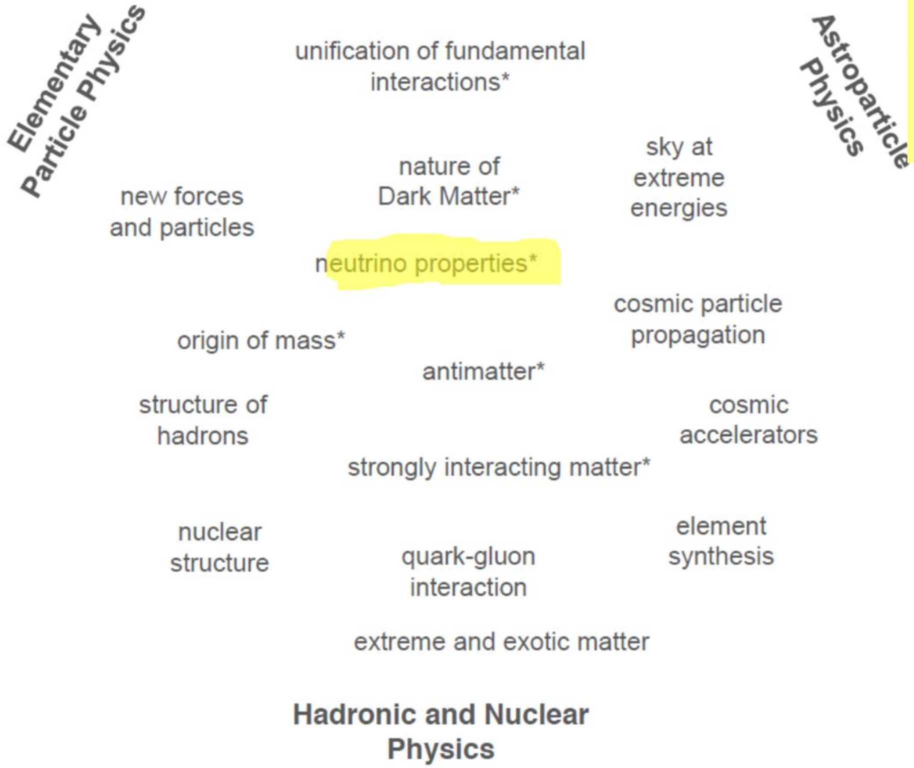
Neutrino Properties

Markus Steidl (KIT), Gabriel Martinez (GSI), (Walter Winter, DESY)

Testing neutrino masses at GeV scale: Theory vs. Experiments
(Rasmus Rasmussen, DESY)



ν-properties with IceCube
(Andrii Terliuk,DESY)

ν-properties with KATRIN
(Markus Steidl, KIT)

ν production in the sources of the UHECR and the role of nuclear physics
(A. Fedynitch, DESY)

ν ***in core-collaps supernovae nucleosynthesis***
(Andre Sieverding, GSI)

GeV neutrino mass models: Experimental reach vs. theoretical predictions

RWR, Walter Winter – Arxiv 1607.07880 – PRD 94, 073004 (2016)

HELMHOLTZ
ASSOCIATION

Rasmus W. Rasmussen
Matter and the Universe
12-12-16

DESY

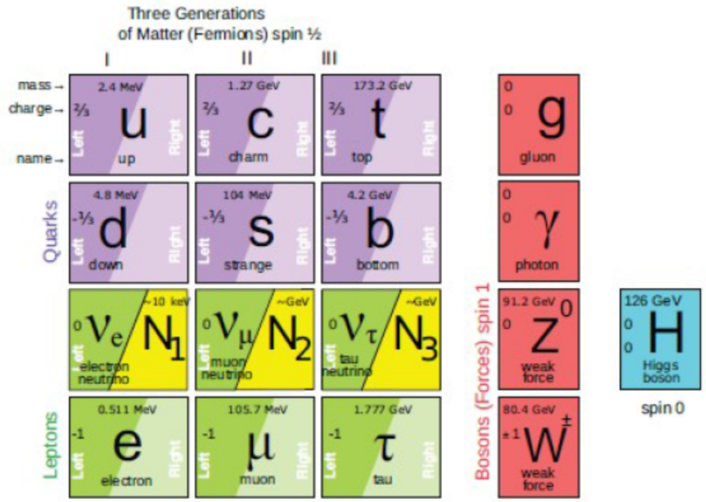
Beyond the SM

- Possible extension: The Neutrino Minimal Standard Model (nuMSM)

[Asaka, Shaposhnikov (2005); Canetti, Drewes, Frossard,Shaposhnikov (2012); Drewes, Garbrecht (2015); Hernandez, Kekic, Lopez-Pavon, Racker, Salvado (2016)..]

- N_1 is dark matter candidate with keV mass and total mixing $|U_I|^2 < 10^{-8}$

- N_2 and N_3 with 100 MeV-100 GeV mass: Origin of neutrino masses and baryon asymmetry



- **We will consider 3 sterile neutrinos at the GeV scale**: No mass degeneracy needed.

Generic assumptions

- We used the Casas-Ibarra parameterization $M_D = U_{PMNS}\sqrt{m_\nu}\,R\sqrt{M_R}$

  [Casas, Ibarra (2001)]

- Here $m_\nu = \mathrm{diag}(m_1, m_2, m_3)$ and $M_R = \mathrm{diag}(M_1, M_2, M_3)$ with $m_1 \in [0, 0.23]\,\mathrm{eV}$ and $M_i \in [0.1, 80]\,\mathrm{GeV}$ with $M_1 < M_2 < M_3$

- The complex matrix R have to satisfy $R^T R = 1$. This means it can be parameterized by rotation matrices with a complex angle

$$R = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13} & -c_{12}s_{23} - s_{12}c_{23}s_{13} & c_{23}c_{13} \end{bmatrix}$$

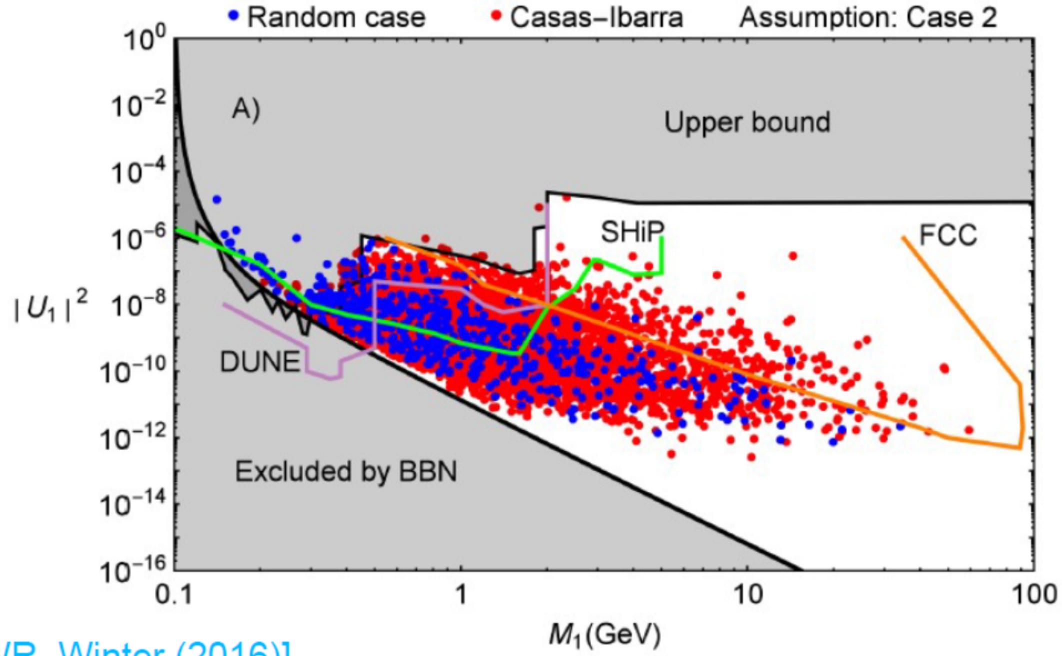
- where $c_{ij} = \cos(\omega_{ij})$ and $s_{ij} = \sin(\omega_{ij})$ with $\mathrm{Re}(\omega_{ij}) \in [0, 2\pi]$ and $\mathrm{Im}(\omega_{ij}) \in [-8, 8]$

All realizations have to obey experimental constraints: Neutrino oscillation data, LFV, neutrinoless double beta decay, direct searches, loop corrections and Big Bang nucleosynthesis

Generic assumption – Total active-sterile mixing for N1

> Casas-Ibarra parameterization can generate the whole parameter space
[Drewes, Garbrecht (2015)]

> But still interesting to investigate the scatter plot of the mixing elements



- FCC Future Circular Collider
- ShiP Search for hidden particles @ SPS
- DUNE Deep Underground Neutrino Experiment

[RWR, Winter (2016)]

DESY

Summary

- Sterile neutrinos are theoretically motivated and can solve many of the problems in the SM
- Generic assumptions generates the whole parameter space
- Predictions from flavor models are more refined in comparison to generic assumptions
- Potential to exclude parameter space of models by measuring the total mixing
- Important to measure the individual mixing elements

ShiP
Dune
FCC

RWR, Walter Winter – Arxiv 1607.07880 – PRD 94, 073004 (2016)

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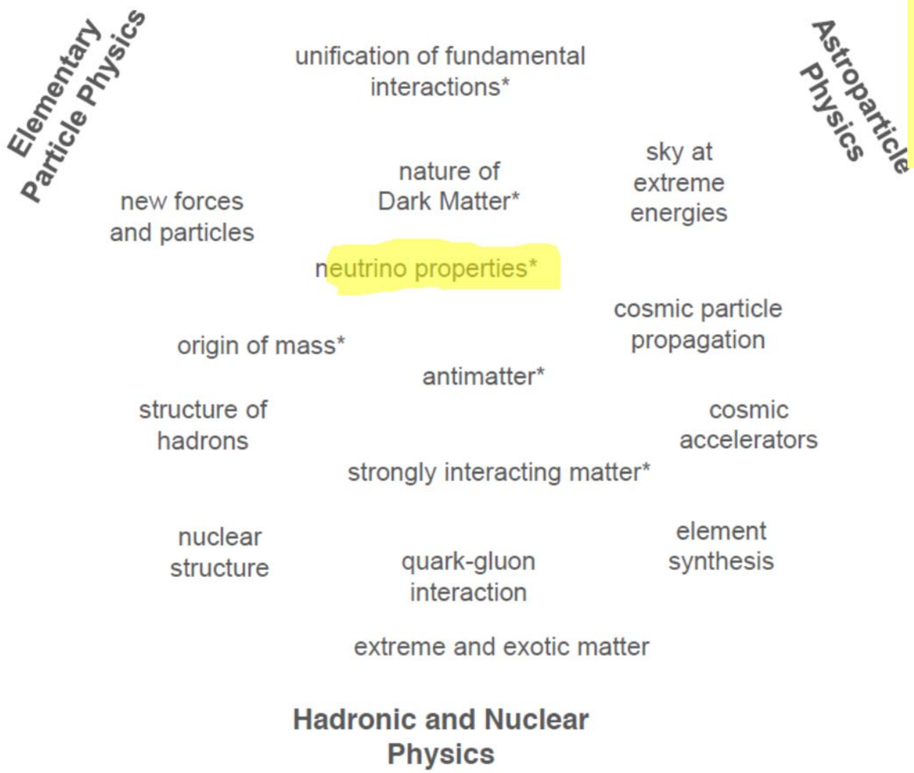

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Neutrinos in core-collapse supernova nucleosynthesis

Neutrino-driven winds and the ν process

A. Sieverding[1], M.-R. Wu[2], G. Martínez-Pinedo[1,3], K. Langanke[1,3],A. Heger[4]

[1]Technische Universität Darmstadt
[2]University of Copenhagend, Nils Bohr institute
[3]GSI Helmholtzzentrum, Darmstadt
[4]Monash Centre for Astrophysics, Melbourne

TECHNISCHE UNIVERSITÄT DARMSTADT

SFB 1245

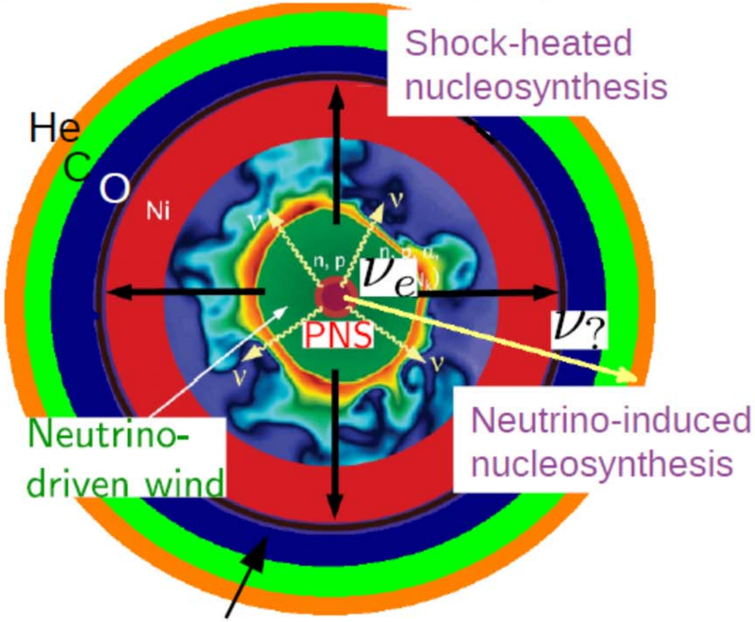
GSI

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

Matter and Universe 2016
Helmholtz institute Mainz
12 Dec. 2016

Neutrinos and nucleosynthesis in supernovae

[Modified from Janka+, PTEP 01A309, 2012]



shockwave (revived mainly by ν-heating)

- neutrino (induced) nucleosynthesis
  - $\rightarrow$ light elements : Li, Be, B, F
  - $\rightarrow$ radioactive nuclei : ^{22}Na, ^{26}Al
    rare isotopes : ^{138}La, ^{180}Ta

- neutrino-driven wind

$$\nu_e + n \rightarrow p + e^-$$
$$\bar{\nu}_e + p \rightarrow n + e^+$$

$\rightarrow$ determine the neutron-to-proton ratio (or equivalently, the electron number fraction per baryon, Y_e) of the ejecta

$\sim 10^{58}$ neutrinos of different flavors in $\sim$ 10 seconds

$\langle E_\nu \rangle \sim 7 - 20$ MeV

$\langle E_{\nu_e} \rangle \lesssim \langle E_{\bar{\nu}_e} \rangle < \langle E_{\nu_{\mu,\tau}} \rangle$

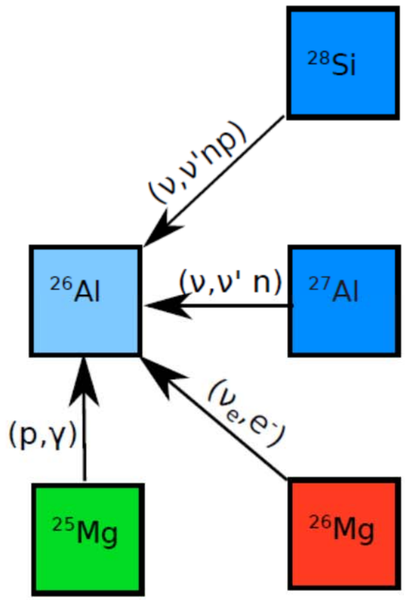
neutrino flavor oscillations

$\nu_e \leftrightarrow \nu_{\mu,\tau}$ & $\bar{\nu}_e \leftrightarrow \bar{\nu}_{\mu,\tau}$

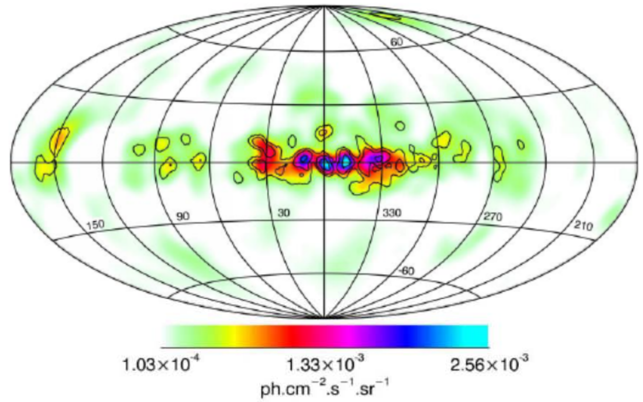
$\nu_e \leftrightarrow \nu_s$ & $\bar{\nu}_e \leftrightarrow \bar{\nu}_s$

when? where? how (much)?

Production channels for ^{26}Al in the ν process

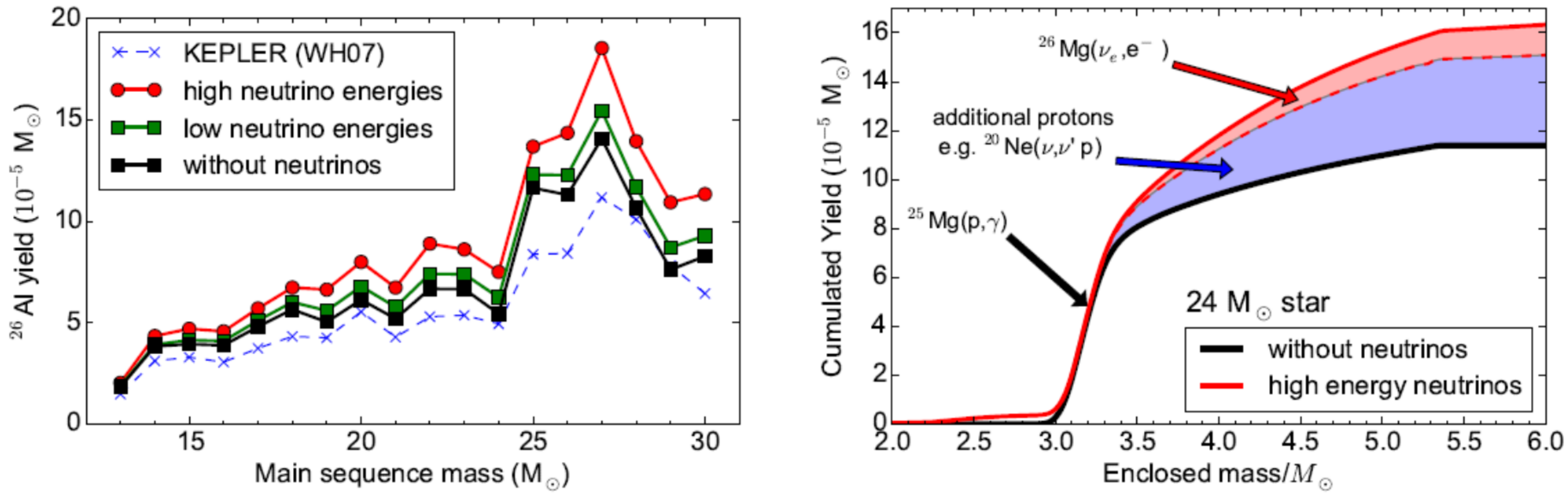


Galactic ^{26}Al emission with *INTEGRAL* SPI



- Different mechanisms:
  - enhancement of p-captures
  - charged-current channel
  - neutral-current channels

Contribution to the production of radioactive nuclei



- ^{60}Fe/^{26}Al ≈ 1.25 (Observations give ≈ 0.35)
- Further contributions from less massive stars, Wolf-Rayet stars, rotating stars

Isotope	without ν	low energy ν	high energy ν
^{26}Al	5.19	5.64	6.56
^{22}Na	0.20	0.27	0.39

- ^{22}Na with a half life of 2.6 yr is affected similarly

Conclusions

- Core-Collapse supernovae are an ideal laboratory to study neutrino properties
- Impact on nucleosynthesis in the neutrino driven wind and the ν process
  - Production of nuclei between Zn and Mo in NDW
  - Light elements in the ν process
  - Increased production of radioactive nuclei (e.g. ^{26}Al)
- Neutrino Oscillations seem to have a minor impact on nucleosynthesis results, but the impact of newly discovered instabilities need to be explored

Neutrino properties are important to understand astrophysical phenomena

Testing neutrino masses at GeV scale: Theory vs. Experiments
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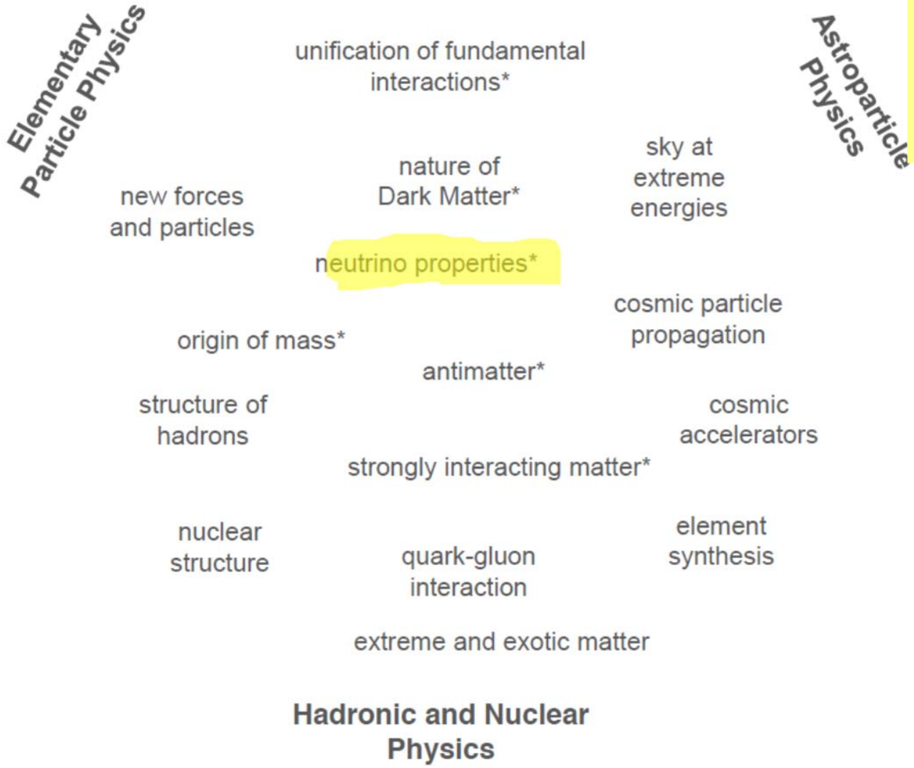
ν-properties with IceCube
(Andrii Terliuk,DESY)



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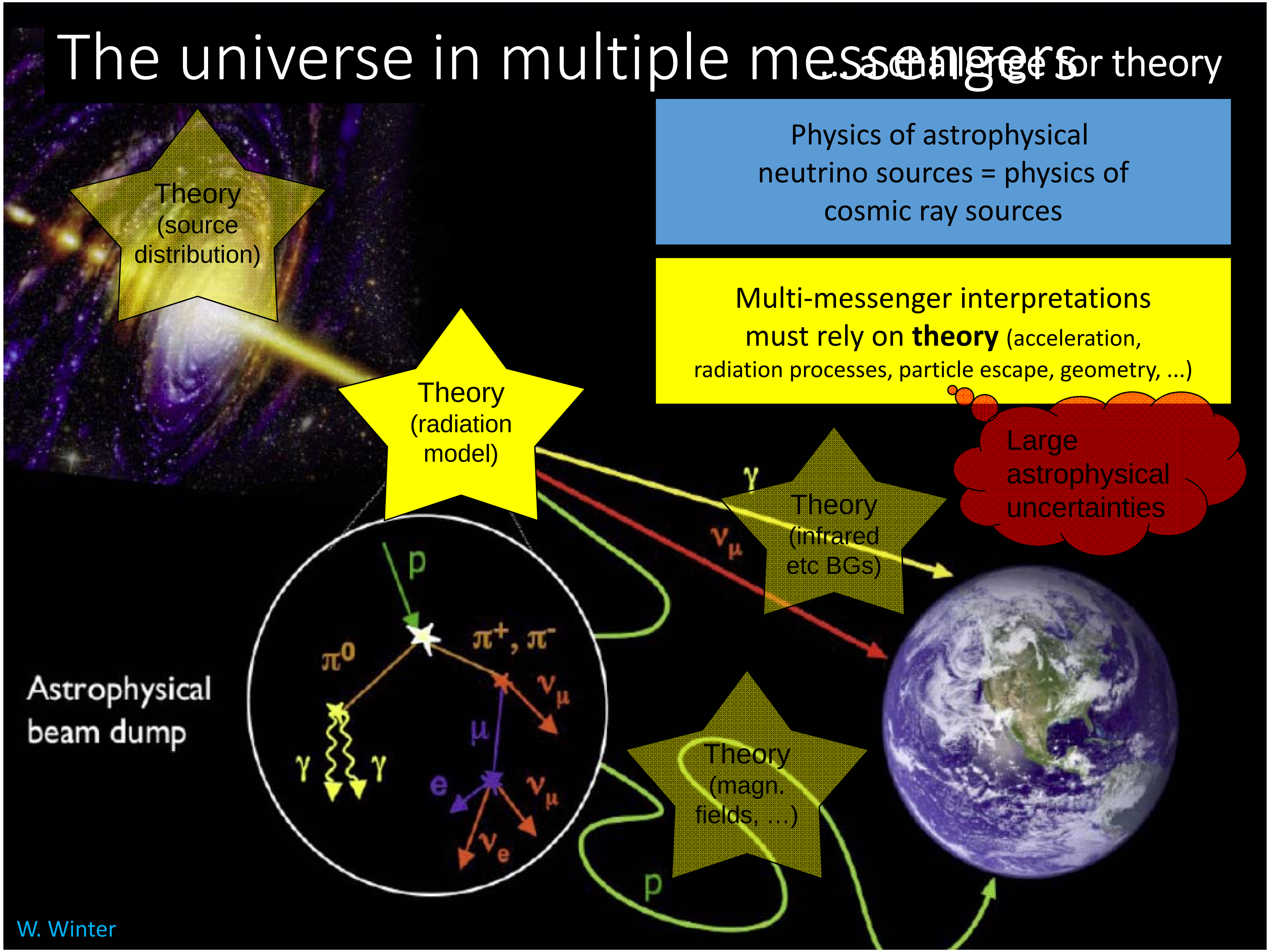


The universe in multiple messengers
... a challenge for theory
Physics of astrophysical neutrino sources = physics of cosmic ray sources
Multi-messenger interpretations must rely on **theory** (acceleration, radiation processes, particle escape, geometry, ...)
Large astrophysical uncertainties
Theory (source distribution)
Theory (radiation model)
Theory (infrared etc BGs)
Theory (magn. fields, ...)
Astrophysical beam dump
p
π^0
π^+, π^-
ν_μ
μ
γ
γ
e
ν_μ
ν_e
γ
ν_μ
p
W. Winter

Neutrino production at the source

Ideal pγ source

$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} n + \pi^+ & 1/3 \text{ of all cases} \\ p + \pi^0 & 2/3 \text{ of all cases} \end{cases}$$

Ideal pp source

$$\mathrm{p} + \mathrm{p} \rightarrow \begin{cases} \pi^+ + \text{anything} & 1/3 \text{ of all cases} \\ \pi^- + \text{anything} & 1/3 \text{ of all cases} \\ \pi^0 + \text{anything} & 1/3 \text{ of all cases} \end{cases}$$

Neutrino production

$$\pi^+ \rightarrow \mu^+ + \nu_\mu,$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

Flavor compositition expected from ideal scenarios

	Source flavor composition ($\phi_e : \phi_\mu : \phi_\tau$)		Earthly flavor composition ($\phi_e^f : \phi_\mu^f : \phi_\tau^f$)		Earthly $\bar{\nu}_e$ fraction $\xi_{\bar{\nu}_e}^f$ in cosmic neutrino flux
pp $\to \pi^\pm$ pairs	(1:2:0)		(1:1:1)		$9/54 = 17\%$
w/ damped $\mu^\pm$	(0:1:0)		(4:7:7)		$6/54 = 11\%$
	ν	$\bar{\nu}$	ν	$\bar{\nu}$	
p$\gamma \to \pi^+$ only	(1:1:0)	(0:1:0)	(14:11:11)	(4:7:7)	$4/54 = 7.4\%$
w/ damped μ^+	(0:1:0)	(0:0:0)	(4:7:7)	(0:0:0)	0

- Clear expectation of flavor composition from idealized models
- Electron anti-neutrino fraction is crucial for the Glashow resonance event rate in neutrino detectors. **Signature** for mechanism in the source!

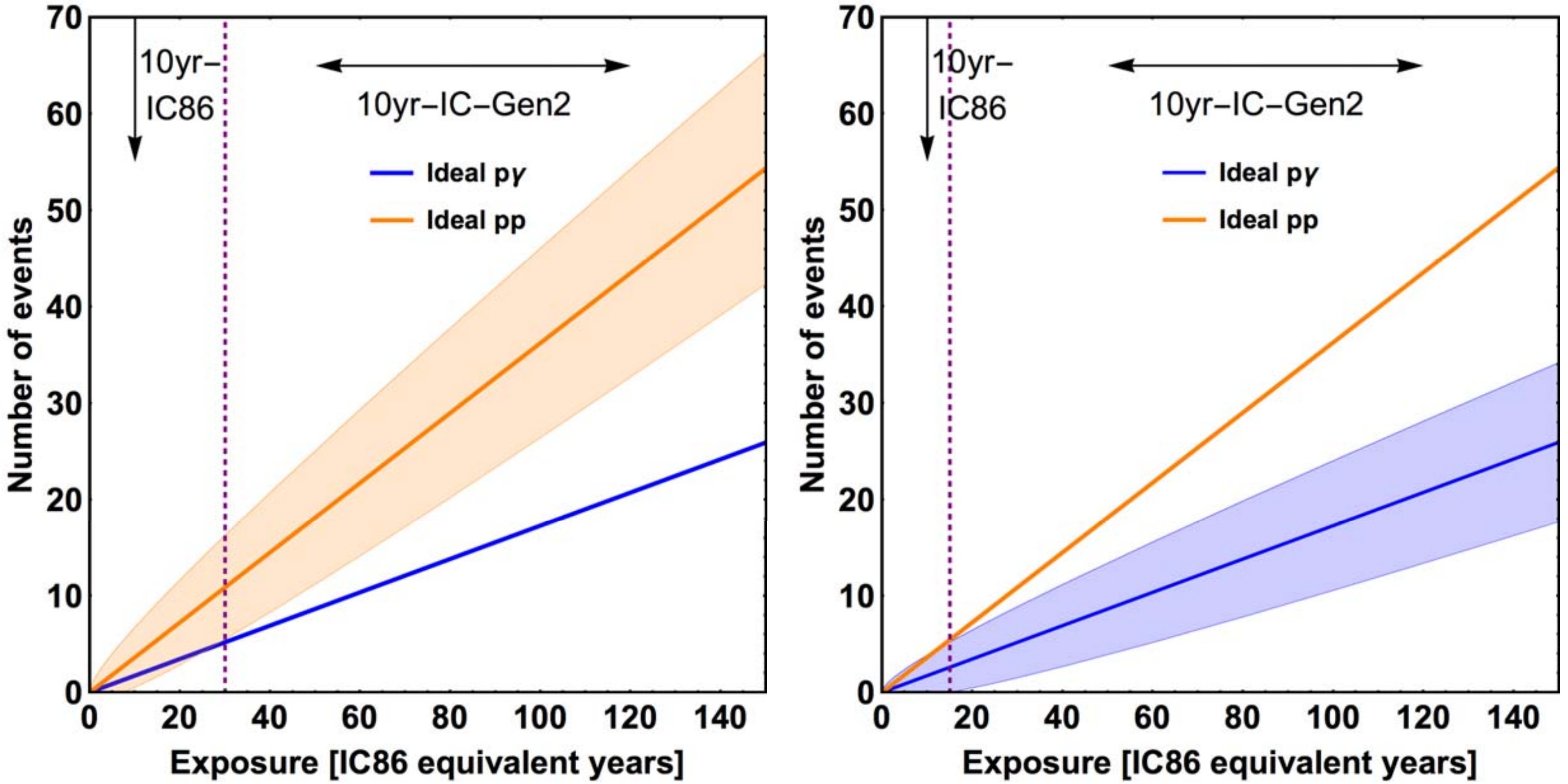
The Glashow resonance

$$\bar{\nu}_e + e^- \to W^- \to \text{hadrons at } 6.3 \text{ PeV}$$

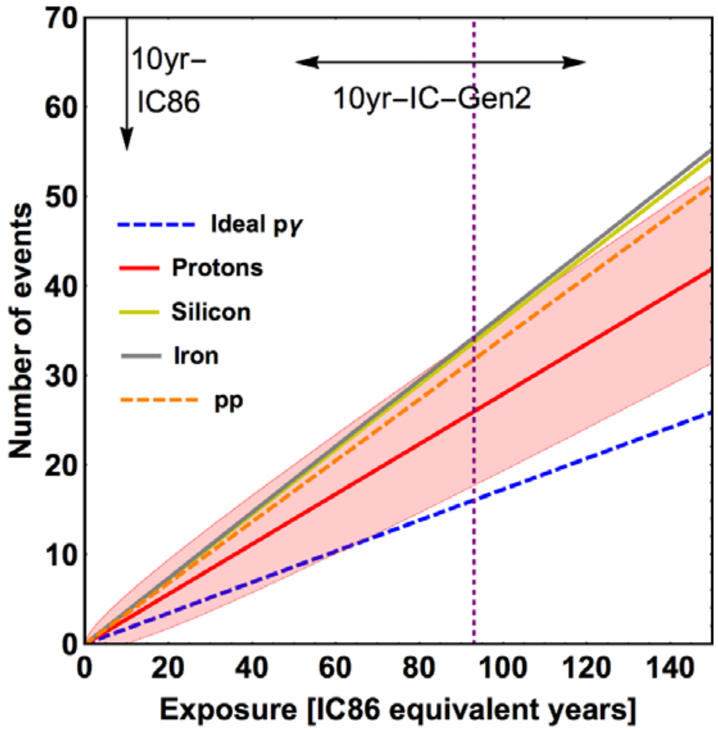
D. Biehl, A. Fedynitch, A. Palladino, T. Weiler and W. Winter, arXiv: 1611.07983

DESY

Discrimination between scenarios



Glashow events from sources of cosmic ray nuclei



> Presence of nuclei in UHECR sources results in higher number of Glashow events

> 95 IC-86 equivalent years needed (~10 years Gen-2)

> …but not from pp sources, or if diffuse flux comes from many different sources types

> More details and other scenarios in **1611.07983**

Summary/Conclusion

> **Astrophysical Neutrino Production Diagnostics with the Glashow Resonance**
>
> Daniel Biehl and Anatoli Fedynitch
> *DESY, Platanenallee 6, 15738 Zeuthen, Germany*
>
> Andrea Palladino
> *Gran Sasso Science Institute, L'Aquila (AQ), Italy*
>
> Tom J. Weiler
> *Department of Physics & Astronomy, Vanderbilt University, Nashville, TN 37235, USA*
>
> Walter Winter
> *DESY, Platanenallee 6, 15738 Zeuthen, Germany*
> (Dated: November 28, 2016)
>
> We study the Glashow resonance $\bar{\nu}_e + e^- \to W^- \to$ hadrons at 6.3 PeV as diagnostic of the production processes of ultra-high energy neutrinos. The focus lies on describing the physics of neutrino production from pion decay as accurate as possible by including the kinematics of weak decays and Monte Carlo simulations of pp and pγ interactions. We discuss optically thick (to photohadronic interactions) sources, sources of cosmic ray nuclei and muon damped sources. Even in the proposed upgrade IceCube-Gen2, a discrimination of scenarios such as pp versus pγ is extremely
>
> **https://arxiv.org/abs/1611.07983**

- Presence of nuclei changes the multi-messenger interpr neutrino sky, UHECR and their sources
- More sophisticated theoretical methods and models are necessary and part of ongoing effort
- Serious uncertainties from nuclear physics: photo-disintegration and *photo-meson production* at XX MeV – X GeV
- Flavor composition of astrophysical neutrinos sensitive to various source scenarios
- Glashow resonance can serve as a discriminator in IceCube Gen-2

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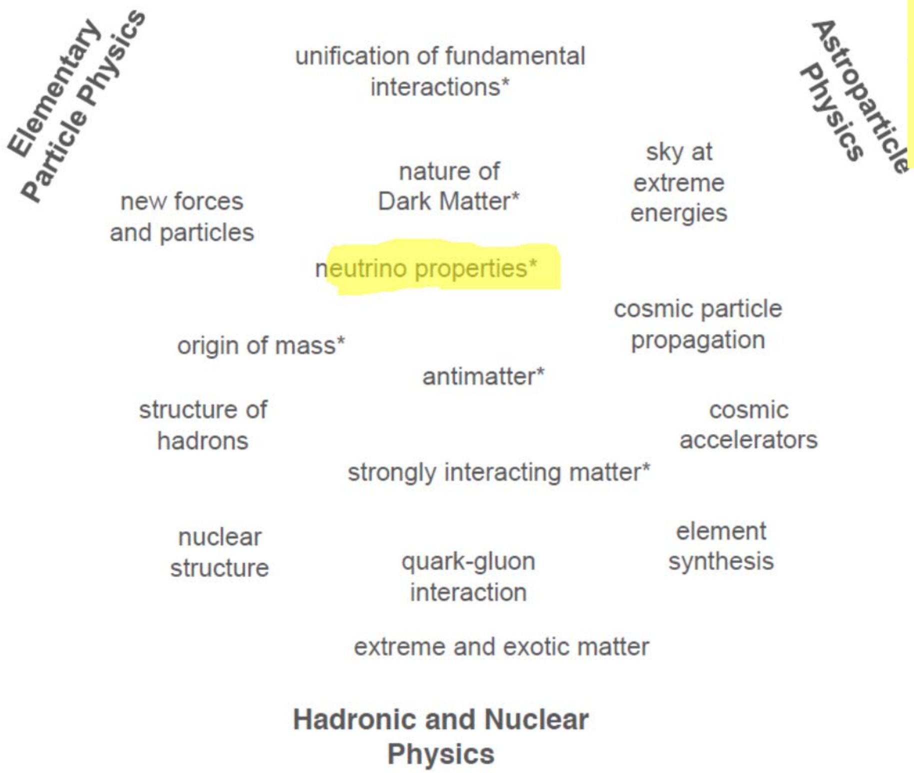
ν-properties with IceCube
(Andrii Terliuk,DESY)



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Testing neutrino properties with KATRIN: status update

Programme Meeting
Matter and the Universe
Mainz, 12-13 Dec., 2018

Markus Steidl, Kathrin Valerius (Karlsruhe Institute of Technology, Institute for Nuclear Physics)

Content

Update on KATRIN commissioning

Informal Report from First Light+

Sensitivity on standard neutrino mass

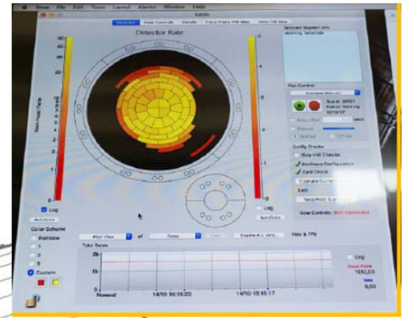
Searches beyond standard neutrino masses

Update on sensitivity on keV sterile neutrinos

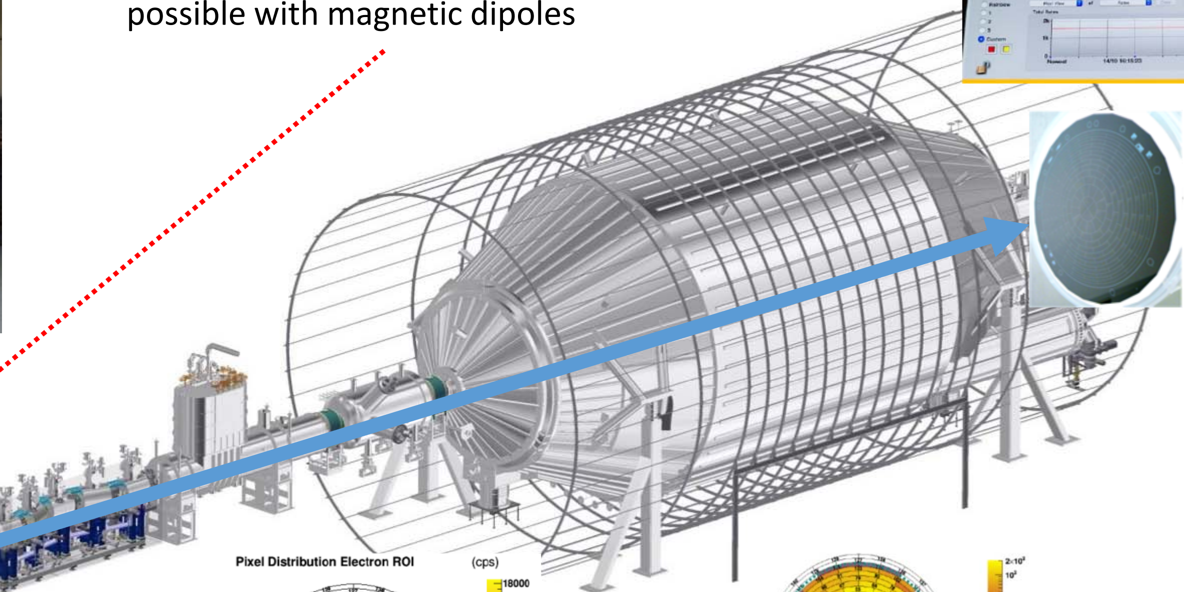
Recent investigations of exotic CC in beta-decay

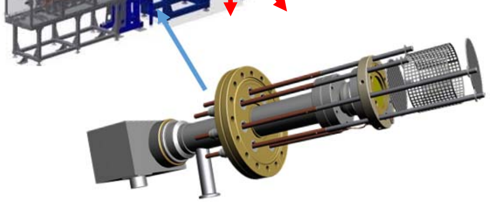
KATRIN First Light & Alignment

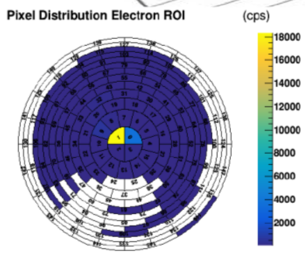
Technical inauguration,
October, 14, 2016



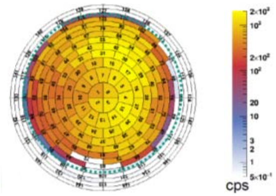
Shift of beam trajectories +- 45 mm
possible with magnetic dipoles





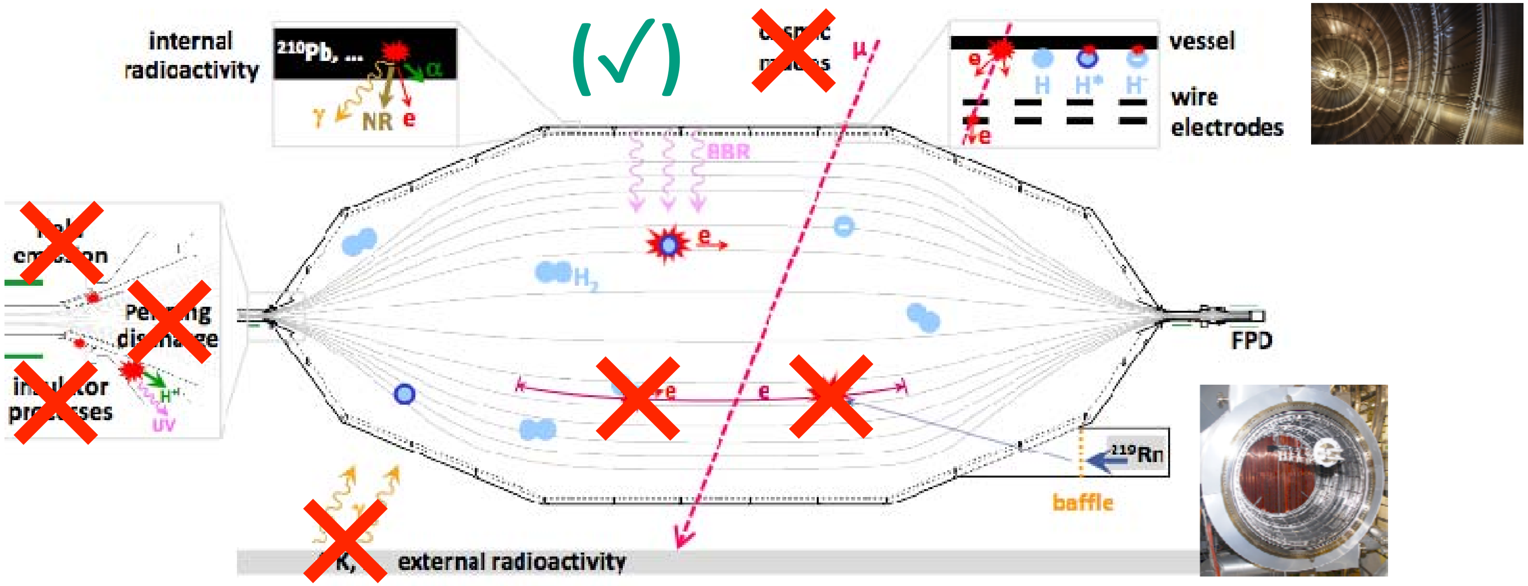


Electron or ion (H+) beam
with diam. ~3 mm



Wide range illumination with electrons
with diam. up to maximal
geometry given by source beam tube

KATRIN spectrometer status: background



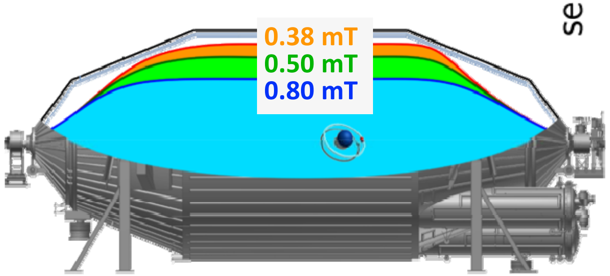
- **8 sources of background investigated and understood**
- **7 out of 8 avoided or actively eliminated by**
  - fine-shaping of special electrodes
  - symmetric magnetic fields
  - LN_2-cooled baffles (cold traps)
  - wire electrode grids

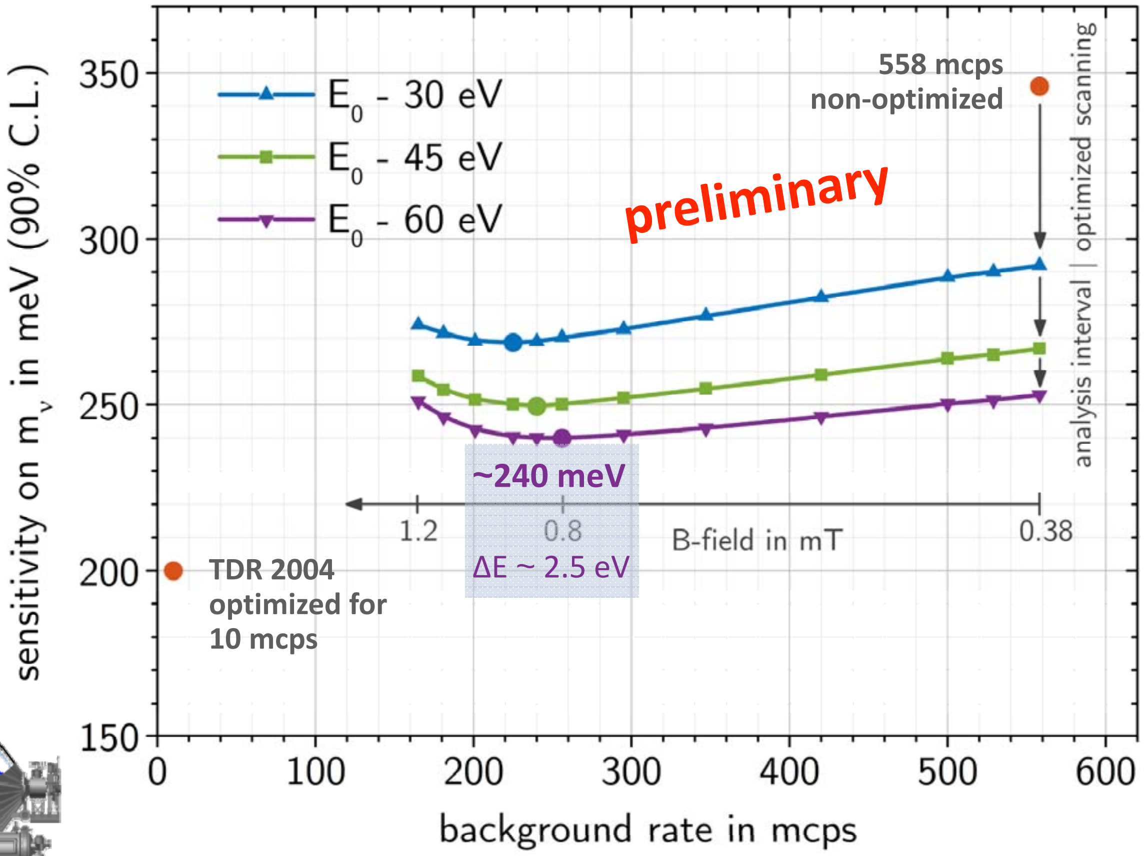
- **1 out of 8 remaining:**
  caused by ^{210}Pb on spectrometer walls (neutral H* atoms ionised by black-body radiation in spectrometer)

- Further **background reduction measures** being studied
- In addition: **several mitigation strategies** currently under investigation:

- **optimized scanning**
- **range of spectral analysis**

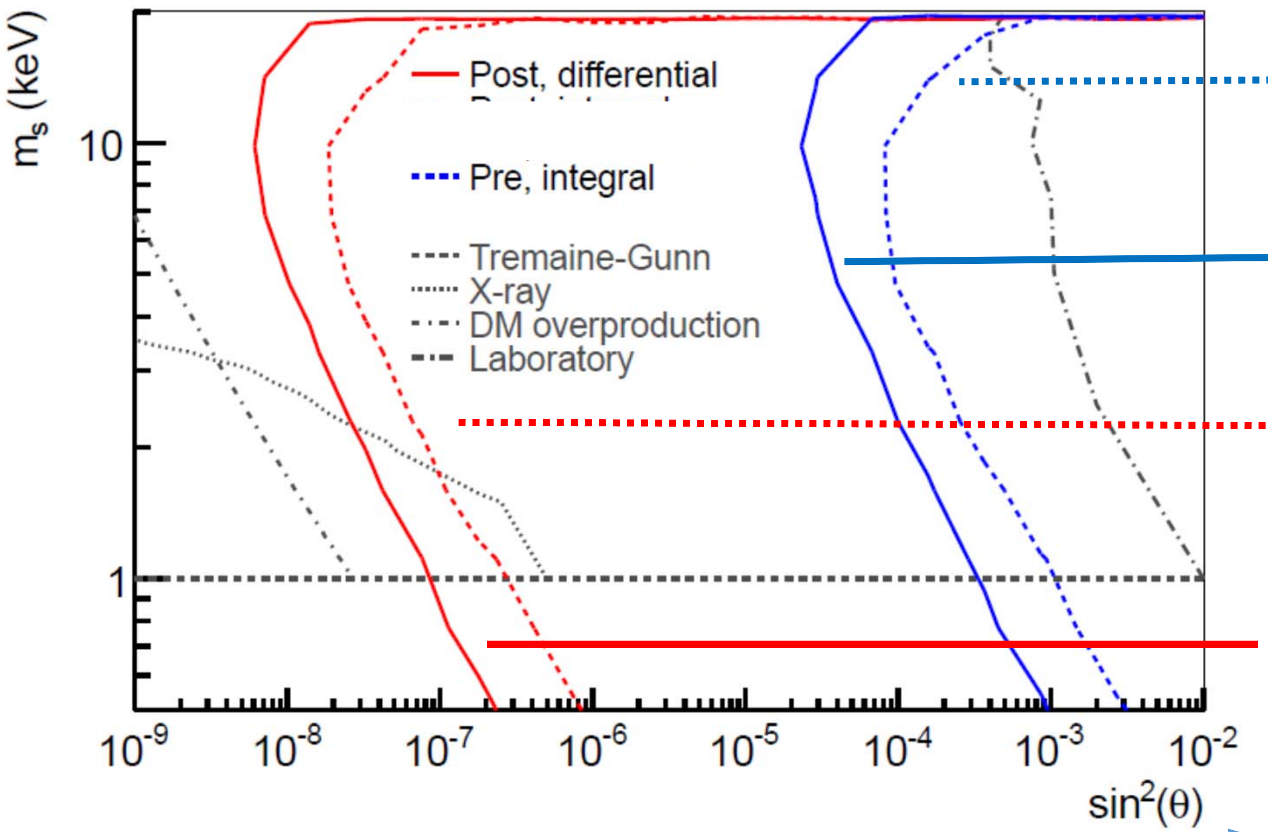
- **flux tube compression by increasing B**





Search for keV-scale sterile ν with KATRIN

Karlsruhe Institute of Technology



KATRIN „as built“ but with reduced source strength, integral

KATRIN „as built“ but with reduced source strength, differential

KATRIN with nominal source strength and optimized
count rate detector, (integral)

KATRIN with nominal source strength and ***optimized***
count rate detector with good energy resolution (differential)

Link to Technologies of other MU topics and MT

Summary & Outlook

- KATRIN celebrated „Technical inauguration (w/o T_2)“. More than a party …
- A first continous 24/7 measurement campaign with the whole beamline, yielding hugh amount of data to check systematics.
- Progress in understanding the elevated background, mitigation measures investigated and analyzed.
- keV sterile neutrinos: sensitivity plots for different KATRIN configurations and extensions (TRISTAN) published.
- Recent detailed innestigations on exotic charged currents with predictions for spectral distortions. Improvements on some couplings seem to be in reach, but needs some more investigations from experiment side to check for degenaracies with systematic instrumental effects.

Contribution to Cross-Topics in Physics & Technology

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ν-properties with IceCube
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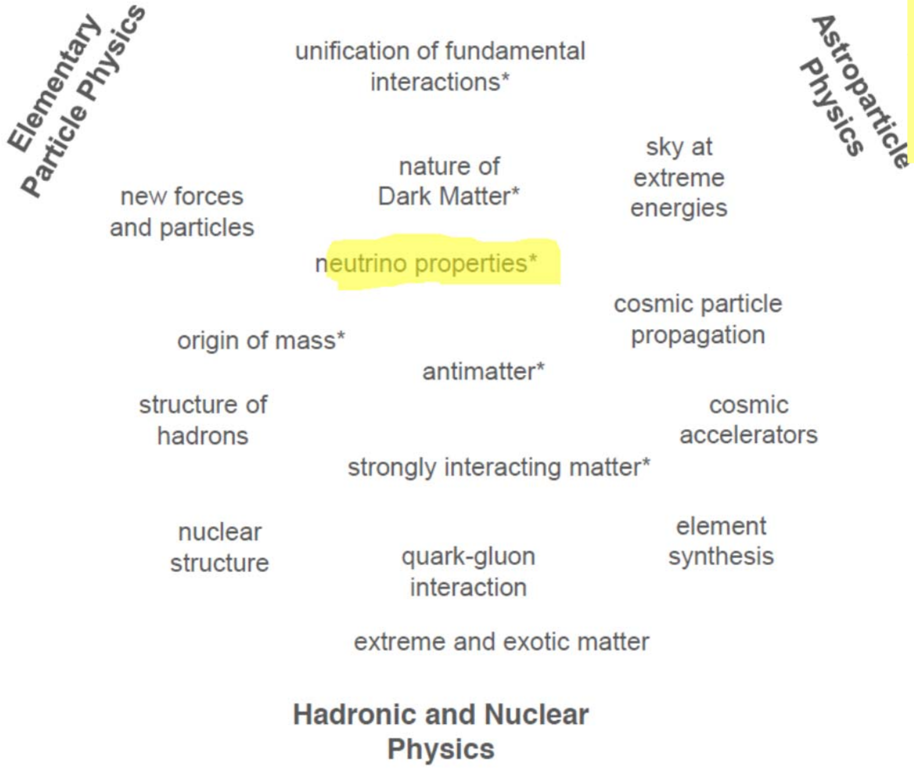

ν-properties [illegible] KATRIN
(Markus Steidl, KIT)

ν production in the sources of the UHECR and the role of nuclear physics
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ν ***in core-collaps supernovae nucleosynthesis***
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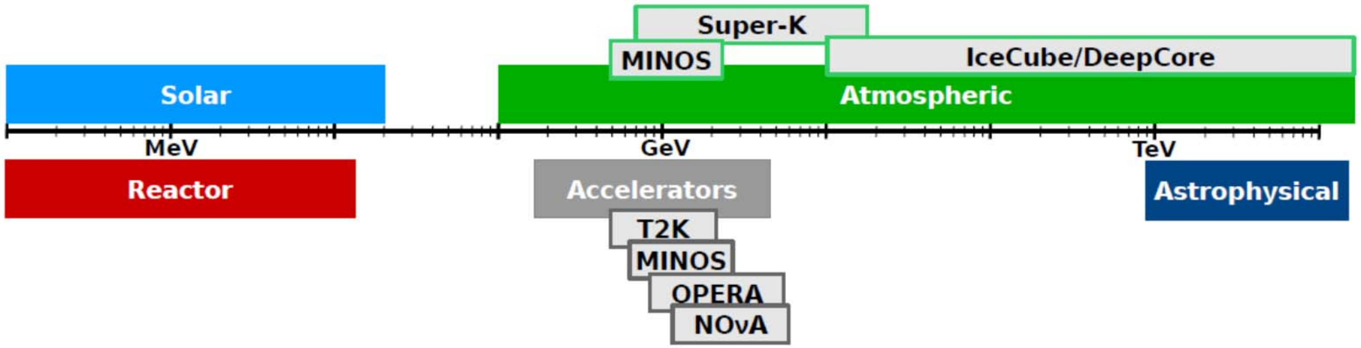
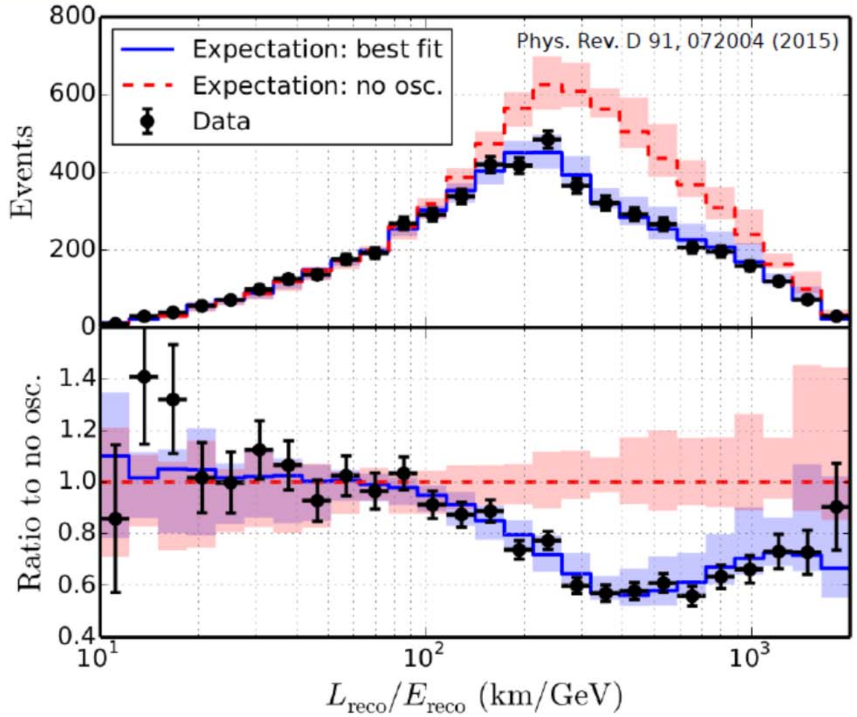
IceCube and the World

> IceCube physics:
- neutrino astrophysics
- cosmic ray physics
- **neutrino oscillations**
- new physics
- and more

> This talk:
- Measurement of neutrino mixing parameters
- Search for sterile neutrinos

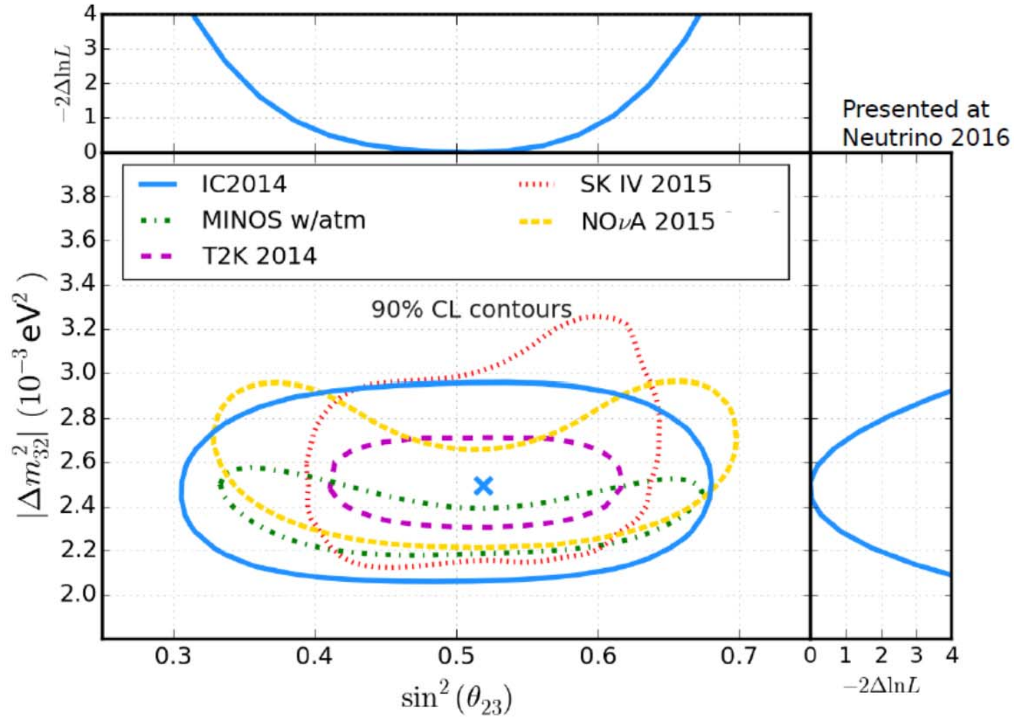


Neutrino oscillations: L/E distribution



- Energy range: 6-56 GeV
- Good data/MC agreement
- Clear signature of muon neutrino disappearance

Neutrino oscillations: results

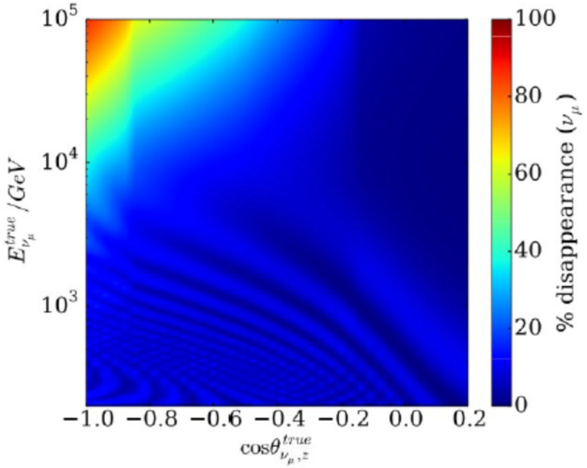


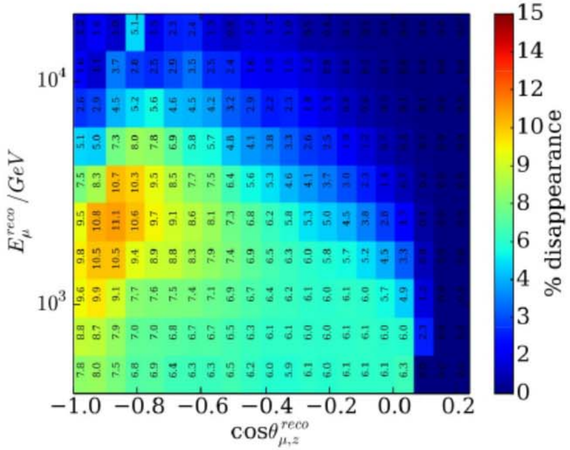
- IceCube DeepCore among leading neutrino oscillation experiments
- 3 years of data used

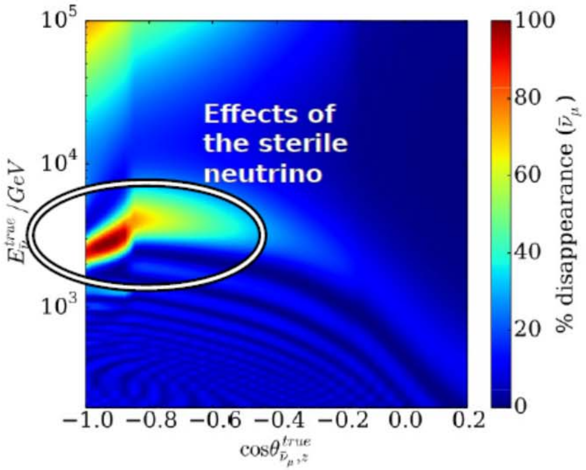
Sterile neutrinos at high energies

> Effects above 100 GeV:

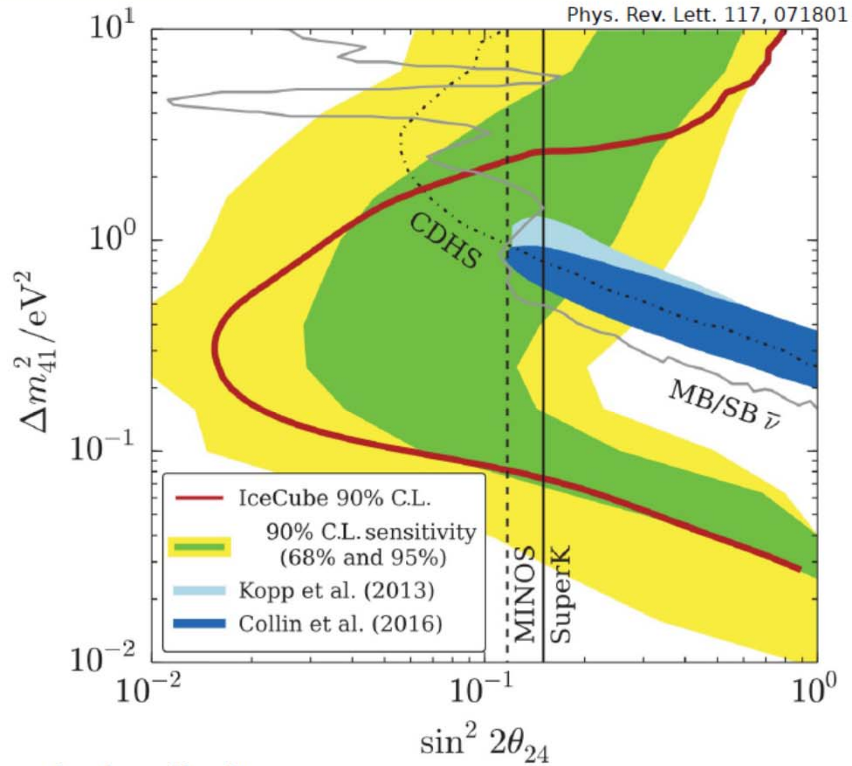
- MSW resonance-like transition to sterile state
- Muon-anti neutrinos
- Energy of resonance $\sim \Delta m_{41}^2$
- Sensitive to angle θ_{24}







Sterile neutrinos at high energies: results



> Strong exclusion limits
> Only 1 year of data used

Conclusions

> Fundamental properties with IceCube Neutrino Observatory:
- Atmospheric neutrino oscillations
- Sterile neutrinos:
  - Strong limits on mixing to muon state
  - One of the leading experiments in the field
- And more (not presented in this talk):
  - Cross section studies
  - Non standard interaction
  - Dark Matter/WIMPs

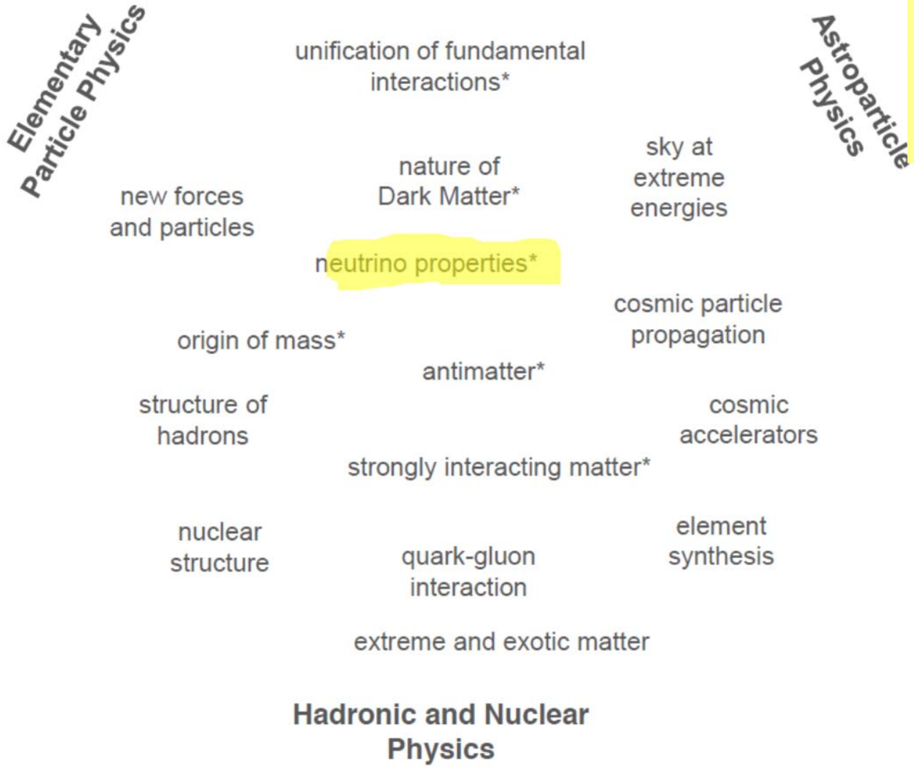
> Next in IceCube:
- New analysis techniques
- More years of data
- Precise measurement of mixing parameters
- Sensitivity to tau neutrino sector

> Future:
- IceCube-Gen2/PINGU:
  - Neutrino mass ordering
  - Precise nutau appearance
  - Sterile neutrinos
  - Dark Matter
  - ...

Testing neutrino masses at GeV scale: Theory vs. Experiments
(Rasmus Rasmussen DESY)

Discussion on definitions of „Cross topic“ <u>Activity.</u>

<u>General feeling that more than having once per year a session should be feasible. But the splendid idea is still missing,</u>



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Thanks to all speakers

Testing neutrino masses at GeV scale: Theory vs. Experiments
(Rasmus Rasmussen, DESY)

Discussion on definitons of „Cross topic“ <u>Activity.</u>

<u>General feeling that more than having once per year a session should be feasible. But the splendid idea is still missing,</u>

ν-properties with IceCube
(Andrii Terliuk,DESY)

ν-properties
KATRIN
(Markus Steidl, KIT)

ν production in the sources of the UHECR and the role of nuclear physics
(A. Fedynitch, DESY)

ν ***in core-collaps supernovae nucleosynthesis***
(Andre Sieverding, GSI)