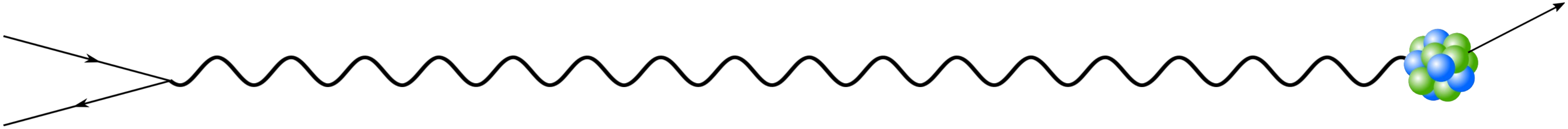
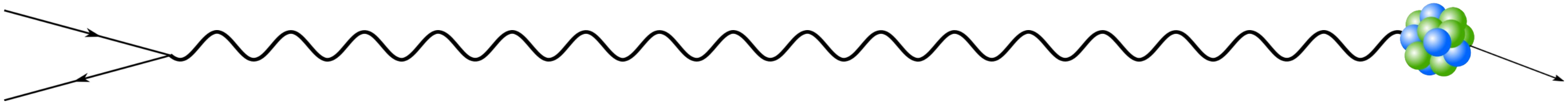
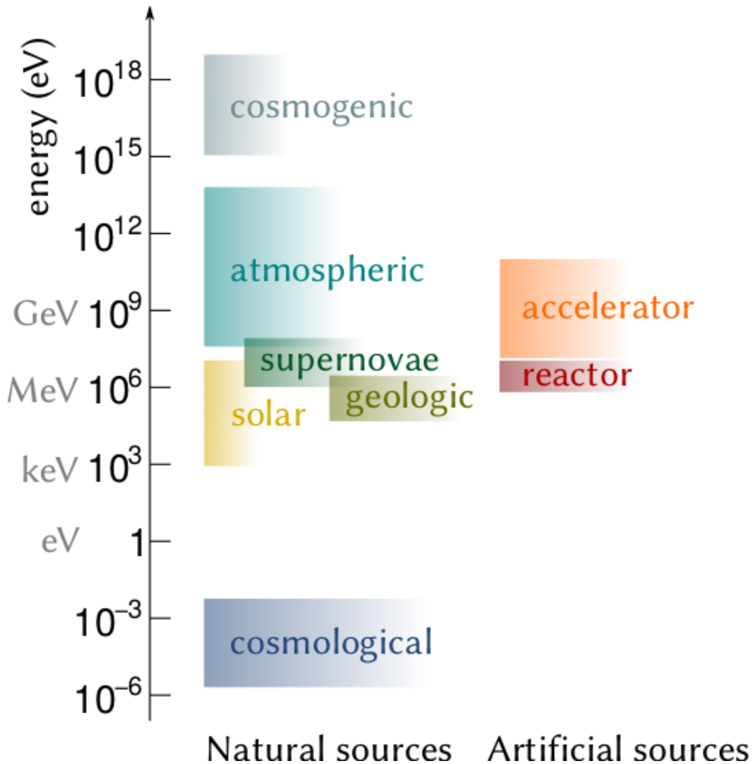
Latest Results from CONUS



Thomas Hugle (on behalf of the CONUS collaboration)
Max-Planck-Institut für Kernphysik, Heidelberg
Weak Interactions and Neutrinos (WIN) 2021

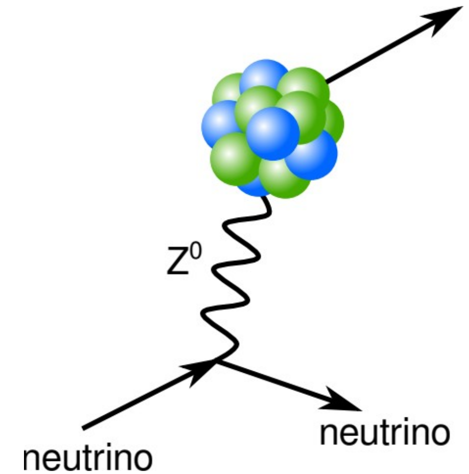
Coherent Elastic Neutrino Nucleus Scattering





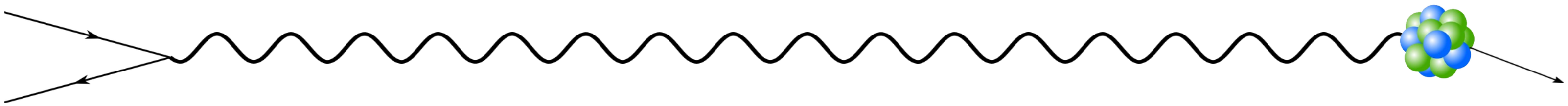
[A. Bonhomme]

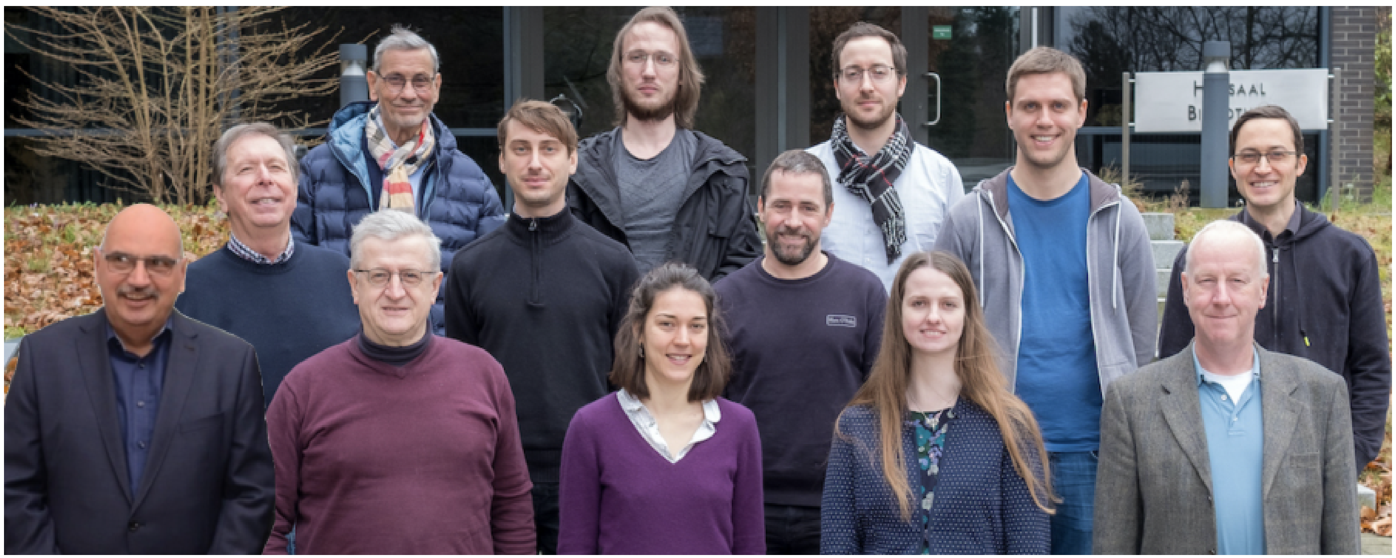
- 1973: neutral current discovered at CERN
- 1974: CEνNS predicted by D. Freedman
- 2017: observed by COHERENT at π-DAR source with CsI[Na]



$$\frac{d\sigma_{SM}(E_\nu, T)}{dT} \simeq \frac{G_F^2}{4\pi} \underbrace{[N - (1 - 4\sin^2\theta_W)Z]^2}_{\approx N^2} \underbrace{F^2(q^2)}_{\to 1} M \underbrace{\left(1 - \frac{MT}{2E_\nu^2}\right)}_{\text{kinematics}}$$

CONUS Collaboration

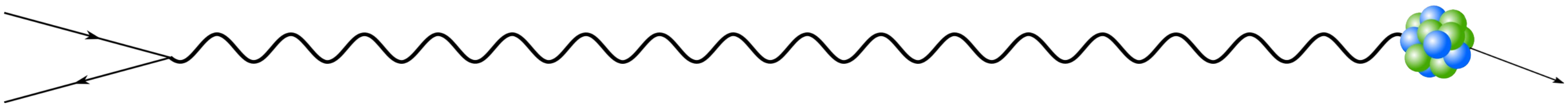




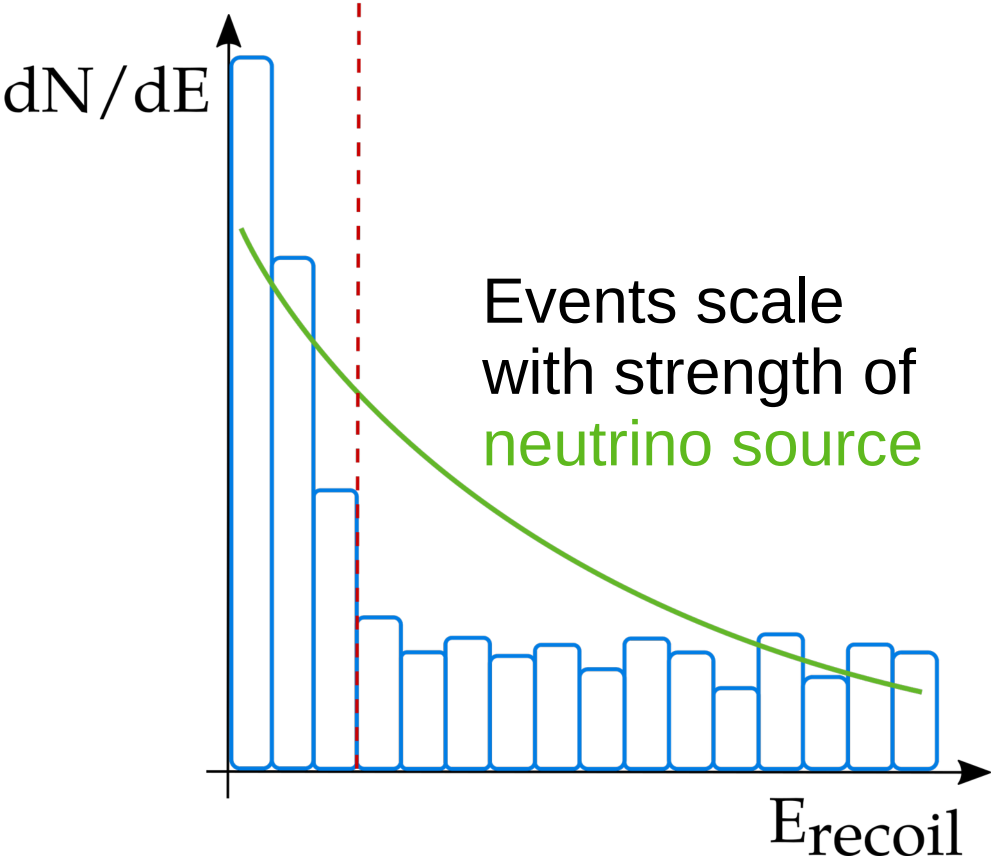
Collaboration:
H. Bonet, A. Bonhomme, C. Buck, J. Hakenmüller, J. Hempfling, J. Henrichs,
G. Heusser, T. Hugle, M. Lindner, W. Maneschg, T. Rink, H. Strecker
- *Max Planck Institut für Kernphysik (MPIK), Heidelberg*

K. Fülber, R. Wink
- *Preussen Elektra GmbH, Kernkraftwerk Brokdorf (KBR), Brokdorf*

CEνNS at Reactors

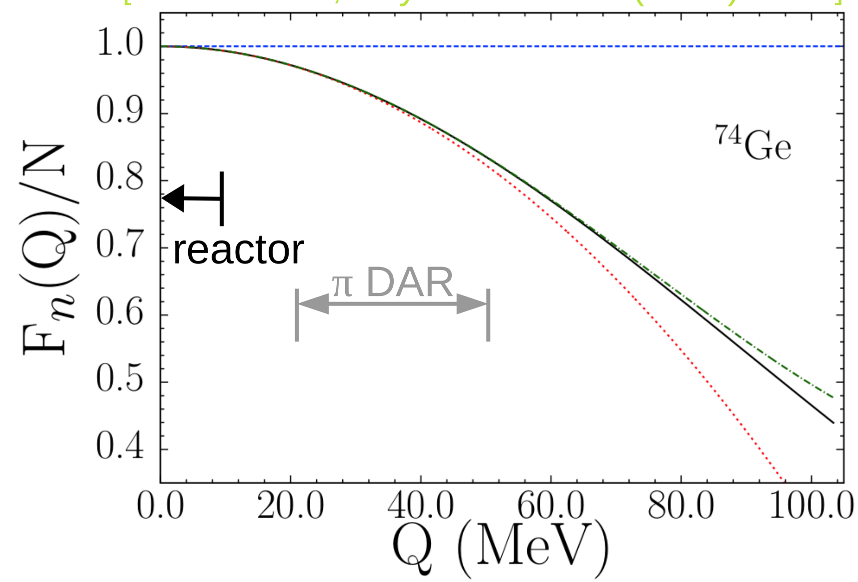


Low noise threshold



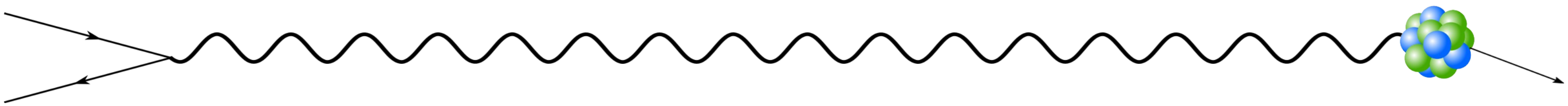
Events scale with strength of neutrino source

[Patton et al., Phys. Rev. C 86 (2012) 0246]



Low background at shallow depth

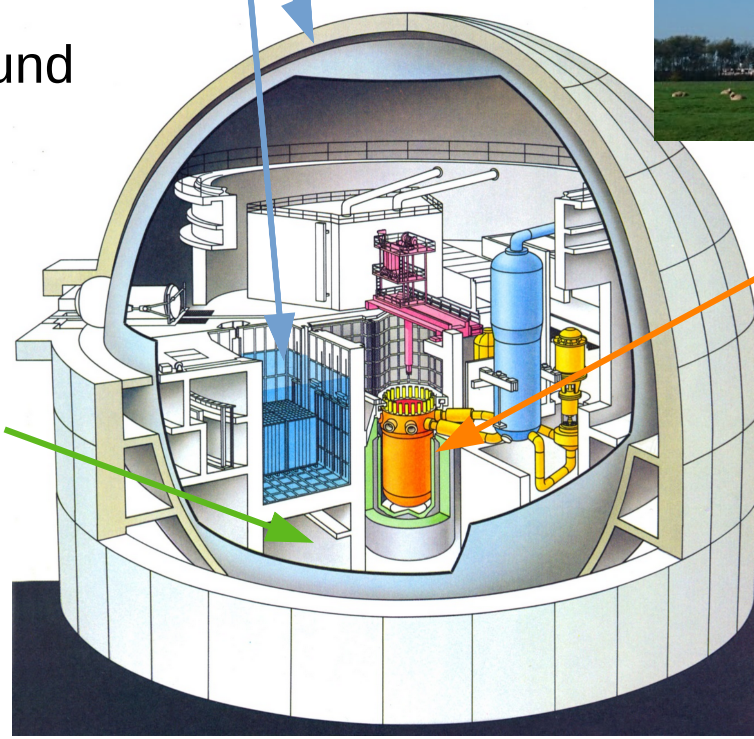
CONUS Experimental Site



[A. Bonhomme]

Overburden:

- 10-45 m w.e. (angle-dependent)
- muon-induced background



CONUS experiment:

- Four 1 kg low threshold Ge detectors
- electric cryocoolers
- elaborate shield

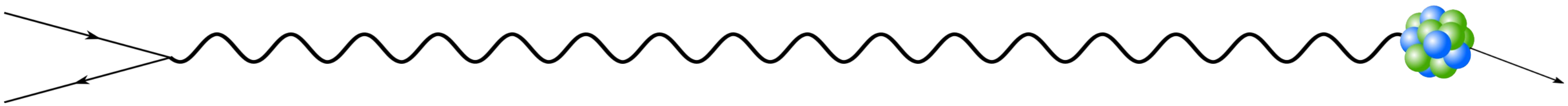
Reactor core:

- thermal power 3.9 GW
- neutrino flux $2 * 10^{13}$ cm^{-2} s^{-1} @ 17 m distance
- high duty cycle (~1 month/yr off)

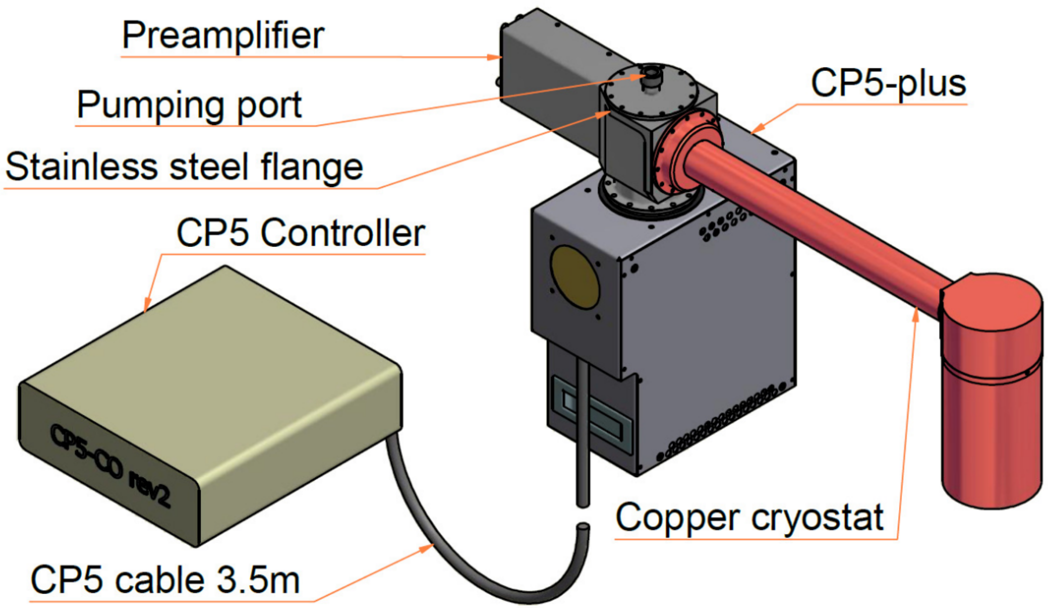
Ain't no lab!

No remote control, no cryogenic liquids, ...

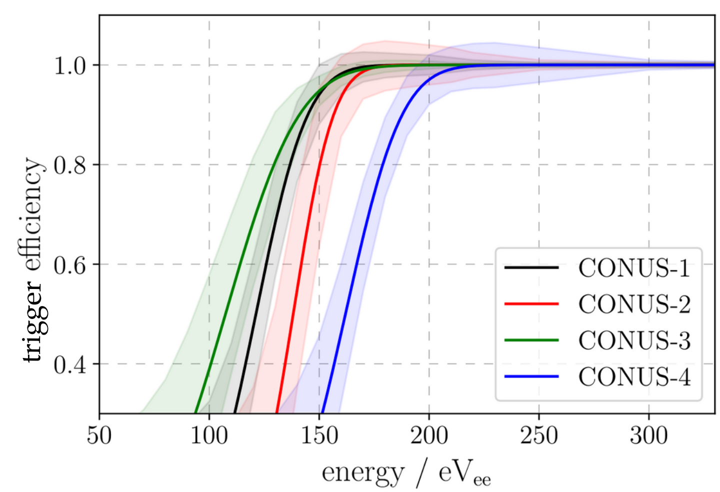
CONUS Detectors



Four p-type point contact HPGe detectors (1 kg each)

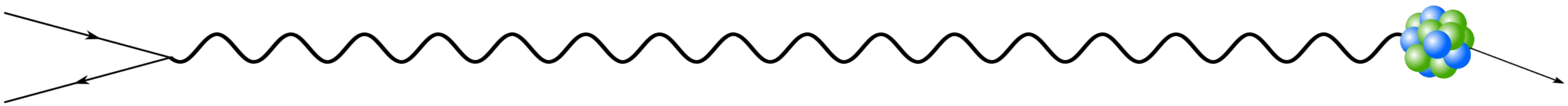


- pulser resolution: ≤ 80 eV_{ee}
- energy threshold: ~300 eV_{ee}
- low background components
- electric cooling (instead of N_2) necessary at KBR



For full discussion see
Eur.Phys.J.C 81 (2021) 3, 267

CONUS Shield Design

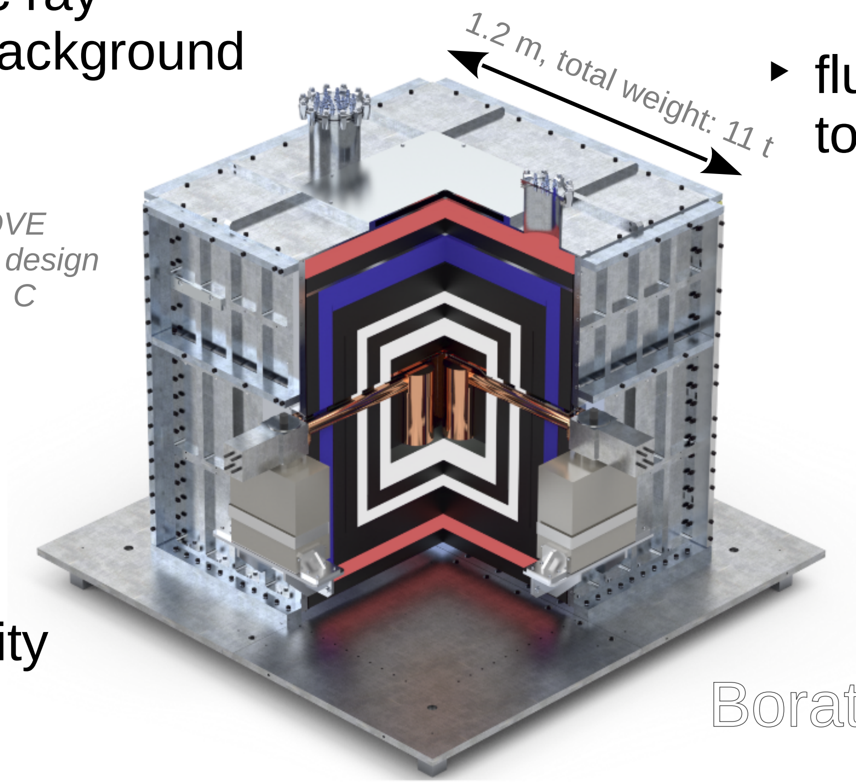


Active muon veto:

- suppress cosmic ray muon-induced background

Steel cage:

- keep everything together
- flushed with breathing air to reduce radon



[Inspired by the GIOVE spectrometer shield design (MPIK, Eur. Phys. J. C (2015) 75: 531)]

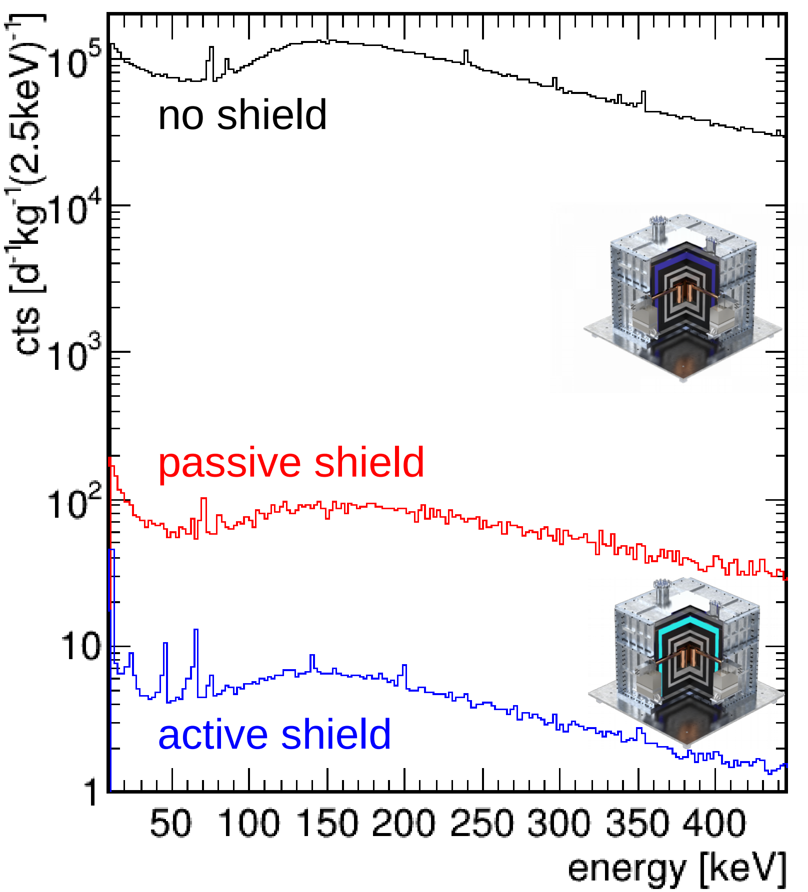
Lead (Pb):

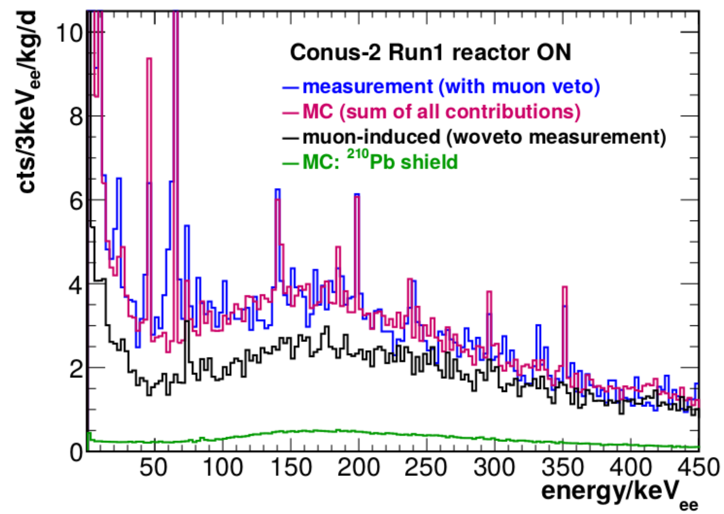
- shield radioactivity
- high radiopurity

Borated PE / PE:

- moderate & capture neutrons

Background Suppression





Residual backgrounds described by Monte Carlo simulations:

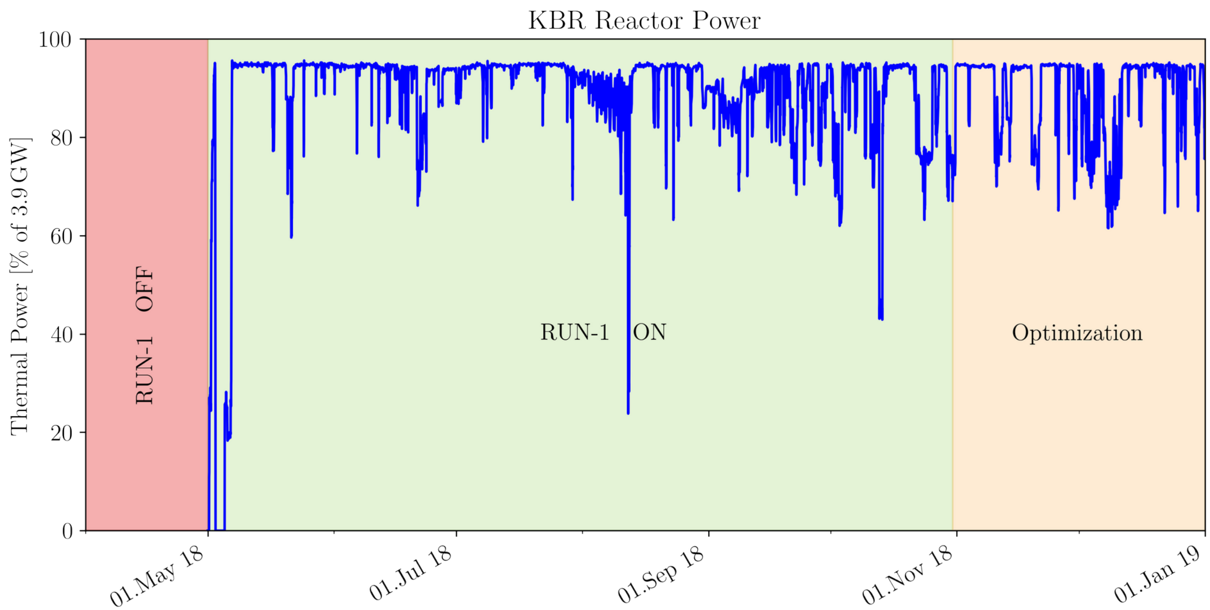
- muon-induced (after ~97% vetoed)
- metastable Ge states
- ^{210}Pb in shield and detector
- radon

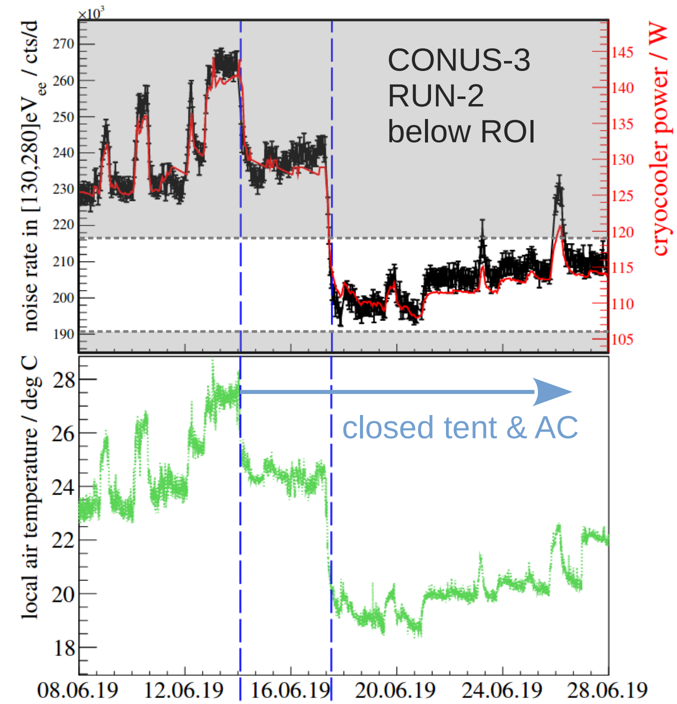
Total suppression factor: 10^4

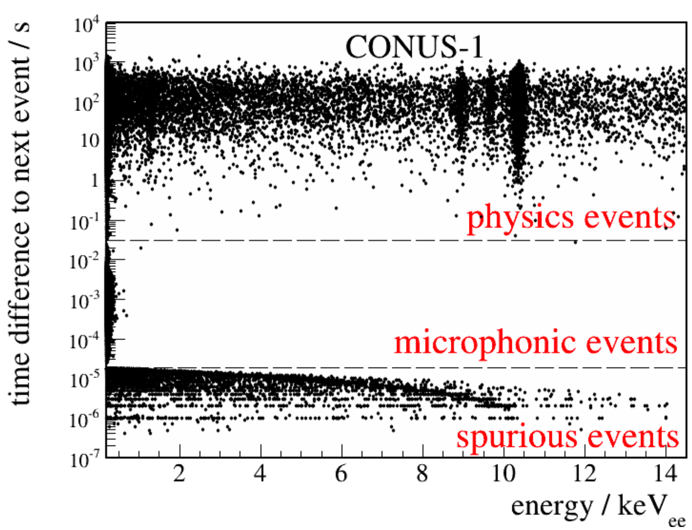
For reactor correlated bkg. discussion see

Eur. Phys. J. C (2019) 79:699 (in cooperation with PTB)

Data Selection & Noise Cuts







Noise-temperature correlation cut

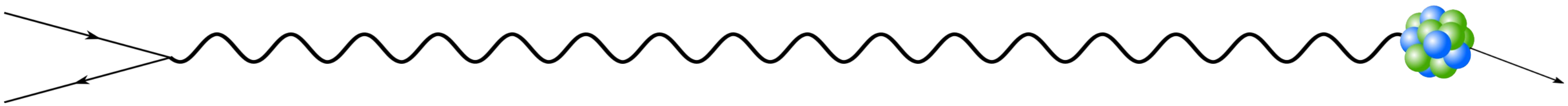
Time-difference distribution cut

Run-1 exposure after cuts:

ON 208.8 kg d

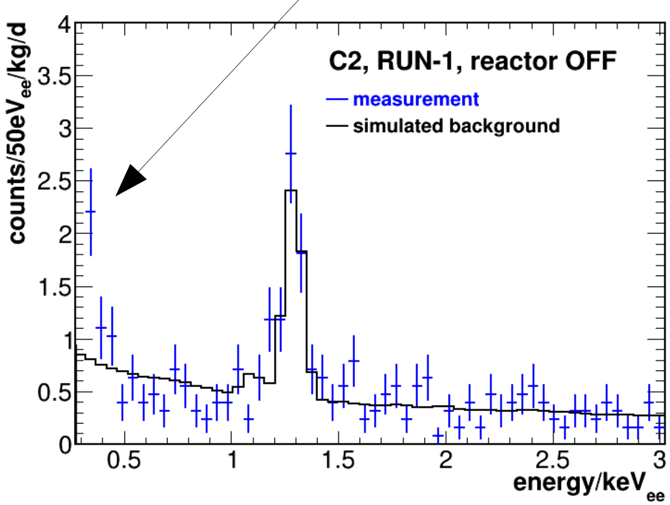
OFF 37.6 kg d

Region of Interest for BSM searches



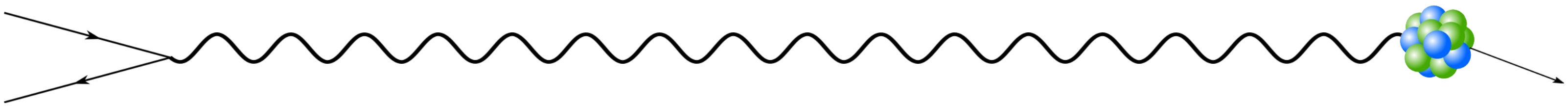
Criteria:

- trigger efficiency: ~100%
- exclude region with temperature correlation
  - fit electronic noise with exponential



Det.	Run	On [d]	Off [d]	ROI [eV$_{ee}$]
C1	R1	96.7	13.8	276 - 741
C2	R1	14.6	13.4	281 - 999
C3	R1	97.5	10.4	333 - 991
total		**208.8**	**37.6**	

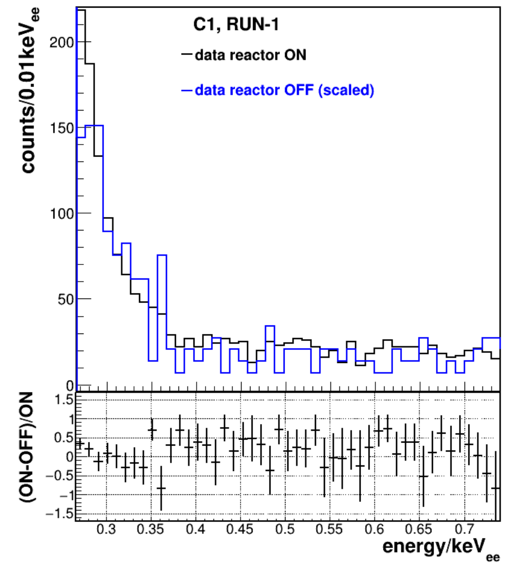
Data Analysis Overview

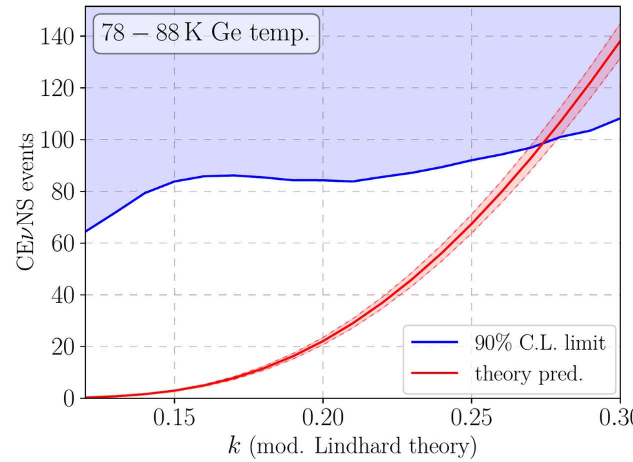


Input for analysis:

- theoretical expectations for BSM
- reactor description
  - fission fractions & thermal power known
  - Huber & Mueller and Kopeikin spectra + Daya Bay correction
- background description
  - Monte Carlo for physics events
  - exponential fit for electronic noise
- selected data for ON / OFF

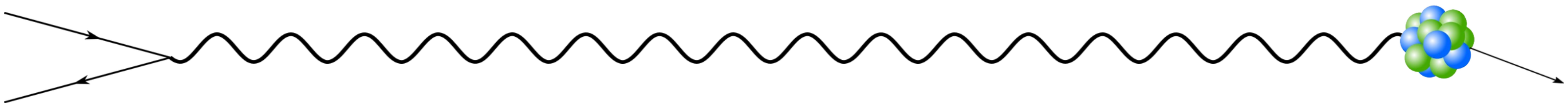
⇒ Run likelihood





For discussion of SM results see
PRL 126 (2021) 4, 041804

Tensor Non-Standard Interactions (NSIs)

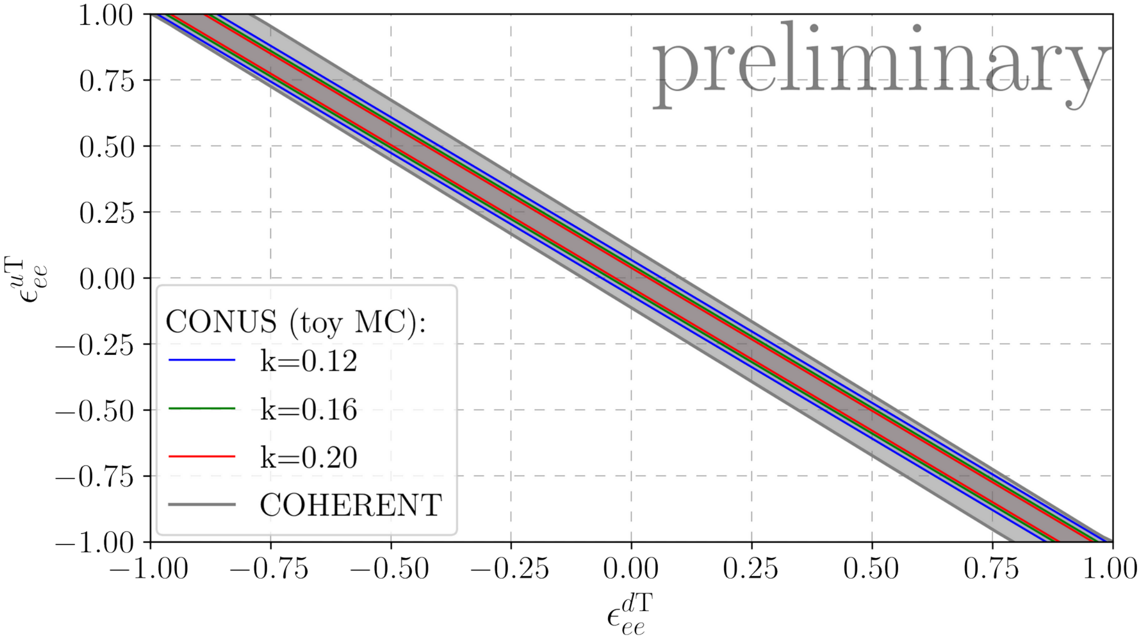


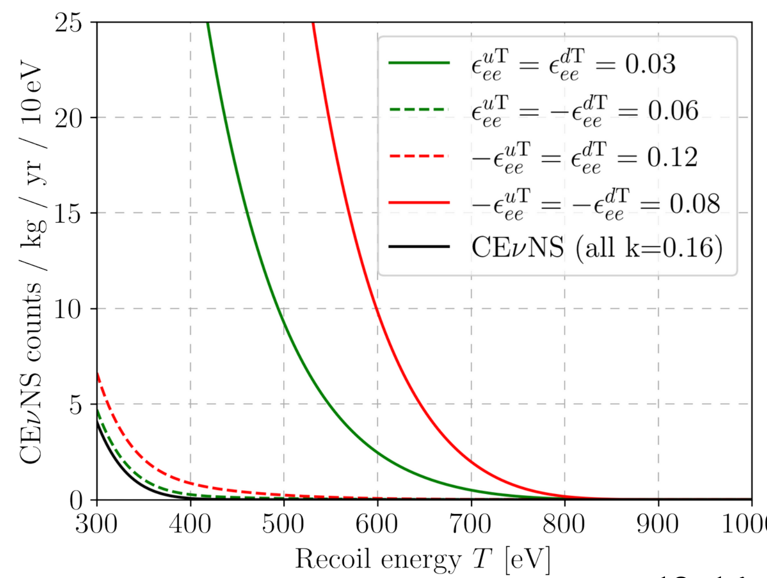
$$\mathcal{O}_{\alpha\beta}^{q\mathrm{T}} = (\bar{\nu}_\alpha \sigma^{\mu\nu} \nu_\beta)(\bar{q}\sigma_{\mu\nu} q) + \mathrm{h.c.}$$

$$Q_{\mathrm{NSI}}^{\mathrm{T}} = \left(2\epsilon_{\alpha\beta}^{u\mathrm{T}} + \epsilon_{\alpha\beta}^{d\mathrm{T}}\right) Z + \left(\epsilon_{\alpha\beta}^{u\mathrm{T}} + 2\epsilon_{\alpha\beta}^{d\mathrm{T}}\right) N$$

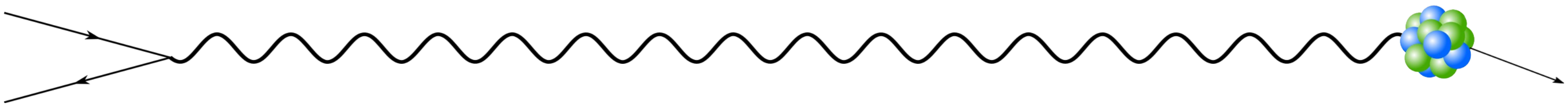
$$\frac{\mathrm{d}\sigma_{\mathrm{NSI}}^{\mathrm{T}}(E_\nu, T)}{\mathrm{d}T} = \frac{4G_F^2}{\pi} {Q_{\mathrm{NSI}}^{\mathrm{T}}}^2 M \left(1 - \frac{MT}{4E_\nu^2}\right)$$

- effective tensor operator
- degeneracy of couplings ϵ can be broken by using different detector materials
- higher kinematic cutoff than SM





Vector Non-Standard Interactions (NSIs)

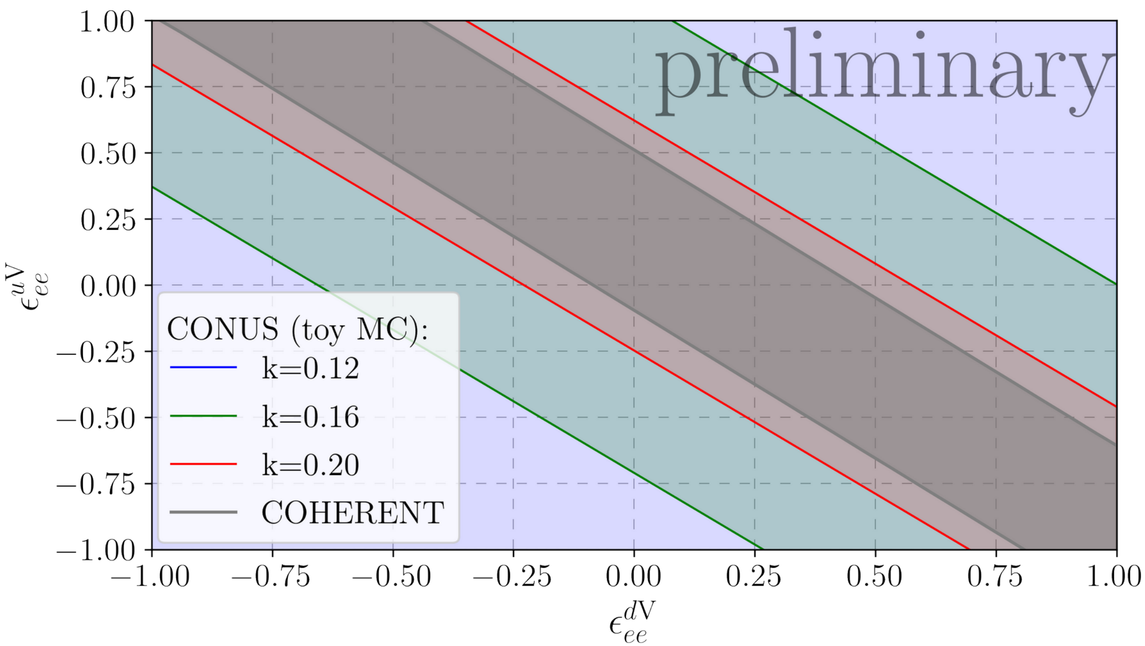


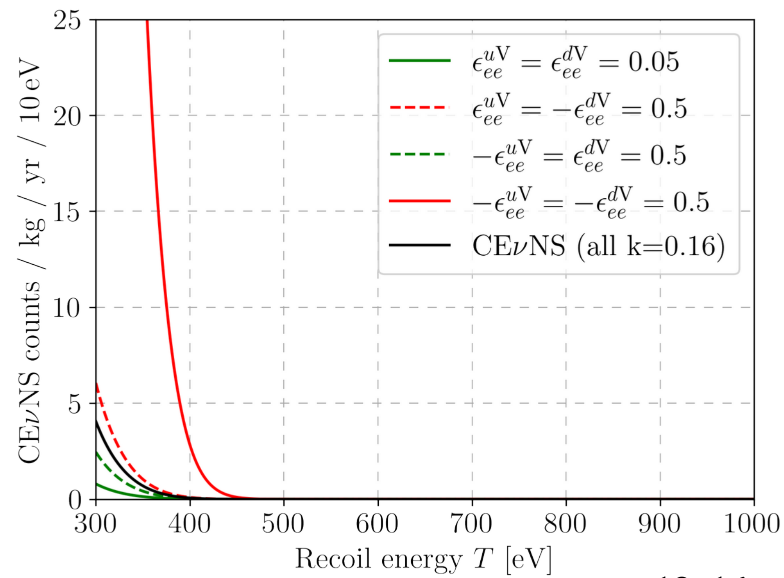
$$\mathcal{O}^{qV}_{\rm NSI} = (\bar\nu_\alpha \gamma^\mu L \nu_\beta)(\bar q \gamma_\mu P q) + \text{h.c.}$$

$$Q^{\rm V}_{\rm NSI} \supset \left(g^p_{\rm V} + 2\epsilon^{u\rm V}_{\alpha\alpha} + \epsilon^{d\rm V}_{\alpha\alpha}\right) Z + \left(g^n_{\rm V} + \epsilon^{u\rm V}_{\alpha\alpha} + 2\epsilon^{d\rm V}_{\alpha\alpha}\right) N$$

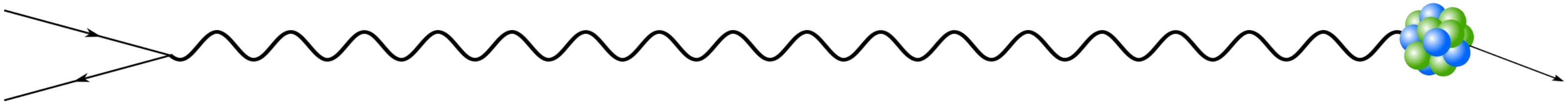
$$\frac{\mathrm{d}\sigma(E_\nu, T)}{\mathrm{d}T} : \quad Q_{\rm SM} \to Q^{\rm V}_{\rm NSI}$$

- effective vector operator (Z’ mediator integrated out)
- degeneracy of couplings ϵ as in tensor NSI case
- destructive interference possible





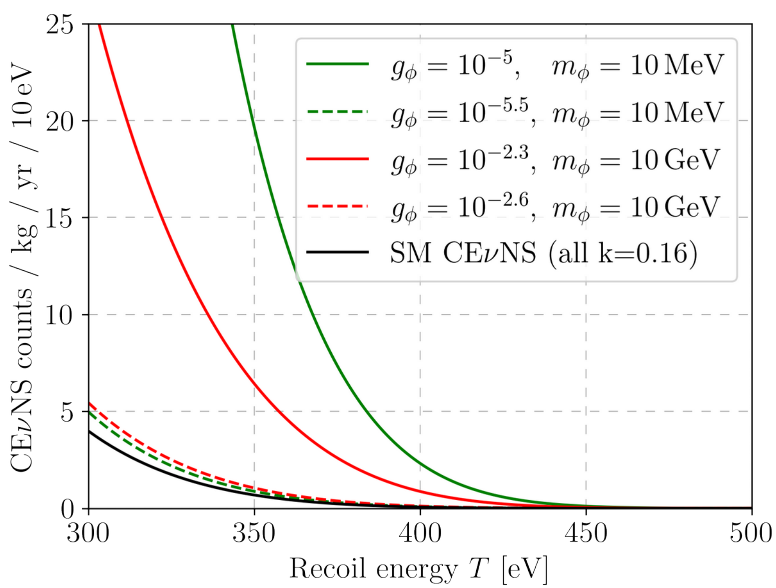
Simplified Models: Light Scalar

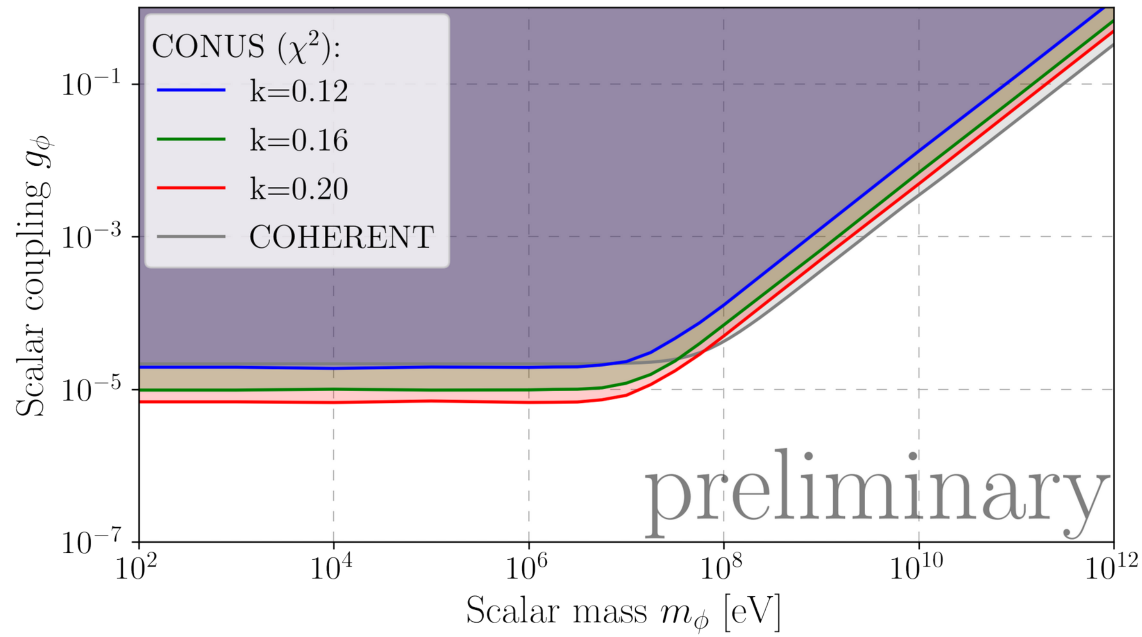


- generic new scalar
- universal couplings
- especially important at low recoil energies

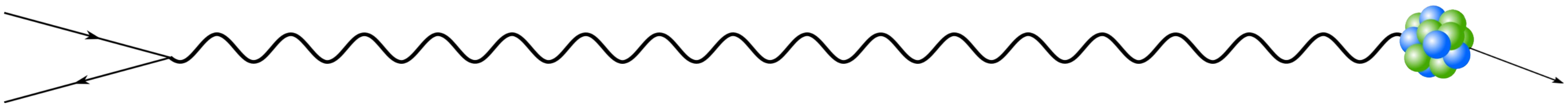
$$\mathcal{L}_\phi \supset \phi \left(g_\phi^q \bar{q} q + g_\phi^\nu \bar{\nu}_R \nu_L + \text{h.c.} \right) - \frac{1}{2} m_\phi^2 \phi^2$$

$$\frac{\mathrm{d}\sigma_\phi(E_\nu, T)}{\mathrm{d}T} = \frac{g_\phi^4 (14N + 15.1Z)^2 M^2 T}{4\pi E_\nu^2 (2MT + m_\phi^2)^2}$$





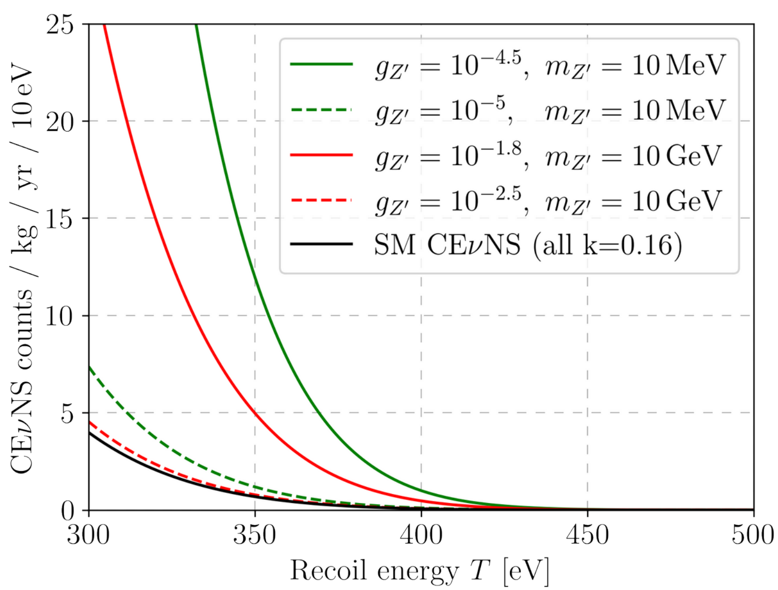
Simplified Models: Light Vector

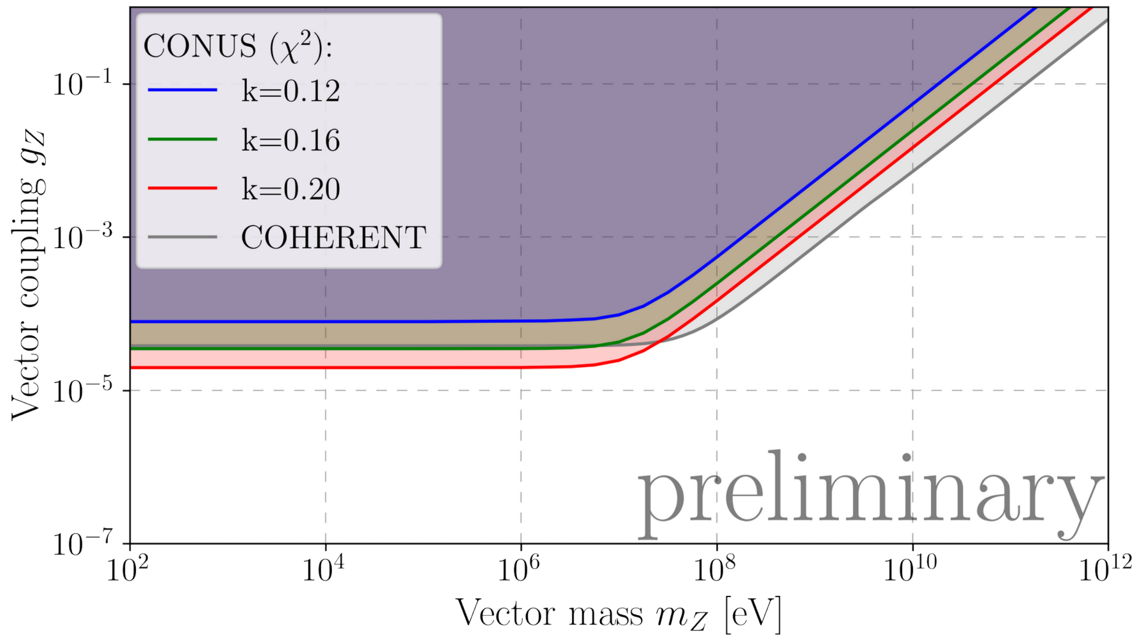


- generic new vector
- universal couplings
- destructive interference possible

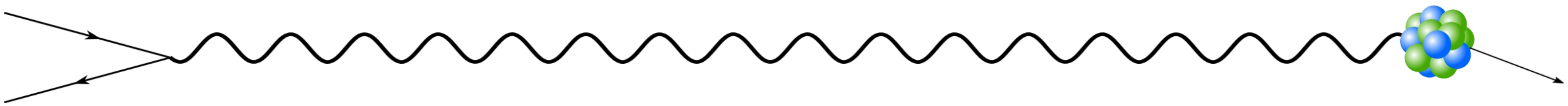
$$\mathcal{L}_{Z'} \supset Z'_\mu \left(g^q_{Z'} \bar{q}\gamma^\mu q + g^\nu_{Z'} \bar{\nu}_L \gamma^\mu \nu_L \right) + \frac{1}{2} m^2_{Z'} Z'_\mu Z'^\mu$$

$$\frac{\mathrm{d}\sigma_{Z'}(E_\nu, T)}{\mathrm{d}T} = \left(1 - \frac{3\, g^\nu_{Z'} g^q_{Z'} (Z+N)}{\sqrt{2} G_F Q_{\mathrm{SM}} (2MT + m^2_{Z'})} \right)^2 \frac{\mathrm{d}\sigma_{\mathrm{SM}}(E_\nu, T)}{\mathrm{d}T}$$





Summary & Outlook



- New CONUS BSM results (papers to appear soon):
  - full-fledged spectral shape analysis of CEνNS channel RUN-1 data
    - competitive limits for tensor NSIs as well as for light scalar and vector mediators; in part of the parameter space even better limits than COHERENT
    - exact strength of limits is quenching dependent

1) Existing data:

- Further analyses; e.g. magnetic moment $\mu_\nu < 10^{-10}\,\mu_B$

2) Continued data taking:

- upgraded DAQ (e.g. pulse shape discrimination, anti-coincidence)
- improved control of environmental parameters (e.g. thermal stability)
- both enables improved data taking in RUN-5 (just started)
- Brokdorf shutdown end of 2021 allows for balanced ON/OFF statistics with improved data