Cryogenics Operations 2006

OPERATION OF CRYOGENICS FOR CERN EXPERIMENTS AND LHC TEST FACILITIES

K. Barth on behalf of CERN-AT-ECR

Workshop on Cryogenics Operations 2006
Stanford Linear Accelerator Center, California,
May 9 - 11, 2006

Outline

- Introduction and historical overview
- Operation & maintenance organization
- Statistics and operational experience
- Management of helium and nitrogen inventory
- Outlook

Historical overview

Origins of the cryogenics for experiments at CERN:

- 1960's: Track chambers: LH_2 / Ne, 30K-range, 35 m^3
  BEBC
  (Multi-) target chambers: LH_2 , 20K-range, 30 m^3
  Dilution refrigerators, 1K-range
- 1970's: Sampling ionization chambers (calorimeters) filled with LAr, 80K-range, 2-4 m^3
  SC magnets
  S.c. magnets as spectrometers in particle detectors
  OMEGA
  Accelerator technology: RF beam separators, high-luminosity insertion s.c. quadrupoles
- 1980's: New generation of "particle transparent" spectrometers for collider physics at ISR & LEP
  ALEPH
  DELPHI
  s.c. solenoids requiring 800 W @ 4.5 K
- 1990's: Development of s.c. 350 MHz accelerating cavities
  s.c. cavities
  Implementation of very large capacity 4.5 K helium refrigeration plants (4 x 18 kW @ 4.5 K) for LEP200

Historical overview

- 1990's to today:
  - Noble liquid calorimetry (LAr, LKr) NA48
  - Test facilities for LHC accelerator and experiments: LHC TF
    s.c. accelerator components: cables, correctors, diodes, etc.
    s.c. detector components: spectrometer magnets, calorimeters
  - CERN Axion Solar Telescope (CAST) CAST
  - COmmon Muon and Proton Apparatus for Structure and Spectroscopy (COMPASS) COMPASS
  - Centralized, CERN-wide distribution of LHe & LN2 to small-scale cryogenic experiments (AD-experiments , ISOLDE etc.)

LHe / LN2

- 2004 - 2006 **ATLAS cryogenic test facility** for testing of the 8 Barrel Toroid coils (370 t total cold mass):
  - 1.2 kW @ 4.5 K refrigerator,
  - 10 kW LN2 pre-cooler
  - LHe centrifugal pumps (80 g/s, 600 g/s)

BT test area

- From 2005 operation of CMS helium refrigeration plant (LHC, PA5) for CMS superconducting coil (field 4 T, cold mass 225 t, stored energy 2.7 GJ):
  - Cooling capacity: 1.5 kW @ 4.5K entropy equivalent
  - 30 kW LN2 pre-cooler (integrated)
  - Cooling method: thermosyphon

CMS Assembly

- <u>From 2006</u> operation of ATLAS (LHC, PA1) refrigeration system for s.c. magnets and calorimeter:
  - Central solenoid (CS): field 2 T, cold mass 5.4 t, stored energy 370 MJ
  - Barrel Toroid (BT): cold mass 370 t, stored energy 1’080 MJ
  - End-Caps Toroids (ECT): cold mass 160 t, stored energy 250 MJ
  - Barrel & 2 End-caps LAr calorimeters (45 m^3 + 2x19 m^3)

ATLAS refrigeration plant:

- 6 kW @ 4.5K main refrigerator (MR)
- 60 kW LN2 pre-cooler (integrated)
- 2 x 1200 g/s LHe centrifugal pumps
- 20 kW @ 40-80K shield refrigerator (SR)
- 20 kW@ 80K nitrogen refrigerator for calorimeters

ATLAS Assembly

Operation & maintenance organization

- Up to 1995 entire operation and maintenance of all cryoplants done entirely with CERN staff and manufacturers of equipment. Two cryogenic groups: ACR = accelerator cryogenics
  ECR = experiment cryogenics
- Outsourcing started in 1995 with a 2-phase contract:
  - Phase 1 (up to March 1998)
    - Duration: 3 years
    - Establishment of preventive maintenance plan, staff for executing maintenance provided by contractor
    - Establishment of operation procedures and documentation Operation done by operators from contractor, but under full CERN responsibility

Operation & maintenance organization

- Phase 2 (1998 to 2001)
  - Duration: 4 years (end of LEP)
  - Contractor fully responsible for maintenance & operation with a result oriented evaluation based on contractual performance indicators related to a financial "BONUS/PENALTY" application

- Second outsourcing contract (2001 – 2007)
  - Duration: 4 years initially, but extendable to cover construction phase of LHC
  - Contractor entirely responsible for operation and maintenance (including resources & spare parts). CERN responsible for coordination with users, cryoplant process control system, external utilities (el. power, cooling & ventilation), supply of cryogens, as well as some special tooling

Operation & maintenance organization

Result oriented performance evaluation:

- Contractor shall ensure production with a minimum of interruptions during the periods of use predefined by CERN
- Contractor periodically produces well defined reports documenting the operation and maintenance activity
- Each plant under production is given a tolerance (T) for the amount of breakdown time lost for production. The sum of all plant tolerances over one year (Ts) is compared to the corresponding sum of all actual recorded breakdown times lost for production (As).
- At the end of each year, a term of Bonus or Penalty payment, BM , is calculated as a percentage of the sum of the values of the maintenance tasks for the elapsed contractual year (Rm).

B/M calculation

if As < Ts :

BM = [(Ts - As) / Ts] x (0.10 x Rm)

if As = Ts :

BM = 0

if As is higher than Ts and lower than 3 x Ts

BM = [(Ts - As) / (2 x Ts)] x (0.10 x Rm)

if As is higher than 3 x Ts

BM = (- 0.10) x Rm

For example, the term BM will be :

a bonus of:	10% of Rm	if As = 0
a bonus of:	5% of Rm	if As = 0.5 x Ts
nil		if As = Ts
a penalty of:	10% of Rm	if As more then 3 x Ts

B/M calculation

As = Sum of “cryogenic breakdowns” during production period

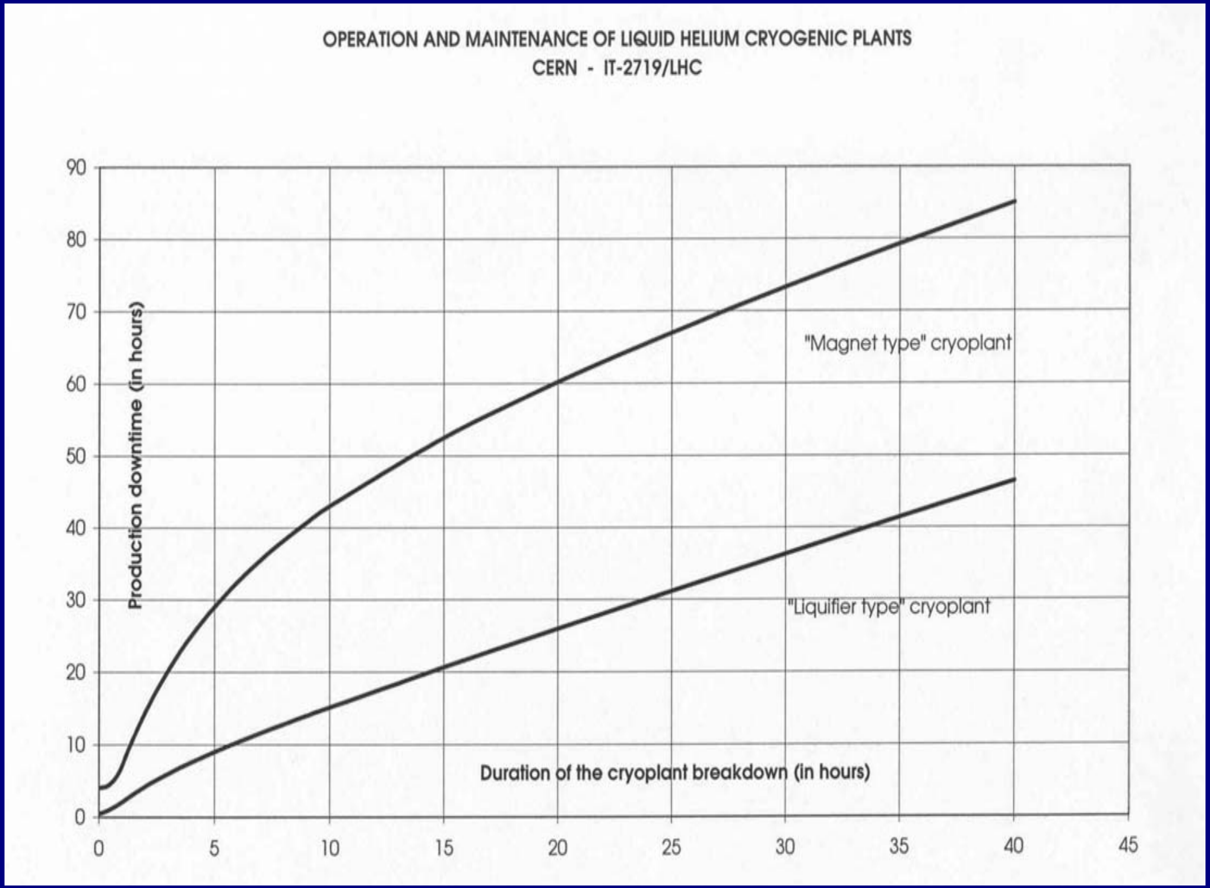
Ts = Sum of tolerances t for the "Cryogenic breakdowns“

Ts = Sum (t)

t = 0.003 * h
  if “magnet type” cryoplant

t = 0.002 * h
  if “liquefier type” cryoplant

h: duration of the LHe cooling production period



Maintenance cost calculation

– Annual cost of maintenance calculated for coming year as the sum of the mean unit costs of maintenance (Mu), applied to all equipment involved in the contract, and for the hourly rate of running as given in the annual production program

– Maintenance cost table calculating for each equipment M:
M = M1+M2+M3*He if Hp+He > 6'000 hours
M = M1+M3*He if Hp+He < 6'000 hours

M1 =	Mean yearly costs for all periodic maintenance tasks to be made at fixed periods, whatever the hourly rate of running.
M2 =	Mean yearly costs for all periodic maintenance tasks to be made during a shutdown when the yearly running hours expected for the coming year (He) and the running hours from since the previous maintenance (Hp), exceeds 6000 hours
M3 =	Mean hourly costs for all maintenance tasks whose cost is proportional to the hourly rate of running.

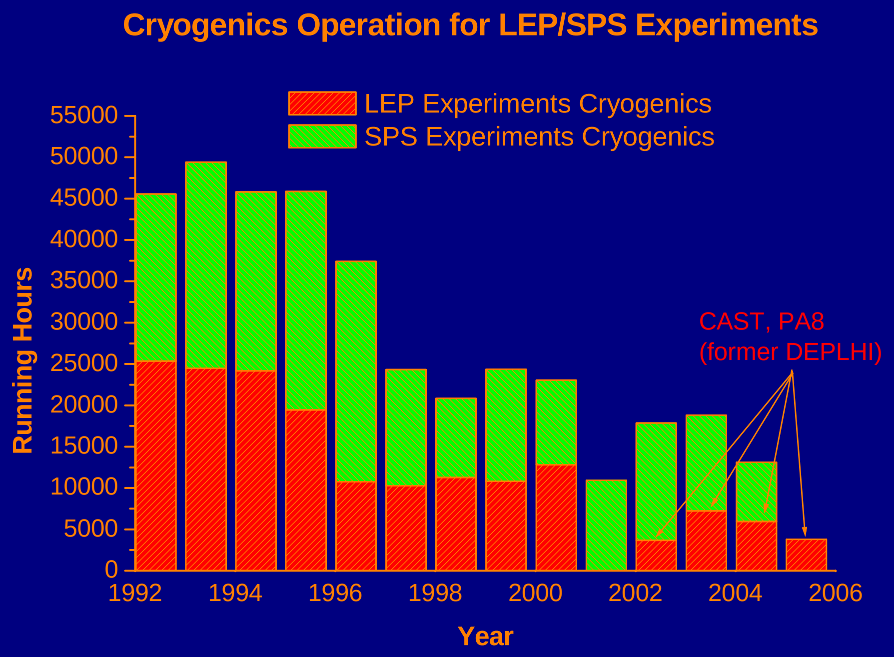
Statistics cryogenics for LEP & SPS

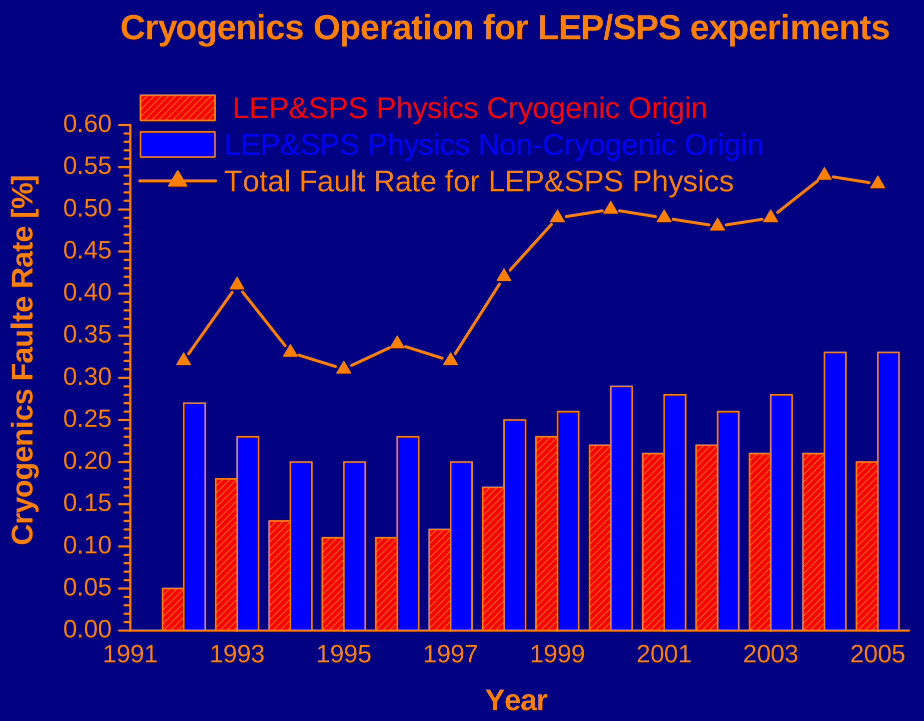
Total running of the CERN cryoplants for experiments:

170’000 hours (LEP) **212’000 hours (SPS fixed-target)**

Integral fault rate for the LEP/SPS experiment cryogenics

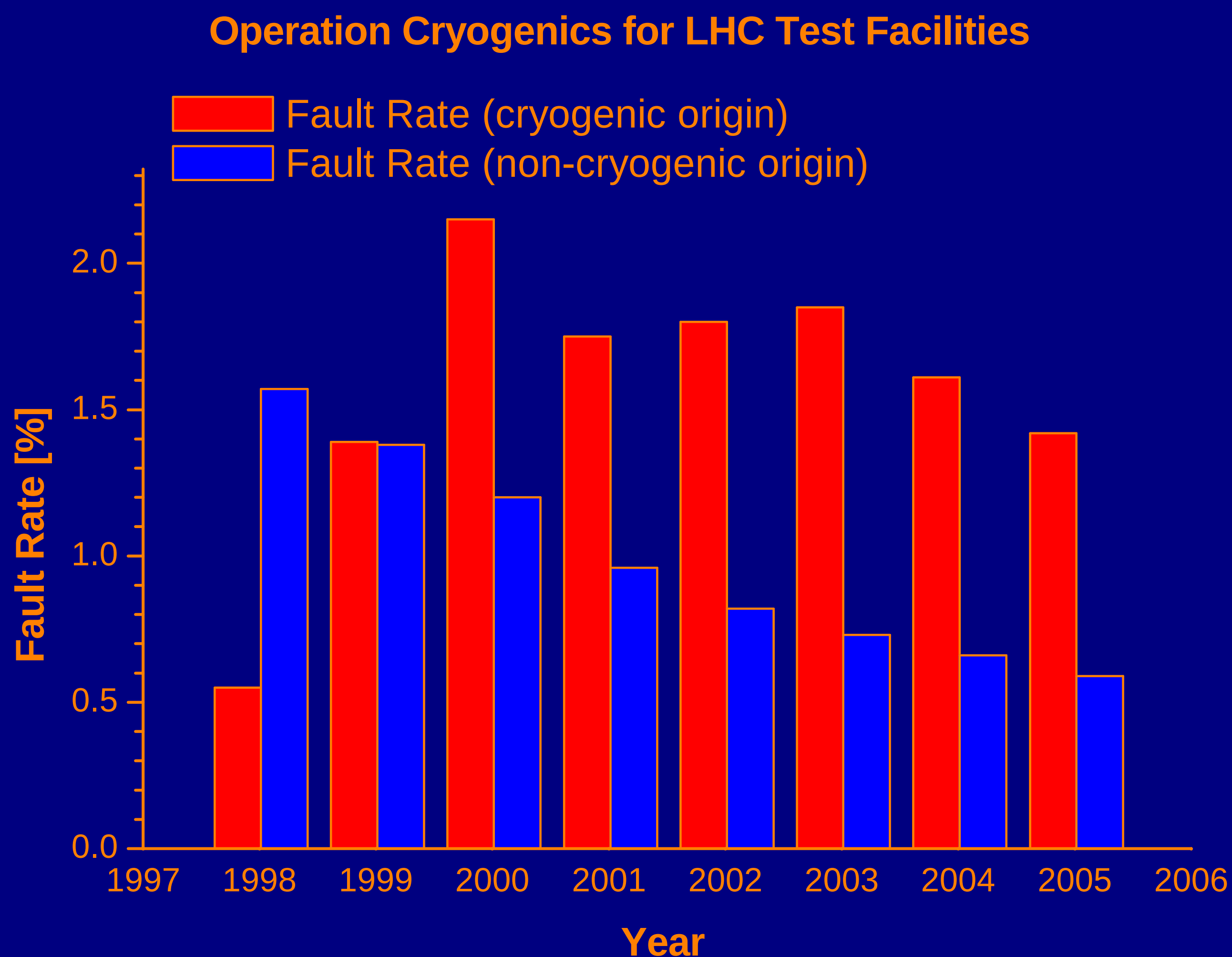
due to cryogenic-origin: **2.0 ‰** due to non-cryogenic-origin: **3.3 ‰**





Statistics cryogenics for LHC test facilities

Total running of cryoplants for test facilities: **184'308 hours**



LHe Supply Contract

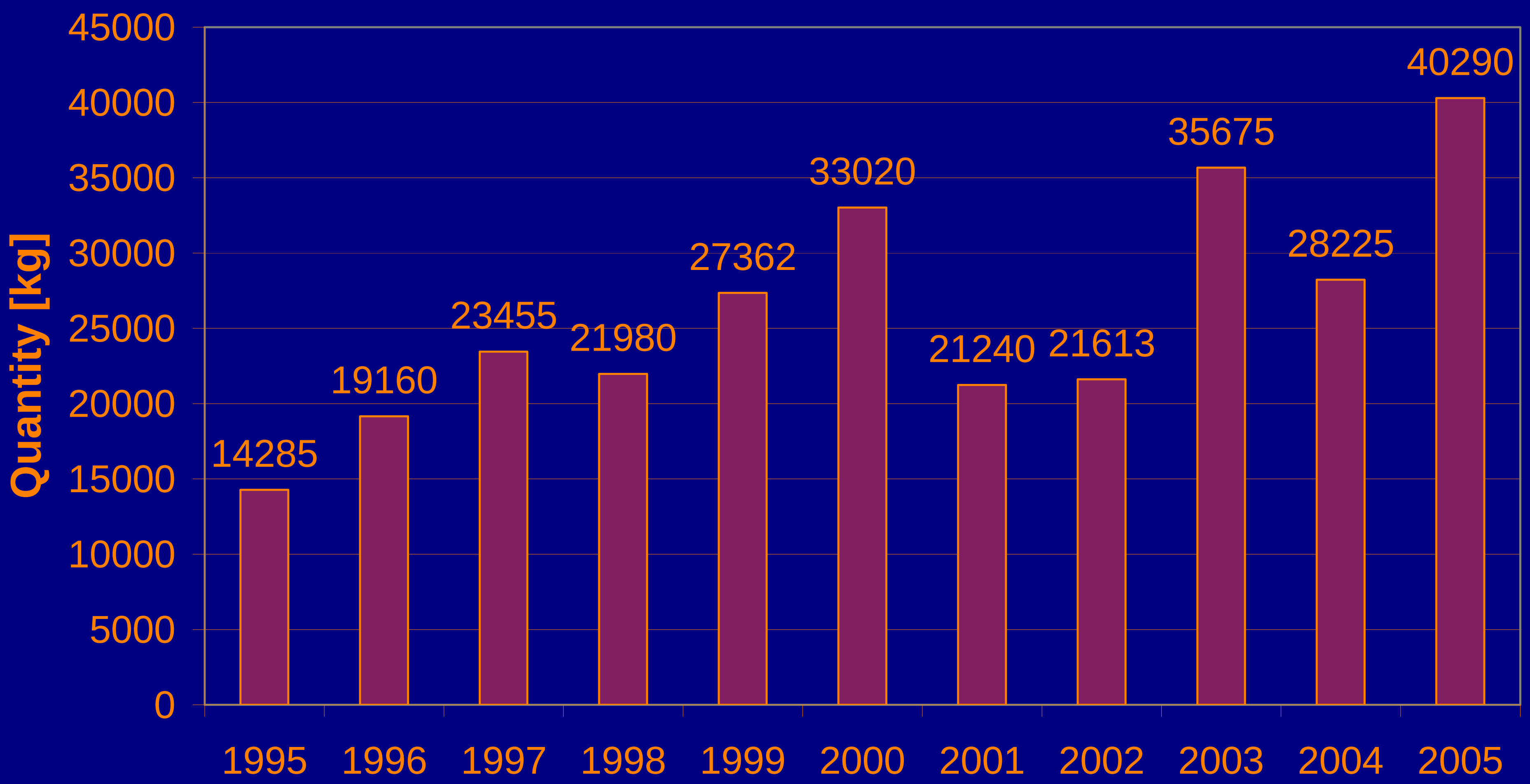
Period: 2000 – 2003

- Split between 3 suppliers (Messer, BOC, CARBAGAS / Air Liquide)
- Total quantity over 3years: 78’000 kg
- LHe deliveries: P=1.5 bar, Qmin =1’500 kg
  GHe deliveries: P = 200 bar, Qmin = 3’000 Nm^3
  high grade and low grade (imp. < 2%)

Period: 2004 – 2007 (Installation & Comissioning LHC)

- Split between 2 suppliers (Air Products, CARBAGAS / Air Liquide)
- Total quantity over 4 years: 280’000 kg
- LHe, GHe delivery conditions as above

CERN Liquid Helium Purchasing 1995 - 2005

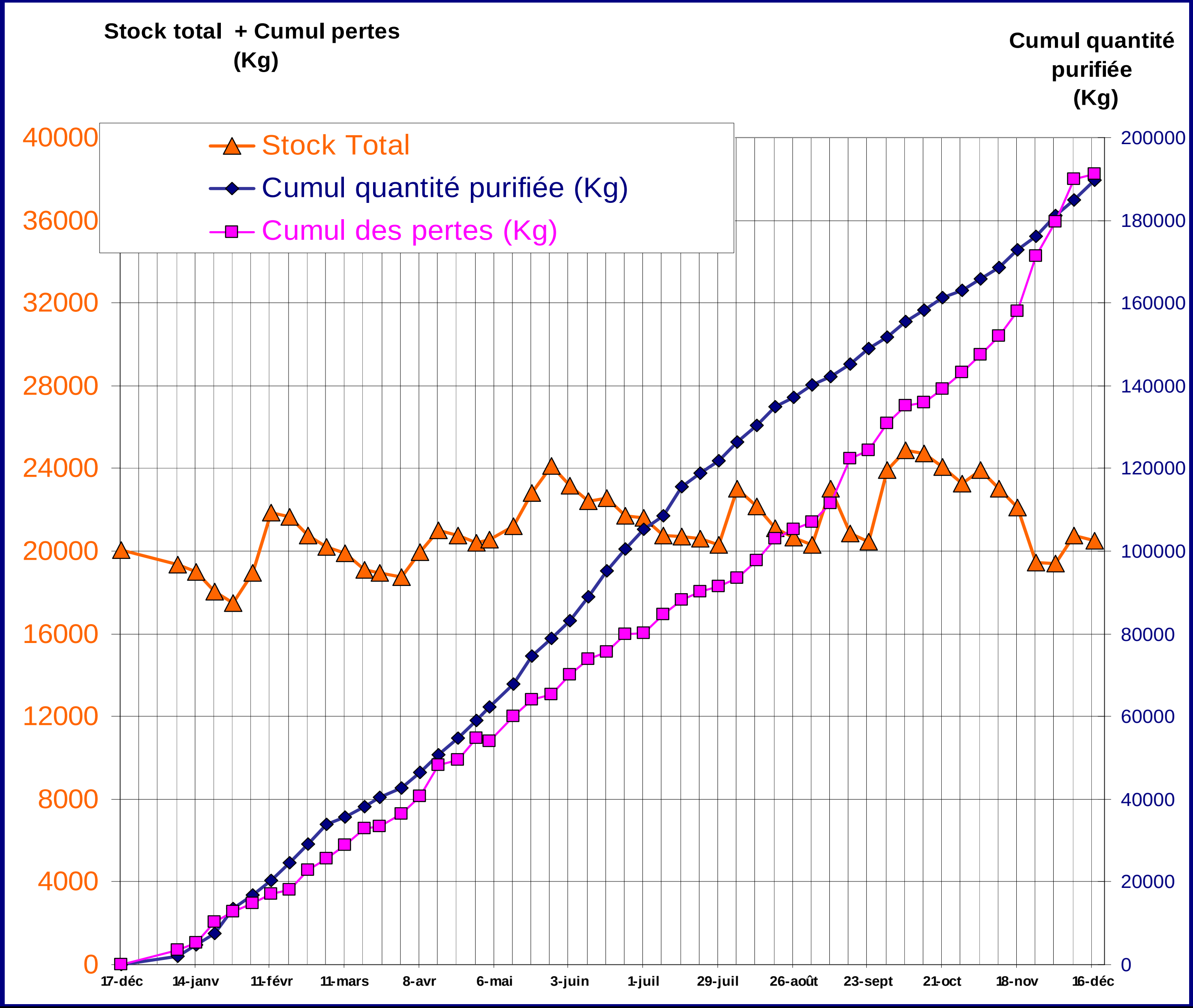


2005 Global He Inventory

Total He turnover:
189'774 kg

Mean stock:
21'000 kg
11 % of turnover

Consumption:
38' 223 kg
20 % of turnover



2005 Operation He Inventory

Total He turnover:

189'774 kg

Mean stock:

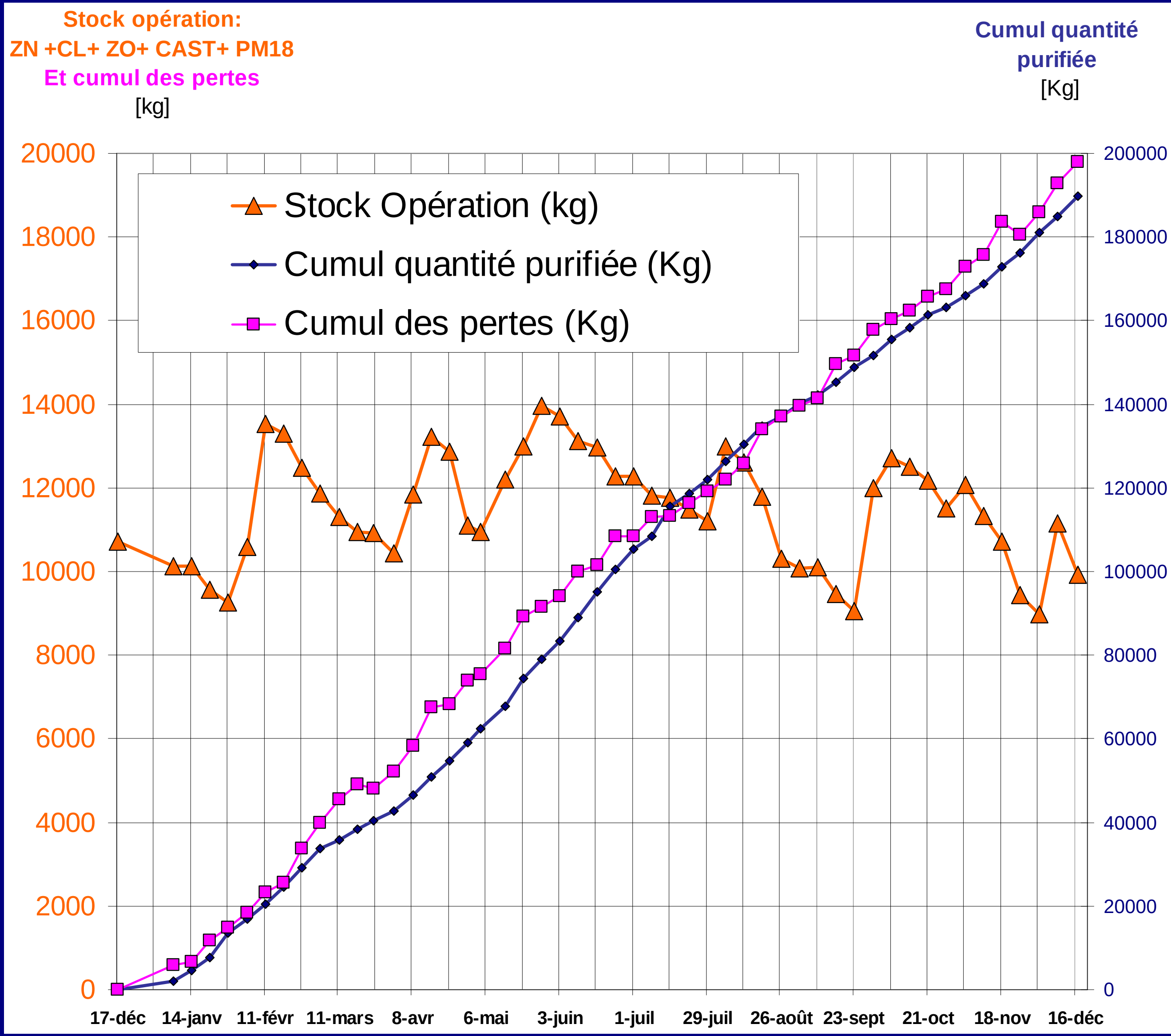
11'000 kg

5.8 % of turnover

Consumption:

19' 804 kg

10.3 % of turnover



2005 He Commissioning Inventory

Total He turnover:

189’774 kg

Mean stock:

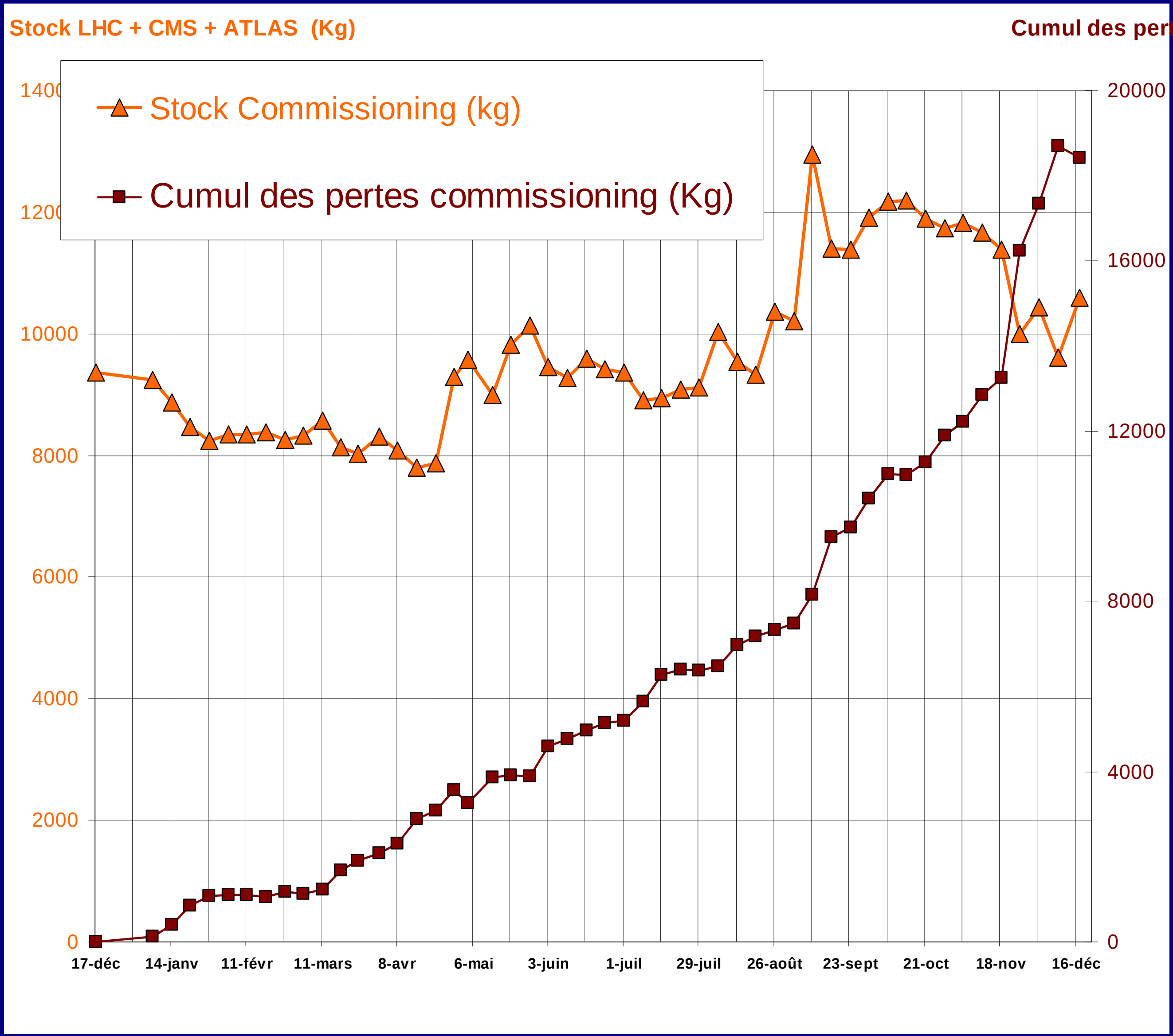
10’000 kg

5.2 % of turnover

Consumption:

18’ 420 kg

9.7 % of turnover



LN2 (large quantities) Distribution

Contract split between

3 suppliers (Messer, Praxair, Air Products)

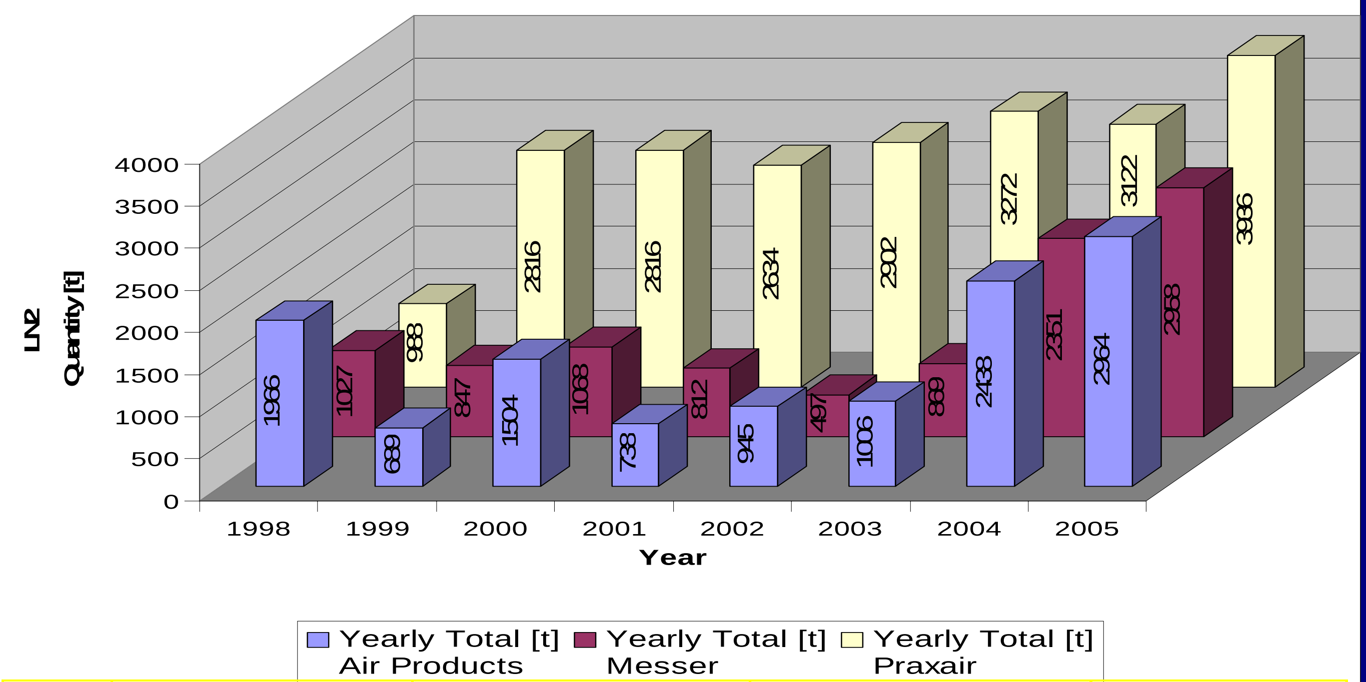
Estimated quantity for 2006: 19’000 t

Min. quantity per delivery: 22 t

CERN-wide
30 reservoirs

6’000 l to 50’000 l

Fulfilling common safety standard.

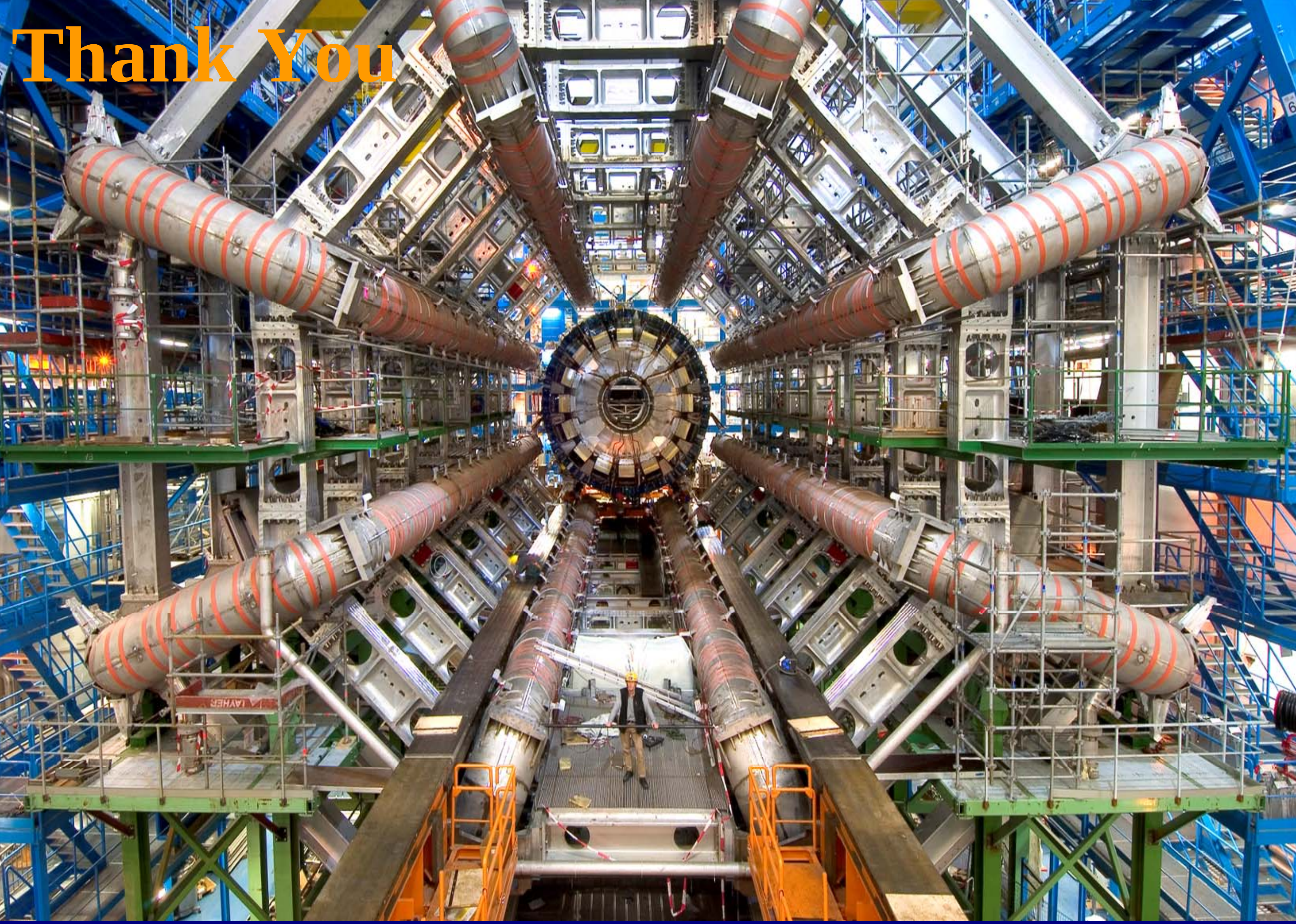


Year	Yearly Total [t] Air Products	Yearly Total [t] Messer	Yearly Total [t] Praxair	Yearly Total [t]
1998	1966	1027	988	3982
1999	689	847	2816	3046
2000	1504	1068	2816	5388
2001	738	812	2634	4183
2002	945	497	2902	4344
2003	1006	869	3272	5147
2004	2438	2351	3122	7912
2005	2964	2958	3936	9858

Outlook

- Hot summer for cryogenics at ATLAS and CMS
- ATLAS ECT cooldown to 80 K for leak setting
- Re-start of fixed target physics program (COMPASS)
- Routine operation of other cryoplants (7) expected to continue reliably
- LHC cooldown needing large quantities of LN2 and LHe delivered in short time (logistics, new contracts)
- Organization of cryogenics operation and maintenance team (in-/out- sourcing)

Thank You



Introduction to Cryogenic Engineering

5. - 9.12.2005

G. Perinić, G. Vandoni, T. Niinikoski,
CERN

Calculation of safety valves for LHe-containers

1. Determination of the maximum heat flux

Possible heat sources:

- loss of vacuum,
- fire,
- electrical heaters,
- quench in superconducting coils, etc.

typical heat flux in case of insulation vacuum loss:

0.6W/cm2	LHe-cryostat with 10 layers superinsul.
3.8W/cm2	LHe-cryostat without superinsulation

from W. Lehmann, G. Zahn, "Safety aspects for LHe cryostats and LHe containers", *Proc. of the Int. Cryog. Eng. Conf.*, **7** (1978) 569-579.

W. LEHMANN und G. ZAHN, "Safety aspects for LHe cryostats and LHe containers", Proc. of the Int. Cryog. Eng. Conf., 7 (1978) 569-579.

2. Determination of the gas flux

a) Blow-off pressure below critical pressure

$$\dot{m}_{blow-off} = \frac{\dot{Q}_{surface}}{q}\left(1 - \frac{\rho_{gas}}{\rho_{liquid}}\right)$$

with $q = \Delta h_{evaporation}$

(in general $\Delta h_{He} \approx \Delta h_{He}$(1,01325bar, 4,222K) = 20.91J/s)

b) Blow-off pressure above critical pressure

$$\dot{m}_{blow-off} = \frac{\dot{Q}_{surface}}{q}$$

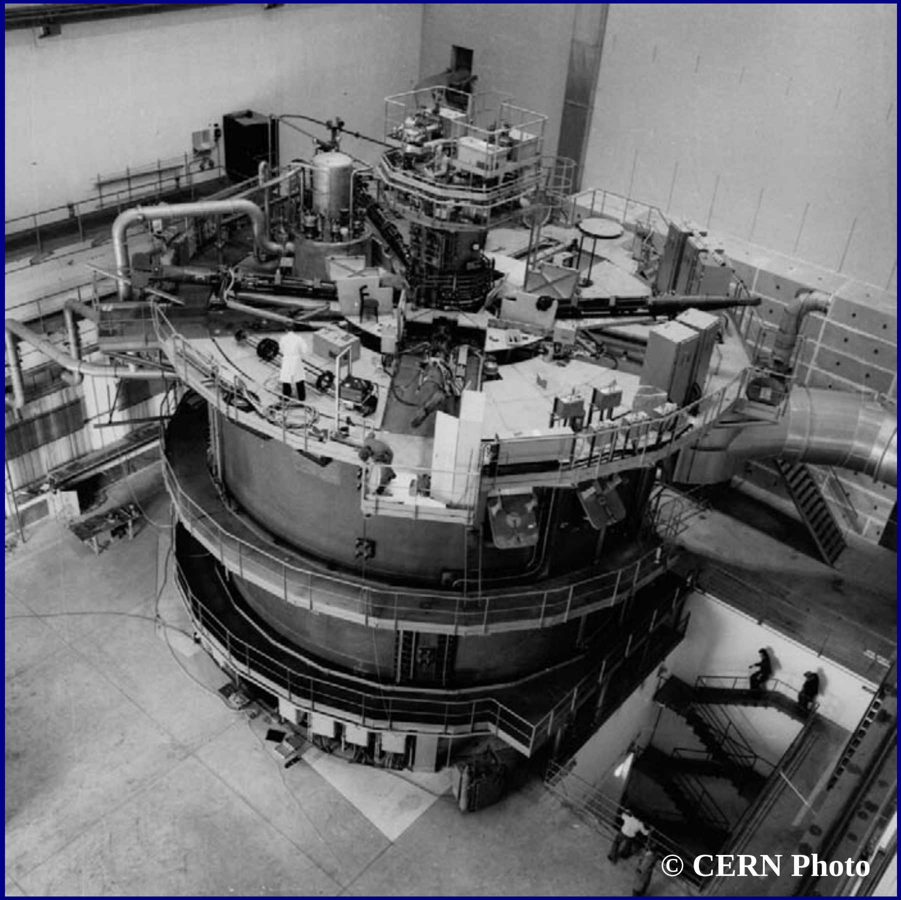
with $q = v\left(\frac{dh}{dv}\right)_{p=const}.$

(up to 5bar V(dh/dV) ≈ Δh_{He}(1,01325bar, 4,222K) = 20.91J/s)

$$\dot{m}_{blow-off} = \max \quad \text{for} \quad v\left(\frac{dh}{dv}\right) = \min$$

BEBC

Big European Bubble Chamber (BEBC):
dismantled on 9 August 1984. Produced direct visual recording of particle tracks. 6.3 million photos of interactions were taken with the chamber in the course of its existence.

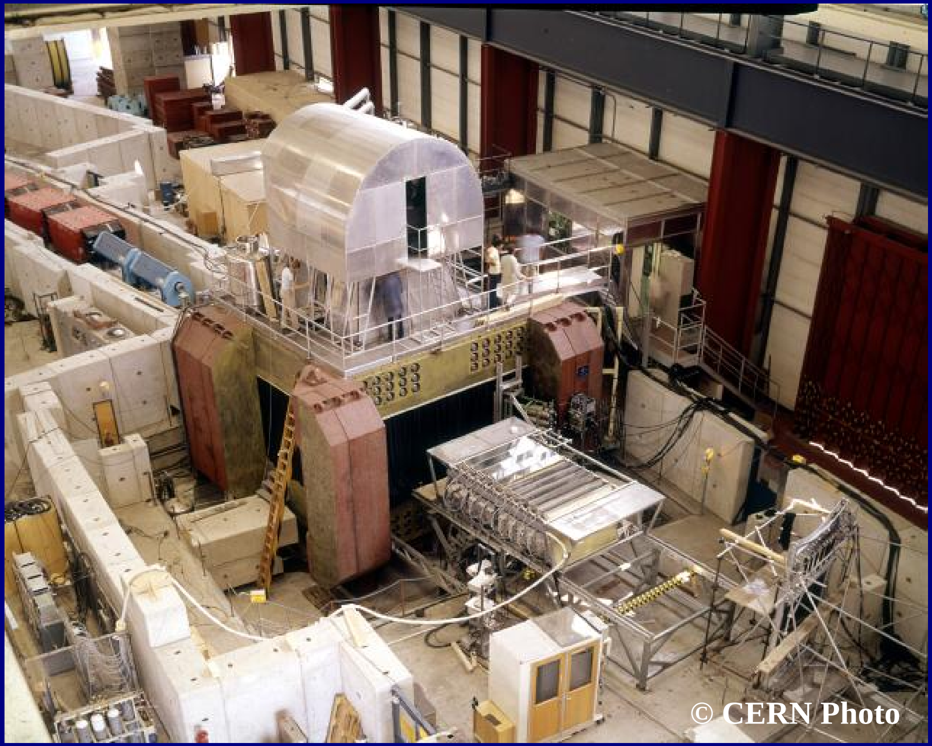


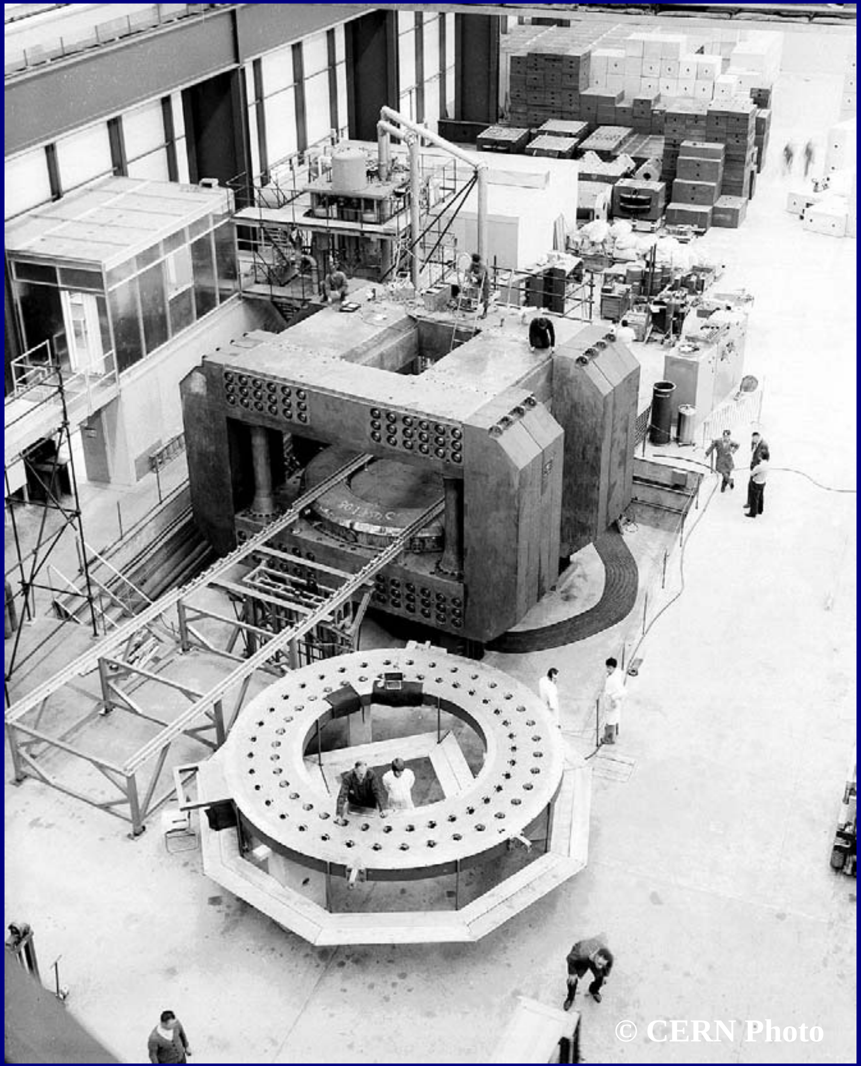
CERN large spectrometer magnets

Grands Aimants Supraconducteurs au CERN (Physique)

Aimant	Vertex (NA49.1)	Vertex (NA49.2)	Dipôle (Atlas)	M1 (CMS)	Omega	BEBC	Aleph	Delphi	Futur LHC CMS	ATLAS
Constructeur	Ansaldo	Alsthom	Ansaldo	Saclay	CERN	CERN	Saclay	RAL	En cours	
Année	78	78	77	79	72	73	87	87	~2001	
Masse Froide (t)	25	25	40	24	30	200	25	25	260	700
Energie Stockée (MJ)	≤ 50			55	50	800	140	120	2520	1490/ 1500
Champ Magnetique (T)	1.5	1.5	1.5	3	1.8	3.5	1.5	1.2	4	2/ 4.2
Courant (A)	5000	5000	5000	4000	5000	5750	5000	5000	20000	20000
Mode de Refroidissement	Pompes à Hélium Liquide	Pompes à Hélium Liquide	Pompes à Hélium Liquide	Bain	circul. He SC	Bain	Thermo siphon	Pompes à Hélium Liquide	Thermo siphon	Pompes à Hélium Liquide

S.c. magnet (4.7 m inner diameter, 3.5 T) contains a large number of optical spark chambers surrounding a hydrogen target. H_2/He refrigerator, 6.7 kW @4.5K

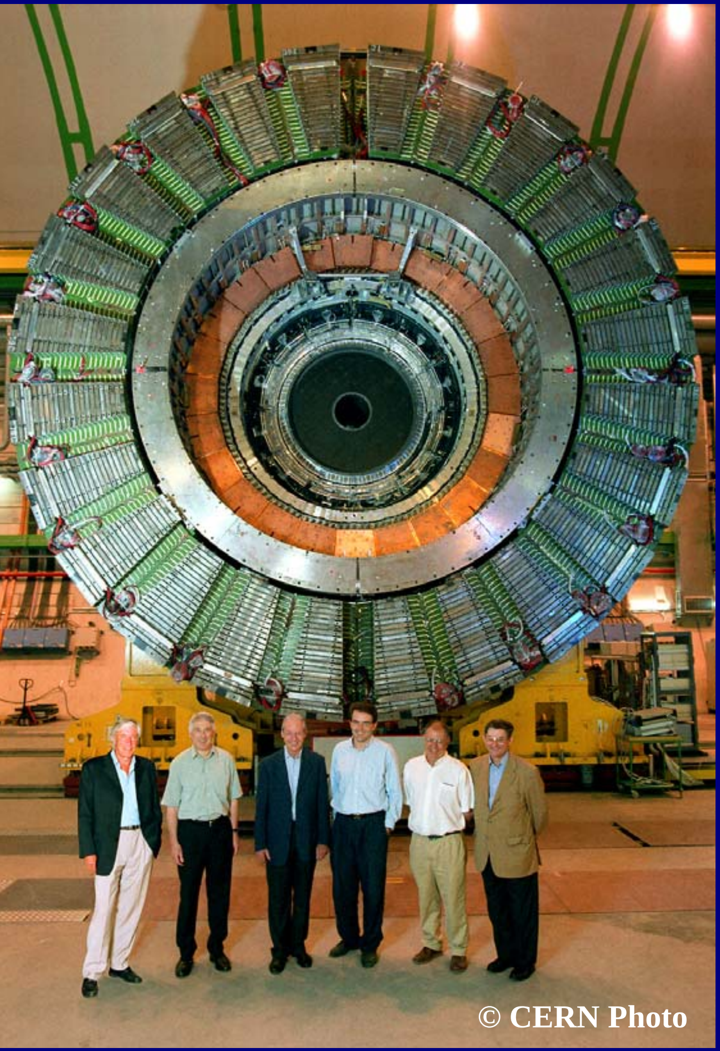


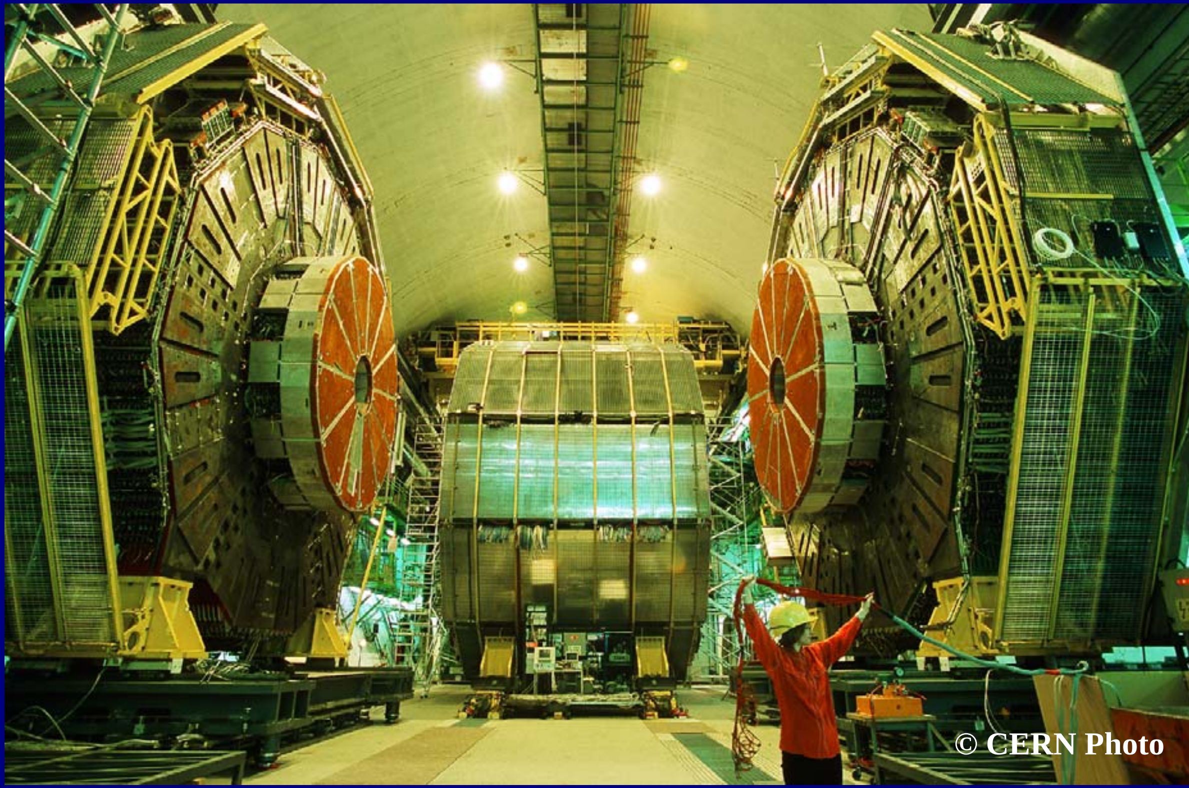


ALEPH & DELPHI

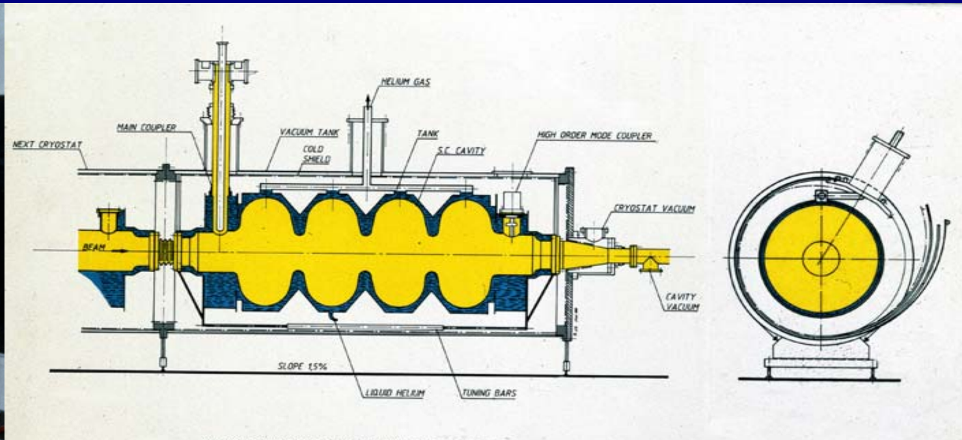
ALEPH: field: 1.5 T, stored energy: 136 MJ, current: 5000 A, inner diameter: 5m

DELPHI: field: 1.2 T, stored energy: 108 MJ, current: 5000 A, inner diameter: 5.2 m

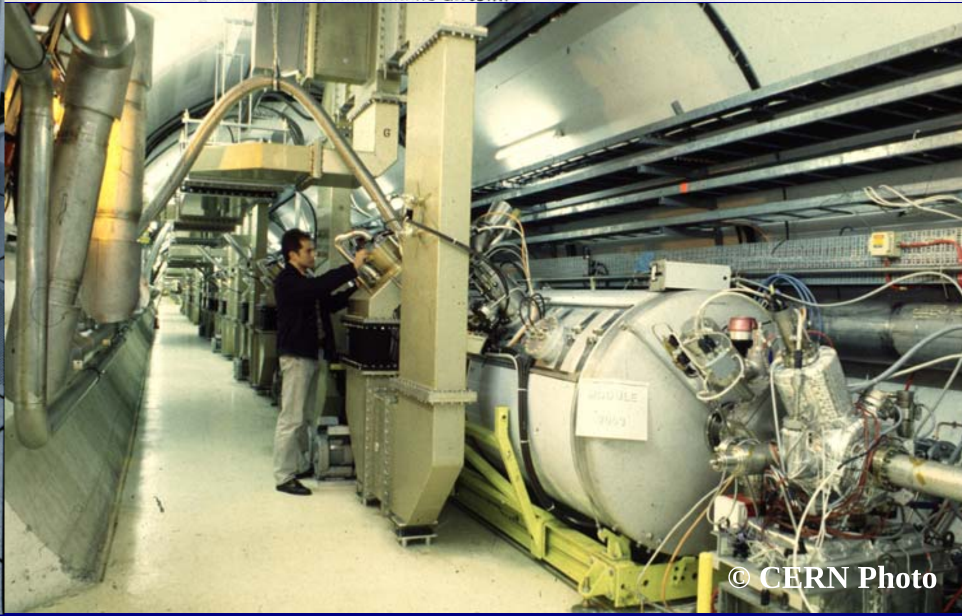




S.C. RF cavities



SUPERCONDUCTING CAVITY WITH ITS CRYOSTAT



NA48 LKR calorimeter

CERN SPS fixed target experiment to study direct CP violation in the neutral kaon system.

Calorimeter uses LKr (10 m^3) for "passive particle" absorption and "active read out" via ionization of the liquid.

Cooling fluid is saturated LN2, heat extraction by re-condensing evaporated Kr via intermediate bath of LAr

Cascade cooling allows operation of LN2 system at 0.5 MPa since Ar triple point (84 K) lower than Kr (114 K)

Uninterrupted LN2 cooling system operation even during detector shutdown in order not to loose Kr!

LHC corrector magnet test facility

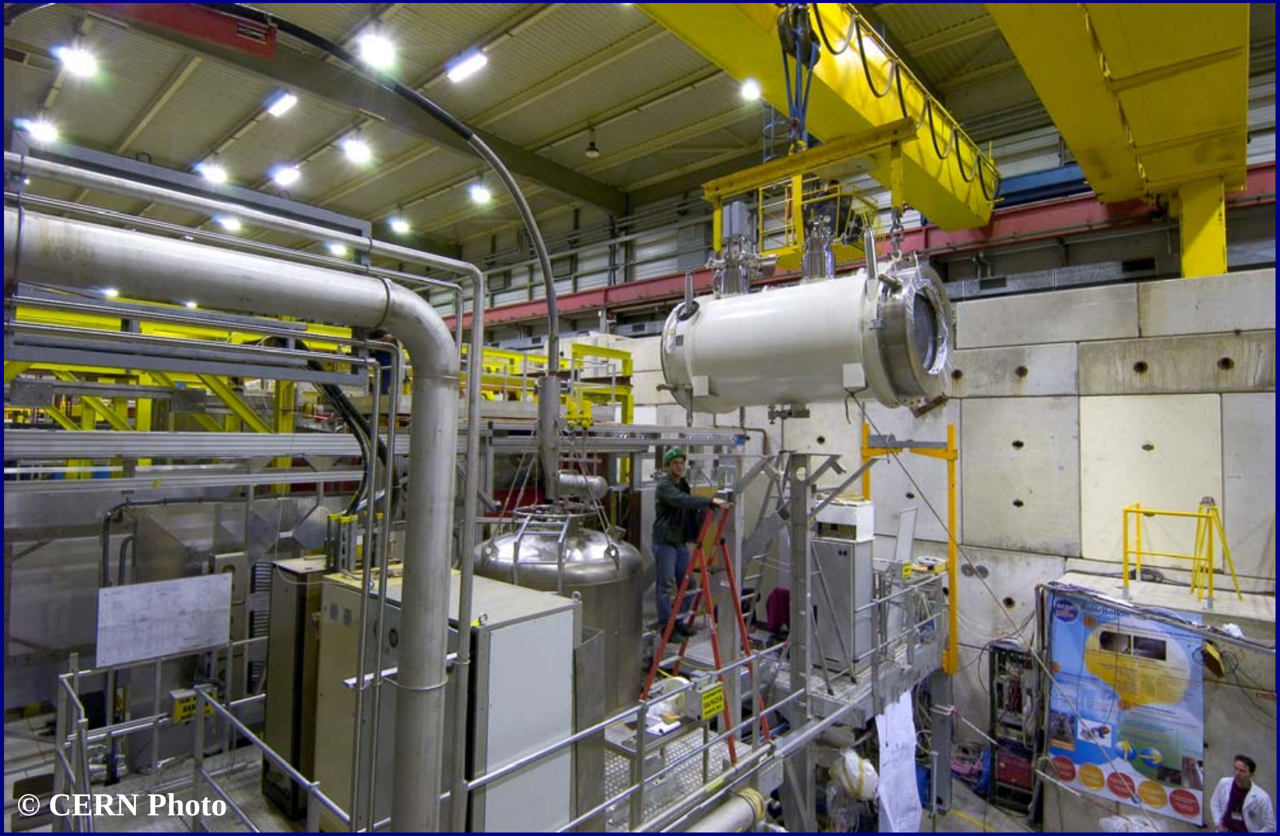
ATLAS BT test facility

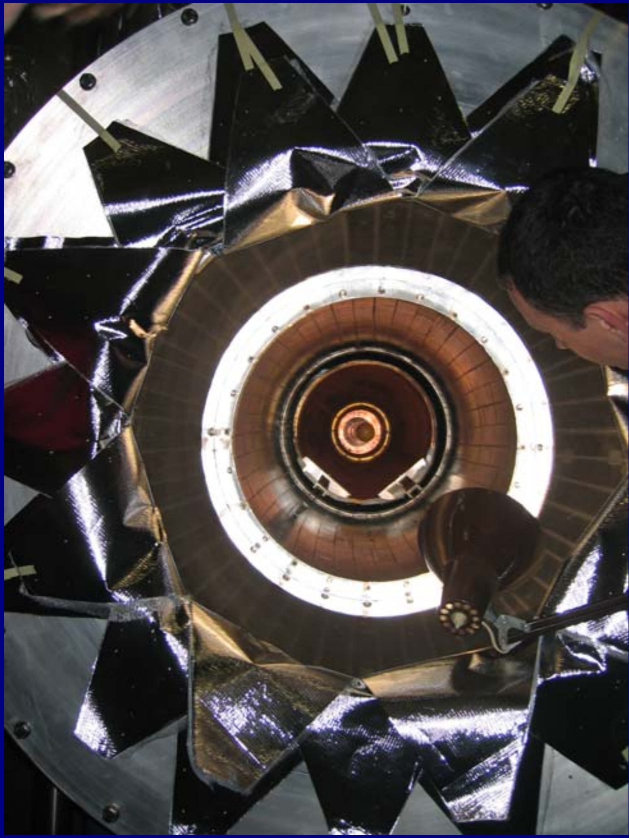
LHC cable test facility:

8 cryostats for s.c. wires testing

1 double-cryostat for s.c. cable test

Solid polarized proton and deuteron targets. Polarized with dynamic nuclear polarization (DNP) in a 2.5 T longitudinal field generated by a s.c. solenoid and cooled to less then 1 K by a dilution refrigerator





CERN Axion Solar Telescope (CAST)

Telescope aiming at the detection of solar axions. Decommissioned 10 m, 9.5 T LHC s.c. dipole prototype to catalyze the conversion of the axions into photons.

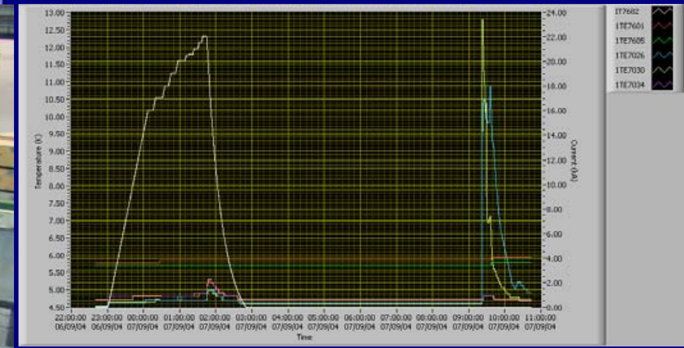
CERN-wide LHe & LN2 distribution

Central He liquefier yearly total production: 220’000 l

Distribution of LN2 from 3 suppliers, 5147 tons in 2005

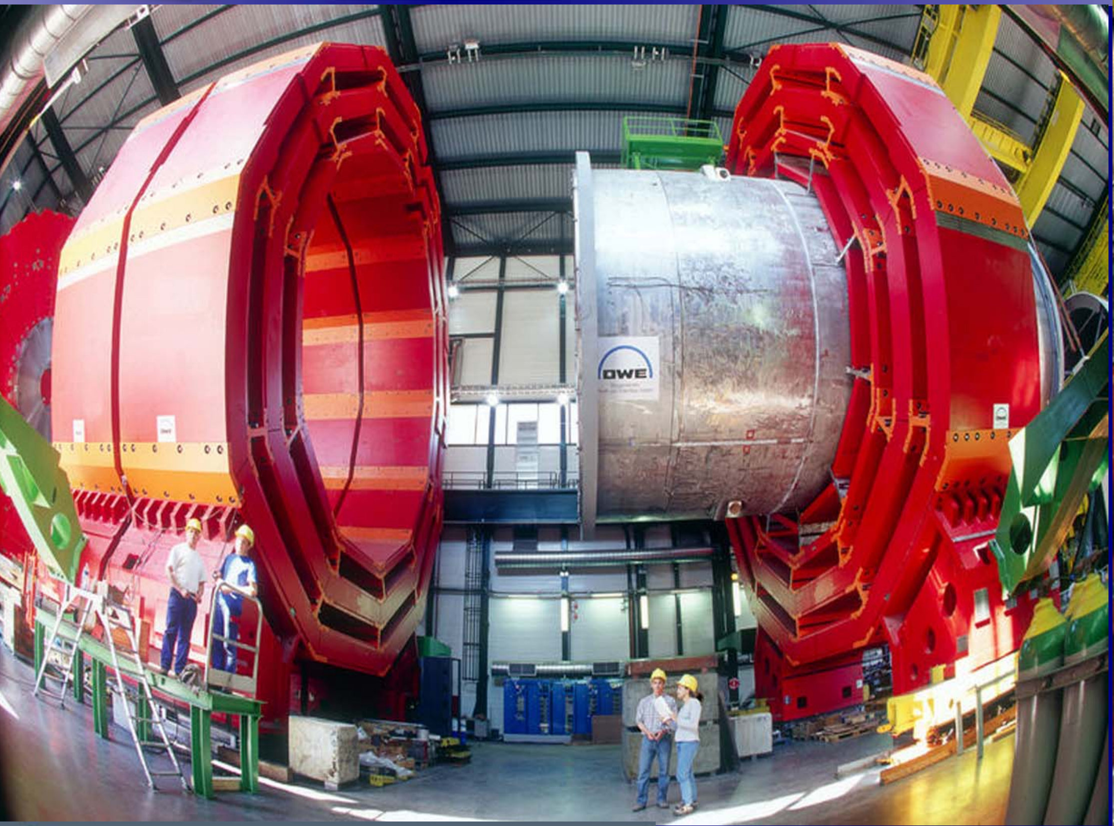
Purchasing of liquid helium from Several suppliers, 40 tons in 2005

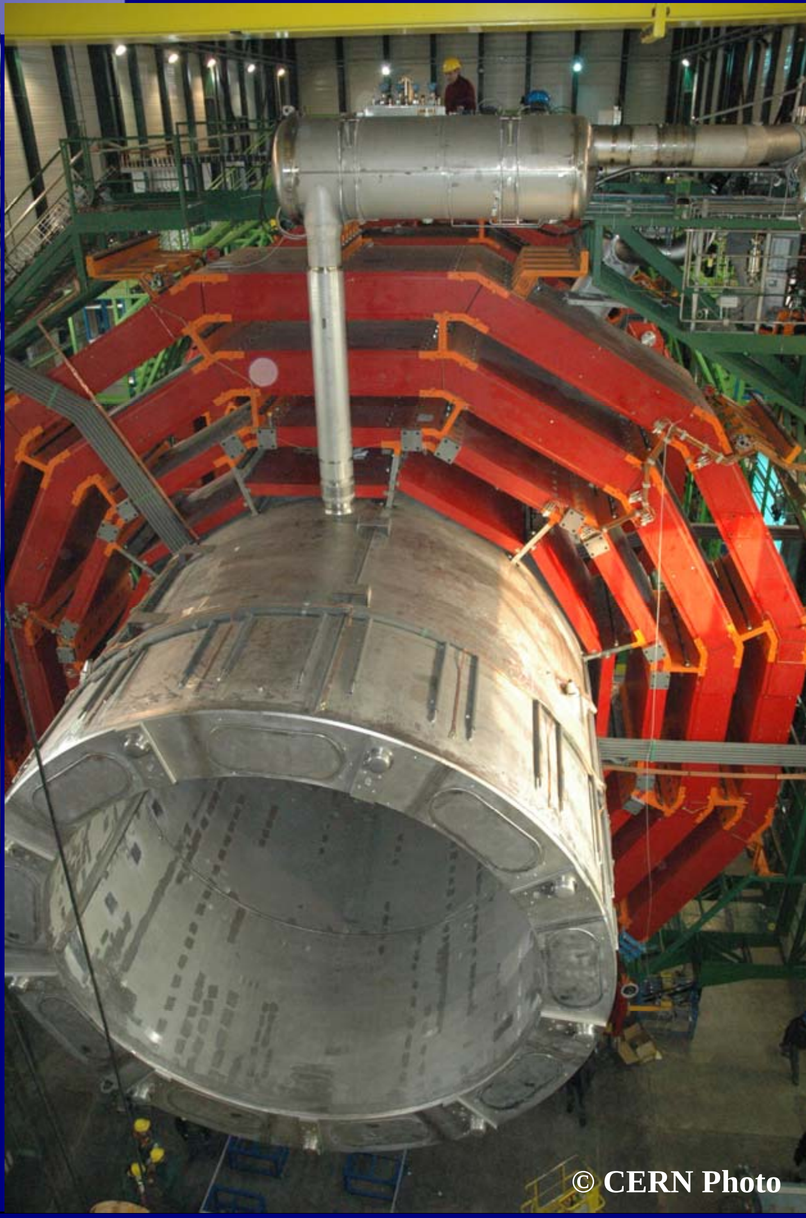
ATLAS barrel toroid integration and test area in building 180

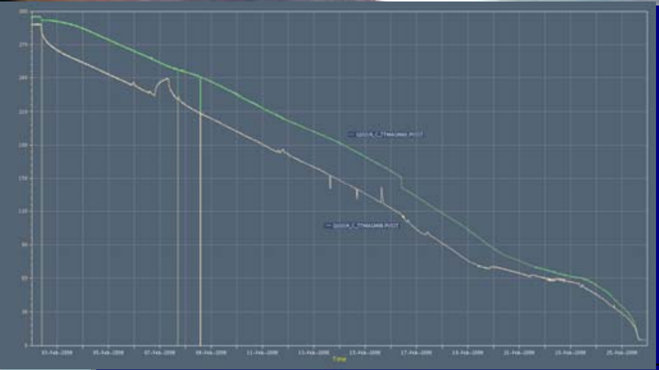


ATLAS 8 BT coils successfully tested @ 22 kA 2004-2005
ECT testing at 80 K scheduled for 2006

CMS Detector







CMS solenoid cooled to 4. 5 K. First ramp-up of current planned for summer 2006.

ATLAS Assembly