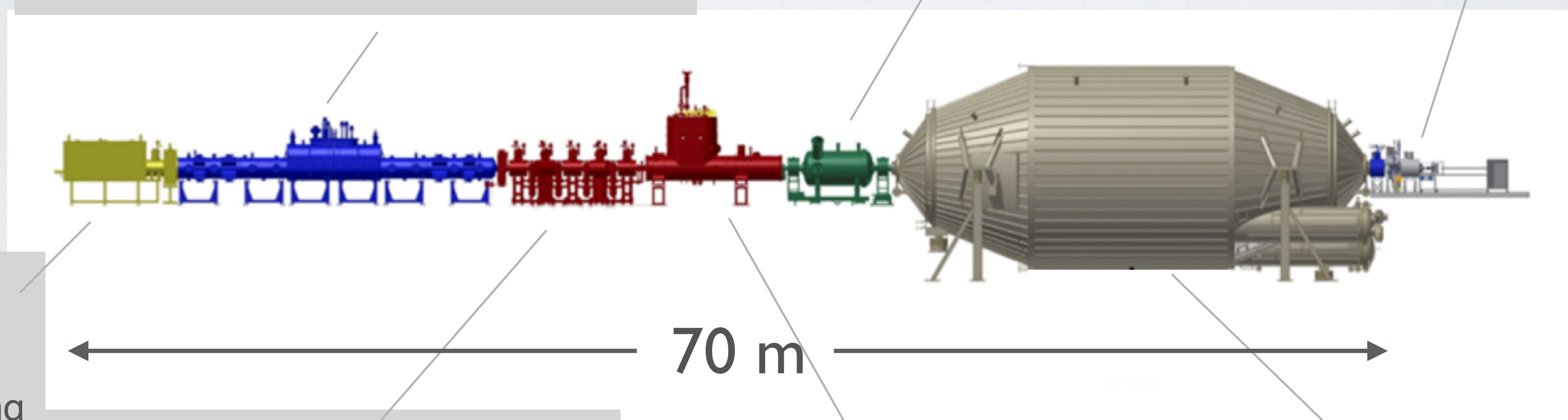
10^{-3} mbar T_2

MAC-E Pre-Spectrometer

Blocks lower energy βs

β Detector

silicon diode array



Rear Wall

For monitoring

Differential Pumping

10^5 Tritium reduction

Cryogenic Pumping

10^7 Tritium reduction

MAC-E Main-Spectrometer

held at ~10^{-11} mbar

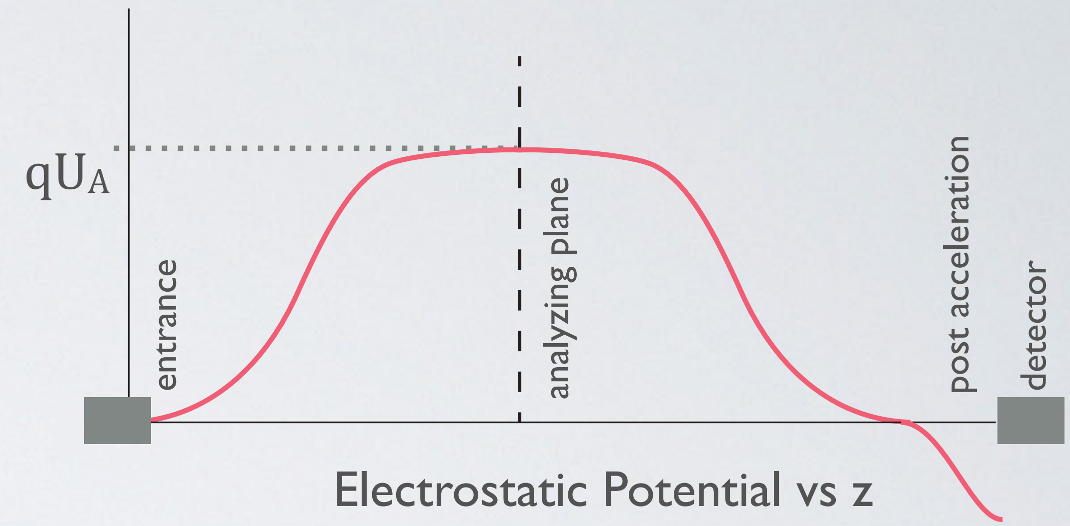
~10^{-20} mbar T_2

The MAC-E Spectrometer

(**M**agnetic **A**diabatic **C**ollimator with **E**lectrostatic Filter)

The MAC-E Spectrometer

1) The Electrostatic Filter



Electrostatic Potential vs z

Kinetic Energy $E = E_{\perp} + E_{||}$

Transmits β's with $E_{||} > qU_A$

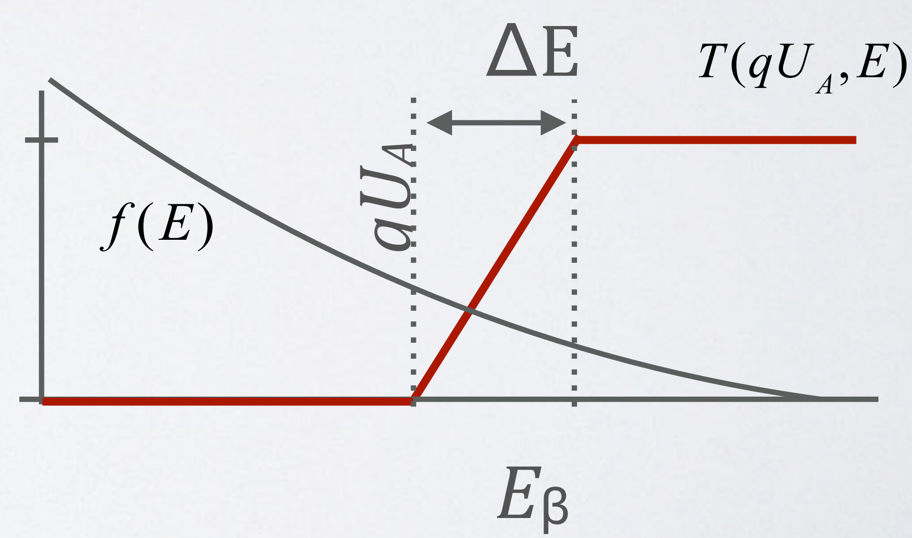
Counting rate vs U_A generates integrated β spectrum

$$F(qU_A) = \int_{qU_A}^{E_{\max}} T(qU_A, E_\beta) f(E_\beta) dE_\beta$$

Resolution

$\Delta E = E_{\perp\max}$ at analyzing plane

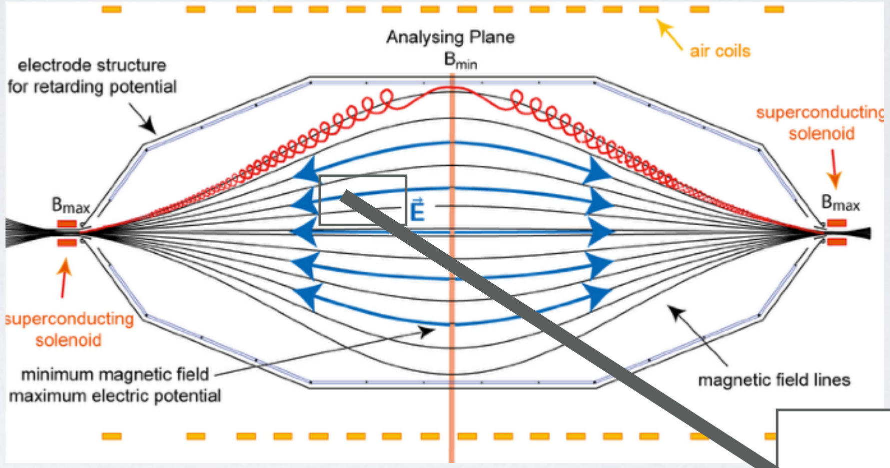
Need to minimize $E_{\perp\max}$

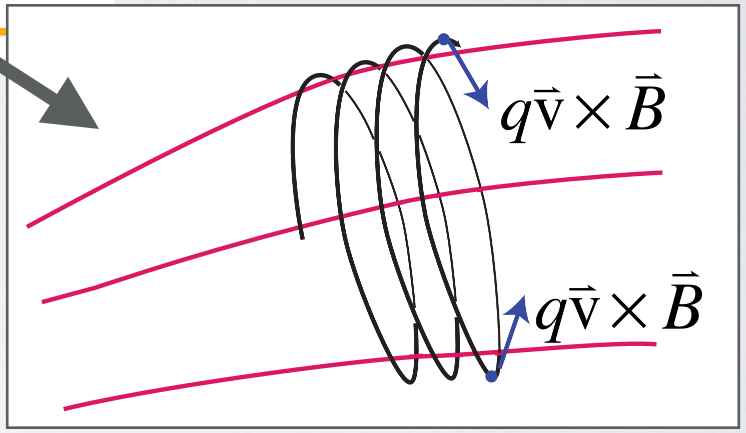


Transmission function $T(qU_A, E_\beta)$ vs E_β

The MAC-E Spectrometer

2) The Adiabatic Magnetic Collimator





B-field guides β's to detector

B_{max} = 6 T

$B_{analyzing\ plane}$ = 0.3 mT

For B, $E_\perp \rightarrow E_{||}$

Adiabatic Process

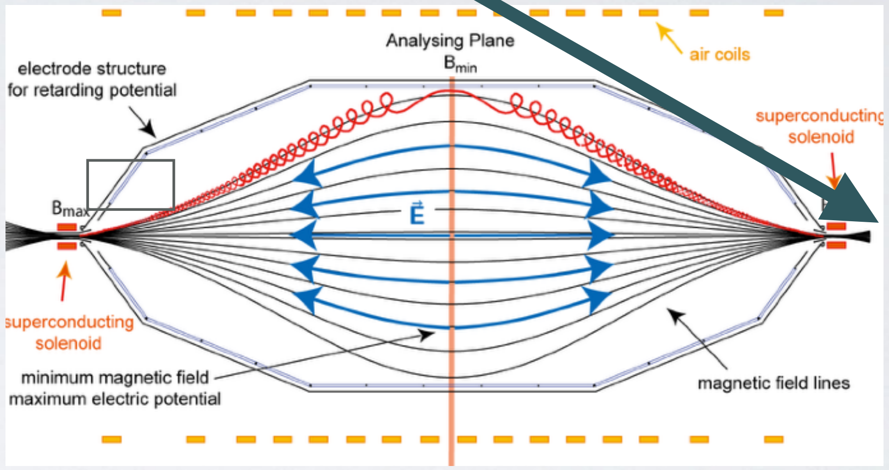
orbital magnetic moment $\mu = IA = \left(q\frac{v_\perp}{2\pi r}\right)\left(\pi r^2\right) = \frac{E_\perp}{B} = \text{constant}$

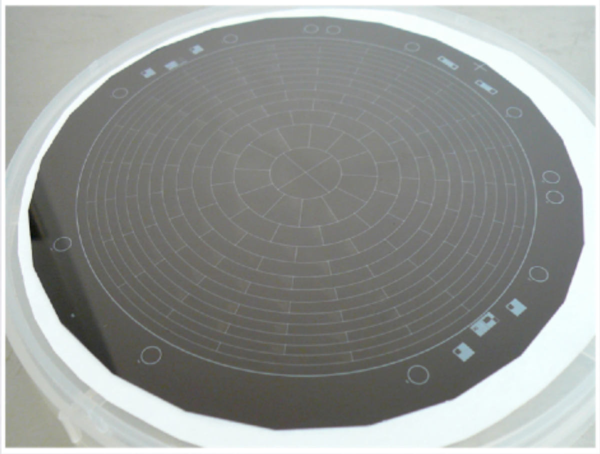
$$\frac{\Delta E}{E} = \frac{B_A}{B_{max}}\frac{\gamma+1}{2} = 5\times10^{-5}$$

$$\Delta E = 0.93\,\text{eV at } 18.6\,\text{keV endpoint}$$

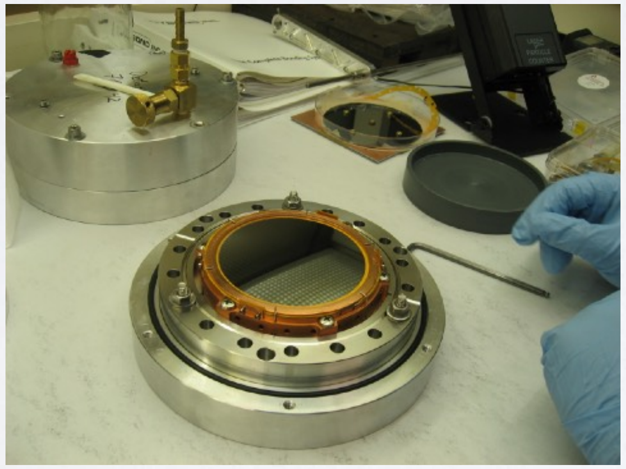
The MAC-E Spectrometer

Segmented Silicon Pin Diode Focal Plane Detector

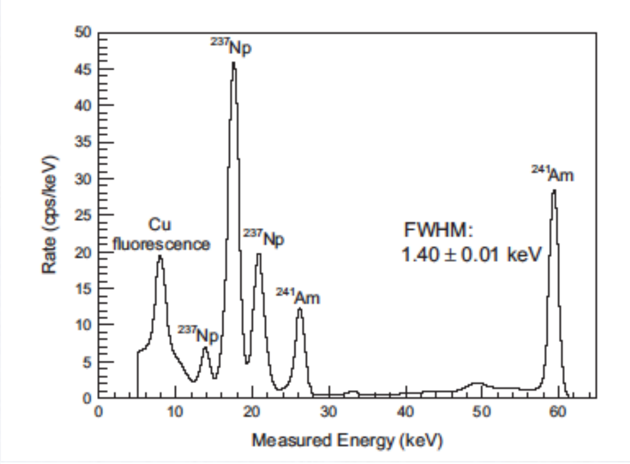




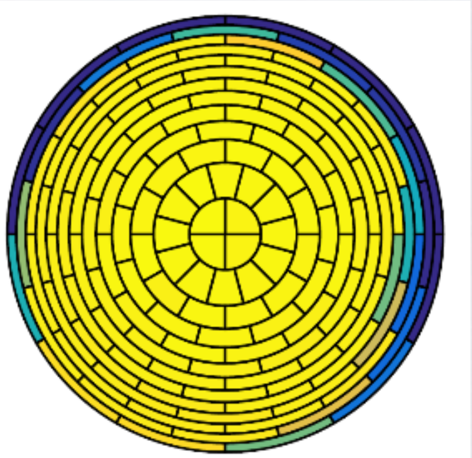
Silicon Wafer



Detector in Mount



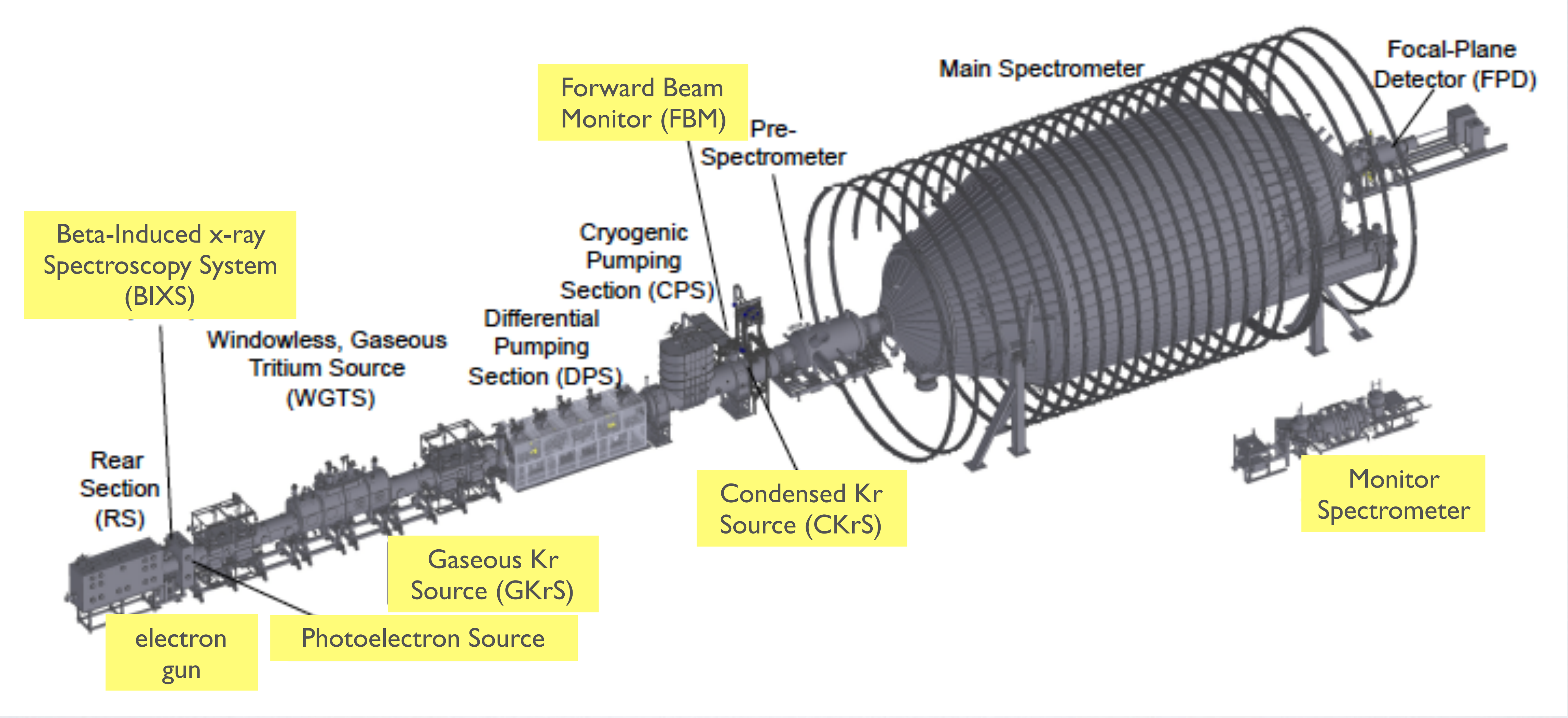
^{241}Am Spectrum



Pixel Hit Map

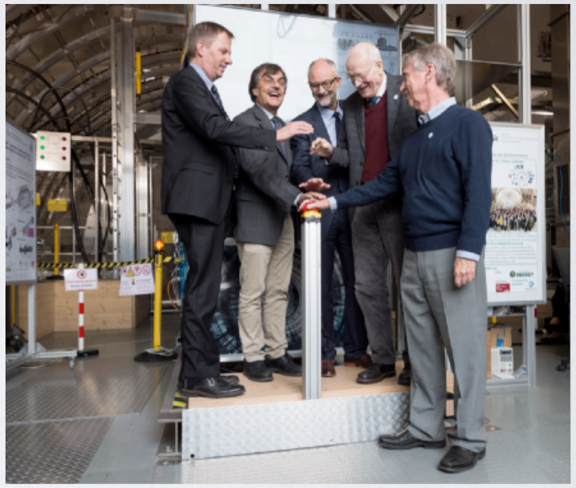
First Light and Krypton Measurements

Monitoring and associated instrumentation



First Light Campaign

- October 2016



- First electrons transmitted through the entire beam line (from rear wall to detector)

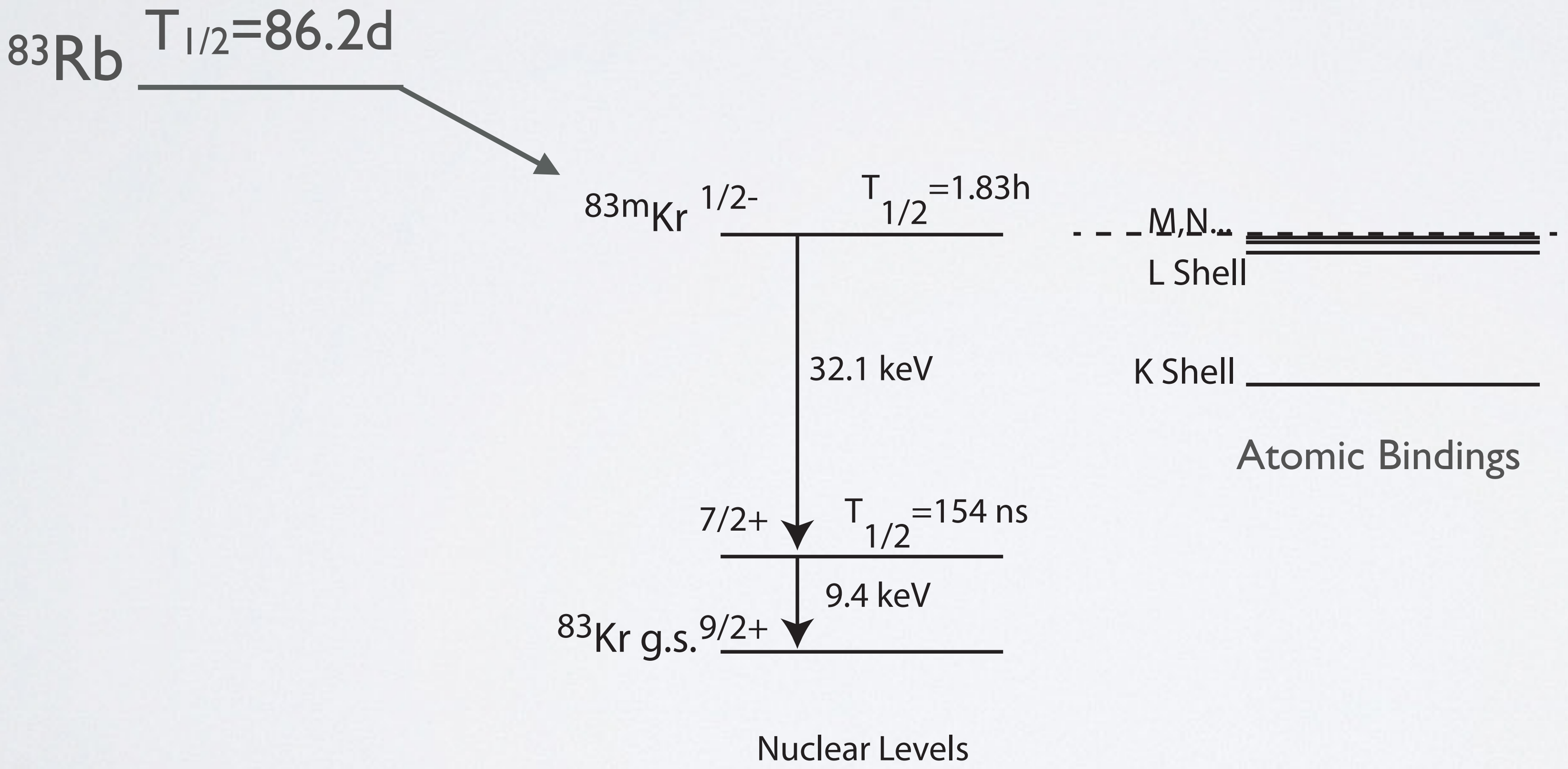
- Source of electrons: produced via photoelectric effect at the rear wall

Krypton Campaign

July 2017

- 2 week run
- System checks include HV calibration and stability

^{83m}Kr provides pseudo-monoenergetic conversion electrons



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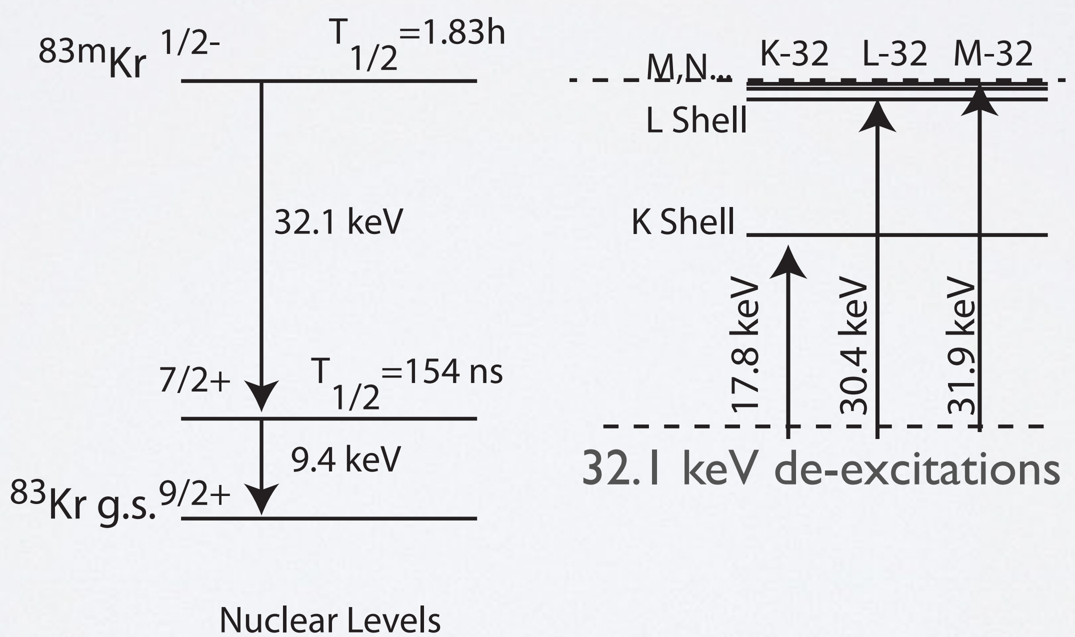

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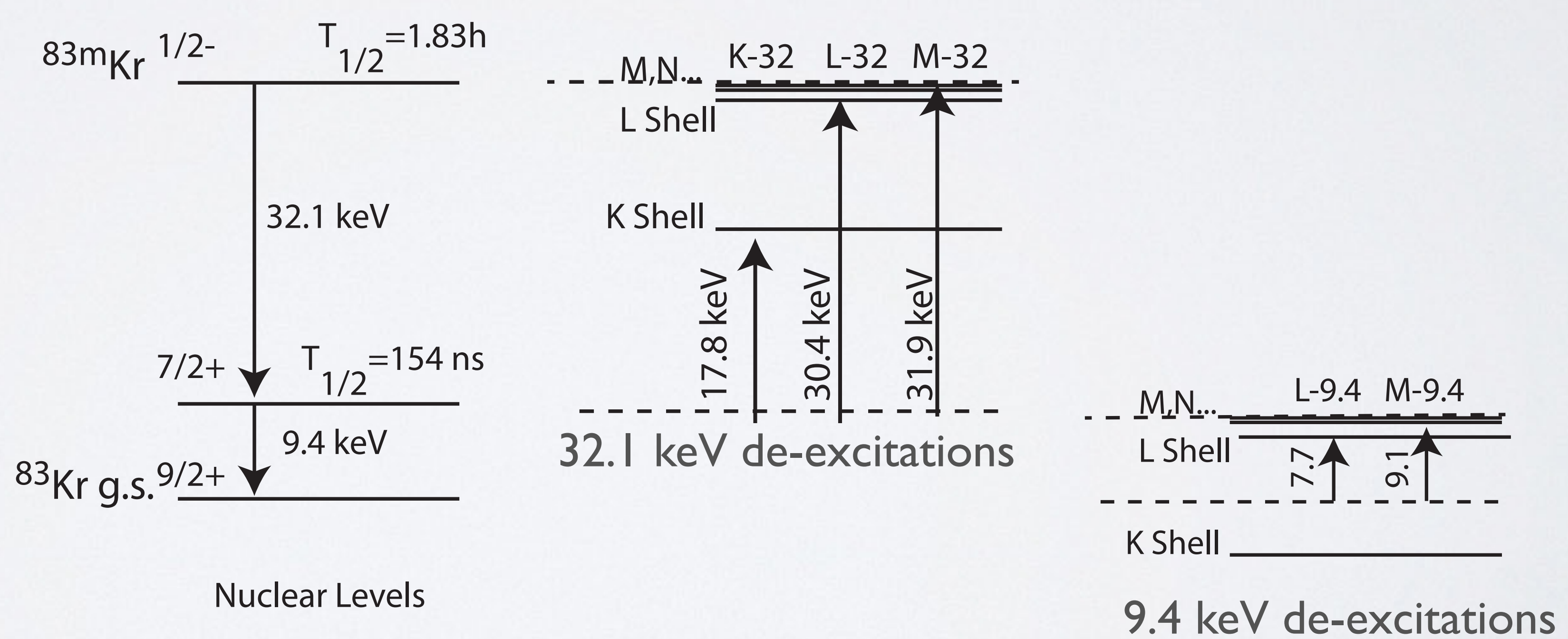
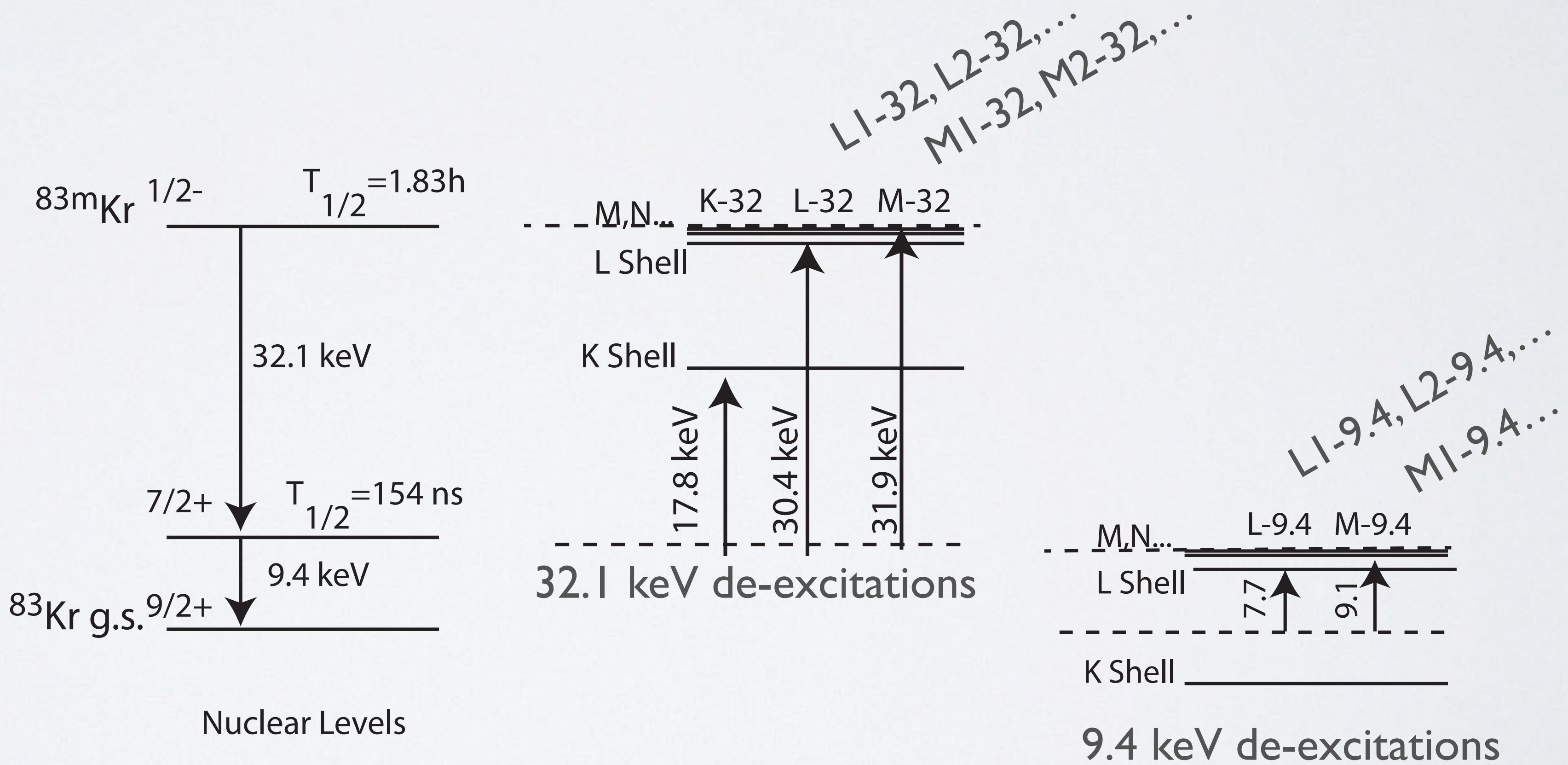
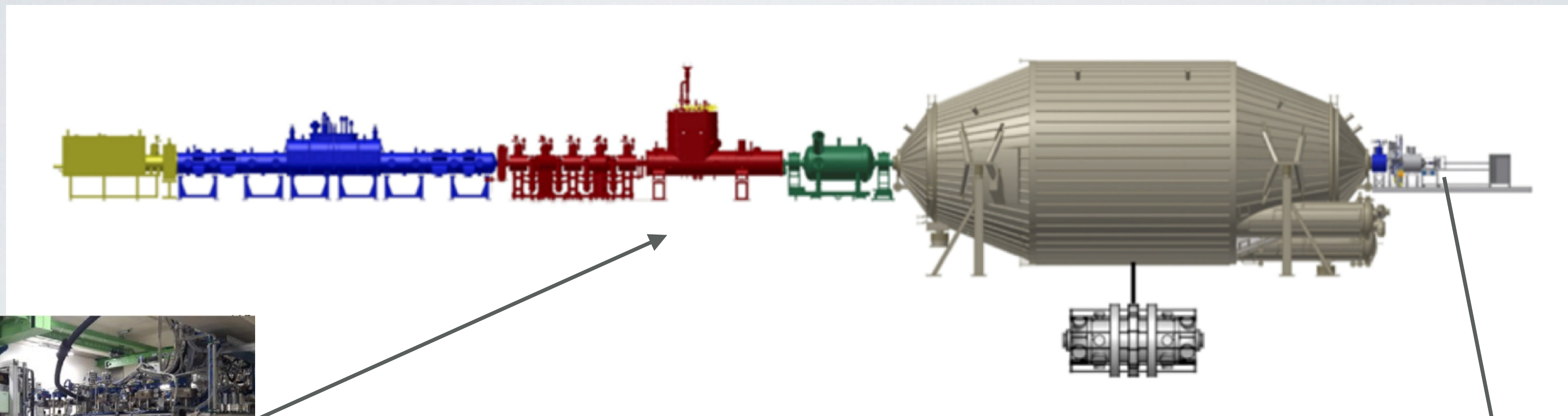


Krypton Campaign



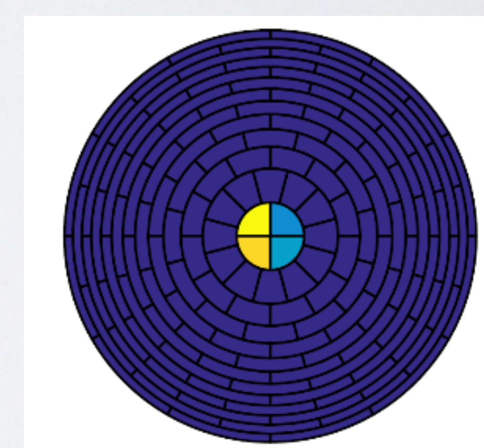
Two Kr Sources Utilized

(+One used in monitor spectrometer)

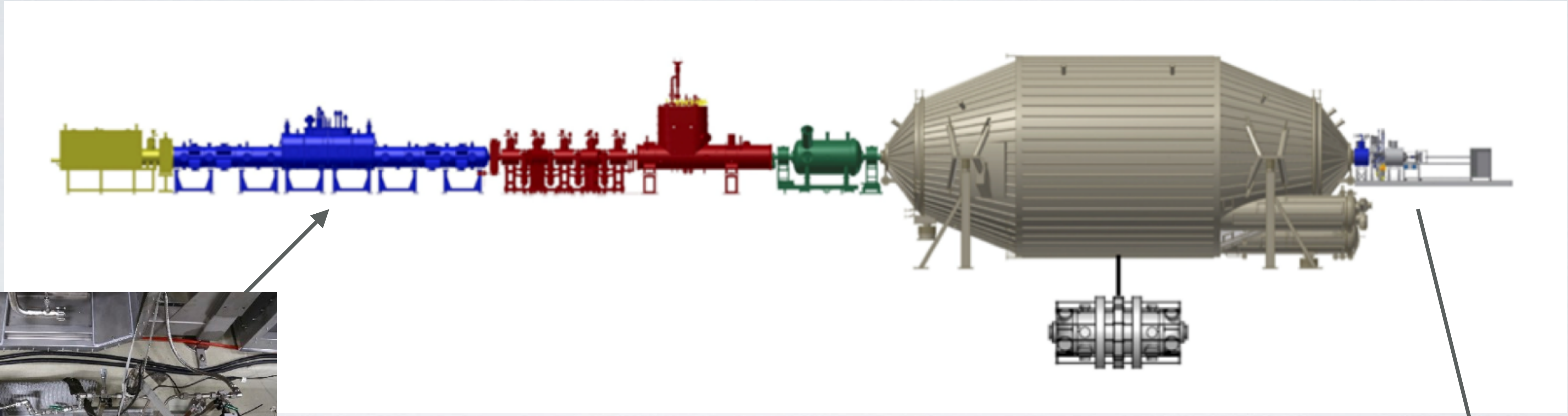


1) Condensed ^{83m}Kr source (CKrS):

- Thin film of ^{83}Rb (activity ~MBq) condensed on cold HOPG substrate, decays into ^{83m}Kr
- Has thin, spot-like spatial distribution which can be moved around in the flux tube

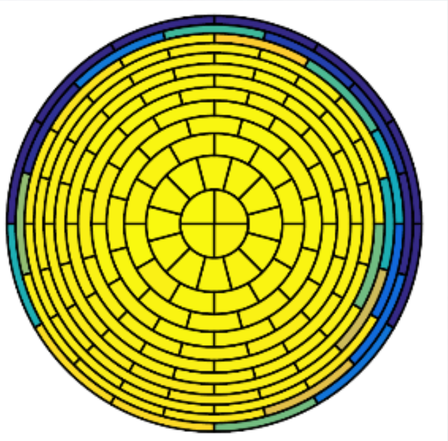


Two Kr Sources



2) Gaseous ^{83m}Kr source (gKrS):

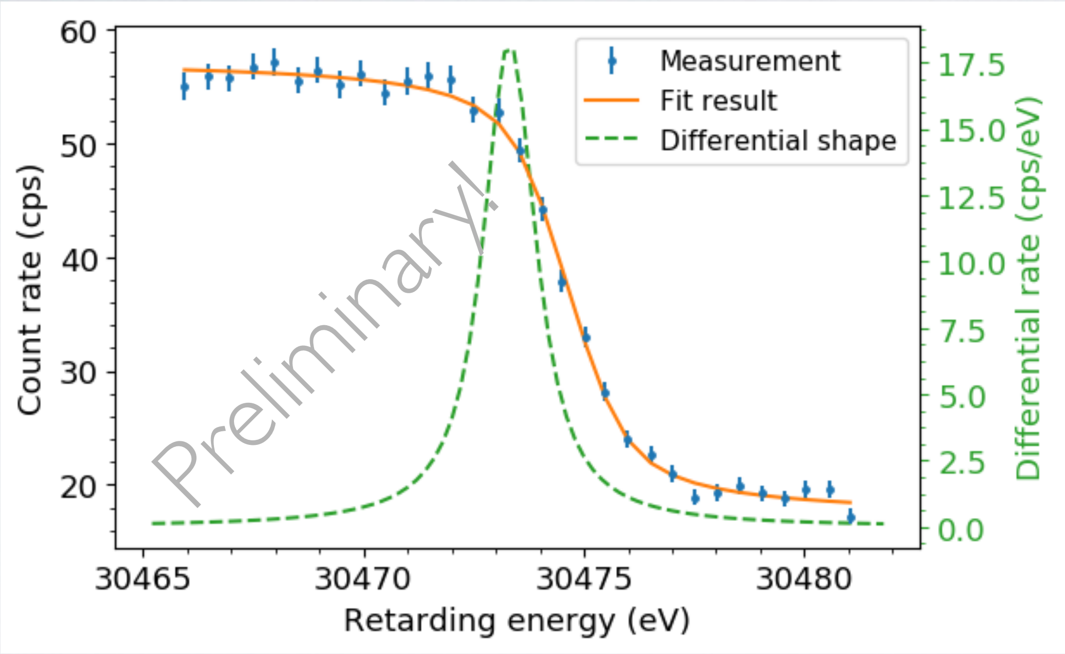
- ^{83}Rb (activity ~1GBq) absorbed into zeolite beads (act as molecular sieve), releasing ^{83m}Kr in its gaseous form into the WGTS
- Has homogeneous spatial distribution
- At a later time, can coexist with Tritium in the WGTS for on-the-spot calibrations



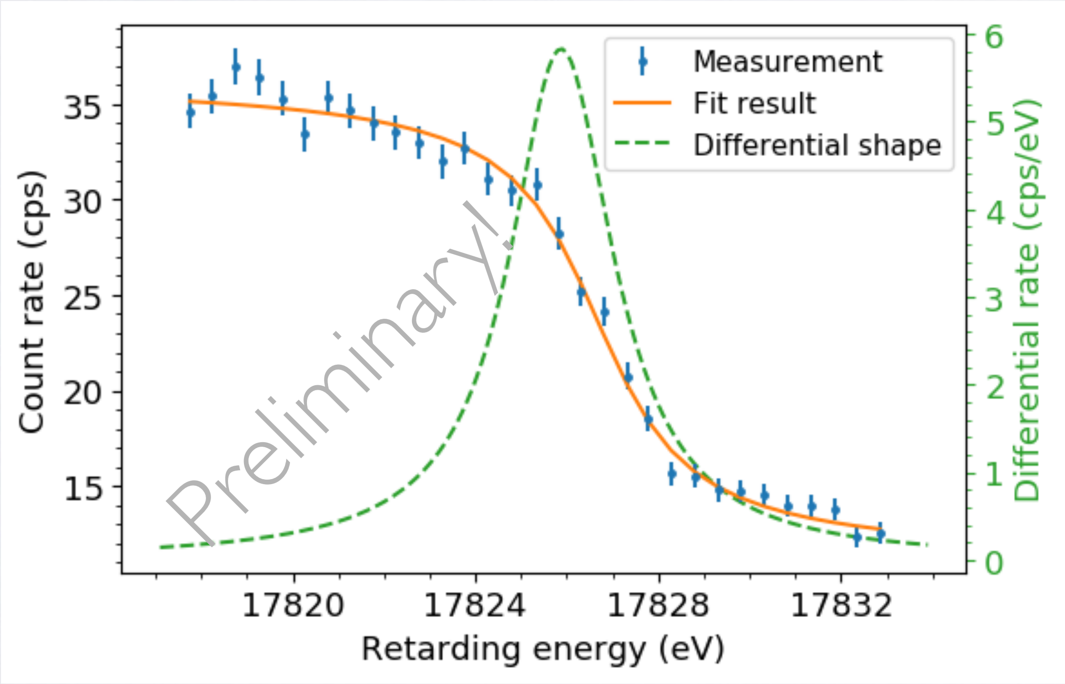
(Preliminary) Kr Results

High resolution line scan

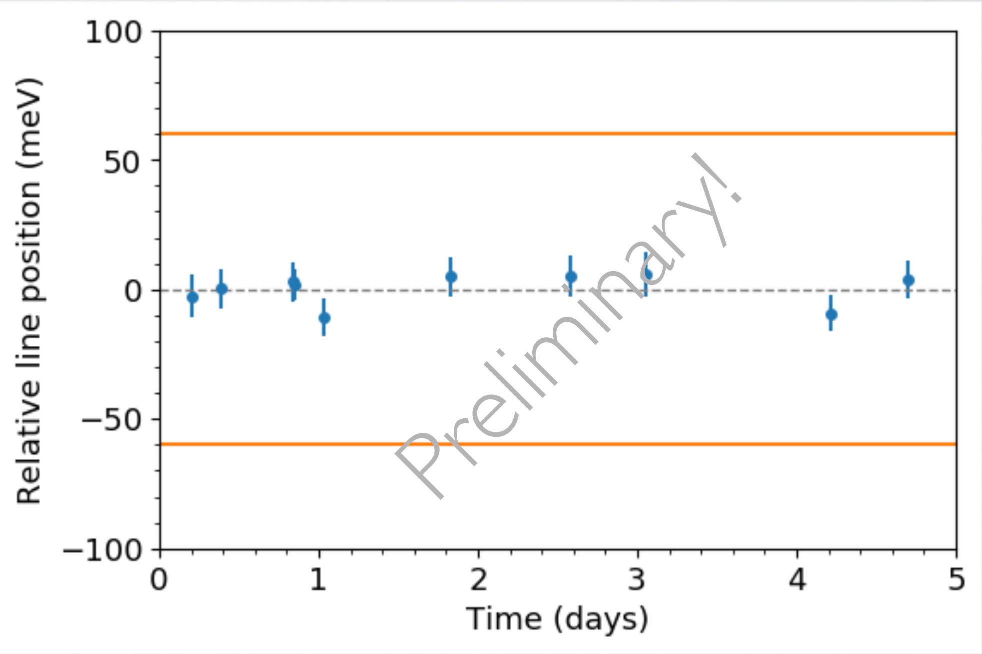
L3-32



K-32



Excellent energy stability



Line position stable, within design limit (± 60meV), shown here for ~1 week of L3-32 line scans using GKrS

(Preliminary) Kr Results

See also:

M. Arenz et al.,
First Transmission of Electrons and Ions through the KATRIN beamline
Journal: JINST 13 P04020 (2018)
DOI:10.1088/1748-0221/13/04/P04020

M. Arenz et al.,
Calibration of high voltages at the ppm level by the difference of ^{83m}Kr conversion electron lines at the KATRIN experiment
Journal: EPJC 78 P368 (2018)
DOI:10.1140/epjc/s10052-018-5832-y

Watch for:
~ half dozen papers in final stages of KATRIN review

Status of First Tritium Running and Outlook

- **May 18 (9:48 am CEDT):** Very First Tritium
  - ➡ Ion-Safety and sub-system check out
  - ➡ D_2, D-T & T_2 molecules
  - ➡ ~1% Tritium
- **May 19: First Energy Spectrum Measurement!**
- **Ongoing : First Tritium**
- **June 7**: Commissioning results to be presented at **Neutrino 2018** by Prof. Diana Parno

Summary and Outlook

- **June 11**: KATRIN inauguration
- **Within the next year:**
  - ➡ Additional commissioning and Kr measurements
  - ➡ Initial Tritium datasets
  - ➡ Phase 0 sterile neutrino search begins

KATRIN collaboration meeting (Feb 2018)

Summary and Outlook

Thank You!

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