Luis Labarga, University Autonoma Madrid
Open Meeting for the Hyper-Kamiokande Project
Kavli-IPMU, Kashiwa, 20120822

The **Laguna feasibility study** for the **Canfranc Underground Laboratory** [**LSC**] to host a **next-generation** mega-ton type **nucleon decay** and **neutrino experiment**

- the context of this talk & brief introduction to LAGUNA
- feasibility study for LAGUNA –WC at the LSC
  - general considerations, geology, etc.
  - cavity support's conceptual design, basic gral. estimates, etc.
  - realistic calculations, design of main cavern, etc.
- cost and time estimates
- summary

What was LAGUNA ?

some sort of first "European approach"
[main funding from E.U., 1.7 M€]
towards next generation liquid [Mt-like]
p-decay and neutrino experiment

➔ The goal was the Feasibility Study
of the seven candidate sites:

- CUPP @ Pyhäsalmi mine, Finland
- IUS @ Boulby mine, UK
- SUNLAB @ Sieroszowice mine, Poland
- IFIN-HH @ Unirea mine, Romania
- LSM @ Frejus tunnel, France
- New-Site @ CNGS beam halo, Italy
- *LSC @ Canfranc RW tunnel, Spain*

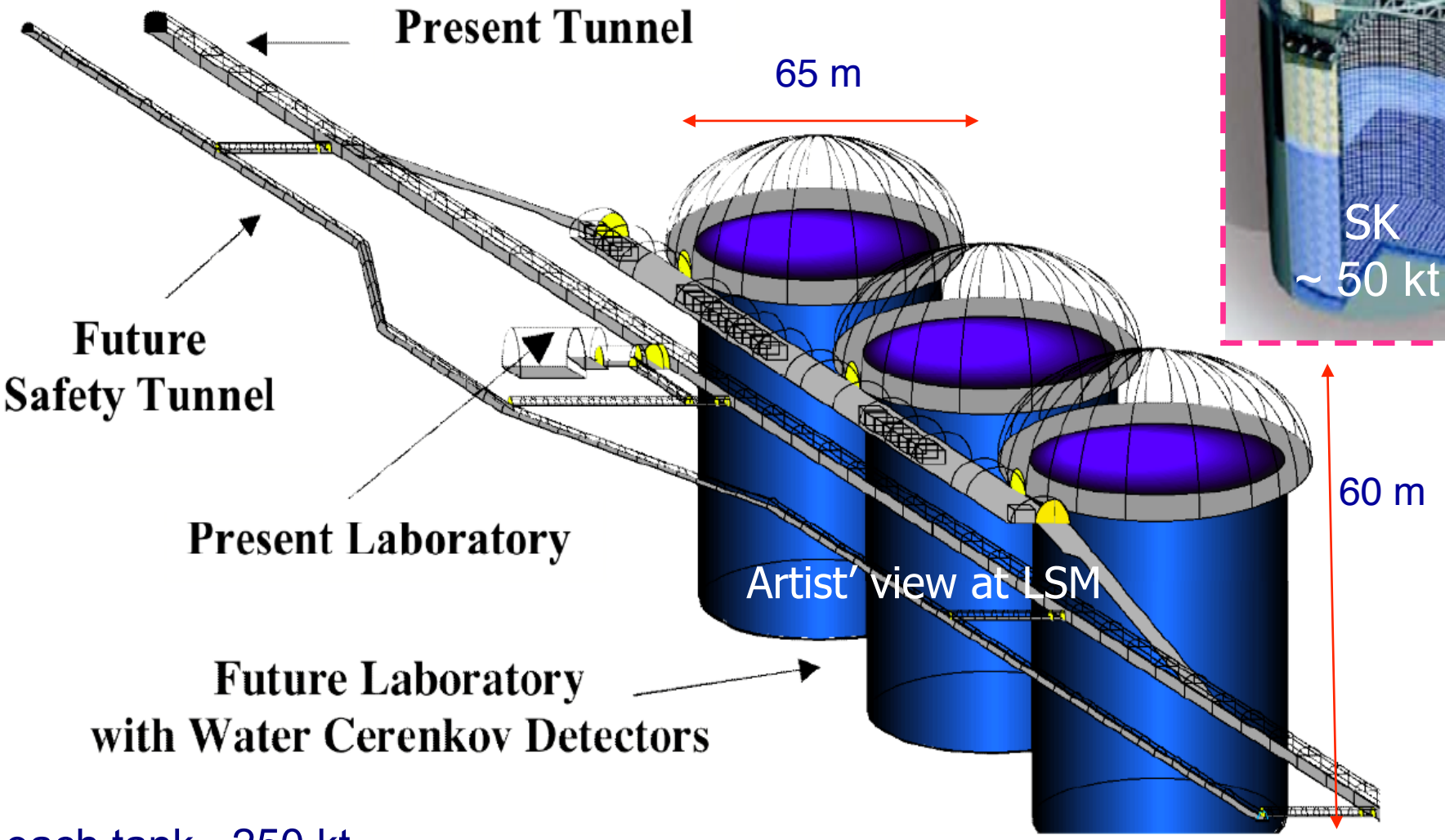
to host any of 3 considered detectors

- Liquid-Scintillator: ~ 0.05 Mt
- Liquid-Argon TPC: ~ 0.1 Mt
- *Water-Cherenkov: ~ 1 Mt*

having in mind a possible new ν beam from CERN, and that the value of θ_{13} might be known within a not too distant future … [now it is known…]

Water-Cherenkov option considered:

⇨ **MEMPHYS**



- each tank ~250 kt
- tank size limited by light attenuation length (λ ~ 80m) and pressure on PMTs
- readout : ~3 x 81K 12" PMTs, 30% geom. Cover
- hopefully with matter-flavour/neutron tagging ⇨ ***Gd*** solute

Some misc. info about the Feasibility Study for LAGUNA @ LSC

- The bulk of the work took ~8 months. The final document was delivered in June 2010. It can be accessed at
  http://www.lsc-canfranc.es/Docs/Experiments/LAGUNA/LSC_Revision_20100512.pdf
  /LSC_MEMPHYS_PLANS_Revision_20100512.pdf

- Most of the technical work was subcontracted; the total cost was ~260 K€

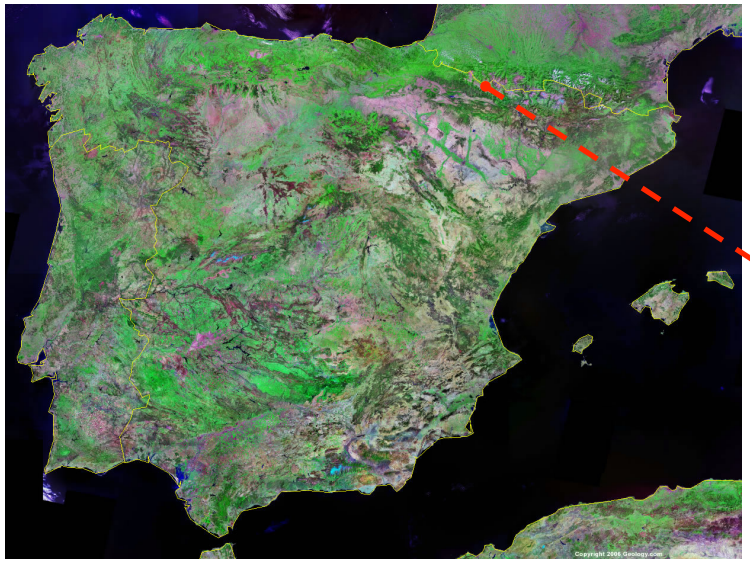
- We were able to form a sort of *"dream team"* as technical partner

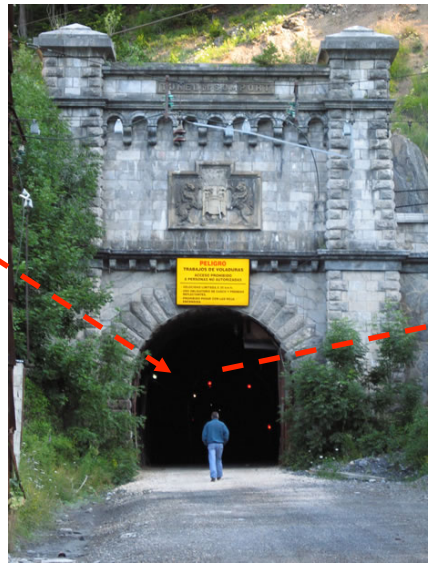
  - a small consulting company **STMR** owned by *Prof. Manuel Romana*, *leader* of the *team*, Professor of Rock Mechanics at the Valencia Polytechnic. Prof. Romana is a most-recognized Spanish expert in the matter, and has deep knowledge of the characteristics of the rock and underground works in the Canfranc area

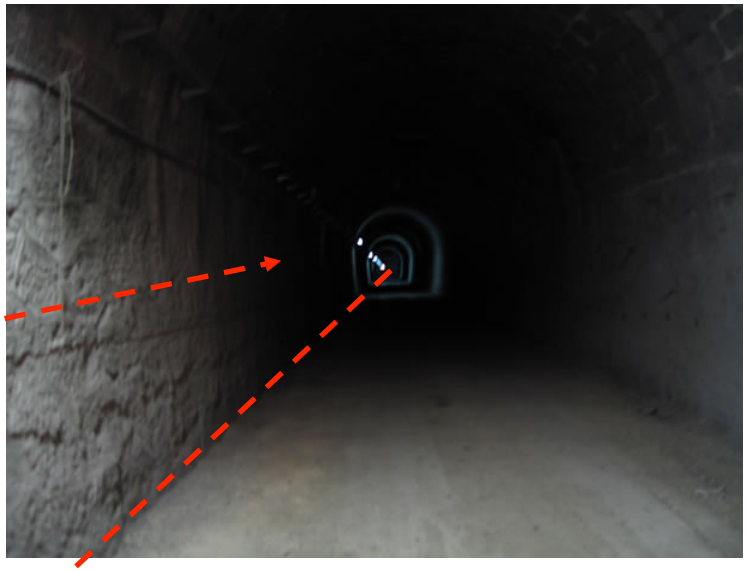
  - **ACCIONA INGENIERÍA**, the civil engineering branch of the Spanish giant ACCIONA, with wide history in the design and monitoring of underground works, particularly road and railway tunnels and hydro-electrical power plant caverns. The head was *Prof. Clemente Saenz*, *co-leader* of the *team*

The rational of this talk is to present ideas, estimates etc. obtained during/from the F.S. that may help towards achieving the best compromise between geology, construction, cost and overall, physics, in the design of the Hyper-Kamiokande project

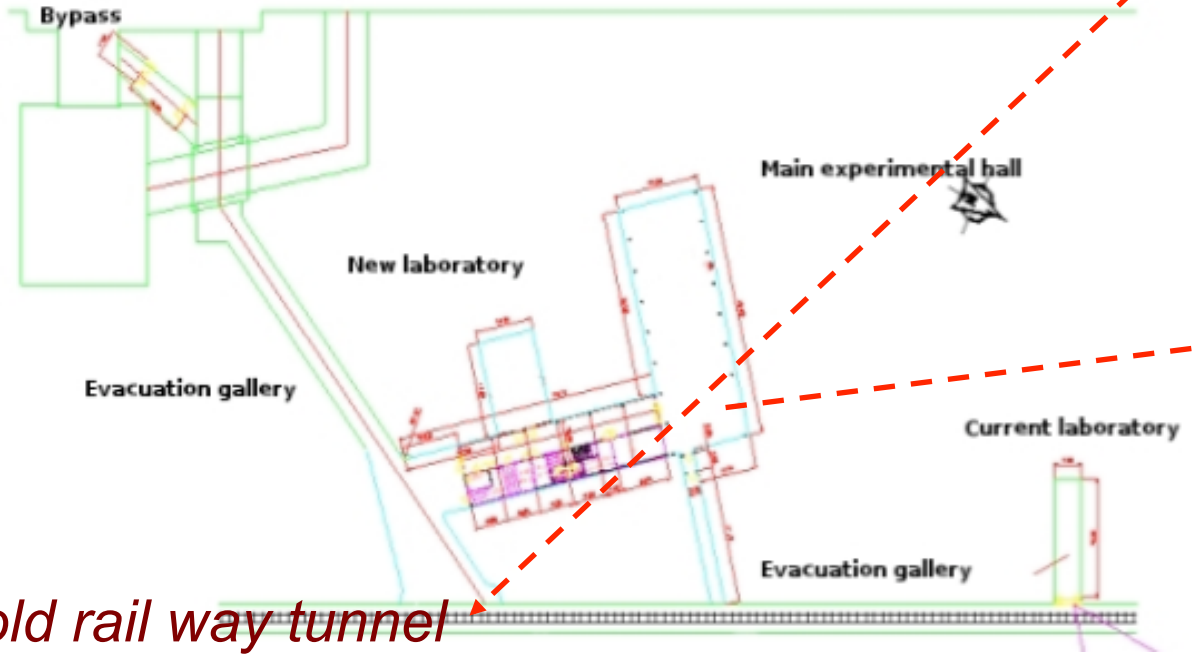
Canfranc Underground Laboratory [LSC, Laboratorio Subterráneo de Canfranc]







new road tunnel (opened 2003)



old rail way tunnel

main Hall, it is not empty anymore: *ArDM*, *NEXT*

General I:

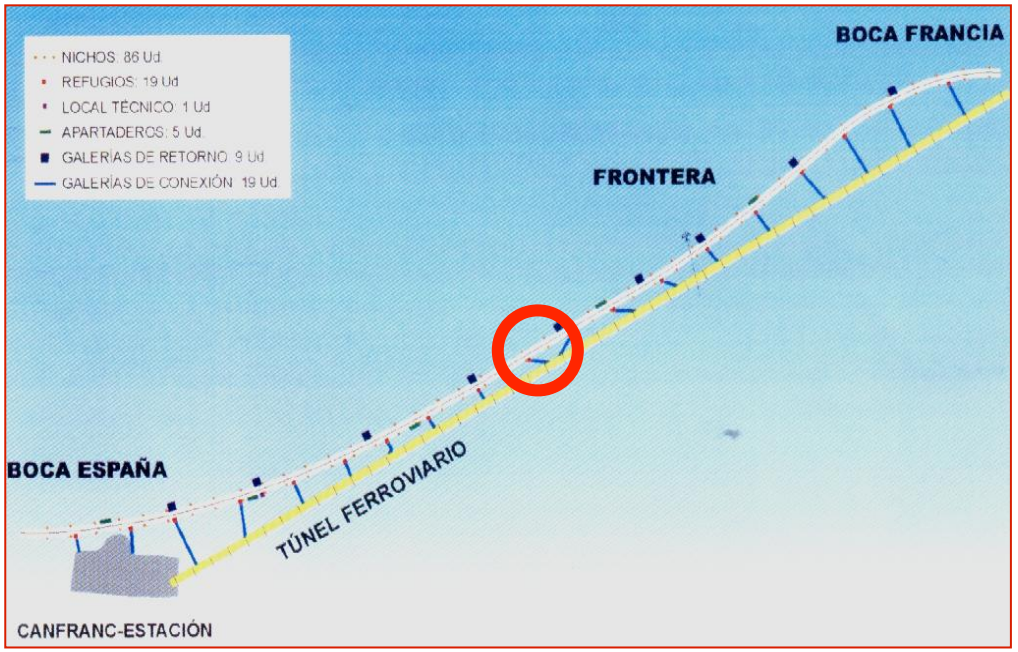
The LSC lies physically in between:

new Road Tunnel opened 2003

- bi-national: Spain – France
- 8.6 Km long (5.7 Spain, 2.9 France)

old Railway Tunnel

- used as service and emergency exit of Road Tunnel
- connecting galleries every 400 m
- current access for Laboratory

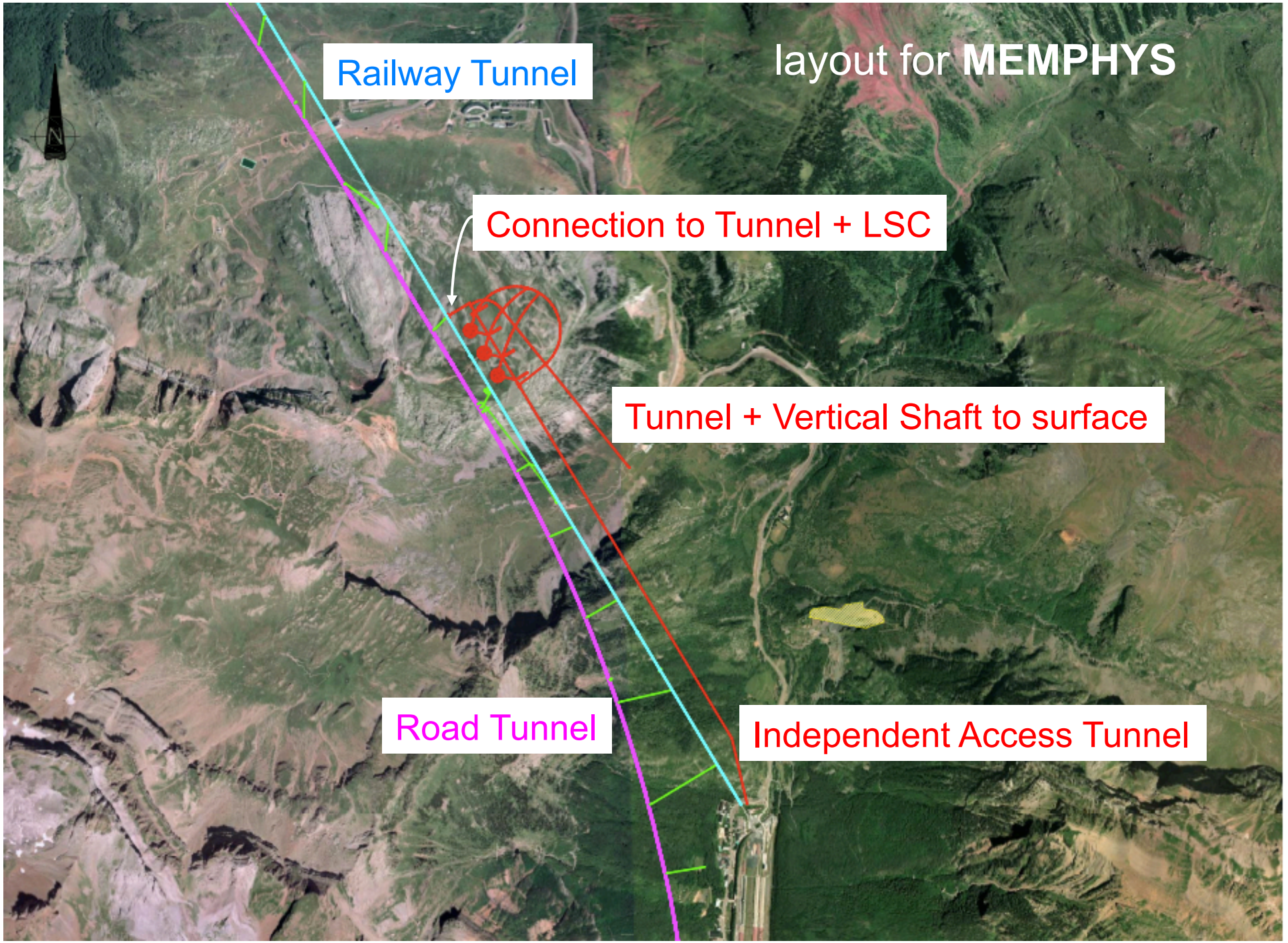


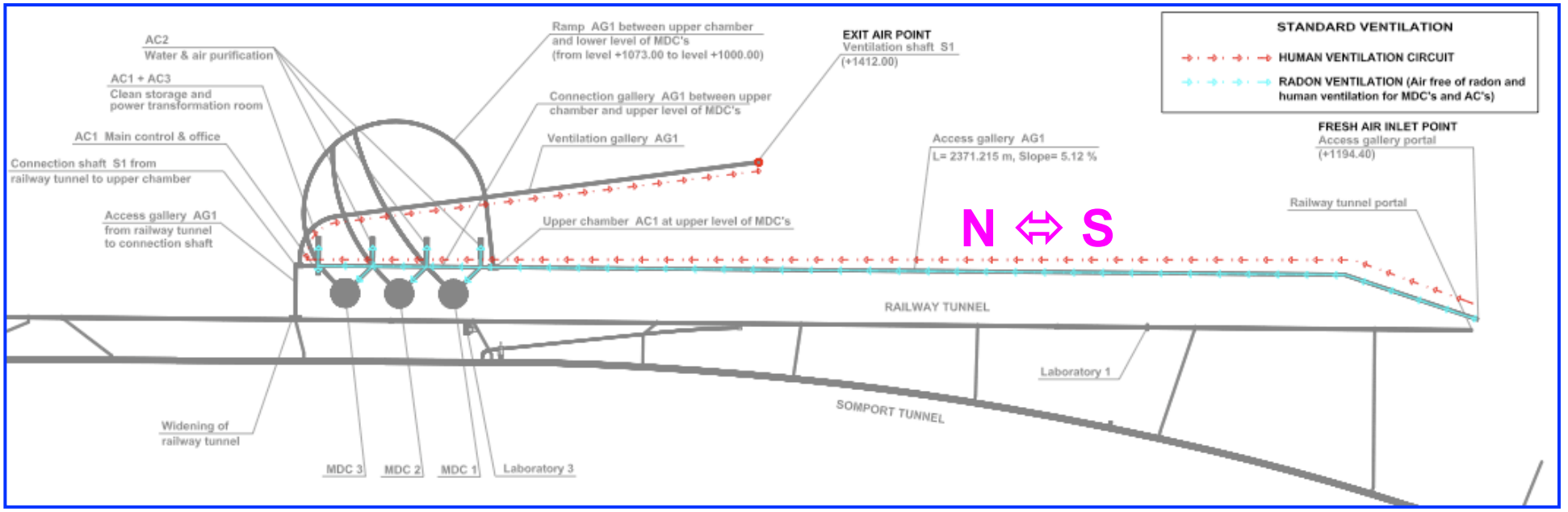
➔ The main layout of the experiment was conceived to interfere neither with the regular running of Road Tunnel nor with the emergency and service purposes of Railway Tunnel

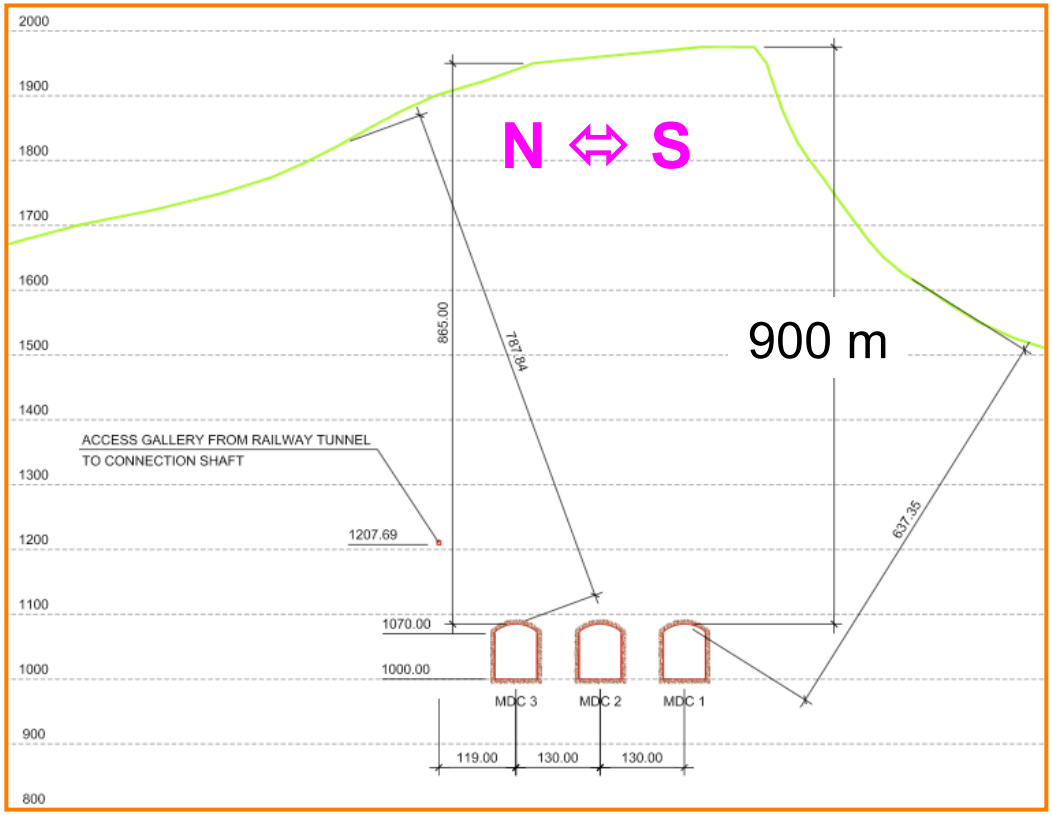
➔ Of course it tries to take the maximum profit of them, but at the same time it must be able to operate independently if necessary

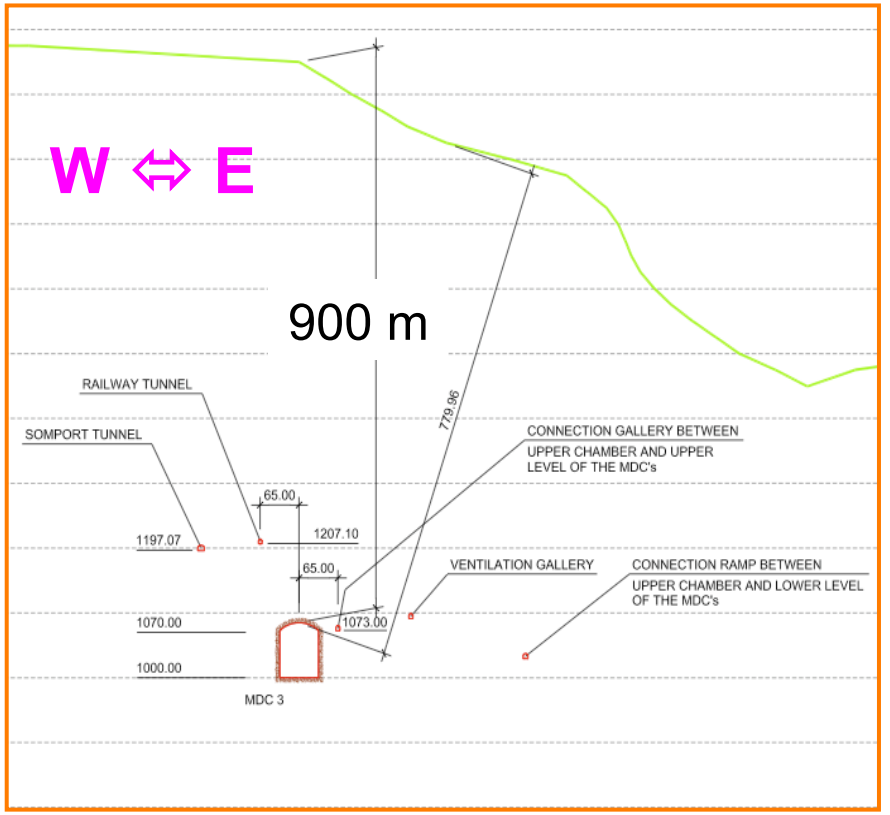
General II:

- ⇨ An independent access tunnel, 2 - 3 Km long, ~ 5 % downwards, almost parallel to existing ones. *Notice that significant depth can be gain by increasing the slope of the tunnel (up to a still safe ~10%)*
  - For construction access (!)
  - For regular operation/running and maintenance access
  - For radon-free air conduction
  - For supplies: energy, water, others
  - For Liquid Scintillator .OR. Liquid Argon supply by truck
  - For ventilation: regular operation/running and fire
- ⇨ A permanent connection with the Road and Railway tunnels and LSC by a vertical shaft
  - For normal operation (connection to LSC)
  - As an emergency escape way
- ⇨ Another tunnel + vertical shaft to the surface
  - For ventilation: regular operation/running and fire

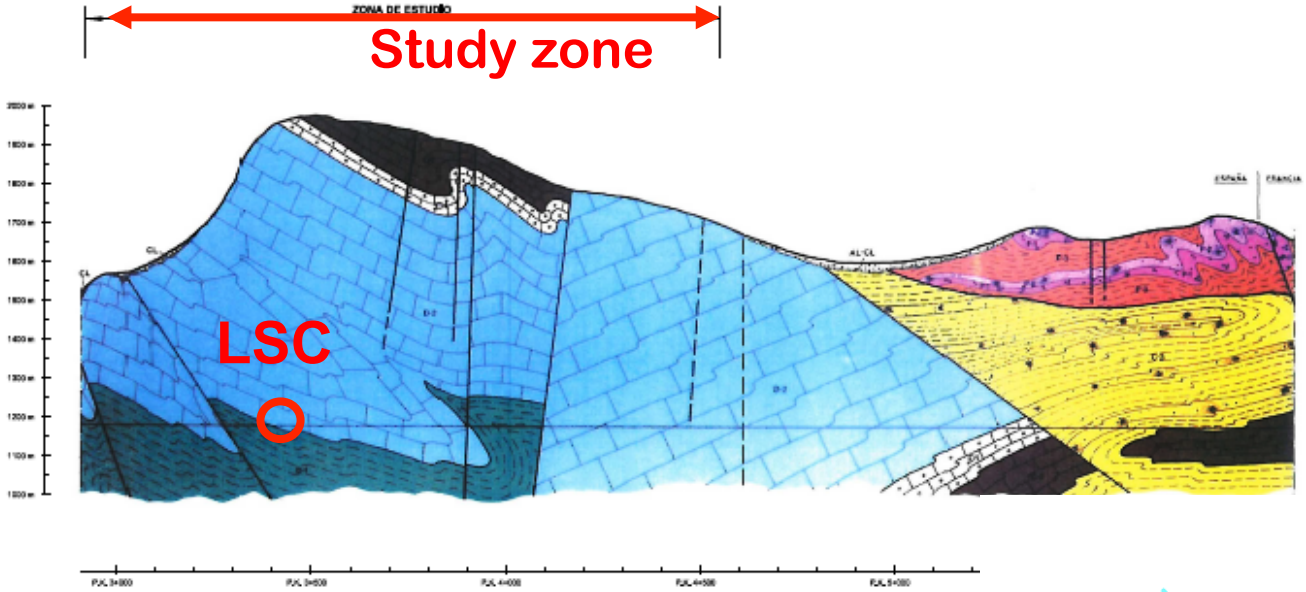

Railway Tunnel
layout for **MEMPHYS**
Connection to Tunnel + LSC
Tunnel + Vertical Shaft to surface
Road Tunnel
Independent Access Tunnel


STANDARD VENTILATION
HUMAN VENTILATION CIRCUIT
RADON VENTILATION (Air free of radon and human ventilation for MDC's and AC's)
AC2
Water & air purification
AC1 + AC3
Clean storage and power transformation room
AC1 Main control & office
Connection shaft S1 from railway tunnel to upper chamber
Access gallery AG1 from railway tunnel to connection shaft
Widening of railway tunnel
Ramp AG1 between upper chamber and lower level of MDC's (from level +1073.00 to level +1000.00)
Connection gallery AG1 between upper chamber and upper level of MDC's
Ventilation gallery AG1
Upper chamber AC1 at upper level of MDC's
EXIT AIR POINT
Ventilation shaft S1
(+1412.00)
Access gallery AG1
L= 2371.215 m, Slope= 5.12 %
FRESH AIR INLET POINT
Access gallery portal
(+1194.40)
Railway tunnel portal
N ⇔ S
RAILWAY TUNNEL
Laboratory 1
SOMPORT TUNNEL
MDC 3
MDC 2
MDC 1
Laboratory 3


2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
N ⇔ S
900 m
865.00
787.84
637.35
ACCESS GALLERY FROM RAILWAY TUNNEL
TO CONNECTION SHAFT
1207.69
1070.00
1000.00
MDC 3
MDC 2
MDC 1
119.00
130.00
130.00


W ⇔ E
900 m
RAILWAY TUNNEL
SOMPORT TUNNEL
779.96
CONNECTION GALLERY BETWEEN
UPPER CHAMBER AND UPPER
LEVEL OF THE MDC's
65.00
1197.07
1207.10
65.00
VENTILATION GALLERY
CONNECTION RAMP BETWEEN
UPPER CHAMBER AND LOWER LEVEL
OF THE MDC's
1070.00
1073.00
1000.00
MDC 3

Geology I: site profile from studies at Road Tunnel construc.

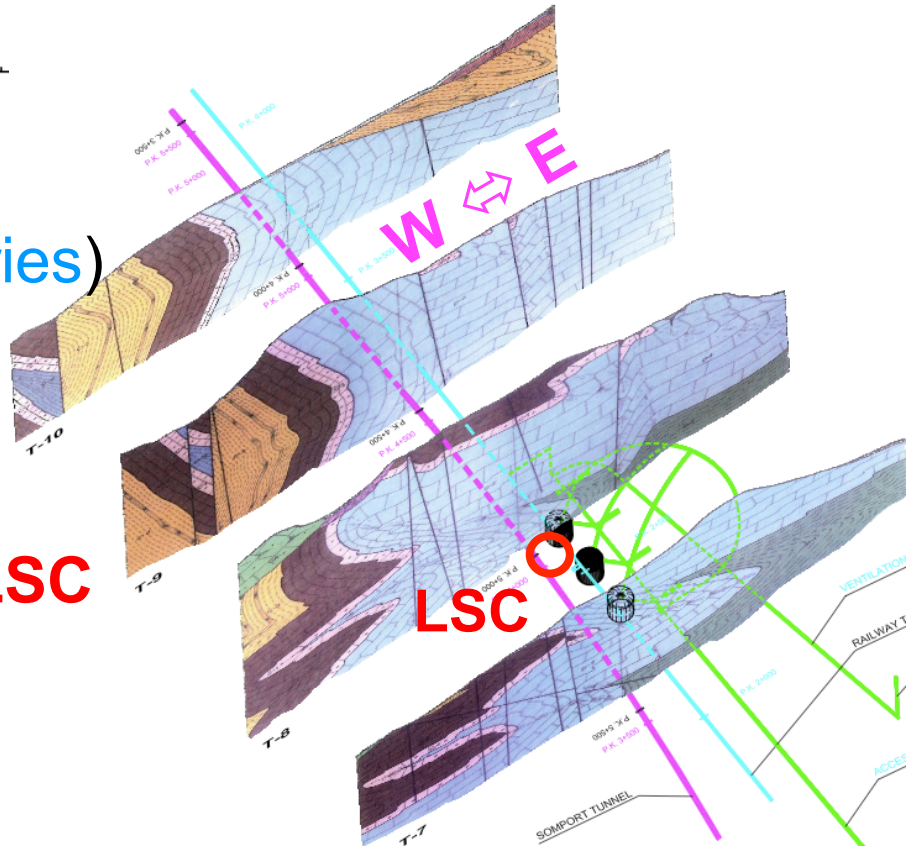


Limestone (Coralline limestone Series)

- Sedimentary
- Bedded texture

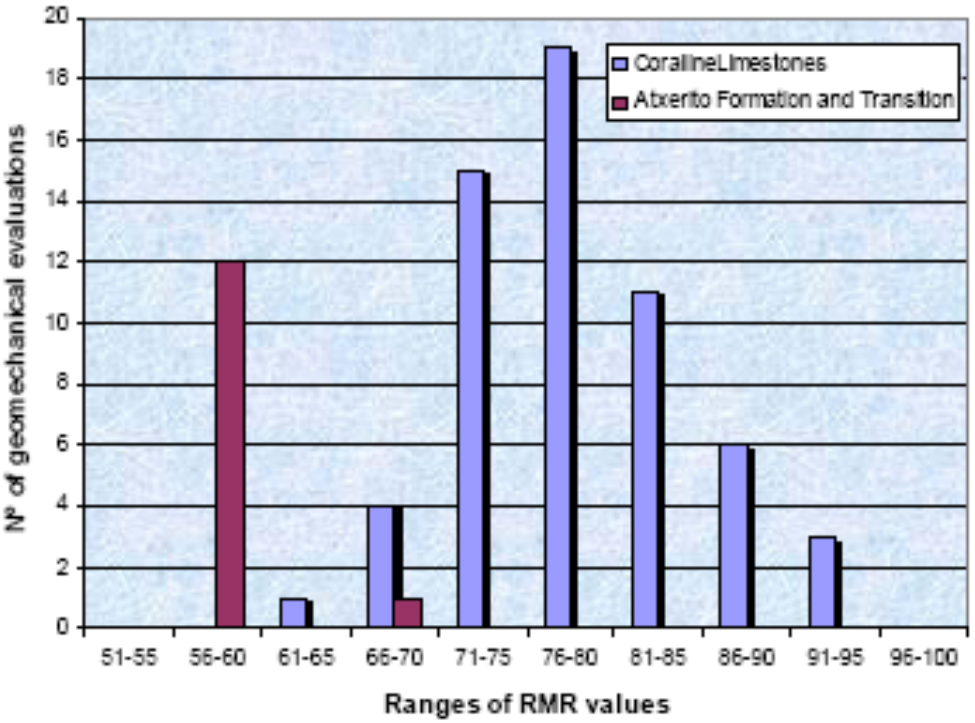
Calcareous slate (Atxerito series) **LSC**

- Metamorphic (low grade)
- Schistose texture

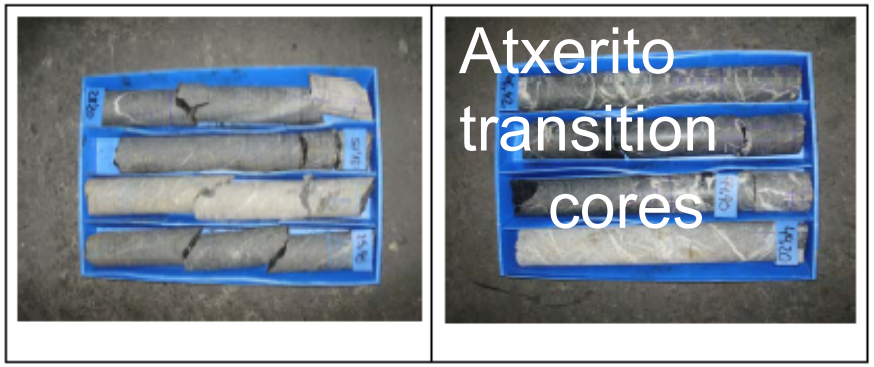


Geology II: geological studies in this FS

- *retrospective analysis* of **falls** in the current **LSC** in order to check the real rock parameters around the laboratory
- revision and analysis of geological data gathered at Road Tunnel excavation phases
- 2 dedicated probing bore-holes (40, 70 m long) in key locations
- laboratory tests



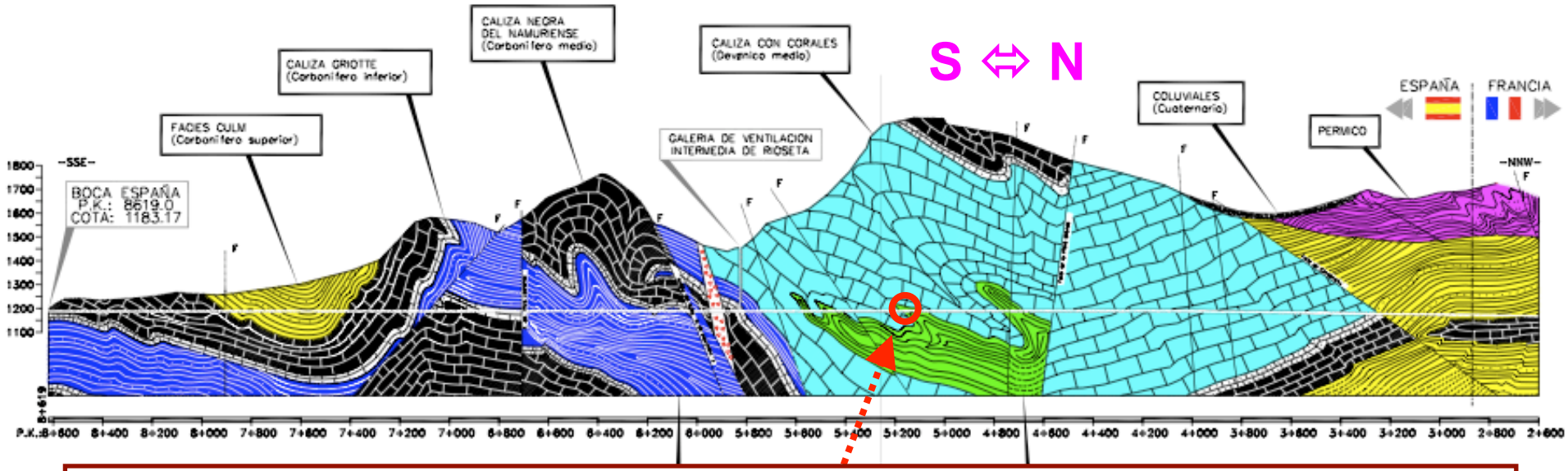
Two boxes of S-1. At left, from 11,00 to 13,25 meters deep. At right, from 37,00 to 39,20.



Two boxes of S-2. At left, from 25,90 to 28,20 meters deep. At right, from 44,20 to 46,420.

Geology III: conclusions and assumptions for calculations

- The rock along the site is mostly good marine coralline limestone
- However, there are regions of medium quality folded "Atxerito" beds and the corresponding transition regions



for the calculations of this study, the rock was assumed to lie in the worst possible location: the "Atxerito" beds

To know the exact distribution of both rocks at larger depths it is necessary a thorough geological-geotechnical bore-holing campaign

Conceptual support design I: there are no precedents

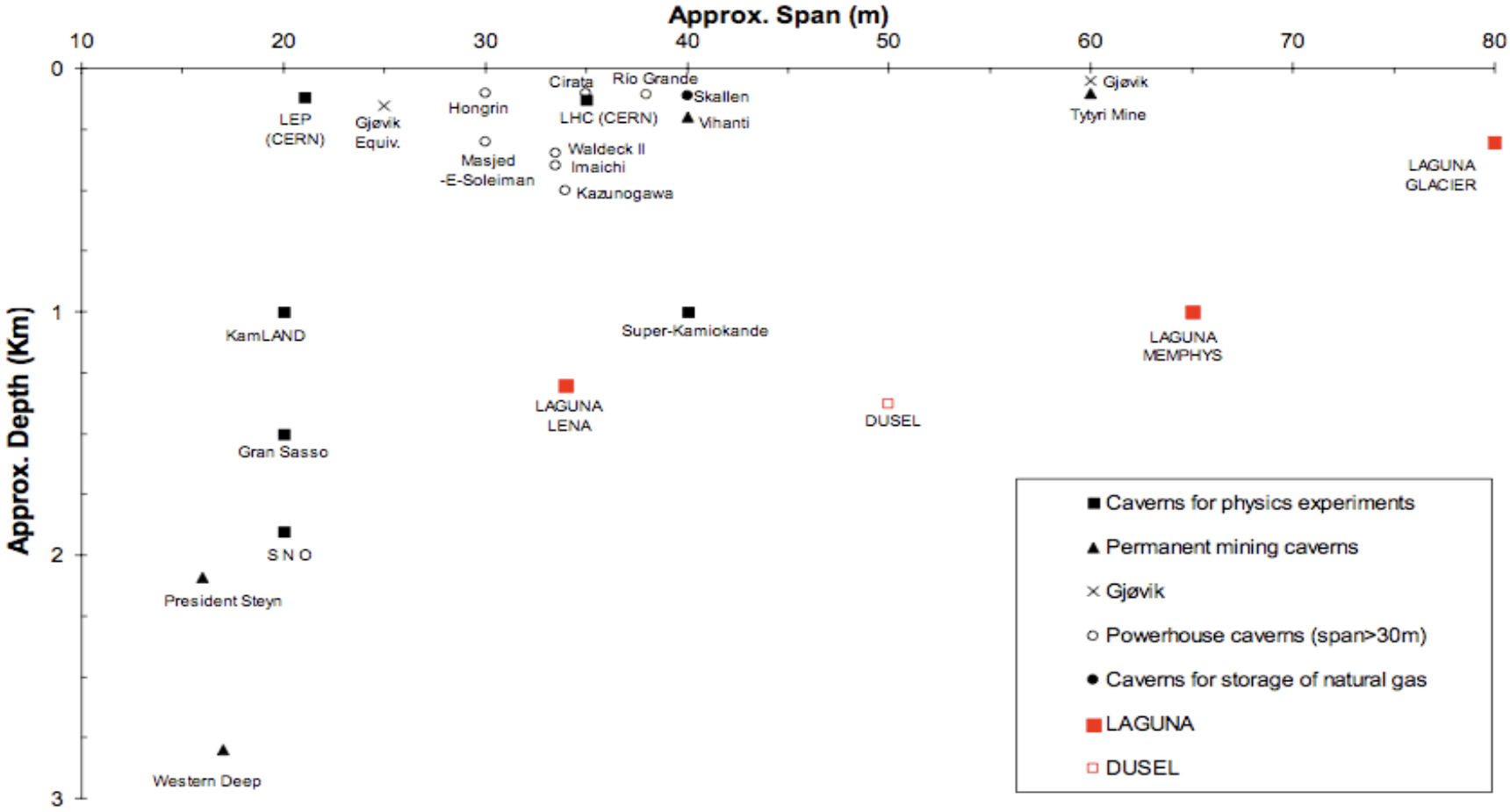


Figure 3.1-5. Scattered plot span vs. depth of permanent large caverns classified by use.

M. Romana: *"we are dealing with world record stuff"*

Conceptual support design II:

It can not be assumed that those huge spans can be supported by conventional methods [cables < 20 m, bolts, shotcrete]:

- they are able to cope with rock stresses near excavation limits
- they are able to cope with “minor” wedges (relative to big spans)
- they are not able to cope with “major” wedges

A complete concrete roof vault is not considered

⇨ Go for a partial concrete structure to cope with potential “major” wedges

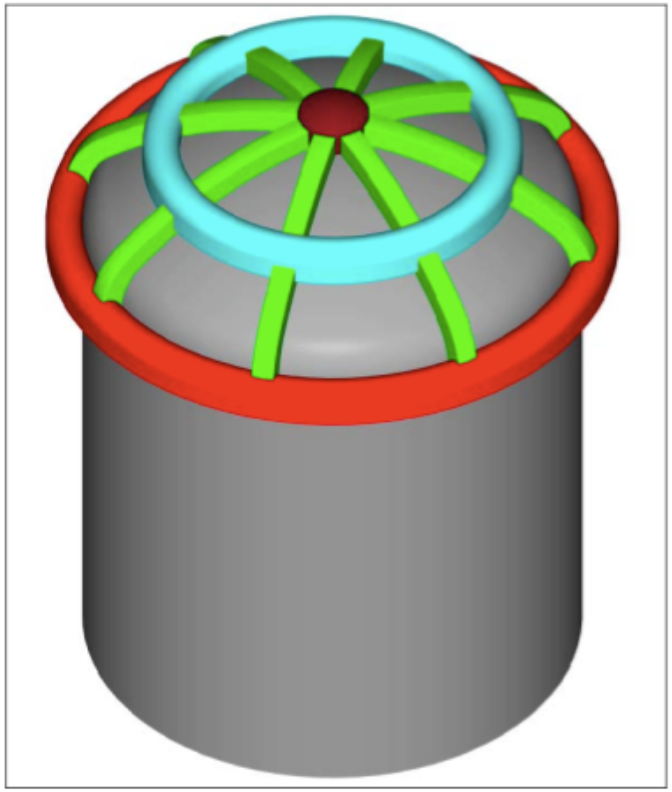


Figure 7.3-2. Perspective view of the vault system.

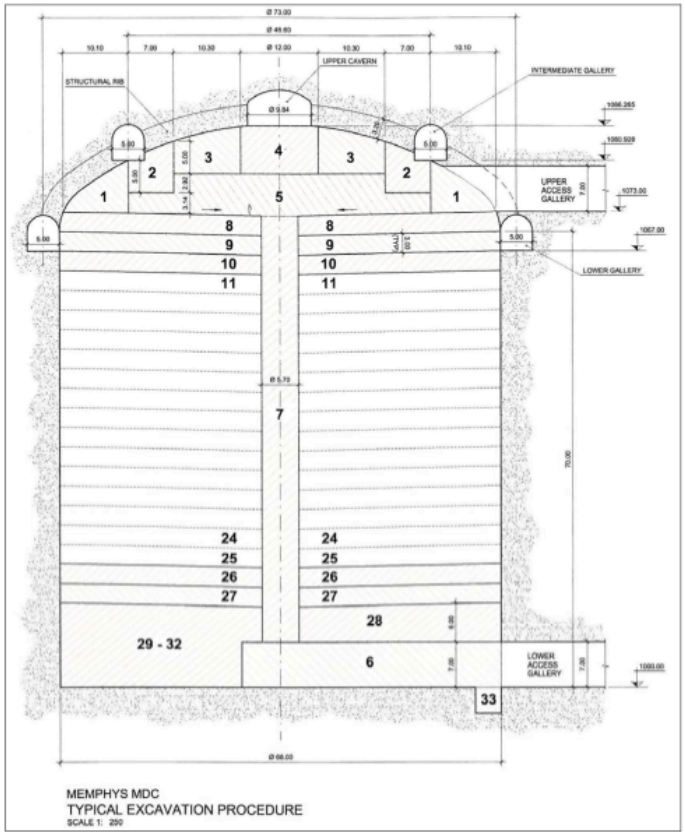
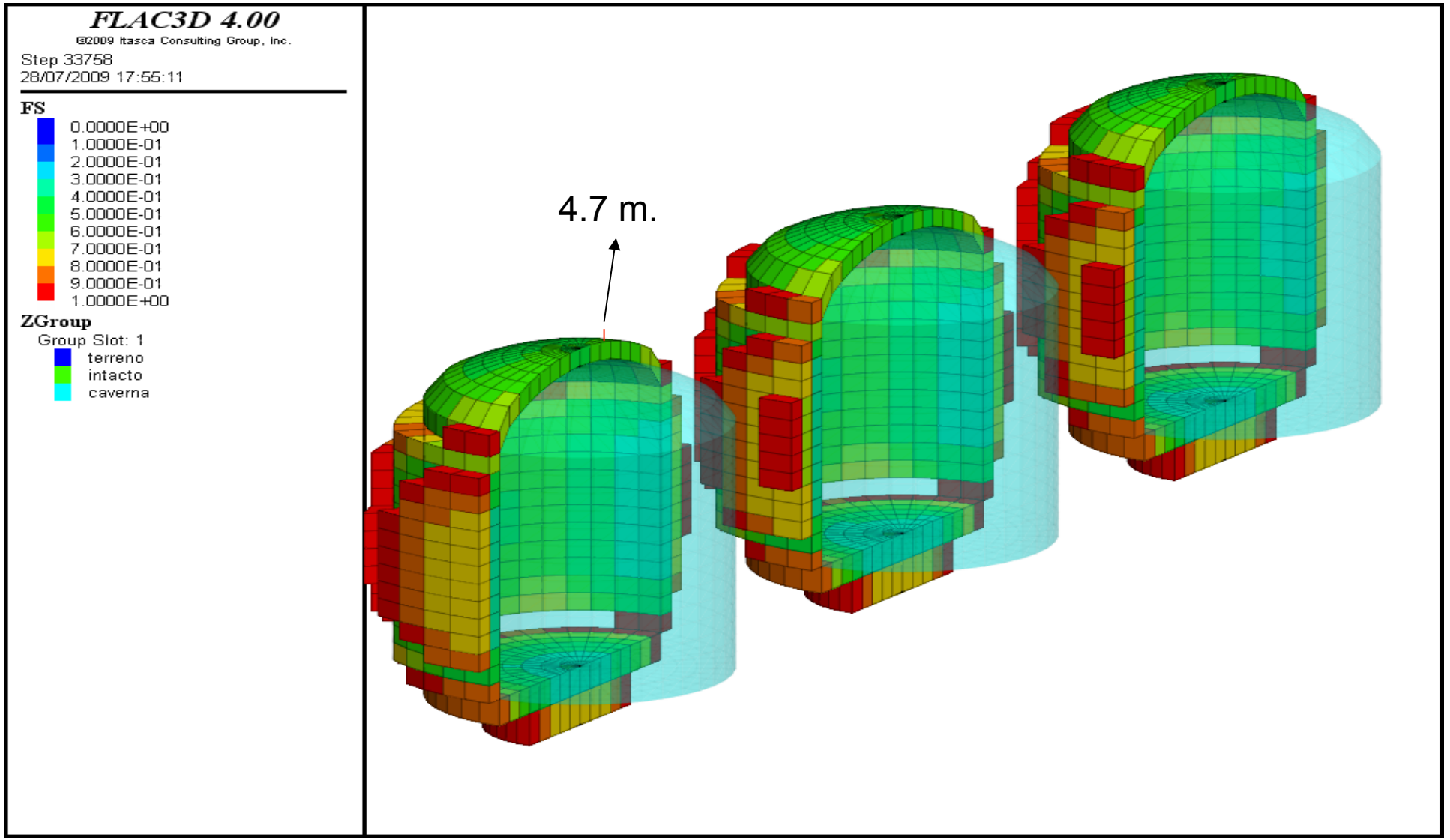


Figure 7.3-3. Excavation sequence for the MEMPHYS caverns.

First estimation of the caverns feasibility:

Modelling / Calculations [elastic]

Three MENPHYS caverns; Plasticity Indicators ⇨ OK

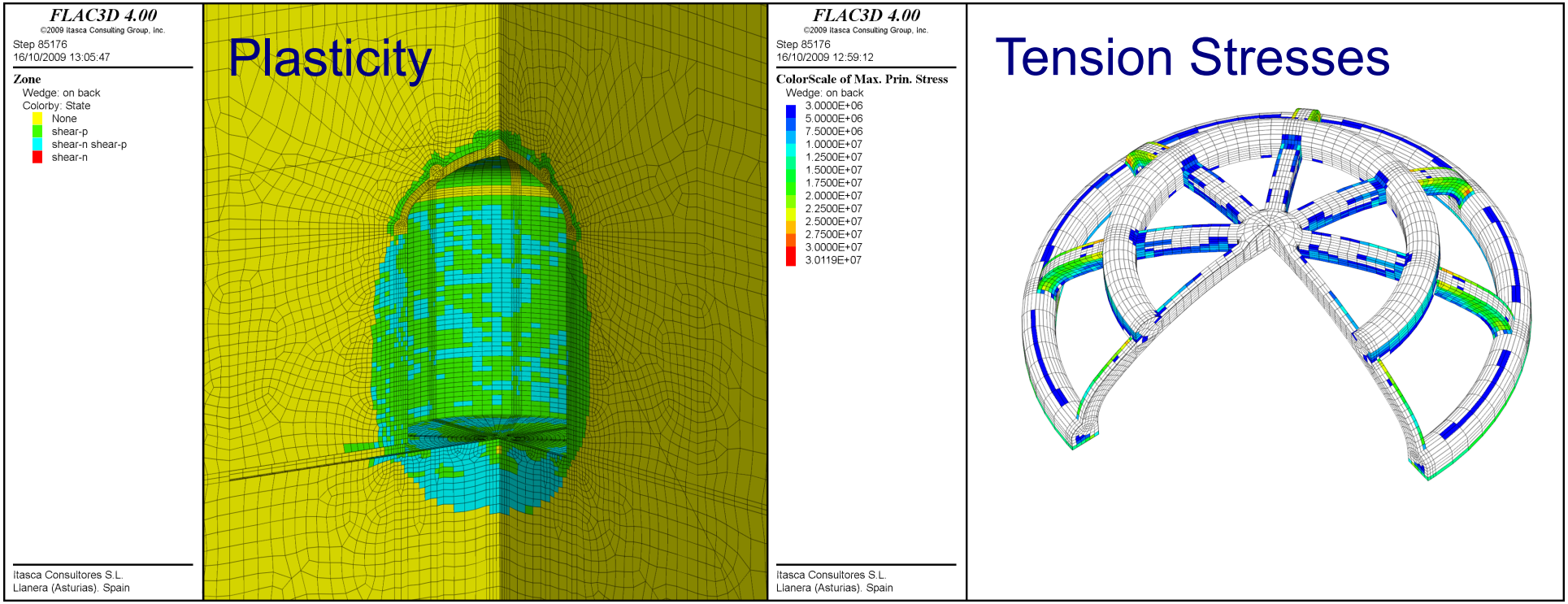


Realistic Calculation: MENPHYS elasto-plastic modelling

- Assumed worst rock conditions
- Almost all construction stages (slightly simplified)
- Three different behaviour laws for concrete

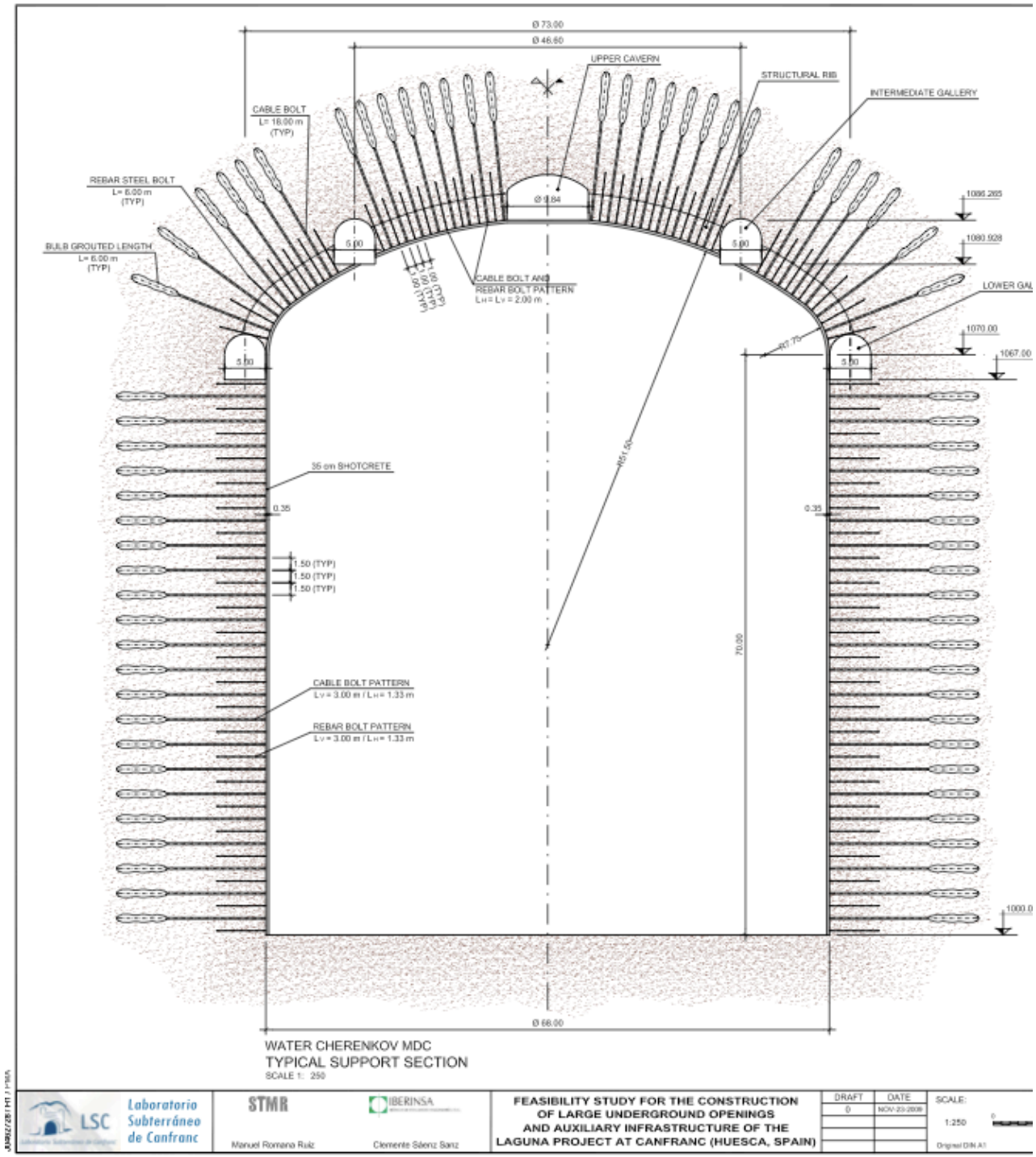
  Elastoplastic / Brittle failure / Softening
- Two different concrete sequences

  Prior to cavern excavation / By stages with cavern excavation
- Concrete needs some reinforcement in the roof lower gallery



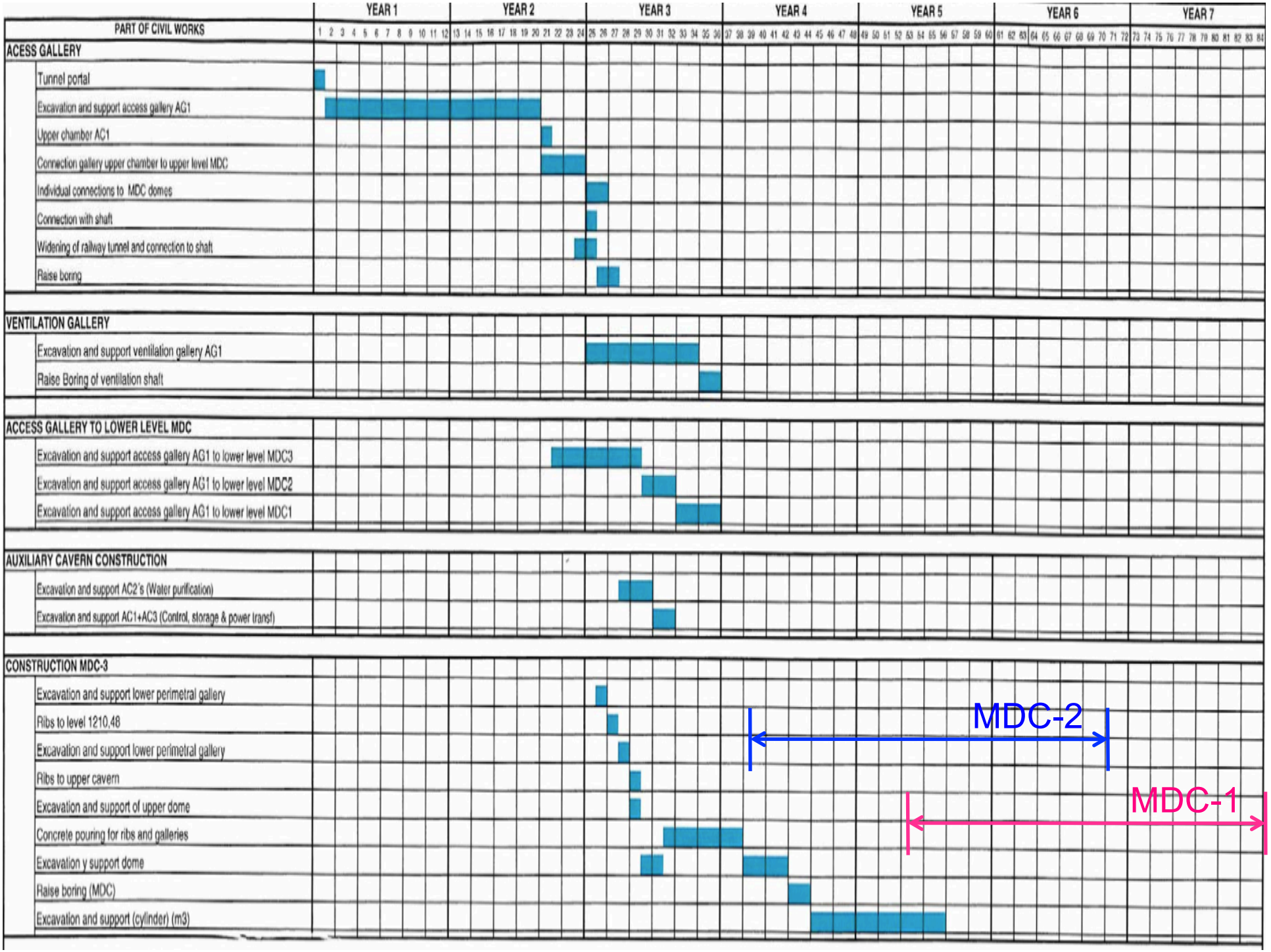
Pre-design
of one of the three
MENPHYS MDCs

after elastic-plastic
structural calculations



MEMPHYS @ LSC : Estimate of Full Cost [detector not included]

CHAPTER 1.- MDC EXCAVATION	
1.1 MDC EXCAVATION	70.600.064,33 €
1,2 MDC SUPPORT	40.095.850,77 €
PARTIAL CHAPTER 1 (euros)	**110.695.915,10 €**
CHAPTER 2.- ACCESS GALLERIES AND CAVERN EXCAVATIONS AND SUPPORT	
2,1 ACCESS GALLERIES	27.959.089,29 €
2,2 AUXILIARY CAVERNS	2.965.952,24 €
2,3 VENTILATION GALLERY AND SHAFT	7.301.460,87 €
PARTIAL CHAPTER 2 (euros)	**38.226.502,40 €**
CHAPTER 3.- INSTALLATIONS	
2,1 CONSTRUCTION INSTALLATIONS	641.750,00 €
2,2 UNDEGROUND INSTALLATIONS	9.993.420,00 €
2,3 SURFACE INSTALLATIONS	251.650,00 €
PARTIAL CHAPTER 3 (euros)	**10.886.820,00 €**
CHAPTER 4.- ENVIRONMENTAL MANAGEMENT	
4,1 ENVIRONMENTAL MANAGEMENT	700.000,00 €
PARTIAL CHAPTER 4 (euros)	**700.000,00 €**
CHAPTERS 1 TO 4 (euros)	**160.509.237,50 €**
HEALTH AND SAFETY	**2.407.639,00 €**
UNDERGROUND MONITORING	**481.528,00 €**
FURTHER SUBSOIL EXPLORATION	**1.029.354,00 €**
DETAILED DESIGN AND PROFESSIONAL ASSOCIATION FEES	**2.639.910,76 €**
TOTAL CONSTRUCTION COST	**167.067.669,26 €**
13% OVERHEAD EXPENSES	**21.718.797,00 €**
6% INDUSTRIAL PROFIT	**10.024.060,16 €**
TOTAL CONTRACTOR BUDGET	**198.810.526,42 €**


YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
YEAR 6
YEAR 7
PART OF CIVIL WORKS
1 2 3 4 5 6 7 8 9 10 11 12
13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29 30 31 32 33 34 35 36
37 38 39 40 41 42 43 44 45 46 47 48
49 50 51 52 53 54 55 56 57 58 59 60
61 62 63 64 65 66 67 68 69 70 71 72
73 74 75 76 77 78 79 80 81 82 83 84
ACESS GALLERY
Tunnel portal
Excavation and support access gallery AG1
Upper chamber AC1
Connection gallery upper chamber to upper level MDC
Individual connections to MDC domes
Connection with shaft
Widening of railway tunnel and connection to shaft
Raise boring
VENTILATION GALLERY
Excavation and support ventilation gallery AG1
Raise Boring of ventilation shaft
ACCESS GALLERY TO LOWER LEVEL MDC
Excavation and support access gallery AG1 to lower level MDC3
Excavation and support access gallery AG1 to lower level MDC2
Excavation and support access gallery AG1 to lower level MDC1
AUXILIARY CAVERN CONSTRUCTION
Excavation and support AC2's (Water purification)
Excavation and support AC1+AC3 (Control, storage & power transf)
CONSTRUCTION MDC-3
Excavation and support lower perimetral gallery
Ribs to level 1210.48
Excavation and support lower perimetral gallery
Ribs to upper cavern
Excavation and support of upper dome
Concrete pouring for ribs and galleries
Excavation y support dome
Raise boring (MDC)
Excavation and support (cylinder) (m3)
MDC-2
MDC-1

Summary

- A thorough Feasibility Study for a ~1Mt WC at the LSC was performed with positive results. The corresponding report can be accessed at
  http://www.lsc-canfranc.es/Docs/Experiments/LAGUNA/LSC_Revision_20100512.pdf
  /LSC_MEMPHYS_PLANS_Revision_20100512.pdf

  Many items have not been presented here due to lack of time (in particular installations and auxiliary infrastructures). Please have a look to the above documents

- The aspects of that F.S. most relevant, in my opinion, to the HK project have been presented.
  - ➔ the layout and its rational for the global infrastructure
  - ➔ ideas and calculations about dealing with "not perfect" rock conditions
  - ➔ a careful and realistic estimate of the cost of the whole project (no det.)
  - ➔ a careful and realistic estimate of the construction schedule

Additional material

Submission to European Strategy Preparatory Group

based on arXiv:1206.0475 by Coloma, Fernandez-Martinez, Labarga submmitted to JHEP[_073P_0612]

A realistic next-generation nucleon decay and neutrino experiment capable to probe leptonic CP violation

Enrique Fernández-Martínez[1,*] and Luis Labarga[2,†]

[1] *CERN Physics Department, Theory Division, CH-1211 Geneva 23, Switzerland*

[2] *Departamento de Física Teórica, Universidad Autónoma de Madrid, Cantoblanco 28049 Madrid, Spain*

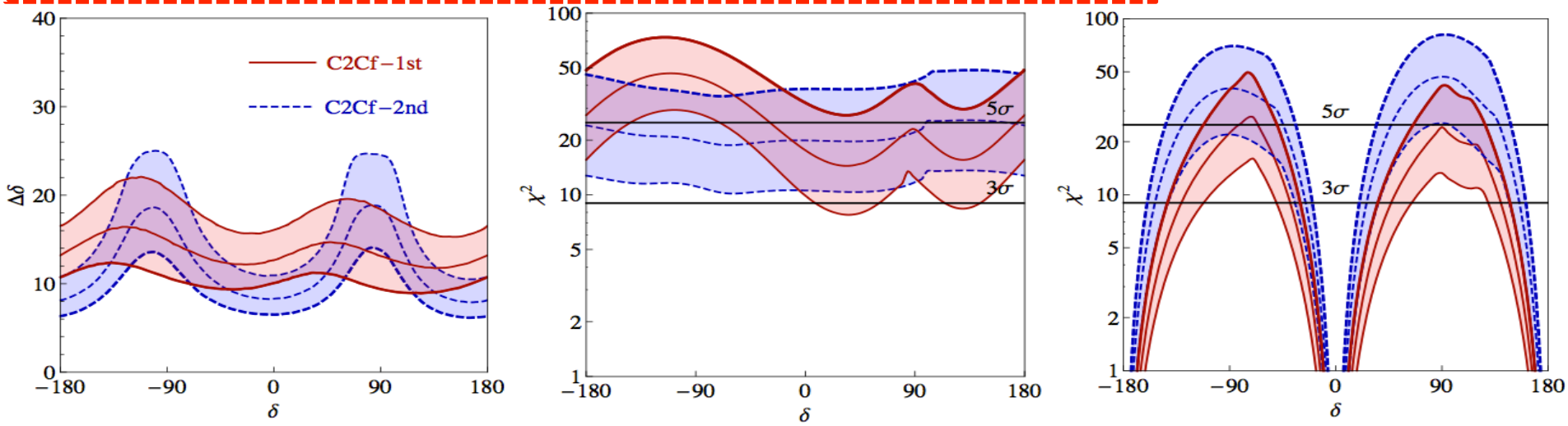


FIG. 3: Comparison of $\Delta\delta$ (left panel), the mass hierarchy (middle panel) and the CPV discovery potential (right panel) for the high energy beam of 0.8 MW close to the first oscillation peak (C2Cf-1st) and the lower energy 4 MW beam close to the second oscillation peak (C2Cf-2) observed at a 650 km baseline corresponding to the CERN to Canfranc distance. For all observables, the thicker lines the correspond to the maximum exposure considered (best results), while the other lines show the results after reducing the statistics by factors of 2 and 4.

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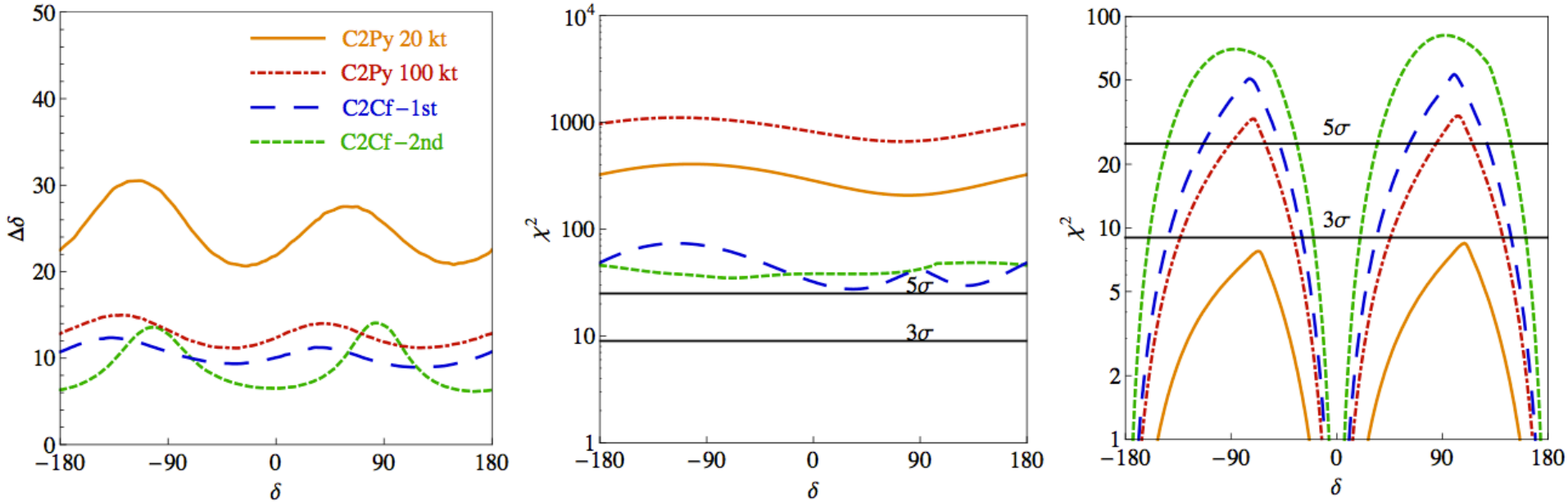

FIG. 4: Comparison of $\Delta\delta$ (left panel), the mass hierarchy (middle panel) and the CPV discovery potential (right panel) for the setups C2Py 20kt, C2Py 100 kt, C2Cf-1st and C2Cf-2nd.