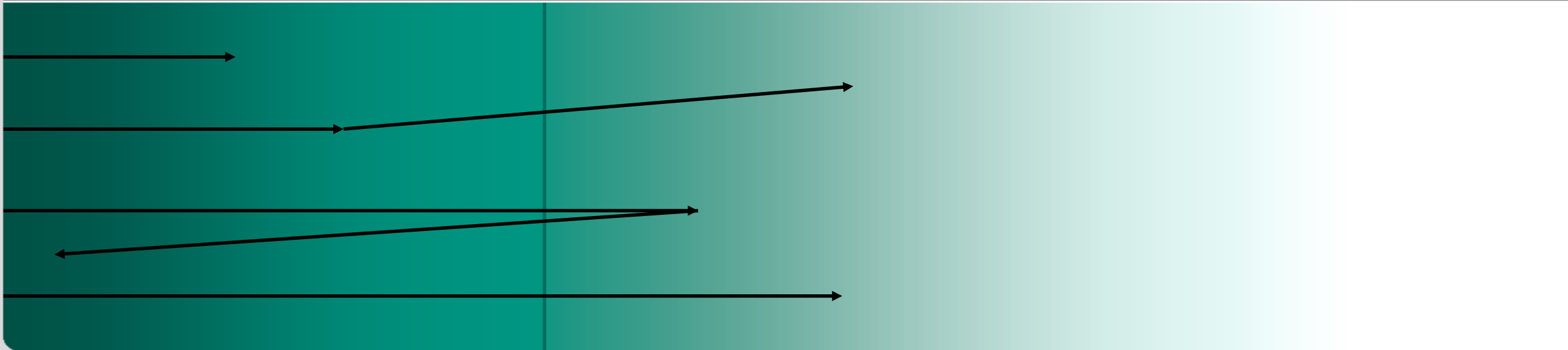


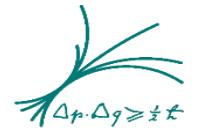


Characterization of the detector dead layer for a sterile neutrino search with KATRIN

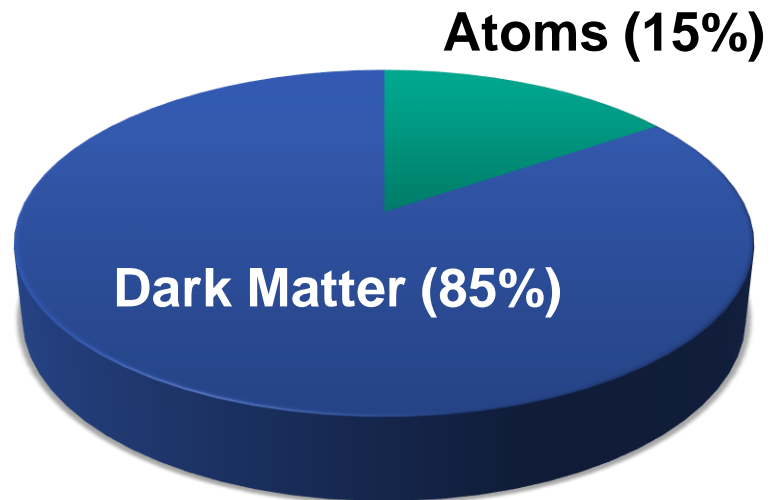
Tim Brunst, IMPRS Young Scientist Workshop at Ringberg Castle, July 18th 2017



Sterile neutrinos in cosmology



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- Discovery of neutrino oscillations proves that $m_\nu \neq 0$
- Sterile neutrinos in the keV mass range are a prime candidate for Dark Matter

Sterile neutrinos in particle physics



- No right-handed neutrinos in the SM

Leptons	Quarks	$2/3$ Left u Right up 2.4 MeV	$2/3$ Left c Right charm 1.27 GeV	$2/3$ Left t Right top 171.2 GeV
		$-1/3$ Left d Right down 4.8 MeV	$-1/3$ Left s Right strange 104 MeV	$-1/3$ Left b Right bottom 4.2 GeV
		0 Left ν_e < 1 eV	0 Left ν_μ < 1 eV	0 Left ν_τ < 1 eV
	Leptons	-1 Left e Right electron 0.511 MeV	-1 Left μ Right muon 105.7 MeV	-1 Left τ Right tau 1.777 GeV

Sterile neutrinos in particle physics



Quarks	2/3	2.4 MeV	Left	u	Right	up
	2/3	1.27 GeV	Left	c	Right	charm
	2/3	171.2 GeV	Left	t	Right	top
	-1/3	4.8 MeV	Left	d	Right	down
	-1/3	104 MeV	Left	s	Right	strange
	-1/3	4.2 GeV	Left	b	Right	bottom
Leptons	< 1 eV	< 1 eV	Left	ν_e	Right	electron neutrino
	~keV	~keV	Left	N₁	Right	sterile neutrino
	< 1 eV	< 1 eV	Left	ν_μ	Right	muon neutrino
	~GeV	~GeV	Left	N₂	Right	sterile neutrino
	< 1 eV	< 1 eV	Left	ν_τ	Right	tau neutrino
	~GeV	~GeV	Left	N₃	Right	sterile neutrino
-1	0.511 MeV	Left	e	Right	electron	
-1	105.7 MeV	Left	μ	Right	muon	
-1	1.777 GeV	Left	τ	Right	tau	

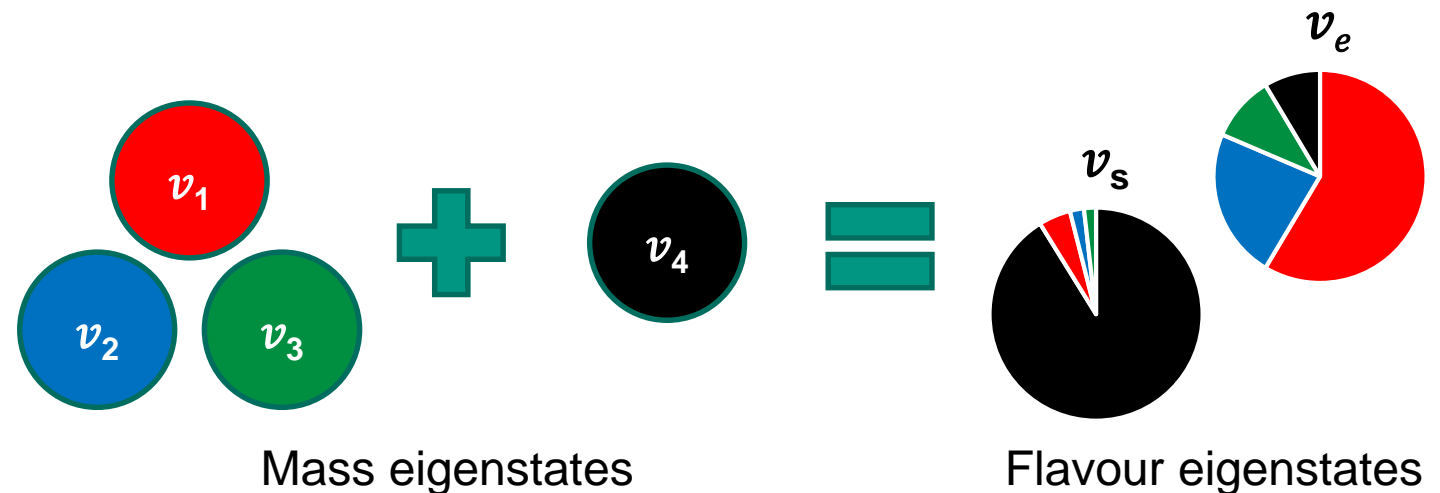
- No right-handed neutrinos in the SM
- Or: right-handed neutrinos are sterile

Sterile neutrinos in particle physics



Quarks	2/3	2.4 MeV	Left	u	Right	2/3	1.27 GeV	Left	c	Right	2/3	171.2 GeV	Left	t	Right
				up					charm					top	
	-1/3	4.8 MeV	Left	d	Right	-1/3	104 MeV	Left	s	Right	-1/3	4.2 GeV	Left	b	Right
				down					strange					bottom	
	0	< 1 eV	Left	ν_e	Right	0	< 1 eV	Left	ν_μ	Right	0	< 1 eV	Left	ν_τ	Right
Leptons															

- No right-handed neutrinos in the SM
- Or: right-handed neutrinos are sterile
- ... but mix with the active neutrinos

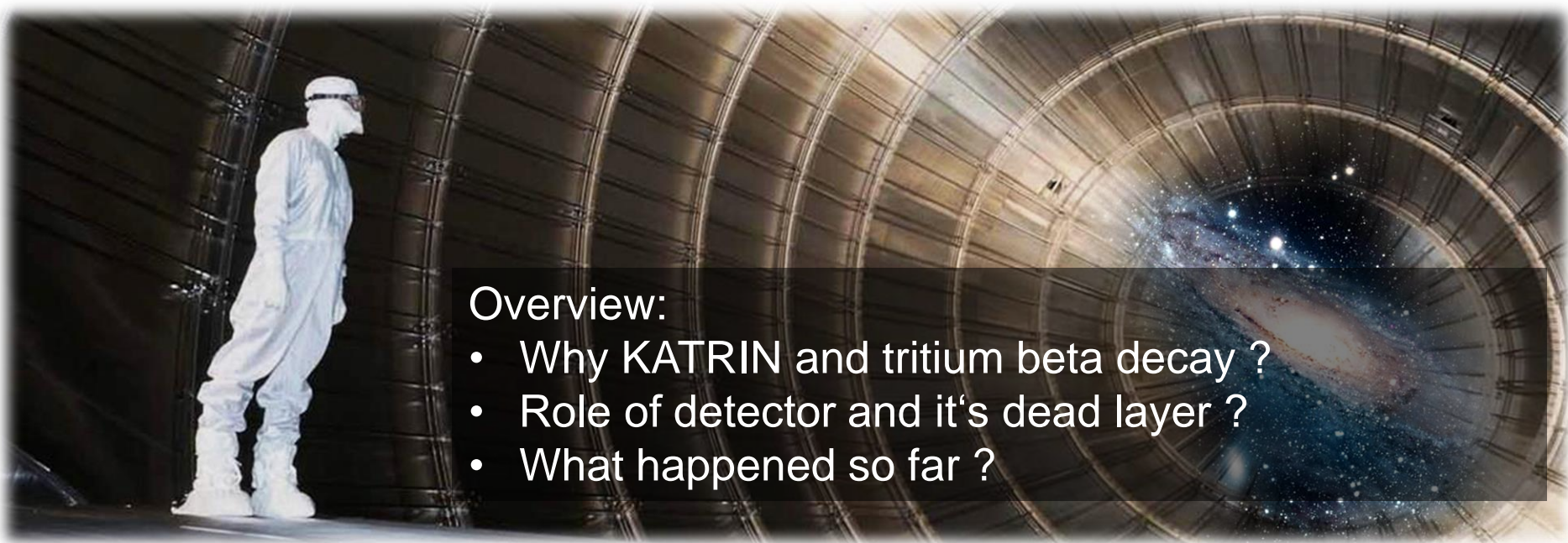


Objective of TRISTAN



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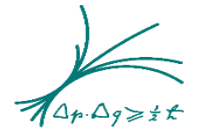
■ Search for **Sterile Neutrinos** in the **Model-Independent** laboratory experiment **KATRIN**



Overview:

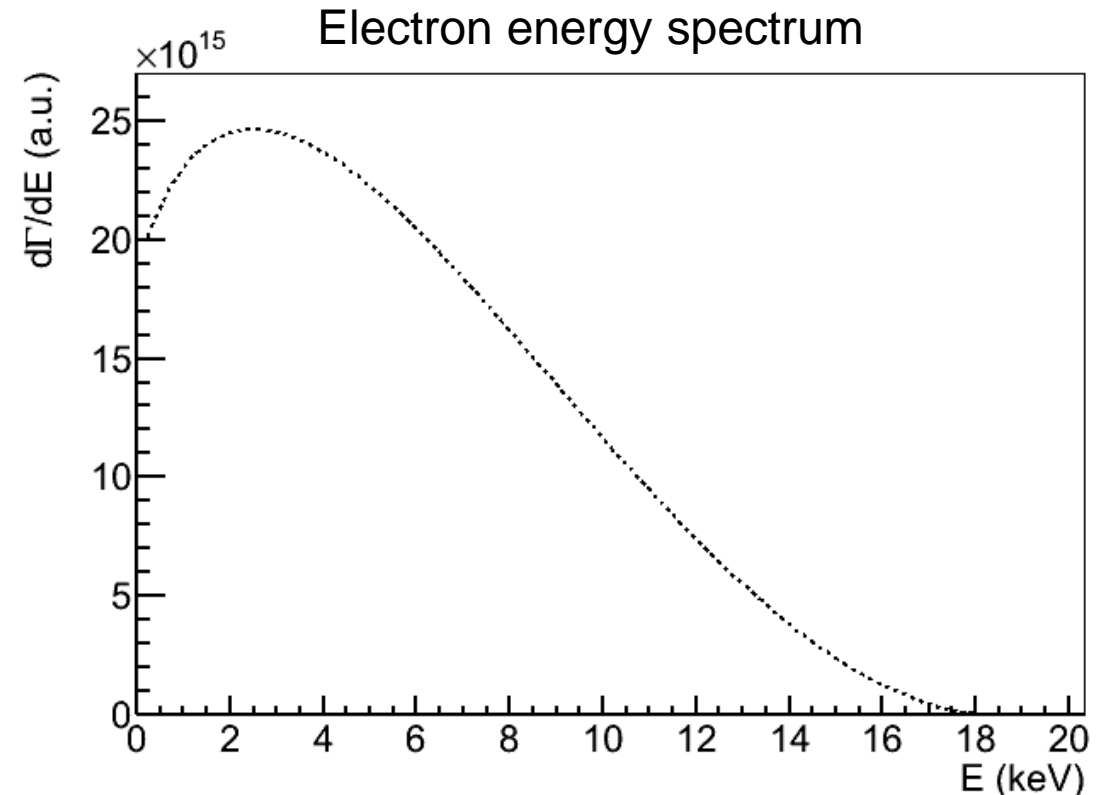
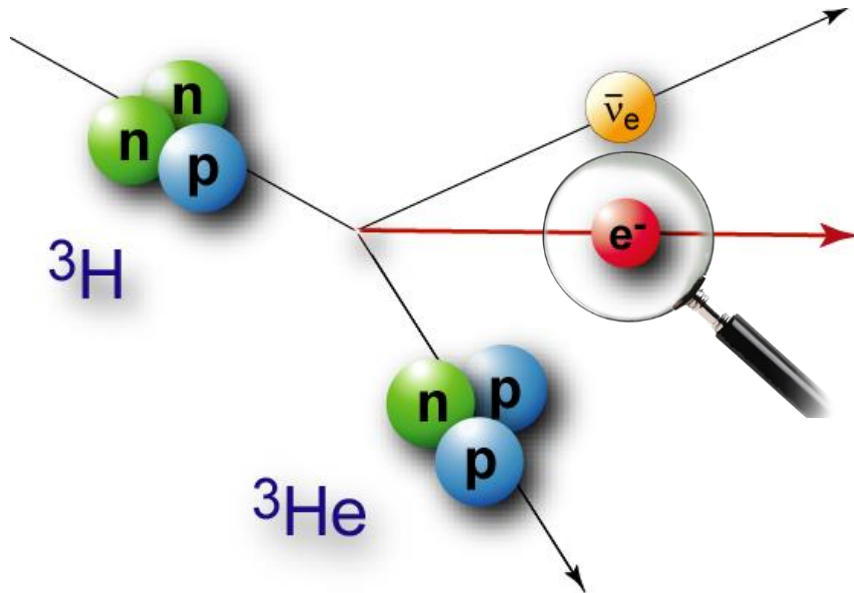
- Why KATRIN and tritium beta decay ?
- Role of detector and it's dead layer ?
- What happened so far ?

Tritium beta decay



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$$\frac{d\Gamma}{dE} \propto C F(Z, E) p(E + m_e)(E_0 - E) \sqrt{(E_0 - E)^2 - m^2(v_e)}$$

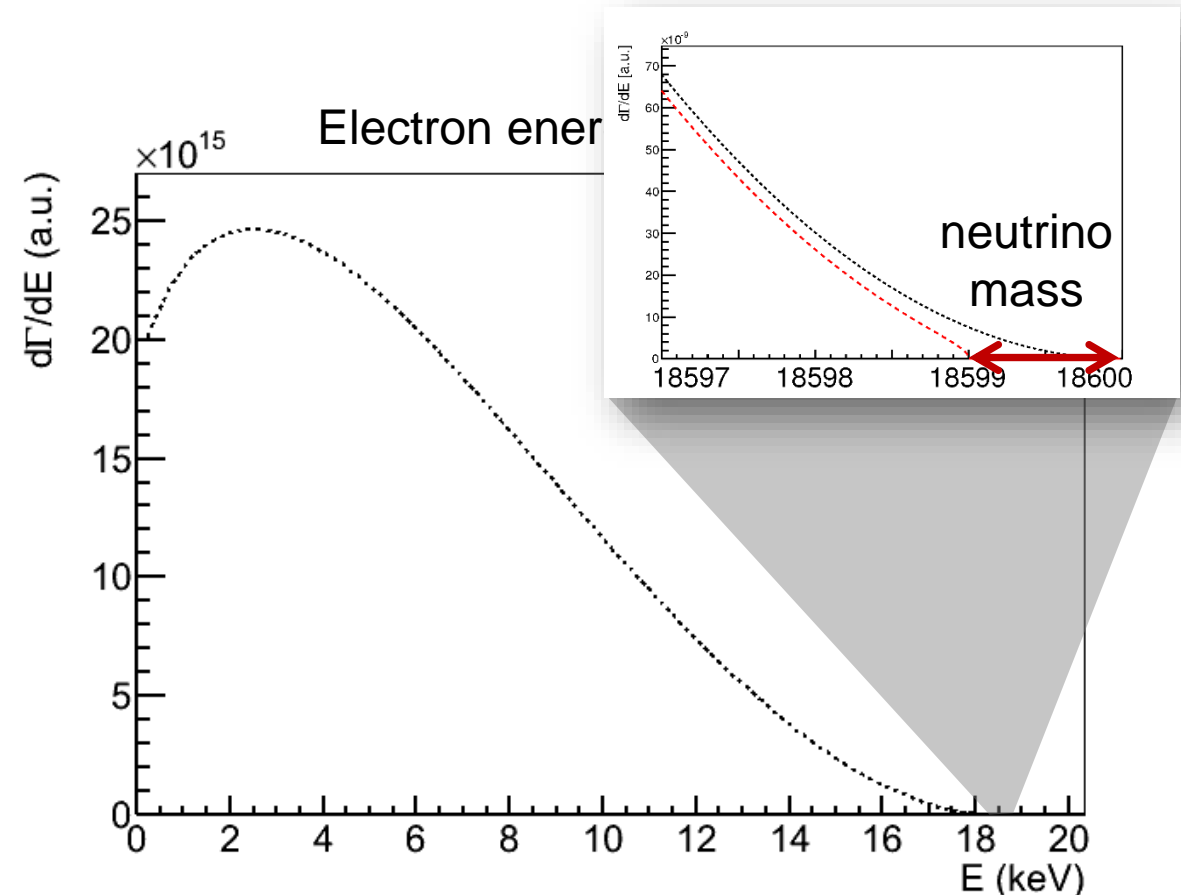
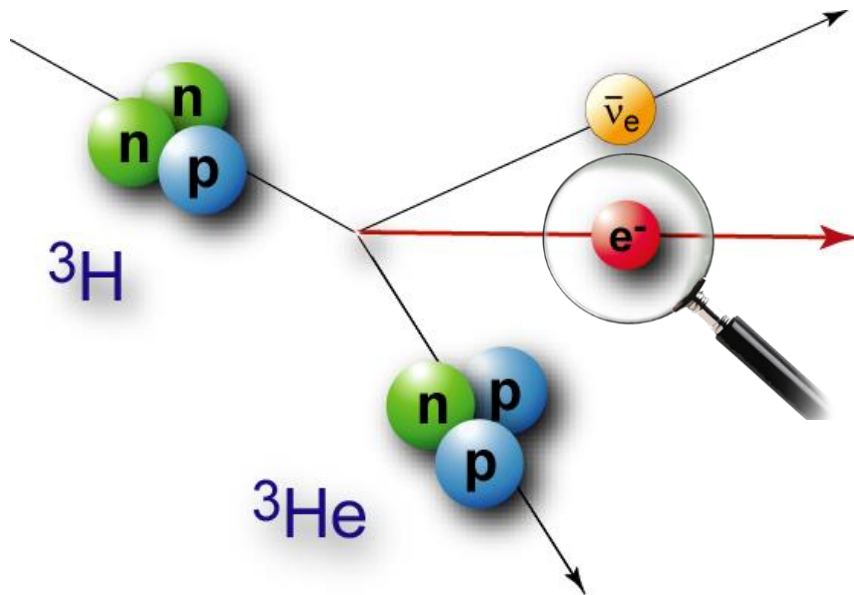


Tritium beta decay



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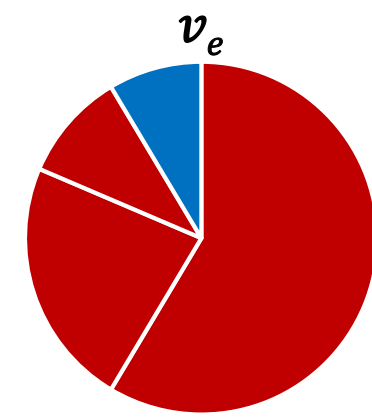
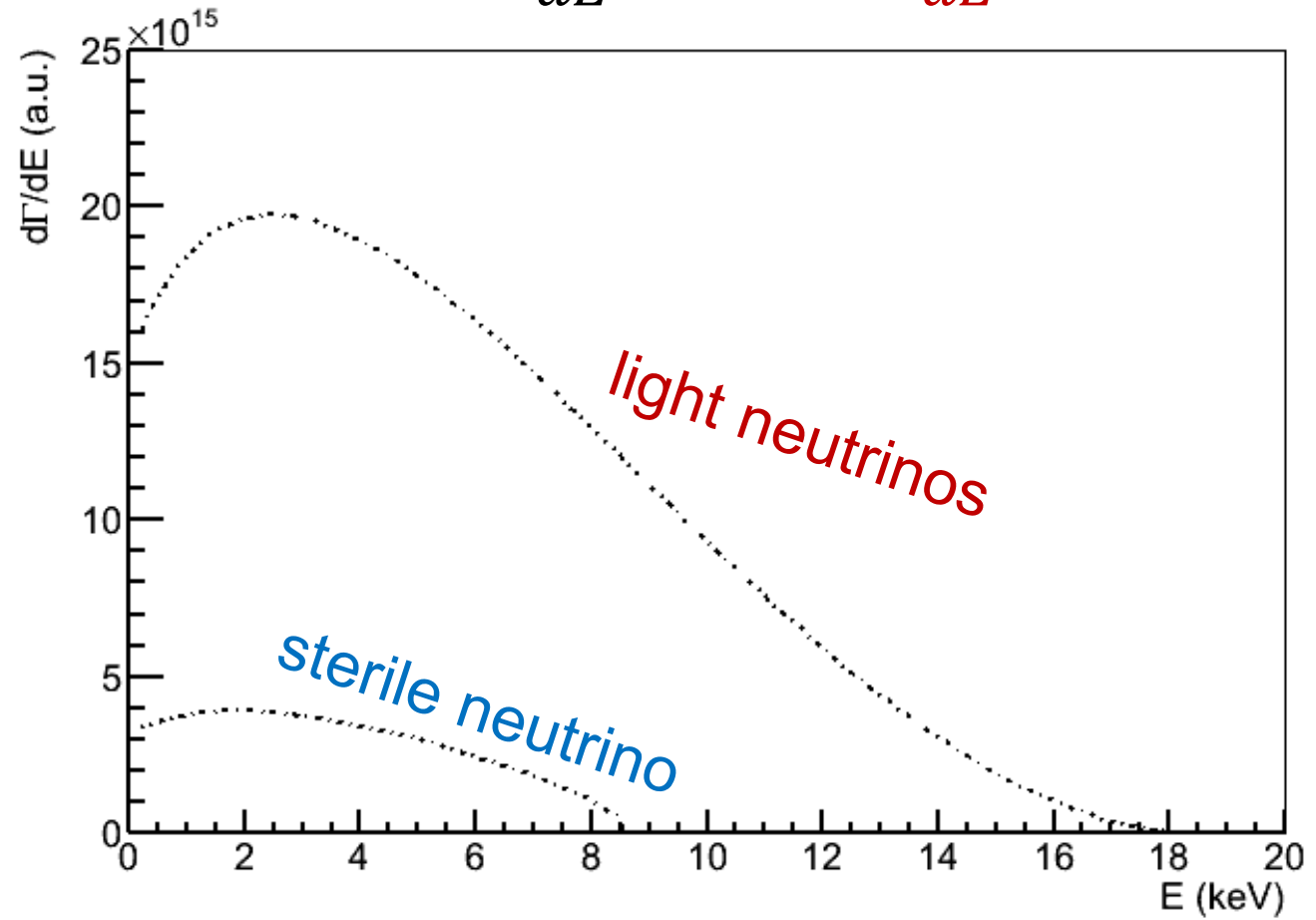
$$\frac{d\Gamma}{dE} \propto C F(Z, E) p(E + m_e)(E_0 - E) \sqrt{(E_0 - E)^2 - m^2(v_e)}$$





Imprint of sterile ν 's on β -spectrum

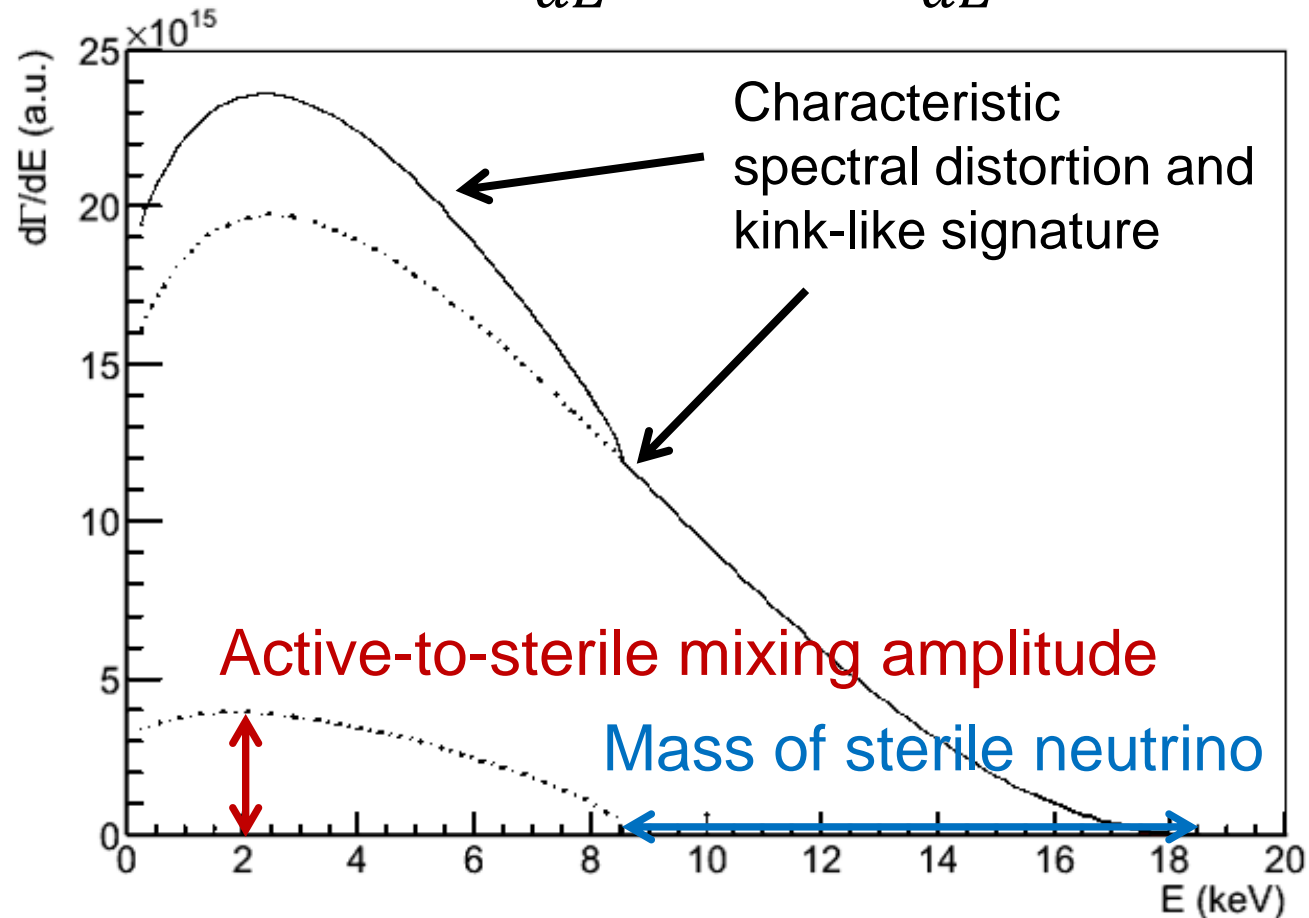
$$\frac{d\Gamma}{dE} = \cos^2(\theta) \frac{d\Gamma}{dE}(m_\beta) + \sin^2(\theta) \frac{d\Gamma}{dE}(m_s)$$





Imprint of sterile ν 's on β -spectrum

$$\frac{d\Gamma}{dE} = \cos^2(\theta) \frac{d\Gamma}{dE}(m_\beta) + \sin^2(\theta) \frac{d\Gamma}{dE}(m_s)$$



KATRIN (KARlsruhe TRItium Neutrino) experiment



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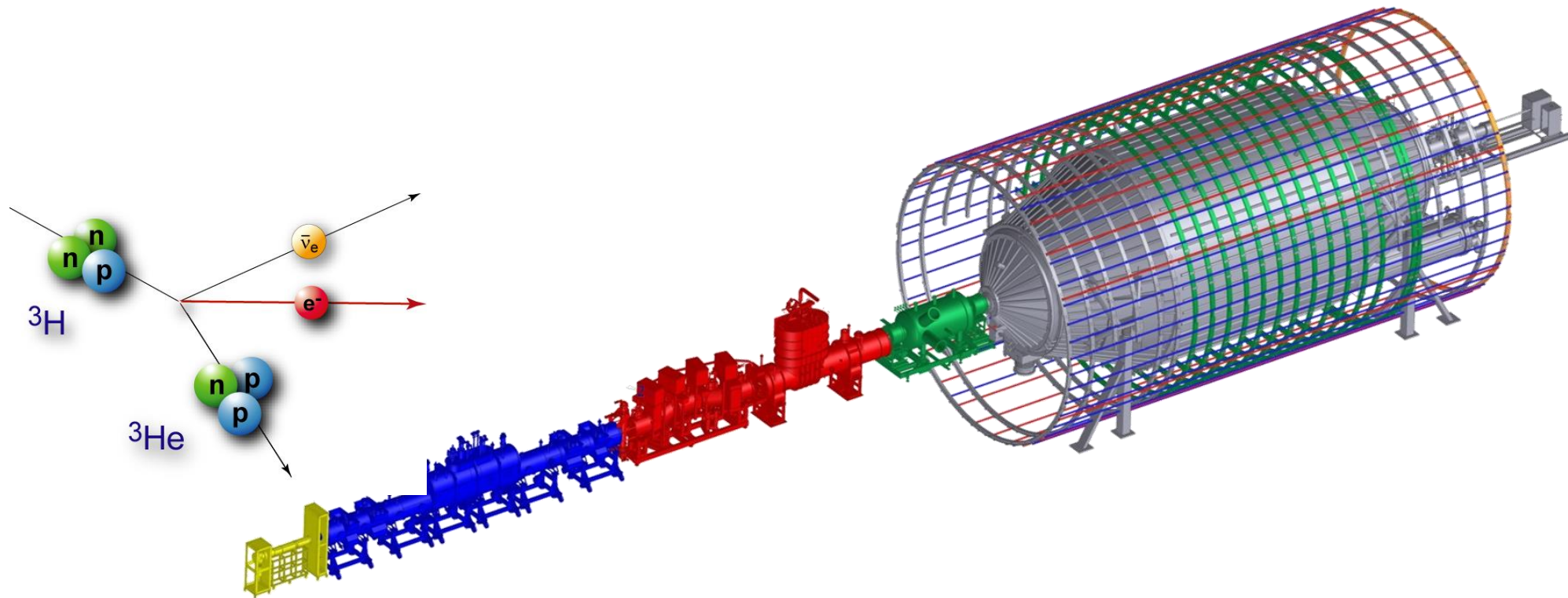


KATRIN overview



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Windowless Gaseous
Tritium Source



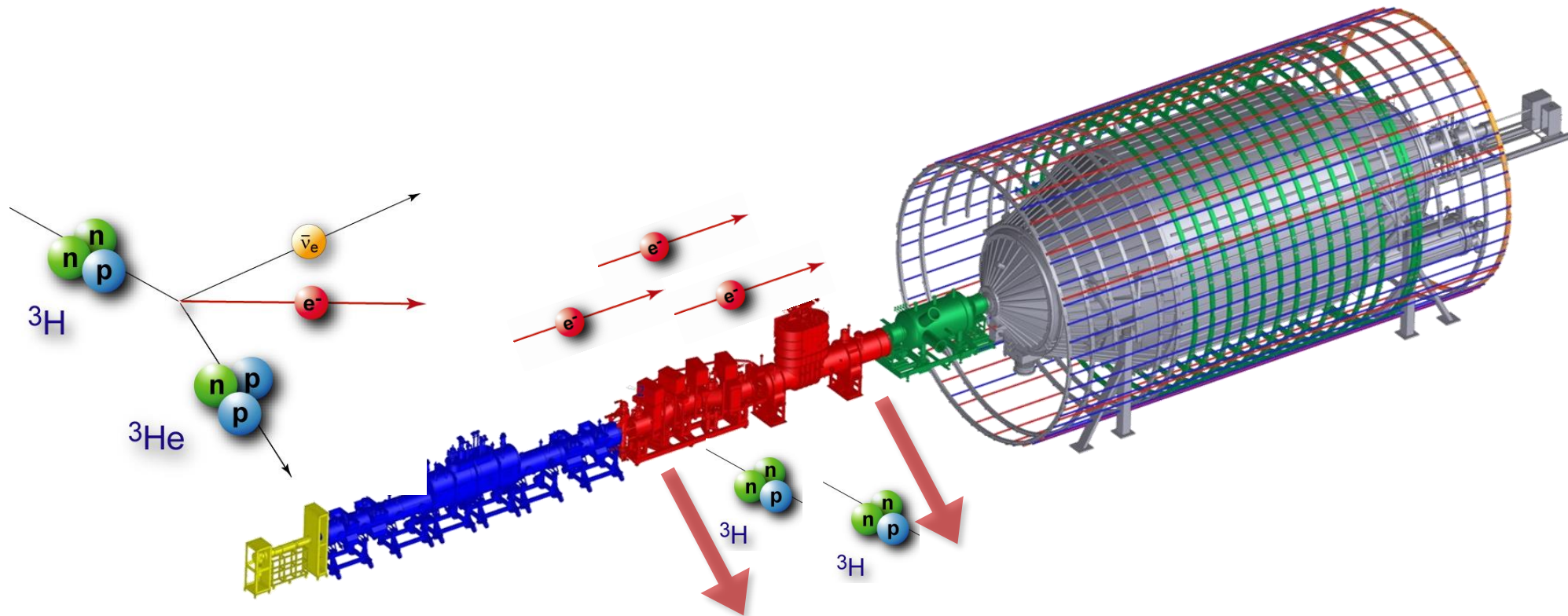
KATRIN overview



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Windowless Gaseous
Tritium Source

Transport and
Pumping Section



KATRIN overview



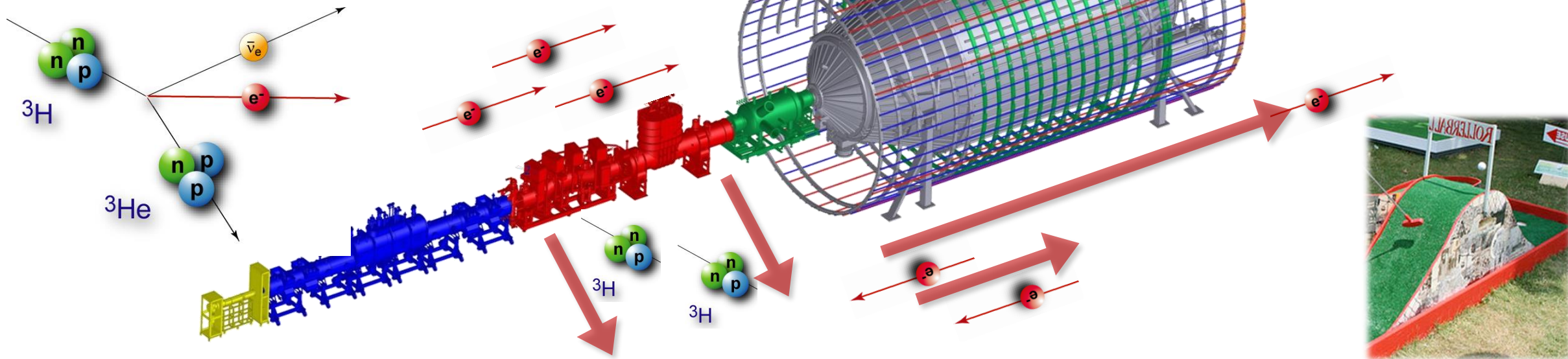
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Windowless Gaseous
Tritium Source

Transport and
Pumping Section

Spectrometer and
Detector Section

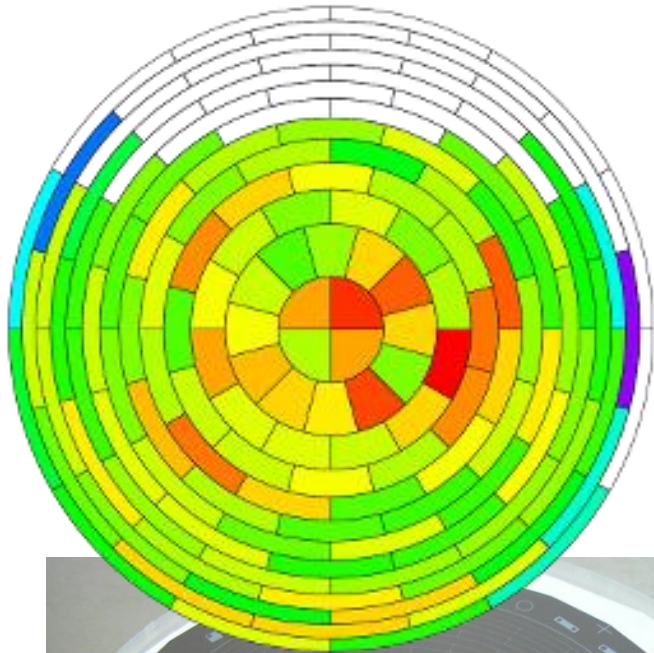
200 meV
(90% C.L.)



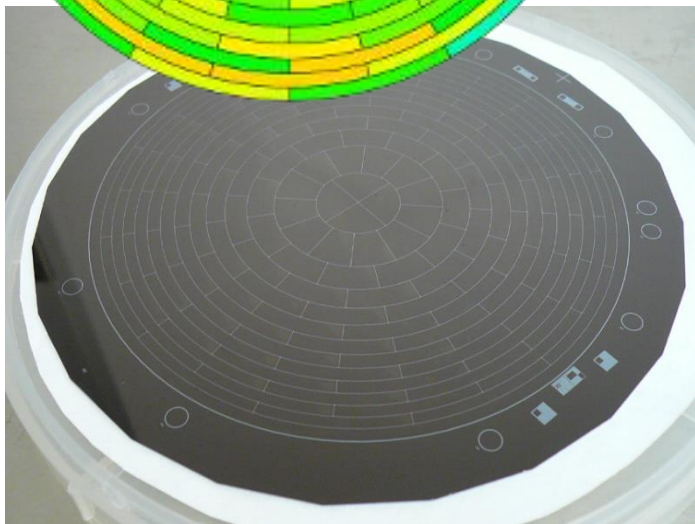
KATRIN detector



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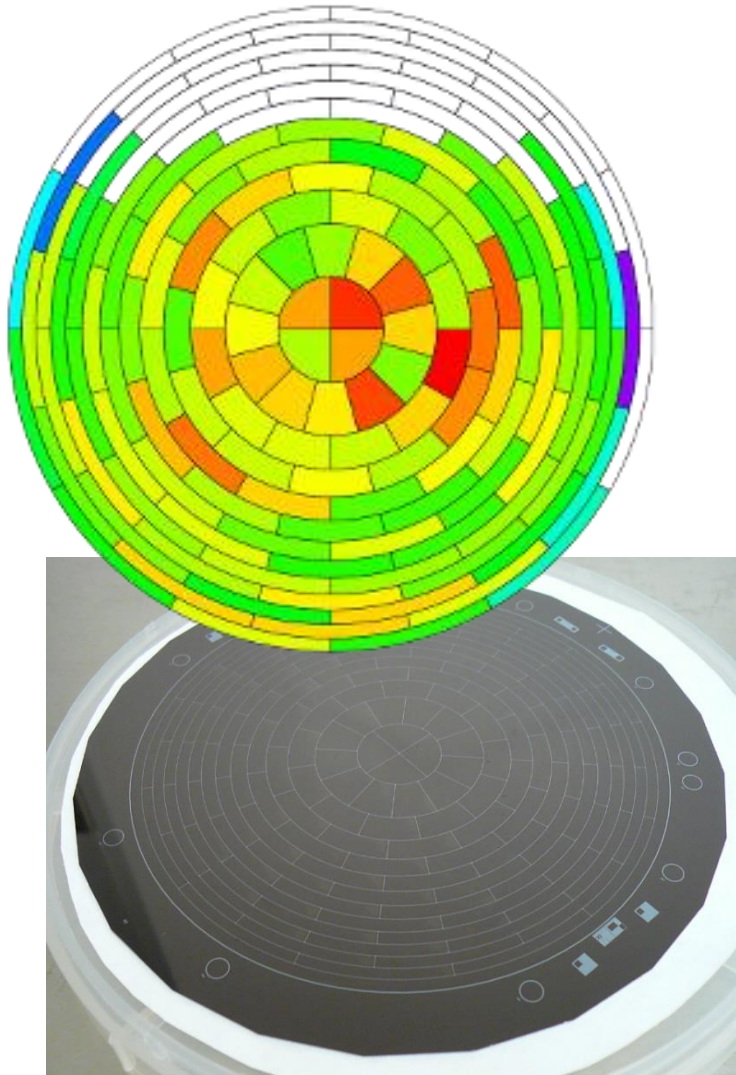
- Silicon PIN-diode array with 148 pixels
- Energy resolution ~ 1.4 keV
- Pile-up ~ 1 % at 1 kHz



KATRIN detector

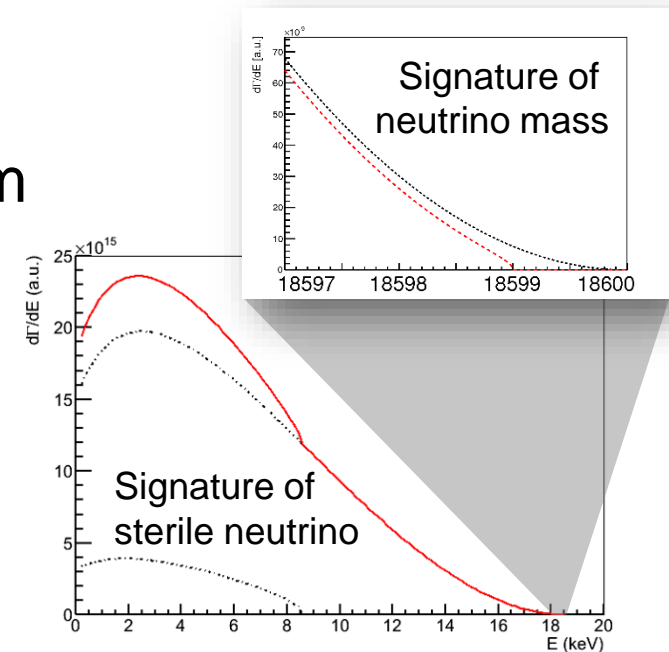


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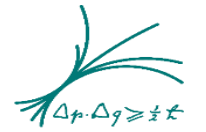


- Silicon PIN-diode array with 148 pixels
- Energy resolution ~ 1.4 keV
- Pile-up $\sim 1\%$ at 1 kHz

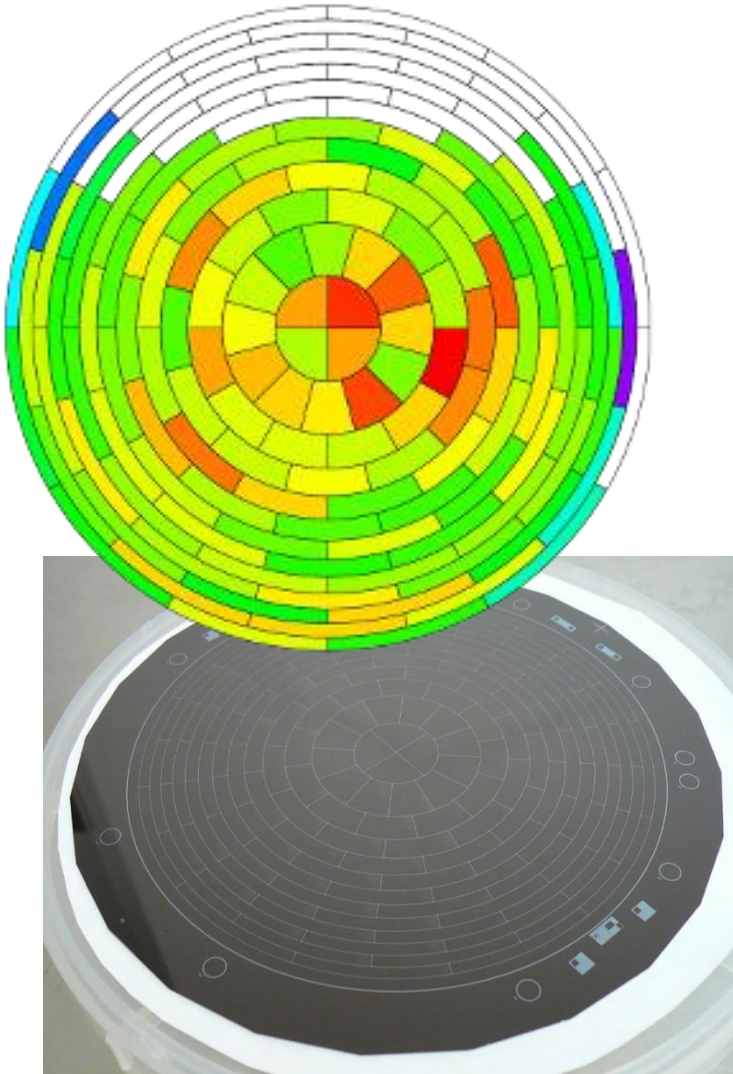
- Neutrino mass: last 50 eV
 - rate ~ 1 Hz
- Sterile neutrino: entire spectrum
 - rate $\sim 10^8 - 10^{10}$ Hz



KATRIN detector



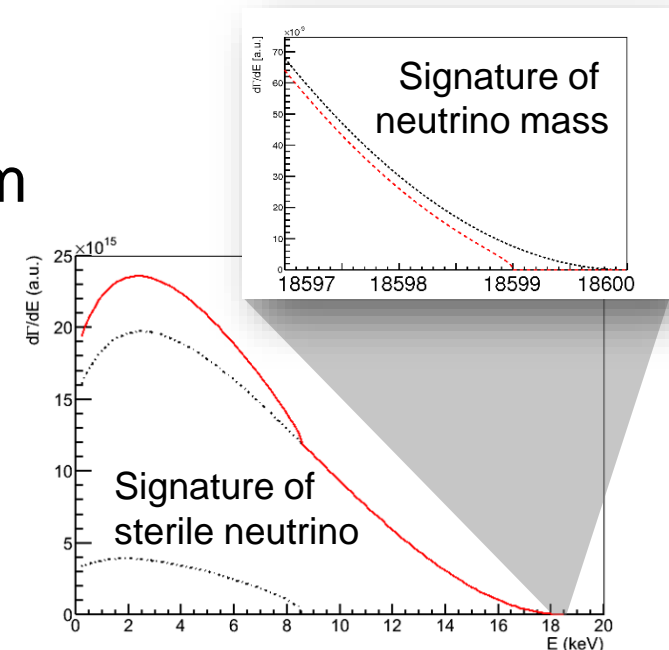
Max-Planck-Institut für Physik
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- Silicon PIN-diode array with 148 pixels
- Energy resolution ~ 1.4 keV
- Pile-up $\sim 1\%$ at 1 kHz

- Neutrino mass: last 50 eV
 - rate ~ 1 Hz
- Sterile neutrino: entire spectrum
 - rate $\sim 10^8 - 10^{10}$ Hz

Does not meet requirements
for a sterile neutrino search



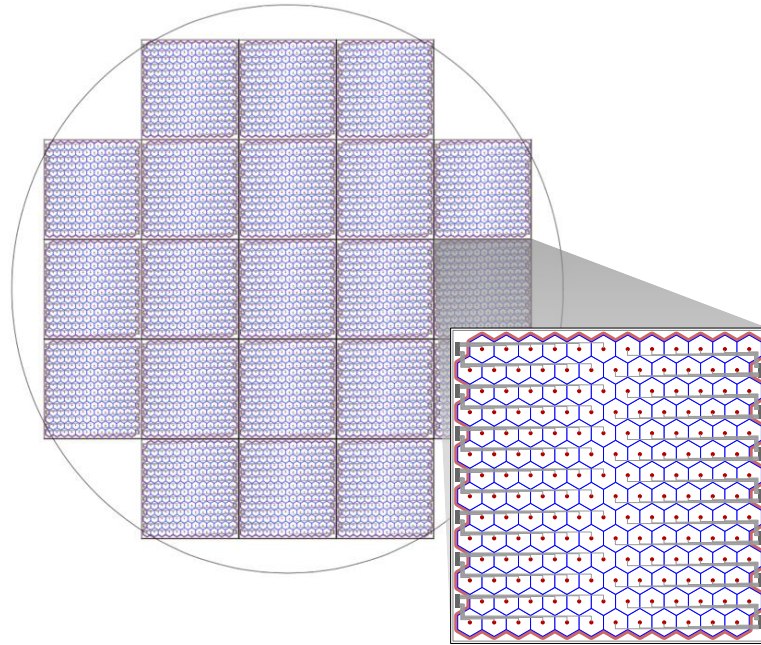
TRISTAN detector



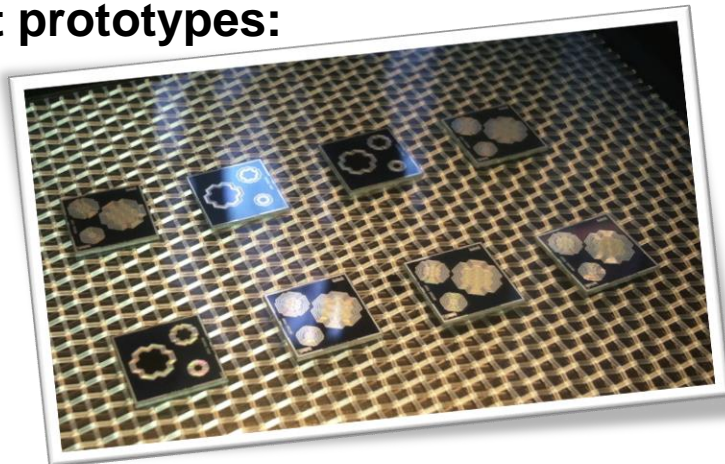
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Develop novel multi pixel detector system:

- Handling of high rates ($>10^9$ Hz)
 - 3000 - 4000 pixels
- Large area coverage (20 cm diameter), small capacitance
 - Multi-drift ring design (SDD)
- Good energy resolution (300 eV @ 20 keV), low threshold (1 keV)
 - **Thin dead layer** (< 100 nm)



First prototypes:

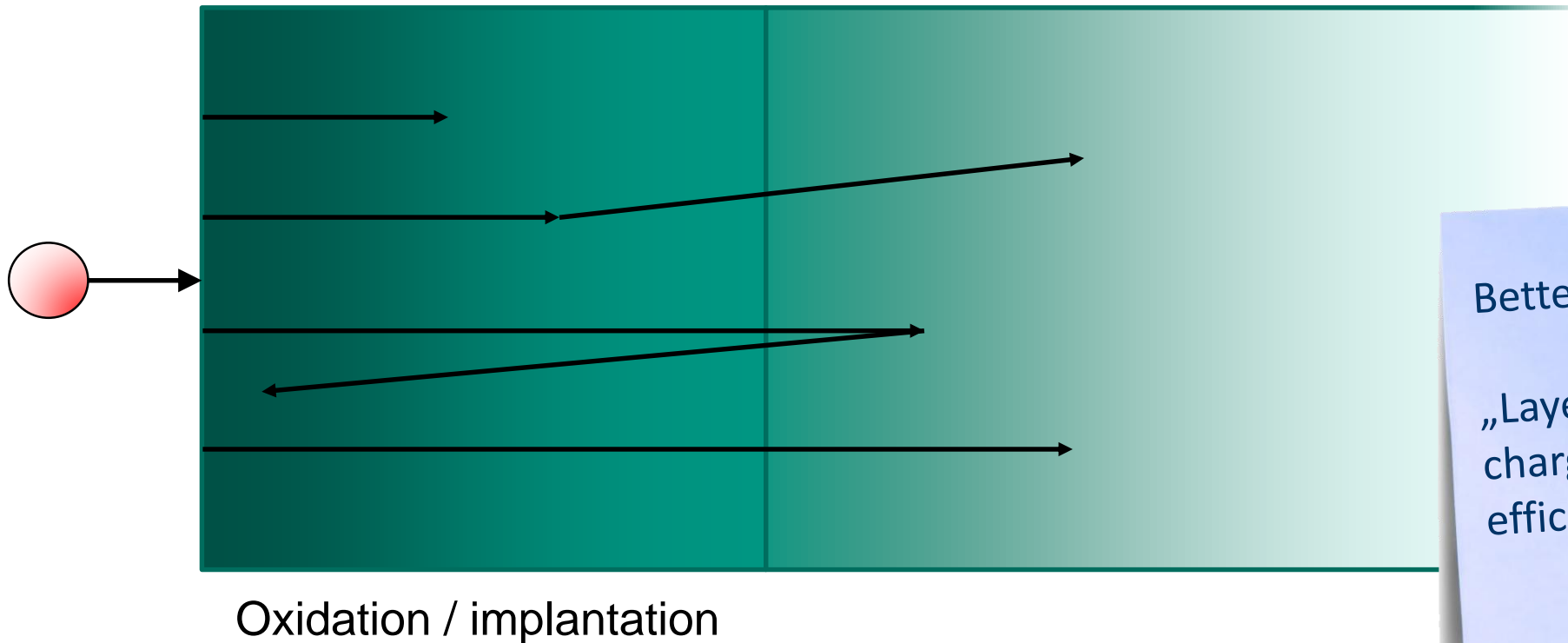


What is a dead layer?



„dead“ layer
($< 100 \text{ nm}$)

sensitive volume
($\sim 450 \mu\text{m}$)

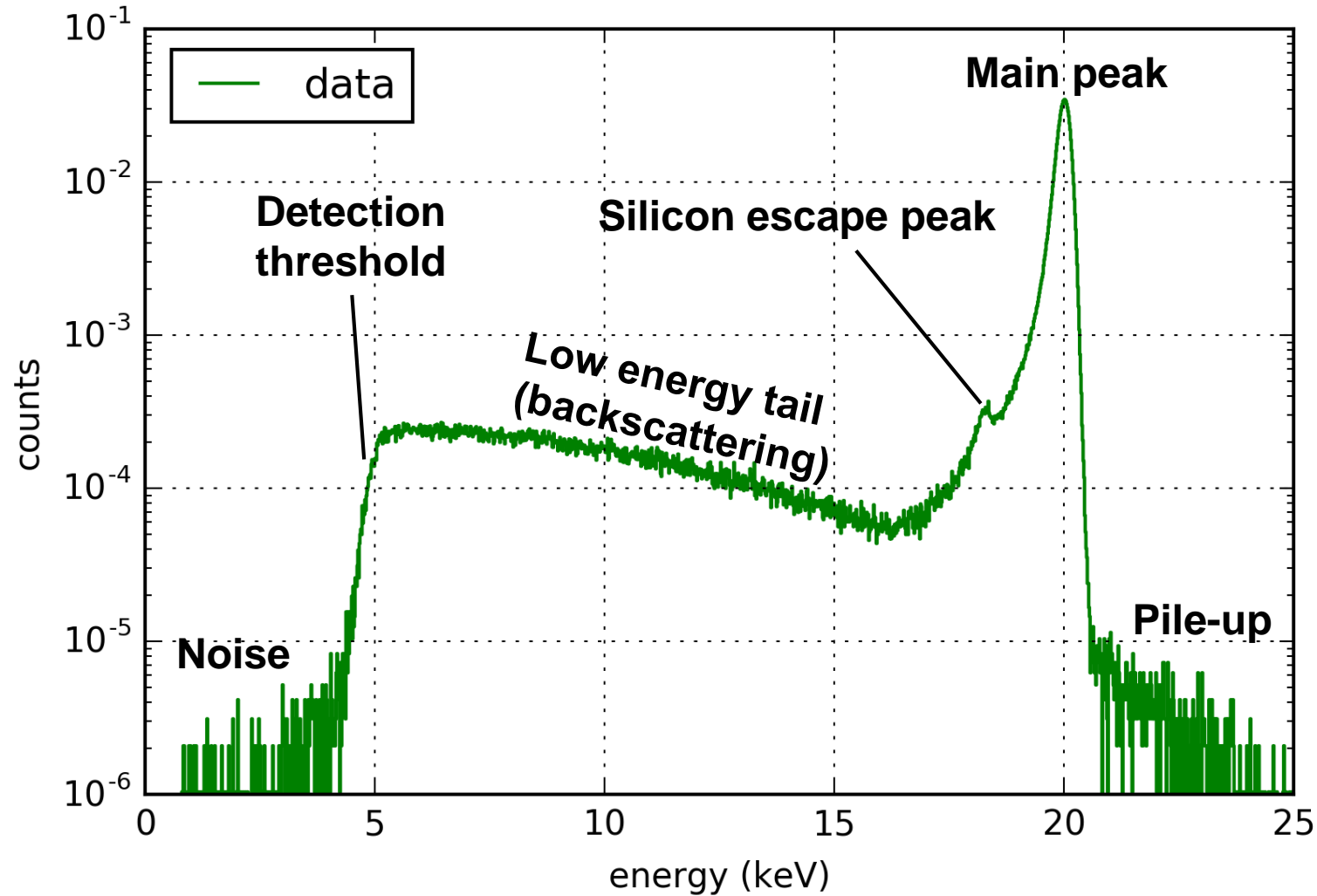


Better:
„Layer of incomplete charge collection efficiency“

Dead layer effect



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Measurement @ HLL:

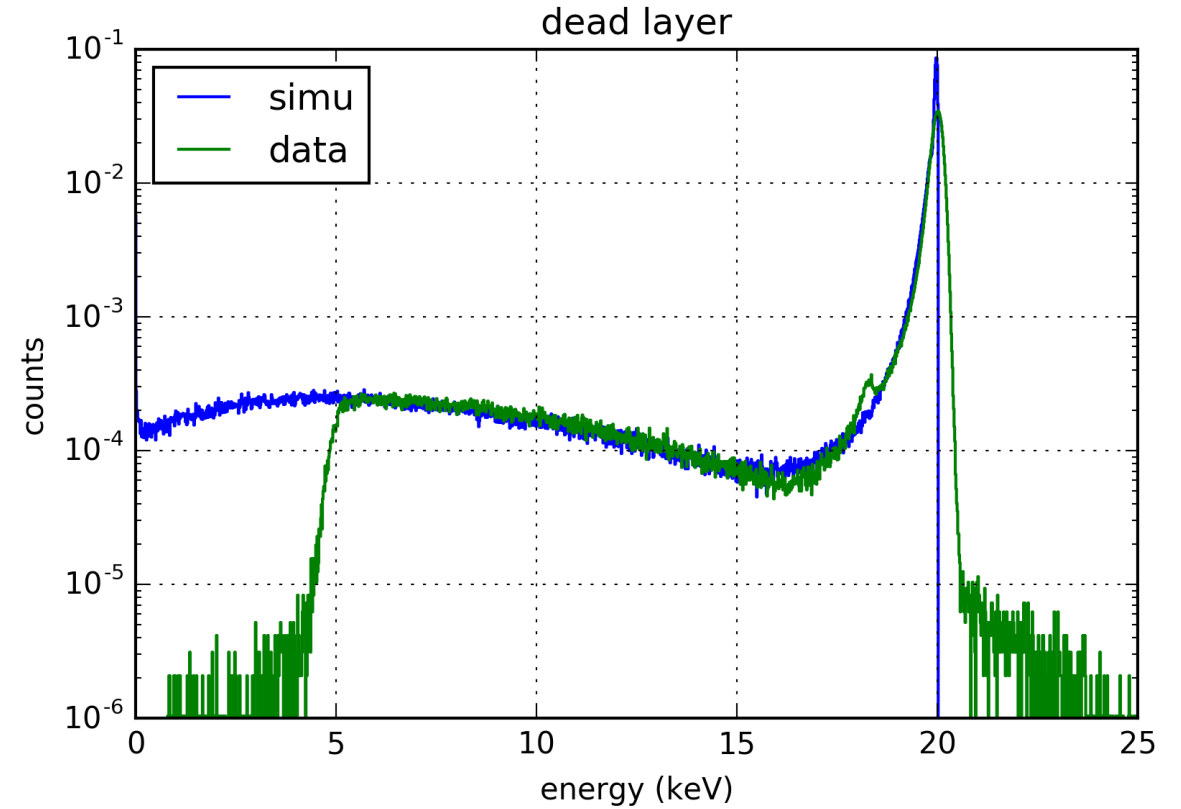
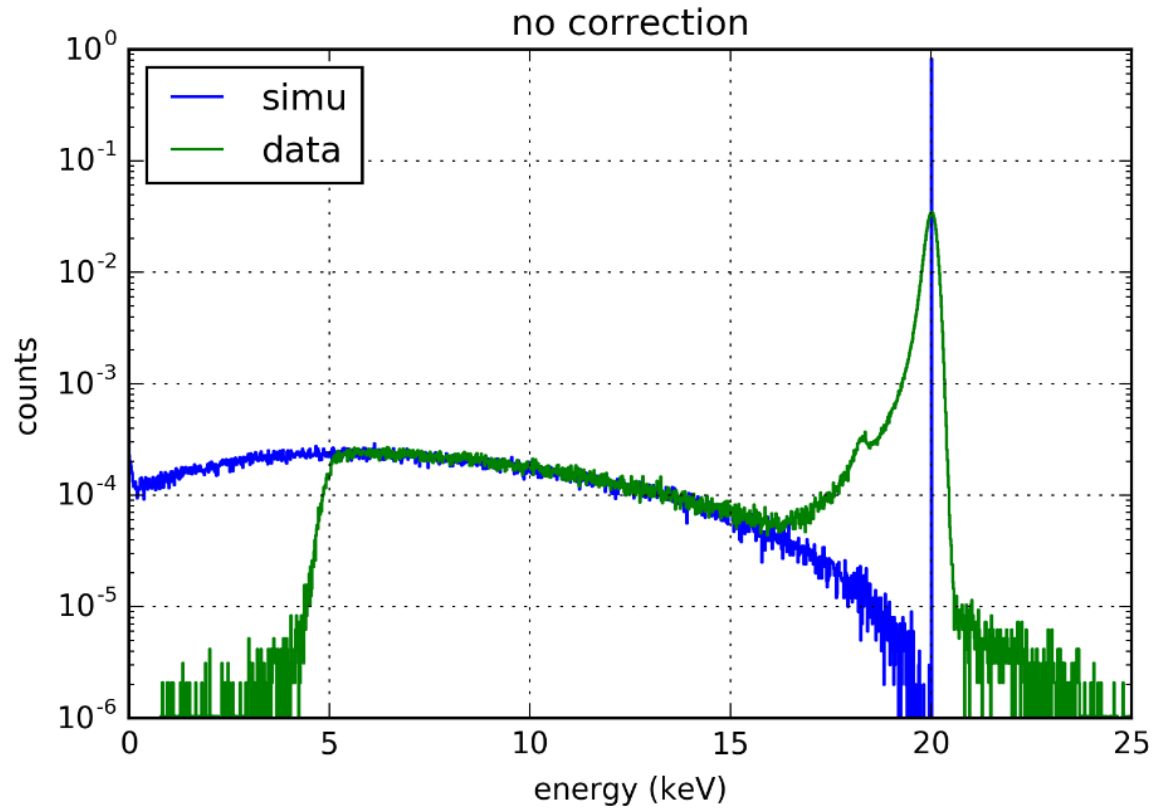
- 20 keV electrons
- ~ 10 kHz on one pixel



Dead layer effect



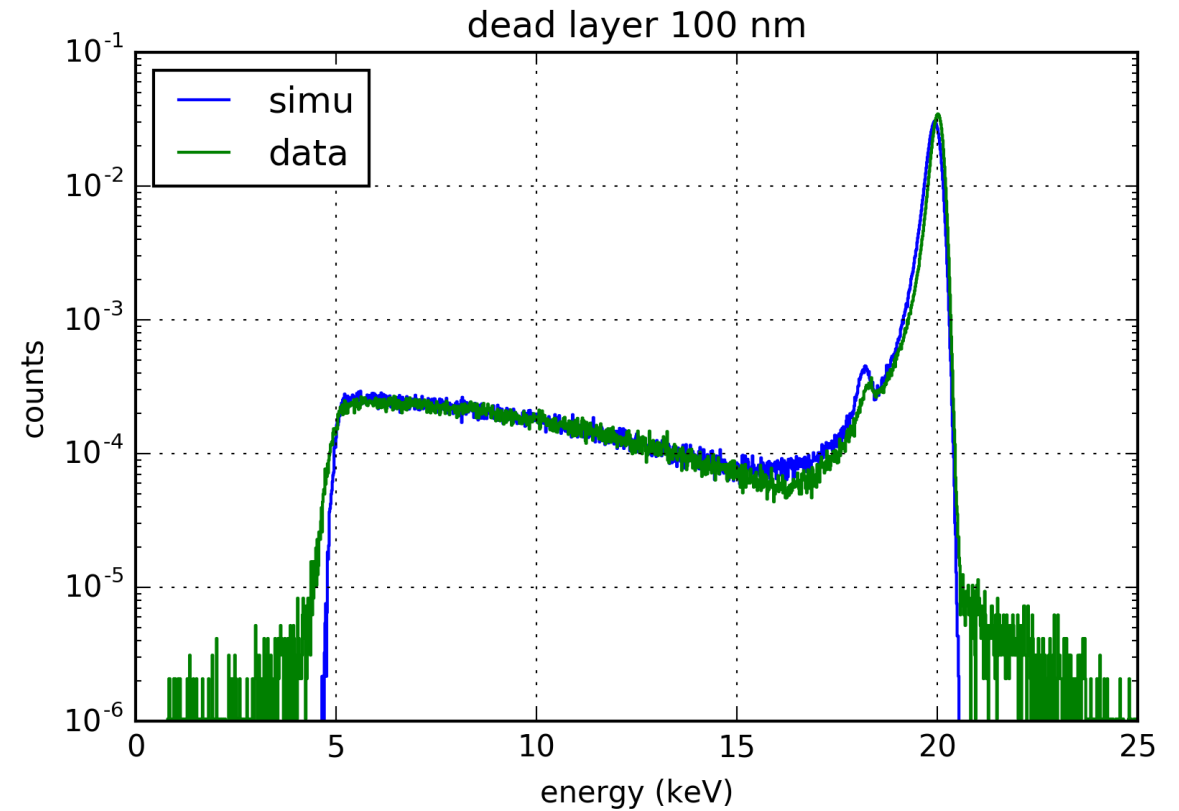
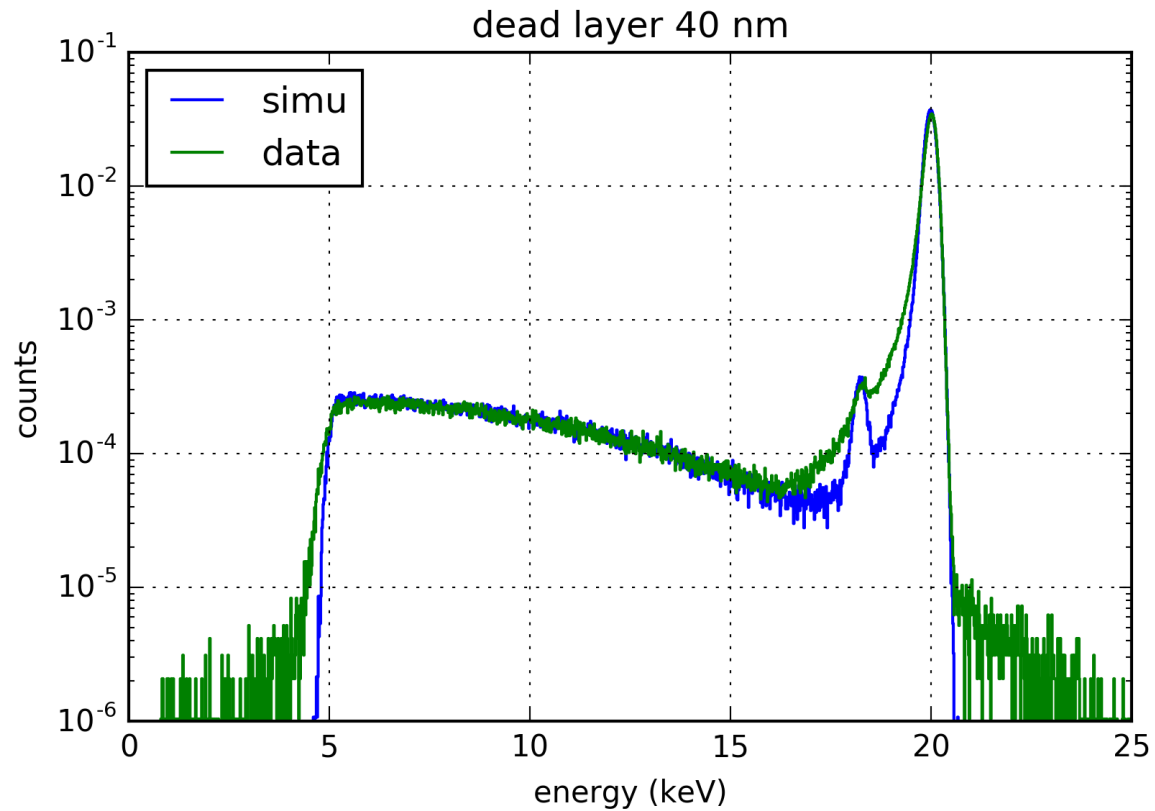
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Dead layer effect

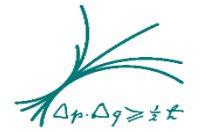


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Measure low energy shoulder, compare with simulations

What is a dead layer... and why do we have to correct for it?

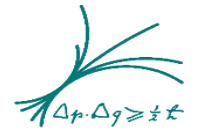


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- Large effect for low incident electron energy
 - Backscattered electrons can pass dead layer several times due to magnetic reflection
- Systematic uncertainty in continuous spectrum
 - Wash out of sterile neutrino signature

TRISTAN in Troitsk

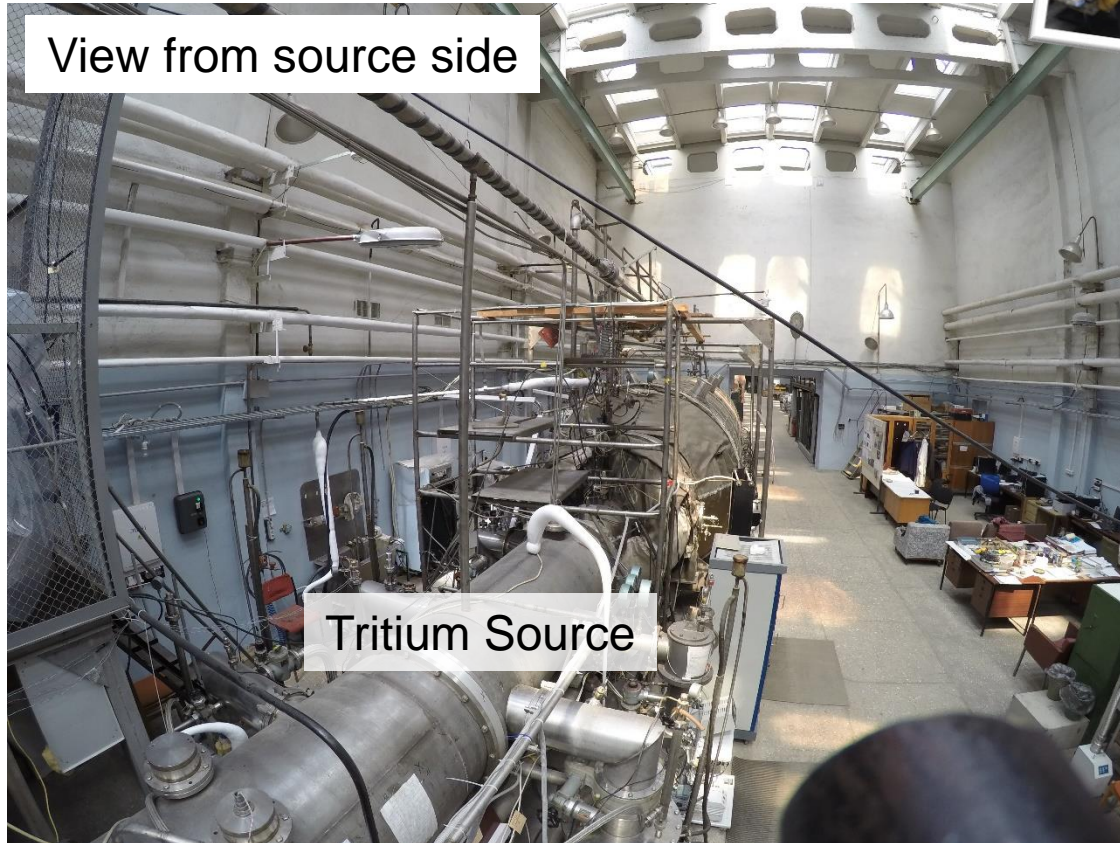
■ May 25th – June 4th 2017



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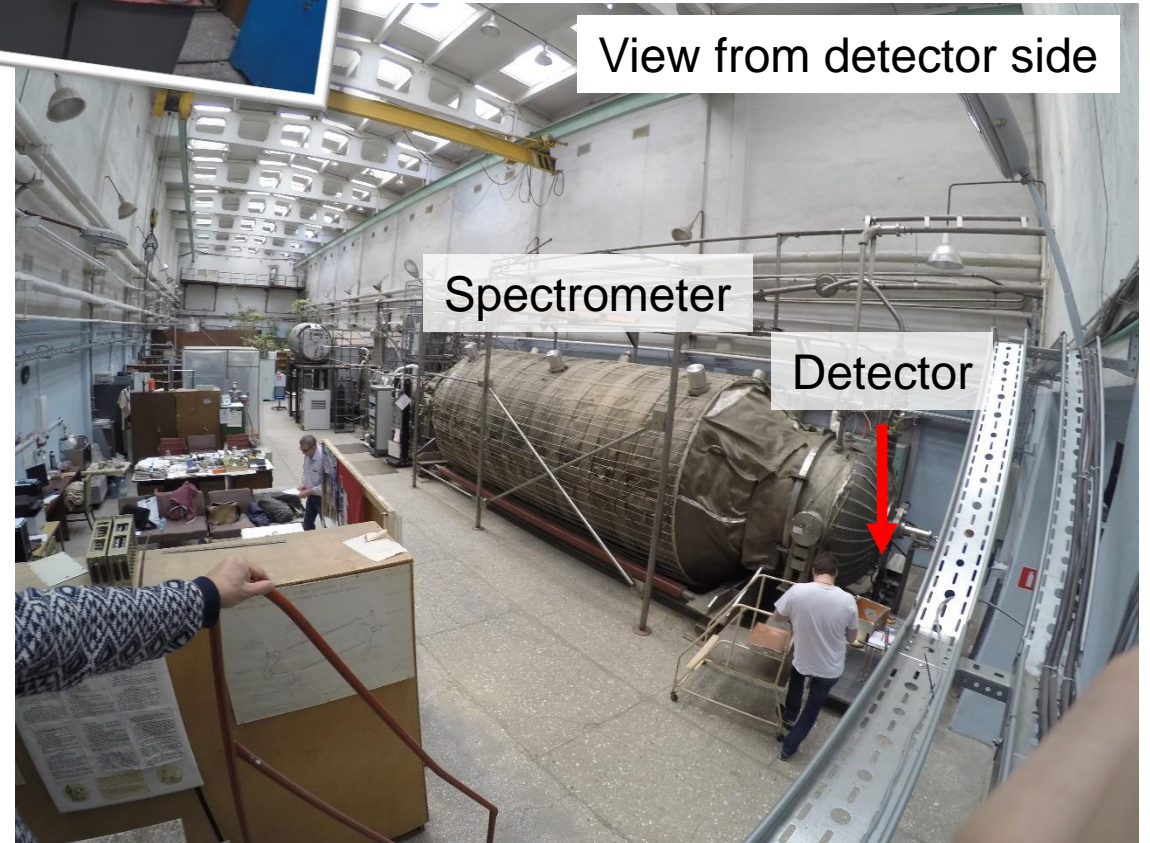


View from source side



Tritium Source

View from detector side



Spectrometer

Detector

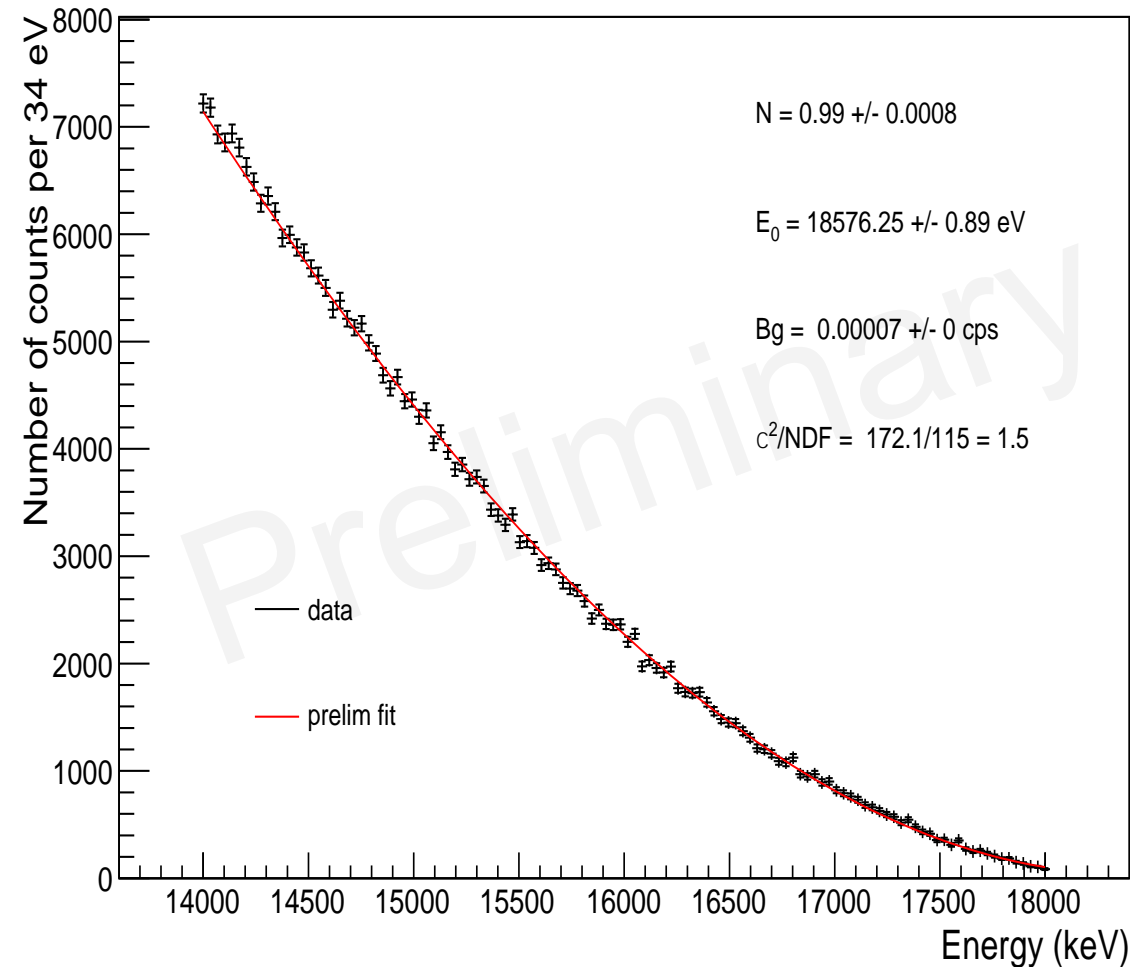


TRISTAN in Troitsk



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- 1mm 7-pixel TRISTAN detector
- Measurement of electrons from
 - Spectrometer walls
 - Electron gun
 - Tritium
- Data analysis is ongoing, first glance at data looks promising

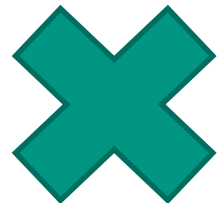
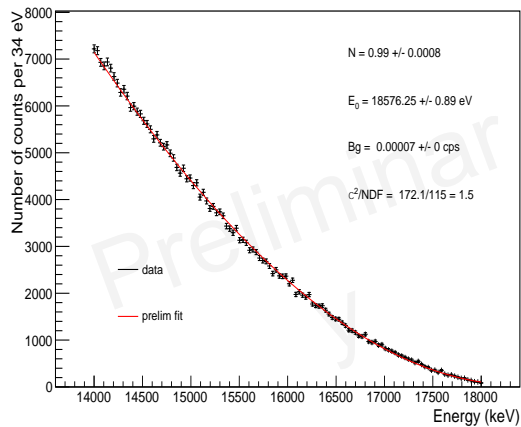


TRISTAN in Troitsk

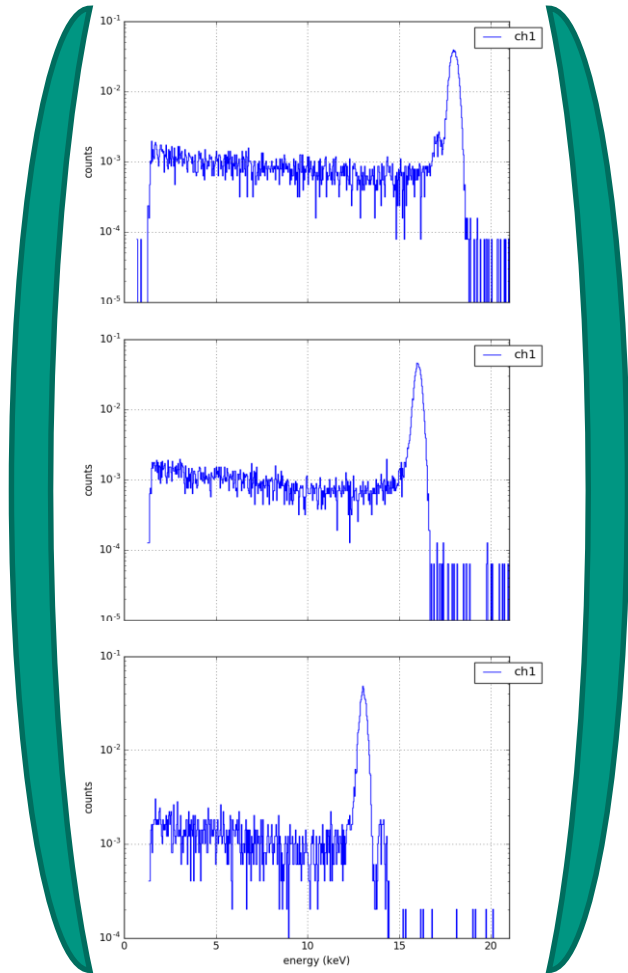


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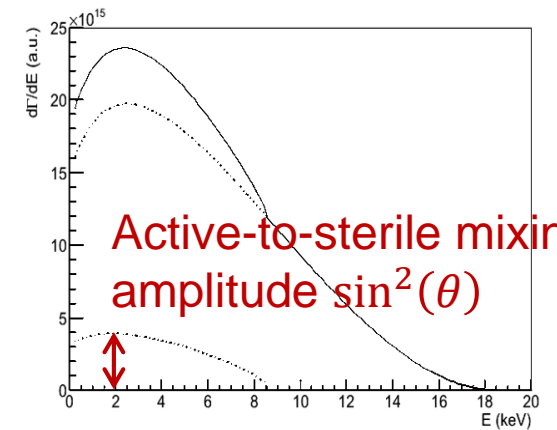
Measured tritium spectrum



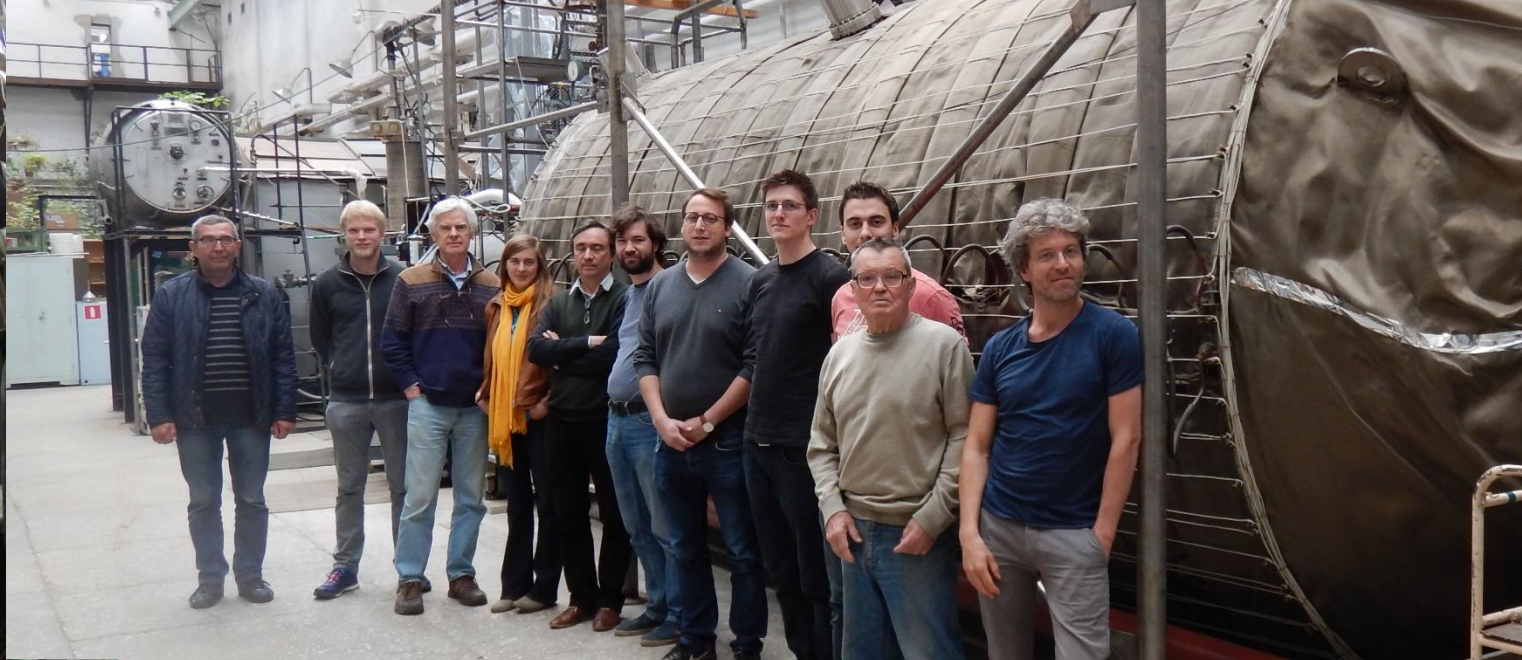
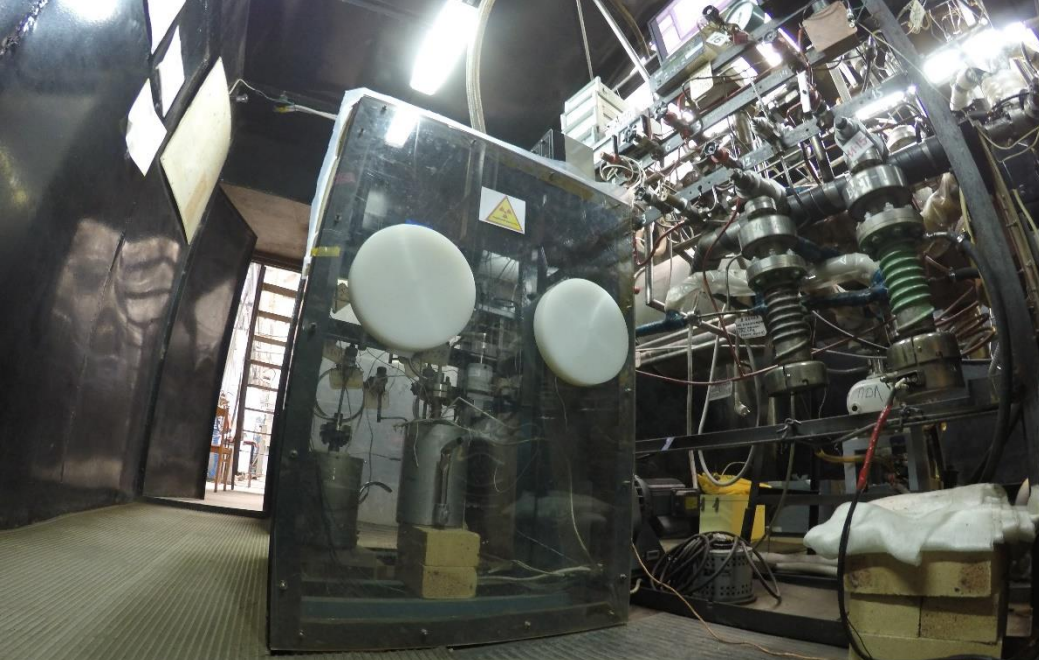
Detector response at different energies



Corrected tritium spectrum



Upper limit on mixing angle



Next visit planned for November 2017

