GLACIER: Physics Prospects With A 100 kton Liquid Argon Detector

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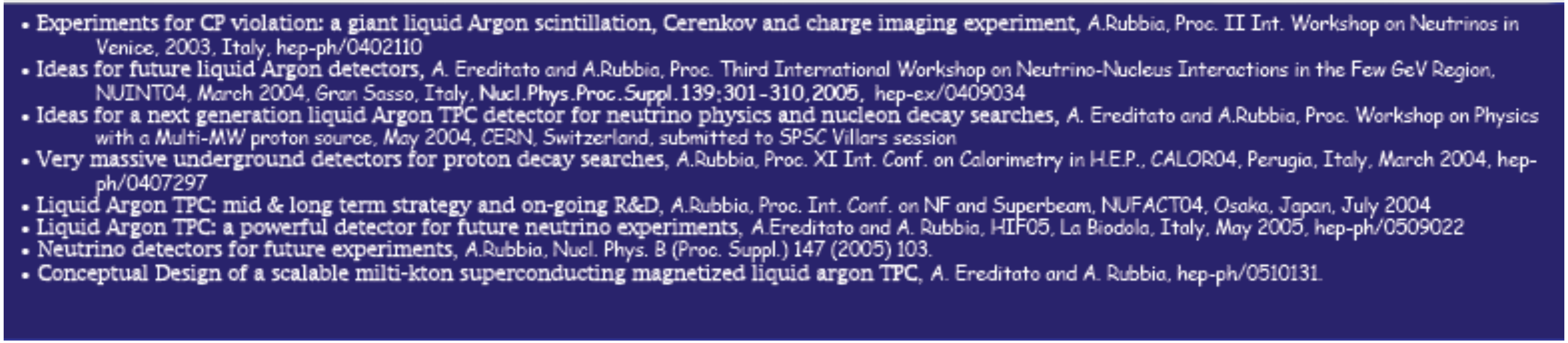
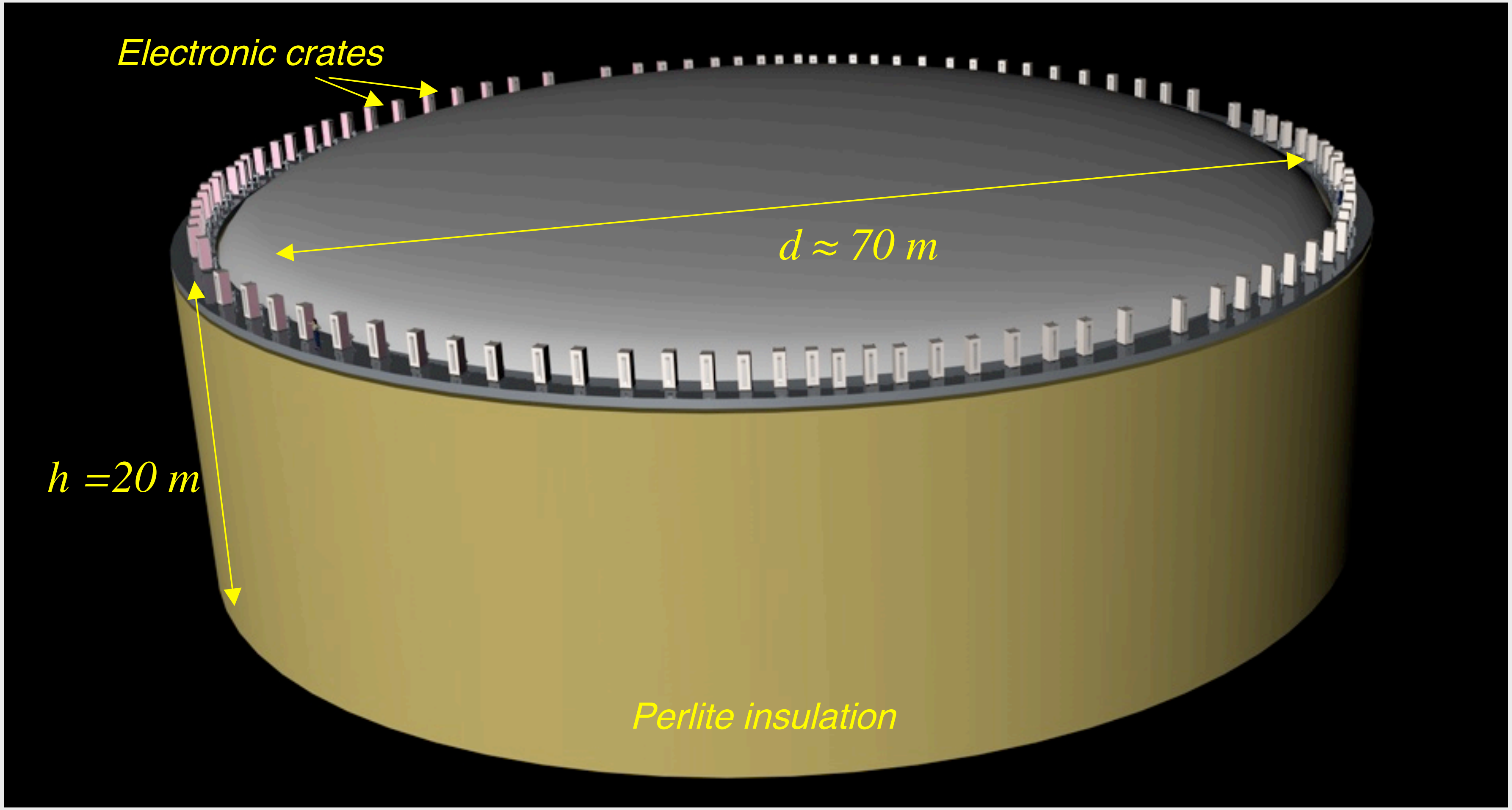
Relevant references



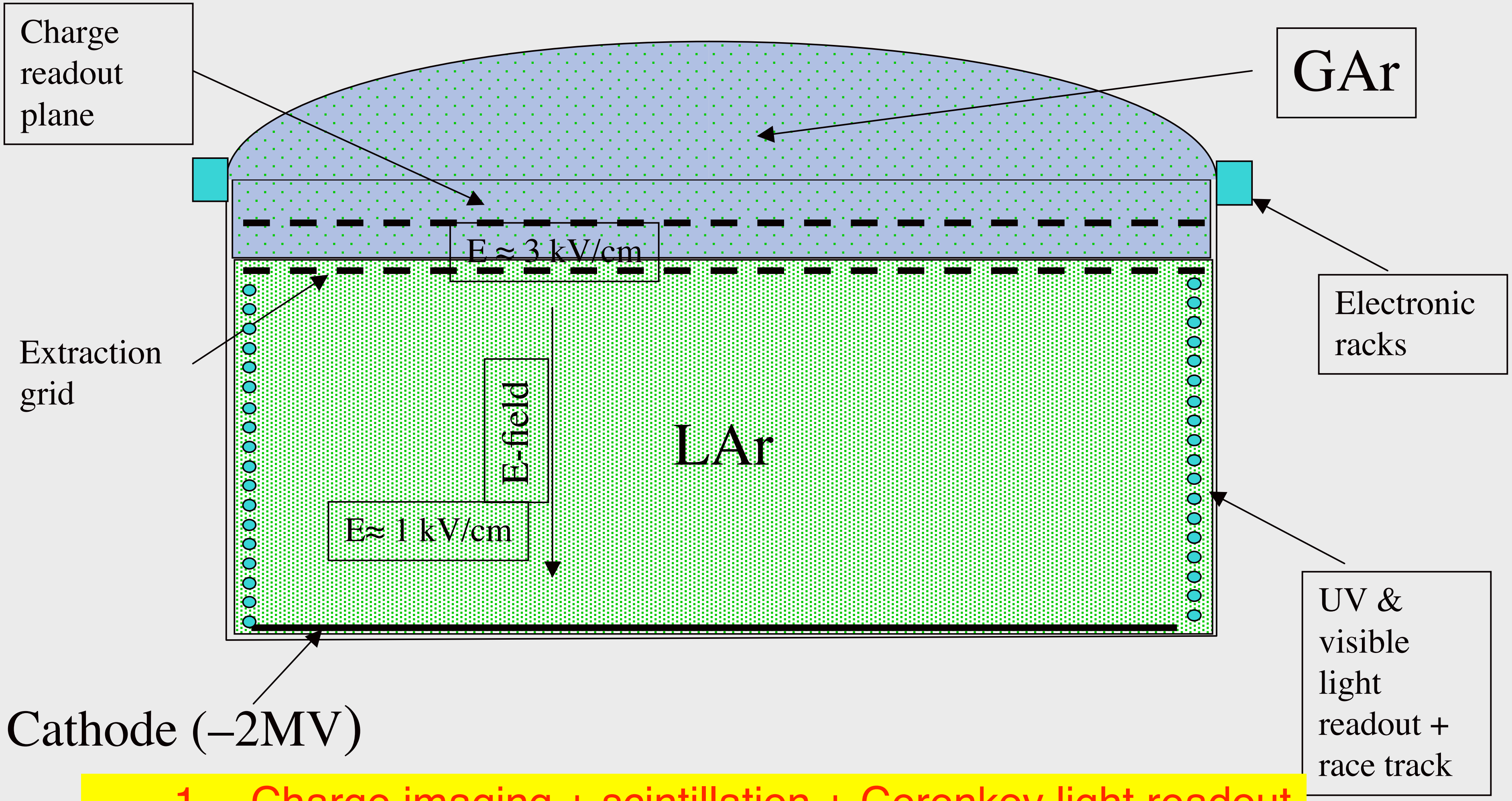
- Experiments for CP violation: a giant liquid Argon scintillation, Cerenkov and charge imaging experiment, *A.Rubbia, Proc. II Int. Workshop on Neutrinos in Venice, 2003, Italy, hep-ph/0402110*
- Ideas for future liquid Argon detectors, *A. Ereditato and A.Rubbia, Proc. Third International Workshop on Neutrino-Nucleus Interactions in the Few GeV Region, NUINT04, March 2004, Gran Sasso, Italy, Nucl.Phys.Proc.Suppl.139:301-310,2005, hep-ex/0409034*
- Ideas for a next generation liquid Argon TPC detector for neutrino physics and nucleon decay searches, *A. Ereditato and A.Rubbia, Proc. Workshop on Physics with a Multi-MW proton source, May 2004, CERN, Switzerland, submitted to SPSC Villars session*
- Very massive underground detectors for proton decay searches, *A.Rubbia, Proc. XI Int. Conf. on Calorimetry in H.E.P., CALOR04, Perugia, Italy, March 2004, hep-ph/0407297*
- Liquid Argon TPC: mid & long term strategy and on-going R&D, *A.Rubbia, Proc. Int. Conf. on NF and Superbeam, NUFACT04, Osaka, Japan, July 2004*
- Liquid Argon TPC: a powerful detector for future neutrino experiments, *A.Ereditato and A. Rubbia, HIF05, La Biodola, Italy, May 2005, hep-ph/0509022*
- Neutrino detectors for future experiments, *A.Rubbia, Nucl. Phys. B (Proc. Suppl.) 147 (2005) 103.*
- Conceptual Design of a scalable milti-kton superconducting magnetized liquid argon TPC, *A. Ereditato and A. Rubbia, hep-ph/0510131.*

GLACIER

Single 100 kton “boiling” cryogenic tanker with Argon refrigeration



Detector Layout (Bi-phase operation)



1. Charge imaging + scintillation + Cerenkov light readout
2. Charge amplification to allow for extremely long drifts

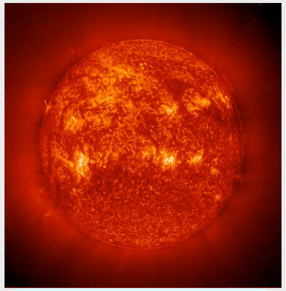
Argon production and filling

Liquid Argon 1st filling time	**2 YEARS (ASSUMED)**
Liquid Argon 1st filling rate	1,2 liters/second or 150 tons/day
Argon gas equivalent	85000 m^3/day
Air volume equivalent (Ar 1%)	8'500'000 m^3/day ≈ $(205\ m)^3$ /day
Ideal power of separation of Argon mixture	600kW (assuming for Argon 354 kJ/kg)
Assumed efficiency	5%
Estimated power for Argon separation	12 MW
Ideal Argon liquefaction power	817kW (assuming for Argon 478 kJ/kg)
Assumed efficiency	5%
Estimated Argon Liquefaction power	16 MW
Estimated total plant power	**≈30 MW**

GLACIER Physics Potential

- Non-accelerator Physics

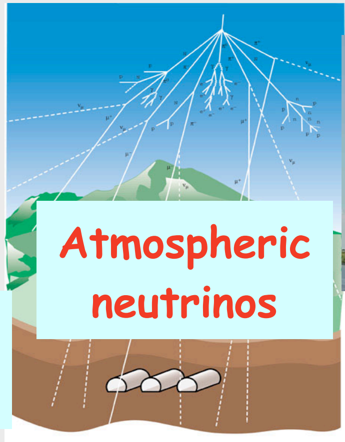
Supernova neutrinos



Solar neutrinos

$p \rightarrow e^+ + \pi^0$

Nucleon stability



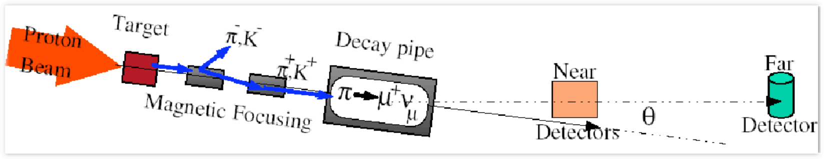
Atmospheric neutrinos

Reactor Neutrinos

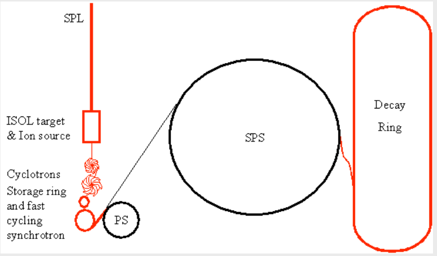
Dark Matter

- Neutrino Physics at accelerators

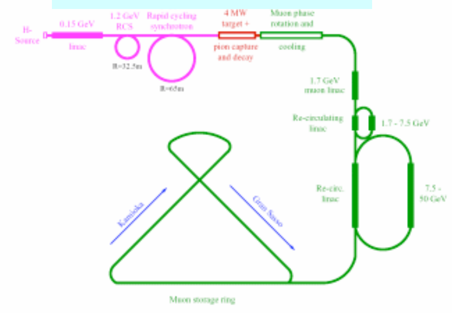
Super Beams



Beta Beams



ν Factory



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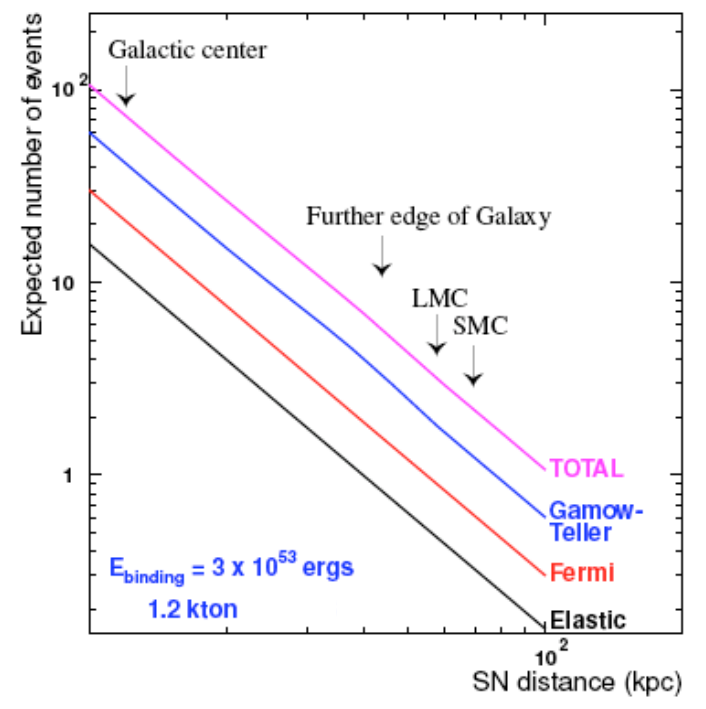
Neutrinos from Supernovae

Eight solar mass equivalent
Supernova at 10 Kpc

Interaction	Rates
$\nu_e^{CC}({}^{40}Ar, {}^{40}K^*)$	$2.5\ 10^4$
$\nu_x^{NC}({}^{40}Ar^*)$	$3.0\ 10^4$
ν_x eES	10^3
$\bar{\nu}_e^{CC}({}^{40}Ar, {}^{40}Cl^*)$	540

380 ν_e CC from
neutronization burst

JCAP 0408:001, 2004
JCAP 0310:009, 2003
hep-ph/0307244

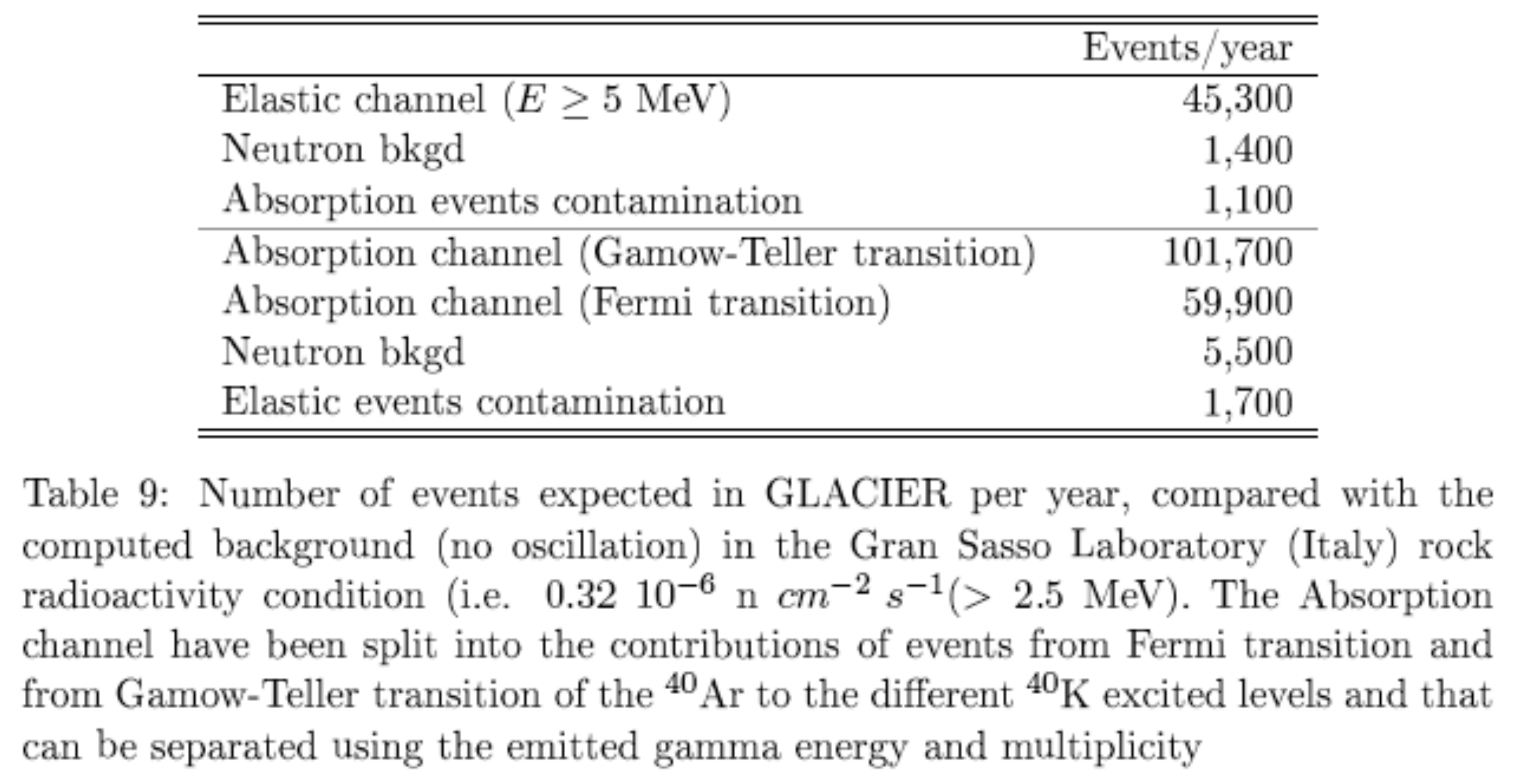


Diffuse (Relic) Supernova Neutrinos

$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$	0.5 Mt.y 5 yrs	[16 – 40] MeV	(40-60)/30 Signal Bckgnd

Solar Neutrinos

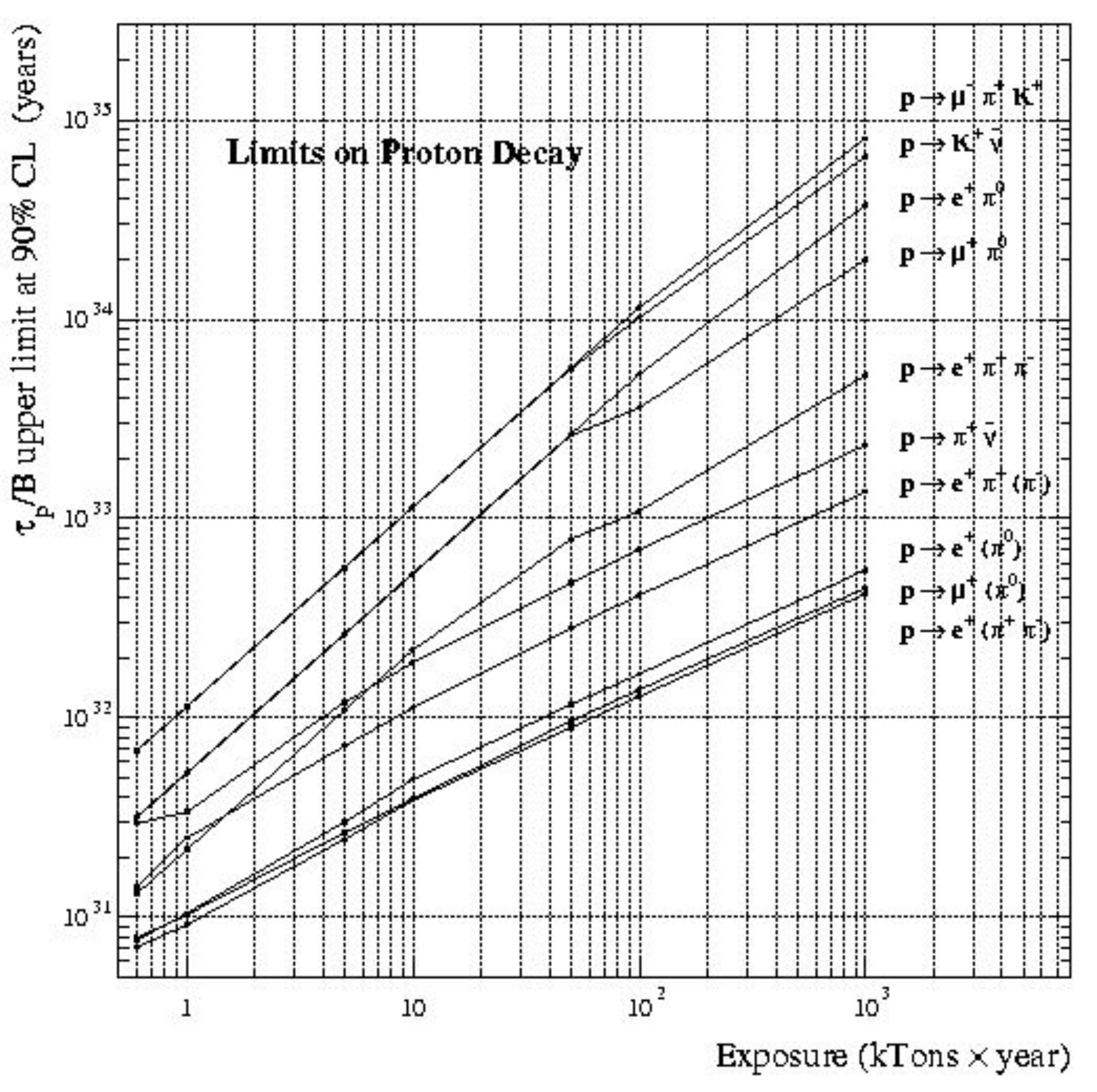
hep-ex/0103008



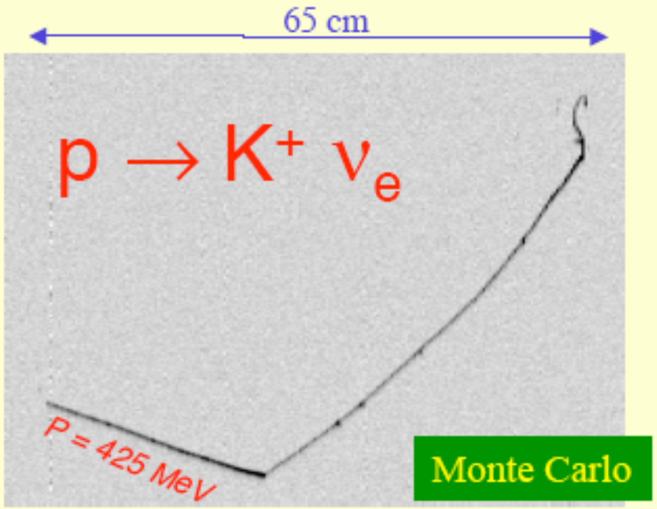
	Events/year
Elastic channel ($E \geq 5$ MeV)	45,300
Neutron bkgd	1,400
Absorption events contamination	1,100
Absorption channel (Gamow-Teller transition)	101,700
Absorption channel (Fermi transition)	59,900
Neutron bkgd	5,500
Elastic events contamination	1,700

Table 9: Number of events expected in GLACIER per year, compared with the computed background (no oscillation) in the Gran Sasso Laboratory (Italy) rock radioactivity condition (i.e. $0.32\ 10^{-6}$ n $cm^{-2}\ s^{-1}(>2.5$ MeV). The Absorption channel have been split into the contributions of events from Fermi transition and from Gamow-Teller transition of the ^{40}Ar to the different ^{40}K excited levels and that can be separated using the emitted gamma energy and multiplicity

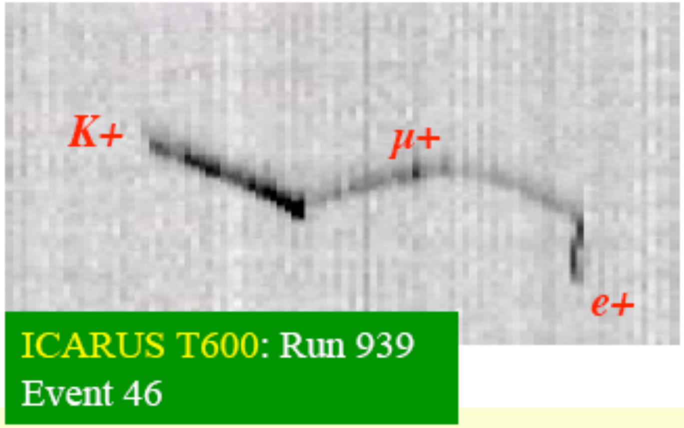
Stability of Ordinary Matter



hep-ex/0103008

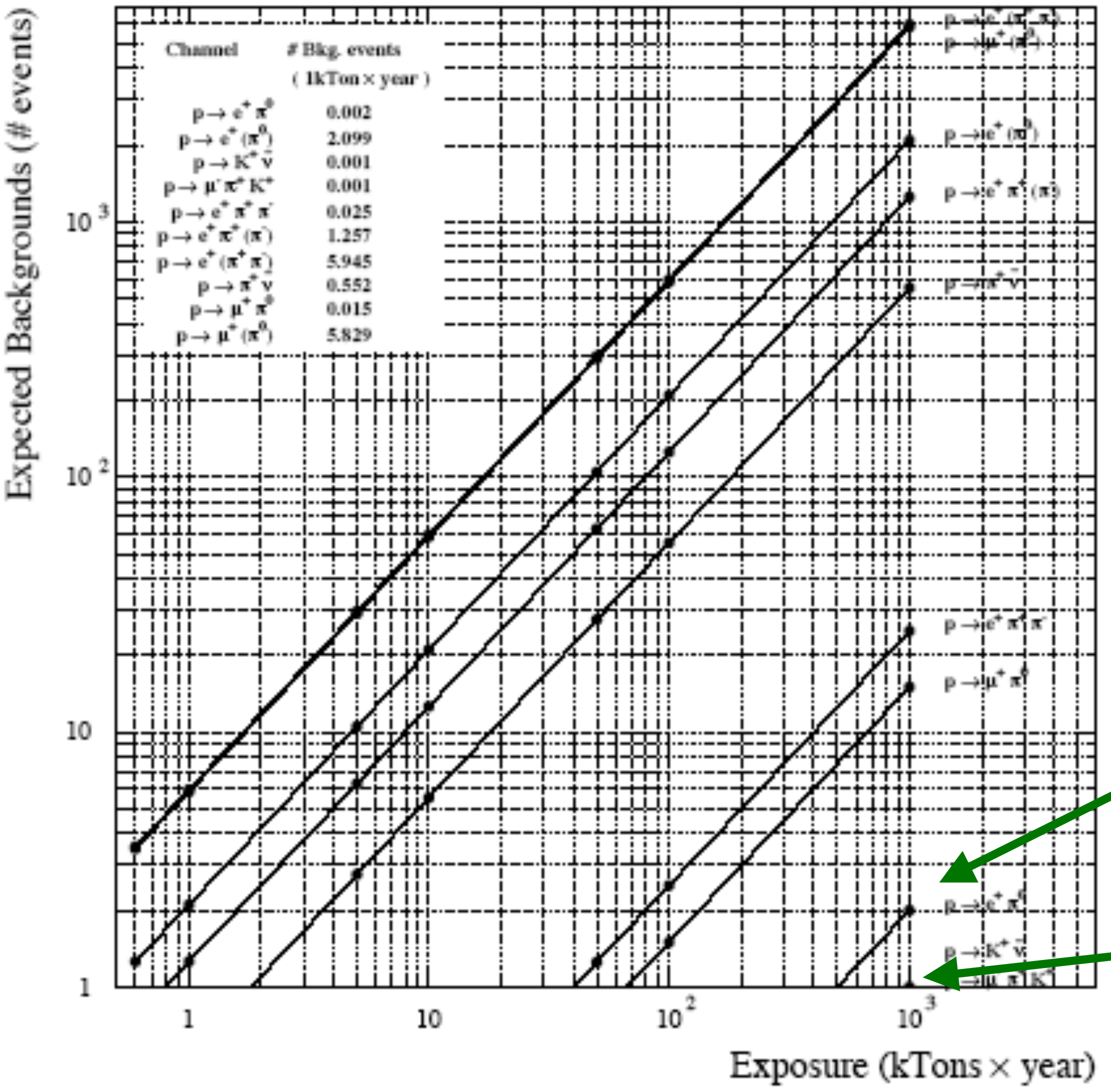


“Single” event detection capability



Expected backgrounds for proton decay

hep-ex/0103008



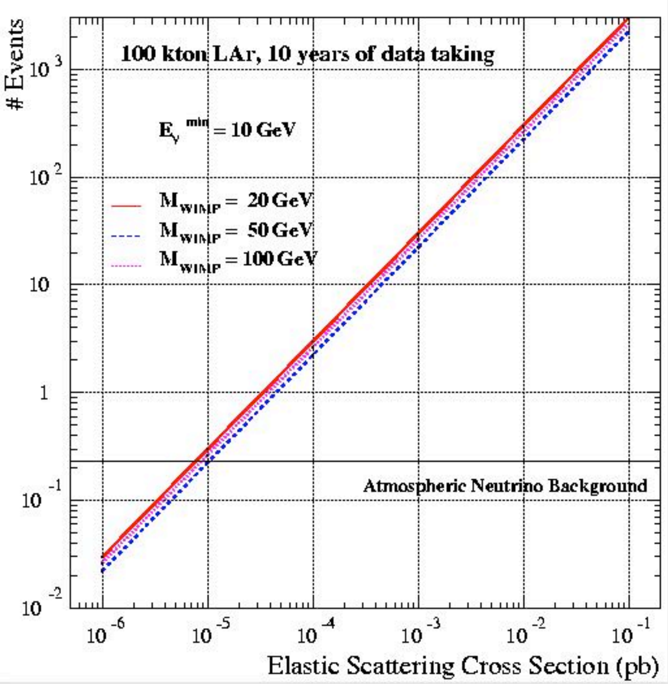
Channel	# Bkg. events (1kTon × year)
$p \rightarrow e^+ \pi^0$	0.002
$p \rightarrow e^+ (\pi^0)$	2.099
$p \rightarrow K^+ \bar{\nu}$	0.001
$p \rightarrow \mu^- \pi^+ K^+$	0.001
$p \rightarrow e^+ \pi^+ \pi^-$	0.025
$p \rightarrow e^+ \pi^+ (\pi^-)$	1.257
$p \rightarrow e^+ (\pi^+ \pi^-)$	5.945
$p \rightarrow \pi^+ \bar{\nu}$	0.552
$p \rightarrow \mu^+ \pi^0$	0.015
$p \rightarrow \mu^+ (\pi^0)$	5.829

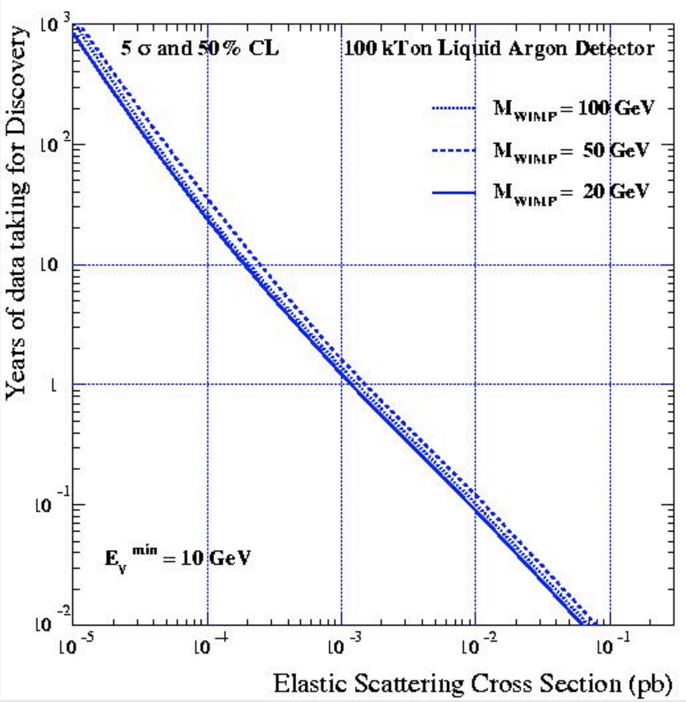
$p \rightarrow e^+\pi^0$

$p \rightarrow K^+\bar{\nu}$

Indirect Dark Matter Detection

- WIMPs accumulate in the center of the Sun
- They annihilate producing among others very energetic ν_e
- Excellent capability to detect high energy ν_e pointing to the Sun





JCAP 0501:001, 2005

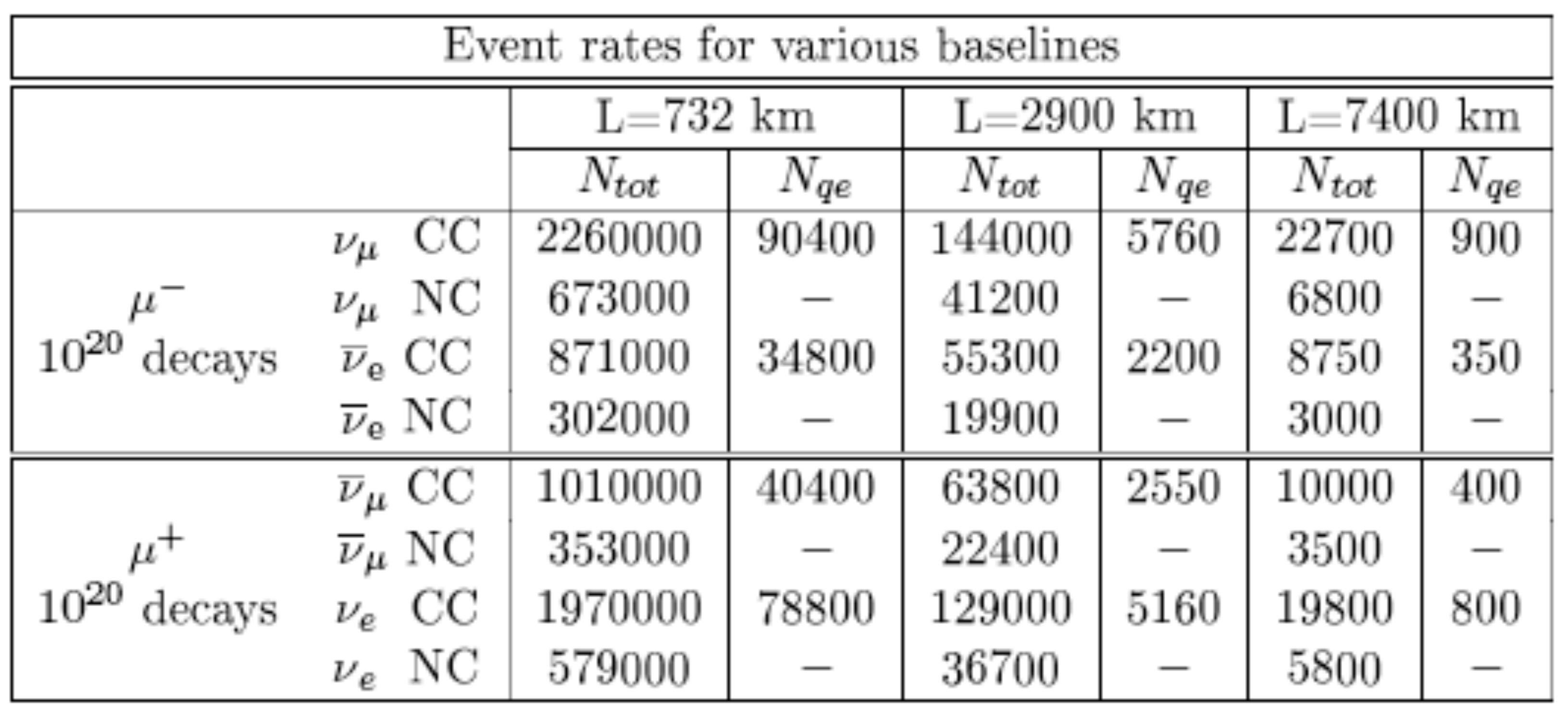
Non-accelerator Physics

SUMMARY

	Liquid Argon TPC
Total mass	100 kton
$p \to e\,\pi^0$ in 10 years	0.5×10^{35} years $\varepsilon = 45\%$, <1 BG event
$p \to \nu K$ in 10 years	1.1×10^{35} years $\varepsilon = 97\%$, <1 BG event
$p \to \mu\pi K$ in 10 years	1.1×10^{35} years $\varepsilon = 98\%$, <1 BG event
SN cool off @ 10 kpc	38500 (all flavors) (64000 if NH-L mixing)
SN in Andromeda	7 (12 if NH-L mixing)
SN burst @ 10 kpc	380 ν_e CC (flavor sensitive)
SN relic	Yes
Atmospheric neutrinos	10000 events/year
Solar neutrinos	324000 events/year $E_e > 5$ MeV

Accelerator neutrinos

EXPECTED RATES AT A NEUTRINO FACTORY



Event rates for various baselines

		L=732 km		L=2900 km		L=7400 km	
		N_{tot}	N_{qe}	N_{tot}	N_{qe}	N_{tot}	N_{qe}
μ^- 10^{20} decays	ν_μ CC	2260000	90400	144000	5760	22700	900
	ν_μ NC	673000	–	41200	–	6800	–
	$\overline{\nu}_e$ CC	871000	34800	55300	2200	8750	350
	$\overline{\nu}_e$ NC	302000	–	19900	–	3000	–
μ^+ 10^{20} decays	$\overline{\nu}_\mu$ CC	1010000	40400	63800	2550	10000	400
	$\overline{\nu}_\mu$ NC	353000	–	22400	–	3500	–
	ν_e CC	1970000	78800	129000	5160	19800	800
	ν_e NC	579000	–	36700	–	5800	–

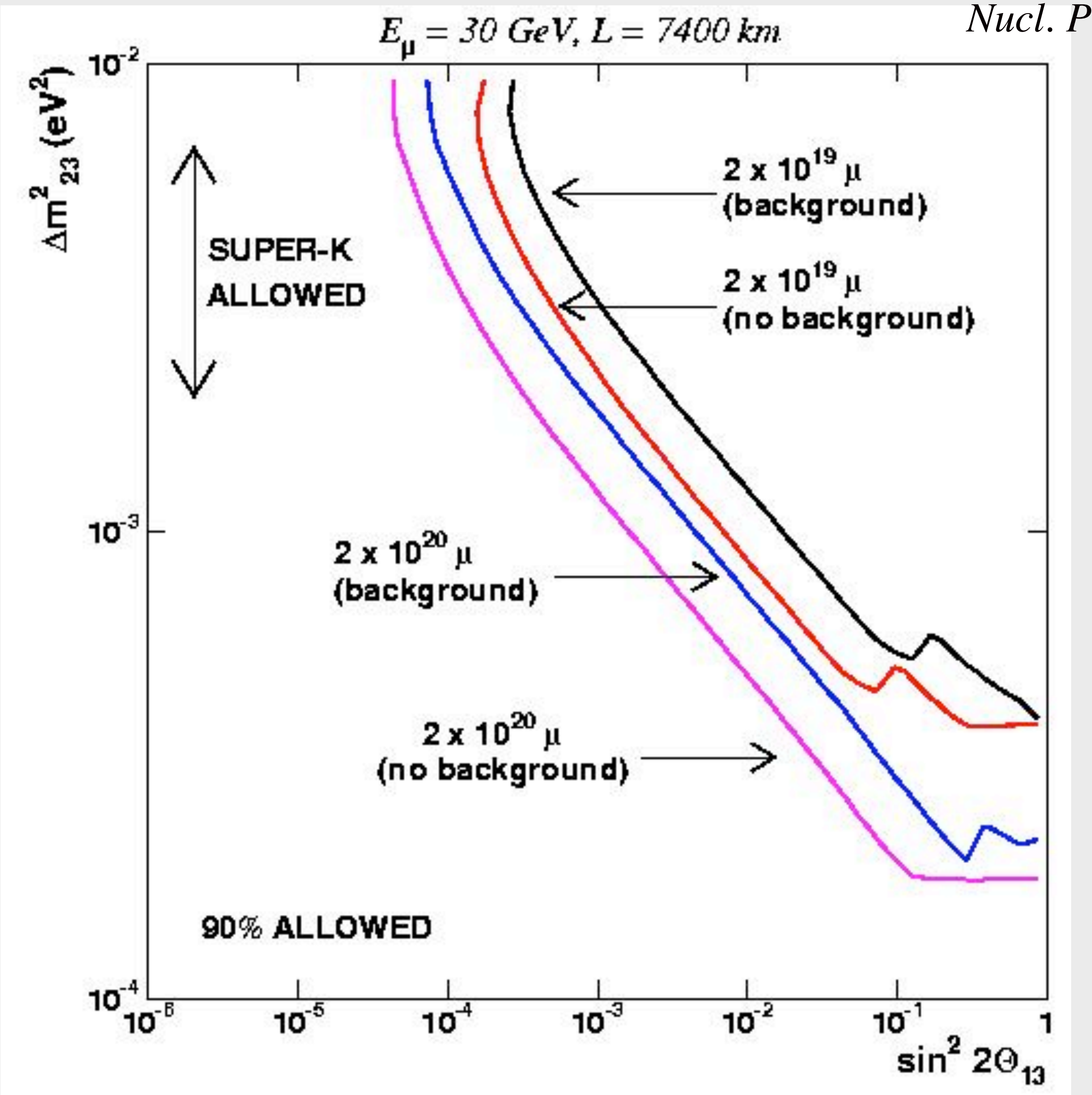
Operation of a 100 kton LAr TPC in a future neutrino facility:

Super-beam: 460 ν_μ CC per 10^{21} 2.2 GeV protons @ L = 130 km

Beta-beam:15000 ν_e CC per 10^{19} ^{18}Ne decays with γ=75

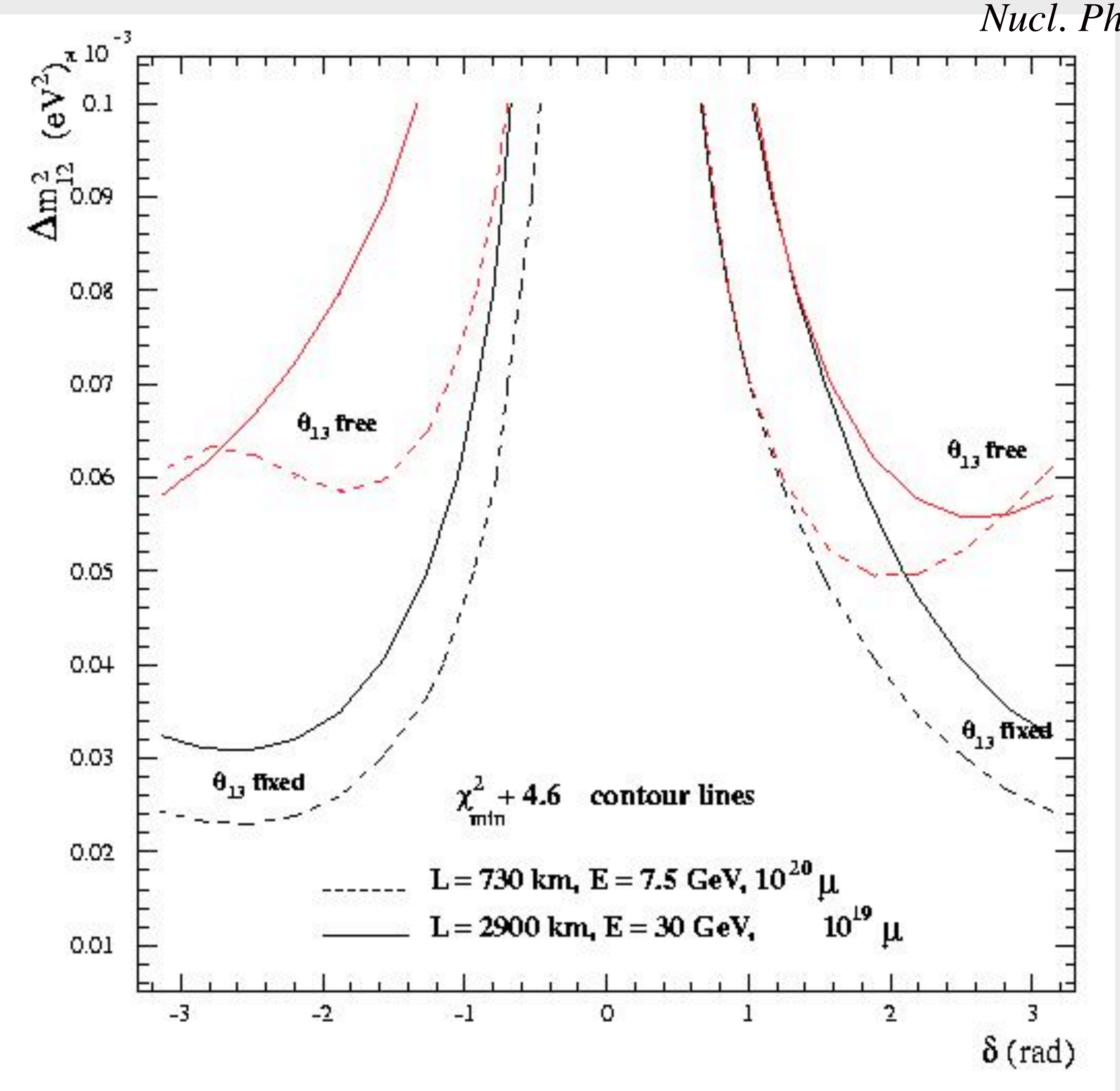
Sensitivity on Θ_{13}

Nucl. Phys. B589 (2000) 577



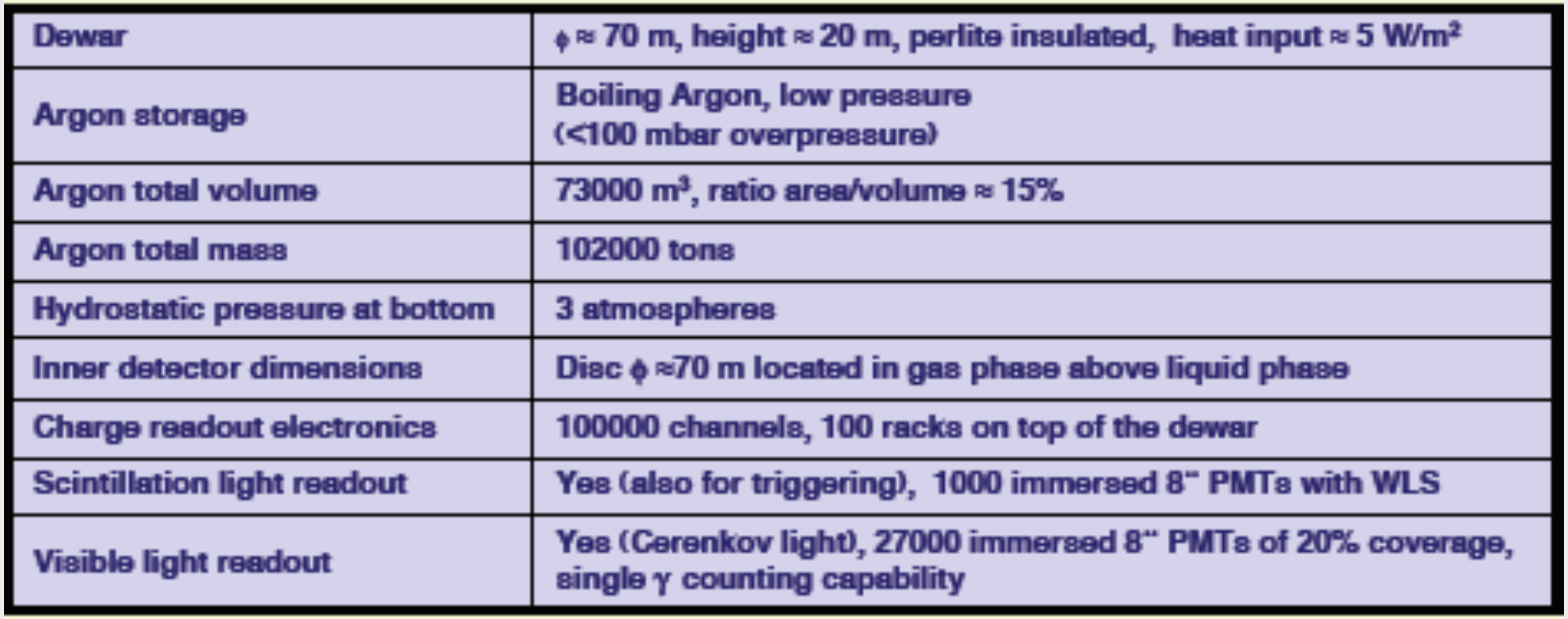
Sensitivity on CP violation in the leptonic sector

Nucl. Phys. B631 (2002) 239



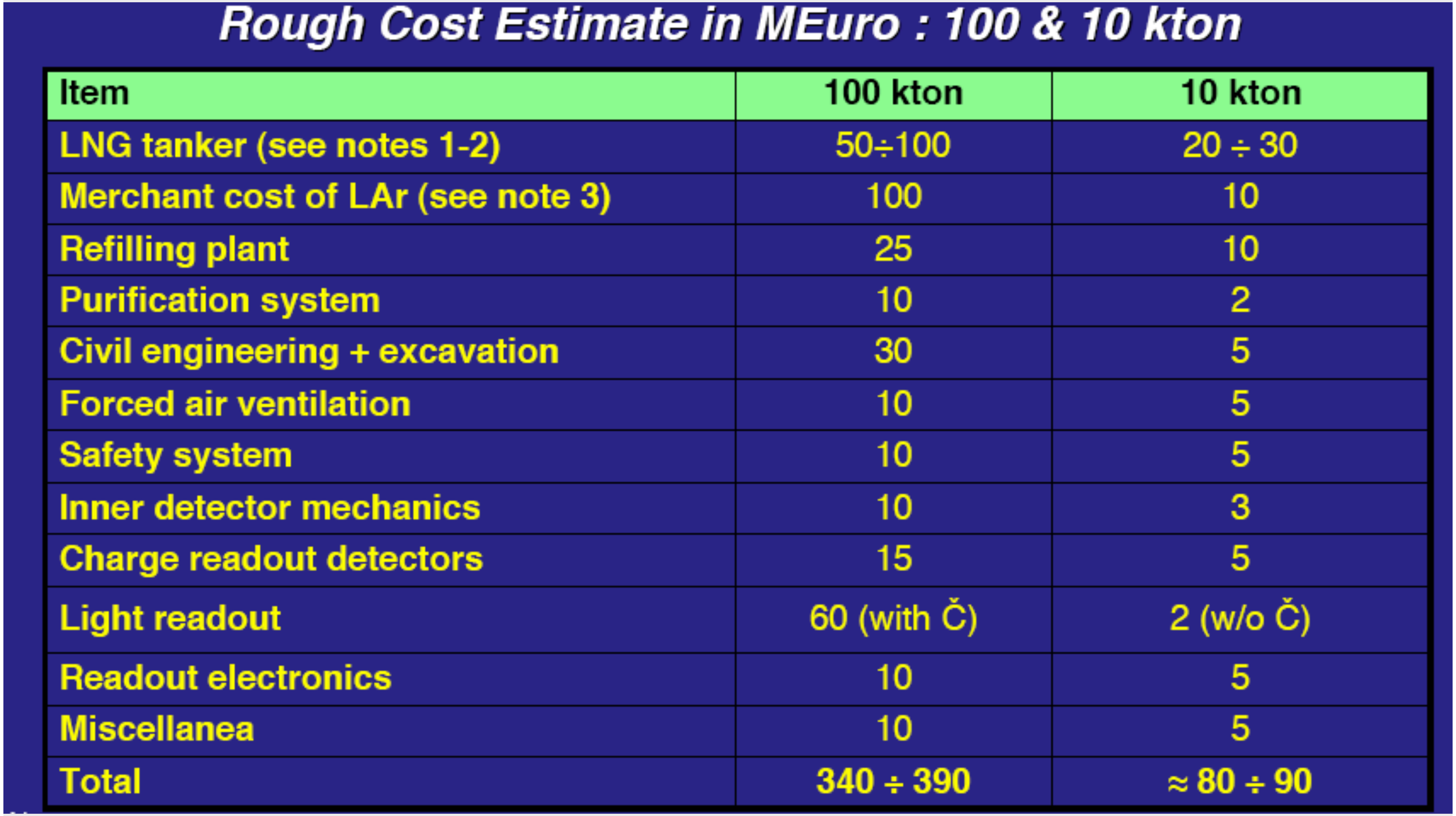
Back–Up

Parameters for a tentative layout



Dewar	$\phi \approx 70$ m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume $\approx$ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx 70$ 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

Cost Estimate

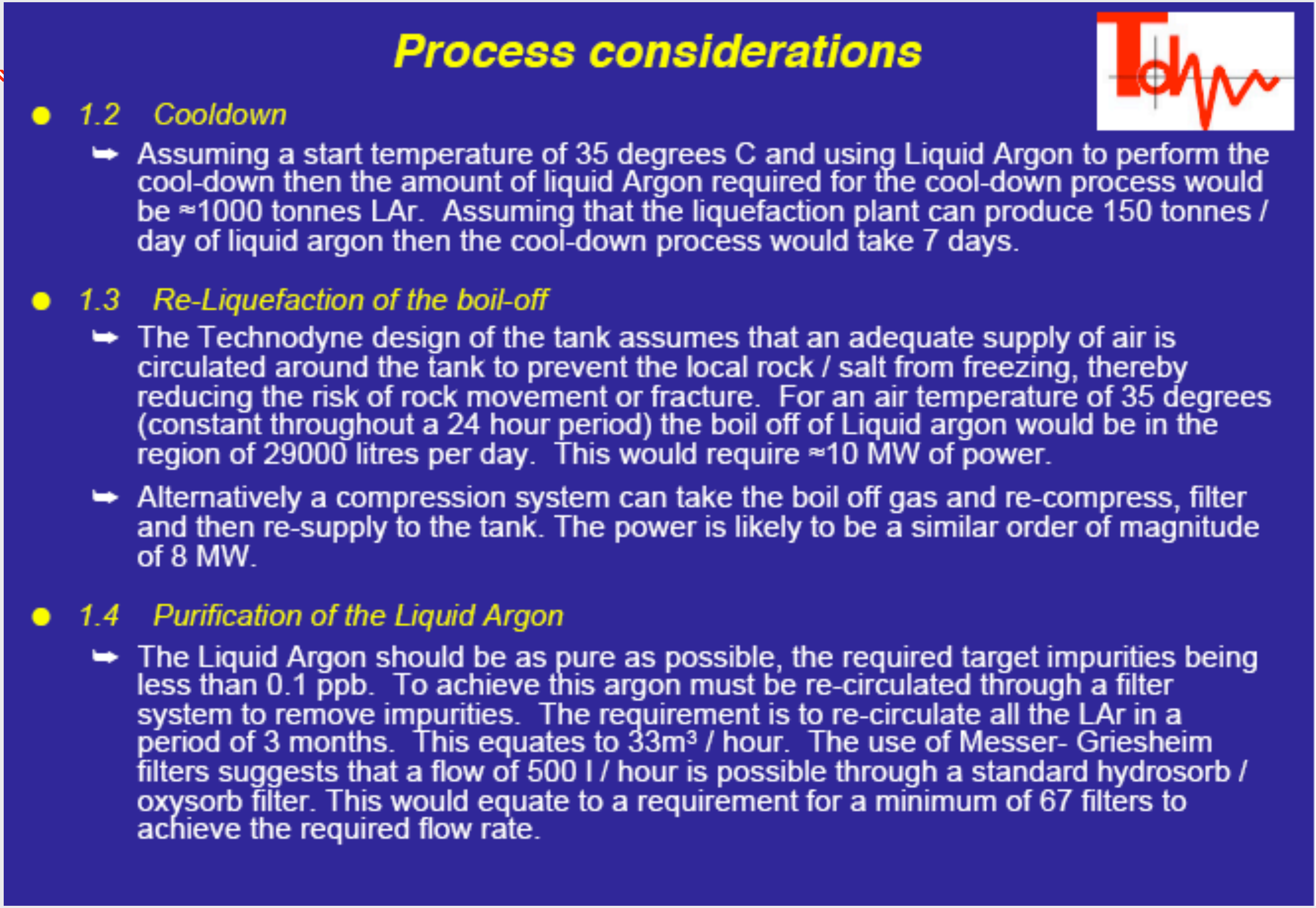


Rough Cost Estimate in MEuro : 100 & 10 kton

Item	100 kton	10 kton
LNG tanker (see notes 1-2)	50÷100	20 ÷ 30
Merchant cost of LAr (see note 3)	100	10
Refilling plant	25	10
Purification system	10	2
Civil engineering + excavation	30	5
Forced air ventilation	10	5
Safety system	10	5
Inner detector mechanics	10	3
Charge readout detectors	15	5
Light readout	60 (with Č)	2 (w/o Č)
Readout electronics	10	5
Miscellanea	10	5
Total	340 ÷ 390	≈ 80 ÷ 90

Process considerations

- There are three major items required for generating and maintaining the Liquid Argon needed in the tank. These are:
    - ➥ Filling the tank with the initial Liquid Argon bulk
    - ➥ Re- liquefaction of the gaseous Argon boil-off.
    - ➥ Continuous purification of the Liquid Argon.
- *1.1 Initial fill*
    - ➥ The requirements for the initial fill are large, corresponding to 150 tonnes of Liquid Argon per day over two years. Argon is a by product of the air separation plant which is usually aimed at a certain amount of oxygen production per day. The amount required is a significant proportion of the current European capacity. Hence new investment will be required by the industry to meet the project requirement. This could either be a specific plant located for the project or increases in capacity to several plants in the area. British Oxygen's largest air separation plant in Poland has the capability to produce 50 Tonnes of Liquid Argon per day. However, this is nearly all supplied to industry and therefore the available excess for a project of this size would be relatively small.
    - ➥ A typical air separation plant producing 2000 tonnes per day of Oxygen would produce 90 tonnes per day of Liquid Argon. This facility would have a 50-60 metre high column, would need approximately 30m x 40m of real-estate, would need 30-35MW of power and cost 45 million euros. Energy to fill would cost ≈25MEuro.
    - ➥ Purchasing LAr costs would be in the region of 500 euros per tonne. Transportation costs are mainly dependant upon the cost of fuel and the number of kilometres between supply and site. To fill the tank would require 4500 trips of 25 tons trucks and would cost ≈30 million euros for transport.



Process considerations

- *1.2 Cooldown*
  - ➥ Assuming a start temperature of 35 degrees C and using Liquid Argon to perform the cool-down then the amount of liquid Argon required for the cool-down process would be ≈1000 tonnes LAr. Assuming that the liquefaction plant can produce 150 tonnes / day of liquid argon then the cool-down process would take 7 days.
- *1.3 Re-Liquefaction of the boil-off*
  - ➥ The Technodyne design of the tank assumes that an adequate supply of air is circulated around the tank to prevent the local rock / salt from freezing, thereby reducing the risk of rock movement or fracture. For an air temperature of 35 degrees (constant throughout a 24 hour period) the boil off of Liquid argon would be in the region of 29000 litres per day. This would require ≈10 MW of power.
  - ➥ Alternatively a compression system can take the boil off gas and re-compress, filter and then re-supply to the tank. The power is likely to be a similar order of magnitude of 8 MW.
- *1.4 Purification of the Liquid Argon*
  - ➥ The Liquid Argon should be as pure as possible, the required target impurities being less than 0.1 ppb. To achieve this argon must be re-circulated through a filter system to remove impurities. The requirement is to re-circulate all the LAr in a period of 3 months. This equates to $33 m^3$ / hour. The use of Messer- Griesheim filters suggests that a flow of 500 l / hour is possible through a standard hydrosorb / oxysorb filter. This would equate to a requirement for a minimum of 67 filters to achieve the required flow rate.