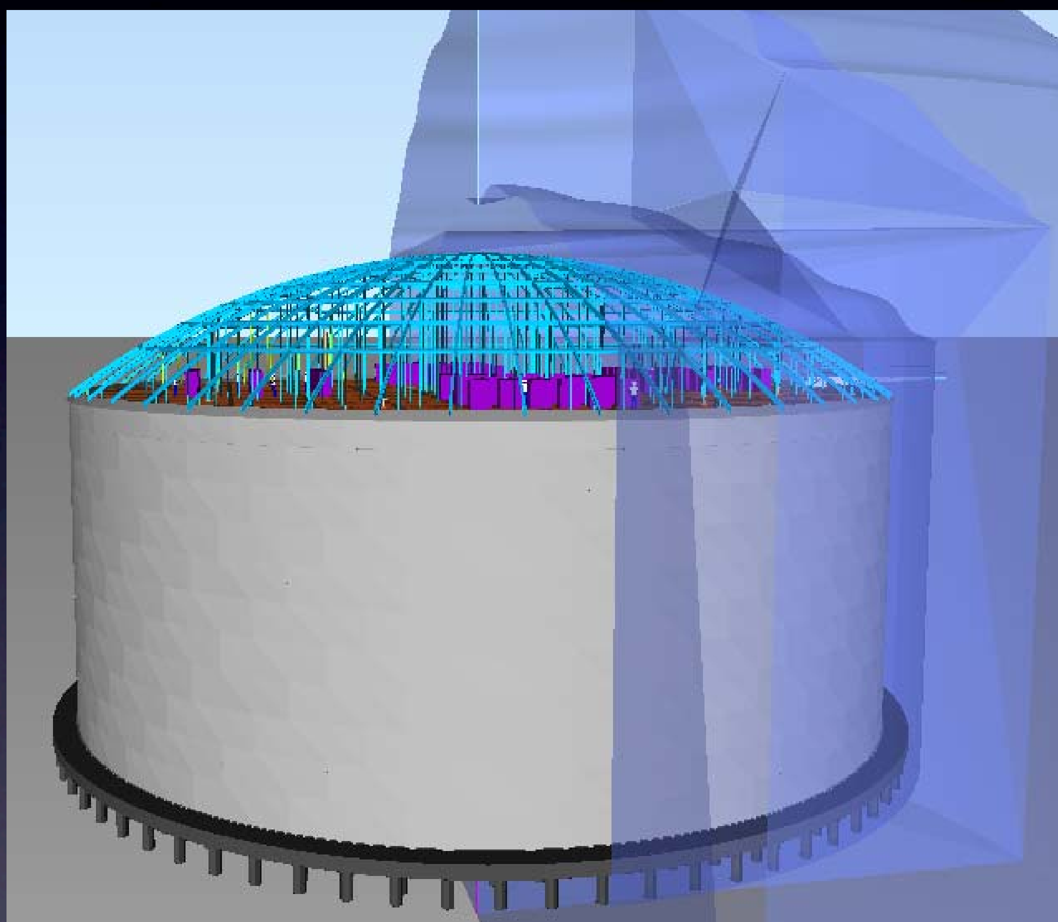


An underground kton-scale pilot project

André Rubbia (ETH Zurich)

Also my own summary of the workshop...

Acknowledgments to FP7 Research Infrastructure "Design Studies" LAGUNA(Grant Agreement No. 212343 FP7-INFRA-2007-1)

2nd International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (GLA2011)

A Giant Liquid Argon detector

- The discovery of a non-vanishing θ_{13} (in T2K/NOvA/reactor experiments) will be the direct experimental proof for the fully 3x3 nature of the PMNS matrix. In this case, **the inescapable and logical next step will be to test the physical complex nature of PMNS via the measurement of the so-called δ phase.** This can be achieved by precision-study of the energy E dependence of the $\nu_\mu \rightarrow \nu_e$ appearance probability at a given baseline L.
- **These measurements require a Giant 100 kton-scale LAr detector located at the proper distance from a MW-power conventional neutrino beam source.**
- *Per se*, the experiment has a statistical sensitivity $\sin^2 2\theta_{13}<0.001$ (90%C.L.), a factor 10x better than T2K&NOvA, a domain inaccessible to disappearance measurements with reactors.
- The unambiguous determination of δ requires in addition that the uncertainty related to the ν-propagation through matter be resolved, for what concerns the as-yet-unknown neutrino mass hierarchy. **At long baselines, one can resolve simultaneously the δ- and the mass hierarchy problems and a comparison of neutrino / antineutrino runs can be helpful.**
- Finally, since the detector is located underground, **an extremely rich non-accelerator related physics programme is achievable**, in particular, a significant extension of the sensitivity in proton decay searches, and the study of a very broad range of neutrinos of astrophysical origin, ranging from lowest MeV energies to several 10's GeV.

How to determine the CP-phase ?

Well-defined phenomenology from 3x3 PMNS matrix formalism ➠ oscillation probability calculable as sum of atmospheric, solar and interference terms

$$P(\nu_\mu \to \nu_e) = \Sigma_{i=1,4} P_i$$

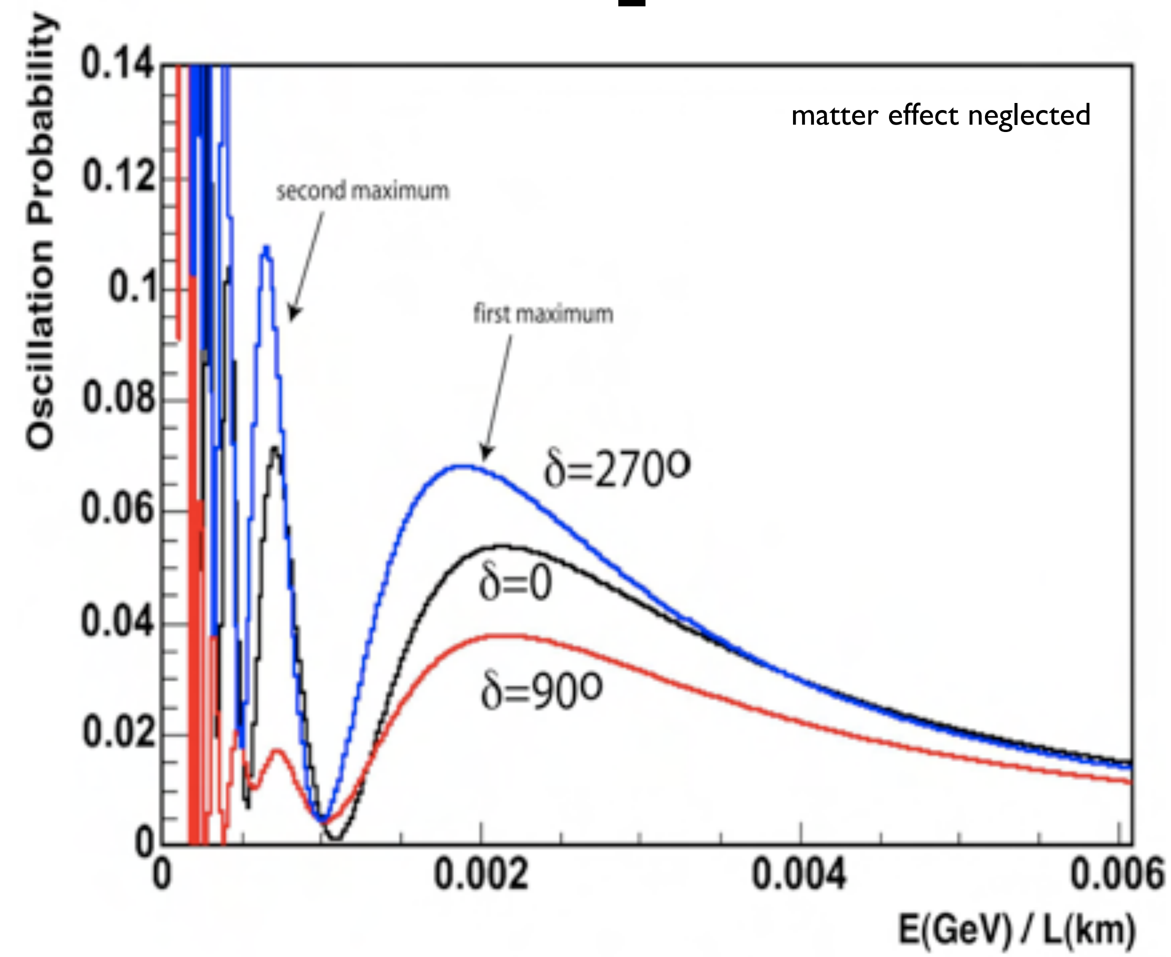
$$P_1 = \sin^2\theta_{23}\sin^2(2\theta_{13})\left(\frac{\Delta_{13}}{B_\pm}\right)^2 \sin^2\frac{B_\pm L}{2}$$

$$P_2 = \cos^2\theta_{23}\sin^2(2\theta_{12})\left(\frac{\Delta_{12}}{A}\right)^2 \sin^2\frac{AL}{2}$$

$$P_3 = J\cos\delta\left(\frac{\Delta_{12}}{A}\right)\left(\frac{\Delta_{13}}{B_\pm}\right)\cos\frac{\Delta_{13}L}{2}\sin\frac{AL}{2}\sin\frac{B_\pm L}{2}$$

$$P_4 = \mp J\sin\delta\left(\frac{\Delta_{12}}{A}\right)\left(\frac{\Delta_{13}}{B_\pm}\right)\sin\frac{\Delta_{13}L}{2}\sin\frac{AL}{2}\sin\frac{B_\pm L}{2}$$

see M. Diwan



- Effect of CP Phase δ_{CP} appears as
  - ν_e Appearance Energy Spectrum Shape in Wide Band Beam at fixed L
    - Peak position and height for 1st, 2nd maximum and minimum
    - Sensitive to all the non-vanishing δ including 180°
    - Investigate CP phase with ν run only, but need WBB
    - Need very good energy resolution and low background systematics
  - Difference between ν_e and $\bar{\nu}_e$ Appearance Behaviors
    - Also in Narrow Band Beam (off-axis)
    - Need both beam polarities with similar statistics to study effect
    - Need good control of systematic errors between neutrino & antineutrino run

Why a Giant Liquid Argon detector ?

- **Motivated by the requirements to perform the precise appearance measurements and to reduce systematic errors**
  - Exclusive final states, low energy threshold on all particles
  - Excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
    - ➡ Suitable for spectrum measurement with needed wide energy coverage
  - Excellent π^0/electron discrimination
    - ➡ Wide band On-Axis beam is tolerable

⇨ Spectrum measurement (1st and 2nd Oscillation Max.) with On-Axis beam with 5years ν beam run, then maybe anti-ν beam run

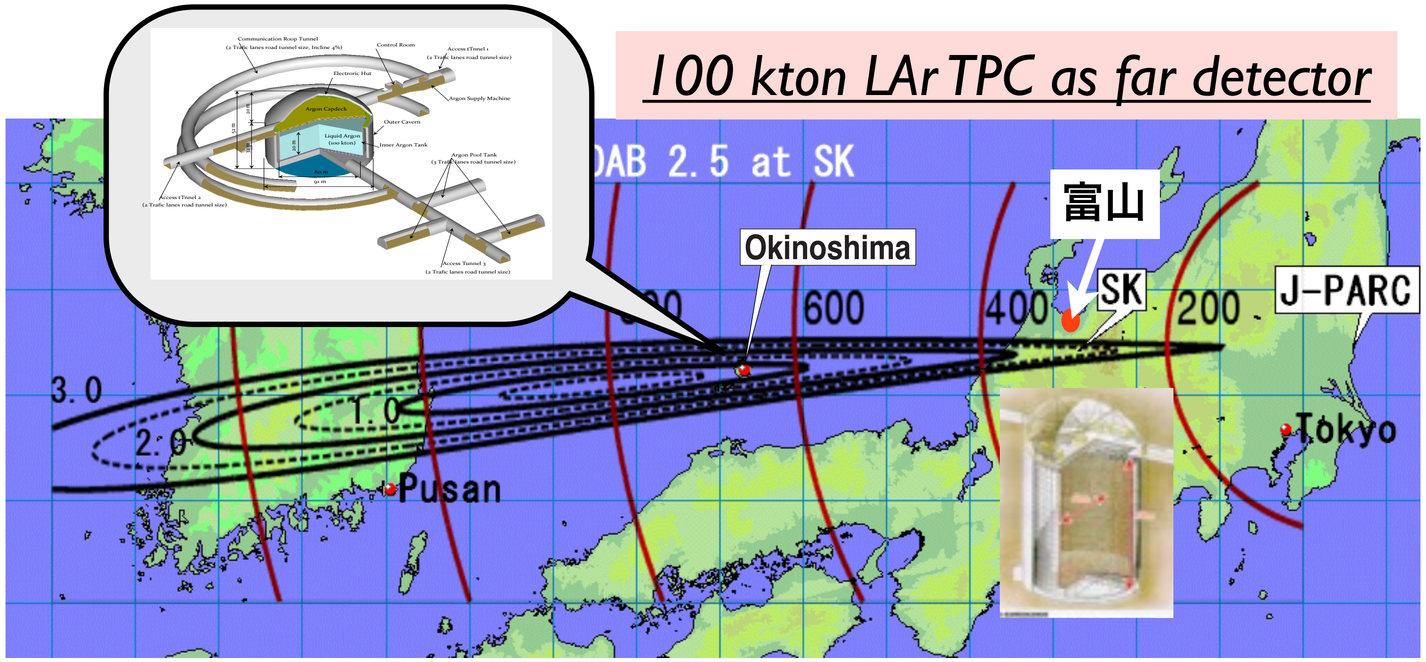
- **Additional requirements**
  - Beam power is MW-range to achieve results within reasonable time scale
  - Long baseline (>600km) to see the 2nd osc. maximum
  - Need On-Axis beam for wide energy coverage

⇨ **100 kton Giant Liquid Argon TPC @ Long Baseline, On-Axis**
Here we consider the Japanese and European scenarios

US scenario (LBNE) : Svoboda, Baller, Diwan, ...

(I) J-PARC to Okinoshima

100 kton LAr TPC as far detector

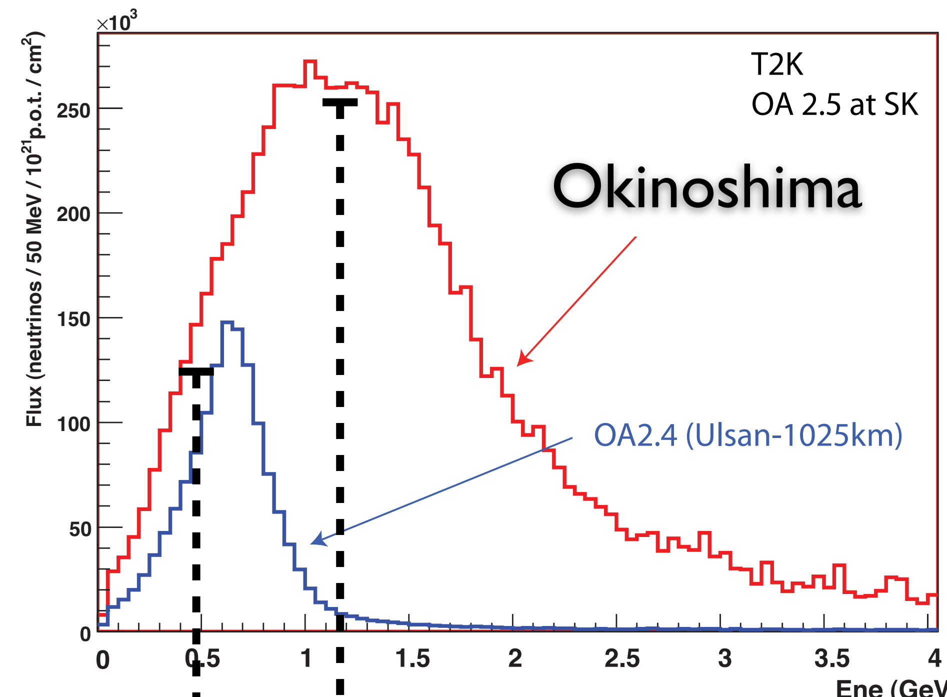


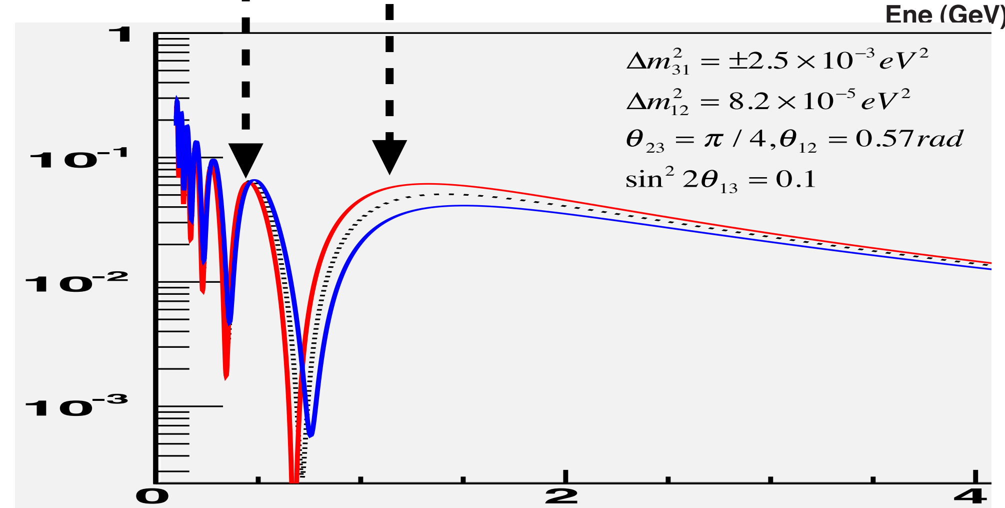
arXiv:0804.2111 [hep-ph] (2008)

P32 proposal (LAr TPC R&D) recommended by J-PARC PAC in Jan 2010

Setup: Baseline = 658 km, Off-axis angle = 0.76°
Existing beam line + upgrade J-PARC MR (1.66MW)

see T. Kobayashi

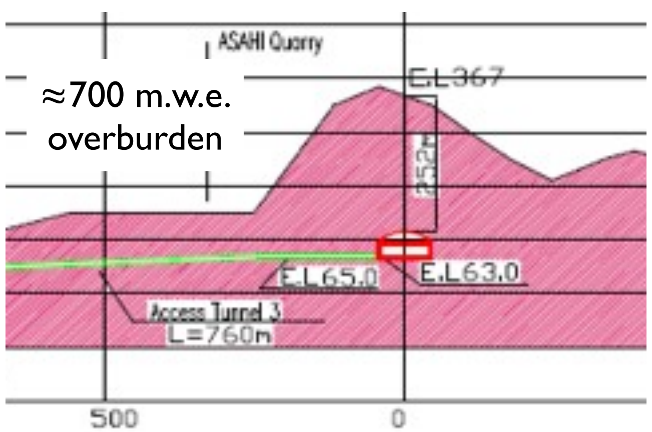


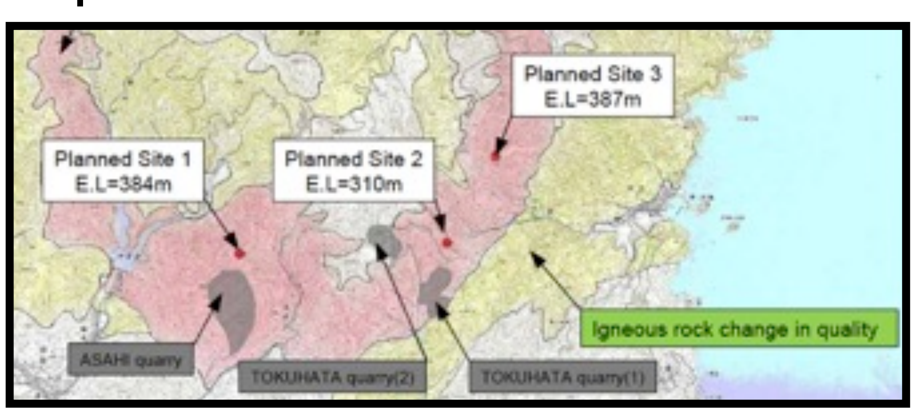


Okinoshima prestudy

see M. Yoshioka

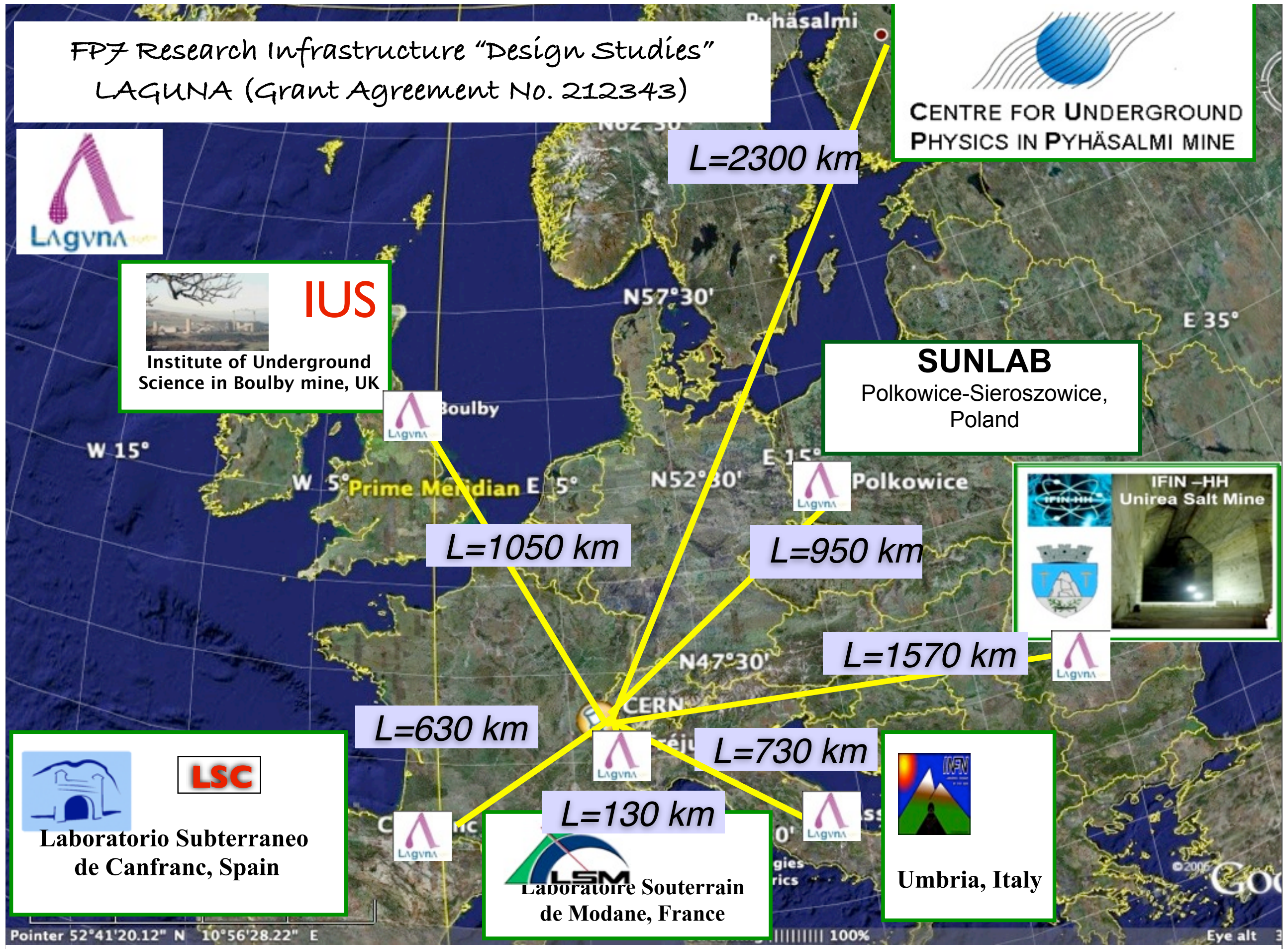
- three best candidate sites on Okinoshima
- bed rock adequate for large cavern
- infrastructure (road, port, electrical power, ...) sufficient
- liquid argon procurement possible via ferries





(2) CERN to LAGUNA

arXiv:1003.1921 (2010)



LAGUNA Design Study: feasibility study of a new deep underground research infrastructure, approved by EC (2008-2011)

Seven → two(+one) sites
Fréjus → Short long baseline
Pyhäsalmi → Long long baseline

Three detector options
GLACIER, LENA, MEMPHYS

Several beam options

Possibly start with upgraded CERN SPS with new beamline, then later upgrade to new CERN HP-SPL or HP-PS accelerators with MW power

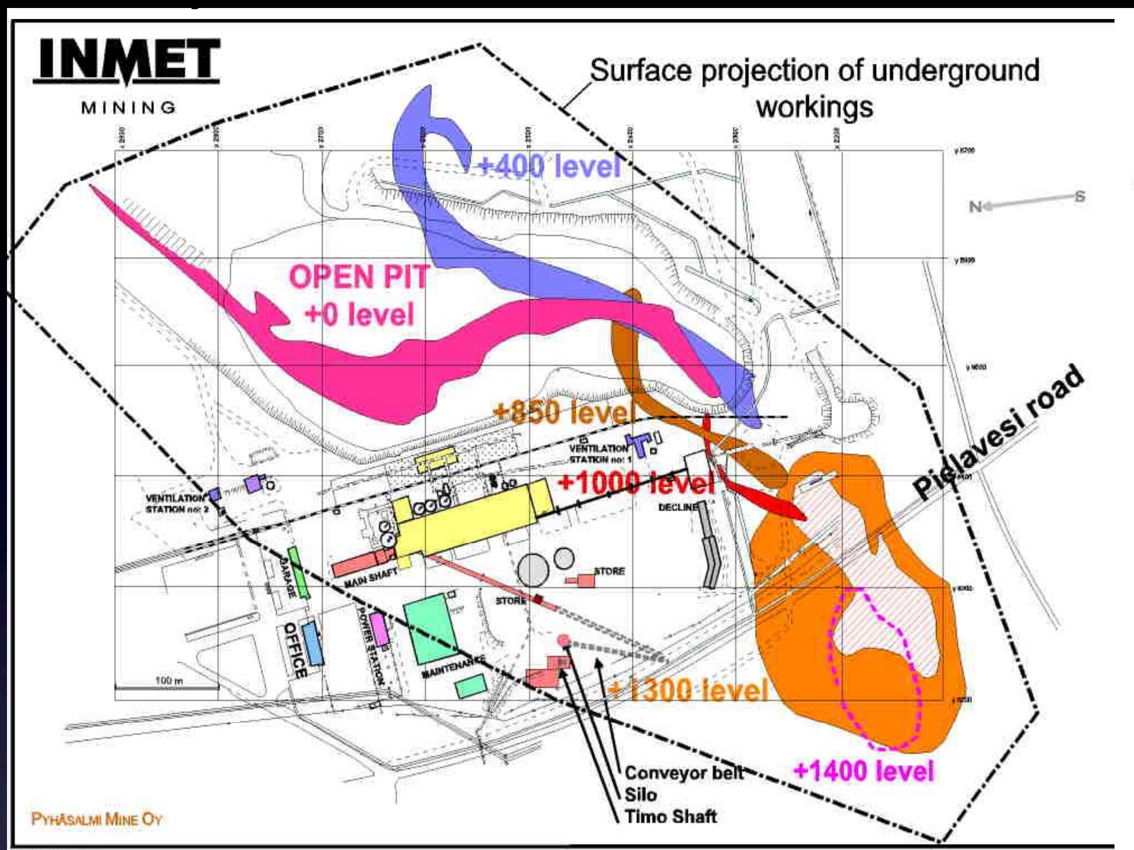
see I. Efthymiopoulos

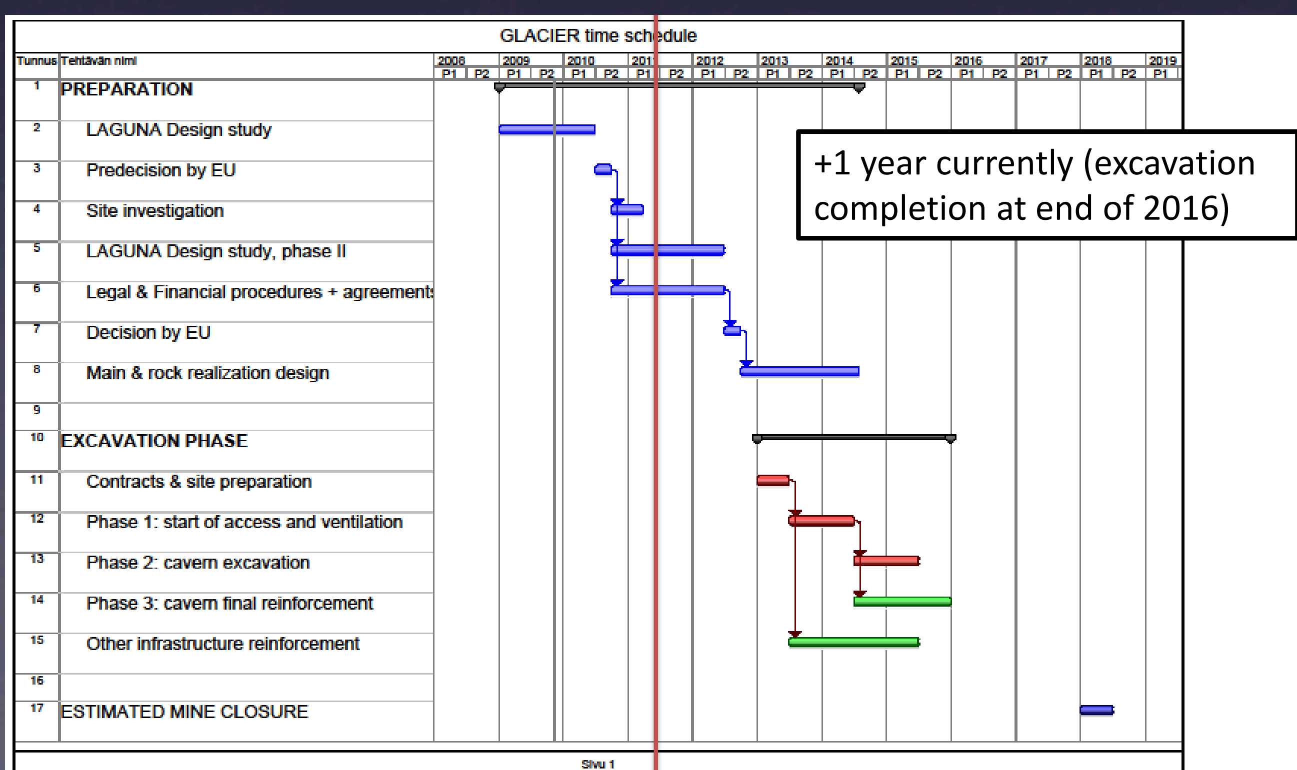
NEW LAGUNA-LBNO: An extension to include study of feasibility of long baseline neutrino beams from CERN and provide a better assessment of the detector costs

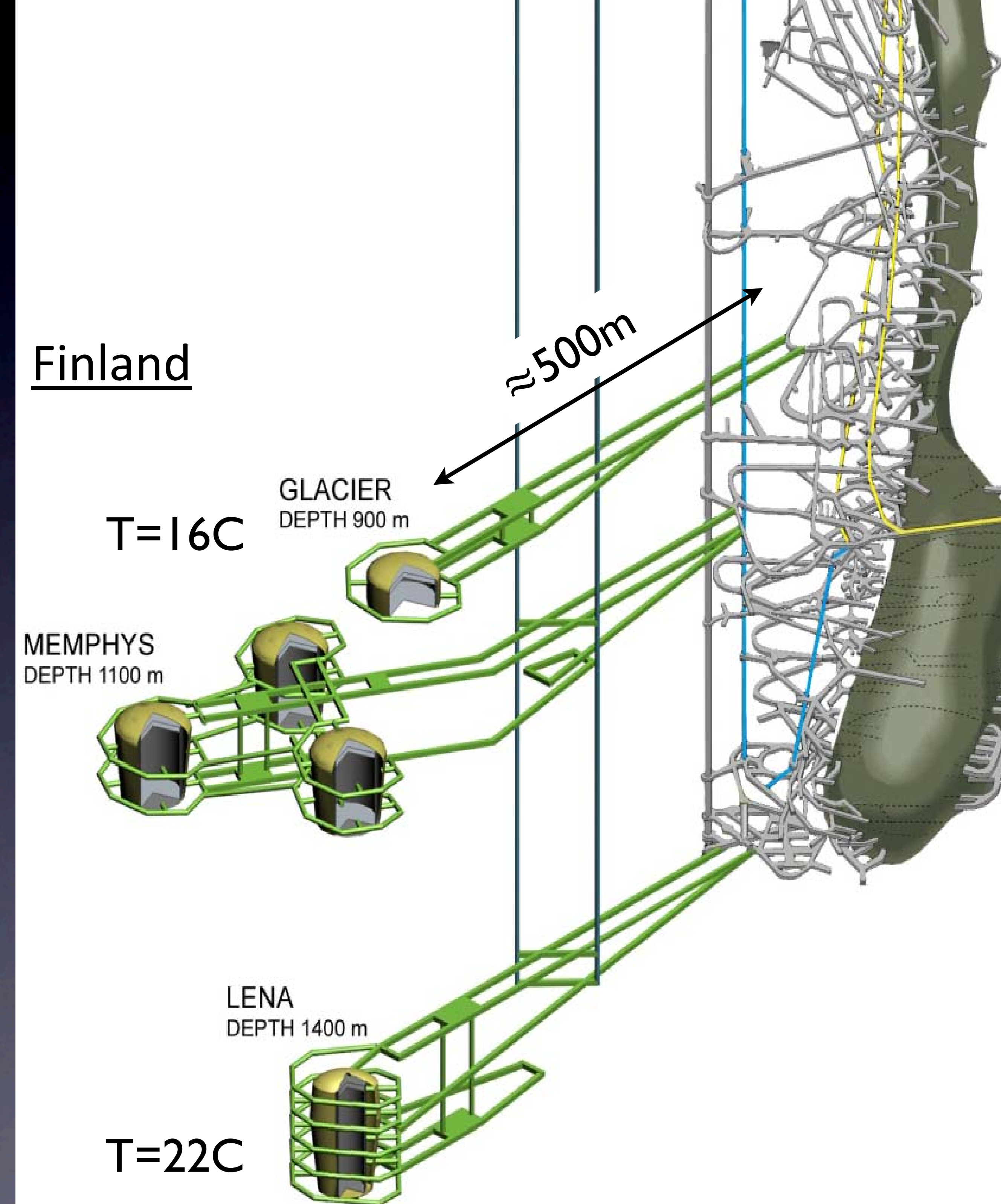
Fully approved !
Duration:
September 2011-July 2013

L. Uotinen

LAGUNA infrastructure at site







Cosmic Ray experiment EMMA at shallow depth

250 m long tunnel and a cavern at 1400m excavated for LAGUNA R&D

Cafeteria, meeting room and sauna at 1400 m below ground

Mobile phones work and internet available also at 1400 m

How to build a Giant Liquid Argon detector ?

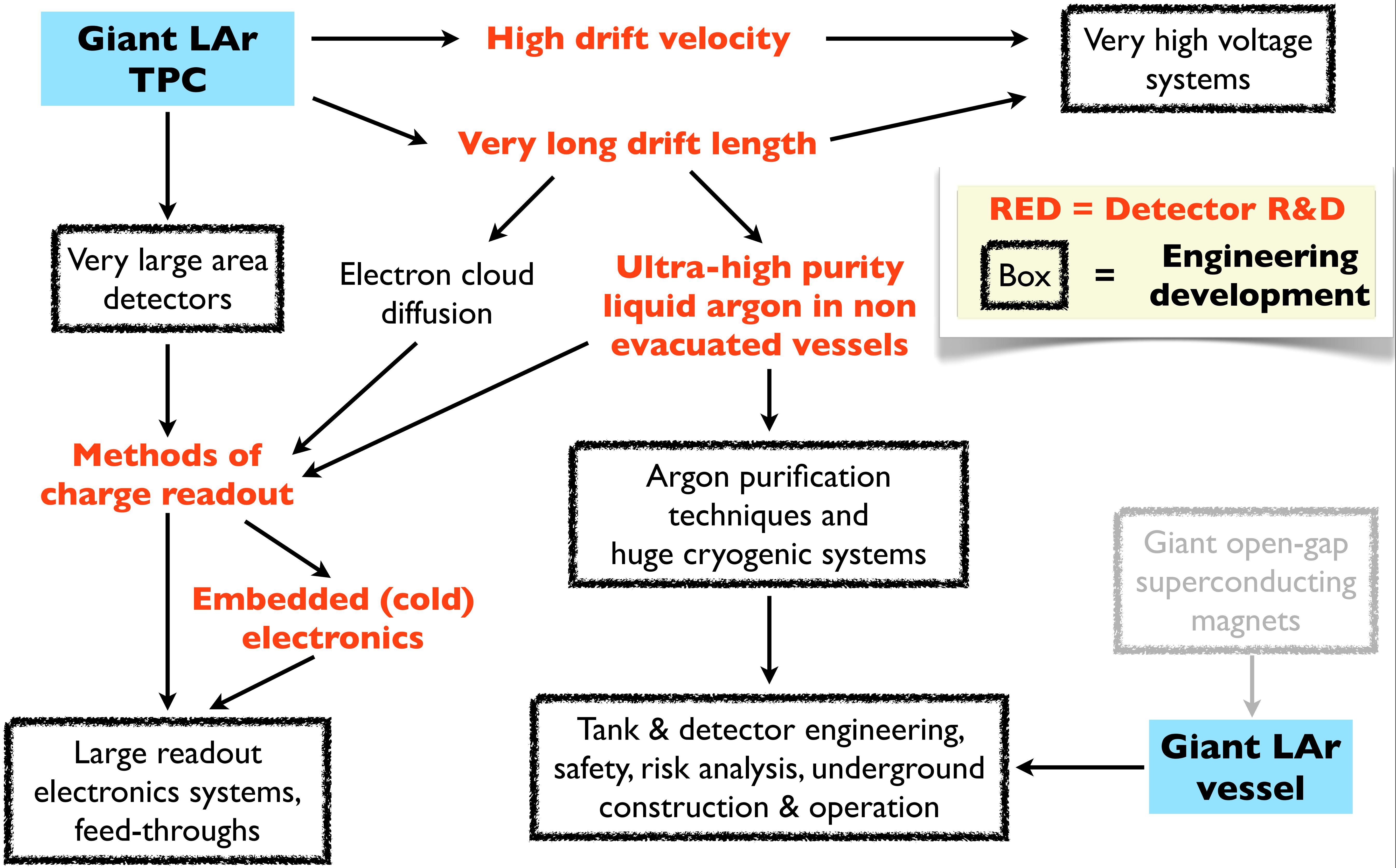
- The realization of a 100 kton LAr TPC demands concrete R&D in several areas. Although correctly relying on the pioneering efforts, it cannot be simply "linearly" extrapolated from the current state-of-art.
- To address this point, a series of workshops dedicated to these issues was initiated to bring together researchers having common interest in realizing a giant neutrino observatory based on the liquid Argon time projection chamber technology combining next-generation searches for proton decay and neutrino physics with natural and artificial sources.

⇨ GLA2010: The 1st International Workshop towards the Giant Liquid Argon Charge Imaging Experiment (Tsukuba, Japan, March 28-31, 2010).

Now: GLA2011 (Jyväskylä, Finland, June 2011)

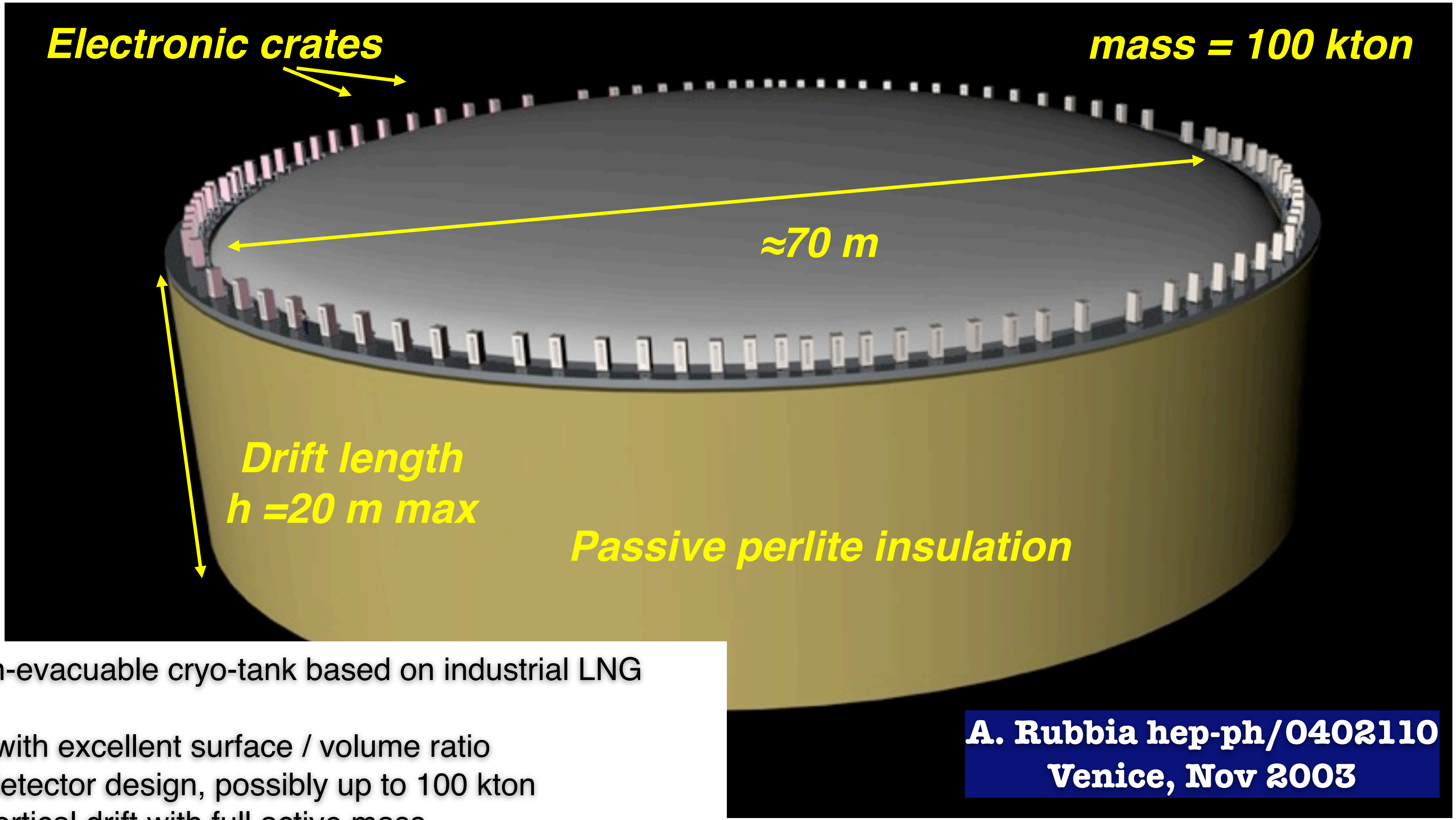
Next: GLA2012 (to be announced after my talk)

The R&D path to Giant LAr detectors



Giant Liquid Argon Charge Imaging ExpeRiment

A scalable detector with a non-evacuable dewar and ionization charge detection with amplification



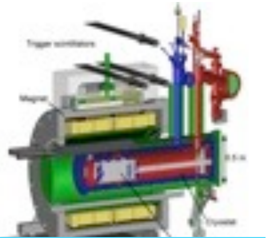
- Single module non-evacuable cryo-tank based on industrial LNG technology
- Cylindrical shape with excellent surface / volume ratio
- Simple, scalable detector design, possibly up to 100 kton
- Single very long vertical drift with full active mass
- Double phase, large area LAr LEM-TPC for long drift paths
- Possibly immersed visible light readout for Cerenkov imaging
- Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector
- Reasonable excavation requirements (<250‘000 m^3)

We have developed an R&D roadmap to address this design→ pto

GLACIER R&D roadmap

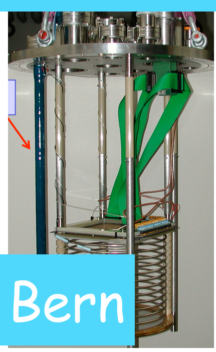
A systematic, comprehensive and staged programme has been implemented

Single phase LArTPC



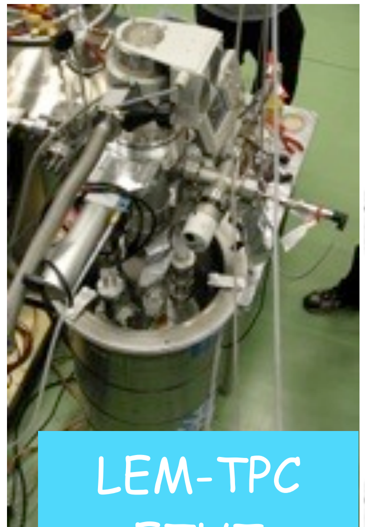
KEK

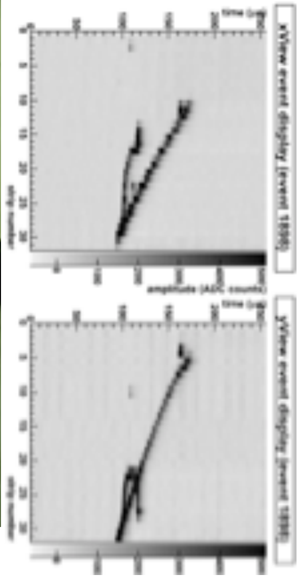
B-field test



Bern

Double phase LAr-LEM TPC

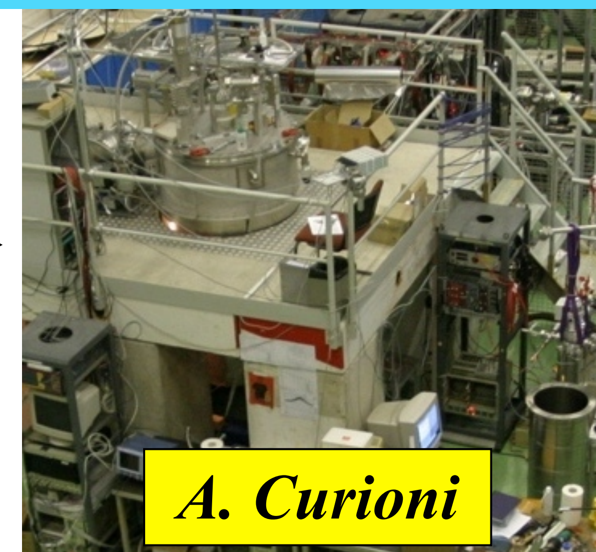




LEM-TPC ETHZ

F. Resnati, M. Zito

ArDM-1t(RE18), presently operating@CERN



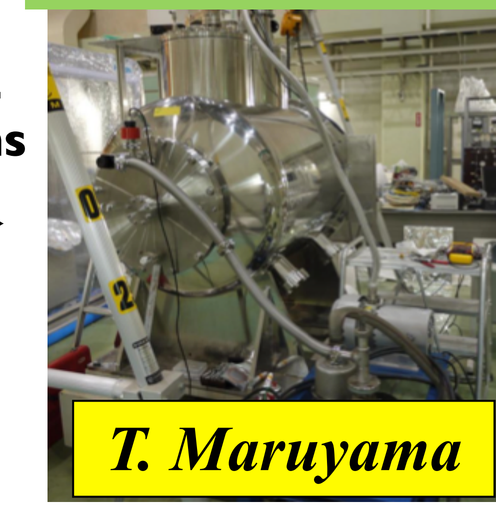
A. Curioni

Move underground at LSC in 2011

Test beams

250L@JPARC

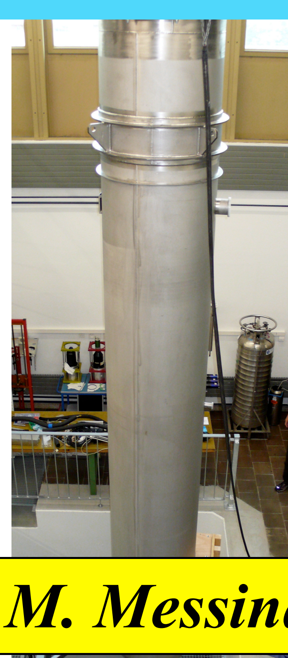
Beam exposed in 2010 (and 2011?)



T. Maruyama

direct proof of long drift path up to 5 m

ArgonTube @Bern



M. Messina

first run in 2011

Test beams

6m3 @ CERN

A. Marchionni

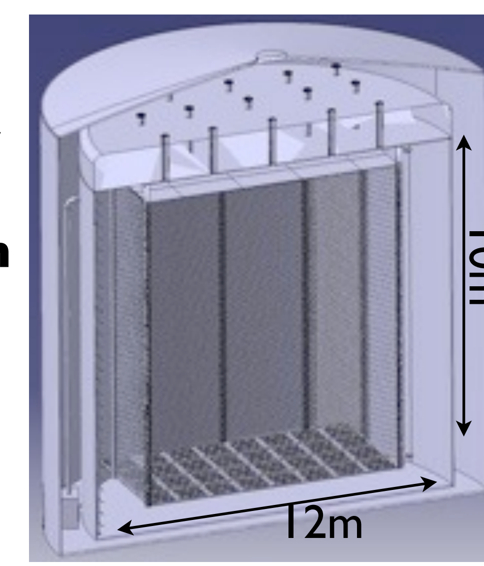
gas flushing: done

LAr: 2012, NA 2013 ?

Charged particles test beam, calorimetry, non-evacuated vessels, LAr purity

Full engineering demonstrator for larger detectors, with a stand-alone short baseline physics programme or underground ?

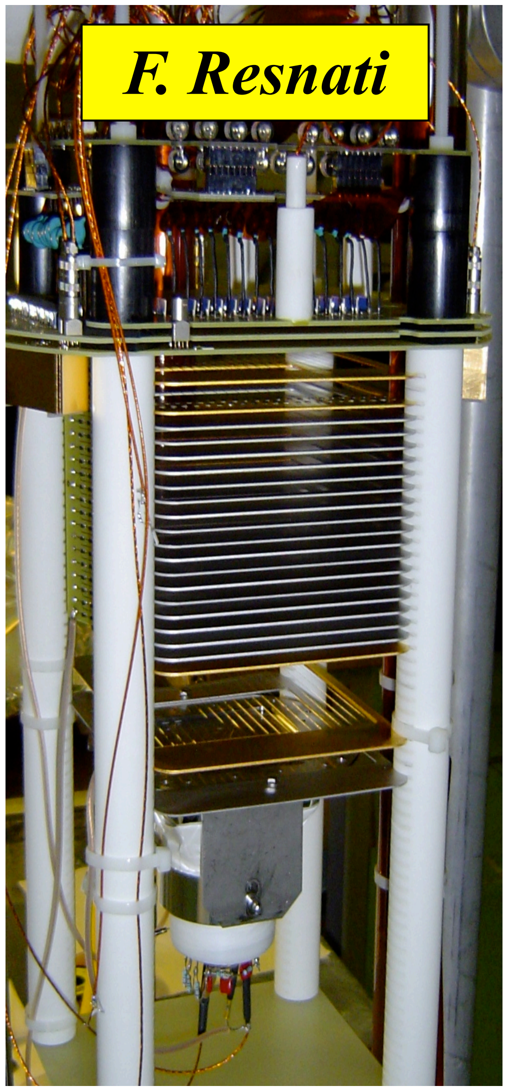
kton-scale



Methods of charge readout

These developments represent major break-throughs in the path towards large detectors!

(1) double phase Ar LEM/THGEM TPC



ETHZ group

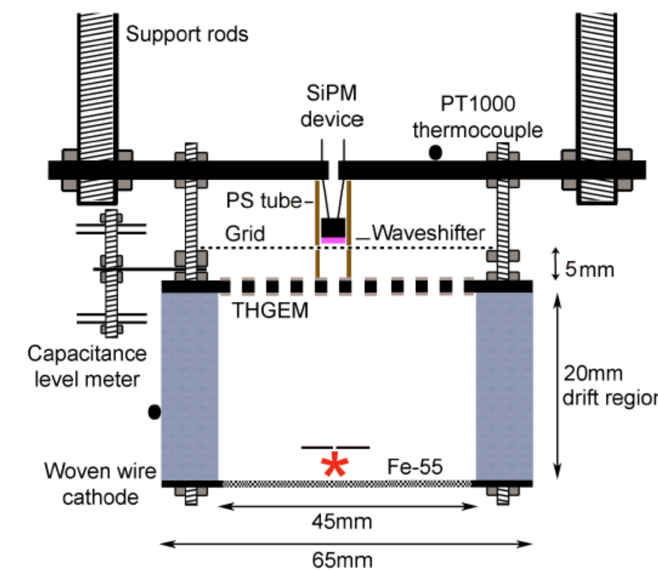
Badertscher et al., IEEE Proc. arXiv0811.3384 and NIMA617:188-192,2010

(2) Double phase + MicroMegas

Saclay group

A. Delbart et al., GLA2010 workshop

(3) secondary scintillation from THGEM (optical readout)



Sheffield group

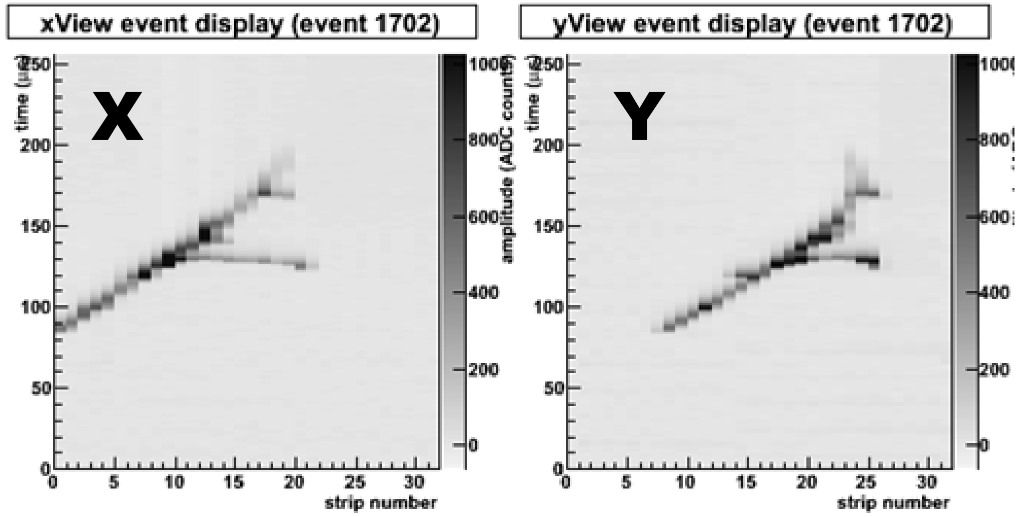
P K Lightfoot et al., JINST 4:P04002,2009

see also A. Bondar et al., arXiv: 1005.5216 (May 28th 2010)

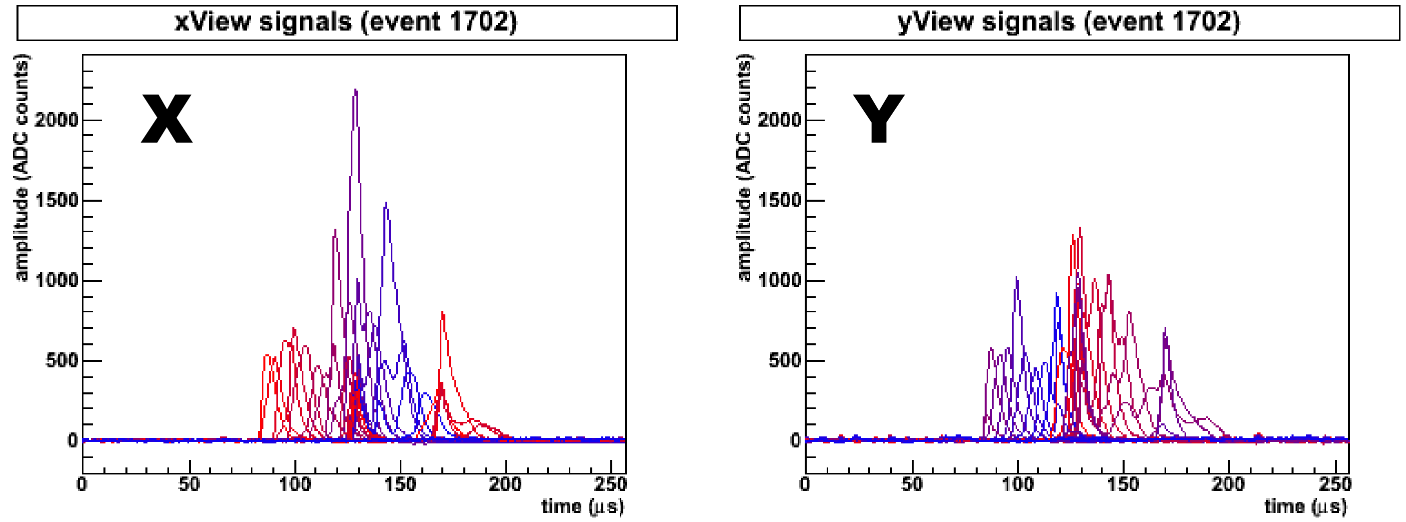
In Collaboration with CERN RD51

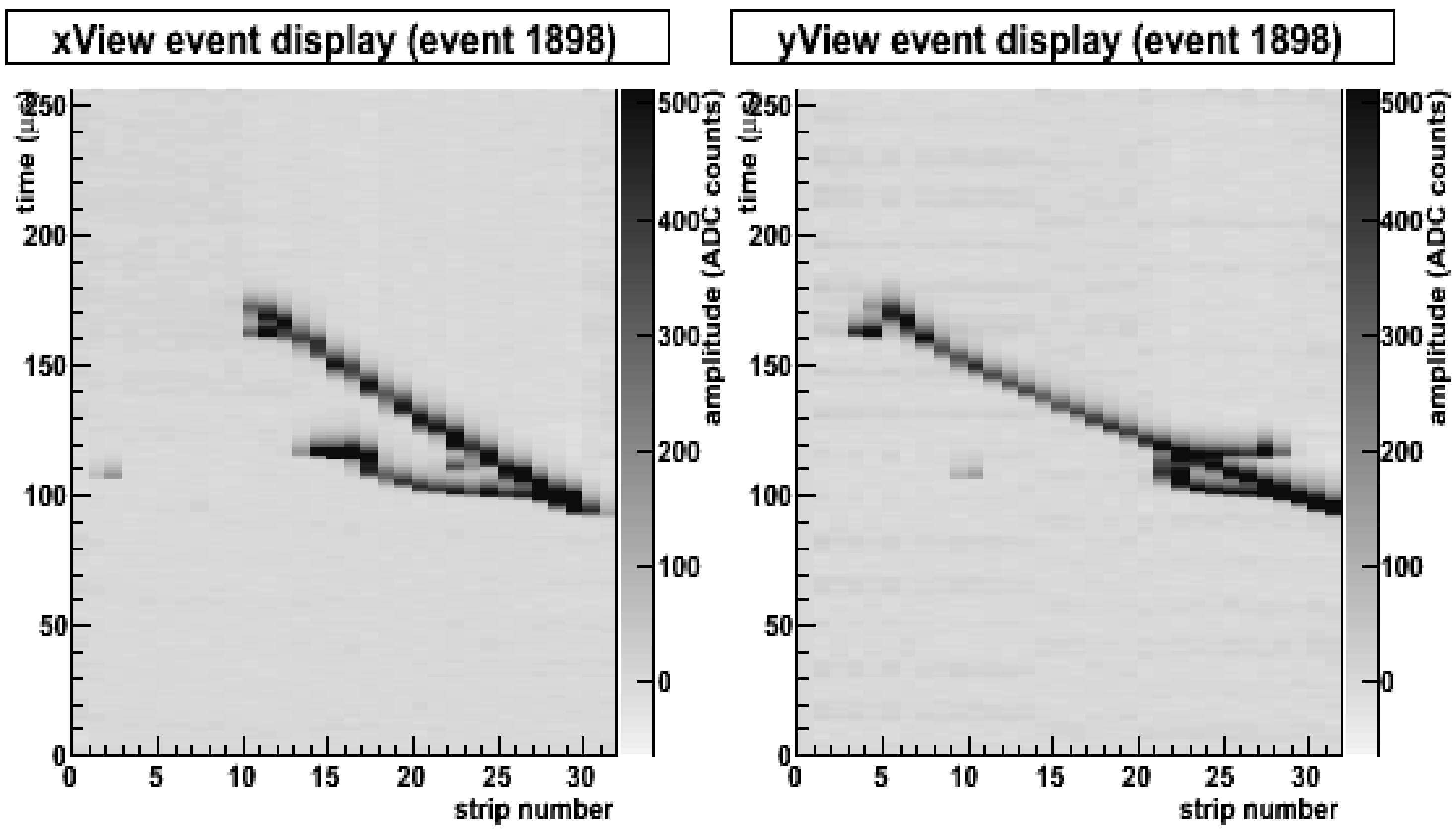
Observation of cosmic rays with a LEM-TPC

Event display: drift time vs position

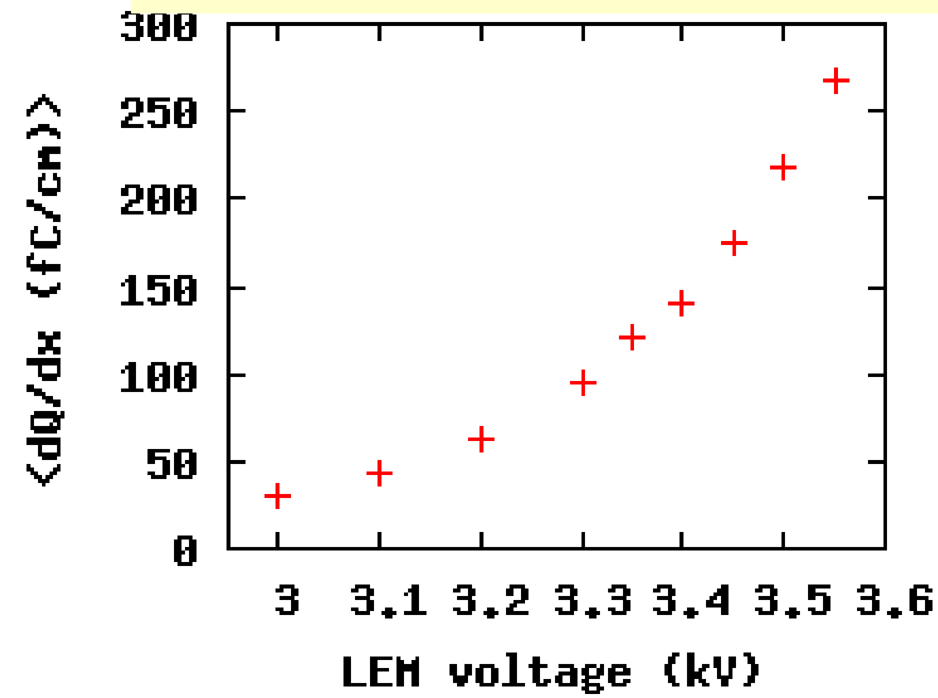


Corresponding digitized signals





Sum of collected charge in X and Y views

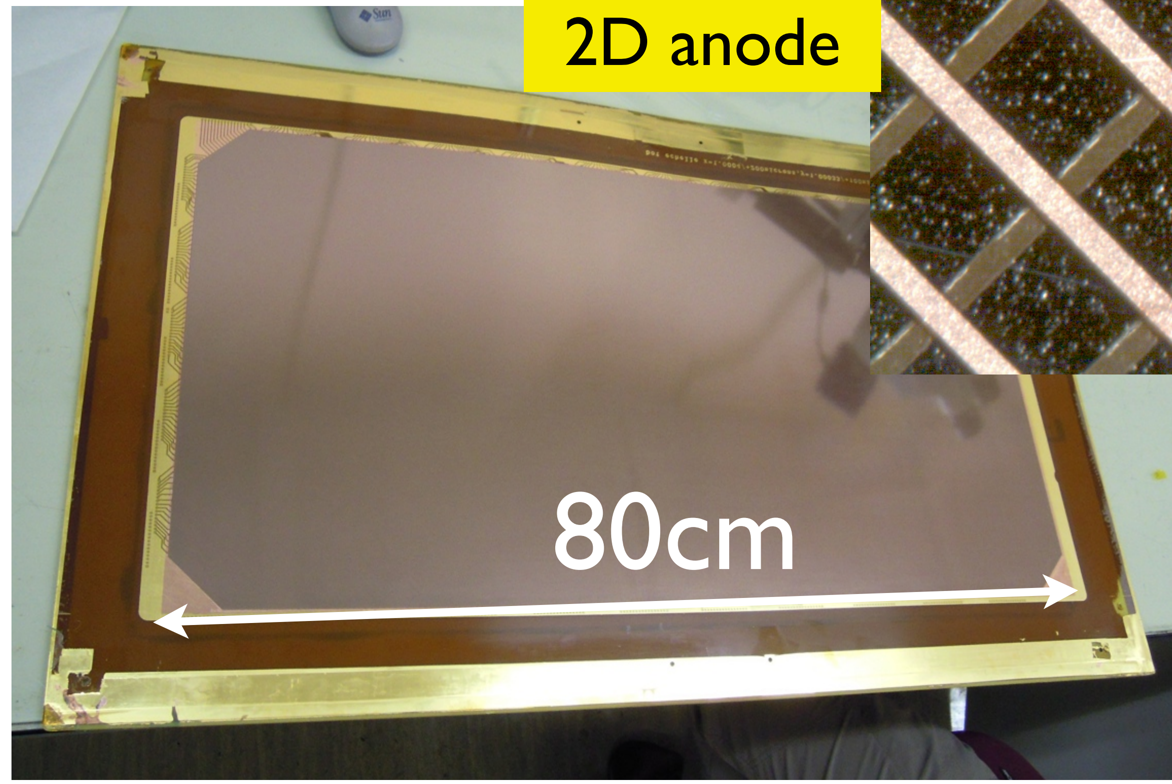


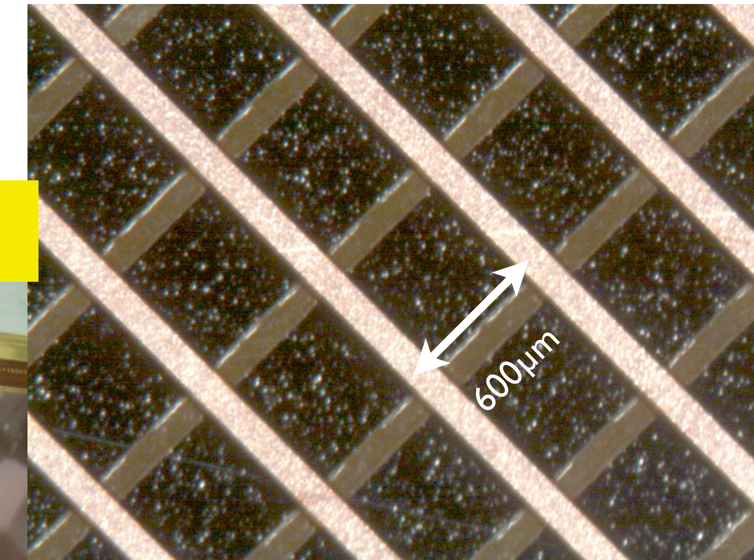
Much improved S/N (>100) compared to single-phase LAr operation (≈15)

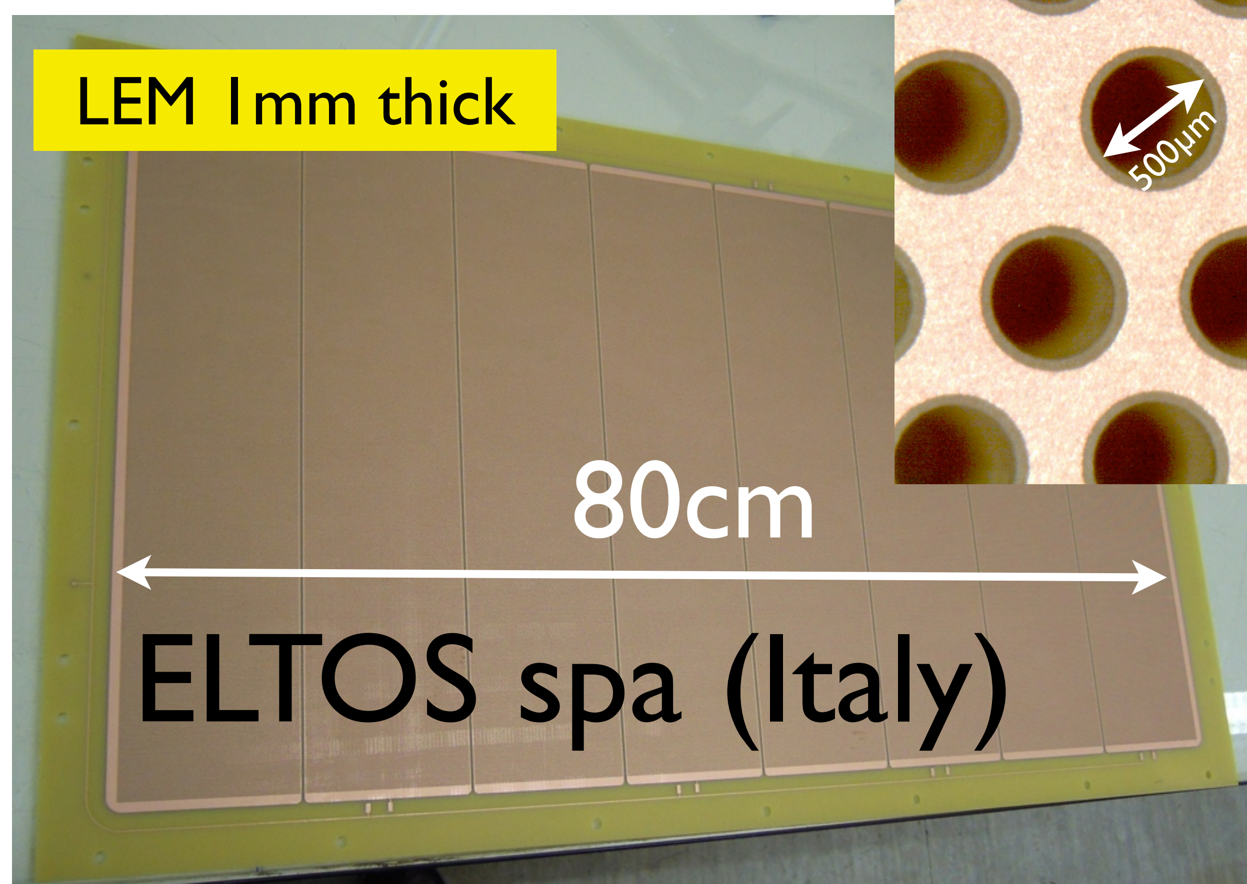
Reached an effective charge gain of ≈27

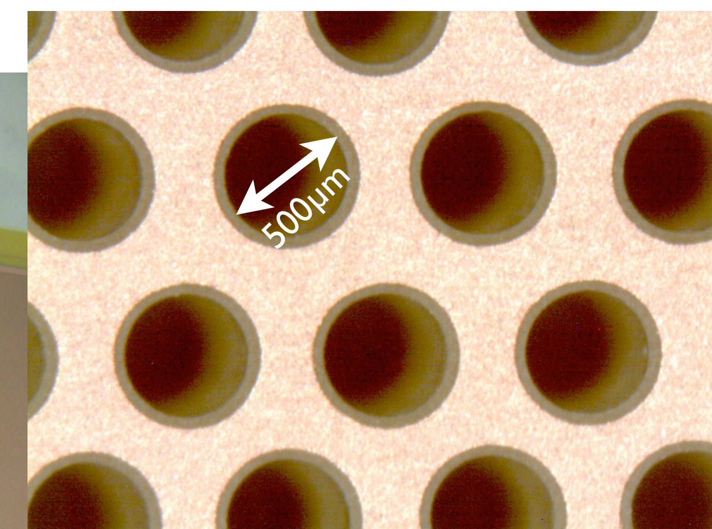
A. Badertscher *et al.*, NIM A 641 (2011) 48

CERN RE18 activities





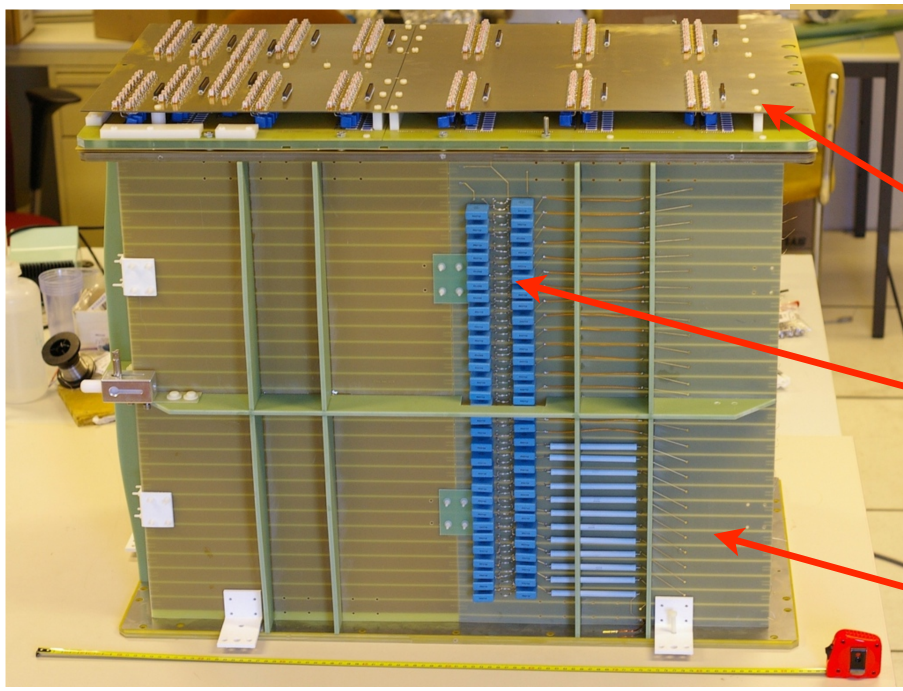




Large area MGPDs

MPGD industrial production aspects and Q&A are crucial components, to be investigated

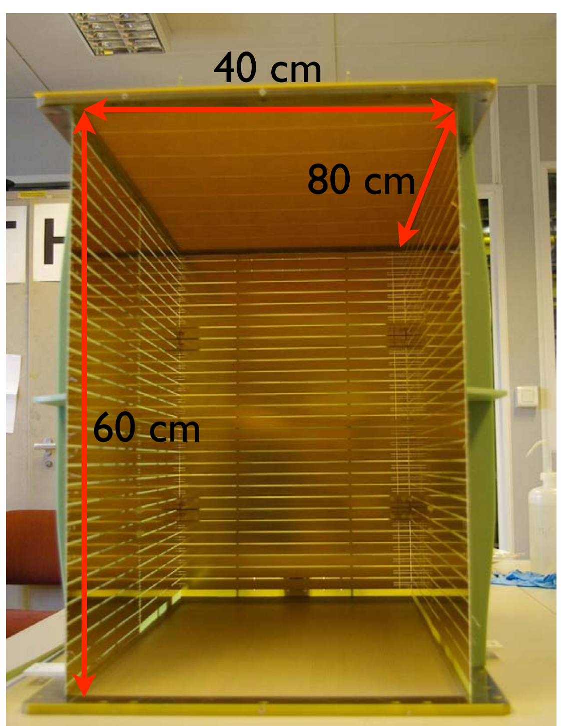
$40x80cm^2$ LEM TPC




Readout sandwich

Voltage multiplier (Greinacher)

Drift cage



F. Resnati
T. Maruyama

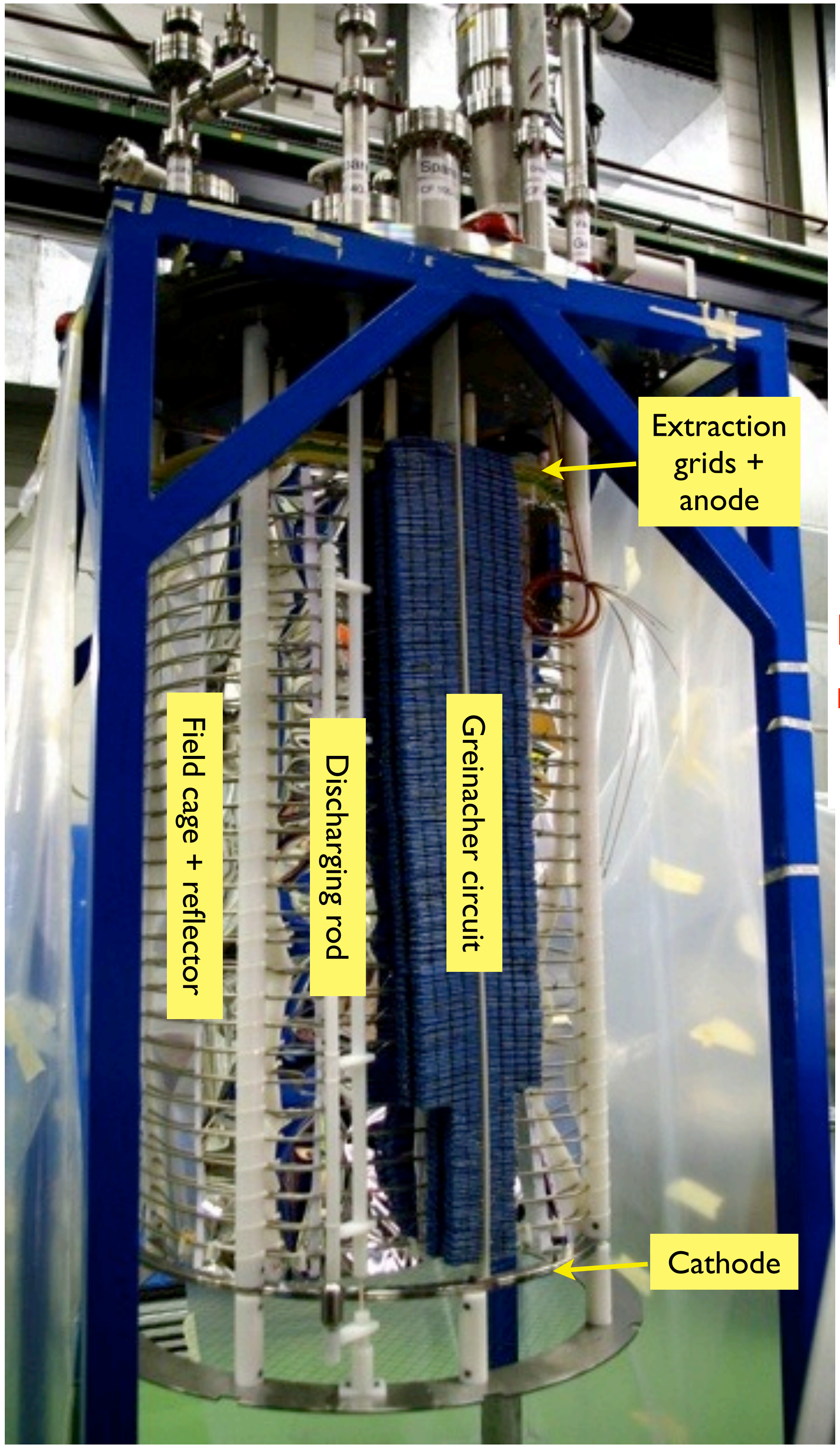
Bulk micromegas

M. Zito

0.5x1.5m**2
MAMMA RD51

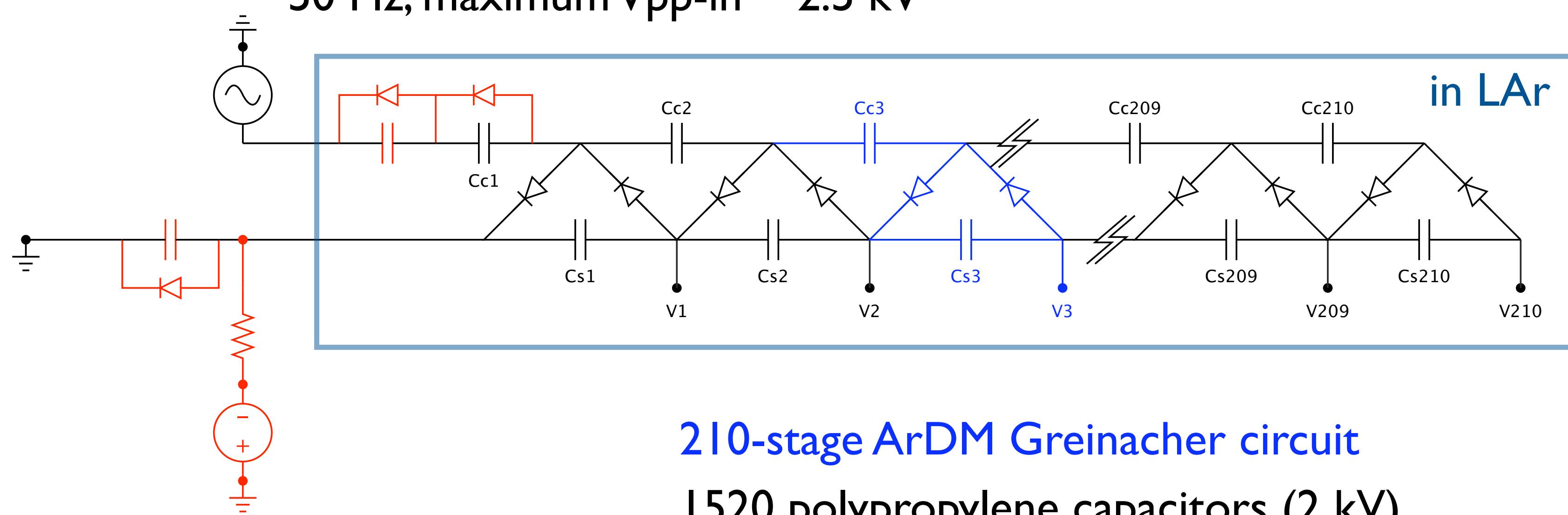
Drift high voltage generator

S. Horikawa et al., arXiv:1009.4908



Novel method of generating drift high voltage

50 Hz, maximum Vpp-in ~ 2.5 kV



DC voltage source for "offset"

maximum V_{DC} = –8 kV

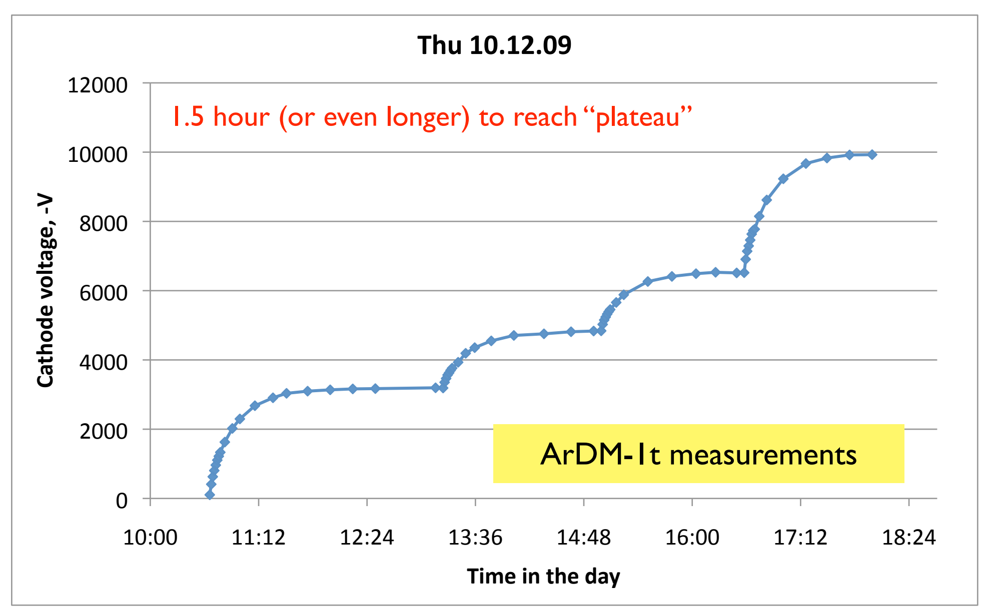
210-stage ArDM Greinacher circuit

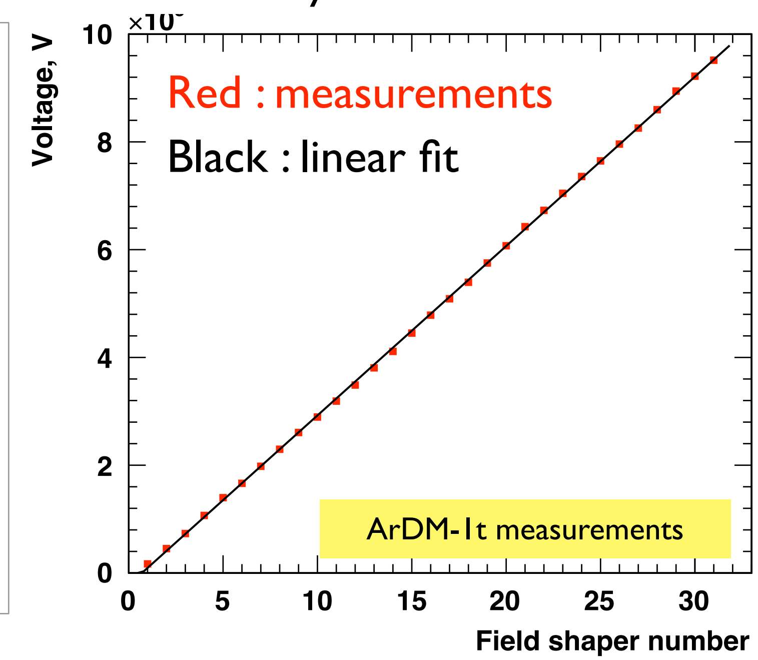
1520 polypropylene capacitors (2 kV)

- St.1–170 : 4 × 82 nF ; St171–210 : 2 × 82 nF

1260 avalanche diodes

- 3 diodes in series at each symbol





Up to now tested up to 70 kV (0.6 kV/cm)

Extrapolation to long drift

Extrapolation of the ArDM design

Up to 2 MV (over 20m drift length)

Changing Cs for fixed Cp = 2.35 pF and Vpp-in = 2E = 2.5 kV

		ArDM				
Drift length	m	1.24	5	10		20
Total output voltage for 1 kV/cm	V	124k	500k	1M		2M
Input voltage Vpp-in = 2E	V	820	2.5k	2.5k	$\times\sqrt{2}$	3.5k
Shunt capacitance, Cp	F	2.35p	2.35p	2.35p	$\times 1/2$	1.18p
Capacitor	F	328/164n	475n	1.90μ		1.90μ
Number of stages, N	–	210	319	638		903
N per 10 cm	–	16.9	6.38	6.38		4.51
Total capacitance	F	125μ	303μ	2.43m		3.43m
Capacitance per 10 cm	F	10.4μ	5.99μ	24.3μ		17.2μ
Total stored energy	J	21.7	948	7.58k		21.5k

Actual ArDM parameters are given just for comparison.

For extrapolation, 2γN = 1.42 is always assumed.

LAr vaporization heat 160 kJ/kg

$$V_{\rm max} = \frac{E}{\gamma}, \quad \gamma \approx \sqrt{\frac{C_{\rm p}}{C_{\rm s}}}$$

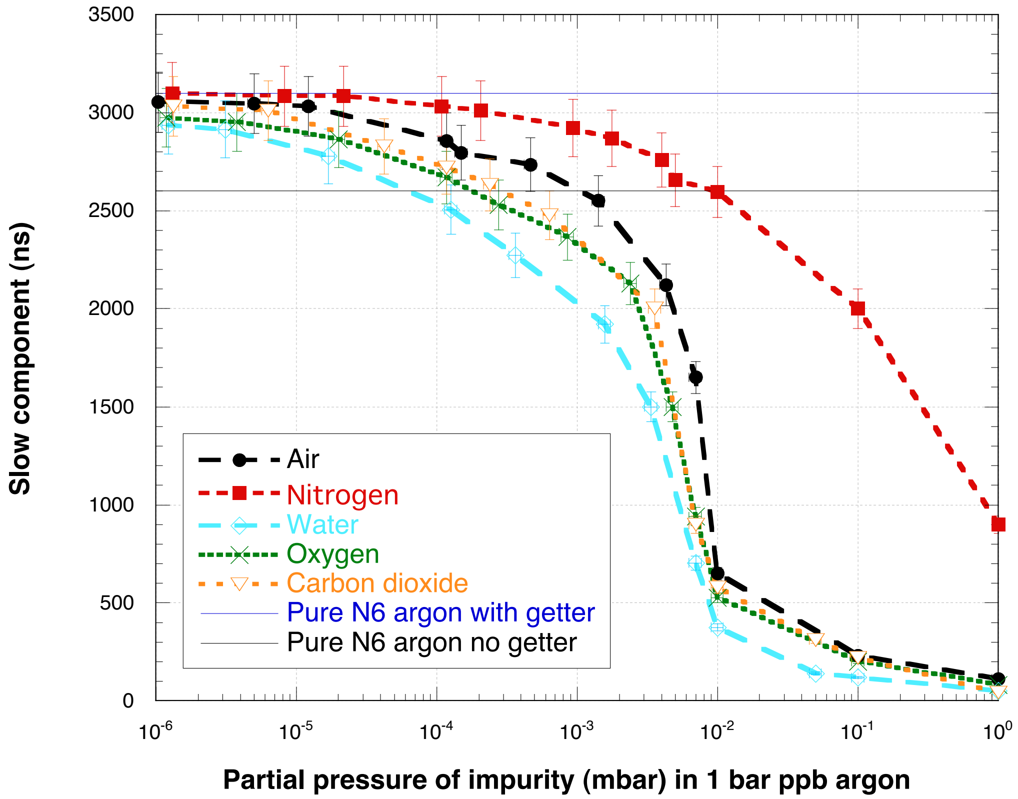
Purification tests on 6m3

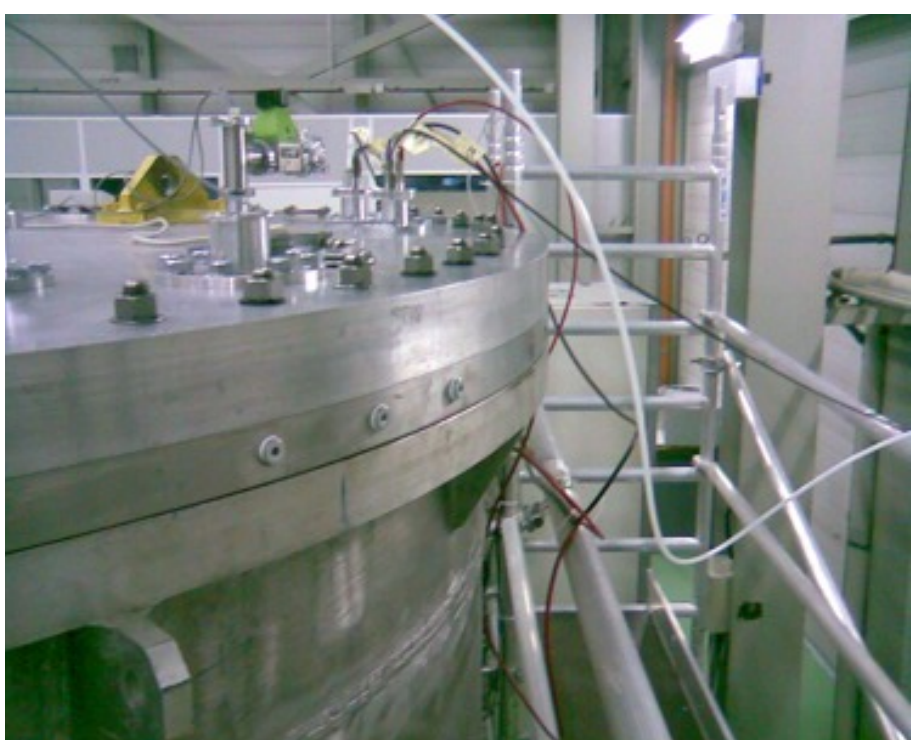
A. Marchionni
K. Mavrokoridis

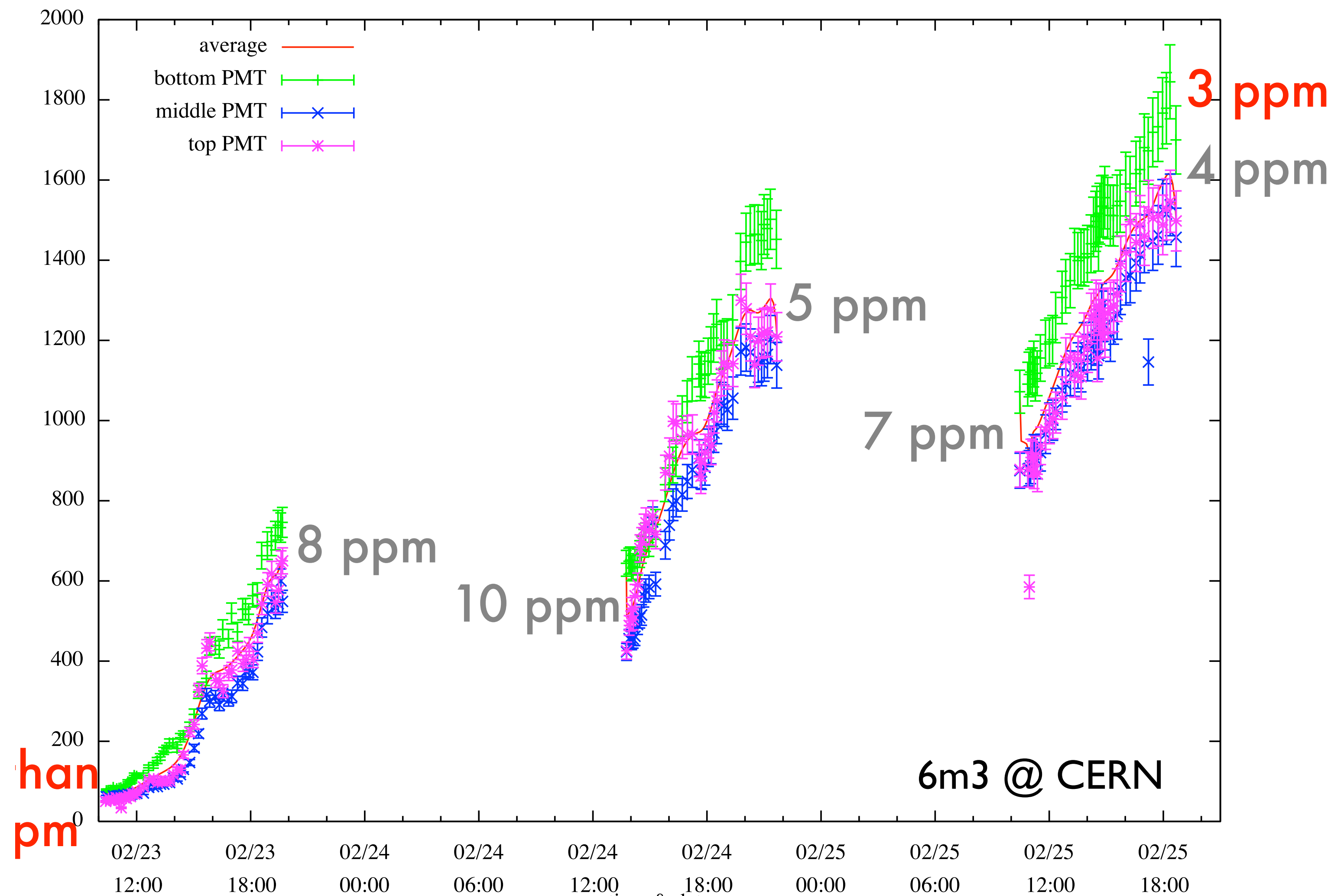
R&D towards non evacuated vessels on large vessel

A. Curioni et al., arXiv:1009.4073

- Purity measured by lifetime of slow component of scintillation light
- First test purging - satisfactory! Piston effect seen
- Reached **3ppm** O_2-equivalent via flushing
- Closed gas recirculation and purification under construction (Q1 2011) : **<1 ppm** O_2-equivalent
- <u>Then</u>: demonstrate achievements in liquid phase







→ LAPD : B. Rebel

Underground storage tank and LAr process

Cooperation with industrial partners after many years of investigations (started in 2004)

Several specialized companies in the LNG field

RHYAL ENGINEERING

- **Initial Concept - 2004**
- **Use existing technology from industry experience**
- **Above ground tank, placed below ground**
- **De-couple the tank from the cavern**
  - **Several sites**
  - **Several seismic levels**
  - **Rock or Salt**

Also: Linde Kryotechnik AG (Zurich) and AirLiquide (Grenoble)

Underground infrastructure

Rockplan, Pentaocean, ...

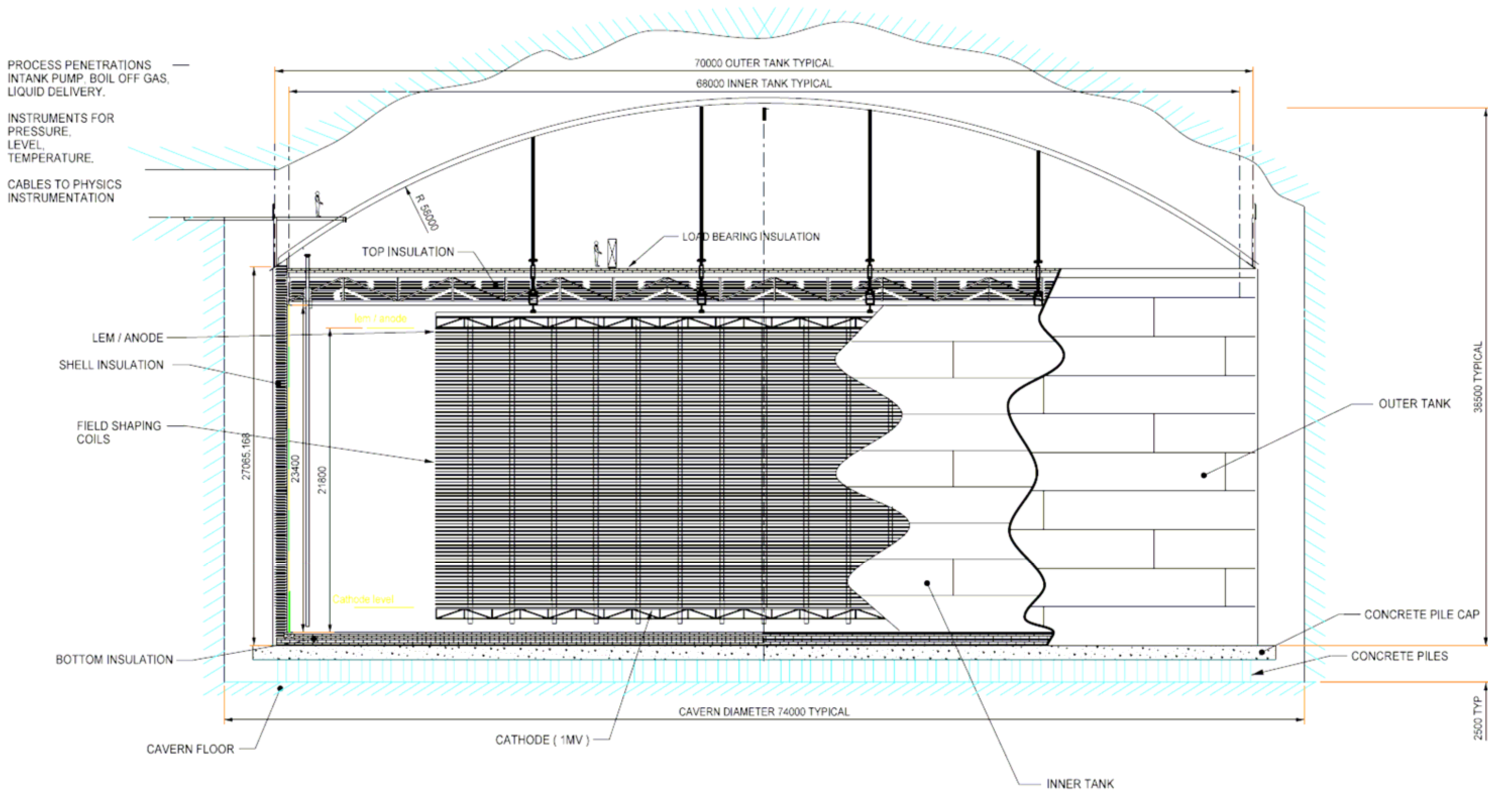
Consulting in underground construction / risk analysis

Alan Auld GROUP LTD

+ CERN LHC/ATLAS/CMS cryogenic experience

Technodyne

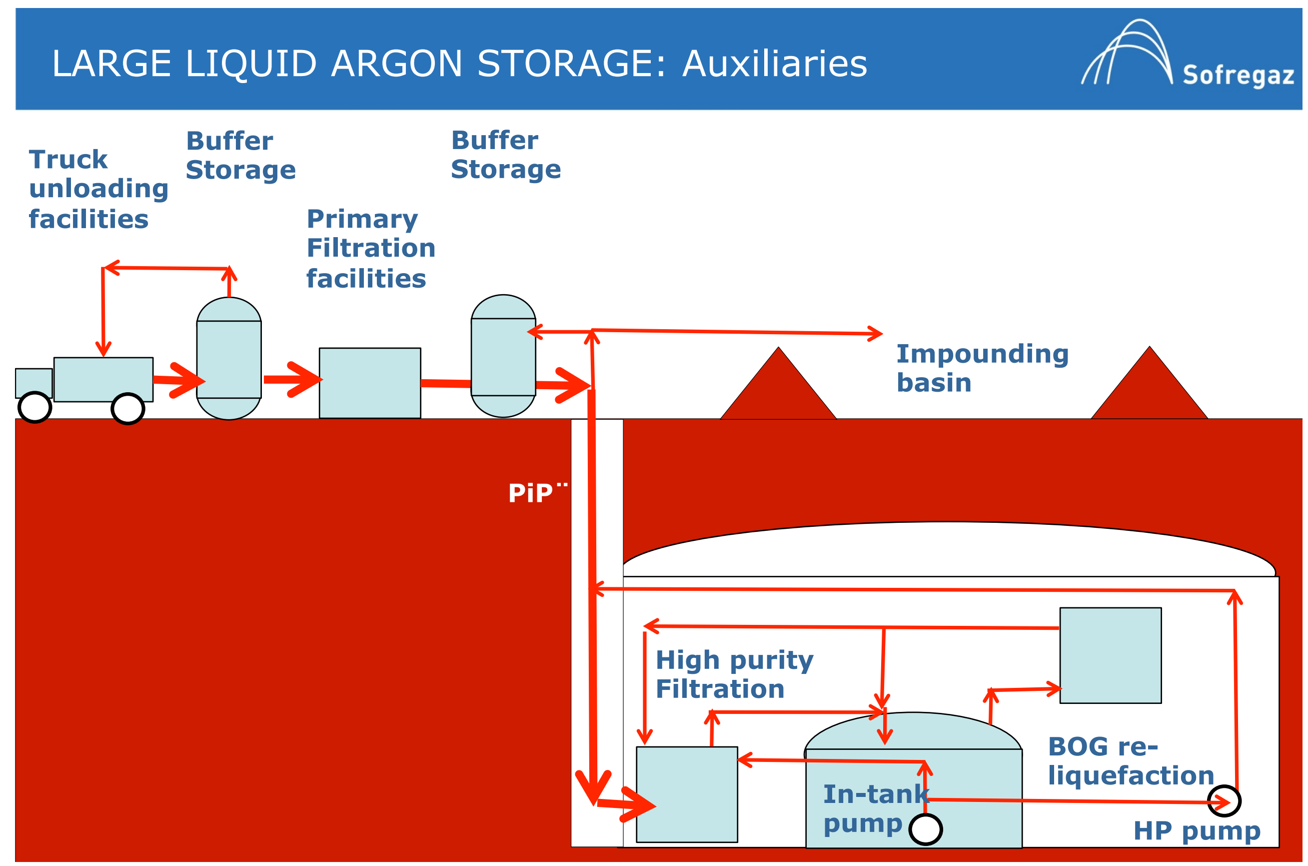
General Arrangement



- Single containment is suitable
  - Full containment not warranted
  - Cavern will contain spill
- Steel / Steel
  - Steel concrete not necessary
  - Membrane not current practice

- Modify design for deck access
- Modify design for sealing of inner tank
- Support for payload

Sofregaz



Scaling parameters

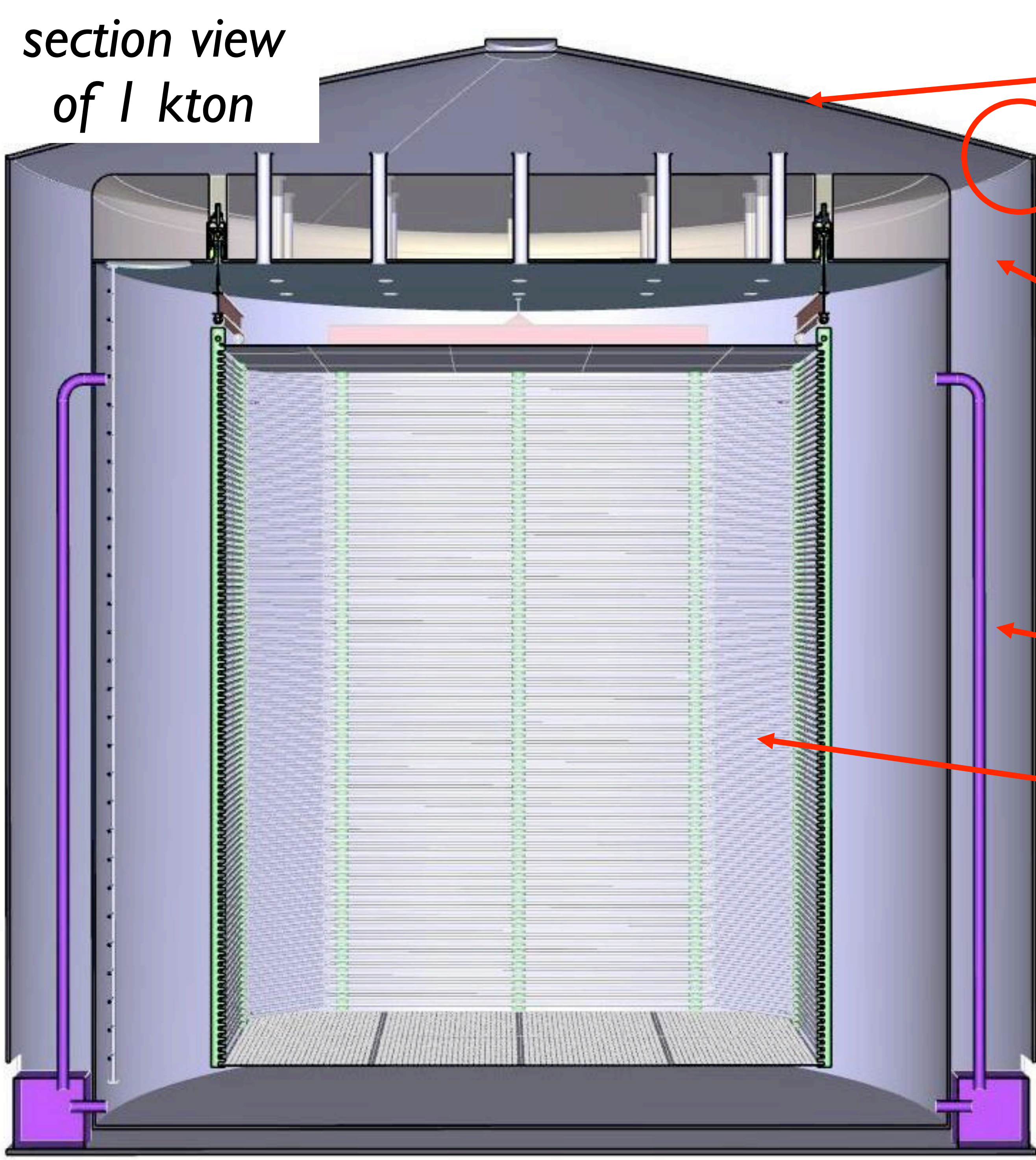
Graded approach towards ultimate mass

	ArDM-1t	6m3	1 kton	5 kton	20 kton	100 kton
Diameter (m)	0.8	1.8	12	22	40	70
Drift length (m)	1.2	2.5	10	10	10	20
Active mass (ton)	0.85	10	1583	5322	17592	107753
Readout area (m^2)	0.5	2	113	380	1257	3848
#readout channels(*)	≈1000	≈2000	70'000	230'000	750'000	2'300'000

(*) assume fixed 1m^2 module with 3mm pitch, 2 views
for large detectors, larger area modules can be considered

Detector conceptual design

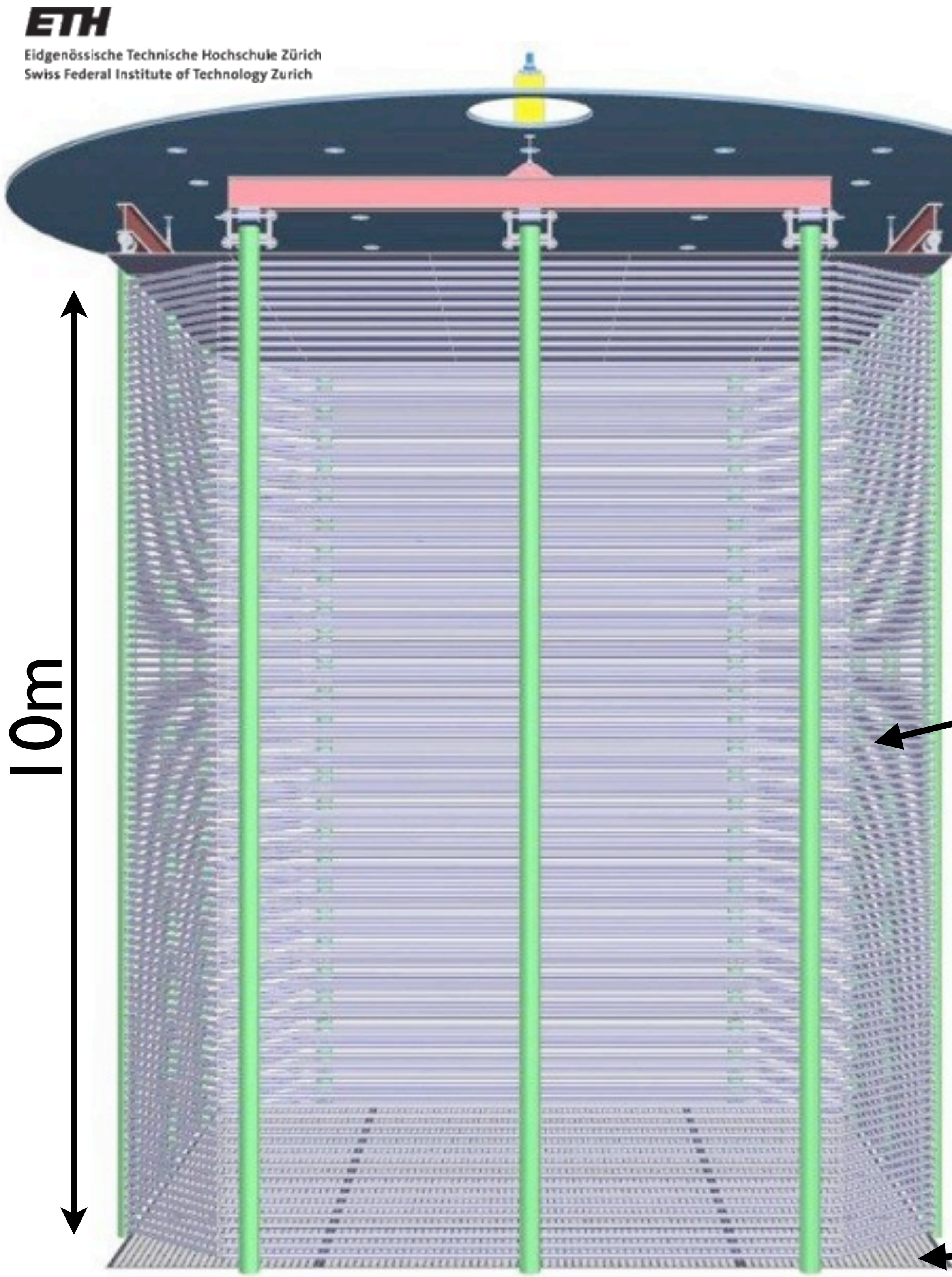
A 1 kton concept has been developed and preliminary engineering studies have been performed. A scaling up to 5 kton can be performed in a few months.



- Outer tank roof
- Access point
- Top insulation Inner Shell
- Outer tank
- Inner Shell
- Detector
- Argon re-circulating system

Inner detector conceptual design

The detector concept was based on scaling up from the double phase ArDM-1t design



Detector hanging system

Anode LEM TPC readout

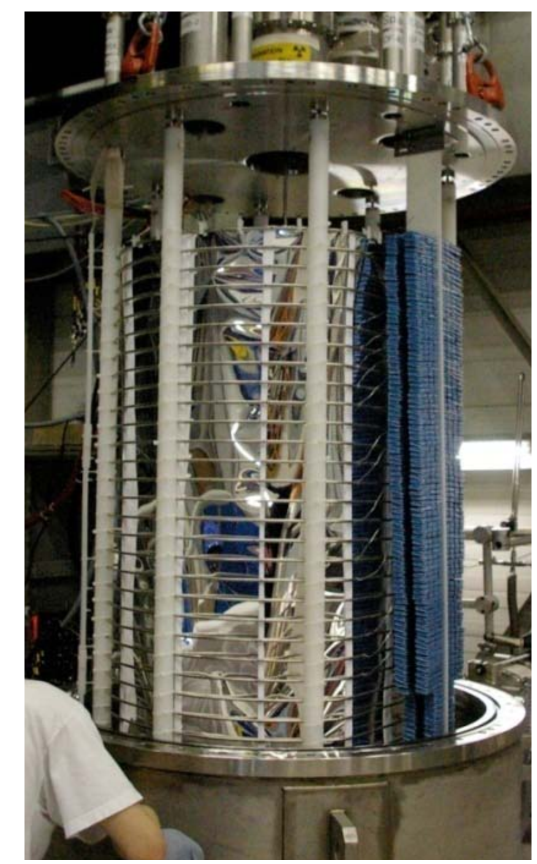
10m

Drift cage
Tubes 5cm diam

Anode (-0.5÷1 MV)

ArDM-1t

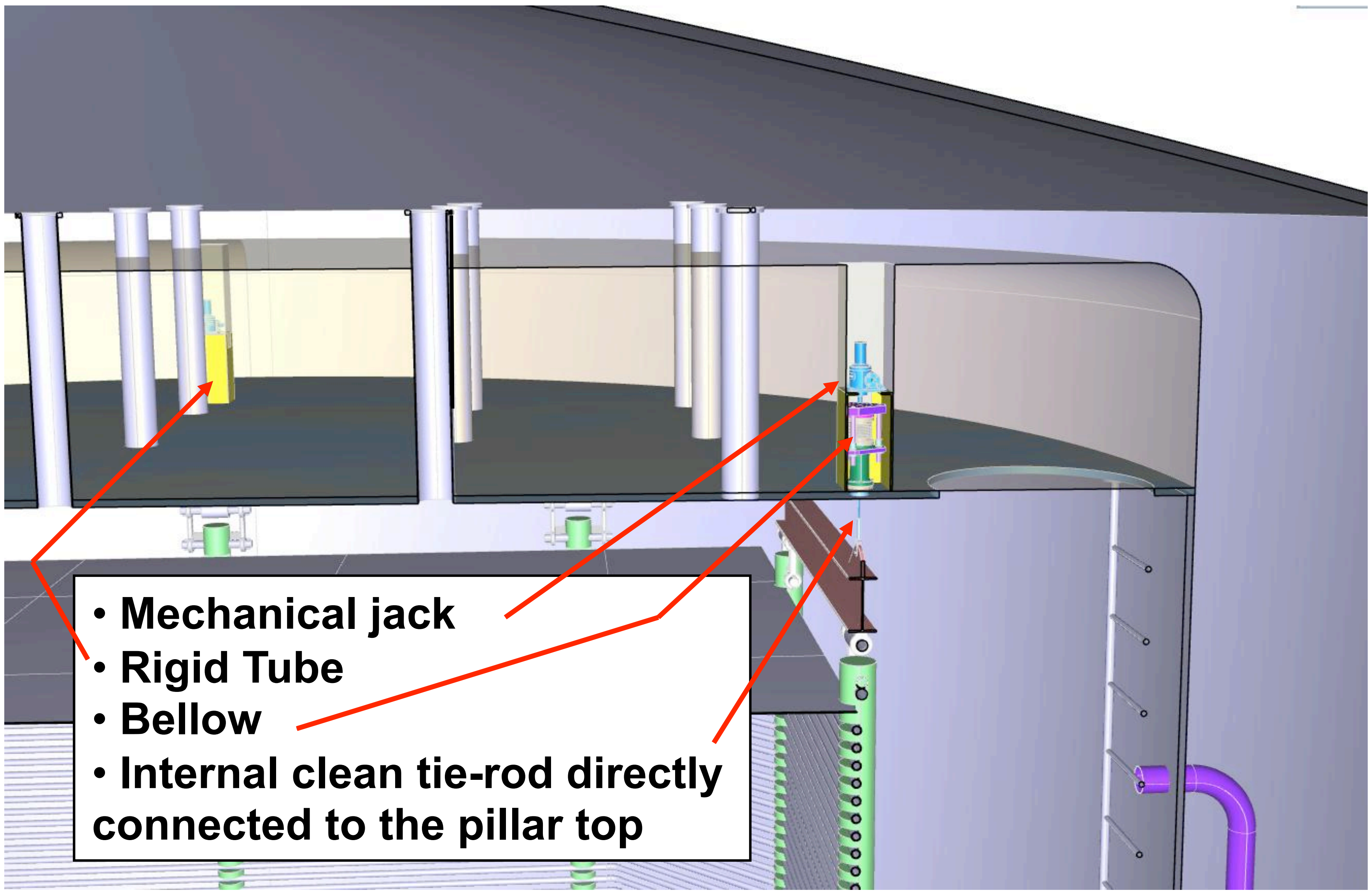
1.2m



Inner detector conceptual design

We have worked on the engineering study of a “hanging detector”
Finite element analyses performed

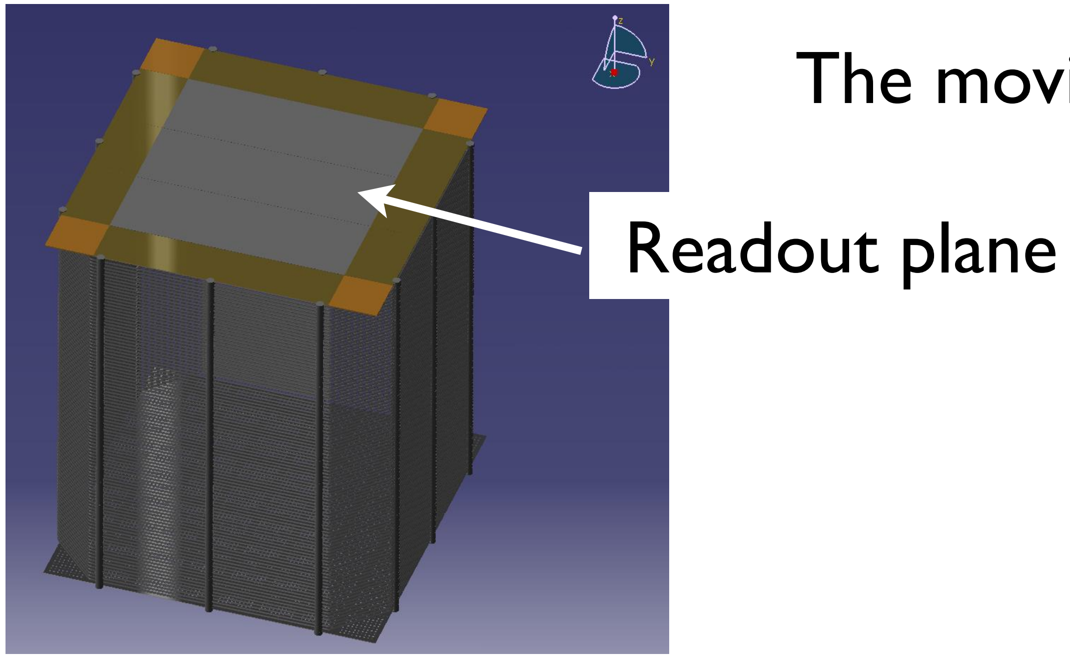
Detector hanging system



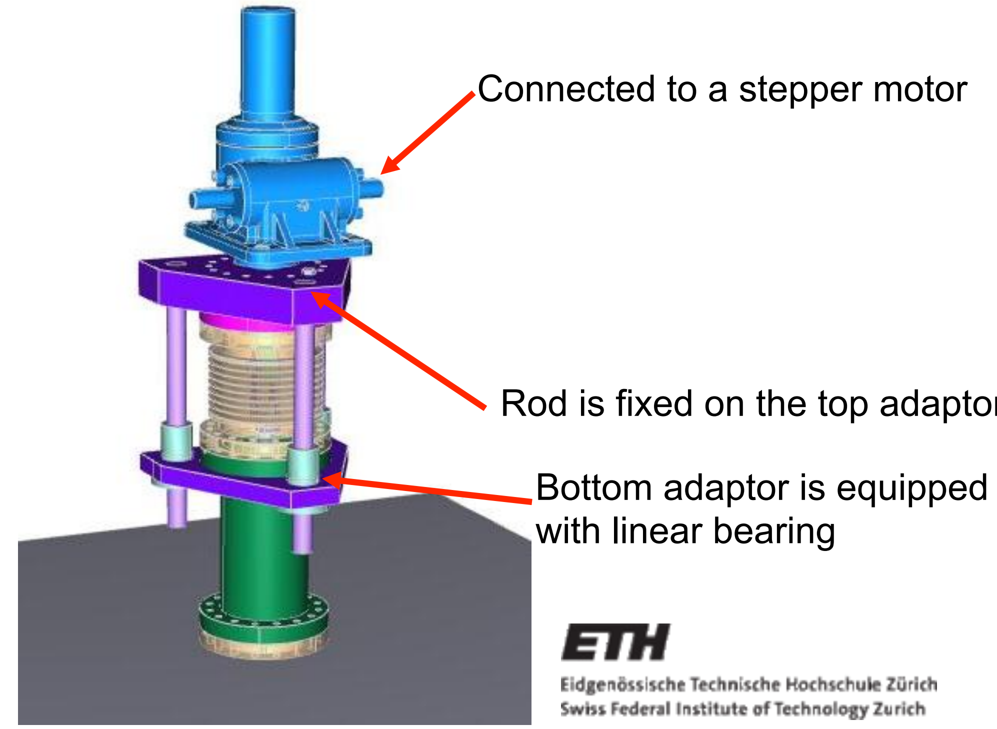
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

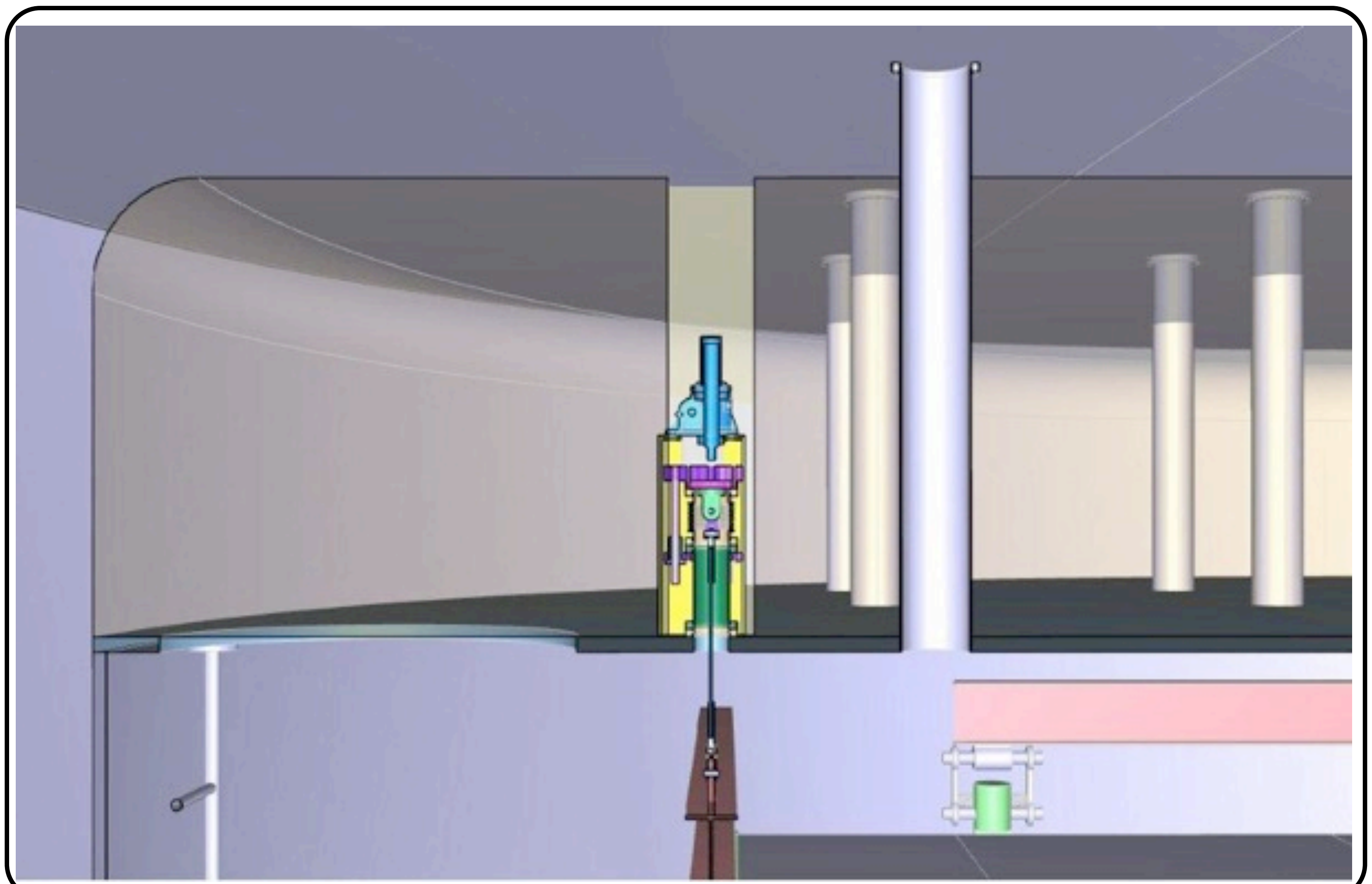
The motor-operated mechanical systems are used to precisely adjust the level of the readout plane at the liquid-gas interface

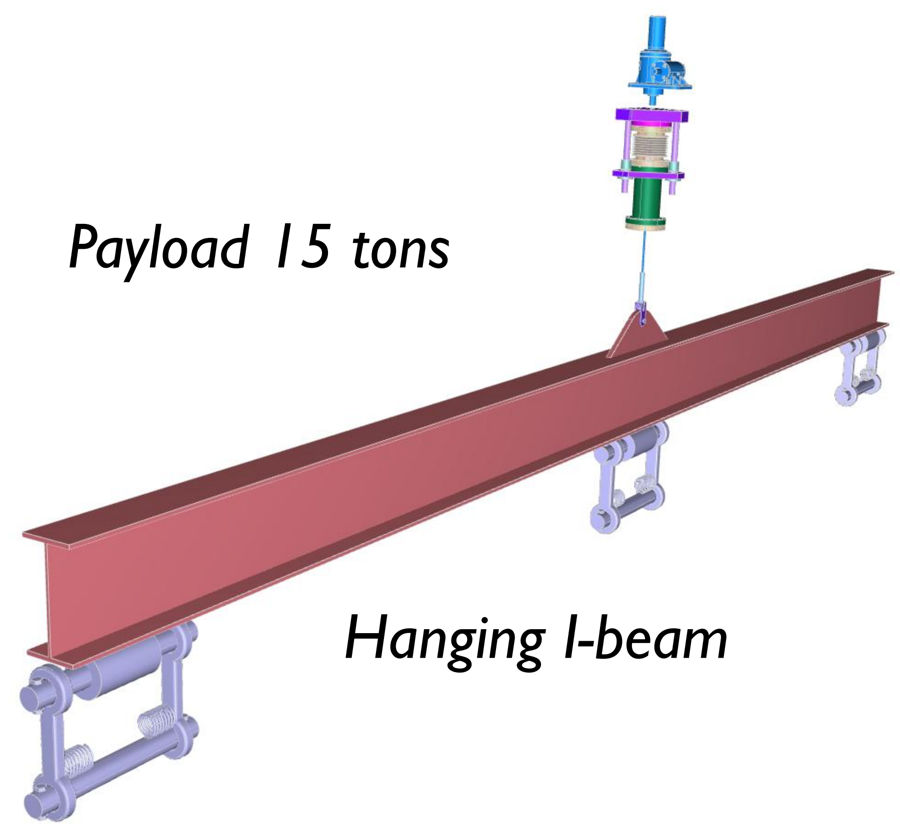
Inner detector moving system



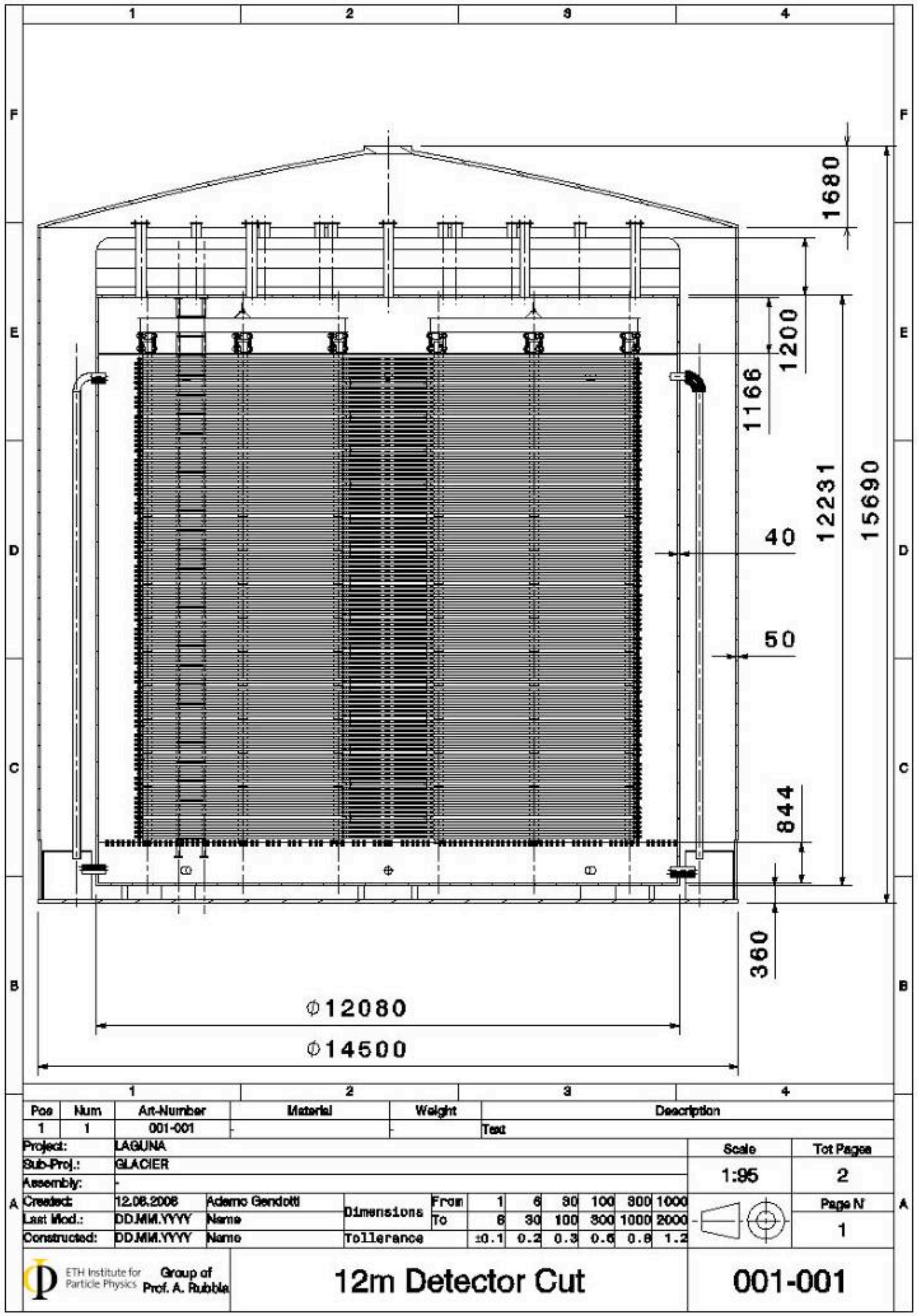
The moving plane is defined by a set of hanging I-beams

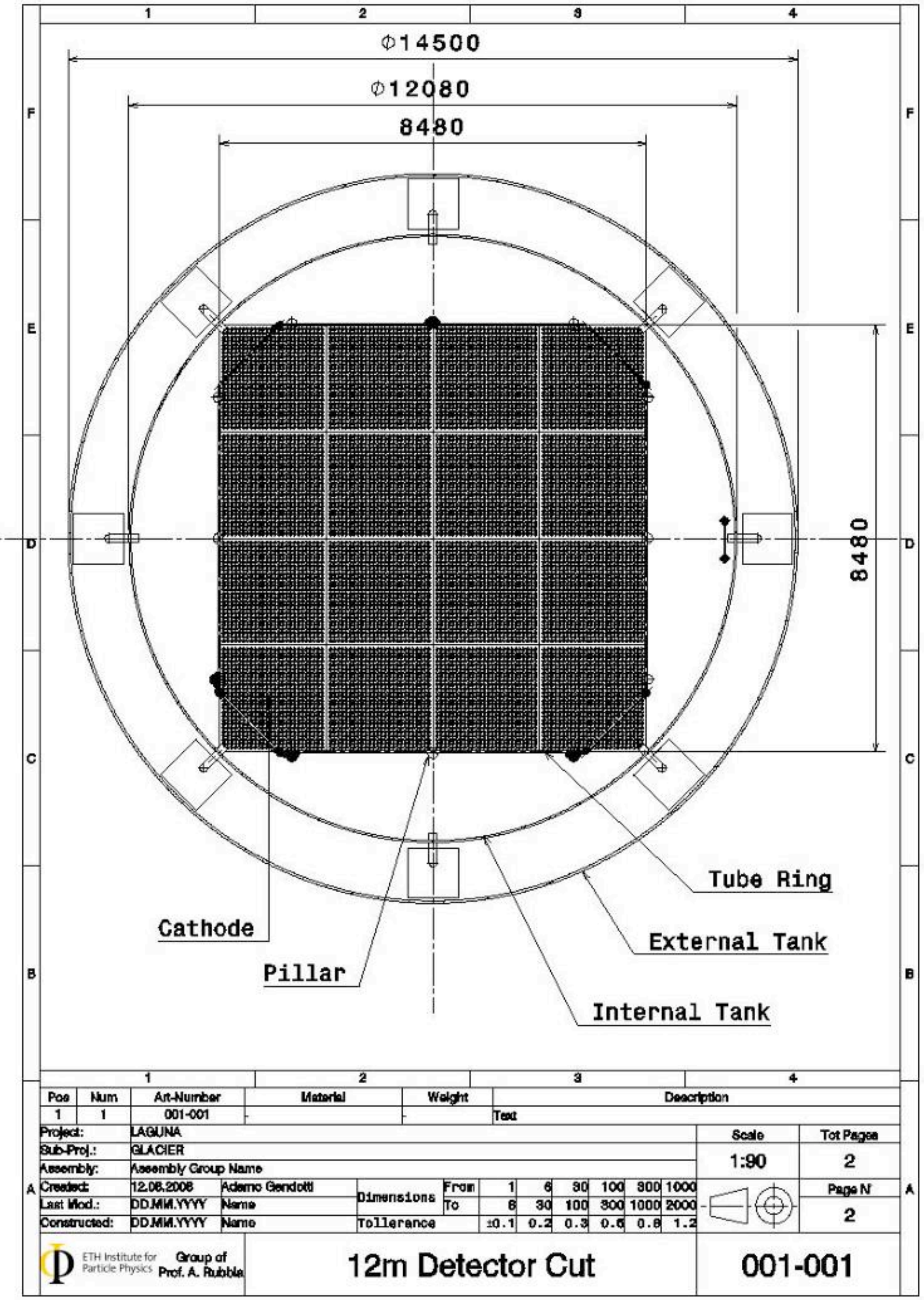






2D drawings


1680
1200
1166
12231
15690
40
50
844
360
Φ12080
Φ14500
Project: LAGUNA
Sub-Proj.: GLACIER
Created: 12.06.2008 Ademo Gendotti
Scale 1:95
Tot Pages 2
Page N° 1
ETH Institute for Particle Physics
Group of Prof. A. Rubbia
12m Detector Cut
001-001

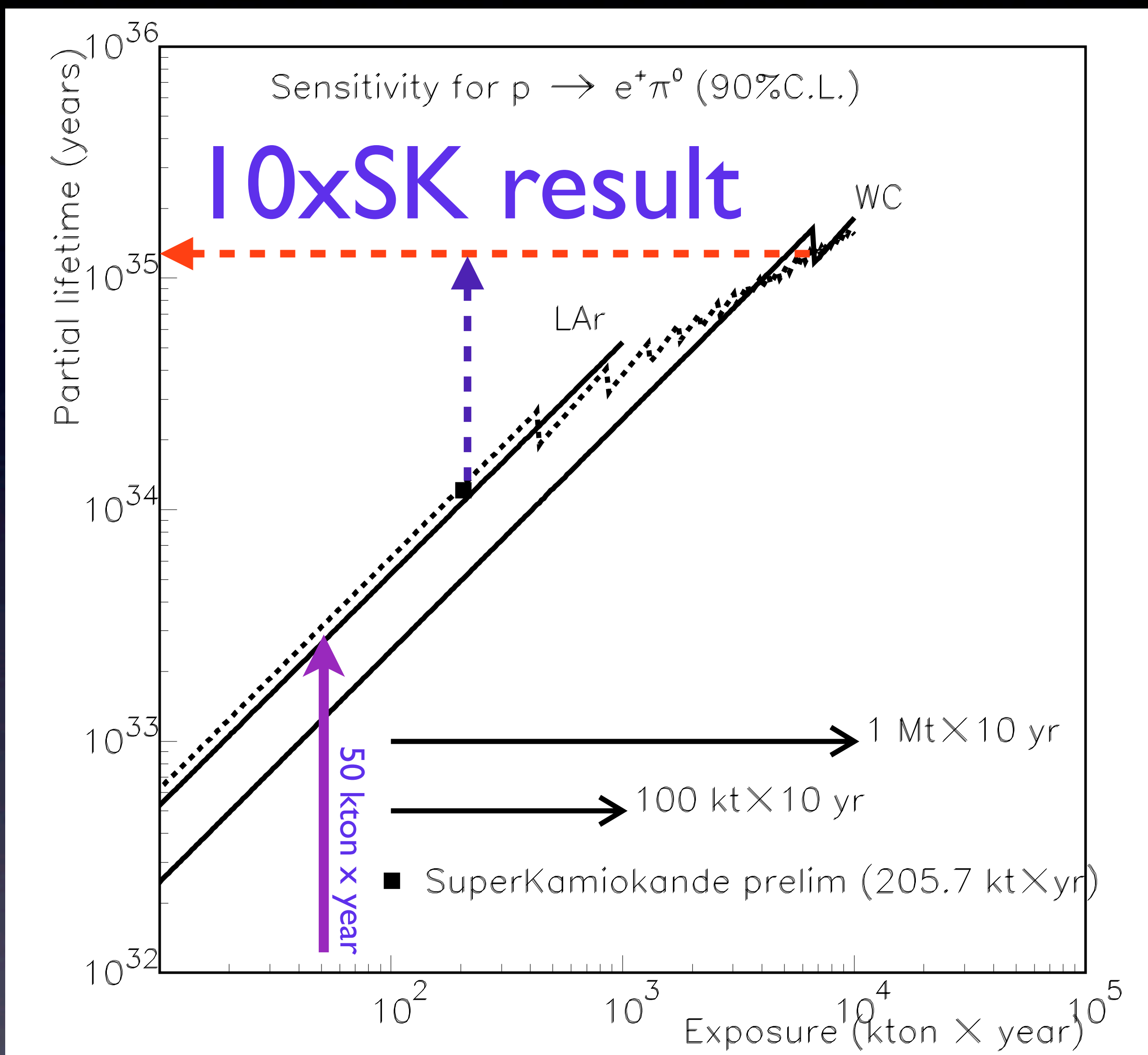

Φ14500
Φ12080
8480
8480
Tube Ring
External Tank
Cathode
Pillar
Internal Tank
Project: LAGUNA
Sub-Proj.: GLACIER
Assembly: Assembly Group Name
Created: 12.06.2008 Ademo Gendotti
Scale 1:90
Tot Pages 2
Page N° 2
ETH Institute for Particle Physics
Group of Prof. A. Rubbia
12m Detector Cut
001-001

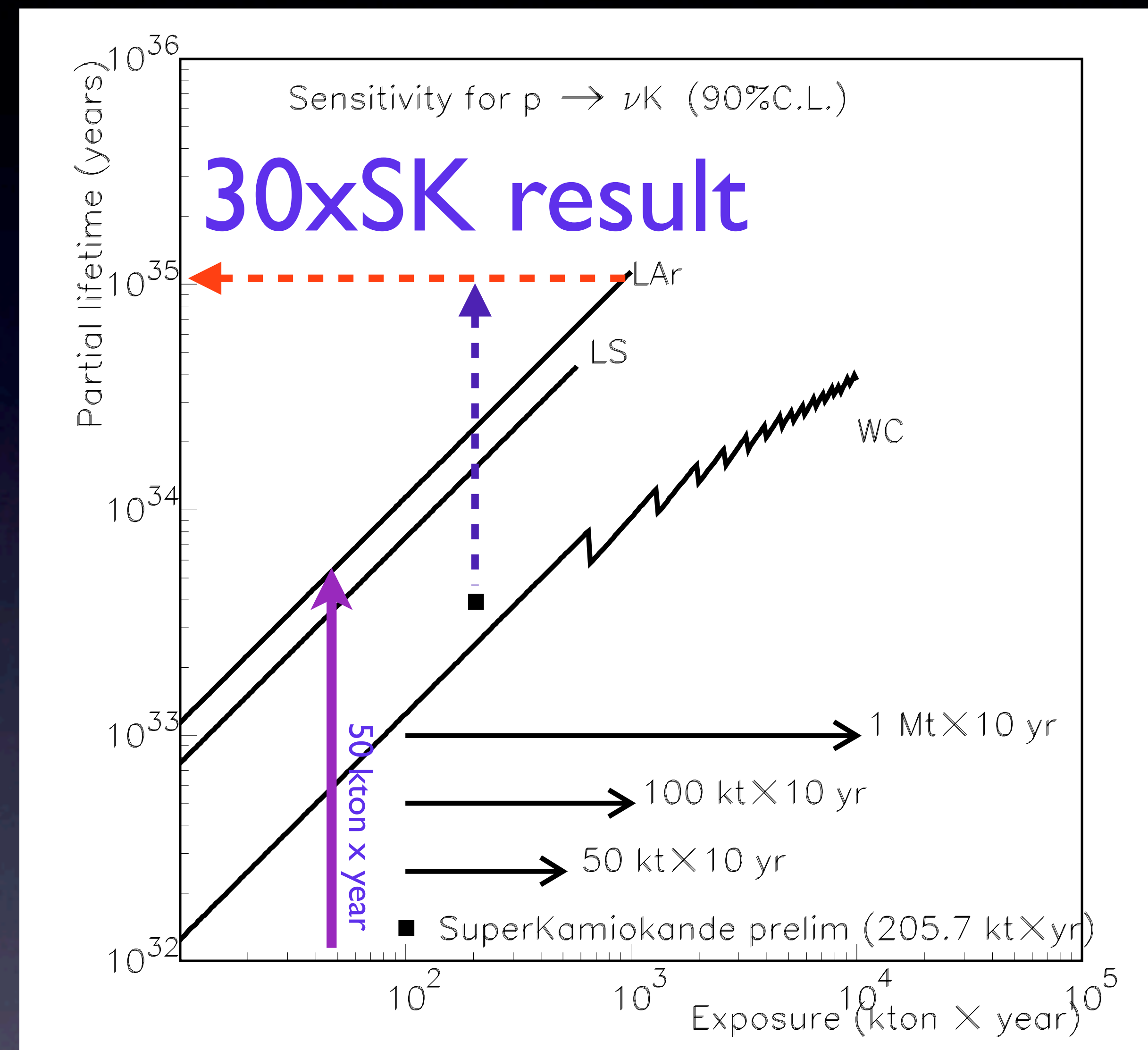
Motivations for an underground pilot

- An in-situ underground “pilot” experiment will bring invaluable information on (a) physics in realistic background conditions (b) technical issues (c) costs (d) risks. Paper studies (and reviews) cannot replace real hardware.
- An underground prototype is needed answer technical and costs issues for an underground operation.
- SuperKamiokande has almost continually operated since 1996 and provided the benchmark for future WC detectors. The LAr community must reach a similar condition with a continuously operating underground detector beyond ICARUS T600 [to be presumably shutdown in 2013 ? Guglielmi’s talk].
- Based on the considerable expertise present in European and international research groups, the technology is sufficiently mature to allow for an early start of detector realization of a pilot facility on the scale of $\approx$5 kton.

Proton decay sensitivity

Expected sensitivity as a function of exposure (kton x year) for assumed efficiency and background





Present best limits SuperK preliminary (90%CL)

$\tau/B(e\pi^0) = 1.2\times10^{34}$ yr and $\tau/B(\nu K) = 0.39\times10^{34}$ yr

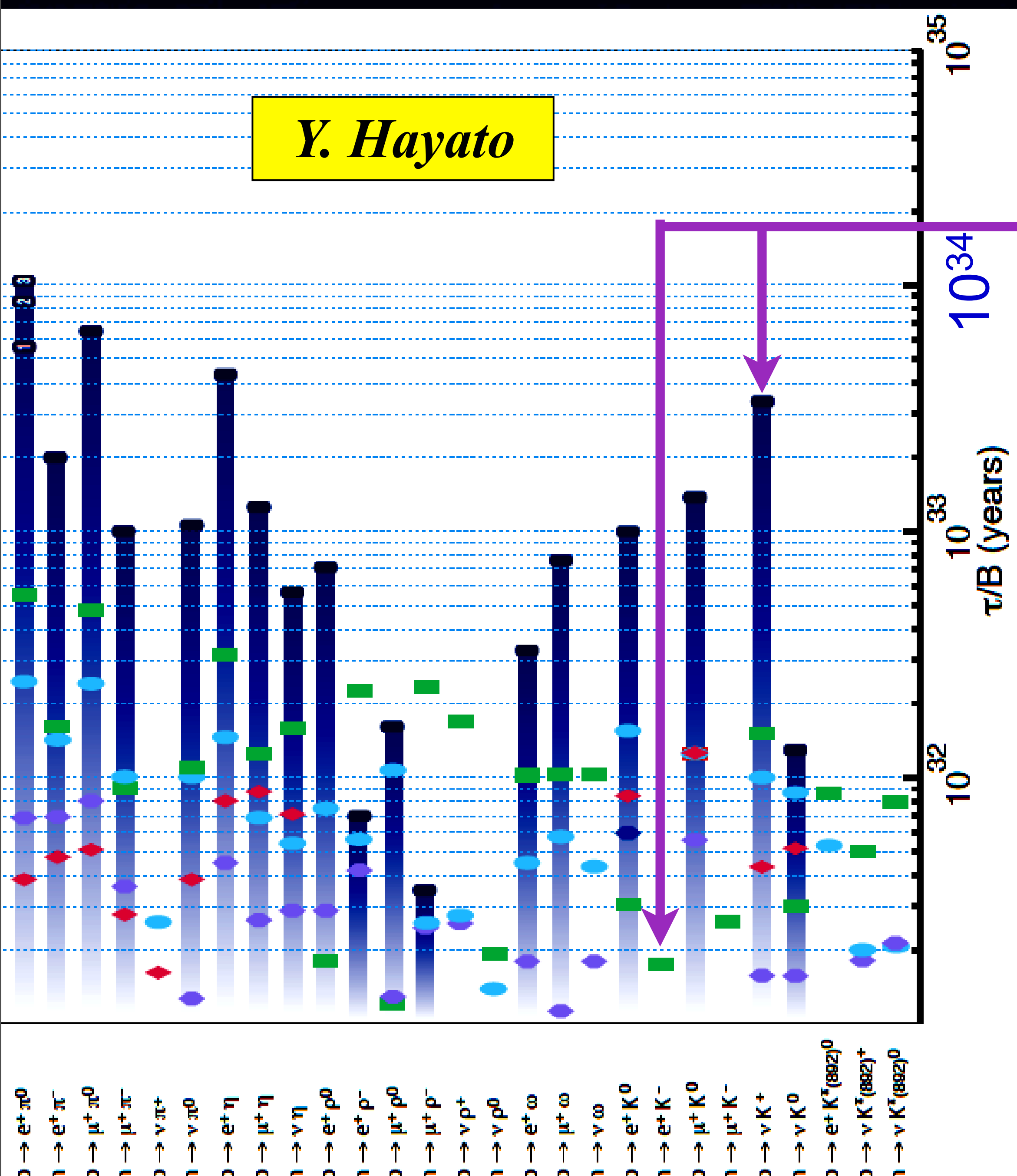
Complementary and competitive to SK for several channels

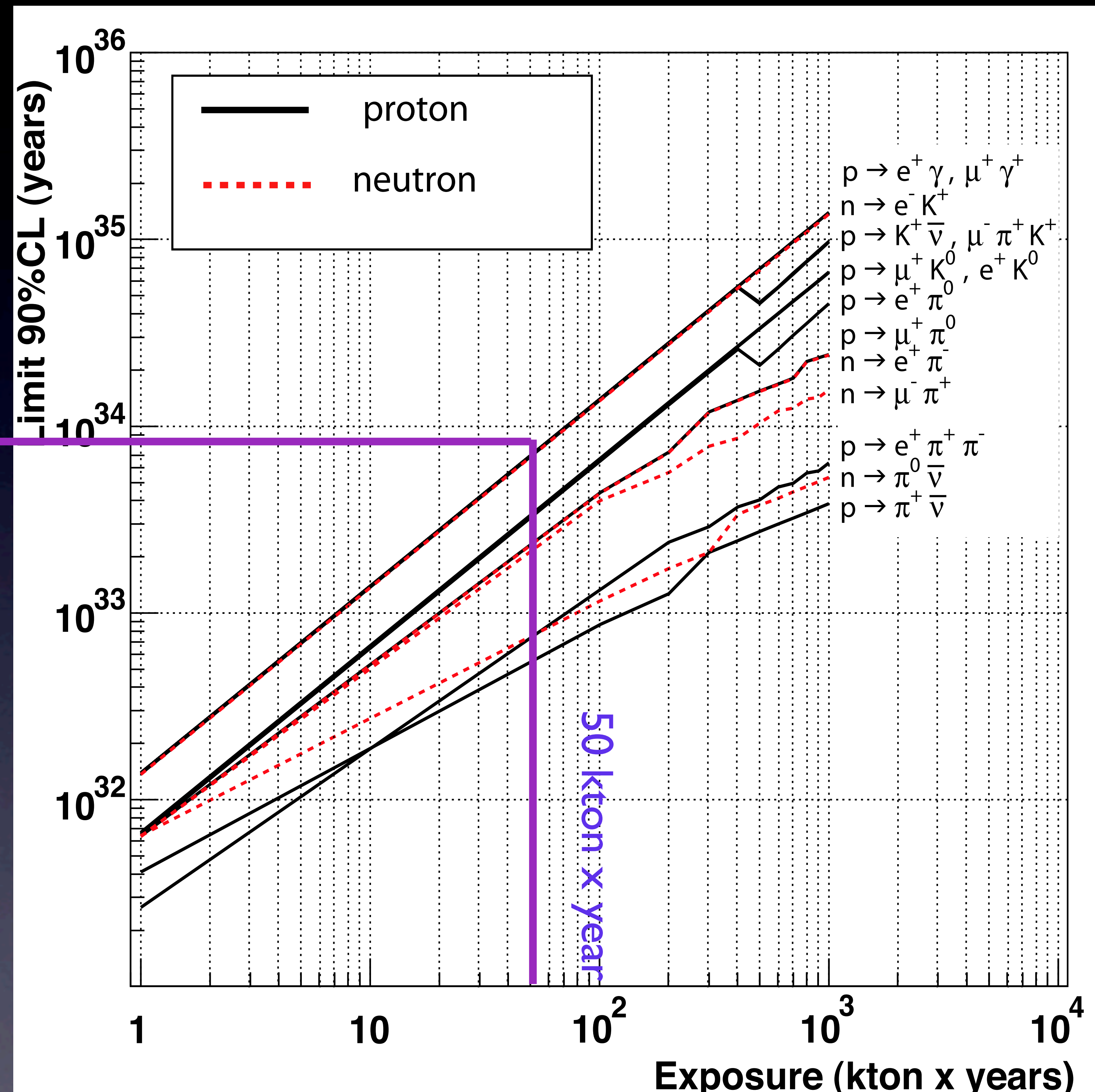
Proton decay “other channels”

Promising channels:

e.g. $p \to \upsilon K^+$, $n \to e^- K^+$

$p \to \mu K^0$, $p \to e^+ K^0$, ...

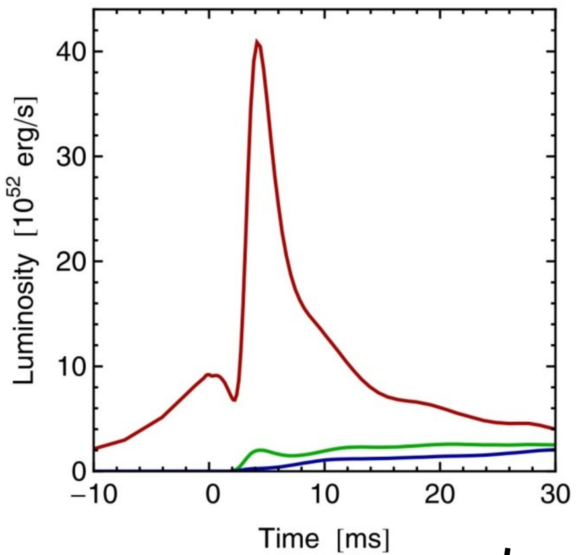




Supernovae type-II

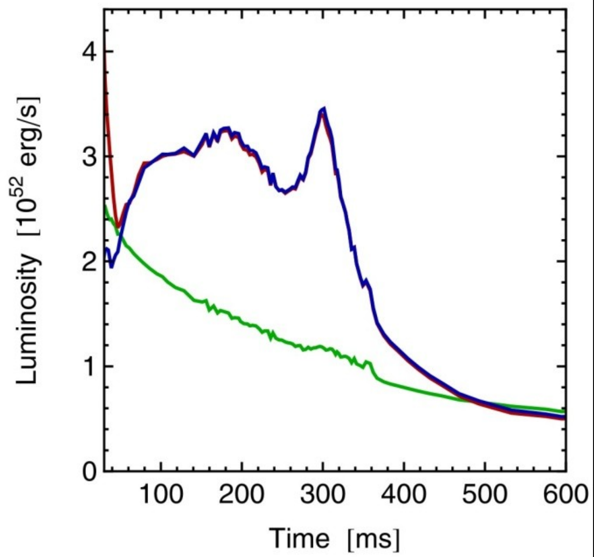
S. Hannestad

Prompt ν_e burst



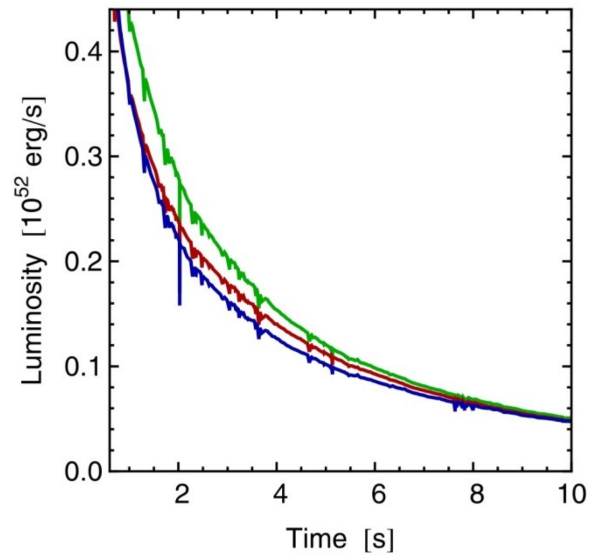
- Shock breakout
- De-leptonization of outer core layers

Accretion



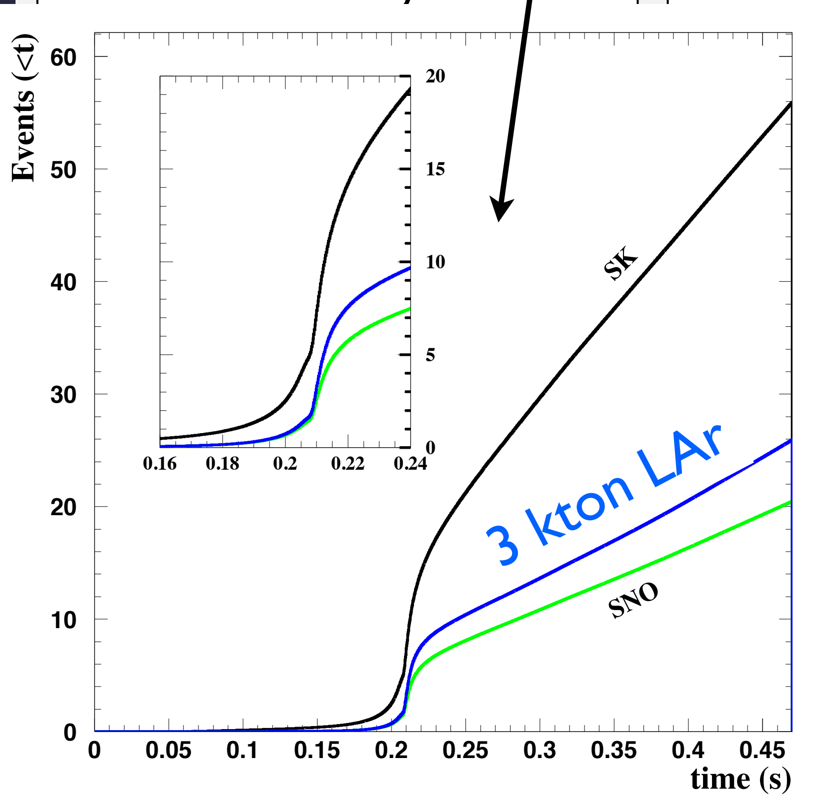
- Shock stalls ~ 150 km
- Neutrinos powered by infalling matter

Cooling



Cooling on neutrino diffusion time scale

Excellent detector to study the prompt burst

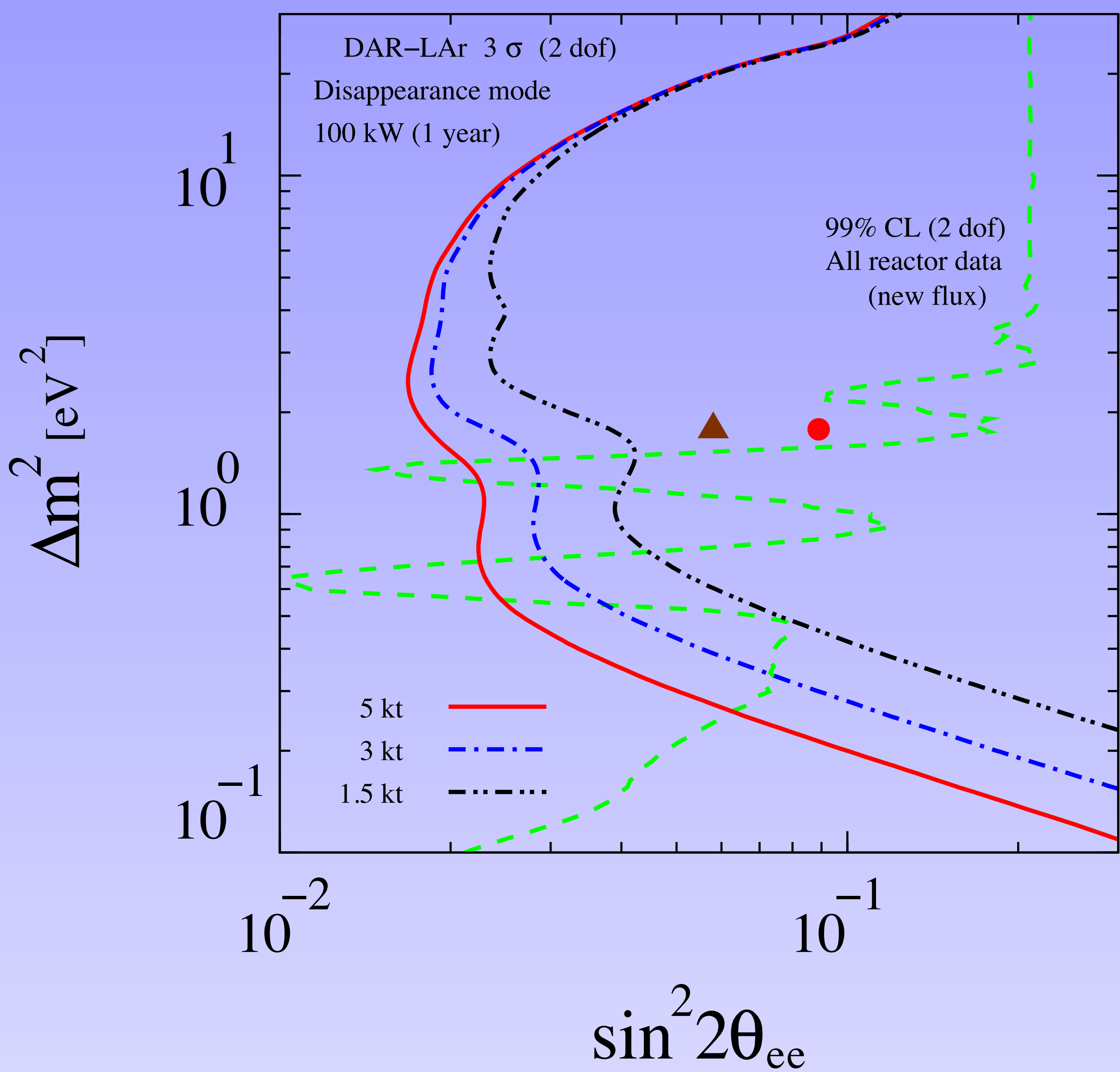


I. Gil-Botella & A. Rubbia, JCAP 0408 (2004) 001
and references therein

Reaction in 3 kton		No oscillation	Oscillation (n.h.) Large θ_{13}	Oscillation (n.h.) Small θ_{13}	Oscillation (i.h.) Large θ_{13}	Oscillation (i.h.) Small θ_{13}
Elastic						
	$\nu_e\, e^-$	20	20	20	20	20
	$\bar{\nu}_e\, e^-$	8	8	8	8	8
	$(\nu_\mu + \nu_\tau)\, e^-$	7	7	7	7	7
	$(\bar{\nu}_\mu + \bar{\nu}_\tau)\, e^-$	6	6	6	6	6
	total $\nu\, e^-$	41	41	41	41	41
Absorption						
CC	$\nu_e\ {}^{40}Ar$	188	962	730	730	730
	$\bar{\nu}_e\ {}^{40}Ar$	15	33	33	75	33
Total		244	1036	804	846	804

Pion decay at-rest experiment

S. Agarwalla



100 kW average source power

Negligible background from cosmic muons

(under 4000 mwe of shielding)

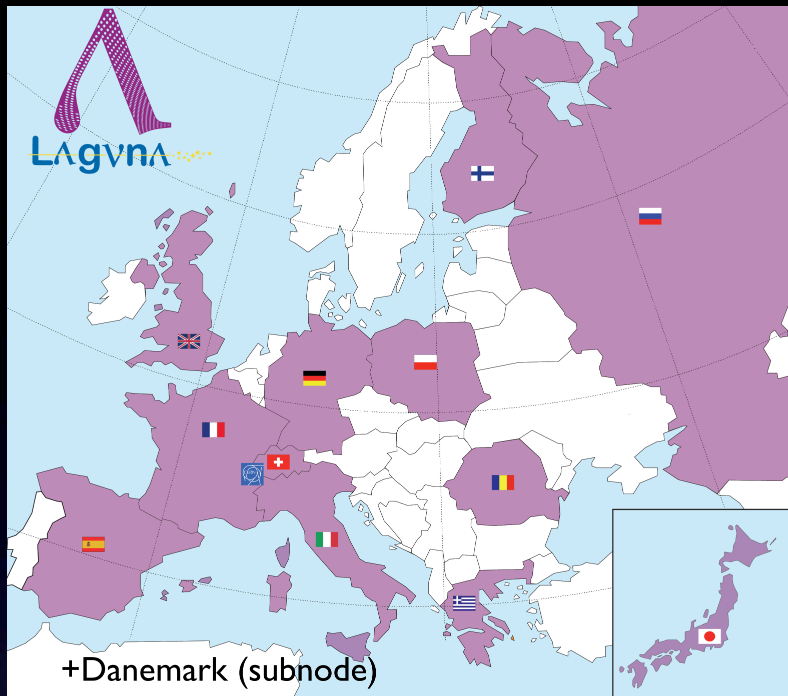
(3+1) model with simple 2-ν approximation

Triangle & Bullet : (3+1) best-fit values for all reactor data with old & new fluxes

Dashed green curve : 99% CL (2 dof) limit from reactor data with new reactor fluxes

Need more studies needed to understand sensitivity to appearance signal ?

LAGUNA-LBNO consortium



13 countries, 45 institutions, ~300 members

France
- CEA
- CNRS-IN2P3
- Sofregaz*

Germany
- TU Munich
- University Hamburg
- Max-Planck-Gesellschaft
- Aachen(**)
- University Tübingen(**)

Switzerland
- University Bern
- University Geneva
- ETH Zürich
- Lombardi Engineering*

Finland
- University Jyväskylä
- University Helsinki
- University Oulu
- Rockplan Oy Ltd*

CERN

Poland
- IFJ PAN
- IPJ
- University Silesia
- Wroklaw UT
- KGHM CUPRUM*

Greece
- Demokritos

Spain
- LSC
- UA Madrid
- CSIC/IFIC
- ACCIONA*

United Kingdom
- Imperial College London
- Durham
- Oxford
- QMUL
- Liverpool
- Sheffield
- RAL
- Warwick
- Technodyne Ltd*
- Alan Auld Ltd*
- Ryhal Engineering*

Romania
- IFIN-HH
- University Bucharest

Denmark
- Aahrus(**)

Italy
- AGT*

Russia
- INR
- PNPI

Japan
- KEK

(=industrial partners*
***=associated)*

LAGUNA - Milestones

LAGUNA Design Study funded for site studies: 2008-2011

Categorize the sites and down-select: Sept. 2010

LAGUNA-LBNO: detector design, costing and LBL beam options ➠ fully funded ! 2011-2014

Critical decision (and $\theta_{13}\neq 0$?) 2014 ?

Phase 1 excavation-construction: 2015-2020 ?

Phase 2 excavation-construction: >2020 ?

The opportunity of "pilot" projects will be discussed within the LAGUNA-LBNO consortium

Conclusions

- **A ~100 kton LAr detector for proton decay, CP violation searches in the leptonic sector and astrophysical neutrino observatory**
- **Achieved many important R&D results**: Several years of investigations led to the definition of a coherent graded strategy path towards the giant liquid argon detector. Real hardware tests have been successfully operated or will soon be.
- **“Underground pilot project”:** An underground 5 kton pilot represents the next milestone for the technology and will have the right mass scale to further demonstrate the physics performance in realistic underground conditions. It has a “startup” physics program, expandable with additional similar or larger detector units. The “pilot” setup can therefore evolve towards the ultimate mass facility.
- → “**white paper**” ?

Acknowledgements

- FP7 Research Infrastructure "Design Studies" LAGUNA (Grant Agreement No. 212343 FP7-INFRA-2007-1)

Backup slides