Underground Physics in the Pyhäsalmi mine

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Underground Physics in the Pyhäsalmi mine

Content

- The Pyhäsalmi mine and Callio Lab
- Cosmic-ray experiment EMMA
- ^{14}C concentration in liquid scintillators
- Measurement of $2\nu2\beta$ half-lives ($\beta^{+}EC$ mode) of ^{78}Kr and ^{124}Xe

The Pyhäsalmi Mine

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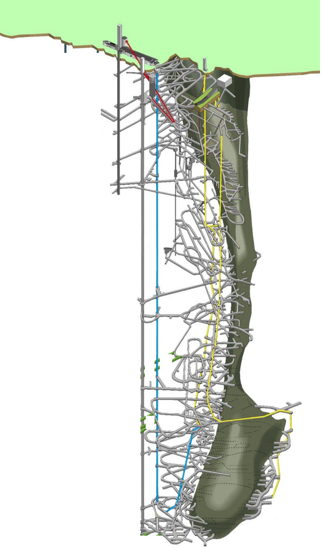
The Pyhäsalmi mine



- Owned by First Quantum Minerals Ltd, Canada
- Active mine; procuding copper (Cu), zinc (Zn) and pyrite (FeS_2)
- The deepest metal mine in Europe
  - 1400 m (4000 mwe)
- Very modern infrastructure
  - lift (of 21.5 tons of ore or 20 persons) down to 1400 metres takes $\sim$3 minutes
  - via 11-km long decline it takes $\sim$40 minutes (by track)
  - good communication systems
  - large caverns in good shape
- Underground mining operation is expected to end in 2019
  - Callio Lab

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The Pyhäsalmi mine – restaurant at 1410 m

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The Pyhäsalmi mine – maintenance hall at 1410 m

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Callio Lab

- Underground mining operation in the Pyhäsalmi mine is expected to end in 2019
- The mine has an excellent infrastructure, large caverns and halls, good location and possibility to excavate larger halls
  - Callio Lab established to operate activities other than mining
- The first deep (1430 m, 4100 mwe) underground laboratory hall (120 m^2, 8 m height) ready for experiments
  - C14 experiment
  - neutron and muon background measurements
  - ideal for small-scale experiments (dark matter, double-beta decay), for prototypes and testing, and for material screening
- Open Call
  - to send a proposal (scientific or commercial)
  - www.calliolab.com

Cosmic-ray experiment

EMMA

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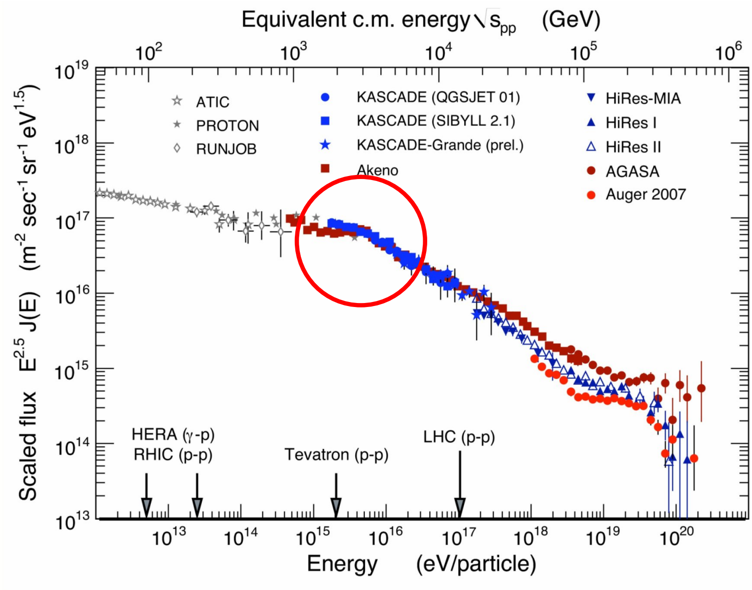
EMMA – the knee



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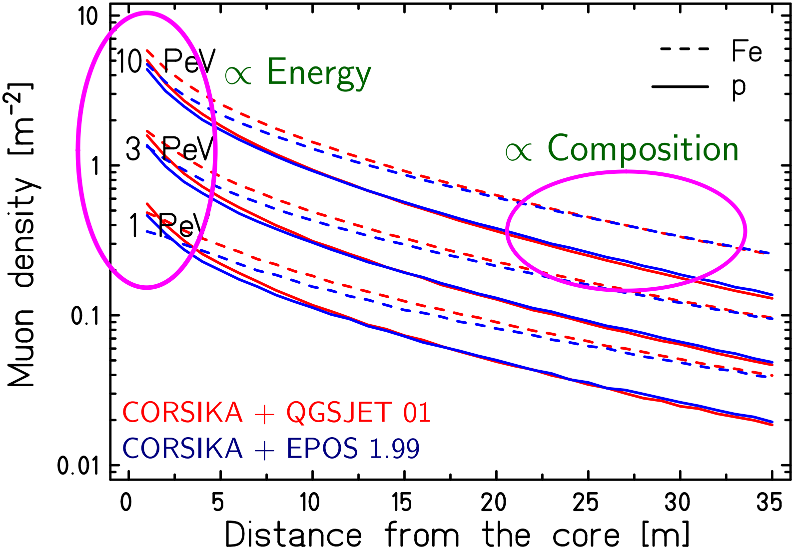
EMMA – muon lateral distribution – cut-off energy 50 GeV (75 m of rock)



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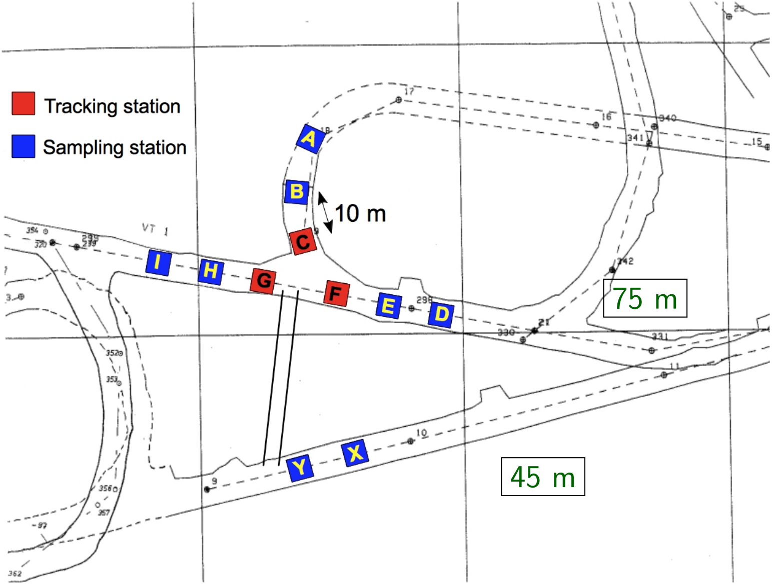
EMMA – detector geometry



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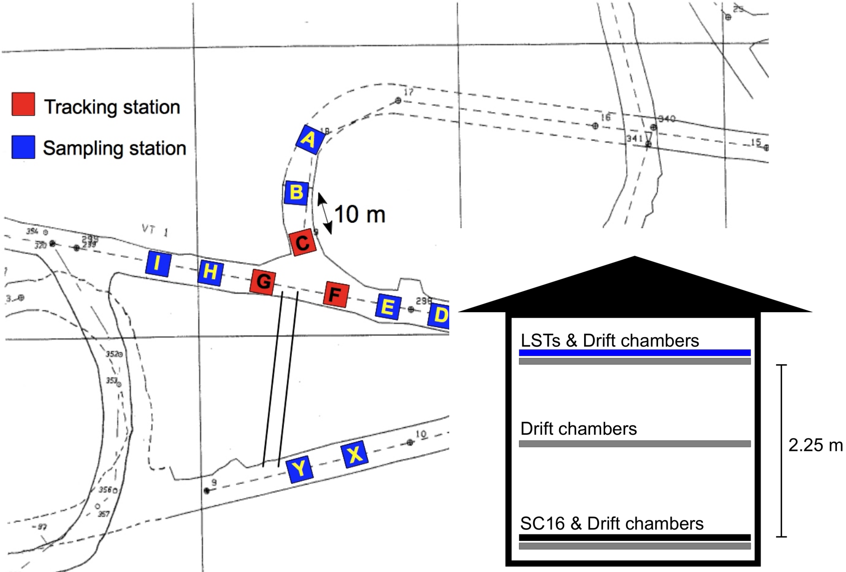
EMMA – detectors in tracking stations



Tracking station

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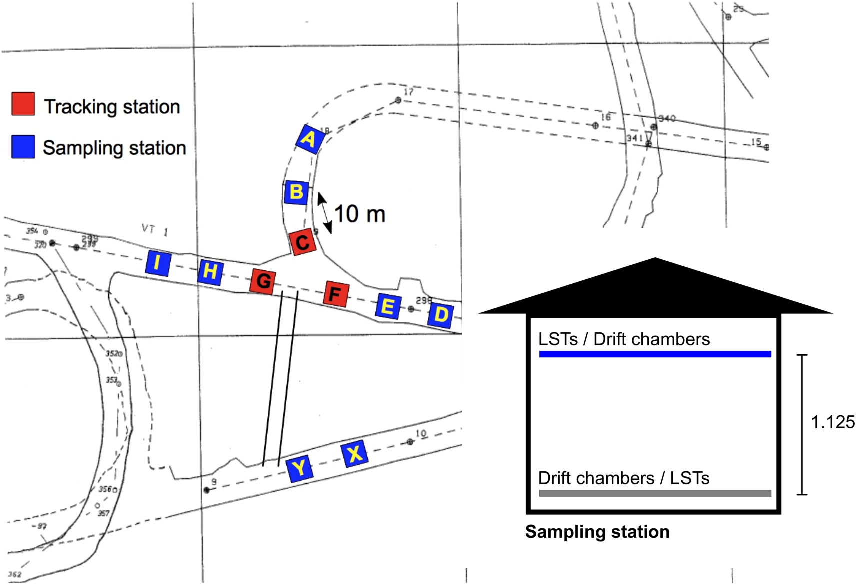
EMMA – detectors in sampling stations



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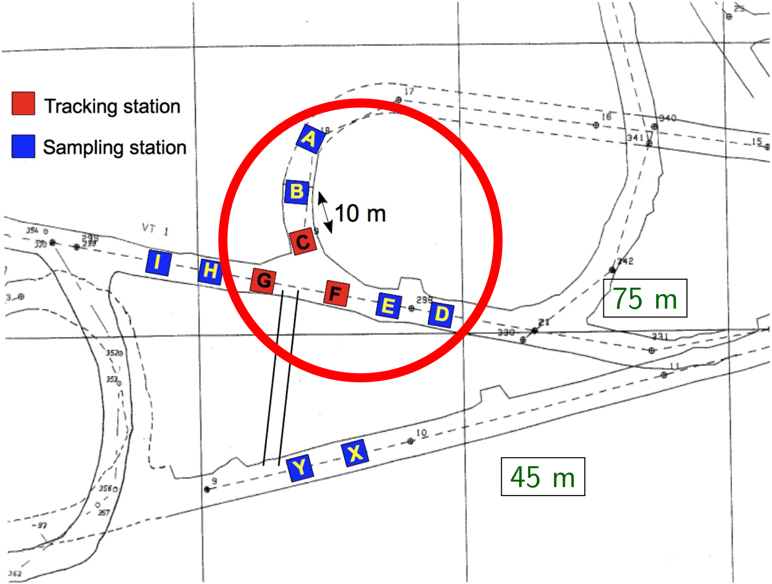
EMMA – DAQ running in 7 stations



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EMMA – gas handling

Total flux $\sim$8 ℓ/min ($Ar:CO_2$, 92:8)

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EMMA – gas handling

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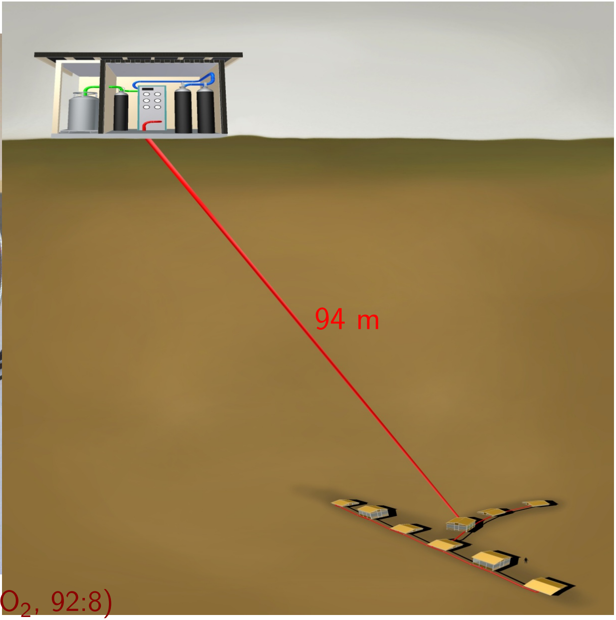
Underground Physics in the Pyhäsalmi mine

EMMA – gas handling



Total flux $\sim$8 ℓ/min (Ar:CO_2, 92:8)

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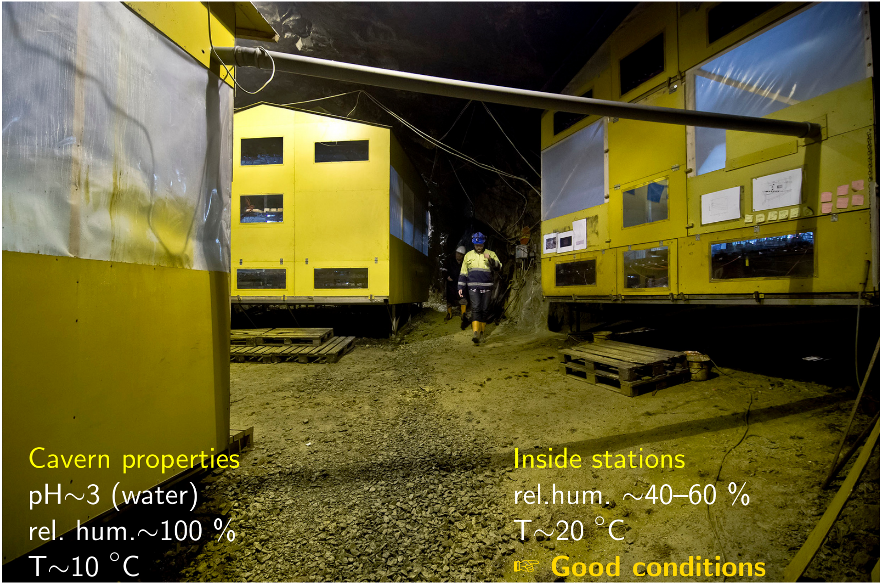
EMMA – stations C, F ja G



Cavern properties
pH∼3 (water)
rel. hum.∼100 %
T∼10 °C

Inside stations
rel.hum. ∼40–60 %
T∼20 °C
☞ **Good conditions**

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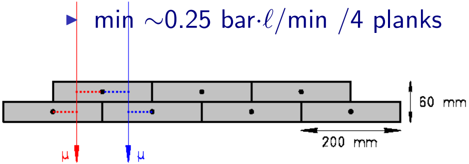
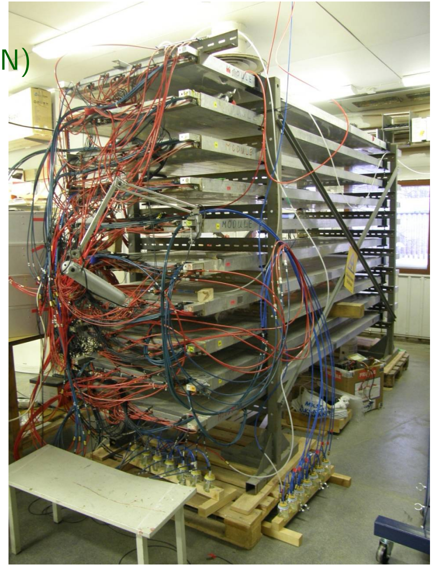
EMMA – drift chambers

- Former muon detectors from the DELPHI experiment at LEP (at CERN)
  - a plank – 7 individual chambers
  - mass 120 kg per plank
  - chamber: 365 cm × 20 cm
  - 3 signals per chamber
- In total 84 planks ($\sim$250 m^2)
  - form the basis of the array
- Position resolution is good: $\sim$1 cm^2
  - needed by tracking
- Ar (92%) : CO_2 (8%) at 1 bar
  - min $\sim$0.25 bar·ℓ/min /4 planks





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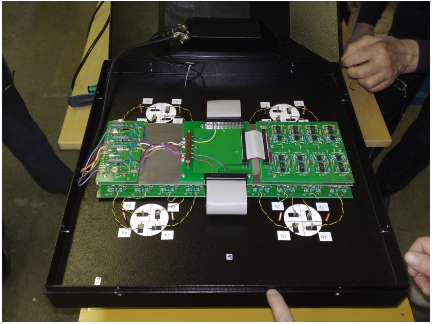
EMMA – scintillation detectors

- SC16 detector
  - 50×50 cm^2, H = 13 cm
  - mass $\sim$ 20 kg per SC16
  - 16 individual pixels of 12×12 cm^2 $\times$ 3 cm pixels
  - APD light collection
  - time resolution good: $\sim$1 ns
- Manufactured by Russian Academy of Sciences
- In total 96 SC16s (24 m^2, 1536 px), 72 SC16s in EMMA (1152 ps)
- Designed especially for
  - large muon multiplisities
  - fast trigger
  - initial guest for the arrival angle



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EMMA – Limited Streamer Tube (LST) detectors

- Muon detectors of KASCADE–Grande experiment (Karlsruhe)
- To be used as the second detector layer at the edge of the array and at 45-level
- Read-out electronics modified and is now being tested
  - LSTs in operation by the end of 2016
- 60 LST modules
  - $\sim 180\ \mathrm{m}^2$
- Properties
  - $2.9\ \mathrm{m} \times 1.0\ \mathrm{m}$
  - pixel size (PAD): $2\ \mathrm{cm} \times 8\ \mathrm{cm}$
  - gas: CO_2 at 1 bar

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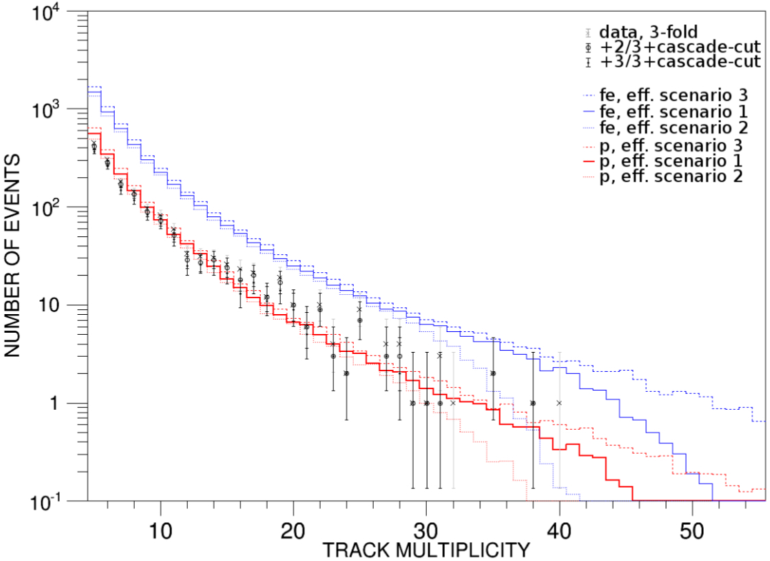
EMMA – first test runs with single stations (station C)



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EMMA – conclusions

- EMMA is an underground cosmic-ray experiment studing the knee region of the energy spectrum
  - at the depth of 75 m $\Longrightarrow$ energy cut-off of 50 GeV
- It consists of 11 detector stations
  - 7 stations currently in the DAQ, all stations by the end of 2016
  - three detector types: drift chambers, small-size plastic scintillation detectors and limited streamer tube detectors
- EMMA can extract the muon multiplicity, the lateral distribution and the arrival angle of an air shower
  - angular accuracy $\sim$1 deg
- Simulations and data analysis packages under development
  - first test runs (with multiplicities only) are looking fine
- Collaboration
  - university of Oulu and university of Jyväskylä (Finland), Russian academy of sciences and Moscow institute of physics and technology (Russia), and university of Aarhus (Denmark)

C14 Experiment

Measurement of $^{14}C/^{12}C$ ratio in liquid scintillator

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C14 – introduction – 1

- Measurement of ^{14}C/^{12}C ratio of several liquid scintillator samples
- Detector development
  - currently the lowest concentration: $^{14}\mathrm{C}/^{12}\mathrm{C} \sim 2 \times 10^{-18}$
  - low-background liquid scintillator detector
- From the ^{14}C half life ($\sim$5700 a) and the age of oil sources,
  - the ratio ^{14}C/^{12}C should be $\sim 10^{-21}$ – 10^{-22}
  - contamination from local environment (U, Th, K, ...)
- Collaboration between
  - university of Oulu, Finland
  - university of Jyväskylä, Finland
  - Russian Academy of Sciences, Russian
- Measurements in two laboratories
  - Baksan Underground Laboratory, Russia, at 4900 mwe
  - Pyhäsalmi Mine (CallioLab), Finland, at 4000 mwe
  - $\sim$similar method, $\sim$similar shielding

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C14 – introduction – 2

- LAB (Linear Alkylbenzene) is currently the favoured liquid scintillator in large LS detectors
  - SNO+ (1 kton) in Canada, JUNO (20 kton) in China
  - ^{14}C concentration of LAB not measured before

- JUNO (Jiangmen Underground Neutrino Observatory)
  - main scientific priority: neutrino mass hierarchy determination
  - supernova neutrinos, solar neutrinos, ...
- In JUNO the upper limit is: $^{14}\mathrm{C}/^{12}\mathrm{C} \sim 10^{-17}$
- The decay energy of ^{14}C is small (Q_β=156 keV)
  - usually below the threshold
- If the ^{14}C concentration too large $\Longrightarrow$ pulses may pile-up
- The ^{14}C concentration (of JUNO) to be measured in Baksan and Pyhäsalmi

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C14 – earlier measurements for $^{14}C/^{12}C$

$^{14}C/^{12}C$ ($\times 10^{-18}$)	Liquid Scintillator	Experiment	[Ref]
(1.94 ± 0.09)	PC+PPO	Borexino CTF	[1]
(9.1 ± 0.4)	PXE+p-Tp+...	Borexino CTF	[2]
(3.98 ± 0.94)	PC-Dodecane+PPO	KamLAND	[3]
(12.6 ± 0.4)	PXE+p-Tp+...	Dedicated setup	[4]

[1] G. Alimonti *et al.*, Physics Letters B 422 (1998) 349

[2] H.O. Back *et al.*, Nuclear Instrum. Methdos A 585 (2008) 48

[3] G. Keefer, arXiv:1102.3786

[4] C. Buck *et al.*, Instrum. and Experim. Techniques 55 (2012) 34

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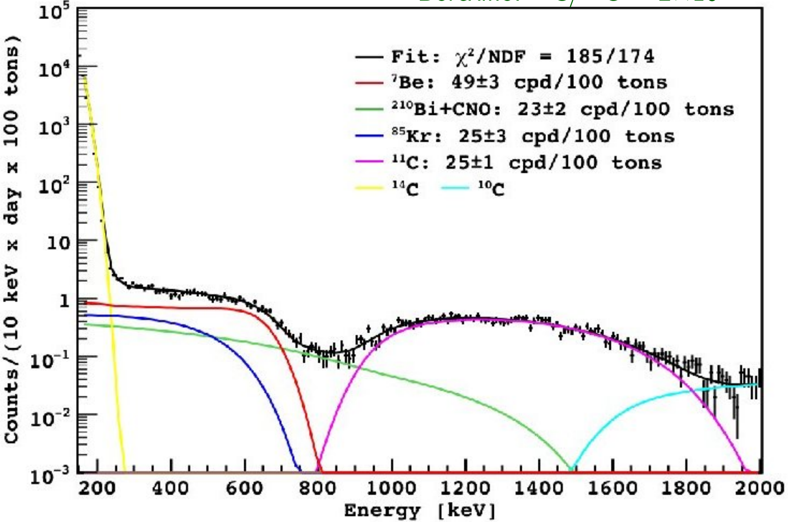
C14 – ^{14}C background in Borexino

Borexino: $^{14}C/^{12}C \sim 2\times10^{-18}$



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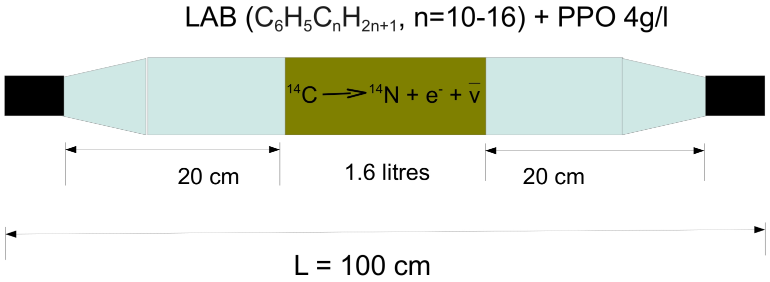
C14 – the instrument



- two low-background PMTs (ET 9302B, 3")
- quartz or acryllic vessel of 1.6 ℓ (1350 g of LAB)
- acryllic light guides (20–30 cm long)
- VM2000 wrapping
- surrounded by thick layers (10–15 cm) of copper and lead
- liquid purified by Al_2O_3

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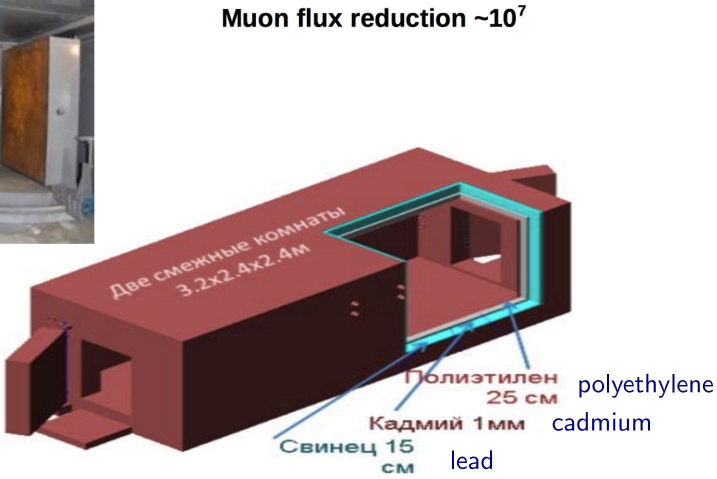
C14 – dedicated low-background hall in Baksan (4900 mwe)



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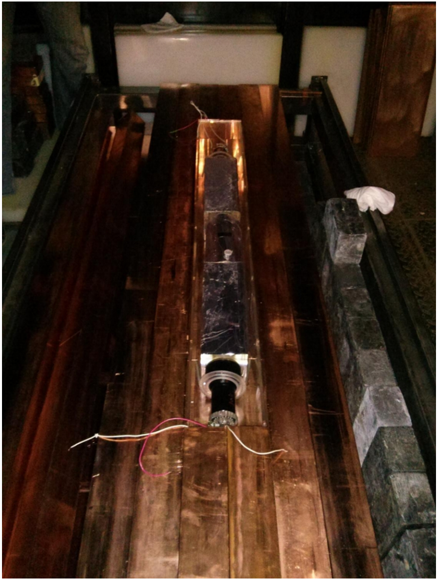
C14 – the shielding at Baksan



- Copper 15 cm

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C14 – the laboratory hall at the Pyhäsalmi mine (Callio Lab 2)

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C14 – conclusions

- Only a few measurement of ^{14}C concentration in liquid scintillators exist
  - the lowest measured concentration is 2×10^{-18} by Borexino CTF
  - concentration of ^{14}C in Linear Alkylbenzene not previously measured
- Measurements started (in Baksan) and to be started (in Pyhäsalmi) for a series of ^{14}C concentration determination
  - a dedicated setup
- ^{14}C concentration of the JUNO experiment will be determined
- An ultimate aim is to find a sample with a concentration of $\sim10^{-20}$
  - low-backgound experiment
- Collaboration
  - university of Oulu and university of Jyväskylä (Finland), Russian academy of sciences

Measurement of $2\nu2\beta$ half lives of ^{78}Kr and ^{124}Xe

(ECβ^+ mode)

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$2\nu 2\beta$ of ^{78}Kr and ^{124}Xe – half-lives of ^{78}Kr

- Jouni Suhonen, Physical Review C 87 (2013) 034318, Analysis of double-β transitions in ^{78}Kr

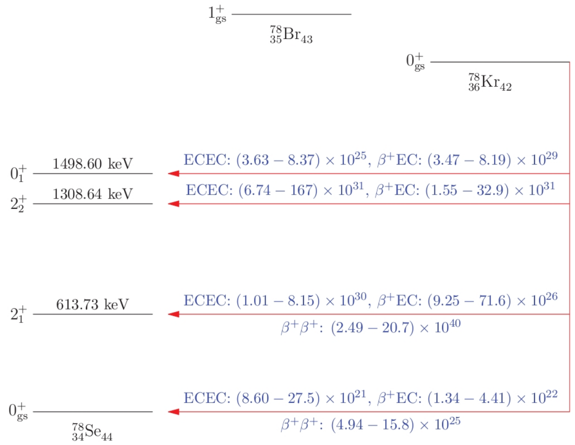

FIG. 2. (Color online) Computed partial decay half-lives of the ECEC, β^+EC, and $\beta^+\beta^+$ decay transitions from the ground state of ^{78}Kr to the ground and excited states in ^{78}Se. The half-lives are given in units of years.

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$2\nu 2\beta$ of ^{78}Kr and ^{124}Xe – $2\nu 2\beta$ half-lives of ^{124}Xe

- Jouni Suhonen, Romanian Journal of Physics 58 (2013) 1232, Positron-emitting and double-EC modes of double beta decay

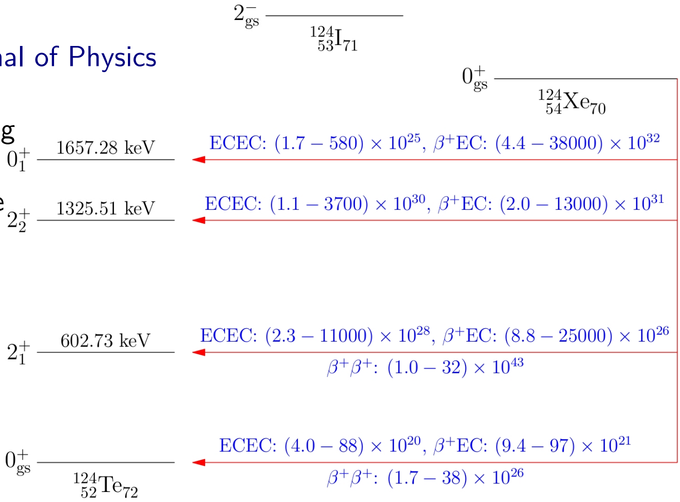

Fig. 1 – Computed partial half-lives (in units of years) for two-neutrino double beta decays of ^{124}Xe.

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$2\nu 2\beta$ of ^{78}Kr and ^{124}Xe – previous measurements

- ^{78}Kr
  - C. Sáenz *et al.*, Phys. Rev. C 50 (1994) 1170, Results of a search for double positron and electron-positron conversion of ^{78}Kr
  - Yu.M. Gavrilyuk *et al.*, Phys. Atom. Nuclei (2000) 2201, New limit on the half-life of ^{78}Kr with respect to the 2K(2ν)-capture decay mode
  - Yu.M. Gavrilyuk *et al.*, Phys. Rev. C 87 (2013) 035501, Indications of 2ν2K capture in ^{78}Kr
  - Yu.M. Gavrilyuk *et al.*, Phys. Atom. Nuclei 76 (2013) 1063, Results of experiments devoted to searches for 2K capture on ^{78}Kr and for the double-beta decay of ^{136}Xe with the aid of proportional counters
- ^{124}Xe
  - A.S. Barabash *et al.*, Phys. Lett. B 223 (1989) 273, Results of the experiment on the search for double beta decay of ^{136}Xe, ^{134}Xe and ^{124}Xe
  - Yu.M. Gavrilyuk *et al.*, arXiv:1507.04520v1 [nucl-ex] 16 Jul 2015, Search for 2K(2ν)-capture of ^{124}Xe

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$2\nu2\beta$ of ^{78}Kr and ^{124}Xe – an idea for the experiment

- Liquid scintillator (LAB) of 500 – 1000 ℓ (active volume)
  - acryllic cylinder with PMTs at the ends
- gamma and neutron shielding by liquid scintillator or water of $\sim$20 tons
- $\sim$5% of enriched Kr and Xe mixed with the liquid
  - the maximum amounts of mixing should be studied
- At the Pyhäsalmi mine (Callio Lab) at the depth of 1430 m (4100 mwe)

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$2\nu 2\beta$ of ^{78}Kr and ^{124}Xe – conclusions

- An idea to measure $2\nu 2\beta$ half lives of the ECβ^+ mode of ^{78}Kr and ^{124}Xe with a liquid scintillator setup
  - active volume 500 – 1000 ℓ
  - active shielding
- Theoretical calculations predict half lifes of 10^{22-23} years
  - possible with a small-scale experiment
- Important for understanding nuclear stucture and matrix elements
- Collaboration
  - university of Oulu and university of Jyväskylä (Finland), Russian academy of sciences

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Conclusions

- The mine provides excellent conditions for scientific work
- More activities (scientific and commercial) are looked for (Callio Lab concept) due to the mine closure in 2019
  - new deep laboratory ready
  - Open Call (at www.calliolab.com)
- Physics studies going on
  - EMMA and C14 running or under construction
  - background measurements to be started (muon and neutron flux)
  - an idea for measuring $2\nu 2\beta$ decay of ^{78}Kr and ^{124}Xe
- Russian institutes have been strongly participated in EMMA and C14 experiments
  - Institute of Nuclear Research of the Russian academy of sciences
  - Moscow Institute of Physics and Technology