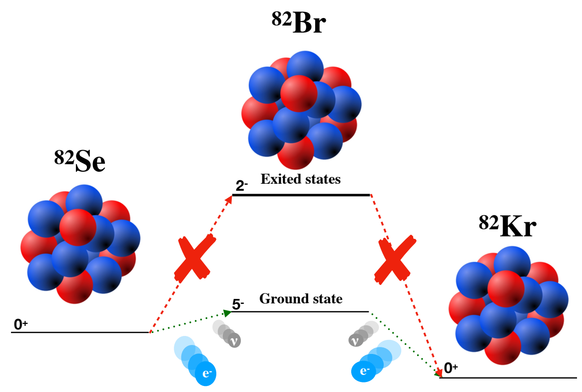
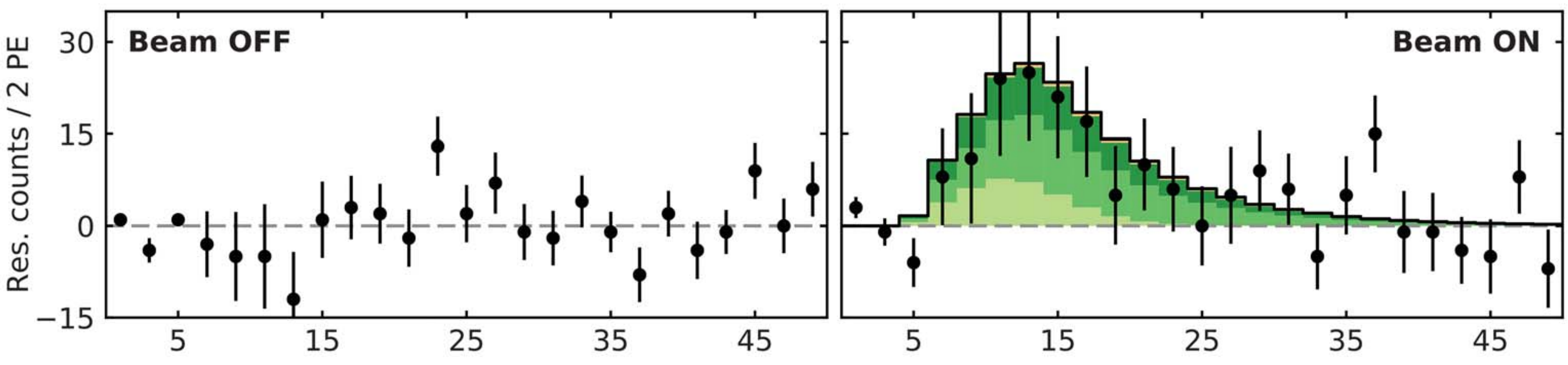
Double Beta Decay [+ CEνNS]



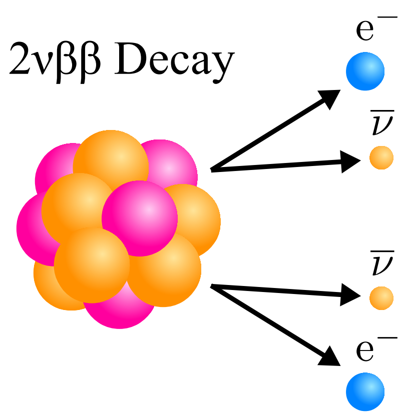
Laura Cardani

Ritiro di Sezione, Giugno 2019



Double Beta Decay

Transition among isobaric isotopes in which Z changes by 2 units

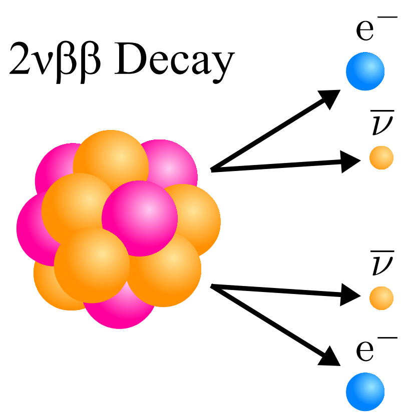


$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{v_e} \qquad (\beta^-\beta^-)$$
$$(A,Z) \rightarrow (A,Z-2) + 2e^+ + 2v_e \qquad (\beta^+\beta^+)$$
$$(A,Z) + 2e^- \rightarrow (A,Z-2) + 2v_e \qquad (EC-EC)$$
$$(A,Z) + e^- \rightarrow (A,Z-2) + e^+ + 2v_e \qquad (EC-\beta^+)$$

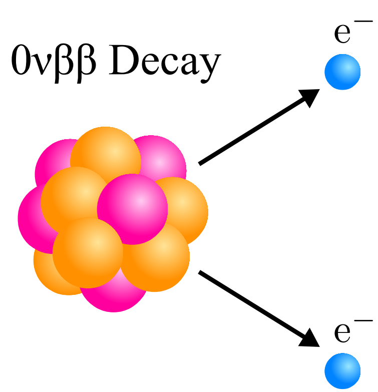
- Rare processes: 10^{18}-10^{21} yr
- Their measurement of primary interest for nuclear physics
- Distortion in their signatures could be hint of New Physics

Neutrinoless Double Beta Decay

Transition among isobaric isotopes in which Z changes by 2 units

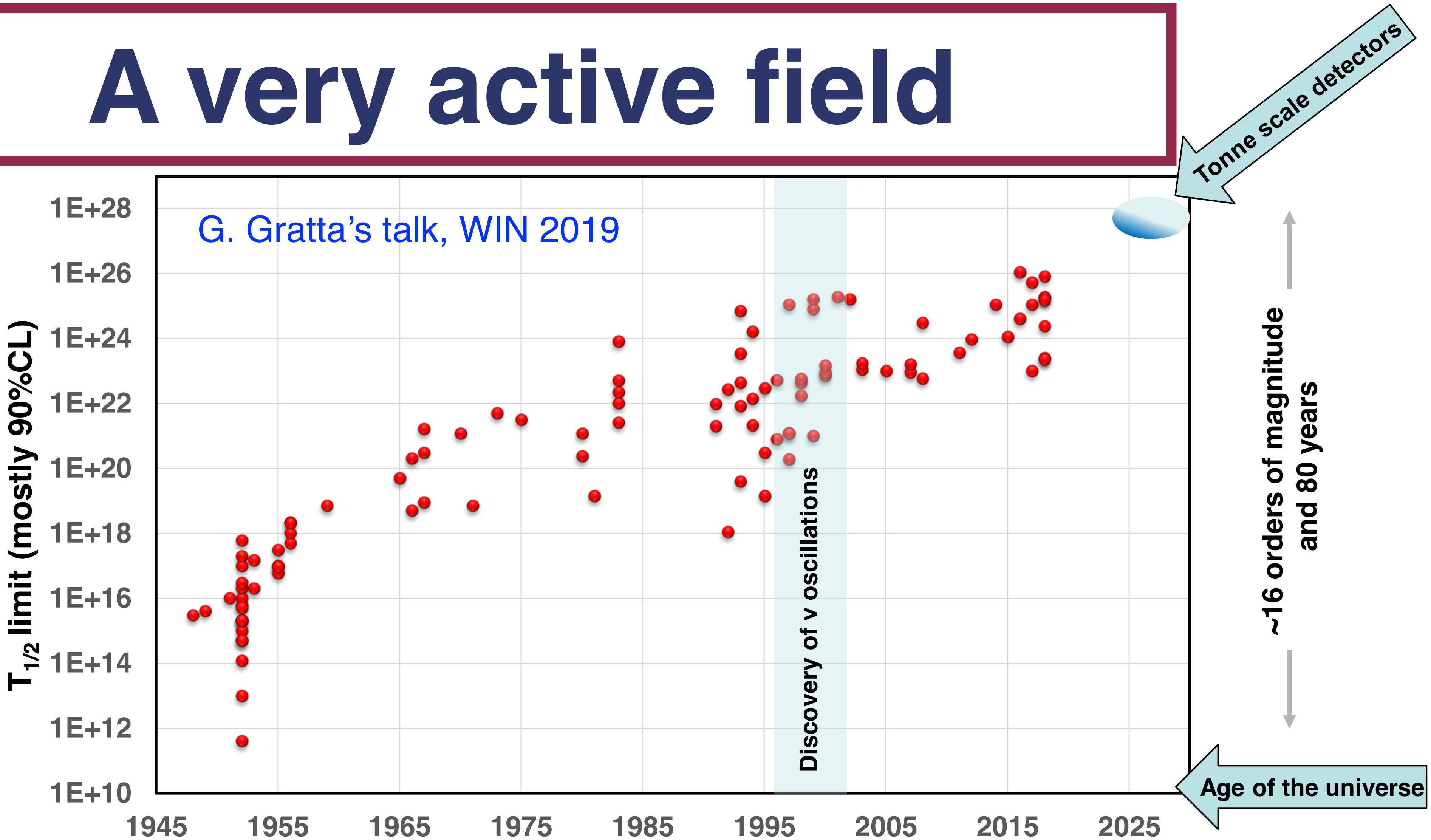


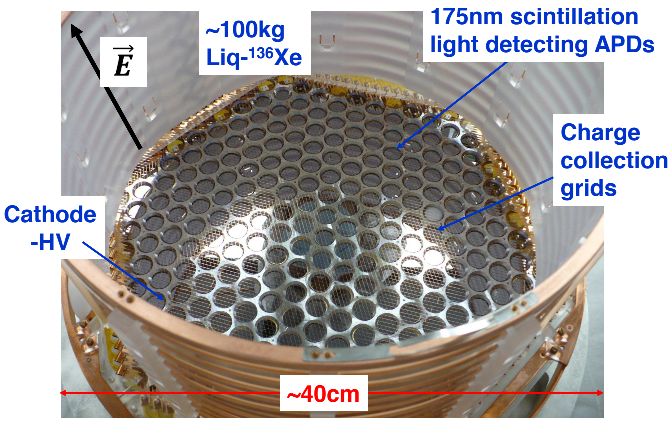
$$(A,Z) \rightarrow (A,Z+2) + 2e^- + \cancel{2\overline{\nu}_e} \qquad (\beta^-\beta^-)$$
$$(A,Z) \rightarrow (A,Z-2) + 2e^+ + \cancel{2\nu_e} \qquad (\beta^+\beta^+)$$
$$(A,Z) + 2e^- \rightarrow (A,Z-2) + \cancel{2\nu_e} \qquad (EC-EC)$$
$$(A,Z) + e^- \rightarrow (A,Z-2) + e^+ + \cancel{2\nu_e} \qquad (EC-\beta^+)$$

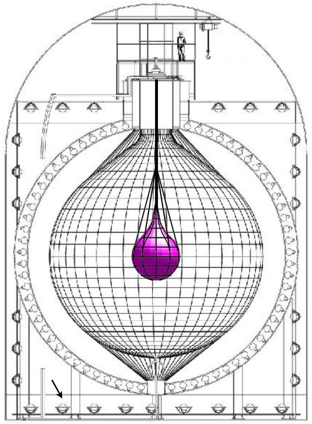


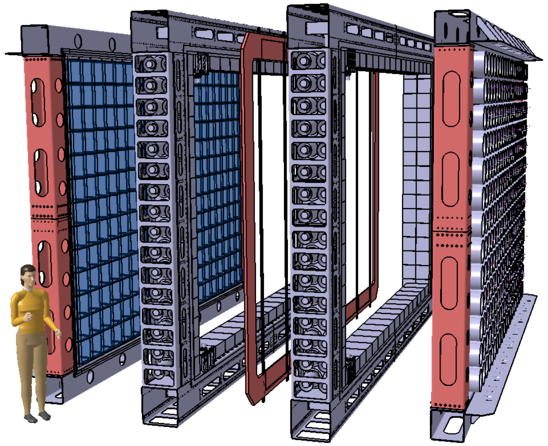
- (Only process that) can establish Majorana nature of ν
- Violates lepton number conservation (actually also B-L)
- The lowest order operator for B-L causes 0νββ and gives Majorana mass: probe new mass mechanisms
- Insight in neutrino absolute mass via $m_{\beta\beta}$

A very active field

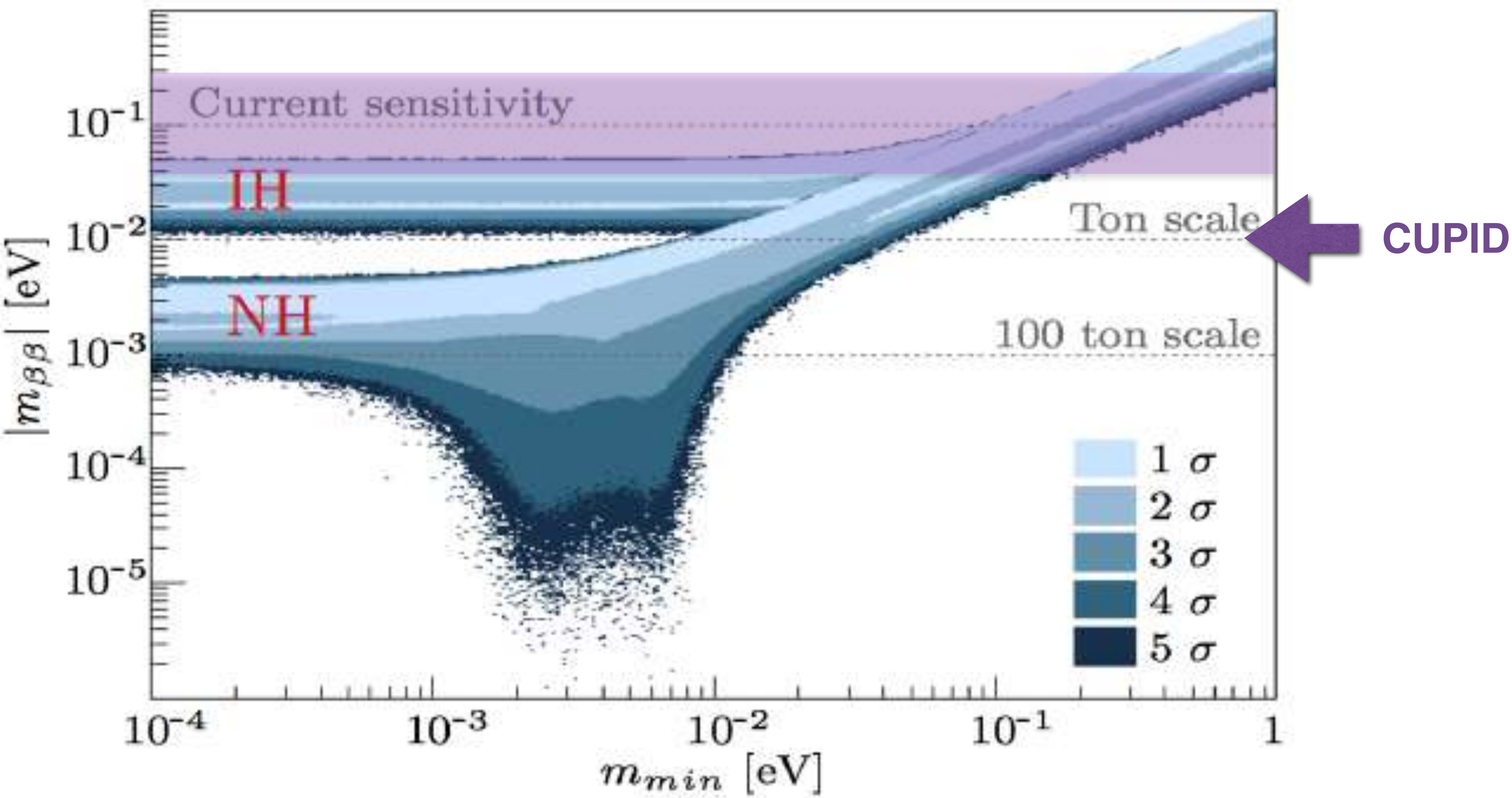






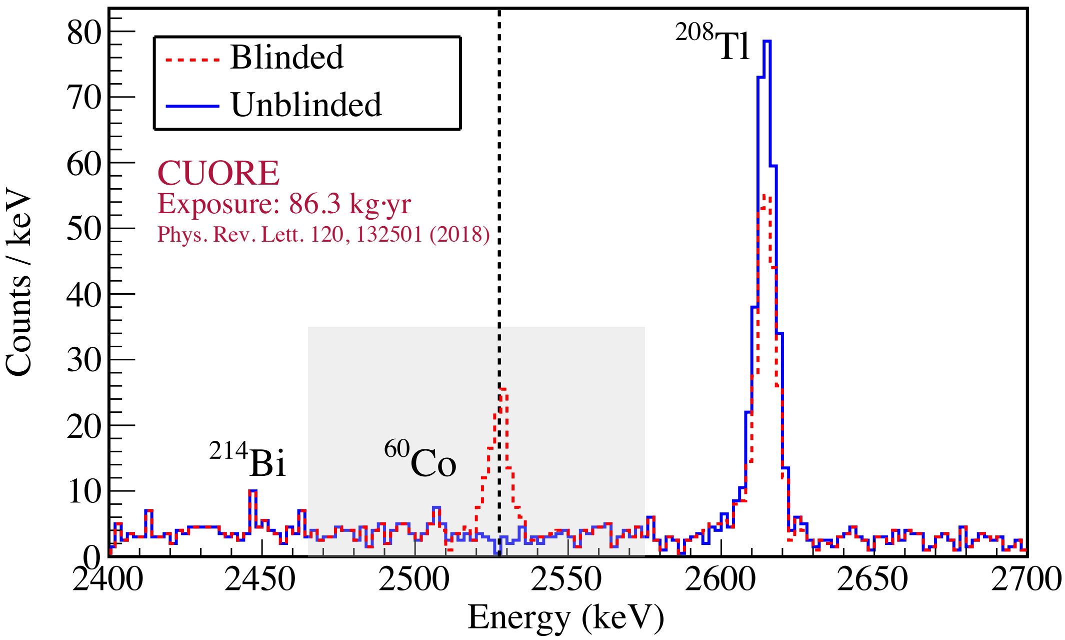


Prospects for the near future



- Some experiments attacking/approaching the IH (also part of NH covered)
- Plan for next 5-10 yr: full coverage of IH region

CUORE



- Tonne-scale experiment operating 206 kg of ^{130}Te (988 TeO_2 crystals, 15 tons of Pb, Cu, TeO_2 at <4K)
- Excellent resolution 7.4 keV FWHM (0.2%)
- Combined with its ancestors, $T_{1/2}>1.5\times10^{25}$ yr, aiming at 10^{26} yr in 5 yr

CUORE collaboration, Phys.Rev.Lett. 120 (2018) no.13, 132501
CUORE collaboration, Int.J.Mod.Phys. A33 (2018) no.09, 1843002

From CUORE to CUPID

CUPID

(Cuore Upgrade with Particle IDentification)

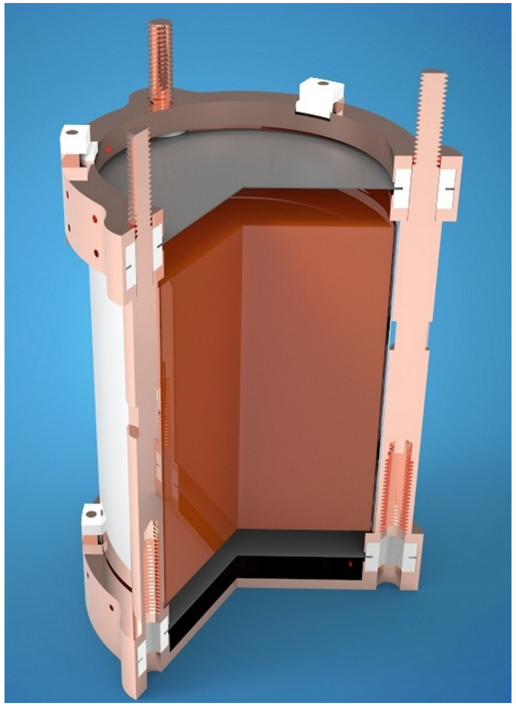
next-generation, tonne-scale, excellent energy resolution

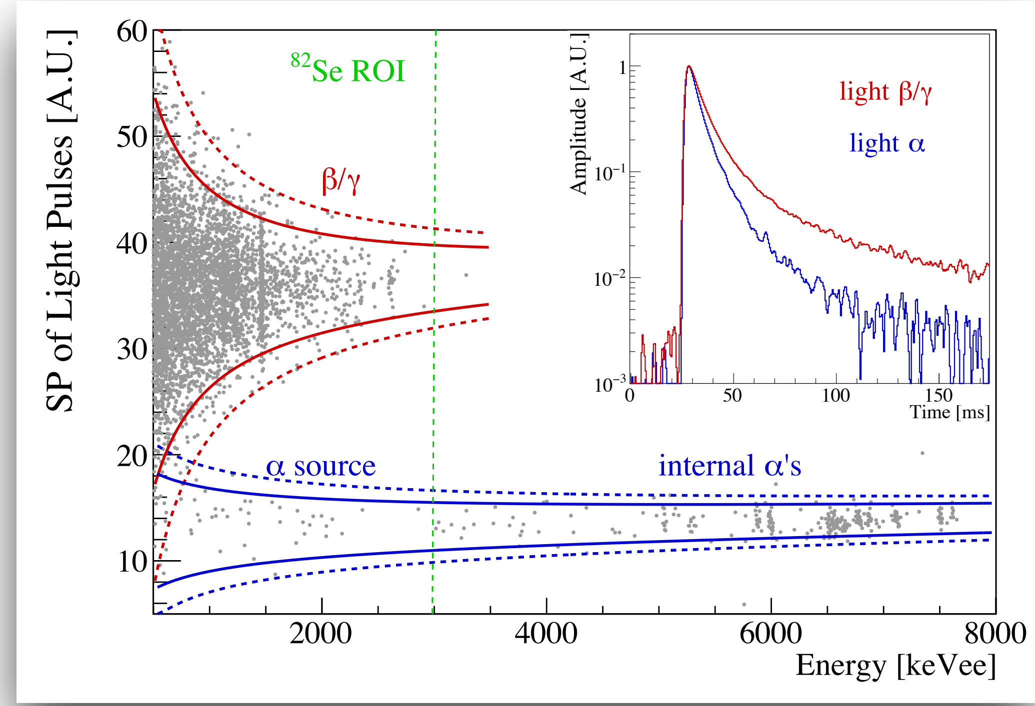
+ background free (and versatility in DBD emitter)

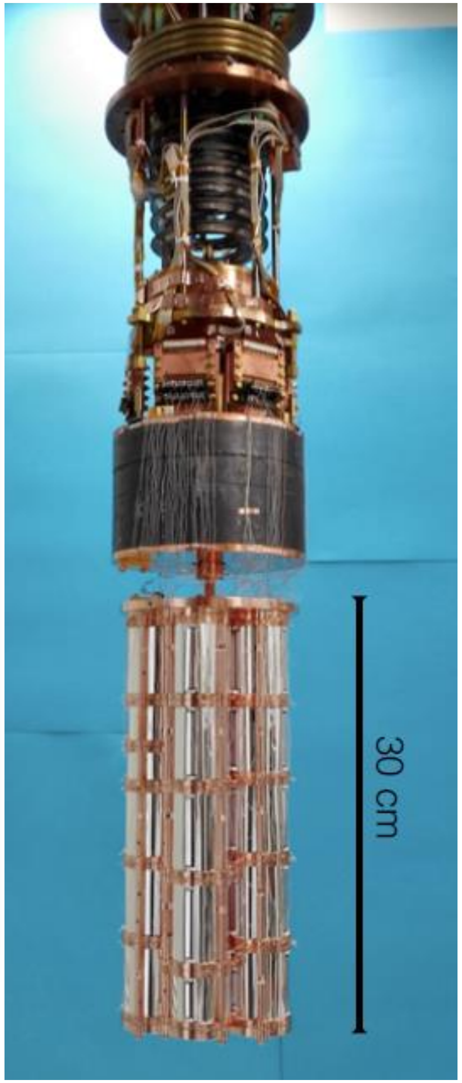
- …m, now optimising cryostat to reach 5 keV
- …mbined with its ancestors, $T_{1/2}>1.5\text{x}10^{25}$ yr, aiming at 10^{26} yr in next 5 yr

The first CUPID prototype

- First medium-scale prototype: CUPID-0 proved rejection of α bkg
- Sensitivity: $5x10^{24}$ yr with 5.3 kg x yr
- Upgrade (early 2019) and now in run II







CUPID-0 collaboration, Phys.Rev.Lett. 120 (2018) no.23, 232502
CUPID-0 collaboration, Eur. Phys. J. C78 (2018) no.11, 888

INFN - Roma

People of our Department involved in cuore/cupid0:
F. Bellini, L. Cardani, N. Casali, C. Cosmelli, A. Cruciani, I. Dafinei, F. Ferroni, V. Pettinacci, C. Tomei, M. Vignati

CUPID PROPOSAL FOR CSN2

Main expertise:
- Growth of large radio-pure crystals
- Detector design and construction in radio-pure environment
- Cryogenic facilities
- Software and Data analysis

Next 5-10 years perspectives:
- Design and construction of tonne-scale experiment CUPID
- Search for 0nDBD and other processes beyond SM

Current Weaknesses or Desirable Skills
- Simulations
- Phenomenology (charge non conservation, Lorentz invariance, CPT violations, Pauli exclusion principle, tri-nucleon decays, …)

Credits to F.Cappella

DAMA and DAMA-Kiev results in the search for double β decay

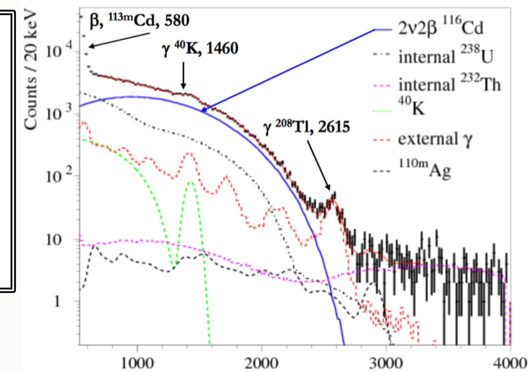
Profiting of the low background features of its set-ups, DAMA has achieved competitive results in the investigation of many rare processes and double beta decays

First or improved results for 2β decays of ~30 candidate isotopes: $^{40,46,48}Ca$, $^{64,70}Zn$, ^{100}Mo, $^{96,104}Ru$, $^{106,108,114,116}Cd$, $^{112,124}Sn$, $^{134,136}Xe$, ^{130}Ba, $^{136,138,142}Ce$, ^{150}Nd, $^{156,158}Dy$, $^{162,170}Er$, $^{180,186}W$, $^{184,192}Os$, $^{190,198}Pt$

The best experimental sensitivities in the field for 2β plus decays:

⇒ $0\nu\varepsilon\beta^+$ or $0\nu2\beta^+$ decays may refine the mechanism of the $0\nu2\beta^-$ decay (Majorana ν mass vs right-handed admixtures in the weak interaction)

⇒ Possible resonant enhancement of the capture rate for $0\nu2\varepsilon$, due to a mass degeneracy between the initial and final nucleus



PRD98(2018)092007

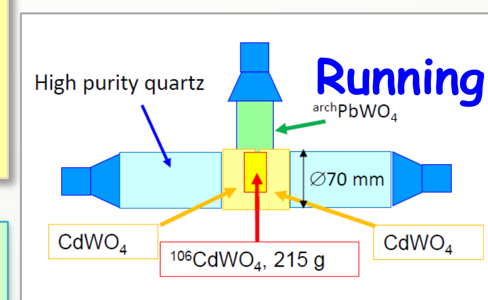
Recent DAMA results

AURORA experiment

Two $^{116}CdWO_4$ crystal scintillators enriched at 82%, mass=1.16 kg, T~4yr

✓ $T_{1/2}(2\nu2\beta) = 2.63^{+0.11}_{-0.12} \times 10^{19}$ yr (the most accurate value)

✓ $T_{1/2}(0\nu2\beta) \geq 2.2 \times 10^{23}$ yr (the best limit for ^{116}Cd) ⇒ $\langle m_\nu \rangle < (1.0\text{–}1.7)$ eV



$^{106}CdWO_4$ crystal scintillator (^{106}Cd @ 66%) in coincidence with two $CdWO_4$

Sensitivity to $2\nu\varepsilon\beta^+$: $T_{1/2} > 4\times10^{21}$ yr (theoretical: $10^{20} - 10^{22}$ yr)

Highly purified Nd_2O_3 source (2.38 kg) in **GeMulti** (4 HPGe) set-up

Study of double coincidences from $2\beta2\nu$ decay ^{150}**Nd**→ ^{150}**Sm**(0_1^+, 740.5 keV)

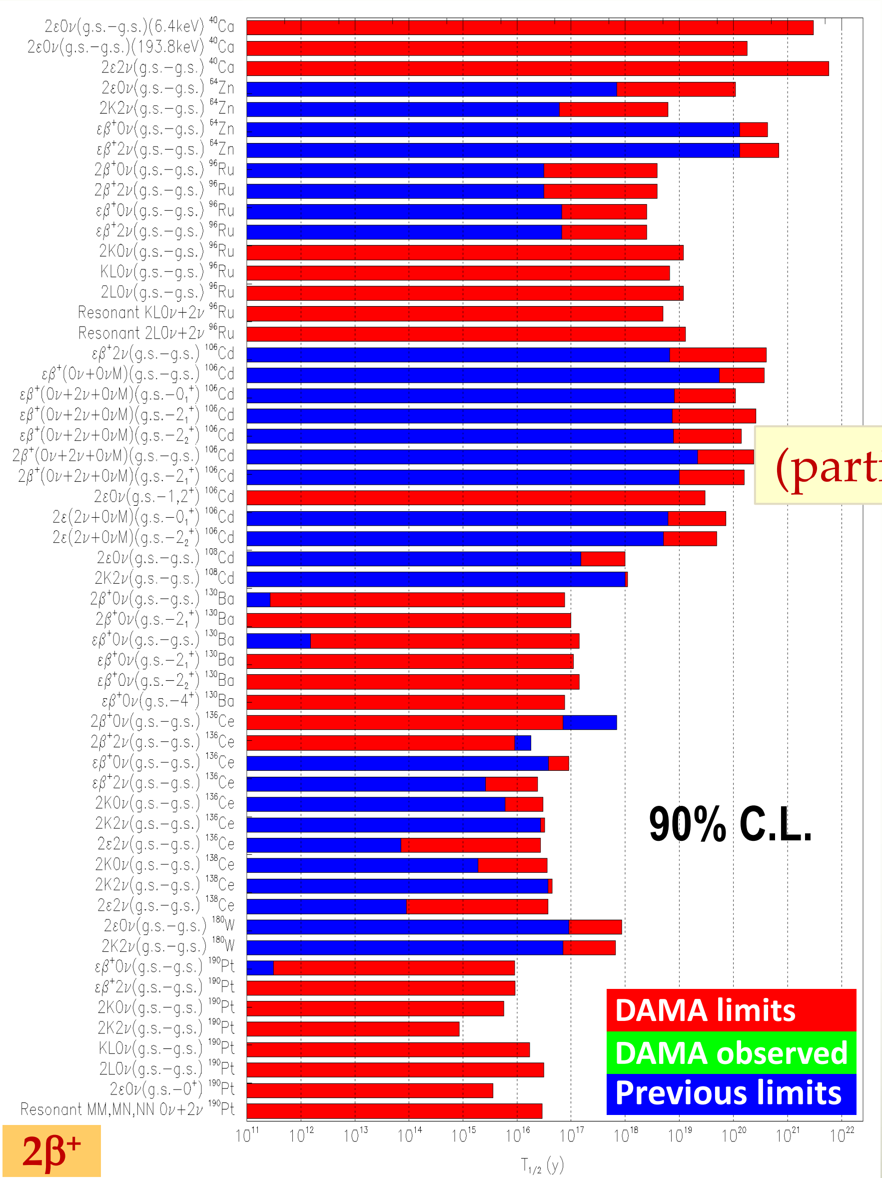
⇒ $T_{1/2}=[4.7^{+4.1}_{-1.9}(stat)\pm0.5\ (syst)]\times10^{19}$ yr in agreement with previous results

Preliminary results in **Nucl.Phys.At.Energy 19(2018)95**

Credits to F.Cappella

Search for ββ decay modes in various isotopes at DAMA and STELLA set-ups

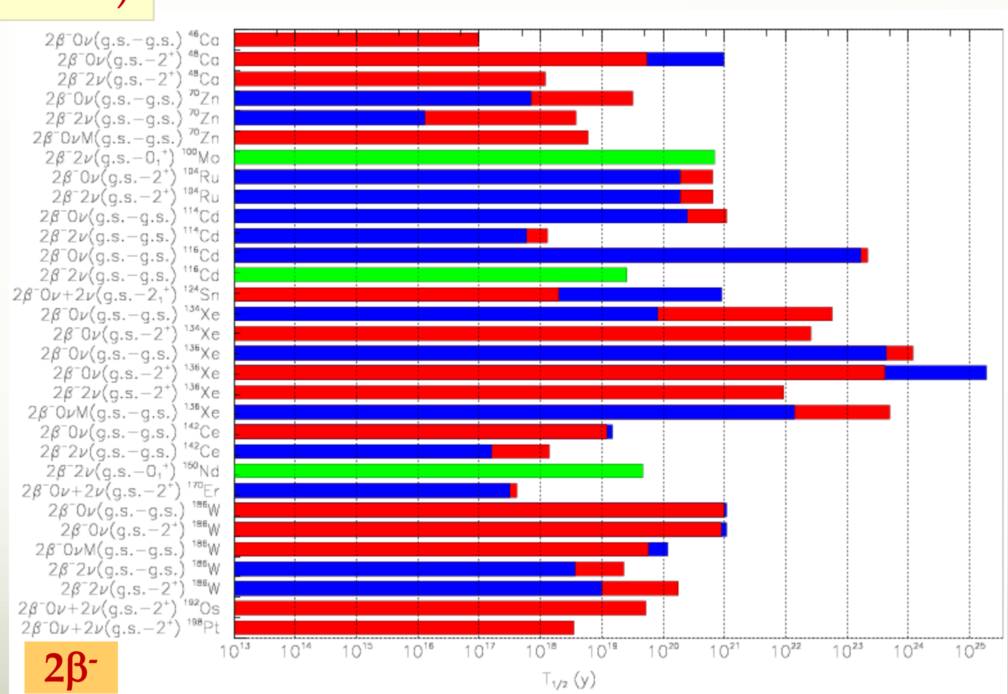
DAMA and DAMA/Kiev



New observations:

ARMONIA:	$2\nu2\beta^-$ decay	$^{100}Mo \rightarrow {}^{100}Ru(0_1^+)$	NPA846(2010)143
AURORA:	$2\nu2\beta^-$ decay	$^{116}Cd \rightarrow {}^{116}Sn$	PRD98(2018)092007
Nd_2O_3-HPGe:	$2\nu2\beta^-$ decay	$^{150}Nd \rightarrow {}^{150}Sm(0_1^+)$	NPAE19(2018)95

(partial list)



Future plans:

- New measurements with highly purified samples installed on HPGe detectors of the STELLA facility
- R&D of radio-pure $Gd_2SiO_5(Ce)$, $SrI_2(Eu)$, $^{116}CdWO_4$ crystal scintillators to study 2β decays of ^{152}Gd, ^{160}Gd, ^{84}Sr, ^{116}Cd

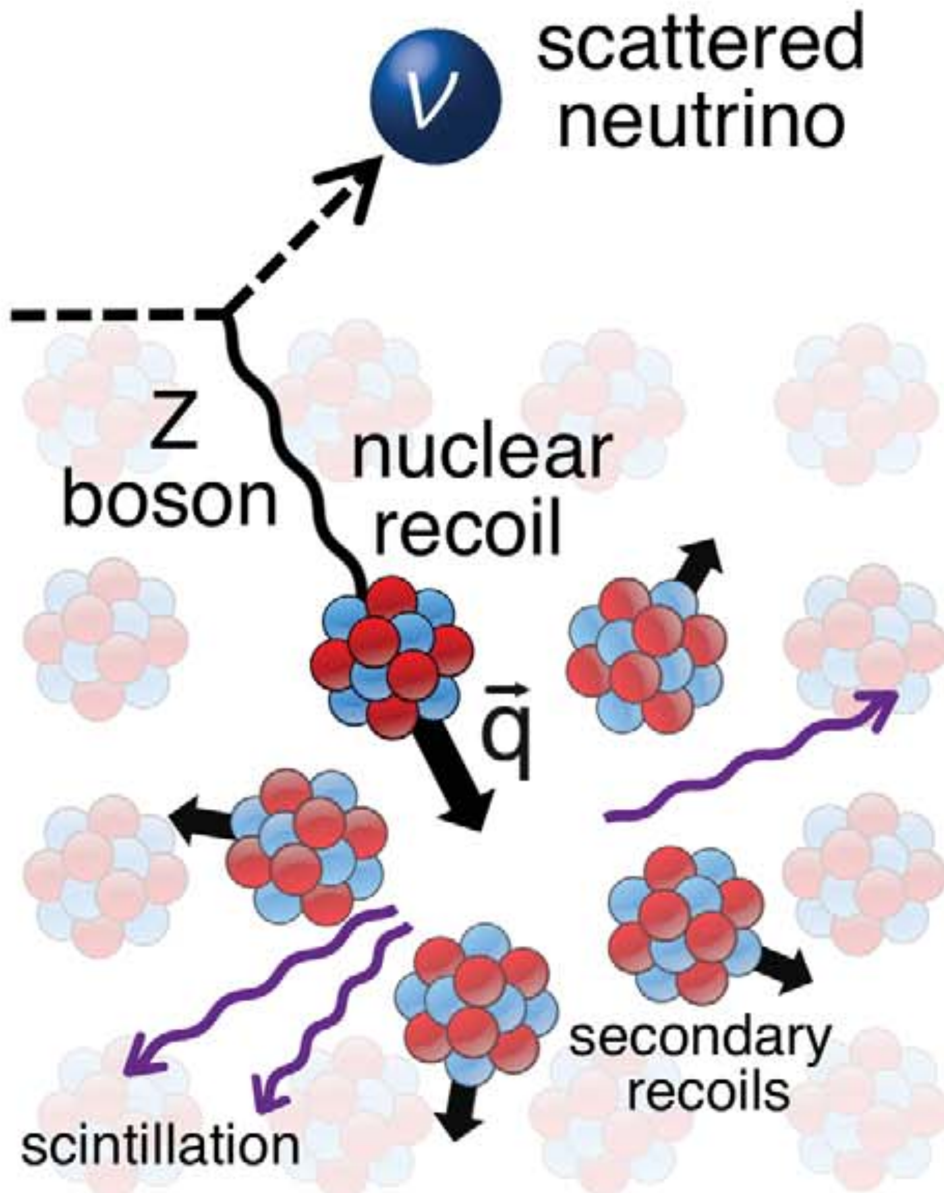
INFN - Roma

People of our Department involved in DAMA (DAMA/Kiev):
F. Cappella, A. Incicchitti, A. Mattei

Main expertise:
- Growth of highly radio-pure scintillation crystals
- Detector design and construction in radio-pure environment
- Simulations and Data Analysis

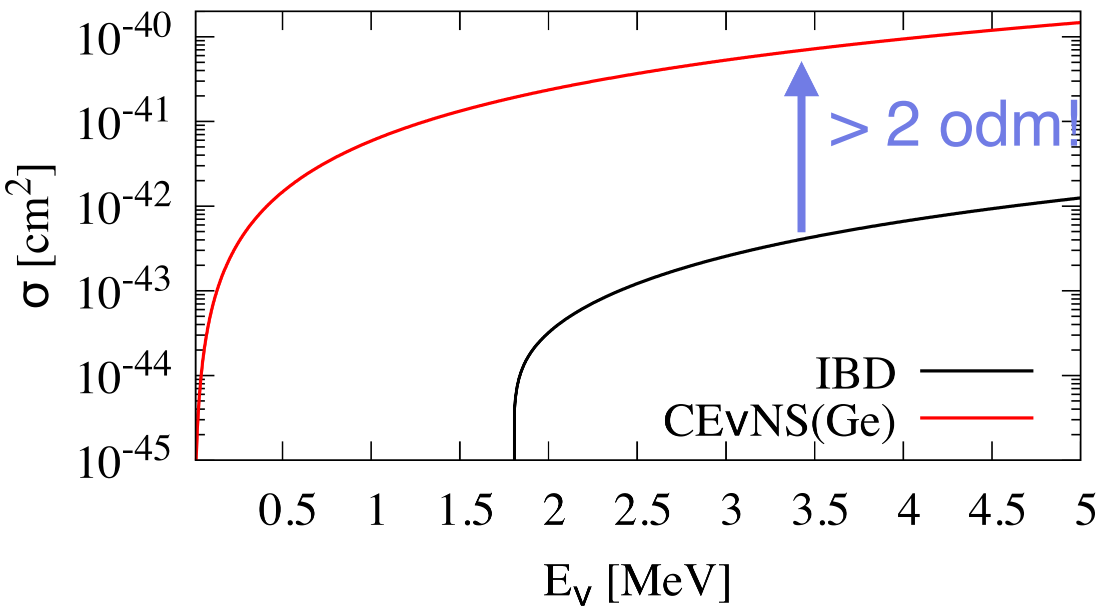
Next 5 years perspectives:
- Development of new highly radio-pure scintillation crystals, also enriched in the isotope of interest
- Measurement and optimisation of detector performances
- Measurements on double beta decay and other rare processes
- Simulation and Data analysis

Neutrino-nucleus coherent scattering



Credits to M.Vignati

Experimental Challenge

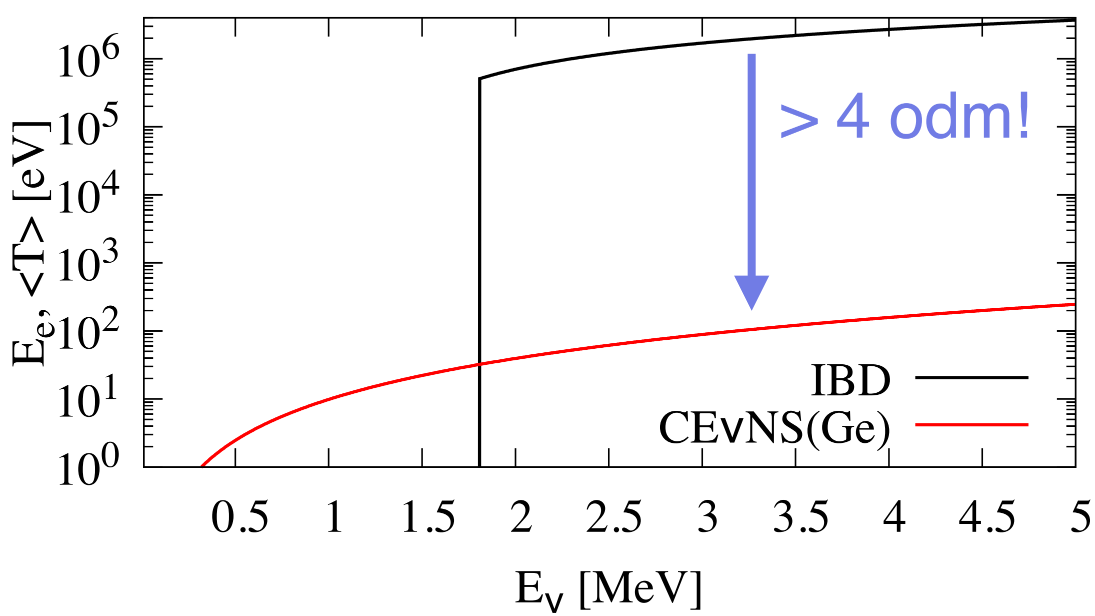


Coherent Elastic ν-Nucleus Scattering

$$\nu(\bar{\nu}) + A \rightarrow \nu(\bar{\nu}) + A$$

Inverse Beta Decay

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



First detection in 2017 using scintillating crystals exposed to a spallation neutron source

D. Akimov et al Science 357 (2017), 1123

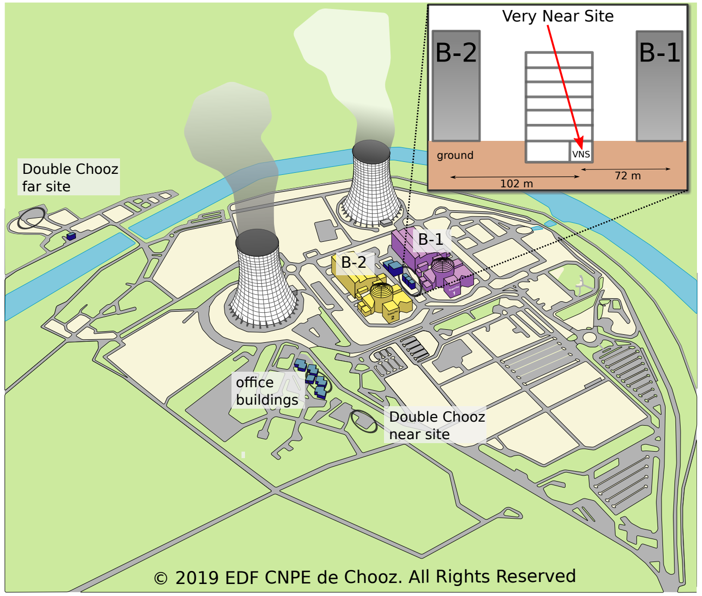
Increasing interest in high precision measurements

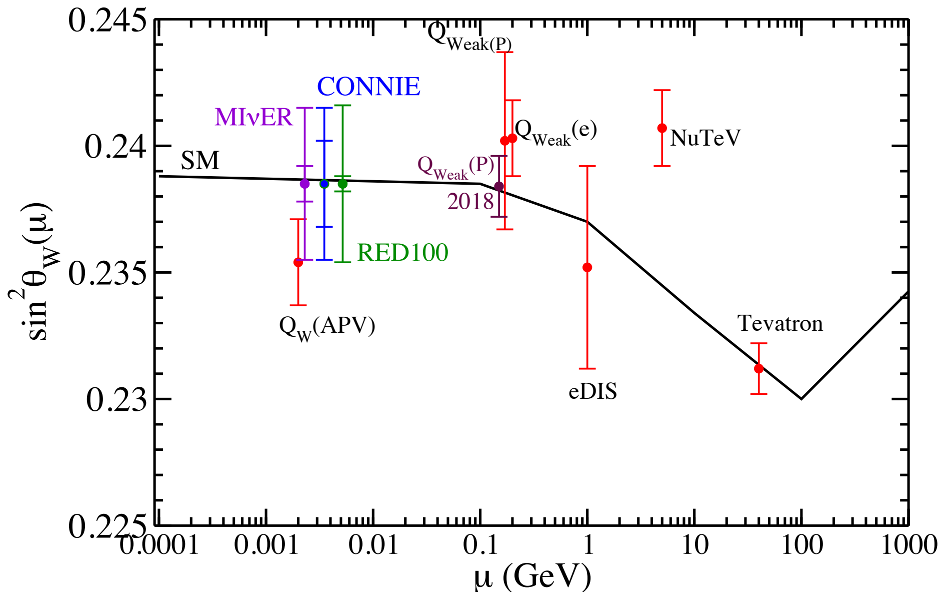
Physics Opportunities

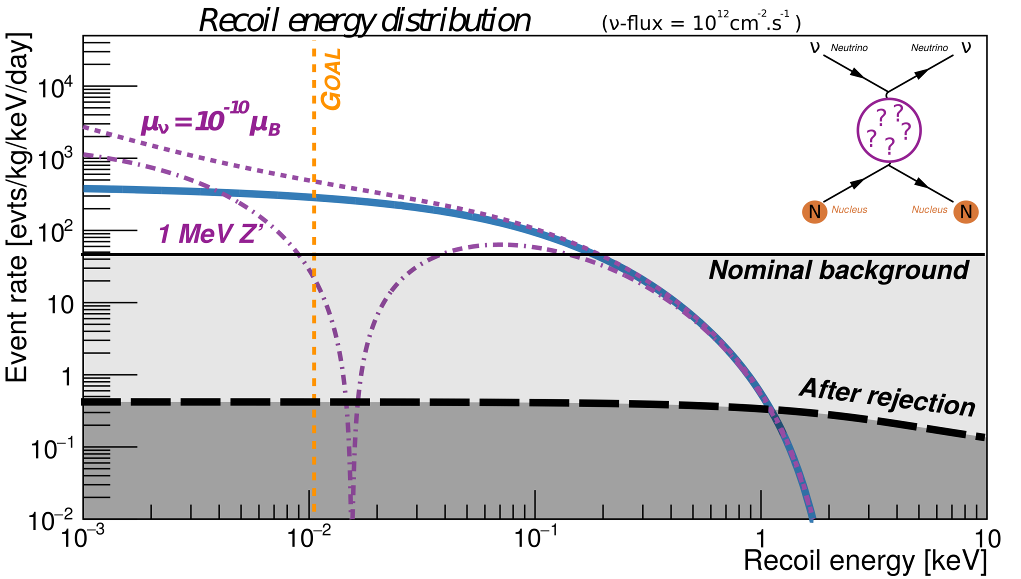
Credits to M.Vignati

- $sen^2(\theta_W)$ at low Q
- Non standard interactions (μ_ν, Z'..)
- Sterile neutrinos
- Background for DM experiments
- Non proliferation

NUCLEUS: Cryogenic detector at 70-100 m from the CHOOZ reactors.







INFN - Roma

People of our Department involved in NUCLEUS (DE) and BullKID (IT):
F. Cappella, L. Cardani, N. Casali, I. Colantoni, A. Cruciani, C. Tomei and.
M. Vignati

PROPOSAL FOR CSN2

Main expertise:

- Development of cryogenic detectors (Angelo's talk)
- Cryogenic facilities
- Radioactivity
- Simulations

Next 5 years perspectives:

- Development of next generation detectors for CEvNS
- Feasibility study of ^{51}Cr (from GALLEX source) instead of reactor

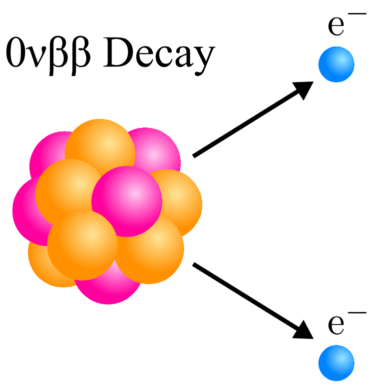
Bellenghi et al, arXiv:1905.10611

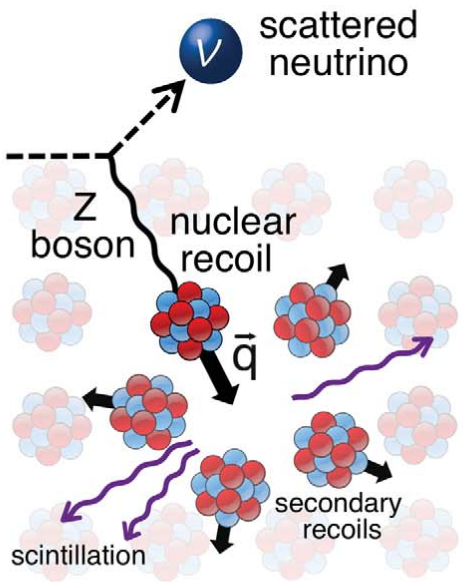
Current Weaknesses or Desirable Skills

- Fabrication of superconducting detectors
- Electronics for microwave detectors

Conclusions

- Double Beta Decay is a unique probe for New Physics
  - Lepton Number Violation
  - Neutrino Nature
- Active field, with projects <hundreds M$
- Down-selection of 2-3 technologies for the long-term future





- Since its observation, CEvNS got a lot of interest
- Now precision measurements in which we can play an important role