Neutrino oscillations from CERN to Pyhäsalmi

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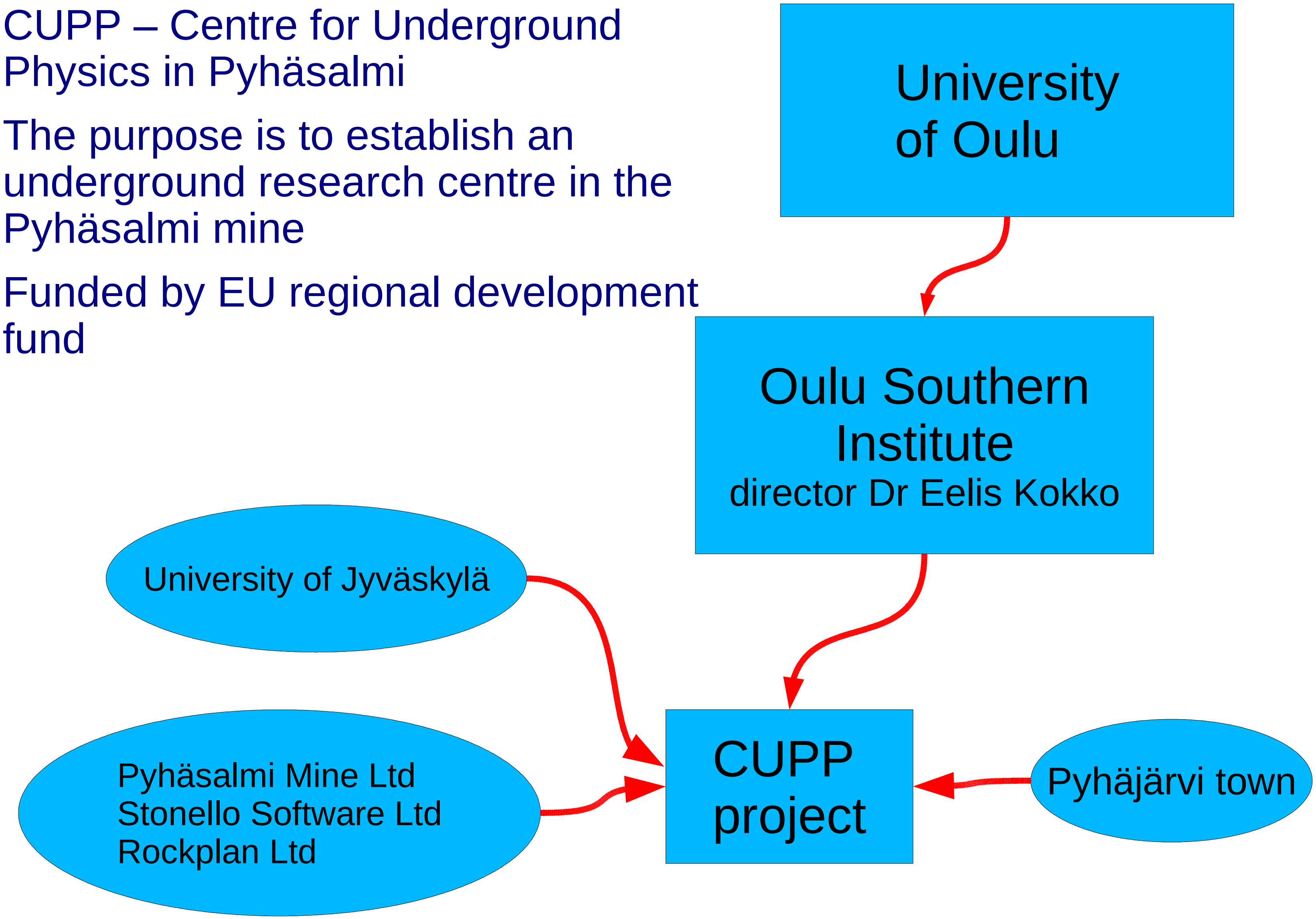
CUPP-project
cupp.oulu.fi

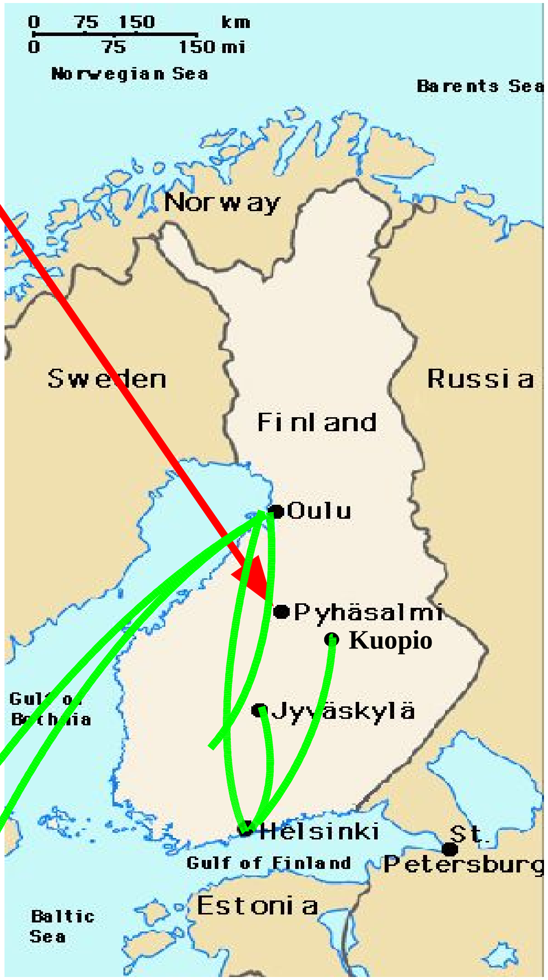
The CUPP project

- CUPP – Centre for Underground Physics in Pyhäsalmi
- The purpose is to establish an underground research centre in the Pyhäsalmi mine
- Funded by EU regional development fund



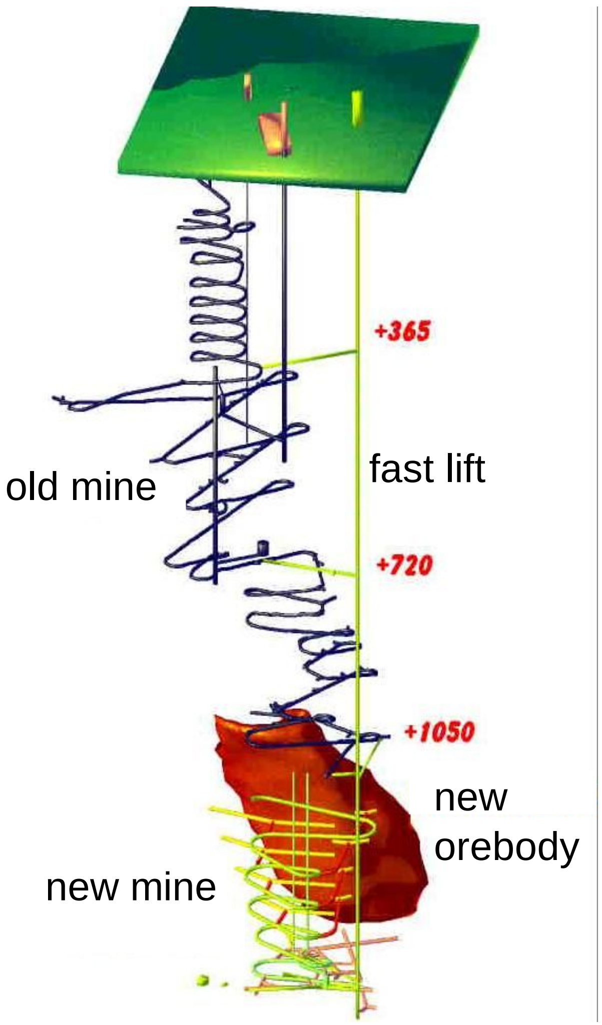
Location of the site

- Main office – University of Oulu
- Pyhäsalmi mine in Pyhäjärvi town
  - Also an abandoned sidemine, down to 700 m available nearby
- Connections
  - roads open all year round
    - Pyhäjärvi-Oulu: 2 h car drive
    - Pyhäjärvi-Jyväskylä: 2 h car drive
  - Pyhäjärvi-Helsinki: bus & train connections
  - 4 aiports within 2 hours drive, connections
    - Oulu-Helsinki: ca 20 flights a day
    - Oulu-Stockholm: 1–4 flights a day
    - Oulu-Copenhagen: 1 flight a day
    - Oulu-Tampere: 2 flights
      - To London, Stockholm, Copenhagen, Tallinn



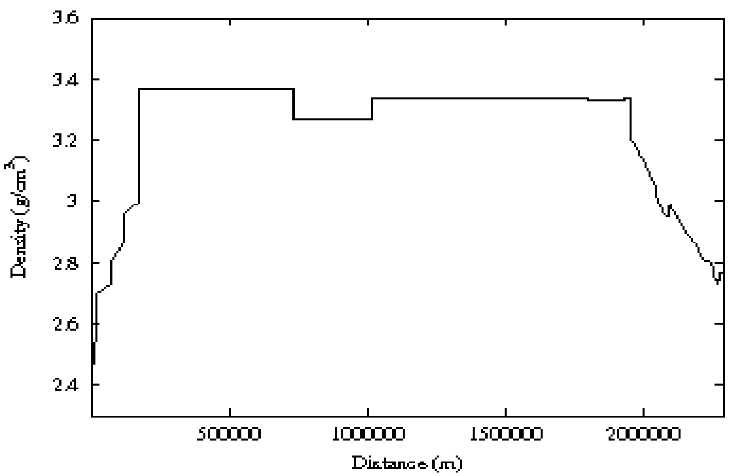
Pyhäsalmi Mine

- Pyhäsalmi Mine Ltd
  - Inmet Mining Corporation, Canada
  - produces zinc, copper and pyrite
- The old mine
  - about 1050 m deep
  - operated 1962–2001
- The new mine
  - active since July 2001
  - known ore reserves until ca 2017
  - greatest depth 1444 m
    - the deepest metal mine in Europe
  - access by lift (2 min) or via decline by car (40 min) or by running (1 h 4 min)



Neutrino baseline from CERN to Pyhäsalmi

- Distance 2288 km
- The baseline density profile modelled
  - Kozlovskaya, Peltoniemi and Sarkamo, hep-ph/0305042
  - good geophysical data available
  - Can do accurate simulations for matter effect



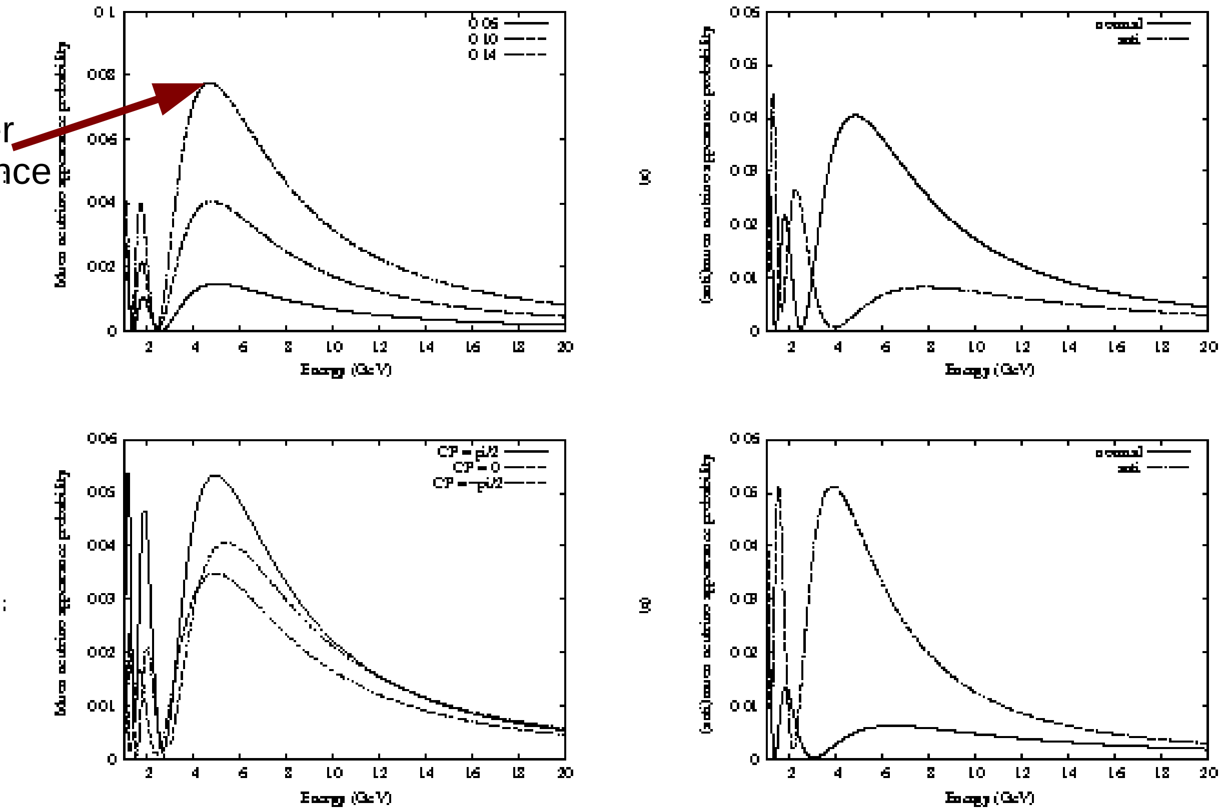
Neutrino beams to Pyhäsalmi

- Neutrino factory
  - 10-50 GeV pure muon (anti)neutrino beam
- Conventional beams (by pion decay)
  - Wide band beam
  - Narrow band beam/off-axis beam
- Betabeams
  - Pure electron (anti)neutrino beam
  - Need higher energies

Oscillation probabilities for L=2300 km

- Sample plots for muon neutrino appearance from electron neutrino beam
  - ”usual best fit parameters”

matter enhance



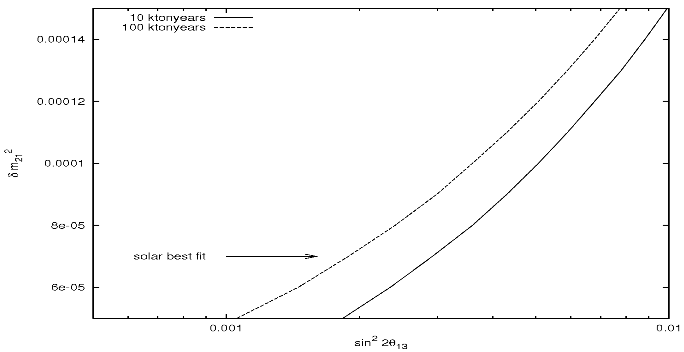
normal hierarchy

Inverted hierarchy

$\mathrm{Sin}^2\,\theta_{13}$=0.1

Experimental potential

- Reach in $\sin^2 2\theta_{13}$
  - 20 GeV,
  - 10^{20} muons per year
  - 10 and 100 ktonyears

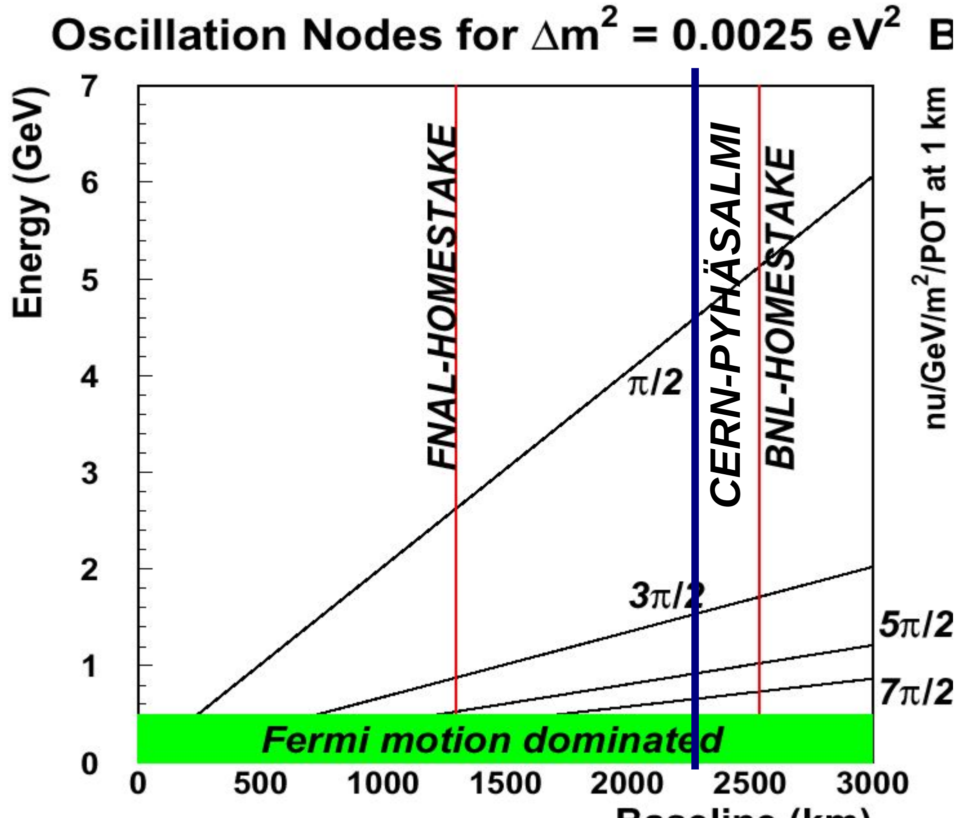


Conventional beam 10-30 GeV

- Duplication of CERN CNGS beam facility
  - Beam cost some 50 MEUR
- Energy range 10-30 GeV
- Study tau appearance
  - Relevance depends on the results of OPERA/ICARUS
- Flux density ca 1/10 of that in Gran Sasso
  - Need larger detectors
- Technically realistic

Conventional wide band beam 1-6 GeV

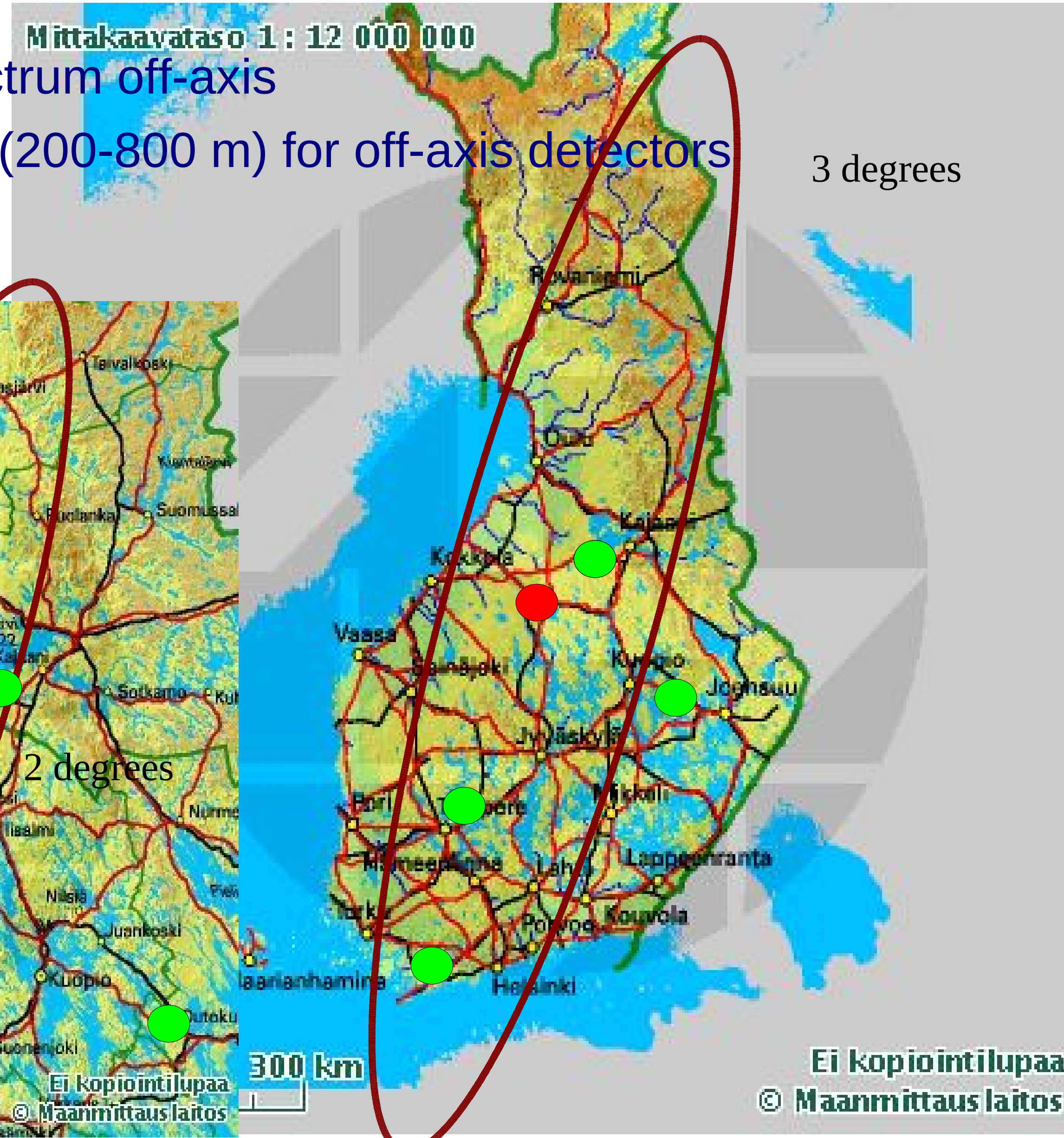
- Observation of multiple nodes
- E.g., with 1 MW beam (from CERN) and 100 kton year:
  - 10 000 muon CC events, 3 500 NC events with no oscillations
- Planned SPL not sufficient – need higher energy or SPS for acceleration



Diwan et al

Off-axis detectors

- Sharper energy spectrum off-axis
- Several other mines (200-800 m) for off-axis detectors
  - Or vice versa



High energy beta beam

- Physically interesting range:
  - antineutrinos: $\gamma \sim 1000$ ($\langle E_\nu \rangle \sim 4$ GeV) for ^6He decay
  - neutrinos: $\gamma \sim 2000$ ($\langle E_\nu \rangle \sim 7$ GeV) for ^{18}Ne decay
- Use LHC to accelerate ions
  - Technically possible
  - Availability and economic feasibility not yet clear
- Longer baseline and higher energy as compared to 130 km
  - Matter effects visible
    - Expect clear difference between neutrinos and antineutrinos
  - Other kind of detector may be preferred
    - e.g. liquid argon, iron calorimeter
  - Event rates an order of magnitude larger
    - For fixed number of decays and fixed L/E
  - May study tau appearance

Other baselines

- ”Magic baseline” 7250 km (Winter et al)
- Clean measurement of mixing angle, insensitive to CP angle
- Distance to Pyhäsalmi:
  - JHF: ca 7200 km [almost perfect baseline!]
  - Fermilab: 6500-7000 km
  - BNL: ca 6200 km

Possibilities to host detectors in Pyhäsalmi

- Technically possible to construct large caverns relatively easy
  - Rock mechanics of 20 m x 20 m x 100 m cavern analysed
  - Very large caverns (1 000 000 m^3) not studied in detail
- No unavoidable restrictions for any detector component or material usually considered
  - Can build own pipeline for liquids
  - Own ventilation system to be built
- Large local production (and demand) of liquid argon
  - World's largest cold process unit of steel in Outokumpu's gigantic stainless steel factories in Northern Finland (Tornio).
  - Several (idependent/competing) factories of liquified gases (Ar, N) within 300 km distance (transport radius)
- Railway transport of heavy items to the site possible
- Environmental risks small
  - Laboratories separated from biosphere
  - Broken experiments can be closed and sealed

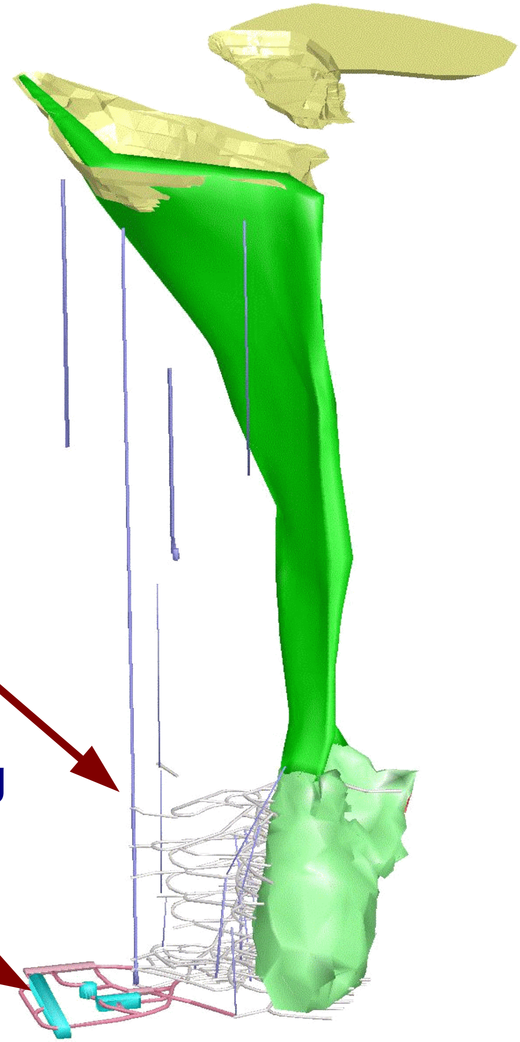
Costs for constructing a deep underground laboratory

- Large underground laboratory hall: typically 200 EUR/m^3
  - Rock construction 40 %
    - excavation, rock removal, shotcreting, bolting, water shielding, etc
  - Building technical works (inner structures etc) 20 %
  - HVAC 5 %
  - Plans, permissions etc 15 %
  - Surprises 20 %
- Additional shielding (for neutrons) or special equipment
  - Extra costs – not excessive
- Access construction:
  - Decline (tunnel, ramp) with heavy truck access: 3000 EUR/m
  - Narrow tunnel: 1000 EUR/m
  - Shaft (7 m) 5000 EUR/m, (2 m) 1000 EUR/m.
  - Own hoist (lift) to surface 2-10 MEUR

Cost summary

- Basic costs (general halls, HVAC, etc): ca 5-10 MEUR
- Access: 2-20 MEUR, depending on depth, location and capacity
- Caverns for experiments
  - LENA: 10 MEUR
    - Compare: an underground oil tank of 45 000 m^3: 7 MEUR
  - Cavern for a 100 kton detector (e.g. Neutrino factory): 12 MEUR
  - Caverns for a Megaton detector (UNO-like): 200 MEUR
    - Several ca 30 m wide caverns - one large sphere with r=70 m very expensive.
- Surface buildings
  - 1-5 MEUR, depending on needs

Depths and locations



- Level 1100 m (3000 m.w.e)
  - Most cost-effective solution
    - Excavated rock can be skipped directly to stopes for backfilling
  - Minimal disturbance to mining
    - Own lift/decline not required (but would be nice)
- Level 1400-1500 m (4000 m.w.e)
  - Need special arrangement if done during mining
  - Own access (lift) necessary
    - Additional cost 3-10 MEUR
    - Improves the usability of the lab
  - May need own decline from 1100 m level
    - Additional cost 5-10 MEUR
- Depths 1500-2500 m (4000-7000 m.w.e.)
  - Possible, but expensive, additional cost ca 30 000 EUR/m.

Conclusions

- Pyhäsalmi site very suitable for long baseline neutrino oscillation studies
  - CERN – Pyhäsalmi baseline 2300 km
  - JHF – Pyhäsalmi baseline 7200 km
- Several neutrino sources technically possible
  - Neutrino factory 5-50 GeV
  - Wide band beam 1-6 GeV
  - Beta beam 4-8 GeV
- Large halls can be constructed deep underground
  - Good logistics
- Good opportunities for large detectors
  - Good transport options
  - Liquid argon nearby
- Environmentally robust and safe site