Résumé des Rencontres de Moriond 2021

http://moriond.in2p3.fr

S. Loucatos
DPhP-Irfu et APC

The 55th **Rencontres de Moriond** session devoted to **ELECTROWEAK INTERACTIONS AND UNIFIED THEORIES** were held remotely from **Saturday March 20th to Saturday March 27th, 2021**.

…..

La Thuile is a pleasant winter sport resort located in the Italian Alps, at 1450 m alt., about 120 km from Geneva. Conference founded in 1966 by Jean Tran Thanh Van.

Meribel 1974

Subventionnée par l'Irfu

Organisateurs CEA:

E. Armengaud,

S. Loucatos

D. Denegri

L. Schoeffel

JM Le Goff

F. Vernizzi

La Thuile 2015


Electroweak Interactions & Unified Theories
Moriond@Home 2021
The unfinished poster ...

Neutrinos

Neutrino oscillations (PMNS matrix)

L. Berns

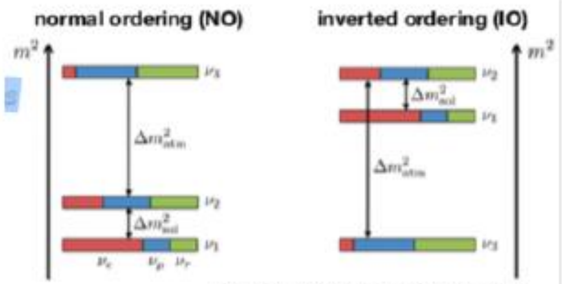
atmospheric | **reactor** | **solar**

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$c_{ij} \equiv \cos\theta_{ij}$
$s_{ij} \equiv \sin\theta_{ij}$

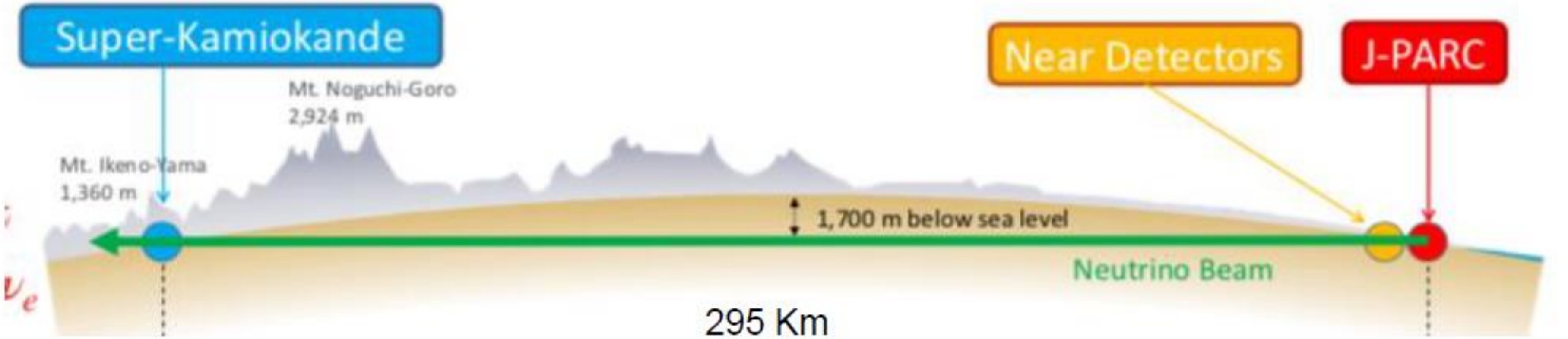
Open questions:

- value of δ_{CP} → if $\sin\delta_{CP} \neq 0$, CP violation
- sign of Δm^2_{32} (mass ordering)
- is θ_{23} maximal? octant? (i.e. $\theta_{23} < \frac{\pi}{4}$ or $\theta_{23} > \frac{\pi}{4}$)



Credit: JUNO Collaboration / JGU-Mainz

- Latest measurements from T2K



Mixing in matter (PDG 2020)

The instantaneous mass eigenstates in matter, ν_i^m, are the eigenstates of the Hamiltonian H in (14.56) for a fixed value of x, and they are related to the interaction basis by

$$\vec{\nu} = \tilde{U}(x)\vec{\nu^m} \,. \tag{14.59}$$

The corresponding instantaneous eigenvalues of H are $\mu_i(x)^2/(2E)$ with $\mu_i(x)$ being the instantaneous effective neutrino masses.

Let us take for simplicity a neutrino state which is an admixture of only two neutrino species $|\nu_\alpha\rangle$ and $|\nu_\beta\rangle$, so the two instantaneous mass eigenstates in matter ν_1^m and ν_2^m have instantaneous effective neutrino masses

$$\begin{aligned} \mu_{1,2}^2(x) = \frac{m_1^2 + m_2^2}{2} + E[V_\alpha + V_\beta] \\ \mp \frac{1}{2}\sqrt{\left[\Delta m^2 \cos 2\theta - A\right]^2 + \left[\Delta m^2 \sin 2\theta\right]^2} \,, \end{aligned} \tag{14.60}$$

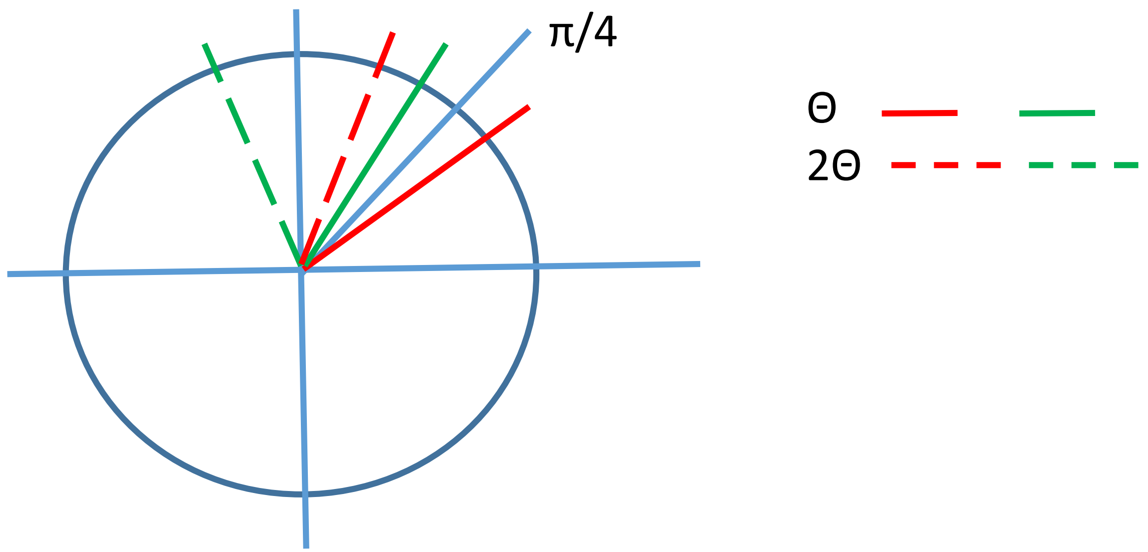
and $\tilde{U}(x)$ is a 2x2 rotation matrix with the instantaneous mixing angle in matter given by

$$\tan 2\theta_m = \frac{\Delta m^2 \sin 2\theta}{\Delta m^2 \cos 2\theta - A} \,. \tag{14.61}$$

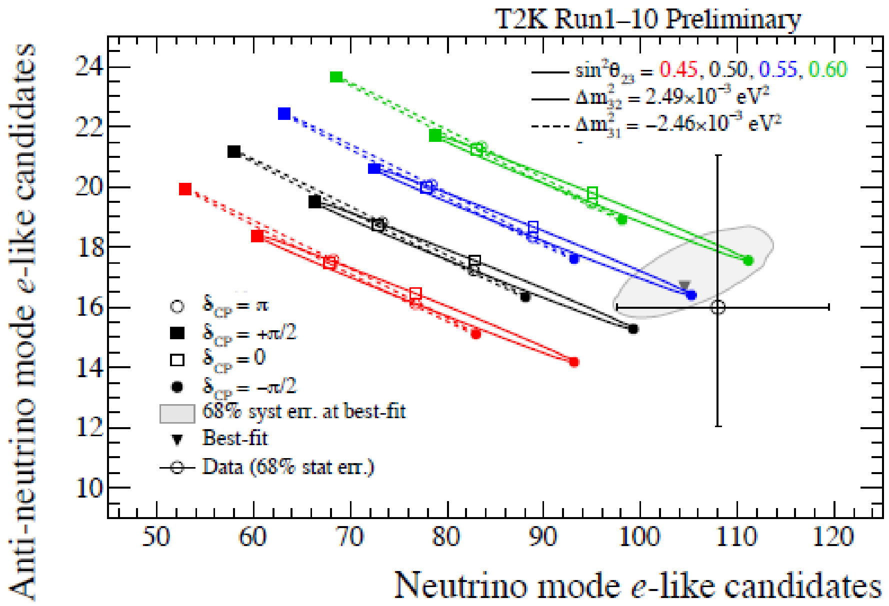
In the Eqs.(14.60) and (14.61) A is

$$A \equiv 2E(V_\alpha - V_\beta)\,, \tag{14.62}$$

and its sign depends on depends on the composition of the medium and on the flavour composition of the neutrino state considered. From the expressions above we see that for a given sign of A the mixing angle in matter is larger(smaller) than in vacuum if this last one is in the first (second) octant. We see that the symmetry about 45 degrees which existing in vacuum oscillations between two neutrino states is broken by the matter potential in propagation in a medium. The expressions



ν_e vs. $\bar{\nu}_e$ appearance



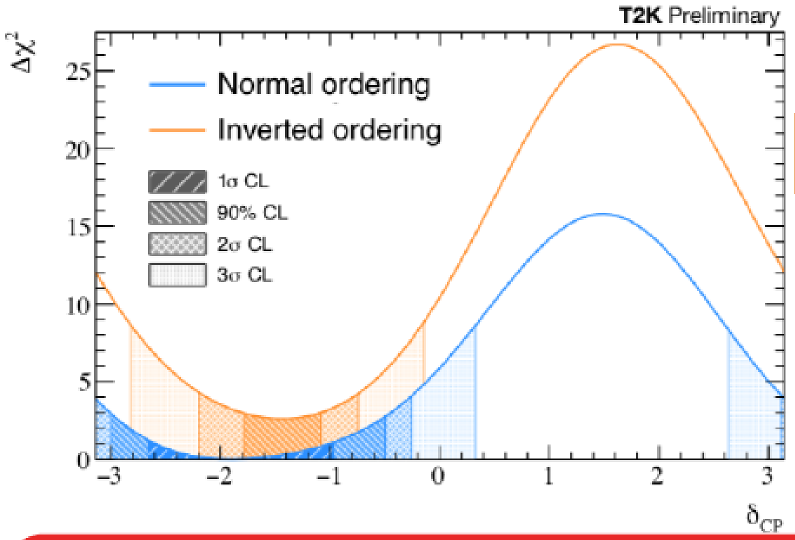
Octant / Mass ordering

	$\sin^2\theta_{23} < 0.5$	$\sin^2\theta_{23} > 0.5$	Sum
NO ($\Delta m^2_{32} > 0$)	0.195	0.613	0.808
IO ($\Delta m^2_{32} < 0$)	0.034	0.158	0.192
Sum	0.229	0.771	1.000

- Bi-event plot illustrates origin of data constraints.
- Best-fit δ_{CP} around **maximal CP-violation** $-\frac{\pi}{2}$
- Weak preference for **Normal ordering** with Bayes factor 4.2 $= P_{NH}/P_{IH}$
- Weak preference for **upper octant** with Bayes factor 3.4 $= P_{upper}/P_{lower}$

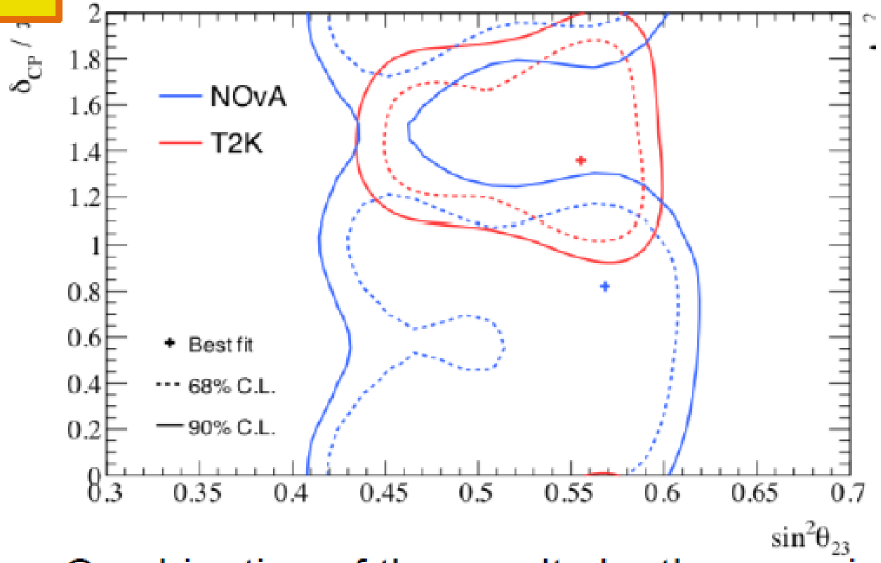
Measurement of δ_{CP}

- Measurement based on $\nu_\mu$anti-ν_μ disapperance and ν_e anti-ν_e appearance



L. Berns

Comparison of results between NOvA and T2K



- Large region excluded at 3σ
- CP-conservation $(0, \pi)$ **excluded at 90%**, π not quite at 2σ
- In checks for biases caused by xsec model choices, left (right) 90% CI edge moves at most by 0.073 (0.080)
- Weak preference of **normal ordering**

28

Combination of the results by the experiments ongoing

- Most of the present data from solar, atmospheric, reactor and accelerator experiments are well explained by the 3ν oscillation hypothesis. The three-neutrino scenario is nowadays well proven and **robust**;

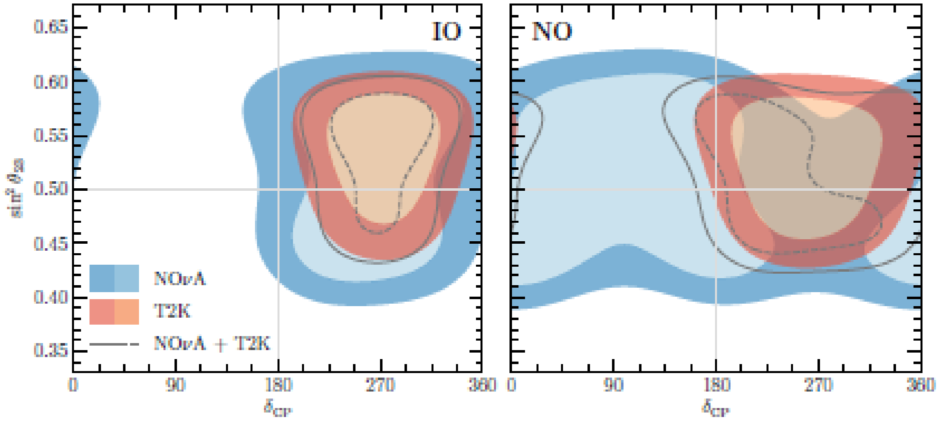
M. Maltoni

M. Maltoni

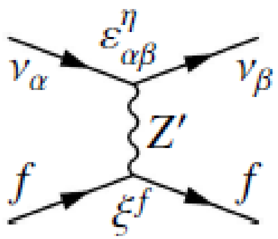
Open issues in 3ν oscillations

- **CP violation**: tension on δ_{CP} between T2K and NOvA for the case of normal ordering (NO);
- **Mass ordering**: due to such tension, long-standing hints in favor of NO is now reduced;
- **θ_{23} octant**: still no clue on deviation of θ_{23} from maximal, and (if so) in which direction;
- future experiments expected to shed light;

¿? can New Physics play a role in their task?



Non standard neutrino-matter interactions



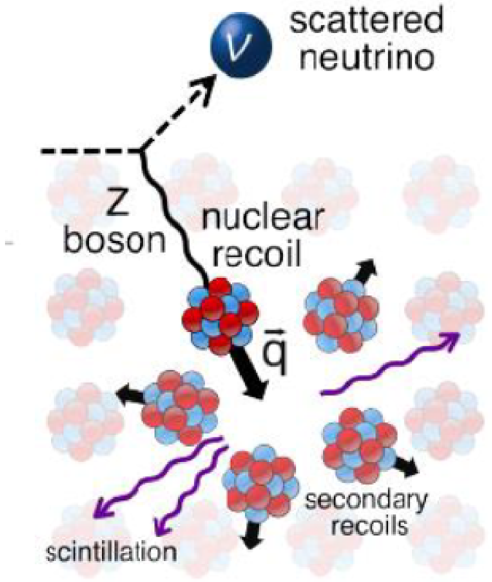
In θ_{12} a new region (LMA-D) appears. And a θ_{12} – mass ordering degeneracy, to be solved by coherent scattering experiments

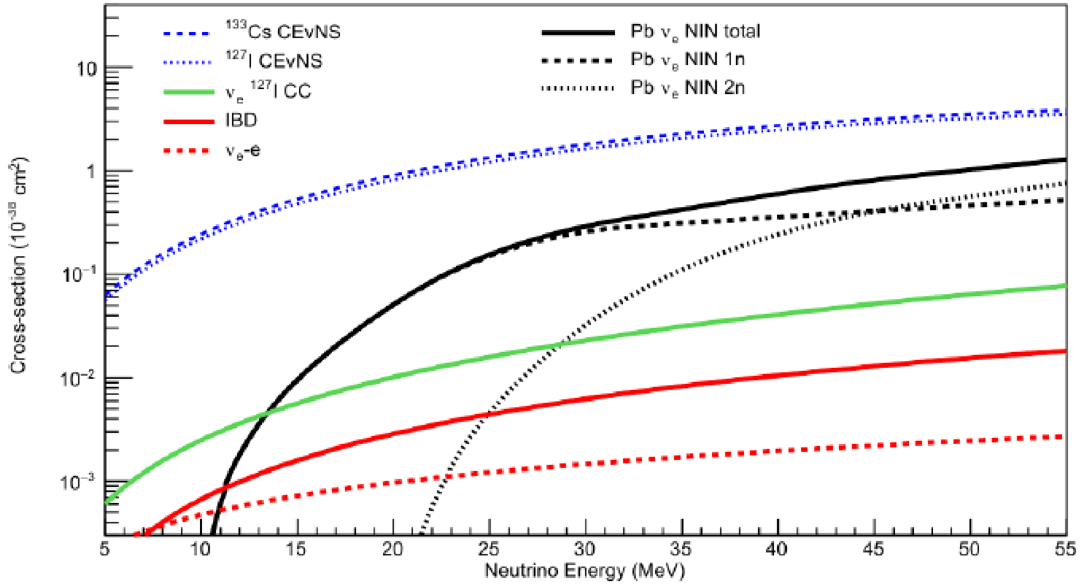
Coherent elastic neutrino-nucleus scattering (CEvNS)

Predicted in

"Coherent effect of a weak neutral current", D. Freedman, PRD v.9, n.5 (1974)

"Isotopic and chiral structure of neutral current", V.Kopeliovich, L. Frankfurt, ZhETF. Pis. Red., v.19 n.4 (1974)





CEvNS cross section in the SM:

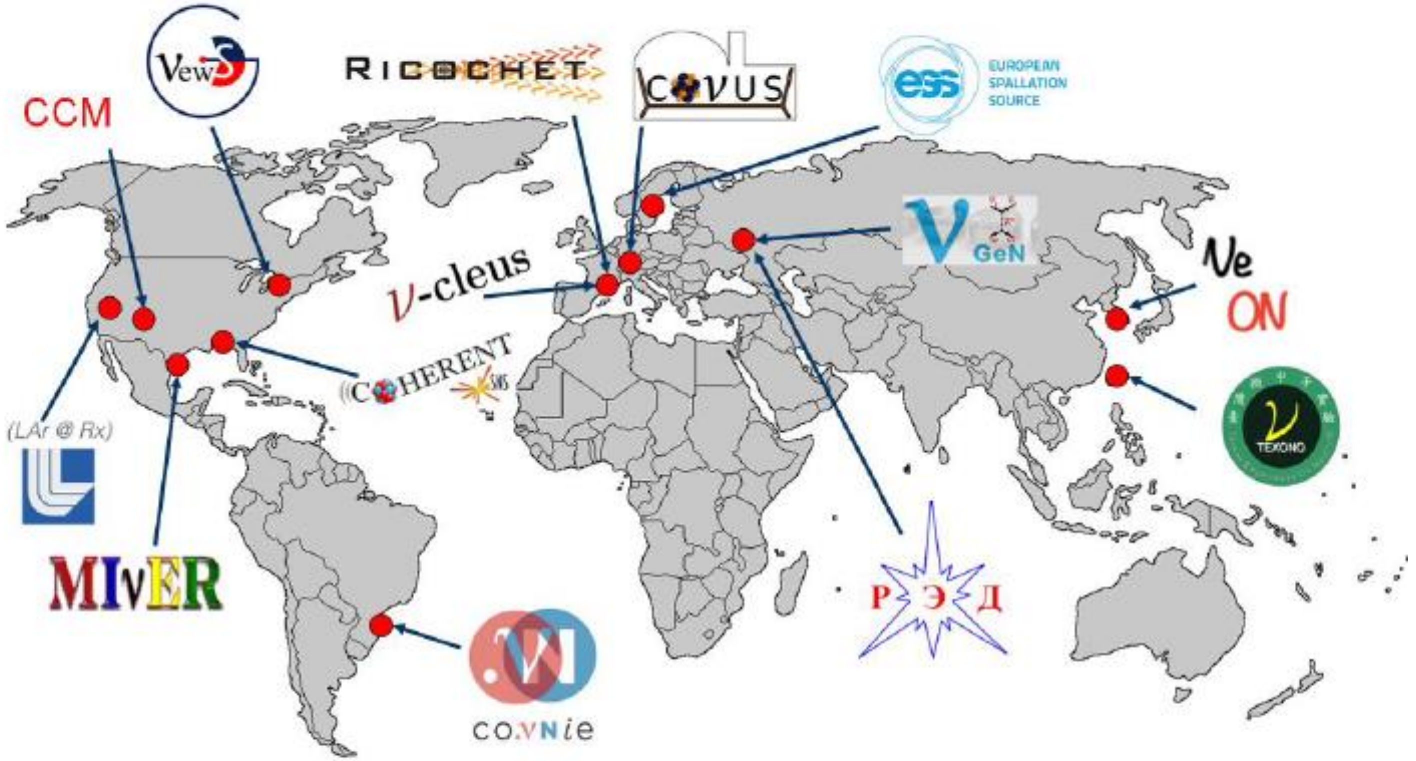
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi}\Big([1-4\sin^2\theta_W]Z - N\Big)^2\Big[1-\frac{T}{T_{max}}\Big]F^2_{nucl}(q^2)$$

$$T_{max} = 2E_\nu^2/(M+2E_\nu)$$

Nucleus	T_{max}, keV (E_ν =5 MeV)	T_{max}, keV (E_ν =30 MeV)
^{12}C	4.44	159.0
^{23}Na	2.32	83.2
^{40}Ar	1.33	47.9
^{74}Ge	0.72	25.9
^{133}Cs	0.40	14.4

CEνNS coherent elastic ν-nucleus scattering

The main goal is to look for new physics using coherent elastic ν–nucleus scattering



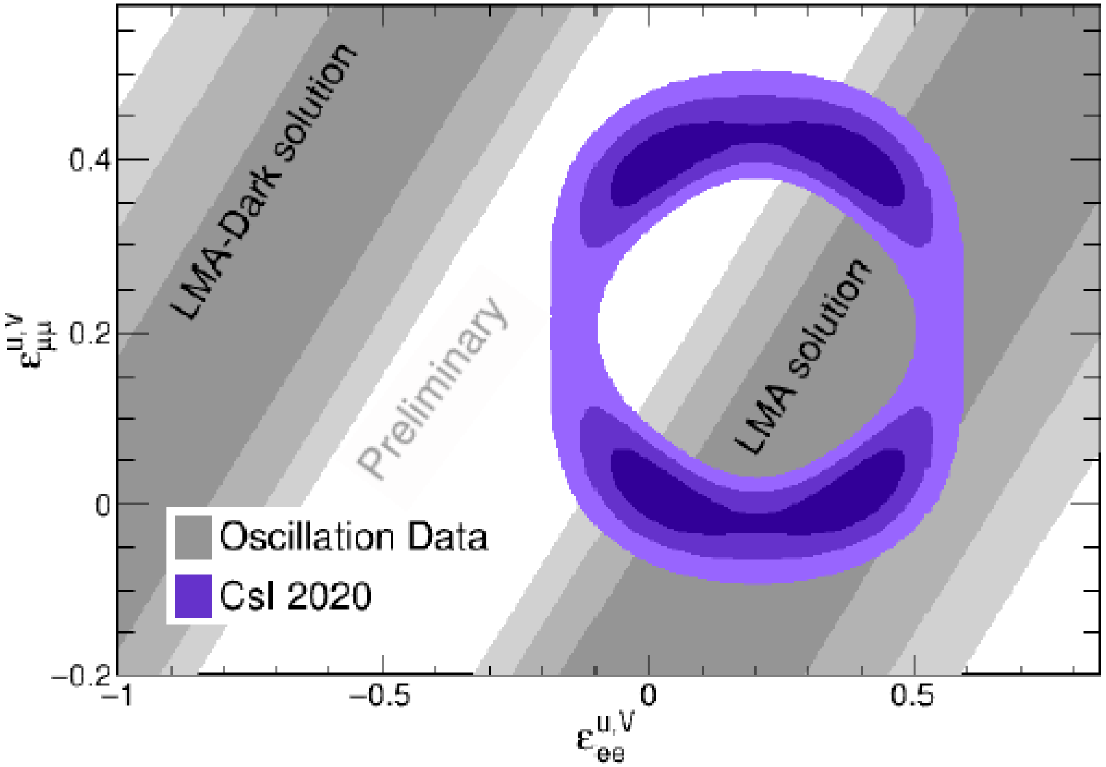
CEνNS search and study experiments around the world

A. Konovalov

COHERENT @ Oak Ridge National Laboratory : CEνNS consistent with the SM

Measurement of $\sin^2\theta W$ (±10%)

See PRD96 11 115007



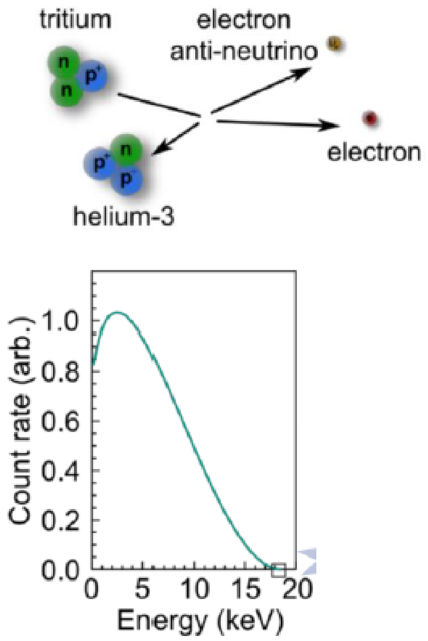
LMA-Dark solution is in tension with the CsI[Na] CEvNS measurement

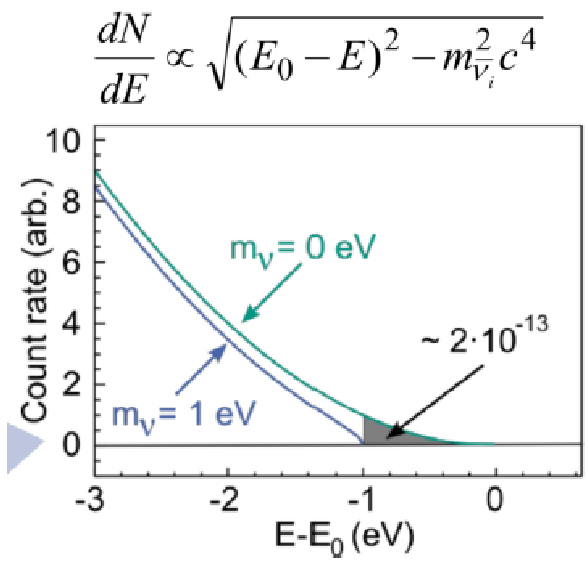
Neutrino Mass

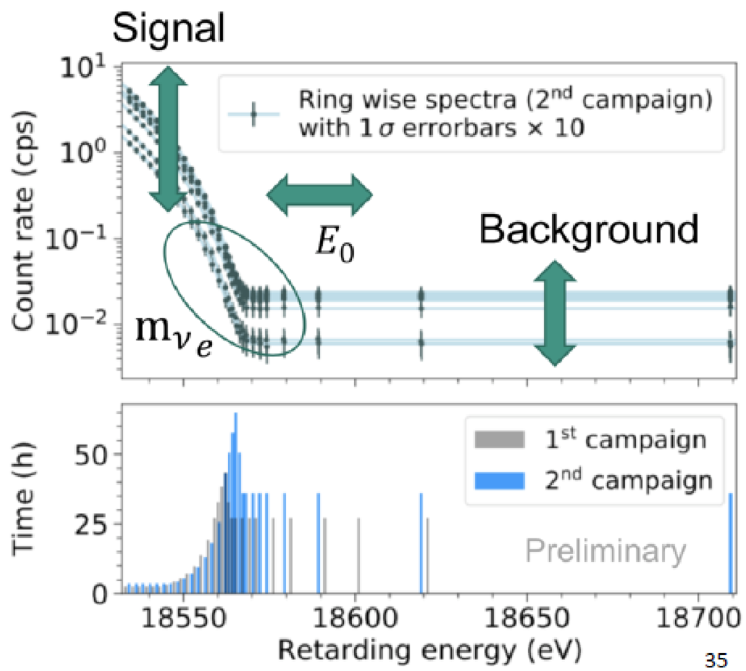
M. Schlösser

- **Karlsruhe Tritium Neutrino Experiment (KATRIN)**

	Cosmology	Search for 0νββ	β-decay & electron capture
Observable	$M_\nu = \sum_i m_i$	$m_{\beta\beta} = \lvert \sum_i U_{ei}^2 m_i \rvert$	$m_\beta^2 = \sum_i \lvert U_{ei}\rvert^2 m_i^2$
Present upper limit	0.12 eV*	0.18 eV*	1.1 eV before Moriond '21
Model dependence	Multi-parameter cosmological model	- Majorana ν - contributions other than m(ν)? - nuclear matrix elements, g_A	**Direct,** only kinematics; no cancellations in incoherent sum



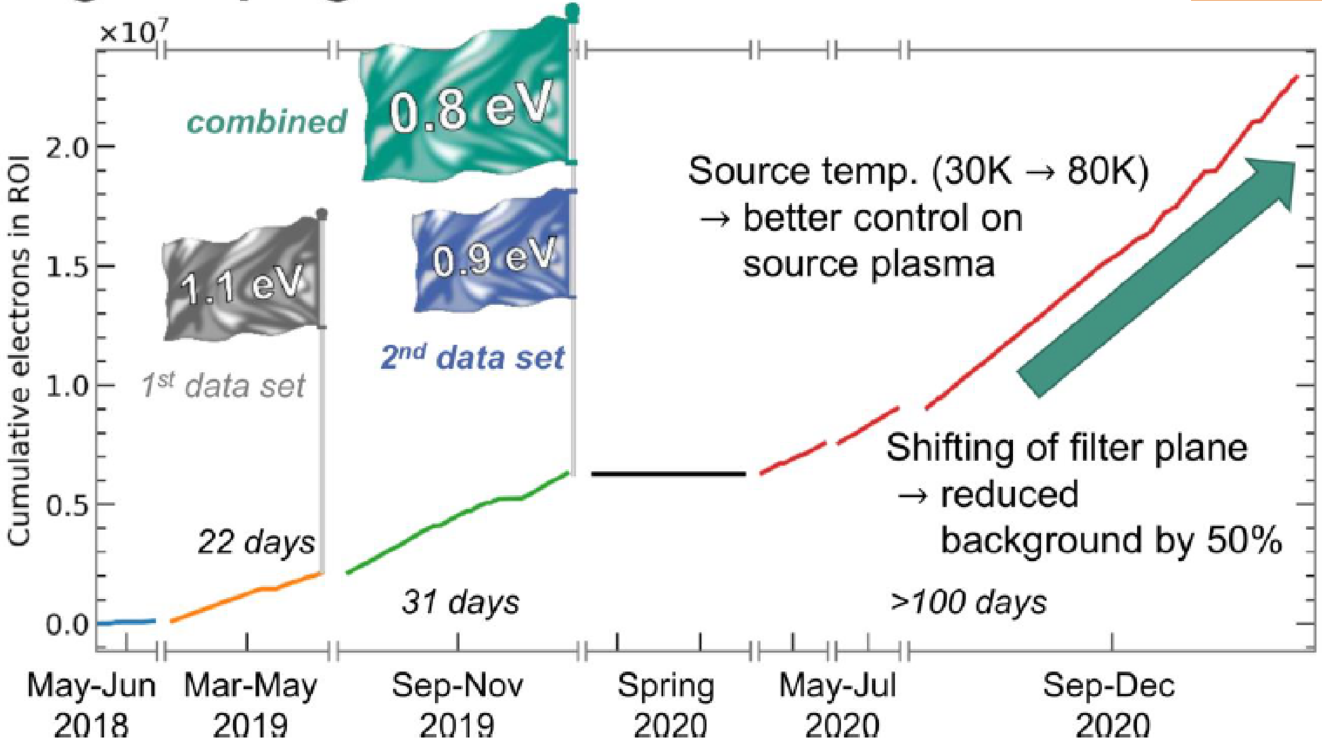




Results

M. Schlösser

Ongoing campaigns



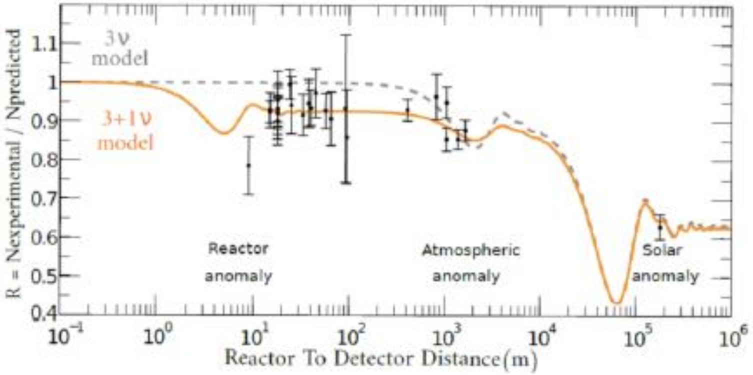
- Combining 1st and 2nd data sets:

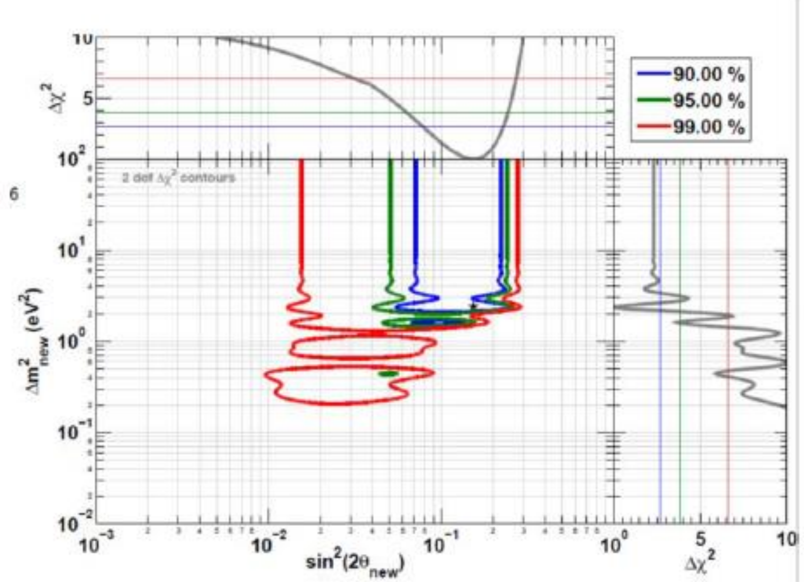
New limit from KATRIN
$m_\nu < 0.8$ eV (90% CL)

- Expected to reach 0.2 eV exclusion sensitivity after the 5 years of planned data taking

Reactor Antineutrino Anomaly

M. Licciardi



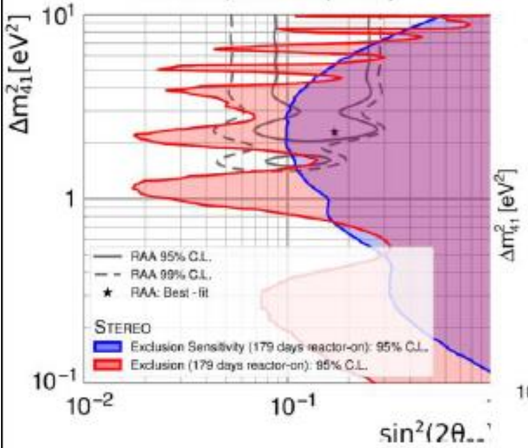


Is extra disappearance related to oscillations into a sterile neutrino?

$L_{osc} \approx$ 2-10 meters

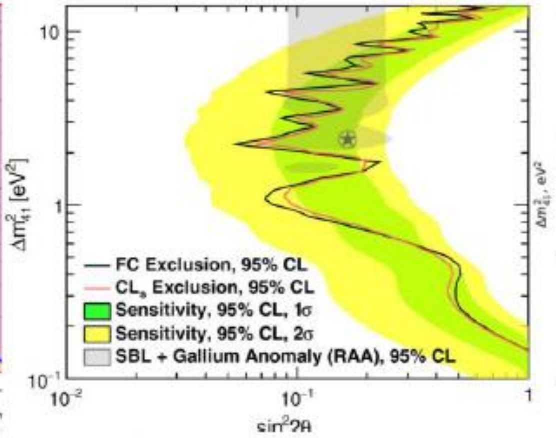
- Investigated by different experiments at reactors
  - Neutrino-4 claims a significant excess, not confirmed

STEREO
PRD 102,052002 (2020)



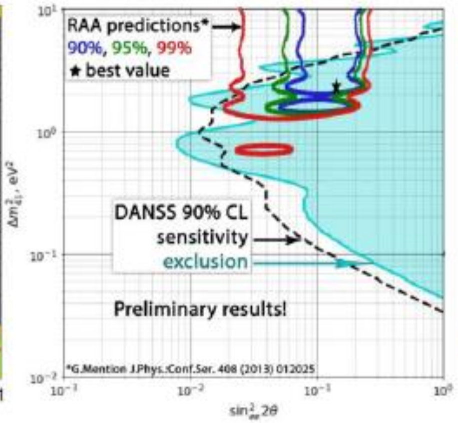
BF RAA excluded > 99% CL

PROSPECT
PRD 103:032001 (2021)



BF RAA excluded > 95% CL

DANSS
arXiv:2012.10255



BF RAA excluded > 5σ

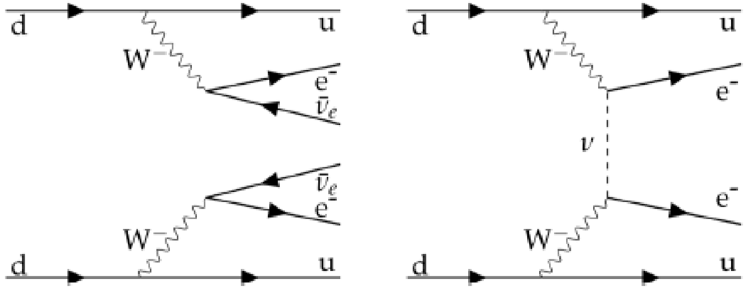
- Strong experimental rejection of the best fit point of the RAA sterile hypothesis (BF RAA)
- More data to come!

Neutrinoless Double-β decay

J. Huang

- Neutrinoless double-β decay
  - Disentangle whether neutrinos are Dirac or Majorana particles
  - Related to the neutrino mass

$$^{A}_{Z}X \to {}_{Z+2}^{A}X + 2e^-$$



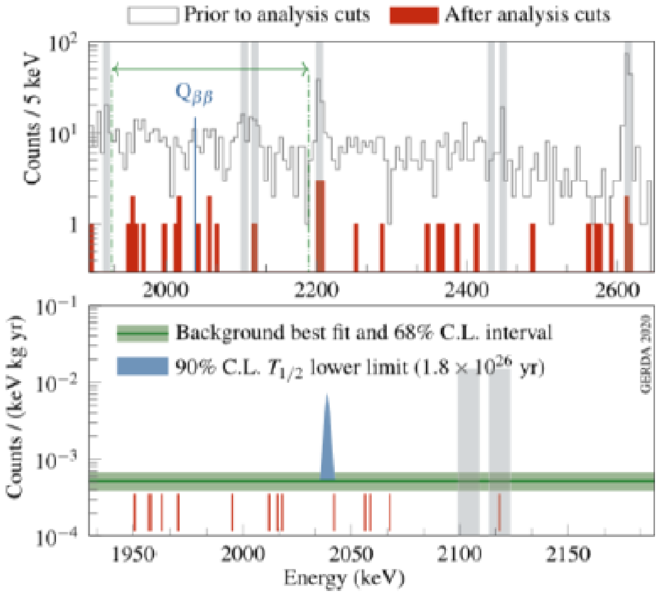
- Searched in many experiments
  - MAJORANA
  - GERDA
  - CUORE
  - CUPID

  ...

$0\nu\beta\beta$ Decay Search in Germanium Detectors

- $^{76}Ge \to {}^{76}Se + 2e^-$
- source is also detector, high efficiency
- best energy resolution and lowest background index in all $0\nu\beta\beta$ decay experiments
- commercial technology, modest cryogenic requirements

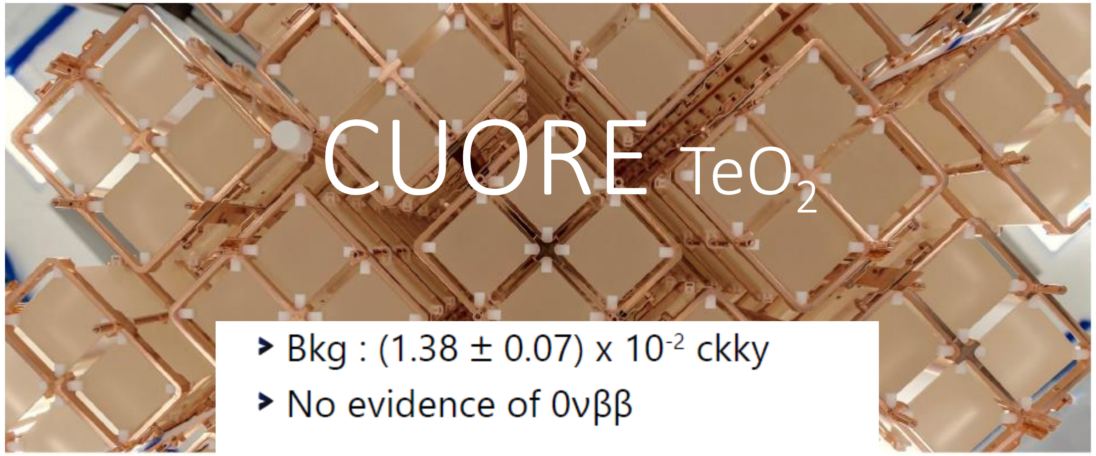
Final GERDA Results, PRL 125 (2020), 252502



- world's best half-life limit: $T_{1/2} > 1.8 \times 10^{26}$ yr at 90% C.L. ($m_{\beta\beta} < 79$–180 meV)
- world's lowest background: $B = 5.2 \times 10^{-4}$ cts/(keV kg yr)

LEGEND-200: physics data taking is expected to start in late 2021

CUORE TeO_2



- Bkg : (1.38 ± 0.07) x 10^{-2} ckky
- No evidence of $0\nu\beta\beta$

$T_{1/2}$ > 3.2 x 10^{25} y (90% C.I.)

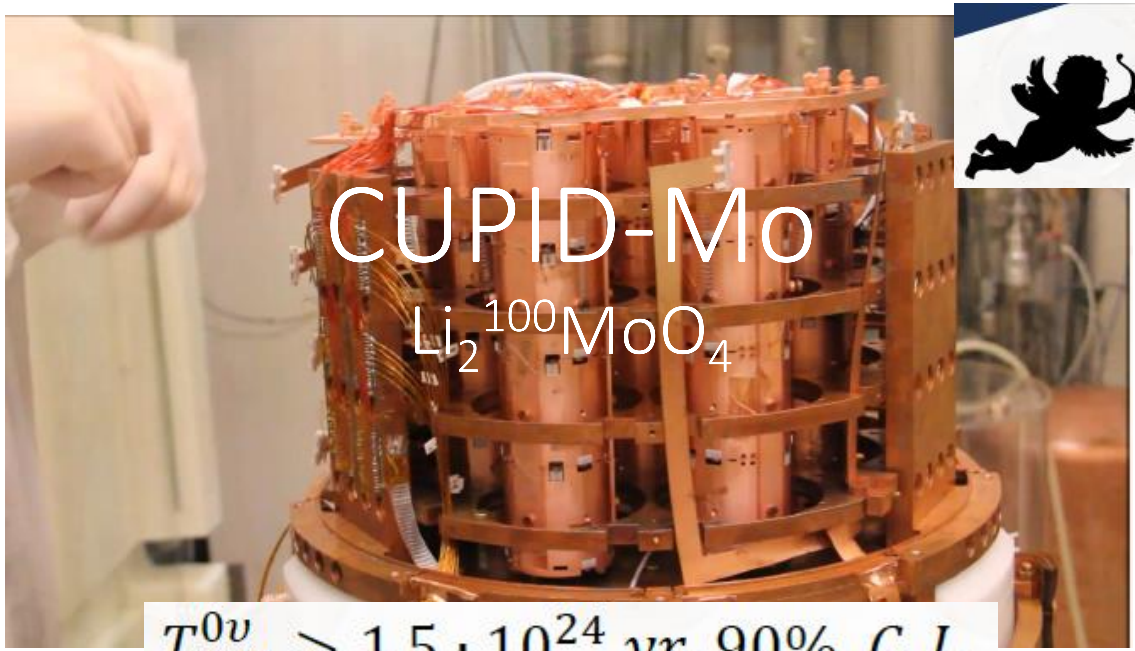
$m_{\beta\beta}$ < 0.075-0.350 eV (90% C.I.)

- Physics results about 130Te $0\nu\beta\beta$ and $2\nu\beta\beta$ released (ground and excited states)
- Raw exposure exceeded 1 ton yr in 2020
- Updated results on $0\nu\beta\beta$ to be released shortly
- Data taking continues smoothly, on track to collect 5 years livetime

S. Pozzi

CUPID-Mo

$Li_2{}^{100}MoO_4$



$$T^{0v}_{1/2} > 1.5 \cdot 10^{24}\ yr, 90\%\ \ C.I.$$

$$m_{\beta\beta} < (0.31 - 0.54)\ eV$$

- **The best limit on $0\nu2\beta$ decay of ^{100}Mo** with exposure of ^{100}Mo only of 1.19 kg×yr, **among 4 best sensitivities to $m_{\beta\beta}$** in the world!
- **The most precise** half-life measurement for the **$2\nu2\beta$ decay** of ^{100}Mo within LUMINEU R&D
- **$Li_2{}^{100}MoO_4$ scintillating bolometers** technology was chosen for ton-scale **CUPID experiment with** an extremely low background index **(10^{-4} counts/keV/kg/yr)** and high discovery potential **($m_{\beta\beta}$~4-8 meV)**

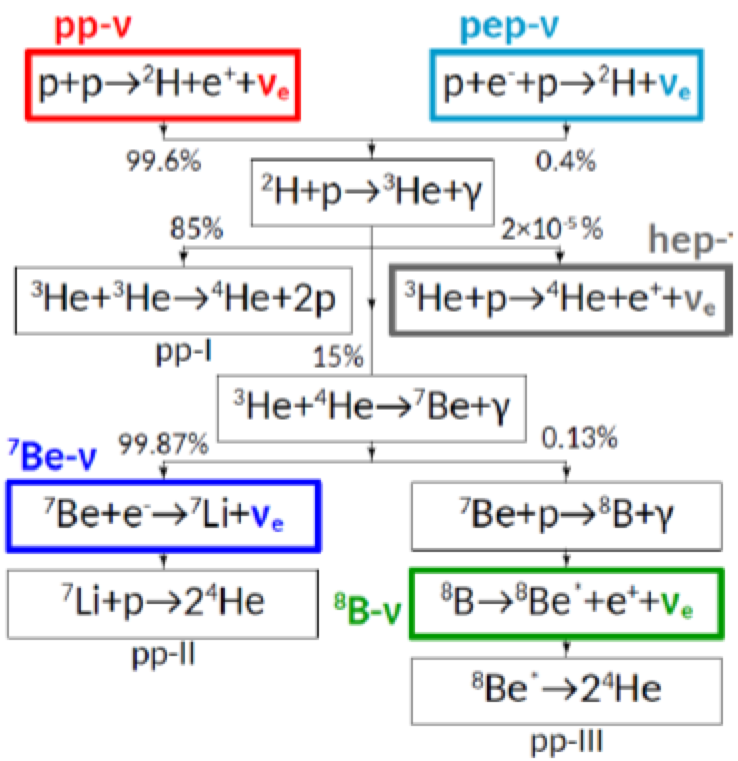
A. Zolotarova

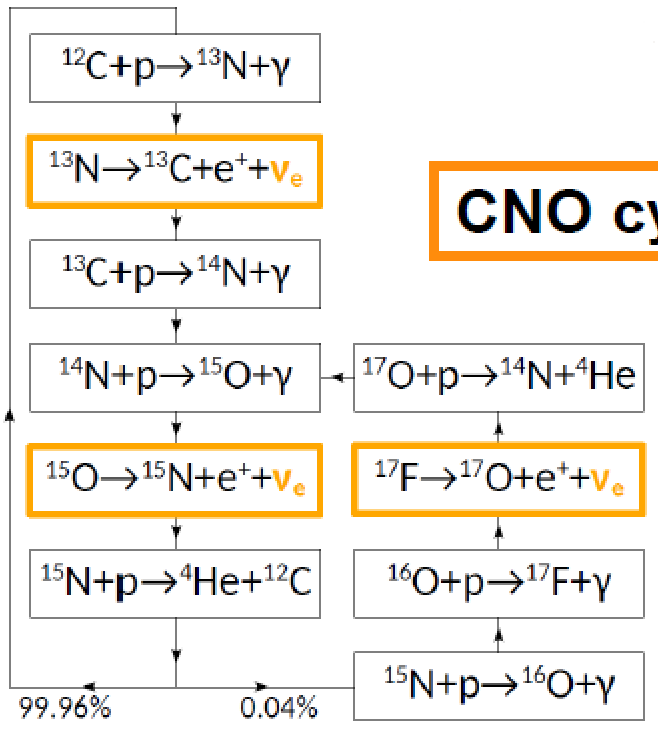
G. Settanta

The Sun's engine

- The solar environment is extreme!
  - A single photon produced in the core needs $\sim 10^5$ years to reach the surface, **neutrinos do not!**
- **2 mechanisms can burn Hydrogen into Helium:**

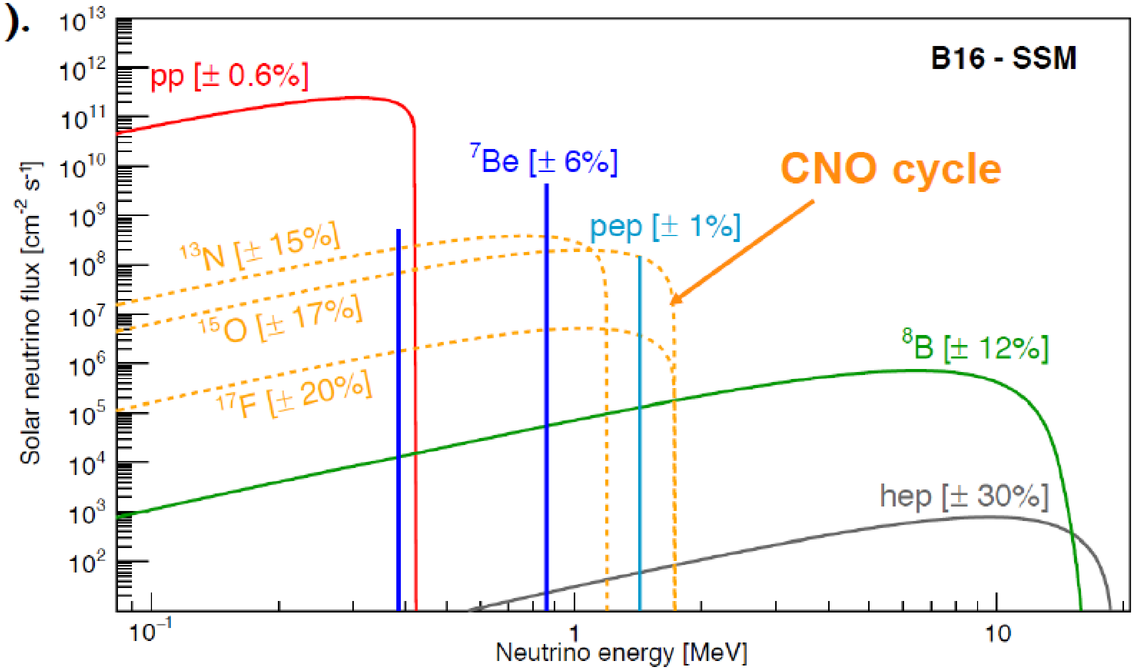
pp chain

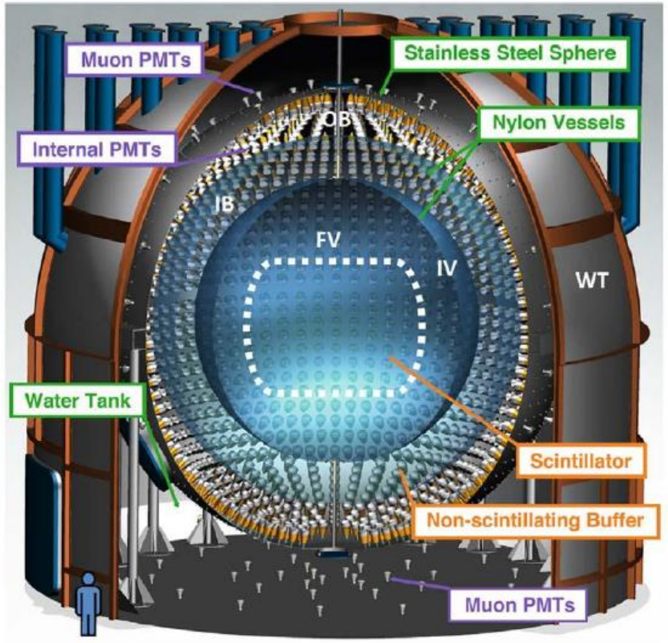




CNO cycle

).





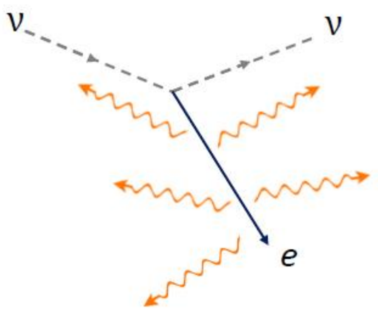
Photon detection system

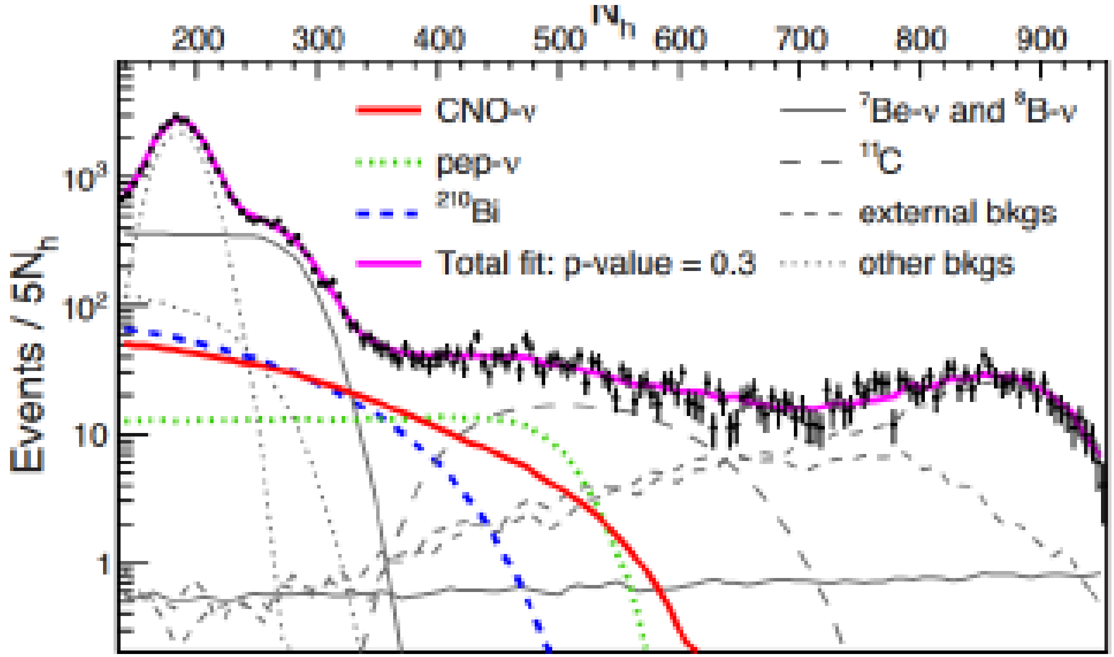
~ 2000 inward – facing PMTs

~ 200 outward – facing PMTs

Detection principle:

ν – e elastic scattering

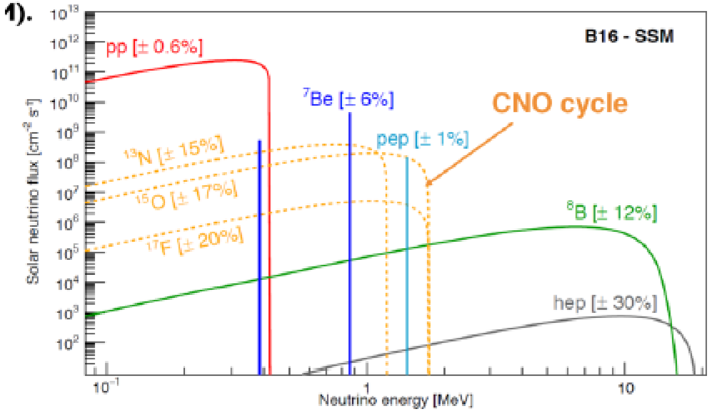


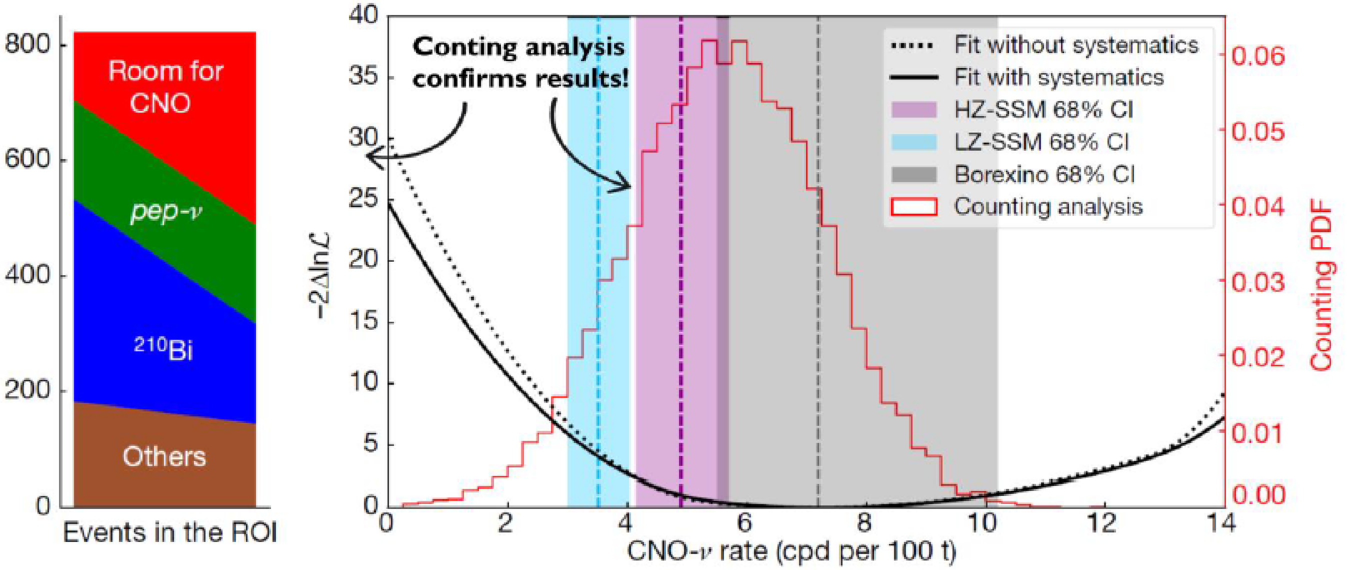


First detection of solar CNO neutrinos at Borexino

G. Settanta

- The metallicity of a star is defined as the relative content of elements heavier then He
- Within the SSM, one can distinguish among high (HZ) and low (LZ) metallicity scenarios.
- Metallicity is linked to the way sound waves propagate in the Sun
  - Indirect constraints
- CNO flux is really sensitive to solar core metallicity





ν(CNO) flux at Earth: 7.0 (−2.0 + 3.0) × 10^8 cm^{-2} s^{-1}

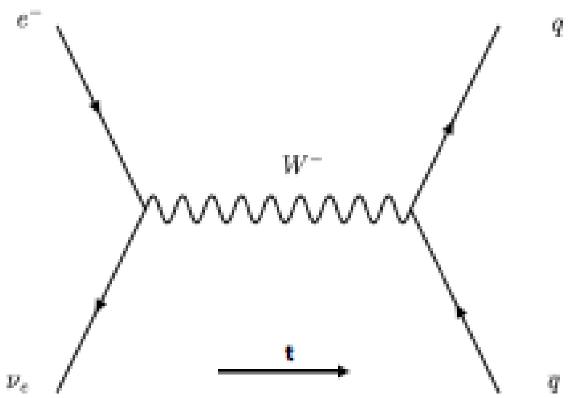
Observation of CNO flux at 5 sigma

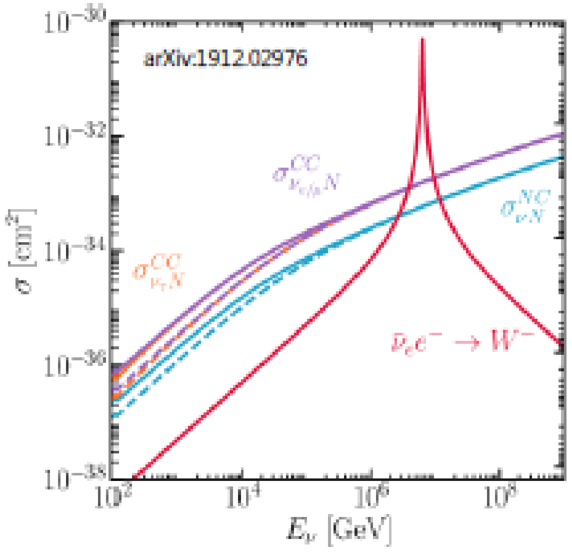
Icecube HE neutrino events

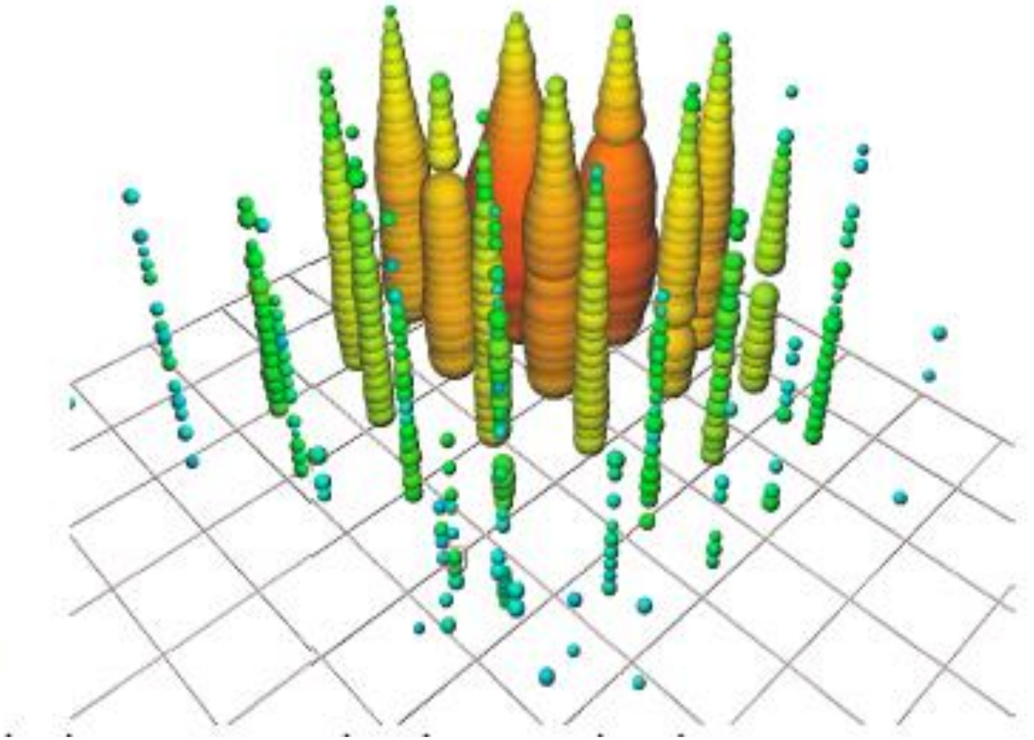
T. Stuttard

The Glashow resonance

- **Resonant production** of on-shell W boson expected in $\bar{\nu}_e - e^-$ interactions when $\sqrt{s} = M_W$
- Requires a **6.3 PeV** $\bar{\nu}_e$ for an e^- at rest
- Beyond reach of terrestrial accelerators, but not astrophysical ones.





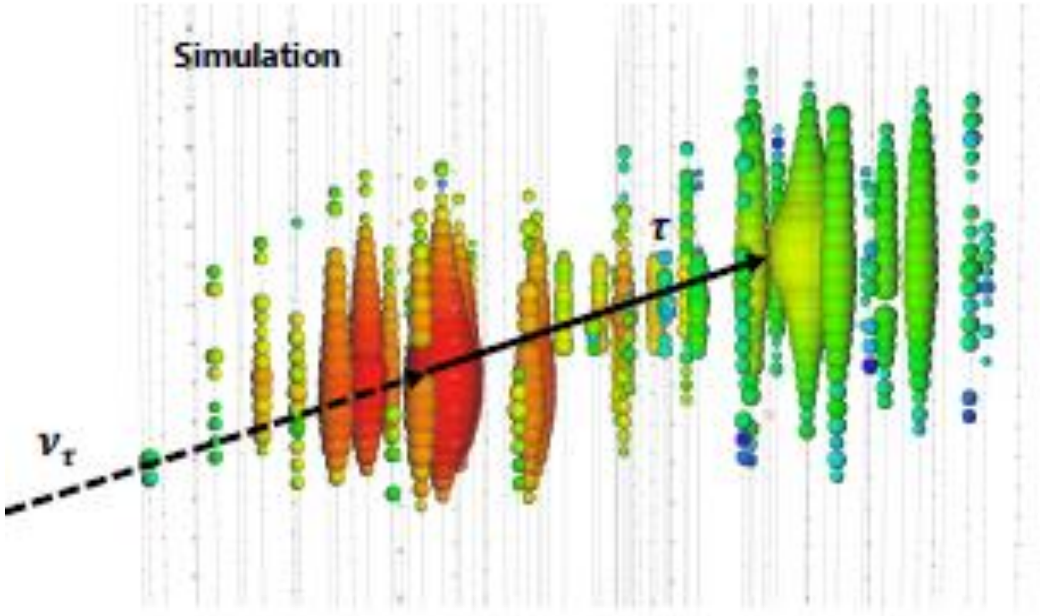


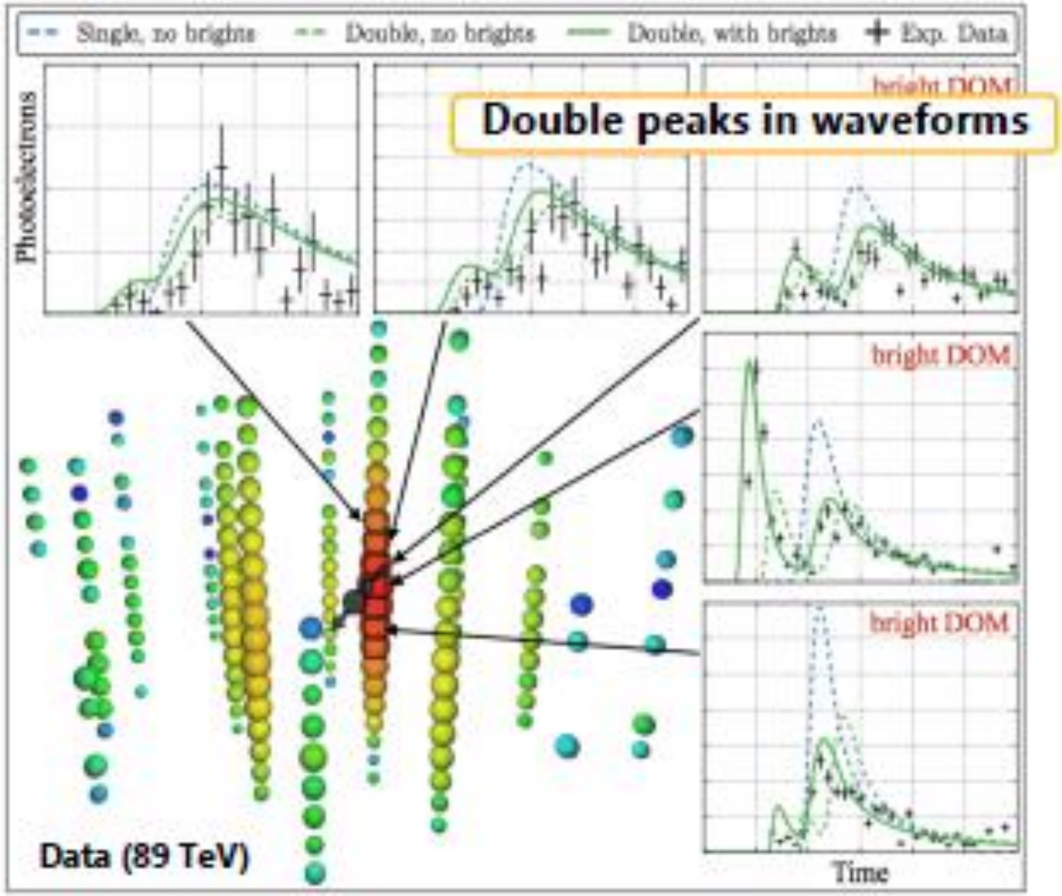
arXiv:2011.03561

T. Stuttard

Identifying astro ν_τ

- **First identification of astrophysical ν_τ**
  - 2 events found in 7.5 yrs (expect 1.5 + 0.8 background)
- Identified via double bang topology
  - ν_τ interaction + τ decay





Matière noire

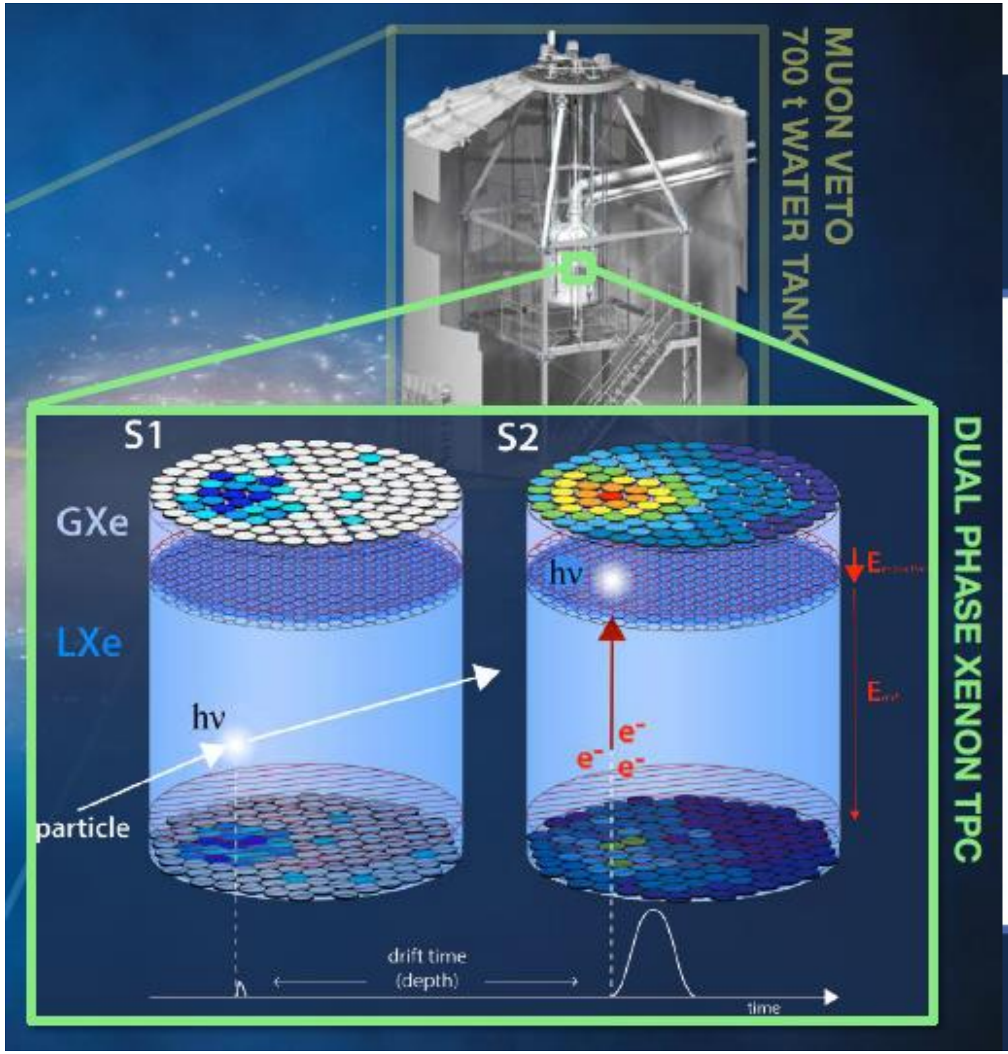
- We see its effects but we do not know its origin
  - Particles?
  - Celestial objects?
  - Modified gravity?
  - Does it interact with the standard matter only with gravity?
- Wide research program to try to detect it:
  - Directly or indirectly
  - Direct searches
    - specific dark matter experiments or at colliders

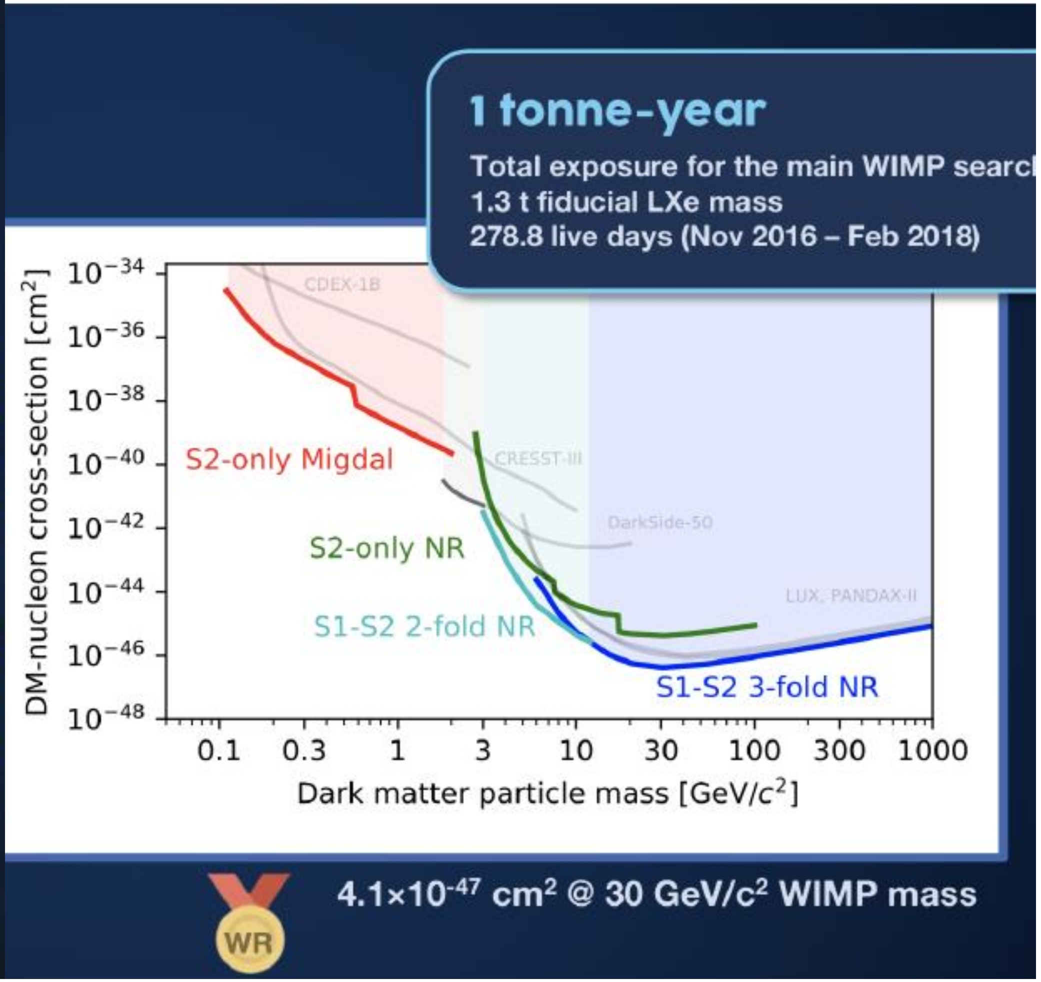
XENON, XENON1T

P. Di Gangi

Dual phase XENON TPC, immersed in a 700 t water tank to veto muons

Best limits on DM- nucleon cross section in most of the mass range

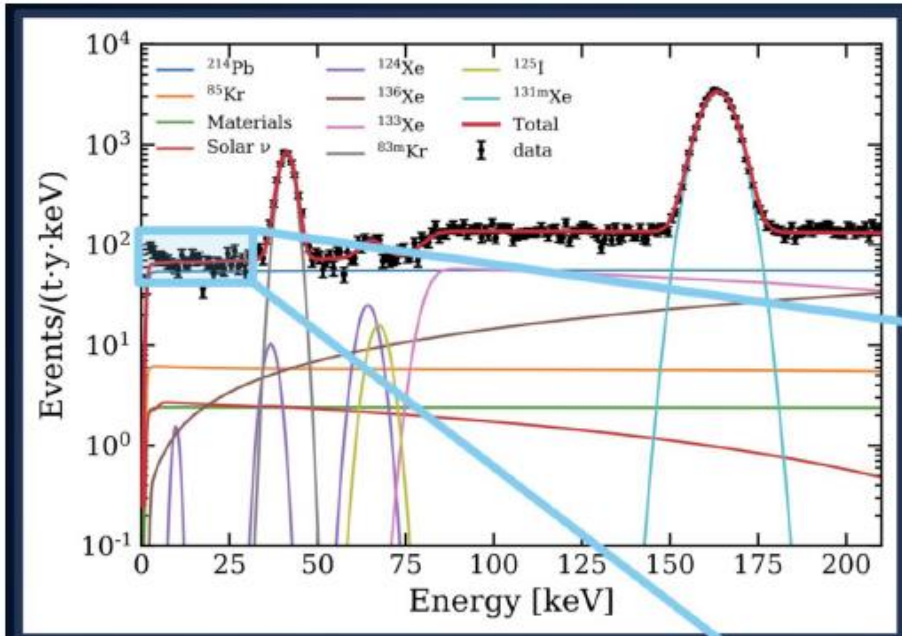




Excess observed in ER

P. Di Gangi

- Low energy excess in electron recoil

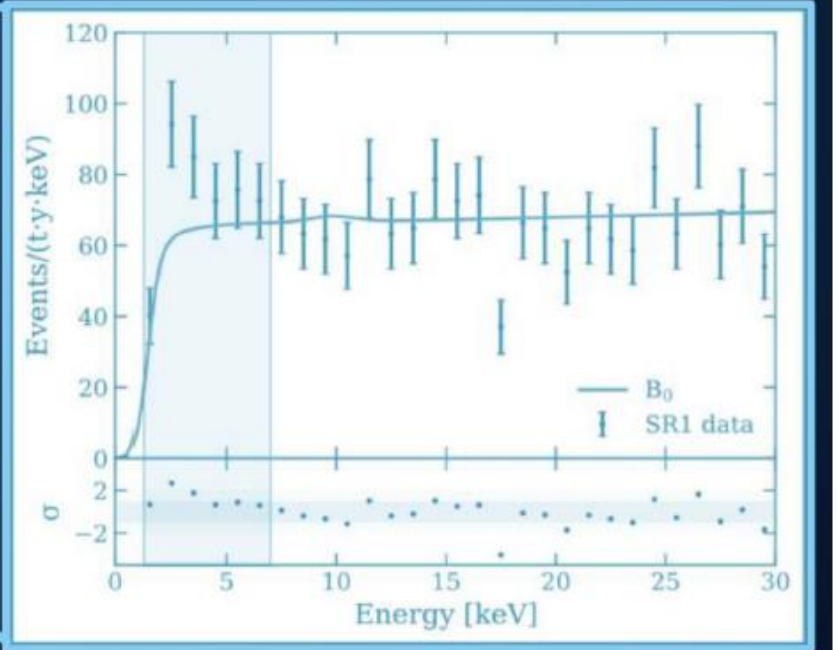


76 ± 2 events/(t·y·keV)
Fitted background in [1, 30] keV

Events in [1, 7] keV	232 ± 15 expected	285 observed

Background model
JCAP04(2016)027
fit to data:
very good across most of the energy range [1, 210] keV

No.	Component	Expected Events	Fitted Events
i	^{214}Pb	(3450, 8530)	7480 ± 160
ii	^{85}Kr	890 ± 150	773 ± 80
iii	Materials	323 (fixed)	323 (fixed)
iv	^{136}Xe	2120 ± 210	2150 ± 120
v	Solar neutrino	220.7 ± 6.6	220.8 ± 4.7
vi	^{133}Xe	3900 ± 410	4009 ± 85
vii	^{131m}Xe	23760 ± 640	24270 ± 150
	^{125}I (K)	79 ± 33	67 ± 12
viii	^{125}I (L)	15.3 ± 6.5	13.1 ± 2.3
	^{125}I (M)	3.4 ± 1.5	2.94 ± 0.50
ix	^{83m}Kr	2500 ± 250	2671 ± 53
	^{124}Xe (KK)	125 ± 50	113 ± 24
x	^{124}Xe (KL)	38 ± 15	34.0 ± 7.3
	^{124}Xe (LL)	2.8 ± 1.1	2.56 ± 0.55

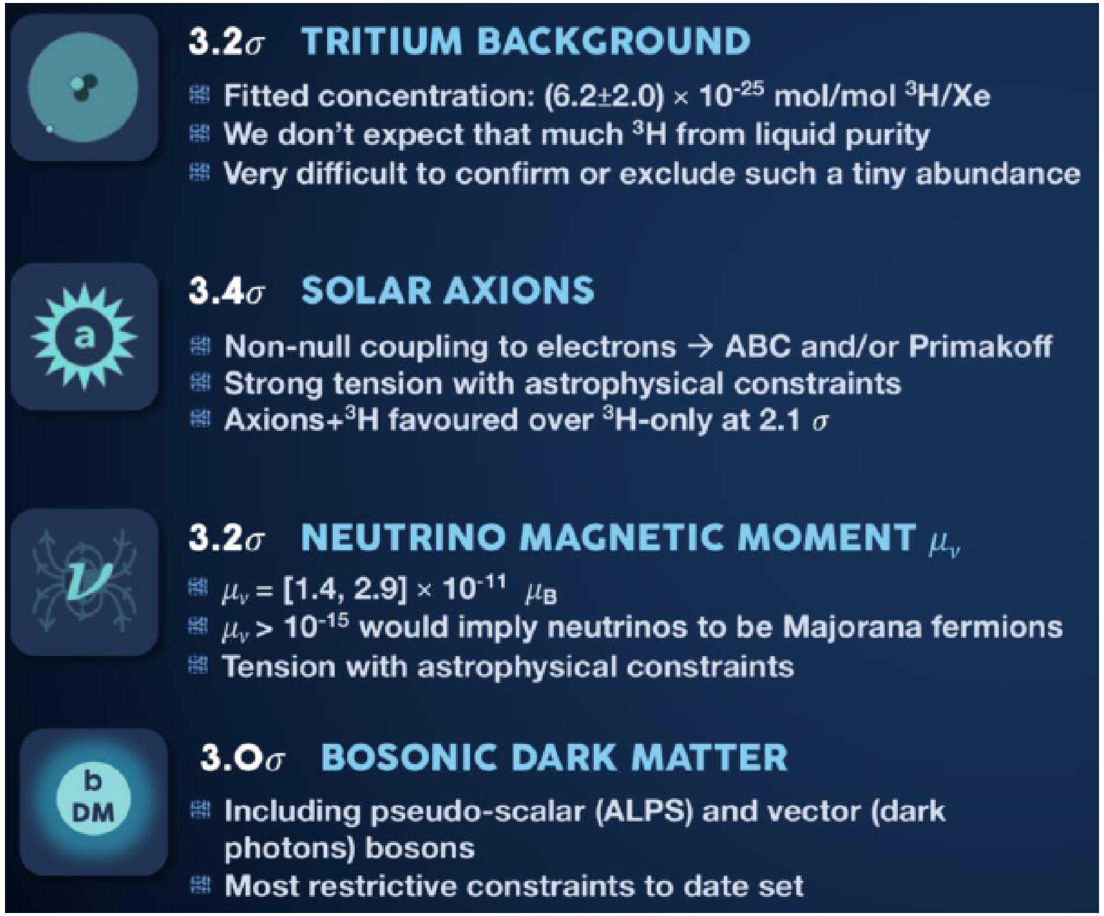


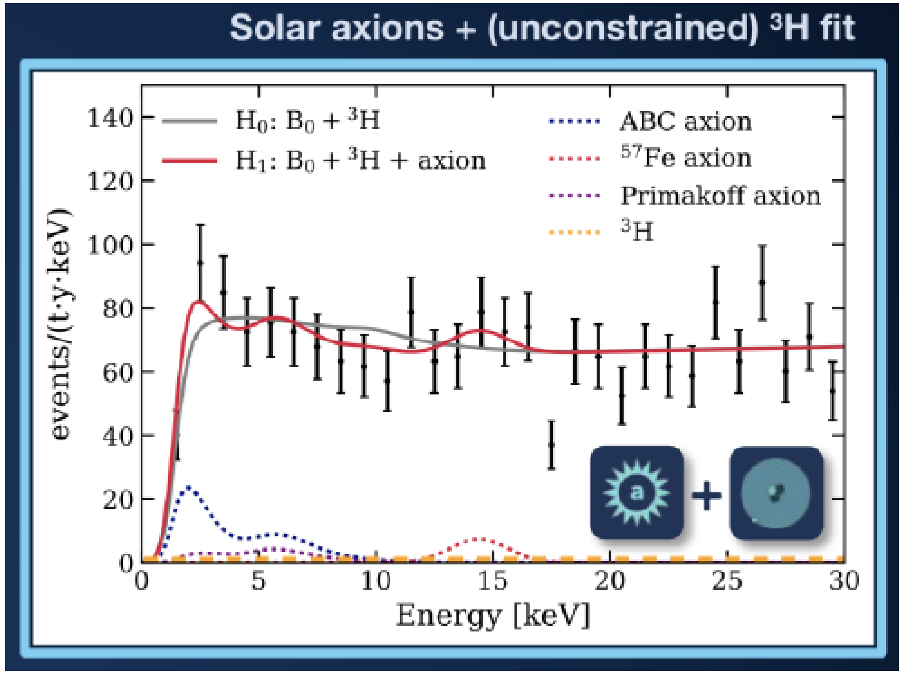
Search in 1 t LXe fiducial mass and 226.9 live days

Possible interpretations

P. Di Gangi

- Could be still New Physics but also Tritium BG





- Should be possible to disentangle between New Physics and BG hypothesis soon with more data from XENONnT

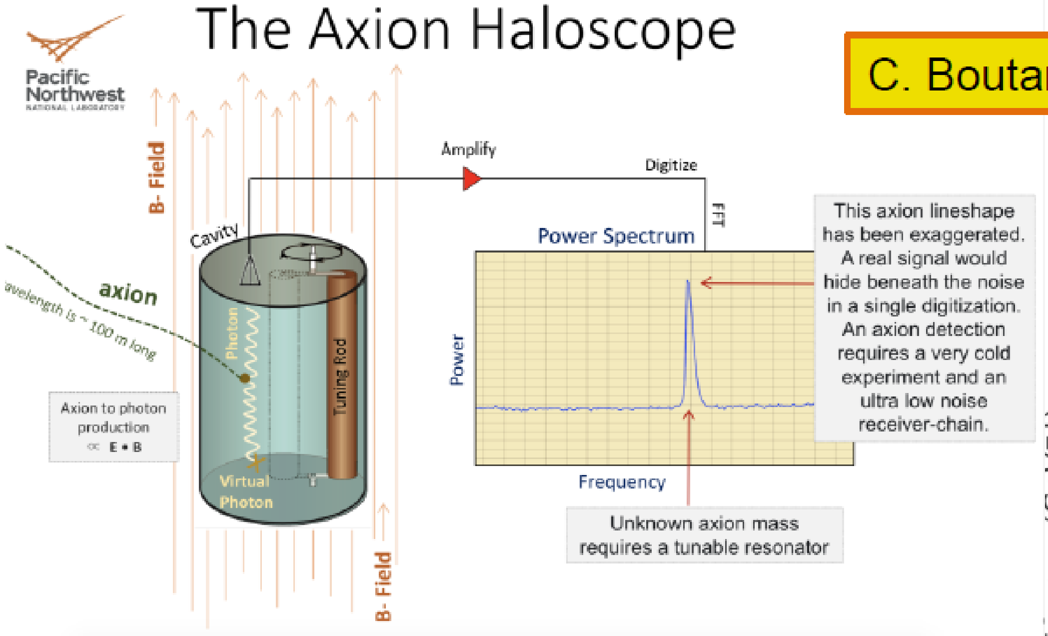
Also detailed theory discussion by M. Fairbain

ADMX (Axion Dark Matter eXperiment)

- Axions could provide a solution to two distinct problems
  - Dark matter
  - Strong CP problem (why nEDM is so small)

The Axion Haloscope

C. Boutan



- Scan over frequency to probe different masses
- Results from 100 MHz scan in 2020
- Plan to scan up to 4 GHz in the next year or two

A few properties of the axion

Cosmological Abundance

$$\Omega_a \sim \left(\frac{5\mu eV}{m_a}\right)^{7/6}$$

(Athermal Production Mechanism)

Mass and Couplings

Generically: $m_a \sim g_{aii} \sim \frac{1}{f_a}$

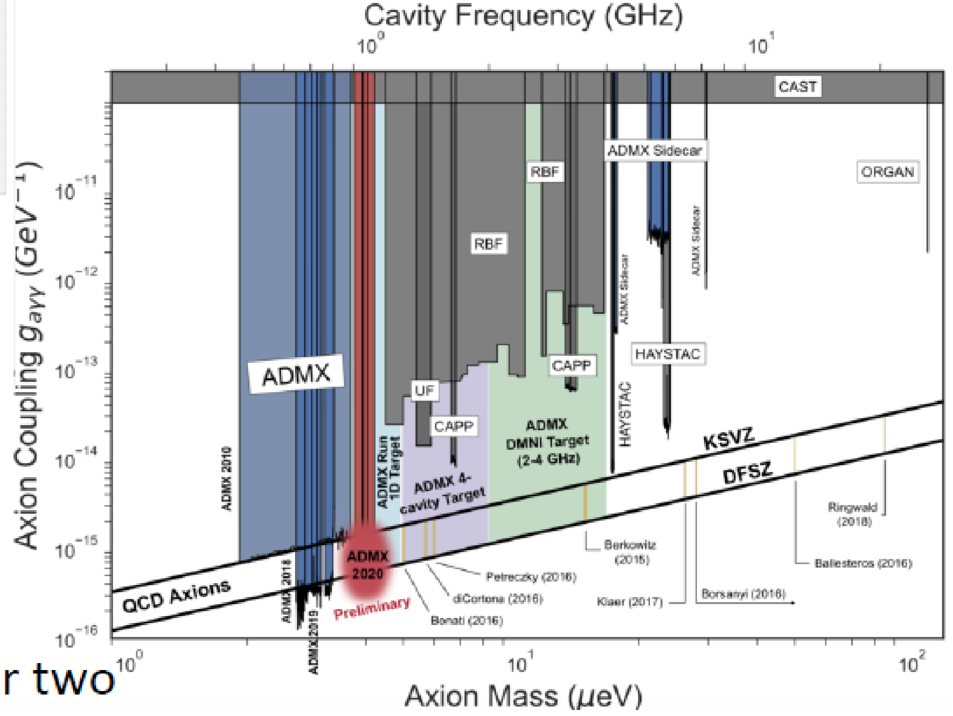
Depends on inflation and who you ask (µeV or peV) $<$ m_a $<$ 10^{-2} eV (too coupled)

Coupling to Photons

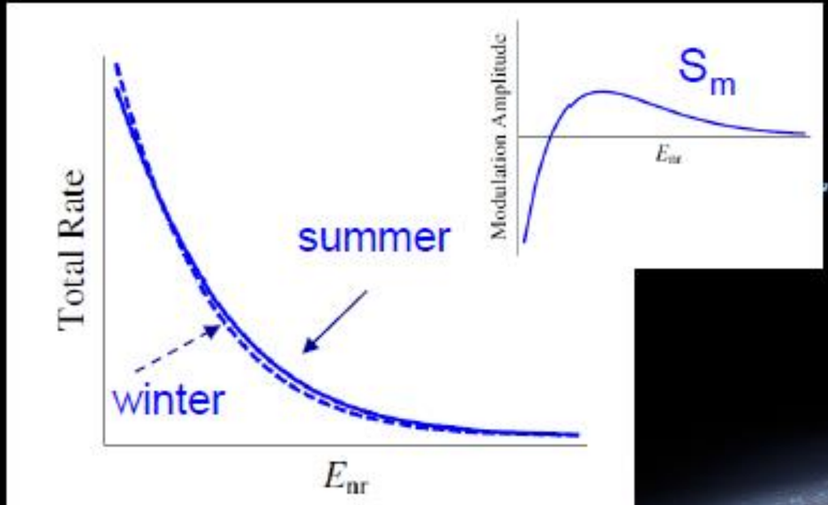
Photon coupling $g_{a\gamma\gamma} = \frac{\alpha g_\gamma}{\pi f_a}$

Axion, γ, γ

$$g_\gamma^2 = \begin{cases} 0.94 KSVZ \\ 0.13 DFSZ \end{cases}$$

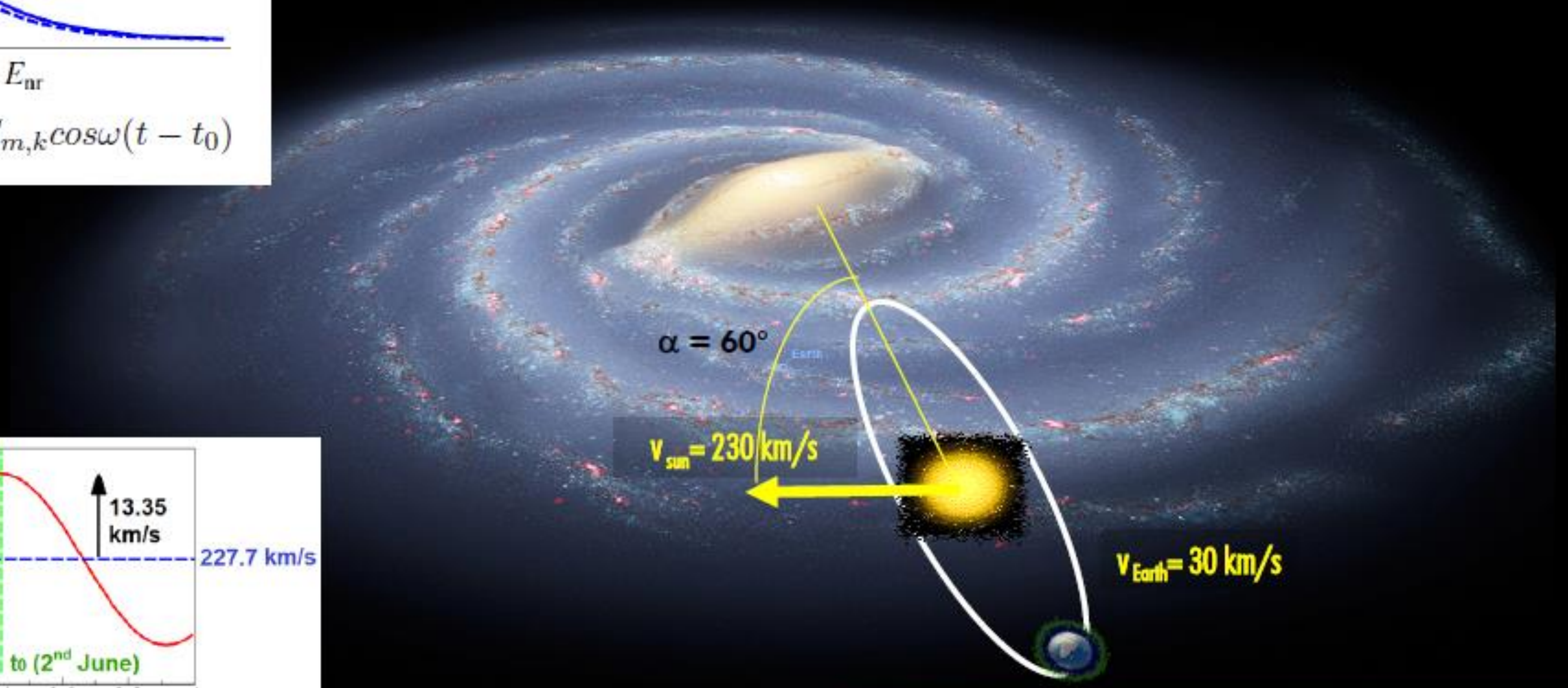


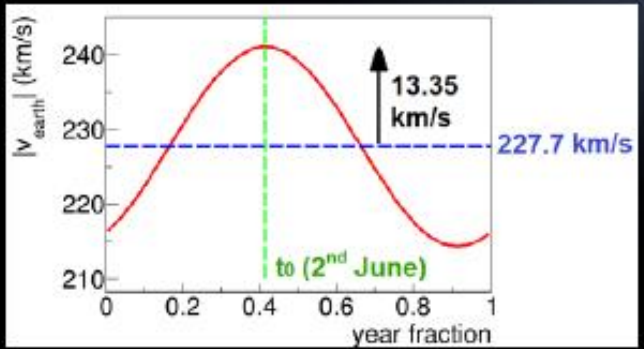
Annual modulation in dark matter interaction rate



$$S_k(t) = S_{0,k} + S_{m,k} cos\omega(t - t_0)$$

Dark matter halo

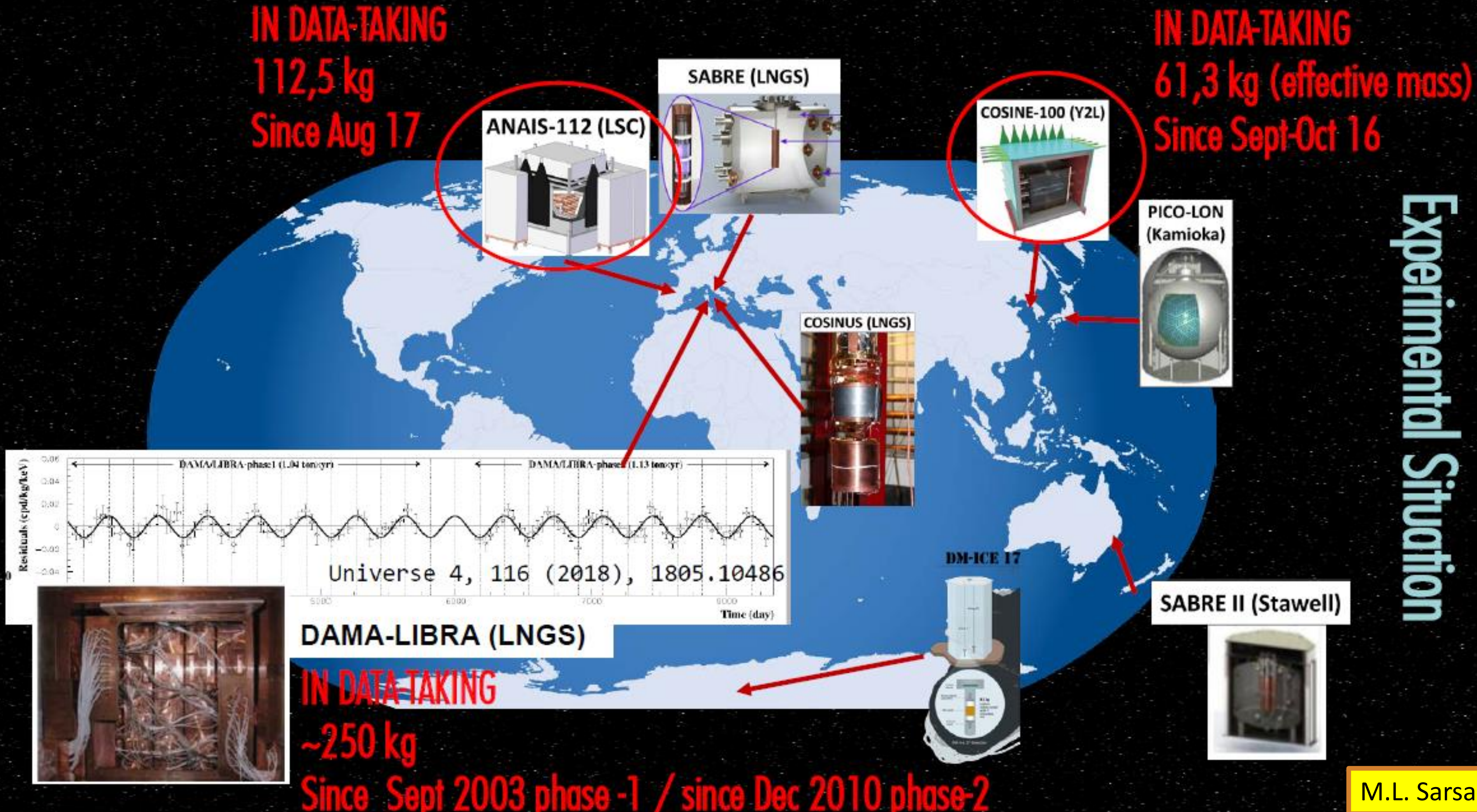




Relative velocity Earth —halo changes along the year

$$S(E_R, t) = \frac{dR}{dE_R} = \frac{\rho\, M_{det}}{2 m_W m_{WN}^2} \int_{v_{min}}^{v_{max}} \frac{f(v)}{v}\, \sigma_{WN}\, dv^3$$

Experimental Situation

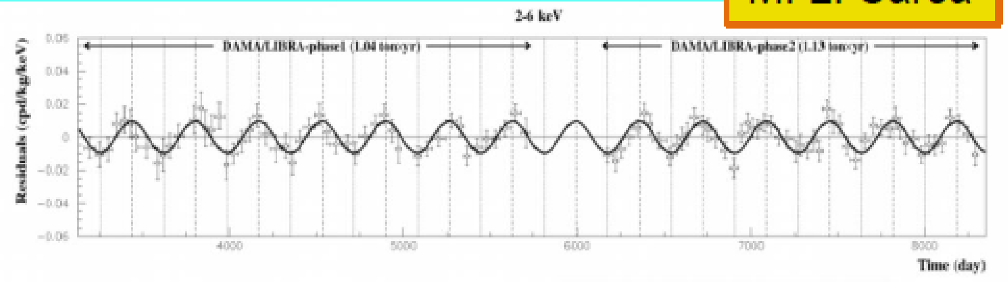


M.L. Sarsa

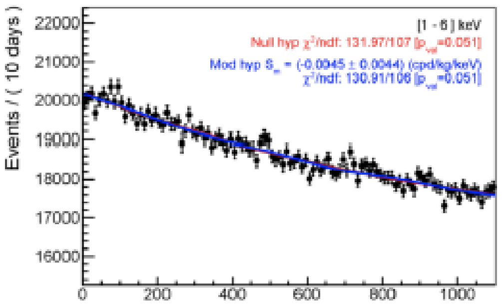
ANAIS-112

M. L. Sarsa

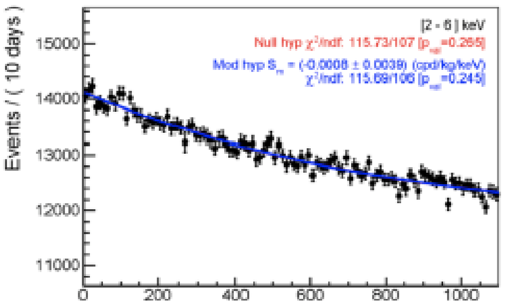
- Check DAMA/Libra modulation result
  - The data of DAMA/LIBRA (NaI(Tl) scintillator) favour the presence of a modulation at 12.9σ CL (2.46 ton × yr) in the 2-6 keV energy region
  - Not confirmed by other experiments



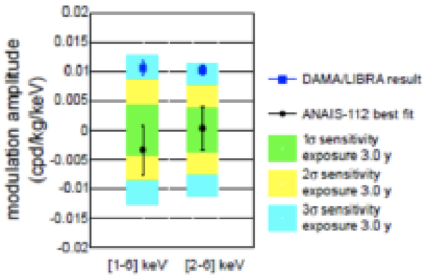
- Aim at Model Independent confirmation or refutation is mandatory using same target
- Results from; Canfranc Underground Laboratory, @SPAIN (under 2450 m.w.e.) taking data since August 2017



days after August 3, 2017 (days)



days after August 3, 2017 (days)



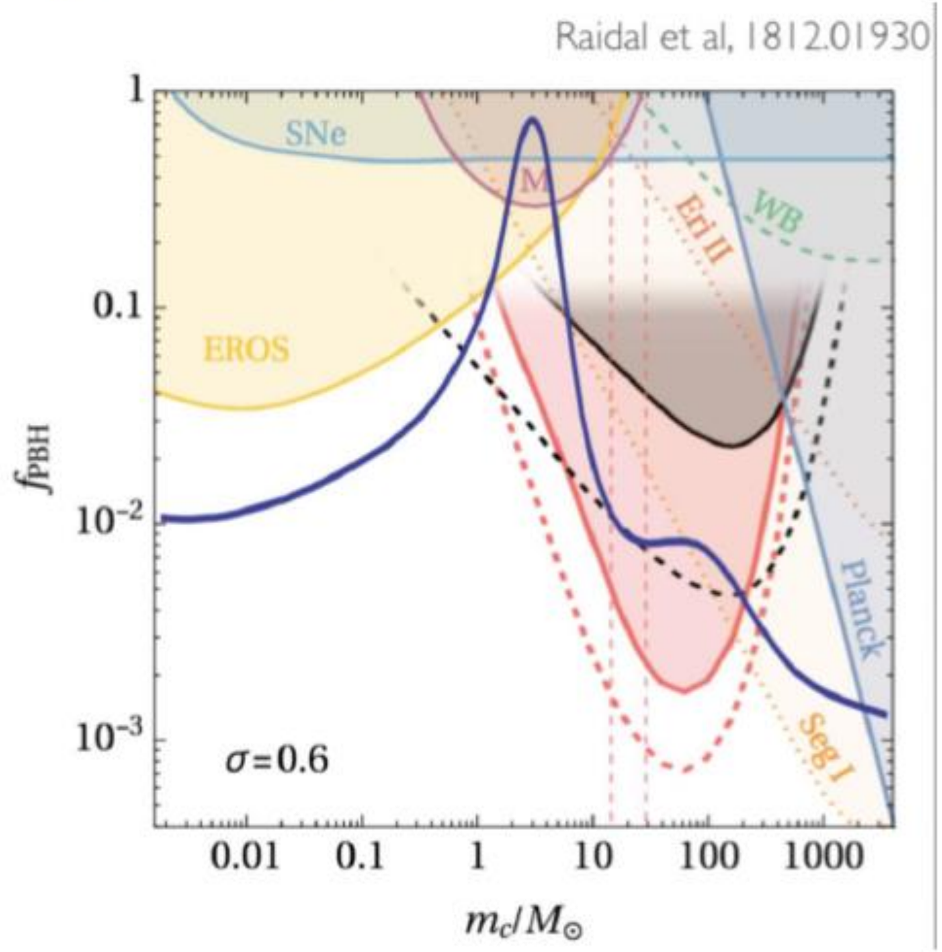
- Best fits are incompatible with DAMA/LIBRA result at 3.3 and 2.6 σ in [1-6] and [2-6] keV energy regions
- Sensitivity is at 2.5 and 2.7 σ in [1-6] and [2-6] keV energy regions

- Some words of caution before refuting the results of DAMA/Libra:
  - response of the two detectors to the energy depositions from dark matter particles could be different
  - Scintillation produced by nuclear recoils is quenched with respect to electron recoils (used for calibration)
  - Today still too many uncertainties in the QF values and dependences for NaI
  - QF has been measured for different quality crystals, results will appear soon

Primordial BH as Dark Matter

S. Clesse

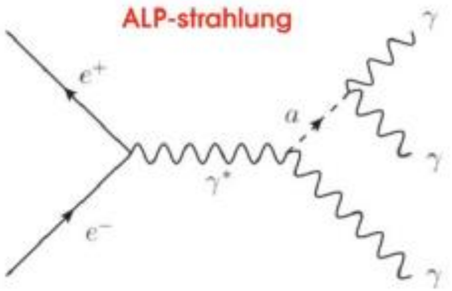
- Can they account for the totality of the DM in the universe?
- Astro/cosmo limits could be evaded if Primordial Black Holes (PBH) are grouped in clusters

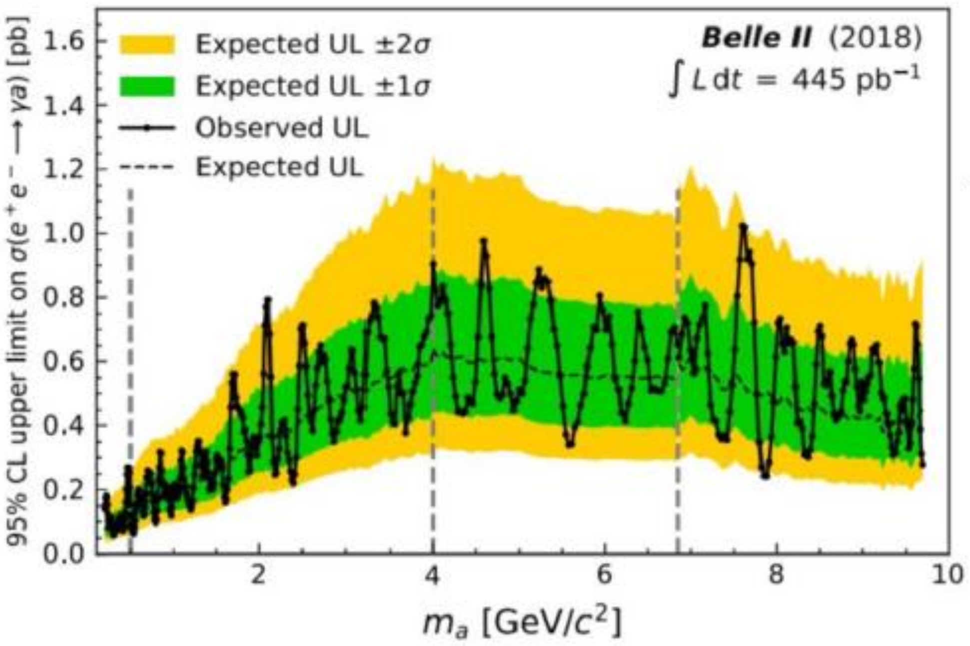


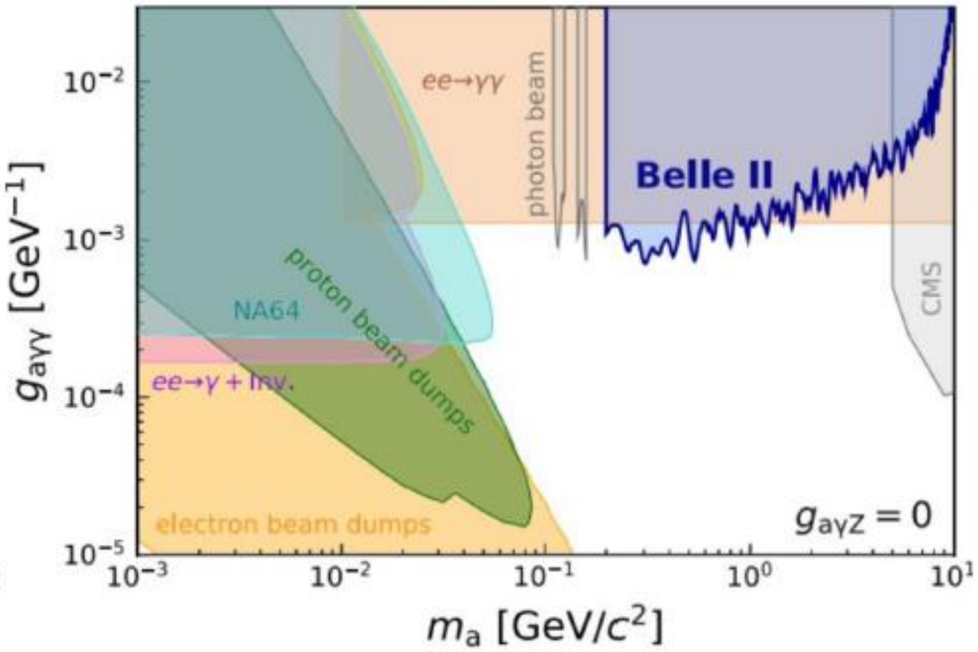
Dark matter at Belle 2

G. De Pietro

- Two searches based on 0.2-0.4 fb^{-1} of the 2018 pilot run
  - New light gauge boson Z' coupling only to 2nd and 3rd generation of leptons (Lμ – Lτ model):
  - Axion-Like Particles $a \to \gamma\gamma$



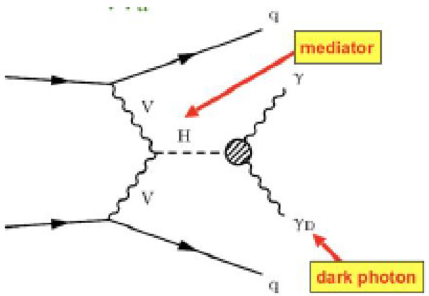




- The limits are the most restrictive to date for $0.2 < m_a < 1$ GeV

Dark Matter at the LHC

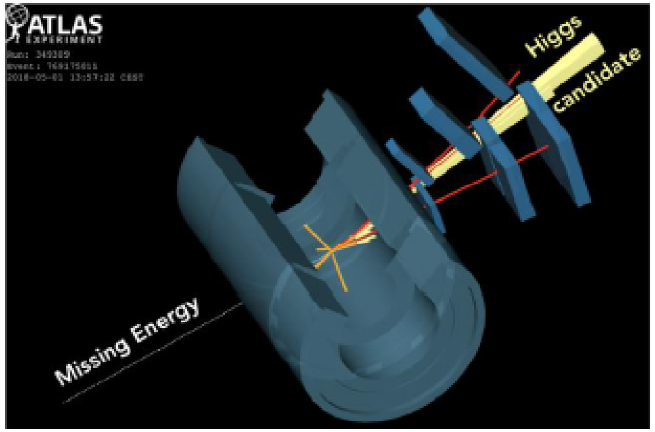
- Many different searches
- CMS: VBF $H \to \gamma\gamma_D$



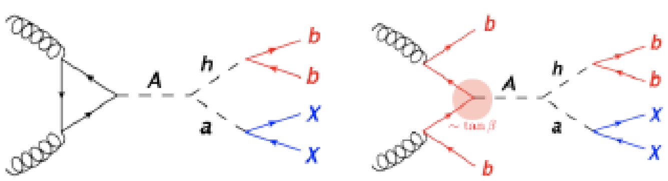
J. Alimena

Mono Higgs to bb candidate

S. Argyropoulos



2HDM + a (pseudo-scalar)

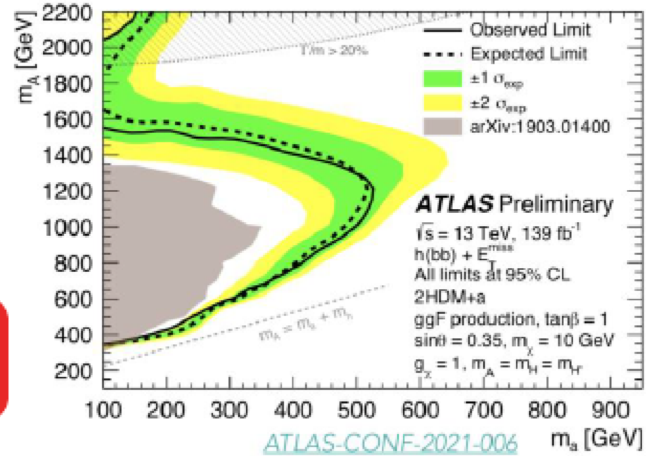


Combination with analysis where H produced in association with a Z boson

For SM-like 125 GeV H boson:

	VBF	ZH	VBF+ZH
Observed 95% CL limits on $B(H \to \gamma\gamma_d)$	0.034	0.046	0.029

gluon fusion , tanβ=1

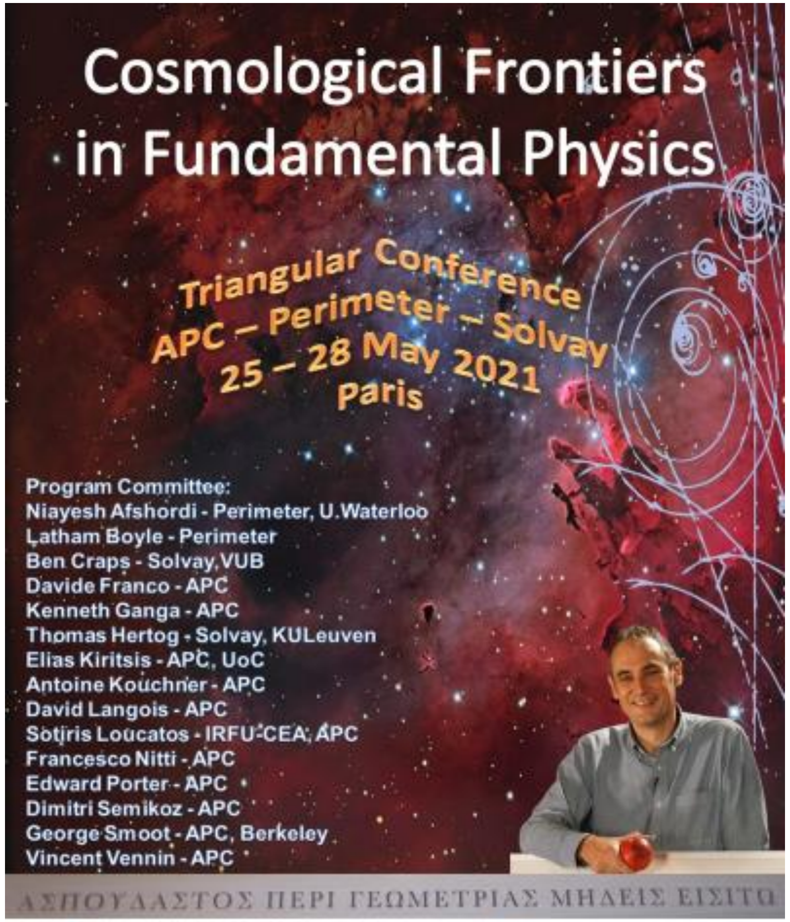


ATLAS-CONF-2021-006

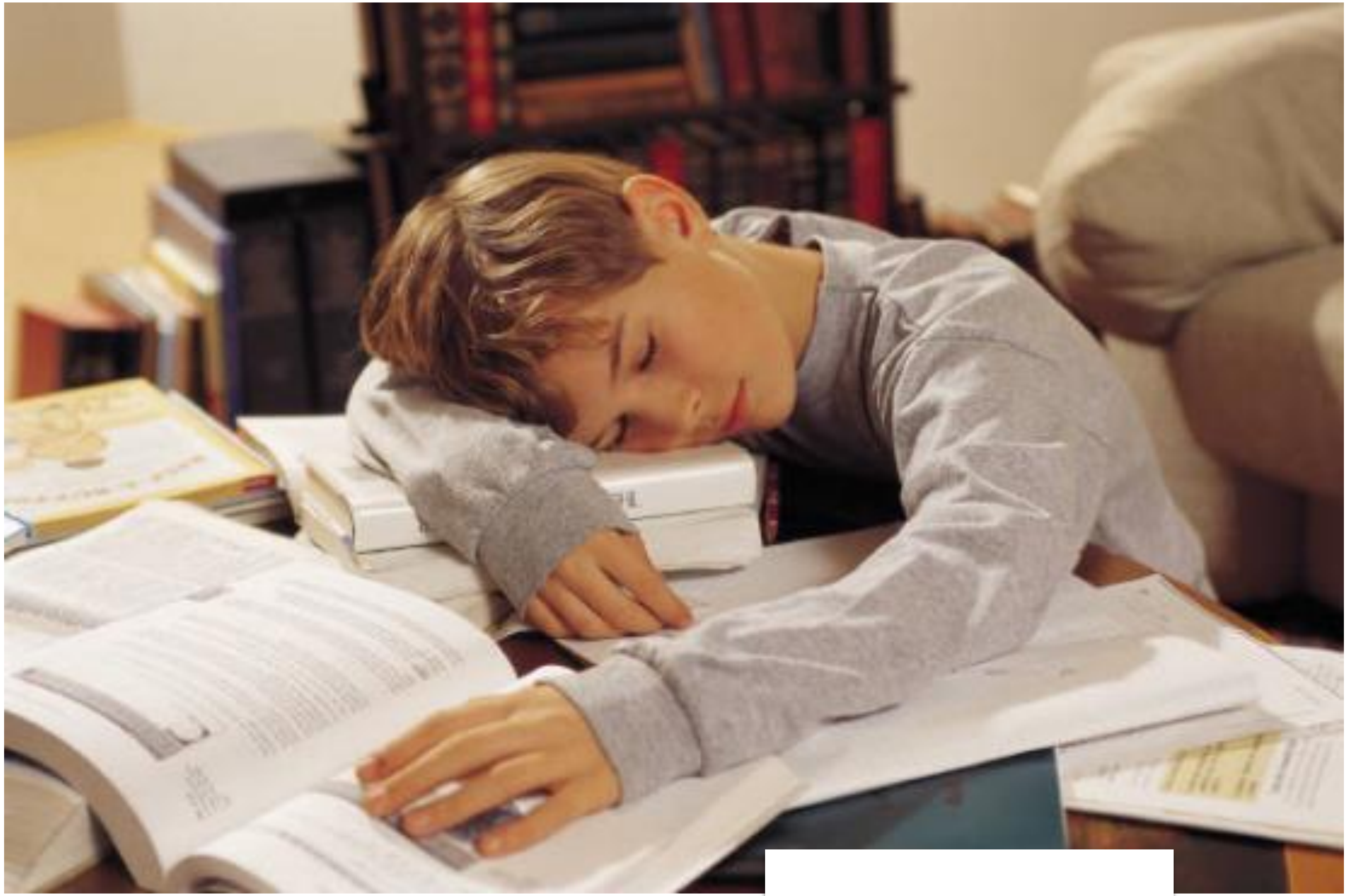
- No signal found yet and exclusion limits derived

Publicité

https://indico.in2p3.fr/event/19568



Merci de votre attention



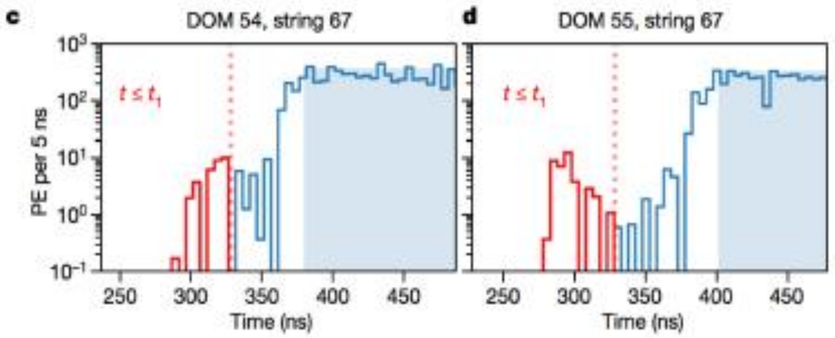
Bonus slides

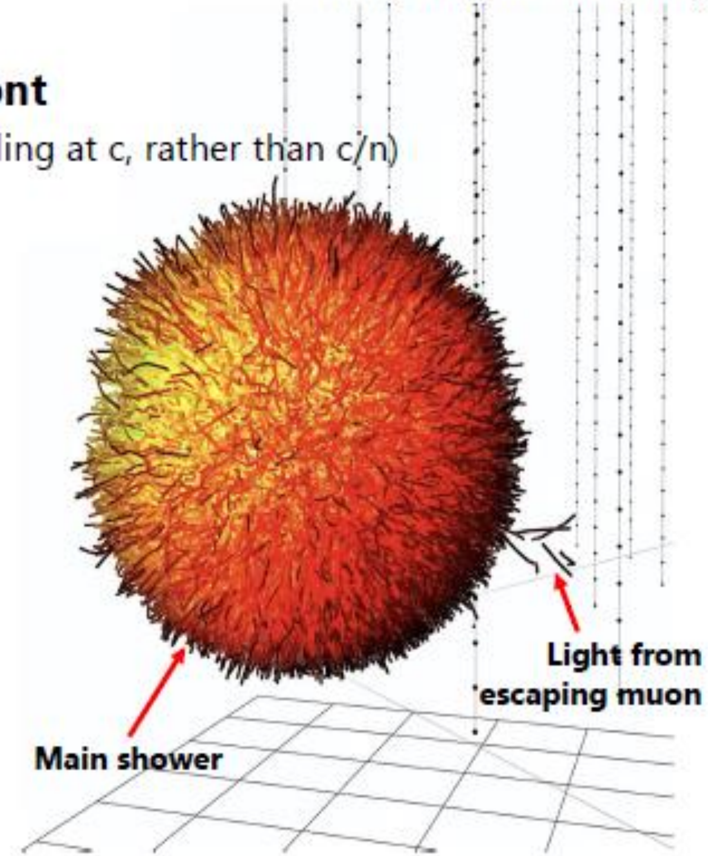
Icecube Glashow resonnance event

Nature **591**, 220–224 (2021)

Early light from muons

- **Light observed ahead of main shower front**
  - Likely due to muons escaping the shower (travelling at c, rather than c/n)
  - Expected in hadronic decay of W⁻
- Leading muon reconstructed as ~26 GeV
  - Consistent with simulation expectation



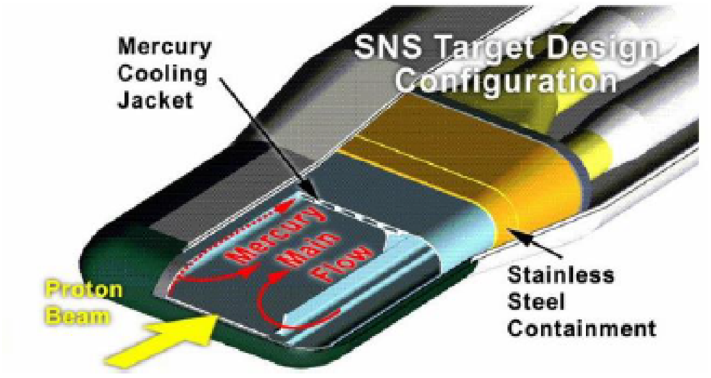


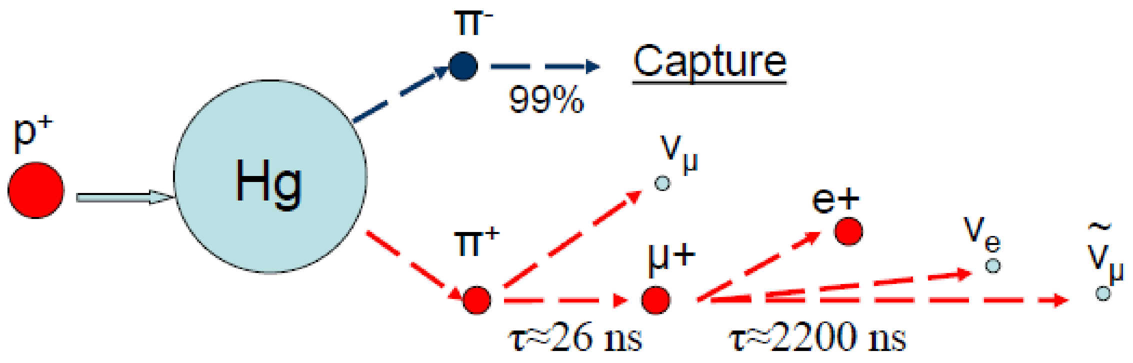
SNS facility at ORNL

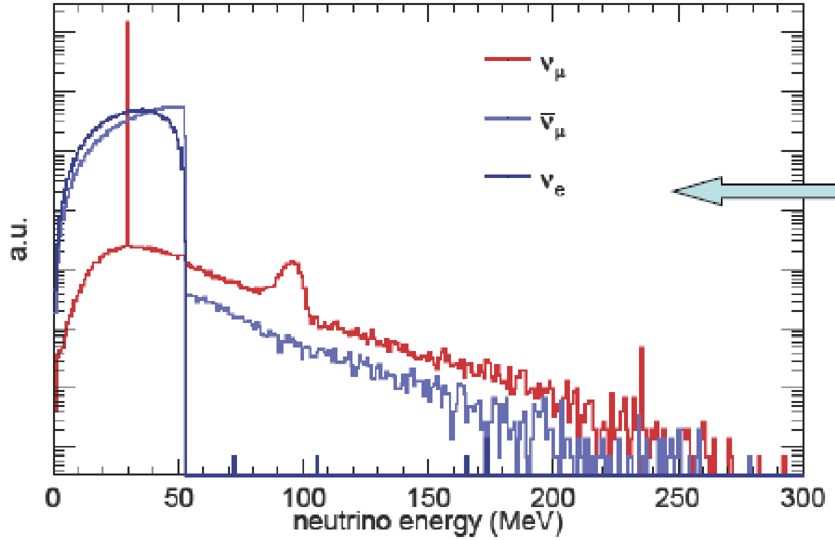
Bunches of ~1 GeV protons on the Hg target with 60 Hz frequency

Proton bunch time profile with FWHM of ~350 ns

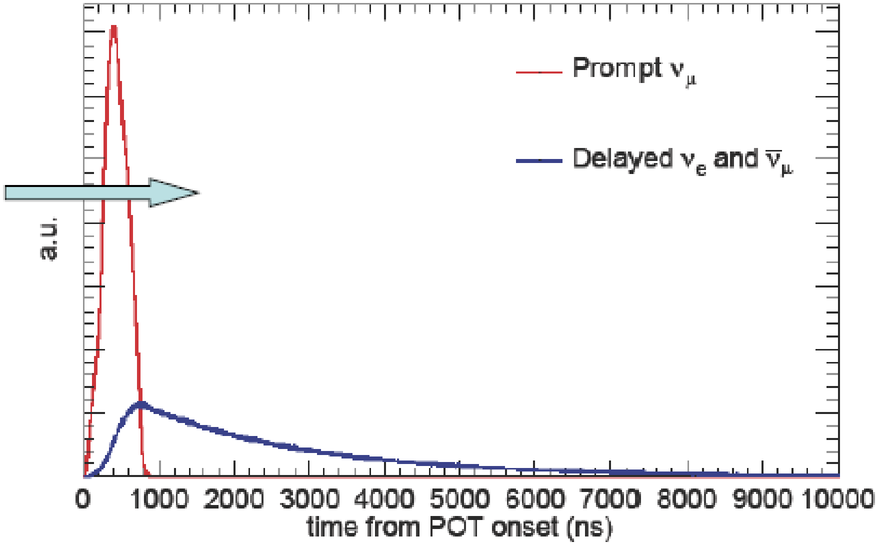
Total neutrino flux of $4.3\cdot10^{7}$ $cm^{-2}*s^{-1}$ at 20m



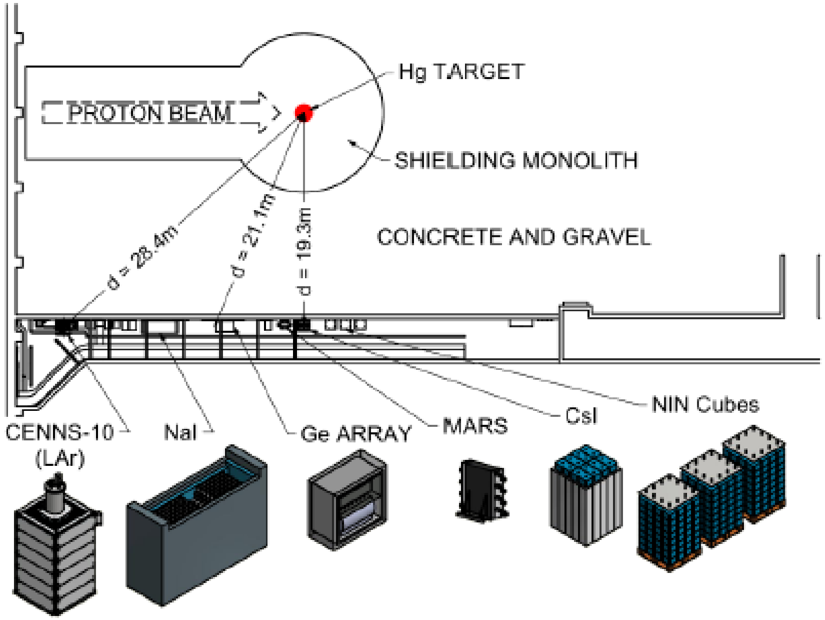




ν energy and timing suit well for CEνNS search



Physics with COHERENT detectors



20 m of steel, concrete and gravel with no voids in the direction of the target

Multiple detectors complement each other in a chase for rich physics

Topic
Non-standard neutrino interactions
Weak mixing angle
Accelerator-produced dark matter
Sterile oscillations
Neutrino magnetic moment
Nuclear form factors
Inelastic CC/NC cross-section for supernova
Inelastic CC/NC cross-section for weak physics