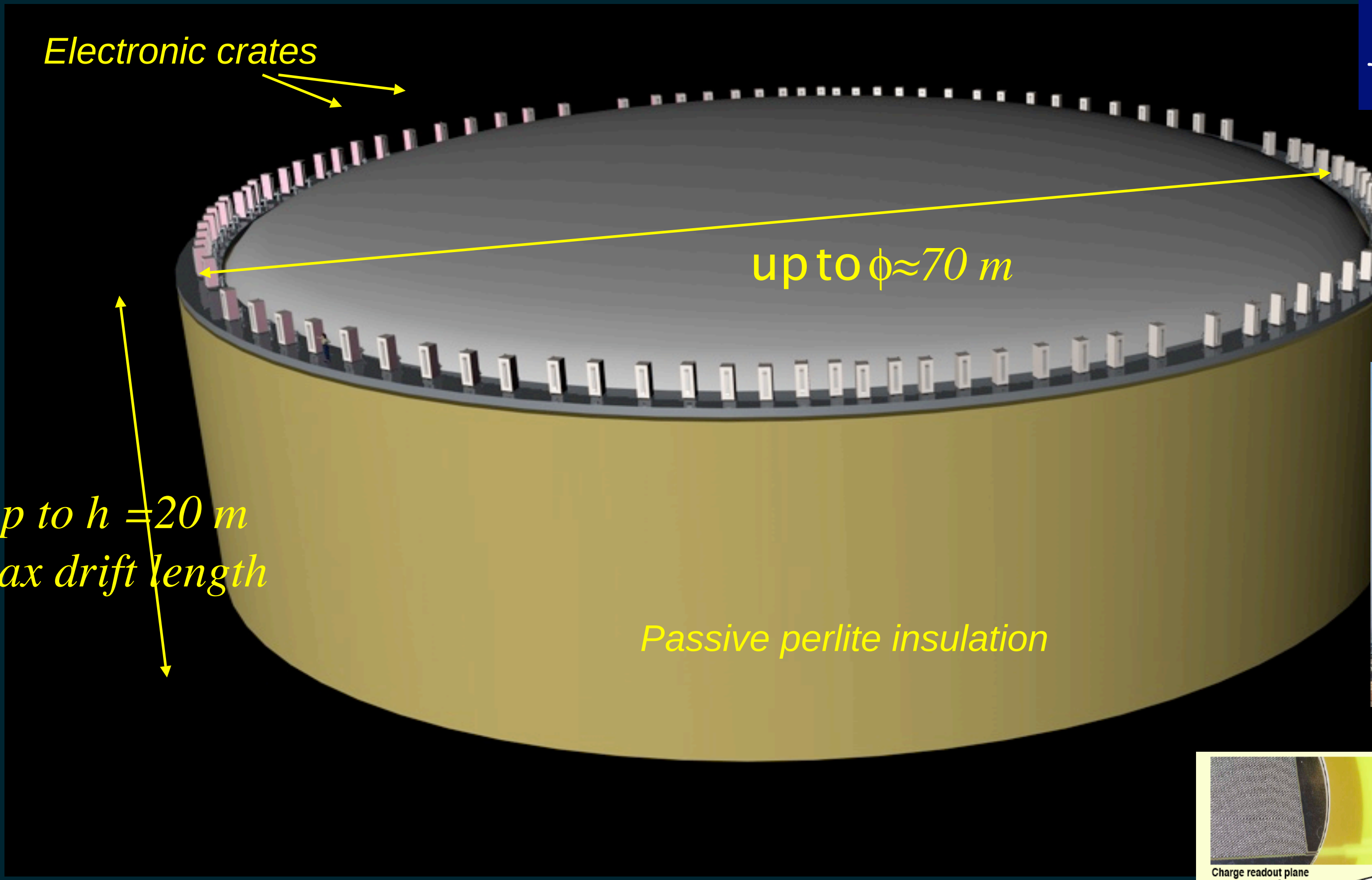
GLACIER: A Giant Liquid Argon Charge Imaging ExpeRiment

André Rubbia (ETH Zürich)

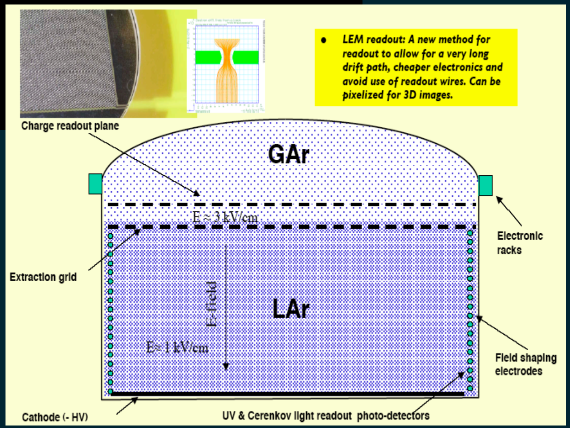
Workshop on Next generation Nucleon decay and Neutrino detectors 2007
Oct 2-5 2007, Hamamatsu Japan

Basic detector concept: a 100 kton LAr TPC

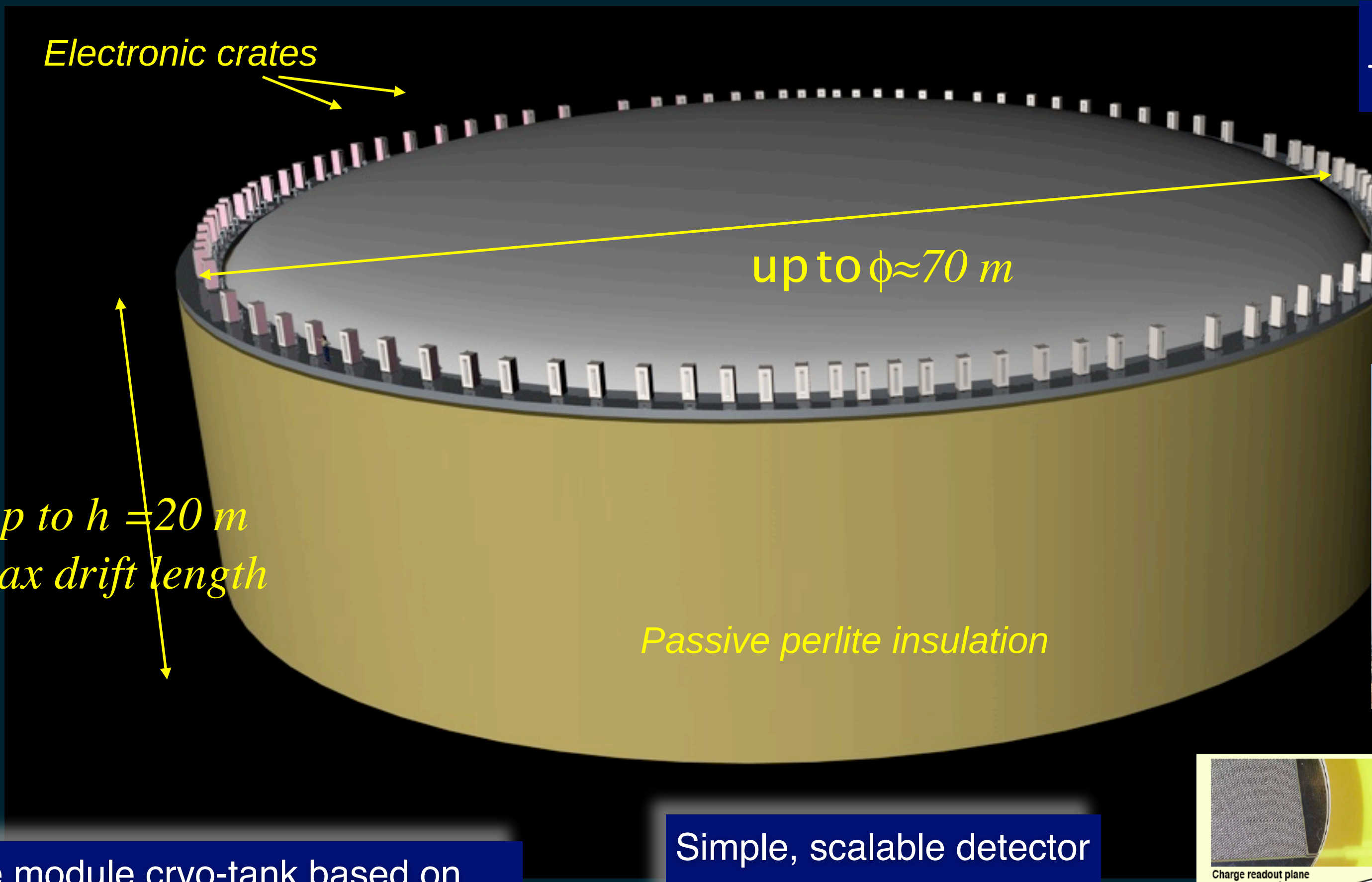


hep-ph/0402110
Venice, Nov 2003

"possibly up to 100 kton"



Basic detector concept: a 100 kton LAr TPC



hep-ph/0402110
Venice, Nov 2003

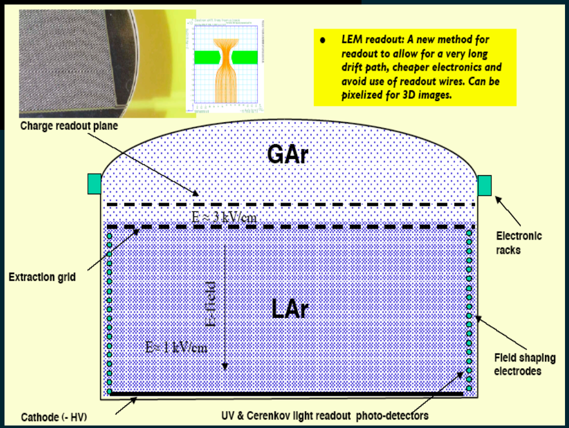
"possibly up to 100 kton"

Single module cryo-tank based on industrial LNG technology

Simple, scalable detector design, possibly up to 100 kton

Modest excavation requirements for "megaton-scale-physics"

Proposed improvements in detector design



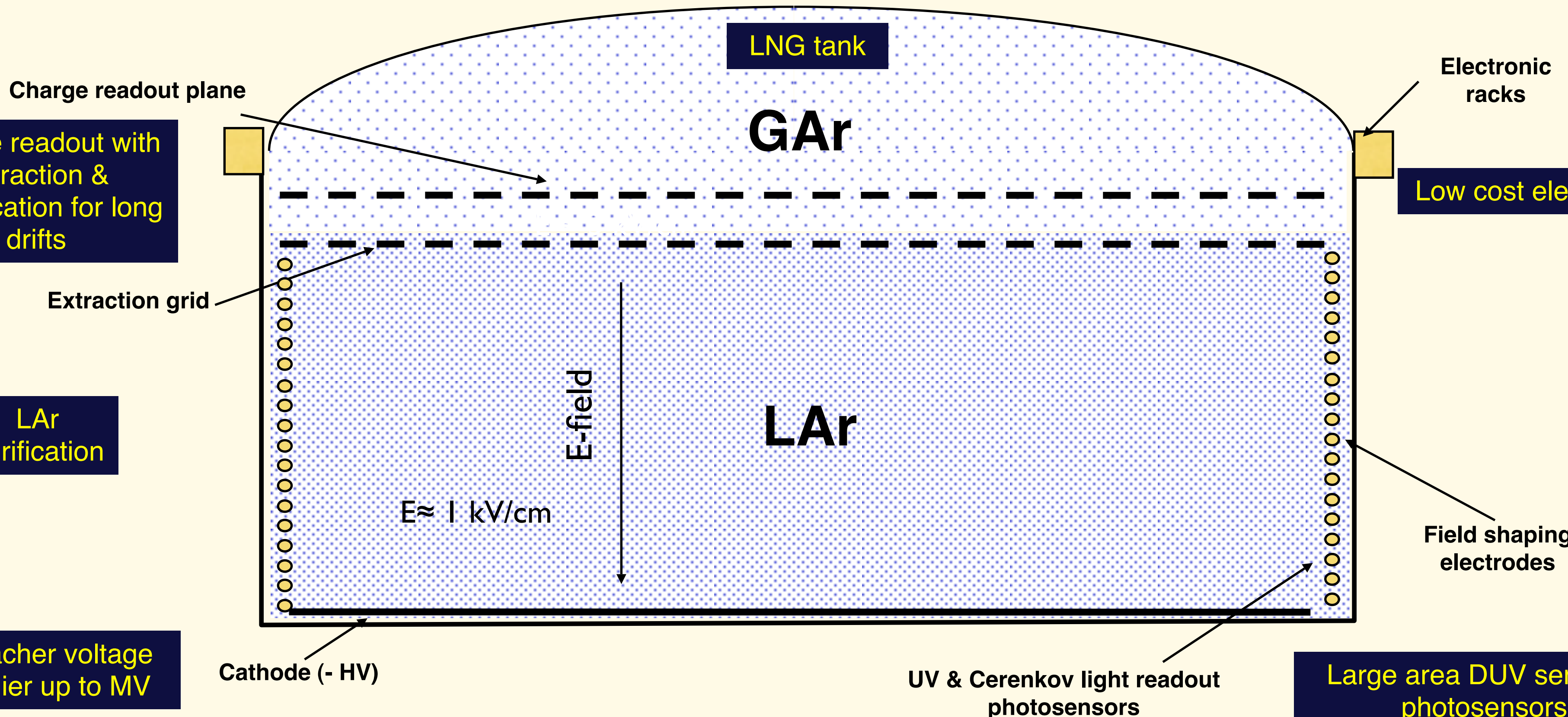
Baseline concept for inner detector

Medium/ Property	BP @ 1atm	Density liquid g/cm^3	W (eV) Q_0=E/W	electron mobility (cm^2/Vs)	W_γ (eV)	Scintillation wavelength (nm)	Lifetime of scintillation	Long-lived metastable isotope
Ar ≈$1/kg	87.3K	1.40	23.8	400	25.0	128	≈10ns / 1.6μs	^{39}Ar ^{42}Ar

Charge readout with extraction & amplification for long drifts

LAr purification

Greinacher voltage multiplier up to MV



Low cost electronics

Large area DUV sensitive photosensors

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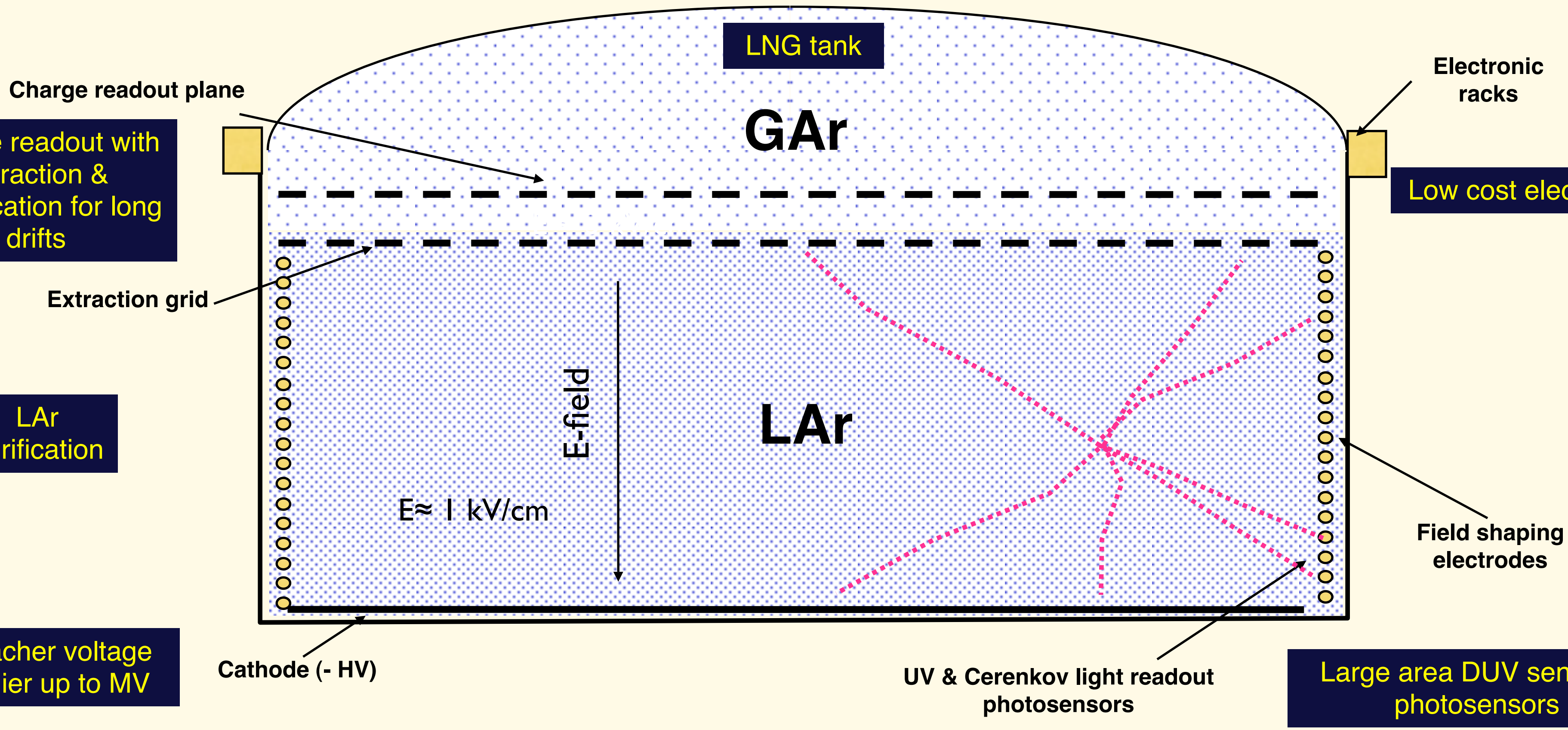

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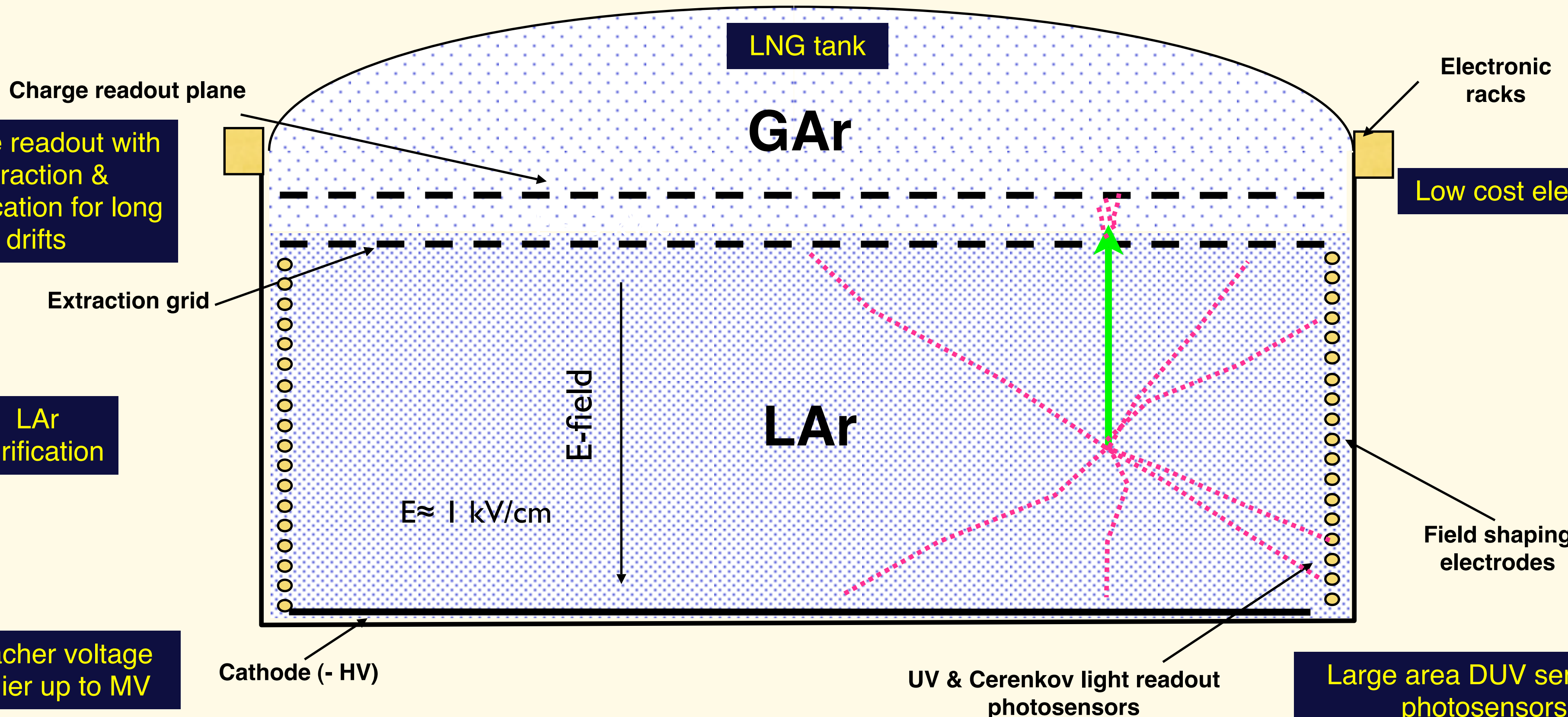


Charge readout with extraction & amplification for long drifts

LAr purification

Greinacher voltage multiplier up to MV

Low cost electronics

Large area DUV sensitive photosensors

Broad and rich research program

- Grand Unification: proton decay investigated at the 10^{35} yr range and study of atmospheric neutrinos (JHEP 0704:041,2007)
  - proton decay OK also "at shallow depth" (green field/hill)
- Low energy astrophysical neutrinos: SN core collapse (all neutrino flavors JCAP 0408:001,2004), relic SN ν (JCAP 0412:002,2004), ...
- Long baseline υ beams: 3rd generation experiment for θ_{13} mixing angle, CP violation and mass hierarchy e.g. with upgraded CERN SPS neutrino beam (JHEP 0611:032,2006)
- etc...

List not exhaustive

LAr TPC as proton decay detector

To reach 10^{35} years sensitivity in lifetime a detector mass of ≈100 kton and 10 years of observation are required

Proton decay signals are characterized by:

★ their topology, with a lepton (electron, muon, neutrino) in the final state and few other particles

★ total energy of the event should be close to the nucleon mass and the total momentum should be balanced, apart from nuclear effects

A LAr TPC provides:

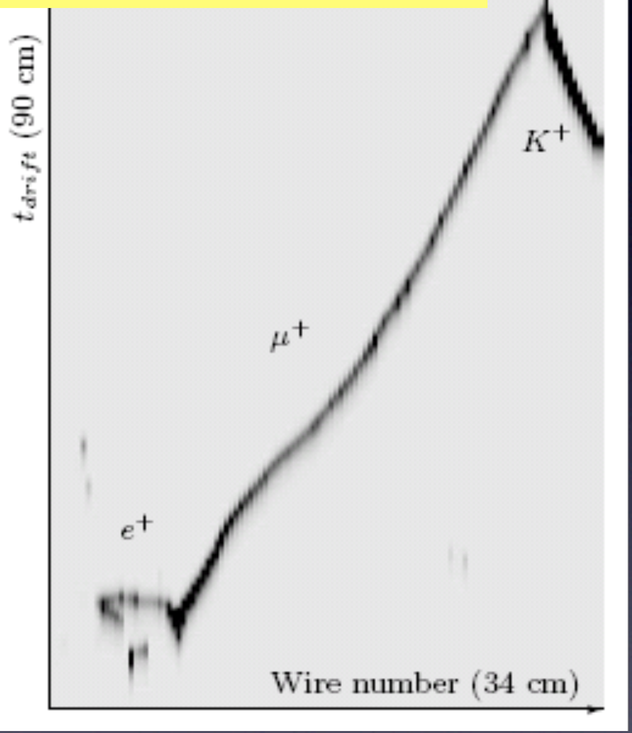
★ excellent tracking and calorimetric resolution to constrain the final state kinematics and suppress atmospheric neutrino background

★ particularly suited to the 100÷1000 MeV/c range

★ particle identification (in particular kaon tagging) for branching mode identification

★ access to many possible decay modes (since particle detection threshold essentially negligible)

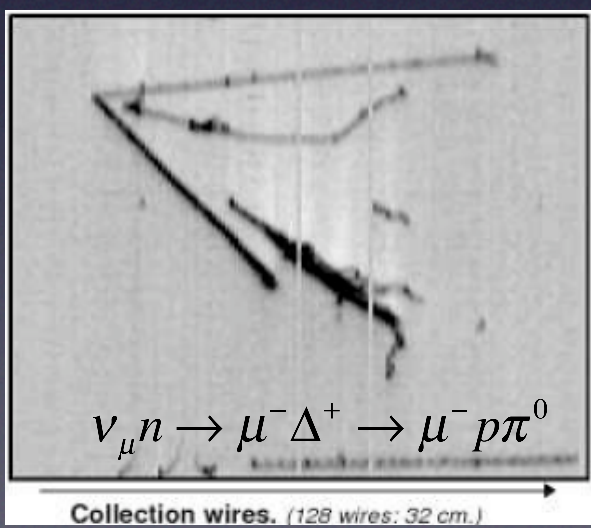
LAr MC: $p \rightarrow K^+ \bar{\nu}$



JHEP 0704:041,2007

LAr TPC as high E neutrino detector

- provides high efficiency for ν_e charged current interactions
- high rejection against ν_μ NC and CC backgrounds also in MultiGeV region
  - e/π^o separation
    - fine longitudinal segmentation (few % X_o) – to be optimized !
    - fine transverse segmentation, finer than the typical spatial separation of the 2 γ's from π^o decay
  - e, μ/π, K, p separation
- embedded in a magnetic field provides the possibility to measure both wrong sign muons and wrong sign electrons samples in a neutrino factory beam
- unlike WC detectors, detection and reconstruction efficiency does *not* depend on volume of detector $\rightarrow$ direct near / far detector comparison (apart from flux extrapolation)



F. Arneodo et al., "Performance of a liquid argon time projection chamber exposed to the WANF neutrino beam", Phys. Rev. D 74 (2006) 112001

Data collected in 1997

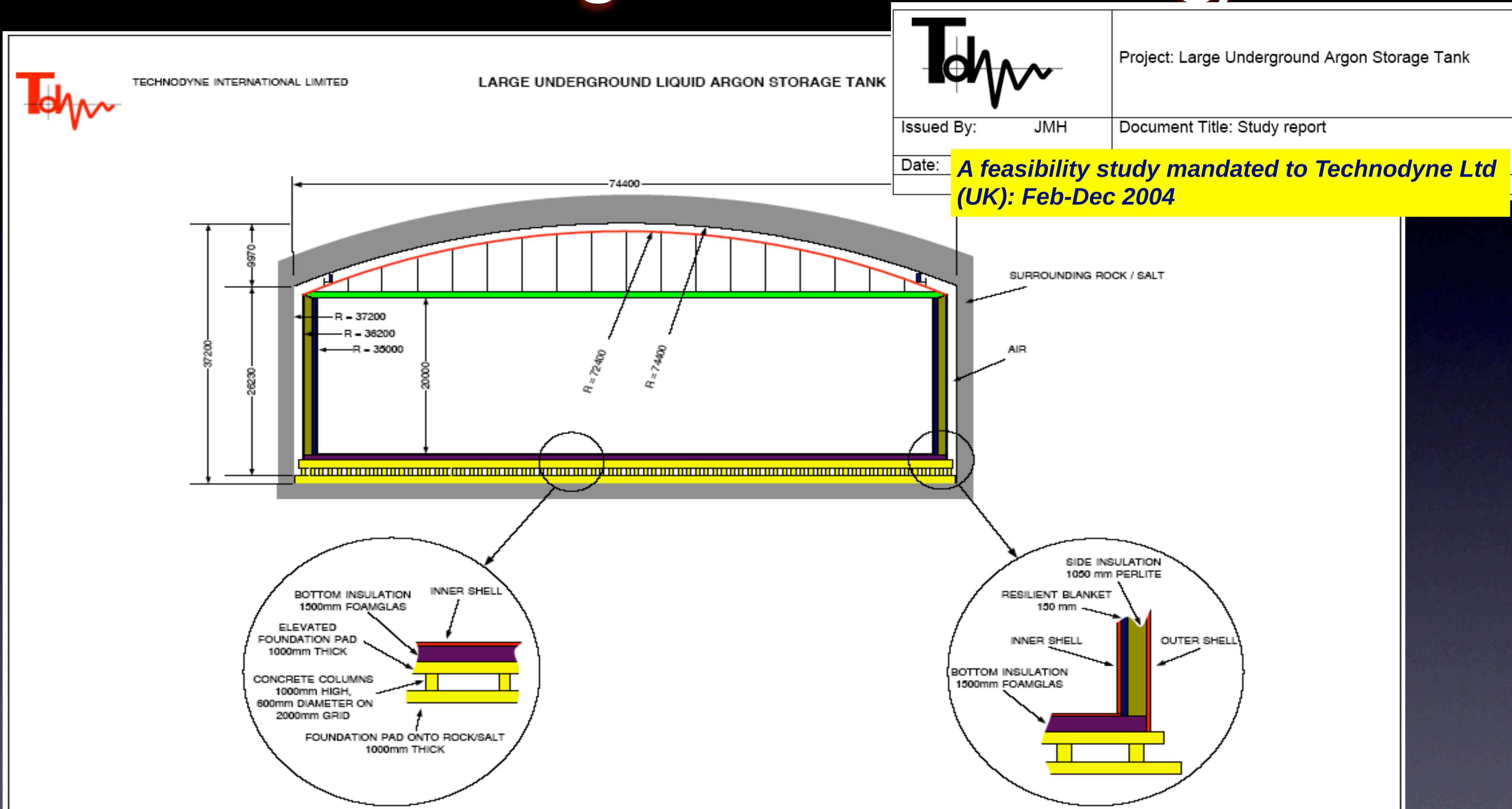
Search for QE events

86 "golden" events with an identified proton of kinetic energy larger than 40 MeV and one muon matching NOMAD reconstruction

R&D program

- Funded R&D setups for charge & light readout, HV, feed-throughs, electronics, purification, long drift paths, ...
(CH-SNF, ETHZ, IN2P3, Granada Univ, UniBe, UniZ)
- Tank design (Technodyne)
- ArDM 1 ton detector (J.Phys.Conf.Ser.39:129-132,2006)
- ArgonTube 5 m drift full test
- Magnetized TPC (NIM A555:294-309,2005)
- ePiLAr in particle beams, possibly magnetized TPC
- Detection of ≈1 GeV neutrino beam
- LOI for 150 ton in T2K 2km site submitted to JPARC PAC & DOE
- European siting possibly at shallow depth to be studied within LAGUNA FP7 DS (PI A. Rubbia) → *see Luigi Mosca's talk*

Tank design: LNG technology



A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004

Tank specifically designed & costed for LAr detector application. Cost uncertainty comes from underground installation (at this stage conservative factor x2)

Scaling parameters & aspect ratio

100 kton:

Dewar	ϕ ≈ 70 m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m²
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m³, ratio area/volume ≈ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc ϕ ≈70 m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single γ counting capability

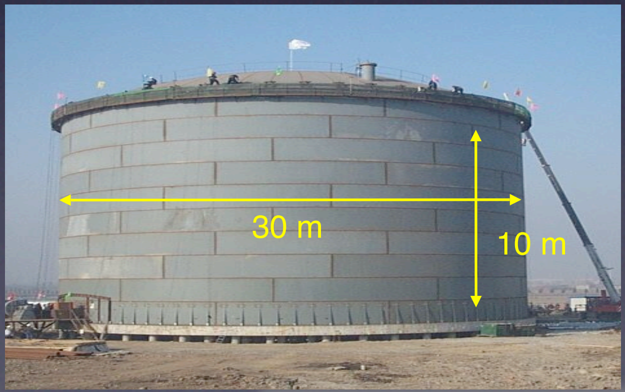
40 kton: Φ=40 m, h=20 m

20 kton: Φ=30 m, h=20 m

10 kton: Φ=30 m, h=10 m

$M \propto \Phi^2 h$ → flexibility, scalability

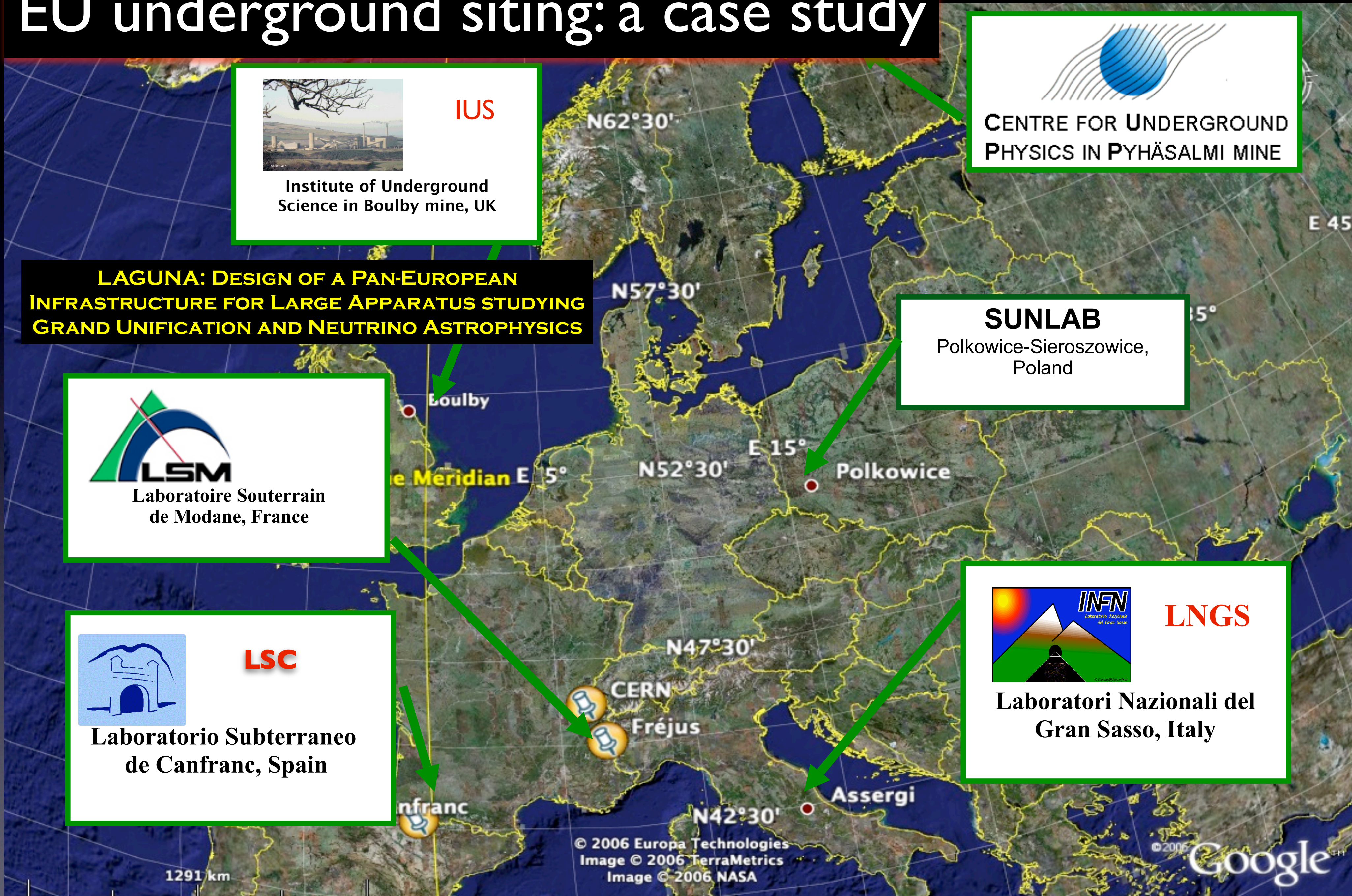
Dimensions confirmed by Technodyne



Dewar	ϕ ≈ 30 m, height ≈10 m, perlite insulated, heat input ≈ 5 W/m²
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	7000 m³, ratio area/volume ≈ 33%
Argon total mass	9900 tons
Hydrostatic pressure at bottom	1.5 atmospheres
Inner detector dimensions	Disc ϕ ≈30 m located in gas phase above liquid phase
Charge readout electronics	30000 channels, 30 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 300 immersed 8" PMTs with WLS

1 kton: 1% prototype: engineering detector, ϕ ≈ 10m, h ≈ 10m, shallow depth?

EU underground siting: a case study



IUS
Institute of Underground Science in Boulby mine, UK

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

LAGUNA: DESIGN OF A PAN-EUROPEAN INFRASTRUCTURE FOR LARGE APPARATUS STUDYING GRAND UNIFICATION AND NEUTRINO ASTROPHYSICS

SUNLAB
Polkowice-Sieroszowice, Poland

LSM
Laboratoire Souterrain de Modane, France

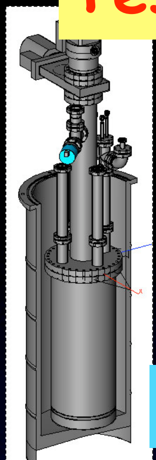
LNGS
Laboratori Nazionali del Gran Sasso, Italy

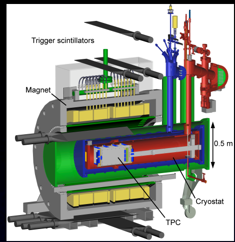
LSC
Laboratorio Subterraneo de Canfranc, Spain

EU underground siting: a case study

Steps towards GLACIER...

Test stands



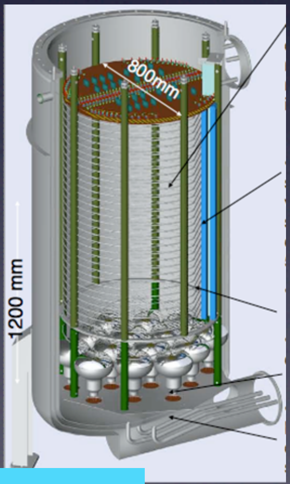


B-field test

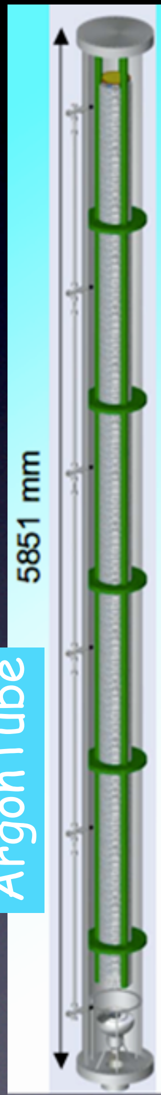
Readout test stand

≈ 10 lt

≈ 0.8 ton

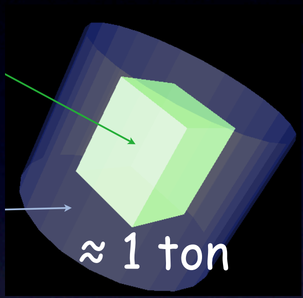


ArDM

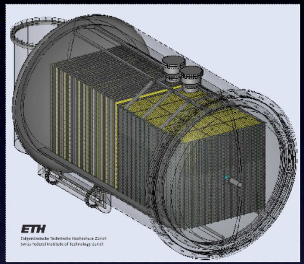


ArgonTube

"Small" size detectors



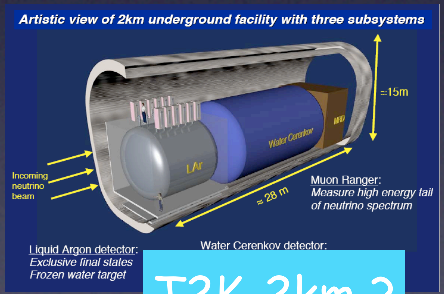
≈ 1 ton



≈ 5 ton

Electron/π^0 separation optimization

Neutrino beam (vtx detector)

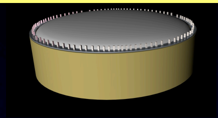


T2K-2km ?

1 kton WC + 150 ton LAr

~ 200000 ν interactions/year

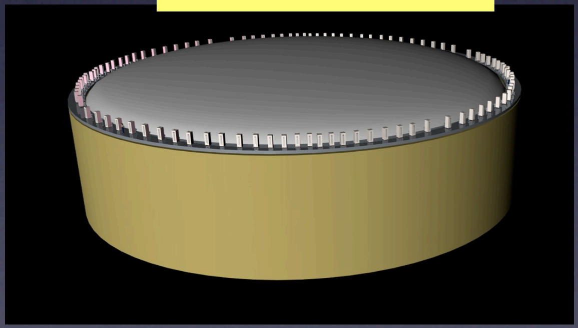
Medium size detector



1÷10 kton

shallow depth location (?)

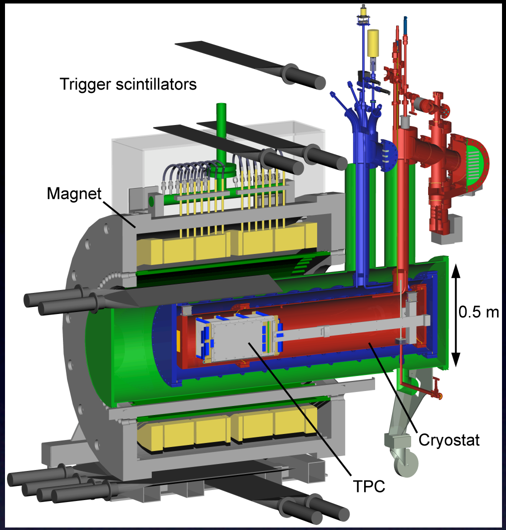
Large size detector



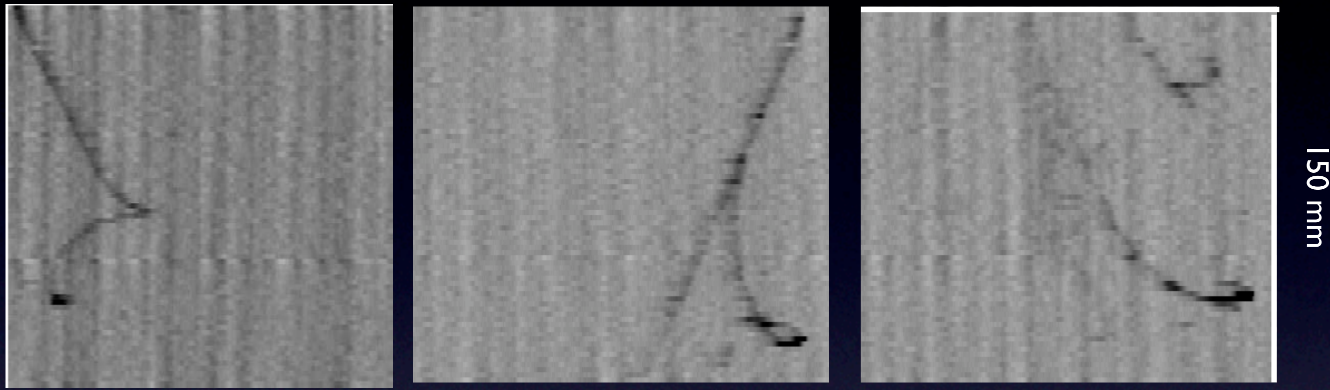
up to 100 kton total mass

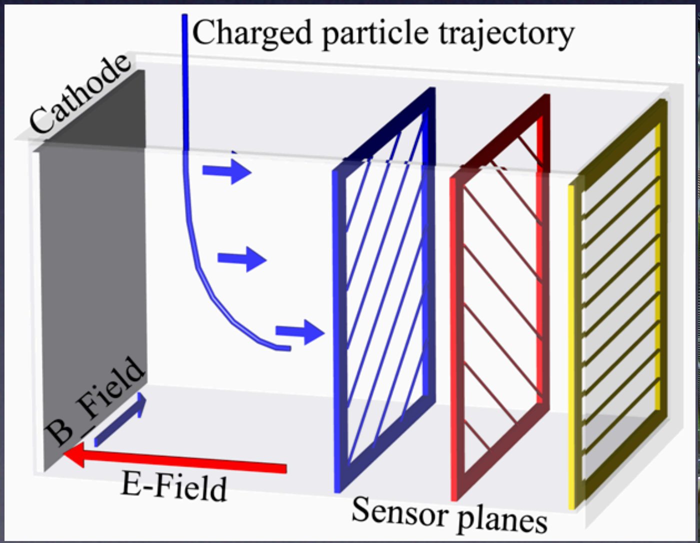
First operation of a LAr TPC embedded in a B-field

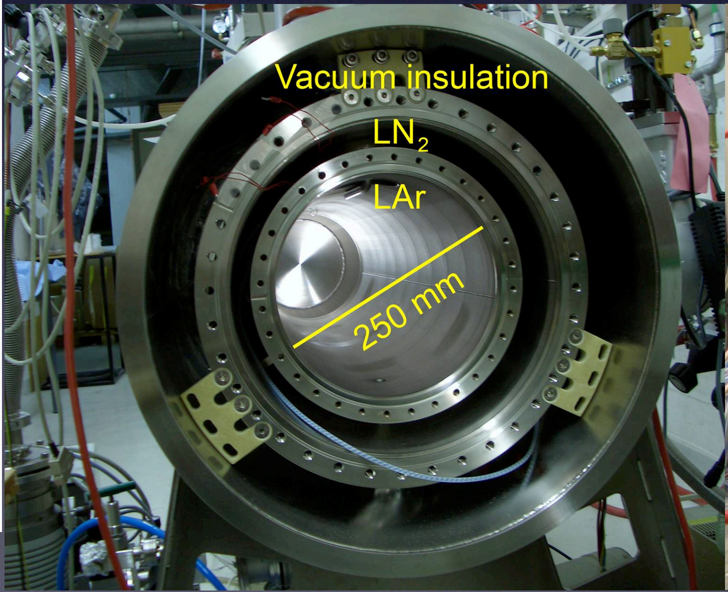
New J. Phys. 7 (2005) 63
NIM A 555 (2005) 294

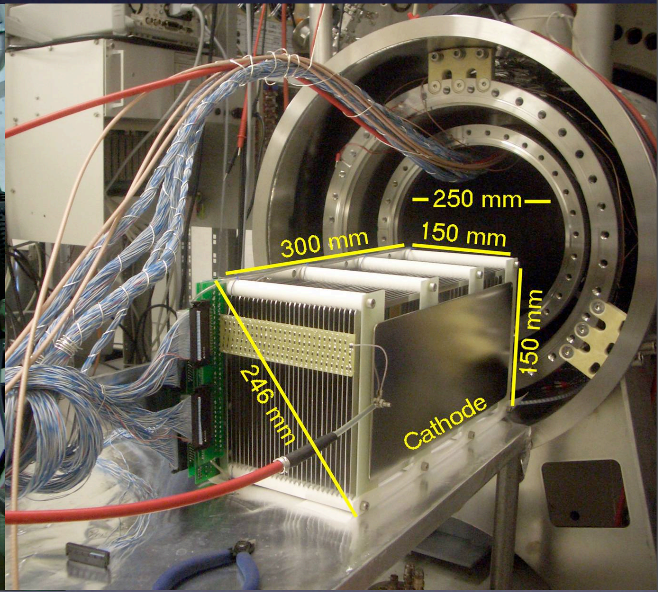


First events in B-field
(B=0.55T):





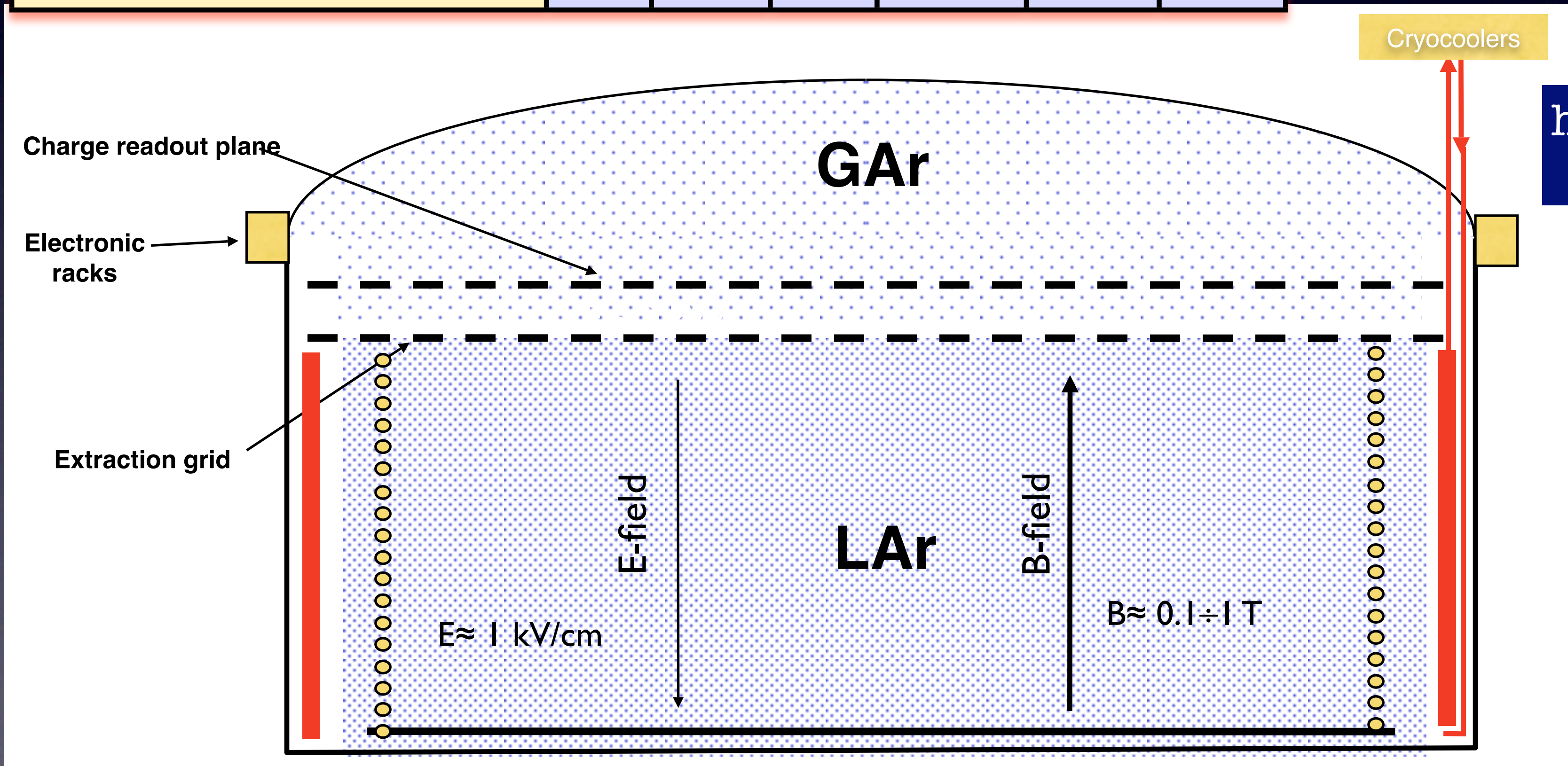




Layout for a magnetized detector

	10 kton LAr			100 kton LAr		
Magnetic induction (T)	0.1	0.4	1.0	0.1	0.4	1.0
Magnetic volume (m^3)	7700			77000		
Stored magnetic energy (GJ)	0.03	0.5	3	0.3	5	30
Magnetomotive force (MAt)	0.8	3.2	8	1.6	6.4	16
Radial magnetic pressure (kPa)	4	64	400	4	64	400

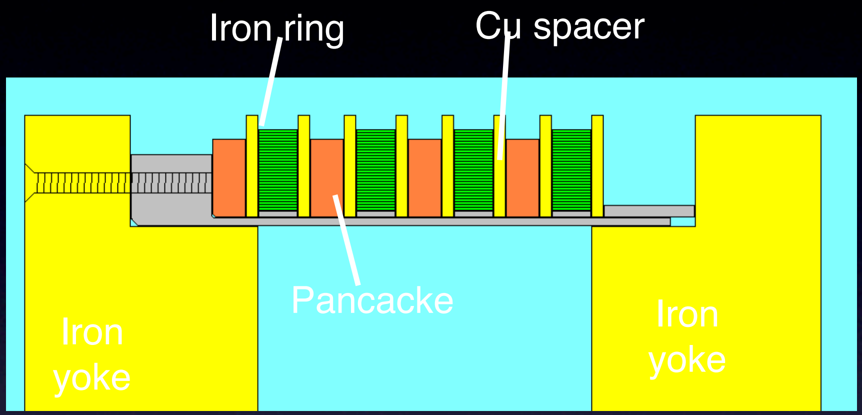
Immersed normal or HTS superconductor solenoid

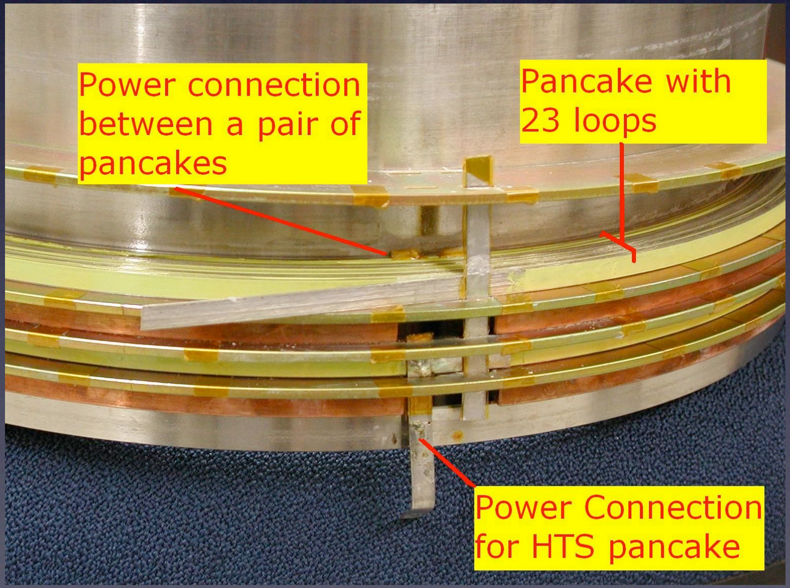


hep-ph/0510131
Frascati, 2005

Small test solenoid built wit HTS wire

Consists of 4 pancakes, total HTS wire length: 80m
BSSCO from American Superconductor





Temperature	LN_2 (77K)	LAr (87K)
Max. applied current	145 A	80 A
On-axis B-field	0.2 T	0.11 T
Coil resistance at 4A	6 $\mu\Omega$	6 $\mu\Omega$

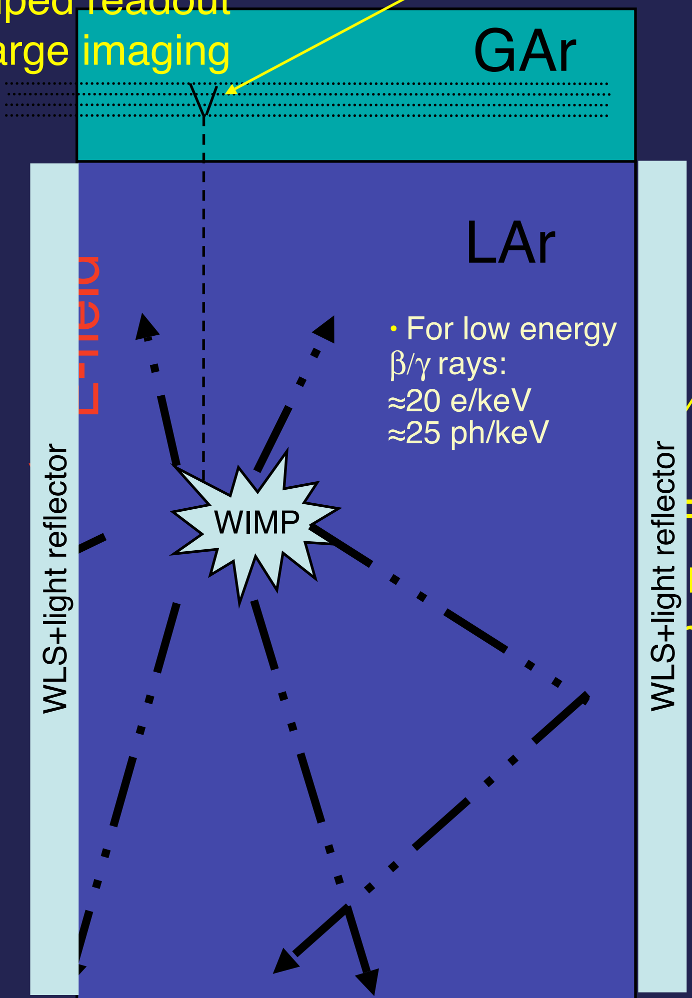
Similar tests performed with YBCO from Superpower Inc

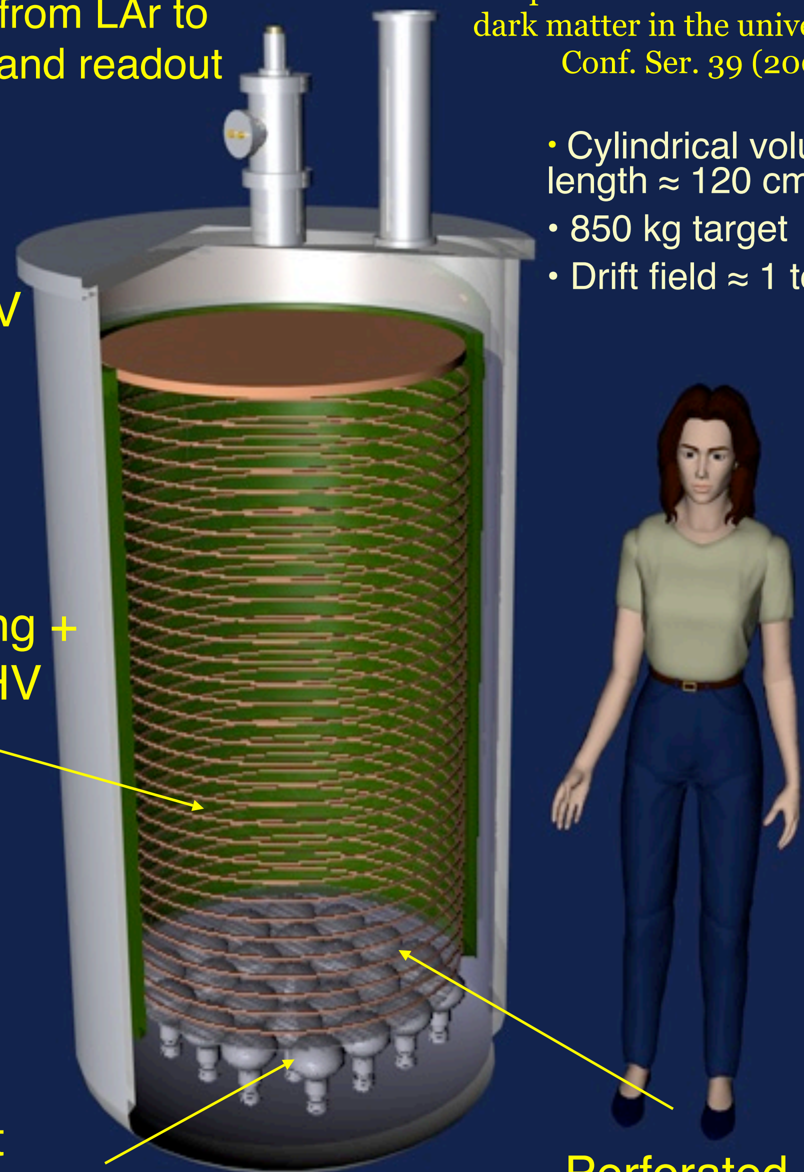
→ must operate at LN2 (or below) temperature (solenoid to be thermally insulated from LAr but still immersed in tank)

ArDM Argon Dark Matter Experiment

CIEMAT - ETHZ -Granada - Sheffield - Warszawa - Zurich

"ArDM: a Ton-scale liquid Argon experiment for direct detection of dark matter in the universe", J. Phys. Conf. Ser. 39 (2006) 129

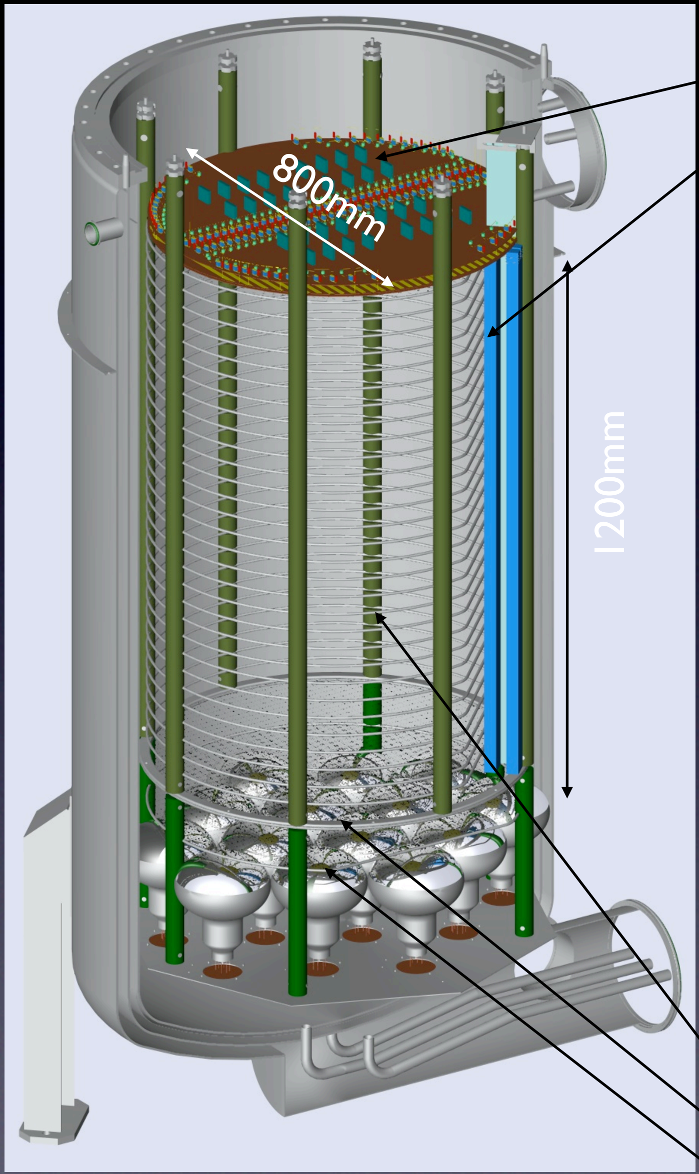




- Cylindrical volume, drift length ≈ 120 cm
- 850 kg target
- Drift field ≈ 1 to 5 kV/cm

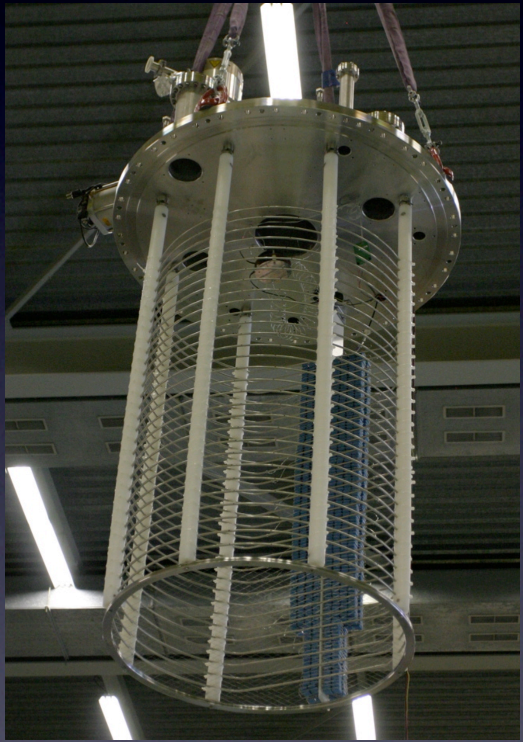
A. Rubbia

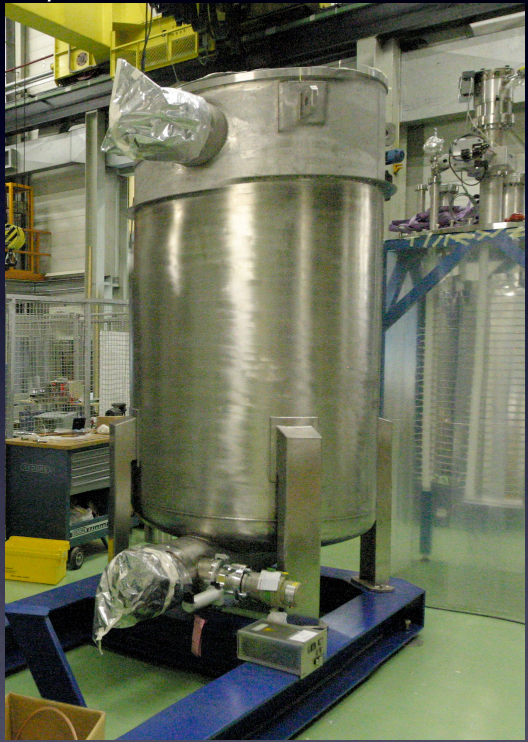
ArDM detector layout



Two-stage LEM

Cockroft-Walton (Greinacher) chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV (E=1-4kV/cm)





Field shaping rings and support pillars

Cathode grid

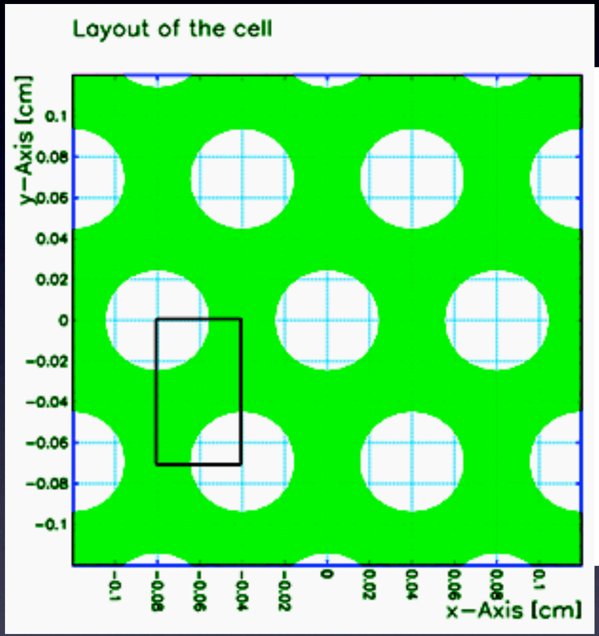
14 PMTs below the cathode to detect the scintillation light

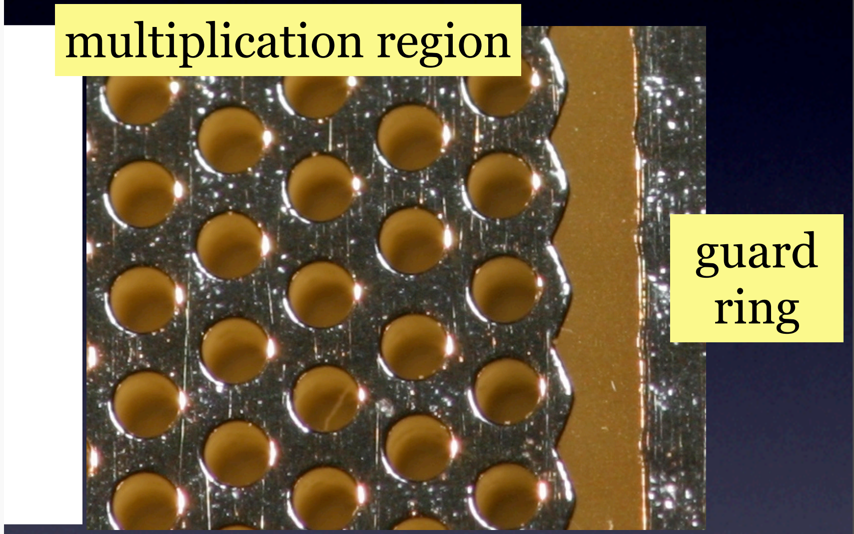
Charge readout system: LEM

GEM: F. Sauli, NIM A386 (1997) 531
Optimized GEM: V. Peskov et al., NIM A433 (1999) 492
THGEM: R. Chechik et al., NIM A535 (2004) 303

LEM (Large Electron Multiplier) is a thick macroscopic GEM

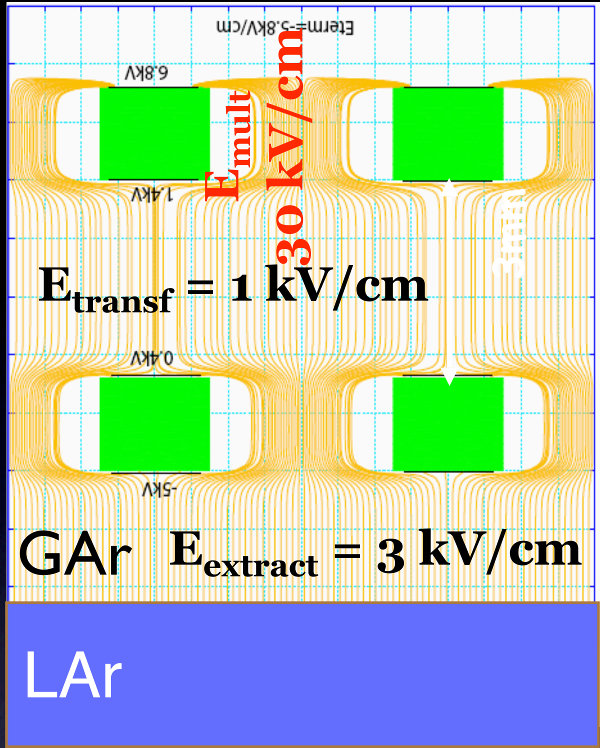
Produced by standard Printed Circuit Board methods

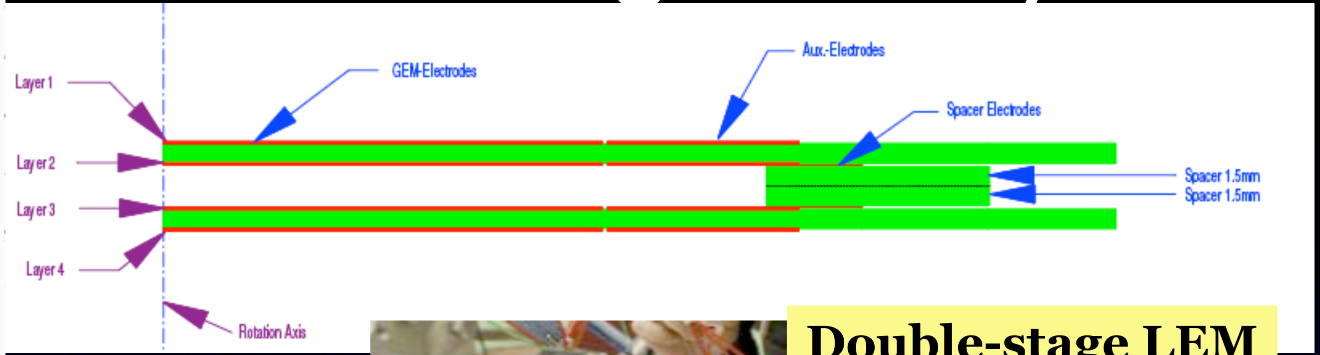


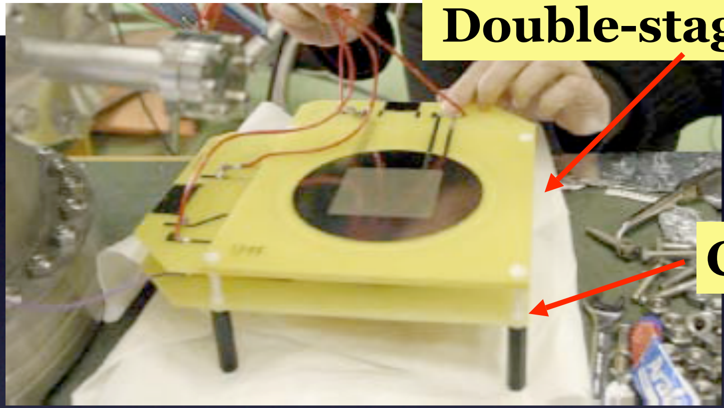


- Double-sided copper-clad (35 μm layer) G-10 plates
- Precision holes by drilling
- Palladium deposition on Cu (<~ 1 μm layer) to avoid oxidization
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm

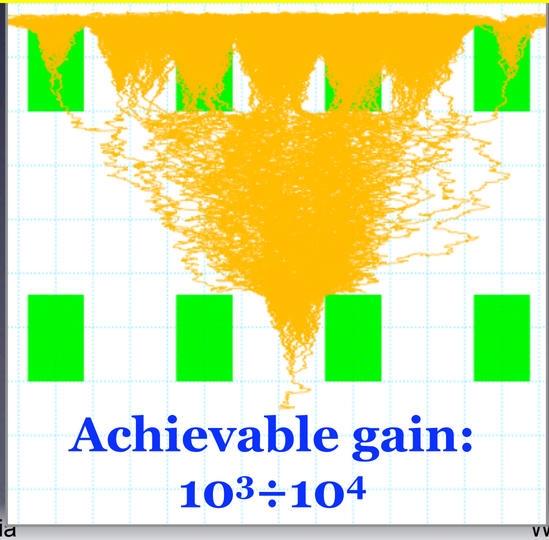
Double stage LEM system

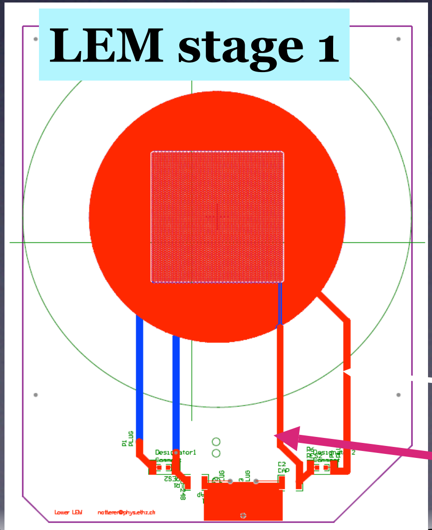


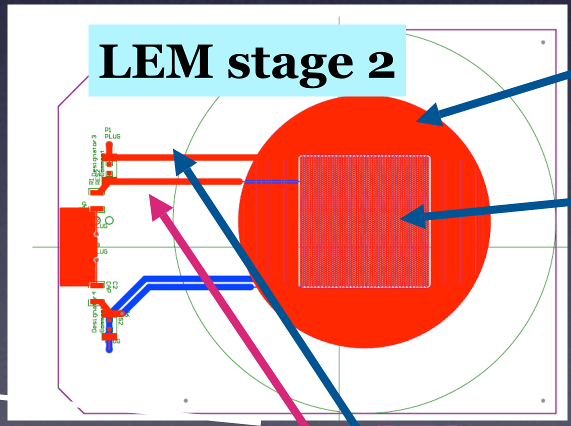




Avalanche simulation







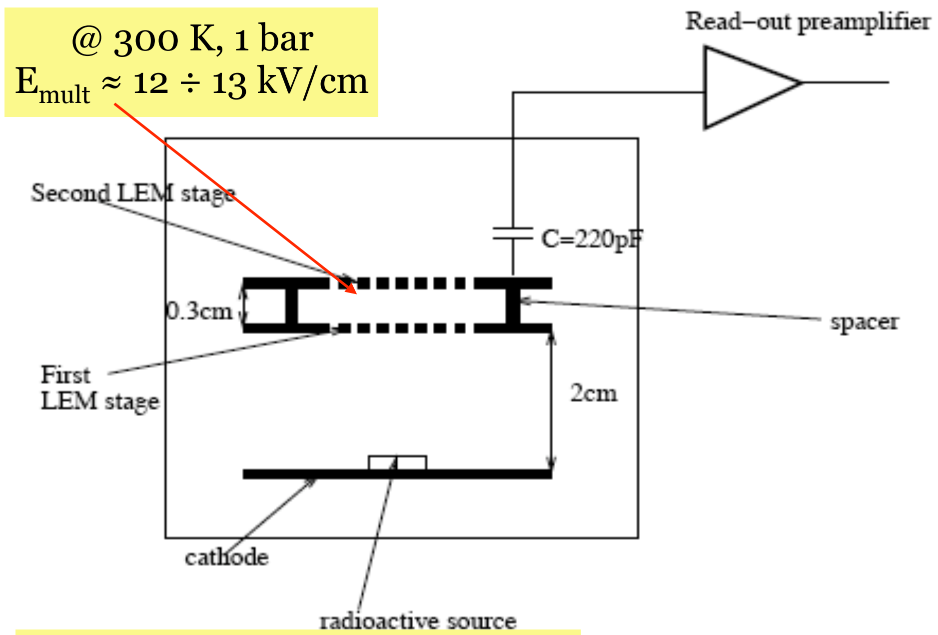
Guard ring

Multiplication area

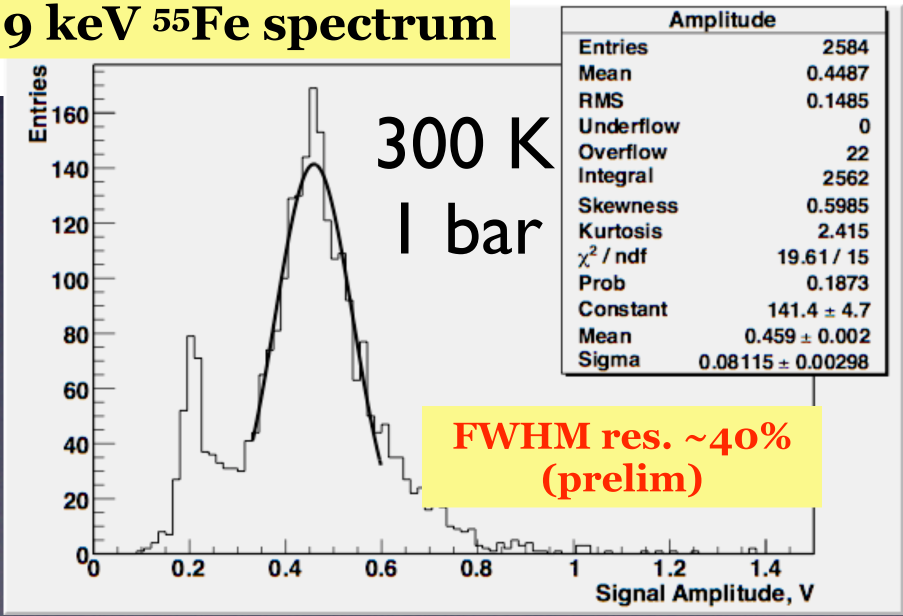
HV connections

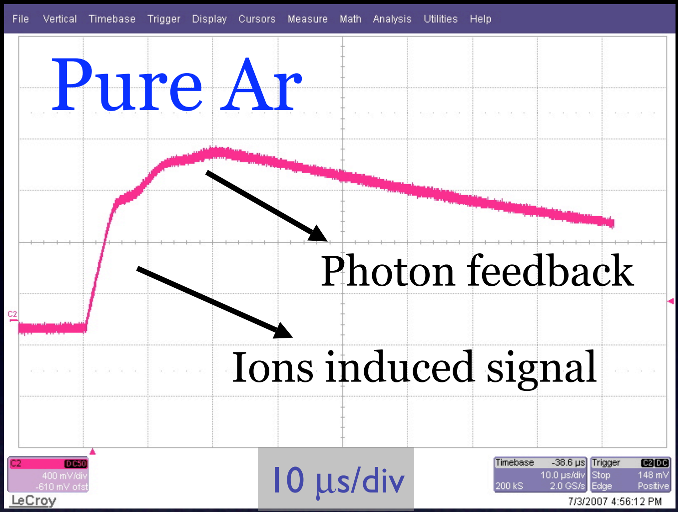
signal readout

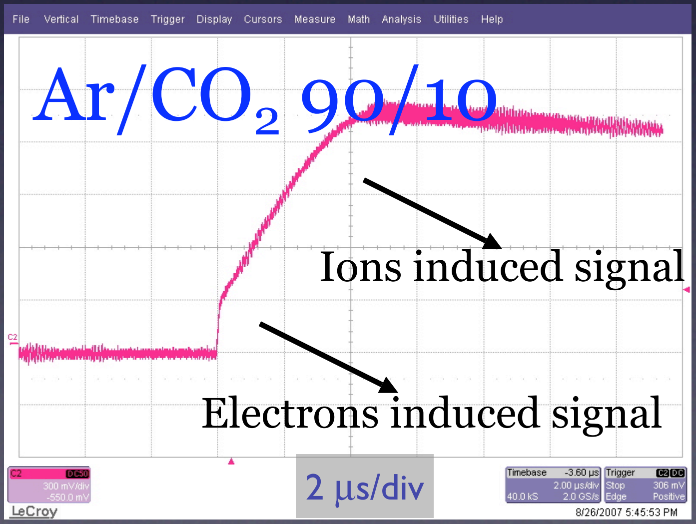
LEM operation in gas



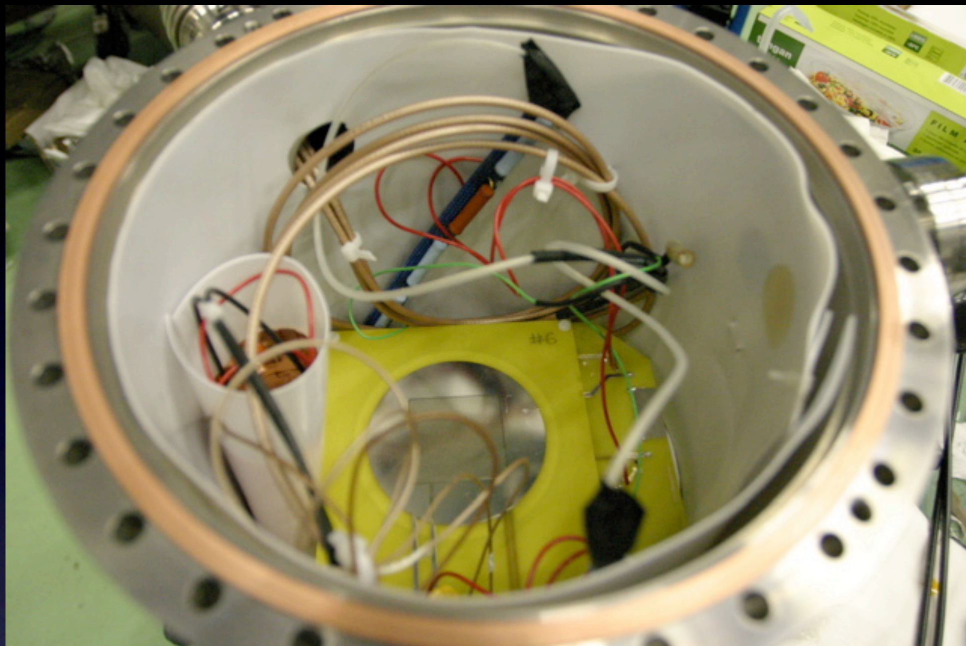
5.9 keV ^{55}Fe spectrum

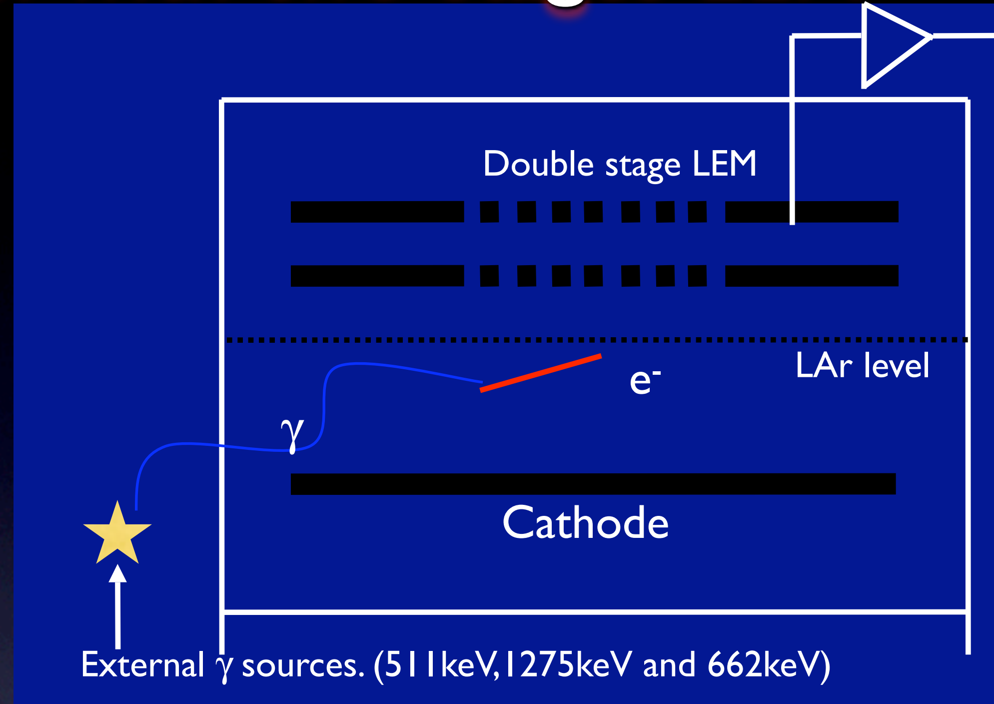


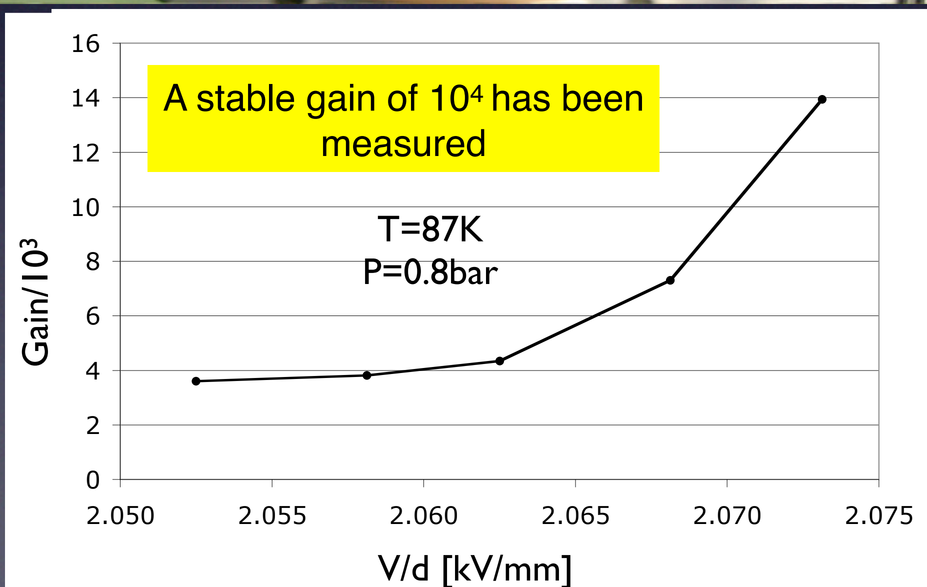


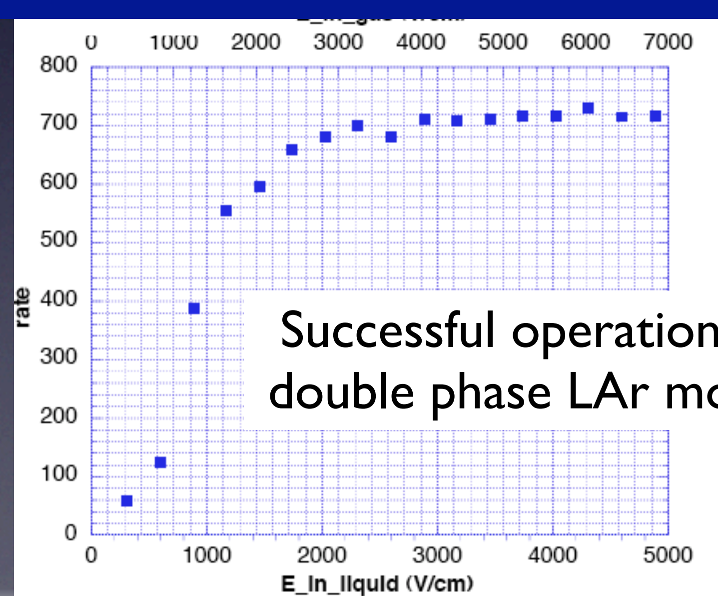


Double phase operation with two stages LEM

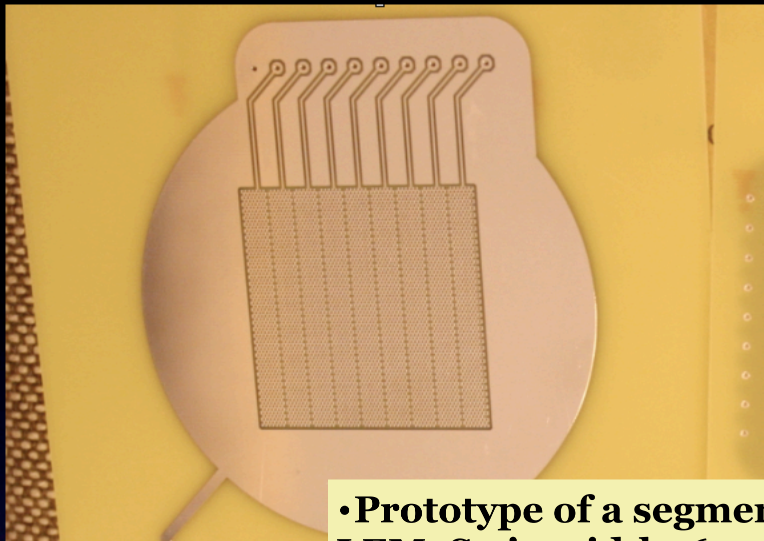








Successful operation in double phase LAr mode



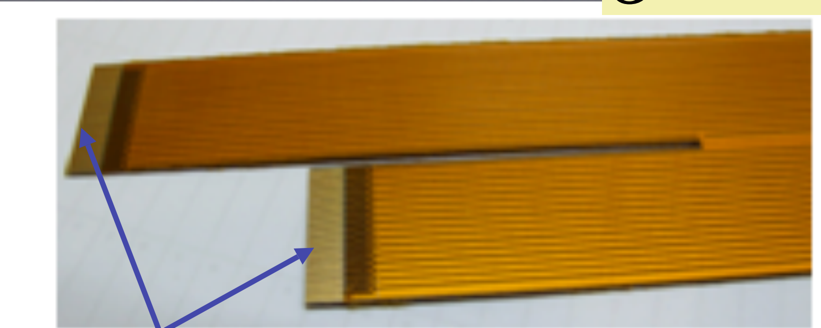
•**Prototype of a segmented LEM. Strip width: 6mm**

Segmented LEM

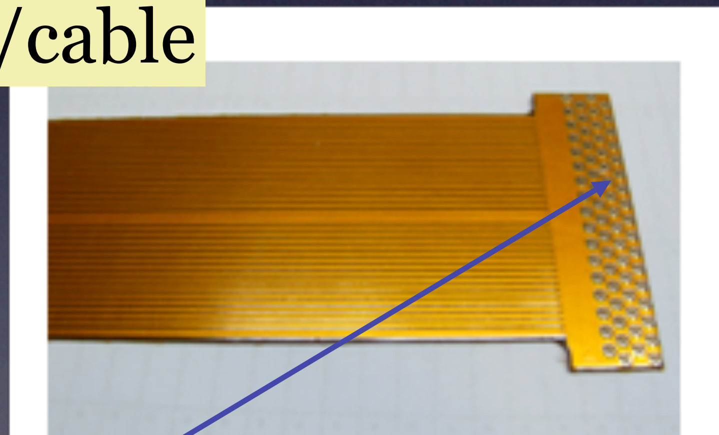
- Final LEM charge readout system will be segmented
- Orthogonal strips readout
- Number of channels: 1024
- Strip width: 1.5mm

- Kapton flex-prints are used for signal transfers to the readout electronics
- The flex-prints, connected on one side to the LEM board, exit the dewar through a slot, sealed with epoxy-resin, in a vacuum tight feed-through flange

32 channels/cable



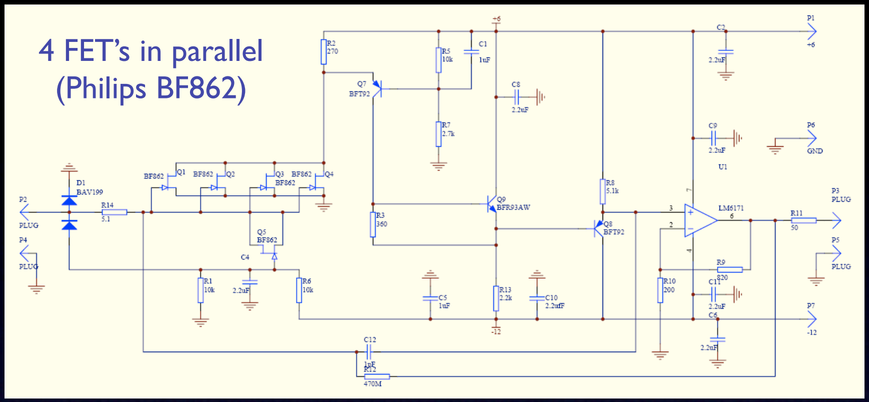
to ZIF connectors on the LEM board



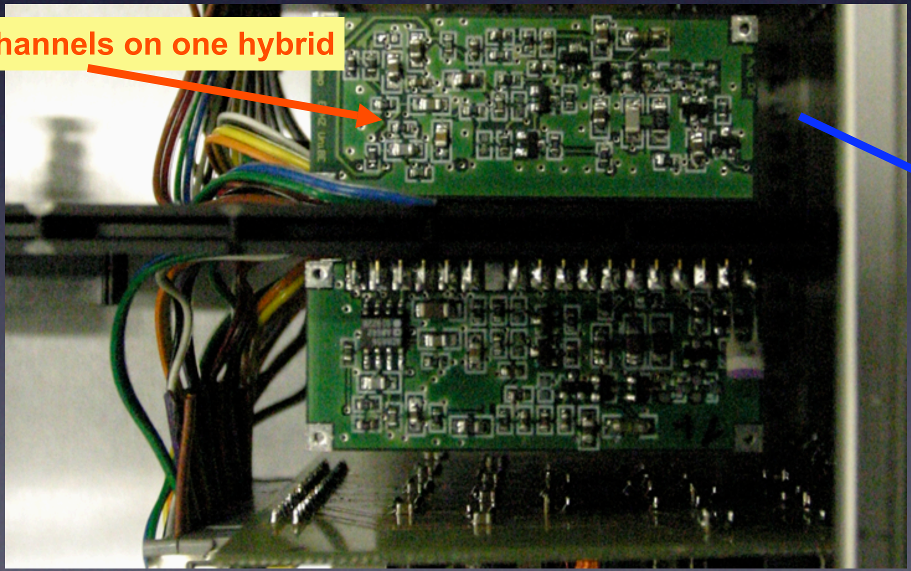
to front-end preamplifers

LEM readout electronics

Low noise charge preamp inspired from C. Boiano et al. IEEE Trans. Nucl. Sci. 52(2004)1931



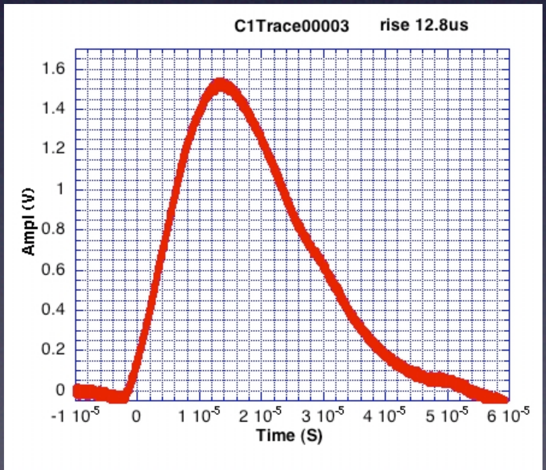
Custom-made front-end charge preamp + shaper G ~15mV/fC



1) Developing A/D conversion and DAQ system:
MHz serial ADC + FPGA + dual memory buffer + ARM microprocessor

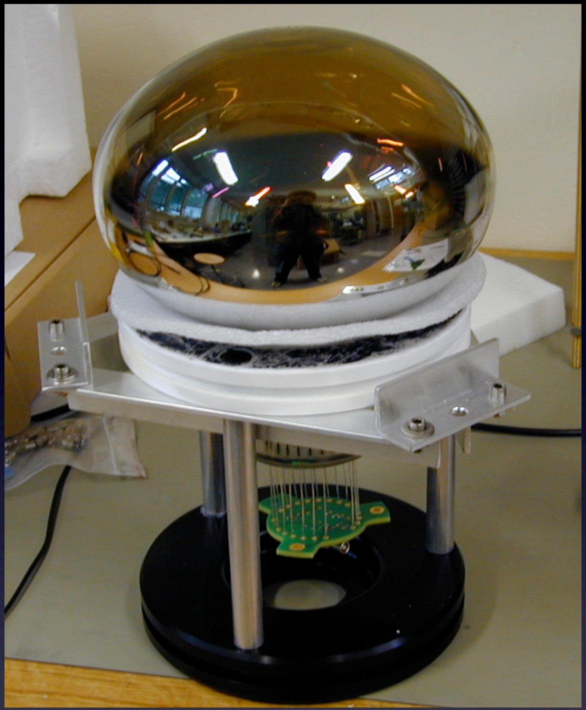
2) Industrial version being developed with CAEN

3) Development of F/E preamp in cold operation with IPN Lyon



Signal from double-phase setup

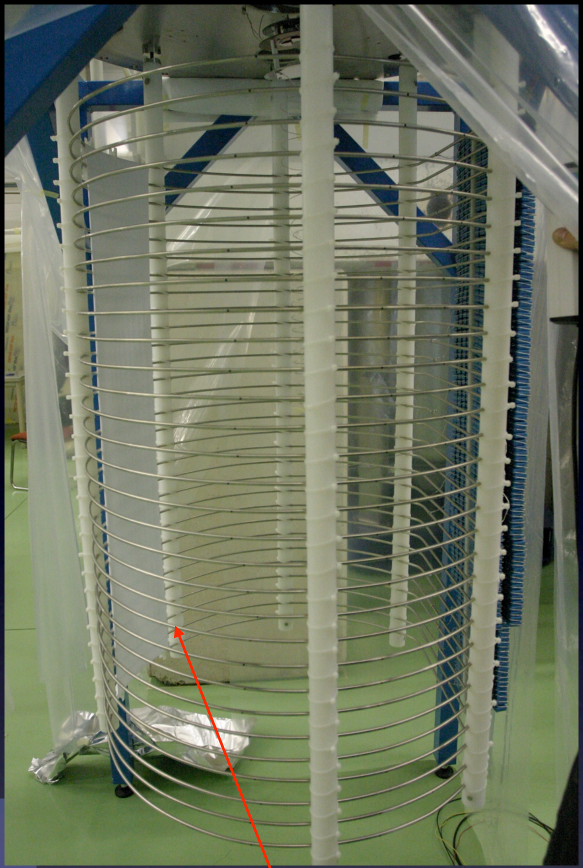
Light readout system

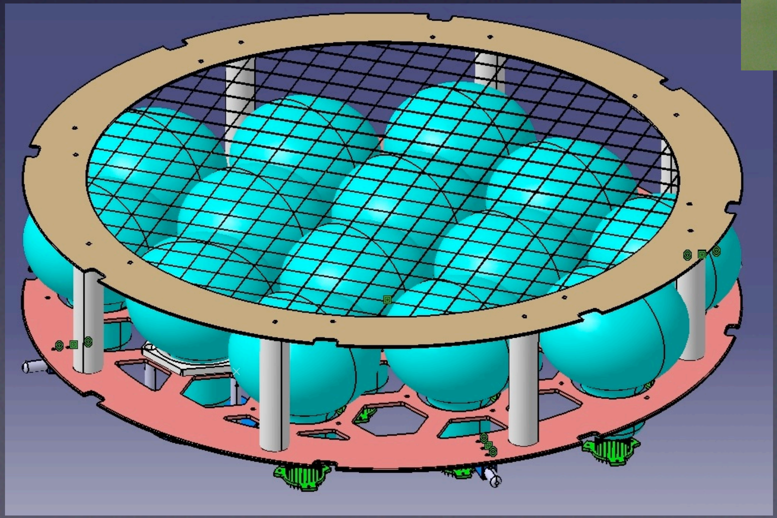


Photomultiplier tube:
Hamamatsu R5912-02MOD
20.2 cm diameter

Wavelength shifter (WLS):
Tetra-Phenyl-Butadiene
(TPB) evaporated on reflector

Reflectivity @430nm ~97%
Shifting eff. 128→430nm
>97%

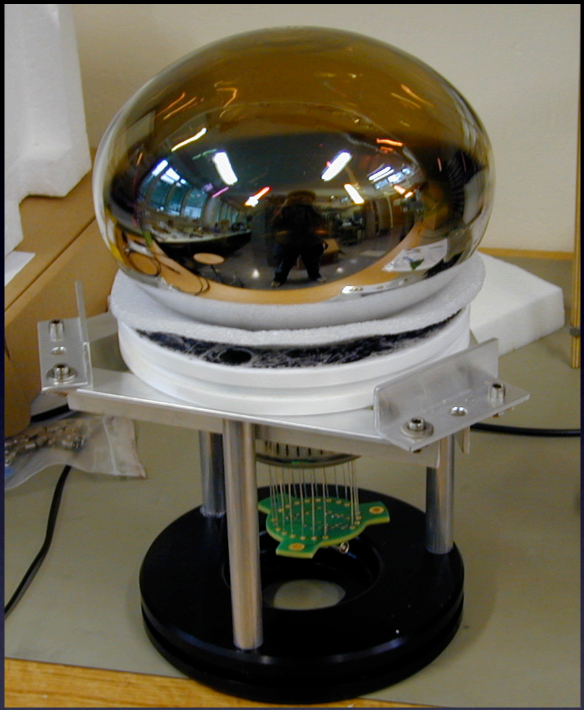




14 PMTs at the bottom
of the detector
immersed in LAr

Tetratex
reflecting foil

Light readout system



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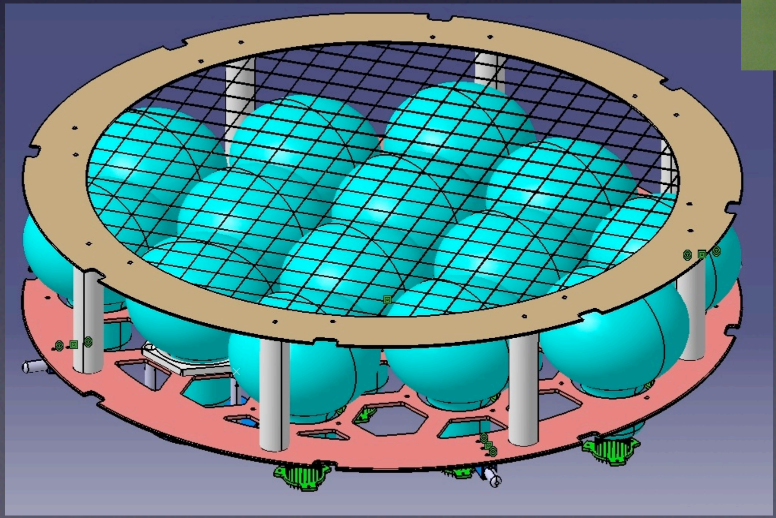
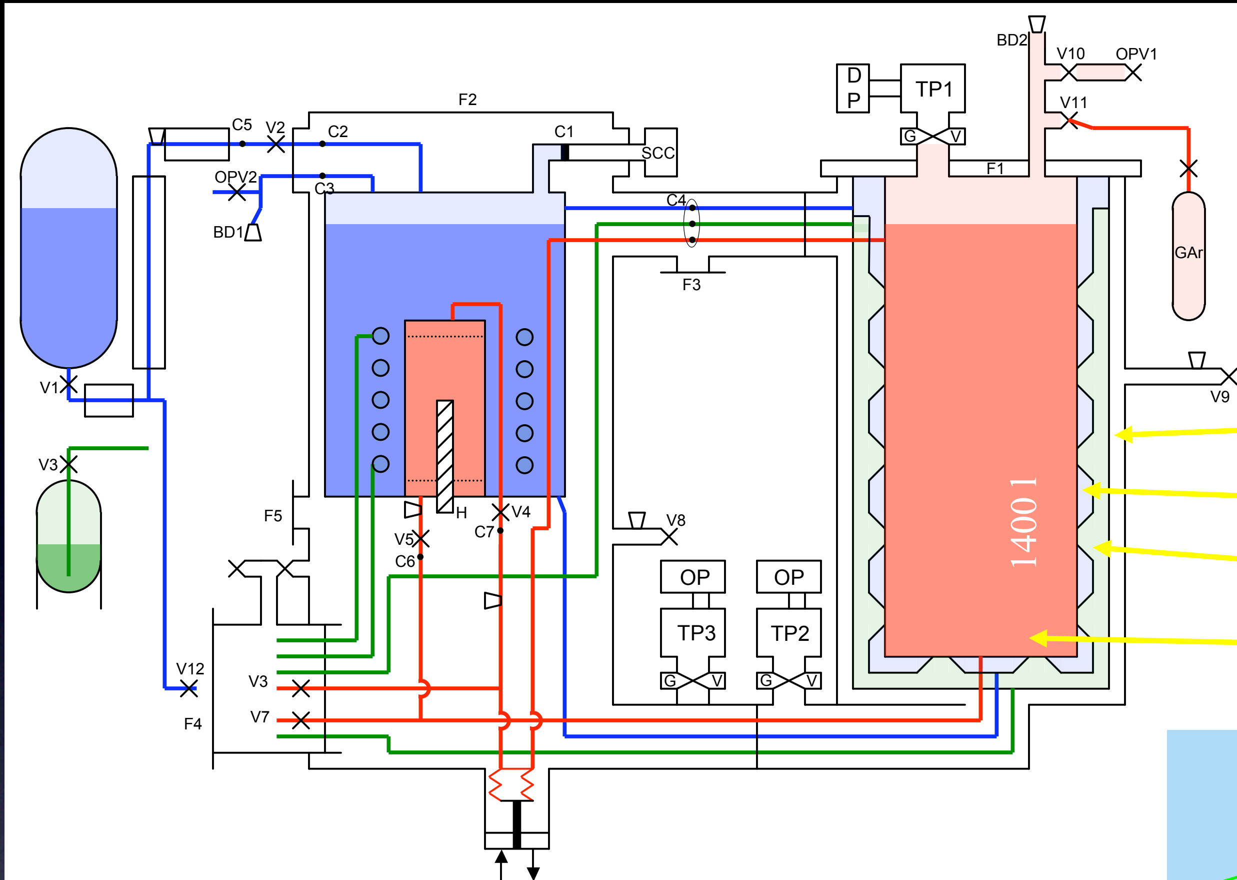


14 PMTs at the bottom
of the detector
immersed in LAr

Tetratex
reflecting foil

Cryogenics and LAr purification

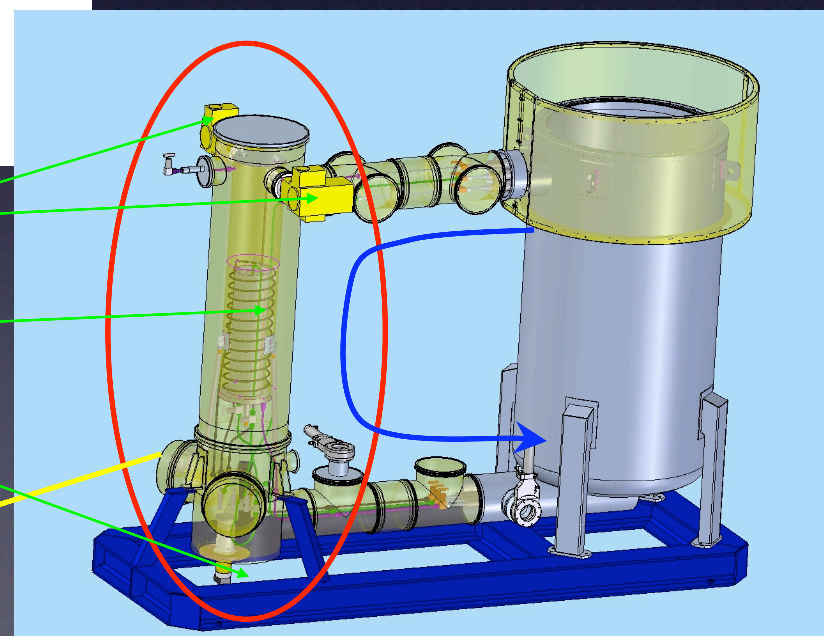


vacuum insulation

LN2 cooling jacket

'dirty' LAr cooling bath

pure LAr closed circuit



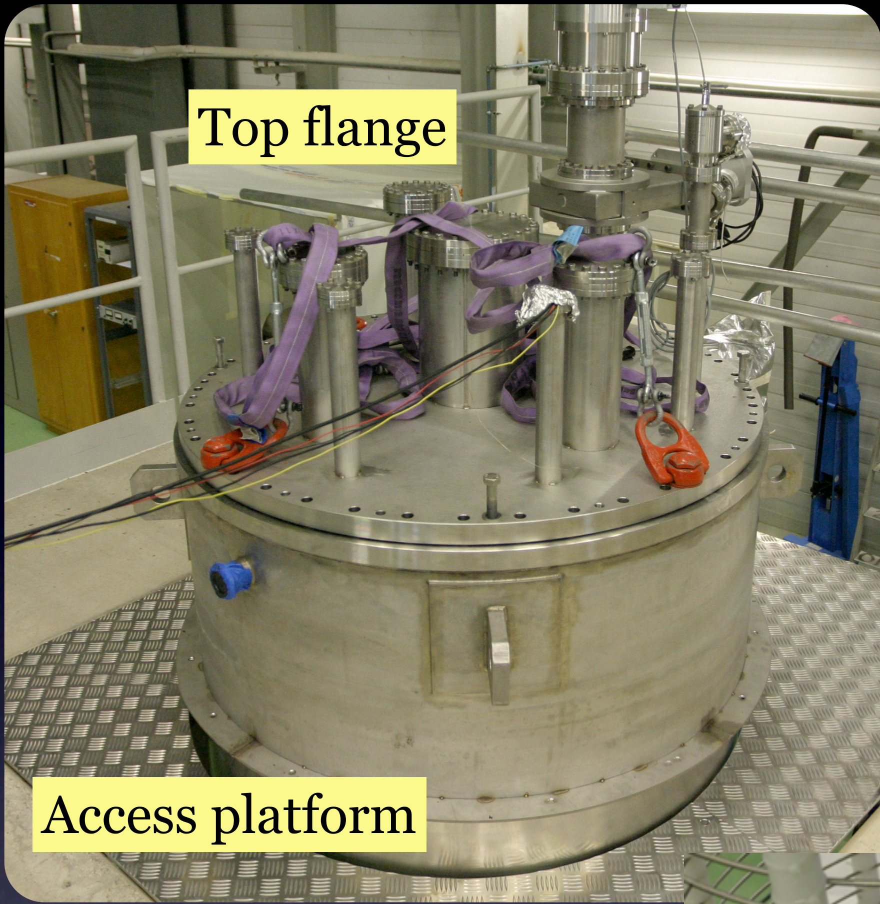
Stirling machines

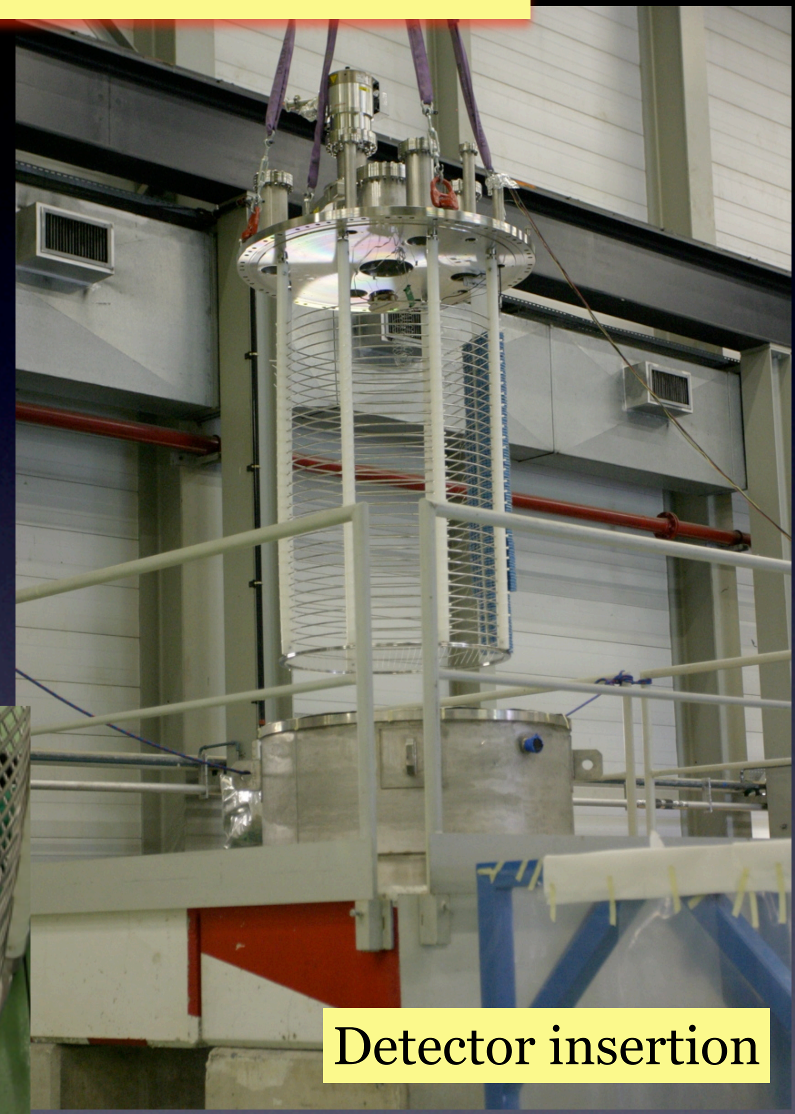
CuO purification cartridge

Bellow pump 7 l/hr

Recirculation and purification system

Assembly at CERN

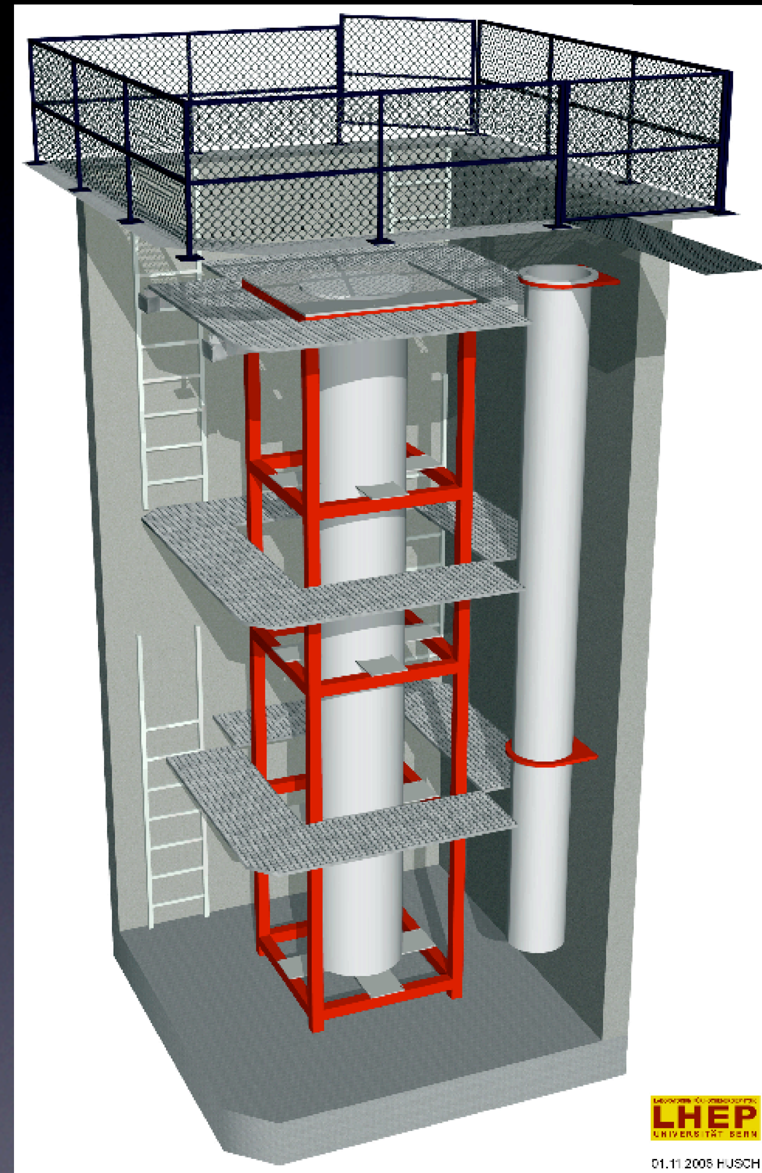




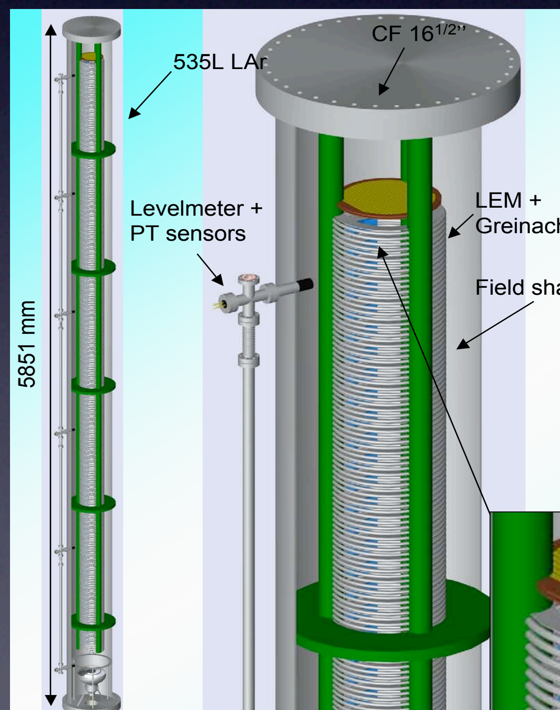
First test in early 2008

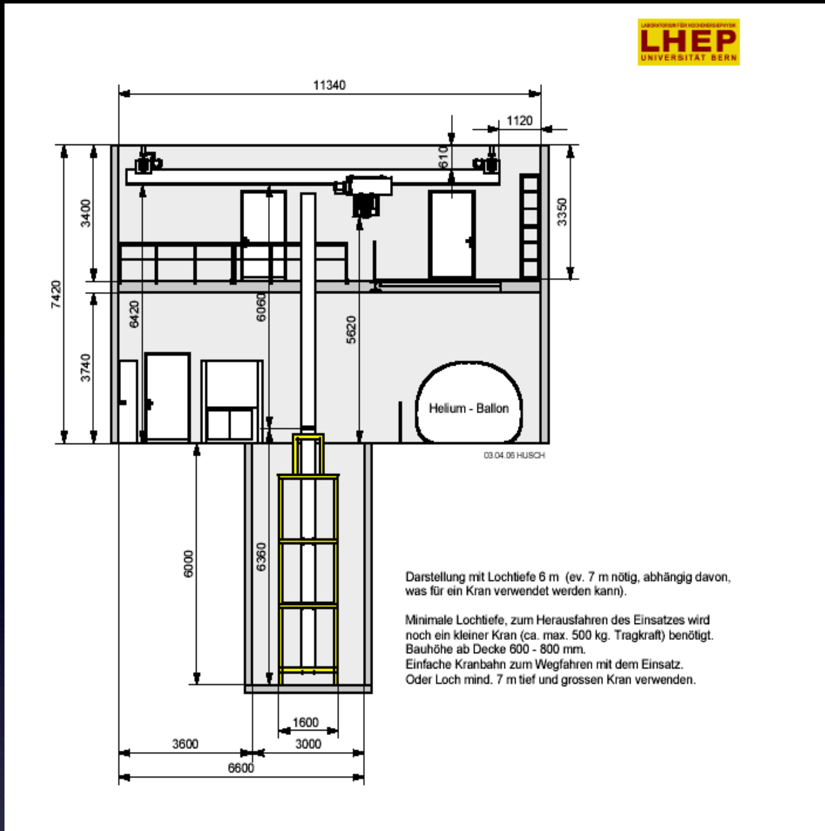
ARGONTUBE

- Full scale measurement of long drift (5 m), signal attenuation and multiplication, effect of charge diffusion
- Simulate 'very long' drift (10-20 m) by reduced E field & LAr purity
- High voltage test (up to 500 kV)



- Measurement Rayleigh scattering length and attenuation length vs purity
- Charge readout and electronics optimization after long drift





Installation at the Uni Bern - Results expected in 2008

Conclusions

- Large liquid Argon TPCs, possibly magnetized, represent a detector technology with high potentials for "next generation experiments", combining new detector developments and excellent physics performance.
- We have presented our R&D program to extrapolate the liquid Argon TPC concept to O(100 kton) detectors. An R&D on magnetization with HTS conductors is also in progress.
- Improved understanding of detector performance does and will require dedicated setups of different sizes. Improved detector simulations, taking into new methods of readout, are needed.
- Our "roadmap" is to converge towards an improved design of a cost-controlled scalable liquid Argon TPC around 2010.

Can we afford high technology ?

This (not too serious) slide was inspired by the talk of Patrick Huber yesterday and some of the remarks that followed it

To my mind, a better measure is "cost / performance" (in any case, I agree that one must estimate cost and performance properly...)

The End

Cost estimates for GLACIER

Item	100 kton	10 kton	1 kton
LNG tank (see notes 1-2)	50÷100	20÷30	8
Inner detector mechanics	10	3	1
Charge readout detectors	15	5	1
Light readout	60 (with Č)	2 (w/o Č)	1
F/E & DAQ electronics	10	5	1
Miscellanea	10	5	1
Detector total	**155 ÷ 205**	**40 ÷ 50**	**13**
Refilling plant	25	10	2
Purification system	10	2	1
Civil engineering + excavation	30	5	2
Forced air ventilation	10	5	1
Safety	10	5	1
Merchant cost of LAr (see note 3)	100	10	1
Grand total	**340 ÷ 390**	**77 ÷ 87**	**21**
Super-conducting magnet	**?**	**60**	**-**

Notes:
(1) Range in cost of tank comes from site-dependence and current uncertainty in underground construction
(2) Cost of tank already includes necessary features for LAr TPC (surface electropolishing, hard roof for instrumentation, feed-throughs,…)
(3) LAr Merchant cost ≠ production cost. Fraction will be furnished from external companies and other fraction will be produced locally (by the refilling plant)