

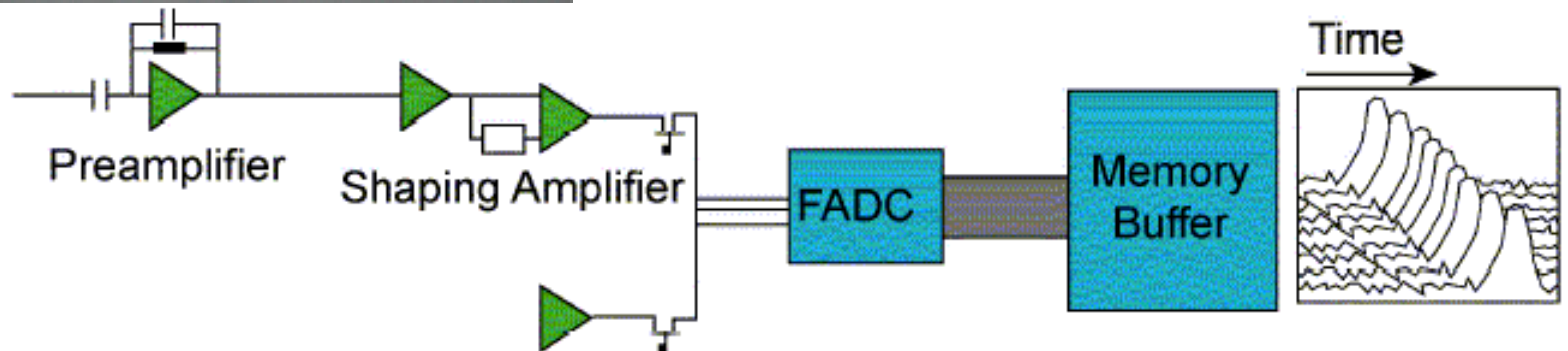
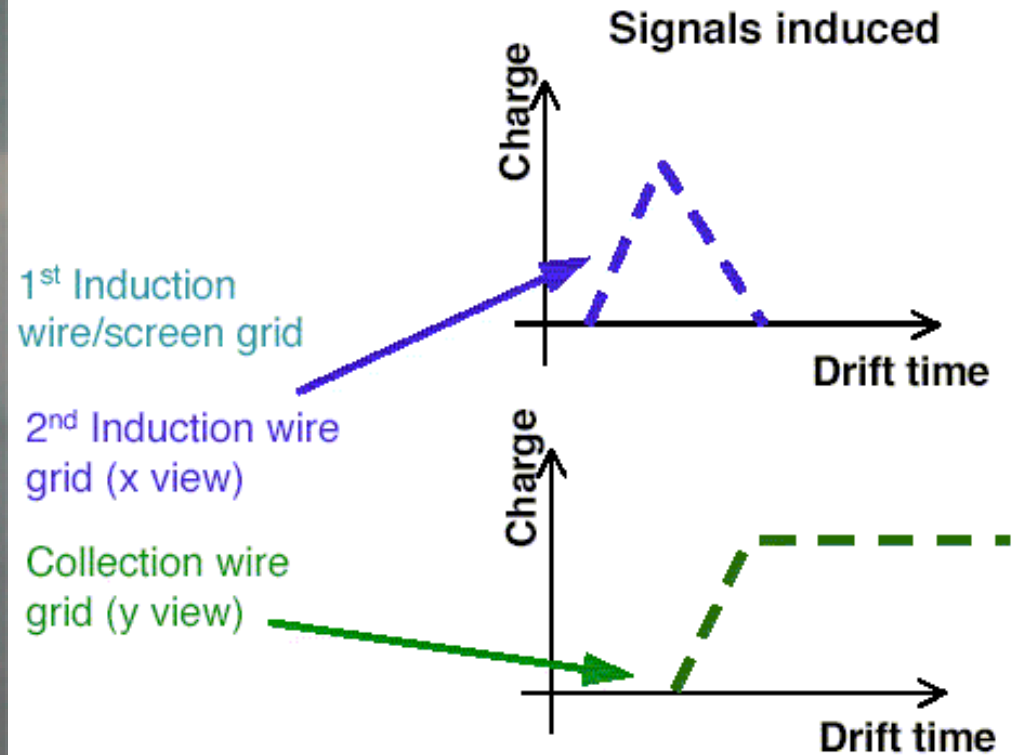
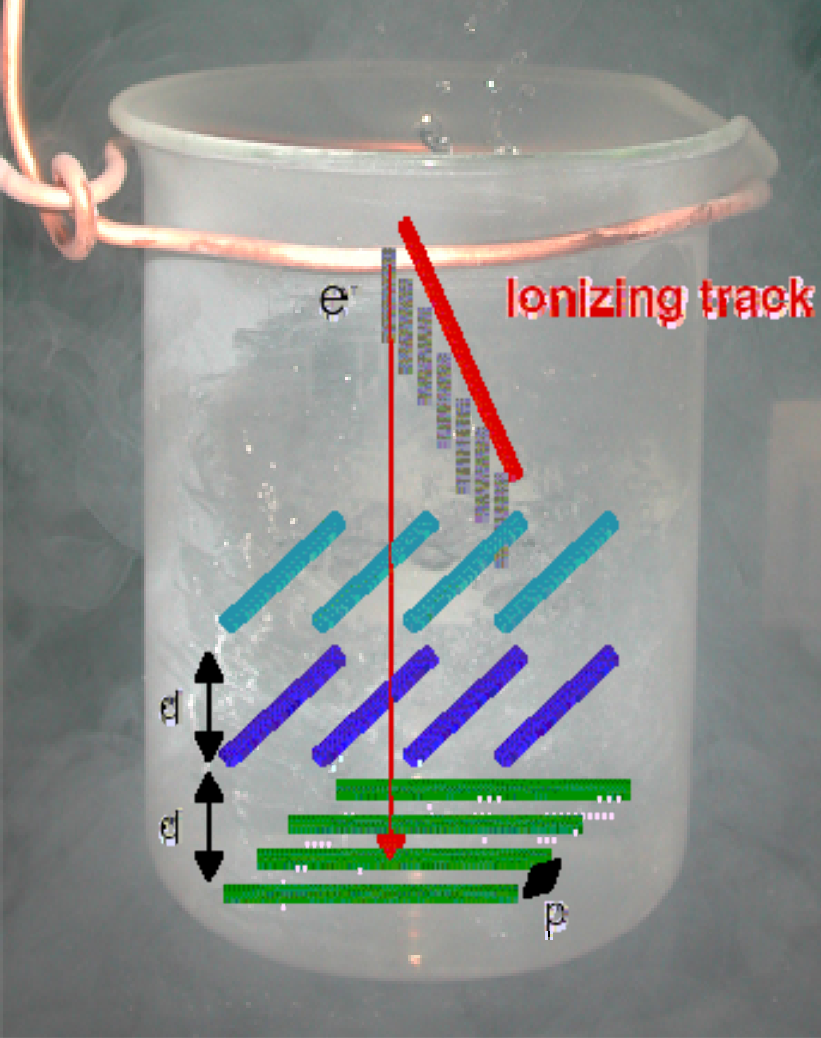
# Challenges to Realize Huge Underground Detectors – Liquid Argon TPC Case

*Alberto Marchionni, ETH Zurich*

*4<sup>th</sup> International Workshop on Nuclear and Particle Physics  
at J-PARC, Mito, March 2008*

- ❖ **LAr TPC working principle and present achievements**
  - detection of ionization and light
  - ICARUS prototypes and the T600 module
- ❖ **R&D steps and physics proposals for a multi-kton LAr TPC**
  - ICARUS, LANND, GLACIER, FLARE, MODULAR
- ❖ **Main R&D items**
  - dewars
  - Argon purification
  - High Voltage systems
  - readout devices and electronics
  - “test” beams
- ❖ **Conclusions**

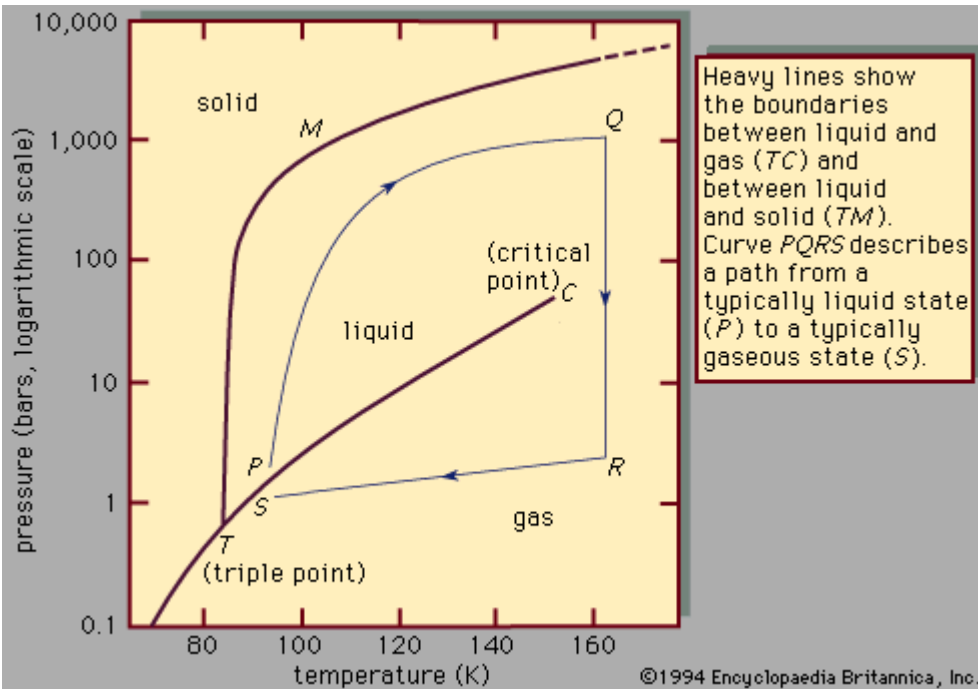
# Liquid Argon TPC



# Use of LAr as detector medium

- **L.W. Alvarez** (late 60'): noble liquids for position sensitive detectors
- **W.J. Willis & V. Radeka** (70'): large LAr calorimeters for HEP experiments
- **H.H. Chen, P.E. Condon, B.C. Barish, F.J. Sciulli** "A neutrino detector sensitive to rare processes. A study of neutrino electron reactions", Fermilab Proposal P-0496, May 1976
  - 'A highly segmented, independently sampled, totally live target consisting of roughly a thousand planes (1 cm thick) of liquid argon'
- **H.H. Chen & J.F. Lathrop** "Observation of ionization electrons drifting large distances in liquid Argon", NIM 150 (1978) 585
  - achieved 7.5 cm drifts
- **C. Rubbia** "The Liquid-Argon Time Projection Chamber: a new concept for neutrino detectors", CERN Report 77-8, May 1977
  - 'It appears possible to realize ... a drift length as long as 30 cm'
- **E. Aprile, K.L. Giboni and C. Rubbia** "A study of ionization electrons drifting large distances in liquid and solid Argon", NIM A241 (1985) 62
  - 'The longest observed drift times in the 10 cm chamber are of the order of 1.8 ms at 10 V/cm. ... an attenuation length of about 7.5 m is expected for a field of 1 kV/cm.'
- **ICARUS Coll.** "ICARUS: a proposal for the Gran Sasso Laboratory", INFN/AE-85/7, Frascati 1985

# LAr thermodynamical properties



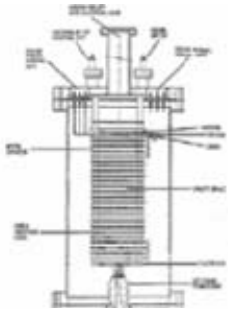
	<b>P (bar)</b>	<b>T (K)</b>	<b>Density (g/cm<sup>3</sup>)</b>
<b>Solid phase</b>		83.0	1.625
<b>Liquid phase</b>	1.00	87.2	1.396
<b>Boiling point</b>	1.013	87.3	1.395
<b>Triple point</b>	0.689	83.8	
<b>Critical point</b>	48.63	150.7	0.553

At the boiling point:

- Heat capacity ( $C_p$ ) 1.117 kJ/kg K
- Thermal conductivity  $1.26 \times 10^{-1}$  J/s m K
- Latent heat of vaporization 161 kJ/kg

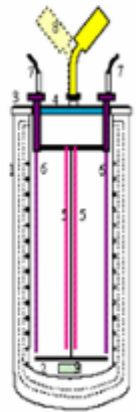
# The ICARUS steps

**24 cm drift wires chamber**



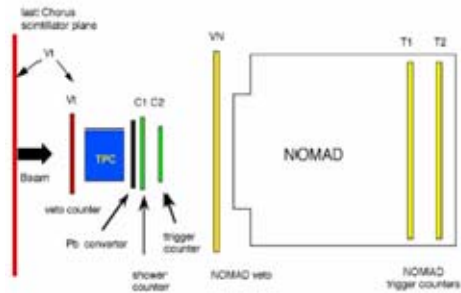
**1987:** First LAr TPC. Proof of principle. Measurements of TPC performances.

**3 ton prototype**



**1991-1995:** First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

**50 litres prototype  
1.4 m drift chamber**



**1997-1999:** Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.



**10 m³ industrial prototype**

**1999-2000:** Test of final industrial solutions for the wire chamber mechanics and readout electronics.

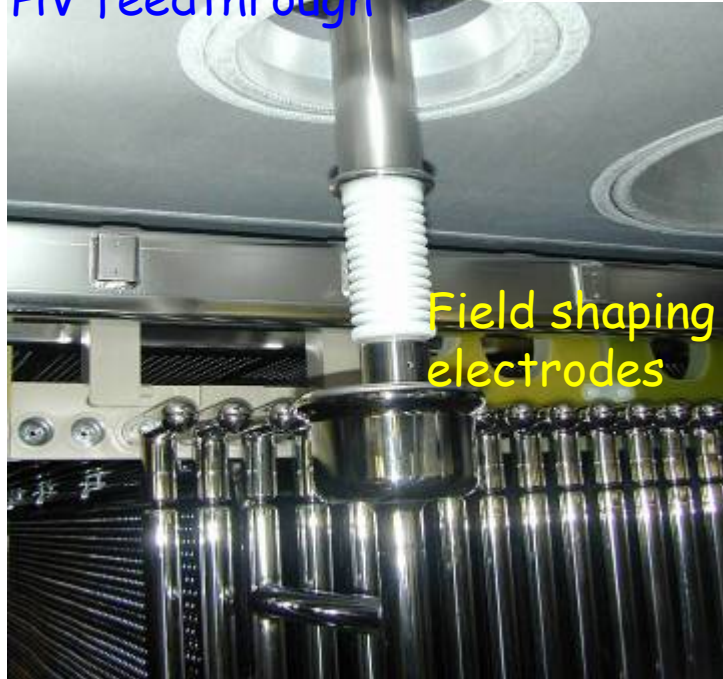


**600 ton detector**

**2001- present:** 300 ton detector tested on surface in Pavia. 600 ton detector being presently assembled at LNGS.

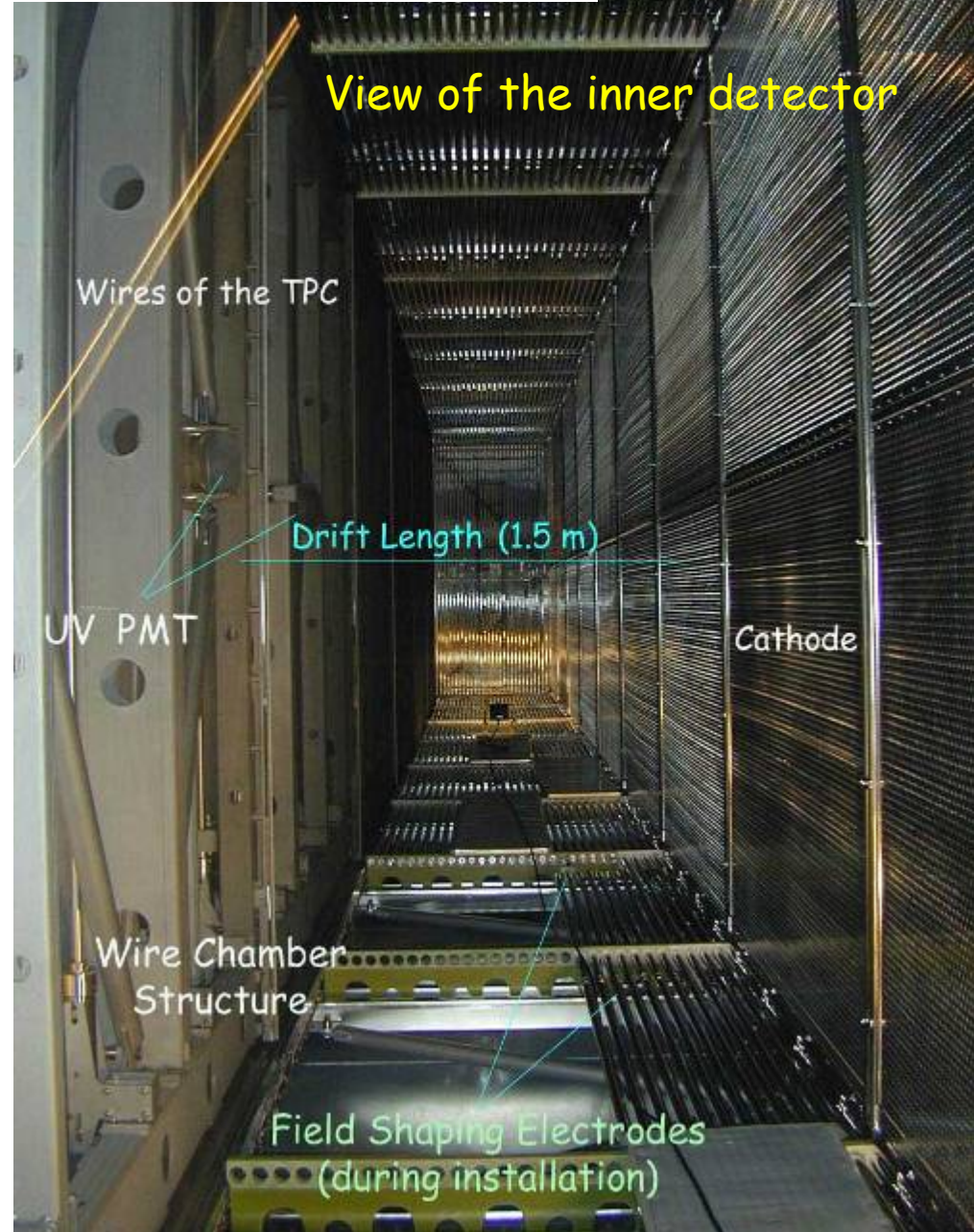
# ICARUS T300 Prototype

HV feedthrough



Field shaping electrodes

View of the inner detector



Wires of the TPC

Drift Length (1.5 m)

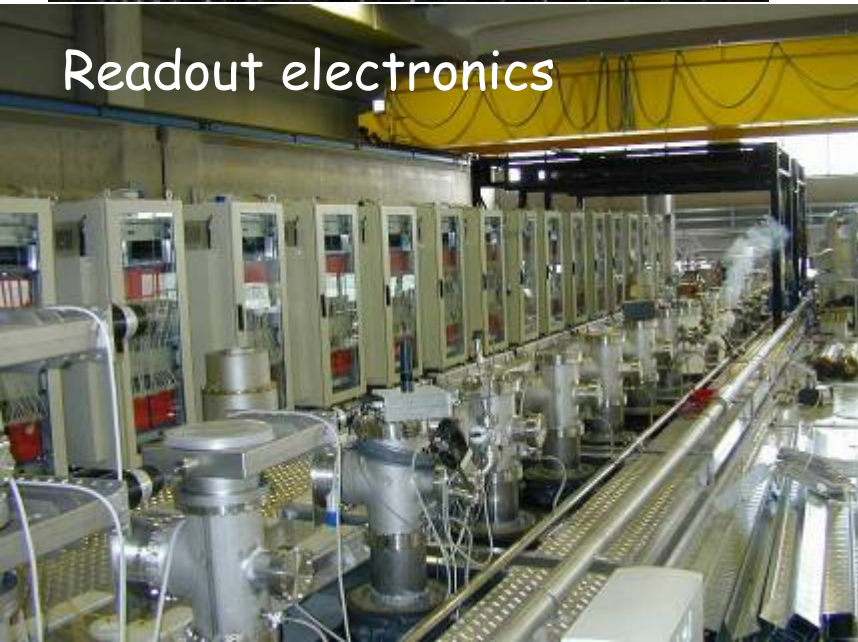
UV PMT

Cathode

Wire Chamber Structure

Field Shaping Electrodes (during installation)

Readout electronics

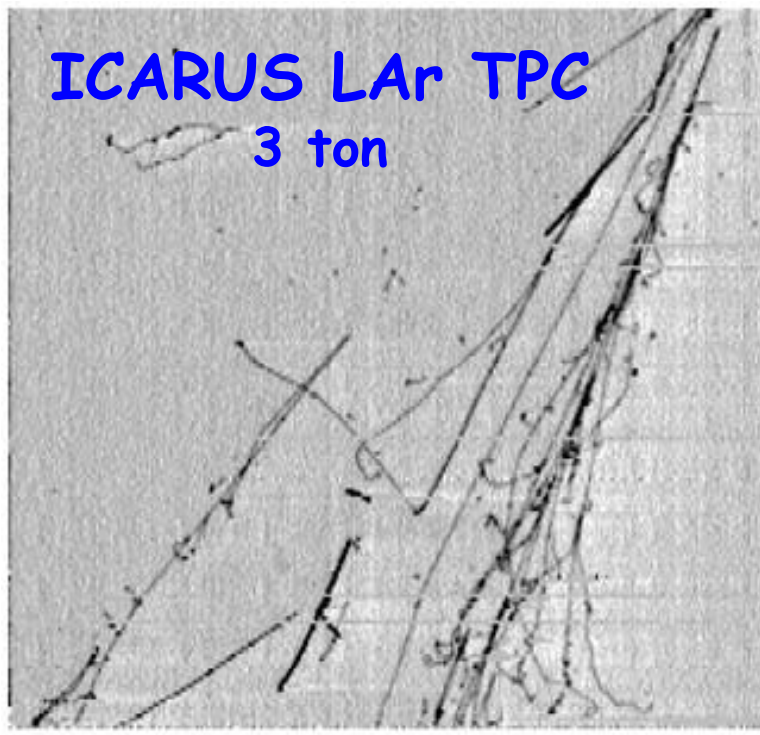
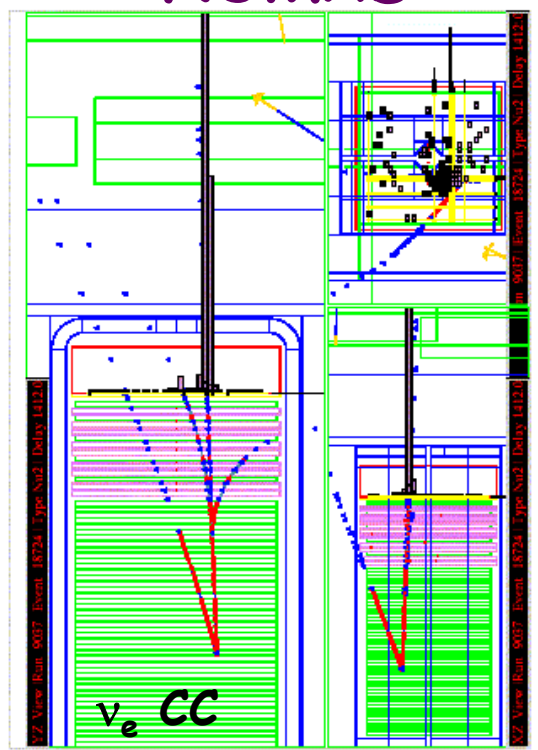


# Gargamelle Bubble Chamber

3 ton sensitive mass  
Heavy Freon



# NOMAD



# ICARUS LAr TPC

3 ton

Bubble $\varnothing$ (mm)	3
Density (g/cm <sup>3</sup> )	1.5
$X_0$ (cm)	11.0
$\lambda_T$ (cm)	49.5
dE/dx (MeV/cm)	2.3

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

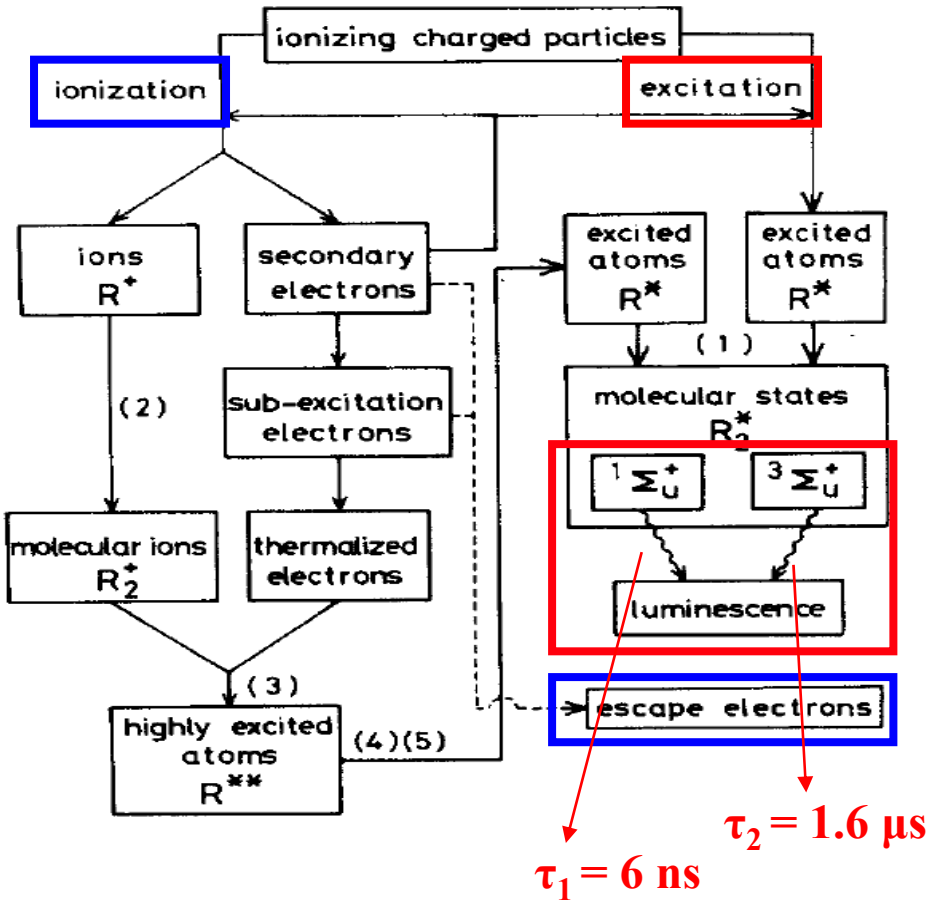
Resolution (mm <sup>3</sup> )	2×2×0.2
Density (g/cm <sup>3</sup> )	1.4
$X_0$ (cm)	14.0
$\lambda_T$ (cm)	54.8
dE/dx (MeV/cm)	2.1

# Processes induced by charged particles in liquid argon

When a charged particle traverses medium:

- **Ionization** process
- **Scintillation** (luminescence)
  - UV spectrum ( $\lambda=128$  nm)
  - Not energetic enough to further ionize, hence, argon is transparent
  - Rayleigh-scattering
- **Cerenkov light** (if fast particle)

 *UV light*  
 *Charge*  
 *Cerenkov light (if  $\beta > 1/n$ )*



M. Suzuki et al., NIM 192 (1982) 565

# Comparison Water - liquid Argon

	Water	Liquid Argon
Density (g/cm <sup>3</sup> )	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 <sup>2</sup> N/dE dx (β=1)	≈160 eV <sup>-1</sup> cm <sup>-1</sup>	≈130 eV <sup>-1</sup> cm <sup>-1</sup>
Muon Cerenkov threshold (p in MeV/c)	120	140
Scintillation	No	Yes (≈50000 γ/MeV @ λ=128nm)
Cost	1 CHF/liter (Evian)	≈1 CHF/liter

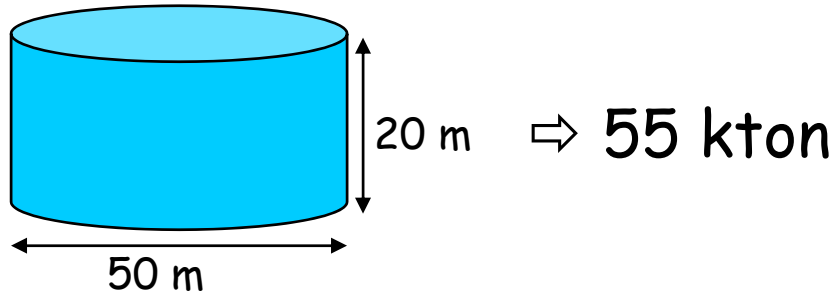
# Comparison Water - liquid Argon

Particle	Cerenkov Threshold in H <sub>2</sub> O (MeV/c)	Corresponding Range in LAr (cm)
e	0.6	0.07
μ	120	12
π	159	16
K	568	59
p	1070	105

- LAr allows lower thresholds than Water Cerenkov for most particles
- Comparable performance for low energy electrons

# A LAr detector ...

- must be BIG to be competitive with other technologies
  - 50 ÷ 100 kton range



- drift lengths of at least a few meters are necessary

## Shopping list for a large LAr detector:

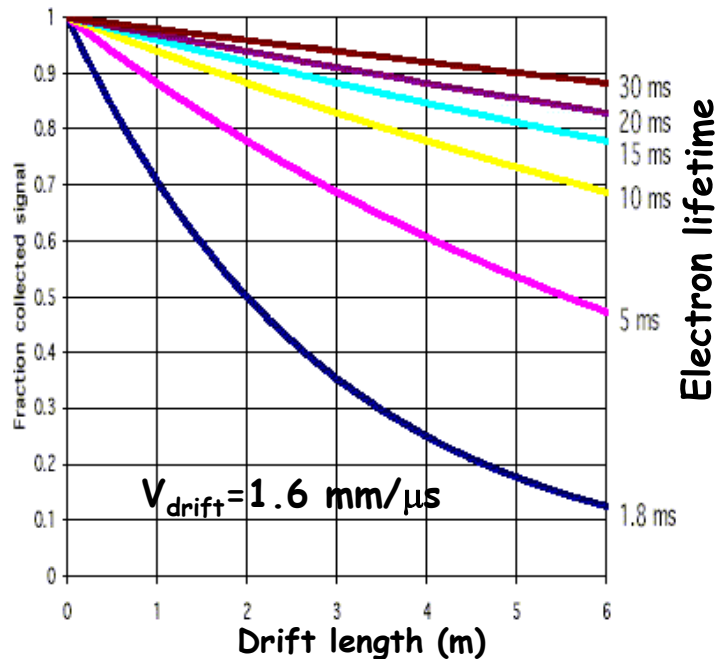
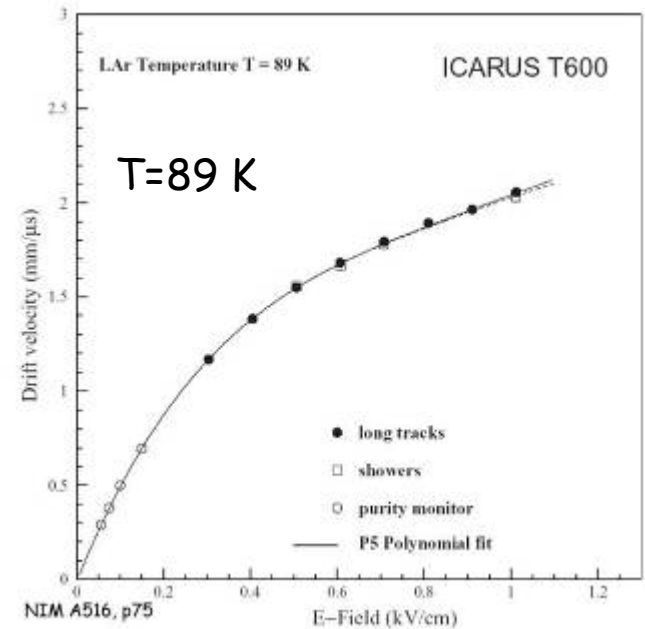
- Dewar
- Argon procurement and purification system
- High Voltage system
- Readout device
- Electronics
- "Test" beams
- Underground construction and operation

# Can we drift over over long distances?

- HV feedthrough tested by ICARUS up to 150 kV ( $E=1\text{ kV/cm}$  in T600)
- $v_{\text{drift}} = (1.55 \pm 0.02) \text{ mm}/\mu\text{s}$  @ 500 V/cm
- Diffusion of electrons:
 
$$\sigma_d = \sqrt{2 \times D \times t}, D = 4.8 \pm 0.2 \text{ cm}^2\text{s}^{-1}$$

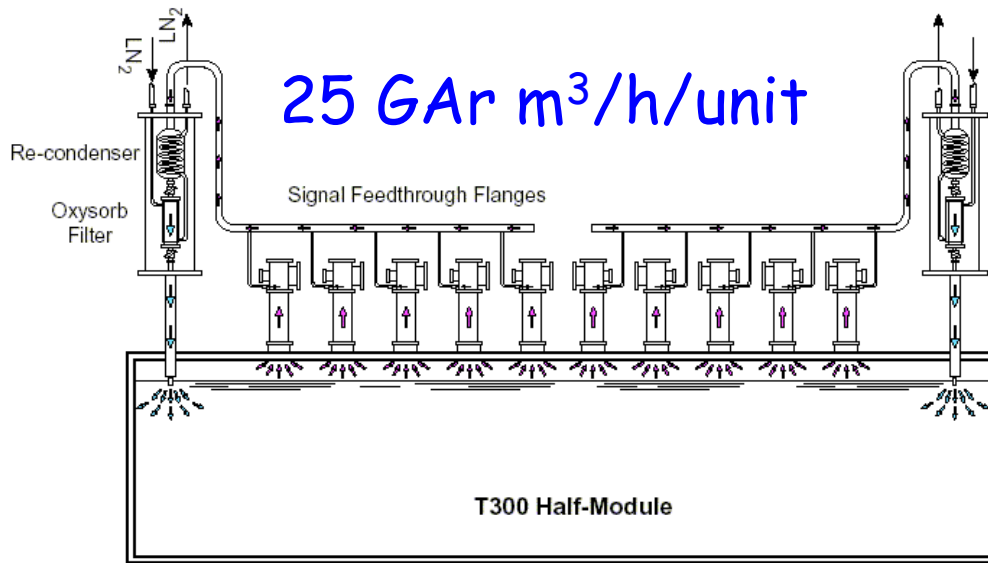
$$\sigma_d = 1.4 \text{ mm for } t = 2 \text{ ms (4 m @ 1 kV/cm)}$$

$$\sigma_d = 3.1 \text{ mm for } t = 10 \text{ ms (20 m @ 1 kV/cm)}$$

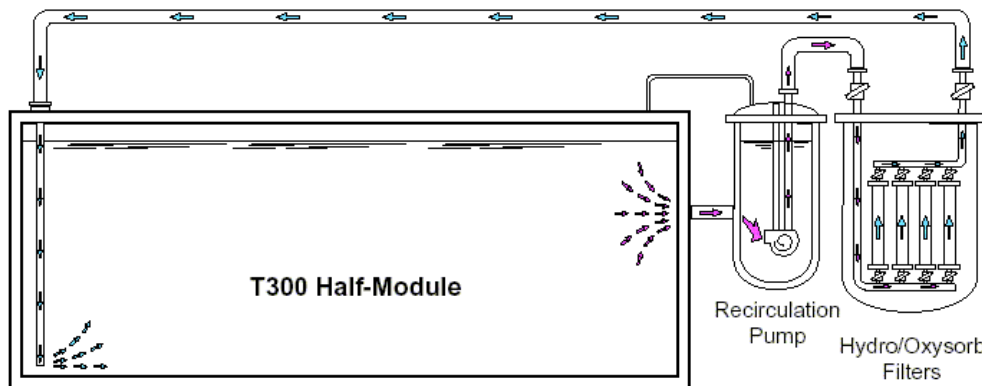


- ❖ to drift over macroscopic distances, LAr must be very pure
  - a concentration of 0.1 ppb Oxygen equivalent gives an electron lifetime of 3 ms
- ❖ for a 5 m drift and <30% signal loss we need an electron lifetime of 10 ms

# Argon purification in ICARUS



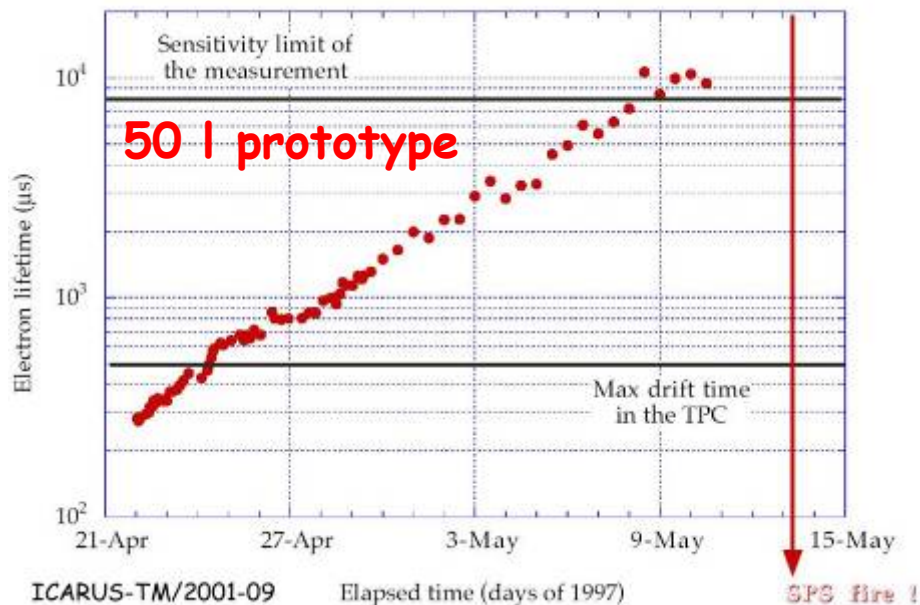
Recirculate **gaseous** and **liquid** Argon through standard Oxysorb/Hydrosorb filters



It was verified that LAr recirculation system does not induce any microphonic noise to the wires, so it can be active during the operation of the detector

2.5 LAr m<sup>3</sup>/h

# Argon purity, electron lifetime in ICARUS

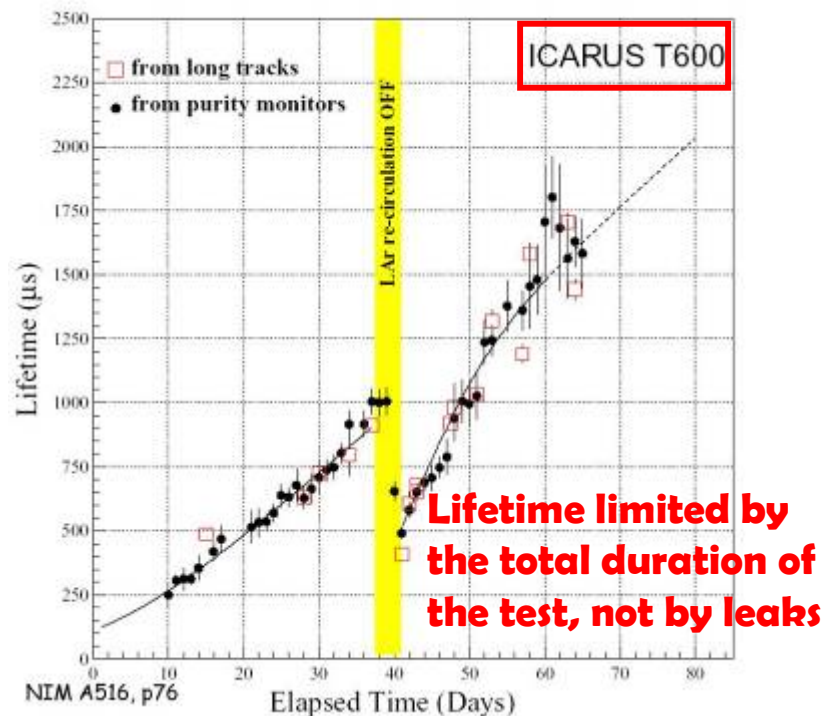


The concentration of impurities,  $N$ , is determined by

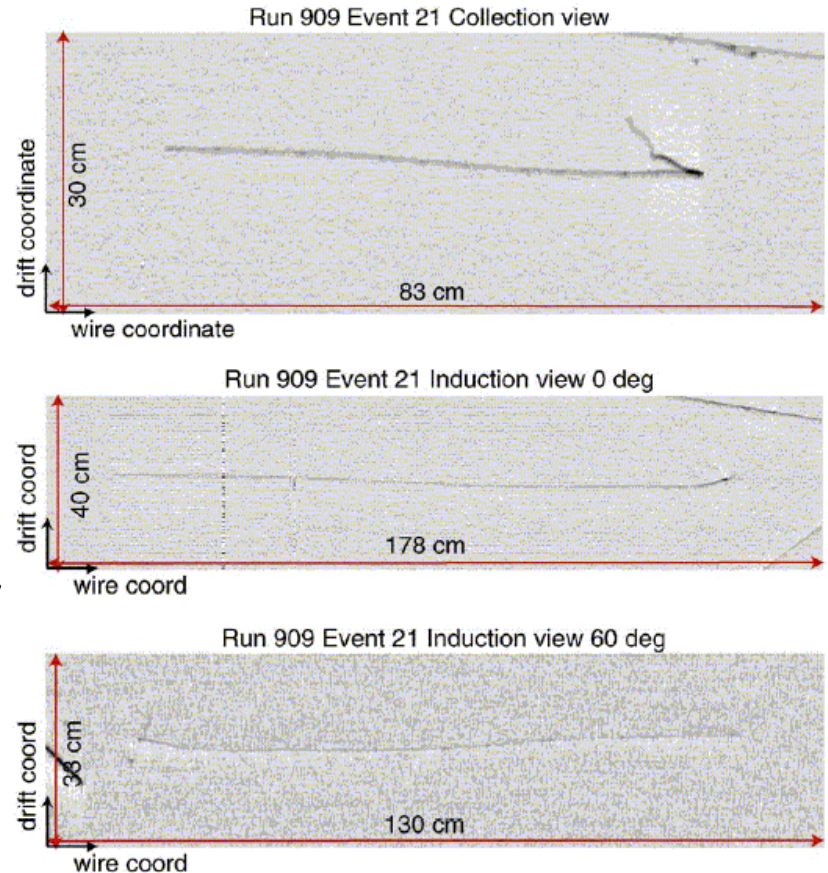
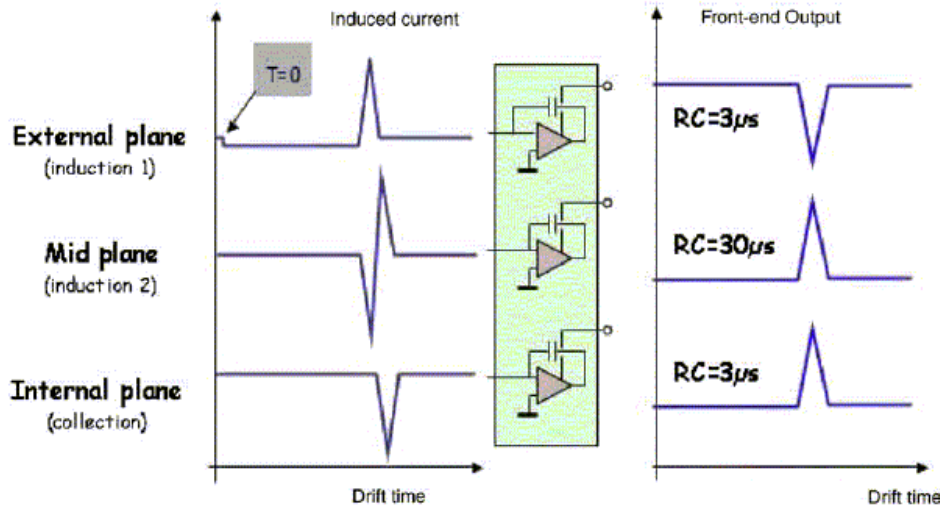
- constant input rate of impurities (leaks)  $\Phi_{in}^0$
- outgassing of material  $A, B$
- purification time  $\tau_c$

$$\frac{dN}{dt} = -\Phi_{out}(t) + \Phi_{in}(t) = -\frac{N(t)}{\tau_c} + \Phi_{in}^0 + \frac{A}{(1+t/t_0)^B}$$

$\Phi_{in}^0 = (5 \pm 5) \times 10^{-3}$  ppb/day oxygen  
 $A = 0.33 \pm 0.07$  ppb/day  
 $B = 1.39 \pm 0.05$



# Signals and event reconstruction from T300



- 3 wire planes ( $0^\circ$ ,  $\pm 60^\circ$ ), 3 mm wire pitch, 3 mm distance between wire planes
- $0^\circ$  wires: 9.4 m long,  $\pm 60^\circ$  wires: 3.8 m
- input capacitance (wire+cable )  
 $0^\circ$  wires:  $\sim 400$  pF,  $\pm 60^\circ$  wires:  $\sim 200$  pF

- ionization signal: 5500 e/mm @ 500 V/cm (before attenuation due to drift)
- Equivalent Noise Charge  $Q_{\text{noise}} = (500 + 2.5 \times C_{\text{input}} [\text{pF}])$  electrons
- **Signal/Noise ratio:  $\sim 10$ : is this enough?**
- each wire digitized at 2.5 MHz by a 10 bit Flash ADC

# Towards large LAr TPCs

Starting from ICARUS (1985), several proposals towards large LAr TPCs:

- LANND 2001
- GLACIER 2003
- FLARE 2004
- MODULAR 2007

...with different approaches:

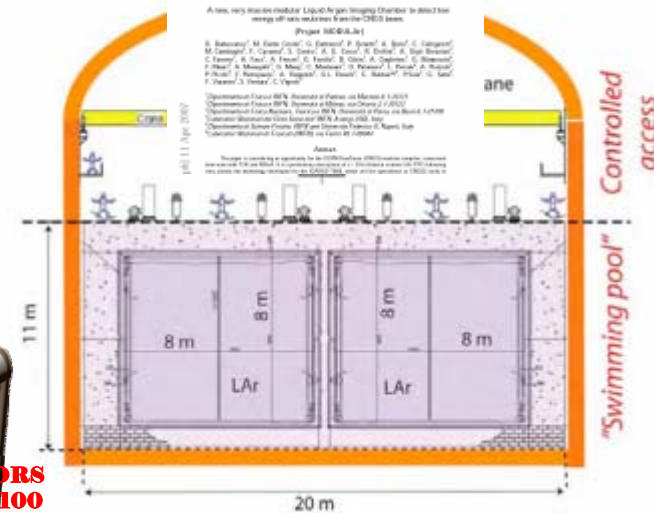
- a **modular** or a **scalable** detector for a total LAr mass of 50-100 kton
- **evacuatable** or **non-evacuatable** dewar
- detect ionization charge in LAr **without amplification** or with **amplification**

# ICARUS



S. Amaro<sup>1</sup>, S. Amoruso<sup>2</sup>, M. Amundin<sup>3</sup>, P. Aprile<sup>4</sup>, M. Armentano<sup>5</sup>, F. Arneodo<sup>6</sup>, A. Badierich<sup>7</sup>, B. Balhousian<sup>8</sup>, M. Baldo-Ceolin<sup>9</sup>, G. Barattini<sup>10</sup>, B. Bickman<sup>11</sup>, P. Bionessi<sup>12</sup>, E. Bernardini<sup>13</sup>, M. Bischoberger<sup>14</sup>, A. Borko di Turbolo<sup>15</sup>, R. Brunetti<sup>16</sup>, R. Brunzoni<sup>17</sup>, A. Busse<sup>18</sup>, E. Calkreuth<sup>19</sup>, M. Campanelli<sup>20</sup>, F. Carbonara<sup>21</sup>, C. Capomonte<sup>22</sup>, D. Cavali<sup>23</sup>, F. Cavasini<sup>24</sup>, F. Cavallini<sup>25</sup>, S. Cerrito<sup>26</sup>, A. Cossini<sup>27</sup>, C. Chen<sup>28</sup>, D. Chen<sup>29</sup>, D.B. Chen<sup>30</sup>, Y. Chen<sup>31</sup>, R. Cif<sup>32</sup>, D.B. Cline<sup>33</sup>, K. Ciuchini<sup>34</sup>, A.G. Cocco<sup>35</sup>, D. Conti<sup>36</sup>, Z. Dai<sup>37</sup>, C. De Vecchi<sup>38</sup>, A. Dibonno<sup>39</sup>, A. Di Cuccio<sup>40</sup>, R. Duda<sup>41</sup>, A. Ereditado<sup>42</sup>, M. Fiksel<sup>43</sup>, A. Ferrel<sup>44</sup>, A. Ferraro<sup>45</sup>, F. Ferrer<sup>46</sup>, G. Fiorello<sup>47</sup>, S. Gall<sup>48</sup>, D. Garcia Gomez<sup>49</sup>, Y. Ge<sup>50</sup>, D. Gibaut<sup>51</sup>, A. Gagli Barolandi<sup>52</sup>, I. Gil-Botella<sup>53</sup>, K. Gironsek<sup>54</sup>, L. Grassi<sup>55</sup>, A. Grigishev<sup>56</sup>, K. Héz<sup>57</sup>, J. Holeczek<sup>58</sup>, X. Huang<sup>59</sup>, C. Juszczak<sup>60</sup>, D. Kiskrewocka<sup>61</sup>, J. Kisiel<sup>62</sup>, T. Kotowski<sup>63</sup>, H. Kusanagi<sup>64</sup>, M. Laffranchi<sup>65</sup>, J. Lapeta<sup>66</sup>, Z. Li<sup>67</sup>, B. Lisowski<sup>68</sup>, F. Lu<sup>69</sup>, J. Ma<sup>70</sup>, G. Mangano<sup>71</sup>, G. Manuzzi<sup>72</sup>, M. Markiewicz<sup>73</sup>, A. Martinez de la Osa<sup>74</sup>, C. Mathey<sup>75</sup>, F. Mausi<sup>76</sup>, D. Maza<sup>77</sup>, A.J. Melgarejo<sup>78</sup>, A. Mengoni<sup>79</sup>, G. Mengoni<sup>80</sup>, M. Mezzina<sup>81</sup>, J.W. Mitecki<sup>82</sup>, C. Montanari<sup>83</sup>, S. Murari<sup>84</sup>, S. Naray-Gombosi<sup>85</sup>, M. Napolitano<sup>86</sup>, J. Nowak<sup>87</sup>, G. Navarra<sup>88</sup>, C. Ocasio<sup>89</sup>, S. Ostrowski<sup>90</sup>, O. Orlandi<sup>91</sup>, O. Palamara<sup>92</sup>, D. Passoli<sup>93</sup>, L. Perini<sup>94</sup>, G. Piuze Mostari<sup>95</sup>, A. Pizzoli<sup>96</sup>, P. Pochini<sup>97</sup>, F. Poeschlauer<sup>98</sup>, W. Podlaskiewicz<sup>99</sup>, M. Poma<sup>100</sup>, T. Ranciaro<sup>101</sup>, A. Rappoldo<sup>102</sup>, G.L. Raselli<sup>103</sup>, J. Roca<sup>104</sup>, E. Rondio<sup>105</sup>, M. Roscini<sup>106</sup>, A. Rubbia<sup>107</sup>, C. Rubbia<sup>108</sup>, P. Sala<sup>109</sup>, R. Santonelli<sup>110</sup>, D. Scatena<sup>111</sup>, E. Segreto<sup>112</sup>, Y. Seo<sup>113</sup>, F. Serrano-Gonzalez<sup>114</sup>, J. Sobczyk<sup>115</sup>, N. Spagnol<sup>116</sup>, J. Stupinski<sup>117</sup>, R. Sulek<sup>118</sup>, M. Szymanski<sup>119</sup>, M. Szwarc<sup>120</sup>, M. Terzano<sup>121</sup>, G. Trinchero<sup>122</sup>, R. Vilella<sup>123</sup>, S. Yoshida<sup>124</sup>, U. Yegorov<sup>125</sup>, H. Wang<sup>126</sup>, X. Wang<sup>127</sup>, G. Xu<sup>128</sup>, Z. Xu<sup>129</sup>, X. Yang<sup>130</sup>, A. Zdzienicka<sup>131</sup>, J. Zolotarev<sup>132</sup>, G. Zou<sup>133</sup>, Q. Zhang<sup>134</sup>, S. Zhou<sup>135</sup>, W. Zuparic<sup>136</sup>

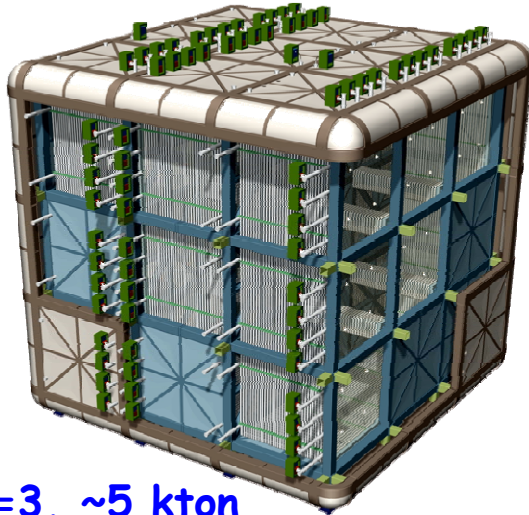
# MODULAR



# LANNDD

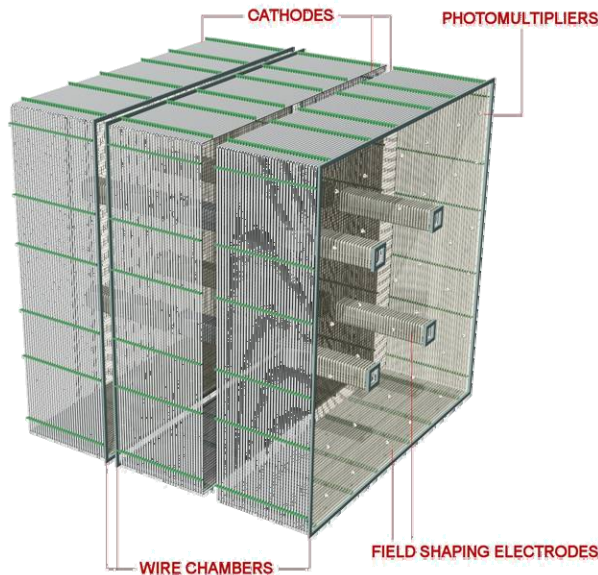
A scalable detector with an evacuable dewar and ionization charge detection without amplification

D.B. Cline, F. Raffaelli, F. Sergiampietri,  
JINST 1, T09001, 2006



$n=3$ , ~5 kton

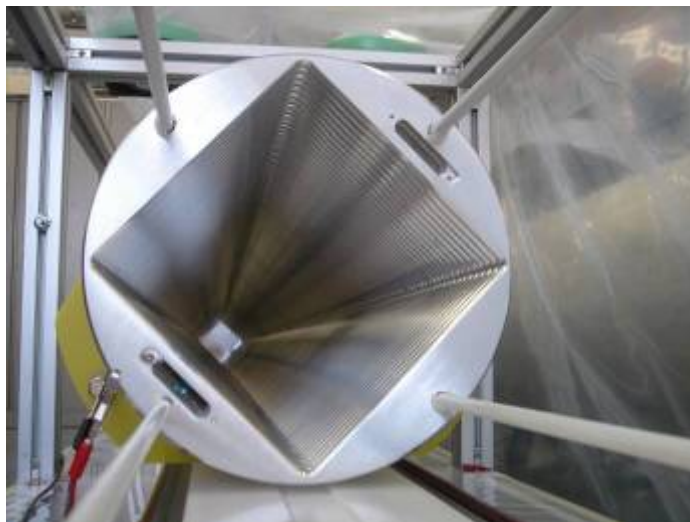
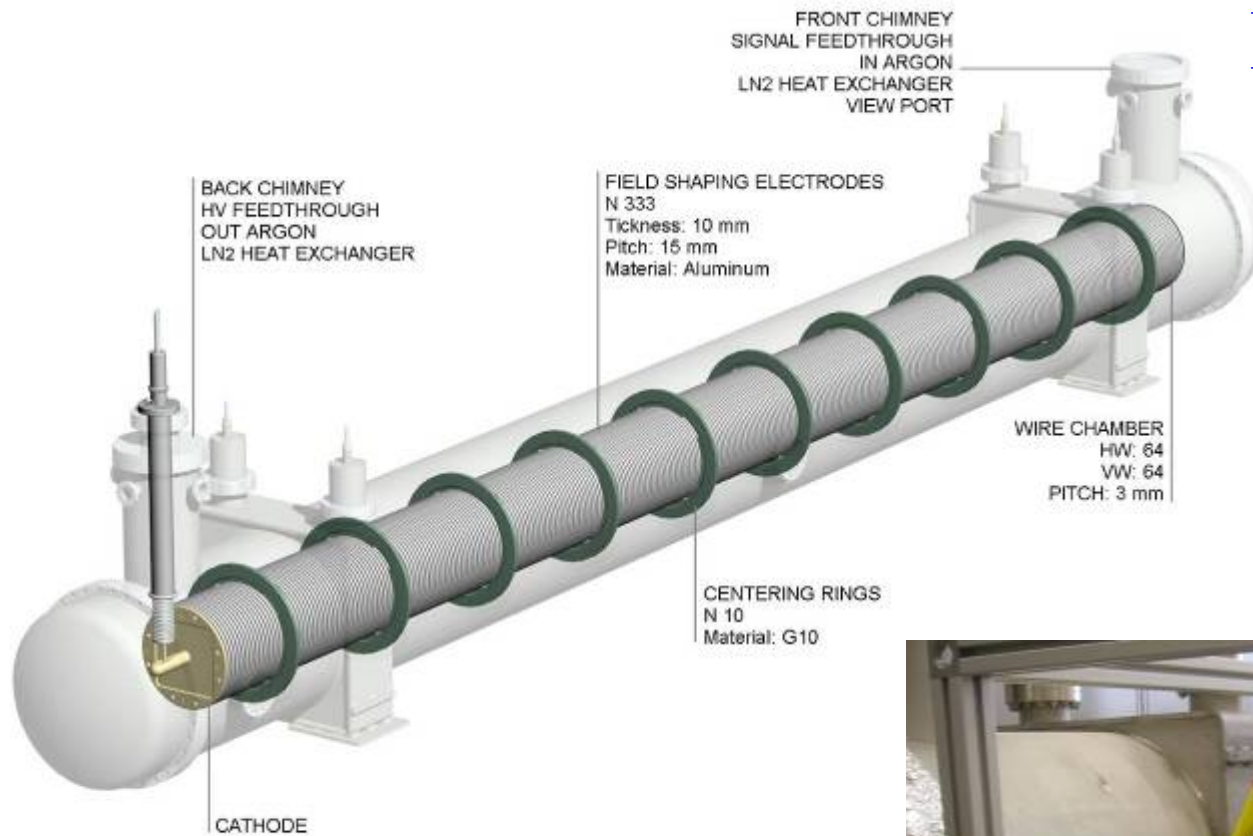
- Drift paths up to 5 m
- Evacuatable dewar with the possibility of checking its tightness
- Use of stainless steel for the inner vessel and for cathodes, wire chamber frames and shaping electrodes
- UHV standards for any device in contact with the argon
- Vacuum insulation, together with the use of superinsulation jacket around the cold vessel, to reduce running costs
- A continuous (not segmented) active LAr volume (high fiducial volume) contained in a cryostat based in a multi-cell mechanical structure
- This solution allows a cubic shape composed by  $n^3$  cells,  $5\text{m} \times 5\text{m} \times 5\text{m}$  in size each



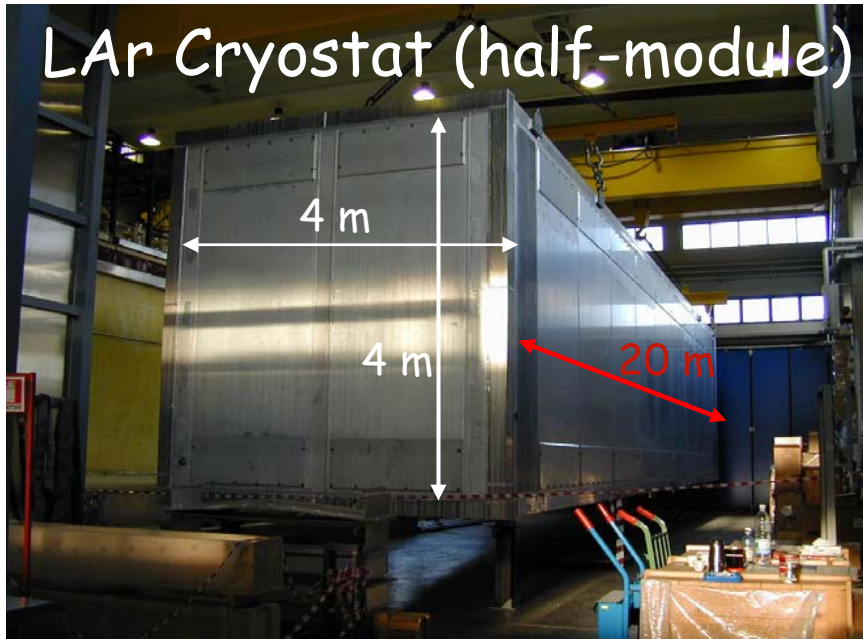
# LANDD 5 m test @ CERN

C. Cerri, D. Cline, F. Sergiampietri

Initial tests foreseen  
by summer '08



# T300 cryostat



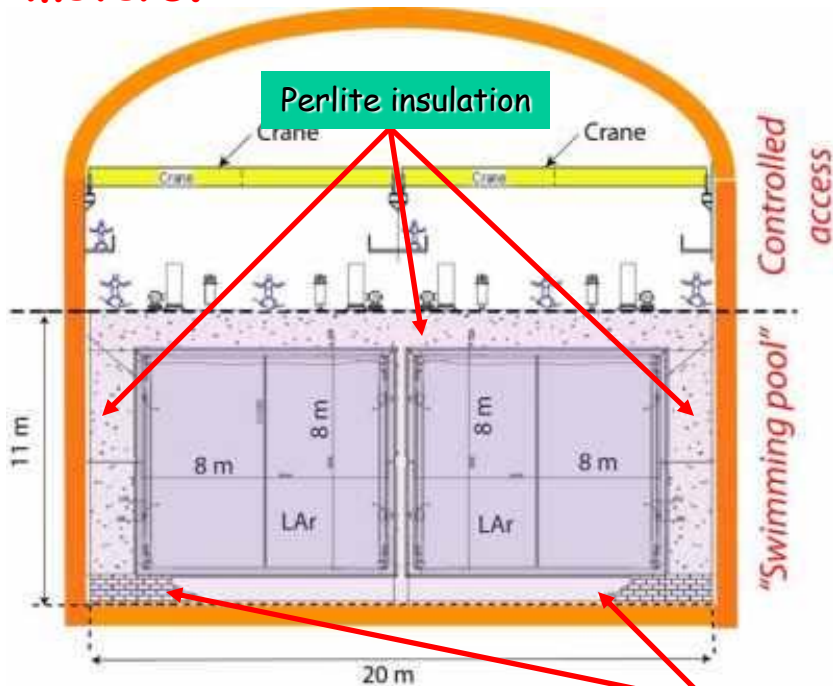
- T300 is a half-module of the T600
- cryostat constructed out of 15 cm thick panels, made of aluminum honeycomb sandwiched between aluminum skins
- thermal insulation panels, 0.5 m thick, made of Nomex (pre-impregnated paper) honeycomb
- cooling performed by circulating LN<sub>2</sub> inside cooling circuits placed immediately outside of the cryostat
- possibility to evacuate the cryostat down to 10<sup>-4</sup> mbar
- ... but relatively large thermal losses, up to 22 W/m<sup>2</sup>

# MODULAR

A modular detector with a non-evacuuable dewar and ionization charge detection without amplification

B. Baibussinov et al., arXiv:0704.1422 [hep-ph]

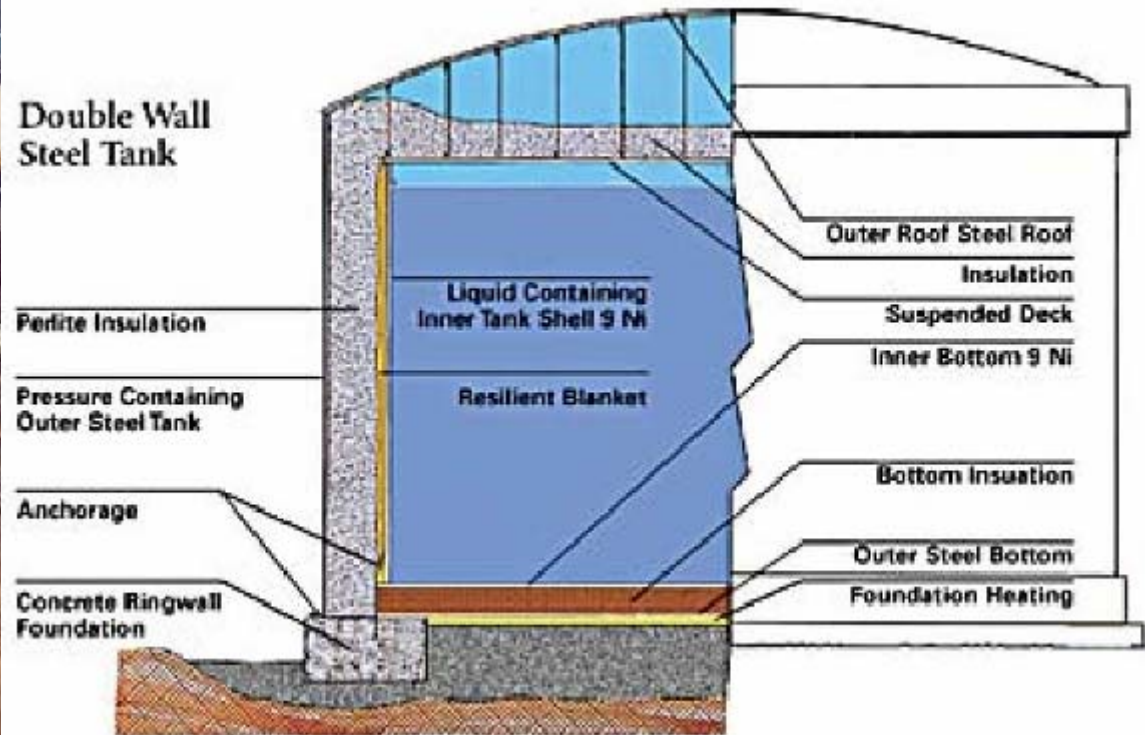
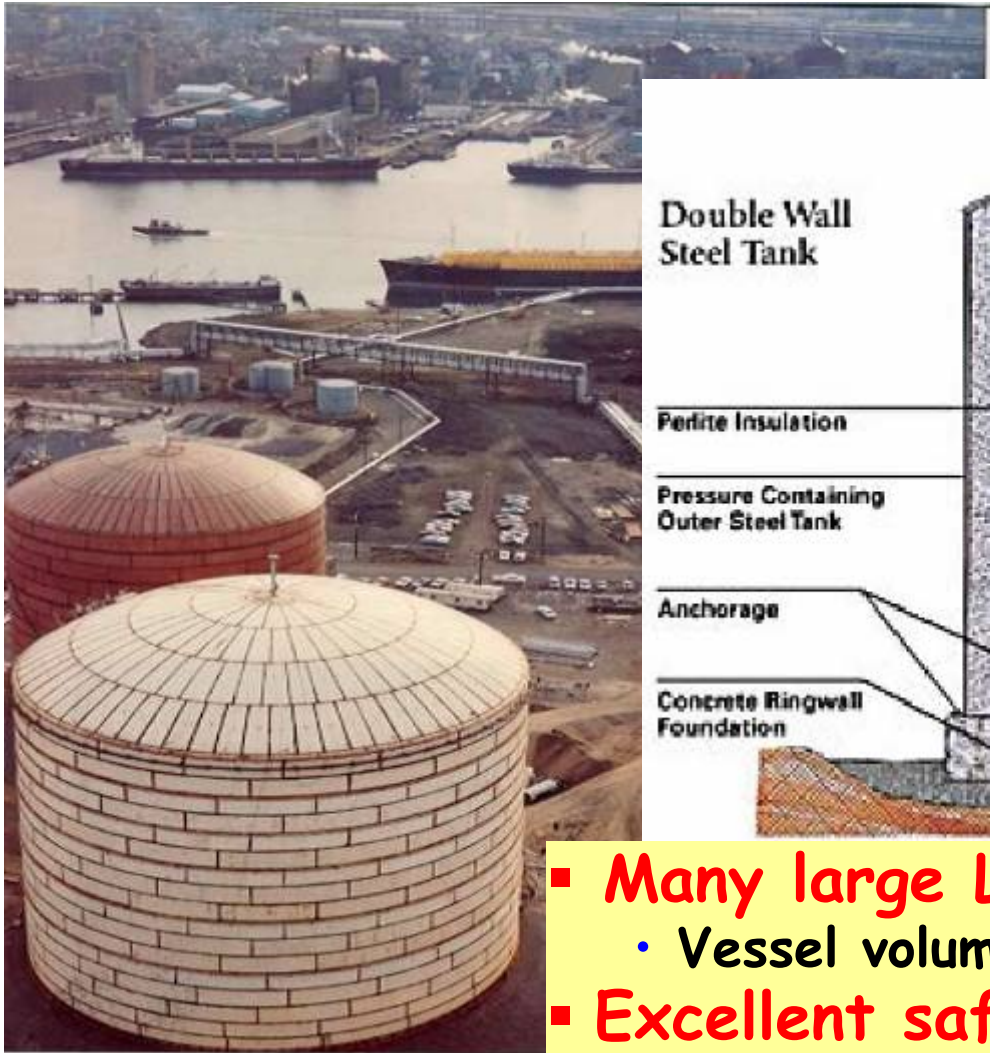
Geometry of an ICARUS-T600 half-module (T300) "cloned" into a larger detector scaled by a factor  $8/3 = 2.66$ : the cross sectional area of the planes is  $8 \times 8 \text{ m}^2$  rather than  $3 \times 3 \text{ m}^2$ . The length of such a detector is **50 meters**.



- 2 modules of 5 kton each with common insulation
- 1.5 m thickness of perlite, corresponding to  $\sim 4 \text{ W/m}^2$  thermal loss
- wires at  $0^\circ$ ,  $\pm 60^\circ$
- $0^\circ$  wires split in two, 25 m long, sections
- 6 mm wire pitch, to compensate for the increase capacitance of the longer wires

Low conductivity foam glass light bricks for the bottom support layer

# Cryogenic storage tanks for LNG



- **Many large LNG tanks in service**
  - Vessel volumes up to 200000 m<sup>3</sup>
- **Excellent safety record**
  - Last serious accident in 1944, Cleveland, Ohio, due to tank with low nickel content (3.5%)

# More on LNG storage tanks



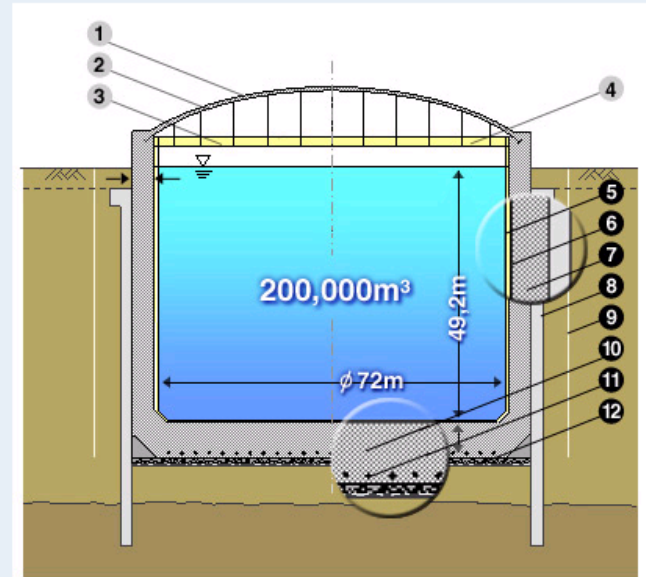
Bird's-eye view of in-ground storage tanks



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 ( $\geq 95\%$ Methane)

- Boiling points of LAr and  $\text{CH}_4$  are 87.3 and 111.6 ° K
- Latent heat of vaporization per unit volume is the same for both liquids within 5%

### Main differences:

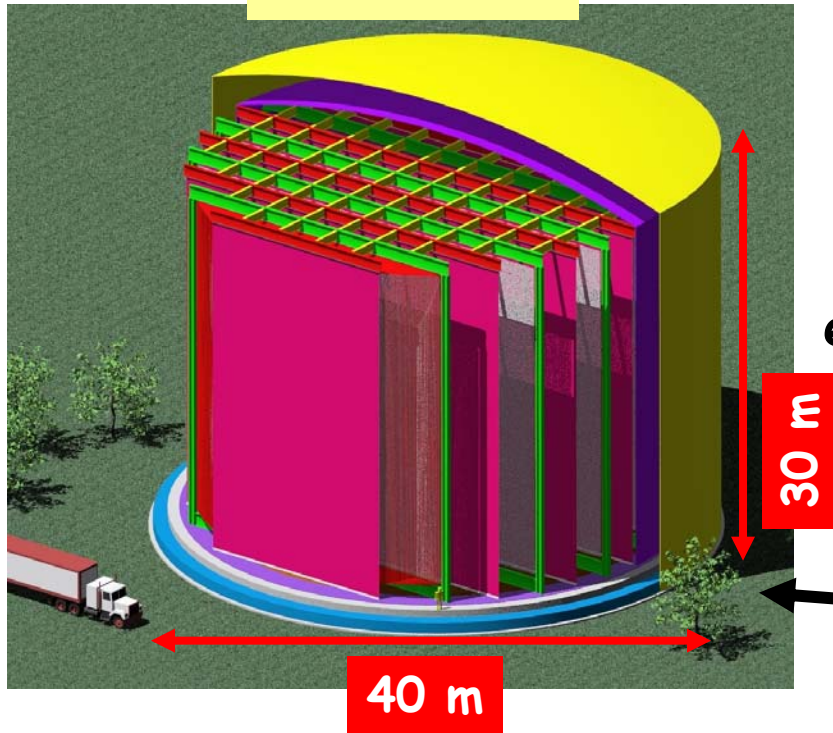
- LNG flammable when present in air within 5 - 15% by volume, LAr not flammable
- $\rho_{\text{LAr}} = 3.3 \rho_{\text{CH}_4}$ , tank needs to withstand 3.3 times higher hydrostatic pressure

50 kton LAr

# FLARE

Fermilab-Proposal-0942, Aug. 2004  
hep-ex/0408121

A scalable detector with a non-evacuatable dewar and ionization charge detection without amplification



LNG style tank: CB&I  
standard design for double  
wall and double roof vessel

- Thermal insulation
  - 1.2 m thick layer of perlite
  - boil-off rate of 0.05%/day (25 ton/day)
  - a cryogenic system is necessary in order to re-liquefy this gas mass
- Wire planes
  - 3 m drift distance, 5 mm wire spacing
  - large wire planes, with the largest of 30x40 m<sup>2</sup>

# Purification starting from air in the Tank

## Warm argon gas used as a piston

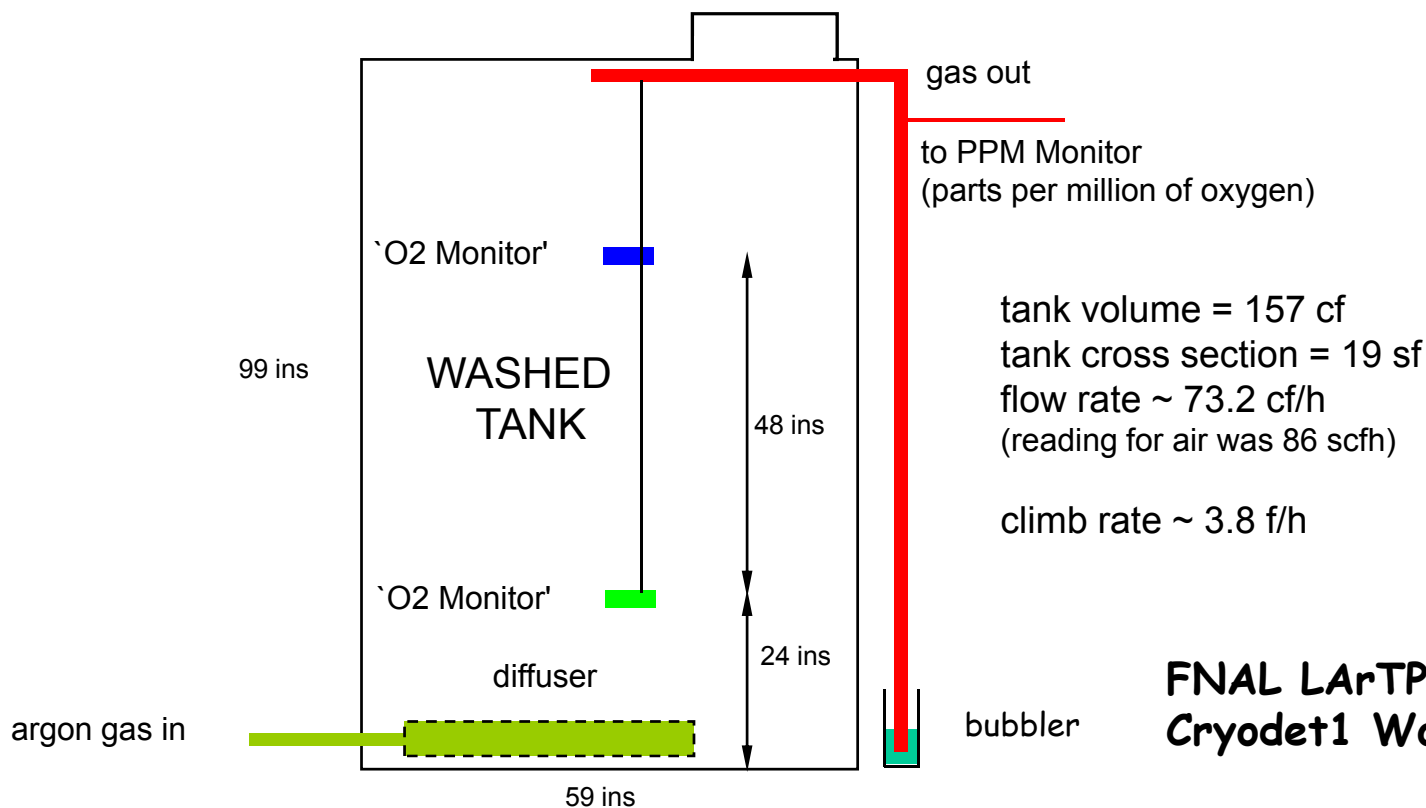
purge oxygen to 50ppm or less  
vertical velocity chosen to control diffusion

## Recirculation to purify warm argon gas

remove water and oxygen, goal is 500ppb oxygen  
i. e., achieve purity similar to that achieved by ICARUS with evacuation

## Liquid purification

Final purity expected to be determined by contaminants from tank walls, TPC materials, flow restrictions due to presence of TPC, leaks, etc.

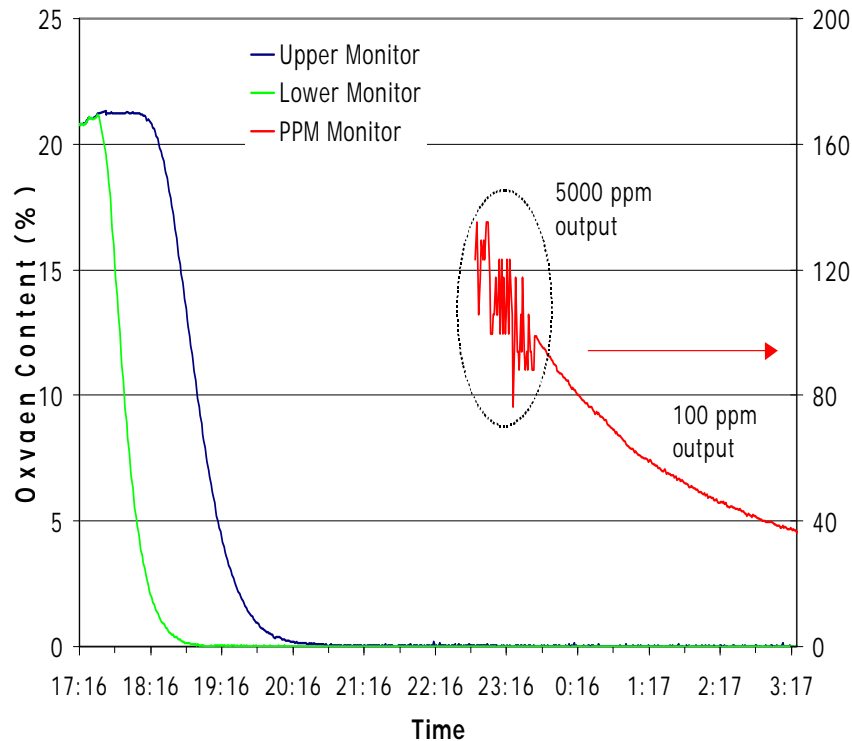


FNAL LArTPC, Gran Sasso  
Cryodet1 Workshop March 2006

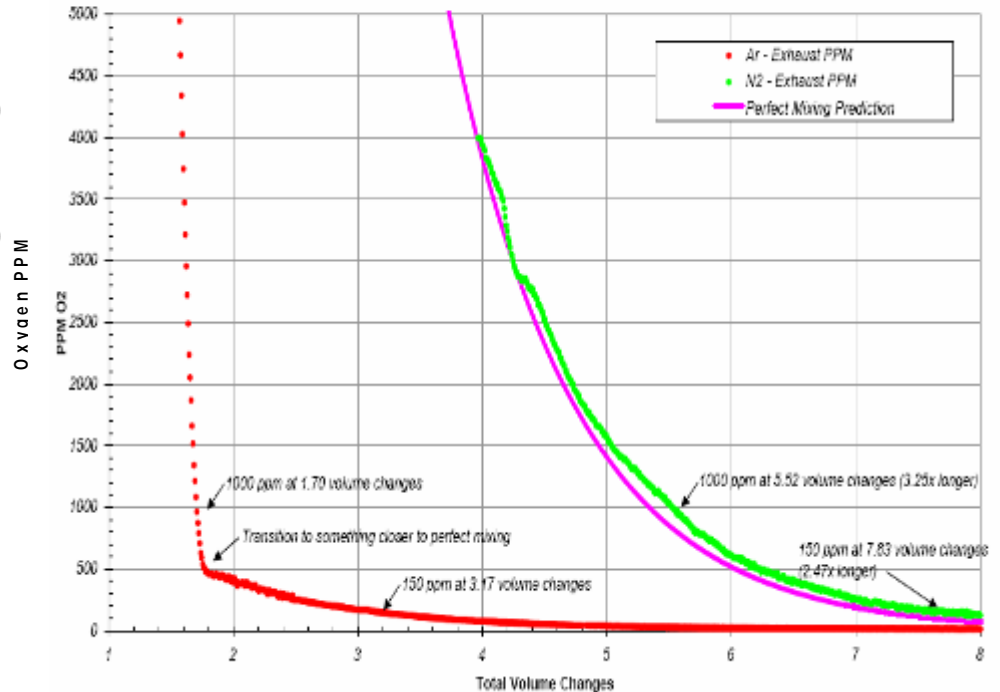
# Measurements using an “Argon Piston” to Purge oxygen

Terry Tape  
6/3/06

## Oxygen Content vs Time



## Comparison of Argon and Nitrogen purges introduced at the bottom of the PAB tank Exhaust stream 0 - 5000 PPM O2 Sensor

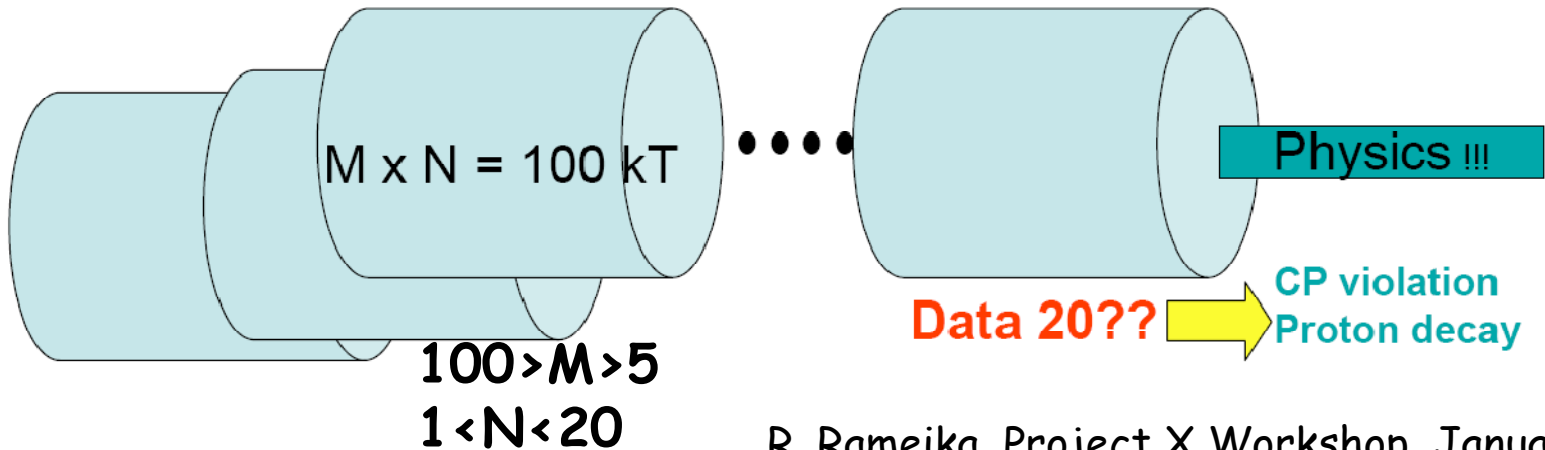


to 100 ppm (reduction of 2,000) takes 6 hrs = 2.6 volume changes  
(cf simple mixing, which predicts  $\ln(2000) = 7.6$  volume changes)

**FNAL LArTPC, Gran Sasso  
Cryodet1 Workshop March  
2006**

# Recently Proposed Strategy @ Fermilab

## Evolution of the Liquid Argon Physics Program



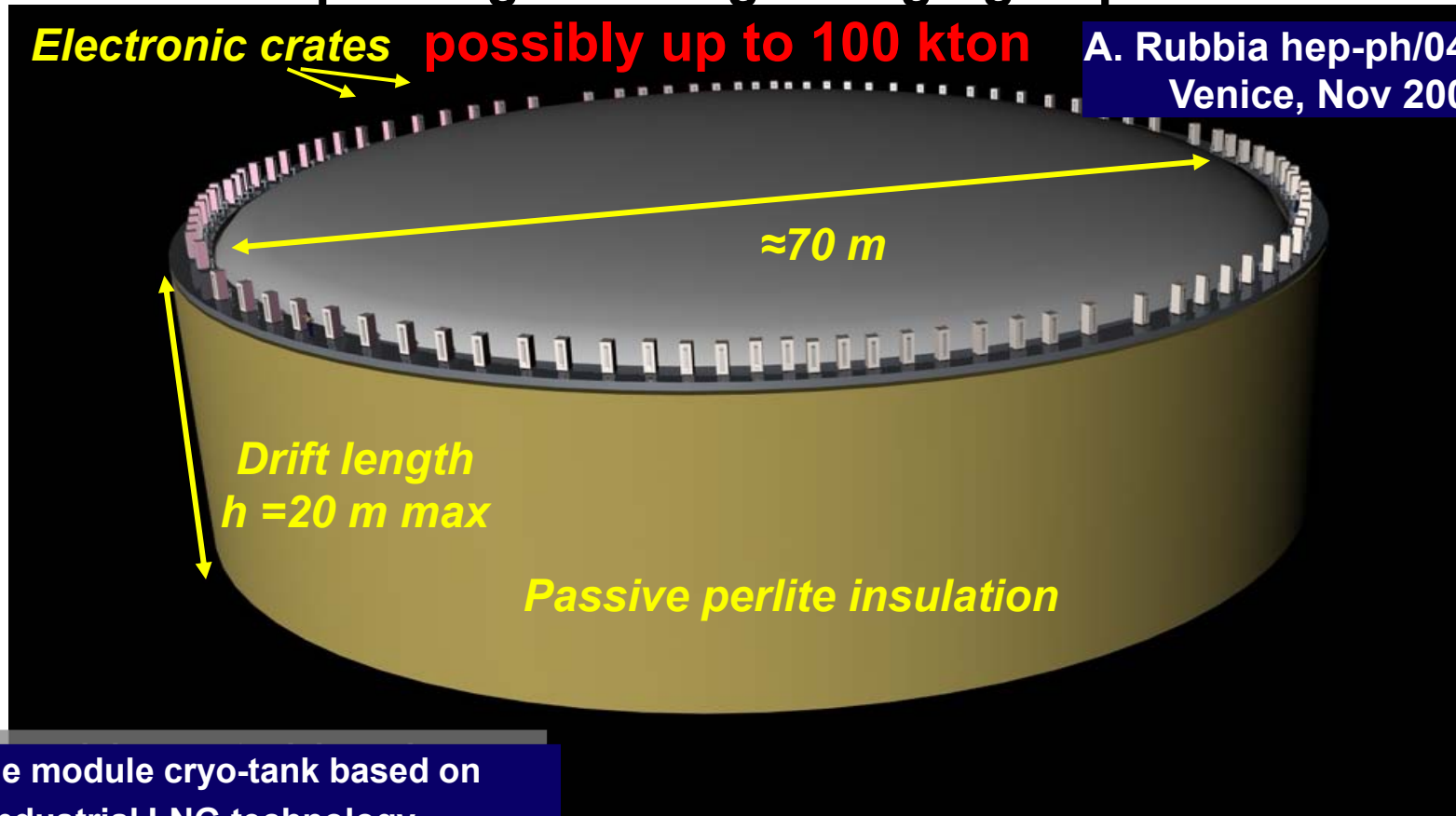
# GLACIER

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

## Giant Liquid Argon Charge Imaging Experiment

**Electronic crates possibly up to 100 kton**

A. Rubbia hep-ph/0402110  
Venice, Nov 2003



Single module cryo-tank based on industrial LNG technology

# GLACIER concepts for a scalable design

- **LNG tank**, as developed for many years by petrochemical industry
  - Certified LNG tank with standard aspect ratio
  - Smaller than largest existing tanks for methane, but underground
  - **Vertical electron drift** for full active volume
- A new method of readout (**Double-phase with LEM**)
  - to allow for very long drift paths and cheaper electronics
  - to allow for low detection threshold ( $\approx 50$  keV)
  - to avoid use of readout wires
  - A path towards pixelized readout for 3D images.
- **Cockroft-Walton (Greinacher) Voltage Multiplier** to extend drift distance
  - High drift field of 1 kV/cm by increasing number of stages, w/o VHV feed-through
- **Very long drift path**
  - Minimize channels by increasing active volume with longer drift path
- **Light readout** on surface of tank
- Possibly immersed superconducting solenoid for B-field

# Scaling parameters

100 kton:

Dewar	$\varnothing \approx 70$ m, height $\approx 20$ m, perlite insulated, heat input $\approx 5$ W/m <sup>2</sup>
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m <sup>3</sup> , ratio area/volume $\approx 15\%$
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\varnothing \approx 70$ m located in gas phase above liquid phase
Charge readout electronics	<b>100000 channels</b> , 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 photon counting capability

10 kton:



Dewar	$\varnothing \approx 30$ m, height $\approx 10$ m, perlite insulated, heat input $\approx 5$ W/m <sup>2</sup>
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	7000 m <sup>3</sup> , ratio area/volume $\approx 33\%$
Argon total mass	9900 tons
Hydrostatic pressure at bottom	1.5 atmospheres
Inner detector dimensions	Disc $\varnothing \approx 30$ m located in gas phase above liquid phase
Charge readout electronics	<b>30000 channels</b> , 30 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 300 immersed 8" PMTs with WLS

1 kton:

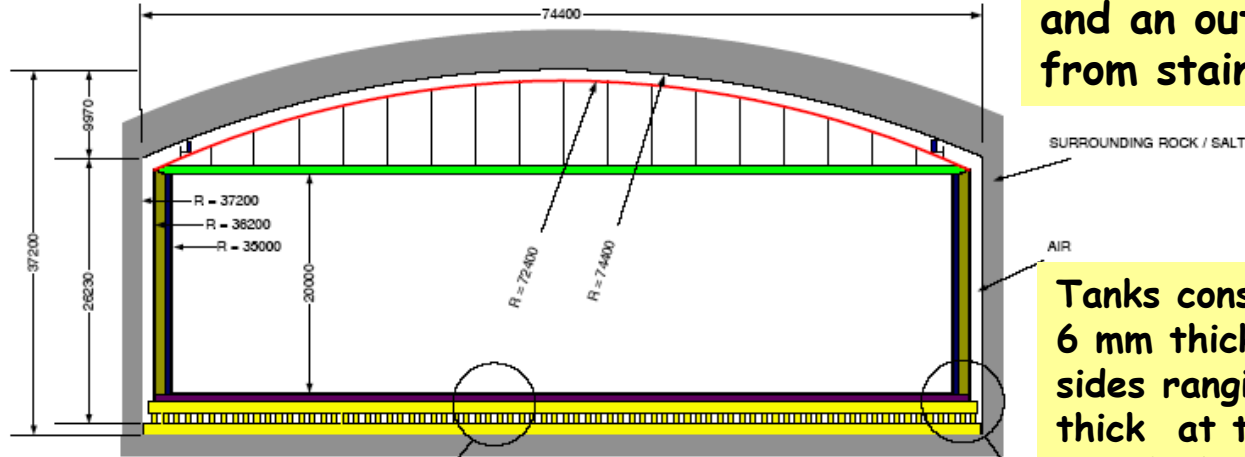
1% prototype: engineering detector,  $\varnothing \approx 10$  m, h  $\approx 10$  m (?)



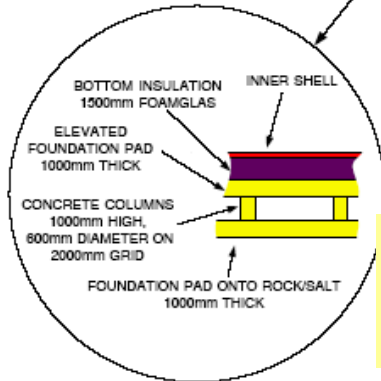
TECHNODYNE INTERN

# Large underground LAr storage tank

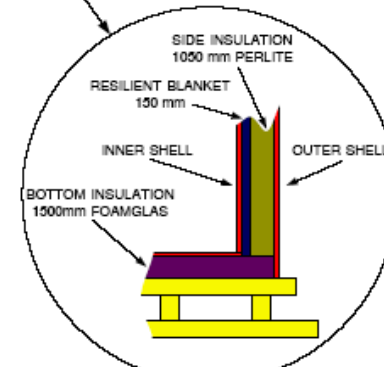
Full containment tank consisting of an inner and an outer tank made from stainless steel



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



Project: Large Underground Argon Storage Tank

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

Estimated boil-off 0.04%/day

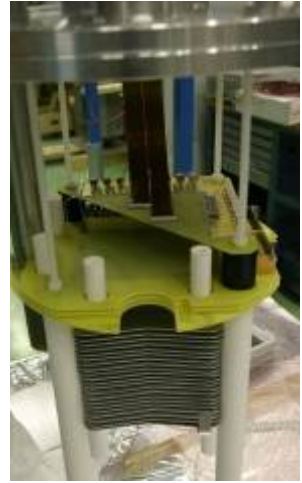
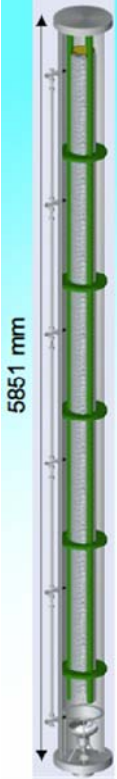
# Personal Considerations

- The dewar technology is the crucial choice for huge LAr detectors
  - A modular approach is unfeasible for ~100 kton LAr mass (cost, complications, ...)
  - Huge evacuable dewars (~40x40x40 m<sup>3</sup>) have quite a complicated mechanical structure and might present safety problems during evacuation
  - Huge non-evacuatable dewars are currently built as LNG containers , also as underground installation
    - heat input and argon consumption have to be carefully evaluated (⇒ running costs)
    - purification of such large volumes starting from air at atmospheric pressure should not be a problem (but R&D on powerful clean cryogenic pumping system is essential)
    - a harder problem is how to check for leaks, which might limit the achievable argon purity, if it is not possible to evacuate the dewar. Will have to rely on careful checks of all welding joints ...
- Novel readout techniques, other than wires, possibly with amplification of the ionization signals, are an essential R&D item
  - amplification allows longer drift paths
  - how to handle, electrically and mechanically, wire lengths ≥ 20 m?

# GLACIER R&D

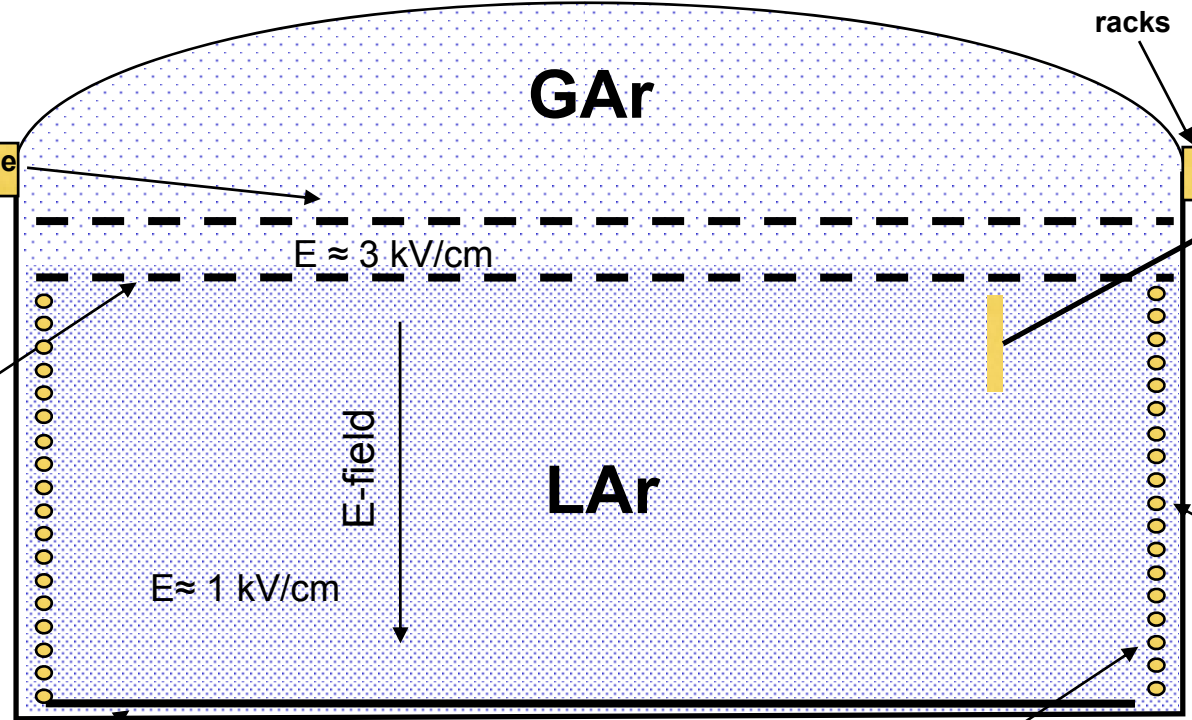
ArgonTube: 5 m drift test

Charge readout with extraction from liquid phase & amplification in gas phase for long drifts



Charge readout plane

Electronic racks



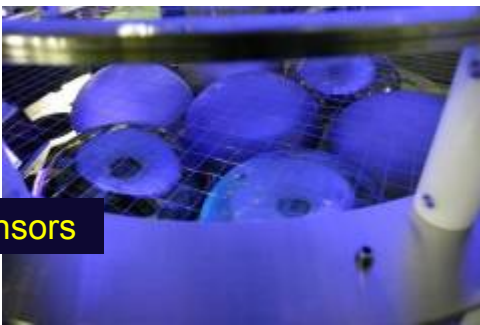
5851 mm

Field shaping electrodes

Extraction grid

UV & Cerenkov light readout photosensors

Cathode (- HV)

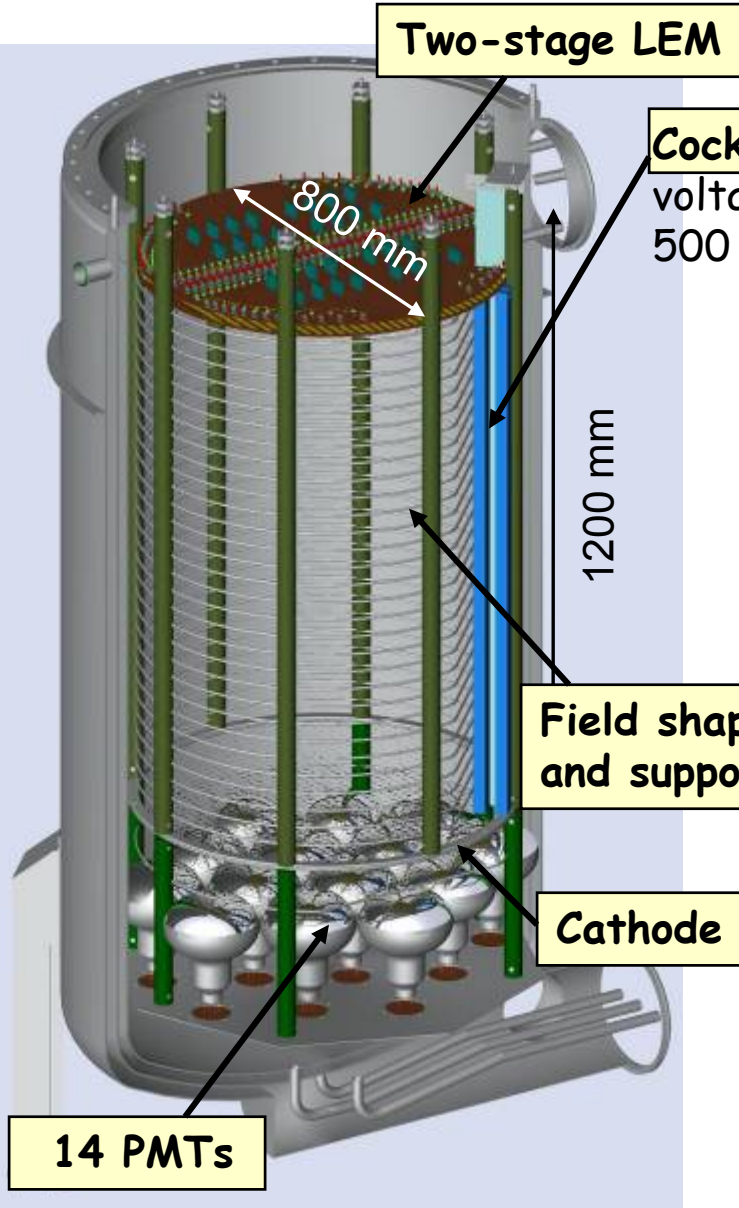


Greinacher voltage multiplier up to MV

Large area DUV sensitive photosensors

# ArDM assembly @ CERN

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



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

**Field shaping rings and support pillars**

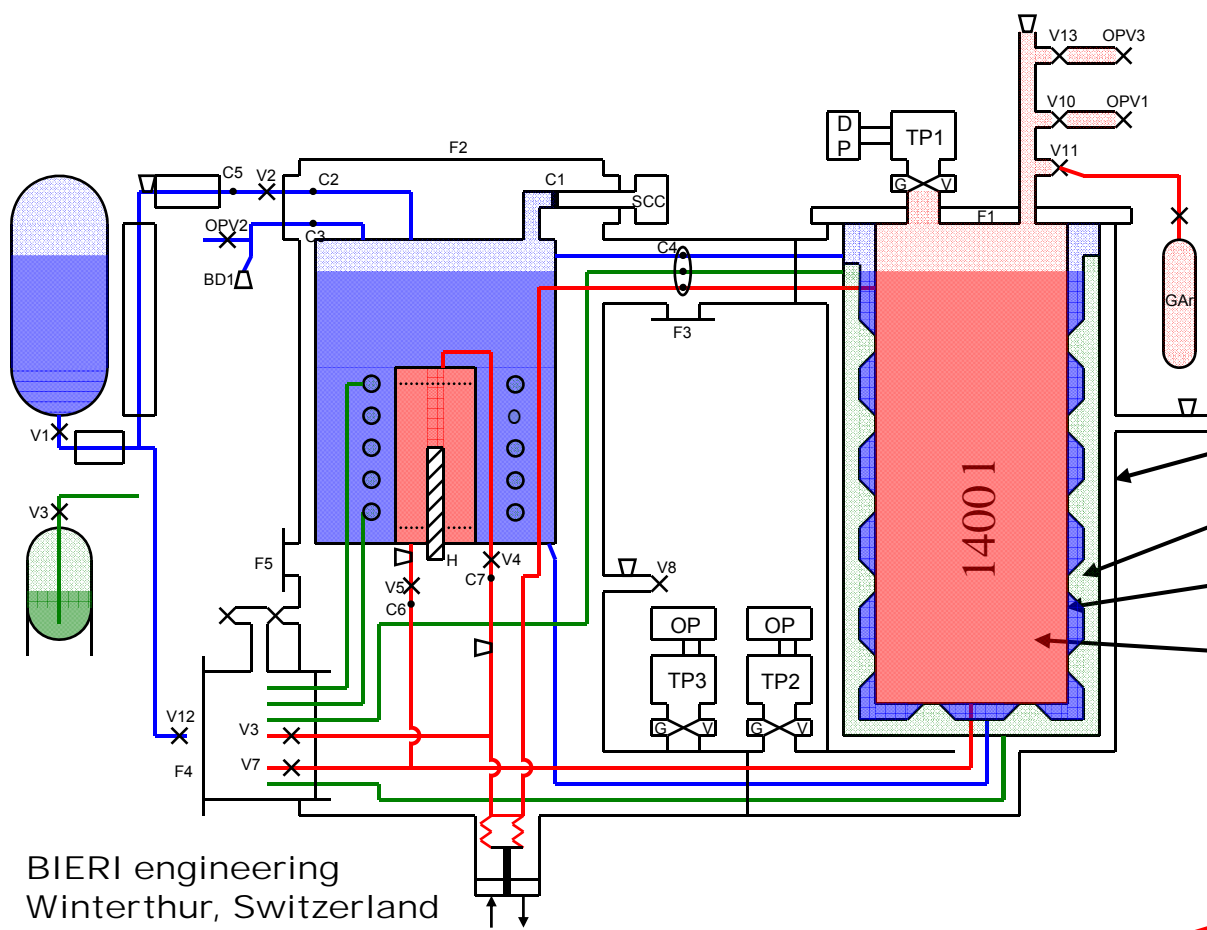
**Cathode grid**

**14 PMTs**



ETHZ, Zurich,  
Granada, CIEMAT,  
Soltan, Sheffield

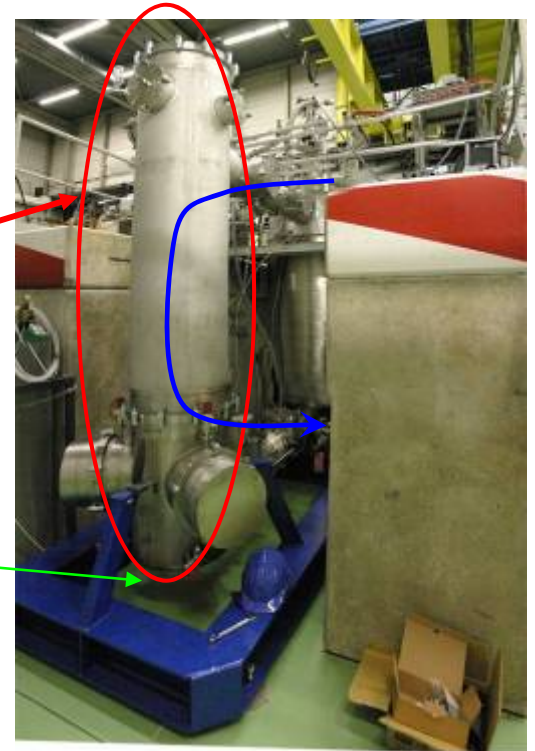
# ArDM Cryogenics and LAr purification



vacuum insulation  
LN2 cooling jacket  
'dirty' LAr cooling bath  
pure LAr closed circuit

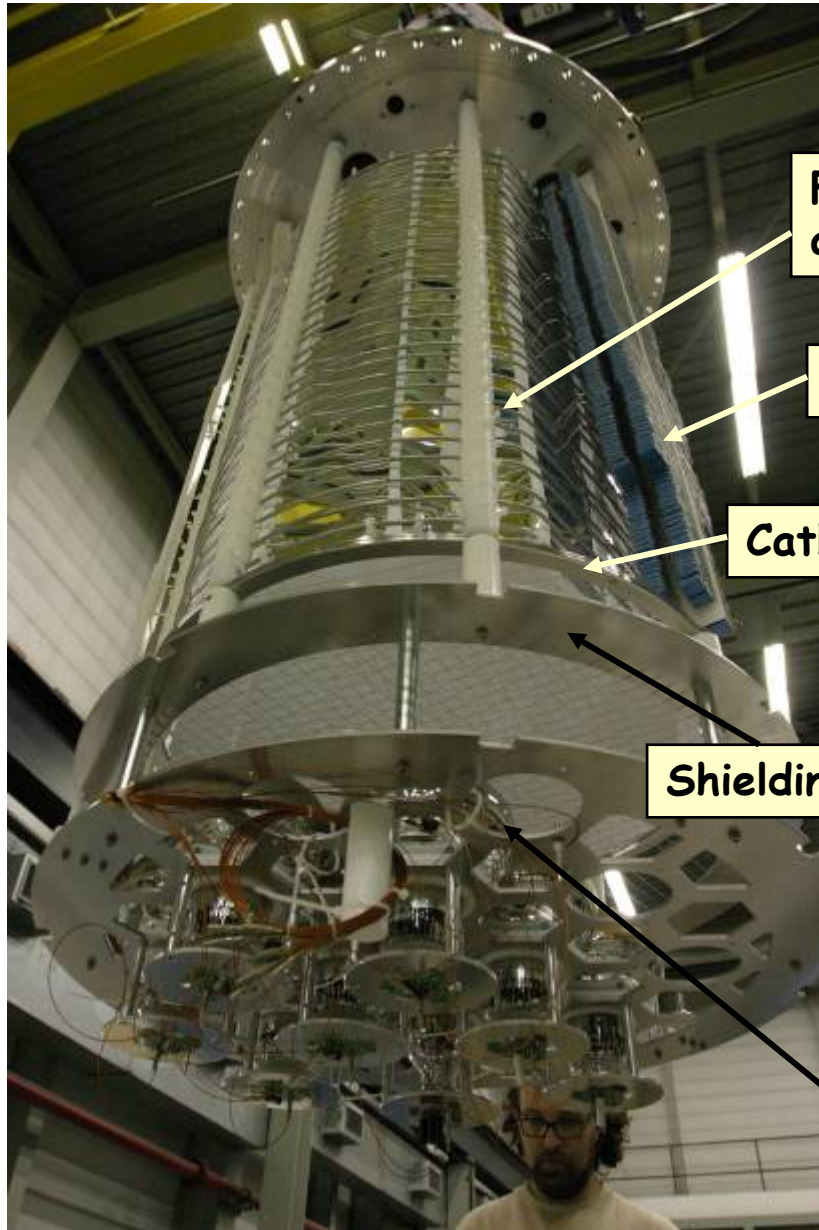
Recirculation and CuO  
purification cartridge

Bellow pump



BIERI engineering  
Winterthur, Switzerland

# ArDM Inner Detector



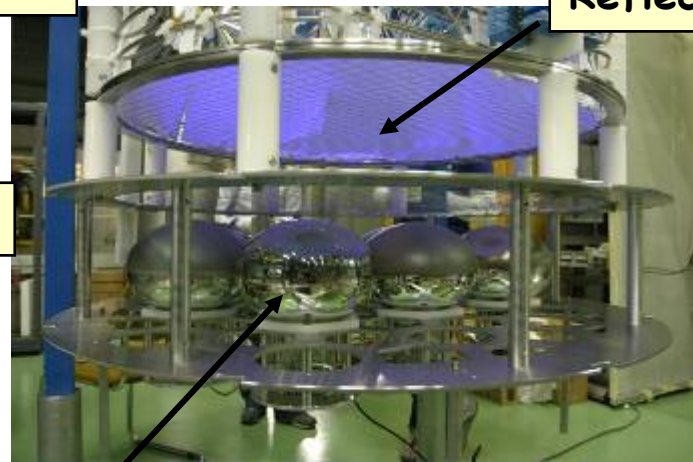
Field shaping rings and support pillars

Cockroft-Walton (Greinacher) chain

Cathode grid

Shielding grid

PMTs



Reflector foils

First fill with LAr by the end of March '08

# ArDM High voltage system

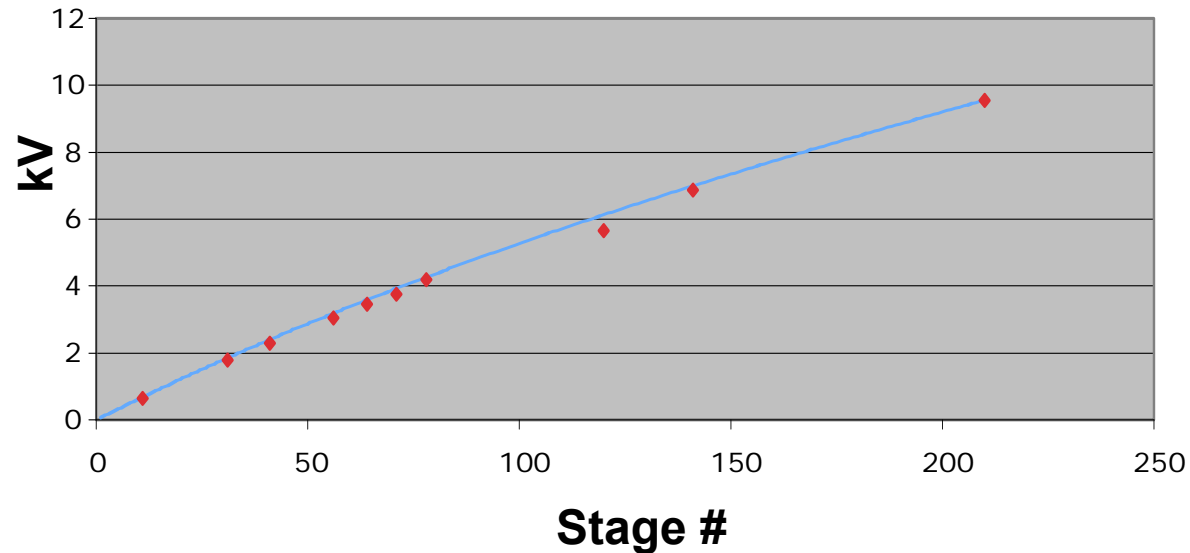
- A cascade of HV multiplication stages (Cockroft-Walton/Greiner circuit) directly connected to the field shaping rings
- Voltage at the last stage designed to reach  $\sim 500$  kV, i.e. 4 kV/cm
- nonlinearity of the voltage distribution can be corrected with proper HV stage connection to each field shaper

30 field shapers

210 stages

cathode

Voltage measurement in air

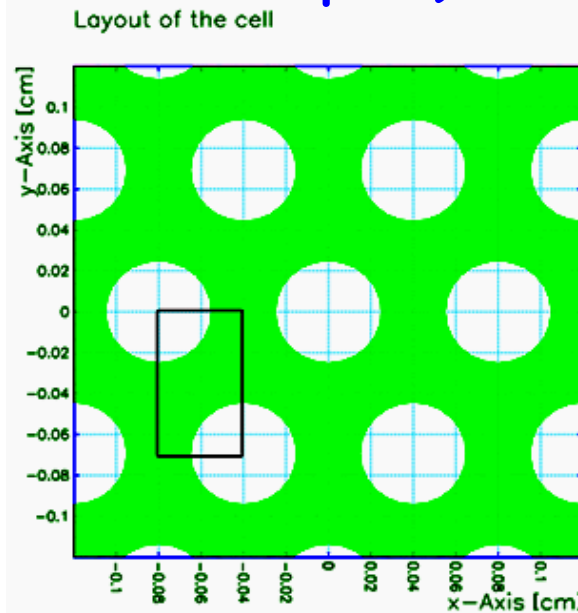


# ArDM Charge Read-Out System: LEM

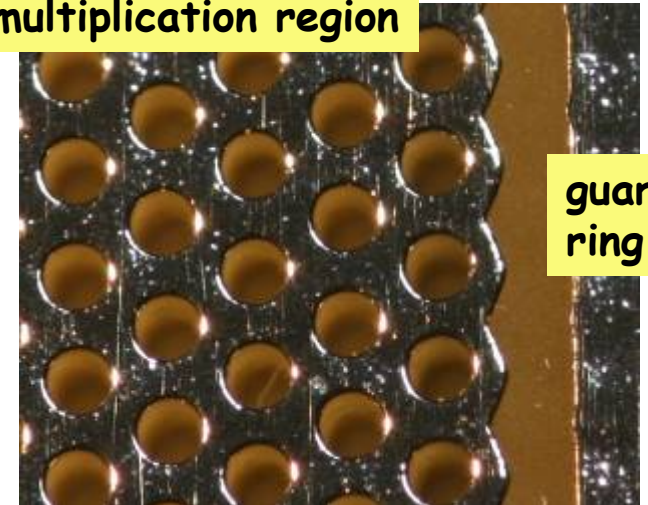
- GEM: F. Sauli, NIM A386 (1997) 531
- Optimized GEM: V. Peskov *et al.*, NIM A433 (1999) 492
- THGEM: R. Chechik *et al.*, NIM A535 (2004) 303
- P. Otiougova (for ArDM Coll.), Proc. TAUP '07

**LEM (Large Electron Multiplier) is a thick macroscopic GEM**

Produced by  
standard Printed  
Circuit Board  
methods

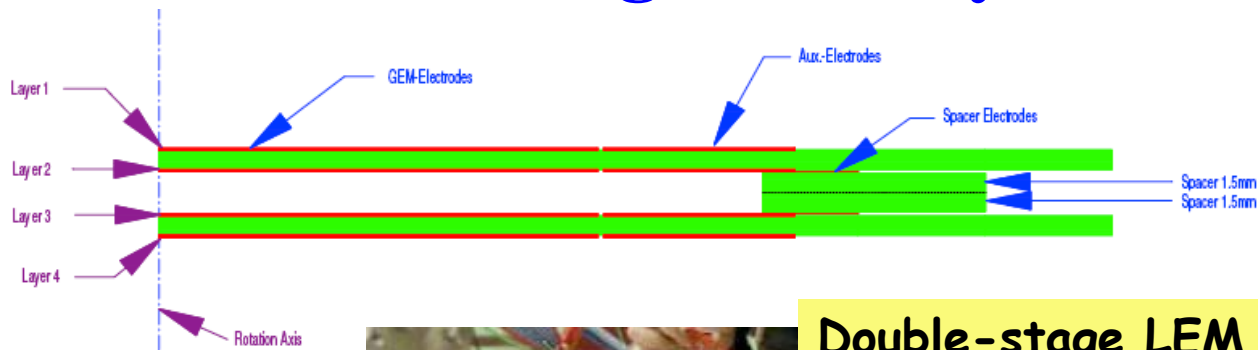
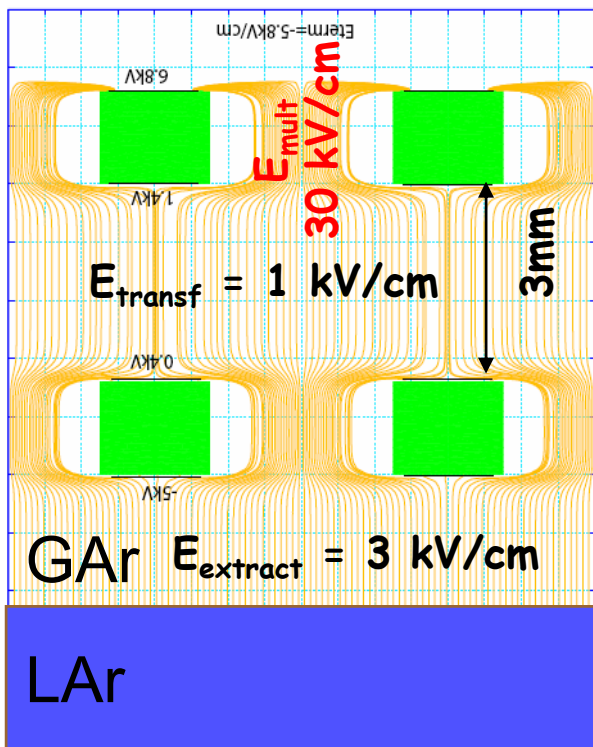


multiplication region

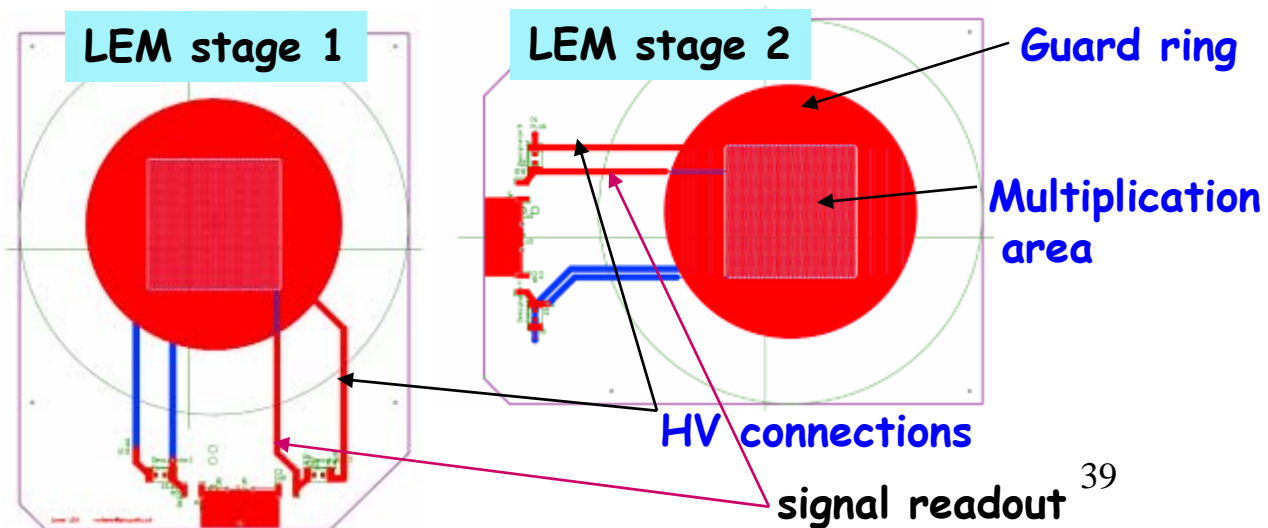
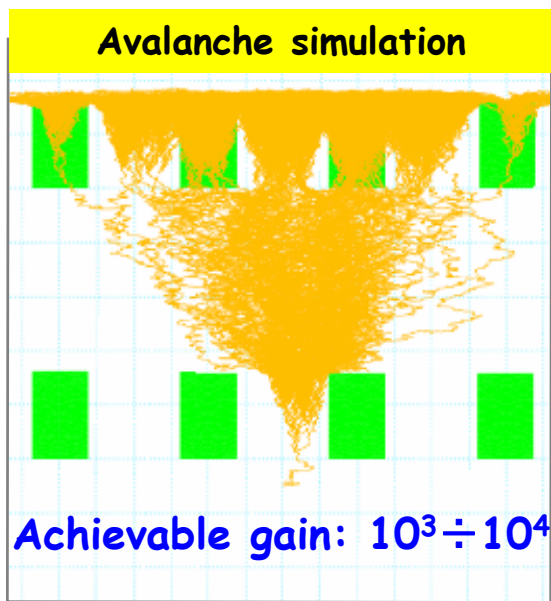
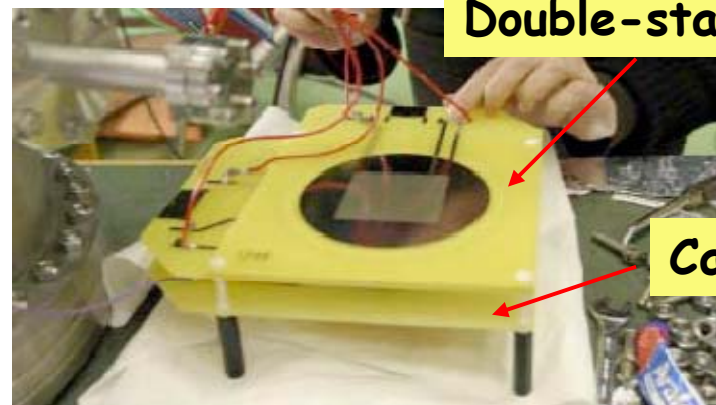


- Double-sided copper-clad (35  $\mu\text{m}$  layer) G-10 plates
- Precision holes by drilling
- Palladium deposition on Cu ( $< \sim 1 \mu\text{m}$  layer) to avoid oxidization
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500  $\mu\text{m}$
- Distance between centers of neighboring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

# Double-stage LEM system

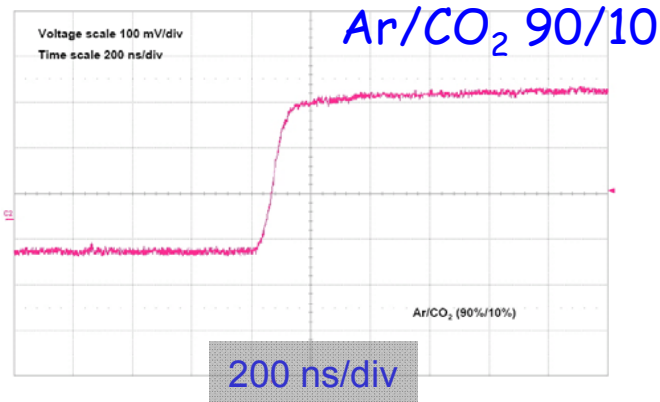
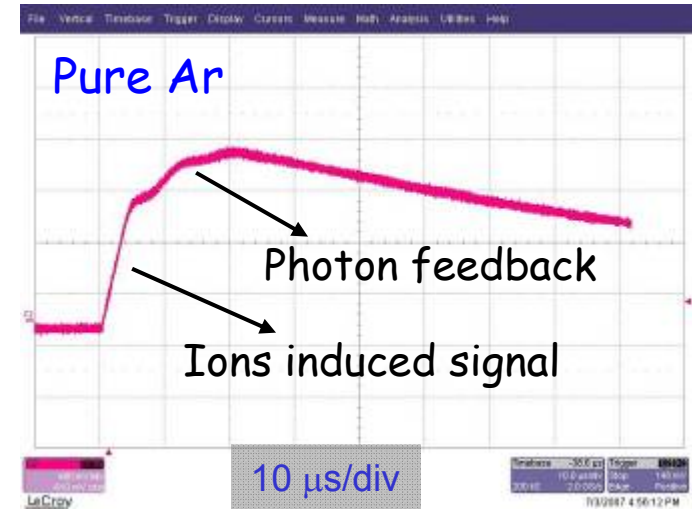
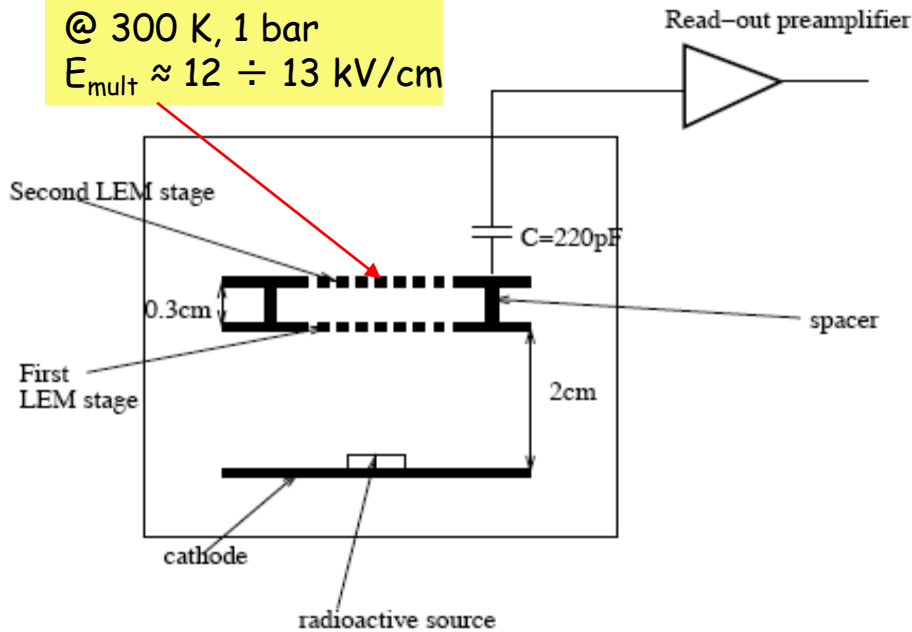


P. Otiougova  
(for ArDM Coll.),  
Proc. TAUP '07

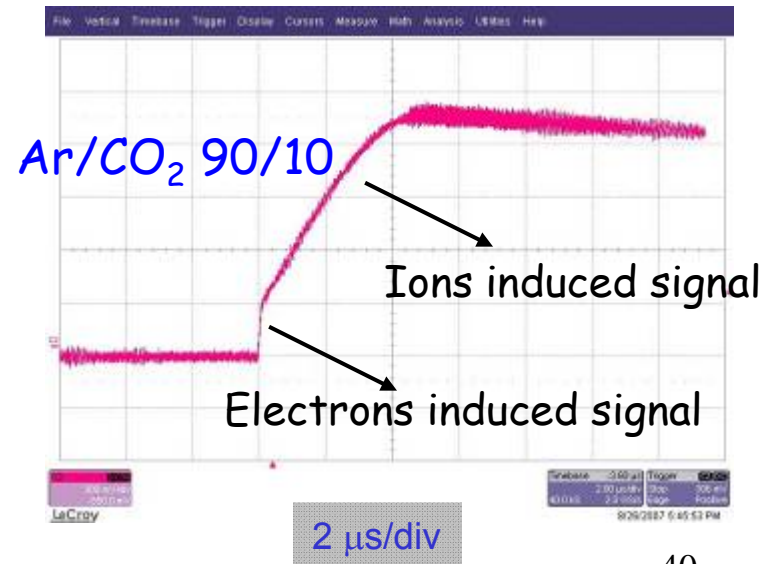


# LEM operation in gas

@ 300 K, 1 bar  
 $E_{\text{mult}} \approx 12 \div 13 \text{ kV/cm}$



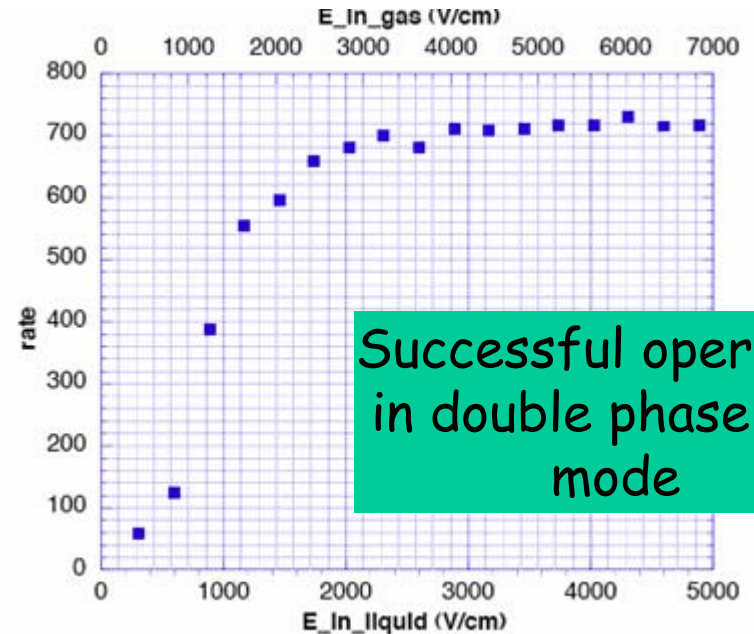
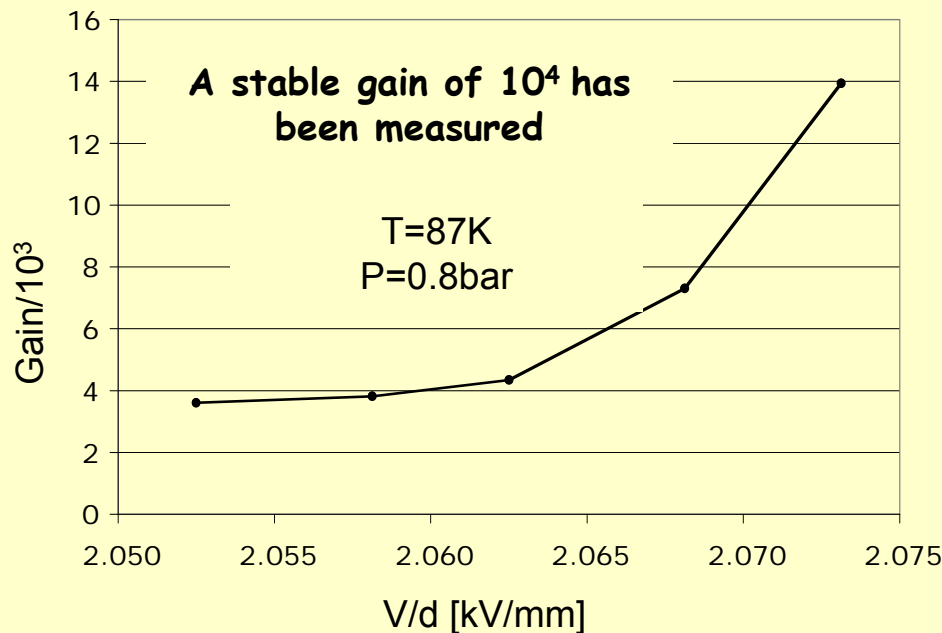
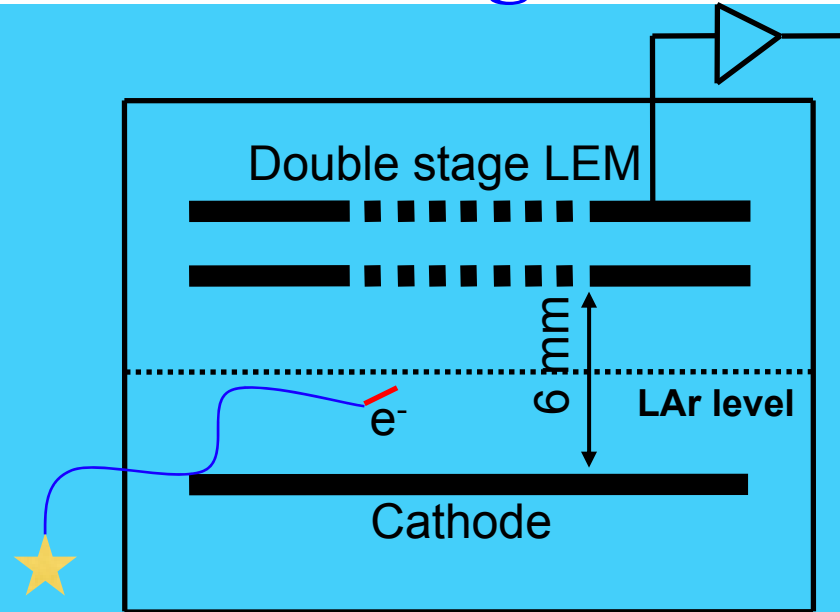
Faster signal achieved by drifting electrons to an anode and so enhancing the electron component signal



# Double phase operation with two stage LEM

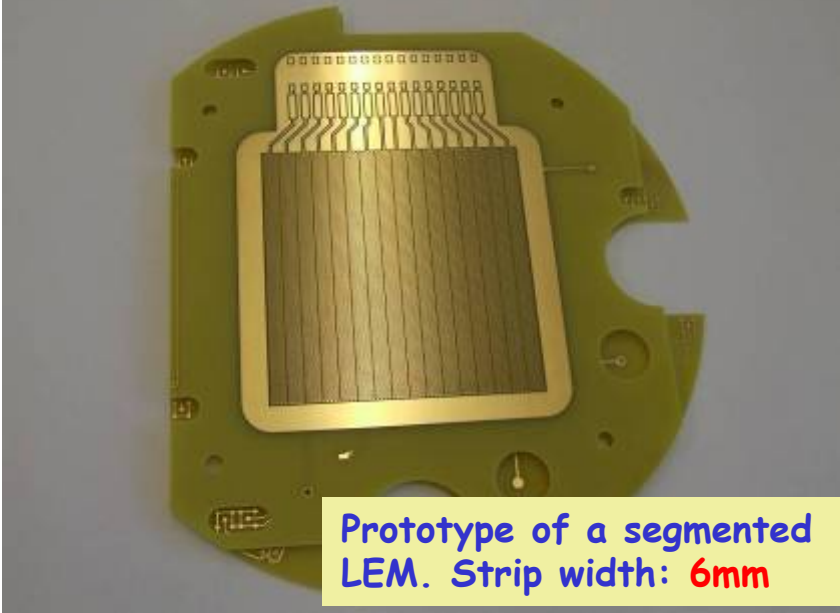


External sources  
(1275keV and 662keV)



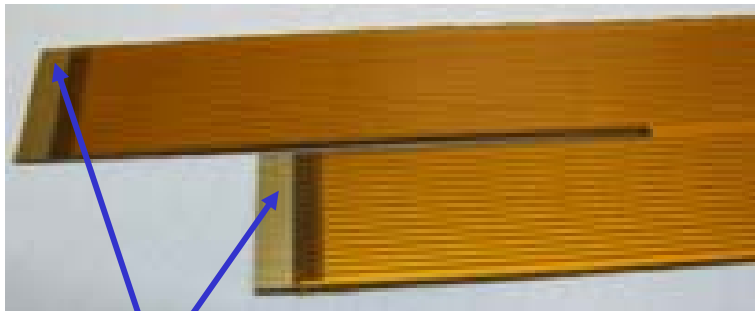
# ArDM Segmented LEM Prototype

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



Prototype of a segmented LEM. Strip width: 6mm

- 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



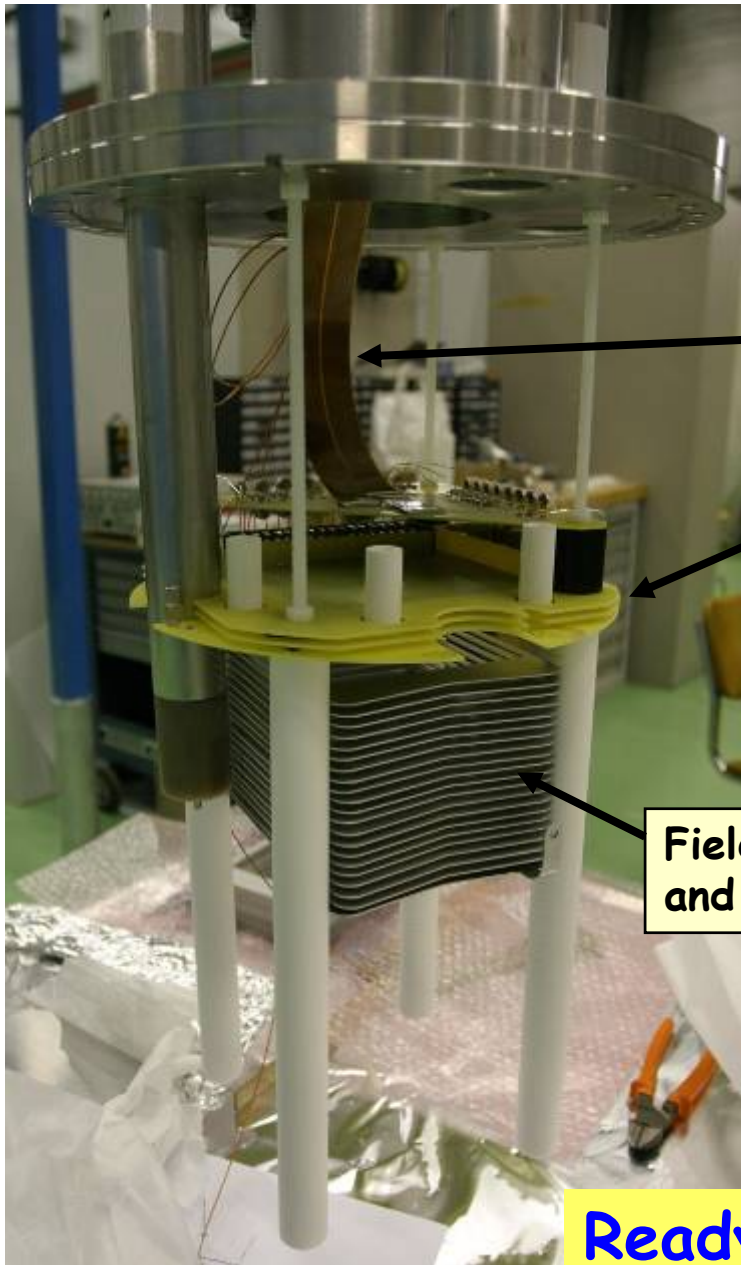
to ZIF connectors on the LEM board



32 channels/cable

to front-end preamplifiers<sup>42</sup>

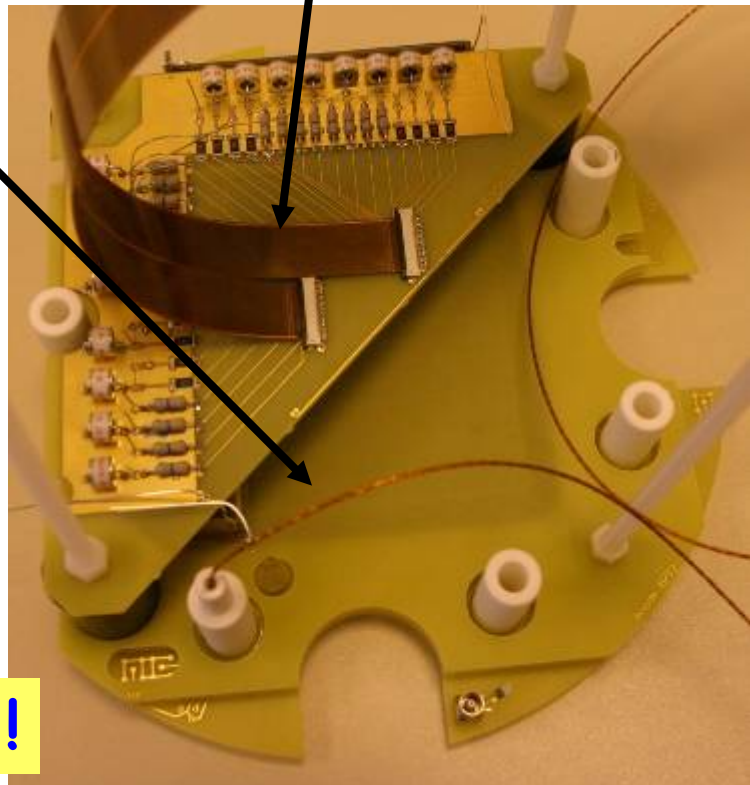
# Test LEM setup for ArDM



Kapton flex-prints

Double-stage LEM + Anode

Field shapers and cathode



Ready for tests !

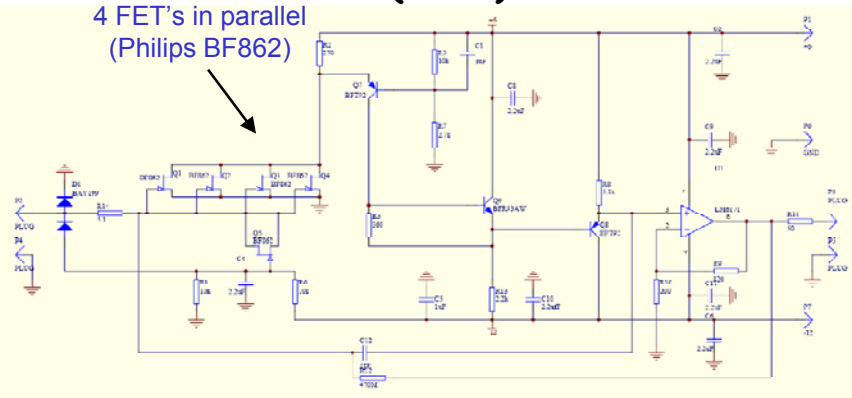
Low noise charge preamp inspired from  
C. Boiano et al. IEEE Trans. Nucl. Sci.  
52(2004)1931

# LEM Readout Electronics for ArDM

CAEN, in collaboration with ETHZ,  
developed A/D conversion and DAQ  
system:

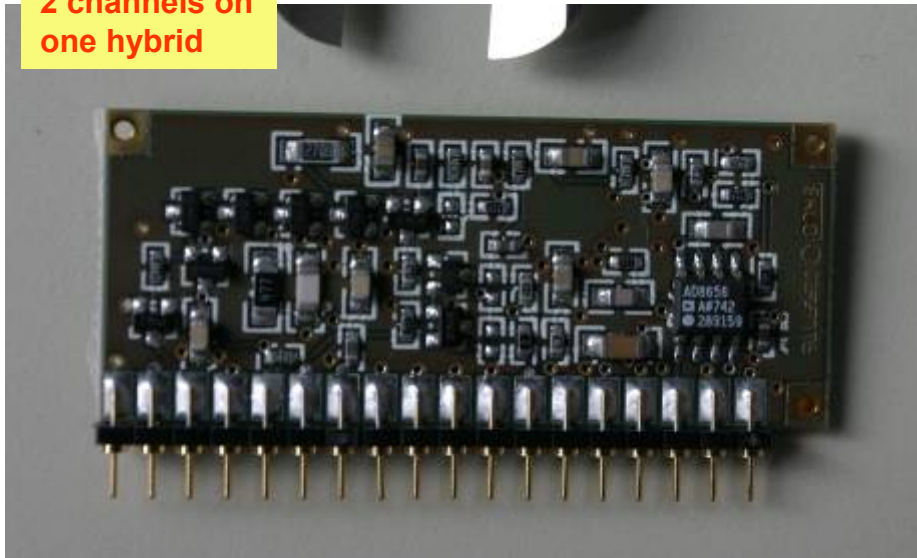
MHz serial ADC + FPGA + dual memory  
buffer + CAEN optical link

4 FET's in parallel  
(Philips BF862)



Custom-made front-end charge preamp + shaper  
 $G \sim 15\text{mV/fC}$ ,  $S/N \sim 10$  @  $1\text{fC}$  for  $C_i = 200\text{ pF}$

2 channels on  
one hybrid



A/D + DAQ  
section



32 channels  
preamplifiers

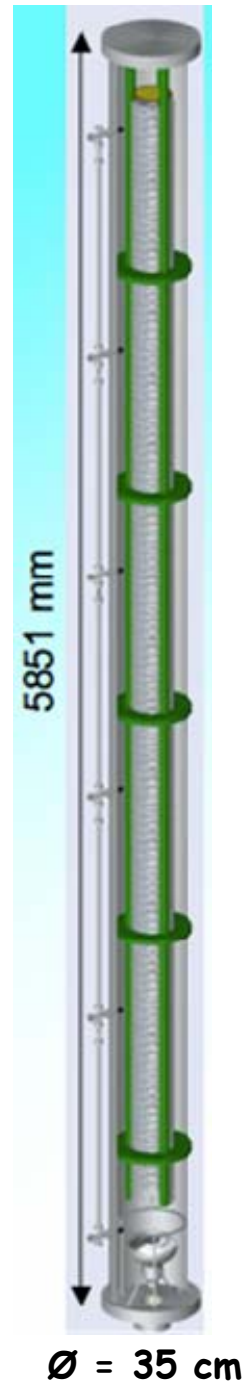
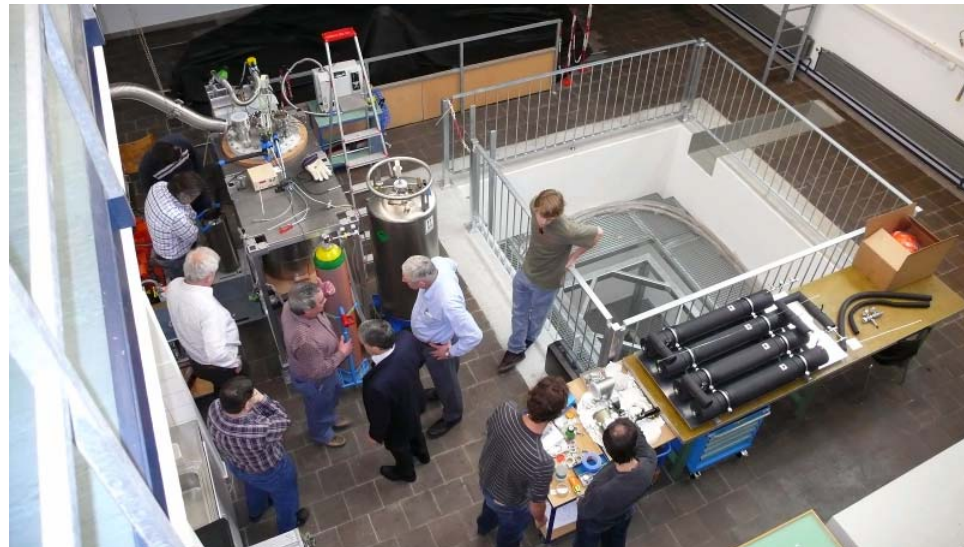
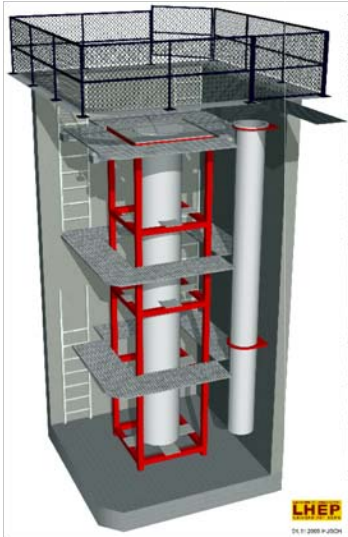
CAEN A2792  
prototype

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

# ARGONTUBE

Bern, ETHZ, Granada

- 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 scatt. length and attenuation length vs purity
- Infrastructure ready
- External dewar, detector container, inner detector, readout system, ... in design/procurement phase



# Conclusions

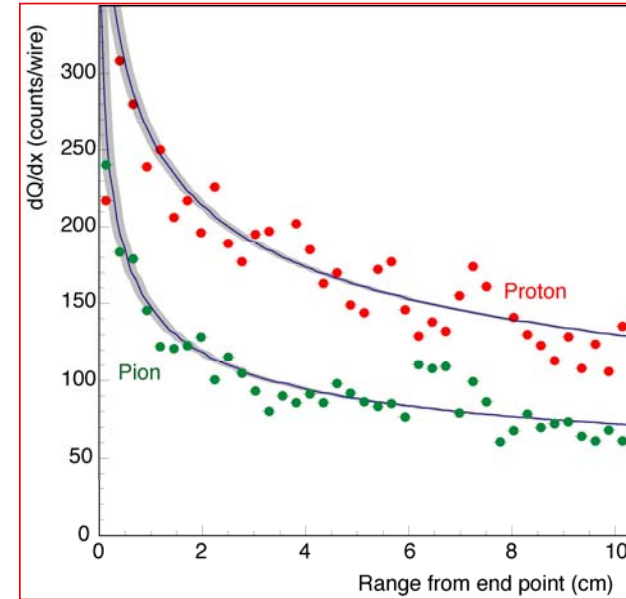
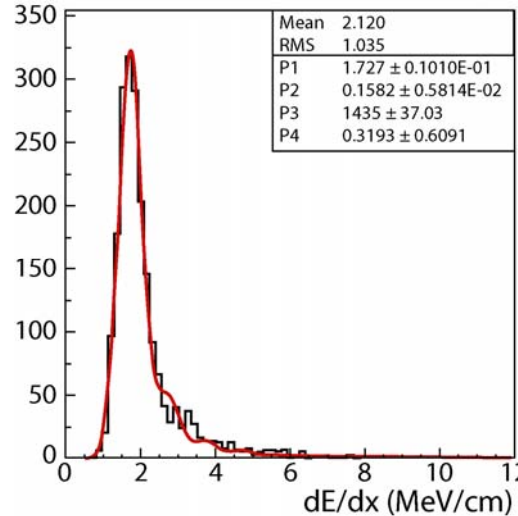
- ❖ The successful operation of the ICARUS T300 module has wakened new interest in LAr TPC detectors for neutrino oscillation measurements and proton decay searches
  - ... but the ultimate physics goals require detectors at least 100 times bigger than T600
  - exposure of 'small' detectors to neutrino beams in "near" locations and maybe to hadrons/electrons test beams is necessary to tune MC programs
- ❖ Several proposals on how to design a multi-kton LAr TPC detector
  - modular/scalable design
  - evacuable/non-evacuatable dewar and Argon purification
  - readout devices (wires vs LEM,...) and analog and digital electronics
  - high voltage systems
- ❖ To move forward from here, a full engineering design is needed for the large dewar, together with continued R&D on readout devices/electronics
- ❖ The synergy between precise detectors for long neutrino baseline experiments and proton decay (and astrophysical neutrinos) apparatus is essential for a realistic proposal for a 50-100 kton LAr detector

# A tracking calorimeter

➤ High granularity: readout pitch  $\approx 3$  mm, local energy deposition measurement, particle type identification

$$T_{kin} = \int \frac{dE}{dx} dx$$

$$\frac{\sigma_{T_{kin}}}{T_{kin}} \approx 4\%$$



➤ Fully homogenous, full sampling calorimeter

Eur. Phys. J. C33 (2004) 233  
Energy resolutions from MC

■ Low energy electrons:

$$\frac{\sigma(E_e)}{E_e} = \frac{11\%}{\sqrt{E_e(\text{MeV})}} \oplus 2.5\%$$

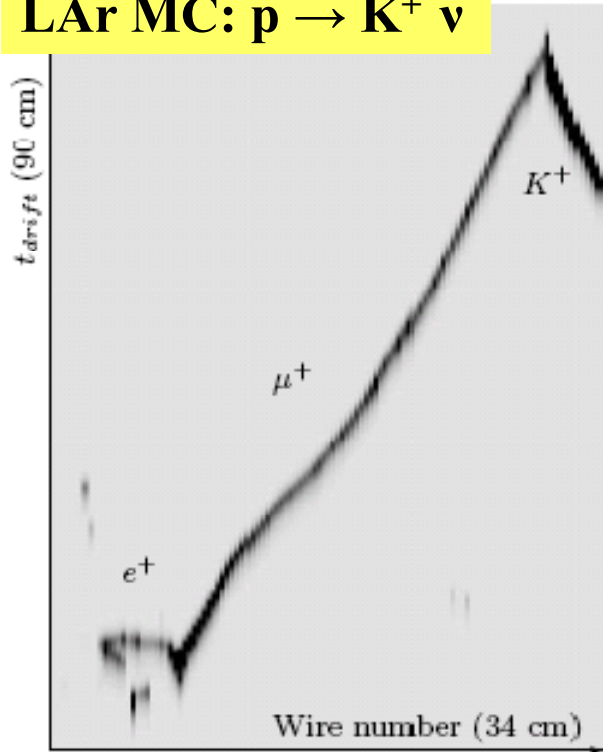
■ Electromagnetic shower:

$$\frac{\sigma(E_{em})}{E_{em}} = \frac{3\%}{\sqrt{E_{em}(\text{GeV})}} \oplus 1.5\%$$

■ Hadronic shower:

$$\frac{\sigma(E_{had})}{E_{had}} \approx \frac{30\%}{\sqrt{E_{had}(\text{GeV})}} \oplus 10\%$$

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

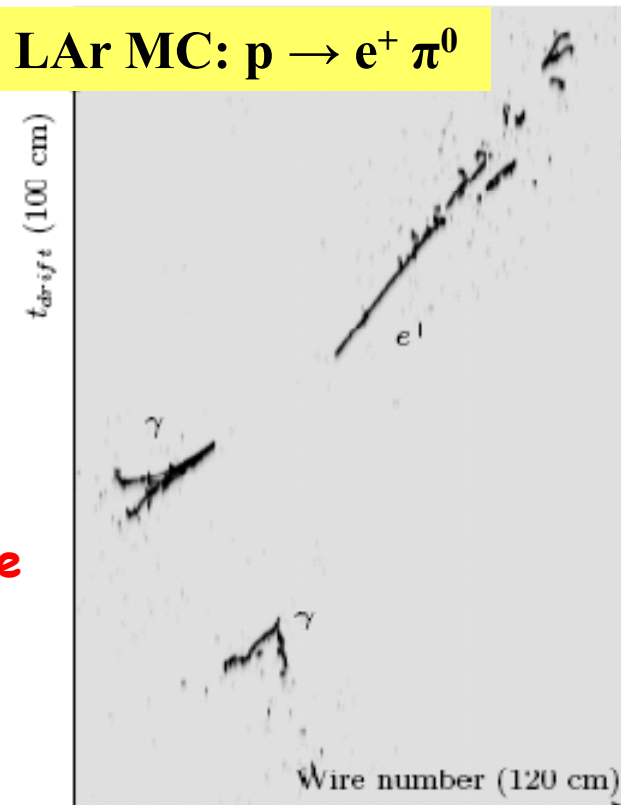


## LAr TPC as proton decay detector

K.L. Giboni "A two kiloton liquid Argon detector for solar neutrinos and proton decay", NIM 225 (1984) 579

ICARUS Coll. "ICARUS II. A second generation proton decay experiment and neutrino observatory at the Gran Sasso Laboratory", Sept. 1993

LAr MC:  $p \rightarrow e^+ \pi^0$



A. Bueno, M. Campanelli, A. Ferrari, A. Rubbia  
"Nucleon decay studies in a large liquid Argon detector", AIP Conf. proc. 533 (2000) 12

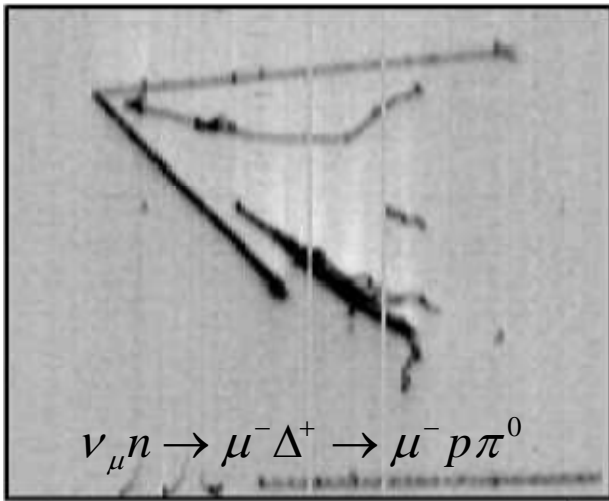
A. Bueno et al. "Nucleon decay searches with large liquid Argon TPC detectors at shallow depths: atmospheric neutrinos and cosmogenic background", JHEP04 (2007) 041

# LAr TPC as neutrino detector

- ICARUS Coll., "The ICARUS Experiment: a second-generation Proton decay experiment and Neutrino Observatory at Gran Sasso Observatory - Initial Physics Program", LNGS-P28/2001, March, 2001
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# LAr TPC as neutrino detector

- provides high efficiency for  $\nu_e$  charged current interactions
- adequate rejection against  $\nu_\mu$  NC and CC backgrounds
  - $e/\pi^0$  separation
    - fine longitudinal segmentation (few %  $X_0$ )
    - fine transverse segmentation, finer than the typical spatial separation of the 2  $\gamma$ 's from  $\pi^0$  decay
  - $e/\mu, h$  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



Collection wires. (128 wires: 32 cm.)

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

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

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

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