



LHC: la sfida tecnologica, lo stato della macchina, le prospettive



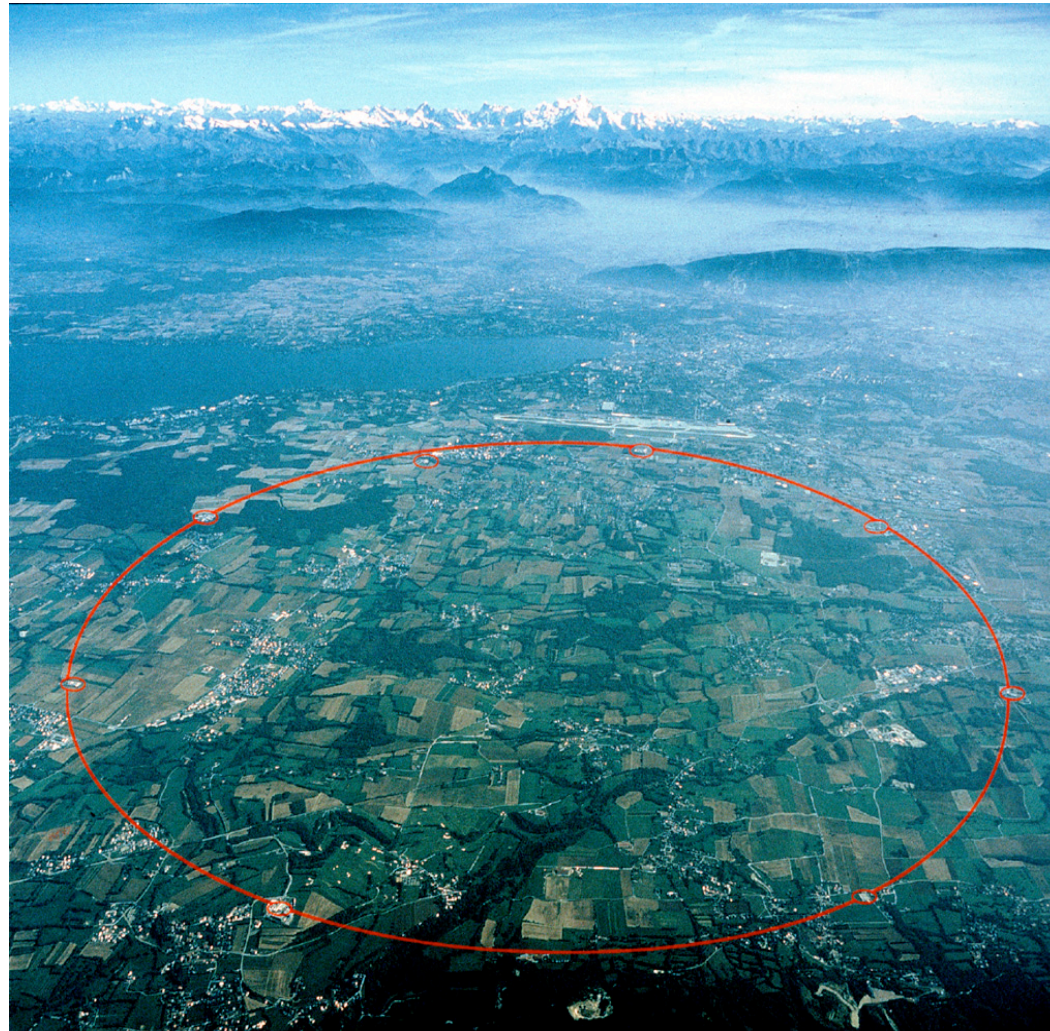
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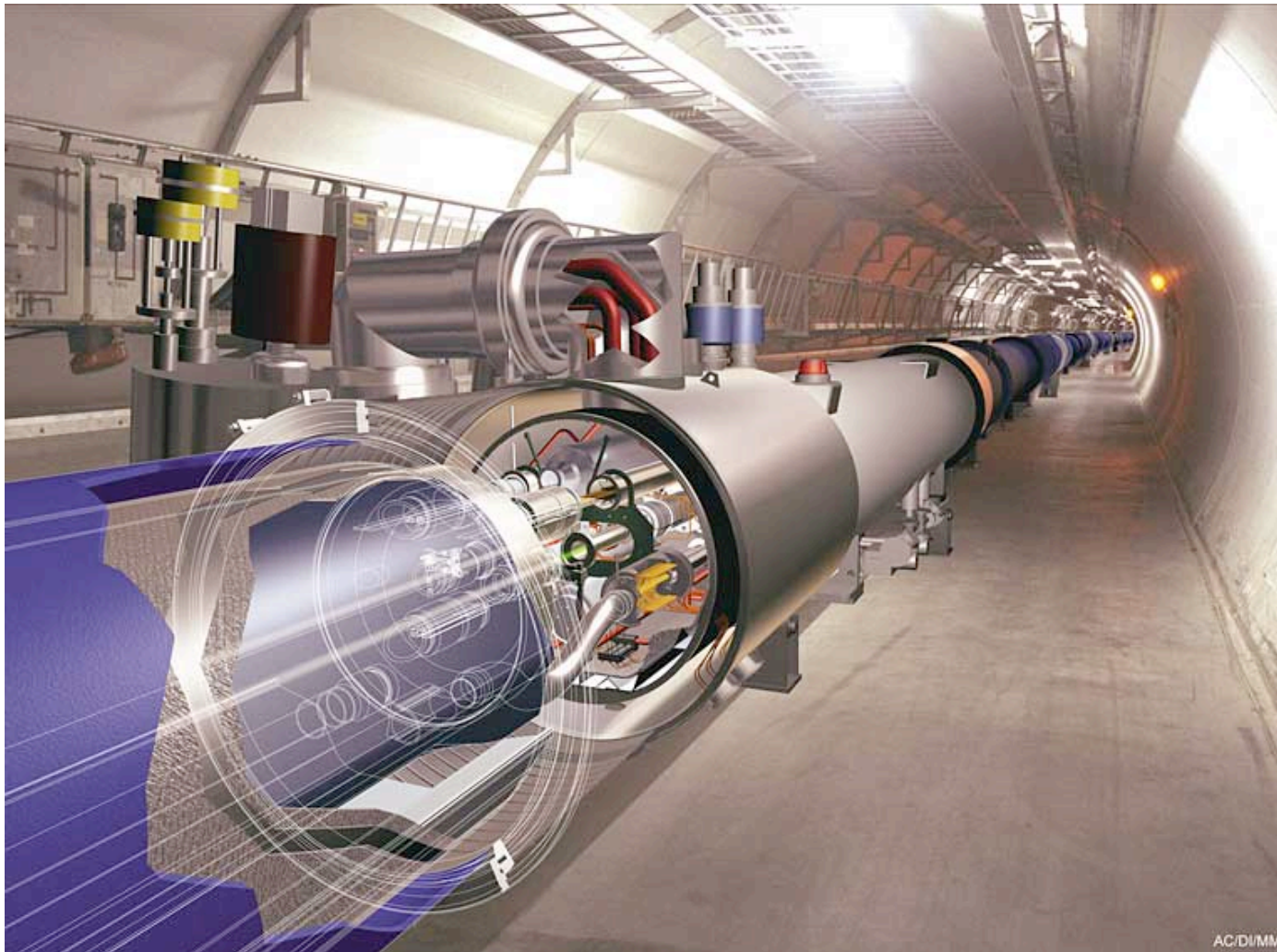
Napoli, 15 Ottobre 2004



Un tunnel da 27 km...

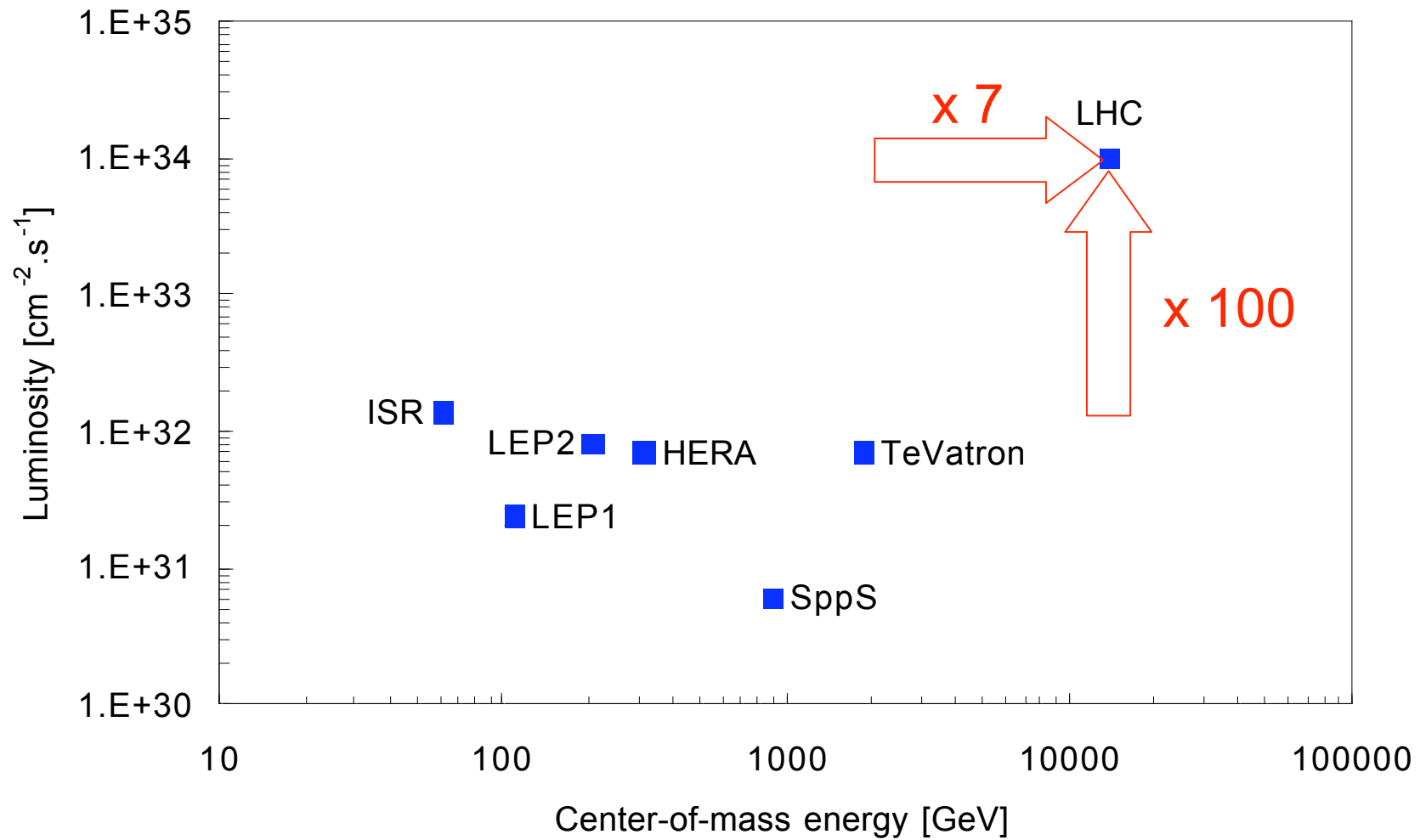


...basato su tecnologia superconduttiva



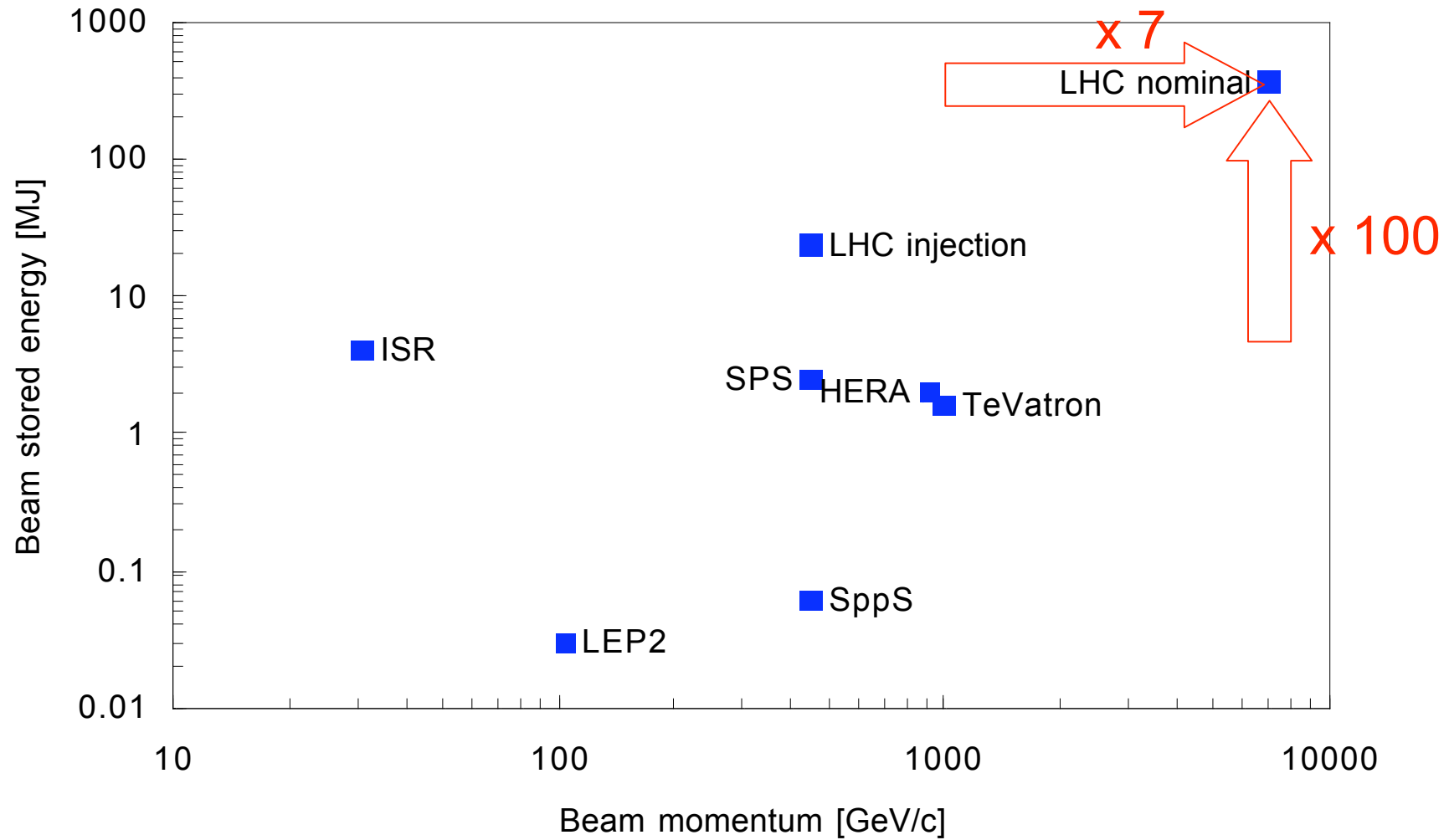


I grandi collisori





Momento & energia stoccata per i grandi collisori





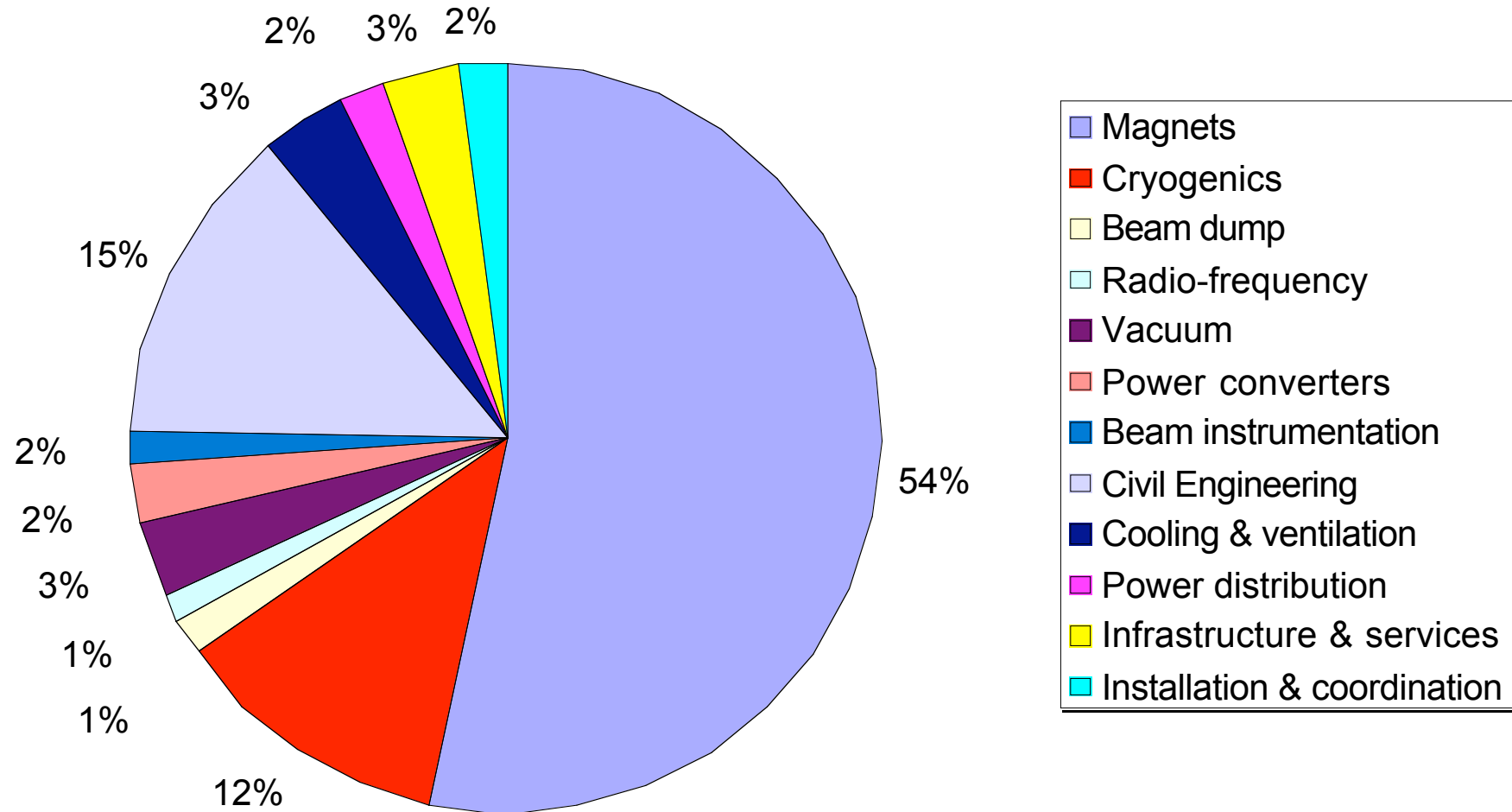
I principali parametri LHC



• Circumference	26.7	km
• Beam energy at collision	7	TeV
• Beam energy at injection	0.45	TeV
• Dipole field at 7 TeV	8.33	T
• Luminosity	10^{34}	$\text{cm}^{-2}\cdot\text{s}^{-1}$
• Beam current	0.56	A
• Protons per bunch	1.1×10^{11}	
• Number of bunches	2808	
• Nominal bunch spacing	24.95	ns
• Normalized emittance	3.75	μm
• Total crossing angle	300	μrad
• Energy loss per turn	6.7	keV
• Critical synchrotron energy	44.1	eV
• Radiated power per beam	3.8	kW
• Stored energy per beam	350	MJ
• Stored energy in magnets	11	GJ
• Operating temperature	1.9	K



Costi per area





Complessità: numero e funzioni dei magneti

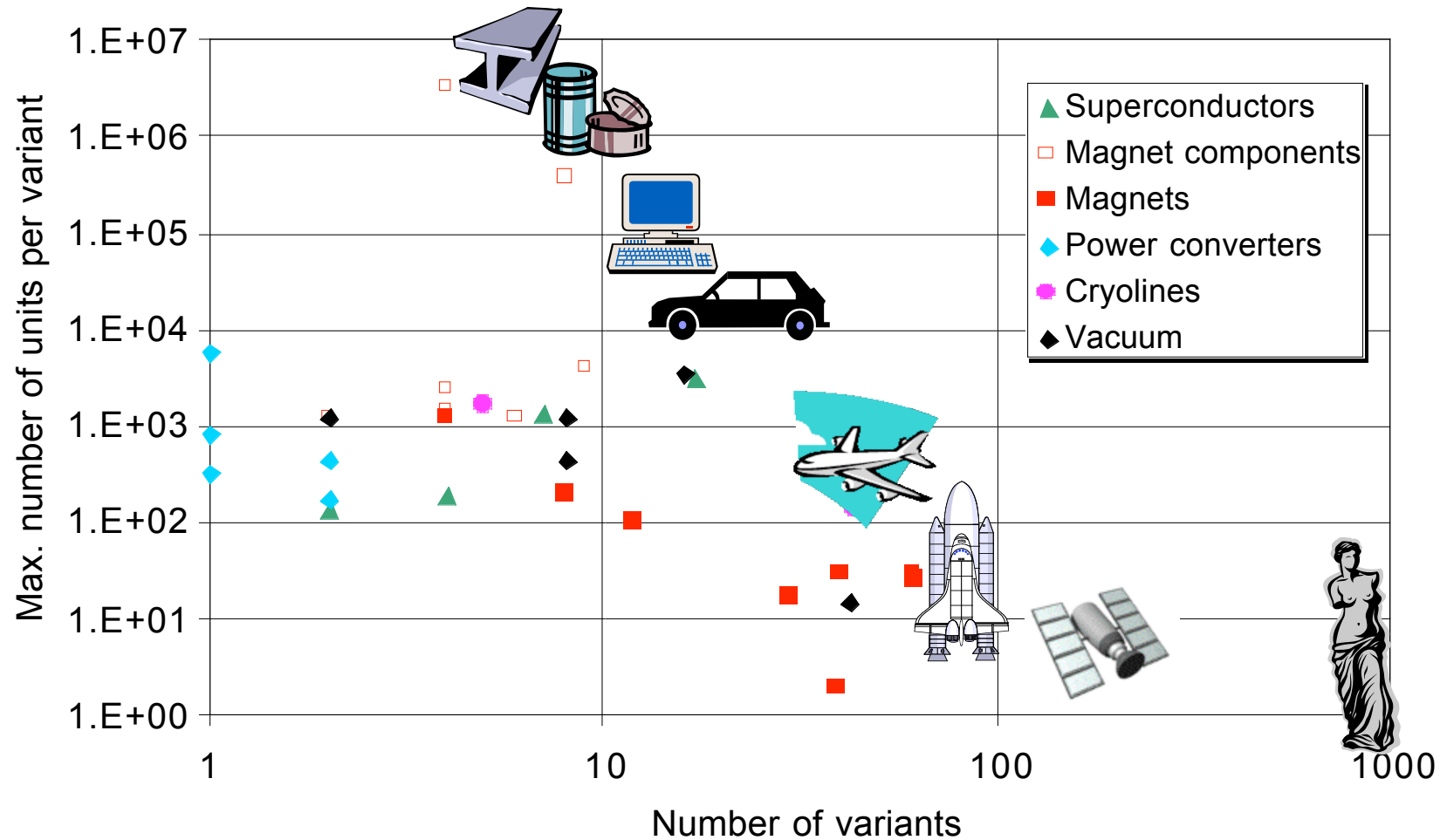


Type	Number	Function
MB	1232	Main dipoles
MQ	392	Arc quadrupoles
MBX/MBR	16	Separation & recombination dipoles
MSCB	376	Combined chromaticity & closed orbit correctors
MCS	2464	Sextupole correctors for persistent currents at injection
MCDO	1232	Octupole/decapole correctors for persistent currents at injection
MO	336	Landau damping octupoles
MQT /MQTL	248	Tuning quadrupoles
MCB	190	Orbit correction dipoles
MQM	86	Dispersion suppressor & matching section quadrupoles
MQY	24	Enlarged -aperture quadrupoles in insertions
MQX	32	Low-beta insertion quadrupoles

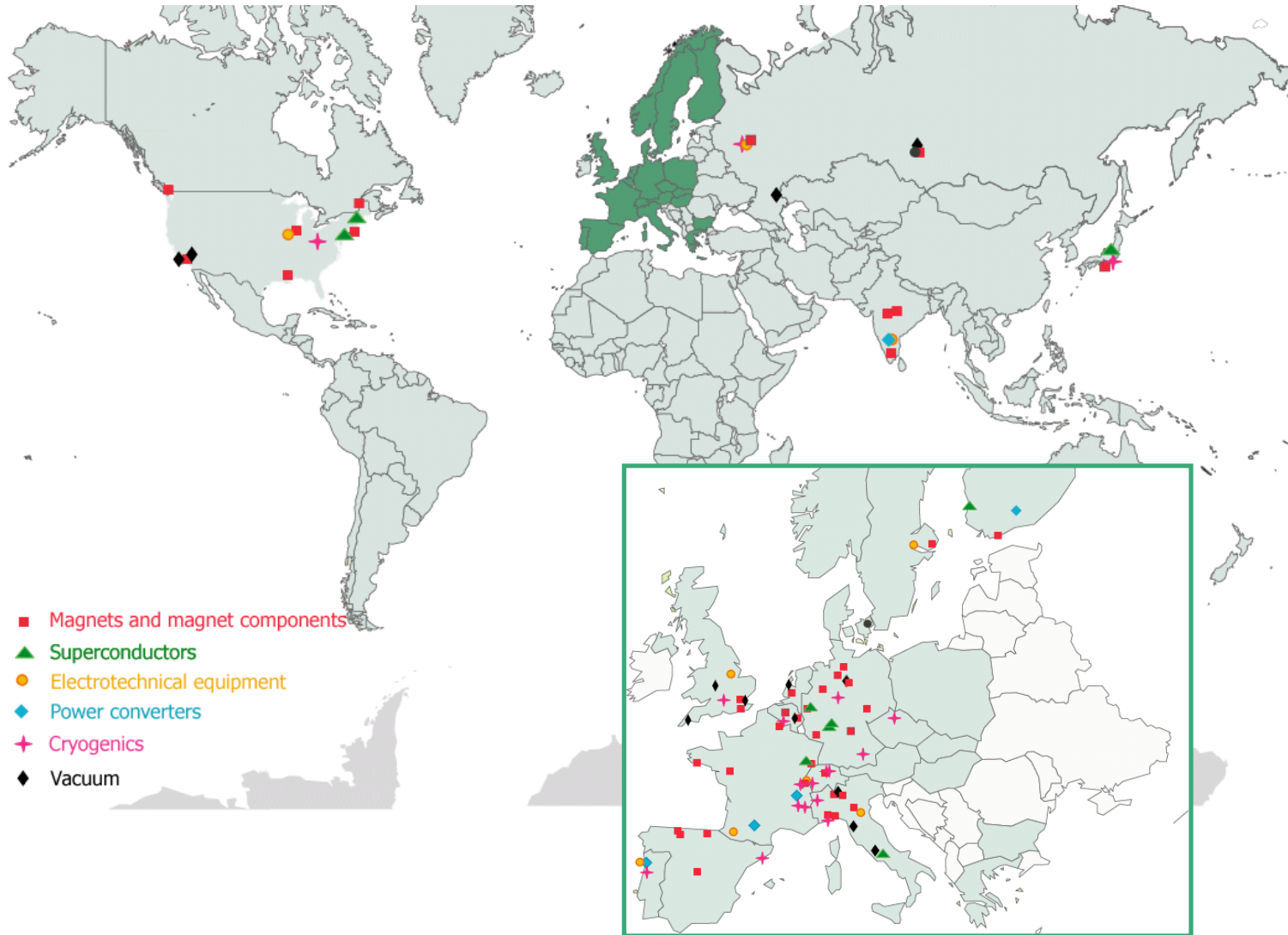


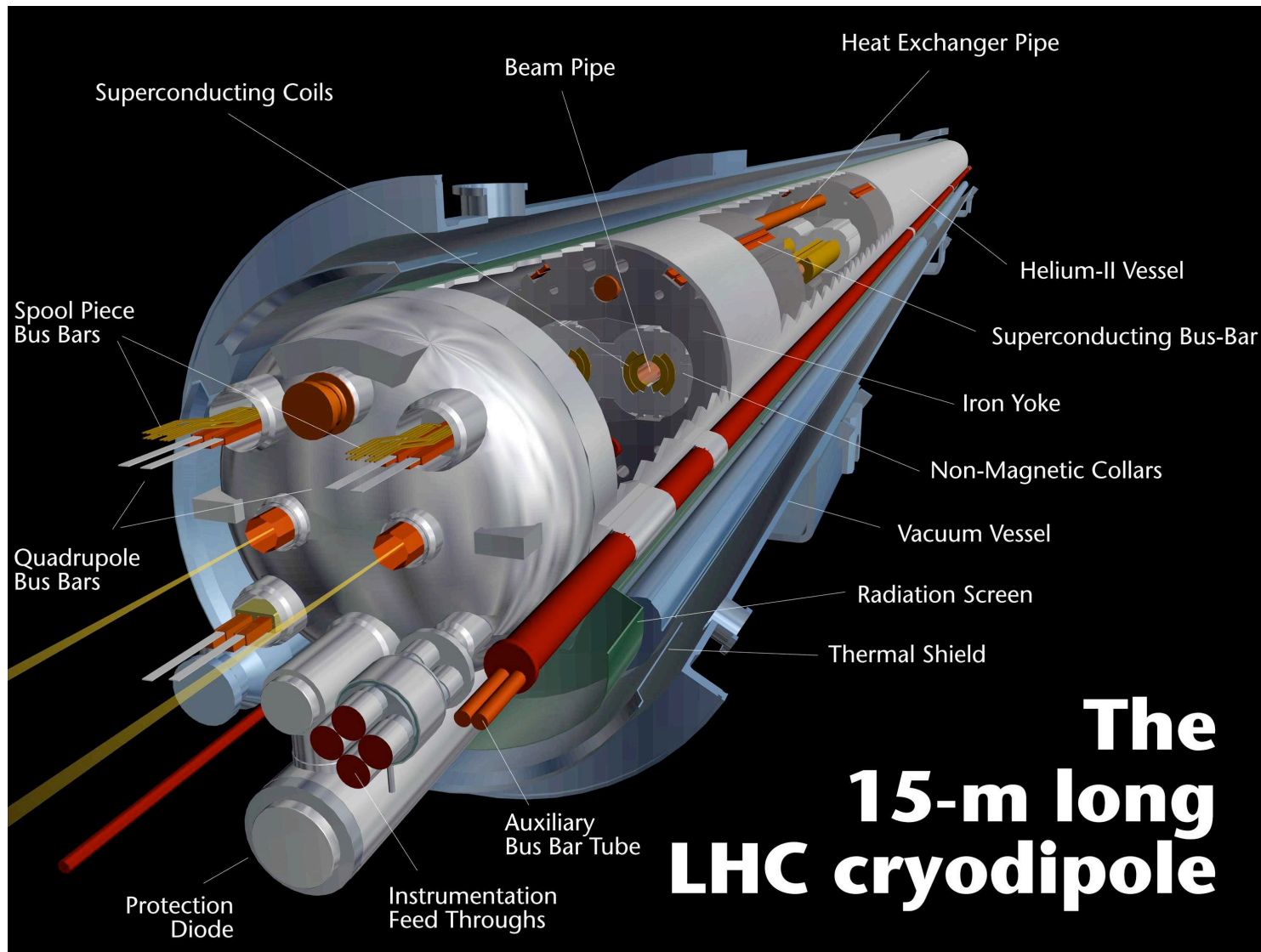
LHC: componenti e scala industriale

(cortesia di Philippe Lebrun)



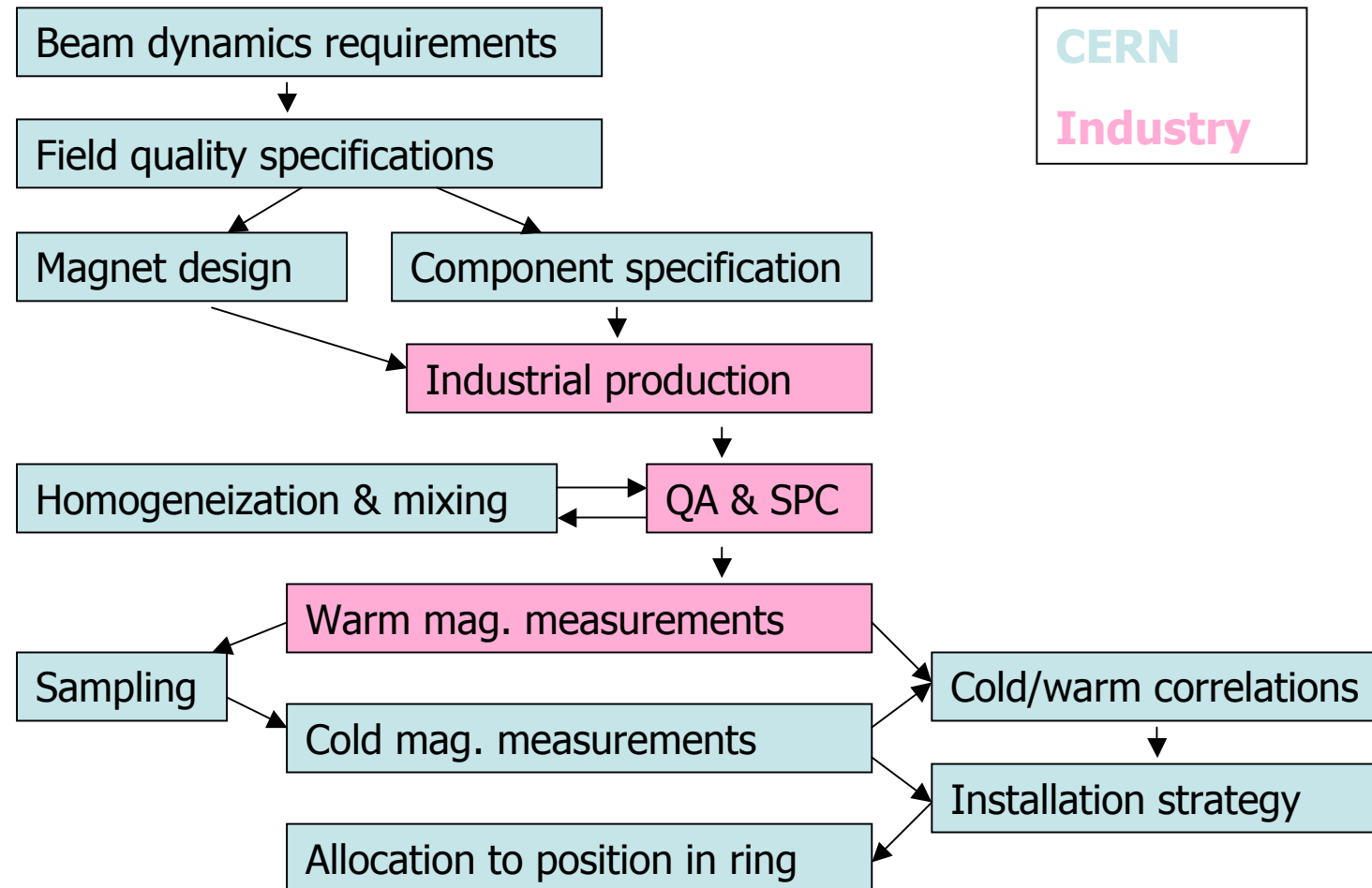
90 contratti principali nel mondo



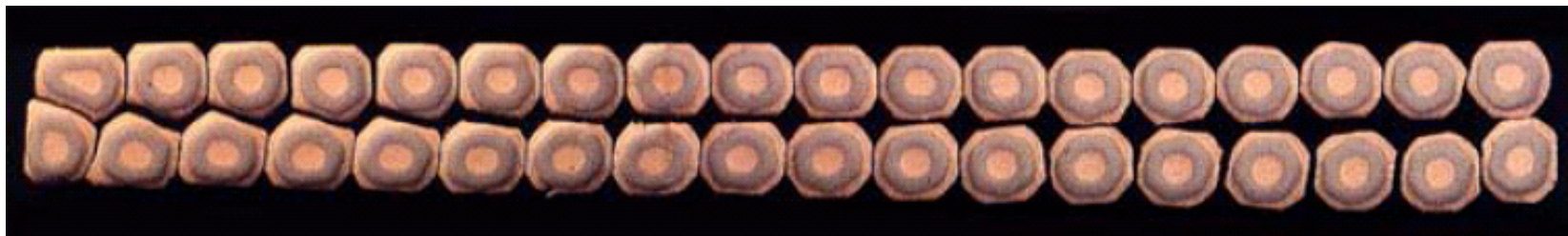
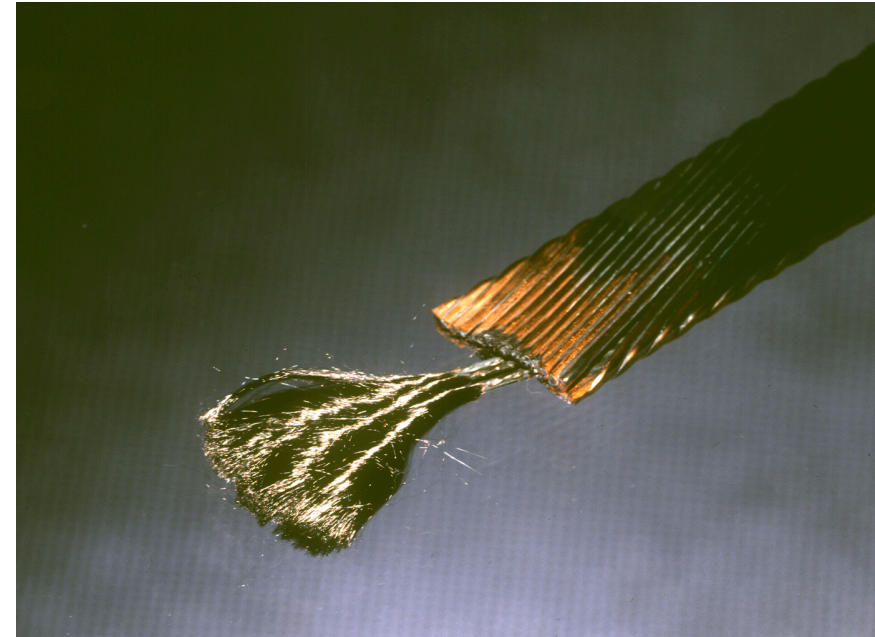
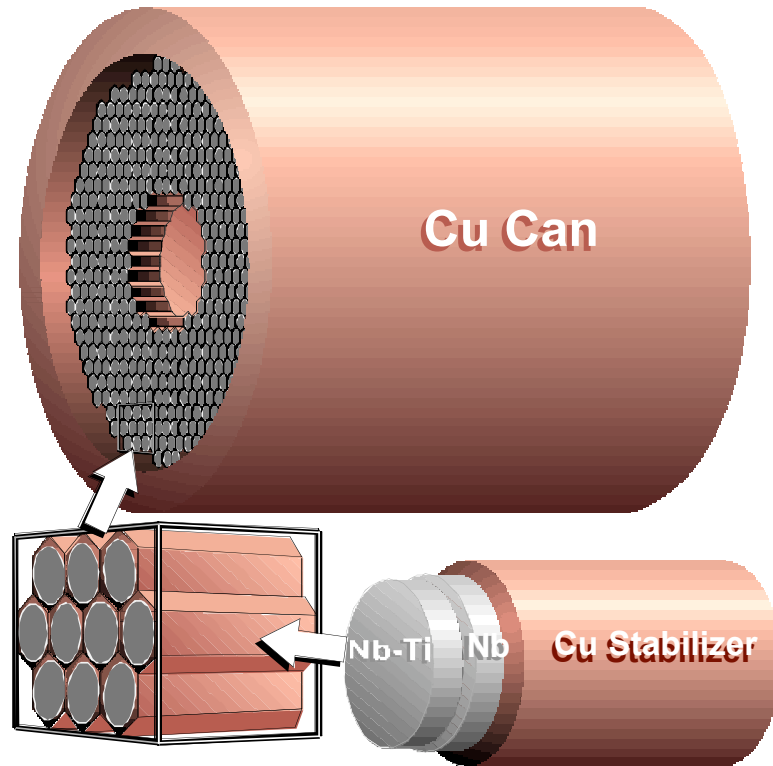




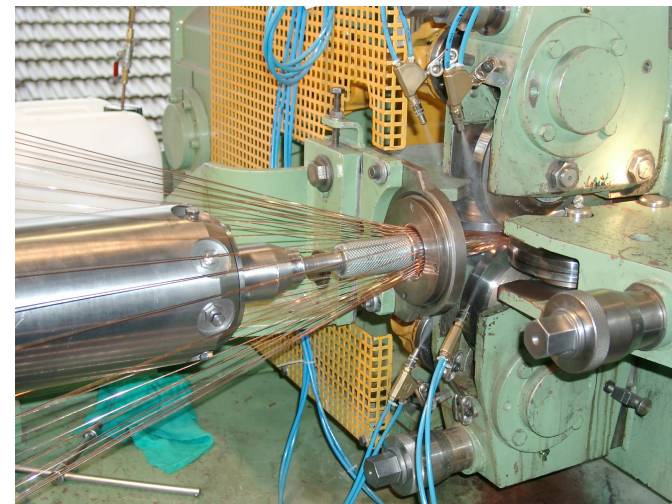
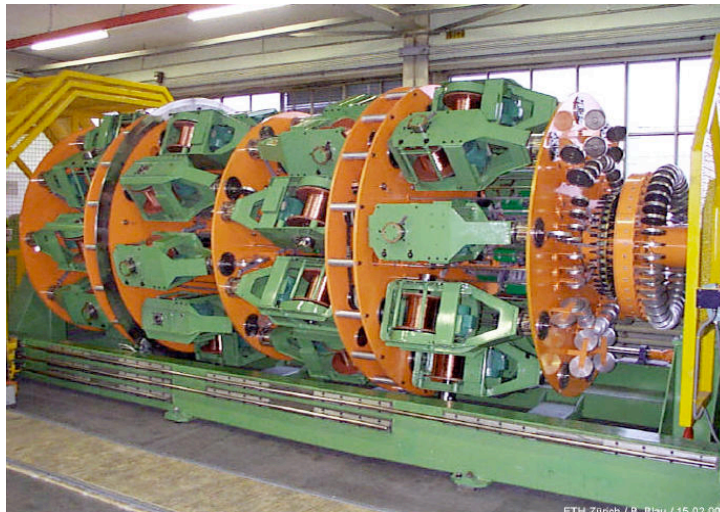
Il lungo cammino verso la qualità di campo



Caratteristiche cavo superconduttore LHC

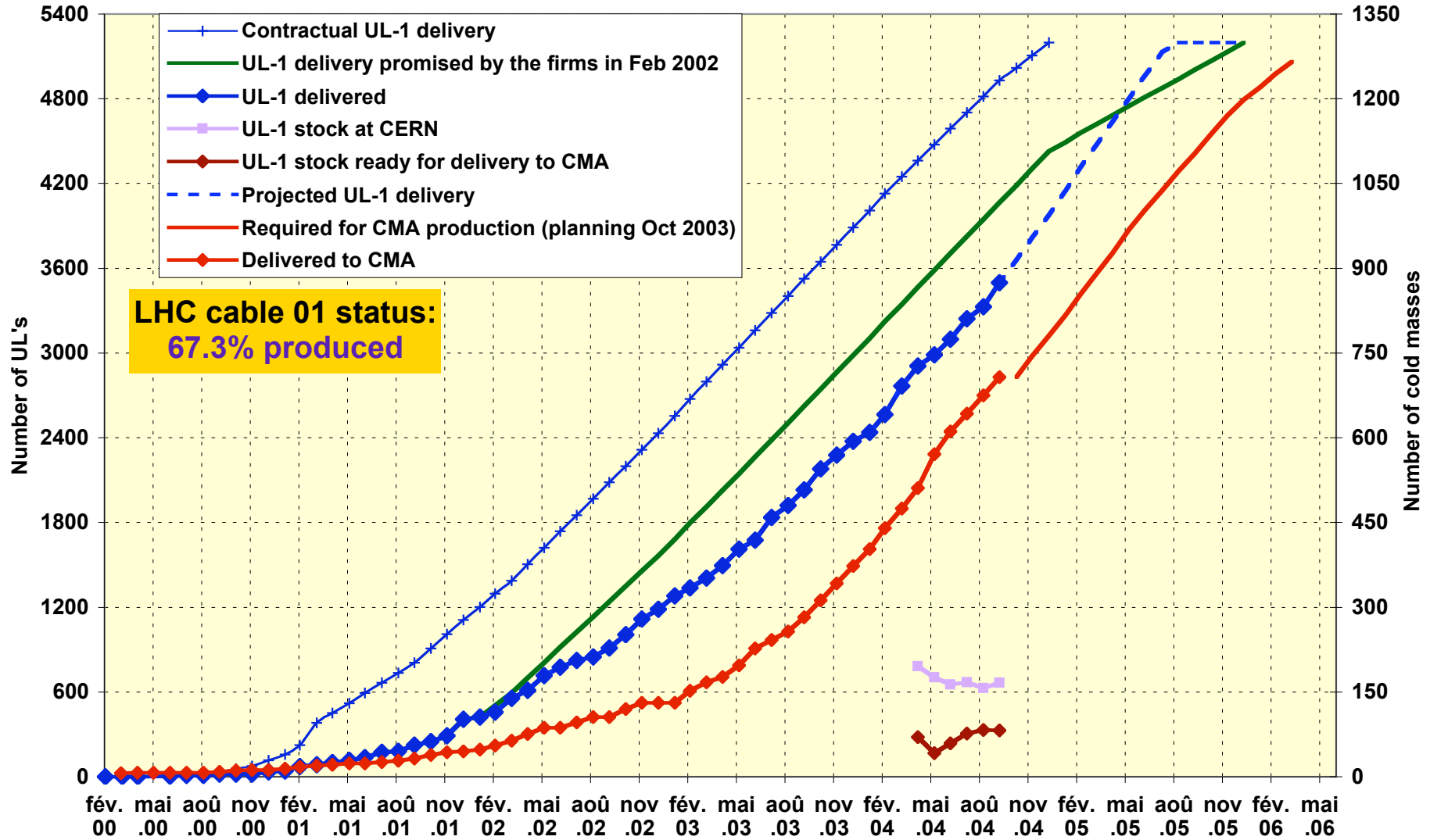


Dalla billetta assemblata al cavo finito





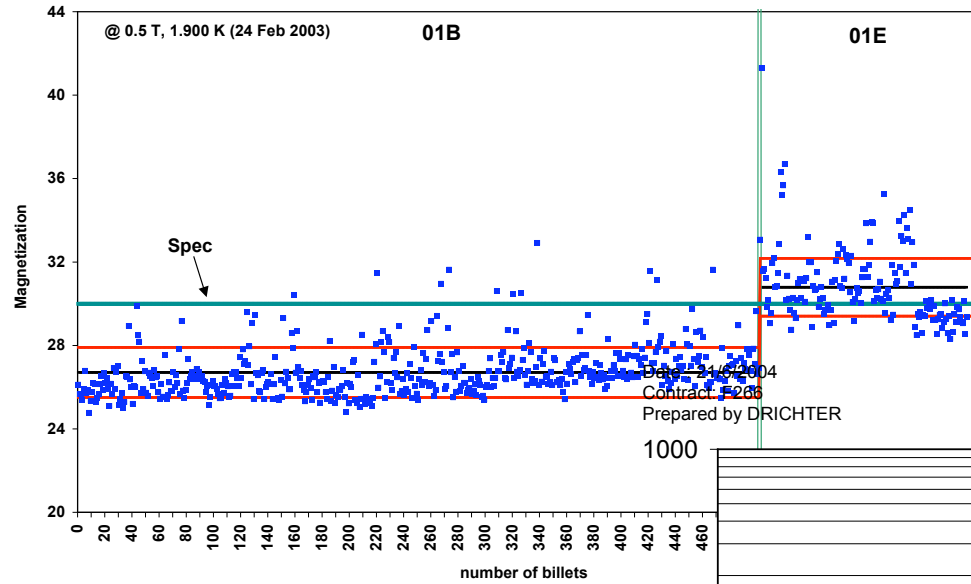
Superconducting cable 1



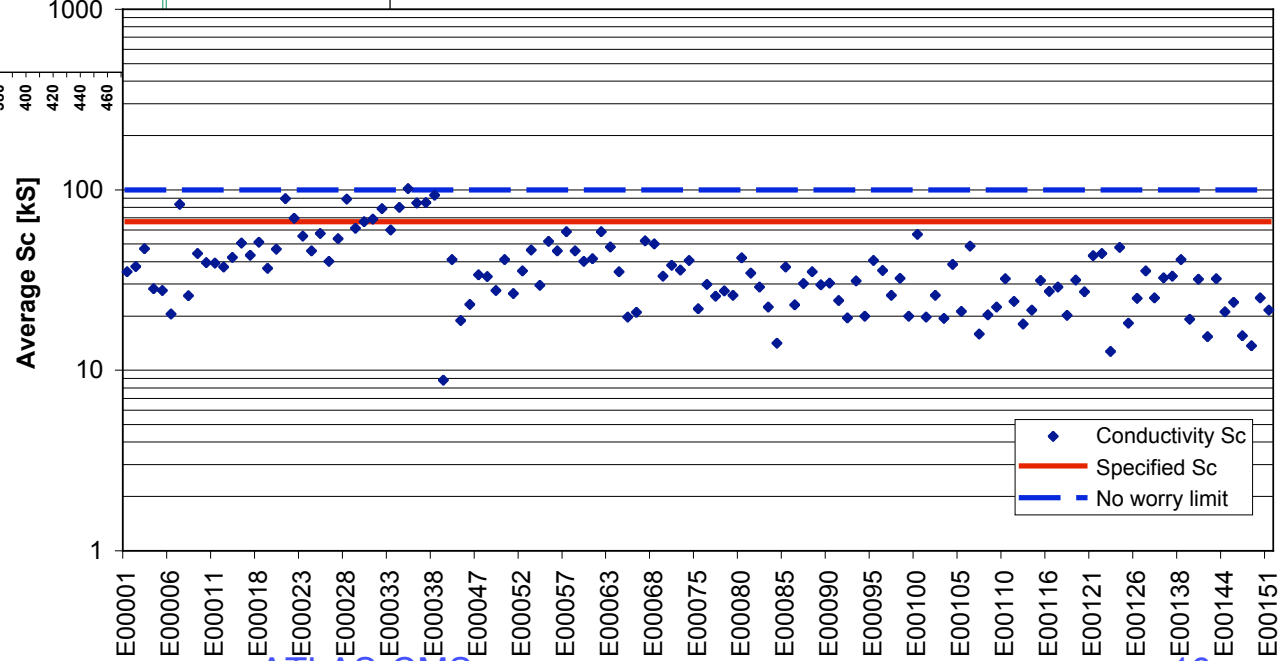
A. Verweij, AT/MAS/SC, 1/10/2004



Principali proprietà cavi



Average Sc measured by CERN
Map from 01E00001 to 01E00151



Lucio Rossi

ATLAS-CMS
Napoli, 15 Ottobre 2004



Gestione di una complicata catena di forniture

Benefici

- Omogenietà dei parametri
- QA
- Economia di scala
- Sicurezza della fornitura
- Ritorno bilanciato

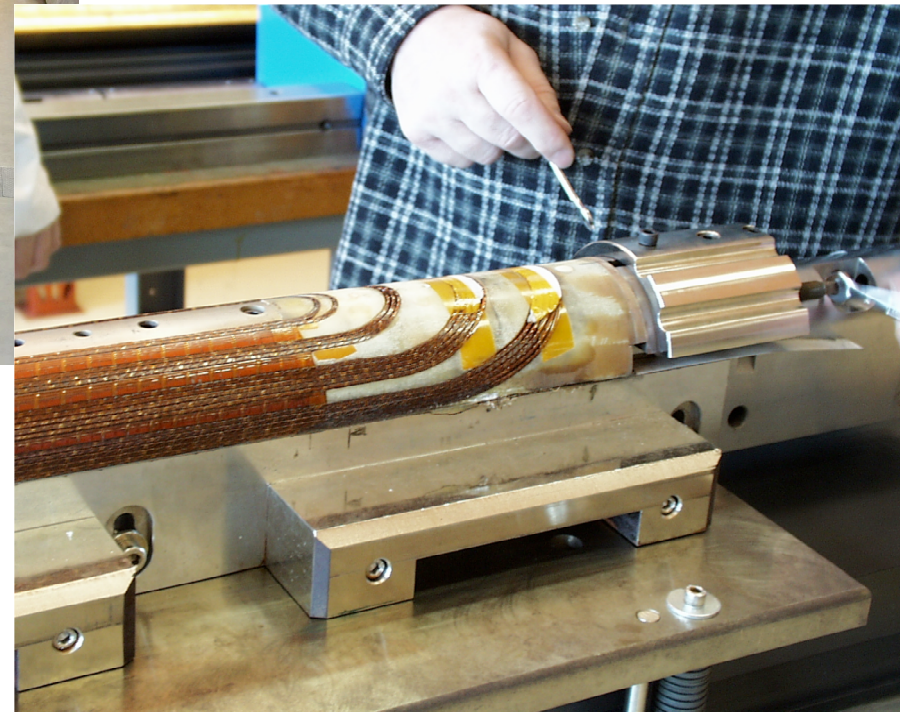
Rischi e svantaggi

- Responsabilità interfaccia
- Lavoro addizionale
- JIT breakdown
- Transporti, storage & logistica

Produzione bobine



ANSALDO

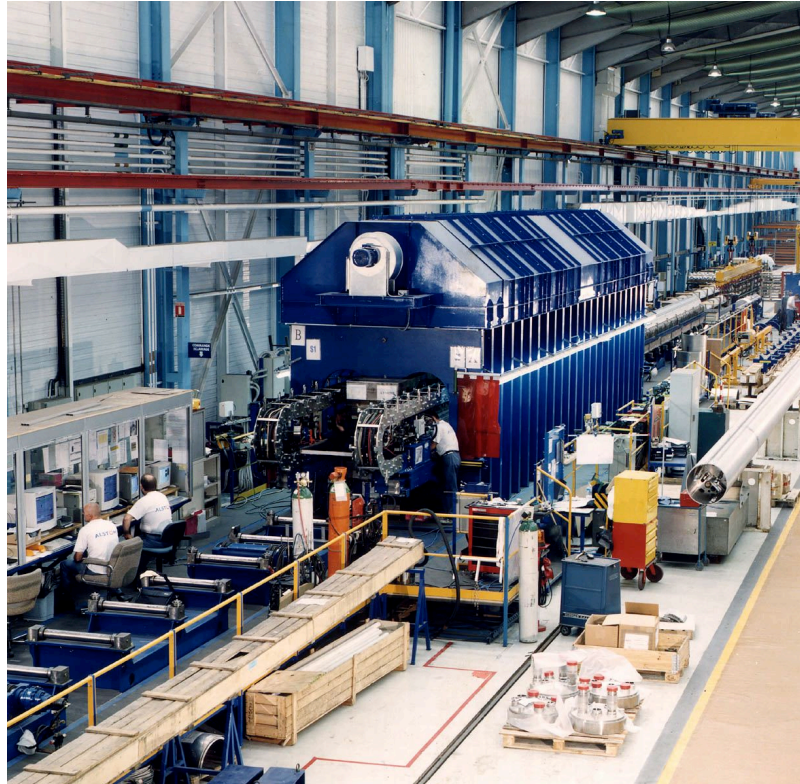


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18

assemblaggio massa fredda

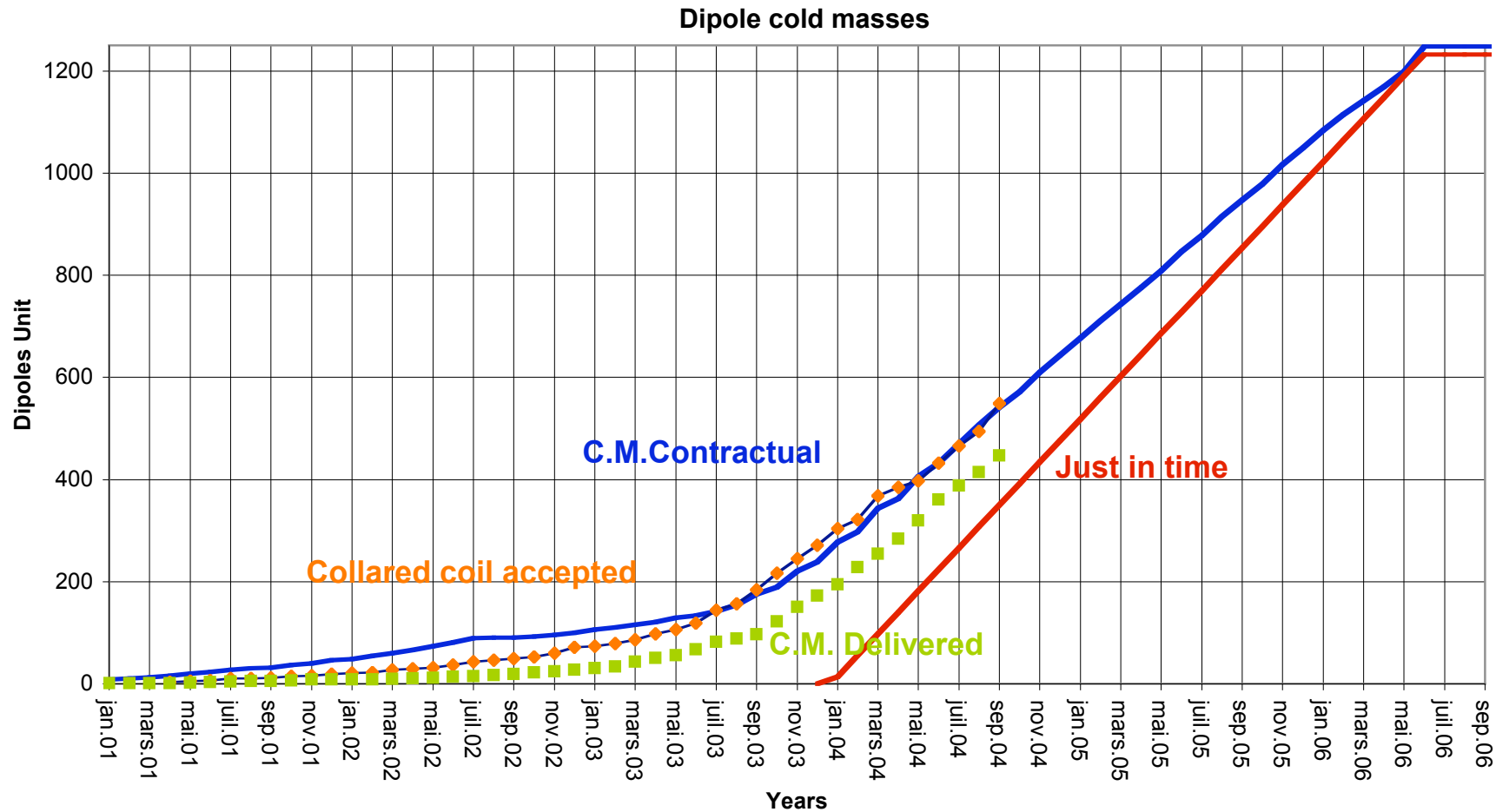


ALSTOM



NOELL

Dipoli (masse fredde)



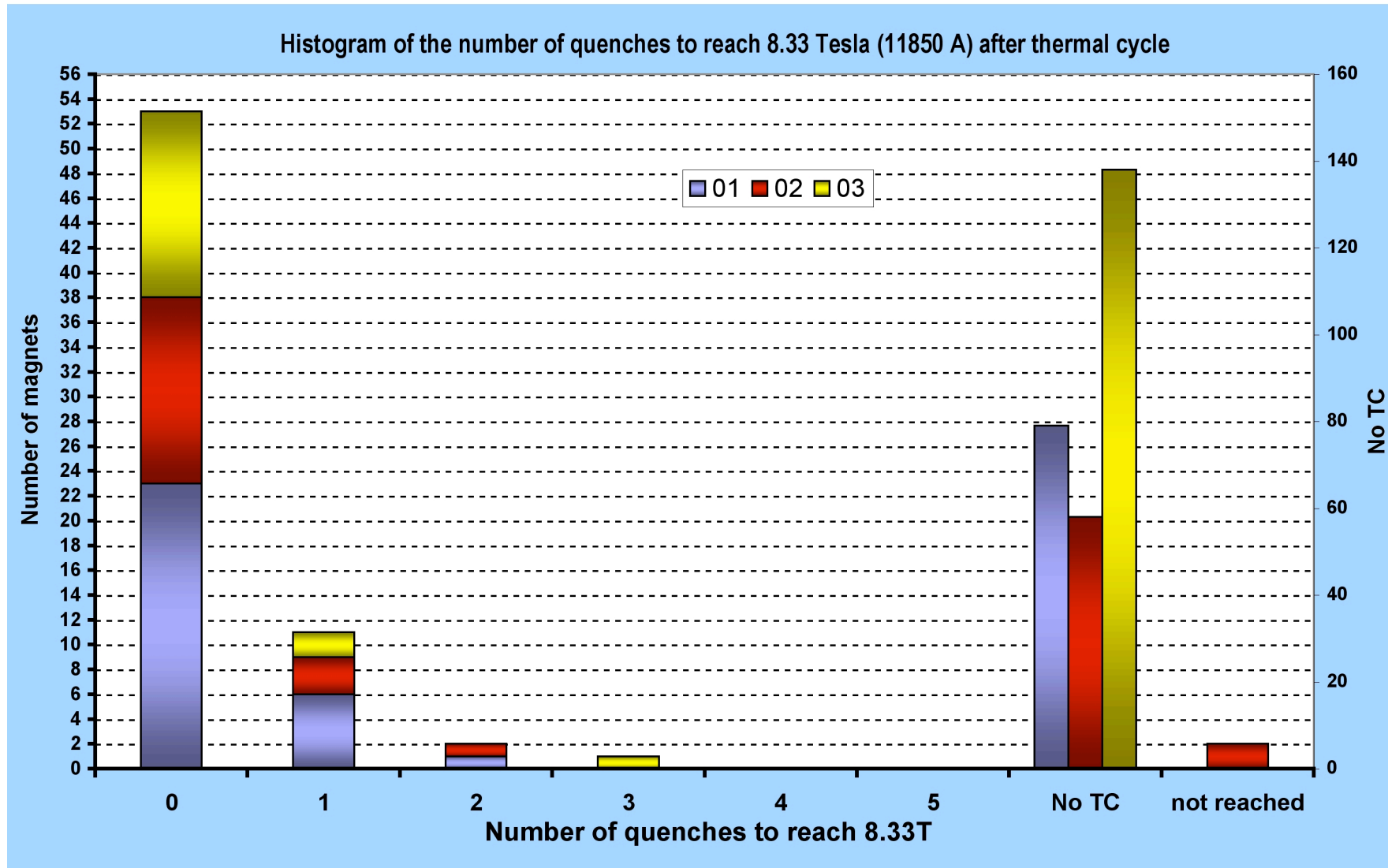


12 banchi di test criogenici 12 magneti/settimana (15 nel 2005?)



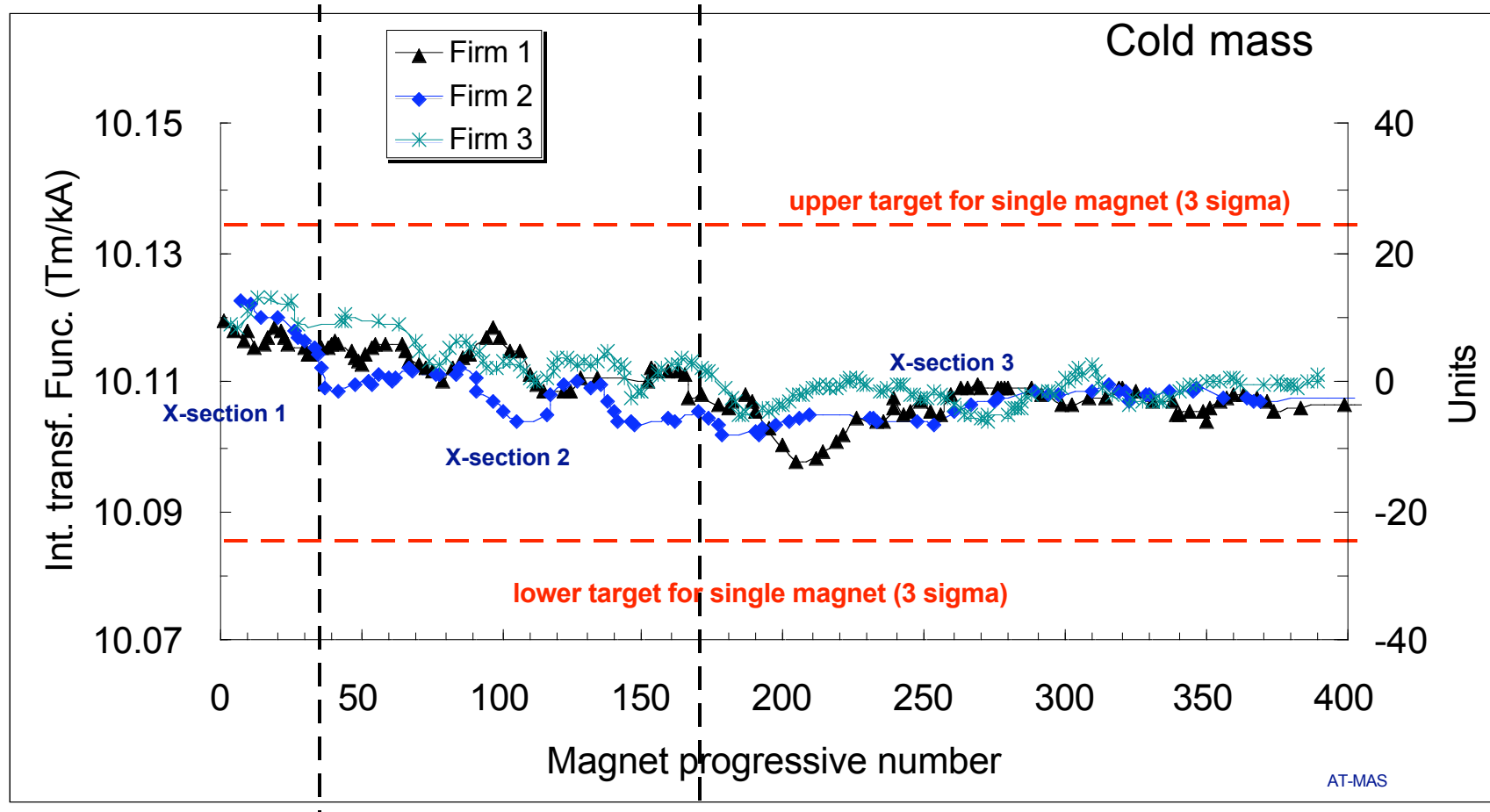


Quench per arrivare a 8.33 T secondo ciclo termico (su ca.360 dipoli)



Dipoli: bending strength

E. Todesco





Ottenere tecnologia avanzata dall'Industria



- Specifiche tipo “built-to-print” and “built to process”, dove il laboratorio mantiene la proprietà intellettuale
 - *Magneti Superconduttori*
- Specifiche funzionali o “chiavi in mano”
 - *Linea Criogenica*

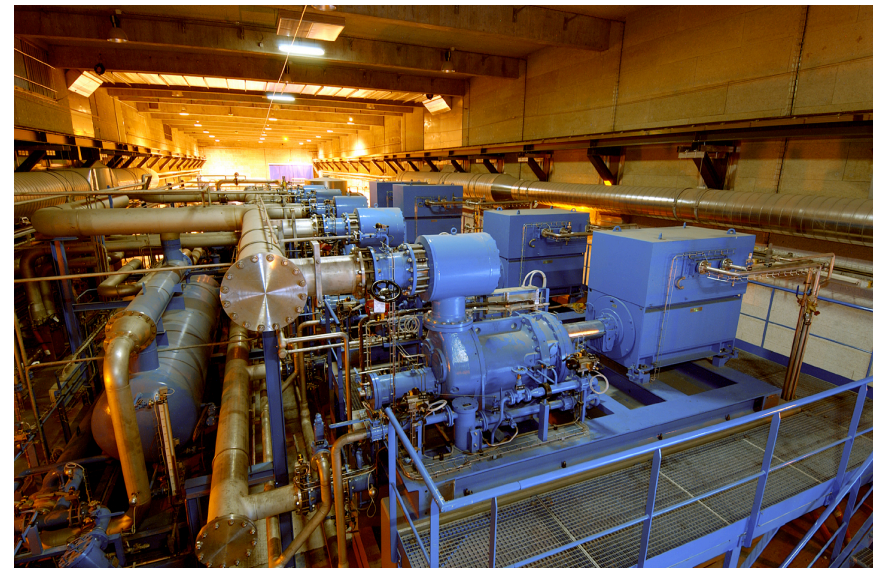
I refrigeratori (a 4.2K) sono OK



AIR LIQUIDE



LINDE



Otto impianti in tutto
140 kW at 4.5 K
~40 000 l/h di elio liquido
32 MWe

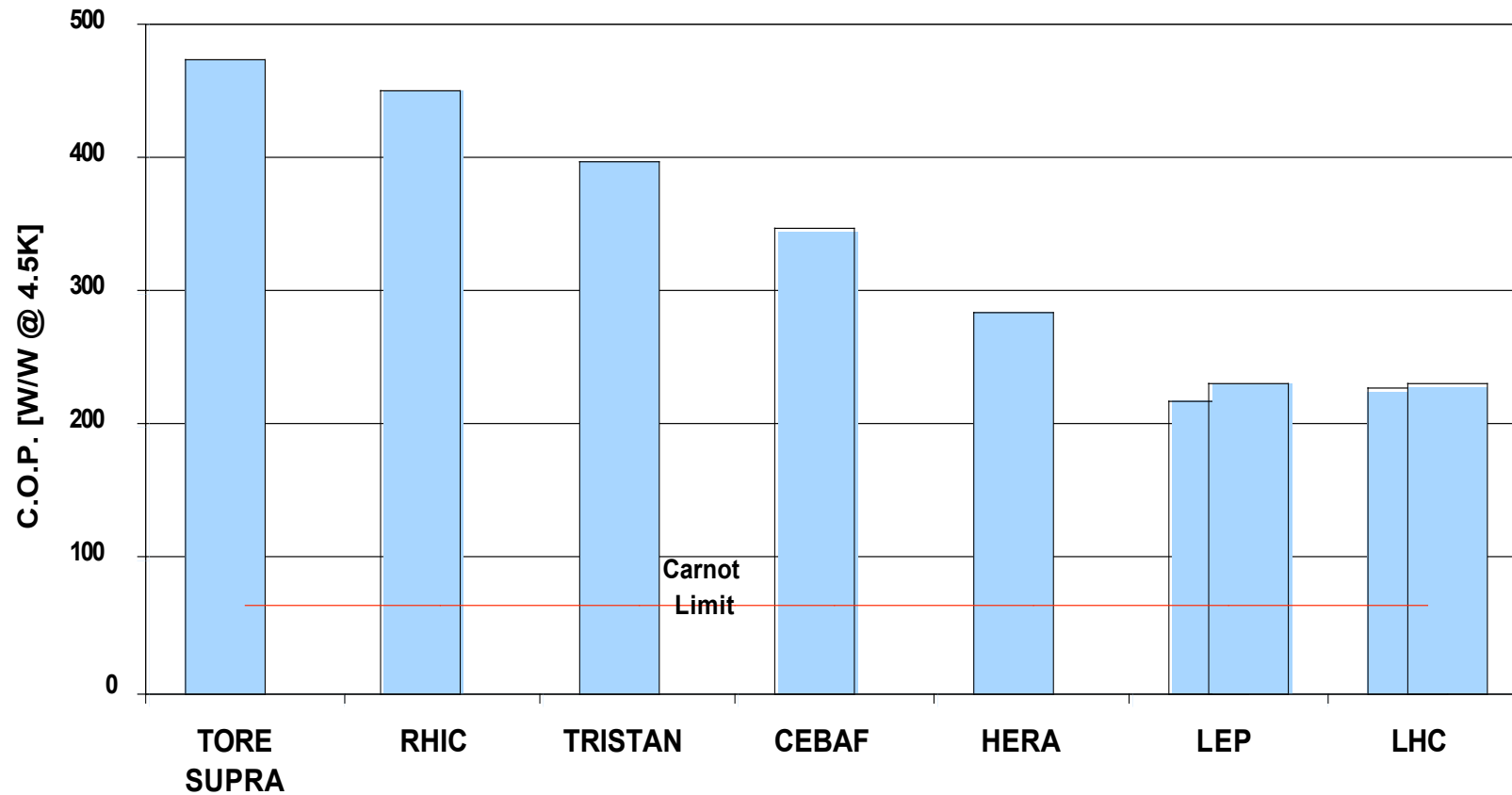
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25

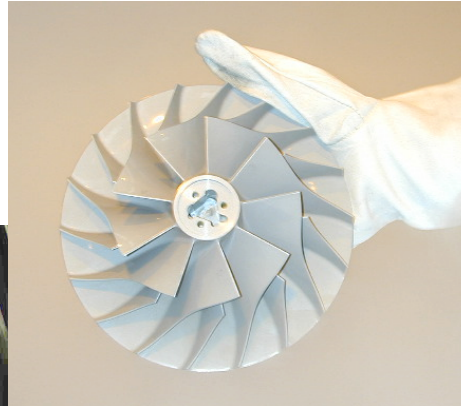


Efficienza dei refrigeratori LHC: il passo è stato LEP2 (fatto per LHC)



Compressori freddi per 1.8 K

IHI-LINDE



Impeller

**Otto unità
2400 W @ 1.8 K l'una**



1st stage



The four stages

Camere a vuoto per i criostati



SIMIC

FCM



Powering the LHC

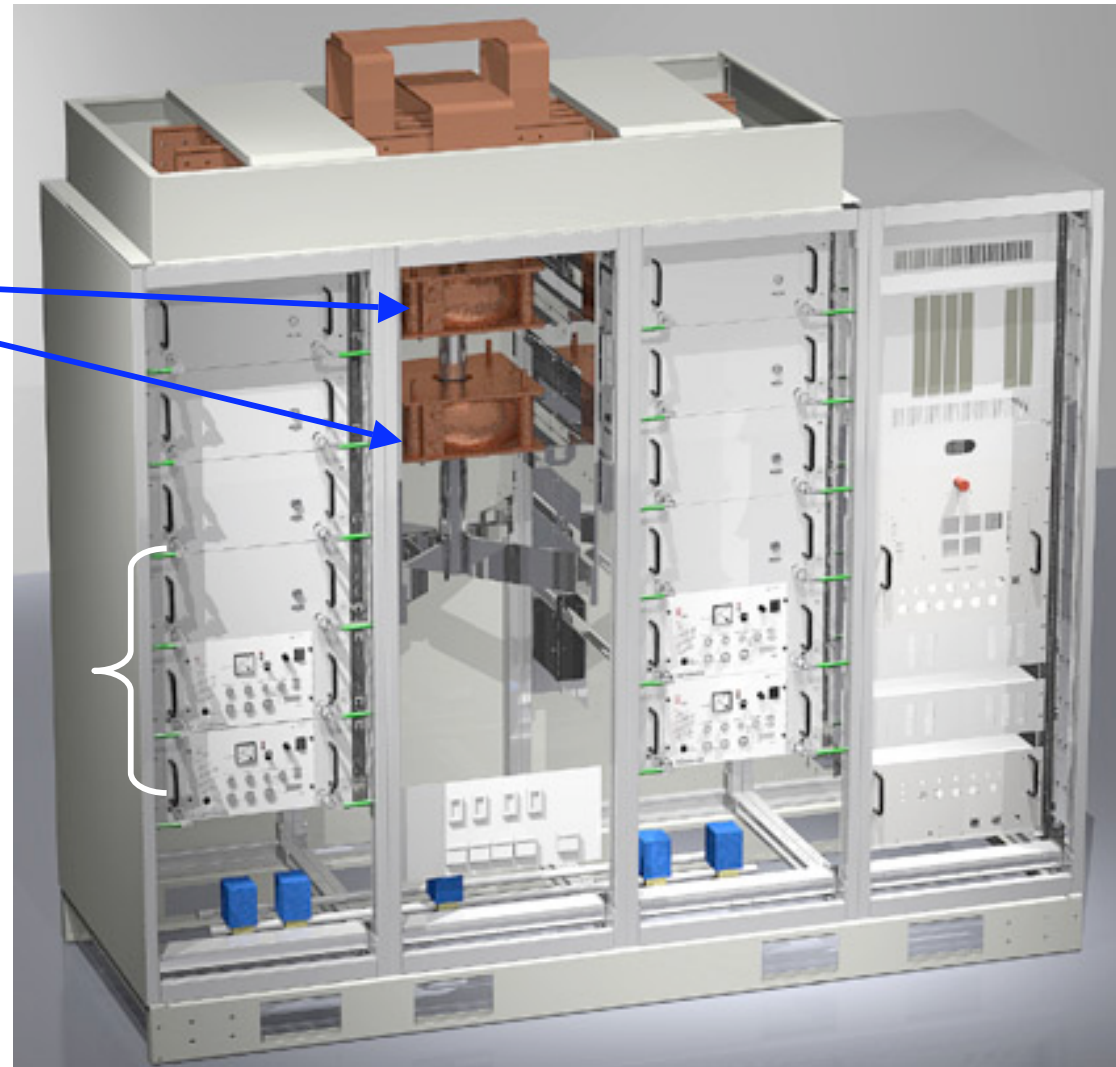
- 1720 power converters
 - high-current (60 A to 12 kA)
 - high-precision (few ppm stability & reproducibility)
 - large dynamic range
 - 1-quadrant, 2-quadrant and 4-quadrant
 - high reliability (MTBF \sim 100 000 h)
 - tracking from sector to sector
- Environmental constraints
 - underground => compactness, efficiency (>80 %)
 - serviceability
 - EMC
 - radiation tolerance (1 Gy/yr for converters in tunnel)

Modular 6 kA, 8 V converter

DCCTs

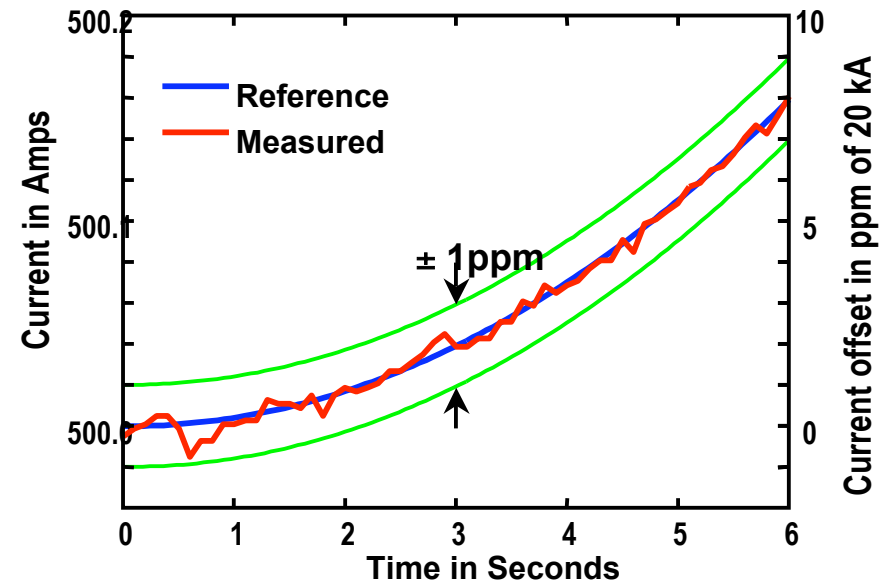
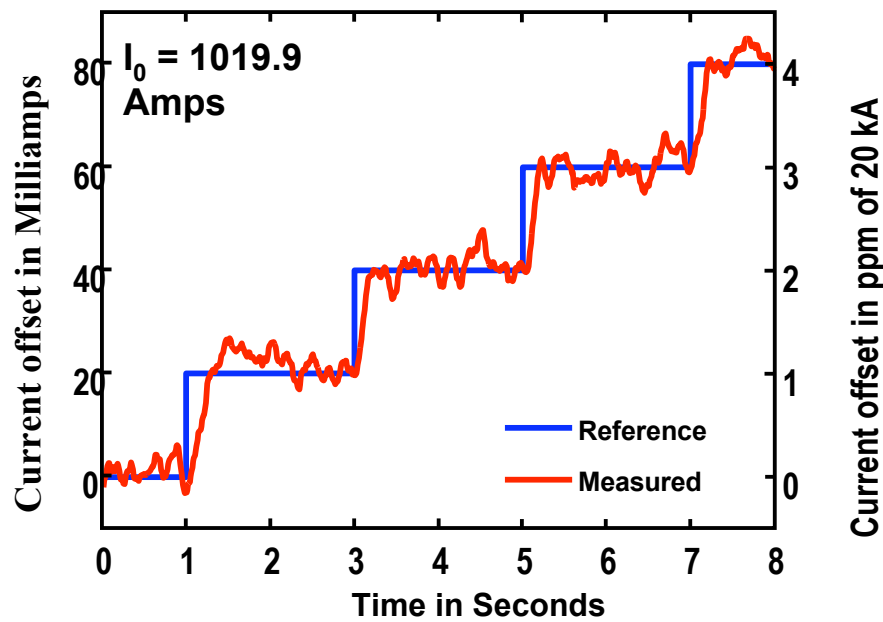
[2kA,8V] converters

KEMPOWER

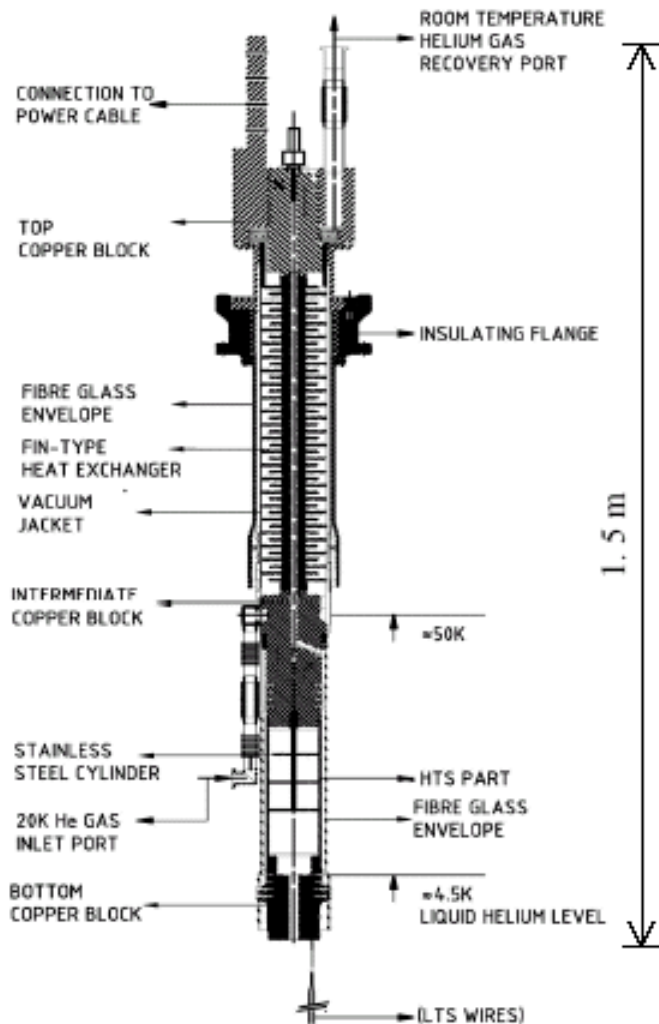


Current tracking performance

F. Bordry



13 kA HTS current leads

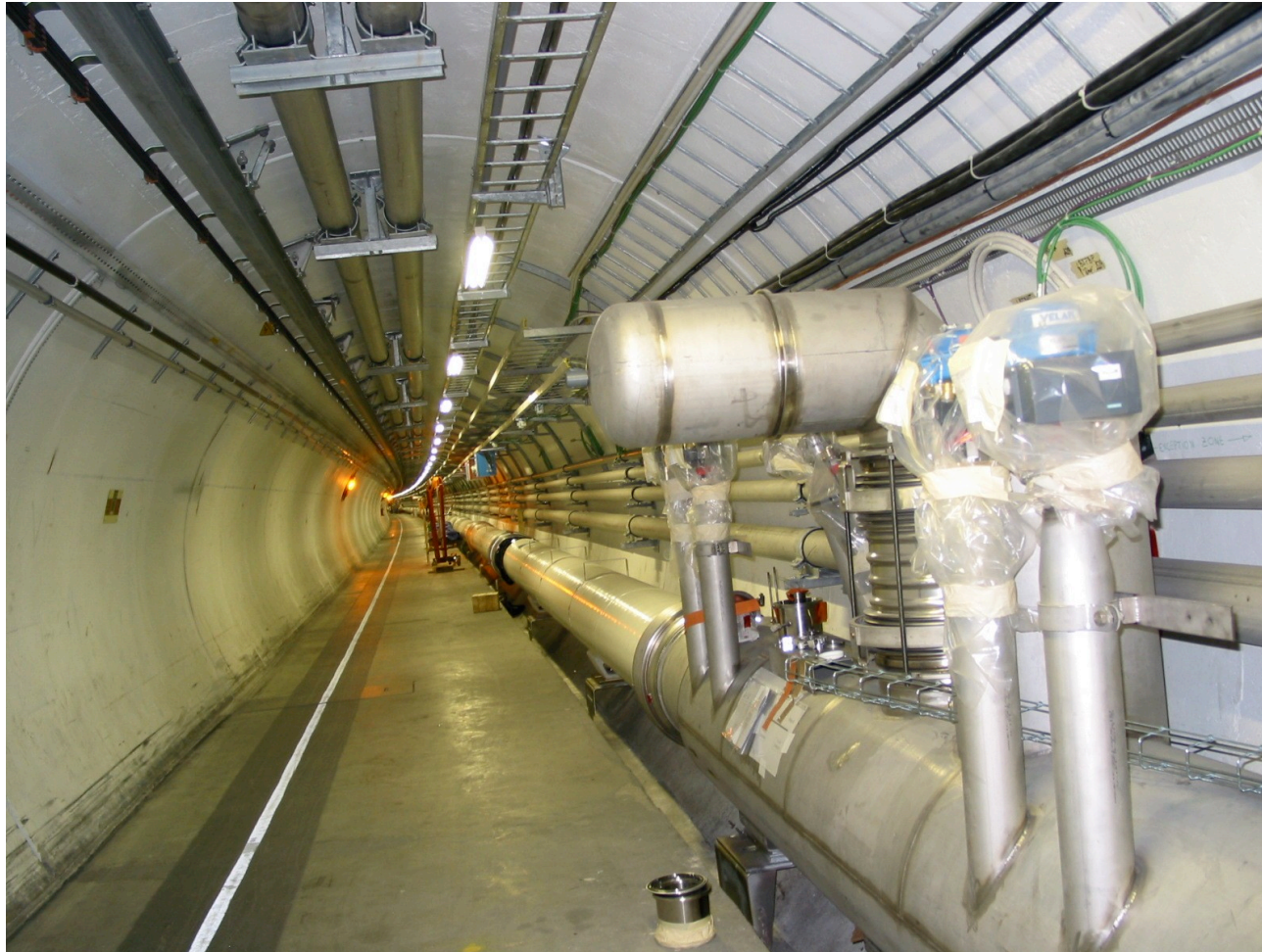




ritardo dell'installazione QRL: modifiche design validate



CERN ripara e reinstalla il primo ottante



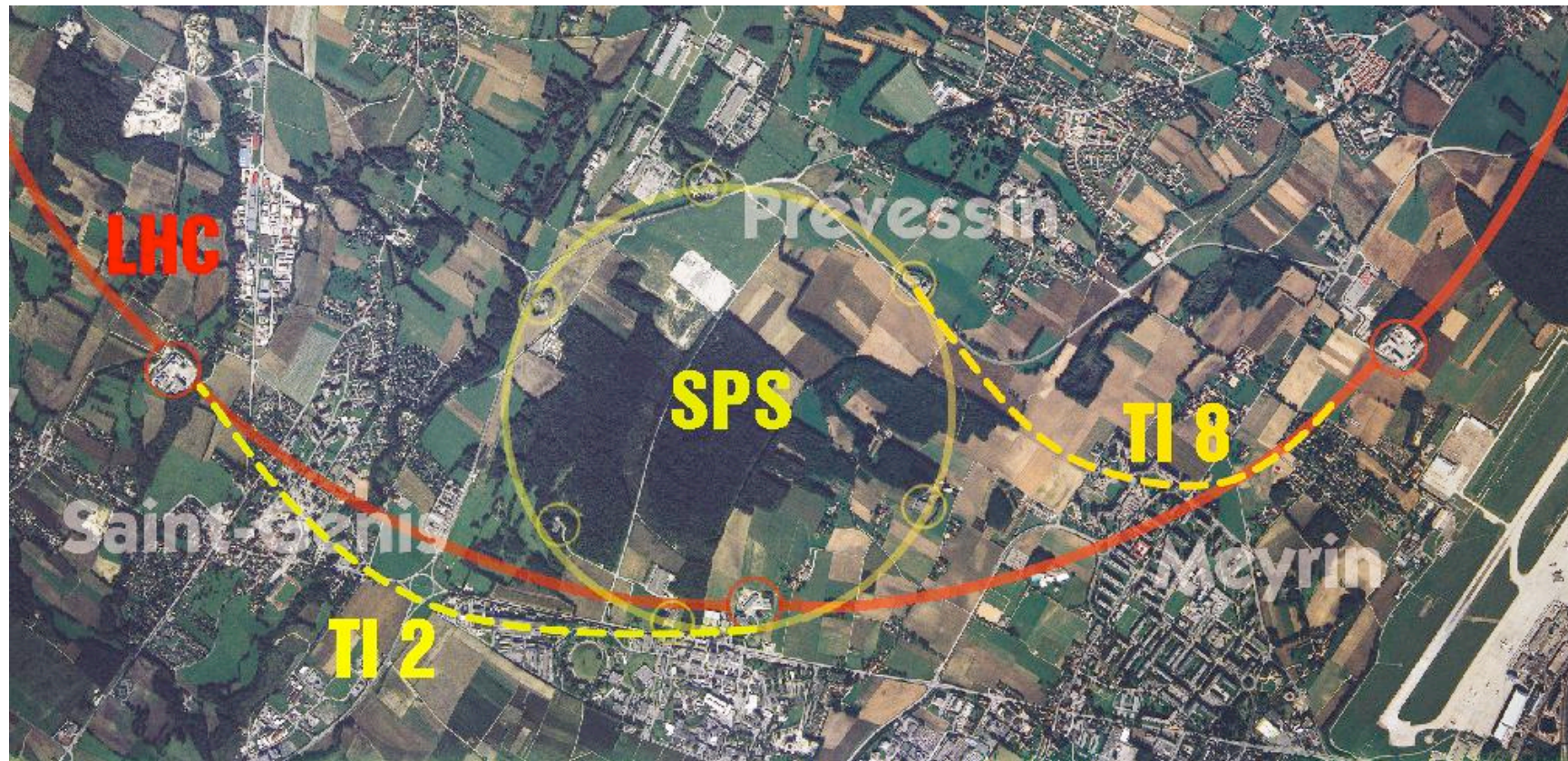
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33

Linea iniezione

5.6 km, 700 magneti

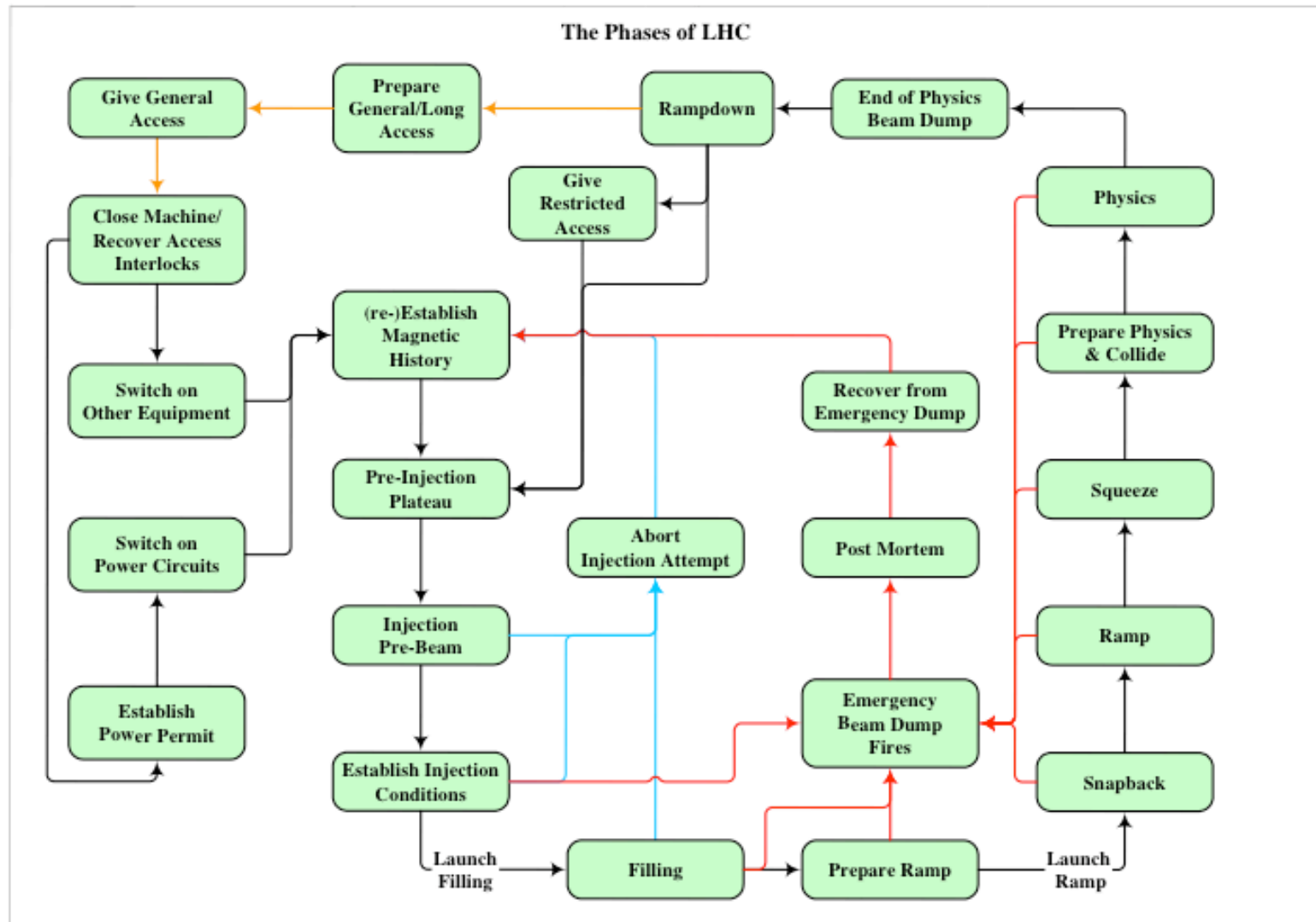


V. Mertens

Linea iniezione TI8: terminata



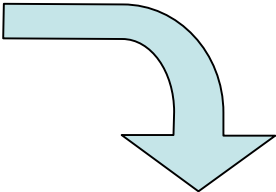
Ciclo LHC





Per arrivare al fascio

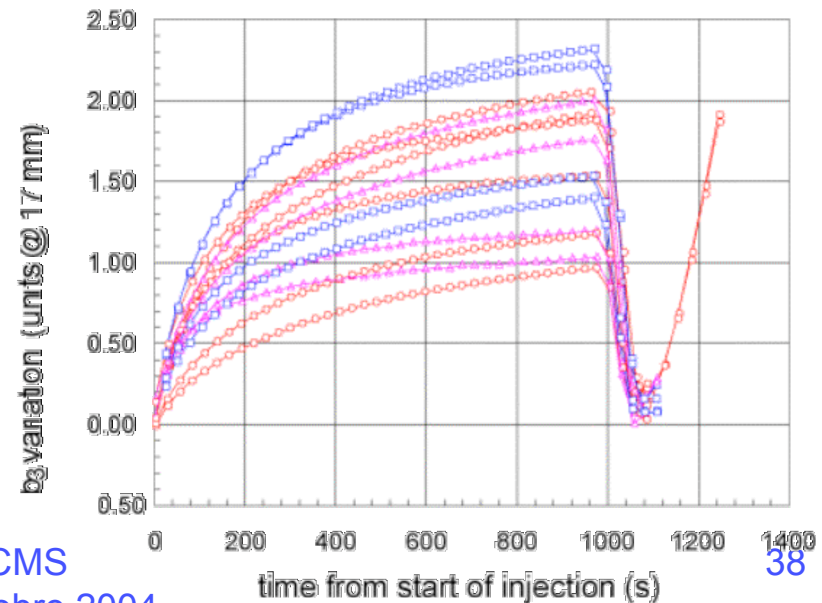
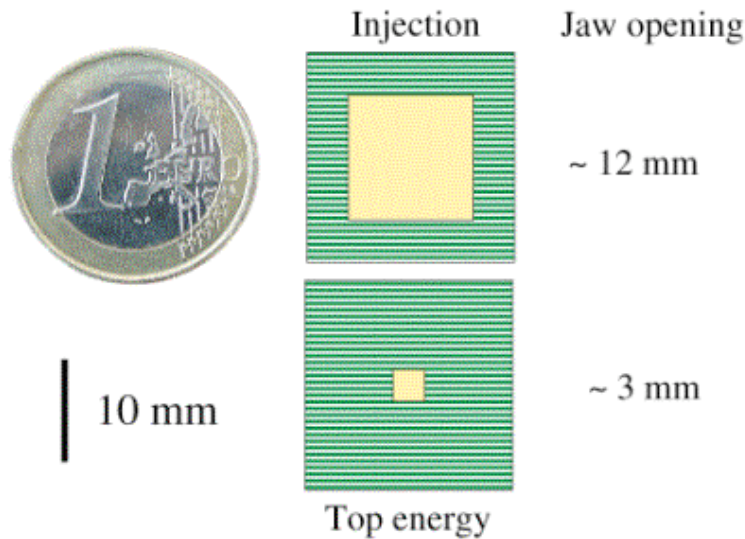
Operational Phases

- **Hardware Commissioning**
 - **Hardware commissioning with power**
 - **Cold checkout**
 - **Very cold checkout**
 - **Initial commissioning with beam**
 - **Initial commissioning for physics**
 - **Re-commissioning after shutdown**
 - **Commissioning with Ions**
 - **First year physics**
 - **Nominal Physics with protons**
 - **Ultimate physics with protons**
 - **Nominal physics with Ions**
 - **TOTEM**
 - **Machine development**
- 
- **Initial commissioning with beam**
 - **Establish circulating beam**
 - **First pass BI commissioning**
 - **Commission ramp – single beam**
 - **Commission squeeze – single beam**
 - **2 beam operation**
 - **etc. etc.**

beam commissioning: Una sfida complessa

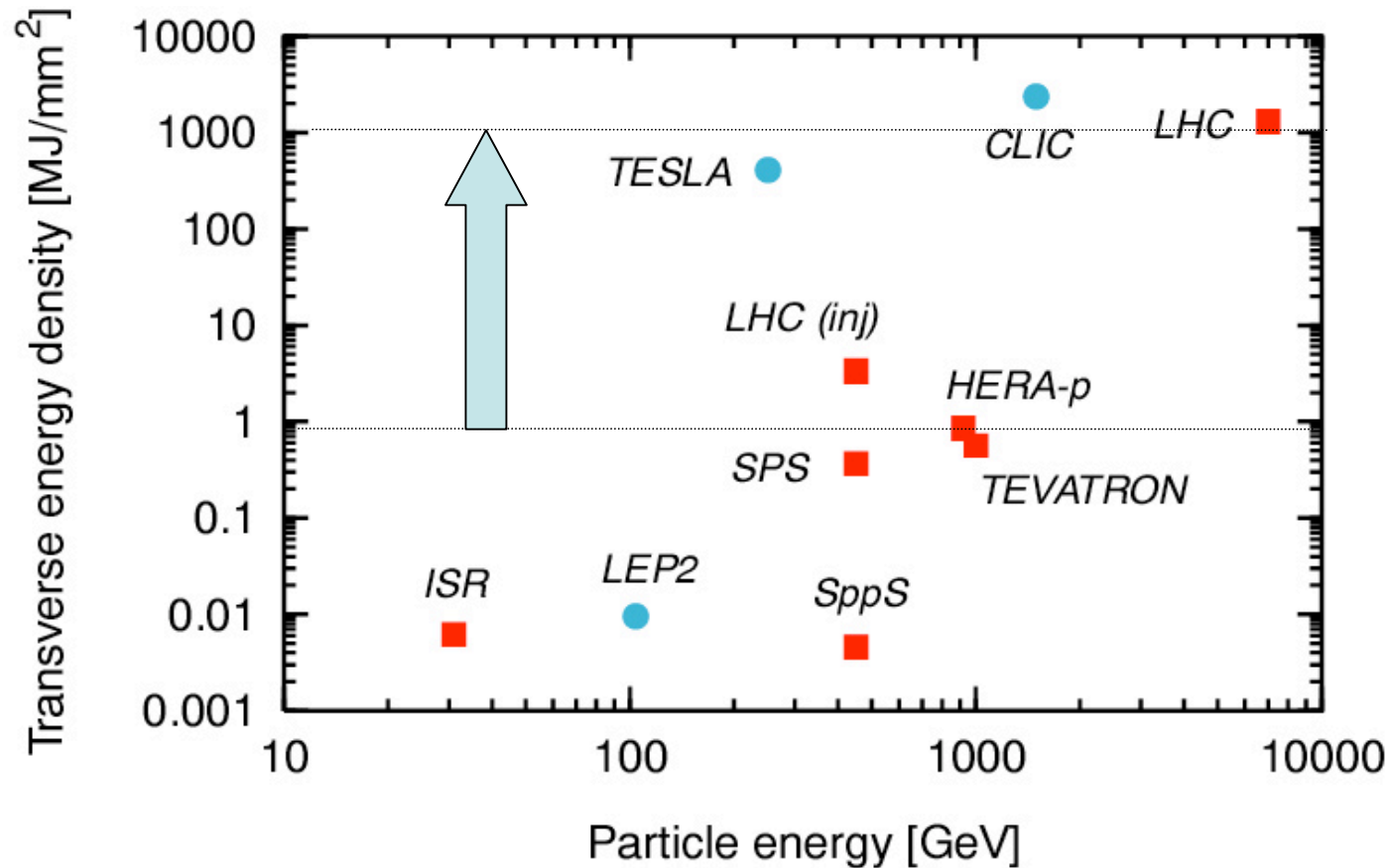
There is a lot of stored energy in the nominal beams

- 7TeV, $N_b = 2808$, $i_b = 1.15 \cdot 10^{11}$, ($\sigma = 3.75 \mu\text{m}$, $\sigma^* = 0.55\text{m}$)
- Stored energy $\sim 360\text{MJ}$ per beam
 - $\sim 0.7\text{MJ}$ melts 1kg copper
 - $\sim 100 \bullet$ more stored energy than SPS / Tevatron / HERA
 - $\sim 1000 \bullet$ more energy density than SPS / Tevatron / HERA



La potenza del fascio LHC

La densità di energia trasversale è una misura del **potenziale danneggiamento** ...
 ... e proporzionale **alla luminosità**



In termini di danneggiamento LHC rappresenta un passo di 3 ordini di grandezza!



Filosofia bilanciata tra necessità esperimenti e macchina



Maximize integrated luminosity

Minimize event pile-up at the start (to event + 2)

Avoid quenches (and damage)

– Reduce energy to get more margin

- Against transient beam losses
- Against magnet operating close to quench limit

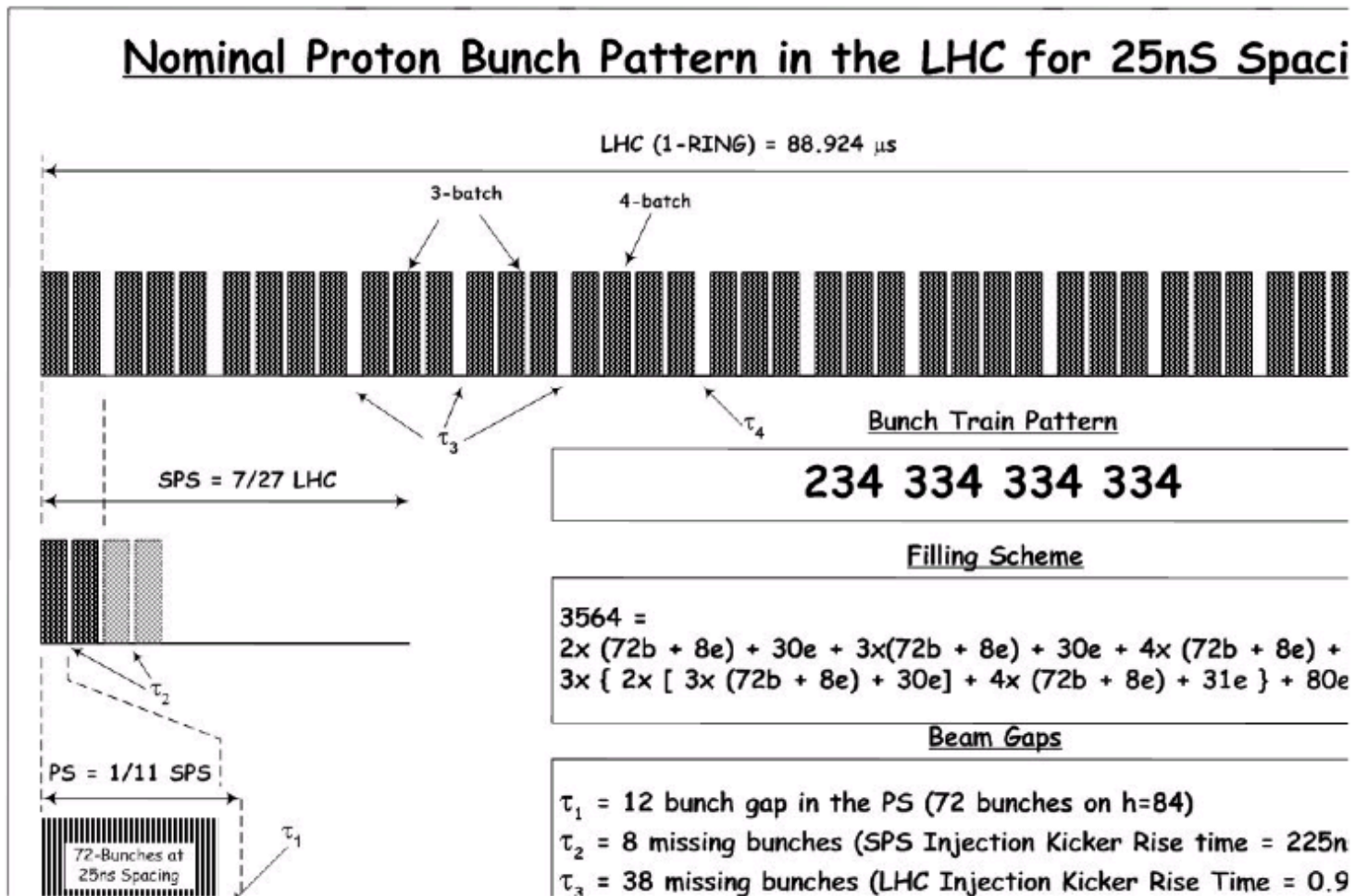
– Reduce total current to reduce stored beam energy

- Lower i_b
- Fewer bunches (we have 25ns 75ns and others available)

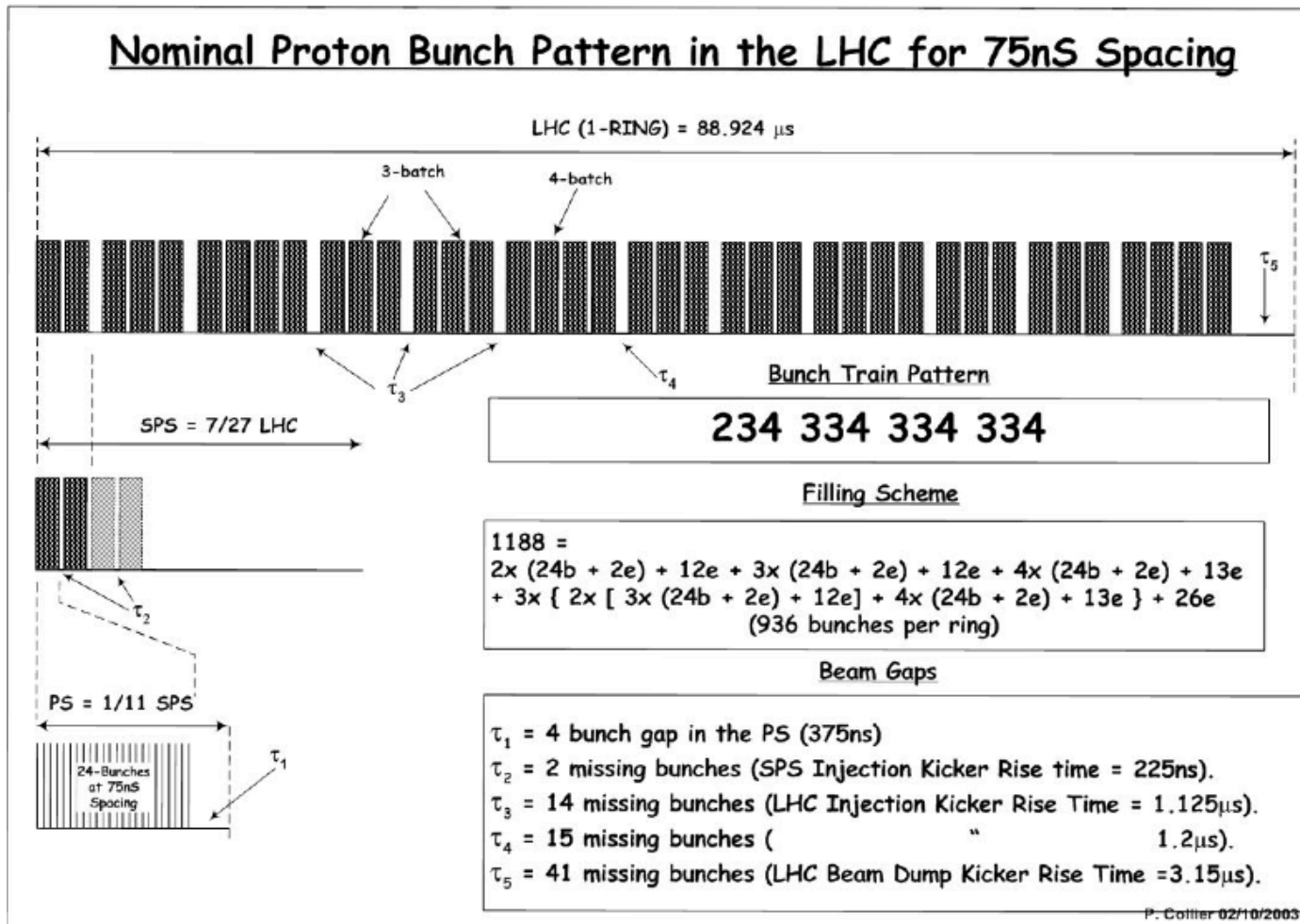
– Higher β^* to avoid problems in the (later part of the) squeeze



Alta luminosità: 39 batch di 72 bunch per ring = 2808 bunch (+756 vuoti)

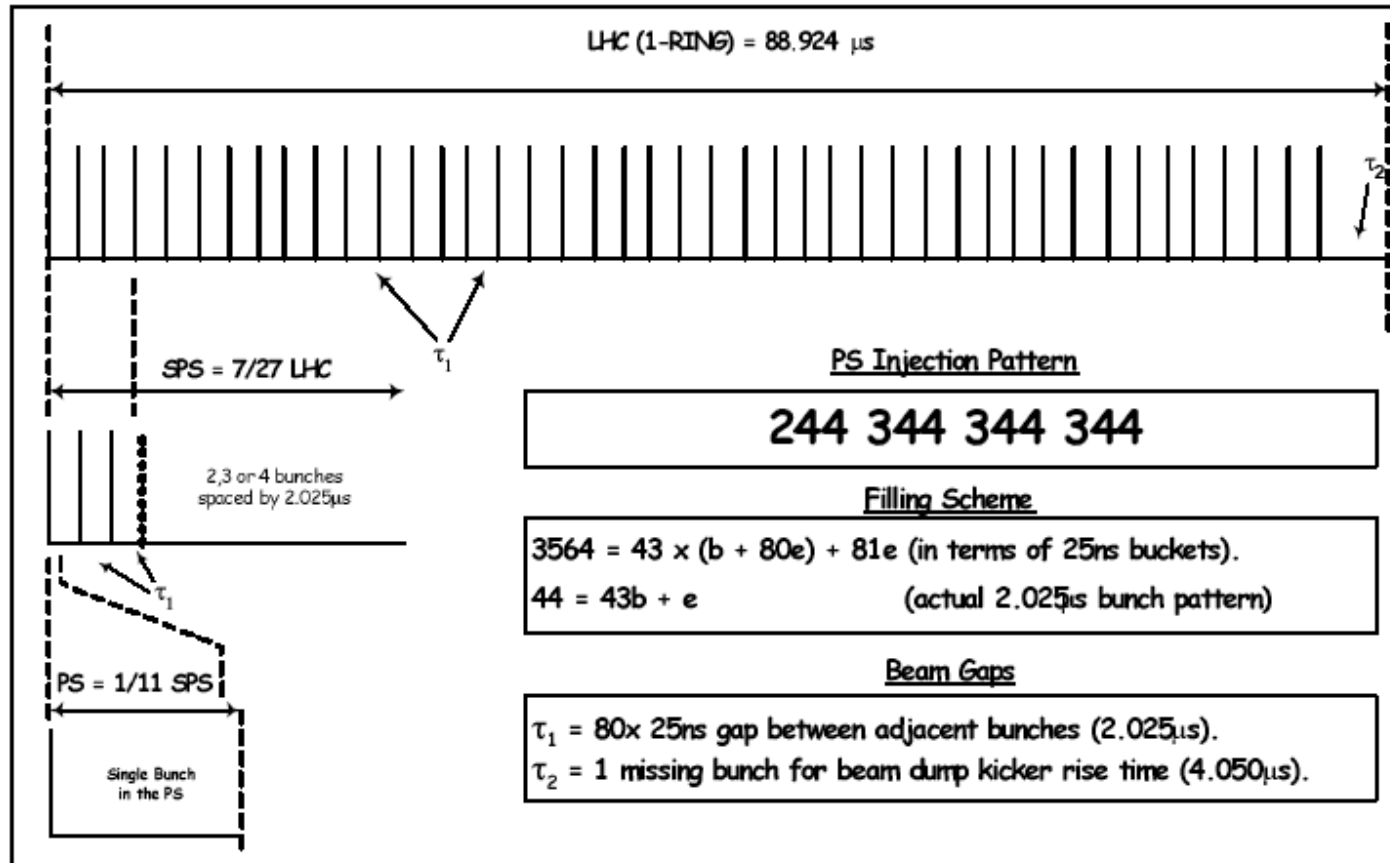


Primo(i) anno(i) di fisica: limitare il beam power massimizzando l'intensità



I 1188 spazi vengono dati come 936 bunch per ring (quindi i vuoti sono 252)

Ma I primi mesi...



Con 43 bunch solamente:

- L'intensità diventa molto maneggevole
- no quench all'iniezione
- no damage a top energy
- due fasci non sono mai insieme nel parte comune di camera vuoto:
- no collisioni parassite
- collisioni sono frontali

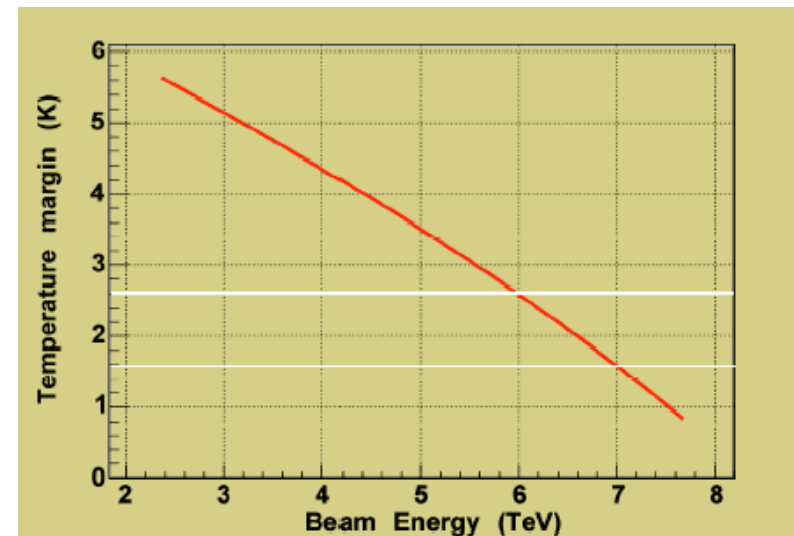
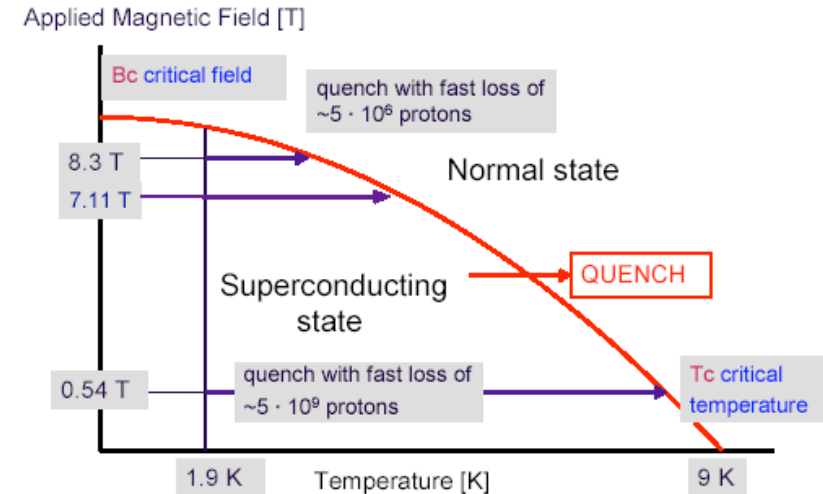
Quench se si passa T_c

- $5 \cdot 10^6$ protoni lo fanno a 7 TeV
- Perdite a:
- Iniezione e rampa
- 7TeV squeeze
- 7TeV adjustments (collimators)

Piu' margine a **6 TeV**

Meno energia depositata a 6 TeV

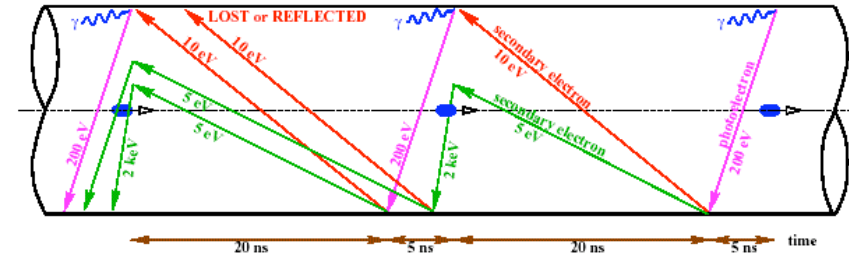
**□ guadagno piu' che
fattore 2 in energia**



Altre considerazioni per stare bassi

Electron cloud

- $i_b < 35\%$ nominal for 25ns spacing
- $i_b \sim$ nominal for > 50 ns



With **lower currents** in mind, a number of machine systems will be staged

- Only 8 of 20 beam dump dilution kickers initially installed
- Collimators (robustness, impedance and other issues)

Start simple, introduce the complexity (and the risk) in a controlled way

Emittance preservation in LHC will need learning

- Assume ϵ of 3.75 μ m at top energy also for reduced i_b



Resulting proposal for early physics running

Start high energy operation at 6TeV or maybe 6.5TeV
Move to 7TeV whenever machine stability permits it (1 step)

Staged approach to get to stable 25ns operation

1. Commissioning and pilot physics run with few bunches

- No parasitic bunch crossings
- Machine de-bugging without crossing angle

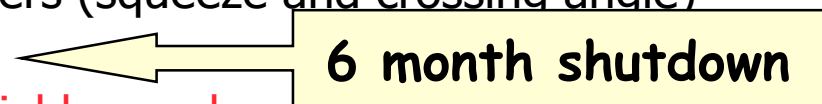
2. 75ns operation

- Establish multi-bunch operation
- Relaxed machine parameters (squeeze and crossing angle)

3. 25ns operation

a) Phase I collimators + partial beam dump

b) Phase II collimators + full beam dump





Proposal for breakdown of a year

Year = 16 weeks Shutdown + 4 weeks MCO + 32 weeks Operation

Operational period = $\{ 25 \text{ days Beam period} + 3 \text{ days Technical Stop} \}_8$

Beam period = 1 day Setting up + 4 days MD(16%) + 20 days
Physics(80%)

First beam period will always be for setting up + a little physics

Results in around 140 days for physics

To be shared between proton running, ion running and TOTEM

**(le slides su operazione e start up sono cortesia di
Roger Bailey, Paul Collier, Rudiger Schmidt, AB dept.)**



Planning

- In giugno 2004: planning che prevedeva fine dell'hardware commissioning in estate 2007 con scenario non limitato in risorse (2-3 fronti di installazione e test)
- **Da allora picco di crisi della QRL: 4 mesi ulteriori di ritardo**
- CERN sta prendendo misure per recuperare e mantenere il 2007 come anno di primo fascio
- La crisi della QRL è "quasi" passata. CERN installerà un ottante
- **Basterà per avere il (un) fascio nel 2007? Questo è l'impegno!**