Towards the GLACIER detector

André Rubbia (ETH Zurich)

Neutrino International Design Study (IDS-NF)
23 March - 27 March 2009 3rd IDS Plenary Meeting
CERN, Geneva, Switzerland

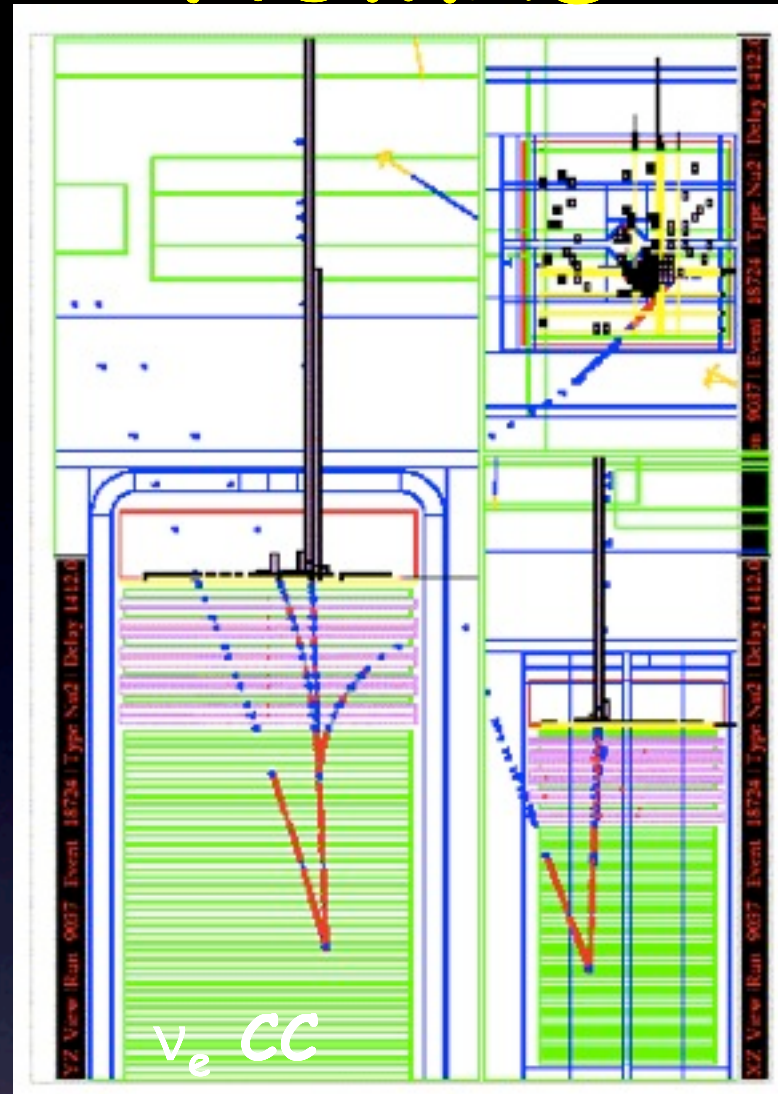
Towards very large LAr detectors

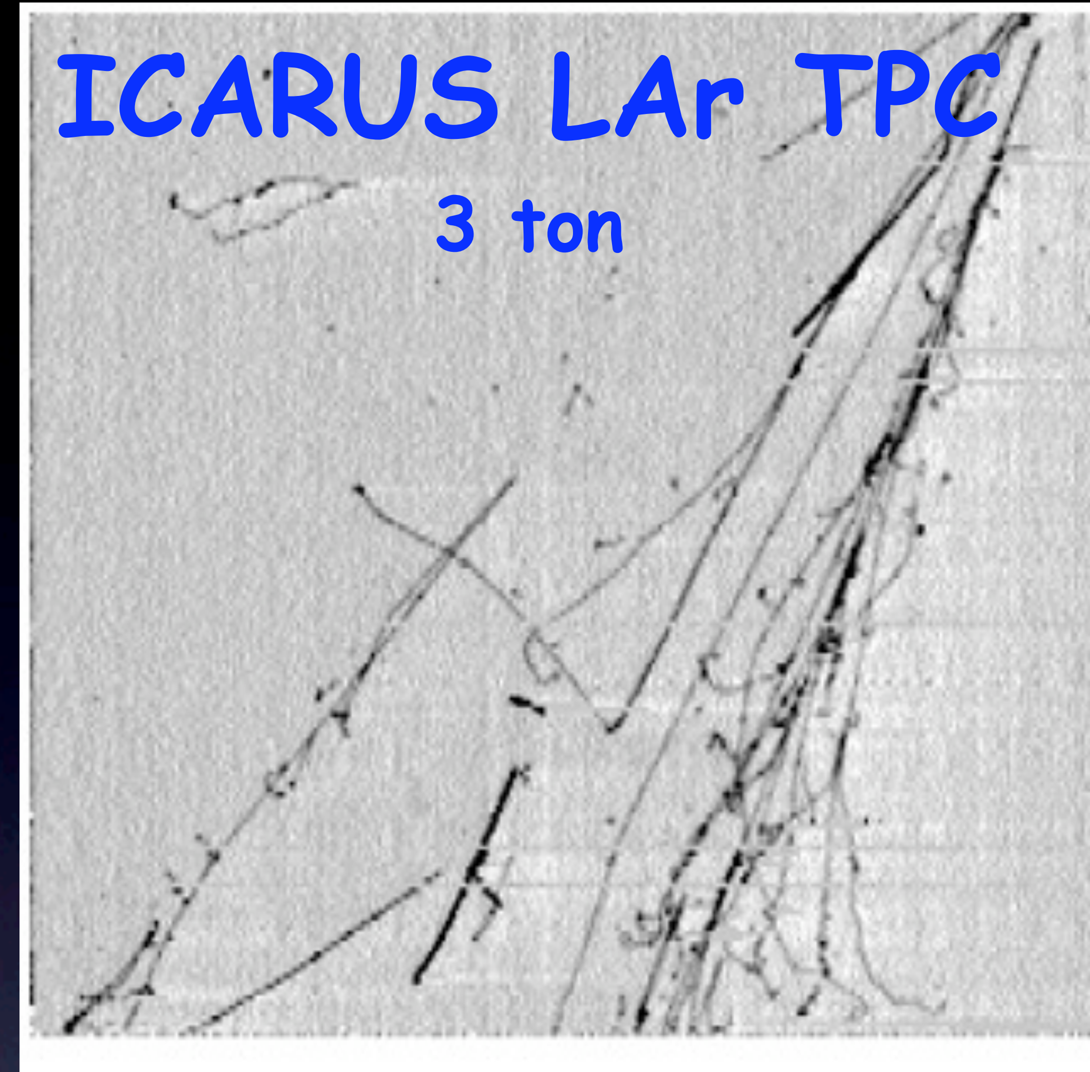
A collaborative effort

- ETH Zurich: A. Badertscher, A. Curioni, U. Degunda, L. Epprecht, A. Gendotti, S. Horikawa, L. Knecht, C. Lazzaro, D. Lussi, A. Marchionni, G. Natterer, F. Resnati, A.Rubbia, T.Strauss, J.Ulbricht, T.Viant
- Uni Bern: A. Ereditato, S. Haug, R. Hänni, M. Hess, S. Janos, F. Juget, I.Kreslo, S. Lehmann, P. Lutz, M. Messina, R. Mathieu, U. Moser, F. Nydegger, H.-U. Schütz, M. Zeller
- KEK: T. Hasegawa, T. Kobayashi, T. Maruyama, K. Nishikawa, M. Tanaka
- IPN Lyon: D.Autiero, E. Bechetoille, B. Carlus, Y. Declais, S. Gardien, C. Girerd, J. Marteau, H. Mathez
- UK groups: *SoI submitted to STFC in March 2009*

Open to new groups

NOMAD





Bubble ∅ (mm)	3
Density (g/cm^3)	1.5
X_0 (cm)	11.0
λ_T (cm)	49.5
dE/dx (MeV/cm)	2.3

2.7 tons drift chambers target
Density (g/cm^3) 0.1
2% X_0/chamber
0.4 T magnetic field
TRD detector
Lead glass calorimeter

Resolution (mm^3)	2×2×0.2
Density (g/cm^3)	1.4
X_0 (cm)	14.0
λ_T (cm)	54.8
dE/dx (MeV/cm)	2.1

Liquid Argon medium properties

	Water	Liquid Argon
Density (g/cm3)	1	1.4
Radiation length (cm)	36.1	14.0
Interaction length (cm)	83.6	83.6
dE/dx (MeV/cm)	1.9	2.1
Refractive index (visible)	1.33	1.24
Cerenkov angle	42°	36°
Cerenkov $d^2N/dEdx$ (β=1)	$\approx$ 160 eV^{-1} cm^{-1}	$\approx$ 130 eV^{-1} cm^{-1}
Muon Cerenkov threshold (p in MeV/c)	120	140
Scintillation (E=0 V/cm)	No	Yes ($\approx$ 40000 γ/MeV @ λ=128nm)
Long electron drift	Not possible	Possible (μ = 500 cm^2/Vs)
Boiling point @ 1 bar	373 K	87 K

When a charged particle traverses liquid Argon:

1. Ionization process
   - We = 23.6 ± 0.3 eV

Ionization charge

2. Scintillation (luminescence)
   - W_γ = 19.5 eV
   - DUV "line" (λ=128 nm ⇔ 9.7 eV)
   - No more ionization: Argon is transparent
   - Only Rayleigh-scattering

Scintillation light (VUV)

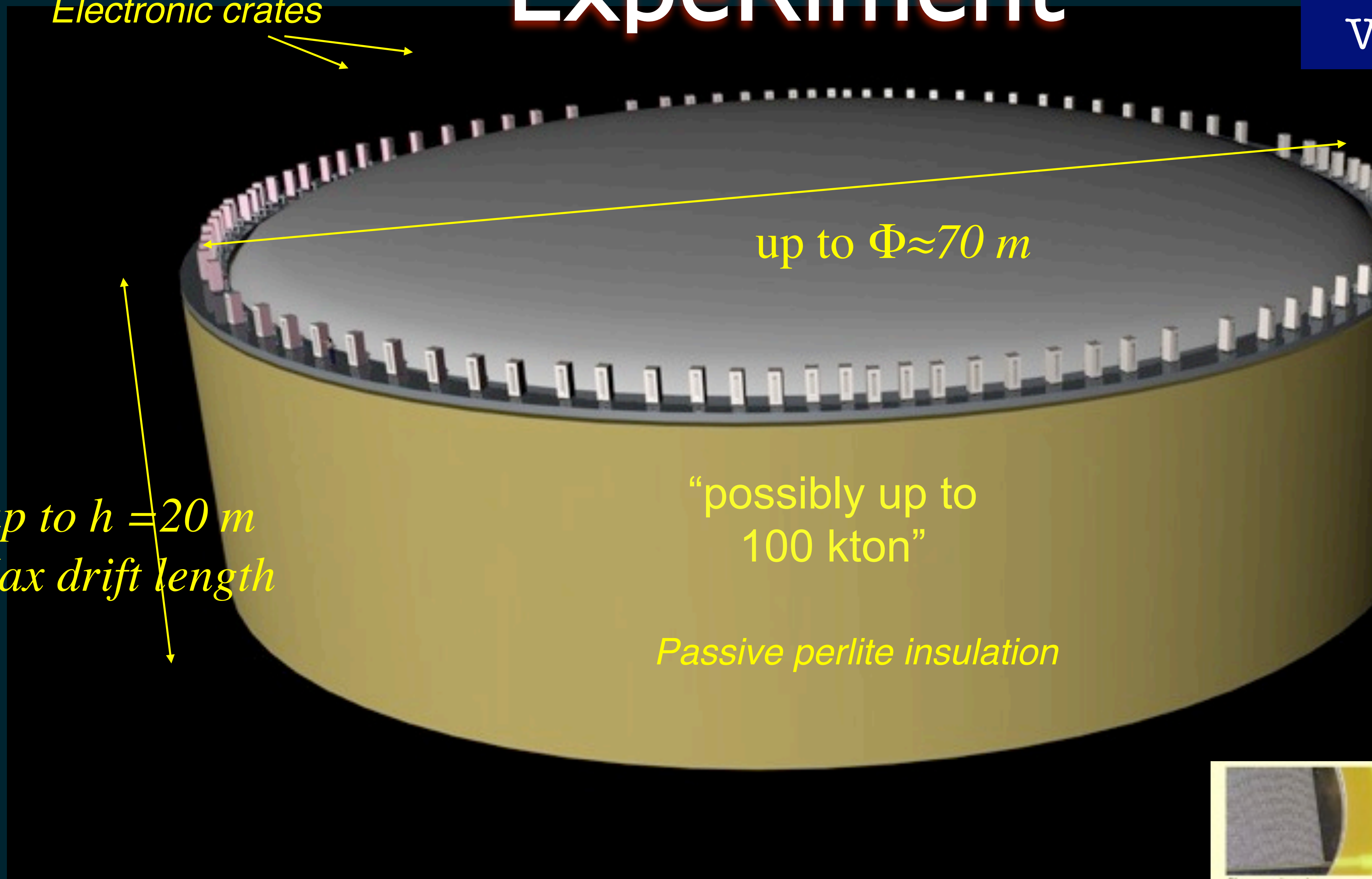
3. Cerenkov light (if relativistic particle)

Cerenkov light (if β>1/n)

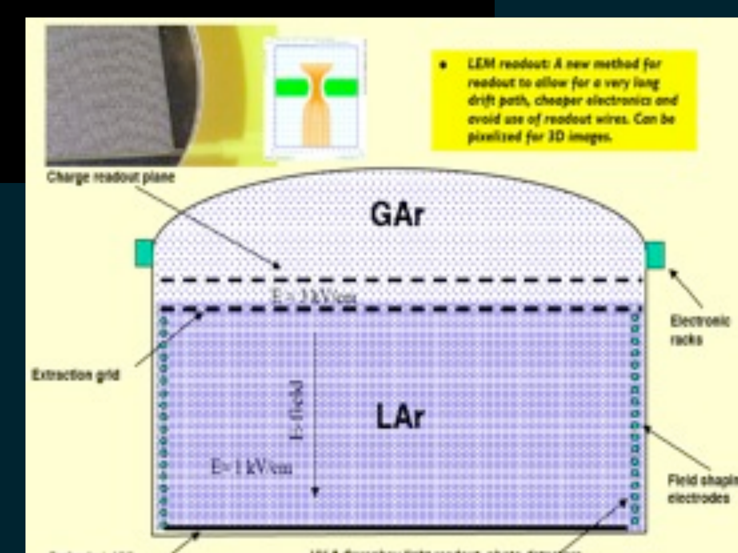
Scintillation & Cerenkov light can be detected independently (hep-ph/0402110)

GLACIER: Giant Liquid Ar Charge Imaging ExpeRiment

AR, hep-ph/0402110
Venice, Nov 2003



A scalable design:



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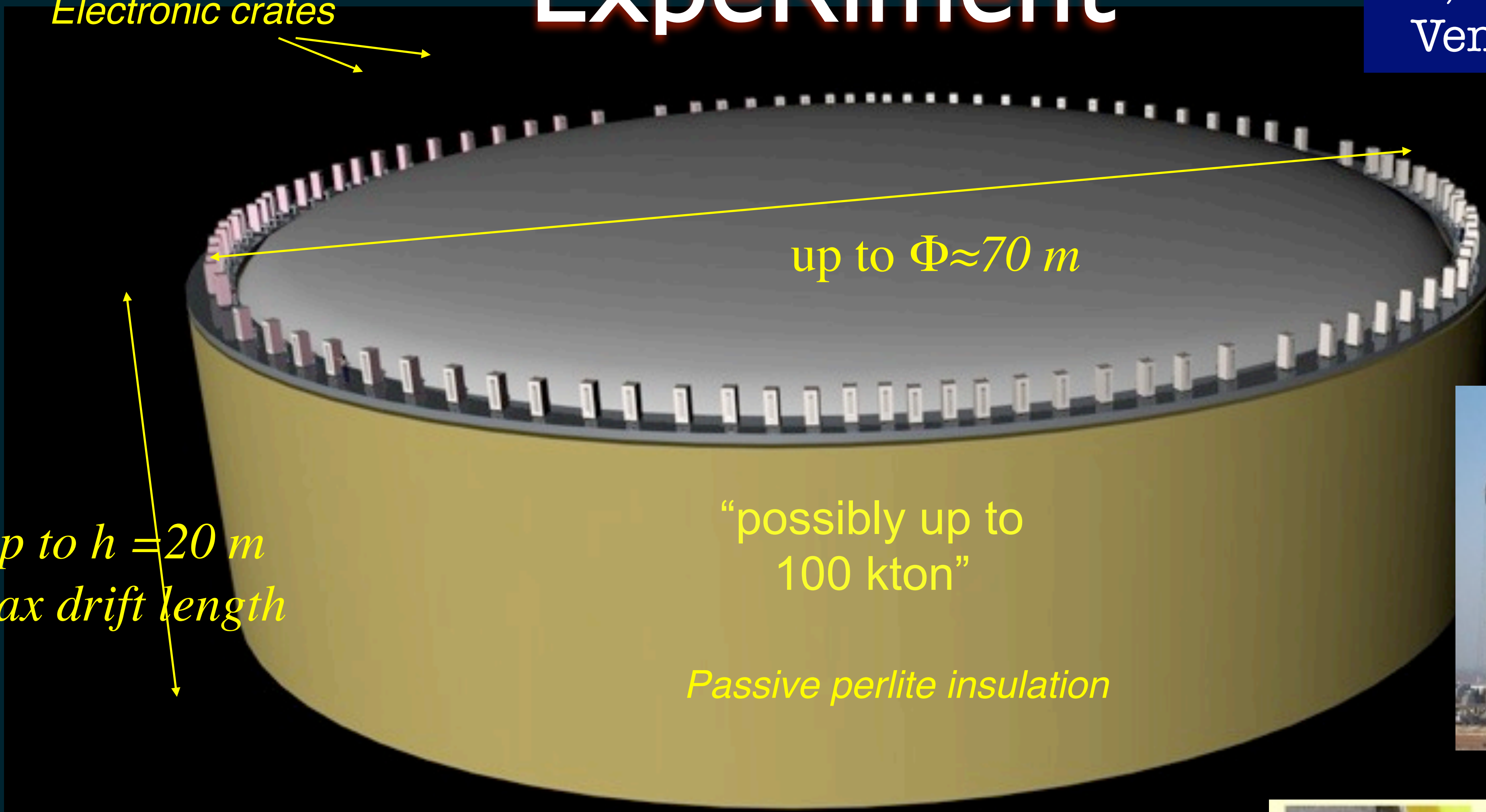
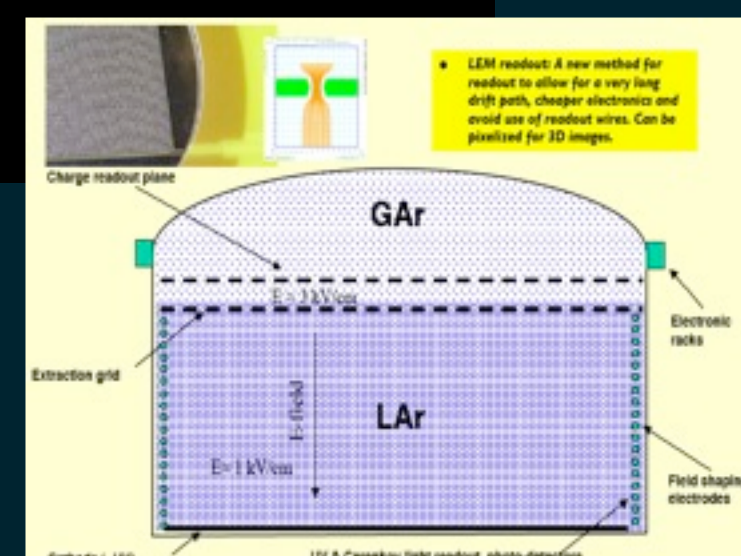




Single module cryo-tank based on industrial LNG technology

Simple, scalable detector design, possibly up to 100 kton

Modest excavation requirements for “megaton-scale-physics”

Based on LAr LEM-TPC readout

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

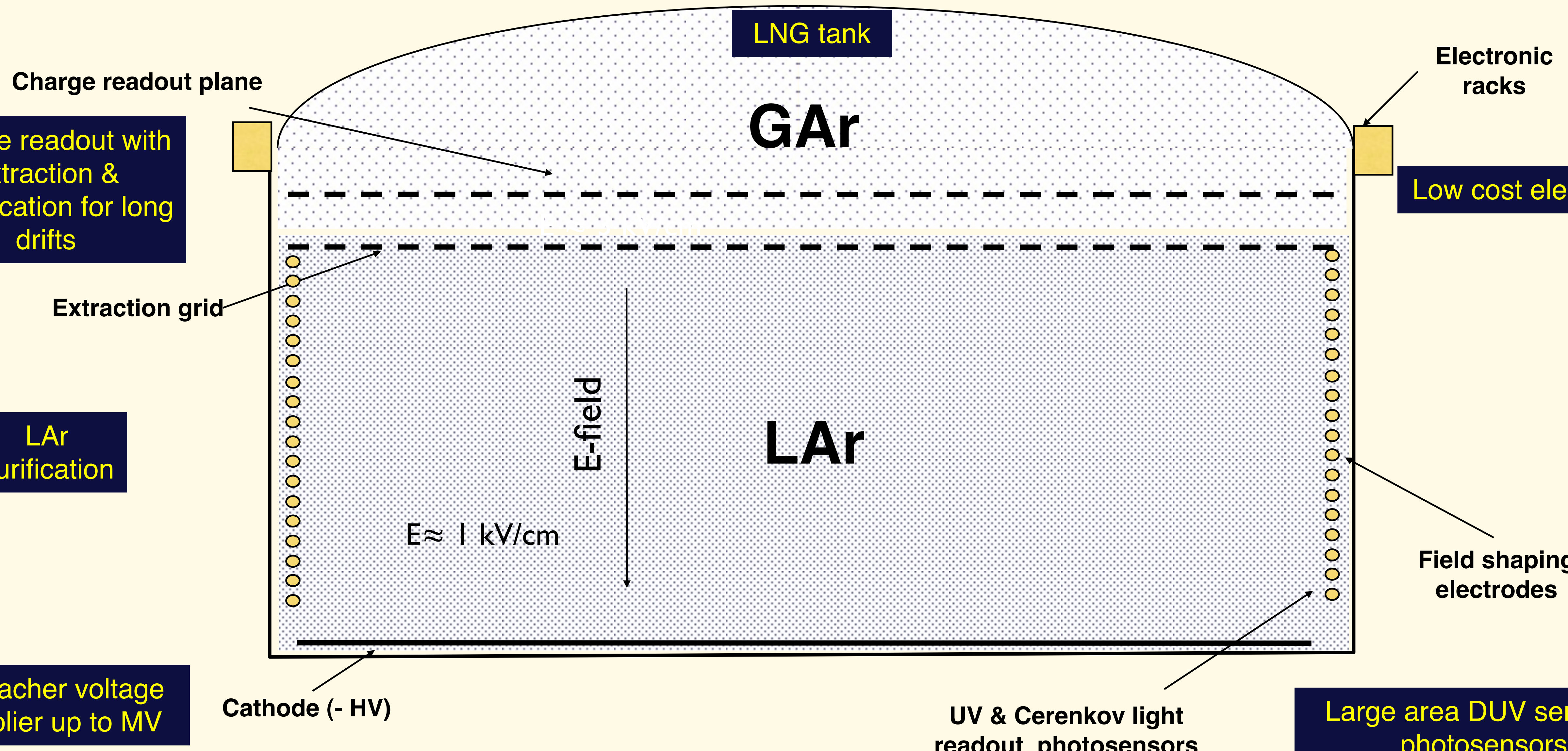
Charge readout with extraction & amplification for long drifts

LAr purification

Greinacher voltage multiplier up to MV

Low cost electronics

Large area DUV sensitive photosensors



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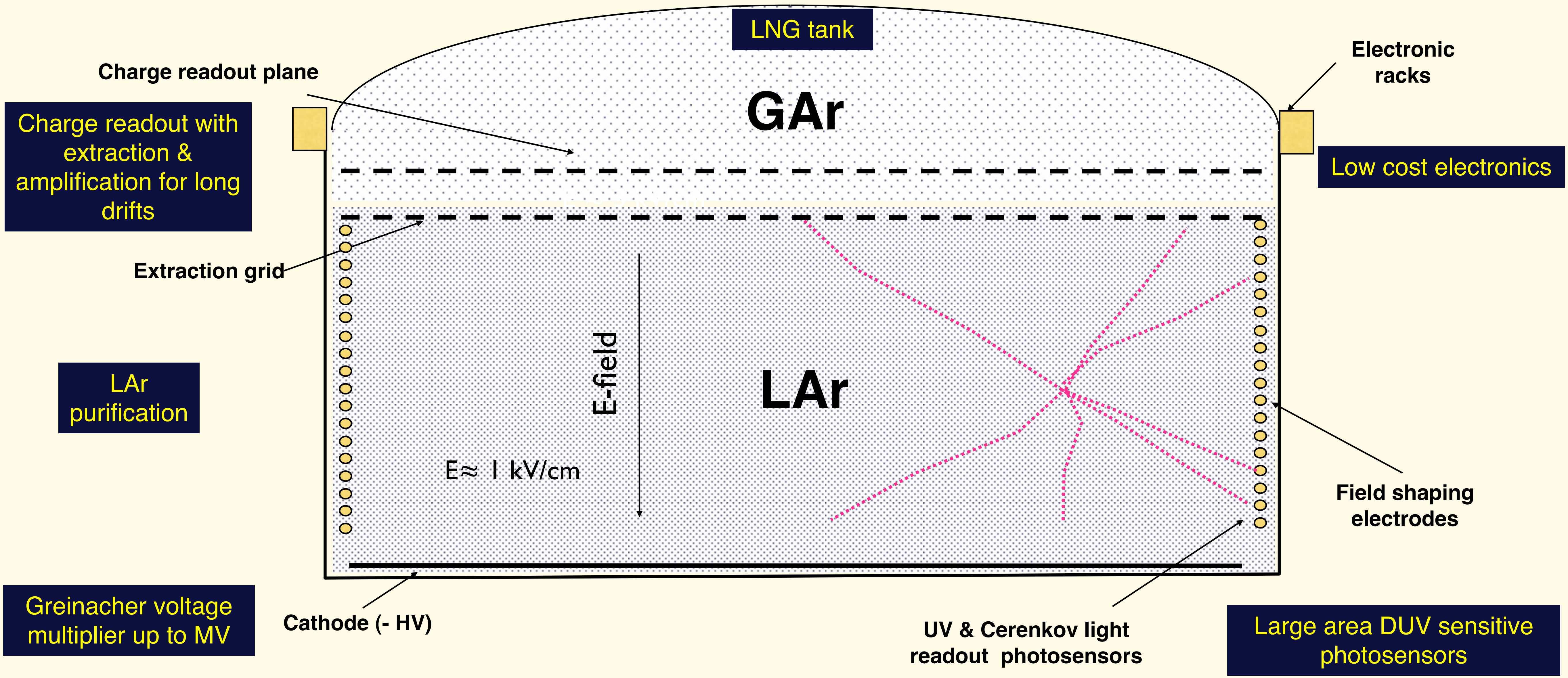

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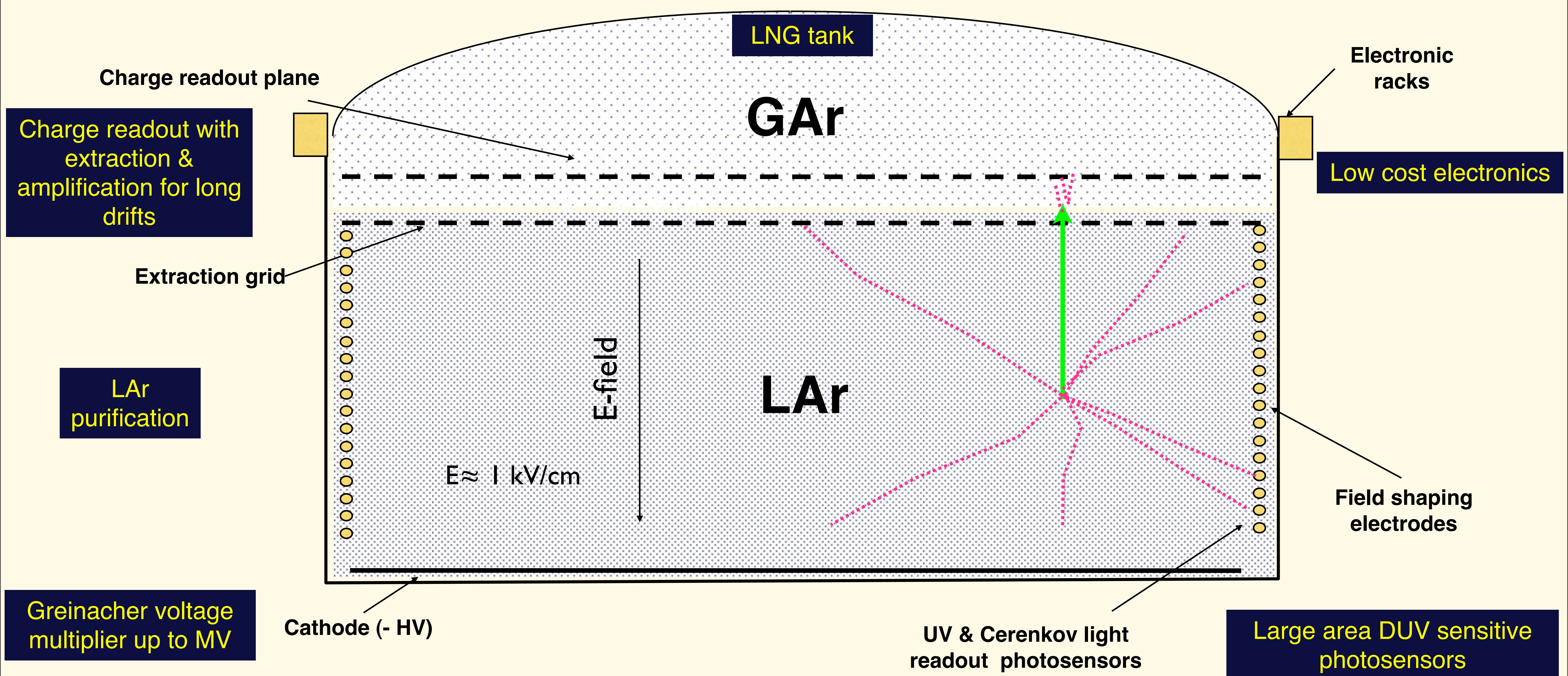
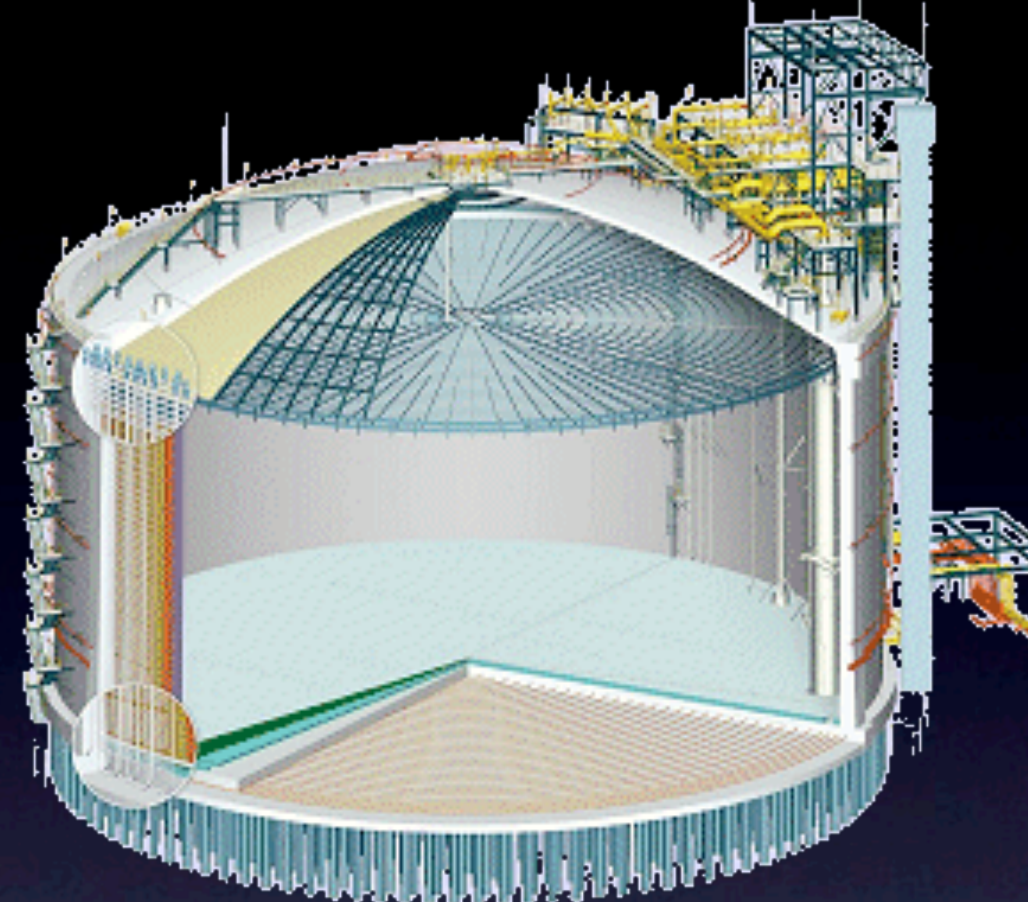
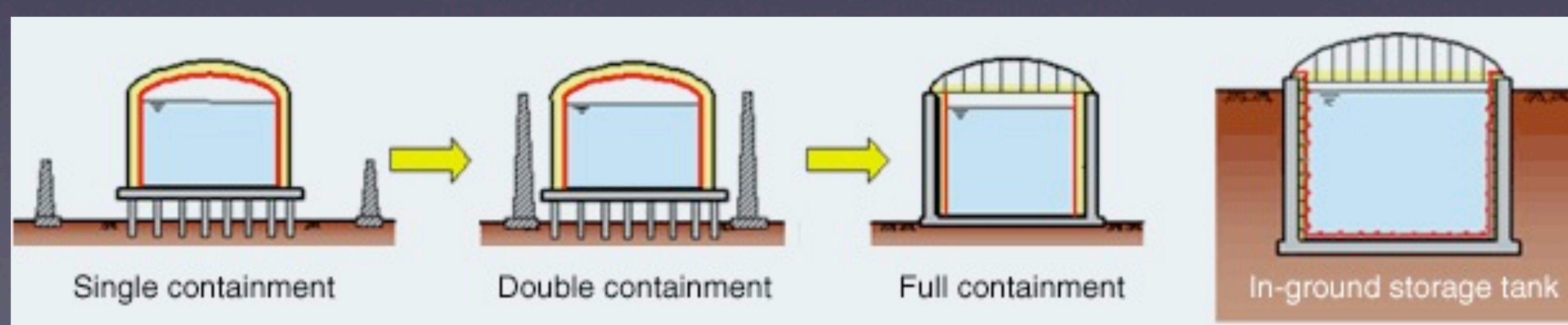


Cryogenic storage tanks for LNG



- Many large LNG tanks in service
(≈300 worldwide in year 2003, now more due to increased use of gas instead of oil/coal/...)
- Vessel volumes typ. 70000→200000 m^3 (Erection time from 2→5 years)
- Excellent safety record (Last serious accident in 1944, Cleveland, Ohio)
- Defined by international design codes and standards (BS7777, EN1473, API std 620, 高圧ガス保安法 LNG 地下式貯槽指針 , ...)

Classified according to containment type:



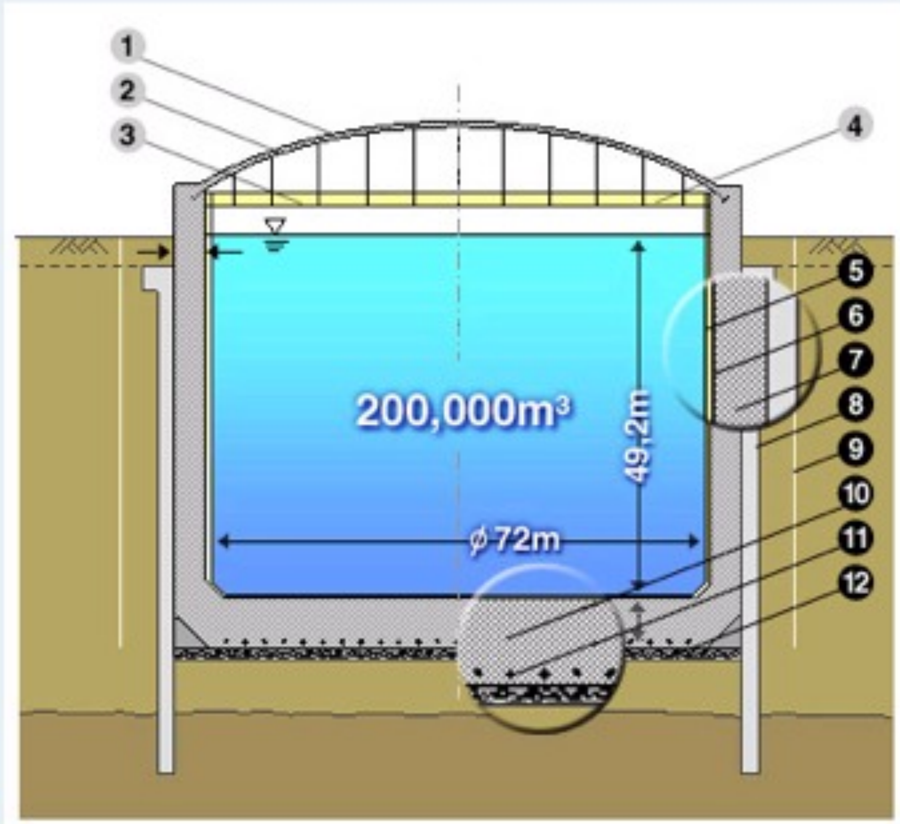
More on LNG storage tanks

Bird's-eye view of in-ground storage tanks

Bird's-eye view of underground storage tanks

In-ground and underground storage tanks from Tokyo Gas

1. Reinforced concrete tank cover
2. Steel roof
3. Suspended deck
4. Glass wool insulation
5. Non-CFC rigid polyurethane form (PUF) insulation
6. 18Cr-8Ni stainless steel membrane
7. Reinforced concrete side wall
8. Reinforced concrete cut-off wall
9. Side heater
10. Reinforced concrete bottom slab
11. Bottom heater
12. Gravel layer

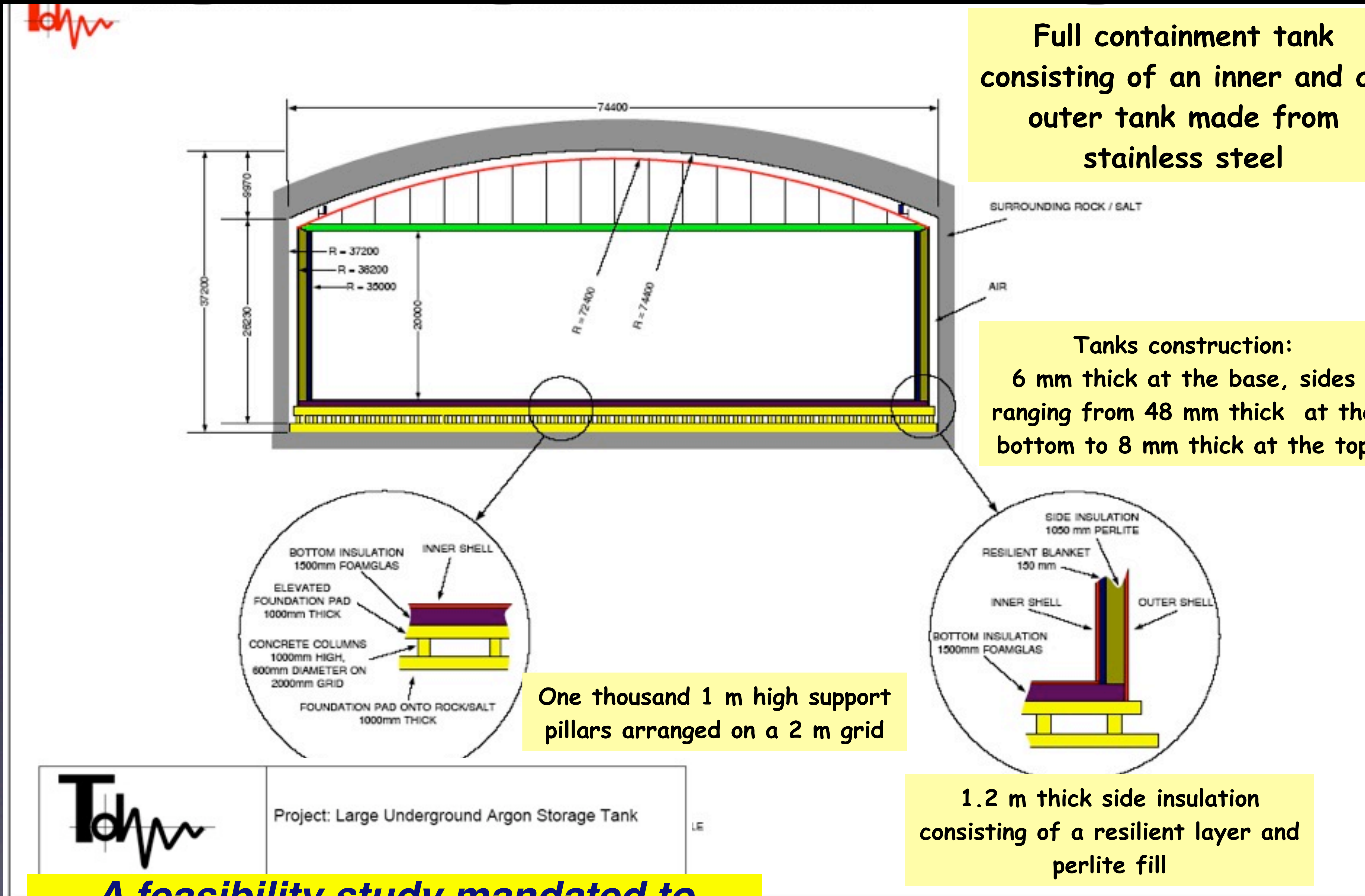


Tokyo Gas

LAr vs LNG (≥ 95% Methane)

- Boiling points of LAr and CH_4 are 87.3 and 111.6 °K
- Latent heat of vaporization per unit volume is the same for both liquids within 5%
- Main differences:
  - LNG flammable when present in air within 5 – 15% by volume, LAr not flammable
  - $\rho_{LAr} = 3.3\ \rho_{CH4}$, tank needs to withstand 3.3 times higher hydrostatic pressure

Large underground LAr storage tank



Full containment tank consisting of an inner and an outer tank made from stainless steel

Tanks construction:
6 mm thick at the base, sides ranging from 48 mm thick at the bottom to 8 mm thick at the top

One thousand 1 m high support pillars arranged on a 2 m grid

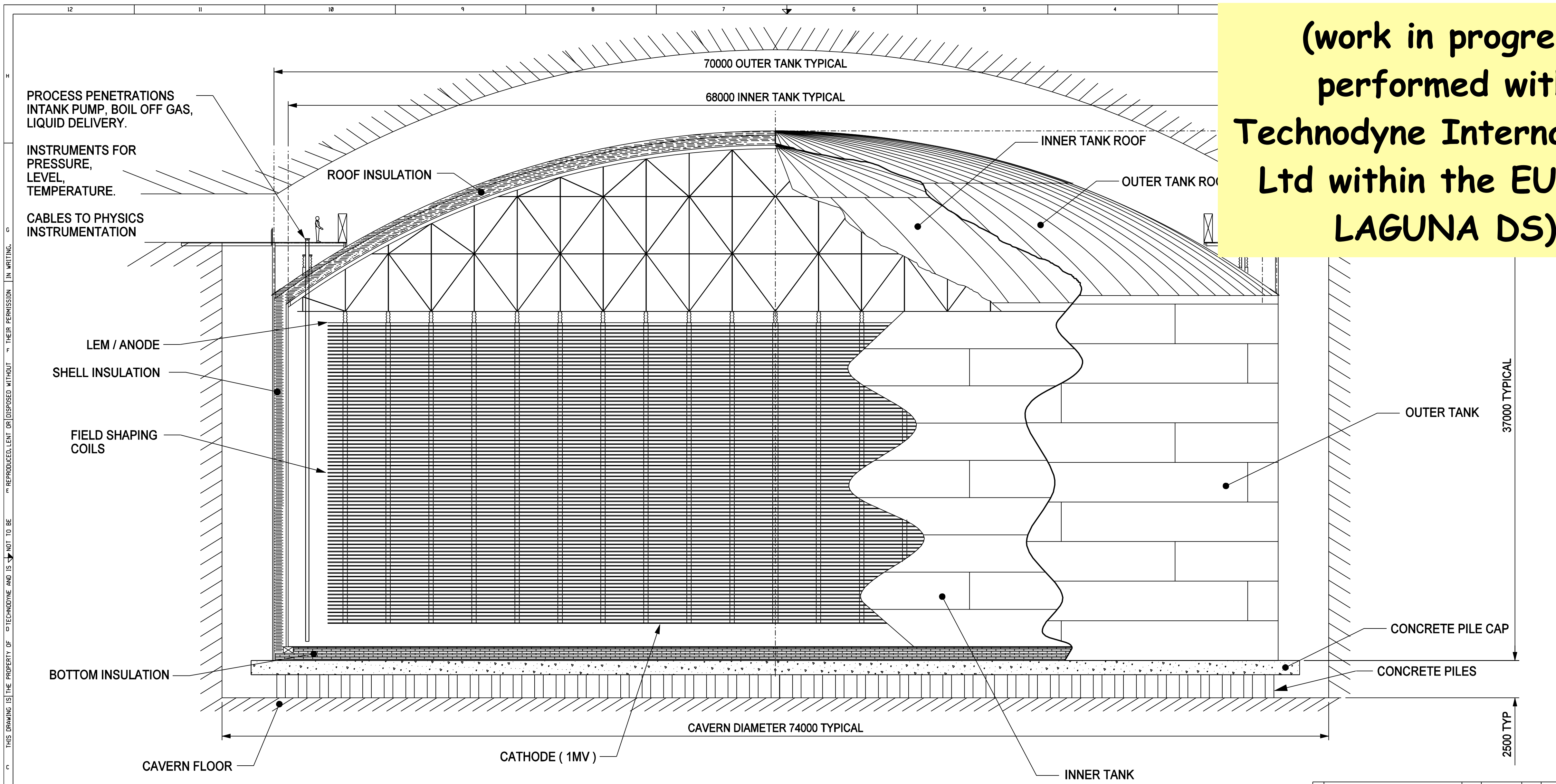
1.2 m thick side insulation consisting of a resilient layer and perlite fill

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

Estimated boil-off 0.04%/day

Engineering of tank & detector

(work in progress performed with Technodyne International Ltd within the EU FP7 LAGUNA DS)



PHYSICS REQUIREMENTS		
ITEM	INNER TANK	OUTER TANK
FLUID	LIQUID ARGON	
TEMPERATURE	-185.9 °C	
FLUID TARGET MASS	100000000 kg	
MAXIMUM DRIFT HEIGHT	20000 mm	
DETECTOR	LEM	
FIELD SHAPING COILS		
CATHODE	1 MV	

DESIGN REQUIREMENTS		
ITEM		
TYPE OF TANK	FULL CONTAINMENT	
SEISMIC HAZARD	REFER TO TABLE	
DENSITY OF FLUID	1392.8 kg/m³	
BOIL OFF DESIGN	< 0.1% / DAY	
AMBIENT TEMPERATURE		REFER TO TABLE
SHELL / BOTTOM MATERIAL	A240 GRADE 304	A553 TYPE 1
ROOF MATERIAL	A240 GRADE 304	

LOCATION	MAXIMUM SINGLE ITEM DELIVERY LENGTH	WIDTH	HEIGHT	WEIGHT
BOULBY, UK				
CANFRANC, SPAIN				
FREJUS, FRANCE				
CASO, UMBRIA, ITALY				
PHYASALMI, FINLAND				
SIEROSZOWICE, POLAND				
UNIREA, SLANIC, ROMANIA				

LOCATION	SEISMIC HAZARD	MINE / ROCK AMBIENT TEMPERATURE
BOULBY, UK	0.03	?
CANFRANC, SPAIN	0.16	?
FREJUS, FRANCE	0.2	28°C
CASO, UMBRIA, ITALY	0.45	?
PHYASALMI, FINLAND	0.02	?
SIEROSZOWICE, POLAND	0.03	?
UNIREA, SLANIC, ROMANIA	0.3	13°C

SEISMIC HAZARD
g Units 10% probability of exceedence in 50 years
Note these figures are estimated from the
European- Mediterranean Seismic Hazard Map
Published by the European Seismolicical Commission
These figures must be confirmed for each site

0	INITIAL ISSUE	RJG	14-JAN-09	JMH	JMH
Rev.	Description	Drawn	Date	Chk'd.	App'd.

EPC Contractor :
Tank Designer : TECHNODYNE INTERNATIONAL LTD.
Unit 16, Shakespeare Business Centre
Hathaway Close, Eastleigh, SO50 4SR, UK
Client Job No.: Technodyne Project Code : C741
Scale : NONE Equipment No.: TK- 101
Client :
Project : LAGUNA STORAGE TANK
Drawing Title : GENERAL ARRANGEMENT
LIQUID ARGON TANK
Drawing No.: C741 - 10 - 001 Sht. 1 of 1 Rev. 0

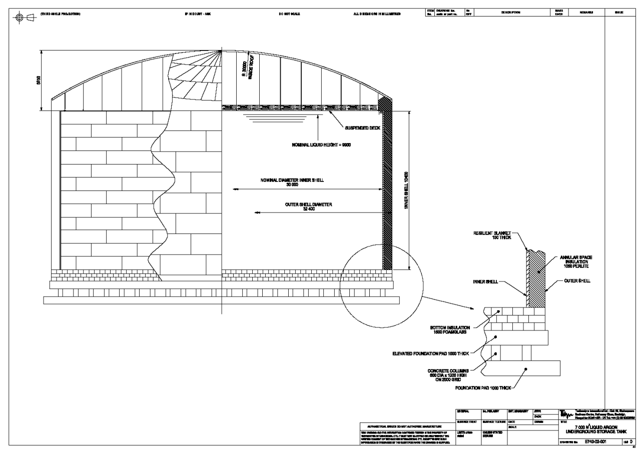
REVISE THIS DRAWING USING CAD SYSTEM ONLY.

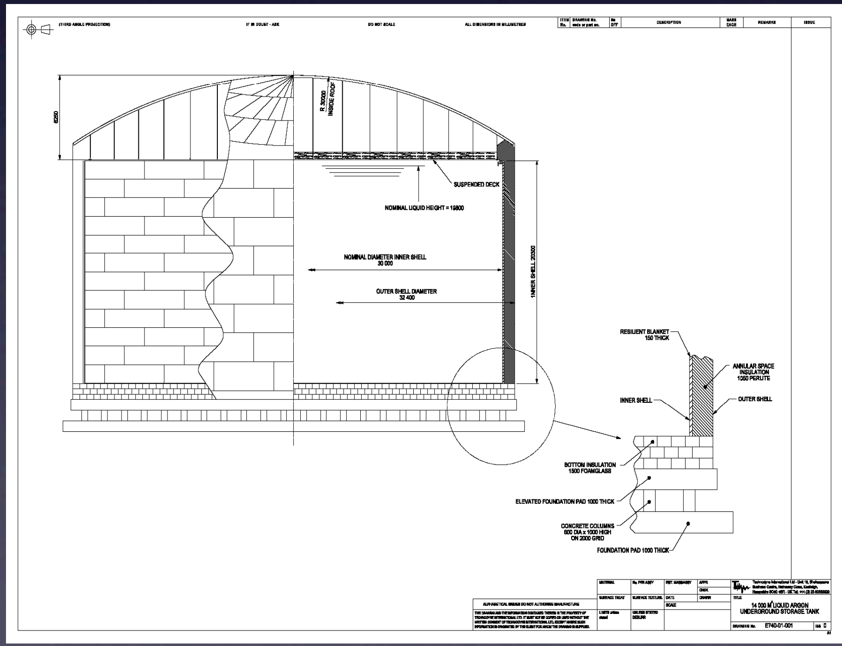
Large LNG scaling parameters

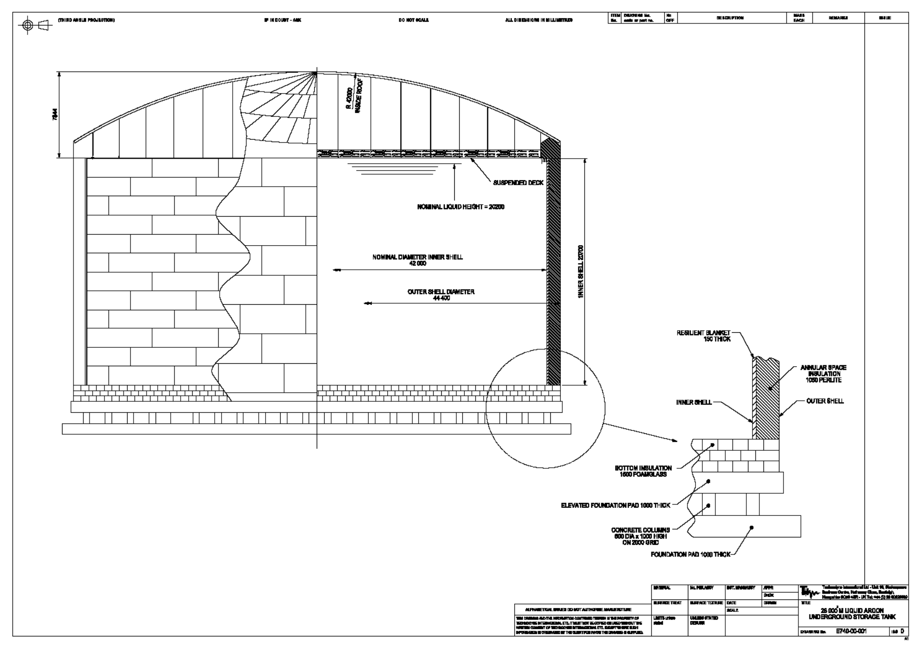
100 kton:
φ ≈ 70m,
h ≈ 20m

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

10 kton → 20 kton → 40 kton





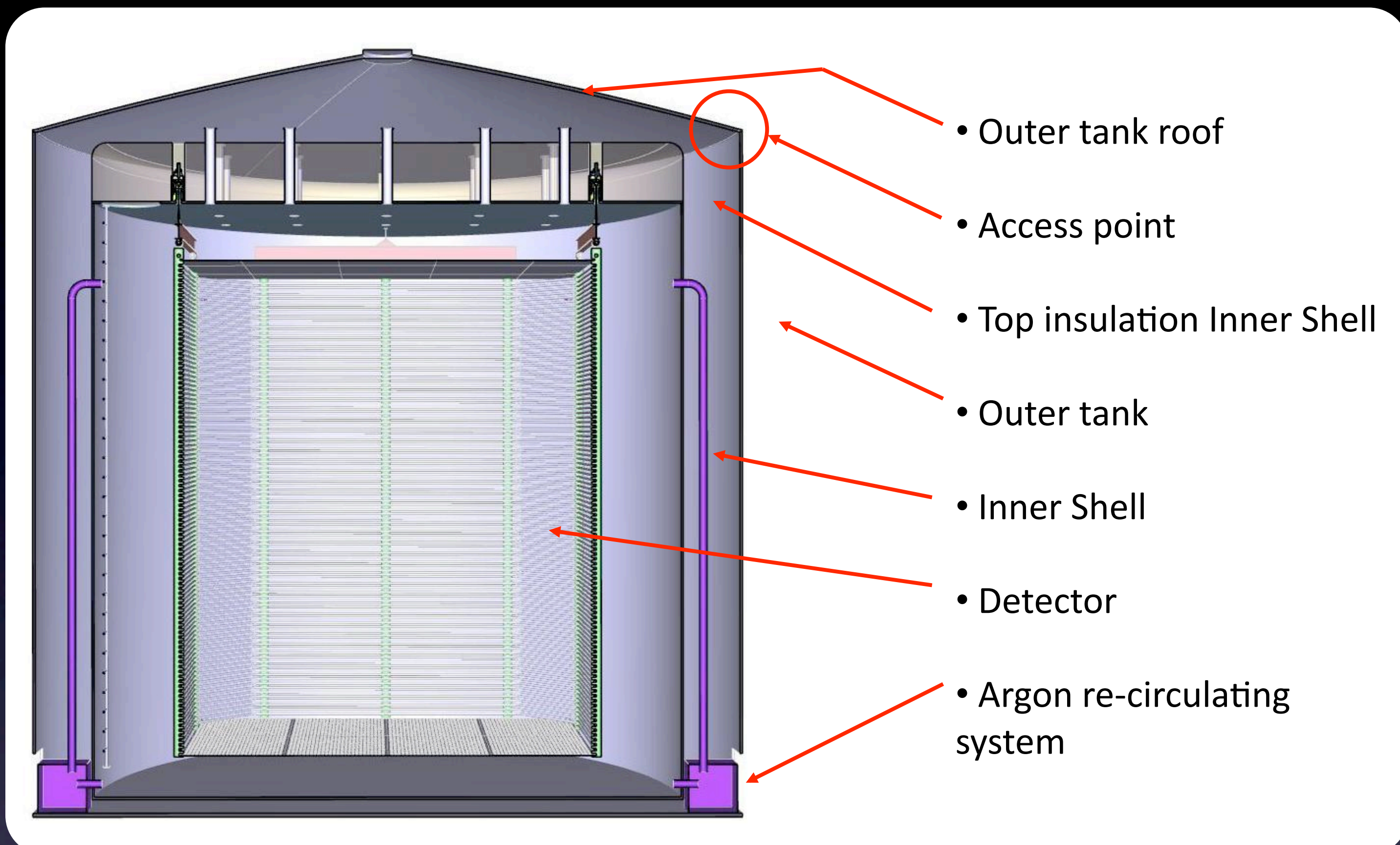


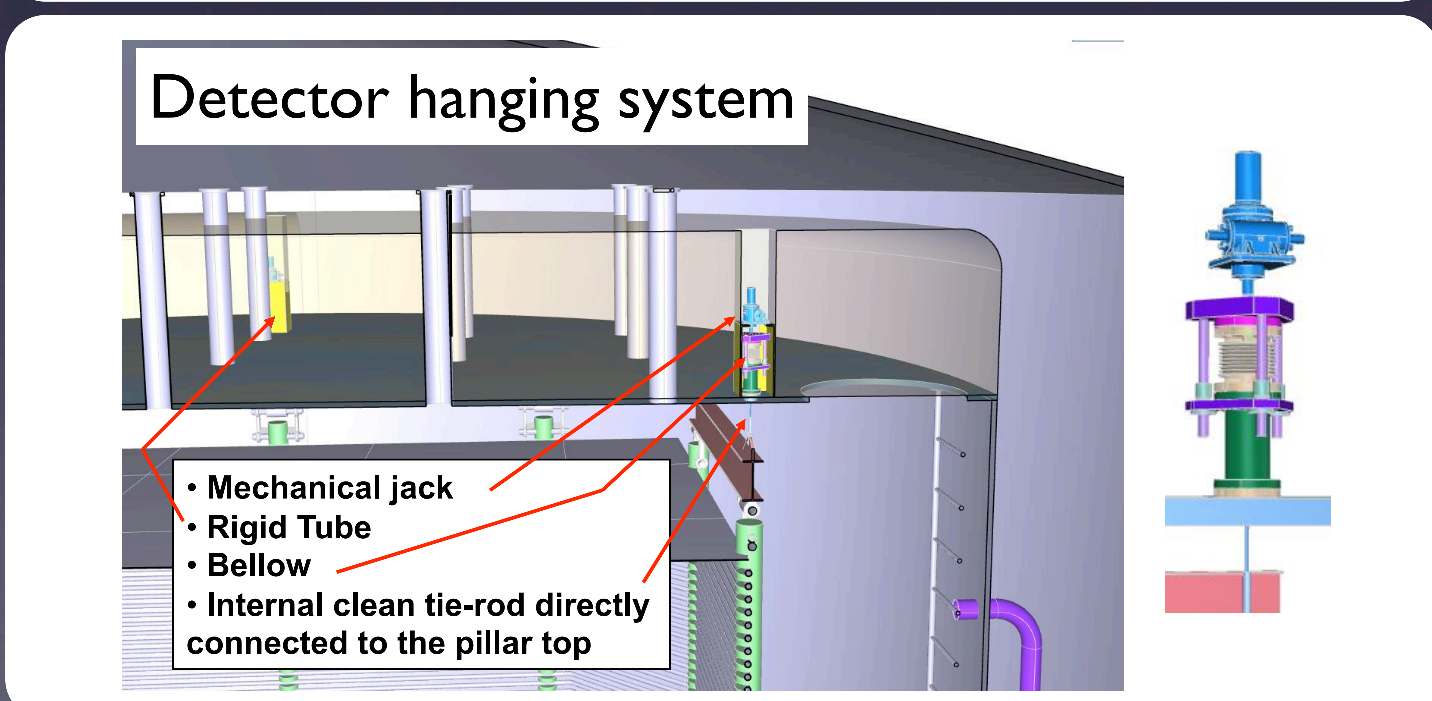
Φ=30 m, h=10 m → Φ=30 m, h=20 m → Φ=40 m, h=20 m

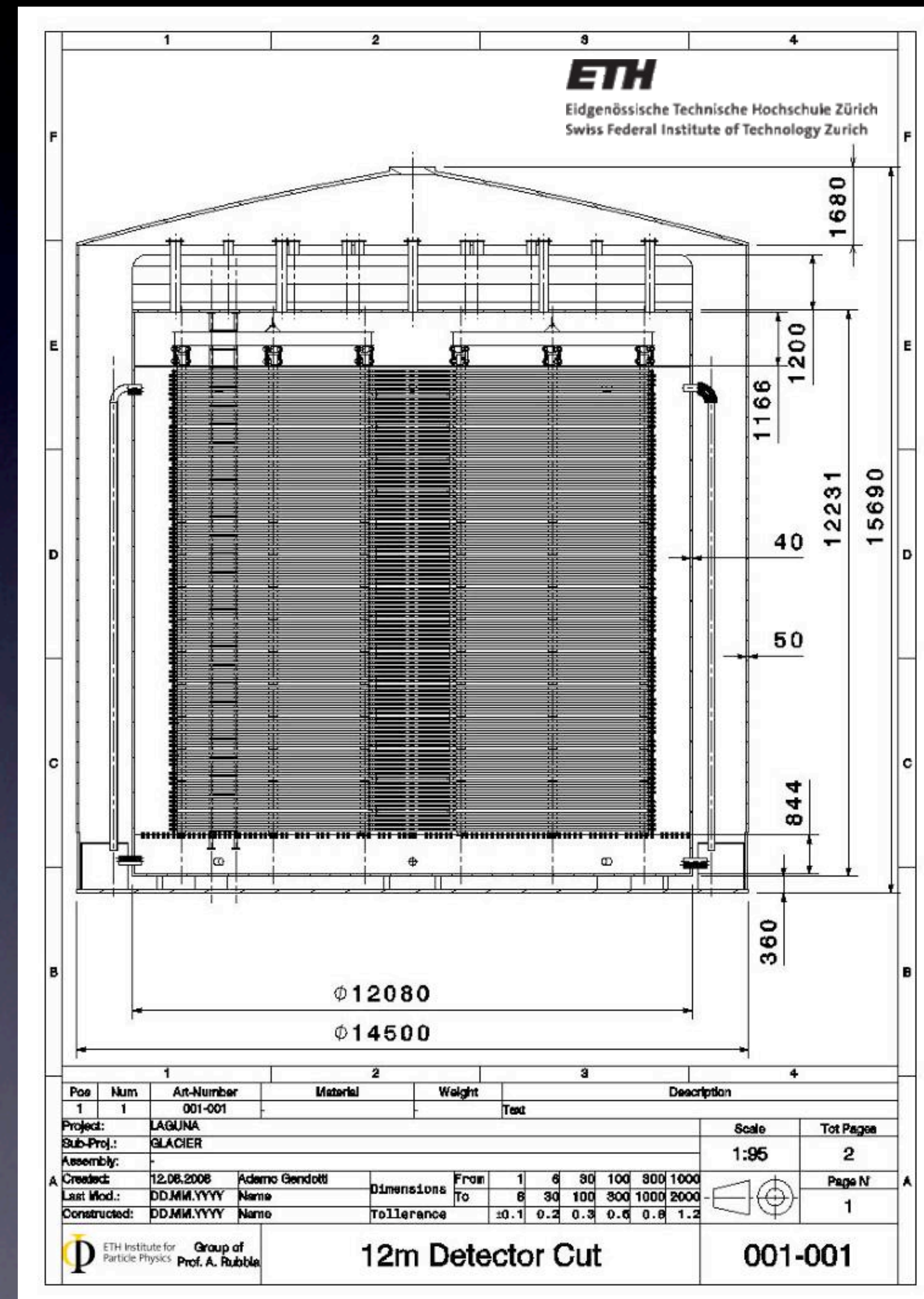
1 kton: near ν's source, engineering detector, φ ≈ 12m, h ≈ 10m, near surface

1 kton tentative general features

- More detailed concepts for a potential 1 kton detector



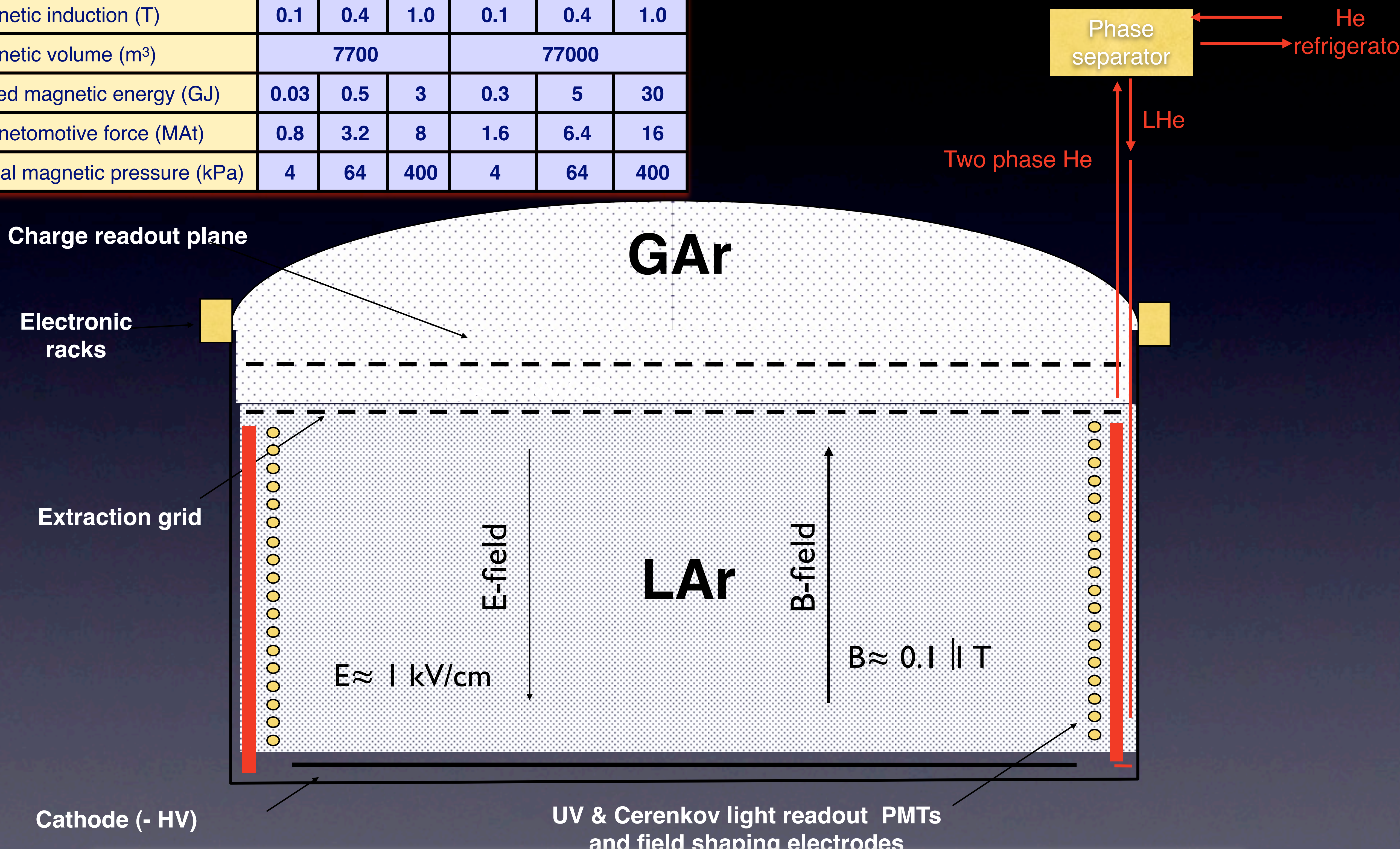




Bigger dreams: magnetized GLACIER

AR, hep-ph/0510131, Frascati, 2005

	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



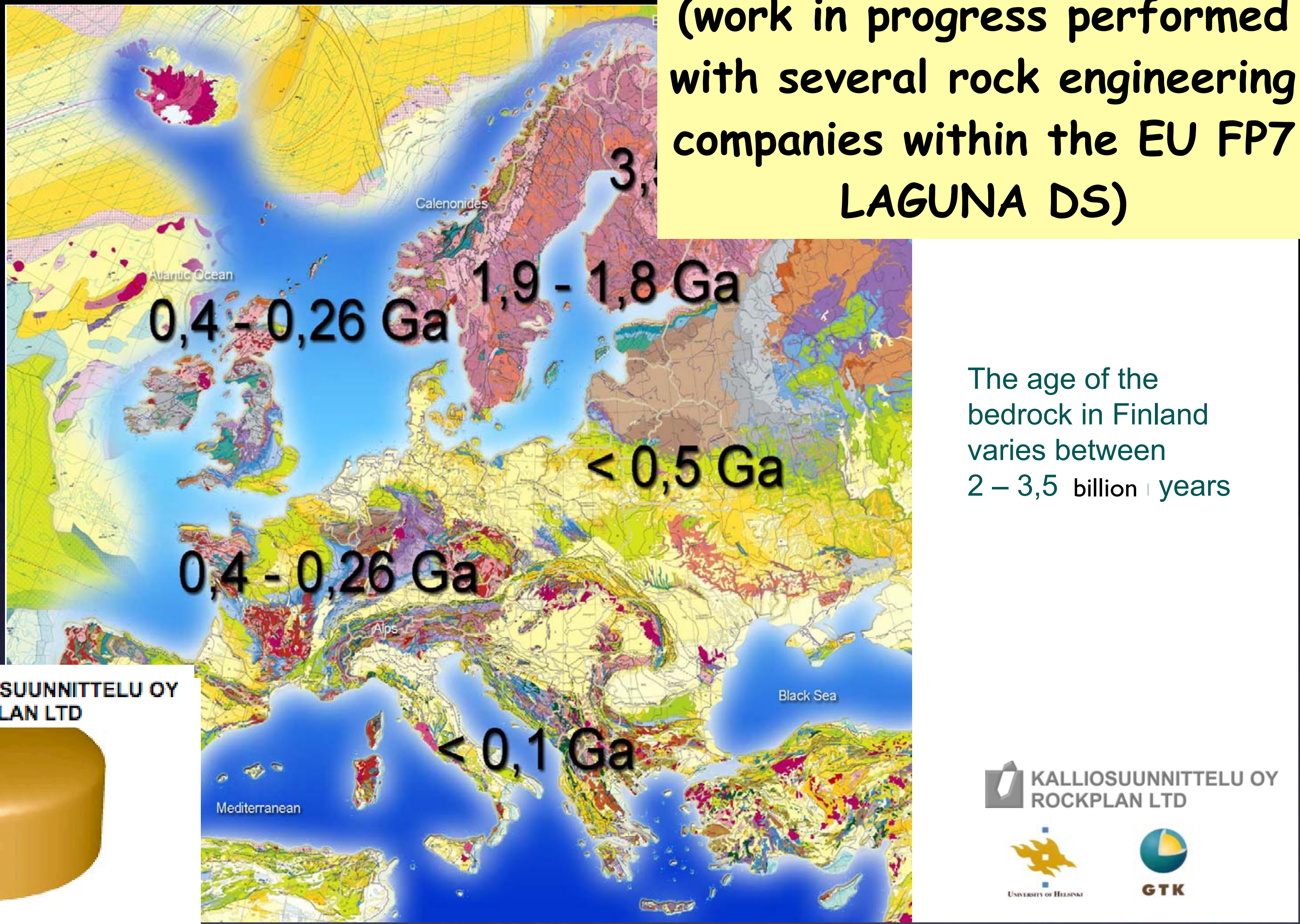
Magnet: solenoidal superconducting coil (LHe or HTS)

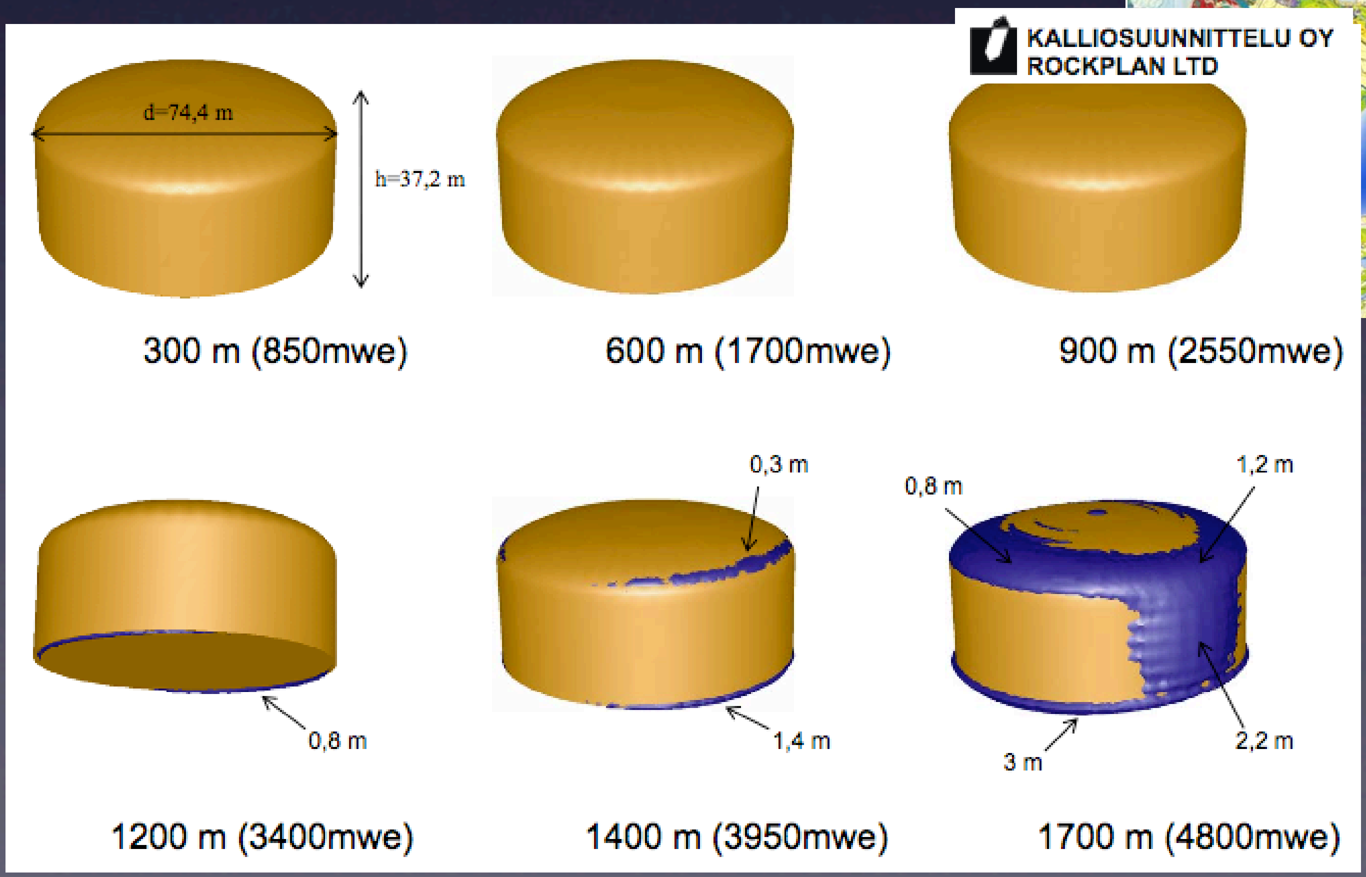
Feasibility of adequate cavern vs depth

Rock mechanics of
x-large excavations

Feasibility assessment
Risk analysis
Cost evaluation

(work in progress performed with several rock engineering companies within the EU FP7 LAGUNA DS)





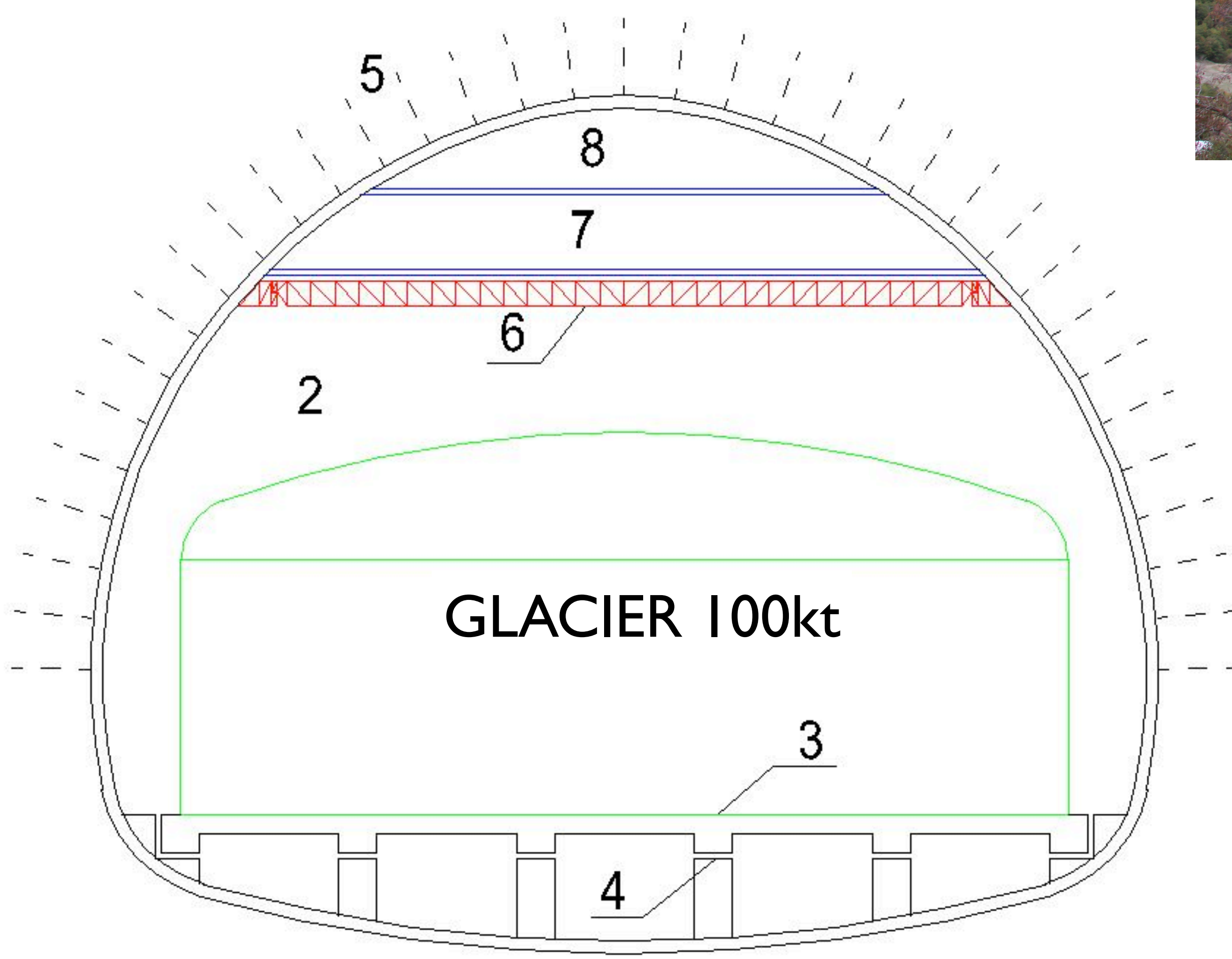
Systematic comparison
of different sites

e.g. rock spalling vs depth

Example of shallow site (Caso, Italy)

(work in progress performed with AGT Ingegneria within the EU FP7 LAGUNA DS)

- Shallow site, overburden ≈ 900 mwe
- Small off-axis w.r.t CNGS, distance CERN ≈ 665 km
- Preliminary rock engineering study



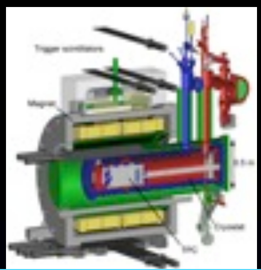
WIDTH OF THE CAVERN : 80 m
HEIGHT OF THE CAVERN : 65 m

1) TANK (DETECTOR)
2) MAIN ROOM - Surface 5.000 m^2
3) FOUNDATION (REINFORCED CONCRETE)
4) SUB-FOUNDATION (REINFORCED CONCRETE) WITH SEISMIC ISOLATION
5) BOLTS FOR LOCAL ROCK STABILITY (IF NECESSARY)
6) GANTRY CRANE FOR CONSTRUCTION AND MAINTENANCE OF THE TANK
7) POSSIBLE LOCATION FOR UNDERGROUND ROOMS
S = 1200 m^2 - V = 11000 m^3 - H = 6 m
(MAIN CONTROL, OFFICE, ELECTRONICS, STORAGE et al.)
8) POSSIBLE LOCATION FOR UNDERGROUND ROOMS
S = 600 m^2 - V = 4000 m^3 - H = 3-6 m
(CLEAN ROOM et al.)

AGT Ingegneria

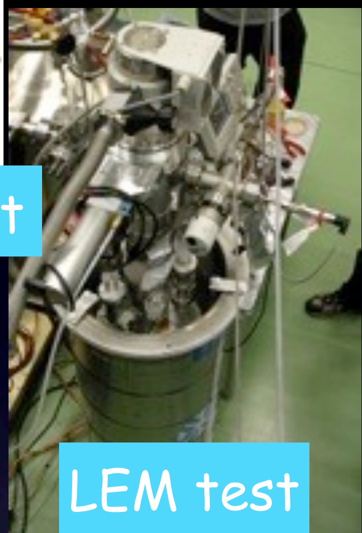
Steps towards GLACIER

- Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?



B-field test

➠



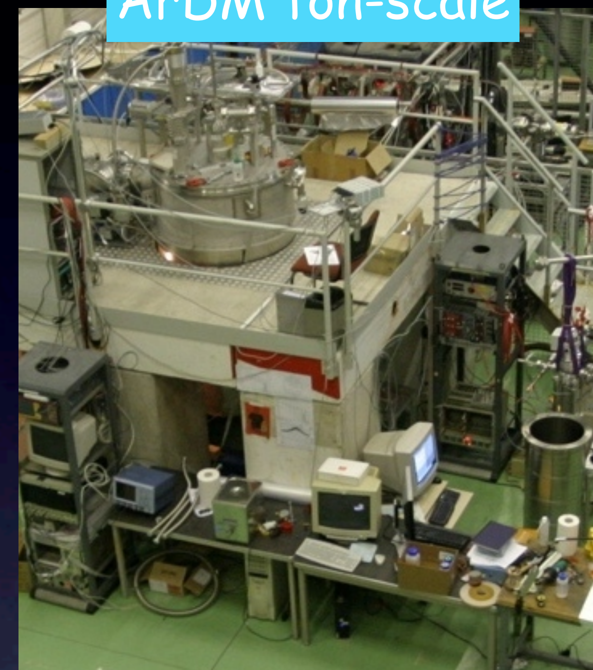
LEM test

proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale

➠

LEM readout on 1x1 m² scale UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM ton-scale



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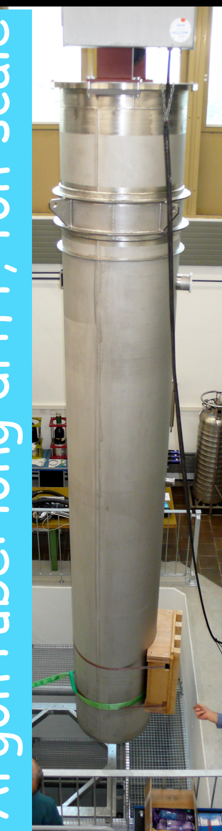
direct proof of long drift path up to 5 m

ArgonTube: long drift, ton-scale



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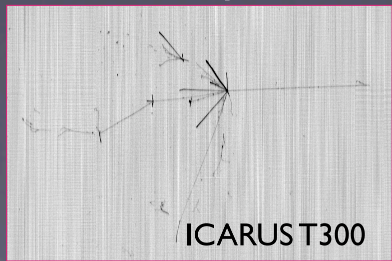
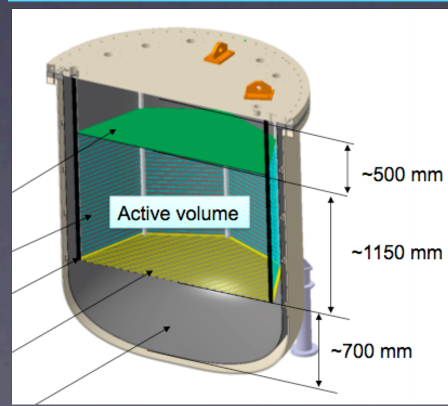
Application of LAr LEM TPC to neutrino physics: particle reconstruction & identification (e.g. 1 GeV e/μ/π), optimization of readout and electronics, possibility of neutrino beam exposure



Test beam
1 to 10 ton-scale



➠

full engineering demonstrator for larger detectors, acting as near detector for neutrino fluxes and cross-sections measurements, …

1 kton

On-going R&D efforts

- Since 2004, several critical issues have been identified and are subject to intense R&D efforts

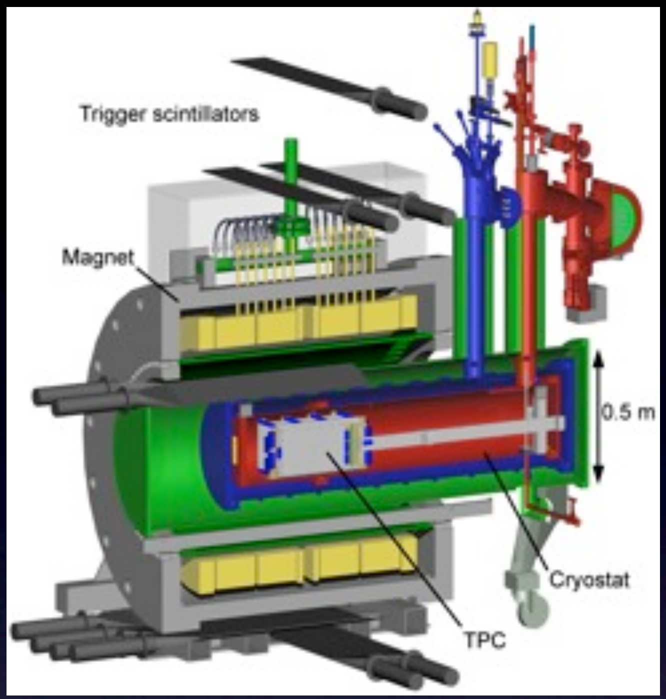
  - LAr tank → design with Technodyne in LAGUNA DS
  - Readout system → novel techniques, other than wires, with charge multiplications (double phase) developed. Proof of principle is achieved.
  - Very long drift → dedicated test
  - HV system → small scale tests successful
  - Readout electronics → new modern solution developed in Collaboration with industry, in addition R&D on warm/cold solutions, ASIC preamplifier working in cold, Ethernet based readout chain + network time distribution
  - LAr purification systems → in Collab. with industry
  - Safety → dedicated Workpackage in LAGUNA DS
  - Test beams → under consideration
  - Detector prototyping

Small setups and proof of principle

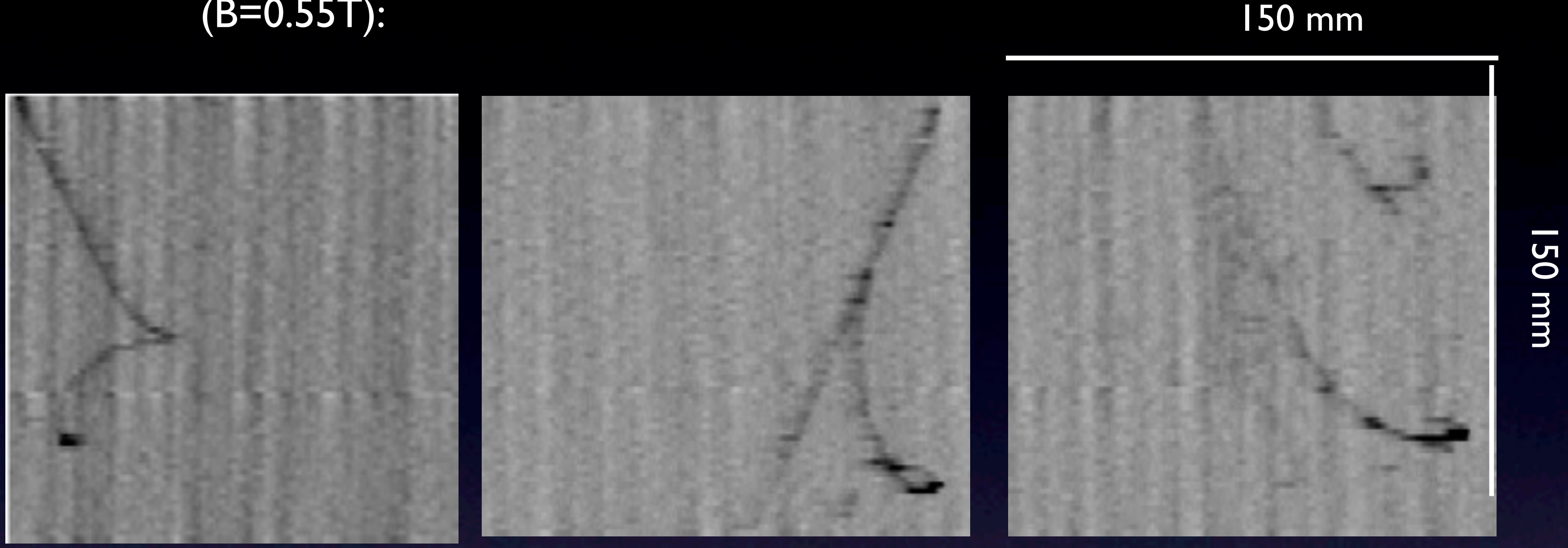
First operation of a LAr TPC with a B-field

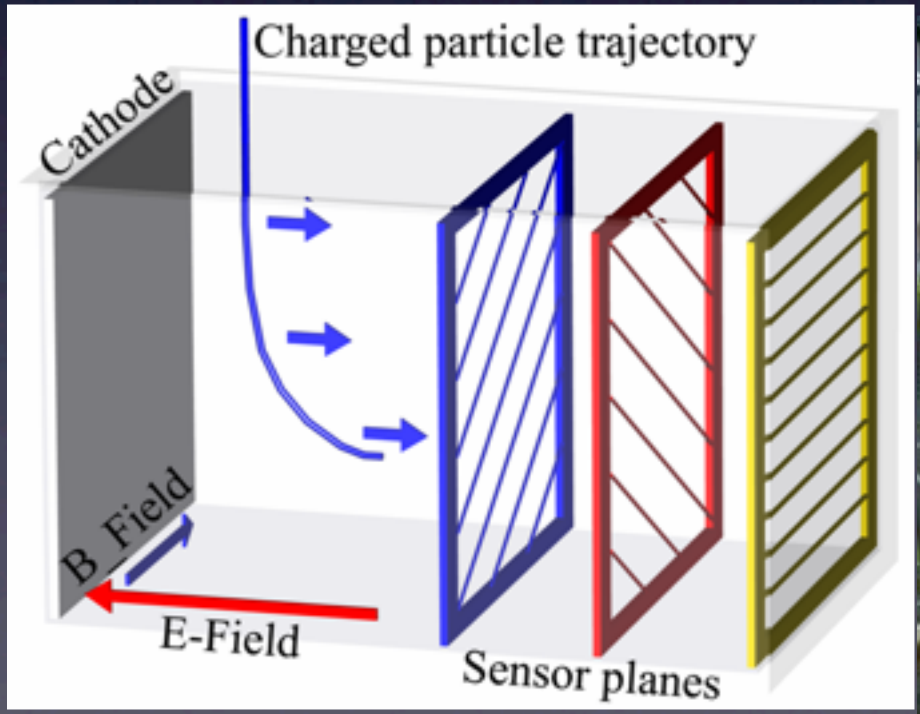
M. Laffranchi, PhD Diss. ETH No. 16002

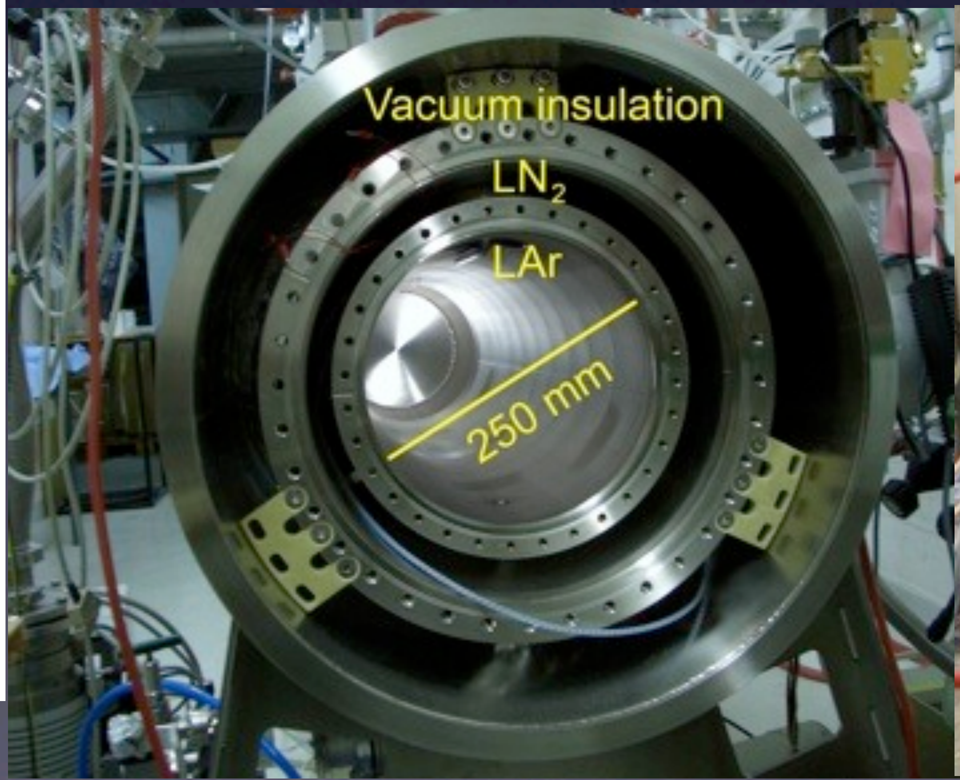
New J. Phys. 7 (2005) 63
NIM A 555 (2005) 294

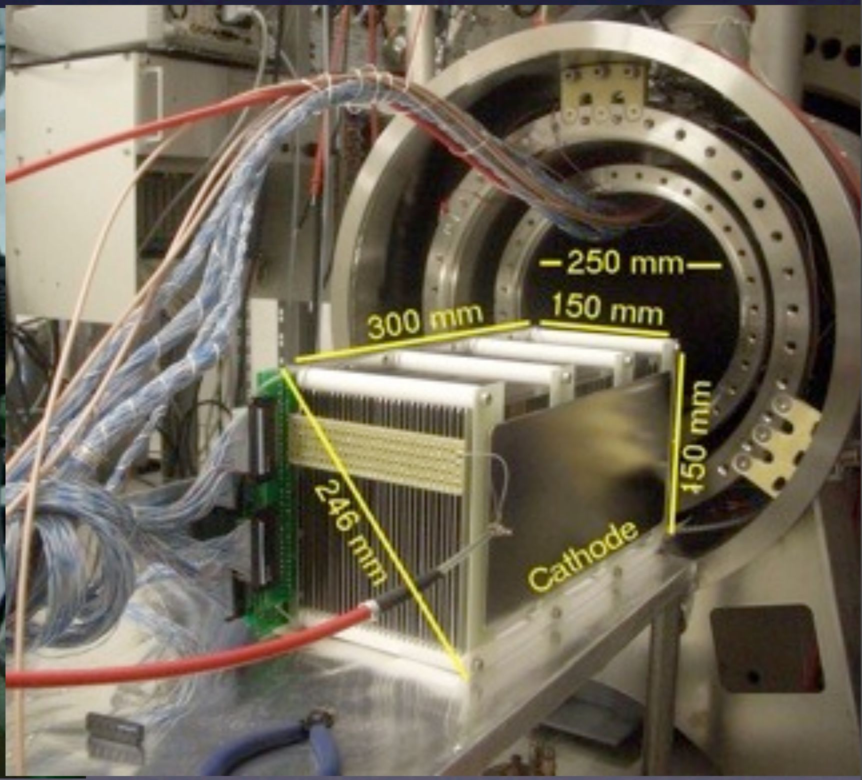


First events in B-field
(B=0.55T):









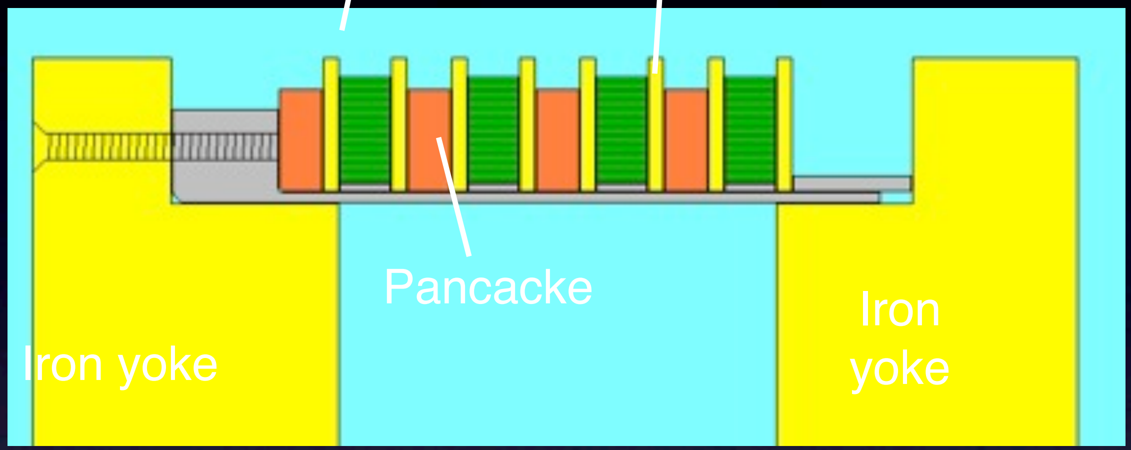
Analysis: correlation between track curvature and energy deposited by Michel e^-

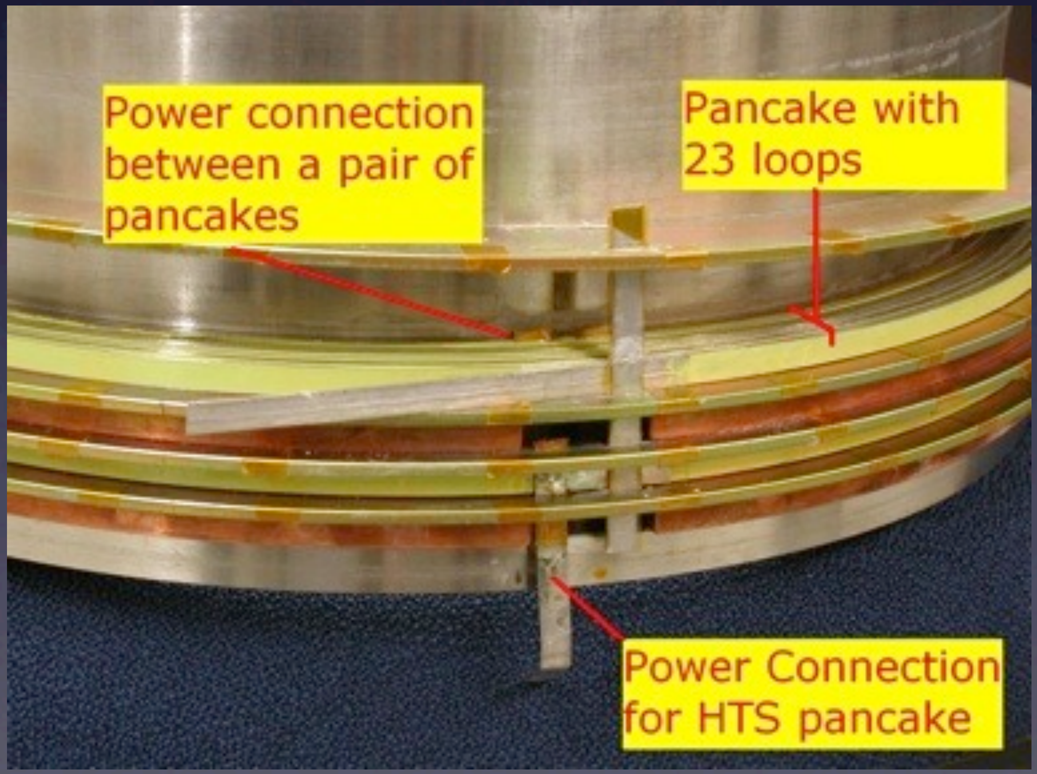
Tuesday, March 24, 2009

Small test solenoid built wit HTS wire

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

T. Strauss, ETH Master's thesis





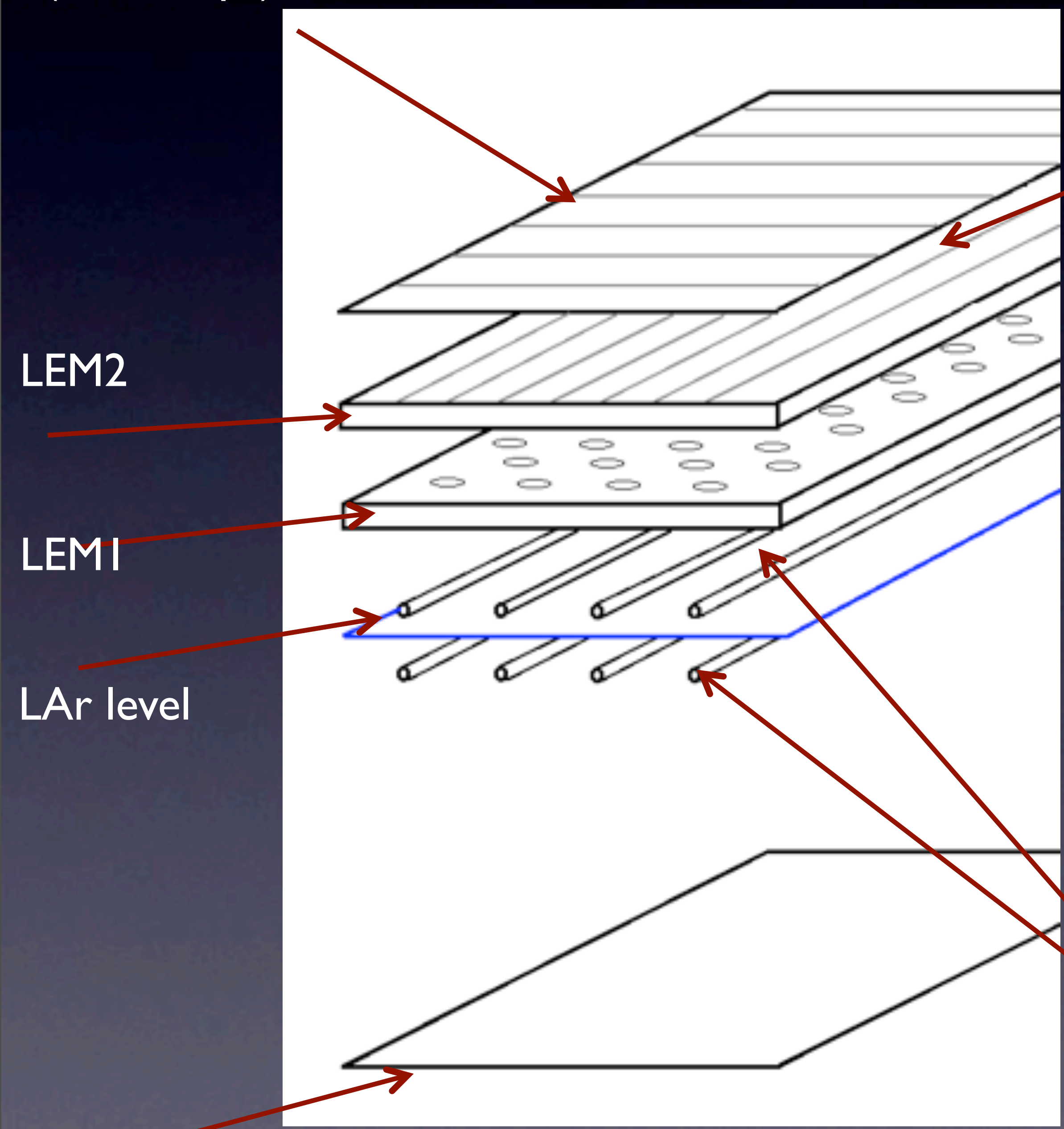
Temperature	LN_2 (77K)	LAr (87K)
Max. applied current	145 A	80 A
On-axis B-field	0.2 T	0.11 T
Coil resistance at 4A	6 μΩ	6 μΩ

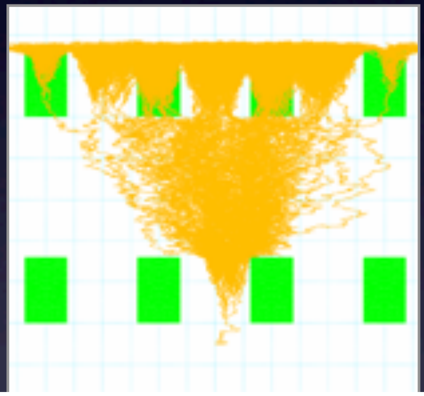
Similar tests performed with YBCO from Superpower Inc

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

Double phase LAr LEM-TPC

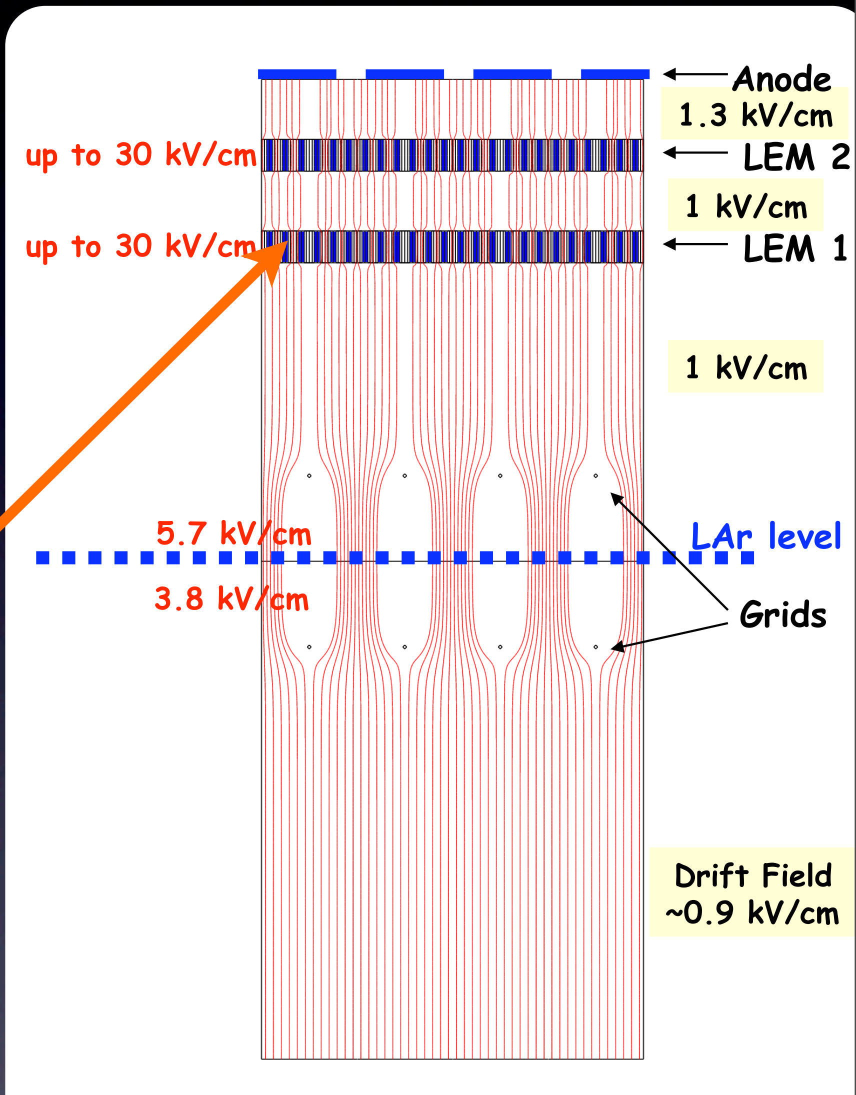
A novel kind of double phase LAr TPC based on a Large Electron Multiplier (LEM) (arXiv:0811.3384)





P. Otyougova, PhD Diss. ETH No. 17704

LEM concept based on pionieering successes of GEM technology



Typical Electric Fields for double-phase operation

$Gain = G_{LEM1} \cdot G_{LEM2} = G^2 = e^{2\alpha x}$

x: effective LEM hole length (~0.8 mm)

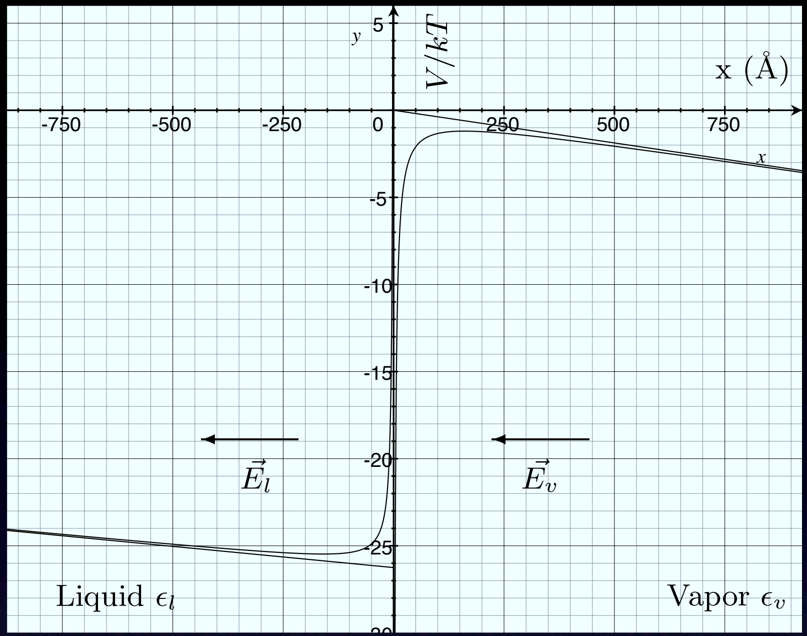
α: 1st Townsend coefficient $\approx Ape^{-Bp/E}$

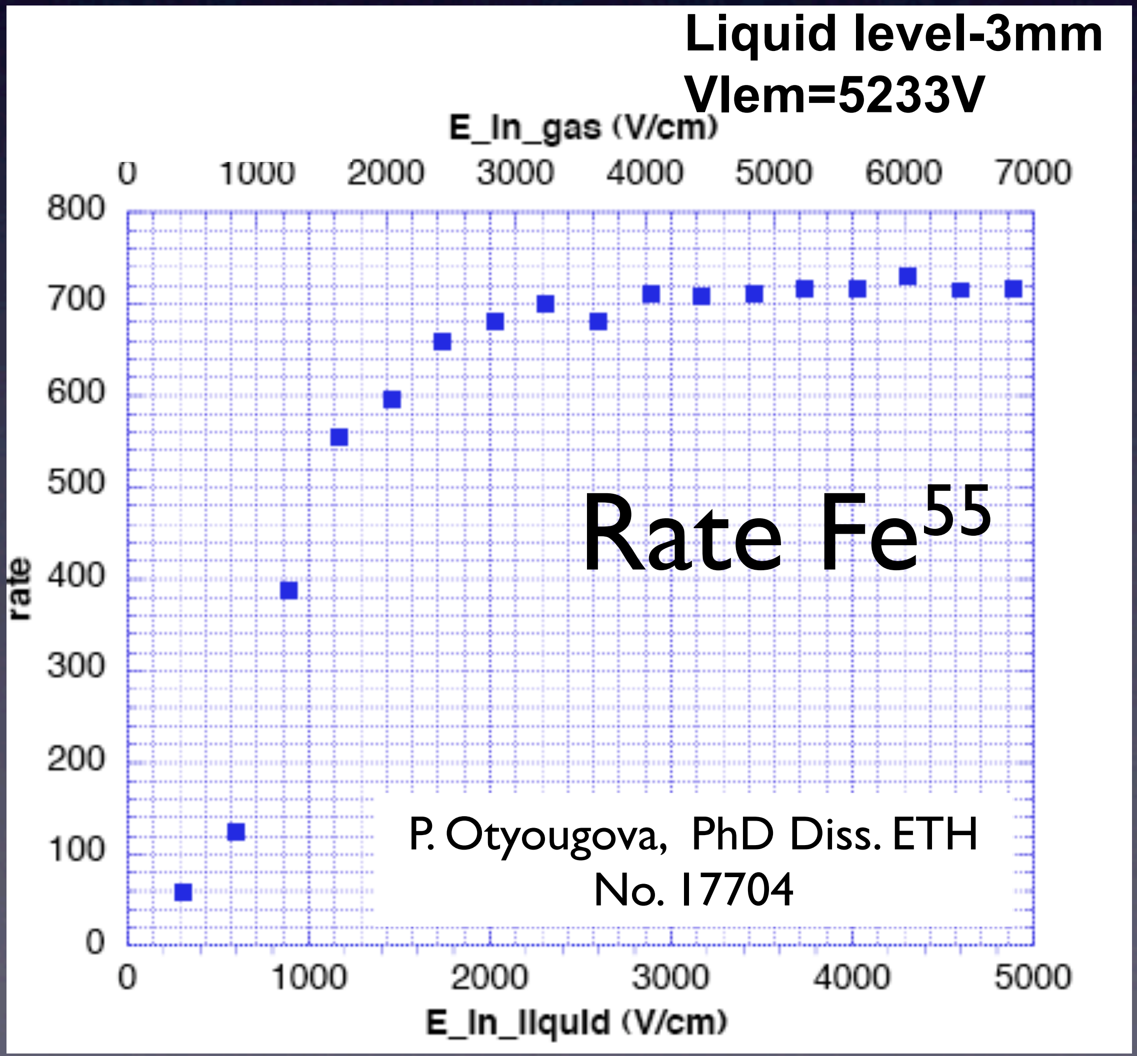
Electron extraction in double phase

- Based on the extraction of the quasi-free electrons from liquid into vapor phase (B.A. Dolgoshein et al., Sov. J. Part. Nucl. 4 (1973) 70.)
- Classical potential barrier at interface of two media with different dielectric constants >> kT
- Time to traverse the barrier given by Shottky model of electric-field-enhanced thermionic emission

Measured extraction rate plateau from LAr as a function of electric field
➟ ≈3kV/cm for fast (μs) extraction

Classical potential as a function of distance from interface





Amplification in pure Argon vapor

- Available flexibility in the amount of multiplication of the primary ionization electrons, thus adapting to a wide range of physics requirements.

- Our measurements are consistent with the numerical estimations obtained with MAGBOLTZ

Gain=$G_{LEM1} \times G_{LEM2} = G^2 = e^{2\alpha x}$
x: effective LEM hole length (x=1 mm)
α: 1st Townsend coefficient $\approx A\rho e^{-B\rho/E}$

Identification: Ar 100%, T=300 K, p=0.98692 atm

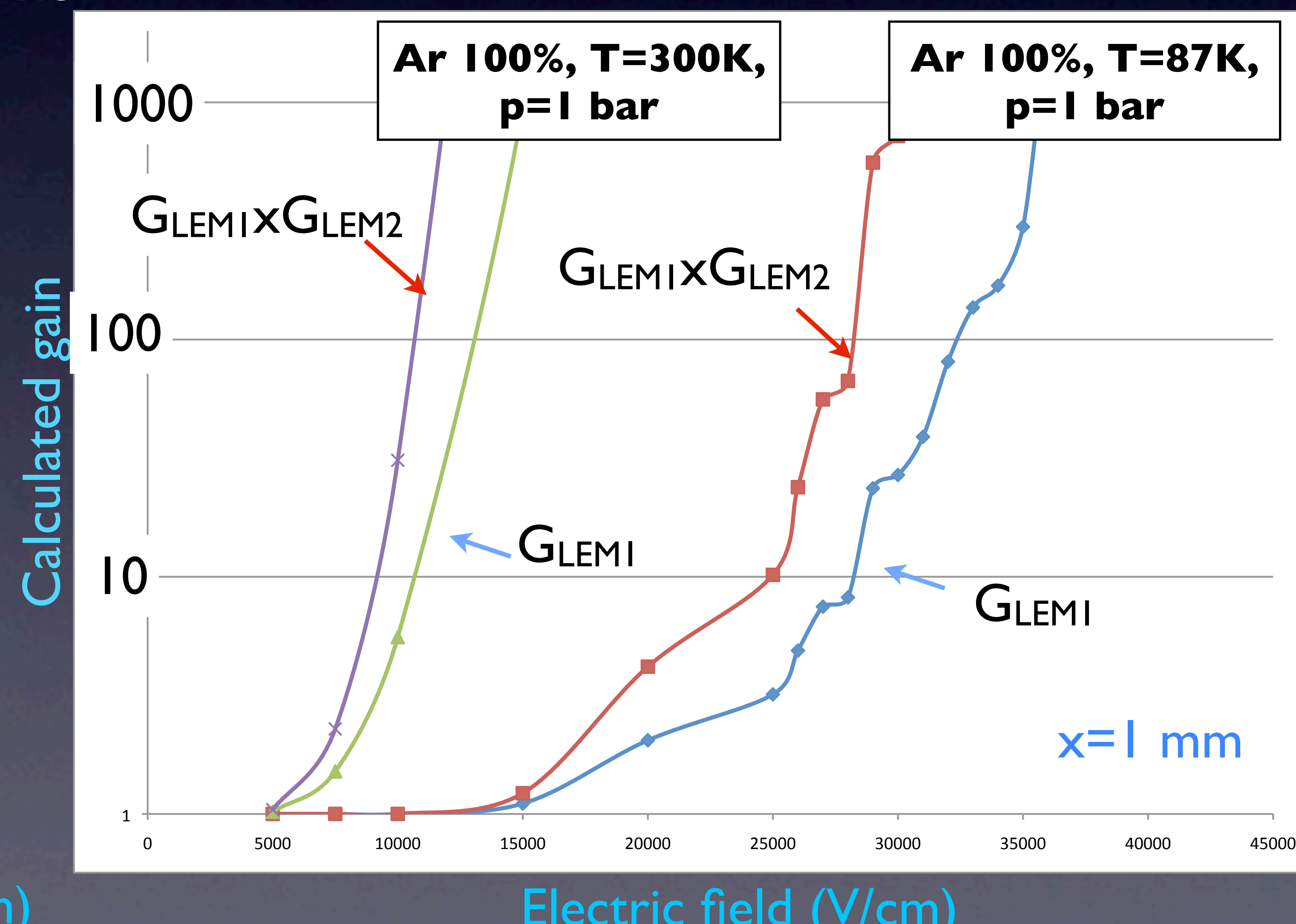
E [V/cm]	Vdrift [cm/microsec]	Diffusion (long, trans) [micron for 1 cm]		Townsend [1/cm]
5000	1.9444	414.988	525.772	0.21176
7500	2.75923	331.35	414.17	4.12663
10000	3.58345	267.645	353.023	17.1651
15000	5.0662	230.553	291.482	68.4514
20000	6.51841	206.387	267.535	148.171

Identification: Ar 100%, T=87 K, p=0.99975 atm

E [V/cm]	Vdrift [cm/microsec]	Diffusion (long, trans) [micron for 1 cm]		Townsend [1/cm]
25000	2.71557	172.604	228.402	11.6052
26000	2.74688	168.666	237.634	15.8598
27000	2.86757	167.336	220.115	20.122
28000	2.95561	172.459	221.546	21.02
29000	2.98084	155.753	209.167	31.6151
30000	3.09984	166.305	206.024	32.9033
31000	3.23889	150.603	209.654	36.6083
32000	3.31229	147.182	202.759	43.9044
33000	3.37025	157.875	203.651	49.1659
34000	3.50178	139.944	202.585	5[illegible].287

Electric field (V/cm)

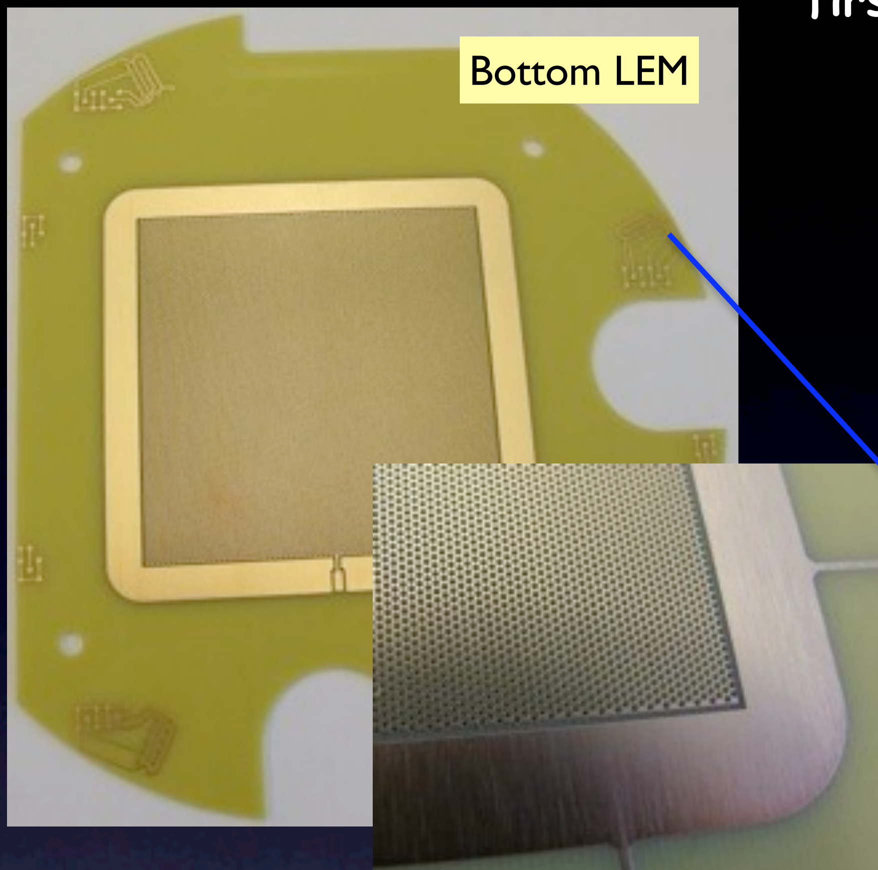
Calculated Townsend(/cm)

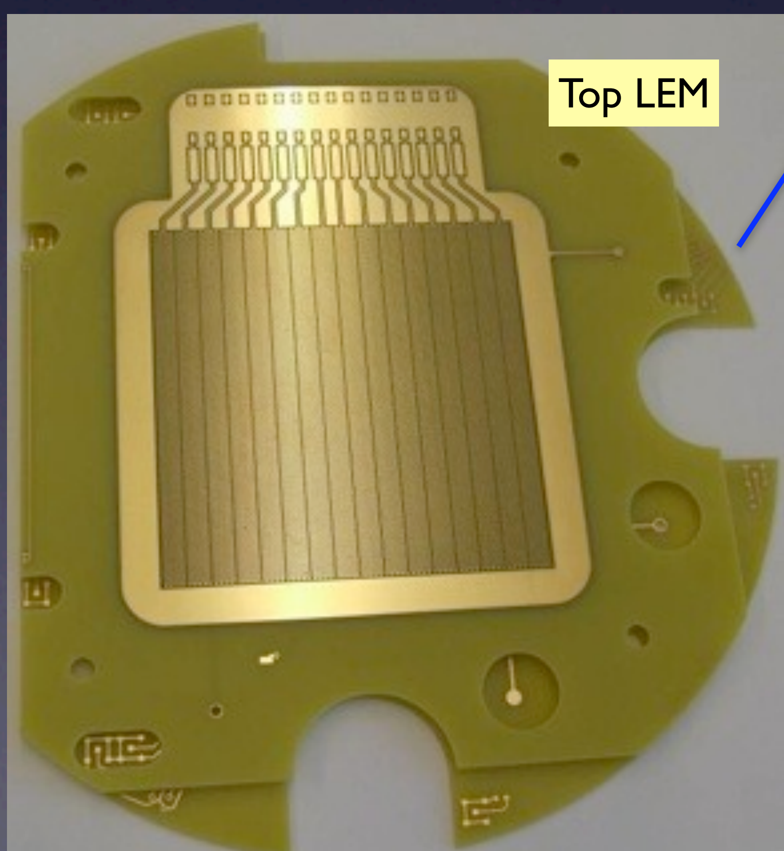


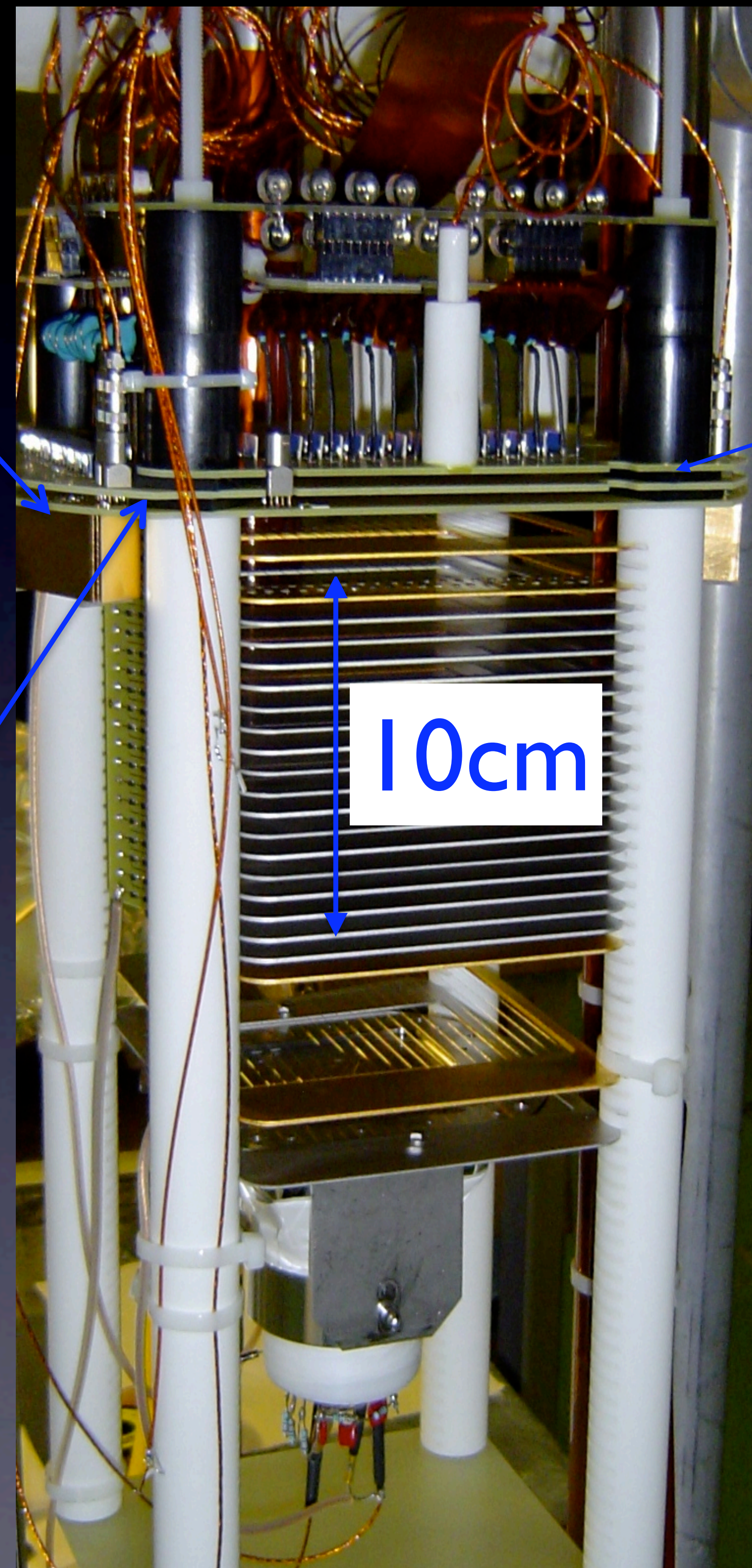
3 lt LAr LEM-TPC prototype

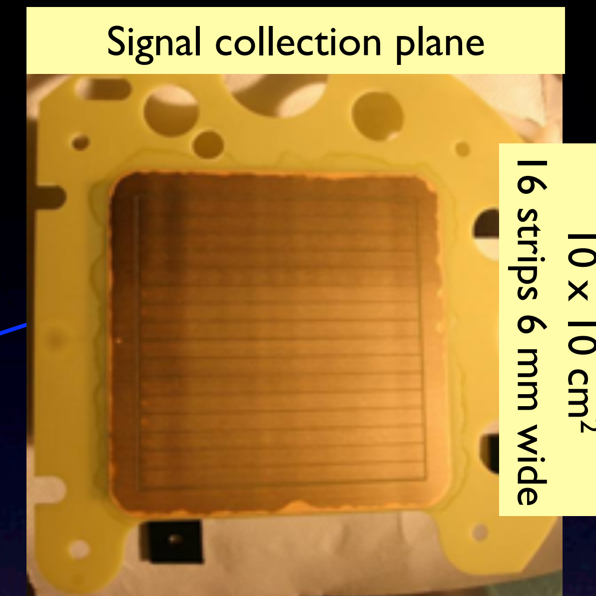
first operation of a 0.1 x 0.1 m^2 test setup

F. Resnati, PhD Diss. ETH







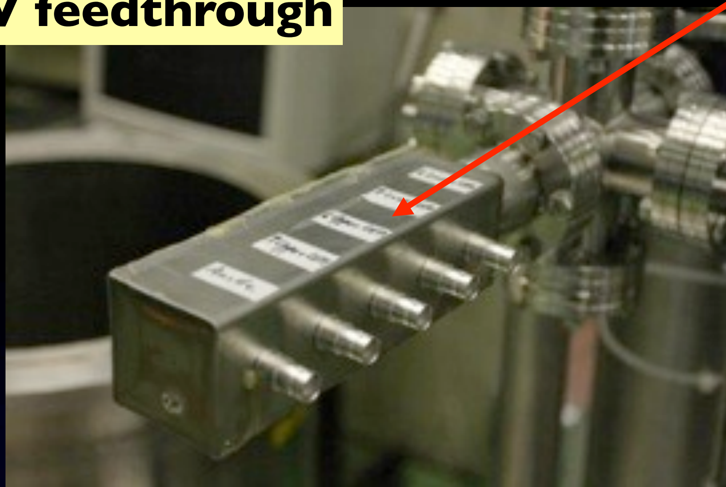


- Produced by standard PCB technique
- Double-sided copper-clad (18 µm layer) FR4 plates, 1.6 mm thick
- Precision holes made by drilling
- Gold deposition on Cu (<~ 1 µm layer) to avoid oxidization
- HV decoupling (cryo-) capacitors & surge arrestors embedded

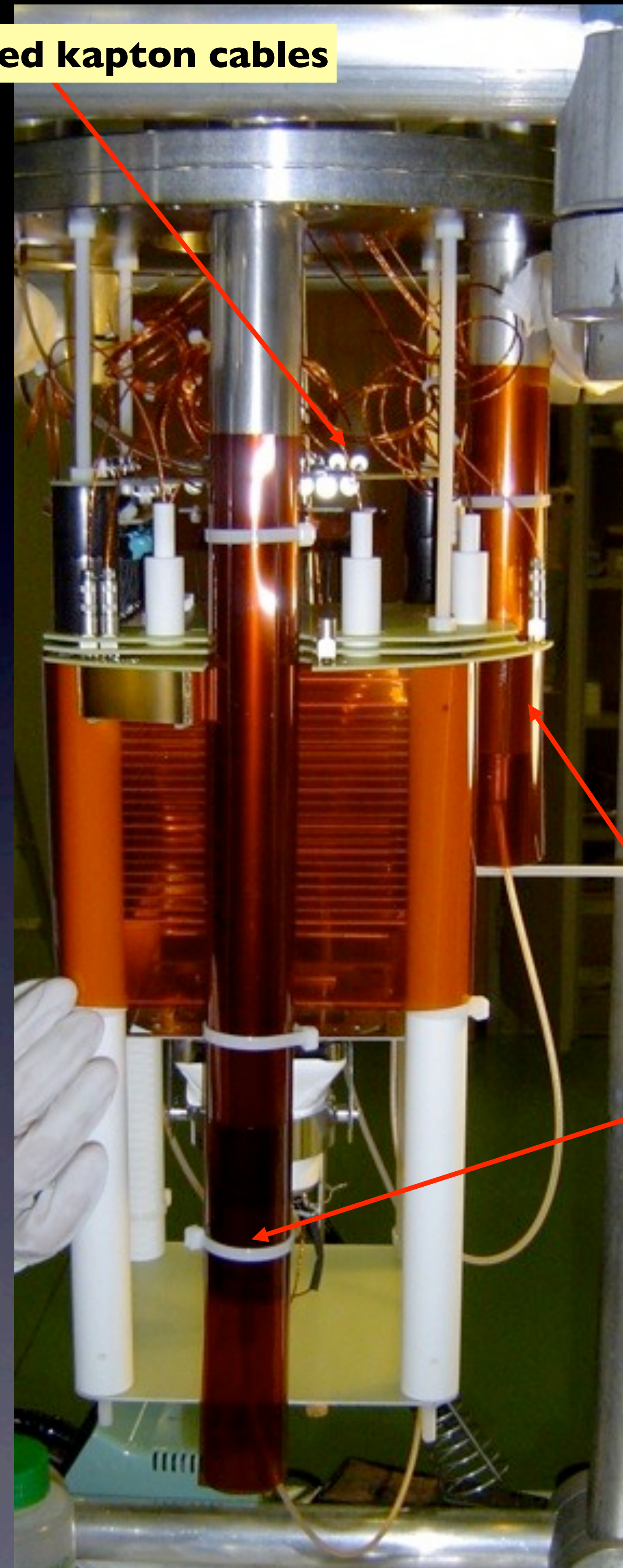
Technical details I

HV feedthrough

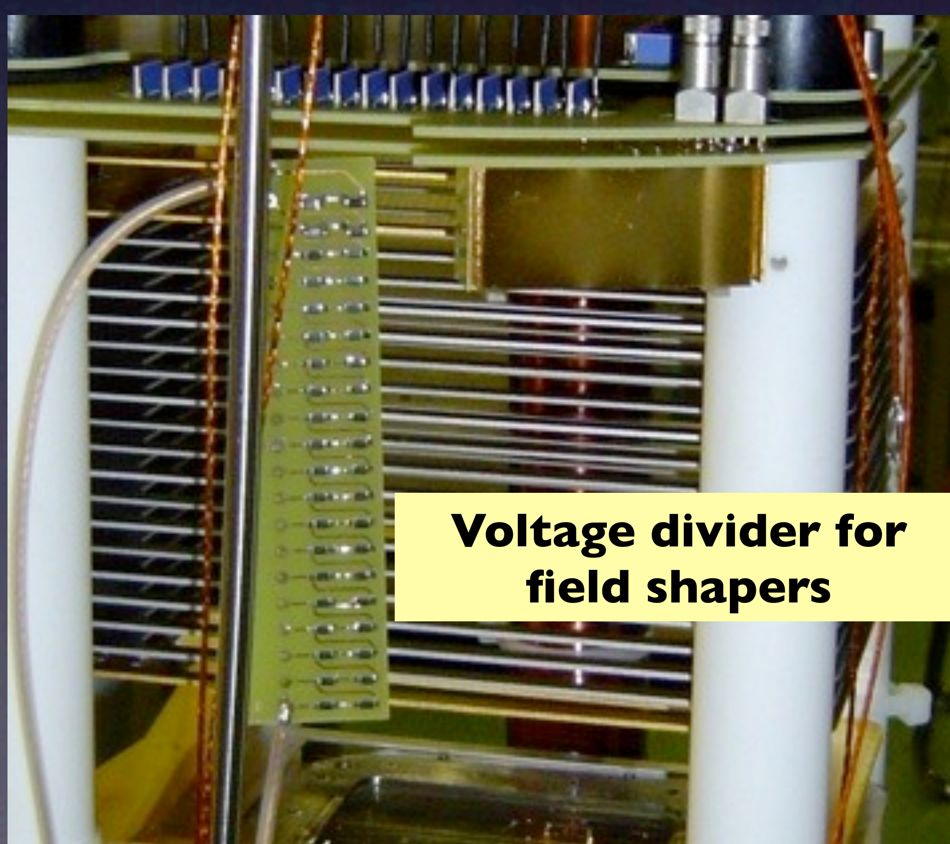
Miniaturized kapton cables



HV connections to LEM planes (~8 kV)



LEMO 30 kV HV connector



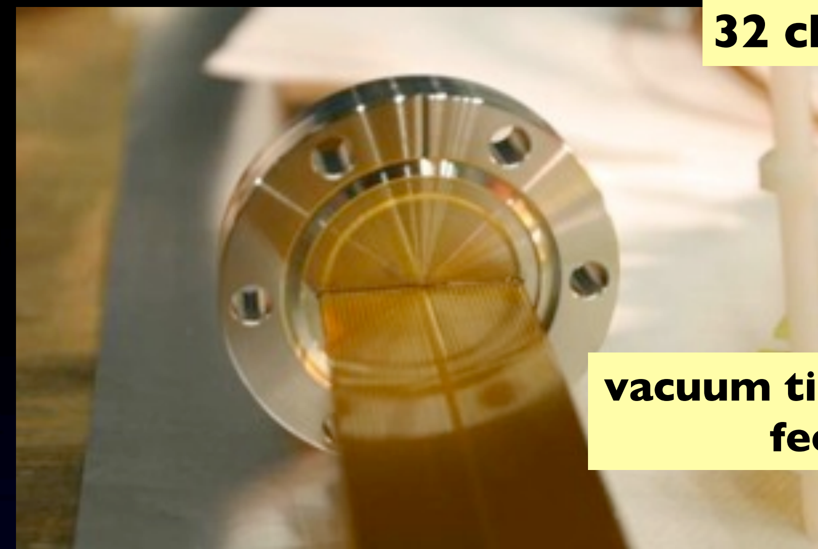
Voltage divider for field shapers

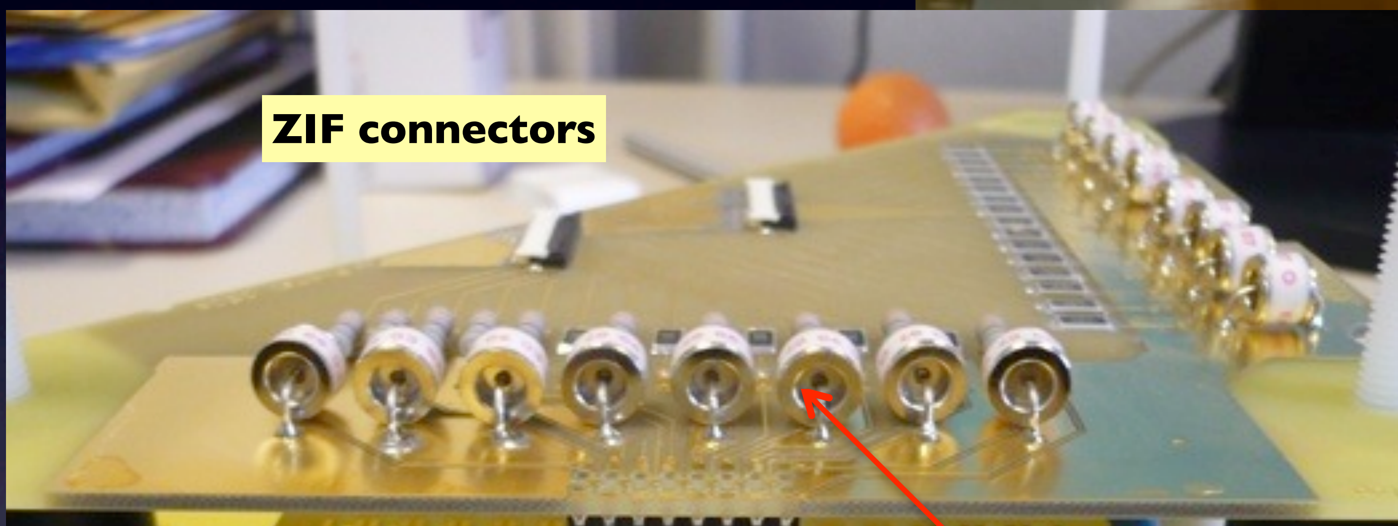
HV connections to cathode and grids (up to ~30 kV)

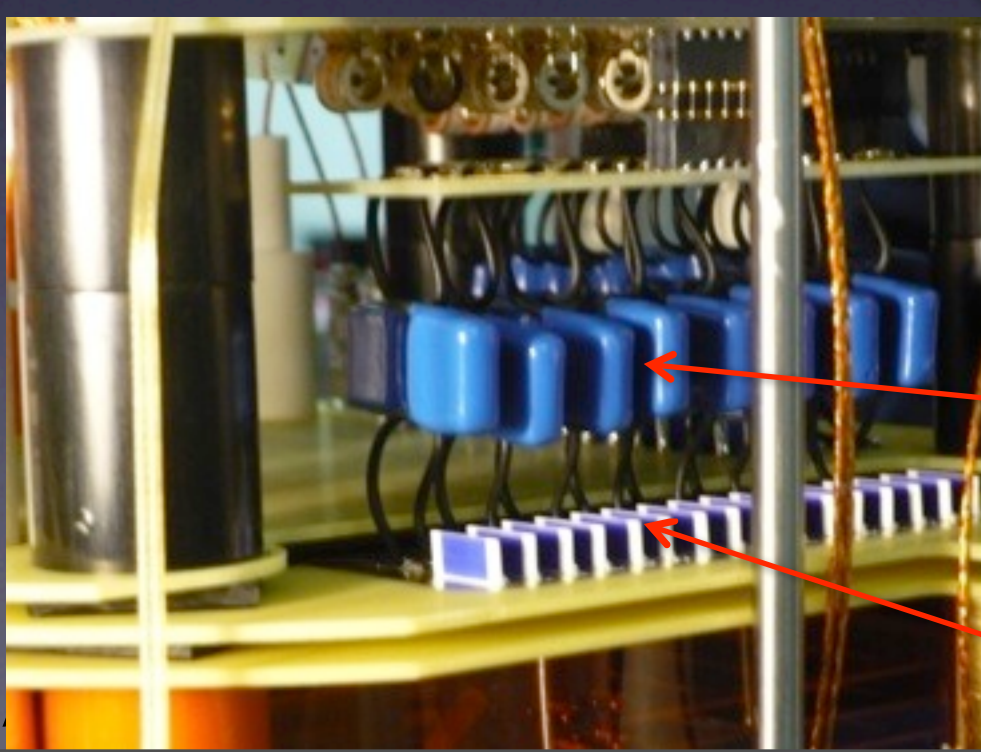
All materials must be compatible with UHV and cryogenic application

Technical details II

kapton flex-prints





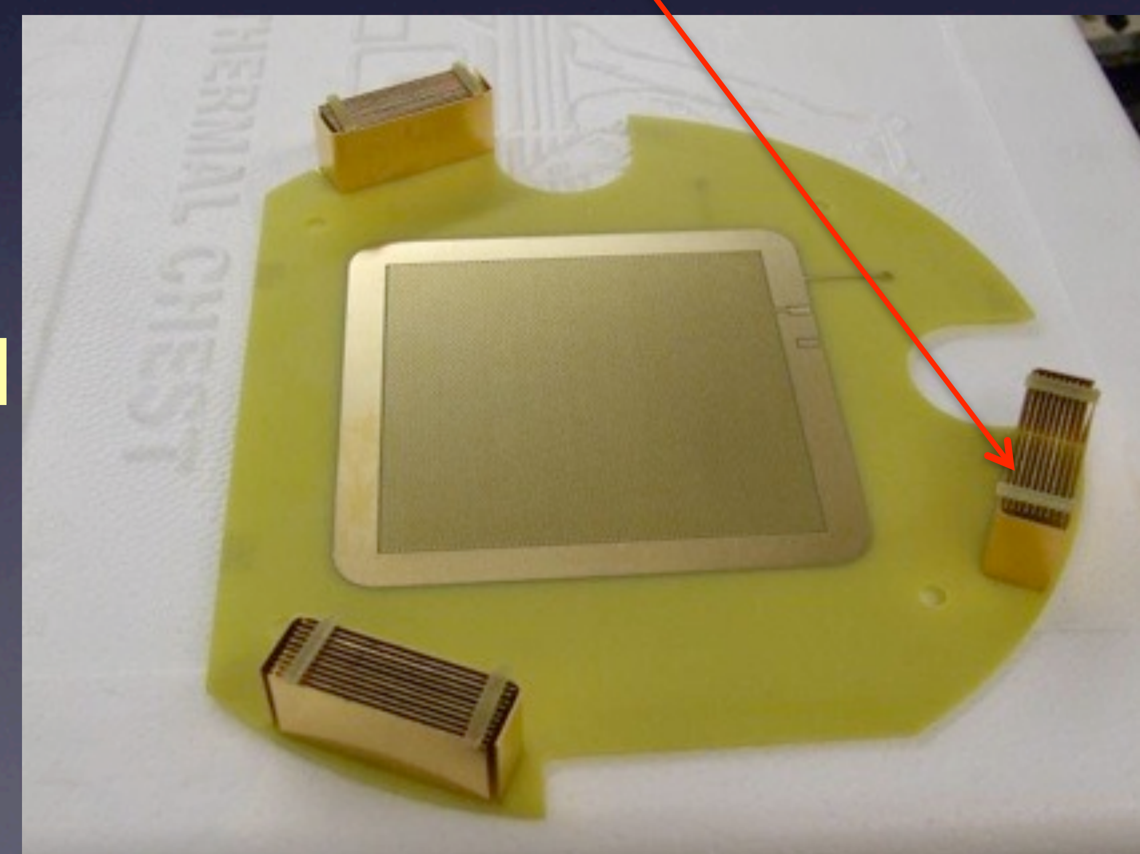


Surge arrestors

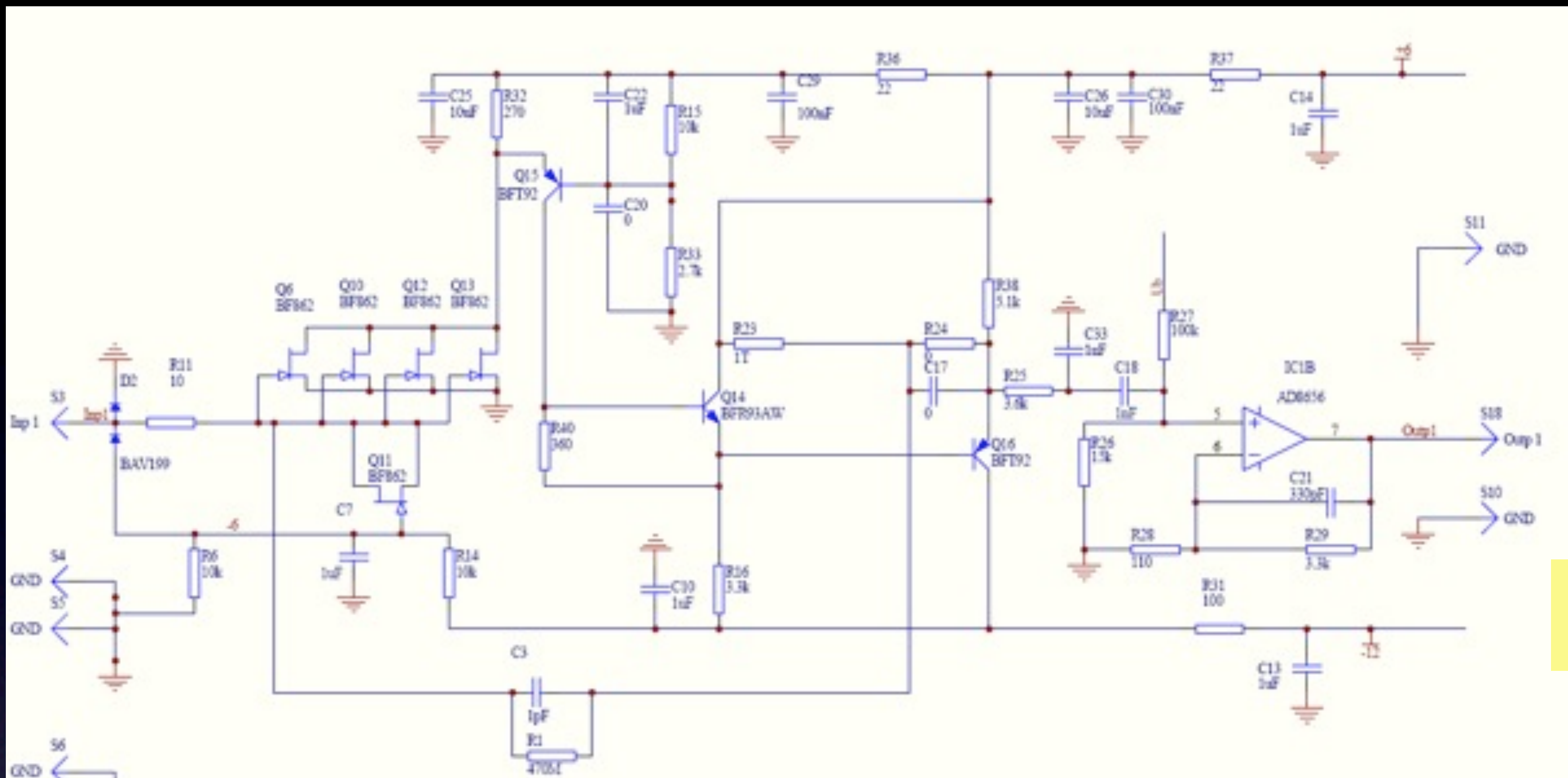
HV cryo-capacitors

HV resistors

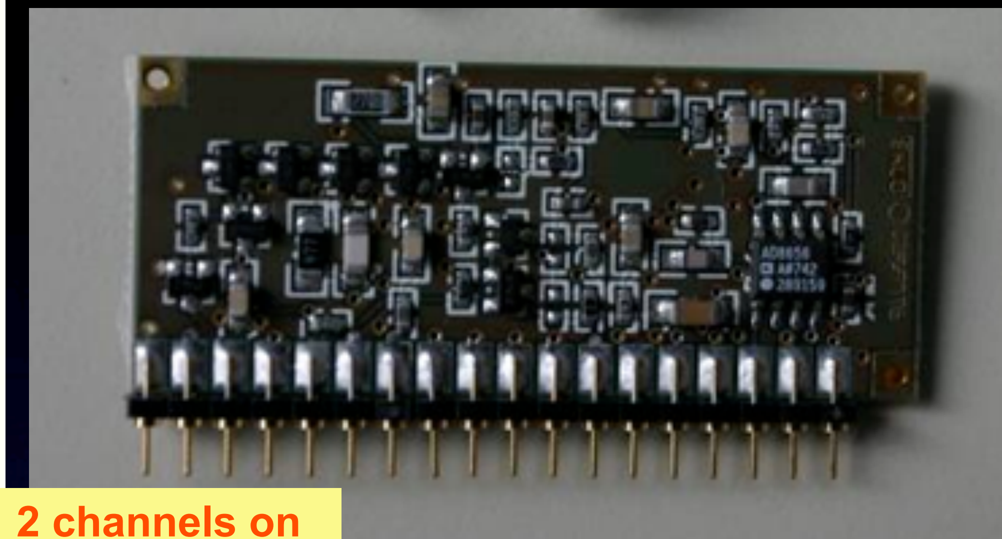
Capacitor-based Levelmeters



ETHZ Preamplifier development



Inspired from C. Boiano et al.
IEEE Trans. Nucl. Sci. 52(2004)1931



2 channels on one hybrid

Custom-made front-end charge preamp + shaper

4 different shaping constants

Measured values

Version	FET integrator decay time constant (μs)	Shaper integration time constant (μs)	Shaper differentiation time constant (μs)	Sensitivity (mV/fC)	Noise (e^-) C_i= 200 pF	S/N @ 1 fC C_i= 200 pF
V1	470	3.6	13	12.5	395	15
V2	470	3.6	1.3	11.9	485	13
V3	470	0.15	0.5	(10)		(6)
V4	470	0.6	2	11.6	620	10

ICARUS electronics
(τ_f=1.6 μs)

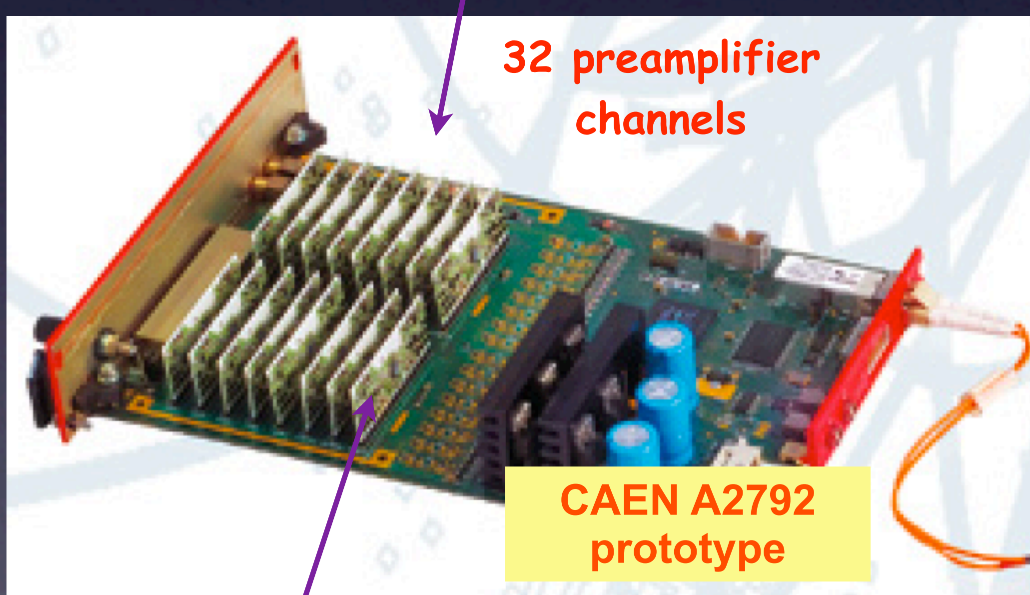
- S/N=10 @ 2 fC, C_i=350 pF
- equivalent to S/N=7 @ 1 fC, C_i=200 pF

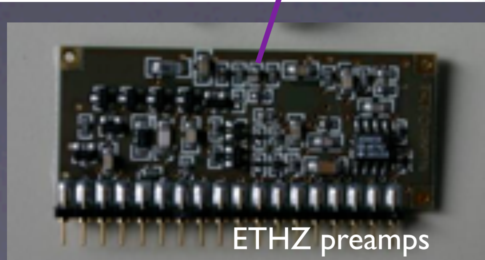
Data Acquisition System development

- In collaboration with CAEN, developed A/D conversion and F/E DAQ system

- 12 bit 2.5 MS/s flash ADCs + programmable FPGA with trigger logic
- Global trigger and channel-by-channel trigger,switch to 'low threshold' when a 'trigger alert' is present
- 1 MB circular buffer, zero suppression capability, 80 MB/s chainable optical link to PC

Commercially available





LEM-TPC operation in pure GAr at 300K

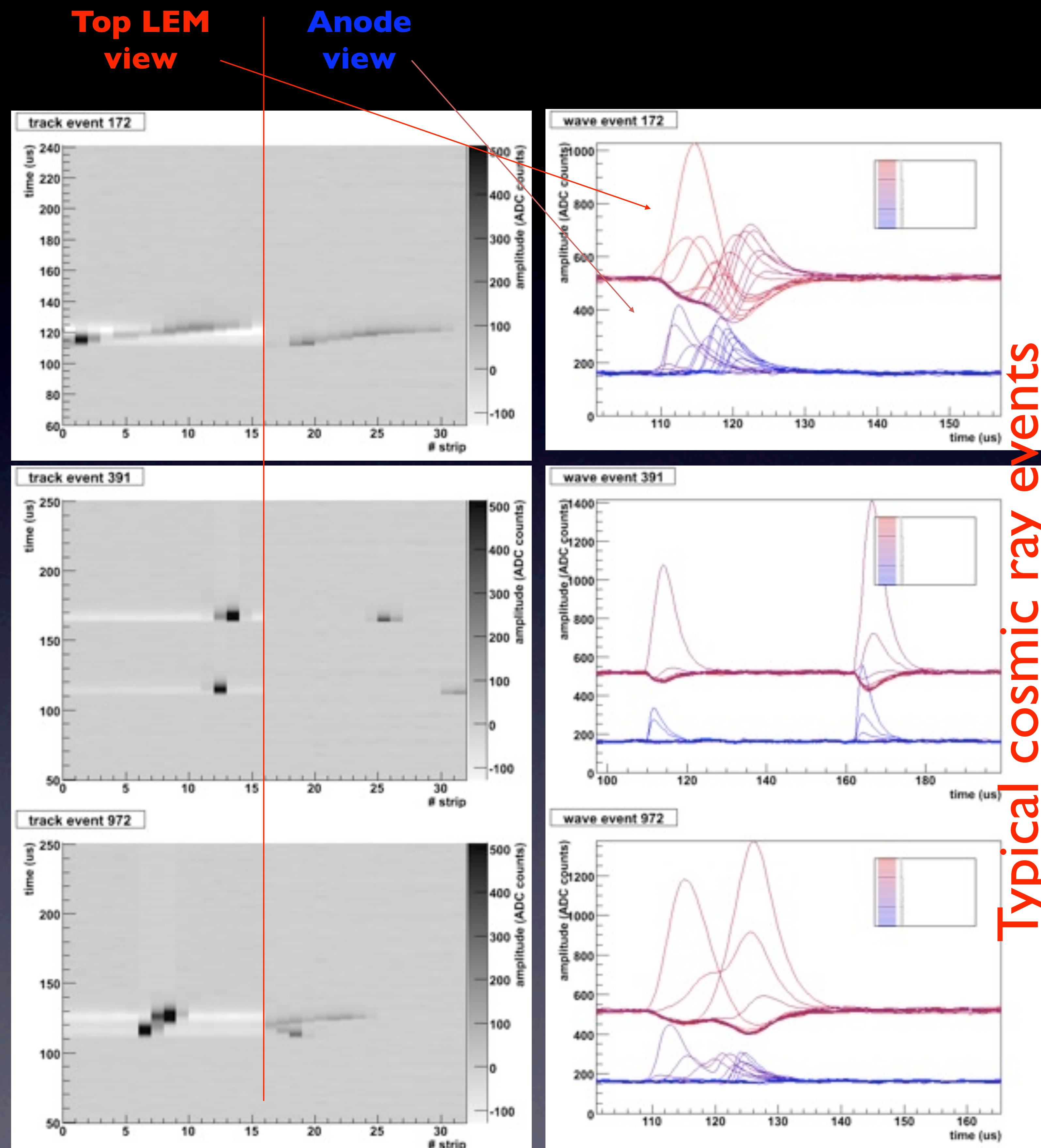
Ar gas (Ar-60) at room temperature @ 1.2 bar

Typical electric field values

	E (V/cm)
Anode-LEM2	**760**
LEM2	**~14 10^3 (*)**
LEM2-LEM1	**590**
LEM1	**~14 10^3 (*)**
Drift	**420**

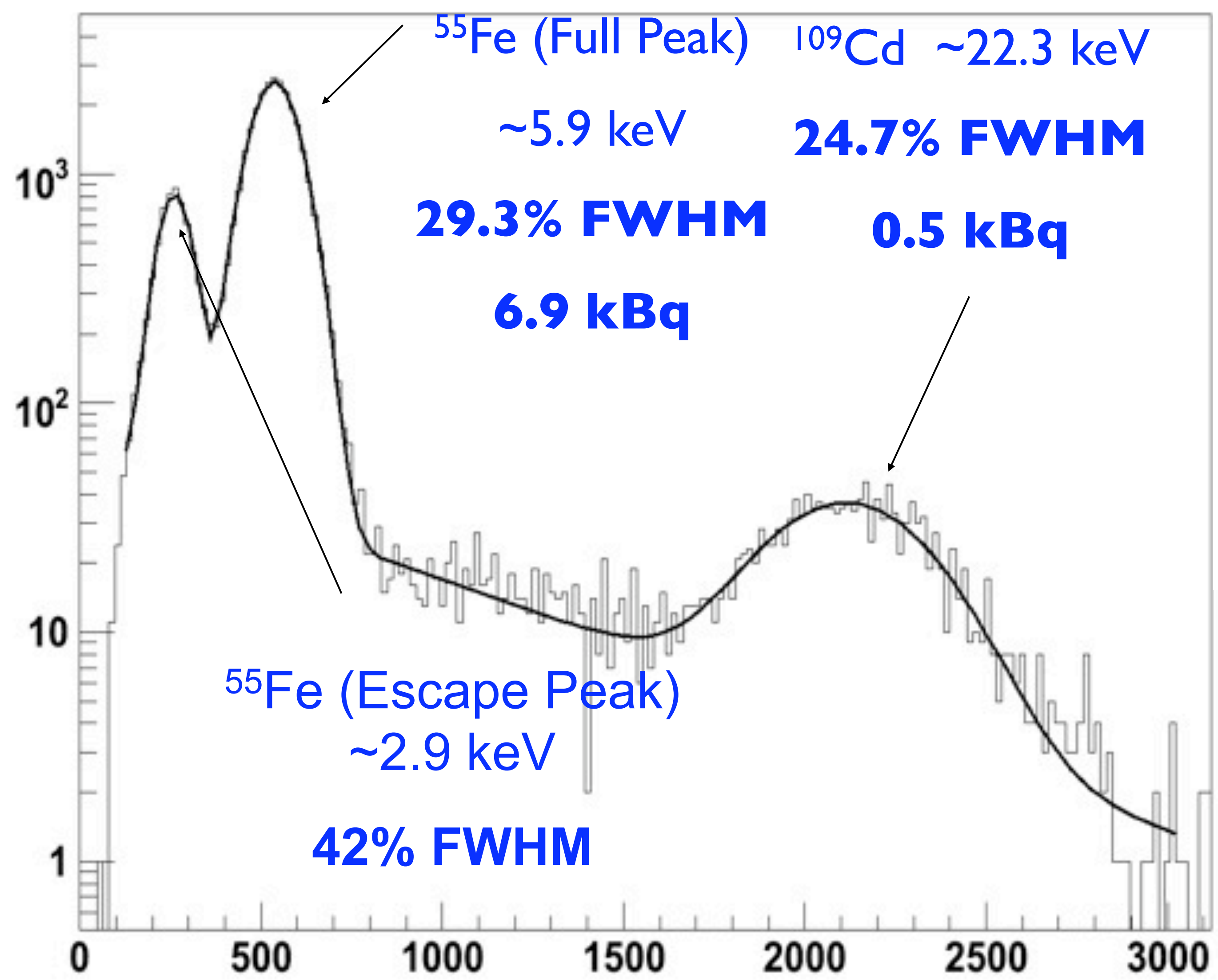
(*) Electric field is defined as $\Delta V/d$

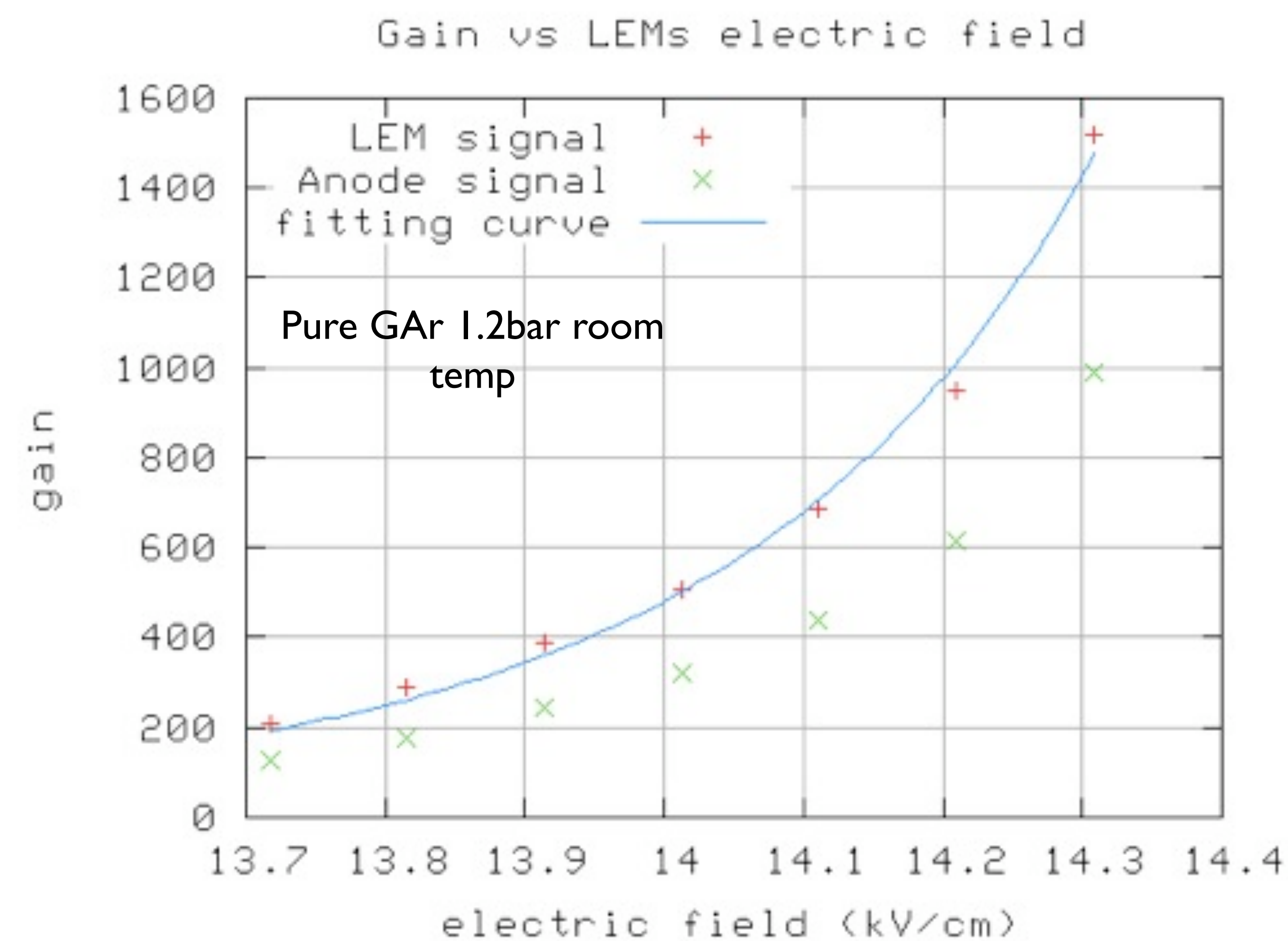
Gain ~ 1000 (see next slides)



Radioactive source Events in GAr

^{55}Fe and ^{109}Cd LEM electrode spectrum





^{55}Fe and ^{109}Cd sources positioned 2cm below the cathode grid

The device gain (G) depends on the electric field in the LEM holes, on the thickness of the LEM and on the gas density:

$G = G_{LEM1} G_{LEM2} = G^2_{LEM} = e^{(2\alpha x)}$; $x \approx 1$mm

$\alpha \approx Ape^{(-Bp/E)}$-Townsend coefficient

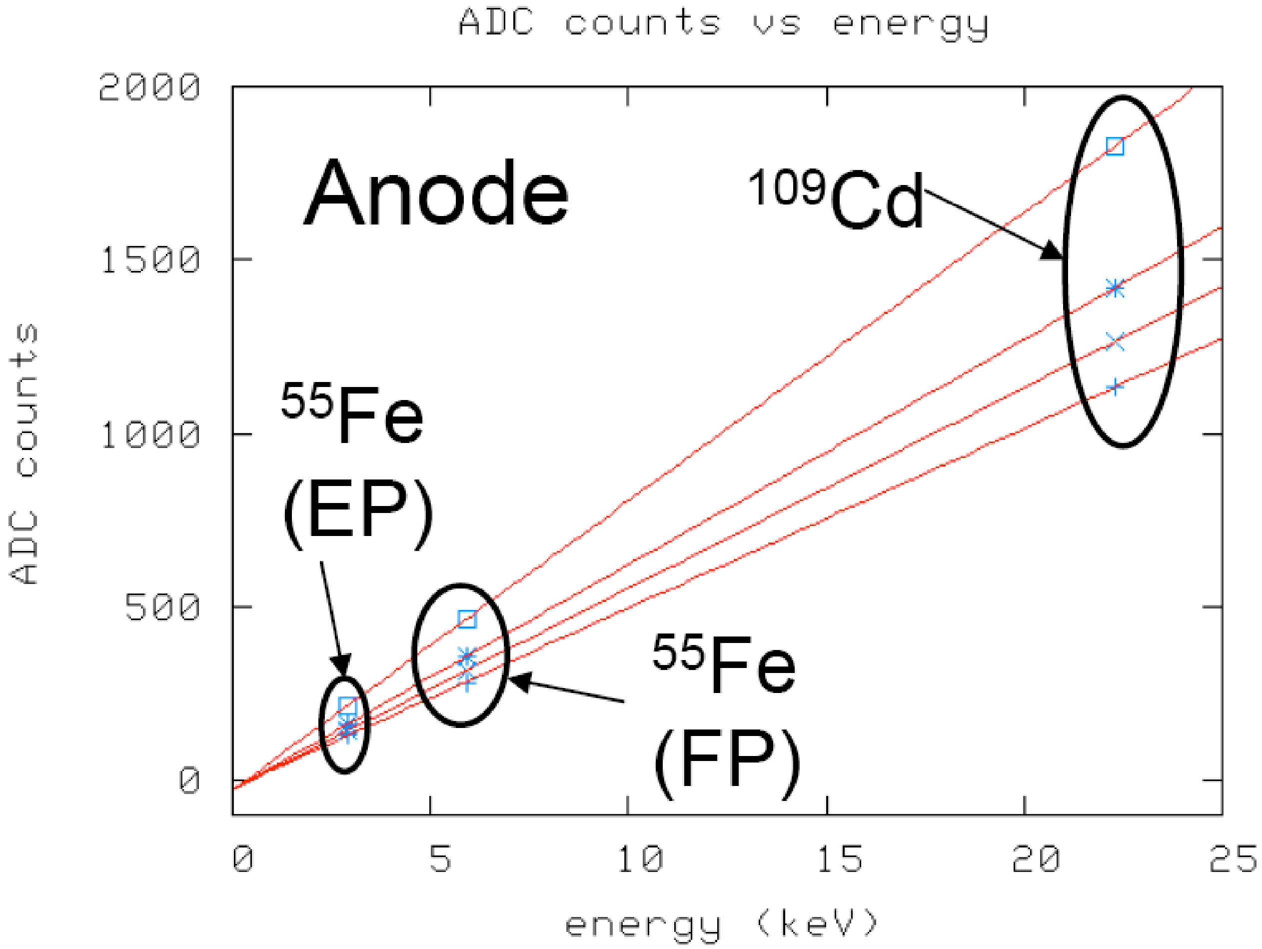
$A = 5.8\ 10^4\ cm^{-1}\ bar^{-1} \pm 30\%$

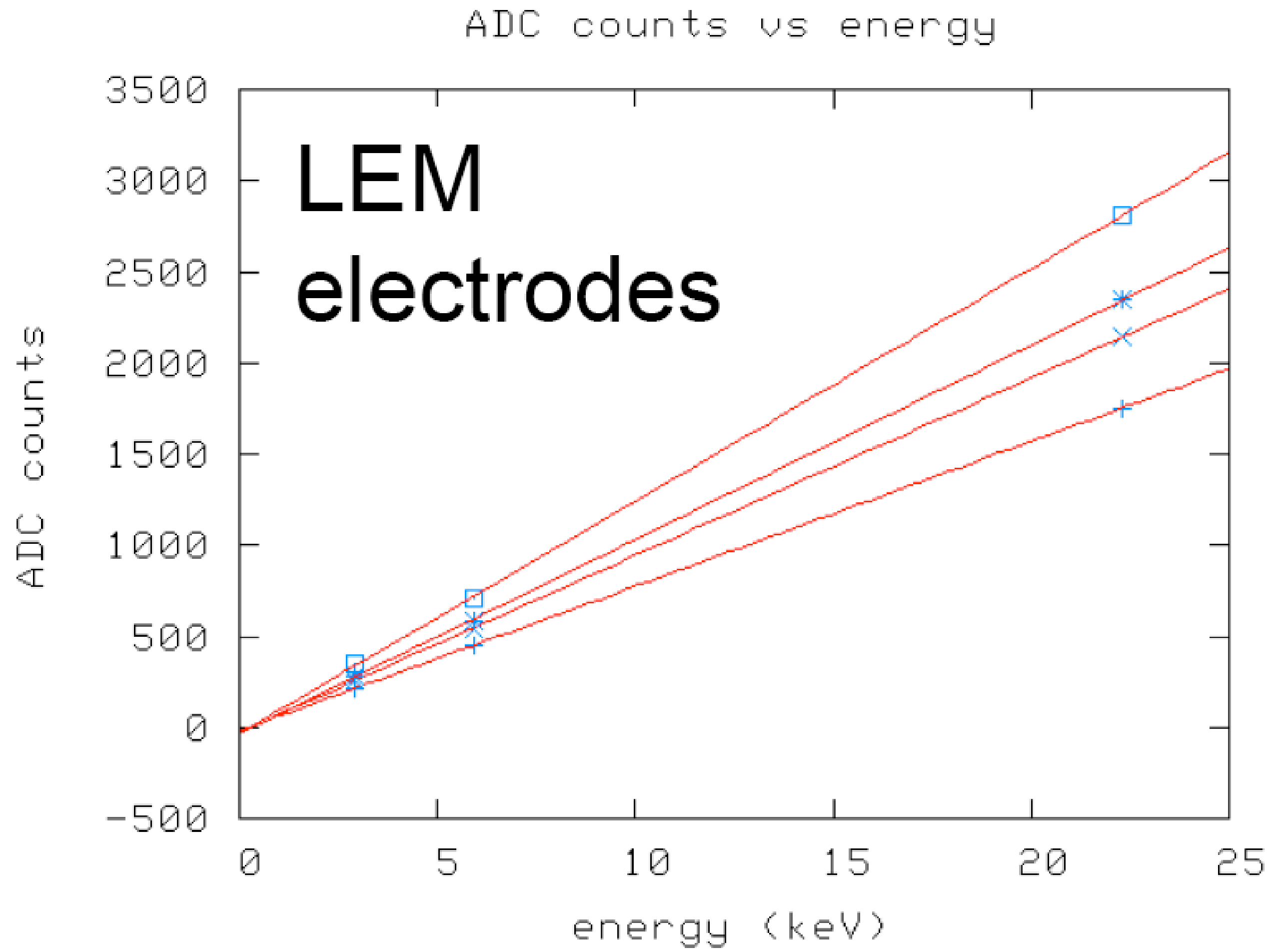
$B = 9\ 10^4 V\ cm^{-1}\ bar^{-1} \pm 4\%$

Gains (and α coefficient) consistent with values estimated with MAGBOLTZ

Linearity of detector

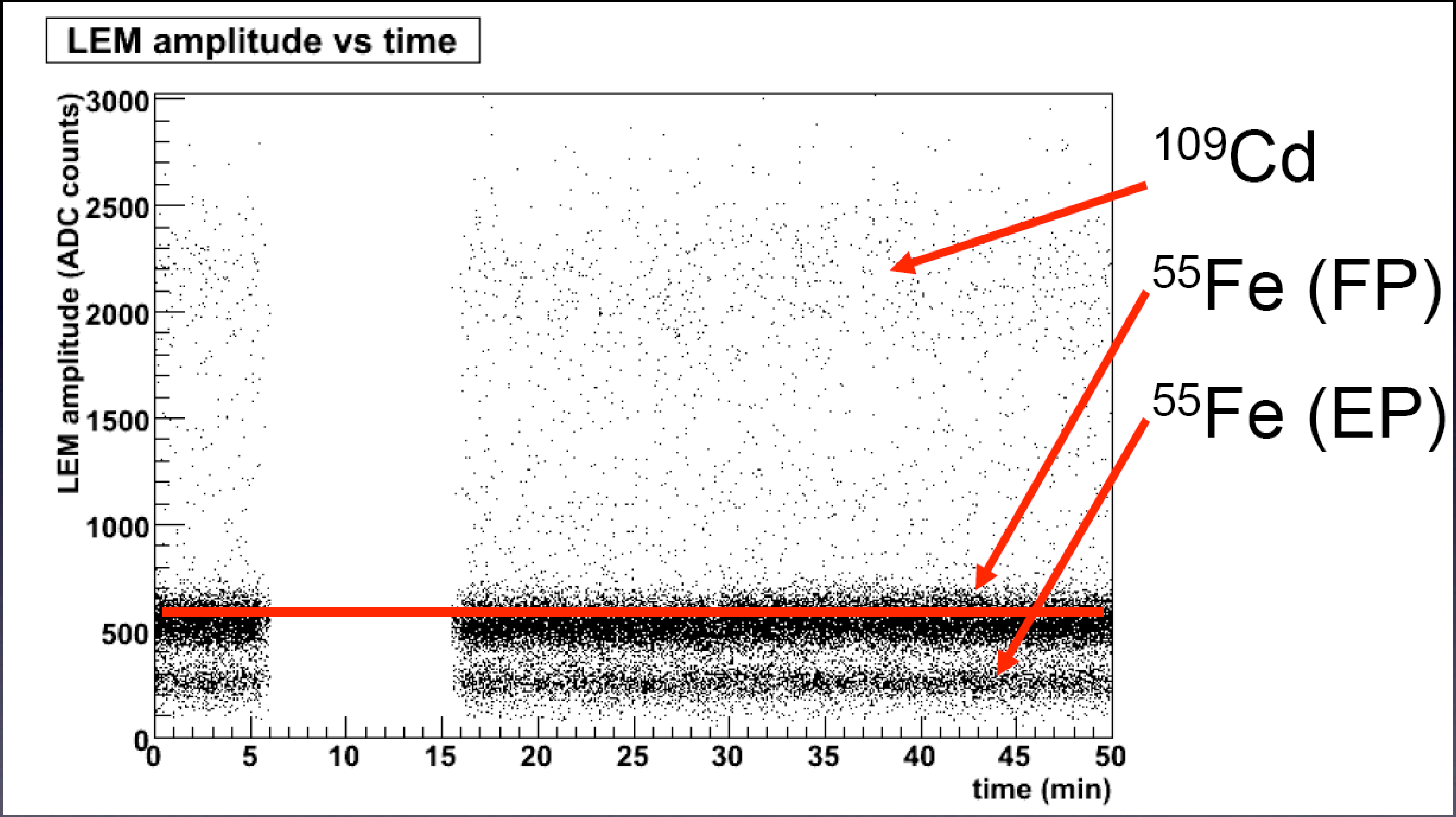
The detector linearity for different gains; both for LEM electrodes and Anode signals





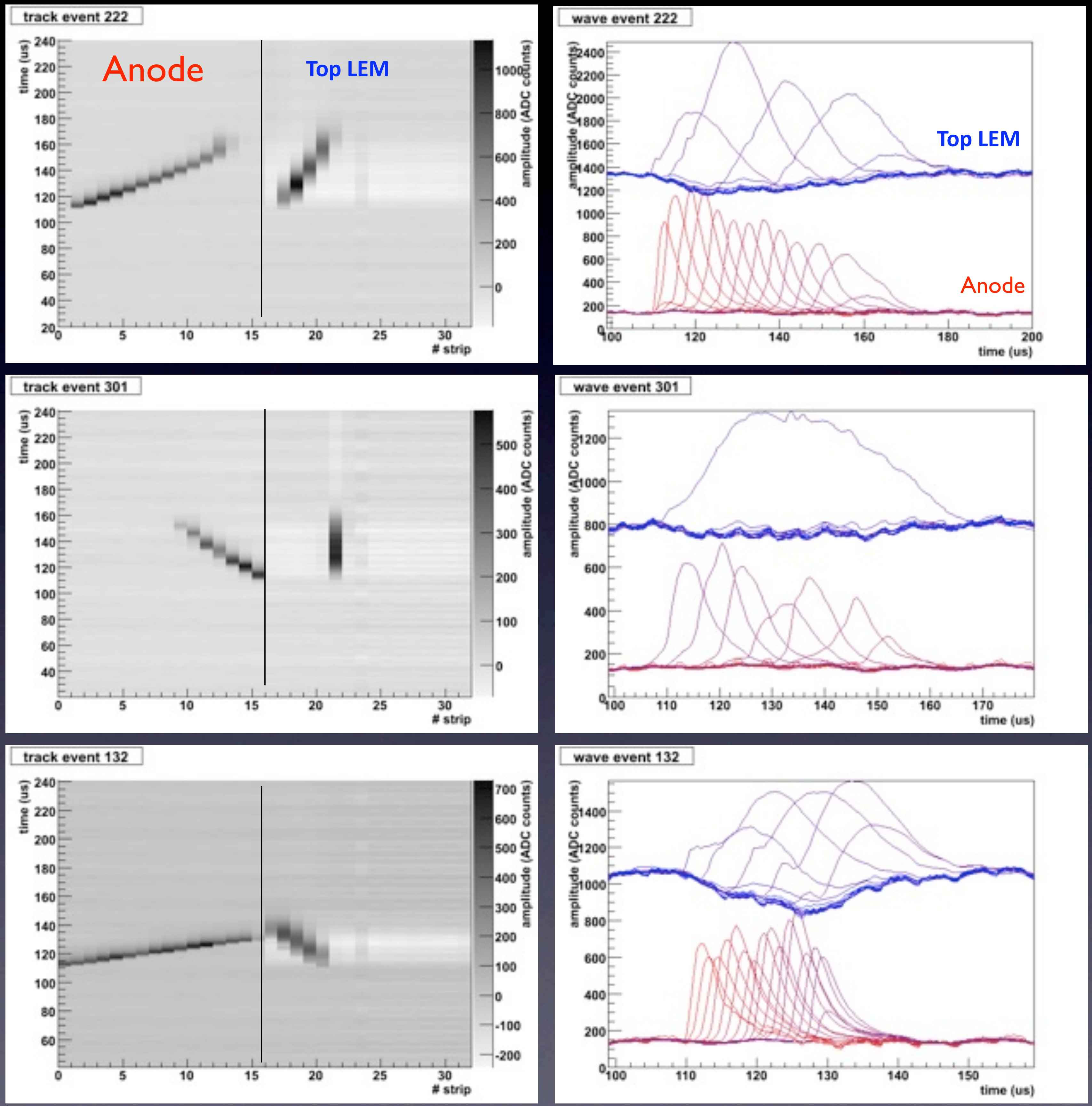
9

Stability with time



Further tests ongoing

LAr LEM TPC operation in double-phase at 87K



Proof of operation of double phase LAr LEM Time Projection Chamber as a tracking device.

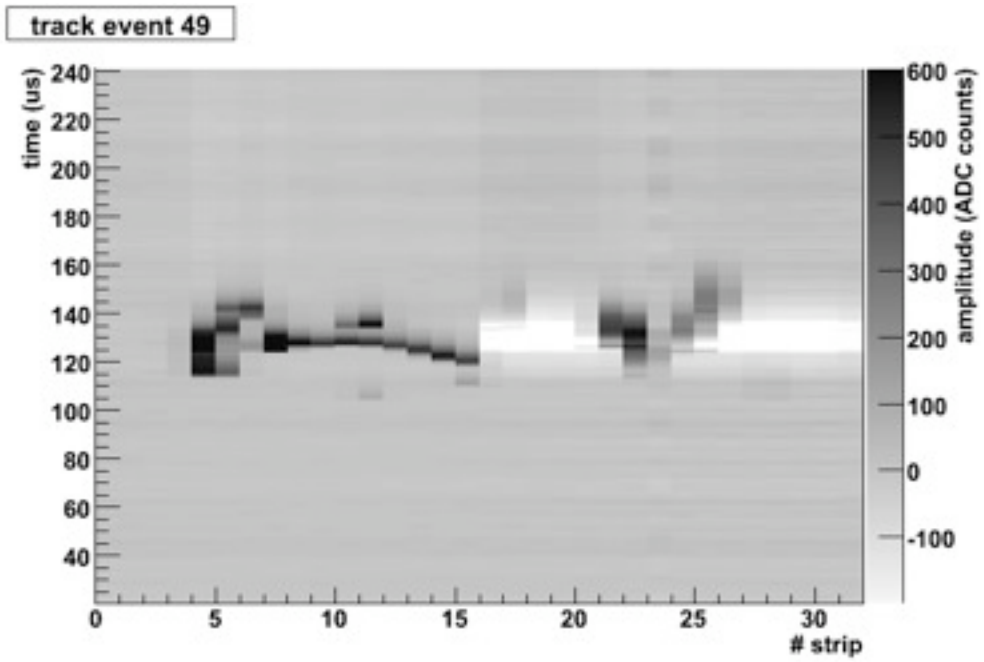
Typical cosmic ray tracks (unprocessed images)

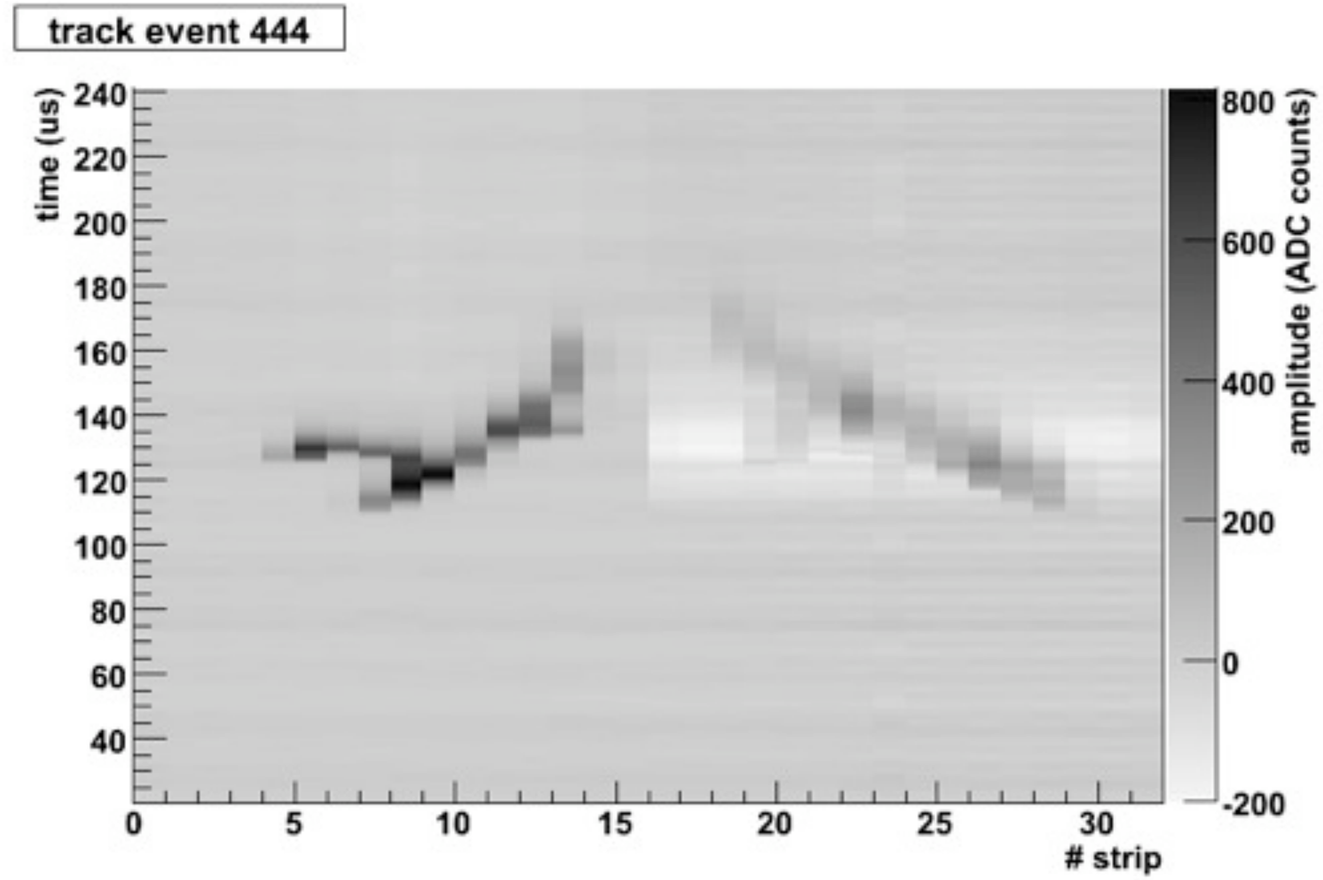
Triggered on PMT or charge signals

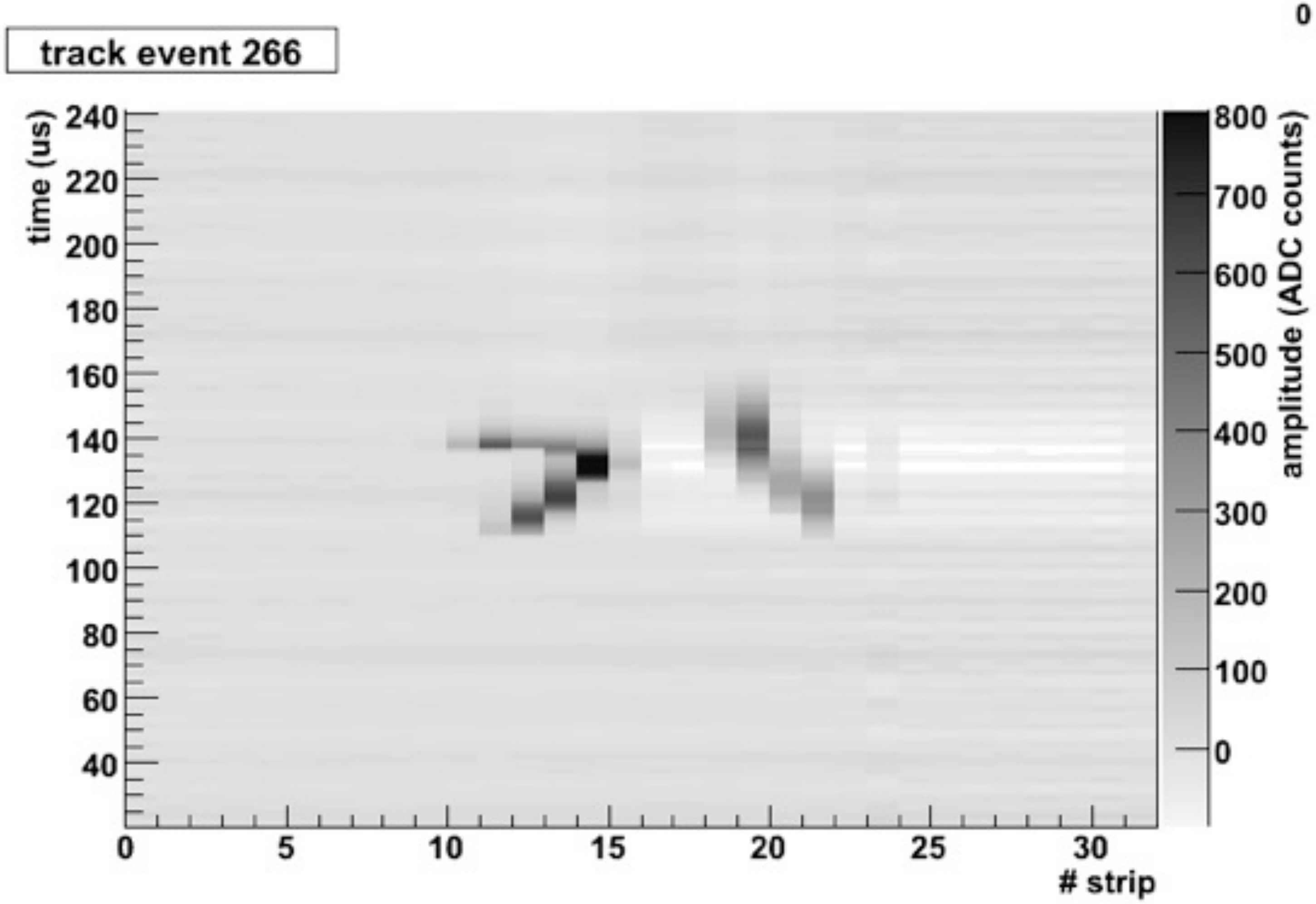
6 mm readout pitch

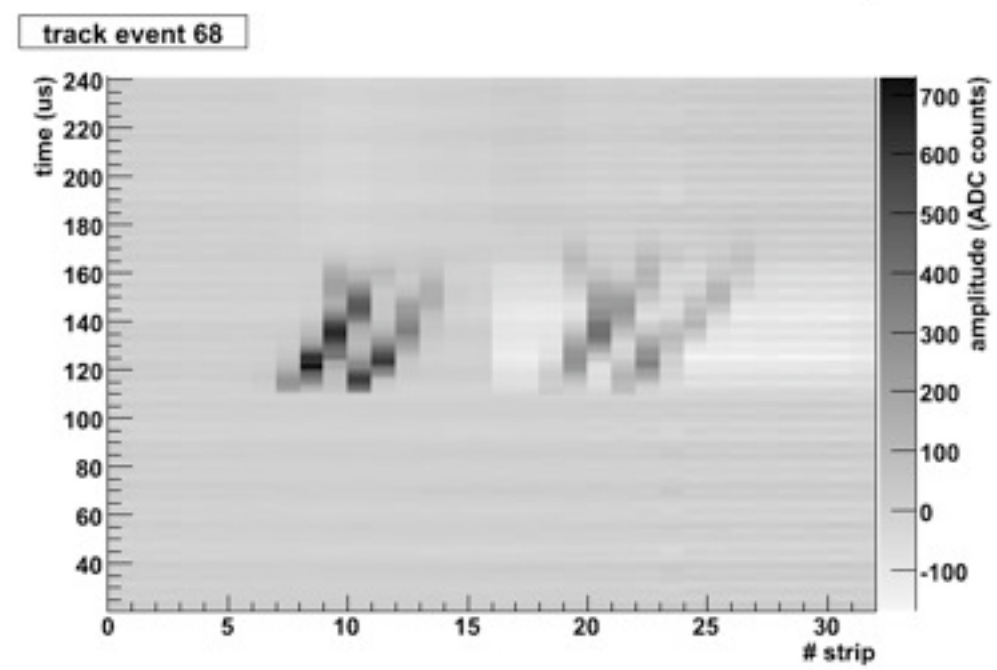
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Double phase LAr LEM-TPC cosmic events









6 mm readout pitch
(LEM with 2.7mm pitch in preparation)

Proportional light: SC & EL signals

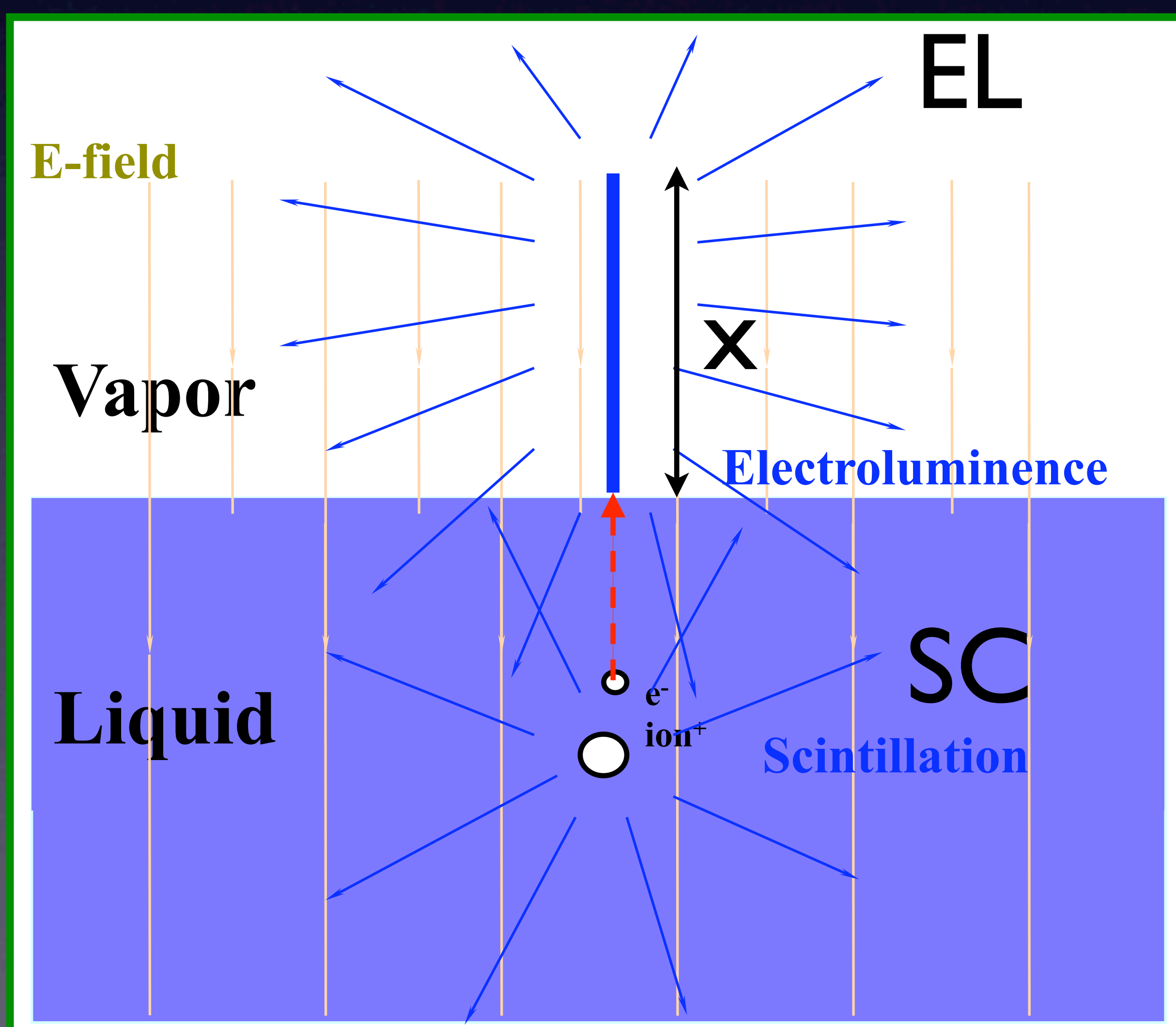
- The proportional light produced in the gas (vapor) phase is a measure of the charge drifted to the interface and extracted from the liquid.
- SC & EL signals can be detected by the same set of photodetectors

$$G_\gamma \approx \alpha\left(E/p - \varepsilon_{thresh}\right)\cdot x\cdot p$$

E=field, ε_{thresh}=threshold field, p=equiv. pressure, x=path, α=constant

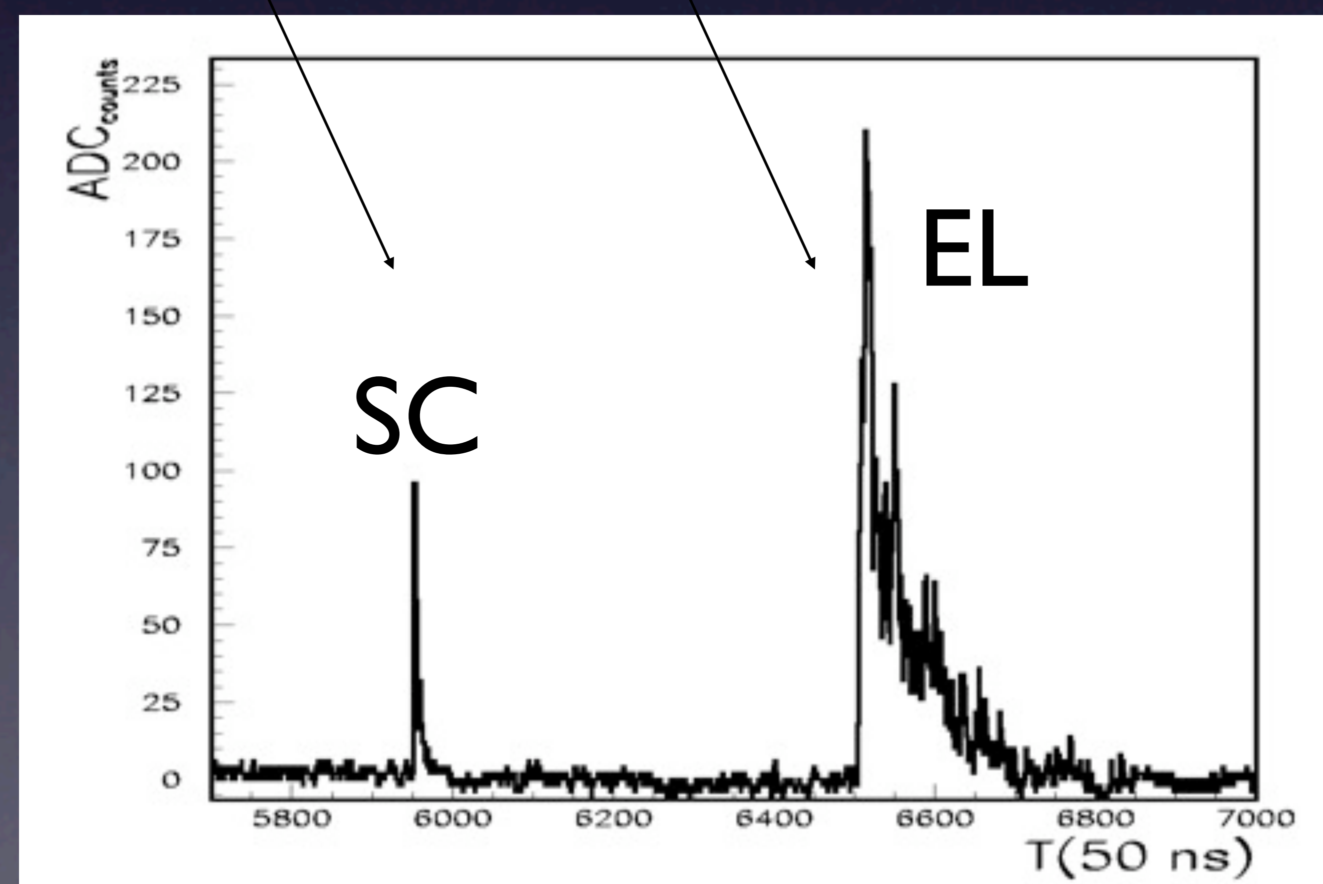
$$\alpha_{LAr} = 87\ \gamma/e \qquad \varepsilon^{LAr}_{thresh} = 0.7kV/cm/bar$$

$$\alpha_{LXe} = 70\ \gamma/e \qquad \varepsilon^{LXe}_{thresh} = 1.3kV/cm/atm$$



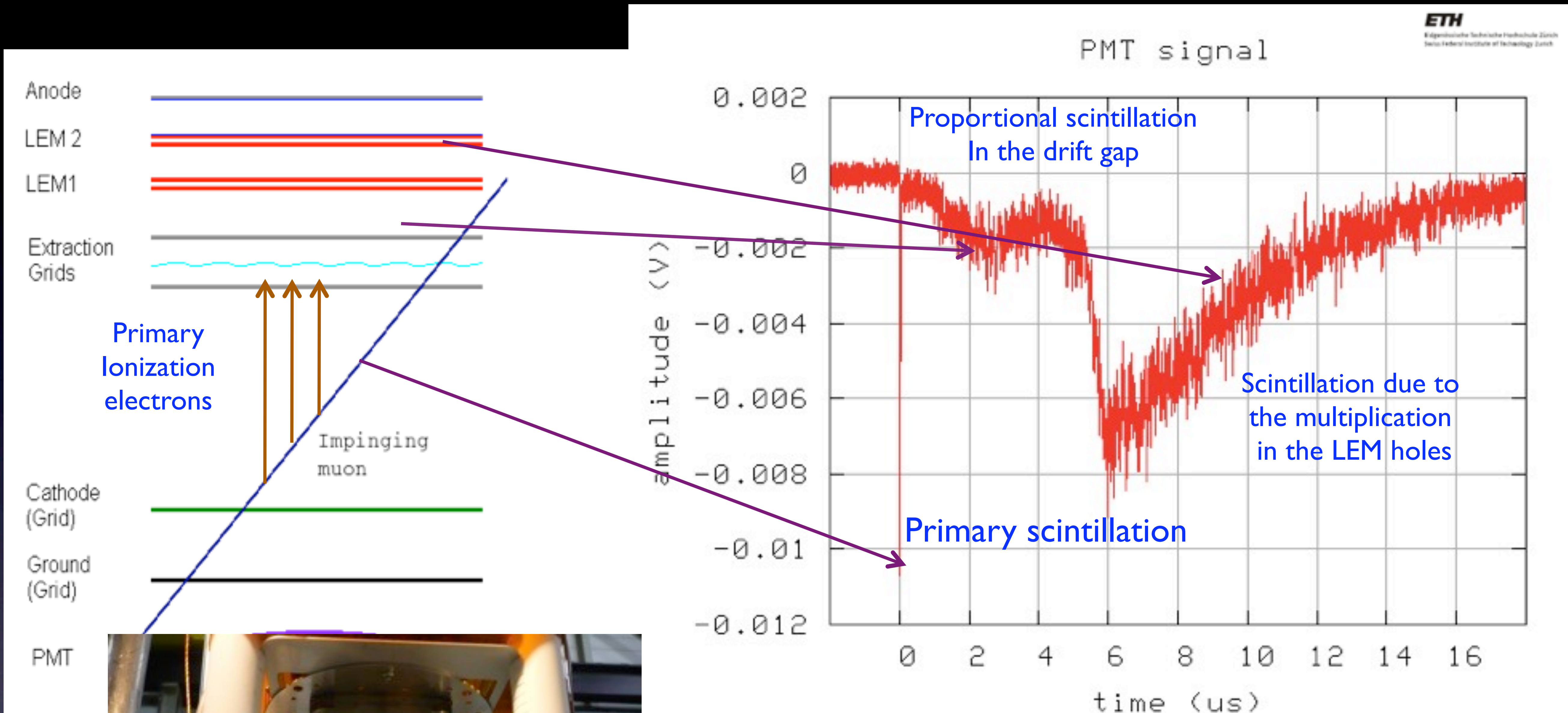
Scintillation SC is a result of:
1.Direct excitation
2.Recombination

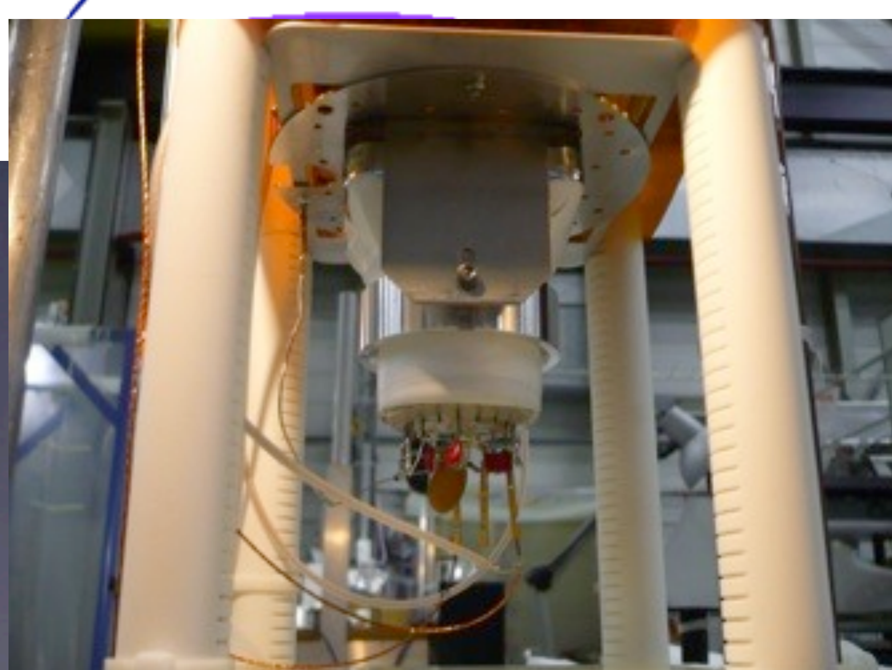
Electroluminescence EL (proportional scintillation) is a result of electron acceleration in the gas



Associated light signals in double phase

The light signal from the PMT installed in the bottom of the LEM-TPC

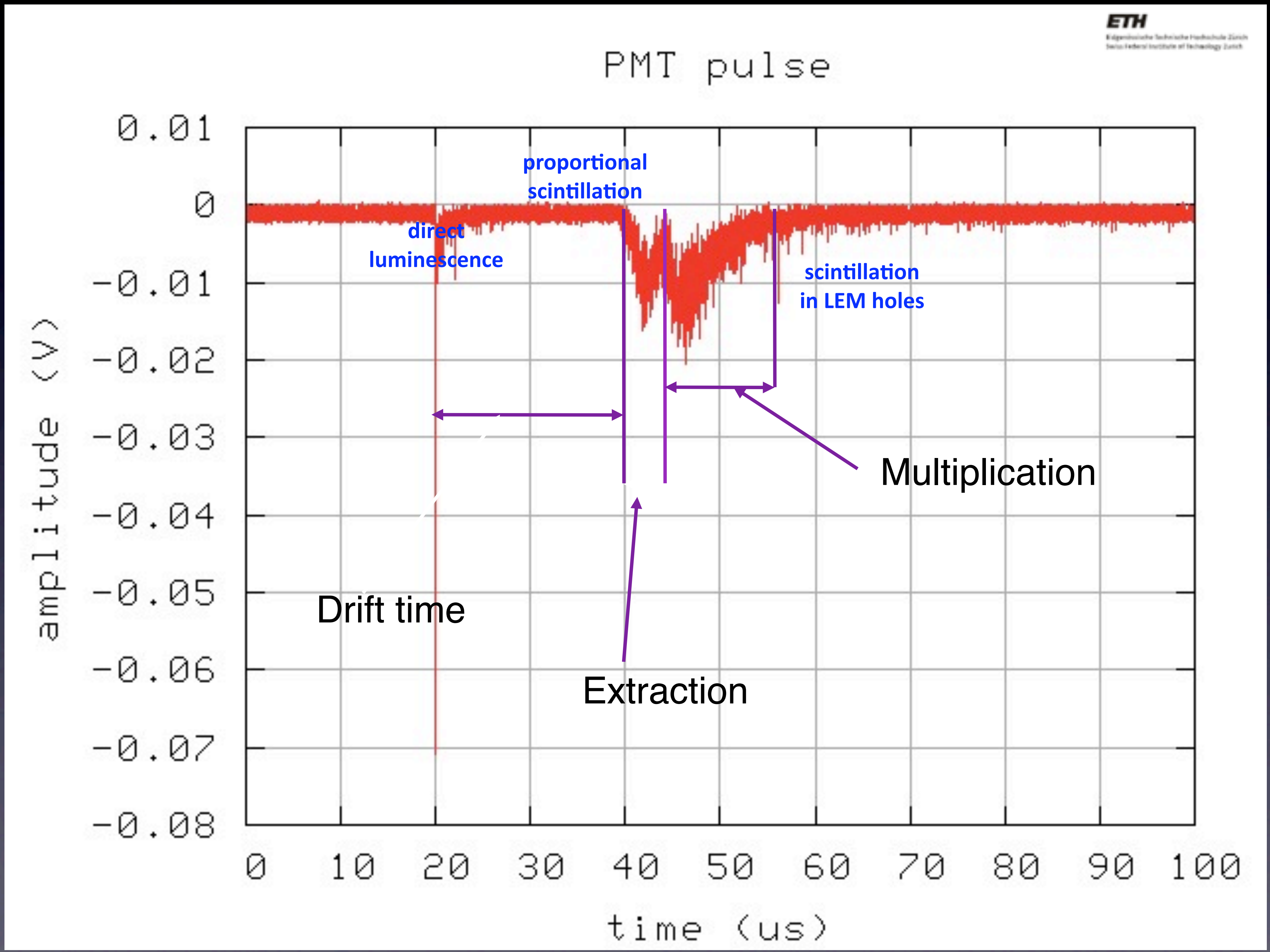




The primary, proportional and LEM-produced lights are well identifiable

Associated light signals in double phase

Typical event with finite drift time



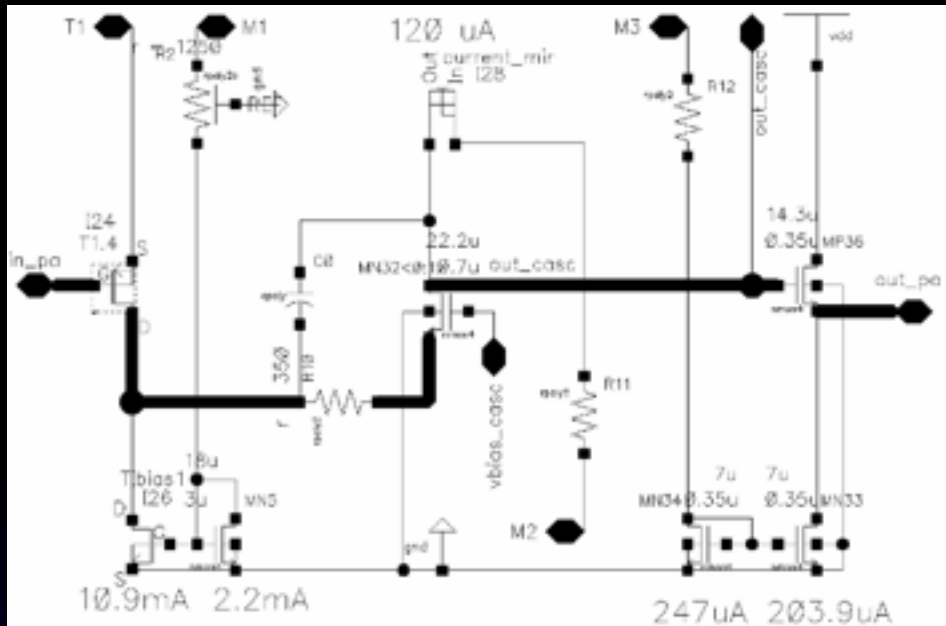
R&D on electronics integrated on the detector

IPNL Lyon in collaboration with ETHZ

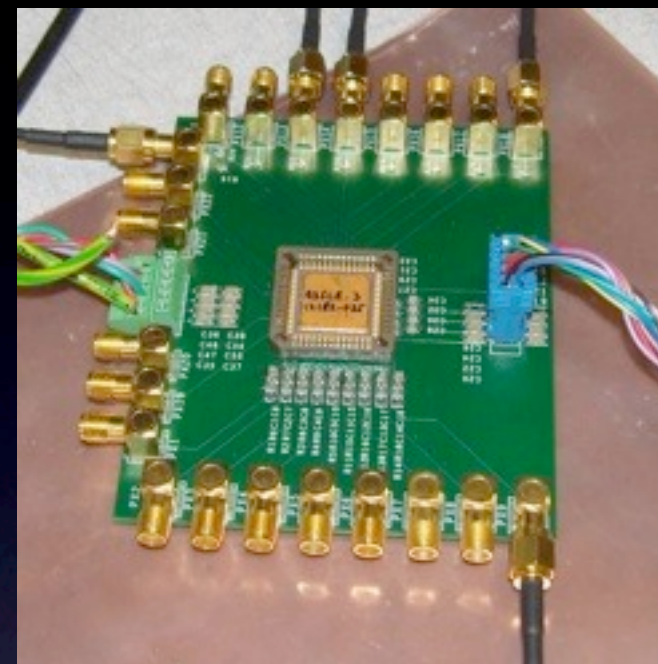
- R&D on an analog ASIC preamplifier working at cryogenic temperature
  - very large scale integration
  - low cost
  - reduction of cable capacitances

- R&D on a Gigabit Ethernet readout chain + network time distribution system PTP
  - further development of the OPERA DAQ, with larger integration, gigabit ethernet, reduced costs
  - implementation in just one inexpensive FPGA of the capabilities provided by the OPERA 'mezzanine' card
  - **continuous and auto-triggerable readout**
  - synchronization and **event time stamp** on each sensor with an accuracy of 1 ns

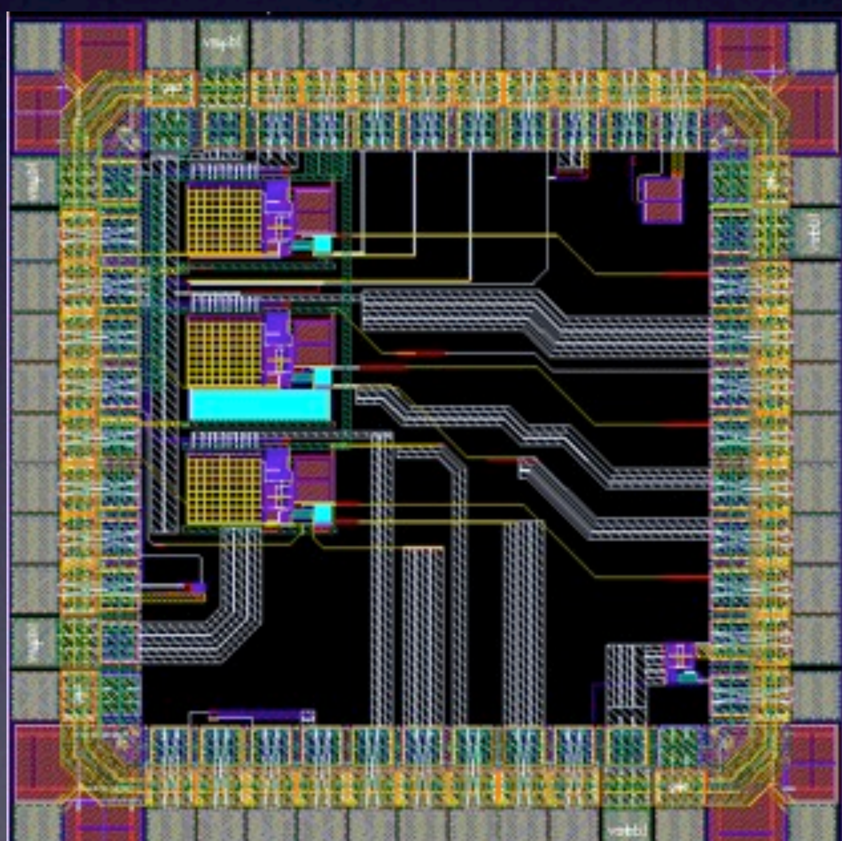
0.35μm CMOS charge amplifier



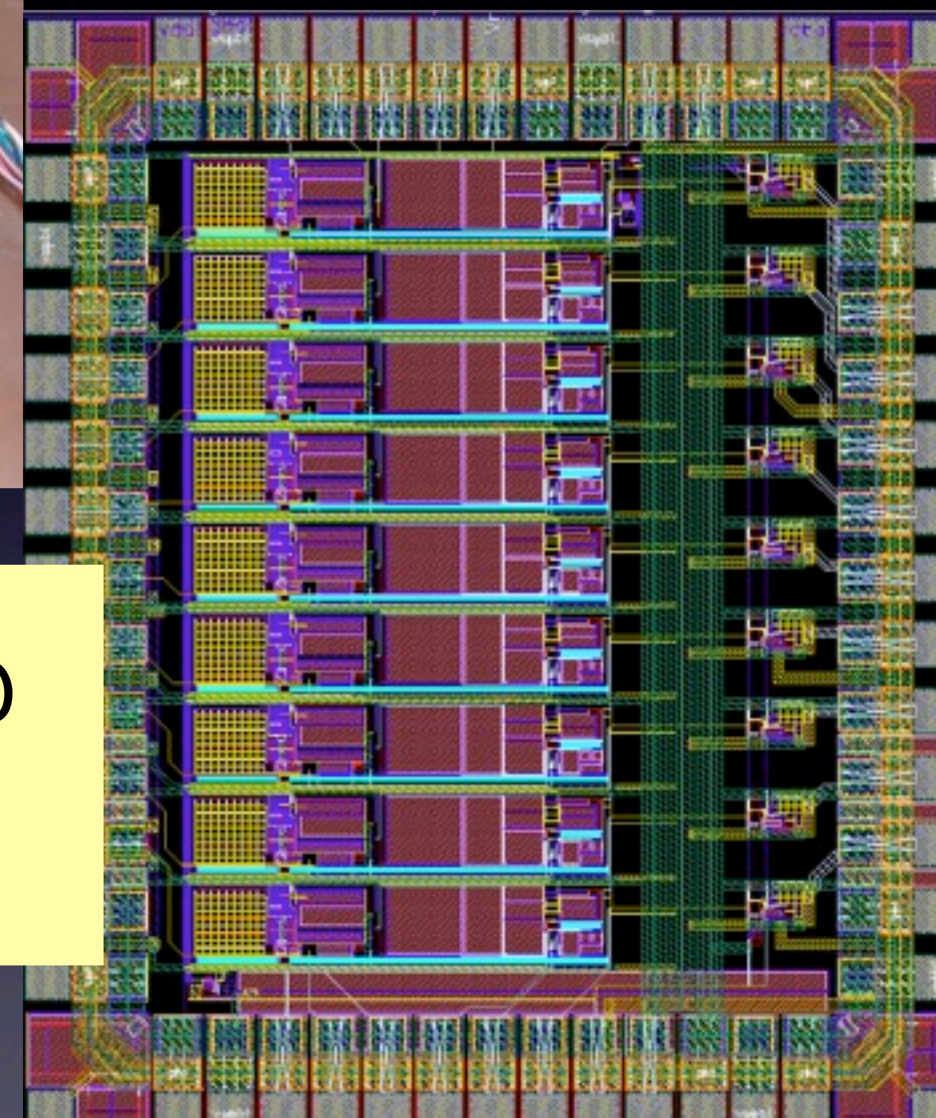
delivered in July 2008



First test (characterization of the components,...)



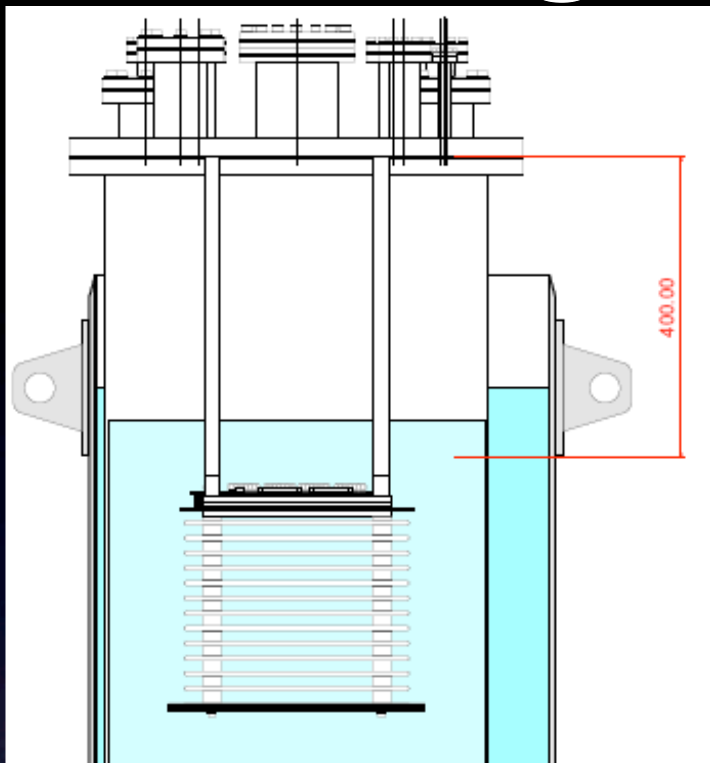
selectable feedback capacitance (500 fF-1 pf) and resistor (2 – 10 MΩ) selectable shaping times (0.5 – 4 μs range)



to be tested on the LEM-TPC setup integrated with IPNL DAQ

E. Bechetoille , H. Mathez, IPNL Lyon
Proceedings of Wolte-08, June 2008

Single phase LAr TPC (Bern)

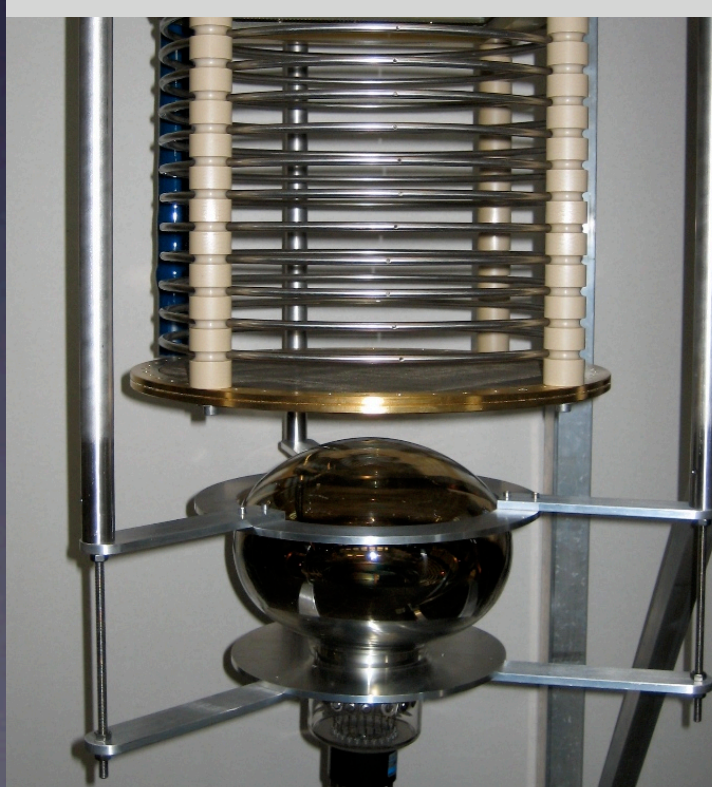


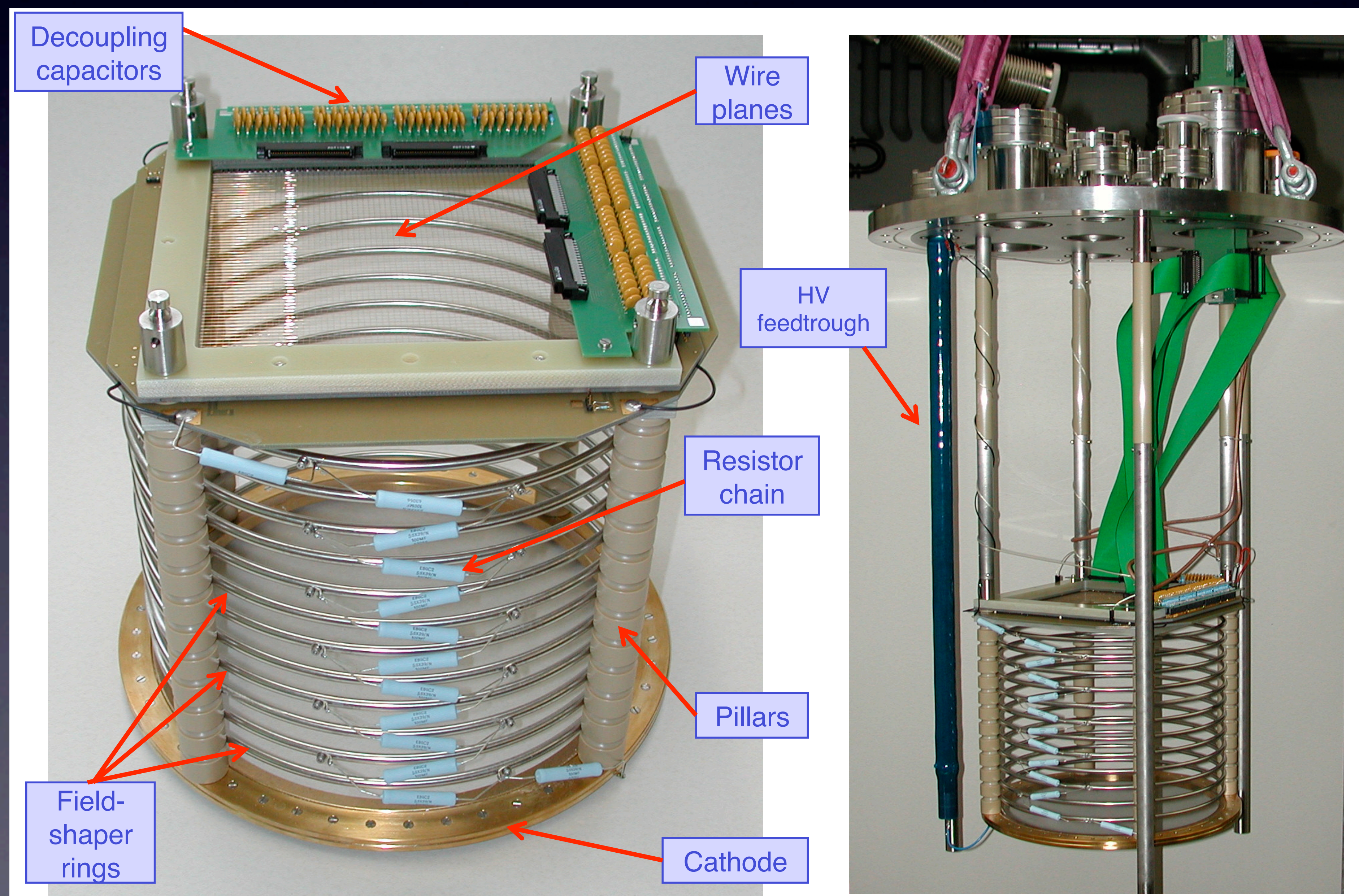
Single phase LAr TPC based on wires

Wire plane 20x20 cm^2, 128 wires, up to 90cm drift length

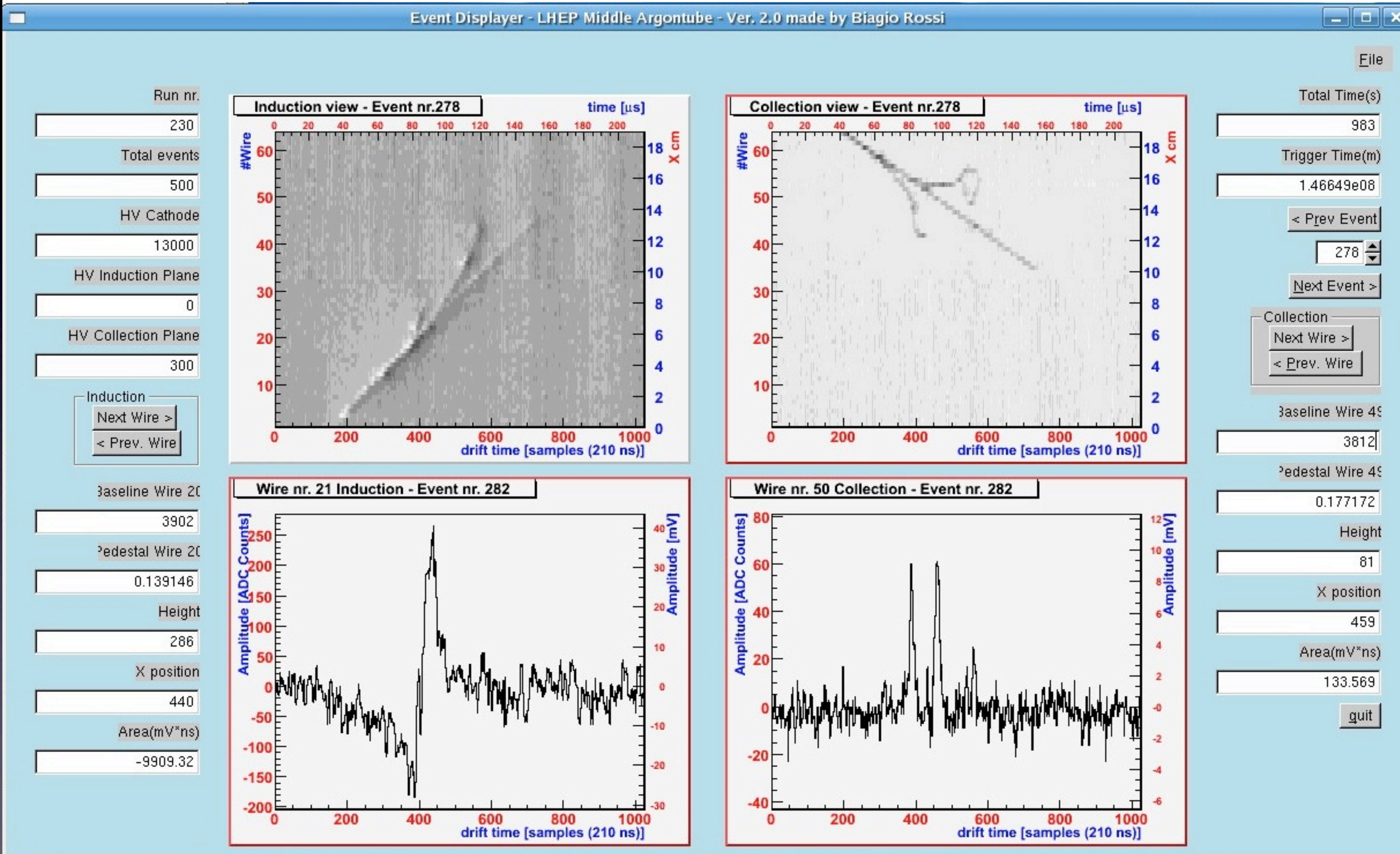
Active volume: up to 36 liters (50kg)

Immersed 8” PMT





Single phase LAr TPC



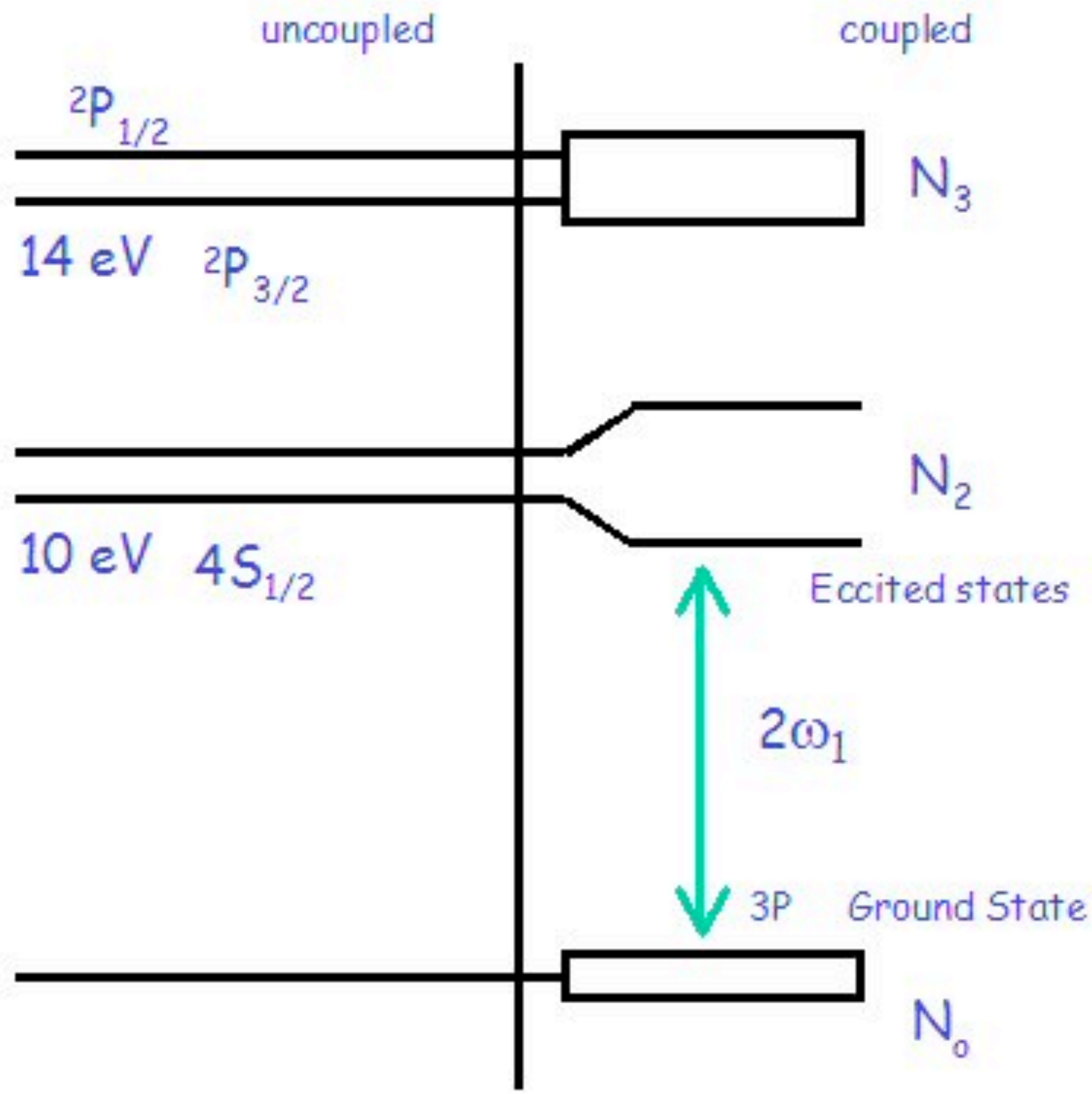
Calibration with Laser

gas | liquid

$I_g = 15.76$ eV $\xrightarrow{\Delta E}$ $I_l \cong 14$ eV

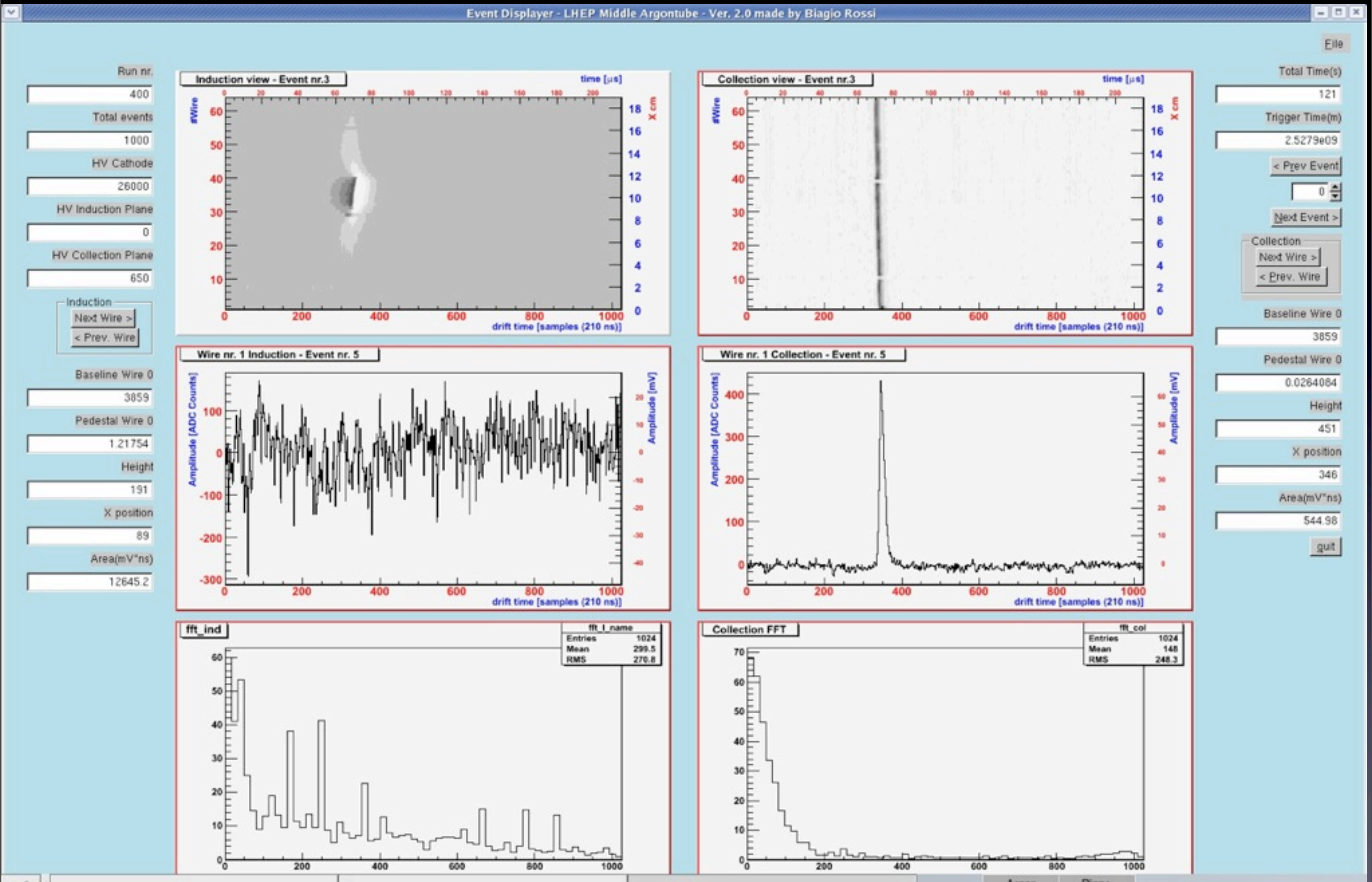
$I_g = 11.72$ eV $\xrightarrow{\Delta E}$ $I_l \cong 9.96$ eV

$E_{ph} = 4.67$ eV $\Longrightarrow 2\omega_1 = 9.34$ eV



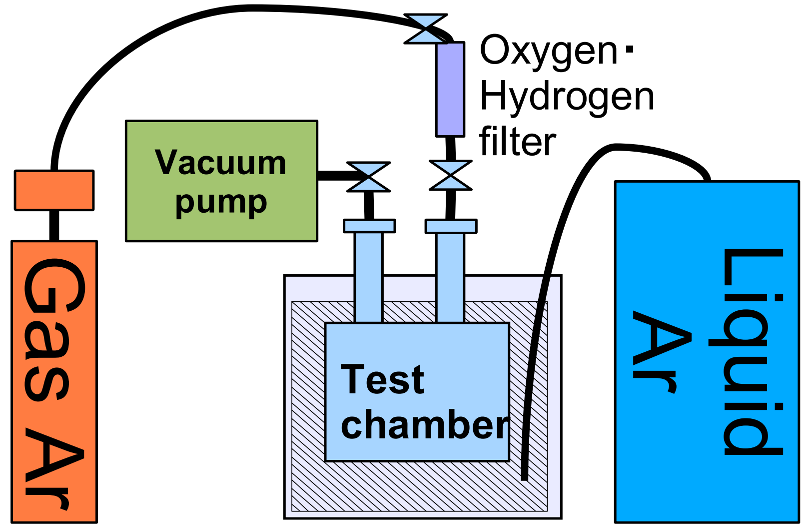
Liquid Argon atoms energy level sketch

LHEP Nd-YAG pulsed laser
4^{th} armonic wavelenght = 266 nm
4^{th} armonic energy E_γ=4.67eV
Intensity up to 10^7W/cm^2

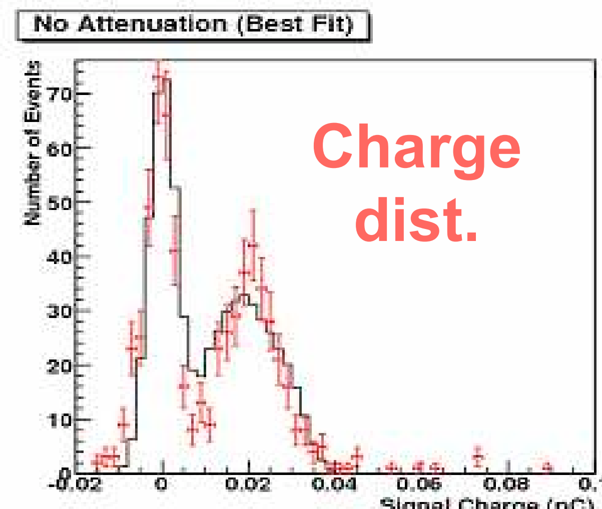


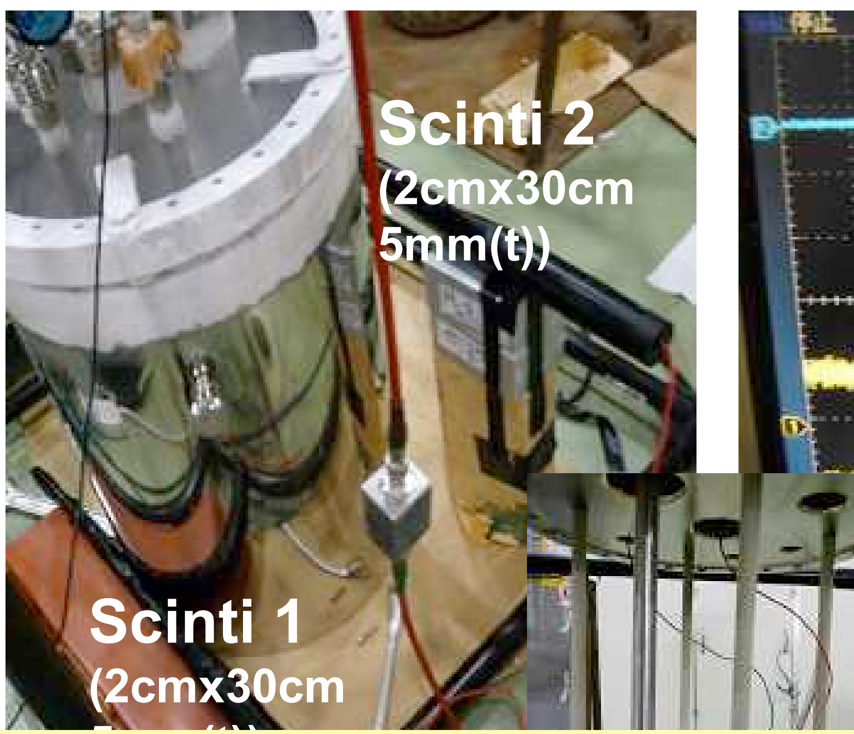
Event Displayer - LHEP Middle Argontube - Ver. 2.0 made by Biagio Rossi
Run nr.
400
Total events
1000
HV Cathode
26000
HV Induction Plane
0
HV Collection Plane
650
Induction
Next Wire >
< Prev. Wire
Baseline Wire 0
3859
Pedestal Wire 0
1.21754
Height
191
X position
89
Area(mV*ns)
12645.2
Induction view - Event nr.3
Collection view - Event nr.3
Wire nr. 1 Induction - Event nr. 5
Wire nr. 1 Collection - Event nr. 5
fft_ind
Collection FFT
drift time [samples (210 ns)]
Amplitude [ADC Counts]
Amplitude [mV]
Total Time(s)
121
Trigger Time(m)
2.5279e09
< Prev Event
Next Event >
Collection
Next Wire >
< Prev. Wire
Baseline Wire 0
3859
Pedestal Wire 0
0.0264084
Height
451
X position
346
Area(mV*ns)
544.98
quit

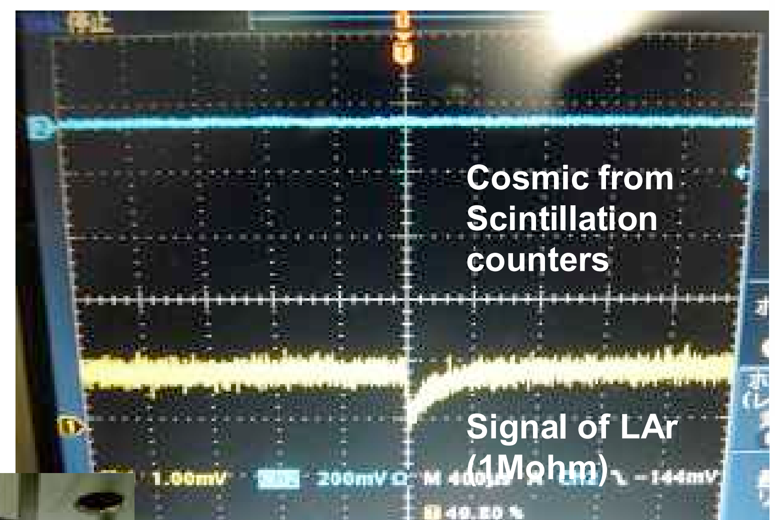
Liquid Argon R&D stand @ KEK

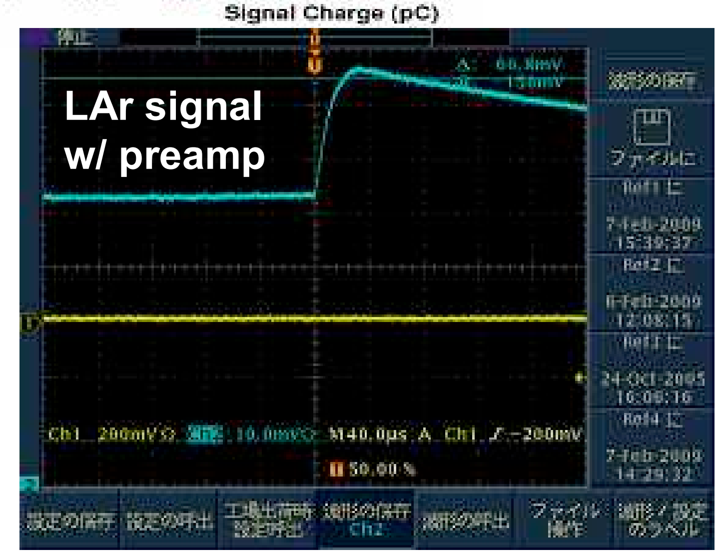


$O_2 < 0.2$ppm









- Operation of a 10L test chamber
  - Successfully observed cosmic muons for ~20 hours without major degradation of the signal
  - Comparison of the signal charge between data and MC prediction consistent with good liquid Argon purity (<10 ppb)

Towards ton-scale double phase LAr LEM-TPCs

The ArDM project
(CERN RE18)

A. Badertscher, U. Degunda, L. Epprecht, S. Horikawa, L. Kaufmann, L. Knecht, M. Laffranchi, D. Lussi, C. Lazzaro, A. Marchionni, G. Natterer, F. Resnati, A. Rubbia*, T. Strauss, J. Ulbricht, T. Viant
ETH Zurich, Switzerland

C. Amsler, V. Boccone, H. Cabrera, W. Creus, P. Otyugova, C. Regenfus, J. Rochet
Zurich University, Switzerland

A. Bueno, M.C. Carmona-Benitez, J. Lozano, A. J. Melgarejo, S. Navas-Concha
University of Granada, Spain

M. Daniel, M. De Padro, L. Romero
CIEMAT, Spain

P. Mijakowski, P. Przewlocki, E. Rondio
Soltan Institute Warszawa, Poland

E.J. Daw, P. Lightfoot, K. Mavrokoridis, M. Robinson, N. Spooner
University of Sheffield, England

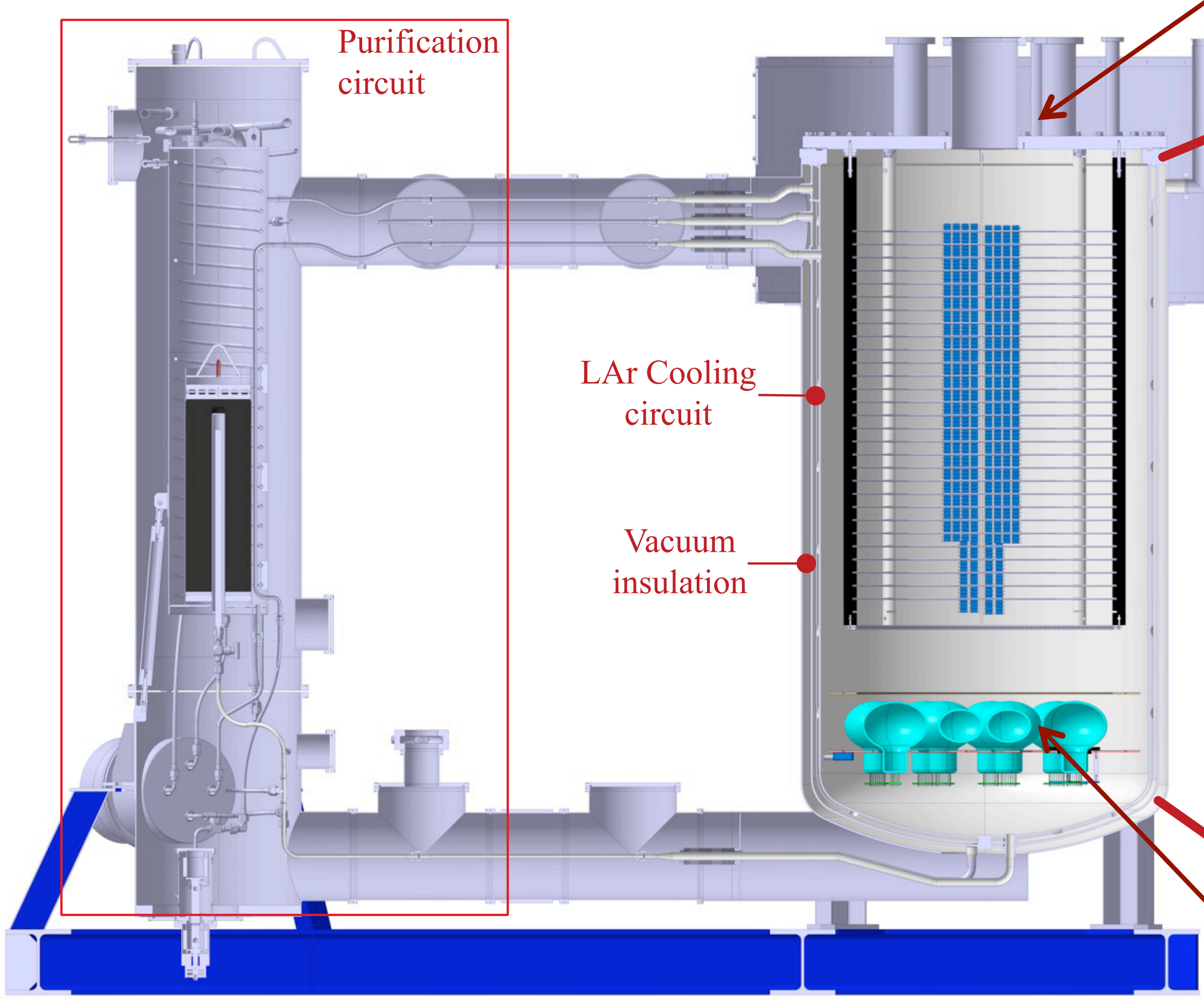
* Contact person

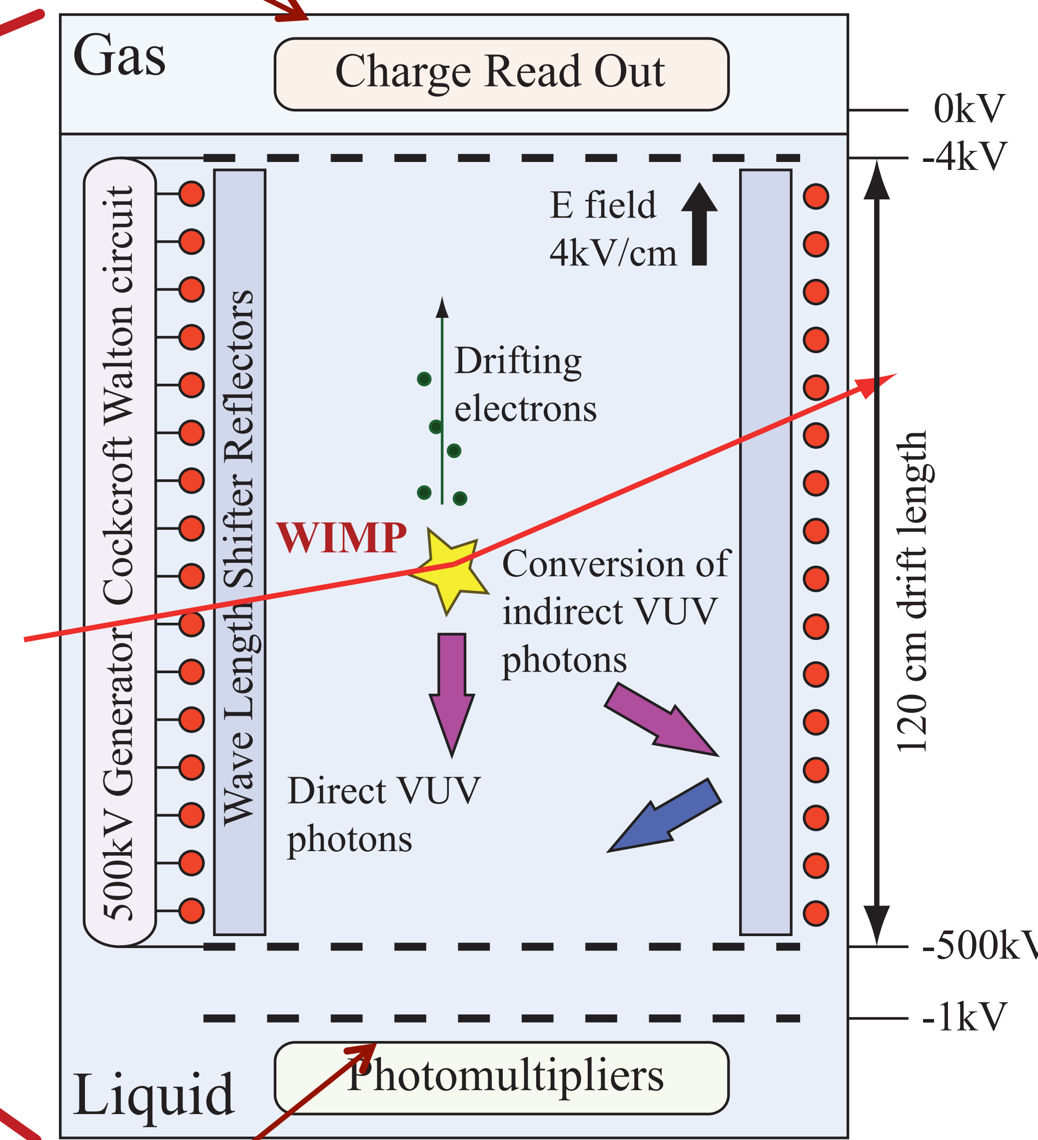
General layout of ArDM

- Cylindrical volume, drift length ≈ 120 cm
- 850 kg target
- Drift field ≈ 1 to 4 kV/cm

Ionization readout

Gain ➡ 10^3



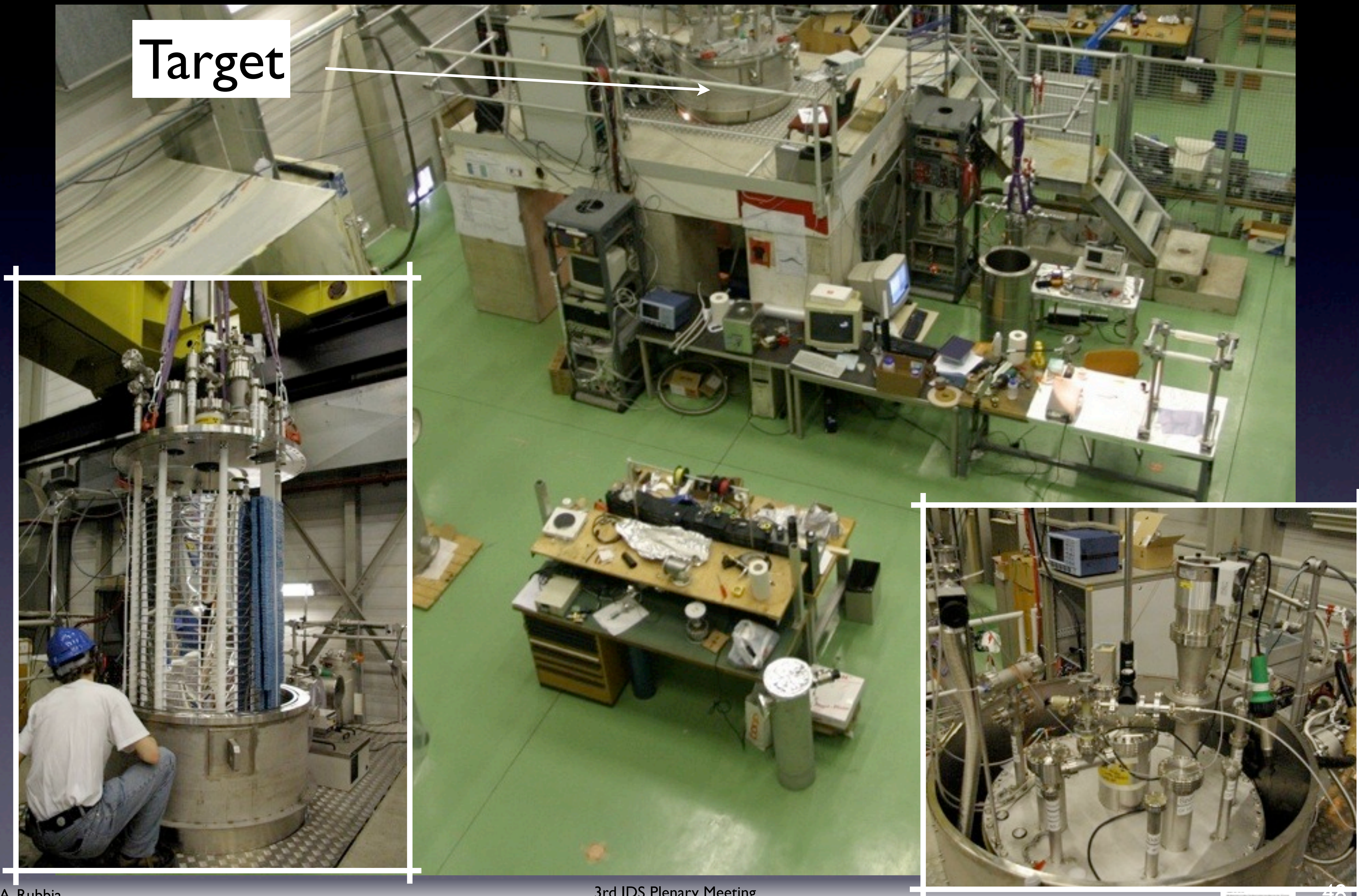


1-2% collection

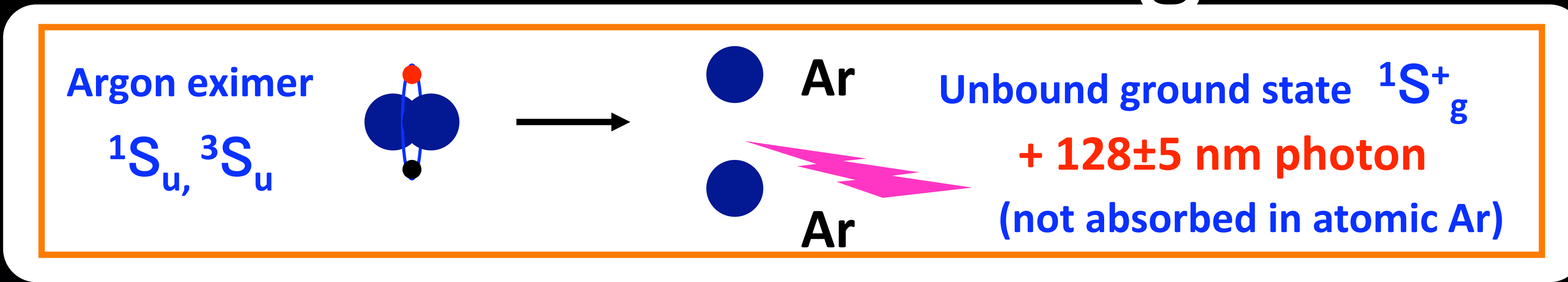
A.Rubbia, "ArDM: a Ton-scale liquid Argon experiment for direct detectionof dark matter in the universe", J. Phys. Conf. Ser. 39 (2006) 129

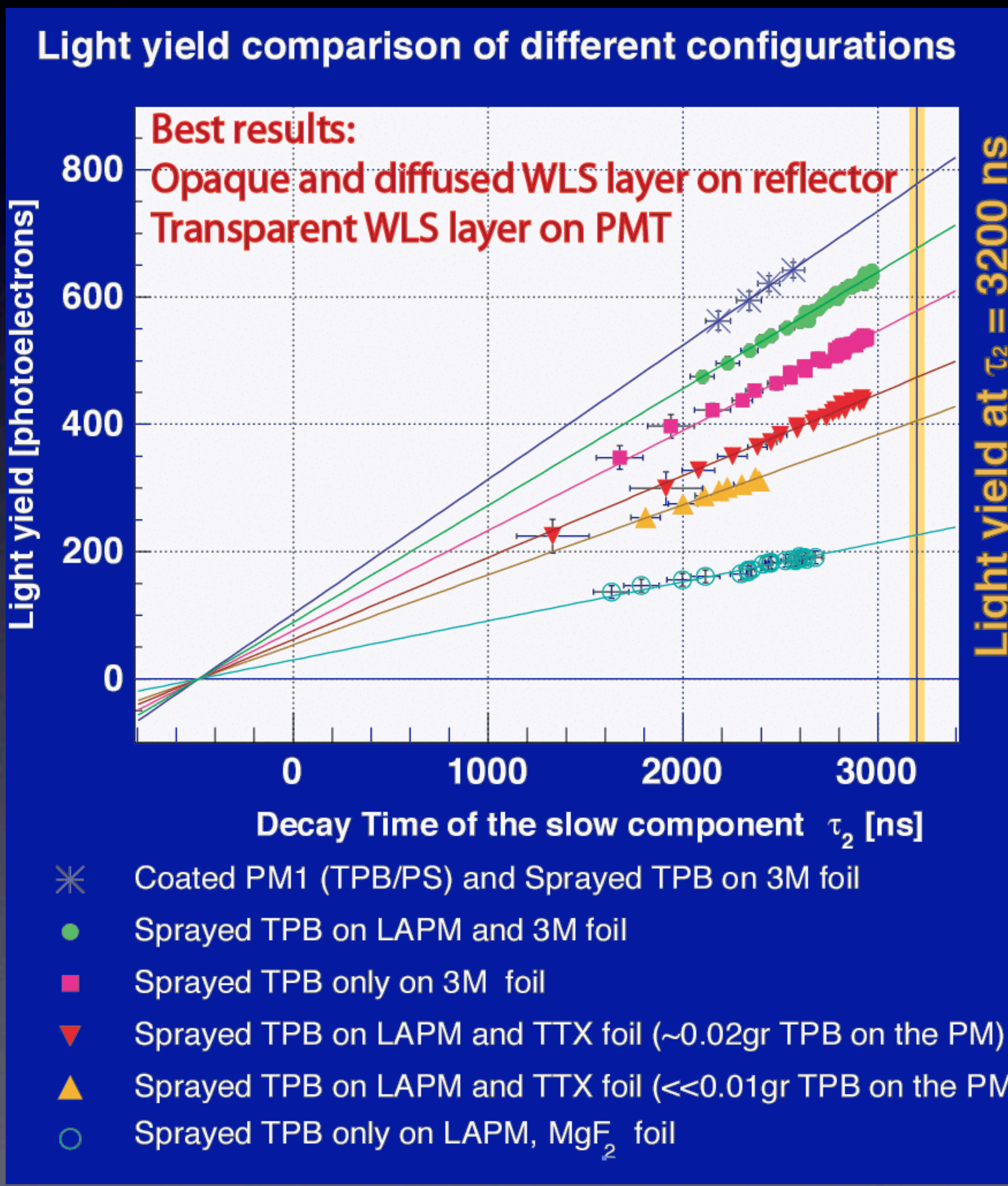
Light readout

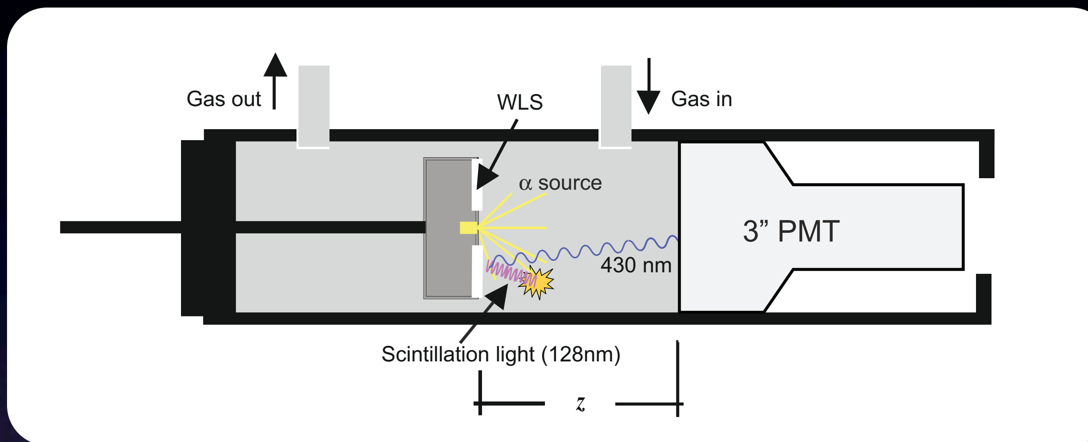
ArDM-1t in operation at CERN

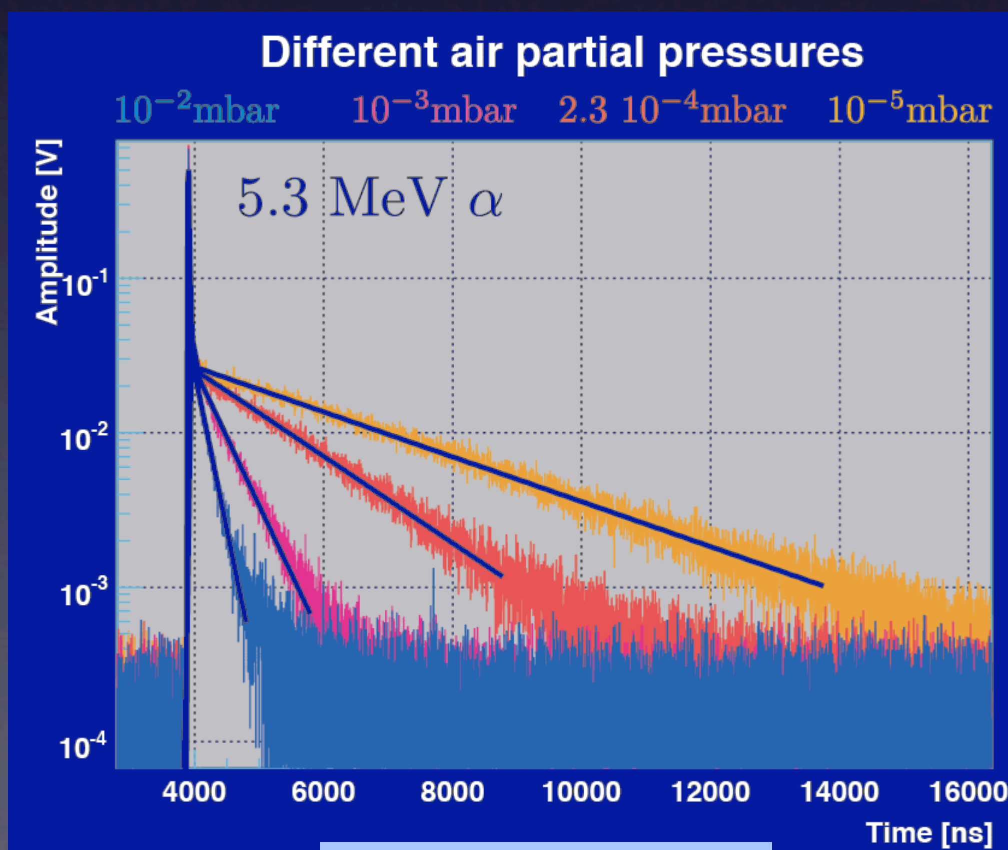


Light readout: wave-length shifters



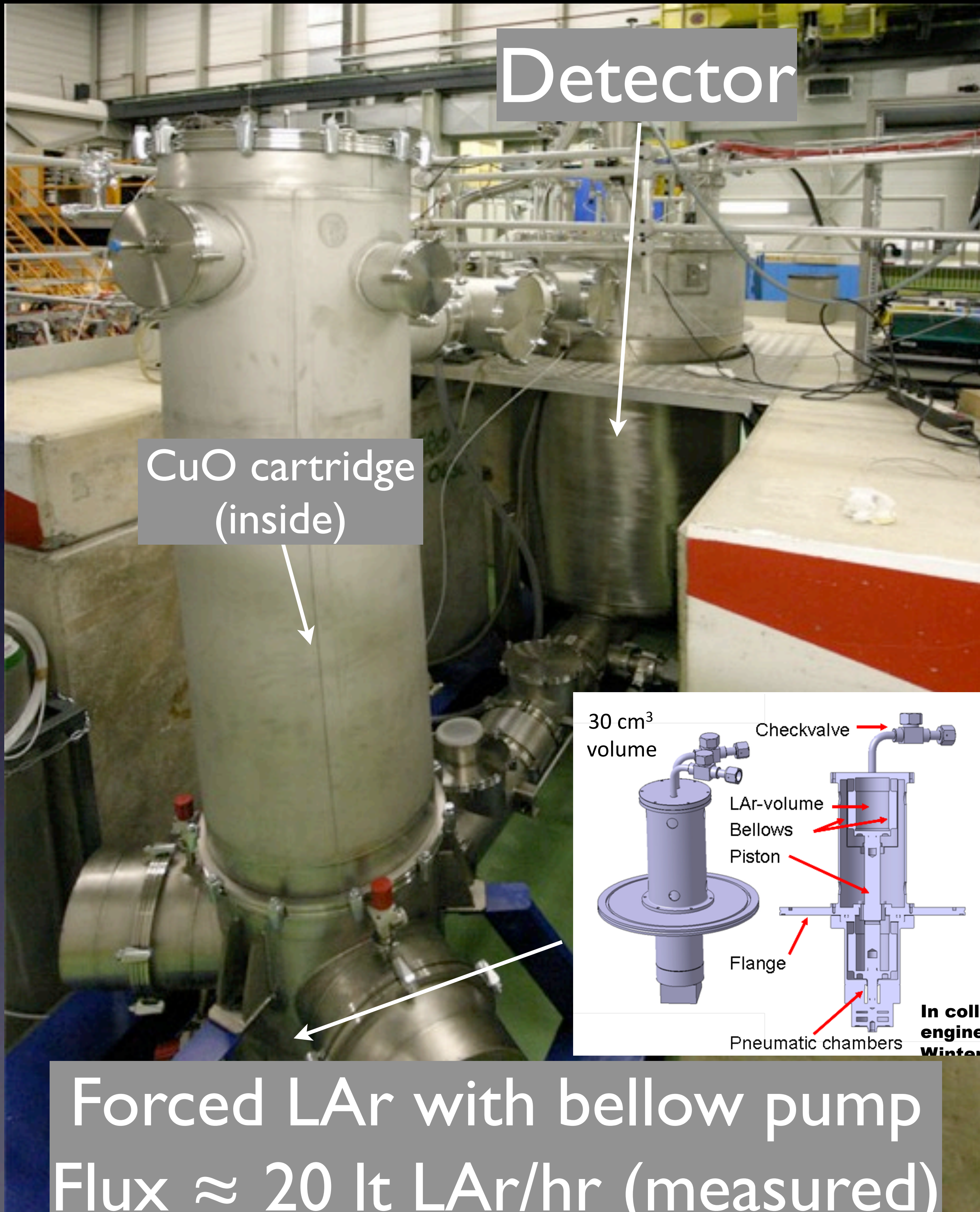


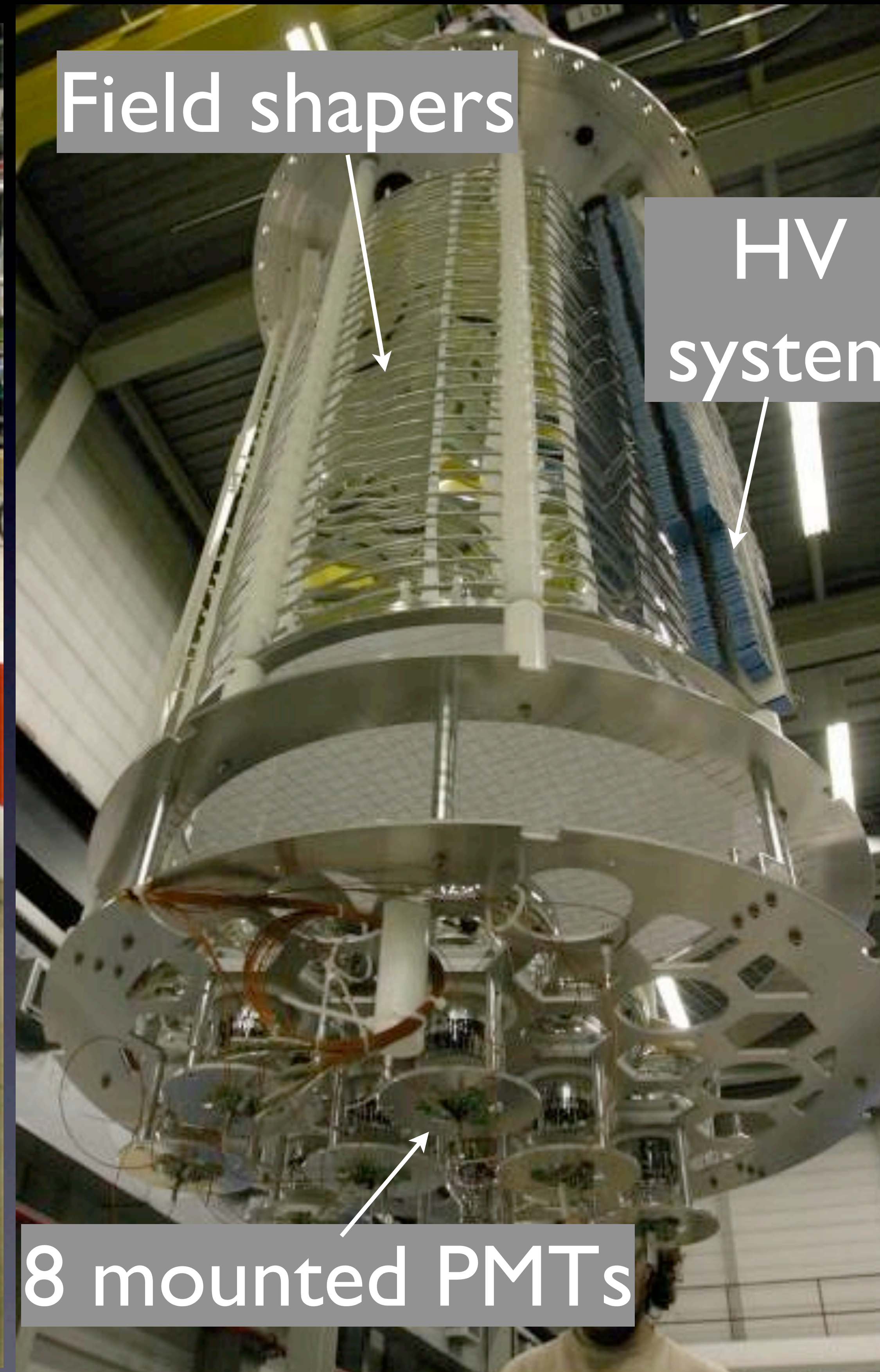




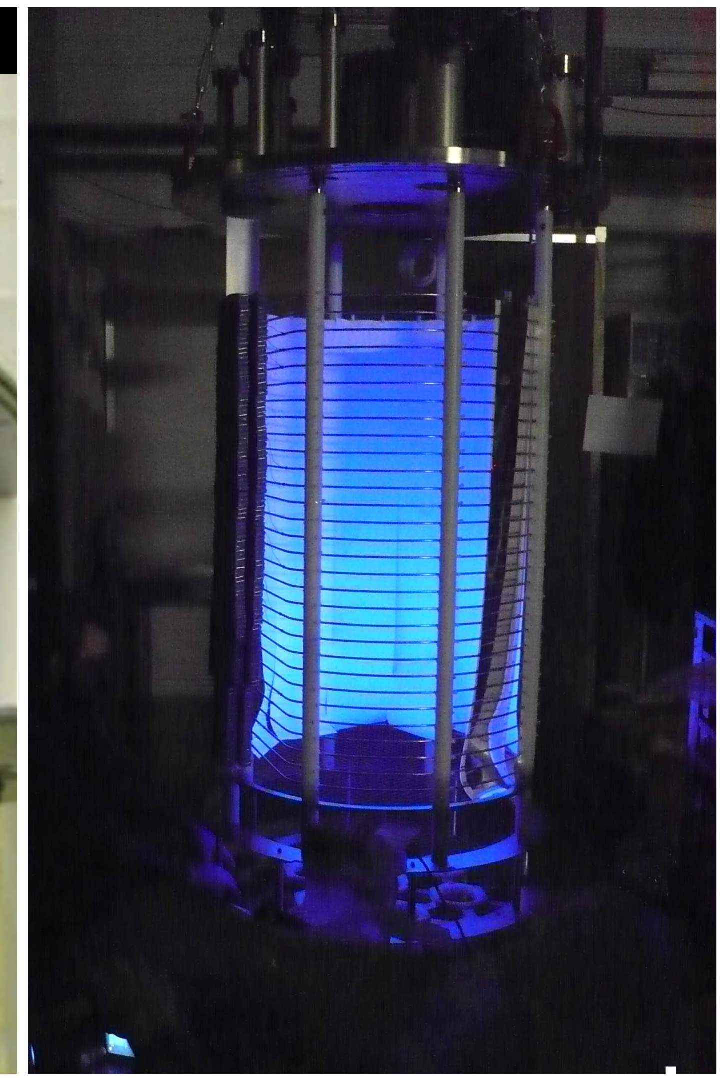
arXiv:0708.2621

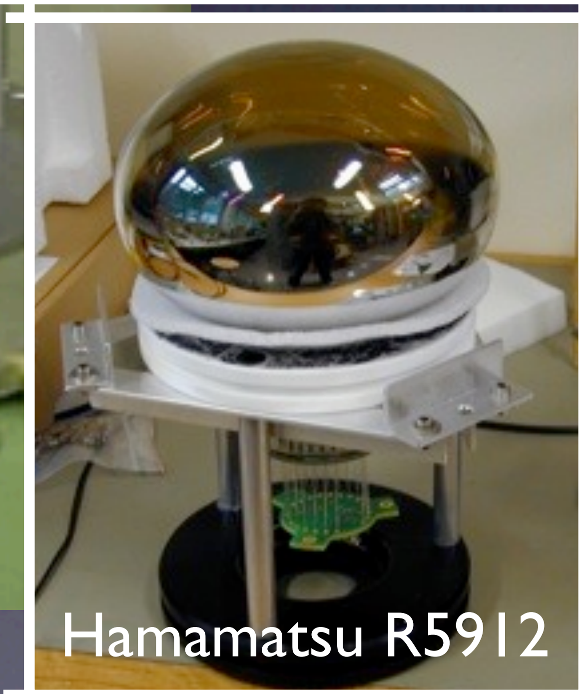
The ArDM-1t assembly at CERN





The assembled light readout system



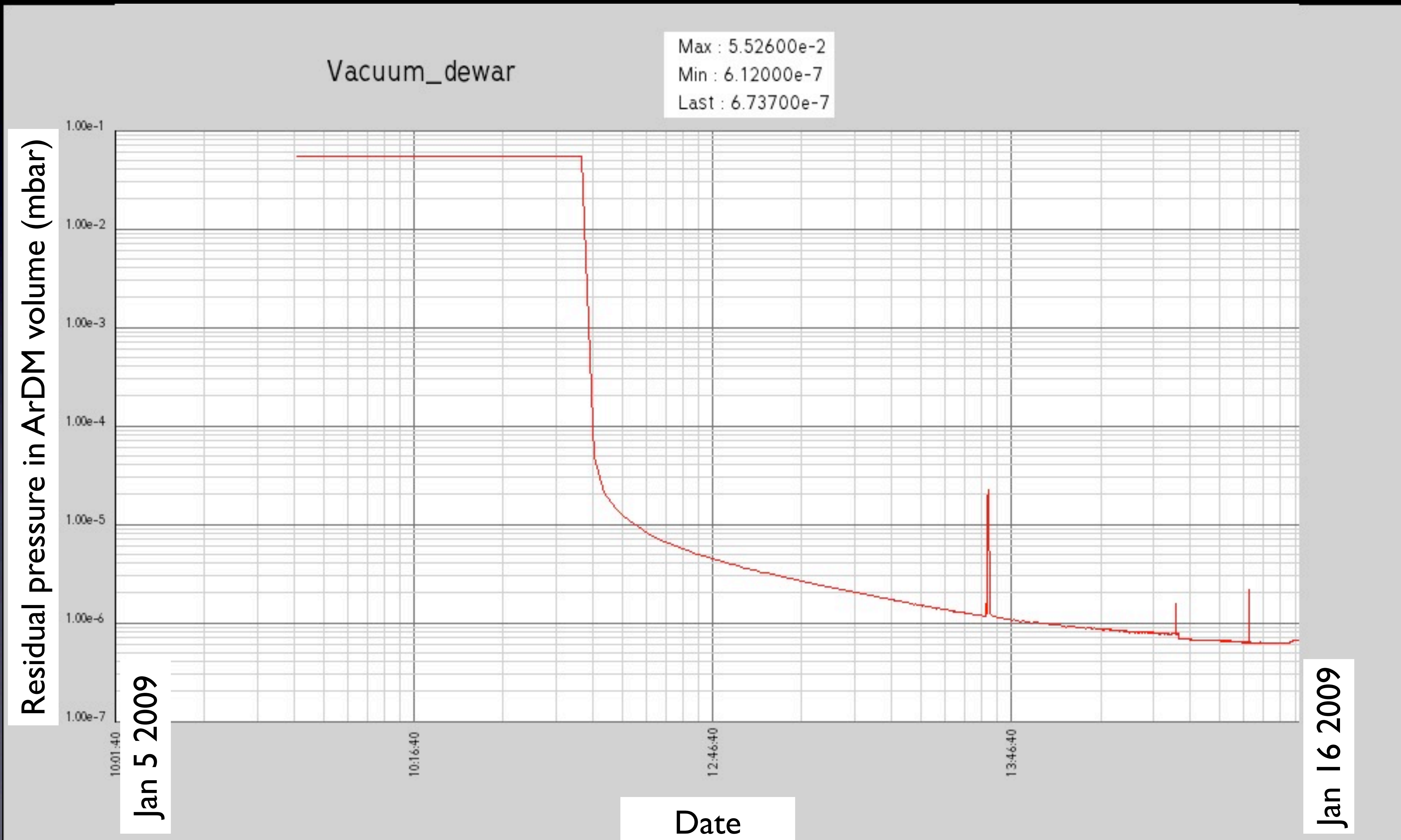

Hamamatsu R5912

Successfully tested at warm & LAr temperature

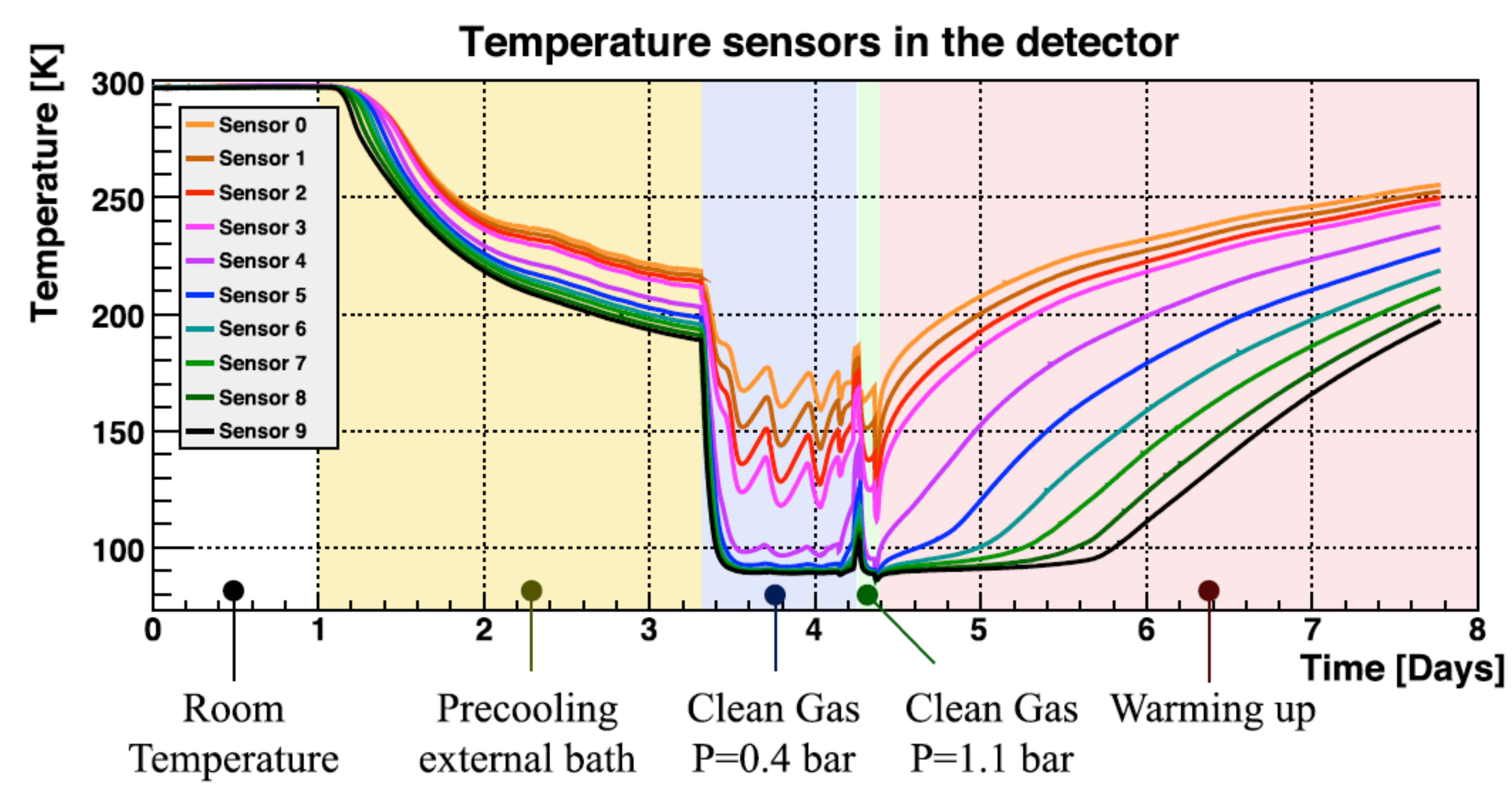
Producer	Model	tubes	Source	Typ. Gain (1500V)
Hamamatsu	R5912/02mod	x5	UniZH	$\approx 1 \cdot 10^9$
Hamamatsu	R5912/01mod	x2	Granada	$\approx 1 \cdot 10^7$
ETL	ETL9357	x1	Granada	$\approx 1 \cdot 10^7$

Detector volume evacuation

To ensure leak tightness (also in cold) and evacuate outgassing from detector elements



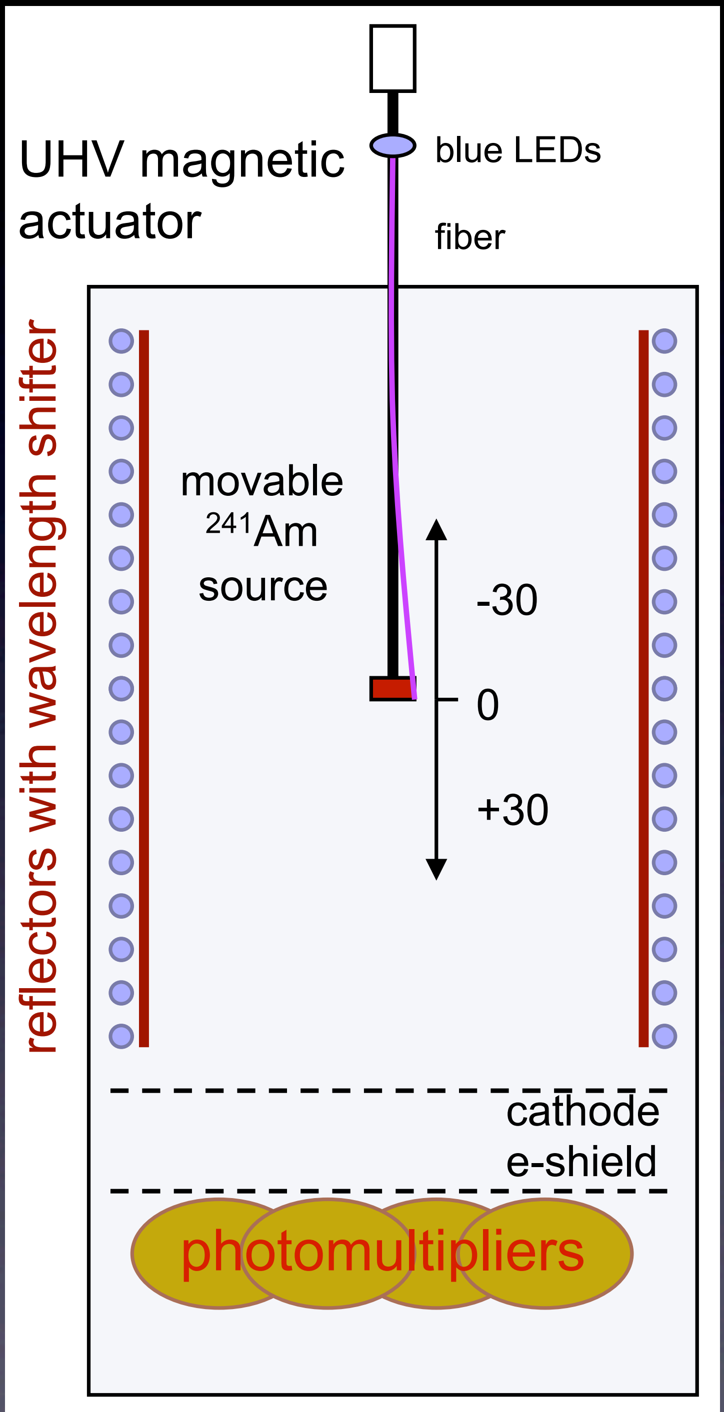
ArDM test in warm & cold GAr



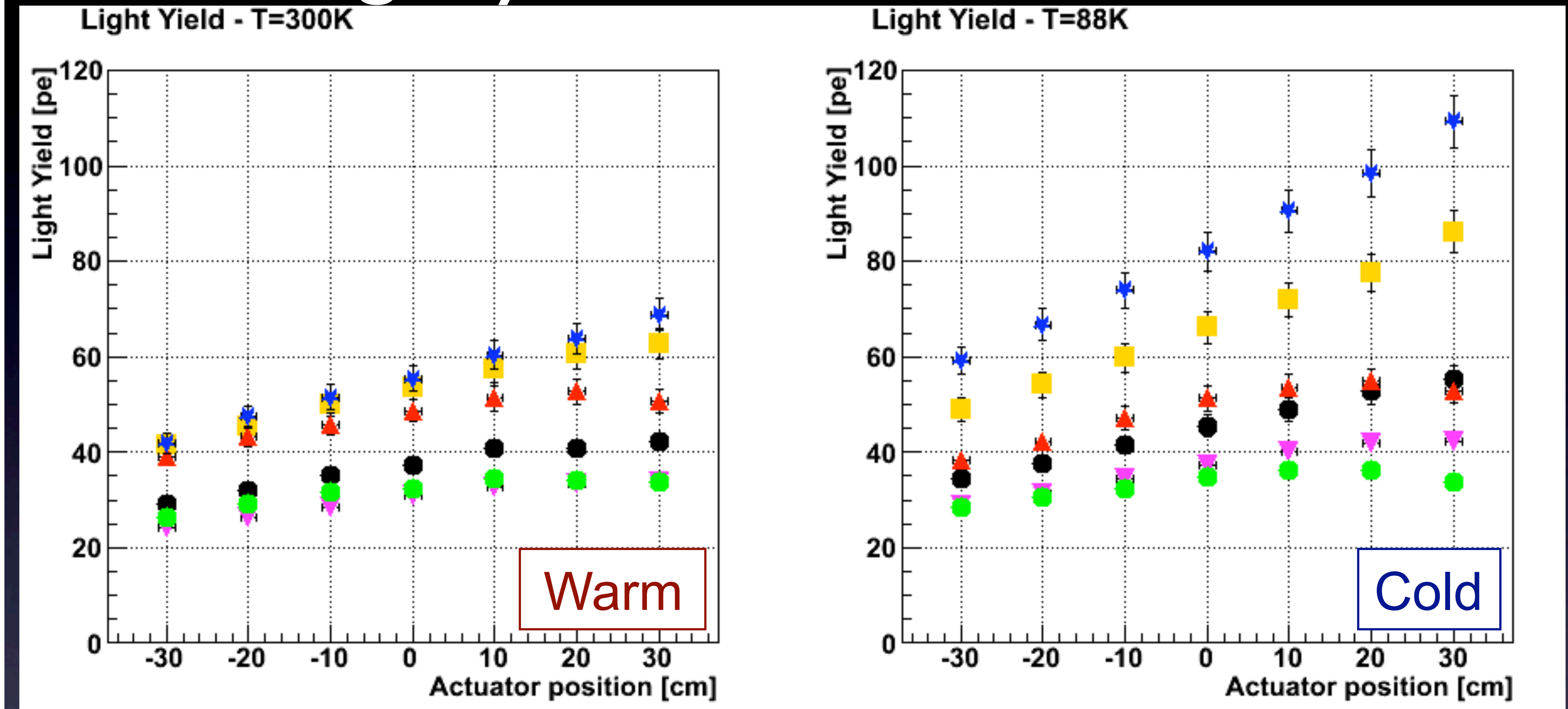
First cooldown (stay cold during 20 hours)

Fill by condensating warm Ar-60 grade gas from bottle

Preliminary light Yield in ArDM



Light yield from α source



- GAr P=1.1bar
- T=300K
- τ_2~2.8μs
- LY values extrapolated to max known purity τ_2=3.2μs

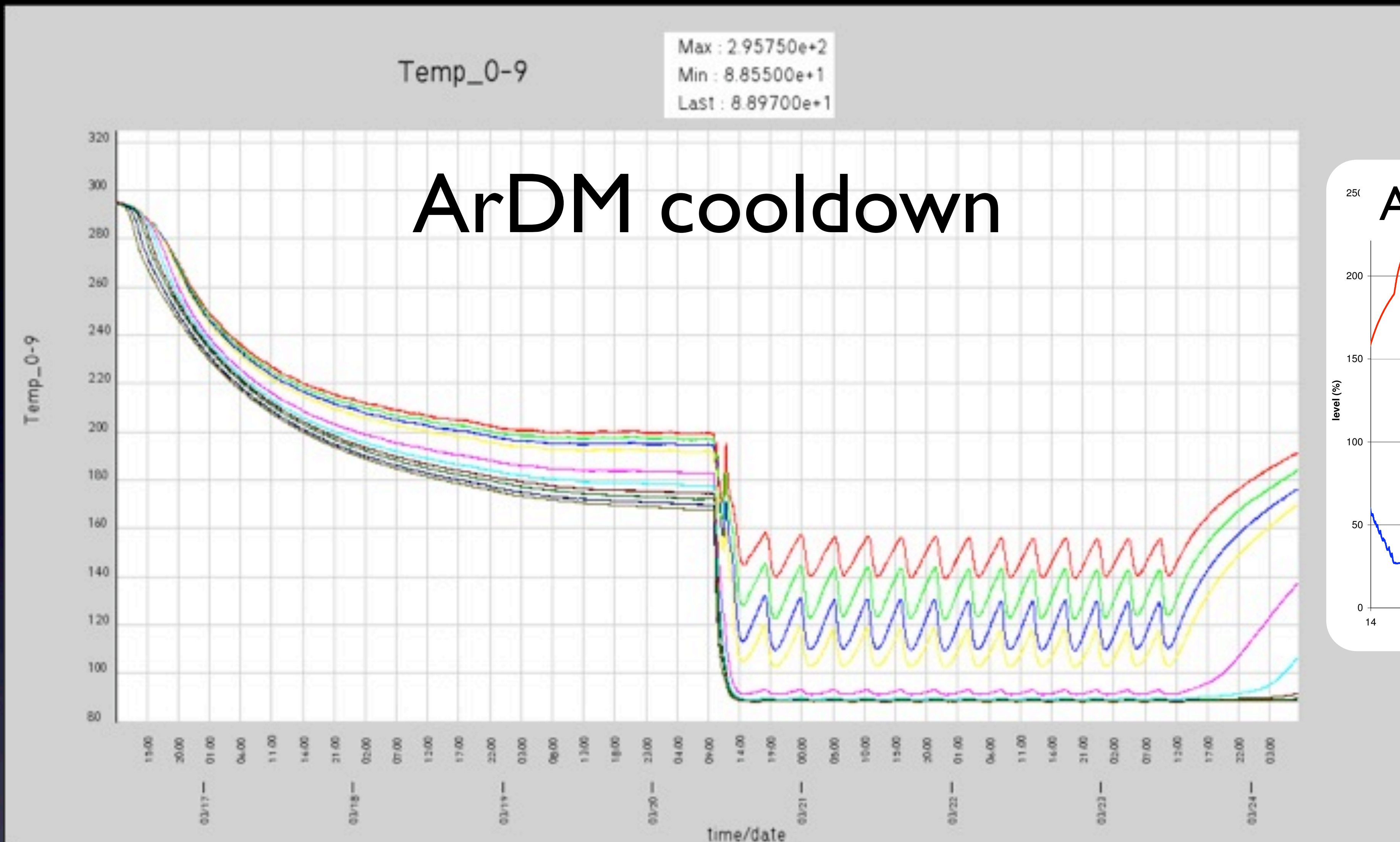
1) ZD0051 - Evap - Side
2) ZD0045 - TPB/PRL - Center
3) ZD0038 - Clean - Center
4) ZD0046 - TPB/PRL - Side
5) ZD0050 - Evap - Center
6) ZD0049 - Clean - Side

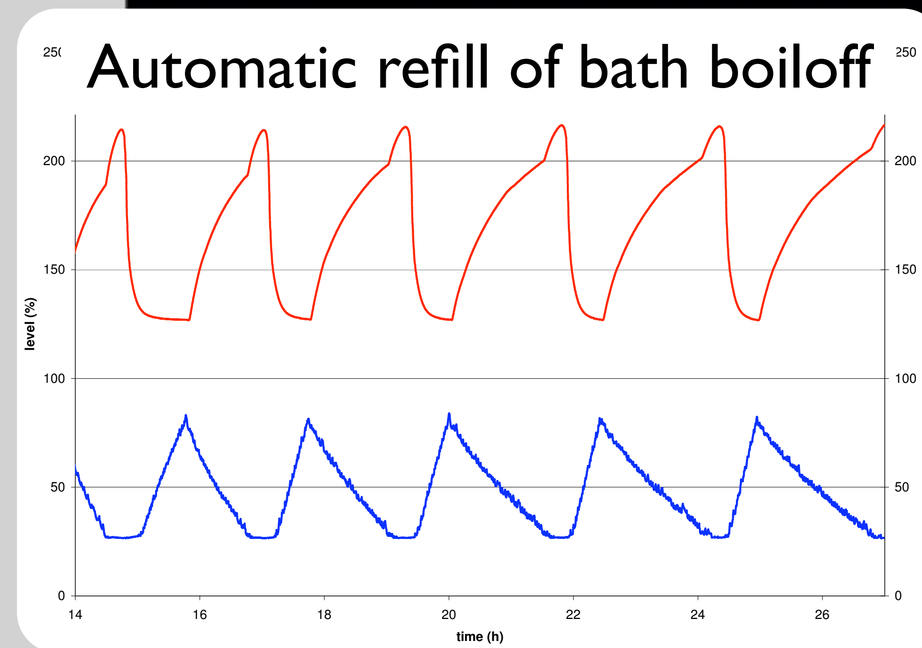
- GAr P=1.1bar
- T=88K
- τ_2~3.7μs
- Value are not extrapolated

Very good cold GAr purity ($\tau_{triplet} \approx$3.5-3.7μs)

Confirms effect of liquid phase trapping impurities

Recent cooldown (March 2009)





Total heat losses = ≈200W @ LAr

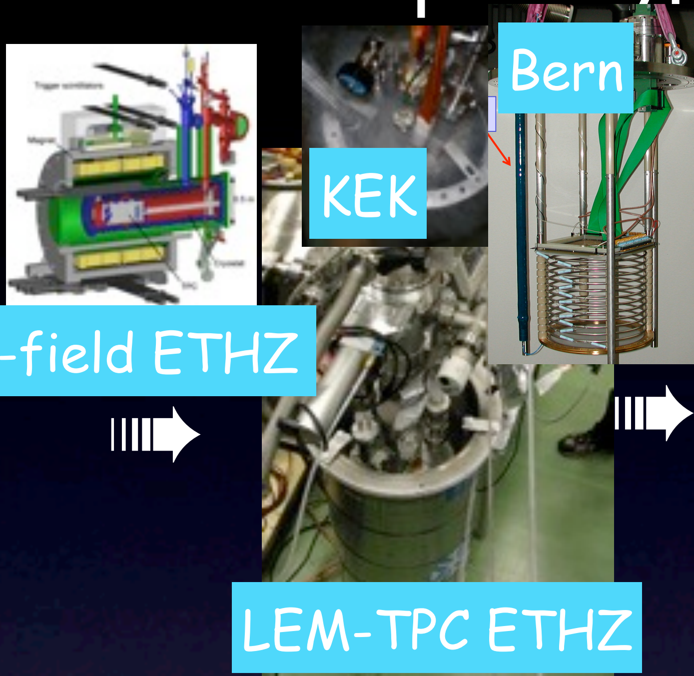
- Purification cartridge impedance + below pump successfully tested
- Cleaniness of LAr purification cartridge proven
- PMT data in cold GAr being analysed

Waiting for CERN SC approval to fill 1-ton LAr (April 09)

Next steps towards very large detectors

Steps towards GLACIER

- Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?



➠ **proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale**

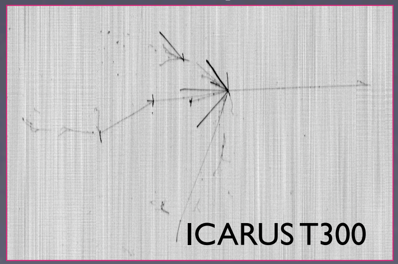
➠ **LEM readout on 1x1 m² scale** UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM CERN RE18

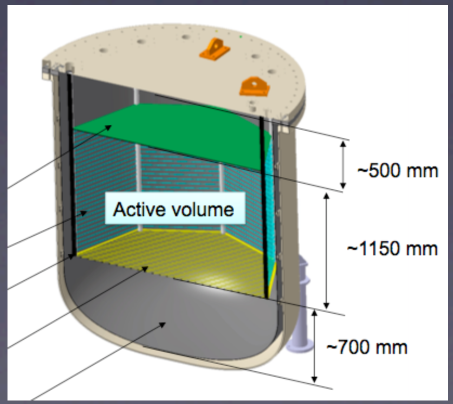
➠ **direct proof of long drift path up to 5 m**

ArgonTube: long drift, ton-scale

➠ **Application of LAr LEM TPC to neutrino physics**: particle reconstruction & identification (e.g. 1 GeV e/μ/π), optimization of readout and electronics, possibility of neutrino beam exposure

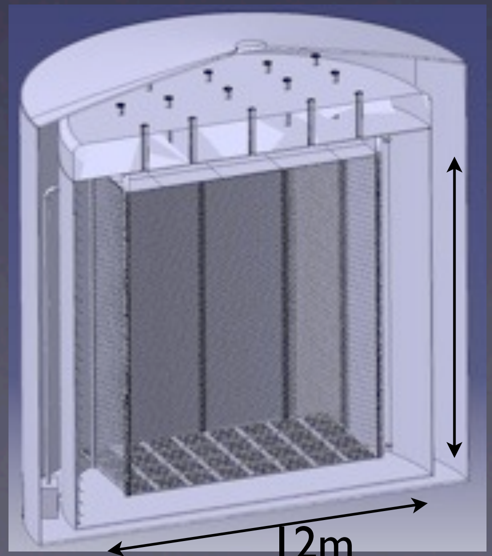


Test beam
1 to 10 ton-scale



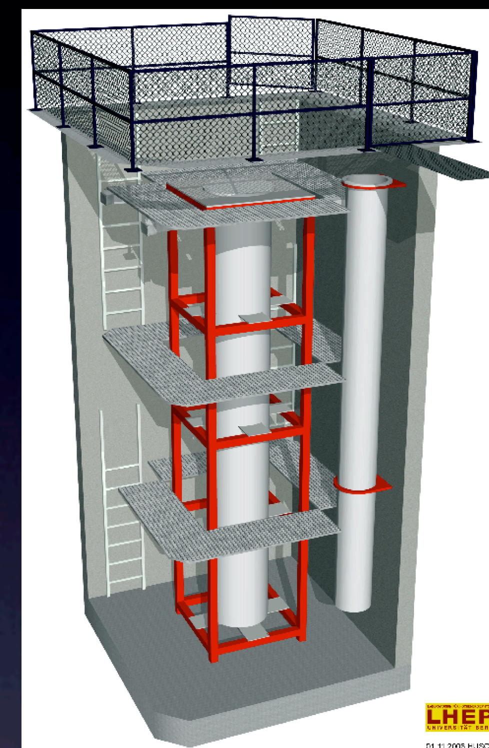
➠ **full engineering demonstrator for larger detectors**, acting as near detector for neutrino fluxes and cross-sections measurements, …

1 kton



ARGONTUBE - 5 meter drift

- 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



Infrastructure ready
External dewar delivered
Detector vessel, inner detector, readout system, … in design procurement phase

Conclusion

- On-going collaborative effort towards very large liquid Argon TPCs to provide "bubble-chamber" quality physics at the relevant mass scale of next generation undergroud detectors.
- The GLACIER design, based on the LAr LEM-TPC concept, represents a scalable, cost-effective LAr detector up to possibly 100 kton, demanding concrete R&D.
- The LAr LEM-TPC concept has been successfully established on small scale.
- ArDM-1t is a real 1-ton scale prototype of the GLACIER concepts.
- ArgonTube will be a dedicated measurement of long drifts (→5m).
- Aggressive R&D on integrated readout electronics (warm/cold options, detector integration…) aimed at potentially reducing costs for large detectors.
- Physics performance of detectors need to be understood with test beam campaings (charged particle and neutrinos).
- After a successful completion of these steps we want to proceed to a proposal for a 100 kton-scale underground device, which would include the discussion of a 1 kton full engineering prototype.